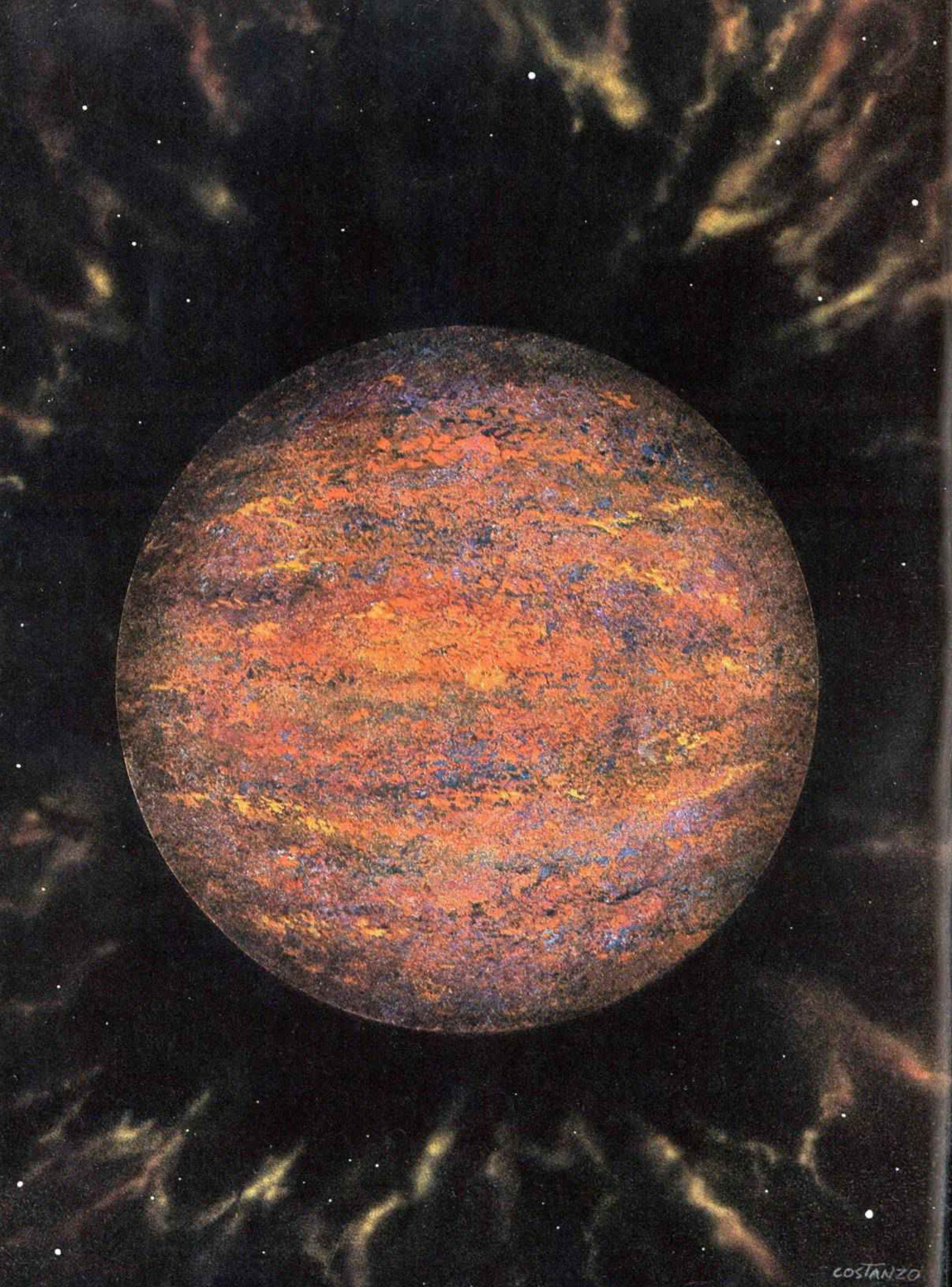

COSTANZO

LIFE ON A NEUTRON STAR

An Interview with Frank Drake

A sphere of matter so dense that every cubic inch weighs a billion tons! Can there be such matter in the universe? Surprisingly, exactly such a form of matter had been hypothesized as long ago as 1939 by Landau in the Soviet Union and Oppenheimer in the United States. But no one at that time actually believed it would ever be observed. Theoretically it would be possible to squeeze all the space out of matter so that the nuclei of the atoms were touching one another. The problem is, of course, how to do it.

