PHOTOELECTRIC AND VISUAL OBSERVATIONS OF X PERSEI

John R. Percy
Erindale Campus
University of Toronto
Mississauga, Ontario
Canada L5L 1C6

Received: June 25, 1992

Abstract

X Persei, the optical counterpart to the X-ray source 4U0352+30, consists of a neutron star secondary accreting from an O9.5IIIe star. Detailed photoelectric (UBV) observations of X Persei have been obtained from (i) the AAVSO Photoelectric Photometry Program and (ii) the Automatic Photometric Telescope (APT) Service in Arizona. These observations (and a light curve based on 30-day means of AAVSO visual observations since 1962) serve to define the complex variability of the star in the last three decades, including an interval since 1989 when the star has been non-variable at the 0.01-magnitude level.

1. Introduction

X Persei (HR 1209, HD 24534, 0349+30, O9.5IIIe, V = 6.0 - 6.8) is the optical counterpart to the pulsating X-ray source 4U0352+30. The system consists of a neutron star secondary accreting from an O9.5IIIe primary via stellar wind processes. The rotation period of the neutron star is 835 seconds, and the orbital period of the system is believed to be 581 days; there is also a suspected X-ray period of 22.4 hours. X Per is a member of the Be class of stars - hot stars which have shown emission in at least one Balmer line on at least one occasion.

In 1989 and 1990, X Per underwent a dramatic phase change, losing its circumstellar shell, infrared excess, and H-alpha emission line (Norton *et al.* 1991). Roche *et al.* (1992) have presented detailed optical and infrared measurements throughout this change, and have compared them with earlier, archival material. They provide, among other things, a 22-year V-band light curve of this star, and suggest that a similar "naked" phase occurred in 1974-77. They examine X-ray data available from this earlier episode, and discuss the X-ray behavior of the system during and after the event. They find a clear correlation between the optical, infrared, and X-ray behavior during the "naked" phase, followed by an extended period when the X-ray behavior appears to be uncorrelated to that in the optical and infrared.

X Per (HR 1209, HD 24534, 0349+30, O9.5IIIe, V = 6.0 - 6.8), has been observed both visually and photoelectrically by the AAVSO. In view by the findings by Norton *et al.* and Roche *et al.*, it seemed timely to examine the AAVSO observations. In addition, I had been gathering photoelectric data on X Per using the Automatic Photometric Telescope (APT) Service on Mt. Hopkins in Arizona, but only since 1989.

2. Photoelectric Observations

X Per has been in the AAVSO photometry program (Percy 1991) since 1983. In this program, differential observations are made, relative to a comparison star and a check star. They are corrected for extinction and reduced to the standard UBV

system using seasonally-determined transformation coefficients and the catalogue (B-V) colors of the stars, because observations are generally made in V only. This procedure results in additional errors of a few millimagnitudes, but this amount is relatively small compared with the typical instrumental error of approximately 0.01 magnitude.

Comparison stars used were HR 1074 = HD 21856 (B1V, V = 5.90, (B-V) = -0.06, (U-B) = -0.85), and HR 1163 = HD 23625 (B2V, V = 6.57, (B-V) = -0.08, (U-B) = -0.61). Data cover JD 2445650 to JD 2447527, and were made by the following observers: William Barksdale (12 observations), Frank Dempsey (2), Robert Johnsson (3), Paul Kneipp (8), George Kohl (32), Thomas Langhans (6), Kenneth Luedeke (10), Russell Milton (14), Harry Powell (4), and Michael Smith (4). These observations are archived at AAVSO Headquarters (Mattei 1992a).

The acquisition and reduction of the APT Service data are described by Seeds (1991). Observations were generally made in UBV, except for intervals when there were instrumental problems with the U filter. The typical accuracy of an APT observation is 0.005 magnitude.

Comparison stars used were HR 1163 (mentioned above) and HR 1197 = HD 24167 (A5V, V = 6.25, (B-V) = +0.20, (U-B) = +0.14). The observations extend from JD 2447790 to JD 2448610, excluding the usual seasonal gaps and the Arizona "monsoon" season in July and August.

3. Visual Observations

Visual observations of X Per have been made by the AAVSO for many decades. Those since 1962 are available in computer-readable form, and can be processed, analyzed, and displayed in a variety of ways, thanks to the computer hardware and software now available at AAVSO Headquarters. Figure 2 is a visual light curve of X Per since 1962, based on 30-day means of visual observations (Mattei 1992b).

4. Results and Discussion

The V light curve of X Per is shown in Figure 1. It covers the last portion of the time interval discussed by Roche *et al.* (1992), but in somewhat more detail. UBV data were obtained only from the APT Service, but since U, B, and V were essentially constant for 1989-92, the U and B data provide little extra information. X Per has shown some tendency to undergo brief minima in U in the past. There is no evidence for such behavior in the present data.

The mean (B-V) of X Per during the 1990-92 minimum was +0.135, in good agreement with the value quoted by Roche *et al.* (1992) for the 1974-77 and 1990-92 minima. The mean (U-B) is uncertain, but appears to be -0.79 during the 1990-92 minimum.

