SECTION II.9

COMPARISON OF ANDROMEDA AND MILKY WAY GALAXIES

Thursday 2 June, 0910 - 1100

Chairman: R. Sancisi

https://doi.org/10.1017/S0074180900242873 Published online by Cambridge University Press

Above: Sancisi (centre left) talking with Blitz during boat trip. LZ

Below: Italians at dinner. Left to right: Phil Seiden, Antonella Natta, Renzo Sancisi, Stefano Casertano and Giuseppe Bertin. LZ

https://doi.org/10.1017/S0074180900242873 Published online by Cambridge University Press

A COMPARISON OF THE ANDROMEDA AND MILKY WAY GALAXIES

Paul Hodge
Astronomy Department, University of Washington, Seattle, WA

ABSTRACT

A comparison of some of the basic properties of M31 and the Milky Way indicates that in almost every respect M31 is larger than the Galaxy. It is more luminous, redder, more massive, and of earlier Hubble type. A detailed comparison of the spiral structure, based on optical tracers, for comparable areas in the outer parts of each galaxy shows differences in the arm spacings, in density enhancement, and in pitch angle.

1. INTRODUCTION

The Andromeda Galaxy, M31, is the nearest spiral galaxy and the only giant spiral in the Local Group. Although not a close match to our Galaxy, it is nevertheless a useful galaxy for comparing with the Milky Way, as it is the only large spiral for which we can obtain detailed information of certain kinds. Recent work, especially at radio wavelengths, has made it one of the most thoroughly-observed galaxies beyond the Milky Way. The following review is not an exhaustive comparison of all features of M31 with those of the Galaxy, which would require vastly more time than is available, but rather is a discussion of some of the more challenging areas of similarity and of contrast between them. Insight into certain questions is certainly gained by their comparison, but it must also be confessed that, frustratingly, some problems that confound students of the Milky Way because of our location in the plane, similarly confound those who study M31 because of its nearly edge-on inclination angle.

2. INTEGRATED PROPERTIES

Table 1 compares some of the basic properties of Andromeda and the Milky Way, as best we can determine them so far. These are not easy parameters to measure and the table indicates the range found in the recent literature. For M31, the Hubble type is clearly Sb; Hubble him-

H. van Woerden et al. (eds.), The Milky Way Galaxy, 423–430.

Table 1. Comparisons of M31 and the Galaxy

Parameter	Galaxy	M31
Adopted distance (kpc)	8.5	765
Hubble type	Sc	Sb
M_B (face-on)	-20.5±.5	-21.2±.4
$(B-V)_T^o$	0.53±.04	0.74±.06
V(R = 8.5 kpc) (km/sec)	220±20	265±10
$\sigma_v(0)$ (spherical component) (km/sec)	130±10	160±30
D_o at 25.0 mag/arcsec^2 (kpc)	24±5	41±2
Effective diameter (D_e) (kpc)	11	16
D (from open-cluster system) (kpc)	40	62
D (from HII-region system) (kpc)	45	50
$D_{26.6}$ (kpc)	34	51
Mass ($M_\odot$)	?	?
M_H ($M_\odot$)	5×10^9	4×10^9

self used it as a typical example and there has been relatively little controversy on the subject, other than to argue about a possible weak bar-like structure in the central bulge (Lindblad, 1956; Sharov and Lyutyi, 1980). For our Galaxy, however, the Hubble type is not so clearly known. Of the eleven different methods recently used to gauge this parameter, two conclude that it is Sb, two that it is Sbc, and seven that it is Sc (Baade 1951, Arp 1964, 1965, Becker 1964, van den Bergh 1968, Georgelin and Georgelin 1976, de Vaucouleurs and Pence 1978, and Hodge 1983).

