LIGHT AND VELOCITY VARIABILITY OF POST–AGB STARS

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Abstract. We have monitored velocity variability in nine proto-planetary nebulae (PPN) over a 5 year interval and have monitored light variability in 40 PPN over a 2 year interval. We find all nine of the objects to vary in velocity and almost all of the 40 to vary in light. Three of the objects display a clear periodicity in their velocity variations, and in all three the light varies with the same period as the velocity. Periodic light variations are found in six other objects. We interpret these as due to pulsation in the PPN.

1. Introduction

Our knowledge of post–AGB stars has expanded greatly as a result of IRAS and follow-up ground-based observations. The present study is part of a larger program to discover and study proto-planetary nebulae (PPN), objects in transition from the asymptotic giant branch (AGB) to the planetary nebula (PN) phase (see Hrivnak, Kwok & Volk 1989; Kwok 1993).

Our candidate objects were selected primarily from IRAS objects which peak in the 25 μm band (due to re-emission from circumstellar dust). The associations of the optical counterparts were in most cases discovered or confirmed by ground-based observations at 10 μm; in a few cases the identification is based simply on the very close positional association of the IRAS source and the optical star.

The spectral energy distributions of the objects show a characteristic double peak, with about equal amounts of energy emitted in the visible and near-infrared (from the reddened photosphere) and the mid-infrared (re-emission from circumstellar dust). Examples are shown by Hrivnak et al. (1989).

R.F. Wing (ed.), The Carbon Star Phenomenon, 293-298.

2. Variability: Why Study?

Variability can be a source of additional information about the nature of these objects. It can be due to a binary companion or can be intrinsic to the star, such as pulsation.

Binarity: Many PN are bipolar. One of the mechanisms which can lead to this is a binary companion, which can cause the AGB star to lose mass preferentially in the orbital plane, thereby producing a torus which retards later mass loss from a fast wind. This is supported by the discovery of several binary PN nuclei, almost all of short period (< 3 d; Bond 1995). Longer-period binaries are harder to discover in PNe, since the "reflection effect" is no longer significant in causing light variations and since small velocities variations are difficult to measure in the intrinsically broad spectral lines of these hot stars. However, by searching PPN of spectral types F and G, one can make use of their many and sharper lines to search for longer-period binaries. From this one can hope to learn more about the mechanisms shaping the nebulae and the properties of binary PN nuclei which may not pass through a common envelope phase.

Pulsation: It is known that some (perhaps most) post–AGB objects vary in light and velocity due to pulsations, such as RV Tauri stars (spectral types G–K; $P = 50 - 150$ d) and UU Her stars (type F). The study of these pulsations can help us to learn more about the physical properties of the star.

No previous study of variability in a sample of PPN has been published. Since we had access to both a good list of candidates and to telescopes well-suited to make these studies, we have undertaken this project.

3. Radial Velocity Study

Radial velocity observations were made over five seasons from 1991 to 1995 (especially 1991–92) at the Dominion Astrophysical Observatory (DAO) in Victoria, Canada. The 1.2-m Coudé telescope was used, equipped with the Radial Velocity Spectrometer and an F–star mask. The typical precision was 0.65 km s^{-1}. S. Morris and A. Woodsworth of the DAO collaborated in the observations. Nine PPN of spectral types F–G and magnitudes $V = 7 - 10$ were observed about 35 times each.

All nine are found to vary, with an average peak-to-peak variation of 10 km s^{-1}. Examples are shown in Figure 1. For three of them a consistent period was found: IRAS 18095+2704 (F3 Ib; $P = 109$ d), 22223+4327 (G0 Ia; 89 d), and 22272+5435 (G5 Ia; 127 d). These are shown in Figure 2. In each case, while a clear periodicity is seen in the velocity curves, the amplitude appears to vary. Only a few observations deviate greatly from the cyclical patterns.

