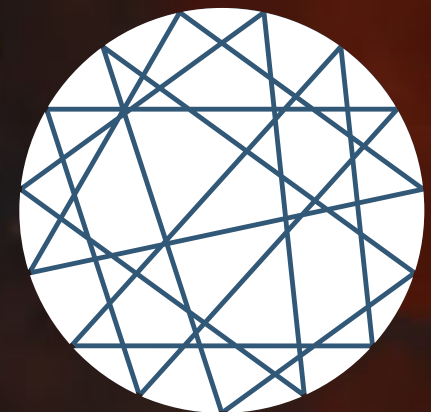


# X-ray Reverberation and X-ray Polarisation: reconciling contradictory views of the corona

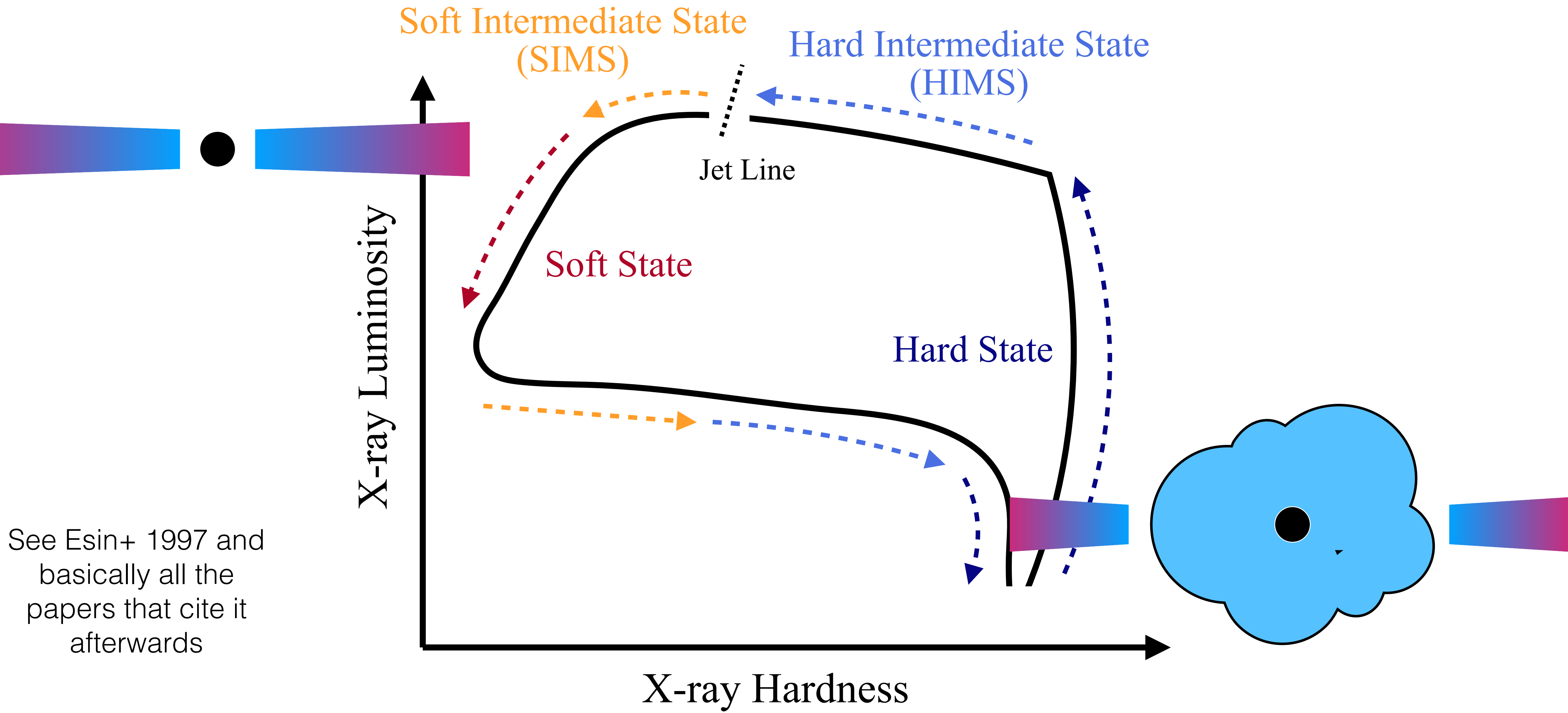


IUSS

Scuola Universitaria Superiore Pavia

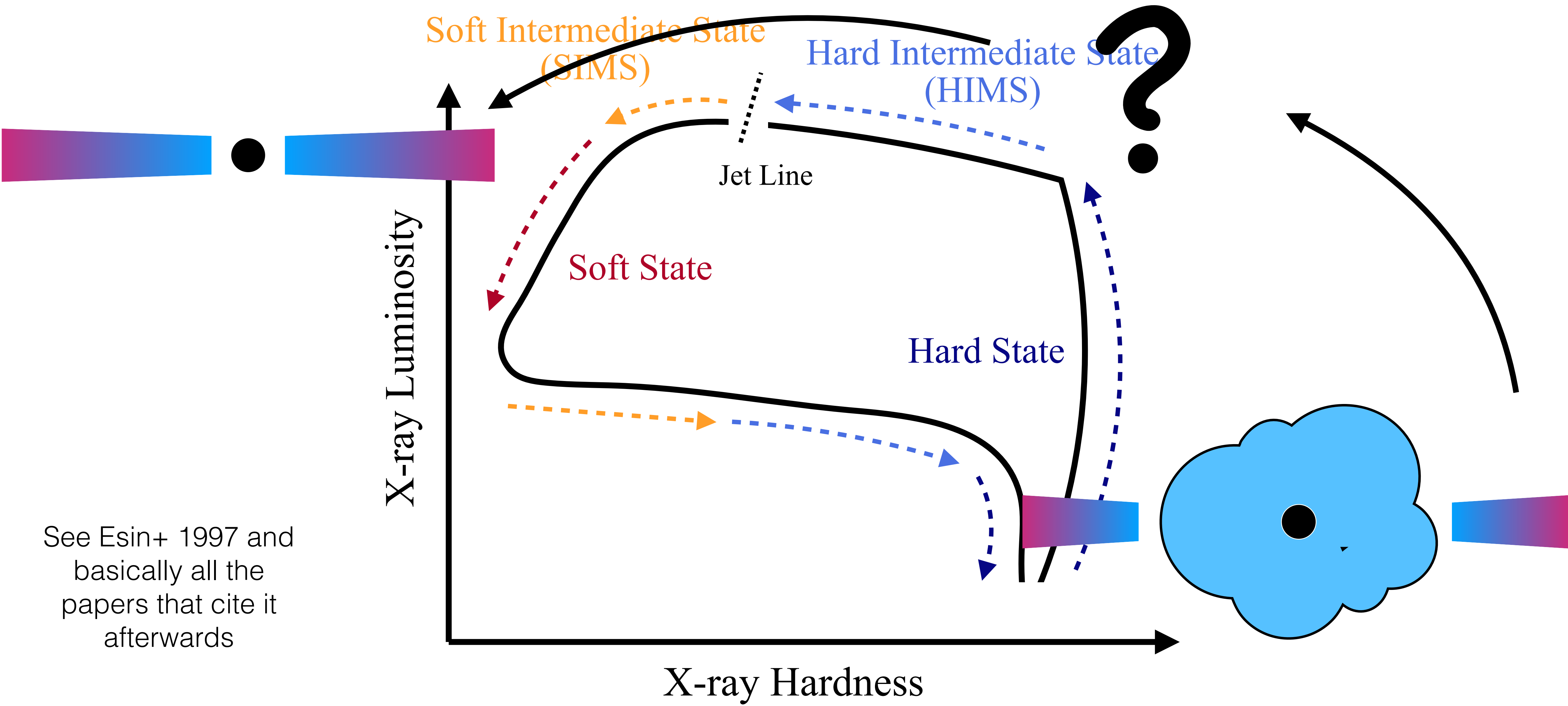
Guglielmo Mastroserio

# Evolution during the outburst on the HID

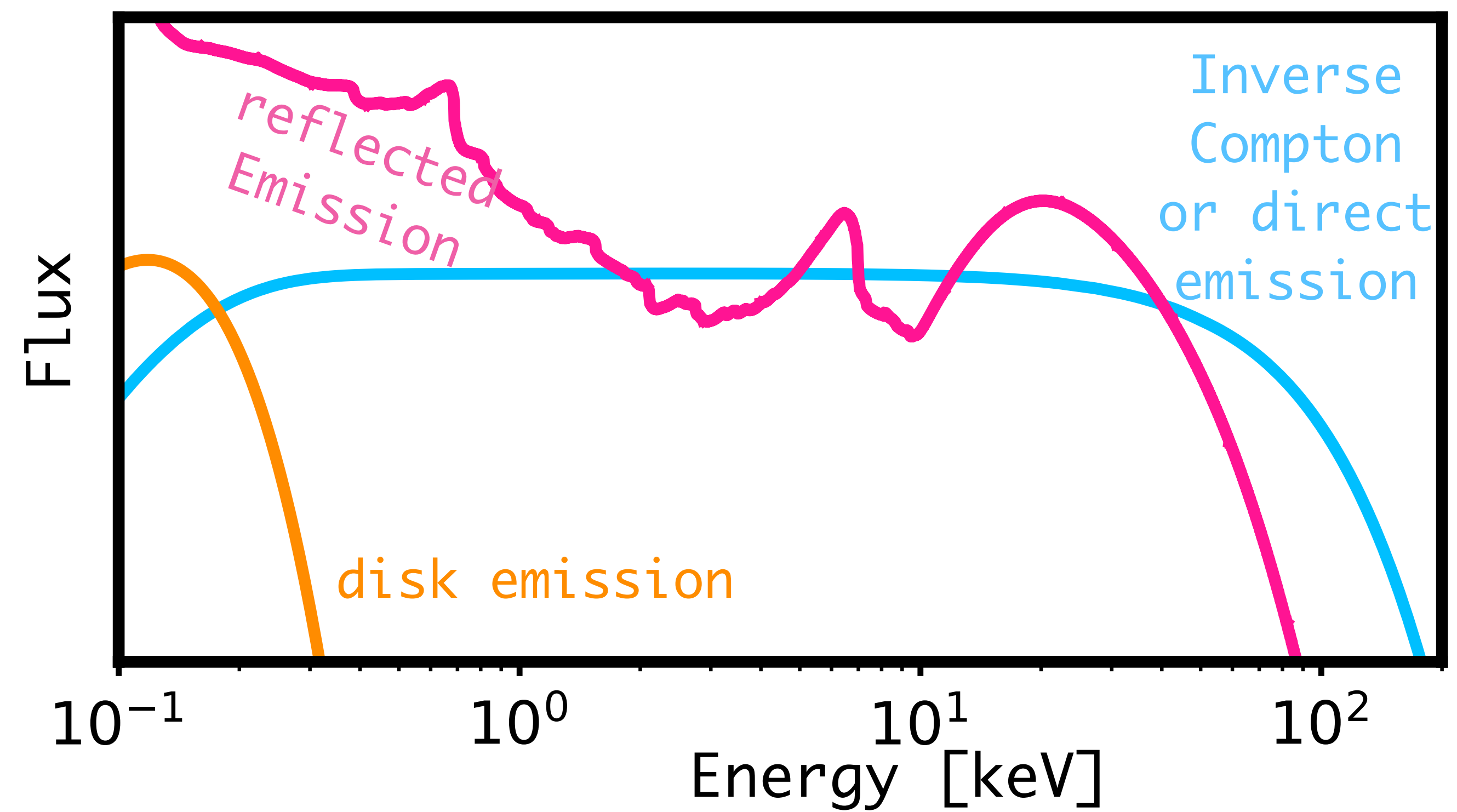
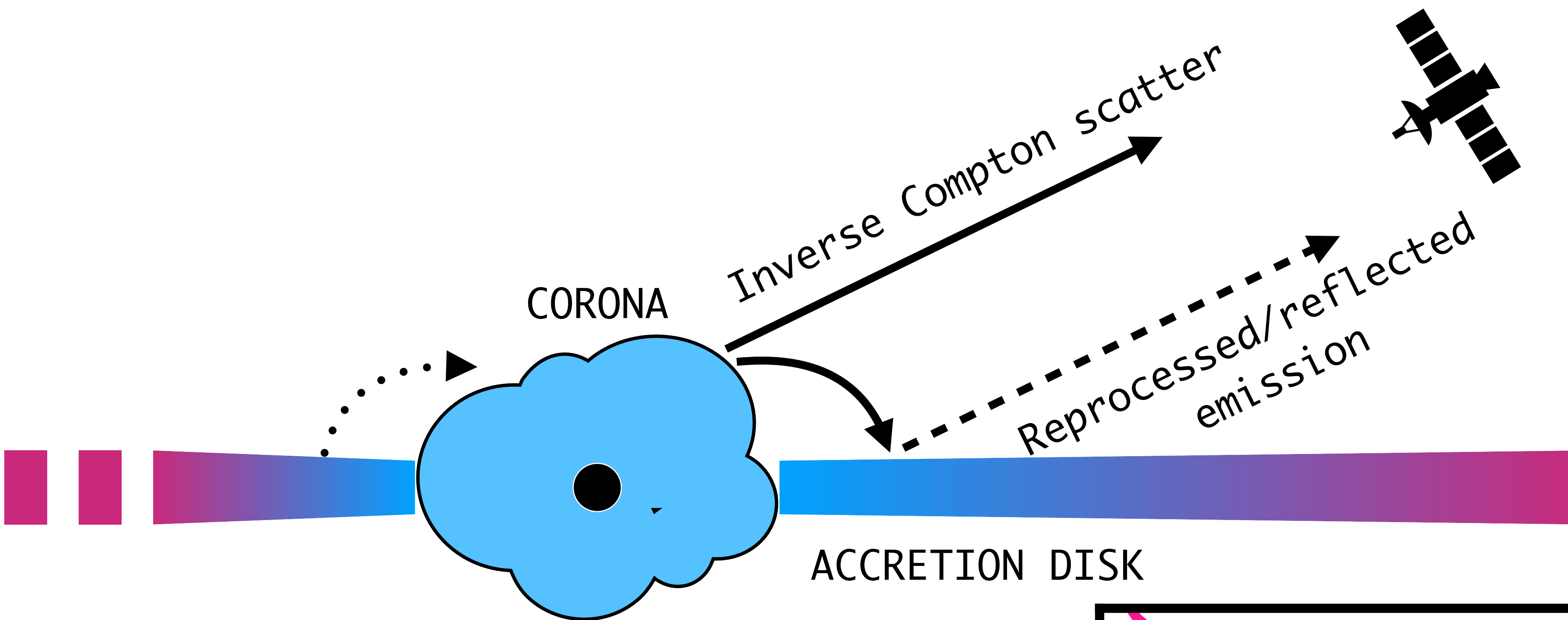


# Evolution during the outburst on the HID

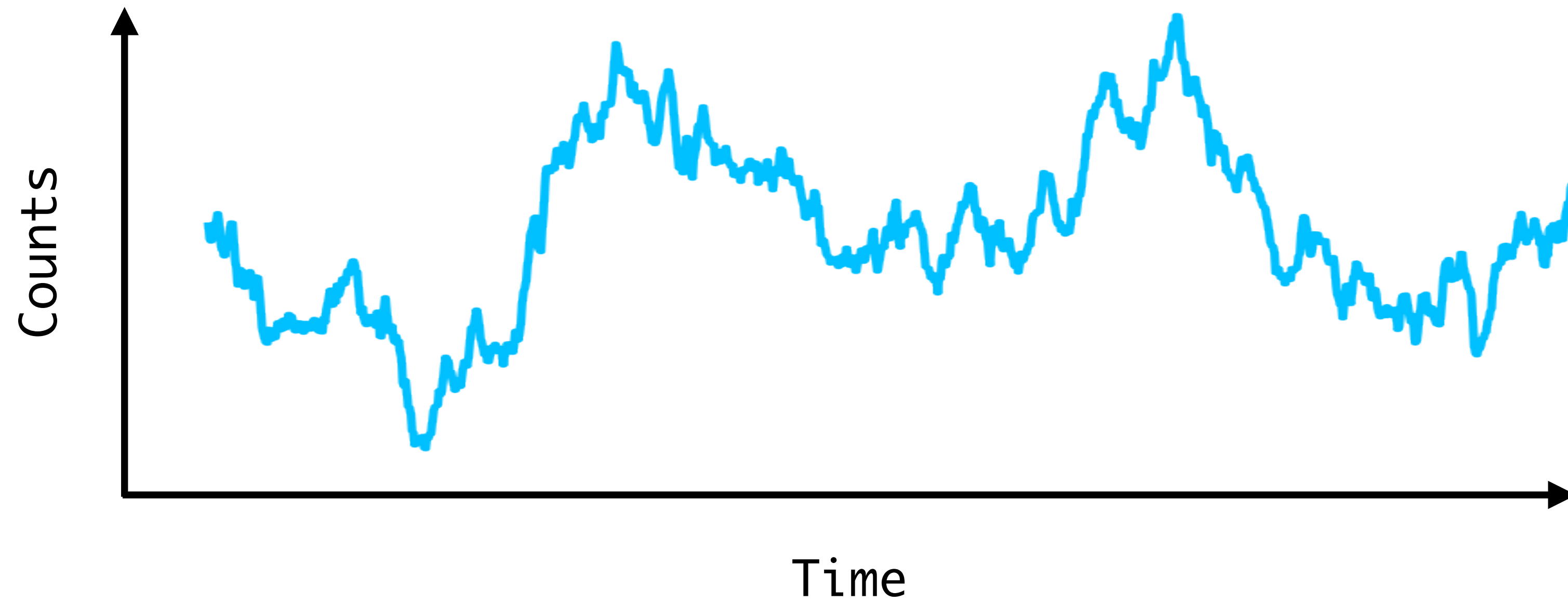
What happens during the transition?



# X-ray emission

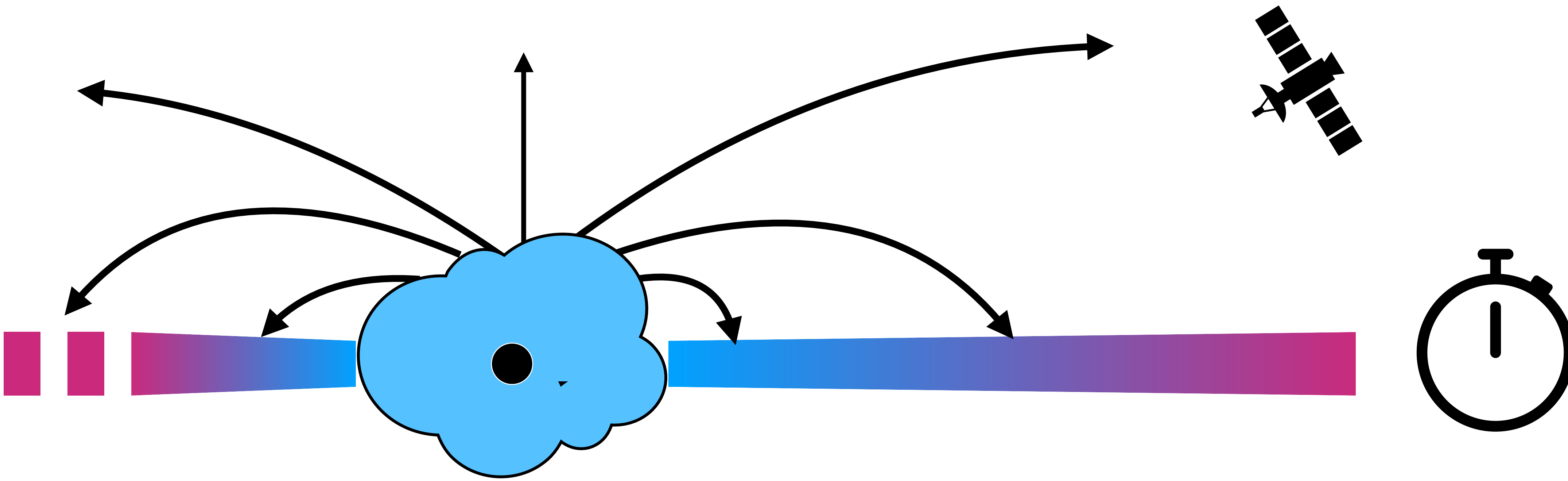


# Timing analysis

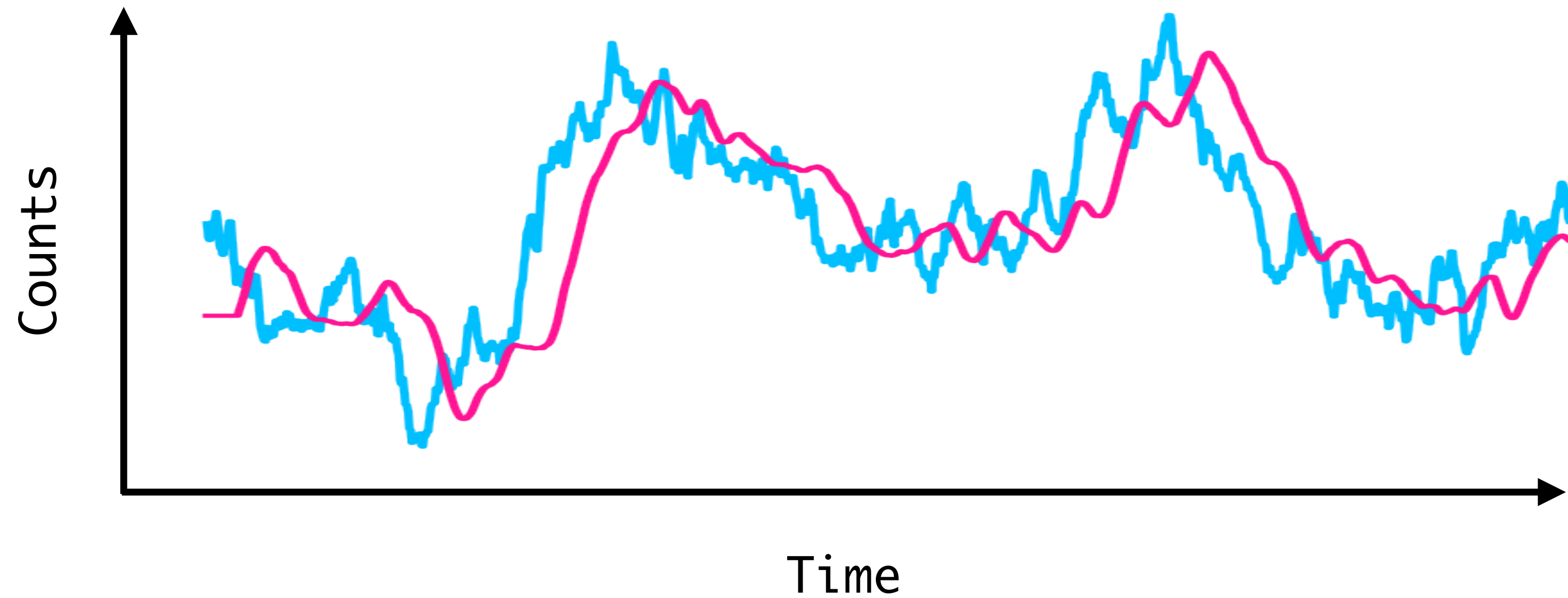


# Simulated light curve

Blue line: Timmer & Koenig simulation from a power density spectrum with a power-law shape (index -2)



