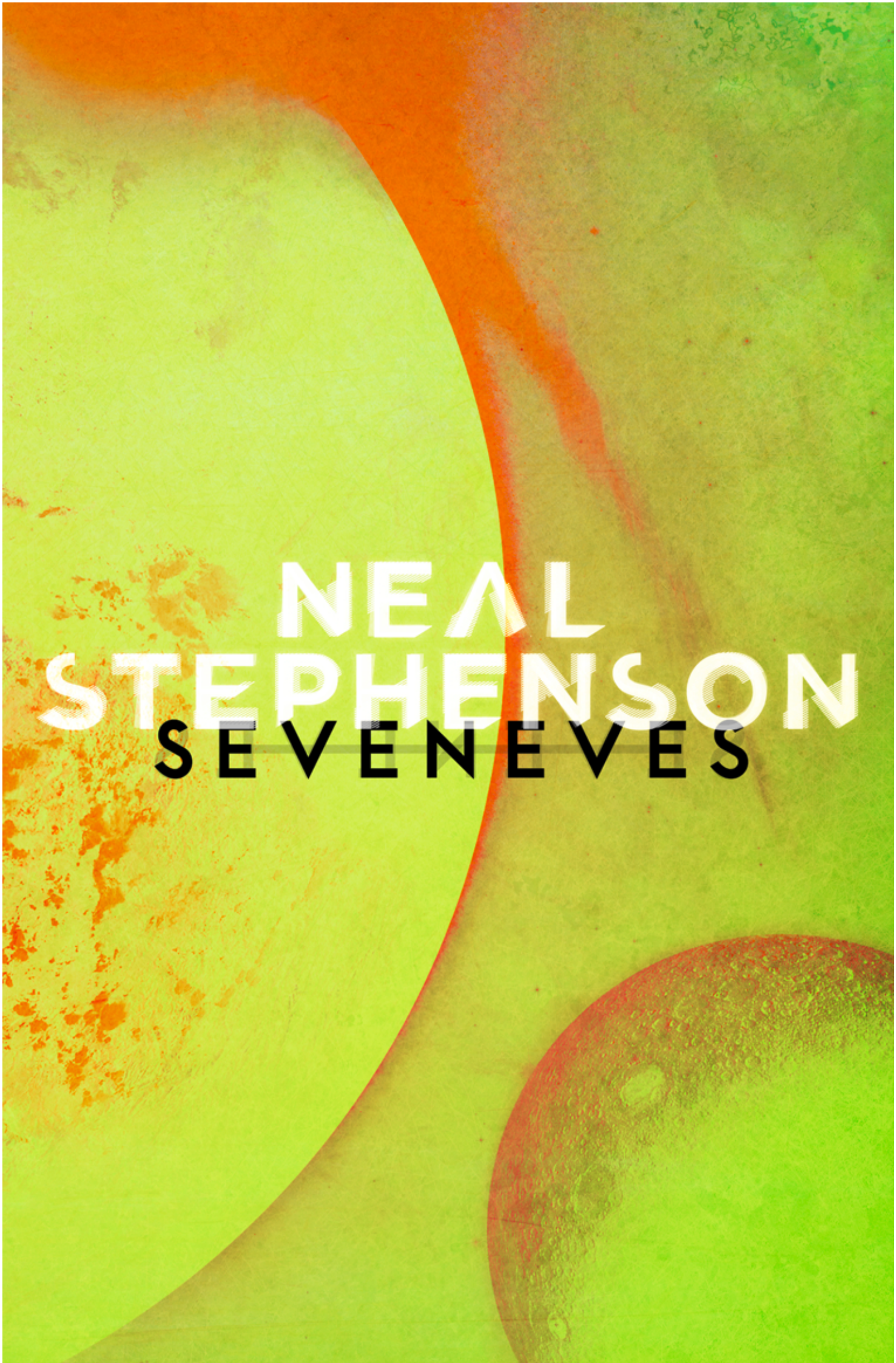
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SEVENEVES
Neal Stephenson

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Dedication

TO JAIME, MARIA, MARCO, AND JEFF

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Part One

The Age of the One Moon

THE MOON BLEW UP WITHOUT WARNING AND FOR NO APPARENT reason. It was waxing, only one day short of full. The time was 05:03:12 UTC. Later it would be designated A +0.0.0, or simply Zero.

An amateur astronomer in Utah was the first person on Earth to realize that something unusual was happening. Moments earlier, he had noticed a blur flourishing in the vicinity of the Reiner Gamma formation, near the moon's equator. He assumed it was a dust cloud thrown up by a meteor strike. He pulled out his phone and blogged the event, moving his stiff thumbs (for he was high on a mountain and the air was as cold as it was clear) as fast as he could to secure the claim to himself. Other astronomers would soon be pointing their telescopes at the same dust cloud—might be doing it already! But—supposing he could move his thumbs fast enough—he would be the first to point it out. The fame would be his; if the meteorite left behind a visible crater, perhaps it would even bear his name.

His name was forgotten. By the time he had gotten his phone out of his pocket, his crater no longer existed. Nor did the moon.

When he pocketed his phone and put his eye back to the eyepiece of his telescope, he let out a curse, since all he saw was a tawny blur. He must have knocked the telescope out of focus. He began to twiddle the focus knob. This didn't help.

Finally he pulled back from the telescope and looked with his naked eyes at the place where the moon was supposed to be. In that moment he ceased to be a scientist, with privileged information, and became no different from millions of other people around the Americas, gaping in awe and astonishment at the most extraordinary thing that humans had ever seen in the sky.

In movies, when a planet blows up, it turns into a fireball and ceases to exist. This is not what happened to the moon. The Agent (as people came to call the mysterious force that did it) released a very large amount of energy, to be sure, but not nearly enough to turn all the moon's substance into fire.

The most generally accepted theory was that the puff of dust observed by the Utah astronomer was caused by an impact. That the Agent, in other words, came from outside the moon, pierced its surface, burrowed deep into its center, and then released its energy. Or that it simply kept on going out the other side, depositing enough energy en route to break up the moon. Another hypothesis stated that the Agent was a device buried in the moon by aliens during primordial times, set to detonate when certain conditions were met.

In any case, the result was that, first, the moon was fractured into seven large pieces, as well as innumerable smaller ones. And second, those pieces spread apart, enough to become observable as separate objects—huge rough boulders—but not enough to continue flying apart from one another. The moon's pieces remained gravitationally bound, a cluster of giant rocks orbiting chaotically about their common center of gravity.

That point—formerly the center of the moon, but now an abstraction in space—continued to revolve around the Earth just as it had done for billions of years. So now, when the people of Earth looked up into the night sky at the place where they ought to have seen the moon, they saw instead this slowly tumbling constellation of white boulders.

Or at least that is what they saw when the dust cleared. For the first few hours, what had been the moon was just a somewhat-greater-than-moon-sized cloud, which reddened before the dawn and set in the west as the Utah astronomer looked on dumbfounded. Asia looked up all night at a moon-colored blur. Within, bright spots began to stand out as dust particles fell into the nearest heavy pieces. Europe and then America were treated to a clear view of the new state of affairs: seven giant rocks where the moon ought to have been.

BEFORE THE LEADERS OF THE SCIENTIFIC, MILITARY, AND POLITICAL worlds began using the word “Agent” to denote whatever had blown up the moon, that word’s most common interpretation, at least in the minds of the general public, had been in the pulp-fiction, B-movie sense of a secret agent or an FBI agent. Persons of a more technical mind-set might have used it to mean some sort of chemical, such as a cleaning agent. The closest match for how the word would be used forever after was the sense in which it was used by fencers and martial artists. In a sword-fighting drill, where one participant is going to mount an attack and the other is to respond in some way, the attacker is known as the agent and the respondent is known as the patient. The agent acts. The patient is passive. In this case an unknown Agent acted upon the moon. The moon, along with all the humans living in the sublunary realm, was the passive recipient of that action. Much later, humans might rouse themselves to take action and be agents once again. But now and for long into the future they would be nothing more than patients.

The Seven Sisters

RUFUS MACQUARIE SAW IT ALL HAPPEN ABOVE THE BLACK RIDGELINE OF the Brooks Range in northern Alaska. Rufus operated a mine there. On clear nights he would drive his pickup truck to the top of a mountain that he and his men had spent the day hollowing out. He would take his telescope, a twelve-inch Cassegrain, out of the back of the truck and set it up on the summit and look at the stars. When he got ridiculously cold, he would retreat into the cab of his truck (he kept the engine running) and hold his hands over the heater vents until his fingers regained feeling. Then, as the rest of him warmed up, he would put those fingers to work communicating with friends, family, and strangers all over the world.

And off it.

After the moon blew up, and he convinced himself that what he was seeing was real, he fired up an app that showed the positions of various natural and man-made celestial bodies. He checked the position of the International Space Station. It happened to be swinging across the sky 260 miles above and 2,000 miles south of him.

He pulled a contraption onto his knee. He had made it in his little machine shop. It consisted of a telegraph key that looked to be about 150 years old, mounted on a contoured plastic block that strapped to his knee with hook-and-loop. He began to rattle off dots and dashes. A whip antenna was mounted to the bumper of his pickup truck, reaching for the stars.

Two hundred sixty miles above and two thousand miles south of him, the dots and dashes came out of a pair of cheap speakers zip-tied to a conduit in a crowded, can-shaped module that made up part of the International Space Station.

BOLTED TO ONE END OF THE ISS WAS THE YAM-SHAPED ASTEROID called Amalthea. In the unlikely event that it could have been brought gently to Earth and laid to rest on a soccer field, it would have stretched from one penalty box to the other and completely covered the center circle. It had floated around the sun for four and a half billion years, invisible to the naked eye and to astronomers' telescopes even though its orbit had been similar to that of the Earth. In the classification system used by astronomers, this meant that it was called an Arjuna asteroid. Because of their near-Earth orbits, Arjunas had a high probability of entering the Earth's atmosphere and slamming into inhabited places. But, by the same token, they were also relatively easy to reach and latch on to. For both those reasons, bad and good, they drew the attention of astronomers.

Amalthea had been noticed five years earlier by a swarm of telescope-wielding satellites sent out by Arjuna Expeditions, a Seattle-based company funded by tech billionaires for the express purpose of asteroid mining. It had been identified as dangerous, with a 0.01 percent probability of striking the Earth within the next hundred years, and so another swarm of satellites had been sent up to drop a bag over it and drag it into a geocentric (Earth rather than sun-centered) orbit, which had then been gradually matched with that of the ISS.

In the meantime, the planned expansion of the ISS had plodded onward. New modules—inflatables and air-filled tin cans sent up on rockets—had been added to the space station at both ends. At the forward end—the space station's nose, if you thought of it as a vaguely bird-shaped object flying around the world—a home was prepared for Amalthea and for the asteroid mining research project that was planned to grow up around it. Meanwhile, at the aft end, a torus—a donut-shaped habitat about forty meters in diameter—was constructed and made to spin like a merry-go-round, creating a small amount of simulated gravity.

At some point during these improvements, people had stopped calling it the International Space Station, or ISS, and begun referring to the old girl as Izzy. Coincidentally or not, this moniker had become popular around the time that each of the station's two ends had come under the management of a woman. Dinah MacQuarie, the fifth child and only daughter of Rufus, was responsible for much

of what went on in Izzy's forward end. Ivy Xiao had overall command of ISS and tended to operate out of the torus at its "stern."

During most of Dinah's waking hours, she was at the forward end of Izzy, in a small workspace ("my shop") where she could look out a small quartz window at Amalthea ("my girlfriend"). Amalthea was nickel and iron: heavy elements that had probably sunk to the hot center of an ancient planet long since blown apart by some primordial catastrophe. Other asteroids were made of lighter materials. In the same way that Amalthea's Earth-like orbit had made her both a dire threat and a promising candidate for exploitation, her dense metallic constitution had made her a bitch to move around the solar system, but a rewarding object of study. Some asteroids were made largely of water, which could be hoarded for consumption by humans or split into hydrogen and oxygen to fuel rockets. Others were rich in precious metals that could be returned to Earth and sold.

A lump of nickel and iron like Amalthea could be smelted into structural materials for the construction of orbiting space habitats. Doing so on anything more than a small pilot scale would require the development of new technology. Using human miners was out of the question, since sending them up to orbit and keeping them alive was expensive. Robots were the obvious solution. Dinah had been sent up to Izzy to lay groundwork for a robot laboratory that would eventually host a staff of six. The budget wars in Washington had reduced that number to one.

Which was how she actually liked it. She had grown up in remote places, following her father, Rufus; her mother, Catherine; and her four brothers to a series of hard rock mines in places like the Brooks Range of Alaska, the Karoo Desert of South Africa, and the Pilbara of western Australia. Her accent betrayed traces of all those places. She'd been home-schooled by her parents and a series of tutors they'd flown in, none of whom had lasted more than a year. Catherine had taught her the finer points of piano playing and napkin folding, and Rufus had taught her mathematics, military history, Morse code, bush piloting, and how to blow things up, all by the age of twelve, when, by family voice vote over dinner, she had been deemed too smart and too much of a handful for life at the minehead. She had been sent off to boarding school on the East Coast of the United States. For her family—though she'd never had an inkling of it until then—was well off.

At school she had developed into a gifted soccer player and parlayed this talent into an athletic scholarship to Penn. During her sophomore year she had blown out her right ACL, terminating her serious athletic career, and turned her attention in a more serious way to the study of geology. That, plus a three-year relationship with a boy who liked to build robots, combined with her background in the mining industry, had made her into a perfect candidate for the job she had now. Working hand in glove with robot geeks on terra firma—a mixture of university researchers, freelance members of the hacker/maker community, and paid Arjuna Expeditions staff—she programmed, tested, and evaluated a menagerie of robots, ranging in size from cockroach to cocker spaniel, all adapted for the task of crawling around on the surface of Amalthea, analyzing its mineral composition, cutting bits off, and taking them to a smelter that, like everything else up here, was specially adapted to work in the environment of space. The ingots of steel that emerged from this device were barely large enough to serve as paperweights, but they were the first such things made off-world, and right now they were weighing down important papers on billionaires' desks all over Silicon Valley, worth far more as conversation pieces and status symbols than as commodities.

Rufus, a die-hard ham radio enthusiast who still communicated in Morse code with a dwindling circle of old friends all over the world, had pointed out that radio transmission between the ground and Izzy was actually rather easy, given that it was line-of-sight (at least when Izzy happened to be passing overhead) and that the distance was nothing by ham radio standards. Since Dinah lived and worked in a robot workshop, surrounded by soldering gear and electronics workbenches, it had been a simple matter for her to assemble a small transceiver following specifications provided by her dad. Zip-tied to a bulkhead, it dangled above her workstation, making a dim static hiss that was easily drowned out by the normal background roar of the space station's ventilation systems. Sometimes it would beep.

A spacewalker gazing at Dinah's end of Izzy, a few minutes after the Agent had fractured the moon, would have seen, first of all, Amalthea: a huge, gnarled twist of metal, still dusty in some places with space debris that had fallen into its evanescent gravitational field over the aeons, gleaming in others where it had been rubbed clean. Scurrying over its surface was a score of different robots, belonging to four distinct "species": one that looked like a snake, one that picked its way along like a crab, one that looked like a sort of rolling geodesic dome, and another that looked like a swarm of insects. These provided sporadic illumination from the blue and white LEDs that Dinah used to track them, from the lasers with which they scanned Amalthea's surface, and from the blinding arcs of purplish light with which they would sometimes slice into it. Izzy was then in Earth's shadow, on the night side of the planet, and so all was dark otherwise, except for white light spilling out from the little quartz window beside Dinah's workstation. This was barely large enough to frame her head. She had straw-colored hair cut short. She had never been especially appearance conscious; back at the minehead her brothers had mocked her to shame whenever she had experimented with clothes or cosmetics. When she'd been described as a tomboy in a school yearbook she had interpreted it as a sort of warning shot and had gone into a somewhat more girly phase that had run its course during her late teens and early twenties and ended when she had started to worry about being taken seriously in engineering meetings. Being on Izzy meant being on the Internet, doing everything from painstakingly scripted NASA PR interviews to candid Facebook shots posted by fellow astronauts. She had grown tired of the pouffy floating hair of zero gravity and, after a few weeks of clamping it down with baseball caps, had figured out how to make this shorter cut work for her. The haircut had spawned terabytes of Internet commentary from men, and a few women, who apparently had nothing else to do with their time.

As usual, she was focused on the screen of her computer, which was covered with lines of code governing the behavior of her robots. Most software developers had to write code, compile it into a program, and then run the program to see whether it was working as intended. Dinah wrote code, beamed it into the robots scurrying around on Amalthea's surface a few meters away, and stared out the window to see whether it was working. The ones closest to the window tended to get most of her attention, and so there was a kind of natural selection at work, in that the robots that huddled closest to their mother's cool blue-eyed gaze acquired the most intelligence, while the ones wandering around loose on the dark side never got any smarter.

At any rate her focus was either on the screen or on the robots, and so it had been for many hours. Until a string of beeps came out of the hissing speaker zip-tied to the bulkhead, and her eyes went momentarily out of focus as her brain decoded the dots and dashes into a string of letters and numbers: her father's call sign. "Not now, Pa," she muttered, with a guilty daughter's glance at the brass-and-oak telegraph key he had given her—a Victorian relic purchased at great price on eBay, during a bidding war that had placed Rufus into pitched battle against a host of science museums and interior decorators.

LOOK AT THE MOON

"Not now, Pa, I know the moon's pretty, I'm right in the middle of debugging this method …"

OR WHAT USED TO BE IT

"Huh?"

And then she brought her face close to the window and twisted her neck to find the moon. She saw what used to be it. And the universe changed.

HIS NAME WAS DUBOIS JEROME XAVIER HARRIS, PH.D. THE FRENCH first name came from his Louisiana ancestors on his mother's side. The Harrises were Canadian blacks whose ancestors had come up to Toronto during slavery. Jerome and Xavier were the names of saints—two of them, just to be on the safe side. The family straddled the border in the Detroit-Windsor area. Inevitably, he had been dubbed Doob by his friends at school when they had still been too young to understand that "doobie" was slang for a marijuana cigarette. The overwhelming majority of people

called him Doc Dubois now, because he was on TV a lot, and that was how the talk show hosts and the network anchormen introduced him. His job on TV was to explain science to the general public and, as such, to act as a lightning rod for people who could not accept all the things that science implied about their worldview and their way of life, and who showed a kind of harebrained ingenuity in finding ways to refute it.

In academic settings, such as when he was keynoting astronomical meetings and writing papers, he was, of course, Dr. Harris.

The moon blew up while he was attending a fund-raising reception in the courtyard of the Caltech Athenaeum. At the beginning of the evening it was a fiercely cold bluish-white disk rising above the Chino Hills. Lay observers would fancy it a good night for moon watching, at least by Southern California standards, but Dr. Harris's professional eye saw a thin border of fuzz around its rim and knew that aiming a telescope at it would be pointless. At least if the objective were to do science. Public relations was another matter; operating more in his Doc Dubois persona, he occasionally organized star parties where amateur astronomers would set their telescopes up in Eaton Canyon Park and aim them at crowd-pleasing targets such as the moon, the rings of Saturn, and the moons of Jupiter. Tonight would be a fine night for that.

But that wasn't what he was doing. He was drinking good red wine with rich persons, mostly from the tech industry, and being Doc Dubois, the affable science popularizer of television and of four million Twitter followers. Doc Dubois knew how to size up his audience. He knew that self-made tech zillionaires liked to argue, that Pasadena aristocracy didn't, and that society wives liked to be lectured to, as long as the lectures were brief and funny. And he knew that his job was to charm these people, nothing more, so that they could later be handed off to professional fund-raisers.

He was going back to the bar for another glass of the pinot noir, fully in the Doc Dubois persona, slapping shoulders and bumping fists and exchanging grins, when a man gasped. Everyone looked at him. Doob was afraid that the poor guy had been struck by a stray bullet or something. He was frozen, poised on one leg, gazing up. A woman followed his gaze and screamed.

And Doob became one of perhaps a few million people around the dark half of the planet all looking up into the sky, in a state of shock so profound as to shut off the parts of the brain responsible for higher functions like talking. His first thought, given that they were in Greater Los Angeles, was that they were looking at a black projection screen that had been stealthily hoisted into the air above the neighboring property, and were seeing a Hollywood special effect thrown onto it by a concealed projector. No one had informed him that any such stunt was under way, but perhaps it was some incredibly bizarre fund-raising gambit, or part of a movie production.

When he came to his senses, he was aware that a large number of telephones were singing their little electronic songs. Including his. The birth cry of a new age.

IVY XIAO WAS IN OVERALL COMMAND OF IZZY AND SPENT ALMOST all of her time in the torus, partly because her office was there and partly because she was more susceptible to space sickness than she liked to admit. That physical separation—Ivy back in the torus, Dinah up in the forward end, close to Amalthea—was symbolic, in many people's minds, of a difference between them that didn't really exist. Other contrasts were obvious enough, beginning with the physical: Ivy was four inches taller, with long black hair that she kept under control usually by braiding it and trapping the braid under the collar of her jumpsuit. She had the build of a volleyball player. Raised in Los Angeles, the only child of high-strung parents, Ivy had SATed, science faired, and spiked her way to Annapolis, then followed that up with a Ph.D. in applied physics from Princeton. Only then had the navy demanded the years of service that she owed it in return for her tuition. After learning how to pilot helicopters, she had spent most of that time in the astronaut program, in whose ranks she had risen quickly. Unlike most astronauts, who were mission specialists—scientists or engineers carrying out specific tasks after the launch vehicle had reached orbit—Ivy, with her training as a pilot, was a flight specialist as well, meaning that she knew how to fly rockets. The days of the Space Shuttle

were long over, so there was no need to joystick a winged vehicle back to a runway. But docking and maneuvering spacecraft in orbit was a good clean match for someone with the motor control of a chopper pilot and the mathematical mind of a physicist.

The pedigree was intimidating, even off-putting to people who were impressed by such things. Dinah, who wasn't, cared little one way or the other. Her informal behavior toward Ivy was interpreted by some observers as disrespectful. Two very different women in conflict with each other made for a more dramatic story than what was actually true. They were continually bemused by the efforts made by Izzy personnel, and their handlers on the ground, to heal the nonexistent rift between them. Or, what was a lot less funny, to exploit it in the pursuit of byzantine political schemes.

Four hours after the moon blew up, Dinah and Ivy and the other ten crew members of the International Space Station had a meeting in the Banana, which was what they called the longest uninterrupted section in the spinning torus. Most of the torus was chopped up into segments short enough that the brain could talk the eye into believing that the floor was flat and that gravity always pointed in the same direction. But the Banana was long enough to make it obvious that the floor was in fact curved through about fifty degrees of arc from one end to the other. "Gravity" at one end of it was aimed in a different direction from that at the other end. Accordingly, the long conference table that ran down its length was curved too. People entering into one end looked "uphill" to the opposite end, but experienced no sensation of climbing as they moved toward it. New arrivals tended to expect that anything placed elsewhere on the table would roll and slide down toward them.

The walls were pale yellow. The usual collection of malfunctioning audiovisual equipment purported to show live video streams of people on the ground, in theory enabling them to teleconference with colleagues in Houston, Baikonur, or Washington.

When the meeting began at A+0.0.4 (zero years, zero days, and four hours since the Agent had acted upon the moon), nothing was working, and so the occupants of Izzy had a few minutes to talk among themselves while Frank Casper and Jibran Haroun wiggled connectors, typed commands into computers, and rebooted everything. Relatively new arrivals to Izzy, Frank and Jibran had made the mistake of letting on that they were good at that sort of thing, so they always got saddled with it. Both of them were more comfortable with it anyway than with making chitchat.

"Primordial singularity" were the first words Dinah heard upon gliding into the room. Gravity here was only one-tenth of that on Earth, and "walking" wasn't the right word for how people moved around—it was halfway between that and flying, a sort of long, bounding gait.

The words had been spoken by Konrad Barth, a German astronomer. It was clear from how the others reacted that Ivy, who was sitting directly across the table from him, was the only other person in the Banana who had the faintest idea what he was talking about.

"And that is?" Dinah asked, since that sort of thing had become her role. Others tended to be so worshipful of Ivy, or so reluctant to show ignorance, that they wouldn't ask.

"A small black hole."

"Why 'primordial'?"

"Most black holes are formed when stars collapse," Ivy said. "But there's a theory that some of them were created shortly after the Big Bang. The universe was lumpy. Some of the lumps might have been dense enough to undergo gravitational collapse. They could form black holes that instead of weighing what a star weighs could be a lot smaller."

"How small?"

"I don't think there's a lower limit. But the point is that one of them could zip through space invisibly and punch all the way through a planet and out the other side. There used to be a theory that the Tunguska event was caused by one, but it's been disproved."

Dinah knew about that, because her dad liked to talk about it: a huge explosion in Siberia, a hundred years ago, that had knocked down millions of trees out in the middle of nowhere.

"That was a big deal," Dinah said, "but not enough to blow up the moon."

"To blow up the moon would take a bigger one, going faster," Ivy said. "Look, it's just a hypothesis."

"But it's gone now?"

"It would be long gone now. Like a bullet through an apple."

It struck Dinah as odd that they were talking about such an event so matter-of-factly. But there was no other way to address it. Emotions were not large enough to encompass such a thing. Besides, it was just a visual effect so far, like something seen in a movie with the sound turned off.

"Is it going to affect the tides?" asked Lina Ferreira. As a marine biologist, Lina would naturally be somewhat concerned about the tides. "Since those are caused by the moon's gravity?"

"And by the sun's," Ivy added with a nod and a little smile. Which was why she was in charge of Izzy and Dinah wasn't. She was willing to correct a Ph.D. marine biologist in front of a roomful of people, but she could carry it off in a way that didn't sting. "But the answer is, probably surprisingly little. The moon's mass is still all there, close to where it was before. It's just spread out a little. But the pieces still have the same collective center of gravity, still in the same orbit as the moon had before. Your tide tables will still pretty much work."

Dinah's facial expression was blank, but she was enjoying Ivy's ability to talk about science with a kind of little-nerd-girl sense of wonder even in spite of the disturbing subject matter. This was why Ivy always got the media interviews, while Dinah had to be dragged out of her den of robots and told, over and over again, to smile. The tone of voice was the giveaway; when Ivy was giving orders or reading PowerPoint slides, she went clipped and military, but when she talked about science her face opened up and her voice went into a vaguely Mandarin singsongy lilt.

"Where are you getting all this?" Dinah asked, drawing startled or disapproving glances from a few who worried that she was being too brusque with the boss. "It's only been, what, four hours?"

"There's a lot of noisy comment thread traffic, as you'd expect, and a few ad hoc email lists sort of congealing out of that," Ivy explained.

A blue screen appeared on the lightweight monitor stretched above one end of the long table, and was replaced by a NASA logo. "Okay, got it," muttered Jibran, who made a sideways bound toward a chair.

Then they were looking at the familiar environs of the ISS Flight Control Room, which was at Johnson Space Center in Houston. The director of mission operations was sitting in front of the camera stroking his iPad. He didn't seem to be aware that the camera was on. A few moments later they heard a door open off camera. The DMO, who was ex-military, stood up out of habit. He reached out and shook hands with a woman who entered from stage right: NASA's deputy administrator, the number two person in the whole org chart and a rare sight at such meetings. She was a retired astronaut named Aurelia Mackey, dressed for business in the environment of D.C., where she spent most of her time.

"Are we on?" she asked someone off camera.

"Yes," said several people in the Banana.

Aurelia looked a little startled by that. Both she and the DMO were looking a little stunned to begin with, of course.

"How are you all today?" Aurelia said, in an absolutely rote, businesslike voice, as if nothing had happened. Running on autopilot while her brain caught up with events.

"Fine," said some people in the Banana, mixed in with a few nervous chuckles.

"I'm sure you are all aware of the event."

"We have a good view of it," Dinah said. Ivy shot her a warning look.

"Of course you do," Aurelia admitted. "I would love to have an extended conversation with you all about what you have seen and what you are experiencing. But this is going to have to be brief. Robert?"

The DMO peeled his eyes off the iPad and sat forward in his chair. “We’re expecting an increase in the number of rocks floating around up there.” He meant loose chunks of the moon. “Not huge because most will be gravitationally bound. But some may have escaped. So other missions are suspended while you batten down the hatches. Make preparations for impacts.”

Everyone in the Banana listened silently, thinking about what that would mean for them. They would tighten precautions, dividing Izzy up into separate compartments so that damage to one wouldn’t suck the air from all. They would review procedures. Lina’s biology experiments might take a hit. Dinah’s robots would enjoy a holiday.

Aurelia spoke into the camera. “All spaceflight operations are suspended until further notice. No one is coming up and no one is going down.”

Everyone in the Banana looked at Ivy.

AS SOON AS THEY GOT INTO IVY’S TINY OFFICE, WHERE SHE FELT IT was okay to let tears come into her eyes, they slipped into their Q code.

Q codes were ham radio slang. Dinah had learned them from Rufus. They were three-letter combinations, beginning with Q. To save time in Morse code transmissions, they were substituted for frequently used phrases such as “Would you like me to change to a different frequency?”

Dinah and Ivy’s Q codes didn’t actually begin with Q. But some of them were three-letter combinations.

Uppity Little Shitkicker was a name that had been hung on Dinah when she had first arrived at private school and, during a soccer scrimmage, intercepted a pass meant for a girl from New York.

Straight Arrow Bitch had been bestowed on Ivy at Annapolis when she had declined to take part in a drinking game during a tailgate party.

The ULS/SAB dynamic was a thing that Dinah and Ivy exploited in meetings, even having meetings-before-meetings to plan how to use it.

Good Looks Wasted had found its way to Dinah in the aftermath of her new haircut, as the result of an improbable chain of “Reply to All” mishaps. She had brought it to Ivy, breathless with excitement, and they had enshrined “GLW” in their private codebook.

“I forgot,” when spoken in a breathy, little-girl voice, was a shorthand way of saying “I forgot to put on my makeup,” quoted verbatim from a NASA PR flack.

SAR was from a tart exchange between Ivy and a NASA administrator who, upon reading one of her reports, had criticized her for having an “almost pathological predilection for unnecessary abbreviations.” This had struck Ivy as a bit odd, given that every other word in NASA prose was an acronym. When Ivy had asked for clarification, she had been told that her abbreviations were “schoolgirlish and recondite.”

Space Camp (which both Ivy and Dinah had attended as teens, though at different times) was what they called not just Izzy, but the whole subculture of NASA manned spaceflight.

“What are you going to say to the Maternal Organism?” Dinah asked, as Ivy rummaged in the back of a storage bin for her bottle of tequila.

Ivy stiffened for a moment, then pulled out the bottle and swung it toward Dinah’s head like a club. Dinah didn’t flinch, just watched it glide to a halt above her head. “What?”

“I can’t believe that the Morg has so taken over my wedding that the first thing that comes into your mind is how *she’s* going to react.”

Dinah looked mildly sick.

“Don’t worry about it,” Ivy said, “you forgot.” *To put on your makeup.*

“Sorry, baby. I was just thinking … you and Cal are still going to get married, and have a great life, no matter what.”

“But the Morg is going to take the hit,” Ivy said, nodding, as she poured tequila into a pair of small plastic cups. “Having to reschedule everything.”

"Sounds like she's kind of in her element doing that, though," Dinah said. "Not to minimize it or anything."

"Totally."

"To the Morg."

"The Morg." Dinah and Ivy tapped their plastic cups together and sipped at the tequila. One of the fringe benefits that came of being in the torus was that you could drink normally instead of sucking everything through tubes. The lower gravity took some getting used to, but they were old hands at it by now.

"What's up with your family? Did you hear from Rufus?" Ivy asked.

"My father desires raw data files from Konrad's Wide-Field Infrared Observation Platform, which he has read about on the Internet, so that he can satisfy his personal curiosity about the thing that hit the moon."

"You going to Morse code those down to him?"

"His Internet is working. He has already created an empty Dropbox folder. As soon as I provide him with the files, he'll go back to his usual grousing about how his taxes are too high and the federal government needs to be scaled back to a size where he can personally stomp it to death with steel-toed boots."

WHAT ASTRONOMERS DIDN'T KNOW OUTWEIGHED, BY AN ALMOST infinite ratio, what they did. And for persons used to a more orderly system of knowledge, with everything on Wikipedia, this created a certain perception of incompetence, or at least failure to perform, on the part of the astronomical profession whenever weird things happened in the sky.

Which was every day, actually. But most of them could be seen only by astronomers and so they were able to keep them a sort of trade secret. Blatantly obvious events such as meteorite strikes caused Doc Dubois's phone to sing. The singing usually portended a series of appearances on talk shows where, among other things, he would be asked to explain why astronomers hadn't predicted this. Why hadn't they seen the meteor coming? Wasn't it just the case that they were a bunch of good-for-nothing propellerheads?

A little bit of humility seemed to go a long way, and if the pundits didn't cut him off too soon he was frequently able to work in a plea for more government support of science. For members of the general public might not care about Wolf-Rayet stars in the Quintuplet Cluster, but they definitely saw why having hot rocks fall on one's head was a good thing to avoid.

He always called it the breakup of the moon. Not the explosion. The term began to gain traction on Twitter, with hashtag #BUM. Whatever you called it, it was an infinitely bigger deal than a single meteor strike. So it seemed to demand more explanation. But there was no way to explain it, yet. Meteors were easy: space was full of rocks too small and dark to be seen through telescopes, and some of them snagged on the atmosphere and fell to ground. But the breakup of the moon could not have been caused by any normal astronomical phenomenon. So Doc Dubois—who spent most of the next week on camera—got out in front of that issue at every chance, always leading with a frank statement that neither he nor any other astronomer knew the cause. That was the pitch, straight down the middle. Then he added the spin: This is absolutely fascinating. It is, as a matter of fact, the most fascinating scientific event in human history. It looks scary and upsetting, but the fact is that no one has been killed by it, save for a few drivers who swerved off roads, or rear-ended stopped traffic, while rubbernecking.

At A+0.4.16 (four days and sixteen hours after the breakup of the moon), he had to amend "no one has been killed" when a meteorite, almost certainly a chunk of moon rock, entered the atmosphere over Peru, shattered windows along a twenty-mile track, and smashed into a farmstead, obliterating a small family.

But the message remained the same: let's look at this as a scientific phenomenon and start with what we know. His friend was a video streaming site called

astronomicalbodiesformerlyknownasthemoon .com, which kept a high-resolution feed of the rubble cloud running around the clock. As soon as possible in the interview, Doc Dubois would get that up on the screen and then begin making observations about the cloud. Because making observations calmed people down. The moon had broken up into seven large pieces, which inevitably became known as the Seven Sisters, and an uncountable number of smaller ones. Gradually the big ones acquired names. Doc Dubois was responsible for many of these. He gave them descriptive names that wouldn't scare people. It wouldn't do to call them Nemesis or Thor or Grond. So instead it was Potatohead, Mr. Spinny, Acorn, Peach Pit, Scoop, Big Boy, and Kidney Bean. Doc Dubois would point those out and then draw attention to the way they moved. This was governed entirely by Newtonian mechanics. Each piece of the moon attracted every other piece more or less strongly depending on its mass and its distance. It could be simulated on a computer quite easily. The whole rubble cloud was gravitationally bound. Any shrapnel fast enough to escape had done so already. The rest was drifting around in a loose huddle of rocks. Sometimes they banged into one another. Eventually they would stick together and the moon would begin to re-form.

Or at least that was the theory until the star party that they threw in the middle of the Caltech campus at A+0.7.0, exactly one week after the event.

Normally they held the star parties up in the hills, where the seeing was better, but seeing giant rocks close to the Earth was so easy that there was no need to go to the trouble of driving up into the mountains. It would have undercut the purpose of the event, which was to get as many members of the general public as possible out in a parklike atmosphere to peer through telescopes and make observations. The Beckman Mall was lined with yellow school buses, interspersed here and there with vans from local and network television, their masts deployed so that they could relay live video downtown. Their reporters stood in pools of light, using as backdrop an open green strewn with telescopes of various types and sizes. Little seven-card decks were handed out, each card depicting a different fragment of the moon from various angles and identifying it by its name. Kids were given the assignment to identify each of the rocks through the eyepiece of a telescope, check it off on a homework sheet, and write down an observation about it. Most of the scopes, obviously, were pointed at the Seven Sisters, but one contingent was looking at a darker part of the sky with binoculars or just their naked eyes, expecting to see meteorites. By Day 7, several hundred of these had entered the atmosphere. Or at least, several hundred large enough to be noticed. Most had burned up before hitting the ground. There had been about a score of incidents in which they drew arc-light trails across the sky, illuminating the ground below with freaky bluish radiance and producing huge sonic booms. Half a dozen had struck the ground, doing greater or lesser amounts of damage. The death toll, though, was still far beneath the statistical ground clutter of shark attacks and lightning strikes.

The evening went fine. Doob, who had raised three children to adulthood, had figured out a long time ago that any event largely organized by elementary school teachers was likely to come off extremely well from a logistical and crowd-control standpoint. So he was able to relax and be Doc, autographing Seven Sisters cards for kids and occasionally slipping into Dr. Harris mode for a discussion with a fellow astronomer.

As he wandered about the place, he had three different chance encounters with the same elementary school teacher, one Ms. Hinojosa, and fell in love with her. This was unusual. He had not been in love with anyone in twelve years. He had been divorced for nine. He found it nearly as shocking in its own way as the breakup of the moon. He tried to deal with it in the same way: by making scientific observations of the phenomenon. His working hypothesis was that the breakup of the moon had made Doob young again, exfoliating layers of emotional callus from his soul and leaving a pink shiny impressionable heart just waiting to be colonized by the first appealing woman who came along.

He was talking to Amelia—for that, as it turned out, was her first name—when a buzz moved slowly over the quad, like a gentle breeze, and caused everyone to look up.

Two of the larger pieces—Scoop and Kidney Bean—were headed right for each other. It would not be the first such collision. They happened all the time. But seeing two big chunks heading right for each other with high closing velocity was unusual, and promised a good show. Doob tried to quiet an unsettled feeling in his chest, which might have been caused by what was happening with Amelia, or by the natural trepidation that any sane person would feel upon seeing two enormous pieces of rock getting ready to smash into each other directly overhead. The good news was that people were beginning to treat the evolution of the swarm as a kind of spectator sport, to see it as fascinating and fun, not terrifying.

Scoop's sharper edge slammed into the divot that gave Kidney Bean its name and split it in half. It all happened, of course, in quiet super-slow motion.

"And then there were eight!" Amelia said. Instinctively she had turned away from Doob and toward her brood of twenty-two students. "What just happened to Kidney Bean?" she was asking, in that teacherly way, scanning for upraised hands, looking for a kid to call on. "Can anyone tell me?"

The kids were silent and vaguely sick looking.

Amelia held up her Kidney Bean card and tore it in half.

Dr. Harris was walking toward his car. His phone rang, so startling him that he almost swerved into a school bus. What was wrong with him? His scalp was tingling, and he realized it was his hairs trying to stand up on his head. He checked the screen of the phone and saw that the call was from a colleague in Manchester. He declined to answer it and found himself looking at a new contact that he had been creating for Amelia: a snapshot of her face, just a silhouette in profile against a bank of TV lights, and her phone number. He tapped the Done button.

