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PHOTOMETRY OF INTERMEDIATE POLARS AO PSC AND V 1223 SGR

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Abstract. We present optical photometric observations of the cataclysmic variables AO Psc and V 1223 Sgr, both of which are believed to contain slowly-rotating white-dwarf pulsars. These objects belong to the new class of intermediate polars in which the magnetized-white-dwarf rotation period lies in between synchronous and extremely fast rotation periods. The observations reported here were carried out from the Kavalur Observatory using a 1 m reflector. High-time resolution light curves depicting a rich variety of flicker phenomena are presented. Results of a periodic analysis to search for coherent periodic modulations in the light curves are also presented. We have also derived the optical pulse profile of AO Psc and point out its similarities to the X-ray pulse profile.

1. Introduction

The galactic X-ray source AO Psc was identified with a 13th magnitude cataclysmic variable by Griffiths *et al.* (1980). Persistent modulation at optical wavelength with a period of 859 s and a binary orbital period of 03.59 hr were subsequently identified (Warner, 1980; Patterson and Price, 1980). X-ray pulsations with a period of 805 s were detected by White and Marshall (1980), and finally a small optical modulation (0.02–0.04 mag.) at the X-ray period was identified by Warner *et al.* (1981). In the presently favoured model of the system, the X-ray and optical pulsations at 805 s period come from the vicinity of the prograde spinning white dwarf, while the optical modulation at the beat period of 859 s arises from the reprocessing of X-ray flux into optical emission from a region of the system co-rotating with the orbital period. The reprocessing region could be the atmosphere of the companion star (Patterson and Price, 1981) or a hot spot where the accretion column from the companion star strikes the disk (Hassall *et al.*, 1981).

The galactic X-ray source 4U1849 − 31 was identified with a 13th magnitude irregular variable V 1223 Sgr by Steiner *et al.* (1981). Optical pulsations with a period of 794 s and semi-amplitude of ~ 15% were also reported by these authors. Warner and Cropper (1984) have presented the results of extensive photometric observations. They claim the detection of an occasional optical-oscillation with a period of 850 s. Brightness variations by 10–20% on time-scales of 100 s have also been reported.

The close resemblance between V 1223 Sgr and AO Psc has been stressed by several

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authors. Based on the relatively slow rotation rates of the white dwarf in the binary systems, the two stars have recently been classified as members of a new group of cataclysmic variables named intermediate polars (Warner, 1983). In polars like AM Her, the white dwarf rotates synchronously with the orbital period, while in DQ Her stars the rotation rate of the white dwarf is extremely fast with periods ranging from 30 to 80 s. In intermediate polars, on the other hand, the white dwarf rotation rates lie intermediate between the two extremes and typically have values in the range of around 700–1200 s. Detailed investigations of the optical pulsations, including the level of modulation, the pulse profile and the rate of spin-up are important for a complete understanding of the accretion torques operating on the white dwarf causing its spin-up, and the role and strength of magnetic fields in these systems. A comparative study in several wavelength bands, of the pulse profiles from slowly rotating white-dwarf pulsars with those from neutron star pulsars can shed considerable light on the accretion phenomena in these systems. With this motivation we conducted photometric observations on the optical counterparts of selected X-ray sources. In this paper we present the optical observation of these two white-dwarf pulsars: namely, AO Psc and V 1223 Sgr.

2. Observations

The observations of V 1223 Sgr and AO Psc have been carried out with the 1 m telescope of the Kavalur Observatory on 3 May and 28 August, 1984, respectively. A single channel high-speed photometer (Sharma *et al.*, 1981) with an EMI 9804 QB photomultiplier, and without filter (white light mode) was used for the observations. Diaphragms of 24.4 arc sec and and 12.4 arc sec were used for the observations of V 1223 Sgr and AO Psc, respectively. Bulk of the data were recorded with an integration time of 1 s. *U*, *B*, *V* filter measurements were occasionally performed to calculate the apparent magnitude of the stars. The sky background and comparison stars were monitored for this purpose.