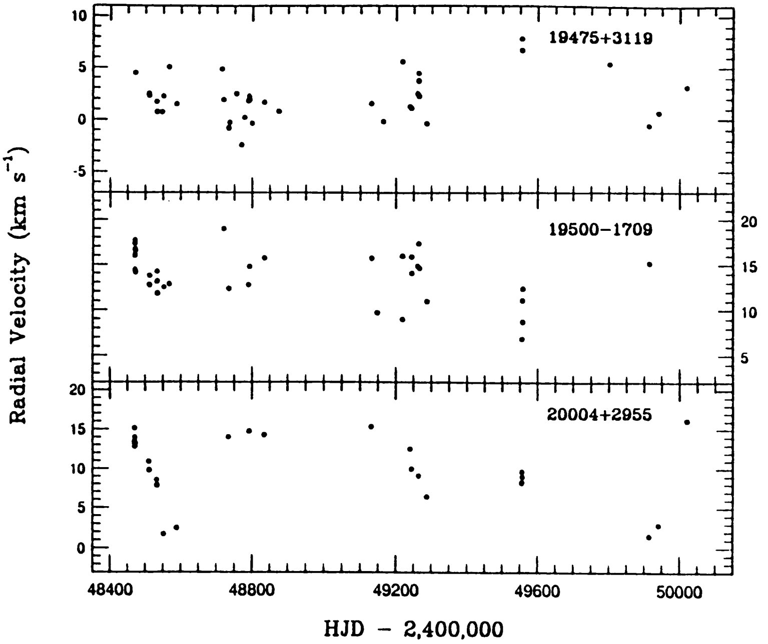

Figure 1. Examples of the radial velocity variation in several PPN. No periods are found for these variations.

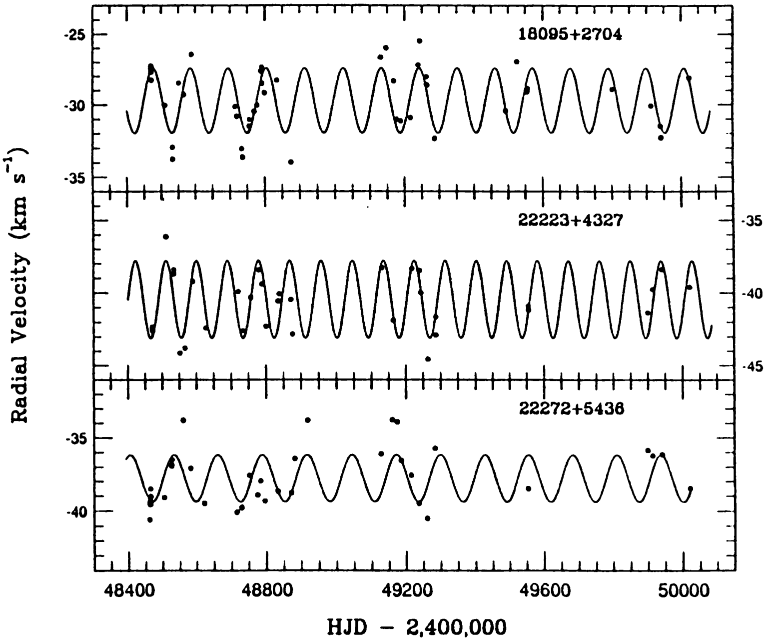

Figure 2. The radial velocity curves for three PPN which show periodic variability: IRAS 18095+2704 (109 d), 22223+4327 (89 d), and 22272+5435 (127 d).

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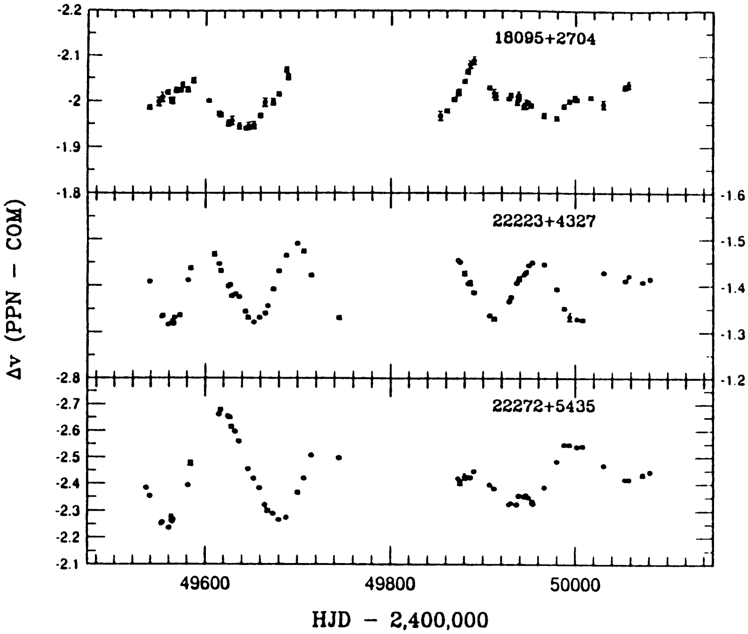

Figure 3. Differential light curves for the three PPN with periodic velocity variability.

