

PV Cephei and Gyulbudaghian's Variable Nebula

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Abstract

The Herbig Ae star PV Cephei is embedded in a dense molecular cloud which also contains Gyulbudaghian's Variable Nebula. While the variability of PV Cephei has been studied intermittently over the past 35 years, little attention has been paid to measuring the variability of the nebula. We report on photometric observations of both objects over the past two years to investigate if there is a relationship between variations of the star and the nebula.

1. Pre-main-Sequence Stars

Young pre-main-sequence stars are intrinsically variable. They are still in the process of contracting onto the main sequence from dense molecular clouds under the influence of gravity. As a young star contracts, it spins up and material not yet drawn into the star forms an accretion disc around it. Material from the disc falling onto the surface of the embryonic star causes apparently random fluctuations in the star's brightness. At the same time the initially weak magnetic field within the gas cloud is concentrated within the contracting star which often results in an active chromosphere, magnetically channelled accretion from the disc onto the star's surface, and material being ejected along the star's rotational axis in the form of bipolar conical winds and collimated jets (Romanova *et al.*, 2009). The jets may collide at high speed with clumps of gas and dust in the surrounding molecular cloud creating the shock features known as Herbig-Haro objects. Pre-main-sequence stars with mass less than about two solar mass are classified as T Tauri stars, those between two and eight solar mass as Herbig Ae stars.

2. PV Cephei

PV Cephei is a fairly typical Herbig Ae star, spectral type A5e, less than a million years old, ~500pc distant, with ~3.5 solar mass and luminosity at its brightest approaching 100 times that of the Sun. It is still in the process of contracting out of the molecular cloud which surrounds the young star. It has a rather massive circumstellar disc, containing about 20% of the mass of the star (Hamidouche, 2010), with an inclination of about 80 degrees relative to our line of sight so we are looking at the disc almost edge-on (Gomez *et al.*, 1997).

Material from the disc accreting onto the surface of the star causes periods of increased brightness (Lorenzetti *et al.*, 2011). Obscuration by either the edge of the disc or dust close to the star may contribute to occasional fading of the star (Elek and Kun, 2010; Kun *et al.*, 2011).

Measurements of red plates obtained with the Crossley reflector at Lick Observatory in 1977-1979 showed the star brightening to magnitude 11 before fading to magnitude 16 (Cohen *et al.* 1981). Little attention was then paid to the star until 2005 when it was observed at magnitude 12 (Elek and Kun, 2010). Between 2007 and 2010 it varied in the range magnitudes 15 to 18 (Kun *et al.*, 2011, Lorenzetti *et al.*, 2011). A search using adaptive optics failed to reveal a close binary companion to PV Cephei, which could act as a possible cause of variability (Connelley *et al.*, 2009).

PV Cephei is located near the edge of a molecular cloud. Outflow from the star towards the north has cleared a conical cavity in the cloud through which the star's light illuminates the surrounding interstellar medium (Levreault, 1984; Arce and Goodman, 2002). Jets emitted by the star have created several Herbig-Haro objects to the north and south of the star as they plough into the surrounding interstellar medium (Reipurth *et al.*, 1997). The northern jet is blue-shifted and the southern jet red-shifted indicating they are tilted out of the plane of the sky by about 10 degrees. The jets are also precessing in a helical manner with a period of approximately 8300 years (Gomez *et al.*, 1997). From the positions of the Herbig-Haro objects, estimates of the velocity of the jets, and the known distance to the star it is estimated that new Herbig-Haro objects have been produced by major emissions from PV Cephei at approximately 2000 year intervals (Reipurth *et al.*, 1997).

3. Gyulbudaghian's Nebula

Light from PV Cephei shining on the inside of the cavity in the surrounding molecular cloud cleared by the northern outflow creates the variable reflection nebulosity variously known as RNO125, GM29 or Gyulbudaghian's Nebula. The opposing outflow is directed into the molecular cloud and its light is heavily attenuated to the point that it is barely visible.

