J. Astron. Space Sci. 14(1), 18–23 (1997)

ASCA X-RAY OBSERVATIONS OF TWO CONTACT BINARIES: SW LACERTAE AND W URSAE MAJORIS

C. S. Choi, U. W. Nam
Korea Astronomy Observatory
36-1 Hwaam, Yusong, Taejon 305-348, Korea
cschoi@hanul.issa.re.kr, uwnam@hanul.issa.re.kr

Y. Kim
Department of Astronomy and Space Science, Chungbuk National University
Cheongju 360-763, Korea
ykkim@astro.chungbuk.ac.kr

(Received April 20, 1997; Accepted May 20, 1997)

ABSTRACT

We present X-ray light curves and the energy spectra for two contact binaries SW Lac and W UMa, which are obtained from the ASCA (Advanced Satellite for Cosmology and Astrophysics) observations. We find that both sources show appreciable flux variations during the observations, and the variations are erratic and are not orbital-phase dependent. From a spectral analysis, we also find that the W UMa spectrum can be reproduced by a variable-abundance plasma model with a single temperature of $T_1 = 6.8 \times 10^6$ K, while the SW Lac spectrum requires two different temperatures: $T_1 = 6.5 \times 10^6$ K and $T_2 = 1.4 \times 10^7$ K.

1. INTRODUCTION

SW Lac (spectral type of G3~8 + G3~8 and orbital period $P_{orb} = 0.3207^d$) and W UMa (F8 + F8 and $P_{orb} = 0.3336^d$) are eclipsing contact binaries. SW Lac is also classified as a W UMa-type binary which shows continuous variations of optical light during a short orbital period of 0.2^d – 0.8^d (for a review see, Guinan & Giménez 1993, Rucinski 1993). It is generally believed that in the binary systems tidal interaction makes the component stars rotate synchronously with their orbital period. Therefore, it is expected that the binary systems would have a high coronal activity, causing the systems to appear as strong X-ray sources.

Since the first detection of X-ray emission from VW Cephei (Carroll *et al.* 1980), about 14 W UMa-type binaries (including the SW Lac and W UMa binaries) have been observed by Einstein (Cruddace & Dupree 1984) and ROSAT X-ray satellites (McGale *et al.* 1996). The measured X-ray luminosities are in the range of $10^{29} - 10^{30}$ erg s^{-1}, which are $10^2 - 10^3$ times brighter than the X-ray luminosity of the quiet Sun. It has been widely believed that the relatively high X-ray luminosity of this type of binaries are caused by the coronal activities enhanced by the magnetic field, which is generated by dynamo action in the convective zone of the component stars. The X-ray observations for the SW Lac and W UMa systems have revealed the following facts. The X-ray spectra of 0.1 – 4.0 keV band can be successfully reproduced by an optically-thin thermal plasma model with a combination of two different temperatures, $T_1 \approx 1 \times 10^6$ K and $T_2 \approx 9 \times 10^6$ K. The measured X-ray fluxes are $F_x = 3.6 - 6.1 \times 10^{-12}$ erg cm^{-2} s^{-1} for the SW Lac system and $F_x = 3.3 - 3.7 \times 10^{-12}$ erg cm^{-2} s^{-1} for the W UMa, respectively. In addition, no noticeable X-ray flux variation caused by eclipsing has been reported so far.

In this paper, we analyze the X-ray light curves and spectra of two contact binary systems SW Lac and W UMa, which are obtained from the ASCA observation.

