Lead-up from ROSAT to XMM-Newton

Joachim Trümper
XMM-Newton 20th anniversary at ESAC Madrid
December 2019
1990/91 ROSAT performed the first all sky survey with an imaging X-ray telescope in half a year - boosting the number sources from 841 (HEAO-1) to about 100,000. In the following 8 years it performed ten thousands of pointed observations for a wide astrophysical community.

Note that the numbers for some of the missions include publications from collimated instruments, e.g. in the case of EXOSAT from the ME-experiment.

In the following I will discuss five scientific topics illustrating the synergy between ROSAT and XMM-Newton.
1. ROSAT 1996: A great surprise: Comets emit X-Rays!

Electron exchange between solar wind ions neutral gas atoms of the coma (Cravens, 1997).

Until now more than 30 comets have been detected by ROSAT, EUVE, XMM-Newton & Chandra)

Comet C/2000 WM1 observed with XMM-Newton (K. Dennerl 2000)

The first XMM-Newton spectrum of a comet (K. Dennerl 2003)
Line Ratios for Solar Wind Charge Exchange with Comets

P.D. Mullen, R.S. Cumbee, D. Lyons et al. 2017

Comet C/2000 WM1 (linear)

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Charge exchange happens at any interface between hot plasma and cool gas
The shrapnells show Mach cones indicating supersonic velocities (Mach numbers 2.4 ... 4) in the surrounding hot ISM ($T \sim 10^6$ K). Obviously they represent compact fragments which are moving with higher velocity than the shock front.
X-ray Spectroscopy of Vela Shrapnel A with XMM-Newton

S. Katsuda & H. Tsunemi 2006

Table 1. Spectral-fit parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Head region in figure 1</th>
<th>Tail region in figure 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_H [10^{20} \text{ cm}^{-2}]$</td>
<td>$3.2^{+1.4}_{-0.4}$</td>
<td>$1.4^{+0.02}_{-0.01}$</td>
</tr>
<tr>
<td>$kT_e [\text{keV}]$</td>
<td>$0.52^{+0.01}_{-0.01}$</td>
<td>$0.37^{+0.01}_{-0.01}$</td>
</tr>
<tr>
<td>C</td>
<td>$2.5^{+0.2}_{-0.6}$</td>
<td>$2.8^{+0.5}_{-0.6}$</td>
</tr>
<tr>
<td>N</td>
<td>$0.55^{+0.06}_{-0.08}$</td>
<td>$0.5^{+0.1}_{-0.1}$</td>
</tr>
<tr>
<td>O</td>
<td>$0.34^{+0.01}_{-0.01}$</td>
<td>$0.4^{+0.01}_{-0.02}$</td>
</tr>
<tr>
<td>Ne</td>
<td>$1.07^{+0.04}_{-0.04}$</td>
<td>$1.28^{+0.09}_{-0.07}$</td>
</tr>
<tr>
<td>Mg</td>
<td>$0.87^{+0.08}_{-0.08}$</td>
<td>$0.96^{+0.07}_{-0.07}$</td>
</tr>
<tr>
<td>Si</td>
<td>$3.3^{+0.3}_{-0.3}$</td>
<td>$3.7^{+0.1}_{-0.1}$</td>
</tr>
<tr>
<td>Fe</td>
<td>$0.96^{+0.03}_{-0.03}$</td>
<td>$1.1^{+0.07}_{-0.07}$</td>
</tr>
<tr>
<td>log($\tau$) [$\text{s cm}^{-3}$]</td>
<td>$10.75^{+0.02}_{-0.02}$</td>
<td>$10.97^{+0.04}_{-0.03}$</td>
</tr>
<tr>
<td>EM[$\text{cm}^{-5}$]</td>
<td>$(2.35^{+0.1}_{-0.03}) \times 10^{17}$</td>
<td>$(0.53^{+0.04}_{-0.02}) \times 10^{17}$</td>
</tr>
<tr>
<td>$\chi^2$/d.o.f.</td>
<td>705/465</td>
<td>698/544</td>
</tr>
</tbody>
</table>

Silicon is overabundant in this and other shrapnels (e.g. G) indicating that they originate in deeper layers of the exploding star.

Note. — Other elements are fixed to those of solar values. The values of abundances are multiples of solar value. The errors are in the range $\Delta \chi^2 < 2.7$ on one parameter.

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Mere accident? Indication of a Si-reach bilateral jet of ejecta in the Vela SNR observed with XMM-Newton (Garcia et al 2017)

Summary of over-abundances in shrapnels of the Vela SNR:
A: Carbon, Silicon
G: Neon, Magnesium, Silicon
D: Oxygen, Neon, Magnesium,
That tells us about the depths the shrapnels are coming from

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3. The thermally emitting isolated neutron stars (XTINS alias Magnificent Seven) discovered by ROSAT

