NON-LOCAL THERMAL EQUILIBRIUM MODEL ATMOSPHERES FOR THE HOTTEST WHITE DWARFS: SPECTRAL ANALYSIS OF THE COMPACT COMPONENT IN NOVA V4743 Sgr*

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Received 2010 January 25; accepted 2010 May 7; published 2010 June 11

ABSTRACT

Half a year after its outburst in 2002 September, nova V4743 Sgr evolved into the brightest supersoft X-ray source in the sky with a flux maximum around 30 Å. We calculated grids of synthetic energy distributions based on non-local thermal equilibrium model atmospheres for the analysis of the hottest white dwarfs (WDs) and present the result of fits to Chandra and XMM-Newton grating X-ray spectra of V4743 Sgr of outstanding quality, exhibiting prominent resonance lines of C VI, C VII, N VI, N VII, and O VII in absorption. The nova reached its highest effective temperature ($T_{\text{eff}} \approx 740 \pm 70$ kK) around 2003 April and remained at that temperature at least until 2003 September. We conclude that the WD is massive, $\approx 1.1–1.2$ $M_\odot$. The nuclear-burning phase lasted for 2–2.5 years after the outburst, probably the average duration for a classical nova. The photosphere of V4743 Sgr was strongly carbon deficient ($N/C \approx 0.01$ times solar) and enriched in nitrogen and oxygen (>5 times solar). Especially the very low C/N ratio indicates that the material at the WD’s surface underwent thermonuclear burning. Thus, this nova retained some of the accreted material and did not eject all of it in outburst. From 2003 March to September, the nitrogen abundance is strongly decreasing; new material is probably already being accreted at this stage.

Key words: novae, cataclysmic variables -- stars: abundances -- stars: AGB and post-AGB -- stars: atmospheres -- stars: individual (V4743 Sgr) -- white dwarfs

Online-only material: color figures

1. INTRODUCTION

Nova V4743 Sgr (Nova Sgr 2002 c) was discovered in outburst in 2002 September and reached $V = 5$ mag on 2002 September 20 (Haseda et al. 2002). It was a very fast nova, with a steep decline in the optical light curve and large ejection velocities. The time to decay by 3 mag in the visual ($t_3$) was 15 days and the FWHM of the Hα line reached 2 400 km s$^{-1}$ (Kato et al. 2002). Estimates of the distance from infrared observations vary from 1200 ± 300 pc (Nielbock & Schmidtobreick 2003) to $\approx 6300$ pc (S. Starrfield & J. E. Lyke 2004, private communication).

In 2002 December, the nova was observed for the first time with Chandra ACIS-S. At that time it was a very soft and moderately luminous X-ray source, with a count rate of about 0.3 counts s$^{-1}$. There were indications that it was not at the peak of X-ray luminosity yet, so a Chandra HRC+LETG observation was only done later, on 2003 March 20. The count rate was astonishingly high, 40 counts s$^{-1}$ during 3.6 hr, then a slow decay, lasting for an hour and a half, was followed by another 1.5 hr of very low luminosity with a measurement of only $\approx 0.02$ counts s$^{-1}$ (Ness et al. 2003; Starrfield et al. 2003). This decline was not due to an eclipse, since the orbital period of the system is 24278 ± 259 s (or 6.74 hr; Wagner et al. 2003) and no eclipse was observed in a following 10 hr XMM-Newton observation two weeks later. An obscuration of a supersoft X-ray source in a nova was observed once before with BeppoSAX, in V382 Vel (Orio et al. 2002). The only reason for this sudden near shutdown of the source may have been the ejection of a new shell of material that was optically thick to supersoft X-rays from the surface (Orio 2008). During the Chandra observation in 2003 March an oscillation with a period of 1324 s was detected, with fluctuations of 20% from the mean count rate (see Starrfield et al. 2003; Ness et al. 2003). The most likely cause of this oscillation is a non-radial pulsation of the white dwarf (WD; Starrfield et al. 2003).

