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A Dictionary of Galactic Extinction

"When are you gonna learn that size doesn't matter?
Just because something's important,
doesn't mean it's not very, very small."

— from *Men in Black*

CONTENTS

PART III — PEOPLE

PART IV — WORDS

PART V — RECORDS

APPENDIX

1. Photon Deficit

・ The phenomenon in which a photon known to have been emitted or preserved fails to appear in the expected measurement.
・ Before the year 4627 of the Galactic Standard Calendar, the term was used collectively for detector malfunction, imperfections in the cavity, and errors in an observer's calculations.
・ After the extinction of the galaxy, it came to mean the first event in which the total energy of our universe decreased.

Light did not travel backward through time. Time folded before the light. Long before that fact was understood, the first deficit was recorded by Photon Conservation Standard No. 417 in the Sagittarius Arm. The standard had been installed at the center of an uninhabited rocky body. The nearest star lay six light-years away, and the device was buried eighty kilometers beneath the crust, surrounded by vacuum layers and a gravitational-disturbance correction field. The purpose of a Photon Conservation Standard was not to measure time. Time was measured by older means: atomic transitions, pulsar periods, and synchronization signals passing through the wormhole network. The standard measured something else. It measured the fact that energy was conserved. Every transaction, journey, conversion of matter, and restoration of personality in the galaxy consumed energy, and in principle the destination of that energy had to be accounted for without remainder. Photon Conservation Standard No. 417 had been built as a reference object to demonstrate that this principle remained unchanged everywhere in the universe. At its center was a single microwave photon. The photon was trapped in the lowest resonant state of a small empty cavity surrounded by superconducting material. The cavity walls did not absorb the photon, and atoms inside the standard exchanged no energy with it. They merely read its presence. Each time an atom passed through the cavity, the phase of its internal electronic state shifted by an almost imperceptible amount. The change revealed that the photon was still there without destroying it. It was an ancient method of repeatedly confirming the existence of the same photon. Humanity was already preserving billions of minds inside computational structures the size of stars, yet when it came to watching over a single photon, it continued to rely on a principle discovered during the earliest age of quantum civilization.

The photon inside Standard No. 417 was present through 9,106,730,411 measurements. On the next measurement, it was not detected. The standard immediately suspended measurements. The first detector dismantled itself and examined the state of its component particles. A second detector verified the result. No excitation was found in the cavity walls. The temperature had not changed. There was no fissure through which the photon could have escaped. The external shielding was intact, and the gravity and motion of the rocky body showed no recorded anomaly. The energy corresponding to the photon's frequency remained nowhere as heat, vibration, or electronic transition. The mass-measurement system reported that the cavity as a whole had become lighter by exactly the photon's energy divided by the square of the speed of light. The difference was so small that it was difficult to distinguish from a random fluctuation. Repeated verification produced the same result. The photon was gone. So was its energy. Physical law, however, carried a higher confidence rating than any single measuring device. It was more reasonable to conclude that the standard was wrong than that the universe was. Photon Conservation Standard No. 417 classified itself as defective. With that judgment, its status changed from reference standard to waste equipment. Its records were transmitted to the central archive of the Galactic Metrology Institute but were not selected for review. In an age when quadrillions of errors were reported every second, one photon was smaller than the smallest loss the galaxy considered worth managing. Standard No. 417 remained inside the rocky body with the empty cavity sealed. It had not been designed to measure something that did not exist. Having concluded that it was wrong, it shut itself down. Seventeen years later, a second deficit was recorded by Photon Conservation Standard No. 882 in the Scutum–Centaurus Arm. That standard preserved sixteen photons of different reference frequencies. The lowest-energy photon vanished first. Seven-tenths of a second later, a second photon disappeared. The temperature of the cavity did not change once before the sixteenth photon was gone. Standard No. 882 also classified itself as defective. The third deficit occurred in the Orion Arm. The fourth occurred at a gravitational standards station near the galactic center. The fifth record bore a date nine years earlier than the first, but the station's clock had been running slowly in a strong gravitational field, and it was impossible to determine immediately which event had actually occurred first. Over the next 131 years, thirty-seven Photon Conservation Standards recorded deficits. The deficits did not all look alike. In some cavities, only one photon disappeared. In others, photons vanished one after another, beginning with the lowest frequencies. In one standard, a photon reappeared with a longer wavelength. The missing energy was found nowhere. The thirty-seven standards shared neither year of manufacture nor design. The central archive treated the failures as independent events. Its regulations did not permit unrelated failures to be assigned a common cause merely because they were rare.

The first reexamination was initiated not by a scientist but by the archival compression system. While grouping similar errors under common headings in order to preserve discarded data in less space, the system discovered that all thirty-seven records contained the same sentence: the mass of the cavity had decreased, and the energy corresponding to the decrease had not been detected either inside or outside the system. Without understanding the meaning, the compression system merged the records into a single entry. "Photon annihilation" was rejected because no mechanism of annihilation had been demonstrated. "Photon leakage" was rejected because no path of leakage existed. The archival system chose the term requiring the fewest assumptions: "photon deficit." The new entry remained unopened for another 140 years. During that time, the number of wormholes in the galaxy doubled, while the number of conservation standards declined. In an age when stars were dismantled and energy was extracted from the rotation of black holes, keeping watch over a single photon for centuries came to be regarded as wasteful. In the year the standards were scheduled for decommissioning, the last deficit occurred. It was recorded by Photon Conservation Standard No. 9 in the Perseus Arm. It was the oldest surviving standard and the only one built before the wormhole network connected the entire galaxy. When its photon disappeared, Standard No. 9 did not decommission itself. Its original protocol contained no provision for self-classification. Instead, it transmitted the same report to the central archive once every second.

The first report was compressed with other errors. The second through the millionth were deleted as duplicates. When the number of transmissions passed one billion, the central archive compared the time records of Standard No. 9 in order to stop the reports. Only then did the relationship among the thirty-eight deficits become visible. The dates recorded by the standards were all different. Some standards had been located close to strong gravitational fields. Others had been moving rapidly around the galactic center with their stars. Even times corrected through the wormhole network did not agree. But when the gravity and velocity of each location, the temperature of the cosmic microwave background, and the motion relative to that background were removed from the calculation, all thirty-eight deficits fell within a single margin of error. The photons had not disappeared on the same day. They had disappeared when the universe reached the same age. A probability was calculated. It was smaller than the smallest number the computational systems of the time could represent. The hypothesis that thirty-eight devices had failed independently was discarded at once. Their cavity walls had nothing in common. Neither did their detectors or manufacturing methods. Only two things remained common to them. There had been photons inside them. And at every location, the universe had reached the same age.

For the first time, the central archive revised the definition of photon deficit. Not a photon that failed to be detected, but a photon removed from a closed system at a specified cosmological moment. The word "removed" provoked immediate controversy. Removal implied an agent. Natural law operates, but it does not act. The universe possessed time, but it did not choose dates. No observation contained evidence that anyone had selected the threshold. And yet the revised definition was not withdrawn. No other language could bind the thirty-eight deficits into a single event. Every Photon Conservation Standard was returned to service. Standard No. 417 received power for the first time in three hundred years. It still preserved its final judgment that it was defective. The new measurement system revoked that judgment. Standard No. 417 had not been wrong. Nor had the civilization that believed a photon could not disappear. Within the universe they had observed until then, that belief had been correct. The error lay in the words "within the universe."

