

A WIDE FIELD SURVEY OF PLANETARY NEBULAE IN M31: A PROGRESS REPORT

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ABSTRACT

We present the first results of a wide field survey for planetary nebulae throughout M31 undertaken at the KPNO 0.9m telescope with the Mosaic camera. So far, images in [O III] λ 5007 and its continuum filter have been analyzed. Our survey appears to be at least 90% complete to about 2 mag below the peak of the planetary nebula luminosity function. Over 900 planetary nebulae candidates have been found within a 12 square degree area.

Key words : M31: planetary nebulae

I. INTRODUCTION

We have recently undertaken a wide field survey to find planetary nebulae throughout M31. The primary goals of this study are to investigate the spatial distribution of the planetary nebulae throughout M31 to provide a catalog of planetary nebulae for the kinematic studies and to study the production of planetary nebulae by different stellar populations with a large range of metallicity and age in M31.

Recently, exciting results have emerged from a very wide field survey of stars in M31 covering about 25 square degrees: within a halo of red giants extending at least 4° in diameter, there exists a giant stream stretching over 2° as well as other large-scale structures (Ibata et al 2001; Ferguson et al. 2002). The kinematics of these stars will provide important clues to understanding the origin of these giant halo structures and their relation to the halo in general, as well as provide very useful information regarding the total mass of M31. Planetary nebulae are an important observational probe for studying the stellar kinematics of this very outlying area in M31 (Merrett et al. 2003). Given the presence of old red giants, there is every reason to expect planetary nebulae in the same field. However, published surveys of the planetary nebulae are limited to a much smaller area of M31 (Ford & Jacoby 1978, Nolthenius & Ford 1987, Ciardullo et al. 1989, Hui 1995).

Extragalactic planetary nebulae have proven particularly useful as probes for studying a variety of important issues in galactic and stellar evolution. First, planetary nebulae are useful for measuring the distances to their host galaxies (e.g., Jacoby 1989). Second, they are useful probes of the chemical evolution of their host

galaxies, in some cases being the only directly accessible probes of chemical abundances (e.g., Richer et al. 1998; Jacoby & Ciardullo 1999; Walsh et al. 1999). Third, planetary nebulae can be used to probe the production and mixing of nucleosynthetic products in their progenitor stars (e.g., Kaler & Jacoby 1989). Finally, planetary nebulae are also useful probes of the gravitational potentials of their host galaxies (e.g., Hui et al. 1995).

Extragalactic planetary nebulae are also a powerful tool for studying the evolution of planetary nebulae, even though their study is more difficult than that of their Milky Way counterparts. Their principal advantage is that their known distances permit the study of their absolute properties. Except for their use as probes of the gravitational potentials of their host galaxies, the confidence with which planetary nebulae can be used to study all of the problems mentioned earlier would be greatly increased if there were a better quantitative understanding of the production of planetary nebulae from different stellar populations (Stasińska & Tylenda 1994; Richer et al. 1997; Stasińska et al. 1998; Stanghellini & Renzini 2000; Gesicki & Zijlstra 2000). A better understanding of the production of planetary nebulae impacts a wide range of other processes, including stellar death rates, white dwarf birth rates, the mass of interstellar gas in galaxies without star formation, and the chemical enrichment of galaxies in helium, carbon, nitrogen, and s-process elements, among others (e.g., Peimbert 1990). Surveys of extragalactic planetary nebulae quickly uncovered that the number of bright planetary nebulae per unit luminosity decreases in redder or more luminous host galaxies (e.g., Peimbert 1990; Hui et al. 1995). Explanations for these trends in terms of both the metallicity or the age distributions of the progenitor stellar populations have been proposed, but no definitive solution has been found.

