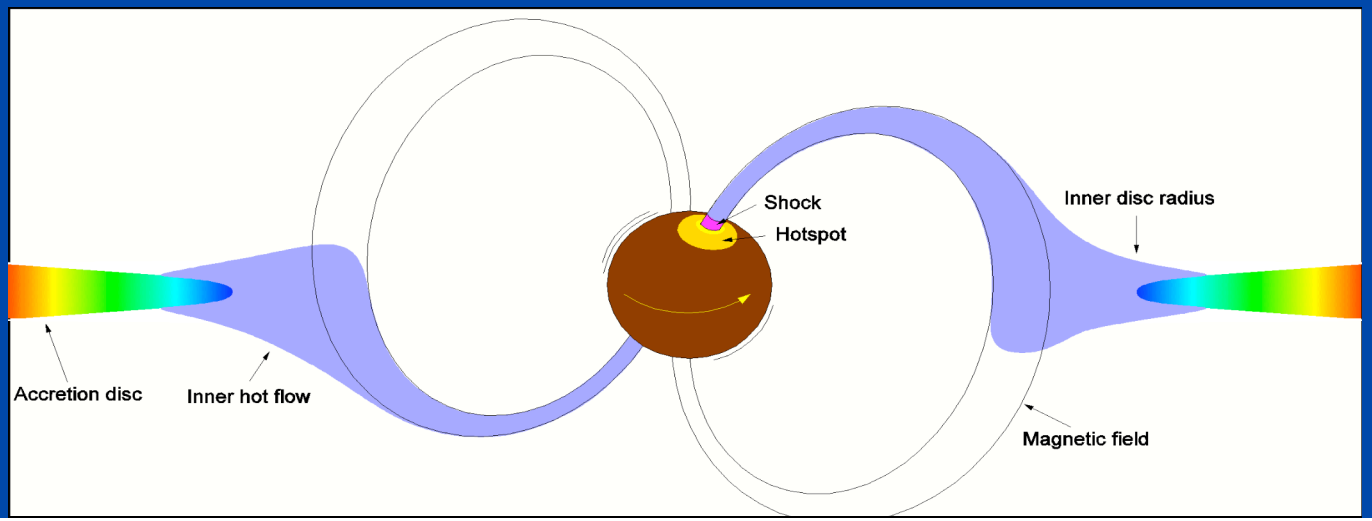
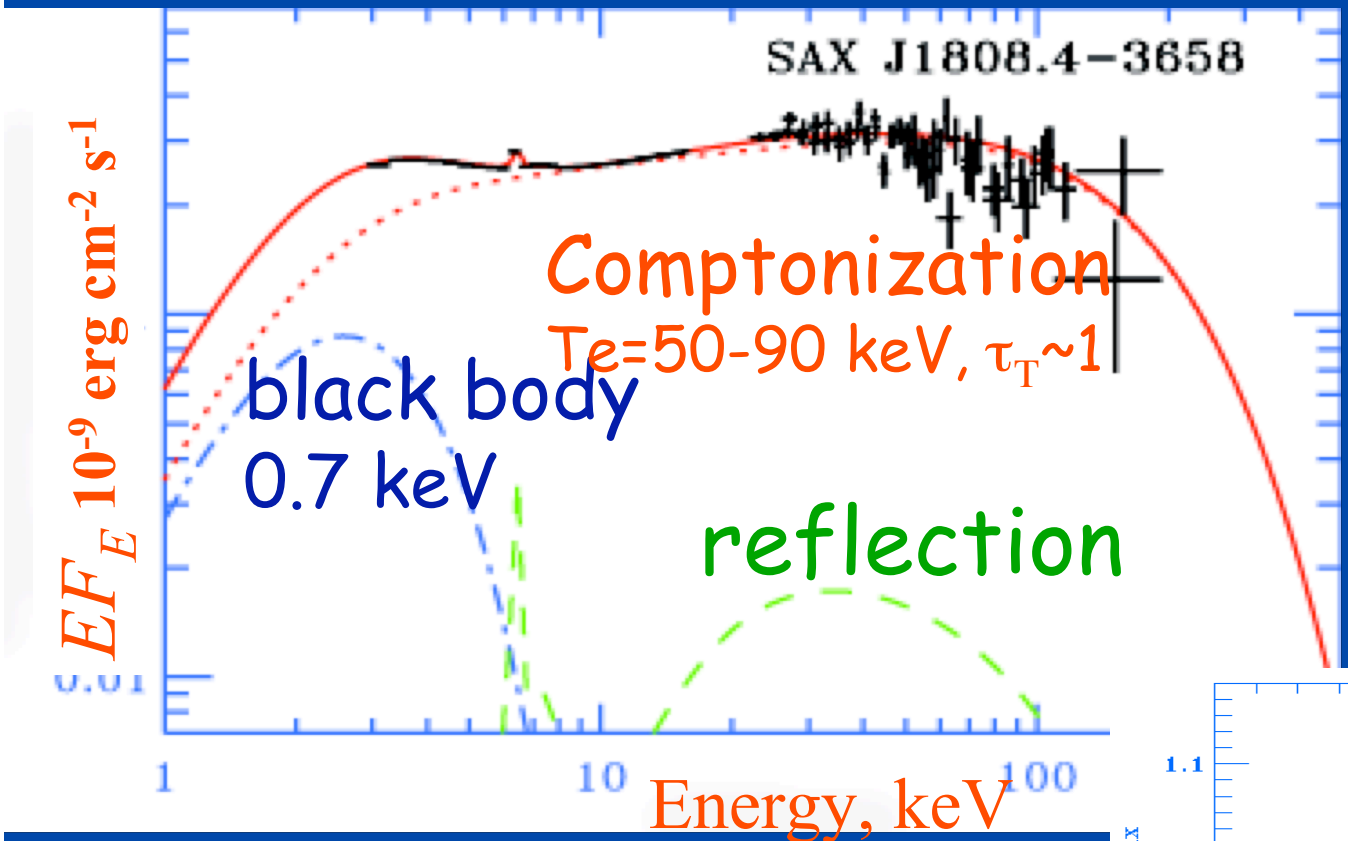
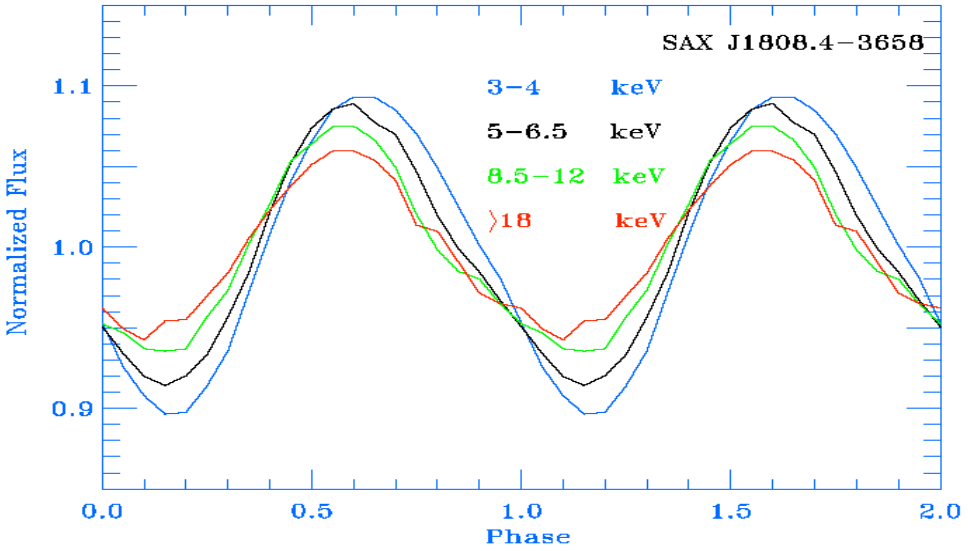
On the nature of pulse profile variations and timing noise in accreting millisecond pulsars, or How to see invisible

