The 2002 outburst of the accretion-powered millisecond pulsar SAX J1808.4-3658

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The object

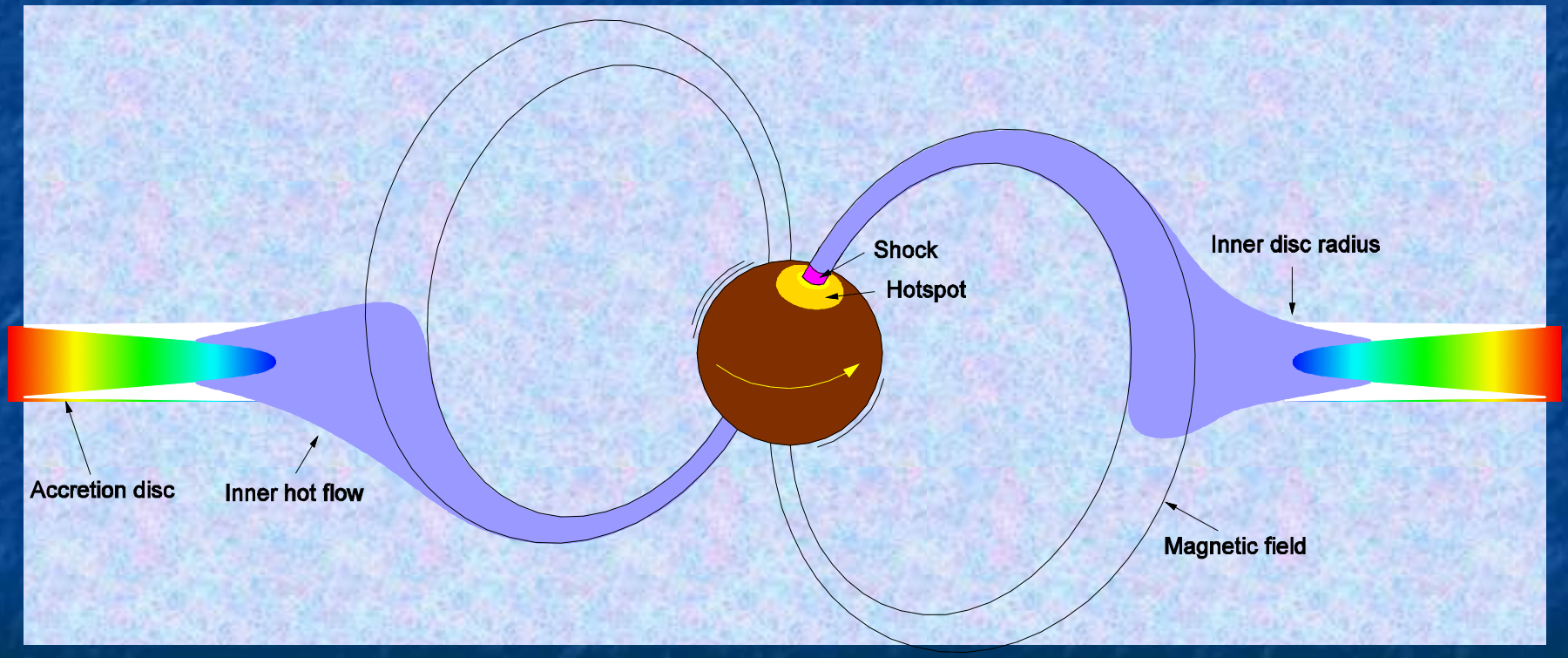
A binary system consisting of a neutron star (~1.4$M_{€}$,~10 km) and a companion

Matter falls onto the NS along magnetic field lines

The NS rotates with the frequency of 401 Hz.

