

Chapter 15

THE MILKY WAY IN RELATION TO OTHER GALAXIES

15.1 Introduction

In this final lecture I will put the Milky Way into perspective among the realm of spiral galaxies. To this end I will first briefly summarize some properties of its nearest neighbors: the other members of the Local Group of galaxies. Then I will try to answer the question of what the Hubble type of the Galaxy is; this is preceded by a review of arguments for the value of the disk scalelength, because this does play a role in some of this. An attempt will be made to identify some external galaxies that bear a close resemblance to our own, followed by some concluding remarks related to our vantage point within the Milky Way. The conclusion will be that we lie in a fairly large galaxy of probably type SbI-II at about 1.5 to 2 scalelengths from the center. Our position close to the plane is a particularly unlucky coincidence that seriously hampers Galactic astronomy, especially in the optical, but the orientation of the plane of the Milky Way in space with respect to the nearby extragalactic universe is particularly favorable for studies of external galaxies.

15.2 Properties of other Local Group galaxies

The Local Group consists of two major spirals, the Galaxy and M31, a smaller spiral M33 and various dwarf systems, of which the Magellanic Clouds and the four dwarfs ellipticals around M31 (M32 and NGC 205, 185 and 147) are the larger ones. Further there is a fair number of small dwarfs, that I will not be concerned with in these lectures. I will not attempt to give a complete description of all features of these galaxies, but rather highlight some interesting and important studies.

Surface photometry of such nearby galaxies, which consequently have a large angular size is difficult. Although studies on photographic plates are available from the earliest days of photometry (de Vaucouleurs (1957) observed the LMC very early on in his studies and determined the exponential nature of its disk), the prime method today is the use of CCD's behind small telescopes (or even only a camera lens and a filter/shutter assembly). This ensures a large field of view, but provides larger pixels, sometimes up to an arcmin. This is of course no problem for large angular size objects.

Kent (1987b) observed among others in such a way the elliptical companions of the Andromeda galaxy. There is a large variety of luminosity profiles. M32 can be represented with an $R^{1/4}$ -law out to 0.34 kpc with an effective radius of 0.11 kpc. The total extent observed (out to 1.0 kpc) shows a more exponential behavior beyond 0.4 kpc, without any indication of a tidal truncation. The integrated absolute magnitude is $M_V = -16.1$ ($2.4 \cdot 10^8 L_\odot$). Studies of stellar kinematics by Dressler and Richstone (1988) and others show evidence for a central black hole of $8 \cdot 10^6 M_\odot$. NGC 205 has a profile that cannot be fit with either an $R^{1/4}$ or an exponential and has a starlike nucleus. The observed extent is 1.6 kpc and the integrated magnitude $M_V = -16.1$ ($2.4 \cdot 10^8 L_\odot$). NGC 185 also has a complicated profile, but no nucleus. Its extent is 1.4 kpc and magnitude -15.1 ($9.5 \cdot 10^7 L_\odot$). Finally, NGC 147 can be fitted very well by an exponential out to the observed maximum radius of 1.1 kpc and the scalelength is 0.5 kpc. The central surface brightness corresponds to about $22.5 B$ -mag arcsec $^{-2}$, typical for irregular dwarfs (in the morphological sense, which means that there is evidence for star formation), although its appearance is that of an old population. The integrated magnitude is -14.7 ($6.5 \cdot 10^7 L_\odot$). Mould et al. (1983, 1984) have used CCD's to measure the brighter part of the color-magnitude diagram of NGC 147 and 205. The metallicities are low and similar ($[Fe/H]$ about -1.2 for NGC 147 and -0.85 for NGC 205) and both systems share the property that no more than 10% of the stars can be of intermediate age.

Of course, a very large body of data exists for the Magellanic Clouds and I will only refer here to the distribution of stars and of star formation. Clearly, both the LMC and the SMC experience current star formation and are rich in interstellar medium. They are companions of the Galaxy at distances of respectively about 50 and 65 kpc. Their integrated (absolute) magnitudes are $M_V = -18.4$ and -17.1 ($2.0 \cdot 10^9$ and $6.0 \cdot 10^8 L_\odot$) and colors ($B - V$) 0.52 and 0.61. So these are more luminous (and bluer) than the companions of M31, although the color is not so blue to infer a major current burst of star formation. De Vaucouleurs (1957) determined the luminosity profile of the LMC and SMC and showed these to follow the exponential law for disks. More recent photometry, including color determinations, have been done by Bothun and Thompson (1988) with a CCD behind a 85-mm lens (the "parking lot camera") in B , V and R . The luminosity profiles are shown in fig. 15.1. Both can be fitted with exponentials.

The LMC has a central surface brightness of $21.3 B$ -mag arcsec $^{-2}$ after correction for

