Discovery of possible non-thermal emission from AM Hercules in the very low state with *Suzaku*

– The second white dwarf pulsar ?? –

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Abstract

In order to search for a second "white dwarf pulsar" (Terada et al. 2008) as a possible particle accelerator of cosmic-rays via rotating magnetic field, an X-ray observation of a promising magnetic cataclysmic variable, AM Her, was performed with Suzaku satellite in November 2008. The object was in the very low state according to the AAVSO optical magnitude, and the X-ray flux during the Suzaku observation was two order of magnitude lower than that taken with Chandra in 2004 in low state. Clear spin modulation was observed in the soft energy band, having the same spin phase as that in the high state with *ASCA* due to the thermal-plasma modulation, whereas shallower spin modulation was observed in harder energy bands. The X-ray spectra can be described by two kinds of model; double thermal plasmas or thermal plasma with power law component, representing thermal or non-thermal origin in hard X-ray band, respectively. The best fit parameters in the former model show too high temperature as > 11 keV and too low abundance as 0.06 ± 0.02 solar. The latter model represents a 1.1 ± 0.1 keV plasma with an abundance of $0.8^{+0.4}_{-0.2}$ solar, and a non-thermal component with the photon index of 2.2 ± 0.2. If the latter model is true, AM Her can be a second white dwarf pulsar with the non-thermal X-ray flux of 4.1×10^{-29} erg/s at 91 pc distance in 0.5 - 10 keV band, which is similar to the AE Aqr case of 6.6×10^{-29} erg/s at 102 pc.

Key words: acceleration of particles – novae, cataclysmic variables – stars: individual (AM Herculis)

1. Introduction

The origin of Cosmic-rays is a long-standing mystery for about 100 years since Hess's discovery. Many active astrophysical objects, like neutron star pulsars, shock regions in supernova remnants, active galactic nuclei, are considered as candidates of the origin of cosmic-ray particles, but there still remains quantitative problems. Recently, *Suzaku* discovered a possible non-thermal pulsation from a magnetic white dwarf(WD), AE Aqr (Terada et.al 2008b), like neutron star pulsars, and WDs are to be re-considered as a quiet-but-numerous particle-acceleration site, which may contribute an important part of soft Cosmic-rays. Here, since magnetic WDs have similar system as neutron star pulsars as rotating magnetic compact objects, AE Aqr is now called as a pulsar equivalent of WD or "WD pulsar".

2. Observation and Data Reduction

In order to search for a second WD pulsar, we have observed a promising magnetic WD, AM Her, which is a prototype star of polars in magnetic cataclysmic variables. The object is one of the two WDs from which both radio and TeV emissions from non-thermal particles are reported by many authors (Bastian et al. 1988; Chanmugam and Dulk 1982; Dulk et al. 1982; Meintjes et al. 1992; Meintjes et al. 1994; Bhat et al. 1991).

The *Suzaku* observed AM Her during the low state to avoid the strong thermal emission from the accretion column on the magnetic pole of the WD. The on-axis observation (OBSID 403007010) was achieved from 20:22:00 29 Oct. 2008 to 07:18:00 1 Nov. for 109 ksec, in addition to the background observation (OBSID 403008010) from 07:18 1 Nov. to 08:15 the next day for 44 ksec.

Table 1. Best Fit Parameters of AM Her Spectra in Quiescence

Model	kT_1 (keV)	kT_2 (keV)	$\Gamma^\dagger$ or Slope‡	Abundance (solar)	Flux§ (10^{-13} erg cm^{-2} s^{-1})	χ^2_ν (d.o.f)
MEKAL	$1.23^{+0.09}_{-0.13}$			$0.06^{+0.03}_{-0.02}$	$1.13^{+0.08}_{-0.11}$	1.30 (51)
CEMEKL		$6.57^{+3.63}_{-2.57}$	$-0.42^{+0.31}_{-0.18}$	$0.48^{+0.22}_{-0.21}$	$1.76^{+0.20}_{-0.54}$	0.32 (50)
MEKAL + MEKAL	$1.02^{+0.07}_{-0.11}$	> 11.1		0.06 ± 0.02	$1.79^{+0.21}_{-0.30}$	0.76 (49)
MEKAL + PL	1.10 ± 0.09		$2.36^{+0.15}_{-0.14}$	$0.80^{+0.40}_{-0.15}$	$1.73^{+1.27}_{-0.08}$	0.61 (49)

† Photon Index of the PL model. ‡ Power of the differential emission measure (DEM), $\alpha - 1$ as presented by $DEM \propto (T/T_{\max})^{\alpha-1} d(T)$ in the CEMEKL model (Done and Osborn 1997), or slope in the CFLOW model. § X-ray flux in 0.5 – 10 keV band.