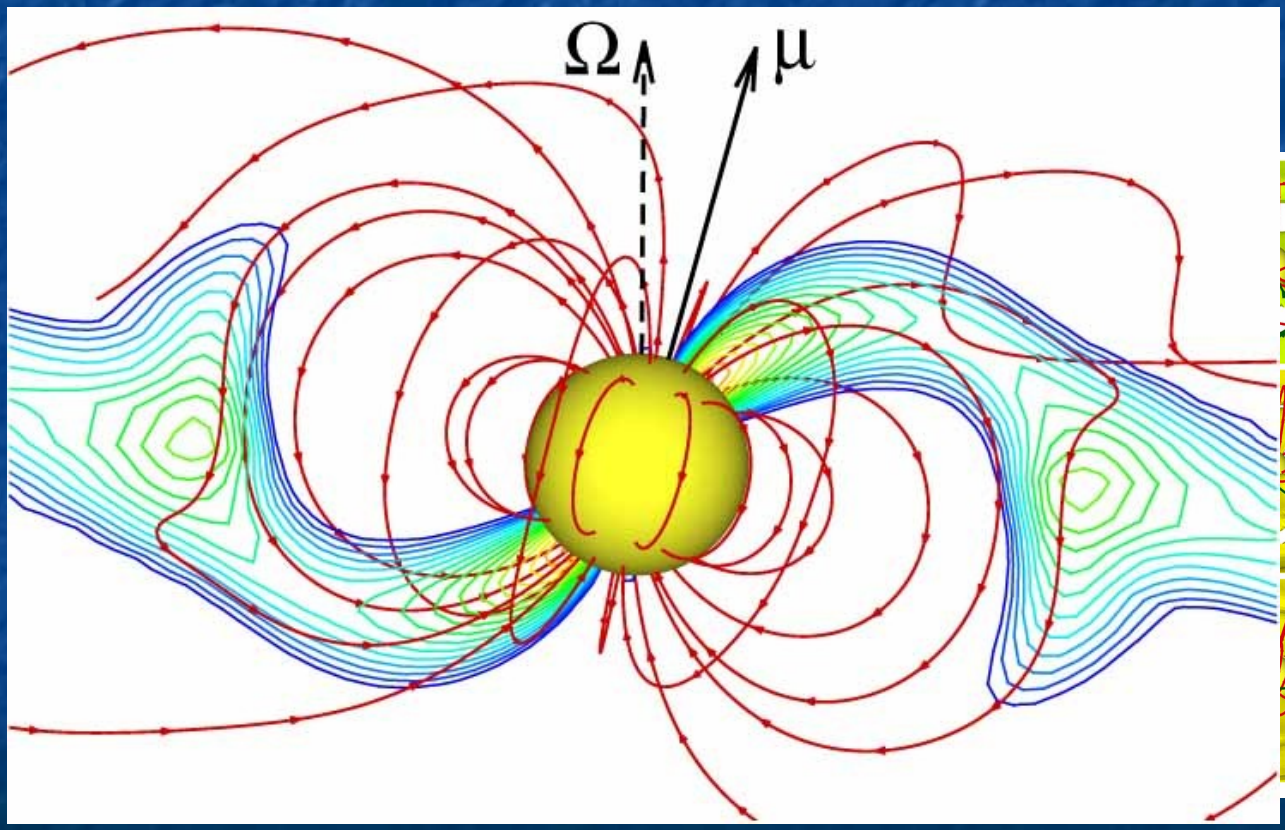
The object

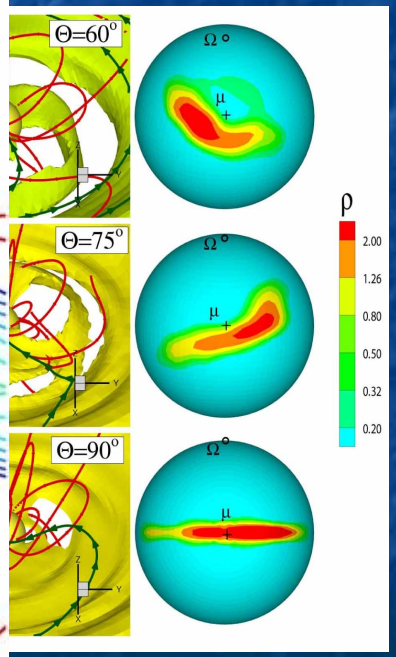
Artist's (Marek Gierliński, PhD) impression



The object

Romanova et al. 2004 MHD simulations





Outbursts

SAX J1808.4-3658 outburst happens roughly each two years

In outburst we can see emission and pulsations; in quiescence we can see nothing.

In 2002, *Rossi X-ray Time Explorer* spent ~700 ks observing the outburst. For the first time, nearly full outburst history has been covered by nearly 100 separate pointings

Our task

Analyse pulse shapes (phenomenology+physical model)

Analyze the energy spectra

-then-

Make constraints on source geometry

Check the physical theory that we expect to describe pulse shapes and spectra

Make constraints on NS equation of state

Stages of the outburst

We determined 4 stages of the outburst:

