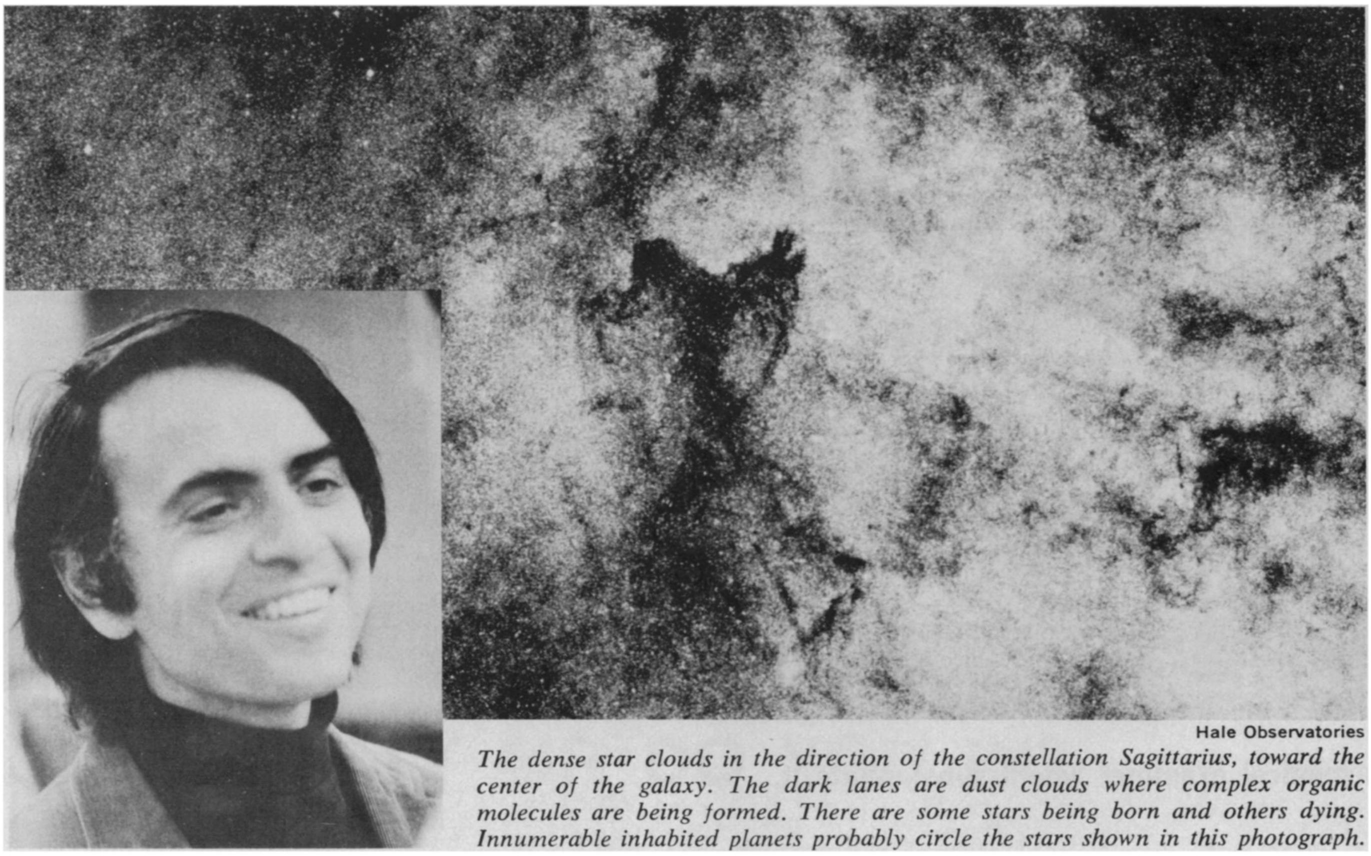

Hale Observatories

The dense star clouds in the direction of the constellation Sagittarius, toward the center of the galaxy. The dark lanes are dust clouds where complex organic molecules are being formed. There are some stars being born and others dying. Innumerable inhabited planets probably circle the stars shown in this photograph.

