PLANETARY NEBULAE: THEIR EVOLUTION AND ROLE IN THE UNIVERSE
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Modern Techniques in Galaxy Kinematics: Results from Planetary Nebula Spectroscopy

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Abstract. We have observed planetary nebulae (PNe) in several early-type galaxies using new techniques on 4- to 8-meter-class telescopes. We obtain the first large data sets ($\gtrsim$ 100 velocities each) of PN kinematics in galaxies at $\gtrsim$ 15 Mpc, and present some preliminary dynamical results.

Planetary nebulae (PNe) have great promise as dynamical tracers of the diffuse stellar population in external galaxies. Especially important is their use in the outer parts of early-type galaxies (ellipticals and S0s), an arena which is not generally accessible with other dynamical tracers. But acquisition of PN velocities in galaxies farther away than a few Mpc has been quite limited. We report here results from new observing programs of early-types at $\gtrsim$ 15 Mpc.

The standard method for acquiring PN velocities involves a narrow-band imaging survey followed by multi-object spectroscopy (MOS). PN MOS in galaxies at $\gtrsim$ 15 Mpc has been not very successful in practice, largely owing to astrometric difficulties. To circumvent this we have developed *masked counter-dispersed imaging*, a technique using a standard multi-slit mask with enlarged (4″) slits to absorb any astrometry errors; we take two images dispersed in opposite directions to permit the velocity determination. Using this technique with FORS2/MXU at UT2 on 28-30 April 2001, we have obtained PN velocities to 4 R_{eff} (effective radii) in the Virgo Cluster giant ellipticals M87 = NGC 4486 (200 PNe; see Fig. 1) and M49 = NGC 4472 (80 PNe, including some obtained with the multi-fiber unit WYFFOS/AF2 at the WHT on 25-28 May 2000).

In the outer regions of M87, the PNe rotate about the minor axis, with lower velocities than the globular clusters (GCs) ($\sim$ 100 km s^{-1} vs. 200-300 km s^{-1}; Côté et al. 2001). The inferred stellar velocity dispersion $\sigma_{\text{p}}(R)$ rises slightly with radius, as seen in the GCs but with lower amplitude. Simple Jeans models suggest the stars and GCs have significantly different dynamics. In M49, the stars and GCs (Zepf et al. 2000) show more consistent kinematics, with $\sigma_{\text{p}}(R)$ constant or slightly rising with radius.

The most efficient technique for finding and measuring velocities of extragalactic PNe is *counter-dispersed imaging* (see the accompanying paper, Douglas et al. 2002). Using the WHT's standard spectrograph ISIS in slitless mode in April 1997 and June 1998, we have obtained 90 PN velocities to 4 R_{eff} in the S0 galaxy NGC 5866. With the newly commissioned PN.Spectrograph (PN.S)

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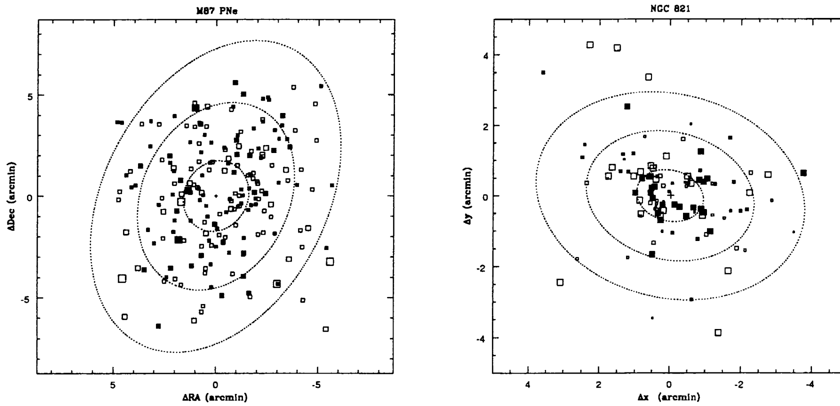

Figure 1. PN velocities in M87 (*left*, 200 PNe at 15 Mpc, using UT2+FORS2/MXU) and in NGC 821 (*right*, 104 PNe at 25 Mpc, using WHT+PN.S). Filled and open boxes represent approaching and receding velocities, respectively, relative to the systemic velocity; the box size indicates the relative velocity magnitude. Dotted lines indicate the stellar isophotes at 1 $R_{\rm eff}$, 2.5 $R_{\rm eff}$, and 4 $R_{\rm eff}$.

at the WHT on 13-18 September 2001, we have obtained 100 PN velocities to 5 $R_{\rm eff}$ in each of the galaxies NGC 821 (E3) and NGC 7457 (S0). NGC 5866 and NGC 7457 show rotational dominance at large radii. In NGC 821, $\sigma_{\rm p}(R)$ declines at large radii, contrary to what would be expected for a round giant elliptical from more radially limited dynamical studies (Gerhard et al. 2001), but similar to what is seen in the E3 galaxy NGC 4697 (Méndez et al. 2001).

The PN.S will embark in March 2002 on a kinematical survey of a dozen nearby bright ellipticals. Key interests in all these PN studies of early-type galaxies are the amount of angular momentum in their outer parts, their distribution of mass, and tracers of their formational processes via relict kinematical substructure. Rigorous analysis of the data will proceed with nonparametric orbit modeling methods designed to include discrete velocity measurements (Romanowsky & Kochanek 2001).

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