ASCA OBSERVATIONS OF THE JET SOURCE XTE J1748−288

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ABSTRACT

XTE J1748−288 is a new X-ray transient with a one-sided radio jet. It was observed with ASCA on 1998 September 6 and 26, 100 days after the onset of the radio X-ray outburst. The spectra were modeled with an attenuated power-law model, and the absorbed 2–6 keV flux was 4.6 ± 1.0 × 10−11 and 2.2 ± 0.8 × 10−12 ergs s−1 cm−2 on 1998 September 6 and 26, respectively. The light curve shows that the steady exponential decay, with an e-folding time of 14 days, lasted over 100 days and 4 orders of magnitude from the peak of the outburst. The spectral index of the radio counterpart was located with the Very Large Array (VLA) at 17h48m05s.06, −28°28′25″ (equinox 2000.0; uncertainty 0″6; Strohmayer et al. 1998). The spectral index of the radio counterpart was 0.2–0.6 (Hjellming et al. 1998a; Rupen & Hjellming 1998), and the radio activity reached a maximum of 350 mJy at 2.25 GHz around 1998 June 16.8 Rupen & Hjellming discovered a one-sided jet expanding by 20 mas day−1 in the VLA images, which corresponds to a velocity of 0.93c at a distance of 8 kpc. The time of the jet ejection was estimated to be around 1998 June 1 by extrapolating the proper motion (Hjellming et al. 1999b). The radio activity of the core lasted 3 months, suggesting a continuous ejection of jet material. Thus, this source is considered to be a jet system, similar to SS 433, which has a persistent jet. Around 1998 August 9, the expansion of the leading edge slowed to a rate of ~5 mas day−1 and the leading edge of the jet brightened dramatically (Hjellming et al. 1999b). Hjellming et al. suggested that the ejected jet material had run into external gas and formed a shock, which was seen as a “hot spot.” After the outburst, the source was observed with ASCA on 1999 September 20 and 26 (Katoni et al. 1999, 2000). The celestial region including the source had been observed with ASCA on 1993 October 1 and 1994 September 22, before the outburst. In this Letter we report the results of all of these observations of a remarkable black hole candidate with a jet, which may be interacting with the circumstellar matter.

1 INTRODUCTION

XTE J1748−288 exhibited an X-ray outburst on 1998 June 4 and was detected by the all-sky monitor (ASM) on the Rossi X-Ray Timing Explorer (RXTE) and BATSE on the Compton Gamma Ray Observatory (Smith, Levine, & Wood 1998; Harmon et al. 1998). The 2–10 keV X-ray flux reached 600 mcrab on 1998 June 5 (Strohmayer et al. 1998). The spectral index of the radio counterpart was located with the Very Large Array (VLA) at 17h48m05s.06, −28°28′25″ (equinox 2000.0; uncertainty 0″6; Strohmayer et al. 1998). The spectral index of the radio counterpart was 0.2–0.6 (Hjellming et al. 1998a; Rupen & Hjellming 1998), and the radio activity reached a maximum of 350 mJy at 2.25 GHz around 1998 June 16.8 Rupen & Hjellming discovered a one-sided jet expanding by 20 mas day−1 in the VLA images, which corresponds to a velocity of 0.93c at a distance of 8 kpc. The time of the jet ejection was estimated to be around 1998 June 1 by extrapolating the proper motion (Hjellming et al. 1999b). The radio activity of the core lasted 3 months, suggesting a continuous ejection of jet material. Thus, this source is considered to be a jet system, similar to SS 433, which has a persistent jet. Around 1998 August 9, the expansion of the leading edge slowed to a rate of ~5 mas day−1 and the leading edge of the jet brightened dramatically (Hjellming et al. 1999b). Hjellming et al. suggested that the ejected jet material had run into external gas and formed a shock, which was seen as a “hot spot.” After the outburst, the source was observed with ASCA on 1998 September 20 and 26 (Katoni et al. 1999, 2000). The celestial region including the source had been observed with ASCA on 1993 October 1 and 1994 September 22, before the outburst. In this Letter we report the results of all of these observations of a remarkable black hole candidate with a jet, which may be interacting with the circumstellar matter.

