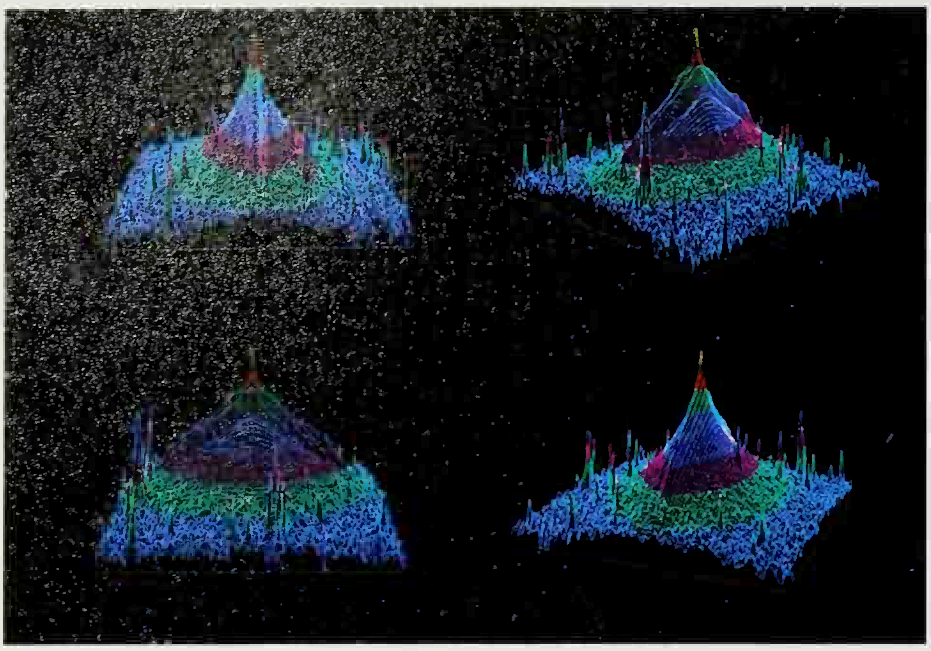

The use of computer graphics such as these displays of optical emission from part of M104 make it possible to 'view' galaxies from various angles.

aged through space, only one-fiftieth of this value. Supposing, though, that the mass discrepancy in clusters were caused entirely by underestimating the masses of galaxies (which is possible but unlikely), then the averaged mass would be brought up to about one-third of the critical value. It seems reasonably certain that galaxies and whatever it is that binds clusters together would not be sufficient to close the universe. Some other material, in between the clusters, is required.

Intergalactic material between clusters

It is possible that gas exists in the space between clusters. Such gas could be electrically neutral or ionized, and, because of the expansion of the universe, it should display a redshift. Observations show that if there is neutral gas spread throughout space, it can be there only in tiny amounts, and that even if it were concentrated into dense clouds, there could be no more than about one-third of the critical density. One instance of a fairly massive cloud of neutral hydrogen is known at a distance of about 10 Mpc. The indications are that this is at least 100 kpc across, and although the average density is low it appears to contain about as much mass as a galaxy. Whether other examples exist remains unknown at present.

We do observe an X-ray background coming apparently from every direction over the whole sky, and this can reasonably be interpreted as emission by an intergalactic ionized gas at about 10^8 K. There is an alternative explanation for this radiation, which is that it comes from a host of faint discrete sources. If this were so it should be possible to detect fluctuations in the amount of radiation over small areas of sky. At present observations are not precise enough for us to establish whether such fluctuations exist. In any case, it seems likely that the density of intergalactic gas required to produce the observed radiation is less than the critical density, although it is just possible that it could equal it. Moreover, there are several problems concerned with maintaining the high temperature required for the radiation and with the effects of the hot gas on clusters and galaxies embedded in it, which make it appear necessary that the density of a 10^8 K intergalactic gas must be significantly below the critical value.

Another possibility is the presence of intergalactic dust. This would redden the light from galaxies, but no such reddening is observed. The amount of any dust present must be far too small to contribute significantly to the total density. Indeed, this is to be expected, because intergalactic material probably contains scarcely any atoms heavier than hydrogen and helium, since heavy atoms are created by nuclear processes inside stars. Moreover, this expected lack of heavy elements also rules out the presence of very large numbers of larger solid objects, of sizes between a few centimetres and planetary sizes, even though they are not ruled out from an observational point of view.

Intergalactic populations of subluminous objects – very cool main sequence stars, white dwarfs, neutron stars and black holes – which could in total contribute more than the critical density are not ruled out by observation. However, it appears unlikely that a large population of low mass main sequence stars could exist outside galaxies, while the other objects form as end products of stellar evolution, so they are also to be expected in substantial numbers only inside galaxies. A final possibility of meeting the mass deficiency is that there might be significant quantities of neutrinos or **gravitons** (gravitational wave packets), but there is no possibility of detecting them if they are there.

Because of all the many uncertainties, the question of whether the mean density is greater or less than the critical value is still unresolved. Nevertheless, since all forms of matter which can be studied with accuracy contribute substantially less than the critical density, and most other forms of material appear implausible, it is fairly widely felt that the total density probably is below the critical value, in which case the universe will expand for ever.

The microwave background radiation

In 1965, Arno Penzias and Robert W. Wilson discovered an unexpectedly strong radiation from space at the short wavelength of 7 cm, in the microwave region of the radio spectrum. It was some 100 times stronger than the radiation to be expected at this wavelength from known sources, and it was found to come equally from all parts of the sky. Studies of it, extended to other wavelengths, have concentrated on two questions: what is the form of the spectrum of the radiation, and how accurately is it independent of direction?

Early observations showed that the spectrum has the form to be expected from a black body (page 47) radiating at a temperature of about 2·7–2·9 K. Such black-body radiation should, at this temperature, have a maximum intensity at a wavelength of about 2 mm, so one important question is whether the intensity actually reaches a maximum at about 2 mm or continues to increase beyond there to shorter wavelengths. However, the answer can not be obtained from ground-based observations, since