The surface of a typical 10 mile diameter neutron star (left) is not a seething inferno of gases like the sun. Instead, its solid surface is surprisingly like a planet's. A leading astronomer speculates that this surface could support a life form more bizarre than the wildest speculations of some science fiction writers. In this illustration artist Victor Costanzo visualizes the tiny, incredibly dense globe of a neutron star — an object whose existence has only recently been uncovered.

Original painting for ASTRONOMY by Victor Costanzo

The suggestion was made that if a large star were to collapse on itself, the gravity would be sufficient to hold the nuclei together against their enormous mutual repulsion once the star had reached a diameter of about 10 miles. Landau and Oppenheimer worked out what would happen in such a star with all these nuclei rubbing against one another and they found that through nuclear reactions, almost all the particles would convert themselves into neutrons. And so they called this hypothetical matter neutron star matter. They showed mathematically that it could exist, though no one ever thought that it would be seen. But since 1967, we have been observing it becouse a pulsar has all the characteristics of a neutron

star and nothing else. (A pulsar is the name given to a neutron star that is rapidly rotating and beaming out regular pulses of energy.)

Dr. Frank Drake, director of Cornell University's 1000 foot Arecibo radio telescope — the world's largest — talked about neutron stars to ASTRONOMY's Terence Dickinson. He spoke of the bizarre nature of these objects and ventured an amazing speculation about life on a neutron star.

First he provided some background information. "If we were to compress Earth to the density of a neutron star," he began, "it would be about 100 yards in diameter. Neutron star matter is totally alien to our experiences. Suppose you had a cubic inch of it in your hand. You let go of it. By the time it reached the floor it would have enough energy to bore a hole all the way through Earth. It would go out the other side and rise six feet off of whatever floor is there and then it would go back down through the hole and oscillate back and forth through Earth for a time no one has ever calculated. By comparison, the matter of which we are made — and our Earth is made — is essentially a high vacuum. It is a vacuum relative to neutron star matter far better than any we can make in our laboratories here on Earth. And yet neutron star matter really exists."

Dr. Drake and other scientists have been studying the nuclear physics that takes place in neutron star matter. They were then able to construct a "model" of a neutron star. They find that the star's interior is almost entirely neutrons with just a small amount of protons and other nuclei. Toward the surface of the neutron star is a region a few miles thick where there are some iron nuclei. The iron nuclei repel one another and arrange themselves in a very regular pattern — a cubic lattice, in the terms of a crystallographer.

This lattice is believed to duplicate the crystalline structure of ordinary table salt. This means the material of a neutron star is acting like a normal solid on Earth, despite the fact that it is an entirely new and different form of matter. Therefore, the exterior of a neutron star is not like a star at all; it is like a planet — like Earth. Earth has a liquid core, like a neutron star, and a solid surface, like a neutron star.

Can we test this theory? "Yes we can," said Drake, "because we would expect the same phenomenon on a neutron star as we see on Earth. If the figure of the object changes, we would expect the crust to crack producing the equivalent of what we call earthquakes. When an object is spinning fast, it's oblate just as Earth is oblate (flattened at the poles). As it spins slower it wants to become more round as the centrifugal force on its equator is reduced and so the shape of the crust is forced to change. As it does so, we should expect to see a cracking of the crust, a starquake in the case of a neutron star. The star will shrink abruptly. Just as when an ice skater pulls in her arms, the neutron star should spin somewhat faster."

Has this ever happened? At the Arecibo observatory, the most famous pulsar, the Crab Nebula Pulsar, was observed for months and all the time a watch was kept for a sudden speeding up of the pulses (and hence the rotation). Suddenly on September 28, 1969, the pulsar abruptly sped up. It has done this four times since then — always abruptly speeding up. This is exactly what was predicted for the idea that the object has a solid crust and has starquakes! The pulsar period shortened by about a millionth of a millionth of a second on those days. And Dr. Drake and his colleagues have calculated that the crust of the pulsar shrank in diameter about 10 millionths of an inch!

