

White holes: cosmic energy machines

White holes are the poor relations of black holes, neglected by the mainstream of astrophysics. A new concept of a cosmic oscillator, however, accords equal roles to both

Jayant Narlikar

BLACK HOLES have occupied the centre stage in astronomy and astrophysics for a decade and a half.

From the "mini", weighing as little as an amoeba or only one hundred-millionth of a kilogram (10^{-8} kg) to the "supermassive" with a mass one thousand million times that of the Sun, they have been invoked to account for a wide range of cosmic phenomena. By contrast, their counterparts, white holes, have been neglected. But some new ideas incorporate both concepts and point the way to a role for white holes that is equally important to that presently accorded to black holes.

What are white holes? To answer this question we first recall the standard description of the birth of a black hole through the phenomenon of "gravitational collapse". A star like the Sun can preserve a steady configuration because the thermonuclear reactions in its core generate high temperatures that result in strong outward pressures. These counteract the tendency for the body to contract under its own gravitational pull. Self-gravity would shrink the Sun to a point in a mere 29 minutes, if the outward thermonuclear pressures were absent.

But when the nuclear fuel runs out, the star contracts until its matter becomes highly dense. The contraction is eventually halted when the subatomic particles enter a "degenerate" state in which the space available for each particle hits a lower limit set by quantum mechanics. The competition for space generates an outward pressure, holding the star in a new equilibrium; the star then becomes a white dwarf or a neutron star, depending on its mass. The greatest mass a white dwarf can have is 1.44 times the Sun's mass; neutron stars cannot be heavier than about two solar masses. Any more massive star that exhausts its nuclear fuel will collapse completely under its own gravity. Supermassive objects—with masses as high as, say, a hundred million times that of the Sun—would collapse even with the resistance provided by thermonuclear reactions; in other words, before the fuel runs out.

An observer watching such a collapse from a nearby star would lose sight of the collapsing object. When the star reaches a point where its total surface area equals that of a sphere of radius $2GM/c^2$, it disappears and becomes a black hole. Here, G is the gravitational constant, c the speed of light, and M is the mass of the star, so the crucial radius, called the Schwarzschild radius, depends only on the collapsing star's mass; for a star of the Sun's mass the Schwarzschild radius equals about 3 kilometres. As the object shrinks further, no signals from it can cross the sphere

with the Schwarzschild radius, not even light. This barrier, containing the black hole, is called the *event horizon*.

Although the observer on another star loses touch with the collapsing object at this stage, the object itself still has a future. An observer sitting on the star's surface could, in theory, trace the history of the object as it continues to shrink until it reaches the so-called space-time singularity, when all its mass is concentrated into a point. Albert Einstein's theory of general relativity suggests that the singularity marks the end of the future of the object. An object the size of the Sun would take 29 minutes to collapse to a singularity under its own gravity—at least that would be the time measured by an observer stationed on its surface before he too vanished into zero dimensions.

An interesting feature of the general theory of relativity is that it should not matter whether time is running backward or forward: it is time-symmetric. In principle, then, there is no reason why a star's collapse could not be reversed. In the gravitational collapse of a massive star, the outer surface crashes through the event horizon into the space-time singularity (Figure 1a). In the time-reversed case, the object emerges from the space-time singularity to come out through the horizon and attain an extended form (Figure 1b). This object is a "white hole".

The argument based on time symmetry applies only to the frame of reference of a person on the surface of the object and moving with it. To a remote observer at rest relative to the centre of the object, the two pictures of expansion or collapse are manifestly not symmetric.

The most dramatic difference in the two pictures as seen by the remote observer is in the nature of radiation he receives from the object. Figure 1a illustrates the situation in the collapsing stage. Imagine a source at B on the collapsing surface, S , sending light waves radially out to the remote observer at A , who is stationary with respect to the centre of the object. The wavelength of the light increases as it passes from A to B for two reasons. First, because the source and observer are moving away from each other the doppler effect causes an increase in wavelength. Secondly, as first discussed by Einstein, light going from an area of strong gravitational field to a region of weak gravitational field increases in wavelength.

