Expanding the Search for Spectroscopic Binaries in Proto-Planetary Nebulae

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- Motivation
- Expectation
- Observations
- Results
- Implications

(expansion of Hrivnak et al. 2011, ApJ, 734, 25)

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(Asymmetrical Planetary Nebulae – VI, Mexico, 2013-11-04)

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1. MOTIVATION: Why search for binaries in post-AGBs?

Shaping of planetary nebulae (PNe):

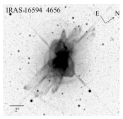
- Many have axial or point symmetry
- Is this due to binary interaction?

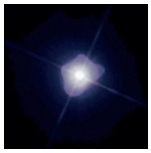
HST images

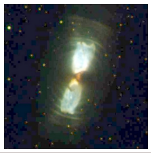
Why search in proto-PNe?

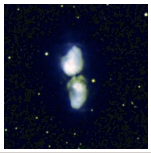
- Preceding stage, should show evidence
- Many already have axial or point symmetry
- Spectroscopically easier than PNe:
  - Many are F-G spectral types
  - More and relatively narrower lines
  - Better precision
  - No strong winds to contend with
- Some show an obscured equatorial region
- How is this formed? – binary?

PPNe









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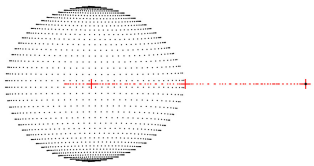
2. OBSERVATIONAL EXPECTATIONS

Expected binary parameters - Illustration:



- PPN: $M_{PPN} = 0.62\ M_\odot$
  Companion: Main Seq, $M_2 = 0.5\ M_\odot$
- PPN just within Roche lobe at SpT=G
- $R_{PPN} = 90\ R_\odot$ → $P_{orbit} = 1.0$ yr
- → $V_{PPN} = 13$ km/s (measure K = Vsin*i* but sin 30° = 0.5)

- But if PPN just within Roche lobe tip of AGB
- $R_{PPN} = 500\ R_\odot$ (2.3 AU) → P_{orbit}=11 yr → $V_{PPN} = 6.3$ km/s

- If $P_{orbit} = 30$ yr → $V_{PPN} = 4.5$ km/s

Search for binaries by radial velocity monitoring – SB1

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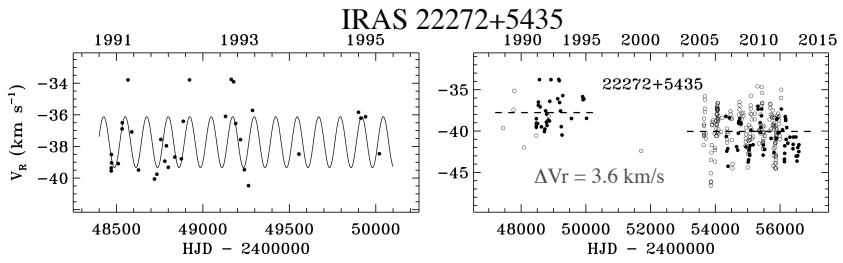
3a. RADIAL VELOCITY OBSERVATIONS

- **Targets: 7 bright PPNe, SpT = F-G Iab**
  - Many, sharp lines (advantage over hot central stars of PNe)
  - V = 7 – 11 mag
  - **Goal - to find binaries** (or at least set limits on them)
- Observations at the Dominion Astrophysical Obs (Victoria, Canada)
  - 1991 – 1995, 2007 – present
  - Coude on 1.2-m with RVS (early), CCD with cross correlation (present)
  - λλ: 4000 – 4600 A
  - Precision ~ 0.6 – 0.7 km/s

- Observations with the Mercator telescope (La Palma)
  - 2009 – present
  - Hermes Spectrograph, CCD with cross correlation pipeline
  - λλ: 3900 – 9000 A
  - Precision ~ 0.1 – 0.2 km/s

4a. RESULTS: Binaries?



