Infinite Worlds

AN ILLUSTRATED VOYAGE TO PLANETS BEYOND OUR SUN

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Twilight of a God

Life and death among the stars is just as inevitable as it is for biology on Earth. Even more deterministic than the apparent abundance of planet formation is the fact that planets will be irrevocably changed by the eventual demise of their parent star. This was deduced even before scientists knew how the Sun was powered. It certainly could not shine forever. The lingering death of Earth is envisioned in the closing chapters of H. G. Wells's *The Time Machine,* when Wells's time traveler stops 30 million years in the future (the Sun's predicted life span at that time, based on the notion it was chemically burning, like a piece of coal; the concept of nuclear fusion had not been theorized yet):

> I stopped very gently and sat upon the Time Machine, looking round. The sky was no longer blue. Northeastward it was inky black, . . . and southeastward it grew brighter to a glowing scarlet where, cut by the horizon, lay the huge hull of the sun, red and motionless. . . .
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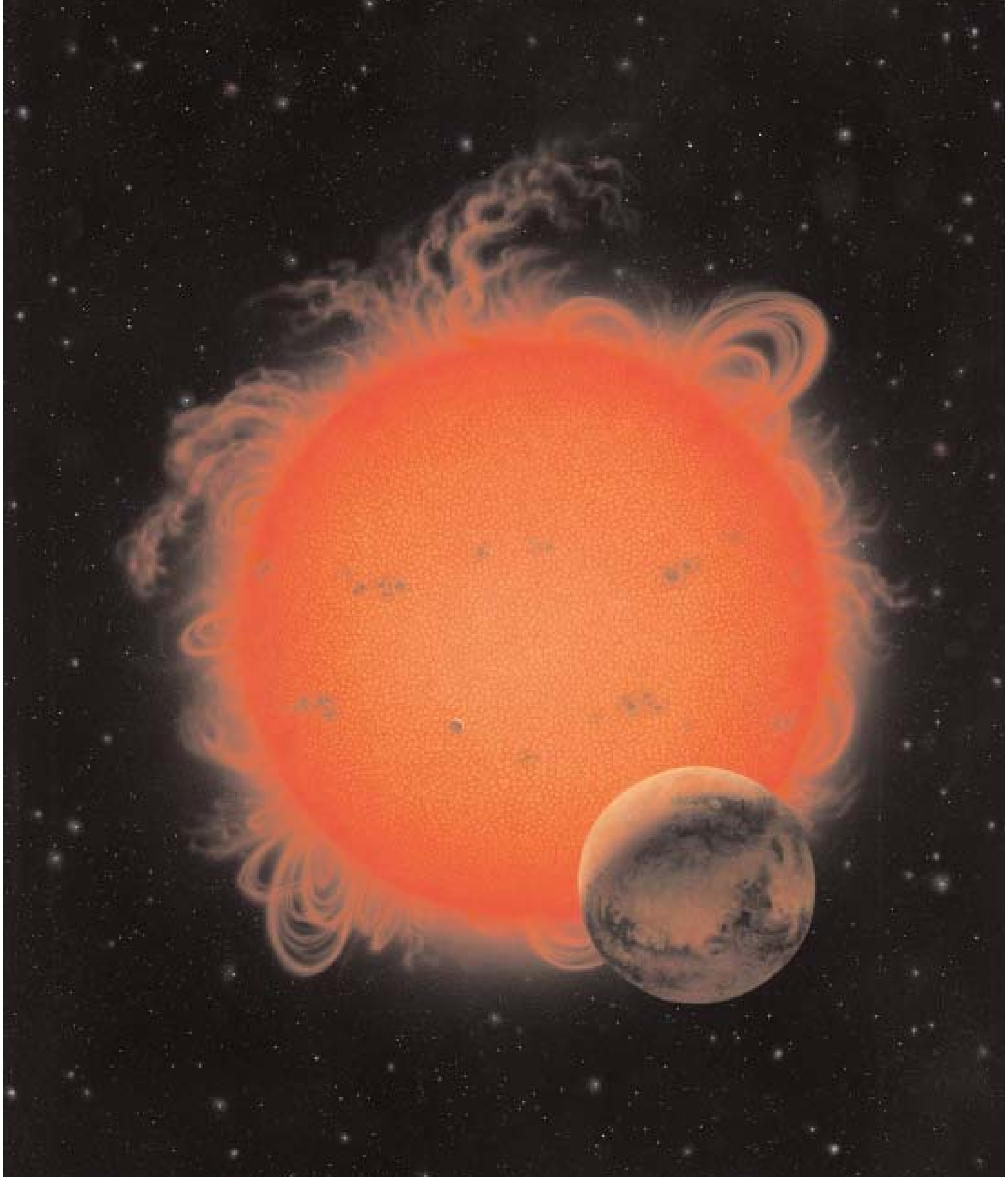
> . . . From the edge of the sea came a ripple and whisper. Beyond these lifeless sounds the world was silent. Silent? It would be hard to convey the stillness of it. All the sounds of man, the bleating of sheep, the cries of birds, the hum of insects, the stir that makes the background of our lives—all that was over.

