Low-luminosity X-ray Sources and the Galactic Ridge X-ray Emission

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The Galactic Ridge X-ray Emission (GRXE)
**X-ray Spectrum of the GRXE**

Above 4 keV:
- Hard thermal continuum ($kT \sim 5-10$ keV)
- He-like and H-like Fe Ka lines (6.67/6.96 keV)
"Origin of the GRXE"

Very hot diffuse plasma

Unbound $\Rightarrow$ Needs $10^{43}$ erg s$^{-1}$ to replenish?

Emission of unresolved sources

What Galactic source population(s)?
GRXE 6.7-keV line $\leftrightarrow$ Galactic NIR light

Revnivtsev et al 2006
Resolving the Galactic Ridge X-ray Emission in a 1 Msec Chandra Observation

[Revnivtsev et al., 2009]

~ $8 \times 10^4$ sources per deg$^2$
X-ray Luminosity Function (XLF) of Galactic Source Populations

→ Luminous XRBs + CVs + Coronally-active stars and binaries (ABs)

Local volume emissivity of active stars and CVs
= $4.5 \pm 0.9 \times 10^{27}$ erg/s (2-10 keV) per $M_{\odot}$

Sazonov et al., 2006; Revnivtsev et al., 2006
A new hard-band selected sample of X-ray sources extracted from the XMM Slew Survey (Saxton et al 2008)

Initial sample of 487 "detections"
$S_X > 3 \times 10^{-12} \text{ erg s}^{-1} \text{ cm}^{-2}$ (2-10 keV)

Extragalactic sample of 219 sources (Warwick et al. 2013)

Galactic sample of 62 sources (Warwick 2014)
An XSS hard-band selected sample of low-luminosity Galactic X-ray sources

46 ASBs ➔ coronally-active dwarf stars and binary systems

16 CVs ➔ magnetic & non-magnetic cataclysmic variables

"Count-limited" sample

Warwick 2014
Source distances are the key to X-ray luminosities, space densities etc.\textcolor{red}{..}

![Graph showing the relationship between X-ray luminosity and distance for 46 ASBs and 16 CVs.]

\[ \text{Spectral Assumptions:} \]
\[ \text{Count/s } \rightarrow \text{ X-ray flux } \rightarrow \text{ X-ray luminosity} \]

\textbf{ASBs:} \[ kT = 3.5 \times 10^7 \text{ K (3 keV)} \] \textit{apec plasma with } \[ Z=0.4 \text{ } Z_\odot \]

\textbf{CVs:} \[ kT = 10 \text{ keV} \] \textit{thermal bremsstrahlung} + Fe lines

\textcolor{red}{★★★★ The coronally-active stars and binaries are preferentially observed in the 2-10 keV band during flare states. ★★★}
Derived X-ray Luminosity Functions

Local volume emissivity of ASBs:
\[ = 1.08 \pm 0.16 \times 10^{28} \text{ erg/s (2-10 keV) / } M_\odot \]

Local volume emissivity of CVs:
\[ = 2.5 \pm 0.6 \times 10^{27} \text{ erg/s (2-10 keV) / } M_\odot \]

[Referenced to a local mass density of 0.04 \( M_\odot / \text{ pc}^3 \)]

Warwick 2014
Derived 2-10 keV X-ray Luminosity Functions

Sazanov et al (2006) XLF

ASBs, CVs, XRBs

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Predicted 2-10 keV Source Counts in the Galactic Plane at $l = 28.5^\circ$

- ASBs
- CVs
- XRBs

- extragalactic sources

Coronally-active stars and binaries dominate at faint levels.
Comparison with Observations

ASCA – Sugizaki et al 2001

XMM – Hands et al 2004

Chandra – Ebisawa et al 2005

\( l = 28.5^\circ \)

\( l = 19^\circ - 22^\circ \)

\( l = 28.5^\circ \)

2 x 100 ks
Observed 2-10 keV Source Counts [normalized to $(S_X/10^{-14})^{-1.5}$]

Warwick 2014
Observed Versus Predicted Source Counts
[normalized to \((S_X/10^{-14})^{-1.5}\)]

ASBs  CVs  XRBs  ➞ extragalactic sources

Warwick 2014
Make-up of the X-ray source population on the Galactic Plane (at $l = 28.5^\circ$)

$\sim 37\%$ of Chandra sources have NIR IDs with $K < 15$
Make-up of the active star population at $S_X \sim 10^{-14}$ erg s$^{-1}$ cm$^{-2}$
(based on Ebisawa et al 2005 NIR data)

active dwarf stars

active binaries

Warwick 2014
Matching the intensity and X-ray spectrum of the GRXE

GRXE Surface Brightness (after subtracting the CXB)

\[ = 4.8 \times 10^{-11} \text{ erg/s/cm}^2 \text{/deg}^2 \text{ (2-10 keV)} \]

Continuum spectrum (>4 keV) \(~\text{CIE plasma at ~ 4 keV}\)
Matching the intensity and X-ray spectrum of the GRXE

Fe-K Line Equivalent Widths

- 6.4-keV line $\rightarrow$ 80 +/- 20 eV
- 6.67-keV line $\rightarrow$ 350 +/- 40 eV
- 6.96-keV line $\rightarrow$ 70 +/- 30 eV
Matching the intensity of the GRXE in the 2-10 keV band

Active Stars $\rightarrow$ 78 +/- 12 %
CVs $\rightarrow$ 16 +/- 4 %
Total $\rightarrow$ 94 +/- 13%

Warwick 2014
Matching the intensity of the GRXE in the harder 6-10 keV band

Active Stars → 62 +/- 10 %
CVs → 21 +/- 5%
Total → 83 +/- 11%

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Matching the measured equivalent widths of the 6.7/6.9-keV Fe-K lines

Step 1: Assume 20% contribution from CVs:
- 6.7-keV line EW ~ 150 eV
- 6.9-keV line EW ~ 100 eV
[eg. Warwick et al. 2013]

Step 2: Add 60%+ contribution from ASBs
Matching the Fe-K line EWs by varying the ASB temperature ($kT$) and abundance ($Z$).

Require Stellar Flares with $kT$ in the range 3-7 keV.
Matching the \( \sim 100 \) eV EW of the 6.4-keV Fe fluorescence line in the GRXE.

Step 1: Assume 20% contribution from CVs:
6.4-keV line EW \( \sim 50-100 \) eV

Step 2: Assume 60%+ contribution from ASBs:
6.4-keV line emission \( \rightarrow \) not generally seen!

Step 3: Assume 10%+ contribution from radiation of XRBs scattered by the ISM:
6.4-keV line EW \( \sim 1000 \) eV (wrt scattered continuum)

[NEXT TALK!]
Conclusions

• We have derived new estimates of the X-ray Luminosity Function (XLF) of coronally-active stars (ASBs) and CVs in the 2–10 keV band.

• Implied X-ray volume emissivity of ASBs+CVs is a factor 2-3 higher than previous estimates (for this hard band).

• ASBs dominate the 2–10 keV X-ray source counts in the Galactic plane at faint fluxes and contribute 60%+ of the GRXE intensity.

• ASBs + CVs + scattered emission can provide a match to the observed spectral form of GXRE including the EWs of the Fe-K lines.