The relative sizes of M31 and the Galaxy can be examined anew. Table 1 summarizes five of the various measures of the diameters. No matter how the diameter is defined, that of M31 is consistently larger than that of the Galaxy by about 50%. For M31 the most distant open cluster, for example, is 139 arcmin from the center (Hodge 1979), which corresponds to 30.9 kpc, while for the Milky Way, Christian and Janes (1979) find Be 20 to be the most distant open cluster, with a distance of 20 ± 3 kpc. The objects are rather comparable. I calculate from Christian and Janes' (1979) CM diagram that the absolute magnitude of Be 20 is M_V = -7.4 ± 0.2. At M31 this would be m_V = 17.2. The integrated brightness of M31's most distant cluster, C1, is estimated from KPNO 4-m plates to be m_V = 17.9.

The outermost luminous blue stars in the anticenter direction are estimated to lie at a distance of 20 kpc (Chromey 1978). For M31, Richter (1971) has catalogued aggregates of OB stars at ∿ 28 kpc.

The neutral-hydrogen diameters of the two galaxies are also in about this ratio. Emerson's (1976) outermost HI contours are at 32.4 kpc, for example, while Baker (1976) finds an HI cut-off for our Galaxy at about 25 kpc from the Galactic center.

When these data are combined with the various photometric measures of size (Table 1), we must conclude that the Milky Way is M31's inferior, being roughly two-thirds as large.

3. STRUCTURE

There are both similarities and striking differences between M31 and the Milky Way in structure. This discussion will concentrate in particular on the spiral structure, but mention should be made of other components as well. Both galaxies have compact nuclei, with that of M31 being somewhat less interesting (that is, less active). The galaxies both have central bulges made up largely of old, metal-rich stars, with that of the Galaxy being somewhat the smaller and bluer of the two (Sharov and Lyutyi 1980; Arp 1965; de Vaucouleurs and Pence 1978). The latter reference attempts to isolate the spheroidal component, assuming it to be structurally governed by an $r^{1/4}$ projected-density law, and finds the Galaxy's spheroid to have a blue absolute magnitude about 1.2 mag fainter than that of M31. The central bulge in both cases contains numerous examples of planetary nebulae (Ford and Jacoby 1978), SN remnants (Blair et al. 1981, Dennefeld and Kunth 1981, D'Odorico et al. 1980, Kumar 1976), novae (Rosino 1972), X-ray sources (van Speybroeck et al. 1979), and dust clouds (Hodge 1980).

The haloes of the two galaxies can also be compared. Both are surrounded by a nearly spherical and extremely extended system of globular clusters. Andromeda has almost three times as many catalogued globular clusters as the Milky Way. Its most distant globular lies at a projected distance of 130 kpc (Sargent et al. 1977), while our Galaxy's system appears to extend out to 116 kpc (Aaronson et al. 1983). Both also are surrounded by a thin population of dwarf elliptical galaxies (van den Bergh 1972, Hodge 1971).

It is on the disk component, especially the spiral-arm structure, however, that I wish to concentrate in this review. Most attempts to disentangle the spiral structure of M31 have used familiar, traditional "tracers": the OB stars, young clusters, HII regions, and HI, in much the same way the local spiral structure is sought in our Galaxy. The difference, of course, lies in the type of difficulty encountered: obscuration and distance uncertainties for the Milky Way, and a steep angle of inclination for M31. All agree that both galaxies have spiral arms, but the literature is full of contradictory interpretations of the detailed spiral structure. For M31, arms are outlined by the counts of brightest stars (van den Bergh 1958, Reddish 1962), by population morphology (Baade 1963), by OB associations (van den Bergh 1964), from radio-continuum data (Pooley 1969, van der Kruit 1972, Berkhuijsen and Wielebinski 1974, Beck 1982), from HI surveys (Roberts 1966, Byrd 1978, Brinks 1985, Walterbos and Kennicutt 1985, Sofue and Kato 1981, and many others), from CO data (Stark 1985), using HII region surveys (Arp 1964, Simien et al. 1978), from ultraviolet images (Deharveng et al. 1980), from Cepheids (Efremov et al. 1981), from surface photometry (Hodge and

Kennicutt 1982), from dust lanes (Hodge 1980), and from young open clusters (Hodge 1979). Although the raw data available for these studies are fairly consistent, their interpretation has been very divergent. While most fits have been of a two-armed trailing spiral pattern, Simien et al. (1978) instead argued for a one-armed leading spiral, with some theoretical justification provided by the work of Kalnajs (1975). Such a contradiction seems to indicate that the situation has been, at least recently, even worse than in the case of our Galaxy.

