Planetary Nebulae in NGC 5128 (Centaurus A)

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Abstract. The study of planetary nebulae (PNe) in the nearby post-merger elliptical galaxy NGC 5128 (Cen A) now has a history of nearly twenty years. As the nearest giant elliptical, it is a prime target for extragalactic PN studies. These studies have addressed many issues including the galaxy's distance, dark matter content, halo structure, merger history, and stellar populations. We review the main PN studies that have been conducted in NGC 5128, and introduce a new study where we measure the [NII]/Hα ratio for 134 PNe. We find that there are no PNe in our sample that are obviously of Type I, supporting the idea that the last major star formation event in the galaxy halo occurred over 1–2 Gyr ago.

1 Introduction

The study of planetary nebulae (PNe) beyond the Local Group has largely been conducted in luminous early-type galaxies where PNe are present in large numbers and are relatively easy to detect. The nearest, easily observable elliptical galaxy, NGC 5128 (Cen A), has thus been a recurring target for PN studies over the last twenty years. At a distance of 3.5–4 Mpc (e.g. Hui et al. 1993a; Harris et al. 1999; Rejkuba 2004), NGC 5128 is ~ 3 mag closer than the ellipticals in the Virgo cluster, which not only makes intrinsically fainter PNe more accessible, it also greatly reduces the problem of contamination from Lyα galaxies at $z = 3.14$. The galaxy is also interesting in its own right as it is clearly the product of a recent merger, exhibiting a warped central gas and dust disk, stellar and HI shells, and both radio and x-ray jets. A thorough review of this galaxy is presented by Israel (1998). Aside from its intrinsic complexity, disadvantages of studying NGC 5128 include its large extent on the sky ($1' \sim 1$ kpc), and its relatively low Galactic latitude ($b = +19$). Nevertheless, modern wide-field and multiplexing instrumentation have made studies both practical and fruitful.

2 PN Surveys

The first PN survey of NGC 5128 was conducted by Hui et al. (1993b), and covered 661 arcmin^2 over 43 CCD fields (see Figure 1). This coverage extended 20 kpc along the major axis an 10 kpc along the minor axis. At these projected distances (~ 4 and 2 r_e, respectively) PNe were detected well beyond the radii at which long-slit spectroscopy was readily obtainable. They identified 785 PN candidates using the method of on-/off-band imaging of the [OIII]λ5007 emission

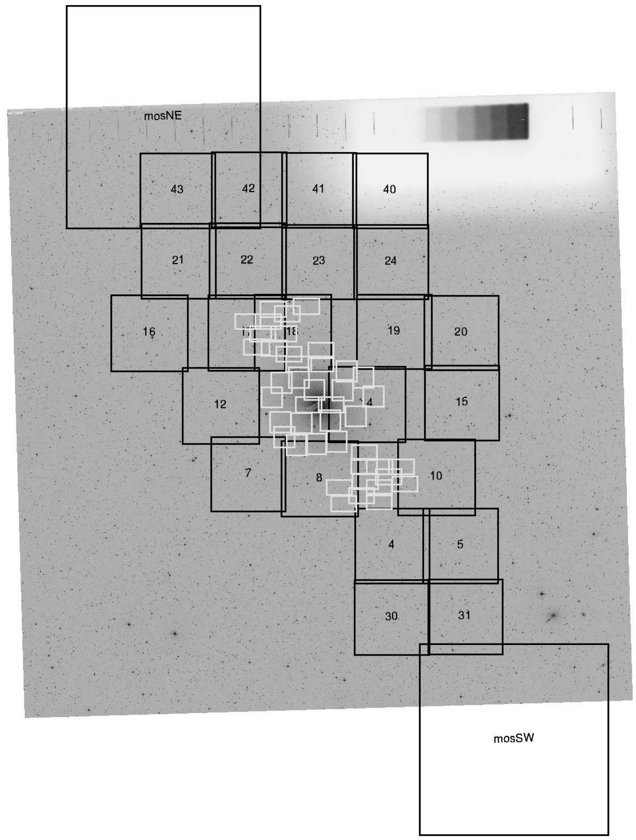

Fig. 1. NGC 5128 PN survey areas. The smaller fields toward the center are the first survey fields by Hui et al. (1993a). The larger fields that cover a much wider region of the halo are from our most recent survey (Peng et al. 2004a).

line. These PNe formed a complete sample for brightest 1.5 mag of the PN luminosity function (PNLF). They also spectroscopically confirmed 432 PNe, on which they based their dynamical studies of dark matter and the intrinsic shape of the potential (Hui et al. 1995).

