Spiral Galaxies



MI04: SA

N4535: SAB

LMC: dwarf irregular, barred



'Normal'' 1/4-law+exp fits



Sersic profiles with different n

Sérsic (1968) generalization:

$$\mu_{ser} = \mu_0 \exp\left[-\left(\frac{r}{r_0}\right)^{\frac{1}{n}}\right]$$

n = 1 \Rightarrow exponential n = 4 \Rightarrow de Vaucouleurs law



Fig. 2.— Sérsic *n* profiles for different values of *n*. The top panel shows profiles with $\mu_e = \max_{n=1}^{\infty} \max_{n=1}^{\infty} \sum_{n=1}^{\infty} \frac{1}{2} \sum_$

Two types of profiles: Freemanl and Freemanll



Radius (")

Fig. 1.— Examples of Type-I (left), Type-II (middle), and "Transition" (right) SB profiles. Blue circles, green squares, red triangles, and purple asterisks are for B, V, R, and H-band respectively. The solid black lines plotted on the B-band and H-band profiles are fits to the outer exponential disk profile.



Type:SABb



Type:SA





Profiles: examples and fits



I/4-law is a bad fit

1/4-law is OK

More examples: decompositions are often degenerate



Bulge-to-disk decomposition of a bulge-less galaxy in different color bands. Note that the disk scale length is shorter in red color as compared with blue bands.



Bulge-to-disk decomposition. Bulge is very small. This is an example of outer disk truncation. M33 is another example of this type of disk.

Again, the disk scale length gets shorter in red.



Fig. 13.— Decomposition results for a galaxy with a truncated disk (UGC 927). Note that sky errors could not account for the truncation.

M33: photometry

No bulge Disk is "truncated": exponent up to 4.5 (8kpc) scale-lengths. Then it sharply declines





Ferguson et al. 2006

Global correlations: slope of Sersic profile for different morphological types and B/D. Bulge gets steeper for earlier type and for spirals with larger bulges



Figure 5. (a) The best-fitting n plotted (in logarithm) versus the morphological type of the galaxy. The galaxies of our sample are represented by the filled circles, the ones of Kent (1986) by crosses. The open circles indicate barred galaxies. No error bars are given in this plot, for clarity. (b) n versus bulge to disc ratio.

Distribution of disk scale lengths is relatively narrow



FIG. 11.—(a) Distribution of apparent disk scale lengths. Scale lengths measured by the "marking the fit" are represented under the shaded histogram. The dotted line denotes scale lengths measured through full B/D decomposition. See text for details. The pileup of gataties at low h is due to the UGC diameter cutoff. It shows that 1' galaxies typically have scale lengths of order 8". (b) Distribution of absolute disk scale lengths. Same as Fig. 8, but scaled ir. distance using heliocentric redshifts and a Hubble constant of 80 km s⁻¹ Mpc⁻¹. The catalog limit naturally disappears, and the distribution is more normally dispersed.



Fig: 1.— Correlations of galaxy's rotational velocity, size, and color with absolute magnitude for our sample. The solid line corresponds to a robust fit by minimisation of the absolute data-model deviations. The fits assume equal weights at all points.



Figure 11. Distribution of inclination-corrected K'-band disc central surface brightnesses, $\mu_{0,K}^{i}$, as a function of bulge-to-total ratio, B/T, for the sample of 65 UMa galaxies.

B/T ratios and Surface Brightness-disk scale length relations for Spirals. Is there a bimodality?

Figure 9. Distribution of inclination-corrected K'-band disc central surface brightnesses, $\mu_{0,K}^i$, as a function of disc scalelength, *h*, measured in kpc (using a distance to UMa of 15.5 Mpc) for the sample of 65 UMa galaxies. The long-dashed lines represent lines of constant total disc luminosity, while the different surface brightness classes are identified by open squares (LSB) and filled squares (HSB).

McDonald et al 2009

Case study: M31

Distance: 700 kpc Disk scale length: 5.7 kpc in R band Rotational velocity: 260 km/s



FIG. 1.—Current coverage of our large panoramic survey of M31 with the INT camera, in standard coordinates (ξ , η). The outer ellipse shows a segment of a 55 kpc radius ellipse flattened to c/a = 0.6, and the major and minor axis are indicated with straight lines out to this ellipse. A Digitized Sky Survey image of the central galaxy has been inserted to scale. The map shows the distribution of RGB stars throughout the halo. The most striking structure in the map is a vast flattened inner structure, of major axis extent ~4°, a messy inhomogenous entity that envelops the familiar bulge and disk of M31.

M3: bulge is a bar



J-band image of the bulge region of M31 Athanassoula 2006

Case study: M31



FIG. 5.—Surface brightness of M31 in the *R* band on linear (*bottom*) and logarithmic (*top*) scales. Deviations from the observational results are less than 0.2 mag.

