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ASTRONOMY AND ASTROPHYSICS

S 10932 Comae – a jumping jack among the cataclysmic variables

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Abstract. We analyse photometric and spectroscopic observations of the optical counterpart of the X-ray source RX J1239.5+2108 (hereafter named S 10932 Comae Berenices), which proved to be a nova-like variable with deep eclipsing minima. It is variable on a variety of timescales. In addition to a “normal brightness state”, in which S 10932 spends most of its time, there are eruption states (like in dwarf novae) as well as low states, more than 1 mag fainter than the normal state. In many respects, its optical behaviour resembles that of an intermediate polar. But besides the orbital period of $2^{h}\,05^{m}$ we did not find any other periodicity which could be ascribed to the rotation of the white dwarf (the main criterion of an object to be an intermediate polar).

Key words: stars: variable: others – X-rays: stars – stars: novae, cataclysmic variables

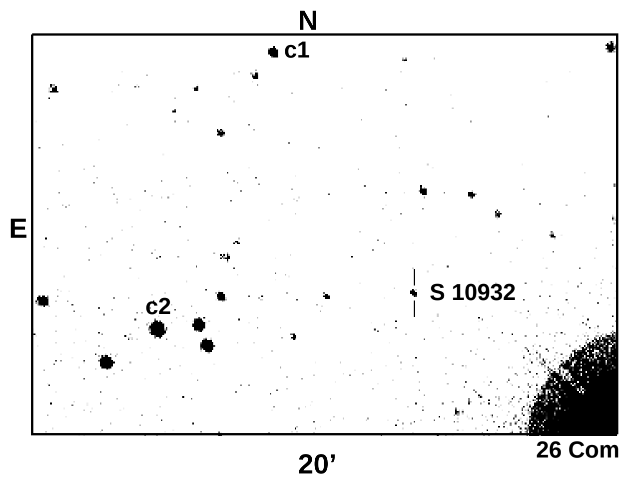

Fig. 1. Finding chart of S 10932 Comae = RX J1239.5+2108 (CCD R-band image taken at Sonneberg 60 cm Cassegrain). c_1 and c_2 are comparison stars.

1. Introduction

Cataclysmic variables (CV) are close binaries with a white dwarf primary which accretes mass by Roche lobe overflow from a secondary star near the main sequence. The brightness behaviour and the spectroscopic appearance of these objects strongly depend on the mass exchange rate (dwarf nova vs. UX UMa star), on the magnetic field of the white dwarf (polar vs. intermediate polar vs. non-polar), and on the mass ratio of the two components (SS Cyg vs. SU UMa).

It is, of course, impossible for any object to reconcile conflicting physical properties. However, our preliminary observational results (Richter & Greiner 1995a) of S 10932 Comae feigned such a behaviour which motivated more detailed follow-up work. Here we report on X-ray, spectroscopic and extensive photometric observations of S 10932 Comae in order to solve the problems.

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2. Observations

2.1. X-ray observations and discovery

As part of a programme of investigating the optical long-term behaviour of selected X-ray sources, we have examined *ROSAT* data in a 100 square degree field centered around 26 Com (for first results on flare stars see Richter, Bräuer & Greiner (1995), on RS Canum Venaticorum stars see Richter & Greiner (1995b) and on supersoft AGN see Greiner et al. (1996)). The Coma field was scanned during the *ROSAT* all-sky-survey in December 1990 for a mean total observing time of 470 sec. Using a maximum likelihood method we detected 238 X-ray sources in the above 10×10 degree field with a likelihood larger than 10. These X-ray sources were identified using (1) the objective prism spectra taken with the Hamburg Schmidt telescope on Calar Alto, (2) including the positional correlation with the X-ray positions which are accurate to typically better than $30''$ and (3) the X-ray to optical intensity ratio for known populations. In the Hamburg objective prism survey (Hagen

