V723 Cas: A dying nova or a new-born SSS?

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The old Classical Nova V723 Cas (**1995**), was detected in X-rays with the XRT aboard *Swift*. Recent observations of optical emission lines from highly ionized iron motivated the 7-ksec observation, and the nova was observed to still be active with an X-ray emission level of 7.8×10^{-13} erg/cm^2/s. The spectrum is that of a Super-Soft-Source (SSS) and peaks at about 0.4 keV. An absorbed blackbody with $T \sim 320,000$ K (about 27 eV), $N_H = 1.7 \times 10^{21}$ cm^{-2} and $R_{WD} \sim 6000$ km ($\log L_X = 36.4$) results in a remarkably good fit to the spectrum. The fact that V723 Cas was found with a SSS spectrum 11 years after the outburst makes this a candidate for a classical nova that has evolved into a permanent SSS according to theoretical calculations by our group. If further observations show that it is still on, we have likely witnessed the white dwarf in a Classical nova beginning its growth to the Chandrasekhar limit.

1. Introduction

Classical Novae (CNe) are the visible events caused by thermonuclear explosions on surfaces of white dwarfs (WD). The fuel is material transferred by accretion from a companion main-sequence star. The evolution of an outburst lasts between six months to three years or sometimes longer. The longest CN explosion lasted 10 years (GQ Mus: Krautter & Williams 1989, Ögelman et al. 1993; 6; 9) and was still seen in X-rays, but then faded away (Shanley et al. 1995; 11). Also, a possible candidate for a long-lasting nova was reported in M31 in terms of spatial coincidence by Orio (2005; 10).

V723 Cas is a slow Classical Nova (CN) that exploded on 24 August, 1995 (Hirosawa et al. 1995; 4) and has been observed extensively during the last decade. Visual maximum was reached 17 December, 1995 of 7.1 mag (Munari et al. 1996; 7). It has been extensively observed from ultraviolet (Gonzalez-Riestra et al. 1996; 2) to radio (Heywood et al. 2005; 3) wavelengths. Recent optical and NIR spectra show that V723 Cas reached its "coronal" phase with high ionization emission such as Fe X (6373 Å) similar to spectra obtained of GQ Mus while it was in its SSS phase (Krautter & Williams 1989; 6) suggesting that nuclear burning was still continuing. However, the only real way to determine if a nova is in the SSS phase is to obtain X-ray observations. As the confirmation of V723 Cas to still be in the SSS phase has important implications, we observed this CN in X-rays with *Swift* and found a clear detection (Ness et al. 2006; 8). There are two possible explanations why V723 Cas could still exhibit the SSS spectrum. One is that a lot of "fuel" has been accreted before the outburst and V723 Cas will soon fade away. The other one is that accretion has set in again and nuclear burning of freshly accreted material keeps the nova burning. Theoretical models have revealed that permanent SSS may form after the outburst of a Classical Nova (Sect. 3.2 and Starrfield et al. 2004; 12). The energy source of the SSS is accreted material that is immediately processed and remains on the white dwarf. In view of this, the latter scenario is particularly interesting in view of Supernovae Ia (SNe Ia).

2. Observations

V723 Cas was observed with the *Swift* satellite on Jan. 31.27 UT for 6.8 ksec by the X-Ray Telescope (XRT) instrument. The XRT was operated in photon counting mode and we extracted 198 counts at the source position and 16 counts in an adjacent background extraction region. The net count rate is thus 0.027 cts/sec and we used standard response files in order to calculate a flux at Earth of 7.8×10^{-13} erg cm^{-2} s^{-1}. The spectrum is unusually soft and peaks at about 0.4 keV (Fig. 1). It can be seen that we have enough signal to attempt a simple model and we choose an absorbed blackbody fit. We fit three parameters, the blackbody temperature (in K), the value of N_H (in $10^{21}\,cm^{-2}$) and a normalization, which can be interpreted as the dilution factor R^2/d^2 with R the radius of an emitting sphere and d the distance to the source. We assume a distance of 2.3 kpc (Chochol & Pribulla 1997; 1), which allows us to convert the normalization into a radius. The radius and the blackbody temperature can then be used to calculate the unabsorbed luminosity. The best-fit model is shown in a light blue color in Fig. 1 and the resulting parameters are given in the upper left corner. We excluded the wavelength range around the C-absorption edge at ~ 43 Å and mark the ignored part of the model with a dashed line. Comparison of the model with the measured spectrum leaves no measured feature unexplained and more refined models are only necessary if observations with higher spectral resolution and/or higher S/N show a more complicated spectrum. The blackbody temperature of $\sim 320,000$ K is equivalent to 27 eV, which is within the typical range of SSS spectra.

