Part II

Planetary Nebulae Surveys and their Distribution in Galaxies

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PLANETARY NEBULAE: THEIR EVOLUTION AND ROLE IN THE UNIVERSE
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A Rich New Vein of Planetary Nebulae From the AAO/UKST Hα Survey

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Abstract. We report on an unprecedented source of Planetary Nebulae (PN) discovered from AAO/UKST Hα survey images of the Southern Galactic Plane. A pristine region of PN discovery space is being sampled due to the excellent depth, coverage, resolution and uniformity of the Hα survey. Large numbers of new PN are being found ($\sim$1000 so far). They are typically more evolved, obscurred and of lower surface brightness than in most other surveys. The doubling of known PN should have a significant impact on many aspects of PN research.

1. Introduction

PN studies are essential for improving our understanding of the later evolution of low mass stars. They provide vital probes for nucleosynthesis processes and for abundance gradients and ISM chemical enrichment, acting as powerful tracers of our Galaxy's star formation history. However, due to the relatively small numbers previously known (i.e. $\sim$1500) compared to those expected ($\sim$20000+) their potential as tracers of galactic structure and as windows to stellar evolution in the critical phase between PN and White Dwarf has only been partially realised. This is particularly true of the evolved PN where there was, until now, a serious paucity for study. The vast majority of known PN have come from Schmidt plate searches. Several newer programmes, based on CCD narrow-band imaging in regions like the Galactic Bulge where expected number densities are high, have revealed new PN over the relatively small areas that can be surveyed, though the numbers remain modest, e.g. Beaulieu et al. (1999) - 56 new PN. Other programmes have made use of specific PN IRAS colours through the far-infrared excess associated with warm dust in the nebulae (e.g. Ratag & Pottash 1991, and Van de Steene & Pottash 1995, who identified 63 new PN and 67 possible PN). Generally though, additions to PN numbers are rather piecemeal;

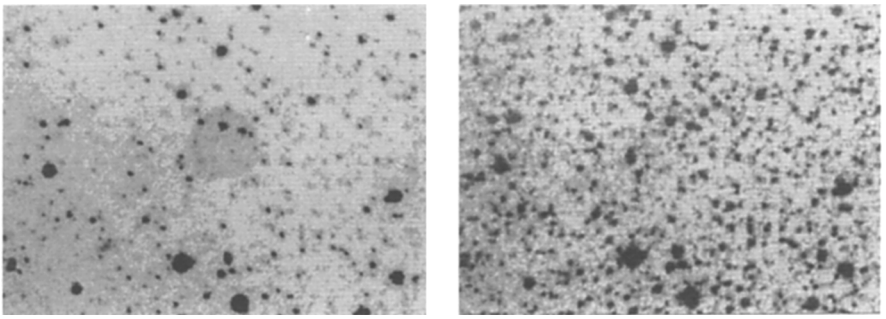

Figure 1. Left image: New PN discovered on a Hα survey exposure; Right: same area from the standard deep 1-hour R survey exposure where the PN remains basically invisible, images are $5 \times 4'$

it is not unusual for papers to be dedicated to a handful of discoveries; e.g. Weinberger et al. (1997) - 3 PN; Beer & Vaughan (1999) - 2 PN. Here we move into a new realm of Galactic PN discovery space by reporting on a significant new source of galactic PN ($\sim$1000 so far) found *solely* from the AAO/UKST Hα survey.

2. The AAO/UKST Hα survey

The AAO/UKST is undertaking a high resolution, narrow-band Hα survey of the Southern Galactic Plane using the world's largest optical interference filter for astronomy (e.g. Parker & Phillipps 2001). A survey of gaseous emission with an unprecedented combination of coverage, resolution and sensitivity is being produced, superior to any existing survey of this type. It covers a swathe approximately 20 degrees wide along the Galactic Plane. Details of the Hα survey can be found on-line at: http://www.roe.ac.uk/wfau/halpha/halpha.html.

3. PN Discovery Technique

The current new PN sample has been discovered from careful visual scrutiny of Hα survey material on a field by field basis by at least two members of the scanning team. Visual scanning remains effective at finding resolved candidate PN on the basis of morphology, isolation and identification as an Hα nebulosity. These objects neither resemble stars (unless they are unresolved/barely resolved) nor, usually, galaxies. Together with their usual low surface brightness they would not normally be detectable via standard star/galaxy separation techniques applied to the SuperCOSMOS digital data currently being produced from survey film scans.

