would affect the potential energy V; or if the galaxies were not, as assumed, all in the same cluster but in neighbouring clusters which overlap in the line of sight, which would affect the kinetic energy T. It is just possible that these and other observational errors could account for all of the 'missing mass'.

There are, however, four other possibilities:

a. that the clusters are indeed unstable and are dispersing;
b. that the masses of galaxies are currently underestimated by large factors;
c. that intergalactic matter in the cluster contributes the required mass;
d. that the mass is present in some other form, as yet undetected.

The first of these runs into the severe difficulty of explaining the large numbers of galaxies still in clusters, since clusters would disperse completely within some 10^9 years, short in comparison with their ages. The first point to be made about b is that masses have been determined for galaxies in clusters as well as for galaxies outside, and there are no significant differences. Now, radio observations of spiral and irregular galaxies have led to mass estimates about three times larger than the earlier ones derived from optical studies alone, so it is possible that even these revised values are underestimates. Arguments that disc systems require substantial outer halos to retain stability also suggest that there might still be quite a large underestimate of their masses but, on the other hand, studies of binary galaxies suggest that there is not.

The third possibility concerns the intergalactic matter in clusters. It is possible to set very good upper limits on the amount of neutral intergalactic gas, by looking for absorption lines (optical or radio) in the spectra of galaxies seen through the gas. If it is evenly distributed in the cluster, such gas certainly contributes insignificantly to the 'missing mass', and although more gas could be present without being detected if it were in separate high density clouds, recent observations suggest that there is unlikely to be enough mass present in such clouds either.

As discussed earlier, the detection of X-ray emission from clusters indicates the presence of an ionized intergalactic gas. Support for this comes from the distorted shapes of several extended radio sources found in clusters, which could be due to the expanding material of the source interacting with intergalatic gas. Further support comes from a recent report by radioastronomers at Cambridge University, England, that the cosmic background radio radiation (page 206) has a lower intensity when seen through clusters, presumably because of absorption by the intracluster gas. Moreover, ionized gas at the temperature of 10^8 K, mentioned previously, would be distributed in the cluster in the same general way as the galaxies, and a dynamical analysis for the Coma cluster suggests that the 'missing mass' must have such a distribution.

From the total X-ray intensity the mass of ionized intergalactic gas can be deduced, but it is only about 10 per cent of the virial theorem mass. However, combined with the known mass in galaxies, this reduces the discrepancy to a factor of about 4. It is reasonable to suppose that the balance could be made up of a combination of errors in galaxian masses and in virial theorem masses. Because of this, it may well not be necessary to invoke d, the presence of other, less normal sorts of intergalactic objects. The possibility of a supermassive black hole or other unseen condensed object at the centre of a cluster would in any case be excluded by the extended distribution required for the Coma cluster.

The mean density of the universe

The rate of expansion of the universe is becoming slower because of gravitational forces. If its average density is larger than a certain critical value, gravity will take over and expansion will eventually stop, to be followed by contraction; the universe is said to be **closed**. If the density is less than this critical value, expansion will continue for ever; the universe is **open**. Using the value of 55 km per s per Mpc for Hubble's constant, this critical density is equivalent to 3·4 hydrogen atoms per m^3. A reasonable estimate for the matter present in galaxies gives, when aver-

The radio structure of the galaxy NGC 1265 in the Perseus cluster, superimposed on an optical print. The swept-back structure is evidence for intergalactic gas in the cluster, sweeping past the galaxy.