The Binary Fraction of Planetary Nebula Central Stars in the Kepler Field

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Introduction & Summary

- Planetary nebulae (PNe) formation may be favored by binary interactions.
- The short-period (P < ≈3 days) binary fraction is 15-20% (e.g. Miszalski et al. 2009). This fraction may be biased because ground-based surveys are limited to variabilities ≥ ≈0.1 mag, due to the difficulty of achieving appropriate time sampling.
- We monitored all 6 PNe central stars in Kepler's 115 square degree field. None were known binaries. Because of the milli-magnitude precision we can detect periodic variables which, due to a longer binary period or a non-favourable inclination have very low amplitude variability.
- **Goal**: Kepler's extraordinary precision allows us to identify CS binaries that are too far apart to identify with ground-based observations. Successful detections can give a handle on how many low-amplitude binaries exist, and how well the current short-period binary fraction gives a lower limit.
- **Results**
  - + 7 PNe candidates (3 found by amateurs) - PaTe 1, though, is not a PN
  - + Abell 61 and NGC6742 show no variability. Although the bright nebula of NGC6742 may mask small variations, we do not think these PN have binary CS. Both are circular.
  - + NGC 6826 has a period of 0.619 days, but only about half the time, and with no consistent RV curve—likely a fast rotatator: 50 +/- 10 km/s (Jevtić et al 2012; Handler et al. 2013). This is a large rotation rate for a CS/WD and it is possibly indicative of a past merger.
  - + Pa 5 has a period of 1.121 days, but has no radial velocity variation (amplitude < 5 km/s) – binary only if nearly face-on
  - + Kn 61 has a very unusual, quasi-period of 6.444 days, but the light curve suggests semi periodic outbursts—possibly an anomalous CV. Almost certainly a binary.
  - + J19311+4324 has a period of 2.928 days and a matching RV curve with an amplitude of 92 km/s, consistent with a binary (double degenerates of 0.59 and 0.71 $M_\odot$)

The Kepler Program

- The superb photometric precision and continuous observation cadence of Kepler provides a unique opportunity to test PN CS for variability due to irradiation of orbiting companions
- 3 PN initially known in Kepler's 115 square degree field; amateur group (see Jacoby et al 2010) found 3 new candidates (Pa 5, Kn 61, PaTe 1, but PaTe 1 was later rejected), and J19311+4324 recently discovered (Aller et al 2011)
- Observations are available for the following quarters:

J19411+4324	Kn 61	NGC 6742	Abell 61	NGC 6826	Pa 5	PaTe 1
1-6, 13	10-13	13	2-7, 10-13	1-7, 10-13	1, 5-7, 10-13	7-9, 11-13

- Kepler light curves provided photometry at 30 minute intervals, as well as metadata noting cosmic rays, systematic trends, and other events affecting the quality of the photometry
- Each quarter of data was analyzed to detect possible periodic components in the signal using the Lomb-Scargle periodogram algorithm. The resulting periodograms were used to identify the strongest periodic component in the light curve.
- In order to combine different quarters of data for an object, it was necessary to normalize the light curves by the median values. Otherwise, differences between quarters result in discontinuities when "stitching" the light curves.
- A periodogram was also generated for the stitched light curve, to get a better signal to noise ratio in detecting the periodic signal.
- To generate the folded light curve, the stitched data was folded at the strongest period from the periodogram. In the phasing process, the data were binned to the median flux values, with 50 bins per quarter of data.

Discussion & Conclusions

- Kepler fulfills its potential in providing excellent photometric data. Variability is clearly detectable to amplitudes < 0.4 mmags.
- But, Kepler's broad bandpass foils the detection in one case (NGC 6742) where the nebula brightness overwhelms variations in the CS brightness.
- Unfortunately, only 5 objects are available to study, so the sample is very small.
- One out of 5 objects is clearly binary. A second is almost certainly a binary seen close to pole on. Both have fully periodic, well behaved lightcurves with very low amplitudes that would be undetected from the ground. This demonstrates that such object are out there to be discovered. One of them, with a ≈3 day period is at the long period end of the CS, short-period binary distribution.

Acknowledgments

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This research also made use of the NASA Exoplanet Archive, which is operated by the California Institute of Technology, under contract with the National Aeronautics and Space Administration under the Exoplanet Exploration Program.

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Miszalski B., Acker A., Moffat A. F. J., Parker Q. A., Udalski A., 2009, A&A , 496, 813

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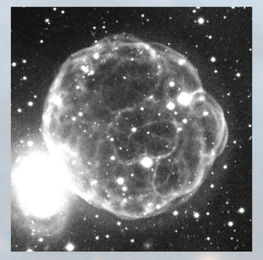
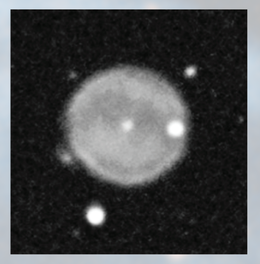
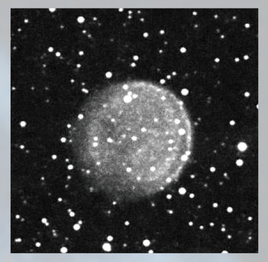
J19411+4324 (V≈14)
(photo: Aller et al, 2011)
7 quarters of data



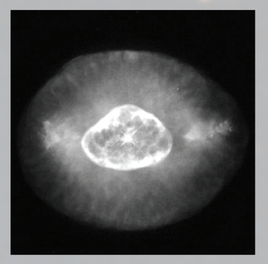
Kn 61 (V≈18)
(photo: Travis Rector)
4 quarters of data