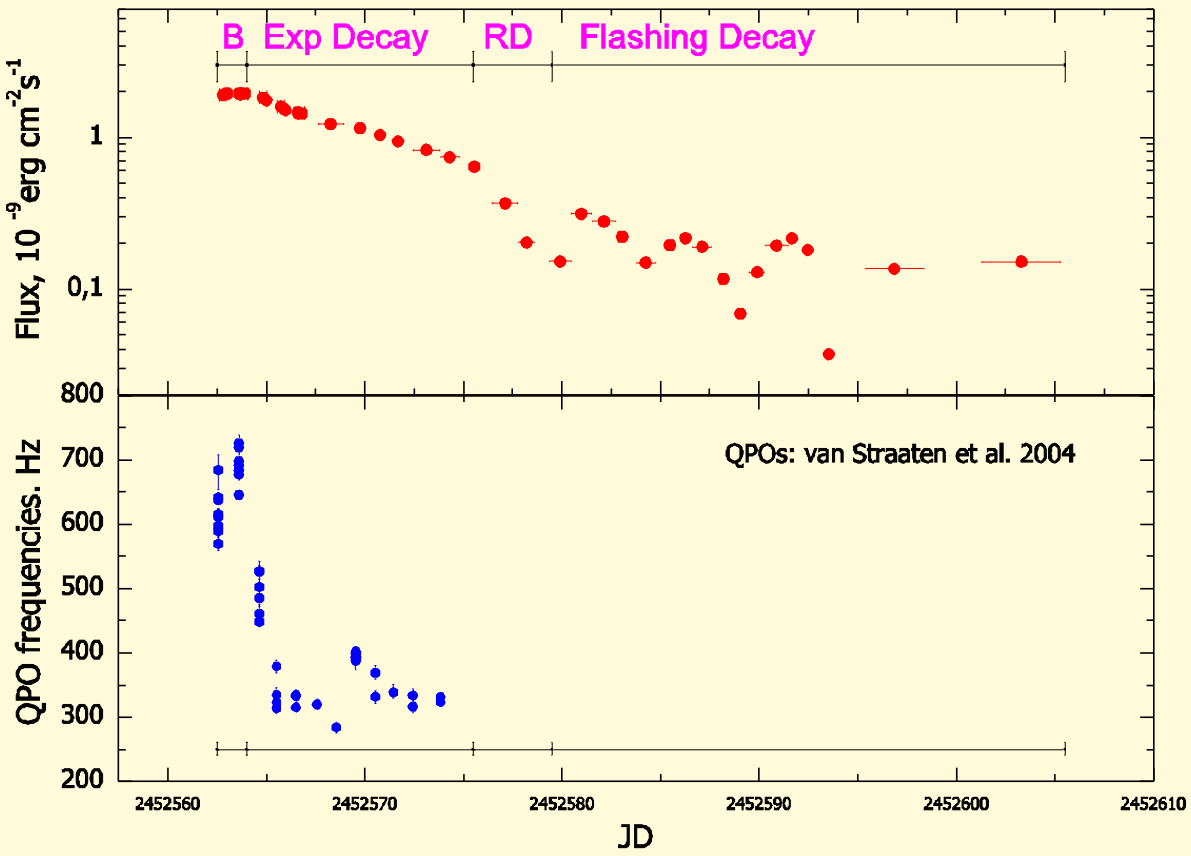
Flare – initial phase. Luminosity is constant, pulse profiles are asymmetric, QPOs in the power spectra ~600-800Hz

Exponential decay – luminosity declines exponentially, pulses are symmetrical, QPO ~ 300 Hz

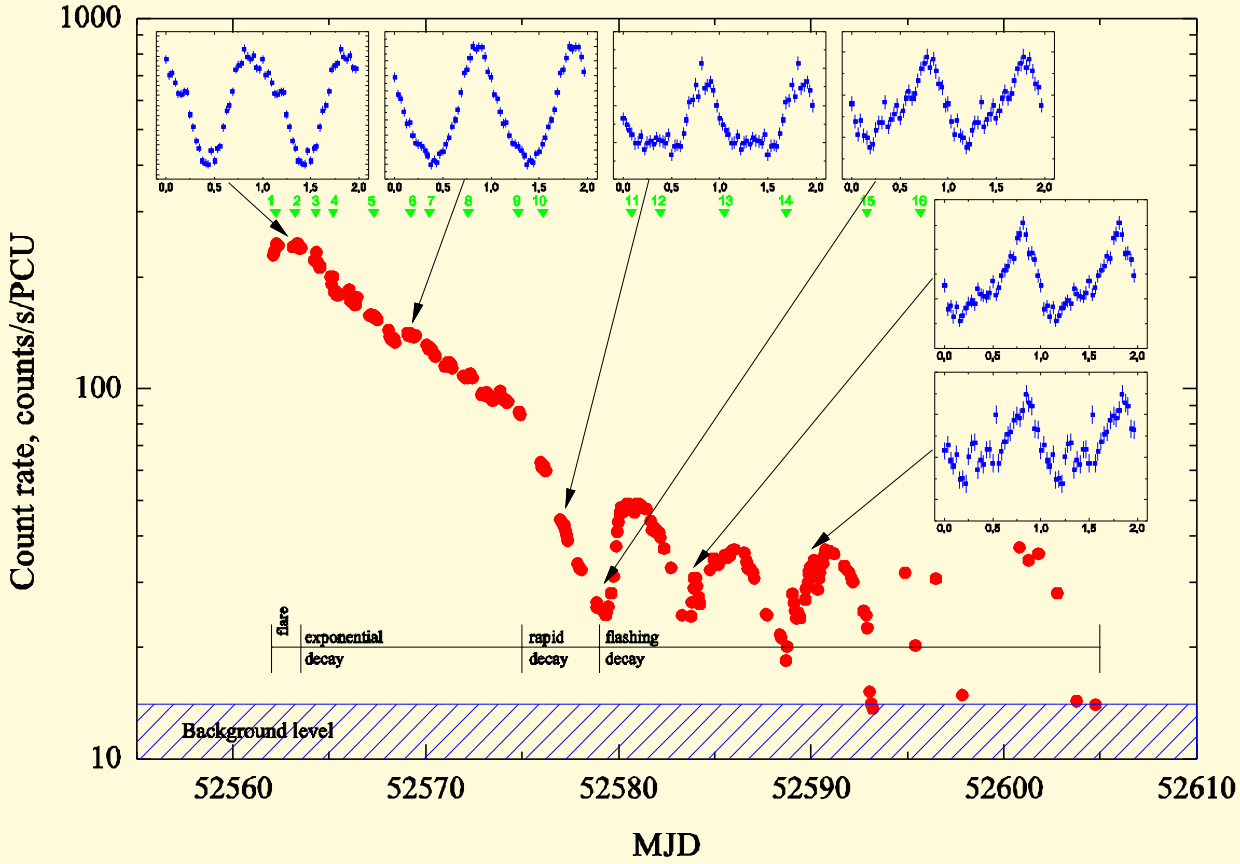
Rapid decay – fast changes in pulse shape

