PASJ: Publ. Astron. Soc. Japan **51**, 39–44 (1999)

A Peculiar X-Ray Transient Source, AX J1842.8−0423, Discovered with ASCA

Yukikatsu TERADA,[1] Hidehiro KANEDA,[2] Kazuo MAKISHIMA,[1], Manabu ISHIDA,[2]
Keiichi MATSUZAKI,[1] Fumiaki NAGASE,[2] and Taro KOTANI[3]

[1]*Department of Physics, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033*
E-mail (YT): terada@amalthea.phys.s.u-tokyo.ac.jp
[2]*The Institute of Space and Astronautical Science, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510*
[3]*The Institute of Physical and Chemical Researches (RIKEN), 2-1 Hirosawa, Wako, Saitama 351-0198*

(Received 1998 August 14; accepted 1998 November 18)

Abstract

A new transient X-ray source, AX J1842.8−0423, was discovered with ASCA in 1996 October in the Scutum arm region. The source exhibited an absorption-corrected 2–10 keV flux of 5.2×10^{-12} erg s^{-1} cm^{-2}, with insignificant intensity variability. The continuous spectrum is approximated by a power-law of photon index 2.9, absorbed by a hydrogen column of $N_{\rm H} \sim 5 \times 10^{22}$ cm^{-2}. The spectrum also exhibits the Fe-K emission line with an extremely large equivalent width of $\sim$ 4000 eV, of which the centroid energy is $\sim$ 6.8 keV. The overall spectrum can be reproduced by a thin-thermal plasma-emission model having a temperature of $\sim$ 5.1 keV, on the condition that the heavy-element abundance is allowed to increase to $3.0^{+4.3}_{-0.9}$ solar abundance. The source was undetectable in a previous observation in 1993 October, as well as in a subsequent observation in 1996 April. The overall source behavior is thus quite peculiar, but may be explained in terms of a close binary involving a magnetized white dwarf viewed from pole-on inclination, where the unusually strong Fe-K line may be the result of resonant scattering of line photons.

Key words: Radiation mechanisms — Stars: individual (AX J1842.8−0423) — Stars: white dwarfs — X-rays: spectra

1. Introduction

Hard X-ray transient sources are often identified as X-ray pulsars orbiting around Be stars, while transient phenomena with much softer X-ray spectra can be seen among low-mass X-ray binaries and black-hole binaries (Tanaka, Shibazaki 1996). The former type of transient sources is preferentially found in galactic-arm regions. In particular, a galactic-plane survey conducted with the Ginga Observatory revealed a high concentration of hard X-ray transients in the Scutum arm region (Koyama et al. 1990, and references therein). The Scutum arm dominates our line of sight toward the galactic longitude of $l \sim 30°$ (e.g., Hayakawa et al. 1977). Many of these Ginga-detected transients show features that are suggestive of X-ray pulsars, and some were actually confirmed to be so.

Following these results, we observed the Scutum arm region several times with ASCA (Yamauchi et al. 1996; Kaneda et al. 1997; Kaneda 1997), wherein a bright transient (AX J1845.0−0433) was discovered (Yamauchi et al. 1995). Here, we report on the ASCA discovery of another transient at a position close to that of AX J1845.0−0433. This new transient exhibits quite peculiar properties, with little resemblance to any known class of galactic X-ray source.

2. Observations

We observed the Scutum arm region three times with ASCA (Tanaka et al. 1994), as summarized in table 1.

The first observation was conducted on 1993 October 19 during the ASCA performance-verification (PV) phase, in the form of 6 consecutive pointings of $\sim$ 20 ks each, onto the galactic plane at $l \sim 28°$ (Yamauchi et al. 1996; Kaneda et al. 1997). The transient AX J1845.0−0433, mentioned above, was discovered on this occasion in one of these fields (Yamauchi et al. 1995). Figure 1a shows an X-ray image of another field (field No.5 of Yamauchi et al. 1996) from the same PV observation, obtained with the ASCA GIS (Gas Imaging Spectrometer; Ohashi et al. 1996; Makishima et al. 1996). There, we see no discrete sources brighter than $\sim 7 \times 10^{-4}$ c s^{-1} per GIS detector.

The second observation was conducted on 1996 October 7 based on a GO-4 proposal, in order to perform a de-

Table 1. Journal of ASCA observations of AX J1842.8−0423.