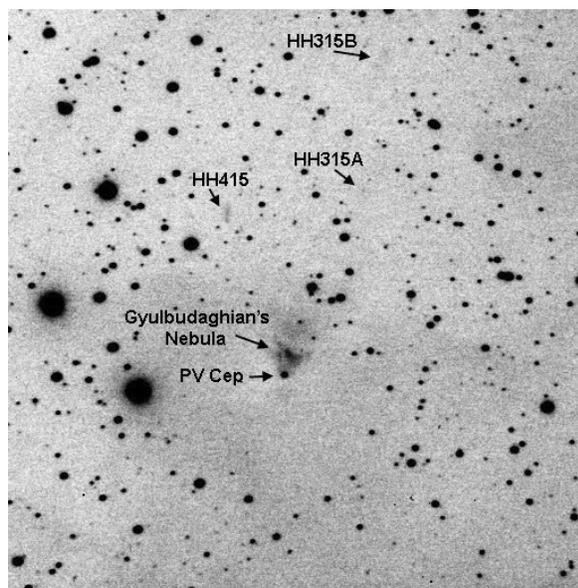


Figure 1. 33 min exposure of the field around PV Cephei.

Figure 1 is a 33-min stacked exposure of the field around PV Cephei taken with a 0.35-m SCT, SXVR-H9 CCD camera, and an R filter on 2011 August 19 when the fan-shaped reflection nebula was relatively bright. It also shows some of the Herbig-Haro objects close to the star.

Although several papers have reported measurements of the variability of PV Cephei, the changing brightness of the nebula has only been commented on qualitatively based on its appearance in photographs and more recently CCD images. For example: “The rapid variability of the nebula indicates that changes in its luminous structure must result from variable illumination.” (Gledhill *et al.*, 1987).

While it has been assumed that the source of this varying illumination is the variability of PV Cephei, no direct evidence has so far been presented to support this assumption. In particular, no one appears to have systematically measured the varying brightness of the nebula and correlated this with the variability of the star.

4. New Observations

The British Astronomical Association's Deep Sky Section has an observing programme to monitor the changing brightness of variable nebulae associated with young stars. As a contribution to this programme, I began monitoring PV Cephei and Gyulbudaghian's Nebula in 2010 March using the equipment listed above. I measured the brightness of PV Cephei by conventional CCD photometry using an R filter because of its predominantly red colour. I took care to measure the sky background outside the area of the nebula. I used a square aperture sufficiently large to encompass the nebula at its brightest to measure the total light intensity from the nebula plus sky background. The level of sky background was estimated by measuring the light intensity in a similar square offset to the east of the star to avoid contamination by the opposing jet hidden within the molecular cloud. The sky background was subtracted from the nebula plus sky background to give a measurement of the light emission from the nebula alone and this was converted to a magnitude using the usual formula. This method has been used consistently throughout the project keeping all aperture sizes constant. The zero point of the nebula magnitude scale was chosen such that the mean magnitudes of the star and the nebula were the same for convenience of graphical representation.

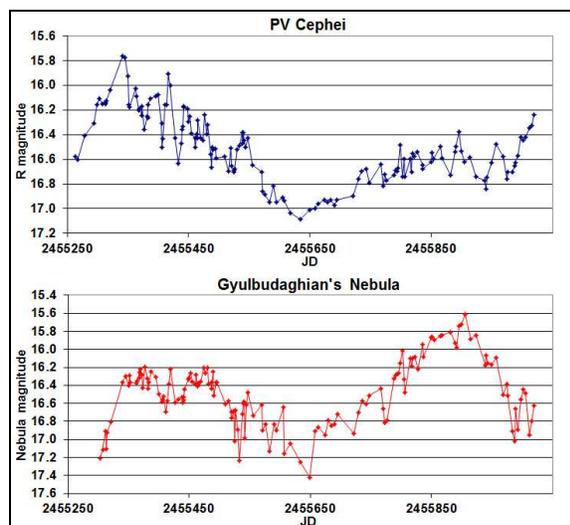


Figure 2. Light curves of PV Cephei and Gyulbudaghian's Nebula.

