1. LARGE-SCALE STRUCTURE OF SPIRAL NEBULAE

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For a discussion of the large-scale structure of spiral nebulae, we should like, of course, to choose a stellar system which we are certain is similar to our own. Since we know that our own Galaxy is a spiral galaxy, this narrows our choice to the spiral galaxies and, of those, we can immediately eliminate the so-called barred spirals, as we know that our galaxy is not a barred spiral. Hence, we need only consider spirals of types Sa, Sb, and Sc on Hubble's system. NGC 4594 is an Sa system with a large central spheroidal system typical of these early-type spirals. Undoubtedly, our Galaxy does not have such a large spheroidal system since it would be obvious as a large bulge which simply has not been observed. Next, M 81 is typical of the Sb spirals in which the central system has shrunk considerably. Finally, M 33 is typical of the Sc spirals in which the central system has shrunk until it actually approaches a semi-stellar point.

There are a number of reasons to believe that our own Galaxy is a spiral of type Sb. Since we are eight or nine kiloparsecs from the galactic center, the picture taken by Mr Code with the Henyey-Greenstein camera gives a first impression of how our Galaxy would look from the outside if it were seen edgewise. In this picture, the galactic center regions and the flattening in the outer parts are visible. On the basis of such a picture alone, we would classify our Galaxy as an Sb spiral. In fact, it is very similar to the spiral NGC 891, also seen edge-wise. In addition to the structural data, we could introduce other evidence; for example, the strength of the nova phenomenon. This is very strong in the Sb spirals like the Andromeda nebula and M 81 and very weak in late spirals like M 101.

For this reason, I should like to describe the Andromeda nebula as an example of the spiral structure of Sb galaxies. We have every reason to believe that something similar, both in features and arrangement, will be found in our own Galaxy. Starting with the center, we have a tiny nucleus, quite sharply defined, with the dimensions, $2''.5 \times 1''.5$. It is an elliptical structure, oriented exactly like the major axis of the whole system. A very

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important feature is that the spiral structure, in the form of dust clouds, reaches right into the nucleus, on both sides. The first spiral arm comes out, swirls around, and then splits into two sections. One continues around, the other shoots further out. The first part of the innermost spiral arm is very disrupted. The clouds forming it are huge flares in a very turbulent state. The next spiral arm, number two, is barely visible because it is filled in with the light of the nucleus, but it shows a remarkable feature. Along one edge, in a dust lane, the first stars appear. These stars are all blue super-giants, and as soon as we find them we also find H II regions. Farther in, neither H II regions nor stars are observed. Hence, at a distance of about 3 kpc from the nucleus, the first stars and the first H II regions are observed in an otherwise dark spiral arm. The next arm is again essentially a dust arm, but everywhere along the outer fringes of this arm are super-giants which are associated with the arm. The huge star association NGC 406 is in the next arm. In this region of the Andromeda nebula the spiral structure is very complicated. The arm branches to form a loop of cloud complexes from this arm to the next. Spiral structure is never as regular as has been thought. Hubble concentrated most of his investigations on the next arm in a region about 50′ from the center of the Andromeda nebula. In front of darker material, this arm appears bright. It is full of giant and super-giant stars, by which it is essentially marked instead of by gas and dust. H II regions are present, but only in the dark lanes or along the edge of a few large dark clouds. Although in other areas there are plenty of O- and B-stars, the H II regions are restricted to these dark areas. Hence, we must conclude that elsewhere dust has already been converted into stars, and dust and gas are essentially absent. Where the arm crosses in front of the nebula, it appears simply as a dark lane. H II regions are present throughout the interior of the lane, thus showing evidence of star formation in the center of the dust lanes. The remaining arms are essentially star arms with relatively few emission nebulae. Skipping one arm, we come to the one about 1°5 from the center of the Andromeda nebula. It is very thin; most of the stars are blue super-giants with red ones among them. Extra-galactic nebulae shine through the arm in large numbers. There are only very few emission nebulae which are associated with O- and B-star associations. Nevertheless, the arm contains a large number of variable stars, many of them Cepheids. Going still farther out, we find the last arm at about 2° from the center of the galaxy. It is still thinner than the preceding one, but even in it an occasional emission nebula is found. Beyond this we find what are apparently remnants of former arms. For example, in a remnant 2° 14′

from the center, we find a little group of B-stars which are about 20 kpc from the nucleus of the Andromeda nebula.

The picture of the spiral structure can be summarized as follows: In the interior, we see the spiral arms essentially as dust arms, but soon, at a distance of about 3 kpc from the center, we can detect the first super-giants and the first emission regions. From there out, the spiral arms are dotted with super-giants and H II regions, but only at the outer fringes of the dust arms. The central parts of the arms still appear only as dust. By the time we reach a distance of about 7 to 8 kpc from the center, the arms appear essentially as arms formed by stars; dust and gas are still noticeable, but they become less and less conspicuous as we go to spiral arms beyond 8 kpc from the center. Beyond this, the arms are thin and primarily represented by stars. At a distance of nearly 2° from the center, far beyond what is usually considered the body of the Andromeda nebula, the outermost arm can still be traced. Of course, this entire spiral structure is embedded in a huge disk of population II stars which extends far beyond the spiral structure. In the region between NGC 205 and the Andromeda nebula, the whole field is covered with population II, including globular clusters.

Discussion

? : Do we know the near side of the Andromeda nebula definitely?

Baade: We conclude that one side is the near side from the orientation and the structure of the absorption lanes.

Oort: How good is the evidence that there are no blue super-giants nearer than 3 kpc to the center?

Baade: The only evidence is that I have been unable to find a single H II region there, although I have made every attempt to do so. I think they would be visible even against the bright background. Also, the structure of the inner spiral arm is very disrupted and gives the impression of being very turbulent.

Lindblad: If you assume that these clouds near the center of the Andromeda galaxy lie in its plane, and try to untilt them, they become extremely elongated along the minor axis. Thus it is interesting that there is fairly good evidence that the clouds do not lie exactly in the nebular plane but are well elevated.

Baade: Yes, there is certainly evidence that the spiral structure in the central region does not lie in the plane.