THE PERIOD OF THE SYMBIOTIC NOVA PU VULPECULAE

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Abstract

PU Vul is a very slowly evolving symbiotic nova. AAVSO observations spanning 15 years are used to show that the system is an eclipsing binary with a period of 13.42 $\pm$ 0.02 years. Modeling of the eclipse shapes indicates that radii of both components of the binary have decreased between 1980 and 1994. The cause for the shrinkage in the size of the giant star is unknown.

1. Introduction

PU Vulpeculae is one of a handful of known symbiotic novae. These objects are similar to classical novae in that they are powered by a thermonuclear runaway on a white dwarf. However, in symbiotic systems the companion is an evolved giant star. PU Vul has been intensely studied since it was discovered in outburst by Honda (Kozai 1979a) and Kuwano (Kozai 1979b). The evolution of PU Vul has been slow. Except for a deep minimum in 1980, the star remained near maximum light for eight years before beginning a gradual decline in 1988. The development has been similar to RT Ser and RR Tel (Kenyon 1986).

The deep minimum of 1980 has been interpreted as either an eclipse or obscuration due to the formation and later dispersion of dust. The question was decided in favor of an eclipse when the ultraviolet (UV) flux and certain high ionization emission lines vanished from the PU Vul spectrum. Garnavich and Trammell (1994) reported the reappearance of He II 4686Å in the spectrum after an absence of at least 6 months and estimated the orbital period of the binary to be 13.5 years. The poorly sampled spectral variations meant that only an approximate period could be found. The extensive observational record of PU Vul from the AAVSO, however, provides a unique and consistent data set for determining the orbital period.

2. Light curve

The light curve of PU Vul consists of 12559 individual visual brightness estimates by observers from the American Association of Variable Star Observers (AAVSO) (Mattei 1995). The observations analyzed here cover 16 years, starting on JD 2443974 (April 10, 1979) and going through JD 2449806 (March 29, 1995). The brightness is recorded to the nearest 0.1 magnitude. Observations more than one magnitude discrepant have been excluded. The edited data have a dispersion about the mean of 0.17 magnitude RMS. However, the density of the observations (an average of 2 estimates per day) permits averaging of the data without a significant loss of time resolution. Figure 1 shows the AAVSO light curve after the data have been treated with a running box-car smoothing algorithm using a box width of 10 days. The smoothed light curve clearly shows the great minimum of 1980 and slow decline into the nebular phase in 1988. There is also an eclipse-like feature in 1994 corresponding to the time of the spectral variations. A comparison with the published photoelectric photometry (e.g., Kolotilov *et al.* 1995) shows that the AAVSO observations reflect all the features of the light curve seen in the higher precision, less well-sampled photoelectric data.