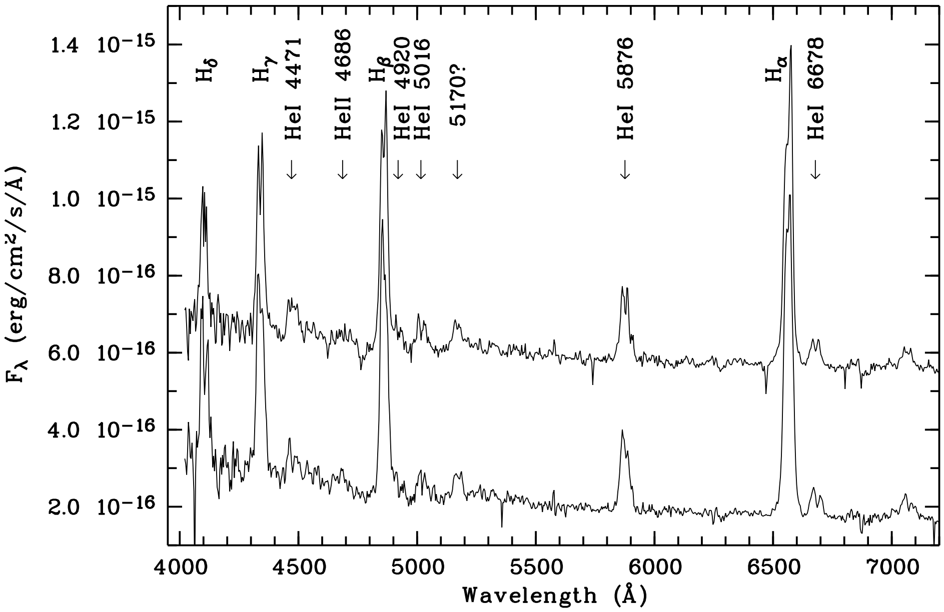

Fig. 2. Two consecutive low-dispersion spectra of S 10932 Comae, the first one being shifted vertically up by 4.e-16 (top spectrum). They are taken at the orbital phases ϕ = 0.645 and 0.821, respectively

et al. 1995) spectra are taken in the 3400–5400 Å range with a dispersion of 1390 Å/mm down to 17–18th mag covering the whole northern hemisphere except the galactic plane ($|b|>20°$).

RX J1239.5+2108 was detected at a mean count rate of 0.05 cts/sec. The hardness ratio suggests a hard X-ray spectrum, but more detailed information cannot be extracted from the low number of detected photons (no pointed observation has ever been performed with ROSAT of this location). If we assume a standard 10 keV bremsstrahlung spectrum this measured count rate corresponds to an unabsorbed X-ray flux in the 0.1–2.4 keV range of the order of 5×10^{-13} erg/cm^2/s and an X-ray luminosity of 6×10^{31} (D/1 kpc)^2 erg/s.

The source RX J1239.5+2108 was noted immediately as a potential cataclysmic variable due to the presence of only one object (within 2′ distance) at the X-ray position (with a 2σ error circle of 30″) on the Palomar Observatory Sky Survey prints, and its X-ray to optical intensity ratio. A first confimation was provided by the Hamburg objective prism spectrum (Bade 1994).

The coordinates (2000.0) of the optical counterpart as measured on POSS print O-1435 (1955 May 21/22) are

R.A. = $12^h39^m32\overset{s}{.}1$, Decl. = +21°08′06″

with an error of about 2″. A finding chart is given in Fig. 1.

2.2. Optical follow-up observations

The object was investigated photometrically and spectroscopically. The long-term behaviour was followed up by use of some 400 archival plates of Sonneberg astrographs 400/1600 mm and 400/2000 mm taken between 1962 and 1995 (limiting magnitude of $18\overset{m}{.}5$ for the best plates), and by more than 1000 plates of the Sonneberg Sky Patrol (SSP) exposed between 1929–1934 and 1939–1995 (limiting magnitude of 14^m for the best plates). The short-term behaviour was investigated by time-resolved differential photometry at the Sonneberg 600/1800 mm reflector, equipped with a 385×578 pixel EEV CCD (see also Wenzel et al. 1995).

Spectroscopic observations of S 10932 were performed on May 12, 1994 using the 1.5m telescope at La Silla equipped with the Boller & Chivens spectrograph. A grating with 200 Å/mm was used, allowing the range 4000–7900 Å to be observed with a dispersion of 3.8 Å/pixel. Two consecutive spectra of 20 min exposure time each were obtained starting at 1:41 and 2:03 UT, respectively. The long slit spectra were corrected for bias and flat-field and calibrated in wavelength using standard MIDAS reduction packages. For flux calibration we used Feige 56.