He had felt that tingling in the scalp once before, on a safari in Tanzania, and had turned around to see that he was being watched, interestedly, by a group of hyenas. The thing that had scared him hadn't been the hyenas themselves. Those, and even more dangerous animals, were all over the place. Rather, it was the sudden awareness that he had let his guard down, that he had been focusing his attention on the wrong thing while the real danger had been circling around behind him.

He had wasted a week on the fascinating scientific puzzle of "What blew up the moon?"

That had been a mistake.

Scouts

"WE NEED TO STOP ASKING OURSELVES WHAT HAPPENED AND START talking about what is going to happen," Dr. Harris said to the president of the United States, her science advisor, the chairman of the Joint Chiefs of Staff, and about half of the Cabinet.

He could see that the president didn't like that. Julia Bliss Flaherty, currently nearing the end of her first year on that job.

The chairman of the JCS was nodding, but President Flaherty was giving him a hard, squinting look, and not just because of the light coming in the window from the skies over Camp David. She thought he was up to something. Trying to shift blame. Trying to push some kind of new agenda. "Go on," she said. Then, remembering her manners, "Dr. Harris."

"Four days ago I watched Kidney Bean break in half," Doob said. "The Seven Sisters became eight. Since then, we've seen a near miss that could have fractured Mr. Spinny."

"I would almost welcome it," said the president, "if we could get rid of those ridiculous names."

"It'll happen," Doob said. "The question is, how long does Mr. Spinny have to live? And what does that tell us?" He clicked a small remote in his hand and brought up a slide on the big screen. Heads turned toward it and he felt a mild sense of relief at not being stared at anymore by the president. The slide was a montage of a snowball rolling down a hill, a fuzzy bacterial culture growing in a petri dish, a mushroom cloud, and other seemingly unrelated phenomena. "What do these all have in common? They are exponential," he said. "The word gets tossed around a lot by people who use it to mean anything that's getting big fast. But it has a specific mathematical meaning. It means any process where the more it happens, the more it happens. The population explosion. A nuclear chain reaction. A snowball rolling down a hill, whose speed of growth is pegged to how much it's grown." He clicked through another slide showing plots of exponential curves on a graph, then to an image of the moon's eight pieces. "When the moon had only one piece, the probability of a collision was zero," he said.

"Because there was nothing to collide with," Pete Starling, the president's science advisor, explained. The president nodded.

"Thank you, Dr. Starling. When you have two pieces, why then, yes, they *can* collide. The more pieces you get, the higher the chances of any two pieces banging into each other. But what happens when they bang into each other?" He clicked the control again and showed a little movie of Kidney Bean's breakup. "Well, sometimes, but not always, they break in half. Which means you have more pieces. Eight instead of seven. Nine instead of eight. And that increase in number means an increase in the odds of further collisions."

"It's an exponential," said the chairman.

"It occurred to me four days ago that it did have all the earmarks of an exponential process," Doob allowed. "And we know what happens to those."

President Flaherty had been watching him intently but she now flicked her eyes over at Pete Starling, who made a dramatic upward zooming gesture with one hand, tracing the profile of a hockey stick.

"When an exponential hits the bend in the hockey stick curve," Doob said, "the result can be indistinguishable from a detonation. Or it can look like a slow, steady increase. It all depends on the time constant, the inherent speed with which the exponential thing happens. And on how we perceive it as humans."

"So it might be nothing," said the chairman.

"It could be that a hundred years will pass before we go from eight chunks to nine chunks," Doob said, nodding at him, "but four days ago I got worried that it might be one of those things that looks more like an explosion. So my grad students and I have been crunching some numbers. Building a mathematical model of the process that we can use to get a handle on the time scale."

"And what are your results, Dr. Harris? I assume you have some, or else you wouldn't be here."

"The good news is that the Earth is one day going to have a beautiful system of rings, just like Saturn. The bad news is that it's going to be messy."

"In other words," said Pete Starling, "the chunks of the moon are going to keep banging into each other indefinitely and breaking up into smaller and smaller pieces, spreading out into a system of rings. But some rocks are going to fall on the ground and break things."

"And can you tell me, Dr. Harris, when this is going to happen? Over what period of time?" the president asked.

"We're still gathering data, tuning the model's parameters," Doob said. "So my estimates could all be off by a factor of two, maybe three. Exponentials are tricky that way. But what it looks like to me is this."

He clicked through to a new graph: a blue curve showing a slow, steady climb over time. "The time scale at the bottom is something like one to three years. During that time, the number of collisions and the number of new fragments are going to grow steadily."

"What is BFR?" asked Pete Starling. For the graph's vertical scale was labeled thus.

"Bolide Fragmentation Rate," Doob said. "The rate at which new rocks are being produced."

"Is that a standard term?" Pete wanted to know. His tone was not so much hostile as unnerved.

"No," Doob said, "I made it up. Yesterday. On the plane." He was tempted to add something like *I am allowed to coin terms* but didn't want things to get snarky this early in the meeting.

Seeing that Pete had been silenced, at least for a moment, Doob tried to get back into his rhythm. "We'll see an increasing number of meteorite impacts. Some will cause great damage. But overall, life is not going to change that much. But then"—he clicked again, and the plot bent sharply upward, turning white—"we are going to witness an event that I am calling the White Sky. It'll happen over hours, or days. The system of discrete planetoids that we can see up there now is going to grind itself up into a vast number of much smaller fragments. They are going to turn into a white cloud in the sky, and that cloud is going to spread out."

Click. The graph continued shooting upward, rocketing up into a new domain and turning red.

"A day or two after the White Sky event will begin a thing I am calling the Hard Rain. Because not all of those rocks are going to stay up there. Some of them are going to fall into the Earth's atmosphere."

He turned the projector off. This was an unusual move, but it snapped them all out of PowerPoint hypnosis and forced them to look at him. The aides in the back of the room were still thumbing their phones, but they didn't matter.

"By 'some,'" Doob said, "I mean trillions."

The room remained silent.

"It is going to be a meteorite bombardment such as the Earth has not seen since the primordial age, when the solar system was formed," Doob said. "Those fiery trails we've been seeing in the sky lately, as the meteorites come in and burn up? There will be so many of those that they will merge into a dome of fire that will set aflame anything that can see it. The entire surface of the Earth is going to be sterilized. Glaciers will boil. The only way to survive is to get away from the atmosphere. Go underground, or go into space."

"Well, obviously that is very hard news if it is true," the president said.

They all sat and thought about it silently for a period of time that might have been one minute or five.

"We will have to do both," the president said. "Go into space, and underground. Obviously the latter is easier."

"Yes."

"We can get to work building underground bunkers for …" and she caught herself before saying something impolitic. "For people to take refuge in."

Doob didn't say anything.

The chairman of the Joint Chiefs of Staff said, "Dr. Harris, I'm an old logistics guy. I deal in stuff. How much stuff do we need to get underground? How many sacks of potatoes and rolls of toilet paper per occupant? I guess what I'm asking is, just how long is the Hard Rain going to last?"

Doob said, "My best estimate is that it will last somewhere between five thousand and ten thousand years."

"NONE OF YOU WILL EVER STAND ON TERRA FIRMA, TOUCH YOUR loved ones, or breathe the atmosphere of your mother planet again," the president said. "That is a terrible fate. And yet it is a better fate than seven billion people trapped on the Earth's surface can hope for. The last ship home has sailed. From now on, launch vehicles will rise up into orbit, but they will not go back for ten thousand years."

The twelve men and women in the Banana sat in silence. Like the destruction of the moon itself, it was too big a thing for them to take in, too large for human emotion to get around. Dinah focused on trivia. Such as: just how damned good J.B.F.—the president—was at saying stuff like this.

"Dr. Harris," said Konrad Barth, the astronomer. "I am sorry, Madam President, but is it possible to get Dr. Harris back into the picture?"

"Of course," said Julia Bliss Flaherty, who, with some reluctance, stepped sideways, making room for the larger frame of Dr. Harris. Dinah thought that he looked shrunken and diminished compared to the famous TV scientist. Then she remembered what he had explained to them a few minutes ago, and felt uncharitable for having drawn that comparison. What must it have been like, to be the only man on Earth to know that the Earth was doomed?

"Yes, Konrad," he said.

"Doob, I'm not disagreeing with your calculations. But has this been peer reviewed? Is there a chance that there is some basic error, a misplaced decimal point, something?"

Harris had begun nodding his head halfway through Konrad's question. It was not a happy kind of nod. "Konrad," he said, "it's not just me."

"We have signals intelligence suggesting that the Chinese figured it out a day before we did," the president said, "and the British, the Indians, the French, Germans, Russians, Japanese—all of their scientists are coming to more or less the same conclusions."

"Two years?" Dinah piped up. Her voice was hoarse, broken. Everyone looked at her. "Until the White Sky?"

"People seem to be converging on that figure, yeah," Dr. Harris said. "Twenty-five months, plus or minus two."

"I know that this is a terrible shock for all of you," said the president. "But I wanted the crew of the ISS to be among the first to know about it. Because I need you. We, the people of the United States and of Earth, need you."

"For what?" Dinah asked. In no sense was she the official spokesman for Izzy's crew of twelve. That was Ivy's job. But Dinah could tell, just from looking at her, that Ivy was in no condition to speak.

"We are beginning to talk to our counterparts in other spacefaring nations about creating an ark," the president said. "A repository of the entire genetic heritage of the Earth. We have two years to build it. Two years to get as many people and as much equipment as we can into orbit. The nucleus of that ark is going to be Izzy."

Absurdly, Dinah felt a mild flicker of annoyance that J.B.F. had appropriated their informal term for the ISS. But she knew how it was. She had spent enough time with the NASA PR people to understand. Things had to be humanized, to be given cute names. All the terrified kids down there who knew they were going to die would have to watch upbeat videos about how Izzy was going to carry the legacy of the dead planet through the Hard Rain. They would take out their crayons and draw cartoon pictures of Izzy with a torus halo and a big rock on her ass and a little anthropomorphic smiley face on the side of the Zvezda Service Module.

Ivy spoke up for the first time in a while. A mere two weeks ago, the postponement of her wedding had seemed a big disappointment. But she had just been told that her fiancé—U.S. Navy commander Cal Blankenship—was a dead man walking and that she would never marry him, never touch him, never see him again except through a video link. To say nothing of everyone else she knew. She looked a little spacey. She was talking in her singsongy voice. "Madam President," she said, "I'm sure you know that there isn't much space up here to accommodate new people. I'm sure this must be a topic of discussion."

"Yes, of course," the president said. "Your job is to—"

"Pardon me, Madam President, can I take this?" Dr. Harris asked. Dinah noted the flick of the president's eyes, the look of shock on her face. The president of the United States had just been interrupted. Shouldered out of the way. As a woman who had made her way up in the world, she probably had some raw nerve endings around that sort of thing.

But this wasn't that. It wasn't J.B.F. asking herself *did he interrupt me because I'm a woman?* They were past all of that now. This was her asking herself *did he interrupt me because the president of the United States doesn't matter anymore?*

"Is Lina there?" Dr. Harris asked. "Pan the camera around please—ah, there you are. Lina, I have read your articles about the swarming behaviors of fish in the Caribbean. Great stuff."

"I didn't know your interests extended to things underwater," said Lina Ferreira. "Thank you."

People were funny, Dinah thought. Talking like this, at a time like this.

"The videos are amazing. They all move in tight formation, until a predator comes through. Then, suddenly, a hole just opens up in the swarm and the predator sails through it and doesn't catch a single fish. A moment later they're back together again. Well, nothing's been decided yet, but—"

"You want to use swarming behavior in the ark?"

"The proposal is called the Cloud Ark," the president cut back in. "And you have it correct. Rather than putting all our eggs in one basket—"

"Eggs … *and sperm,*" Jibran muttered, in his Lancashire accent, so low that only Dinah picked it up.

"We will take a distributed architecture," J.B.F. said, with perhaps too careful enunciation, as if she had learned the phrase ten minutes ago. "Each of the ships that will make up the Cloud Ark will be autonomous to an extent. We will mass-produce them, I am told, and send them up just as fast as we can. They will swarm around Izzy. When it is safe to do so, they can dock together, like Tinkertoys, and people can move from one to the other freely. But when a rock approaches, fwoosh!" And she spread her fingers apart, the purple lacquered nails darting away from one another.

But what about Izzy? Dinah wondered. She thought better of asking just now.

"In order to make ready for that, there are tasks for all of you," the president said. "And that is why I asked the director to join us on this call." Meaning Scott Spalding, the director of NASA. "I'm going to turn it over to Sparky, so that he can walk you through the details. As you can imagine, I have some other concerns to look after, and so I am going to bid you goodbye at this point."

The twelve in the Banana mustered a low murmur of thanks to usher the president out of whatever conference room this transmission was coming from. Someone torqued the camera around until it was pointing at Scott Spalding. He had managed to find a blazer but he was tieless, and probably would be for the remainder of his life. As a young astronaut, Sparky had been slated for an Apollo mission that had been canceled during the budget cutbacks of the early 1970s. He had stuck with the program, getting his Ph.D. during the hiatus in manned spaceflight that followed. His run of bad luck had continued when a planned mission on Skylab was scrubbed because of the spacecraft's untimely descent into the atmosphere. His perseverance had paid off in the 1980s with a series of Shuttle missions that had turned him into a past master of the astronaut corps, equally at home fixing busted solar panels and quoting the poetry of Rainer Maria Rilke. After a couple of decades working at tech startups with varying levels of success, he'd been brought back to NASA a few years ago as

part of some dimly conceived repurposing of the agency's mission. Most of the people in the Banana found him likable, if somewhat opaque, and had the general feeling that he would back them up in a pinch.

Exactly what Rilke poems Sparky thought could address the world's current predicament, it was impossible to guess. For a moment there, after the camera swung around to autofocus on his sagging and creased face, it almost seemed like some poetry might be on the tip of his tongue. Then he shook it off and found the camera's lens with his pale eyes. "Words fail me," he said, "so I am just going to concentrate on business. Ivy, you remain in charge. There's no one better. Your job is to keep things running up there, communicate with us down here, let us know what you need. If after all of that you find yourself with some free time, let me know and I'll find you a hobby." He winked.

And from there he went down the list.

Frank Casper, a Canadian electrical engineer, and Spencer Grindstaff, an American who specialized in communications and who had been doing mysterious work for intelligence agencies, were going to work on establishing the network infrastructure needed to support the activities of the Cloud Ark. Jibran, an instrumentation specialist who was always getting roped into such problems anyway, would work with them.

Fyodor Panteleimon, their grizzled space walk specialist, and Zeke Petersen, a more boyish-looking American air force pilot who also had many hours of experience in space suits, would begin preparing for the arrival of new modules that, they were assured, were being designed and built with un-NASA-like haste and would begin arriving at Izzy in less than a month. Dinah found that time estimate to be ludicrously optimistic until she remembered that essentially all the world's resources were being thrown at this.

Konrad Barth was simply asked to stay on after the meeting for a talk with Doob. It was obvious enough that he would soon be repurposing every astronomical gadget on the space station to the problem of looking for incoming rocks. This was a topic no one wanted to dwell on. If Izzy got hit by a rock of any size, it was all over. In that sense there really was no point in talking about it.

The life scientists were Lina Ferreira; Margaret Coghlan, an Australian woman studying the effects of spaceflight on the human body; and Jun Ueda, a Japanese biophysicist running some lab experiments about the effects of cosmic rays on living tissues. Also in that general category was Marco Aldebrandi, an Italian engineer who focused on the more practical matter of running the life support systems that kept the rest of them alive. Of those four, Lina already had a special status in that she had actually done work on swarming. It wasn't that closely related to what she had been doing on the space station, but now she was going to have to dust it off and make it her life's work. Sparky gave her carte blanche to hole up in a quiet place and cram her brain with papers on that topic for a little while, getting back up to speed. Margaret and Jun were told to put their more abstract research work out the airlock and work under Marco on readying Izzy for a large expansion in population.

That covered eleven of the twelve. So far, Sparky hadn't said a word to Dinah.

Meetings had never been her strong suit. She felt like she was playing an away game whenever she sat down in a conference room. Her awareness of this got in the way and turned into a self-fulfilling prophecy. It had always been thus. The fact that the world was ending changed nothing. As Sparky kept ticking down the list, telling each person what they would be doing in the coming weeks, she kept feeling more and more the point of focus precisely because she hadn't been focused on yet. And when it became clear that she was last on Sparky's list, she had a good long while, as he talked to Margaret and Jun and Marco, to wonder what that meant. Being Dinah, her first assumption was that she was considered so important that she was being saved for last. But by the time Sparky finally spoke her name, she had arrived at a different guess as to what was happening. Her heart was already thumping and her pinkies tingling, her tongue bulky in her mouth.

"Dinah," Sparky said, "you're indispensable."

She knew exactly what this meant, in meeting-speak: they would put her out the airlock if they could.

"You have such a wide range of capabilities and we all admire your attitude so much."

Sparky hadn't said a word to anyone else about their attitude.

"Obviously, asteroid mining—which you've devoted so much of your career to—is a project with a long-term payoff. But we are in short-term mode now."

"Of course."

"I am detailing you to assist Ivy and look for ways that you can put your amazing skill set to use in supporting the activities of the others. Fyodor and Zeke can only go on so many space walks. Maybe your robots can be put to use doing things that they can't."

"As long as it involves cutting through iron, they'll be awesome," Dinah said.

"Sounds great," Sparky said, missing the sarcasm entirely. In his own mind he was finished with the conversation, tolerating a few moments' small talk before the after-meeting with Doob and Konrad.

Dinah thought better of herself than this. How could she let herself get into this frame of mind at such a time?

Because maybe there was actually a good reason for how she was feeling.

She was halfway through saying goodbye to Sparky when she pivoted back. "Hang on a sec," she said. "I respect what you said about short-term mode. I get that. But if, or when, this Cloud Ark thing works, you know what's next, right?"

Sparky was in no mood. Not so much annoyed with her as bewildered. "What's next?"

"People need a place to live. And if the surface of the Earth is going to be burned off, we're going to have to make those living places up here, out of stuff we can get our hands on. Asteroids. Of which we have a lot more now, thanks to the Agent."

Sparky put his hands over his face, exhaled, and sat motionless for about a minute. When he took his hands away, she could see he'd been weeping. "I wrote half a dozen goodbye letters to old friends and family before this meeting," he said, "and when it's over I'm going to keep working my way down the list. Maybe I'll write half of all the letters I want before their intended recipients get killed by the Hard Rain. The point being, I guess, that I am thinking like the dead man walking that I truly am. Which is wrong. I should be thinking about what you are thinking about. The future that you and a few others may look forward to if all of this other stuff works."

"You really think we're looking forward to it?"

Sparky winced. "Not in the sense of thinking that that future's going to be great but in the sense of at least thinking about it. I don't disagree with you. But what do you want me to do now?"

"Watch my back," Dinah said. "Don't let them ditch Amalthea. Don't let them cut up all of my robots for spare parts. You want me to work on other stuff for a while, fine. But when the sky turns white and the Hard Rain begins to fall, the Cloud Ark needs to have a viable program for making things out of asteroids or else there is no way people are going to stay alive up here for thousands of years."

"I have your back, Dinah," said Sparky, "for what that is worth." And his eyes strayed in the direction of the door through which the president had exited.

AT A+0, THE TWELVE-PERSON CREW OF THE INTERNATIONAL SPACE Station had included only a single Russian: Lieutenant Colonel Fyodor Antonovich Panteleimon, a fifty-five-year-old veteran of six missions and eighteen space walks, the éminence grise of the cosmonaut corps. This was unusual. In the early years, out of the ISS's usual crew of six, at least two had normally been cosmonauts. The addition of Project Amalthea and of the torus had expanded the station's maximum capacity to fourteen, and the number of Russians had typically varied between two and five.

The moon had disintegrated only two weeks before Ivy, Konrad, and Lina had been scheduled to return home, to be replaced by two more Russians and a British engineer.

Since that rocket and its crew were ready to go anyway, Roskosmos—the Russian space agency—went ahead and launched it from the Baikonur cosmodrome on A+0.17.

The Soyuz spacecraft docked at Izzy's Hub module without incident. Unlike Americans, who liked flying things by hand, the Russians had made docking into an automated process a long time ago.

The Soyuz—the workhorse, for decades, of human space launch—was a stack of three modules. At its aft end was a mechanical section containing engines, propellant tanks, photovoltaic panels, and other equipment that didn't require an atmosphere. Its forward section was a more or less spherical vessel meant to be pressurized with breathable air, and containing enough empty space for cosmonauts to move around, work, and live. In the middle was a smaller bell-shaped section containing three couches where the space-suited occupants would ride into space and later descend back to Earth cloaked in a fiery comet tail. Accommodations in that section were extremely cramped, but it didn't matter since it was only used briefly during launch and reentry; the orbital module, which was the larger sphere on the front, was where the cosmonauts spent most of their time. And on its nose was the mating contraption that enabled it to connect with the space station, or any other object suitably equipped.

Until a couple of years ago the Soyuz capsules had usually docked at the aft end of the Zvezda module, which had been the "tail" of the ISS. More recently a new module called the Hub had been attached to the Zvezda, extending the main axis of the space station "rearward," and providing the axle around which the torus revolved. In order to maintain compatibility with the ubiquitous and time-tested Soyuz, the Hub had been equipped with a suitable port and hatch.

Since the other eleven were busy with the tasks that Sparky had given them, Dinah floated "aft" down the whole length of Izzy—for her shop was attached to its "forward" end—and opened the docking hatch to greet the new arrivals. She was expecting to see a few humans floating free in the orbital module of the newly arrived Soyuz. Instead she saw the head and arm of a single cosmonaut, whom she vaguely recognized as Maxim Koshelev. He was embedded in a nearly solid mass of vitamins.

"Vitamins" was a term of art used by spaceflight geeks to mean any small, lightweight stuff of extraordinary value. Microchips, medicine, spare parts, ukuleles, biological samples, soap, and food all fell under the general heading of "vitamins." Humans, of course, were the most important vitamin of all, unless you were one of those who believed that all space exploration should be conducted by robots. Dinah had sat in many a conference where her colleagues in the asteroid mining industry had argued passionately that rockets, which were so expensive, should *only* be used to transport vitamins. Bulk materials such as metals and water should never be launched from the ground; they ought to be obtained from the billions of rocks that were wandering around in space already.

A sealed box of hypodermic syringes tumbled out and caromed off her forehead, followed by a vac-packed bag of lithium hydroxide gravel, a bottle of morphine, a reel of surface-mount capacitors, and a rubber-banded bundle of number two lead pencils, presharpened. Once Dinah had pawed those out of the way she was able to more fully take in the scene: Maxim, jammed in a narrow human-sized tunnel through a mass of vitamins that had been packed into the Soyuz until it couldn't hold any more.

Someone down in Tyuratam had had the foresight to cram in a few folded-up garbage bags. Taking the hint, Dinah peeled one of them open and used it to corral all the items that had escaped so far and were threatening to go on a random walk around Izzy. Then she began raking out more. Lots of stuff escaped, but most of it went into the bag. Maxim eased himself out into the Hub for a stretch. He'd been crammed into this thing for six hours. Dinah, who was smaller, went into the space he'd vacated and began throwing vitamins out to him; he just held up a garbage bag to catch them.

After a minute she excavated a human thigh in a blue jumpsuit, then a shoulder, then an arm. The arm moved and pushed more vitamins at her, exposing a face that Dinah recognized from having scanned her Wikipedia entry half an hour ago. This was Bolor-Erdene, a woman who had once been rejected from the cosmonaut program because she was too small to fit into any of the standard space

suits. She was riding in a couch that had clearly been jury-rigged for the purpose. It was strapped to a part of the orbital module called the Divan with an improvised scheme of cargo webbing that was still dusty from the roads of Kazakhstan. Dinah wondered if it was the last dirt she would ever see, then tried to suppress that thought.

So, both Bolor-Erdene and Maxim had ridden in the orbital module, which was unprecedented; humans were supposed to ride only in the reentry module aft of it.

It would have been indiscreet to point this out, but those two, by riding up front, had signed up for a one-way journey that could have turned into a suicide mission had anything gone wrong. The orbital module was jettisoned during the reentry process, and burned up in the atmosphere. Only the passengers in the reentry module could even theoretically make it back alive.

The vitamin bagging proceeded through the hatch into the reentry module and went viral as faces and arms were freed. In the three couches, where humans were *supposed* to ride, were the two other scheduled cosmonauts, Yuri and Vyacheslav, and the Brit, who was named Rhys.

Bolor-Erdene, Yuri, and Vyacheslav took their first chance to unstrap and move up through the orbital module into the Hub. Rhys requested that he be given a moment.

Dinah went into the Hub to greet the other four. In normal times these moments were at least a little bit ceremonious, with the new arrivals being greeted with hugs, or at least high fives, as they glided through the hatch, and photographs taken. The impending deaths of everyone on Earth cast a bit of a pall over this occasion, but Dinah felt she should at least say a few words to each of them.

Bolor-Erdene urged Dinah to address her as Bo. She was obviously of Far Eastern stock, and yet there was something in her eyes and cheekbones that did not look precisely Chinese. Dinah's preliminary googling had already told her that Bo was Mongolian.

Yuri and Maxim were coming to ISS for their third and fourth times, respectively. Vyacheslav seemed to be a last-minute substitution for a younger cosmonaut who would have been making his first trip to the ISS. Vyacheslav had done two previous stints. So, all the Russians except for Bo were old hands at this, and once they had exchanged brief greetings with Dinah they glided through the middle of the Hub, looking about curiously since some of them hadn't seen it before, and then through the hatch into the Zvezda module, which was like home to them. They exchanged clipped remarks in Russian of which Dinah understood about 50 percent. Everyone who worked on Izzy had to have at least working knowledge of Russian.

Rhys Aitken was an engineer who had made a career of building strange new constructs, usually for wealthy clients. Until seventeen days ago, his mission had been to lay groundwork for the addition of a second, larger torus, built around a newer Hub aft of the existing one and intended for space tourists. This was part of a public-private partnership between NASA and Rhys's employer, a British billionaire who had been one of the early movers in the space tourism industry. Rhys had a new mission now, but he was still a perfect fit for the job.

Dinah went back through the orbital module and peered through the hatch at him, lying there patiently motionless in his couch.

"First time in space?" Dinah asked him, though she already knew the answer.

"Don't you have Google up here?" he responded. From an American it would have been simply obnoxious, but Dinah had spent enough time around Brits to take it as intended.

"You just don't seem very eager to explore your new home."

"I'm stretching it out. The process of discovery. Besides, I was warned not to move my head."

"To avoid nausea. Yeah, that's good advice," Dinah said. "But you have to move it eventually." A loose packet of cucumber seeds, stenciled in Cyrillic, floated past her head. She plucked it carefully out of the air. Finding herself in range, she stuck out her hand. "Dinah," she said.

"Rhys." He extended his hand while gazing rigidly ahead, as he'd been instructed. But in the time-honored manner of most human males, he allowed his eyeballs to swivel her way so that he could check her out, then turned his head so that he could check her out better.

"You're going to regret that," she said.

"Oh, my goodness," he exclaimed.

"You have a few minutes before it all comes up. Come on out, I'll get you a bag."

DURING ONE OF MANY RECENT SLEEPLESS "NIGHTS," DINAH HAD found herself worrying about transistors. Modern semiconductor technology had found a way to make them very small. So small that they could be destroyed by a single hit from a cosmic ray. This didn't much matter down on the ground, because the stakes were lower and cosmic rays were mostly blocked by the atmosphere. But electronics that had to work in space were a different matter. The world's military-industrial complexes had put a lot of money and brainpower into making "rad-hard" electronics, more resistant to cosmic ray strikes. The resulting chips and circuit boards were, by and large, clunkier than the sleek consumer electronics that earthbound customers had come to expect. A lot more expensive too. So much so that Dinah had avoided using them at all in her robots. She used cheap, tiny off-the-shelf electronics in the expectation that a certain number of her robots would be found dead every week. A functional robot could carry a dead one back to the little airlock between Dinah's workshop and the pitted surface of Amalthea, and Dinah could swap its fried circuit board out for a new one. Sometimes the new one would already be dead, struck by a cosmic ray while it was just sitting there in storage. But the vitamins shipped up on the ISS supply missions always had more of them.

The only shielding from cosmic rays was matter. A thick atmosphere such as Earth's would do the trick, or a much thinner bulwark of solid heavy material. Of course, Dinah happened to have one in the form of Amalthea itself. Any object nestled up against Amalthea's surface would be shielded from cosmic rays coming from roughly half of the universe—the half blocked from view by the asteroid. For the same reason, the ISS was always shielded by the Earth from any cosmic rays approaching from that direction. So there was a sweet spot, on the side of Dinah's shop that faced toward Earth but was "under" the bulk of Amalthea, where cosmic rays could only squirt in from a relatively narrow band of space. Dinah stored her spare chips and circuit boards in that general area, just to improve their odds, and she limited the amount of time that her robots spent roaming about on the side of Amalthea that faced deep space.

In clear view of her window was a hollow in Amalthea's side, perhaps an ancient impact crater, big enough to accommodate a watermelon.

On Day 9—five days before the conference in the Banana when Doc Dubois had told them about the Hard Rain and the president had told them that they were never coming home—she had programmed several of her robots—the ones with the most effective cutting heads—to begin making that hollow deeper. Perhaps she'd had a premonition of what was about to happen. Or perhaps she was just doing her job; mining robots would need to have the ability to carry out programmed activities such as boring tunnels into rock, and it was high time she began experimenting with such tasks.

But after that conference in the Banana, she had gone back to her little shop and, as an alternative to crying all night or sticking her head out the airlock, she had altered the program that those little robots were following and told them to begin bending the tunnel, curving it gently as it delved into the asteroid. Until then, the robots had been moving directly away from her and she'd been able to look through her tiny quartz window, into the watermelon-sized hollow, and straight down the tunnel that the robots were cutting. She had to flip a welding glass down over the window when she did this because they were cutting with plasma arcs whose brilliant purple light would burn her eyes. But by the time that the five new arrivals got to Izzy on A+0.17, the robots had disappeared around the bend in the tunnel that they had made. The universe could not see them. Cosmic rays ran in straight lines, like light, and they could not negotiate that bend.

Dinah had them carve a little hollow into the side of that tunnel: a storage niche. She packaged up all of her spare chips and PC boards into a bundle. It was a small one, given how tiny and powerful modern chips were—a cube small enough to hold in one hand. Normally this would have been a bad idea—a single cosmic ray might shoot through the entire stack and kill every board at once.

She handed it off to an eight-legged robot and sent that robot through the airlock and down the tunnel. Seeing through the remote eye of its video camera, manipulating a data glove connected to its grappling arms, she maneuvered it into the niche and then made it splay out its arms and go rigid so that it couldn't drift out. Her transistors were now safe.

Rhys watched her do it. He had been on Izzy for five hours. He was too sick to do anything except lie very still. Dinah, whose shop was full of zip ties and clamps and other useful devices, had helped him wedge his head between a couple of pipes, padding them with foam to make it a little more comfortable. She had left him with a supply of barf bags and gone about her work.

"What do you call that type?" he asked.

"A Grabb," she answered. "Short for Grabby Crab."

"Good name, I suppose."

"It's the most obvious body type for something that's meant to pick its way around on a rock. Each leg has an electromagnet on its tip, so it can stick to Amalthea, which is mostly iron. When it wants to pick up that foot, it just switches off the magnet."

"I'm sure you've already thought of this," Rhys said delicately, "but you could hollow out the whole asteroid this way. Create a shielded environment. Maybe even fill it with air."

Dinah nodded. She was busy, placing the Grabb's eight arms one by one, making sure each of them was stuck to a wall of the niche. It would be embarrassing if all of her vitamins floated out and got lost. "We've discussed it. Me and the, like, eight thousand engineers on the ground who are working on this."

"Yes, I didn't suppose it was a solo effort."

"The constraint is working gas. The plasma cutters are very powerful, but they require some gas flow. Almost any gas will do. But industrial gases are rare and valuable up here, and they have this annoying habit of escaping into space."

"But if you were hollowing something out, as opposed to working on its surface—"

"Exactly," Dinah said. "You could seal the exits and recapture the used gas, and recycle it."

"So you're way ahead of me, in other words."

Dinah's upper face was obscured in a VR rig but a smile spread below it. "That's the thing about space," she said. "So many smart people are so interested in it that it's difficult to come up with a really new idea."

There was a pause in the conversation while she switched control to a different robot and got it moving down the tunnel.

"Moving my eyeballs oh so slightly, I see at least three other morphologies in your bestiary."

"The Siwi is adapted from a robot that was made for exploring collapsed buildings. Which in turn was obviously adapted from a snake."

"A sidewinder, presumably, given the name."

"Yeah. The electromagnets are arranged around the Siwi's body in a double helix, so by turning some on and others off, it can sort of roll diagonally along the surface with minimal power usage."

"The thing that looks like a Buckyball seems to be using a similar trick."

"You nailed the name. We do in fact call those Buckies. Technically speaking, it's a thing called a—"

"Tensegrity."

Dinah felt herself blushing. "Of course, you'd know all about those. Anyway, because it's big and roughly spherical, it can roll in any direction by playing tricks with electromagnetics and making its struts get longer or shorter. The brains live in that sort of nucleuslike package suspended in the middle."

"Grabbs, Siwis, and Buckies. What do you call the tiny ones?"

"Nats. Our attempt to build a swarm. Lina's been moonlighting on it."

There was a little gap in the conversation while both of them considered the unfortunate choice of wording.

"It's pretty experimental still," Dinah continued. "But the idea is that they can latch on to each other as needed, like ants making an ant-ball to cross a river. I know this must all seem pretty weird. It's not normal engineering."

"I'm not a normal engineer. I've been doing biomimetics—which is what you are doing—for a while. Except I build things that stand still."

"Okay. You get it then." Dinah peeled off the 3-D goggles she'd been using to see through the eyes of the Grabb. The second robot, the Siwi, had perched itself in the tunnel behind the Grabb and raised its head, cobralike, to shine light on it and shoot video. Gazing at the flat-panel screen, Dinah made the Siwi pan back and forth to inspect the Grabb's position, ensuring there was no way those circuit boards could drift away.

"Yes. I get it," Rhys said. Then he added, "It's not for me to tell you your business. But you know what hermit crabs do, don't you?"

It took Dinah a few moments to access the memory. She had never been a beach kind of person. "They use the discarded shells of other crabs as shelter."

"Not of other crabs, but of mollusks. But yes, you have it."

Dinah thought about it for a moment, then turned to look at him. He seemed slightly less green and sweaty than before. "I think I see where you are going."

"Better yet," Rhys said, "consider the foraminifera."

"What are they?"

"The biggest single-celled organisms in the world. They live beneath the Antarctic ice. And as they grow, they take grains of sand from their environment and glue them together to form hard outer skins."

"Sort of like Ben Grimm?" she asked.

It was a throwaway reference to a comic book character, the armor-plated member of the Fantastic Four. She didn't expect him to pick up on it. But he shot back: "To name another cosmic ray victim, yes. But without the alienation and self-pity."

"I always wanted skin like the Thing."

"It wouldn't suit you nearly as well as the skin God gave you. But as a way for you to protect your robots from cosmic rays, while giving them the freedom to roam around—"

"I think I'm in love," she said.

He clapped a bag over his mouth and threw up.

HOW DO YOU TELL THE WORLD THAT IT'S GOING TO DIE? DOOB WAS glad he didn't have to say it. Instead he just stood behind the president of the United States. His job was to look serious—which wasn't difficult—as part of a Mount Rushmore of eminent scientists lined up behind a semicircle of world leaders. He stared at the back of J.B.F.'s head as she explained it into a teleprompter. Bracketing her were the Chinese and the Indian presidents, saying the same things at the same time in Mandarin and Hindi. Fanning out into the wings were the prime ministers of Japan, the United Kingdom, France, and (acting as a sort of proxy for most of Latin America, as well as his own country) Spain; the chancellor of Germany; the presidents of Nigeria, Russia, and Egypt; the pope; prominent imams from the main branches of the Islamic faith; a rabbi; and a lama. The announcements were made simultaneously, so that as much of the human race as possible would hear the news at the same instant, and not have to await translations.

If the task had fallen to Dubois Jerome Xavier Harris, Ph.D., he would have said something like this: Look, everybody dies. Of the seven billion people now living on Earth, basically all will be dead a hundred years from now—most a lot sooner. No one wants to die, but most calmly accept that it's going to happen.

A person who died two years from now in the Hard Rain would be no deader than someone who died seventeen years from now in a car crash.

The only thing that had changed now was that everyone knew the approximate time and manner of their death.

And knowing that, they could make preparations. Some of those were internal: making your peace with your God. Others had to do with passing on one's legacy to the next generation.

And that was where things got interesting, because none of the traditional legacy-passing schemes was going to survive the Hard Rain. There was no point in drawing up a last will and testament, because all of your possessions were going to be destroyed along with you, and there would be no survivors to receive them.

The legacy was instead going to consist of whatever the people of the Cloud Ark did in the centuries and millennia to come. The Cloud Ark was the only thing that mattered.

They did it at Crater Lake, Oregon. The State Department had commandeered the rustic lodge perched high above the lake on the crater's rim, flown in the dignitaries, crammed the nearby campgrounds and parking lots with security and media and logistics. At this very moment, marines out on the highway were turning back disappointed holidaymakers, telling them the park was closed, letting them know that they should turn on their radios and listen to the news if they really wanted to understand why. To put the disruption of their vacations into perspective.

The weather was clear, which meant it was cold. The lake down in the crater was the purest blue Doob had ever seen, the sky above it a lighter tint of the same color. He and all the others stood with their backs to it during the announcement. Some political genius on the president's staff had figured out just how the imagery was supposed to work. The cameras were up on a scaffolding so that they could shoot downward, ensuring that the panorama of the crater, Wizard Island with its sparse covering of trees, and the snow-streaked mountain rim were all there in the high-definition backdrop of the shot. The message was there for anyone who wanted to read it. Between six and eight thousand years ago, an unimaginable catastrophe had befallen this place. The surviving humans had kept the story alive in legends of an apocalyptic struggle between the gods of the sky and of the underworld. Now, it was beautiful. The president and some of the other leaders were weaving that story into their announcements. Doob and the scientists around him—professors from great universities all over the world—couldn't hear what was being said. The leaders were projecting their words outward into the world, and the sounds coming out of their mouths were swallowed up in the rushing of the wind over rocks and through trees. Doob, four meters behind the president, watched the wind mess with her hair. J.B.F.'s hair had been much commented on during the days before Zero, when such things had actually seemed important to commentators in the world of fashion and politics. It was dusky blond, streaked with silver. She wore it straight and shoulder-length. She was forty-two years old, which made her the youngest president of the United States, edging out J.F.K. by a year. She had flirted with politics during her student years at Berkeley but then opted for an M.B.A. and a stint with a high-powered business consultancy before taking a job at a clever but struggling Los Angeles tech firm. Under her leadership the company had turned its fortunes around to the point where it had been acquired by Google in a deal that had made her wealthy. She had married an actor turned producer, ten years older, whom she had met at a dinner party in Malibu. He already had dogs in various political fights, since a number of his films had been overtly political documentaries or thrillers with political overtones. Latino, with some family history of persecution under Castro, Roberto was something of a political chameleon, mixing libertarianism and populism in a way that intrigued both sides without repelling anyone save the most hard-core extremists. He got away with it because he was handsome, charming, and, as he freely admitted, not book-smart enough to puzzle out all the issues.

