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THE EVOLUTION OF BARYONIC MASS OF ELLIPTICAL GALAXIES IN THE SLOAN DIGITAL SKY SURVEY

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ABSTRACT

Stellar mass is an important parameter of galaxies. We estimate the dynamical mass of an elliptical galaxy by its velocity dispersion and effective radius using the Hernquist model in the framework of MOdified Newtonian Dynamics (MOND). MOND is an alternative theory to the dark matter paradigm. In MOND the dynamical mass is the same as the baryonic mass or luminous mass, and in elliptical galaxies most of the baryons reside in stars. We select elliptical galaxies between redshift 0.05 and 0.5 from the main galaxy sample and the luminous red galaxy sample in the Sloan Digital Sky Survey. We find that the stellar mass-to-light ratio at different redshift epochs can be fitted by a gamma distribution, and its mean is smaller at smaller redshifts.

Key words: Elliptical galaxies - Velocity Dispersion - MOND - SDSS - Mass-to-Light Ratio

1. BACKGROUND

Stars are the most conspicuous component of a galaxy. It is easy to conceive that many physical properties of a galaxy, such as luminosity, colour, size, structure, metallicity, star formation activity, etc., are well correlated to the stellar mass (see e.g., Kauffmann et al., 2003a,b; Shen et al., 2003; Blanton et al., 2005; Gallazzi et al., 2005; Gallazzi & Bell, 2009; Cappellari et al., 2012). Stellar mass is a crucial parameter in understanding galaxy evolution.

MOdified Newtonian Dynamics (MOND) is a theory proposed as an alternative to the dark matter hypothesis, to explain the mismatch between the observed luminous mass and the dynamics of galaxies (see e.g., Milgrom, 1983; Bekenstein & Milgrom, 1984). In essence, one can deduce the baryonic mass of a galaxy by MONDian dynamics. Even if MOND is not a fundamental theory, we deem that it is an effective way to estimate the baryonic mass of a galaxy. Since most of the baryonic mass in elliptical galaxies resides in stars, MOND may serve as a straightforward method to find their stellar mass.

2. DYNAMICS AND MASS MODEL

Interpreted as a theory of modified gravity, MOND can be expressed as a nonlinear Poisson equation (Bekenstein & Milgrom, 1984),

$$\nabla \cdot [\tilde{\mu}(|\mathbf{g}|/a_0)\mathbf{g}] = \nabla \cdot \mathbf{g}_{\rm N} = -4\pi G\rho\,. \qquad (1)$$

Here $\mathbf{g}$ and $\mathbf{g}_{\rm N}$ are the gravitational acceleration in MOND and in Newtonian dynamics, respectively. $\tilde{\mu}(x)$ is called the interpolation function with $\tilde{\mu}(x) \approx 1$ for $x \gg 1$ (Newtonian regime) and $\tilde{\mu}(x) \approx x$ for $x \ll 1$ (deep MOND regime). $a_0 \approx 1.2 \times 10^{-10}$ m s^{-2} is the acceleration scale of MOND.

We adopt a (spherical) Hernquist model for the stellar mass distribution of elliptical galaxies

$$\rho(r) = \frac{M r_{\rm h}}{2\pi r (r+r_{\rm h})^3}\,, \quad \mathbf{g}_{\rm N}(r) = -\frac{GM\,\hat{r}}{(r+r_{\rm h})^2}\,, \qquad (2)$$

where M is the total mass, $r_{\rm h} \approx 0.55\,r_{\rm eff}$ ($r_{\rm eff}$ is the effective radius or half light radius). With a local stellar mass-to-light ratio Υ, the surface brightness and cumulative surface brightness are

$$\begin{aligned} I(R) &= 2\int_R^\infty \frac{\rho(r)}{\Upsilon}\frac{r\,{\rm d}r}{\sqrt{r^2-R^2}}\,, \\ S(R) &= \int_0^R I(R')2\pi R'\,{\rm d}R'\,, \end{aligned} \qquad (3)$$

where R is the projected radius from the centre of the spherical system.

The velocity dispersion of a spherically symmetric stellar system is given by

$$\frac{{\rm d}\rho\sigma_r^2}{{\rm d}r} + \frac{2\beta}{r}\rho\sigma_r^2 = -\rho|\mathbf{g}| = -\rho g\,, \qquad (4)$$

