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SUZAKU OBSERVATION OF THE CLASSICAL NOVA V2491 CYG IN QUIESCENCE.

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ABSTRACT

We present *Suzaku* XIS observation of V2491 Cyg (Nova Cyg 2008 No. 2) obtained in quiescence, more than two years after the outburst. The nova was detected as a very luminous source in a wide spectral range from soft to hard X-rays. A very soft blackbody-like component peaking at 0.5 keV indicates that either we observe remaining, localized hydrogen burning on the surface of the white dwarf, or accretion onto a magnetized polar cap. In the second case, V2491 Cyg is a candidate "soft intermediate polar". We obtained the best fit for the X-ray spectra with several components: two of thermal plasma, a blackbody and a complex absorber. The later is typical of intermediate polars. The X-ray light-curve shows a modulation with a ∼38 min period. The amplitude of this modulation is strongly energy dependent and reaches maximum in the 0.8–2.0 keV range. We discuss the origin of the X-ray emission and pulsations, and the likelihood of the intermediate polar scenario.

Subject headings: cataclysmic variables: general — nova: individual (V2491 Cyg)

1. INTRODUCTION

Cataclysmic variables are close binary systems consisting of a white dwarf (WD) primary and a low-mass late type main sequence star transferring material via Roche-lobe overflow. If enough material is accumulated, the temperature and the pressure at the bottom of the accreted envelope can be high enough for a termonuclear runaway and a classical nova (CN) explosion (see e.g. Starrfield et al. 2012; Wolf et al. 2013). When the ejected envelope becomes transparent to soft X-rays the system is observed as a super-soft X-ray source (SSS) revealing the hot WD atmosphere and nuclear burning (e.g. Orio et al. 2001; Krautter 2008; Orio 2012).

V2491 Cyg was detected by Hiroshi Kaneda on 2008 April 10.728 at V=7.7 (Nakano et al. 2008). The nova was very fast: t_2 (time needed to decrease in luminosity by 2 mag) in the V band was 4.6 days and the ejecta velocity reached 4860 km s^{-1} (Tomov et al. 2008a,b). The nova had a short unusual "re-brightening" at the end of April, then reached the minimum brightness – V ∼16 after about 150 days. The interstellar reddening was E(B-V) = 0.43 (Rudy et al. 2008) corresponding to a hydrogen column N(H)=2.5×10^{21} cm^{-2} (Bohlin et al. 1978).

Jurdana-Sepic & Munari (2008) discovered a persistent optical counterpart at V≃17.1, which had a short dimming before the nova outburst. No previous outburst was known, but several authors suggested that an early transition of the optical spectrum to the He/N type (Tomov et al. 2008a), the velocity of the ejecta, and the rapid visual decay were all typical of the recurrent novae (RNe). However, this hypothesis has not been proven.

V2491 Cyg is the second out of three examples of CNe detected in X-rays before the outbursts (see Hernanz & Sala 2002 for V2487 Oph and Schmeer & Gualdoni 2008 for Nova 2008 Car). Pre-nova X-ray observations of V2491 Cyg obtained with *ROSAT*, *XMM-Newton*, and *Swift* were discussed in Ibarra et al. (2009). These authors found that the quiescence X-ray spectrum was variable on a time scale as short as 4 days and that one of the analysed *Swift* spectra was noticeably softer than at other epochs. The unabsorbed X-ray flux varied in the range from 1 to 30×10^{-12} ergs cm^{-2} s^{-1} (Ibarra et al. 2009), corresponding to $L_X = 1.2 - 4\times10^{35}$ erg s^{-1}, assuming a distance of 10.5 kpc (Helton et al. 2008). These values of the X-ray luminosity before the outbursts imply that the mass accretion rate can be as high as $\sim10^{-8}$ $M_\odot$ yr^{-1} for a 1.3 $M_\odot$ WD (Hachisu & Kato 2009), close indeed to the expected RN range, with recurrence times ∼100 years (Wolf et al. 2013).

During the outburst V2491 Cyg was observed with *XMM-Newton* (Ness et al. 2011; Takei et al. 2011), *Suzaku* (Takei et al. 2011) and extensively monitored with *Swift* (Kuulkers et al. 2008; Osborne et al. 2008; Page et al. 2010). Page et al. (2010) followed V2491 Cyg with *Swift*, from the day after the nova discovery until the pre-outburst flux level. The spectrum was quite hard before day 25 after the explosion and shortly thereafter the object evolved into a SSS. The peak soft X-ray lu-

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minosity remained constant for only two days and than faded slowly for 18 days, an unsual trend for post-nova SSS, most of which show an almost flat light curve after the peak and later fade rapidly. The WD in V2491 Cyg was among the hottest ever observed (Ness et al. 2011), therefore it must be very massive (Starrfield et al. 2012; Wolf et al. 2013). Quite surprisingly, the WD did not seem to cool before the SSS final decay, while the luminosity significantly decreased, as if the nuclear burning region was shrinking on the surface of the WD itself, at constant temperature (most nova SSS are observed to cool, see e.g. the review by Orio 2012).