GREENHOUSE EARTH *Within a billion years Earth will become a "moist greenhouse" with a scalding surface because the Sun is continuing to brighten as it ages (this is counterintuitive to earlier, "non-nuclear" solar theories that predicted the Sun would dim over time), and the rising temperatures will cause the oceans to boil away. Most surface life will become extinct. Eventually the only water will pool at the bottom of the deep-sea trenches, where bacteria will still survive as the last life forms on Earth. The habitable zone that Earth now occupies will move farther out into the Solar System.*



The Earth is a child of the Sun. However, our parent star is indifferent to our fate. The Sun has nurtured life on Earth for billions of years. But the Sun is a fusion engine that cannot keep the thermostat constantly regulated for our survival. It is presently converting hydrogen into helium through nuclear fusion. Eventually nuclear fusion reactions at the Sun's center will move out to an expanding shell around an inert core of helium "ash." This will make the core gradually heat up, and the Sun's rate of fusion will increase, making it grow steadily brighter.

Roughly a billion years from now the Sun will grow bright enough to evaporate away Earth's oceans. Like an evil genie let out of a bottle, carbon dioxide locked away for eons in ocean sediments will be released back into the atmosphere. Earth will become perpetually cloudy, and surface temperatures and pressures will rise as the carbon dioxide enriches the atmosphere. This will make the atmosphere more efficient at trapping solar radiation through the "greenhouse effect." Earth will become hellish like Venus, and only the hardiest microorganisms may find these conditions livable.

The final stages of the Sun's existence will be punctuated by relatively swift and major changes in size and temperature. The helium ash core will contract, releasing gravitational energy. Some of this energy will heat up the center, while the rest of the heat will cause the Sun's outer layers to expand. As the Sun swells, its outer atmosphere will grow thinner and cooler. The expanding Sun will engulf Mercury, and then Venus. As the Sun continues to balloon to the size of Earth's orbit, our planet's fate will lie in a precarious balance.

Earth will be so close to the Sun's outer atmosphere that it will raise a tidal bulge in the Sun; this will cause the Sun's outer envelope to gradually spin faster. Earth will slow in its orbit and move inward toward the Sun, possibly falling inside the Sun's extended atmosphere. In this case Earth would spiral into the Sun and vaporize. However, Earth's

RED GIANT SUN, FIVE BILLION YEARS OLDER *In about five billion years the Sun will expand into a red giant. Mercury and Venus will be engulfed by the Sun's outer atmosphere. Earth will be baked into a solid waterless rock and may also be swallowed. Mars, perhaps the last surviving terrestrial planet, is seen in the foreground.*

orbital decay will be counterbalanced by the fact that the expanding Sun will lose mass through a continuous stellar wind of gas streaming off it. Earth's orbit thus would widen as the Sun loses mass into space. So our planet may be spared the final indignity of being burned to a cinder.

The red giant Sun will briefly contract until it becomes so hot in its center that it triggers helium fusion at the core, where helium atoms will collide to create carbon and oxygen atoms. The Sun will burn helium for just 100 million years more. Near the end of its life the Sun's surface will pulsate and shudder with seismic energy from changes in the activity of the fusion furnace. With each pulse, which will last about a year, the surface layers will expand and cool. Each time this happens some of the stellar exterior will be flung into space.

