COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 5388

Konkoly Observatory
Budapest
3 March 2003

HU ISSN 0374 – 0676

THE 2002 OUTBURST OF THE INTERMEDIATE POLAR GK PERSEI

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GK Per (Nova Per 1901/A 0327+43) is an intermediate polar with $P_{\rm orb} = 1.99$ days (Crampton et al., 1986) and $P_{\rm spin} = 351$ sec (Watson et al., 1985). Fluctuations by about 1 mag appeared after the nova explosion. Later, they developed into infrequent 2–3 mag outbursts (e.g. Hudec, 1981; Sabbadin & Bianchini, 1983) which were accompanied by brightenings in X-rays (e.g. King et al., 1979). The model for the thermal instability of the disk was able to reproduce the basic features of the outbursts although some problems remained (Kim et al., 1992). Dramatic variations of the energetics of the outbursts and the recurrence times occurred during the last five decades (Šimon, 2002). Nowadays, the outbursts of GK Per are quite infrequent and occur once per about 3 years. The last outburst in 2002 gave an opportunity to check if the trends in the outburst properties, determined by Šimon (2002), still hold because the activity of dwarf novae is known to undergo large, rapid changes.

This analysis makes use of the visual data of GK Per, obtained from the database of AFOEV, (CDS, Strasbourg, France) and VSNET (Japan). The reason is that the monitoring of dwarf novae is almost entirely the domain of the associations of amateur observers. The observations are mostly visual but they are very numerous and come from a large number of observers. The objectivity of the features in the light curves can therefore be assessed very well. Visual data, if treated carefully, can be very useful for analysis of long-term activity (e.g. Percy et al., 1985; Cannizzo & Mattei, 1992; Richman et al., 1994). Accuracy even better than 0.1 mag can be achieved by averaging the data, which is quite sufficient for analyses of these large-amplitude variable stars. In addition, modern methods for the data processing enable a better evaluation of the important information contained in this kind of data.

In order to smooth the light curve of GK Per, the observations were binned into one-day means. The resulting curve was then fitted by the code `HEC13`, written by Dr. P. Harmanec and based on the method of Vondrák (1969 and 1977). This method can fit a smooth curve no matter what the course of the data is. After several trials the input parameters of the fit $\epsilon = 10^{-1}$, the length of the bin $\Delta T = 5$ days were found to satisfy the course of the data. These parameters were adjusted so that just the main course of the curve was reproduced. The standard deviation of the residuals of the fit was 0.1 $m_{\rm v}$ but it should be kept in mind that this value reproduces both the observational inaccuracies and the real fluctuations which are observed during the outbursts of GK Per (e.g. Morales- Rueda et al., 1996).