A second observation was proposed by us to the XMM-Newton Project Scientist as a target during the Discretionary Time. The nova was observed for 10 hr with this satellite on 2003 April 4 (Orio et al. 2003). Three X-ray telescopes with five X-ray detectors were all used: the European Photon Imaging Camera pn (EPIC-pn; Strüder et al. 2001), two EPIC MOS cameras (Turner et al. 2001), and two Reflection Grating Spectrometers (RGS-1 and RGS-2; den Herder et al. 2001). The observation lasted a little over 36,000 s. The data obtained by the two EPIC MOS cameras suffered from very severe pile up, but the operation of the pn camera was switched to timing mode and yielded a measured average, background-corrected EPIC-pn count rate of 1348.0±0.3 counts s$^{-1}$ (Orio et al. 2003), with variations by 40% (Leibowitz et al. 2006). The RGS count rates were about 57 counts s$^{-1}$, and the unabsorbed flux was

* Based on observations collected with XMM-Newton, an ESA Science Mission with instruments and contributions directly funded by ESA Member States and the USA (NASA).
1.5 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1}, \text{ consistent with the flux measured 16 days earlier with Chandra (Leibowitz et al. 2006)}. Most of the variability is well represented as a combination of oscillations at a set of discrete frequencies lower than 1.7 mHz (Leibowitz et al. 2006). At least five frequencies preserve their coherence over the 16 day time interval between the two observations. The 1324 s period detected with Chandra could be split into two periods, of 1310.1 s and 1371.6 s, both of which are consistent in the Chandra data but it may not have been resolved (Leibowitz et al. 2006). In that paper, we suggested that a period in the power spectrum of both light curves at the frequency of \( \lesssim 0.75 \text{ mHz} \) (corresponding to 1371.6 s) is the spin period of the WD in the system, and that other observed frequencies are signatures of non-radial WD pulsations.

The X-ray evolution was followed with 10,000 s long exposures with the Chandra LETG in 2003 July and September and in 2004 February, and with a 30,000 s observation with XMM-Newton in 2004 September. By this time, the nova X-ray luminosity had decayed by 5 orders of magnitude, but the period of \( \approx 1370 \text{ s} \) was still detectable. However, the signal-to-noise ratio (S/N) of the RGS spectra at this epoch was very poor.

We have performed a non-local thermal equilibrium (NLTE) spectral analysis of the grating spectra obtained between 2003 March and 2004 February, with NLTE model-atmosphere techniques. The Tübingen NLTE Model-Atmosphere Package (TMAP) model-atmosphere code and the construction of the model atoms that are used are described in Section 2.1. An attempt to determine photospheric parameters with an XSPEC fit procedure is presented in Section 3.1. This is followed by a detailed investigation of the observed, flux-calibrated spectrum of V4743 Sgr (Section 3.2). In Section 4, we describe how our models fit the Chandra and XMM-Newton observations to interpret the post-evolution in the 18 months after the outburst of V4743 Sgr.

2. THE USE OF MODEL ATMOSPHERES

A previous analysis of Chandra LETG-S observations of V4743 Sgr (Petz et al. 2005), done with the PHOENIX NLTE models with solar abundances, reached \( T_{\text{eff}} = 580 \text{ kK} \). The fit of the model to the data was still poor, and this is not surprising because in the phase directly after the outburst, i.e., when the H burning is still ongoing (for years), the surface composition of the WD is poorly known, but is very unlikely to be solar. With the PHOENIX code, the nova atmosphere is approximated as an expanding, but stationary in time structure. Recently, van Rossum & Ness (2010) presented a new version of PHOENIX that considers mass loss as well as velocity fields. In the future, such codes will become a powerful tool for the analysis and understanding of novae and other supersoft sources.

However, in order to make progress, we decided to neglect the velocity field, and to use our static NLTE models to investigate basic parameters such as \( T_{\text{eff}} \) and surface composition. This is not fully justified because especially in the first spectra the lines were significantly blueshifted, but our aim is at least a qualitative modeling of the XMM-RGS and Chandra-LETG observations done between 2003 March and 2004 February. We started with the highest S/N spectrum, the one obtained with the XMM-Newton RGS gratings on 2003 April 4, that we used as a template to adjust the abundances. We then proceeded to also fit the Chandra spectra with the same model, checking whether the abundances we obtained were suitable, and adjusting \( T_{\text{eff}} \) for each epoch. In this way, we obtained the evolution of \( T_{\text{eff}} \) and the duration of the constant bolometric luminosity phase.