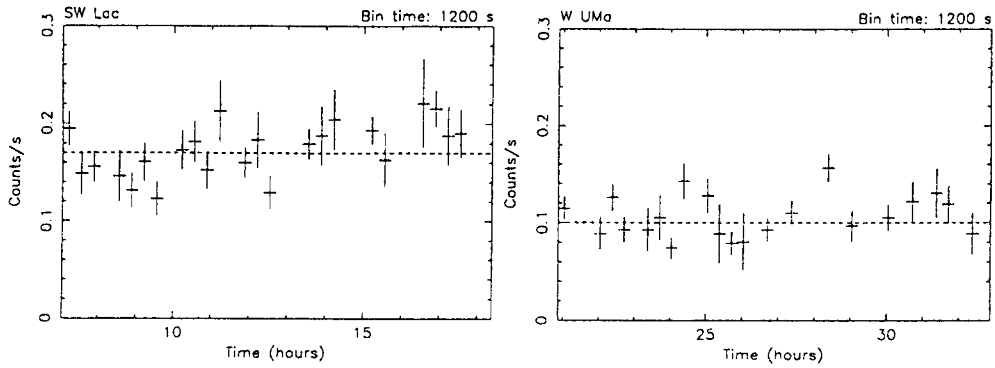
2. OBSERVATIONS

The observation of SW Lac was carried out on 1994 July 8 from 6:29 to 17:39 UT from the ASCA satellite, while W UMa was carried out on 1994 April 17 from 20:34 to 8:17 UT on the following day. These observations fully cover the orbital periods of the binaries. The ASCA satellite (Tanaka *et al.* 1994) is equipped with four thin-foil X-ray telescopes which focus X-rays onto four focal plane detectors, two of which are Solid-state Imaging Spectrometers (SIS0 & SIS1) and the other two are Gas Imaging Spectrometers (GIS2 & GIS3). The half-power diameter of point spread function of the telescopes is $\sim 3'$. Each SIS consists of 4 CCD chips with an energy resolution of about 2% at 6 keV and about 5% at 1.5 keV. The SISs were operated in 1-CCD mode for these observations, yielding a square field of view of $11.2' \times 11.2'$. On the other hand, the GISs have an energy resolution of about 7.7% at 6 keV, and provide a circular field of view of 50′ regardless of their observational mode. The detection limit of both the instruments is $F_x \sim 10^{-14}$ erg cm^{-2} s^{-1} for a typical exposure time of 40 ksec in the energy range of 2 – 10 keV. A spectroscopic study is possible for sources with fluxes greater than 10^{-12} erg cm^{-2} s^{-1}.

3. DATA ANALYSIS AND RESULTS

3.1 Light Curves

We use the SIS0 data in our analysis because they provide us an energy spectrum of high spectral resolution and sensitivity. The source data for each observation are extracted from the region of CCD centered from the image centroid and has widths of $\delta x = \pm 3.5'$ and $\delta y = \pm 4.0'$, while the background data are taken from source-free regions. The background has one order of magnitude smaller count rate than that from each source. We apply standard data analysis procedures (Day *et al.* 1995) to reject X-ray contamination by the bright Earth and by effects of the high-energy particle background regions. In this procedure, data are rejected when pointing direction of the telescope is less than 20° from the Earth's limb. Hot and flickering pixels are also removed from the SIS0 data. The net exposure times, after excluding contaminated data, are 13,320 s for SW Lac and 13,721 s for W UMa, respectively. The total count rate of the screened data is about 0.17 counts s^{-1} and 0.12 counts s^{-1} for SW Lac and W UMa, respectively, after the background subtraction.



(a) (b)

Figure 1. X-ray light curves for SW Lac (a) and W UMa (b). The crosses indicate the accumulated data with a time resolution of 1,200 s after background subtraction. The horizontal dashed lines represent a constant flux level.

In Figure 1a and 1b, we present the X-ray light curves obtained by using the SIS0 detector. The data are binned in 1,200 s intervals. From the light curves, we see clearly that there is no eclipsing feature although double minima are apparent in optical light curves (*see, e.g.*, Rucinski 1993 , Jeong *et al.* 1994). Instead, both light curves show erratic variations of X-ray flux with an amplitude of about a few ten percent. The data is fitted to a model with constant fluxes of 0.17 counts s^{-1} and 0.10 counts s^{-1} (dashed lines in the figure). We calculate χ^2–values to be χ^2/ν (degree of freedom) = 39.3/22 and = 43.8/20 for SW Lac and W UMa, respectively. These values implying that the flux fluctuation is substantial. We also investigate folded light curves, which are obtained by using the orbital periods and the ephemerides listed in Table 3 of McGale *et al.* (1996). However, we find no evidence that the flux variations are orbital-phase dependent.

3.2 Spectral Analysis

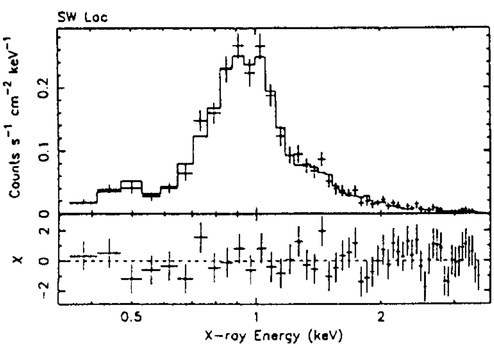
Figure 2a and 2b show the obtained spectra of SW Lac and W UMa, respectively. Each spectrum is extracted from the whole light curve data, and it is rebinned to provide better data statistics per bin. We truncate the data above $\sim$ 3 keV because not only the count rates are negligible in this energy region, but also they are insignificant in this spectral analysis.