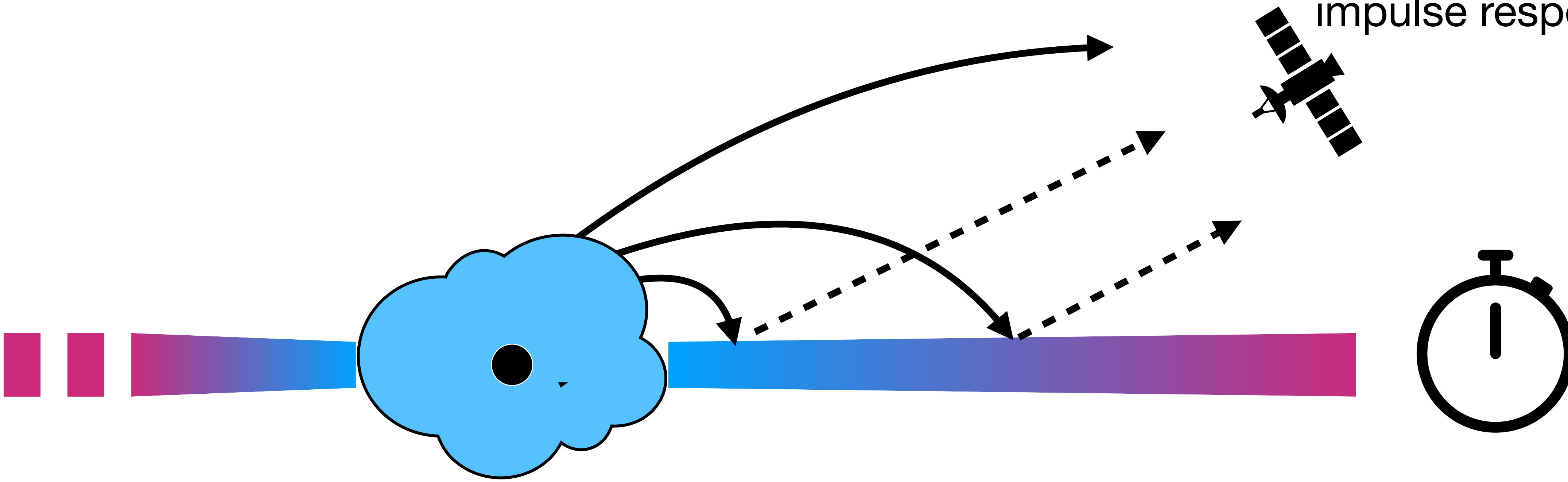
# Timing analysis



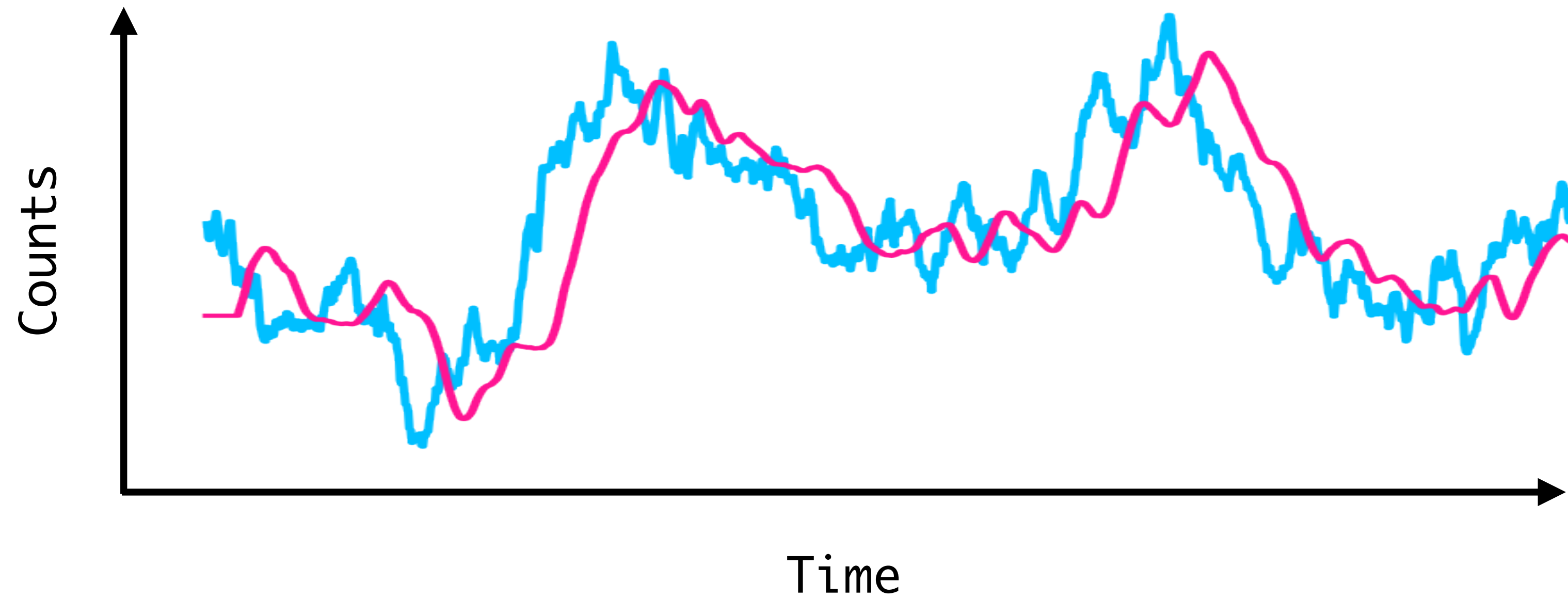
# Simulated light curve

**Blue line:** Timmer & Koenig simulation from a power density spectrum with a power-law shape (index -2)

**Pink line:** resulting light curve after the convolution with a simplified disk impulse response function



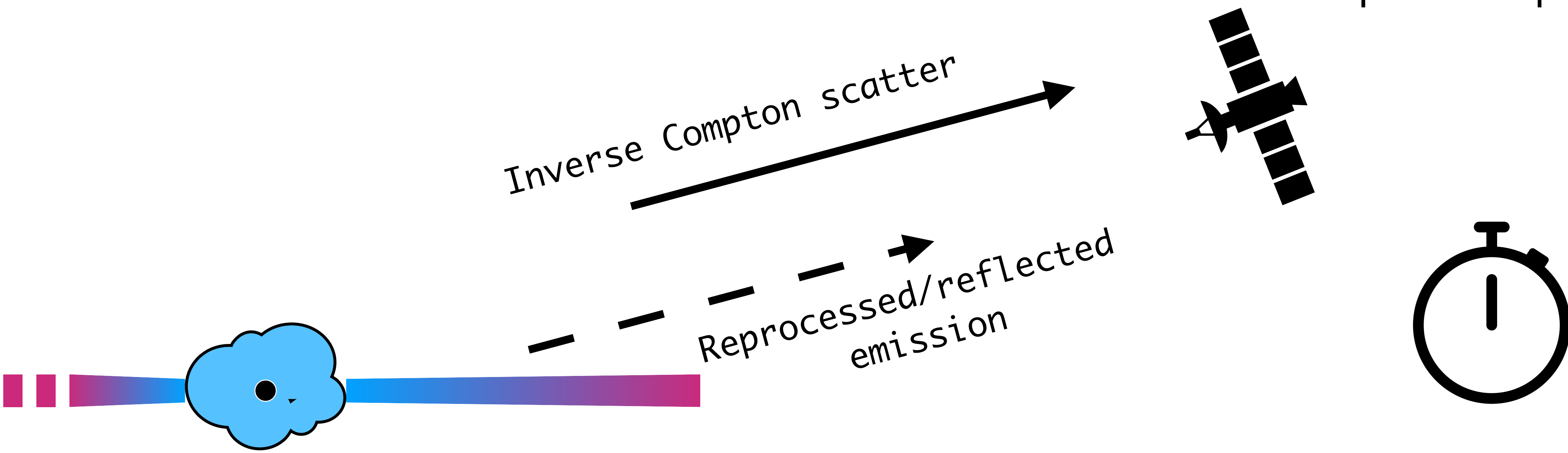
# Timing analysis



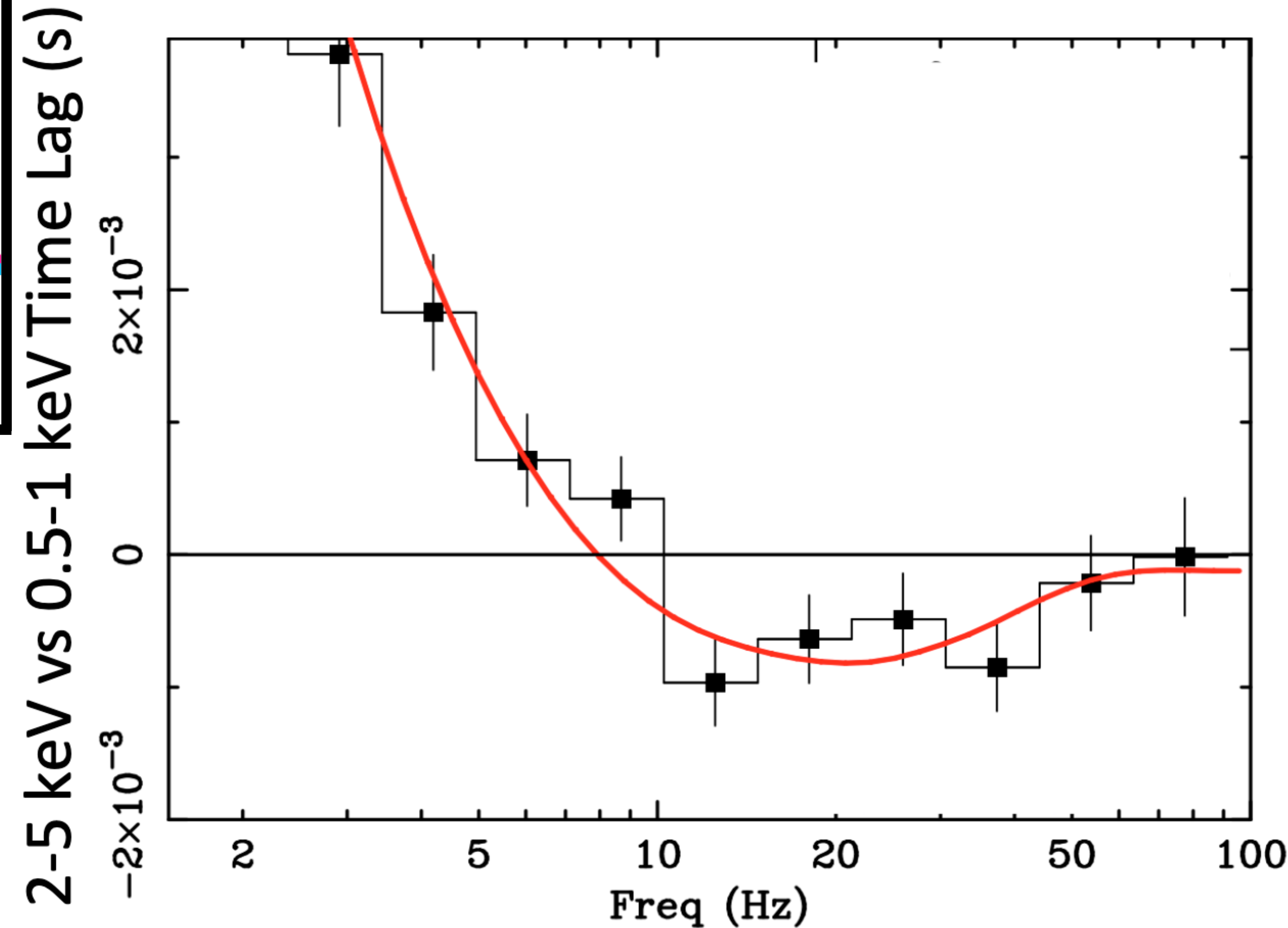
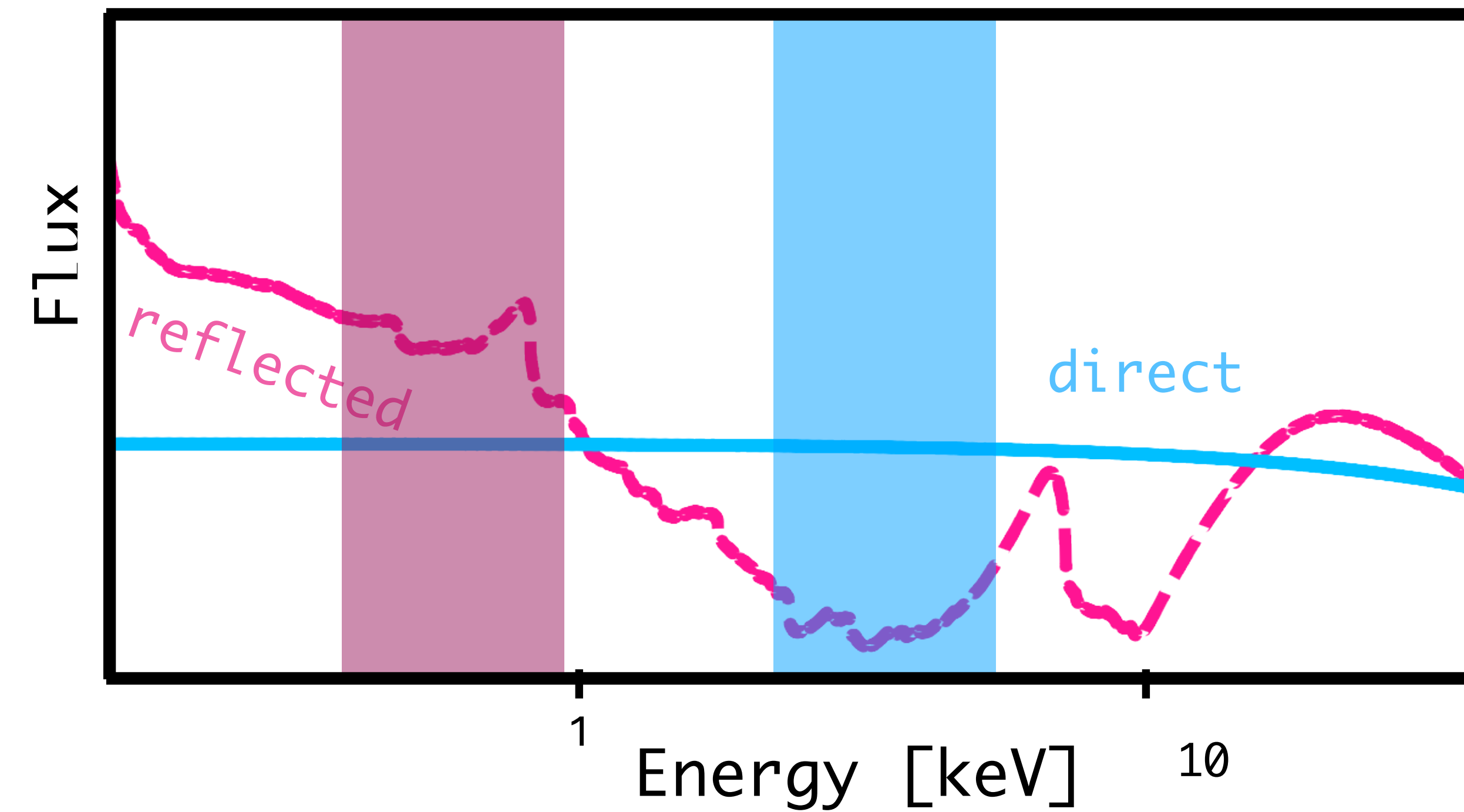
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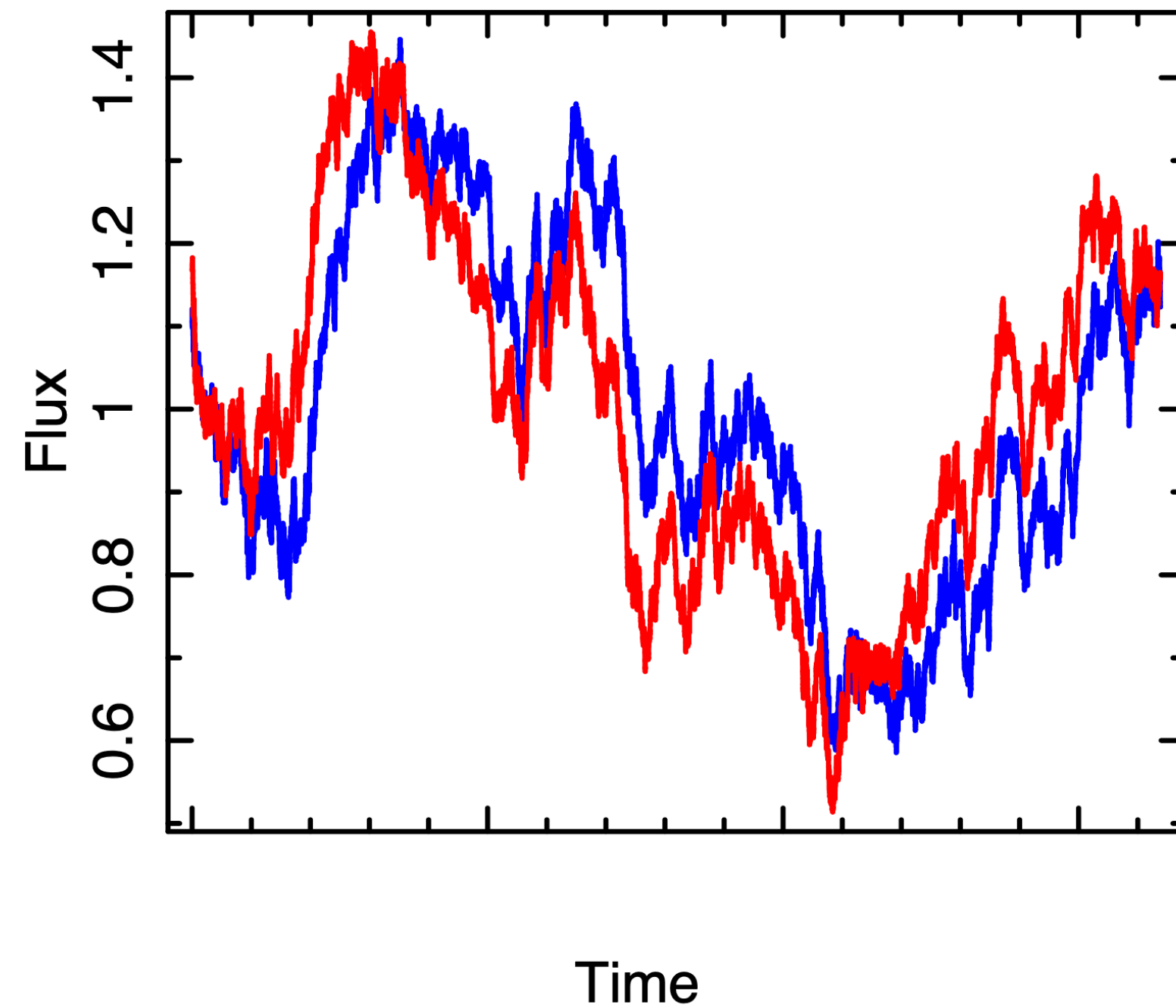
# Time lags in Black Hole Binaries



See also: De Marco+ 2017; Kara+2019; Wang+ 2021,  
and for AGN: McHardy+ 2007; Fabian+ 2009; De  
Marco+ 2013 and Kara+2016 for reviews

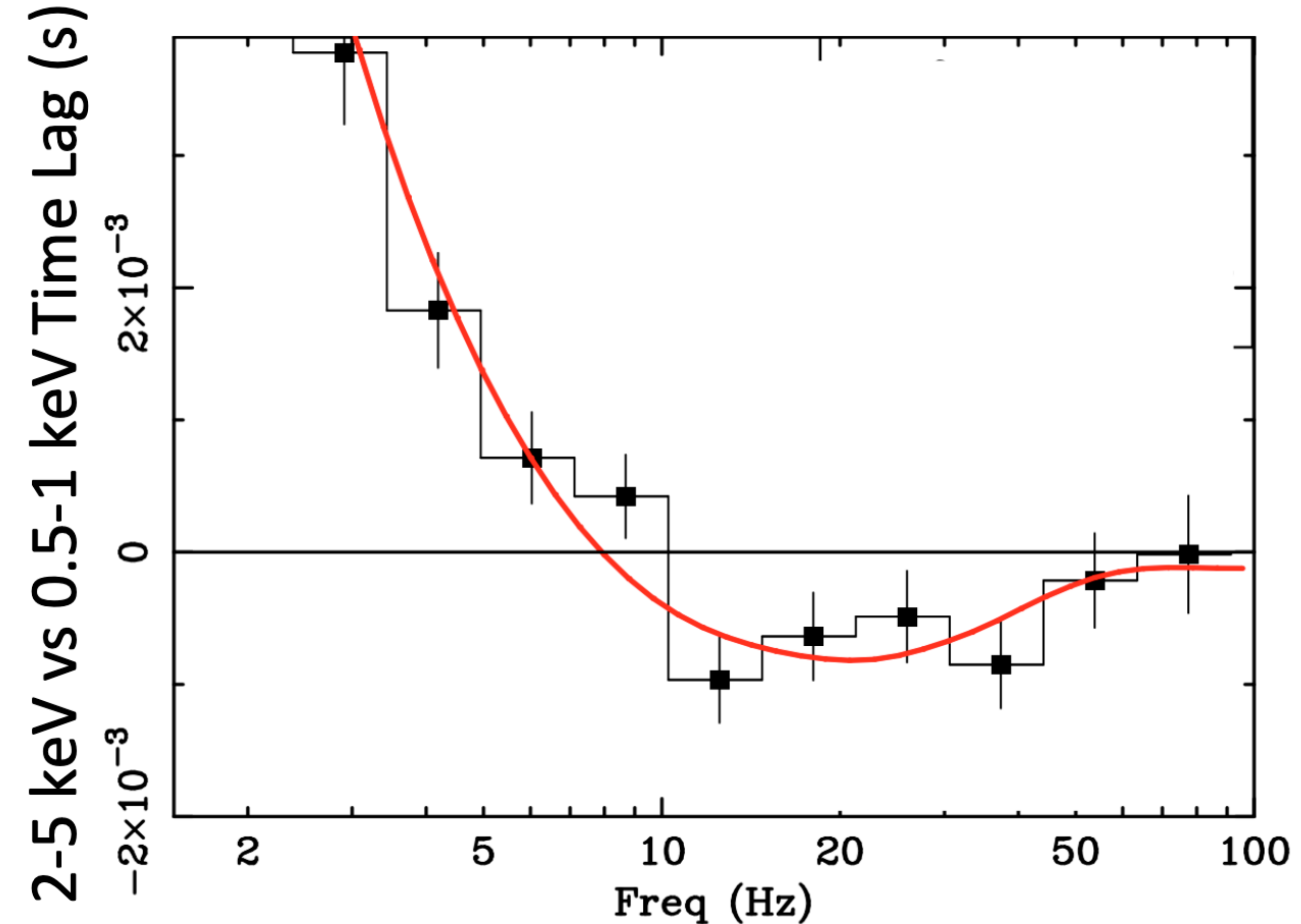
De Marco+ 2021

# Time lags in Black Hole Binaries

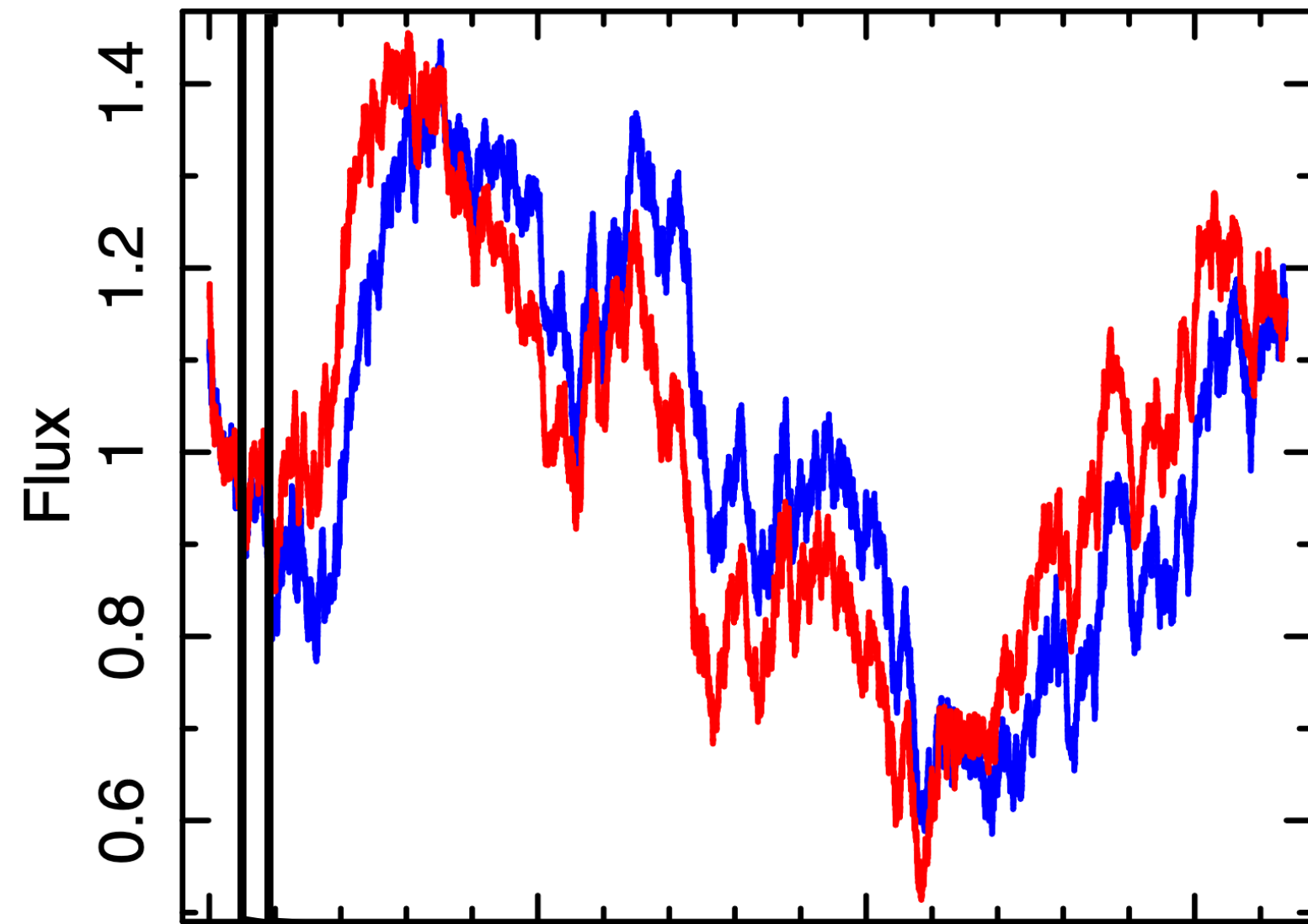


Long time scales:

