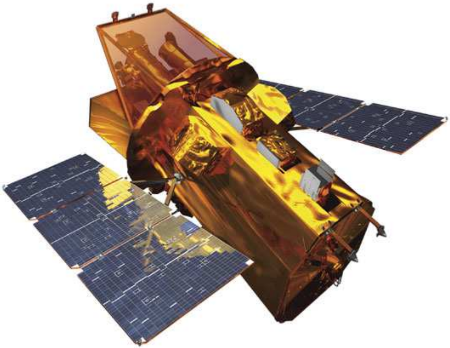
Evidence of mass ejection in Her X-1

Dmitry Klochkov

IAA Tübingen

Swift/BAT

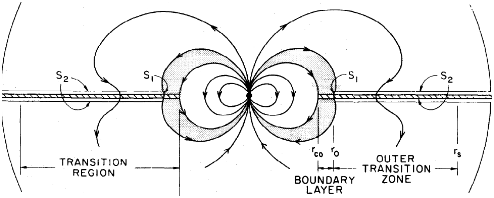


While searching for bursts, *BAT* points at different locations of the sky, thus, performing an all-sky monitoring in hard X-rays.

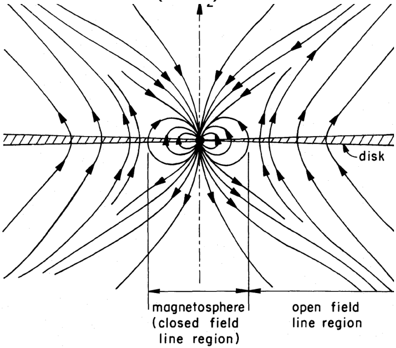
The total count rate measured by the *BAT* detector can be used to search for coherent pulsations exhibited by X-ray sources in the FoV (1.4 sterad!)

Accretion torque models

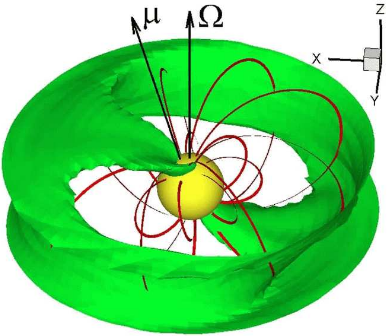
Ghosh&Lamb (1979)



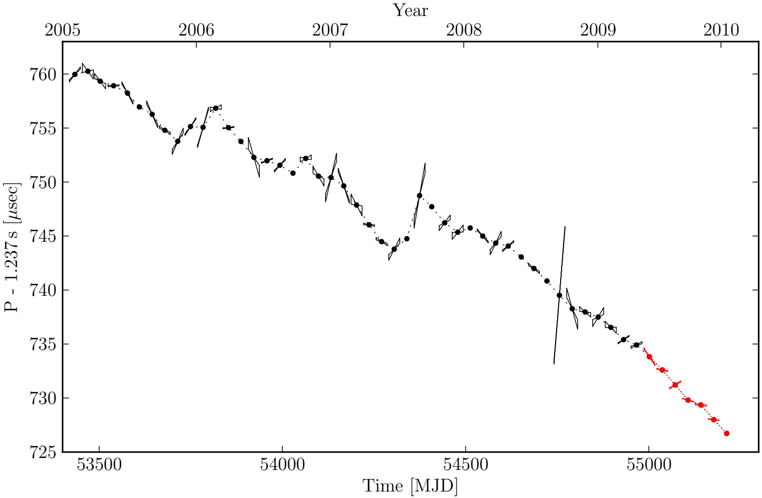
Lovelace et al. (1995)



Romanova et al. (2009)