Shortward of the onset of the SSS continuum a very weak peak at ~ 12 Å can be seen, which may be due to Ne X. Unfortunately, this line is only detected with three counts and we have to check the reliability of this observation. Below 20 Å we detect 14 counts from the source and 10 counts from the background, such that the source has an excess of only 4 ± 1.1 counts. Three of these four counts have been detected at the wavelength of the Ne X line at 12.12 Å. While the probability to measure 14 or more counts when 10 are expected from the background is ~ 13 per cent (assuming Poissonian statistics), the probability to find three out of four at one specific wavelength is much lower. However, no other emission lines can be identified, but the presence of this line would suggest that the burning white dwarf is surrounded by a nebular collisionally ionized and excited shell. As the photon energy provided by the continuum does not reach the excitation energy, this line must be collisionally excited. The regions where this line, and possibly other, non-detected lines reside, are then detached from the hot plasma and they originate most likely from the outer regions.

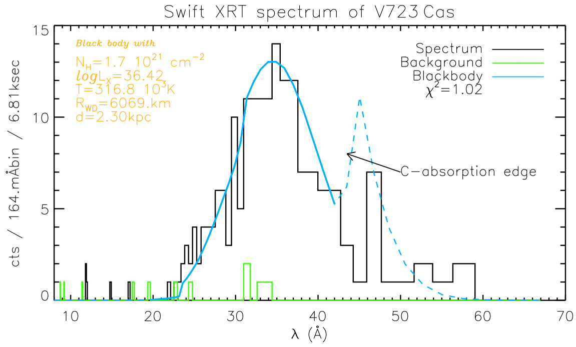

Figure 1. *Swift* XRT spectrum of V723 Cas taken on Jan. 31.27 UT. The spectrum can be fit with an absorbed blackbody spectrum (light blue color). The normalization results in a radius of ~ 6000 km assuming a distance of 2.3 kpc, which leads to an unabsorbed luminosity of $\log L_X = 36.42$ (cgs units). The dashed line style of the continuum model marks wavelength regions that did not contribute to the fit. A very weak peak at ~ 12 Å is possibly due to Ne X, which may indicate the presence of a collisionally excited nebular shell around the hot white dwarf.

3. Discussion

3.1. SN Ia

Possibly related to Classical Novae are SN Ia explosions, which involve a white dwarf, growing to the Chandrasekhar mass limit of $1.4\,M_\odot$. The main problem in understanding the progenitors of SN Ia explosions is how the white dwarf reaches the Chandrasekhar limit. In a CN explosion the accreted material and some of the WD material are ejected during the explosion and the WD effectively loses mass. So, CNe cannot be the direct progenitors. Alternatively, a binary system of two white dwarfs (double-degenerate) may merge. However, it is not clear how many such systems exist and whether the time scales for such a merger are short enough to explain the frequency of SN Ia explosions. One proposal for the progenitors of SNe Ia is the class of SSS (Starrfield et al. 2004; 12).

3.2. Super Soft X-ray Sources (SSS)

The class of Super Soft X-ray Sources (SSS) was discovered by *Einstein*, but only classified as such by ROSAT. The origin of SSS is not entirely clear, but it is commonly accepted now that they are the result of thermonuclear burning in the envelopes of mass-accreting white dwarfs in close binary systems (Kahabka & van den Heuvel 1997; 5), thus there is a strong link between SSS and CNe. Starrfield et al. (2004; 12) calculated evolutionary models where a standard CN is evolving with accretion setting in while the white dwarf is still hot. Their calculations showed that with