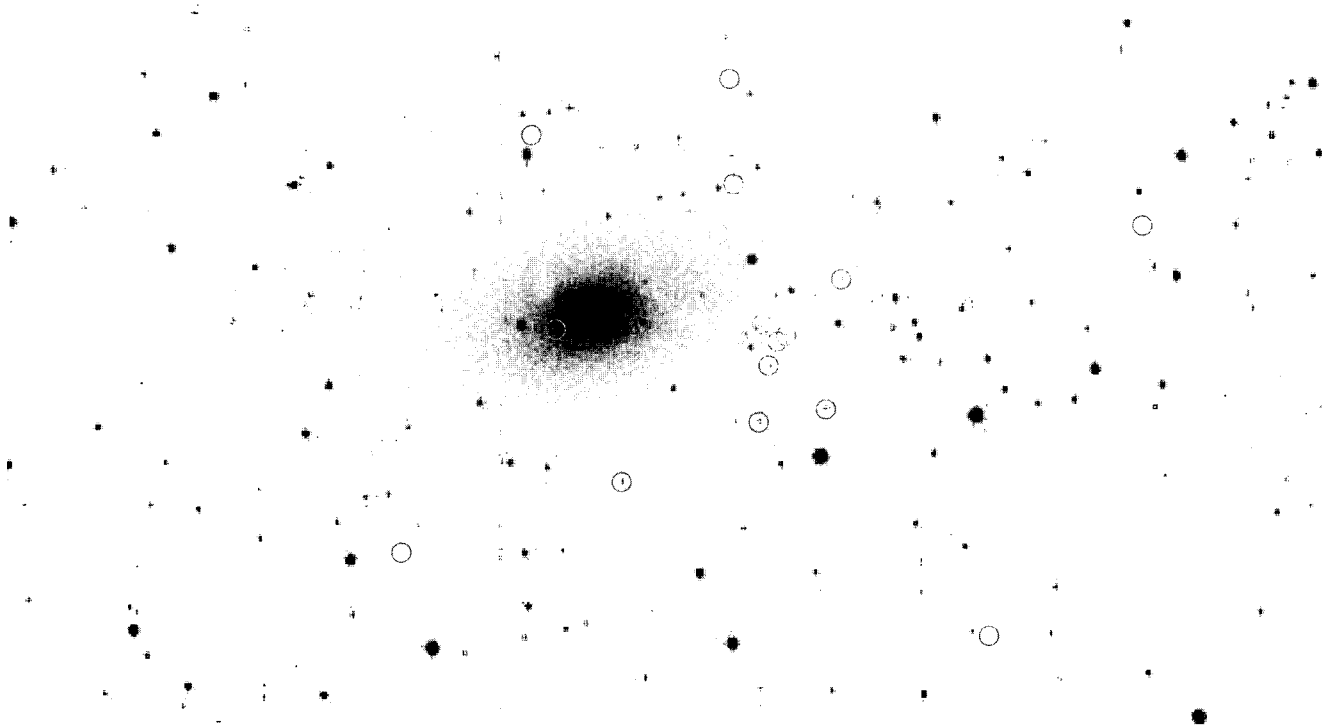


Fig. 1.— Here, we present the [O III] λ 5007 image of the area including NGC 205. The circles surround all of the known planetary nebulae within 2.7 mag of the PNLF peak in M31. All are detected.

A uniformly-deep survey of planetary nebulae arising from stellar populations in which the metallicity and age vary significantly in a known way, like those in M31, would be a welcome first step.

TABLE 1
FILTER DETAILS

Filter	λ_c (\AA)	FWHM (\AA)
[O III] λ 5007	5027	53
[O III] λ 5007 continuum	5305	241
H α continuum	6088	273
H α	6575	80
[S II] $\lambda\lambda$ 6716,6731	6736	80

II. OBSERVATIONS AND REDUCTIONS

The observations were obtained on 5-8 October and 26 November-2 December 2003 at the Kitt Peak National Observatory (KPNO) 0.9m telescope with the Mosaic camera. The Mosaic camera is an array of eight $2k \times 4k$ SITe CCDs. The CCDs' $15\mu\text{m}$ pixels subtend 0.423 arcseconds on the sky. The final images cover approximately a square degree on the sky. Images were acquired through five filters: [O III] λ 5007, H α , [S II] $\lambda\lambda$ 6716,6731, and continuum filters at 5300\AA

