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The August 1993 outburst of the black hole candidate GRO J0422+32*

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Abstract. One year after the X-ray outburst, the optical counterpart of the black hole candidate GRO J0422+32 underwent an unexpected one-month outburst beginning on 10 August 1993. CCD photometry was obtained for the optical counterpart with the 1.5-m telescope at Calar Alto on 6 consecutive nigths since the onset of this event, never seen before in other transients belonging to the black-hole class. Two spectra were also taken with the 2.2-m telescope on 14 August. We suggest the Mass Transfer Instability model as possible explanation of the event on the basis of the observational facts presented here.

Key words: X-ray: bursts; stars – stars: GRO J0422+32 – instabilities – accretion disks

1. Introduction

Low Mass X-ray Binaries (LMXBs) are systems formed by a low-mass companion and a compact object. A subclass of LMXBs are the Soft X-ray Transients (SXTs, so called X-ray Novae, although the physics is quite different from the classical novae). In these systems, sporadic outbursts are produced due to some poorly understood mechanism for which some mass is sporadically transferred onto the compact primary via an accretion disk. There are two types of SXTs. In Type I, the compact object is a weakly magnetized neutron star, whereas in Type II, the compact object is likely to be a black hole. This Type II class comprises so far on the order of fifteen members. Normally they brighten in the course of a few days to become one of the brightest sources in the X-ray sky, then declining in brightness over the next few months. The X-ray spectra is often dominated with an ultrasoft component and a hard X-ray tail. Only the latter component was detected in GRO J0422+32 (sometimes referred as Nova Persei 1992), that emerged in the X–ray sky on 5 August 1992 (Paciesas at al. 1992). The source was also observed by the X-ray all-sky monitor WATCH on GRANAT since 11 August (Castro-Tirado, Brandt & Lund 1992). The optical counterpart was discovered ten days later at the Crimean Astrophysical Observatory (Castro-Tirado et al. 1992). The object increased in brightness by 9.5 magnitudes. Among the most important results, spectroscopical observations during quiescence have revealed that the compact object is likely to be a black hole (Casares et al. 1995, Filippenko, Matheson & Ho 1995). The discovery of secondary outbursts (*mini-outbursts* hereafter) one year after the main outburst (August and December 1993) was quite unusual. We performed optical observations during the August 1993 mini-outburst, and the results are presented here.

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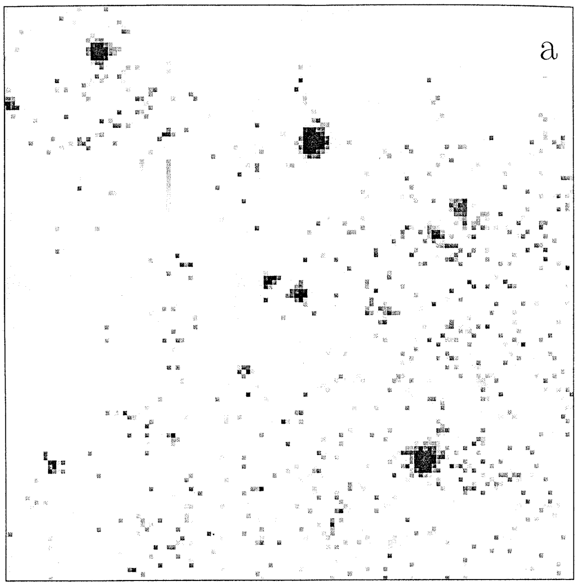
2. Instrumentation

Observations of the optical counterpart of GRO J0422+32 were carried out on the 1.5 m Spanish telescope at the German- Spanish Calar Alto Observatory. The CCD used was a THX CCD (1024 x 1024 pixels), that yielded a 5.46' x 5.46' square field. Typical exposures were 300 s for the V filter. More than 90 CCD images were analyzed. The data were reduced using IRAF. The images were processed to eliminate the electronic bias and flat field corrected to remove the pixel-to-pixel sensitivity variations. The optical light curve was obtained when using the differences in flux between the object and 10 field stars. The net counts were integrated within a 9.6" aperture. The seeing was during most of the time of the order of 1.0" (FWHM 3 pixels). Two spectra covering the region 4000-7000 Å were taken on 14 August at the Cassegrain focus of the 2.2 m telescope in Calar Alto. The Tek #6 CCD at the Boller & Chivens spectrograph was used, with a grating with 600 l/mm, providing a dispersion of 2.9 Å/pixel. The integration times were 10 and 45 minutes. The seeing was of the order of 1.0".

