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Talk Plan
1. Introduction
2. Analysis and Results
   1. X-ray
   2. NIR
3. Discussion
4. Summary
What is the Galactic Ridge X-ray Emission?

The Galactic Ridge X-ray Emission (GRXE)

- Apparently diffuse X-ray emission of low surface brightness has been known to exist along the Galactic Plane (|l|<45°, |b|<1°; Worral et al., 1982).
- $L_X \approx 2 \times 10^{38}$ erg/s (2-6 keV; Warwick et al., 1985)

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**X-ray Spectrum**

- Thermal spectrum (kT~5-10keV)
- Highly ionized emission line, especially strong Fe K lines (6.7 keV)

How to produce such high temperature X-ray Emission?
What makes the Fe K line of the spectrum?
→ It had been a mystery for about 30 years.

(Koyama et al. 1986)
Recently Progress

Recently, Revnivtsev et al (2009) has shown that the majority (~80%) of the Fe K-band emission was resolved into point sources using the deepest X-ray observations (~900 ks) made with the Chandra X-ray Observatory (good spatial resolution of ~0.5″).

The remaining problems are

“What are the populations constituting the GRXE?”

“Which class of sources contribute to the Fe K lines?”

Some candidates

- Magnetic cataclysmic variables (Yuasa et al., 2012, Hong et al., 2012)
- Late-type stars with enhanced coronal X-ray activity (Revnivtsev et al., 2011)
Candidates and Strategy

• However, it is difficult to constrain the nature of the sources from X-ray data alone, because most of these sources are detected only with a limited number of X-ray photons even with the deepest observations.

• Then, we focus on NIR.
  • NIR has almost the same penetrating power as the X-rays into deep interstellar extinction at Galactic Plane

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>1. X-ray</td>
<td>Detect X-ray point sources</td>
</tr>
<tr>
<td>2. NIR Imaging</td>
<td>Search NIR counterparts</td>
</tr>
<tr>
<td>3. NIR spectroscopy</td>
<td>Obtain NIR spectra of NIR identified sources</td>
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</tbody>
</table>
We studied two GRXE fields with deep X-ray observation using Chandra.

### X-ray and NIR Imaging Analysis

<table>
<thead>
<tr>
<th></th>
<th>Chandra Bulge Field (CBF)</th>
<th>Ebisawa field (EBF)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>X-ray</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Num. of sources</td>
<td>2,002</td>
<td>274</td>
</tr>
<tr>
<td>Satellite</td>
<td>Chandra/ACIS-I</td>
<td>Chandra/ACIS-I</td>
</tr>
<tr>
<td>Reference</td>
<td>Morihana et al. (2013)</td>
<td>Ebisawa et al. (2005)</td>
</tr>
<tr>
<td><strong>NIR Imaging</strong></td>
<td></td>
<td></td>
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<tr>
<td>IDed sources</td>
<td>222 (down to Ks~16 mag)</td>
<td>148 (down to Ks~15 mag)</td>
</tr>
<tr>
<td>Telescope</td>
<td>IRSF/SIRIUS</td>
<td>NTT/SofI</td>
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</table>
X-ray Results

We classified X-ray sources into three groups based on X-ray hardness (colors) and made composite X-ray spectrum of each group.

- Thermal emission (high temp)
- Fe line
- Low variability

- Thermal emission (high temp)
- Fe line
- Flare-like variability

- Thermal emission (low temp)
- No Fe line

Cataclysmic Variables

Late-type stars on flare

Late-type stars on quiescence

(Morihana et al., 2013)
1. Introduction

2. Analysis and Results

3. Discussion

4. Summary

**X-ray Results**

- We constructed combined spectra cumulatively from brightest to the faintest in hard group.

- **Hard and faint sources more contribute to the Fe K line.**

- X-ray flux of the Fe K line,
  - ~62% of the X-ray flux of the Fe K line comes from hard group (mainly CVs)
  - ~32% of them comes from medium group (mainly late-type stars on flare).