Observation date	Exposure	Count*	Flux †
1993 October 19	20 ks	$<5.4 \times 10^{-4}$	<0.19
1996 October 7	35 ks	1.47×10^{-2}	5.2
1997 April 21	10 ks	$<7.6 \times 10^{-4}$	<0.13

*The source count rate (c s^{-1}) per one GIS detector in 0.7–10 keV.

†In units of 10^{-12} erg s^{-1} cm^{-2}, after vignetting correction and removing the absorption. For the 1993 and 1997 observations, we assume the same spectrum as the 1996 observation.

tailed study of the galactic ridge X-ray emission (GRXE, e.g. Worrall et al. 1982; Koyama et al. 1986; Kaneda et al. 1997). We pointed ASCA for 35 ks in the same direction as that shows in figure 1a, since the absence of any noticeable discrete sources in this region was thought to be ideal for the GRXE study. However, this time, we unexpectedly detected a bright transient source at the rim of the GIS field of view, as shown in figure 1b. This is the transient source we are reporting in the present paper.

The third observation was performed on 1997 April 21, when we made a series of short (~ 10 ks each) pointings onto the general Scutum arm region as a part of the galactic-plane survey project (e.g., Kinugasa et al. 1997). Figure 1c shows a synthesis image obtained on this occasion. Thus, after only half a year, the transient source again faded away below the detection limit of ASCA.

During these three observations, the GIS data were acquired in the standard PH (pulse height) mode, whereas those from the SIS (Solid-state Imaging Spectrometer; Gendreau et al. 1993; Yamashita et al. 1997) instrument were acquired in the 1-CCD or 4-CCD mode. Because the transient source was entirely outside the SIS field of view in the 1996 observation, the present paper concentrates on the GIS data. After standard data filtering, the exposure time for the 1996 data became about 21 ks.

3. Results

3.1. *Source Position*

By analyzing the GIS data from the 1996 observation, we determined the position of the X-ray transient to be $(l, b) = (28\overset{\circ}{.}03, -0\overset{\circ}{.}07)$, or $(\alpha, \delta) = (18^{\mathrm{h}}42\overset{\mathrm{m}}{.}8,\ -4^\circ 23')$ in equinox 2000.0, with a positional uncertainty of $\sim 3'$. We hence designate the source AX J1842.8−0423. Although the source appears to be extended in figure 1b, it is consistent with a point source when the instrumental response is considered. Furthermore, the flux variation over 6 months clearly argues against this object being extended. We searched the Uhuru (4U), HEAO-1 (1H),

