Discovery of non-thermal emission from the classical nova V2491 Cygni

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Abstract

We report the long-awaited discovery of non-thermal X-ray emission from classical nova explosions with a target-of-opportunity observation of V2491 Cygni using the Suzaku observatory. Two 20 ks observations were conducted 9 and 29 days after the outburst on 2008 April 11, yielding wide energy range spectra by combining the X-ray Imaging Spectrometer and the Hard X-ray Detector onboard Suzaku. As a result, super-hard continuum emission extending up to 70 keV was detected successfully on day 9, but it was not present on day 29. This is the highest energy at which X-rays have been detected from classical novae. The spectrum is well explained by an extremely flat power-law emission with a photon index of 0.1 attenuated by a heavy extinction. The power-law emission indicates the presence of an accelerated population of electrons with a non-thermal energy distribution. The extremely flat photon index is too hard for standard diffusive shock acceleration, suggesting that other mechanisms such as acceleration by multiple shocks or magnetic reconnections might take place.

Key words: stars: novae — X-rays: stars

1. Introduction

Classical novae are caused by sudden thermonuclear runaway on the surface of white dwarfs in cataclysmic variables. The released energy and mass propagate through circumstellar matter, which are expected to form a shock structure similar to those of supernova remnants but in much smaller scales both in time and space. Existence of non-thermal emission is reported in some supernova remnants, but no clear detection has been made from classical novae, as it requires observations with sufficient agility and sensitivity in the super-hard X-ray band (>10 keV). Suzaku has unprecedented sensitivity in the super-hard X-ray band, and its target-of-opportunity observation is best-suited to search for a non-thermal X-ray emission from classical novae.

Successful detection of non-thermal X-rays will make classical novae another agent of cosmic particle acceleration. In addition, as super-hard X-ray photons can penetrate through an extreme extinction, it will eventually give a tool to unveil the currently-inaccessible phenomena shielded by thick ejecta in the initial phase of classical nova explosions.

In this proceedings, we present the results of super-hard X-ray studies of the classical nova V2491 Cygni using the Suzaku observatory. Suzaku has taken two observations during the early phase, and we focus on the detection of super-hard X-ray emission extending up to 70 keV, the highest energy X-rays ever reported from classical novae. The details of these results are described in Takei et al. (2009).

2. V2491 Cygni

A very good chance occurred in the constellation Cygnus. The classical nova V2491 Cygni was discovered on 2008

