the fusion of the two organelles. Stern is impressed with the plentiful electron-micrographic evidence of such fusion and at present marginally prefers this mechanism over the first.

"At certain times in the life cycle the mitochondria and chloroplasts can come into very close contact," he notes. "There is probably plenty of opportunity for sequence transfer through fusion of the organelles." Stern acknowledges, however, that there is no reason to suggest that transfer is necessarily the result of just one mechanism. Different mechanisms might operate during different transfers. "But," he says, "I doubt there is a specialized vector system."

Stern is now interested in determining whether the chloroplast DNA might in some cases be functional in the mitochondrial genome. "We have to start by showing it is transcribed," he says, "and then go from there." Chloroplast sequences have been located very close to some functional mitochondrial genes, "but that doesn't prove anything." Stern's current guess, however, is that some of the transferred sequences will be shown to be functional.

In any case, Stern and Palmer conclude that "the widespread presence of ctDNA sequences in plant mtDNA is best regarded as a dramatic demonstration of the dynamic nature of interactions between the chloroplast and the mitochondrion, similar to the ongoing process of interorganellar DNA transfer already documented between mitochondrion and nucleus and between chloroplast and nucleus."—**ROGER LEWIN**

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New Light on Dark Matter?

It fills the universe, it is utterly invisible, and it may not even exist; meanwhile, the hypotheses are getting more exotic

The "Inner Space/Outer Space" workshop* at the Fermi National Accelerator Laboratory was intended as a comprehensive overview of the connection between particle physics and cosmology, vintage 1984. In that it succeeded admirably. Only a few years old, this field continues to be one of the most vigorous and productive in physics.

The "inflation" theory of the early universe continued to hold center stage, as it has for several years now (*Science*, 28 January 1983, p. 375); people are currently exploring such ideas as supersymmetry and the more exotic grand unified theories in an effort to bring the detailed predictions of inflation more closely in accord with observation. Also on display were the newly revived, 60-year-old "Kaluza-Klein" models of the fundamental forces, which assume that we live in a universe having not just the 4 dimensions of ordinary space and time, but 5 dimensions, 11 dimensions, or more. (The champion theory at Fermilab called for 950 dimensions.)

But it was clear that the most baffling single problem in this field continues to be the large-scale structure of the universe, together with its relationship to the so-called dark matter, or "missing mass" (*Science*, 4 March 1983, p. 1050). This mysterious, utterly invisible ectoplasm fills the universe and has surely had a profound effect on cosmic evolution. But no one really knows what it is. The better the observations become, in fact, and the more carefully the situation is analyzed, the more the theorists are being forced into exotic hypotheses—not the least of which is that the cosmos is filled with "string."

One emerging insight, emphasized by a number of participants at Fermilab, is that *the* dark matter problem is actually *two* dark matter problems that may well involve different phenomena. The "large-scale" problem is usually phrased in terms of the quantity Ω, the ratio between the observed average mass density of the universe and a certain critical density at which the kinetic energy of cosmic expansion just balances the potential energy of gravitation. The overwhelming theoretical predilection these days is for an Ω precisely equal to 1, largely because $\Omega = 1$ is a prediction of the inflation models, which nicely explain such things as the homogeneity and isotropy of the universe.

However, in observational reality the ordinary "baryonic" matter in the universe—the stuff composed of protons, neutrons, and electrons—falls short by an order of magnitude. The best evidence for that comes from observations of the cosmic abundance of light elements such as deuterium, helium-3, and lithium-7, which were primarily produced by nucleosynthesis in the Big Bang; as Gary Steigman of the Bartol Research Foundation explained at Fermilab, the latest measurements and the latest calculations agree beautifully, but only if the baryonic matter density is less than about 15 percent of the critical density.

Thus the large-scale dark matter problem: what, if anything, makes up the remaining 85 percent?

The "small-scale" problem has to do with the dynamics of galaxies and clusters of galaxies. The situation is fraught with observational ambiguities, as Kitt Peak National Observatory's Jay Gallagher pointed out at length to the Fermilab participants, but essentially it boils down to the fact that spiral galaxies are rotating much too fast. Especially in the outer regions, there never seem to be enough visible stars to hold a given galaxy together by gravity; it is as if the galaxy were embedded in an extended halo of invisible mass that *can* hold it together. (To be precise one should actually talk about the enhancement of density over a constant background; the large-scale dark matter, if it were uniformly distributed, would have no gravitational effect on individual galaxies.)

