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Published in:
Astronomy & Astrophysics

Astron. Astrophys. 331, 328–334 (1998)

ASTRONOMY
AND
ASTROPHYSICS

Modelling the temporary X-ray off-state of CAL 83

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Received 26 May 1997 / Accepted 31 October 1997

Abstract. The X-ray light curve of CAL 83 as measured with the *ROSAT HRI* covering $\sim 1\frac{1}{2}$ years (from July 95 to Dec 96) is derived. These observations show the pre-off state (persistent state), the April 96 off-state and the post off-state which returns after some decline to its previous persistent level. The intensity variations are discussed in the model of variations of the temperature of the envelope of the nuclear burning white dwarf. In order to explain the observed X-ray off-state a drop in temperature from 4.5×10^5 K to at least 3.2×10^5 K (i.e. by 40%) is required. This might have been achieved - assuming an accretion rate close to $\dot{M}_{\rm RG}$ of a $\sim$ 1M$_\odot$ white dwarf - if the radius of the envelope of the white dwarf increased by a factor of ∼2.0 possibly due to an increased mass accretion episode onto the white dwarf. CAL 83 resembles then the supposed wide binary supersoft source (and symbiotic star) AG Dra where a radius expansion by a factor of ∼2 and a temperature drop by ∼35% has been required in order to model the observed X-ray fall in 1994. In both systems the accretion rate is supposed to be close to $\dot{M}_{\rm RG}$ and to pass episodically above this value and to cause the X-ray fall. The main differences between the two systems are the nature of the donor star, the mass of the white dwarf, and the size of the binary orbit. It is not known whether CAL 83 is similar to the supersoft X-ray transient RX J0513.9-6951 as no recurrent X-ray off-states have been found for CAL 83. The extreme short duration of $<$ 100 days of the X-ray off-state would require in case of an unstably nuclear burning white dwarf (a recurrent supersoft source) a white dwarf mass of $M_{\rm WD} > 1.2$ M$_\odot$.

Key words: X-rays: stars – stars: individual CAL 83 (LMC) – stars: evolution – white dwarfs – Magellanic Clouds

1. Introduction

CAL 83 can be considered as the prototype supersoft X-ray source. It was discovered with the *Einstein* satellite (Long, Helfand, and Grabelsky 1981) and identified in the optical with a blue emission line star (Pakull et al. 1985). The discovery of an orbital period of 1.04 days established the close binary nature of this source (Smale et al. 1988). CAL 83 has been detected with the *ROSAT PSPC* during the *ROSAT* all-sky Survey (*RASS*) as a bright and luminous X-ray source. The source has also been contained in a few additional X-ray pointings as a serendipitous source at a large off-axis angle (Greiner et al. 1991). In each case the source has been detected with a comparable X-ray flux. No indication of an X-ray low or off state has been found in any of the *ROSAT* observations. This led to the view, that CAL 83 is not only on in X-rays since its discovery with the *Einstein* satellite but also apparently a persistent X-ray source. From *Einstein* observations (Brown et al. 1994) it follows, that possibly CAL 83 varies in X-rays (by a factor of up to ∼27). But this may be due to instrumental effects (E. Gotthelf, private communication). Variability has also been found in the UV by Gänsicke et al. (1996) who observed CAL 83 during high and low intensity states. This is very similar to what has been found for the recurrent supersoft LMC transient RX J0513.9-6951 (Schaeidt et al. 1993). In this transient it is believed that very large mass accretion rates close to 10^{-6} M$_\odot$ yr^{-1} (Southwell et al. 1996) lead occasionally to a bloated white dwarf with an extended envelope so large that it prevents the detection of the source in X-rays during these periods. The mechanism behind this recurrent blow-up of the white dwarf envelope is not yet completely understood. It may be due to unstable nuclear burning on a massive (M$_{\rm WD}$ $\sim$ 1.3 M$_\odot$) white dwarf (Kahabka 1996a) or due to episodic mass-transfer from the donor star, caused by a mechanism like magnetic star spots crossing episodically the L1 point (cf. Southwell et al. 1996; Alcock et al. 1996; Pakull et al. 1993). In section 2 the *ROSAT HRI* observations of CAL 83 are presented and a description of the observed intensity variations in terms of temperature variations is given. Applying a standard *ROSAT PSPC* spectrum the required range of temperature variations is constrained using white dwarf model atmosphere spectra. In section 3 possible interpretations of the results are given. The mechanism proposed in this work for the X-ray and optical dip is opposite to the mechanism defended by Alcock (1997) i.e. an episode of increased mass accretion compared to a decrease in the mass accretion rate. Unstable nuclear burn-

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ing cannot be excluded even at high mass accretion rates and a possible recurrence is investigated.