Compilation by F. Haberl 2018

<table>
<thead>
<tr>
<th>Object</th>
<th>$kT_{\infty}$ (eV)</th>
<th>$P$ (s)</th>
<th>p.f. $^a$ (%)</th>
<th>$\dot{P}$ (s s$^{-1}$)</th>
<th>$B_{\text{dip}}$ (10$^{13}$ G)</th>
<th>$\tau$ (Myr)</th>
<th>$t_{\text{kin}}$ (Myr)</th>
<th>$m_B^b$ (mag)</th>
<th>$d^c$ (pc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RX J0420.0–5022</td>
<td>48</td>
<td>3.45</td>
<td>17</td>
<td>$-2.8 \times 10^{-14}$</td>
<td>1.0</td>
<td>1.95</td>
<td>?</td>
<td>26.6</td>
<td>~345</td>
</tr>
<tr>
<td>RX J0720.4–3125</td>
<td>84–94</td>
<td>16.78</td>
<td>8–15</td>
<td>$-1.40 \times 10^{-13}$</td>
<td>5.0</td>
<td>1.91</td>
<td>0.85</td>
<td>26.6</td>
<td>$286^{+37}_{-23}$</td>
</tr>
<tr>
<td>RX J0806.4–4123</td>
<td>95</td>
<td>11.37</td>
<td>6</td>
<td>$-5.50 \times 10^{-14}$</td>
<td>2.5</td>
<td>3.24</td>
<td>?</td>
<td>&gt;24</td>
<td>~250</td>
</tr>
<tr>
<td>RX J1308.6+2127</td>
<td>100</td>
<td>10.31</td>
<td>18</td>
<td>$-1.12 \times 10^{-13}$</td>
<td>3.5</td>
<td>1.45</td>
<td>0.55/0.90/1.38</td>
<td>28.4</td>
<td>?</td>
</tr>
<tr>
<td>RX J1605.3+3249</td>
<td>100</td>
<td>?</td>
<td>&lt;2</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>0.45</td>
<td>27.2</td>
<td>~390</td>
</tr>
<tr>
<td>RX J1856.5–3754</td>
<td>61</td>
<td>7.06</td>
<td>1</td>
<td>$-2.97 \times 10^{-14}$</td>
<td>1.5</td>
<td>3.80</td>
<td>0.42–0.46</td>
<td>25.2</td>
<td>120$^{+11}_{-15}$</td>
</tr>
<tr>
<td>RX J2143.0+0654</td>
<td>104</td>
<td>9.43</td>
<td>4</td>
<td>$-4.00 \times 10^{-14}$</td>
<td>1.9</td>
<td>3.72</td>
<td>?</td>
<td>&gt;26</td>
<td>~430</td>
</tr>
</tbody>
</table>

For the brightest source RX J856-3754 the distance is known well by HST measurements

Trümper, Burwitz, Haberl, Zavlin 2004:

The neutron star has a small hot polar cap seen in X-rays and a radius $R_{\infty} = 16.8$ km, corresponding to $R \sim 13$ km for $M = 1.4$ $M_\odot$

This result requires a stiff equation of state of the high density nuclear matter

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RX J1856-3754 is one of the calibration sources of XMM-Newton and Chandra.
The diagram shows the stability of the pnCCD over a period of 17 years.
K. Dennerl, V. Burwitz, private communication 2019
A smaller cluster falling into the Coma cluster
Intensity fluctuations at the center are due to previous mergers

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XMM-Newton: Turbulence in the Coma galaxy cluster resulting from previous mergers
P. Schuecker, A. Finoguenov, F. Miniati, H. Böhringer & U. Briel 2004

Temperature

Pressure

Pressure map of the inner region

Entropy

Residual substructure

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Selection of a representative, volume-limited sample of 93 systems from the clusters found in the ROSAT Survey (z < 0.1)

Detailed, deep study of a cluster sample with XMM-Newton and structural analysis

Statistics of Morphologies

volume –lim. sample:
30% regular
60% disturbed
10% intermed.

Compared to flux-limited (traditional):
41% regular
45% disturbed
(rest intermed.)

Cool-Core-Statistic
vol.-lim.: 39%
flux-lim.: 53 -60%
Planck: 29%

ROSAT and Planck are not so different if compared using similar selection!

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5. ROSAT discovery of tidal disruptions by massive black holes

S. Komossa & N. Bade 1999

The X-ray light curves

N. Bade, S. Komossa, M. Dahlem 1996

TDE host galaxy NGC 5905; a very nearby giant barred spiral galaxy.
Circle: ROSAT HRI X-ray error box.

M.J. Rees 1988, 1989

Theoretical prediction
Flows of X-ray gas reveal the disruption of a star by a massive black hole

J.M. Miller, J.S. Kaastra, M.C. Miller and 18 co-authors

In the galaxy PGC 043234

$L_x = 3.2 \times 10^{44} \text{ erg/s}$ (XMM-Newton)

The best-fit photoionized absorption model for the outflowing gas detected in each spectrum is shown in red

Modest outflow speeds of few $\times 100 \text{ km s}^{-1}$ are observed

PGC 043234 was not detected in the ROSAT All Sky Survey:

$L_x < 4.8 \times 10^{40} \text{ erg s}^{-1}$

The gray band depicts the $t^{5/3}$ flux decay predicted by fundamental theory

M.J. Rees 1988

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The Future: Lead-up to the third decade of XMM-Newton and to ATHENA

eROSITA on SRG:

Launched in July 2019 on the Russian SRG
- 4 years all-sky survey, sensitivity ~ 20 x ROSAT all sky survey
> 3 years pointed observations

eROSITA with will discover many new sources, which can be studied with the advanced instruments of Athena
- cryogenic X-ray spectrometer X-IFU and
- wide field imager WFI

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THANK YOU !