3. Spectroscopic results

Both spectra of S 10932 Comae are very similar and show a low-excited spectrum of strong Balmer emission lines and fainter ones of HeI and (even fainter) HeII (see Fig. 2). The emission lines are clearly double-peaked suggesting a high inclination of the binary system. We have measured the radial velocities of HeI λ6678 and λ5875, and Hα through Hδ, and find identical values of 580±70 km/s for the rotation velocity.

The general appearance resembles that of a dwarf nova in quiescence. The low-excitation state of the spectral lines argues against a polar nature of S 10932 Comae.

4. Description of the brightness behaviour

Photometrically, this star displays fireworks of brightness changes combining characteristics of different subclasses of cataclysmic variables (CV): deep double eclipse minima with variable depths lasting 10 minutes, short brightness dips and humps (both ≈1 mag) within several hours, dips and humps (≈1.5 mag) within several days, high (m_{pg} ≈16.5) and low (m_{pg} ≈18) states

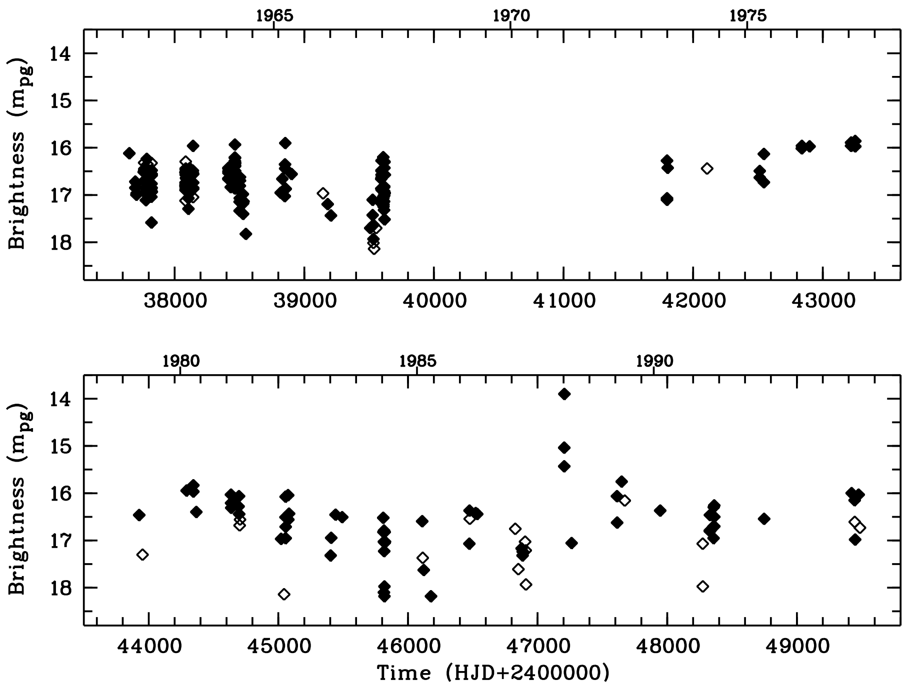

Fig. 3. Long-term light-curve of S 10932 derived from the astrographic plates taken in 1962 to 1995. Full symbols are individual measurements with a typical error of ±0.08 mag while open symbols have a slightly increased error of ±0.14 mag. Clearly visible is the flaring activity on timescales of 100 days, and the major flare 1988 (probably a dwarf nova outburst).

of brightness. To carry the matter to an extreme, the object occasionally has eruptions (≈4.5 mag) which last probably a few days. A complete long-term light-curve from astrograph plates from 1962 to 1995 is given in Fig. 3.

4.1. Orbital period

The double-peaked nature of the emission lines (see previous chapter) led to the assumption that the line of sight is nearly parallel to the orbital plane (inclination angle near 90°). Indeed, photoelectric measurements show deep eclipsing minima with variable amplitudes (1.4 ... ∼4 mag). These amplitudes are, together with that of the nova-like variable NN Ser (=PG 1550+131, see Haefner 1989) and the dwarf nova IP Peg, one of the largest known in CVs. CCD measurements in different colour bands were taken with the 60 cm Cassegrain at Sonneberg during 10 nights. Examples are given in Fig. 4 for 1994-May-11/12 and 1996-Jan-04/05. The minima show prolonged egress shoulders which are typical of many eclipsing CVs. However, the form and the amplitude of the minima vary from time to time, even between consecutive minima (comp. 1996-Jan-04/05). It makes therefore no sense to present a superposition of all minima.