An astronomer can measure this increase in wavelength if he can identify some emission lines in the spectrum of the object. If the wavelength of a line produced in the observer's laboratory at A is λ_0 and the wavelength of the same line

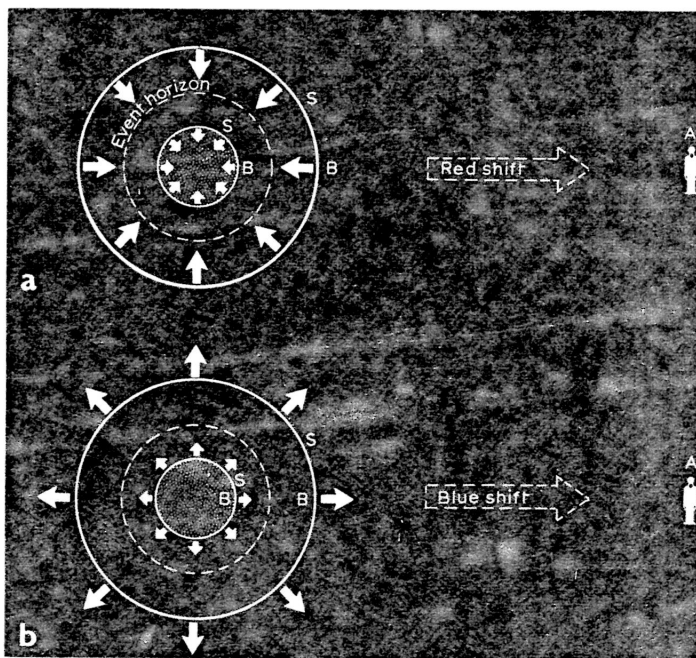


Figure 1a Gravitational collapse of a massive object leads to the formation of a black hole (once the surface S has receded behind the event horizon) and ends in a space-time singularity. **b** In the time-reversed case a massive object emerges from a singularity and expands rapidly; this is a white hole

observed in the spectrum of the collapsing object is λ , then the fractional increase $z=(\lambda-\lambda_0)/\lambda$ is called the *red shift* of the spectral line.

Consider next what happens in the case of a white hole. The radiation from *B* to *A* is again subject to both doppler and gravitational effects (Figure 1b). However, they no longer act in the same way. As before, the gravitational effect tends to increase the wavelength, because light is passing from a region of strong gravity near *B* to a region of weak gravity near *A*. Notice, however, that the surface *S* is now moving *towards A* and the doppler effect tends to decrease the wavelength, to produce a *blue shift*.

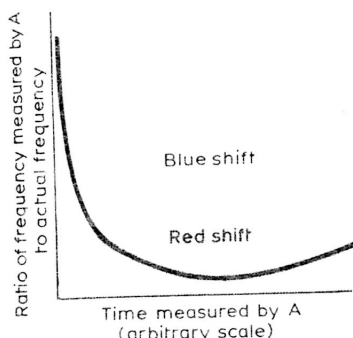


Figure 2 The shift in frequency of radiation from a white hole as measured by an external observer

The net effect at *A* will now depend on the dynamical details of a white hole's expansion. Qualitatively the answer is illustrated in Figure 2 where the observed spectral shift is plotted against the time measured from the instant that the first signal from *B* reached *A*. Notice that in the initial stages the doppler effect dominates and there is a strong blue shift. But when, however, the expansion slows down, the gravitational effect begins to assert itself. Eventually the blue shift declines to zero and changes over to a red shift. The epoch of blue shift is usually confined to the time when the object is still inside the event horizon.

To someone familiar only with black holes, this behaviour of a white hole comes as a surprise. But it is based on a reasonable argument; and the strong blue shift seen in the early stages of explosion justifies the adjective "white".

