Searching for long period binary central stars of planetary nebulae with SALT HRS

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1. BINARIES SHAPING PLANETARY NEBULAE

Planetary nebulae (PNe) are the ionised envelopes of low to intermediate mass stars ejected near the end of their lives (e.g. **Figure 1**). A stellar (or even planetary) companion is the leading explanation for their complex and diverse shapes (De Marco 2009).

Historically only a dozen or so binary central stars were known (Bond 2000), but recent efforts have boosted this to about 50 examples. The majority of these are post-common-envelope binaries with orbital periods of 1 day or less **(Figure 2)**. Companions are usually main sequence stars, but double white dwarfs are also seen. Massive photometric surveys such as OGLE are an efficient means to discover them (Miszalski+2009), but the method is heavily biased to the shortest period systems.

Binaries with orbital periods of a few days or longer are predicted by population synthesis models (e.g. Nie+2012) and observed in related objects such as post-AGB binaries (Van Winckel 2003), but only a handful have been observed in PNe (**Figure 2**). Whether a large fraction of PNe might host such binaries remains uncertain as there are too few binaries known.

In late 2016 we started a systematic radial velocity (RV) monitoring survey of several central stars of PNe with **SALT HRS** to search for long period binaries. With these new discoveries we will build a less biased orbital period distribution to empirically constrain population synthesis models that simulate the evolution of interacting binary stars. These models include physics about several uncertain interaction processes, such as the common-envelope phase. Improving our understanding of these processes will have wide ramifications for binary stellar evolution.

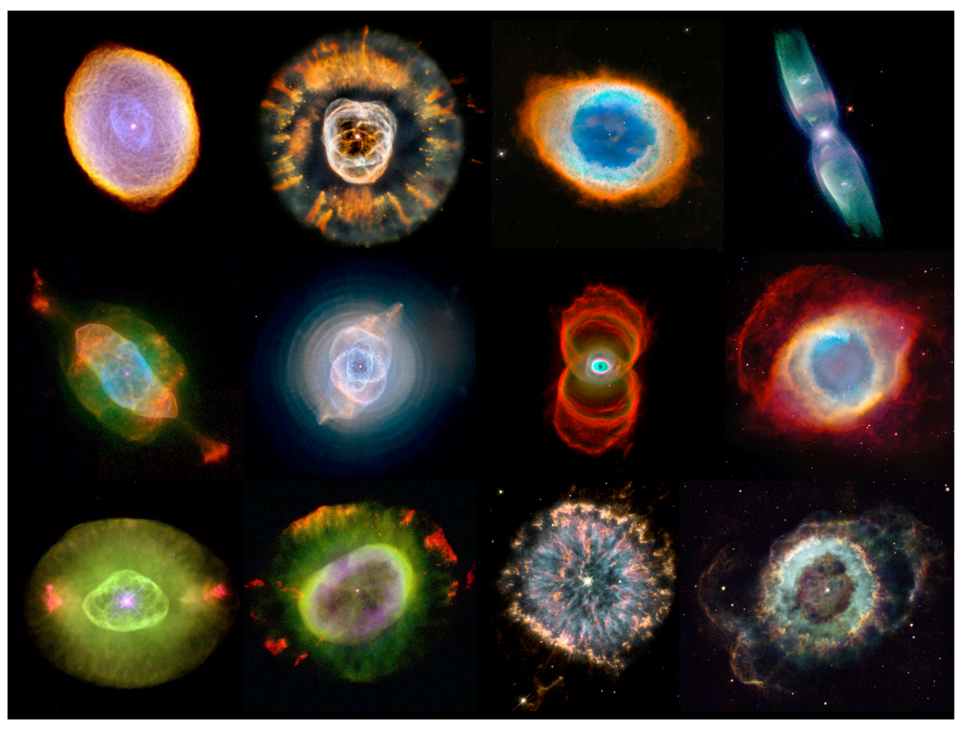


Figure 1. *Hubble Space Telescope* images showing a glimpse of the diverse morphological features of PNe.