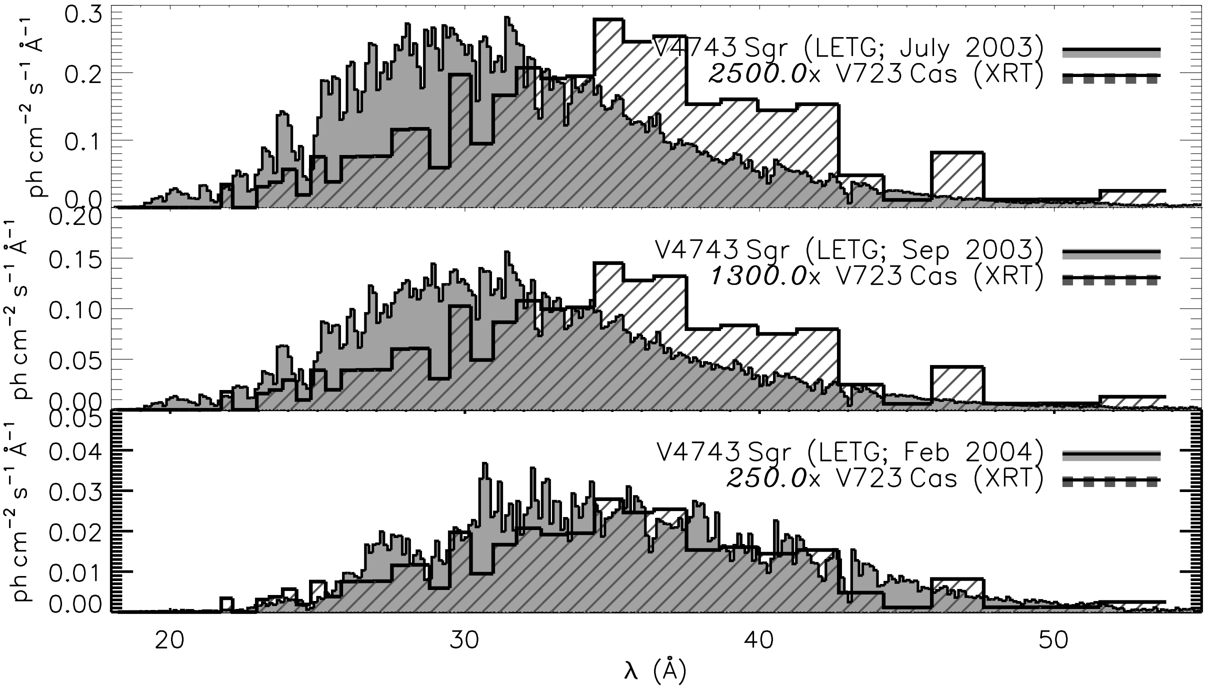

Figure 2. Two possible scenarios of what to expect next from V723 Cas. *V723 Cas will turn off very soon*: Comparison of *Chandra* LETG observations along the evolution of V4743 Sgr (light shades) with V723 Cas (rescaled as shown in legend). V4743 Sgr is hotter during the two observations of July and September 2003, but in February 2004 the spectrum of V4743 Sgr agrees quite will with that of V723 Cas, scaled with a factor 250.

a large range of parameters the accreted material can be nuclearly processed right away (steady burning), since the white dwarf is hot. If the accreted material is burnt, the ashes remaining on the surface of the white dwarf are not explosive and another thermonuclear runaway will not happen. This model also explains why most SNe Ia are hydrogen+helium deficient.

4. Conclusions

11 years after the outburst, V723 Cas (1995) has now been detected in X-rays with an extremely high detection likelihood (45.5σ). This detection is remarkable, since no other CN has been found to be bright in X-rays after such a long time. The only other example is GQ Mus, which survived for 9 years (Krautter & Williams 1989, Ögelman et al. 1993; 6; 9) until it finally turned off (Shanley et al. 1995; 11). In order to place V723 Cas in the evolution of a CN we show in Fig. 2 a comparison of *Chandra* LETG spectra of the CN V4743 Sgr (2002) taken during different times of the SSS phase. We overplot the rescaled *Swift* XRT spectrum of V723 Cas, individually rescaled for comparison, and it can

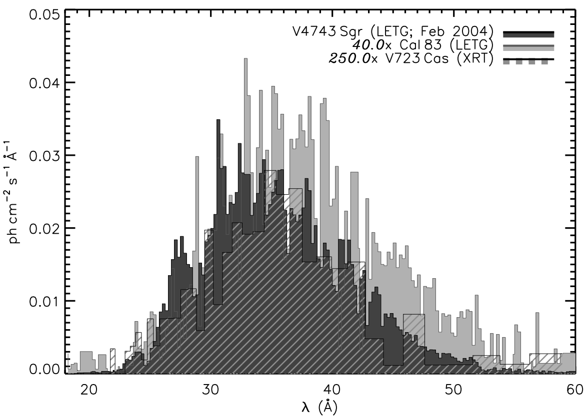

Figure 3. Two possible scenarios of what to expect next from V723 Cas. *V723 Cas has entered a stage of a permanent SSS*: Comparison of the *Chandra* LETG spectra of the latest stage of V4743 Sgr and of the SSS Cal 83 with our *Swift* XRT spectrum of V723 Cas. All three spectra agree well and at this stage neither scenario can be excluded.

be seen that the shape of our spectrum agrees well with the last spectrum of V4743 Sgr taken in February 2004, before V4743 Sgr turned off. The resemblance is not surprising because V723 Cas is a slow nova which presumably took place on a low-mass WD. Thus more mass should have been left behind to burn and had weaker Eddington winds to drive additional mass loss (i.e longer SSS phase). Also the maximum temperature would be lower since low-mass WDs can't burn as hot since they have lower surface gravities. From the present data situation we can not rule out that V723 Cas is turning off similarly to GQ Mus, but the resemblance with the final phase of V4743 Sgr doesn't necessary imply that it is turning off.