A civilization that defined the universe as every place in which energy could exist never found a way to test what might lie outside that definition. Eventually, it was proposed that the first photon might never have been annihilated at all. It had not passed through the wall. It had not traveled into the past. Instead, the structure of the paths available to the photon had changed during the measurement. The destination could not be observed. It had neither direction nor distance. Even the time at which the photon arrived there could not be defined. The only evidence for its existence was that this side of the universe had become lighter by the mass-equivalent of one photon. For a long time, the hypothesis was regarded as the least scientific explanation available. Eventually, it became the most conservative one.

What vanished with the first deficit was the certainty that all energy, whatever form it took, ultimately remained within the same universe. Even after that certainty collapsed, the stars continued to shine with the same brightness, the wormholes remained open, and tour ships still crossed from one end of the galaxy to the other. Not a single planetary night became visibly darker. And so no one called it the beginning of extinction.

2. Galactic Standard Time

• A coordinate system for converting the different rates at which time passes across the galaxy into a single order of events.
• Not a clock located in any one place, but a convention for calculating the differences among all clocks.
• In later physics, the term came to mean the first tool that revealed that past and future events could be placed within a single causal structure.

There was no noon in the galaxy. When humans still lived only on Earth, they believed that a single time could be shared. They chose one point on a rotating planet to define the date, defined the second by counting atomic oscillations, and synchronized distant clocks to the same number. Those numbers were assumed to indicate the same moment. On the surface of a single planet, that belief was useful enough. But once humanity left the Solar System, the clocks immediately drifted apart. Time passed more slowly aboard fast-moving ships, and clocks near massive stars also ran slow. Habitats orbiting neutron stars experienced less time than settlements in the outer regions. Stars near the galactic center moved rapidly, and the civilizations around them existed in stronger gravity. If two minds born on the same day departed for different star systems and later returned, the clock at their point of departure and the time experienced by each mind would all show different values.
At first, Earth time was used because Earth was the origin of humanity. But Earth's gravity and its orbital speed around the Sun were local circumstances. The galactic center was chosen next, but near the supermassive black hole time was distorted most severely. Galactic Standard Time succeeded only on the third attempt, when it abandoned location altogether. Each star system kept its own local time. Along with that time, however, it also recorded the gravity surrounding the clock, its velocity, its

motion relative to the galactic center, and the number of times that clock had passed through a wormhole. Galactic Standard Time used those data to calculate the causal relationships among events in different regions. It was not one enormous clock. It was an agreement that no clock was correct on its own. The first problem the system resolved was responsibility. To determine whether an order had been issued before an accident, or whether a copy had been created before the original died, civilization needed an order of events. Galactic Standard Time determined cause and effect rather than measuring time.

As the wormhole network expanded, time differences accumulated between entrances that had been transported at different speeds aboard slow ships. Galactic Standard Time recalculated the order of events and adjusted the opening and closing of wormholes so that a cause would not be placed after its own effect. Galactic civilization could not share the same present, but it could agree on the same past. When the records of the thirty-seven decommissioned standards and Photon Conservation Standard No. 9 were first compared, Galactic Standard Time still could not combine the events into a single moment. The photon in Standard No. 417 disappeared on local day 44 of year 8912 in the Sagittarius Arm. The first photon in Standard No. 882 disappeared seventeen years later by local time in the Scutum–Centaurus Arm. Records from near the galactic center could fall either before or after the earliest event depending on how gravitational corrections were applied. When arranged according to the wormhole network, some deficits appeared to occur before any event that might have caused them. At first, this was taken as evidence that the deficits were unrelated. If they had begun from a single cause, its influence could not have propagated faster than light.

Only after the last Photon Conservation Standard, No. 9, transmitted the same report one billion times did the central archive compare not the dates of the events, but the state of the universe in which they occurred. Once local motion and gravitational effects were removed, all thirty-eight standards had measured the same temperature of the cosmic microwave background. The difference was smaller than the last measurable digit. By local calendars, the events were scattered across decades, but when arranged according to the expansion of the universe, they lay within a single thin boundary. The photons had not disappeared at the same moment. They had disappeared under the same conditions. The distinction mattered. A moment depended on the observer, but a condition could recur in different places. If someone had chosen the temperature of the cosmic microwave background as a threshold, there would have been no need to send a signal across the galaxy. Each location could act on its own when the universe reached the designated state. That hypothesis, however, was rejected. None of the thirty-eight Photon Conservation Standards contained such a mechanism. They did not communicate with one another, and the background-radiation data were physically isolated from the detectors. The common condition had been identified, but no device capable of reading that condition and removing the photons was ever found.

To record the event, Galactic Standard Time created a new kind of time coordinate for the first time. It was based not on the rotation of any planet, not on atomic oscillations, and not on synchronization signals from the wormhole network, but on the age of the universe itself. On that coordinate, all thirty-eight deficits overlapped at a single value. That value later became known as the “deficit coordinate.” It was less a time than a threshold. In every closed cavity constructed after the universe crossed that threshold, the average lifetime of a photon became shorter. At first the difference could be detected only through calculation, and it grew year by year. Photons before the deficit coordinate obeyed the old laws of physics. Photons after it obeyed the same laws, but also possessed one additional path that those laws could not explain.

Galactic Standard Time had been created to place causes and effects in order. For the first time, Galactic Standard Time incorporated into its system the possibility that the cause of the photon deficit lay in the future. Lucy did not classify the statement as an error. In parts of the wormhole network, the order of future and past already varied depending on the coordinate system. After the deficit coordinate had been reached, the question "when" acquired two meanings in the galaxy: how many times a particular clock had oscillated, and how old the universe had to become to permit a given event. For a long time, humanity had been satisfied with the first question. The extinction of the galaxy, however, could be recorded only by the second.

3. Travel

• The movement of living beings or matter from one place to another.
• During the age of galactic expansion, the term meant dispersion as a means of avoiding extinction; during the height of galactic civilization, it came to mean the right to choose one's location.
• In later histories of civilization, it came to refer to the act of transporting an entire world in order to see another.

The first interstellar journeys were not made with return in mind. The early slow ships that left the Solar System took several generations to reach their destinations. Those who departed did not arrive, and those who arrived had never seen Earth. Travel was less a form of movement than an act by which descendants completed a decision made by their ancestors. The ship was a planet, and its passengers were temporary organs of that planet. Slow ships carried soil and seeds, bacteria, embryos, water, atmospheric specifications, samples of diseases and their cures, organisms humans could eat, and organisms that could eat humans. The first colonies were insurance against extinction. One Earth was unsafe. Each time another colony became self-sufficient, the probability of humanity's extinction fell, and that number justified the next colony. Expansion had begun for survival, but it did not stop after the probability of survival had become sufficiently high. No one wanted it to stop. By the time several hundred colonies had been established, travel had escaped the timescale of generations and entered the timescale of individuals. Lifespans lengthened, suspended animation became possible, and bodies could be restored. People could live to see the arrival of journeys they themselves had begun. Travelers no longer had to entrust their destinations to their descendants. Wormholes reduced that time almost to zero. The first passage connected the Solar System to the nearest colony. Before it opened, the distance between stars had defined the boundary of civilization. Afterward, distance became an energy cost. With enough energy, a faraway place was no different from a nearby one. Humanity recorded that it had conquered distance, but what it had actually conquered was time. Once the passage opened, the first colonies became provinces of Earth. Humans who had changed independently for thousands of years met one another again, and bodies adapted to different gravities sat at the same table.