M31

Stellar halo extends to 200 kpc. Some indications that outer halo was accreted: destroyed satellites



The remnants of galaxy formation from a panoramic survey of the region around M31 McConnachie et al 2009, Nature 461, 66



A tangent-plane projection of the density distribution of stellar sources in our extant PAndAS imaging is shown, with colours and magnitudes consistent with RGB stars at the distance of M31. The inset shows the central parts of our survey at higher resolution. Dashed circles represent the maximum projected radii of 150 and 50 kpc from M31 and M33, respectively. Scale images of the disks of M31 and M33 are overlaid. Visible dwarf satellites are indicated with roman numerals. Numbers in circles indicate the largest and most obvious substructures detected in a visual inspection of the image: 1, M33 structure; 2, 125-kpc stream (stream A); 3, stream C; 4, eastern arc (stream D); 5, giant stellar stream; 6, northwest minor-axis stream; 7, southwest cloud. Features 1, 6 and 7 (and part of 4) are new discoveries. Stellar sources were identified by using star-galaxy classification techniques described previously. Candidate RGB stars were selected by their position in a colour-magnitude diagram relative to theoretical isochrones for a 12-Gyr population at the distance of M31, using only stellar sources with $i_0 < 23.5$. A projection of the stellar density distribution within a putative metallicity range -2.5 < [Fe/H] < -0.6 dex was created with $0.02^{\circ} \times 0.02^{\circ}$ pixels, smoothed with a Gaussian filter with dispersion 3 arcmin, and displayed with square-root scaling. The inset was created by combining, with a red-green-blue colour scheme, three such maps of M31 with metallicities of -0.4 < [Fe/H] < +0.2 dex, -1.3 < [Fe/H] < -0.4 dex and -2.3 < [Fe/H] < -1.3 dex, respectively (each with $0.01^{\circ} \times 0.01^{\circ}$ pixels, smoothed with a Gaussian filter with 2arcmin dispersion) and displayed with logarithmic scaling. Not all structures are visible with this (or any other) choice of metallicity cut, filter and scaling.

The remnants of galaxy formation from a panoramic survey of the region around M31 McConnachie et al 2009, Nature 461, 66

The evolution of M33 about M31 along an orbit consistent with the angular positions, distances₂₆ and radial velocities of M31 and M33 and with M33's proper motion23. Here, M33 starts 3.4Gyr ago at a distance of $r \approx 200 \text{ kpc}$ on the far side of M31 falling down the line of sight (Z) to the Milky Way. After 800Myr, M33 reaches pericentre and proceeds across our line of sight towards the southeast, reaching apocentre about 900 Myr ago before falling back towards M31 to its current position. Dots tracing the orbit are separated by 49Myr to give a sense of the speed along the orbit. The lower inset shows a perpendicular view of M33's orbit. **b**, Quantification of the expected K-band surface brightness of M33 at different times from face-on and edge-on perspectives. The inner red/orange region with μ_{K} < 22 mag arcsec⁻² defines the size of the usual optical disk of M33 seen in images. The initial equilibrium models³⁰ for the two galaxies consist of a disk, bulge and dark-matter halo with structural parameters that accurately reproduce the observed surface brightness profiles and rotation curves. Because the mass profile of M31 beyond 100kpc is not well constrained by observations, we appeal to cosmological arguments₂₄ that predict a mass of $2.5 \times 10_{12}$ solar masses within r<280kpc.



NGC 891: streams and tidal tails





Figure 1. Surface density map of RGB stars over the surveyed area around NGC 891. The over-densities of old RGB stars detected in the present study reveal a large complex of arcing streams that loops around the galaxy, tracing the remnants of an ancient accretion. The second spectacular morphological feature is the dark cocoon-like structure enveloping the high surface brightness disk and bulge.

The bulge and the disk of the galaxy are found to be surrounded by a previously undetected large, flat, and thick cocoon-like stellar structure at vertical and radial distances of up to \sim 15 kpc and \sim 40 kpc, respectively.

Disk-bulge correlations



Color of bulges closely correlates with disk colors for Sb galaxies

Figure 5. Disk colors against bulge colors from Peletier 5: Balcells (1996). Bulge colors are measured at $r_e/2$ or 5", whichever is larger, and Lisk colors are measured at 2 major-axis scale lengths. Color differences are, on average, of order 0^m 1 for all passband combinations. Central colors are measured in special regions where extinction is minimal.

Disk thickness: edge-on galaxies

Joachim, Dalcanton 2006, ApJ, 131, 226

We model the surface brightness of each disk component as a radially exponential disk. We adopt the luminosity density L of each disk component to be

$$L(R, z) = L_0 e^{-R/h_R} f(z),$$
 (1)

where (R, z) are cylindrical coordinates, L_0 is the central luminosity density, h_R is the radial scale length, and f(z) is a function describing the vertical distribution of stars.

Throughout, we adopt a generalized vertical distribution

$$f(z) = \operatorname{sech}^{2/N}(Nz/z_0), \qquad (2)$$

where z_0 is the vertical scale height and N is a parameter controlling the shape of the profile near the midplane. For appropriate choices of N, this equation can reproduce many popular choices for the vertical distribution of star light. With N = 1equation (2) becomes the expected form for a self-gravitating isothermal sheet (Spitzer 1942; van der Kruit & Searle 1981a, 1981b, 1982). When $N \to \infty$, equation (2) reduces to $f(z) \propto e^{-z/h_z}$, where $h_z = z_0/2$. Previous fits to the vertical distribution

Disk thickness: edge-on galaxies

Joachim, Dalcanton 2006, ApJ, 131, 226

Summary

- Two types of profiles: Freeman I (surface brightness increases monotonically) and Freeman II (surface brightness pause before it goes up in the bulge)
- "I/4" law for bulges is a good fit for early type spirals with large bulges.
- Late type spirals are better fit with exponential bulges.
- On average the scale-lengths correlate: $R_{bulge}/R_{disk} = 0.13$
- Disk scale lengths for normal galaxies are in the range 3-6kpc
- Dwarf irregulars have shorter scale-lengths: (1-2)kpc
- Bright galaxies are redder and more metal-rich.
- Colors of bulges and disks of late-type spirals correlate.