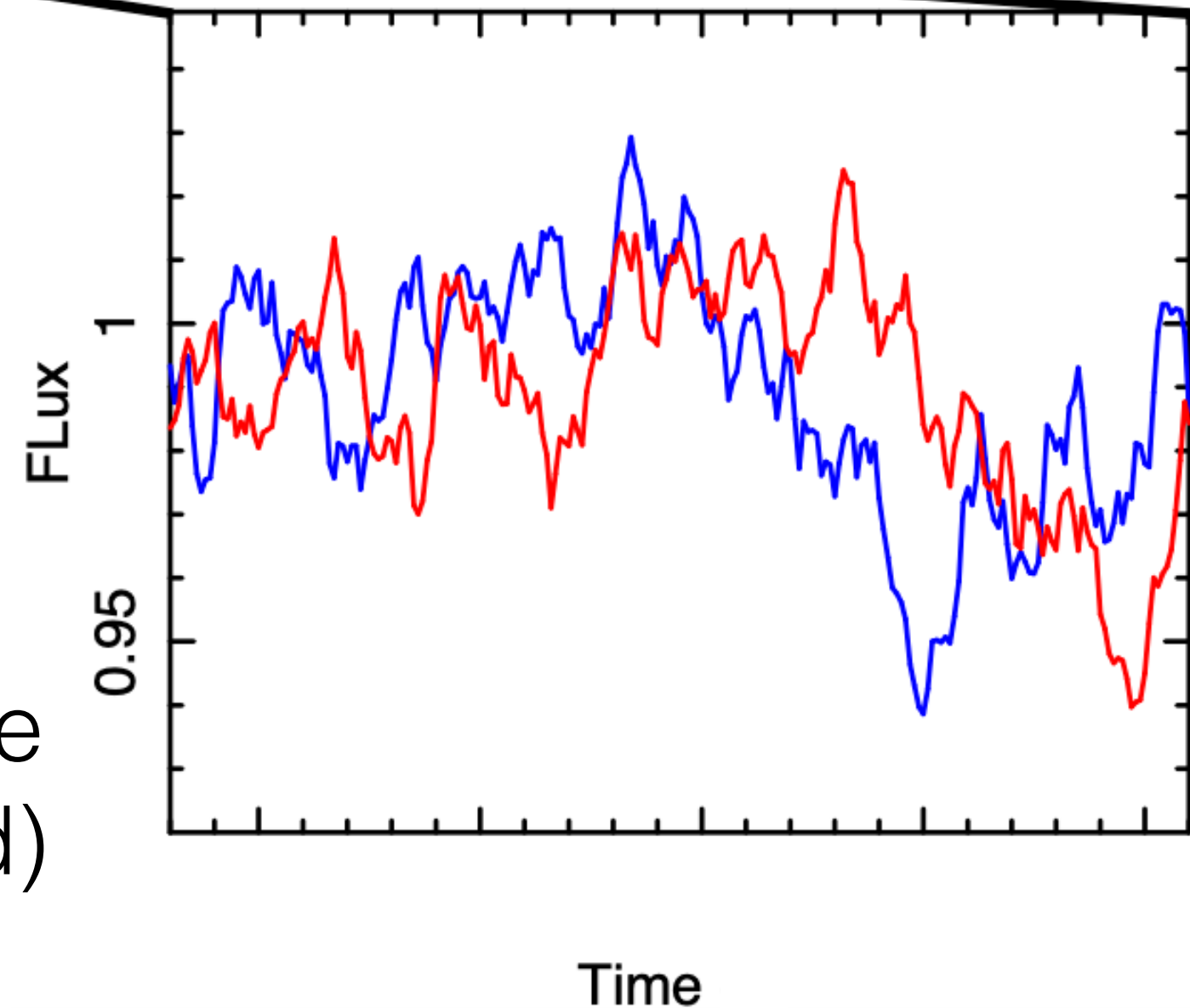
the high energy light  
curve lags the low  
energy light curve  
HARD LAGS



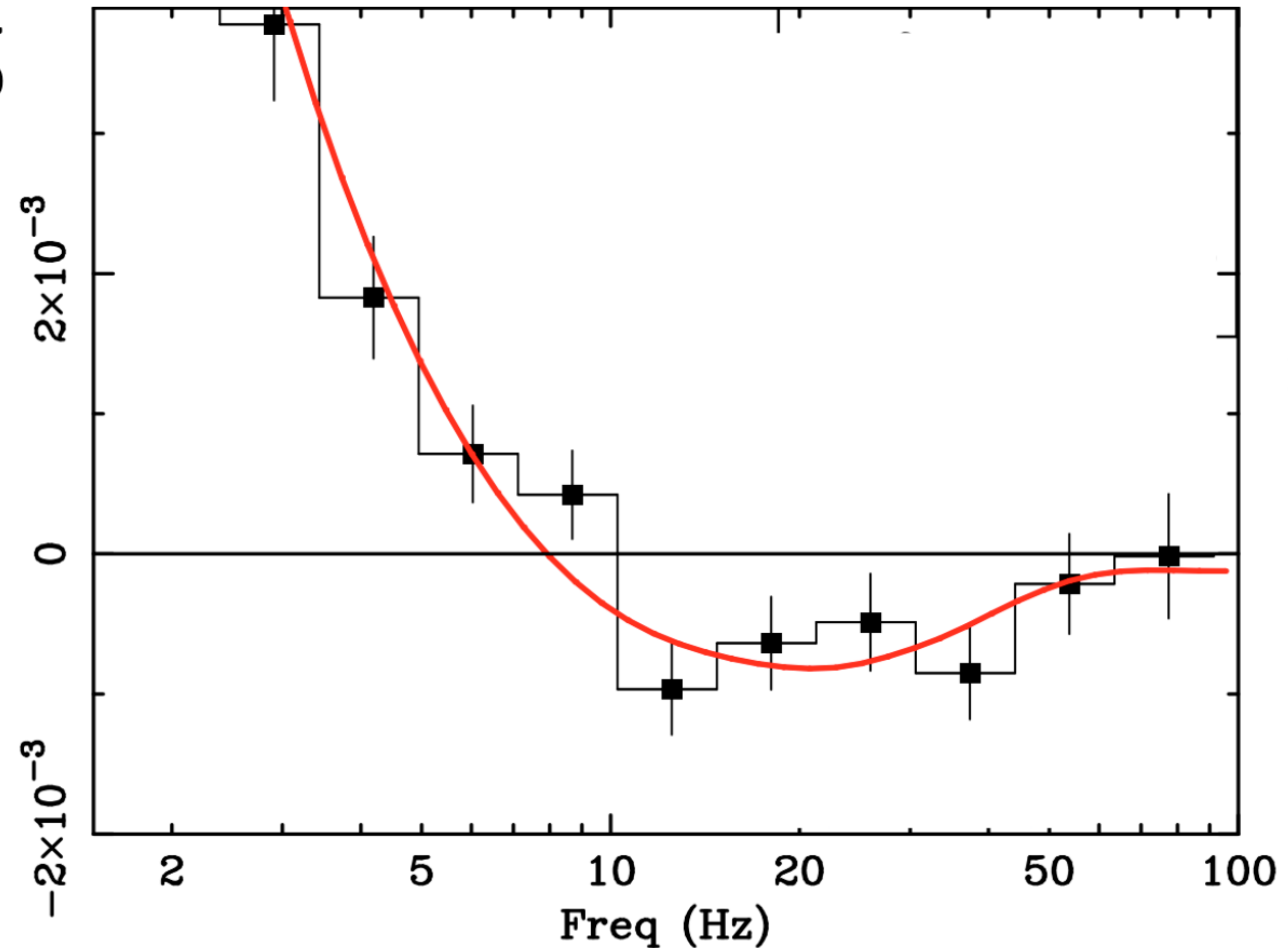
# Time lags in Black Hole Binaries



Short time scales:

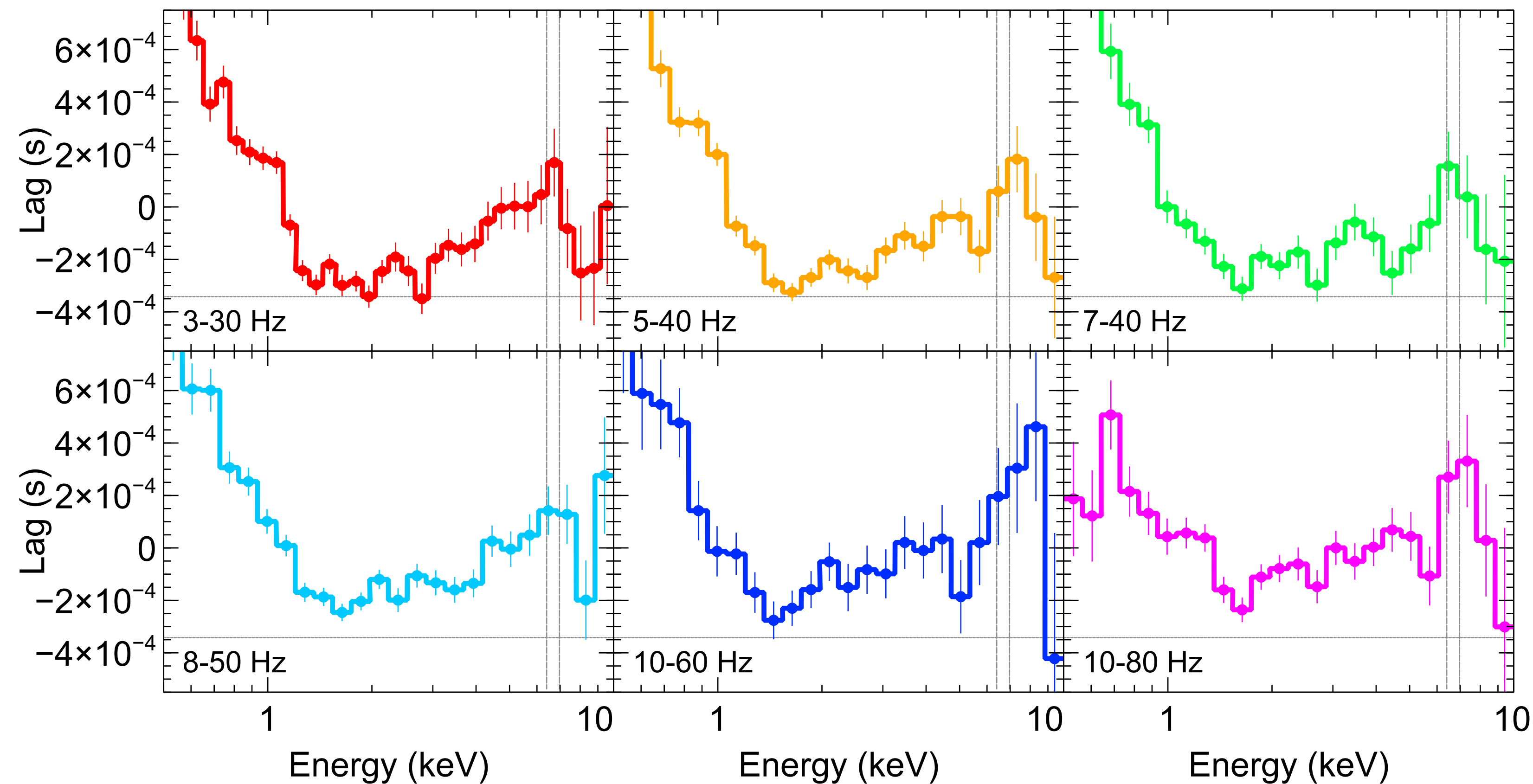
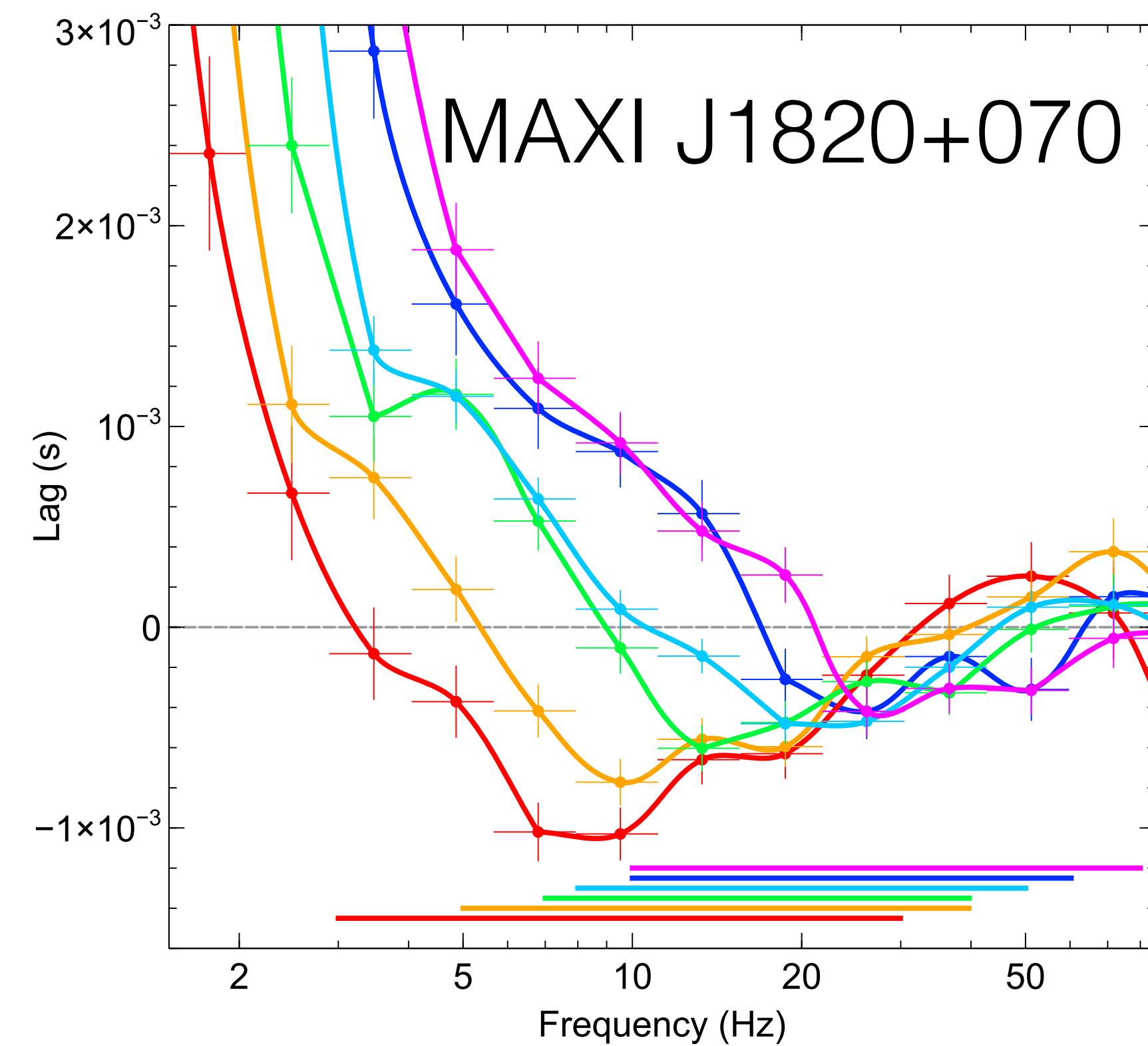


2-5 keV vs 0.5-1 keV Time Lag (s)

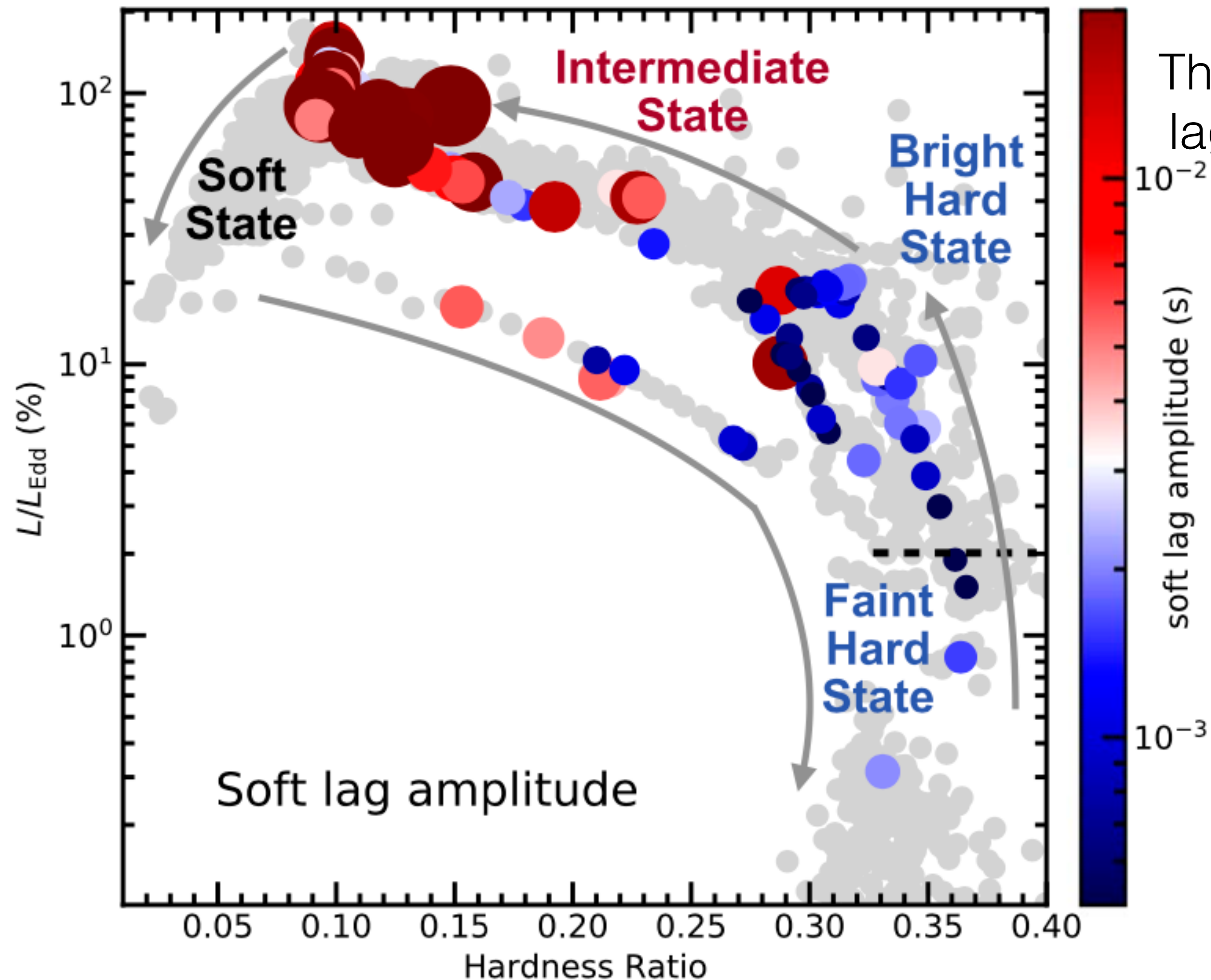


# Time lags in Black Hole Binaries

Soft lags and iron line feature in the lag energy spectra have been observed for the first time using the NICER telescope

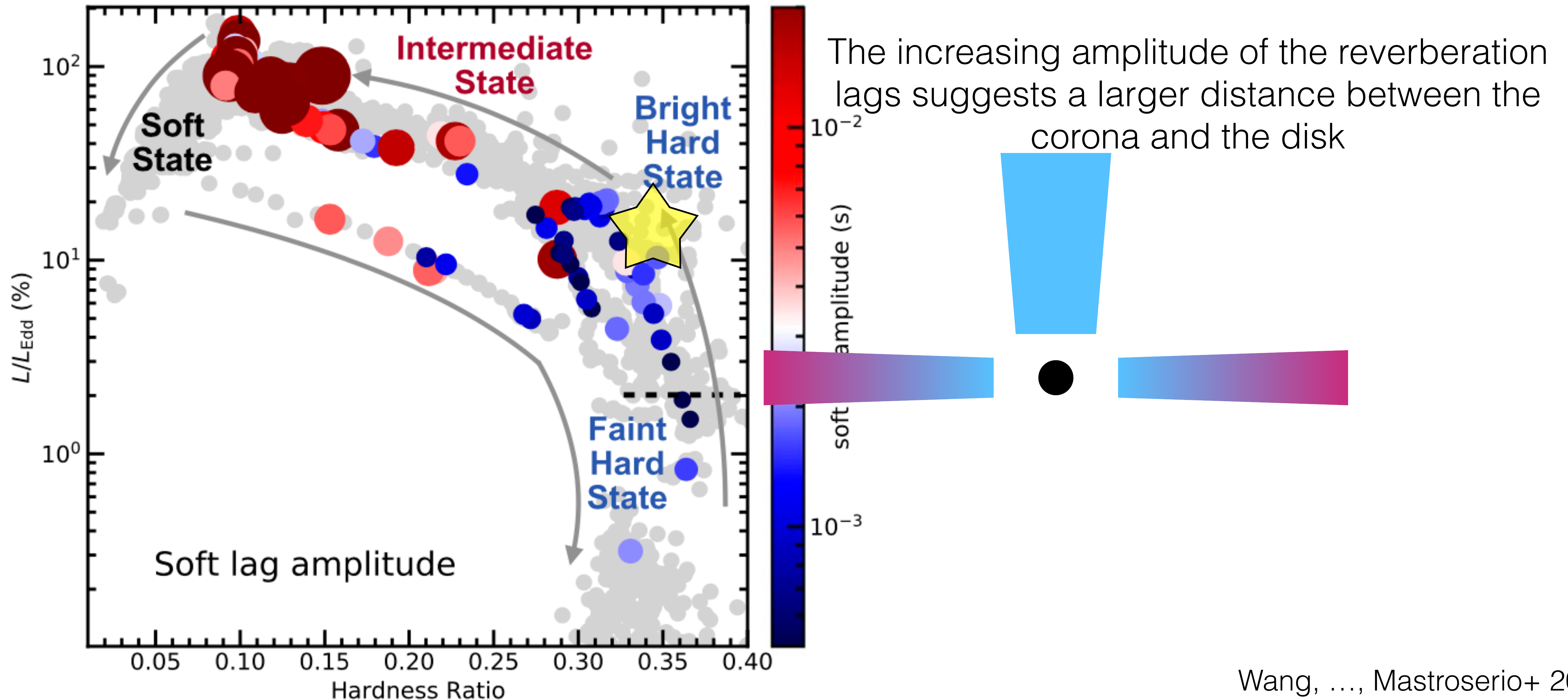


# Interpretation of the reverberation lags during the outburst

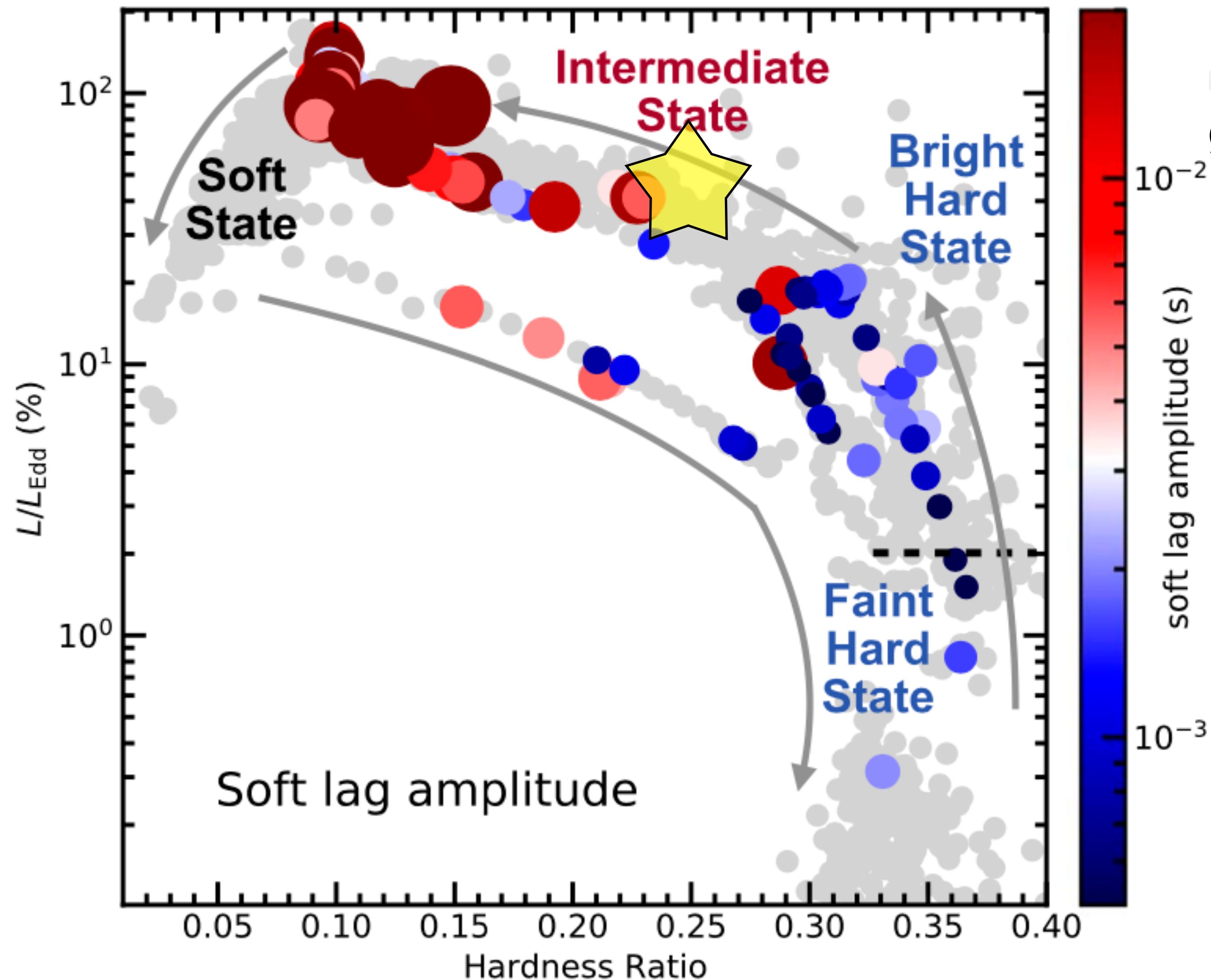


The increasing amplitude of the reverberation lags suggests a larger distance between the corona and the disk