2. *ROSAT* observations

The *ROSAT* X-ray telescope (XRT) and focal plane detectors (*PSPC* and *HRI*) have been described by Trümper (1983). The observations presented here are part of a series of pointed follow-up observations of supersoft sources to study the long-term soft X-ray light curves of these objects. The analysis of *HRI* data has been performed with the *EXSAS* software (Zimmermann et al. 1994).

The *ROSAT HRI* observations reported in this paper comprise the pre-off state phase preceeding the off-state by ∼280 days, the early decline to the off-state, the off-state itself and the post-off-state recovery. The discovery of the X-ray off-state has been reported by Kahabka (1996b, 1997) and the recovery from the off-state by Kahabka, Haberl and Parmar (1996). The analysis of these observations is mainly restricted to the study of the timing behavior of the source as no energy resolved information is available to generate X-ray spectra.

2.1. The X-ray position of CAL 83

A standard source detection procedure has been applied to the two observations preceeding the off-state in April 96. CAL 83 was detected in the first observation with high significance. The deduced X-ray position is R.A.(2000) = $5^h43^m33.7^s$, Decl.(2000) = $-68°22'18''$. This position is $5''$offset from the optical position (van Paradijs 1995). The positions are however consistent considering the error circle of the *HRI* point-spread-function. This offset is also consistent with the *ROSAT* attitude error.

2.2. The July 95 to Dec 96 X-ray light curve of CAL 83

In Fig. 1 the *ROSAT HRI* light curve of CAL 83 is presented covering $\sim 1\frac{1}{2}$ years of observation.

The pre-off-state phase is covered by two observation sequences (600643h and 300516h). The latter observation covers the decline towards the April 96 off-state. The three sequences have been performed with the *ROSAT HRI* in March and April 1996 (cf. Table 2). In the third sequence no significant detection has been achieved at the position of CAL 83. The source has been found with a significance of only 2σ with an upper limit count rate of 4.8×10^{-3} sec^{-1}. The flux variation from sequence 1 to 3 comprises a factor of >43.

The X-ray light curve as obtained from this observation is given in Fig. 2. There is a possible decrease of the X-ray countrate seen which happens from the first to the second sequence. Combining these three intervals one can determine a constraint on a possible decline (decay) time of the X-ray flux of CAL 83. It is found, that in order to describe the intensity decline from sequence 1 to sequence 2 an e-folding time of ∼44 days is required, while for the decline from sequence 1 to sequence 3 a much shorter e-folding time of ∼5.5 days is required. This shows, that the minor intensity decline observed in the first two sequencess is not due to an exponential decline leading to the observed off state in sequence 3. Possibly CAL 83 turned off much faster somewhere between day 10 and day 30. A lower limit to the decay time would then be ∼5.5 days, which is comparatively short.

The observations following the X-ray off-state are *ROSAT HRI* target of opportunity (TOO) observations. They were initiated quite late as the off-state was not immediately recognized. Variability is clearly detected during the four TOO observations.

Table 1. Time intervals and mean *ROSAT HRI* count rates of CAL 83. Observations were retrieved from the public *ROSAT* archive (AR). are pointed observations belonging to the author (P) or are *ROSAT HRI* target of opportunity observations initiated by the author (TOO).

AR/ TOO	Observation Sequence	Time (JD - 2440000)	*HRI* count rate (1/s)
AR	600643h	9928.059	0.208±0.018
AR	600643h	9937.610	0.190±0.017
AR	600643h	9937.740	0.216±0.019
AR	600643h	9950.900	0.230±0.019
AR	600643h	9951.030	0.178±0.017
AR	600643h	9951.820	0.240±0.020
AR	600643h	9956.730	0.206±0.018
AR	600643h	9956.799	0.143±0.016
AR	600643h	9956.860	0.241±0.020
AR	600643h	9956.929	0.256±0.020
P	300516h	10170.000	0.193±0.018
P	300516h	10179.799	0.163±0.017
P	300516h-1	10200.000	0.006±0.004
TOO	180124h	10300.000	0.226±0.017
TOO	180124h-1	10340.000	0.194±0.014
TOO	180163h	10390.000	0.149±0.013
TOO	180163h-1	10430.000	0.217±0.017

Table 2. Time intervals of observation sequences (observation IDs WG300516H and WG300516H-1) and mean *ROSAT HRI* count rates of CAL 83. Compared to Table 1 a slightly different count rate is given for the off-state observation due to a different procedure to determine count rates.