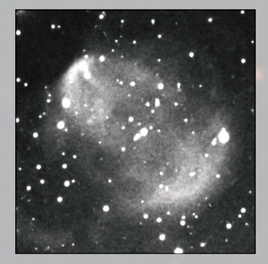
NGC 6742 (V≈19)
(photo: Adam Block)
1 quarter of data



Abell 61 (V≈17)
(photo: Jim Shuder)
10 quarters of data

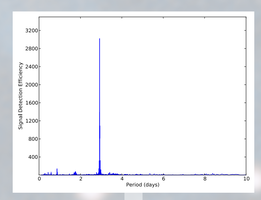


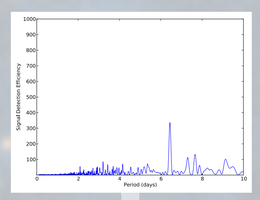
NGC 6826 (V≈11)
(photo: Bruce Balick)
7 quarters of data

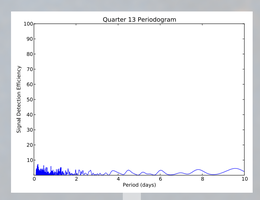


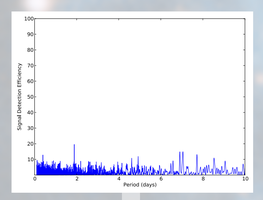
Pa 5 (V≈16)
(photo: Jacoby et al)
8 quarters of data

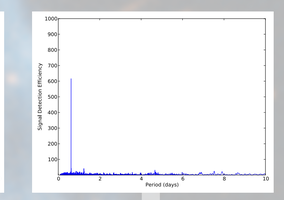
Lomb-Scargle Periodograms (all quarters combined)

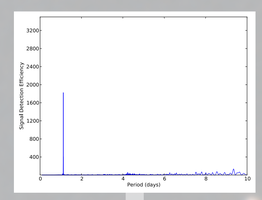




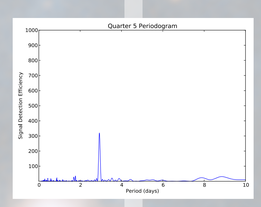


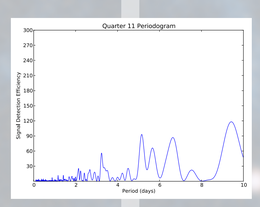






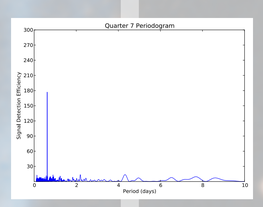
Best Quarter Periodograms

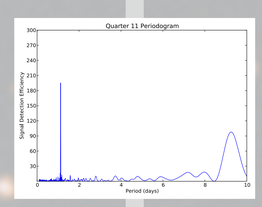




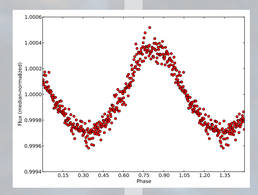
No evidence of variability.
Only 1 quarter of data
Photometry degraded by noise from bright nebula

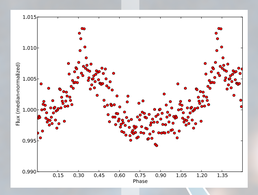
No evidence of variability
Ironically, also known as variable star NSV 11917 (Drummond 1980, PhD thesis)



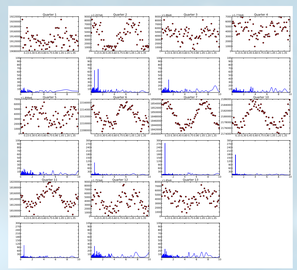


Phased Light Curves (all quarters combined)

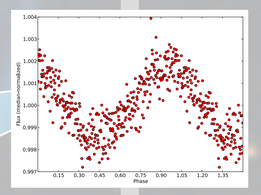


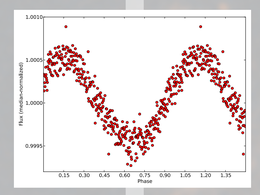


Per-quarter plots showing intermittent periodic effects in NGC 6826

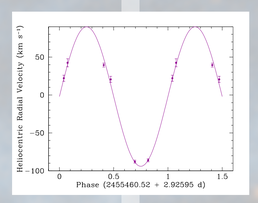


Ask us for a larger copy, or see http://i.imgur.com/r3sTH.jpg

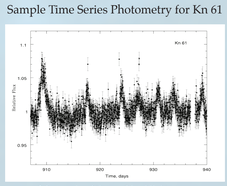




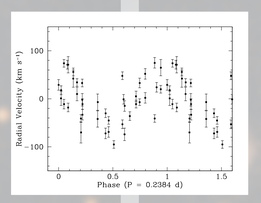
Radial Velocity Curves



Sample Time Series Photometry for Kn 61



A few weeks of the combined light curve, after Kepler's corrections, normalization, and stitching



Strong periodic variable: +/- 0.03%
Period: 2.928 days
RV variable: +/- 92 km/s
RV Period: 2.926 days
Excellent binary CS candidate

Strongly variable: 10%
Quasi-periodic: 2-6 days.
Probable wind/disk outbursts.
Likely a CV-type object.

Strong periodic variable: +/- 0.2%
Dominant periodicity at: 0.619 days
Occasional periodicity at 1.238 days
Periodicity appears in about half the quarters
Weak RV variability: 0.238 days (~ 1/5 of 1.238 days)
Not likely to be binary CS; probable effects of a high rotation rate (unexplained in the case of a single star): v sin(i) = 50±10 km/s
(Handler et al. 2013)
(see also Jetvić et al 2012)

Strong periodic variable: +/- 0.05%
Period: 1.121 days
No RV variability: <5 km/s
Possible binary CS if seen close to face-on
(see also Østensen et al 2010)