# Classifying Radio Galaxies

## A study of 19 extended radio sources establishes four morphological classes and a suggested evolution

### BY DIETRICK E. THOMSEN

Galaxies appear to be the most striking feature in the visible sky. Cosmologists regard them as the primary and most meaningful articulation of organized matter from the primeval formlessness of the universe. In the last 50 years much effort has gone into studies of their physics and their morphology. A kind of taxonomy of galaxies has been established, and cosmologists have tried to arrange the different morphological classes in an evolutionary sequence.

The radio sky exhibits sources analogous to galaxies, some of which are associated with optical galaxies. They range from the fairly compact quasars to extended sources larger than optical galaxies, some of which form the largest known physically connected objects in the universe.

A systematic study of 19 of these extragalactic radio sources that accomplishes for them what has been done in the classification of optical galaxies has now been completed by scientists at the Radio Astronomy Institute in Stanford, Calif. They have distinguished at least four classes of such sources and arranged them into a tentative evolutionary sequence. The report (by M.A. Stull, K.M. Price, L.R. D'Addario, S.J. Wernicke, W. Graf and C.J. Grebenkemper) is in the August ASTRONOMICAL JOURNAL.

They used a five-element interferometric radio telescope belonging to Stanford University to obtain two-dimensional maps of 16 of the radio sources and one-dimensional (east-west) scans of three others at a frequency of 10.7 gigahertz. Using such a high frequency was a new departure in systematic studies of the structures of such sources. ''In spite of the development during the past decade of large aperture-synthesis radio telescopes,'' the observers say, ''relatively few studies have been made, either of the overall structure of extragalactic sources at frequencies above 5 gigahertz or of the two-dimensional distribution of linearly polarized radiation at any frequency.'' But only such studies and their comparison with similar studies at lower frequencies can reveal the information these astronomers wanted for their morphological attempt.

Stanford Radio Astronomy Institute

*Five-element interferometer made maps.*

Technology makes general overviews more difficult in radio than in light. The optical telescope, like the human eye, is a synthesizing instrument. It takes a fairly wide range of frequencies and images them together. The photographic plate or the eye that records the image mixes the effects of the frequencies. (In our perception colors mix; that's why painting is the kind of art it is.) To separate the frequencies and get specific information about certain ones requires application of a spectrograph to separate them.

A radio telescope is more like an ear in that it perceives different frequencies separately. Unlike an ear, which can receive a wide range of frequencies simultaneously and hold them all in consciousness separately (a faculty that makes harmonic music possible), a radio telescope usually receives only one (or a narrow band) at a time. To get another it must be retuned.

Getting the kind of general picture that a photograph gives is thus a difficult and laborious process in radio observing. The radio astronomer must pick a variety of frequencies for scanning according to the ranges where he thinks significantly different astrophysics is going on.

One of the main differences between the newly completed studies and those at lower frequencies is that the degree of polarization in extended components is often higher and seldom or never substantially lower than at lower frequencies. The Stanford astronomers can explain this by assuming that the depolarization is mostly caused by Faraday rotation, a rotation of the plane of polarization caused by magnetic fields in the source, but there are some cases where Faraday rotation will not explain all the depolarization.

Another general characteristic of the high-frequency maps is that they often show the presence of a centrally located compact source between the lobes of what had been supposed to be double sources. These compact sources have self-absorption spectra—their flux tends to increase as frequency goes up, indicating self-absorption of their own output at lower frequencies—and they coincide with the nucleus of an optical galaxy in cases where one can be identified. Such central sources are widespread enough to lead the observers to suggest that some, and maybe all, the nuclei of radio galaxies remain active throughout their lives. (Simply from the geometric appearance as well as some of the astrophysical data, observers have tended to think that these double-lobed radio sources were matter ejected from the optical galaxies that lie between the lobes. Now Stull and his colleagues see radio activity from the centers as well.)

The Stanford astronomers feel they can divide extragalactic radio sources into four classes. They admit that their sample of 19 sources is a bit small for sweeping generalizations, and their selection is not entirely without bias, though they tried to make it so. There may be other classes and perhaps sequences of classes parallel to the ones they establish. ''The claim we do make is that all 19 sources we have observed fall into a strictly limited number of categories, while these categories form a well-defined sequence. And that in itself we consider remarkable.''

The first class consists of compact sources. They are single quasar-like objects and have self-absorption spectra, low, and often variable, polarization and usually variable intensity.

Core-halo sources form Class II. These

are dominated by a quasar-like central source but possess an outer halo of radio-emitting matter that extends primarily in two directions from the central source.

Class III is made up of triple sources. These have a central source with the outer regions organized into two small main components. The flux density of all three components is relatively comparable at low frequencies. There also seems to be diffuse emission from the area between the core source and the outer components.

Double sources constitute Class IV. These have two main outer components with tails extended inward toward the center but with their outer edges sharply defined. Two subclasses can be discerned: IV-A, in which the quasar-like central object is there, but very faint compared to the outer lobes (the general discovery mentioned earlier), and IV-B, in which no quasar-like central component has been detected at centimeter wavelengths.

