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High energy radiation from white holes

COMPARED to black holes, their time-reversed versions, white holes have attracted little attention from theoreticians. Here we point out possible ways in which white holes may be useful to high energy astrophysics.

Basically a white hole is an object exploding from a highly dense or a singular state. It may be a case of delayed big bang[1] in a Friedman universe, or it may be an instance of a collapsing object reversing implosion to explosion. For the latter possibility unconventional equations of state[2] or negative energy fields[3] are required if the theoretical framework is that of general relativity[4]. We will take the white hole to be an object exploding from a singularity and obeying Einstein's equations of gravitation subsequent to the singular event. Before turning to the astrophysical implications we calculate the spectral features to be expected from a white hole.

For simplicity we make the following assumptions: (1) The white hole emerges from the singularity as a spherical object of uniform density and zero pressure in the comoving frame of the outward moving particles; (2) the light emitted by the white hole is monochromatic and is being emitted radially outwards from the surface at a uniform rate in the comoving frame of reference; (3) the space-time exterior to the object is empty.

The comoving frame of reference in the interior will be denoted by coordinates (r, θ, Φ, t) in terms of which the line element within the object is given by

$$ds^2 = c^2\, dt^2 - S^2(t)\, [dr^2/(1-\alpha r^2) + r^2\, (d\theta^2 + \sin^2\theta d\Phi^2)] \quad (1)$$

where c = speed of light, $S(t)$ is the expansion factor and α a parameter related to the mass M and the comoving radius r_b of the object by

$$2GM = \alpha r_b^3\, c^2 \quad (2)$$

The similarity of equation (1) to the Robertson–Walker line element of cosmology is well known. Also, if we change t to $-t$, equation (1) represents a freely collapsing ball of dust.

For convenience we will measure t from the instant of explosion so that $S(0) = 0$. For $t > 0$, $S(t)$ satisfies the equation

$$S\dot{S}^2 = \alpha c^2\, (1-S) \quad (3)$$

so that it attains its maximum value $S = 1$ at

$$t = t_0 = \pi/(2c\sqrt{\alpha}) \quad (4)$$

We will investigate light emission from the white hole in the interval $0 < t < t_0$.

The space exterior to the white hole is described by the Schwarzschild line element

$$ds^2 = [c^2 - (2GM/R)]\, dT^2 - dR^2/[1-(2GM/c^2R)] - R^2\, (d\theta^2 + \sin^2\theta d\Phi^2) \quad (5)$$

A typical Schwarzschild observer has R = constant, θ = constant, Φ = constant. We wish to calculate the spectrum of radiation from the white hole as seen by a Schwarzschild observer with $R = R_1 \gg 2GM/c^2$. In accordance with our assumption (2) we will take the luminosity spectrum of the white hole as $L\, \delta(\nu-\nu_0)$, where L = constant.

To calculate the spectrum received at R_1, define

$$S = \sin^2\theta,\ 0 \leqslant \theta \leqslant \pi/2 \quad (6)$$

Then θ as a function of comoving time coordinate t is given by

$$t = (2t_0/\pi)\, (\theta - \sin\theta\cos\theta) \quad (7)$$

The white hole bursts out of the Schwarzschild radius at $t = t_c$, $\theta = \theta_c$, where

$$\sin\theta_c = (\alpha r_b^2)^{\frac{1}{2}} \quad (8)$$

Suppose two successive light signals are sent out from the surface at comoving instants t and $t+dt$ and are received by the observer at R_1 at instants T and $T+dT$ measured in the Schwarzschild coordinate. Then a straightforward calculation shows that

$$dT/dt = \sin\theta/\sin(\theta+\theta_c) \quad (9)$$

So an electromagnetic wave of frequency ν_0 emitted from the surface appears to the receiver to have the frequency

$$\nu = \nu_0\, [\sin(\theta+\theta_c)/\sin\theta] \quad (10)$$

A result of this type but in different forms had been obtained earlier by others[5,6] but the above form is suitable for working out the spectrum of the radiation as seen by the Schwarzschild observer. Under our assumption (2), $L/h\nu_0$ photons of frequency ν_0 are being emitted per unit t-time from the surface. The number emitted in the interval $[t, t+dt]$ is therefore $Ldt/h\nu_0$. The same number must be received in the interval $[T, T+dT]$, but with frequencies in the range $(\nu, \nu+d\nu)$ where $d\nu$ is related to dt through equations (7) and (10).
A simple calculation gives

$$dt = (4t_0\nu_0^3 \sin^3\theta_c\, d\nu)/(\pi\, (\nu^2+\nu_0^2-2\nu\nu_0\cos\theta)^2) \quad (11)$$

Writing $E = h\nu$, $E_0 = h\nu_0$, the number of photons in the range $[E, E+dE]$ received from the white hole per unit area at $R = R_1$ is given by

$$N(E)dE = (Lt_0/\pi^2R_1^2)E_0^2\sin^3\theta_c dE/(E^2+E_0^2-2EE_0\cos\theta_c)^2 \quad (12)$$

For $E \gg E_0$

$$N(E)\, dE \cong Lt_0\, E_0^2\, (\sin^3\theta_c/\pi^2\, R_1^2)\, dE/E^4 \quad (13)$$

The energy spectrum $I(E)$ is given by

$$I(E) = EN(E) \propto E^{-3} \quad (14)$$

This is the spectrum at the high energy end under the simplifying assumptions made here. More general (and perhaps more realistic) assumptions can lead to different types of spectra which we have also worked out. We now wish to indicate possible fields in high energy astrophysics where white holes may find applications.

(i) The hard electromagnetic radiation from white holes situated at the centres of, say Seyfert galaxies, can be a source of background X and gamma radiation. The energy spectrum (14) seems, at first sight to be too steep compared to the observed[7] spectrum $\propto E^{-1.2}$. But absorption effects in the gas present in the nuclei surrounding the white hole tend to flatten the spectrum given by equation (14). Detailed calculation with available data[8,9] shows that these absorption effects can in fact flatten the E^{-3} spectrum to $\sim E^{-1}$ form in the range 0.2 keV to 1 keV. At lower energies, the ultraviolet radiation seems to be of the right order of magnitude to account for the infrared emission of $\sim 10^{45}$ erg s^{-1} through the dust grain heating mechanism[10].

(ii) The transient nature of X-ray and gamma-ray bursts[11] suggests a white hole origin. The shape of the spectrum at the emitting end is likely to be more complicated than the very simple form assumed in the above example. In general, however, the spectrum should soften with time.

(iii) Although we have worked out the spectrum of photons, it is not difficult to see that similar conclusions will apply to particles of non-zero restmass provided they have very high energy. It is possible therefore to think of white holes in the Galaxy on the scale of supernovae, yielding high energy cosmic rays right up to the highest energy observed.

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