

Ecyc in Her X-1: status in April 2018

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Outline

- Her X-1: interesting characteristics
- Cyclotron line
- Variability of the cyclotron line energy E_{cyc}
- Luminosity dependence of E_{cyc} (neg/pos)
- Long-term decay of E_{cyc}
- Physics of accretion
- Summary / What can Insight/HXMT do?

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Her X-1: interesting characteristics

- X-Ray Binary Pulsar (NS + A/F star HZ Her)
 - $P_{\text{orb}} = 1.70 \text{ d}$
 - $P_{\text{dip}} = 1.62 \text{ d}$
 - $P_{\text{super}} = 35 \text{ d}$ (variable !)
 - $P_{\text{pulse}} = 1.24 \text{ sec}$ (variable !)
 - inclination $\sim 85^\circ$
 - binary eclipses ($\sim 6 \text{ h}$)
- Structured pulse profiles (variable !)
- 35d clock (variable !)
- Cyclotron Line at $\sim 37 - 40 \text{ keV}$ (variable !)
(Cyclotron Resonant Scattering Features - CRSF)

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Discovery of the first Cyclotron Line

Tübingen / MPE - HEXE
Balloon observation of Her X-1
Texas, 3 May 1976
(Trümper et al. 1977, 1978)

first direct measurement of
the field strength of a NS:

$$B \sim 3 \times 10^{12} \text{ Gauß}$$

today we know ~34 objects
with cyclotron lines (CRSF)

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EVIDENCE FOR STRONG CYCLOTRON LINE EMISSION IN THE HARD X-RAY

SPECTRUM OF HERCULES X-1

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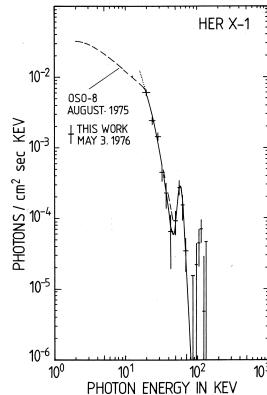


FIG. 2.—Decomposed X-ray spectrum of the Her X-1 pulsar. Solid line, two-dimensional spectrum with a Gaussian fit to the OSO-8 August 1975 observation. Dashed line, spectrum of this work. For comparison, a hard X-ray spectrum of Her X-1 observed by OSO-8 during the 1975 August outburst is shown (Staubert et al. 1977).

The Astronomical Journal, 219:L105-110, 1978 February 1
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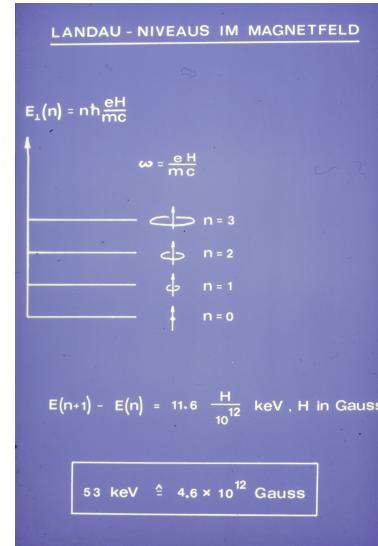
ApJ 219 (1978) L105

Cyclotron Resonant Scattering Feature (CRSF)

$$E_{\text{cyc}} = n \frac{\hbar e}{m_e c} * B$$
$$= n 11.6[\text{keV}] * B[\text{Gauß}] / 10^{12}$$

$$B_{12} = (1+z) E_{\text{obs}} / 11.6 \text{ keV}$$

z gravitational redshift



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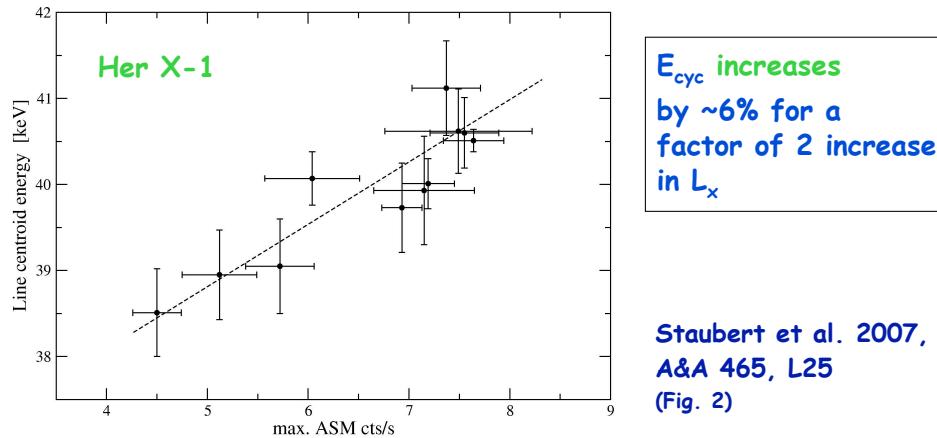
(53 keV emission, 38 keV absorption)