Baklanov et al. (2008) reported a variation with a period of 0.09580(5) days in the B and V bands between 10 and 20 days after the outburst. This variation may have been the orbital modulation of the binary system. However, Shugarov et al. (2010) did not detect the above period, although they monitored V2491 Cyg in optical for more than one year. Also Darnley et al. (2011) ruled out eclipsing orbital periods shorter than 0.15 days. Page et al. (2010) observed V2491 Cyg during the decline to quiescence, but did not detect any modulation with a period ~ 0.1 days in X-rays and UV. While the 0.09580(5) days period has not been confirmed, another variability on a shorter timescale has been reported by several authors. Shugarov et al. (2010) detected a possible 0.02885 days (41 min) period. Darnley et al. (2011) found evidence of a $\sim$0.025 days (36 min) modulation in the B band, but, unfortunately, their data were too sparse for period analysis. Ness et al. (2011) reported oscillations of the X-ray flux with a period of 37.2 min on day 39 after the outburst, however this variability was not observed in simultaneous UV observations and in the X-ray light curve obtained later, on day 49 after the nova explosion.

Several authors discussed the possibility of a magnetic scenario for V2491 Cyg (see Hachisu & Kato 2009; Ibarra et al. 2009; Takei et al. 2011). Hachisu & Kato (2009) proposed that magnetic activity explains the rebrightening seen in the optical light curve, and that V2491 Cyg is a polar. However, Page et al. (2010) argued against this possibility. Using the synchronization condition they showed that if V2491 Cyg is a polar it should host one of most magnetic WDs known in binaries, assuming the WD mass about $1.3 M_{\odot}$ and 0.0958 days orbital period. Although V2491 Cyg has a number of properties that are quite typical of magnetic WDs, such as strong Fe emission features at 6.4, 6.7, and 7.0 keV, high X-ray luminosity in the range 2.0-10 keV (Takei et al. 2011), the existing data do not allow to finally prove or disprove the magnetic scenario.

The indications of large WD mass and high $\dot{m}$ suggest that this nova is a rather "extreme" accreting WD, with characteristics we expect in a type Ia supernova (SN) progenitor and possibly with a strong magnetic field. We observed this intriguing CN with the *Suzaku* X-ray Imaging Spectrometer (XIS) in quiescence in order to monitor wether if the WD is still hot and to shed some light on its possible magnetic nature.

2. OBSERVATIONS AND DATA ANALYSIS

V2491 Cyg was observed with the *Suzaku* XIS on 2010 November 3 with an exposure time of 74.4 ks (for details see Table 1). The data were processed and analysed using HEASOFT v.6-13. We read the event files with XSELECT v2.4b and generated the detector and mirror responses using *xisarfgen* and *xisrmfgen* tools. We combined the XIS 0 and XIS 3 data from the front-illuminated (FI) CCD chips using *addascaspec* and the XIS 1 data from the back-illuminated (BI) CCD were analysed separately. The spectral analysis was performed with XSPEC v.12.8.0. The X-ray light curves were extracted after the barycentric correction and processed with XRONOS package.

3. RESULTS

3.1. *Spectral analysis*

The background subtracted 0.3–10.0 keV spectra of V2491 Cyg are presented in Figure 1. The combined XIS 0 and the XIS 3 data are plotted in black, while the XIS 1 data are plotted in red. Solid lines show the best fit. The dashed lines represent the components of this model. The spectra seem to have a very soft component and a harder one with emission lines of highly ionized Fe, in particular the Fe XXV line at 6.7 keV that indicates a thermal plasma. In order to fit the harder portion of the spectra we started with one thermal plasma component. However neither one, nor two components of collisionally-ionized diffuse gas (*APEC* model in XSPEC, calculated using the ATOMDB code v2.0.2) did not provide a statistically significant fit of the spectra with any temperature. The multi-temperature plasma emission model based on the *MEKAL* code (*CEMEKL*) also does not provide a good fit. We tried to add a reflection component, taking into account the presence of the very strong Fe Kα reflection line, but it resulted in unphysical values of the fitting parameters. The reflection scaling factor (R$=\Omega/2\pi$), which is the covering fraction of the reflector viewed from the plasma, was close to 10. Such a value of R would imply that the source of the X-ray emission is hidden by a Compton-thick material and that we only see the reflected component, which is a rather unlikely possibility. Moreover, R$=10$ implies that the EW of the Fe Kα reflection line should be $\approx$1.5 keV (George & Fabian 1991), which is much larger than the EW inferred from the Gaussian fit of the line that we will show below.

The very flat slope in the 3.0–5.0 keV range points toward a complex absorption. The fit with the two-component thermal plasma model was much improved after multiplication with a partially covering absorber (*PCFABS* in XSPEC). We derived the following values of the column density and covering fraction of the partially covering absorber: N(H) $= 10$–17×10^{22} cm^{-2} and CvrFract $= 0.66$. Page et al. (2010) also used a partially covering absorber with almost the same value of N_H in their model to fit the spectra of V2491 Cyg obtained after day 80.

In order to fit the soft excess, seen in the XIS 1 data at 0.5 keV, we added a blackbody component that was absorbed only by the simple absorption. We will further discuss why the blackbody component is not effected by the partially covering absorber. By adding to this four components a Gaussian to represent the Fe Kα line at 6.4 keV, we finally obtained a statistically acceptable result with a value of χ^2 equal to 1.1. The abundance of the thermal plasma components is $0.63^{+0.27}_{-0.20}$ with respect to solar. The value of N(H) derived from our fit

TABLE 1
Observational log of the *Suzaku* observations of V2491 Cyg.

