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Abstract: Studies the activity of massless and faster-than-light particles, neutrinos and tachyons that are claimed to be existent in particle physics. Importance of neutrinos and tachyons with regard to cosmology and astrophysics; Significance in the energy producing nuclear reactions; Question surrounding their relationship with general relativity and the gravitational field and the curvature of space time.

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ODD PARTICLES OUT

When particle physics meets general relativity ghost neutrinos percolate through the primeval void, and galaxies take leave of each other at speeds faster than light.

To be a cosmologist, or even to dabble in cosmology, requires a certain playful turn of mind. One must be willing to follow the mathematics wherever it leads, and since it is almost guaranteed to lead to absurdity and paradox, the mind that ventures there must be capable of being amused by absurdity and paradox. Cosmology is that way, of course, because it has a giant paradox at its beginning. It uses the laws of physics, which are supposed to be general, universal, nonarbitrary, to make statements about the most arbitrary, unique, serf-contained System there is: the one and only universe we know about.

When other branches of physics are mated with cosmology, the offspring can be very strange, especially those that arise from a mating of relativity and particle physics. The particle physics in question is not the relatively straightforward behavior of garden variety neutrons and protons, but the more exotic activity of massless and faster-than-light particles, neutrinos and tachyons. Recently the people who gave us ghost neutrinos, Talmadge M. Davis and John R. Ray of Clemson University, have been thinking about what neutrinos, ghost or otherwise, would do to cosmology and astrophysics and have communicated their conclusions to colleagues (LETTERE AL NUOVO CIMENTO 12:249; PHYSICS LETTERS 51A:199; essay in Gravity Research Foundation's 1975 contest).

Neutrinos and tachyons do not have the same status in physics. Neutrinos, the elusive, Weakly interacting, putatively massless particles that conveniently carry away energy from such processes as nuclear beta decay, are indisputably real. The evidence for their existence, direct and indirect, is Overwhelmingly convincing.

Tachyons remain hypothetical. They are particles that are supposed to go faster than light. For decades the conventional textbook wisdom was that no such things could exist. Then someone noticed that the equations of special relativity permitted the existence of particles that go faster than light provided they are always in motion and never go slower than light. It is a case of following where the mathematics leads, and in this case it leads to a number of experiments to look for tachyons. (So far there is no definite evidence for them.)

Of course a lot of physicists pooh-pooh the whole idea of tachyons. But then for decades a lot of physicists pooh-poohed the whole idea of magnetic monopoles. Arid now look (p. 118). So maybe there's a future for tachyons too.

Because of their reality and because they are given important roles in traditional cosmology and astrophysics, neutrinos deserve closer attention. They are attributed important roles in the early dynamics of the big bang, and they are of considerable significance in the energy-producing nuclear reactions that go on in stars. The question is how do they fit into this setting, how do they relate to general relativity and its artifacts, the gravitational field and the curvature of space-time.

When Davis and Ray did the calculation for the simplest kind of space-time, flat and plane-symmetric, they got a distinct shock. The energy-momentum tensor, the mathematical quantity that describes a body's relation to the gravitational field and its effect on space-time curvature, vanishes for neutrinos. It is zero, and so is their gravitational effect. Yet the neutrinos exist. Their wave equations, the expressions that describe the matter waves associated with them according to the famous particle-wave duality, continue to have value. It is the wave equations by which a particle physicist judges that something exists.

So the neutrinos are ghosts, matter that does not contribute to the gravitational field. This is one of those amusing paradoxes. It turns a basic axiom of physics upside down. Obviously Isaac Newton Was not hit on the head by a falling neutrino, but a falling neutrino may knock physics in the head, because worse was to follow.

Davis and Ray next took up neutrinos in a spherically symmetric space-time. This is important because astrophysicists want spherically symmetric stars to emit neutrinos, so the neutrinos have to be able to operate in that kind of geometry. The result is that not only does the energy-momentum tensor vanish, the wave equations vanish too. No neutrinos, not even ghosts can exist. The two theorists' reaction to this is worth quoting:

"'Ghost neutrinos' appear in a natural way in general relativity. When we first found them in the plane-symmetric metric, we were sure we had made a mistake; however, these solutions are a definite prediction of the theory."

So how to get out of the dilemma? One could introduce a dependence on time into the equations. This can lead to non-ghost solutions. For spherical symmetry one can average the energy-momentum tensor over a unit sphere. This will allow neutrino emission from a spherical star but only in case of exact spherical symmetry, and exact symmetry is hard to find in nature.

One can also endow neutrinos with a rest mass. Theory has considered them massless because that is the nearest way to deal with them, but experiment has never proven their masslessness. If they have even a very tiny rest mass, the energy-momentum tensor does not vanish, and they are no longer ghosts.

But all of these escapes lead to serious drawbacks in their turn, and Davis and Ray finally come to suggest: "Perhaps there is no classical theory of neutrinos." That's the crux of the mismatch. Neutrinos are objects of quantum physics; general relativity is a classical theory based on smooth continuous quantities rather than the intrinsic jumpiness of the subatomic world. Mixing classical and quantum theories usually raises hell.

At the moment there is no quantum theory of gravitation. General relativists are straining for one, but they have not had much success. Yet the early history of the universe must have been dominated by quantum gravity. Davis and Ray remark: "It may be that these 'ghost neutrino' solutions are some type of 'relic' from the quantum theory of gravity. In some way the vacuum state in quantum gravity may be 'bubbling' with virtual neutrinos and antineutrinos. These classical solutions with 'ghost neutrinos' are possibly all that is left of the quantum theory of gravity in the classical limit where general relativity is valid."

The tachyon question is basically, why, if tachyons exist, we don't see them. Some time ago J. Richard Gott III proposed that a given universe can be dominated either by tachyons or nontachyons, and the two kinds of universe are separated by an intrinsically impenetrable barrier and don't mix. Ray's latest effort in this line inclines in that direction. Following some work of A. Petrov, he studies a cosmological "dust" solution (that is, one that permits particulate matter to exist) that would include tachyons, and finds that it allows only tachyon dust. The dust particles are identified With galaxies or clusters of galaxies, and they expand away from each other with speeds greater than that of light.

Ray goes on to point out that by properly selecting space-time symmetries, one can come up with dust solutions that are either all tachyon or all nontachyon. So perhaps at the moment of its birth a universe has a choice which it will be. "The idea being that at each singularity [big bang] there is a certain probability amplitude for the Universe to emerge as either type." This would be the original, ultra-primeval roll of the cosmic dice--or maybe an intelligent hand at the switch.

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By Dietrick E. Thomsen

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