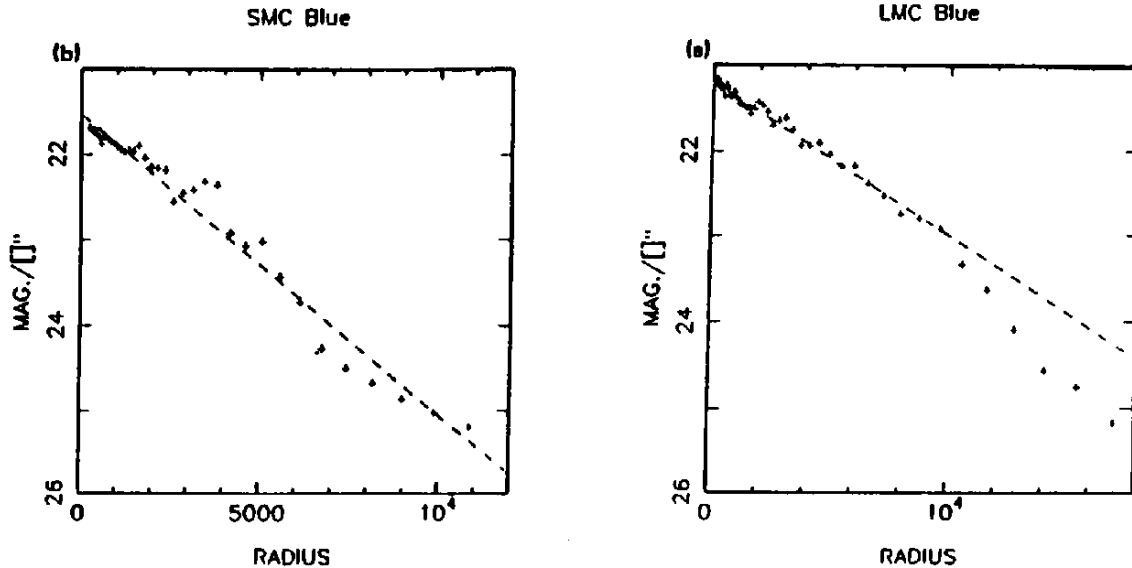


Figure 15.1: Radial light profiles of the Magellanic Clouds, obtained with the “parking lot camera”, which is a CCD behind a camera lens and a field of view of 6.5 by 10.4 degrees. The pixel size measured 73 arcsec. The data are shown for the B -band and fits to exponential disks are shown by the dashed lines. The horizontal scale is in arcsec. The surface brightness is not corrected for inclination. From Bothun and Thompson (1988).

inclination. This is somewhat bright, even for a normal spiral and shows the possible effect of star formation in a late-type system. The scalelength is about 1.5 kpc. This is large for a galaxy that does not show obvious spiral structure (see M33 below). The bar also has a radially exponential surface brightness distribution; most bars in spiral galaxies however, have a fairly constant surface brightness. At 2σ a faster decline than the exponential sets in in all colors and this may indicate the onset of a truncation of the stellar distribution caused by the tidal field of the Galaxy during a period of close proximity. The detailed color distribution shows mostly random star formation over recent times with a small suggestion that the most recent star formation is concentrated towards the bar, in which case this bar may not be a feature in the mass distribution, but rather outline the area of most recent star formation activity. In many respects the LMC simply is a small spiral, except that the star formation does not proceed in a manner that is organized over the disk in a pattern of spiral structure. Clearly, interaction with the Galaxy may be suspected as the cause of this. Schwering (1988) has recently produced maps of infrared IRAS brightness of both Clouds. This traces dust that is heated by hot stars and the observed distributions correspond closely with that of tracers of recent star formation.

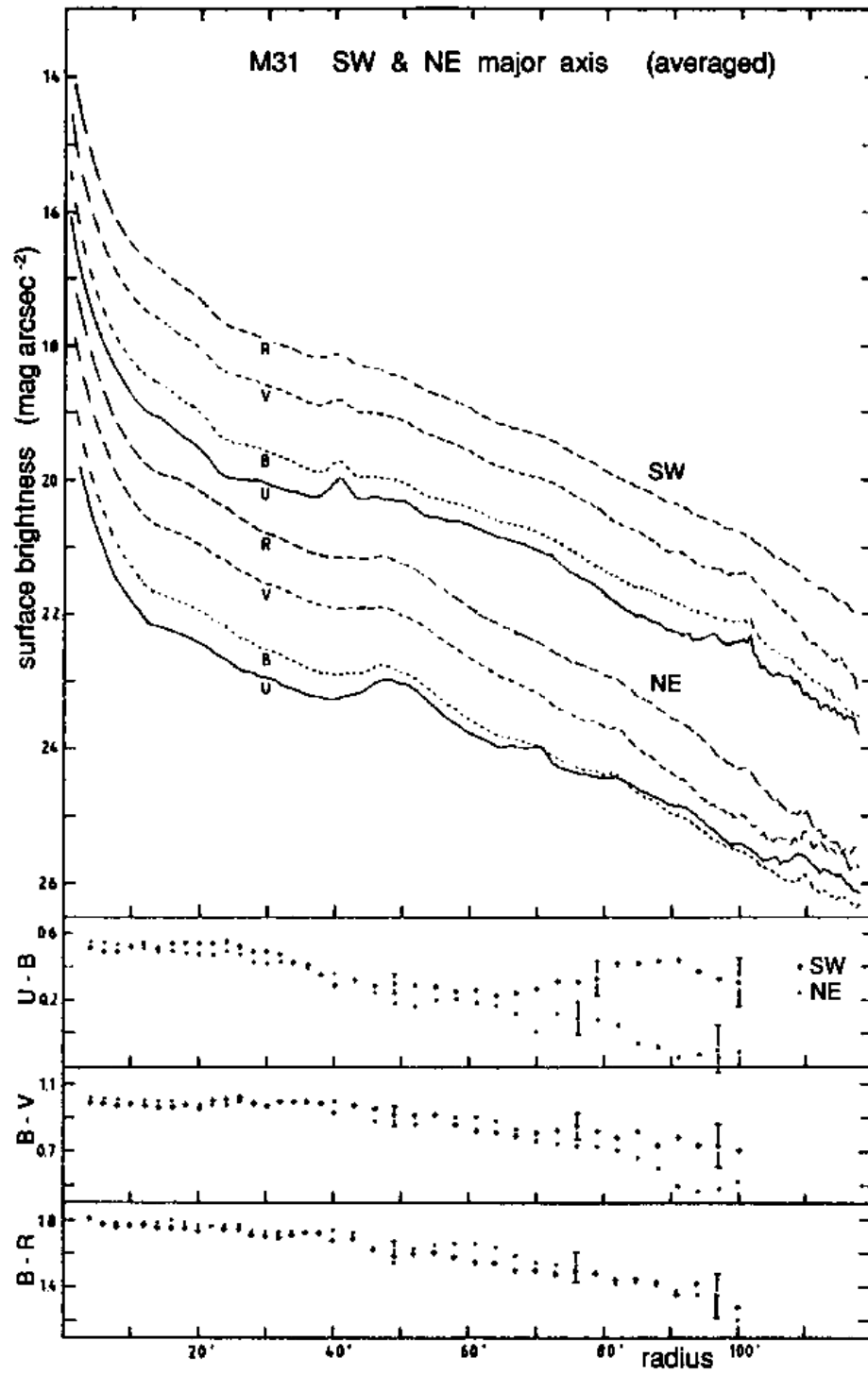


Figure 15.2: Radial light and color distributions along the major axis of M31 in U , B , V and R . The profiles of the SW side have been shifted upwards by 3 mag. Colors have not been corrected for foreground reddening. From Walterbos and Kennicutt (1987).