Date and time	Instrument	Exposure (s)	Count rate (cts s^{-1})
2010-11-03 10:32:11	*Suzaku* XIS 0	74400	0.0494 ± 0.0010
2010-11-03 10:32:11	*Suzaku* XIS 1	74400	0.0681 ± 0.0012
2010-11-03 10:32:11	*Suzaku* XIS 3	74400	0.0550 ± 0.0010

Notes. *Suzaku* XIS FI are XIS 0 and XIS 3 detectors with front-illuminated (FI) CCDs, while *Suzaku* XIS BI is the XIS 1 that utilizes a back-illuminated (BI) CCD

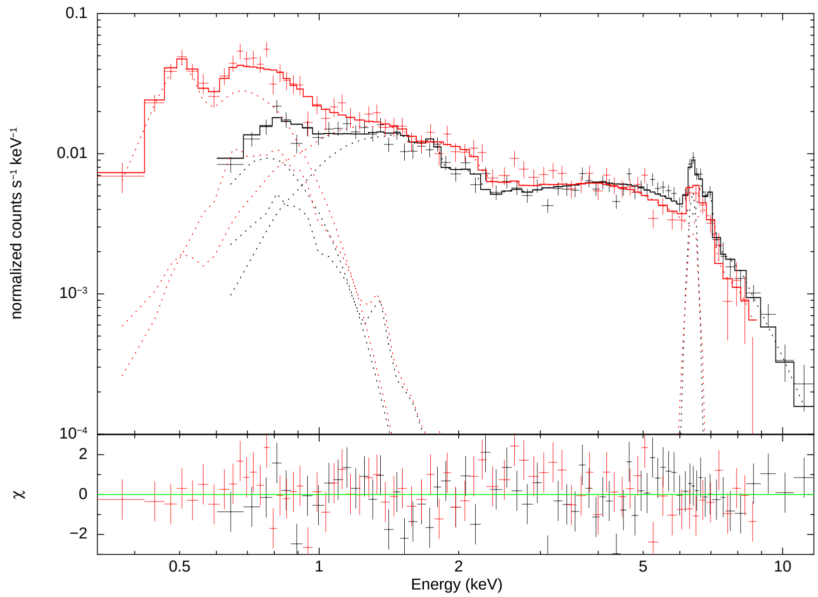

Fig. 1.— *Suzaku* XIS spectra of V2491 Cyg. The BI CCD data have been plotted in red and the FI data have been plotted in black. The solid lines represent the fit with wabs×(bb+pcfabs×(apec+apec+gauss)) model. The components of the model have been plotted with the dashed lines.

is in agreement with the pre-outburst values reported by Ibarra et al. (2009) and with the estimates based on the interstellar reddening. The components and parameters of the fit are presented in Table 2.

The origin of the blackbody-like component in the spectra of V2491 Cyg is not quite clear. Page et al. (2010) speculated about the possibility of long-lasting hydrogen burning on the surface of the WD in this system. Aiming at distinguishing the possible sources of the soft X-ray emission in V2491 Cyg we compared the blackbody model with a WD atmosphere model, since the latter better describes the hydrogen burning on a WD. We used in XSPEC the publicly available tabulated Tübingen Non Local Thermal Equilibrium Atmosphere Model (NLTE TMAP) for a WD atmosphere in spherical or plane-parallel geometry in hydrostatic and radiative equilibrium, described by Rauch & Deetjen (2003), with chemical composition of elements from H to Ni #007 and $\log g = 9$. The blackbody and the NLTE TMAP are statistically equal, – both give the value of $\chi^2 = 1.1$. The values of the temperature and luminosity, and hence the emitting area, derived from the blackbody and WD atmosphere model are comparable (see Tab. 2).

Finally we isolated the 5.0–9.0 keV region and for simplicity fitted it with a power-law continuum with $\Gamma = 2.0$ and three Gaussians representing the Kα fluorescent line of Fe I (corresponding to 2p $\rightarrow$ 1s electron transition), a Fe XXV resonance line and a Lyα line of Fe XXVI (see Figure 2). The N(H) and parameters of the partially covering absorber were fixed to the values of the best-fitting model in Table 2. First, we fixed the centroids of the lines to the rest values and the Gaussian widths to zero, since the natural widths of the lines and the broadening due to thermal motions of the emitting atoms are negligible compared with the instrumental resolution of the *Suzaku* XIS detectors, which is $\sim$130 eV at 6 keV. This fit does not provide a good result, leaving a residual excess between the 6.4 and 6.7 keV lines. This may be due to the complex structure of the Fe XXV feature: it consists of the resonance line, the forbidden line, and two intercombination lines. Moreover, there are dielectric satellite lines in the range of 6.61–6.68 keV (Hellier & Mukai 2004). Therefore, we varied the centroid position of Fe XXV feature and significantly improved the fit. The best fitting parameters for the Fe K complex and the EWs of the lines are presented in Table 3. The EW of the Fe Kα line in the *Suzaku* spectra is $\sim$246 eV, which is comparable with the value measured on day 60 and 150 after the outburst (Takei et al. 2011).

The flux ratio of the Fe XXVI and Fe XXV lines gives an estimate of the highest temperature in the post-shock region (Schlegel et al. 2014). From the fit of the Fe Kα complex of V2491 Cyg we found that this ratio is $\sim$0.7 (see Table 3), which corresponds to a ionization temperature of about 10 keV (Schlegel et al. 2014). This value is close to that derived from the global fit (see Table 2).

3.2. *Timing analysis*

For the timing analysis of V2491 Cyg we initially combined the FI and BI data in the 0.3–10 keV range and de-

TABLE 2
THE PARAMETERS OF THE BEST FITTING MODELS – WABS×(BB/"*atm*"+PCFABS×(APEC+APEC+GAUSS)) FOR V2491 CYG X-RAY SPECTRA, WHERE "*atm*" IS THE WD ATMOSPHERE MODEL.