2.1. Model Atmospheres and Atomic Data

For a reliable analysis of X-ray observations of the hottest WDs, detailed NLTE model atmospheres that consider opacities of all elements from hydrogen up to the iron-group (IG) elements (cf. Rauch 1997, 2003) are required. Thus, for our analysis, we employed the plane-parallel, static models calculated with the TMAP\(^\text{10} \) (Werner et al. 2003). The construction of model atoms, which are used within TMAP, follows Rauch & Deetjen (2003). Some details for these extremely hot model atmospheres in the MK–\( T_{\text{eff}} \) range are summarized briefly in the following.

Since the surface composition is unknown, we started with the calculation of exploratory H–He+C+N+O models and later included Ne, Mg, Si, and S, as well as the IG elements. The IG elements (Sc–Ni) and Ca are treated with a statistical method (Rauch & Deetjen 2003) and are represented by one generic model atom.

Beside an element selection, the construction of the model atoms also has to be performed with care. An unrealistic upper cutoff in the number of considered IG ionization stages causes an artificial overpopulation of the highest ionization stage, and thus, affects its lines and the flux level. In Figure 1, the impact of IG opacities on the astrophysical flux is demonstrated.

For all values of \( T_{\text{eff}} \), the necessary ionization stages of all atoms are determined in advance by test calculations. The selection criterion is that at least the ion (e.g., in the case of species X) \( X^{n+} \) that is dominant in the line-forming region has to be included together with the neighboring two, i.e., \( X^{(n-1)+} \) and \( X^{(n+1)+} \). Thus, the model atoms contain in general three to five ionization stages. For example, in the case of our generic IG model atom, IG \( \text{xvii} \) is dominant at \( T_{\text{eff}} = 700 \text{ kK} \) and \( \log g = 9 \text{ cm s}^{-2} \) (Figure 2). We therefore selected the ionization stages \( \text{xiv} \text{–xviii} \). Statistics of the model atoms are shown in Table 1. In total, 228 atomic levels treated in NLTE, 360 additional levels in LTE, and 349 individual line transitions are considered.

Figure 1. Comparison of synthetic spectra (\( T_{\text{eff}} = 700 \text{ kK}, \log g = 9 \)) from models with different elemental composition (see labels). The abundances are given in Table 3 (model A). For clarity, the H–He and H–Fe spectra are shifted in \( \log F_{\lambda} \) by +2 and –4, respectively.

(A color version of this figure is available in the online journal.)
Figure 2. Ionization fractions of the generic IG model atom in a $T_{\text{eff}} = 700$ kK, log $g = 9$ model. IGXVII is dominant in the line-forming region ($-5.6 < \log m < 0.5$).

(A color version of this figure is available in the online journal.)

Table 1

Statistics of the Model Atoms Used in our Calculations of the NLTE Model Atmospheres with $T_{\text{eff}} = 0.7$ MK

| Ion     | $N$  | $L$ | $R$ | Ion     | $N$  | $L$ | $R$ |
|---------|------|-----|-----|---------|------|-----|-----|
| H i     | 5    | 11  | 10  | Ne vii  | 10   | 50  | 12  |
| H ii    | 1    | —   | —   | Ne viii | 8    | 18  | 15  |
| He i    | 1    | 25  | 0   | Ne ix   | 11   | 9   | 13  |
| He ii   | 10   | 22  | 45  | Ne x    | 1    | 0   | 0   |
| He iii  | 1    | —   | —   | Mg ix   | 3    | 23  | 1   |
| C iv    | 5    | 11  | 6   | Mg x    | 2    | 3   | 1   |
| C v     | 29   | 21  | 60  | Mg xi   | 5    | 6   | 3   |
| C vi    | 15   | 21  | 26  | Mg xii  | 1    | 0   | 0   |
| C vii   | 1    | —   | —   | Si x    | 1    | 31  | 0   |
| N v     | 5    | 15  | 6   | Si xi   | 3    | 23  | 1   |
| N vi    | 17   | 7   | 33  | Si xii  | 5    | 4   | 6   |
| N vii   | 15   | 21  | 30  | Si xiii | 1    | 0   | 0   |
| N viii  | 1    | —   | —   | S xiv   | 9    | 21  | 10  |
| O vi    | 5    | 30  | 6   | S xvi   | 9    | 1   | 15  |
| O vii   | 19   | 7   | 32  | S xv    | 1    | 0   | 0   |
| O viii  | 15   | 30  | 30  | IG xiv  | 6    | 0   | 20  |
| O xiv   | 1    | —   | —   | IG xv   | 6    | 0   | 20  |

