Dynamics of Stars and Globular Clusters in Galaxy Halos

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Abstract. We have obtained kinematical data in the halos of the giant ellipticals M49 and M87. These include globular cluster velocities in M49 to 10 $R_{\rm eff}$ and planetary nebula velocities in M49 and M87 to 4 $R_{\rm eff}$. We report initial results, including dynamical comparisons between the diffuse stellar components and globular cluster systems.

1 Introduction

Understanding globular cluster system (GCS) dynamics can reveal much about the formation histories of GCSs, and of their host galaxies in general. Since GCs can be found in large numbers in the halos of galaxies, they are handy tracers of the *mass distribution* there; and their *orbital distributions* should be indicators of how they were formed in and/or acquired by their host galaxies. Various theories for GCS formation make different predictions about the GCS dynamics. E.g., GC formation in cooling flows (for cD galaxies) would produce radial orbits; galaxy mergers would produce GCS strong rotation at large radii [5].

To make useful dynamical constraints, ~100s of GC velocities are required around each galaxy. Due to various observational challenges, such data have been obtained for only a few galaxies. But the advent of more powerful multi-object spectrographs (e.g., VIMOS on the VLT) will greatly facilitate this field. To adequately interpret GCS dynamics, one must compare the dynamics of the diffuse stellar component at similar radii. The stars cannot be assumed to have the same dynamics as the GCs; rather, any differences should tell us something important about the differences in formation. Currently, the only way to constrain the dynamics of the stars in elliptical galaxy halos is via observations of planetary nebulae (PNe), which fairly represent the underlying old stellar population.

Measuring velocities for PNe in galaxies much beyond the Local Group has been laborious until now – new instruments and techniques having been developed to enormously increase the efficiency of this process. Here we present observations of PNe in the elliptical galaxies M49 and M87, and of GCs in M49. We also give some modelling results.

2 Observations: GCs and PNe in M49 and M87

M49 = NGC 4472 (E2, $M_B = -21.7$, $D = 15$ Mpc) is the brightest galaxy in the Virgo Cluster. Its GCS is known to be bimodal in its properties, with a metal-rich subsystem more centrally concentrated than the metal-poor one. The GCS kinematics have been previously studied by [10] who measured 144 velocities to $\sim 5R_{\rm eff} \sim 30$ kpc. They detected little rotation, and found that the metal-poor GCs have a higher velocity dispersion than the metal-rich GCs.

Further wide-field photometric studies have provided a sample of 1500 GCs out to $\sim 13R_{\rm eff}$ [8], raising the opportunity to study the mass and rotation at radii rarely possible for a galaxy of any type. Using these data, we selected targets for spectroscopic follow-up with the WYFFOS/AF2 multi-fibre spectrograph on the 4.2m William Herschel Telescope (WHT) at La Palma. We observed on 1–4 May 2002, using the R600R grating to acquire the Ca II triplet near 8500 Å. For 66 of the GCs observed, we estimate that the signal-to-noise ratio was adequate to measure a velocity; most of these are found at radii of $\sim$ 4–10$R_{\rm eff} \sim$ 30–70 kpc.

Spectroscopic data sets for PNe at distances >10 Mpc are very sparse. Thus, while M49 should have a large population of PNe, there have been no successful velocity measurements of them. On 27–29 March 1995 at the KPNO 4-m Mayall telescope, X. Hui et al. used narrow-band imaging to find 200 PNe in M49. We have pursued spectroscopic follow-up, first using WYFFOS/AF2 at the WHT on 25–29 May 2000. We also used a new technique, *masked counter-dispersed imaging*, on the FORS2+MXU multi-slit spectrograph at UT2 on 28–30 Apr 2001; this approach obviates any astrometric problems with enlarged slits. These programmes yielded 80 PN velocities to $\sim 4R_{\rm eff}$, to ~ 15 km s^{-1} accuracy.

M87 = NGC 4486 (E2, $M_B = -21.5$, $D = 15$ Mpc) is the cD galaxy in the Virgo Cluster. It has a rich system of PNe (338 identified [2]), but spectroscopic follow-up programmes have been relatively unsuccessful. On the same UT2 programme described above, we measured 200 velocities to $\sim 4R_{\rm eff}$; this is currently by far the largest sample of PN velocities around a galaxy at this distance.

3 Results: Rotation, Mass, Anisotropy

The areal coverage of PNe in M49 is too incomplete to allow for a reliable measure of rotation. The areal coverage of the new GC sample is good, and should allow for picking up any rotation at large radius. In M87, the PN system doesn't rotate significantly until $R > 20$ kpc, where it shows a rotation of $\simeq 120$ km s^{-1} about the minor axis. The GCS at these radii shows a similar rotational axis but a much larger amplitude (200–300 km s^{-1} [3]); this does not depend discernibly on metallicity. Previously, the stars had been assumed to rotate as rapidly as the GCS, posing problems for some galaxy formation models (see [6]).

In M49, the PN system's projected velocity dispersion radial profile, $\sigma_p(R)$, matches on well to the stellar data at $\sim 1R_{\rm eff}$ [4], and is constant or rising at larger radii. The GC data show a similar behaviour but with a slightly higher amplitude. In M87, the stellar $\sigma_p(R)$ increases with radius. This is also observed in the GCS [3], but with a much higher amplitude. Dynamical models are required to see if these are projection effects or to signatures of differing dynamics.