The SMC much more resembles dwarf irregulars, such as have been observed for example in the Virgo cluster. The face-on central surface brightness is $22.3 B$ -mag arcsec $^{-2}$ (assuming an inclination of 60°), which is more typical for dwarfs. The scalelength of the fit in fig. 15.1 is 0.96 kpc. Colors reveal coherent patterns of star formation, although these are not organized in spiral structure.

M33 definitely is a small Sc spiral with essentially no bulge component. Its luminosity distribution is closely exponential, although the photometry by Kent (1987b) shows a central increase in surface brightness over the exponential. This is not a bulge component, because the light is there still dominated by the spiral structure and area's of obvious star formation. The scalelength is about 1.7 kpc and the central surface brightness $21.05 B$ -mag arcsec $^{-2}$. The integrated absolute magnitude is -18.6 ($2.4 \cdot 10^9 L_\odot$) and the color ($B - V$) 0.50. All these numbers are remarkably close to those of the LMC and the only difference really is the spiral structure in M33. Also the gas masses of M33 and the LMC are similar ($9.5 \cdot 10^8$ and $5.4 \cdot 10^8 M_\odot$), just as the total infrared fluxes from IRAS ($1.2 \cdot 10^9$ and $8.9 \cdot 10^8 L_\odot$). M33 is at a projected distance of about 175 kpc from M31 and therefore these galaxies have probably had much less interaction with each other than the LMC and the Galaxy. Deul (1988) has recently obtained maps of M33 in the IRAS bands and in HI. The average dust-to-atomic gas ratio is in M33 much lower than that in the Galaxy.

Finally I turn to the Andromeda galaxy. Most of what follows is based on the extensive study by Walterbos (1986, see also Walterbos and Kennicutt, 1987 and references therein), who observed M31 in radio continuum, obtained multi-color optical surface photometry and used the IRAS results. The optical data are illustrated in fig. 15.2, where the profiles along the major axis have been plotted. Interestingly, no color gradient has been seen in the bulge and a small, but significant bluing is seen in the disk. The latter could be due to metallicity, but also the contribution from young stars is a serious possibility. The profiles can be decomposed well into an $R^{1/4}$ -bulge and an exponential disk.

A comparison of Andromeda to the Galaxy is made in table 15.1. We see that the disk of M31 is slightly bigger, but the bulge is nearly 3 times brighter. The HI, radio continuum and IR luminosities are all lower in the Andromeda galaxy. M31 has not been mapped completely in CO; it is known that both M31 and the Galaxy have a ring of molecular gas. In Andromeda it peaks at about 10 kpc galactocentric radius, while in the Galaxy this occurs at about 4.5 kpc. The surface density of molecular gas in M31 is a factor 3 to 4 lower than in the Galaxy, although the neutral gas surface densities are somewhat higher. All information points to a lower current star formation activity in the

Table 15.1: Comparison of M31 and our Galaxy

	M31	Galaxy
Bulge:		
Luminosity (L_{\odot})	$7.7 \cdot 10^9$	$2 \cdot 10^9$
Luminosity (fraction of total)	0.25	0.12
Effective radius (kpc)	2.2	2.7
Axis ratio	0.57	0.85
Velocity dispersion (km s^{-1})	155	130
Number of globular clusters	400–500	160–200
Disk:		
Luminosity (L_{\odot})	$2.4 \cdot 10^{10}$	$1.7 \cdot 10^{10}$
Scalelength (kpc)	6.4	5.0
$(B - V)$ (errors about 0.1)	0.76	0.85
HI gas content (M_{\odot})	$3 \cdot 10^9$	$4 \cdot 10^9$
Rotation velocity (km s^{-1})	260	220
IRAS Infrared luminosity (L_{\odot})	$2.6 \cdot 10^9$	$1.5 \cdot 10^{10}$
Gas metallicity gradient (dex kpc^{-1})	-0.04	-0.08

Andromeda galaxy.

15.3 Disk scalelength and the Hubble type of the Galaxy

An important question is what Hubble type applies to the Galaxy. The answer is to some extent dependent on what we think the disk scalelength is, so that I will discuss this again in somewhat more detail than I have done above. As presented in more detail earlier in this course, the surface brightness of the Galaxy as measured with Pioneer 10 shows a disk scalelength of 5.5 ± 1.0 kpc. Now we look at further evidence to derive a best value.

It is important to realize that the value of 3.5 kpc that is often seen in the literature is essentially based on a single argument by de Vaucouleurs (1979). He takes the value for the local disk surface brightness from star counts in the polar caps, assumes that the central value is Freeman's canonical one and a distance to the Galactic centre. Other methods used by de Vaucouleurs are difficult to evaluate. He uses also the distribution of total gas within the sun; in some late-type galaxies the CO-distribution follows that of the blue light. However, the Galaxy shares with M31 and NGC 891 a central depression and

there is no supporting evidence that this behavior also applies to such galaxies. Finally, he uses the surface density of HI beyond the solar circle. There are two problems there. In the first place the derived surface density from observations depends very sensitively on the assumed rotation curve and varies much between various publications. Secondly, in external galaxies the scalelength of the HI is different from that of the light. From the sample of Wevers et al. (1986) the ratio of HI to blue scalelength is 1.85 ± 0.35 .