Notes. The notation is: $N =$ levels treated in NLTE, $L =$ LTE levels, and $R =$ radiative bound-bound transitions. For the generic IG model atom (which represents Ca, Sc, Ti, V, Cr, Mn, Fe, Co, and Ni), the number of individual lines which are combined into so-called superlines is given in parentheses.

3. SPECTRAL ANALYSIS

A first grid of models is composed of H+He+C+N+O with solar abundance ratios (Asplund et al. 2000) within $T_{\text{eff}} = 0.45–1.05$ MK and a fixed surface gravity of log $g = 9$ (Figure 3). We note that all synthetic energy distributions (SEDs) in our model grids described here are available in Virtual Observatory (VO) compliant form from the VO service TheoSSA\(^{11}\) provided by the German Astrophysical Virtual Observatory (GAVO\(^{12}\)) as well as tables\(^{13}\) for the use with XSPEC\(^{14}\).

\(^{11}\) http://vo.ari.uni-heidelberg.de/satr-0.01/TrSpectra.jsp?
\(^{12}\) http://www.g-vo.org
\(^{13}\) http://astro.uni-tuebingen.de/~rauch/TMAF/TMAF.html
\(^{14}\) http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec

We started with the XMM-Newton RGS spectra of 2003 April (Table 2). The data were reduced with the ESA XMM-Newton Science Analysis System\(^{15}\) (SAS) software, version 5.3.3, using the latest calibration files available. The RGS dispersion gratings cover the 5–35 Å wavelength range (2.48–0.35 keV), although we obtained useful signal only in the 5–26 Å range (2.48–0.48 keV). The RGS data are piled up, but in a dispersion instrument, piled-up events at a discrete wavelength increase in pulse height amplitude by an integer multiple of the intrinsic energy. Furthermore, since the softness of the source precludes any intrinsic photons from higher spectral orders, we can confidently identify events that occur within the higher order spectral masks for an on-axis point source as piled-up first-order photons. This is verified by line matching of the piled-up events using the first-order response matrix. Source events dominate over background and scattered source light in the first three orders. Consequently, we added events within the second- and third-order extraction masks to the first-order events, thus reclaiming the piled-up events and increasing the S/N of the spectra.

In a first step, we compared our SEDs with the XMM-Newton observation of V4743 Sgr via XSPEC. We let the neutral hydrogen column density $N_{\text{H}}$ (cm$^{-2}$) and $T_{\text{eff}}$ vary as free parameters in XSPEC. XSPEC determines $T_{\text{eff}} = 709$ kK and log $N_{\text{H}} = 20.58$. In Figure 4 (top panel), we show this XSPEC fit. The reader may miss the typical XSPEC residuals at the bottom of the plots. Since our models do not include all the elements with all the lines that may be exhibited in the observation, the residuals are not that helpful as in comparisons of simple models where continuum slope and a handful of

\(^{15}\) http://xmm.esa.int/sas/
We achieved a much better fit at [C] = −2.0, \( T_{\text{eff}} = 610 \text{ kK} \), and \( \log N_{\text{H}} = 20.54 \) for \( \lambda < 26 \text{ Å} \) (Figure 4).

