Suzaku Observation of a New X-ray Outburst from the Accreting Young Star Illuminating McNeil's Nebula

Kenji Hamaguchi[1,2], Nicolas Grosso[3], Joel H. Kastner[4], David A. Weintraub[5], Michael Richmond[4]

[1] CRESST and X-ray Astrophysics Laboratory NASA/GSFC, Greenbelt, MD 20771
[2] Department of Physics, University of Maryland, Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250
[3] Observatoire astronomique de Strasbourg, Université de Strasbourg, CNRS, INSU, 11 rue de l'université, 67000 Strasbourg, France
[4] Rochester Institute of Technology, 54 Lomb Memorial Drive, Rochester, NY 14623
[5] Vanderbilt University, Nashville, TN 37235
E-mail(KH): Kenji.Hamaguchi@nasa.gov

Abstract

A deeply embedded young stellar object (YSO) in the L1630 dark cloud has been observed undergoing a new strong optical/near-infrared outburst in 2008 August. The star, V1647 Ori, is the same star that underwent an accretion-powered outburst in 2003−2005; during this eruption we recorded, for the first time, a sustained X-ray outburst from a rapidly accreting YSO. The X-ray activity is suspected to be driven by a star-disk magnetic dynamo, accompanied by rapid mass accretion. However, observations that might support or refute this hypothesis have been limited in quantity and quality.

We triggered a ToO observation of V1647 Ori with *Suzaku* for 40 ksec on 2008 October 8 using Director's Discretionary Time. During the observation, V1647 Ori showed a gradual flux decrease by a factor of 5 and then displayed an abrupt flux increase by an order of magnitude. The spectrum clearly displays emission from Helium-like iron, which is a signature of hot plasma ($kT \sim$5 keV). Such X-ray properties were also seen in an *XMM-Newton* observation during the first outburst, but it has rarely been observed for other YSOs. Hence, the new outburst started in 2008 is likely driven by a mechanism similar to that of the first outburst. The Suzaku/XIS spectrum of V1647 Ori also shows a remarkable fluorescent iron K line with an equivalent width of ∼600 eV. Such a large equivalent width indicates that a part of the incident X-ray emission that irradiates the circumstellar material is hidden from our line of sight.

Key words: stars: formation — stars: individual (V1647 Ori) — stars: pre-main-sequence — X-rays: stars

1. Scientific Objective and a *Suzaku* Observation

Certain young stars dramatically increase their mass accretion rates by orders of magnitude. These events are possibly triggered by thermal disk instabilities and traced by dramatic increases in optical/near-infrared (NIR) luminosities. They are crudely classified as either FU Ori or EX Lup type outbursts.

The deeply embedded young stellar object (YSO) in the L1630 dark cloud ($d \sim$400 pc), V1647 Ori, had a strong optical/NIR outburst in 2003 December. This eruption afforded the first opportunity to record the sustained X-ray outburst of a rapidly accreting YSO (Kastner et al. 2004; Grosso et al. 2005; Grosso 2006; Kastner et al. 2006). Multiple *Chandra* and *XMM-Newton* observations through this outburst demonstrated that the average X-ray flux level followed the variation in the optical and NIR brightnesses. This result appears to be explained best as star-disk magnetic reconnection activity generated in association with the episode of very rapid mass infall.

In 2008, V1647 Ori began a new optical/NIR outburst (Itagaki et al. 2008; Aspin 2008; Aspin et al. 2009). *Chandra* triggered an anticipated Target of Opportunity (ToO) observation of V1647 Ori for 20 ksec on September 18 (Weintraub et al., in prep.), in which X-ray emission is observed to be elevated to a level two times higher than that observed by *Chandra* on 2004 March 7 (Kastner et al. 2004) during the previous outburst in 2003−2005. This new X-ray eruption offers us the first (and possibly only) opportunity to measure X-ray emission during two outbursts from the same YSO.

Suzaku triggered a ToO observation of V1647 Ori for ∼87 ksec on 2008 October 8 using a part of the Directors' Discretionally Time. The XIS image detected a bright X-ray peak at the position of V1647 Ori while the HXD spectrum showed no hint of signal from V1647 Ori.