Flashing decay – asymmetric pulses with a second peak

Stages of the outburst



Outburst lightcurve + pulses



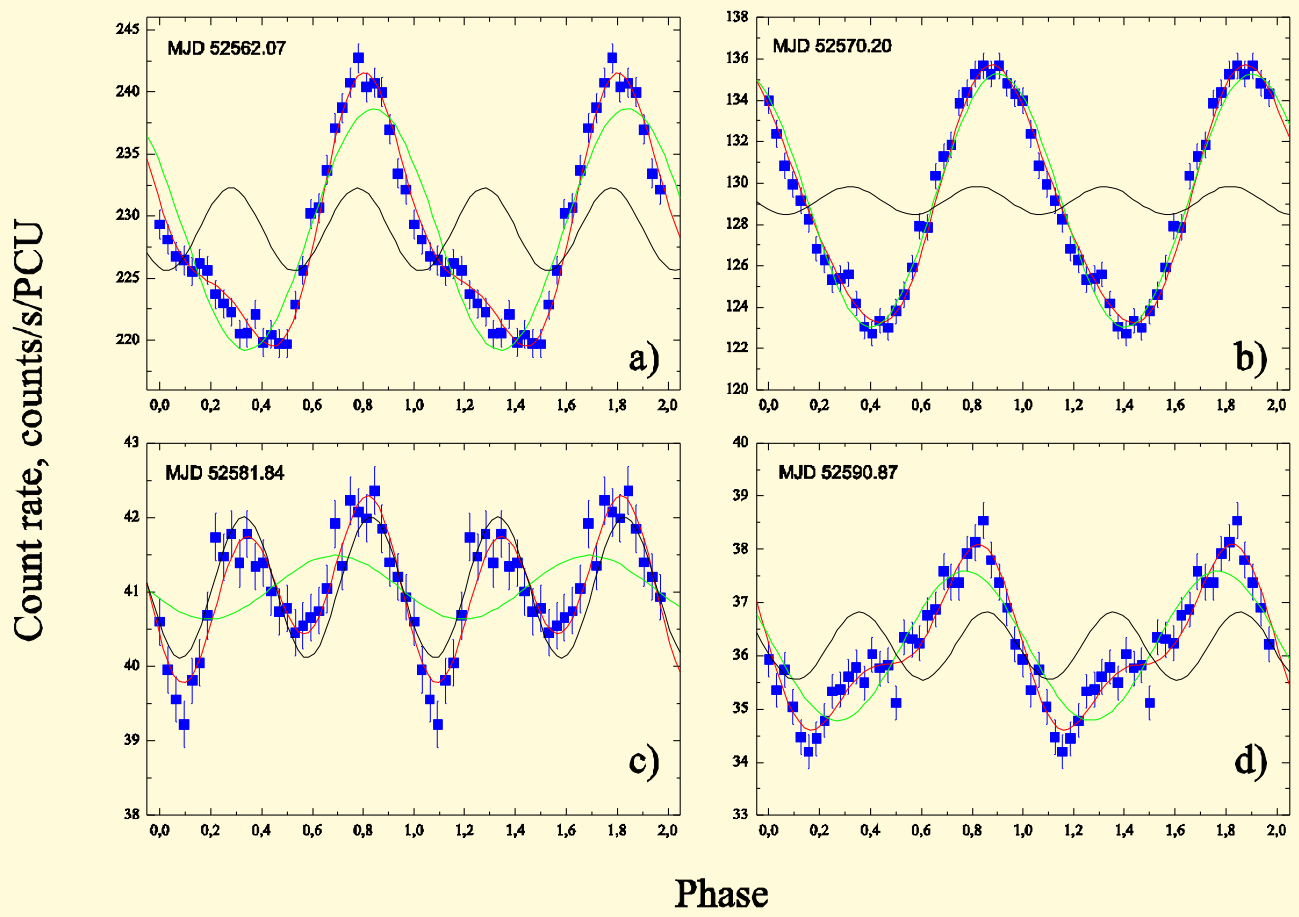
Fitting profiles with two harmonics

Simple phenomenological description – not necessarily physical, but expressing the observed data in numbers

