Dark-Matter Distribution inferred from High-accuracy Rotation Curves

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Abstract. Using high-accuracy rotation curves of spiral galaxies, we derive distributions of the surface mass density. Comparing with the luminosity profiles, we show that the dark mass in disk and bulge distributions follows those of luminous (stellar) mass, while luminous mass in halos does not follow dark mass. The dark-mass fraction (DMF) increases with the radius in the disk, and rapidly toward edge in the halo. In some galaxies, DMF increases toward the center, indicating a massive dark core.

Keywords: Dark Matter; Galaxies; Mass-to-Luminosity Ratio

1. Introduction

Dark mass dominates the mass of galaxies (e.g., Rubin et al 1985; Kent 1987; Forbes 1992; Persic et al 1996). On the other hand, the total mass of galaxies is approximately proportional to the luminous mass (Burstein et al 1997). This indicates that the dark mass follows the luminous mass in a large scale. A question may arise, whether the dark mass in individual galaxies locally follows the luminosity mass, or they are decoupled from each other. This may be answered by mapping the dark mass in individual galaxies. We have shown that the CO molecular line is useful to derive accurate rotation curves, because of its high concentration in the center as well as for its negligible extinction (Sofue 1996, Sofue et al 1997, 1998, 1999). Recent high-dynamic-range CCD spectroscopy in optical lines has also made it possible to obtain high accuracy rotation curves (Rubin et al 1997; Sofue et al 1998). In this paper, we discuss the general properties of high-accuracy rotation curves, and use them to derive distributions of surface mass density, mass-to-luminosity ratio, and the dark mass fraction. Based on these, we discuss the correlation of dark and luminous mass in galaxies.

2. General Properties of Rotation Curves

In Fig. 1 we show well-sampled rotation curves obtained by combining CO, CCD Hα, and HI observations. We may summarize the universal properties of rotation curves as follows.

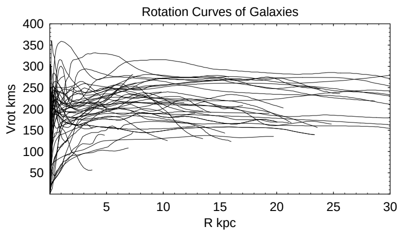

Fig. 1. High-accuracy rotation curves of Sb, Sc, SBb and SBc galaxies.
Figure 0.

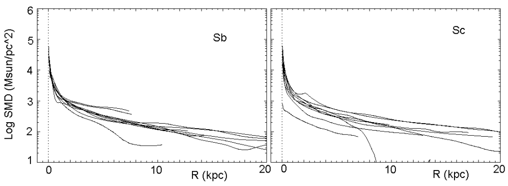

Fig. 2. Surface-mass density profile for Sb and Sc galaxies (Takamiya and Sofue 1999).

Figure 0.

(1)Massive galaxies show very steep rise of rotation in the central region. The rotation velocity often starts from a finite value at the center. However, small-mass galaxies tend to show gentler rise.
(2) Steep central peaks and/or shoulders corresponding to bulges;
(3) Broad maximum in the disk; and
(4) Flat rotation toward the edge.

3. Surface-Mass Density

We have developed a method to derive a differential surface mass density as a function of radius in order to compare the mass distribution with observed profiles of the surface luminosity, once an accurate rotation curve of a galaxy is given (Takamiya and Sofue 1999). We assume that the 'true' mass distribution in a real disk galaxy will be sandwiched by calculated spherical and flat-disk distributions. The obtained SMD profiles are shown in Fig. 2. Sb and Sc galaxies show similar surface-mass distributions. In the disk region at radii 3 to 10 kpc the SMD decreases exponentially outward. In the bulge region, some galaxies show steep increase of SMD toward the center, indicating high density cores. The LMC shows a similar mass distribution as inferred from an analysis of the HI line data obtained by Kim et al (1998) (Sofue 1999).