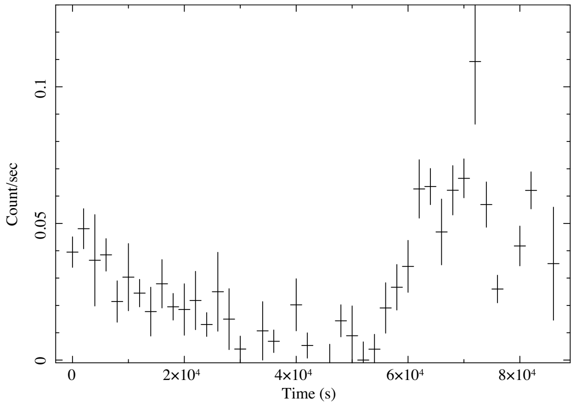

Fig. 1. Background subtracted XIS0+1+3 light curve of V1647 Ori between 1−8 keV. Each bin has 2000 sec.

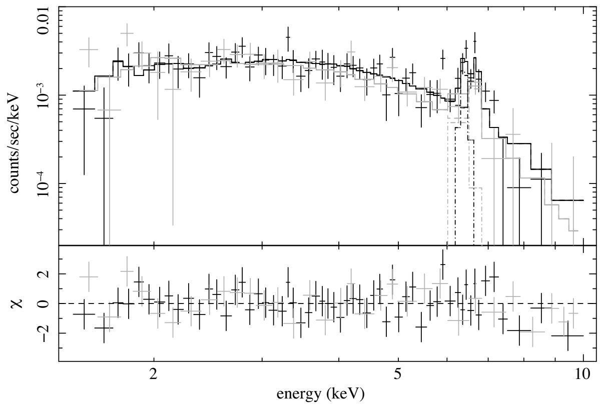

Fig. 2. *Top*: XIS FI (*black*) and BI (*grey*) spectra of V1647 Ori. The solid lines show the best-fit model. The dot-bar lines show a 6.4 keV Gaussian component to account for strong fluorescent iron line emission. *Bottom*: residuals of the χ^2 values from the best-fit model.

2. Light Curve and Spectrum

Fig. 1 shows the background subtracted X-ray light curve of V1647 Ori covering the energy range 1−8 keV, combining all the XIS (0+1+3) data. The count rate varied strongly, by a factor of ∼18 or larger, during the observation. The X-ray light curve shows gradual decrease, to almost zero, over the first ∼60 ks of the observation, then a sharp increase in flux at ∼60 ksec followed by a decay with significant spikes and dips.

The spectrum (Fig. 2) is well fit by a model of 1-temperature thin-thermal plasma emission (APEC) with a 6.4 keV Gaussian component to account for strong fluorescent iron line emission, suffering photoelectric absorption by neutral gas. The inferred hot plasma temperature (∼4.1±1.5 keV), elemental abundance (∼0.5±0.2 solar) and hydrogen column density ($\sim 3.6\pm0.8\times10^{22}$ cm^{-2}) are similar to those inferred for V1647 Ori during the *XMM-Newton* observation in 2004 (Grosso et al. 2005). One remarkable difference, however, is the equivalent width (EW) of the iron fluorescent line at 6.4 keV. The EW in 2008, ∼600 eV, was about a factor of 6 higher than that during the *XMM-Newton* observation in 2004 (∼109 eV).

3. Discussion

The flux of X-ray emission from V1647 Ori strongly varied, by at least a factor of 18, during the *Suzaku* observation. The lowest count rate is not well constrained given the contamination from the north-east soft source, but the *XMM-Newton* observation in 2004 showed a similar range of variation of between $0.5-12\times10^{-13}$ ergs cm^{-2} s^{-1}. Both observations showed similar abrupt flux increases with correspondingly increase in hardness ratio (HR) and no significant HR variation after the increase. The plasma parameters derived from the *Suzaku* spectra were similar to the best-fit result of the *XMM-Newton* spectrum ($kT \sim 3$ keV, $N_{\rm H} \sim 2.9\times10^{22}$ cm^{-2} and $Z \sim 0.8$ solar, model #1 in table 1 of Grosso et al. 2005). This strongly suggests that the new outburst in 2008 was driven by a mechanism similar to that of the first outburst, which started in 2003 October and lasted for ∼2 years.

The observed iron fluorescent line EW is ∼10 times as large as that for a 4 keV plasma irradiating source to be hidden from direct view (∼60eV, Drake et al. 2008). Assuming a reflector with with solar iron abundance, ∼90% of the plasma must be blocked by an optically thick absorber and cannot be seen directly by us. Such a geometry is plausible if most of the plasma is hidden behind the stellar core (see figure 8 and the discussion section in Hamaguchi et al. 2005).

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