and neutrons. To detect the predicted solar neutrino flux, you need an immense amount of chlorine, so American physicists have poured a huge quantity of cleaning fluid into the Homestake Mine in Lead, South Dakota. The chlorine is microchemically swept for the newly produced argon. The more argon found, the more neutrinos inferred. These experiments imply that the Sun is dimmer in neutrinos than the calculations predict.

There is a real and unsolved mystery here. The low solar neutrino flux probably does not put our view of stellar nucleosynthesis in jeopardy, but it surely means something important. Proposed explanations range from the hypothesis that neutrinos fall to pieces during their passage between the Sun and the Earth to the idea that the nuclear fires in the solar interior are temporarily banked, sunlight being generated in our time partly by slow gravitational contraction. But neutrino astronomy is very new. For the moment we stand amazed at having created a tool that can peer directly into the blazing heart of the Sun. As the sensitivity of the neutrino telescope improves, it may become possible to probe nuclear fusion in the deep interiors of the nearby stars.

But hydrogen fusion cannot continue forever: in the Sun or any other star, there is only so much hydrogen fuel in its hot interior. The fate of a star, the end of its life cycle, depends very much on its initial mass. If, after whatever matter it has lost to space, a star retains two or three times the mass of the Sun, it ends its life cycle in a startlingly different mode than the Sun. But the Sun's fate is spectacular enough. When the central hydrogen has all reacted to form helium, five or six billion years from now, the zone of hydrogen fusion will slowly migrate outward, an expanding shell of thermonuclear reactions, until it reaches the place where the temperatures are less than about ten million degrees. Then hydrogen fusion will shut itself off. Meanwhile the self-gravity of the Sun will force a renewed contraction of its helium-rich core and a further increase in its interior temperatures and pressures. The helium nuclei will be jammed together still more tightly, so much so that *they* begin to stick together, the hooks of their short-range nuclear forces becoming engaged despite the mutual electrical repulsion. The ash will become fuel, and the Sun will be triggered into a second round of fusion reactions.

This process will generate the elements carbon and oxygen and provide additional energy for the Sun to continue shining for a limited time. A star is a phoenix, destined to rise for a time from its own ashes.* Under the combined influence of hydrogen fusion in a thin shell far from the solar interior and the high temperature helium fusion in the core, the Sun will undergo a major change: its exterior will expand and cool. The Sun will become a red giant star, its visible surface so far from its interior that the gravity at its surface grows feeble, its atmosphere expanding into space in a kind of stellar gale. When the Sun, ruddy and bloated, becomes a red giant, it will envelop and devour the planets Mercury and Venus - and probably the Earth as well. The inner solar system will then reside within the Sun.

* Stars more massive than the Sun achieve higher central temperatures and pressures in their late evolutionary stages. They are able to rise more than once from their ashes, using carbon and oxygen as fuel for synthesizing still heavier elements.

Billions of years from now, there will be a last perfect day on Earth. Thereafter the Sun will slowly become red and distended, presiding over an Earth sweltering even at the poles. The Arctic and Antarctic icecaps will melt, flooding the coasts of the world. The high oceanic temperatures will release more water vapor into the air, increasing cloudiness, shielding the Earth from sunlight and delaying the end a little. But solar evolution is inexorable. Eventually the oceans will boil, the atmosphere will evaporate away to space and a catastrophe of the most immense proportions imaginable will overtake our planet.* In the meantime, human beings will almost certainly have evolved into something quite different. Perhaps our descendants will be able to control or moderate stellar evolution. Or perhaps they will merely pick up and leave for Mars or Europa or Titan or, at last, as Robert Goddard envisioned, seek out an uninhabited planet in some young and promising planetary system.

* The Aztecs foretold a time 'when the Earth has become tired. . ., when the seed of Earth has ended.' On that day, they believed, the Sun will fall from the sky and the stars will be shaken from the heavens.

The Sun's stellar ash can be reused for fuel only up to a point. Eventually the time will come when the solar interior is all carbon and oxygen, when at the prevailing temperatures and pressures no further nuclear reactions can occur. After the central helium is almost all used up, the interior of the Sun will continue its postponed collapse, the temperatures will rise again, triggering a last round of nuclear reactions and expanding the solar atmosphere a little. In its death throes, the Sun will slowly pulsate, expanding and contracting once every few millennia, eventually spewing its atmosphere into space in one or more concentric shells of gas. The hot exposed solar interior will flood the shell with ultraviolet light, inducing a lovely red and blue fluorescence extending beyond the orbit of Pluto. Perhaps half the mass of the Sun will be lost in this way. The solar system will then be filled with an eerie radiance, the ghost of the Sun, outward bound.

When we look around us in our little corner of the Milky Way, we see many stars surrounded by spherical shells of glowing gas, the planetary nebulae. (They have nothing to do with planets, but some of them seemed reminiscent in inferior telescopes of the blue-green discs of Uranus and Neptune.) They appear as rings, but only because, as with soap bubbles, we see more of them at the periphery than at the center. Every planetary nebula is a token of a star *in extremis*. Near the central star there may be a retinue of dead worlds, the remnants of planets once full of life and now airless and ocean-free, bathed in a wraithlike luminance. The remains of the Sun, the exposed solar core at first enveloped in its planetary nebula, will be a small hot star, cooling to space, collapsed to a density unheard of on Earth, more than a ton per teaspoonful. Billions of years hence, the Sun will become a degenerate white dwarf, cooling like all those points of light we see at the centers of planetary nebulae from high surface temperatures to its ultimate state, a dark and dead black dwarf.

Two stars of roughly the same mass will evolve roughly in parallel. But a more massive star will spend its nuclear fuel faster, become a red giant sooner, and be first to enter the final white dwarf decline. There should therefore be, as there are, many cases of binary stars, one component a red giant, the other a white dwarf. Some such pairs are so close together that they touch, and the glowing stellar atmosphere flows from the distended red giant to the compact white dwarf, tending to fall on a particular province of the surface of the white dwarf. The hydrogen accumulates, compressed to higher and higher pressures and temperatures by the intense gravity of the white dwarf, until the stolen atmosphere of the red giant undergoes thermonuclear reactions, and the white dwarf briefly flares into brilliance. Such a binary is called a nova and has quite a different origin from a supernova.