With the currently best value for the central surface brightness and its scatter (see elsewhere in this course) and the Pioneer value for the local surface brightness it would follow that $h = 4.2 \pm 1.0$ kpc, if $R_o = 8.5 \pm 1.0$ kpc. This already revises de Vaucouleurs' estimate. The outer HI cannot be used well; Blitz et al. (1983) show an HI distribution that is flat out to 16 or 20 kpc and no reliable value for h can be extracted with this method.

A useful estimate comes from the observation (see my first set of lectures), that young stars are seen in the anticenter direction out to at least 22 kpc. This puts R_{\max} at 20 to 25 kpc. For external edge-on galaxies van der Kruit and Searle (1982) find $h/R_{\max} = 4.2 \pm 0.6$ and it would follow that $h = 5.4 \pm 1.0$ kpc.

There are also estimates possible from stellar dynamics. Lewis (1986; Lewis and Freeman, 1989) has measured the velocity dispersion of old disk giants as a function of galactocentric radius and finds these to show an e-folding of 8.7 ± 0.6 kpc. If, as discussed in detail earlier, this velocity dispersion falls with an e-folding twice that of the stars then we expect $h = 4.4 \pm 0.3$ kpc.

A final method involves the asymmetric drift. The relevant equation is

$$\frac{\partial \ln \langle V_R^2 \rangle}{\partial R} + \frac{\partial \ln \rho}{\partial R} = \frac{V_t^2 - V_{\text{rot}}^2}{R \langle V_R^2 \rangle} - \frac{1}{R} \left\{ 1 - \frac{B}{B-A} \right\}. \quad (15.1)$$

Now in earlier times the first term on the left was set equal to zero in the absence of any detailed knowledge. However, we now know that it is not negligible at all (see the data of Lewis above) and is most likely equal to $-1/h$. Using this and usual values for the local Oort constants leads with Plaut's (1965) data for old disk variables to $h = 4.3$ – 5.8 kpc.

From this discussion I conclude that there is ample support for a value for h as indicated by the Pioneer photometry and none for the old value of 3.5 kpc. The best value for h is 5.0 ± 0.5 kpc.

Classical ways to determine the morphological type of the Galaxy have involved arguments concerning the luminosity of the bulge, the spiral structure as determined from HI studies or the distribution of HII regions, and the local disk surface brightness. De Vaucouleurs has used over the years many such arguments and concluded on this basis on a classification of SAB(rs)bc (de Vaucouleurs and Pence, 1978). In all subdivisions in this scheme the final classification is intermediate between two designations and the suspicion is that this indicates uncertainty rather than precision.

Hodge (1983) used the scalelength h_{HII} of the number distribution of HII regions to derive a type Sc, based on a relation between this parameter and the integrated magnitudes of spirals. In this plane the types Sb, Sc and Sd form parallel sequences. Since all spirals appear to have the same central surface brightness, this segregation is only possible if the ratio between h_{HII} and h_{light} depends on type (being smaller for earlier types). Now, Hodge and Kennicutt (1983) have found a general similarity between these two scalelengths. Their figure however contains mostly Sc galaxies and the Sb's may not follow this relation. Indeed one of the two Sb's (NGC 2841) has h_{HII} 2.6 kpc and h_{light} 5.4 kpc. Also for M31 a fit to the number counts of HII regions gives $h_{\text{HII}} = 3.0 \pm 0.6$ kpc (van der Kruit, 1987), which is also smaller than the 6 kpc for the surface brightness. Hodge's value for h_{HII} for the Galaxy is 2.35 ± 0.05 kpc, which would be consistent with the Galaxy also being of type Sb. However, using other data h_{HII} can also be estimated as 4.6 ± 1.0 kpc (van der Kruit, 1987).

Color is known to correlate with Hubble type, as discussed above. For the Galaxy we unfortunately only know the color of the local disk and that with a large uncertainty, namely $(B-V) = 0.85 \pm 0.15$. This is determined from the color of the galactic background starlight at high latitudes and is not necessarily typical for the disk as a whole. It would indicate a type of about Sb, but we are probably living in a region with relatively low current star formation.

Another property that can in principle be used is the gas content. Wevers (1984) has for this purpose defined a parameter, which is the logarithm of the ratio of surface brightness in the B -band to the HI surface density, both evaluated at 3 optical scalelengths. For the Galaxy this property comes out as 0.5 ± 0.3 in solar units (van der Kruit, 1986). This is similar to Sb galaxies (it is negative for Sc galaxies) and therefore points to such a classification.

One of the major criteria for the Hubble classification is the bulge-to-disk ratio. Quantitative determinations of this parameter show indeed a correlation as expected, but there is a large scatter within each type. The actual number gives Sbc as the most probable type, although the whole range from Sab to Scd is consistent (van der Kruit, 1987).

The most compelling argument appears to come from the CO distribution. As I discussed also above, Young (1987) has reviewed the observed radial distributions. Sc galaxies show a central peak in the CO intensities, while at least 40% (improved resolution may increase this number) of the Sa and Sb galaxies have a central hole. In this respect the Galaxy is similar to Sb galaxies, while at present no Sc galaxy is known, which in its CO distribution resembles the Galaxy. This observation seems to point rather decisively to Sb.

Finally, we may try to find galaxies that in their properties closely resemble the Galaxy and then look at their classification. From the section above it follows that M31 (SbI-II) is similar in many respects (including the central hole in the CO distribution), but it has

a lower current rate of star formation. This may well be within the range encountered within any particular type. A galaxy that is in many respects very similar to the Galaxy is NGC 891 (van der Kruit, 1984). Not only are the photometric parameters of bulge and disk of the two systems very similar, but also the CO and HI distributions and number of globular clusters are very closely the same. Both systems are seen edge-on. The appearance of the Milky Way from the southern hemisphere in the winter, when the Galactic Centre culminates near the zenith in the middle of the night, is strikingly similar to pictures of NGC 891. Indeed many illustrations comparing photographs of NGC 891 and of the Milky Way with super-wide angle camera's have been published and the strong resemblance has been stressed often (e.g. King, 1976). NGC 891 is invariably classified Sb.