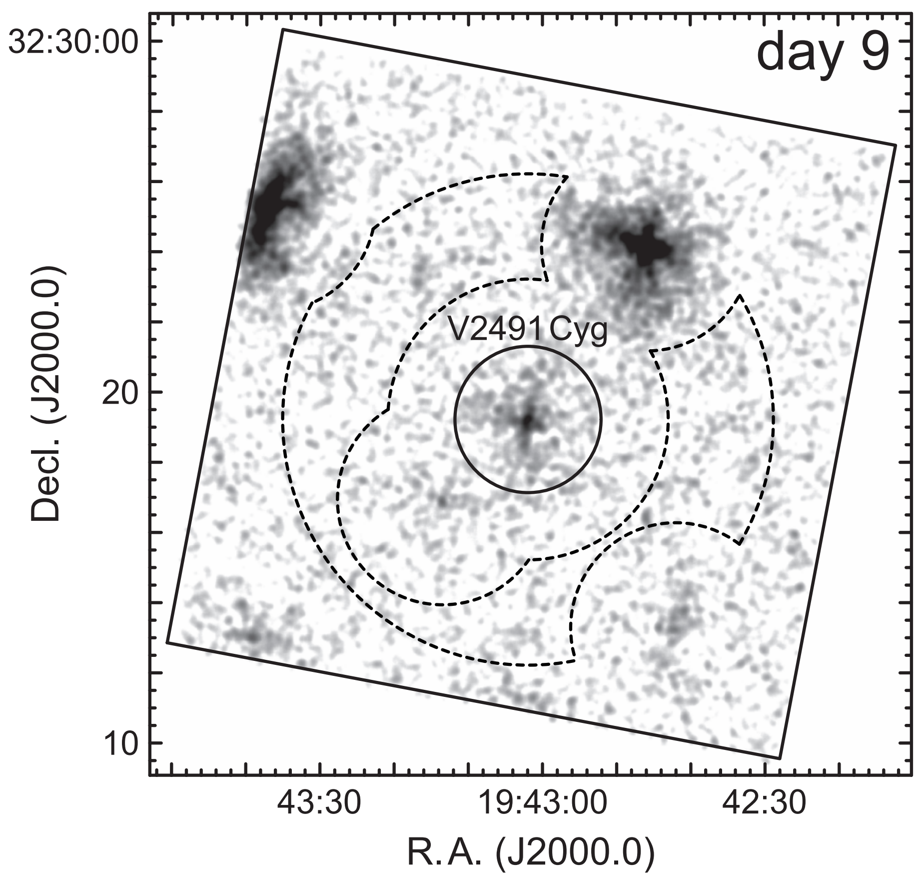

Fig. 1. Smoothed XIS image on day 9. Events recorded by the three CCDs in the 0.2–12.0 keV were used, excluding those in the 5.0–7.0 keV range to eliminate the signals from the calibration sources at the corners. The solid and the dashed circles indicate the source and background accumulation regions, respectively.

April 10.728 UT (Nakano et al., 2008; Samus, 2008). This nova showed a brightness of 7.7 mag at the discovery and 7.1 mag at the peak one day later (Nakano et al., 2008). V2491 Cygni was classified as an extremely fast nova (Tomov et al., 2008a) from a rate of decline of $t_2 \sim 4.6$ d (Tomov et al., 2008b). Based on an empirical relation (Della Valle & Livio, 1995), a distance was estimated as ~10.5 kpc (Helton et al., 2008). As a consequence of the rapid evolution, the white dwarf mass is considered to be high (Hachisu & Kato, 2009). After the outburst, an intense monitoring campaign was conducted by Swift for more than half a year (Kuulkers et al. 2008; Osborne et al. 2008; Page et al. 2008; Page et al. 2009).

Surprisingly, some distinctive characteristics of classical novae were found in several observations. In general, classical novae continue to monotonically decline in the optical brightness, but V2491 Cygni exhibited a clear rebrightening around day 15. A sudden release of magnetic energy were considered to explain such an unusual behavior by Hachisu & Kato (2009). In addition, V2491 Cygni is also one of a few examples with X-ray detection prior to the nova explosion (Ibarra & Kuulkers, 2008; Ibarra et al., 2008, 2009). The optical rebrightening and the pre-nova X-ray activity suggest that V2491 Cygni might host a magnetic white dwarf.

3. Observations

Two observations of V2491 Cygni were performed using the Suzaku satellite 9 and 29 days after the outburst. Suzaku provides simultaneous observations with two instruments in operation (Mitsuda et al., 2007): the X-ray Imaging Spectrometer (XIS: Koyama et al. 2007) and the Hard X-ray Detector (HXD: Takahashi et al. 2007; Kokubun et al. 2007), which cover the energy range of 0.2–12 keV and 10–600 keV, respectively. The details of the observations are described in Takei et al. (2009).

XIS is equipped with four X-ray charge coupled devices (CCDs) at the foci of four X-ray telescope modules (Serlemitsos et al., 2007). Three of them (XIS0, 2, and 3) are front-illuminated (FI) CCDs sensitive in the 0.4–12 keV energy range; the remaining one (XIS1) is a back-illuminated (BI) CCD sensitive over 0.2–12 keV. XIS2 has not been functional since 2006 November, and