Parameter	+Blackbody	+Atmosphere
N(H)[1]	$0.25^{+0.08}_{-0.06}$	$0.19^{+0.09}_{-0.07}$
$N(H)_{pc}$[2]	$13.3^{+3}_{-2.4}$	$10.8^{+2.5}_{-2.0}$
CvrFract[3]	$0.66^{+0.03}_{-0.03}$	$0.63^{+0.03}_{-0.03}$
$T_{bb/atm}$ (eV)	77^{+7}_{-9}	$85.9^{+2.2}_{-1.5}$
T_1 (keV)	$0.24^{+0.24}_{-0.24}$	$0.29^{+0.05}_{-0.03}$
T_2 (keV)	$11.3^{+1.8}_{-1.5}$	$15.0^{+4.3}_{-2.4}$
$Norm_1$[4]	5^{+8}_{-5}	$6.9^{+4.6}_{-2.8}$
$Norm_2$[4]	$14.6^{+1.1}_{-1.0}$	$14.1^{+1.1}_{-1.0}$
$Flux_{abs}$[5]	$1.92^{+0.03}_{-0.23}$	$1.93^{+0.11}_{-0.6}$
$Flux_{unabs}$[5]	6.66	3.95
$Flux^{bb/atm}_{abs}$[6]	0.346	0.284
$Flux^{bb/atm}_{unabs}$[6]	7.80	2.66
χ^2	1.1	1.1
$L_{2.0-10.0keV}$[7]	1.82	1.82
$L_{bb/atm}$[8]	$1.4^{+2.4}_{-0.7}$	$1.72^{+2.9}_{-0.9}$
$R_{bb/atm}$ cm[9]	$1.2^{+1.0}_{-0.4}$	$1.4^{+0.9}_{-0.5}$

Notes. The errors represent the 90% confidence region for a single parameter.
[1] $\times 10^{22}$ cm^{-2}
[2] $\times 10^{22}$ cm^{-2}, N(H) of the partial covering absorber.
[3] Covering fraction of the partial covering absorber.
[4] Normalization constants of the apec model ($\times 10^{-4}$ cm^{-5}).
[5] The X-ray flux ($\times 10^{-12}$ erg cm^{-2} s^{-1}) measured in the range 0.3–10.0 keV. $Flux_{unabs}$ represents the value of the X-ray flux, corrected for the interstellar absorption only.
[6] The X-ray flux ($\times 10^{-12}$erg cm^{-2} s^{-1}) of the blackbody and WD atmosphere components measured in the range 0.2–10.0 keV.
[7] The X-ray luminosity ($\times 10^{34}$ erg s^{-1} $D^2_{10.5kpc}$). We assumed D=10.5 kpc (Helton et al. 2008).
[8] The bolometric X-ray luminosity ($\times 10^{35}$ erg s^{-1} $D^2_{10.5kpc}$) of the blackbody and atmospheric components. $L_{bb/atm}$ were calculated based on the normalization constants of the models. The atmospheric model gives the value of the WD radius $R_{WD} = 10^{-11} \times \sqrt{norm} \times D$, which can be translated to the L_{atm} using the Stefan-Boltzmann law.
[9] The radius of the emitting region ($\times 10^7$ cm $D_{10.5kpc}$)

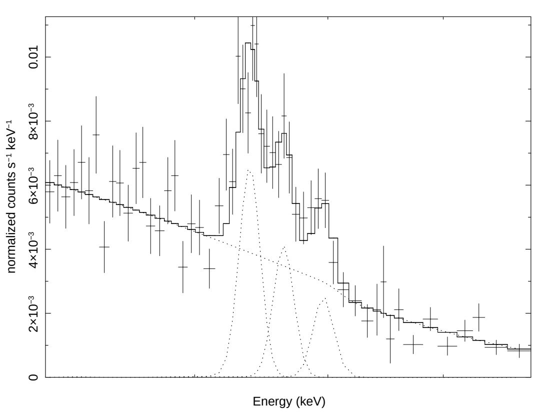

FIG. 2.— The *Suzaku* XIS spectra of V2491 Cyg in the 5.0–9.0 keV range showing the Fe K complex. The three Gaussians represent the Fe I, Fe XXV and Fe XXVI lines.

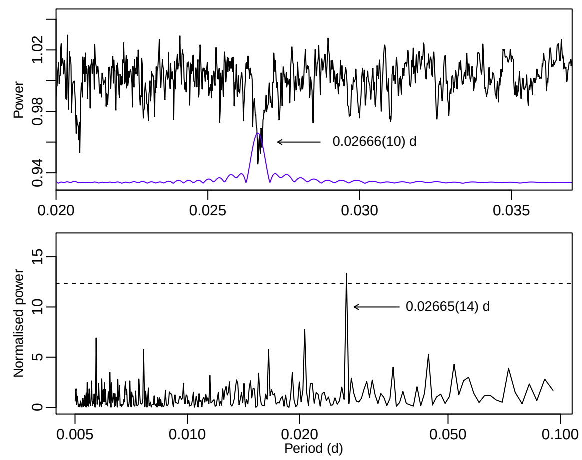

FIG. 3.— Periodogram of the *Suzaku* light curve of V2491 Cyg. We analysed the BI data in the 0.3–10.0 keV energy range binned every 80 seconds. The upper power spectrum was obtained with the PDM method and the bottom plot with the LS method. The highest peaks are marked with the arrows together with the corresponding values of the periods. The false alarm probability of 0.3% level is marked with the dashed line in the bottom plot.

