Probing the kinematics of early-type galaxy halos using planetary nebulae

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Received –, accepted –
Published online later

Key words Galaxies: general – galaxies: haloes – galaxies: elliptical and lenticular, cD – galaxies: kinematics and dynamics – planetary nebulae: general

We present first results of a study of the halo kinematics for a sample of early type galaxies using planetary nebulae (PNe) as kinematical tracers. PNe allow to extend up to several effective radii ($R_e$) the information from absorption line kinematics (confined to within 1 or 2 $R_e$), providing valuable information and constraints for merger simulations and galaxy formation models. We find that the specific angular momentum per unit mass has a more complex radial dependence when the halo region is taken into account and that the halo velocity dispersion is related to the total galaxy luminosity, isophotal shape, and number of PNe per unit of luminosity.

1 Introduction

Early type galaxies, despite their regular and simple morphology if compared to the spirals, have a complex dynamical structure which is mostly dominated by the random motions of the stars. The dynamical structure and its relation to the galaxy’s structural and morphological parameters are the relic of galaxy formation and evolution processes. The connection between morphological properties of early type galaxies and their kinematics motivated several authors to revise the original Hubble classification scheme which is influenced by the galaxy’s orientation relative to the observer. Bender & Kormendy (1996) distinguish between “boxy” and “disky”; more recently Emsellem et al. (2007) refined the distinction between “slow” and “fast” rotators, according to their specific angular momentum per unit mass instead of the $V/\sigma$ ratio (e.g. Illingworth 1977). Disky ellipticals have significant rotation with $V/\sigma \geq 1$ and are generally axisymmetric. Boxy ellipticals have little or no rotation, show a range of values for $V/\sigma$ including strongly anisotropic systems ($V/\sigma << 1$), can be triaxial, and are generally more massive (i.e. Bender 1988; Bender et al. 1989; Kormendy & Djorgovsksy 1989). Slow rotators appear to be massive systems, are nearly round with a significant kinematic misalignment, implying a moderate degree of triaxiality, and span a moderately large range of anisotropies. Fast rotators appear to be rather flattened systems, with no significant kinematic misalignments, are nearly axisymmetric, and span a larger range of anisotropies (Cappellari et al. 2007).

Differences in galaxy properties can be the result of different formation scenarios. Numerical simulations of merging galaxies suggest that the less-luminous fast rotators with disky isophotes are preferentially formed through a series of minor mergers with less massive companions. On the other hand, the more luminous slow rotators with boxy isophotes are thought to form through a violent major merger between galaxies of similar mass (e.g. Naab et al. 1999; Naab & Burkert 2003). Moreover, numerical simulations of galaxy formation in a cosmological context predict particular radial profiles for the total and dark matter distribution (e.g. Dekel et al. 2005; Naab et al. 2007) and for kinematic prop-
Fig. 1  ESO digital sky survey images of NGC 1023 (upper panels) and NGC 3379 (lower panels) with the PNe positions marked with green crosses. Red lines represent the contour levels of the mean line of sight velocity (left panels) and velocity dispersion (right panels). North is at top, East at left.

...properties such as $V/\sigma$, orbital distribution and angular momentum (e.g. Abadi et al. 2006, Naab et al. 2006). The comparison of merger simulations and model predictions with kinematic observations out to large radii is a key point for understanding galaxy mass distributions and formation processes. Spirals have the advantage that their kinematics can be easily measured from neutral and ionized gas out to several scale radii, but the situation is more complex for early type galaxies, in which the absence of gas and the rapid fall-off of the stellar light allows for kinematic measurements only within 1 or 2 effective radii (e.g. Bender et al. 1994; Kronawitter et al. 2000; Saglia et al. 2000).

Planetary nebulae (PNe, hereafter) help to overcome this difficulty, since their bright $\text{O III}$ emission makes them easily observable far from the center of early type galaxies, where the stellar light is too faint for absorption line spec...
troscopy (e.g. Hui et al. 1995; Arnaboldi et al. 1996). A dedicated instrument was installed at the William Herschel Telescope: the Planetary Nebulae Spectrograph (PN.S, Douglas et al. 2002). A long-term observational campaign of early type galaxies has been undertaken, aimed at quantifying the halo kinematics and dark matter content in these systems. A series of papers has already been published, presenting the initial results of the PN.S survey (Romanowsky et al. 2003; Douglas et al. 2007; Noordermeer et al. 2008; De Lorenzi et al. 2008; Napolitano et al. 2008). To obtain a general overview of the outer halo kinematics in these systems and the constraints implied for formation scenarios, Coccato et al. (2008, C+08 hereafter) studied the kinematic properties of the outer halos of 16 early-type galaxies using PNe. Here we present first results from this project.

2 First results

We illustrate the kinematic analysis of two galaxies in the project, NGC 1023 and NGC 3379. Their PNe samples were taken from Noordermeer et al. (2008, N+08 hereafter) and Douglas et al. (2007, D+07 hereafter), respectively. Two-dimensional velocity and velocity dispersion fields were obtained applying an adaptive Gaussian kernel smoothing to the measured PN radial velocities as described in C+08, and are shown in Figure 1.