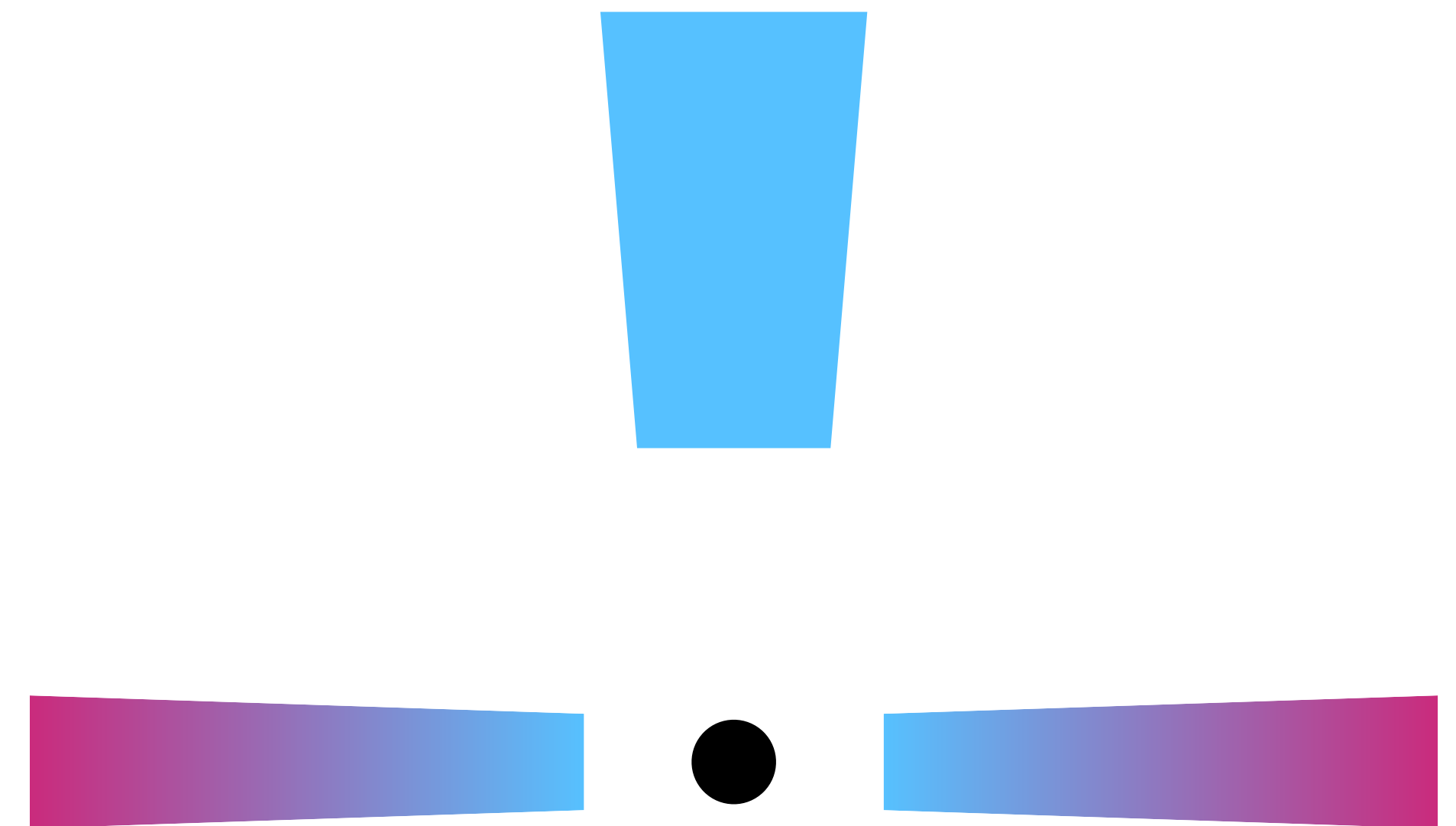
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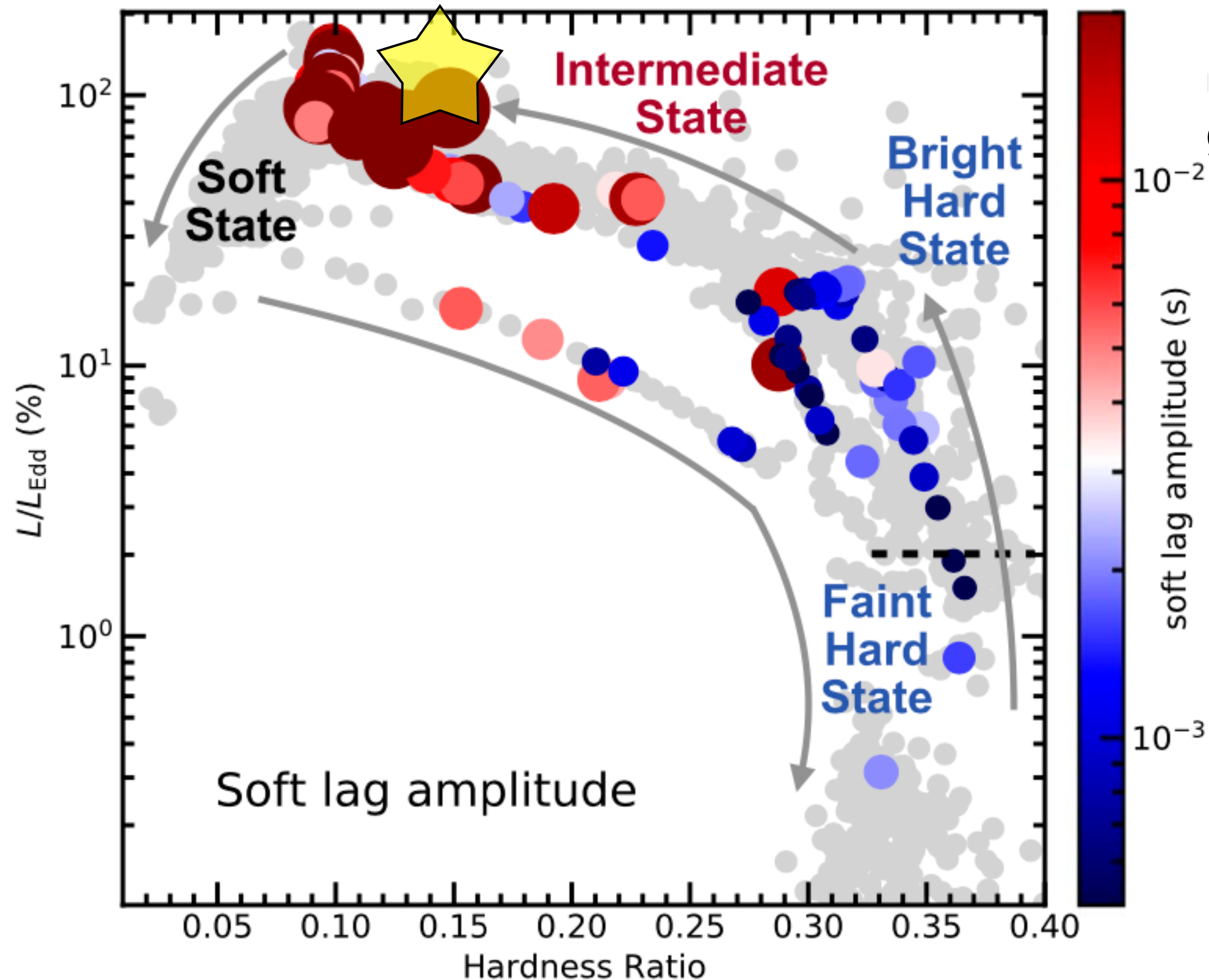
# Interpretation of the reverberation lags during the outburst



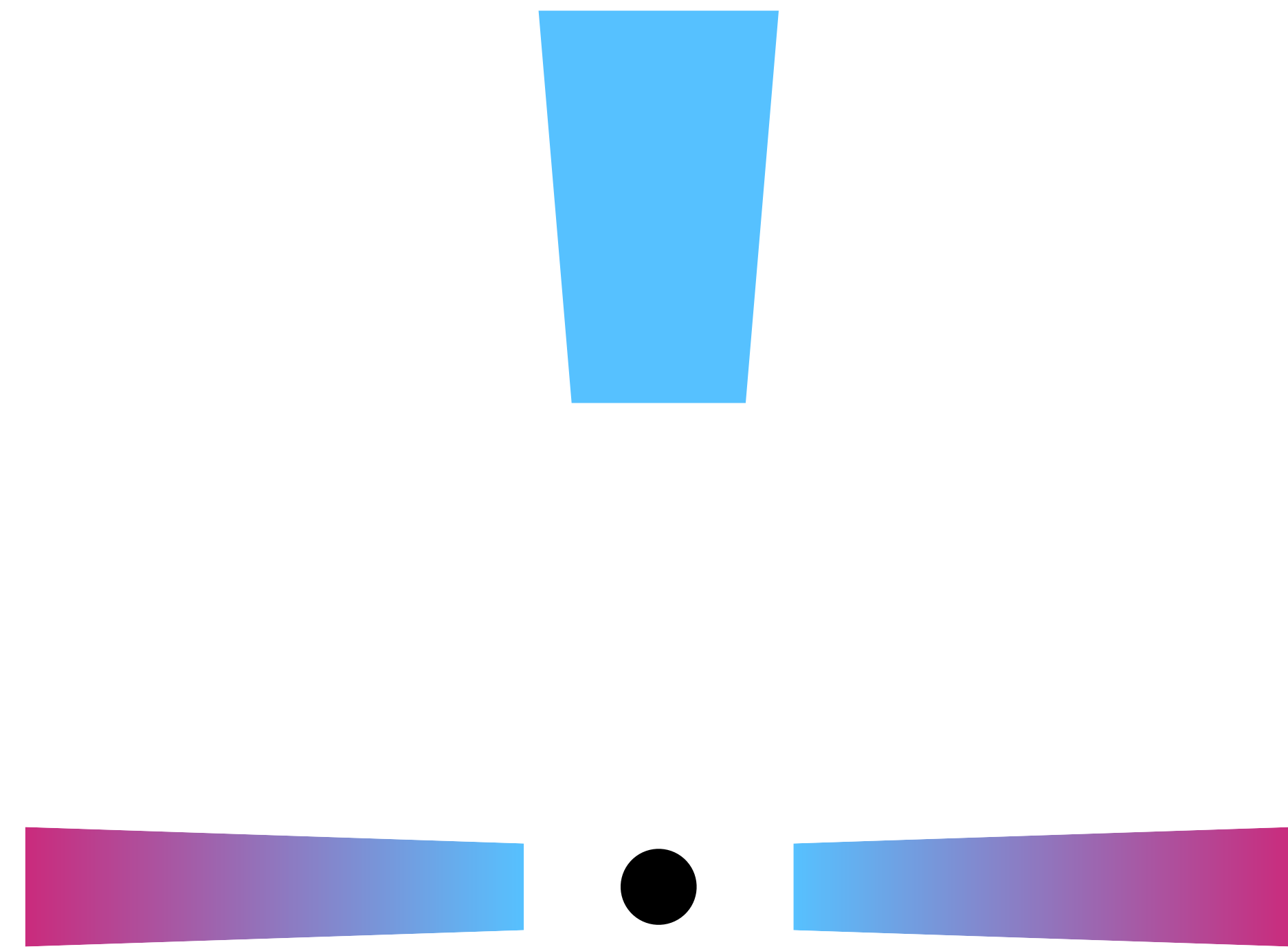
the increasing amplitude of the reverberation lags suggests a larger distance between the corona and the disk



# Interpretation of the reverberation lags during the outburst

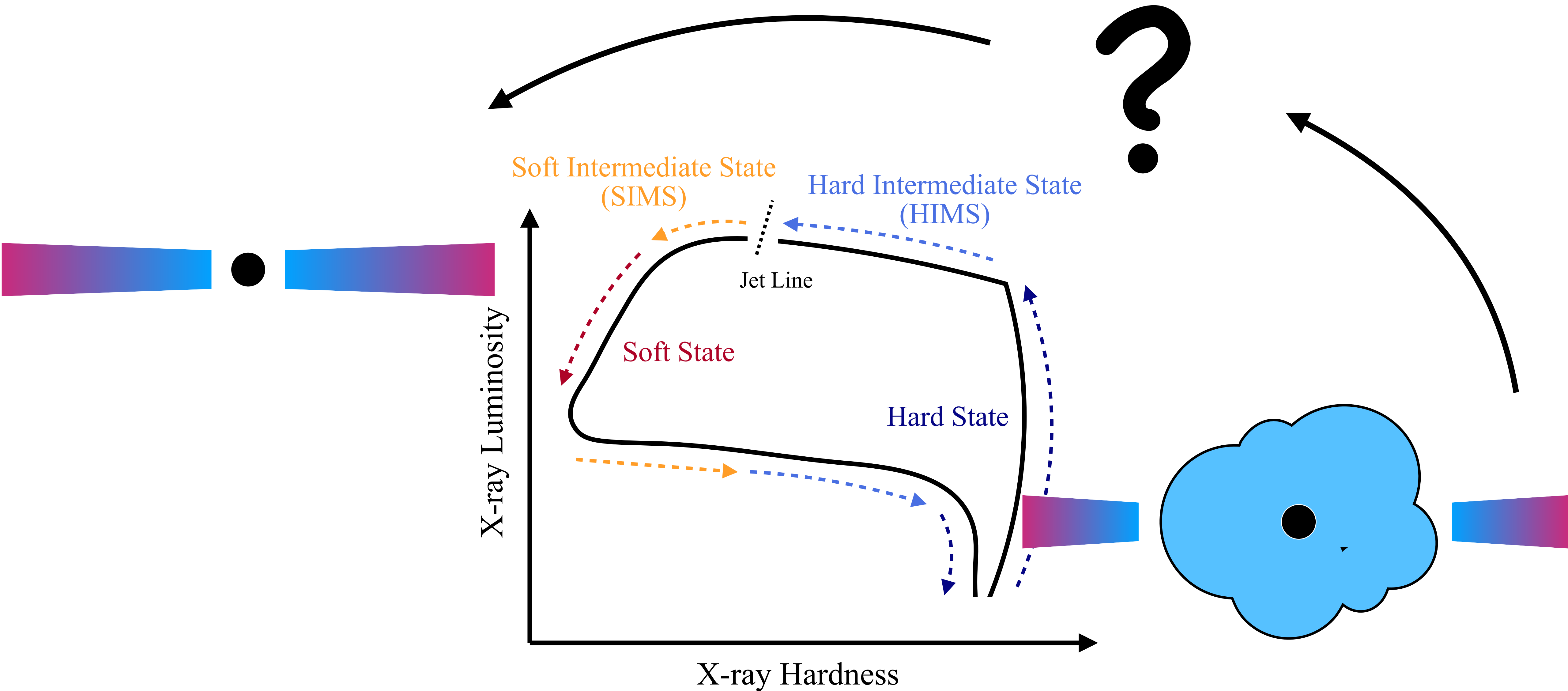


the increasing amplitude of the reverberation lags suggests a larger distance between the corona and the disk

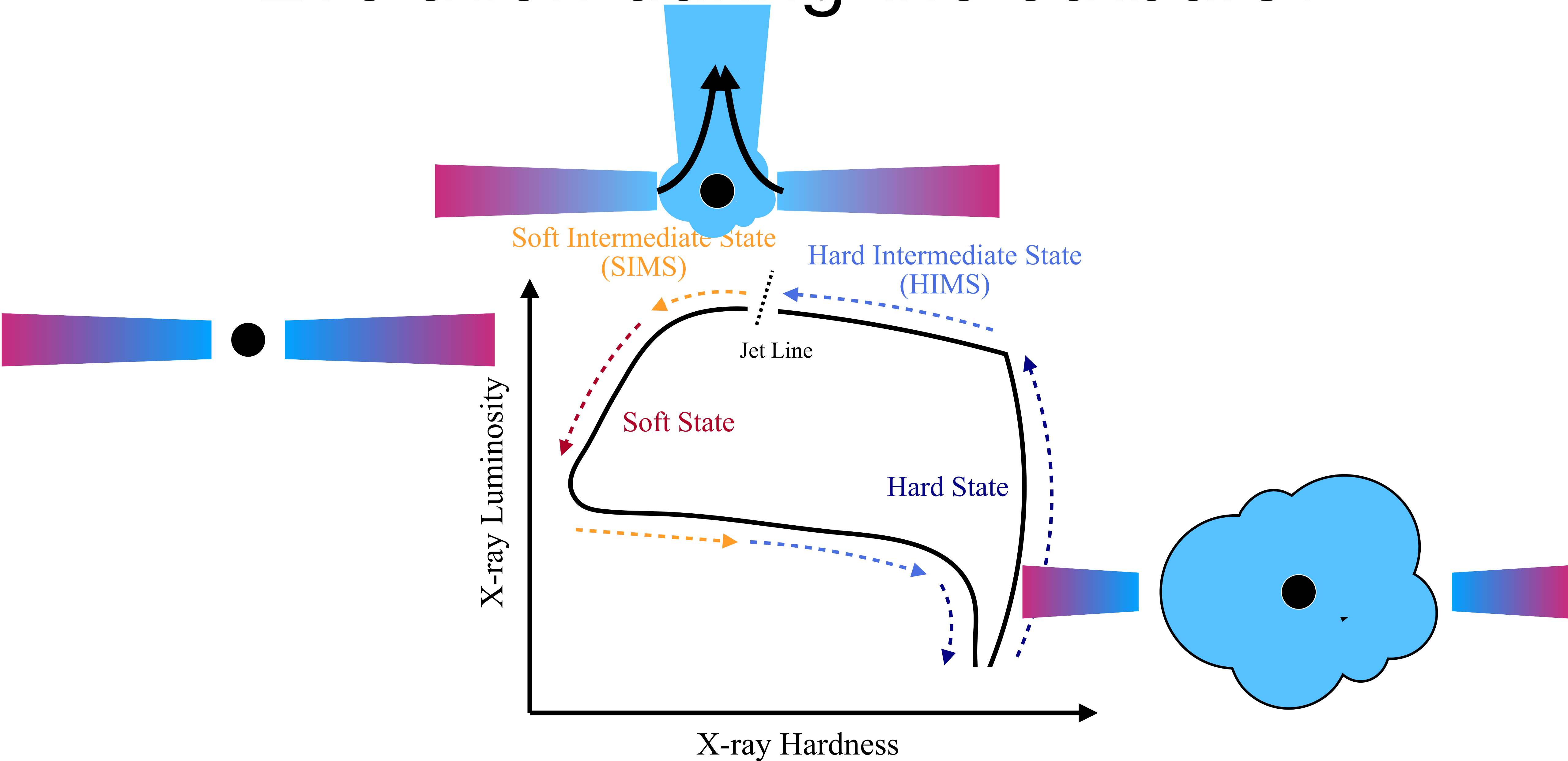


# Evolution during the outburst

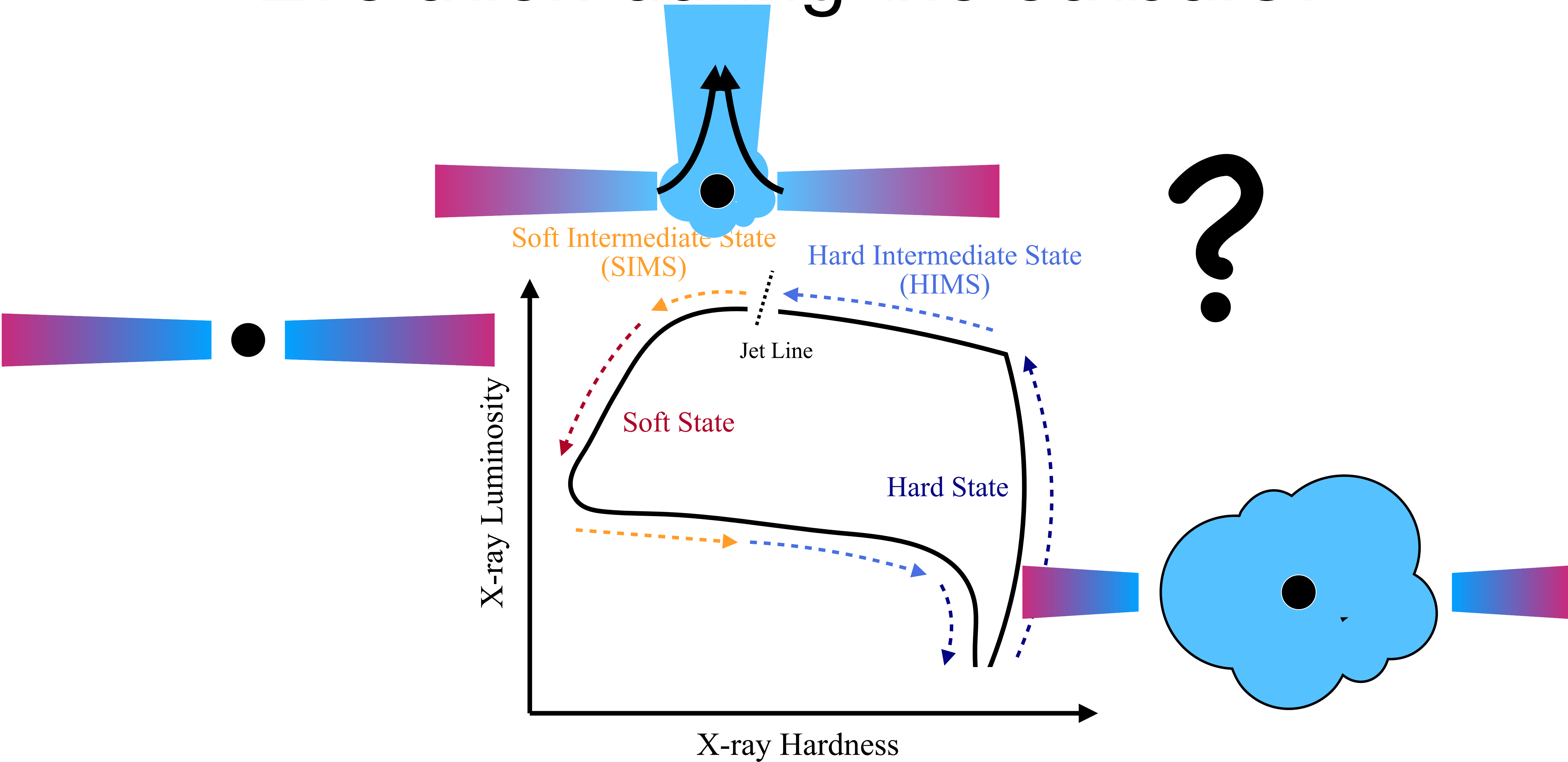
What happens during the transition?