Positive correlation of E_{cyc} with L_x

- observed in persistent sources at moderate luminosity

observations 1996 / 2006

$$E_{\text{cyc}} [\text{keV}] = 40 + 0.66 (\text{max. ASM cts/s} - 6.8)$$

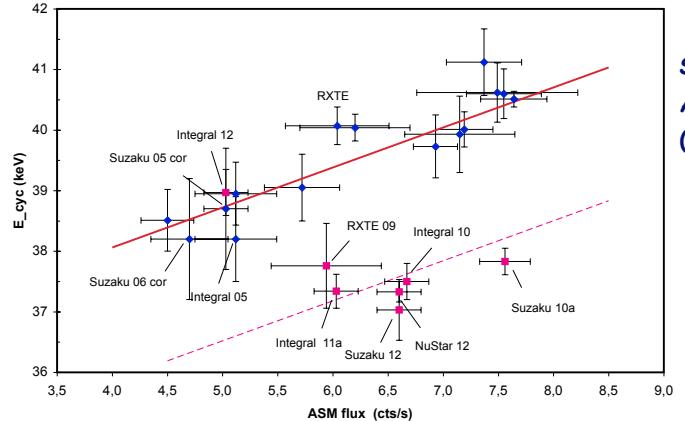


E_{cyc} increases
by ~6% for a
factor of 2 increase
in L_x

Staubert et al. 2007,
A&A 465, L25
(Fig. 2)

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Variation of E_{cyc} with pulse phase



Staubert et al. 2014,
A&A 572, A119
(Fig. 1)

$$(E_{\text{max}} - E_{\text{min}}) / \langle E \rangle \sim 25 \%$$

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Negative correlation of E_{cyc} with L_x

- observed in outbursts of transients at high luminosity

V 0332+53

Tsygankov et al. 2010, MNRAS 401, 1628

outburst 2004 / 2005

Fig. 2

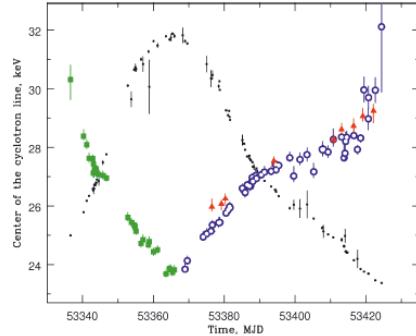
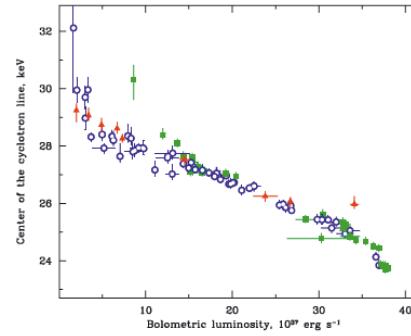


Fig. 3

E_{cyc} drops
by ~7% for a factor
of 2 increase in L_x



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Sources with correlation of E_{cyc} with L_x

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

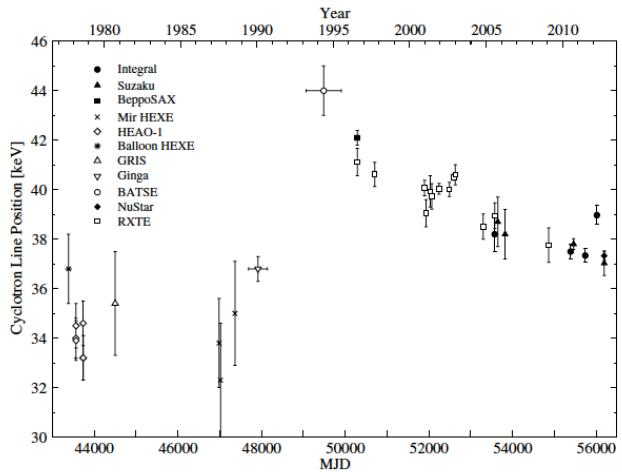
V 0332+53 Mihara 1995, PhD thesis Univ. Tokyo first discovery
Tsygankov et al. 2006, MNRAS 371, 19
Klochkov et al. 2011, A&A 532, A126 (pulse-to-pulse)

