Variability in black hole X-ray binaries and its connection to accretion geometry

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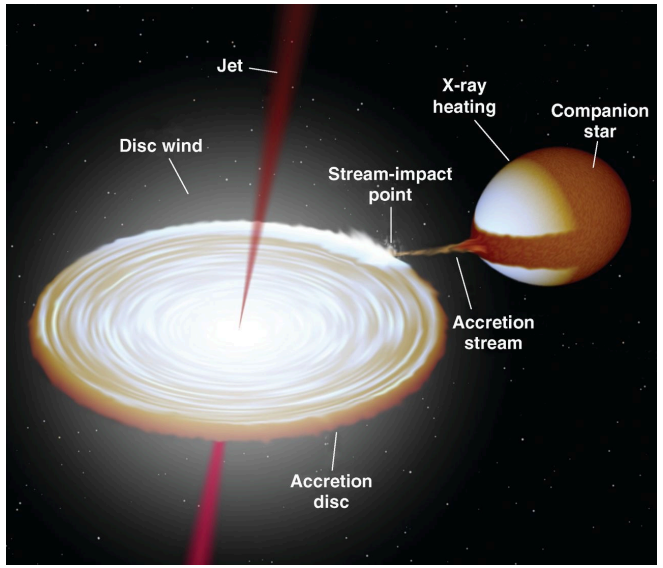
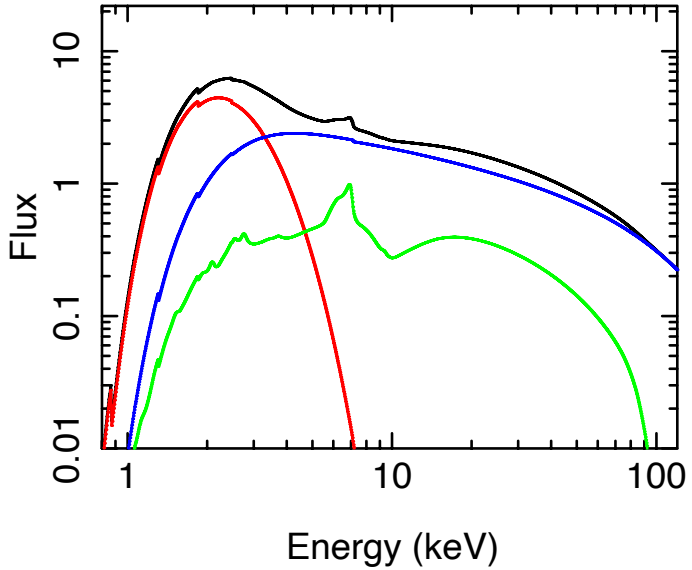
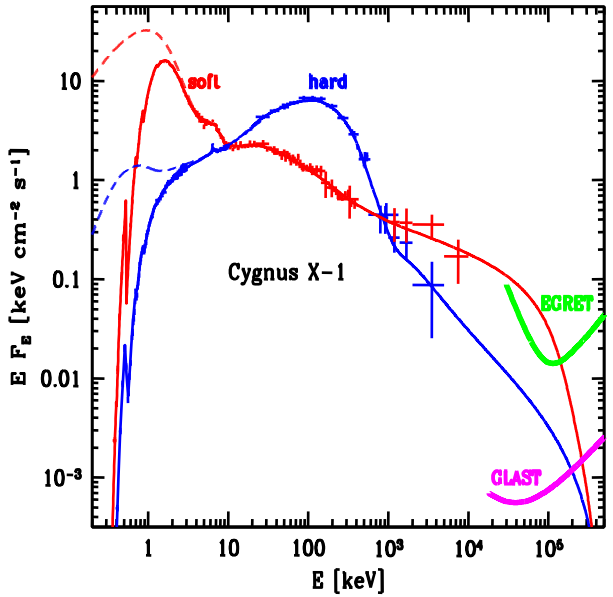
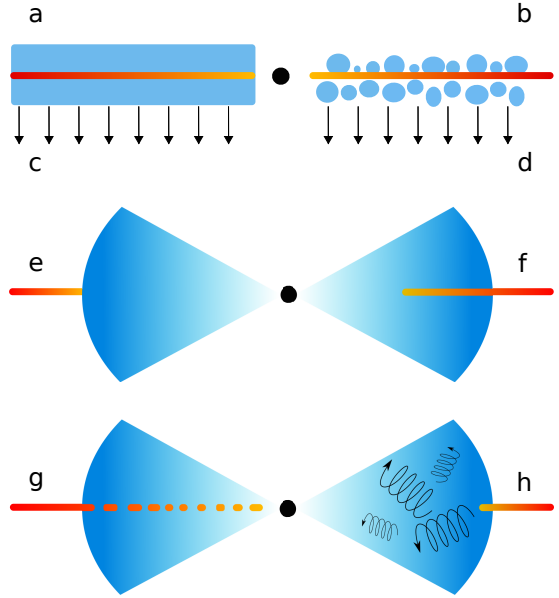
Accreting BH X-ray binaries

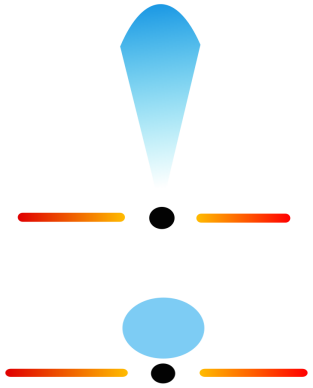






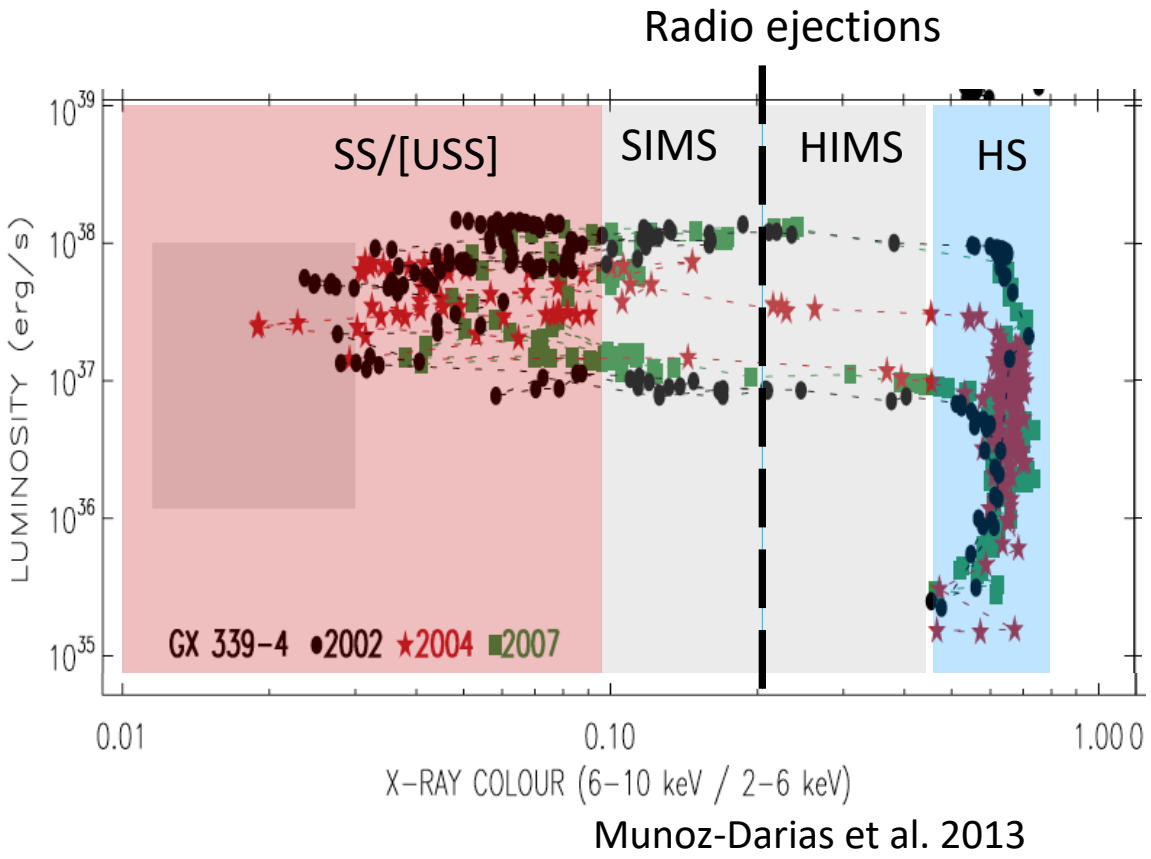
Zdziarski & Gierlinski, 2004





- Soft state - standard accretion disc (~1keV), minor contribution from hot medium
- Hard state - accretion disc + hot medium (aka corona), power-law with 100 keV cut-off
- Reflection/reprocessing

Long-term evolution of an outburst



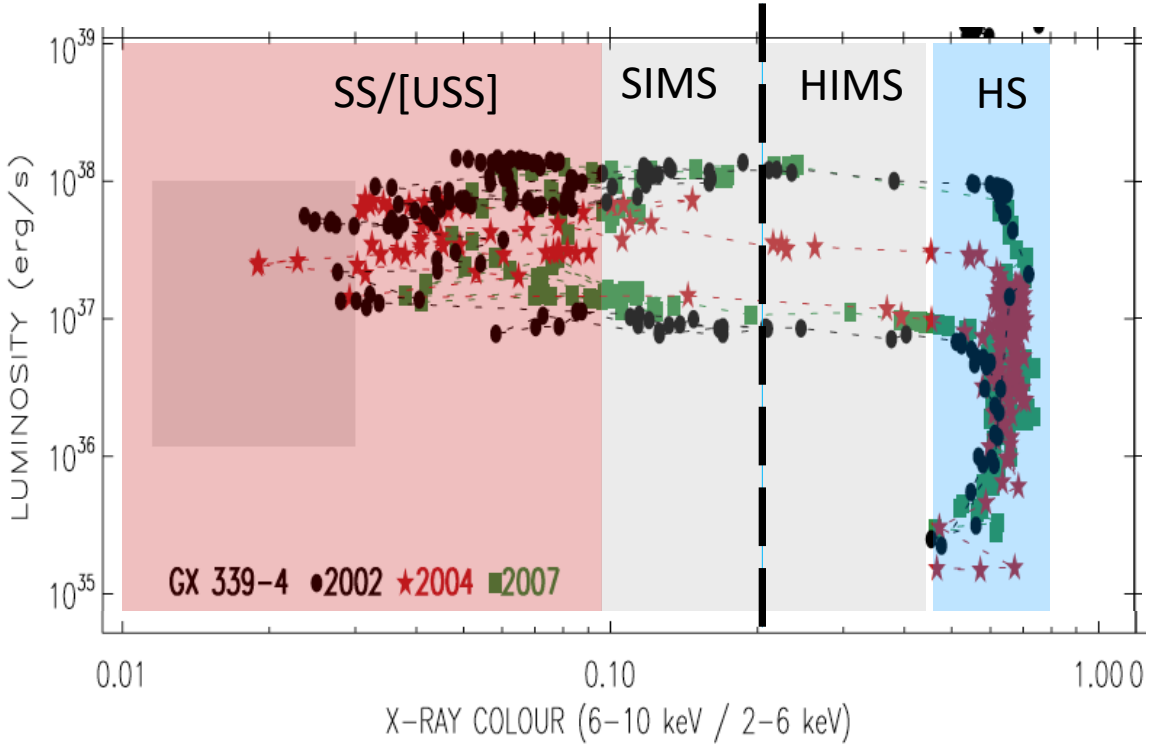
Munoz-Darias et al. 2013

Hard State – Hard-Intermediate State – Soft-Intermediate State – Soft State – [Very High State/Ultrasoft State]