# Evolution during the outburst



# Evolution during the outburst



# Imaging X-ray Polarimetry Explorer IXPE



# Polarization in black hole X-ray binaries

See review by Dovčiak et al. 2024

Cygnus X-1

~4%  
**Hard State**

**Krawczynski+2022**, also Steiner+  
2024, Kravtsov in press for more  
polarisation detections of the source

IGR J17091–3624

~9%  
**Hard State**

Ewing, Parra, Mastroserio+ 2025

4U 1630-472

~8% **Soft State**  
~6.7% **Steep PL State**

Rawat+2023,2024; Ratheesh+2024;  
Rodriguez Caverio+ 2024;  
Kushwaha+2024; Tomaro+2024

GX 339-4

~1%  
**Soft Intermediate State**

Mastroserio+ 2025

Swift J1727.8-1613

~3-4%  
**Intermediate State**

Veledina+ 2023; Ingram+ 2024;  
see also Podgorny+ 2024;  
Svoboda+2024 and more coming

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**~1%  
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**Swift J1727.8-1613**

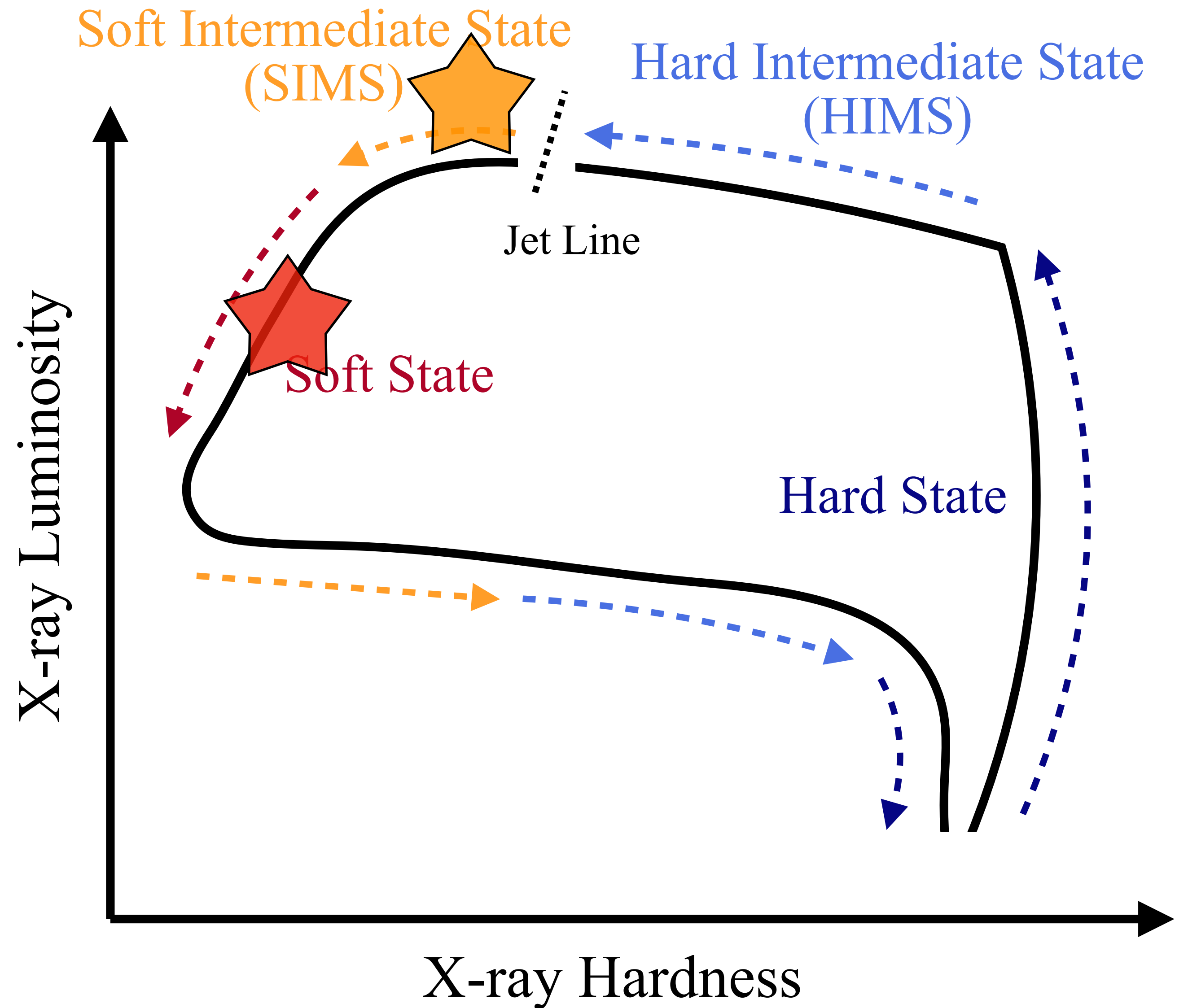
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Intermediate State**

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see also Podgorny+ 2024;  
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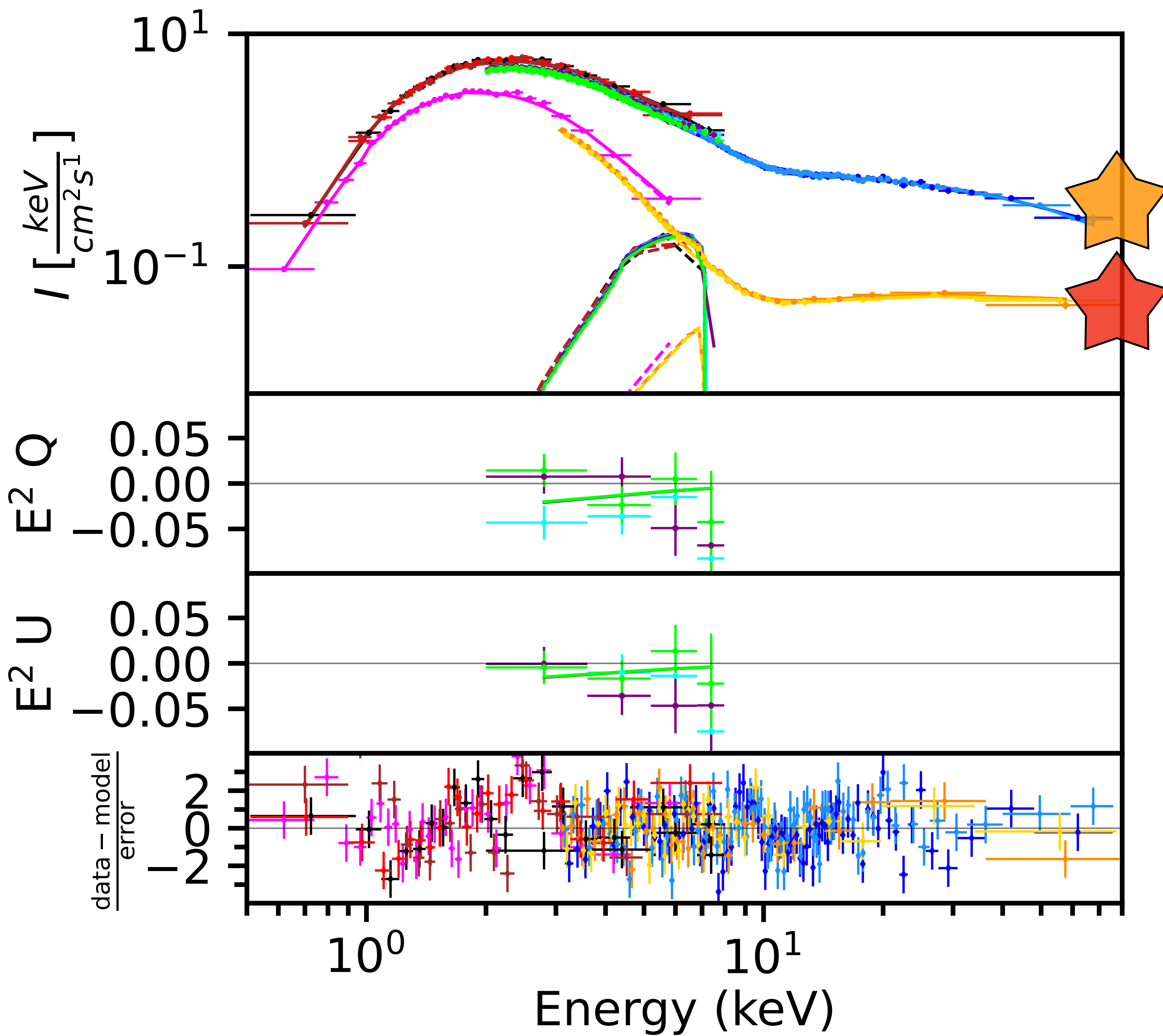
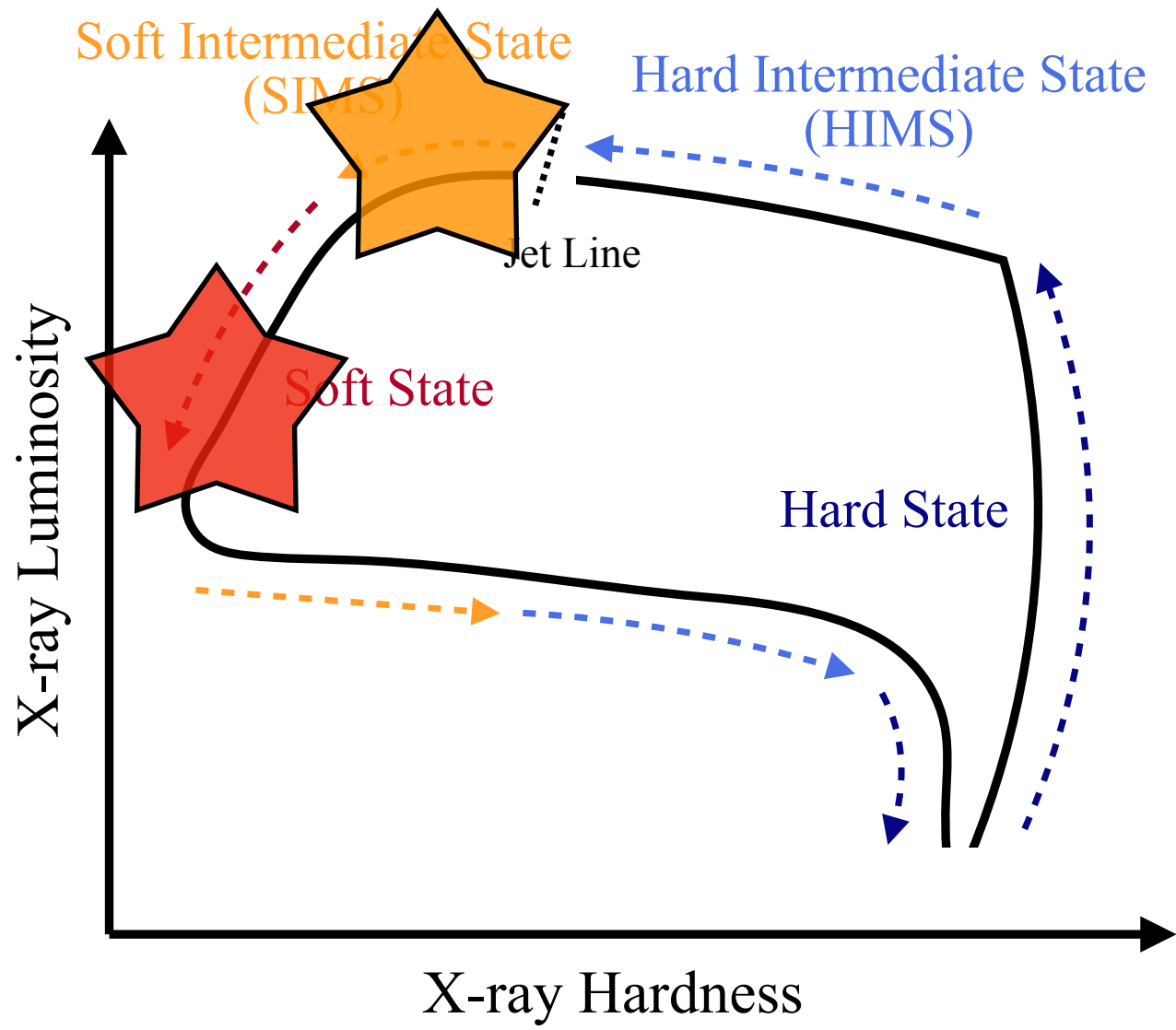
# GX 339-4 outburst 2023 HID

Epoch 1:  
soft intermediate state  
type-B QPO

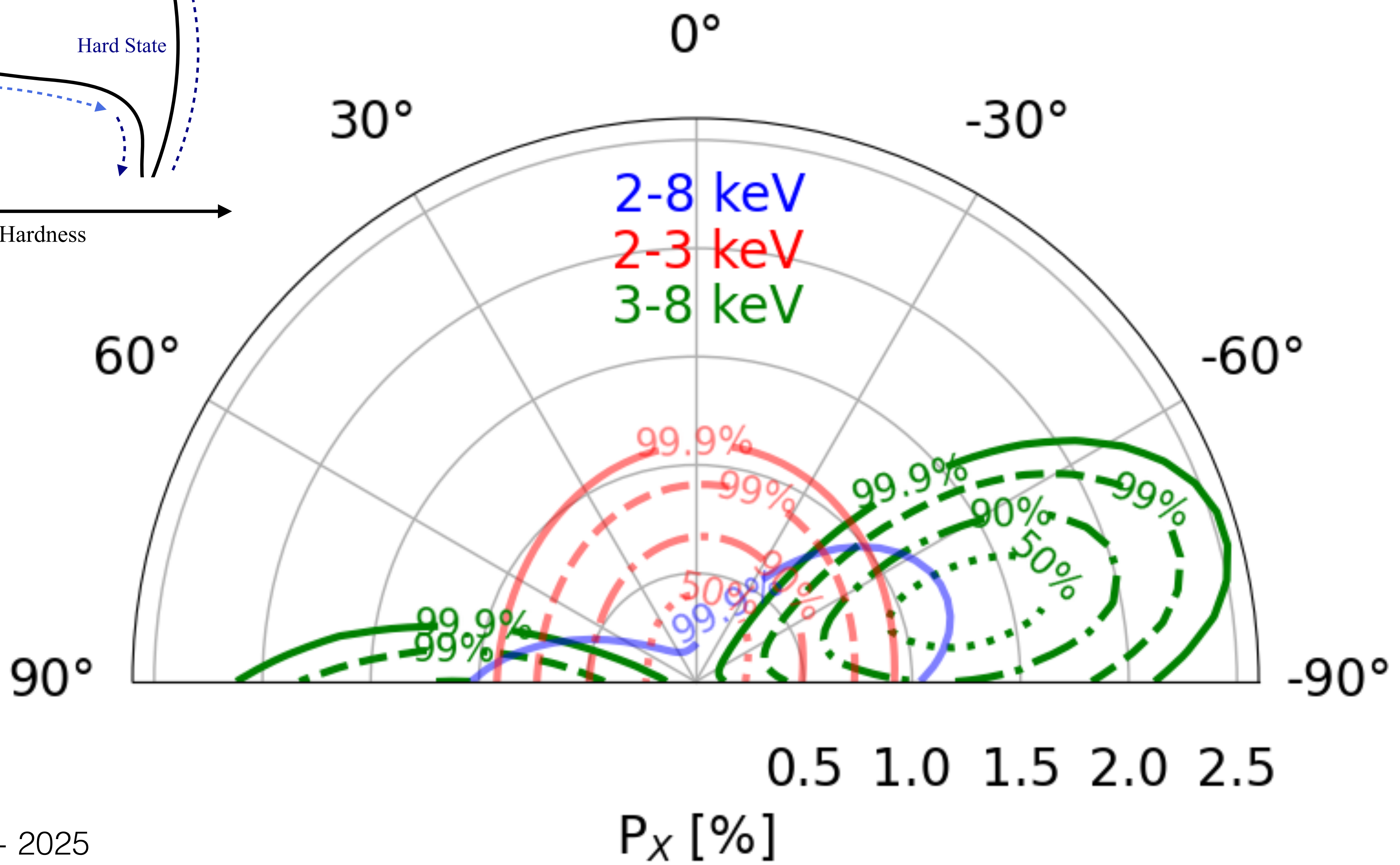
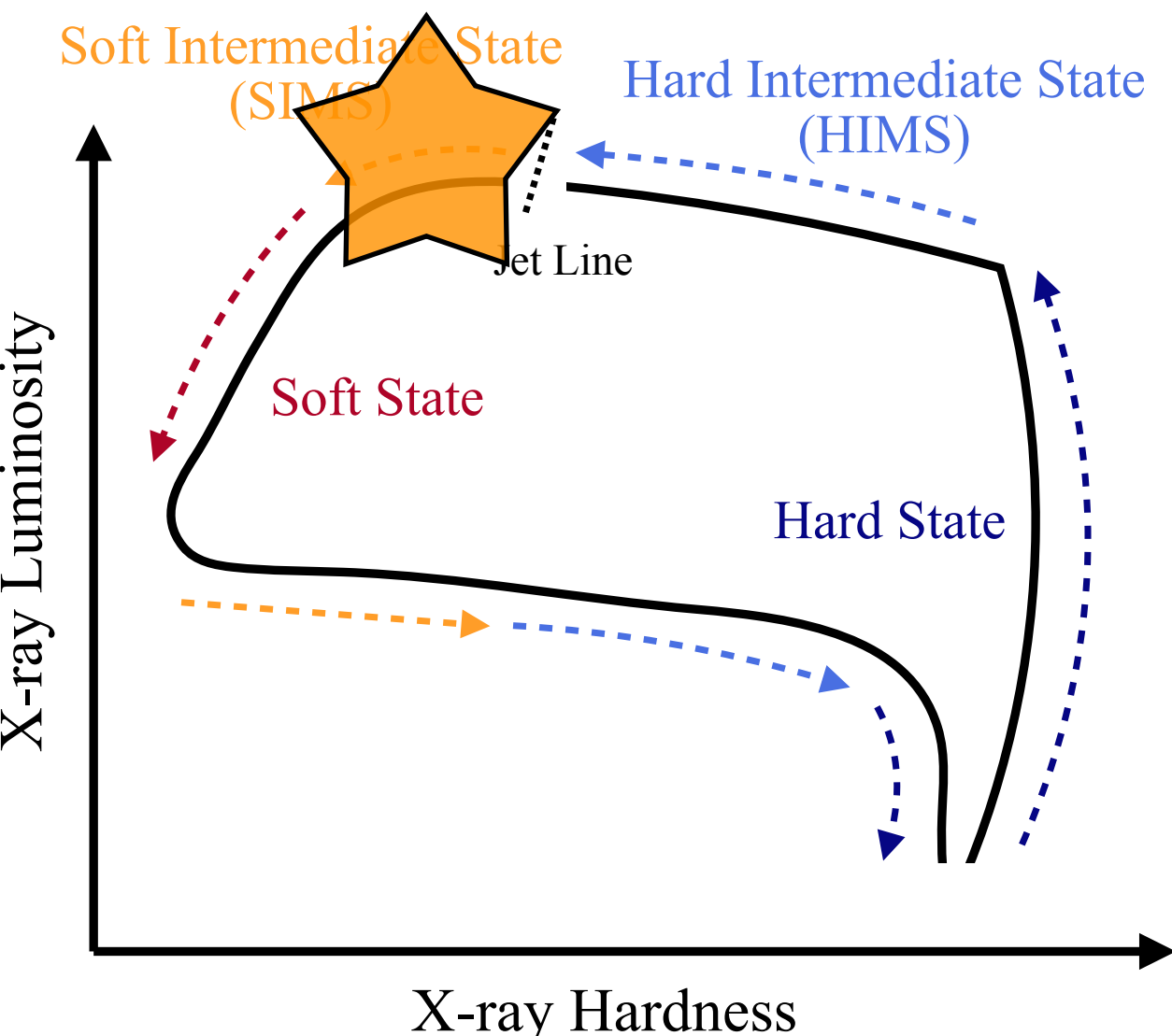
Epoch 2:  
soft state

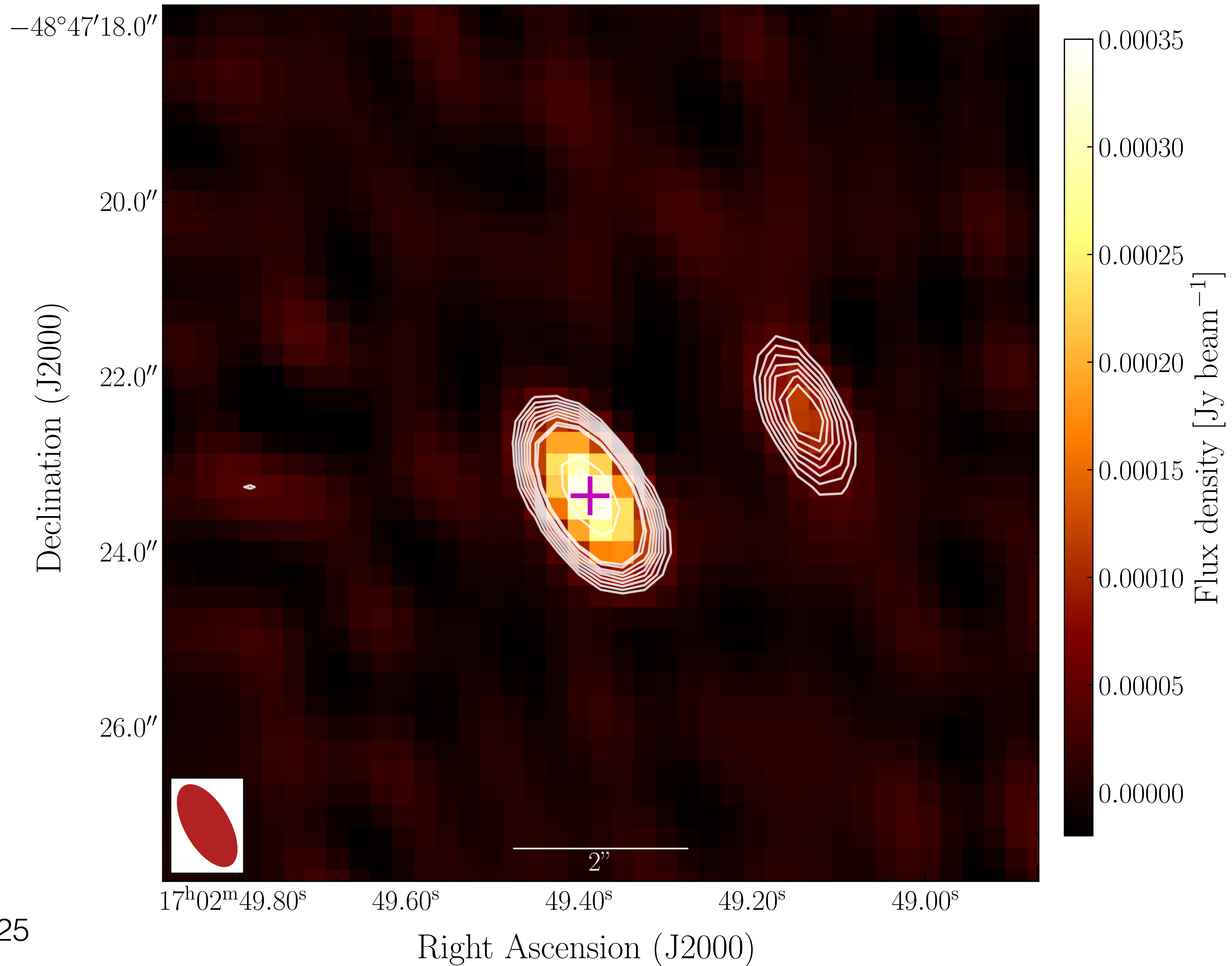


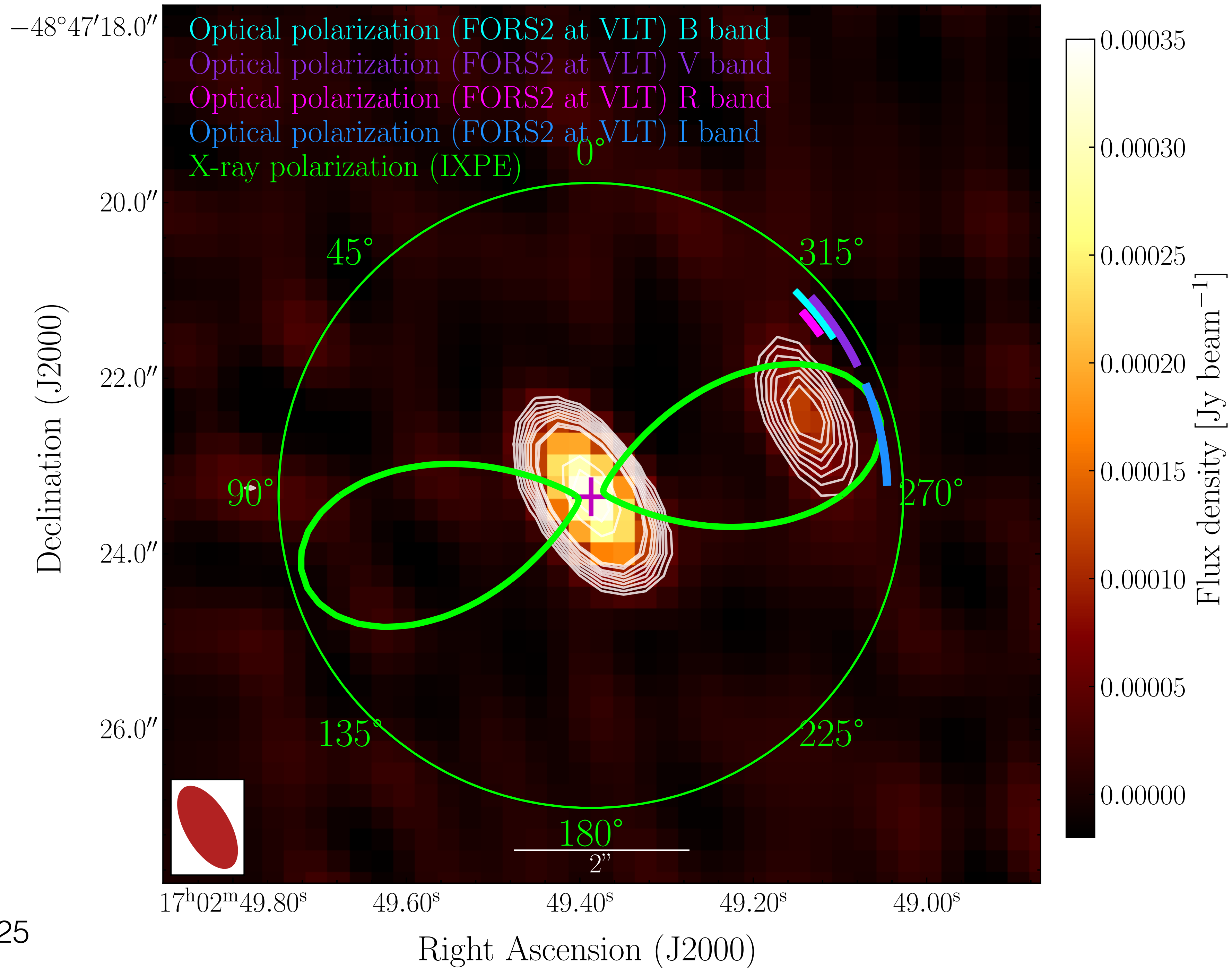
# Simultaneous fit of epoch 1 and epoch 2