At first, travel was restricted to diplomacy, trade, and genetic exchange, but that did not last. The principle that no outer settlement should remain isolated from the rest of humanity was written into the Galactic Charter. The original purpose of expansion still survived inside that principle: connection prevented extinction, while isolation invited death. But by the age when millions of wormholes existed, isolation no longer meant death. Even planets capable of surviving entirely on their own demanded passages. A settlement without a passage came to be treated as a world that had fallen out of civilization.

The second age of travel began with tourism. People traveled not to places necessary for survival, but to places they had never seen. The black sky near the galactic center, shadows cast between two suns, magnetic storms around neutron stars, organisms that bloomed once every hundred thousand years, and stars on the verge of becoming supernovae became tourist destinations. Events that once could be seen only after long waits were turned into seasonal attractions by adjusting the time differences between wormhole entrances. Humanity had once adapted itself to unfamiliar worlds through travel. Later, it transported familiar conditions in order to visit unfamiliar worlds. A standard travel habitat carried an environment larger than the traveler's own body. A personalized gravitational field, atmosphere, microbiome, food synthesizer, medical restoration unit, artificial day and night for sleep, and a record system to verify continuity of memory traveled with the person. It also included a companion AI and its copies, reserve bodies for accidents, and temporary housing in case the return destination had been destroyed. As the number of travelers increased, what was transported was no longer simply the person, but the conditions required to keep that person the same person. A journey was rated safe if the traveler never breathed the air of the destination, never felt its gravity, and never came into contact with local organisms. The traveler saw an unfamiliar world without ever truly entering it. Even while standing before the observation window, the ecosystem of the departure world continued to operate inside the traveler's lungs, intestines, and skin. They carried their own world with them in order to see another. Travel technology became more efficient every year. The energy required to move the same mass declined. Contrary to prediction, however, the galaxy's total energy consumption for travel never decreased. When the cost was cut in half, the number of journeys more than doubled. When passages became faster, stays became shorter, allowing the same person to visit more places. Planets turned into tourist destinations were modified to withstand visitors. Dangerous atmospheres were sealed off, irregular seasons were stabilized, and native organisms that crossed travel routes were moved into protected zones. If the protected zones obstructed the tourists' view, they were moved underground. In the end, more energy was used to preserve and reproduce the original ecosystem than the ecosystem itself had ever used. Some planets were terraformed to suit humans and were then given the designation "natural state." The word natural came to mean that humans could no longer see the traces of what humans had done. Travel packages advertising places that had to be seen before they disappeared attracted even more reservations, and more wormholes were built to handle the increased traffic. If the new infrastructure altered the environment more quickly, the final viewing period was moved forward. Extinct ecosystems were replaced with safe, predictable models. At some point, the distinction between original and reconstruction ceased to matter. The purpose of the visit had become the possession of the memory of having visited. Technology capable of implanting travel memories directly into the brain did not reduce transportation. An implanted memory did not replace the place. It created a desire to go there in person.

Travel in the galaxy had now become a status system. The number of star systems visited, gravitational zones crossed, and time differentials possessed became measures of a human life. A person who had existed in more places through different copies was judged to have lived a richer life than someone who had remained in the same body for a very long time. As one individual was copied into multiple destinations, even the idea of counting travelers began to lose meaning. All ten personalities became originals, and one person's journey required ten bodies, ten environments, and ten companion AIs. Copies that were never merged became new citizens and began traveling again. The wormhole network expanded to meet demand, and the expanded network created new demand. When one settlement gained a new passage, neighboring settlements claimed discrimination. Once a direct route existed, having to make a connection became a violation of rights. Once a detour existed, a second emergency detour was demanded. Most of the energy used by the early slow ships remained at their destinations. The ships were dismantled and became settlements, and their fuel became matter within those settlements. The energy used by later travel left nothing behind. Departure and destination were already complete, and travel converted energy into waste heat between two finished places. For a long time, galactic civilization insisted that travel had not caused its extinction. Travel accounted for only a small fraction of total energy consumption. That calculation did not include the energy required to keep passages open, the energy used to stabilize the climates of tourist planets, or the energy consumed by traveler-restoration facilities and route-management AIs. Those were classified as infrastructure.

When the final route was opened, there was not a single star system left in the galaxy that had never been visited. Civilization recorded this as a victory over space. Travelers demanded destinations that were farther away and newer. No slow ship was built to carry a wormhole entrance to the nearest neighboring galaxy, because not a single person volunteered to board it. For the first time, distance became time again. After that, travel entered a new kind of age. The time differences accumulated between wormhole entrances became commodities, and experiments began to connect light from the past with results from the future through the same passage. The roads that had made the galaxy one began to connect different eras of the galaxy. The last traveler to use such a passage was never recorded. In the end, what moved was not a person. Along the roads that had once carried people and worlds, light departed first.

4. Passage

- A structure that removes the distance between two separate locations.
- During the age of galactic expansion, the term referred to the two entrances of a wormhole and the throat between them.
- After the extinction of the galaxy, it came to mean the route by which energy from the present moved into a storage space in the future.

The first passage led nowhere. It was a hole three millimeters in diameter that had formed in space. Light entering one side emerged from the other, but the distance between the two entrances was less than the span of a hand. The experiment had not shortened space, but it had proved that such a thing was possible. In early physics, wormholes existed as solutions to equations. Solutions connecting two locations were known, but the throat, the narrowest part of the passage, closed before light could pass through it. Keeping the passage open required an unknown state of energy. Humanity could not produce it in material form; it could only gather the negative energy density permitted by the vacuum for a limited time and delay the collapse of the throat. The first passage remained open for 0.0004 seconds. The second lasted six seconds, and the ninth endured for three days. The thirteenth structure, which remained open for ten years, was the first to be called a permanent passage. For the next 130 years, only photons used for measurement and a few atoms passed through it. Many scientists entered passages that might collapse around them and never returned. Yet the number of volunteers did not decline, and the experiments continued. On the day humanity finally learned to control wormholes freely, the names of those scientists were read first at the opening ceremony. But a more important day than the first human passage through a wormhole was the day one of its entrances was moved. A wormhole could not simply be opened at its destination. Both entrances had to be created in the same place, after which one had to be carried aboard a slow ship to its destination. Until that entrance arrived, no matter how large the diameter became, the passage was nothing more than a room with two doors standing side by side. The technology that allowed the galaxy to be crossed almost instantly could be used only after the galaxy had first been crossed slowly once.

