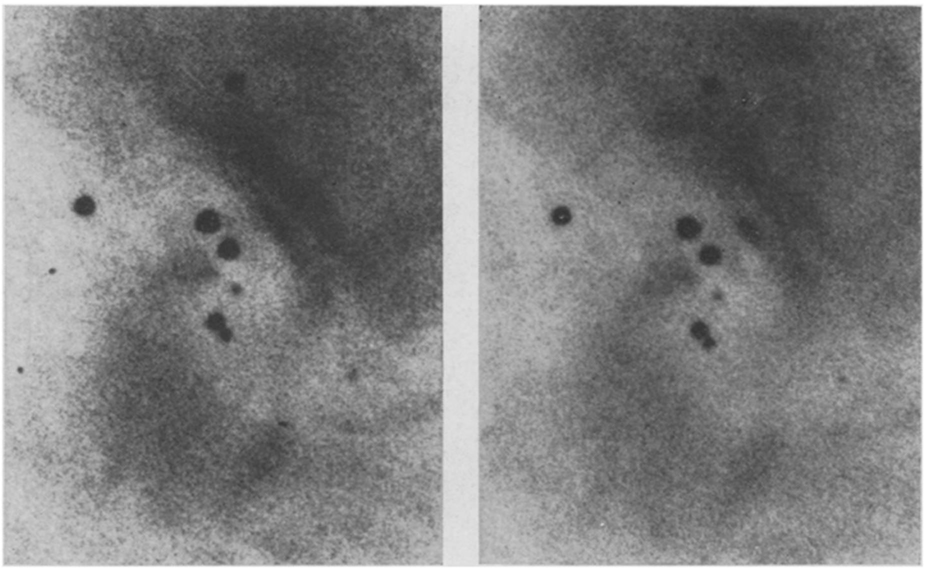
Models from pulsar anomalies

Theorists speculate about cause of recent changes in pulsation rates

by Dietrick E. Thomsen



Lick Observatory

Before and after: Changes in Crab's wisps (above dots) indicate activity.

Last fall two pulsars, NP 0539 in the Crab nebula, and the pulsar in the constellation Vela, suffered sudden increases in the rate of their pulsations. Until they occurred, the pulsation rates of all the known pulsars had been decreasing. After the mysterious increases the two affected pulsars resumed their slowdown (SN: 1/10, p. 43).

Before these events most pulsar theorists had concentrated attention on the magnetic fields and charged particles supposed to form a kind of atmosphere around the pulsar; it is in this atmosphere that astronomers believe the observed radiations are generated. The speed-ups increased attention to the internal structure of the pulsar itself; some astronomers assumed that some change in the body of the pulsar was responsible for the apparent aberration.

Theorizing about the structure of pulsars has led one physicist, Dr. Roman Smoluchowski, professor of solid state sciences at Princeton University, to predict when the next pulse-rate increase will occur. Dr. Smoluchowski says that it will happen in NP 0531 in the fall of 1971, give or take half a year.

He reaches this conclusion by starting from the theory of the structure of neutron stars. A majority of pulsar astronomers believe that pulsars are neutron stars, which are often described as being bodies composed of tightly packed neutrons. In detail, their structure is somewhat more complicated according to the latest theories.

Ordinary stars are gaseous bodies, but neutron stars are so dense and under such extreme pressures that the matter in them assumes the form of solids and liquids instead.

Some months ago Dr. Malvin A. Ruderman of Columbia University proposed a model in which a neutron star is described as comprising a solid outer shell with a liquid core, both unlike solids or liquids found anywhere else and both the product of the star's peculiar genesis.

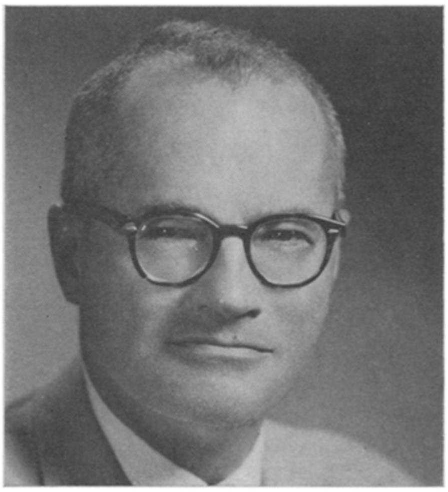
Neutron stars are supposed to be created when an ordinary star explodes into a supernova. The outer parts of the star are blown into a large diffuse nebula according to theory, and the inner parts are squeezed into a neutron star. The Crab nebula is a case in point: Its explosion was recorded in 1054 A.D.; the pulsar NP 0532 is taken to be its neutron star.