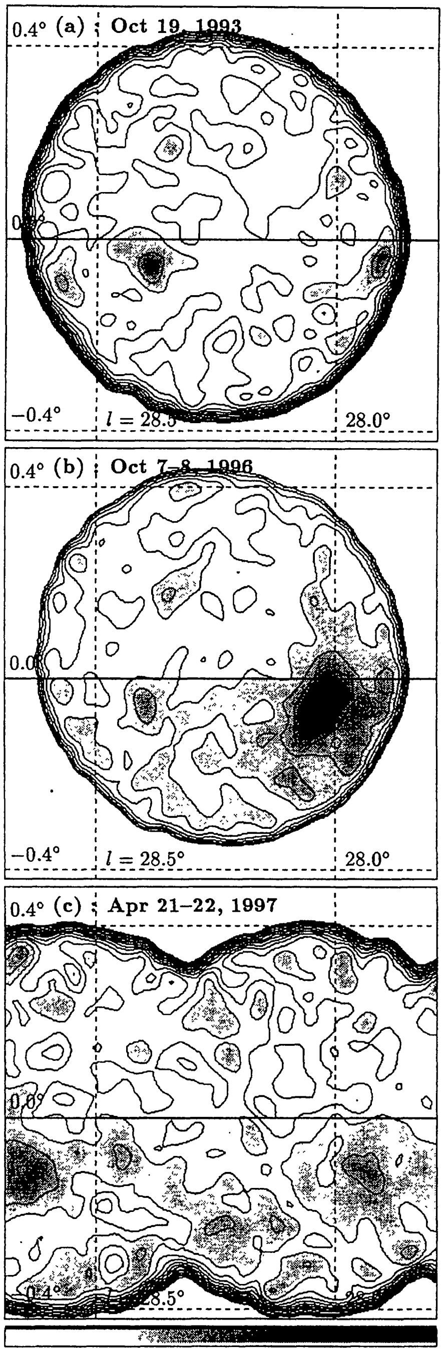

Fig. 1. X-ray images of the Scutum arm region, observed with the two GIS detectors (GIS 2+GIS 3) in 0.7–10 keV in 1993 October 19 (panel a), 1996 October 7 (panel b), and 1997 April 21 (panel c). The non X-ray background (NXB) was subtracted using the night earth data, while the cosmic X-ray background and the galactic-ridge emission are included. The images were corrected for vignetting of the X-ray telescope, and smoothed with a Gaussian kernel of $1'$. The mosaic image in panel (c) was synthesized from several partially-overlapping pointings onto the galactic plane, shown after an exposure a time correction. Gray scales and contours are drawn with logarithmic levels, which are common to three panels, with a step increment by a factor of 1.28.

Ariel-5 (3A), and ROSAT catalogues for a possible counterpart of this source, but found none.

3.2. Source Intensity and Variability

We accumulated the GIS (GIS 2 plus GIS 3) events in the 1996 data within a circle of radius 2′ centered on AX J1842.8−0423. The obtained data include background, which in turn consists of non-X-ray background, the cosmic X-ray background absorbed by the galactic disk, and the GRXE intrinsic to the on-plane region. When integrated over a circle of 2′ radius, the GRXE flux amounts to ∼ 20% of the source flux from AX J1842.8−0423. We need not worry about stray-light contamination, since there are no bright sources within ∼ 2° of the transient.

In order to correctly subtract the GRXE flux, which is known to depend significantly on the latitude (Yamauchi, Koyama 1993), we produced a background spectrum using the same GIS field from the 1996 data, at a source-free position having the same galactic latitude as AX J1842.8−0423. Although the GRXE brightness is known to also depend on the galactic longitude, this dependence is at most ∼ 30% on a scale of ∼ 3′ (Kaneda 1997). Therefore, residual errors associated with the GRXE subtraction are < 6% of the transient source flux. For a cross confirmation, we compared the overall GIS spectra in the 1993 data between the AX J1842.8−0438 position and the position used for the background, and found that they agree within a typical background uncertainty.

Thus, we subtacted the background, and determined the 0.7–10 keV source count rate in the 1996 data to be 1.47×10^{-2} c s^{-1} per GIS detector. The corresponding 3σ upper limits, determined from the background counts, were $\sim 5.4 \times 10^{-4}$ c s^{-1} in 1993 and $\sim 7.6 \times 10^{-4}$ c s^{-1} in 1997.

Figure 2 gives the background-inclusive 0.7–10 keV light curve of AX J1842.8−0423 in 1996. The variability of the data is insignificant, with the hypothesis of a constant count rate yielding a reduced χ^2 of 1.06 ($\nu = 25$). On a time scale of ∼ 2 ks (binning of figure 2), the rms intensity variation is < 30% of the mean count rate. We also carried out a Fourier analysis of the light curve over the period range from 62.5 ms to 1000 s, but no periodicity was found. The amplitude of any periodic variation is less than 5% of the mean count rate.

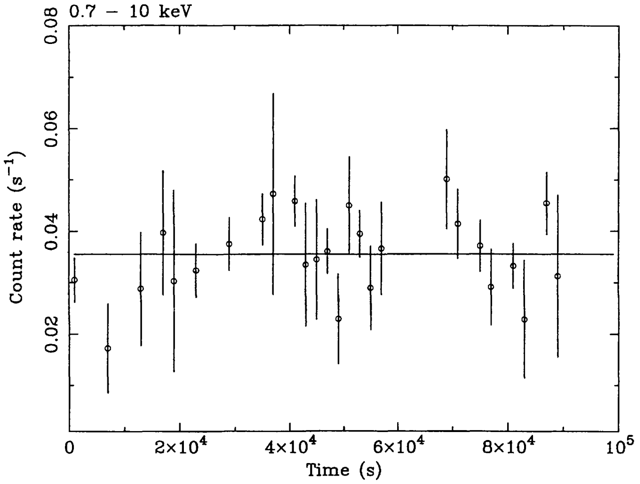

Fig. 2. X-ray light curve of the transient source AX J1842.8−0423 obtained in 1996 with the GIS (GIS 2+GIS 3) in 0.7–10 keV, using a data-integration radius of 2′. The data include background of $\sim 1.6 \times 10^{-4}$c s^{-1}. Each bin consists of a 2 ks exposure. The straight line indicates the average count rate.