- Disc truncation at high distance in quiescence and (dim) hard state
- q-loop and movement inward: which particular moment is debated
- Variability properties depend on the state

Long-term evolution of an outburst

Radio ejections



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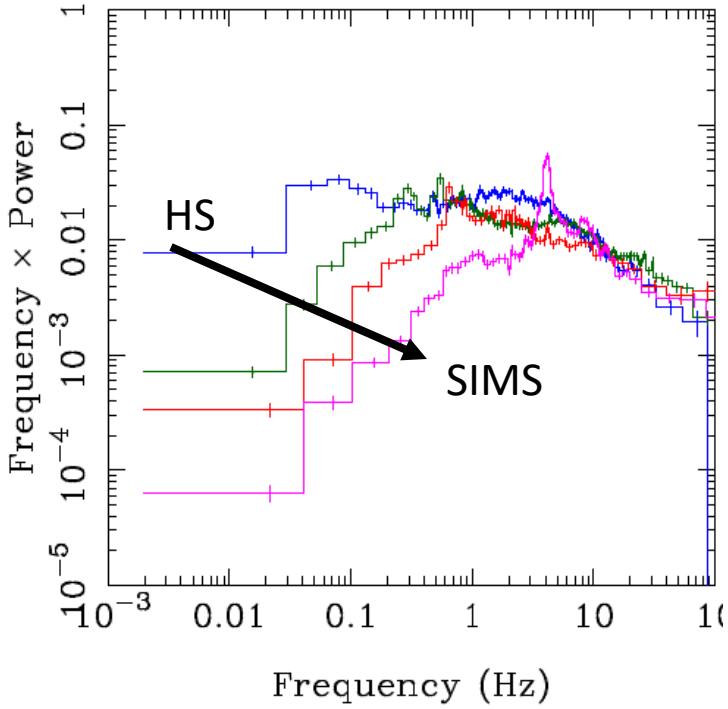
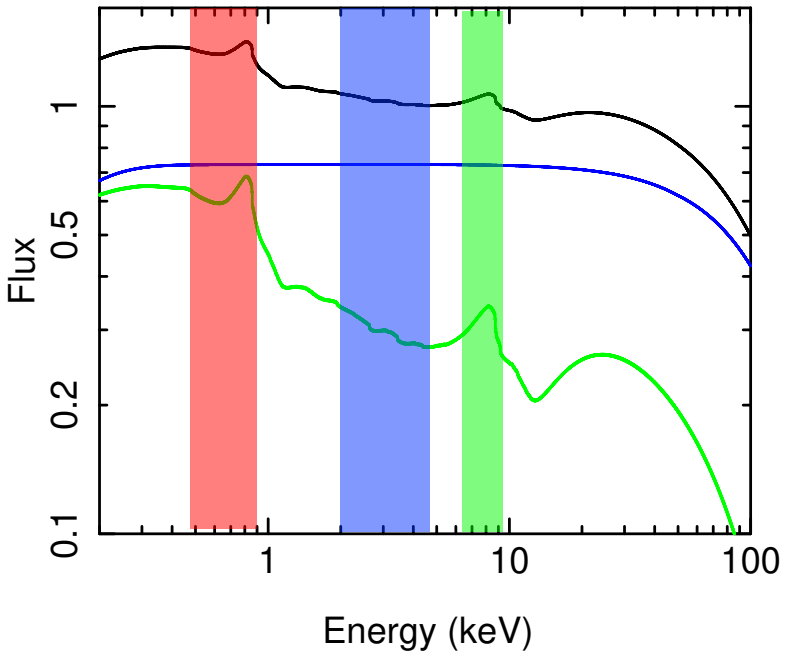


Done et al. 2007

Variability: mass accretion rate fluctuations converted to X-ray light-curves + echoes

Fast aperiodic variability: echoes from the disc

- light-crossing delays (10^{-3}-10^{-2} sec)
- suppression of high-frequency variability



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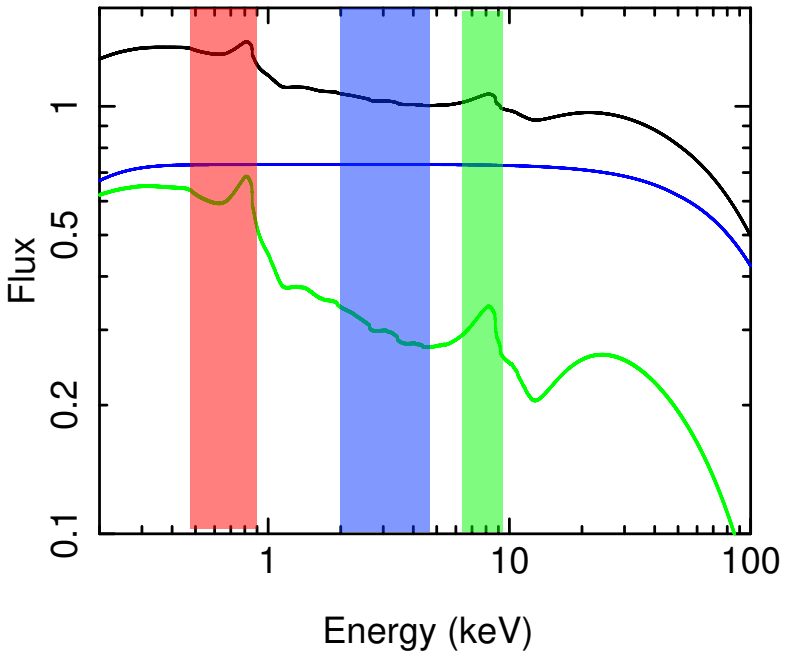
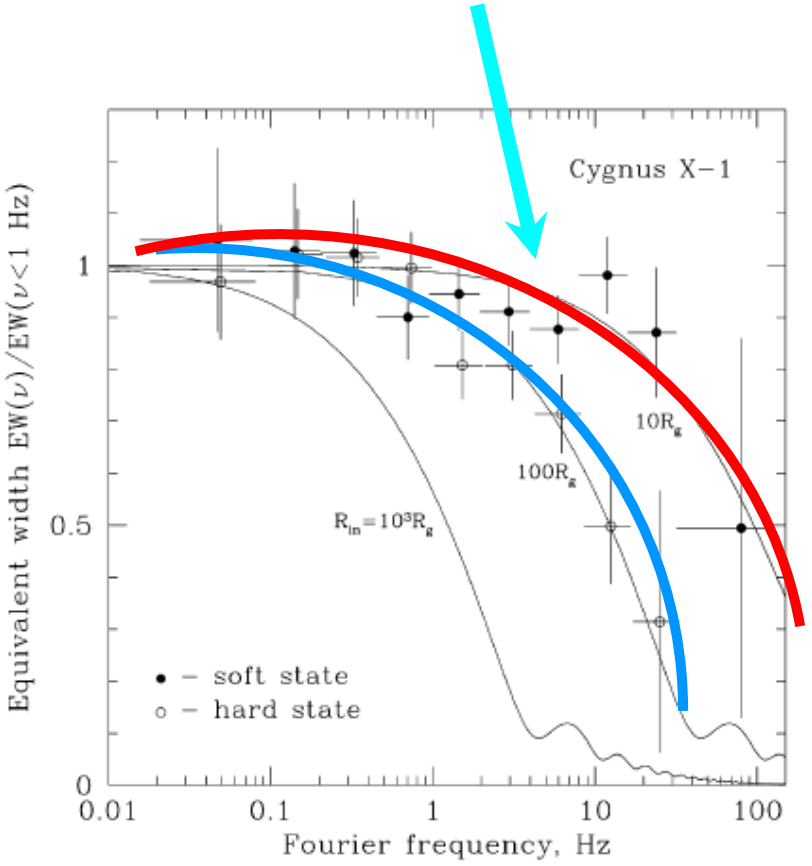
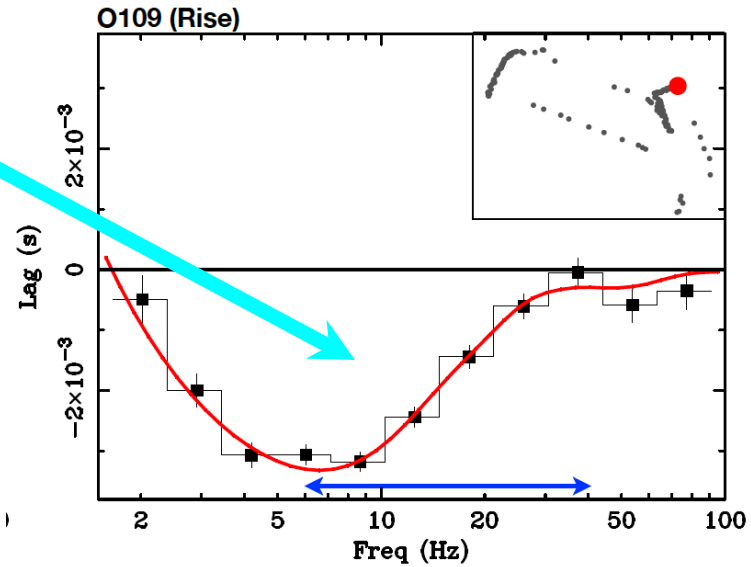