positive correlation: $E_{\text{cyc}} \sim L_x$

Her X-1	Staubert et al. 2007, A&A 465, L25 first discovery Klochkov et al. 2011, A&A 532, A126 (pulse-to-pulse)
A 0535+26	Klochkov et al. 2011, A&A 532, A126 (pulse-to-pulse) Müller, D. et al. 2013, A&A 552, A81 (pulse phase resolved) Sartore, N. et al. 2015, ApJ 806, 193
GX 304-1	Yamamoto et al. 2011, PASJ 63, 751 Klochkov et al. 2011, A&A 542, L28
Vela X-1	Fürst et al. 2011, ApJ 780, 133
Cep X-4	Fürst et al. 2015, ApJ 806, 24
V 0332+53	Caballero-Garcia et al. 2016, A&A 589, A9, Doroshenko et al. 2017, MNRAS 466, 2143, Vybornov et al. 2018, A&A, arXiv: 1801.01349
1626.6-5156	DeCear et al. 2013, ApJ 762, 61

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Variation of E_{cyc} with time



Staubert et al. 2014,
A&A 572, A119
(Fig. 4)

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Her X-1: Long-term decay of E_{cyc}

Staubert et al. 2014, A&A 572, A119

best fit with two variables (Flux and Time): $E_{\text{cyc}} = E_0 + a * (F - F_0) + b * (T - T_0)$

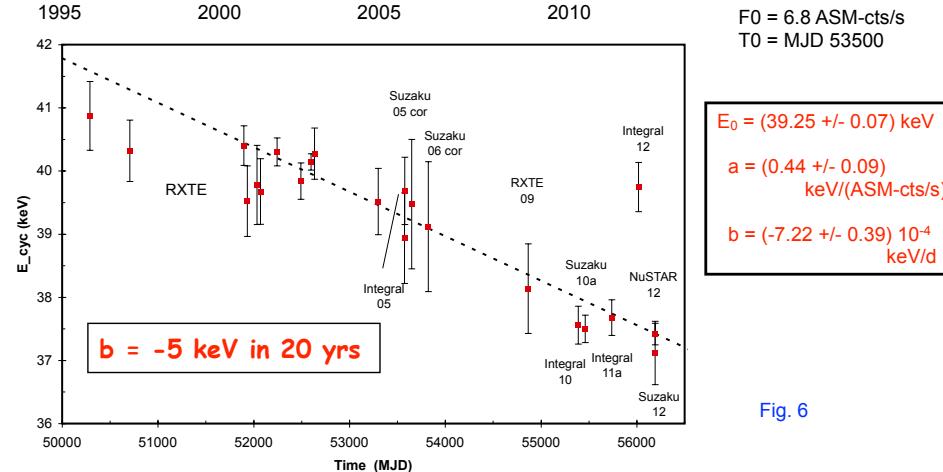
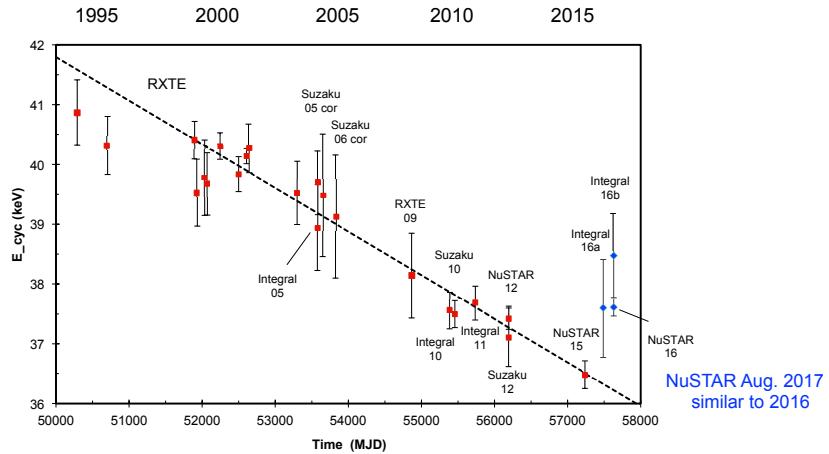


Fig. 6

2017: 20 year decay of E_{cyc} has ended !!