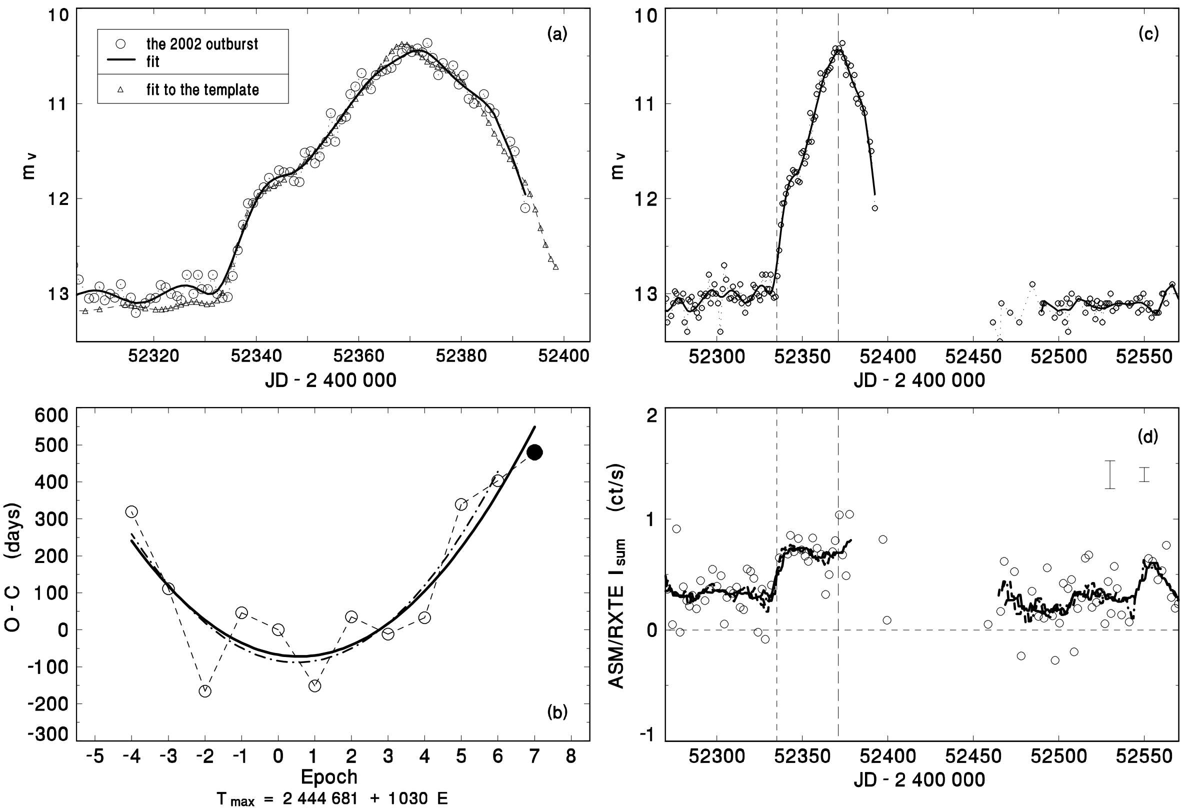

Figure 1. **(a)** The optical light curve of the 2002 outburst. The empty circles represent the one-day means while the solid curve denotes their fit by the code HEC13. For comparison, the empty triangles mark the fit to the template outburst used in Šimon (2002), shifted by 1107 days. **(b)** The $O-C$ diagram for the outbursts over the interval following the dramatic change of the outburst behaviour. The position of the 2002 outburst is marked by the filled circle. The solid and the dashed parabolae represent the fits with and without the 2002 outburst. **(c and d)** Relation between the outburst light curves in the optical and hard X-ray (1.5–12 keV) passbands. Two-day means of the $ASM/RXTE$ data, formed from the original daily means that had $\sigma_q < 0.4$ count/sec, are plotted. The larger error bar denotes the typical σ_q of the daily means while the smaller one marks the standard deviation of the two-day means. The two-sided moving averages for $Q=6$ days (dashed line), $Q=8$ days (dot-dashed line) and $Q=10$ days (solid line) are shown in **d**. The dashed vertical lines mark the moments of the onset and the maximum light of the outburst in the *optical* region.

The moment of the light maximum $T_{\rm max}$ = JD 2452371±2 was determined by fitting a polynomial to the upper part of the outburst light curve. The peak magnitude, $m_{\rm max}$, was determined to be 10.4. In order to assess the profile of the curve with respect to the previous events, a match of a template (the same as the one used in Šimon (2002); the preceding outburst with the maximum in JD 2451280) was applied. Also the template was smoothed by `HEC13` with the above-mentioned parameters. The result can be seen in Fig. 1a.

The relation of the 2002 outburst to the previous evolution of the recurrence time $T_{\rm C}$ can best be assessed from the $O-C$ diagram. The method of the $O-C$ residuals from some reference period (e.g. Vogt, 1980; Šimon, 2000) enables us to determine $T_{\rm C}$ in a dwarf nova and to analyse its variations. This method is not sensitive to the exact length of the reference period. The ephemeris, representative of the recent interval and determined by Šimon (2002), was used (Eq. 1). The position of the 2002 outburst in the $O-C$ diagram is marked in Fig. 1b along with the quadratic fits.

