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On the origin of the iron fluorescent line emission from the Galactic Ridge

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HIGHLIGHTS

- We resolved the 6.4, 6.7, and 7.0 keV lines.
- mCVs contributes 20% of the 6.4 keV line of GRXE.
- Significant contribution from hSSs to the 6.4 keV line of GRXE.

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ABSTRACT

The Galactic Ridge X-ray Emission (GRXE) spectrum has strong iron emission lines at 6.4, 6.7, and 7.0 keV, each corresponding to the neutral (or low-ionized), He-like, and H-like iron ions. The 6.4 keV fluorescence line is due to irradiation of neutral (or low ionized) material (iron) by hard X-ray sources, indicating uniform presence of the cold matter in the Galactic plane. In order to resolve the origin of the cold fluorescent matter, we examined the contribution of the 6.4 keV line emission from white dwarf surfaces in the hard X-ray emitting symbiotic stars (hSSs) and magnetic cataclysmic variables (mCVs) to the GRXE. In our spectral analysis of 4 hSSs and 19 mCVs observed with Suzaku, we were able to resolve the three iron emission lines. We found that the equivalent-widths (EWs) of the 6.4 keV lines of hSSs are systematically higher than those of mCVs, such that the EWs of the merged hSSs and mCVs are 179^{+46}_{-11} eV and 93^{+20}_{-3} eV, respectively. The EW of hSSs compares favorably with the typical EWs of the 6.4 keV line in the GRXE of 90–300 eV depending on Galactic positions. Average 6.4 keV line luminosities of the hSSs and mCVs are 9.2×10^{39} and 1.6×10^{39} photons s^{-1}, respectively, indicating that hSSs are intrinsically more efficient 6.4 keV line emitters than mCVs. We estimated required space densities of hSSs and mCVs to account for all the GRXE 6.4 keV line emission flux to be 2×10^{-7} pc^{-3} and 1×10^{-6} pc^{-3}, respectively. We also estimated the actual 6.4 keV line contribution from the mCVs with a known space density, which is as much as 20% of the observed GRXE flux, and for the hSSs, for which only five hSSs are known, we noted that they could contribute a significant percentage to the observed GRXE flux since we believe there is still more hSSs yet to be discovered in the Galaxy. We therefore conclude that the GRXE 6.4 keV line flux could be significantly explained by hSSs and mCVs 6.4 keV line flux.

1. Introduction

Presence of the seemingly extended hard X-ray emission from the Galactic Ridge has been known since early 1980s (Galactic Ridge X-ray Emission; GRXE: Worrall et al., 1982; Warwick et al., 1985; Koyama et al., 1986). Strong iron K-line emission at ~6.7 keV in the GRXE indicates its thermal plasma origin (e.g., Koyama et al., 1986; Yamauchi and Koyama, 1993). More precise iron line diagnostics of the GRXE has been made possible with X-ray CCD cameras on-board ASCA (Kaneda et al., 1997) and Chandra (Ebisawa et al., 2005). These instruments revealed that the line centroid energies in the GRXE are systematically lower than 6.7 keV (the energy expected from He-like ion in thermal equilibrium plasma), which imply that either the line emission is from non-ionization equilibrium plasma or there is an additional 6.4 keV fluorescent line emission. Suzaku, for the first time, resolved the GRXE iron line emission into three narrow lines, the from neutral or low ionized (6.4 keV), He-like (6.7 keV), and H-like (7.0 keV) ions (Ebisawa et al., 2008), concluding that the GRXE iron line emission is both from hot thermal plasmas and fluorescence by cold materials.

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Regarding the origin of the GRXE, there is a strong argument in favor of collection of faint point sources as opposed to diffuse emission (e.g., Revnivtsev et al., 2006, 2009, 2010; Krivonos et al., 2007 and references therein), although the question remains "what are these Galactic point sources?" Candidate point sources for the GRXE are cataclysmic variables (CVs) and active binaries (ABs). CVs are known to have such strong emission lines and hard spectra, but most of them are brighter than $\sim10^{31}$ erg s^{-1}, and their population may not be sufficient to account for all the GRXE. Revnivtsev et al. (2009) proposed that ABs dimmer than $\sim10^{31}$ erg s^{-1} are likely candidates to account for the majority of the GRXE. However, ABs are well known to have thermal but much softer continuum spectra than CVs. Yuasa (2010) proposed that intermediate polars (IPs), which are a subclass of magnetic CVs (mCVs), are main sources of the hard X-ray emission of the GRXE, giving support to the point source scenario for the origin of the GRXE. Yuasa, 2010 concluded that combination of IPs and ABs will explain most of the 6.7 keV and 7.0 keV emission lines in the GRXE as well as the continuum emission above 20 keV, whereas an *ad hoc* additional 6.4 keV line component is needed to explain the entire GRXE by the point source model.

This X-ray fluorescence is, on the other hand, believed by some authors to be due to irradiation of the molecular clouds by X-ray photons or it may be as result of cosmic-ray particle bombardment (Koyama et al., 1986, 2007; Doggrel et al., 1998, 2009; Murakami et al., 2000; Valinia et al., 2000; Yusef-Zadeh et al., 2007; Capelli et al., 2011). This is also likely, since the Galactic γ-ray *diffuse* emission above $\sim$100 keV is successfully explained by the cosmic-rays and interstellar matter interaction model (e.g., Strong et al., 2005).