trended the light curves with an three-order polynomial. We searched periodic variations using both the phase dispersion minimisation (PDM) method, introduced by Stellingwerf (1978) and the Lomb-Scargle (LS) method (Scargle 1982). We found a peak at 0.02666(10) days with the PDM and at 0.02665(14) days with the LS method (see Figure 3). We did not detect any reliable periodic signal close to the proposed orbital period of 0.09580(5) days (Baklanov et al. 2008). A false alarm probability level of 0.3% is marked with the horizontal line in the LS periodogram. The peak that corresponds to the 0.0266 days period lies above this line and can be considered statistically significant at the 3σ (99.7%) level. In order to further investigate the significance of the highest peak, we applied the bootstrap method. We repeatedly scrambled the data sequence and calculated the probability that random peaks in the 0.005–0.1 days range reach or exceed the peak of the unscrambled periodogram. We performed 10000 simulations and found that the probability that the peak is real is 99.7%.

The next step was to study the energy dependence of the pulses. We extracted the light curves from the FI and BI data independently in the following energy ranges: 0.3–0.8 keV, 0.8–3.0 keV, 3.0–5.0 keV and 5.0–10.0 keV. The comparison of the light-curves in different ranges is presented in Figure 4. We noticed that the amplitude of the variations in the BI light curve is larger than in the FI data. In the 0.3–0.8 keV BI light curve a flare-like event can be seen, that is almost absent in the FI data in the same energy range because of the low sensitivity of the FI CCD in the soft X-rays. We verified that this flare was not a background event. We convolved the BI light curves in different energy ranges with the same period 0.0266 days (38.3 min) and found that the amplitude of the modulation decreases with energy. The modulation is present only in the range below 3 keV.

We also calculated the hardness ratios $HR^i = N^i{}_m/N^i{}_n$, where i is a phase interval and $N^i{}_m$, $N^i{}_n$ are the number of photons in the energy ranges m and n, respectively. It can be seen from Figure 5 that $HR^i =$

TABLE 3
THE BEST-FIT PARAMETER VALUES FOR THE FE K LINES FITTING.

Parameter	Fe I	Fe XXV	Fe XXVI
Energy center (keV)	6.40 (frozen)	$6.65^{+0.03}_{-0.03}$	6.97 (frozen)
EW (eV)*	246^{+53}_{-50}	133^{+48}_{-34}	132^{+56}_{-45}
$\mathrm{Flux_{unabs}}$**	7.20	4.95	3.49

Notes. χ^2 is 0.98. All the parameters were derived at 90% confidence level.
* Equivalents width.
** The X-ray flux ($\times10^{-14}$ erg cm^{-2} s^{-1}).

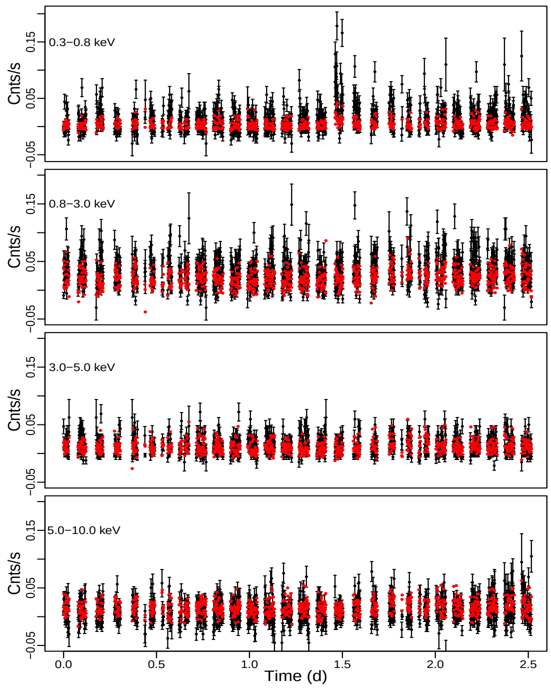

FIG. 4.— The X-ray light curve of V2491 Cyg binned every 80 seconds. The BI data are plotted in black and FI data - in red.

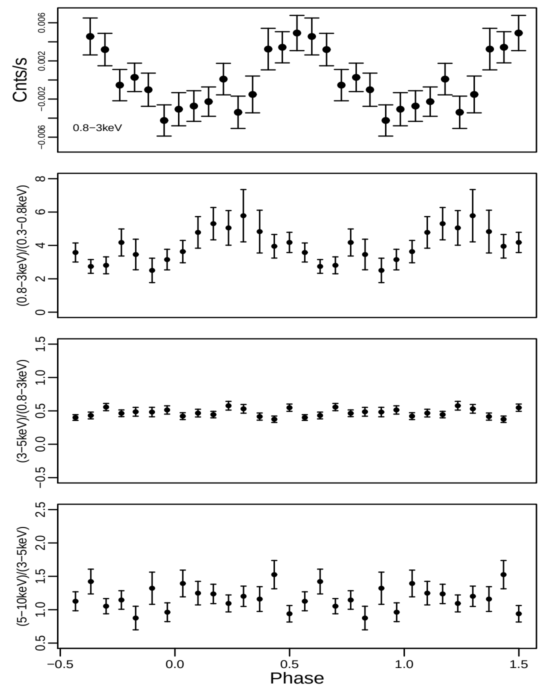

FIG. 5.— Top panel: the *Suzaku* FI+BI light curve in the range 0.8–3 keV binned every 80 s and folded with the period of 0.0266 days. Lower panels: variations of the hardness ratios ($\mathrm{HR}^i = \mathrm{N}^i{}_m/\mathrm{N}^i{}_n$) in different energy ranges (m and n) during the 0.0266 days period.