Using spherical isotropic Jeans models, we deproject the data for $\sigma_p(R)$ to find the radial mass profile $M(r)$. For M49, the stellar and GC data both indicate the dominance of a dark halo outside 2 $R_{\rm eff}$ (see Fig. 1). Using the stellar or GC data, the derived slope of $M(r)$ is different, suggesting that the stars and GCs have very different dynamics. For M87, we also infer a dark halo, and again see evidence for differing stellar and GCS dynamics (Fig. 1). $M(r)$ inferred from the GCs is close to what is inferred from more robust techniques (see below), implying that the GCS as a whole is roughly isotropic – while the stars are not.

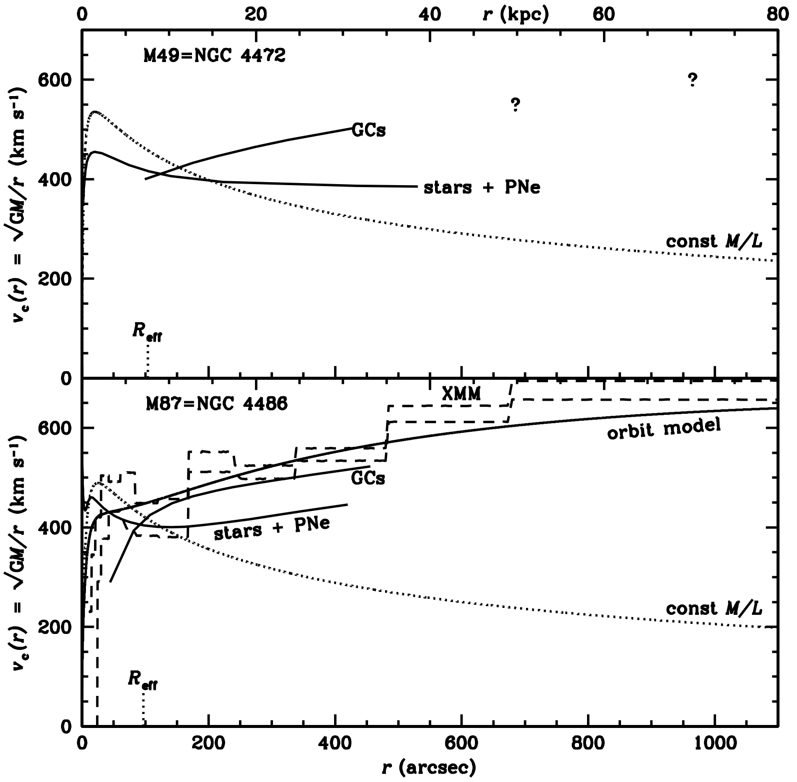

Fig. 1. Modelled circular velocity radial profile for M49 and M87. Shown are results from isotropic Jeans modelling (*solid curves*) using the stellar (including PNe) data and globular cluster data, and constant M/L model (*dotted curves*). For M87, our best-fit orbit model is also shown, as well as X-ray constraints (*dashed lines*). For M49, the radial locations of our new globular cluster constraints are indicated by "?".

We next allow for M87 to have an orbital anisotropy β that is constant with radius. In this case, we start with $M(r)$ which is well known in this region from X-ray studies [7]; we then assume a value for β and project to obtain the model's predicted $\sigma_{\mathrm{p}}(R)$, which we compare to the data. We infer that the metal-poor GCS may be somewhat tangentially anisotropic at $R \simeq$ 20–30 kpc, and isotropic or somewhat radial at larger radii. The metal-rich GCS appears to be slightly radially anisotropic at all radii. Note that this approach and results follow [3]. The diffuse stellar component in M87 presents a different picture. Its orbits appear to be radial inside 1 R_{eff} (as found by many previous dynamical studies), changing over to being highly tangential outside this radius. Thus, *the stellar orbital anisotropy resembles that of the metal-poor GCS component more than that of the metal-rich.*

More rigorous determinations of the dynamics of these systems require modelling methods that allow for arbitrary radial variation in the orbital anisotropies, and that exploit fully the information contained in discrete velocity data (rather than binning in radius and computing velocity moments). We developed such a method based on the now established approach of orbit modelling [9]. Our analysis of the integrated stellar spectroscopy and GC velocity data for M87 yielded $M(r)$ that agrees well with that found using X-ray data (see Fig. 1), a consistency that is encouraging for the reliability of these two independent techniques. Efforts are underway to model both M87 and M49, including our new PN velocity data.

To compare with such "high-end" galaxies as M49 and M87, one should extend such studies to fainter ($\sim L^*$) early-types. And in fact we have already successfully probed the stellar halo kinematics in several of these galaxies as part of an ongoing programme with the Planetary Nebula Spectrograph [1] – data that so far suggest that fainter ellipticals have much less dominant dark halos. It would be important to acquire complementary data on GC velocities in these galaxies; the new generation of multi-object spectrographs on 8m-class telescopes should make this feasible.

References

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