On this basis I conclude that the most likely Hubble type of the Galaxy is Sb, where the strongest evidence comes from the CO distribution, the gas content and the strong resemblance to NGC 891. It is doubtful that we will ever be able to do better, because no quantitative observable correlates so strongly with morphological type so as to allow the exclusion of all but one classification bin. Sc is almost certainly ruled out but Sbc is not.

The luminosity class is more difficult to determine, but a comparison to the Virgo cluster galaxies can be made. For this we look at the photometry of Watanabe (1983) in the 6°-core of the cluster, combined with Sandage-Tammann classifications. For Sc and Sb galaxies it turns out that all 6 with class I or I-II have disk scalelengths larger than 4 kpc, while for the 25 of class II this is only the case for 5 of these. The 6 of class I and I-II have central surface brightness 20.6 ± 0.7 B-mag arcsec⁻² and the 5 of class II 21.2 ± 1.0 . For the Galaxy this parameter is 21.1 ± 0.3 . In view of this limited statistics of the two photometric disk parameters, I conclude that the Galaxy is probably not of luminosity class II, but most likely I-II. We probably live in an SbI-II galaxy and these systems are among the largest spiral galaxies in the universe.

15.4 The Milky Way compared to other galaxies

We have seen that we live in a relatively large spiral galaxy of intermediate Hubble type. I have already indicated above that 10% of all disk stars in the universe live in spirals with a disk scalelength larger than 4 kpc. In this final section I will make some further remarks on this and on the location and orientation of the Galaxy in space. First I will discuss the question of its appearance in relation to known nearby galaxies. In the semi-popular literature and fundamental textbooks one often sees M31 or M81 illustrated as galaxies looking much like our own.

De Vaucouleurs (see e.g. de Vaucouleurs and Pence, 1978) has through the years

used various arguments to identify systems that would bear a close resemblance. De Vaucouleurs and Pence have concluded on this basis that the morphological classification is SAB(rs)bcII and have published a sketch of what this morphology implies for the outsider's view. This is partly based on known morphological features, mainly from HI distributions and the distribution of HII regions, such as the definition and pitch angle of the spiral arms and the possible presence of a central bar and ring. They further identify galaxies of similar morphological type, for which the photometric parameters are also similar. These parameters are however integrated parameters, such as absolute magnitude, colors, diameter, mean surface brightness and hydrogen index (HI-mass to total light ratio). The galaxies are NGC 1073, 4303, 5921 and 6744. Grosbøl's (1985) photometry gives for the first three galaxies disk scalelengths of respectively 5.0, 2.6, 2.9 kpc on a distance scale with a Hubble constant of $75 \text{ km s}^{-1} \text{ Mpc}^{-1}$. NGC 1073 has an HI-profile with a width of only about 95 km s^{-1} ; its inclination is small and is in the range $20\text{--}30^\circ$, so that the rotation velocity is at most 130 km s^{-1} and much smaller than that of the Galaxy. NGC 6744 is a southern galaxy for which no surface photometry is available; its rotation velocity estimated from the HI-profile is about 210 km s^{-1} . Also the HI content is similar to that of the Galaxy.

I have searched the available data for galaxies that are similar to our own in some parameters, that are not governed by the morphology of the spiral structure. These are a disk photometric scalelength (which is Hubble constant dependent) of 4 to 6 kpc, a bulge luminosity of about 10 or 20% of the total, a bulge effective radius of 2 to 3 kpc, a disk color ($B - V$) of 0.6 to 0.8, a rotation velocity (in the flat part) of 210 to 230 km s^{-1} and an HI content of a few times $10^9 M_\odot$. Note that the disk luminosity is not a parameter on which restrictions are put, since the galaxies are supposed to conform to Freeman's law and therefore this is set by the scalelength. Also the integrated luminosity enters through the selection on rotation velocity via the Fisher-Tully relation. Finally, the Hubble type is somewhat restricted through the ratio of bulge-to-total luminosity and disk color. Of course, the number of galaxies for which all this information is available is not very large; it is mainly set by the requirement that full surface photometry is available, so that disk - bulge separation can be performed. This does eliminate most of the photographic work, because often this only extends to the brighter isophotes when special short exposures have been taken. The rotation velocity and HI content are known already from single dish 21-cm line observations.

I have already indicated the resemblance of the Galaxy to NGC 891 above. This similarity cannot come from a survey as described, since for edge-on galaxies all but the integrated disk luminosity and color are known. However, leaving these aside, NGC 891 does still come out as a close twin. Some galaxies suggested before and that are very often seen in the literature as such, then do not conform to these strict limits, if applied all at the same time. E.g. M31 (as already seen above) has too large a disk scalelength,

Table 15.2: Parameters for our Galaxy and two closely similar galaxies

	Galaxy	NGC 891	NGC 5033
Distance (Mpc)		9.5	14
Bulge:			
R_e (kpc)	2.7	2.3	2.9
b/a	0.7	0.7	?
$L_{\text{bulge}} (L_{B,\odot})$	$2 \cdot 10^9$	$1.5 \cdot 10^9$	$4 \cdot 10^9$
Disk:			
μ_o (B -mag arcsec $^{-2}$)	22.1	22.9 (old disk)	22.0
h (kpc)	5	4.9	5
$L_{\text{disk}} (L_{B,\odot})$	$1.7 \cdot 10^{10}$	$6.7 \cdot 10^9$ (old disk)	$1.7 \cdot 10^{10}$
$(B - V)$	0.8	0.9 (old disk)	0.6
R_{max} (kpc)	20–25	21	22
$L_{\text{bulge}}/L_{\text{tot}}$	0.12	0.07	0.19
V_{rot} (km s $^{-1}$)	220	225	215
$M_{\text{HI}} (M_{\odot})$	$8 \cdot 10^9$	$4 \cdot 10^9$	$4 \cdot 10^9$

too bright a bulge and too large a rotation velocity. M81 has also rotates too fast (about 255 km s $^{-1}$) and has much too small a scalelength (2.5 kpc according to Kent, 1987a). NGC 4565 has too bright a bulge and too high a rotation velocity (about 260 km s $^{-1}$). Finally, the Sbl galaxy NGC 3200, which was proposed by Rubin (1983) to be similar to the Galaxy on the basis of its rotation curve, does not qualify on the basis of the disk scalelength of about 8 kpc on the distance scale used here (Kent, 1986).