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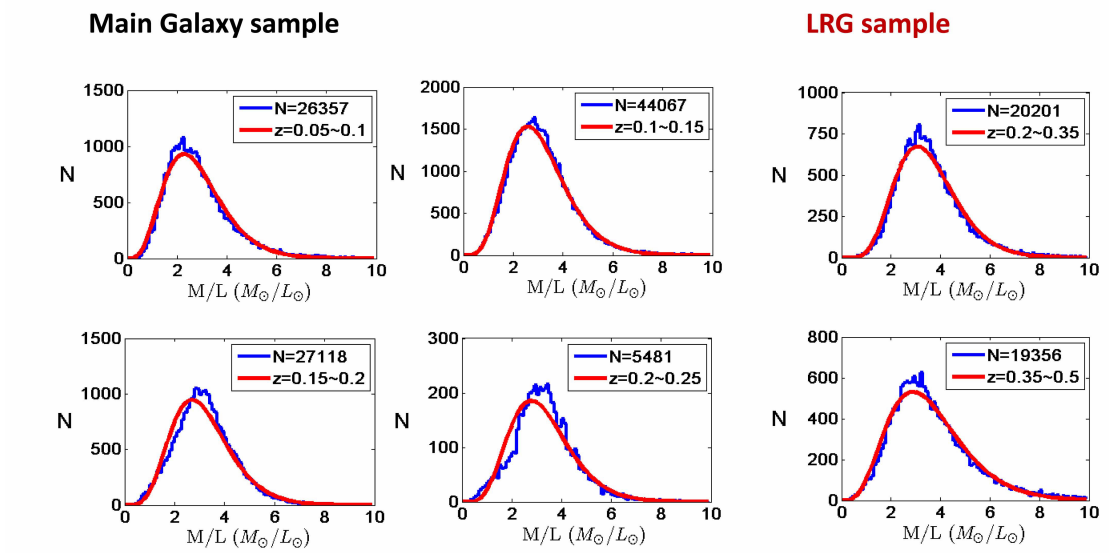

Figure 1. The stellar mass-to-light ratio distribution of elliptical galaxies in the Main Galaxy sample and the Luminous Red Galaxy sample of SDSS. The red lines are the best-fit gamma functions.

and for an isotropic system (i.e., $\beta = 0$), $\rho\sigma_r^2 = \int_r^\infty \rho\, g\, \mathrm{d}r'$. The velocity dispersions projected along the line of sight of the system weighted by surface brightness and cumulative surface brightness are (for $\beta = 0$)

$$\begin{aligned} \sigma_I^2(R) &= \frac{2}{I(R)} \int_R^\infty \frac{\rho\sigma_r^2}{\Upsilon} \frac{r\,\mathrm{d}r}{\sqrt{r^2 - R^2}}\,, \\ \sigma_S^2(R) &= \frac{1}{S(R)} \int_0^R \sigma_I^2(R') I(R') 2\pi R'\,\mathrm{d}R'\,. \end{aligned} \quad (5)$$

3. RESULTS

We select elliptical galaxies from the spectroscopic redshift database of SDSS Data Release 8. We take galaxies from $z = 0.05$ to 0.5 in which there are two samples: the Main Galaxy sample (MG sample, $z \sim 0.05 - 0.25$) and the Luminous Red Galaxy sample (LRG sample, $z \sim 0.2 - 0.5$). We adopt $fracDeV$=1 as the criterion for an elliptical galaxy. We have 103023 galaxies in the MG sample and 39566 galaxies in the LRG sample. To study redshift evolution we divide the MG sample into 4 redshift ranges ($z = 0.05 - 0.10$, $0.10 - 0.15$, $0.15 - 0.20$ and $0.20 - 0.25$) and the LRG sample into 2 ($z = 0.20 - 0.35$ and $0.35 - 0.50$).

The velocity dispersion of an elliptical galaxy measured by SDSS is an average over an aperture radius 1.5". We thus use the cumulative surface brightness weighted velocity dispersion $\sigma_S(R)$ discussed in section 2 (the local mass-to-light ratio Υ is assumed constant over the galaxy). The total stellar mass of the elliptical galaxy can be computed with the MOND gravity, which is characterised by a canonical interpolation function

$$\tilde{\mu}(x) = \left[1 - \frac{2}{(1+\eta x^\alpha) + \sqrt{(1-\eta x^\alpha)^2 + 4x^\alpha}}\right]^{1/\alpha}. \quad (6)$$

We calculate the stellar mass-to-light ratio of each galaxy in the two samples with $\eta = 0$ and $\alpha = 1$ (the so called Bekenstein form). Figure 1 shows its distribution in different redshift ranges. The distribution can be fitted by gamma functions, as seen in Figure 1. The mean of the best-fit gamma functions is given in Table 1. Apparently, the mean increases as redshift increases (cf. e.g., Jiang & Kochanek, 2007).

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Table 1
THE MEAN OF THE BEST-FIT GAMMA FUNCTION OF THE STELLAR MASS-TO-LIGHT RATIO DISTRIBUTIONS.

redshift	0.05-0.10	0.10-0.15	0.15-0.20	0.20-0.25	0.20-0.35	0.35-0.50
MG sample	2.85	3.11	3.21	3.31	–	–
LRG sample	–	–	–	–	3.57	3.63

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