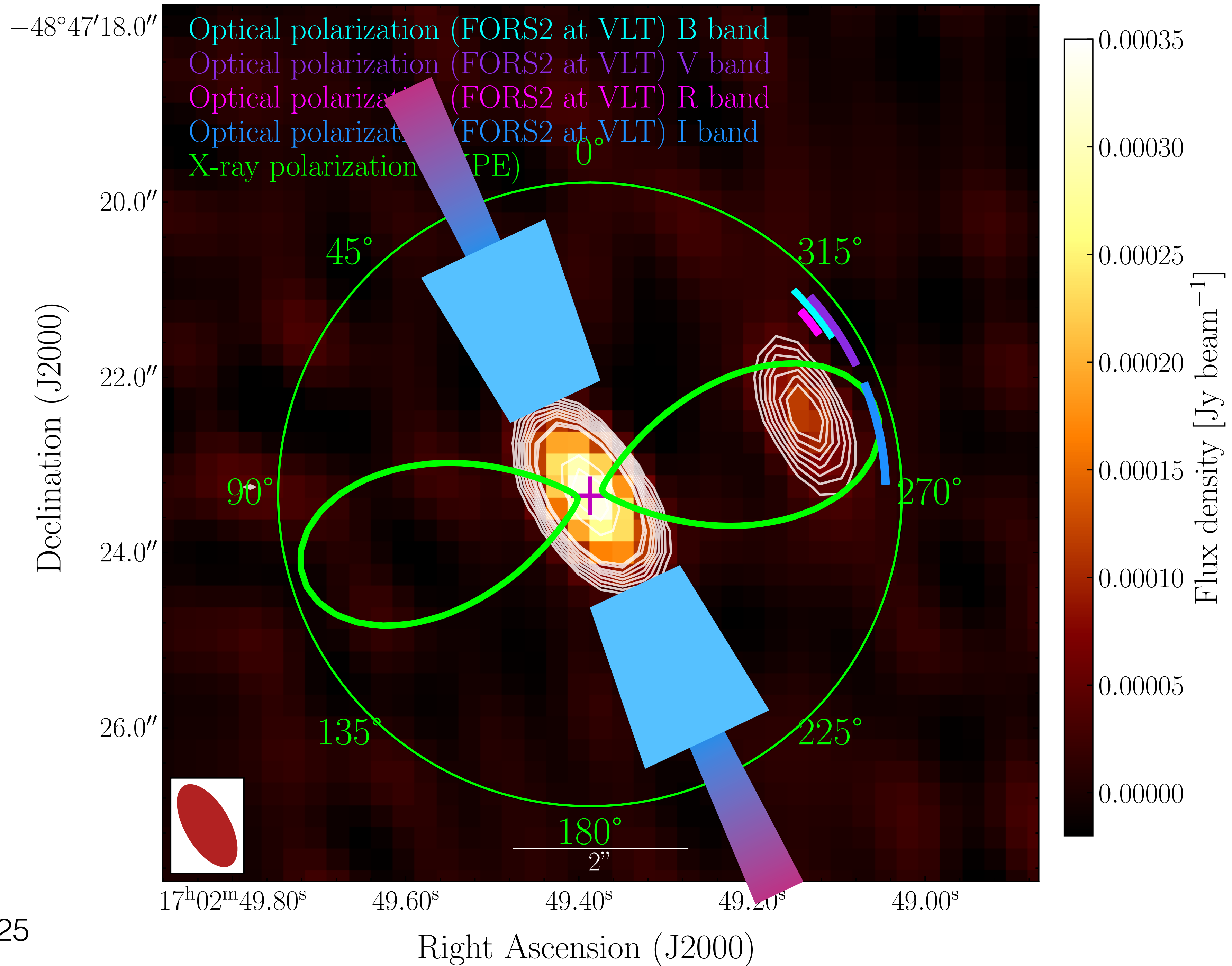


# IXPE epoch 1

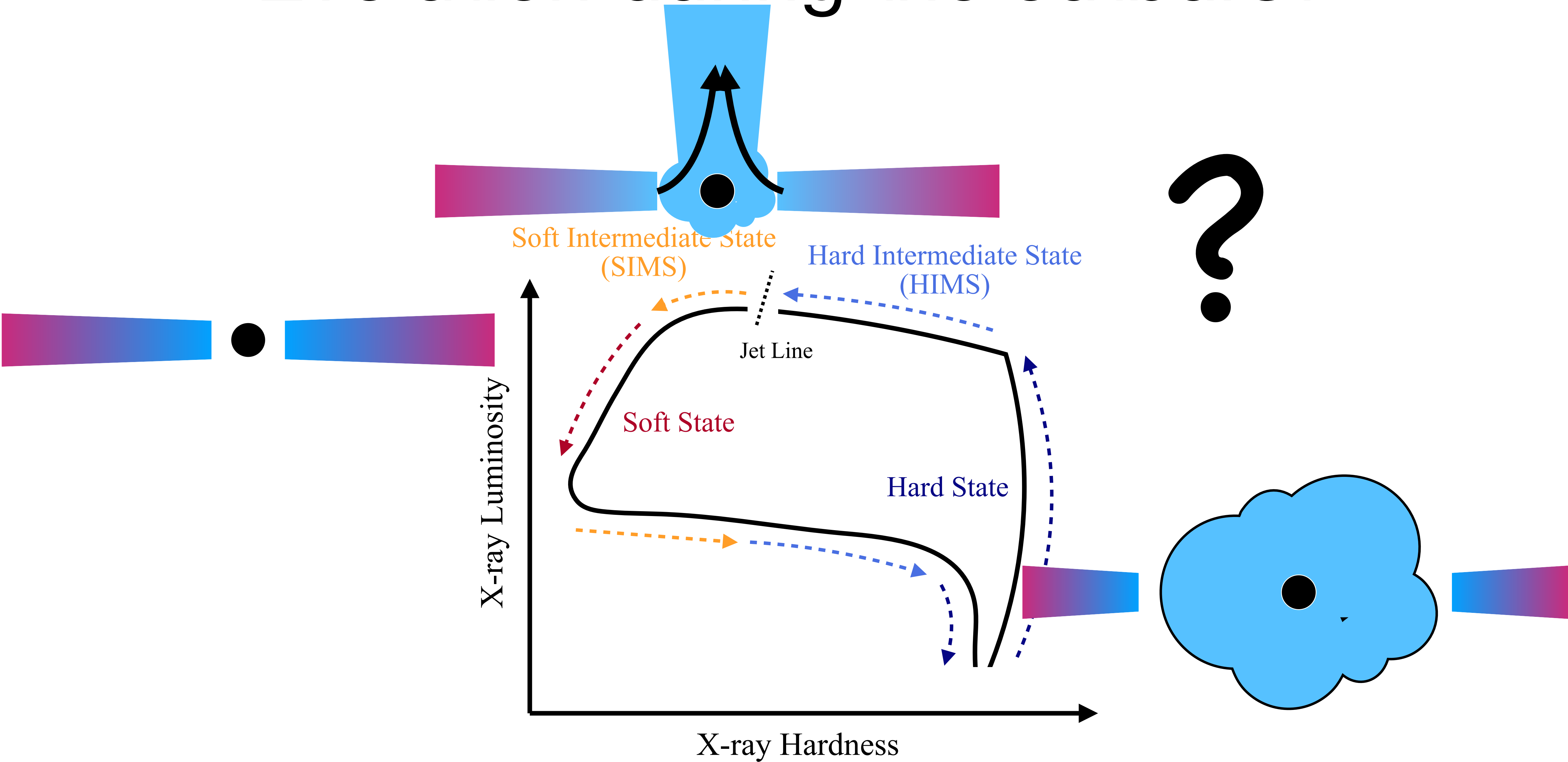




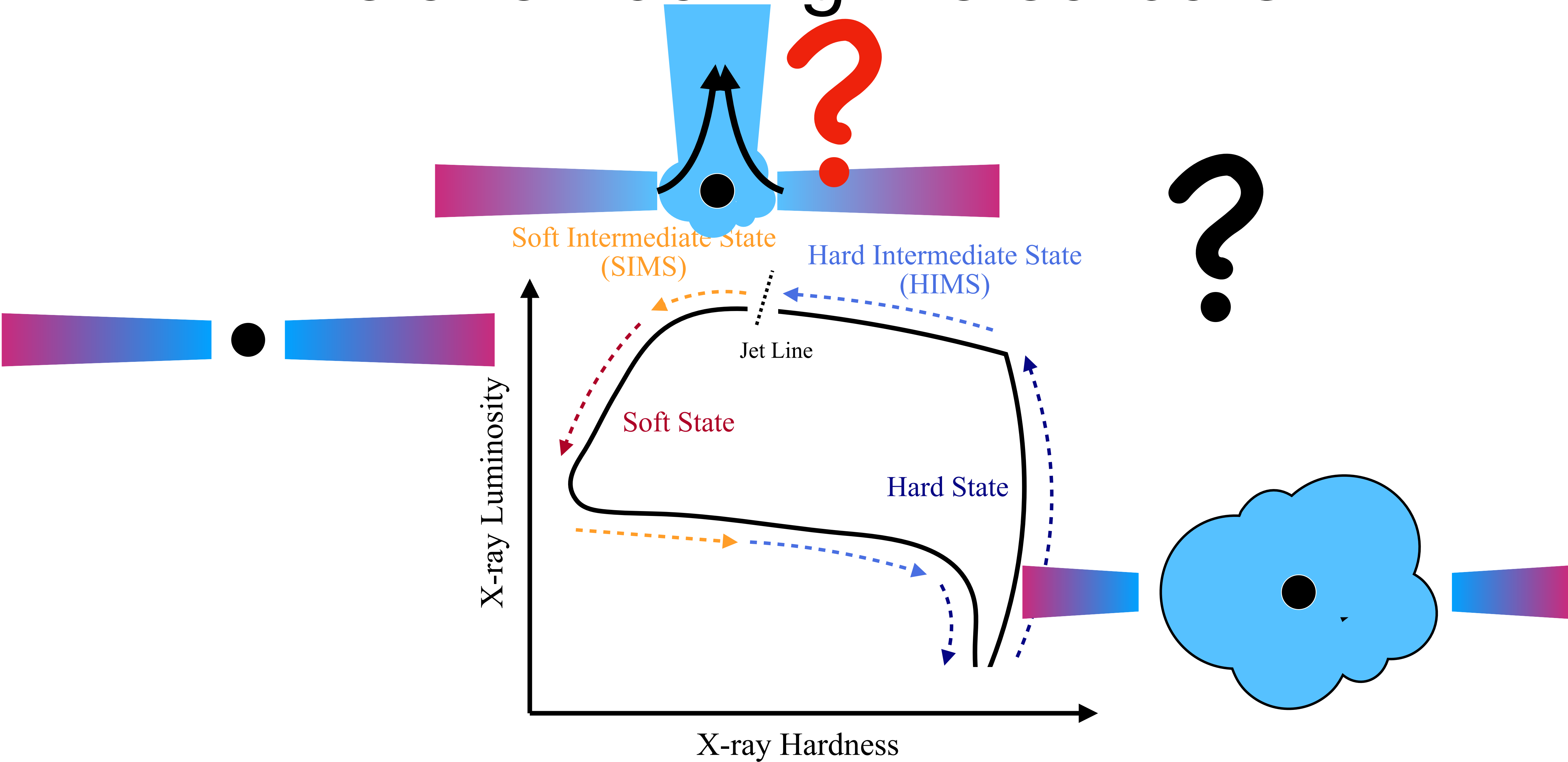




# Evolution during the outburst



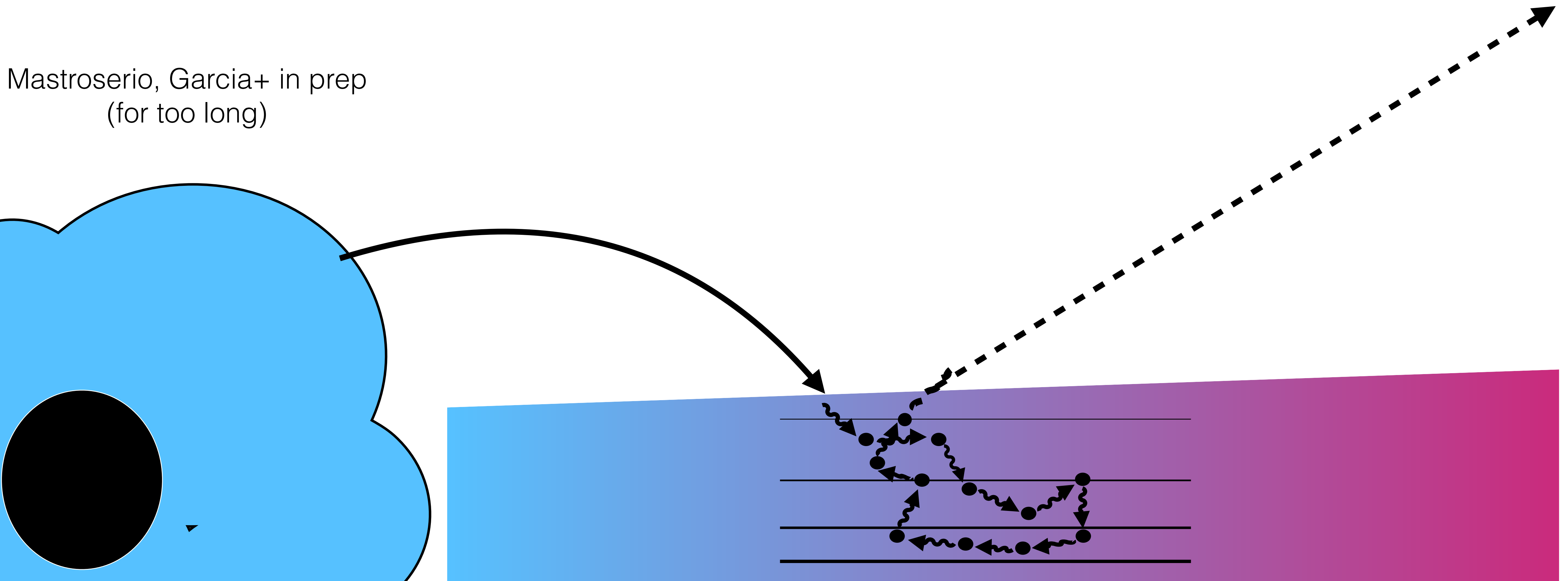
# Evolution during the outburst



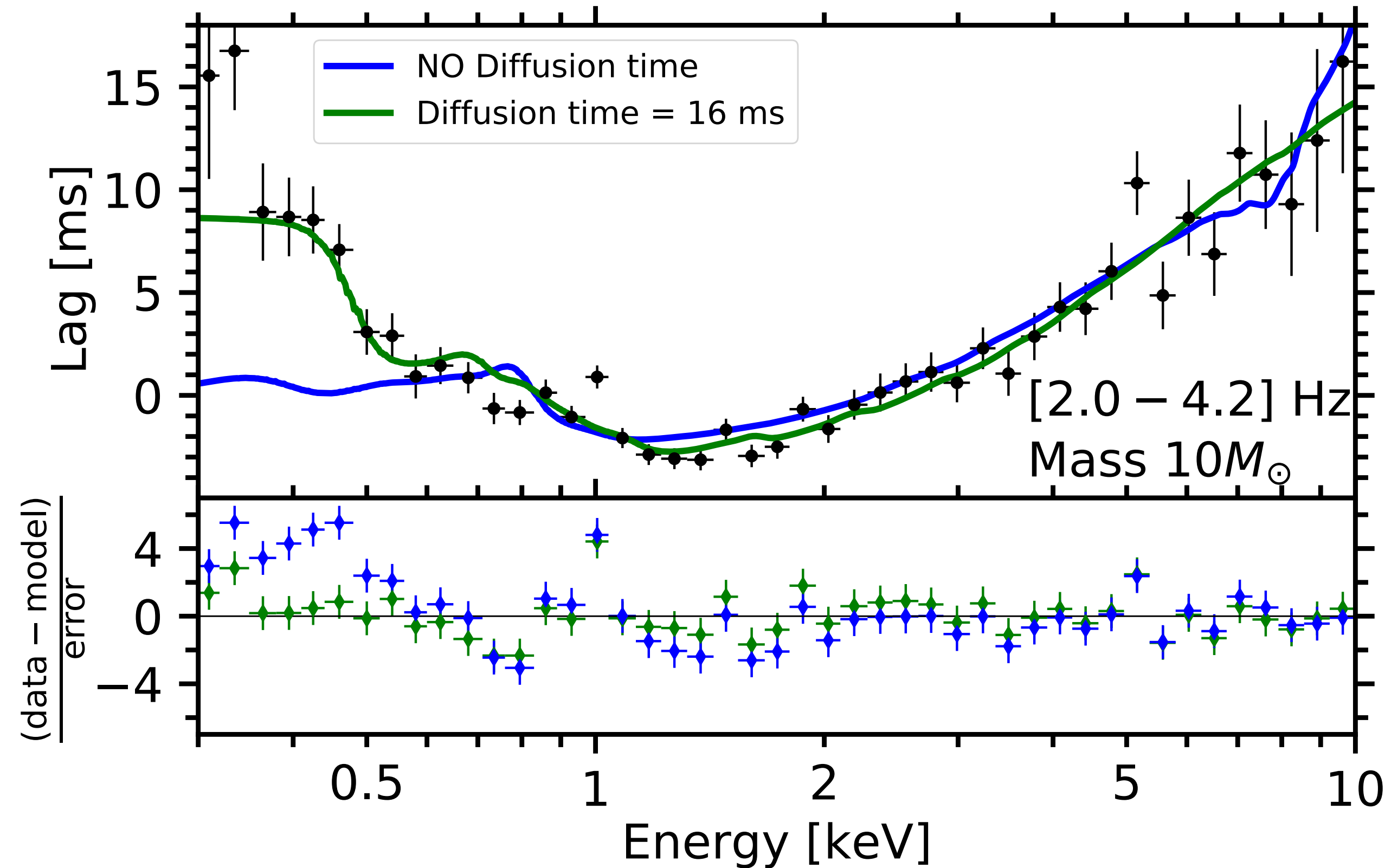
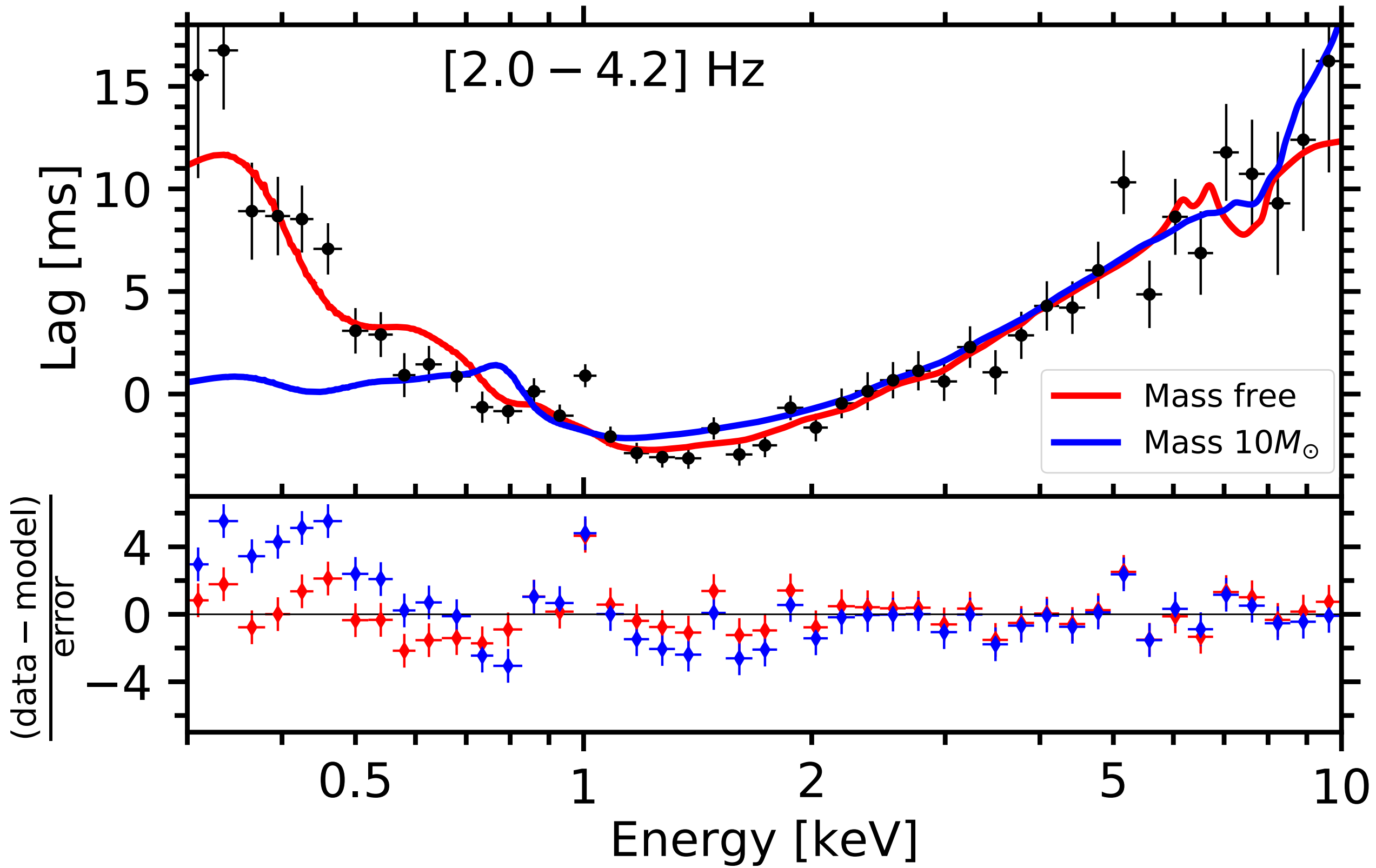
# Possible solutions

**Diffusion time:** the time that photons take to be reprocessed in the accretion disk

Mastroserio, Garcia+ in prep  
(for too long)

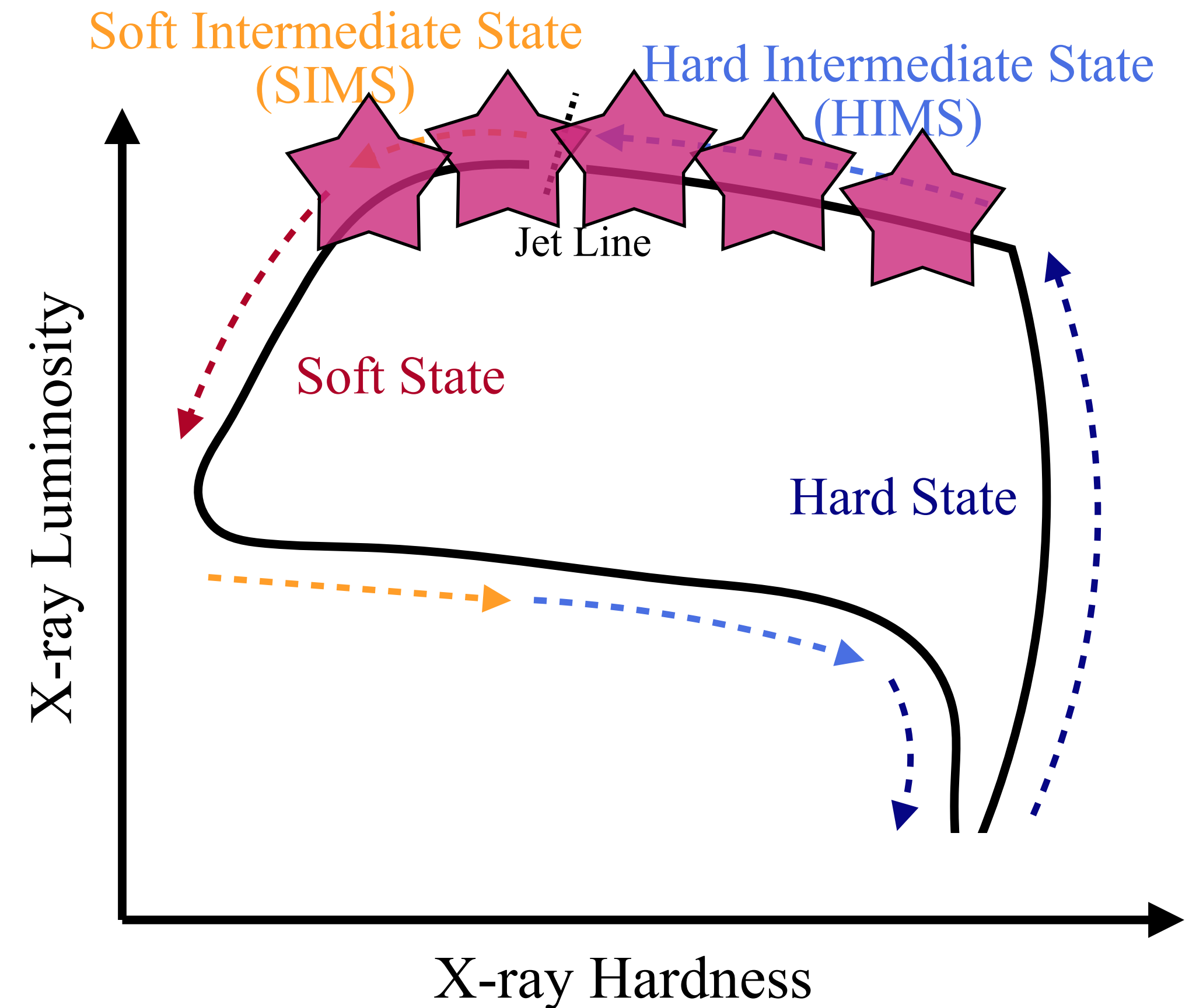
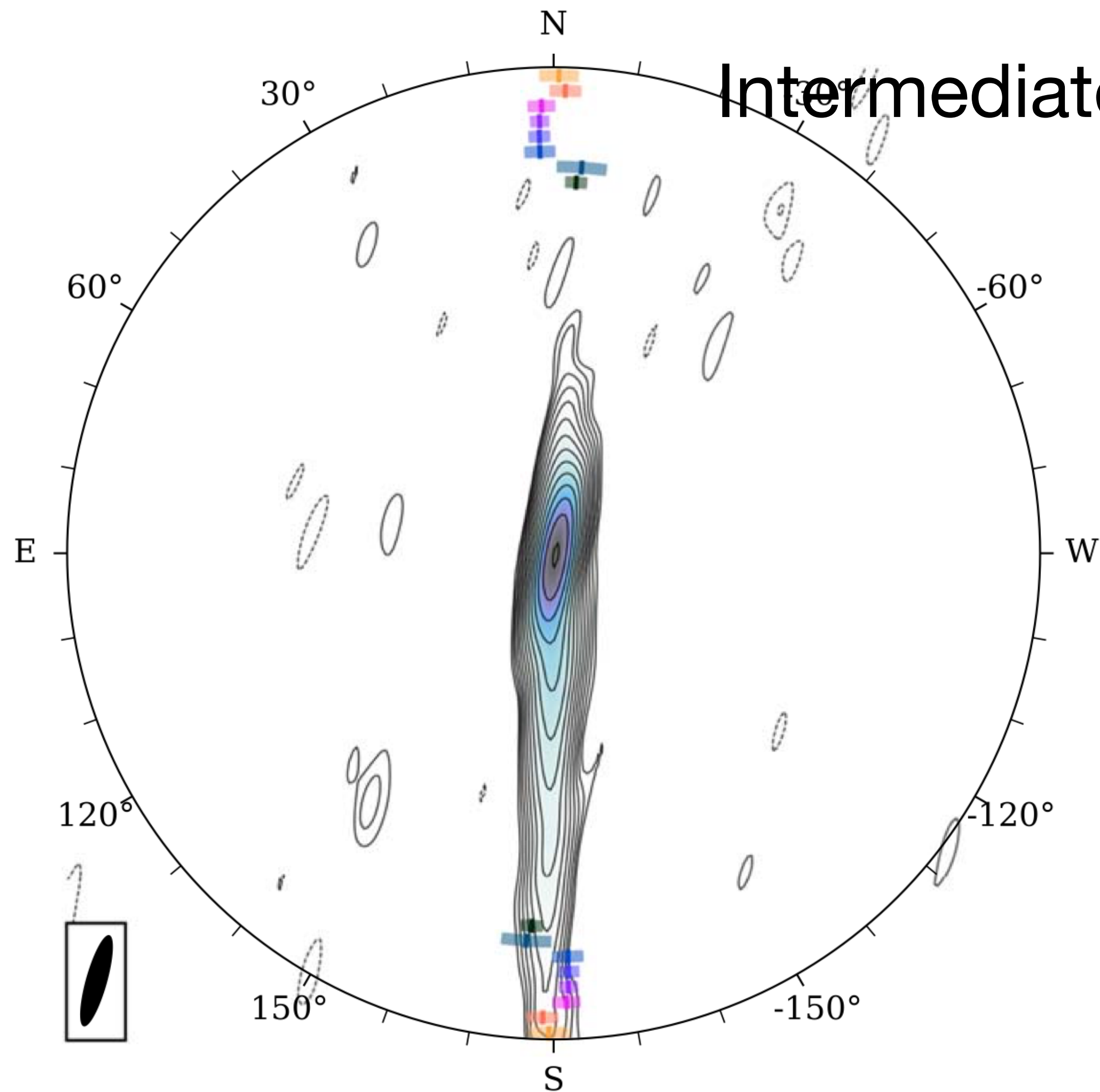