Obs./ Seq.	Time [UT 1996] start	end	*HRI* count rate [1/s]
1/1	28-Mar – 05:52:40	06:22:40	0.206 ± 0.011
1/2	7-Apr – 01:17:40	01:42:40	0.156 ± 0.012
2/3	28-Apr – 04:04:07	05:19:07	0.0047 ± 0.0024

2.3. A representative *ROSAT PSPC* spectrum of CAL 83

As the *ROSAT HRI* provides no spectral information (resolution) it cannot be deduced from the observations whether the

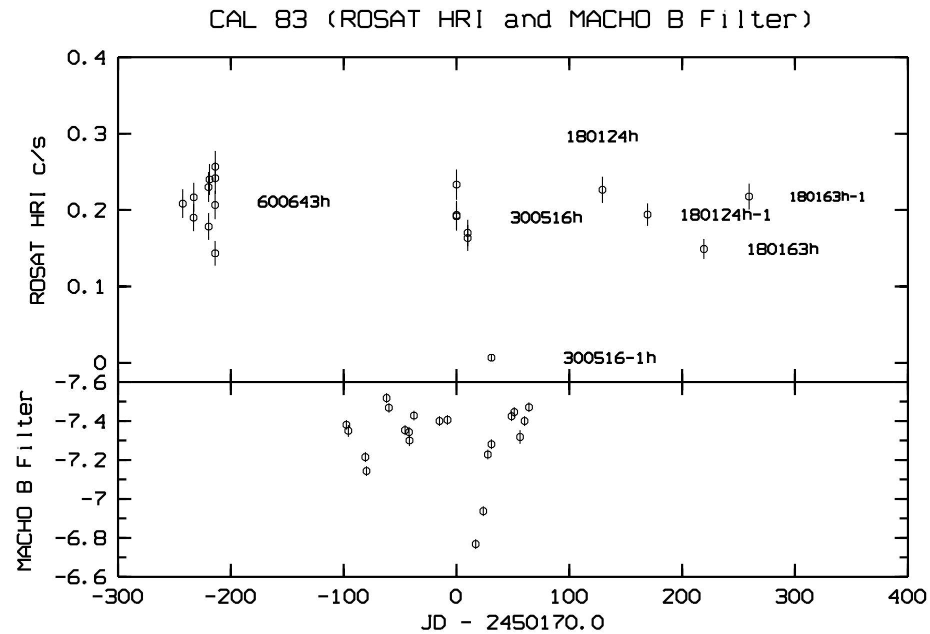

Fig. 1. Upper panel: *ROSAT HRI* X-ray light curve of CAL 83 covering the pre-off-state, the early decline, the off-state, and the post-off state recovery. Lower panel: MACHO B Filter light curve covering part of the X-ray light curve (from Alcock et al. 1997).

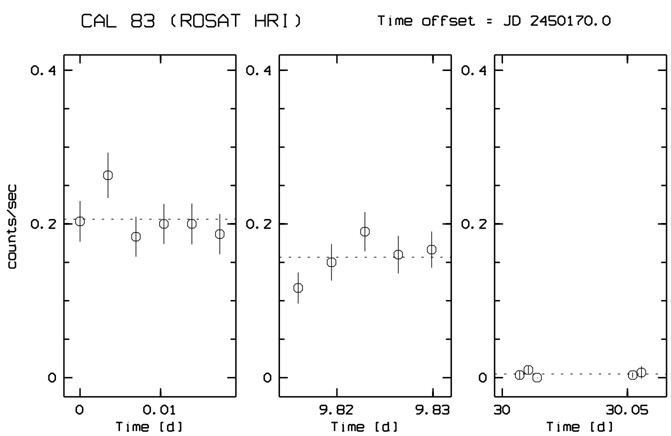

Fig. 2. X-ray light curve of CAL 83 during days 0-1, 9-10, and 30-31 counted from JD 2450170.0 (27.5 Mar 1996). Data points and the mean count rate (dashed line) are given.

observed intensity variations are due to changes in the luminosity, due to variations in the temperature or due to variations in the absorbing column density. The last option is the most unlikely as it would not be understood what might be the source of additional absorbing column density. But a huge stellar flare from the donor star shrouding the binary system with plasma may be a plausible scenario. Luminosity changes with a time scale of a few tens of days would also be hard to understand. What remains are temperature variations of the white dwarf envelope. This could e.g. come about due to a variable mass accretion rate onto the white dwarf e.g. due to changes in the mass loss rate of the donor star. An analysis of the pointed *ROSAT PSPC* observation retrieved from the public *ROSAT* archive (observation 500131p) has been performed. A spectral fit has been applied to the data assuming LTE and NLTE white dwarf atmosphere

Table 3. Parameters of a LMC LTE and NLTE white dwarf atmosphere spectral fit applied to a *ROSAT PSPC* observation of CAL 83 (observation 500131p).

