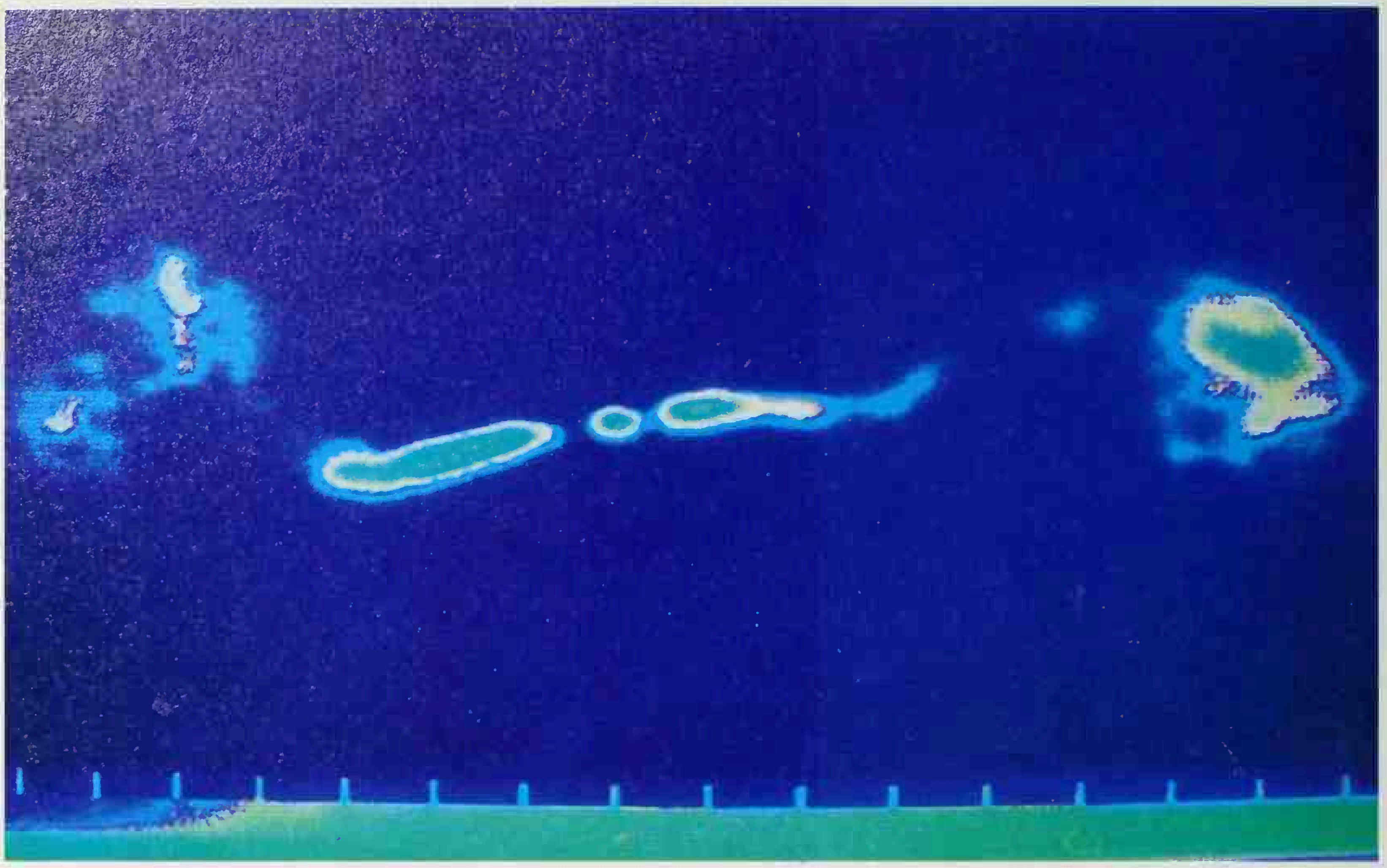

A 'photograph' made from radio observations of 3C 499, showing the extended lobes of radio emission on either side of the parent galaxy.

tified as a quasar only if it is related to a starlike optical object.

Some two-lobed sources are very large, extending over several Mpc. The normal structure within each component is a strong head with a tail extending back towards the centre, and quite often there are inner maxima in the intensity, much closer in than the outer lobes but aligned along the same axis.

In most cases, the radio waves show polarization, in amounts up to 20 per cent. Polarization is related to the strength and direction of a magnetic field, and in some sources the field is uniform over remarkably large volumes of space. The most powerful radio sources radiate about 10^7 times more energy at radio wavelengths than the Galaxy does, while irregular variations within a few months are observed in many compact sources.

Opposite page, top:
Image-processed optical CCD picture of the active galaxy M87, showing the various bright knots along its jet.

Opposite page, bottom:
The apparent superluminal velocity (see page 214) of the quasar 3C 273. Over a period of 3 years it has appeared to expand by 25 light-years.

The active galaxy M 87

M 87 is a giant E0 galaxy, about 10^{13} solar masses, and the third brightest member of the Virgo cluster. Optically it displays a strong jet, similar to the jet seen in the quasar 3C 273. As the third brightest radio source in the sky, it is also known as Virgo A; it appears bright because it is very close to us, only about 15 Mpc away. At radio wavelengths it is seen to have two jets, one coincident with the optical jet and one opposite it, as well as a fainter outer halo. The core is very compact, emitting about 1 per cent of the radio energy from a region no more than about 0·1 pc across. M 87 is also an X-ray source.

Early in 1978, evidence from optical astronomy helped towards an understanding of the nucleus; it is found to be very bright in relation to the rest of the galaxy, compared with ordinary ellipticals, while the spectral lines reveal a sharp increase in the velocity range in the nucleus region. These optical observations, together with the observed radio structure, indicate not only an unusual concentration of mass at the galaxian centre but also an energy source there, and the most plausible explanation is considered to be the presence of a black hole of about $5 \times 10^9\ M_\odot$. Although not at all conclusive, this is the strongest evidence available for the existence of a black hole in an extragalactic object.

Energy sources

The first energy source proposed for radio galaxies was the collision of two galaxies in a cluster, partly because the very strong source Cygnus A looks like two galaxies colliding. However, many radio sources appear optically normal, and in any case collision would not give either synchrotron radiation or a two-lobed structure. It is now believed that radio sources originate in violent events within single galaxies, which are related to the energy sources in quasars and active galaxian nuclei.

Various possible sources for such violent releases of energy have been suggested. The energy release from the gravitational collapse of an object of some 10^6–$10^8\ M_\odot$ was one, but it would tend to happen too quickly and again not produce two lobes or the fast particles which give synchrotron radiation, and the collapsing body would probably be unstable anyway. Another was a multiple outburst of supernovae where, in conditions of high stellar density in