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THE FAR FUTURE

Little science fiction deals with truly grand perspectives in time. Most stories and novels envision people much like ourselves, immersed in cultures that quite resemble ours, and inhabiting worlds which are foreseeable extensions of the places we now know.

Such landscapes are, of course, easier to envision, more comfortable to the reader, and simpler for the writer; one can simply mention everyday objects and let them set the interior stage of the reader's mind.

Yet some of our field's greatest works concern vast perspectives. Most of Olaf Stapledon's novels (Star Maker, Last And First Men) are set against such immense backdrops. Arthur C. Clarke's Against the Fall of Night opens over a billion years in our future. These works have remained in print many decades, partly because they are rare attempts to "look long" -- to see ourselves against the scale of evolution itself.

Indeed, H.G. Wells wrote The Time Machine in part as a reaction to the Darwinian ideas which had swept the intellectual world of comfortable England. He conflated evolution with a Marxist imagery of racial class separation, notions that could only play out on the scale of millions of years. His doomed crab scuttling on a reddened beach was the first great image of the far future.

Similarly, Stapledon and Clarke wrote in the dawn of modern cosmology, shortly after Hubble's discovery of universal expansion implied a startlingly large age of the universe. Cosmologists believed this to be about two billion years then. From better measurements, we now think it to be at least five times that. In any case, it was so enormous a time that pretensions of human importance seemed grotesque. We have been around less than a thousandth of the universe's age. Much has gone before us, and even more will follow.

In recent decades there have been conspicuously few attempts to approach such perspectives in literature. This is curious, for such dimensions afford sweeping vistas, genuine awe. Probably most writers find the severe demands too daunting. One must understand biological evolution, the physical sciences, and much else -- all the while shaping a moving human story, which may not even involve humans as we now know them. Yet there is a continuing audience for such towering perspectives.

"Thinking long" means "thinking big." Fiction typically focuses on the local and personal, gaining its power by unities of time and setting. Fashioning intense stories against huge backdrops is difficult. And humans are special and idiosyncratic, while the sweep of time is broad, general and uncaring.

We are tied to time, immense stretches of it. Our DNA differs from that of chimps by only 1.6 percent; we lords of creation are but a hair's breadth from the jungle. We are the third variety of chimp, and a zoologist from Alpha Centauri would classify us without hesitation along with the common chimp of tropical Africa and the pygmy chimp of Zaire. Most of that 1.6 percent may well be junk, too, of no genetic importance, so the significant differences are even smaller.

We carry genetic baggage from far back in lost time. We diverged genetically from the Old World monkeys about 30 million years ago, from gorillas about ten million years ago, and from the other chimps about seven million years ago. Only 40 thousand years ago did we wondrous creatures appear -- meaning our present form, which differs in shape and style greatly from our ancestor Neanderthals. We roved further, made finer tools, and when we moved into Neanderthal territory, the outcome was clear; within a short while, no more Neanderthals.

No other large animal is native to all continents and breeds in all habitats, from rainforests to deserts to the poles. Among our unique abilities which we proudly believe led to our success, we seldom credit our propensity to kill each other, and to destroy our environment--yet there are evolutionary arguments that these were valuable to us once, leading to pruning of our genes and ready use of resources.

These same traits now threaten our existence. They also imply that, if we last into the far future, those deep elements in us will make for high drama, rueful laughter, triumph and tragedy.

While we have surely been shaped by our environment, our escape from bondage to our natural world is the great theme of civilization. How will this play out on the immense scale of many millennia? The environment will surely change, both locally on the surface of the Earth, and among the heavens. We shall change with it.

We shall probably meet competition from other worlds, and may fall from competition to a Darwinian doom. We could erect immense empires and play Godlike games with vast populations. And surely we could tinker with the universe in ingenious ways, the inquisitive chimpanzee wrestling whole worlds to suit his desires. Once we gain great powers, we can confront challenges undreamed of by Darwin. The universe as a whole is our ultimate opponent.

In the very long run, the astrologers may turn out to be right: our fates may be determined by the stars. For they are doomed.

Stars are immense reservoirs of energy, dissipating their energy stores into light as quickly as their bulk allows. Our own star is 4.3 billion years old, almost halfway through its eleven billion year life span. After that, it shall begin to burn heavier and heavier elements at its core, growing hotter. Its atmospheric envelope of already incandescent gas shall heat and swell. From a mild-mannered, yellow-white star it shall bloat into a reddened giant, swallowing first Mercury, then Venus, then Earth and perhaps Mars.