THE STARFOLK

". . . Life on Earth is intimately bound to stellar events. Human beings are here because of the paroxysms in dying stars thousands of light-years away."

by **Carl Sagan**

The emergence of man was a process wending through billions of years of time and driven by gravitation and nuclear physics, by organic chemistry and natural selection. Matter of which we are made was generated in another place and another time, in the insides of a dying star five billion or more years ago.

The universe is put together in such a way as to permit, if not guarantee, the origin of life and the development of complex creatures. It is easy to imagine laws of physics that would not permit appropriate nuclear reactions, or laws of chemistry that would not permit appropriate configurations of molecules to be assembled. But we do not live in such universes. We live in a universe remarkably hospitable to life.

No element is unique to our solar system or our planet. There are 250 billion suns in our Milky Way galaxy, and billions of other galaxies in the heavens. Perhaps half of these stars have planets at biologically appropriate distances from the local sun. The initial chemical constituents for the origin of life are the most abundant molecules in the universe. Something like the processes that on Earth led to man must have happened billions of other times in the history of our galaxy. There must be other starfolk.

The evolutionary details would not be the same, of course. Even if the Earth were started over again and only random forces again operated, nothing like a human being would be produced—because human beings are the end-product of an exquisitely complicated evolutionary pathway full of false starts and dead ends and statistical accidents. But we might well expect, if not human beings, organisms functionally not very different from ourselves. Since there are second and third generation stars much older than our Sun, there must be, I think many places in the galaxy where there are beings far more advanced than we in science and technology, in politics, ethics, poetry and music.

There is an intimate connection between stars and life. Our planet was formed from the dregs of starstuff. The atoms necessary for the origin of life were cooked in the interiors of red giant stars. These atoms were forced together, to form complex organic molecules, by ultraviolet light and thunder and

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lightning, all produced by the radiation of our neighboring Sun. When the food supply ran short, green-plant photosynthesis developed, driven again by sunlight, the sunlight off which almost all the organisms on Earth, and certainly everyone we know, live out their days.

Our Sun is only approaching vigorous middle-age. It has perhaps another five or ten billion years of stellar life ahead of it.

And what of life on Earth and man? They, too, for all we know, may have a future. And if not, there are billions of other stars and probably billions of other inhabited planets in our galaxy. What is the interaction between stars and life later on?

The death of stars is taking astronomers into unexpected and almost surreal celestial landscapes. One of these is the supernova explosion, the death throes of stars slightly more massive than our Sun. In a brief period of a few weeks to a few months, such an exploding star may become brighter than the rest of the galaxy in which it resides. In supernovas, elements like gold and uranium are generated from iron. The supernovas are the long-sought philosophers' stone, converting base metals into gold.

Having blown away most of its star-stuff—destined, some of it, to go into later generations of formation of stars and planets and life—the star settles down to a quiet old age, its fires spent, as a white dwarf. A white dwarf is constituted of matter in a state which physicists, with no moral imputation intended, call degenerate. Electrons are stripped off the nuclei of atoms. The protective shields of negative electricity are removed. The nuclei can move much closer together and a state of extraordinary density results. Typical degenerate matter weighs about a ton per thimblefull. Some white dwarfs, properly considered, are vast stellar crystals able to hold up the weight of the overlying layers of the star. Some white dwarfs are largely carbon. We may speak of a star made of diamond.

But for more massive stars, the white dwarfs—their embers slowly fading, decaying into black dwarfs—are not the end state. Degenerate matter cannot hold up the weight of a more massive star, and another cycle of stellar contraction thus ensues—the matter being crushed together to more and more incredible densities until some new regime of physics is entered, until some new force surfaces to stop the stellar collapse. There is only one further such force known: it is the nuclear force that holds the nucleus of the atom together. This nuclear force is responsible for the stability of atoms and, therefore, for all of chemistry and biology. It is also responsible for the thermonuclear reactions in the insides of stars which make stars shine and thereby in a quite different way, drives planetary biology.

