Long-term change in the cyclotron line energy in Hercules X-1

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R. Staubert HEAD Fifteenth Div. Meeting, Naples, Florida, 05 April 2016

Variability in the Cyclotron Line Energy E_{cyc} in Hercules X-1

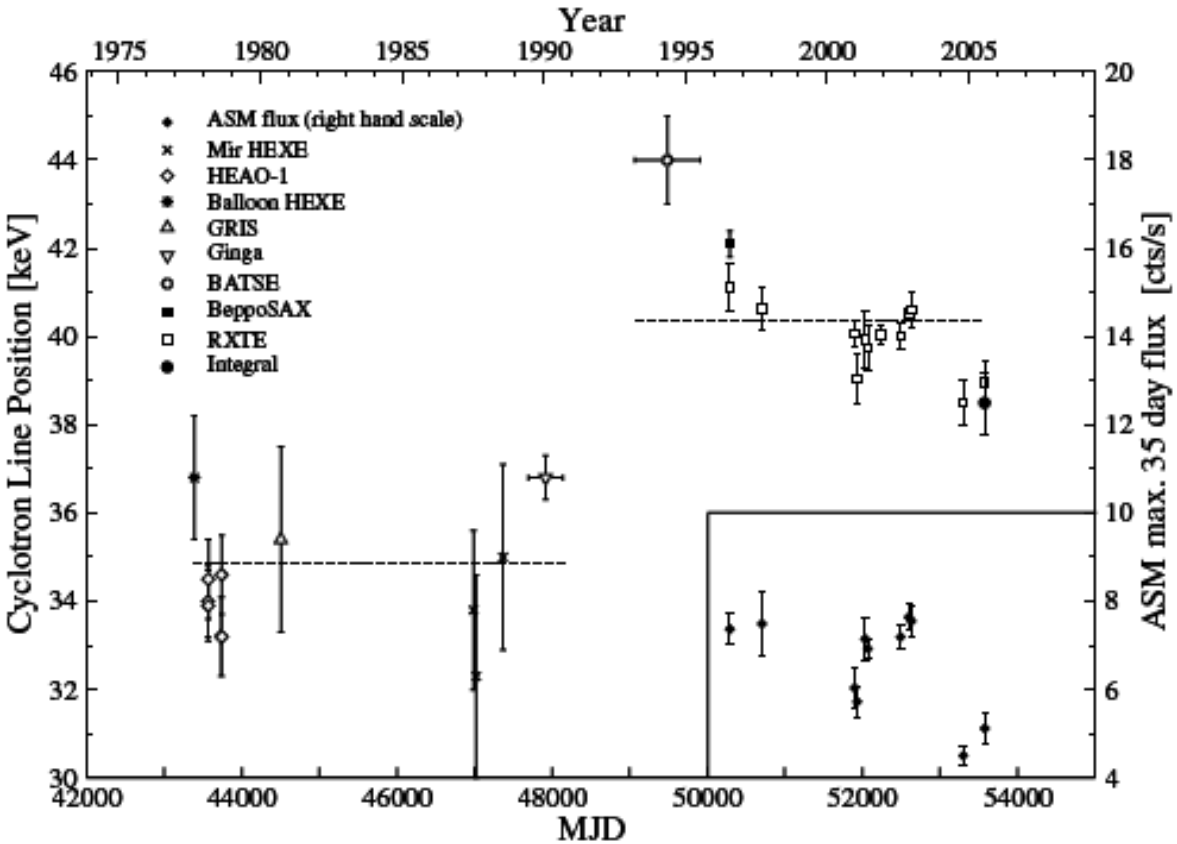
E_{cyc} varies with

- pulse phase (not discussed here)
- 35d phase (not discussed here)

- luminosity
- time (long-term, 10s of years)