How would an observer at *A* see the white hole? While examining the spectral shift we considered the radial rays from the white hole. Its overall appearance, however, depends also on non-radial rays. Moreover, the observer at *A* forms a picture of the white hole on the basis of all the light rays that reach him at the same time. Not all of these rays will have left the object when it was of the same size. Some rays, which took a longer time to travel, left the white hole earlier (when it was smaller) while others, which took less time to travel, would have left the white hole later (when it was bigger). We also have to take into account the passage of light rays through the highly curved space-time near the expanding object. In the very early stages the white hole

appears to expand at a rate several times the speed of light, as I explain in an article written with R. C. Kapoor in *Astrophysics and Space Sciences* (vol 53, p 155).

What of the blue shift of light from white holes? Can we relate this property to any observable features of the Universe? In 1975, Krishna Apparao and I discussed this point in a simplified model of a white hole (*Astrophysics and Space Sciences*, vol 35, p 321). We assumed the white hole to be made of homogeneous dust, that is, matter free of pressure. That assumption enabled us to calculate explicitly

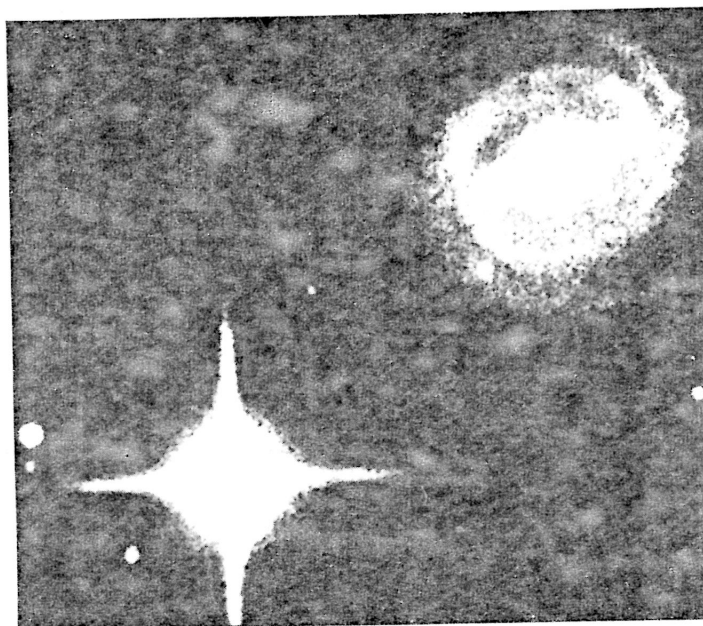
many dynamical effects associated with the white hole. For example, if the expanding surface *S* emits monochromatic radiation of fixed intensity, then during the time of the strong blue shift the intensity of the white hole varies simply in proportion to the cube root of the frequency. Conversely, given the observed relation between intensity and frequency of radiation from an exploding object, we can determine the spectrum of the emitting surface *S*.

The exploding nuclei of galaxies such as the Seyfert galaxies (Figure 3) could be candidates for white holes. Transient X-ray sources in our own Galaxy could be associated with white holes of stellar mass. Sir Fred Hoyle has argued that "extra-supermassive" white holes on the scale of 10^{14} solar masses have ended up as large clusters or super-clusters of galaxies. And, of course, on the largest scale, the Universe itself, expanding from the big bang, may also be looked upon as a white hole erupting from a singularity.

The short period of large blue shift should manifest itself as a burst of high frequency photons (Figure 2). Could the bursts of gamma rays detected by astronomers over the past

decade, and still not accounted for, possibly be white holes? Our simple model of 1975 showed that a white hole with the mass of a star can explain a galactic gamma-ray burst 10 seconds long. The "softening" of the spectrum (the steady increase in the relative proportion of lower energy photons) is a stamp of white-hole radiation that is often found in gamma-ray bursts.