We wondered whether the small wavelength interval (18–38 Å) of our XMM-Newton RGS spectra leads in the XSPEC fit procedure to a smaller \( N_{\text{H}} \), than found by Petz et al. (2005, \( \log N_{\text{H}} = 21.60, T_{\text{eff}} = 580 \text{ kK} \)) obtained fitting the Chandra LETG spectrum (18–58 Å). In Section 4, we show however that we fitted the Chandra LETG spectrum of 2003 March 19 and used the same wavelength range as Petz et al. (2005), deriving \( T_{\text{eff}} = 601 \text{ kK and } \log N_{\text{H}} = 20.95 \) for the [C] = −2.0 model. A decreasing \( N_{\text{H}} \) from March to April is consistent with intrinsic absorption of the ejecta clearing up.

### 3.2. Spectral Analysis of the Flux-calibrated Spectrum

Before we start a detailed analysis, we will mention that the calibration of the instruments that were used to obtain our data is still an issue. Different calibration products (response matrices and effective areas) may play an important role in the results obtained from fits to X-ray spectra. Cross calibration between instruments has improved over the years (see, e.g., Beuermann et al. 2006, 2008) but there is room yet for further improvement.

While the wavelength scale of X-ray grating instruments is generally very well known, the effective areas of these instruments are less well calibrated. For example, a comparison between the continuum calibrations of the gratings and CCD instruments are less well calibrated. For example, a comparison between the gratings and CCD instruments on board XMM-Newton by Stuhlinger et al. (2008) shows deviations between the RGS and the EPIC-pn of 3% above 0.5 keV and about 10% below that energy. While not negligible, these deviations are still smaller than the deviations between data and model caused by simplifications in the atmosphere modeling, and can therefore be ignored.

The preliminary analysis presented in the last section shows clearly that the carbon abundance in V4743 Sgr is strongly sub-solar. The determination of \( T_{\text{eff}} \) and a more precise abundance determination is hampered by the complex XSPEC fitting procedure and the necessity to calculate extended grids of models with different \( T_{\text{eff}} \) if the abundances are changed. The latter results in unreasonable computational times.

A more straightforward approach is to use the flux-calibrated spectra instead of count-rate spectra. However, these spectra contain uncertainties in the flux. We tried to calibrate the RGS spectra of V4743 Sgr in two different ways. One way is by making use of the provided XMM-SAS pipeline products, the so-called “fluxed” spectra. Such spectra are, e.g., shown by BiRD,\(^{16}\) the Browsing Interface for RGS Data, with the purpose of visualizing the data free from the peculiarities of the instrument. However, RGS fluxed spectra are computed in the pipeline by dividing the extracted spectrum by the effective area calculated from its corresponding response matrix. This procedure neglects

\(^{16}\) http://xmm.esac.esa.int/BiRD/
the redistribution of monochromatic response into the dispersion channels, and therefore these spectra should not be used for very detailed analysis. The second version of the flux-calibrated spectrum is calculated by XSPEC and is not independent from the models which are used within the XSPEC fit procedure (Figure 5).

We are aware of these uncertainties, but with the aim of determining $T_{\text{eff}}$ within an error range of about 10% and element abundances within 0.5 dex, we used the flux-calibrated spectra. We calculated synthetic profiles of the resonance lines of the two highest ionization stages of C, N, and O (Figure 6). These appear to be strongly dependent on $T_{\text{eff}}$ within the parameter range of our grids.

The best XSPEC fit of the [C] = −2.0 model yields $T_{\text{eff}} = 610$ K. Since the maximum flux level is not well reproduced by this fit (Figure 4), we estimate that $T_{\text{eff}}$ of V4743 Sgr may be slightly higher. Thus, we selected models with $T_{\text{eff}} = 600–800$ K and model A abundances (Table 3) for a comparison with the RGS fluxed spectrum (Figure 7). The flux level below $\lambda \lesssim 30$ Å is strongly dependent on $T_{\text{eff}}$ and at first glance, we can achieve good agreement with the RGS flux level at $T_{\text{eff}} = 700$ K and $\log N_{\text{HI}} = 20.90$. Moreover, the prominent absorption lines N v λ 28.79, 24.90, 23.77, N vi λ 24.78, 20.91, 19.82, 19.32, and O vii λ 21.60 are well reproduced by our model. A detailed inspection of the O viii λ 18.96 resonance line shows that the observed continuum flux on its high-energy wing is much lower than in the synthetic spectrum. A stronger N vii bound-free ground-state absorption edge (18.59 Å) could probably decrease this flux. Consequently, we increased the nitrogen abundance in the following models.