Juri Poutanen (Univ. of Oulu, Finland)
+ Askar Ibragimov, Marja Annala



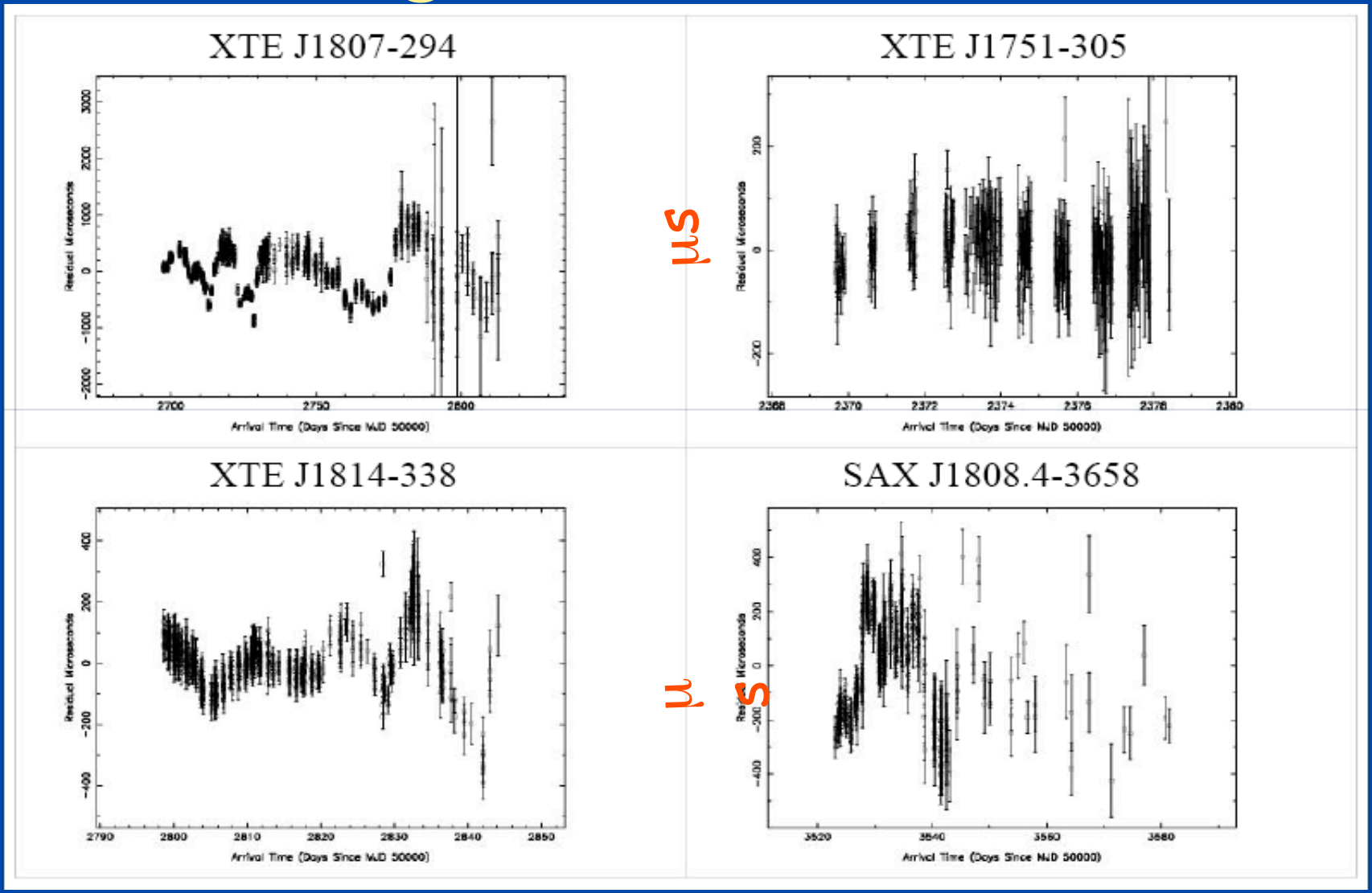
Spectral energy distribution





Poutanen & Gierlinski (2003).