There is considerable overlap between fields so many candidate PN are seen on more than one survey field. Potential contamination from galaxies and reflection nebulosities is eliminated via comparison with the matching, contemporaneous broad-band R exposures which accompany each Hα exposure. Their appearance remains essentially the same between the two exposure types. These

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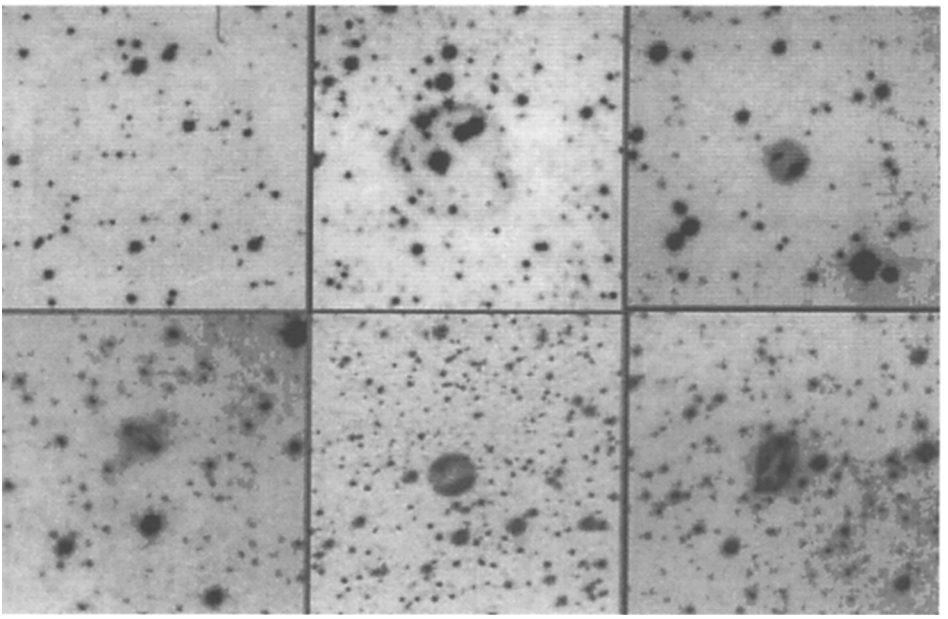

Figure 2. Sample of new PN discovered from visual scans of the AAO/UKST Hα survey exposures - all images $4 \times 4'$

15-minute SR (short-red) exposures are well matched in depth to point source continuum objects such as stars in the 3-hour Hα exposures. The great majority of HII regions are rejected on the basis of environment (i.e. in general star forming regions) and morphology (i.e. irregular shapes, dust-lanes etc). Comparison with mid-infrared images from MSX can also prove valuable in this regard (Cohen and Parker, these proceedings). Remaining contaminating HII regions are often identified via follow-up spectroscopy. SNRs are eliminated by their strong [SII] spectral signature and filamentary morphology. Likewise the occasional Herbig-Haro object is removed on the basis of environment (in star forming regions) and morphology. Ordinary nebulosities around bright stars are identified via spectroscopy. The majority of PN discovered have classic PN-type morphologies (i.e. bi-polar, symmetric rings, shells, discs or ovals). Occasionally, neither the candidate morphology and/nor spectroscopy are sufficiently conclusive to merit a definite PN designation. Such candidates are recorded as possible PN in the database. Only 4 contaminating galaxies have been found from the follow-up spectroscopy and these were local galaxies with active star formation. Hα images of some of the new PN discovered are given in Fig.2

The new PN are given a unique catalogue identifier based on the initials of the prime discoverers (Parker, Hartley, Russeil) and a concatenation of the RA hours and minutes and the DEC degrees and minutes of the J2000 co-ordinates (e.g. PHR1706-3528). The standard PN Glll.l±bb.b designation is also given. The J2000 RA/DEC's determined for the new PN are generally accurate to 1-5″ as evidenced by the agreement with the positions of known PN. This accuracy may decrease for large candidates where a subjective assessment is made as to