The only galaxy that conforms to all these criteria is the Sbc(s)I–II spiral NGC 5033. Photometry of this galaxy has been given by Wevers et al. (1986) and Kent (1987a). The assumed distance is 14 Mpc. The disk is not entirely exponential, but the profiles from these studies can be represented reasonably well with the parameters $R_e = 2.9$ kpc and, for a color $(B - V) = 0.9$ and a flattening of 0.5, luminosity $4 \cdot 10^9 L_{B,\odot}$ for the bulge and for the disk $\mu_o = 22.0$ B -mag arcsec $^{-2}$ and $h = 5$ kpc. An optical picture is shown in fig. 15.3. Some parameters for the three galaxies are collected in table 15.2.

For NGC 891 the disk parameters apply only to the old disk population and for the bulge-to-total luminosity ratio it has been assumed that the younger populations provide as much B-light as the old disk.

It is interesting to note that NGC 5033 has a somewhat brighter bulge and lower HI mass than the Galaxy; on this basis the latter would be of somewhat earlier Hubble type than Sbc. This offsets the comparison to M31, which would make the Galaxy of slightly

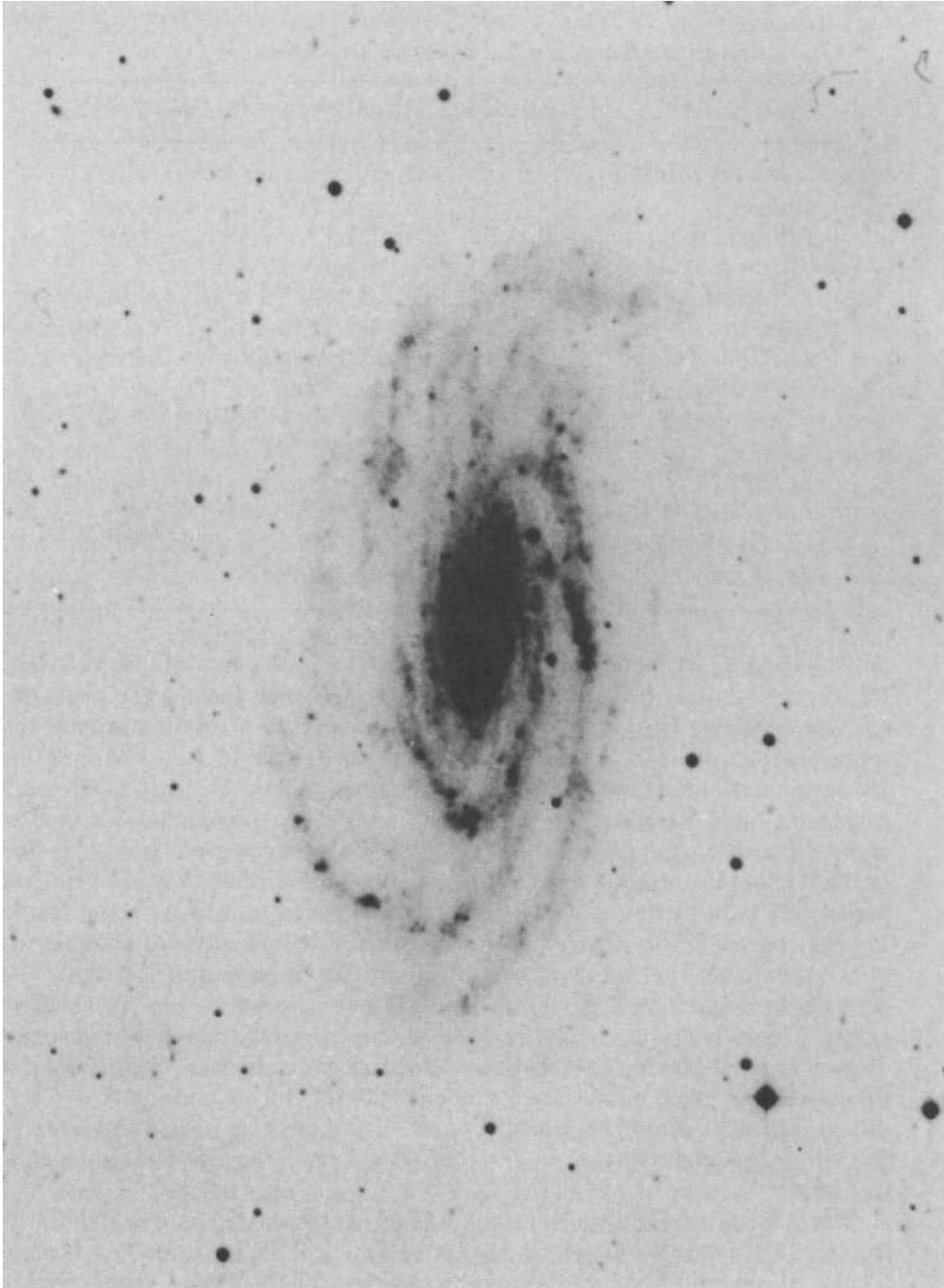


Figure 15.3: A IIIa–J photograph of the Sbc(s)I–II galaxy NGC 5033. This galaxy is similar to the Galaxy in its photometric parameters of disk and bulge, disk color, rotation velocity and HI-mass to total-light ratio.

later type than Andromeda (Sb).