Parameter	unit	LTE value	NLTE value
$N_{\rm H}$	$[10^{20}{\rm cm}^{-2}]$	$8.87^{+1.55}_{-1.30}$	$6.07^{+\gtrsim 0.33}_{-\gtrsim 0.47}$
log g		9.0	
$T_{\rm eff}$	$[10^5$ K]	$5.16^{+0.13}_{-0.12}$	$\lesssim 4.03$
R	$[10^9$ cm]	$1.00 - 1.14$	$\gtrsim 1.03$
$L_{\rm bol}$	$[10^{37}\ erg\ s^{-1}]$	$5.81^{+0.13}_{-0.20}$	$\gtrsim 2.0$
DOF		36	36
χ^2/DOF		1.18	1.48

models (with LMC abundances) resulting in the spectral parameters given in Table 3 (cf Fig. 3). These values will be considered as the nominal (high intensity state) spectral parameters of CAL 83.

2.4. *LTE White dwarf atmosphere spectra; predicted count rate changes due to temperature changes and predicted ratio of HRI to PSPC count rates*

The *ROSAT HRI and PSPC* count rate was calculated for LTE white dwarf atmosphere models (log g=9.0) and $N_{\rm H} = 8 \times 10^{20}{\rm cm}^{-2}$ for a temperature grid $T_{\rm eff} = 3.0 - 4.5 \times 10^5$ K, step size 0.5×10^5 K and these count rates were normalized to the count rates for $T_{\rm eff} = 4.5 \times 10^5\ K$. The result of this calculation is given in Fig. 4. It is obvious that the *HRI* is more sensitive to temperature variations than the *PSPC*.

The X-ray off-state can in this model be explained if the temperature dropped from $4.5 \times 10^5\ K$ to below $3.2 \times 10^5\ K$.

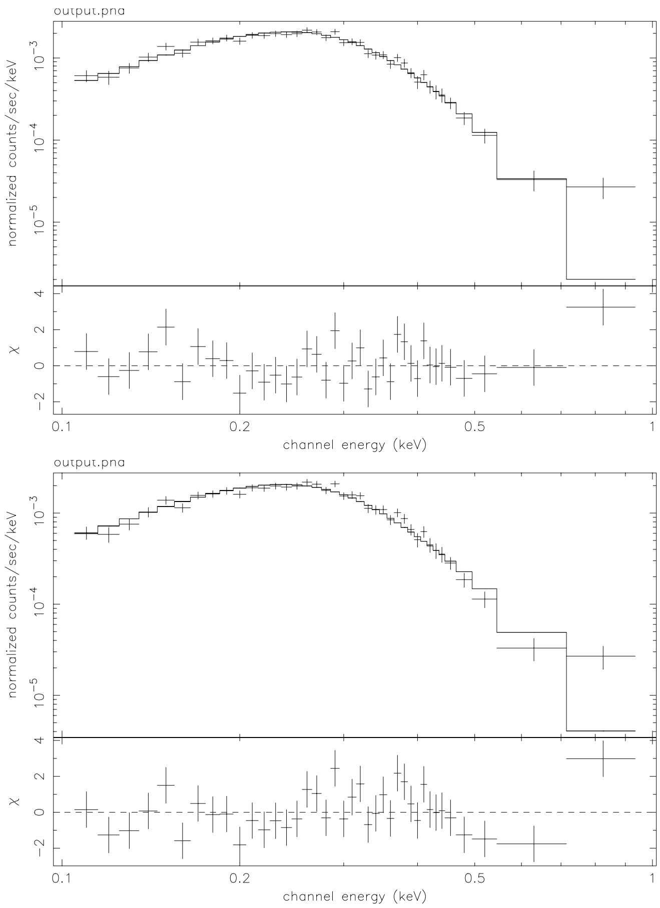

Fig. 3. ROSAT PSPC spectrum of CAL 83, observation 500131. The best-fit LMC LTE (upper panel) and LMC NLTE (lower panel) white dwarf atmosphere spectrum is given (cf. Table 3 for the parameters) together with the observed data.

This corresponds, assuming a constant bolometric luminosity, to an increase in the radius of the white dwarf envelope by a factor of $\sim$2.0. The minor intensity decline (by a factor of $\sim$0.66) after the recovery from the off-state can be explained if the temperature decreased slightly from $4.50 \times 10^5\ K$ to $4.37 \times 10^5\ K$. The required change in radius would only be $\sim$6%.

