Research Program:
- Studying evolved or “dying” stars
- Highlight student research opportunities
**Proto-Planetary Nebula Phase**

1. **Protoplanetary nebula**
2. **Planetary nebula**
3. **White dwarf**

**The death of a low-mass (Sun-like) star**

*Stellar death* depends on the star's mass. If under about 10 times the mass of our Sun, the star will die as a planetary nebula surrounding a carbon-oxygen core — a white dwarf.

**Unique research program with a long history at VU**

**Proto-Planetary Nebulae:**
- Observed from large ground-based telescopes & from space to determine various properties
  - of the central star – temp, composition, variability
  - of the nebulae – shape, comp, dynamics

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[Image of protoplanetary nebulae and a white dwarf]
Unique research program with a long history at VU

Central star:

- Q - Do the central stars vary in brightness?
  - due to interactions with a binary companion
  - due to pulsation of the central star

Brightness monitoring program:

- We began at the VU Obs in 1994 to monitor brightness changes in the brighter PPNe visible from the NH
- Primarily observed by VU students
- Found them all to vary in brightness, but complicated
  (Also being studied by a group in Russia)

Light Curve studies over 1994 – 2007 (14 years)

Sample Light Curve – cyclical variation, changing amplitude
Some Results: showing only a few years + Periods

Results of formal period analysis

P₁ = 88 d
P₂ = 127 d
P₃ = 85 d

Patterns:

- P₂ ~ 0.95 P₁

Unique research program with a long history at VU

Goals of the research program:

- To obtain light curves of their variations with time and
  from these
  (1) find the period of and amplitude of variation.
  (2) try to use these light curves and periods as
diagnostic tools to understand what is going on inside
these unusual stars (with help of theorist).
(3) investigate, over interval 20-25 years, if one can
see monotonic changes in the period as the stars evolve
(evolution in real time!)
Pulsational Light Curves (7 yr) – Fainter MWG PPNe

Fainter PPNe from the Milky Way Galaxy
• # = 9, both O-rich and C-rich, all observed from VUO + SARA
• V = 13 – 15 mag
• P found for 6 of 9; P = 25 – 135 d (with multiple P)

2008 2011 2014

Fitted with 4 P: \( P_1 = 71 \) d

2008 2011 2014

Fitted with 4 P: \( P_1 = 96 \) d
Unique research program with a long history at VU

Focus for this summer:

(1) Continue our long series of obs at VU Obs and analyze these data

(2) Compute periods from the more recent data and compare with earlier data to investigate period changes that might be due to the evolution of the stars.

   Expected to shorten be a few days over 20 years

(3) Analyze data from PPNe in the Southern Hemisphere that have been observed through the SARA consortium

Plans for summer 2017

General Student Research Program: (2-4 students)
1. Observing - night schedule (training at telescope, students working in pairs)
2. Data reduction - afternoons
   - to measure the brightness variations from the CCD images.
3. Data analysis - to determine P values and LC changes
4. Background to the science - reading & tutorials
5. Assignment of an individual subset of PPNs for study
6. Report (progress) - at end of the summer
7. Presentations - summer poster session, VU colloquium, & perhaps state-wide or national conference

See posters from last summer across from NSC 145
Unique research program with a long history at VU

Observation carried out primarily by VU students

2016
Cole Hancock
Abigail Vance
Katie Willenbrink

2015
Stephen Freund
Cole Hancock
Chris Morrissey
Abigail Vance
(Andrew Webb)

Recent publication including VU observations

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STUDIES OF VARIABILITY IN PROTO-PLANETARY NEBULAE. II. LIGHT AND VELOCITY CURVE ANALYSES OF IRAS 22272+5435 AND 22223+4327

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Details

**Returning research student:** Observing + more advanced assign. for PPN analysis and report for publication

**Details:**
1. 2-4 students
2. 9-10 weeks, dates TBD
3. Expect VU housing at no cost

**Funding:**
- National Science Foundation (2)
- Possibly from Indiana Space Grant Consortium
- Other possibilities: MSEED, …