Imagine a star more or less like the Sun, but a few times more massive, near the end of its days of converting simple nuclei into more complex nuclei. It produces the last series of complex nuclear reactions it is able to—and then collapses. As its size decreases, it spins more and more rapidly, like a pirouetting ice skater bringing in her arms. Only when the density in its interior becomes comparable to the density of matter inside the atomic nucleus does the collapse stop. It is a simple matter in elementary physics to calculate at what stage the collapse will end. It ends when the star is about a mile across and rotating about ten times a second.

Such an object is a rapidly rotating neutron star. It is, in truth, a giant atomic nucleus a mile across. Neutron star matter is so dense that a speck of it—just barely visible—would weigh a million tons. The Earth would not be able to support it. A piece of neutron star matter, if it could be transported to the Earth without falling apart, would sink effortlessly through the crust, mantle and core of our planet like a razor blade through warm butter.

Such neutron stars were theoretical constructs, the imaginings of speculative physicists—until the pulsars were discovered. Pulsars are sources of radio emission. Some of them are associated with old supernova explosions. They blink at us as if the beam of some cosmic lighthouse swept by us ten times a second. The details of the emission from pulsars are best understood if they are the fabled neutron stars. Because of the loss of energy to space which we observe, the rotation rate of an isolated neutron star must slowly decline, even though it is a stellar timekeeper of extraordinary accuracy. The observed decay of pulsar periods is just about what is expected from neutron star physics.

The first pulsar to be detected was called, by its discoverers, only half impishly, LGM-1. The LGM stood for "little green men." Was it, they wondered, a beacon from an advanced extraterrestrial civilization? My own view when I first heard about pulsars was that they were perfect interstellar navigation beacons, the sorts of markers that an interstellar spacefaring society would want to place throughout the galaxy for time-and-space fixes for their voyages. There is now little doubt that pulsars are neutron stars. But I would not exclude the possibility that if there are interstellar spacefaring societies, the naturally formed pulsars are used as navigation beacons.

The state of matter in the inside of such a neutron star is still not understood. We do not know if a surface crust comprising a neutron crystal lattice overlies a core of liquid neutrons. Should the core be solid, starquakes are expected—a shifting of the matter under enormous stress in the interior of the star. Such starquakes should produce a discontinuous change in the period of rotation of the neutron star. Such changes, called "glitches," are observed.

Some were disappointed to learn that pulsars were neutron stars and not interstellar radio communication channels. But pulsars are hardly uninteresting. Indeed, a star more massive than the Sun which fits into a sphere a mile across and rotates ten times every second is, in a certain sense, much more exotic than a civilization slightly more advanced than we on the planet of another star.

But there is another and much more profound way in which neutron stars and supernova explosions

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are connected with life. In a supernova explosion, as we have already mentioned, vast quantities of atoms from the surface of the star are ejected at very high velocities into interstellar space. In the case of the neutron star, there is, because of its rapid rotation, a zone, not far from its surface, which is rotating at almost the velocity of light. Particles are ejected from that zone at speeds so great that the theory of relativity must be taken into account to describe them. Both supernova explosions and the high-velocity zone surrounding neutron stars must produce cosmic rays—the very fast charged particles (mostly protons, but containing all the other elements as well) which pervade the space between the stars.

Cosmic rays fall on the Earth's atmosphere. The less energetic particles are absorbed by the atmosphere or deflected by Earth's magnetic field. But the more energetic particles, the ones produced by supernovas or neutron stars, penetrate to the surface of the Earth. And here they collide with life. Some cosmic rays penetrate through the genetic material of life forms on the surface of our planet. These random, unpredictable cosmic rays produce changes, mutations, in the hereditary material. Mutations are variations in the blueprints, the hereditary instructions, contained in our self-replicating molecules. Like a fine watch repeatedly hit with a hammer, the functioning of life is unlikely to improve under such random pummelings. But as sometimes happens with watches or bulky television sets a random pummeling does occasionally improve the functioning. The vast bulk of mutations are harmful, but the small fraction of mutations that are an improvement provide the raw material for evolutionary advance. Life would be at a dead end without mutation. Thus, in yet another way, life on Earth is intimately bound to stellar events. Human beings are here because of the paroxysms in dying stars thousands of light-years away.