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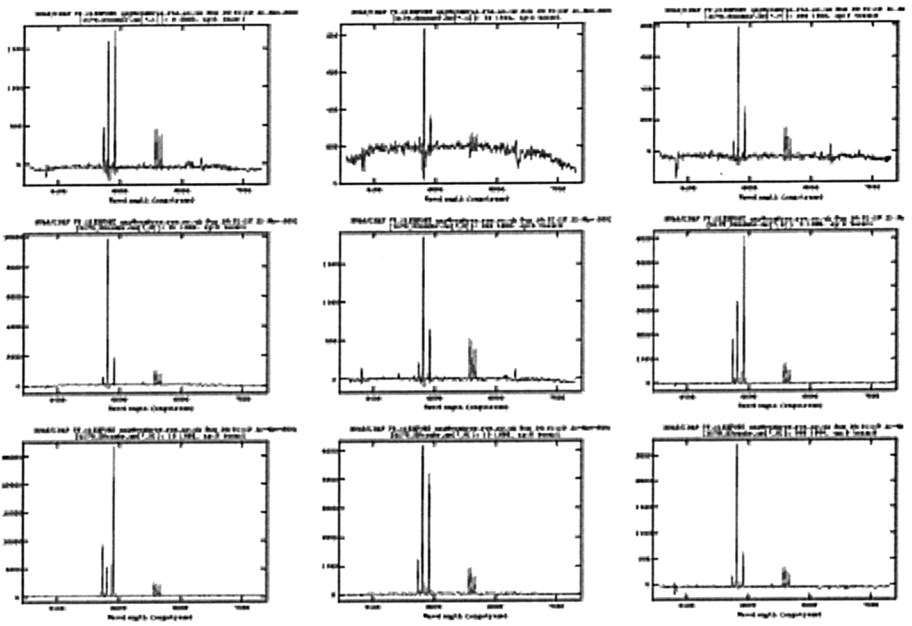

Figure 3. Plot of consecutive 6dF MOS fibre spectra of candidate PN in a single Hα survey field taken with a 1200R grating (high resolution) around Hα

the object's geometric centre. Positions are determined via reference to the on-line SuperCOSMOS sky survey (SSS) data making use of the WCS in the image fits header. Since the PN are generally invisible on the broad-band R SSS images, PN positions are determined via reference to the surrounding star pattern which appears essentially identical on the Hα image and SSS counterpart. The measured angular extents represent an estimate of image size as seen in Hα light to the nearest arcsecond. The accuracy depends on the morphological preciseness of the PN with outer boundaries being harder to determine for more diffuse candidates.

4. The PN Catalogue

The new PN catalogue being assembled, the preliminary version of which has been distributed on cd-rom at this meeting (Parker et al. these proceedings), contains over 900 new and possible PN discovered from scrutiny of 68% of the Hα survey fields. A large programme of follow-up spectroscopy is underway to confirm identification, to give velocities for kinematics, to specify excitation class, determine line diagnostics such as electron density and to tie in the spectral information with the observed morphology. More than 700 spectra have already been obtained from a variety of 2m class telescopes. Examples of candidate PN spectra taken from consecutive fibres with the 6dF MOS system on the UKST (e.g. Watson, Parker & Miziarski 1998) are given in Fig.3.

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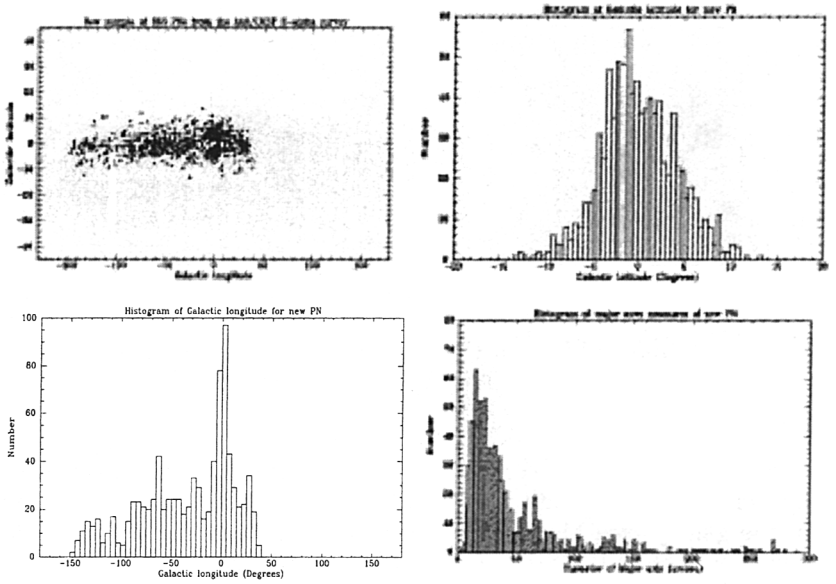