One case of clear velocity change beyond pulsation (Inc. obs. by Zacs et al 2009)

- IRAS 22272+5435 ΔVr (initial – current) = 3.2 km/s
- P > 25 years, K = 1.6 km/s
- Limiting case: If we assume P = 25 yr, K = 1.6 km/s, $M_{PPN} = 0.62\ M_{\odot}$, and $e = 0$, then M_2 = depends on inclination i:
- $i = 25^{o}$ from model (Ueta et al. 2001, mid-IR) → $M_2 = 0.37$ (+/-0.05)
- If circular orbit, a = 8.5 AU = 1800 $R_{\odot}$ >> R(AGB) >> R(PPN)
- Would survive detached at tip of AGB

→ Possibly a binary

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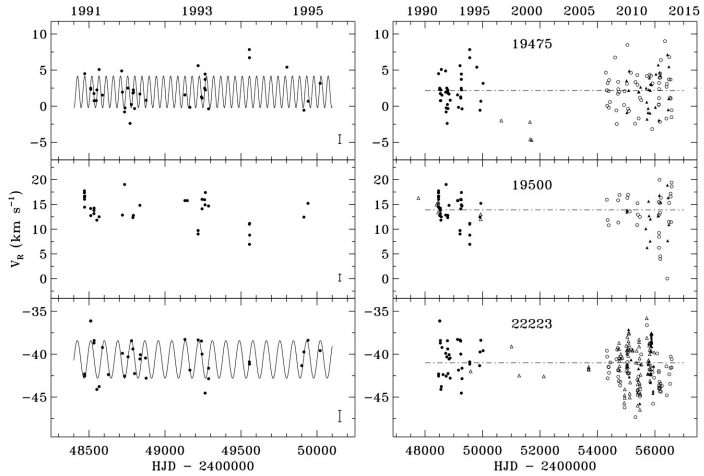
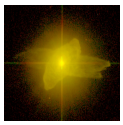
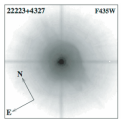
4a. RESULTS: Binaries?

These 3 show no long-term variations beyond pulsation



HST images





DAO observations (filled/open circles), Hermes (filled triangles), others others (open triangles).

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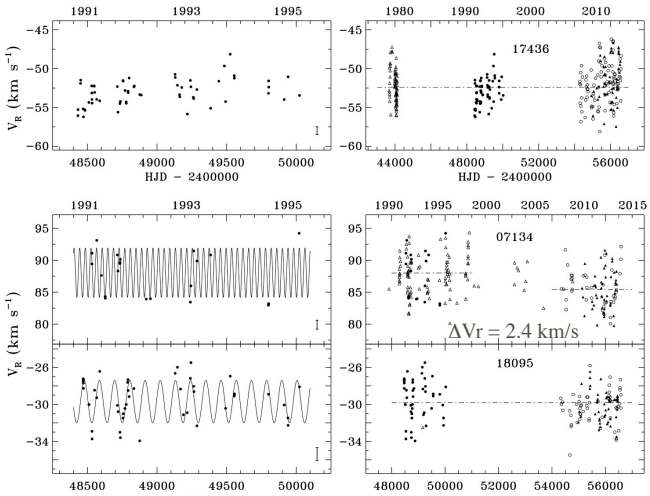
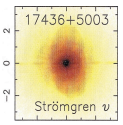
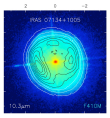
4a. RESULTS: Binaries?

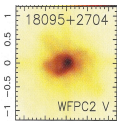
1 of these 3 shows long-term variations beyond pulsation



HST images







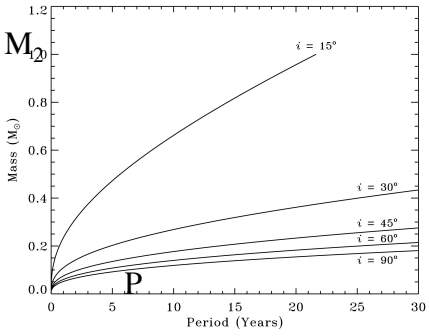
Only 2 of 7 shows long-term variations beyond pulsation, which is consistent with the SB rate for normal F-G stars.