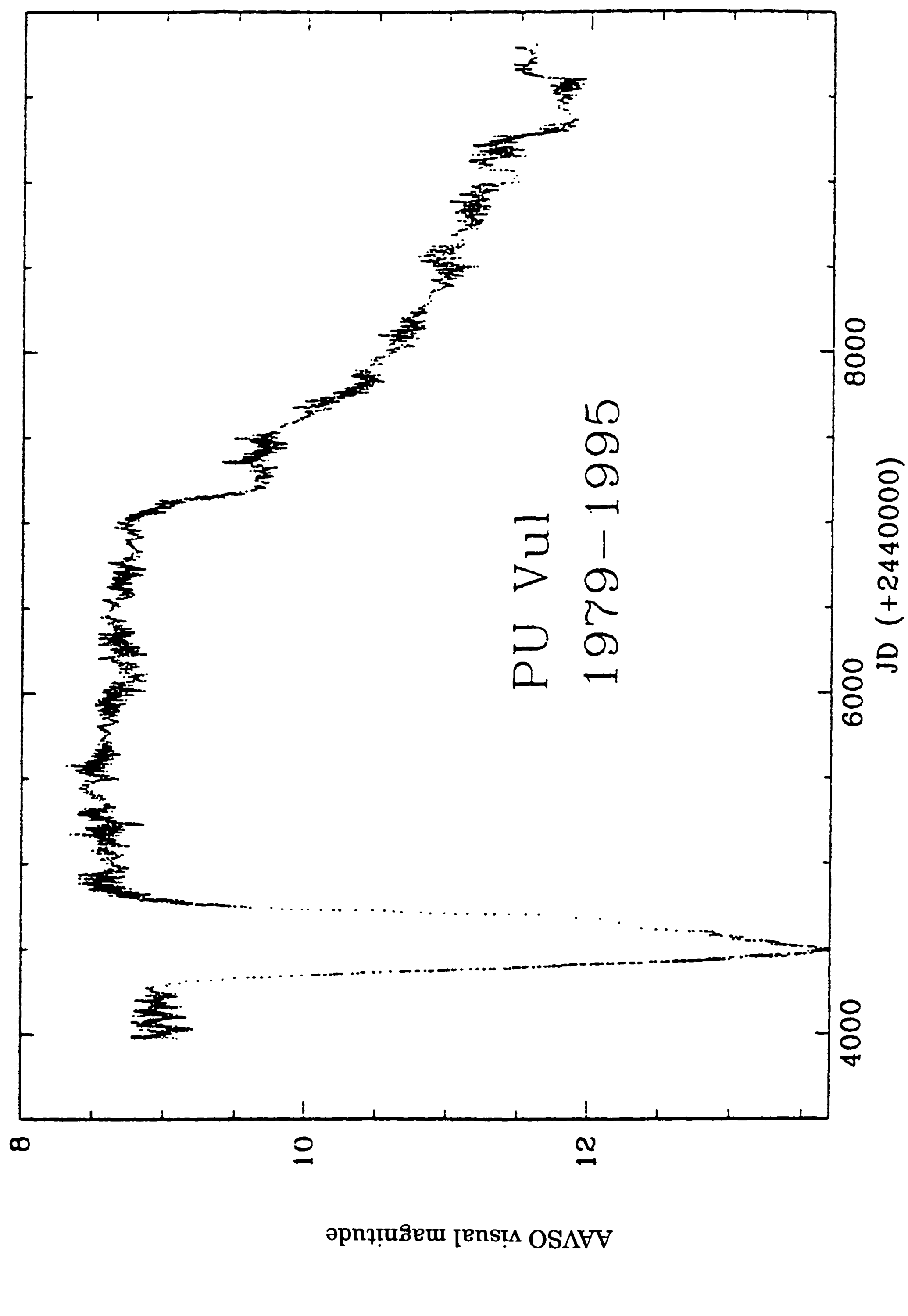

Figure 1. The AAVSO light curve of PU Vul from 1979 to 1995. The 12559 raw observations were processed with a 10-day running boxcar smoothing algorithm to produce the final light curve. The minimum near JD 2444500 is the 1980 eclipse and the feature at JD 2449400 is the 1994 eclipse.

3. Orbital period

The behavior of the spectrum of PU Vul and the shape of the light curve in 1994 are strong evidence for an eclipse of the white dwarf. Supposing that the deep minimum of 1980 was also due to an eclipse (of the pseudophotosphere of the nova shell), we can estimate the orbital period of the system.

Assuming the the eclipses of 1980 and 1994 are symmetric, the steep sides of ingress and egress can be used to estimate the time of mid-eclipse. For the 1980 event this assumption is questionable since the light curve shows unmodeled variability both out of and during eclipse. Bisecting the eclipse light curves gives JD 2444545 ± 8 and JD 2449445 ± 5 as the dates of mid-eclipse in 1980 and 1994, respectively. The resulting ephemeris for the date of mid-eclipse is

$$\mathrm{JD} = \underset{\pm 5}{2449445} + \underset{\pm 9}{4900}\,\mathrm{E}, \qquad (1)$$

or a period of 13.42 ± 0.02 years. This period is slightly shorter than the one found by Kolotilov *et al.* (1995) from photoelectric photometry, but within the errors of the two estimates.

Considering the differences between the two observed eclipses, it is worth checking whether an eclipse might have been missed in 1986/87. The light curve shows a precipitous drop beginning near JD 2447000, which is within the estimated errors of the date for mid-eclipse of a 6.7-year orbit. However, ingress is expected some 150 to 200 days earlier, so it is unlikely that this sudden brightness change is another primary eclipse.

For a circular 14-year orbit, the primary and secondary are in perfect alignment on JD 2446995. No noticeable eclipse is expected, since the giant is contributing little to the total light. But the fact that the nebular phase begins precisely midway between the eclipses may not be a coincidence. Unlike classical novae, the pseudophotosphere of PU Vul lies totally within the Roche lobe of the primary, and the giant's tidal force could affect the density distribution of the expelled gas. Modeling is needed to test this speculation.