The leading one-armed spiral pattern, based primarily on HII regions, fits rather poorly the young open clusters' positions. Although the fit within ∿ 50 arcmin of the center looks reasonable, in the outer parts, where the open clusters better define a pattern than the sparser HII regions, the fit is seriously deficient. The clearly-defined arm segments near the major axis at 70-90 arcmin clearly have a slope opposite to that of the model. Arp's two-armed spiral also does not fit these segments, but at least they are roughly parallel, with pitch angles of the same

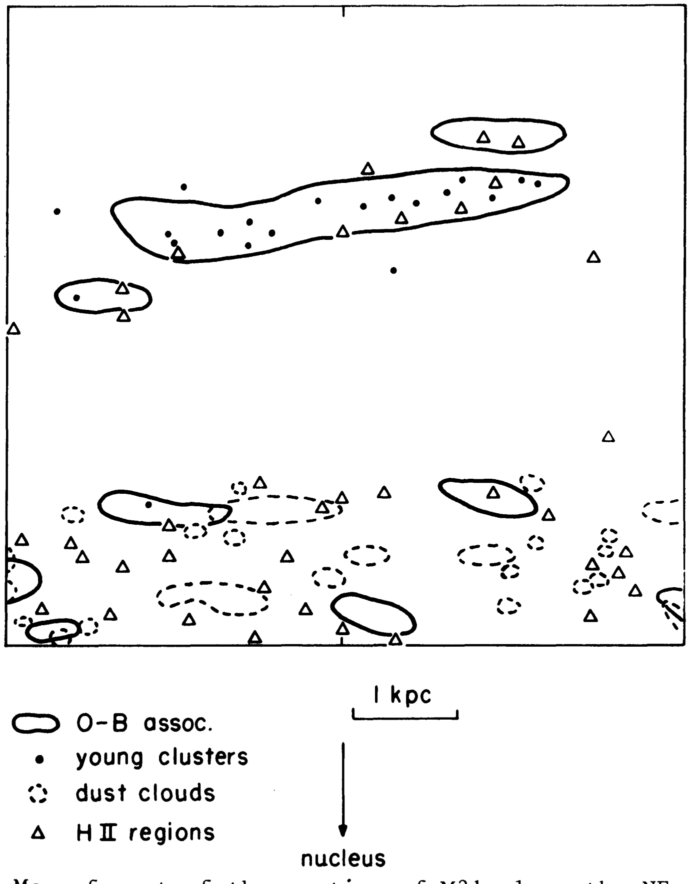

Figure 1. Map of part of the portion of M31 along the NE axis, rectified to face on, and extending from 7 to 14 kpc. Spiral-arm tracers are identified. Baade's arms N_3 and N_4 are conspicuous.

https://doi.org/10.1017/S0074180900242873 Published online by Cambridge University Press

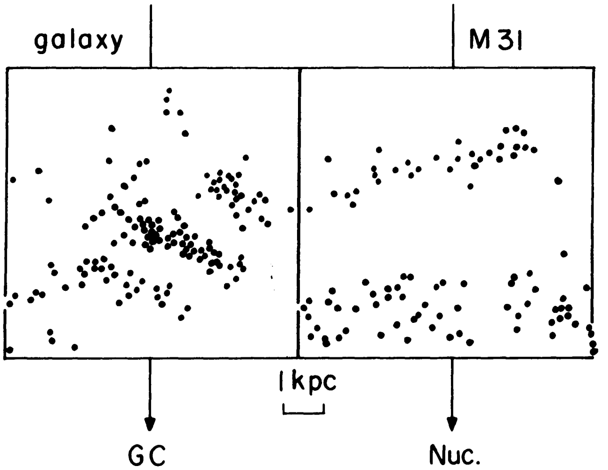

Figure 2. A comparison of the area in Figure 1 and a comparable area in the Milky Way galaxy, with the same kinds of tracers plotted.

magnitude and the same sign. It is clear that the arms of M31 are not to be fit to a simple, perfect logarithmic spiral pattern. Byrd's (1978) gravitationally-distorted spiral pattern looks much more promising. Perhaps the moral of this comparison is that students of the Milky Way's spiral structure should not be too discouraged if their data do not fit a perfect mathematical model, as M31 does not attain such perfection, nor do many other galaxies.