and 6070\AA , whose characteristics for the 0.9m telescope may be found in Table I. The [O III] λ 5007 filter was designed for use at the KPNO 4m telescope. As a result of the 0.9m telescope's slower focal ratio, this filter's bandpass is shifted by about $+6\text{\AA}$ to wavelengths somewhat too red for objects with blue-shifted velocities, as is the case of planetary nebulae in M31. Consequently, the planetary nebulae with the highest velocities of approach, $\sim 600\text{ km/s}$, on a part of the approaching side of M31's disk and in a cone centered on the bulge, fall on the blue wing of the [O III] λ 5007 filter and the magnitudes measured for these objects may be too faint by up to 0.8 mag. We shall recalibrate these objects using imaging obtained elsewhere. Standard stars were observed on the nights that were deemed photometric or nearly so. On two occasions, a single standard star was observed on each of the Mosaic camera's eight CCDs in all five filters to permit a better photometric calibration of the data.

Originally, we planned to observe a $6^\circ \times 6^\circ$ area centered on the nucleus of M31. The weather and programme scheduling only permitted the observation of thirteen fields with the [O III] λ 5007 and 5300\AA continuum filter, covering the bulge, most of the disk, and some of the halo on the south-east side of the galaxy. The four central fields, including all of the bulge and much of the disk, were observed in all five filters in order to permit the cataloguing of H II regions and supernova remnants. M32 and NGC 205 are within the

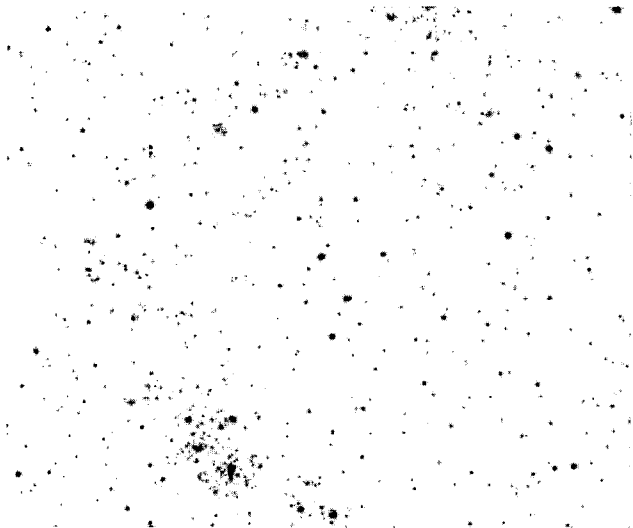


Fig. 2.— This image presents a section of the outer disk of M31 in the light of $H\alpha + [N II]\lambda 6584$, demonstrating the wealth of detail to be studied.

area covered by the four central fields. For each field and in each filter, sets of five dithered images were obtained in order to eventually fill in the gaps between the CCD detectors.

The data were reduced using the `mscred` package within the Imaging Reduction and Analysis Facility (IRAF)* environment. We adopted the reduction sequence presented by Valdes (2001), of which the following is a brief summary. The bias images obtained during the run were subtracted of overscan and combined to form a master bias image. This master bias image was then subtracted from all other overscan-subtracted images. Flat field images were taken of the illuminated screen on the dome wall daily. Several times during the run, evening or morning twilight flat fields were obtained since we found that the illumination of the dome flats depended sensibly upon the pointing of the telescope. The dome flats were combined and used to correct the pixel-to-pixel sensitivity variations. The sky flats were combined and used to correct for the large-scale variations. During these preliminary reductions, all of the images were corrected for the cross-talk between the pairs of CCDs connected to a single controller. Astrometric solutions were then determined for all of the images of a given field in all filters. All of the images of a given field were re-interpolated to a common coordinate system and then summed to produce the final images in each filter.

Examples of our data are shown in Figs. 1 and 2. The first presents the area including the dwarf spheroidal galaxy NGC 205. All of its known planetary neb-