Pulse profiles has been fitted with the formula of two harmonics

$$F(\varphi) = \overline{F}[1 + a_0 \cdot \cos(2\pi(\varphi - \varphi_0)) + a_1 \cdot \cos(4\pi(\varphi - \varphi_1))]$$

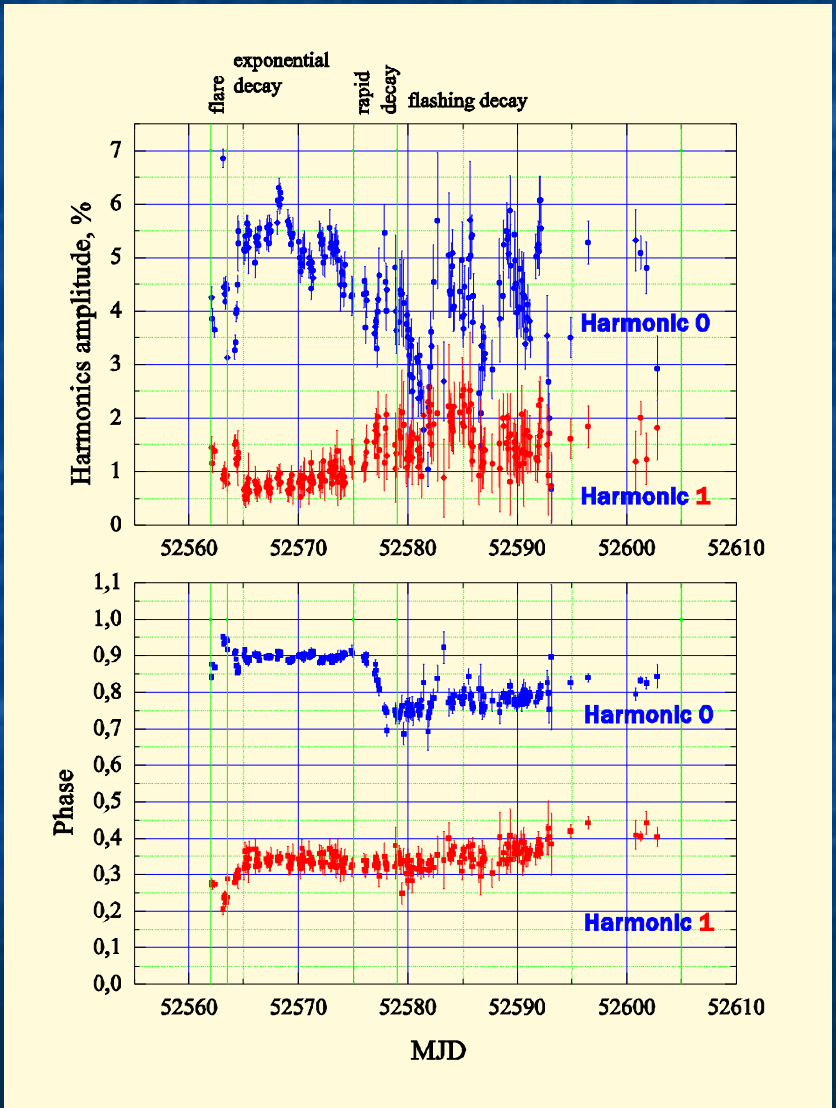
Fitting profiles with two harmonics



Fitting profiles with two harmonics

Behavior of the two harmonics during the outburst.

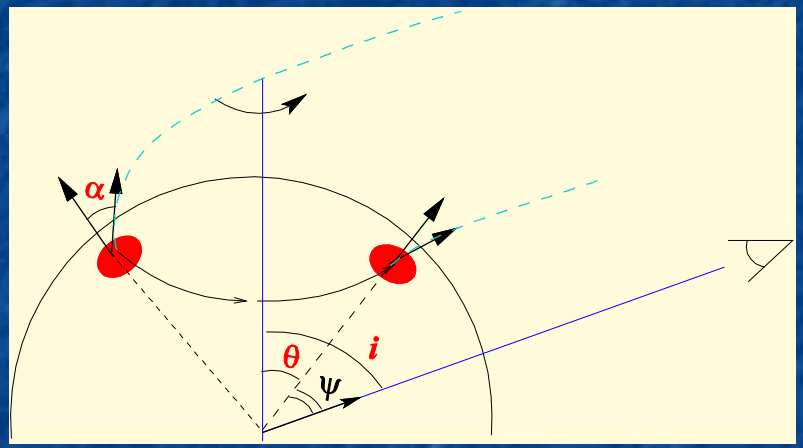
Each outburst stage shows different parameter values.



