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TACHYONS AND COSMOLOGY

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Abstract : Cosmology and high energy astrophysics provide interesting settings for the study of faster than light particles, often called tachyons. Some examples of this are given and their possible implications are discussed.

Introduction : Tachyons, or superluminal particles, have been discussed by theoretical physicists largely as curosities. Their existence appears to present paradoxical situations ; but these can be resolved with a suitable interpretation of what is observed (cf. Sudarshan 1970). A few suggestions leading to experiments for their detection have so far yielded negative results. For this reason it is worthwhile investigating possible astrophysical settings in which tachyons could be produced or could play an important part. Astronomy has, more than once, shown that new things, not necessarily found on the Earth, exist in the vest extraterrestial world. The existence of particles of energy way above that produced in the largest man-made accelerators, has been demonstrated in the cosmic rays, for example. In this lecture I propose to discuss some situations where tachyons could give useful information—if they do exist in the universe !

Primordial Tachyons : It was shown by Raychaudhuri (1974) that tachyons produced in a bag bang, when the universe is supposed to have originated, may encounter a time-barrier. This result is briefly described as follows.

In the flat space of special relativity we can assign an imaginary mass iM_0, or a real mass-parameter M_0 to a tachyon. Thus a tachyon moving with a velocity $v>1$ (=velocity of light) would have energy and momentum given respectively by

$$E=\frac{M_0}{\sqrt{v^2-1}} \quad , \quad P=\frac{M_0 v}{\sqrt{v^2-1}} \tag{1}$$

so that

$$P^2-E^2=M_0^2 \, . \tag{2}$$

Thus the momentum of tachyon has a lower bound M_0.

Consider now an expanding universe. For simplicity I will discuss the Robertson-Walker model with $k=0$. This has the line-element

$$ds^2 = dt^2 - S^2(t)\,[dr^2 + r^2\,(d\theta^2 + \sin^2\theta d\varphi^2)] \tag{3}$$

where $S(t)$ is the expansion factor and t the cosmic time. The coordinates r, θ, ϕ are the same for an comoving observer (the so called fundamental observer).

A tachyon trajectory can be described, without loss of generality by $\theta=$constant, $\phi=$constant. At a typical point (r, θ, ϕ, t) on its trajectory the tachyon has a velocity

$$v(t) = S(t)\frac{dr}{dt}$$

in the rest frame of a fundamental observer. Let P be the corresponding momentum. Assuming that the tachyon is subject to no other forces except gravitation, its trajectory is a space-like geodesic. A simple calculation shows that the tachyon momentum statisfies the relation

$$P(t)\; S(t) = \text{constant} = M_0 S_m\;, \tag{5}$$

where S_m is the value of $S(t)$ when $P \to M_0$. In an ever expanding universe with $S \to \infty$, the tachyon will eventually encounter this epoch, $t = t_m$ when $S = S_m$.

Raychaudhuri (op. cit.) concluded on this basis that since for $t > t_m$ $P(t) < M_0$, the trajectory cannot be continued and he took this as a result against the existence of tachyons. However, Narlikar and Sudarshan (1976) have studied the problem in some detail and drawn certain interesting conclusions which are summarized below.

(i) Although the trajectory does not continue in the region $t > t_m$, it does proceed in the region $t < t_m$, *forward* in r, but *backward* in time. The same conclusion is arrived at if the tachyon is regarded as a quantum particle of spin zero and imaginary mass im_0. Its wavefunction ϕ then satisfies a Klein Gordon equation, which in curved space is taken as

$$\left(\Box + \frac{1}{6}\,R - M_0^2\right)\,\phi = 0 \tag{6}$$

The operator $\Box + \frac{1}{6}R$ is chosen for reasons of conformal invariance (Narlikar and Sudarshan, op. cit). Near $t = t_m$ a plane wave is split into two components. One, in $t > t_m$ is rapidly damped with a time scale

$$\zeta \sim (H_m\, M_0^2)^{-\frac{1}{3}} \tag{7}$$

where $H_m =$ Hubble constant at epoch t_m. (The units are $c=1$, $h=1$). This is the familiar tunnel effect. There is however, the second component which is reflected back and heads towards the $t=0$ epoch.

(ii) The existence of the time barrier places an upper limit on the quantity M_0 in the following way. Suppose at an early primitive epoch t_0, the tachyon was highly energetic with momentum $M_0\beta_0$. It will servive to the present epoch t_p provided

$$S(t_0)\,\beta_0 > S(t_p)\,. \tag{8}$$

Suppose further that at $t=t_0$ the tachyons were in thermodynamic equilibrium with ordinary matter, e.g. electrons, neutrinos, photons etc. At that epoch, we may equate tachyon energy with say electron energy. Since for $\beta_0 >> 1$, the former is $\approx M_0\beta_0$ we set

$$M_0\beta_0 \cong m_e\,\gamma_e \tag{9}$$

where m_e=electron rest mass and γ_e=energy per unit rest mass of the electron. From (8) and (9) we get

$$\frac{M_0}{m_e} \lesssim \gamma_e \frac{S(t_0)}{S(t_p)}\,. \tag{10}$$

Identifying t_0 with the epoch of element formation and using the Einstein de Sitter model we get $\gamma_e \approx 10$, and

$$\frac{M_0}{m_e} \lesssim 1.8\times 10^{-11}\,. \tag{11}$$

(iii) The low values of this limit prompted Narlikar and Sudarshan (op cit) to consider the possibility of the microwave background photons and/or neutrinos being tachyonic. It seems that the present laboratory data is not accurate enough to rule out this possibility. Tachyonic neutrinos or photons would, however, require a considerable modification of the existing theories of elementary particle interactions.

Black Holes : Recently Narlikar and Dhurandhar (1976) have considered tachyon trajectories near black holes or highly collapsed objects. Extensive work on the spacelike trajectories near black holes has been done by Honig et al (1974). I will describe briefly some of the salient results in this area.

(i) Raychaudhuri (1974) had shown that a radially infalling tachyon bounces from the black hole. The bounce occurs inside the Schwarzschild barrier. Narlikar and Dhurandhar (op cit) investigated the temporal aspects of such a trajectory. It turns out that if we identify the points in the maximally extended Schwarzschild space-time such that the Kurskar-Szekeres coordinates (u, v) and $(-u\ -v)$ represent the same space-time point, then an infalling tachyon which crossed the point with the Schwarzschild radial coordinate r, at time t, will recross the same point r at a time t' while moving outwards. The relation of t to t' will depend on r and the energy of the tachyon. Thus if $r<2.56\,m$ (m= mass of the central object) $t'>t$ while if $r>3.27m$, $t'>t$. For $2.56<r<3.27m$, the sign of $t'-t$ depends on the tachyon energy per unit mass-parameter. (For details see Narlikar and Dhurandhar, op cit).

(ii) An infalling tachyon with-zero angular momentum may or may not fall into singularity. The details are discussed by Honig et al (1974). If it bounces, it re-emerges in another direction. The angular deflection has been calculated by Narlikar and Dhurandhar (1976).

Concluding Remarks : There are several questions about the role of tachyons in astrophysical situations. Some are briefly outlined below.

(i) Does the presence of tachyons in a collapsing body halt the collapse ? The standard singularity theorems deal with non-space-like geodesics only. So this is an open question.

(ii) Can one see tachyons emerging from white holes, assuming that they exist ? Preliminary work on this problem has been undertaken by Narlikar and Dhurandhar.

(iii) To what extent can tachyons bring back information from inside a Schwarschild barrier ? Does their presence modify the entropy theorems of black holes ?

References

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