$\mathrm{N}^i{}_{0.8-3}/\mathrm{N}^i{}_{0.3-0.8}$ showed hardening at pulse minimum while $\mathrm{HR}^i = \mathrm{N}^i{}_{3-5}/\mathrm{N}^i{}_{0.8-3}$ and $\mathrm{HR}^i = \mathrm{N}^i{}_{5-10}/\mathrm{N}^i{}_{3-5}$ were constant within the errors.

In order to localize the pulsating component we subdivided the 0.3–3.0 keV energy range in three spectral intervals: 0.3–0.6 keV, 0.6–1.0 keV, 1.0–2.0 keV and 2.0–3.0 keV. The energy intervals were chosen based on the spectral fit. We expected the 0.3–0.6 keV range to be dominated by the blackbody, the 1.0–2.0 and 2.0–3.0 keV intervals to represent mostly the high temperature thermal plasma emission, and the 0.6–1.0 keV range to include emission from the blackbody and two thermal plasma components at the same time. The result can be seen in Figure 6. The periodic variation is observed between the 0.6–2.0 keV , but it is almost negligible in the harder ranges. The pulse profiles are roughly phase aligned. There is a slight shift between the maxima of the profiles that is within the errors. In the 0.3–0.6 keV energy range the variations have the same amplitude, but are irregular.

In order to asses the stability of this period we split the *Suzaku* light curve in two intervals and searched the period in each of them. In Fig. 7 the periodogram (left panels) and the phase folded light curves (right panels) of the first and the second parts of the dataset are plotted together. The light curves were folded with the same period of 0.0266 days in order to compare the pulse profiles. We found that the ∼38 min period does not seem to be stable: the best-fit periods measured in the first and the second halves of the observation are different by 1.4%.

The energy dependence of the amplitude and the hardening at minimum suggest that absorption causes the observed 38.3 min modulation in the X-ray flux. The absence of clear modulation in the 0.3–0.6 keV range (where the blackbody emission dominates) indicates that the blackbody-like component is not affected by the partially covering absorber. This is the reason why we only applied the interstellar absorption to the blackbody component. Evans & Hellier (2007) discussed the geometry which allows to observe a blackbody-like component in a soft IP even when the accretion curtain crosses the line of sight.

4. DISCUSSION

4.1. *The blackbody-like component*

Using the *fakeit* tool in XSPEC, we found that the count rate obtained with *Suzaku* corresponds to a 0.039 cnts s^{-1} *Swift* count rate, which is comparable with the last *Swift* observations presented in Page et al. (2010),

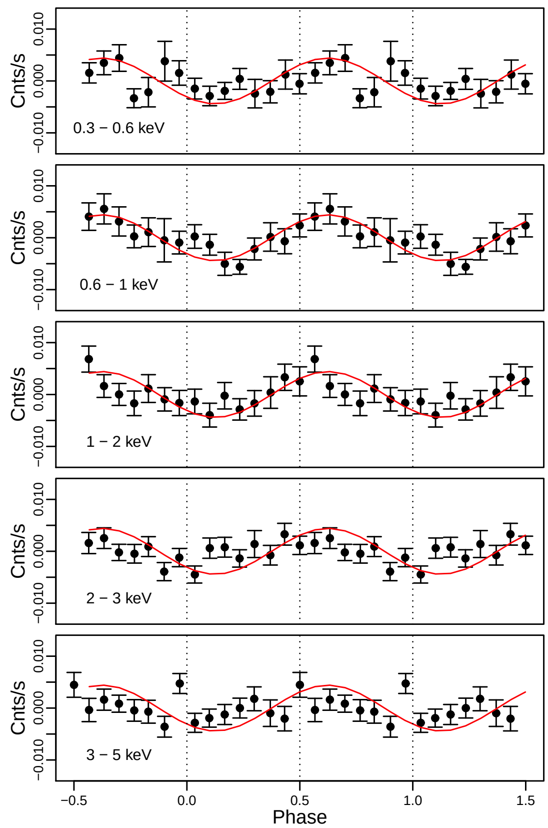

FIG. 6.— The *Suzaku* BI light curves of V2491 Cyg in different energy ranges folded with the period of 0.0266 days. The corresponding energy range is indicated in the bottom-left corner of each plot.

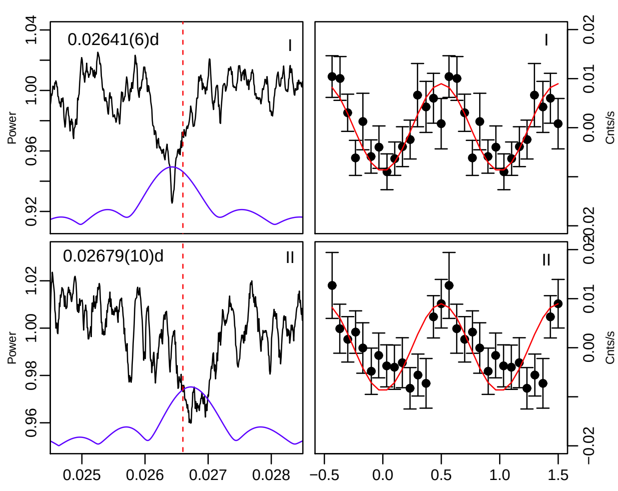

FIG. 7.— Left panels: power spectra of the first (top) and the second (bottom) halves of the *Suzaku* XIS BI observation of V2491 Cyg obtained with the PDM method. The red dashed line represent the mean period – 0.0266 days (38.3 min). Periods measured in each half are marked. Right panels: the first (top) and the second (bottom) halves of the *Suzaku* XIS BI light curve folded with the 0.0266 days period (38.3 min). We analysed the light curve extracted in the 0.8–3.0 keV energy range and binned every 80 s.