These CCD eclipse observations, CCD measurements by Kato et al. (1996a) and a few reliable photographic eclipse observations on short-exposed archival plates (≤ 30 min) lead to an improved determination of the orbital elements compared to Wenzel et al. (1995) of

$$\mathrm{Min_{HJD}} = 2449486.48193(\pm 2) + 0.^{d}0870386706(\pm 30) \times E.$$

To be exact, the times of minima depend on colour, in B being about 25 sec earlier than in R. This can easily be explained by

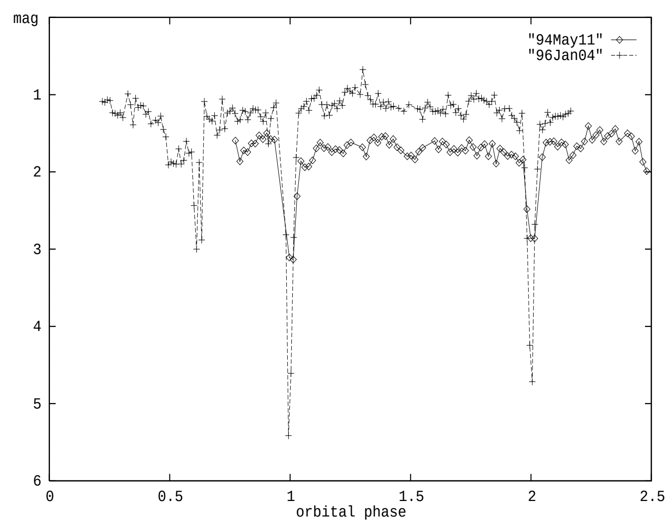

Fig. 4. CCD observations in Johnsson R-band of S 10932 Comae at the Sonneberg 60 cm reflector on May 11, 1994 (◇) and Jun 4, 1996 (+, with dips, s. 4.4). The magnitudes are brightness differences to comparison star 1. (see Fig. 1).

the fact that basically two objects are eclipsed: at first the hotter one (white dwarf) and then the cooler one (bright spot).

The individual eclipse times together with the O-C values are given in Table 1. This period of $P_{orb} = 2^h\,05^m$ is at the lower border of the well-known period gap of CVs between about 2^h and 3^h.

Table 1. Individual eclipse times observed with the CCD camera (CCD), photographically with the Sonneberg astrograph 400/1600 mm (GC) and by Kato *etal* 1996a at Ouda station (Ouda, integration times between 20 and 60 sec). (col. – colour (Johnsson's system), Δt – exposure/integration time in seconds)

Instr.	HJD (2400000+)	E	O–C (d)	col.	Δt (sec)
GC	37778.386	–134516	–0.00217	B	1800
GC	45044.468	–51035	+0.00462	B	1800
GC	45814.407	–42189	-0.00046	B	1080
GC	46910.398	–29597	–0.00040	B	1320
GC	47612.455	–21531	+0.00268	B	720
CCD	49484.39297	–24	–0.00003	R	80
CCD	49484.48022	–23	+0.00018	R	80
CCD	49486.48240	0	+0.00047	R	80
CCD	49488.39654	22	–0.00024	R	80
CCD	49488.48385	23	+0.00003	R	80
CCD	49511.46160	287	–0.00043	R	80
CCD	49748.46836	3010	+0.00003	R	80
CCD	49758.47767	3125	–0.00011	R	80
CCD	49771.44638	3274	–0.00016	B	80
CCD	49771.53334	3275	–0.00024	B	80
CCD	49787.37358	3457	–0.00103	B	90
CCD	49787.46124	3458	–0.00041	B	90
CCD	49787.54842	3459	–0.00027	B	90
CCD	49787.63531	3460	–0.00042	B	90
CCD	49788.41972:	3469	+0.00064:	V	80
CCD	49788.50576	3470	–0.00036	V	80
CCD	49788.59273	3471	–0.00043	V	80
Ouda	50084.35030	6869	–0.00026	V	
Ouda	50085.22081	6879	–0.00013	V	
Ouda	50085.30771	6880	–0.00027	V	
Ouda	50086.26540	6891	–0.00001	V	
Ouda	50086.35239	6892	–0.00006	V	
Ouda	50087.30973	6903	–0.00014	V	
CCD	50087.57025	6906	–0.00074	R	60
CCD	50087.65795	6907	–0.00008	R	60

4.2. Large-amplitude outbursts

Three outbursts were found which may be that of a dwarf nova. The dates of these three outbursts of S 10932 are 1959 Feb 8, 1988 Feb 15 and 1996 Jan 1 (see Fig. 5), and Table 2 gives the individual measurements (crosses denote observations of low accuracy).