2 THE OBSERVATION

The log of the observations of XTE J1748−288 by ASCA is shown in Table 1. In observation 4, XTE J1748−288 was near the center of the field of view (FOV), and data from both the Gas Imaging Spectrometer (GIS) and the Solid-State Imaging Spectrometer (SIS) were obtained. The other observations were performed as parts of the Galactic plane survey program (Koyama et al. 1997) and the Galactic center region observations (Maeda et al. 1999; Sakano et al. 1999) and provided no SIS data because XTE J1748−288 was out of the SIS FOV. Observations 2A and 2B were performed very close in time, and they are regarded as one data set hereafter. A simultaneous observation with RXTE was performed during observation 4 (Revnivtsev, Trudolyubov, & Borozdin 2000).

In all observations, the PH mode with nominal bit assignments was used for the GIS (Tanaka, Inoue, & Holt 1994). In observation 4, the 1-CCD FAINT mode was used for the SIS. Unless specified, all data were processed using the standard event selection criteria and data reduction methods.9

3 THE DATA ANALYSIS

3.1 The Image

The GIS image of observation 4, when XTE J1748−288 was near the center of the FOV, is shown in Figure 1. Because XTE J1748−288 was rather faint at that time, other sources are recognizable by eye in the figure. In addition to XTE J1748−288, 1E 1743.1−2843, which is the brightest source in the FOV, Sgr B2, and an unidentified source labeled AX J1747.0−2837 are seen in the image. AX J1747.0−2837 is located at 17h47′02″, −28°37′4″ (equinox 2000.0; uncertainty 1″). The extended source in the background of these sources is Galactic ridge emission. Sgr B2, 1E 1743.1−2843, and the Galactic ridge emission can contribute contaminating background photons to the analysis of XTE J1748−288. Sgr B2

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7 ASM/RXTE Team; quick-look results provided via http://space.mit.edu/RXTE/ASM_lc.html.
8 Green Bank Interferometer Monitoring Program; see http://www.gb.nrao.edu.
9 ASCA Guest Observer Facility; see http://heasarc.gsfc.nasa.gov/docs/ascia/abc/abc.html.
and the Galactic ridge are especially significant iron line emitters (Murakami et al. 2000), and their photons must be removed carefully from the spectrum of XTE J1748–288.

### 3.2. The Light Curve

The temporal activity of XTE J1748–288 was estimated from the GIS data. We collected photons within 6' of XTE J1748–288 in observation 3, when the source was rather bright, and within 2' in the other data sets. To estimate the background level of each observation, photons were collected from the annular region around the source for each data set. The thickness of the annulus was set to be 6'–10' for the data taken in observation 4 and 6'–8' for the others. Assuming that the background count rate is proportional to the sampling area, we estimated the contribution of the background component in the source region for each data set from the photons in the annular region. The source was significantly detected in observations 3 and 4, but not in 1 or 2. The absorbed 2–6 keV fluxes with statistical 90% errors in observations 3 and 4 were $4.6^{+0.8}_{-0.7} 	imes 10^{-11}$ and $2.7^{+0.6}_{-0.8} 	imes 10^{-12}$ erg s$^{-1}$ cm$^{-2}$, respectively. The 90% confidence upper limits for observations 1 and 2 were $9.3 	imes 10^{-13}$ and $4.9 	imes 10^{-13}$ ergs s$^{-1}$ cm$^{-2}$, respectively, in the same band. The light curve is shown in Figure 2 together with the ASM/RXTE and BeppoSAX data.