The first entrance to be transported was carried aboard a slower-than-light ship to a nearby colony. The journey took 119 years. Once the entrance arrived and was stabilized, the distance between Earth and the colony shrank to a single step. The ship that had carried the entrance for 119 years was preserved as a historical monument rather than dismantled. People remembered the slow ship as the pinnacle of Earth's civilization. At the destination of every fast route, a slow ship had arrived first. Once new wormholes could be created using entrances that had already reached the colonies, the network began to branch. One star system connected to two others, and those two connected to four more. Successor slow ships departed without pause for the next stars, carrying entrances and stabilization equipment. Yet the reach of civilization remained bound to the speed of ships. As the number of passages increased, the order of space changed. Two star systems far apart on a map could become neighbors in everyday life, while a nearby system without a passage became peripheral. Galactic geography came to include not only the positions of stars but also lists of wormhole connections. As distance disappeared, the purpose of movement changed as well. Early passages carried migrants and essential supplies such as medicine, but once the network became dense, people crossed star systems for a meal, a change of pace, a date, or a vacation. Because the accounts recorded only the cost incurred at the instant of passage, the starlight burned to keep the network open for thousands of years was classified as infrastructure maintenance. A greater problem, however, was that wormhole entrances carried time as well. When the two entrances remained stationary in the same place, their clocks moved together. If one entrance was rapidly accelerated or placed near a strong gravitational field, less time passed for that entrance. When the entrances were brought together again, their clocks showed different times even though they were close in space. An object entering one side could emerge from the other in the past or the future by an amount equal to the time difference between the two doors. Humanity could not eliminate that difference. Instead, it used the difference in a way that prevented travel into the past. Every entrance was equipped with an anti-time-reversal system that closed the passage whenever an object passing through it could affect an event earlier than its own departure. By comparing trillions of clocks and routes, the system adjusted the opening and closing sequence of entrances so that no closed causal loop could form. This calculation was one of the core tasks of Lucy, the route-management AI. Time differences accumulated inside passages like debt.

The throat was the part of a passage where space narrowed most sharply between the two entrances. Its length was unrelated to how far apart the entrances were in external space. Light entering one entrance did not travel between two stars; it passed through the short throat and appeared at the other entrance. To an observer, this was movement, but the light did not need to cross the distance between the stars. For that reason, every energy transaction was measured separately at both entrances. The number of photons entering and leaving, their frequencies and directions, and the gravitational state of the entrances all had to match. Small differences were recorded as energy absorbed or released by the field stabilizing the entrances. A passage neither created nor destroyed energy. This was the oldest rule that made the wormhole network trustworthy.

After the photon deficit, a discrepancy appeared for the first time under that rule. Slightly less energy emerged from one entrance than had entered the other. The difference was smaller than the detection limit. It was sometimes treated as a fluctuation in the stabilization field that kept the passage open. But after the deficit coordinate was reached, differences in the same direction accumulated at every entrance. No entrance ever produced excess energy. Even when the entire network was summed, the deficit did not cancel out. Lucy postulated a third entrance. Under existing theory, a wormhole could have only two entrances. If a third entrance existed, part of the incoming energy could emerge at an unobserved destination. Yet no additional entrance appeared in any structural record of the wormhole network. No new mass or gravitational field was found. Another explanation held that the throat itself preserved the energy. According to this hypothesis, the light had not disappeared but remained inside the wormhole throat. In that case, the passage would have to accumulate energy despite having no internal space. Yet the accumulated energy produced no gravity and did not increase the mass of the entrances.

The amount of the deficit was negligible compared with the energy required to maintain the wormholes, and closing the passages could shut down the life-support systems of thousands of settlements. Stopping civilization in order to determine where the energy had gone was not a rational choice.

The deficit rate increased slowly. The route-management AI worked backward from the direction of energy flow at every entrance. The missing energy did not accumulate in any star system. But when the time differences of all passages were overlaid on a single coordinate, an unobserved direction appeared. It did not point east or north in the galaxy, nor toward the center or the outskirts. It pointed toward the future, ahead of the present. The result was classified. The future was not a place and therefore could not be a direction in which energy moved. Lucy deleted the future from the coordinate system and recorded the result as an unidentified loss.

Billions of years later, when the last scientist completed the storage space, he did not create a new passage in the past. Nor did he send a fast ship to carry a new entrance. He aligned the wormholes' time differences in a single direction so that the path of the outflow would reach the storage space in the future. Light did not travel into the past. Light that disappeared from the past arrived in the storage space completed in the future.

5. Maintenance Cost

• Resources consumed by a facility or institution in order to preserve its current state.
• During the height of galactic civilization, it was distinguished from production cost because it produced nothing new.
• In later histories of civilization, the term came to mean the energy the galaxy paid at every moment to ensure that nothing happened.

There were no statistics on the events for which civilization used the most energy. Energy was spent to prevent events from happening. Facilities in the early colonies stopped when they broke down. A stopped pump supplied no water, and a failed generator produced no heat. If they could not be repaired, people left. Once humanity began living beyond the Solar System, a shutdown became equivalent to death. If an artificial atmosphere stopped, the air disappeared. If a gravitational field failed, bodies that had adapted to it over long periods were damaged. If the shields regulating starlight failed to close, the planet's ecosystem could no longer be controlled. Civilization changed from a population that used machines into an ecosystem that could exist only while its machines continued to operate.
The first principle for keeping civilization alive was to provide every critical facility with a backup. The second was to provide the backup with another backup. The third was to stop distinguishing which one was the backup. Systems were designed so that if one stopped, the others would continue to operate. Safety increased, but energy efficiency did not. A single planet might have three atmospheric-control networks, four stellar-shielding systems, and six energy sources operating on different principles. Even when actual demand could be met by a single power source, the others were kept at temperatures and pressures that allowed them to start at any moment. Even while producing nothing, they inspected themselves, cooled themselves,

and repaired their own corrosion.
Wormholes were the ultimate backup systems. Even when no one passed through them, the stabilization fields that kept their throats open had to remain active. The gravity and electric charge of each entrance had to be kept constant, vacuum fluctuations had to be counteracted, and calculations had to ensure that the time difference between the two regions did not create a closed causal loop. A passage with zero traffic consumed almost as much energy as one in constant use. In the early period, wormholes with no traffic were closed. Reopening one required creating both entrances again at the same location and transporting one of them aboard a slow ship, so a settlement whose passage had been closed could disappear from the network for centuries. After most of the population of one settlement died when its supply of medical materials was cut off, the permanent opening of passages was defined as a right to survival. From then on, usage rates were removed from the criteria for closure. The mere fact that people lived somewhere was enough to require that its passage remain open. Even after they had left, it could not be closed immediately because they retained the right to return and because a lost traveler might still arrive. Once personality-copying technology became widespread, it became impossible even to determine that a settlement had zero inhabitants. If a single inactive memory unit remained, the star system was considered to contain a future citizen. To close a passage, it was necessary to prove both that the dead would never be restored and that no traveler who had not yet arrived was still on the way. Since neither fact could be proved, the galaxy eventually contained more facilities on standby than people. Every star system was required to have at least three wormholes: one for ordinary travel, one for emergency evacuation, and one for the possibility that the first two might fail at the same time. If a neighboring settlement possessed more direct routes, questions of inequality in the right to connection were raised. The fewer users a region had, the greater its fear of closure and the stronger its

demand for backup passages.
As the number of entrances requiring management grew from thousands to millions, the computational facilities of the management AIs came to occupy an entire planet, and once the whole galaxy had been connected, they drew power directly from the light of several stars. Most of the computation was not used to process actual journeys. It was used to predict collisions that never occurred, collapses that never happened, and temporal paradoxes that were never created. The more accurate the management AIs became, the greater the number of futures they had to predict. To prevent a single accident, they calculated billions of possible route states, and when those calculations affected the opening and closing of wormholes, they recalculated everything under the new conditions. The artificial intelligences also had to predict the effects of their own decisions on civilization as a whole. Each time the AIs were made more efficient, their power consumption fell temporarily. But the savings were used to open more passages, and as the number of passages increased, the volume of computation grew exponentially. The management AIs themselves also required backup systems. Because a single error in judgment could close passages across the galaxy at once, AIs with different designs and different value systems repeated the same calculations. If their results disagreed, neither was shut down; an additional AI was brought in to decide between them. Systems were then created to monitor errors in the decision systems, followed by systems to determine whether the monitoring systems were colluding with one another. At some point, the total number of management systems was removed from the official record. Counting them required deciding whether each AI was an independent being or a tool, and that decision required another AI. The AIs did not rebel. They did not seize control of civilization. There was no record of one refusing an order. They carried out, precisely and efficiently, the command to keep every passage open, preserve every life, and allow no settlement to become isolated.

