Publ. Astron. Soc. Japan 36, 799–806 (1984)

The Transient X-Ray Source 4U 1543−47 Observed from Tenma

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(Received 1984 March 30; accepted 1984 June 1)

Abstract

The strong transient X-ray source, 4U 1543−47, was observed between August 17 and August 24, 1983, with the fan-beam scanning counters on board the Tenma satellite. This is the second observation of an outburst from this source. On August 20, its intensity rose to about one half that of Sco X-1 in the 1.5–3.75-keV energy range. During the rise to maximum brightness, a hardening of the spectrum was observed. After reaching the maximum brightness, the intensity was roughly constant and the spectrum was consistent with either a thermal bremsstrahlung spectrum with $kT=1.6$ keV or a power-law spectrum with a photon index of 5.3, but was inconsistent with a blackbody spectrum.

Key words: X-ray novae; X-ray sources.

1. Introduction

A bright transient X-ray source in the constellation of Lupus was observed with the fan-beam scanning counters on board the X-ray astronomy satellite Tenma (*IAU Circular*, No. 3854, 1983). The observed location of this source agrees with that of 4U 1543−47.

The existence of this source was first reported by Matilsky et al. (1972) based on Uhuru observations from August 1971 through Feburuary 1972. Belian et al. (1973) observed the initial outburst at 19h 52m UT on July 26, 1971 with the Vela satellite. X-ray emission from this source was continually observed by Li et al. (1976) with the OSO-7 satellite between November 1971 and December 1972. Li et al. (1976) distinguished four qualitatively different phases in the results from the Vela, Uhuru, and OSO-7 satellites. In the first phase, the flux rose and stayed at a maximum of about twice that of the Crab Nebula, in the range 2–6 keV, for about 2 d. The second phase, lasting for about 110 d, until November 20, 1971 was characterized by a slow irregular decrease in intensity and a relatively constant spectrum. In the third phase, the intensity dropped rapidly over about a onemonth period with associated spectral softening. In the fourth phase, after January 6, 1972 the intensity fluctuated irregularly with a complex spectrum.

The outburst of 4U 1543−47 was observed with Tenma about 12 yr after the last observation of the outburst. This observation provides an important opportunity to investigate the nature of X-ray novae.

2. Observations and Results

The sky region around 4U 1543−47 was in the field of view of the Tenma scanning detector (ZYT) between April 3 and August 24, 1983. The ZYT system consists of a pair of proportional counters each having an effective area of 63 cm^2 and a field of view of $2^\circ \times 25^\circ$ (FWHM). The counters have a common view axis inclined by 29° with respect to the satellite spin axis, and their long sides are tilted by $\pm 20^\circ$ from the meridian plane to form a crisscrossed pair. Hence the detector scans a wide sky region ($\sim$0.7 sr) as the satellite spins and can determine the position of a X-ray source with a reasonable accuracy ($\sim 1^\circ \times 1^\circ$).

The proportional counters have 50-μm thick Be windows and are filled with a mixture of Xe (97%) and CO_2 (3%) at 1.1 atm. They are sensitive to X-rays with energies in the range, 1.5–25 keV. Further details of the instrument are given by Tanaka et al. (1984).

On August 17, a new transient X-ray source was detected with the ZYT, as it flared up rapidly. The determined location of this source was

$$\alpha = 237.^\circ 0 \pm 1.^\circ 0 \ (1950)\,, \quad \delta = -47.^\circ 5 \pm 1.^\circ 0 \ (1950)\,. \tag{1}$$

Following our observation, Blissett et al. (*IAU Circular*, No. 3858, 1983) determined the location of this source more precisely from observations with EXOSAT. Subsequently, Pedersen et al. (*IAU Circular*, No. 3858, 1983) discovered the optical counterpart, a $m_v =$ 14.9 star, which brightened by $\sim$1 mag during the X-ray outburst. Since the EXOSAT and optical source positions are consistent with 4U 1543−47 (Matilsky et al. 1972), we consider that 4U 1543−47 flared up again in August 1983.