H.G. Wells foresaw in The Time Machine a dim sun, with a giant crablike thing scuttling across a barren beach. While evocative, this isn't what astrophysics now tells us. But as imagery, it remains a striking reflection upon the deep problem that the far future holds -- the eventual meaning of human action.

About 4.5 billion years from now, our sun will rage a hundred times brighter. Half a billion years further on, it will be between 500 and a thousand times more luminous, and seventy percent larger in radius. The Earth's temperature depends only slowly on the sun's luminosity (varying as the one fourth root), so by then our crust will roast at about 1400 degrees Kelvin, room temperature is 300 Kelvin. The oceans and air will have boiled away, leaving barren plains beneath an angry sun which covers thirty-five degrees of the sky.

What might humanity -- however transformed by natural selection, or by its own hand -- do to save itself? Sitting further from the fire might work. Temperature drops inversely with the square of distance, so Jupiter will be cooler by a factor of 2.3, Saturn by 3.1. But for a sun 500 times more luminous than now, the Jovian moons will still be 600 degrees Kelvin (K), and Saturn's about 450 K. Uranus might work, 4.4 times cooler, a warm but reasonable 320 K. Neptune will be a brisk 255 K. What strange lives could transpire in the warmed, deep atmospheres of those gas giants?

Still, such havens will not last. When the sun begins helium burning in earnest it will fall in luminosity, and Uranus will become a chilly 200 K. Moving inward to Saturn would work, for it will then be at 300 K, balmy shirtsleeve weather -- if we have arms by then.

The bumpy slide downhill for our star will see the sun's luminosity fall to merely a hundred times the present value, when helium burning begins, and the Earth will simmer at 900 K. After another fifty million years --how loftily astrophysicists can toss off these immensities! -- as further reactions alter in the sun's core, it will swell into a red giant again. It will blow off its outer layers, unmasking the dense, brilliant core that will evolve into a white dwarf. Earth will be seared by the torrent of escaping gas, and bathed in piercing ultraviolet light. The white-hot core will then cool slowly.

As the sun eventually simmers down, it will sink to a hundredth of its present luminosity. Then even Mercury will be a frigid 160 K, and Earth will be a frozen corpse at 100 K. The solar system, once a grand stage, will be a black relic beside a guttering campfire.

To avoid this fate, intelligent life can tinker -- at least for a while -- with stellar burning. Our star will get into trouble because it will eventually pollute its core with the heavier elements that come from burning hydrogen. In a complex cycle, hydrogen fuses and leaves assorted helium, lithium, carbon and other elements. With all its hydrogen burned up at its core, where pressures and temperatures are highest, the sun will begin fusing helium. This takes higher temperatures, Which the star attains by compressing under gravity. Soon the helium runs out. The next heavier element fuses. Carbon bums until the star enters a complex, unstable regime leading to swelling. (For other stars than ours, there could even be explosions (supernovas) if its mass is great enough.)

To stave off this fate, a cosmic engineer need only note that at least ninety percent of the hydrogen in the star is still unburned, when the cycle turns in desperation to fusing helium. The star's oven lies at the core, and hydrogen is too light to sink down into it.

Envision a great spoon which can stir the elements in a star, mixing hydrogen into the nuclear ash at the core. The star could then return to its calmer, hydrogen-fusing reaction.

No spoon of matter could possibly survive the immense temperatures there, of course. But magnetic fields can move mass through their rubbery pressures. The sun's surface displays this, with its magnetic arches and loops which stretch for thousands of kilometers, tightly clasping hot plasma into tubes and strands.

If a huge magnetic paddle could reach down into the sun's core and stir it, the solar life span could extend to perhaps a hundred billion years. To do this requires immense currents, circulating over coils larger than the sun itself.

What "wires" could support such currents, and what battery would drive them? Such cosmic engineering is beyond our practical comprehension, but it violates no physical laws. Perhaps, with five billion years to plan, we can figure a way to do it. In return, we would extend the lifetime of our planet tenfold.

To fully use this extended stellar lifetime, we would need strategies for capturing more sunlight than a planet can. Freeman Dyson envisioned breaking up worlds into small asteroids, each orbiting its star in a shell of many billions of small worldlets. These could in principle capture nearly all the sunlight. We could conceivably do this to the Earth, then the rest of the planets.

Of course, the environmental impact report for such engineering would be rather hefty. This raises the entire problem of what happens to the Earth while all these stellar agonies go on. Even if we insure a mild, sunny climate, there are long term troubles with our atmosphere.

Current thinking holds that the big long term problem we face is loss of carbon dioxide from our air. This gas, the food of the plants, gets locked up in rocks. Photosynthetic organisms down at the very base of the food chain extract carbon from air, cutting the life chain.