However, …

4a. RESULTS: Constraints on Possible Binaries

What about possible bias - selection effects? - Chose brightest, more likely seen at low inclination (less obscuration), more pole-on. Does this invalidate the results?

Non-detection still sets important constraints on possible binaries



M_2 and P for various inclinations (i)
(Assuming M_{PPN}=0.62 $M_\odot$, K=2.0 km/s, circular orbits)
(see Hrivnak et al. 2011, ApJ, 734, 25)

If M_2 &	i > 15°	i > 30°	i > 45°
0.4 $M_\odot$	P > 3.5 yr	P > 24.5 yr	
0.25 $M_\odot$	P > 1.1yr	P > 8 yr	P > 23 yr

or, for example
• M_2 > 0.3 $M_\odot$ is excluded for P<13 yr at i>30°

Any undetected binaries have low mass or/and long periods

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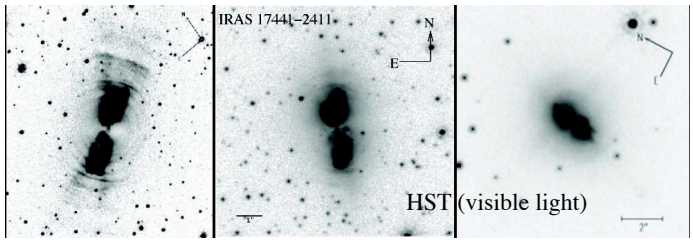
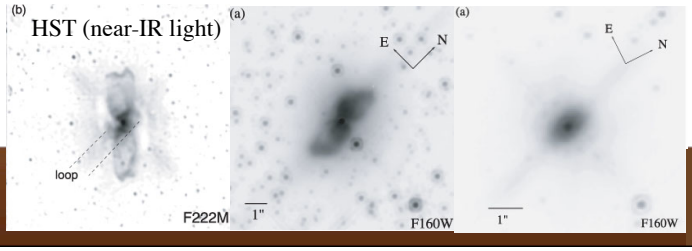
3b. NEW OBSERVATIONS: Edge-on Binaries

Ideally like to observe edge-on PPNe, no inclination ambiguity

- but they possess an obscuring torus



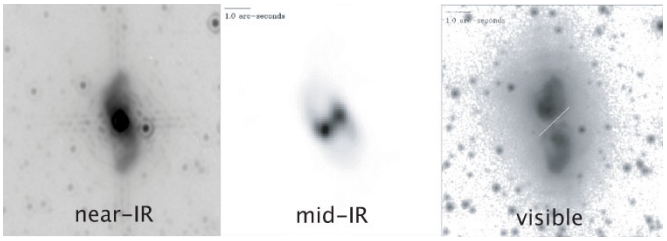
However, each of which has a visible star in near-IR



(Different orientation than visible images)

3b. NEW OBSERVATIONS: Edge-on PPNe with Near-IR Spec

Ideally then, let's observe them in the near-IR



New observing program: ex. IRAS 17441-2411

- Began 4 years ago – Near-IR, high-resolution spec, 8-m telescope
- ESO (Kerber, Seifahrt – ESO) CRIRES (R=100,000)
- Gemini-S (Hinkle – NOAO) Phoenix (R=70,000) - discontinued
- Data reduction in process, complicated
- If ΔV_R > 15-20 km/s (larger than pulsation) → (possible/likely) binary