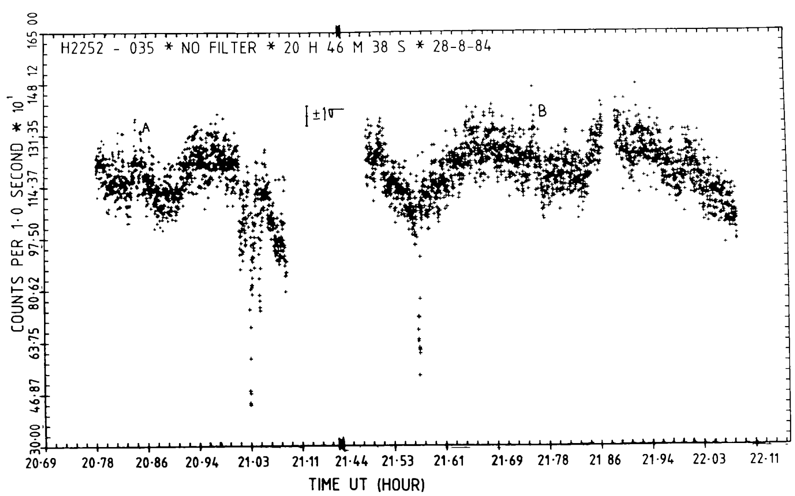

Fig. 1. High time-resolution light curves of AO Psc.

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3. Results and Discussions

3.1. AO Psc (H2252 – 035)

In Figure 1 we present one of the high time-resolution (1 s) light curves of AO Psc obtained on 28 August, 1984. No filter was used for these observations. One can see about four cycles of the well-known 859 s optical pulsations from the binary system. The variations in the pulse profiles from cycle to cycle can also be seen distinctly. The average peak to peak modulation is about 14%.

One can see flares lasting about 80–100 s at 20.84 and 21.76 UT marked A and B in Figure 1 and shown enlarged in Figure 2. The flares appear to be triangular in shape with decay times only slightly longer than the rise times. They have typical magnitudes of ~ 0.25. It is also to be noted from Figure 2 that the short duration flickers (flares) are seen prominently at the minima as well as at the maxima of the dominant optical pulsation light curves of the ibnary binary system, while Warner *et al.* (1981) had noted that the minima between two humps are relatively quiet.

The sharp decrease in intensity at about 21.03 UT could be attributed to thin passing clouds. While the observations were stopped for a while at 21.10 UT due to non-photometric sky conditions, the sky was good at 21.57 UT. The decrease in white light intensity at this time represents a change of about 0.7 mag. The duration of the decrease is about 10 s. In the expanded light curve shown in Figure 2 we have deleted this sharp decrease in order to magnify the persistent smaller amplitude flickers. At 22.10 UT, the differential *V* magnitude of AO Psc is 13.40.

We have searched for the periodicities in the sytem with an epoch folding algorithm, the result of which is shown in Figure 3 where the chi-square values are plotted against trial periods. The derived mean period is found to be $\sim 900 \pm 80$ s. The large width of the chi-square distribution is consistent with that predicted by the relationship between the total length of data T and the true period P_0, namely, FWHM $\simeq P_0^2/T$.

The folded average pulse profile corresponding to a period of 900 s along with X-ray profiles in two energy bands at the X-ray period of 805 s (White and Marshall, 1981)

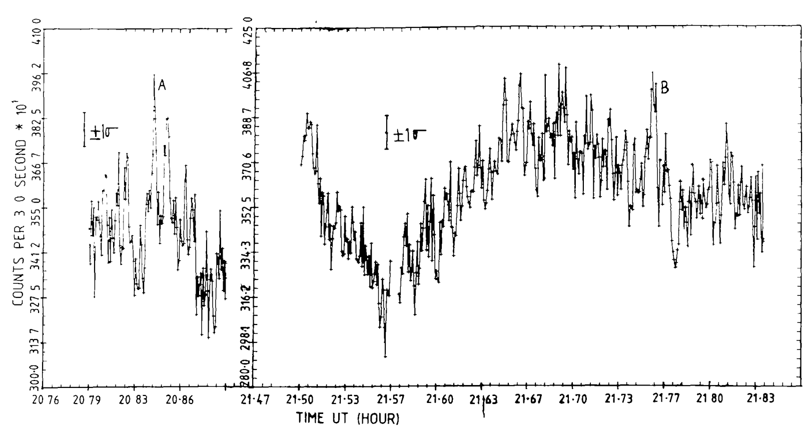

Fig. 2. Expanded view of portions of the light curves showing flares.

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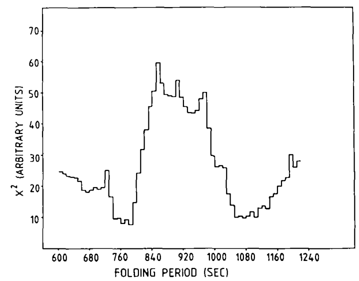

Fig. 3. Results of the epoch folding algorithm of AO Psc data.