Having thus settled into a family life, and made a much-discussed decision to keep her maiden name, Julia Bliss Flaherty had swung her sights around to politics. She had narrowly lost a senatorial race in California. Visibly pregnant by the time Election Day arrived, she had soon given birth to

a baby with Down syndrome and become a human Rorschach blot for all sorts of angst around amniocentesis and selective abortion. Making the rounds of talk shows to discuss those topics, she had drawn the eye of national political campaigns on both sides of the aisle. During the following presidential campaign, she had found herself in the unusual position of being on both parties' vice presidential short lists. She was staunchly middle-of-the-road, with enough ambiguity in her politics to extend the Democrats' reach rightward and the Republicans' leftward. No one had expected her to end up in the Oval Office; that was never seriously expected, nowadays, of vice presidents. But the scandal that had brought down the president in only the tenth month of his inaugural year had elevated her to the presidency and made her hairstyle fair game for dissertation-length treatments in the press. Much of it was about those glints of silver. Were they natural, or artificial? If natural, why didn't she get rid of them? The technology existed. If artificial, then wasn't it really just a sneaky trick to make her look older, more serious? Either way, should a woman in today's society need to make herself look matronly in order to be taken seriously?

Doob was pretty sure that no such articles would ever again be written after the announcement that J.B.F. was making today. And indeed he felt the requisite shame over the fact that he was paying any attention whatever to the president's hair, on this of all days.

But this was how the mind worked. The mind couldn't think about the End of the World all the time. It needed the occasional break, a romp through the trivial. Because it was through trivia that the mind was anchored in reality, as the largest oak tree was rooted, ultimately, in a system of rootlets no larger than the silver hairs on the president's head.

The announcements all started at the same time but some went on longer than others, the imams and the pope segueing into prayers. The president and other secular leaders, having finished their remarks, stood there uncomfortably for a minute or two, then began to shuffle away toward aides who enveloped them in big warm coats. Doob and the other scientists, as much a part of the backdrop as Crater Lake, were obliged to remain in place until the last prayers ended.

He thought he might come up here with Amelia and watch it happen. It would be a fine place to observe the White Sky and the beginning of the Hard Rain. During the announcement, he had seen a single bolide streak across the sky south of them, a trail of white fire bright enough to leave a slow-fading blue streak in his vision, popping apart into two, then five discrete chunks before it all went over the horizon. It was too far away for him to feel its radiant heat on his face. But people who had been closer to recent events reported that the warmth was palpable. It was also fleeting, since the bolides came and went at hypersonic velocities. But when the Hard Rain began in earnest, they'd be coming in thick and fast, their fiery trails crisscrossing the sky and then merging into a continuous sphere of broiling heat. Even those people who were fortunate enough—if that was the right word—not to get hit directly by a rock would be driven beneath cover. And it would have to be something like a sheet of metal that would reflect heat and not catch fire. That would buy them some time, but soon the air itself would become too hot to breathe. He had been wondering at what point during all of that he should just end his own life.

It was three weeks and a day since the disintegration of the moon, and a mere twelve days since he had convinced himself that the Hard Rain was going to happen. He was astonished in a way that the world's leaders had responded so quickly. But they had been driven to it by the spread of rumors. The same calculations had been made by astronomers all over the world. They were accustomed to working in the open, sharing their ideas on email lists. Anyone who really wanted to know, and who had an Internet connection, could have learned about the Hard Rain a week ago. The president and the other leaders, he reckoned, had been impelled to do this sooner rather than later so that they could focus openly on the development of the Cloud Ark.

And also so that they could give the peoples of the world some agency. Not to be confused with the Agent that had torn up the moon. "Agency," in the lingo of the sorts of people who had set up this announcement, meant giving people options, giving them some things that they could do to have an

effect—imaginary or not. There was nothing they could do, of course, about the Hard Rain. And very few of them could contribute on a technical level to the Cloud Ark—there were only so many people qualified to go on space walks or assemble rocket engines, and those had already been mobilized.

But there were things that people could do to help the Cloud Ark achieve its mission, and thereby become a part of the legacy that would be carried forward into space.

Once the announcements and the prayers were finished, three people converged on the central lectern where the president had spoken a few minutes earlier. They were going to talk in English and their words would be translated into as many languages as the organizers had been able to find interpreters for. First up on the dais was Mary Bulinski, the United States secretary of the interior, an inveterate hiker and climber, spry at sixty. By training she was a wildlife biologist. Next was Celani Mbangwa, a big South African woman and a well-regarded artist. Last was Clarence Crouch, the Nobel Prize–winning geneticist from Cambridge, moving slowly on a cane because his own genes had played a nasty trick on him and he had come down with colon cancer. He was being assisted over the rocky ground by one of his postdocs, Moira Crewe, who never seemed to leave his side. Clarence's wife had committed suicide ten years ago and King's College was the only thing that was keeping his body and his soul together.

They had all been made aware of what was going to happen several days ago so that they would have some time to recover from the shock and make themselves presentable on television. They had been flown as soon as possible to Oregon and ensconced in rooms at the lodge on the rim. Doob and other scientists, filtering in from all over the world, had set up a kind of war room in a meeting room downstairs, trying to figure out what exactly Mary and Celani and Clarence were going to say. Because that was an essential part of the announcement. No one was really expecting mass panic or chaos. There would be some of that, of course. But billions of people would want to know how they could be useful. And some answers needed to be provided for them.

And so it didn't matter that Mary and Celani and Clarence were standing with their backs to Doob and talking into a cold wind, because he knew what they were going to say, had gone over the text a hundred times.

Mary's piece of it was to talk about how the Cloud Ark was going to preserve the genetic legacy of the Earth's ecosystems, largely in digital form. They couldn't send giraffes into space, or keep them alive once up there, but they could preserve samples of their tissue. Space was a pretty effective refrigerator. Better yet, the genetic sequences could be recorded by feeding samples into machines, taking the DNA strands apart one base pair at a time, and preserving them as strings of data that could easily be archived and replicated. Special machines would be sent up on the Cloud Ark, machines that could take those digital records and turn them back into functioning DNA and embed them in living cells, so that giraffes and sequoias and whales could be reconstituted from raw elements at some point down the road, perhaps thousands of years in the future. How could ordinary people help? By collecting samples of living things in their environment, especially rare or unusual ones, and taking pictures and GPS readings with their smartphones, and sending them to certain addresses, postage free.

In a way Mary had the hardest job, because this part of the plan was utter BS and she had to know it. Biologists had long ago collected all the samples that mattered. All the flowers and raccoon skulls and bird feathers and sticks and snails that got mailed to those addresses by helpful kids would end up being destroyed. All the genetic sequencing machines were already operating full tilt, around the clock, and the machines that made more of those machines were doing likewise. Nevertheless, she managed to sell it, or so Doob guessed from the set of her shoulders and the movements of her head as she spoke into the teleprompter.

Celani's job was to convince the people of the world that they could contribute to a literary, artistic, and spiritual legacy that would outlive them. All the world's books and websites were already being archived. What was wanted now was for people to write stories and poems, draw pictures, or

simply aim cameras at themselves and shoot photos or videos that would one day be browsed by the distant descendants of the Cloud Ark pioneers. This was an easier thing to explain convincingly, since it was legitimate, and simple. Archiving lots of digital files and sending them into space was straightforward.

Clarence, the last up, had some explaining to do.

Doob knew the text of his talk by heart. They had discussed various ways of saying this, but Clarence had gravitated toward the High Church phrasings that came naturally to him.

"The time has come for a great Casting of Lots," he announced. "The Lord has seen fit to populate the Earth with people of many colors and kinds. A burden has now been laid on us, as it was once laid on Noah. Like him we must populate our Ark in a manner respectful of the diversity of life around us. Mary Bulinski has already spoken of how we will preserve the legacy of the world's plants, animals, and other life-forms. We will not do this as Noah did, by bringing them aboard the Ark two by two. There is not room for them, and there is no way to keep them alive. We go another way where the plants and the animals are concerned.

"The peoples of the world are a different matter. We will need people in that Ark. It is not an automatic mechanism. It will require the ingenuity and adaptability of human minds. We will populate it. We will begin with astronauts, cosmonauts, military, and scientists whose skills are needed. But there are only so many of those, and they are drawn from only a small portion of the world's peoples."

This question—how many?—had bedeviled them all along. In two years, how many humans could be launched into space, assuming that rocket factories all operated full-time, and we weren't too fussy about safety procedures? Estimates varied through two orders of magnitude, from a few hundred to tens of thousands. They had no idea. And it was one thing to get them up there and another thing to keep them alive. The most solid estimates that Doob had seen were converging on a number somewhere between five hundred and a thousand. But they had carefully scrubbed Clarence's speech of any specific numbers, or even hints.

"We ask every village, town, city, and district to perform a Casting of Lots and to choose two young persons, a boy and a girl, as candidates for training and inclusion in the crew of the Cloud Ark. We do not seek to impose any rules or procedures upon how the selection is made. Our objective is to preserve, as best we can, the genetic and the cultural diversity of the human race. We trust that the candidates selected will exemplify the best features of the communities from which they were chosen."

The statement was subtly self-contradictory. Clarence was saying that they were not going to impose any rules. But they had already done so by insisting that there had to be both a boy and a girl. They knew perfectly well that many cultures would have trouble with that.

"The boys and the girls so chosen," Clarence went on, "will be gathered together in a network of camps and campuses, where they will be trained for the mission they are to undertake, and launched into the Cloud Ark as room is made for them."

Doob, aware that he might be in the background of some camera angle, did his best to maintain a poker face. Clarence wasn't exactly lying. But he was leaving a lot out. How many boys and girls would end up in those camps? More than could be transported to or accommodated in any conceivable space ark. How many of them could really be trained to do anything useful?

In reality it would be much more selective than Clarence made it sound. Only some of those chosen in the Casting of Lots would actually be collected. Those belonging to rare or distinctive ethnic groups probably had a leg up. Once they got to the training center, they would begin to understand that not all of them were actually going to get launched into space before the Hard Rain. It would get competitive. Perhaps brutally so. Doob didn't like to think about it.

For the thousandth time in the last three weeks, he mused about how funny the mind was. It didn't matter that conditions in the training camps might become unpleasant. It was nothing. And

yet the thought of young persons being cruel to each other upset him more than the fact that most of them were going to die.

A curtain twitched up in a window of the lodge, and Doob looked to see Amelia, arms crossed, elbows on the windowsill, looking down at him from the room they had shared the last three nights. She had stayed inside so that she could watch it on the TV in the room, let him know how it had looked on video, how the commentators and pundits had framed it.

It was Thanksgiving week. School was out. She'd flown up to Eugene on Wednesday, rented a car, and driven here to be with him.

The staff at the lodge, still unaware of what was about to happen, had served the traditional turkey dinner on Thursday afternoon. The scientists, politicians, and military who had come here from all over the world to contemplate the end of days had tried to see the humor in the holiday. In a way, though, Doob actually *was* thankful. He was thankful that Amelia had come up to spend time with him. He was thankful that she had shown up in his life at exactly the moment when he most needed to have someone around.

On Day 7, when he had met Amelia and fallen for her in the same instant, he'd felt foolish. He'd wondered what was going on in his brain for it to react so. But she'd let him know, in the correct, even steely manner of an elementary school teacher, that the interest was reciprocated. The school where she taught was less than a mile from the Caltech campus and so they would get together for quick early dinners before she went home to grade papers and he went back to his office to check and recheck his calculations about the exponential, the White Sky. The split between the joy of new love and the growing awareness of what was going to happen was almost too wide for his mind to address. He would wake up every morning and enjoy those first few moments of consciousness before his mind swung uncontrollably to one topic or the other.

After he had come back from Camp David and the teleconference where he'd explained matters to the crew of the International Space Station, she had asked him what was troubling him, and he had told her. That night was the first time they had slept together. But they slept together four times before he found himself able to have sex. It wasn't so much the dread of the catastrophe that got in the way. Disasters could be sexy. He'd had some of the best sex of his life while on the road to attend loved ones' funerals. What weighed him down and left him impotent was the stress and distraction of having to communicate what he knew to one person at a time.

Problem solved. Everyone knew now.

Clarence wound up his announcement with some inspiring talk about how the young men and women who ascended to the safety of the Cloud Ark would build a new civilization in space and populate it with the genetic legacy of all mankind. Frozen sperm, eggs, and embryos would be sent up there too, so that even those who were left behind to die on the Earth's surface could enjoy some hope that their offspring would one day grow to maturity in orbiting space colonies, and commune with their departed ancestors through digitally preserved letters, photographs, and videos. To Doob, this part of the talk seemed tacked on, something put in there just to hold out a glimmer of hope. But he knew that it was, in a way, the most important thing that any of the speakers would say today. The rest of the message had been stunningly grim, too shocking for most people to take in. The news anchors covering the announcement had been sworn to secrecy and briefed on it yesterday, just to give them some time to recover emotionally in the hope that they could hold it together on air. The announcement *had* to conclude with some straw for people to grasp at. This kindly, ancient Cambridge professor, hollowed out by cancer, speaking in the cadences of the King James Bible about the new world in the heavens that would be populated by the children of the dead, venerating their ancestors' JPEGs and GIFs, was the closest thing to an uplifting message that anyone was going to see today. He had to sell it, and he did. And Doob and all the other scientists who were now running the Cloud Ark program, along with the world's military and politicians and business leaders, had to follow through.

Moira Crewe, Clarence's postdoc, and Mary Bulinski each got a hand under one of Clarence's arms and helped him down the steps to the rim of the crater, where a few shell-shocked journalists had gathered to ask questions. For the most part, though, the place was dead quiet. None of the usual post-news-conference hubbub. Most of the networks had cut back directly to their headquarters.

Doob looked up at the window. Amelia tucked her hair behind her ear and drew back from the glass. He trudged back to the lodge on legs stiff with cold. He was thinking about those frozen sperm samples and eggs. How long would they last? It was known that such cells could be thawed and used to produce normal babies after as long as twenty years in the freezer. Cosmic rays might complicate things. A single ray passing through a human body might damage a few cells—but bodies had a lot of spare cells. The same ray passing through a single-celled sperm or egg would destroy it.

The bottom line was that every man now on Earth could ejaculate into a test tube, every woman could go in for the much more complicated process of having her eggs harvested, embryos could be gathered and put on ice by the millions, but none of it would make a bit of difference unless there were healthy young women willing to receive those donations into their own wombs and gestate them for nine months. In time the population would grow. A new generation of—to put it bluntly—functional uteruses would come online in fourteen or fifteen years. And a second generation would be available in thirty. But by then, many of the frozen samples that the people of Earth were pinning their hopes on would be past their expiration dates.

Most of the people on the Cloud Ark were going to have to be women.

There were other reasons for it besides just making more babies. Research on the long-term effects of spaceflight suggested that women were less susceptible to radiation damage than men. They were smaller on average, requiring less space, less food, less air. And sociological studies pointed to the idea that they did better when crammed together in tight spaces for long periods of time. This was controversial, as it got into fraught topics of nature vs. nurture and whether gender identity was a social construct or a genetic program. But if you bought into the idea that boys had been programmed by Darwinian selection to run around in the open chucking spears at wild animals—something that every parent who had ever raised a boy had to take seriously—then it was difficult to envision a lot of them spending their lives in tin cans.

The system of camps where the young people chosen in the Casting of Lots would be taken for training and selection was going to be a roach motel for boys. Young men would go in, but they wouldn't come out. Save for a few lucky exceptions.

He had been drifting toward the lodge for a couple of minutes, nagged by the vague sense that there was something he ought to be doing.

Talking to the media. Yes, that was it. Normally, camera crews would be homing in on him. And normally he would be trying to dodge them. But not today. Today he was willing to stand around and talk, to be Doc Dubois for the billions of people out there in TV land. But no one was coming after him. Anchors of many nations were gazing soulfully into their teleprompters, intoning prepared remarks. Journalists of lesser stature—tech bloggers and freelance pundits—were filing their reports. Doob noticed a familiar face, Tavistock Prowse, off in a corner of the parking lot. He had set up a tablet on a tripod, aimed its camera at himself, and clipped on a wireless mike, and was delivering some kind of a video blog entry, probably for the website of *Turing* magazine, which had employed him for these many years. Doob had known him for two decades. He looked terrible. Tav had showed up this morning. He didn't have the credentials or the access to get the advance warning, so all of this was news to him. Doob had pinged him a few times last night, on Twitter and Facebook, trying to give him a heads-up so that his old friend wouldn't be wrong-footed by the announcement, but Tav hadn't responded.

It didn't seem like a great moment to be doing an impromptu interview with Tav and so Doob pretended he had not seen him. He flashed his credentials at the Secret Service guys stationed at the

lodge's entrance, but this was just to be polite—they knew who he was and had already pulled the door open for him.

He passed the elevators and climbed the stairs to the room, just to get blood moving in his extremities. Amelia had left the door ajar. He hung up the DO NOT DISTURB placard, locked the door behind him, and collapsed into a chair. She was still at the window, leaning back perched on its broad rustic sill. This side of the lodge was facing away from the sun, but the light of the sky came in and illuminated her face, showing the beginnings of lines below her eyes, around her mouth. She was second-generation Honduran American, some kind of complicated African-Indian-Spanish melange, big eyed, wavy haired, alert, birdlike, but with that essentially positive nature that any schoolteacher needed to have. It was a good trait in current circumstances.

"Well, that's over," she said. "It must be a big load off of your mind."

"I have ten interviews in the next two days," he said, "explaining the whys and the wherefores. But you're right. That's easy, compared to breaking the news."

"It's just math," she said.

"It's just math."

"What about after that?" she asked.

"You mean, after the next couple of days?"

"Yeah. Then what?"

"I hadn't really thought about it," he admitted. "But we have to keep gathering data. Refining the forecast. The more we know about when the White Sky is going to happen, the better we can plan the launch schedule, and everything else."

"The Casting of Lots," she said.

"That too."

"You're going, aren't you, Dubois?" She never called him by his nickname.

"Beg pardon?"

Irritation flashed over her face—unusual, that—and then she focused on him, and she gradually became amused. "You don't know."

"Don't know what, Amelia?"

"Obviously, you're going."

"Going where?"

"To the Cloud Ark. They're going to need you. You're one of the few who can be useful up there. Who can actually help its chances of survival. Be a leader."

It really hadn't occurred to him until she said it. But then he saw that it was probably true. "Oh, Jesus Christ," he said, "I think I would rather croak down here. With you. I was thinking we could come up here, camp out on the rim, and watch it. It's going to be the most amazing thing ever."

"A real hot date," Amelia said. "No, I think I'll be spending that day with my family."

"Maybe you and I could be family by then."

Tears gleamed in the pouches beneath her eyes, and she ran a finger under her nose. "That has got to be the strangest proposal ever," she said. "The thing is, Dubois, that my husband is going to be in orbit and I'm going to be in California."

"I could look for a way to—"

She shook her head. "They will never, ever agree to bringing a thirty-five-year-old schoolteacher up to the Cloud Ark."

He knew she was right.

"A frozen embryo, though—that seems like a possibility."

"That has got to be the strangest *proposition* ever," Doob said.

"We live in strange times. I'm fertile right now. I can tell. No more condoms for you, tiger."

So it was that, half an hour after Doc Dubois had listened with high intellectual skepticism to the soothing speech of Clarence Crouch, and picked it apart logically in his mind, proving to himself

that it was just a comforting sop for the bereaved billions, a distraction to keep them busy with sex during the two years they had left, he was in Amelia's arms, and she in his, as they got busy making an embryo for him to carry up into space for implantation in some other, unknown woman's womb.

He was already thinking about the videos he was going to make to teach his baby about calculus when he climaxed.

DINAH WAS GLAD NOT TO HAVE BEEN ON THE PLANET WHEN THE Crater Lake announcement was being made. She sat alone in her workshop, peering out her window past the craggy black silhouette of Amalthea at the luminous blue limb of the Earth below. She knew the time of the announcement and she knew how long it was supposed to last. She chose not to watch the video feed. It hit her as strange that the Earth itself did not change its appearance in any way. Down below, seven billion people were hearing the worst news imaginable. They were going through a collective emotional trauma unknown in the history of the human race. Police and military were being deployed in public spaces to "maintain order," whatever that meant. But Earth looked the same.

Her radio started beeping. She looked down, blinked away tears, and saw Alaska, bent over the curve of the world far to the north.

WE ARE PROUD THAT YOU ARE UP THERE

She recognized her father's fist—his touch on the Morse key—as easily as his smell or his voice. She returned:

I WISH THAT I COULD SEE YOU AGAIN

AUNT BEVERLY IS SOWING SOME FLATS OF POTATOES. WE WILL BE FINE.

She cried for a while.

QSL, he signaled, which was a Q code meaning, in this case, "Are you still there?"

She sent QSL back, meaning "Yes."

She knew that the purpose of Q codes was to make communication more efficient, but she understood now that they could serve another purpose. They could enable you to eke out a few scraps of useful information when words were too difficult.

YOU BETTER GET TO WORK KIDDO

AND YOU SHOULD STOP POUNDING THAT KEY AND HELP BEV

LOVE YOU QRT

QRT

"It's still a miracle to me that you can make sense of that."

She turned around to discover Rhys Aitken, poised in the hatchway that connected her shop to the SCRUM: the Space Commercial Resources Utility Module, which was the large can-shaped object that connected Izzy's forward end to Amalthea. Along its sides, the SCRUM sported several docking ports where other modules could be connected. Owing to various delays and budget cutbacks, only one of those ports was currently in use, and Rhys was now hovering in it. Tucked under one of his arms was a bundle, wrapped in a blanket.

She sniffled, suddenly aware that she was a mess. "How long have you been there?"

"Not long."

She turned her back on him, grabbed a towel, and dried her eyes and nose. Rhys filled the time with some gentle patter. "I couldn't stand watching the announcement any longer, so I tried to make myself useful. Discovered something marvelous. Water runs downhill. All right, I already knew that, actually. There's a section of the torus, underneath the deck plates, where condensation tends to collect—it's been a maintenance issue, something we've been keeping an eye on.

"So, I brought you something," he concluded.

She turned and looked at the bundle under his arm. "A dozen roses?"

"Perhaps next week. Until then—" and he held it out.

She took it from him. Like everything else up here it was, of course, weightless, but she could tell by its inertia that it had some heft.

She peeled back the blanket and heard a crinkling, crackling noise, then saw underneath it a layer of the metallized Mylar sheeting that they used all over Izzy as thermal shielding. The object beneath that was lumpy and irregular. And it was cold. She peeled away the Mylar to reveal a slab of ice. It was oval and lens shaped: a frozen puddle.

"Perfect," she said.

A few drops of water spun away from it, gleaming like diamonds in the shaft of sunlight spearing in through her little window. She captured them using the same towel she'd just used to dry her face. But not before pausing, just a moment, to admire their brilliance. Like a little galaxy of new stars.

"You'd said something about a cryptic message from Sean Probst."

"All of his messages are that way," she said, "even after they've been decrypted." Sean Probst was her boss, the founder and chairman of Arjuna Expeditions.

"Something about ice, anyway," Rhys went on.

"Hang on, let's get this in the airlock before it melts any more."

"Right." Rhys pushed himself to the far end of the shop, where a round hatch, about half a meter in diameter, was set into the curved wall. "I see green blinkies all about, so I'll just open this?"

"Fine."

He actuated a lever that released the latching mechanism, then pulled the hatch open to reveal a little space beyond. This was the airlock that Dinah used when she needed to bring one of her robots inside for maintenance, or send one back out onto Amalthea. Human-rated airlocks were big—they had to accommodate at least one person in a bulky space suit—and complicated and expensive, partly because of safety requirements and partly because they were designed by government programs. This one, by contrast, had been prototyped in a few weeks by a small team at Arjuna Expeditions, and was meant for smaller equipment. It was roughly the dimensions of a big garbage can. To save space on the inside, it protruded from the side of the module, jutting into space like a stubby, oversized fire hydrant. At its far end was a dome-shaped hatch that Dinah could open and close from inside her shop using a mechanical linkage of pushrods and levers straight out of a Jules Verne novel. At the moment, of course, that hatch was closed, and the airlock was full of air that had gone chilly, since the sun had not been shining on its outside until a few minutes ago.

Dinah gave the chunk of ice a gentle push and it glided across the shop to Rhys. "Up and under!" he called, and caught it.

"What?"

"Rugby," he explained, and slid the ice into the airlock. "Have you got a Grabb or something that can come round and fetch this?"

"In a minute," she said. "It'll keep in there for now."

"Right." He closed the inner door and dogged it shut. Then he turned back and looked at Dinah, and she looked at him, and they appraised each other for a few moments.

"So water condenses and puddles at this one place in the torus," she said, "which you can reach by pulling up a deck plate?"

"Yes."

"And it freezes?"

"Well, normally, no. I may have helped it freeze by fiddling with certain environmental controls."

"Ah."

"Just trying to save energy."

She was floating in the opposite end of the shop, near the hatch where it connected to the SCRUM. She looked through and verified that no one was around. Some of them, she knew, were in a meeting in the torus, and others were doing a space walk.

"Now, *technically* …" she began.

"Technically, this is wrong," he said. She admired the self-aware bluntness. "It is wrong because when you open the outer hatch and put that piece of ice out in space, where your robots can muck about on it, it is going to sublimate."

Sublimation was essentially the same thing as evaporation, skipping the liquid phase; it just meant a process by which a solid, exposed to vacuum, gradually turned into vapor and disappeared. Ice tended to do this pretty quickly unless it was kept extremely cold.

"So Izzy is going to lose water," Dinah said, "which is a scarce and valuable resource."

"It'll never be missed," Rhys said blithely. "This isn't the old days. Now that those people have made that announcement, rockets will be coming up here thick and fast."

"Still, what Sean wants me to do is an Arjuna Expeditions project. A commercial thing. A private thing. And that water is a shared—"

"Dinah."

"Yes?"

"Snap out of it, love."

A long silence followed, concluded by a big sigh from Dinah. "Okay." Rhys was right. Everything was different now.

"Now, what is it he wants, and how does ice enter into it?"

Her mild annoyance at his curiosity finally gave way. Maybe he could help. She turned her head toward the window and nodded at the familiar bulk of Amalthea, a few meters away. "That's been my career, and my family's career," she said. "Working with minerals. Hard rock. Metallic ore. All of the robots are optimized for crawling around on a big piece of iron. They use magnets to stick to it. Their tools use plasma arcs or abrasive wheels to work it. Now, Sean's basically telling me to shelve all of that. The future is ice, he says. That's all he wants to hear about. All he wants me to work on."

"There's lots of it on Earth," Rhys pointed out, "but you never think of it as a mineral."

She nodded. "It's an annoyance you have to clear out of the way."

"Your colleagues down on the ground? Also working on ice?"

"Judging from email traffic, this is a company-wide directive," she said. "They're buying ice by the truckload, dropping it on the floor of the lab, refrigerating the building—fortunately it's winter in Seattle; they only need to drop the temperature a few degrees. They're all buying long underwear at REI so that they can work in a refrigerator."

"What's it like working for Mr. Freeze?"

"I was going to say the Penguin," Dinah said, "but people in Seattle don't carry umbrellas."

"Nor do they wear top hats, in my experience. No, it's definitely a Mr. Freeze scenario."

"Anyway," Dinah said, "yesterday's shipment of vitamins contained a few of these."

She opened a storage cubby next to her workstation and took out a bag made of the metallic gray plastic used to protect sensitive electronics from static electricity. Taped to it was a NASA business card.

"Nice to have friends in high places," Rhys remarked. He had noticed the name on the card: Scott "Sparky" Spalding, the NASA administrator.

Dinah smiled. "Or low, as the case may be."

It was a weak joke. Rhys didn't respond. Dinah felt her face get a little warm. Not so much because of the failed attempt at humor as out of a kind of political defensiveness. "Scott told me a couple of weeks ago that he wouldn't ditch me out. That he had my back."

"What does that mean exactly?"

"That the robot work would keep going. That I would have a job. I didn't believe him. But I guess he's been talking to Sean Probst. Because Sean FedExed these to Sparky a couple of days ago, and now they're here."

She parted the bag's ziplock closure, inserted her thumb and index finger, and pulled out a contraption about the size of a grain of rice. From a distance it looked like a photovoltaic cell, just a flake of silicon, but with a few tiny appendages.

"What are the dangly bits?" Rhys wanted to know.

"A locomotion system."

"Legs?"

"This one happens to have legs. Others have things like little tank treads, or rolling cylinders, or slammers."

"Slammers? Is that a technical term?"

"A mining thing. A way of moving heavy equipment around on the ground. I'll show you later."

"So," Rhys said, "it would appear that the agenda is to evaluate a number of different ways that robots could crawl around on ice without drifting off and getting lost."

"Yeah. Apparently all of these work, more or less, on the ground in Seattle. I'm supposed to evaluate their performance in space."

"Well!" Rhys said. "How fortunate for you, then, that—"

"That I have my very own chunk of ice. Yeah. Thanks for that."

"All the sweeter for being contraband?" he asked, raising his eyebrows.

The double meaning was clear enough. "Not as romantic as a dozen roses," she countered.

"Still," he said, "what is it that a man is trying to say with a dozen roses? Simply that he is thinking of you."

Shortly after she'd arrived on Izzy she had rigged up a curtain that she could draw across the opening of her shop's hatch. It wasn't much—just a blanket—but it shielded her visually when she wanted to take a nap in her shop, and it sent the message that she was not to be disturbed, at least without knocking first. She reached up now and drew the curtain across the hatchway. Then she turned back toward Rhys, who looked very keen, and very ready.

"How's your space sickness?" she asked. "You seem a little more, uh, sprightly."

"Never better. All bodily fluids fully under control."

"I'll be the judge of that."

THE RUSSIAN INVASION BEGAN A WEEK LATER, WITH A SPATE OF flights producing what NASA described as "mixed results" and Roskosmos termed "an acceptable fatality rate."

Seen from a distance, Izzy consisted almost entirely of solar panels. Structurally, these were to the space station as the wings of a bird were to its body, in the sense that their purpose was to have as much surface area as possible with minimal weight.

Most of the mass, strength, and brains were in the "body"—a stack of can-shaped modules running up the middle between the "wings"—which was tiny by comparison. From many angles you couldn't even see it. The only parts of the stack big enough to be noticed from a distance were the add-ons from recent years: Amalthea at one end and the torus at the other.

The solar panels—as well as some other, vaguely similar-looking structures whose function was to radiate waste heat into space—were held in place by the Integrated Truss Assembly. The word "truss," when used by structural engineers, just meant something that looked like a radio tower or a steel bridge: a network of struts joined into a lattice, giving maximum stiffness with minimum weight. In some parts of Izzy, those struts were visible, but more commonly they were covered up by panels that made them look more solid than they were. Behind those panels resided unfathomably complex wiring, plumbing, batteries, sensors, and mechanisms for deploying and rotating solar panels. With a few minor exceptions, none of the Integrated Truss Assembly was pressurized—none of it was meant to hold air or accommodate human beings. It was like the mechanical works on the roof of a skyscraper, exposed to the elements and rarely visited by humans. Astronauts went there on space

walks to mess with the wiring or fix things that weren't working, but most of Izzy's crew spent their whole missions inside the much smaller stack of cans that made up the station's "body."

That was going to have to change.

Izzy herself could only expand so much. This was not a question of stacking on more cans, or adding additional tori. Beyond a certain point you simply couldn't jam more complexity into such a focused volume. Electrical power was needed to run just about everything. Whenever it was used, waste heat was generated. The heat would build up in the space station and cook the occupants unless it was collected by a refrigeration system and piped out to radiators that would "shine" the heat, in the form of infrared light, into space. Jamming more people and systems into the central body of the space station would just require more solar panels, more batteries, more radiators, and more plumbing and wiring to connect them all. And this didn't even address the human factors: how to supply people with food, water, and clean breathable air, and how to recycle carbon dioxide and sewage.

Knowing this, the brain trust behind the Cloud Ark—an ad hoc working group of governmental space agency veterans and commercial space entrepreneurs—had opted for the only strategy that could possibly work, which was decentralized and distributed. Each arklet, as the component ships were being called, would be small enough that it could be heaved into orbit on the top of a single heavy-lift rocket. It would draw power from a small, simple nuclear reactor fueled by isotopes so radioactive that they would throw off heat, and thereby generate electricity, for a few decades. The Soviet Union had used such devices to power isolated lighthouses, and they had been employed in space probes for decades.

Each arklet would accommodate a small number of people. The number kept changing as different designs were drawn up, but it meandered between about five and a dozen. Much depended on how rapidly it would prove feasible to mass-produce inflatable structures; these made it possible to create much more spacious volumes by housing people in what amounted to thick-skinned balloons. But making balloons that could withstand atmospheric pressure indefinitely while also standing up to solar radiation, thermal swings, and micrometeoroids was no small project.

It went without saying that, in the long run, the Cloud Ark as a whole was going to have to be self-sustaining in terms of food production. Water would have to be recycled. Carbon dioxide exhaled by humans would have to be used to sustain plants, which would produce oxygen for the humans to breathe and food for them to eat. All of this had been the subject matter of science fiction stories and practical experiments for decades. Those experiments had produced mixed results that were now getting a lot of attention from people who understood such things a lot better than Dinah. But she gathered that she had better get used to a low-calorie vegetarian diet, and occasional oxygen shortages.

Isolated arklets wouldn't survive for long. It didn't matter how good their internal ecosystems were. Things would go wrong, people would get sick, supplies and nutrients would run low, and people would just plain go crazy from being cooped up with the same few individuals.

The design of the arklets, and of the whole Cloud Ark system, kept changing. One day it was all about being "fully distributed," which meant that in the long run there was no central depot—no Izzy—and that all exchanges of material and "human resources" between arklets would happen through "opportunistic docking," meaning that two arklets would agree to come together and connect nose-to-nose for a time so that food, water, vitamins, or people could be exchanged. This was envisioned as market driven, without any central command and control mechanism.

The next day a new edict would be handed down to the effect that overall coordination would be handled by a command center on Izzy. The space station would also serve as a central depot for anything that could be stockpiled. The torus—or tori, since Rhys was on track to construct a second one—would be available for rest and recreation; arklet dwellers going stir-crazy from living in tin cans and suffering loss of bone density from floating around in microgravity would be rotated through and allowed to vacation there.

The schemes envisioned by the Arkitects, as Dinah and Ivy started calling them, ping-ponged back and forth between those two extremes, and seemed to reflect the existence of at least two factions. The centralizing faction pointed to the dangers of prolonged zero-gee existence as a reason for rotating people through the torus. The decentralizers came back a couple of days later with a sketch of the so-called bolo scheme, wherein a pair of arklets would connect to each other with a long cable and then begin spinning around their common center of mass, creating simulated gravity in each arklet that was stronger and better than what could be achieved in a torus. A couple of days after that, the centralizers posted an animated simulation of what would happen when two bolos ran into each other and got their cables tangled. It was funny in a kind of slapstick-horror way.

None of this really mattered in the short term, because, even on a hysterically accelerated schedule, it was going to take weeks to design and manufacture even a single arklet. And it would take longer to ramp up the production lines for the giant heavy-lift rockets needed to boost them into space. What Izzy's crew would be seeing in the meantime was a hodgepodge of preexisting spacecraft, mostly Soyuz capsules, being sent up using the existing stock of rockets. These would carry "Pioneers" whose job would be to build new extensions onto Izzy's Integrated Truss Assembly: for docking many arklets at a time, for storing material, and for making it all run. The Pioneers would spend most of their time in space suits performing EVAs: extravehicular activities, a.k.a. space walks. There would be something like a hundred Pioneers all told. They were being trained now, and their space suits were being hastily manufactured.

But Izzy in her current form couldn't support anything like a hundred new people. She didn't even have the spacecraft docking ports needed to berth their vehicles when they arrived. So in order to accommodate the Pioneers who would begin arriving in a few weeks, the Arkitects sent up Scouts. The qualifications for being a Scout seemed to be a shocking level of physical endurance, a complete disregard for mortal danger, and some knowledge of how to exist in a space suit. All of them were Russian.

There wasn't room for them on the space station. Actually, to be precise, there was plenty of physical space to accommodate them, but the support systems weren't there. The CO_2 scrubbers could only handle the output of so many lungs. The entire space station had only three toilets, one of which was almost twenty years old.

The Scouts were going to live most of the time in their space suits. This made sense as far as it went, since their mission was to work to exhaustion every day. Sixteen hours in a space suit meant sixteen hours that the Scout was not imposing a direct burden on Izzy's life support systems.

At Zero, the total number of functioning space suits in the known universe had been something like a dozen. Production had been ramped up since then, but they were still a scarce resource. In its most common form, the Orlan space suit used by the Russians could only function independently for a couple of hours, which was fine since normal people were completely exhausted by that point anyway. Beyond that, its internal reserves were used up. So, the Scouts would mostly be working on umbilicals. Their suits would be connected to an external life support system by a bundle of plumbing and cables that would supply air and power while taking away waste and excess heat.

During the few hours they were allowed to rest, the Scouts needed a place to go and to climb out of their space suits.

Whoever was running things at Roskosmos had pulled up an old idea for an emergency crew rescue device and begun actually producing them. It was called Luk. The word meant "onion" in Russian. It was pronounced similarly to "Luke," but English speakers inevitably started calling it "Luck."

In the best traditions of Russian technology, Luk was straightforward. Take a cosmonaut. Enclose him in a large plastic bag full of air.

With any normal plastic bag material, the cosmonaut will suffocate or the bag will pop, because plastic bags aren't strong enough to withstand full atmospheric pressure. So, fill the bag with only as

much air as it can handle—some fraction of one atmosphere—and then place another bag inside of it. Inflate that bag with air at slightly higher pressure. That's still not enough air to keep a cosmonaut alive, so put a third bag inside of the second bag and inflate it to higher pressure yet. Keep repeating, like with Russian nesting dolls, until the innermost bag has enough air pressure to keep a human alive—then put the cosmonaut inside of that one. All of those layers of translucent plastic gave it an appearance reminiscent of an onion.

The scheme had many advantages. It was cheap, simple, and lightweight. Deflated, a Luk could be pleated and rolled up for storage in a backpack-sized container.

Of course, the air inside the innermost bag would get fouled with carbon dioxide as the occupant breathed, but this could be handled as it usually was on spaceships and submarines, by passing the air over a chemical such as lithium hydroxide that would absorb the CO_2. As long as a bit of oxygen was bled in to replace what was being used, the occupant would be fine.

Heat produced by the occupant's body would build up in the atmosphere of the innermost bag and become stifling. A cooling system was required.

Getting in and out of the Luk could be problematic. The Russians had somehow determined that just about anyone—or at least anyone capable of meeting the physical standards of the cosmonaut program—could force their body through a hole forty centimeters in diameter. Accordingly, each Luk included a flange—a forty-centimeter ring of fiberglass with bolt holes spaced around its periphery. All the layers of plastic converged on it, further enhancing its onionlike appearance. This became the onion's cut-off stem. To keep the air from rushing out through that forty-centimeter hole, it was equipped with a stout diaphragm of much thicker plastic that could be put into place after the cosmonaut had climbed inside.