The birth of stars generates the planetary nurseries of life. The lives of stars provide the energy upon which life depends. The deaths of stars produce the implements for the continued development of life in other parts of the galaxy. If there are on the planets of dying stars intelligent beings unable to escape their fate, they may at least derive some comfort from the thought that the death of their star, the event that will cause their own extinction, will, nevertheless, provide the means for continued biological advance of the starfolk on a million other worlds. □

OFF *the* BEAT

Physics is as physics does

The recent survey that shows (again!) that students dislike physics and physicists (SN: 10/13/73, p. 230) leads me, as a former physics student, to comment. It is true that physics is dismally taught in most of our high schools and many colleges, but the matter will not be rectified by teaching physics as if it were one of the humanities.

Physics *is* one of the humanities. It has a beauty and an intellectual value all its own which must be taken on its own terms. In my undergraduate days the problem was that physics was taught for engineers. Since there are many more engineers than physicists, this practice may persist in some places. Students wasted a lot of time with such artifacts as frictionless ladders and bridge catenaries when they might have been working on something of physical interest (Hamiltonian dynamics, perhaps).

Physics should be taught as for physicists. It is not poetry nor prose, painting nor sculpture, and it will only suffer if it is taught as if it were one of them. Physics has its own integrity and is its own justification for being.

It is true that I did not apprehend this until several years after I last had to worry about integrating the most devilish differential equation a textbook writer could devise. (There is a beauty in differential equations too, but it is seldom apprehended while one is taking a course in them.)

Let us take Maxwell's equations as an example. Too often they are taught as a handful of formulas to plug into problems. They have all the limpid brevity of a haiku, and the beauty of their conciseness should be appreciated. Yet the profundity contained within that small collection of symbols is awesome. To be a little Pythagorean, in them is contained one of the foundation stones of the universe. If the students haven't learned that, they haven't learned any physics. Professor Hla Shwe of East Stroudsburg State College has rewritten part of the book of Genesis as follows:

"And the earth was without form and void. . . . And God said,

$$\text{'Curl } \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J}$$

$$\text{Curl } \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\text{Div } \mathbf{B} = 0$$

$$\text{Div } \mathbf{D} = \rho\text{'}$$

And there was light."

But then nobody likes to go to Sunday school either.

—*Dietrick E. Thomsen*

Sagan, Starfolk, UFO's

Carl Sagan, whose article "The Starfolk" appears in this issue, has probably spent more time studying and writing about the possibilities of intelligent extraterrestrial life than any other scientist in the past decade. So it's natural that he gets many questions about UFO's. But, like most other scientists, he puts little credence in UFO reports. "I don't think UFO's are connected with the problem of intelligent extraterrestrial life," he says, adding, with a smile: "They might be connected to the problem of *terrestrial* life with some *undetermined* degree of intelligence." Speaking to a capacity audience at the Goddard Space Flight Center a few weeks ago during the height of the flurry of UFO reports—"UFO flap, I believe is the technical term"—Sagan summarized his view of the situation this way: "The remarkable thing about UFO stories is that there are many interesting reports which are unreliable; there are many reliable reports which are not very interesting; but I don't know of any that are both interesting and reliable."

Sagan, in response to questions, also had some less than kind words for Erich Von Daniken's book *Chariots of the Gods*, which attempts to show that Earth was visited in the past by beings from other planets. "The book is absolutely dreadful," he says. "The only thing worse is the ABC documentary on the subject [*Ancient Astronauts*]. ABC's program had every conceivable error."

—*Kendrick Frazier*