By way of concluding remarks I will repeat some statements concerning galactic and extragalactic research that I have made previously in the literature. The first concerns the fact that astronomy has developed first in the northern hemisphere, while the Galactic Center is at negative declinations. As a matter of fact, the present location on the sky has the lowest declination that the Center gets during the precession cycle of 26,000 years. Half a cycle ago or in the future, the declination is $+18^\circ$. However, the Magellanic Clouds are always southern objects: the LMC does not get further to the north than declination -60° and the SMC -45° . M31, which is currently 41° above the equator can actually attain declinations between 10° and 57° .

The location of the sun in the Galactic plane is also amusing to consider. Its velocity relative to the local standard of rest is such that in the plane the epicycle excursion (period $1.7 \cdot 10^8$ years compared to a rotation around the center in $2.4 \cdot 10^8$ years) takes it in towards the Center by 0.11 kpc in $2.0 \cdot 10^7$ years and out by 0.57 kpc from the present radius after $1.0 \cdot 10^8$ years from now. More interesting is the vertical motion. At present the location is about 12 pc from the plane as estimated from the curvature of the ridge-line in the Pioneer 10 surface brightness distribution of the Milky Way. The vertical period is $7 \cdot 10^7$ years and in about $1.5 \cdot 10^7$ years it will be about 85 pc from the plane. This is interesting, because then it will be situated above much of the dust lane. Had the evolution of life on earth proceeded slower by 0.5%, we would have been allowed a much less obscured view of the Galactic Center. We are even more unlucky, since stars of the solar age have a velocity dispersion of 20–25 km s^{-1} in the z -direction and stars with such a vertical velocity in the plane move out to z about 300 pc. Only 2% of the old disk stars are 12 pc or less from the plane. If the dust lane has a thickness of 100 pc, no less than 90% or so of all old disk stars are above or below this layer.

There is one aspect in which we are probably extremely fortunate and that is the orientation of the Galaxy with respect to the Local Supercluster. Our Galaxy is situated somewhere towards its outer boundaries and the Virgo Cluster appears to be the center. Now the plane of the supercluster is oriented with an angle of 73° relative to the plane of the Galaxy and the Virgo Cluster is located only 15° from the Galactic pole. So, as seen from Virgo ours would be one of the most face-on oriented spirals in the nearby universe, since an inclination of 15° or less occurs only in 4% of all cases for random orientations. This enables us a rather unobscured view of the many galaxies in the central area's of the Local Supercluster. We are also fortunate to have a large Sb as M31 nearby (0.7 Mpc),

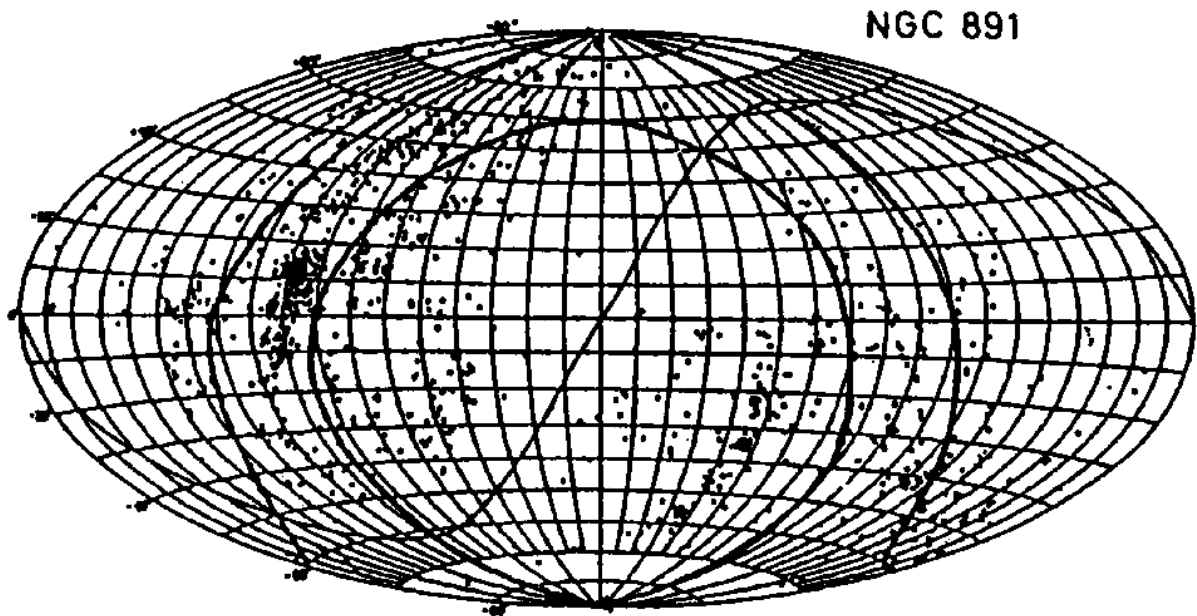
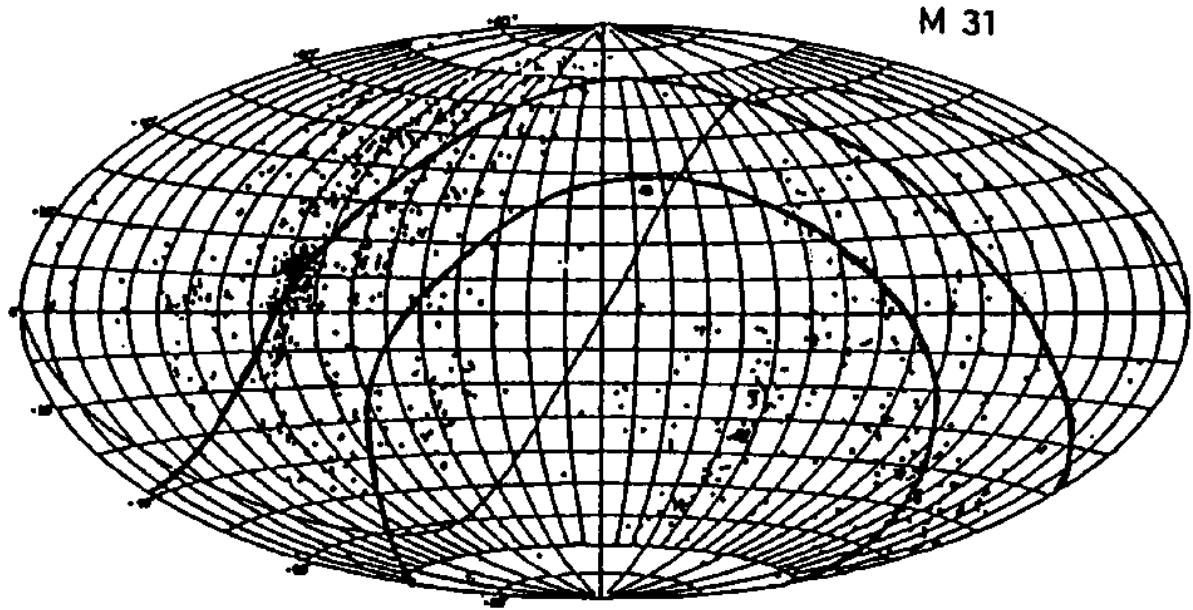