So, the general procedure for using the Luk was to unfold the bag and find the flange, then pull it over one's head, squirm through it until the shoulders and pelvis had passed through, draw the feet up inside of it, then find the diaphragm and lock it into place, sealing oneself inside. At this point the Luk was still a giant wrinkled mass of plastic hanging around the occupant like a sleeping bag.

Once the Luk was free in the vacuum of space, it was okay to open the valve that flooded air into its many interstitial layers. Whereupon it would expand to the size of a mobile home, and drift around aimlessly until a rescue vehicle could get to it.

On its outer hatch, the rescue vehicle would need to have an adapter with a bolt pattern made to engage with the holes on the Luk's flange. Once an airtight connection had been made between Luk and vehicle, the hatch could be opened, the diaphragm removed, and the cosmonaut brought in from the cold. Or, given the difficulties of getting rid of excess thermal energy in space, from the heat.

The Orlan suit was built around a hard upper torso, or HUT: a rigid shell for containing the wearer's trunk, with connection points for the arms, legs, and helmet. The back of the HUT was a door with an airtight gasket around its edge. To put the suit on, you opened that door, threaded your feet down the legs, thrust your hands along the arms and into the attached gloves, and ducked into the helmet. The door was then closed behind you. From that point on the suit was an independent system.

Roskosmos had constructed a number of Vestibyul modules, this being a newly invented thing that they had cobbled together from existing parts in about two weeks. Its purpose was to serve as a jury-rigged bridge connecting Luk to Orlan.

The Vestibyul was barely large enough to accommodate a supine human. At one end was a flange that mated with the forty-centimeter ring on a Luk. Having slithered feetfirst from the Luk into the Vestibyul, a cosmonaut had just enough wiggle room to get his feet aimed down the legs of the Orlan suit that was attached to the other end, its door hanging open. Before doing this, however, he would seal off the Luk by manually putting its diaphragm into position and bolting it into place with a ratchet wrench.

Having donned the Orlan, he could then activate a mechanism, built into the Vestibyul, that would close the suit's door behind him. The small amount of residual air in the Vestibyul would hiss

out into space and the cosmonaut would be free to depart. At the end of the workday, the whole procedure was reversed. Just like a suburban commuter sleeping in a split-level home with his car parked in the garage, the cosmonaut would enjoy a few hours of rest and relaxation floating around the confines of the Luk with his space suit docked at the end of the adjoining Vestibyul.

There were a number of catches.

> Luk, Vestibyul, and suit formed a closed system. The only way to escape from that system was to successfully don the suit, get the door closed, and spacewalk to an airlock. If anything went wrong that prevented donning the suit and closing the door, rescue was impossible, or at least spectacularly improbable. A perforated Luk, probably caused by a micrometeoroid, caused a fatality on the second day of the Scout program. After that, the Luk/Vestibyul systems were brought forward to huddle in the shelter of Amalthea. The asteroid wouldn't stop all incoming rocks, but it would stop many.
>
> Since there was no practical way in or out of the system, the Scouts had to fly up from Baikonur in their space suits, preattached to their Vestibyuls and Luks. This was necessitated anyway by the fact that none of this equipment could be accommodated inside of a normal space capsule. So they had to fly up crammed, six at a time, into cargo carriers that were not rated for human use and that had no onboard life support. They were, therefore, living off their space suits' internal supplies of air and power from shortly before launch until their arrival at ISS. This journey could not be accomplished in less than six hours and so supplemental air and power had to be delivered to the suits en route. The failure of systems responsible for doing that accounted for two fatalities in the first crew of six Scouts and one fatality in the second crew.
>
> The capabilities of the suits were being wildly overstretched by these new mission parameters, and of course the Luks didn't really have significant life support systems of their own, so everything depended on umbilical lines that linked these contraptions to Zavod modules. Zavod was simply the Russian word for "factory." This was another new device that had been cobbled together in two weeks from existing technology. As long as the Zavod was supplied with power, water, and a few consumables, it was supposed to keep a cosmonaut alive by scrubbing CO2 out of the air, collecting urine, and removing their body heat. The heat was gotten rid of by freezing water on a surface exposed to the vacuum and then letting it sublimate into space. Failures of Zavod modules accounted for four fatalities among the first three crews sent up. Two of these were caused by a bug in the software, subsequently fixed by a patch transmitted up from the ground. One was a leaky hose. The other was never explained, but the fatality was witnessed by Izzy's crew, watching through windows and video feeds, and seemed to match the profile for hyperthermia. The cooling system had failed and the cosmonaut had lost consciousness and succumbed to heatstroke. After that, they had stopped using the jerry-built cooling systems that had shipped up with the Luks and simply used ziplock bags full of ice, delivered daily.

None of this even accounted for mishaps that occurred while the Scouts were actually working. A damaged umbilical nearly killed a Scout on A+0.35, and he was obliged to disconnect himself from his Zavod and execute a heroic and perilous move to the nearest airlock, where they got him inside the space station with less than a minute to spare.

Two days later a Scout simply disappeared without explanation, possibly the victim of a micrometeoroid, or even of suicide.

So, of the first crew of six Scouts, two were dead on arrival and one was killed in the Luk failure the next day. Of the second crew, one was dead on arrival. All six of the third crew made it to Izzy alive. Of the fourteen total survivors, four died from Zavod failures, one disappeared, and one was forced to "retire" from being a Scout and confine his activities to Izzy because of equipment failure.

Ivy, being at the top of the org chart, was responsible for all strange and extraordinary decisions: the problems that no one else knew how, or was willing, to handle. It became her problem to decide what they were going to do with dead people.

Oh, there was a procedure. NASA had a procedure for everything. They had long ago anticipated that an astronaut might die of a heart attack or some mishap during a mission. Since two hundred pounds of rotting flesh could not be accommodated inside of the space station where people lived and worked, the general idea was to let them freeze-dry in space, and then place them aboard the next earthbound Soyuz capsule. Only the middle section of the Soyuz, the reentry module, ever made it back to Earth. The spheroidal orbital module, perched on top of it, was jettisoned before reentry. Eventually it burned up in the Earth's atmosphere. The customary procedure, therefore, was to pack the orbital module with trash so that it would be burned up as well.

Bodies were not trash, of course, but burning them up in the atmosphere seemed as good a way as any to dispose of them—the space-age equivalent of a Viking funeral.

The normal up/down cycle of launch and reentry had, of course, been suspended. Things were supposed to go up, but not come down. Those orbital modules could be preserved and used as habitats, or for storing supplies. The "trash" could be picked over and used again. Bags of fecal material could become fertilizer in hydroponic farms.

Ivy made a unilateral decision that they would carve out an exception to that new policy. The deceased were moved into an empty orbital module docked at the truss. This was left open to space, so that freeze-drying of the bodies could happen out of sight and out of mind. When it filled up with dead people, they would have some kind of ceremony, the thing would be deorbited, and they would watch in silence as it drew a white-hot streak across the atmosphere below.

But it wasn't full quite yet.

They had eight working Scouts until such time as another heavy-lift rocket could be prepared and sent up with a fresh half dozen. These worked in fifteen-, sometimes eighteen-hour shifts divided into three-hour phases. Each of those phases consisted of two hours' actual work followed by an hour of resting in situ, or, using the obvious anagram, in suit.

Dinah, working in her robot shop, didn't have a direct view of what they were doing, since her window faced away from the truss where they spent all of their time. She could watch their activities on video feeds if she wanted, but she had other things she needed to be doing.

After the micrometeoroid/Luk incident, Dinah had scored a small victory for robotdom by putting her flock to work getting the surviving Luks squared away. Amalthea was attached to the forward end of Izzy, which, because of its orbital direction, was most exposed to impacts from space junk. In effect the asteroid had been put there as a sort of battering ram, protecting everything aft of it from collisions. There was enough space on its aft side that several Luks could nestle there, improving their odds of long-term survival as well as cutting down on cosmic ray exposure.

Dinah's crew of iron-mining robots had been made obsolete, at least for the time being, by her boss's pivot toward frozen water. So, when not making tiny critters scurry around on slabs of contraband ice, she had made the older robots useful by getting them to drill holes and anchor some connection points—eye bolts, basically—into Amalthea's back side and then moor the Luks to them using cables. This was not a hard-and-fast mooring system, so at first they tended to drift around and lazily bump into each other like a string of balloons. But after a day or two they settled into a stable configuration that just happened to block Dinah's view out her window. All she could see now was plastic. She didn't mind. After seeing the risks that the Scouts were taking, she didn't mind anything at all.

Individual layers of the Luk were fairly transparent, but the view was gauzy because the layers were so many. She could make out the form of her neighbor's body but not see the face. It was definitely a woman.

The Scouts' shifts overlapped around the clock. The woman outside Dinah's window came back in from her shift every day around what for Dinah was the middle of the morning. Dinah could see her clambering laboriously along the surface of Amalthea, using the mooring points, planning each move, avoiding the cables and the umbilicals. She must have been exhausted beyond words. Dinah had once done a two-hour stint in a space suit and been wiped out for a day. Sometimes Dinah would send a Grabb or a Siwi out to afford the woman an extra handhold when it looked like she needed one. The woman would turn her head and look at Dinah through the glass dome of her helmet and blink her eyes in what Dinah took to be an expression of gratitude. Eventually she would reach the open portal of her Vestibyul and go back into it, whereupon (unseen by Dinah) the automatic mechanism would do its thing, locking her suit into its socket, equalizing the pressure, opening the door, and enabling her to extract her head, arms, and body. Finding the ratchet wrench floating at the end of its chain of plastic zip ties, the woman would reach "above" her head and remove the twenty-four bolts securing the Luk diaphragm onto its flange, carefully rethreading each bolt into its hole so that it wouldn't drift around loose, and then she would finally pull herself through the forty-centimeter portal into the comparatively spacious environment of the Luk. Along the way she would collect her "mail," which was deposited in each Vestibyul during the occupant's shift. This consisted of food; drink; toiletries; a bag of ice that would turn into water, providing a simple temperature-control scheme; bags for disposal of feces; and, in her case, tampons.

Because of the roundabout and improvised manner in which things were working now, Dinah did not have a way to communicate with this woman directly, or even to learn her name. This seemed ridiculous, but it was the same general phenomenon that had made it impossible for the firemen to talk to the police officers on 9/11. The Scouts were just using different radios with different frequencies, and Dinah didn't have one.

By checking biographies on the NASA website, and by the process of elimination, she determined that this was Tekla Alekseyevna Ilyushina. She was a test pilot. She had competed in the most recent Olympics as a heptathlete and taken a bronze medal. As such she might have had glorious career options as a propaganda idol during the old Soviet days. But the recent conservative drift of Russian culture had left few slots available for women in male-dominated professions such as the military or the space program. Consequently much of her work experience had been outside of Russia, working for privately funded aerospace companies. She had returned a few years ago to become one of two active female cosmonauts. Dinah was cynical enough to see politics as the basis of that; in order for Roskosmos to remain on speaking terms with NASA and the European Space Agency, they had to have at least one or two females qualified to go into space.

Tekla was thirty-one. She had been somewhat glammed up for her official cosmonaut photograph, with a stiff, outmoded Princess Di hairdo that didn't suit her at all. During the most recent Olympics she had been rated one of the fifty hottest female athletes by a click-bait website, but she was buried in the back of the rankings. Dinah thought her comely, with the high cheekbones, the green eyes, the blond hair, and all the other attributes one would expect of a Slavic superwoman. But she understood why Tekla had been rated number forty-eight out of fifty, for she had a kind of chilly, strong-jawed look about her that forced the makers of the website to be selective about camera angles, and, Dinah suspected, to make some use of Photoshop. The sort of men who would browse that kind of website would find Tekla off-putting in a way they couldn't quite put their finger on. They would be intimidated by the taut cords of her deltoids during the shot put competition. Dinah made a point of not reading any of the comment threads. She already knew what those would say.

Tekla had been sent up here to die, and she probably knew it.

At the end of each shift when she squirted through the flange to float free in the milky plastic bubble of the Luk, she would peel off the fluid cooling garment that she wore against her skin all day long. This was made of stretchy blue mesh with plastic tubing stitched between its layers. It had no effect until it was plugged into a pump that circulated cool water through the tubes. Tekla must have hated it after sixteen hours, and so it came off first. Then, peeling her underwear down to her knees, she would deflate and remove the foley catheter that had been draining her bladder while she'd been at work. She would wipe herself down with premoistened towelettes that had been provided in her "mail," and stuff those into a refuse bag. It appeared that she had shaved her head, or simply given herself a buzz cut, prior to leaving Earth, so she didn't have to mess with hair. Only then would Tekla open up her packet of emergency rations and begin to eat. This often led to defecation, which she had to handle in the crudest way possible, with a plastic bag and another series of premoistened towelettes. All of it went into her refuse bag, which she deposited in her Vestibyul for collection during her next shift. Then Tekla would turn off the white LED strip that provided the Luk's only illumination, and sometimes spend a little while gazing at the screen of a tablet computer before sliding a blindfold over her eyes and falling asleep.

Izzy circled the Earth every ninety-two minutes, passing through a complete day/night cycle each time, and so half the time that Tekla was asleep Dinah could look right out her window and see her suspended there, all but naked, floating in the Luk like a fetus in its bubble of amniotic fluid.

Dinah watched Tekla go through this routine for about a week, and found it all inordinately distracting. She brought Ivy, and later Rhys, into the chop shop to behold the sleeping Tekla through the window. They talked of Tekla and emailed each other pictures of Tekla that they had dug up on the Internet.

"That could be you or me, honey," Dinah said to Ivy.

"It is us," Ivy said, "it's just a matter of degree."

"Do you think we're going to end up like that?"

Ivy thought about it, shook her head. "Look, the way she's living isn't sustainable."

"You think it's a suicide mission?"

"I think it's a gulag," Ivy said, "a little gulag right outside your window."

"You think she's in some kind of trouble?"

"I think we're all in some kind of trouble," Ivy reminded her.

"Oh yeah, I forgot."

"She's lucky, remember?" Meaning that Tekla had at least found a way off the planet.

"She doesn't look lucky," Dinah said. "I've never seen anyone so isolated. Does she talk to someone on that tablet? Or is she just surfing?"

"I can ask Spencer, if you want," Ivy said. "I'm sure he's logging all the packets."

Dinah knew that Ivy was only kidding, but she answered, "Nah. She deserves that much privacy at least."

Rhys's reaction was to become aroused. He was reasonably discreet about it. But the elapsed time between his seeing Tekla and having sex with Dinah was, generously estimating, perhaps half an hour. Not that Rhys really needed a lot of help to start his motor. And not that Dinah did either. She had always known they were going to do it.

She had known this based on the way he smelled, at least when he was not in the middle of being sick. In other times and places, the way he smelled would not have been enough. They'd have dated first, or something. There'd have been complications having to do with existing relationships, incompatible lifestyles, fraternization policies. But here it was just automatic. And it was tremendous.

Based on what she was hearing from Internet buzz from the ground, it was also pretty universal. The human race might be about to disappear, but not before putting on a two-year frenzy of recreational sex.

Actually sleeping together was another matter. Rhys didn't seem to mind it in principle. But it was difficult logistically. Astronauts generally slept in bags that kept them from floating about at random while they were unconscious. The bags were designed for one person. NASA hadn't gotten around to manufacturing two-person bags yet, so if they felt drowsy afterward, they would improvise, swaddling themselves together with whatever they could cobble up. But it never lasted more than a few minutes. Then he would go back to his duties, and if she felt like a nap, she would climb into a bag that she kept in her shop, sometimes peeking out the window, guiltily, at poor Tekla.

One day, after Tekla had left for work, Dinah took one of the chocolate bars she had brought up from Earth, wrote her email address on the wrapper, and handed it off to a Grabb, which she then put out the airlock. She piloted the Grabb across Amalthea's surface to the mooring point where Tekla's Vestibyul was cabled in place, then made it climb along the cable (which was easy, it had an algorithm for that) and clamber into the Vestibyul, where it took up position and waited, holding the chocolate bar out in a free claw.

When Tekla came back at the end of her shift, Dinah got the satisfaction of watching her unwrap the bar and eat the chocolate. She held up one hand and sort of waved through the plastic. Dinah couldn't resolve her facial expression.

The Grabb was still in the Vestibyul, and would remain trapped there until Tekla's next departure. Seeing Tekla float over in that direction, Dinah turned to her computer and switched on the video feed from the Grabb. She was fascinated to see Tekla's face, clearly resolved, float into the frame.

She didn't look that bad. Dinah had been expecting someone who looked like a concentration camp survivor. But she appeared to be getting enough food.

Of course, she could not see Dinah. And there was no audio hookup. Since there was no sound in a vacuum, space robots didn't come with microphones or speakers.

Tekla was just staring at the Grabb, impassive, perhaps wondering whether it could see her.

Dinah slipped her hand into the data glove, did the thing that made it connect to the Grabb's free claw, and waved.

Tekla's green eyes flicked down in their sockets as she observed this. Still no emotion.

Dinah was mildly offended. Was the Grabb not adorably cute, in its ugly mechanical way? Was the wave not an amusing gesture?

Tekla held up the candy bar wrapper. On it, beneath Dinah's email address, she had written NO EMAIL.

What did that mean? That she lacked an email address? That her tablet couldn't receive it?

Or was she imploring Dinah not to communicate with her that way?

The Grabb had a headlamp, a high-powered white LED that she could switch on by hitting a key on her keyboard. Dinah turned it on, saw the glow on Tekla's face, the highlights on the lenses of her eyes.

Did the Russians even use the same Morse code as Americans?

Tekla had to know it. She was a pilot.

Dinah made the light flash with the dots and dashes for M O R S E.

Tekla nodded, and Dinah could see her mouth making the word *"Da."*

Dinah signaled:

DO YOU NEED ANYTHING?

The faintest trace of a smile came over Tekla's lips. It was not a warm kind of smile. More bemused.

She held up what was left of the chocolate bar, and pointed to it.

Dinah returned:

TOMORROW

Tekla nodded. Then she turned away, her buzz-cut blond hair glinting in the light of the LEDs, and drifted back into the middle of her onion.

"FIVE PERCENT" WAS HOW IVY BEGAN THE NEXT MEETING IN THE Banana.

It was full to capacity: the original twelve-person crew of Izzy, the five who had come up on the Soyuz on A+0.17, and Igor, the Scout who had come in from the cold when his suit had failed. He, Marco, and Jibran had prepped for the meeting by jury-rigging some fans to blow more air through the space, so it wouldn't fill up with carbon dioxide. This had prompted Dinah to joke that perhaps all meetings should take place in hermetically sealed rooms, so that they could only go on for so long. No one, with the possible exception of Rhys, had seen it as funny. Anyway, the roar of ventilation was even louder than it usually was in space, and so Ivy had to speak up and use her Big Boss Voice.

"This is Day Thirty-Seven," Ivy went on. "That's ten percent of a year. If it's true that we had two years from Zero to the Hard Rain, then we have already burned through five percent of the time during which we can expect to receive any help from Earth. Five percent of the time needed to turn this installation into a society and an ecosystem that is sustainable indefinitely."

Ivy was standing with her back to the big screen, so she couldn't see the reaction of the Arkitects down below, in some conference room at the other end of the video link. For today's meeting, there were three of them: Scott "Sparky" Spalding, who was still the administrator of NASA; Dr. Pete Starling, the president's science advisor; and Ulrika Ek, a Swedish woman who had worked as a project manager for one of the private commercial space startups until recent events had forced a career change: she was now coordinating the activities of several different space agencies and private companies as they worked on the Cloud Ark. Apparently, she had become the Arkitect-in-chief.

"Apparently" being the key word, since every time Dinah had any contact with the ground she was reminded of how little she understood of what was happening there. On one level she was one of the luckiest people in the human race. She was going to get to stay alive. At the same time, she and the others got very little information from the planet, and had to piece things together from a jumble of clues.

She'd compared notes on this with Ivy, who had confirmed that even she had little to go on, and what she did hear contradicted itself from hour to hour.

It had all become Kremlinology. Back in the heyday of the Soviet Union, the only way for Westerners to guess what was going on there was to look at the lineup of dignitaries on Lenin's Tomb in the May Day parade, and riddle it out from the seating chart and who shook hands with whom. Now Dinah was doing the same thing with these three faces on the screen. Sparky was no use. He'd spent so much time in space that he had developed a kind of thousand-light-year stare. He was famous for being oblivious to the political side of things.

His opposite in that respect was Pete Starling. Pete's job was to mutter scientific explanations into the president's ear. He'd been doing rather a lot of it in the last thirty-seven days. He had a background running big science programs at universities, climbing the ladder from Mankato State to Georgia Tech to Columbia to Harvard in a mere ten years. Why was he sitting in on this meeting? There was little he could contribute. He must be here as the eyes and ears of J.B.F.

But why should J.B.F. care? No decisions were going to be made here; it was just a status report, a check-in.

As soon as Ivy finished her sentence, the corners of Pete's mouth turned down. He looked at Ulrika Ek, a somewhat matronly woman in her late forties, extremely good at her job, according to Rhys. On the high-def video feed, Dinah saw the slightest deflection of her eyes, noticing the turn of Pete Starling's head, but not exactly acknowledging it.

Ulrika clearly didn't like him. But there was a reason she was a well-regarded project manager. "Ivy," she said, "just for clarity, when we speak of 'this installation' we're using the term in an elastic sense. Of necessity."

Ivy turned to look at the screen. "'Installation' probably isn't the right word," she admitted. "Since it's not installed anywhere."

Pete Starling spoke up. "I believe that where Ulrika is going is that the Cloud Ark is a fluid concept that may paradigm-shift beyond recognition as we proceed adaptively through the next ninety-five percent of the timeline."

Ivy's brow furrowed. Something was going on, some kind of political tussle down on the ground. It was important to people like Pete.

"This is not efficient use of time," Fyodor said. "I am working to extend truss to receive Pioneers." Fyodor's English was excellent, but when he was annoyed, as he was now, he dropped his articles. "I have eight suits outside, five inside, for unlucky number of thirteen."

It had become common to use a form of synecdoche in which "suit" denoted "a person qualified to perform extravehicular activities who is equipped with a space suit that still works."

"Pioneers arrive in two weeks, this is still true? Then I need more Scouts yesterday, as saying goes."

When Fyodor had come up to Izzy six months ago, it had been understood as a valedictory mission before getting shunted to an administrator's job at Roskosmos. Not that he hadn't taken his duties seriously, but he always seemed to be taking the long view, perceiving Izzy through the eyes of a future bureaucrat who would need to make it run smoothly until his retirement. That had all changed on Zero, of course. It had changed even more with the Russian invasion. No new rank or title had been bestowed on Fyodor. None was needed. All the Russians just accepted him, implicitly and without question, as their leader. And his manner had changed accordingly. He was scrupulously respectful of Ivy's authority, but there was no question that he was the boss of all things suit related, and the authority had seemed to make him physically larger and more imposing, his creased face tougher, his voice firmer.

Sparky answered him. "Fyodor, that fuel pump has been fixed. It was just a bad sensor. So the launch is going up as scheduled …" He checked his wristwatch, did a mental calculation. "Fourteen hours from now. Six hours after that, you'll have your suits."

"And the Zavods, the Vestibyuls—the things I mentioned."

"We have had teams of engineers working on those fixes around the clock, Fyodor."

"I am very worried about door closing mechanisms."

THE REMAINDER OF THE MEETING HAD TO DO WITH THE PIONEERS who would start coming up in another two weeks, and who would live, for the time being, in rigid or inflatable habitats more accommodating than Luks. These would be docked along a series of pressurized tubes, little different in principle from the big spiral-wound ventilation ducts seen in warehouses, that would ramify outward from attachment points in the truss. Little of it concerned Dinah and so her attention drifted to her laptop. She had other things she could be working on, and Ivy's reminder about the 5 percent had not left her in a mood to woolgather during a long meeting.

Most of her work of late had been on ice crawlers. And, as of the most recent shipment, ice tunnelers. But she had resolved that she would not shut down her progress on the iron-mining robots. Even if she only spent fifteen minutes a day on them, it was better than suspending work altogether. She was afraid that if she ever did that the entire project would disappear.

To that end, she kept a window open in the lower left corner of her screen, showing video from Amalthea, mostly the point-of-view cameras of robots that were actually doing things. It was always there in her peripheral vision as she attended to email and scheduling spreadsheets and Gantt charts.

And at some point she noticed something that wasn't quite right. A few minutes later, she noticed it again and put her other work on hold. She expanded the window and took control of the robot that was transmitting the video. She swiveled its camera around until she had a view of the thing that had been bothering her.

It was Tekla, floating in her Luk. She was bright blue, which meant that she had donned her cooling garment. That was normal. She did it every day as she got ready for her shift. The next step should have been to squirm feetfirst through the Luk's flange into the Vestibyul. But she wasn't doing that. She was going back and forth between the Vestibyul and the middle of the Luk. She would go through the flange headfirst (which was abnormal) and do something for a minute or two, then withdraw into the Luk and thumb away on her tablet for a while.

She was late. Every other day, she'd been in her suit and out on the truss by this time.

Dinah wasn't the only person who had become distracted by her laptop. Fyodor—normally not a fan of email and other such modern diversions—was watching his screen too, occasionally making eye contact with the equally distracted Maxim, who kept making a gesture like tugging at an imaginary beard.

Something was wrong.

What had Fyodor said? *I am very worried about door closing mechanisms.*

He wasn't just saying that in the abstract. He was referring to a specific situation. He was talking about Tekla.

Tekla could clamber from her Luk, through the Vestibyul, and into her suit, but she couldn't close the door behind her back. She needed the mechanism for that. If it didn't work, then she couldn't seal the suit. And if the suit wasn't sealed, she was trapped inside her OVL (as they had taken to calling the combination of the Orlan suit with the Vestibyul and the Luk).

It was not exactly an emergency, but it was bad. In order to get "mail" she had to detach her suit from the Vestibyul, leaving it open for the delivery to be made in her absence. "Mail" included food, water, ice, and fresh CO_2 scrubber canisters.

Dinah didn't know how long Tekla could survive without "mail," but she doubted it was more than a day. The heat would get her first.

They had to figure out some way to get Tekla inside Izzy. And since the OVL was jury-rigged, it didn't have a docking port like a normal spacecraft. There was no hatch, no way of mating to an airlock.

She studied Fyodor's face through the rest of the meeting, which went on for another half hour, and began to understand something: he was getting ready to sacrifice Tekla. "Ready" in the sense of emotionally hardening himself to that reality.

Dinah understood NO EMAIL now. It was simply part of being a Scout that you would probably not survive. And if you knew you were going to be sacrificed, it wouldn't help matters to be spamming the Scout email list with pleas for help and goodbye messages. Tekla could communicate with Fyodor, and Fyodor only, and that was for a reason. It was a reason that the defenders of Leningrad, Stalingrad, and Moscow would have understood and accepted perfectly well. But it was a little bit out of step with the modern ethos.

Correction: with the modern ethos as it had existed during the Age of the One Moon.

It was perfectly in step with how things were now.

Part of her wanted to go and plead with Fyodor to mount a dramatic and heroic rescue mission. There had to be a way to make it happen. They had all seen *Apollo 13,* they quoted lines of dialogue from it all the time.

But she already knew the answer. The Pioneers would begin arriving, shiploads of them, in two weeks. All of them would die on arrival if the correct preparations had not been made. No time could be spared. More Scouts were on the way to replace Tekla.

And for once she was glad that the meeting ran long, that Sparky didn't stick to the agenda, and that Pete Starling exploited it to fill time with more buzzwords. Because an idea was slowly taking shape in her head. She would have to run it by Ivy and Rhys and perhaps Marco, she would want to have Margie Coghlan—the closest thing they had to a doctor—standing by, but she could do it with no help at all from Fyodor or any of the other suits.

Fyodor was typing something with his index fingers. She locked her eyes on his face and kept them there until he was finished. He seemed to have detected her gaze on him, because he then looked up and stared straight into her eyes, maintaining a perfect poker face.

She stared back.

Awareness crept into Fyodor's expression. Awareness that Dinah knew about the problem. Fyodor knew the layout of Izzy better than anyone. He knew where Dinah spent her time, and that Dinah only had to look out her window to see what was going on. She could see him putting this all together in his head.

He was expecting her to make some emotional appeal. So, it was important for her to stay cool. As soon as she turned on the waterworks, she would lose his respect, and his attention, forever.

"Fyodor," she said, "I got this."

He blinked in surprise, then, after some hesitation, made the tiniest of nods.

"Got what?" Pete Starling asked, over the video link. "Am I missing something?"

"No," Dinah said. "We are just proceeding adaptively to leverage our core competencies."

BASED ON STATS FROM THE *50 HOTTEST OLYMPIANS* WEBSITE, IVY WAS a fairly close match for Tekla physically. Tekla was huskier, but Ivy was an inch taller. So, the first thing they did was to stuff Ivy into the small airlock that Dinah used for her robots. With her head tucked and her knees drawn up to her chest, she fit into it with room to spare. Dinah took a picture, then appended it to an email message with detailed instructions.

Spencer Grindstaff, who, as a young CIA contractor, had cut his teeth hacking into email systems operated by foreign governments, figured out a way to send email to Tekla's tablet by wrapping it in an envelope that made it look like it came from Fyodor.

Dinah watched Tekla read that email. She looked up from the tablet toward the window, then turned her gaze toward the airlock. Until then, Dinah had worried that Tekla might be losing consciousness, since she hadn't moved in several hours. She guessed that Tekla was trying to conserve oxygen and reduce thermogenesis by moving as little as possible.

Dinah zip-tied a high-powered LED light to the inner hatch of the airlock, then closed it. She opened the valve that dumped its air into space, allowing it to "fill up" with vacuum, and then actuated the lever—a simple mechanical linkage—that flipped the outer hatch open. She could see the white glow of the LED reflecting against the plastic of Tekla's Luk bubble a few meters away, and she saw Tekla's head turn as the light got her attention.

Several robots had to act in concert to move Tekla's Luk bubble around until it was pressed against the airlock. This was a somewhat maddening process, like trying to grab an inflated balloon with a pair of needle-nosed pliers. Dinah had been trying to do it with Siwis—Sidewinders—of which she now had a dozen in operation. A Siwi could join head-to-tail with another Siwi to double its length, and the process could be repeated indefinitely to construct a sort of smart, instrumented tentacle. By planting the tail of one Siwi against Amalthea, and bolstering the connection by holding it down with a couple of anchored Grabbs, she was able to make another Siwi slither up the first one and connect to its head, which was projecting up into space. A third Siwi climbed up the first two and concatenated itself, and so on and so forth, building a stalk that reached up from the surface of the asteroid and began to curve around the bubble in which Tekla was imprisoned.

So far so good. But the longer the chain grew, the worse it behaved. The Siwis were constructed like caterpillars, consisting of many identical segments connected by flexible joints. The joints were motorized, and the motors were supposed to follow commands embedded in Dinah's code, and it was all supposed to work in a predictable way. The problem was that each joint had a bit of flexibility, which as far as Dinah was concerned was error. Those errors accumulated as the length of the chain grew, so that by the time she had connected three Siwis together, she found it difficult to know, let alone control, the position of the end of the stalk. And when she tried to apply force by making the chain curve around the slippery, bulgy surface of the Luk, matters only got worse.

Rhys showed up a few hours into the project and watched. He'd be silent for hours, then suddenly ask a question that was strangely off-kilter and yet showed he was thinking about the problem.

"What if you turned all the motors off and let the whole thing go slack?" he asked.

"Aren't you supposed to be building a torus?" she demanded, and turned around to give him her best attempt at a killing look.

"First we have to solve this problem," he said gently.

She had more to say, but instead she went silent. Rhys was clowning around with his necklace again. He was in the habit of wearing a chain around his neck—nothing fancy or bulky, just a simple loop of twisted-link jewelry chain in stainless steel, which he used as a way to keep thumb drives and other important small objects from floating away. At the moment, though, he had removed all of that stuff, leaving the chain unencumbered, and he had got it spinning around his neck. It had opened up into a broad, undulating oval that didn't touch his neck or collar anywhere, so it was just orbiting around him in free space. Dinah had seen him do this before, typically while bored in meetings. He had learned a few tricks for speeding it up and coaxing it into different shapes by blowing on it with a drinking straw or flicking it with a fingernail. It didn't form a perfect circle, as one might expect. The moving train of links could be molded into almost any shape, and would stay that way until disturbed. When Dinah turned around and noticed he was doing it again, she was about to roll her eyes and say something like *For fuck's sake can't you do anything useful with that brain,* but the look on Rhys's face suggested that he was up to something more than just playing around.

The chain had been running in an elongated racetrack shape, nearly buzzing his neck on one turn, but he flicked at the straightaways and broadened it into something approaching a circle, then ducked out of it, leaving the loop spinning in midair. "Channeling the wisdom of my ancestors, if you must know," he said.

"You had ancestors in zero gee?"

"Alas, no. My great-great-great-great-uncle John Aitken was an eccentric Victorian meteorologist with an even more eccentric hobby: studying the physics of moving chains. Unfortunately for him, he had to do it in his drawing room in Falkirk, where there is, I'm sorry to say, gravity. He had to approximate this sort of thing"—Rhys nodded at the whirring loop of chain—"by building exceedingly clever machines."

"Then he must have been a clever man indeed."

"Fellow of the Royal Society and friend of Lord Kelvin, since you mentioned it. Do you see where I'm going?"

"Well, a minute ago you gave me a fat clue by suggesting that I turn off all of the motors in the Siwi train. Were I to do that, it would go completely limp and become, for all practical purposes, a length of chain."

"Yes," Rhys drawled, and poked an index finger up into the chain's path. It caught on his knuckle, hiccupped, and suddenly wrapped around his hand in a chaotic tangle.

"That's confidence-inspiring," Dinah said.

"Hold on, it turns out my uncle John knew a few things. And later on, another chap, name of Kucharski, in Berlin, worked on this stuff too." Rhys was untangling the chain, looking for its clasp. When he found it, he undid it, converting the chain from a loop into a segment about as long as his arm. "Unfortunately there's gravity in Berlin too, so he had to do stuff like this on tables. Hold it right there, would you please?" And he got Dinah to pinch the middle of the chain between her fingers, keeping it fixed in space. From there, he drew the two ends back toward himself, forming the chain into a skinny, elongated U. "You can let go now, gently."

Dinah released the chain and allowed herself to float back from it, since Rhys had taken on something of the air of a magician in performance. He let go of one of the ends, kept the other grasped between his thumb and index finger. "What happens if I pull?" he asked. "Any predictions?"

"The whole thing will move back toward you, I guess."

"Let's try it. Hold your finger up just there."

Dinah pointed "up" and allowed Rhys to reach out with his free hand and grasp her gently by the wrist, arranging her hand so that the finger was several inches away from the vertex of the U-shaped bend in the chain. "Here goes nothing," he said, and began to pull the chain toward him—away from Dinah. Contrary to what she'd expected, the bend started to propagate away from Rhys, and toward Dinah, until finally the free end hurtled around, like a whip cracking, and made several quick turns around her finger, snaring her. "Gotcha," he said, and began pulling her toward him.

"Just like a bullwhip," she observed, unwinding the chain from her finger too late to avoid being drawn into close, cozy contact with Rhys.

"It is exactly the same physics," he confirmed. "Kucharski called that thing—the traveling U-shaped bend—a *Knickstelle*. It means something like 'kink place.'"

"Chains, whips, and now kinks. I'm learning so much about your Victorian ancestors, Rhys."

"You probably thought this was a mere diversion," he said.

"Oh, no. I see your point. Rather than trying to control the Siwi chain, like a tentacle, all clenching muscles, let it relax and whip around the Luk like a smart chain."

This little digression into nineteenth-century physics turned out to be one of those "one step back, five steps forward" sorts of trades. It was the work of a few minutes to concatenate four more Siwis onto the existing chain, then turn off all the motors except a few that she used to fashion a U-shaped bend. Applying tension to one end of it caused the *Knickstelle* to propagate just as in Rhys's demonstration, so that the end of the chain whipped lazily around the entire circumference of the Luk. Several attempts were required before the grappler at the end of the chain was able to snag a handhold on the far side, but then the Luk was securely captured in the chain's embrace. Grabbs could scuttle along it carrying the ends of cables anchored to other parts of Amalthea, or Izzy, and thus the Luk was gradually ensnared in a loose web of hardware that Dinah used to draw it away from the position where it had been anchored, and pull it up snug against the module containing Dinah's shop. As it came closer, the vague nimbus of white light thrown against the Luk by the LED in the airlock narrowed and sharpened, and was finally all but snuffed out as the big balloon enveloped the protruding stub of the airlock chamber. The airlock was now poking into the nested layers of the Luk like a finger prodding a balloon.

Even after the success of the whip-cracking gambit, this took most of a day. Rhys drifted off, as was his habit. Bo, the Mongolian cosmonaut, slipped into Dinah's shop, observed silently for a couple of hours, and then began finding ways to make herself useful. She learned how to use the data glove and the mouse-and-keyboard interface just by watching Dinah, and by the end of the day was piloting Grabbs around, and manipulating Siwis, like an old hand.

Margie Coghlan showed up to watch the final preparations. She was an Australian physiologist who had been sent up to Izzy a few months ago to study the effects of spaceflight on human health. Dinah had always found her a little brusque, but maybe that was just an Australian thing. She brought with her a box of medical supplies and surgical equipment. All the astronauts on the ISS had medical training. Dinah and Ivy had done their time working in Houston emergency rooms stitching up trauma victims and setting bones. But Margie was the best.

"Not exactly what you signed on for," Dinah said.

"None of us is getting what we signed on for," Margie observed.

"With the possible exception of Tekla," said another voice. Ivy's. She was not in Dinah's shop—that was full now with Dinah, Bo, and Margie—but she was in the adjacent SCRUM.

"Ivy, you ready to set another record?" Dinah asked.

"Ready to try," Ivy said.

This was Q code for the number of women on the space station at one time. The old record had been four, set in 2010. They had tied it months ago when Margie and Lina had come up to Izzy,

joining Ivy and Dinah. They had broken it when Bo had turned up in the Soyuz launch three weeks ago. Tekla would make six, if they could only get her through the airlock.

Or the number might drop back if this went wrong.

"Bo, thanks for helping. You should probably go out with Ivy."

"Good luck," Bo said, and, pushing off from the inner hatch of the airlock, drifted across Dinah's shop and out through the hatch into the SCRUM, where Ivy hovered, waiting.

"Everything sealed up behind you?" Dinah asked, more out of nervousness than anything else. It was out of the question that Ivy would get that wrong. Since the breakup of the moon, they'd intensified their precautions anyway, keeping the various modules of Izzy separated by airtight hatches wherever possible so that the perforation of one module by a bolide wouldn't lead to the destruction of the whole complex.

Ivy didn't answer.

"You know what to do with that hatch if this all goes sideways," Dinah went on.

"You talk a lot when you're nervous," Ivy said.

"I concur," Margie said. "Are we going to do this or not? That woman might be asphyxiating out there."

"Okay. Giving her the signal now," Dinah said.