The star's high declination means it can be followed throughout the year from the UK. During the following two years PV Cephei varied between magnitudes 15.8 and 17.1. Over the same interval, the nebula followed a broadly similar pattern with two bright episodes separated by a deep fade (Fig. 2).

A search for periodic signals in the light curves of PV Cephei and the nebula failed to reveal any significant signals with period between 2 and 200 days.

Figure 3 shows images of the field around PV Cephei taken at various times between 2010 April and 2012 March to illustrate the variability of the nebula. Each image is typically a stack of 25-30 one minute exposures

5. Correlated Variation

To investigate whether there is a relationship in time between these two light curves, a Discrete Correlation Function (Edelson and Krolik, 1988) was computed adding a variable delay to the light from the star. Maximum correlation occurs when the star's light is delayed by 27 ± 2 days relative to that of the nebula. Figure 4 shows the two light curves superimposed with this delay.

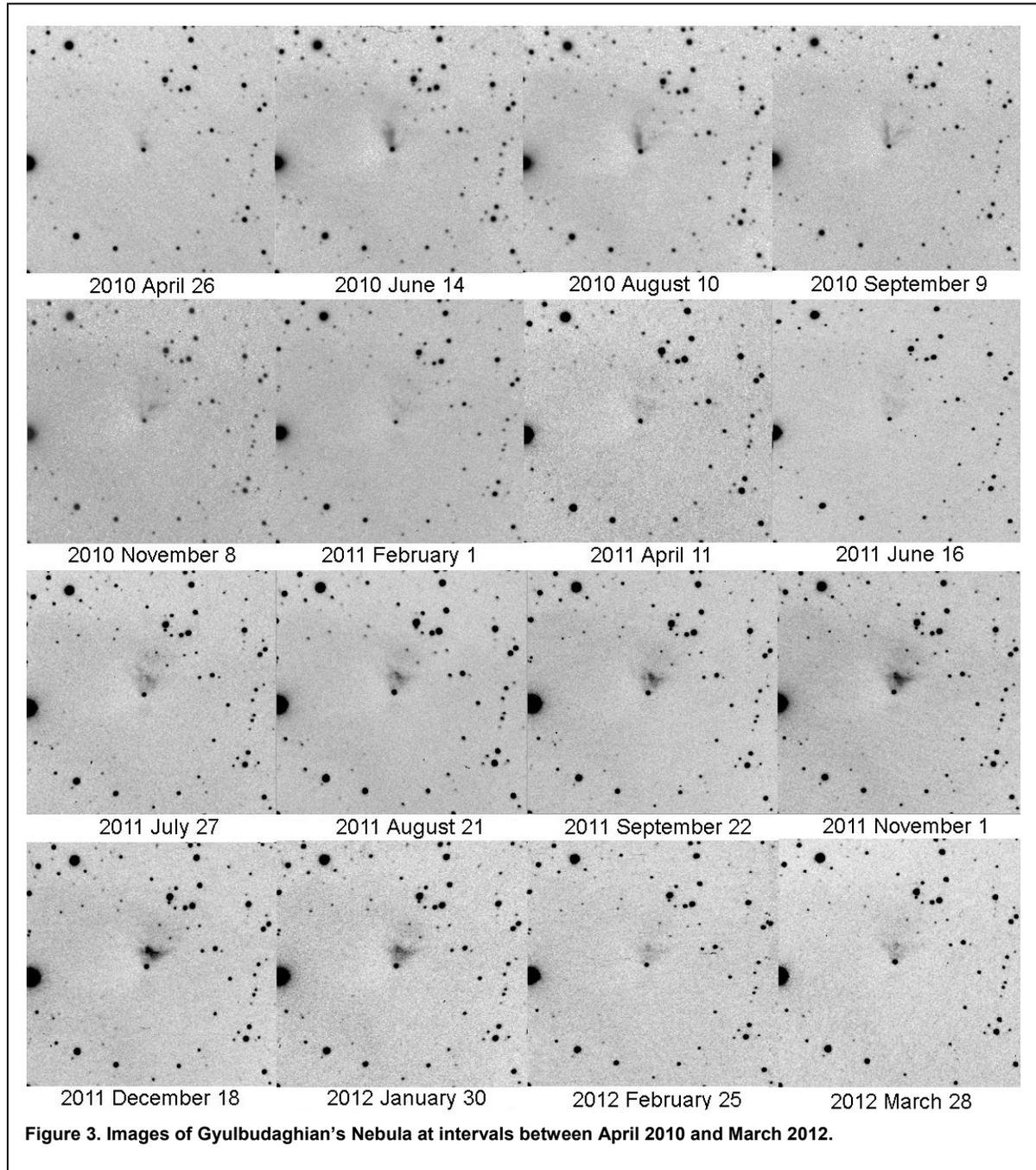


Figure 3. Images of Gylbudaghian's Nebula at intervals between April 2010 and March 2012.

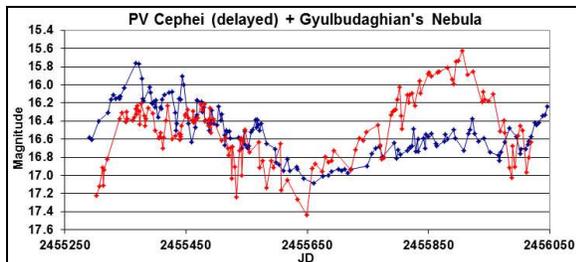


Figure 4. Superimposed light curves of PV Cephei (delayed by 27 days) and Gyulbudaghian's Nebula.

For the first time this provides evidence in support of a direct correlation between changes in the light output of the star and the brightness of the nebula. However, while the major increases and decreases of the two light curves are consistent, the amplitudes of these changes do not follow each other with the same degree of consistency. In particular, the increase in brightness of the star in the latter part of 2011 was considerably less than the corresponding increase in brightness of the nebula.