At first glance, the three eruptions (Fig. 5) seem to be very dissimilar. The 1959 eruption might probably be a kind of flare with a duration of a few hours, and as we will show below, other but smaller flares are indeed observed (see 4.3). But taking into account that the 1959 observations are all from sky patrol plates and S 10932 is here near the plate limit, the uncertainties are large. Thus, we actually may observe a part of a brightness variation with considerably longer timescale.

As the 1988 outburst is concerned, only the rise (which lasted longer than 1 day) and the maximum brightness could be be observed. The duration of the outburst is therefore unknown, and so we cannot distinguish between a normal dwarf nova outburst or perhaps a superoutburst.

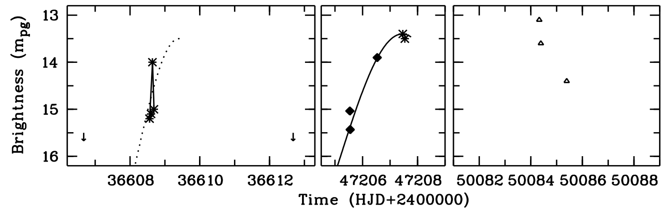

Fig. 5. The outbursts of S 10932 Comae in 1959 (left panel), 1988 (middle) and 1996 (right). The two different curves shown in the left panel represent two possible interpretations of the sparse data taking into account the statistical errors. Asterisks denote patrol plate measurements with typical errors of ±0.3 mag, and upper limits are shown as arrows. Triangles (right panel) are V band measurements by the Ouda team (VSNETalert 306 and 307, Kato et al. 1996) transformed into photographic magnitudes using B–V=–0.4.

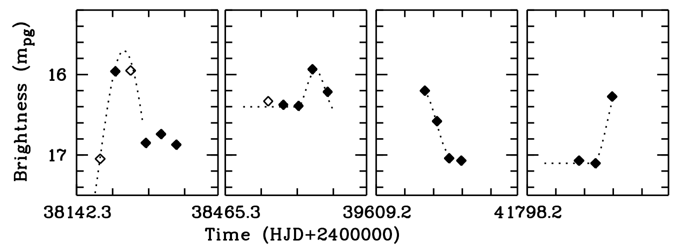

Fig. 6. "Flares" of S 10932 Comae. Symbols are the same as in Fig. 3. For the time axis only the start time is given, and tickmarks are plotted every 0.1 day.

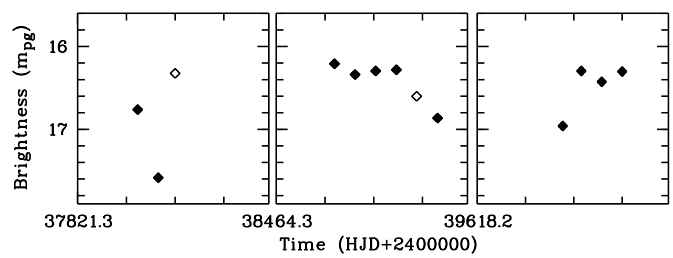

Fig. 7. Short dips of unknown nature in the lightcurve of S 10932 Comae. Symbols and tickmarks are the same as in Fig. 6. Note that the middle panel is preceeding the second panel in Fig. 6, thus the dip is certainly shorter than 0.75 days.

Recently, a third outburst was reported (Kato et al. 1996). Seemingly, only the decline was observed (by about 1 mag within one day). If all three eruptions are of the same nature, the cycle length is about $C = 8/n$ years.

Three further outbursts seem to be indicated in 1934 Jan. 22, 1955 Feb. 25 and 1996 Mar 27 (Kato et al. 1996b), but being at the utmost plate limit they are probably spurious.