4. Stellar component properties

The 1994 eclipse is shown in Figure 2. The ingress and egress are fast and the eclipse appears total. There are four sources of light expected from the system at this time: The cool giant, the nebular gas, the white dwarf (WD), and its hot, dense wind. The giant is probably a small contributor since the visual brightness of PU Vul before outburst was about 15th magnitude. From the recent spectra it is clear that the nebular lines are not significantly affected by the eclipse and must originate from a large volume surrounding both stars. The total disappearance of HeII 4686Å during eclipse and its rapid recovery argues that the wind is localized to the vicinity of the WD.

The slow decline in the visual brightness that began in 1987 and continued through 1994 was not present during the total eclipse. This fact implies that decline is primarily due to the fading of the WD+wind. The light during the minimum of the 1994 eclipse allows us to estimate the giant+nebular contribution to the visual flux at V= 11.8 magnitude. Removing the relatively constant contribution of the giant+nebula light, we find that the WD+wind visual flux is well represented by an exponential decay from JD 2447800 to JD 2449800. The e-folding time of the decay is 810 days (1.34 millimagnitudes/day) over almost four half-lives. This result is, of course, restricted to a small wavelength band, and a study of the bolometric flux is needed to fully understand the nature of the WD+wind.

By assuming that the giant and WD+wind are uniform disks and that the nebular

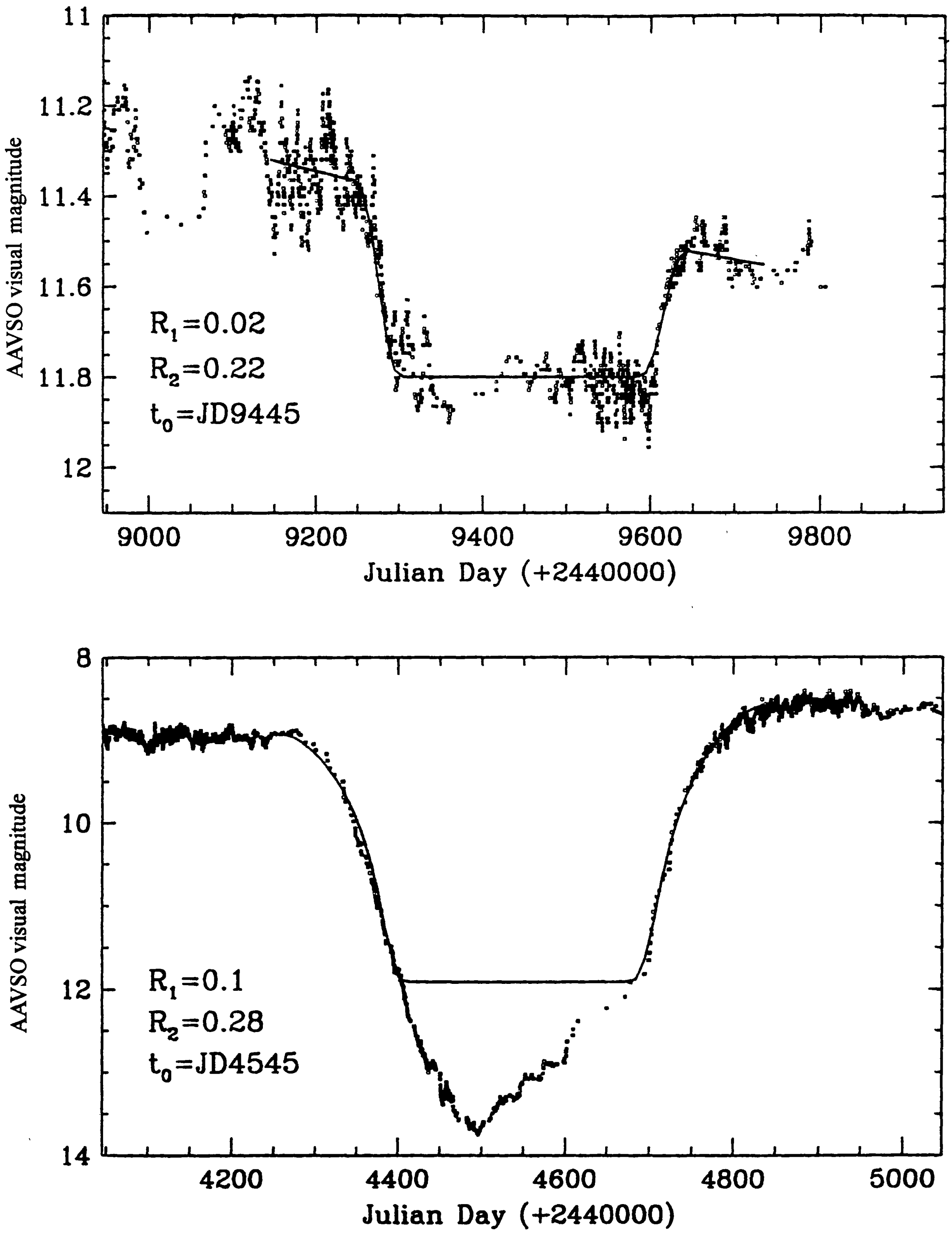

Figure 2. Model fits to the eclipses of PU Vul. The 1994 eclipse is shown at the top and the 1980 eclipse below. The scaled radii of the primary (R_1) and secondary (R_2) used in the models are also shown.

component is constant during the eclipse, we fit the observed 1994 eclipse for a zero inclination orbit. The giant radius scaled to the orbital radius is $R_2/a = 0.22$. Because partial eclipse phases are so short (close to the 10-day resolution limit), it is difficult to determine an accurate size for the WD+wind source. The total time for the eclipse is 390 days, while the time of totality is 310 days, so the diameter ratio of the two stars is about 0.1. The resulting best fit to the 1994 eclipse is shown as a solid line in Figure 2.