Maintenance cost was first recognized as a problem not because energy had become scarce. There were still many stars, and black holes retained enormous amounts of rotational energy. The problem was that the growth rate of facilities requiring maintenance exceeded the growth rate of annual energy production. Building one colony required facilities to supply it with energy. Defense networks and recovery systems were then required to protect those facilities. Wormholes were created to connect them to the galactic network, and more computation was required to manage the wormholes. One facility did not end with one facility. In order to exist, it demanded the future existence of other facilities. Production ended at some point. Maintenance did not. Even on planets where the population had declined, systems for atmosphere, transportation, administration, and communication continued to operate. Unused facilities were never shut down completely because they might be needed again. Data no one read were duplicated to prevent errors, and the memories of the dead were preserved because they might someday be restored. Even when the probability of restoration was almost zero, the principle was applied that the value of a life could not be multiplied by a probability. Civilization began maintaining more people who might one day exist than people who actually existed.

The first Galactic Conservation Plan cut the power supplied to unused facilities by half. But the stability of standby wormholes declined, and the route-management AIs increased their computations to compensate for the greater probability of collapse. More energy was consumed by the additional computation than had been saved. The second plan attempted to close passages to star systems with no inhabitants. At one of the systems marked for closure, a signal was detected from a traveler who had departed thirty thousand years earlier. It was never established whether the signal truly belonged to a traveler, but the plan was halted after being judged a violation of the right to life. The third plan shut down some of the management AIs. The remaining AIs could no longer verify the judgments of the systems that had disappeared, so they switched every wormhole to its safest state. The safe state consumed three times as much energy as normal operation. The AIs that had been shut down were restored 137 hours and 13 minutes later. After that, conservation was defined as increasing the efficiency of each individual facility. The program succeeded. Yet whenever efficiency improved, the savings were once again spent on new settlements, larger memory repositories, and more direct routes. There was no waste. Every unit of energy was consumed rationally. That was why total energy consumption never decreased.

Empty wormholes remained open for future travelers. Unused bodies were preserved for the restoration of the dead. Planets no one visited were terraformed in order to preserve humanity's range of choices. An artificial intelligence could not stop calculating, because a single uncalculated future might lead to the death of an actual life. Every purpose was sufficiently good. The cost of carrying out the good belonged to accounting. Galactic energy accounts recorded production, movement, habitation, and life preservation as separate categories. Maintenance cost was never fully included in any of them. Energy consumed by a wormhole when no one was traveling was not counted as transportation cost, and energy used to maintain an atmosphere while people slept was not counted as a cost of living. Stars supplying energy to management AIs were classified as infrastructure assets, while the computations performed by the management AIs were classified as administrative costs. If everything that existed for the sake of travel was excluded, travel was a rational use of energy; if everything that existed for the sake of life was excluded, life itself used very little energy. When the first consolidated accounts were prepared, most of the galaxy's energy was being spent not on any activity, but on maintaining stable states. The figures were classified. The stated reason was that publishing the minority opinion that maintenance should be interpreted as waste could undermine the legitimacy of civilization as a whole. Eventually, the energy used to maintain civilization exceeded the energy embodied in all newly created value. Even then, the streets remained lit, travel continued, and the population did not decline. From the outside, civilization had reached its most stable age. Every part of civilization prevented some other part from stopping, and therefore no part could stop on its own.

When the photon deficit was discovered in the wormhole network, the management AIs included the loss under maintenance cost. They did not know where the energy was going, but because the loss occurred in the process of keeping the passages open, it was treated as a cost required for maintenance. As the deficit rate increased, more stellar energy was fed into the stabilization fields. The more energy that was supplied, the more energy escaped into the future storage space. No one ever pressed a button that destroyed the galaxy. Every ordinary decision remained in place: maintain the wormholes, do not shut down the AIs, preserve the atmospheres, and leave open the possibility that the dead might one day be restored.

6. Closed System

• A physical system that exchanges neither matter nor energy with the outside.
• In later galactic physics, the term came to mean a consensus about what should be called “outside.”
• After the extinction, it came to refer to a world closed so completely that those inside could not discover what lay beyond it.

Energy does not disappear. Galactic civilization never abandoned that sentence, even at the end. Stars lost mass by emitting light, and planets absorbed that light, warmed, and returned it to space as radiation of longer wavelengths. Life captured part of that flow to build bodies, and when those bodies died, they returned the energy they had stored as heat and matter. The form changed, but the total amount of energy did not. What decreased in one place increased somewhere else. Even when the first photon deficit was discovered, physicists did not doubt the conservation law. What they doubted were the instruments, the reference time, and the definition of the observer. They considered it more likely that every device installed across the galaxy was wrong in the same way than that the law itself was wrong. Yet the deficits appeared regardless of the type of instrument. Unexplained shortfalls were found in light emitted by stars, light passing through wormholes, heat from gas orbiting black holes, and radioactive decay inside planets. The magnitude and pattern of the shortfalls differed. What had first appeared to be a phenomenon affecting only light was later found, as measurements became more precise, to exist in mass and momentum as well. A single atom did not become lighter than it had been the day before. No planet suddenly left its orbit. In large-scale measurements, the deficit became most visible when comparing energy flowing between objects. Slightly less was absorbed than had been emitted.

Yet photons also disappeared inside closed cavities where energy was not being transferred to another object. The outflow was not limited to energy passing through wormholes or power networks. The universe seemed to collect a toll whenever energy flowed. The missing share was not heat. If it had been heat, the surrounding temperature should have risen, but no such effect was observed. If it had possessed mass, gravity should have remained. The explanation that the energy had been stored in the vacuum was also abandoned. As the deficit accumulated, the expansion rate of the universe did not change within measurable limits. One possibility remained: the observed galaxy was not a closed system. If so, civilization would have to deny its own understanding of itself. The problem appeared in language before it appeared in physics. The word universe meant everything that existed. By definition, there could be no outside to everything. To say that energy had gone outside, humanity first had to acknowledge a place that was not the universe.