As a graphic demonstration of some of the similarities and differences in the spiral arms of the two galaxies, I have taken a section of the NE portion of M31 that corresponds in location to the solar neighborhood of the Milky Way. In Figure 1 I have plotted a rectified face-on map of the area in question, in which I have identified positions of young open clusters, dust clouds, OB associations, and HII regions, from the sources listed above. Two spiral-arm crossings are obvious. The inner has a pitch angle of perhaps 5°. They are separated by approximately 4 kpc at the position of the optical major axis, which vertically crosses the center of the diagram. All of the optical tracers agree remarkably well.

Figure 2 compares this map with a similar one for the Milky Way, plotted to the same scale and for the same distance from the nucleus (based on the summary diagram in Bok and Bok (1981)). Although the diagrams show a general similarity, there are three conspicuous differences: (1) the arms of M31 are much better defined, with interarm areas almost empty of tracers, (2) the M31 arms are at least twice as widely-spaced, and (3) the pitch angle for the M31 arms is much smaller. These facts, of course, have been known for many years; Fig. 2 merely supplies an especially graphic demonstration of these important differences.

There is not space to cover many other interesting comparisons that could be made, especially about the radial distributions of different components of the galaxies, rotational parameters, kinematics, warping of the plane, velocity dispersions, and so on. Much progress is being made in these fields. Questions do remain, however. I particularly point out that for both galaxies we still cannot answer the following rather basic questions:

1. How many arms are there?
2. What are the shapes of the arms?
3. What dominates the spiral pattern, generally and in detail?
4. What is the history of star formation in the plane and in the halo?
5. What is the total mass?
6. How is the mass distributed?

REFERENCES

Aaronson, M., Schommer, R., and Olszewski, E.: 1983, preprint
Arp, H.: 1964, Astrophys. J. 139, 1045
Arp, H.: 1965, Astrophys. J. 141, 43
Baade, W.: 1951, Publ. Obs. Univ. Michigan 10, 16
Baade, W.: 1963, Evolution of Stars and Galaxies (Harvard Univ. Press)
Baker, P.: 1976, Astron. Astrophys. 48, 163
Beck, R.: 1982, Astron. Astrophys. 106, 121
Becker, W.: 1964, Z. Astrophys. 58, 202
Berkhuijsen, E.M., and Wielebinski, R.: 1974, Astron. Astrophys. 34, 173
Blair, W.P. and Kirshner, R.P.: 1981, Astrophys. J. 247, 879
Bok, B.J., and Bok. P.F.: 1981, The Milky Way (Harvard Univ. Press)
Brinks, E. and Burton, W.B.: 1985, this volume
Byrd, G.: 1978, Astrophys. J. 226, 70
Christian, C., and Janes, K.: 1979, Astron. J. 84, 204
Chromey, F.: 1978, Astron. J. 83, 162
de Vaucouleurs, G., and Pence, W.D.: 1978, Astron. J. 83, 1163
Deharveng, J.M., Jakobsen, P., Milliard, B., and Laget, M.: 1980, Astron Astrophys. 88, 52
Dennefeld, M., and Kunth, D.: 1981, Astron. J. 86, 989
D'Odorico, S., Dopita, M., and Benvenuti, P.: 1980, Astron. Astrophys. Suppl. 40, 67
Efremov, Y.N., Ivanov, G.R., and Nikolov, N.S.: 1981, Astrophys. Space Sci. 75, 407
Emerson, D.T.: 1976, Monthly Not. Roy. Astron. Soc. 176, 321
Ford, H., and Jacoby, G.: 1978, Astrophys. J. Suppl. 38, 351
Georgelin, Y.M., and Georgelin, Y.P.: 1976, Astron. Astrophys. 49, 57
Hodge, P.: 1971, Ann. Rev. Astron. Astrophys. 9, 35
Hodge, P.: 1979, Astron. J. 84, 744
Hodge, P.: 1980, Astron. J. 85, 376
Hodge, P., and Kennicutt, R.: 1982, Astron. J. 87, 264
Hodge, P.: 1983, paper submitted

