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MASS ESTIMATION OF THE ELLIPTICAL GALAXY NGC 5846

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Abstract. Determining the masses of early-type galaxies remains a challenging task, especially probing the masses of their outer halos. In this contribution we constrain the mass of the well-studied elliptical galaxy NGC 5846, the brightest galaxy in the group. The isolation of the NGC 5846 Group is what makes it favourable for using different "test-particles" as mass tracers. We use the "tracer mass estimator" (TME) method on several different families of tracers such as globular clusters (GCs), planetary nebulae (PNe) and dwarf galaxies, thus probing the total dynamical mass to much larger radii than by using stellar kinematics. The mass of NGC 5846 is also assessed from the X-ray observations of hot coronal gas and compared to the results obtained using the TME methodology.

1. INTRODUCTION

Observations of cool gas through its 21-cm line emission in spiral galaxies established that these galaxies reside in massive dark halos. Since early-type galaxies lack this powerful tracer of overall mass distribution, their masses, and especially masses in their outer parts that are expected to be dominated by dark matter, are not so well constrained. Possible approaches in probing for the dark-matter halos in ellipticals include the study of stellar kinematics, X-ray halo properties, tracer methods and gravitational lensing. Stellar kinematics is very difficult to use in the outer parts because they are very faint, and various works suggest that dark matter is not dominant in the inner parts of early-type galaxies, to approximately $2R_e$, where R_e is the effective radius (see, for example, Deason et al. 2012; Samurović, 2012). On the other hand, the abundance and quality of the data available on various tracer populations are increasing.

In order to tackle the issue of early-type galaxies masses, we chose the elliptical NGC 5846 because of its favourable position. Elliptical galaxies are difficult to find in isolation, and NGC 5846 is no exception – it lies at the the center of a group of overwhelmingly ellipticals, and is the third biggest galaxy in the Local Supercluster. Nevertheless, NGC 5846 is found in relative isolation; there are no background sources, and also not that many foreground ones. This galaxy is thus very well observed. Its effective radius is equal to 61 arcsec (see Pota et al. 2013, hereafter P13).

In determining mass of the elliptical galaxy NGC 5846 we mainly concentrate on an approach based on the use of various tracers, "Tracer Mass Estimator" (TME) method, proposed by Evans et al. 2003. We used the following tracer populations:

globular clusters (hereafter GC, SLUGGS survey, P13), planetary nebulae (hereafter PNe, Coccato et al. 2009) and dwarf galaxies (hereafter dwE, Mahdavi et al. 2005). Its mass was also assessed using the X-ray methodology (Machacek et al. 2011). In Section 2 we present the methodology that we use and briefly compare our results with the results coming from the Jeans modelling; we present our conclusions in Section 3.

2. METHODOLOGY AND RESULTS

2. 1. TRACER MASS ESTIMATOR METHOD

TME is a simple method that is derived to deal with tracer populations in particular. It is a generalization of projected mass estimator methods (Bahcall & Tremaine 1981) for the most common case when the number density of tracer population does not follow the dark matter density. The estimate of the enclosed mass is derived based on the projected positions and line-of-sight (LOS) velocities (with respect to the systemic velocity) for a given population of tracers. The population of tracers is assumed to be spherically symmetric and with a number density that obeys

$$\rho(r) = \rho_0 \left(\frac{a}{r}\right)^{\gamma}, \tag{1}$$

for three-dimensional radius spanning from $r_{\rm in}$ to $r_{\rm out}$.

Here a is a constant, and the exponent γ is determined from a surface density of a tracer population (see below).

The enclosed mass (supported by random motions) for isotropic case is given by:

$$M_p = \frac{C_{\rm iso}}{GN} \sum_i v_{\rm losi}^2 R_i, \tag{2}$$

where $C_{\rm iso}$ has a form

$$C_{\rm iso} = \frac{4\gamma}{\pi} \frac{4-\alpha-\gamma}{3-\gamma} \frac{1-(r_{\rm in}/r_{\rm out})^{3-\gamma}}{1-(r_{\rm in}/r_{\rm out})^{4-\alpha-\gamma}} \tag{3}$$

for isothermal potential (gravity field is assumed to be scale-free, $\psi = -v_0^2 \log r$, see Evans et al. 2003 for details). It is reasonable to assume $r_{\rm in} \approx R_{\rm in}$ (the same is also true for the outermost radius), especially for larger radii.

The total mass of the galaxy must account in for the rotational component as well, given by

$$M_{\rm rot} = \frac{v_{\rm rot}^2 R_{\rm out}}{G}. \tag{4}$$

We used three different populations of tracers: GCs, PNe and dwE. For all of them, the same methodology was applied, which we are going to present in detail only for the GC population, and for the other two samples only the outline of the results is given.

