Part IV

THE LARGE-SCALE STRUCTURE OF GALAXIES

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PAPER 75

RADIO EVIDENCE ON THE LARGE-SCALE STRUCTURE OF OUR OWN AND EXTERNAL GALAXIES
INTRODUCTORY LECTURE by

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The subject matter of this session includes both 21-cm and continuum evidence on large-scale features, i.e. features ranging in size from spiral arms to whole galaxies, of our own and of external galaxies. Because the individual papers deal with only some of the separate facets of the subject it is desirable to outline the main lines of investigation and to indicate their interrelations and their physical significance.

We should first consider the significance of the different types of observations. The 21-cm line observations are definite in referring to interstellar neutral atomic hydrogen (H I regions); the problems here are those of observation and measurement and of interpretation. The continuum observations, on the other hand, refer to at least two quite distinct sub-systems in a galaxy: to ionized interstellar gas (H II regions), and to regions emitting a nonthermal component. H II regions emit radio waves by the well-known thermal process involving free-free transitions, and absorption in these regions can also be important. The nonthermal component is the dominant one in the meter-wavelength range. Following Shklovskii's suggestion, the mechanism of emission is now believed to be the synchrotron mechanism, in which radiation is emitted by relativistic electrons spiralling around lines of magnetic force in interstellar space. The main evidence for this mechanism is the observed linear polarization of the radio and optical emissions from a very few discrete radio sources. Workers are currently trying to extend this evidence by studying the polarization of other regions. If this hypothesis is correct then theory suggests that sources of the nonthermal radio emission (i.e., regions characterized by magnetic fields and high-energy electrons) are likely also to be regions favorable to the production of cosmic rays. Hence, studies of this component are related to those of the origins of cosmic rays in the Galaxy. But it should be emphasized that there is always the possibility that one or more other nonthermal mechanisms may also operate.

1. THE 21-CM OBSERVATIONS OF OUR OWN GALAXY

Two aspects are discussed here: the spiral structure and shape of the galactic disk (Oort, paper 76), and the region of high gas velocities near the galactic center (Rougoor and Oort, paper 77). A great deal has already been

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published on the former but the major conclusions—the derived form of the spiral arms and the extreme flatness of the H I disk in the central regions (deviations from a plane not more than about 30 parsecs over a circle of diameter 14,000 parsecs)—are of such importance to astronomy that a review and assessment of the current state of this subject has been included in this Symposium.

The latter aspect, the high-velocity region near the galactic center, is one of the really intriguing discoveries of radio astronomy. In this region great masses of gas are observed moving outward from the center with velocities of 50 or 100 km/second. The study of this phenomenon may well supply major clues to our understanding of the circulation of the interstellar gas, and indeed, of the structure and dynamics of spiral galaxies.

It will be noted that there is no paper devoted to observations of H I regions outside the galactic disk. Is there no gas? Is there gas but is it too difficult to observe? Or is this simply an unexplored field?

2. THE CONTINUUM

In order to interpret the observations in terms of the locations of H II regions and of the sources of nonthermal emission, we must have some means of separating the two components. The basic clues come from the theoretically known behavior of H II regions in emission and absorption. Given a kinetic temperature of about 10,000 °K, these regions will appear in absorption when seen against a background having a brightness temperature $T_B > 10{,}000$ °K, in emission when $T_B < 10{,}000$ °K. It is observed that for wavelengths greater than about 10 m the sky brightness temperature is generally greater than 10,000 °K; therefore at such wavelengths H II regions appear in absorption. Studies in this wavelength range capable of revealing the distribution of H II regions in the general vicinity of the sun and probably of delineating the nearer spiral arms are described (Shain, paper 81). The observational data consist of detailed surveys on two wavelengths: at 16 m, where absorption is intense, and at 3.5 m, where it is generally weak.