In Figure 7, the $T_{\text{eff}}$ dependency of the strengths of prominent bound-free absorption edges (for an identification, see Figure 9) is shown. Especially, the N v i and N vii ground-state edges at 22.46 Å and 18.59 Å, respectively, appear very sensitive on $T_{\text{eff}}$. In order to improve the fit, we performed some fine-tuning of the abundances (cf. Table 3, model B). For example, in the case of sulfur, model A (Table 3) yields a much too strong S xiv line at 32.51 Å, i.e., the sulfur abundance is too high in the relevant $T_{\text{eff}}$ range. In the case of nitrogen, we find prominent absorption edges as well as absorption lines in the observation which are suitable to adjust the abundance. In the case of other species, it is difficult to determine their abundances precisely.

### Table 3

| Element | Model A | Model B |
|---------|---------|---------|
| H       | −0.573  | −0.688  |
| He      | 0.497   | 0.382   |
| C       | −2.614  | −1.513  |
| N       | 0.386   | 1.803   |
| O       | 0.425   | 1.528   |
| Ne      | −0.333  | −0.474  |
| Mg      | 0.000   | −0.454  |
| Si      | 0.000   | 0.167   |
| S       | 0.000   | −1.583  |
| IG      | 0.000   | 0.828   |

Notes. Solar abundances are taken from Asplund et al. (2009). We note that in model B the abundances for Ne, Mg, S, and IG (Ca–Ni) are determined upper limits. An error range of ±0.3 dex is estimated from detailed comparison with the observations.

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**Figure 5.** Comparison of the RGS fluxed spectrum of V4743 Sgr obtained from the XMM-Newton pipeline (thick line) with the absolute flux calculated by XSPEC (thin line, see the text for details). The XSPEC spectrum is convolved with a Gaussian of 0.10 Å (FWHM) in order to match the resolution of the binned RGS fluxed spectrum. Note that both spectra agree well for $\lambda \lesssim 32$ Å. The marks indicate positions of lines that are included in our models.

(A color version of this figure is available in the online journal.)

**Figure 6.** Synthetic profiles of the O vii, O viii, N v i, N vii, C v, and C v i resonance lines, calculated from H+He+C+N+O model atmospheres with $T_{\text{eff}} = 0.4$–1.0 MK, $\log g = 9$, and solar abundances. The nitrogen lines of the cooler models that appear in emission are shifted for clarity.

(A color version of this figure is available in the online journal.)
Figure 7. Top: SEDs of our model with $[\text{C}] = -2.0$ and $T_{\text{eff}} = 600$–800 kK. They are normalized to the $T_{\text{eff}} = 700$ kK flux level at 38 Å for this comparison. The positions of lines are marked. Bottom: comparison of the synthetic spectra of our $[\text{C}] = -2.0$, $T_{\text{eff}} = 700$ kK model with the RGS fluxed spectrum of V4743 Sgr.

(A color version of this figure is available in the online journal.)

Figure 8. Comparisons of the SED of our $T_{\text{eff}} = 750$ kK model B (thin line, Table 3) to SEDs of models where the abundance of one element (indicated by labels) is increased by a factor of 10. The positions of ground-state absorption edges are marked at the top.

(A color version of this figure is available in the online journal.)

Figure 9. Dependence of the strengths of the N vi and N vii ground-state thresholds (positions marked by the arrows) on $T_{\text{eff}}$. The SEDs are compared with the RGS fluxed spectrum of V4743 Sgr and normalized to match the flux at 38 Å. The SEDs were convolved with a Gaussian of 0.10 Å (FWHM). Positions of ground-state thresholds are marked at the top, of those line transitions just below those marks.