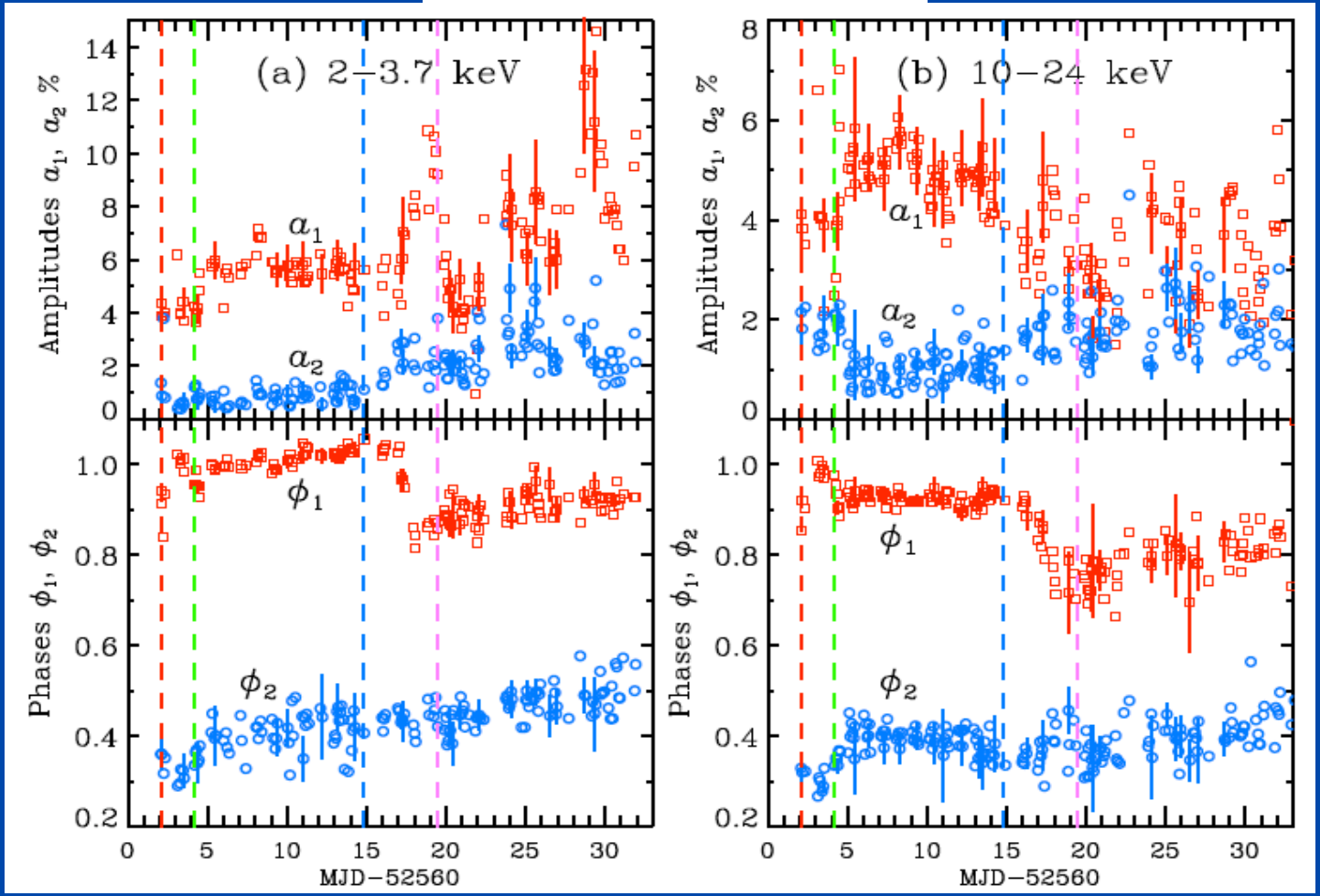
Timing noise: residuals



A. Patruno

Variations of pulse phases and amplitudes

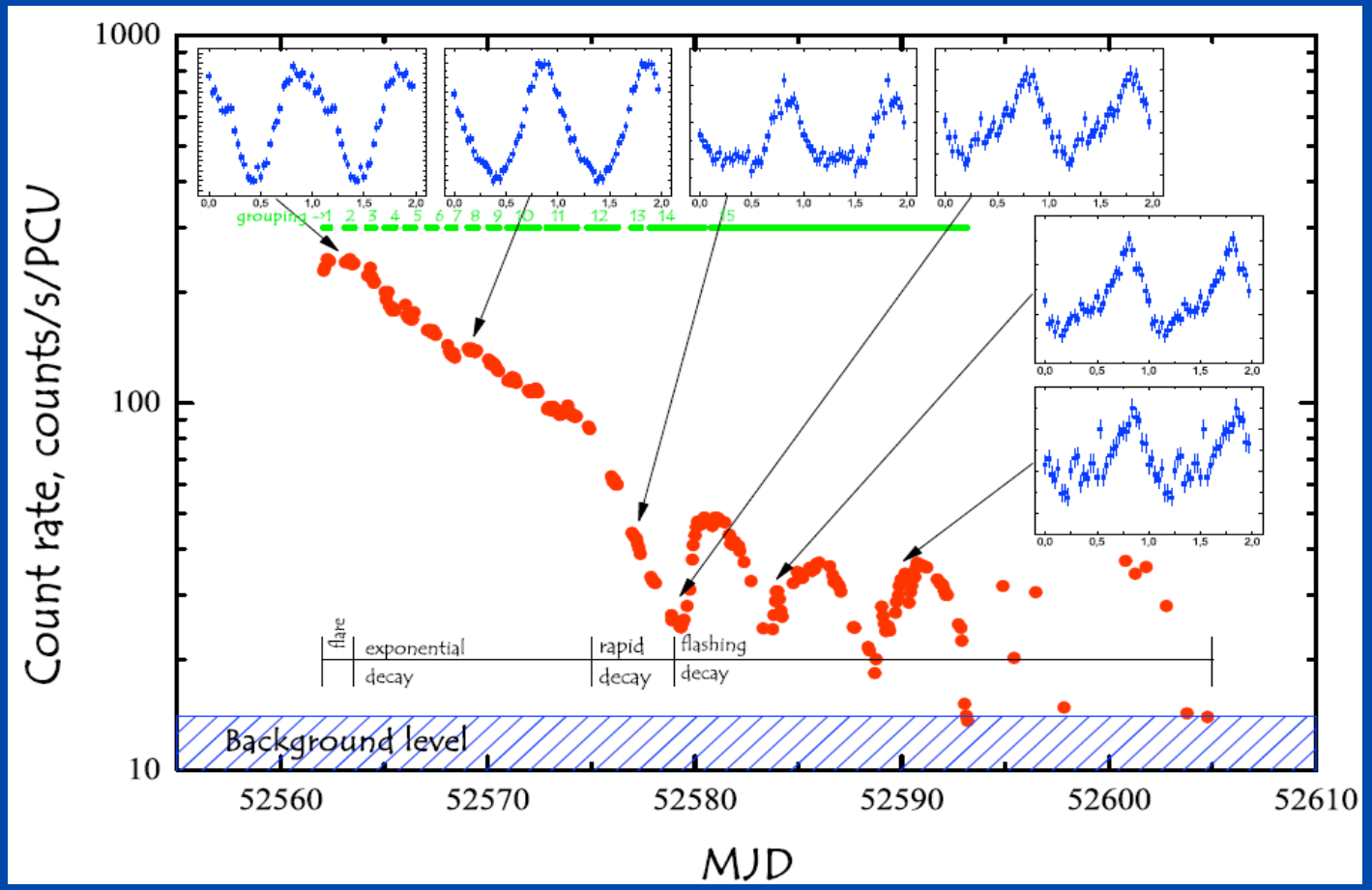
SAX J1808.4-3658



$$F(\phi) = \overline{F}\{1 + a_1 \cos[2\pi(\phi - \phi_1)] + a_2 \cos[4\pi(\phi - \phi_2)]\}$$

Ibragimov & Poutanen 2009

Pulse profile variations



- Pulse profile is stable during high flux level and varies in the end of the outburst.
- Spot wandering? Secondary spot is visible?
- Accretion disk recedes from the star?

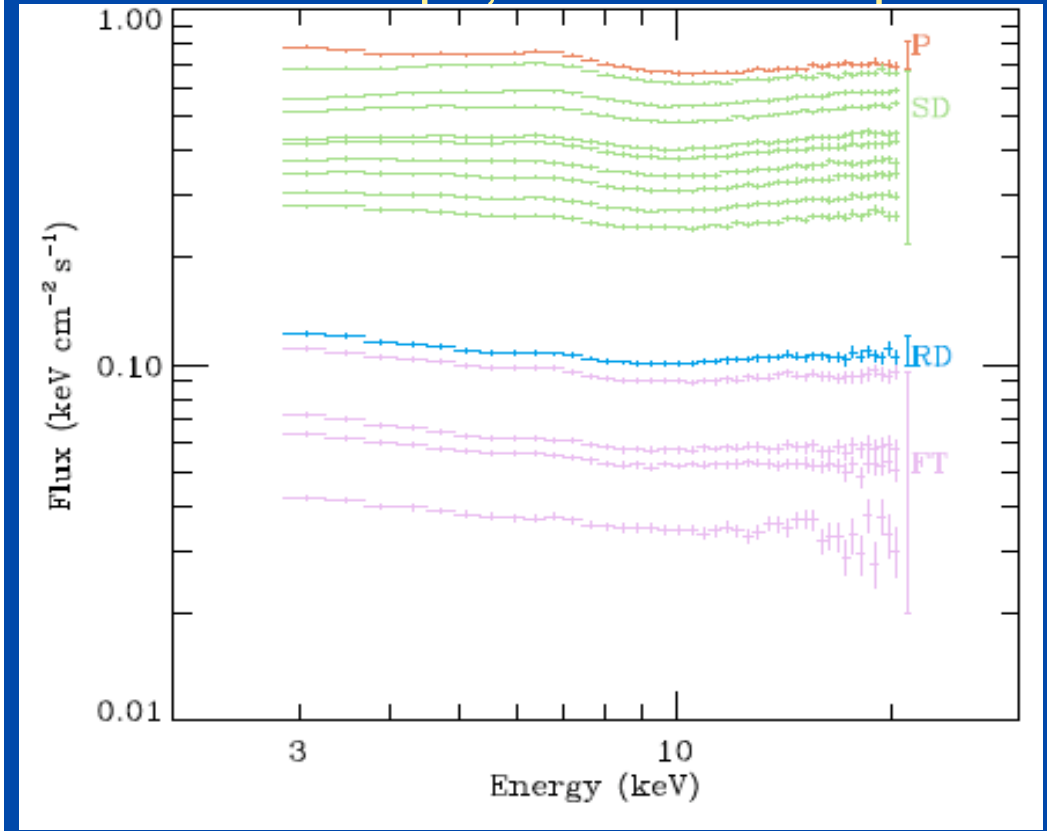
Hartman et al. (2008)
Ibragimov & Poutanen (2009)