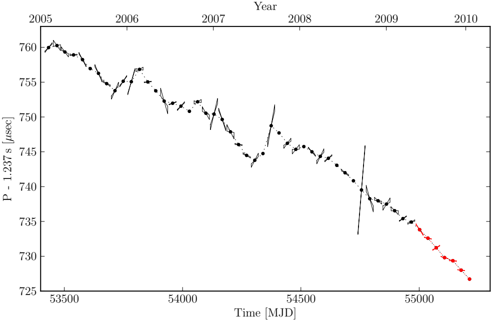


Measured P and $\dot{P}$

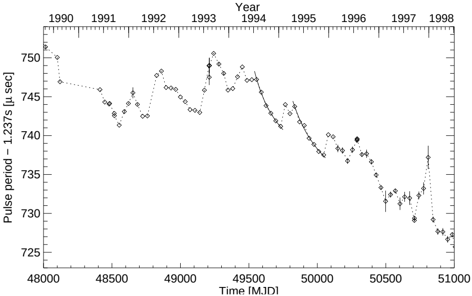


Klochkov et al. 2009 +

Comparison with BATSE

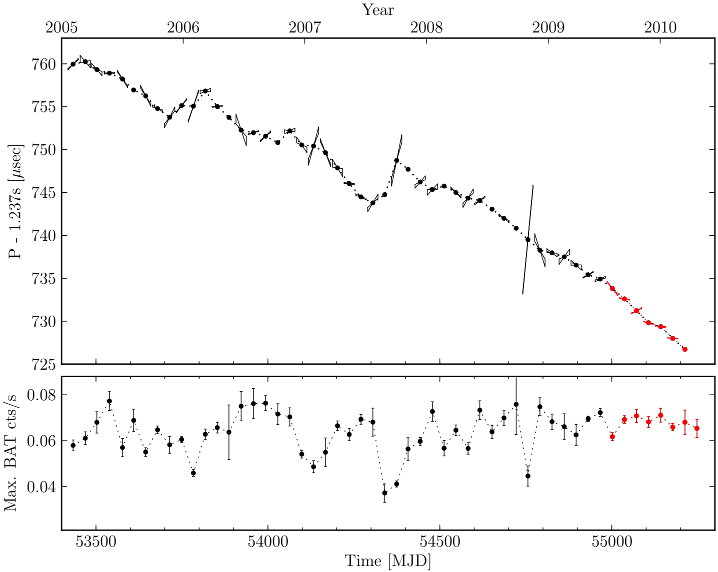


Klochkov et al. 2009 +

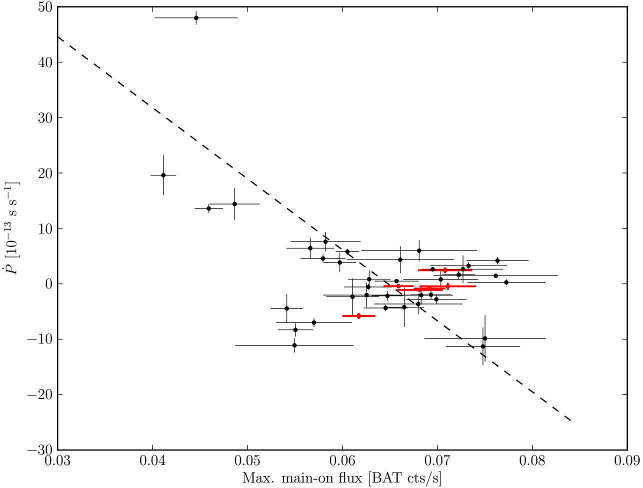


CGRO/BATSE Archive,
R. Staubert, priv. comm.