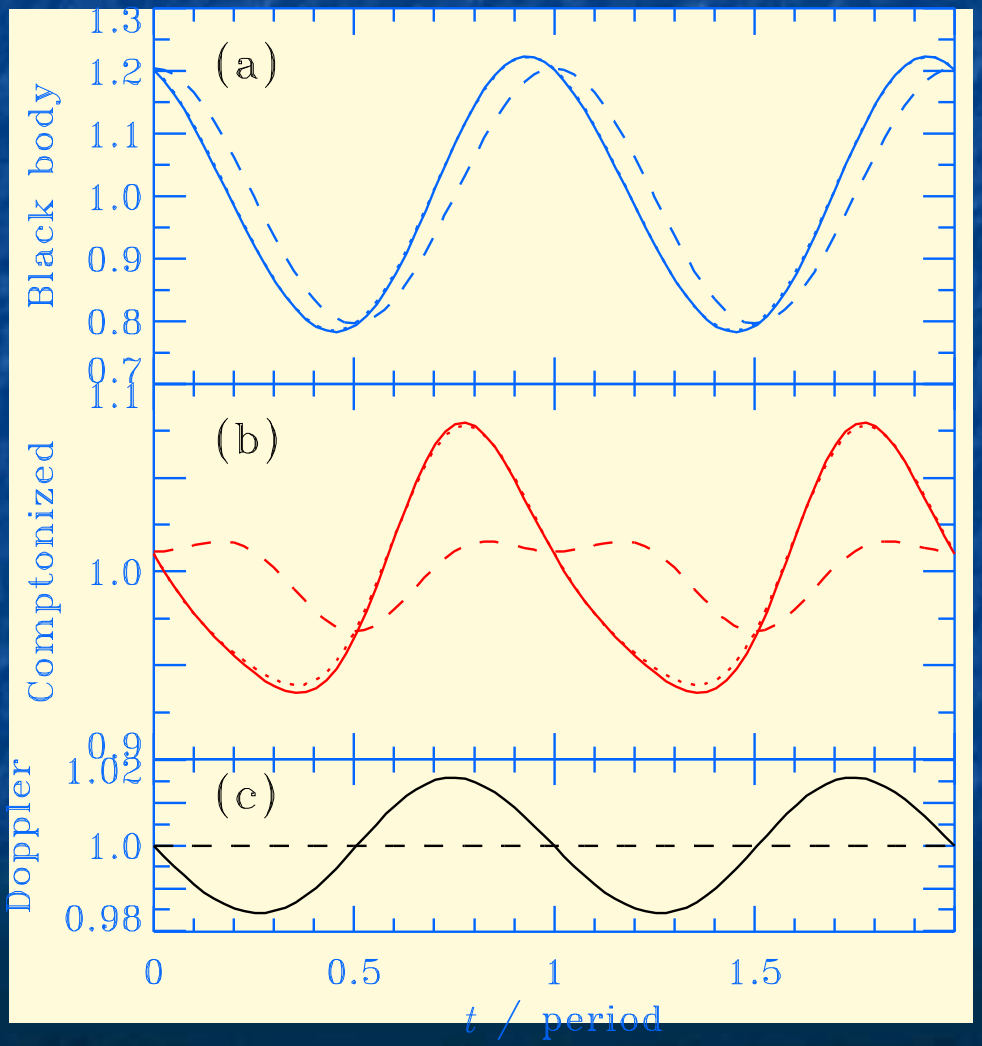
Future work: modeling a pulse

Intrinsic spectrum (blackbody + Compton scattered) > assume angular distribution of spectral components > Lorentz transform to the non-rotating frame, account for relativistic aberration and Doppler boosting
> Gravitational light deflection > obtain model spectrum as function of phase > Compare with data in 2 terms