In much the same way, galaxies in the large clusters seem to be moving too fast, as measured by the scatter in their red shifts; unless the clusters are embedded in a substantial haze of invisible mass, they would have long since flown apart.

Thus the small-scale dark matter problem: what is this stuff?

Now, from a strictly observational standpoint there is no real reason to get excited. Technical advances during the last 5 years or so have considerably speeded up the tedious business of measuring galactic red shifts—the Harvard-Smithsonian Center for Astrophysics is now compiling some 2000 red shifts per year—and this has correspondingly im-

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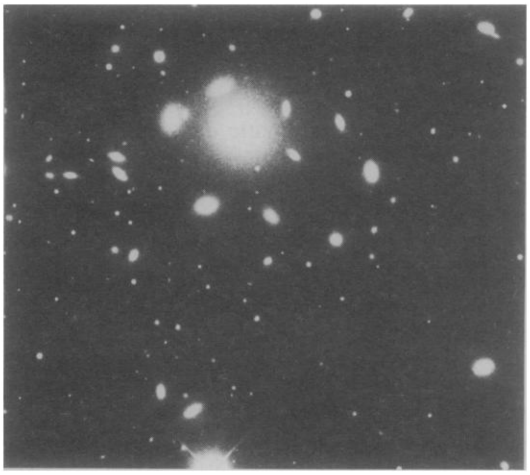

Cosmic ectoplasm

In clusters like this one, in Coma Berenices, the glowing matter in the galaxies represents only a fraction of the mass. Without some kind of invisible matter—dim stars, "Jupiters", swarm of black holes, or Something Else—the galaxies would fly apart.

proved the astronomers' ability to estimate cluster masses. The striking thing is that the latest figures are quite consistent with Steigman's estimate of the baryon density from Big Bang nucleosynthesis. In other words, the small-scale dark matter could in principle be explained away as a swarm of very dim stars, or free-floating Jupiter-sized "planets," or some other kind of ordinary baryonic matter that just happens to be nonluminous.

However, the small-scale dark matter *does* become a problem when one considers how the galaxies and clusters might have formed. The natural assumption is that galaxies and clusters are primordial density fluctuations that have been amplified by gravity. But if that is the case, and if all the matter is indeed made of baryons, then why did primordial matter prefer to form clumps on scales of 10^{12} solar masses (galaxies), or 10^{15} solar masses (superclusters)? There is nothing special about those numbers.

And how does one explain the remarkable uniformity of the 3 K background radiation, which was emitted from the cooling cosmic plasma only 100,000 years after the Big Bang? To get pure baryonic galaxies today, the universe would have needed density fluctuations of at least 0.1 percent at the time the background radiation was emitted. Yet the latest measurements of the background limit the fluctuations to less than one tenth that value.

Finally, how does one explain the distribution of clusters and superclusters, the so-called large-scale structure of the universe? The evidence from the latest red shift surveys, reviewed at the Fermilab conference by Marc Davis of the University of California, Berkeley, has now convinced most astronomers that the clusters and superclusters display a rather frothy structure of clumps and voids on a scale of some 25 megaparsecs. Indeed, the void discovered in Boötes just a few years ago—the famous "Hole in Space" (*Science*, 27 November 1981, p. 1016)—now seems to be fairly typical.

What makes this structure so hard to understand is that the galaxies seem to be almost as old as the universe itself, while most clusters are loosely bound, erratically shaped, and in general quite young looking. This sounds innocent enough: just assume that the individual galaxies formed first—somehow—and that gravity later led them to congregate into clusters and superclusters. The problem is that when this idea is tested in computer simulations it just never seems to work out; unless one imposes very precise and rather ad hoc initial conditions on the distribution of the galaxies, the result is a model universe with either far too much structure, or virtually none at all.