almost 250 days after the outbursts. Page et al. (2010) obtained the best fit of the X-ray spectra of V2491 Cyg with an optically thin hard X-ray plasma and added a blackbody for the SSS phase. These authors also showed that the temperature of the blackbody initially increased and then stabilised around day 57 at the value ~ 70 eV. Further decrease of the X-ray flux in the soft X-ray range seemed to result of a shrinking of the emitting region. The emitting region continued to shrink even after it reached the size of the WD, instead of becoming cooler at a constant radius like in many other novae (see Rauch et al. 2010, for V4743 Sgr).

In our data we found that the blackbody-like component is still present and has a temperature 77^{+7}_{-9} eV. The normalization constant of the blackbody model gives a luminosity 1.4×10^{35} $D^2_{10.5kpc}$ erg s^{-1} and an emitting radius 1.2×10^{7} $D_{10.5kpc}$ cm. A close emitting radius value was found in the fit with the stellar atmosphere model with a slightly higher temperature. Such a radius of the emitting region is too large for a polar cap on a magnetic WD, but is still more than an order of magnitude smaller than a WD radius. The fit with the WD atmosphere model is statistically indistinguishable from the one with a blackbody and does not allow to choose between the localized hydrogen burning and the polar cap as a possible source of the soft X-ray radiation.

The constant-temperature at decreasing radius, well below the WD radius dimensions, derived by Page et al. (2010) was not observed in other novae and contradicts the models. We are intrigued by the possibility that we still observe the same blackbody component after more than two years. Could it be due to residual nuclear burning, possibly continuing in this post-outburst quiescent phase in a smaller region than the whole WD? Orio & Shaviv (1993) predicted the possibility of localized thermonuclear burning on a WD. Other authors have argued that the burning would not remain localized and eventually the thermonuclear flash would propagate over the whole WD surface, (e.g. Glasner et al. 2012), very differently for instance from helium burning on a neutron star.

On the other hand, a distinct blackbody component with temperature in the range 20–100 eV, heavily absorbed by dense material partially covering the X-ray source, is observed in many IPs (Evans & Hellier 2007; Anzolin et al. 2008; Bernardini et al. 2012, and references therein). These objects form a growing group of so-called "soft IPs", including fifteen confirmed IPs (Bernardini et al. 2012). Bernardini et al. (2012) in their nine objects sample found two new IPs with a blackbody component with T_{bb}=70–80 eV. These authors showed that the WD spot area (the source of a blackbody radiation) is 4.5×10^{14} D^2_{900pc} cm^2 in V2069 Cyg and 6.3×10^{13} D^2_{1kpc} cm^2 in RX J0636. These values are still smaller than the size that we obtained for V2491 Cyg (1.8×10^{15} $D^2{}_{10.5kpc}$ cm^2), but can be comparable taking into account uncertainties in the distance determination for both of them.

It should also be stressed that with the existing data, we cannot rule out that the supersoft flux has more than one origin, for instance that there are unresolved narrow emission lines merging with the soft continuum and making the source appear more luminous in the supersoft range. In archival data of V2487 Oph and V4743 Sgr (Hernanz 2014, Zemko et al., in prep.) we found that the post-outburst RGS spectra, albeit with low signal-to-noise ratio, still show emission lines in the softest range. At this stage, this possibility is only speculative, but it should be taken into account as it may imply a lower supersoft X-ray luminosity that estimated in our broad-band fit with *Suzaku*.

In calculating the luminosity we assumed the widely adopted distance d=10.5 kpc (Helton et al. 2008). Munari et al. (2011) independently found 14 kpc using the interstellar Na I line to evaluate the reddening. Although these distances have been inferred with the maximum-magnitude rate-of-decay (MMRD) relationship and these values may thus be highly uncertain (the relationship does not hold for RNe and sometimes is not very precise for CNe, moreover the nova had a rare secondary optical maximum), the optical and especially the supersoft X-ray luminosity in the outburst indicate that the distance cannot be much smaller. Especially the large supersoft X-ray flux (Page et al. 2010; Ness et al. 2011) is evidence of a distance of at least 10 kpc, otherwise the WD would have been underluminous compared with the models of the same high effective temperature (from 9×10^5 to a 10^6 K, see Starrfield et al. 2012; Wolf et al. 2013) and also with previous observations of novae in the SSS phase (see Orio 2012, for a review).