### 3.3. The Spectrum

In observation 3, XTE J1748–288 was rather bright, which made the background estimation less difficult. The background spectrum used to plot the light curve was also used for spectral fits. The GIS spectrum taken in observation 3 is shown in Figure 3. Because XTE J1748–288 is only marginally detected in observation 4, the background component must be subtracted very carefully. The 6'–8' annular region used for the background estimation to plot the light curve is not sufficiently accurate since the extended background source has a structure finer than a few arcminutes, as seen in Figure 1. To minimize the uncertainty due to the selection of a background region, we obtained a background spectrum from the source position when it was quiescent. We collected photons within 2' of XTE J1748–288 in observations 1 and 2, when the source was inactive and fainter than the detection limit, and used them as the background component. The intensity of the non-X-ray background depends on the po-

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**Table 1**

| Observation | Start (MJD) | End (MJD)   | Effective Time (ks) | Remark  |
|-------------|-------------|-------------|---------------------|---------|
| 1           | 1993 Oct 1, 21:20 (49,261.89) | 1993 Oct 2, 10:20 (49,262.43) | 15 | GIS only |
| 2A          | 1994 Sep 22, 03:50 (49,617.16) | 1994 Sep 23, 12:10 (49,618.51) | 58 | GIS only |
| 2B          | 1994 Sep 24, 02:00 (49,619.08) | 1994 Sep 24, 14:40 (49,619.08) | 20 | GIS only |
| 3           | 1998 Sep 6, 09:10 (51,062.38) | 1998 Sep 6, 17:50 (51,062.74) | 5 | GIS only |
| 4           | 1998 Sep 26, 03:30 (51,082.15) | 1998 Sep 28, 17:20 (51,082.69) | 20 | GIS + SIS |

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**Figure 1.** GIS image taken in observation 4. The energy band of 2.9–5.9 keV was used. Data of both GIS2 and GIS3 were combined and convolved with a two-dimensional Gaussian ($\sigma = 3$ pixels). The X-rays from the calibration sources were removed. XTE J1748–288 and the nearby sources 1E 1743.1–2843, Sgr B2, and an unidentified source AX J1747.0–2837 are indicated.

**Figure 2.** Light curve of XTE J1748–288. The data of the ASM/RXTE (see footnote 7) with 1 $\sigma$ errors, the MECS/BeppoSAX (Sidoli et al. 1999), and ASCA with 90% errors are plotted. Upper limits (90%) obtained with ASCA on 1993 October 1 (MJD 49,261) and 1994 September 22 (MJD 49,618) are also shown. The dashed line is an exponential decay with an $e$-folding time of 14 days. The convergence of the ASM data to a constant level of $\sim 0.07$ crab is artificial as a result of the data selection threshold applied here.
sition in the FOV and might cause a systematic error in background estimation (Makishima et al. 1996). However, the position dependence is significant only in the soft band below 1 keV and does not affect the following discussion. After correcting for vignetting effects in the GIS, the resultant background was subtracted from the source spectrum taken in observation 4. The GIS spectrum taken in observation 4 is shown in Figure 4. Even after this careful treatment, the background estimation may have a systematic uncertainty. The negative data points below 2 keV may be due to overestimation of the background component.

We tried spectral fits of the GIS data with several spectral models. The statistical quality of the data did not allow us to determine an emission model uniquely. The spectra are well fitted by an attenuated power-law model, an attenuated optically thin thermal plasma emission (Mewe, Gronenschild, & van den Oord 1985), and an attenuated blackbody model. The best-fit parameters of each model are shown in Table 2.

Although the goodness of the fits was already satisfactory, inclusion of a Gaussian line at iron K energy into the power-law model improved the fit. The parameters of the Gaussian model are also shown in Table 3. Even after the inclusion of a Gaussian line at 6.9 keV into the fit model, the residuals of the data taken at observation 3 still showed a feature that can be fitted with a Gaussian line at 5.9 keV (Kotani et al. 2000).

XTE J1748–288 was in the FOV of the SIS in observation 4 but not in the other observations. That makes the background subtraction of the SIS difficult. Since the FOV of the SIS is smaller than that of the GIS, photons detected farther than 4.5' from the source in the SIS image obtained in observation 4 were used for the background estimation. Because the effective exposure time of observation 4 is only 20 ks, the statistical quality of the resultant background spectrum was low. Still, spectral fits of the SIS were found to be consistent with those of the GIS.

