ASCA OBSERVATIONS OF X-RAYS FROM YSOs

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ABSTRACT.

We report two remarkable results from YSOs found with the hard X-ray band observations of ASCA (> 2 keV).

We observed an extremely large flare on a T Tauri star V773 Tau. The peak luminosity in the 0.7–10 keV band is 1.2×10^{33} ergs s^{-1} at a distance of 150 pc, which is among the highest luminosities of flares on low mass young stellar objects. The temperature at the flare peak is about 10 keV, which is substantially higher than any other flares found in cool stars. It decreased as the flux decreased, but remained still high at about 6 keV. The absorption column is 3.5×10^{22} H cm^{-3} at the flare peak, and 3.0 $\times10^{22}$ H cm^{-3} at the decay tail. Due to these large absorptions, the flare X-rays are invisible in the soft X-ray band of < 2 keV. Based on these high quality X-ray spectra during a full phase of the flare, we discuss the flare physics.

We found hard X-rays from three embedded protostars EL29, WL6 and YLW15 in the ρ Oph cloud with either a flare-like or a sinusoidal flux variations. We discuss the hard X-rays from the protostars, particularly, the highly variable phenomena.

1. A Giant X-ray Flare on a WTTS V773 Tau

During the ASCA observation of the Barnard 209 dark cloud (1995 February 16–17), V773 Tau (= HD283447) showed a giant flare; the X-ray flux suddenly increased by more than 20 times of the pre-flare, then decreased with an exponential time scale of about 8 ks. Figure 1 shows 3 energy bands (0.7–1.2 keV, 1.2–1.7 keV, 1.7–10 keV) X-ray light curves. A flare feature is visible only in the hard band. Due to the earth occultation, the real flux maximum was not detected. We should note that the flux level after the flare was still higher than that of the pre-flare.

Analyzing the high quality X-ray spectra during a full phase of the flare (each of the data-set is described in figure 1), we found that V773 Tau is likely to be emitting steady X-rays with the same flux level as at the pre-flare phase. The plasma temperature and the abundance at the pre-flare phase were determined to be about 1.3 keV and 0.1 solar (we fixed the N_H to the visual extinction of 3×10^{21} cm^{-2}; Welty 1995). We also determined the physical parameters of the flare by subtracting the pre-flare spectrum. The time history of the best-fit flare parameters are shown in figure 2. The peak luminosity in the 0.7–10 keV band was 1.2×10^{33} ergs s^{-1} at a distance of 150 pc, which is among the highest luminosities of flares on low mass young stellar objects. At the flare, The plasma temperature rapidly increased to $\sim$10 keV at the flare peak, then decreased gradually to $\sim$6 keV. Also the absorption column and the apparent metal abundance increased to 3.5×10^{22} H cm^{-3} and one solar, respectively, at the flare peak. Then both decreased gradually with the flare decay.

Although the flux (the emission measure, E.M.) was not significantly increased at the data 0, an on-set of the X-ray flare is noted at the data 0 by a sudden appearance of a high temperature plasma behind the large absorbing matter, possibly the circumstellar disk (Beckwith et al. 1990). The gradual decrease of the absorption would be explained that the X-ray emitting region moved to less absorbed positions. An alternative explanation would be that the flare originated in a dense absorbing matter, then the hot plasma evaporated and/or expanded the surrounding gas, hence the absorption decreased. Since we see shoulder structures in the temperature and N_H at data 4, we suggest that a re-heating event (additional small flare) occurred during the decay phase of the large flare at a different position, where absorption column is different from the site of the original large flare. To test this scenario, we applied a simple quasi-static cooling model (van den Oord & Mewe 1989), which predicts a constant value of $T^{3.25}$/EM in the cooling phase. Then we found that the simple cooling model is valid in the first 3 phases (data 1–3), but is violated at the last 2 phases (data 4–5). Applying the simple cooling model to these decay phenomena (data 1–3), we estimated the electron density to be 2×10^{11} cm^{-3}, which is comparable to that of the solar flare. On the other hand, the geometrical flare size was determined to be 4.6×10^{11} cm, which is equal or even larger than the stellar size of 2.9×10^{11} cm (Bouvier et al. 1995), but one order of magnitude smaller than the semi-major axis of the V773 Tau binary system, 5.1×10^{12} cm (Welty 1995). The variable abundances along the flare phase is puzzling, but would have a strong impact on the estimation of real abundances of stellar flares.

2. Hard X-ray Variations of Class I Protostars in the ρ Oph Dark Cloud

On 1993 August 20, we observed the Rho-Oph dark cloud and detected hard X-rays from Class I sources (Koyama et al. 1994, Kamata et al. 1997). One of the sources (EL29) showed a flare-like variability, while another (WL6) exhibited sinusoidal variation with no large spectral change. The later would be due to a spin of the protostar. The sinusoidal period of about 1 day is shorter than spin periods of TTSs of $\sim$3–7 day. The flare spectrum of EL29 showed significantly higher absorption of $N_H = 2\times10^{23}$ cm^{-2} than that found in the quiescent spectrum ($N_H = 4\times10^{22}$ cm^{-2}). Thus we inferred that the X-ray flare arises through the dense disk along the line of sight. The quiescent X-rays, on the other hand, would be coming from a large region on the stellar surface, hence are less absorbed by the gas disk. We note these phenomena are similar to those found in the large flare on V773 Tau.