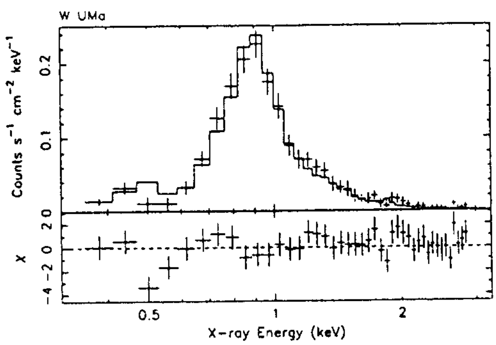
From recent ASCA observations of coronal X-ray sources, many investigators have pointed out that some available plasma models, such as that of Raymond & Smith (1977) and "meka"(Mewe *et al.* 1986, Kaastra & Mewe 1993) model, do not provide a sufficiently good fit to the obtained spectra particularly in the energy region of 0.7 – 1.5 keV. Most recently, Mewe *et al.* (1995) developed a new version of the meka code (so called "mekal") for better fits to the data. This code actually gives a better fit to the Fe L-shell emission region of $\sim$ 0.9 – 1.3 keV. This code includes line emissions from several elements, *i.e.*, He, C, N, O, Ne, Na, Mg, Al, Si, S, Ar, Ca, Fe, and Ni. Therefore, we adopt the mekal code. To fit the obtained spectra, we also use the XSPEC spectral analysis package (version 9.0).

Table 1. Best-fit results for the obtained two spectra.

Parameters	Units	Best-fit values	
		SW Lac	W UMa
T_1	10^7 K	$0.65^{+0.05}_{-0.06}$	$0.68^{+0.03}_{-0.03}$
EM$_1$[a]	10^{52} cm^{-3}	$6.97^{+1.36}_{-1.06}$	$6.96^{+1.57}_{-1.50}$
T_2	10^7 K	$1.37^{+0.18}_{-0.14}$	...
EM$_2$[a]	10^{52} cm^{-3}	$9.44^{+1.42}_{-1.31}$	...
N_H^b	10^{20} cm^{-2}	< 1.8	< 2.7
Abundances[c]		$0.41^{+0.21}_{-0.12}$	$0.24^{+0.08}_{-0.06}$
Flux[d]	10^{-12} erg cm^{-2} s^{-1}	3.50	2.36
χ^2/ν		41.88/48	41.43/40

NOTE: Errors and upper limits are determined at 90% confidence level for a single parameter.
[a] Emission Measure EM $\equiv \int n_e^2\, dV$. we adopt the distances 65 pc for SW Lac and 46 pc for W UMa.
[b] The hydrogen equivalent absorption column density.
[c] Coronal element abundances are relative to solar photospheric values (Anders & Grevesse 1989).
[d] Calculated in the energy range of 0.4–3.0 keV.





(a) (b)

Figure 2. X-ray spectrum of SW Lac (a) and W UMa (b). Each of the spectra was extracted from the whole data of the light curve. In the figures, the crosses and the solid lines represent the data and the best-fit model curve, respectively.

The best-fit (solid lines) to the observed spectra are shown in Figure 2a and 2b. The best-fit parameters and their 90% confidence uncertainties are listed in Table 1. In the fitting process, we allow the elemental abundances to vary relative to the solar photospheric values (Anders & Grevesse

1989). In our analysis, we do not include interstellar/circumstellar matter absorption, because we find no significant absorption feature from the obtained spectra. We find the upper limits of the absorption column density to be $N_H < 1.8 \times 10^{20}$ cm^{-2} and $N_H < 2.7 \times 10^{20}$ cm^{-2} for SW Lac and W UMa, respectively. From this analysis, we find that unlike the spectral analysis by McGale *et al.* (1996), which requires a two-temperature model to fit both spectra, our result indicates that the W UMa spectrum can be better described by a single-temperature model with variable abundances. On the other hand, the SW Lac spectrum requires a two-temperature model for acceptable fit. The derived coronal element abundances for both binaries are lower by a factor of 4 compared to that of the solar photosphere.

4. DISCUSSION

Followings are the findings we obtain from the analysis of the light curves. The averaged fluxes during the observations are $F_x = 3.5 \times 10^{-12}$ erg cm^{-2} s^{-1} (0.4 – 3.0 keV) for SW Lac and $F_x = 2.4 \times 10^{-12}$ erg cm^{-2} s^{-1} for W UMa. These fluxes are consistent with those measured by Cruddace & Dupree (1984), when we extend the energy band to their one (0.1 – 4.0 keV). We find no eclipsing feature from the X-ray light curves, although primary and secondary eclipses are evident in optical light curves (Rucinski 1993, Jeong *et al.* 1994). This can be explained by an extended nature of coronal plasma which is possibly larger than the extent of the component stars. We also find that the fluctuation of the flux is considerable to the constant fluxes of 0.17 counts s^{-1} and 0.10 counts s^{-1}. This variations may indicate that coronal plasma are distributed inhomogeneously within the binary systems, i.e., non-uniformly distributed magnetic loops around the component stars.