The count rate ratio *HRI* to *PSPC* has been calculated for a LTE WD atmosphere spectrum for $N_H = 8. \times 10^{20}$ cm^{-2} and temperatures in the range $3.0 - 4.5 \times 10^5\ K$. The result is given in Fig. 5. A *PSPC* count rate of $\sim 1.0 - 1.3\ s^{-1}$ is predicted. This is consistent with the result of Greiner et al. (1991) who deduce a *PSPC* count rate of 0.98 s^{-1}).

3. Discussion

A possible scenario is discussed for the X-ray off-state of CAL 83, i.e. the expansion of the atmosphere of the white dwarf due to an increased mass transfer event. The time scale involved with the X-ray turn-off and the duration of the X-ray off-state as well as the duration of the X-ray turn-on can be used to constrain the mass of the white dwarf and the effective mass accretion rate onto the white dwarf.

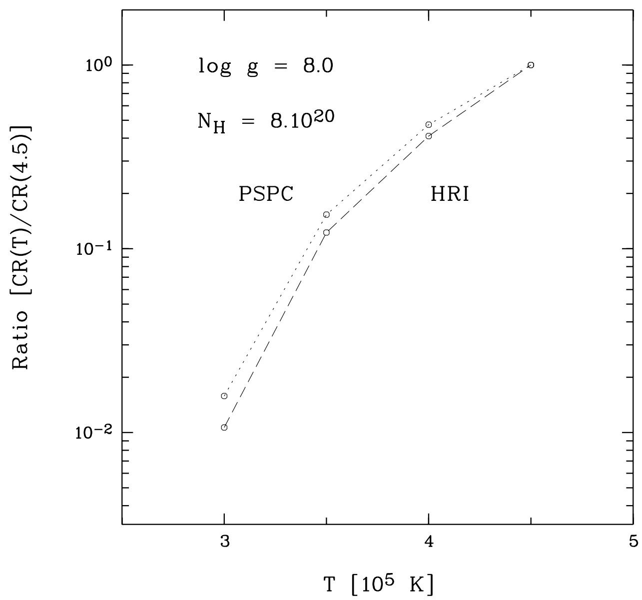

Fig. 4. Ratio of *ROSAT HRI* and *PSPC* count rates (at temperature T) to count rates at temperature $4.5 \times 10^5\ K$ for a LTE white dwarf atmosphere model (log g=8.0, N_H = 8.10^{20} cm^{-2}).

3.1. The April 96 X-ray fall

If the accretion rate onto the white dwarf in CAL 83 is close to $\dot{M}_{\rm RG}$, then variations of the radius of the envelope can be caused by variations in the accretion rate. According to the parameters in Table 3 the derived luminosity is $\sim 6.10^{37}$ erg s^{-1}, i.e. somewhat below the Eddington luminosity of a 1. M$_\odot$ white dwarf. In order to refine this result (assuming that a non-LTE spectrum is a better approximation than a LTE spectrum) we fitted a non-LTE spectral model with LMC abundances to the same data and derive a lower bound on the luminosity of $\gtrsim 2. \times 10^{37}\ erg\ s^{-1}$ (we are bounded by the model atmospheres to temperatures above $4.10^5\ K$). If CAL 83 was shortly before the off-state close to the Eddington luminosity then an enhanced mass accretion event may have blown up the envelope and have caused the derived temperature drop of 40%. The time scale involved with the atmospheric expansion can be estimated in a similar way as has been done for AG Dra by Greiner et al. (1997). This allows one to constrain the mass of the white dwarf and the mass accretion rate onto the white dwarf. The expansion velocity can be estimated from Equation 15 of Fujimoto (1982) as

$$\frac{dR/R}{dt} = \frac{d(lnR)}{d(ln\Delta M)} \left(\frac{\dot{M} - \dot{M}_{\rm RG}}{\Delta M}\right) \tag{1}$$

Fitting the *ROSAT HRI* count rate change by a factor of >42 by a temperature decrease from 4.5 to $3.2 \times 10^5\ K$ one gets dR/R

