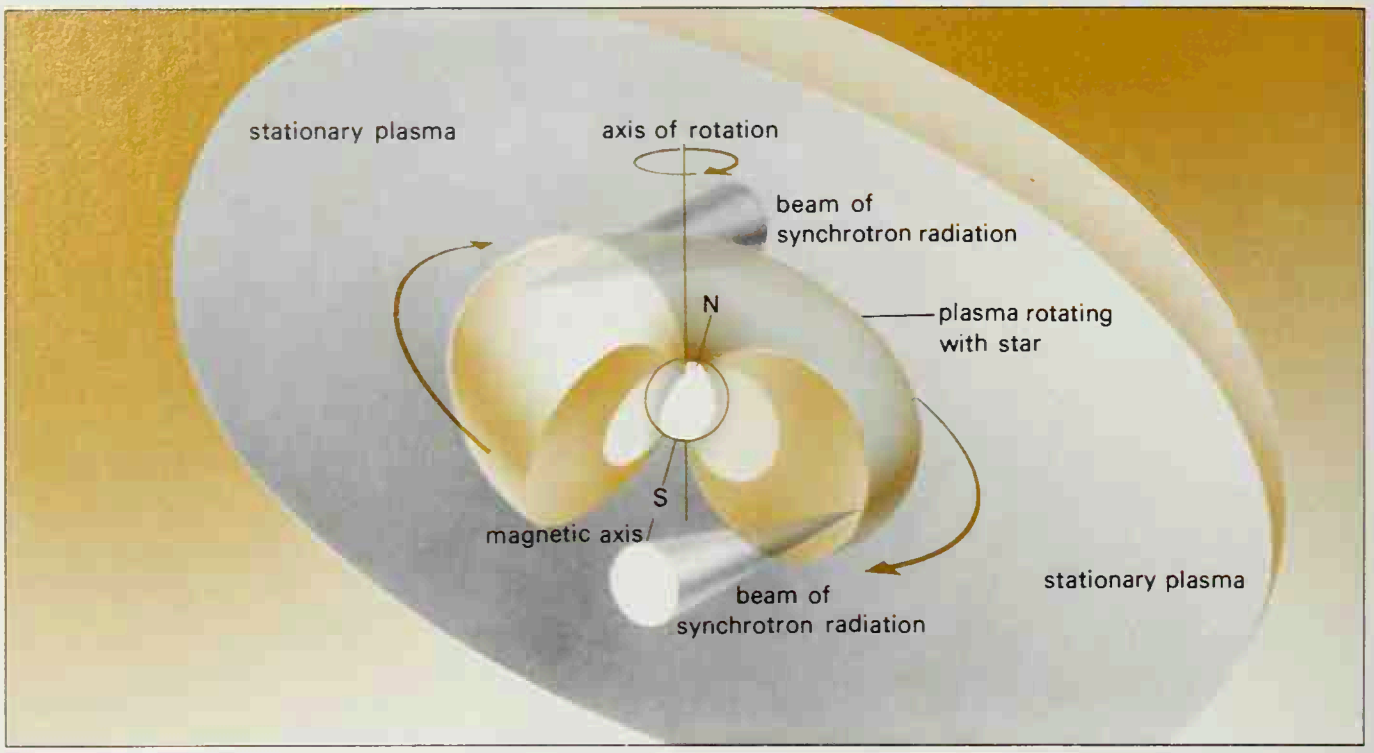

Fig. 3·26 A 'lighthouse theory' model of pulsar emission from a rapidly rotating magnetic neutron star. The magnetic field is exceptionally strong and rotates with the star. Swept up plasma is accelerated until, at the periphery where it decouples from the magnetic field, highly directional radio beams are emitted.

The Crab pulsar has a period of 33 milliseconds (ms), and, although extremely regular, it was eventually observed to be increasing gradually. This was only just perceptible, but its existence proved dramatically important in solving a mystery of the Crab Nebula, which is the remnant of a supernova explosion observed by Chinese and Arabic astronomers in 1054 AD. The mystery arose over the radio, optical and X-ray emission we now detect from it. This radiation gives every evidence of being emitted by the synchrotron process, so that its intensity must depend upon the strength of the magnetic field and the energy of the electrons. As the field in the Crab is known, the electron energies can be calculated, and it is found that up to 10^{14} electron volts are needed to explain the X-ray emission. Yet such high energy electrons would lose energy within the nebula itself in a few months. As the supernova occurred over nine hundred years ago, the mystery was how the electrons could obtain their high energies. The existence of a spinning neutron star solved the problem: the loss of energy it suffers by its observed slowing down is sufficient to explain the energy required to feed the electrons to produce the observed radiation. In fact, the neutron star acts as a powerhouse.

Observations of a few pulsars, of which the Crab is one, have shown that the regular periods occasionally go haywire and suffer a hiccup, known in the jargon as a **glitch**. These are now believed to be starquakes, caused by stresses as the neutron star undergoes its spin down. Eventually these are sufficient to cause the crust to deform and, being extremely rigid, it cracks. This causes an internal readjustment which manifests itself to us as a glitch. It is now generally suspected that neutron stars are born spinning exceedingly quickly but gradually lose energy and rotate more slowly until, after a few thousand years, their periods settle down to the order of seconds.

One pulsar (known as PSR 1937 +215) has a period of only 1·55 milliseconds, one-twentieth of that of the Crab pulsar. This is so fast that it must be spinning at about 90% of its disruption speed, if current theories are correct. It has been tentatively identified with a 22nd magnitude object, and if this is verified will be only the third pulsar to be optically confirmed, the Crab and the Vela pulsar (known to be a star of 25th magnitude), being the others. One other 'millisecond pulsar' is now known, and their high rate of spin suggests that they are very young objects.

The discovery that the pulsar 1913 +16 is one component of a binary system with an orbital period of 7·75 hours, offered the possibility of an independent test for the various gravitational theories which have been proposed. Studies have shown that both stars are compact objects with masses of about 1.4 $M_\odot$ (in accordance with the theoretical predictions for neutron stars), and that they are in a very close orbit, which is also highly eccentric. Einstein's general relativity theory (and one or two other versions, especially the Brans-Dicke theory) predict that when ultra-dense objects like these are in such close orbits, they should lose energy by the emission of gravity waves (page 244), and cause the orbital period to decrease. Such a decrease has now been detected for this object, and it proves to be of precisely the right amount. Moreover, theory also predicts that an eccentric orbit should precess, and this has also been confirmed, measurements having shown that it occurs at the enormous amount of 4·2 degrees per year (which may be compared with the 43 arc sec. per century for the precession of the perihelion of Mercury). There is just a slight shade of doubt over the nature of the pulsar's companion star, which could possibly be a white dwarf or helium star. However, the likelihood of this is very small indeed, and for the moment this object appears to provide striking confirmation that the theory of general relativity is correct.

Neutron stars are also thought to be associated with the sources of gamma rays which have been detected by certain spacecraft. The Crab pulsar, the Vela pulsar, and another object known as Geminga