POPIPlaN: A Deep Morphological Catalogue of Newly Discovered Southern Planetary Nebulae

Henri M. J. Boffin[1]
David Jones[1]
Yuri Beletsky[2]
Mario van den Ancker[1]
Jonathan Smoker[1]
Dimitri Gadotti[1]
Ivo Saviane[1]
Sabine Moehler[1]
Valentin D. Ivanov[1]
Linda Schmidtobreick[1]
and the UT1 team*

[1] ESO
[2] Las Campanas Observatory, Chile

Planetary nebulae (PNe) are amongst the most complex and varied of celestial objects, displaying a wide range of shapes and colours that are difficult to explain. Using the FORS2 instrument — mostly when no other observations can be performed — we have started to build up a homogeneous morphological catalogue of deep two-colour narrowband images of newly discovered PNe. The catalogue will be public and should soon become an invaluable tool for the community.

Planetary nebulae are a fleeting phenomenon lasting a few tens of thousands of years, thought to be the final swansong for stars of 1 to 8 $M_\odot$. During this dying phase, their small but hot core is unveiled, and starts to cool down to become a white dwarf. The ejected envelope is ionised and emits strongly in the lines of several elements. The misnomer "planetary" stems from the fact that some of these nearby objects resemble the discs of the giant planets in the Solar System when viewed with a small telescope. PNe are essential for the understanding of the evolution and mass loss of Sun-like stars, and because they lose much of their processed material into the interstellar medium, they contribute significantly to our Galaxy's chemical evolution. In fact, the late stages in the evolution of Sun-like stars are the main contributors of carbon enrichment in the Universe — the main reason that we are all "stardust". Moreover, planetary nebulae can be detected out to large distances from their strong emission lines and thus serve as a means whereby the motions and abundances of stars in the halo regions of distant galaxies can be investigated.

Morphology of planetary nebulae

Quite astonishingly, PNe display great variation in their shapes, ranging from spherical through to highly asymmetric, including complex substructural features like jets, filaments and rings. One estimate has it that approximately 80 % of all planetary nebulae exhibit non-spherical morphologies (Parker et al., 2006). The debate as to why this is so has been raging for decades (see Balick & Frank, 2002), and despite the numerous advances in the last ten to twenty years, a convincing answer is still lacking, although the binary hypothesis is gaining more and more ground (De Marco, 2009). Stellar or even sub-stellar companions can interact with upper asymptotic giant branch (AGB) stars and shape the ejected envelope (and therefore the subsequent nebula) either by strong interactions such as common envelopes (Paczynski, 1976; Sandquist et al., 2008) or wider binary interactions such as wind accretion and gravitational focusing (Theuns et al., 1996; Nagae et al., 2004).

The binary hypothesis faces, however, an apparent paradox: the fraction of stellar companions to the progenitors of AGB stars (the precursor stage to a planetary nebula) that may interact is of the order of 30 % (Duquennoy & Mayor, 1991), so how can the fraction of non-spherical PNe be as high as 80 %? Several authors have noted that this discrepancy could be explained if not all the 1–8 $M_\odot$ stars produce a PN. Moe & De Marco (2006) argued that only ~ 20 % of intermediate-mass stars make a PN, while the remainder transit between the giant and white dwarf phases with invisible, or under-luminous nebulae (De Marco, 2011). Soker & Subag (2005) predicted the existence of a large (relative to that of non-spherical PNe), hidden population of spherical PNe that would only be found by deep searches. As noted by De Marco (2011), this prediction has been partly borne out by MASH, a deep PN survey that doubled the fraction of spherical PN from ~ 10 % to ~ 20 % (Parker et al., 2006; Miszalski et al., 2008) and by the Deep Sky Hunters survey, which found a similar fraction in the very faint population (Jacoby et al., 2011).