The 1980 eclipse from the AAVSO data is also shown in Figure 2. This eclipse does not have a flat bottom, so it was not total. However, the eclipse depth indicates these variations at minimum were a very small fraction of the total nova light output. The decline and rise contain most of the information about the size of the pseudophotosphere and so only the first three magnitudes of fading will be used for the fit. Again assuming uniform disks and zero inclination, a simulated eclipse is shown as a solid line in Figure 2. The scaled diameters for the components are $R_1/a = 0.28$ and $R_2/a = 0.10$. The diameter ratio is 0.36, which is close to the results of an analysis of the 1980 eclipse carried out by Vogel and Nussbaumer (1992) before a period was known.

Clearly, the primary (white dwarf) radius has shrunk by a large factor between eclipses. This shrinkage is expected, since in 1980 we are really measuring the size of the pseudophotosphere created by the expanding ejecta of the nova explosion. Oddly, however, the size of the secondary (giant) has also decreased between 1980 and 1994. It is nearly impossible to fit the 1980 eclipse using the same diameter of the giant derived from the 1994 eclipse.

There are a number of reasons why the diameter of the giant star may have changed between eclipses. The secondary may be a semiregular variable. Further brightness estimates as the system light fades may reveal such a regular variation in the secondary. Alternatively, the secondary may have expanded due to heating from the nova explosion. Finally, the secondary may be unstable and its expansion may have triggered the nova explosion by increasing the accretion rate onto the white dwarf. The historical light curve by Liller and Liller (1979) shows a number of small outbursts over the past century, which may have been caused by the instability of the secondary.

5. Conclusions

PU Vul is an eclipsing binary. Analysis of eclipses in 1980 and 1994 provide a period of 13.42 ± 0.02 years. While the light curve shows a rapid variation exactly halfway between these eclipses, it is unlikely to be due to another primary or a secondary eclipse. Therefore, the next eclipse of the white dwarf is expected to begin toward the end of February, 2007.

Modeling the shape of the two eclipses implies that the radius of the secondary star (giant) decreased by 20% between 1980 and 1994.

References

Garnavich, P., and Trammell, S. R. 1994, *IAU Circ.* No. 6089.
Kenyon, S. 1986, *The Symbiotic Stars*, Cambridge University Press, Cambridge.
Kolotilov, E. A., Munari, U., and Yudin, B. F. 1995, *Mon. Not. Royal Astron. Soc.*, **275**, 185.
Kozai, Y. 1979a, *IAU Circ.*, No. 3348.
Kozai, Y. 1979b, *IAU Circ.*, No. 3344.
Liller, M. H., and Liller, W. 1979, *Astron. J.*, **84**, 1357.
Mattei, J. A. 1995, visual observations from the AAVSO International Database, private communication.
Vogel, M., and Nussbaumer, H. 1992, *Astron. Astrophys.*, **259**, 525.