4. DISCUSSION

4.1. The Temporal Behavior

In the light curve, the ASCA flux in observation 3 (1998 September 6) is on the extrapolation line from ASM and BeppoSAX data. It is remarkable that the exponential decay with an e-folding time of 12–16 days lasts from the peak of the outburst for over 100 days and 4 orders of magnitude. This is one of the best examples of the steady exponential decay following an outburst shown by a black hole candidate. On the other hand, the flux in observation 4 (1998 September 26) is below the extrapolation line by 1 order of magnitude. Thus, there may be a transition from the exponential decay phase to another phase—perhaps the off-state phase—in the period between the two ASCA observations. In the decaying phase of black hole candidates, it is usual to observe a hump in the light curve or a relaxation of the timescale of decay. The sudden drop in the light curve of XTE J1748–288 is distinct from the behaviors of such black hole candidates.

The flux at observation 4 is inconsistent with the value of 10 mcram obtained with RXTE (Revnivtsev et al. 2000). The spectral analysis with the Proportional Counter Array (PCA) may be very difficult when the source is faint because of the many background sources in the PCA FOV. We point out the possibility that the RXTE flux is contaminated by nearby sources, as Revnivtsev et al. suggested in their paper.

It is fortunate that the source position was monitored with ASCA 5 yr before the discovery. Although the data taken in observations 1 and 2 provide only upper limits, they constrain the flux level of the black hole candidates before the onset of an activity. The mass overflow instability model (e.g., Hameury, King, & Lasota 1986) predicts a certain hard X-ray luminosity even in the quiescent phase to trigger an outburst. Assuming a power-law spectrum with the same parameters as those for observations 1 and 2, the flux in observation 4 falls below the extrapolation line by 1 order of magnitude. This is consistent with the observation that the energy was lower than for observations 1 and 2. We tried spectral fits of the GIS data with several spectral models, including a Gaussian line at iron K energy into the power-law model, an attenuated optically thin thermal plasma, and a blackbody model. The best-fit parameters of each model are shown in Table 2.

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### Table 2: Best-Fit Parameters

| Observation | \( N_0 \) \((10^{22} \text{ cm}^{-2})\) | \( \Gamma \) | \( kT \) (keV) | Reduced \( \chi^2 \) (degrees of freedom) |
|-------------|----------------|-----|-------------|----------------|
| **Power Law** | | | | |
| 3 ............ | \( 6.0^{+1.3}_{-1.1} \) | 1.56^{+0.31}_{-0.31} | ... | 0.94 (180) |
| 4 ............ | 18.5^{+10.9}_{-7.3} | 8.1^{+3.2}_{-3.8} | ... | 1.05 (187) |
| **Blackbody** | | | | |
| 3 ............ | 2.86^{+0.80}_{-0.60} | ... | 1.72^{+0.21}_{-0.18} | 1.00 (180) |
| 4 ............ | 13.3^{+21.8}_{-6.1} | ... | 0.39^{+0.30}_{-0.19} | 1.05 (187) |
| **Optically Thin Plasma** | | | | |
| 3 ............ | 5.65^{+0.80}_{-0.61} | ... | >11.2 | 0.94 (180) |
| 4 ............ | 14.5^{+27.6}_{-5.7} | ... | 0.67^{+10.6}_{-4.5} | 1.05 (187) |

Note.—For flux, see the text.
observation 3 in Table 2 and a distance of 8 kpc, the upper limit of the luminosity above 7 keV in observations 1 and 2 is calculated to be $6.1 \times 10^{33}$ and $3.2 \times 10^{33}$ erg s$^{-1}$, respectively. With such a low hard X-ray luminosity, it would be difficult to trigger an outburst via the mass overflow instability unless the companion star is less massive than 0.4 $M_\odot$, according to an estimation by Mineshige et al. (1992). That consideration favors the disk instability scenario (e.g., Osaki 1996) rather than the mass overflow instability as the cause of the outburst of XTE J1748$-$288.

