Mass Distributions in Early-type Galaxy Halos

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Abstract. One of the most promising avenues for determining the distribution of mass in the outer parts of early-type galaxies is through the kinematics of planetary nebulae (PNe). We have used new techniques and instrumentation on the WHT and the VLT to obtain velocities for hundreds of PNe around several nearby galaxies. We show simple mass models and describe more rigorous orbit modeling methods for the combined analysis of different dynamical constraints in galaxy halos.

The halo masses of nearby early-type galaxies (ellipticals and S0s) are still poorly known. X-ray gas emission and stellar absorption line studies indicate that dark matter is dominant in the outer parts ($\gg R_{\rm eff}$, an effective radius) of some ellipticals [1] [2], but strong general constraints on the radial mass distributions $\rho(r)$ are less forthcoming. For this purpose, kinematical tracers such as globular clusters (GCs) and planetary nebulae (PNe) are quite promising – PNe especially so because they directly couple to the stars.

Until now, measuring extragalactic PN velocities in the large numbers (hundreds) needed for dynamical analyses has been prohibitively inefficient. We have pursued a multi-pronged program using improved techniques, including multi-fiber spectroscopy with WYFFOS+AUTOFIB2 on the 4.2-m WHT, masked counter-dispersed imaging with FORS2+MXU on UT2, and counter-dispersed imaging with the newly-commissioned *Planetary Nebula Spectrograph (PN.S)* on the WHT. We have so far obtained velocities of 100–200 PNe in each of the galaxies NGC 821 (E3), NGC 4472 (E1), NGC 4486 (E1), and NGC 7457 (S0), at distances of 15–25 Mpc, and to radii of 5–6 $R_{\rm eff}$.

For illustrative purposes, we first model the data using the spherical isotropic Jeans equations (see Fig. 1). For NGC 4472 and NGC 4486, both the stellar and GC data indicate that the circular velocity profile $v_{\rm c}(r) \equiv [GM(r)/r]^{1/2}$ is constant or rising with radius at 4 $R_{\rm eff}$. The inferred profile differs depending on whether the stellar or GC data are used, indicating that the assumption of isotropy is probably wrong for one or both subsystems. NGC 821 is not yet modeled, but the projected velocity dispersion profile $\sigma_{\rm p}(R)$ suggests the presence of a dark halo that is less dominant than in the previous two galaxies; NGC 4697 is a similar elliptical whose PN dispersion profile also declines with radius [3]. For NGC 7457, $\sigma_{\rm p}(R)$ suggests a dominant dark halo.

More rigorous determinations of $v_c(r)$ require sophisticated modeling methods that allow nonparametrically for variations in the orbital anisotropies, and that exploit fully the information contained in discrete velocity data. We have developed such a method based on the now established approach of orbit modeling [4]. Upon analysis of the published integrated stellar spectroscopy and GC velocity data for NGC 4486, we have found a density law of $\rho(r) \sim r^{-1.5}$ at 4 $R_{\rm eff}$ (see Fig. 1). This implies that the galaxy is embedded in a core of a massive dark halo associated with the Virgo Cluster itself, as also evidenced by the galaxy's X-ray emission [5]. Similar results have been found for the Fornax Cluster cD galaxy NGC 1399 [6].

Further orbit modeling is now underway in these galaxies, incorporating the constraints from all the available data (integrated stellar light, PNe, GCs, X-rays), and further observations with the PN.S are planned for a dozen nearby ellipticals. This approach should provide strong new limits on the mass distribution in early-type galaxy halos.

References

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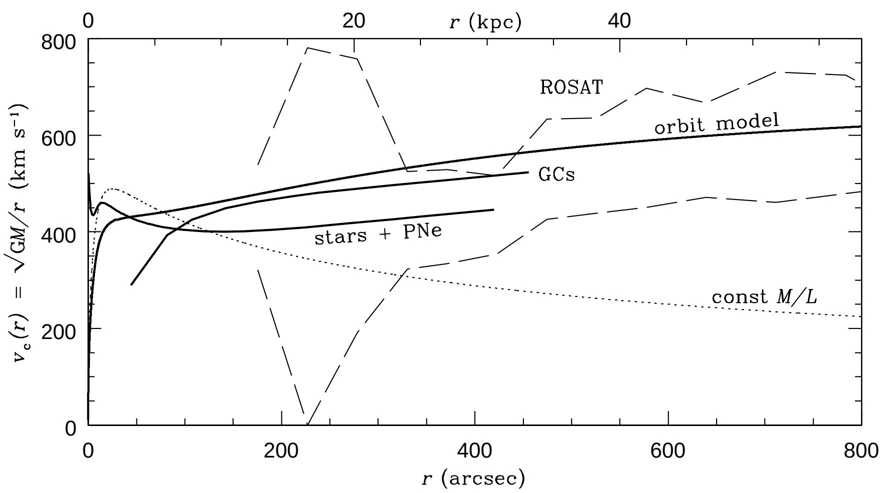

Fig. 1. Modeled circular velocity radial profile for NGC 4486. Shown are the results from Jeans modeling, using the stellar (including PNe) data and globular cluster data; a constant M/L model; confidence limits from ROSAT X-ray constraints [5]; and a best-fit orbit model. The effective radius is $R_{\rm eff} \simeq 100''$.