2.a. Light Curves

The X-ray light curves for three energy channels, corresponding to 1.5–3.75 keV (Ch-1), 3.75–7.5 keV (Ch-2), and 7.5–11.25 keV (Ch-3), are shown in figure 1. No significant flux from the transient source was detected during the observation in channel 4, which covers 11.25–17.5 keV. The data shown in figure 1 were obtained by folding each continuous data set, lasting around 10 or 20 min, with the spin period of the satellite, $\sim$30 s. Each folded data set was then fitted to the triangular collimator response on the condition that the spin axis and the source positions were fixed, the counting rates from the source and the background were left as free parameters. The source counting rates were obtained after aspect correction. The Crab Nebula flux corresponds to a counting rate of about 1.7 counts s^{-1} cm^{-2} in channel 1. The error bars are for statistical uncertainty at the 90% confidence level. Where no error bars are shown, the errors are smaller than the plotting symbol.

On August 17, 4U 1543−47 was first detected at about one twentieth of the Crab Nebula intensity in channel 1. Its intensity increased rapidly and reached a maximum of about ten times that of the Crab Nebula (1.5–3.75 keV) on August 20. After that, the intensity was approximately constant until August 24 when the observation was terminated. The source flux increased by a factor of 100 in about 2 d. This rise is similar to that of the

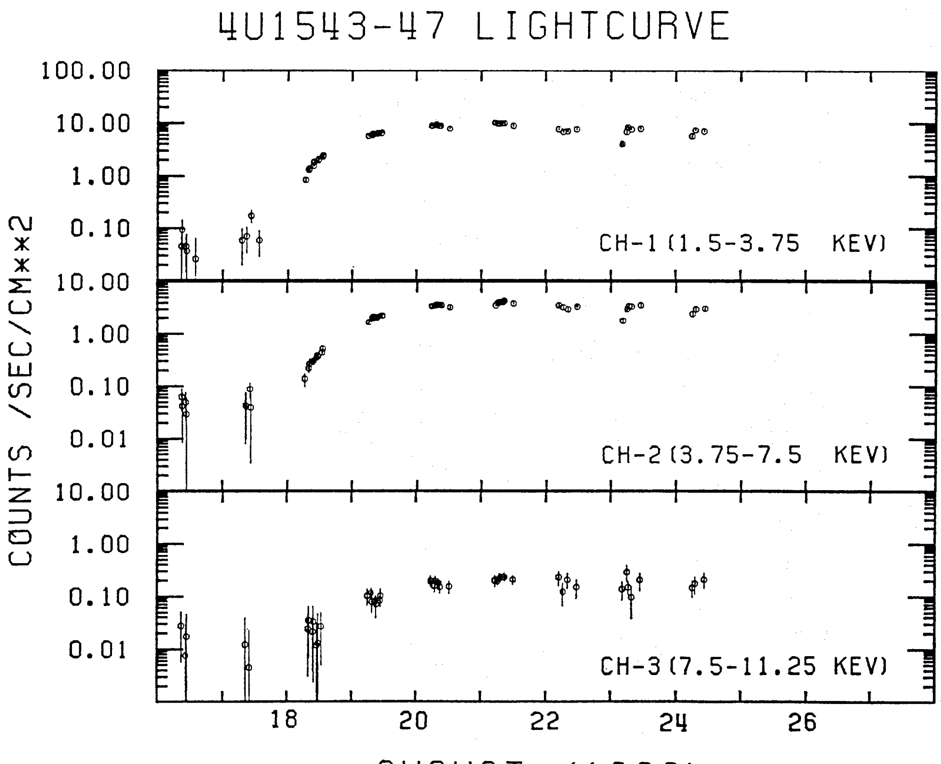


Fig. 1. Counting-rate histories for the transient X-ray source 4U 1543−47. The corresponding counting rate for the Crab Nebula is about 1.7 counts s^{-1} cm^{-2} for Ch-1, 1.0 counts s^{-1} cm^{-2} for Ch-2, and 0.3 counts s^{-1} cm^{-2} for Ch-3. The error bars represent a statistical 90% confidence level. Where no error bar is shown, the error is smaller than the plotting symbol.