3. Observations

The first CCD images were taken on 10 August, and showed GRO J0422+22 as a faint star at V = 18.7 ± 0.1 (B = 19.9



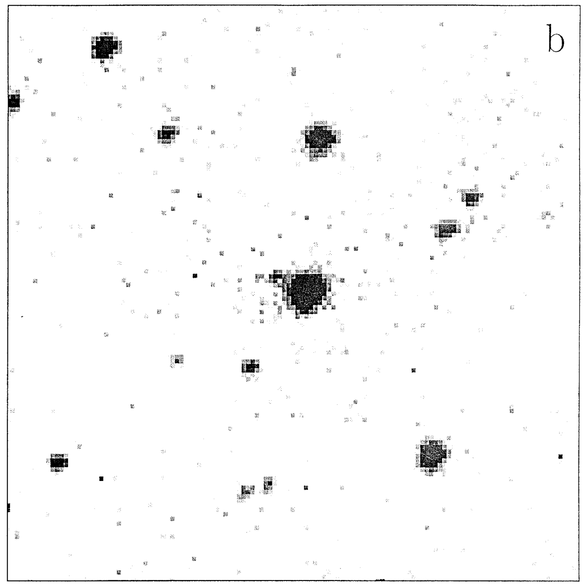


Fig. 1a and b. V-band images of V 518 Per (= GRO J0422+32). The field of view is 1.5' x 1.5' with north at the top and east to the left. **a** on 10 Aug 1993. **b** on 14 Aug, during the maximum of this unusual secondary outburst.

$\pm$ 0.2, R = 17.6 $\pm$ 0.1, I = 17.0 $\pm$ 0.1). The object was not observed in the V-band until 13 August, when it was found to be at V = 15.1 (Fig. 1), indicating that GRO J0422+32 underwent an unexpected increase in brightness by 3.6 magnitudes (Castro-Tirado & Ortiz 1993, Filippenko & Matheson 1993a). Two spectra were also taken on 14 August (Fig. 2), but no emission lines characteristic of the optical counterparts of these objects (Bradt & McClintock 1993) like HeII (4686 Å) and NIII (4640 Å), were detected. Fig. 3 shows the GRO J0422+32 optical light curve based on our measurements -denoted by circles- in the BVRI photometric bands during a 100-day interval around the August 1993 episode. Other magnitudes reported elsewhere have been included: diamonds represent the data from Chevalier & Ilovaisky (1995), the triangles were reported by Beskin et al. (1993) and the squares have been derived from the data of Callanan et al. (1995). A more detailed light curve at the time of the maximun can be seen in Fig. 4a. The optical maximum (V = 15.15) was reached on 14 August. After that, a constant decrease in brightness is seen during the next four days, prior to a slow reflare lasting 6 days until 30 August, when the phase of rapid decline began, with V = 16.8 on 6 September (Chevalier & Ilovaisky 1993b), 18.2 on 8 September (Zhao et al. 1993a) and 19.0 on 11 September (Beskin et al. 1993, Guarnieri et al. 1993). The latter value is similar to the state prior to the mini-outburst. Two somewhat shorter episodes following this mini-outburst seem to be present in the V and R-bands data.

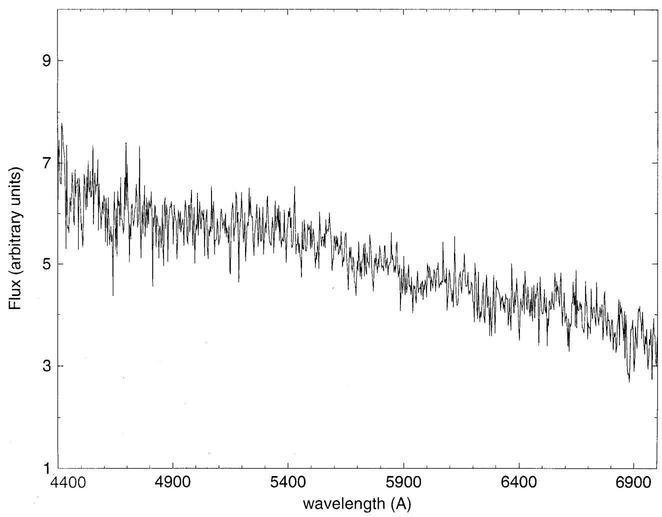


Fig. 2. 45-min optical spectrum of GRO J0422+32 taken on 14 Aug 1993 (03:41-04:26 UT) at the 2.2-m telescope at Calar Alto. The star BD+28 4211 was used for calibration. No emission lines are seen over the blue featureless continuum.