4.2. The X-Ray Source

It is difficult to determine whether the iron line detected in observations 3 and 4 is intrinsic to XTE J1748$-$288 or originated in the Galactic ridge, even after the careful background subtraction procedure described above. The negative flux below 2 keV in Figure 4 suggests that the background component is slightly overestimated, and thus the excess at the iron K energy is a significant and real structure. We tried several other background subtraction methods and detected the iron line in all cases. On the other hand, the absence of any iron line in the BeppoSAX spectrum of XTE J1748$-$288 on 1998 August 26 casts serious doubt on the ASCA detection, although the source was at an off-center position in the Medium-Energy Concentrator Spectrometer (MECS), where the energy resolution is not the best (Sidoli et al. 1999). The possibility that the iron line is not related to XTE J1748$-$288 cannot be rejected at this stage. The origin of the iron line must be determined in a future observation with a mission of higher sensitivity and spatial resolution.

The blob of XTE J1748$-$288 ejected on 1998 June 1 was observed to brighten and decelerate to 0.23$c$ around 1998 August 9 (Rupen & Hjellming 1998), probably crashing to circumstellar matter. The shock temperature of a blob decelerated from 0.93$c$ to 0.23$c$ would be $\approx 100$ MeV if the blob consists of baryonic plasma. Because such a blob would emit X-rays via bremsstrahlung or synchrotron processes, one might suspect that the X-rays observed with ASCA on 1998 September 6 and 26 originate from the colliding blob. However, we point out that the temporal behavior of the X-ray luminosity of such a plasma would be different from that observed. The X-rays from a cooling plasma via radiation or expansion will not show an exponential decay but rather a power-law–like light curve. Thus, the colliding blob is probably not the dominant X-ray source. The upper limit of the flux, $2.2^{+0.6}_{-0.8} \times 10^{-12}$, gives an upper limit of the density of the blob, $\lesssim 10^3$ cm$^{-3}$, assuming a blob dimension of $10^{16}$ cm. That figure gives an upper limit of the mass of $10^{28}$ g or $10^{-6} M_\odot$. This discussion is based on the flux level of observation 3. As for observation 4, the possibility of emission from the colliding blob cannot be rejected based on the temporal behavior. The X-rays observed in observation 4 may be emitted from or contaminated by the blob.

5. Summary

The new Galactic jet source XTE J1748$-$288 was observed with ASCA four times: twice in the quiescent phase before the outburst and twice $\approx 100$ days after the onset of the outburst on 1998 June 4. The flux was below $10^{-13}$ ergs s$^{-1}$ cm$^{-2}$ in the quiescent phase and $4.6^{+1.0}_{-0.8} \times 10^{-11}$ and $2.2^{+0.8}_{-0.6} \times 10^{-12}$ ergs s$^{-1}$ cm$^{-2}$ on 1998 September 6 and 26, respectively. The light curve decayed exponentially with an $\tau$-folding time of 12–16 days, over 100 days and 4 orders of magnitude. The temporal behavior suggests that a colliding jet blob is not the dominant X-ray source, at least on 1998 September 6. There is an indication of an iron line in the spectra even after the careful background subtraction. A hot jet, an accretion column, or an accretion disk may account for the X-ray emission. The upper limit of the flux constrains the ejected mass to be less than $10^{28}$ g.

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TABLE 3

| Observation | Centroid Energy (keV) | Flux (photons cm$^{-2}$ s$^{-1}$) | Degrees of Freedom | $\Delta \chi^2$ |
|-------------|----------------------|-------------------------------|------------------|-----------------|
| 3           | 6.73$^{+0.03}_{-0.02}$ | $<0.28$ | $2.7^{+0.4}_{-0.4} \times 10^{-4}$ | 177 (−3) | −4.51 |
| 4           | 6.92$^{+0.16}_{-0.13}$ | $<0.66$ | $2.5^{+0.5}_{-0.5} \times 10^{-5}$ | 184 (−3) | −5.35 |