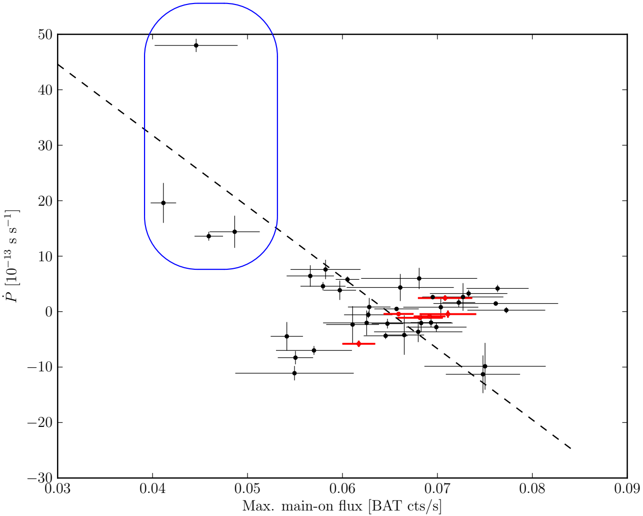
Measured P, $\dot{P}$, and L_X



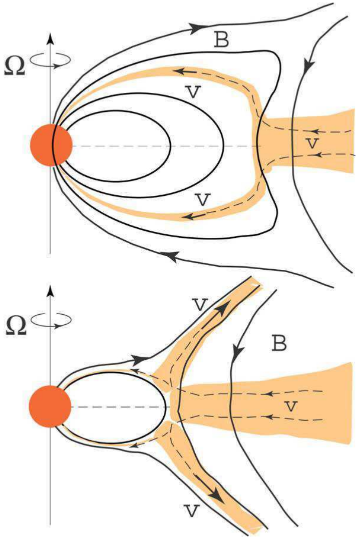
Strong spin-down episodes

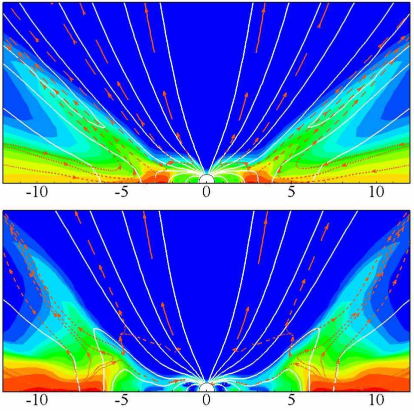


Strong spin-down episodes



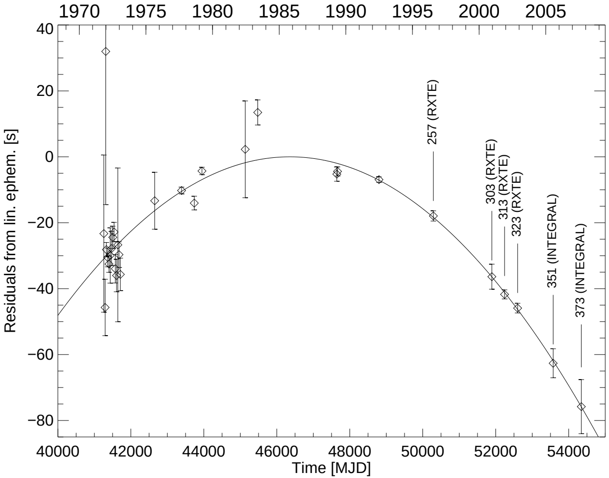
Wind ejection





MHD simulations
by Romanova et al. (2009)

Secular decrease of the orbital period



Staubert, Klochkov & Wilms (2008)

Observed $\dot{\boldsymbol{P}}_{\mathbf{orb}} = \mathbf{-4.85(13) \times 10^{-11}\,d\,d^{-1}}$, $\boldsymbol{L}_{\mathbf{X}} \simeq \mathbf{2 \times 10^{37}\,erg\,s^{-1}}$ – cannot be reconciled within conservative scenario *(e.g. Deeter et al. 1991)*

Non-conservativeness parameter *(e.g. Ritter & Kolb 1992)*:

$$\eta = -\frac{\dot{M}_x}{\dot{M}_o} \leq 1, \quad \dot{M}_o < 0\,.$$

The ejected mass carries away the specific angular momentum of the NS: $j_x = \omega_{\rm orb} a_x^2 = \omega_{\rm orb} a^2 (M_o/(M_x + M_o))^2$. Using the Kepler's 3-rd law and the total angular momentum balance,

$$\dot{J} = j_x(\dot{M}_x + \dot{M}_o),$$

we obtain:

$$\frac{1}{3}\frac{\dot{P}_{\rm orb}}{P_{\rm orb}} = -\frac{\dot{M}_x}{M_x}\left[1 - \frac{q}{\eta} - \left(1 - \frac{1}{\eta}\right)\frac{q/3 + 1}{q + 1}\right].$$

Non-conservative scenario

From the total angular momentum balance and the observed L_X (which can be converted into $\dot{M}_X$) one gets $\boldsymbol{\eta} \sim$ **0.1 – 0.4**(!).