A possible explanation for this arises from consideration of the mechanisms involved in these changes. It is likely that a steady brightening of the star is caused by a major accretion event. This in turn causes the nebula to brighten. If either the edge of the circumstellar disc or the dust clouds which are in continual movement around the star happen to partially obstruct the light it emits in our direction, this may reduce the apparent increase in the star's brightness. Movement of dust around the star may also create a shadowing effect and lead to the varying pattern of illumination we see in the nebula.

It is interesting to calculate the light travel time from the star to the nebula to see if this is consistent with the observed delay between their respective light curves. Using the published distance to the star, the apparent inclination of the outflow, the distance in images from the star to the nebula and the image plate scale, this light travel time works out at approximately one month.

Only continuing observation will reveal whether this apparent correlation is maintained in the future.

6. Acknowledgements

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7. References

Arce H. G., Goodman A. A. (2002). *Ap. J.* **575**, 911.
 Cohen M., *et al.* (1981). *Ap. J.* **245**, 920.

Connelley M. S., *et al.* (2009). *Astron. J.* **138**, 1193.
 Edelson, R. A., Krolik, J. H. (1988). *Ap. J.* **333**, 646.
 Elek E., Kun M. (2010). *Journal of Physics Conference Series* **218**, 12021.
 Gledhill T. M., *et al.* (1987). *Monthly Notices of the Royal Astronomical Society* **229**, 643.
 Gomez M., *et al.* (1997). *Astron. J.* **114**, 265.
 Hamidouche, M. (2010). *Ap. J.* **722**, 204.
 Kun M., *et al.* (2011). *Monthly Notices of the Royal Astronomical Society* **413**, 2689.
 Levreault R. M. (1984). *Ap. J.* **277**, 634.
 Lorenzetti D., *et al.* (2011). *Ap. J.* **732**, 69.
 Reipurth B., *et al.* (1997). *Astron. J.* **114**, 2708.
 Romanova, M. M., *et al.* (2009). *Monthly Notices of the Royal Astronomical Society* **399**, 1802.