The Magnificent Seven as soft X-ray sources

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In cooperation with:
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Outline

• The influence of absorption
• The inhomogenous interstellar medium
• A model ISM distribution
• Applications
• Outlook
• Summary
# The Magnificent Seven in X-rays

<table>
<thead>
<tr>
<th>Object</th>
<th>EPIC PN:</th>
<th>kT [eV]</th>
<th>N(H) ([10^{20} \text{ cm}^{-2}])</th>
<th>PM [mas/yr]</th>
<th>Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>RX J0420.0-5022</td>
<td></td>
<td>45</td>
<td>1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RX J0720.4-3125</td>
<td></td>
<td>85-95</td>
<td>1.2</td>
<td>97</td>
<td>Y</td>
</tr>
<tr>
<td>RX J0806.4-4123</td>
<td></td>
<td>96</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1RXS J130848.6+212708</td>
<td></td>
<td>86</td>
<td>4.3</td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>RX J1605.3+3249</td>
<td></td>
<td>96</td>
<td>2.0</td>
<td>145</td>
<td>Y</td>
</tr>
<tr>
<td>RX J1856.5-3754</td>
<td></td>
<td>60</td>
<td>0.7</td>
<td>332</td>
<td>N</td>
</tr>
<tr>
<td>1RXS J214303.7+065419</td>
<td></td>
<td>101</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Zane et al. 2005, Schw dope et al. 2005, Haberl et al. 2004

- soft blackbody-like spectra (\(\lesssim 90 \text{ eV}\))
- probable cyclotron lines
- no non-thermal spectral component
- nearby
The consequences of absorption

Only nearby X-ray thermal neutron stars at low N(H) found
⇒ more distant sources ⇒ harder & fainter
The inhomogenous Interstellar Medium

Within one kpc around the sun

The close solar neighbourhood

Galactic center

~1300 pc

~1700 pc

z=0 pc

Tunnel to GSH 238+00-250 pc

Galactic center

Lallement et al. 2003
Breitschwerdt et al. 2005

Henbest & Couper 1994

Ophiuchus clouds

Taurus dark clouds

Pleiades bubble

Loop I

Lupus Tunnel

Lupus clouds

Chamelecon

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Galactic center
A model for $N(H) - 1$. The solar neighbourhood

Lallement et al. 2003:
Na D absorption lines toward 1000 sight lines at $d<350$ pc

Line widths $\Rightarrow N(\text{Na}) \Rightarrow n(\text{Na})$ by inversion method (Vergely 2001)

Ferlet et al. 1985

$n(\text{Na}) \Rightarrow N(\text{Na}) \Rightarrow N(H)$

Drawbacks:

- Na is no perfect H tracer, especially for $H_2$; a priori $n(\text{Na})$
- Possible underestimation by 30% comparing to Na UV lines
- Not applicable for $\log N(\text{Na})<11$
A model for $N(H) - 2$. Radii larger than 230 pc

Analytical model:
Exponential density factors for $H \text{I} \& H_2$ according to
Popov et al. 2000,
Zane et al. 1995, Bochkarev 1992,
Dickey & Lockman 1990

Test:
• Open Cluster extinctions
  Piskunov et al. 2006
• Pulsar PSR B0656+14

Extinction model:
Combined extinction surveys
Hakkila et al. 1997

$E(B-V) \Rightarrow N(H)$
Paresce et al. 1984,
Predehl & Schmitt 1995,
**Application 1 – check distances**

In the direction of
**RX J1856.5-3754**
(l=359°, b=-17°)

For EPIC PN: 130 – 140 pc
(see talk by F. Haberl)

Kaplan et al. 2002: 140 ± 40 pc
Walter & Lattimer 2001: 117 pc

towards R CrA
@ 130 pc: 0.7 \(10^{20}\) cm\(^{-2}\)
@ 140 pc: 1.0 \(10^{20}\) cm\(^{-2}\)

