in a continuous outflow from the nucleus. The origin of the hot plasma is another problem; again, it could involve a black hole.

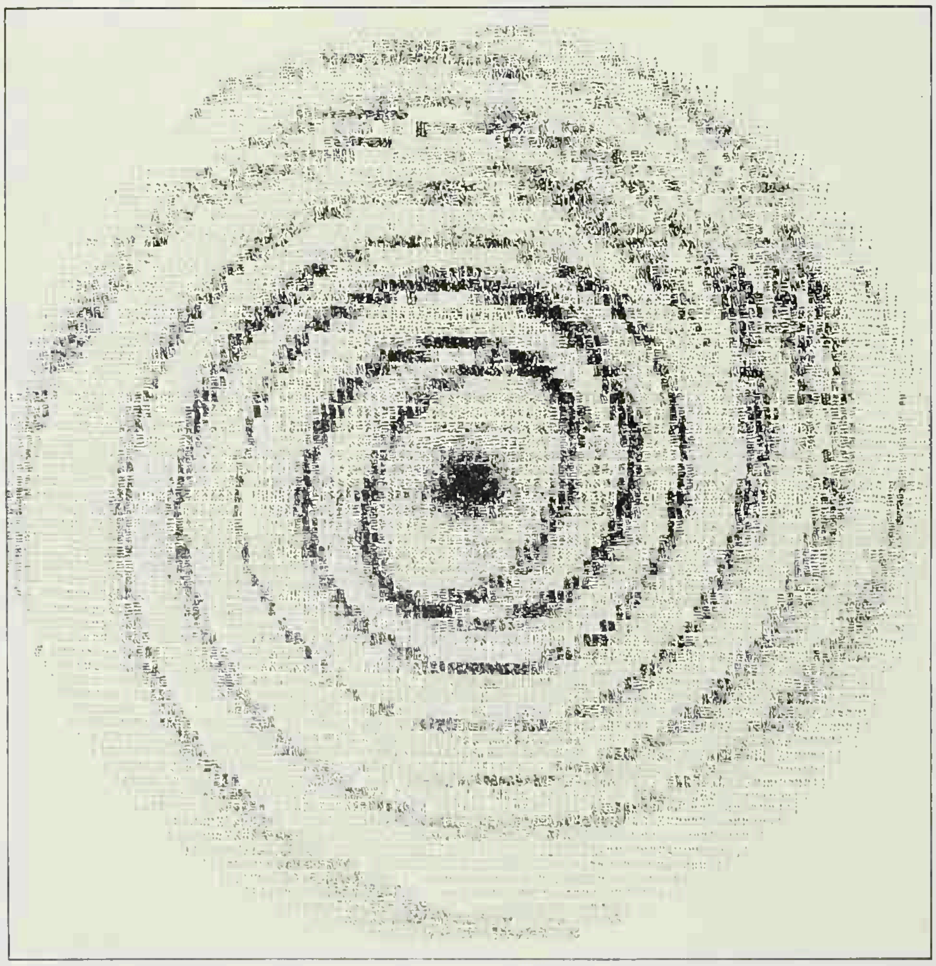
Apparent superluminal velocities

Since about 1972 it has been possible to observe the structure of some of the compact radio sources, using very long base-line interferometry (page 242), and they are found to be double-lobed, similar to extended sources. The angular sizes of less than 0·01 arc sec. correspond to actual dimensions of only a few parsecs. Now, in at least four cases – three quasars and one galaxy – structural changes which have taken place over several years give an apparent velocity of expansion much greater than the speed of light. This is based upon the assumption that the distances are given by interpreting the redshifts in accordance with Hubble's law. As one of the sources is a galaxy (3C 120) this can not easily be questioned.

It is a fundamental result of modern physics, well verified experimentally, that nothing physical can move faster than the velocity of light. This result is, indeed, an essential part of the theory of relativity. However an *appearance* can move faster than light, so long as no direct *physical* motion is involved. This is now thought to be the explanation of the phenomena observed, especially after examination in detail of one such source, the nearby quasar 3C 273, well-known for its visible jet as well as for its association with a galaxy. It is believed that jet processes are producing a beam of highly energetic electrons travelling at close to the speed of light. Under such circumstances, despite what might be thought at first, if the beam is directed towards us rather than across the line of sight, the material excited by the electrons can appear to move at greater than the speed of light. In the case of 3C 273 the beam is probably within about 12° of our line of sight. The other instances almost certainly have the same cause, and statistical studies are likely to show that because we may expect the beams to be randomly orientated in space, only a few such examples will be visible to us.

As far as the gravitational redshift hypothesis is concerned, it requires a large mass in a small volume. We then have to face problems of stability, while, in addition, the nature of the emission lines in the spectrum implies a large region of relatively low density gas through which the gravitational field is uniform. All in all, an object of the order of 10^{11} $M_\odot$ only 10 kpc away seems to be required, the observational consequences of which would be enormous.

Fig. 7·10
A computer representation of the possible optical appearance of our Galaxy seen face on from outside, based on an interpretation of the observations using the density-wave theory. The structure is essentially a four-fold spiral. The Sun is located about two-thirds of the way towards the top edge of the picture.



The formation and evolution of galaxies

Galaxies formed about 10^{10} years ago, at an earlier epoch in the development of the universe, so galaxy formation must be related to cosmological processes. Our ideas of how galaxies formed are much less coherent even than our ideas about star formation. There are various competing theoretical models, all of them primitive.

It is generally accepted that the galaxies formed by condensation from a primaeval 'intergalactic' material, and that this must have contained irregularities from the earliest stages of the expansion of the universe: the growth of chance fluctuations in an initially uniform medium would not be efficient enough. In one class of theories, unevenness in the distribution of the material led to instabilities and so to the collapse under gravity of parts of the material to form galaxies. Rotation would then come about by interaction between neighbouring galaxies or clusters of galaxies. In another class of theories, the early irregularities took the form of vortexes in turbulent motion, which naturally led to the formation of rotating systems. Presumably galaxies formed in clusters, as stars do.

There is, however, a third, quite different idea: that galaxies emerge from white holes at their centres. A white hole is the exact reverse of a black hole; nothing can enter it and there is a steady outflow of matter. Such white holes (if there are such things) must have been in existence from the start of the universe, and each would cease to exist when it had thrown out all the mass which it contained.

Accepting the idea that the galaxies all formed from the same material at about the same time, the differences between them must have arisen from different evolutionary developments after they formed. Two major properties of a galaxy are its mass and its angular momentum, but since all the Hubble types have a wide range of mass, it seems that mass is not decisive. On the other hand, angular momentum appears to be linked with Hubble type and can in outline explain the different developments. The flattening of an elliptical galaxy can be related to its rotation, while in a disc galaxy, faster rotation means a slower collapse, so that up to the present time less of the interstellar gas has been used forming stars.