Constructing an Average Hard X-ray Spectrum of Intermediate Polars

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Abstract

Using wide-band X-ray spectra of Intermediate Polars (IPs) measured with Suzaku, we estimated white dwarf masses in each system, and compared them with that of non-magnetic cataclysmic variables. In addition to classical IPs whose masses are in good agreement with previous reports, we also successfully estimated masses of two IPs recently found by the INTEGRAL mission.

Key words: accretion, accretion disks – novae, cataclysmic variables – X-rays: binaries

1. Introduction

An Intermediate Polar (IP; e.g. Patterson 1994) is a binary system which consists of a moderately magnetized white dwarf (WD; B 0.1-10 MG) and a Roche-lobe-filling low mass companion, and is a subclass of magnetic cataclysmic variables. Because of its intense three Fe lines and high temperature optically thin thermal continuum ($kT > 10$ keV), some authors have been suggesting that they are the origin of the apparently extended X-ray emission along the Galactic plane (Revnivtsev et al. 2006, Krivonos et al. 2007) especially in the hard X-ray band.

To study this idea by comparing their spectra in the hard X-ray band where an IP thermal spectrum is thought to have an exponential cut off, we have been observing IPs using Suzaku. In this paper, we estimate WD masses of 17 IPs by fitting spectra with an emission model which involves few physical assumptions, and obtain their average mass to enable future comparison between IP spectra and that of the Galactic ridge emission.

2. Methods

2.1. How to estimate WD masses?

In magnetic CVs, gas accreting from a companion low-mass star is channeled with a strong magnetic field of a WD, and falls onto magnetic poles of the WD with almost its free-fall velocity. Near the WD surface, the velocity exceeds the sound velocity of the gas, and a shock stands thereby. The shock converts the bulk motion energy of the gas into its internal energy, namely

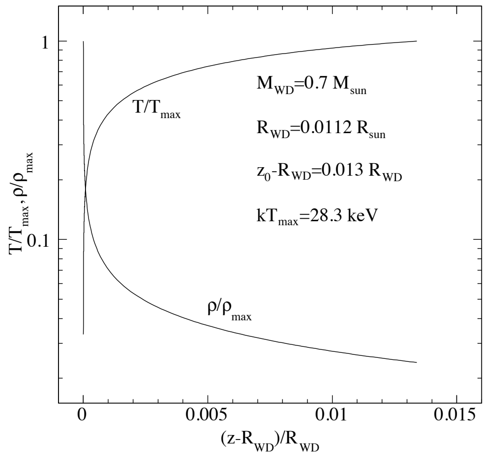

Fig. 1. Normalized density and temperature profiles of an accretion column for a 0.7-$M_\odot$ WD. Abscissa is a height from the WD surface.

the gas is heated. The temperature of the shock-heated gas simply depends on the depth of the gravitational potential of the WD. By equating a free-fall velocity and a boundary condition of a strong shock, the temperature can be written as,

$$kT = \frac{3}{8}\frac{GM}{R}\mu m_{\rm H} = 16\left(\frac{M_{\rm WD}}{0.5M_\odot}\right)\left(\frac{R_{\rm WD}}{10^9\ {\rm cm}}\right)^{-1}\ {\rm keV}. \quad (1)$$

With typical parameters of WDs, this temperature exceeds 10 keV, and thus a post-shock region filled with the heated gas emits hard X-rays. We can measure this temperature using X-ray data, and that results a relation between $M_{\rm WD}/R_{\rm WD}$. Since another WD mass-radius relation has been also constructed theoretically (e.g. Nauenberg 1972), $M_{\rm WD}$ and $R_{\rm WD}$ can be separately calculated by equating them. Using many X-ray satellites, multiple authors have been performing this estimation using, mainly, continuum spectra of magnetic CVs (e.g. Ishida 1991; Cropper et al. 1999; Ramsay 2000; Suleimanov et al. 2005; Brunschweiger et al. 2009).

Because of the high temperature, it requires a sensitive hard X-ray detector to measure the shock-temperature accurately based on a continuum spectrum. In addition to that, emission lines from heavy atoms also serves information of the gas temperature, and therefore, good energy resolution is appreciated especially below 10 keV. From these viewpoints, Suzaku, which has two complementary detectors of X-ray Imaging Spectrometer (XIS; Koyama et al. 2007) and Hard X-ray Detector (HXD; Takahashi et al. 2007; Kokubun et al. 2007), is very suitable for this study.