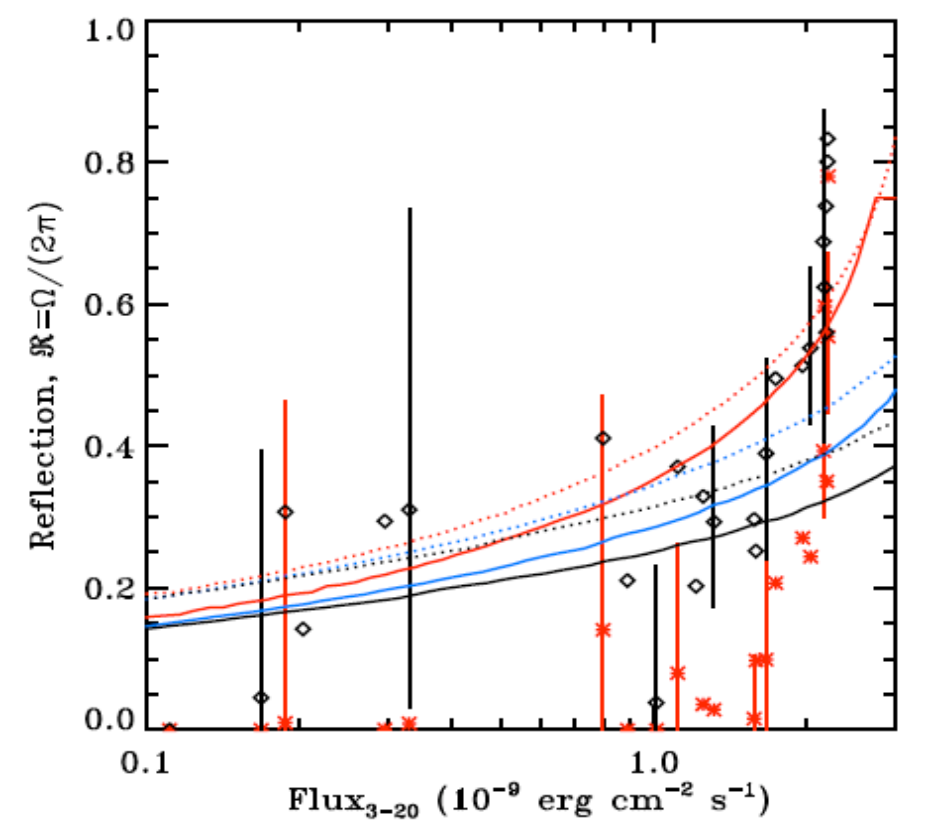
Evidence for a receding disk

Reflection - flux correlation

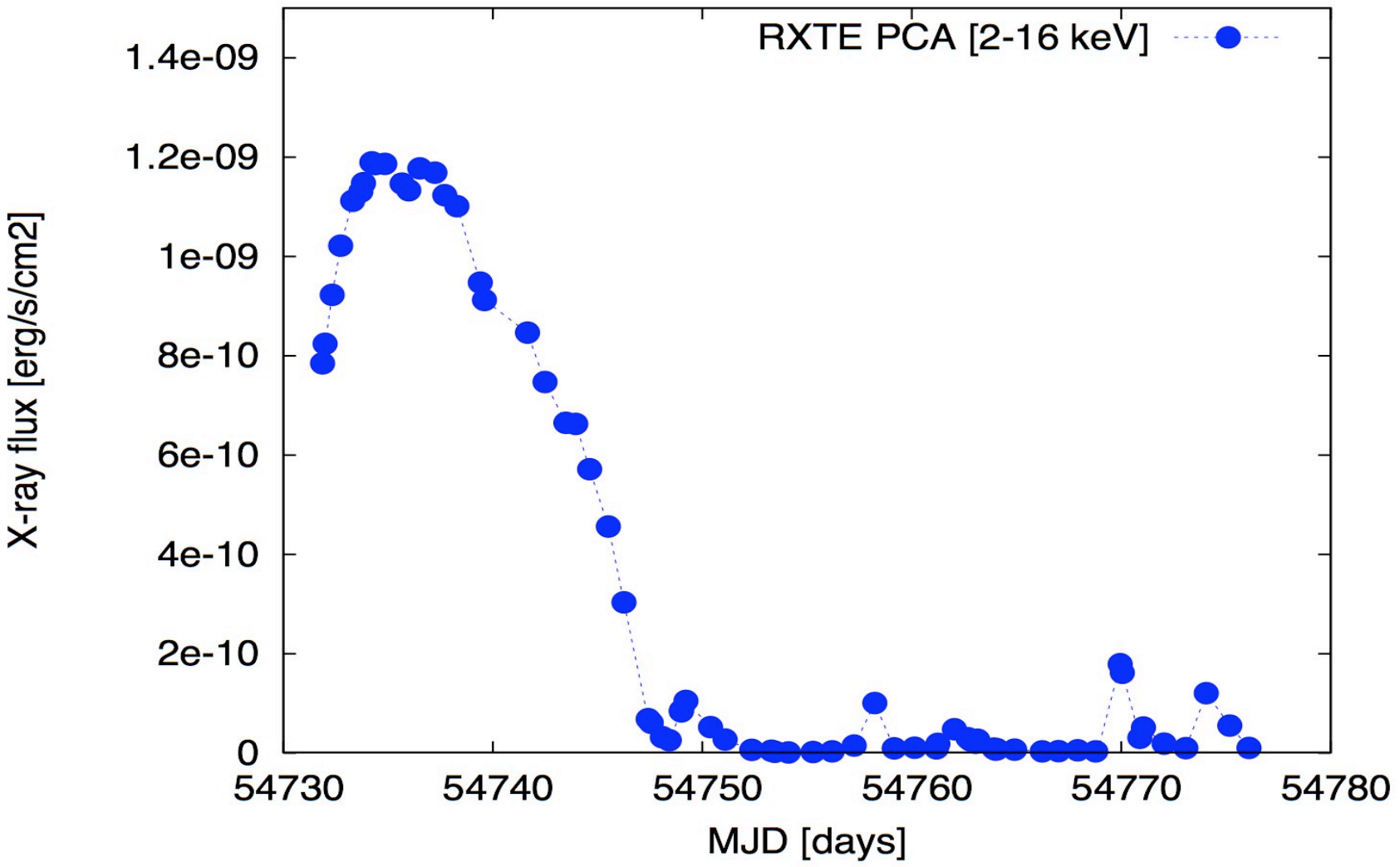
Reflection tells what is the solid angle occupied by the accretion disk as viewed from the hotspot.