R. Staubert HEAD Fifteenth Div. Meeting, Naples, Florida, 05 April 2016

Long-term evolution of E_{cyc}



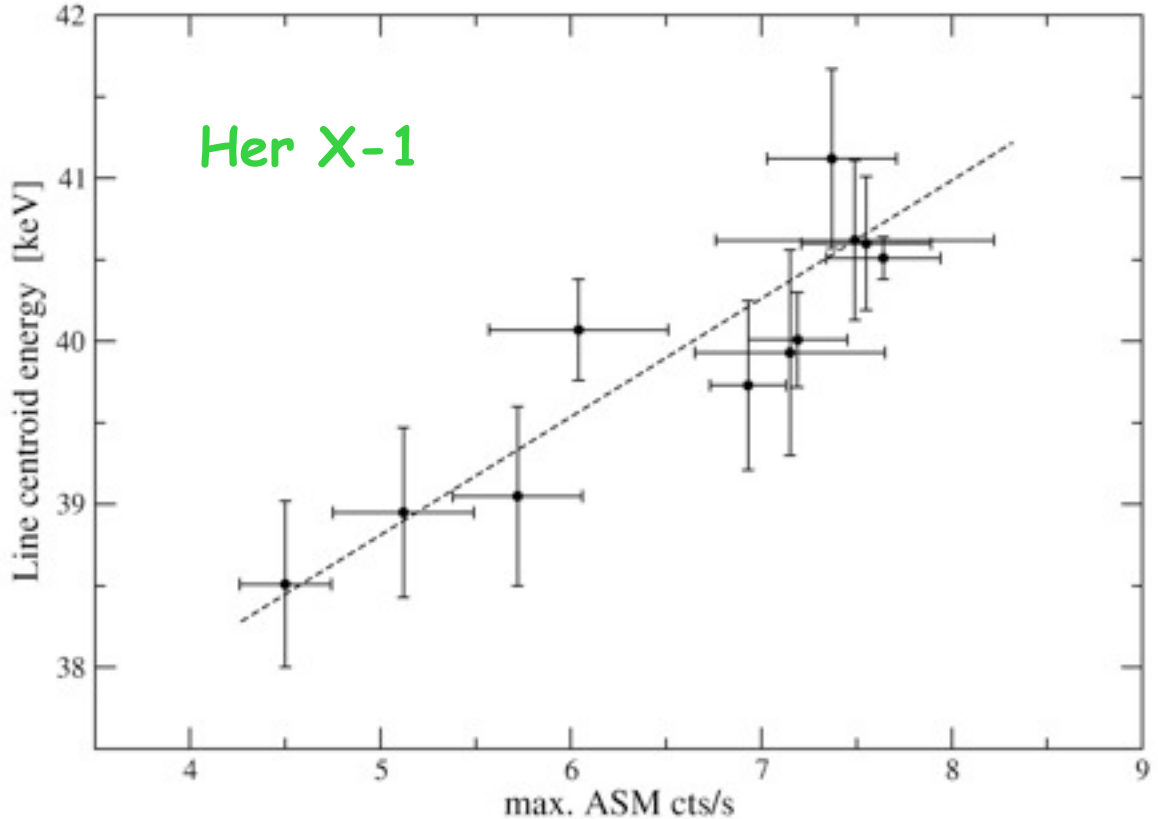
Her X-1 **2007**

Staubert et al. 2007, A&A 465, L25

- upward jump in E_{cyc} btw. 1991 and 1993
- apparent decay after 1993: is it real?
- does E_{cy} correlate with flux?