The recent publication of the Macquarie/AAO/Strasbourg Hα PNe catalogue (MASH) presented about 1200 new, spectroscopically confirmed Galactic PNe, boosting the number of Galactic PNe by nearly 80 % and offering considerable scope to address problems in PN research afresh. MASH presents a most homogeneous sample of PNe over a wide evolutionary range, including evolved PNe and those interacting with the interstellar medium (ISM). The MASH PNe are typically more evolved, obscured, of larger angular extent and lower surface brightness than those in most other surveys. As such the MASH catalogue is an invaluable source for further studies requiring the use of large telescopes.

Miszalski et al. (2009), for example, revealed, by cross-correlating the MASH and OGLE-III catalogues and obtaining follow-up imaging with 8-metre-class telescopes, morphological trends induced by the presence of a close binary companion. Canonical bipolar nebulae, low ionisation structures (LIS), particularly in ring configurations, and polar outflows or jets were identified as being prevalent amongst PNe with binary central stars, and therefore associated with the influence of a binary central star. If this association were confirmed, it would help to fast track the discovery of the binaries in PNe and thereby constrain their role in the shaping (and possibly formation) of PNe.

* The UT1 team is comprised of all people involved in the operations of Antu, the Unit Telescope 1 of ESO's Very Large Telescope: Andrea Ahumada, Karla Aubel, Yuri Beletsky, Henri Boffin, Claudia Cid, Lorena Faúndez, Dimitri Gadotti, Patricia Guajardo, Sylvain Guieu, Michael Hilker, Wolfgang Hummel, Valentin Ivanov, David Jones, Sabine Moehler, Andres Parraguez, Ferdinando Patat, Retha Pretorius, Myriam Rodrigues, Leo Rivas, Ivo Saviane, Linda Schmidtobreick, Alain Smette, Jonathan Smoker, Mario van den Ancker, and Sergio Vera.

Morphological studies of PNe require an extensive and homogeneous database. Schwarz, Corradi, & Melnick (1992) imaged 255 PNe, through Hα+[N II] and [O III]5007 Å filters with EFOSC2 at the New Technology Telescope, during commissioning time, when the instrument rotator was not available. This catalogue proved very useful and continues to be well cited. More recently, Sahai, Morris & Villar (2011) produced a catalogue of 119 young PNe imaged by the Hubble Space Telescope, which they used to devise a new classification system.

The POPIPlaN survey

The availability of the MASH catalogue, which provides us with the necessary homogeneous sample to perform a detailed morphological classification, coupled to the great collecting power of the Very Large Telescope (VLT), prompted us to start POPIPlaN — the Paranal Observatory Project to Image Planetary Nebulae. The MASH survey generally provides only modest quality images, given that it was a photographic survey from a Schmidt telescope (spatial sampling of 1 arcsecond per pixel and limited dynamic range) at a relatively poor seeing site. High-quality images were desperately needed and this is exactly the aim of POPIPlaN: to create a homogeneous and complete morphological catalogue of the newly discovered MASH southern PNe, using deep, narrowband imaging with the FORS2 instrument at the VLT.

This new catalogue will by no means duplicate any existing one, but on the contrary provide much needed material required for follow-up studies. These will include, but not be limited to: derivation of statistics regarding various shapes, such as LIS, rings and jets; determination of binarity and the relationship between the presence of certain morphological traits and a central binary; studies of the interaction of PN envelopes with the ISM; analysis of the link between PNe and symbiotic stars; deeper and more detailed study with HST or adaptive optics instrumentation; kinematical studies of the newly discovered structures; and understanding the formation of the nebula and the timing of the formation of jets.

A proposal was submitted to the OPC and POPIPlaN was granted 66 hours in Observing Period 88 (P88) (Prog. 088.D-0514(A); PI: H. Boffin) and 66 hours in P89 (Prog. 089.D-0357(A); PI: H. Boffin). A proposal has also been submitted for P90 to finish the catalogue.