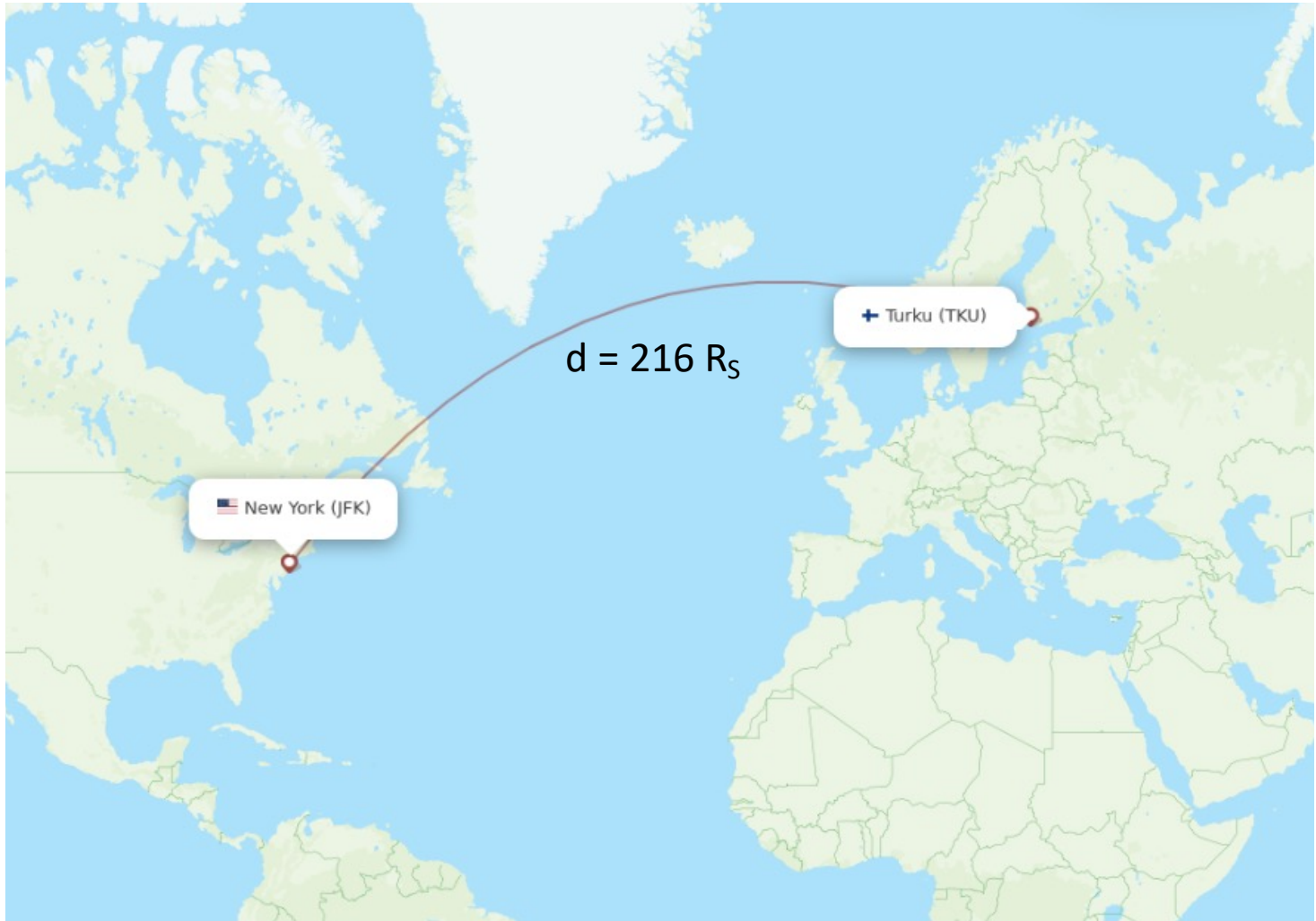
Reynolds et al. 1999
Poutanen 2002
Uttley et al. 2014
De Marco et al. 2021
Kara et al. 2019

Revnivtsev et al. 1999, 2006
Gilfanov et al. 2000
Axelsson & AV 2021

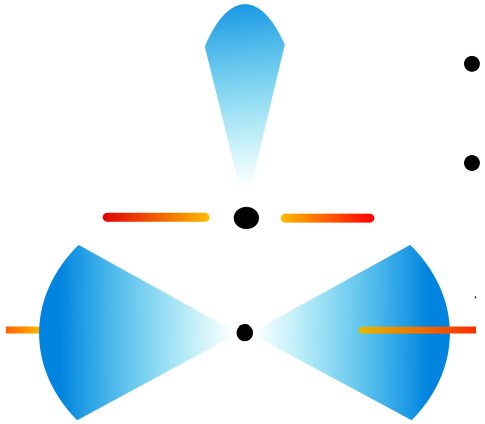
Fast aperiodic variability: echoes from the disc

6465 km / c = 0.0216 sec

Delays between Turku and JFK



Fast aperiodic variability: echoes from the disc



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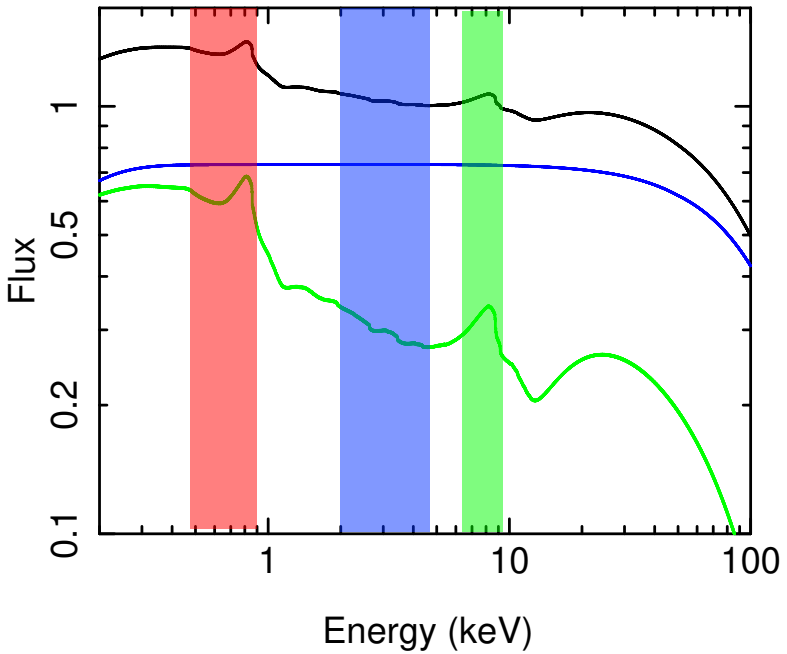