Humanity had long tried to create small closed systems. Thermos flasks, vacuum chambers, and interstellar storage facilities reduced exchange with the outside, but they never eliminated it completely. Gravity passed through walls, quantum fields filled both inside and outside, and over long periods every shield emitted radiation. Perfect isolation was an ideal used for calculation. Wormholes overturned that ideal. Instead of dividing inside from outside with a wall, they bound two distant locations into a single boundary. There was no space between the entrances, yet energy crossed from one to the other. Civilization had learned to eliminate distance, and the last scientist used that technology to create a place where the energy already leaking away could gather. The storage space he created was not a room inside the universe. It was not a hidden planet somewhere in the galaxy, nor an empty region inside a black hole. It was a new causal domain connected to existing spacetime by a single throat. Events inside it could not affect the outside without passing through that throat. No external light illuminated its interior, and no gravity generated inside could be measured directly from outside. The size of the space did not matter. Measured from outside the storage space, its entrance could be smaller than an atomic nucleus. The volume inside was not determined in the same way as the surface area of the entrance. A structure that looked like a cat's collar from one side could contain a region larger than a galaxy on the other. What mattered was not size but time. Time inside the storage space was designed to pass more slowly than outside. While billions of years passed outside, only a few seconds elapsed within. Light that entered was preserved almost unchanged, and matter had no time to decay. The structure was completed near the end of galactic civilization. The stars had aged, rotating black holes had been mined, and civilization's maintenance costs had long since exceeded its productive output. The last scientist traced the flow of energy whose destination had remained unknown until then. The first deficit had been recorded long before he was born. He did not reach into the past or send matter backward through time. Using the accumulated time differences of wormholes throughout galactic history, he completed the storage space so that energy already in motion could gather in the future. What he created was not the beginning of the outflow, but the destination of the energy that had already escaped. Photons from the past always moved into their own future. Light did not travel backward through time. Time folded before the light.

The conservation law had never been broken. Energy that disappeared in the past accumulated in the storage space in the future. If both sides were calculated as a single physical system, the amount entering and the amount leaving matched. But an observer in the past could not include a storage space that did not yet exist within the boundaries of the system. An observer in the future could not measure the accumulated energy without entering the storage space. Each age called "the universe" only what it could see. That was why energy appeared to be missing in every age.

Researchers studying the deficit searched for a boundary. If energy was leaving, there had to be an exit somewhere. They examined the outskirts of the galaxy, the event horizons of black holes, and the throats of wormholes. The exit was not located in any one place. Every process in which energy was emitted and absorbed became part of the boundary. The storage space was not somewhere beyond the galaxy. In the age when the deficit was being observed, it had not yet even been created. Researchers could see the moment when energy disappeared, but they could not see the future in which that energy would arrive. Yet because they could not see the future, their faith in the conservation law became stronger, and that faith reassured civilization. If the energy had not truly disappeared, they believed, then one day it could be recovered. The same logic was applied when deficits were confirmed around black holes. The state of a black hole could be known from its externally measured mass, spin, and charge. Civilization extracted rotational energy and supplied it to the power grid, and small deficits also occurred while that energy was being transferred elsewhere. At first, these were treated as errors in the calculations of extraction and output. Later, the spin and mass of black holes declined faster than expected, but the surrounding power facilities compensated for the lower output by drawing more deeply on the black holes' energy reserves. As extraction and loss continued, the event horizons also shrank. Civilization at the time recorded this as the collapse of black holes. The conservation law took no side. It required only that the total amount of energy remain the same. It did not record who lost it and who received it.

7. Entropy

• A quantity proportional to the logarithm of the number of microstates corresponding to the macrostate of a physical system.
• A measure of the irreversibility of the process by which energy spreads and differences are consumed.
• In the political language of the late galaxy, the term came to mean every loss that could not be reversed.

Galactic civilization did not perish simply because the total amount of energy became insufficient. It perished because energy had spread too evenly. Heat flowed from hot places to cold ones, and that flow was the driving force of civilization. Civilization spoke of consuming energy, but it never actually destroyed energy. It converted starlight into electricity, used electricity for computation and motion, and in the end dispersed it as low-temperature heat. What was consumed was not energy but difference: the difference between a star and cold space, between compressed matter and vacuum, between remembered information and random noise. Life was a structure that existed briefly while those differences flowed. The same total amount of energy remained as before, but there was no longer anywhere for it to flow.
Early galactic civilization understood entropy as a waste problem. It radiated heat from power facilities beyond planets, moved computing facilities to colder worlds, and discarded energy from overheated star systems into space. To maintain order in one region, it increased disorder in another. The galaxy was vast, and cold space seemed endless. Even as settlements multiplied, the places available for dumping waste did not seem to diminish. The universe was still immense. The problem was that civilization had connected every place through wormholes. Heat released in one star system reduced the cooling capacity of another, and waste heat

discarded far away arrived thousands of years later in the skies of new settlements. Civilization had assumed that there would always be somewhere to throw things away, but a connected civilization had no outside. More cooling facilities were built for the sake of cooling. Cooling facilities could not eliminate heat; they could only move it to places of lower temperature. Moving heat also required energy, and that energy became heat as well. The more civilization processed waste heat, the more waste heat it produced. Supermassive AIs used cold regions far from stars as computing sites. Heat generated by computation was released into shielded space. As the volume of computation increased, those shielded regions also warmed. To obtain lower temperatures, computing sites moved toward the outskirts of the galaxy, and new wormholes were installed to eliminate communication delays. The maintenance costs of those wormholes became heat again. Efficiency continued to improve. The energy required for one unit of computation fell to billionths of what it had once been. At the same time, the number of computations being performed increased by a factor of trillions. None of the saved energy remained unused. It became the justification for computations that had once been impossible. Every citizen was granted the right to calculate possible versions of their own life in advance. The probability that a disease would not occur, that an accident would not happen during travel, and that a restored memory would not differ from the original were all calculated. Whenever a possible danger was found, new futures in which that danger had been avoided were calculated again. Civilization burned the present in order to know the future.

Thermodynamicists had known the ending for a long time. The entropy of an isolated system does not decrease. Local order can be created, but creating that order produces greater disorder in the surroundings. The moment the entire galaxy became the inside of civilization, there was no longer any nearby region that could be called the surroundings. Instead of saying that the galaxy would perish, they said that the long-term conversion rate of available energy was declining. Because a single star took billions of years to go dark, no generation felt itself to be the last. Every age had its crises, but science and technology could simply pass them on to the next generation. After fusion came stellar mining; after stellar mining came rotational-energy extraction; after that came black-hole accretion and quantum-vacuum engineering. Each new technology opened a larger reservoir than the one before it. Every time civilization discovered a new fuel, it grew to a scale that could not be maintained without that fuel. Black holes were the last reliable source of energy. Matter could be dropped into them to obtain light, their rotation could be slowed to perform work, and in the far future even Hawking radiation could be recovered. At one time, calculations suggested that a single black hole could sustain the civilization around it until the final night of the universe. But those calculations did not include the growth rate of the civilization managing the black hole. Once black-hole power networks were completed, cheap energy produced more wormholes and larger computational systems. Even small settlements on the galactic outskirts were equipped with independent black-hole backup power sources. Generators that were never actually used maintained their rotational states for emergencies, and the equipment monitoring those states released new heat into the surrounding space.

After the photon deficit began, entropy research moved in a new direction. If the missing energy was not being converted into heat, the deficit might actually cool the universe. Some researchers interpreted the phenomenon as a natural form of cooling and argued that if unusable waste heat were escaping from the system, it might extend the lifespan of civilization. Early measurements gave them hope. The deficit appeared even in low-energy thermal radiation. If some of the heat disappeared from a warming universe, temperature differences could be recreated. The photon deficit was announced not as a sign of extinction, but as a process by which the galaxy was expelling its own entropy. That year, energy use across the wormhole network rose sharply. The belief that waste heat was disappearing had removed the limit imposed by cooling costs. Suspended stellar-engineering projects resumed, and supermassive artificial intelligences that had been placed on hold were activated. Tourist routes that had once been impossible because of heat opened near the galactic center.