The averaged spectrum of protostars exhibited the 6.9 keV H-like Fe line, which implies an extremely hot temperature ($>$ 10 keV), significantly higher than that of T Tauri stars of $\sim$several keV.

From these X-ray emitting YSOs, we found bipolar flows with radio observations (Sekimoto et al. 1997). This places the sources to be protostars at the dynamical mass

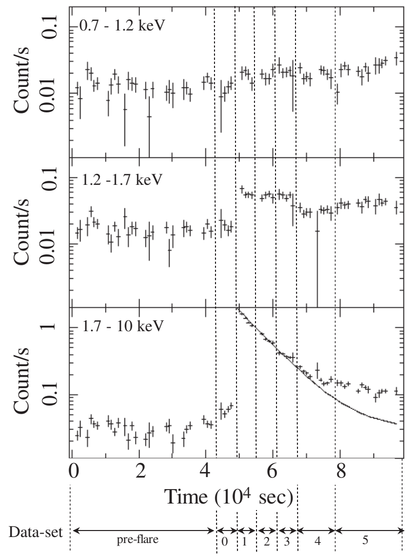

Fig. 1. X-ray light curves of V773 Tau (GIS 2+3) in three energy bands. The epoch is from 16 Feb. 1995 16h 00m 00s. Each time bin width is 1024 sec. The flare is visible only in the 1.7–10 keV band. In the 1.2–1.7 keV band, the flux changes like a step-function; the intensity drops near the exponential tail in the 1.7–10 keV band (at the data 4). The solid line is the best-fit exponential model (e-folding time is 8 ks) with fixed constant flux to the pre-flare level.

accretion phase. The common feature of these out-flows is that the blue and red lobes are largely overlapped, suggesting nearly pole-on geometry. On the other hand, no significant X-ray has been reported from out-flow sources, VLA 1623 (Kamata et al. 1997), L1551 IRS5 and L1551 NE, HL Tau (Carkner et al. 1996), all these would be edge-on systems (André et al. 1990, Ohashi et al. 1996).

Consequently, we propose a unified picture of protostars; every protostar emits X-rays, but the X-rays can only be detected from pole-on viewing angle, where X-rays are less absorbed by dense circumstellar disks.

On 1997 Mar 2–3, we re-observed the central region of the cloud with 100 ksec exposure, and found that WL6 and EL29 became very faint. In stead, new hard X-ray ($>$ 2 keV) objects appeared at the positions of other Class I stars. The brightest was YLW15, on which a large flare had been detected with the ROSAT deep pointing observation (Grosso et al. 1997). The out-flow map of YLW15 (Bontemps et al. 1996) has also a signature of pole-on configuration, confirming our unified picture.

In the hard band ($>$ 2 keV), we detected three flares on the YLW15 with about 20 hours interval. It would be worth to note that the time interval of 20 hours is comparable to the spin period of the protostar WL6, which we suggested from the sinusoidal X-ray light curve. It is also comparable to the period of the inner-most Keplarian orbit (r = several $\times 10^{-2}$ AU). Accordingly, the quasi-periodicity of the flares would be related to the spin of the central star or/and rotation of the circumstellar disk.

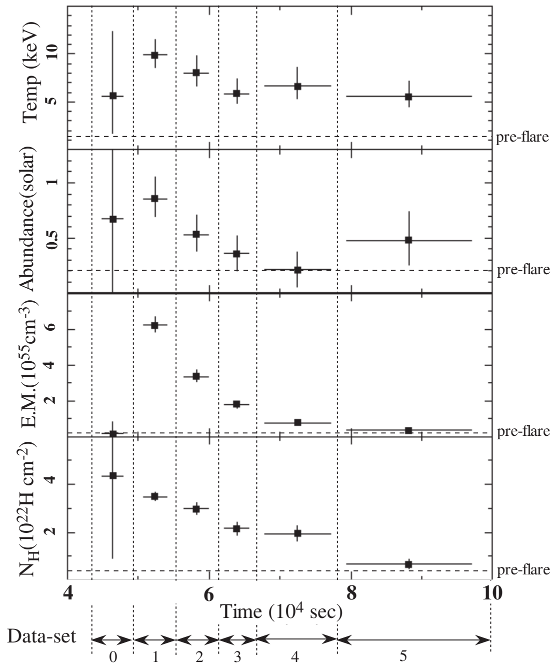

Fig. 2. Evolution of the best-fit parameters during the flare phase. The parameters at the quiescent are also shown for comparison.

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