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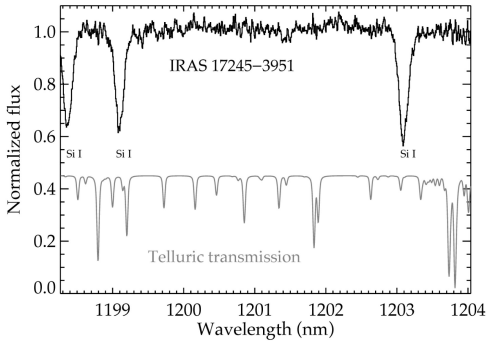
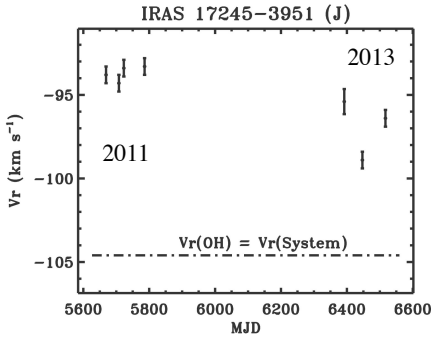
4b. RESULTS: Edge-on PPNe

- **Preliminary results for IRAS 17245-3945** (J & K bands)





  - ΔVr (Obs – System) ~ 10 km/s
  - Tantalizing, but more work on data reduction and more observations needed over a longer temporal baseline.
- **Very preliminary results for IRAS 17150-3224 & 17441-2411**
  - Lower S/N, only in K band, spectra are messy and results less precise – in progress.

5. IMPLICATIONS: of Radial Velocity Study of PPNe

- **Implications of small or on long-term velocity variations:**
  - Any binaries have long P (> 30 yr) or low mass (<0.3 $M_\odot$)
  - (Secondary brown dwarf or a massive planet - would not be detected)
  - If long P, then effect on shaping is small (Huggins ??)
- **Implications of fact that these stars are F-G supergiants with expanding CSE:**
  - They will not pass through a CE phase
  - All PPNe are not formed or shaped by CE interaction
- **Implications of short-term variability**
  - All PPNe vary due to pulsation (we find P(LC) = P(Vr)) →

- **Where are the binaries?**
- **RV Studies continuing**

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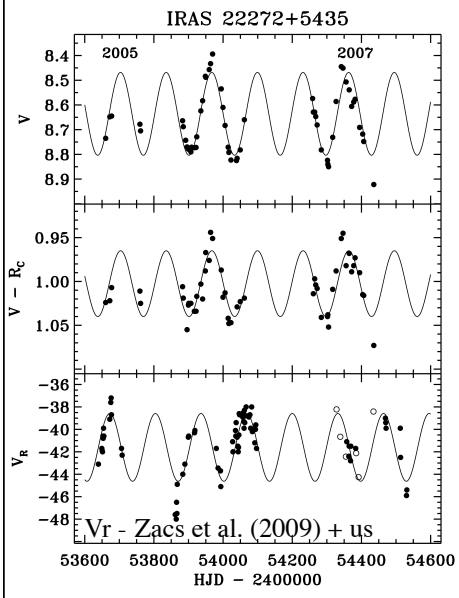
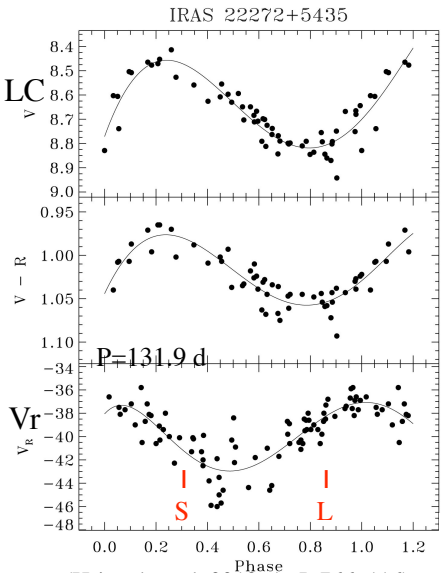
5. Pulsation Studies are giving us new insight to be exploited.





(Hrivnak et al. 2013, ApJ, 766, 116)

Star is brightest, hottest when smallest (differ from Cepheids)