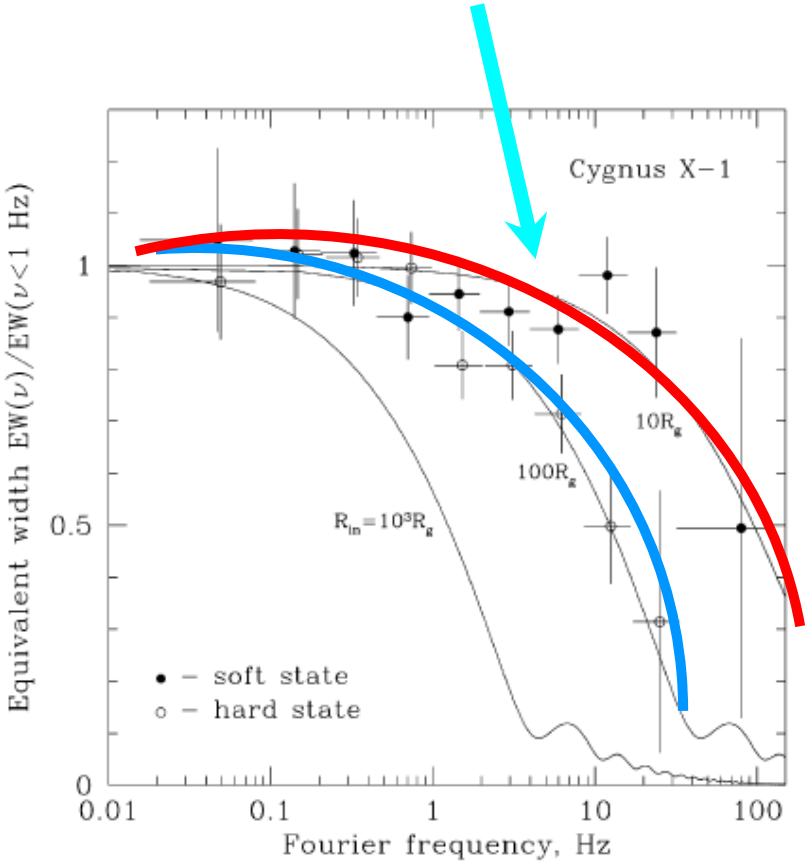

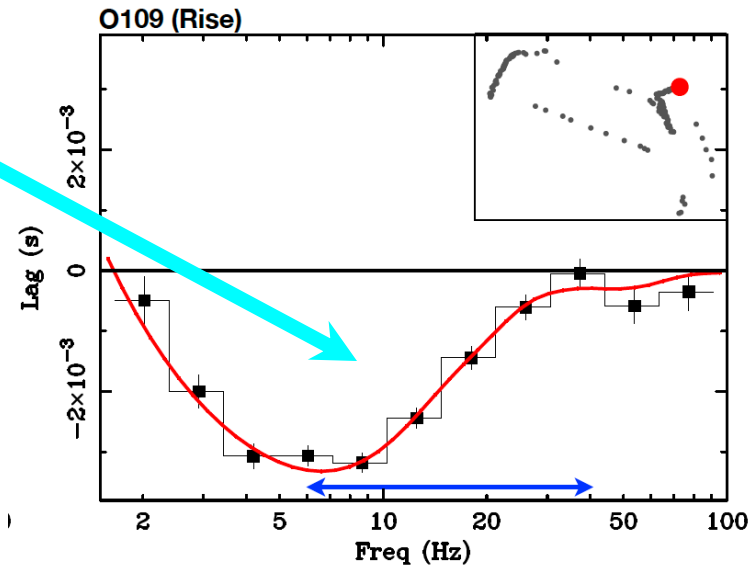

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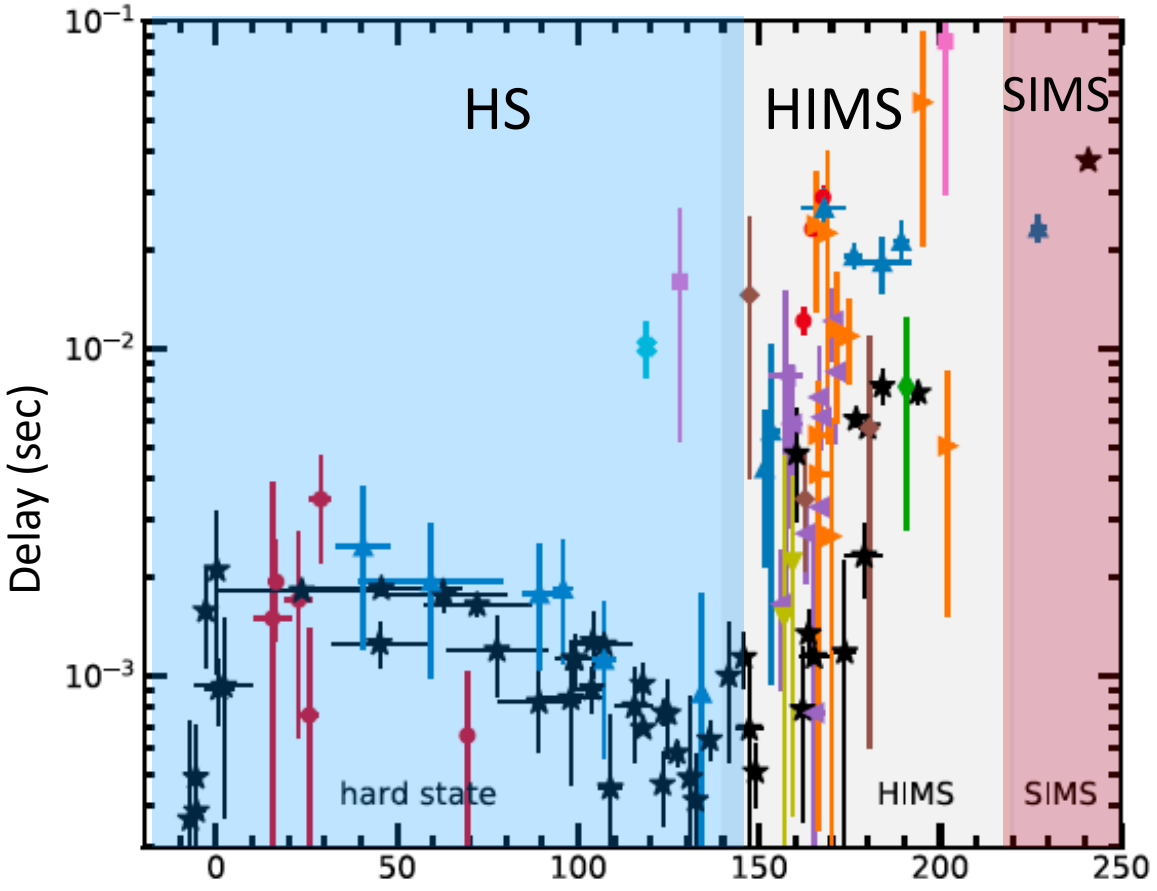
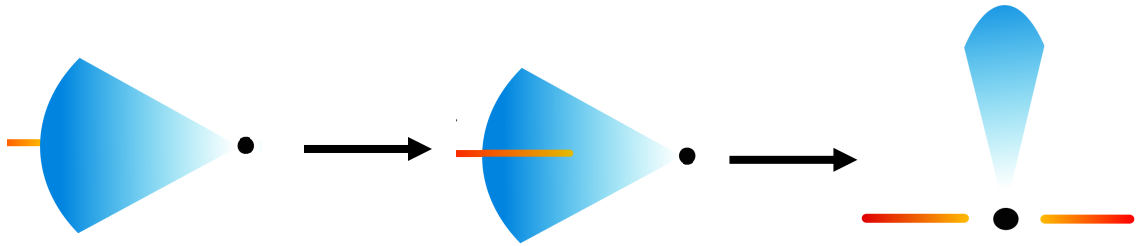
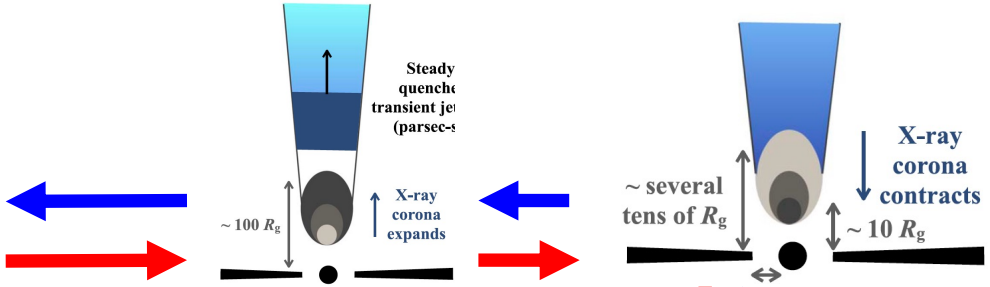


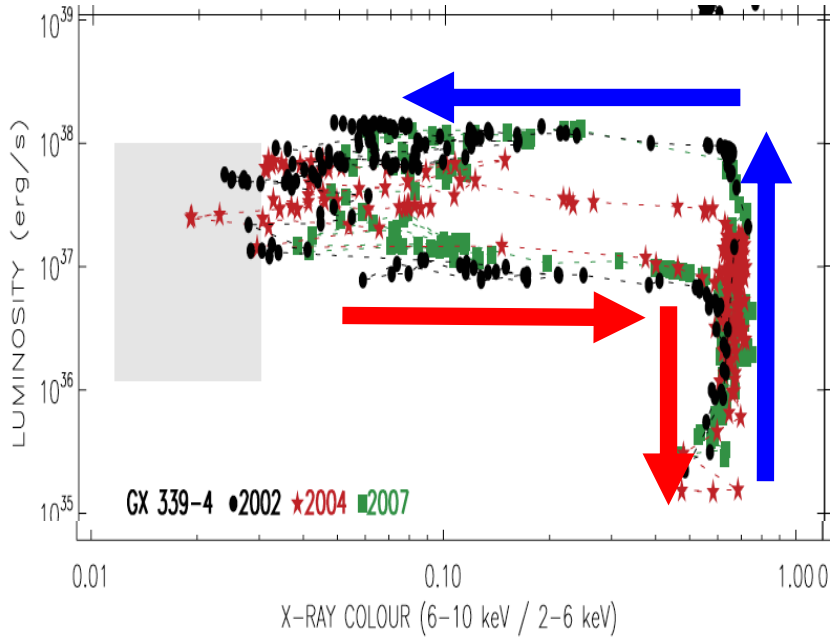


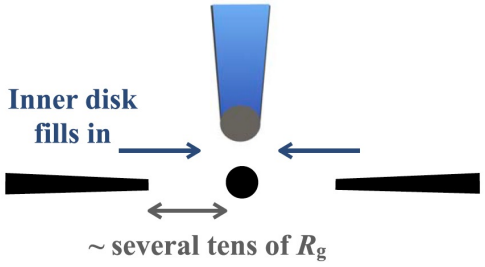
De Marco et al. 2016, 2021
Wang et al. 2021, 2022
Mendez et al. 2022

Accretion geometry

Disc @ ISCO

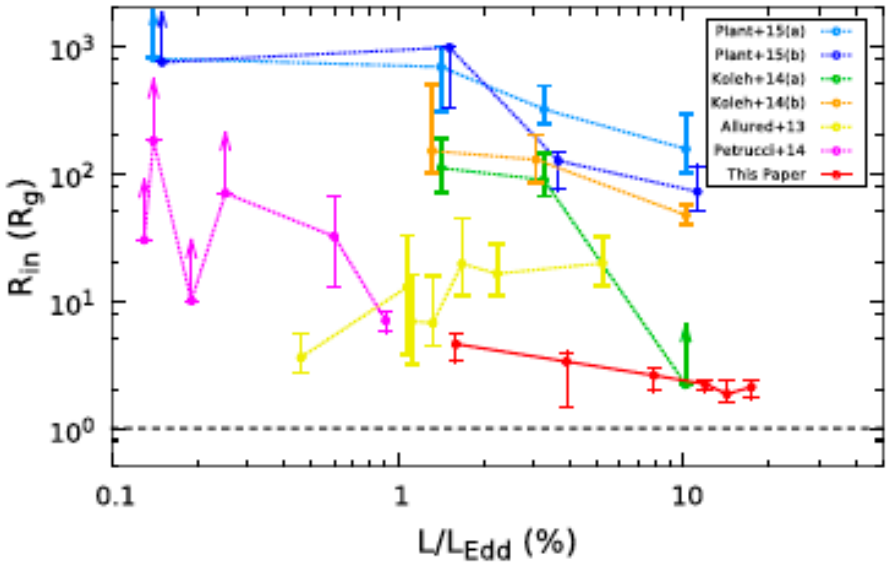






Wang et al. 2022

- Conventional tools of spectroscopy and timing probe the inner radius of the disc in the bright hard state and state transitions
- Inferred radii do not match even for the same data



Garcia et al. 2015

Accretion geometry

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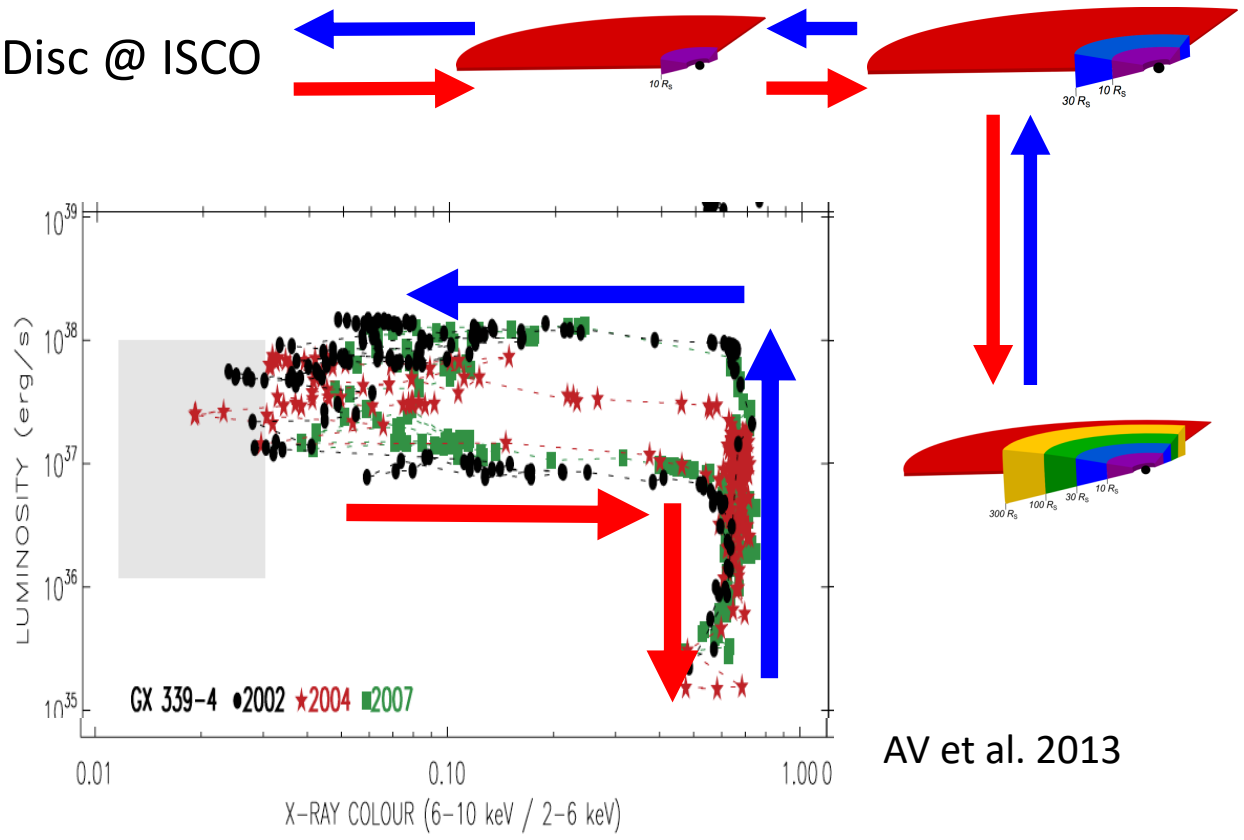