Non-conservative scenario

From the total angular momentum balance and the observed L_{X} (which can be converted into $\dot{M}_X$) one gets $\boldsymbol{\eta} \sim$ **0.1 – 0.4**(!).

Schandl & Meyer (1994) estimated strength of the accretion disk wind in Her X-1 taking into account *irradiation* from NS:

$$2\dot{M}_{\mathrm{acc}} \leq \dot{M}_{\mathrm{wind}} \leq 5\dot{M}_{\mathrm{acc}} \quad (q < 0.3).$$

Boroson et al. (2001) used UV data from HST to infer the wind strength in the system:

$$\dot{M}_{\mathrm{wind}} \sim 2 \times 10^{18} \Omega/4\pi \,\mathrm{g\,s^{-1}} \quad (q \sim 0.1!)\,.$$

Matter ejection

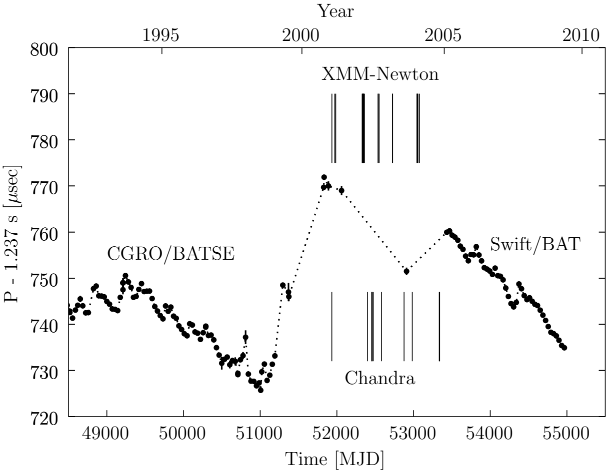
During strong spin-down episodes, the spin-down power of NS $I\omega\dot{\omega}$ is spent to expel accreting matter from the inner disk radius $R_d \sim R_c$:

$$I\omega\dot{\omega} \sim \dot{M}_{\rm ej}\frac{GM}{R_c}\,.$$

For the observed parameters of Her X-1:
$\dot{M}_{\rm ej} \sim 0.5\dot{M}_x \simeq 10^{17}\,{\rm g\,s^{-1}}$, $\dot{P} \simeq 10^{-12}\,{\rm s\,s^{-1}}$, and $R_c \simeq 1.3\times10^8$ cm, the equation is satisfied!

Direct observations of the outflow

Ji et al. 2009 (*Chandra* data): An accretion disk corona is present in Her X-1 ⇒ There should be a **permanent coronal accretion disk wind!**
Idea of XMM proposal: try to compare soft X-ray spectra during spin-down and equilibrium episodes (unfortunately rejected..)



Summary & Conclusions

- For the first time the pulse period derivative of Her X-1 was measured for a long regular series of observations.
- This allowed us for the first time to test the correlation between $L_{\rm X}$ and the locally measured spin-up rate of NS in Her X-1.
- We argue that together with the long-term decrease of $P_{\rm orb}$ the measured spin-up/spin-down behaviour requires the presence of mass ejection from the inner parts of the accretion disk with $\dot{M}_{\rm ej} \geq \dot{M}_{\rm acc}$ which is consistent with the spectroscopic X-ray and UV observations.
- The mass ejection episodes take place during strong spin-downs associated with small X-ray luminosity.

Our work stresses the importance of the disk outflows for the torque interaction between the accretion disk and NS in Roche lobe overflowing neutron star X-ray binaries.