2.2. Model of an accretion column

In the present study, we utilized a 1-demensional accretion column model of Suleimanov et al. (2005) which takes into account the gravitational force of a WD inside the column. By assuming a free-fall ideal gas stream, a strong shock, a optically thin thermal cooling only, and soft landing onto WD atmosphere, we numerically solved the continuity, momentum conservation, energy conservation, and ideal-gas law, and obtained profiles of density and temperature for an assumed $M_{\rm WD}$ which is a free parameter.

We present the profiles calculated for $M_{\rm WD} = 0.7\ M_{\odot}$ in Figure 1. To construct a total emission spectrum from the accretion column and to perform spectral fittings, we convolved the profiles with a spectrum of a single temperature plasma.

3. Result and discussion

We fitted 17 IP spectra obtained with Suzaku XIS/HXD over the 3-40 keV band using the spectral model calculated above. We took into a patchy absorption (i.e. partial covering) caused by pre-shock gasses as previous reports (e.g. Cropper et al. 1999; Suleimanov et al. 2005). Table 1 lists the obtained best fitting WD masses. Although we do not present individual fitting statistics, fits are acceptable in all cases except for EX Hya which gave $\chi^2_\nu(\nu) = 1.22(1667)$. The result of classical IPs are in good agreement with the previous studies. It should be noted that WD masses of two IGR sources were also estimated.

In Figure 2, we compare the derived $M_{\rm WD}$ distribution with that of non-magnetic CVs (nmCVs) compiled by Ritter & Kolb (2003). Mean values are 0.78 and 0.83 $M_{\rm WD}$ for IP and nmCV, respectively. Although our IP sample is still small, the present result does not show large deviation from the nmCVs mass distribution. We expect that the sample will be increased by observing other INTEGRAL-found IPs (Barlow et al. 2006) that has no $M_{\rm WD}$ estimations so far.

Table 1. Estimated WD masses in units of $M_{\odot}$.

Name	$M_{\rm WD}$	Name	$M_{\rm WD}$
FO Aqr	$0.62^{+0.08}_{-0.03}$	EX Hya	$0.46^{+0.01}_{-0.02}$
XY Ari	$0.62^{+0.03}_{-0.03}$	NY Lup	$1.10^{+0.04}_{-0.06}$
MU Cam	$0.83^{+0.18}_{-0.12}$	GK Per	$0.75^{+0.46}_{-0.17}$
BG CMi	$0.90^{+0.39}_{-0.18}$	AO Psc	$0.43^{+0.03}_{-0.03}$
V709 Cas	$1.00^{+0.12}_{-0.11}$	V1223 Sgr	$0.81^{+0.03}_{-0.04}$
TV Col	$0.80^{+0.08}_{-0.06}$	RXS J2133	$1.00^{+0.18}_{-0.13}$
TX Col	$0.53^{+0.06}_{-0.05}$	IGR J17303	$1.00^{+0.17}_{-0.26}$
YY Dra	$0.59^{+0.05}_{-0.05}$	IGR J17195	$0.88^{+0.13}_{-0.12}$
PQ Gem	$1.20^{+0.08}_{-0.24}$		

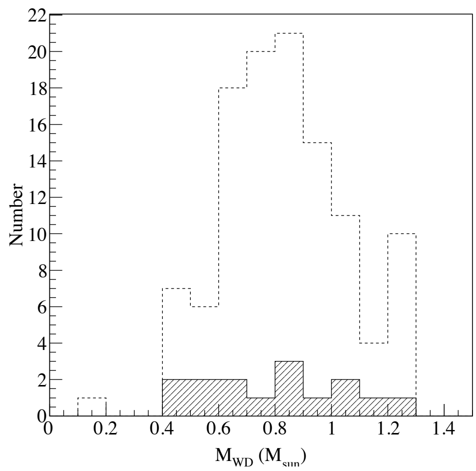

Fig. 2. $M_{\rm WD}$ distribution for 17 IPs (hatched region; this study) and 114 non-magnetic CVs (dashed line; Ritter & Kolb 2003).

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