# Reprocessing time



# Swift J1727.8-1613

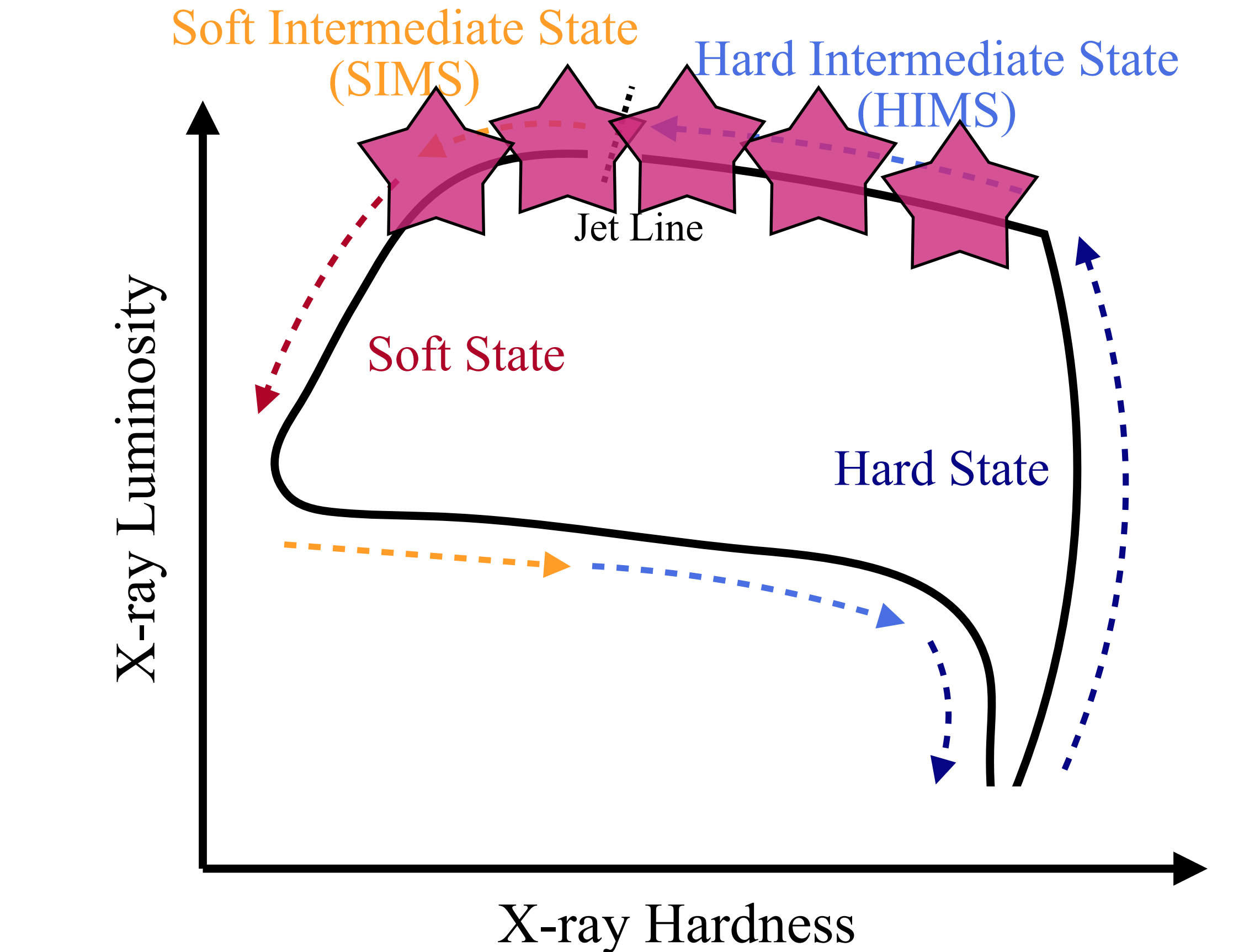
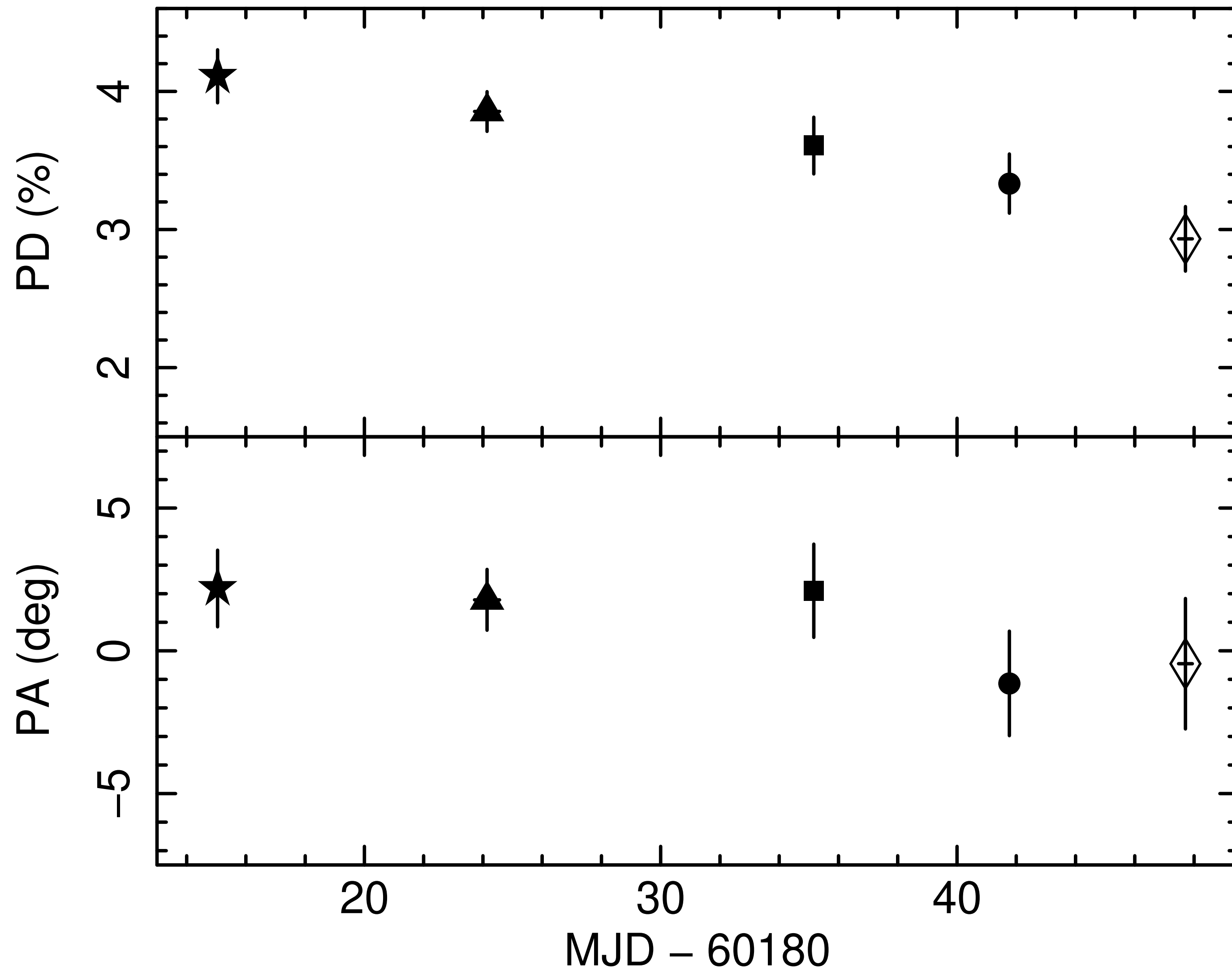
Intermediate state: polarization aligned with the radio jet



Wood+ 2024, Ingram+ 2024

# Swift J1727.8-1613

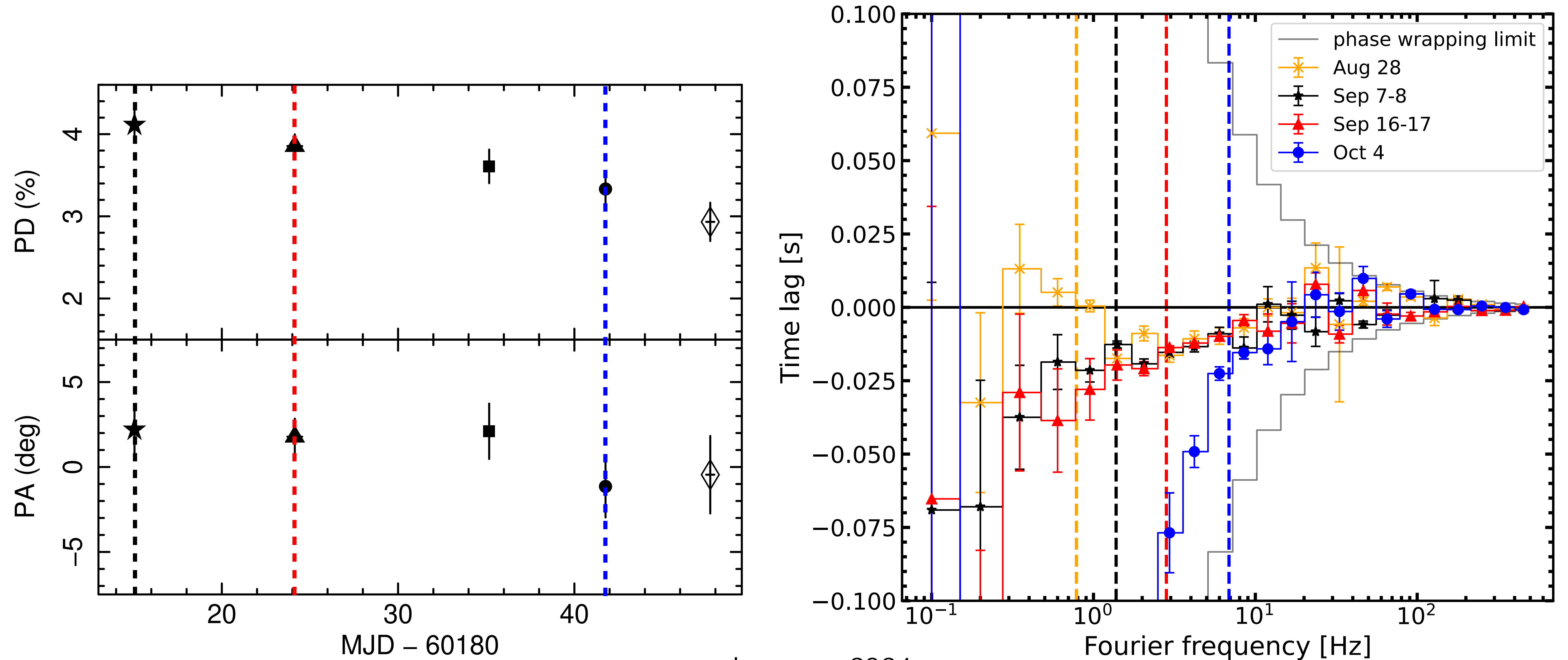
Polarization is almost constant during the outburst



Veledina+ 2023; Ingram+ 2024;  
see also Podgorny+ 2024; Svoboda+2024 for  
polarization in the soft state and the intermediate state

# Swift J1727.8-1613

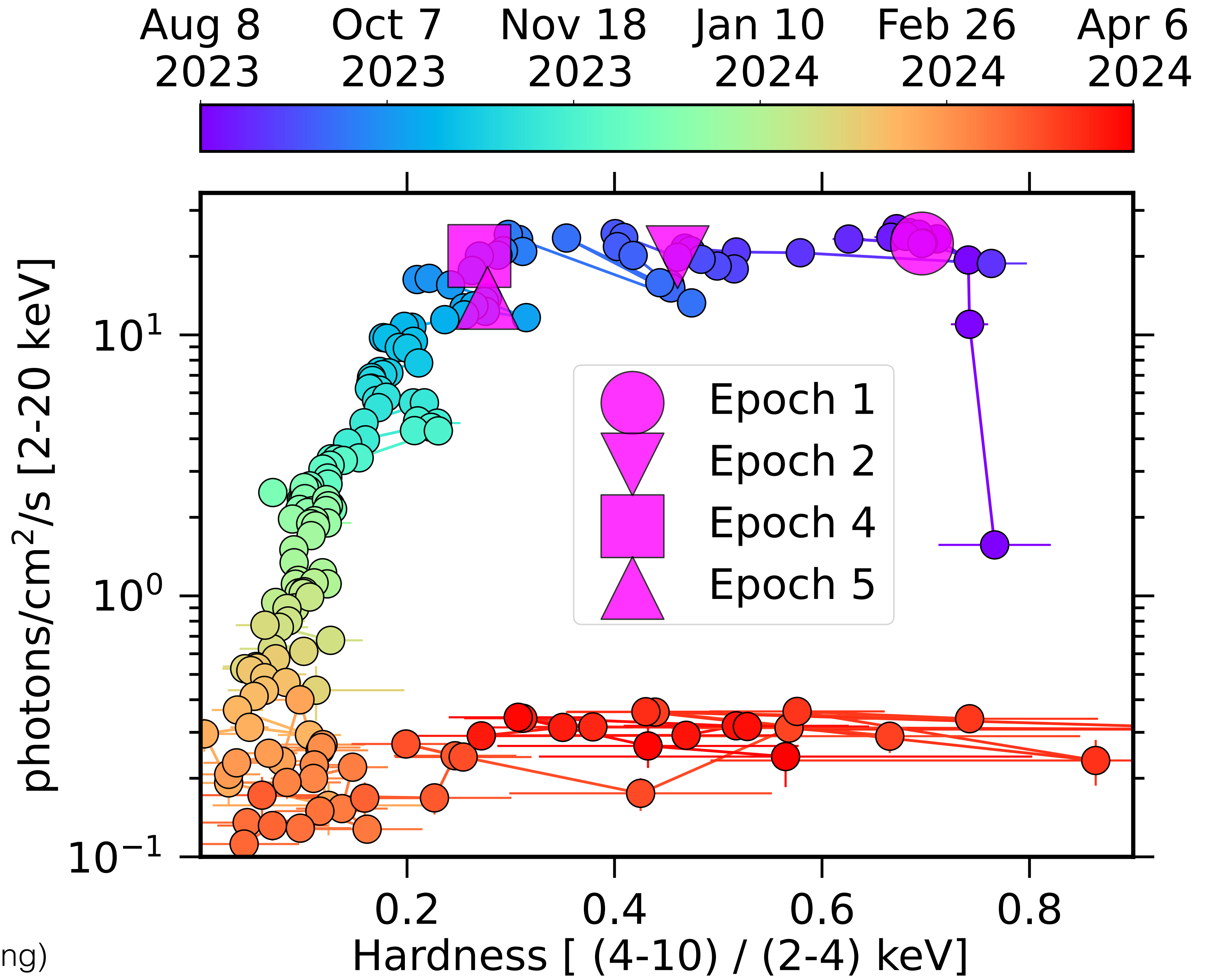
Reverberation lags changes during the outburst



# Swift

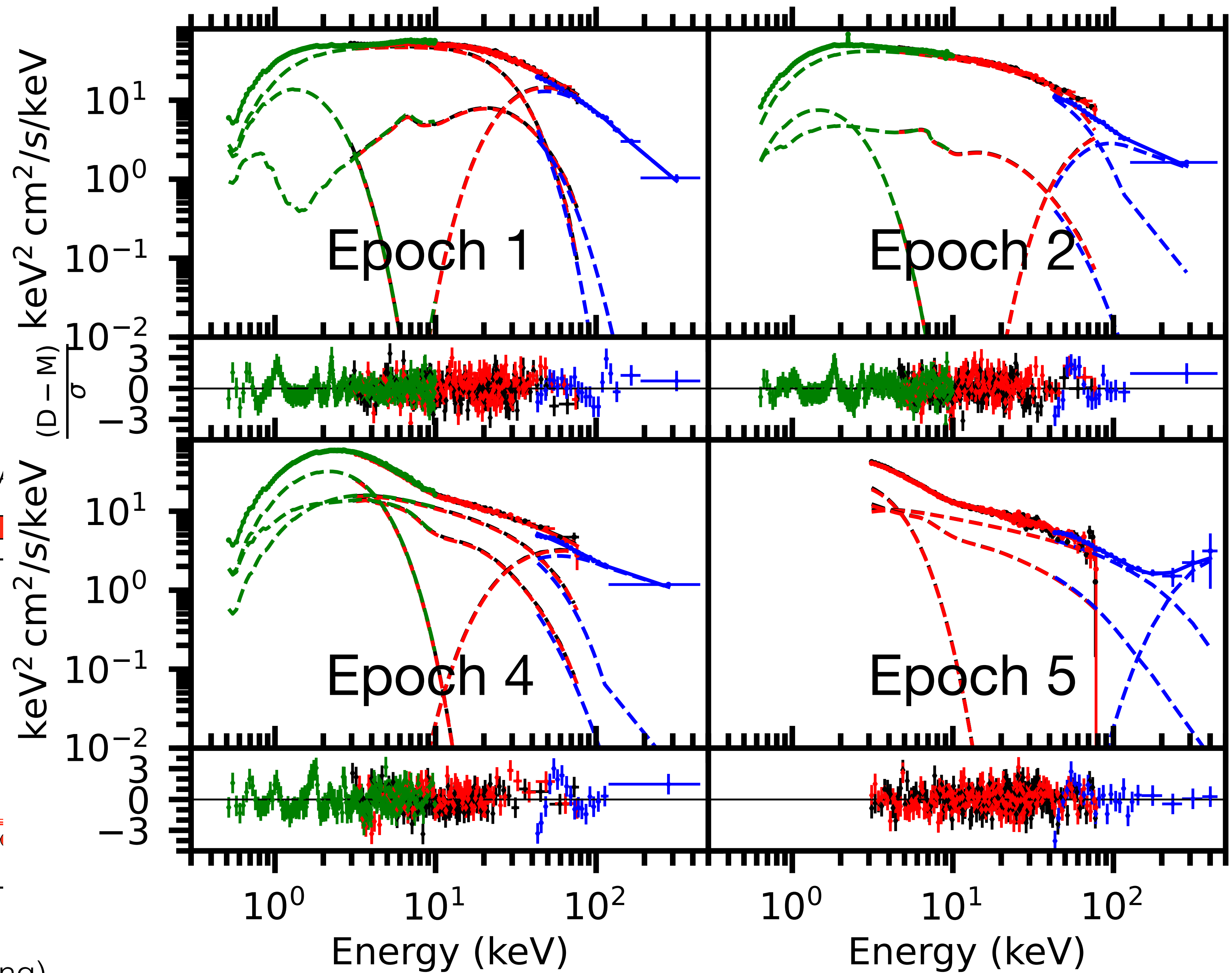
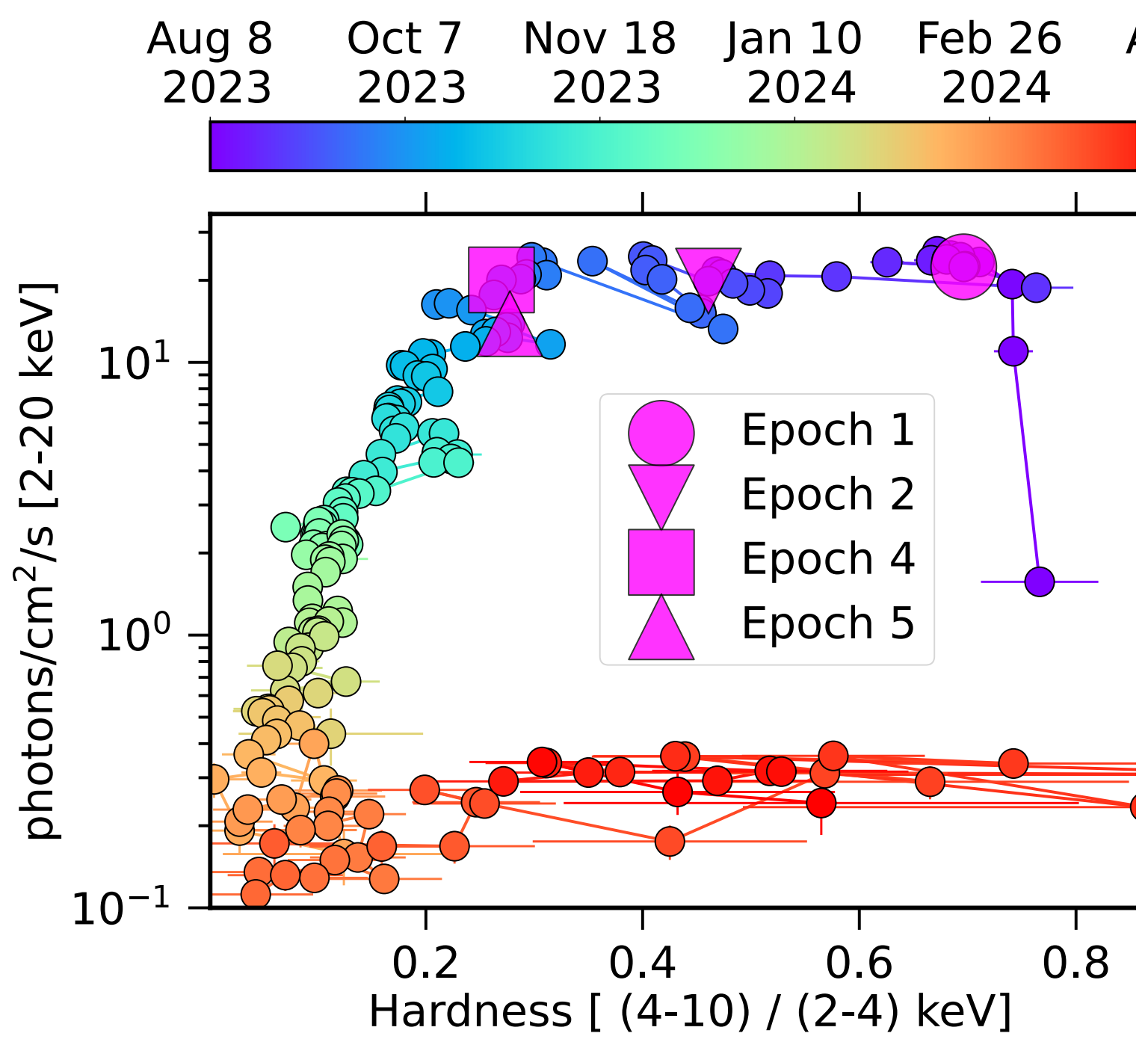
## J1727.8-1613