The upshot of all this is a restatement of the small-scale dark matter problem from the theoreticians' point of view: namely, that the dynamics of the cosmos make no sense unless there is something else out there besides baryons. So again, what is it?

For a brief period in the early 1980's, many cosmologists were convinced that they had found an elegantly simple solution to both the large-scale and the small-scale problems simultaneously: simply assume a tiny mass for the neutrino, perhaps a few dozen electron volts. It was perfect. Neutrinos would certainly be invisible, since they hardly interact with anything. And yet they were produced in abundance during the Big Bang, so that even a tiny mass would allow them to dominate the universe gravitationally and raise Ω up to 1.

Perhaps most impressive of all, a number of independent groups calculated in 1980 that massive neutrinos in the early universe would have formed gravitational "traps" for baryonic matter, with a natural mass scale on the order of 10^{15} solar masses—superclusters. They argued that the massive neutrinos could thus have catalyzed the formation of superclusters without violating the 3 K background limits on initial density fluctuations. Furthermore, since there seemed every reason to think that the massive neutrinos would also have congregated in the clusters and around individual galaxies, they might be the stuff of the mysterious halos as well.

Unfortunately, at Fermilab it was apparent that the massive neutrino has lost a lot of its luster. Independent Soviet and American experiments have indeed reported positive evidence for a neutrino mass. But that was in 1980, and most physicists now regard those results as either inconclusive or wrong. (Columbia University's Frank Sciulli reviewed a number of more sensitive experiments that are now under way around the world; they should be producing results, yea or nay, within about a year.)

Worse, the massive neutrino models have never been able to explain the fact that the galaxies are old and the clusters are young. Quite the opposite: they make the embarrassing prediction that the clusters and superclusters formed first, and that the galaxies are young.

Worst of all, it now appears that the neutrinos do not even get the clustering right. Computer models of a neutrino-dominated universe, such as those shown at Fermilab by Simon White of the University of Arizona, consistently reveal far too much clustering—at least if they incorporate reasonable values for such things as the Hubble parameter and the age of the universe.

More generally, David N. Schramm of the University of Chicago pointed out that the same particle cannot be the solution of both dark matter problems. If the stuff that clusters around the galaxies is also the large-scale $\Omega = 1$ dark matter, then one would expect to find $\Omega = 1$ in galaxies. In fact, the previously mentioned red shift surveys are telling us that the small-scale matter has an Ω of at most a few tenths.

The upshot of all this was a general body of opinion at Fermilab that the massive neutrino, while it may still turn out to contribute to the large-scale dark matter, cannot do the whole job. Something else is needed.

One effect of this impasse is that people have begun to rethink what the structure problem really is. While it is true, for example, that glowing matter in the galaxies outlines a rather frothy cosmic structure, it does not logically follow that all the (baryonic) matter follows the same pattern. James Bardeen of the University of Washington suggested at Fermilab that baryonic matter is in fact very widely distributed—even in the famous voids—but that galaxies, for some reason, have only formed where the density fluctuations are most extreme.

Many of the Fermilab participants seemed taken with Bardeen's idea. Such a "2σ" effect would imply that the large-scale structure is mostly illusion. But that would certainly make it easier to reconcile with the smoothness of the 3 K background. Moreover, Neta Bahcall of the Space Telescope Science Institute reported on recent statistical studies that showed much tighter groupings among the brighter clusters than among the dimmer ones—almost, she said, as if the glowing matter in galaxies represented the peaks of a mountain range instead of the underlying continent.

It is not at all clear what the implications of such a 2σ effect would be for the dark matter problem. But the idea is still very new, and in any case the massive neutrino hardly marks the limits of the particle theorists' ingenuity. Popular dark mass particles discussed at Fermilab included the axion, predicted in certain unified field theories, and the gravitinos and photinos, predicted in theories of supersymmetry (*Science*, 29 April 1983, p. 491).

For cosmological purposes such particles are known as "cold" dark matter, as opposed to "hot" dark matter comprised of massive neutrinos; ultimately the term refers to the exceedingly weak interactions of the particles, and the fact that relic particles produced in the Big Bang would today be moving much more slowly than massive neutrinos.