Photoelectric coverage is reasonably complete from late 1986 to the present. The rise to maximum in 1986-88 is nearly linear, and reaches a peak in early 1988 (JD 2447180-7260). After the seasonal gap, the decline is nearly linear, reaching minimum on JD 2447590. From then until early 1992, the magnitude is almost constant, although both the AAVSO and the APT data suggest that there was a brightening of about 0.03 magnitude by early 1992.

As noted by Roche *et al.* (1992), X Per still showed emission lines on JD 2447925 - almost a year after the brightness reached a minimum. The excess V emission in Be stars is thought to be due to continuum radiation from the disc. There must therefore have been enough gas in the disc to generate H-alpha line emission, but not enough to generate significant continuum radiation.

A notable feature of the APT data is the lack of variability of X Per, on time

scales from hours to months, during the interval of observation. The scatter of the variable is no greater than that of the check star - a few millimagnitudes. This indicates that the actual variability of X Per can be no greater than about 0.01 magnitude. Be stars typically show short-term photometric variability of a few hundredths of a magnitude (Percy 1987) due to non-radial pulsation, or possibly rotation (Balona 1990).

The visual means (Figure 2) cover a 30-year interval. Knowing that the star has been constant since 1989, we can deduce that the precision of the visual means is slightly better than 0.1 magnitude. The visual light curve shows all of the main features of the photoelectric light curve of Roche *et al.*, including minima around JD 42000-43300, 44100, 44600, 45800, 46000-46500, and 47500-, and maxima around 43500, 44400, 45200, 46000, and 47100. The visual magnitudes are, on the average, about 0.25 magnitude brighter than the photoelectric V magnitudes, as might be expected.

5. Conclusions

Figures 1 and 2 show, very effectively, how visual and photoelectric observations can complement each other. X Per should obviously be monitored at all times, using both techniques. X Per and other Be stars should also be monitored spectroscopically. This project would be a useful and interesting one for amateur observers.

6. Acknowledgements

I thank the Natural Sciences and Engineering Research Council of Canada for a research grant, Howard Landis for reducing and archiving the AAVSO photometry, and Michael Seeds for serving as Principal Astronomer and coordinator for the APT Service. I also thank the AAVSO visual observers and headquarters staff for making Figure 2 possible.

References

Balona, L. A. 1990, *Mon. Not. Roy. Astron. Soc.*, 245, 92.

Mattei, J. A. 1992a, photoelectric observations from the AAVSO international database, private communication.

Mattei, J. A. 1992b, visual observations from the AAVSO international database, private communication.

Norton, A. J., Coe, M. J., Estela, A., Fabregat, J., Gorrod, M. J., Kastner, J., Payne, B. J., Reglero, V., Roche, P., and Unger, S. J. 1991, *Mon. Not. Roy. Astron. Soc.*, 253, 579.

Percy, J. R. 1991, *IAPPP Communications*, No. 45, 33.

Percy, J. R. 1987, in *The Physics of Be Stars*, eds. A. Slettebak and T. P. Snow, Cambridge University Press, 49-65.

Roche, P., Coe, M. J., Fabregat, J., McHardy, I. M., Norton, A.J., Percy, J. R., Reglero, V., Reynolds, A., and Unger, S. J. 1992, preprint.

Seeds, M. A. 1989, in *Remote Access Automatic Telescopes*, eds. D. Hayes and R. Genet, Fairborn Press, Mesa, Arizona, 163.