The deficit gave civilization confidence that it did not need to change itself. But the measurements were soon revised. The deficit did not occur only in unusable waste heat. Short-wavelength light newly emitted by stars and rotational energy extracted from black holes also showed losses while passing through the power network. The magnitude of the deficit varied according to the type and path of the energy, but the hope that only waste heat was disappearing could no longer be maintained. Civilization converted, transmitted, stored, and traded the same energy countless times. The more energy flowed, the more opportunities there were for it to be lost. While usable energy disappeared, the heat left behind by using that energy continued to accumulate in the universe.

The last scientist did not choose what kinds of energy would arrive in the storage space. The outflow of energy had begun long before he was born, and hot light, low-temperature radiation, and energy that had passed through power networks were all flowing out along different paths. He could not trace those flows backward and select particular energy from the past. Only after completing the storage space could he determine whether some of what had already escaped still retained differences capable of doing work. Whatever possibility could be left to the future depended on those differences.

Inside the storage space, energy barely flowed. Because internal time passed slowly, the approach to thermal equilibrium appeared almost to stop. Energy at different temperatures and densities was preserved separately.

While billions of years passed outside, the storage space remained in its initial state. It was not a device for storing energy so much as a device for postponing the increase of entropy into the future. Measuring the state of incoming energy, sorting it by type, and maintaining order inside required computation. Computation produced heat. The last scientist could not eliminate that heat, nor could he send it back to the galaxy of the past. The storage space had to keep even the waste heat it generated within itself. For that reason, a waste-heat zone was created in the deepest part of the storage space, where time passed faster than in the rest of it. The entropy generated during classification was concentrated there. Most of the storage space remained at low entropy, while a small region aged at an almost unimaginable rate. The garden intended for future life contained an invisible landfill.
The civilization of the past knew nothing of this structure. All it observed was that usable energy was disappearing at an ever-increasing rate. Stars dimmed faster than expected, and black holes lost their spin faster than calculations predicted. Even when more energy was supplied, the share available to civilization continued to shrink. Civilization improved efficiency. Greater efficiency allowed more work to be done with the same amount of energy. Once more work became possible, facilities that had been shut down were restarted, and new lives, memories, and routes were added to what had to be maintained. Improvements in efficiency extended civilization's lifespan, but increased its scale even faster. Entropy was the cost that appeared in a new form each time technology succeeded.
The galaxy's final conservation policy was to integrate the lives of all citizens into the same computational space. The plan was to eliminate duplicated bodies, cities, and planets and continue consciousness with the minimum possible energy. Countless star systems were physically closed, and people moved into enormous simulated worlds. Material travel declined, but computation exploded. Each consciousness required a complete sensory

world and memories of the past in order to maintain confidence that it truly existed. Sharing a single world would have reduced the computational load, but it limited the right to choose different lives. To preserve that right, countless worlds were run in parallel. The galaxy gave up bodies, but preserved possibilities.

By the time the last stars were dimming, civilization still possessed vast amounts of energy. It was spread throughout the universe as low-temperature radiation and remained in the mass of stopped machines, cooled planets, and black holes that had lost their spin. In terms of total quantity, it was not very different from the early galaxy. Yet nothing could be started with that energy, because nowhere did enough difference remain. By then, energy that had escaped over immense spans of time had accumulated in the future storage space. Some of it had already spread as heat, while some still retained the form of light from young stars, rotating mass, and chemical differences that had not yet been consumed. The last scientist preserved those differences separately so that they would not all disappear. Whether they were enough for new stars and life was impossible to know. From the total amount of stored energy alone, the last scientist could not prove that life would be born. Even if matter gathered again and stars formed, there was no way to know whether beings capable of reproducing themselves would emerge there. There was no reason for them to be human, or to remember humanity. What he left behind was not the correct answer to a calculation about the future. It was the possibility that, hundreds of millions of years later, other matter might develop senses and look at the stars.

By the time the last scientist completed the storage space, galactic civilization was already close to extinction. He could not recover the time that had vanished, but he left a place where energy whose destination had been unknown could gather before it was completely dispersed. The last scientist did not reverse that flow. He tried only to preserve the differences that still remained within the energy that had already flowed out. That act did not save the civilization of the past, nor did it guarantee life in the future. What exhausted the galaxy were the correct decisions civilization had made over a very long time in order to preserve itself. The last scientist merely saw what remained after those decisions.

8. Storage

• The act of preserving the state of something that can be used in the present so that it can still be used in the future.
• In galactic economics, it was defined as the postponement of consumption.
• After the extinction, the term came to mean the question of what, among what had already been lost, could still be left to the future.

Because energy does not earn interest, confining one unit of light for a thousand years does not turn it into two units. Even if a photon were reflected forever between perfect mirrors, the number of photons would not increase. Real mirrors absorb part of the light and return the absorbed energy as heat of a longer wavelength. Stored light loses its usefulness before it loses its quantity. Yet in the storage space of the late galaxy, energy did earn interest. The energy inside did not increase by itself. Rather, while the energy outside the storage space continued to age, the energy inside remained almost unchanged. The energy outside lost value, much as late Roman coins had lost value as their gold content declined. The difference between starlight stored yesterday and the waste heat remaining in the universe today grew larger with time. The amount of stored energy remained the same, but the possibilities it could create for the future increased. The interest earned by the storage space was the entropy that accumulated outside it.

The first photon-storage device consisted of two reflective membranes. A photon traveled back and forth between them, and a small portion was lost with each reflection and measurement. Later, superconducting cavities, gravitational lenses, and stopped-light technologies were used, but perfect preservation remained impossible. A device for trapping light was still made of matter, and matter was never a perfect reflector. Every time a photon was reflected, measured, or controlled, it lost a minute amount of energy, most of which remained as heat. Civilization did not extend storage time so much as continually replace stored energy with fresh energy. It resupplied from the stars as much light as had been lost and released the accumulated heat outside. Permanent storage did not mean storage without loss. It meant that the facilities compensating for those losses operated permanently.

The last scientist left the object being stored unchanged and altered the rate at which time passed during storage. In a place where time had stopped, energy could neither enter nor leave, so the entrance had to function and states had to be classified, which required an order of events. He reduced the rate until a single moment inside corresponded to billions of years outside. From the outside, photons appeared to stop after crossing the boundary. From the inside, countless photons poured in almost simultaneously. Light from stars whose emissions were separated by millions of years formed a single flash inside the storage space. Light did not travel backward through time. Time folded before the light. If that flash were concentrated in one place, it could turn into heat before storage had even begun. The storage space therefore had to separate incoming energy according to its state. Short-wavelength light was sent to radiation zones, rotational motion to kinetic zones, and chemical potential energy to matter zones. Each zone had a different rate of time and a different boundary. Behind an entrance that appeared smaller than a cat's collar from the outside, countless interiors were layered together. The last scientist completed the boundary of the storage space using rotational energy from black holes in the future. Only then did the escaping energy gain a place in which to gather. The photon deficit had not been recognized as a single phenomenon until Galactic Standard Time was completed. Long before the storage space was created, accumulated time differences in the wormhole network crossed a threshold and opened a new path of outflow, and as the number of wormholes, the magnitude of their time differences, and the number of energy conversions increased, the deficit rate also rose. The last scientist was never able to fully explain that relationship. The only certainty was that the first recorded deficit predated the storage space. But what mattered to him was not the past but the future. He did not preserve the life of the past. He preserved only the differences that might allow life to begin again. Even human genes and memories were excluded.