The nice thing about primordial cold matter is that it would have naturally trapped the primordial baryons in clumps with the mass of galaxies, which is exactly what one needs if the galaxies are to be old. Arizona's Simon White showed computer simulations, similar to the ones that neutrinos failed so miserably, in which cold dark matter produced a large-scale structure very much like the structure we actually see. Of course, this picture does rely on unobserved particles—neutrinos, at least, are known to exist—but such is the state of particle theory that one has to take such possibilities seriously.

Several groups have proposed a varient of this model featuring cold, heavy neutrinos: the particles first catalyze galaxy formation, thus solving the small-scale dark matter problem, and then after a billion years or so decay into a uniform background of light neutrinos, thus solving the large-scale $\Omega = 1$ problem. Such particles have already been postulated in certain unified theories for mathematical reasons, so the model is not totally ad hoc.

Finally, for a completely different approach, the participants at Fermilab heard from Tufts University's Alex Vilenkin about cosmic string.

Strings, he explained, are something like quantum vortices in superfluid helium, and something like defects in a crystalline lattice. (More precisely, they are linear topological defects in field theories that have spontaneous breaking of CP symmetry.) But the upshot is that they would be infinitesimally thin, about 10^{-30} centimeter; enormously massive, about 10^{22} grams per centimeter; and exceedingly taut, about 10^{42} dynes tension. Thus, said Vilenkin, only infinite strings and closed loops of string are possible. A string with two ends would quickly collapse and dissipate.

Now, if such theories actually describe nature, said Vilenkin, then strings could have been produced abundantly in the early universe. While no one argues that they are candidates for the dark matter, they might have been excellent seeds for galaxies: calculations show that they would have gathered primordial gas around themselves at just about the right mass scale. Moreover, since big loops tend to shed little loops, large-scale and small-scale structure would be correlated in a certain way that does, in fact, resemble the way galaxies are correlated. Finally, the loops would have collected enough mass in their immediate vicinity to have collapsed into 10^6 solar mass black holes. Not only does our own galaxy seem to have such a black hole in its center (*Science,* 21 May 1982, p. 838), but quasars and other active galaxies are thought to be powered by central black holes.

However, what really got the Fermilab physicists excited about the string model is that it actually has observable consequences. An infinite string would deflect light and act as a gravitational lens, noted Vilenkin, so one could look for lines of double quasar images across the sky. Ripples in the string, especially in the loops, would also be a potent source of gravitational radiation. One could observe the very long wavelength waves by looking for gentle perturbations in the motion of Earth, using pulsars as clocks. In the case of the recently discovered millisecond pulsar, the observational limits on such radiation are already approaching the predicted value.

—M. MITCHELL WALDROP

NMR with No Magnetic Field

Zero-field NMR makes it possible to obtain high-quality spectra from powders and polycrystalline solids

A new technique to extend nuclear magnetic resonance (NMR) spectrometry to polycrystalline and amorphous solids has been developed by Alexander Pines, Daniel Weitekamp, and their colleagues at the University of California, Berkeley. The technique is called zero-field NMR because the spectrum is produced in the absence of an external magnetic field. The technique thus measures directly the effect of the magnetic field created by each atom's nuclear spin on the spin of nearby atoms and provides information about couplings and interatomic distances.

The new technique bucks the recent trend in conventional NMR spectrometry toward insertion of the sample in ever higher magnetic fields; higher fields are used to increase sensitivity and resolution. Except for single crystals, however, higher fields are of little value for the study of dipole couplings in solids. The problem is analogous to the problems associated with x-ray diffraction studies of amorphous or polycrystalline materials.

When a single crystal is placed in a beam of x-rays or in a magnetic field, each molecule in the crystal has the exact same orientation with respect to the beam or the field. The x-ray diffraction pattern or the chemical shifts of the NMR spectral lines change as the spatial orientation of the crystal is changed. By correlating these changes with that orientation, it is possible to extract structural information.

In a polycrystalline or amorphous solid, however, the orientation of each molecule with respect to the x-ray beam or magnetic field is random. For x-rays, this produces a diffraction pattern with limited information content. In NMR, individual spectral lines coalesce into a "powder pattern"—a broad, relatively featureless spectrum in which most structural information is lost.