POPIPlaN, was specifically designed as a filler for Unit Telescope 1 (UT1) at the VLT, to be carried out in service mode by Paranal staff. The observations are done in twilight, or under thin (THN) or thick (THK) clouds. We have analysed the weather statistics for the last two years and find that there are THK conditions on at least part of 15 nights per period that could be used by our programme, as well as other occasions with THN conditions and strong wind from the north. Although the majority of our programme was done with the MIT CCD of FORS2, some of the observations were also performed when the blue E2V CCD was installed in FORS2 and nothing else could be observed. Our strategy proved extremely efficient as in P88 our programme was 95 % completed, with 230 observations done, either during bad weather or twilight. For each object, we take images, with a sampling of 0.25 arcsecond (2 × 2 pixel binning), in Hα+[N II] (with the H_Alpha+83 FORS2 filter) and [O III] (O III+50 filter), and exposure times between 240 s and 450 s, the majority being 300 s. For some objects, we have also obtained images in [O II] 3727 Å and [S III] 6723 Å as well as in the *B*- and *I*-broadband filters in order to help identify the central star. The constraints were set such that images could be taken when the seeing was below 1.2 arcseconds, or 1.4 arcseconds for a small subset, but in reality, most of the images have been taken under much better seeing conditions. Some of our images have a full width at half maximum of about 0.4 arcseconds!

POPIPlaN images

The images obtained in P88 unveil, as expected, a wide variety of intricate shapes and structures, revealing for the first time in these objects, rings, multipolar and imbricated shells and other low ionisation structures, as well as shocks. Figures 1–3 show some of the images obtained. Photometric follow-up has already been started for those PNe showing clear rings or jets, as they most likely harbour close binaries at their centre.

Since POPIPlan is aimed at creating a catalogue of great value to the community, the data have no proprietary period, thus allowing anyone to make use of them as soon as possible and prepare follow-up observations. In addition, all the images are reduced by us and made available as FITS files and as JPEG images. A colour-composite image is also produced. Sizes and important morpho-

Figure 1. Colour-composite of the planetary nebula PN G061.4-09.5, a magnificent example of an elongated elliptical planetary nebula, with a barrel-like waist and "ansae" marking the ends of the extended ellipse. The image is based on two exposures of 240 s, taken through the Hα and [O III] filters with FORS2 on the VLT. The image covers 2.36 × 1.6 arcmin^2 on the sky. In all figures, North is up and East is to the left.

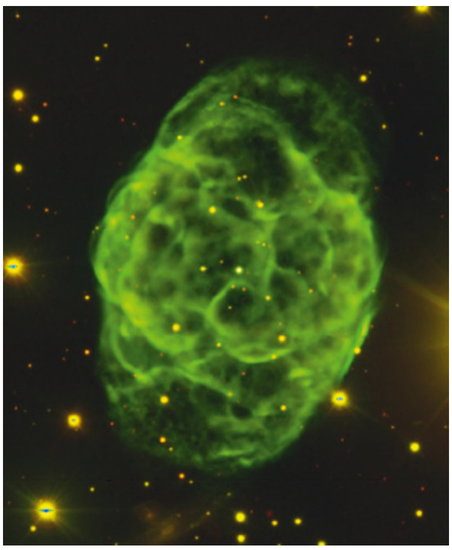

Figure 2. Colour composite of PN G059.7-18.7, showing an intricate network of low ionisation features. Slightly to the south a pair of more distant galaxies can be seen. The image size is 2.37 by 3.1 arcminutes.

Figure 3. Collage of four images of planetary nebulae imaged in POPIPlaN. (Upper) PN G247.8+04.9 (image: 5.4 by 2.6 arcminutes) is a very extended and evolved nebula showing a clear signature of interaction with the interstellar medium; (middle left) PN G250.3-05.4 contains a slightly brighter X-shaped core (image size 2.5 by 1.4 arcminutes); (middle right) PN G224.3-03.4 is a round nebula whose southeastern edge appears greatly enhanced, most likely due to the interaction with the ISM (image size 2.5 by 1.4 arcminutes); (lower) PNG 307.3+02.0 is a canonical bipolar nebula with a bright ring-like waist (seen almost edge-on).

logical features will be indicated. In the future, all images will also be made available through the VizieR interface of the CDS in Strasbourg. The catalogue is temporally available on a web page[1].

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Links

[1] POPIPlaN images available: http://www.eso.org/~hboffin/POPIPlaN/