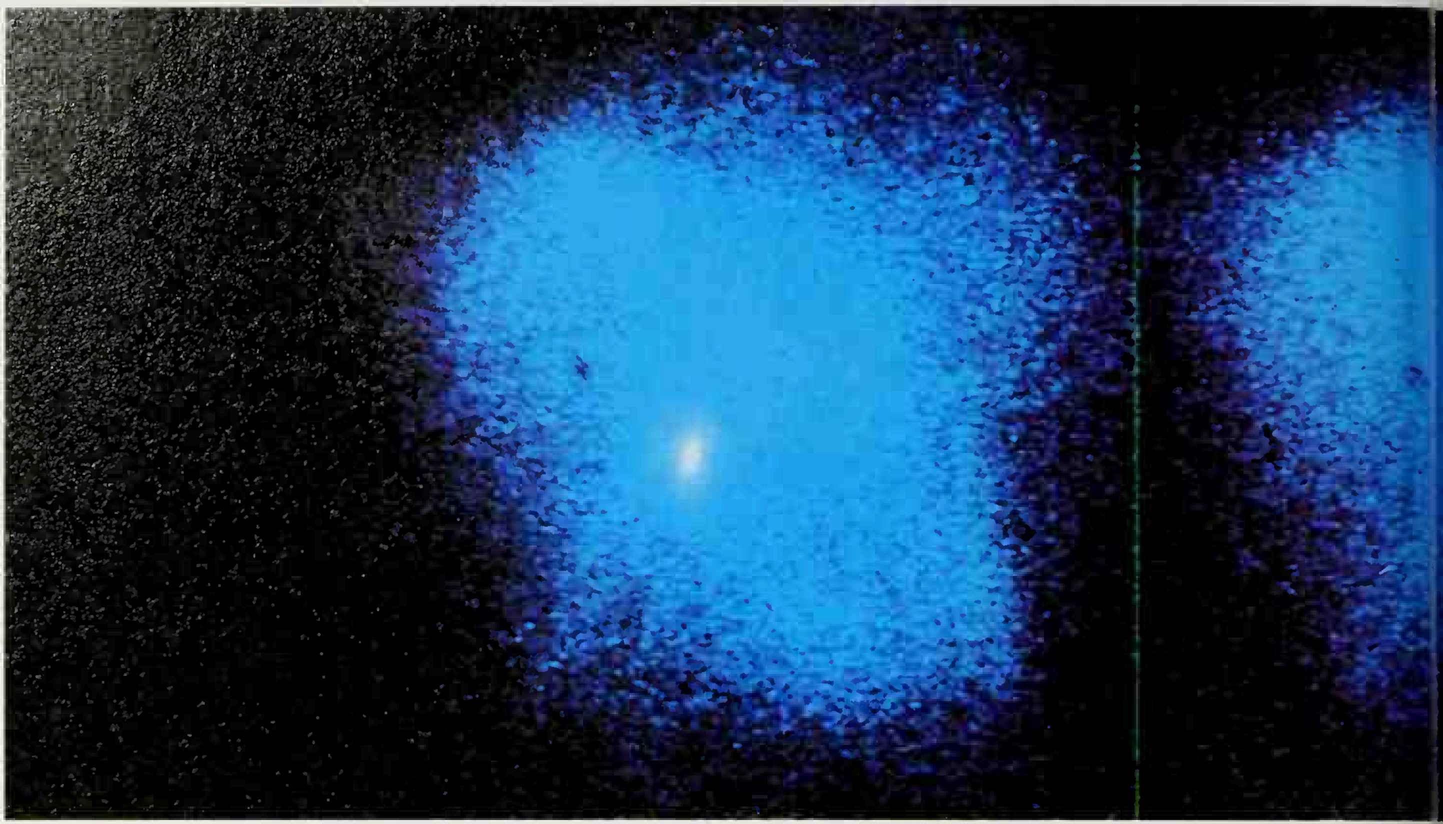
This pair of X-ray observations of the Crab pulsar by the Einstein satellite shows 'on' (left) and 'off' phases, just like those seen at optical wavelengths (page 71).



body, nuclear particle or photon of radiation, inside this boundary is forever trapped and isolated from the rest of the universe. Other names for this boundary are **event horizon** and 'speed of light surface'. This then is the concept of a black hole; events within this horizon are completely unknown to an external observer, and the theory ensures 'cosmic censorship' by stating that naked singularities can never exist, they will always be clothed by a black hole.

The size of the Schwarzschild radius R_s, is given by a simple expression:

$$R_s = 2GM/c^2,$$

M being the mass of the body. For the Sun, R_s turns out to be 3 km. Because the Sun is much larger than this we need not worry, but if it were to shrink to this size, then it would indeed become a black hole. A neutron star has a mass equal to the Sun and a radius of 10 km, therefore if it were to shrink by only a factor of three, it would turn into a black hole. How can it be made to shrink? Simply by adding mass until its critical mass is exceeded and it will then immediately collapse into a black hole. All further 'information' would then be lost (another form of 'censorship') because we can never know what happens in the depths of a black hole. Anything can go in but nothing, not even light, can escape. Black holes could act as the ultimate refuse disposal agent for the Galaxy, swallowing everything and spewing out nothing.

Do black holes exist? How can they form? These two most tantalizing questions can be partially answered if we consider the evolution of a massive star. As it evolves it eventually exhausts its nuclear fuel and explodes as a supernova. One of three events can then ensue: the core can be completely destroyed in the supernova explosion; or if something of the core remains and is sufficiently small, it will form a neutron star; if, though, it is too massive the core will collapse to form a black hole. For stars whose masses greatly exceed 10 $M_{\odot}$, their fate is either complete disruption or the formation of a black hole. Because we know such massive stars exist in the Galaxy, we suspect the existence of black holes as one natural end-product of stellar evolution. Other mechanisms for black-hole formation involve the influx of material on to a neutron star which is a member of a binary system, thus easing it over its critical mass so it will collapse; or, more speculatively perhaps, the collapse of the massive, dense, central regions of globular clusters and giant galaxies. The sizes of black holes and other stars are shown in Fig. 3·27.

If we were to witness a massive star collapsing to a black hole (albeit from a safe distance so that we were not swallowed inside the Schwarzschild radius) we would again have a surprise. Someone in a space suit orbiting the star would be trapped with the collapse and would plunge into the singularity to be crushed out of existence as the gravitational forces increased. Indeed, if they fell in feet first they would be stretched like a piece of spaghetti because the gravitational force on the feet would vastly exceed that on the head. To us watching from a distance, however, the events of the plummet into oblivion would seem to take an infinite time to reach the point of no return – the Schwarzschild radius. These and other more peculiar effects are a consequence of the theory of relativity and the extreme distortions of space and time by the singularity (see Chapter 8).

Black holes are masses which do not radiate, hence the name. However, their gravitational fields are still present and can influence any close passers-by. This gives us a clue for black hole detection. As a member of a binary system, a black hole might visibly perturb the orbit of an observable primary. If this mass can be found then the mass of the secondary might be deduced, and if it turns out to be too great for a white dwaf or a neutron star, then it must be a black