Interesting points in

Vela X-1

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Outline

- Vela X-1: the system / characteristics
- Strong variability / off-states / quasi-periods
- Cyclotron lines
- Flux dependence of $E_{\text{cyc}}$
- Long-term decay of $E_{\text{cyc}}$
- Summary
Vela X-1 System

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Kretschmar et al. 1997, 
A&A 325, 623

\[ P_{\text{pd}} = 283 \text{ sec} \]
\[ L_x = \sim 10^{36} \text{ erg/s} \]
\[ E_{\text{cyc}} = \sim 27 \text{ keV and } \sim 54 \text{ keV} \]

wind-fed accretion
(highly structured, clumpy wind)
Vela X-1: interesting characteristics

- X-Ray Binary Pulsar (NS + BO 5Ib super giant)
  \( P_{\text{orb}} = 8.96 \, \text{d} \)
  \( P_{\text{pulse}} = 283 \, \text{sec} \)
  binary eclipses

- Sinusoidal double peak pulse profiles (variable !)

- Highly variable flux: strong flares, off-states

- Quasi-periodicities

- Cyclotron Lines at \(~25 \, \text{keV}, ~50 \, \text{keV}\)
  variable: flux- and time dependent !!

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Inter-stellar and stellar-wind environment


Inter-stellar environment of Vela X-1
(H(alpha) + NII)

Plasma density simulations

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Strong Flux Variations

Staubert et al. 2004, Proc. 5th INTEGRAL Workshop (ESA SP-552)

INTEGRAL 2003
resolution: 280 sec

- flares
  (up to 7 Crab)
- off-states

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Quasi-periodic Variations

Staubert et al. 2004, Proc. 5th INTEGRAL Workshop (ESA SP-552)

INTEGRAL 2003
resolution: 280 sec

- QPOs:
  P ~ 2640 sec
  P ~ 6740 sec

Figure 7. A special part of the light curve of Vela X-1 of the Nov2Dec 2003 observation. In these data quasi-periodic modulations lasting for a few cycles are apparent. The periods are around 2640 s and 6740 s, respectively. The dotted line connects the data points (280 s integration), the solid line is the best fit sine curve (with an additional exponential component for the left train).

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**Discovery of the Cyclotron Line**

*MPE/Tübingen Mir-HEXE (750 cm²)*

Two observations in Nov 1988 (total ~ 5 ksec)

Kendziorra et al. 1992, NASA SCP-3137, 217  
Kretschmar et al. 1996, A& A Suppl. 120, 175

Two cyclotron lines: ~27 keV (fundamental) and ~54 keV

(today we would rather say: ~25 keV and ~50 keV, and the fundamental is sometimes not very prominent)

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Discovery of flux dependence

**NuSTAR: two observations 53 ks**

Vela X-1:
- Fundamental: ~25 keV
- Harmonic: ~50 keV/2
- Anti-correlation between the two lines

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Discovery of time dependence

Vela X-1:
- Fundamental: not seen
- Harmonic: ~53 -58 keV
- Flux dependence (role-off like in GX 304-1)
- Time dependence: decay by 0.36 keV/yr (similar to Her X-1)

LaParola et al. 2016, MNRAS 463, 185

Swift/BAT from 2004 to 2015

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### Sources with correlation of $E_{\text{cyc}}$ with $L_x$

**negative correlation:** $E_{\text{cyc}} \sim 1/L_x$

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<tr>
<th>Source</th>
<th>Reference</th>
<th>Notes</th>
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<td>V 0332+53</td>
<td>Mihara 1995, PhD thesis Univ. Tokyo</td>
<td>first discovery</td>
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<td>Tsygangov et al. 2006, MNRAS 371, 19</td>
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<td>Klochkov et al. 2011, A&amp;A 532, A126 (pulse-to-pulse)</td>
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**positive correlation:** $E_{\text{cyc}} \sim L_x$

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<td>Her X-1</td>
<td>Staubert et al. 2007, A&amp;A 465, L25</td>
<td>first discovery</td>
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<td>Klochkov et al. 2011, A&amp;A 532, A126 (pulse-to-pulse)</td>
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<tr>
<td>A 0535+26</td>
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<td>Yamamoto et al. 2011, PASJ 63, 751</td>
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<td>V 0332+53</td>
<td>Caballero-Garcia et al. 2016, A&amp;A 589, A9,</td>
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Sources with time dependence of $E_{\text{cyc}}$

long-term decay of $E_{\text{cyc}}$

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**Vela X-1 is a very interesting source with two CRSFs**

1) confirmed:
   - Positive correlation of $E_{\text{cyc}}$ with $L_x$ for fundamental
   - Decay of $E_{\text{cyc}}$ with time (0.36 keV/yr, La Parola et al. 2016)

2) future:
   - Does decay of $E_{\text{cyc}}$ time end some time??

**What can HXMT do?**
**Participate in further monitoring of $E_{\text{cyc}}$**
   - try to coordinate with NuSTAR, INTEGRAL, Astrosat !!

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Thank you for your attention

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