4. Light–Curve Study

The light-curve study has been carried out over the last two seasons, 1994–1996, using the 0.4-m telescope at the Valparaiso University Observatory. A CCD (Photometrics Star I) detector is used with a standard V (and occasionally R) filter. The precision is < 0.01 mag, except for the faintest stars. The program includes 40 PPN, with a range in magnitude of $V = 7 - 14$ and in spectral type of O to M. Included among these are the nine for which we have studied the radial velocity. Four Valparaiso University undergraduate students have assisted in the observing during the summer months. We plan to continue this light-curve study, and additional observations are being made this summer.

The three PPN with periodic radial velocity curves all have light curves showing light variations with the same period as the velocity variations. However, the variability does not have a simple periodic form, but varies in amplitude for each of the three. These are shown in Figure 3. The variability ranges from 0.15 mag in IRAS 18095+2704 to 0.50 mag in IRAS 22272+5435.

While all three exhibit similar periods in the velocity and light variations, the relative phasing of their velocity and light variability differs among the three: IRAS 22272+5435 is brightest when it is at its average size and expanding and faintest when at its average size and contracting;

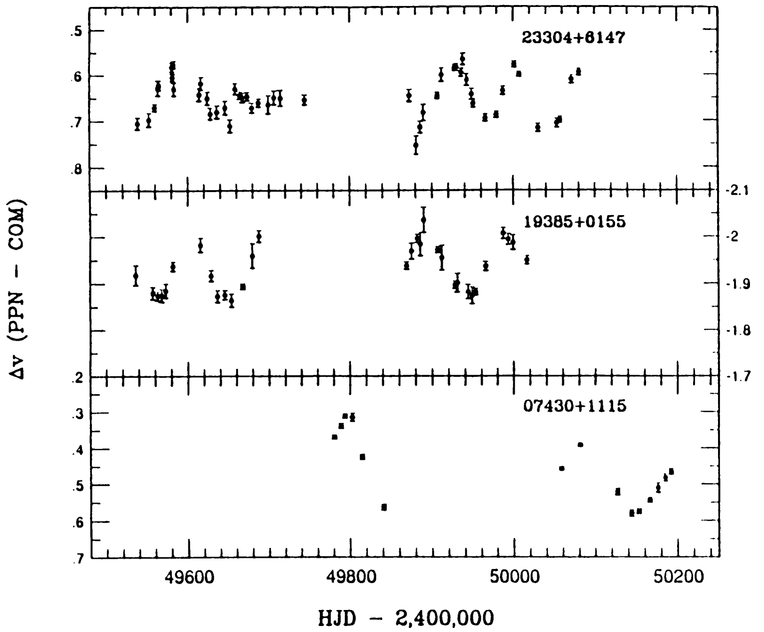

Figure 4. Examples of other PPN candidates with periodic light variability: IRAS 23304+6147 (84 d), 19385+0155 (96 d), and 07430+1115 (146 d).

IRAS 22223+4327 is brightest when smallest, faintest when largest; and IRAS 18095+2704 is brightest when smaller than average size and contracting, and faintest when larger than average size and expanding.

We interpret this variability as due to pulsation in the stars, rather than a binary nature. There are several reasons for this interpretation: (*a*) the amplitudes of the variation change, (*b*) the periods are short for a binary companion to orbit a giant star, and (*c*) the periods of the light and velocity are the same, while in a binary system in which the light variation was due to tidal distortion the light would have two maxima in each orbit.

Most of the others among the 40 sources show light variations, although in only a few others is a periodicity found. The light variation in V is typically 0.15 to 0.35 mag. The following is a preliminary summary of the light variations detected:

- Periodic variability was found in nine PPN (including the three discussed above), with periods ranging from 25 to 146 days, and with varying amplitudes. These objects have spectral types F–G. Examples are shown in Figure 4.
- Short-time-scale variability (< 10 d) was found in many of the objects, especially those of early spectral types, O–B.
- Several have unusual light curves, such as a periodic variation that appears in one season and not the next, or an unusual shape.

5. Conclusions

As a result of this study of the velocity and light variations in PPN, we have found the following:

1. (Almost) all PPN vary in light and velocity.
2. This variability is due to pulsation; no binaries were discovered.
3. The variability does not have a simple periodic form; rather, it varies in amplitude or period, or there may exist multiple periods.
4. In the three cases with periodic velocity variability, the light varies with the same period as the velocity. However, the phase relationship between the light and velocity curves is different in each case.
5. There appears to be a general trend of period with spectral type, with later spectral types (G) possessing the longer periods (80–150 d), middle spectral types (A–F) possessing the middle periods (25–100 d), and early spectral types (O–B) showing short-time-scale variability.

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