4.2. *The 38 min period*

In our *Suzaku* observations we detected the X-ray light curve modulation with a period of 38.3 min (0.0266 days). Shugarov et al. (2010) detected a 0.02885 days (41.54 min) modulation in optical data in the *V* band obtained between 2008 May 02 and 2009 November 23. We analysed the same dataset with the PDM method and found that the 0.02885 days period is most probably a daily alias of a 0.02655 days (38.23 min) period, which is very close to the one we found in X-rays. Our analysis of the energy dependence of pulses indicates that absorption causes the observed 38.3 min modulation and the timescale implies that the absorber is somewhere close to the WD. The detected 38.3 min modulation may be the WD rotational period. However, the peak that corresponds to this period in the LS periodogram is not as prominent as usually measured in IPs. There is a small, but puzzling difference in periods measured in the first and in the second halves of the *Suzaku* exposure. However, given the data quality, we cannot rule out that the modulation is strictly periodic. On the other hand, if the 38.3 min period is not related to the WD spin, it is not clear what else may play a role in the time-dependent and compact absorber causing this modulation.

4.3. *Magnetic driven accretion in V2491 Cyg*

Some indications of a magnetic nature of V2491 Cyg can be found in spectral characteristics, also discussed by Takei et al. (2011). These are our main findings:

- The hard X-ray band (2.0–10.0 keV) luminosity of V2491 Cyg is 1.82×10^{34} erg s^{-1}, which is higher than in most IPs (L_X is usually $\lesssim 10^{33}$ erg s^{-1} Warner 2003; Pretorius & Mukai 2014). In IPs the moderately hard X-ray emission mostly originates in high energy plasma produced by the accretion shock on the surface of the WD.

- The observed blackbody-like component may place V2491 Cyg in the group of "soft IPs". The blackbody temperature and the emitting area are comparable with these systems.

- If V2491 Cyg is a "soft IP", the soft X-ray flux emitting region underwent a seamless, early transition from nuclear burning to accretion spot emission, taking into account the observations of Page et al. (2010).

- There are two optically thin plasma components with characteristic temperatures ∼0.2 keV and ∼10–20 keV, which may be due to a temperature gradient in the post-shock region.

- We need a complex, partially covering absorber with N(H)$\sim 10^{23}$ cm^{-2} to fit the data, like in many IPs. This phenomenon is usually caused by the accretion curtains crossing the line of sight (Evans & Hellier 2007; Anzolin et al. 2008).

- The equivalent width of the Fe Kα line in V2491 Cyg is very large, 246 eV, like usually in IPs (see Norton et al. 1991; Ezuka & Ishida 1999, for the Fe lines in IPs). This is evidence of reflection of the X-ray emitting plasma, most probably from the surface of the WD (George & Fabian 1991). It may also indicate copious X-ray emission above the *Suzaku* XIS detectors' range. However, the observed Compton thin absorber can also contribute to the 6.4 keV line (see Ezuka & Ishida 1999; Eze 2015).

- The most widely accepted proof of an IP, in which the WD is not synchoronized with the orbital period, is the detection of the spin period in X-rays. The X-ray flux is modulated because the accretion channeled to the pole is shocked, so it is self-occulted and partially absorbed as the WD rotates. We detected an X-ray flux modulation with a period of ∼ 38 min that can be attributed to the WD spin. Energy dependence of the amplitude of the pulses supports this assumption and is consistent with the accretion curtain scenario (Rosen et al. 1988; Hellier et al. 1991).

- However, this period is probably not entirely stable. On the other hand, detection of the spin period may not always be possible. Ramsay et al. (2008) suggested that if the magnetic and rotational axes of a WD are closely aligned, the spin rotation may be undetectable.

5. CONCLUSIONS

We presented the *Suzaku* XIS observation of the CN V2491 Cyg obtained in quiescence, more than two years after the outburst. The very high X-ray flux that we measured is close to the pre-outburst level (Ibarra et al. 2009) and to the values that were obtained about 250 days after the outburst (Page et al. 2010). It indicates a high X-ray luminosity, and hence high accretion rate. We found that the spectral characteristics of the nova are very typical of “soft IP”, such as the presence of a blackbody-like component with $T_{bb} = 77$ eV, optically-thin thermal plasma emission with two characteristic temperatures and a partially-covering absorber. The hard band X-ray luminosity also indicates magnetic driven accretion. We detected the energy dependent X-ray flux modulation with period ~ 38 min that may be attributed to the WD rotation. However, there are uncertainties in the stability of the 38 min period, and in the origin of the blackbody-like component which may be due to residual and localized nuclear burning.

Magnetic WDs in novae have been observed in three systems: in two IPs (GK Per and DQ Her) and in one polar (V1500 Cyg). There are also several other IP candidates: V1425 Cyg, V533 Her and V842 Cen[3], V4743 Sgr (Leibowitz et al. 2006; Dobrotka & Ness 2010). Little is known how the magnetic field changes the nova evolution, it may really steer the path towards, or away from, a type Ia SN explosion in RNe.

If V2491 Cyg is NOT an IP, more questions remain unresolved. The first concerns the possible confinement of nuclear burning. A second question arises if accretion is channeled through the boundary layer of a disk; in this case the observed X-ray light curve modulation is most probably a quasi periodic oscillations, originating in the inner part of the accretion disk. However, this does not explain the energy dependence of the amplitude of the pulses.

An important measurement in further observations would be that of the orbital period. The *Suzaku* observations, presented in this paper, lasted for slightly shorter than two days and we did not find the orbital modulation, usually observed in X-rays in IPs (Parker et al. 2005).

To conclude, V2491 Cyg seems to be a puzzling key object to understand the secular evolution of novae. We suggest that it should still be observed in different wavelengths. A hard X-ray observation with *NuSTAR* would explain the origin of the strong 6.4 keV line. New soft X-ray observations would clarify the stability and nature of the $\sim$38.3 min modulation of the X-ray flux. Finally, with optical observations we may measure the orbital period.

Facilities: Suzaku.

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