Small rotation is observed in the E1 galaxy NGC 3379, while higher rotation velocities are observed in the SO galaxy NGC 1023. The kinematics of the PNe system is in good agreement with the stellar absorption line kinematics in the radial region in which both data sets overlap, as shown in N+08 and D+07. As a general result, PNe turn out to be reliable tracers of the stars and this property reflects also in their spatial distribution, not only in their kinematics. In fact, the radial profile of the PNe number density agrees well with the stellar surface brightness in the region in which these data overlap. In the outermost regions, the PNe counts follow the extrapolation of the fit to the stellar light (see C+08 and references therein for a more exhaustive compilation).

The first physical quantity we study using the velocity and velocity dispersion fields for these 2 galaxies is the radial profile of the specific angular momentum per unit mass ($\lambda_R$, as defined in Emsellem et al. 2007). In particular we are interested in probing $\lambda_R$ into the halo regions, extending the previous information confined within $0.5R_e$ from integral field absorption line kinematics. In Figure 2 we compare the outer $\lambda_R$ (out to $7 - 8R_e$, obtained from PNe kinematics) with the inner values for NGC 1023 and NGC 3379, and with the general trends observed for slow and fast rotators (Emsellem et al. 2007). Both NGC 1023 and NGC 3379 are classified as fast rotators, they have a monotonically rising $\lambda_R$ within $0.5R_e$ reaching 0.4 and 0.15 respectively. Their halos, however, behave differently. In NGC 3379, $\lambda_R$ remains almost constant, ranging between 0.2 and 0.15; in NGC 1023, $\lambda_R$ keeps rising up to 0.5 at $R = 2 - 3R_e$ and then declines monotonically, almost approaching the slow rotator regime. This is a consequence of the combined effects of the declining rotation curve and the rising velocity dispersion profile observed in NGC 1023 (see N+08).

The second aspect of our study is to compare the halo kinematic properties with other physical properties of the galaxies, such as luminosity (total $B$-band magnitude), shape parameter ($\alpha_B$), and number of PNe per luminosity in the $B$ band ($\alpha_B$, Jacoby 1980). The halo kinematics were parameterized by the outermost value of the velocity dispersion derived from the PNe data ($\sigma_{LAST}$), and determined for a sample of early type galaxies from the literature with PNe measurements (see C+08 for references).

In Figure 3 we show this comparison with the following results:

1. More luminous galaxies tend to have larger values of the dispersion measured at the outermost observed point. This is related to the fact that more massive galaxies have generally higher values of the velocity dispersion.
2. Galaxies with higher values of $\sigma_{LAST}$ are preferentially boxy in shape ($\alpha_4 < 0$). This is also a reflection of the known trend for massive ellipticals to be more boxy in shape (e.g. Bender et al. 1989; Napolitano et al. 2005).
3. Galaxies with higher $\sigma_{LAST}$ have smaller $\sigma_B$ values (i.e., less PNe per luminosity in the $B$-band). As discussed in Buzzoni et al. (2006), this is probably a consequence of massive early-type systems harboring a larger proportion of stars on the Horizontal Branch that do not enter the PN stage.

3 Conclusions

We have presented first results from the study of the kinematic properties of early type galaxy halos by means of PNe velocities. Good agreement is observed between absorption

![Fig. 2](image-url)
Fig. 3 Comparison between \( \sigma_{\text{LAST}} \) and other galaxy properties: number of PNe per unit total B-band luminosity (upper panel), isophotal shape (central panel) and total B-band magnitude. We refer to C+08 and references therein for the computation of these quantities.

line kinematics and PNe kinematics, as well as between PNe radial distribution and stellar surface brightness profile (see C+08 and references therein). This strongly supports that PNe are reliable tracers of the stellar kinematics.

The results for NGC 1023 and NGC 3379 show that the halo \( \lambda_R \) radial profile can show different behavior from the profile measured within \( \sim R_e \). In addition, the PNe kinematics allow us to probe the relation between the halo velocity dispersion and other galaxy properties, such as luminosity, shape parameter and number of PNe per luminosity unit.

The results of this study, even if they are obtained for a small sample of galaxies, will provide new constraints for models of elliptical galaxy formation. Most of the merger simulation papers to date compare their remnants to data within an effective radius or so. We expect that extending the predictions of the simulations to outer radii and comparing with data of the kind presented here will shed new light on the merger formation histories of elliptical galaxies.

Acknowledgements. We would like to thank Eric Emsellem for providing the \( \lambda_R \) radial profiles from the SAURON data.

PD is supported by the DFG Cluster of Excellence “Origin and Structure of the Universe”. FDL is supported by the DFG Schwerpunktprogram SPP 1177 “Witnesses of Cosmic History”. MRM is supported by an STFC Senior Fellowship. NRN has been funded by CORDIS within FP6 through a Marie Curie European Reintegration Grant, contr. n. MERG-FP6-CT-2005-014774, co-funded by INAF. AJR is supported by the National Science Foundation Grant AST-0507729, and by the FONDAP center for Astrophysics CONICYT 15010003.

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