3.3. X-Ray Spectrum

Figure 3 shows the background-subtracted GIS spectrum of AX J1842.8−0423 accumulated within a radius of 2′. The spectrum thus exhibits a moderately hard continuum, and a significant low-energy absorption. The most outstanding feature is the very conspicuous emission line at 6–7 keV, which can be attributed to the Fe-K emission line. In contrast, the spectrum bears no clear evidence of low-energy atomic lines.

We fitted the spectrum to an absorbed power-law model, plus a Gaussian profile with a free width representing the Fe-K emission line. This model gave an acceptable fit to the data, with a reduced χ^2 of 0.66 ($\nu = 70$). We obtained a photon index of 2.9 ± 0.4, an absorbing column density of $N_\mathrm{H} = (5.6^{+3.7}_{-0.9}) \times 10^{22}$ cm^{-2}, and an absorption-corrected 2–10 keV flux of 5.2×10^{-12} erg s^{-1} cm^{-2}. Here and hereafter, we use the single-parameter 90% confidence limits. For the Gaussian line, the centroid energy is found at $6.78^{+0.10}_{-0.13}$ keV, the line equivalent width is extremely large at $4.0^{+1.0}_{-0.5}$ keV, and the line width is not statistically significant (270^{+430}_{-270} eV). The best-fit model is shown in figure 3a.

Since the derived line center energy implies a highly ionized Fe species, we next fitted the spectrum with a thermal plasma emission model (Masai 1984). When the abundances of heavy elements are allowed to float under the constraint of the solar abundance ratios, the fit became acceptable with a reduced χ^2 of 0.84 ($\nu = 76$), as shown in figure 3b. We obtained a temperature of $5.1^{+5.0}_{-1.9}$ keV, and a $3.0^{+4.3}_{-0.9}$ solar abundance. The absorption became $N_\mathrm{H} = (3.9^{+1.1}_{-1.1}) \times 10^{22}$ cm^{-2}, which agrees, within errors, with that derived with the power-law plus Gaussian fit; also, the absorption-corrected 2–10 keV flux remained essentially the same. Except for the very large abundance, the fit results are physically reasonable: the Fe-K line center energy is confirmed to be consistent with

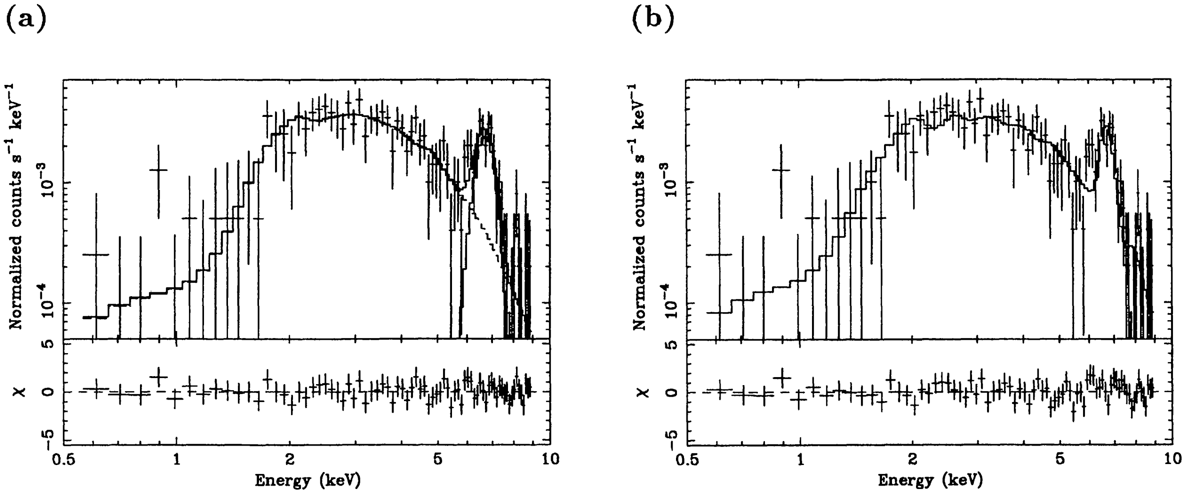

Fig. 3. Background-subtracted X-ray spectrum of the transient AX J1842.8−0423, obtained with the GIS (GIS 2+GIS 3) using a data integration radius of $2'$. The solid histograms represent the best-fit model to the data. The best-fit parameters are given in the text. (a) A fit with an absorbed power law and a Gaussian distribution with a free width. (b) A fit with the plasma emission model wherein the abundances are allowed to float under the constraint of the solar ratios.

the ionization degree specified by the continuum temperature (assuming ionization equilibrium), and the relatively high temperature explains the apparent lack of low-energy lines.

