Measure Silicon X-ray absorption towards bright sources in the Galactic Bulge

How to measure the Si gas to dust ratio with Chandra HETG

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Outline

• Dust content with Si in interstellar matter with Chandra HETG

• Broadband hydrogen equivalent absorption comparison in bright Low-Mass X-ray Binaries: 4U 1636-53, Ser X-1, GX 3+1, 4U1728-34, 4U 1705-44, GX 340+0, GX 13+1, GX 5-1

• Goal: obtain Si gas to dust optical depth ratio toward 8 bright sources in the Galactic Bulge
Cross section per Hydrogen nucleus for the Weingartner & Draine (2001) dust model based on Crystalline Olivine.

Scattering contributes significantly to the extinction.
Scattering significantly contributes to the extinction

Corrales et al. 2016:
Data

- New Chandra data with very low systematic uncertainty

<table>
<thead>
<tr>
<th>sources</th>
<th>total exposure time</th>
</tr>
</thead>
<tbody>
<tr>
<td>4U 1636-53:</td>
<td>127.9 ks</td>
</tr>
<tr>
<td>4U 1705-44:</td>
<td>131.3 ks</td>
</tr>
<tr>
<td>4U 1728-34:</td>
<td>111.1 ks</td>
</tr>
<tr>
<td>GX 13+1:</td>
<td>141.8 ks</td>
</tr>
<tr>
<td>GX 3+1:</td>
<td>212.6 ks</td>
</tr>
<tr>
<td>GX 340+0:</td>
<td>144.9 ks</td>
</tr>
<tr>
<td>GX 5-1:</td>
<td>92.6 ks</td>
</tr>
<tr>
<td>Ser X-1:</td>
<td>120.3 ks</td>
</tr>
</tbody>
</table>

(See also Zeegers et al. 2017, Rogantini et al. 2019)
Bright sources in the Galactic Bulge

Wisconsin H-Alpha mapper (WHAM) survey

Sources labeled in Black: part of our current survey

Blue: our newly proposed data of the highly absorbed sources in the Galactic Bulge.
### Chandra nH v.s. Missions nH

(Broadband nH: 1-7 keV)

<table>
<thead>
<tr>
<th>ObsID</th>
<th>$N_{H,22}(1)^a$</th>
<th>Si (1)$^b$</th>
<th>$N_{H,22}(2)^c$</th>
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</thead>
<tbody>
<tr>
<td>Chandra</td>
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<td></td>
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<tr>
<td>2708</td>
<td>4.88 ± 0.04</td>
<td>2.1 ± 0.1</td>
<td>3.87 ± 0.27</td>
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<tr>
<td>11815</td>
<td>4.97 ± 0.03</td>
<td>2.1 ± 0.1</td>
<td>3.59 ± 0.25</td>
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<tr>
<td>11816</td>
<td>4.91 ± 0.04</td>
<td>2.1 ± 0.1</td>
<td>3.50 ± 0.26</td>
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<tr>
<td>11814</td>
<td>4.99 ± 0.03</td>
<td>2.0 ± 0.1</td>
<td>3.48 ± 0.26</td>
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<tr>
<td>11817</td>
<td>5.00 ± 0.03</td>
<td>2.0 ± 0.1</td>
<td>3.55 ± 0.25</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>RXTE</th>
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</table>

Inclusion of Scattering for various Missions
Broadband nH v.s. Si abundance

( abundance relative to ISM from Wilms, Allen, & McCray 2000 )
Gas Optical depth
previous data

- Si optical depth comparison between different instruments.

Schulz et al. 2016

Hydrogen column density broad band

Not comply with Wilms, Allen, McCray prediction
High resolution structure of the Si K edge

Only see this structure when look at the HETG grating data at the highest resolution.
2 eV resolution
Two extreme cases of High resolution structure in Si edges

Significant gas and dust optical depths

212.6 ks

Dominant dust, weak gas edge depths

92.6 ks

GX 3+1

GX 5-1
Optical depth
Gas v.s. dust

Case A: gas
Case B: gas + dust

Mathis, Rumpl, & Nordsieck (1977, MRN) constructed their classic interstellar dust model.
Summary and Outlook

We obtained gas to dust optical depth ratios for X-ray sources in the Galactic Bulge

- These ratios are data reliant, independent of any edge modeling
- The data show a variety of possibilities ranging from very dusty edges as for GX 5-1, several edges that are compatible with the MRN dust size distribution, to some edges indicating either larger grain sizes or little dust contribution
- We now focus on using silicate models (i.e. Zeegers et al. 2017) to determine mass column densities, abundance, and possibly modified cross sections
- We also will include ionized Si models (Gatuzz et al. 2020) in our final fits to account for possible variabilities.