(A color version of this figure is available in the online journal.)

because they do not exhibit significant features in the XMM-Newton observation. However, this can be used to determine at least upper abundance limits. Figure 8 demonstrates how the SEDs change if the abundance of one particular element is artificially increased by a factor of 10. We note that only nitrogen, oxygen, silicon, and the IG elements have an influence on the flux in the RGS wavelength range if their abundances are increased.

We compared the strengths of the N vi and N vii edges in our models with the observation (Figure 9). With these models (Table 3, model B), we achieve the best fit at $T_{\text{eff}} = 740$ kK and $\log N_{\text{H}} = -20.85$.

In Figure 10, we show a comparison of TMAP SEDs with the flux-calibrated Chandra spectra from 2003. In 2004, the measured flux level and thus $T_{\text{eff}}$ are much lower and we disregard that observation here. Furthermore, for reasons of simplicity, we used a $T_{\text{eff}} = 720$ kK model with model B abundances (Table 3) and varied only the C and N abundances in order to improve the fit. The observed strengths of the N vi and N vii resonance lines as well as their ground-state edges are well reproduced for all observations. Since the N vi/N vii ionization balance is very sensitive to $T_{\text{eff}}$ (Figure 6), $T_{\text{eff}} = 720$ kK appears a good estimate. Our model fits show that the N abundance is
show that V4743 Sgr was at a maximum of $T_{\text{eff}}$.

The C lines, e.g., at about 34 Å are well matched in September, decreasing from March to September by a factor of about 10. The C lines, e.g., at about 34 Å are well matched in September, while they appear too weak in March and July. A higher C abundance would result in the appearance of a strong C\textit{vi} ground-state absorption edge at 25.3 Å that is not visible in the observation.

In a last step, we used the SEDs of our model A and model B grids (Table 3) for a comparison with the \textit{XMM-Newton} observation with \textit{XSPEC} (Figure 11). The differences in the SEDs of the best-fitting models A and B are small. If we assume the mean $T_{\text{eff}}$, we are able to constrain the $T_{\text{eff}}$ range of V4743 Sgr to $T_{\text{eff}} = 740 \pm 70$ K. The deviations of the abundance of both models (Table 3) show the difficulty of a precise abundance determination if only a few spectral lines are available for the analysis.

4. THE SPECTRAL EVOLUTION OF V4743 SGR

We then proceeded to fit the \textit{Chandra} LETG spectra at three different epochs using the same models. The LETG spectra were reduced using the CIAO software,\textsuperscript{17} version 4.1.1.

In the first 18 months after the outburst of V4743 Sgr, \textit{Chandra} LETG spectra were obtained roughly every three months (Table 2). These observations allow an investigation of the spectral evolution, e.g., on the change of its $T_{\text{eff}}$. In Figure 12, we compare the observations with SEDs of our grid (models B). No individual fine-tuning of the model abundances for the different spectra was performed. Although this might improve the fit, we estimate that the impact on the determined $T_{\text{eff}}$ is small.

The \textit{Chandra} observations (energy range 0.22–0.69 keV) show that V4743 Sgr was at a maximum of $T_{\text{eff}}$ ($\approx$700 K) for about one year, then $T_{\text{eff}}$ appears to decrease by about 10% in the following six months (Figure 12, left panel).

In order to judge the quality of our spectral analysis of the 2004 April \textit{XMM-Newton} observation that covers a smaller energy range (0.32–0.69 keV), we restricted the fit range of \textit{XSPEC} (Figure 12, right panel) for the \textit{Chandra} observations. With this restriction, the determined $T_{\text{eff}}$ is in general higher and the interstellar neutral hydrogen density is smaller, but the deviations are within our expected error range of about 10%.

5. RESULTS AND CONCLUSIONS

We have calculated NLTE model atmospheres including opacities of the elements H, He, C, N, O, Ne, Mg, Si, S, and Ca–Ni and fitted \textit{XMM-Newton} RGS spectra and \textit{Chandra} LETG spectra of V4743 Sgr.