4. Discussion

We discovered a new transient X-ray source, AX J1842.8−0423, in the Scutum arm region. The spectrum is represented by either a power-law model with a Gaussian line, or a high-metallicity plasma emission model. Although the object falls in the $0^{\circ}\!.2 \times 4^{\circ}\!.0$ elongated error region of the Ginga source No.3 (Koyama et al. 1990), the two objects are unlikely to be identical, because the photon index of the present source ($\sim$ 2.9) is much larger than that of the Ginga source (1.9 ± 0.2).

4.1. Distance and Luminosity Estimates

According to Koyama et al. (1990), the high concentration of X-ray transients at $l \sim 30^{\circ}$ may be understood by presuming that these sources are located at a distance of $\sim$ 10 kpc from us, where our line-of-sight becomes tangential to the Scutum arm. All of these Ginga transients exhibit a heavy photoelectric absoprtion of $N_{\mathrm{H}} \sim 10^{23}$ cm^{-2}, which is thought to be mostly interstellar (Koyama et al. 1990). In comparison, the present transient, AX J1842.8−0423, exhibits a somewhat lower absorption, indicative of a closer distance. We hence denote the distance of AX J1842.8−0423 as d_5, in unit of 5 kpc.

Then, the absorption-corrected 2–10 keV luminosity becomes $1.6 \times 10^{34} d_5^2$ erg s^{-1}. If the absorption is partially intrinsic to the source, d_5 can be considerably smaller than unity, and hence the luminosity may be reduced.

4.2. Nature of AX J1842.8−0423

Can AX J1842.8−0423 be an X-ray pulsar? X-ray pulsars typically have luminosities in the range of 10^{34-38} erg s^{-1}, with a photon index of 0.5–1.5 (White et al. 1983; Nagase 1989). The luminosity of AX J1842.8−0423, as estimated above, is reasonable for an X-ray pulsar. Although the observed spectral slope is significantly steeper than those of typical X-ray pulsars, some "anomalous" pulsars (e.g., Corbet, Mihara 1997) exhibit photon indices in the range 3–4, like the present object. However, an X-ray pulsar would not normally exhibit Fe-K lines with equivalent widths in excess of $\sim$ 1 keV (Nagase 1989). Even when an X-ray pulsar emits unusually strong Fe-K lines, e.g., during binary eclipses, there is a dominant contribution from the fluorescent 6.4 keV component (Nagase et al. 1994), in disagreement with the observed line energy of $\sim$ 6.8 keV. These facts, together with the non-detection of coherent pulsation, argue against this source being an X-ray pulsar.

Given the successful thin-thermal fit (figure 3b), we prefer an interpretation in terms of optically thin emission from a hot plasma with a temperature of $\sim$ 5 keV. Figure 4 summarizes the available constraints on the size r and the electron density n_{e} of the candidate plasma, assuming it to be a uniform sphere. The source size must be $r \lesssim 0.5$ ly, because the source declined in half

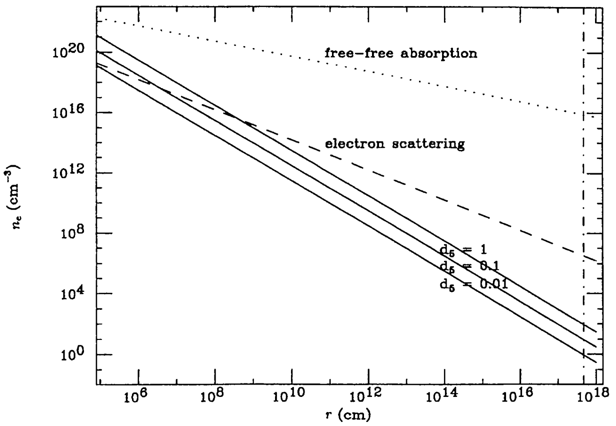

Fig. 4. Constraints on the size r and the electron density n_e of the source. The solid lines indicate the emission measure for a distance of 5 kpc ($d_5 = 1$), 500 pc ($d_5 = 0.1$), and 50 pc ($d_5 = 0.01$). Along the dashed line, the optical depth for electron scattering becomes unity, and along the dotted line that for free–free absorption becomes unity. The dash-dotted line represents the size upper limit set by the transient time scale.