AV et al. 2013

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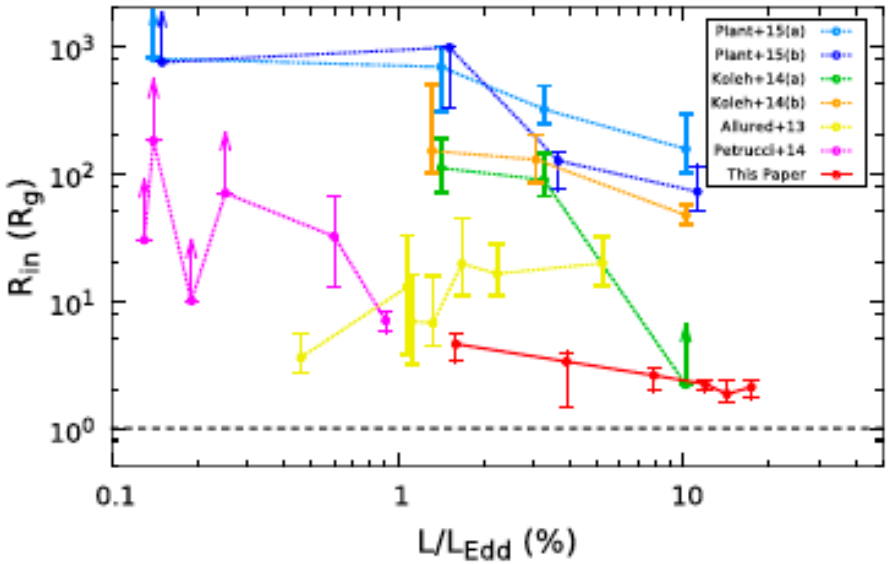
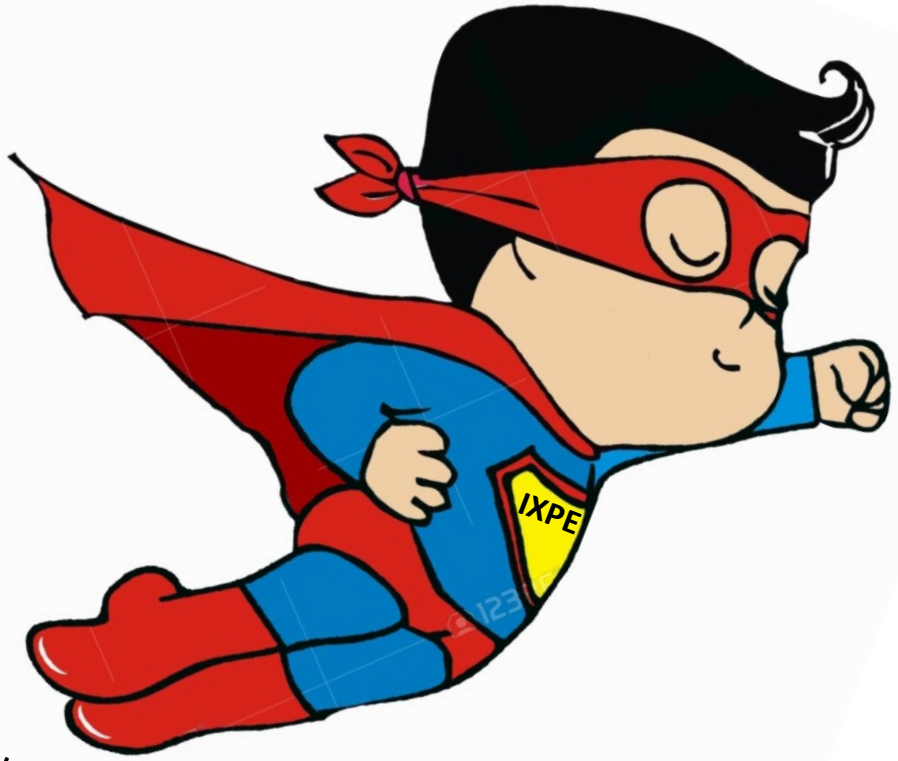


Garcia et al. 2015

Imaging X-ray Polarimetry Explorer



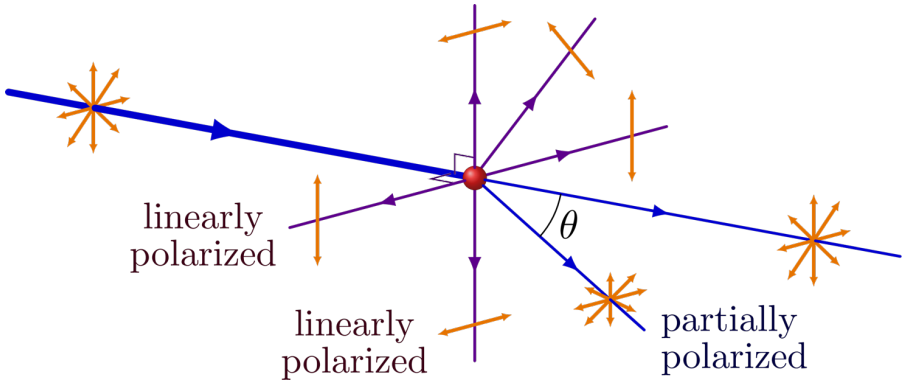
Clipart-library.com

X-ray polarimetry: independent tool to probe the accretion geometry

Can check spectro-timing constraints

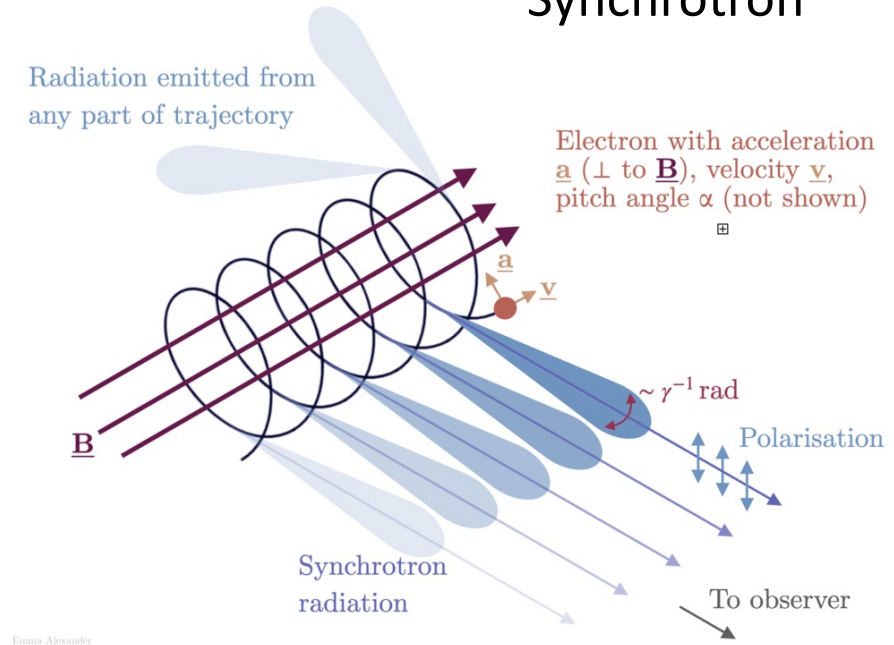
How to produce polarization in accreting BHs?

