A Relook At the Tachyon

By: Paul Karl Hoiland

Abstract: Via a look at the math and the modern theory behind tachyons one can discover that inspite common belief the tachyon does have a place in our current best models.

With an equation of state of

$$L = -V(T)\sqrt{1 + g^{\mu\nu}\partial_\mu T \partial_\nu T}$$

and a metric representation of

$$ds^2 = -dt^2 + a^2(t)(dx^2 + dy^2 + dz^2)$$

the evolution of the Einstein equation

$$G_{\mu\nu} = \kappa T_{\mu\nu}$$

\is given by

$$H^2 = (\frac{\dot{a}}{a})^2 = \frac{\kappa}{3}(\rho_T + \rho_M)$$

$$\frac{\ddot{a}}{a} = -\frac{\kappa}{3}(\frac{1}{2}\rho_T + \frac{3}{2}p_T + \frac{1}{2}\rho_M)$$

and an equation of motion of

$$\ddot{T} + 3H\dot{T}(1 - \dot{T}^2) + \frac{V'(T)}{V(T)}(1 - \dot{T}^2) = 0$$

and the density and pressure of

$$\rho_T = \frac{V(T)}{\sqrt{1-\dot{T}^2}}$$

$$p_T = -V(T)\sqrt{1-\dot{T}^2}$$

The equation of state becomes in a dominate mode

$$w_T = \frac{p_T}{\rho_T} = \dot{T}^2 - 1$$

where

$\dot{T}^2 < \frac{2}{3}$ and $-1 < w_T < -\frac{1}{3}$.

One will note that wT is always negative no matter what is the form of the r(z) and V (T (z)). On the surface this makes tachyon matter very much fitting the form of dark matter that always displays negative vacuum pressure and is one of the reasons inspite of all the other studies suggesting tachyon states ought to be unstable the subject still surfaces(1).

When we start with the potential

$$V(T) = V_0\left(1 + \frac{T}{T_0}\right)\exp\left(-\frac{T}{T_0}\right)$$

With the dimensionless variable

$y = \frac{dT}{dt}$,

the equation of motion becomes

$$\frac{dx}{ds} = y$$
$$\frac{dy}{ds} = \frac{x(1-y^2)}{1+x} - \beta y(1-y^2)^{\frac{3}{4}}(1+x)^{\frac{1}{2}}\exp(-\frac{x}{2})$$

where we have

$$\beta = \sqrt{3V_0\kappa T_0}$$

w_T Starts at -1 and evolves to 0. These modes themselves show the field eventually decays. The question is how long do they take to decay? Another valid question is do they decay into stable states?

Incidents like the reports out of CERN of superluminal velocity for neutrinos always bring this subject back up. In general, all tachyon states have negative energy and negative mass. Given that the events at CERN cannot be showing an example of neutrinos becoming tachyons. But the idea that there could exist superluminal states for matter cannot be ruled out.

The first question concerns decay. Particle decay is a Poisson process, and hence the probability that a particle survives for time t before decaying is given by an exponential distribution whose time constant depends on the particle's velocity:

$P(t)= e^{-t/(\gamma t)}$

where t is the mean lifetime of particle at rest and γ is the Lorentz factor.

However, tachyon states are never at rest. The tachyon field has a potential which has an unstable maximum at the origin and decays to almost zero as the field goes to infinity. In essence the tachyon decays over time into a more stable, positive mass particle. While the decay time is finite, nothing in essence forbids them to persists long enough to be actually measured. In fact, some have looked at a tachyon field in conjunction with a scalar as a possible explanation for accelerated expansion(2). In this case such a particle could have a very long persistence in cosmic terms. Other have postulated that inflation may have been caused by tachyon decay(3). Another place tachyons appear is in stringf theory and Brane Theory(4).

One interesting aspect out of D-strings is that This seems strange because if the tachyon fully condenses, the D-brane should disappear and there should be no open string excitations. All excitations should be described in terms of closed strings when in essence, the Standard Model requires both sets. Furthermore, detailed calculations demonstrate that the energy of emitted radiation from unstable D_p-brane diverges for p = 0, 1, 2, and is formally finite for p > 2(5). But when one adds in a space-like linear dilaton background the expression for closed string radiation is finite, and the tachyons assume a weakly coupled state which persists(6).

However, most described above are based on time-like tachyon profile, which only depends on the time direction. Light-like has further been studied in other articles. Both sides and types have been shown to do more than just simply decay and may well take part in some physical processes conjectured to occur under super symmetry approaches like String theory and Brane theory.

One interesting aspect out of these is the idea of the vacuum undergoing first a reheat and then a rapid inflation(7). In essence, such a rapid inflation could bring about several effects including a transition in the resultant vacuum to one with a different value for C. This being the case, there are no free tachyon states. Instead you end up with normal particles of positive mass moving at a superluminal velocity in relation to the normal vacuum state inside an altered microscopic bubble. In all fairness, this is not a warp bubble in either the classical aspect or even newer ideas. This is simply a Lorentz invariant bubble of space-time with a different vacuum expectation value. But it would signal that such a formation at whatever energy level would have been triggered by the formation of an unstable condition with tachyon generation that first reheated the vacuum and then rapidly decayed with a resultant different vacuum solution.

Reference

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