The fit to the RGS spectra (Table 2) based on these models (Table 3) is best at a $T_{\text{eff}}$ of about 740 ± 70 K, log $g = 9$, and log $N_H = 20.7 \pm 0.3$. Although this fit is not perfect and there are uncertainties in the so-called RGS fluxed spectrum used for our spectral analysis, the overall flux distribution as well as prominent line features are well in agreement with the observation (Figure 11). The photospheric abundances have been adjusted and we can give at least upper limits for N, O, Si, and Ca–Ni (Figure 8). The determined C/N ratio is very low (Table 3), indicating that the material on the WD surface has been processed through thermonuclear burning. We expect that freshly accreted material after the outburst or dredged-up material from the WD interior would have a very different range of abundances and suggest this is proof that the WD is retaining some accreted material after each outburst. This may imply that V4743 Sgr is on a track toward supernova Ia explosion, although it retains after each outburst only just enough material to burn in less than 2.5 years.

\textsuperscript{17}http://cxc.harvard.edu/ciao/
The fit to the *Chandra* LETG grating spectra shows that V4743 Sgr reached its highest temperature around 2003 April and remained at that temperature at least until 2003 September. The duration of the constant bolometric luminosity phase at constant $T_{\text{eff}}$ was between 2 and 2.5 years, probably the average for a classical nova (e.g., Orio et al. 2001). In Shara et al. (1979), $T_{\text{eff}}$ of the constant bolometric luminosity phase is 780,000 K for a 1.25 $M_\odot$ WD. $T_{\text{eff}}$ of the calculations is not always published in papers on nova-outburst models (cf. Kovetz & Prialnik 1994; Prialnik & Kovetz 1995), but published values range from 460,000 K for a 0.8 $M_\odot$ (Shara et al. 1979) to an extreme 2,500,000 K for a 1.4 $M_\odot$ WD accreting at a very high rate. The value of $T_{\text{eff}}$ is dependent on mass accretion rate, the chemical composition, and the WD temperature at the onset of hydrogen burning, but generally a value of about 700,000 K is only reached for $M > 1.1 M_\odot$ (D. Prialnik 2009, private communication). To summarize, the peak $T_{\text{eff}}$ of about 740 K indicates that the WD is very massive, with $\approx 1.1–1.2 M_\odot$.

To explain the apparently decreased nitrogen abundance in the months after the outburst (Figure 10), we conjecture that new material is probably already being accreted at this stage, while CNO burning at the bottom of the envelope is already proceeding at a lower rate before turnoff.

A crucial point for the understanding of processes during the nova outburst may be the time-dependent prediction of surface abundances as well as the spectral analysis of high-resolution X-ray spectra taken from outburst to the end of surface H burning. The inspection of available *Chandra* and *XMM-Newton* observations can provide valuable insights into the dynamics and evolution of these events.

**Figure 12.** Comparison of *Chandra* and *XMM-Newton* observations of V4743 Sgr (Table 2) with our SEDs from model grid B (Table 3). $N_{\text{H}}$ and $T_{\text{eff}}$ were determined with XSPEC. The fit range was restricted to 18–56 Å (0.22–0.69 keV, left panel) and 18–38 Å (0.32–0.69 keV, right panel) to represent the *Chandra* and *XMM-Newton* wavelength ranges, respectively.

(A color version of this figure is available in the online journal.)
observations of V4743 Sgr, taken in the 18 months after the outburst, has shown that obtaining new X-ray grating spectra of future novae every week is highly desirable.

In applications to novae, TMAP still lacks some physics, most notably the velocity fields. Although TMAP is not especially designed for the calculation of SEDs at extreme photospheric parameters, it is a flexible and robust tool for the determination of basic parameters like $T_{\text{eff}}$ for line identifications (cf. Rauch et al. 2008), and to derive a reliable range of abundances in the WD atmosphere.

T.R. is supported by the German Aerospace Center (DLR) under grant 05 OR 0806. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France. M.O. is supported by Chandra-Smithsonian and XMM-Newton NASA grants for the data analysis. This research has made use of software provided by the Chandra X-ray Center (CXC) in the application packages CIAO, ChIPS, and Sherpa.

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