We might fix this by bioengineering organisms that return carbon dioxide. Then we would need to worry about the slow brightening of our sun, which would make our surface temperature about 80 degrees Centigrade in 1.5 billion years. Compensating for this by increasing our cloud cover, say, would work for a while. A cooling cloud blanket will work for a while. Still, we continually lose hydrogen to space, evaporated away at the top of the atmosphere. Putting water clouds up to block the sunlight means that they, too, will get boiled away. Even with such measures, liquid water on Earth would evaporate in about 2.5 billion years from now. Without oceans, volcanoes would be the major source for new atmospheric elements, and we would evolve a climate much like that of Venus.

All this assumes that we don't find wholly new ways of getting around planetary problems. I suspect that we crafty chimpanzees probably shall, though. We like to tinker and we like to roam. Though some will stay to fiddle with the Earth, the sun and the planets, some will move elsewhere.

After all, smaller stars will live longer. The class called M dwarfs, dim and red and numerous, can burn steady and wan, for up to a hundred billion years, without any assistance. Then even they will gutter out. Planets around such stars will have a hard time supporting life, because any world close enough to the star to stay warm will also be tide locked, one side baked and the other freezing. Still, they might prove temporary abodes for wandering primates, or for others.

Eventually, no matter what stellar engine we harness, all the hydrogen gets burned. Similar pollution problems beset even the artificially aged star, now completely starved of hydrogen. It seethes, grows hotter, sears its planets, then swallows them.

There may be other adroit dodges available to advanced lifeforms, such as using the energy of supernovas. These are brute mechanisms, and later exploding stars can replenish the interstellar clouds of dust and gas, so that new stars can form -- but not many. On average, matter gets recycled in about four billion years in our galaxy. Our own planet's mass is partly recycled stellar debris from the first galactic supernova generation. This cycle can go on until about 20 billion years pass, when only a ten-thousandth of the interstellar medium will remain. Dim red stars will glow in the spiral arms, but the great dust banks will have been trapped into stellar corpses.

So unavoidably, the stars are as mortal as we. They take longer, but they die.

For its first fifty billion years, the universe will brim with light. Gas and dust will still fold into fresh suns. For an equal span the stars would linger. Beside reddening suns, planetary life will warm itself by the waning fires that herald stellar death.

Sheltering closer and closer to stellar warmth, life could take apart whole solar systems, galaxies, even the entire Virgo cluster of galaxies, all to capture light. In the long run, life must take everything apart and use it, to survive.

To ponder futures beyond that era, we must discuss the universe as a whole.

Modern cosmology is quite different from the physics of the Newtonian worldview, which dreamed uneasily of a universe that extended forever but was always threatened by collapse. Nothing countered the drawing-in of gravity except infinity itself. Though angular momentum will keep a galaxy going for a great while, collisions can cancel that. Objects hit each other and mutually plunge toward the gravitating center. Physicists of the Newtonian era thought that maybe there simply had not been enough time to bring about the final implosion. Newton, troubled by this, avoided cosmological issues.

Given enough time, matter will seek its own kind, stars smacking into each other, making greater and greater stars. This will go on even after the stars gutter out.

When a body meets a body, coming through the sky . . . Stars will inevitably collide, meet, merge. All the wisdom and order of planets and suns will finally compress into the marriage of many stars, plunging down the pit of gravity to become black holes. For the final fate of nearly all matter shall be the dark pyre of collapse.

Galaxies are as mortal as stars. In the sluggish slide of time, the spirals which had once gleamed with fresh brilliance will be devoured by ever-growing black holes. Inky masses will blot out whole spiral arms of dim red. The already massive holes at galactic centers will swell from their billion-stellar-mass sizes at present, to chew outward, gnawing without end.

From the corpses of stars, collisions will form either neutron stars or black holes, within about a thousand billion years (in exponential notation, 10[sup 12] years). Even the later and longest-lived stars cannot last beyond 10[sup 14] years. Collisions between stars will strip away all planets in 10[sup 15] years.

Blunt thermodynamics will still command, always seeking maximum disorder. In 10[sup 17] years, the last white dwarf stars will have cooled to be utterly black dwarfs, temperatures about 5 degrees Kelvin (Absolute). In time, even hell would freeze over.

Against an utterly black sky, shadowy cinders of stars will glide. Planets, their atmospheres frozen out into waveless lakes of oxygen, will glide in meaningless orbits, warmed by no ruby star glow. The universal clock would run down to the last tick of time.

But the universe is no static lattice of stars. It grows. The Big Bang would be better termed the Enormous Emergence, space-time snapping into existence intact and whole, of a piece. Then it grew, the fabric of space lengthening as time increased.