Future work: modeling a pulse



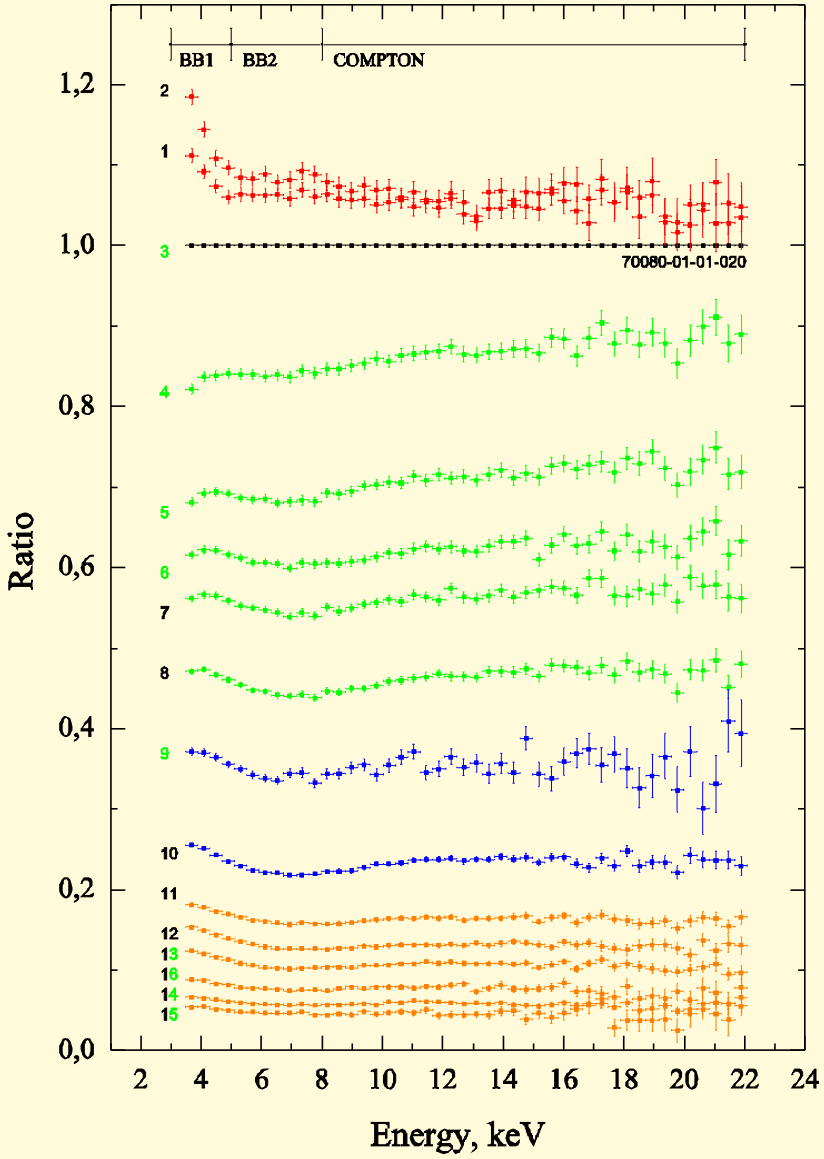
Dashed lines: slow pulsar
Solid lines: fast pulsar