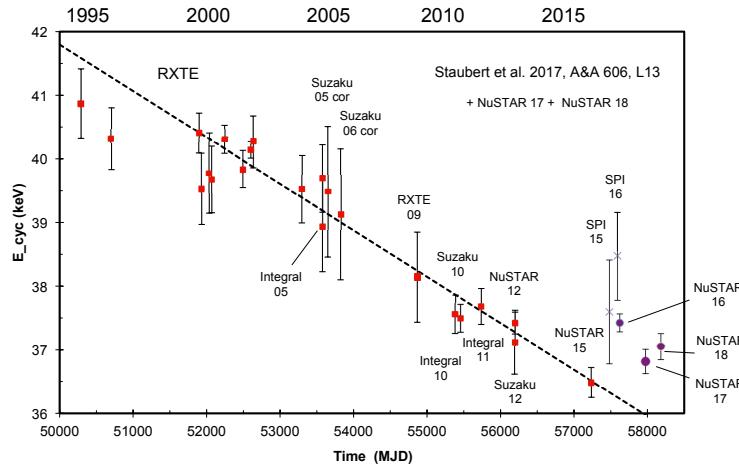
Staubert et al. 2017, A&A 606, L13 (Fig. 1)



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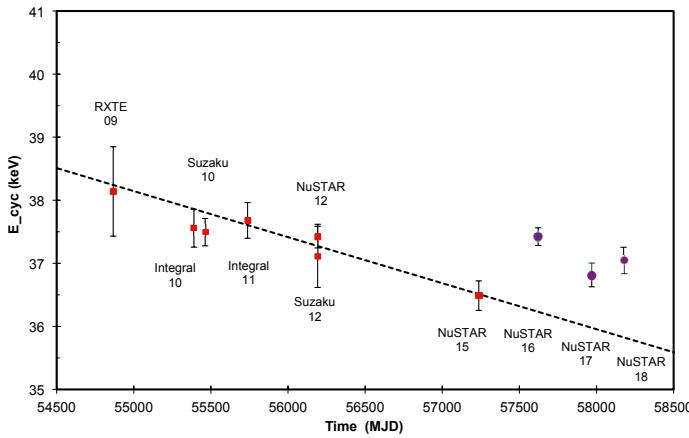
April 2018: end of decay confirmed - turn-up?

Staubert et al. 2018, proposal for INTEGRAL AO-16



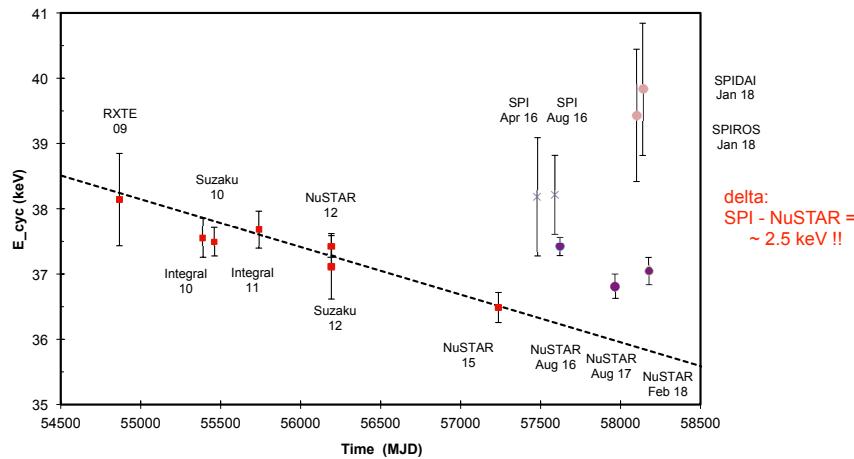
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Current situation 1: NuSTAR



