Unrequited search for heavy neutrino

Is there some impending crisis in the relationship between particle physics, neatly but incompletely described, and the qualitative properties of the Universe at large?

THE general belief that most of the mass of the Universe, perhaps four-fifths of it, consists of matter than cannot be seen (and which is thus called 'dark') is apparently undimmed by the equally general failure to tell what it may consist of. No sooner, it seems, does a candidate constituent make its appearance in the literature than there emerges a group of Jeremiahs eager to demonstrate that the candidate will not measure up to the role that astrophysics and cosmology require it to play. Not much has recently been heard of the axion as a generalized cement that will hold the Universe together. Is the idea that a neutrino with a mass equivalent to about 17,000 electron-volts (17 keV) also now destined for oblivion?

It is a curious tale. The idea of the 17-keV neutrino goes back to J. J. Simpson in 1985, which is why it is sometimes called Simpson's neutrino. The original evidence was that of a kink in the energy spectrum of electrons from the β-decay of tritium at an energy of about 17 keV, interpreted as the emission of neutrinos with such a mass in partnership with the electrons whose energy had been measured. Simpson estimated that heavy neutrinos might account for about 3 per cent of the total. More accurately, while most decays of tritium nuclei would yield an electron and an ordinary neutrino, 3 in 100 would yield an electron and a heavy neutrino.

Since then, several groups have sought to replicate the findings by studying the β-decay of other nuclei. In a particularly elegant measurement based on the incorporation of ^{14}C into a sample of germanium wired to function as an electron detector, Sur *et al.* from the Lawrence Berkeley Laboratory produced evidence to support Simpson's conclusion, suggesting a 1 per cent admixture of heavy neutrinos in the decay products of ^{14}C (*Phys. Rev. Lett.* **66**, 2, 444; 1991). Similar conclusions were reached at Oxford from measurements of ^{32}S (Hime, A. & Jelly, N.A., *Phys. Lett.* **B257**, 441; 1991).

Unfortunately, such evidence is hardly ever compelling. People looking for a small kink in a measured curve necessarily contaminated by background must wave their hands vigorously if they are to carry conviction. Direct detection of the particle necessarily carries greater weight. The trouble, here, is that the particle is a neutrino. So what, if it exists, is this neutrino?

Like the others, it is electrically neutral and capable of interacting with other forms of matter only weakly. As particles go, the mass is tiny — a few per cent of the electron mass — but that is far greater than the mass required to close the Universe if it were supposed that all extant neutrinos have the same mass. Simpson's neutrino, if it exists, must be a rarity among neutrinos. The manner of its first discovery also suggests that it belongs to one of the families of neutrinos linked to other particles (and, indirectly, to each other) by the weak nuclear interaction. That seems generally agreed. But not much else.

One obvious difficulty is that Simpson's neutrino cannot be either of the two particles associated with the electron and the muon in the standard scheme of things; the mass is too great for that. But, for the past two years, people have been reasonably confident that there are only three families of two neutrinos (an ordinary and an anti-neutrino), linked with and characteristic of one of three lepton-pairs — electrons, muons and tauons. If Simpson's neutrino is neither the electron nor the muon neutrino, it must be that associated with the tauon.

But that raises problems. James M. Cline and Terry P. Walker from the Ohio State University at Columbus now argue that, if Simpson's neutrino is the tauon-neutrino, there are difficulties about its lifetime (*Phys. Rev. Lett.* **68**, 270; 1992). On the standard model of weak nuclear interactions, the neutrino should be stable against radiative decay, with a lifetime of about 10^{22} seconds. But, the argument goes, if the microwave background radiation is not to be "unacceptably" distorted, the lifetime of Simpson's neutrino must be less than 10^6 seconds (a couple of weeks or thereabouts). The gap between the two limits seems unbridgeable.

Cline and Walker, with admirable cheerfulness, chase the issue into a cul-de-sac by supposing that Simpson's particle does not have the properties described by the standard model of the weak interaction, but that it may be something different. But even with that extra freedom, it seems that Simpson's neutrino cannot be easily accommodated. Several cosmological considerations constrain the properties of the 17-keV neutrinos, For example, reconstructions of the formation of ^4He in the early Universe are possible only if the Simpson particle is accompanied by another electrically-neutral weakly interacting particle, but apparently inescapable difficulties still arise in reconciling expectation with reality. Further arguments with similar conclusions attend the discussion of the emission of neutrinos from the five-year supernova SN1987A.

What Cline and Walker modestly conclude is that, "if Simpson's neutrino survives, it surely will point to exciting and surprising new particle physics in the neutrino sector". Their readers will be forgiven for asking whether that state of affairs may not already have been reached, even if nobody has yet been able to define what the "new particle physics" consists of. The simple way out, of course, would be to insist that the laboratory experiments are faulty, or that their admittedly hazardous interpretation is wrong, but that would be unpardonably unfashionable and dangerous as well.

Yet the argument continues. Enqvist, Kainulainen and Thomson (from Copenhagen, Copenhagen and Manchester respectively) argue that there would be advantages if the lifetime of the Simpson neutrino were greater than the decoupling time of electron neutrinos in the supposed Big Bang, but less than the time at which nucleosynthesis began (*Phys. Rev. Lett.* **68**, 744; 1992). Gorski, Silk and Vittorio (from Princeton, Berkeley and Aquila in Italy respectively) argue more broadly that the issue of whether the doctrine of cold dark matter can be reconciled with what is known of the anisotropy of the microwave background will be settled (or otherwise sharpened) by the latest analysis of data from the Japanese COBE satellite, due out any day (*Phys. Rev. Lett.* **68**, 733; 1992), but that little can be done until then to reconcile the Simpson experiments with their cosmological implications.

Where all this will lead is anybody's guess. It will be a remarkable development if a sketchy laboratory observation of irregularity in an experimental curve leads directly to an upheaval in cosmology, but this year is, after all, the fourth centenary of the occasion when Galileo first set his heliocentric cat among the Vatican's pigeons. It is possible, of course, that Simpson's neutrino will not "survive" the year, but otherwise it is in everybody's interest to decide what the dark matter is made of. **John Maddox**