$$T_{\rm max} = 2\,444\,681 + 1030\ E \qquad (1)$$

The 2002 outburst of GK Per was covered by the All Sky Monitor (*ASM*) onboard the *Rossi X-ray Timing Explorer* (*RXTE*) satellite (`http://xte.mit.edu/`). Although the signal was relatively weak, the main trends in the X-ray light curve could be determined with certainty by a careful fitting. The *ASM*/*RXTE* data cover a large part of the outburst (although partly affected by the interval of the seasonal invisibility) and so they give us a rare opportunity to compare the behaviour in the hard X-ray and optical regions. In order to lower the noise of the X-ray data, only daily means with the quoted uncertainty, $\sigma_{\rm q}$, smaller than 0.4 count/sec were used. Two-day means were then calculated. We note that the rapid fluctuations in Fig. 1d are likely to be mainly caused by the observational noise. The data were therefore carefully smoothed. The two-sided moving averages were calculated for $Q = 6$, 8 and 10 days. Q refers to the semi-interval of days, within which the data were averaged. The resulting X-ray light curve is shown in Fig. 1d. The individual fits to the *ASM* data are in good agreement. The optical light curve is shown on the same scale for comparison (Fig. 1c).

This analysis of the 2002 outburst and its comparison with the previous dramatic evolution of the activity (Šimon, 2002) revealed that the outburst parameters stabilized. The very good agreement between the profile of the whole observed part of the 2002 event and the template (even including the most variable rising branch) reflects the large similarities in the processes involved. Notice particularly the rapid initial rise by about 1.0 $\rm m_v$, followed by a significantly slower rise to the maximum. This can be interpreted in terms of the inside-out type of outburst (Smak, 1984; Hameury et al., 1998). In this case, the heating front (HF) starts in the inner disk region, propagates outward and need not reach the outer disk radius. Nevertheless, we note that the stabilization of $m_{\rm max}$ of the recent outbursts in GK Per suggests that the extent of the disk brought to the hot state stabilized – most probably the outer radius of the disk was reached by the HF. The shape and slope of the rising branch are the most sensitive to the location of the start of the HF. The almost identical profiles then also suggest that the onset of the HF occurred in quite a similar disk region.

The trend in the $O-C$ curve continues (Fig. 1b). The fit with the 2002 event differs just a little from that without it. $T_{\rm C}$ is governed by the disk viscous time scale for the inside-out type outbursts and therefore depends on the viscosity parameter in quiescence $\alpha_{\rm cool}$. It therefore appears that $\alpha_{\rm cool}$ appears to have remained almost the same for the recent several outbursts.

The relation between the optical and X-ray light curve is complicated in GK Per. The rise of the outburst in the X-ray region is very fast and coincides with the initial rapid rise in the optical passband. It displays a clearly flat profile later on although the optical flux further increases. The end of the outburst is affected by the conjunction with the Sun but the data are consistent with the simultaneous finish of the optical and X-ray outburst. We emphasize that the relation between the start of the optical and X-ray outburst is not trivial in GK Per. The relatively faint and short optical outburst in 1978 was accompanied by the X-ray brightening, whose onset preceded the optical rise by about 40 days (King et al., 1979; Bianchini & Sabbadin, 1985). Indeed, the models by Kim et al. (1992) predict that a brightening in X-ray and UV can precede the optical outbursts in GK Per by 80–120 days. Such a precursor was definitely absent in the 2002 event. The discordance between the optical and X-ray curves can imply a large change of the geometry of the accretion flow, e.g. blocking of hard X-rays by the thickened disk (Yi et al., 1992). Another alternative can be the radiation drag (Yi & Vishniac, 1994). We can conclude that the relation between the optical and X-ray course during the 2002 outburst confirms the stabilization of the activity of GK Per because it displays quite similar properties as in the two previous events in 1996 and 1999 (Šimon, 2002).

Acknowledgements: This research has made use of NASA's Astrophysics Data System Abstract Service, the AFOEV database, operated at CDS, France, and the observations provided by the ASM/RXTE team. I am indebted to Dr. Harmanec for providing me with the program HEC13. The support by the project ESA PRODEX INTEGRAL 14527 is acknowledged. Naturally, my thanks also to numerous amateur observers worldwide whose observations made this analysis possible.

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