3. Analyses and Results

The X-ray flux obtained with *Suzaku* was low as 1.8×10^{-13} ergs/s/cm^2 in 0.5 – 10 keV band; it is four order of magnitude lower than that observed in high state with *ASCA* (Ishida et al. 1997; Terada et al. 2004) or *Ginga* (Ishida et al. 1991; Beardmore et al. 1995), and two order of magnitude lower than *Chandra* result in another low state (Girish et al. 2007). After the barycentric correction (Terada et al. 2008a), we found a spin period at $P_{\rm xis} = 0.1289273(2)$ days on the BJD 2454771.852, which is consistent with previous observations. Fig. 1 shows the energy-resolved light curves folded at the period $P_{\rm xis}$. In the softer energy bands, clear spin modulations were found in the pulse profiles, whose spin phase was consistent with that in the high state (Fig. 1 bottom). Thus, this fact implies that the origin of the soft X-ray emission should arise from the thermal plasma of the accretion column. On the other hand, shallower modulations were seen in harder bands; it is consistent with being constant above 7 keV, indicating that hard X-rays may have another origin than thermal plasma.

The X-ray spectra could not be represented by single thermal model, MEKAL, as summarized in table 1. One possibility is a multi-temperature plasma from a post-shock materials in the accretion column, proposed by Hōshi (1973) and Aizu (1973), and the spectra can be described by such a cooling flow model named CEMEKL.

To search for other possibilities, we backed to a simple MEKAL model and tried to add another component in the harder X-ray band. We got statistically acceptable fittings both with thermal or non-thermal origins; MEKAL + MEKAL model or MEKAL + Power Law (PL) model, respectively. However, in the MEKAL + MEKAL model, the temperature of the higher plasma became high as > 11 keV and the best-fit metal abundance was very low as 0.06 ± 0.02, although normal accretion plasma has an abundance of sub-solar value. Thus, we concluded the double MEKAL is unphysical. On the other hand, another trial of MEKAL + PL presented reasonable results as shown in table 1; 1.1 ±0.1 keV plasma with normal metal abundance of $0.80^{+0.40}_{-0.15}$ solar. If this model is true, AM Her should be another "white dwarf pulsar" with a photon index of 2.2 ± 0.2 and a non-thermal X-ray flux of 4.1×10^{-29} erg/s at 91 pc distance in 0.5 - 10 keV band; this flux is similar to the AE Aqr case of 6.6×10^{-29} erg/s at 102 pc.

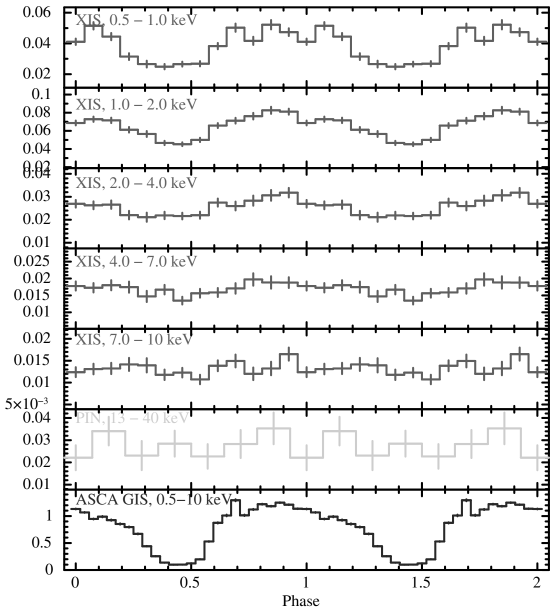

Fig. 1. Light curves folded at the spin period of $P_{\rm XIS} = 0.1289273$ days shown in 0.5 – 1.5, 1.5 – 4.0, 4.0 – 10.0, 13 – 40 keV bands from top to bottom panels, respectively. The upper four panels are taken with *Suzaku*, and the lowest panel shows the same plot but with *ASCA* GIS in 1993 (Terada et al. 2004). The phase 0.0 corresponds to BJD 2454771.852.

References

Aizu K 1973 Progress of Theoretical Physics, 50, 344
Bastian T. S et al. 1988 ApJ, 330, 518
Beardmore, A. P. et al. 1995 MNRAS, 272, 749
Bhat, C. L. et al. 1991 ApJ, 369, 475
Chanmugam G. and Dulk G. A 1982 ApJL, 255, L107
Dulk G. A et al. 1983 ApJ, 273, 249
Girish, V. et al. 2007 ApJ, 658, 525
Hōshi, R., 1973 Progress of Theoretical Physics, 49, 776
Ishida M. et al. 1991 ApJ, 367, 270
Ishida M. et al. 1997 MNRAS, 287,651
Meintjes P. J et al. 1992 ApJ, 401, 325
Meintjes P. J et al. 1994 ApJ, 434, 292
Terada Y. et al. 2004 PASJ, 56, 533
Terada Y. et al. 2008a PASJ, 60, S25
Terada Y. et al. 2008b PASJ, 60, 387