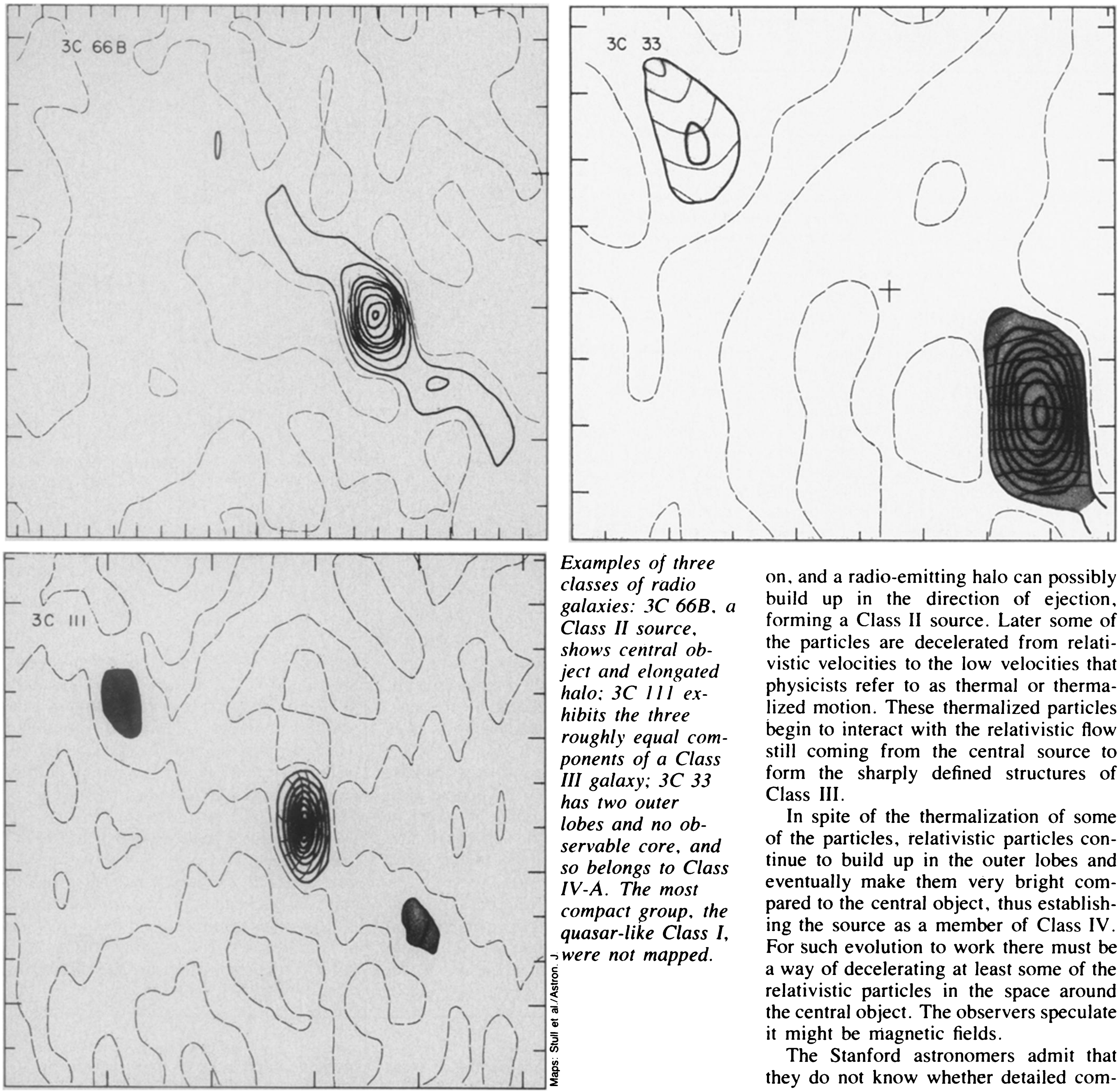
The six observers say these classes could form an evolutionary sequence in either direction, from I to IV or from IV to I. The sequence they propose for further consideration by astrophysicists runs from I to IV.

The proposed history goes like this: The radio source starts out as a compact quasar-like object which emits a continuous stream of charged particles flying at relativistic speeds. At first the density of whatever matter there may be in the space surrounding the object is zero or nearly so. Thus the flow of the outward streaming matter is not obstructed, and there is no appreciable radio radiation from the surrounding space.

Gradually the density of matter in the neighborhood increases as ejection goes on, and a radio-emitting halo can possibly build up in the direction of ejection, forming a Class II source. Later some of the particles are decelerated from relativistic velocities to the low velocities that physicists refer to as thermal or thermalized motion. These thermalized particles begin to interact with the relativistic flow still coming from the central source to form the sharply defined structures of Class III.

In spite of the thermalization of some of the particles, relativistic particles continue to build up in the outer lobes and eventually make them very bright compared to the central object, thus establishing the source as a member of Class IV. For such evolution to work there must be a way of decelerating at least some of the relativistic particles in the space around the central object. The observers speculate it might be magnetic fields.

The Stanford astronomers admit that they do not know whether detailed computation based on this proposal will give the required structures and observed polarization characteristics. But in support of their evolutionary hypothesis, they cite two observed peculiarities: A double-source structure near the nucleus of at least one Class II object (3C 274) and defined components near that of another (3C 66B). "Presumably the particle density is high in those regions and accounts for the formation of such structures." They also point out, to make their hypothesis more plausible, that the boundaries of the radio sources need not correspond to sharp edges of clouds of particles; they could be merely standing wave patterns or shock fronts in a more diffuse sea of matter. ". . . Our classification scheme may reflect a tendency of such shocks or wave patterns to occur at increasingly great distances from the optical object with advancing age." ☐



*Examples of three classes of radio galaxies: 3C 66B, a Class II source, shows central object and elongated halo; 3C 111 exhibits the three roughly equal components of a Class III galaxy; 3C 33 has two outer lobes and no observable core, and so belongs to Class IV-A. The most compact group, the quasar-like Class I, were not mapped.*

Maps: Stull et al./Astron. J.