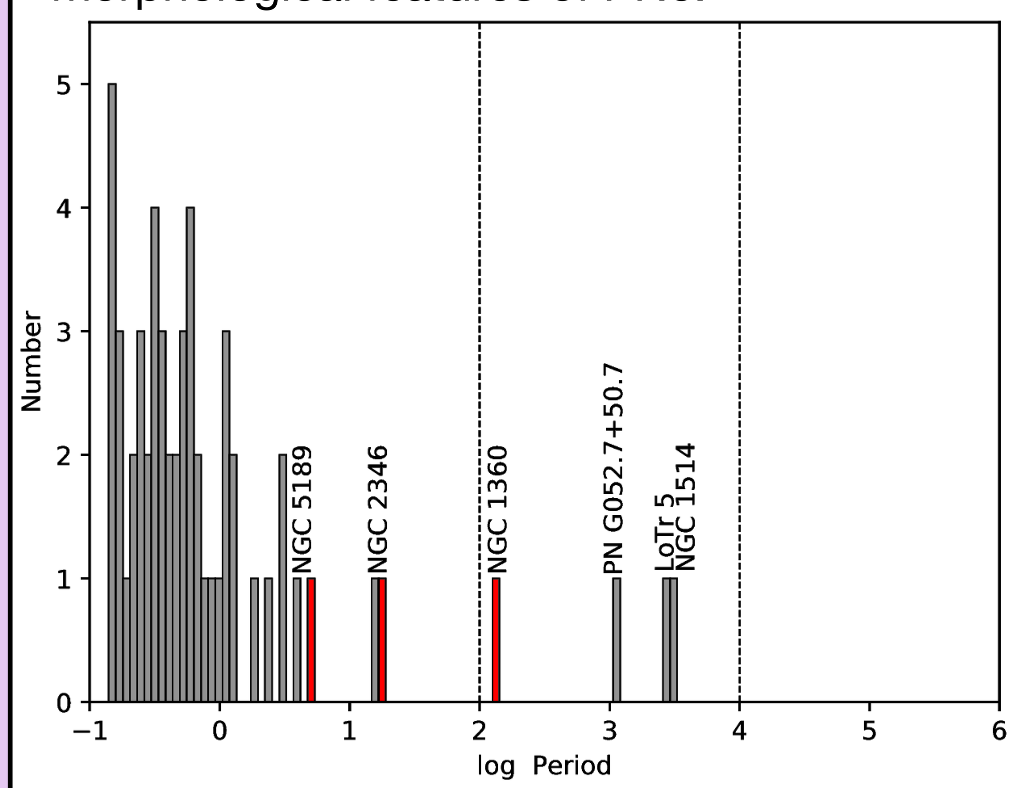
