before the emission lines could be identified; only in 1963 was Maarten Schmidt able to recognize them as familiar lines but with unprecedentedly large redshifts. Within the next two years Allan Sandage recognized the existence of radio-quiet quasars. It has been estimated that around a million QSOs are detectable and that the QSS are outnumbered about 100 to 1 by radio-quiet objects.

Emission line redshifts have been determined for some hundreds of quasars. The distribution in redshift is smooth, and values range from $z = 0{\cdot}04$ up to 3·78, although almost all are below 2·4. If the redshifts are related to the quasar distances by Hubble's law, most quasars are very much more distant than ordinary galaxies or even active galaxies. Most astronomers now accept that there is a continuous progression through Class 1 Seyferts, N galaxies and quasars and that their distances are indeed great. From Seyferts to quasars we progress towards relatively more intense nuclei, a quasar appearing starlike because its distance makes the rest of the galaxy undetectably faint. As for Class 1 Seyferts, the emission lines in the quasar spectrum suggest the presence of a low-density plasma similar to a gaseous nebula.

## BL Lacertae objects

The object BL Lacertae, once classified as a variable star, was identified with a radio source in 1968, and now about 40 objects like it are known. They are essentially similar to quasars and the nuclei of Seyfert and N galaxies, except that the optical spectrum of the compact object is a continuum; no emission lines are seen. Some appear in the nuclei of elliptical galaxies, some are associated with nebulosity, but most appear stellar on the best available plates.

In many of their properties, they are like more extreme versions of quasars and N galaxies; for example, in the form of the spectrum, the rapid variations of intensity at all wavelengths (within a few weeks), and the strong polarization of their radiation, which may reach 30 per cent. Almost all of those known are radio sources, but none is associated with a large extended source as many quasars are. None is yet identified as an X-ray source. They radiate most strongly in the infrared.

It has been suggested that the BL Lacertae objects are young quasars which have not yet ejected much plasma or gas. This would explain the lack of association with extended radio sources and also the absence of emission lines, believed in quasars to come from ejected gas outside the central region. On the other hand, the fact that some BL Lacertae objects are seen in elliptical galaxies has led to the suggestion that they are old active objects.

## Extragalactic radio sources

The first radioastronomy surveys of the sky, made at various wavelengths in the late 1940s and 1950s, showed hundreds of discrete sources, but it required optical identification to establish how many are extragalactic, for from radio observation alone we have no certain knowledge of the distance. It turns out, however, that fewer than 10 per cent of the identified sources are galactic; these are mostly H II regions and supernova remnants, and are concentrated towards the plane of the Milky Way. Identified extragalactic sources are more evenly distributed over the sky and, although nearly a third of the brightest sources are not identified, it is clear from their distribution that almost all the unidentified sources are extragalactic too. Some very strong sources are associated with faint galaxies, and similar objects farther away will still be reasonably strong radio sources but invisible optically.

Extragalactic optical identifications which have been made are, in rough order of increasing absolute radio luminosity:

a. normal spiral galaxies. These are relatively nearby and have thermal radio emission similar to galactic sources. They are not classed as 'radio galaxies';
b. Seyfert galaxies;
c. certain bright early type (E and SO) galaxies. Most such galaxies are not detected as radio sources at all, but some of the largest ones, particularly cD galaxies, are very strong sources. There is generally nothing special about the optical appearance. Often, the brightest galaxy in a cluster is a strong radio source;
d. N-type galaxies;
e. radio quasars, QSS, if their redshifts are interpreted as indicating their distances.

### Structures of radio sources

Some sources are compact, with a single component centred on the nucleus of the optical object, but most have an extended structure, typically in two similar lobes roughly symmetrical about the optical nucleus (Fig. 7·9). Both structures are found associated with all the different types of optical object, although most compact radio sources are found to be associated with quasars or galaxies with bright nuclei. It should be noted that a particular radio source can be iden-

*Fig. 7·9: The relative linear sizes of a sample of typical extended radio sources. Sources of such different extent have essentially similar structures. Notice the small central component of 3C 236, with structure aligned with the outer lobes. (See page 210).*