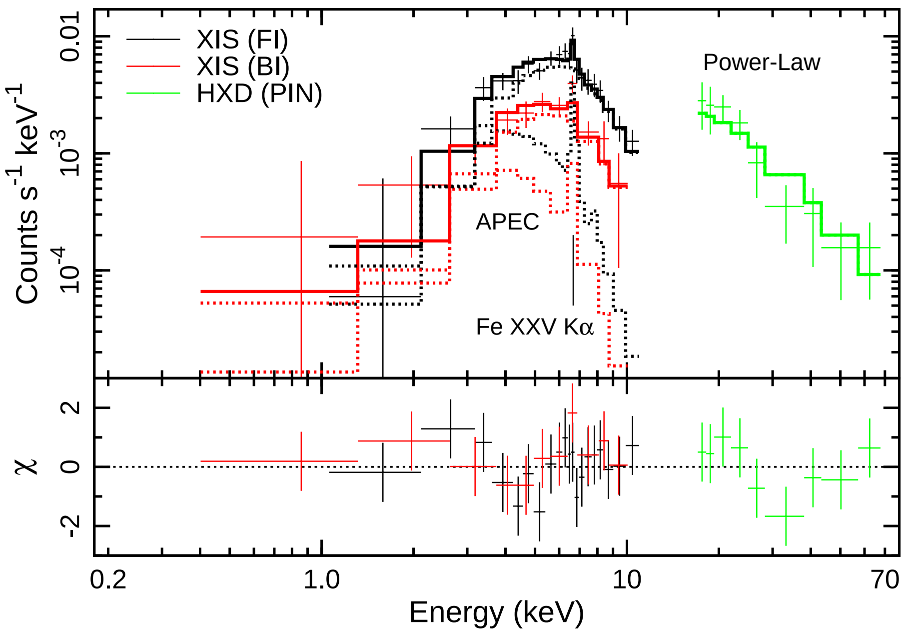

Fig. 2. Background-subtracted spectra and the best-fit model on day 9. The two XIS FI spectra with nearly identical responses were merged, while the BI spectrum was treated separately. The best-fit model is shown with thick lines (solid for total and dashed for each component) for FI, BI and PIN in different colors. The lower panel shows the residual from the best-fit model.

we use the remaining CCDs. XIS was operated in normal clocking mode with a frame time of 8 s, and the net exposure time is ∼20 ks in both observations.

In contrast, HXD is a non-imaging X-ray detector consisting of several components sensitive at different energy ranges. We focus on the PIN detector sensitive in the 10–70 keV energy range. Passive fine collimators restrict the Field of View (FoV) to $34' \times 34'$ with a full width at half maximum. For the narrow FoV and low background environment in a low earth orbit, the PIN achieves unprecedented sensitivity in the super-hard X-ray band.

4. Analysis

We extracted the XIS and PIN spectra for both observations. The procedures are described in Takei et al. (2009). The resultant XIS image and background-subtracted spectra on day 9 are shown in figure 1 and 2, respectively. As a results, we found a clear detection extending up to 70 keV on day 9. Such a detection was not present on day 29.

In our spectral fitting, an optically-thin thermal plasma (APEC; Smith et al. 2001) plus power-law model was well explained the entire spectra on day 9, in which this model is attenuated by an interstellar extinction model (TBabs; Wilms et al. 2000). The best-fit power-law index is ∼0.1, and other best-fit parameters are summarized in Takei et al. (2009).

5. Discussion

We discovered the super-hard X-ray emission extending up to 70 keV from the classical nova V2491 Cygni. The spectra are well explained by an extremely flat power-law emission with a photon index of ∼0.1. Meanwhile, the super-hard component had decayed to an undetectable level on day 29, in which the observation was performed with almost the same exposure time (Takei et al. 2009).

Power-law emission suggests that an accelerated population of electrons has non-thermal power-law energy distribution. Such non-thermal particles are also suggested in radio observations and theoretical studies of other classical novae. Evidence of synchrotron emission was found in a high-resolution radio interferometer observation of the classical nova RS Oph (Rupen et al. 2008). In addition, the presence of diffusive shock acceleration are also argued by Tatischeff & Hernanz (2007). In this observations, we discovered the evidence of non-thermal emission from classical novae in the X-ray energy band for the first time.

Assuming that the dominant radiation is due to common mechanisms of non-thermal emission (e.g., inverse Compton, synchrotron, and bremsstrahlung), an extremely flat power-law emission indicates the injected electron has quite flat population. Standard diffusive shock acceleration model cannot make such a flat population, suggesting that other mechanisms such as acceleration by multiple shocks (Schneider 1993) or magnetic reconnections would be necessary to explain the nature.

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