Positive correlation of E_{cyc} with L_x

- first detection in a persistent source at moderate luminosity



Staubert et al. 2007, A&A 465, L25

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

in V 0332+63 (at high luminosity) E_{cyc} is known to decrease with L_x

observations 1996 / 2006: E_{cyc} [keV] = 40 + 0.66 (max. ASM cts/s - 6.8)

Objects with E_{cyc} increasing with increasing L_x

Her X-1 Staubert et al. 2007, A&A 465, L25

GX 304-1 Yamamoto et al. 2011, PASJ 63, 751
Klochkov et al. 2012, A&A 542, L28
Rothschild et al. 2016 (see poster)

A 0535+26 Klochkov et al. 2011, A&A 532, A126

Vela X-1 Fürst et al. 2014, ApJ 780, 133

Cep X-4 Fürst et al. 2014, ApJ 806, L24

to be confirmed:

GX 301-2 La Barbera et al. 2005, A&A 438, 617

4U 1538-522 Hemphill et al. 2016, MNRAS accepted
(arXiv: 1603.02198)

Only one object with E_{cyc} decreasing with increasing L_x :

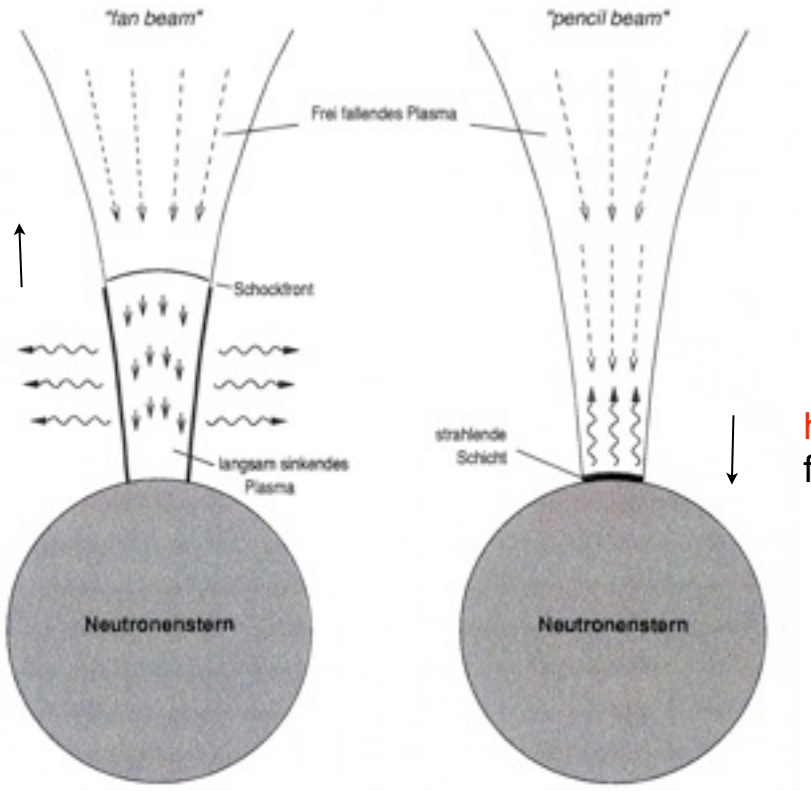
V 0332+53

Tsygangov et al. 2006, MNRAS 371, 19

Klochkov et al. 2011, A&A 532, A126 (pulse-to-pulse)

Two accretion regimes

height increases
for increasing L_x



observations:
Staubert et al. 2007, A&A 465, L25
Klochkov et al. 2011, A&A 532, 126