Scattering



Hard state: Compton scattering in the corona (inflow) or in the outflow

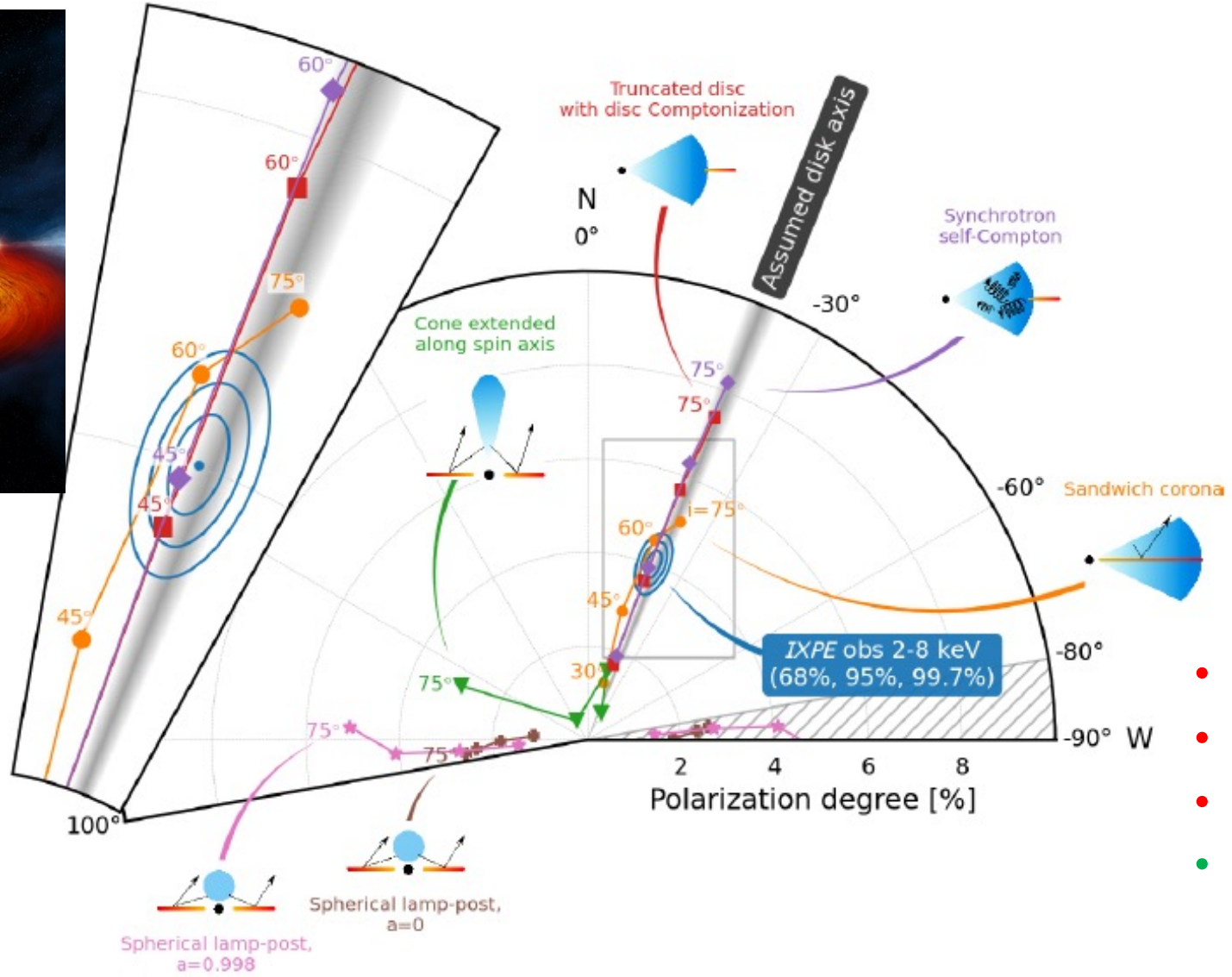
Synchrotron

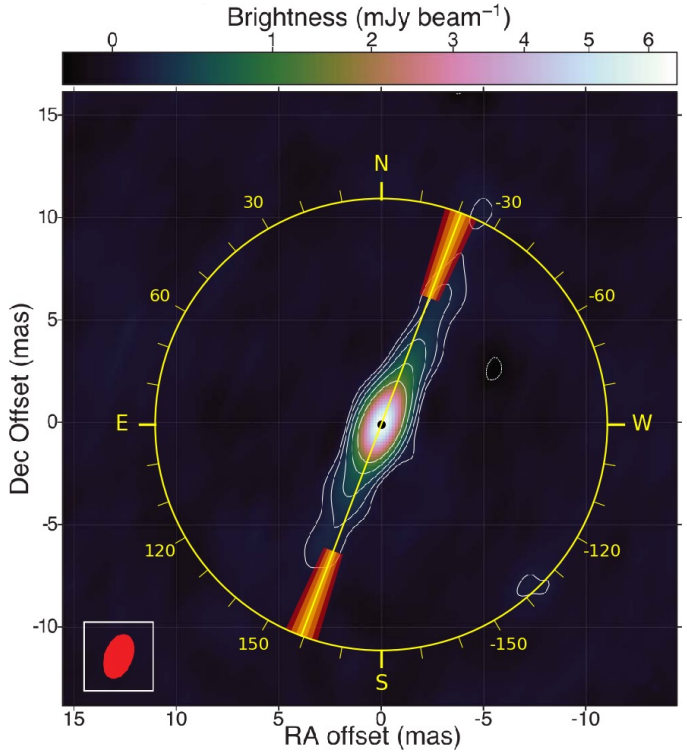


synchrotron emission of the jet

GR & SR effects modify the polarization produced in the local frame

Source 1: prototypical Cyg X-1





- Not cone-like
- Not spherical lamppost
- Not jet
- Elongated in the direction orthogonal to the jet (presumably, along the disc)

Krawczynski, Muleri, Dovciak, AV et al. 2022

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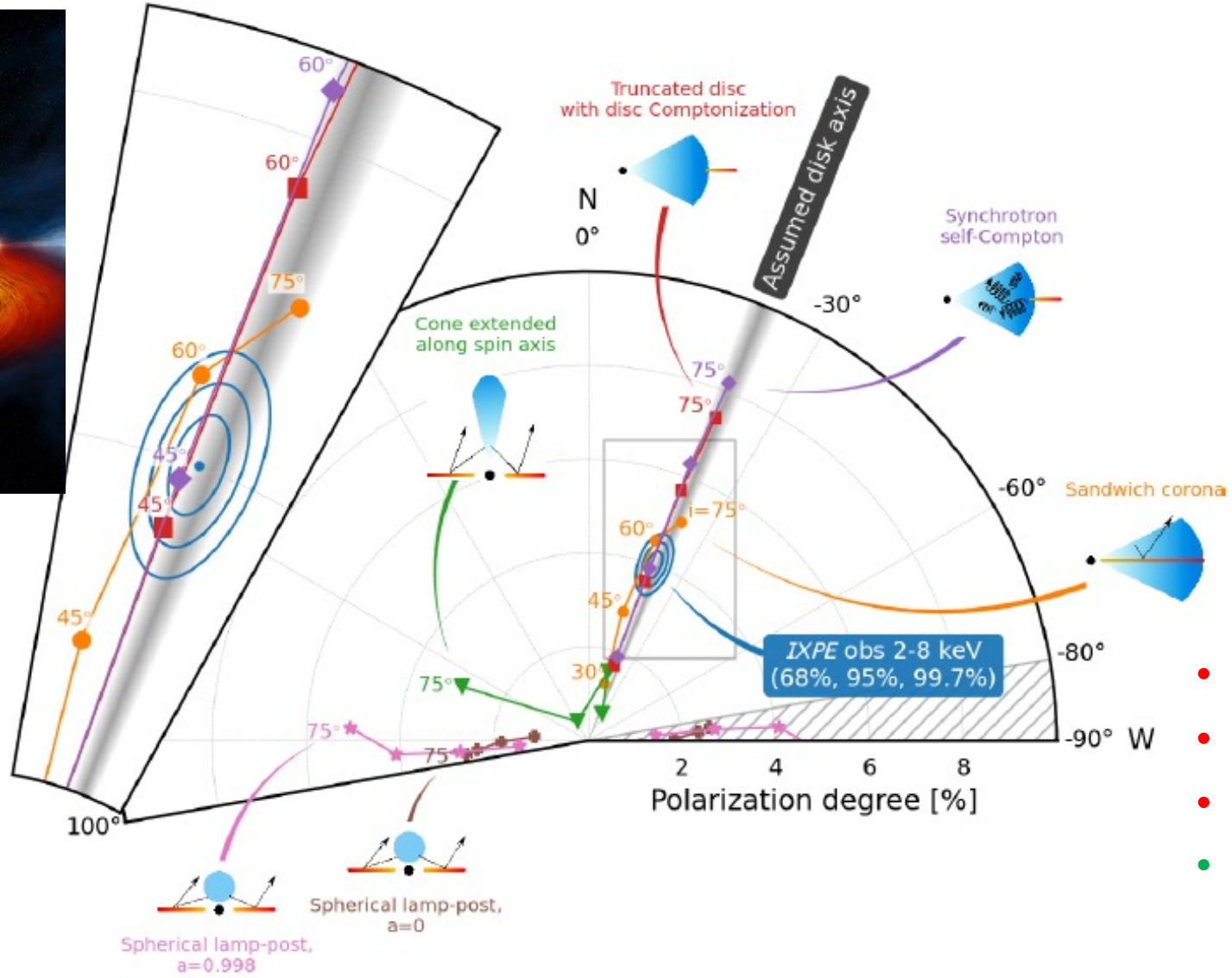

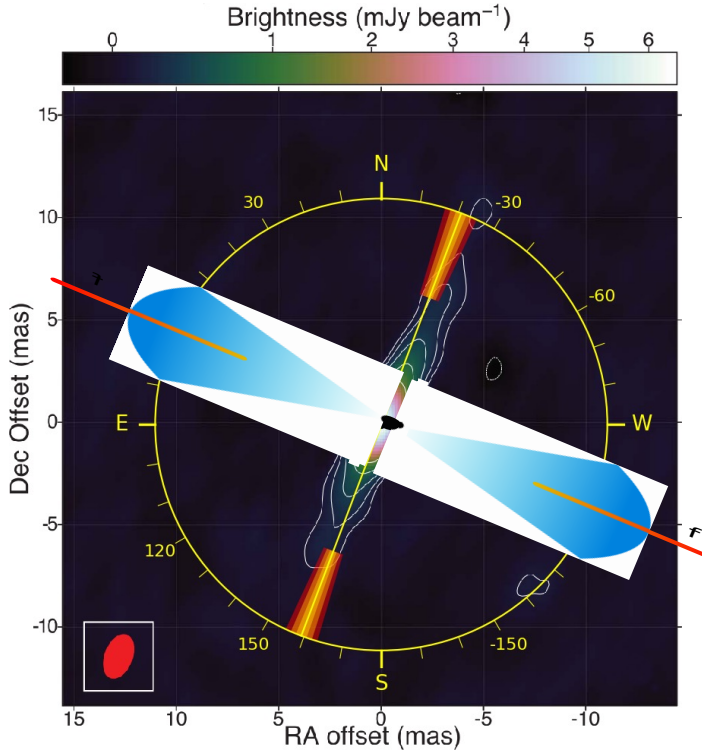

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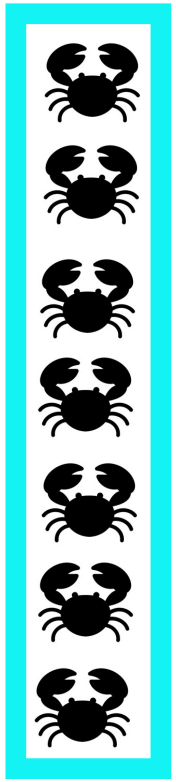
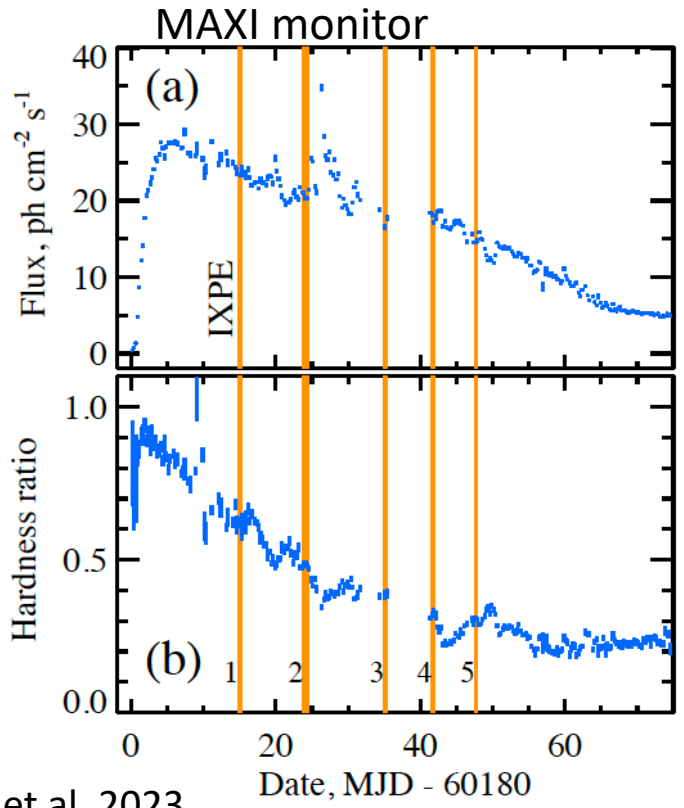
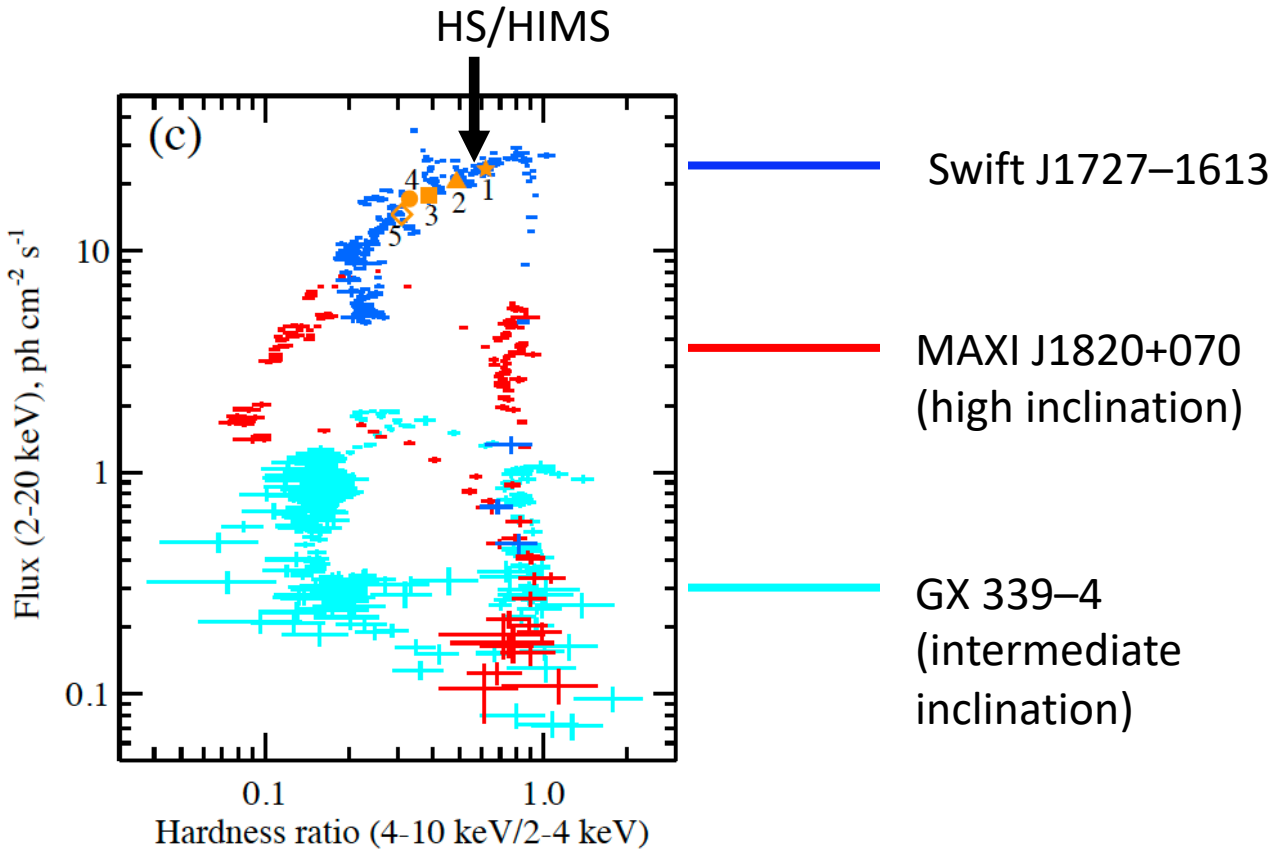
Krawczynski, Muleri, Dovciak, AV et al. 2022