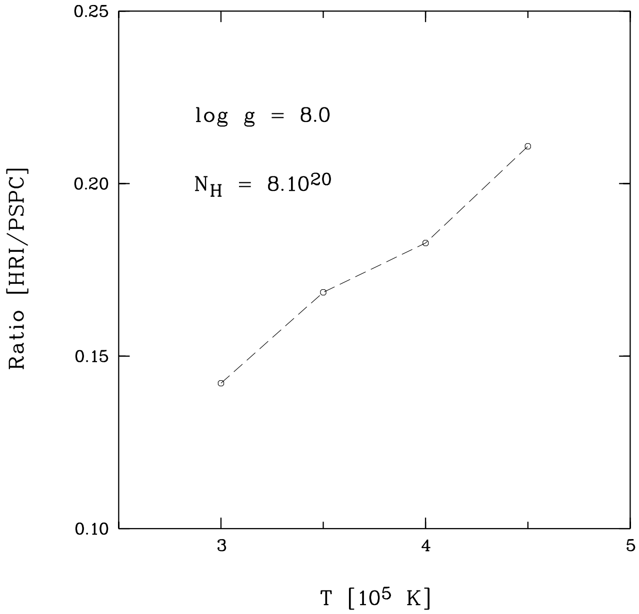

Fig. 5. Ratio *ROSAT HRI* to *PSPC* count rate (for temperature $3. \times 10^5$ to 4.5×10^5 K) for a LTE white dwarf atmosphere model (log g=8.0, N_H = 8.10^{20} cm^{-2}).

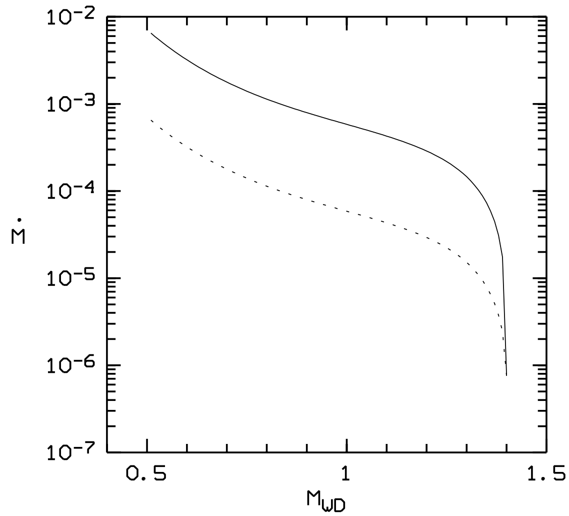

Fig. 6. Solid line: Mass accretion rate $\dot{M}$ ($\mathrm{M}_\odot$ yr^{-1}) as a function of the mass of the white dwarf M_{WD} ($\mathrm{M}_\odot$). Dotted line: Same curve but for a 10 times larger value of $\frac{d(ln\Delta M)}{d(lnR)}$ (cf. text).

= 1.0 assuming adiabatic expansion at constant luminosity. With dt = 20 days one obtains

$$\frac{dR/R}{dt} = 18.3 \ \mathrm{yr}^{-1} \tag{2}$$

Using a relation between the mass of the envelope of the white dwarf and the mass of the white dwarf at the onset of envelope expansion (Kahabka 1996a)

$$log\Delta M = -3.532 + 1.654(M_{\mathrm{WD}})^{-1.581} ln(1.4 - M_{\mathrm{WD}}) \tag{3}$$

and using a relation between the radius and the mass of the white dwarf (Nauenberg 1972)

$$\frac{dR}{d(M_{\mathrm{WD}})} = -2.61 \times 10^8 \times \left(\left(\frac{M_{\mathrm{WD}}}{1.43}\right)^{-2/3} - \left(\frac{M_{\mathrm{WD}}}{1.43}\right)^{2/3}\right)^{-1/2} \times \left(\left(\frac{M_{\mathrm{WD}}}{1.43}\right)^{-5/3} + \frac{M_{\mathrm{WD}}}{1.43}\right)^{-1/3}\Bigg) \tag{4}$$

one can constrain from equation (1) the mass accretion rate $\dot{M}$, which is then only dependent on the mass of the white dwarf. If one uses the approximation $\dot{M}_{\mathrm{RG}} \approx 8.5 \times 10^{-7}(M_{\mathrm{WD}} - 0.52)$ $\mathrm{M}_\odot$ yr^{-1}, $\dot{M}$ can be determined. It has to be noted that we used the mass-radius relation of a not expanded white dwarf envelope, but what goes into Equation 1 is the relative change of the radius with the mass of the white dwarf $\frac{dR/R}{d(lnM_{\mathrm{WD}})}$, which may be assumed to be similar for an expanded atmosphere (which has to be shown). It also has to be noted that a values of 0.1-0.5 is derived for the quantity $\frac{d(lnR)}{d(ln\Delta M)}$ which is a factor of 10 smaller than the value of typically 3-4 used by Greiner et al. (1997) for modelling the X-ray fall of AG Dra. In Fig. 6 $\dot{M}$ is given as a function of the white dwarf mass.