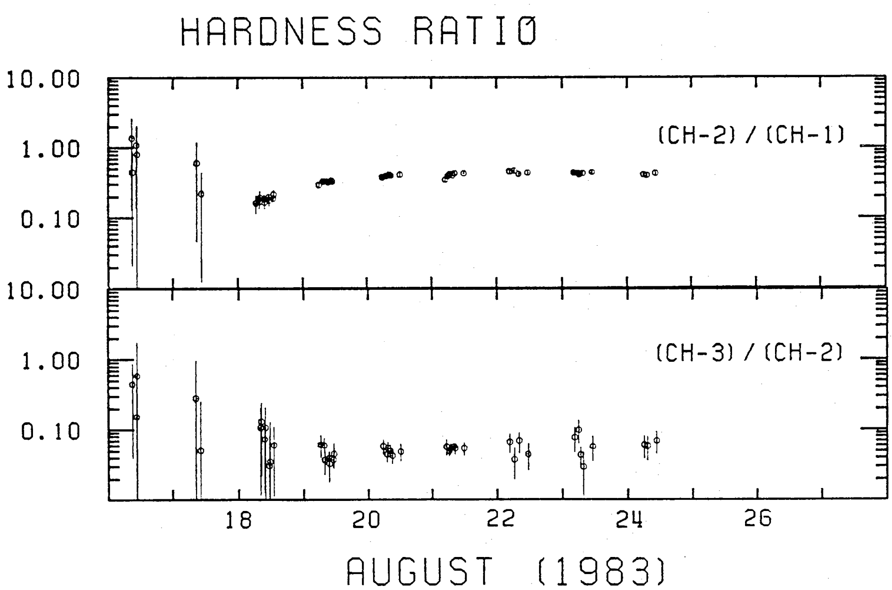


Fig. 2. Hardness-ratio histories for the transient source 4U 1543−47. The energy range for each channel is 1.5–3.75 keV (Ch-1), 3.75–7.5 keV (Ch-2), and 7.5–11.25 keV (Ch-3). The error bars are the same as in figure 1.

previous outburst in 1971. However, it is faster than the intensity increase of similar X-ray sources, about 8 d for A 0620−00 (Elvis et al. 1975) and more than 4 d for Cen X-4 (Kaluzienski et al. 1980).

2.b. *Hardness Ratio*

Figure 2 shows the history of the hardness ratio, Ch-2/Ch-1 (3.75–7.5 keV/1.5–3.75 keV) and Ch-3/Ch-2 (7.5–11.25 keV/3.75–7.5 keV). The error bars show statistical uncertainty at the 90% confidence level. In the history of Ch-2/Ch-1, a spectral hardening is seen during the rise phase of the intensity. It should be noted that the transient source A 0620−00, on the contrary, showed a softening during its rise phase (Ricketts et al. 1975), and A 1524−62 also showed a softening during its rise or precursor phase (Kaluzienski et al. 1975). The ratio Ch-3/Ch-2 is constant during the observation within the statistical accuracy.

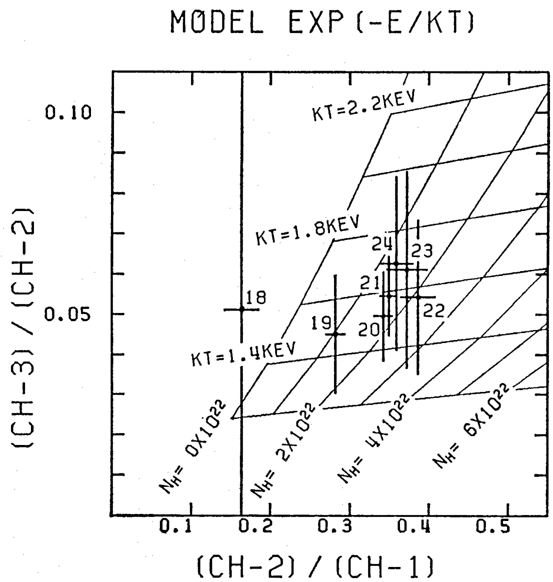
2.c. *Color–Color Diagram*

In order to examine the spectral characteristics of this source, the observed color–color relation, Ch-3/Ch-2 versus Ch-2/Ch-1, is compared with three model spectra in figures 3a–c. Each point is the average over one day. The grid lines on each diagram show the positions of representative points for various values of the two parameters representing the model spectra.

In figure 3a, the model spectrum is a simple formula [exp $(-E/kT)$] simulating the thermal bremsstrahlung spectrum with photoelectric absorption (Brown and Gould 1970), where the parameters are the temperature (kT) and the column density (N_{H}) for the absorption. In figure 3b, the model spectrum is represented by a power-law spectrum ($E^{-\alpha}$), where the parameters are the photon index (α) and the column density (N_{H}). Both of these models can explain all the data and hardening of the spectra in the rise phase can be explained by an increase in the absorption.

