Streaking through the universe

Cosmology and particle physics have usually been performed in separate compartments, but nowadays they come more and more together. Astrophysics is beginning to concern itself with the inner working of the bodies that make up the cosmologists' universe and therefore with the (sometimes quite bizarre) nuclear and particle physics of these bodies. At the same time, when cosmologists turn their attention to the very early moments in the history of the universe, before atomic nuclei or atoms formed, they must deal with the behavior of large aggregates of elementary particles.

One particle of great cosmological interest is the neutrino. The neutrino is very elusive: It lacks any rest mass so it only exists in flight. The only forces it responds to are those of the so-called weak interaction, which means that neutrinos rarely interact with other matter. A neutrino can go right through the solid earth and interact with nothing on the way.

It is precisely this touch-me-not characteristic that makes neutrinos of special cosmological interest. Theory says that the big bang that started the universe produced a large amount of neutrinos. Because they so seldom interact with anything else, most of them should still be around flying back and forth across the universe. The cosmological, or better general relativistic, question is: What does their presence do to the shape of the universe? How do they alter or influence the gravitational fields?

The Einstein equations of general relativity are a way of determining the gravitational field or the curvature of space at any point. The ultimate cause of the curvature is the presence of matter. Neutrinos are matter; what effect do they have? Talmadge M. Davis and John R. Ray of Clemson University in Clemson, S.C., decided to find out by calculating an exact solution for the Einstein equations taken together with the Dirac equation for particles with zero rest mass that describes the behavior of neutrinos.

The result, reported in PHYSICAL REVIEW D [Vol. 9, p. 331 (1974)], is a surprising zero. Zilch. Rien de rien. The physical quality that accounts for the curvature of space at any point is the energy-momentum tensor which can be written down as an array of numbers, each of which represents a different component of the momentum and energy at the point. For neutrinos the energy-momentum tensor comes out zero, which means that their presence makes no contribution to space curvature, and, Davis and Ray conclude, the "gravitational field is exactly the same as for the vacuum case." No operation using the gravitational field could detect the presence of neutrinos.

Yet in the universe described by the Davis-Ray solutions the neutrinos still exist. The other mathematical quantities that describe their presence do not vanish. Neutrinos exist and can have physical effects and yet make no additional contribution to the gravitational field. Therefore Davis and Ray refer to them as ghost neutrinos.

Matter that does not contribute to the gravitational field would strike most physicists as bizarre. There is of course no experimental evidence that this exercise in mathematical physics corresponds to the actual condition of the real world. Yet, in particle physics especially, mathematics has often gone ahead of physics, and some of its wilder-seeming predictions have come true. ☐

Solar neutrinos: Change the theory

One of the most notorious problems bedeviling physicists at present is the solar-neutrino problem. Basically it is that the sun gives off far fewer neutrinos than it ought. Raymond Davis Jr. of Brookhaven National Laboratory and collaborators have been trying for a couple of years now to observe solar neutrinos with an apparatus set up in a mine near Lead, S.D. They find as few as one-tenth the number of neutrinos the sun ought to radiate.

Theorists of nuclear physics are very sure that their theory of the nuclear processes that produce neutrinos is correct, so at first the onus of explaining the discrepancy fell on those who make theoretical models of the sun. A number of suggestions were made, including a proposal that there is vertical mixing in the sun that disturbs the neutrino-producing layers or that the sun's thermonuclear furnace has shut off. But none of the proposed alterations in solar models went down very well, and physicists began to think of altering the particle physics of neutrinos.

John N. Bahcall, Niccolà Cabbibo and A. Yahil have suggested that the neutrino, instead of being a stable, massless particle as current theory proposes, has instead a small rest mass and is able to decay radioactively into something else in less time than the particle takes to get to the earth from the sun.

Now there is an experimental result that tells against the decaying-neutrino suggestion and a theoretical suggestion of yet another way to change the solar-neutrino theory.

In an experiment suggested by Lowell L. Wood and Jonathan I. Katz of the Lawrence Livermore Laboratory, John R. Morton III and Leland M. Richards of LLL's Nuclear Test Division looked for decay products of antineutrinos in the radiation from an underground nuclear explosion. (Theoretically antineutrino decay is the same as neutrino decay.)

Morton and Richards report in the April PHYSICAL REVIEW C that they find none.

Meanwhile Arrigo Finzi of the Israel Institute of Technology at Haifa says that if physicists are willing to violate present theory in as radical a way as suggesting neutrino decay, they might also be willing to consider a variation in the strength of what they call the weak interaction. The only forces to which a neutrino responds are those of the weak interaction. When a neutrino is produced or when it interacts with other matter, the events occur under the influence of the weak interaction.

In the April 1 ASTROPHYSICAL JOURNAL Finzi proposes that the Fermi coupling constant, which measures the strength of the weak-interaction forces, be not in fact constant but vary with the strength of the gravitational field at any point. This could explain the discrepancy in the solar-neutrino flux.

The variation of the Fermi coupling constant would create some havoc in particle physics, Finzi admits. It would be especially hurtful to theories that seek to unite the weak interaction and the electromagnetic interaction, since for them to succeed with a varying Fermi coupling constant the basic unit of electric charge would also have to vary, and physicists have strong reasons for rejecting that.

Finzi suggests that the possible variation of the Fermi coupling constant can be tested by an improved version of the classic Eötvös experiment, which measured the strength of gravitational forces.

If Finzi is right, he may have the solution to the problem. If he is wrong, and if searches keep turning up no evidence for neutrino decay—Morton and Richards are going back to the search with a more sensitive experiment—then solar physicists may be forced to the option that the sun's thermonuclear furnace is turned off. In that case it is not clear whether it is turned off for good (some models provide for an off-again, on-again sun). If it is, the long-run result will be highly detrimental to the earth. Nevertheless it seems unlikely that anybody alive now need worry about the consequences. ☐