EPIC-pn Observations of Cygnus X-1
Preliminary Results

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with

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1. Science from bright sources
2. Observing bright sources with XMM-Newton
3. Cyg X-1 as a test case
4. Timing Results
5. Spectral Results
6. Outlook
Why bright sources?, I

What we want to learn:

1. What does the accretion region look like: "accretion geometry"
2. What are the physical processes responsible for the broad-band emission?
3. Is there evidence for GR effects?

AGN and BHC have similar geometry $\implies$ study similar physical processes!

X-rays produced close to event horizon, observations give one of the few constraints to study physics in the strong gravitational field limit.
Bright (\( > 100 \text{mCrab} \)) sources are crucial for our detailed understanding of accretion as a physical process.

- **test relativity** (variable and broad Fe K\( \alpha \) lines)
- **Accretion geometry**: Comptonization versus jet emission, reflection, . . .
- **strong short term variability out to \( > 100 \text{Hz} \) (10% rms \( \implies \) produced close to compact object?)
- **variability on all timescales** (\( \dot{M} \) variations? – cannot study with AGN at all!)
- **high resolution X-ray spectroscopy** \( \implies \) stellar winds, absorption dips, . . .

*(Note: complementary to AGN studies!)*

Need high SNR high time resolution observations
### Bright Sources with XMM

**What is available? – Look at XMM UHB:**

<table>
<thead>
<tr>
<th></th>
<th>MOS</th>
<th>pn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time res.</td>
<td>Live time [%]</td>
</tr>
<tr>
<td>MOS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full frame (600×600)</td>
<td>2.6 s</td>
<td>100.0</td>
</tr>
<tr>
<td>Large window (300×300)</td>
<td>900 ms</td>
<td>99.5</td>
</tr>
<tr>
<td>Small window (100×100)</td>
<td>300 ms</td>
<td>97.5</td>
</tr>
<tr>
<td>Timing uncompressed (100×600)</td>
<td>1.5 ms</td>
<td>100.0</td>
</tr>
<tr>
<td>pn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full frame (376×384)</td>
<td>73.4 ms</td>
<td>99.9</td>
</tr>
<tr>
<td>Ext. full frame (378×384)</td>
<td>200 ms</td>
<td>100.0</td>
</tr>
<tr>
<td>Large window (198×384)</td>
<td>48 ms</td>
<td>94.9</td>
</tr>
<tr>
<td>Small window (63×64)</td>
<td>6 ms</td>
<td>71.0</td>
</tr>
<tr>
<td>Timing (64×200)</td>
<td>0.03 ms</td>
<td>99.5</td>
</tr>
<tr>
<td>Burst (64×180)</td>
<td>7 μs</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Important to note:

cps limit of EPIC pn timing mode due to telemetry, NOT due to camera capabilities!

Therefore:

- Give EPIC-pn as much telemetry as possible
  $\implies$ switch off EPIC-MOS (sorry!)

- Only transmit those events that are interesting
  $\implies$ only throw away soft photons

Modified Timing Mode: increase lower energy discriminator in EPIC pn from 200 eV to 2.8 keV.
Why Cyg X-1?

Cyg X-1 is ideal target for testing modified timing mode:

- Never before observed with *XMM-Newton* (Earth avoidance zone).
- Interesting soft spectrum (RGS!)
- Fe Kα line variable, might be broad
- Strong, energy dependent variability
- Long term variability well studied (*RXTE* campaign since 1999, so previous history of source well known)

Observing Log:

<table>
<thead>
<tr>
<th>Date</th>
<th>XMM</th>
<th>RXTE</th>
<th>INTEGRAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>14/15 Nov 2004</td>
<td>17600</td>
<td>12000</td>
<td>58000</td>
</tr>
<tr>
<td>20/21 Nov 2004</td>
<td>17700</td>
<td>16700</td>
<td>80000</td>
</tr>
<tr>
<td>26/27 Nov 2004</td>
<td>20000</td>
<td>26000</td>
<td>79000</td>
</tr>
<tr>
<td>02/03 Dec 2004</td>
<td>10000</td>
<td>10000</td>
<td>80000</td>
</tr>
</tbody>
</table>

(plus simultaneous radio [Ryle] and optical [Crimea])
Previous History

The graph shows the RXTE ASM cps data from 1996 to 2004. The x-axis represents Julian Days (JD) minus 2450000, while the y-axis represents RXTE ASM cps. The data fluctuates significantly during the period, with peaks and troughs visible.
Will concentrate on first observation here.
Overall EPIC-pn lightcurve (observation 1, 10 s bins)
Total power spectral density (multiplied with frequency, log binned)

Standard triple Lorentzian shape known from RXTE-PCA, characteristic for hard state.

Pottschmidt, Wilms, Nowak et al., 2003
PSDs for 3–5, 5–7, and 7–9.5 keV (multiplied with frequency, log binned)

→ narrower energy bands than with the RXTE
Energy resolved rms: *Influence of reflection component*?  
(cf. Revnivtsev et al., 2000)
Overall spectrum

But: Different single/double fraction as low energy split partners disappear $\implies$ different energy redistribution

Timing mode requires recalibration!
Comparision of standard timing mode and modified timing mode for Vela X-1.
Complications, II

$P_{I_{\text{timing}}} \text{ vs. } P_{I_{\text{modified}}}$:
- 200 eV gap: lower energy threshold for standard timing mode
- shape of low energy distribution
  - width of peak: energy randomization in chain, high $E$ events: wrong assignment of simultaneous events

$\implies$ Use distribution to build RMF based on existing (calibrated) timing mode RMF.
Fit of eqpair model to RXTE/INTEGRAL.

\( \chi^2 / \text{dof} = 235 / 228, \)
\( kT_{\text{in}} = 1 \text{ keV}, \tau_e = 1.13, \)
\( \ell_h / \ell_s = 2.86, \)
\( \Omega / 2\pi = 0.31 \)
Spectral Fits

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eqpair to

$XMM/RXTE/INTEGRAL$

(no fit – DON’T take this serious!)
Modified timing mode works in principle, first results are promising, so far no show stoppers...

Still to do:

- higher order Fourier quantities (time lag, coherence, rms-flux)
- Fe $K\alpha$ variability
- spectral calibration
- Fourier frequency resolved spectroscopy
- broad-band analysis

(most of the work, really...)