Flux drops, reflection drops $\Longrightarrow$ disk is moving out

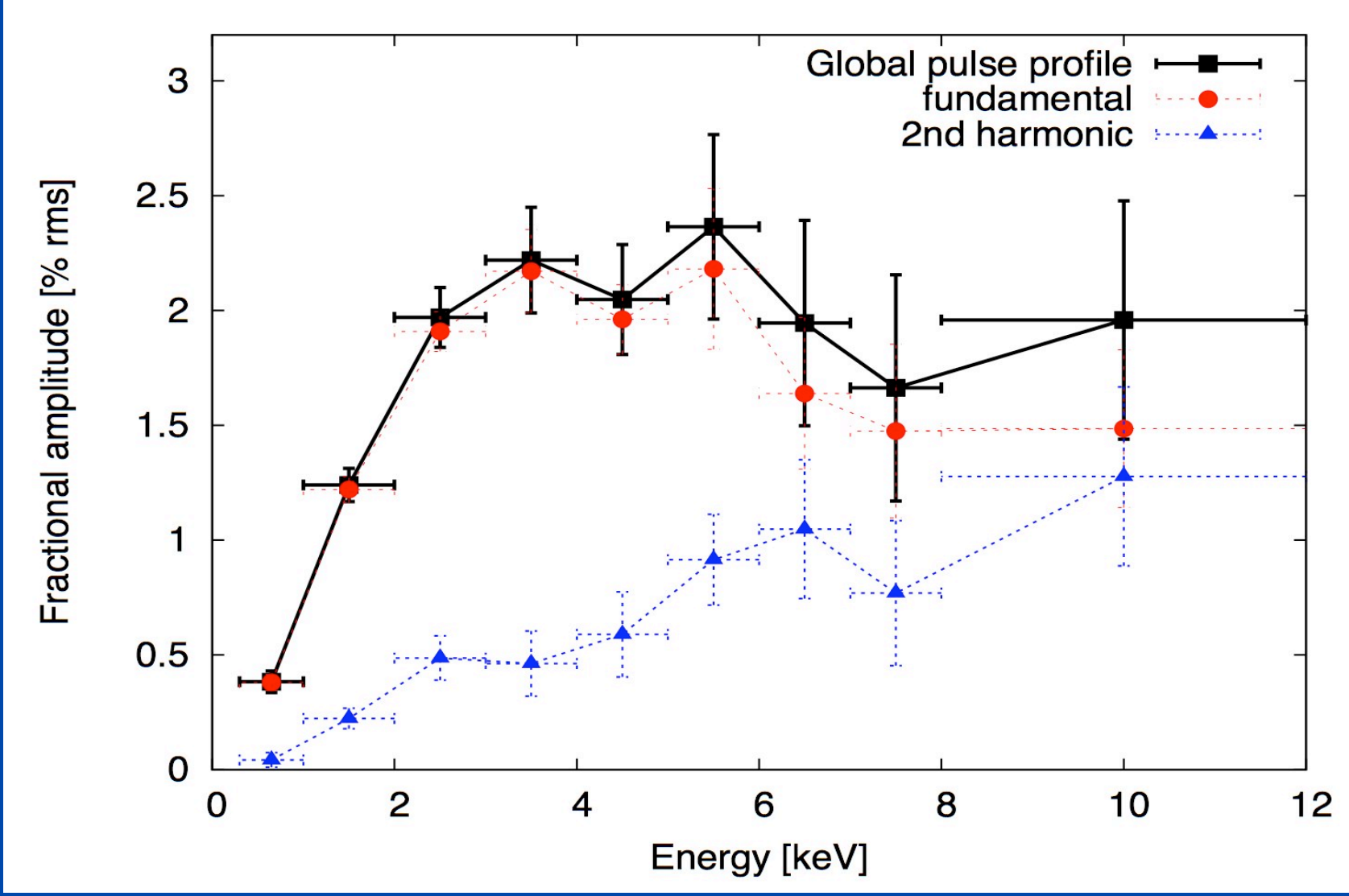




SAX J1808 in October 2008

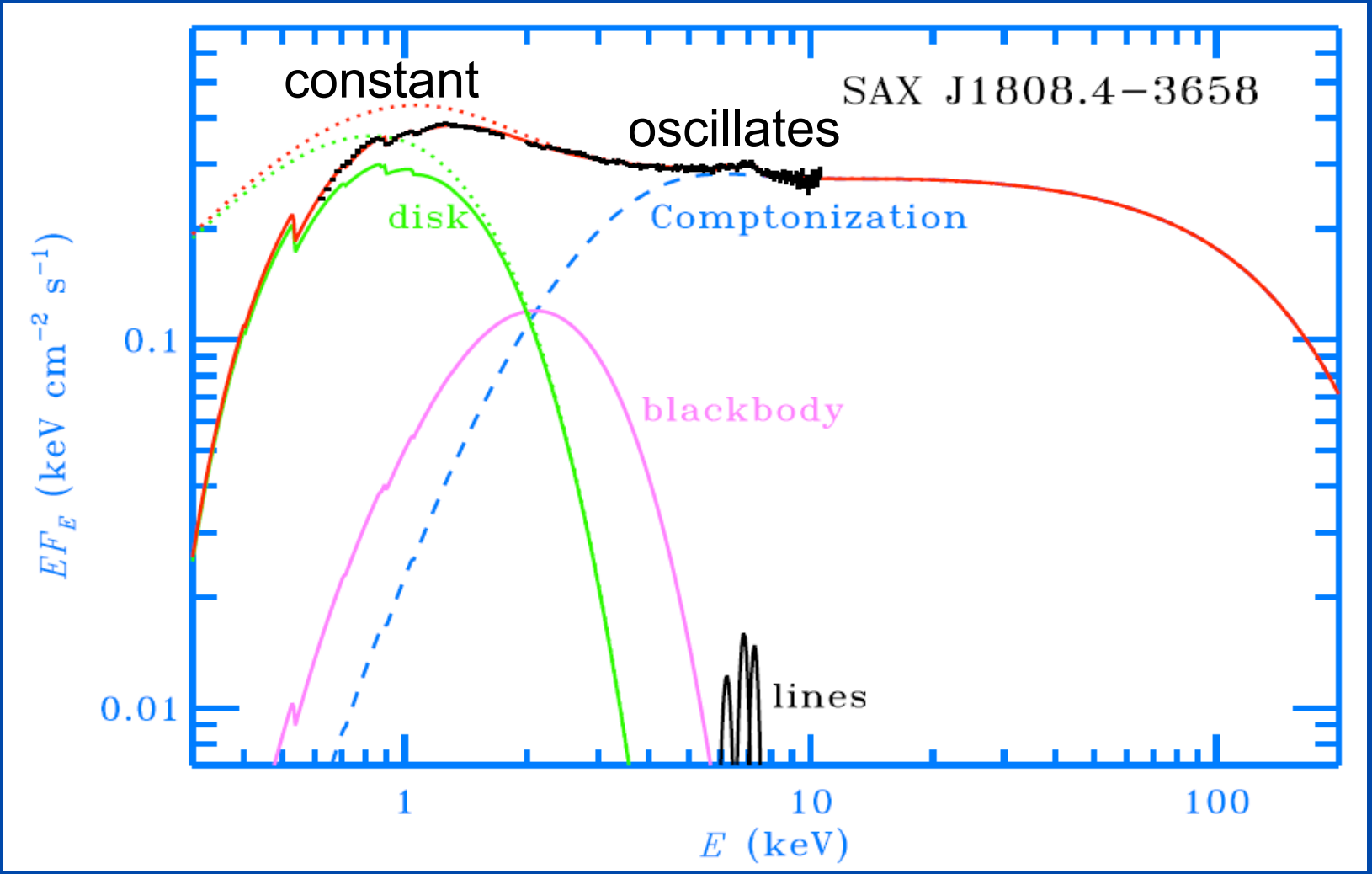


SAX J1808 in October 2008



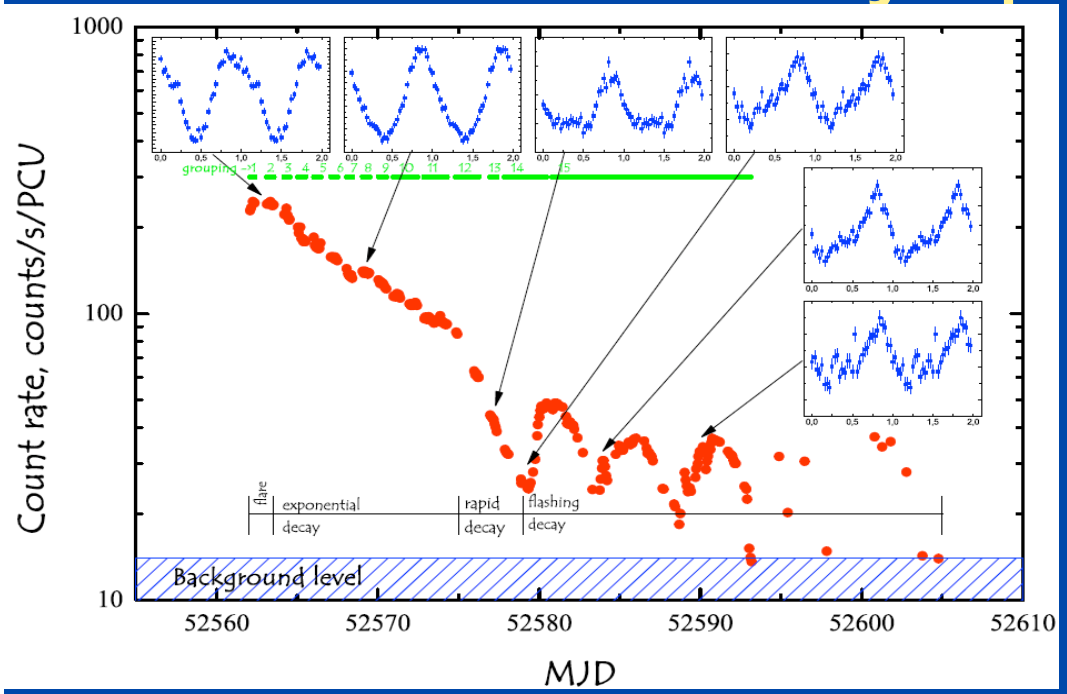
Patruno et al. 2009

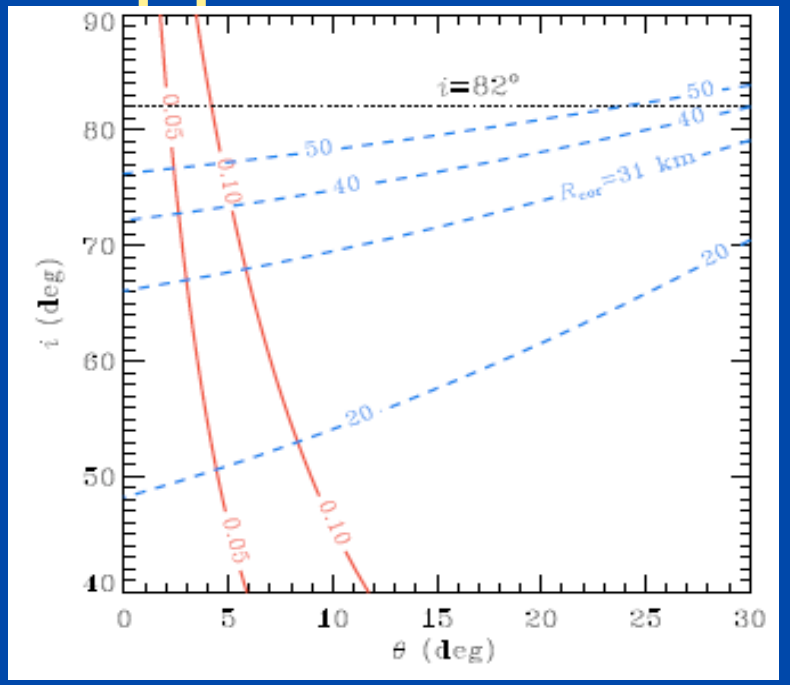