The Sun will look deceptively redder as space around the Solar System is filled with dust that scatters blue light. Background stars will disappear behind this stellar pollution "smog." The Sun itself will slowly become embedded in a cocoon of dust of its own making and will grow smaller and hotter as it loses layers that are too hot to condense into dust. As the upper gas layers strip away, the hot stellar core will be slowly exposed. Light from the core will make brilliant "sunbeams" that shine through the mottled clouds of dust around it. Finally, the remnant solar core will shrink and heat up to a fierce blue-white brilliance to become a white dwarf star. A flood of ultraviolet radiation will cause the gases in the surrounding nebula to glow.

Our galaxy is littered with such opulent death shrouds from dying stars. They are called planetary nebulae because, when viewed through a telescope over a century ago, some resembled the disks of planets. But the fact that many planetary nebulae are not spherical but more hourglass shaped may be indirect evidence for extrasolar planets. One of the most striking examples is the planetary nebula M2–9, nicknamed the Siamese Squid or Twin Jet. It appears much like a pair of exhausts from jet engines. The ejected gas is moving at over 200 miles per second. Any surviving planets around this star would be bathed in a glow of ultraviolet light, and the sky would be filled with the eerie wisps of fluorescing gases ejected from the star.

PLANET NEAR THE SIAMESE SQUID NEBULA *This view is from a hypothetical world near the planetary nebula M2–9, dubbed the "Siamese Squid" because of its symmetrical jets. Different minerals in the surface rock fluoresce in pink and green colors, caused by the white dwarf's fierce ultraviolet glow rather than from the nebulosity. The planet is near the star's spin axis, and so the view is almost down the center of one of the twin jets the star is ejecting. It would be unusual to find a planet in an orbit so high above the star's ecliptic plane, but planet discoveries so far have taught us to expect the unexpected.*

PLANET INGESTION IN THE HD 82943 SYSTEM *HD 82943, a solar-type star in the constellation Hydra, has been shown to contain a significant amount of lithium-6, inferring that it swallowed one or more large planets during its history. Two giant planets still orbit this world. When a planet fell into the star it likely formed a comet-like tail. This image shows the view from the vantage point of a moon orbiting a second planet. The outermost planet, with three tiny, hypothetical satellites, is seen in the distance at upper left.*

The strange elongated shapes in many planetary nebulae could come from a large planet or brown dwarf being swallowed by a dying star. Computer simulations by theoretical astrophysicists Mario Livio and Lionel Siess show that a large planet that is engulfed by a red giant star continues to orbit inside the star for thousands of years before it is completely vaporized. "You have to remember that these stars are super-tenuous gas balls with their matter smeared over an absolutely huge volume," says Livio. "Their outer regions are as rarefied as what we would consider a good vacuum on Earth."

Their modeling shows that when a large planet spirals inward it sheds material that stays in the plane of the planet's orbit to form a doughnut-shaped cloud around the star. Later, when the star's hot core is exposed, its radiation drives a fierce stellar wind of matter away from it. The wind blows in all directions, but because the slow-moving gas in the doughnut impedes its expansion, it escapes fastest along the star's rotation axis in opposite directions, forming exquisitely symmetrical double-lobe features. "The doughnut acts like a corset, and the wind blows two bubbles perpendicular to the corset," says Livio.

The gravitational energy dumped by the rapidly orbiting planet as it spirals into the stellar core should also raise the star's spin rate. Also, a large swallowed-up planet would contaminate the star with its heavier elements. Astronomers have observed the predicted effects of stars swallowing a planet or brown dwarf. The stars emit unexpectedly large amounts of infrared radiation from dust, and their light shows the spectral fingerprint of lithium, an element that does not normally survive very long in a star. Its presence may not necessarily indicate planet ingestion, however, since lithium can also be dredged up as a star's churning convection zone deepens into the layer in which lithium was burned. Thus, only a few stars showing the presence of lithium may have actually swallowed planets. About 8 percent of red giant stars are candidates for planet ingestion. Some researchers have used this estimate to predict the ratio of Jupiter-sized planets in close orbits around stars in our galaxy. But the next step in planet hunting requires finding out more about how our own Solar System was put together.