# I. PERSPECTIVE

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# LARGE-SCALE STRUCTURE OF SPIRAL GALAXIES: PROBLEMS OLD AND NEW

Morton S. Roberts
National Radio Astronomy Observatory,* Green Bank, W.Va. U.S.A.

Introductory remarks for IAU Symposium No. 84 are made. These include a brief history of previous symposia dealing with galactic structure, basic research problems in this area, and parallels regarding our galaxy which can be drawn from extragalactic research.

Twenty-five years ago, almost to the day, Symposium No. 1 of the International Astronomical Union convened at Groningen in the Netherlands. The subject matter was coordination of galactic research; the bulk of the discussion was devoted to optical studies. Topics such as radio spectral line work, so prominent in today's work, were barely touched upon. This particular subject was in its infancy; the 21-cm line of neutral hydrogen had first been observed only two years previous to that Symposium. The discovery of the OH radical lay 10 years in the future. Radio spectroscopy is but one example of the remarkable increase in the scope of galactic studies and of all areas of astronomical research that has occurred in the intervening quarter of a century.

At this Symposium we shall hear of results derived from essentially the entire electromagnetic spectrum; from $\gamma$-rays to decametric radio waves, covering a span of fifteen orders of magnitude in wavelength and in photon energy. The emphasis will be the opposite of the meeting 25 years ago, for surprisingly little will be presented on optical studies of our own galaxy. The reasons for this change are obvious; the greater wavelength coverage yields extensive new information on different constituents of our galaxy both thermal and nonthermal. Of equal import is our ability to see much further into our galaxy. The peculiar circumstance (or is it just selection?) of a galaxy filled with dust particles whose size is comparable to the wavelength of visible light restricts our view to a distance of just a few kiloparsecs in the galactic plane. The corresponding area that can be surveyed is a few percent of this plane and the information so gathered, though interesting and detailed, is only of the local structure. The prominent spiral arms,

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located some 5 kpc from the center, as well as the nuclear region, features that define other galaxies, are not visible to our narrow band eyes; but they are prominent at other wavelengths. Out of the plane we are far less restricted by dust but are hindered by a fainter population of stars so that detailed studies are again limited to comparable distances.

It is traditional in an introductory talk such as this to list the significant problems of research peculiar to the topic of the Symposium. It is a somewhat strange custom, in that the participants have already assembled and either are prepared to talk about recent, often puzzling observations posing even newer problems, or else they wish to present solutions to problems and questions they themselves have posed. I do not mean to imply that these observations and solutions are not significant but rather that the two lists may be uncoupled.

Instead of presenting my own list, I prefer again to look back, this time 15 years to the Canberra Symposium on "The Galaxy and the Magellanic Clouds". At that time Professor Oort summarized, under the heading Structure of the Galaxy, the relevant areas of research and the associated problems. Here is his list, somewhat recast into a series of questions:

1. What is the rotation curve for our galaxy?
2. Why is the HI distribution warped in the outer regions?
3. How may we explain the general problem of the origin and conservation of spiral structure?
4. How might we understand the large scale HI distribution in our galaxy?
5. What conditions give rise to the complex observations of the central region of our galaxy?
6. How do we explain the high-velocity gas that is observed?
7. What is the strength and distribution of the galactic magnetic field?
8. What is the distribution and origin of the thermal and non-thermal components of the general galactic background?
9. What is our distance from the galactic center, and what are the components of our motion with respect to the center?
10. What is the mass density near the sun and how is this mass distributed among the various constituent components?
11. What is the density and velocity distribution of old disk objects and of halo objects of different metal abundances?
12. What can we say of the origin and evolution of our galaxy?

I think we have made progress in most, if not all, of these areas. If the questions are not firmly answered we at least have a better understanding of them with, in a number of instances, viable and competing theories. How well any special problem, or all of them, are understood and answerable today, I leave to you to decide, preferably at the end of this Symposium.

Let me instead turn to galaxies other than our own, to systems which we are able to study from outside their confines. By finding common, large-scale properties of other spiral systems we can be guided in describing and understanding our own galaxy. Turning to other spiral systems for such guidance dates back to 1852 when Stephen Alexander suggested that our Milky Way had spiral arms. This approach was further elaborated on at the turn of the century by Cornelis Easton. We now know that the features they describe were local--that an overall view was limited by interstellar extinction. An inauspicious beginning whose lesson is caution. But there are similarities that we do recognize and with the proper caution we may well draw other parallels.

In spiral galaxies, the distribution of light is centrally concentrated, in marked contrast with that of the neutral hydrogen which lacks such a concentration and often shows a pronounced central minimum. This feature in the HI distribution in our galaxy was first described by Hugo van Woerden. There are a number of explanations, including efficient star formation in this region of a galaxy. The parallel between the nuclear bulge and elliptical galaxies, the latter also being poor in neutral hydrogen, is often made. That the interstellar gas may be in some form other than HI is also a viable suggestion, one prompted by the abundance of observed molecules and inferred presence of significant amounts of molecular hydrogen in the galactic nuclear region.