<table>
<thead>
<tr>
<th>Source</th>
<th>(N(H)) ([10^{20}\text{cm}^{-2}])</th>
<th>Hom. (N(H))</th>
<th>Lal+analyt</th>
<th>Lal+Hak</th>
<th>Distances [pc]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RX J1856.5-3754</td>
<td>0.7</td>
<td>3.6 (_{140})</td>
<td>2.5 (_{135})</td>
<td>n.a.</td>
<td>130 - 140</td>
</tr>
<tr>
<td>RX J0420.0-5022</td>
<td>1.6</td>
<td>1.2 (_{140})</td>
<td>2.0 (_{135})</td>
<td>1.8 (_{135})</td>
<td>...340</td>
</tr>
<tr>
<td>RX J0720.4-3125</td>
<td>1.2</td>
<td>2.5 (_{140})</td>
<td>1.8 (_{135})</td>
<td>1.8 (_{135})</td>
<td>240 - 270</td>
</tr>
<tr>
<td>RX J0806.4-4123</td>
<td>1.0</td>
<td>1.3 (_{140})</td>
<td>n.a.</td>
<td>n.a.</td>
<td>235 - 245</td>
</tr>
<tr>
<td>RBS 1223</td>
<td>4.3</td>
<td>1.2 (_{140})</td>
<td>3.0 (_{135})</td>
<td>n.a.</td>
<td>...410</td>
</tr>
<tr>
<td>RX J1605.3+3249</td>
<td>2.0</td>
<td>2.3 (_{140})</td>
<td>3.1 (_{135})</td>
<td>n.a.</td>
<td>...420</td>
</tr>
<tr>
<td>RBS 1774</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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**Graph:**
- Popov 2000 / Zane et al 1995
- Lallement 2003
- Lallement 2003 + 30%
Application 2 – Population synthesis

Reminder: population synthesis by Popov et al. 2000, 2003:

- Gould Belt: 20 NS Myr\(^{-1}\)
- Gal. Disk (3kpc): 250 NS Myr\(^{-1}\)

• Cooling curves by Kaminker et al. 2002
• Flat mass spectrum

18°

Gould Belt

ROSAT

3 kpc

Arzoumanian et al. 2002

\(R_{GB} = 300..500 \text{ pc}\)
Population synthesis - recent improvements

1. Spatial distribution of progenitor stars

- Gould Belt: Hipparcos stars up to 400 pc
- Age: spectral type & cluster age (OB ass)
- Star associations birth rate $\sim N_{\text{star}}$
- Field stars

2. Spatial distribution of ISM
   + new cross sections & abundances

   instead of:

   now:
   (same scale)

Further improvements:
- Mass spectrum (see talk by S. Popov)
- Fainter XMM EPIC PN count rates
- Cooling curves (Grigorian et al. 2000, Popov et al. 2006)
First results

The new initial distribution of progenitor stars:

For comparison: ROSAT, old ISM distribution, masses etc. as before

Count rate > 0.05 cnts/s

Dark areas: ~ 0.001 sources / square degree

Outlook (1)

Different $\log N - \log S$ curve for distinct sky regions

Population synthesis for fainter (XMM) sources
X-ray thermal neutron star candidate search:

- at larger \(N(H)\) ŷ harder sources with XMM & ROSAT (difficult to distinguish from other objects)
- very faint soft XMM sources

Survey of the deepest XMM-Pointings

Special treatment at low energies
[0.15 .. 2.0 keV]
Summary

Interstellar absorption results in fainter and harder counterparts of X-ray thermal neutron stars

The ISM is highly inhomogenously distributed
Our N(H)-models account for it and can be used
• for distance estimations in the solar vicinity
e.g.
  RX J1856 : 135 ± 25 pc
  RX J0720 : 255 ± 25 pc
  RX J0806 : 240 ± 25 pc

• as ingredient in population synthesis models aiming for individual log N-log S curves in distinct sky regions

Considering the spatial distribution of progenitor stars in population synthesis results in an enhancement of predicted neutron star numbers towards some lines of sight in the sky