Assuming that each outburst will stay two days above the plate limit of SSP ($14^{\rm m}\!.0$) we can estimate the cycle length C by use of the formula given by Wenzel and Richter (1986). We get

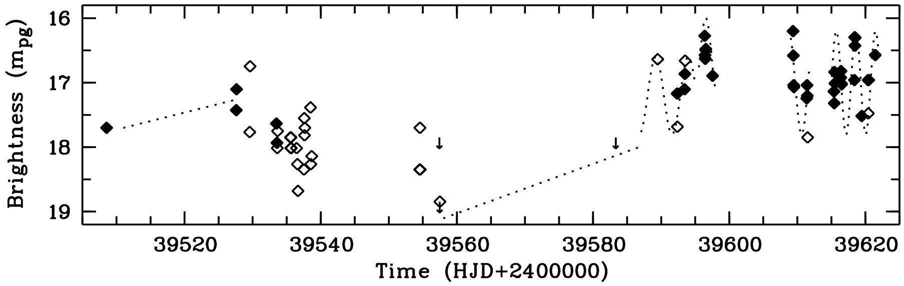

Fig. 8. The best observed low state of S 10932 Comae. Note the onset of oscillations after recovery to the normal state.

Table 2. Dates of the two outbursts observed in 1959 and 1988, observed with the Sonneberg Sky Patrol (SSP) and the Sonneberg GC-astrograph (400/1600 mm). The 1959 observations are at the extreme plate limit and therefore very uncertain (about ±0.5 mag). Δt – exposure time in minutes.

Inst.	Date	HJD (2400000+)	m_{ph} (mag)	ϕ	Δt (min)
		First outburst			
SSP	1959 Feb 6	36606.671	[15.5	.978	50
SSP	8	36608.558	15.2:	.658	60
SSP	8	36608.600	15.1:	.140	60
SSP	8	36608.642	14.0:	.623	60
SSP	8	36608.685	15.0:	.117	60
SSP	12	36612.674	[15.5	.947	40
		Second outburst			
GC	1988 Feb 13	47205.539	15.1	.917	16
GC	13	47205.551	15.4	.055	16
GC	14	47206.536	13.6	.372	16
SSP	15	47207.466	13.4:	.057	50
SSP	15	47207.540	13.5:	.961	40
GC	Apr 06	47258.420	[16.8	.475	16
GC	10	47262.415	17.2	.374	18
GC	10	47262.499	[16.8	.339	40
GC	11	47263.569	17.1:	.644	40
GC	13	47265.515	18.0	.990	40

a very rough C value of about 700 ($\pm$300) days; this means that n will be about 4. According to the Kukarkin-Parenago relation the outburst amplitude to be expected for this cycle length is A = 6.3 mag (see formula (1) in Richter and Bräuer, 1989) and not 3.5 mag as it is the case in S 10932.

A similar case is the extreme intermediate polar EX Hya, the outburst amplitude (3 mag) of which is also much too small for its cycle-length (near 600 days); see discussion in Richter and Bräuer (1989).

4.3. Flares

Besides the two eruptions, S 10932 occasionally shows "flares" with a duration of <2 hours with an amplitude <1.5 mag. Examples are given in Fig. 6. Similar events have sometimes also been observed in other CVs. They may, at least partially, be flare-like events on the surface of the secondary component which is, as a rule, a red star at or slightly above the main sequence. A flare of the intermediate polar TV Col (A≈2 mag, duration >1 hour) is described in Szkody and Mateo (1984). An intense flare with an amplitude of more than 2 mag of the secondary component of the polar AM Her was observed by Shakhovskoj et al. (1992) (for a discussion of flare events in CVs see also la Dous 1993).

4.4. Dips

Another characteristic feature of S 10932 are sporadic dips in the lightcurve of short duration, lasting not much longer than 1 hour (Fig. 7). They have nothing to do with the still shorter eclipsing minima which last only 10 minutes. Also these dips are not unique by themselves. Buckley and Schwarzenberg-Czerny (1992) describe a sudden and brief decrease in brightness of unknown kind in the intermediate polar EX Hya (already mentioned in 4.2) which may be a similar event like those observed in S 10932.