In the outer part of a galaxy the generally planar HI distribution is often found to be warped or bent. So often, in fact, that it appears that an undistorted plane is the exception to the rule. In our galaxy such a warp was recognized by Frank Kerr and independently by Bernard Burke over 20 years ago. Several suggestions as to the mechanism responsible for these warps have been put forth: tidal effects, galactic winds, and precession; the first has received the most attention. However, the large sample of warped galaxies now available places severe constraints on the tidal model. Renzo Sancisi in a recent review of this problem concludes that the origin and survival of warps is puzzling--that frequently only distant dwarf companions are visible so that a tidal explanation becomes difficult. Although tidal effects may be important in some instances, there is a need to re-examing other explanations.

A third aspect of the HI distribution concerns the correlation between HI and optical spiral arms. The Westerbork data for such galaxies as M81 and M101 show what at first sight appears to be excellent agreement between these two. But a more detailed examination shows significant and extensive regions of anticorrelation. There are bright, optical arm features with only relatively weak HI emission and the converse, high HI surface density in regions of faint spiral features. We can understand the first of these anticorrelations as possibly due to more extensive ionization by the high-luminosity stars which define the arms. But the second anticorrelation indicates regions in which the star formation rate is low although at least one constituent for such processes, HI, is plentiful. Perhaps we are witnessing two different star formation mechanisms: In the inner regions, a large-scale efficient one such as shocks caused by density waves while in the outer regions only a local mechanism is operative in triggering star formation.

The measurement of the distribution of light and of radio continuum radiation out of the plane of the galaxy is an observationally difficult experiment. We turn to other galaxies for at least an indication of what might be expected. The observations here are difficult too, but tractable; modern data are few. Westerbork continuum data for two edge-on systems, NGC 891 and NGC 4631, are available. They both show an extension of several kiloparsecs perpendicular to the plane. These results imply a thick disk of continuum radiation rather than a spherical halo. Extension of such a model to our Galaxy is tempting but premature.

Information on the optical luminosity at large distances from the plane is also scant. What little is available is consistent with a spherical halo of low luminosity light out to several tens of kiloparsecs. This leads us to the next aspect of extragalactic studies which have an important bearing on our understanding of galactic structure--rotation curves.

The modern data, both 21-cm and optical, show that most rotation curves, when they extend far enough, become flat and remain so out to the last measured point. Here I ignore the important small-scale oscillations in the rotation curve which are probably indicative of streaming motions. As with warps so with flat rotation curves; they are common, so common that a decreasing rotation curve at a large radius becomes an interesting exception. In at least two instances, M81 and NGC 4361, a decrease is seen and can be attributed to observations of material that lies in a tidal link to a neighboring galaxy.

These kinematic data, together with the pertinent photometry, demand an increasing M/L ratio with distance from the center; the mix of stellar types clearly changes with distance. A not too surprising result for the high-luminosity stars which are responsible for much of the light and little of the mass in the inner regions of a spiral galaxy have become very rare at the large radii to which the more extensive measurements refer.

It must also be stressed that rotation curves contain no information on the 3-dimensional distribution of matter. One must assume a model and various geometries, such as a spherical halo or a thin disk, can equally well fit the data. The latter model has the awkward feature that, unlike a sphere, the gravitational attraction at a given point is determined by <u>both</u> the mass interior and exterior to that point. In essence you have to know the answer, or to anticipate it, as with a Brandt curve, in order to obtain the answer.

As a final aspect of extragalactic studies, let me turn to the immediate environs of galaxies. I mentioned earlier that the bending of galaxies might be difficult to explain in terms of a tidal mechanism, at least for some of the warped systems now recognized. Such a mechanism has had much greater success in explaining the tails and plumes extending from galaxies and the bridges connecting galaxies, features seen both optically and in 21-cm. The Magellanic Stream, so prominent in

21-cm Southern Hemisphere observations, is far from unique. There are about a dozen other instances of such HI features now recognized. Martha Haynes, who has found a number of new examples, will summarize the status of these data later in the Symposium.

That such perturbations are frequent and ongoing, even for our own galaxy, will add a new complication to the previous picture of isolated systems. Matter is being pulled out; what happens to it and how much will fall back in? Yet another preview of later discussion.

The period dating from the first IAU Symposium has been exciting and productive. The continuing development of new instrumentation for both space and ground-based observations promises an even more fruitful period ahead. But it is more than instrumentation that is needed; Democritus over two millennia ago eloquently described another vital ingredient:

> "Who seeks will find the good only
> with labor and pains; the bad, how-
> ever, is found by everybody without
> seeking".