The GCs sample used in this paper is taken from the SLUGGS survey (P13), and it consists of 195 objects. First, we transfer from to the coordinate system fixed to the major and minor axes of the galaxy, and express galactrocentric distances as equivalent two-dimensional radius:

$$R = \sqrt{qX^2 + \frac{Y^2}{q}} \tag{5}$$

where q is the ratio between major and minor axes of the galaxy. Here we used the value from 2MASS Ks-band which is supposed to be least prone to extinction (Jarrett et al. 2003) of 0.95.

In order to extract the rotational component of the velocity from the total observed LOS velocity (with respect to the value of the systemic velocity taken from NED, Cappellari et al. 2011) the fit based on the cosine function was used (rotational velocity should change like the cosine function with the change of the phase angle in the system of the galaxy). The value of the rotational velocity that we obtained (see Figure 1) is $v_{\rm rot} = (5 \pm 24)$ km/s. Since this is consistent with zero, in our calculations we neglected the rotational component and only take into account the randomly supported component, $M \approx M_p$.

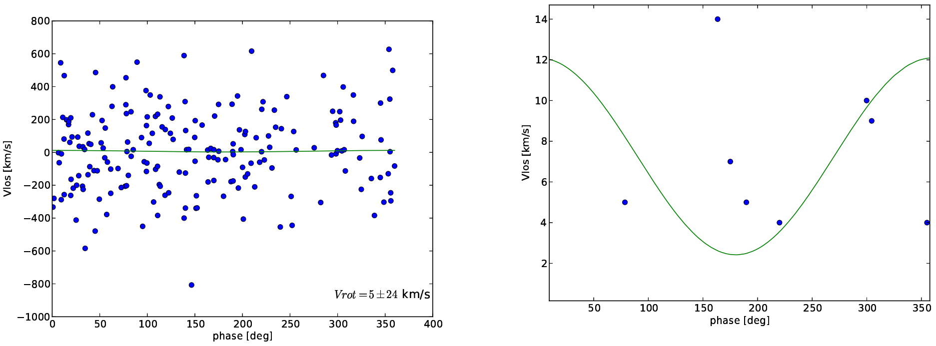

Figure 1: Left panel: Rotational velocity fitted to the observed $v_{\rm los}$, x-axis is the phase angle in the coordinate system where x-axis is fixed to the receding part of major axis. Right panel: zoomed in part of the plot in the left panel.

Surface density of GC population is shown in Fig. 2, and because we assumed that the number density is a power-low, the exponent γ is calculated from the least-square fit to the radial distribution of the objects. Here R is a two-dimensional radius, and to reconstruct the three-dimensional γ-parameter, we add one to the surface density value of the exponent. The best-fitting value is $\gamma = 2.48 \pm 0.44$.

Using this value for the exponent, and assuming $\alpha \approx 0$, we obtain the following value:

$$M_{\rm GC} = (3.4 \pm 0.2) \times 10^{12} M_\odot, \tag{6}$$

for $R \approx 10R_e$.

For the PNe population we obtained the following: $v_{\rm rot} = (-10 \pm 26)$ km/s, which is consistent with zero, so we can again consider that the contribution to the mass comes from the randomly supported component, M_p.

We calculated $\gamma = 2.46 \pm 0.21$, and used it to estimate the mass interior to $\sim 10R_e$:

$$M_{\rm PNe} = (1.25 \pm 0.02) \times 10^{12} M_\odot. \tag{7}$$

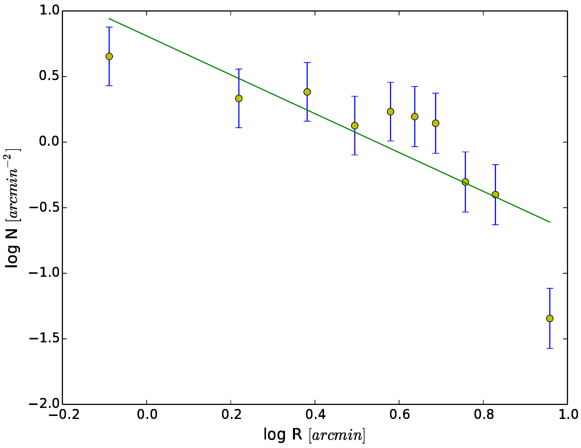

Figure 2: Surface density of the GC tracer population; $N \propto R^{-\gamma}$ is fitted.

For dwE we apply the same approach, but take into account that due to the larger radii at which those satellites reside, we are no longer probing the mass of the galaxy NGC 5846 only, but rather the gravitational potential of the group.

From the sample of 80 dwE (Mahdavi et al. 2005), we obtained the value: $v_{\rm rot} = (-92 \pm 58)$ km/s, thus here we take into account the rotational component.

Using Eq. 4 we obtain: $M_{\rm (dwE)\ rot} = (2.1 \pm 2.5) \times 10^{12} M_{\odot}$. Using $\gamma = 2.25 \pm 0.36$, we obtain the total mass of the group equal to:

$$M_{\rm dwE} = (6.6 \pm 0.4) \times 10^{13} M_{\odot}, \tag{8}$$

at 145 arcmins.