4.5. Brightness states

Most of the time S 10932 is in a "normal" brightness state with small variations between about 16^{m} and 17^{m}. And so, the spectra descipted in chapter 3 (Fig. 2) as well as most CCD measurements taken until now are normal state data. But occasionally, the brightness drops to low states (about $17\overset{m}{.}5$–$18\overset{m}{.}5$) which last some weeks or even months and which are characteristic of the so-called anti-dwarf novae like TT Ari and KR Aur (see La Dous 1993 for a discussion). A well observed example of such a low state is shown in Fig. 8: The beginning of the next normal state is characterised by brightness oscillations (or a series of small outbursts) with an amplitude of about 1 mag and a quasiperiod of about three days. Some other examples of small, short outbursts are given in Fig. 9. Occasionally, the drop to the low state is of very short duration (few days, see Fig. 10). The observation at JD=2445814.407 (exposure time of 18 min.) is that of an eclipsing minimum, see also Table 1.

5. Discussion

5.1. What type of object is S 10932?

With its very lively brightness changes S 10932 combines features of (1) dwarf novae (DN) and anti-dwarf novae (ADN) as well as (2) intermediate polars (IP) which deserve separate discussion:

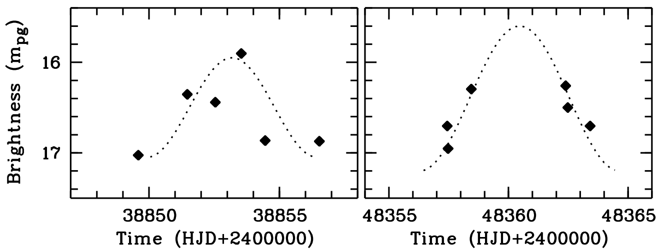

Fig. 9. Two examples of small amplitude outbursts of S 10932 Comae.

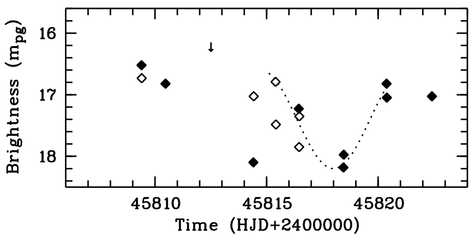

Fig. 10. Brightness drop of S 10932 Comae into a low state with very short duration ($18^{\rm m}$ at 45814.4 ist an eclisping minimum).

1. The combination of DN and ADN features (in having short outbursts of large amplitude as well as two constant brightness levels) is intriguing. Based on the well-known standard disk instability model of cataclysmic variables, DN and ADN cannot arise in the same object. As a consequence of small mass exchange DN have instable disks. In contrast, ADNs have stable disks for most of the time due to a larger mass transfer rate. The high states of ADNs correspond to the outburst state of DNs which is evidenced by spectroscopic observations: The spectra during high states of ADNs are similar to those of DNs during outburst in that they are rather featureless with mostly broad absorption troughs of Balmer lines and small emission cores. But the normal-state spectra of S 10932 (Fig. 2) look like those of dwarf novae in quiescence. They were taken immediately after the end of one run of the CCD measurements (JD 2449484). So, the normal state of S 10932 seems to correspond to the minimum brightness level of a DN and not to the high level of an ADN!
   A relationship to the ADN is also very improbable from the view of the period length: All ADN hitherto known have periods above the gap and, if the theory of Livio and Pringle (1994) is correct, that the ADN phenomenon is caused by starspots on magnetic active secondaries, no such objects should exist below the gap.
   Apart from S 10932 there is one other CV known to have two preferred brightness levels as well as eruptions which look like those of a dwarf nova, namely V426 Oph (Wenzel & Splittgerber 1990). But in contrast to S 10932, the brightness difference between the two levels is only about 0.6 mag and the cycle length is much smaller (13^d in the normal state, 22^d in the low state). It was not possible for S 10932 to determine the level where the outburst started from and ended, because these times are not documented on our plate material. But for the 1988 outburst we know that some 50 days after brightness maximum the object was near the low state which provoces the question: What is the nature of the low brightness states of S 10932 (and similarly V426 Oph)? A possible explanation may be that during a low state the mass exchange rate between the two binary components is drastically reduced (as is assumed in the low state of AM Her stars). But then also other DN should show such phenomena!
2. If S 10932 is an intermediate polar, we would expect to find the white dwarf rotation period which is one of the main criteria of an IP classification. Our search, however, was negative for periods larger than 1 minute. This minimum period is determined by the shortest exposure times of our CCD photometry of 15 sec (plus 20 seconds for readout). So, either S 10932 is indeed no IP, or the period is lower than 1 minute, or the magnetic axis of the white dwarf is aligned with the rotation axis, and so no lighthouse effect can be seen.