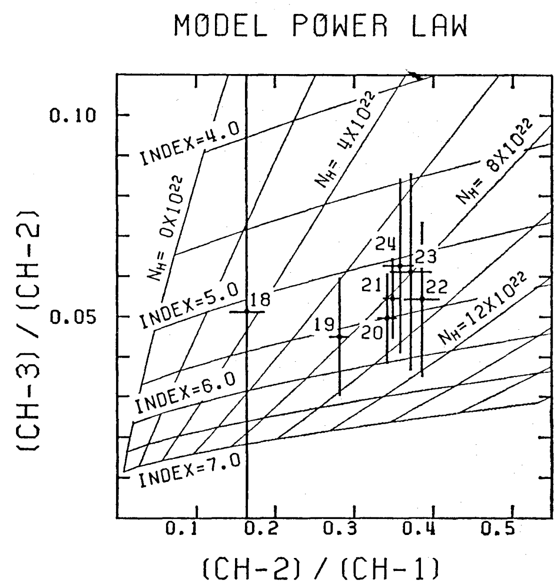
In figure 3c, the data are compared with a blackbody spectrum with photoelectric absorption. It is clear that the observed data are inconsistent with the blackbody spectrum.

At maximum intensity, on August 21, the spectral parameters are listed in table 1 for the thermal bremsstrahlung and the power-law spectra. Its very soft spectrum indicates

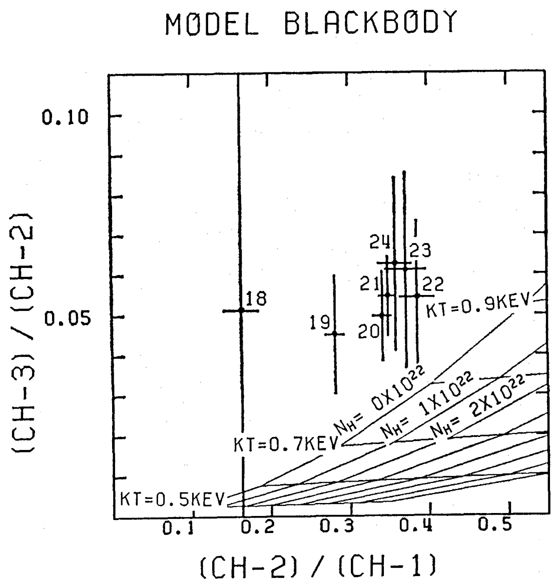


(a)

Fig. 3a. See the legend on the next page.



(b)



(c)

Fig. 3. The color–color diagrams for the transient source 4U 1543−47. Each datum is averaged over one day and the number for each datum represents the day of observation in August, 1983. The grid lines show the positions of representative points for various two-parameter trial spectra. The trial spectra are thermal bremsstrahlung (a), power law (b), and blackbody spectra (c) including photoelectric absorption.

that this source belongs to the category of soft transient sources (Kaluzienski et al. 1977; Cominsky et al. 1978).

2.d. *Luminosity*

The luminosity of this source is also listed in table 1. From the luminosity, we can estimate some physical parameters of this source. For this purpose, we adopt the thermal bremsstrahlung model, because the power-law model requires an unusually steep index and

Table 1. Spectral parameters of 4U 1543−47.

Formula	A	α or kT	N_H (H atoms cm^{-2})	Luminosity (erg s^{-1})
$AE^{-\alpha}$	$7.2\pm0.3\times10^3$	5.3 ± 0.3*	$8.2\pm1.0\times10^{22}$	$1.1\pm0.3\times10^{38}$ $(D^\dagger/1\ kpc)^2$ ††
$A\exp(-E/kT)$	$1.44\pm0.07\times10^2$	1.6 ± 0.1 (keV)	$1.6\pm0.5\times10^{22}$	$4.5\pm0.5\times10^{37}$ $(D^\dagger/1\ kpc)^2$

* Photon index.
† Distance to 4U 1543−47.
†† Luminosity above 1.5 keV.

large column density, although the power-law model leads to similar conclusions.