Poutanen & Gierlinski 2003

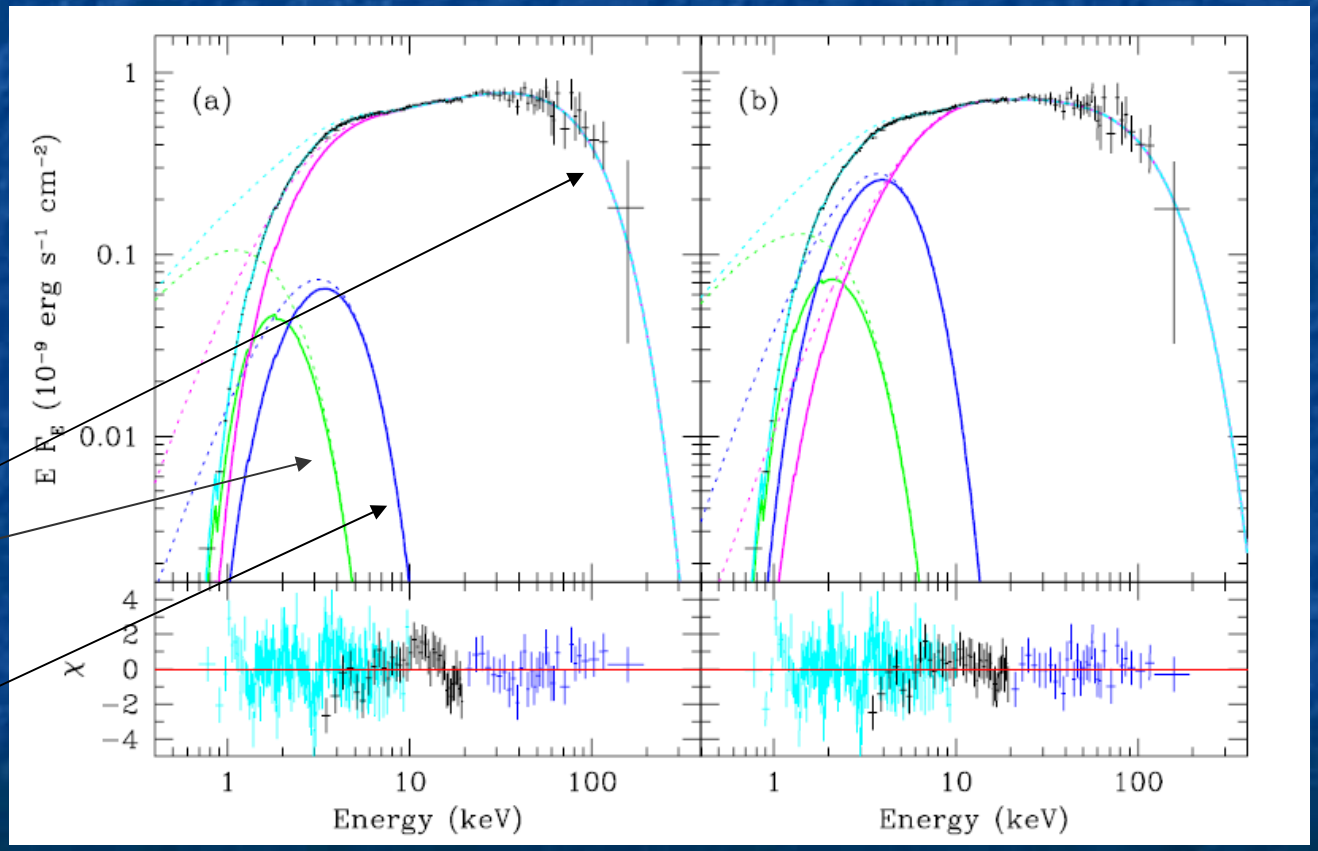
Ratios

Spectrum is composed from the several components - how to distinguish? Check ratio between spectra.



Spectral components

Similar object XTE J1751-305 (1-150 keV)



Compton

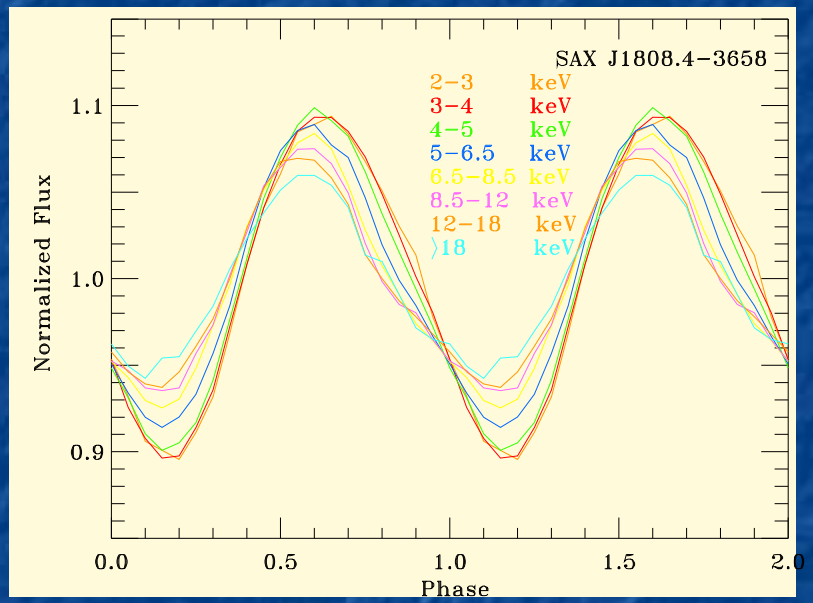
Disk

Hot spot

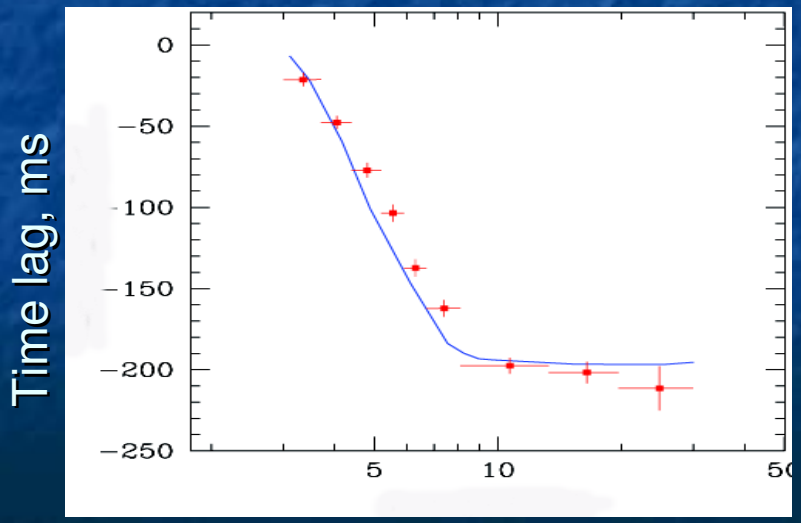
Gierlinski and Poutanen 2005

…expect the same in SAX J1808.4-3658

Future work: time lags



Within pulse, hard X-rays delays comparing to soft ones. Cause: different emission angular patterns of emission for soft and hard X-rays (blackbody and Comptonized emission)



Data from the previous outburst of the source (Gierlinski et al.,2002).

Future work: summary

- Will compare model of a pulse to the observed pulses an derive source parameters
- Will analyze the energy spectra taken during the outburst
- Will analyze time lags
- Will analyze phase-resolved energy spectra
- And make constraints on source conditions

Thank you