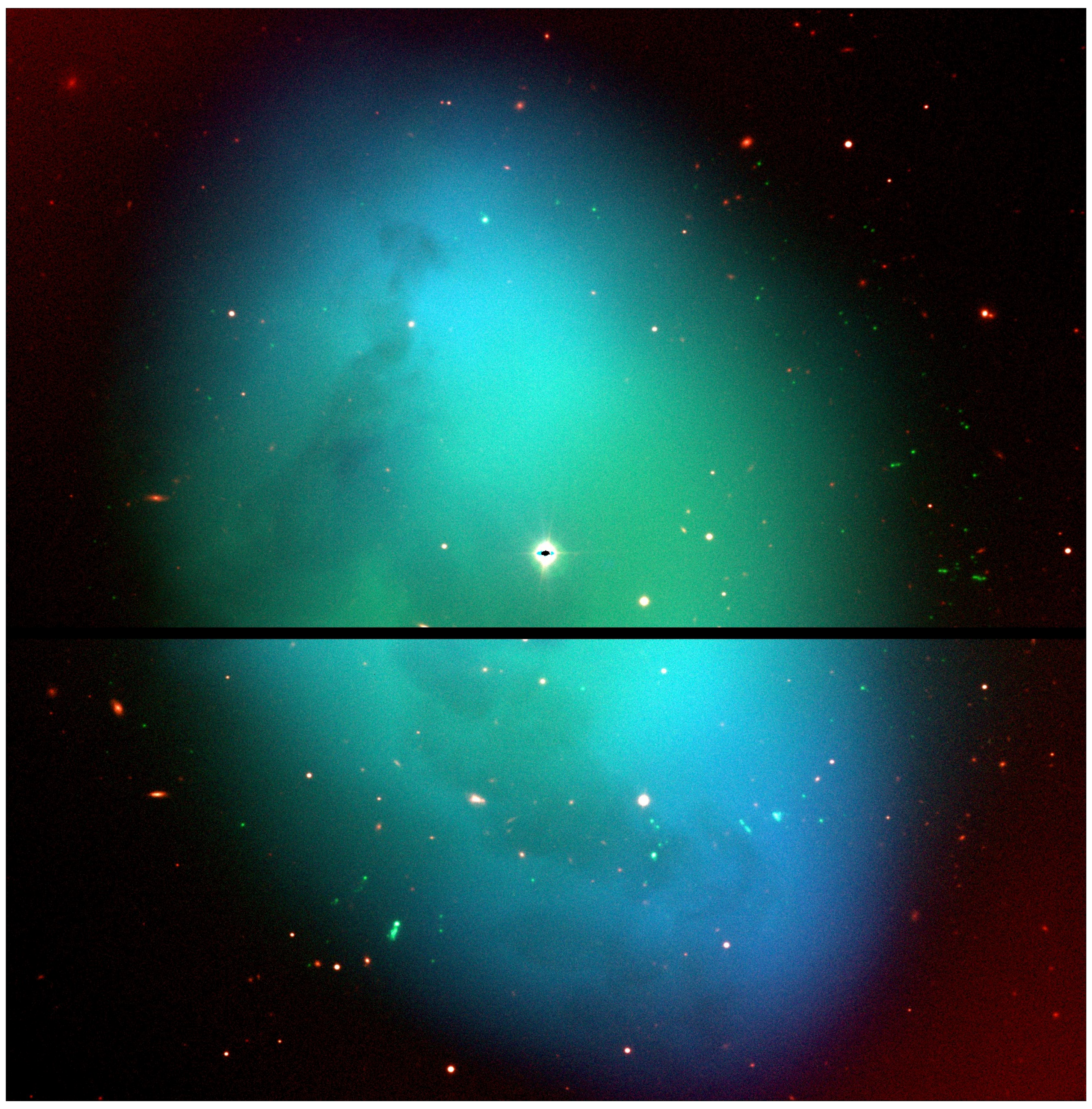