Larger CCD cameras and fiber spectrographs allowed us to conduct a second, wider PN survey of the NGC 5128 halo. This survey covered nearly 3 deg^2 on the sky and extended to 100 kpc along the major axis and 40 kpc along the minor axis (Figure 1). In total, we increased the number of imaged PNe to 1141, 780 of which are spectroscopically confirmed. The spatial distribution of PNe is concentrated toward the major axis, mirrors that of the low surface brightness halo light seen in deep photographic imaging by Malin (1978), although the most distant PNe in our sample are ~ 30 kpc beyond the light seen in the photographic images.

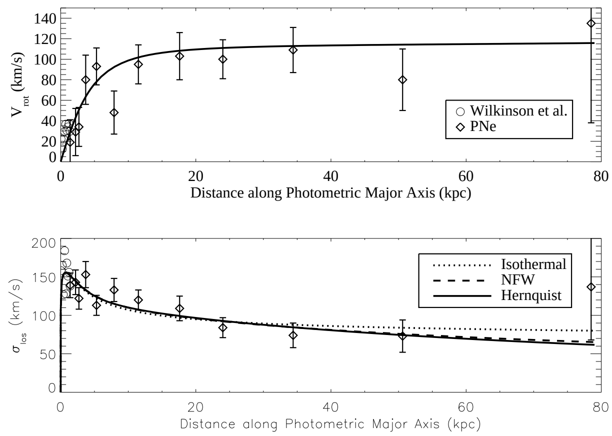

Fig. 2. (a) Major axis rotation curve. We fit a parametrized flat rotation curve. (b) Jeans Equation fit to the major axis velocity dispersion profile. In the bottom panel is the best fit line-of-sight velocity dispersion profile for three different dark halo mass models.

3 Mass Estimates

PNe are some of the most effective kinematic tracers in the halos of elliptical galaxies, where their radial velocities can be used to constrain the dynamical mass of their parent galaxies (e.g. Arnaboldi et al. 1998; Romanowsky et al. 2003). Hui et al. (1993) used the original sample of 432 PN velocities to derive a total mass of $3.1 \times 10^{11} M_{\odot}$ and $M/L_B \sim 10$ out to a radius of 25 kpc. Our recent work, which extends out to 80 kpc, shows that the total mass increases only slowly with radius. The fitted major axis rotation curve and velocity dispersion profile are shown in Figure 2. Although the rotation curve remains flat, the dispersion profile falls with radius. Within this volume, we estimate a dynamical mass of $\sim 5 \times 10^{11} M_{\odot}$ and $M/L_B \sim 13$ (Peng et al. 2004a). These numbers are relatively unchanged whether we use the tracer mass estimator (Evans et al. 2003) or spherical Jeans equation under the assumption of isotropy. While it may be that this value for M/L_B can be produced from theoretical expectations (see Napolitano, this volume), the value we derive is certainly low, like the ones seen in the sample of Romanowsky et al. (2003), when compared to luminous ellipticals such as M87 and M49 (Côté et al. 2001, 2003).

4 The Two-dimensional Velocity Field

One of the advantages of using PNe as kinematic probes is that we get full two-dimensional spatial information on the stellar velocity field. When there are hundreds of measured PNe, we can construct velocity maps that are similar

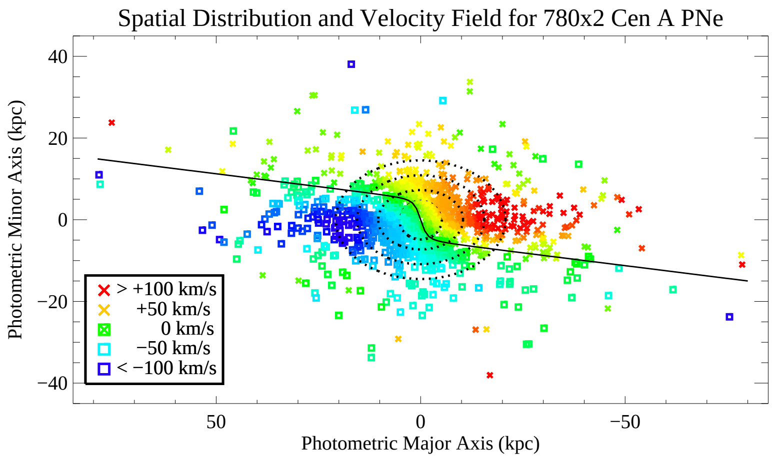

Fig. 3. Smoothed antisymmetrized velocity field with zero velocity contour (ZVC) plotted. Dotted ellipses trace the rough isophotes for NGC 5128 from 1–4 r_e. PN with velocities larger than systemic (receding) are represented by crosses, and those with velocities smaller than systemic (approaching) are represented by open boxes. The color of each point shows the magnitude of the velocity with respect to systemic. Notice how the rapid major axis rotation is only present within ± 7 degrees of the major axis, while the rest of the galaxy halo undergoes a slower minor axis rotation.