In the space program that she had dreamed of when she'd been a little girl with a "Snoopy the Astronaut" poster on the ceiling of her shack in the hinterlands of South Africa, or watching live feeds from the space station on satellite TV in western Australia, the signal would have been a terse utterance into a microphone, or a message struck out on a keyboard. But what she actually did was drift over to her little window and peer through fourteen layers of milky translucent plastic at Tekla, almost close enough to reach out and touch, and give a thumbs-up.

Tekla nodded and held up a small object next to her head. It was a folding knife with a belt clip and a lanyard, which she had prudently wrapped around her wrist. Using one thumb she snapped its serrated blade open.

Dinah nodded.

Tekla nodded back, then drifted out of view, headed toward the airlock.

"Here she comes," Dinah said.

She had already sized Margie up as a woman of some physical strength. She was stocky, but in a powerful rather than a flabby way.

Dinah got a grip on the mechanical linkage that would swing the outer hatch of the airlock closed. "Brace me," she said.

She was worried about all that plastic. Shreds of it were certain to get caught in the hatch's delicate seal.

The principle was simple enough. She'd run through it in her head a hundred times. If Tekla cut a slit, a few inches long, through the innermost layer of the Luk, air would rush out into the space between it and the next layer, which was at a lower pressure. If Tekla put her head and shoulder into that slit, she'd become like a cork in a champagne bottle, and the pressure would try to force her out. If she then cut a slit through the next layer, and the next, and the next, a wave of pressure would build up behind her and spit her out like a watermelon seed. And as long as she kept aiming for the white LED on the airlock's inner hatch, she would be projected into that airlock.

At that point she'd be naked and unprotected in the middle of a jet of air that would be exploding away from her into the vacuum. And at that point—

There was a whoosh and a meaty thunking impact.

"Jesus Christ, I think that was it," Margie said.

"She is out," Bo confirmed. Bo, out in the next compartment, had a tablet on which she was watching a video feed from a nearby Grabb. "I mean she is in the airlock."

Dinah hauled on the handle, swinging the outer hatch closed. Her body, in accordance with Newton's Third Law, moved in the opposite direction, stealing her force, but Margie's arms caught her in a bear hug and pushed back—Margie had found a way to brace herself.

Bo gasped. "You are smashing her foot!"

"Oh, shit."

"Her foot is sticking out."

"Dinah," Ivy said, "you have to open the hatch a little, her foot's caught."

Dinah relaxed her arms. What if Tekla was unconscious? What if she was unable to draw herself up into the fetal position they'd shown her in that photograph?

The change in Bo's and Ivy's tone told her otherwise. "She's in!" Ivy exclaimed.

"Close the hatch, close it!" Bo was shouting.

Dinah swung the handle all the way around and snapped it into its locked position. It didn't feel quite right, but at least it was closed.

Meanwhile Margie was actuating the valve that let air into the airlock. This was supposed to be a gradual process, but she just let it go explosively, with a sudden movement of the air that tugged at their diaphragms and popped their ears.

"Blood is coming out," Bo said dully. "Leaking out of the hatch."

"Fuck!" Dinah said. Because that meant two bad things at once: the outer hatch wasn't really closed, and Tekla was hurt.

"Let's get it open," Margie said.

In the end it took all four of them: Dinah, Margie, Bo, and Ivy, all crammed into the space with their fingers under the rim of the hatch, pushing against the wall with all the strength in their legs and their backs, to break the seal. Whereupon air whooshed out of the compartment and the hatch flew open, like when you finally break the seal on a vacuum-packed jar and the lid flies off.

Tekla was in there, drawn up into the prescribed fetal position, a solid mass of red.

They all stared at her speechless for a moment.

Her head moved. She turned her face up toward them, revealing a huge red smear where an eye ought to have been.

The only thing that kept Dinah from screaming like a little girl was her gorge rising up into her throat. Bo drew in a long breath and began muttering something.

Tekla's hands unfolded and gripped the rim of the chamber. The lanyard of the knife was still wound around her right wrist. The handle of the knife trailed after it. Dinah supposed that its blade had been snapped off until she understood that the whole thing had become embedded in Tekla's forearm.

Tekla pulled herself out a few inches, then stopped. Her head was now projecting into the room.

An eye opened. A bloodshot eye in a bloody face. But a normal, working eye.

Dinah's ears began working again and she realized that she was hearing a loud hissing noise. It was the sound of air escaping from the International Space Station, not through a huge leak but through small gaps in the airlock's outer seal. The air was flowing past Tekla's body, creating a vacuum behind her, a vacuum she had to fight in order to advance into the room.

She felt embarrassed then, in the manner of a hostess who forgets to properly welcome a guest, and she reached down and grabbed one of Tekla's hands. Margie got the other and with a final sucking, squelching noise they dragged Tekla's blood-lubricated form out of the airlock chamber and into the space station.

Dinah half closed the inner hatch of the airlock. The Big Hoover, as old-school astronauts referred to the vacuum of space, took care of the rest, and slammed it closed with frightening violence.

They'd lost a measurable percentage of the atmosphere in this module. Not enough to cause oxygen deprivation but more than enough to set off alarms all over Izzy, and all the way down to Houston.

Maggie got to work on Tekla's arm, which was bleeding quite a lot, while Ivy and Bo, now blue-gloved, cleaned off her face with towelettes. The picture was getting clearer. The basic idea had worked. Tekla's knife work had been true and well aimed, and perhaps more effective than was really good for her. She had been spat out of the Luk's outermost layer, and into the airlock chamber, with great force, slamming her face into a metal fitting along the way and opening up big lacerations above and below the eye. These had bled profusely. In the same moment the blade of her knife had caught on something and turned back on her and been jammed into her forearm. She had lain dazed for a moment, one leg hanging out the open hatch as Dinah had tried to close it on her, then had come to and drawn herself up as planned. For a few moments during all of this she had been exposed to vacuum, which hadn't done her bleeding wounds any favors, but air had rushed into the lock and equalized the pressure before irreparable damage could be inflicted.

As Dinah had worried, scraps of plastic had gotten caught in the outer hatch's gasket, accounting for those hissing air leaks. But most of them drifted off into space when she swung the hatch back open again, and the remaining bits, stuck to the gasket by Tekla's freeze-dried blood, she was able to pick clean using a programmed swarm of Nats. She ended up leaving that project as an exercise for Bo, who was climbing the robot learning curve with remarkable speed.

She drifted down the length of Izzy to the Hub and thence out to the torus, where Maggie, getting advice from trauma surgeons down in Houston, was working on Tekla's arm. This was a lot easier in the weak gravity of the torus—no globules of blood drifting around. Lina Ferreira and Jun Ueda, both also life scientists, were filling in as assistants.

Ivy was in her office fielding a shit storm of angry reaction from people down in Houston.

They were doing the surgery under local anesthesia, so Tekla was awake. They'd cleaned her up, and closed the lacerations around her eye socket with butterfly bandages and Krazy Glue. The silvery-blond stubble that covered her scalp was still darkened with coagulated blood along that side. The whites of her eyes were red, and she had thousands of tiny red marks all over her face. Dinah had been warned to expect those. They were called petechiae: broken capillaries just under the skin, caused by exposure to vacuum. But from the way her eyes moved in their sockets and focused on things, Dinah could see that her vision was basically intact.

"That was uncalled for," Tekla said to her.

"True," Dinah said.

"I shall be in trouble."

"So are we," Dinah said, nodding in the direction of Ivy's office. "We are all in trouble … with a bunch of dead people."

Tekla reacted very little, but among Margie and Lina and Jun there was a collective intake of breath, a momentary halt in the proceedings.

"Margie," said a Texan voice from the ground, "this dead surgeon would like you to clamp off that arteriole before it starts bleedin' again."

"Those of us who are going to live," Dinah said, "have to start living by our own lights."

Pioneers and Prospectors

"THE ICEMAN COMETH."

"Ah." Rhys sighed. "I was wondering which of us would be first to go there." He pulled out, drifted away, and did a peel-and-knot on the condom so expertly that it created dark stirrings of jealousy in Dinah's heart. But at least he didn't let anything get loose in Dinah's shop.

"This may have been your last delivery," Dinah said. "Of ice, that is."

"You've got your freezer?"

"Coming up on tomorrow's launch from Kourou."

"Any chance of getting them to send up a martini shaker with it?"

"We use plastic bags for that."

"Well, I hope that my deliveries—of ice, that is—have contributed something to whatever the hell you've been doing."

"Check this out," she said. She'd already wrapped herself in a blanket, but now she prodded the wall with a toe and drifted over to her workstation. With a bit of clicking around she brought up a video. The opening shot was stark: a cube of ice in a black chamber, lit up by bright but cold LEDs.

"From Arjuna HQ, I presume?" Rhys, still naked, came up behind her and wrapped an arm around her waist. She liked to think of it as an affectionate gesture. In part it was. But she'd been in zero gee long enough to understand that he also just didn't want to drift away while watching the movie.

"Yes."

A bearded strawberry-blond man entered the frame carrying a sheet of corrugated cardboard —the lid of a pizza box.

"That's Larz Hoedemaeker, I think—one of the guys I've been working with a lot."

Larz angled the pizza lid slightly toward the camera. It was mostly covered by iridescent fingernail-sized objects, like silicon beetles. Hundreds of them.

"That's a lot of Nats," Rhys remarked.

"Well … the whole point is to make a swarm."

"I understand. But it seems they've found a way to ramp up production."

Larz folded the cardboard diagonally to make it into a crude trough and then angled it down toward the block of ice. The Nats avalanched down and tumbled onto it in a heap. Quite a few of them skittered off and tumbled onto the floor. Larz exited the frame for a moment, then returned, pushing a wheeled swivel chair. He arranged this behind the block of ice, then disappeared again, then came back carrying a clock that he had apparently just taken down from the wall of an office. He balanced this on the seat of the swivel chair, leaning back against its lumbar support, so that it was clearly visible in the frame of the video. Then he departed.

A few moments later the lights got much brighter. "Simulating solar radiation," Dinah explained. "The Nats are solar powered, so the only way to test them is to have a light source as bright as the sun."

The clock's minute hand now began to sweep forward. "Time lapse?" Rhys asked.

"Yeah. This stuff happens slowly, as you've seen."

The Nats that had scattered to the floor scurried around aimlessly for a bit, then seemed to find the block of ice, and scaled its vertical sides. "Pretty good adhesion, you'll note," Dinah said.

Meanwhile the heap of Nats on top spread out like a pat of butter softening on a pancake, distributing themselves in a somewhat random but basically even layer atop the ice block. A few of them appeared to sink into the ice. "Melting their way in?" Rhys asked.

"No. Uses too much energy—and wouldn't work in zero gee. They are mechanically tunneling. See the piles forming?" She pointed to the top of the ice block, where mounds of white had begun

to form around the exits of the tunnels. “That is spoil being carved out and ejected by the tunneling Nats.”

“You can’t make mounds in zero gee either,” Rhys pointed out.

“One thing at a time!” she said, elbowing him. “The other guys are working on it, see?” She used the cursor to point out another Nat that was making its way along the surface. It seized hold of some little ice grains from a mound, then backed away and headed toward the edge of the ice block.

“How’s it doing that?” Rhys asked.

“You know how when your hand is wet and you reach into the freezer and pick up an ice cube, it’ll stick to your skin? That’s all there is to it,” Dinah said. “And that is also how they crawl around on the ice without falling off.”

The minute hand on the clock began moving faster, and even the hour hand could be seen sweeping around now. The surface of the ice block became pitted and then began to sink toward the floor as material was removed. But at the same time, one edge of the block developed a bulge that grew into a cantilevered prong, like the horn on an anvil.

“What are they building?” Rhys asked.

“Doesn’t matter. This is just a proof of concept.”

The growth stopped, the clock dial slowed to normal time, another engineer walked in to snap some pictures of the result. Then the video cut away to a black screen.

“Interesting!” Rhys said.

She grabbed his hand before he could get away. “Hang on. Check out the superfast version.”

This started a moment later. It was just the same movie, shown ten times faster. So it only lasted for a few seconds. The Nats were invisible because of the speed of their movement—just a jittery gray fog that came and went in patches. This drew the eye to the block of ice. Shown at this speed, it looked less like a crystalline slab and more like an amoeba, sinking down at one end while smoothly projecting a pseudopod into space.

“One has to assume,” Rhys said, “that there’s a reason why Sean Probst is so very keen on making ice sit up and do tricks for him.”

“Yeah. But he’s not sharing it with me.”

“Is there any way,” he wondered, “of joining those Nats end to end?”

“Into a chain?”

“Yes. The Siwis are serviceable, but much more complicated than they need to be.”

“You have got chains on the brain. Yes, there’s a way. And you can join them side to side to make a sheet.”

“Uncle John is calling to me from beyond the grave, telling me to make something of his hobby.”

“Well, stay in my good graces,” she said, “and I’ll let you play with some.”

DAY 56

As of A+0.56, the Hub module around which the torus spun was no longer the aft-most part of Izzy. They called it H1 now. A larger hub, called H2, had been sent up on a heavy-lift booster from Cape Canaveral and mated with it.

H2 had originally been planned as the basis of a large space tourism operation. Rhys's original mission, for which he'd been planning and training for two years, had been to get that up and running. It had a new purpose now, of course, but functionally it would look the same: H2, the big central module, with a new and larger torus rotating around it. That new torus, inevitably called T2, was going to be assembled in space from a kit of rigid and inflatable parts, some of which had been shipped up packed inside of H2, others to follow later on subsequent launches. For the time being, H2 had four fat spokes extending from it to terminate in stubs where other parts, forming the rim of the wheel, would be added later.

The Scouts by then had achieved their basic mission, which had been to employ the Integrated Truss Assembly as a backbone to support a tree of hollow pipes, each about fifty centimeters in diameter, with wide spots every ten meters or so. A human being, provided they were reasonably fit, and did not suffer from claustrophobia, and did not have too much stuff in their pockets, could move through a tube of that diameter, somewhat like a hamster scurrying through a plastic tube in a cage. The wide spots were there so that two people going opposite directions could pass each other. Spherical modules served as connectors and branch points. The tubes terminated in docking locations where spacecraft of various types could lock on to the space station and establish solid, airtight seals.

For it had been obvious from the beginning that docking sites were going to be, in the lingo of Pete Starling, "the scarce resource," "the long pole," "the critical path." Building rockets, spacecraft, and space suits was no easy matter, but at least these things happened on the ground, where colossal resources could be thrown into beefing up production. An armada of space capsules hurled into orbit would have nowhere to go, however, unless they could dock somewhere. And the docking sites had to be built the hard way: on site, in orbit.

Docking was no joke, and required specific technology, but it was thoroughly understood and it had been done many times. The Chinese space program had standardized on the same system used by the Russians, so their spacecraft, like the Russians', could dock at the ISS. So far so good. But the fact remained that every manned spacecraft launched into orbit needed to reach a specific destination within a couple of days' time, before the occupants ran out of air, food, and water. The task of the Scouts, therefore, had been to vastly increase the number of docks in the quickest and cheapest possible way. Docks couldn't be too close together, so the distances between them had to be spanned by hamster tubes. Bracketed to the outside surfaces of those tubes, and still being installed by fresh waves of Scouts, were runs of plumbing and wiring, and structural reinforcements tied into the adjacent trusses.

The initial tube tree, built between about A+0.29 and A+0.50 by Tekla and the other first-wave Scouts, sported half a dozen docking locations. These were spoken for immediately by the first wave of so-called Pioneer launches: three Soyuz spacecraft, two Shenzhous, and a space tourism capsule from the United States.

Encouraged by the success of the launch that had carried Bo and Rhys, the Russians had found ways to cram five or six passengers on each Soyuz.

The Shenzhou spacecraft was based on the Soyuz design, except larger, and updated in various ways. Like the Soyuz, it was meant to carry a crew of three—but this was based on the assumption that those three would want to return to Earth alive. Modified for one-way trips, each Shenzhou carried half a dozen. And the American tourist capsule brought a complement of seven astronauts.

So, all told, the first wave of Pioneers brought three dozen people to Izzy, more than doubling its population. They were obliged to live in their space capsules, which had their own toilets, CO_2 scrubbers, and heat rejection systems. This made for crowded conditions, but it was a step up from the Luks.

On A+0.56, when the H2 module came up on the giant Falcon Heavy rocket, Tekla and the other surviving Scouts spent a day pulling out all that had been stuffed inside of it and anchoring it temporarily to the outside of the module. They then moved into H2, turning it into a Scout dormitory and saying goodbye to their increasingly tatterdemalion Luks, which were deflated, patched, folded up, and stored for later use in emergencies.

About two-thirds of the Pioneers had previous experience doing EVAs or had been hastily trained over the last few weeks. There were not enough space suits to go around—these were being produced as fast as possible on the ground—but the existing ones could be shared. Work shifts were shortened from fifteen to twelve hours, and then to eight, so that fresh bodies could be rotated through the available suits two or three times a day. The spacewalkers divided their time between assembling the T2 torus and extending the tube trees to provide docking space for the next wave of launches.

The remaining Pioneers, the non-spacewalkers, devoted themselves to other activities inside the pressurized parts of the space station. Dinah found herself with two assistants: Bo, who had seemingly assigned herself to the task, and Larz Hoedemaeker—the guy from the video. Larz was a young Dutch man who had been pursuing a graduate degree in robotics at Delft when he had been recruited by Arjuna Expeditions. Dinah knew him as a prolific email correspondent, always willing to answer her questions or supply code patches on short notice. Owing to some lapse in communications, she hadn't even known that he would be one of the passengers on the American tourist capsule that had arrived on Day 52 (for people were now dropping the A+ notation and simply referring to days by their numbers).

All she knew was that a large strawberry-blond man suddenly appeared in her shop, intent on hugging her. This was unusual. To put it mildly, the International Space Station, until now, had never been the kind of place for surprise visits.

Larz had a fistful of chocolate bars in one hand and a camera in the other, and all manner of stuff was spilling out of the pockets of his coverall: vials of morphine, antibiotics, reels of microchips on paper tape, disposable contact lenses, condoms, packets of dehydrated coffee, tubes of exotic lubricants, spare leads for mechanical pencils, bundles of zip ties. The policy now seemed to be that everyone being packed onto a ship first had to be so laden down with vitamins that they could hardly move.

Larz was an enjoyable person, and his first day on Izzy was pure fun for Dinah, who had not been able to have a face-to-face conversation with a colleague in a year. She showed him around the shop, such as it was, and let him drive robots around on the surface of Amalthea, and brought a few of her "Grimmed" robots in so that he could admire them. For, inspired by Rhys's comment of a few weeks ago, Dinah had been putting her otherwise idle robots to work making armor for other robots. The orderly way to do it would have been to bring pieces of the asteroid back to her little zero-gee smelter and produce nice little ingots of pure steel, then weld them onto the frames of the Grabbs. But this was making things too complicated. Amalthea was already made out of perfectly sound material. Maybe it was not structural-grade steel, but it was good enough to serve as radiation shielding. So she had just been slicing pieces of it off, leaving them in their original rough shape, and armoring Grabbs with overlapping plates of the stuff. They looked like walking asteroids now.

"It is an art project," Larz said. For a moment she thought he was trying to insult her. Because she had met a few engineers in her day who never would have combined art and engineering. But his face was happy and guileless, and it was clear that he was paying her a compliment.

Once she'd gotten a bit used to him, she broached the subject that had been on her mind now for several weeks: Why ice? Given that they had direct access to a giant chunk of iron, why was

Arjuna now putting all of its efforts into working with a material that for all practical purposes didn't exist on Izzy?

"Some things are not always explained to me," Larz said, "but you know that we have talked for some time about going after a comet core."

"Sure," Dinah said. "We've talked about it. But those things are huge. What are we going to do with a few gigatons of water?"

Larz just blinked and looked mildly uneasy.

"It would take forever to move something that big!" Dinah said. "It is, like, a tenor twenty-year project! We don't have that much time."

"Under the old conditions, yes."

"What do you mean, the old conditions?"

"Back in the day—before the Agent—when we talked about moving comets, we were talking about sending up a big mirror. Focusing the sun's light on the comet core, boiling off a little water, pushing it slowly to a new trajectory. Yes. That would take a long time. Like pushing a bowling ball with a feather."

"And what about that has changed?" Dinah asked. "Physics is physics."

"Yes," Larz said, "and some physics is *nuclear* physics."

"We're going to use nukes? I thought that was—Jesus. I don't even …"

"You don't appreciate how much things have changed down there," Larz said.

"I guess not!"

"The Arkitects came out and said, 'Listen, there is no way of making this work with solar cells. We can't make enough of them, fast enough, for thousands of arklets. They are big and cumbersome.'"

"I'd been wondering about that."

"We have to use nukes, is what they said."

"RTGs?"

Radioisotope thermoelectric generators were the power units used to run most space probes. At the heart of each was a puck of an isotope so radioactive that it remained hot for decades. Energy could be extracted from that heat in various ways.

"Those are not nearly powerful enough," Larz said.

LARZ GOT MESSAGES FROM THE GROUND IN THE FORM OF ENCRYPTED email, a spate of capital letters in groups of five that looked like something straight out of an Enigma message. In the big nylon wallet that, for Larz, passed as a briefcase was a stack of pages. On each of these was printed a different grid of random capital letters. About half an hour of laborious pencil-and-paper work went into decrypting each message. Dinah couldn't believe her eyes. People used crypto all the time to send email, of course, and it was standard practice for all Arjuna Expeditions email to be enciphered. But apparently that was no longer good enough for Sean Probst. Dinah got used to seeing Larz toiling over these sheets. He wrote a little Python script to make it easier, but he still wrote the messages out by hand.

One day, two weeks after he'd arrived, he decrypted a message with some surprising news. The boss was coming. As in, Sean Probst, the founder and CEO of Arjuna Expeditions.

"How can that even happen?" Dinah asked. "How can anyone just come up to Izzy? Don't you need a launch vehicle? A spacecraft? A place to dock it? *Permission?!*"

These were largely rhetorical questions. Sean had made seven billion dollars from an Internet startup before throwing his energies into asteroid mining. Along the way he'd sunk a billion or two into other private space startups.

"He's coming up alone," Larz said, "in a Drop Top."

It took Dinah a moment, and a quick Google search, to access the memory. Also referred to as "the Convertible," the Drop Top was one of the more creative recent approaches to space tourism. It was based on the idea that what tourists really wanted to experience was the direct view of the Earth,

the stars, and (until it had ceased to exist) the moon. Conventional space capsules had tiny windows. What you really wanted to do was stick your head into a transparent bubble so that you could enjoy a clear view out in all directions. In other words, you wanted to be in a space suit, basically floating free in space. The Drop Top was a small, simple capsule, capable of carrying four astronauts, dressed in custom-made space suits with bubble helmets. During the ascent through the atmosphere, and the reentry, they were protected by a sturdy aeroshell. But while they were orbiting the Earth, the shell retracted, like the roof of a convertible, exposing them completely to space, and even giving them some freedom to spacewalk.

"I don't think a Drop Top can reach an orbit this high, can it?" Dinah asked.

"Sean's coming up alone. It is some kind of special one-passenger model—the extra mass is being used for propellant."

"And then what? He just goes to an airlock and knocks on the door?"

"Basically, yes," Larz said. "What will they do? Tell him to go away?"

DAY 68

"This whole thing is bullshit," said Sean Probst as soon as he got his helmet off.

Dinah smiled. It was not that she was happy about the bullshit. When it came to preserving the human race and the genetic heritage of the Earth from destruction, any whiff of bullshit was bad. But she did feel a certain sense of relief. In the back of her mind she had been quietly tallying up the BS for weeks now. No one else here would speak of it, and most of them seemed smarter, better informed than she was.

She knew Sean Probst by his reputation, by his signature on her paychecks, and by the emails he sent her at three o'clock in the morning of whatever time zone his private jet had most recently taken him to. Sean yielded to no one in his knowledge of all things space related. When he walked into a space station and called bullshit, things were about to become entertaining.

One of the few appealing things about him was that he had figured out that his personality was a problem and, in classic "get it done" style, had hired a coach to make him less of an asshole. She could see that working in his face.

"Not your part of it—that's awesome," he admitted.

"I figured you would have said something earlier if that were not the case," Dinah said.

Sean nodded. Done.

His arrival at the space station had been unconventional, and roundabout. There was no docking station to accommodate the Drop Top. There couldn't possibly be, since the Drop Top didn't even have a port or an airlock. So there'd been no way to attach it to Izzy. He had brought the little convertible in under manual control, tapping the thrusters one at a time, spitting bullets of spent propellant into space, then pausing for one, five, or ten minutes to ponder the consequences. Space nerd that he was, he knew perfectly well that orbital mechanics did not obey the rules of earthbound physics. He had enough humility, and enough spare oxygen, to take it slow. Eventually he had drifted close enough to Amalthea that a three-Siwi train with a Grabb on its head had been able to reach out and grapple a fitting on the edge of his cockpit. He had then ejected himself from the vehicle, floating free in space, and gone on a little tour of inspection, firing off occasional messages to Dinah so that she could know where he was. Since there was no direct radio connection, these had to be relayed through a server in Seattle.

He was in a tubesuit: a tourist product that in some ways was less capable, in others more so, than the government-issue ones used by cosmonauts and astronauts. It had no legs at all, since legs were pretty useless in space. It looked like a test tube with a pair of arms and a bubble-shaped dome on the top. The arms had shoulder and elbow joints, but no hands as such. Gloves were notoriously the most troublesome parts of space suits. Instead, the tubesuit's arms terminated in rounded-off stumps. Projecting from each of these was a skeletal hand consisting of a thumb and three fingers, actuated by steel cables that ran through airtight fittings into the arm-stumps. The occupant could slip his hand into a glovelike contraption inside the stump that would pull on the metal tendons as he moved his fingers, thereby actuating the external digits and enabling him to grab things and perform a few simple operations. There was nothing about it that couldn't have been built by a tinkerer in an inventor's lab in 1890, or 1690 for that matter. People who had used them reported that they worked surprisingly well—better in some ways than conventional space suit gloves, which were stiff and fatigued the hands.

There was plenty of extra room inside the stumps, and so when not using the clawlike hands he could pull his fingers free of the internal glove and let them rest on internal touchpads and joysticks where he could type and swipe to his heart's content. The suit had some tiny thrusters that enabled the user to "fly" it around. Sean had put these to work at some length, wandering around the outside of Izzy and inspecting the work of the robots, the modifications made to the truss, and other curiosities.

Finally he had found his way to an airlock at the aft end of H2, where Dinah had let him in, and he had blurted out his opinion.

He looked like any nondescript thirty-eight-year-old nerd at a graduate physics seminar or a sci-fi convention, with stringy dishwater-blond hair stuck to his head by sweat, and a few days' darker stubble. In his official photos he wore contacts, but today he wore thick-lensed eyeglasses. He pulled one arm, then the other, out of the suit and then pushed himself up and out through the big opening at its top where the head-dome had been attached.

"I've been having trouble seeing the long-term sustainability angle," Dinah admitted. For she was not above dangling bait.

"Ya think?!" he shouted. "Has anyone done even the most basic mass balance calculation on this Cloud Ark concept?" Sean was from New Jersey.

She wasn't sure what he meant, so she stalled for time. "People have been pretty distracted. I wouldn't be the first to know."

"They wouldn't tell you!" he shouted. "Because you would see right away that it is bullshit!"

"What is?" Ivy asked, floating toward them with an interested look on her face. "And who the hell are you?"

Before Sean could explain who the hell he was, he was distracted, to put it mildly, by the appearance of a six-foot-tall Amazon with a shaved head and prominent facial scars, headed for him across H2 as if she had been launched out of a cannon. Tekla drove her shoulder into Sean's midsection, slamming him back against a bulkhead. A moment later she was on him. She grabbed an outstretched arm and put Sean into a joint lock that looked pretty much inescapable.

By now Dinah had spent enough time with Tekla to know that she was a practitioner of Sambo, a Soviet combat martial art with many similarities to jujitsu. Out of idle curiosity, Dinah had watched a few YouTube videos featuring Sambo practitioners in action. But she had never imagined, until now, that it could be done in zero gravity.

Sean had made his entry through H2 because it had a useful assortment of airlocks and docking ports on its aft end. But, unbeknownst to him, H2 had been doing double duty as the dormitory where the surviving Scouts lived. His arrival had awoken Tekla, who was off shift at the moment and had been sleeping in her bag.

Dinah tried to imagine what this encounter must have looked like from Tekla's point of view. Sean's arrival was unannounced. Dinah herself hadn't really known when, or whether, he was going to arrive until the Drop Top had swum into view outside her little window. So, from Tekla's point of view, this guy was an intruder. And when she'd heard Ivy say "Who the hell are you?" she had realized that his presence on Izzy was completely unauthorized.

"Oh, this is awkward," Dinah said.

"Tap! Tap!" Sean kept saying. He was slapping Tekla's leg with his free hand.

"Commander, would you like me to restrain him?" Tekla asked. "What are your orders?"

"He's not dangerous," Dinah put in.

"Let him go, Tekla," Ivy said.

Somewhat reluctantly, Tekla relaxed her grip and allowed Sean to float free. He drifted away from her, sizing her up with a certain degree of bewilderment.

"Sean," Dinah said, "you've already made Tekla's acquaintance. I would like you to meet Ivy Xiao, commander of this installation. Ivy, say hello to Sean Probst."

"Hello, Sean Probst," Ivy said, then turned to look at Dinah. "Did you know he was coming?"

"I had heard rumors," Dinah said. "But I did not think them firm enough to distract you by repeating them. I am sorry."

Ivy looked at Sean long enough to make him uncomfortable. Tekla, hovering almost within reach, did much to help supply the hostile atmosphere that Dinah suspected Ivy was reaching for.

"The closest analogy in the law for what I am here is the captain of a ship," Ivy said. "Do you know the etiquette, Sean, for coming aboard a ship?"

Sean calculated.

"Commander Xiao," he said, "I humbly and respectfully request permission to come aboard your ship."

"Permission granted," she said. "And welcome aboard."

"Thanks."

"But!"

"Yes?"

"If anyone asks, you'll please tell them a little white lie, which is that you requested permission *first,* and *then* came aboard."

"I'm happy to do that," he said.

"Later on we'll evolve some sort of common law, I guess. A constitution for this thing."

"People are working on that, actually," Sean offered.

"That's nice. But right now we have nothing of the sort and so we have to be mindful."

"It is so noted," Sean said.

"Now," Ivy said, "you were saying something about bullshit when I interrupted."

"Commander Xiao," Sean said, "I have the utmost respect for your past accomplishments and for the work you have been doing."

"Do you hear a but coming?" Ivy asked Dinah. "I hear a but coming."

Sean stopped.

"Go on," Ivy said. For at the end of the day, to go on was what Sean wanted, so they might as well get it over with.

HE WORKED IT OUT FROM FIRST PRINCIPLES ON THE WHITEBOARD IN the Banana. Beginning with the Tsiolkovskii equation, a simple exponential, he developed some simple estimates, which he then developed into an ironclad proof, that the Cloud Ark was bullshit.

Or at least that it had been bullshit until he, Sean Probst, had shown up to address the problems he had noticed. Problems that could only be handled by him personally.

It occurred to Dinah to ask herself whether Sean was really rich anymore.

Rich people no longer kept their wealth in gold. Sean's wealth was in stock—mostly stock in his own companies. She hadn't been following the stock market since the Crater Lake announcement, but she'd heard that it had not so much crashed as basically ceased to exist. The whole concept of owning stock didn't really mean much anymore, at least if you thought of it as a store of value.

But legal structures, police, government agencies, and so on still existed and still enforced the law. The law stated that Sean, by virtue of majority ownership of Arjuna Expeditions, still controlled it. And through overlapping relationships with other space entrepreneurs, he still had enough pull to get himself launched to Izzy. So that counted as wealth of a sort.

Having settled that in her mind, she focused her attention back on what Sean was saying.

"Cloud Ark as distributed swarm: fine. I get it. Sign me up. Much safer than putting all our eggs in one basket. What makes it safer? The arklets can maneuver out of the way of incoming rocks. Other advantages? They can pair up to make a bolo, and spin around each other to make simulated gravity. Keeps people healthier and happier. How do they do this? By flying toward each other and grappling their tethers together. What happens when they want to break up the bolo, and go solo? They decouple the tethers and go flying off in opposite directions, unless they use their engines to kill that centrifugal motion. What do all of these activities have in common?"

They'd gotten used to Sean's habit of asking, then answering his own questions, so were caught off guard now that he actually seemed to be expecting an answer.

Dinah and Ivy had been joined by Konrad Barth, the astronomer; Larz Hoedemaeker; and Zeke Petersen. The latter finally rose to the bait.

"Use of the thrusters," he said.

Sean nodded. "And what happens when we are using the thrusters?"

Dinah had an advantage, since she already knew that Sean was concerned about mass balance. "We're dumping mass. In the form of used propellant."

"We're dumping mass," Sean said, nodding. "As soon as the Cloud Ark runs out of propellant, it loses the ability to do all of the things that make it a viable architecture for long-term survival. It becomes a big sitting duck."

He let them roll that around in their heads for a bit, then went on: "Mind you, almost everything else that we do up here can be done with minimal effect on mass balance. We can recycle our urine to make drinking water and our poo to make fertilizer. Very few of our activities involve just releasing mass into space in a way that we can't get it back. This is the exception. I have been ranting and raving about this ever since the idea of the Cloud Ark was announced. So far all I get in return, from the powers that be, are vague answers and hand-wavy happy talk."

Ivy and Dinah looked at each other in a way that foretold a one-on-one, after-meeting tequila session.

So, Dinah thought, Ivy had been wondering about this too, in the back of her mind. Worrying about it. Trying to read the tea leaves during those teleconferences down to the ground.

It was something to do with Pete Starling, she now saw. Which meant that it was somehow related to J.B.F.

Zeke was one of those open-faced, basically optimistic team players one saw frequently in the junior officer ranks of the military. "This is so obvious, in a way," he pointed out. "They *have* to have thought of this." Which was Zeke's way of saying *I'm sure that this is all being handled by people above our pay grade.*

"You would think," Sean said, nodding.

Konrad shifted in his chair uneasily and thrust his bearded face into his hand. Unlike Zeke, he was not the sort to place the sunniest interpretation on the problem.

"If the world were run by scientists, engineers," Sean said, "then this would be a no-brainer. We have to go get more mass. Stockpile it so we don't run out."

"It's got to be water. You're talking about a comet core," Dinah said.

"It's got to be water," Sean agreed. "You can't make rocket fuel out of nickel. But with water we can make hydrogen peroxide—a fine thruster propellant—or we can split it into hydrogen and oxygen to run big engines."

"I'm waiting for the other shoe to drop in what you just said," Ivy muttered. Then she spoke up more clearly: "But the world isn't run by scientists and engineers—is that where you're going with this?"

Sean turned his hands palm up and shrugged theatrically. "I'm not a people person. People keep telling me this. Some who *are* people persons might be focusing on that angle."

"The people angle," Konrad said, just clarifying.

"Yeah. The seven billion people angle. Seven billion who need to be kept happy, and docile, until the end. How do you do that? What's the best way to calm down a scared kid, get them to go back to sleep? Tell them a story. Some shit about Jesus or whatever."

Zeke winced. Konrad rolled his eyes, then glanced at the ceiling and pretended he hadn't heard this.

The idea Sean was playing with here was so monstrous in a way that it was almost inconceivable: that everything they were doing up here was a lullaby for the seven billion down below. That it could not actually work. That they were just putting on a show of getting ready. That the people of the Cloud Ark would live only a few weeks longer than the ones left behind.

As such, Ivy and Dinah and Konrad and Zeke ought to have been freaking out at this point.

But none of them—not even Zeke—reacted very much.

"You've all thought it too," Sean said. "Even an Asp-hole like me can see it in your faces."

"Okay, maybe we've all thought it," Dinah admitted. "How could you not think it? But, Sean, what you might not have seen, being based on the ground, is how serious everyone up here is about making this work. If it were just a Potemkin village, we'd be seeing different stuff."

Sean held his hands up, palms out, placating her. "Can we just agree that there might be a range of views down on the ground? And that some people, perhaps highly placed, see its primary function as an opiate of the masses? Like the video you pop into your car's DVD player to keep the kids quiet during a long drive."

"People like that are not going to be our friends when it comes to getting the resources we need," Ivy said.

"Their strategy is always going to seem a little off-kilter, a little beside the point. Opaque. Frustrating."

They were definitely talking about Pete Starling.

Sean continued. "To the extent that such people control launch sites and policy, we have a problem. Fortunately, they don't control everything."

They were now talking about Sean Probst, and his loose circle of billionaire friends who knew how to make rockets.

"There's a lot about this Cloud Ark thing that I, and my associates, don't know yet. We can't sit around waiting for perfect knowledge. We have to act immediately on long-lead-time work that addresses what we do know. And what we do know is that we need to bring water to the Cloud Ark. Physics and politics conspire to make it difficult to bring it up from the ground. Fortunately, I own an asteroid mining company. We have already identified some comet cores in easy-to-reach orbits. We're narrowing down the list. And we're preparing an expedition."

Konrad well understood the timing of such missions. "How long, Sean?"

"Two years," Sean said.

"Well," Ivy said, "I guess you'd better get on it, then. How can we help?"

"Give me all of your robots," Sean said. He turned to look at Dinah.

"SINCE WE HAVE DECLARED OPEN SEASON ON BULLSHIT …" DINAH began as soon as she had gotten Sean Probst alone in her shop.

Sean held both of his hands up like a fugitive surrendering to the FBI. "Where would you like to begin?"

"You said that you have identified some comets. That you were narrowing down the list. That's crap. You wouldn't have come up here without a specific plan."

"We're going after Greg's Skeleton."

"What?"

"Comet Grigg-Skjellerup. Sorry. Somebody's offspring called it Greg's Skeleton and the name stuck." Sean always referred to children as offspring.

She'd heard of it. "How big is that?"

"Two and a half, three kilometers."

"That's a lot of arklet fuel."

Sean nodded. He crossed his arms over his body and looked around the shop.

"Hard to move something that big."

Still no answer.

"You're going to jam a nuke into it and turn it into a rocket, aren't you?"

He raised his eyebrows briefly. Since this was the only plausible way of moving something that huge, he didn't consider it worthy of an extended answer.

"We got really lucky on the timing," he remarked.

"You're going to fly a radioactive ice ball the size of the Death Star back here just as the shit is hitting the fan—then what?"

“Dinah, I need to share something with you in confidence.”
“Well, it’s about fucking time is all I can say.”

DAY 73

Doob had almost been to space once, about ten years ago. An acquaintance of his who had made a lot of money in hedge funds had dropped twenty-five million dollars on a twelve-day trip to the International Space Station aboard a Soyuz capsule. It was traditional for the customer to designate a backup—a sort of understudy—who would take his place in the event of some illness or mishap. Since the backup might be swapped in at any time up to shortly before launch, they had to go through all the same training as the customer. And that was really the point, as far as the hedge fund man was concerned. An introvert, he needed someone who could act as a connection to the general public and put an appealing face on the whole thing. So he had selected Doc Dubois as his understudy. They'd set up a website and a blog, and arranged for photographers to follow Doob's progress through the training program, with occasional glimpses of the hedge fund man in the background. In effect, Doob had acted as a publicity decoy. No one made any bones about this. Doob had been more than happy to do it. The training had been great fun, the hedge fund man had been generous in his spending on the website, and Doob had been able to produce a lot of good video explaining fun facts about spaceflight.