Kalnajs, A.: 1975, "La Dynamique des Galaxies Spirales", ed. L. Weliachew, Paris, CNRS No. 241
Kumar, C.K.: 1976, Pub. Astron. Soc. Pacific 88, 323
Lindblad, B.: 1956, Stockholms Obs. Ann. Bd. 19, No. 2
Pooley, G.: 1969, Monthly Not. Roy. Astron. Soc. 144, 101
Reddish, V.: 1962, Z. Astrophys. 56, 194
Richter, N.: 1971, Astron. Nachr. 292, 275
Roberts, M.S.: 1966, Astrophys. J. 144, 639
Rosino, L.: 1972, Astron. Astrophys. Suppl. 9, 347
Sargent, W.L.W., Kowal, C., Hartwick, D., and van den Bergh, S.: 1977, Astron. J. 82, 947
Sharov, A.S., and Lyutyi, V.B.: 1980, Astr. Zh. 57, 449
Simien, F., Athanassoula, E., Pellet, A., Monnet, G., Maucherat, A., and Courtès, G.: 1978, Astron. Astrophys. 67, 73
Stark, A.A.: 1985, this volume
Sofue, Y., and Kato, T.: 1981, Pub. Astron. Soc. Japan 33, 449
van den Bergh, S.: 1958, Pub. Astron. Soc. Pacific 70, 109
van den Bergh, S.: 1964, Astrophys. J. Suppl. 9, 65
van den Bergh, S.: 1968, Comm. D. Dunlap Obs. No. 195
van den Bergh, S.: 1972, Astrophys. J. 171, L31
van der Kruit, P.C.: 1972, Astrophys. Lett. 11, 173
van Speybroeck, L., Epstein, A., Forman, W., Giacconi, R., Jones, C., Liller, W., and Smarr, L.: 1979, Astrophys. J. 234, L49
Walterbos, R.A.M., and Kennicutt, R.: 1985, this volume

DISCUSSION

E. Athanassoula: The analyses of spiral structure in M31 mentioned by you (Baade + Arp; Simien et al.) try to fit one single logarithmic spiral to the whole galaxy. By relaxing this assumption and using a Fourier analysis which allows for several components, Considère and I (1982, Astron. Astrophys. 111, 28) find back the one-armed leading spiral first proposed by Kalnajs (1975) and Simien et al. (1978). However, in the outer regions (beyond 65' or 70') we find a two-armed trailing spiral with pitch angle 8°. It is thus no surprise that the extrapolation of the one-armed spiral does not fit the outer regions you showed.

H. van Woerden: Is your pitch angle of 5° in M31 based on an analysis of the run of arms all around the system?

Hodge: No, it is based on one segment only, and the value is 5° ± 5°.

P. Pismis: Your Table 1 shows that M31 is in many respects, including the arm spacing, larger than our Galaxy. Could this be due to an overestimate of the distance to the Andromeda Nebula or does a physical cause underlie the difference?

Hodge: I do not think such an overestimate of the distance is very likely. As to the spacing of the arms, the experts for our Galaxy do not seem to find compelling reasons to expect this to be equal to that in Andromeda. It seems preferable to consider the "arms" in our Galaxy as a complex set of portions of arms and spurs, rather than changing the distance scale.

W.L.H. Shuter: Your type estimate of Sc for our Galaxy is based on a scale of R_o = 10 kpc. What would happen if R = 8.5 kpc?

Hodge: It would make the Galaxy slightly earlier, but not much.

Hodge burns his lips at conference dinner, while Baud and Van der Laan discuss arrangements for after-dinner lecture. At right: Kormendy LZ

https://doi.org/10.1017/S0074180900242873 Published online by Cambridge University Press