to those derived from integral field spectrograph observations, but that extend much farther out into the halo. In the case of NGC 5128, Hui et al. (1995) determined that the kinematic axis of rotation was not aligned with either of the photometric axes, suggesting that the intrinsic shape of the potential is triaxial. Since then, we have used our more extensive PN data to show that the zero-velocity surface not only does not coincide with the photometric axes, but is in fact twisted in an 'S'-shape (Figure 3). This severe twist, which asymptotes to a minor axis angle of 83 degrees, suggests that the potential could be triaxial, tending toward prolate (Statler 1991).

Separate lines of evidence, which include our survey of globular clusters in this system (Peng et al. 2004b) indicate that there may be a substantial intermediate age population of stars with an mean age of ~ 5 Gyr (Peng et al. 2004c). Bekki et al. (2003) have already produced simulations of globular cluster velocity fields that result from galaxy mergers. In the future, it will be valuable to compare the PN velocity field to those produced by merger simulations to constrain the types of mergers that could have produced this galaxy.

5 PNe as Stellar Populations

One of the useful characteristics of PNe is that, like globular clusters, it is possible in priniple to obtain both their radial velocities *and* some information on their ages or abundances, producing a chemodynamical picture of the galaxy. The metallicity distribution of the field star population of NGC 5128 has been measured using Hubble Space Telescope color-magnitude diagrams of the red giants and is generally metal-rich (Harris & Harris 2002). Assuming that the PNe trace the same stellar population, this is one way to derive the overall properties of the PN system. However, one can derive abundances from PNe directly from their emission line spectra, although this requires a significant investment in observing time.

Through a heroic effort, Walsh et al. (1999) derived [O/H] for 5 PNe in NGC 5128, finding that they were generally sub-solar in abundance with a mean value of ~ -0.5. Walsh (this volume) has also recently obtained spectra of much higher quality for ~ 50 PNe, showing that these types of observations are now possible and interesting.

Another way to link PNe with their progenitor stellar populations is to find PNe in globular clusters. Minniti & Rejkuba (2002) found one such object in an NGC 5128 globular cluster. However, these objects appear to be rare, and no other PNe in extragalactic clusters have been reported.

We have investigated the PN population in NGC 5128 by looking for the young, Peimbert (1978) Type I PNe, which should have progenitors that are younger than 1–2 Gyr. In the Milky Way, these PNe are found in the disk, and are rich in N and He due to the dredge-up and hot-bottom burning processes found only in these more massive stars. Because obtaining spectra of sufficient quality to derive N or He abundances would have been prohibitively expensive, we instead chose to measure the [NII] lines $\lambda\lambda 6548, 6584$ and compare their fluxes to Hα. This [NII]/Hα ratio can be used as a crude estimator of relative nitrogen abundance. Type I PNe in both Magellanic Clouds have very high [NII]/Hα ratios.

We used the 2-degree Field spectrograph on the Anglo-Australian Telescope to observe 221 PNe in NGC 5128. Of these, we detected Hα at $>$ 3-sigma in nearly all of them (219), and both Hα and [NII]λ6584 in 134 PNe. Because these were fiber observations and some of the PNe sit atop the bright galaxy continuum, it was also important that we model the galaxy and subtract it off. In order to do this, we used the models of Bruzual & Charlot (2003) to obtain a best fit simple stellar population to the blue side of the spectrum (used in Peng et al. 2004b). We then scaled this model to the appropriate flux level, and shifted it to the expected mean velocity at that position, as derived from our 2-d PNe velocity field. Only after this continuum subtraction did we measure the line fluxes.

Figure 4 shows the distribution of measured [NII]/Hα values, with incompleteness setting in for values less than ~ 0.55. In order to determine whether any PNe at the high end of the distribution could plausibly be of Type I, we compared them to the extragalactic PNe found in the Magellanic Clouds (Stanghellini et al.