Spectral energy distribution



Poutanen, Patruno et al., in preparation

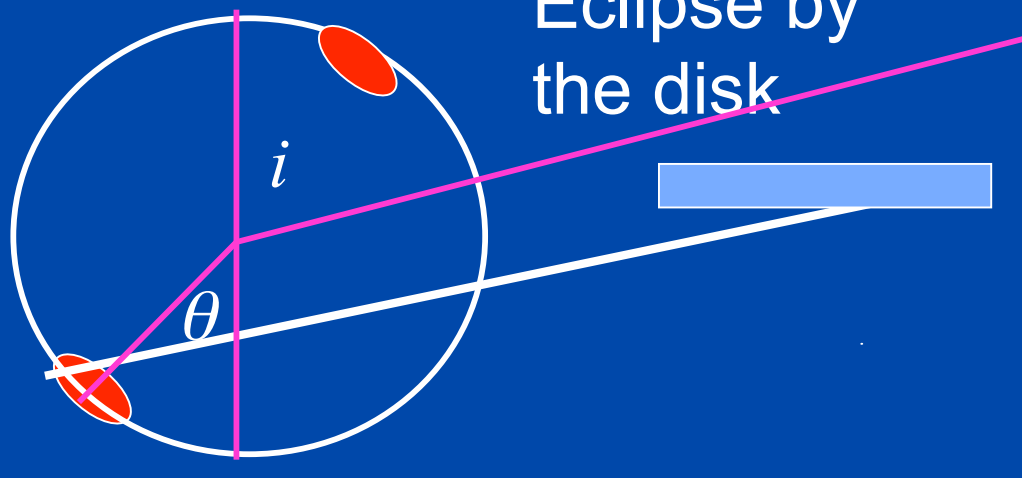
Inner disk radius at the moment of secondary spot appearance





$$R_{disk} = 26 \pm 8 \ \text{km}$$

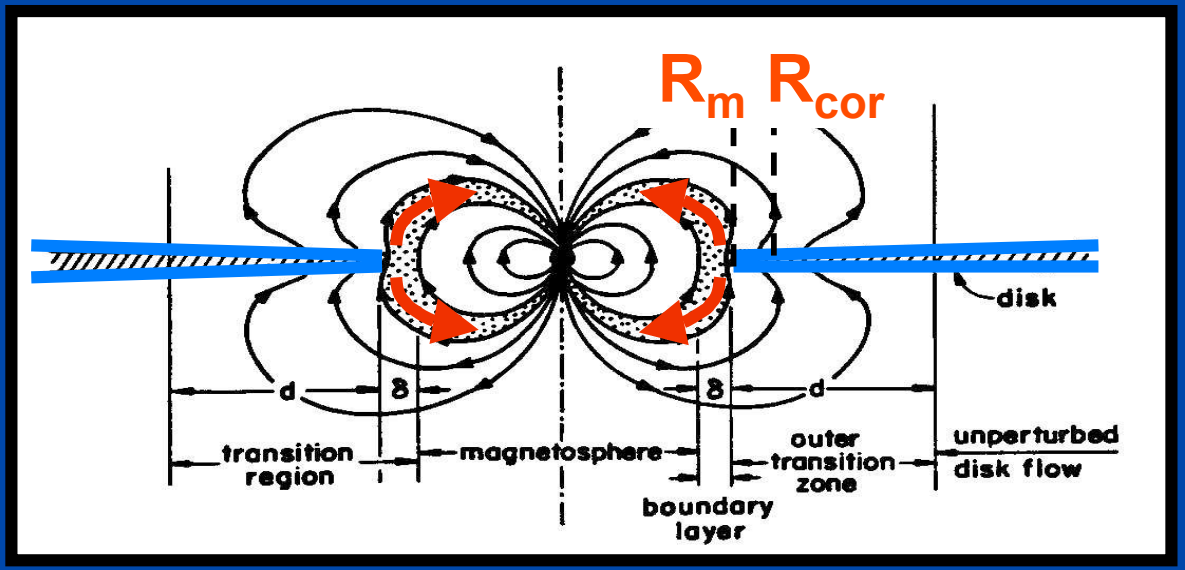
$$\text{for } 50 \le i \le 70 \ \text{deg}$$