Figure 2. (left) Orbital period distribution of PNe adapted from Miszalski+2018. SALT HRS discoveries so far are shown in **red**. Dashed lines enclose periods largely unexpected by population synthesis models.

2. SALT HRS AS AN IDEAL RADIAL VELOCITY MACHINE

The High Resolution Spectrograph (HRS, Crause+2014) of SALT is a dual-beam, fibre-fed échelle situated underneath SALT inside a vacuum tank within a controlled environment. The medium resolution (R~43 000) mode is ideally suited to finding long orbital period binaries with its stability and sensitivity to small RV changes over long timescales. The queue-scheduled operation of SALT (Väisänen+2016) provides an efficient means to obtain well-sampled RV time-series. Given the long orbital periods we can afford to be patient and are relatively unaffected by bad weather. We aim to obtain 15-20 spectra per object and check variability as the data come in so that adjustments can be made to the sampling rate thanks to the flexibility of the SALT queue. The program is well matched to poorer seeing conditions as our focus is on central stars with V < 15 mag. The broad wavelength coverage of HRS is also very helpful when it comes to measuring RV variability of a wide variety of absorption and emission line features.



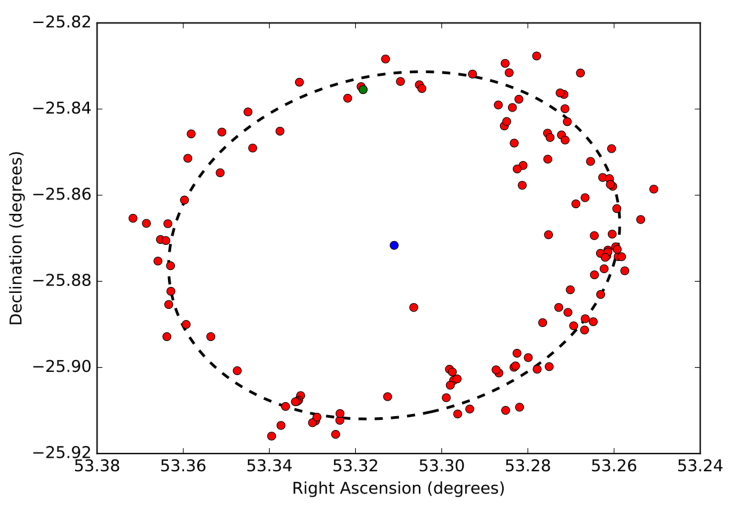


Figure 3. (left) VLT FORS2 image of NGC1360 made from I-band (red), Hα +[NII] (green) and [OIII] (blue) filters (Miszalski+2018). NGC1360 is a prolate ellipsoid (Goldman+2004) and the image measures 7.0 x 7.1 arcmin^2 with North up and East to the left. We discovered a new ring of low-ionisation filaments (green knots) around the central star (bright star above centre). Fitting an ellipse to the ring **(below)** gives an additional constraint on the nebula inclination that is consistent with spatio-kinematic modelling results (Goldman+2004).