4. Discussion

Both the overall optical and X-ray light curves for GRO J0422+32 during the first months since the onset of the source (Kato, Mineshige & Hirata 1995, Harmon et al. 1993) resemble the light curves of other type II SXTs (Tanaka et al. 1992). After the main outburst in August 1992, and the expected secondary maximum that took place in December 1992 (Harmon et al. 1992), GRO J0422+32 returned to a faint state prior to the August (this paper) and December 1993 (Zhao et al. 1993b) mini-outbursts. These two episodes are the main difference with respect to other type II SXTs. What could trigger the August (and possibly December) 1993 events? There are two competing models for explaining the outbursts. One of them is the Mass Transfer Instability model (MTI; Hameury, King & Lasota 1990 and references therein), where the outburst is due to a sudden increase of the mass transfer rate of the companion star. The other one is the Disk Thermal Instability model (DTI; Mineshige & Wheeler 1989, Ichikawa & Osaki 1992 and references therein),

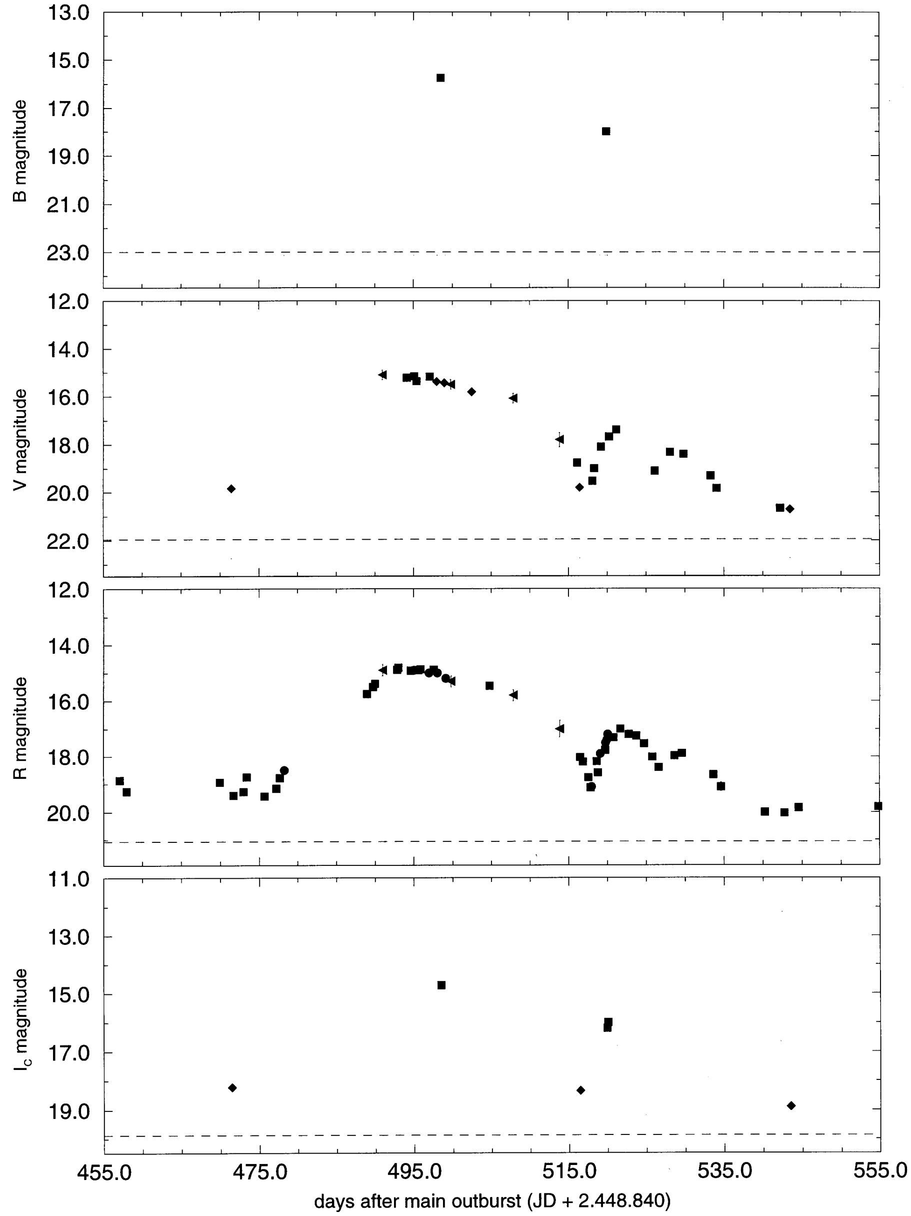


Fig. 3. The BVRI bands light curve of GRO J0422+32 during the August 1993 mini-outburst. References to other observations are described in the text.

where the accretion disk in the quiescent state undergoes a thermal ionization instability of hydrogen and helium which leads to the so called limit-cycle (or monocycle) behaviour of the disk, allowing for recurrence times of up to 60 yr ($\geq$ 62 yr for GRO J0422+32, Castro-Tirado et al. 1993).