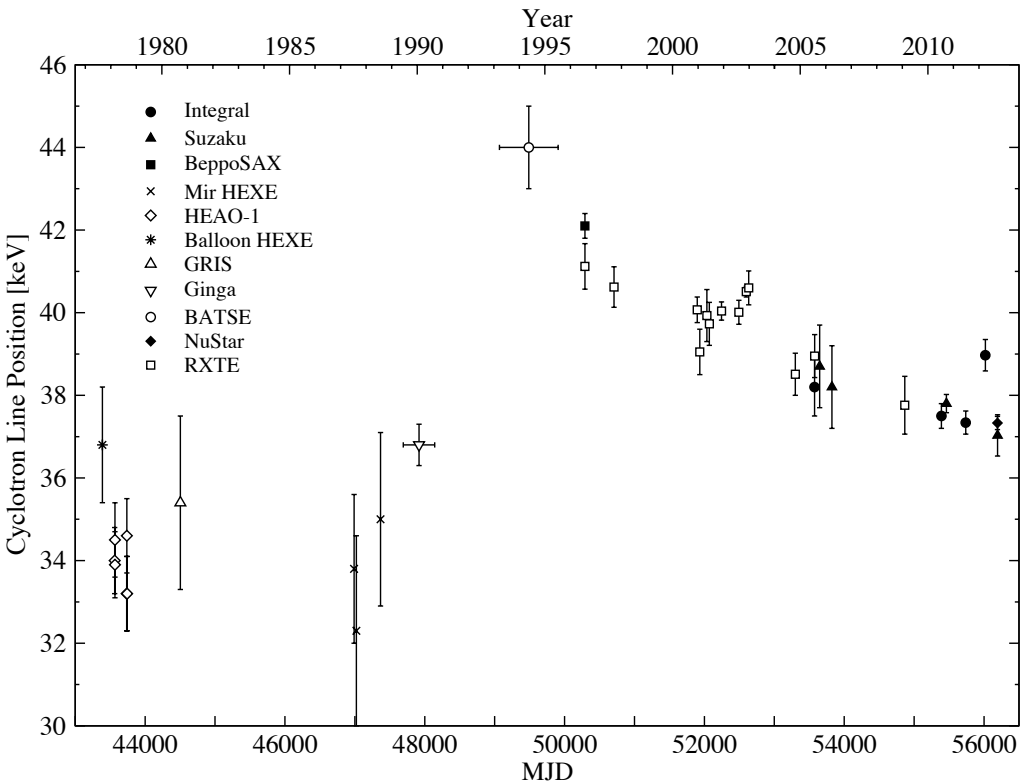
theory:
Becker et al. 2012, A&A 544, 123