The concept of a white hole was mooted in the early 1960s. Why has it not caught on? I can think of two reasons. The first is a matter of taste. The formation of a black hole is fairly well understood in astrophysical terms. Its end, that is, the singular future that lies ahead for the collapsing object, is no doubt peculiar; but, at the same time it is hidden from the external observer by the event horizon. By contrast the white hole originates in a space-time singularity and the horizon does not prevent us from viewing this strange event. The physicist tends to be unfavourably disposed toward systems whose beginning he cannot understand, and this

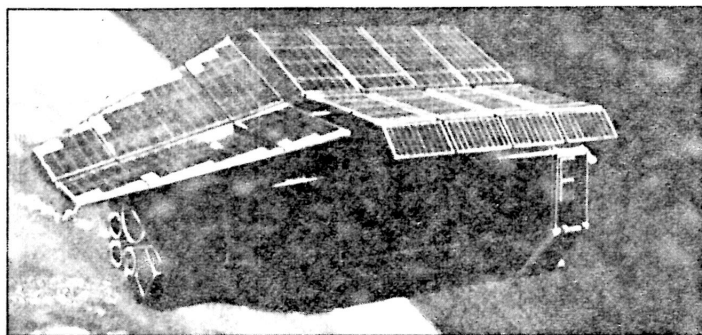


Royal Observatory, Edinburgh



Royal Observatory, Edinburgh

Figure 3 Is there any evidence for white holes? Seyfert galaxies, such as these barred spirals NGC 3783 (above) and NGC 1365 (left) have extraordinarily violent processes occurring in their nuclei. Could these explosive nuclei indeed be white holes?



X-ray satellites, such as NASA's Einstein Observatory (now defunct) reveal energetic events within the Universe

NASA

attitude accounts for part of the antipathy towards the concept of white holes. (Strangely enough, this attitude does not manifest itself in cosmology where the singular origin of the Universe is accepted as a matter of fact.)

The second reason is a mathematical one, raised in 1974 by D. M. Eardley (*Physical Review Letters*, vol 33, p 442). Eardley discussed the strange topology of space-time near the origin of a white hole and argued that the expanding surface S "sees" an avalanche of incoming matter from the surroundings. This apparent infall is so fast as to smother the expanding white hole. Eardley's argument suggests that a white hole would be a highly unstable object and that soon after its formation it would be converted into a black hole as it gathered surrounding matter. For this reason a white hole cannot serve as a viable energy machine.

A white hole enthusiast may react to the above criticism both positively and negatively. A negative response would run something as follows. One could point out that supporters of the concept of massive black holes are also batting on a sticky wicket. There is as yet no general relativ-

istic demonstration that a collapsing and rotating super-massive object of about 100 million solar masses can survive as a single coherent entity to become a black hole. Yet many theories based on black holes proceed on the tacit assumption that such objects exist in the Universe. One could also point out that explosions on a large scale are observed in the Universe, and on empirical grounds these could be considered evidence for white holes. Nor can the stability argument be regarded as the last word, as we do not know whether general relativity itself will be valid right up to the space-time singularity.

But we can be more constructive than this, using a new idea that unifies the concepts of black hole and white hole. Let me go back to my earlier discussion of gravitational collapse. I noted that a star collapses if the internal pressures in the object cannot resist the gravitational contraction. This argument tacitly assumes that once the collapse begins there is no hope of stopping it at a *later* stage. The reason behind this assumption is that the force of gravitational contraction becomes stronger as the collapse proceeds and the gap between its power and the resistance offered by any surviving internal pressures widens with time. Indeed, general relativity tells us that any agency put in to oppose gravity must have energy. The energy has an equivalent mass and so it attracts matter and therefore increases the force of gravity. For this reason, beyond a certain stage, any remedial measure to counteract gravity becomes self-defeating.