So despite the fact that the Crab Nebula Pulsar is six thousand light-years from us, it has been possible to detect a motion of about 10 millionths of an inch. "Ten millionths of an inch doesn't seem like a very big earthquake," Drake continued, "but in the gravity of a neutron star, that is an enormous event because the gravity is about a trillion times the gravity of Earth. When the surface of a neutron star shrinks 10 millionths of an inch, the amount of energy released is the same as the crust of Earth falling 100 miles!"

If there are starquakes, it means the crust is cracking and sliding over itself — something like the continental drifting that builds mountains on Earth. "Therefore," Dr. Drake concluded, "there ought to be mountains, perhaps even continents on the surface of neutron stars. But these 'mountains' would be no higher than about 1/2 of an inch." (A 1/2 inch mountain on a 10 mile object has about the same ratio one to the other as the mountains of Earth compared to the diameter of Earth.)

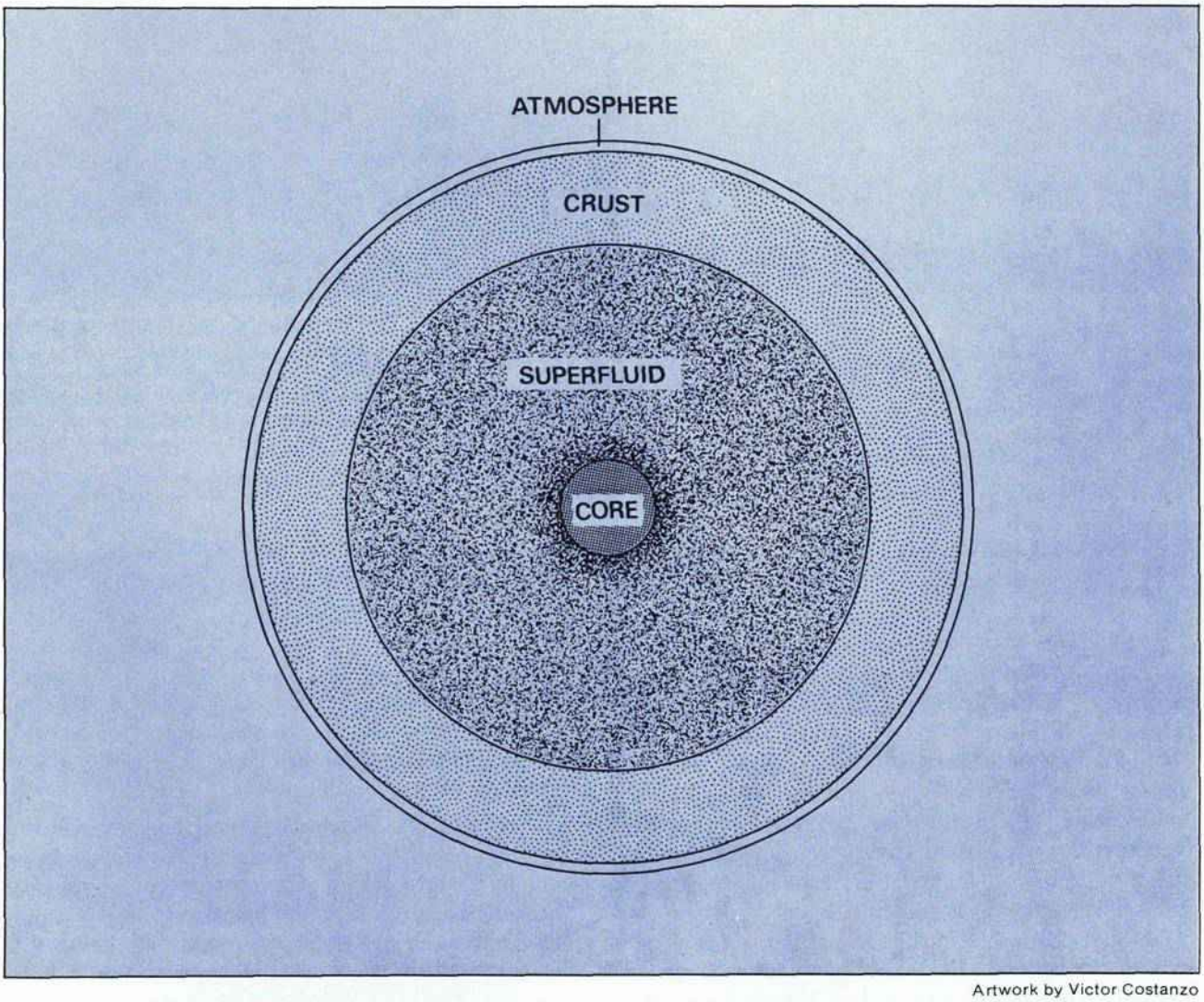
"In a very real sense we have here a scaled down version of Earth." He continued the incredible comparison. "This means we should have 1/2 inch mountains on these objects. And that's a great convenience to any space scientists out there because the atmosphere of a neutron star is only about a 1/4 of an inch high. So if you want to go into outer space from a neutron star you don't need a rocket, you just climb to the top of the nearest mountain and you're there. Well now that's a convenience, but it's not as easy as it sounds, because as you climb, you're fighting the intense gravity. If you work it out, the amount of energy