Figure 4. Plots for new PN sample (none common to published catalogues). Left top: l,b plot ; Right top: latitude histogram - note PN found right down to $|b| = 0°$; Left bottom: longitude histogram; Right bottom: Histogram of major axis diameter in arcseconds

5. Basic properties of the new sample

A large fraction of our sample are of low surface brightness with average angular sizes of 51″ and median of 27″ but with objects extending to several arcminutes. This compares with an average of $< 10''$ for PN in the Acker et al. (1992) catalogue. This may indicate that many of our sample are in a highly evolved state and/or local, where the central star has faded from easy optical detection and the nebula itself is dissolving into the ambient ISM. Another great advantage of this new survey is that all the discoveries originate from the same observational data ,potentially yielding the largest and most homogeneous catalogue to date.

5.1. Some basic statistics and plots

A few basic plots of the new data are provided here for convenience in Fig.4. The labels describe the plots which include an l,b plot and a histogram of galactic latitude for about 900 new/probable PN. Note in particular that the zone of avoidance at low b previously seen in plots of this type is essentially absent in this new plot as we are able to find PN right down to $|b| = 0°$.

5.2. A few highlights from the new sample

To indicate the various areas of PN research that this significant new sample can address we give a few examples of highlights discovered so far, including identification of several rare and unusual objects.

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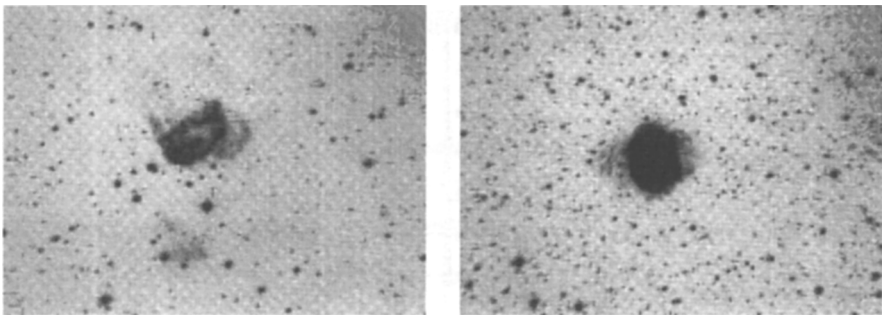

Figure 5. Examples of known PN showing new external shells and ansae revealed by the new deep AAO/UKST Hα imaging

- Discovery of 7 Wolf-Rayet central stars of new PN from follow-up spectroscopy of $\sim$ 700 candidate PN including the possible first WN central star in the galaxy (see Morgan & Parker, these proceedings). This compares with only 56 WR CSPN currently known (Jeffery et al. 1996).

- Discovery of several candidate halo PN with velocities $>$ 300km/s towards the Galactic Centre.

- Discovery of a PN in an old open cluster (Parker et al. in preparation). This is an extremely rare and valuable find as the known cluster (and hence PN) distance enables accurate estimates of PN parameters.

- Identification of large numbers of evolved PN, many with angular sizes in excess of $100''$ extending to $8'$.

- Discovery of several PN pairs with separations of $< 2'$

- Revelation of additional shells, ansae and lobes around many known PN (see Fig.5). This may help with addressing the problem of PN missing mass, with many indicating evidence of previous episodes of ejecta. Their new angular dimensions should lead to re-evaluation of many statistical distance estimates.

- Specific discovery of two faint equidistant lobes $10.7'$ either side of the well known bi-polar PN NGC2899 (Parker, 2000), probably making this object one of the largest and closest PN to the Sun.

- Discovery of several hundred PN in the Galactic Bulge region, many of which have already been confirmed via FLAIR/6dF MOS spectroscopy on the UKST. These Bulge PN can act as valuable test particles for studying the dynamics of our galaxy.