When the matter in such a star is squeezed to densities between 10^8 and 10^{14} grams per cubic centimeter, says Dr. Ruderman, the electrons in the atoms are accelerated to near the speed of light. At such speeds the attractive forces of the nuclei do not hold the electrons, and the electrons do not form clouds around the nuclei, screening and neutralizing their positive charges.

The lack of an electron screen gives the repulsive forces among the nuclei free play, and the mutual repulsions balanced by gravitational attractions constrain the nuclei to arrange themselves into a solid lattice of the type called body-centered cubic.

Dr. Ruderman calculates that the melting point of this neutron star solid is about 10 billion degrees K. when the density is between 10^{12} and 10^{14} grams per cubic centimeter. "A neutron star, whatever its original temperature," says Dr. Ruderman, "will cool below such melting temperatures in well under a minute." This would permit the crust to crystallize down to a depth where the density is 10^{14} grams per cubic centimeter soon after the star is formed.

For a neutron star with a mass about equal to the sun's mass, and with a supposed radius of 10 kilometers, the crust would be about 200 meters deep. A lighter neutron star, say a third the mass of the sun, would not be so dense and the crust would take up most of the star's radius.



Orren Jack Turner

Smoluchowski predicts speedups.

Inside the crust is a fluid in which mostly neutrons and a few protons play the part of the atoms of a normal liquid. The neutron star fluid would be a frictionless, zero-viscosity superfluid of the sort that liquid helium becomes when it is cooled below two degrees K.

The increases in pulse rate, Dr. Ruderman suggests, result from sudden readjustments of stresses in the crust of the neutron star. The stresses are caused by the gradual slowing of the star's rotation as a result of its loss of energy through radiation.

When a neutron star is first formed it spins rapidly, and centrifugal forces give it an oblate shape. As the spinning slows, the centrifugal forces drop off, and the star's self-gravitation pulls it more and more toward a spherical shape. The drop-off of the centrifugal forces produces stresses in the crust since the crust originally solidified in

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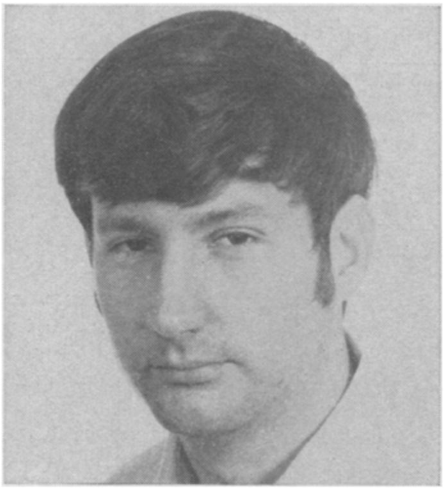
Princeton Univ.

Welch: Plastic deformation theory.



Lick Observatory

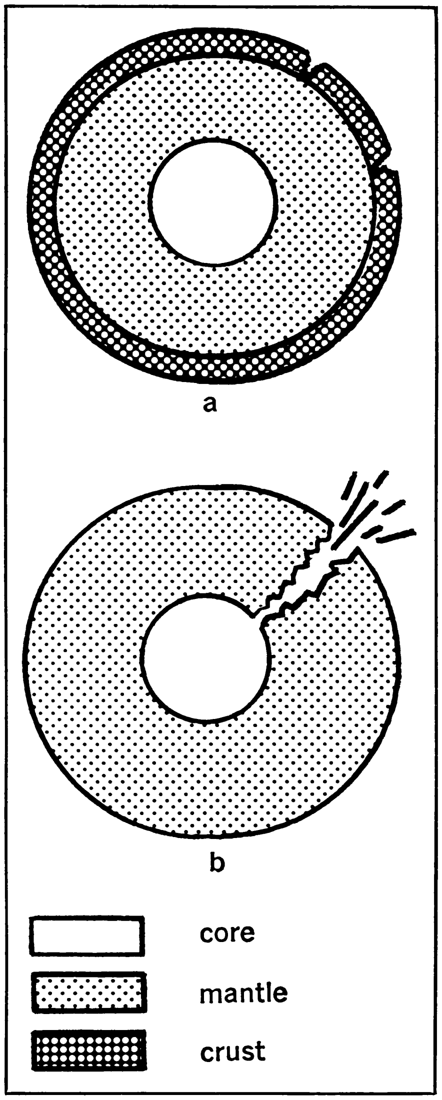
Scargle: Sudden release of energy.

the oblate shape and cannot readjust gradually. When the stress becomes too great, the crust readjusts violently, and the sudden change in shape gives the star's rotation a kick. But the braking effect of the pulsar radiation remains; after the kick the slowing of the rotation resumes.