Figure 15.4: The zones of avoidance, defined by galactic latitude less than 15° , as seen from M31 and NGC 891, shown by the thick lines. The coordinates are R.A. and Dec and the center of the figure is at R.A. $6^{\text{h}} 40^{\text{m}}$, Dec 0° . The underlying distribution is that of bright galaxies from the original Shapley-Ames catalogue and the thin line indicates the Galactic plane. From M31 this distribution would be different only in detail, but for NGC 891 it only shows the general features. From both galaxies much of the Local Supercluster appears at low latitudes, especially from NGC 891, and many galaxies would be heavily obscured. From van der Kruit (1987).

because even in the core of the Virgo Cluster, which for a cluster is rather rich in spirals, the mean separation between two spiral galaxies with scalelengths larger than 4 kpc is 0.8 Mpc.

The favorable location of the Virgo Cluster does not apply for such galaxies as M31 or NGC 891. To illustrate this I calculated the extent on the sky of the zone of avoidance for these two galaxies (defined by latitudes $\pm 15^\circ$ as seen from their disks) and superposed these on the distribution of bright galaxies as illustrated in the original Shapley-Ames catalogue (fig. 15.4). The Virgo Cluster is at about R.A. 12^{h} , Dec $+15^\circ$ and the plane of the Local Supercluster crosses the equator at about right angles at about R.A. 12^{h} and 0^{h} . This is of course only the approximate view from NGC 891, but for M31 the change would in general not be perceptible, except for the Local Group galaxies. From M31 the case is much worse than from our Galaxy. The Virgo Cluster is located at a latitude of about 16° , which would not rule out studies of this cluster, but would make it much more difficult. Studies of our Galaxy from M31 are equally hampered by large inclination as we are when observing M31. Our Galaxy would have an inclination of about 70° . Of course most bright spirals will be seen from similar distances and at about the same inclination as from our position. Generally for most the latitude is lower and less favorable.

NGC 891 is a much more outlying member of the Local Supercluster at a distance of about 26 Mpc from the Virgo Cluster (assuming that it is 20 Mpc from us). From NGC 891 our Galaxy will have an inclination of 72° , but it will of course be seen at latitude almost zero. The zone of avoidance actually almost coincides with the plane of the Local Supercluster. The Virgo Cluster appears at a latitude of only a few degrees and extragalactic astronomy from NGC 891 would be very seriously hampered. The relevant parameters for the appearance of some large, major galaxies as seen from NGC 891 are given in table 15.3.

It is evident that many spirals nearby to NGC 891 cannot be studied due to the low latitude. Especially the large Sb-galaxies M31 and NGC 4258 are cases of bad luck: these are seen almost exactly edge-on and would offer a unique opportunity to study the distribution of the stellar populations, but are only 3° from the plane.

Table 15.3: The appearance of some major galaxies as seen from NGC 891

Galaxy	D(Mpc)	$ b (^{\circ})$	$i(^{\circ})$
Ellipticals:			
M87	26.1	2	–
NGC 5128 (Cen A)	13.5	1	86(dust)
Sb-galaxies:			
M81	8.3	2	62
M31	8.8	3	90
GALAXY	9.5	2	72
NGC 7331	10.5	74	38
NGC 4258	11.4	3	88
Sc-galaxies:			
NGC 925	1.7	57	56
IC 342	5.9	2	62
NGC 628	4.8	1	53
NGC 6946	8.7	55	68
M101	11.1	14	71
M51	13.6	10	54

The question of course arises, whether we in the Galaxy are also missing some unique chances due to the orientation of the plane and therefore the zone of avoidance. Such a case has recently appeared in the literature. Lynden-Bell et al. (1988) have suggested the presence of a “Great Attractor” at $\ell = 307^{\circ}$, $b = 9^{\circ}$. This is right in our zone of avoidance and would, if indeed present, have revealed itself had we been able to look in that direction unhampered by obscuration. The equatorial coordinates of the Great Attractor are R.A. = $13^{\text{h}} 15^{\text{m}}$, Dec = -53° . It can be seen from fig. 15.4, that this position also happens to be in the zones of avoidance of M31 and NGC 891. We might in this respect not be the only unfortunate astronomers in the nearby universe.

15.5 References

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