Black Holes as Detectors of Tachyons.

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We add one more item to the rapidly growing repertoire of black holes by suggesting a scenario in which they can be used to detect tachyons. The suggestion here is based on some results derived recently about the interaction of a flux of tachyons with a rotating (Kerr) black hole (1).

In the last decade considerable theoretical work has been done on the properties of tachyons (*i.e.*, particles travelling faster than light), even though their existence still remains to be established. One convenient way to study them is through the use of the so-called superluminal frames (2) in which tachyons appear to move with speeds less than the light speed while bradyons (*i.e.*, particles travelling faster than light) as tachyons. Causality and other apparently paradoxial problems associated with tachyons can be better understood this way. Attempts have also been made to formulate models of laboratory interactions of tachyons with other forms of matter in order to arrive at a laboratory experiment for their detection (see (3) for example). The results of such attempts have so far been in the negative. The negative results do not necessarily rule out tachyonic existence; rather they rule out the assumptions and parameters of the specific interaction models proposed. It is therefore desirable to look for a model which makes the minimum set of assumptions. The effect proposed below is expected to be of this type.

We assume that like ordinary matter tachyons obey the rules of general relativity. In particular, a tachyon in a gravitational field, not interacting through any other physical force, is expected to move in a spacelike geodesics. Also it is expected that they obey the law of conservation of energy and momentum in any physical process. With this minimal set of assumptions we propose to examine the interaction of tachyons with black holes. We would like to point out that these are the assumptions usually made in the previous discussions of tachyons in gravitational fields such as in cosmology

(1) S. V. DHURANDHAR and J. V. NARLIKAR: *G.R.G. Journ.* (to be published).
(2) E. RECAMI: *Causality and tachyons in relativity*, Report INFN/AE-78/2 (Frascati, 1978) and in the book *Tachyons, Monopoles and Relared Topics*, edited by E. RECAMI (Amsterdam, 1978).
(3) J. DHAR and E. C. G. SUDARSHAN: *Phys. Rev.*, **174**, 1808 (1968).

or near black or white holes ([4-9]). The new concept presented here, in contrast to previous such discussions referred to above, examines how the parameters of a black-hole change if it is bombarded by a flux of tachyons. In particular, we look for situations where such a bombardment leads to a violation of the conventional laws of black-hole physics. It is by looking for evidence for such violation that we suggest that the existence of tachyons may be established.

A tachyon radially approaching a Schwarzschild black hole of mass M gets bounced at the radial co-ordinate (in geometrical units $G = 1$, $c = 1$)

$$R = \frac{2M}{1 + \Gamma^2}, \tag{1}$$

where Γ = energy per unit metamass of the tachyon in the asymptotically flat rest frame of a Schwarzschild observer ([7,8]). Where does the bounced tachyon go? It emerges from the black-hole horizon into the region III of the extended Schwarzschild space-time ([7]). If we choose to identify the regions I and III as is sometimes suggested ([10]) the tachyon will emerge in our part of space-time with some acausal effects in the region $R < 2.56M$ and depending on Γ, in part of the region $2.56M < R < 3.27M$ (cf. ([9]) for details). Whatever the interpretation, we may term this process as elastic scattering since it leaves the black hole unchanged. It turns out, however, that if it comes in with a large enough angular momentum, the tachyon will be captured by the black hole, *i.e.*, it falls into the space-time singularity. This results in a change of the basic parameters of the black hole—its mass and angular momentum.

A more interesting case of this type arises when we consider tachyon trajectories near a Kerr black hole. Let us denote by M and $S = aM$ ($a > 0$), the mass and angular momentum of the Kerr black hole. Let Γ and h denote the energy and angular momentum per unit mass parameter of the incoming tachyon moving in the equatorial plane of the black hole. What is the condition that the tachyon is captured by the black hole? It can be shown cf. ([1]) that the condition is

$$F\left(\frac{h}{M}, \Gamma; \frac{a}{M}\right) > 0, \tag{2}$$

where

$$F(x, y; \lambda) = 18(1 + y^2)(\lambda y - x)^2(\lambda^2 y^2 - x^2 + \lambda^2) - \tag{3}$$
$$- (\lambda^2 y^2 - x^2 + \lambda^2)^2 - 16(\lambda y - x)^2 + 27(1 + y^2)^2(\lambda y - x)^4 + (1 + y^2)(\lambda^2 y^2 - x^2 + \lambda^2)^3 .$$

In fig. 1 is plotted the curve $F(x, y; 0.8) = 0$. The shaded regions are the zones of avoidance: a tachyon with $h = Mx$ and with $\Gamma = y$ in the shaded region will be bounced and not captured.

([4]) R. W. FULLER and J. A. WHEELER: *Phys. Rev.*, **128**, 919 (1962)
([5]) F. SALZMAN and G. SALZMAN: *Lett. Nuovo Cimento*, **1**, 859 (1969).
([6]) G. CAVALLERI and G. SPINELLI: *Lett. Nuovo Cimento*, **6**, 5 (1973); **22**, 113 (1978).
([7]) A. K. RAYCHAUDHURI: *Journ. Math. Phys.*, **15**, 856 (1974).
([8]) E. HONIG, R. C. ROEDER and K. LAKE: *Phys. Rev. D*, **10**, 3155 (1974).
([9]) J. V. NARLIKAR and S. V. DHURANDHAR: *Pramana*, **6**, 388 (1976).
([10]) W. ISRAEL: *Nature*, **211**, 466 (1966).