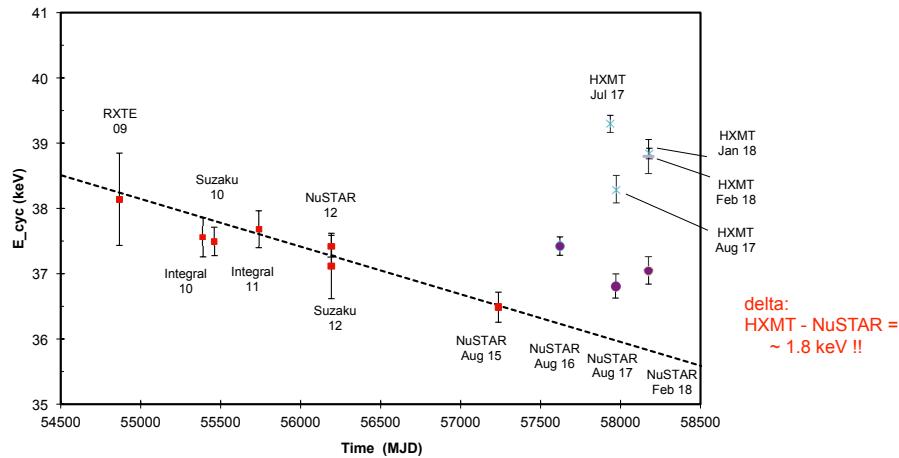
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Current situation 2: NuSTAR and SPI



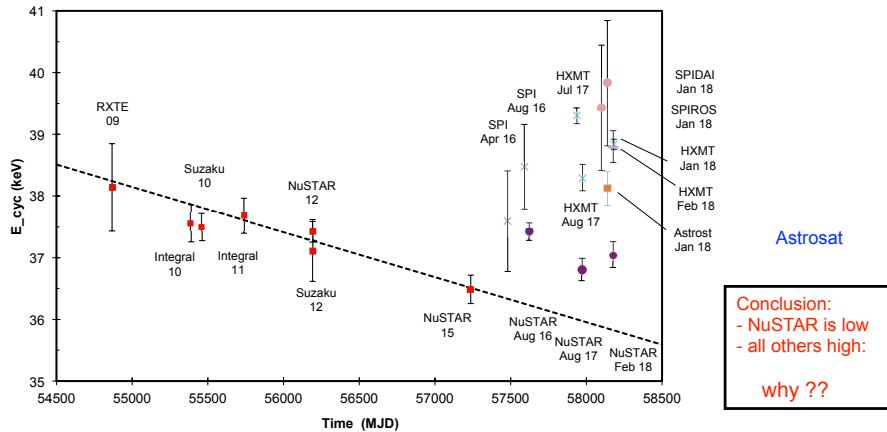
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Current situation 3: NuSTAR and HXMT



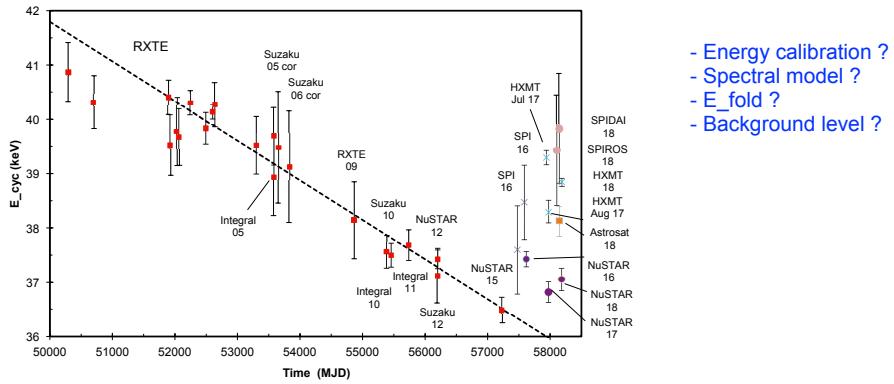
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Current situation 4: all satellites



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Question: what is the reason for the difference ??