a year. The observed source flux constrains the emission measure according to $n_e^2 r^3 \sim 9 \times 10^{56} d_5^2$ cm^{-3}. In order for the source to be optically thin against electron scattering, we require $n_e r < 1.6 \times 10^{24}$ cm^{-2}. Similarly, the optically thin condition for free–free absorption requires $n_e^2 r < 3.0 \times 10^{49}$ cm^{-5}, assuming an electron temperature of 5 keV and one solar abundance. (The results are not much affected if an abundance of 3 × solar is employed.) Therefore, putting aside the unusually large abundance, the data may be interpreted consistently in terms of optically thin emission from a plasma with $r = 10^{8.5-17.7}$ cm if we assume $d_5 = 1$. Smaller sizes are allowed if d_5 is decreased.

What is the nature of this hot plasma source? Although the large abundance reminds us of a supernova remnant, the transient nature rules out this interpretation. In view of the thin-thermal nature and the allowed source size (figure 4), the object may be either a white-dwarf (WD) binary, or a stellar coronal source. In these cases, the source distance should be considerably smaller than 5 kpc, e.g., $d_5 = 0.1$–0.01, because these objects have X-ray luminosities in the range of 10^{30-32} erg s^{-1}. This, in turn, requires the observed absorption to be mostly intrinsic, rather than interstellar. Such an intrinsic absorption up to several-times 10^{22} cm^{-2} is not rare among WD binaries, while quite unusual among coronal sources. Therefore, AX J1842.8−0423 can be a close binary containing a WD. The continuum temperature of ~ 5 keV and the transient nature are both consistent with this interpretation. Particularly, the so-called AM Herculis-type objects (or "polars"), in which the WD rotation is phase-locked to the orbital revolution, can often become transient X-ray sources (e.g., Warner 1995).

If the source is actually an AM Herculis-type object at a typical distance of 100 pc, the mass-donating star is expected to have an optical V-mag of 12 or so. We hence searched the catalogue of cataclysmic variables (Lewin et al. 1999) for a possible counterpart. However, none was found. Optical searches in more general sense are practically impossible, because the source location is subject to a rather large uncertainty (~ 3′) and the region, right on-plane, is very crowded. A search through radio catalogues yielded one positional coincidence with a source designated PMN 1842−0423 (Giffith et al. 1995). However, this source is classified as an H II region, and may not be related to AX J1842.8−0423.

4.3. The Strong Iron-K Line

Assuming that the WD-binary interpretation gives a possible account of the object, the remaining problem is how to interpret the very high metallicity. Although WD binaries often exhibit highly ionized Fe-K lines, the implied abundances are usually sub-solar (Ishida et al. 1994). Therefore, the present object may be in some extraordinary condition; either the accreting matter is abnormally metal-enriched, or some special mechanism apparently enhances the Fe-K line.

As for the latter possibility, we notice that the accretion column of a magnetized WD is usually quite opaque to resonance scattering of the Fe-K lines (Hellier et al. 1998). Then, if the emission region at the magnetic pole has a flat coin-shaped geometry, the resonance scattering will make the Fe-K line photons escape preferentially along the magnetic axis. This can enhance the line equivalent width up to a factor of 2 or so. An additional collimation of the Fe-K line photons may be achieved by the vertical velocity gradient in the post-shock emission region, because the associated Doppler effect would reduce the resonant trapping of Fe-K photons along the field line. If, furthermore, the object is an AM Herculis-type viewed nearly pole-on to its orbital plane (as well as to one of the magnetic poles), an enhanced Fe-K line would be observed together with little orbital intensity modulation. In this geometry, the pre-shock accretion stream would intervene between the emission region and the observer, causing the intrinsic absorption. Furthermore, the limited condition of the pole-on geometry explains why objects like the present one are rather rare. Thus, all essential features of the source may be qualitatively explained.