### Spectral fitting of Fe K line

<table>
<thead>
<tr>
<th>Group</th>
<th>$E_{\text{gm}}$ (keV)</th>
<th>EW$_{\text{gm}}$ (eV)</th>
<th>$F_{\text{pow}}/10^{-13}$ (erg cm$^{-2}$ s$^{-1}$)</th>
<th>$f_{\text{pow}}^{(PS)}$</th>
<th>$F_{\text{gm}}/10^{-13}$ (erg cm$^{-2}$ s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong> Hard (blue)</td>
<td>6.69$^{+0.05}_{-0.05}$</td>
<td>268$^{+244}_{-99}$</td>
<td>12.02$^{+0.58}_{-0.54}$</td>
<td>0.68$^{+0.04}_{-0.03}$</td>
<td>0.98$^{+0.12}_{-0.12}$</td>
</tr>
<tr>
<td><strong>B</strong> medium</td>
<td>6.70$^{+0.08}_{-0.08}$</td>
<td>413$^{+203}_{-210}$</td>
<td>5.01$^{+0.51}_{-0.55}$</td>
<td>0.28$^{+0.04}_{-0.03}$</td>
<td>0.50$^{+0.34}_{-0.19}$</td>
</tr>
<tr>
<td><strong>C</strong> soft (red)</td>
<td>6.74$^{+0.05}_{-0.04}$</td>
<td>581$^{+100}_{-131}$</td>
<td>27.22$^{+0.54}_{-0.54}$</td>
<td>0.04$^{+0.01}_{-0.01}$</td>
<td>&lt;0.04</td>
</tr>
<tr>
<td>All PS</td>
<td>6.70$^{+0.08}_{-0.08}$</td>
<td>321$^{+116}_{-122}$</td>
<td>17.18$^{+0.71}_{-0.70}$</td>
<td>...</td>
<td>1.58$^{+0.60}_{-0.51}$</td>
</tr>
<tr>
<td>Total emission</td>
<td>6.74$^{+0.05}_{-0.04}$</td>
<td>581$^{+100}_{-131}$</td>
<td>27.22$^{+0.54}_{-0.54}$</td>
<td>...</td>
<td>3.82$^{+0.50}_{-0.51}$</td>
</tr>
</tbody>
</table>

(Morihana et al., 2013)
We carried out NIR spectroscopic observations using Subaru/MOIRCS.

Normalized Intensity

WeIR spectra of identified X-ray sources

HI (Brγ), HeI, HeII emission

l-exposed 24 NIR spectra
**Source Classification**

<table>
<thead>
<tr>
<th>X-ray</th>
<th>NIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>hard</td>
<td>HI, HeI, HeII emission lines</td>
</tr>
<tr>
<td>medium</td>
<td>Absorption lines (F–M types)</td>
</tr>
<tr>
<td>soft</td>
<td>Absorption lines (F–M types)</td>
</tr>
</tbody>
</table>

- Cataclysmic Variables
- ? unexpected sources
- Late-type stars on flare
- Late-type stars on quiescence

- Most sources with hard X-ray spectrum (11 of 13) have NIR spectra with absorption lines.

- There is a possibility that the unexpected class sources are only with high extinction.

- We found that there is a possibility to exist new class sources.
Candidate population of new class sources

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2. Analysis and Results
3. Discussion
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Pre Cataclysmic Variables

- detached binaries including white dwarf and dwarfs
- NIR spectra: K, M-type spectra
- X-ray spectra: thermal spectra with Fe K line

Symbiotic binary

- detached binaries composed of white dwarf and red giants
- NIR spectra: K, M-type spectra
- X-ray spectra: thermal spectra with Fe K line

(Matranga et al. 2006) (Eze et al. 2010)
1. Introduction

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3. Discussion

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Summary

• We identified X-ray point sources with NIR.

• As the results, we found that X-ray hard sources most contribute (~67%) to the Fe K line emission of the GRXE.

• We carried out NIR spectroscopic observation for NIR identified sources of X-ray point sources using Subaru/MOIRCS.

• Based on X-ray and NIR spectral features, we found that hard and faint sources have NIR absorption lines.

• There is a possibility to exist new class of sources contributed to the GRXE.
Normalized counts/sec/keV

Energy (keV)

(Ebisawa et al., 2008)
X-ray spectra

We classified dim X-ray point sources into three groups based on X-ray hardness (hard, medium, soft)

• Thermal emission (high temp)
• Fe line
• Low variability

• Thermal emission (high temp)
• Fe line
• Flare-like variability

• Thermal emission (low temp)
• No Fe line

Cataclysmic Variables

Late-type stars on flare

Late-type stars on quiescence

(Morihana et al., 2013)
KS test (Kolmogorov-Smirnov test)

- The test examines the degree of non-uniformly in the degree of photon arrival times against a uniform distribution.

- $P_{KS} < 5 \times 10^{-3}$ — variable (101/1097)
- $5 \times 10^{-3} \leq P_{KS} < 5 \times 10^{-2}$ — marginally variable (316/1097)
- $P_{KS} \geq 5 \times 10^{-3}$ — non variable (680/1097)
EBF

(l,b)=(28.5,0.0) field observation

X-ray image
(Chandra)
274 X-ray sources
(Ebisawa et al., 2005)

2MASS

ESO, NTT/SOFI
148 sources Ided
Down to Ks~15 mag
(Ebisawa et al., 2005)

SUBARU
MOIRCS
Well-exposed
44 sources
NIR IDed late-type star CV Newclass