Hunting for the missing mass

Neutrinos now seem to be poor candidates to supply the mass to close the Universe. Cosmologists should now deal with an observation suggesting that the problem of the missing mass is illusory.

THE cosmologists' hunt for what they call the missing mass is not just an hilarious entertainment mounted for the benefit of ordinary people. The underlying issue is whether the visible mass of the Universe, including that of the stars that constitute the galaxies, is substantially all there is. If so, the average density of the Universe is roughly 10^{31} g cm^{-3}, rather less than 10 per cent of the critical density needed to decelerate the expansion to zero — to bring it to a halt. Those who search for missing mass are therefore looking for some means of equipping the Universe with perhaps ten times as much matter as can now be seen. Whatever it is, it cannot by definition radiate, and must be in other ways inconspicuous.

The particular contribution of P. Hut and S.D.M. White (p.637, this issue) is their judicious examination of whether neutrinos (and antineutrinos) will fill the bill. The conclusion is that, with the constraints of particle physics on the one hand and of cosmology on the other, two of the three known species of neutrinos must carry mass and that the heavier of them, at least, must be radioactive. There are two ways of regarding this result. Optimists will take it as a prediction to be confirmed. Pessimists, likely to be the vast majority, will take it as a sign that the missing mass, whatever it is, does not consist of neutrinos.

But why take all this trouble? Why now further strain credulity by asking whether the missing mass may be made of axions, or photinos, whose very existence remains to be demonstrated? Would it not be simpler if cosmologists abandoned their general belief that there is missing mass, reconciling themselves instead to the notion that the Universe will go on expanding and the galaxies receding from each other indefinitely?

The trouble, as Dennis Sciama said in a Royal Society lecture last year, is that the problem of the missing mass "will not go away" (*Proc. R. Soc.* A **394**, 1-17; 1984). Hut and White say that the roots of the problem are in part "philosophical" — and do not by that imply that they have a prejudice about the kind of Universe in which they would prefer to live. Put simply, their point is that the near-coincidence between the density of the Universe and the critical density that would be needed to close it, and which differs merely by an order of magnitude, cannot be a chance coincidence.

Sciama points out that the coincidence is even more startling than it seems. Discrepancies between the density of the Universe and the critical density can only grow with the passage of time. So if the difference now is represented by a factor of ten, it must have been quite minuscule at the very early stages in the evolution of the Universe. So (simplifying a little), near-equality of the density and the critical density must be a feature of the system.

This provides *post hoc* support for the fashionable notion of the "inflationary universe", most simply regarded as evolution in two distinct phases, in the first of which the full menagerie of material particles allowed by some correct Grand Unified Theory are transformed into each other, creating matter at such a rate that the density stays critical. Affectionately, Sciama notes the similarity between this state of affairs and Hoyle's steady-state universe of more than thirty years ago. This picture has the advantage also of explaining why the microwave background radiation is isotropic to within one part in 1,000. And it makes the search for missing mass respectable.

There are also observations which have that effect, broadly speaking of two kinds. First, it is known from observations of spiral galaxies that individual stars appear to experience gravitational forces greater than can be accounted for by the masses of other visible stars as well as gas and dust clouds. Even the motion of the Solar System perpendicular to the plane of the Galaxy seems to be governed by a gravitational force twice as great as that inferred from the known distribution of massive objects. And the in-plane velocities of stars in other spiral galaxies do not decrease with distance from the centre as quickly as expected, supporting the idea that spiral galaxies have massive haloes. The most recent but perhaps most persuasive evidence that there is missing mass on a substantial scale comes from the behaviour of clusters of galaxies, which appear uniformly to be more tightly bound gravitationally than the sizes of their members would suggest. So the hunt has seemed a hunt for something real.

What, then, will the mass-hunters make of the results of a discordant investigation just published. (Tyson, J.A., Valdes, F., Jarvis, J.F., & Mills, A.P., *Astrophys. J. Lett.* **281**, 59; 1984)? The design of this gigantic computer exercise (at Bell Laboratories) is based on the expectation that light from a distant galaxy should be affected by the gravitational field of galaxies standing closer along the line of sight, with the result that, in general, the apparent shape of a distant galaxy should be distorted by those lying in the foreground. Tyson and his colleagues have worked with the images of galaxies on a series of 35 plates exposed at the prime focus of the 4 m telescope at Kitt Peak, and containing altogether more than 200,000 images of galaxies, down to the 24th magnitude.

The procedure is to separate the galaxies into two groups, consisting of more and less distant objects, and then to select pairs of galaxies (separated by less than a minute of arc), of which there were nearly 28,000. The effect of foreground galaxies on the shapes of distant objects is assessed by the computation of a combination of the second moments about the centroid of an image. Obviously the interpretation of this data must boil down to looking for significantly systematic departures from circularity or ellipticity along the vector to the putatively deflecting star. Because many of the distant images will be only a few pixels across, only large numbers will ensure a meaningful result.

For the mass-hunters, the outcome is disconcerting. Distant galaxies in pairs separated by more than 10 seconds of arc are undistorted, but smaller angular separations bring misshapen images of the more distant galaxies. Tyson and his colleagues say that their estimates (of the mass of the nearer galaxy) would have to be in error by two or three standard deviations to be consistent with the larger estimates of mass produced by other methods. Their best estimate of the density of the Universe is a mere three per cent of the critical density (with a two standard deviation chance that the two densities are the same).

What is to be made of this unexpected challenge? First, more analysis (which Tyson *et al.* promise) is needed; obviously the technique itself is full of promise. Tyson and his colleagues, in explanation of the conflict with measurements suggesting there is lots of missing mass, say that, hitherto, people have concentrated on the brighter galaxies. Not all those who hunt for missing mass are dismayed by what has happened. One well-known practitioner is attracted by the possibility that the Tyson result is correct, relishing the idea that "it's telling us something about gravity we didn't know before". **John Maddox**