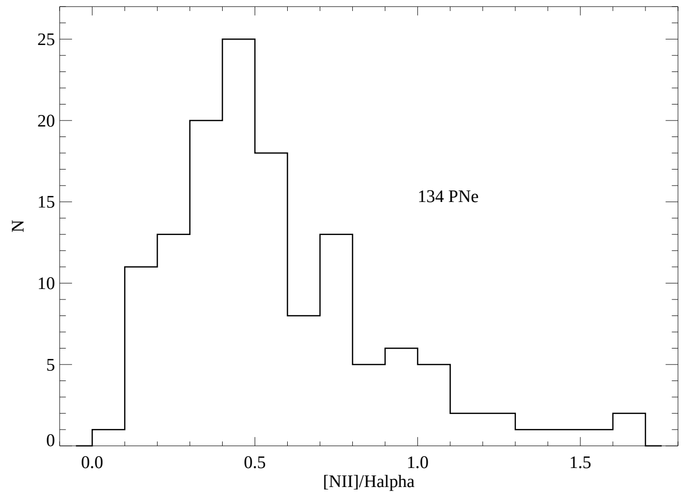

Fig. 4. Distribution of measured [NII]/Hα. Our sample is complete for all values greater than ~ 0.55.

2002, 2003), M31 (Jacoby & Ciardullo 1999), and NGC 5128 (Walsh et al. 1999). In Figure 5, we plot the value of [NII]/Hα against the brightness in [OIII]λ5007. A general trend in metallicity is evident with the SMC being most metal-poor, and NGC 5128 being most metal-rich. It is known that the Type I PNe in the Clouds are typically faint, and this is seen here, where the objects that have high [NII]/Hα (relative to the galaxy mean) are all at the faint end. These PNe can have [NII]/Hα values that are $\sim$ 10 times higher than what is typical in these galaxies. In NGC 5128, however, while the overall population has fairly high [NII]/Hα values, we see no evidence for outliers that would be good candidate Type I PNe. Even the PN from Walsh et al. (1999) that was tentatively determined to be Type I, does not stand out from the crowd. It is important to note that the cutoff values of N/O and He/H typically used to define Type I PNe are defined only for the Galaxy, and may not apply to systems of different metallicities.

6 Conclusions

Only in the Milky Way and M31 are there more known PNe than in NGC 5128. Starting with Hui et al. (1993a), extragalactic PN studies in NGC 5128 have addressed a wide array of issues from its distance, dark matter content, stellar populations, and formation history. We now know that while the halo of this galaxy does contain dark matter, it falls into a growing class of elliptical galaxies that have low to moderate mass-to-light ratios. It's 2-dimensional halo kinematics are consistent with a triaxial potential, and a galaxy that was formed in a

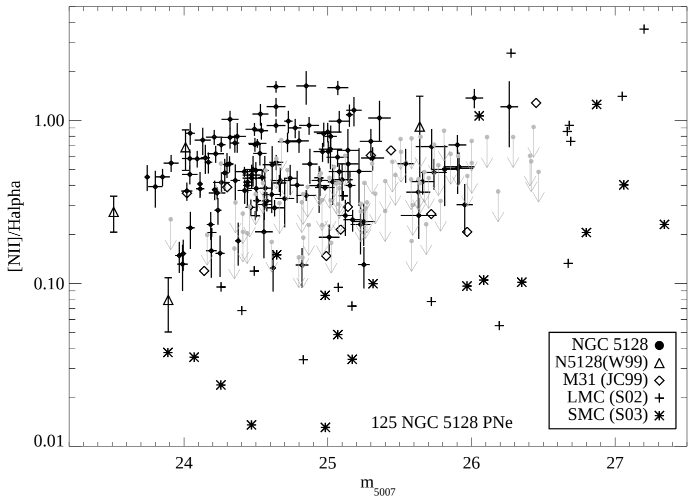

Fig. 5. [NII]/Hα versus m_{5007}. NGC 5128 values (points with error bars) show no evidence for obvious Type I PNe. Gray points are those for which we can only derive an upper limit for [NII/Hα.

recent merger. However, this merger was likely not so recent as to have produced many stars younger than ~ 2 Gyr that would now be detectable as Type I PNe. Future deep, wide-field imaging and spectroscopy will be able to probe the PN abundance distribution and the star formation history of this galaxy, as well as enable studies of the PN stage of stellar evolution in an entirely different environment from that in the Local Group.

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