Eclipse by the disk

Neutron star magnetic field and magnetosphere-disk interaction

$$R_m = \left(\frac{B_0^2 R_{ns}^6}{2\dot{M}\sqrt{2GM}} \right)^{2/7}$$



At the moment of secondary spot appearance, we measure the luminosity ⟹ accretion rate ⟹ B-field

$$\mu_{25} = (9 \pm 5)\ k_A^{-7/4}\ \mathrm{G\ cm^3}$$

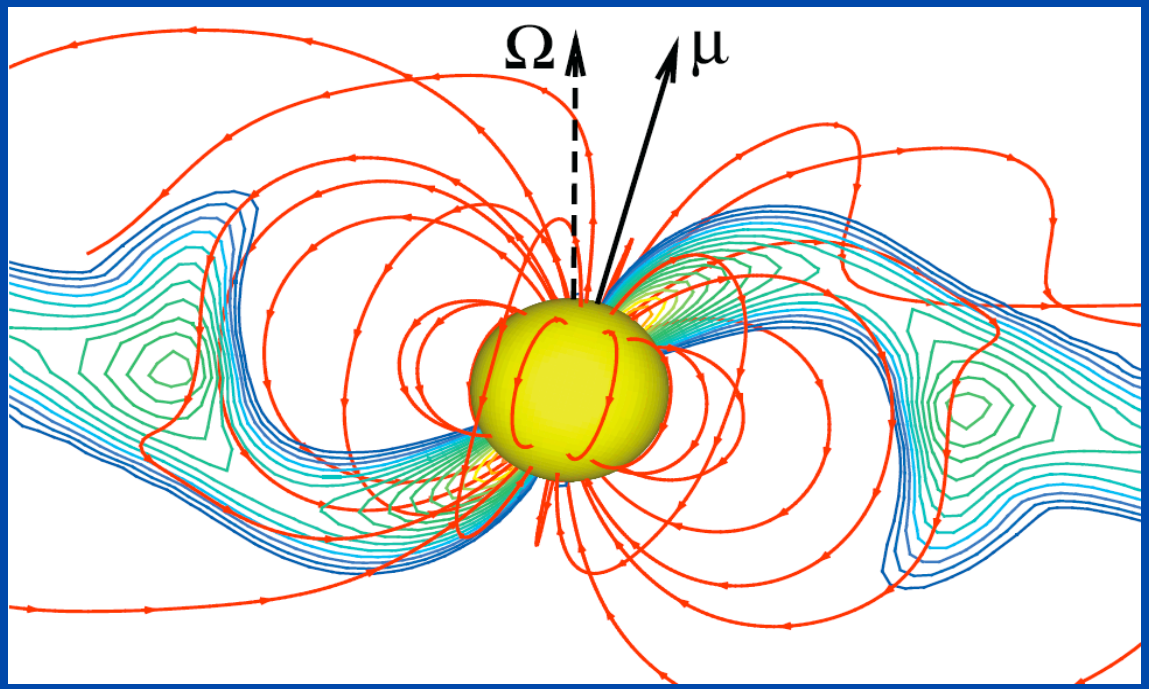
$$B_0 = (0.8 \pm 0.5)\ 10^8\ k_A^{-7/4}\ \mathrm{G}$$

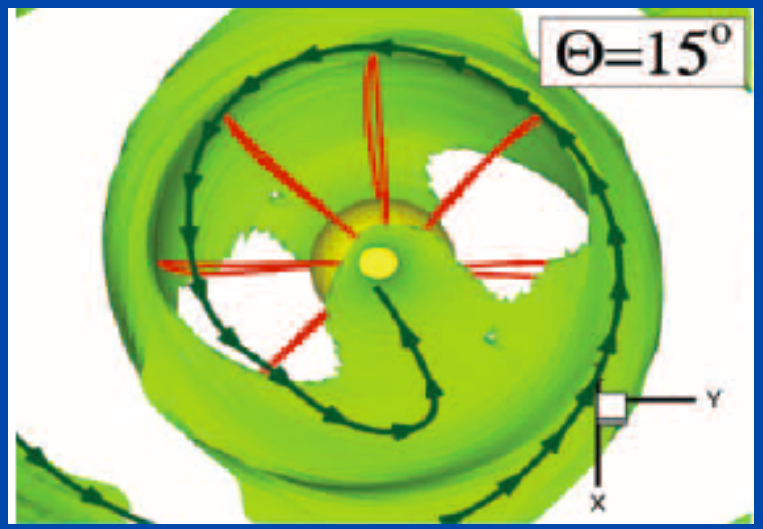
$$k_A = R_{disk}/R_m$$

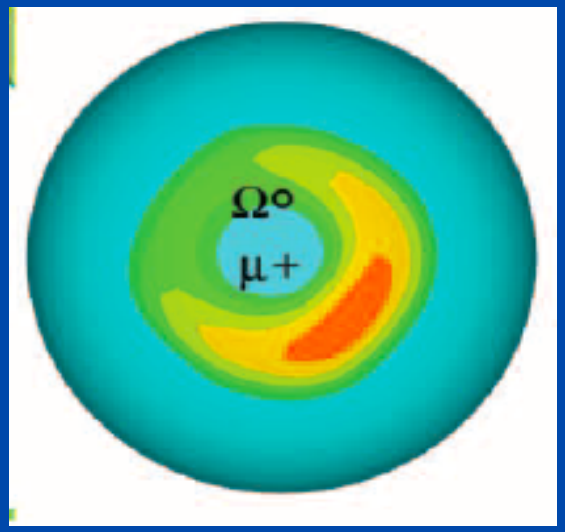
Consistent with the results obtained from the spin-down of the source by Hartman et al. (2008)