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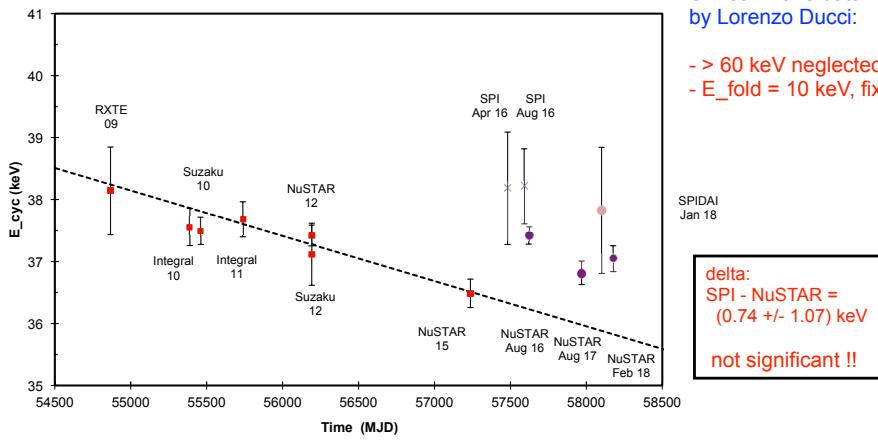
- Energy calibration - channel-keV-conversion? **unlikely**
Systematic uncertainties claimed:
 - SPI: 0.1 keV (Jean-Pierre Roques)
 - NuSTAR: < 0.2 keV (Felix Fürst)
 - HXMT: ??
 - Astrosat: ??
- Spectral model ? **unlikely**
The same model has always been used („high-e-cut“ with „gabs“)
- E_fold ? **possible !?**
Sometimes „high“ values are fitted (should be around 10 keV !?)
- Background level ? **possible !?**
Usually background levels are estimated using models instead of on-off observations - not so for pulse-on minus pulse-off and for NuSTAR !!

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Latest news of 09 April: NuSTAR and SPI

Re-analysis of
SPI Jan 2018 data
by Lorenzo Ducci:

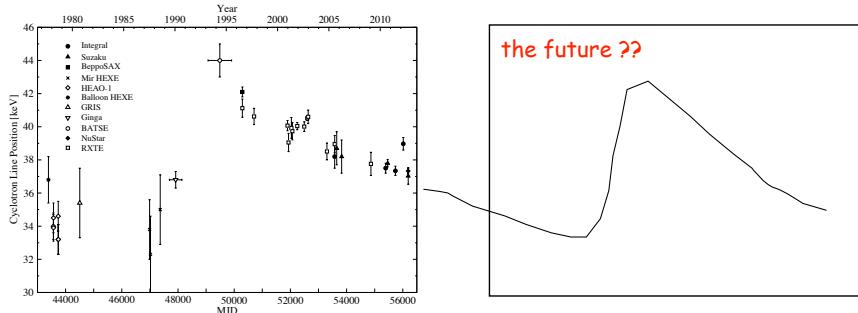
- > 60 keV neglected
- $E_{\text{fold}} = 10 \text{ keV}$, fixed



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Very-long-term behavior of E_{cyc} ??

Her X-1



does E_{cyc} possibly follow a cyclic behavior on long time scales?

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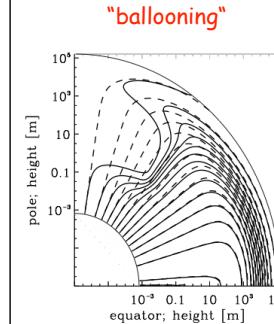
Basic questions about accretion onto NSs

Assume continuous accretion (e.g. 10^{17} g/s):

- what happens to the accreted material? does it accumulate?
- is the material "incorporated" into the crust?
- is the accretion mound static (in "equilibrium")?
- can the accretion mound grow or shrink (height/total mass)?
- can the B-field configuration change? (e.g. "ballooning")
- does material "leak out" to the sides at the base of the accretion mound?
- how much total mass can be "stored" in the mound?
(until the B-field "breaks")
- can the B-field be "screened" or "buried"?
- what is the dynamical evolution of the mound?

Why does Ecyc increase with Lx?

Why does Ecyc change with time? Is there a cycle?



$$M_{\text{acc}} \sim 10^{-5} M_{\odot}$$

Payne & Melatos 2004
MNRAS 351, 569

$10^{-5} M_{\odot}$ far too high !

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Summary: E_{cyc} in Her X-1

1) confirmed:

Positive correlation of E_{cyc} with L_x (co-existing with decay)
Decay of E_{cyc} with time (20 years)

2) confirmed: Decay of E_{cyc} has ended (~ 2015)

3) future:

Turn-up of E_{cyc} ??
Cyclic behavior of E_{cyc} with time ??

What can HXMT do?

1) Participate in further monitoring of E_{cyc}
in coordination with NuSTAR, INTEGRAL, Astrosat !?

2) Observe one full Main-On (~ 10 days)

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A proposal to the high energy X-ray community

- NuSTAR
- INTEGRAL (IBIS and SPI)
- Insight / HXMT
- Astrosat

Do repeated coordinated (simultaneous) observations
of a few CRSF sources, e.g.

- Her X-1
- Vela X-1
- GX 301-2

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Thank you for your attention

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