Why Galaxies Care About AGB Stars:
A Continuing Challenge through Cosmic Time
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Variability in Post-AGB Stars: Pulsation in Proto-Planetary Nebulae

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Abstract. We have been intensely monitoring photometric variability in proto-planetary nebulae (PPNe) over the past 25 years and radial velocity variability over the past ten years. Pulsational variability has been obvious, in both the light and velocity, although the resulting curves are complex, with multiple periods and varying amplitudes. Observed periods range from 25 to 160 days, and the periods and amplitudes reveal evolutionary trends. We will present our observational results to date for approximately 30 PPNe, and discuss these results, including the search for period changes that might help constrain post-AGB evolutionary timescales.

Keywords. AGB and post-AGB, stars: variable

1. Introduction

Proto-planetary nebulae (PPNe) are post-AGB objects in transition between the AGB and PN phases in the evolution of low- and intermediate-mass stars. They consist of a luminous central star of intermediate temperature (5000−30000 K), surrounded by a detached, expanding shell of gas and dust. It is a short-lived phase (few $\times$ 10^3 yr). Their identification and study began with the *IRAS* satellite ∼30 years ago.

As post-AGB stars, it is not surprising that PPNe might vary due to pulsation. As they evolve in the post-AGB phase, they pass through the extension of the Cepheid instability strip (Kiss *et al.* 2007). There are several motivations for this study. (1) Pulsation provides an opportunity to determine fundamental properties of PPNe. The period (P) and amplitude, when combined with stellar pulsational models, can be used to find PPNe masses, which have not been measured directly (none are in known binaries). (2) Pulsation is a driver of mass loss, which is poorly understood physically, so it might lead to new insights. (3) The pulsation period is expected to change as the post-AGB star evolves, and this has the potential to help us measure the timescale of this evolution.

2. Light Curve and Radial Velocity Curve Studies

Light curve studies of PPNe have been carried out primarily by two groups (Arkhipova *et al.* 2010; Arkhipova *et al.* 2011; Hrivnak *et al.* 2010; Hrivnak *et al.* 2015) and examples of light curves are shown in their work. Our observations are carried out primarily at the Valparaiso Univ. Observatory by undergraduate students. About 20 objects have been observed annually for 25 years (1994−2018). Additional observations are from the SARA telescopes at KPNO and CTIO over 8−10 yr. We have also used ASAS and ASAS-SN survey data to find periods for additional stars, particularly in the southern hemisphere.

These light curves display cyclical behavior with varying amplitudes, with a few also showing longer-term increases or decreases in brightness. Periods range from 25 to 160 days (SpT=A−G), with hotter B types varying on shorter timescales of days or less. Amplitudes (ΔV) range from 0.1−0.7 mag (V, peak-to-peak), with cooler ones having larger ΔV. The stars are redder when fainter. The light curves are thus seen to be complex, with changing amplitude and multiple P values (P_1, P_2, ...). A period ratio of $P_2/P_1 = 0.90{-}1.10$ is found in most cases.

Closer examination reveals several trends in the light curve properties. Most significant is a linear correlation of P_1 with $T_{\rm eff}$; P is seen to decrease with increasing $T_{\rm eff}$ from 5000−8000 K. This is seen in both C-rich and O-rich stars. (See an early example in Hrivnak *et al.* 2010.) The amplitude of the pulsation also decreases with increasing $T_{\rm eff}$.

We have also begun in 2007 to monitor the radial velocity of a subset of seven bright PPNe using the 1.2-m telescope at the Dominion Astrophysical Observatory (Victoria, Canada) and the 1.2-m Mercator telescope with Hermes spectrograph at La Palma. This allows us to get contemporaneous light, color, and radial velocity curves. Similar periods are found in the radial velocity as in the light and color curves. Phase comparisons show that the light and color curves are in phase, while the radial velocity curves differ by a quarter of a cycle (Hrivnak *et al.* 2013).

3. Discussion and Conclusions

Theoretical models predict that for post-AGB stars, $T_{\rm eff}$ will increase with time. Using the current models of Miller Bertolami (2016), combined with our observed $P{-}T_{\rm eff}$ relationship, predicts a change of P with time of −0.05 day/yr or −1 day over 20 years. This is potentially observable! However, in a preliminary analysis we find it difficult to measure reliable period changes in these complex light curves.

The contemporaneous light, color, and radial velocity curves show that these stars are brightest when hottest and smallest. This agrees with the expectations from radial pulsations with the κ mechanism operating in the He II ionization zone. Note that this phase relationship is different from that found for Cepheids, in which the radial velocity is half a cycle out of phase with the light curve and the star is brightest when hottest and about average size and expanding (so called "phase lag"). New pulsation models are needed to update the early work and make use of these contemporaneous light and velocity curves to determine masses for these post-AGB objects.

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