height decreases
for increasing Lx

$L_{crit} \sim 10^{37}$ erg/s

$L_X > L_{crit}$ $L_x < L_{crit}$

Long-term evolution of E_{cyc}



Her X-1 **2014**

Staubert et al. 2014
A&A 572, A119

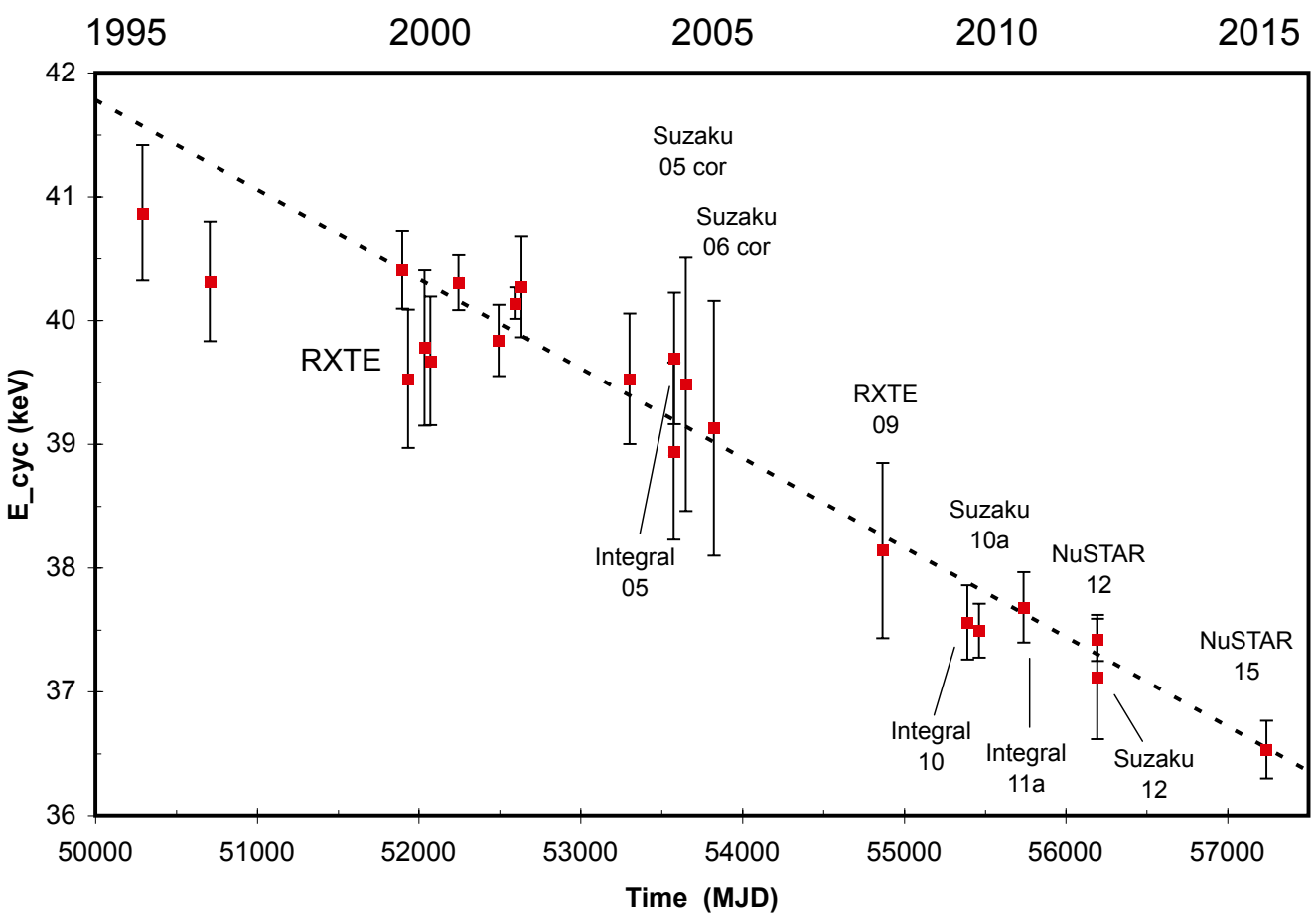
Staubert et al. 2016
A&A in print
arXiv: 1603.07090

NuSTAR 2015:
34.8 +/- 0.2 keV
at MJD 57238

57238

the decay of E_{cyc} continued !!

Her X-1: continued decay of E_{cyc} - new NuSTAR point



Her X-1 2016

Staubert et al. 2016
A&A in print
arXiv: 1603.07090

E_0 = (39.25 +/- 0.07) keV

a = (0.44 +/- 0.09) keV/(ASM-cts/s)

b = (-7.22 +/- 0.39) 10^{-4} keV/d

b = -5 keV in 20 yrs

F0 = 6.8 ASM-cts/s
T0 = MJD 53500

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

Physics of the E_{cyc} change with time ??

Ideas (comments /questions):

- Change of the global dipole field of the NS? unlikely

more likely a local phenomenon:

- Accretion mound structure changes due to continuous accretion?
  - increase of the height of the accretion mound? dipole: -5 keV means +400 m !?
  - hot spot area is increased, B-field is diluted?
  - B-field is "screened" or "buried"? total mass needed? time scale?

- "Ohmic dissipation" of B-field? on "diffusion" time scale:

$t = 4 \pi R^2 \sigma / c^2$, needs small R and small sig!

- Thermo-magnetic effects or Hall effect? heating due to accretion?
- ??????