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6. Importance of the new PN catalogue

It is difficult not to underrate the importance of this large new PN sample for research into stellar evolution and Galactic structure. We will not only double PN numbers, providing a boon for various statistical studies, but will contribute particularly to the faint end of the PN luminosity function. Studies of interactions with the ambient ISM for the large numbers of evolved PN found will also be enhanced. Such PN are excellent probes of PN-ISM interactions (e.g. Xilouris et al. 1996). The few 'senile' PN found so far have merited detailed follow-up (e.g. Romano et al. 1997). Evidence suggests that evolved PN are expanding more slowly than those less evolved (Hippelein and Weinberger, 1990) and many are interacting directly with the ISM (Tweedy & Kwitter 1994) providing data for ISM studies on small scales. Finding evolved PN and their central stars can help us understand stellar evolution during the critical transition phase between PN and white dwarf (Napiwotzki 1995). Jacoby and van de Steene (1995) give a compelling overview of why it is important to identify remnant PN. There is a severe paucity of observational data of evolved PN (Tweedy & Kwitter 1996) which our new catalogue should help address.

7. Future prospects

SuperCOSMOS digital data from the original Hα/SR film pairs will soon become available for the Hα survey and our subjective visual scanning programme will be replaced by objectively identifying, over the entire survey, very faint or missed PN and by revealing the expected large numbers of compact/barely resolved PN to which our simple visual searches are insensitive (via processing Hα/SR quotient imaging). Note that $\sim$ 30% of PN in previous catalogues have angular size $< 6''$ so large numbers of faint point source/barely resolved candidates can be expected from our survey from the quotient imaging. This technique works well because the Hα and SR data point spread functions are very similar (same point source depth, same telescope, emulsion etc). A preliminary study from SuperCOSMOS data in one bulge field found 300 candidate PN (Peyaud 2001). Six examples are given in Fig.6 with basic quotient imaging (not yet fully processed). Many have already been verified as PN via follow-up spectroscopy with the 6dF MOS system on the AAO/UKST. In a future catalogue release the PN images will be replaced by full-resolution SuperCOSMOS pixel data for the Hα and SR images. For particularly faint candidates or those in very crowded star fields these will be supplemented/replaced by the quotient imaging.

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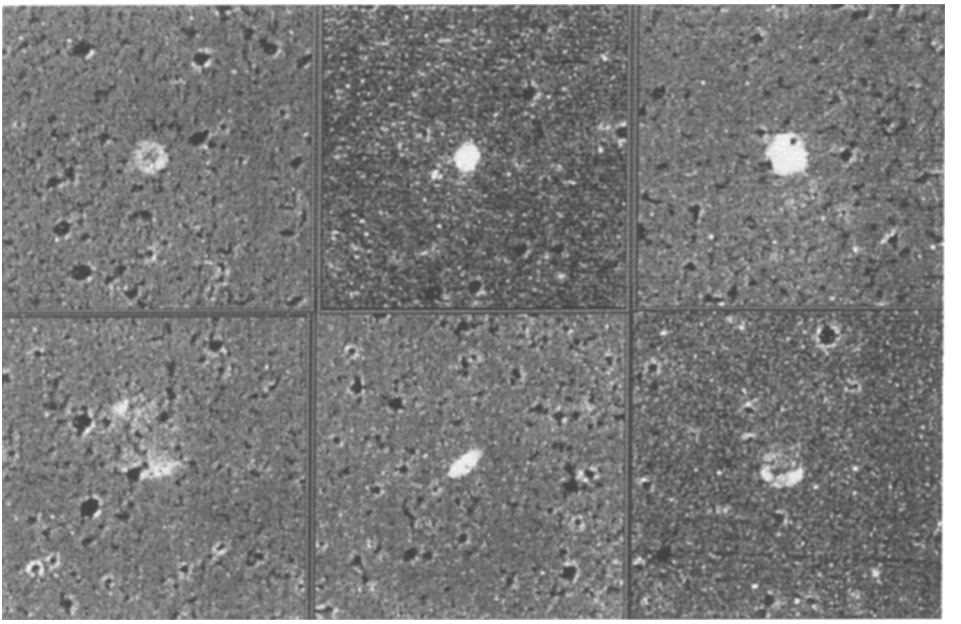

Figure 6. Faint, new Galactic Bulge PN discovered from SuperCOSMOS data via basic quotient imaging of the matched Hα and SR data

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