Source1: exceptionally bright Swift J1727.8-1613

- X-rays: a very rapid flux increase, over 2 Crab in the first MAXI detection
- q-loop pattern in hardness-flux diagram
- Flat-spectrum radio source, signatures of an outflow







AV et al. 2023

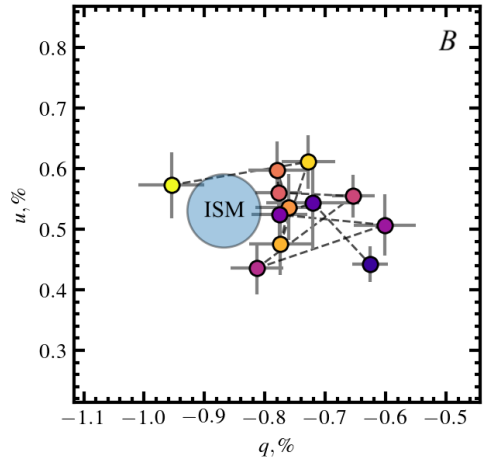
Ingram, Bollemeijer, AV et al. 2023

The source orientation

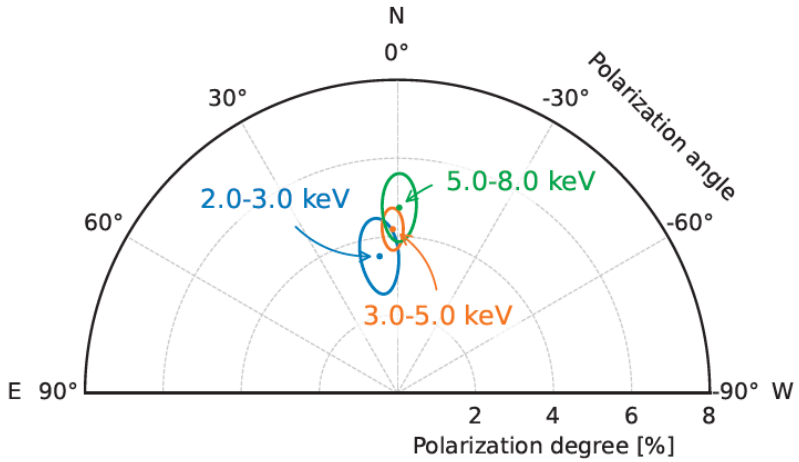
- Sub-mm polarization (Vrtilek et al. 2023): North-South direction

Date	PD (%)	PA (°)
September 3	2.1+/-0.2	-3.4+/-1.5
September 4	1.9+/-0.2	-4.1+/-3.5