The dotted straight line OP has the equation

$$y = \frac{aM}{a^2 + r_+^2}\, x\,, \qquad r_+ = M + \sqrt{M^2 - a^2}\,. \tag{4}$$

For points below this line and lying in the unshaded part the capture of tachyons results in a decrease of the surface area of the black hole! This region of fig. 1 is indicated by I.

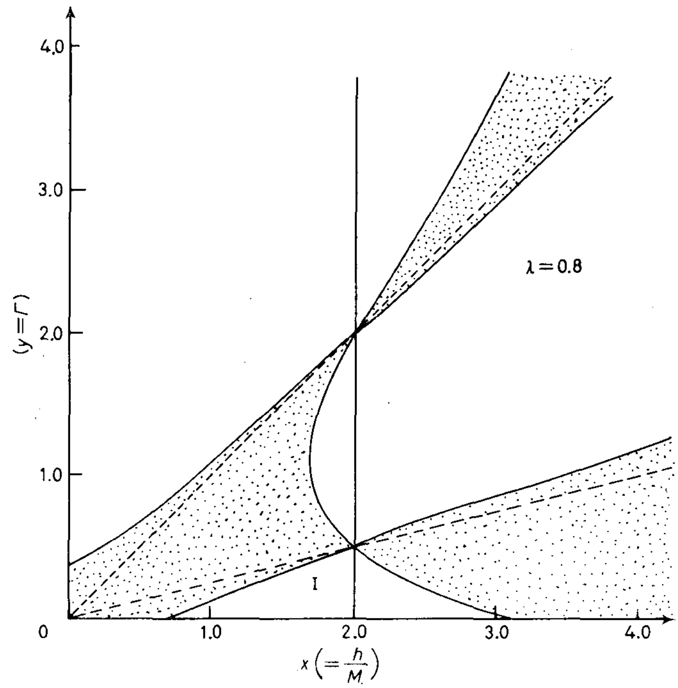

Fig. 1.

In the more general case of nonequatorial tachyon trajectories (Dhurandhar, preprint), investigations along the lines adopted by CARTER [11], show that when the black hole is rotating sufficiently rapidly ($\lambda > 4/(3\sqrt{3})$) it is possible with a judicious choice of the initial values of the tachyon parameters to decrease the area of the black hole.

This apparent violation of the second law of black-hole physics is due to the fact that the focusing theorem on which the « proof » of this law is based fails for such tachyons (cf. [1] for a detailed discussion). It is this result which suggests a test for detecting cosmic tachyons with observations of rotating black holes.

A common scenario for rotating black holes is found in the astrophysics of binary stars. The strongest case for black-hole detection, though still unconfirmed, is the binary system associated with Cygnus X-1. The mass M of the black hole can be reasonably well determined from the parameters of the binary system. The observa-

[11] B. CARTER: *Phys. Rev.*, **174**, 1559 (1968).

tional and theoretical expertise still cannot determine the angular momentum of the black hole. (In principle, this is measurable from the precession of an orbiting gyroscope.) Assuming, however, that it is possible to measure the parameter a for a Kerr black hole, we can then measure its area

$$A = 8\pi M(M + \sqrt{M^2 - a^2})\,. \tag{5}$$

Calculations show that a continuous bombardment of tachyons originating, say, in the binary companion, will have $h > 0$. If they happen to be in the unshaded area I to begin with, the area of the black hole will start decreasing although its mass will increase. This makes the point $(h/M, \Gamma)$ move to the left in fig. 1. However, as λ also increases, the boundary of I moves in such a way that the point will always remain in I. Thus the conditions for area decrease remain favourable for a beam of tachyons of given h and Γ.

The differential changes in the mass M and angular momentum S of the black hole due to a source of tachyons with constant-energy and angular-momentum parameters Γ and h respectively satisfying the conditions of decrease in area of the black hole, are given by

$$\Delta M = m\Gamma\,, \qquad \Delta S = mh\,, \tag{6}$$

where $m(\ll M)$ is the mass parameter of the tachyons. M may be obtained as a function of $\lambda = S/M^2$ if the initial mass M_0 and angular momentum S_0 are given by

$$\frac{M}{M_0} = \frac{\zeta - \sqrt{\zeta^2 - 2\zeta\lambda + \lambda\lambda_0}}{\lambda}\,, \qquad \zeta = \frac{h}{2\Gamma}\,, \qquad \lambda_0 = \frac{S_0}{M^2}\,.$$

To fix ideas we take $\lambda_0 = 0.4$ initially as seems to be required by the stability arguments of BARDEEN [12] and $\zeta \simeq 5$. The area decreased as $\lambda \to 1$ is then as much as 40%. The time scale over which this area decrease is achieved will depend, of course, on the tachyon accretion rate. Beyond $\lambda = 1$ lies the intriguing possibility of the disappearance of horizons and the emergence of the naked singularity.

One of us (S.V.D.; preprint) has examined this possibility in further detail. If one assumes that the bombardment by tachyons is slow then it is possible to make a « quasi stationary approximation » in which the black hole is assumed to evolve through a succession of stationary states with steadily increasing λ. It can be shown that in a finite time the stage $\lambda = 1$ is reached. Since for a Kerr black hole $\lambda = 1$ corresponds to zero surface gravity, the third law of black-hole physics is violated.

The area decrease and the possibility of seeing naked singularity do not violate any of the conventional wisdom of black-hole physics. They simply demonstrate the unusual results to be expected when tachyons are around. We therefore suggest that the ability to measure the area of a black hole as well as the search for naked singularities in the universe will provide tests for the existence of cosmic tachyons.

([12]) J. M. BARDEEN: in *Black Holes*, edited by B. S. DEWITT and C. DE WITT (New York, N. Y., 1973), p. 273.