The luminosity must be less than the Eddington luminosity,

$$L_E=1.3\times10^{38}\,(M/M_\odot)\ \mathrm{erg\ s^{-1}}\,, \tag{2}$$

where M is the mass of the X-ray source and $M_\odot$ is the solar mass. Therefore the distance to this source D is given by

$$(D/1\ \mathrm{kpc})\lesssim1.7\pm0.1\ (M/M_\odot)^{1/2}\,. \tag{3}$$

If the energy source is gravitational energy, which is released by the matter falling onto the X-ray star, the required mass accretion rate is

$$\dot{M}=(5.3\pm0.6)\times10^{-9}(r/10\ \mathrm{km})(M/M_\odot)^{-1}(D/1\ \mathrm{kpc})^2\eta^{-1}M_\odot\ \mathrm{yr}^{-1}\,, \tag{4}$$

where r is the radius of the X-ray star and η is the efficiency for conversion of gravitational energy to radiation energy.

3. Discussion

The source 4U 1543−47 is a recurrent X-ray nova, since the outburst of this source was observed previously in 1971. Further, it belongs to the category of soft transient sources because of its very soft spectrum.

The soft transient source is generally considered to be the consequence of episodic mass transfer in a binary system containing a neutron star or black hole. Various mass exchange mechanisms have been proposed so far. One possible mechanism for such a mass exchange is instabilities in a quasi-stable accretion disk surrounding the compact star (e.g., Osaki 1974). Some constraints can be placed on this model by our observations. Assuming an outburst duration of one half year, based on the fact that this source was observed for about one year in 1971, the total energy emitted from this source during this outburst is about

$$7\times10^{44}(D/1\ \mathrm{kpc})^2\ \mathrm{erg}. \tag{5}$$

Thus the required mass stored in the disk is approximately

$$3\times10^{-9}(D/1\ \mathrm{kpc})^2(r/10\ \mathrm{km})\eta^{-1}(M/M_\odot)^{-1}M_\odot\,. \tag{6}$$

If this material is gradually stored in the disk over the 12 yr, the time between outbursts, the mass-transfer rate from the primary to the disk is

$$2\times10^{-10}(D/1\text{ kpc})^2(r/10\text{ km})\eta^{-1}(M/M_\odot)^{-1}M_\odot\text{ yr}^{-1}\ .$$

The quiescent intensity of this source is less than 1 μJy (Bradt and McClintock 1983). Therefore the mass-leakage rate from the disk onto the neutron star normalized by the star-to-disk exchange rate is less than 0.002, during the 12-yr interval since the preceding outburst.

Several authors have proposed that the mass-transfer mechanism is attributable to phenomena taking place in the primary star. For example, the outbursts may be due to Roche-lobe overflow by post-main-sequence expansion of the primary star (van den Heuvel 1975), instabilities in the primary star (Bath et al. 1974), or contraction of the Roche lobe caused by the decreasing distance between the primary and secondary in an eccentric binary orbit (Clark and Parkinson 1975). In particular, Li et al. (1976) proposed a model for 4U 1543−47, in which the sudden accretion is due to Roche-lobe overflow by a long-period variation in the radius of a red-giant primary star so that the matter accretion takes place only when the radius expands with irregular intervals of a few years. This model can explain the luminosity of 10^{37-38} erg s^{-1} and the rise time of about 2 d. However, if the interval between outbursts is 12 yr, it would be too long compared with the variation period of this type star, typically 100 to 1000 d.

4. Conclusion

We observed the transient X-ray source 4U 1543−47 with Tenma. It is a recurrent X-ray nova and belongs to the category of soft transient sources. Further, we found several notable phenomena associated with this source:

1) The X-ray intensity increased by a factor of 100 within two days.

2) The spectrum could not be represented by a blackbody spectrum, and it is extremely soft, $kT\sim1.6$ keV for a thermal bremsstrahlung spectrum or a photon index of about 5.3 for a power-law spectrum.

3) There was a spectral hardening during the rise phase.

For more detailed discussions, investigations of the properties of the optical counterpart are required.

We are grateful to Professors S. Hayakawa, F. Nagase, Y. Ogawara, Y. Tanaka, and K. Yamashita, and Drs. S. Hunter, H. Kunieda, T. Murakami, and Y. Tawara for stimulating discussions and advice on the manuscript. We also acknowledge all the members of Tenma team for their help in spacecraft operation and data reduction.

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