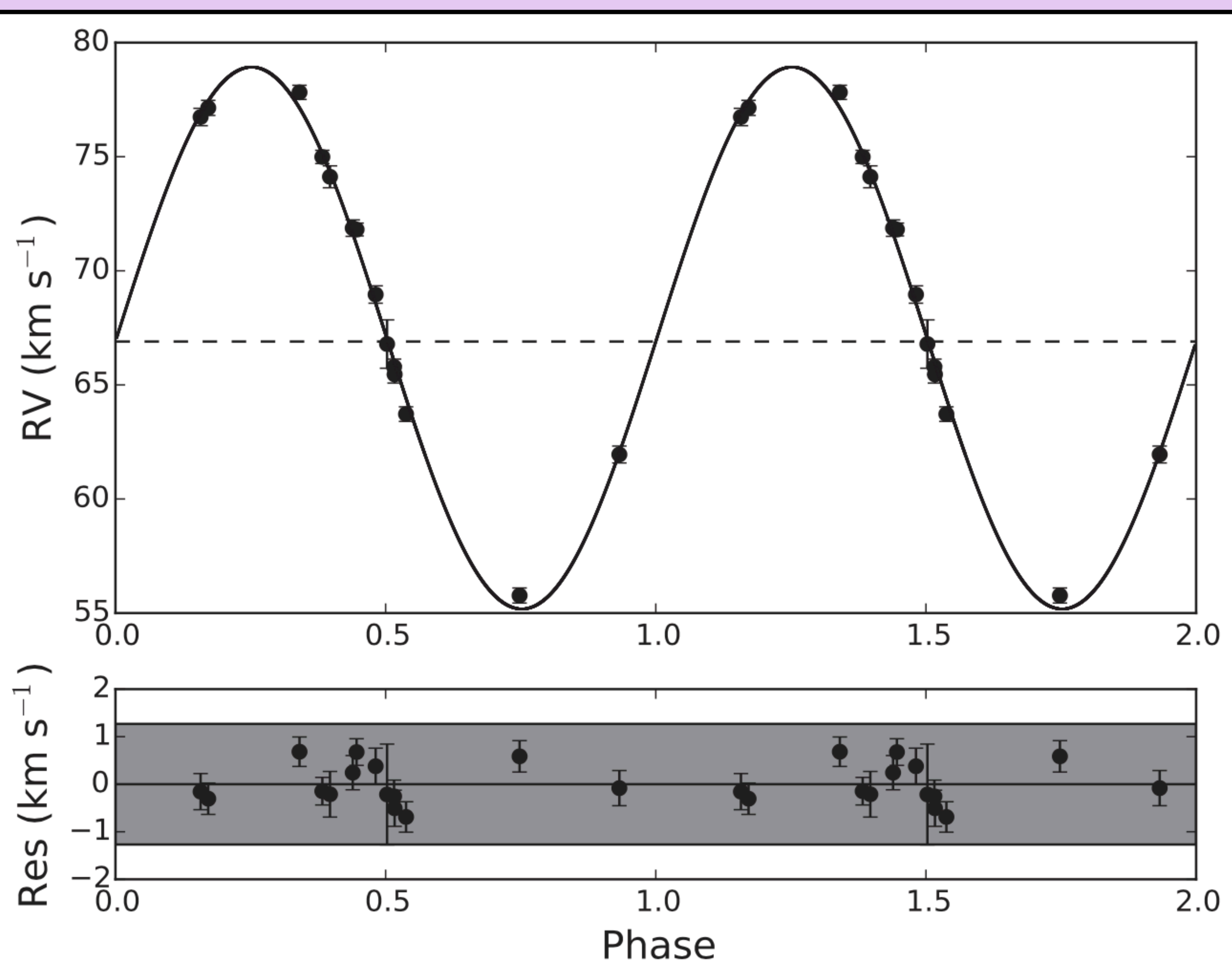


Figure 4. SALT HRS RV measurements of OV λ4930 phased with the 141.6 day orbital period (Miszalski+2018). The shaded region shows the residuals are within 3σ of the Keplerian orbit fit (solid line) where σ=0.42 km s^{-1}.

3. FIRST DISCOVERY: NGC1360

Between October 2016 and March 2017 we obtained 14 HRS spectra of HIP 16566, the V=11.34 mag central star of NGC1360 (PN G220.3−53.9, **Figure 3**). RV measurements were made using the emission line OV λ4930 and a circular Keplerian orbit was fit with a period of 141.6 days (**Figure 4**). Taking the RV semi-amplitude of K=11.8 km s^{-1} and assuming the orbital plane inclination matches the nebula inclination of 30 ± 10 deg (Goldman+2004), we find a companion mass of 0.68 +0.62/-0.21 Msun. The relatively soft *Chandra* X-ray emission (Kastner+2012) and the lack of any mid-infrared excess from *Spitzer* (Miszalski+2018) argues strongly against a main-sequence companion. Instead, the most likely companion is a more massive white dwarf. NGC1360 therefore has the longest orbital period of any double degenerate binary known.

NGC1360 appears to have gone through a common-envelope interaction, with nebula features typical of post-common-envelope PNe (**Figure 3**), albeit with an orbital period considerably longer than predicted by most population synthesis models. We expect NGC1360 and other binary central star discoveries made by SALT HRS will help refine these models and their predictions.

4. FUTURE WORK

SALT HRS observations are ongoing and many new binaries are being monitored. Two new binaries with orbital periods of 18.15 and 4.83 days are being prepared for publication. Other objects require more intensive sampling or a longer time baseline before their orbital periods can be established. In about 2 years the greater time baseline will allow us to announce non-detections and robust survey statistics that will include the first empirical estimate of the percentage of PNe with long period binaries.

5. REFERENCES

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