COSMOLOGICAL IMPLICATIONS OF A POSSIBLE CLASS OF PARTICLES ABLE TO TRAVEL FASTER THAN LIGHT

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Abstract

We discuss the possible cosmological implications of a class of superluminal particles, in a scenario where: a) Lorentz invariance is only an approximate property of the equations of a sector of matter; b) several critical speeds of matter in vacuum exist. The Big Bang scenario and the evolution of the very early universe, as well as large scale structure, can be strongly influenced by the new particles.

1. THE NEW PARTICLES

In a recent paper [1], we proposed a new class of non-tachyonic superluminal particles assuming the existence of several critical speeds of matter in vacuum (like those of light and sound in a defectless, perfectly transparent crystal at zero temperature). Considering an analogy with sine-Gordon solitons in a galilean world, we pointed out that the apparent Lorentz invariance of the laws of physics does not imply that space-time is indeed mikowskian.

Special relativity is usually presented as an intrinsic property of space-time and geometry is the startpoint of the theory of gravitation in general relativity. However, a look to various dynamical systems would suggest a more flexible view with the properties of matter playing the main role. In a two-dimensional galilean space-time, a sine-Gordon soliton of the form:

$$\phi_v(x,t) = 4 \arctan \left[ \exp \left( \pm \omega c_0^{-1} z \right) \right]$$

with:

$$z = (x - vt) \left(1 - v^2/c_0^2\right)^{-1/2}$$

(1)

(2)
has speed $v$, critical speed $c_0$ and all kinematical properties of a "relativistic particle", $c_0$ playing the role of the speed of light. An "absolute rest frame" would be provided by the rest frame of the dynamical system, but it cannot be felt by the soliton unless the soliton is accelerated to a speed extremely close to $c_0$ (enough to feel the small distance structure of the dynamical system). Similarly, Lorentz invariance can be only an approximate property of equations describing a sector of matter above a given scale and an absolute rest frame can exist without contradicting the minkowskian structure felt by ordinary particles. Then $c$, the speed of light, will not necessarily be the only critical speed in vacuum. Superluminal sectors may exist related to new degrees of freedom not yet unraveled experimentally.

The new particles would not be tachyons: they may feel different minkowskian space-times with critical speeds $c_i \gg c$ (the subscript $i$ stands for the $i$-th superluminal sector) and behave kinematically like ordinary particles apart from the difference in critical speed. The "ordinary" sector will contain "ordinary" particles with critical speed $c$. Each sector will have its own Lorentz invariance, but interaction between two different sectors will break both Lorentz invariances. Lorentz invariance will be simultaneously apparent for several sectors in at best one inertial frame (the "vacuum rest frame", i.e. the "absolute" rest frame). Superluminal particles will have [1] rest energy:

$$E_{\text{rest}} = mc_i^2$$

for inertial mass $m$ and critical speed $c_i$. Energy and momentum conservation will not be spoiled by the existence of several critical speeds in vacuum: conservation laws will as usual hold for phenomena leaving the vacuum unchanged. If superluminal particles couple weakly to ordinary matter, their effect on the ordinary sector may occur basically at very high energy and short distance, far from the domain of conventional tests of Lorentz invariance. Thus, nuclear and particle physics experiments may open new windows in this field.

At $v > c$, the new superluminal particles are kinematically allowed to emit "Cherenkov" radiation (on-shell ordinary particles) in vacuum; at $v > c_i$, they can emit particles of the $i$-th superluminal sector. "Cherenkov" radiation in vacuum provides a signature for the production of superluminal particles at high energy accelerators, but the ability to radiate in vacuum will depend on the produced particles. Hadron colliders are the safest way to produce superluminal particles, as quarks couple to all known interactions. For the far future, one may think of a high energy collider as the device to emit modulated and directional superluminal signals.

Each superluminal sector may be protected by a conserved quantum number and each sectorial "lightest superluminal particle" may be stable, but this is not unavoidable and we may be inside a sea of long-lived superluminal particles which decay into ordinary particles or into lighter superluminal ones. Such decays could play a cosmological role, and even be observable. As the graviton is an "ordinary" gauge particle associated to the local Lorentz invariance of the ordinary sector, superluminal particles will not couple to gravity in the usual way. Each sector may generate its own "gravity" associated to the sectorial Lorentz invariance. Concepts so far considered as very fundamental (i.e. the universality
of the exact equivalence between inertial and gravitational mass) will become approximate sectorial properties.

Even if such a scenario brings us somehow back to ether, it is not in contradiction with modern particle physics where the vacuum is clearly not empty and has an important internal structure which is just starting to be explored. Gravitational properties of vacuum remain basically unknown and new forces may have governed the expansion of the Universe.