Dr. Ruderman makes no definite predictions from his model.

In the pulsar lattice postulated by him, the spacing between nuclei is about 5 x 10^{-12} centimeter, or 10 times the nuclear size. The relative openness of this lattice and the other properties of the neutron star solid, such as melting point and density, led Dr. Smoluchowski and Dr. David O. Welch, assistant professor of solid state sciences at Princeton, to conclude that, instead of being rigid and brittle throughout, the solid was susceptible to gradual deformation like a plastic.

The conditions in the neutron-star solid at 10 billion degrees K., Drs. Smoluchowski and Welch contend, correspond to those in ordinary metals at 10 degrees K. At such temperatures ordinary metals are subject to plastic deformation, and from this they conclude that under the hypothesized conditions the neutron-star solid should also be subject to plastic deformation.



Robert Trotter

Pulsar speed-up theories include (a) quakes and (b) volcanic bursts.

As a result of their calculations Drs. Smoluchowski and Welch propose a model in which a neutron star consists of a super-fluid core surrounded by a solid mantle that deforms gradually as the shape of the star changes, and a thin brittle shell that cracks from time to time.

For the slower spinning, older pulsars, which are changing shape slowly, starquakes should be rare; for the fastest pulsar, NP 0532, Dr. Smoluchowski gives the expected frequency as something between 1.5 and 5 years, but he leans toward a 2-year period, and on this he bases his prediction of 1971.

"If it doesn't happen," he says, "we will have to go back to the drawing board."

Meanwhile others are at the drawing board producing different theories.

Dr. Freeman Dyson of the Institute for Advanced Study at Princeton proposes a volcano theory of pulsar-rate increases. He accepts the notion of a liquid core surrounded by a solid crust. But he suggests that fissures form in the crust and go all the way through. Liquid matter from the core comes through the fissure under high pressure, in analogy to a terrestrial volcano, and the reaction to this release of liquid gives the star's rotation a kick.

Two astronomers at the Lick Observatory of the University of California at Santa Cruz, Dr. Jeffrey D. Scargle and E. A. Harlan, propose still another theory, in which changes in the body of the pulsar have nothing to do with the changes in pulse rate. Their hypothesis arises from observations of changes in the so-called wisps in the Crab Nebula, long, stringy features of the nebulosity. These wisps underwent changes in brightness and shape at a time that suggests the changes may be somehow connected with the rate increase of NP 0532.

So much energy is involved in the changes in the wisps that if they are connected to the rate changes, Dr. Scargle and Harlan reason, that amount of energy could not have been released by a simple change in the shape of the pulsar body. They suggest therefore that some as yet unexplained mechanism stores up energy in some part of the plasma of charged particles that surrounds the pulsar. From time to time this energy is suddenly released. Part of it sends out streams of particles that activate the wisps; part of it reacts back on the pulsar body to give it a kick.

Dr. Scargle and Harlan suggest that since activity in the wisps comes at approximately two-year intervals, that may be the periodicity of the pulse-rate increases, but they do not go so far as to predict the date of the next one. If their theory is correct, the next one will have to be accompanied by activity in the wisps. For the starquake theory, it need not be.

Both these theories have their drawbacks.

The theory of Dr. Scargle and Harlan cannot be applied to observations of the Vela pulsar or any other because none of them is surrounded by a visible nebulosity in which activity can be seen. The starquake theory suffers because it makes starquakes extremely rare events in most pulsars. On this basis, says Dr. Ruderman, it is a surprise that a quake should have been seen in the Vela pulsar after only one year of observation. And he adds, "It makes one a little uncomfortable with the idea of starquakes. I'm a proponent of this model, but I don't think there's more than a 50-50 chance that that's what's happening." ☐