- Optical polarization (Kravtsov et al. 2023): roughly North-South direction

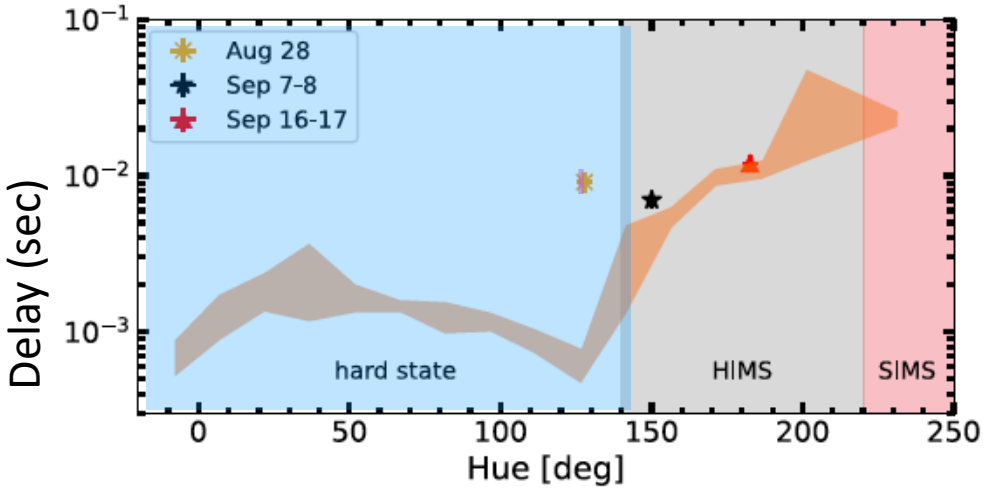


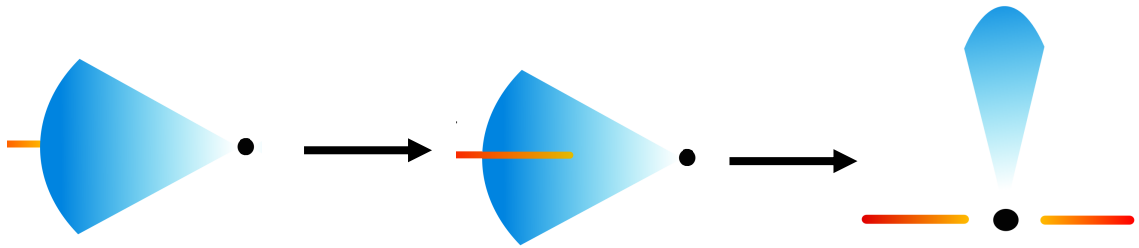
- X-ray polarization: North-South

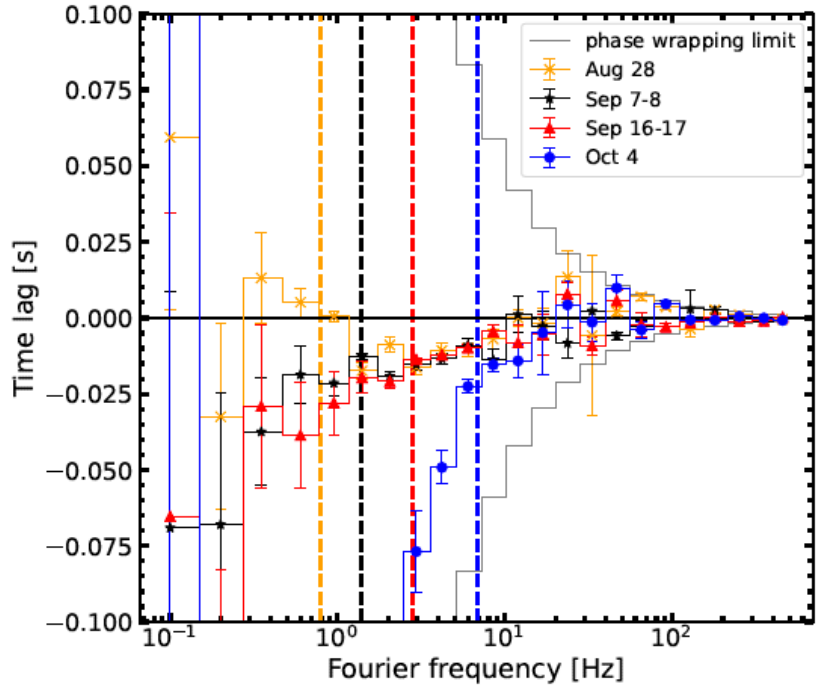


AV et al. 2023

Aperiodic variability: echoes from the disc



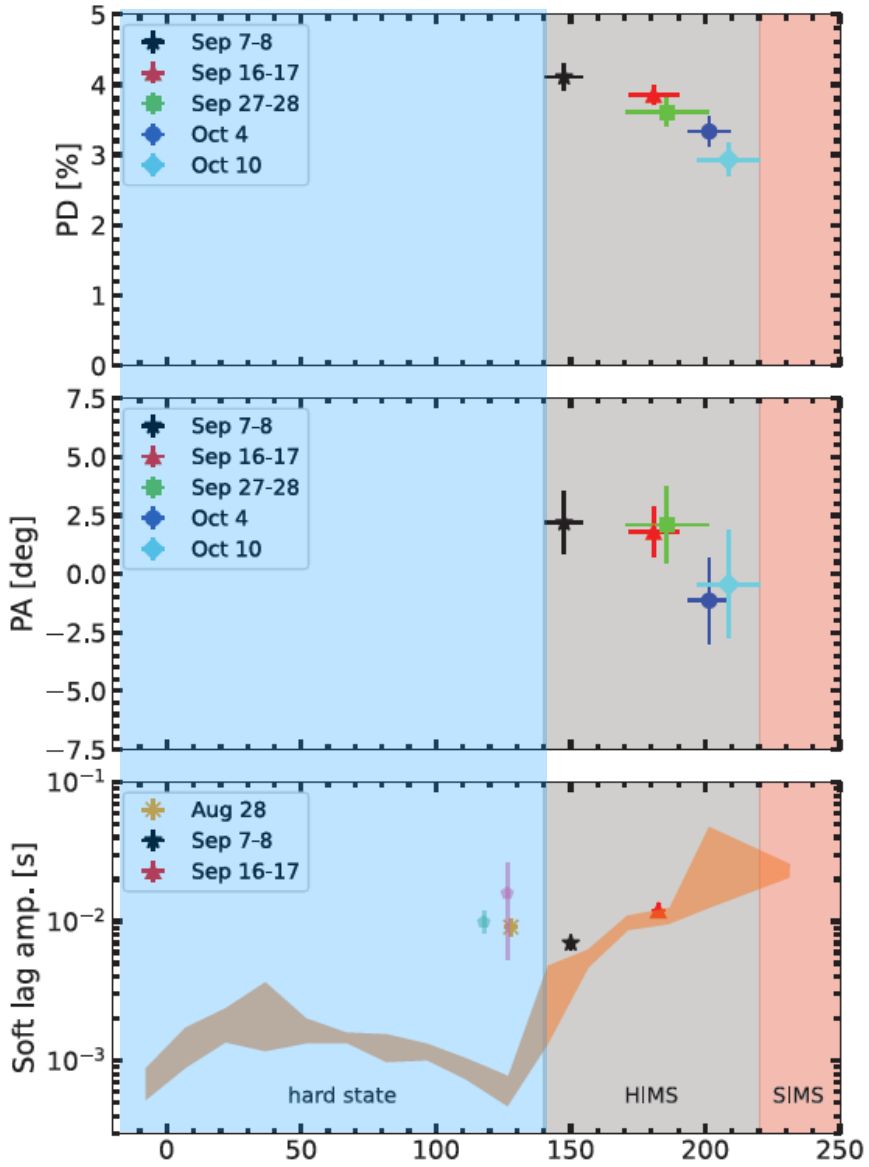




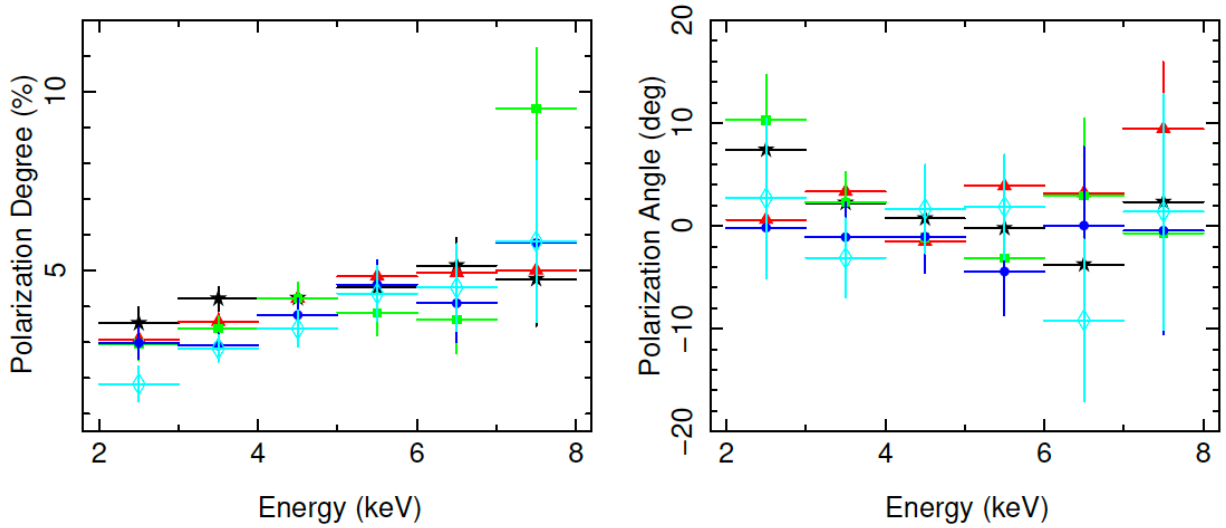
Expected change of PA by 90°

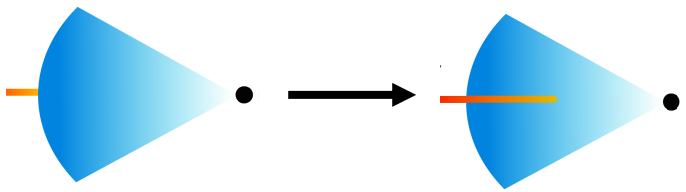
Ingram, Bollemeijer, AV et al. 2023

Fast aperiodic variability: echoes from the disc?



- No significant changes of PA
- PD increasing with energy



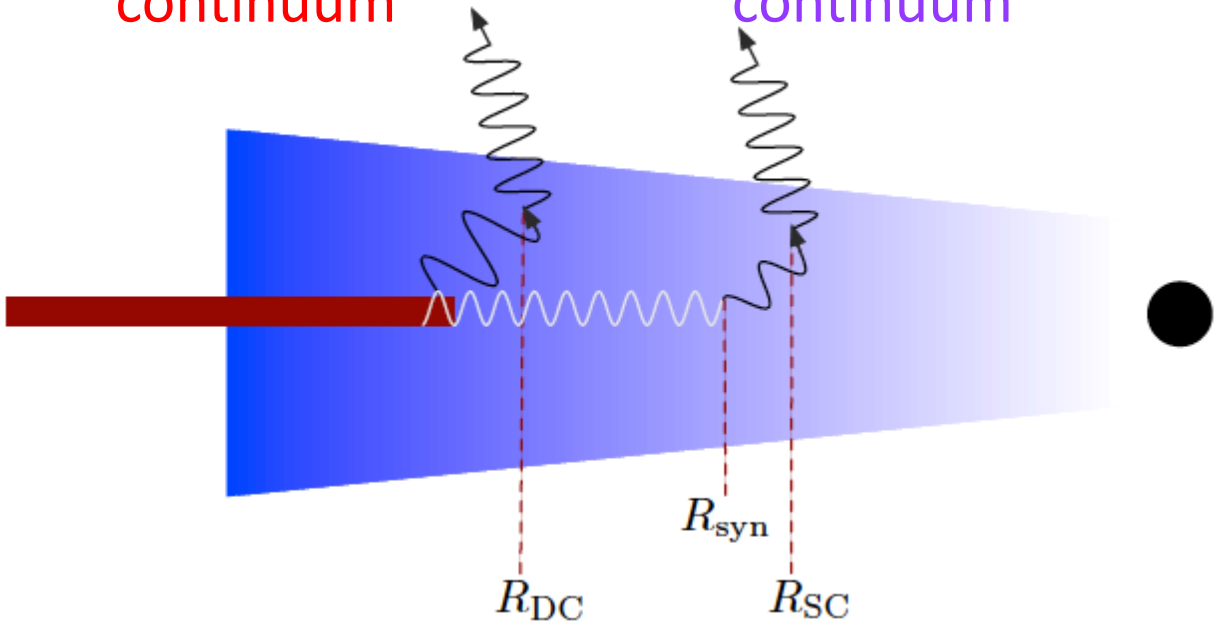


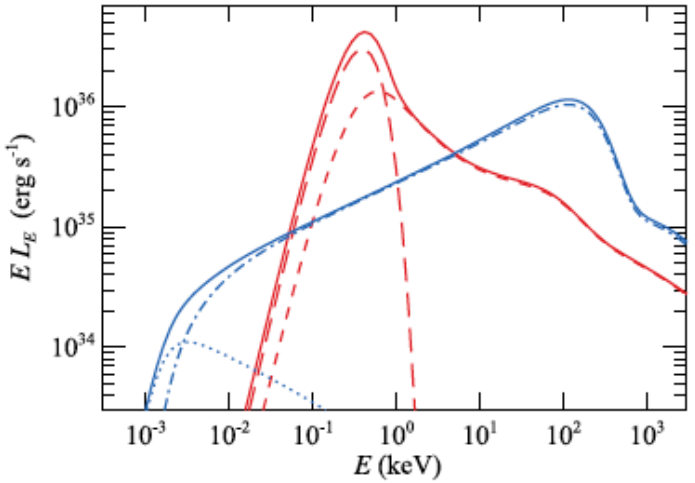
Ingram, Bollemeijer, AV et al. 2023

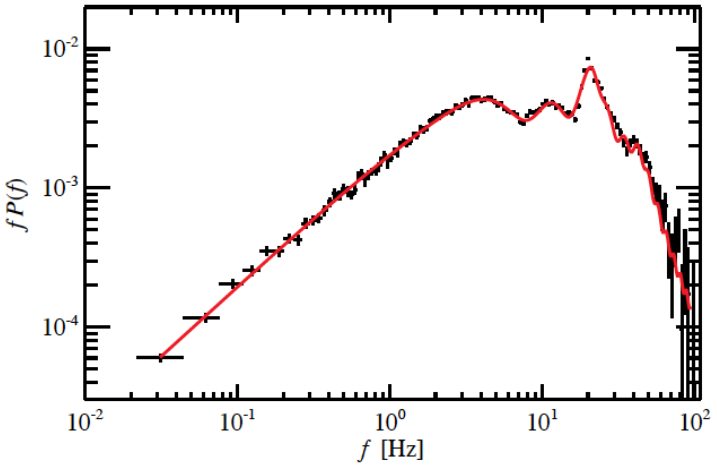
Fast aperiodic variability: interplay of several spectral components?

Disc Comptonization continuum

Synchrotron Comptonization continuum



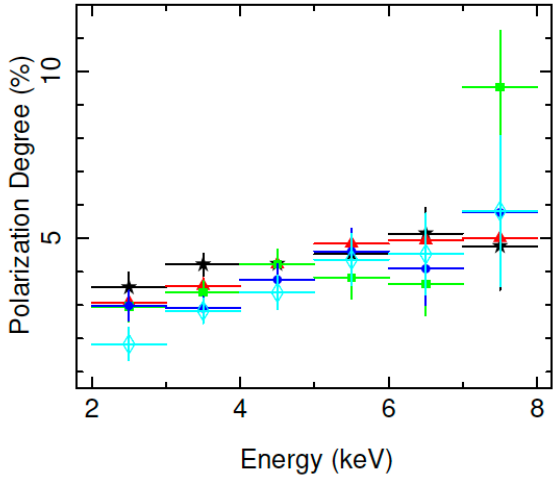


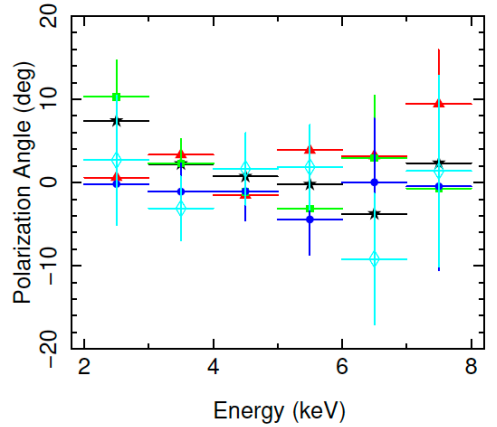


AV 2016, 2018

Summary

- Fast timing properties have been used to infer accretion geometry, under the assumption of their reverberation origin
- Corona assumed to be elongated in the disc plane or vertically extended





- IXPE results: high PD and trend with energy: extended, not spherical/lamppost
- PA aligned with jet: corona is extended in the plane of accretion disc
- X-ray PA remained unchanged throughout the state transition: soft lags seen in the HIMS are dominated by processes other than light-crossing delays