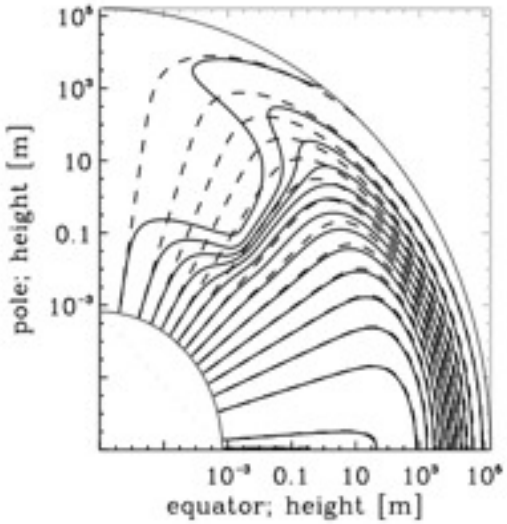
Basic questions about accretion onto NSs

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

- 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 decrease with time?

"ballooning"

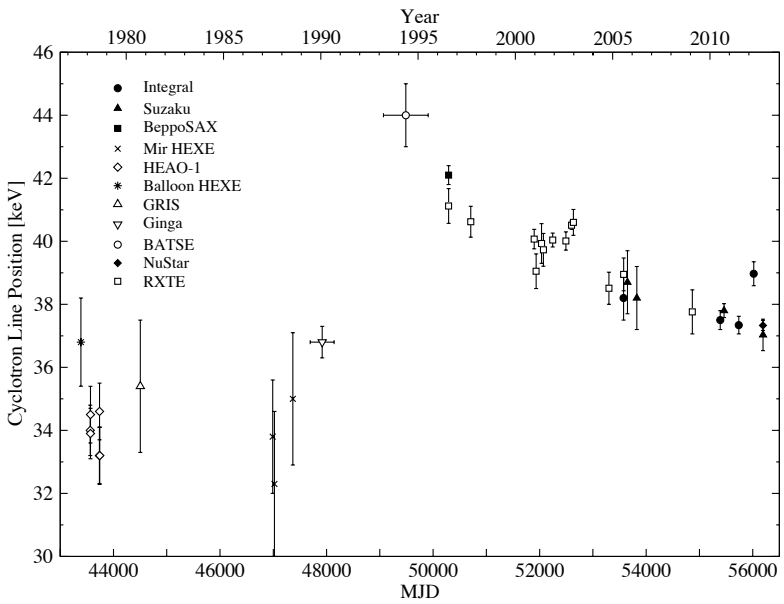


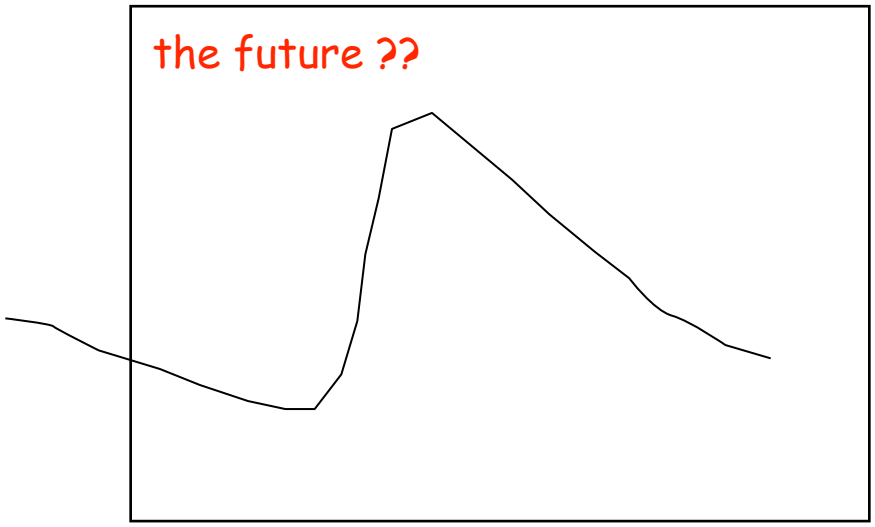
$M_{acc} \sim 10^{-5} M_O$

Payne & Melatos 2004
MNRAS 351, 569

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

Her X-1





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