5.2. Companion and distance limit

Our spectra extend up to 8000 Å in wavelength and the continuum of S 10932 is basically flat even at the longest wavelengths without any sign of a (assumed late-type) companion.

According to Patterson (1984) the absolute magnitude of the secondary is expected to be

$$M_V(2) = 17.7 - 11.00 \log P(hr).$$

In our case we get $M_V(2) = 14.2$. With an expected spectral type of M 4.5 (from the compilation by Ritter and Kolb 1993) we get a colour index of about 1.5, so that M_B will be 15.7.

A lower limit of the distance can be estimated if one assumes that during the deepest minima (A = 4.4 mag) only the eclipsing component is visible.[1] The deepest minimum of about $B \sim 20\overset{\rm m}{.}3$ is therefore an upper limit of the M star's magnitude. If we neglect any other contribution of light and the effects of interstellar extinction, we get a minimum distance of d = 72 pc which in our case ($b = 83°$) is nearly identical with the distance z from the galactic plane. And if we assume that during the deepest minimum the secondary of S 10932 contributes to half of the total light we have d = 120 pc.

Assuming that during low brightness state S 10932 does have no accretion disk at all (which is to be verified by spectroscopic and/or high speed photometric observations) we can check the above-mentioned distance estimate. At the bottom of the low state, the combined magnitude of the primary and secondary components would then be about $19^{\rm m}$, and if the secondary is really of $20\overset{\rm m}{.}3$ magnitude, and if we take d = 120 pc, the white dwarf would be about $B \sim 19\overset{\rm m}{.}3$ corresponding to an absolute magnitude of $13\overset{\rm M}{.}7$, a value which is not implausible.

Another rough estimate of the distance is possible if we assume that the outburst luminosity is $M_V(max) = 5.64 -$

[1] This assumption is not strictly fulfilled due to the colour dependence of the minimum as mentioned above.

$0.259P(hr) + \Delta M_V(i)$ (see Patterson 1984 and Warner 1987) where $\Delta M_V(i)$ is a correction term for orbital inclination i, given by Paczynski and Schwarzenberg-Czerny (1980). If we assume $B - V \sim 0$ (Vogt 1982) and if we neglect again any contribution of interstellar extinction we get a distance of about 200 pc for $i = 85°$ and of 300 pc for $i = 81°$, which is consistent with our estimate of the above-mentioned minimum distance. Nevertheless, the last estimate must be taken with caution because firstly S 10932 is an untypical object, and the formulae given by Paczynski and Schwarzenberg-Czerny (1980) are getting instable towards $i = 90°$.

5.3. Mass accretion rate

During the ROSAT observation in December 1990 S 10932 was in a normal state as can be seen from archival plates. At an approximate distance of 200 pc its X-ray luminosity is 2×10^{30} erg/s, i.e. at the lower end of the distribution of CV X-ray luminosities in this energy range. Using the correlation (Patterson & Raymond 1985) between the accretion rate $\dot{M}$, and the X-ray luminosity (or F_X/F_V) this suggests an accretion rate as low as 10^{14} g/s in S 10932 during its normal state. At this accretion rate the inferred absolute magnitudes of the disk ($M_V \approx 13.5$) and the X-ray illuminated white dwarf ($M_V \approx 13.0$) are compatible with the observed values (see paragr. 5.2). This low accretion rate is also well below the critical limit for a thermally stable accretion disk of $\dot{M}_{crit} \approx 2.7\times10^{17}$ $(P_{orb}/4\text{ h})^{1.7}$ g/s (van Paradijs 1996), compatible with the strong optical variations we found.

6. Conclusion

S 10932 is a nova-like variable at the lower boundary of the period gap. It has similarities with dwarf novae, but its photometric behaviour is untypical. In many respects it reminds one of an intermediate polar like EX Hya which also shows eruptions similar to dwarf novae, but we did not succeed in finding any periodicity other than the orbital period. Thus, a better knowledge is needed of the duration of the eruptions, the cycle lengths and the outburst spectra. But since the outbursts are extremely rare such data are difficult to obtain. Furthermore, also detailed photometry and spectroscopy during the rare low states are of interest.

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