This argument does have a loophole. Suppose there exists a gravity-opposing agency with negative energy, which grows in strength faster than gravity as the object contracts. Such an agency generates a repulsive force which eventually becomes so strong as to halt the contraction of the object and to make it "bounce". Recently Apparao and I explored the possibility of the existence of such bouncing objects (*Astrophysics and Space Sciences*, vol 81, p 397).

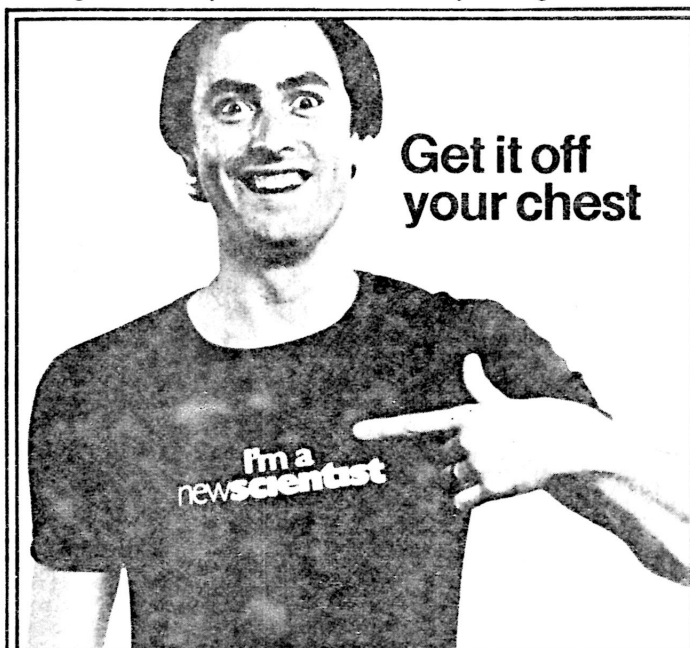
In the early days of general relativity, Einstein himself proposed a repulsive force, the so called λ -force. This force grows in strength as the distribution of matter expands and is not useful in the present context. Another repulsive force, the so-called C -field that Fred Hoyle and I used in the context of the steady-state cosmology, does however fill the bill admirably. It modifies the scenario of gravitational collapse in the following way.

A massive object containing a small quantity of C -field begins to collapse when the pressure is no longer adequate to prevent it. At this stage the C -field is also ineffective in stopping gravitational contraction. However, as the object shrinks the C -field grows in strength and ultimately succeeds in causing a bounce. The object thereupon begins to expand, and it will rapidly pick up speed. As it continues to expand, the speed drops and the expansion eventually comes to a halt. This completes one cycle of oscillation.

This oscillator therefore resembles a black hole during contraction and a white hole during expansion. The resemblance is not exact, however! At no stage does the outer surface of the object go inside the event horizon. This condition is satisfied even though the minimum size of the oscillator is quite small (Figure 4).

The massive oscillator combines most of the virtues of the black hole and the white hole without their awkward features such as the space-time singularity and the event horizon. And it provides a useful explanation for the power house that fuels certain cosmic sources. The purist may, however, still balk at the idea of a negative-energy field, even though to date the C -field is not known to have led to any conceptual difficulty either in classical or quantum physics. In the last analysis the need for such ideas will be dictated by observations of violent phenomena in the Universe. $\square$

Professor Jayant Narlikar is an astrophysicist at the Tata Institute of Fundamental Research, in Bombay, India. His book, *The Lighter Side Of Gravity*, was published recently by W. H. Freeman.



Come out of the closet and tell the world that you're a scientist and proud of it. With your *New Scientist* T-shirt, no-one can mistake you for a dustbin man, an astronaut or a politician. The message is printed in white on a good-quality dark blue shirt and costs only £2.95 inc. postage & packing. State size: small, medium or large. Send your cheque or P.O., payable to New Scientist, to the Publisher, New Science Publications, Commonwealth House, 1-19 New Oxford Street, London WC1A 1NG. Please allow 21 days for delivery.