With the birth of space-time came its warping by matter, each wedded to the other until time eternal. An expanding universe cools, just as a gas does. The far future will freeze, even if somehow life manages to find fresh sources of power.

Could the expansion ever reverse? This is the crucial unanswered riddle in cosmology. If there is enough matter in our universe, eventually gravitation will win out over the expansion. The "dark matter" thought to infest the relatively rare, luminous stars we see could be dense enough to stop the universe's stretching of its own space-time. This density is related to how old the universe is.

We believe the universe is somewhere between 8 and 16 billion years old. The observed rate of expansion (the Hubble constant) gives 8 billion, in a simple, plausible model. The measured age of the oldest stars gives 16 billion.

This difference I believe arises from our crude knowledge of how to fit our mathematics to our cosmo-logical data; I don't think it's a serious problem. Personally I favor the higher end of the range, perhaps 12 to 14 billion. We also have rough measures of the deceleration rate of the universal expansion. These can give (depending on cosmological, mathematical models) estimates of how long a dense universe would take to expand, reverse, and collapse back to a point. At the extremes, this gives between 27 billion and at least 100 billion years before the Big Crunch. If we do indeed live in a universe which will collapse, then we are bounded by two singularities, at beginning and end. No structure will survive that future singularity. Freeman Dyson found this a pessimistic scenario and so refused to consider it.

A closed universe seems the ultimate doom. In all cosmological models, if the mass density of the universe exceeds the critical value, gravity inevitably wins. This is called a "closed" universe, because it has finite spatial volume, but no boundary. It is like a three dimensional analog of a sphere's surface. A bug on a ball can circumnavigate it, exploring all its surface and coming back to home, having crossed no barrier. So a starship could cruise around the universe and come home, having found no edge.

A closed universe stars with a big bang (an initial singularity) and expands. Separation between galaxies grows linearly with time. Eventually the universal expansion of space-time will slow to a halt. Then a contraction will begin, accelerating as it goes, pressing galaxies closer together. The photons rattling around in this universe will increase in frequency, the opposite of the red shift we see now. Their blue shift means the sky gets brighter in time. Contraction of space-time shortens wavelengths, which increases light energy.

Though stars will still age and die as the closed universe contracts, the background light will blue shift. No matter if life burrows into deep caverns, in time the heat of this light will fry it. Freeman Dyson remarked that the closed universe gave him "a feeling of claustrophobia, to imagine our whole existence confined within a box." He asked, "Is it conceivable that by intelligent intervention, converting matter into radiation to flow purposefully on a cosmic scale, we could break open a closed universe and change the topology of spacetime so that only a part of it would collapse and another would expand forever? I do not know the answer to this question."

The answer seems to be that once collapse begins, a deterministic universe allows no escape for pockets of spacetime. Life cannot stop the squeezing.

Some have embraced this searing death, when all implodes toward a point of infinite temperature. Frank Tipler of Tulane University sees it as a great opportunity. In those last seconds, collapse will not occur at the same rate in all directions. Chaos in the system will produce "gravitational shear" which drives temperature differences. Drawing between these temperature differences, life can harness power for its own use.

Of course, such life will have to change its form to use such potentials; they will need hardier stuff than blood and bone. Ceramic-based forms could endure, or vibrant, self-contained plasma clouds --any tougher structure might work, as long as it can code information.

This most basic definition of life, the ability to retain and manipulate information, means that the substrate supporting this does not matter, in the end. Of course, the style of thought of a silicon web feasting on the slopes of a volcano won't be that of a shrewd primate fresh from the veldt, but certain common patterns can transfer.

Such life forms might be able to harness the compressive, final energies at that distant end, the Omega Point. Frank Tipler's The Physics of Immortality makes a case that a universal intelligence at the Omega Point will then confer a sort of immortality, by carrying out the computer simulation of all possible past intelligences. All possible earlier "people" will be resurrected, he thinks. This bizarre notion shows how cosmology blends into eschatology, the study of the ultimate fate of things, particularly of souls.

I, too, find this scenario of final catastrophe daunting. Suppose, then, the universe is not so dense that it will ever reverse its expansion. Then we can foresee a long toiling twilight.

Life based on solid matter will struggle to survive. To find energy, it will have to ride herd on and merge black holes themselves, force them to emit bursts of gravitational waves. In principle these waves can be harnessed, though of course we don't know how as yet. Only such fusions could yield fresh energy in a slumbering universe.