2. COSMOLOGICAL IMPLICATIONS

If superluminal sectors exist and Lorentz invariance is only an approximate sectorial property, the Big Bang scenario may become quite different, as: a) Friedmann equations do no longer govern the global evolution of the Universe, which will be influenced by new sectors of matter coupled to new forces and with different couplings to gravitation; b) gravitation itself will be modified, and can even disappear, at distance scales where Lorentz invariance does no longer hold; c) at these scales, extrapolation to a "Big Bang limit" from low energy scales does not make sense; d) because of the degrees of freedom linked to superluminal sectors, the behaviour of vacuum will be different from standard cosmology; e) the speed of light is no longer an upper limit to the speed of matter. No basic consideration seems to prevent "ordinary" interactions other than gravitation from coupling to the new dynamical sectors with their usual strengths. Conversely, ordinary particles can in principle couple to interactions mediated by superluminal objects. Conventional covariant derivatives can be used for all particles and gauge bosons independently of their critical speed in vacuum. However, experience seems to suggest that superluminal particles have very large rest energies or couple very weakly to the ordinary sector.

Each sectorial Lorentz invariance is expected to break down below a critical distance scale, when the Lorentz-invariant equations (and Lorentz-covariant degrees of freedom) can no longer be used and a new dynamics appears. For a sector with critical speed $c_i$ and apparent Lorentz invariance at distance scales larger than $k_i^{-1}$, where $k_i$ is a critical wave vector scale, we can expect the appearance of a critical temperature $T_i$ given approximately by:

$$k T_i \approx \hbar c_i k_i$$

where $k$ is the Boltzmann constant and $\hbar$ the Planck constant. Above $T_i$, the vacuum will not necessarily allow for the previously mentioned particles of the $i$-th sector and new forms of matter can appear. If $k_0$ stands for the critical wave vector scale of the ordinary sector, above $T_0 \approx k^{-1} \hbar c k_0$ the Universe may have contained only superluminal particles whereas superluminal and ordinary particles coexist below $T_0$. It may happen that some ordinary particles exist above $T_0$, but with different properties (like sound above the melting point).

If Lorentz invariance is not an absolute property of space-time, ordinary particles did most likely not govern the beginning of the Big Bang (assuming such a limit exists) and dynamical correlations have been able to propagate must faster than light in the very early Universe. The existence of superluminal particles, and of the vacuum degrees of freedom which generate such excitations, seems potentially able to invalidate arguments leading to
the so-called "horizon problem" and "monopole problem", because: a) above $T_0$, particles and dynamical correlations are expected to propagate mainly at superluminal speed, invalidating conventional estimates of the "horizon size"; b) below $T_0$, the annihilation of superluminal particles into ordinary ones is expected to release very large amounts of kinetic energy from the rest masses ($E = mc^2$, $c_i \gg c$) and generate a fast expansion of the Universe. Conventional inflationary models rely on Friedmann equations and in principle cannot hold in the new scenario. New inflationary models can be considered, but their need is far from obvious. If a "Big Bang" limit exists, and if a generalized form of Friedmann equations can be written down incorporating all sectors and forces, a definition of the horizon distance would be:

$$d_H(t) = R(t) \int_0^t C(t')R(t')^{-1} dt'$$

where $d_H$ is the generalized horizon distance, $R(t)$ is the time-dependent cosmic scale factor and $C$ is the maximum of all critical speeds. This definition is realistic even for ordinary particles, which can be radiated by superluminal ones at $v > c$ or produced by their annihilation. $C$ can be infinite if one of the sectors has no critical speed (as in the usual galilean space-time), or if an infinite number of superluminal sectors exist. The homogeneity and isotropy of our Universe, as manifested through COBE results, are now natural properties.

The coupling between the ordinary sector and the superluminal ones will influence black hole dynamics. A detectable flux of magnetic monopoles (which can even be superluminal) is not excluded, as the "horizon problem" can be eliminated without the standard inflationary scheme. Long range correlations introduced by superluminal degrees of freedom can also play a role in the formation of objects (i.e. strings) leading to large scale structure of the Universe.

Physics at grand unified scales can present new interesting features. Grand unified symmetries are possible as sectorial symmetries of the vacuum degrees of freedom, even if ordinary particles do not exist above $T_0$. But analytic extrapolations (e.g. of running coupling constants) cannot be performed above the phase transition temperature. If $kT_0$ is not higher than $\approx 10^{14} GeV$ ($k_0^{-1} \approx 10^{-27} cm$, time scale $\approx 10^{-38} s$), the formation of a symmetry-breaking condensate in vacuum may have occurred above $T_0$ and remain below the transition temperature. Because of superluminal degrees of freedom and of phase transitions at $T_0$ and at all $T_i$, it seems impossible to set a "natural time scale" based on extrapolations from the low energy sector (e.g. at the Planck time $t_p \approx 10^{-44} s$ from Newton’s constant). Arguments leading to the "flatness" or "naturalness" problem, as well as the concept of the cosmological constant and the relation between critical density and Hubble’s "constant" (one of the basic arguments for dark matter at cosmic scale), should be reconsidered.

At lower temperatures, superluminal particles do not disappear. In spite of limitations coming from annihilation, decoupling and "Cherenkov radiation", they can produce important effects in the evolution of the Universe. Superluminal matter may presently be dark, with an unknown coupling to gravitation and coupled to ordinary matter by new,
unknown forces.

Reference

[1] L. Gonzalez-Mestres, "Properties of a possible class of particles able to travel faster than light", Proceedings of the Moriond Workshop on "Dark Matter in Cosmology, Clocks and Tests of of Fundamental Laws", Villars (Switzerland), January 21-28 1995, Ed. Frontières. Paper astro-ph/9505117.