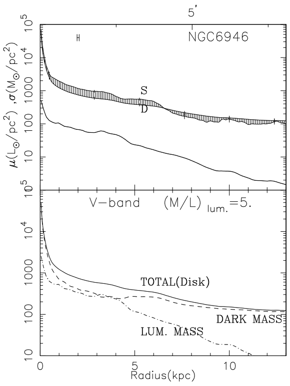

Fig. 3. Dynamical mass and luminosity profiles (upper panel), and dark and luminous masses (lower panel) for NGC 6946 (Takamiya and Sofue 1999).

Figure 0.

4. Correlation of Dark and Luminous Mass Distributions

The surface mass density can be directly compared with observed surface luminosity, from which we can derive the mass-to-luminosity ratio (M/L). By subtracting the luminous mass we can, then, derive the distribution of dark mass. Fig. 3 shows a typical case for NGC 6946, which was found to be rather general for many other galaxies. The general correlation between luminous mass and dark mass can be summarized as follows.
(1) Luminous mass (stars) in disk and bulge approximately follows the dark mass, and vice versa.
(2) The dark mass fraction increases with the radius in the outer disk.
(3) The total dark mass and total luminosity of galaxies are correlated as a whole.
(3) However, luminous matter in the halo (e.g., beyond ~ 5 disk scale radii) does not follow dark mass.

5. Mass-to-Luminosity Ratio and Dark-Mass Fraction

Radial variations of the M/L and dark-mass fraction are shown in Fig. 4 as normalized at $R = 2$ kpc (Takamiya and Sofue 1999). We have defined a quantity DMF by $1 - a/(M/L)$ with a a constant and M/L being normalized at $R = 2$ kpc. Although the dark mass and luminosity are correlated in the disk and bulge in general, the detailed distribution of M/L and DMF indicates that they are not constant, but

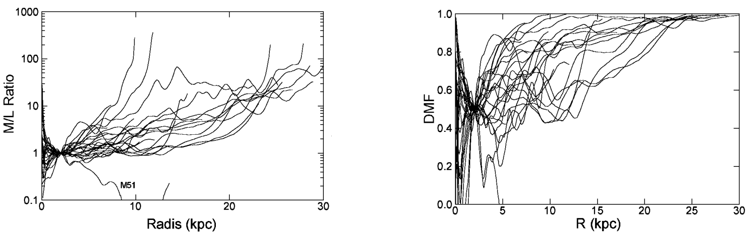

Fig. 4. M/L ratio (left panel: Takamiya and Sofue 1999) and dark-mass fraction for Sb and Sc galaxies

Figure 0.

vary significantly within a galaxy. M/L and DMF behavior in spiral galaxies may be summarized as follows.

(1) M/L and DMF vary drastically within the central bulge. In some galaxies, it increases toward the center, suggesting a dark massive core.
(2) M/L and DMF gradually increase in the disk region, and the gradient increases with the radius.
(3) M/L and DMF increase drastically toward the outer edge, indicating massive dark halo.

References

Burstein, D., Bender, R., Faber, S.M., Noltehnius, R. 1997 AJ 114, 1365.
Forbes, D.A. 1992, A&AS, 92, 583
Kent, S. M. 1987, AJ 93, 816.
Kim, S., Stavely-Smith, L., Dopita, M. A., Freeman, K. C., Sault, R. J., Kesteven, M. J., and McConnell, D. 1998, ApJ 503, 674.
Persic, M., Salucci, P., & Stel, F. 1996, MNRAS, 281, 27
Rubin, V., Kenney, J.D.P., Young, J.S. 1997 AJ, 113, 1250.
Rubin, V., Burstein, D., Ford, W.K.,JR., & Thonnard, N. 1985, ApJ, 289, 81
Sofue, Y. 1996, ApJ, 458, 120
Sofue, Y. 1999, PASJ, 52, in press.
Sofue, Y., Tutui, Y., Honma, M., and Tomita, A., 1997, AJ, 114, 2428
Sofue, Y., Tomita, A., Honma, M., Tutui, Y. and Takeda, Y. 1998, PASJ 50, 427.
Sofue, Y., Tutui, Y., Honma, M., Tomita, A., Takamiya, T., Koda, J., & Takeda, Y. 1999, ApJ, 523 in press
Takamiya, T., and Sofue, Y. 1999, to appear in ApJ.