High civilizations will rise, no doubt, mounted on the carcass of matter itself -- the ever-spreading legions of black holes. Entire galaxies will turn from reddening lanes of stars, into swarms of utterly dark gravitational singularities, the holes. Only by moving such masses, by extracting power through magnetic forces and the slow gyre of dissipating orbits, could life rule the dwindling resources of the ever-enlarging universe. Staying warm shall become the one great Law.

Dyson has argued that in principle, the perceived time available to living forms can be made infinite. In this sense, immortality of a kind could mark the cold, stretching stages of the universal death.

This assumes that we know all the significant physics, of course. Almost certainly, we do not. Our chimpanzee worldview may simply be unable to comprehend events on such vast time scales. Equally, though, chimpanzees will try, and keep trying.

Since Dyson's pioneering work on these issues, yet more physics has emerged which we must take into account. About his vision of a swelling universe, its life force spent, hangs a great melancholy.

For matter itself is doomed, as well. Even the fraction which escapes the holes, and learns to use them, is mortal. Its basic building block, the proton, decays. This takes unimaginably long -- current measurements suggest a proton lifetime of more than 10[sup 33] years. But decay seems inevitable, the executioner's sword descending with languid grace.

Even so, something still survives. Not all matter dies, though with the proton gone everything we hold dear will disintegrate, atoms and animals alike. After the grand operas of mass and energy have played out their plots, the universal stage will clear to reveal the very smallest.

The tiniest of particles -- the electron and its anti-particle, the positron -- shall live on, current theory suggests. No process of decay can find purchase on their infinitesimal scales, lever them apart into smaller fragments. The electron shall dance with its anti-twin in swarms: the lightest of all possible plasmas.

By the time these are the sole players, the stage will have grown enormously. Each particle will find its nearest neighbor to be a full light-year away. They will have to bind together, sharing cooperatively, storing data in infinitesimally thin currents and charges. A single entity would have to be the size of a spiral arm, of a whole galaxy. Vaster than empires, and more slow.

Plasmas held together by magnetic and electric fields are incredibly difficult to manage, rather like building a cage for jello out of rubber bands. But in principle, physics allows such magnetic loops and glowing spheres. We can see them in the short-lived phenomenon of ball lightning. More spectacularly, they occur on the sun, in glowing magnetic arches which can endure for weeks, a thousand kilometers high.

Intelligence could conceivably dwell in such wispy magnetic consorts. Communication will take centuries . . . but to the slow thumping of the universal heart, that will be nothing.

If life born to brute matter can find a way to incorporate itself into the electron-positron plasma, then it can last forever. This would be the last step in a migration from the very early forms, like us: rickety assemblies of water in tiny compartment cells, hung on a lattice of moving calcium rods.

Life and intelligence will have to alter, remaking their basic structures from organic molecules to, say, animated crystalline sheets. Something like this may have happened before; some theorists believe Earthly life began in wet clay beds, and moved to organic molecules in a soupy sea only later.

While the customary view of evolution does not speak of progress, there has been generally an increase of information transmitted forward to the next generation. Complexity increases in a given genus, order, class, etc. Once intelligence appears, or invades a wholly different medium, such "cognitive creatures" can direct their own evolution. Patterns will persist, even thrive, independent of the substrate.

So perhaps this is the final answer to the significance of it all. In principle, life and structure, hopes and dreams and Shakespeare's Hamlet, can persist forever -- if life chooses to, and struggles. In that far future, dark beyond measure, plasma entities of immense size and torpid pace may drift through a supremely strange era, sure and serene, free at last of ancient enemies.

Neither the thermodynamic dread of heat death nor gravity's gullet could then swallow them. Cosmology would have done its work.

As the universe swells, energy lessens, and the plasma life need only slow its pace to match. Mathematically, there are difficulties involved in arguing, as Dyson does, that the perceived span of order can be made infinite. The issue hinges on how information and energy scale with time. Assuming that Dyson's scaling is right, there is hope.

By adjusting itself exactly to its ever-cooling environment, life -- of a sort -- can persist and dream fresh dreams. The Second Law of Thermodynamics says that disorder increases in every energy transaction. But the Second Law need not be not the Final Law.

Such eerie descendants will have much to think about. They will be able to remember and relive in sharp detail the glory of the brief Early Time -- that distant, legendary era when matter brewed energy from crushing suns together. When all space was furiously hot, overflowing with boundless energy. When life dwelled in solid states, breathed in chilly atoms, and mere paltry planets formed a stage.

Freeman Dyson once remarked to me, about these issues, that he felt the best possible universe was one of constant challenge. He preferred a future which made survival possible but not easy. We chimps, if coddled, get lazy and then stupid.

The true far future is shrouded and mysterious. Still, I expect that he shall get his wish, and we shall not be bored.