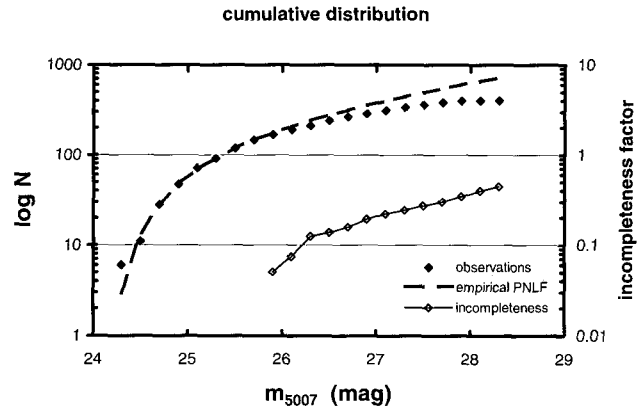


Fig. 3.— Here, we present the cumulative PNLF for the SExtractor sample (left and bottom axes; instrumental magnitudes). At this point, we have not defined statistically-complete samples (Ciardullo et al. 1989). Nonetheless, comparison with the empirical PNLF shows that this sample is 90% complete to 2 mag below the peak of the PNLF in the bulge of M31.

ulae that are within 2.7 mag of the PNLF peak in M31 are recovered. The second presents a gallery of H II regions in the outer disk of M31.

III. PN SELECTION

We plan to search for planetary nebulae using the usual comparison of on- and off-band images, e.g., Ciardullo et al. (1989). In the four central fields where the light is dominated by M31's disk, however, we shall include information from the $H\alpha$ and $[S II]\lambda\lambda 6716, 6731$ images in which filters planetary should be faint and invisible, respectively. In the ten halo fields, the planetary nebula selection will be based entirely upon the $[O III]\lambda 5007$ on- and off-band images. In the disk of M31, we shall also catalogue H II regions and supernova remnants through a comparison of the $[O III]\lambda 5007$, $H\alpha$, and $[S II]\lambda\lambda 6716, 6731$ images. It may also be possible to study the diffuse ionized gas in the disk of M31 from these data.

In our initial search for planetary nebulae, the $[O III]\lambda 5007$ images were searched for point sources using the SExtractor package. The $[O III]\lambda 5007$ point sources without a counterpart in the 5300\AA continuum images were deemed to be planetary nebula candidates. Our initial trial with SExtractor yielded 407 $[O III]\lambda 5007$ point sources without continuum magnitudes and another 563 with continuum magnitudes. We expect that the entire first group are candidate planetary nebulae. Most of the second group are also likely to be candidate planetary nebulae, but they are generally fainter than the first group. This initial search for planetary nebula candidates yielded fewer objects in the bulge of M31 than the survey of Ciardullo et al. (1989).

We suspected that our results might differ from

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those of Ciardullo et al. (1989) due to a difference in sensitivity. We then re-interpolated the four central fields to a common coordinate system and combined the overlapping images to produce a deeper image of M31's bulge. We filtered this image to produce an unsharp-masked image in order to better reveal the point sources. DAOphot was then used to find these point sources and to perform the subsequent photometry on the original $[\text{O III}]\lambda 5007$ and 5300\AA continuum images that was used to obtain magnitudes. This attempt yielded 300 candidate planetary nebulae within a radius of 0.25° of the nucleus of M31, about 100 more than the SExtractor attempt (considering both groups of SExtractor candidates).

Comparing our recovery of planetary nebulae with the known planetary nebulae in the central part of M31, M32, and NGC 205, our automated techniques appear to be having trouble recovering objects in the presence of varying backgrounds. It is therefore clear that we shall have to improve our search techniques and criteria in order to produce a final set of planetary nebula candidates throughout M31, M32, and NGC 205.

IV. PRELIMINARY RESULTS

We fit analytical planetary nebula luminosity functions to our two sets of planetary nebula candidates. The results based upon the SExtractor sample are shown in Fig. 3. The results indicate that both sets of candidates are approximately 90% complete within the first two magnitudes of the luminosity function. The depth and completeness will likely improve once we are able to recalibrate the magnitudes of the planetary nebulae with the highest radial velocities.

As a result of our better spatial resolution compared to published studies (Ciardullo et al. 1989), some interesting inferences may be drawn. On the one hand, our higher spatial resolution allows us to conclude that a fraction of the planetary nebula candidates found in previous studies may be artifacts, and we consequently recover fewer candidate planetary nebulae. On the other hand, our higher spatial sampling reduces our sensitivity to diffuse sources, i.e., the stellar background light in M32 and the bulge of M31, which will likely make our survey less sensitive to fainter planetary nebulae. Clearly, understanding our observational limitations and the resultant completeness of our sample of planetary nebula candidates will require a careful, detailed study.

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