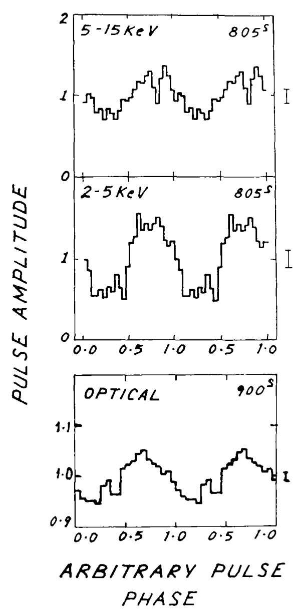

Fig. 4. Pulse profiles of AO Psc in different energy bands. X-ray light curves are taken from White and Marshall (1981).

is shown in Figure 4. The unfiltered optical profile is not sinusoidal in nature. It does not resemble the one presented by Motch and Pakull (1981) in the *W*-band (λ_{eff} = 3255 Å) with a Walraven photometer. The modulation seen from the optical pulse profile has an average semi-amplitude of 5.5%.

The variation between the pulse profiles in the three energy ranges is interesting. It poses a major challenge to models of emission mechanisms. The similarity in the pulse profiles in the optical band and the 2–5 keV X-ray band is striking. There is an indication of an interpulse in both profiles. Since the optical pulsations is believed to be due to re-processed X-ray photons, this similarity may be indicative of the energy of X-ray photons taking part in this process. Both the X-ray pulse profiles show a double pulse at the peak of the main pulse. This is absent in the optical profile. Instead the latter shows a smearing of the profile as may be expected from a re-processing mechanism for its origin.

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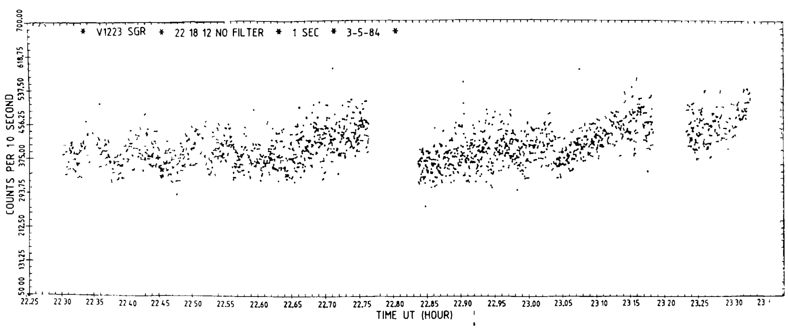

Fig. 5. High time-resolution light curves of V 1223 Sgr.

3.2. V 1223 Sagittarii

In Figure 5 we present the light curves of V 1223 Sgr with an integration time of 1 s. Although the typical flickers on time-scales of minutes seen in cataclysmic variables are evident in the light curves, the optical pulsations at 794 s are not seen at the typical modulation level of 15% (Warner and Cropper, 1984). However, a period folding analysis gives a period of the pulsations as 780 $\pm$ 90 s. The large uncertainty in the pulse period results from the relatively short duration of the total observation time and the large true period. The white light pulse profiles of V 1223 Sgr is shown in Figure 6. The optical modulation is seen to be not strictly sinusoidal and has a peak to peak amplitude of about 5%. At 22.20 UT the measured differential V magnitude of V 1223 Sgr is 13.60.

4. Conclusions

We have presented high time-resolution light curves of AO Psc and V 1223 Sgr. We confirm the presence of dominant optical pulsations in AO Psc and V 1223 Sgr at 900 $\pm$ 80 s and 780 $\pm$ 90 s, respectively. The uncertainty in the pulse periods is consistent with that predicted by the relationship between the length of data and the relatively large pulsation period. We have also presented the optical pulse profiles of AO Psc and V 1223 Sgr. The optical profile of AO Psc shows remarkable similarities

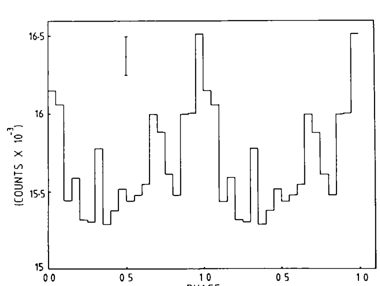

Fig. 6. White light pulse profiles of V 1223 Sgr.

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to the low-energy X-ray profile which is consistent with the models of reprocessing of X-ray photons to produce optical pulsations.

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