It seems reasonable to think that the August 1992 outburst can be explained, similarly to the leading black hole candidate GS 2023+338 (Wagner et al. 1994) by the DTI model. This is supported by the expected delay of both the soft X-rays and the optical emission, that are produced in the outer parts of the disk, with respect to the hard X-rays (produced in the inner disk). The MTI would explain the December 1992 secondary maximum as the result of the heating of the secondary by the X-rays produced during the previous three months (as it has been proposed for type II SXTs by Cheng, Livio & Gehrels 1993). A sudden increase of mass from the secondary towards the compact object via the accretion disk is triggered. After the rapid decline observed in mid April 1993, the source was found in July 28 to brighten at V = 19.2 (Chevalier & Ilovaisky 1993a), but this was not the real quiescent state (V = 20.7, Zhao et al. 1993c, Chevalier & Ilovaisky 1995), so it means that during $\sim$ 100 days the compact object was accreting from the disk at a low accretion rate and the companion was heated undergoing a new mass transfer instability, that led to the August 1993 mini-outburst. In that case, an increase of the optical light, previous to the emission of the X-rays, should have been observed. This is what is expected for the instability beginning in the outer parts of the disk. And this is what our observations showed: an increase of 3.6 magnitudes in 4 days, with very weak X-ray emission (suggested by the absence of the He lines and specially the Bowen blend at 4640 Å in the spectrum taken on 14 August). Only broad Balmer absorption lines were visible in the blue continuum one day earlier (Filippenko & Matheson 1993a). Weak He lines were first detected on 17 Aug (Harlaftis

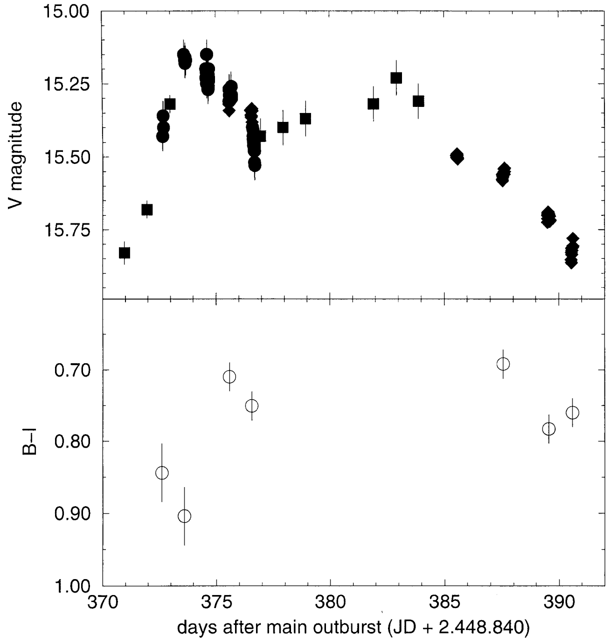


Fig. 4. a A more detailed light curve in the V band at the time of the maximum during the 1993 August mini-outburst. **b** The color-magnitude diagram showing how GRO J0422+32 becomes bluer as the outburst takes place, based on our photometry and on the data provided by Chevalier & Ilovaisky (1995). This behaviour provides support for the MTI model.

et al. 1994), and observed at least until 23-24 Aug (Harlaftis et al. 1994, Filippenko & Matheson 1993b), close in time to the detection of soft X-rays on 26 Aug by ASCA (Tanaka 1993). The lines became undetectable again by 10 Sep (Beskin et al. 1993). Additional support for the MTI model comes from the flux delay between the blue and red continuum between 17 and 23 Aug as pointed out by Harlaftis et al. (1994), and can be seen in Fig. 4b which shows how GRO J0422+32 becomes bluer as the outburst takes place. Callanan et al. (1995) has also pointed out that the no-detection of brightening between the August and December 1993 mini-outbursts goes against the predictions of the DTI model. They also derive the ratio between the X-ray and optical luminosities. For the August 1993 mini-outburst, $L_x/L_{bol} \leq 0.5$, which is a value at least 8 times smaller than in the case of the main episode in August 1992, suggesting that the optical brightening is intrinsic to the accretion disk, and not to the reprocessing of X-rays.

5. Conclusions

We have reported here an unusual outburst for GRO J0422+32 in August 1993. This is the first time that a rather bright optical outburst has been recorded in a type II SXT after the main X-ray outburst and secondary maximum. It can be explained by the MTI model as the result of the heating of the secondary by the X-rays produced during the three previous months. We suggest that a low accretion process may trigger an outburst not as bright as the main one that occurs every few decades. Whether these “mini-outbursts” are usual or not among type II SXTs during the long intervals between the main outbursts will be known only if deep photographic plates are continously taken for sky patrol archives and continuous monitoring of the counterparts is carried out. In case of a positive detection, a quick follow-up response would be required in order to study its emission throughout all the spectrum. This will lead to a better understanding of the mechanisms involved in the low-rate accretion processes in SXTs.

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