required to climb that 1/2 inch mountain exceeds the total energy your metabolism can produce in a lifetime. So this isn't a job for individual scientists, it's a job for families. They climb up the mountain, passing the torch from father to son and mother to daughter until finally at maybe the fifth generation they get to the top and look out into space."

As incredible as this mountain climbing anecdote sounds, Dr. Drake did not stop there. The gravity and the temperature (100 million degrees) would seem to make the concept of life on a neutron star not worth discussing, but life on these objects may not be impossible. "It may be more reasonable than the life which is filling this room,"

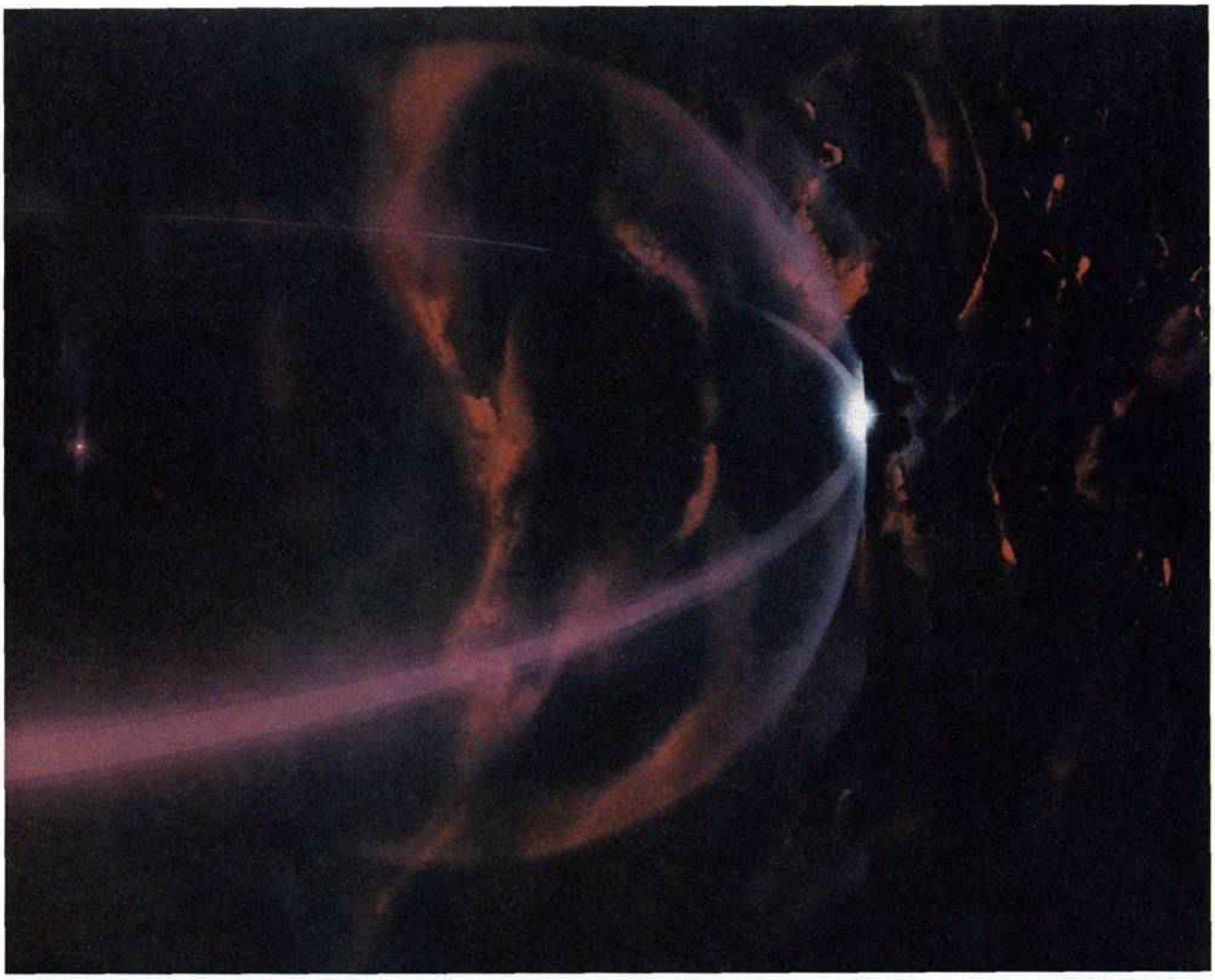
"In the exterior layers of these objects, we don't have atoms," he continued, "but we do have atomic nuclei. And we have more varieties of atomic nuclei in a neutron star than we have varieties of atoms on our Earth. And from what we know of nuclear physics, those nuclei might combine together to form enormous supernuclei, or macronuclei, analogous to the large molecules which make up Earth life. And so as far as we know, it is possibly feasible to reproduce exactly the evolution which occurred on Earth but substituting for atoms and molecules, nuclei and macronuclei. So indeed there could be creatures on neutron stars that are made of nuclei. The temperatures are just right to make the required nuclear reactions go."