As the wavelength decreases, the observed brightness temperatures fall faster than the thermal emission from H II regions, and at decimeter wavelengths prominent H II regions appear in emission. In the past these regions have been studied, particularly at the Naval Research Laboratory in Washington, but mainly on an individual basis. Many of the regions observed are known optically and such studies have helped provide a basis for a major extension of the subject. There is now reasonable evidence that the rapid decrease in emission with decreasing wavelength is a normal feature of nonthermal sources and may be used to distinguish the nonthermal sources from the H II regions. In comparing detailed surveys on wavelengths in the decimeter- and meter-wavelength ranges, e.g. the Dwingeloo 22-cm and the Sydney 3.5-m surveys, many sources are observed that are relatively much more intense at the shorter wavelength and are presumably H II regions (Mills, paper 79, and Westerhout, paper 80). The systematic study of the disposition of such regions at distances beyond the optical limits is now possible.

Over nearly all the sky the observed radiation at intermediate wavelengths, e.g. 1 to 3 m, is mainly caused by the nonthermal component. But it is probable that at some much shorter wavelength thermal emission from ionized gas, less concentrated than in prominent H II regions, will begin to dominate the rapidly decreasing nonthermal component. This is a promising future field for both observation and interpretation.

In the intermediate wavelength range the main features are caused by nonthermal emission, and the more obvious problems relate to disentangling the effects of contributions of two or more systems within our Galaxy from one another and from the extragalactic contribution. There are certainly two contributing systems within our own Galaxy: a system concentrated in the galactic disk, and one very widely distributed with a roughly spherical distribution. Shklovskii's recognition of this latter component and his explanation in terms of a "corona" of relativistic electrons and magnetic fields is one of radio's spectacular contributions to astronomy. The most recent discussion of the form of this corona is given by Mills (paper 79). There may be a third contributing system, distributed broadly as the Population II stars in the Galaxy, but this is still in question.

Thus, accepting the synchrotron mechanism hypothesis, radio observations of galaxies recognize three forms of matter, all of them interstellar: neutral atomic hydrogen, fully ionized atomic hydrogen, and an interstellar medium without a recognized name, characterized by high-energy electrons and magnetic fields. Bearing in mind the possibility of other mechanisms, we shall tentatively call such regions "synchrotron regions."

In our Galaxy all three show a concentration toward the galactic plane. In the case of the nonthermal component the total emission from the galactic corona is much greater than from the disk, the vast bulk of the corona more than counterbalancing the intenser emission from the disk. Radio evidence on the existence of either H I or H II regions except in the disk is lacking.

Little has been published of the relative distributions of the three components in the disk. The H II regions are presumably just those parts of a larger hydrogen complex where O and B stars exist and produce extensive ionization. One interesting observation is that the equatorial surface defined by the synchrotron regions appears similar to that defined by the H I regions —very flat in the center but distorted in the outer parts. The disk, however, is thicker than either the H I or the H II disks. The outstanding new information is Mills's recognition and location of spiral structure from a 3.5-m continuum survey.

3. THE FEATURES OBSERVED IN EXTERNAL GALAXIES

The distributions of H I and synchrotron regions are being studied in the nearer external galaxies. A single example of an H II region, 30 Doradus, has been observed (Shain, paper 81). A most interesting feature of the H I observations is that certain galaxies (the Clouds of Magellan were the first observed) appear to lie in vast clouds of neutral hydrogen. The density of hydrogen decreases outward more slowly than the density of the stars.

This feature is matched by the synchrotron regions, which extend to great distances from, for example, the Andromeda nebula. How these features vary with galactic type, our ability to recognize details of structure and to separate distinct components, and the observation and measurement of rotation are subjects of current research (Volders and van de Hulst, paper 78).

Thus radio observations supplement optical ones in the study of galactic structure. The optical ones show us primarily the disposition of the stars, the radio ones primarily the interstellar gas. Combining the two we may hope to obtain a picture with far better perspective than either alone could give.

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