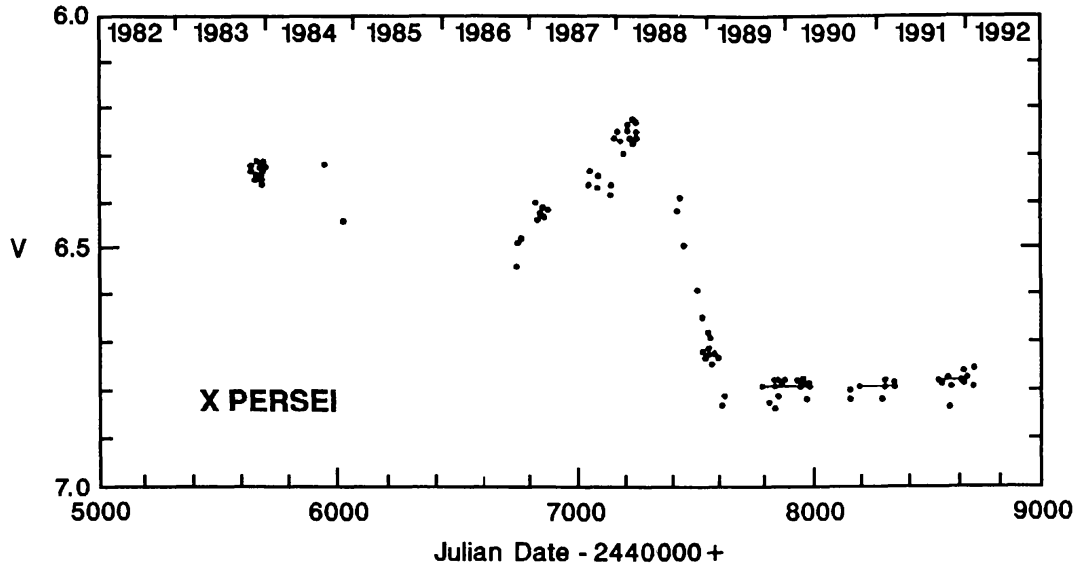

Figure 1. Photoelectric (V) observations of X Persei. The filled circles are individual observations made by observers in the AAVSO Photoelectric Photometry Program; the line segments represent the APT observations, which show little or no variability at the 0.01-magnitude level since 1989.

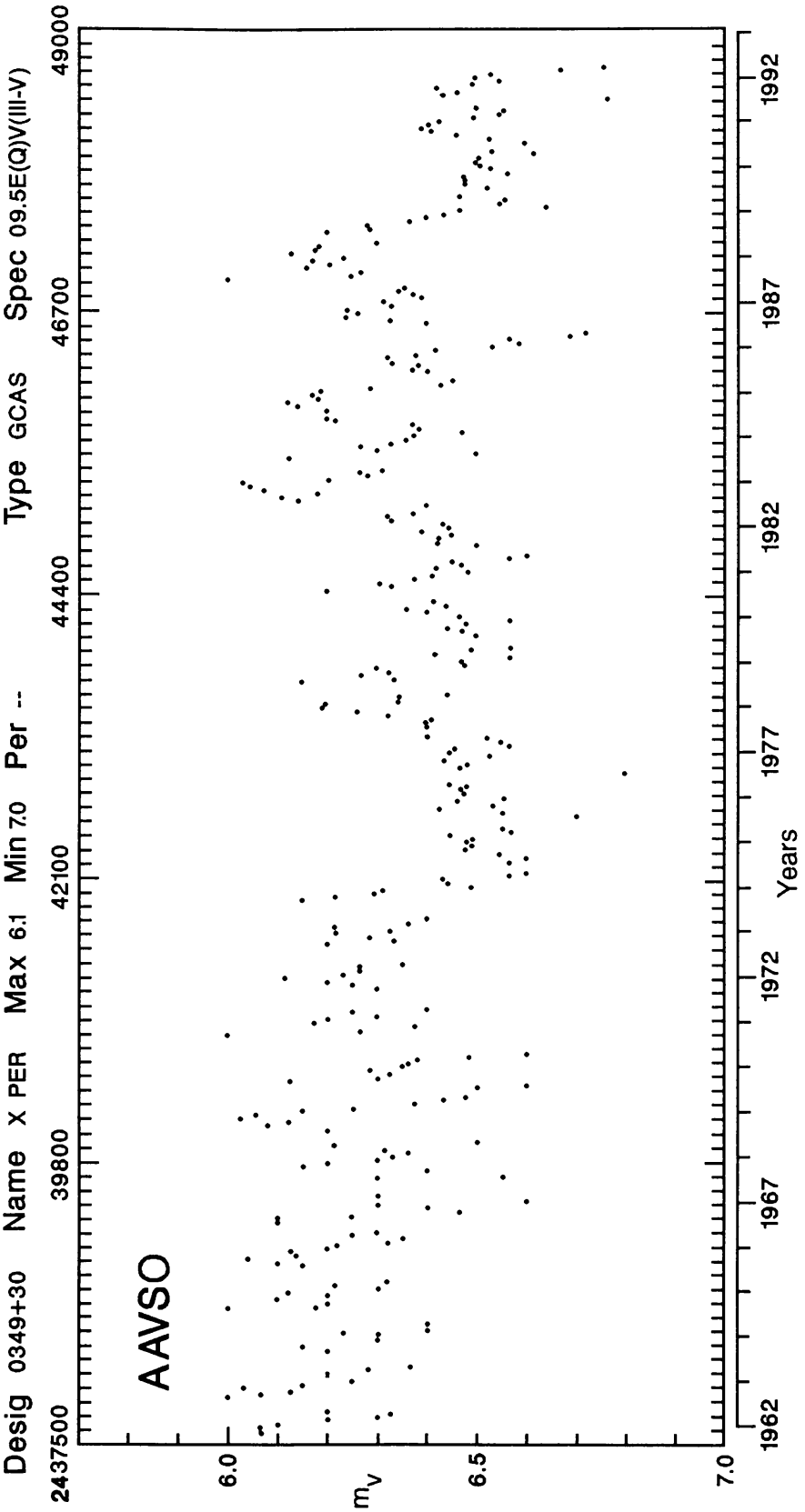

Figure 2. Thirty-day means of AAVSO visual observations of X Persei since 1962. [Ed. note: The number of observations in the averaging interval significantly affects the average value.]