And there had even been the small chance that he might go. A week before the scheduled launch, he had flown to Baikonur, bringing his wife and kids with him, video crew in tow. They had watched in a certain amount of amazement as the launch vehicle, a fantailed Soyuz-FG, had been towed horizontally across the steppe on a special train, complete with smoke-belching locomotive, to the launch pad. And this really was little more than a pad, a concrete slab on the almost lunar surface of the Kazakh steppe with a few pieces of apparatus around it to hoist the rocket up off the train and pump fluids into it. The contrast with the NASA way of doing things was stark to the point of being somewhat hilarious. Doob's youngest son, Henry, eleven years old at the time, had failed to pay attention to the elevation of the mighty rocket to its vertical position because he was distracted by the sight of a couple of stray dogs copulating a hundred meters away from ground zero. The launch bunker, shockingly close to the pad, had a little vegetable patch out in front of it where the technicians were growing cucumbers and tomatoes; they explained that the concrete wall soaked up sunlight during the day and helped keep the vegetables warm at night.

Three days before launch, the hedge fund man had been nipped by a stray dog while rehearsing a launch pad escape sequence, and everything had been thrown into disarray as the dog was chased across the steppe by militiamen in wheeled vehicles, locals on horseback, and a helicopter gunship. After they had run it to ground they had shipped it off to a veterinary lab to be checked for rabies. Only three hours before launch, word had come back that the dog was clean. Doob's name had been struck from the manifest and replaced by that of the hedge fund manager. Both relieved and disappointed, Doob had stood on terra firma, very close to the launch pad. Tavistock Prowse had come out to cover the launch. He had come equipped with all kinds of electronic gadgets that had seemed cool at the time. He had stood there on the steppe, facing Doob and the rocket, aiming a video camera at him and catching his narration as the giant vehicle had fired up its engines and hurled itself into the sky.

More than anything else, that image had made Dr. Harris into Doc Dubois and launched his career. It had also led, within days, to divorce proceedings initiated by his wife. She had a number of complaints about his performance as a husband, many of long standing, some that she could barely articulate. But somehow all of them had been summed up and crystallized by the fact that, after largely ignoring his responsibilities as a husband and father for several weeks while training for this launch in Russia, he had spent the actual moment of launch not gathered in a safe place with his children but outside, dangerously close to the rocket, with his bro Tav, ingratiating himself to millions of followers with excited and hilarious commentary.

One way or another, Doob had been paying for it ever since. Partly in the negative sense of suffering just penalties for his sins but partly in the more positive sense of spending time with his kids

when he could. And this had become more difficult as they had graduated from school and gone out into the world. He was making a particular effort to do it now that they were all under a death sentence.

On A+0.73, Doob flew into Seattle, rented an SUV, and drove to the campus of the University of Washington. Along the way he stopped at a couple of outdoor stores to pick up some camping equipment. This was now expensive. People had begun hoarding that sort of thing in anticipation of a collapse of civilization. But only a few people. Most understood that there was little point in taking to the hills when the Hard Rain began. Freeze-dried food and backpacking stoves were difficult to come by, but down sleeping bags and fancy tents were still in stock.

Henry was now a junior in the computer science department, living with some of his friends near the campus in a rental house, a classic Seattle down-at-heels Craftsman bungalow half digested by blackberries and English ivy.

In a certain way it made no sense anymore to speak of anyone as being a student at a particular stage in a degree program. And yet people went on thinking this way, kind of in the way that someone who has just been diagnosed with a terminal illness will go on getting up and going to work every morning, not so much out of habit as because the knowledge of impending doom makes them wish to assert an identity.

He was tempted to park the SUV illegally, since, according to his calculations, the authorities were not likely to catch up with him and demand payment of the parking ticket before the end of the world, but it seemed that most of the people of Seattle were still obeying the rules and so he did likewise.

He found Henry, all four of his housemates, and five other students all crammed into the ground floor of the bungalow, keeping it warm in the January chill with their body heat and the warmth emanating from a rat's nest of PCs, laptops, and routers. A quick census of empty pizza boxes suggested that they had been working all night.

"I'll explain it to you while we drive" had been Henry's promise to his dad when Doob had asked him on the phone last night what he was doing. This morning, other than getting up from his La-Z-Boy to give his dad a hug and tell him "I love you," he didn't have much more to say.

Every parent of a teenager gets used to it: the moment in a child's life when he or she decides that certain facts are just too much trouble to explain to Mom or Dad. The parents can't, and needn't, know every last little thing. They just have to accept this, be content with what they can glean on their own, and move on. Henry, of course, had passed through that veil some years ago. Doob had swallowed his pride and accepted it as every parent must. It was part of growing up. But back in those days the subject matter had been fundamentally uninteresting: the size of Henry's collection of Magic: The Gathering cards, the weight lifting program assigned him by his football coach, and who had a crush on whom at school. It was easy for Doob to pretend he didn't care about that stuff.

What he was seeing over the shoulders of the students in this room looked a good deal more interesting. And that, in a way, hurt.

All of them, of course, knew that Henry was the son of the famous Doc Dubois. While trying to play it cool, they all sought a chance to shake his hand and say hi. Doob chewed the fat with them while his eyes strayed to the stuff they had blue-taped to the walls of the bungalow: printouts of CAD drawings, schedule grids, Gantt charts, maps. He was obviously looking at some sort of engineering project in the works, but he couldn't make out what, exactly. On the kitchen table a MakerBot was producing a small plastic part, watched intently by a young woman who was talking on her phone in a mix of English and Mandarin.

Conversation was interrupted by the *beep-beep-beep* of a backup alarm, loud and growing louder. Someone pulled the front door open, letting in a wash of wet, cool Pacific air, to reveal a Ryder box truck backing up onto the lawn, heading straight for the front door. Some unkillable instinct in Doob's head made him glance disapprovingly at the muddy ruts it was leaving in the lawn, made him issue a little *tut-tut-tut* at these irresponsible youth for damaging the grass—grass that in two years

would be a thin smear of carbon black over a lifeless cake of hardened clay, presuming it didn't suffer a direct hit and become part of a huge glass-lined crater.

The truck didn't stop soon enough and wrecked a wooden banister beside the front steps.

Everyone laughed. The laughter had a curious tone, a mixture of childish delight with something darker, expectant of much worse to come.

These kids were really adapting better than he was.

He had no idea what was going on, but it seemed to involve throwing everything into the back of the box truck. He stood around for a while with his hands in his pockets, since he didn't know which stuff was going and which was staying. But when they threw in the sofa it became clear they were abandoning the house. He began helping. After a certain point the box truck filled up. Then they began pulling things out of it and putting them back in in a more orderly style. Doob finally hit his stride, stepping into the role of wily old man with excellent packing skills and pointing out ways to use the space more efficiently.

Eventually someone went and got another box truck. Apparently the rental agency was letting them take them for free. Some day laborers wandered down the street from a home improvement center and helped pack. The home improvement market had gone bust. Doob saw traces of Amelia in their faces and wondered how they had first heard the news.

Six of the kids packed themselves and their computers, clothes, and as many tools as they owned or could borrow into the SUV that Doob had rented at the airport. They roped a couple of bicycles and some camping gear to the luggage rack. Doob had no idea where they were going, or why, but they seemed to be planning to construct a new civilization out of blue tarps and zip ties.

They ended up in a caravan of twenty vehicles, headed east out of town at about two in the afternoon. At this time of the year, at Seattle's high latitude, that gave them about two hours of remaining daylight.

Most of the kids fell asleep immediately. Henry, riding shotgun, made a touching effort to stay awake and then fell into slumber. Henry was a sweet kid and Doob knew that when he woke up he would apologize. But Henry wasn't a parent, and he didn't understand that when you were, almost nothing was more satisfying than seeing your kid sleep.

So, feeling as content as it was possible to be under the circumstances, Doob drove into the darkling mountains with his SUV-load of slumbering passengers. The caravan gradually dissolved into the general stream of traffic. Most of the passenger cars peeled off at the suburban exits, before the road began to gain serious altitude. Doob wondered, as he always did, what the hell they were doing: Continuing to go to jobs and school, just to fill the days before the end? But it was none of his business.

Beyond Issaquah, any vehicle still on the interstate was probably headed for the high cold desert on the east side of the mountains. A few people were still interested in skiing—skiing!—but those cars were easily identified. Most of the other vehicles fit the general description of those that had been a part of their original caravan from the university: heavy-laden box trucks, SUVs and pickups with provisions and camping gear.

Doob realized that he had somehow become a sort of Okie.

Except that the Okies had at least known where they were going.

The eternal Seattle drizzle turned into alternating belts of mist and cold rain, forcing him to keep one hand busy on the wiper control. The raindrops became cloudy with ice as he gained altitude, and then turned into snow. The roadway was still clear, but the shoulders became fuzzy with slush that gradually encroached on the traffic lanes. The speed of travel dropped to forty, thirty, twenty miles an hour, and the road ahead congealed into a slurry of taillights as lowering steel-gray clouds clamped down on the remaining traces of daylight.

A few semi-articulated rigs were laboring up the approach to the pass in the slow lane. Some of these were just conventional boxy trucks and so there was no guessing what might be in them,

but Doob thought he was picking out an unusual amount of weird industrial traffic: tankers carrying cryogenic liquids, flatbeds with bundles of tubing and structural steel.

The clouds flashed, bright enough to make some of the sleeping students flinch and stir in the backseat. Out of habit, Doob began counting *zero Mississippi one Mississippi two …* and when he reached something like nine or ten he felt, as much as heard, the sonic boom. As a child he'd have assumed it was a lightning bolt. Now he interpreted all such events as incoming chunks of moon shrapnel. This one had passed within about three kilometers. A secondary boom, several seconds later, suggested that it had hit the ground, as opposed to just breaking up in the atmosphere as most of them did. So it had been a relatively large piece.

It had been a day or two since Doob had checked the site where his grad students had been tallying observed bolides vs. the predictions of their model. He didn't check it very often because, after some jitter in the first few weeks, the model had been refined to the point where it tracked observations to within a reasonable statistical range. This, of course, was good news for the model and bad news for the human race, since it meant that they were still on track for the White Sky to happen, and the Hard Rain to begin, in another twenty-one or twenty-two months. If memory served, strikes like the one he had just observed were probably happening about twenty times a day worldwide. So it was mildly remarkable that he'd been close to one, but nothing to write home about.

A few minutes later the taillights ahead of him flared as people applied their brakes. After inching along for a short distance traffic came to a complete stop. This woke up some of the students, who remarked on it sleepily. After ten minutes had passed without movement, Henry climbed out, stood up on the SUV's running board, and began loosening ropes holding a bicycle in place on the roof.

Doob sat warm and safe in the driver's seat and watched his son pedal off between the lanes of stopped traffic with precisely the same heartsick feeling as when the boy had gone off on his first solo bicycle ride in the streets of Pasadena.

He was back all of three minutes later. "A rig jackknifed just before the top of the pass," he said. "An oversized load, a piece of a gantry, I think."

Gantry. There was a word that activated deep memories in Doob's brain. Only used in connection with launch pads, only spoken by the likes of Walter Cronkite and Frank Reynolds in the deep nicotine-cured anchorman tonalities of the Apollo days.

Nothing was happening, so they pulled their winter coats out of the back, bundled up, and hiked up the road to see. A lot of people were doing this. This struck Doob as unusual. The normal behavior was to wait in the car, thumb the iPhone, listen to a book on tape, and wait for the authorities to come and deal with it.

The stranded truck was only about half a mile ahead of them. It looked to have gone into a spectacular skid. The colossal weight of the gantry—a welded steel truss looking like a section of a railway trestle—had swung the rear end of the truck forward and sideways, sweeping across all lanes of traffic and finally grinding to a stop by flopping over onto its side and then destroying about a hundred yards of guardrail. Behind it a few cars had spun out as their drivers had stomped the brakes, and a few people were dealing with the aftermath of minor rear-end fender benders, but no one seemed to have gotten seriously injured.

The pedestrian traffic toward the crash had been considerable, and yet Doob saw few of the sorts of people he would classify as gawkers or rubberneckers. Where were they all going? As he and Henry and the other students drew closer he saw cars moving around, headlights sweeping across the wreck to better illuminate it, and then he saw a stream of people squeezing through the gap to the other side, or clambering through the space between the tractor and the trailer. Self-appointed safety wardens had stationed themselves at critical locations to focus the white beams of their LED flashlights on trip hazards and useful handholds. Doob and the others crowded through those gaps and then broke free to the far side of the wreck. The view here was worth a look. The wet interstate,

completely empty of traffic, stretched away from them. A ski area, lit up for night use, spread up the mountainside to their right. In the distance maybe ten, twenty miles away, a streaky patch of mountainside was flickering a lambent orange through intervening veils of snow and mist: the impact site of the bolide. Doob saw now how it had all happened. The meteor had passed overhead. To him it had just been a flash above the clouds, but to the people cresting the pass at the same moment it must have been visible as it streaked into the ground and plowed up a mile-long stretch of forest. Cars must have faltered and strayed out of their lanes. The driver of the truck had been forced to apply his brakes and the tires of the trailer had broken loose from the slushy pavement.

The number of people on this side of the wreck must have been well over a hundred.

Twenty minutes later, there were enough of them to flip the rig back up onto its wheels. Like a work crew of Egyptian slaves moving a great block of stone, all of these people in their parkas and their microfiber gloves and snow pants just got under the thing and started lifting it. Towing straps had been fetched from toolboxes and anchored to the other side of it, and run to the trailer hitches and the bumpers of several pickup trucks that had four-wheeled their way to the scene, and they pulled while the humans pushed, and with surprising ease the whole thing came up, balanced for a moment on half of its wheels—the only sound now being the skidding of pickup tires as the drivers burned rubber—and then dropped into place. A huge uproar of people shouted *Whoo!* as much in relief as in exultation. Doob exchanged thumping, mittened high fives with twenty people he'd never met before and would never see again.

Getting the truck pointed in the right direction again, and back on its way down the interstate, was a more tedious operation that would likely span another couple of hours. But within a short time they were at least able to open one lane. By then, people with four-wheel-drive vehicles had already begun to cut across the median strip and claim lanes on the wrong side of the interstate, which was sparsely trafficked by veering cars holding their horn buttons down in long Dopplered howls of protest.

Another slowdown caught them an hour later when they entered a low plume of thick smoke drifting across the highway and bringing visibility down to almost nothing. Galaxies of red and blue flashing lights emerged from the murk and then receded: places where emergency vehicles had clustered to stage firefighting efforts, or to aid locals affected by the strike. At one place, sitting in the middle of the road, festive with road flares, was a rock the size of a car, which had struck the pavement hard enough to pierce it and lever up thick shards bristling with snapped rebar. Not the meteorite itself, but ejecta: shrapnel hurled out from the impact site.

There was another delay, this one purely for gawking, at the place where the interstate crossed the Columbia River, almost a mile wide, at Vantage. Something was going on down below the bridge, on the eastern bank of the river where the low span angled up away from the water to let big barges pass beneath it. Blinding lights had been elevated on poles, creating a mottled spill of daylight where something huge and cylindrical was being winched up off a barge.

With all of those complications it was well after midnight when they reached the town of Moses Lake and turned off the interstate to follow almost all of its traffic in the direction of the Grant County International Airport.

That was its official name. When Doob woke up the next morning, crawled out of the tent he had shared with Henry, and stood up and looked about, he immediately dubbed the place New Baikonur. It was at the same latitude as Baikonur and it was in the same sort of steppe country.

And like the steppe of old it was populated by nomads. Space Okies. At least ten thousand, he guessed.

They seemed orderly enough. Long straight lines had been chalked out on the dry lakebed, apparently with the same equipment used to stripe football fields. These delineated streets and avenues that, for the most part, were being respected by newly arrived tent pitchers. Portable toilets

huddled at strict intervals, though Doob's nose told him that some were using pit latrines, or just pissing on the sagebrush.

Henry had filled him in a little during the last hours of the drive. It had been an air force base, part of the northern line of defensive installations from which the U.S. would have defended itself against Communist aggression, had that ever been necessary. Its 13,500-foot runway suggested it might have had offensive purposes as well. It had been an alternate landing site for the Space Shuttle, never used. In any case it was ridiculously oversized for the town of Moses Lake and had tended to be used by the aerospace industry in recent decades for various training and experimental purposes. Blue Origin had used it to test a VTOL craft in 2005, operating from a trailer on the empty lakebed west of the airport where New Baikonur was arising now, and where Doob was walking about trying to track down the scent of frying bacon.

Some giant, windowless aircraft hurtled overhead, deploying a phalanx of tires from its belly, and made a long, slow landing on the big runway, using every one of the 13,500 feet. A cargo carrier.

He came to a broad avenue that led directly into the encampment's center. And there was no mistaking where and what the center was: a concrete pad, still being poured one patch at a time, with a mixed assortment of cranes rising up from what he took to be its center.

They were assembling a rocket there.

It was a big rocket.

It all more or less made sense. There was no cargo too big to be barged up the Columbia River and then trucked the last few miles to Moses Lake. There was no airplane that couldn't be accommodated by that runway. There was no object that the aerospace machine shops of the Seattle area couldn't build. And from this latitude, the same as Baikonur, a well-worn and understood flight plan could take payloads to Izzy.

A mere four days later, Doob stood in the bed of a rusty pickup truck with a random assortment of space rednecks, hoisting a longnecked beer bottle into the sky in emulation of the rocket lifting off from the pad. They all hooted and screamed as they watched it arc gracefully downrange and take off in the general direction of Boise. And the next morning, when they had all sobered up, they got busy building another rocket.

DAY 80

"We talk about sending stuff to orbit as if orbit is a place, like Philadelphia, but it's actually a lot of places, a lot of different ways to be in space. Any two objects in the universe can theoretically be in orbit around each other.

"Most of the orbits that matter to us involve something tiny orbiting around something huge, like a satellite around the Earth, or the Earth around the sun. So, a quick way to label and classify orbits is according to 'What is the huge thing in the middle?'

"If the huge thing in the middle is the Earth, we call it a geocentric orbit. If it's the sun, it's a heliocentric orbit. And so on. Since the moon broke up, we've mostly focused on geocentric orbits. The moon, back when it existed, used to be in such an orbit; it revolved around the Earth. Most of its pieces still remain in geocentric orbits. A small number of those just happen to intersect the Earth's atmosphere. When that happens, we get a meteorite.

"So much for Orbits 101. But keep in mind there can be different levels. So, the old Earth-moon system was, as a whole, revolving around the sun in a heliocentric orbit. And if you zoom way out and look at the entire Milky Way galaxy, you can see that our whole solar system is very slowly revolving around the black hole at its center, in a galactocentric orbit."

The voice was that of famous astronomer and science popularizer Doc Dubois. The images accompanying it were an animation zooming in and out of the solar system. Dinah was getting snatches of it over the shoulder of Luisa Soter, a recent arrival to Izzy and hands-down winner of the "least like a traditional astronaut" competition. Born in New York City to parents who had fled political repression in Chile, she had been raised in a polyglot bohemian household in Harlem, walking through Central Park every day to the Ethical Culture School on West Sixty-Third. She'd followed that up with a succession of degrees in psychology and social work from UCLA, Chicago, and Barcelona. After a few years of work with economic refugees trying to enter Europe on leaky fishing boats, she'd been awarded a genius grant that had given her the freedom to travel the world for a few years doing research on other economic migrants.

Two weeks ago she'd been yanked out of a Fulbright scholarship at the University of St. Andrews in Scotland, given some basic training in how to live in space, strapped into a rocket, and shot up here in a tourist capsule.

Dinah, along with everyone else, made the obvious assumption that Luisa's job was to be the first shrink and social worker in space. Judging from some interactions that had been happening as crowding and stress had gotten more intense, she was going to have her work cut out for her. A bunch of desperate people crowded aboard a pitching and rudderless fishing boat was an uncomfortably close match for the situation up here.

Luisa had a relaxed self-confidence that made it easy for her to admit that she knew absolutely nothing about such topics as orbital mechanics. But it was more than just that; she knew how to use her own ignorance as an icebreaker in conversations. Izzy was full of people who were skewed toward the Asperger's end of the social spectrum, and there was no better way to get them to start talking than to ask them a technical question.

But when everyone else was busy, Luisa was not above googling her question down to Earth and latching on to a YouTube video, as she was doing now.

Dinah, floating behind Luisa's shoulder, watched as the animation was replaced by a live shot of Doc Dubois and a stocky, bald white man standing next to each other on the flat pan of gray-brown dirt that she now recognized as the Moses Lake spaceport. In deep background behind them was another rocket being stacked on the pad, one stage at a time, by a tangled-looking arrangement of cranes, gantries, and cables.

Dinah vaguely recognized the one who wasn't Doc Dubois; he was a tech pundit who popped up frequently on television and YouTube. He turned toward the camera and spoke: "This is Tavistock Prowse, coming to you from the world's newest spaceport here in Grant County, Washington. I'm here with a man who needs no introduction, Doc Dubois, to talk about some of the recent controversial events surrounding the Arjuna Expeditions launches, many of which are originating from the improvised launch complex that you can see directly behind us. Arjuna has prepared an animation that explains what they are all about. So pop some popcorn and pull up a chair."

Their image was replaced by a view of Earth that zoomed back, tilted, and panned to show it in its orbit around the sun. This was helpfully traced out by a thin, curved red line. The animation panned back. The orbits of Venus, Mercury, then Mars and Jupiter came into view. "Traditionally," Doc Dubois said, "when we talk about asteroids, we're talking about the asteroid belt, which is out between Mars and Jupiter."

A ring of dust, with a few larger clumps, was now spattered into the huge gap between those two planets' orbits. "There's a lot of material out there that Our Heritage might one day be able to exploit, but it's too far away to be easily reached by any spacecraft we have now."

So Doc Dubois, in keeping with his rep for staying in touch with the zeitgeist, had adopted the Our Heritage phrasing, a suddenly popular buzzword and hashtag meaning "whatever gets accomplished in the distant future by the descendants of the people who make it onto the Cloud Ark," or, to put it bluntly, "the only reason to go on living for the next twenty-two months."

The animation began zooming back in, to the point where it showed nothing beyond Earth's orbit. "But astronomers have known for a long time that not all of the asteroids are out beyond Mars. There are much smaller—but still significant—populations of asteroids in heliocentric orbits not that different from Earth's."

A finer and sparser dust of particles was now drawn in, forming a sort of fuzzy halo around the red line that represented Earth's orbit.

"And that's where Amalthea came from, is that correct, Doc?"

"Yes, bringing a hunk of metal that big from all the way out between Mars and Jupiter would have taken forever. Because we found it in an Earth-like orbit, it was a little easier."

"And what do you mean by an Earth-like orbit?"

"These rocks all revolve around the sun just like the Earth. Some are a little inside Earth's orbit, some a little outside of it, some cross the Earth's orbit twice every time they go around the sun. We used to worry about those."

"Now, not so much," Tav put in.

Doc paused, and apparently thought better of acknowledging the joke. "Because we *were* worried about them, we made an effort to find them and to know their exact trajectories—their orbital parameters."

Back to Doc and Tav, now walking across the pounded earth of the spaceport with a big truck in the background emblazoned with the Arjuna Expeditions logo.

"In recent years, companies like Arjuna Expeditions have mapped a whole lot more of those asteroids in the hopes of mining them. What we're seeing in the last few weeks is a concerted effort by Arjuna, and an alliance of other private space companies, to throw those efforts into high gear."

"What exactly is Sean Probst thinking, Doc?" Tav asked.

"He's not telling us. But the science of orbital mechanics doesn't leave a whole lot to the imagination. In Part Two of this video, you can learn more about the dance of orbiting bodies in space, and the intricate choreography needed to make an asteroid show up in the right place at the right time."

Luisa's finger hovered over the link that would play the next video, but before tapping it, she turned around to look at Dinah. "Just trying to figure out what you do for a living," she said, in an accent that came from everywhere, but mostly from New York. "You're with Arjuna, right?"

"Shh!" Dinah warned her jokingly. "I'm still trying to stay friends with the Russians."

"What's that about?" Luisa asked.

She was referring to a recent series of testy meetings, and sometimes out-and-out confrontations, between the Russians—still thinking and acting as a bloc under the leadership of Fyodor Antonovich Panteleimon—and the Arjuna contingent, which actually prided itself on being "disruptive." This was a commonplace bit of biz jargon. But try explaining to a grizzled cosmonaut why being disruptive was a good thing.

Dinah was inclined to say something like "It's cultural," but she felt a little intimidated about using that sort of cocktail-party banter around someone with Luisa's credentials.

"Look, surprises in space are almost always bad," Dinah said. "Traditionally, every mission is planned out to the nth degree, and there's a contingency plan for everything. You don't improvise. You *can't* improvise, because there's nothing to improvise *with*."

"I'm just remembering the duct tape in *Apollo 13*."

"Yeah, that was one of the rare exceptions," Dinah said, "and people are still talking about it decades later. So, to the Russians, the idea that someone can just show up unannounced, and make a claim on our resources—"

"What resources?" Luisa asked.

"They're breathing our air," Dinah said. "Taking up space, using bandwidth, you name it. Larz hitched a ride up here on the assumption he'd stay on Izzy and work for us—instead he's taking off with Sean. And they are taking almost all of my robots."

"But they're sending more, yes?"

"Absolutely. Look, all I'm saying is that it was a surprise. And the sooner Sean and Larz get out of here, and on their way, the less likely it is that Fyodor is going to strangle them with his bare hands."

"On their way to where?" Luisa asked.

"A different orbit."

"Heliocentric or geocentric?" Luisa asked, deadpan, then gave Dinah a wink.

"Geocentric first. Then heliocentric," Dinah answered with a trace of a smile.

"But I thought we were already in a geocentric orbit."

"The wrong one, as far as Sean is concerned. Izzy's orbit is angled with respect to the equator. It has to be that way so Baikonur can launch to it—Baikonur is as far north as Seattle. But when you are doing interplanetary stuff, which is what Sean has in mind—basically, whenever you want to get out of low Earth orbit—you want to be in an orbit that's closer to the equator. Because that's pretty much where the rest of the solar system is—including the big chunk of ice that Sean wants to grab and bring back here."

"Ymir," Luisa said, pronouncing it as she'd heard Sean do: *ee-meer*. A word from Norse mythology referring to primordial ice giants. Sean's code name for a particular hunk of ice that his project had identified, and that he meant to bring back.

"Yeah. Not an official name. Sean doesn't divulge much."

"And how do you get from one to the other?" Luisa asked. "From a geocentric orbit—that's what we're in now, right?"

"Yes."

"To a heliocentric one?"

"Well, first he's going to have to do a plane change—from the angled Izzy orbit we're in now, to one closer to the equator. He'll rendezvous with the rest of his gear."

"Why didn't they just send everything up here?"

"Plane-change maneuvers are expensive. It's not too bad if the only thing plane-changing is Sean and Larz and a Drop Top, but it would be ridiculously wasteful to send the whole expedition package up here only to plane-change later." Dinah didn't mention the other reason, which was that

the biggest part of Sean's package was so screamingly radioactive that it couldn't be allowed anywhere near Izzy.

"Okay. But we're still talking geocentric, right?"

"Correct, we're still just a few hundred miles high."

"So, how do they get from the rendezvous point to a heliocentric situation?"

"There's a bunch of different ways to do it," Dinah said, "but if I know Sean he'll go through the L1 gateway."

"I have no idea what that is," Luisa said, then finally lost a fight to suppress a giggle. "But once again I feel that I have been dumped into a sci-fi movie when I hear people around me talking like that."

"Doc Dubois probably covers it in that video," Dinah said, nodding at Luisa's tablet, "but the gist of it is really straightforward." Looking around, she spied a mesh bag stuffed with clothing. She pulled it out of its niche and let it drift in the center of the cabin. "The sun," she said. Now patting herself down, she found in her pocket a small plastic bottle of pills—antinausea medication she had fetched for one of the new arrivals. She opened it up and pulled out the ball of cotton stuffed into its top, then let the cotton drift in the air a little closer to Luisa. "The Earth, in its heliocentric orbit." The sick crew member would have to wait for a few minutes. Dinah carefully tapped a few pills free from the bottle's open neck and let them float for a moment while she pocketed the bottle. Then she began to arrange the pills in the space already staked out by the "sun" and the "Earth."

"Asteroids?" Luisa guessed.

"These are more like abstract mathematical points," Dinah said. "They're called the Lagrange points, or the libration points, and there's five of them around every two-body system. Always in the same basic geometry. Two of them, L4 and L5, are way off to the sides. I'm not going to try to show you those because we don't have room. But the other three are all along the line running between the sun and the Earth." She pushed off and glided to the far side of the "sun" and stationed a pill there, exactly on the opposite side from where the "Earth" was. "This is L3, very far away, invisible to us because the sun's always in the way, not that useful."

Gliding back toward the hovering cotton ball, she stopped herself against a bulkhead and placed a second pill out beyond it. "This is L2, outside of Earth's orbit." Finally, she put a pill in between the "sun" and the "Earth" but much closer to the latter. "And this is—"

"L1, by process of elimination," Luisa said drily, and laughed. "You space people love to count down, I know your ways."

"It's where the gravity of the sun and the Earth balance," Dinah said, "and people sometimes call it a gateway because it's an easy place to effect a switchover between a geocentric and a heliocentric orbit. This even happens naturally sometimes: an asteroid in a heliocentric orbit will wander close to L1 and get captured by the Earth. Or, going the other way, there's a case where an Apollo upper stage orbiting around the Earth passed near L1 and got ejected into a heliocentric orbit for a number of years. Later it came back through the same gateway—only to get ejected again."

Luisa nodded. "Like changing from the D to the A train at Columbus Circle, in New York terms."

"A lot of people have used the analogy of a switching yard or a train station to describe it, yeah," Dinah said.

"So you think Sean and his crew are headed that way."

"Once they get all their—" Dinah paused.

"Their shit together?" Luisa suggested.

"Thank you, yes," Dinah said with a smile. "They need to get to a higher orbit than we are in now if they are going to reach L1. That means burning their engines, expending a lot of fuel in just a few minutes, and then coasting for a few weeks. They'll have to pass through the Van Allen belts and soak up a lot of radiation. No avoiding it, unfortunately. L1 is four times farther away than the moon."

"Or what used to be the moon," Luisa said under her breath.

"Yeah, which means that in a few days Sean and his crew are going to be farther away from Earth than any humans who have ever lived. When they get to L1—which will take five weeks—they'll have to execute another burn that will switch them from the D to the A train—place them into a heliocentric orbit. And from there they can plot whatever course is going to get them to the comet."

Luisa had gotten a bit sidetracked by the first part of what Dinah had said. "Farther away from Earth than anyone in history," she repeated. "I wonder if there might be a certain feeling of jealousy at work in Fyodor's reaction, knowing that after all the time he has spent in space—"

"Some rich whippersnapper is going to show up and make his accomplishments look minor," Dinah said, nodding. "Could be. Fyodor's got the Russian granite face, you can't tell what's going on inside."

"Anyway," Luisa said, "they go and fetch the big ball of ice and then reverse all of those steps to come back to what by that point will hopefully be the Cloud Ark."

"Not exactly," Dinah said. "And that's where things get interesting."

"Oh, I thought they were already pretty interesting!" Luisa said.

Dinah was limited, here, in what she was allowed to say. "Maneuvering a space vehicle—which is designed and engineered to be what it is—around the solar system is one thing. Moving a huge raggedy-ass ball of ice is another."

"It's going to take a long time," Luisa said, nodding. "And it might not work."

"Yeah. Look, I just make robots."

"All of which will be making the trip?"

"Yes," Dinah said. "They'll be needed on the comet's surface, for anchoring cables and netting. It's a big chunk of ice. It's brittle. We don't want it to fall apart like a dry snowball when thrust is applied."

"A dry snowball," Luisa repeated. "Is that a thing, where you come from?"

"The Brooks Range? Yeah. Terrible place to make snowballs."

"Unless you're the kid sister," Luisa said, "and everyone's throwing them at you."

"No comment on that."

"In Central Park," Luisa said, "the snowballs were wet and they were hard."

DAY 90

When Ivy had opened the meeting on Day 37 with the words "five percent," Dinah and most of the others on Izzy had looked around themselves and seen a lack of progress that had troubled them. Which, of course, had been Ivy's point. On that day, twenty-six people had been in space, eight of whom were just barely surviving in temporary Luk shelters. The Banana had, with a bit of crowding, accommodated everyone.

On Day 73, when Ivy had opened another meeting in the Banana with the words "ten percent," the situation had been transformed. There had been no question anymore of fitting Izzy's whole population into the Banana; most of them had had to watch the meeting on video feeds. Thanks to Sean Probst and his Arjuna launches out of Moses Lake, no one quite knew what the total off-Earth population was anymore. Allegedly there was a Google Docs spreadsheet where it was being kept track of, but no one could agree on where it was. The population had certainly gone into the triple digits at least a week before.

In the first two weeks of its operation the new shake-and-bake spaceport at Moses Lake had launched three rockets. One had crashed into a high-end vineyard near Walla Walla, destroying several acres of grapes that would have made excellent wine, had there been enough time left on Earth's clock to age it properly. The others had made it to Izzy.

Most of Arjuna's big payloads, though, were being launched not from Moses Lake but from sites nearer the equator, whence they could get into orbits closer to the plane of the ecliptic. At least two heavy-lift rockets, one from Canaveral and one from Kourou, had effected a rendezvous and docking maneuver in a low orbit above Earth's tropics. Others were said to be in the works. But little was known of this project. Communication wasn't Sean Probst's strong suit, and his career in private enterprise had instilled a habit of playing his cards close to his vest. In this he seemed to be of one mind with the small cohort of people aboard Izzy, like Spencer Grindstaff and Zeke Petersen, who had impressive security clearances. Dinah and Ivy, comparing notes and sharing fragments of circumstantial evidence, had assembled at least a vague theory of what was going on. Ostensibly, Sean Probst was a wild card. But Arjuna had been mailing Nats to Sparky for weeks, and Sparky had been giving them top priority on launches to Izzy. It seemed, therefore, that Dinah's results —the feedback she was sending to Arjuna about which Nats worked in space and which didn't— were of great interest to NASA. And it was significant that at least one of Sean's payloads had been launched from Canaveral—which was, of course, NASA's flagship launch facility. Even more so was a launch out of Vandenberg Air Force Base that added a small additional module to the growing Arjuna complex. They knew it was small because of the size of the rocket used, and they knew it was top secret spook stuff because of the precautions that had been taken on the ground—that much had been reported by ordinary citizens, who had been forced to the shoulder of Highway 101 by a long military convoy, and who had aimed long lenses at the launch pad only to find their view blocked by tarps and camo nets.

The next rocket out of Moses Lake had made an uneventful journey to Izzy. Its upper stage, lacking a place to dock, flew in formation with the space station about a kilometer "aft." Fyodor stared at it balefully out the window and made repeated suggestions that its stores should be confiscated. Its cargo manifest was unusual:

> Spare propellant, and other consumables, that would enable Sean's Drop Top to execute a plane-change maneuver and rendezvous with *Ymir* in equatorial orbit (for the word "Ymir" was now being used to denote both the spaceship that Sean was assembling and its faraway destination)
>
> Ice
>
> Fiber for combining with ice to make a stronger material called pykrete

Several thousand Icenats: tiny robots optimized for crawling around on ice

Fyodor, and perhaps others as well, coveted the ice and the propellant. Pete Starling had begun rattling legal sabers down on the ground, threatening to seize the Moses Lake spaceport—a scheme that vanished overnight after Sean began to rattle sabers of his own, threatening to make a YouTube video exposing the Cloud Ark scheme as a poorly conceived panacea at best. It was strange, to say the least, that such open conflict could exist between the government's left and right hands, but the world had become a strange place. Talking of it over meals or during after-work drinking sessions, Dinah and Ivy and Luisa could only speculate at the shouting matches that must be happening down on the ground between the Oval Office, the military, Arjuna Expeditions, and the Arkitects.

Dinah mostly just kept her head down and worked, programming the robots that Sean was going to take with him on his expedition. A comet core was not a solid piece of ice so much as an aggregation of shards, loosely held together by its own self-gravity—which was extremely weak. Merely touching it could cause big pieces to separate. Arjuna Expeditions had known this for many years and had put millions of dollars into inventing technology for capturing such difficult objects. Though "technology" might be too fancy a word for techniques that would have been recognizable to Stone Age hunter-gatherers: surround it with a net, draw the net closed with a loop of string.

Actually performing that feat in space was what Sean described as "an asymmetrical problem," programmer-speak meaning that there were a lot of contingencies and detail work, so it wasn't amenable to One Big Solution. Robots would probably end up swarming all over the surface of Comet Grigg-Skjellerup, cinching the net down and reinforcing weak spots by melting the ice, mixing the water with fiber, and letting it refreeze into pykrete. Dinah had offered to help out with that, and had been excited by the thought until Sean had brought her down to earth by pointing out some awkward realities. Communication between Izzy and *Ymir* was going to be limited by their one radio. They wouldn't be able to send video. And latency was going to be significant: for a large part of the journey there would be a delay of several minutes as the signals traversed a distance comparable to that between the Earth and the sun. So programming robots on the surface of the comet would be nothing like looking out her window at the ones on Amalthea. Anything Dinah had to contribute, she had to contribute now.

In any case, Izzy's population had dropped by two, and the level of tension and drama had fallen precipitously, when Sean and Larz had departed in the Drop Top on A+0.82. The plane-change maneuver took them to a rendezvous above the equator with *Ymir*. After more rendezvous operations extending over a week, and incorporating yet more payloads launched from Cape Canaveral as well as from private spaceports in New Mexico and West Texas, *Ymir* made a long burn of her main engine that placed her into a transfer orbit bound for L1. A few days after that, she beat the Apollo record for distance traveled from Earth.

Konrad Barth came to Dinah's shop and knocked politely, for she happened to have her curtain drawn, and everyone knew that she and Rhys sometimes had sex on the other side of it. He entered, looked about nervously, and asked her if she knew anything about what *Ymir* was going to do. Before she could answer, he shook her off, took out his tablet, and tapped in his password. Then he spun it around to show her a photograph.

It took her a while to understand what she was seeing. Clearly, it was a picture of a man-made object in space. And it was a good picture, but surrounded by a glamor of pixels that spoke of considerable enhancement. Konrad had taken the picture using one of Izzy's optical telescopes. He had turned it away from its usual objective, which was the system of fragments churning around the former center of the moon, and aimed it at this man-made object. The object was big and complicated, at a guess the largest thing humans had ever assembled in space with the exception of Izzy herself. The picture had been taken from a great distance while both Izzy and the object were moving with respect to each other, and he'd toiled with image processing software to reduce the blur. She could see clearly enough that, like Izzy, it consisted of a stack of modules that had been sent up atop different

rockets and plugged together. The one on its tail sported a large nozzle bell, and was obviously its main propulsion unit. Some of the modules just looked like propellant tanks. Others looked like habitations. But far and away the most prominent, and the weirdest, part of this thing was a long spike or probe that extended from its forward end, making it ten times as long as it would have been otherwise. It was a truss, recognizably made in the same way as the new trusses on Izzy.

"Wow," Dinah joked, "a space station with its own radio tower!"