From the spectral analysis, we find that the W UMa spectrum can be reproduced by the mekal model with a single temperature of $T = 6.8 \times 10^6$ K. This is inconsistent with the result of McGale *et al.* (1996) which requires two temperatures for fitting. By contrast, the SW Lac spectrum is better fitted by the two temperatures of $T_1 = 6.5 \times 10^6$ K and $T_2 = 1.4 \times 10^7$ K. The different temperature structure between the two sources is not unexpected because the SW Lac spectrum (Fig. 2a) shows two spectral peaks at $\sim$ 1 keV while the W UMa spectrum (Fig. 2b) shows a single peak at $\sim$ 0.9 keV. Cruddace & Dupree (1984) analyzed X-ray spectra of 44i Bootis (G2 + G2 and $P_{orb} = 0.2678^d$) and VW Cephei (G8 + K0 and $P_{orb} = 0.2783^d$) observed from the Einstein satellite. According to their study, both spectra of those binaries could be described by a two-different coronal temperatures, $T_1 \approx 6.4 \times 10^6$ K and $T_2 \approx 3.5 \times 10^7$ K. From this result, we readily find that the cooler component of $T \approx 6 \times 10^6$ K is consistent with our estimate. In addition, the plasma temperature of the W UMa system is also consistent with the cooler component. It may be that the cooler temperature is common in W UMa-type binaries. There is a factor of 2 difference between ours and Cruddace & Dupree's determination of temperatures of the hotter component, although they have similar spectral types and rotational periods. However, we note that this might be due to poor statistics in the data above $\sim$ 1.5 keV mainly caused by short exposure time. The ASCA and Einstein observations are still not enough to constrain temperatures of these type binaries accurately.

Additionally, the high spectral resolution and sensitivity provided by the ASCA/SIS enable us to study the element abundances of coronal X-ray sources. According to recent studies about late-type binaries such as RS CVn- and Algol-type binaries (Antunes *et al.* 1994, Singh *et al.* 1996), the derived element abundances (*e.g.*, O, Ne, Mg, Si, S, Fe etc.) are low by a factor of 2–4 compared to those of the solar photosphere. We arrive at a similar result of element abundances, although our data is not sufficient enough for the precise determination of element abundances.

ACKNOWLEDGEMENTS: The authors would like to thank Dr. Han, Cheongho for careful reading of the manuscript. This research makes use of data obtained through the High Energy Astrophysics Science Archive Research Center Online Service, provided by the NASA/Goddard Space Flight Center. Support for this study was provided in part by the research project 97-5600-000 of the Korea Astronomy Observatory.

REFERENCES

Anders, E. & Grevesse, N. 1989, Geochim. Cosmochim. Acta, 53, 197

Antunes, A., Nagase, F. & White, N. E. 1994, ApJ, 436, L83

Carroll, R. W., Cruddace, R. G., Friedman, H., Byram, E. T., Wood, K., Meekins, J., Yentis, D., Share, G. H. & Chubb, T. A. 1980, ApJ, 235, L77

Cruddace, R. G. & Dupree, A. K. 1984, ApJ, 277, 263

Day, C. S. R., Arnaud, K., Ebisawa, K., Gotthelf, E., Ingham, J., Mukai, K. & White, N. E. 1995, The ABC Guide to ASCA Data Reduction (Greenbelt: NASA/GSFC)

Guinan, E. F. & Giménez, A. 1993, in The Realm of Interacting Binary Stars, eds. J. Sahade, G. E. McCluskey, Jr. & Y. Kondo (Kluwer: Dordrecht), 51

Jeong, J. H., Kang, Y. W., Lee, W. B. & Sung, E. C. 1994, ApJ, 421, 779

Kaastra, J. S. & Mewe, R. 1993, A&AS, 97, 443

McGale, P. A., Pye, J. P. & Hodgkin, S. T. 1996, MNRAS, 280, 627

Mewe, R., Kaastra, J. S. & Liedahl, D. A. 1995, Legacy, 6, 16

Mewe, R., Lemen, J. R. & van den Oord, G. H. J. 1986, A&AS, 65, 511

Raymond, J. C. & Smith, B. W. 1977, ApJS, 35, 419

Rucinski, S. M. 1993, in The Realm of Interacting Binary Stars, eds. J. Sahade, G. E. McCluskey, Jr., & Y. Kondo (Kluwer: Dordrecht), 111

Singh, K. P., White, N. E. & Drake, S. A. 1996, ApJ, 456, 766

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