In this paper, we study the origin of the 6.4 keV emission line in the GRXE, examining if this emission could be fully resolved by a collection of point sources. We focused on hard X-ray emitting symbiotic stars (hSSs) and magnetic CVs (mCVs) observed with the Suzaku satellite (Mitsuda et al., 2007), since they are known to be significant 6.4 keV line emitters (e.g., Ezuka and Ishida, 1999; Yuasa et al., 2010; Luna and Sokoloski, 2007; Smith et al., 2008; Keno et al., 2009; Eze, 2011). We studied 4 hSSs and 19 mCVs (one polar and 18 IPs), all observed with the Suzaku satellite, and estimated their contributions to the 6.4 keV line emission flux of the GRXE. Our goal is to determine if they are the main sources of the GRXE 6.4 keV line emission flux, or if some additional sources are required.

2. Data selection

Our target sources, hSSs and mCVs, were selected based on the fact that they have been observed with Suzaku and have strong Fe Kα emission lines with hard X-ray emission above 20 keV. All the four hard X-ray emitting symbiotic stars, SS73 17, RT Cru, T CrB, and CH Cyg observed with Suzaku were selected. In selecting the mCVs (polars and IPs), we used a CV catalog (Ritter and Kolb, 2003) and the IP catalog[1]. Five sources in the catalog, AE Aqr, AM Her, GK Per, 1RXS J070407.9 + 26250, and 1RXS J180340.0 + 40121 were dropped, even though observed with Suzaku, because they appear to had been too faint during their observations or have particular emission mechanism (AE Aqr: e.g., Wynn et al., 1997). A total of 23 sources were thus selected (Table 1).

3. Data analysis and results

Analysis of our data were done using version 2 of the standard Suzaku pipeline products, and the HEASoft[2] version 6.10. The data were reduced as follows: All data collected when the satellite was in the South Atlantic Anomaly were discarded for both the XIS sensors and the HXD PIN detectors. Also discarded, were the data obtained when the Earth elevation and Earth-day elevation angles were respectively less than 5° and 20°. These were done to reduce the effects of contamination due to the background X-ray spectrum. In majority of the sources we used a 250" radius to extract all events for the XIS detector for the production of the source spectra but in some cases where the 250" radius overlaps with the calibration sources at the corners, we adjusted the radius accordingly. The XIS background spectra were extracted with a 250″ radius with no apparent sources and were offset from both the source and corner calibrations. The radius was also adjusted accordingly in some cases where it overlaps with the calibration sources at the corners. Response Matrices File and Ancillary Response File were generated for the XIS detector using the FTOOLS `xisrmfgen` and `xissimarfgen` (Ishisaki et al., 2007), respectively. Suzaku XIS 0, 2, and 3 have front-illuminated (FI) chips with similar features, so we merged the spectra of XIS 0 and 3, which we hereafter refer to as XIS FI (XIS 2 has been out of service since November 9, 2006 due to an anomaly). XIS 1 is back-illuminated (BI), and we hereafter refer it to as XIS BI.

In the HXD PIN detector analysis, we used the non-X-ray background files and response matrix files appropriate for each observation provided by the Suzaku team. We used the `mgtime` FTOOLs to merge the good time intervals to get a common value for the PIN background and source event files. The source and background spectra extraction were done for each observation using the `xselect` filter time file routine. We corrected for the dead time of the observed spectra using the `hxddtcor` in the Suzaku FTOOLS. According to the standard analysis procedure, exposure time for all observations for the derived background spectra were increased by a factor of 10 to take care of the event rate in the PIN background event file which is made 10 times higher than the real background for suppression of the Poisson errors. We assumed a cosmic background model obtained with the HEAO-1 satellite (Boldt, 1987).

Table 1
The symbiotic stars, polars, and intermediate polars used in this work.

Source name	ObsID	Obs. start (UT) Date/time	Exp. (ks)
Symbiotic stars			
CH Cyg	400,016,020	2006-05-28/07:28	35.2
T CrB	401,043,010	2006-09-06/22:44	46.3
RT Cru	402,040,010	2007-07-02/12:38	50.9
SS73 17	403,043,010	2008-11-05/16:30	24.9
Polars			
V1432 Aql	403,027,010	2008-04-16/21:33	24.9
Intermediate polars			
NY Lup	401,037,010	2007-02-01/15:17	86.8
RX J2133.7 + 5107	401,038,010	2006–04-29/06:50	62.8
EX Hya	402,001,010	2007-07-18/21:23	91.0
V1223 Sgr	402,002,010	2007-04-13/11:31	46.2
MU Cam	403,004,010	2008-04-14/00:55	50.1
V2400 Oph	403,021,010	2009-02-27/11:42	110.0
YY Dra	403,022,010	2008-06-15/18:37	27.4
TV Col	403,023,010	2008-04-17/18:00	30.1
V709 Cas	403,025,010	2008-06-20/10:24	33.3
IGR J17303 – 0601	403,026,010	2009-02-16/10:09	27.7
IGR J17195 – 4100	403,028,010	2009-02-18/11:03	26.9
BG CMi	404,029,010	2009-04-11/12:11	45.0
PQ Gem	404,030,010	2009-04-12/13:46	43.2
TX Col	404,031,010	2009-05-12/19:19	51.1
FO Aqr	404,032,010	2009-06-05/08:14	33.4
AO Psc	404,033,010	2009-06-22/11:50	35.6
IGR J00234 + 6141	405,022,010	2010-06-25/00:06	77.4
XY Ari	500,015,010	2006-02-03/23:02	93.6

[1] http://asd.gsfc.nasa.gov/Koji.Mukai/iphome/catalog/alpha.html
[2] See http://heasarc.gsfc.nasa.gov/lheasoft/ for details.