The above possibility is empirically supported by X-ray observations of several magnetic WD binaries. For example, the AM Herculis-type binary RX J1802+1804 (Ishida et al. 1998) exhibits a continuum temperature of 7 keV, an Fe-K line equivalent width of 4 keV, and insignificant X-ray variability in the ASCA band. Therefore, this object shares many important characteristics with the present transient, AX J1842.8−0423. Furthermore, another AM Herculis-type object, AX J2315−592, which is a transient source and is likely to be viewed nearly pole-on, exhibits an iron abundance as high as 3 solar (Misaki et al. 1996). These examples suggest that the apparent enhancement of the iron lines is a common feature of AM Herculis-type objects with nearly pole-on inclination, and that AX J1842.8−0423 belongs to the same class. A more detailed mumerical evaluation of this scenario will be reported elsewhere.

Although AX J1842.8−0423, itself, may be difficult to observe again, some useful information can be obtained by studying other AM Herculis-type objects. Specifically, we may observe those AM Herculis-type objects of which our line-of-sight is known to become nearly pole-on over certain phase intervals of their rotation. If the Fe-K line becomes significantly stronger during the pole-on phase, our hypothesis would be significantly reinforced.

We thank the members of the ASCA team for spacecraft operation and data acquisition. Our particular thanks are due to the ASCA galactic plane survey team, lead by Prof. S. Yamauchi, for allowing us to use the survey data obtained in 1997.

References

Corbet R.H.D., Mihara T. 1997, ApJ 475, L127

Gendreau K.C., Bautz M., Ricker G. 1993, Nuc. Instr. Meth. A355, 318

Griffith M.R., Wright A.E., Burke B.F., Ekers R.D. 1995, ApJS 97, 347

Hayakawa S., Itoh K., Matsumoto T., Uyama K. 1977, A&A 58, 325

Hellier C., Mukai K., Osborne J.P. 1998, MNRAS 297, 526

Ishida M., Greiner J., Remillard R.A., Motch C. 1998, A&A 336, 200

Ishida M., Mukai K., Osborne J.P. 1994, PASJ 46, L81

Kaneda H. 1997, PhD Thesis, The University of Tokyo

Kaneda H., Makishima K., Yamauchi S., Koyama K., Matsuzaki K., Yamasaki N.Y. 1997, ApJ 491, 638

Kinugasa K., Torii K., Hashimoto Y., Tsunemi H., Hayashida K., Kitamoto S., Kamata Y., Dotani T. et al. 1997, ApJ 495, 435

Koyama K., Kawada M., Kunieda H., Tawara Y., Takeuchi Y., Yamauchi S. 1990, Nature 343, 148

Koyama K., Makishima K., Tanaka Y., Tsunemi H. 1986, PASJ 38, 121

Lewin W.H.G., van Paradijs J., van den Heuvel E.P.J. (ed) 1999, X-ray binaries (Cambridge University Press) in press

Makishima K., Tashiro M., Ebisawa K., Ezawa H., Fukazawa Y., Gunji S., Hirayama M., Idesawa E. et al. 1996, PASJ 48, 171

Masai K. 1984, Ap&SS 98, 367

Misaki K., Terashima Y., Kamata Y., Ishida M., Kunieda H., Tawara Y. 1996, ApJ 470, L53

Nagase F. 1989, PASJ 41, 1

Nagase F., Zylstra G., Sonobe T., Kotani T., Inoue H. 1994, ApJ 436, L1

Ohashi T., Ebisawa K., Fukazawa Y., Hiyoshi K., Horii M., Ikebe Y., Ikeda H., Inoue H. et al. 1996, PASJ 48, 157

Tanaka Y., Inoue H., Holt S.S. 1994, PASJ 46, L37

Tanaka Y., Shibazaki N. 1996, ARA&A 34, 607

Warner B. 1995, Cataclysimic Variable Stars (Cambridge University Press, Cambridge) ch5

White N.E., Swank J.H., Holt S.S. 1983, ApJ 270, 711

Worrall D.M., Marshall F.E., Boldt E.A., Swank J.H. 1982, ApJ 255, 111

Yamashita A., Dotani T., Bautz M., Crew G., Ezuka H., Gendreau K., Kotani T. et al. 1997, IEEE Trans. Nucl. Sci. 44, 847

Yamauchi S., Aoki T., Hayashida K., Kaneda H., Koyama K., Sugizaki M., Tanaka Y., Tomida H. 1995, PASJ 47, 189

Yamauchi S., Kaneda H., Koyama K., Makishima K., Matsuzaki K., Sonobe T., Tanaka Y., Yamasaki N. 1996, PASJ 48, L15

Yamauchi S., Koyama K. 1993, ApJ 404, 620