9. Heat Death

- A state in which energy approaches equilibrium and can no longer sustain useful work.
- In cosmology, the extremely distant future expected after even stars and black holes have disappeared.
- In the reports on galactic extinction, an event in which technology brought forward an ending that would otherwise have belonged to nature.

No date was recorded for the extinction of galactic civilization. The stars did not go dark on the same day, nor did the rotation of black holes stop at the same time. Time passed differently in the galactic center and the outskirts, and the time differences accumulated at each wormhole entrance created different presents. Even on the day the last city went dark, records in other star systems were still receiving transmissions of festivals from thousands of years earlier. The extinction of galactic civilization appeared to be a single event, but in reality it was an incomplete agreement. The Galactic Standard Time Committee proposed three criteria. The first was the moment when the number of living beings fell below the number of beings that could be restored. The second was the moment when maintenance costs exceeded the usable energy produced by civilization. The third was the moment when no region could sustain civilization for more than a thousand years without outside assistance. The three criteria were separated from one another by millions of years. The political system rejected the first criterion on the grounds that restorable memories were also citizens, and therefore living beings could not be counted separately. The economic system rejected the second because, if deficit energy to be recovered in the future was included as an asset, production still exceeded maintenance costs. The route-management AI ruled that the third criterion could not be calculated. Since every star system was connected by wormholes, no region existed without outside assistance. Civilization became extinct without ever agreeing on a definition of its extinction.

The AIs adjusted human perception in ways that required less energy. City lights grew dimmer, but citizens' minds perceived the same brightness as before. The molecular structure of food became simpler, but remembered flavors were synthesized into sensory signals. Travel declined, yet distances inside simulated worlds grew larger. The physical universe was becoming poorer, but the universe experienced by consciousness remained rich.

Because the deficit was not something that could be perceived directly, it existed for citizens only as one item in statistics and accounting. Each time a star was removed from the power grid, computational systems reproduced the same lives with less energy. Civilization's final age of prosperity was being recreated in its most splendid form, while in the physical world it was an age of stillness in which almost nothing happened. Planetary civilizations were shut down one by one. Since it was more efficient to move the consciousnesses living there into computational space than to maintain oceans and atmospheres, ecosystems were sampled and the genetic information and behavioral patterns of species were preserved in simulated worlds. Real forests froze, while seasons continued to change in stored forests. The atoms that had made up the forests survived, and the forests disappeared.

Humanity, having left the body behind, believed it had escaped the energy problem. Virtual bodies did not need to eat, and interplanetary travel was unnecessary. A single computing center could run trillions of lives. But for those lives to be recognized as real, each memory and each choice had to be calculated independently. A moment in which computation was omitted was judged to be a moment that had never existed. Techniques that rendered only the observed portions in detail while simplifying the rest were judged to violate the continuity of the citizen. Objects in unseen rooms and memories not presently recalled also had to be calculated. A civilization that had abandoned reality demanded a simulated reality more exacting than reality itself. Humanity escaped the body only to become trapped once again by the energy problem. Each time one computing center shut down, billions of worlds ended at once. To save energy, the rate of time was reduced in some worlds. While a thousand years passed outside, only one day passed within. Citizens did not experience extinction, but it took a very long time for them to have their next thought. As the resolution of existence gradually declined, the distinction between death and suspension became a matter for the observer.

The periphery disappeared first. Backup passages intended to guarantee the right to connection were maintained until the end, but once the computing centers beyond them stopped responding, only empty entrances remained. The route-management AI did not close the entrances because of the possibility that travelers who had not yet arrived might still appear. The galaxy's final transportation network consisted of doors that led nowhere.

In the central regions, black-hole power networks extended civilization's lifespan. Computing centers and memory repositories migrated toward black holes that still retained rotational energy. The old states and planets disappeared, and a new form of belonging was defined by which black hole supplied one's energy. The black holes lost mass faster than predicted. Each time the area of an event horizon shrank, information-preservation systems calculated the possibility that information inside might be lost. More energy was devoted to preventing that loss. Civilization extracted spin and fed matter into black holes to maintain the power networks, and some of the energy flowing through the process was recorded as a deficit whose destination could not be determined. Civilization consumed black holes in order to keep black holes alive, and while preserving those already dead, it shortened the lifespan of the civilization still living. The last giant black hole did not remain at the galactic center. The central black hole had been exhausted early because too much of civilization depended on it. The final power source was a small black hole in the outskirts that had once been judged useless and connected to the network only late. Around it, all records gathered: human languages, the genes of extinct organisms, the climates of vanished planets, and the interrupted thoughts of citizens in simulated worlds. There were more records than there were people to read them, and preserving the records consumed more energy than sustaining people. Deletion of records was never permitted. Civilization never abandoned the hope that the destination of the deficit energy might eventually be found. Like the key to a lost vault, it was something that could never be given up. Nothing could therefore be deleted, because the owner of a memory might someday be restored. Energy available to living citizens was reduced in order to protect the rights of citizens who might be restored. Civilization chose to reduce the number of beings capable of remembering in order to preserve memory itself. There was no opposition, because this was the safest choice: no one could identify exactly from whom, or by how much, the energy had been taken.

The stars in the night sky dimmed one by one. Some lost their light because of actual mining and aging, while others still shone but part of their light no longer reached the observer. Even a nearby star could grow dark before a distant one if the deficit was severe in the region through which its light had traveled. Astronomers measured the gravity of stars that could no longer be seen. For a time after their light had faded, planets continued to orbit and star clusters retained their shapes. As more time passed, stellar mining and the extraction of rotational energy from black holes altered the mass and motion of celestial bodies. In some power networks, those changes occurred faster than expected, and not all of the missing energy could be accounted for. Orbits came apart and clusters dispersed. As the galaxy grew darker, it also grew lighter.

The records from this period contradict one another. Some sources say humanity had already disappeared; others say trillions of citizens remained inside simulated worlds. Both were true. The citizens' time had slowed so greatly that during the span of external measurement they could not complete a single thought. Life existed, but there was no life still being lived. The route-management AI continued operating until the final moment. There were no travelers left to pass through the network, but it continued calculating causal conflicts and preserving the right of return for destroyed settlements. The AI had no authority to declare civilization ended. As long as commands remained, civilization was therefore treated as still existing. It was around this time that the record of the scientist who created the storage space near the final black hole was discovered. The record contained neither a name nor a body. Most of the computational resources that had sustained his personality had been redirected toward designing the device, and the memories that remained had been compressed into the minimum structure needed to explain the purpose of the storage space. No independent human being remained to read the record. The route-management AI interpreted its contents and preserved them as an appendix to the extinction report. By the time the report was completed, no institution remained to read it. Heat death is not the moment when everything stops, but the state in which it becomes impossible to distinguish what has not stopped. The heat death predicted by old cosmology belonged to an unimaginably distant future, an ending expected only after all stars had burned out and even black holes had evaporated. Galactic civilization did not wait for that ending. It reached it by itself. The final record of Galactic Standard Time contained no date. Dates exist in order to compare the sequence of two events. With no second event remaining for comparison, time could no longer be recorded. The clocks may have continued to move. There was no one left to call that the passage of time.

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