Two New Close Binary Central Stars of Planetary Nebulae from a Critically Selected Southern Hemisphere Sample

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Abstract. I present the results of time-resolved photometry of a selection of central stars of planetary nebulae. The study reveals periodic variability in two of the eight central stars observed, those of NGC 6026 and NGC 6337. The variability matches that expected from a binary system in which a hot primary irradiates a cooler secondary star.

1. Introduction

Soker (1997) explained planetary nebula (PN) structures using orbital interactions in a binary system, with the companion to the PN progenitor being either stellar or substellar (brown dwarf or planet). Using this theory he classified a large number of PNe, based on their morphology, as either: single progenitor, close stellar companion with no common envelope (CE) phase, close stellar companion with a CE phase, or substellar companion with a CE phase. These predictions provide a good basis for testing the binary theory of PN shaping.

It is understood that for close stellar companions undergoing a CE phase, a significant fraction should become systems with orbital periods on the order of a few days or less. To date, thirteen central stars of planetary nebulae (CSPNe) have been identified as close binaries, with orbital periods determined to be < 16 days (Bond 2000). Bond (2000) gives the fraction of detectable close binaries from a random sample as $\sim 10 - 15\%$.

Here I present the use of time resolved photometry of CSPNe to search for the sinusoidal variations in brightness that would be associated with an irradiated hemisphere of a stellar companion to the central star. Eight southern hemisphere CSPNe classified by Soker (1997) as having a stellar companion that underwent a CE phase were observed. The results support the classification of NGC 6026 and NGC 6337 as close binary stars. I present orbital periods for these systems. My detected binary fraction is also compared to that discovered previously.

2. Observations

The photometric data consist of V-band CCD photometry obtained from 30 April - 4 May, 2002 at the Cerro Tololo Interamerican Observatory (CTIO) 0.9m telescope with the T2K Imager. The observations were carried out such that every object was observed each night for at least one hour and the five-night
The exposures were reduced using the DAOPHOT package of IRAF. The resulting photometry was then analyzed by incomplete ensemble photometry (Honeycutt 1992). The zero points are instrumental magnitudes dependent on the instrumental response of the CTIO 0.9m system.

The light curves were analyzed with periodogram, a program which uses the period search technique of Scargle (1982) as modified by Horne & Baliunas (1986).

Six of the eight stars showed no unambiguous variability. Five of the six: He 2-141, NGC 3132, NGC 4361, NS 238, and Sp 3, were observed on at least four nights, with $55 \leq t \leq 78$ minutes of consecutive observations on at least one of those nights. K 1-1 was observed on three nights with a maximum duration of 64 minutes.

3. NGC 6026

The light curve of NGC 6026 (Figure 1) shows obvious variability and suggests a well-behaved periodic nature over the four nights on which observations were made. The periodogram for NGC 6026 showed periodic variability with a strong one day alias, resulting in a preliminary period of 0.263 days. This period was taken as a starting point for fitting a sine curve of the form

$$V = V_{\text{mean}} + K \sin \left[ \frac{2\pi(T - T_o)}{P} + \phi \right]$$

where $V$ is the instrumental magnitude, $K$ is the semiamplitude, and $P$ is the period; either $T_o$ or $\phi$ is a fitted parameter. For the photometry we fit for $T_o$ plus the remaining parameters and set $\phi = 0.75$ as is appropriate for variation
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Figure 2. Light curve for NGC 6337 by night (left) and the phase-folded light curve of NGC 6337 for the ephemeris in equation 3 (right). The remaining parameters from the sine fitting are $V_{\text{mean}} = 9.3210(7)$ mag (instrumental) and $K = 0.087(1)$ mag.

4. NGC 6337

As with NGC 6026, the light curve of NGC 6337 in Figure 2 shows apparently well-behaved periodic variability. The periodogram showed periodic variability with a strong one day alias. The peak with the most power was located at a period of 0.173 days. Since NGC 6337 appears as a ring, the nebular background close to the central star is at a minimum, allowing more accurate photometry. This, along with the obvious slope to each night of observation allowed all but the highest peak to be rejected. The corresponding period was taken as a starting point for fitting a sine curve of the same form as Equation 1, for NGC 6026. The derived photometric ephemeris for minimum light in NGC 6337 is then

$$T = 2452395.7969(5) + 0.1735(3)E.$$  (3)

Figure 2 shows the light curve folded on this ephemeris and the sine curve fit. The rms variation of the data from the fitted sine curve is 0.016 magnitude.

The remaining parameters from the sine fitting are $V_{\text{mean}} = 12.041(1)$ mag (instrumental) and $K = 0.209(3)$ mag.
5. Comments on Masses, Inclinations, and Binary Fractions

The short orbital periods allow limits to be placed on several of the binary system parameters. Taking the masses of both CSs to be $\sim 0.6 M_\odot$, typical of CSPNe, Kepler’s 2nd law gives the binary separation as a function of secondary mass. The small deviation from a sine curve, short orbital periods, and significant reflection effects observed in the two systems suggest that the companions are cool dwarf stars which do not fill, or just fill, their Roche lobes. To find an upper limit for the secondary masses, I will assume that both secondaries are Main Sequence stars and do not fill their Roche lobes. This condition is met for the two systems, according to their corresponding orbital periods and for $M_1 = 0.6 M_\odot$, by $M_2(NGC6026) \leq 0.8 M_\odot$ and $M_2(NGC6337) \leq 0.3 M_\odot$. These correspond to binary separations of $a(NGC6026) \leq 1.93 R_\odot$ and $a(NGC6337) \leq 1.26 R_\odot$.

A few comments may be made about the binary system inclinations as well. Corradi et al. (2000) show that the ring-like structure of NGC 6337 is the narrow waist of a nearly pole-on bipolar PN. The inclination of the PN then must be $\leq 15^\circ$ for the bright inner ring to have no apparent ellipticity. NGC 6026 does not appear ring-shaped, but as a partial ellipse with a very faint south-east edge. If this PN is what Bond (2000) refers to as a “wedding ring” PN, then the inclination must be intermediate and can be roughly determined from the ellipticity of the observed PN. The ellipse measures $\sim 32'' \times 42''$, giving an inclination of $\sim 40^\circ$. If the binary mechanism for shaping PNe is correct, then the close binary CSs must have inclinations equal to those of the PNe.

Finally, previous studies have found the fraction of detectable close binary CSPNe to be $\sim 10 – 15\%$ (Bond 2000). The binary fraction found here is 25%, much higher than previous studies, though the low number of statistics means that the results are reasonably similar. Since the sample observed in this study was not randomly selected, but was based on the classifications of Soker (1997), it would be interesting to increase the number of CSPNe observed. If the 25% binary fraction persisted, the binary mechanism for PN shaping would be strongly supported, specifically the scenario outlined by Soker (1997).

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