Another exciting scenario would be that V723 Cas has entered a stage of a permanent SSS. We illustrate this possibility with Fig. 3, where we show the resemblance of V723 Cas, not only with V4743 Sgr in the latest stage, but also with the permanent SSS Cal 83. This scenario can also be tested by further observations, monitoring the evolution of the spectrum. Theoretical models by Starrfield et al. (2004) predict that it is possible that accretion can resume before the white dwarf has completely cooled down, and freshly accreted material can then continuously burn. This steady-burning scenario allows the white dwarf to grow in mass, because if the accreted material is immediately processed, the explosive nature of the accreted material is taken out, thus, no CN outburst that would effectively lead to mass loss occurs. A white dwarf growing in mass is the essential ingredient for a SN Ia explosion at some point in the future (depending on accretion rate and initial white dwarf mass) by simply reaching the Chandrasekhar mass limit. This situation constitutes a single-degenerate SN Ia progenitor scenario, but an object experiencing the transition from a nova into a permanent SSS is yet to be discovered, and with V723 Cas a hot candidate is found.

With the present data situation we are not able to distinguish between these two scenarios. Figs. 2 and 3 quite clearly show that V723 Cas may be shortly before tunring off and this *Swift* observation may well be the last and only time V723 Cas has been seen in the SSS stage. As nova explosions are complex events, all of them having been observed to behave differently, it is the more important now to establish a precise time of turn-off. As being the longest-lasting nova in recorded history, V723 Cas marks a corner stone for future surveys of nova observations, and determining the precise time of turn off is an important reason to carry out further observations. The second scenario is even more exciting, as V723 Cas may be a new-born SSS, and the progenitor for the class of SSS has been found. In that picture V723 Cas is the progenitor of a SN Ia progenitor and is thus, again, a corner stone in the evolution of SNe Ia.

V723 Cas therefore deserves intensive further studies in X-rays, and we are following this nova with *Swift* and will also try to convince *XMM-Newton* to carry out deeper observations.

REFERENCES

[1] Chochol, D., & Pribulla, T. 1997, Contrib. Astron. Obs. Skalnate Pleso, 27, 53

[2] Gonzalez-Riestra, R., Shore, S. N., Starrfield, S., & Krautter, J. 1996, IAU Circ, 6295, 1

[3] Heywood, I., O'Brien, T. J., Eyres, S. P. S., Bode, M. F., & Davis, R. J. 2005, MNRAS, 362, 469

[4] Hirosawa, K., Yamamoto, M., Nakano, S., Kojima, T., Iida, M., Sugie, A., Takahashi, S., & Williams, G. V. 1995, IAU Circ, 6213, 1

[5] Kahabka, P., & van den Heuvel, E. P. J. 1997, ARA&A, 35, 69

[6] Krautter, J., & Williams, R. E. 1989, ApJ, 341, 968

[7] Munari, U., Goranskij, V. P., Popova, A. A., Shugarov, S. Y., Tatarnikov, A. M., Yudin, B. F., Karitskaya, E. A., Kusakin, A. V., Zwitter, T., Lepardo, A., Passuello, R., Sostero, G., Metlova, N. V., & Shenavrin, V. I. 1996, A&A, 315, 166

[8] Ness, J.-U., Starrfield, S., Schwarz, G., Vanlandingham, K., Wagner, R. M., Lyke, J., Woodward, C. E., Lynch, D. K., & Krautter, J. 2006, IAU Circ, 8676, 2

[9] Ögelman, H., Orio, M., Krautter, J., & Starrfield, S. 1993, Nature, 361, 331

[10] Orio, M. 2005, American Astronomical Society Meeting Abstracts, 206

[11] Shanley, L., Ögelman, H., Gallagher, J. S., Orio, M., & Krautter, J. 1995, ApJL, 438, L95

[12] Starrfield, S., Timmes, F. X., Hix, W. R., Sion, E. M., Sparks, W. M., & Dwyer, S. J. 2004, ApJL, 612, L53

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