Konrad smiled weakly. "Look at the 'top' of the 'radio tower,'" he suggested. He spread his fingers on the tablet, zooming in on a thick blur of pixels at its tip. This seemed to have a roughly arrowhead-like shape, a small dark tip sitting on a thicker white base, itself resting on a dark base plate.

He was looking at her as if he expected her to understand—or as if she must be privy to secrets.

Which she was. But she couldn't reveal them.

"I'm not a nuclear physicist," she said, "but it's screamingly obvious that the people aboard that ship—it's *Ymir,* isn't it—?"

"Of course."

"—that they want to be as far away as possible from whatever that is, and so they mounted it at the end of the longest stick they could build."

"It is something that makes a lot of neutrons," Konrad said.

"How do you know that?"

"This thing"—he indicated the fat white layer in the middle of the sandwich, like the marshmallow in a s'more—"is probably polyethylene or paraffin, which would be good at absorbing neutrons. Gamma rays might be produced in the process, and so this base plate"—he pointed to the dark graham cracker at the bottom—"is probably lead."

Dinah already knew what it was, because Sean had told her: the core of a large nuclear power plant, rated at a thermal output of four gigawatts, somewhat hastily reengineered for this purpose. But she had been sworn to secrecy, and so all she could do was let Konrad piece it together himself. "Well," she said, "those are impressive precautions on what is probably a suicide mission anyway."

"They want to be alive and capable of doing something when and if they get where they are going," Konrad said.

"Do you suppose anyone has taken pictures like this from Earth?" Dinah asked. "Because I haven't seen anything in the media."

"It was concealed by a fairing until they made their transfer burn," Konrad said. "I took this a couple of hours ago, when I had my one and only clear shot."

They had timed that burn so that they would cross the former moon's orbit at a time when most of the debris cloud was on the opposite side of the Earth, thus minimizing the chance of colliding with a rock.

Nevertheless, a few days after they had passed that distance, and become the longest-range travelers in human history, they stopped communicating.

Until then *Ymir* had been using powerful X-band radios to communicate over the Deep Space Network—a complex of dishes in Spain, Australia, and California that had been used for decades to talk to long-range space probes. Now she had gone silent. She was still out there—Konrad could still pick her up as a white dot on his optical telescope. Since she was merely coasting for thirty-seven days, not firing her engines, there was no way to tell whether the crew was still alive. A perfectly shipshape *Ymir* and a crumpled wad of space junk would have looked and behaved the same.

They drew some hope from the fact that *nothing* came back from her. *Ymir* had automatic systems that were supposed to phone home without human intervention. If those had continued to function while communication from humans had ceased, it would suggest that the crew were all dead or incapacitated. But the fact that all human and robotic signals had been cut off at the same time

suggested that it was a radio problem—perhaps damage to the X-band antenna, or to the transmitter itself.

Ymir became tricky, then impossible to see as she approached L1, since that put her squarely between Earth and the sun. She was assumed to have reached that point on Day 126, whereupon she was scheduled to make another burn that would put her into a heliocentric orbit: an ellipse that would intersect with "Greg's Skeleton" over a year later—sometime around A+1.175, or a year and 175 days post-Zero. Once *Ymir* disappeared, from their point of view, into the fires of the sun, there was nothing they could do except wait for her to reach a place where she was observable. If *Ymir* had suffered a catastrophic failure and been turned into a floating piece of space junk, she would probably cycle back on the return leg of the same orbit and pass close to the Earth again—though L1 was such an unstable place from an orbital dynamics standpoint that she could just as easily wander off into a heliocentric orbit, especially if she'd taken a big hit from a rock that had knocked her off course.

As the calendar progressed through the 130s and to Day 140—two weeks after *Ymir* ought to have passed through L1—and she did not appear on that return leg, it became clear that she must have transferred to a heliocentric orbit, whether by accident or because of a controlled burn. Assuming the latter, Sean and the other half-dozen members of the crew would have nothing to do for the next year but float around in zero gee and wait. There was nothing that could be done to speed up the journey; it was a matter of getting two orbits to graze each other.

These events, which would have seemed of world-historical significance a few months ago, now seemed like below-the-fold news compared to all that was happening in what had formerly been the sublunary realm.

The fuss and excitement surrounding Sean and Arjuna, the Moses Lake spaceport, and the voyage of *Ymir* had drawn attention away from the routine, faithful, grind-it-out progress being made the whole time by NASA, the European Space Agency, Roskosmos, China National Space Administration, and the space agencies of Japan and India. These organizations were staffed by conservative old-line engineers, not far removed culturally from the slide-rule-brandishing nerds of Apollo and Soyuz fame. In fact, some of them *were* those nerds, just a lot older and a lot crustier. They were baffled, nay, infuriated by the ease with which a few upstart tech zillionaires could command the world's attention and go rocketing off on ill-advised, hastily planned missions of their own choosing. The departure of Sean and Larz from Izzy had occasioned a big sigh of relief, and a return to the steady and unimaginative work that these people were best at.

And anyone paying attention to the numbing details expressed in the spreadsheets and the flowcharts would see the value of that work on A+0.144, when Ivy opened a meeting in the Banana with the words "twenty percent" (for the latest projections from the astrophysical lab of Dr. Dubois Jerome Xavier Harris at Caltech, and from the other labs doing the same calculations at other universities around the world, were that the White Sky would happen on or about A+1.354, or one year and 354 days after the breakup of the moon; they were one-fifth of the way there).

The purpose of the Scouts—the first wave of what amounted to suicide workers such as Tekla, who had arrived starting on Day 29—had been to build out the improvised network of hamster tubes and docking ports that would make it possible for a much larger population of so-called Pioneers to reach Izzy. The basic distinction between a Scout and a Pioneer was that the Scout went up knowing there was no place to dock, but the Pioneer knew that, at least in theory, there would be an available port for their spacecraft, with pressurized atmosphere on the other side of it. The promise had failed in one case, with the result that half a dozen Pioneers crammed aboard a Soyuz had silently asphyxiated. The problem was traced to a defect in a hastily built docking mechanism. Three Chinese taikonauts lost their lives when the hamster tube in which they were moving was pierced by a micrometeorite and lost pressurization. But from about Day 56 onward, Pioneers were arriving at a rate of between five and twelve per day. There was a lull once all the available docking spaces were occupied, but

after that it began to snowball as spacecraft began to dock to other spacecraft, and the hamster tube network was built out, and inflatable structures were deployed.

Izzy, which had been a complicated and hard-to-understand contraption even before all of this had happened, was now an utterly bewildering maze of modules, hamster tubes, trusses, and ships docked to ships docked to ships, "like a freakin' three-dimensional domino game," as Luisa put it. The only way to get one's bearings, looking at a rendering of the complex, was by picking out the rugged and asymmetrical shape of Amalthea at one end and the two tori at the other. Those were "forward" and "aft," respectively, and the axis between them was the basis for the traditional nautical directions of "port" and "starboard" as well as "zenith" and "nadir," which were space lingo for basically "up away from Earth" and "down toward Earth." If you arranged yourself so that your back was to the tori and your face toward Amalthea, with the "port" stuff on your left hand and the "starboard" stuff on your right, then your head would be aimed toward the zenith and your feet toward the nadir and the surface of Earth four hundred kilometers below.

That, however, was the privileged view of people outside the thing in space suits. Inside, it was still easy to get lost in the three-dimensional domino game. Felt-tip markers, always a scarce resource even on Earth, became objects of great value as people used them to mark directions on the walls of hamster tubes and habitat modules.

"IT'S JUST A CHRONOLOGICAL ACCIDENT THAT I'M HERE AT ALL," IVY mused, during one of her and Dinah's increasingly rare drinking sessions. All of their original stashes of booze had long since been consumed, but new arrivals were kind enough to slip them bottles from time to time.

"I disagree," Dinah said. It wasn't exactly a scintillating response. But she'd been caught off guard by the suddenness with which Ivy had dropped her guard.

"If the moon had blown up two weeks later, some Russian sourpuss would be in charge up here and I'd be on the ground, married and pregnant."

"And under the same death sentence as everyone else."

"Yeah, well, there's that."

Dinah reached for the bottle and refilled the shot glasses, trying to stretch out the moment. It had never been easy to get Ivy to open up, even back in the happy days before Zero.

"Look, Ivy, it's *not* an accident that you were in charge of Izzy. They gave you the job for a reason. You're the last girl in the world—or out of it—who should be suffering from impostor syndrome."

Ivy stared at her through a somewhat amused silence. "Go on," she finally said. "What is this impostor syndrome you speak of?" For they'd talked about it before—but usually with Dinah being the one who felt it.

"Don't try to deflect this. What's going on?"

Ivy glanced at the ceiling: a sort of visual signal, borrowed from the Russians, to remind Dinah that you never knew when someone was listening. Then she looked into Dinah's eyes. But only for a moment. She was fundamentally a shy person, who preferred inspecting her shoes while baring her soul.

"You and Sean Probst made great sparring partners," Ivy said.

"He was so fucking obnoxious! He needed someone to—" Dinah cut herself short then, because Ivy had gotten a sort of sad, wry look on her face and held up one hand to stop her.

"Agreed! Yes. Thanks for doing it," Ivy said. "He needed someone like you around. Sometimes it almost looked like a comedy act between you two. And the way that the Russians reacted to him—Tekla first of all, of course, but later Fyodor proposing to place all Arjuna personnel under arrest and confiscate everything they'd brought up with them—that was great drama. Tabloid stories and comment threads galore down on the surface. But I barely survived it."

"What do you mean, you barely survived?"

"You wouldn't believe some of the conferences I had with Baikonur and Houston. People down there wanted me to take a very hard line. To do what Fyodor wanted."

"But you didn't," Dinah pointed out.

Ivy met her gaze again. Then, after a moment, she gave a little nod.

"So you won," Dinah went on.

"I won a Pyrrhic victory," Ivy said. "I negotiated a less draconian solution. The *Ymir* expedition went on its way with no obvious hard feelings."

"And how is that Pyrrhic?"

"I don't want to make my problems yours," Ivy said.

"Who else are you going to talk to?"

"Maybe no one," Ivy returned, showing a flash of something like anger. "Maybe that's what a leader is, Dinah. The one person who can't—who *shouldn't*—share her problems with anyone else. It's sort of an old-fashioned idea. But the human race might need such people going forward."

Dinah just stared back at her. Finally, Ivy relented, and spoke in tones almost devoid of feeling: "My position as the head of the space station came under serious challenge. It made me aware of politics on the ground that have been going on for some time—but that were invisible to me until the Sean Probst controversy surfaced them. Since then, I believe that my authority has been further undermined by people on the ground, leaking things to the press, saying things in meetings."

"Pete Starling."

"No comment. Anyway, I think I am going to be replaced before long."

Ivy's eyes had reddened slightly. She made another glance at the ceiling, but the expression on her face suggested she didn't care who might have heard her. Then she looked at Dinah and smiled. "How have you been doing, sister?" she asked in a weak voice.

"I've been pretty good," Dinah said.

"Really? That's music to my ears."

"Bo, Larz, the others who've come up to work in my crew, they seem to respect what I've done," Dinah said.

"I think it's because of what you did for Tekla," Ivy said.

"Oh really? Not just my amazing natural competence?"

"There are a lot of people on the ground who are competent in the way you mean," Ivy said, "and we are going to be seeing a lot of them up here in the next few weeks. Believe me. I've read their CVs."

"I'm sure you have."

"But everyone kinda senses now that some other qualities are going to be needed besides just pure competence. That's why people are deferring to you."

Another awkward silence. Ivy seemed to be suggesting that she, Ivy, was no longer being given that kind of respect.

"That, and your amazing competence," Ivy added.

Consolidation

EARTH'S ATMOSPHERE DIDN'T JUST STOP. IT PETERED OUT UNTIL IT became indistinguishable, by most measuring devices, from a perfect vacuum. Below about 160 kilometers of altitude, the air was still thick enough to rapidly drag down anything placed in orbit, so those altitudes were used only for short-term satellites like the early space capsules. The higher the altitude, the thinner the air and the more slowly orbits decayed.

Izzy was four hundred kilometers up. Its acres of solar panels and radiators made it extremely draggy in comparison to its mass. Or at least that had been the case until Amalthea had been bolted onto it, suddenly making it far heavier.

Somewhat paradoxically to laypersons, the added mass of the asteroid made Izzy much better at staying aloft. Before Amalthea, the station had lost two kilometers of altitude every month, making it necessary to reboost it by firing a rocket engine on its aft end. In the early days, that engine had been the built-in one mounted on the Zvezda module. But in general they simply used the engine belonging to whatever spacecraft happened to be docked to Izzy's aft-most module.

In those days Izzy had been like a kite: all surface area, no mass. In technical terms, it had had a low ballistic coefficient: a way of saying that it was strongly affected by what little atmosphere there was. Once Amalthea had been attached, it was like a kite with a big rock strapped to it. It had a high ballistic coefficient. The rock's momentum bulled through the evanescent atmosphere and led to much slower orbital decay. But by the same token, when it came time to reboost Izzy's orbit, a longer burn and a larger amount of propellant were needed in order to accelerate all of that iron and nickel.

Since the Scouts and the Pioneers had begun adding more bits onto Izzy, its ballistic coefficient had been dropping again, and boost burns had come more frequently. And it was always the case that thrusters had to be fired every now and again to correct the station's altitude. All of it grew more problematic as more was added onto the basic structure. Izzy had been an ungainly construct even before all the new pieces had been added onto it. Thrust applied to one part of it would ramify through the other modules as various parts of the truss and other structural members took up the strain and passed it on down the line. To put it in the simplest possible terms, Izzy had gotten all floppy as more stuff was attached to it, and its floppiness made it difficult to reboost the orbit or even to tweak the angle at which it "flew" through space. They had allowed the orbit to decay by a serious amount, over sixteen kilometers, during the busiest part of the Pioneers' efforts, but now reboosting had to become a routine operation. And every firing of the engine on the bottom of H2 revealed structural weaknesses that had to be jury-rigged, sometimes literally with zip ties and duct tape, before it could proceed.

During the span of time from about A+0.144 to 250, the watchword was "consolidation," inevitably trimmed to "consol." It basically meant the retrofitting of new trusswork around the hamster tubes and other sprawling constructs that had been added to the truss during the frantic first couple of months. Other problems were addressed at the same time, most notably the building of more radiators for dumping waste heat into space. These didn't work if they were too closely spaced —they just shone heat on one another. So the heat rejection complex waxed enormous and ended up growing generally aftward, like an empennage—the feathers on the butt of an arrow. It was no mere figure of speech. In the same way that an arrow's heavy head and spreading feathers kept it pointed straight forward, the combination of massive Amalthea at the forward end and the heat radiators trailing away aft helped keep Izzy pointed in the right direction and somewhat reduced the demand for thruster firings. It also protected the radiators from micrometeoroids. Rocks could theoretically come from any direction and strike the space station, but they were most likely to hit its forward end, and so forward-facing surfaces of the space station's modules had generally been equipped with shields. Amalthea, of course, was the biggest and best shield of all.

The number of solar panels might have grown too, had they been doing things the old way. But very early in the Cloud Ark project it had become obvious that, while photovoltaics might be a useful adjunct, the only sure way to keep everything running was with the small nuclear devices called RTGs, or radioisotope thermoelectric generators. These made heat all the time, whether you wanted them to or not, and so created further demand for radiators.

The radiators were, in essence, a gigantic exploit in zero-gravity plumbing. The excess heat had to be collected from where it was produced (mostly, the inhabited and pressurized parts of Izzy) and transported to where it could be gotten rid of (the "empennage" growing to aft). The only plausible way of doing this was by using a fluid, pumping it around a loop, heating it up at one end and cooling it off at the other. At the hot end they used heat exchangers and so-called cold plates that just soaked up heat from wherever it was a problem. At the cold end the fluid fanned out through networks of thin tubes, like capillaries, sandwiched between flat panels whose sole purpose was to become slightly warm and shine infrared light into deep space, cooling down Izzy by warming up faraway galaxies. Joining the hot and cold ends of the loop was a system of pumps and pipes that got bigger every day and that was prone to many of the same kinds of trouble as bedeviled earthbound plumbing. Making it twice as complicated was that some of the loops used anhydrous ammonia and others used water. Ammonia worked better, but it was dangerous, and you couldn't easily get more of it in space. If the Cloud Ark survived, it would survive on a water-based economy. A hundred years from now everything in space would be cooled by circulating water systems. But for now they had to keep the ammonia-based equipment running as well.

Further complications, as if any were wanted, came from the fact that the systems had to be fault tolerant. If one of them got bashed by a hurtling piece of moon shrapnel and began to leak, it needed to be isolated from the rest of the system before too much of the precious water, or ammonia, leaked into space. So, the system as a whole possessed vast hierarchies of check valves, crossover switches, and redundancies that had saturated even Ivy's brain, normally an infinite sink for detail. She'd had to delegate all cooling-related matters to a working group that was about three-quarters Russian and one-quarter American. The majority of all space walk activity was related to the expansion and maintenance of the cooling system and, uncharacteristically for her, she was content just to get a report on it once a day.

All of that plumbing, and all of those radiators, needed to be supported by Izzy's structure just like anything else—they were especially prone to troubles under the general heading of "too floppy to survive reboost." So, proceeding in the same general putting-out-fires mode, Ivy and the engineers on the ground next had to steer the program in the general direction of "consol," or, as Ivy put it privately, "defloppification," of the space station's overall structure. And since it was out of the question to take apart what the Scouts and Pioneers had put in place, this took the form of building what amounted to external scaffolding around what was there. Viewed from a kilometer away, it looked quite similar to what one saw when some old and treasured building was being renovated: a latticework of structure, ugly but serviceable, grew around the underlying object, enveloping it and strengthening it without actually penetrating it.

In the early going, sections of truss were assembled on the ground, launched up whole, and slammed into place by teams of spacewalkers, buying large increases in structural integrity quickly and expensively. That approach soon fell prey to the law of diminishing returns and it became clear that the Arkers, as they'd started to be known, couldn't be forever dependent on ground-based engineers custom-building structures.

The ground-based engineers didn't even really know what was going on with Izzy anymore. Their CAD models had fallen behind. Dinah knew it because of a sudden surge in messages from exasperated engineers requesting that she send a robot out to such-and-such a place and aim its camera at such-and-such a module so that they could see what was actually there.

The Arkers needed tools and materials for building their own structures in situ. These started to arrive around Day 220. And it was a measure of how much things had changed on the ground that the solutions came in more than one form, from more than one source, often with little to no coordination. In the old days a proposed system would have been given a three-letter acronym and bounced back and forth between different agencies and contractors for fifteen years before being launched into space.

The single most useful structure-building system turned out to be a rough-and-ready implementation of an old but good idea. It was a little bit like the machine used by gutter and downspout contractors, mounted in the back of a truck, fed by a large roll of sheet metal, which would be bent into a gutter shape and extruded in pieces as long as you liked. This machine did much the same thing, except that it bent the sheet metal ribbon into a simple beam with a triangular cross section and then welded the edges together to make it permanent. It had been invented and prototyped long ago in the West, but the Chinese space agency had perfected it in the first couple of hundred days post-Zero and begun to launch the machines up with crews who knew how to use them. As long as they were supplied with electricity and rolls of aluminum they would go on pumping out beams forever. Connecting segments of beam into more complex structures, such as trusses and scaffolding, was a little more difficult. Welding in space, while possible, was complicated, and there wasn't enough equipment. Instead they ended up using Tinkertoy-like connectors, again mass-produced by the Chinese, into which the ends of the triangular beams could be inserted, then tightened down using screws. At first many of these were shipped up in bulk from the ground, but on A+0.247 they took delivery of a 3-D printer that had been optimized to make more of them, with options for modifying the angle at which the beams would be inserted. This gave them the ability to design and build trusses on the fly, which was not possible with the mass-produced connectors. And as a last resort, Fyodor had an electron-beam welding machine that would work in zero gravity and a vacuum, undoubtedly the most expensive welder ever made, a marvel of Russian ingenuity, and he had trained Vyacheslav to use it. Vyacheslav then trained Tekla and two of the other spacewalkers, who set up a job queue and took turns drifting around Izzy's increasingly complex structure tacking down a weld here and a weld there. Thus, constructed largely by the Chinese and the Russians, the scaffolding grew and stiffened. The reboost burns no longer produced alarming pops, bangs, and groaning noises. The hamster tubes gradually disappeared within shrouds of structural reinforcement and shielding. New docking ports began to sprout at Izzy's extremities, like buds on tree branches, in preparation for the next phase: the coming of the first arklets.

Down on the Earth, it was August, the second-to-the-last August that there would ever be. A dozen new or reconditioned spaceports had come into operation. Heavy-lift rockets could now be launched to Izzy from eight different locations around the world. Around those launch pads, rocket stages and three different styles of arklet were beginning to pile up like so much ammunition at a firing range.

DAY 260

"You're going, Dr. Harris," said Julia Bliss Flaherty.

From time to time Doob became distracted by the sheer oddity of the fact that he now met with the president on a regular basis. It was a lot less weird, in the big scheme of things, than the fact that the moon had exploded and that everyone was going to die. But his mind, born and raised in a world free of such prodigies, was more comfortable being freaked out by little things, such as talking to the president. In the Oval Office. With her science advisor Pete Starling on one side and the White House communications director on the other. And a butler pouring ice water into crystal tumblers.

He saw the usefulness of the butler. But what was the point of having the communications director here? Margaret Sloane was good at her job, and the perfection of her grooming was a perpetual source of wonderment, but it had become pretty clear that she was out of her depth in any technical discussion beyond "big rocks from space are dangerous."

They were all looking at him as if he was expected to say something.

What had been the president's words? *You're going*.

Did that mean he was on his way out? Going to be replaced by someone younger and more web-savvy, like Tav Prowse?

Into the awkward silence, Margaret Sloane poured an explanation. "Your skills and your presence have done so much to calm the waters. To give the people of the United States, and of Earth, something to pin their hopes on in the guiding concept of Our Heritage. Your willingness to roll up your sleeves, go to places like Moses Lake, Baikonur, the rocket factories—that has all been so appreciated. But we feel that the time has come—"

"To replace me with a fresh face, I get it," Doob said. "To tell you the truth, that's fine. I would like to spend more time with my kids and my new wife. Tav will do a great job."

For once, the president looked flummoxed. Her eyes flicked toward Margaret.

"That's not where we were going with it at all," said Margaret. "We need you—the people of the world need you—to take the next step—to advance to a higher level."

"We are asking you," said the president, a bit testy with Doob's slowness and with Margaret's breathy and roundabout phrasings, "to travel into space on or about Day 360, and to become part of the population of the Cloud Ark."

"I don't want to go!" Doob blurted out. It was rare for him to forget himself in that way, so he then just sat for a few moments, stunned by his own ineptitude.

"Dr. Harris," said the president after a few moments, "as you probably know from your high school civics class, the person who sits where I'm sitting has a lot of powers. One of them is that I can grant reprieves and pardons for convicted criminals. Every inmate who goes to the execution chamber in Texas goes there in part because I made the decision not to pardon him or to commute his sentence. I have never exercised that power in the case of a death row inmate. In effect, however, I *am* exercising it in your case *now*."

The president paused there for a moment, and Doob became aware that she was waiting for his attention.

He was staring at a flower arrangement on the table in front of him. Wondering how long it would be before anyone cultivated flowers on the Cloud Ark. He reached for his tumbler and took a sip of water.

J.B.F. unnerved him when she was like this. It took a certain conscious and deliberate act of will for him to peel his eyes off the flowers and look up into her eyes. They stared back at him wide and unblinking.

"By virtue of being on the surface of this planet, you are under a death sentence," said the president. "I just pardoned you. You can go into space and live. I cannot. Do you understand that, Dr.

Harris? I cannot even pardon myself in this case without flagrantly violating the Crater Lake Accord, which makes national leaders and their families ineligible. Now, what the hell is your problem?"

Doob's honest answer, had he voiced it, would have been most impolitic: *I have become convinced that the Cloud Ark scheme cannot possibly succeed. I have been playing along in public just to keep people happy. I would rather die quickly on the ground with my loved ones than slowly, alone, in space.*

"There are others who deserve it more than I do," he said. And in the same moment he cursed himself for saying something so lame. So easily refuted. Because in all honesty he was a fine choice for inclusion on the Cloud Ark's roster.

"I couldn't disagree more!" exclaimed Pete Starling, with a nervous chuckle. "Doob, you're going to be so useful up there, I'm afraid you'll never get a moment's rest! You have multiple core competencies with surprisingly minimal Venn. You can pivot from working on astrophysics problems, to teaching the young Arkers, to podcasting to folks on the ground, without skipping a beat!"

Doob turned to look into Pete Starling's eyes as he was saying those words and understood, with a shock like diving into cold water, that Pete was lying.

Not about Doob's usefulness. In that he was sincere. He was lying about something more fundamental.

He didn't believe that the Cloud Ark was going to work any more than Doob did.

He needed Doc Dubois to go up there and lie for him.

Now, Doob was a scientist who had spent decades of his life training in a particular discipline, namely, to seek and to speak the truth. Even among hard scientists—a notoriously blunt crowd—he had a reputation for saying what he thought. Never mind whose feelings he wounded, whose careers got damaged as a result. This seemed to come across, somehow, on camera. The very reason that so many people trusted him when he went on TV was that he was a straight shooter, he said things that offended the powerful, he stirred things up, and he didn't care. Certain of those moments had been enshrined forever in YouTube clips and Reddit memes: taking down a Republican senator who didn't believe in evolution, destroying a climate change denier in an impromptu sidewalk confrontation, reducing a movie star to tears on the *Today* show by telling her that her stand against childhood vaccination made her personally responsible for the deaths of thousands of babies.

So, in a way, there were two questions in his head at the same time: whether he *would* lie, and whether he *could* lie.

As to the first question, was it okay for him to lie if it would make billions of people go to their deaths a little happier?

As to the second, would people sense it? Would they detect a shift in the tone of his voice, the set of his face, when he was just standing there in front of the camera talking shit?

That was the real question. Whether he could pull it off. Because if he couldn't pull it off—if he couldn't lie convincingly—then there was no point in even trying.

And he was pretty sure that he couldn't do it.

One of the ice cubes in Doob's glass let out a little pop as it underwent thermal fracturing.

Doob thought of Sean Probst, now half a year into his quest to fetch a big piece of ice. He couldn't believe it had been that long already.

You could get used to anything. You got used to it and then time raced by, and before you knew it, time was up.

He remembered people asking difficult questions around the time of Sean's departure for the L1 gate. What the hell was this crazy billionaire doing? Clearly, it was not part of the official plan. The official plan did not seem to recognize a need for a huge piece of ice. But Sean Probst believed it was so important that he was willing to go up there personally and take care of the problem. There was a good chance he would die in the process, or come back so broken from radiation exposure and long-term weightlessness that his health would never recover. And so people had asked Doob what

he thought Sean was thinking. And Doob, who hadn't studied it at the time, had answered vaguely, saying that water was always a good thing to have in space: you could drink it, grow crops with it, use it for radiation shielding, split it into hydrogen and oxygen for rocket fuel, or pipe it through hoses to radiate excess heat into space. All of which was quite true, but sort of begged the question. It was so blindingly obvious that NASA must have thought of it already. What additional demand for water was Sean Probst seeing that NASA had failed to notice, or turned a blind eye to?

Later Doob had figured it out based on background conversations with people at Arjuna and scuttlebutt reaching him through friends working on the planning of the Cloud Ark. It was all about propellant. The Cloud Ark would have to burn a lot of it. Sean didn't think they had enough.

So he had gone up there and done something about it.

Because Sean wasn't a talker. He was a doer. And as such he didn't have to agonize, as Doob was doing now, about what he was going to say. What his public stance was going to be. How he was going to be positioned and perceived.

"That's a hundred days from now," Doob said.

He'd been silent for so long that the other occupants of the Oval Office were a bit startled. J.B.F.'s attention had wandered to a tablet on her desk, and Pete Starling was looking out the window.

"I beg your pardon, Dr. Harris?" said the president, turning that gaze back upon him. But he no longer felt intimidated by it. He was going to go somewhere where she could never look at him again.

"This is 260," Doob said. "You said you wanted me to go up there around 360."

"Yes," said Maggie Sloane, relaxing into an entirely new posture. "That's not the first wave—which is going to be more exploratory, more of a dress rehearsal—but it would be the first *real* wave of Arkers going into space, and our thought was that we would embed you with them. You could partake of their experiences and show the people of Earth what a day in the life of an Arker consists of. Providing a sense of continuity."

Holy shit, Doob thought. Seven years a Ph.D. candidate, two postdocs at major European research institutions, a tenured position at Caltech, shortlisted for a Nobel Prize, and here he was, with the fate of the human race at stake, being positioned as an *observer* to *provide a sense of continuity*.

"I can do that," he said. *And some other things as well, as long as I'm up there.*

What were they going to do, yank him back down to the planet?

The worst they could do was to stop broadcasting his stuff, and that would be fine with him. There had to be something he could do up there that would be more useful than talking into a camera. Sean Probst had identified one problem with the Cloud Ark and taken action to remedy it; in a hundred days, what could Doob learn that might be useful? What actions could he take, once he got up there, to give the whole thing a better chance of success?

"A hundred days," he said. "Three months for me to spend with my wife and my kids and my embryo."

"Embryo?" Pete Starling repeated, not getting it.

Margaret Sloane, mother of three, picked it up instantly. "Amelia's pregnant?" she asked, with the warm smile that, until Zero, had been the normal response to such blessed events. Nowadays, people's reactions were a bit more complicated, of course; but it was hard to shed old habits.

"Not anymore," Doob said. "We froze the embryo. My only condition is that it travel up into space with me."

"Consider it done," said the president, in a tone, and with a look, that told them the meeting was over.

DAY 287

"Got any tater-related humorous items for me?" Ivy asked. "'Cause oh, man, could I ever use some comic relief."

Dinah wasn't sure how she felt about Ivy looking to her doomed family as a source of casual amusement, but as they were only some 433 days away from the end of the world, she didn't really think there was much point in getting shirty about it.

The situation did breed a kind of coarseness toward those stuck on the ground. It was humanly impossible to extend to seven billion people the full sympathy that each of them deserved. Dinah had begun to hear instances of dark humor over the radio, and had noticed herself being at least a little bit amused by it.

Nor was that dark humor restricted to Arkers, as Dinah's family demonstrated. They were intelligent people—you had to be, to do what they did—but they went in for a certain brand of mining-camp humor, heavy on the practical jokes and novelty items that you'd never see in a boardroom or a faculty lounge. And once they'd latched on to something that they thought was funny, they'd never let go of it. A half-serious Morse code message about planting a flat of potatoes, transmitted by Rufus shortly after the Crater Lake announcement, had sprouted into a whole subgenre of running jokes about the preparations that the MacQuarie clan was making for the Hard Rain. In her occasional care packages from the ground, Dinah was now accustomed to finding fingerling potatoes, still with real dirt on them, or plastic parts for Mr. and Mrs. Potatohead toys. She even had a rusty old Idaho license plate duct-taped to the wall of her shop now, emblazoned with the slogan FAMOUS POTATOES, courtesy of Rufus, who'd gotten it from a mining industry pal in that state's silver-rich panhandle.

"Is that a no?" Ivy asked.

"Oh, I have potato shit all over the place now," Dinah said. "I'm just no longer sure that they're joking."

"What do you mean?"

"At first I thought it was their way of saying, 'We know we are screwed, no point in being babies about it, let's laugh it up until the end.' But now I'm starting to ask myself what it is they're doing. I mean, they're up there in the Brooks Range with all of this equipment. They could drive down to Fairbanks any time they feel like it, and from there go anywhere in the world. Check out the pyramids. See the *Mona Lisa*. Visit old friends and family. Instead they're up in the most godforsaken place I've ever seen, doing what?"

"Prepping?" Ivy said.

"That's the only thing I can think," Dinah said. "Prepping for a fiveto ten-thousand-year stay."

"They're not the only ones," Ivy said.

It took Dinah a few moments to catch her friend's meaning. Then it was clear, just from the look on Ivy's face. "Are you shitting me? Cal?"

Ivy made just a suggestion of a nod with her eyes. "Mixed in with the stuff you'd expect from a fiancé—which is *none of your business*—he asks me questions about things like the comparative merits of lithium versus sodium hydroxide scrubbers. He requests copies of Luisa's PDFs about the sociology of persons confined in small places for long periods."

"He can't think you're not going to notice that."

"Sure. I'm going to read between the lines."

"What do you suppose he's thinking?"

"Well," Ivy said, "he does have sole authority over a huge submarine designed to ride out global thermonuclear warfare. And when the United States ceases to exist, I guess there'll be no one above him, chain-of-command-wise. What's a commander to do?"

"But how would it work?"

"I think a lot depends," Ivy said, "on whether the oceans boil dry. If I were him, I'd make for the Marianas Trench and keep my fingers crossed."

"I would think it would be even harder than staying alive in space."

Ivy looked at her friend with dry amusement.

"What?!" Dinah said.

"Staying alive in space is going to be a piece of cake, remember?"

"Oh yeah, sorry. I forgot …" *To put on my makeup.* "It would present some fascinating challenges," she corrected herself, switching to her best NASA PR voice.

"I think it's like what we are doing," Ivy said. "You have to break it down into a lot of little things and solve them one at a time, or you get overwhelmed."

"Is that what we're doing?"

"Yeah." Ivy rolled her eyes.

"What's on your mind? Other than the need for comic relief?"

"You. How you're doing. Your health," Ivy said.

"Oh my god, is this an actual meeting? Are we on official business here?"

Ivy ignored her. "You haven't been logging much T2 time."

T2—the second torus, which Rhys had been responsible for building—had started to spin on Day 140. Its simulated gravity was one-eighth of Earth normal, only a little greater than that on the first torus. It was bigger and spun more slowly, which Rhys hoped would make it a little more comfortable. Simply being in it helped counteract some of the negative effects of living in space for extended periods of time. People who lived without gravity suffered a gradual loss of bone density and muscle mass. Eyes went out of shape and vision deteriorated. Space station crews tried to fight this by using exercise machines that placed stress on the bones, but these were stopgap measures meant for people who were only going to be in space for a few months. Dinah, Ivy, and the other ten members of the original Izzy crew had now been up here for close to a year. During the first few months after Zero, no one had paid much attention to long-term health issues. Everyone was going to die. Scouts were showing up dead on arrival. It had been all emergency, all the time. But during the months of hamster tube building and structural consolidation, the life scientists had been quietly having their say. This wasn't the first time Dinah had been nudged in recent weeks about her failure to spend more time in the simulated gravity field of T2.

"It's just hard to go back and forth between gravity and no gravity," Dinah said. "It makes me barf. And none of my stuff is in T2." She was referring, as Ivy would know, to the shop where she worked on her robots.

"But isn't that mostly remote work? Writing code?"

"Yeah, I just like to be where I can see them out the window."

"Don't they have little cameras on them?"

Dinah had no answer for that.

"Whatever you're doing here," Ivy continued, "you could do from a cabin in T2, where the gravity would build your bones."

"It's also Rhys," Dinah admitted. "Things have been a little weird with him and I just don't want to—"

"Rhys never even goes to T2," Ivy said. "He's been hanging out with the inflatable structures team."

"Okay," Dinah said. "Give me a place to work on T2 and—"

"There's another thing," Ivy said, and let out The Sigh. The Sigh was what Ivy did when the powers that be were making her do something ridiculous. It would never show up in the transcript of a meeting, but it changed everything.

"I don't even want to guess," Dinah said.

"We have all become characters in a reality TV show," Ivy said. "You might not be aware of it."

"Nah, I haven't been watching much TV."

"Well, it's all people have to do anymore, down on the ground. The economy is shutting down, and people are just eating beans and entertaining themselves with screen time."

"Okay."

"I've been asked to pay more attention to message shaping."

"Message shaping? What's that?"

Ivy let out The Sigh.

"Okay, never mind," Dinah said.

"People want to know what became of their Uppity Little Shitkicker."

"Really?"

"Yeah," Ivy said. "People like their ULS. They remember the thing you did with Tekla. Tekla porn is a big thing now too, by the way."

"I don't want to hear about it."

"Anyway, people are asking where is plucky Robot Girl and her mechanical menagerie."

"That explains some weird emails I have gotten."

"From random strangers?"

"No, from my own family! I don't read the ones from random strangers. How about you? What's your role on the reality TV show, Ivy?"

Ivy stared at her coolly. "I'm the uptight bitch who can't handle it."

"Oh."

"To American viewers, I'm not fully American. To Chinese viewers, I'm a banana."

"I'm sorry, Ivy."

"That's the bad news."

"Okay, and what is the good news?"

"All the people saying mean things about me on the Internet are gonna be dead in four hundred and thirty-three days," she said, deadpan.

Okay. It was an example of that dark humor thing.

"After that, none of it matters—except my ability to be of service to Our Heritage."

"Okay, baby, how can I help you?" Dinah asked. "We could take a selfie, you and me, and I could post it on the Uppity Little Shitkicker blog."

"You and I are going to go for a ride on the first operational bolo," Ivy said, "and you are going to be reminded of what one gee feels like."

Casting of Lots

DURING THE FIRST FEW DAYS AFTER THE MOON HAD BLOWN UP, Doob had spent hours gazing up at Potatohead, Mr. Spinny, Acorn, Peach Pit, Scoop, Big Boy, and Kidney Bean. They were visible in the daytime, just as the moon had formerly been, and even on the rare day when it was cloudy in Pasadena, or he was stuck indoors, he could pull up a window on the screen of his computer and watch them on a live video feed.

After he had figured out that they were going to kill everyone on Earth, he had become a lot less interested in staring at them. He had, in fact, sometimes gone for weeks without looking up at the gradually spreading cloud of debris. Sometimes while walking across a dark parking lot or driving down the highway he would catch sight of the moon-chunks in the sky and deliberately turn his gaze away from them. They filled him with horror and even a kind of shame over the fact that he had once found the whole thing such a fascinating science treat. He did not want to be reminded of it. Instead he tracked the slow disintegration of the moon-pieces through spreadsheets and plots shared with him by his graduate students and his colleagues. He did everything he could to reduce the whole state of affairs to two numbers. One of these was the Bolide Fragmentation Rate, or BFR, which was a measure of how frequently big rocks were being made into small rocks. The other was, quite simply, how many days remained before the White Sky.

On Day 7, minutes after they had met, he and Amelia had watched Kidney Bean fracture into two big chunks, later dubbed KB1 and KB2 (though attempts had been made at the time to give them cutesy names of their own). Three weeks later Scoop had collided with Big Boy and broken into three pieces, SC1, SC2, and SC3. Big Boy itself was now BB1, still fairly recognizable, plus a whole family tree of bits that had shrapneled off its smaller piece, BB2. These were given code numbers such as BB2-1-3, meaning the third-biggest fragment of the largest fragment of the second-biggest piece of Big Boy. Beyond about that level it became difficult, and somewhat pointless, to keep track of them all. Mr. Spinny had caused all sorts of havoc before finally breaking in half; its wayward children MS1 and MS2 had gone winging off in opposite directions and ended up in big eccentric orbits around the rubble cloud's shared center of mass, occasionally looping in from a great distance and slamming into one of the slower-moving pieces. MS2 had broken Acorn into three pieces just three days before Doob's memorable Oval Office chat with the president. While he'd been flying back to L.A., a hunk of it the size of an oil tanker had slammed into the Indian Ocean and kicked up a tsunami that had killed forty thousand people on the west coast of India.