$$\mu_{25} = (5 \pm 3)\ \mathrm{G\ cm^3} \Rightarrow 0.8 \le k_A \le 2.5$$

MHD simulations of accretion on to an inclined dipole

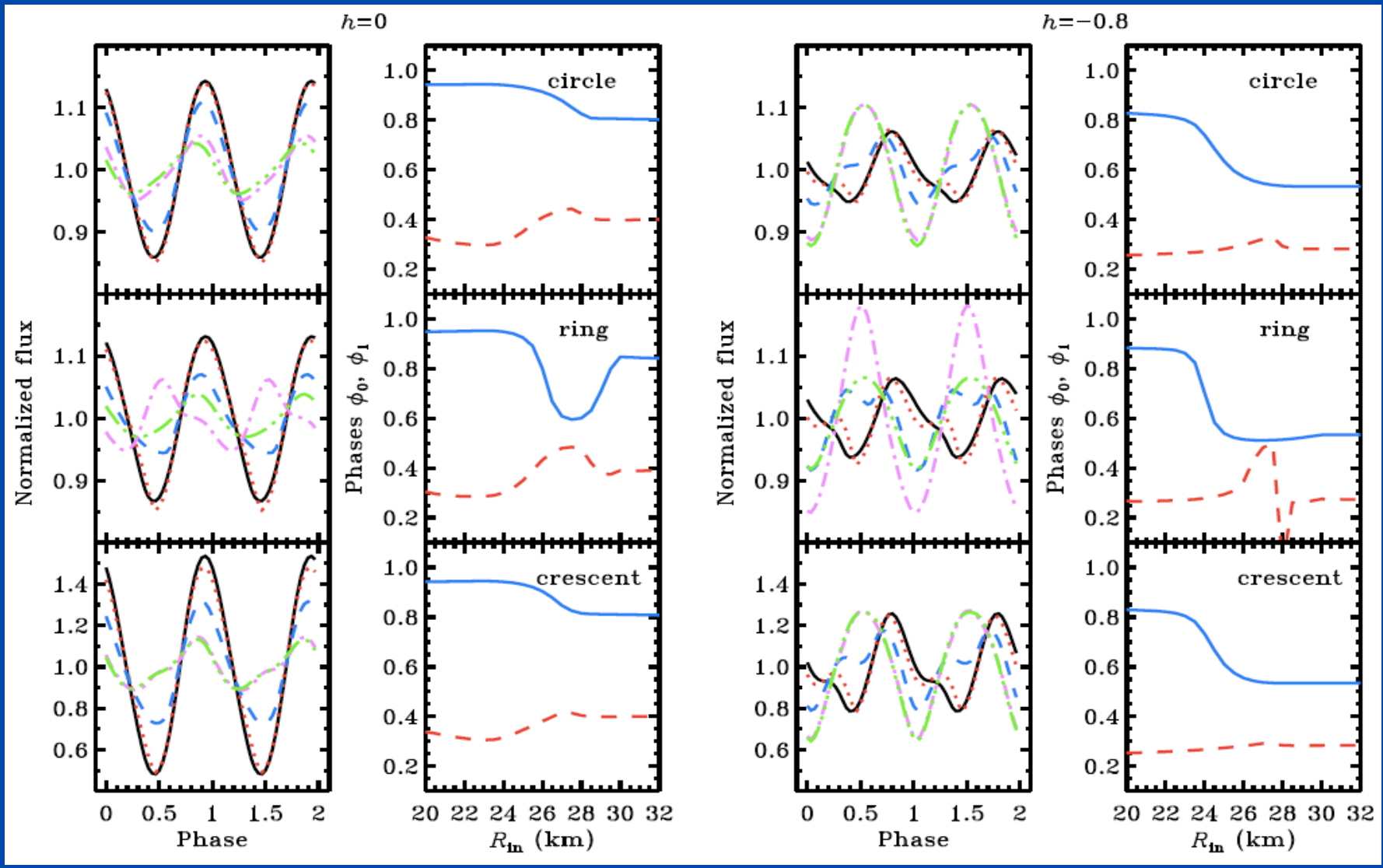






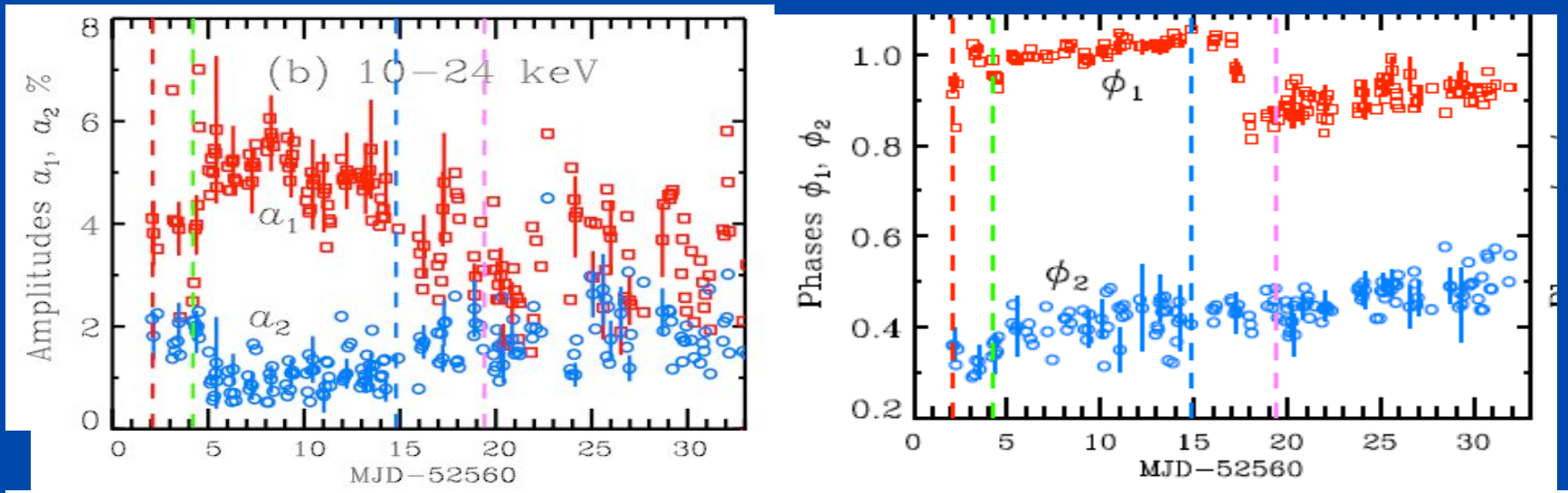
Romanova et al. 2004

Pulse profiles as a function of inner disk radius



Pulse phases and amplitudes

for varying inner disk radius



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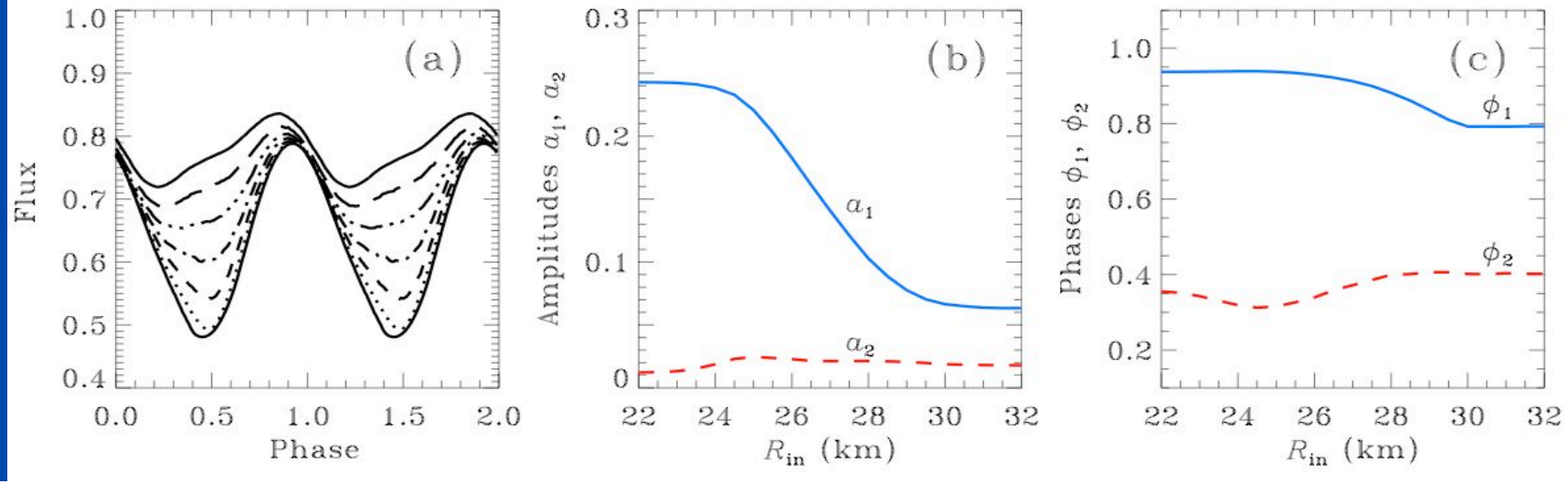

Summary

- Timing noise and phase jumps can be caused by inner disk radius variations and changing visibility of the secondary spot
- Variations of reflection $\Rightarrow$ varying inner radius of the accretion disk
- RMS(E) $\Rightarrow$ presence of the disk
- Change of the pulse profile $\Rightarrow$ appearance of the 2nd spot $\Rightarrow$ disk radius $\Rightarrow$ B-field
- The pulse profile variations allow us to understand the geometry of accretion and to put constraints on the disk-magnetosphere interaction models.