The nature of such creatures is as bizarre as the neutron stars themselves. Drake believes they would be so small, a microscope would be required to see them. But they would have all the complexity we do. They could have a brain for example. Yet their life functions proceed at the speed of light, so a lifetime isn't 60 of our years, it's a fraction of a second. Every second of our time would



Artwork by Victor Costanzo

Unlike a normal star, a neutron star has a solid surface of incredible density — so rigid that steel would seem like water by comparison. It is on this surface that Dr. Drake envisions a possible evolution of complex life forms.



Field Enterprises Educational Corp. Artwork

Rapidly spinning neutron stars are also pulsars because of the unique lighthouse-like flashes of energy they emit. At far left is the neutron star rotating several times per second. In its gravitational grip is an immense magnetic field that also rotates at the same rate. At the outer edge of this field, charged particles are accelerated to the velocity of light by the tremendous rotation speed. A beam of particles thrown free from the magnetic field form a "hot spot" (right) that is seen from afar as a pulse of light. The energy emitted there also illuminates the surrounding nebula (remnants of the star's outer layers that were ejected in the pulsar's formation).

span several generations on a neutron star. Since the creation of the Crab Nebula Pulsar in the year 1054, there's even been time for an intelligent species to evolve there.

"And for all we know," said Drake, "out there on a neutron star there's a scientist who is the size of a pinhead describing something which is even more bizarre. He may be trying to show that there could be life 'out there' in those places, the ordinary stars, which are very high vacuums to him. It just could be that it is not they who are preposterous, it is we. Because if you were a neutron star scientist and you looked out into space with a good telescope, you might find some very strange objects which are almost completely a high vacuum and near absolute zero by your standards. Temperatures of a few thousand degrees by earthly standards are about a thousandth of a degree above absolute zero by neutron star standards."

The comparison continued as Dr. Drake pictured a famous neutron star scientist saying, "Our theoreticians have predicted things called atoms ... almost empty space ... we never thought they could exist but they seem to exist out there. Could there be life? Suppose those things bond together to make a big molecule? Well it wouldn't be alive. After all, the temperature is too low and everything happens so slowly that nothing ever changes."

Frank Drake's fertile mind has not yet run dry. He said that if such life exists and has achieved interstellar travel they may be navigating through Earth right now! They would think they were passing through a vacuum. And as they passed through at the speed of light nothing would change. To them, we would be indistinguishable from rocks, and life here would be preposterous.