After he got home from his trip to D.C., he and Amelia checked into a suite at the Langham, a palatial hotel in Pasadena, so that they could spend a few days together before he went out on a round-the-world journey. All through their romantic dinner on the terrace he made a concerted effort not to look at the remains of the moon. Later they went back to their suite and made love. After twenty minutes' postcoital cuddling, Amelia rolled over on her side and went to sleep, inviting Doob to spoon with her, but Doob, unable to relax, pulled his tablet onto his lap, put on his reading glasses, and started killing time on the Internet. The French doors to the balcony were open, and at some point the breeze coming in through them obliged Amelia to snuggle deeper under the blankets. Doob got up and walked over to close the doors, and was confronted by the sight of the moon-cloud, directly in front of him, hanging over the lights of L.A., and now something like four times the diameter of the original moon. It was arresting, partly because it had been so long since he had looked squarely at it, and so he stood there for a while observing. Peach Pit was still largely in one piece, but other than that the original Seven Sisters were no longer discernible.

Out of curiosity he consulted an app that told him when Izzy would be passing over, and saw that it was going to happen in about ten minutes. So he stood there and waited for it. As he waited, his attention turned again and again to the pieces of the moon. What was their future? He knew that

they would shatter into an uncountable number of fragments and become the White Sky and then the Hard Rain. But what was the final *distribution* of sizes going to be, how many big ones and how many small? They had some models based on the simplifying assumption that all moon rock was basically the same, but clearly that wasn't true.

They had done some analysis on the original chunks, trying to figure out why Peach Pit was so resistant to fragmentation, and determined that it was simply the inner core of the old moon. Which was confirmed anyway by an analysis of its mass: Peach Pit was much denser than the other bits, suggesting that it consisted mostly of iron as opposed to rock. The moon had had an iron core, but, relative to overall size, this was much smaller than the Earth's; most of the moon was cold, dead stone.

And yet the core was there, and was thought to consist of a ball of solid iron surrounded by a somewhat hotter jacket of molten iron mixed with various other elements. All of this had been stripped bare and exposed to space by the Agent. For the first few hours, Peach Pit had literally glowed with radiant heat. Or so they guessed, since the dust kicked up by the cataclysm had cloaked it for a while. Some of the core's outer jacket of molten metal must have been torn away, dispersed into the rubble cloud as gobbets and slugs and droplets of melt that soon cooled and hardened. As much was proved by metal-rich bolides that had since plowed into the Earth and been dug up and analyzed. By the time the dust had literally settled to the point where Peach Pit and its siblings were clearly observable, an outer crust had formed over it, consisting of melt that had cooled swiftly as it radiated its heat into space. The cooling had continued ever since. Now, the better part of a year later, Peach Pit, or PP1 as it was now designated, was still warmer than the other parts of the moon. It had shown greater resistance to fragmentation. Other rocks bounced off it, or dashed themselves to pieces on its gleaming surface. A few significant chunks—PP2, PP3, and so on—had been ripped off in the early days when it had still been soft, but now it was clad in a mile-thick armor of solidified iron that was proof against just about any calamity short of a second Agent.

Doob became so absorbed in such thoughts that he almost missed the transit of Izzy across the sky. It angled directly over the rubble cloud, seeming to weave among the giant tumbling boulders, though this was of course an illusion. It had long been the brightest man-made object in the sky, and it was brighter now that so many pieces had been added onto it. The effort had been impressive. Stirring, even. But seeing it against the scale of the disaster behind it forced him to ask himself what was the point. What was the longer-term plan for the Cloud Ark? The swarm concept was a nice architecture, much more survivable than One Big Ship, but where was it going to go?

No one seemed to be talking about that. He understood why. Survival was the first imperative. Long-term strategy came next.

The amount of iron in PP1 was for all practical purposes infinite. It would take humans many thousands of years to find uses for that much metal.

But it was way up high. Hard to reach.

And yet they had to reach it.

And it was closer, easier to reach, than the Arjuna asteroids that Sean Probst was so excited about.

Feeling an idea take shape in his head, like an iron core congealing deep in a moon, he put it on hold and forced himself to turn his attention to more immediate questions. A few days ago in the Oval Office he had formed a resolve to get his ass into space and begin making things happen up there. Which was fine. But he had three months left on terra firma. He couldn't neglect his responsibilities here. Some of which—the most important—were to his kids, to Amelia, and to their frozen embryo. But on top of that he had been given other jobs, and if he screwed them up badly enough, e.g., because he was standing on hotel balconies in the middle of the night thinking about how much iron was in PP1, then they might not send him up to the Cloud Ark at all. He hadn't wanted to go, but once he had assented to the idea, he had begun wanting it more than anything, and he now feared that they

would take it away from him. And if they sensed that fear, they could use it to control him. Better to overperform, to exceed expectations, to act like it was nothing at all.

SEVENTY-TWO HOURS LATER HE WAS LOOKING OUT THE WINDOW OF a U.S. Navy helicopter banking through a misty Himalayan valley as it lined up its final approach to a runway in Bhutan. Or perhaps *the* runway in Bhutan was the more correct phrasing.

There were about 750,000 people in this country, which meant that they were entitled to supply two candidates for the Cloud Ark. The arithmetic was a little fuzzy; if the same ratio were applied consistently all over the world, something like twenty thousand candidates would be gathered in. If an arklet could accommodate five people, then four thousand arklets would be needed in the swarm. Each arklet required a heavy-lift rocket to get it into orbit, and some assembly and prep work once it had reached Izzy.

Could it be done? If the entire industrial capacity of the world were thrown into the production of rockets, arklets, space suits, and the other goods needed? Perhaps. But probably not. Doob was privy to some recent estimates that put the numbers at closer to one-quarter of that figure.

And anyway, could the arklets really support five humans each? Without a doubt they were large enough for five people to bang around in, but it was not at all clear that each could be self-sufficient in food production. Building a sustainable ecosystem in a tube the size of a railway tank car was no small task. Biosphere 2, a well-known experiment in the Arizona desert, had attempted to support eight people on an ecosystem the size of a couple of football fields, and been unable to make it work long term. But its mission had been clouded by political strife and odd quasi-spiritual factors. A more down-to-earth project run by the Soviets had determined that eight square meters of algae—an expanse of pond scum about the size of two ping-pong tables—was needed to keep a single human supplied with oxygen. In the space between the hard inner hull and the inflated outer hull of a single arklet there was more than enough room. But much more real estate would be needed if the arklet were also to produce food. And those calculations didn't even begin to address the real complications of keeping thousands of people alive in space for many years. It wasn't enough just not to asphyxiate and not to starve. People would need medicine, micronutrients, recreation, stimulation. Ecosystems would get out of whack and need to be repaired with pesticides, antibiotics, and other hard-to-make chemicals. The thrusters that kept the arklets out of trouble would need to be refueled, and not only that but they would need maintenance and repair. The idea of a completely decentralized Cloud Ark was a chimera; it was not sustainable without a mother ship, a central supply dump and repair depot. The only plausible candidate for that was Izzy. But Izzy wasn't designed for anything like that purpose. They'd been trying to make it over by cramming it with vitamins, but that only delayed the moment when they'd run out of all the goods they didn't know how to produce in space, and people would begin dying in quantity.

From the fact that he had gotten nowhere raising awkward questions about this, Doob inferred that the Arkitects knew about it, and were on it, and just didn't want to talk about it because public doubt and controversy were not going to help. Doob's job, clearly, was to act like everything was okay. Today, that meant scooping up two young people from the Himalayan kingdom of Bhutan.

Did the little performance he was about to put on really mean that twenty thousand people from all over the world were going to end up living happily in the Cloud Ark? He just had to shut down the little Rain Man in his head—"Doob, as in dubious"—and not even think about it.

They had taken off two hours ago from the *George H. W. Bush,* a supercarrier keeping station in the Bay of Bengal. Doob had viewed the ship through the eyes of a man who, in a few months, would be making a permanent move to its orbiting equivalent. She was a completely artificial island, thousands of people densely packed into a wad of pure technology. The professionalism of the crew and the efficiency with which she ran were amazing. Could something like that be duplicated in space, with people chosen by lot from all over the world, and trained in camps over the course of a single year?

He reckoned he would know more in about half an hour.

The navy chopper plunged into a fog-stuffed slot between mountains and knifed through steam and mist for a few minutes. The airport's sole runway came into view, startlingly close to them. The chopper flared to a perfect landing a stone's throw from the terminal building. Doob became aware that his jaw was clenched, and tried to relax it. He had made the mistake of googling this place and learned that it was bracketed by eighteen-thousand-foot mountain peaks, that only eight pilots in the world were certified to land here, and that even they didn't attempt it unless the sun was shining on the runway. Obviously the kinds of guys who flew choppers for the navy operated according to different rules, but it had still been a white-knuckle approach as far as Doob was concerned, and it made him wonder how he was going to react to being hurled into space on top of a hastily constructed tube full of explosive chemicals.

He shifted in his seat and felt a thick manila envelope slide out of his lap and to the deck with a solid *thunk* that almost woke up Tavistock Prowse. Tav had been sitting across from him for the entire duration of the flight, and had been sleeping for the last half hour—prostrate from jet lag. He was a bulky man, not especially tall, but constructed like a wrestler. The bald spot on the back of his head, which had been faintly visible even when he'd been in college, had expanded mercilessly, leaving just a monklike fringe of close-cropped hair around the back of his bullet-shaped head. Perhaps to draw attention away from it, he wore glasses with massive black frames. At one point a serious weight lifter, he had softened and spread in the last decade, and even more so since Zero. It was strange in a way to see him unconscious, for he never seemed to stop moving.

Doob had a pretty good idea why. Tav was hoping he'd get picked. If he worked hard enough, popped up on enough news feeds, garnered enough followers on Twitter, maybe some important person would decide that the Cloud Ark needed a professional communicator—the first, or the last, journalist. To Doob it seemed like long odds. A lot of people with Ph.D.s and even Nobel Prizes were ahead of Tav in line. But you never knew. And he couldn't fault the guy for trying.

He bent forward and retrieved the envelope from the deck. It was a centimeter thick. It was labeled PARO, BHUTAN in neat block letters. The flap had never been opened. He was supposed to have spent the last couple of hours reading its contents, familiarizing himself with the task to be performed. Instead of which he had been looking out the window at the steamy green plains and lazily braided rivers of Bangladesh.

Hoping to make the most of the two or three minutes it would take to get the chopper's door open, he plucked it up off the floor, tore it open, and pulled out a sheaf of pages. This was enough to wake Tav up, but not enough to make him move. He gazed at Doob and watched him read.

"If it's wearing red, yellow, or both, it's a lama," he said. "Bow to it."

"Isn't that a camel from South America?"

"With one L. A holy man. Put the palms of your hands together and make a little bow."

"I don't believe in—"

"It's not gonna kill you, is it? If he's got a big yellow scarf over his left shoulder, he's the king. Bow lower in that case."

"Thanks. Anything else?"

Sitting next to Doob was Mario, their photographer: a man in his thirties with a short, dark mustache, a New York accent, and no expectation whatsoever of being picked for the Cloud Ark. On the flight over he had divided his time between reading his own copy of the same dossier and playing a video game on his phone. He had been on many more of these than Doob or Tav. Getting into the spirit of things, he pocketed his phone and piped up: "People are going to hand you things. Some of them might be really crusty and old and funny smelling. Those things are probably really important. *Really* important."

"Then why are they—"

"Because they believe you are going to take it all up into space and preserve it."

"Oh."

"So if anyone hands you anything, even if you have no idea what on God's green Earth it might be, look impressed, bow, take it carefully, admire it, and then hand it off to the helper kid."

"Helper kid?"

"People have been deputized to follow you around and help you carry all of the priceless national treasures that are going to be bestowed on you. They'll look after the stuff and bring it all back here to the chopper so you can keep your hands free for making those little bows and shaking hands with the king or whatever. As soon as we get back to the aircraft carrier, we'll throw it overboard."

"Done this before, have you?"

"This is my seventy-third abduction run. Let's go." Mario stood up, carefully, letting his cameras and bags swing free, patting each one as it settled into place. Tav and Doob were undoing their seat belts and watching him for cues. Mario took two steps toward the door, which the pilot had just swung open. Cold damp air, scented with pine and coal smoke, was pouring in.

Doob almost rear-ended Mario as he stopped suddenly and turned around to look him in the eye. "One other thing."

"Yes?" Doob said.

"What is about to happen is going to be incredibly fucking sad. Like maybe the saddest thing you have ever seen. Try to hold it together."

Mario held Doob's gaze until Doob nodded and said, "Thanks." Then he turned around and bolted for the door so that he could get some good pictures of Dr. Harris emerging from the chopper.

Dr. Harris paused in the open hatchway. Spread out in front of him were at least two dozen people in red and yellow clothing, drawn up in readiness to extend greetings.

He put his palms together in front of his chest and bowed. In front of him, Mario's shutter began to whirr. Behind him, faint digitized clicks spilled out of Tav's phone as he live-tweeted it.

THE KING DROVE HIM UP THE MOUNTAIN IN HIS PERSONAL LAND Rover, Doob riding shotgun in the passenger seat on the left—for Bhutan, as it turned out, was a drive-on-the-left country. Mario sat in the back angling to get both of them in the photo, and Tav sat next to Mario muttering voice memos into his phone. The king apologized for today's murky weather, which was blocking potentially spectacular views of high mountains all around.

"But I suppose that is a very small matter in the larger scheme of things," he concluded.

They had stopped at an intersection in the town of Paro to let three boys kick a soccer ball across the road in front of them. Piled up on the road behind them was a small motorcade of lama-packed Toyotas.

"So much joy they take in this simple game," the king mused. "They know, of course. All of them know about the disaster that is to come. When they are thinking of it, it makes them sad. But at other times, they are as you see them—oblivious."

The boys got out of their way and the king eased forward into the intersection. The town had a surprisingly Alpine look to it, with deep brown weather-beaten structures of wood built on stone foundations.

"Until a few days ago," the king went on, "they might have consoled themselves by imagining that they would be the ones chosen."

"In the Casting of Lots," Doob said.

"Yes." The king shot him a keen look. "I was responsible for choosing, you know." He glanced back at Tav. "That is off the record."

"No, Your Highness, I did not know that," Doob said.

"We received guidelines, I suppose you could call them. Saying that it was not a literal casting of lots. The choice is best not left to chance—we must send only the finest candidates. Bhutan has only two places in the Cloud Ark. It would be foolish to waste them on someone unable to represent our people. So, it was a selective process."

"Most people have come to the same conclusion," Doob said. "A pool of promising candidates is identified and then the choice is made from among them by some process which might be random—just so no one person carries the entire responsibility."

"When you are a king you sometimes have such responsibilities whether you want them or not. In this case, though, I was able to involve some of the lamas. There are precedents for such a selection procedure in the way that certain reincarnate lamas are identified—the drawing of lots from an urn is sometimes used."

Tav couldn't resist asking from the backseat: "What does the doctrine of reincarnation have to say about the situation we are faced with now?"

The king smiled. "Mr. Prowse, this is only a journey of ten kilometers. I am taking it slow. If we had a road trip ahead of us of ten thousand kilometers—an enjoyable thought—I might be able to impart enough information to you about what reincarnation means to my people that we would be able to have an intelligent conversation about it."

"Fair enough. Sorry," Tav said, glancing up from the screen of his phone when his brain detected a pause in the king's speech. "You have to understand, my job is to communicate with geeks. People who like math. So I was trying to imagine—"

"When seven billion die, and only some thousands remain, where do the seven billion souls go?"

"Yes."

They turned off what Doob guessed was the main road and onto a fork that wound through a wooded hamlet above the river. This hooked onto a bridge that took them across a fast-running, cold-looking stream, green and milky with rock flour carried down from melting glaciers thousands of meters above their heads. Doob still couldn't get over the fact that in a little more than a year those glaciers would be gone, the rock beneath them exposed for the first time in millions of years, and no scientist would be there to record it.

"We don't believe in anything as simple as metempsychosis—the movement of an individual soul from one body to another. That's not what we mean by reincarnation at all."

"What do you believe in, then?" Doob asked. Tav had lost interest and was belaboring his phone with his thumbs.

"A better analogy might be to a burned-down stump being used to ignite a new candle. But I won't be able to give you a satisfactory answer, Dr. Harris. The teachings are esoteric—deliberately hidden from the uninitiated, specifically to prevent false interpretations. How an enlightened lama would think about the question of the seven billion is as far beyond my comprehension as are the quantum gravity theories that you study in your work."

On this side of the river the ground rose almost vertically. The mountain barrier was cleft by a steep-sided valley that zigzagged up and away from them; the road leaped up into it and switchbacked up a stone cliff, fringed here and there with clusters of hardy evergreens that had found toeholds in crevices. Tendrils and torn veils of mist drifted across the face of the rock, providing occasional glimpses of a white tower, high above them, that had somehow been constructed on the precipice. It was one of those buildings, like some monasteries in Greece and Spain, whose whole point was to proclaim to those below, "This is how far we will go to achieve separation from the world."

They drove up a road between long green terraces until the ground became too steep for wheels, and then the king stopped the Land Rover and set the brake. "How's your cardio?"

"Could be better," Doob said, "but I don't have a heart condition, or anything like that."

"We are at about three thousand meters above sea level. You are welcome to await the chosen ones here in my vehicle, or—"

"I could use a walk, thanks," Doob said, and glanced back at Mario, who shrugged philosophically, and at Tavistock Prowse, who appeared to be biting his tongue.

As they hiked up the trail, followed at a respectful distance by an entourage of lamas, children, photographers, and officers of the Bhutanese military, the king told Doob that the place they were

going was called the Tiger's Nest and that it was one of the most sacred sites in their religion, being the spot where Guru Rinpoche, the Second Buddha, had, in the eighth century, flown in from Tibet on the back of a tiger. Later a temple complex had been built around the caves where Padmasambhava (for apparently this was an alternate name for the same personage) had lingered to meditate.

Doob pleased himself by suppressing the urge to point out to the king that tigers were not capable of flight. This was only partly because he was gasping for air. He did not really care about the plausibility of the story, given the astonishing beauty of the place through which they were hiking. It was one thing to be fed a line of religious hokum in a desert hellhole that had nothing to recommend it as a site for tourism. But in order to go for a few hours' walk with a king in Shangri-La, he would put up with any amount of fairy tales and metaphysical ramblings.

Small temples and devotional sites emerged from the mist every few minutes. They stopped part of the way up to enjoy a serving of chai in a little café with a fine view of the Tiger's Nest. Tav, at the end of his rope physically, announced he would go no farther. Doob, Mario, and the king pushed on along the increasingly precarious walkway to the gates of the monastery itself. This, the king had already informed Doob, was off-limits, and in any case would have made a poor showing as a site for a ceremony, being rather cramped, dark, mazy, and ancient. Crag-dwelling hermit monks didn't go in much for grand ceremonial courtyards.

Instead there was a sort of wide spot in the ledge just before the entrance to the white temple. Waiting there were the two Arkers, a boy and a girl, both in their early twenties, clad in what Doob assumed was traditional costume: For the boy, a robe that stopped at his knees, with a large white scarf over his shoulder and crossed to his hip. For the girl, a bolt of colorfully woven cloth, wrapped around her waist and falling to her ankles as a sort of columnar skirt, with a yellow silk jacket above that, draped with many necklaces of turquoise and other colorful stones.

Had she been here, Amelia, in a single glance, would have noticed a hundred details about the weaving, the embroidery, the jewelry, the drape of the fabrics, the choice of colors. She would have charmed the king right out of his saffron scarf. She would have climbed out of the Land Rover back in Paro and made friends with the soccer-playing boys. Amelia, not Doob, was the person who ought to be doing all of this.

But Amelia wasn't going to the Cloud Ark and Doob was.

The boy and the girl—Dorji and Jigme, respectively—were backed up by some leathery oldsters in similar but simpler costumes, presumably their families, and several lamas. Prayer wheels were spinning, bells were chiming back inside the monastery, monks were chanting.

Everyone was crying.

They all bowed to their king.

Doob was glad Tav had not come this far.

Some kind of conversation took place in the local language. Doob didn't even know what the name of that language was. Mario, oblivious to the emotional tenor of the proceedings, darted around snapping photographs, dropping to his knees or even throwing himself flat on the ground so that he could get mountain peaks or temple roofs in the backdrop of shots.

Doob, who had no idea what was going on, couldn't take his eyes off the faces of the elders, who were doing their best to hold it together in the presence of their monarch but clearly suffering through ruinous emotional pain as they prepared to say goodbye to Dorji and Jigme forever. It was almost worse than watching your kid die, Doob thought. Then there was finality, certainty, a grave site to visit. Whereas these two were just going to hike off into the mist. A thunder of helicopter blades would announce their departure, and after that the family members would get vague assurances that Dorji and Jigme were going into space to carry forward the cultural legacy of Bhutan. Assurances that, Doob was pretty sure, were going to be fundamentally dishonest. These people were going to go to their deaths in fifteen months consoling themselves with that belief.

He now understood his job a lot more clearly. Why were the doomed people of Earth not going completely berserk? Oh, there had been some outbreaks of civil disorder, but for the most part people were taking it surprisingly calmly.

It was because events like this were happening in every city and province with more than a few hundred thousand people, and they were being stage-managed well enough to convince people that the system was working.

When he was a kid he had read the Greek myth of Theseus and the minotaur, which hinged on the premise that the people of Athens had somehow been persuaded to select seven maidens and seven boys by lot, every few years, and send them to Crete to serve as monster chow. This had always struck him as the weakest point of what was otherwise a great yarn. Who would do that? Who would choose their kids by lot and send them to such a fate?

The people of Bhutan, that was who. And the people of Seattle and of the Canelones district of southern Uruguay and of the Grand Duchy of Luxembourg and the South Island of New Zealand, all of which Doob was scheduled to visit in the next two weeks to collect the maidens and the boys they had chosen by lot. They would do it if they could be made to believe it would protect them.

As Mario had predicted, Doob was presented with some extremely old-looking artifacts by almost equally old-looking monks who smiled at him through tears and backed away, bowing, once Doob had accepted their prayer wheels and sutras and carvings into his hands.

The king took Dorji and Jigme by the hand, turning his back on the mourners or the well-wishers or whatever they were, and nodded at Doob as if to say “your move.”

Doob bowed one last time, then turned around and began leading them down the mountain.

DAY 306

Arklet 1, which had been sent up on Day 285, turned out to have a few teething problems with its maneuvering thrusters, and so the first bolo coupling in the history of the Cloud Ark took place between Arklet 2 and Arklet 3. Those had been launched on Days 296 and 300, respectively. These first three Arklets represented competing designs and so they all looked a little different. No matter; they were destined to be punched out in different factories and launched on different types of heavy-lift rockets from different spaceports, so minor variations in styling were to be expected. They all had the same general shape, though: a cylinder with domed end caps. That was for the ineluctable reason that they had to be pressurized in order to perform their basic function of keeping humans alive, and pressure sooner or later made everything round. Dinah thought that the pressure hulls looked like the big liquid propane tanks seen next to cabins and mobile homes in the rural mining camps where she had grown up. Others likened them to railway tanker cars, or stubby hot dogs.

They were just big aluminum cans with domes welded onto the ends. The walls of the can had a thickness of about a millimeter. The domes were a bit sturdier. The thickest and strongest parts of the hull were in the places where the domes overlapped the ends of the can. The analogy was to a plastic soda bottle, whose thin walls could be crumpled in one hand when the lid was off, but which became amazingly stiff and strong when it was pressurized. Or at least that was what NASA was saying to people who were alarmed by the idea of living one millimeter away from the vacuum of space.

The first three arklets were launched "naked" and smooth, but the hundreds to follow would come up clothed in translucent fabric jackets, pleated and wrinkled during the passage through the atmosphere, protected beneath fiberglass fairings. Once in space the blanket would be inflated to form a flexible outer hull somewhat larger than the inner one. It was in that inter-hull space where food would be grown, making use of sunlight that would diffuse through the fabric. It was not clear yet whether each arklet could be self-sufficient in terms of food production—probably not—but growing some food was better than growing none. Having some green stuff on board helped reduce the load on the CO_2 scrubbers, and having water between humans and space helped stop some incoming radiation.

One of the end caps sported a docking port, designated in NASA public-relations cant as the "front door." It was a bit of a misnomer since it was the *only* door. Once sealed up inside the pressure hull, the occupants could only get out of it by docking the arklet to something with breathable air on the other side of it.

The opposite end of the arklet was called the "boiler room." Mounted outside of it was the trash-can-sized nuclear generator that supplied the arklet with power. Around that were various fittings for connection of plumbing lines, electrical mains, cooling equipment, and the like, none of which would ever be used except in the case when a number of arklets decided to dock themselves together and form a semipermanent cluster.

Those sturdy, thick rings where the domes met the main body served as attachment points for anything of a structural nature—anything that would exert significant forces on the body of the arklet. Radiating from each of those rings were eight stubby, radial spokes, extending outward to halolike rings where thrusters and grappling equipment were attached. Those parts were shipped inside of the arklet, then, once it was in space, extracted through the docking port by spacewalkers and bolted on in zero gee. The halos also served to stiffen and stabilize the inflatable outer hull in arklets so equipped, but in the first three test units they just projected out into space like bicycle rims, studded with small thruster nozzles and laced through with plumbing.

Spanning the distance between the "front door" halo and the "boiler room" halo was a single long spindly member, hinged at the "front" or forward end so that it could, on command, snap up and out, projecting sideways from the arklet for a distance of about ten meters. Mounted to the end

of this arm were a camera, a target, and an electromechanical grappling device, collectively known as the Paw. A cable ran from the Paw back down the length of the arm to a reel near the docking port, where 250 meters of it were wound up like thread on a spool. The arm, the Paw, the rope, and the reel were all there to achieve a specific maneuver, never before attempted, denoted in official NASA engineering documents as the Bolo Coupling Operation but referred to everywhere else as the High Five.

On Day 306, after Arklets 2 and 3 had been assembled and checked out, the first Bolo Coupling Operation was initiated. It happened several kilometers away from Izzy. It was done quietly and secretly, in case it failed, but lots of video was taken, in case it succeeded. The operation had many possible failure modes, which was engineering-speak meaning that it could go wrong in so many different ways that trying to think them all through was impossible. So each of the two arklets needed to have a qualified pilot: someone who understood orbital mechanics and spaceship propulsion well enough to bring an errant craft back in hand by manual control. Few such people had ever existed, and only four of them were aboard Izzy. Right now, down on the ground, thousands of young people selected in the Casting of Lots were learning how to do it by piloting virtual arklets in video game simulations, but none of those people was ready, or in orbit, yet. So Ivy ended up at the controls of Arklet 2, with Dinah as passenger and general assistant. Piloting Arklet 3 was a recent arrival, Markus Leuker, a Swiss air force pilot turned astronaut and a veteran of two previous missions to the ISS. His background piloting high-performance fighter jets through Alpine valleys seemed like a reasonable qualification for this job. His assistant was Wang Fuhua, one of the first Chinese taikonauts to have reached Izzy during the Pioneer days of a few months back.

After a good night's sleep and a light breakfast, the four participants met in the Banana to go over the details one last time with engineers on the ground, then ascended a spoke into the weightless environment of H1 and glided up the Stack—the central axis of the space station—snaking through work bays and temporary supply dumps until they reached a docking node that, after a few twists and turns, led them into a hamster tube. One after the other they slithered down it. Dinah, in number three position behind Markus, found it difficult to keep up with him; the soles of his feet kept getting farther and farther away. "Just like scaling the Daubenhorn," he said at one point, "except without the annoyance of gravity!"

"Is that a mountain?" Dinah asked, since the hamster tube was long, and she felt that a bit of light conversation would help ease the lump in her stomach.

"Yes, a famous *Klettersteig* where I grew up—you must come and give it a try one of these days," Markus called back.

A common error in etiquette, among people who had only recently arrived at Izzy, was to talk about Earth as a place that it was possible to go back to. As if this were a temporary mission like all of the previous ones. Dinah said nothing. Markus would realize his mistake, if he hadn't already.

"Oh, well," he added. Yes, he had realized it.

"What's a *Klettersteig*?" Dinah asked, trying to move on.

"It is a mountain climb that is preengineered with cables, ladders, and so on."

"To make it easier," Dinah guessed.

"Oh, no. It is not easy. It is a way to take a climb that would be impossible, and make it merely extremely difficult."

"Okay," Dinah said. "A good metaphor for what we are trying to do up here, then."

"Yes, I suppose so!" Markus said, cheerfully enough.

They came to a junction of hamster tubes, and after scrutinizing the felt-tipped annotations on the walls left by past travelers, they went their separate ways, Dinah leading Ivy to the right while Fuhua and Markus headed straight on. After passing three occupied docking ports, and exchanging perfunctory greetings with the people living in the capsules on the other sides, they came to the end of the hamster tube and passed through a docking port.

They floated into a tubular space four meters in diameter and twelve meters long, illuminated by icy bluish-white LEDs. Its wall was a smooth cylinder of aluminum, striped with bar codes and stippled with batch numbers from the mill that had produced it. A long, straight weld ran up its length. At the far end, the curve of its "boiler room" dome, penetrated by many plumbing and electrical connections, was visible through a flat fiberglass grate—a disk of industrial catwalk material in a bilious shade of green. A ladder, made of the same material, extended "up" from there to the "front door," through which Dinah, and now Ivy, entered. It put Dinah immediately in mind of Markus with his talk of *Klettersteig*s. You didn't need to have a ladder unless you were expecting gravity, or a reasonable facsimile of it. The grate at the far end of the arklet was going to end up serving as the floor.

Or as *a* floor—the lowermost story. The arklet was long enough to divide vertically into as many as five stories by inserting more of those grated disks. Cleats for that purpose were attached to the walls at regular intervals, but the grates hadn't been installed yet.

Dinah pushed off against the top rung of the ladder and flew "down" until she could arrest her momentum against the boiler room grate, then spun herself about so that her feet were touching it and her head was pointed back "up" toward the front door. This brought her eyes level with several flat-panel screens that had been mounted to the walls. They served as status indicators and control panels for the equipment mounted to the outside of the dome. The little nuke was the only thing that mattered to them at the moment. It had a screen all to itself. Dinah woke it up with a tap. It refreshed itself with a graphical display, showing the temperature of the plutonium pellet at its core, its current output level, the RPMs and health metrics of the Stirling engine that converted its heat into electrical power, and the charge level of the batteries and of the supercapacitor that served as a buffer to store energy when it wasn't needed and release it when it was. Everything seemed normal there. Not much could really go wrong with these things. This one was brand new.

She pivoted to another display that gave her information about the array of thrusters mounted to the halo just outside. Arklets were pretty short on windows; the only place you could see out was at the forward end, where a couple of small portholes had been let into the dome adjacent to the docking hardware. Just below one of them was what the engineers called a couch and what the casual observer would be more likely to describe as an expensive lawn chair that had somehow found its way into space. Ivy had already strapped herself into it and was waking up another bank of flat-panel screens there. Dinah could hear her murmuring into the microphone on her headset, which she had jacked into the assortment of plastic boxes that, in this context, passed for a control panel. She was running through a checklist with mission control and talking to Markus, who by now must be strapped in at the controls of Arklet 3.

Gazing around, Dinah saw the gleam of a camera lens, no larger than a raven's eye, set into a tiny plastic pod on the wall in the middle of the arklet.

Then, for no particular reason, she started crying.

There'd been surprisingly little of this. Certain Morse code messages from Rufus were guaranteed to turn on the old waterworks. Ivy and Dinah permitted themselves to shed tears in each other's presence when no one else was around, and a few other people such as Luisa had joined that club more recently. But there was always something to do, some emergency to take care of, always people around watching. No privacy. This empty arklet was the largest volume of uninterrupted, unoccupied space that Dinah had been inside of since boarding the Soyuz capsule at Baikonur a year and a half ago. It seemed vast to her, and she felt alone in it, and she couldn't help herself. She knew that the camera was watching her and that she was being recorded on digital video that was being archived. Psychologists in Houston might be judging her fitness for duty at this very moment. But she didn't care. She'd stopped caring about what the people in Houston thought a long time ago. Once she started crying, it developed a kind of unstoppable momentum and she just had to let it run for a while. Her thoughts had begun to ramble away from her own family and situation and toward the Arkers who

would live and die in tin cans like this one. If it didn't work—if the whole Cloud Ark idea was just a panacea, as some people suggested—then the last thoughts and impressions ever recorded by a human soul might take place in an environment exactly like this one. And maybe Dinah would be that soul.

The problem with crying in zero gee was that tears didn't run down your cheeks. They built up in jiggling sacs around your eyes, and you had to shake them off or dab them away. Dinah didn't have anything to dab with—the plastic coveralls they wore were notoriously nonabsorbent—and so she just drifted in the bottom of the arklet, looking at the light from the control screens through bags of warm salt water.

"Some assistant you are!" Ivy called back, after letting her go on for a few minutes.

"Sorry," Dinah blurted out. "That was mission critical."

"Try not to short out any of the equipment. Tears conduct electricity."

"I think they made it all pee-proof. Remember, these things are designed for amateurs."

"Tell me about it," Ivy snorted. "The user interface is so easy to use, I can't do anything."

Something light whacked into Dinah's head. Through the tears she vaguely saw a white object caroming off the nuclear reactor's user-friendly control panel. Pawing it out of the air, her hands recognized it as a packet of tissues. A high-value black market item. She tore it open, pulled out a few sheets, and began the somewhat delicate process of soaking up the tear-globs without smashing them into sprays of equipment-shorting droplets.

"I mean, my God, what would Markus think of you?" Ivy demanded.

It took Dinah a few moments to catch up. "Him and me? You think?"

"It is so obvious."

After a thrilling first few weeks, things had kind of trailed off with Rhys. It was okay. Easy come, easy go. She had never seen him as a stable long-term prospect. The times they'd been living in, and the place they'd been living, weren't really conducive to long-term pair bonding. Luisa, wearing her anthropologist hat, had watched the spontaneous, mostly short-lived couplings of Izzy's inhabitants with a combination of dry amusement, scientific fascination, and frank, hilarious envy.

"I don't know," Dinah said, "I see where you're going, but he seems a little Captain Kirk."

"You need a little Captain Kirk in your …"

"In my *what*?"

"In your *life*. Rhys is too introspective."

"Is that a euphemism of some kind?"

"He's depressed."

"Gosh, I wonder why."

"No, not that way. Not about the world ending and everyone dying. I mean that when he's working on a project he's full of energy but when it's finished he just kind of collapses."

On the tip of Dinah's tongue was a remark about how well that observation aligned with Rhys's lovemaking style, but she held back. "You realize that all of this is being recorded?"

"Get used to it," Ivy said, and Dinah could sense her shrug from twelve meters away. "Hang on, gonna give the forward thrusters a little pop—backing out of our parking space."

She wasn't kidding. The thrusters gave off something very like a bang when they went off. Dinah, who actually wasn't hanging on, felt a few moments of disorientation as the whole arklet moved backward around her while she remained motionless. The green grid dropped away from her and the front door approached—but all so slowly that she needed only to reach out and glide a hand along the ladder to control her relative motion. In a few seconds the forward end of the arklet reached her and she stopped herself against one of the struts of Ivy's couch. Next to it was a knot of straps and pads, like a rock-climbing harness, which Dinah now spent a couple of minutes untangling and climbing into. The bangs of the thrusters, the hisses and clicks of the associated plumbing, and Ivy's murmuring into the microphone served as accompaniment while she got herself strapped in and donned a headset of her own. That enabled her to hear the clipped military-style transmissions

among Dinah, Markus, and their controller on Izzy. An engineer in Houston weighed in every few minutes with questions and observations.

Once they had drifted well clear of Izzy, they initiated a programmed burn a few seconds long that took them to a slightly higher orbit. For a while they could see nothing but empty space through the windows. The sun must have risen over the Earth's limb, because bright round spots appeared on the wall.

Ivy said, "I have Three on radar and am engaging MAP." That being the three-letter acronym for Monitored Autonomous Piloting. The operation they were about to perform—the High Five—was deemed way too ticklish to be handled by noob spaceship pilots. It had to be a robotic operation the whole way. But the algorithms, and the sensors that told them what was happening, were all brand new, so experienced pilots had to sit at the controls, watching through the window and taking over if and when the robo-pilot started acting screwy.

The thrusters began to pop in a different rhythm, a patter of tiny firings very different from how a human being would operate them. The star field swung past the windows, the splotches of sunlight veered around the walls, and suddenly Arklet 3 rotated into view, a few hundred meters away. It too was flying under MAP, coming about until its front door was aimed their way. Dinah stifled the impulse to wave at Markus and Fuhua. It was unprofessional, and anyway they wouldn't be able to see her through the tiny porthole.

A spindly white arm swung outward from the side of Arklet 3 and locked into position, extended off to one side. A few moments later they heard and felt their own arm actuating likewise, and watched an animation of it on a flat screen.

"Bringing up the Paw camera," Dinah muttered, and tapped a control that flooded a screen with high-resolution video from a telephoto lens mounted at the end of the arm. This showed nothing, at first, but the blue limb of the Earth's atmosphere down in one corner. Then a targetlike pattern veered across the screen, slowed, and veered back. All of this was accompanied by more fidgety percussion from the thrusters. The feed was remarkably close, and clear. Comparing it to the direct view out the porthole, Dinah could see the target on the end of Arklet 3's extended arm, looking tiny from this distance. But the machine vision system now in control of their little spacecraft had found it, and recognized it, and …

"We have a lock," Ivy said. "We see you, Three."

"We see you, Two," Markus answered. "It proceeds."

It proceeded with a longer firing of the aft thrusters that nudged them forward enough that Dinah could feel the pressure on her bottom, sense the straps of the harness tightening. The target flailed around some, but a few moments later, the lock was reestablished. Dinah could see Arklet 3 growing larger. Numbers on a screen, gauging the distance between the ships—or, to be precise, between the two ships' outstretched Paws—were counting down.

"It is all nominal," Ivy said, but the last word was drowned out by a digital voice making an announcement over the arklet's rudimentary PA system: "Bolo Coupling Operation entering its terminal phase. Prepare for acceleration." And then in classic NASA style it counted down: "Five, four, three, two, one, grapple initiated."

At "one" the test pattern on the screen disappeared in shadow, for it was too close now for the camera to even see it. The Paws of Arklet 2 and Arklet 3 slapped together, like runners exchanging a high five as they passed each other going opposite ways. Strange whiny noises propagated down the arm into the hard shell of the arklet.

"Grappling achieved," said the voice.

Dinah's ears finally identified the whiny noise as the sound of cable unwinding from a spool. She felt a lurch in her stomach as the arklet did a half somersault, reversing its direction so that it was pointed back at its bolo partner.

As she knew, having studied this maneuver for weeks, the two arklets were now joined together by a cable. They had flown right past each other, but the tension in that cable had spun them around so that they were pointing toward each other again—she verified this with a glance out the window, which gave her a view of the nose of Arklet 3 slowly receding as it “backed away” from them. The spool of cable mounted next to its docking port was in motion, unwinding as the two craft gained distance from each other. In the exact center, the cables of Arklets 2 and 3 were clasped together by a coupling device that could be remotely disengaged whenever they made the decision to go their separate ways.

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