2. 2. X-RAYS

In Fig. 3 we present the estimates of the cumulative mass and the mass-to-light ratio profile of NGC 5846 based on the X-ray methodology (see, e.g., Samurović, 2007 for details). The mean value of the temperature ($T \sim 1$ keV) is taken from Machacek et al. (2011) and is based on the Chandra observations.

2. 3. JEANS MODELLING FOR THE GLOBULAR CLUSTER POPULATION

In Fig. 4 we present the results of the dynamical modeling of NGC 5846 based on GCs. The details of the modeling are given in the contribution by Samurović (these Proceedings) and also in Samurović (2014). From Fig. 4 one can see that using the Newtonian approach, the increase of the mass-to-light ratio suggests significant amount of dark matter in this galaxy beyond $\sim 2R_e$. Using the Navarro, Frank & White (NFW, 1997) model one can fit the observed velocity dispersion throughout the whole galaxy: the parameters of a fit are given in the caption of Fig. 4.

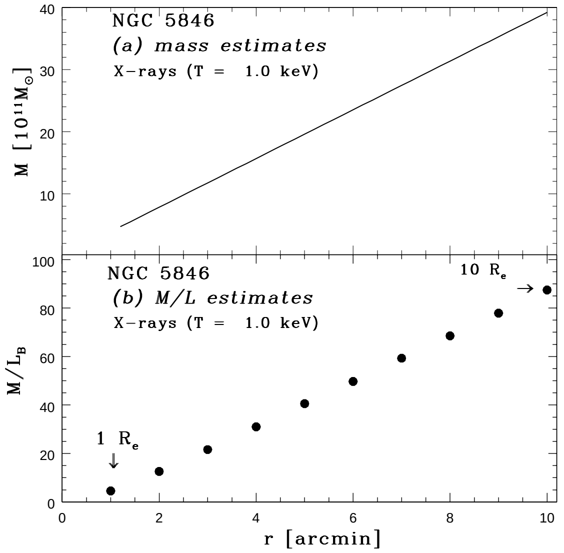

Figure 3: Upper panel: cumulative mass estimate of NGC 5846 based on the X-ray methodology is expressed in units of $10^{11} M_\odot$. Lower panel: mass-to-light ratio in the B-band of *NGC* 5846 based on the X-ray methodology. The estimates are given for ten positions and the innermost (at $1R_e$) and outermost ($10R_e$) points are indicated. In both panels, the value of the temperature used is $T = 1$ keV.

3. CONCLUSIONS

Our most important results are:

- We found that the TME approach (based on GCs and PNe) gives a good assessment for the mass of NGC 5846, which is also consistent with the estimate based on the X-ray methodology.
- Using the TME approach in the case of the population of dwE we get a significantly larger mass but at a significantly larger distance (at 145 arcmins; for the distance we used a value of $D = 25.0$ Mpc from Tully et al., 2009).
- Using the Jeans modelling, we confirm that a significant amount of dark matter is needed to fit the observed M/L_B beyond $\sim 2R_e$.

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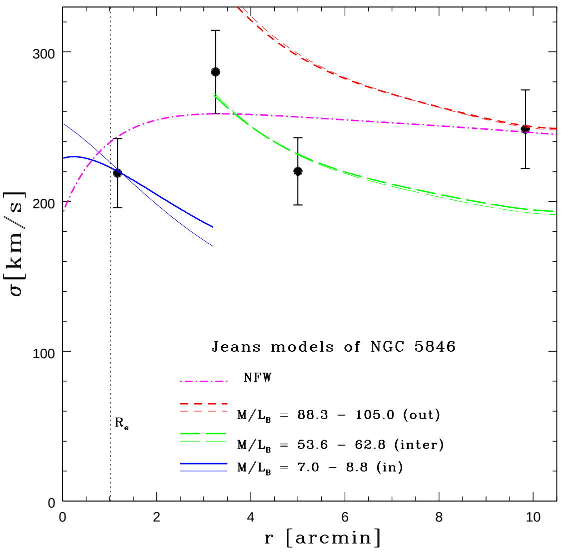

Figure 4: The Jeans Newtonian modeling of the projected velocity dispersion of NGC 5846. The thick lines are for isotropic cases and the thin lines are for fits based on $\beta_{\rm lit}$. The three regions are as follows: inner region (interior to $2R_e$, solid lines), intermediate region (between $2R_e$ and $6R_e$, long dashed lines), and outer region (beyond $6R_e$, short dashed lines). The mass-to-light ratio in these regions are $M/L_B = 7.0(8.8), 53.6(62.8)$ and $88.3(105.0)$ for the isotropic (anisotropic) cases. The thick dot-dashed line is for the isotropic NFW model for which the stellar $M/L_B^* = 7.0$, $r_s = 350$ arcsec, and $\rho_s = 0.0200\ M_\odot{\rm pc}^{-3}$.

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