Assuming realistic values of $\dot{M}_{\mathrm{RG}}$, i.e. $\sim 10^{-6}$ $\mathrm{M}_\odot$ yr^{-1}, a very large white dwarf mass close to the Chandrasekhar mass is found. Assuming a value of $\frac{d(lnR)}{d(ln\Delta M)}$ which is a factor ∼10 larger (dotted curve in Fig. 6), a white dwarf mass of 1.2 $\mathrm{M}_\odot$ would require a $\dot{M}$ of $\sim 2.10^{-5}$ $\mathrm{M}_\odot$ yr^{-1}. It has to be noted that in order to reproduce the optical spectrum of CAL 83 Popham & Di Stefano (1996) need a white dwarf mass of $\sim$ 1.2 $\mathrm{M}_\odot$. The radius of a 1.2 $\mathrm{M}_\odot$ white dwarf would be a factor of $\sim$ 2.6 smaller than the radius of $\sim 10^9$ cm found from the white dwarf atmosphere spectral fit which would indicate that CAL 83 is in a slightly expanded state. This would be in agreement with rapid accretion onto the white dwarf, strong winds and a possible jet as proposed by Southwell et al. (1997) (but see that we favor a much larger mass accretion rate of $\sim 10^{-6}$ $\mathrm{M}_\odot$ yr^{-1} for CAL 83 than the value of $\sim 10^{-7}$ $\mathrm{M}_\odot$ yr^{-1} stated in Southwell et al. (1997)).

3.2. X-ray turn-on

From the duration of the X-ray turn-on of CAL 83, which has been found to be <100 days (Kahabka, Haberl & Parmar 1996), an independent estimate of the mass can be obtained if the model of a contracting white dwarf envelope is applied (cf. Kahbaka 1996a). Assuming that no mass has been lost from the envelope during the expansion phase, then the observed turn-on time constrains the mass of the white dwarf to > 1.1 $\mathrm{M}_\odot$.

3.3. X-ray recurrence

No second X-ray off-state has been found during the subsequent *ROSAT HRI* target of opportunity observations. CAL 83 therefore cannot be classified as a recurrent supersoft source. The variability observed (the X-ray dip) can be due to several reasons, e.g. variations in the mass accretion rate e.g. variations in the mass loss rate of the donor star or unstable nuclear burning. The last option cannot be excluded but it has to be investigated if the short < 100 days off-period can be explained with such a model. Assuming that the duration of the X-ray off-state is determined by

$$t_{\text{recur}} - t_{\text{on}} \; < \; 100 \; days, \tag{5}$$

with the recurence time t_{recur} and the X-ray on-time t_{on} then the function f_0 derived in Kahbaka (1995)

$$f_0 \; = \; t_{\text{on}} \times \left(1 - \frac{t_{\text{on}}}{t_{\text{recur}}}\right) \tag{6}$$

can be used to constrain the ratio $\frac{t_{\text{on}}}{t_{\text{recur}}}$ to

$$\frac{t_{\text{on}}}{t_{\text{recur}}} > \frac{f_0}{100 \; days}. \tag{7}$$

f_0 depends on the mass of the white dwarf. For $M_{\text{WD}} >$ 1.1 $M_{\odot}$ it follows that f_0 <20 years (f_0 ≈5 years for M_{WD} = 1.2 $M_{\odot}$).

From the *ROSAT HRI* TOO observations following the X-ray off-state at intervals of 40-50 days and covering in total 230 days the recurrence time can be constrained to t_{recur} >0.6 years. With Equation 7 the on-time can then be constrained for a 1.2 $M_{\odot}$ white dwarf to t_{on} >10 years. It has to be noted that a recurence period of ≈0.5 years is predicted for a 1.2 $M_{\odot}$ white dwarf accreting at a rate of $\dot{M} \approx 10^{-6}$ yr^{-1} according to hydrodynamic calculations of Prialnik & Kovetz (1995).

The observational history of the system has been followed up since the *Einstein* discovery in 1980 and the sampling was rather sparse. Less than two off-states may have occurred. During the period of *ROSAT* observations of ∼6 years at most one off-state has happened and one has been observed. This would constrain the white dwarf mass to $M_{\text{WD}} > 1.2$ $M_{\odot}$ if the system would undergo unstable nuclear burning.

3.4. How similar is CAL 83 to the recurrent supersoft transient RX J0513.9-6951 ?

RX J0513.9-6951 has been found to recur with a period of ∼100-200 days (Southwell et al. 1996). The X-ray on-time is $\sim 20 - 30$ days. CAL 83 therefore would show a considerably longer on and recurrence time. Possibly CAL 83 and RX J0513.9-6951 are not that different in terms of white dwarf masses and mass accretion rates. But whether CAL 83 has a mass close to the Chandrasekhar mass or somewhat lower may not be completely conclusive.

