Superluminal Particles, Cosmology and Cosmic-Ray Physics

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Abstract

Non-tachyonic superluminal sectors of matter (superbradyons), with critical speeds in vacuum much larger than the speed of light, can quite naturally exist and play an important role in both cosmic-ray physics (anomalous high-energy events) and cosmology (big-bang physics, alternatives to inflation, dark matter...). They can even be the real "elementary" particles. An updated discussion of the subject is presented, in relation with recent theoretical and experimental results. Prospects for future searches are also reexamined. Lorentz symmetry violation (LSV) models based on mixing with superbradyons are compared with LDRK (linearly deformed relativistic kinematics) and QDRK (quadratically deformed relativistic kinematics) such as defined in our previous paper physics/0003080 .

1. Superbradyons

Introduced in [3], superbradyons are superluminal particles with positive mass and energy, and critical speeds in vacuum much larger than the speed of light c (see [3-13] and references therein). They can be assumed to be the actual building blocks of matter and to provide an alternative to inflationary cosmological models. They can also be invoked to explain the absence of the Greisen-Zatsepin-Kuzmin (GZK) cutoff or be the basic ingredient of new models to solve the dark matter problem. Present low-energy bounds on LSV do not allow to exclude the possible existence of such particles and, to date, no fundamental argument has been provided to preclude their existence. We therefore must consider the possibility that superbradyons exist and play a real dynamical and cosmological role. The energy E and momentum p of a superbradyon with mass m and critical speed $c_i \gg c$ will be given by the generalized relativistic equations:

$$p = m\, v\, (1 - v^2 c_i^{-2})^{-1/2} \qquad (1)$$

$$E = m\, c_i^2\, (1 - v^2 c_i^{-2})^{-1/2} \qquad (2)$$

$$E_{rest} = m\, c_i^2 \qquad (3)$$

where i stands fot the i-th superluminal sector of matter, v is the speed and E_{rest} the rest energy. Each superluminal sector of matter will have its own Lorentz

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invariance with c_i defining the metric. We call the sector made of particles with critical speed in vacuum $= c$ the "ordinary" sector (for "ordinary" particles or "bradyons"). Being able to write formulae (1-3) for all sectors simultaneoulsy requires the existence of an "absolute" rest frame (**the vacuum rest frame**, VRF, possibly close to that suggested by the study of cosmic microwave background radiation), the only one where this will be possible. Furthermore, interactions between two different sectors of matter will break the two sectorial Lorentz invariances and deform their associated relativistic kinematics.

2. New Phenomenological Issues

A specific property of LSV induced in the "ordinary" sector of matter by the mixing with superbradyons is that the LSV energy dependence can follow many different patterns according to the details of the mixing. It may even happen that the effective LSV parameter (basicallly, the deformation term in the hamiltonian divided by the squared momentum scale) induced by the mixing decreases after some critical energy instead of growing [11] as in LDRK (linearly with energy) and QDRK (quadratically with energy). There are several recent phenomenological controversies where superluminal particles are potentially able to play a decisive role (see [11-13] and references therein):

2.1. Cosmological Issues

From a theoretical point of wiew, as cosmological observations appear to confirm some basic aspects of the inflationary scenario (see [16] and references therein), it seems compelling that any alternative to standard inflation incorporates two essential properties: a) superluminal expansion; b) entropy production. Big-bang models where "ordinary" matter would be composite and made of superluminal particles present interesting potentialities in the field. It is even possible [6,12,13] to postulate the existence of a fundamental length scale a_i for each superluminal sector of matter, besides the usual (Planck) scale a associated to the "ordinary" sector. We expect $a_i \ll a$. Our Universe may then originate from a set of transitions at the a and a_i scales where "ordinary" matter cannot exist at length scales below a , and similarly for the i-th sector of matter below a_i .

2.2. The TeV Region

Recent speculations from extragalactic astronomy that photons in the TeV region may be being observed when, according to special relativity, they should not, have led to interpretations based on LSV models of the LDRK type (linearly deformed relativistic kinematics, see [11]). But these models (see [2,14,15] and references therein), where the LSV parameter increases linearly with energy, lead to severe consistency problems related to the global implications of LDRK

[11]. Instead, there may be at least two suitable alternatives to LDRK based on superluminal particles [12,13]:

a) Superluminal particles are emitted by gamma factories and emit in turn "Cherenkov" radiation ("ordinary" or superluminal particles) or decay later into photons which reach the detector.

b) There is a very small mixing between the photon and a superluminal particle, vanishing in the zero-momentum limit, reaching its maximum at TeV energies and then decreasing for some dynamical reason. Such a mixing would lead to LSV effects in the photon propagator at TeV energies, but the effective LSV parameter would not rise as energy increases further and global inconsistencies can in principle be avoided.

More generally, suggestions that LSV may produce observable effects at energies far below those of the highest-energy cosmic rays seem difficult to reconcile in a consistent way with standard deformed relativistic kinematics (DRK) models where the parameter driving LSV would vary like a power of momentum. But an effect due to mixing with the superluminal sectors of matter, leading to a very small LSV with observable effects for a given "ordinary" particle in a precise energy range, can be an alternative to these models.

2.3. The UHECR Region

A similar phenomenological pattern can be imagined for events originating from ultra-high energy cosmic rays (UHECR). From an experimental point of view, it is not clear by now whether the GZK cutoff exists or not. It is even not excluded that the cutoff be delayed (see [1] and references therein), so that it would not be at work below an energy threshold higher than that expected from standard theoretical calculations.

If the GZK mechanism is just delayed, a very small mixing of "ordinary" UHECR with superluminal particles [12,13] can account for such a behaviour similarly to the previous sub-section, and reproduce the delayed cutoff. An important conceptual question is how the internal structure of the "ordinary" ultra-high energy particle (UHEP) would be altered by such a mixing.

2.4. Direct Signatures

As discussed in [4,8,10], the direct signature of a superbradyon with $c_i \gg c$ colliding with any terrestrial absorber, including the atmosphere, would be unique because of the kinematics (1-3). The main feature of the event would be its lack of directionality, due to the very large incoming $E \ / \ p$ ratio. The only possible background would be a non-relativistic "ordinary" neutral superheavy object, but such an exceptional competitor can also be ruled out in a certain number of cases. Superluminality would often be impossible to fake, especially if the superbradyon is relativistic with respect to its own superluminal sector and if there are several events [12,13]. Cherenkov radiation in vacuum, interactions or decays of superluminal secondaries, energy spectra of the observed events... would be crucial for event analysis.

2.5. Conclusion and Comments

LSV models based on a small mixing with superbradyons may provide original solutions to present phenomenological controversies and puzzles concerning not only basic cosmology or dark matter, but also the properties of high-energy and ultra-high energy cosmic rays. Thus, rare and anomalous vents in UHECR cosmic-ray experiments or TeV gamma physics may potentially provide clues to the understanding of fundamental Big-Bang dynamics.

It therefore seems also necessary to complete previous studies ([4,6,10,11] and references therein) and further explore the implications of superbradyons for Planck-scale dynamics, string models and other possible ingredients of current cosmological models. The validity of standard quantum mechanics for superluminal sectors is not obvious, although we have always assumed. In particular, the question of the universality of the Planck constant is worth exploring.

More details on the ideas presented here can be found in references [12] and [13], as well as in subsequent papers of the same series (*Deformed Lorentz symmetry and High-Energy Astrophysics*, see arXiv.org).

3. References

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