3.5. The optical dip

An optical dip has been observed about 17 days before the X-ray off-state. The duration of the optical dip is constrained to ≲20 days. The duration of the X-ray off-state was ≲100 days. While the rise from the optical dip with a duration of ≈ 30 day has been observed, the X-ray rise has not been seen. The depth of the optical dip was ~ 0.7 mag. The optical dip may be due to the difference in light from the irradiated accretion disk and the expanded white dwarf envelope as a consequence of a change in the radius of the envelope similar to RX J0513.9-6951 (Reinsch et al. 1996). In the latter source a optical brightness change of ΔV = 0.9 mag has been observed. But this would not explain why the optical dip preceeds the X-ray dip by about 20 days. An alternative explanation has been given by Alcock (1997) where a mass transfer event (deficit) is caused by magnetic activity on the donor star and is passed through the disk. It leads in their model to cessation of nuclear burning and a cooling white dwarf condition (cf. Kato (1997) for calculations of the duration of the X-ray turn-off). But this scenario may not work as before the cooling of the envelope of the white dwarf can take place the residual envelope has to be consumed by nuclear buring. The involved timescale is at least one month for a Chandrasekhar mass white dwarf and much longer for lower masses.

To overcome this problem and to give a physical link to the envelope expansion model one could think about a "modulated" mass transfer from the donor star, i.e. a mass transfer enhancement followed by a mass transfer deficit in the form of a wave. This mass transfer wave goes through the disk in the form of a density wave and arrives after a time mainly determined by the viscosity of the disk at the white dwarf envelope and triggers the envelope expansion. Then the density wake follows and causes the white dwarf envelope to settle back to its equilibrium configuration. The X-ray signature is a drop of the persistent X-ray flux due to envelope expansion and the subsequent rise as the envelope settles back again. The optical light curve is mainly the light curve of the irradiated accretion disk (and of the irradiated donor star). As the density enhancement is fed into the disk (rim) the disk starts to flare and its temperature increases due to the increased $\dot{M}$. This should give a rise in the optical flux which is possibly not observed or at least not so clear from the observations as the optical data do not cover a reasonably long time before the X-ray and optical dip. Then the density wake follows reducing the disk flaring and causing a drop in the temperature which together result in the observed optical dip. After this disturbance the disk settles back into its equilibrium state. The time scale involved with the length of the wave (disturbance) is most possibly the convective time scale of the donor star. The disturbance may be connected to a huge star spot crossing the L1 point and affecting the mass transfer process. It is the convective time scale scale τ_{conv} of an evolved star. The other time scale is the viscous time scale τ_{visc} of the accretion disk. It determines the time which is required for the disturbance to arrive at the white dwarf envelope and to trigger the expansion. From the observations one derives the following constraint

$$\tau_{\text{visc}} + \tau_{\text{conv}} \approx 20 \; days. \tag{8}$$

4. Conclusions

The intensity variations observed in the light *ROSAT HRI* light curve of CAL 83 can be explained by variations of the temperature of an expanding white dwarf envelope. The X-ray off state requires a temperature change from $\sim 4.5 \times 10^5$ K to $\leq 3.2 \times 10^5$ K. Such a temperature change may be due to an increase in the mass accretion rate onto the steady burning white dwarf. This interpretation is opposite to the interpretation of Alcock et al. (1997) who defend a decrease in the mass accretion rate. From the observed X-ray turn-off time scale we can - assuming an adiabatic expansion of the white dwarf atmosphere - constrain a temperature and radius change. This allows to constrain the mass of the white dwarf to $\gtrsim$1.2 $M_\odot$ assuming realistic values for the mass accretion rate onto the white dwarf (in excess of the mass accretion rate leading to a red giant configuration) of several 10^{-6} $M_\odot$ yr^{-1}. It is not known that X-ray off-states recur in CAL 83. This could be due to the fact that radius expansion is not triggered by weak flashes but by episodic mass transfer. The X-ray fall may have been triggered by an enhanced mass transfer event onto the white dwarf due to a density wave passing through the disk caused by a mass transfer variation possibly connected with magnetic star spot activity of the donor star.

Acknowledgements. I thank D. Bhattacharya for reading the manuscript and discussions. I thank Frank Haberl for comments on the quality of the X-ray off-state data of CAL 83 and for helping to schedule the *ROSAT HRI* TOO observations. I thank Arvind Parmar for initiating *SAX LECS* observations of CAL 83. I thank Wouter Hartmann for making me the LTE and NLTE white dwarf atmosphere models available. P.K. is a Human Capital and Mobility fellow. The *ROSAT* project is supported by the Max-Planck-Gesellschaft and the Bundesministerium für Forschung und Technologie (BMFT).

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