Spectral analysis  
of 4 epochs during  
the transition



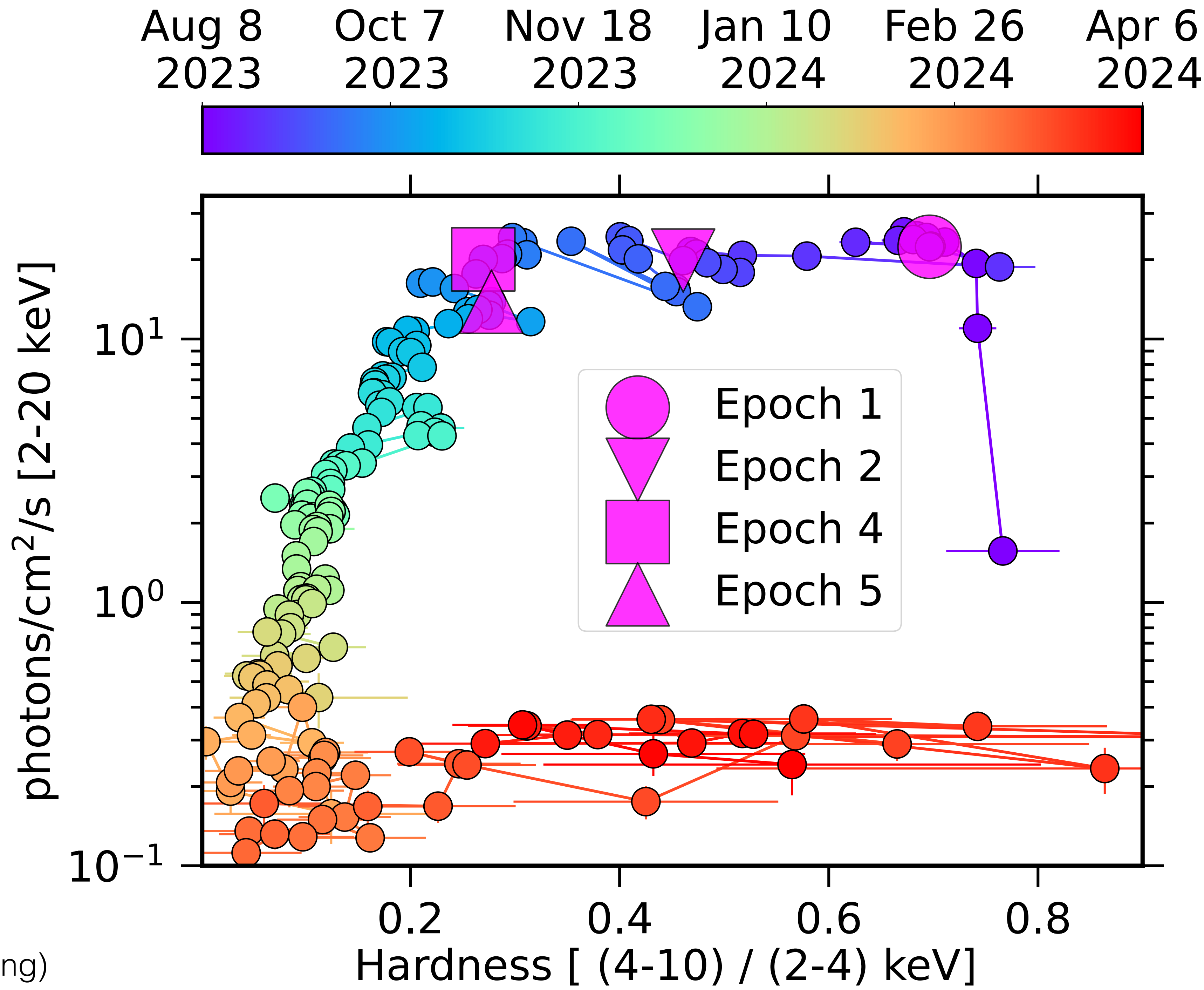
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Spectral analysis  
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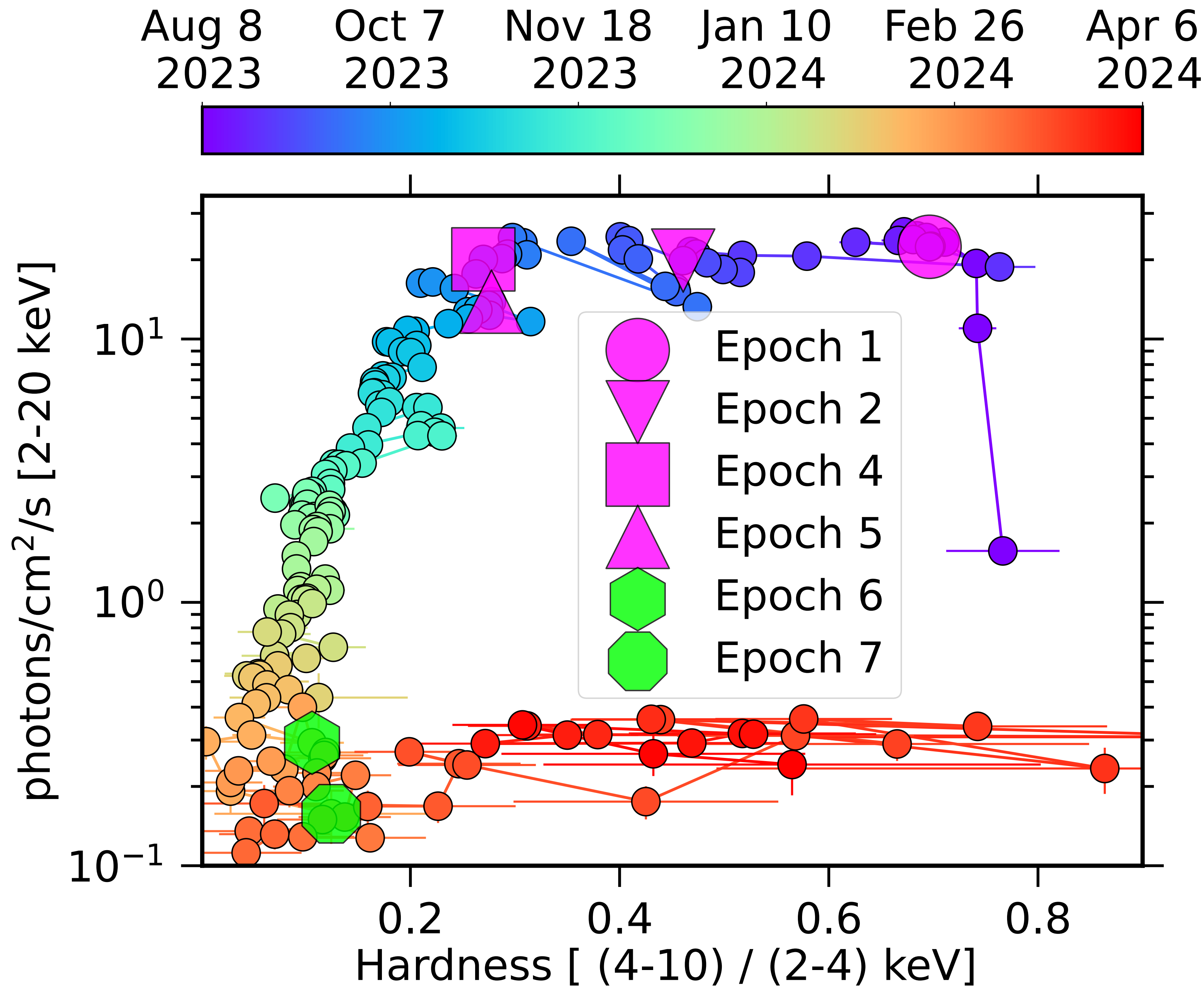
# Swift

## J1727.8-1613



# Swift J1727.8-1613

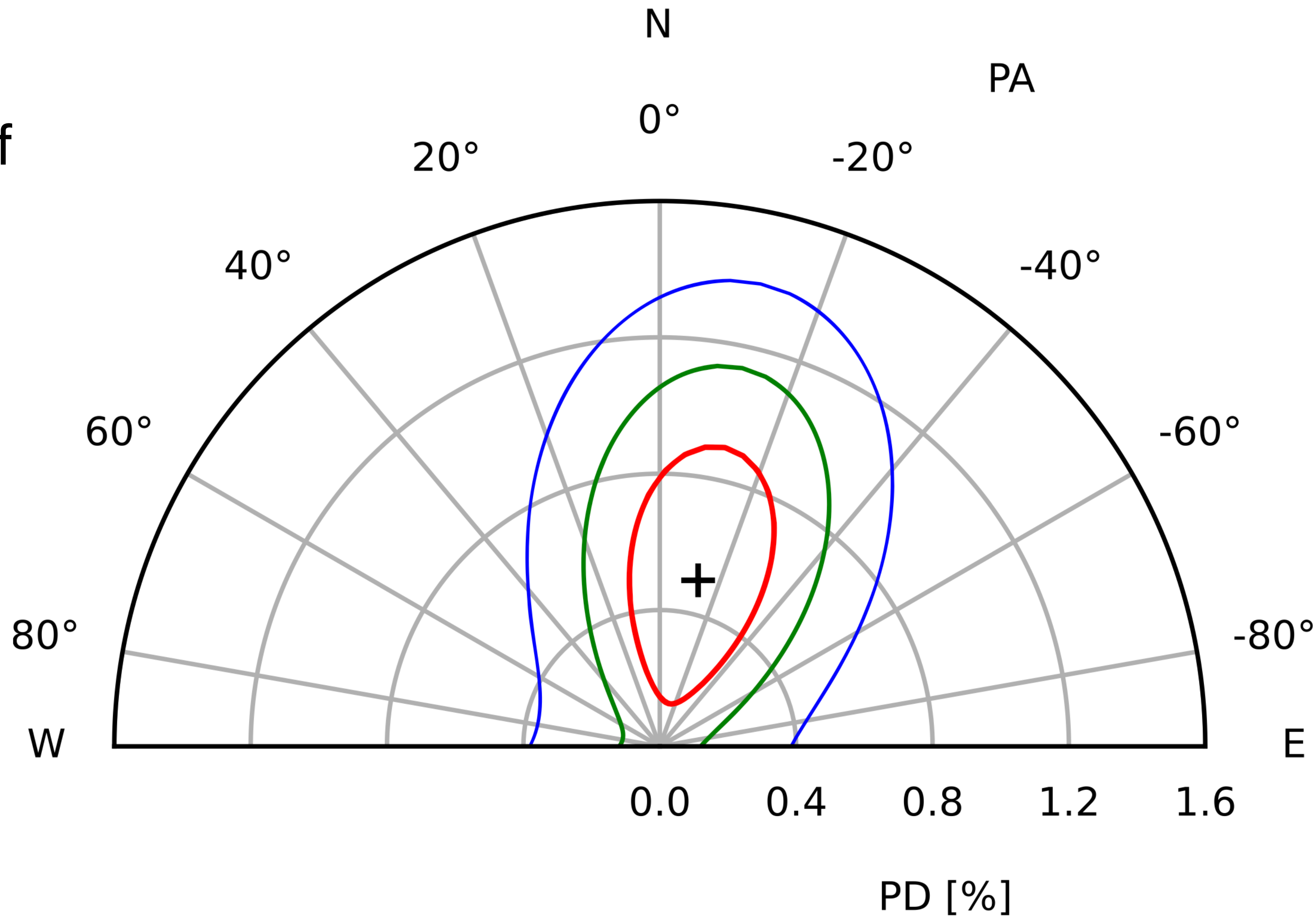
IXPE observed in  
the soft state



# Swift J1727.8-1613

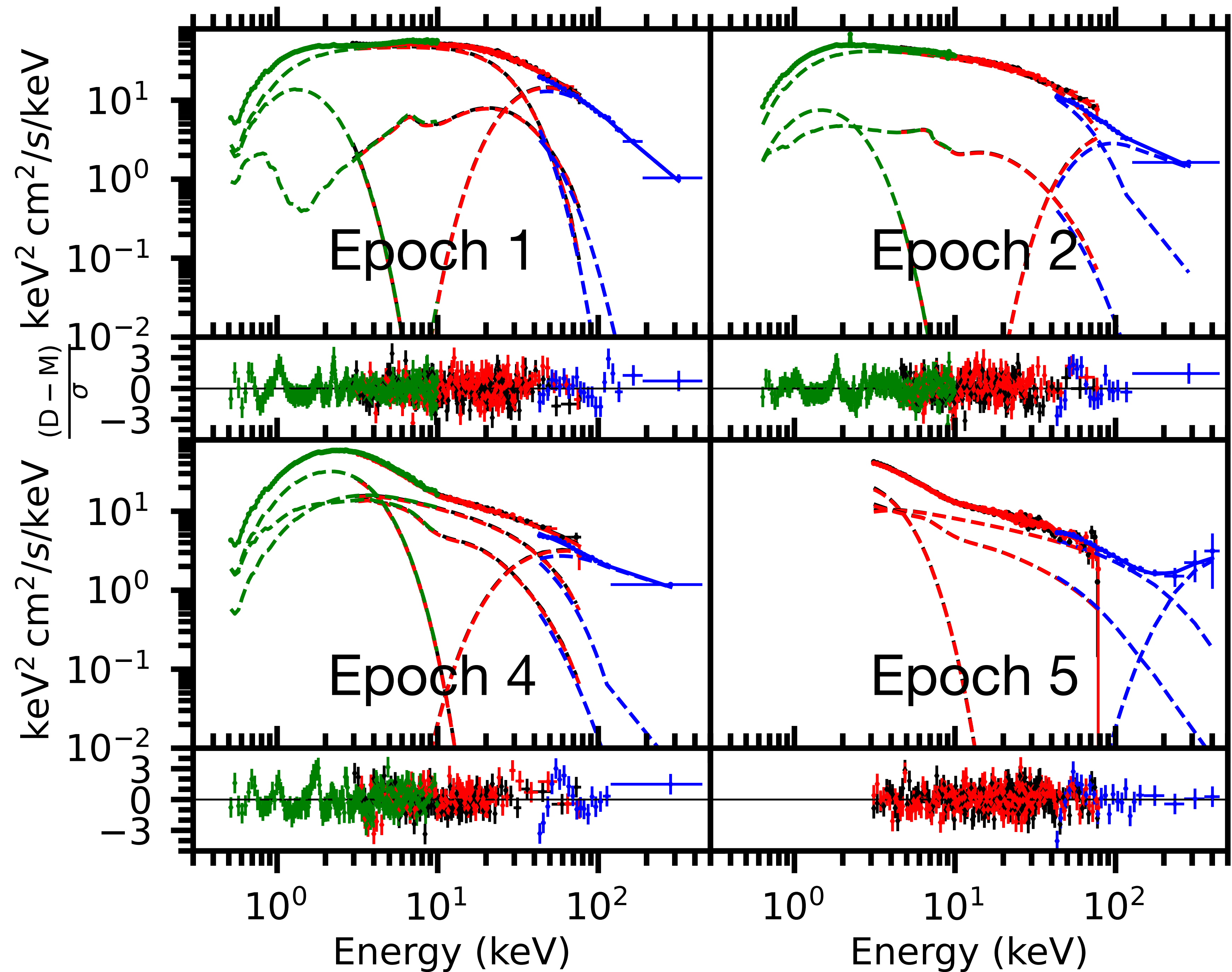
Only upper limit of  
the soft state  
polarization  $< 1\%$

Very high or low  
inclination of the  
system is  
disfavourde

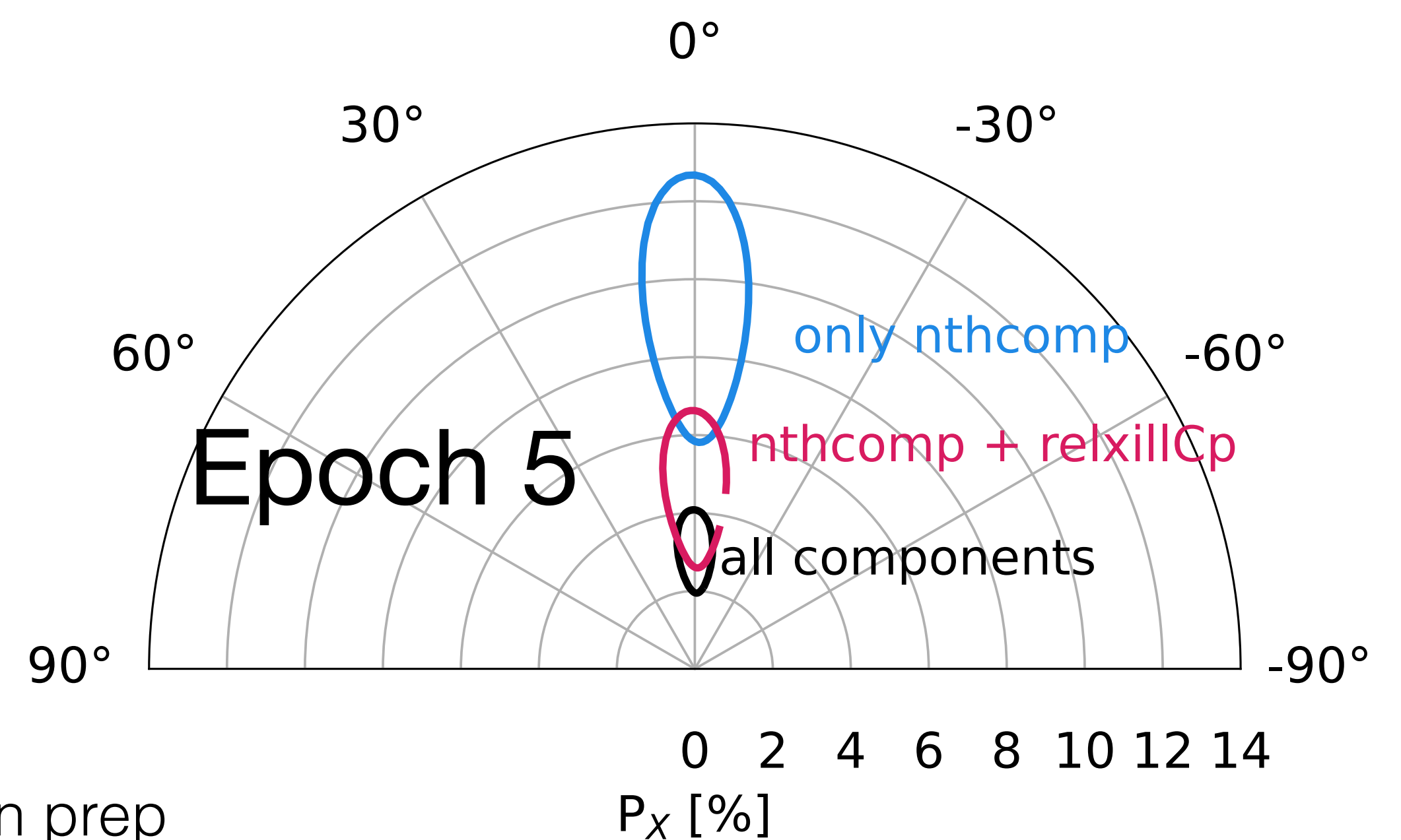
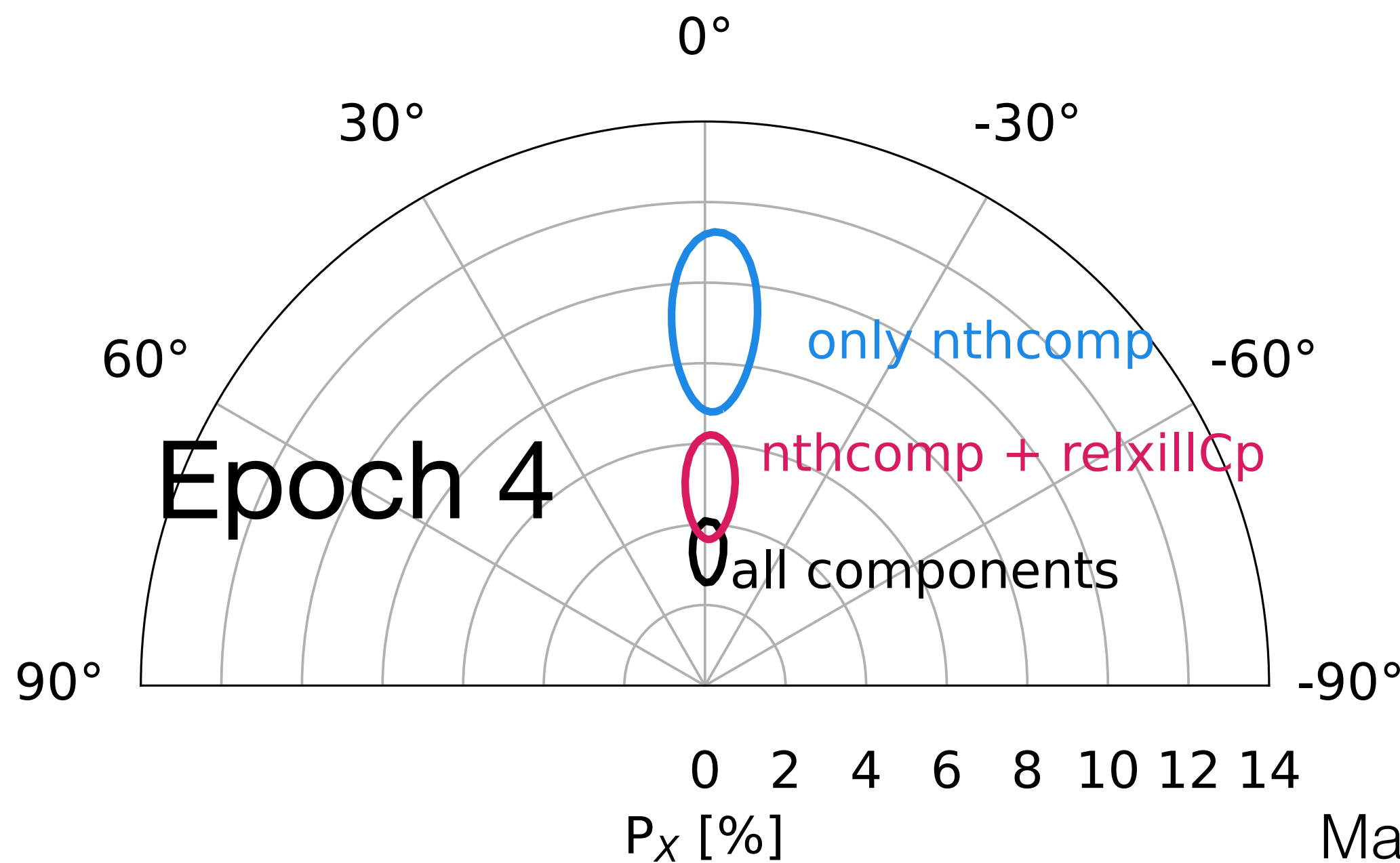
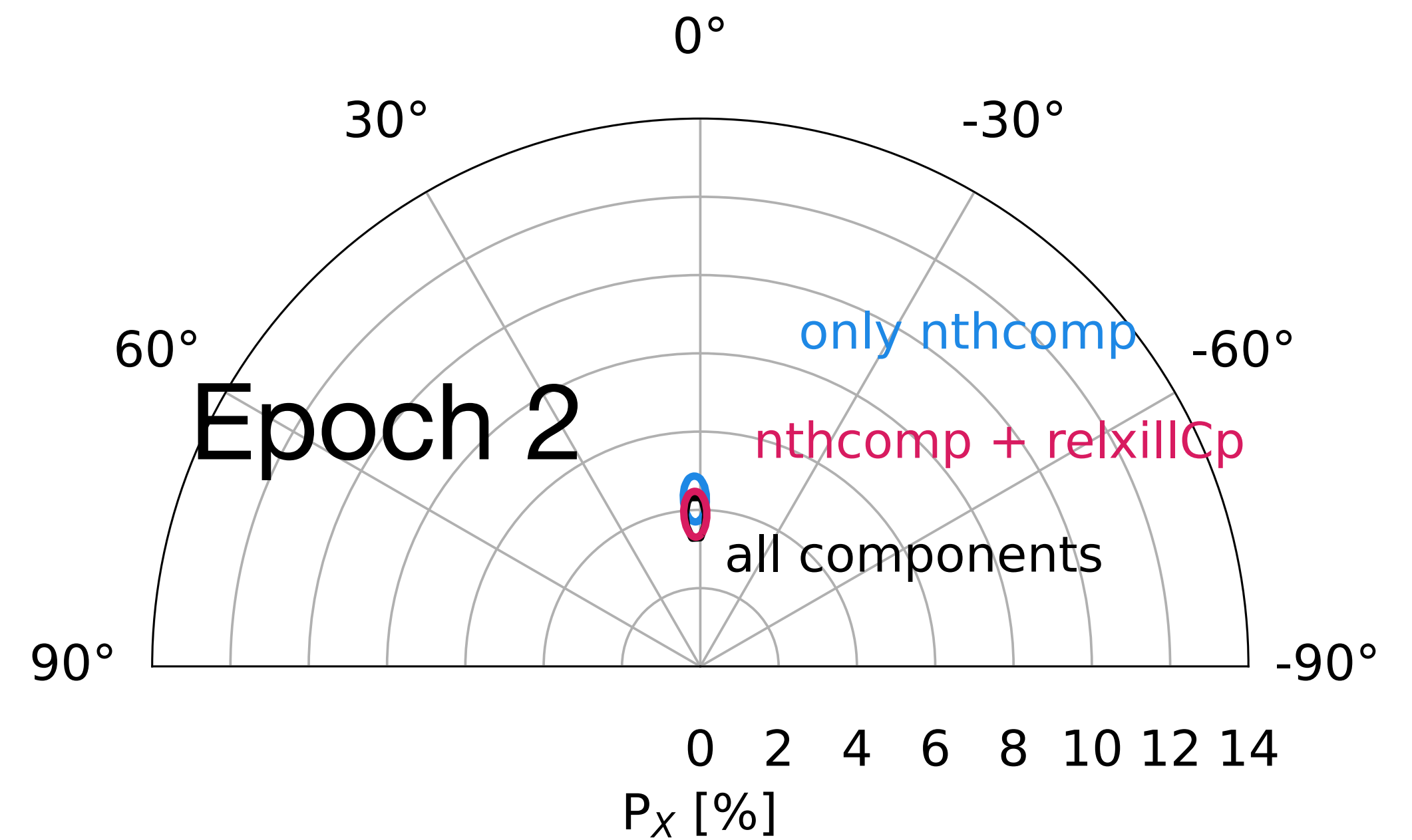
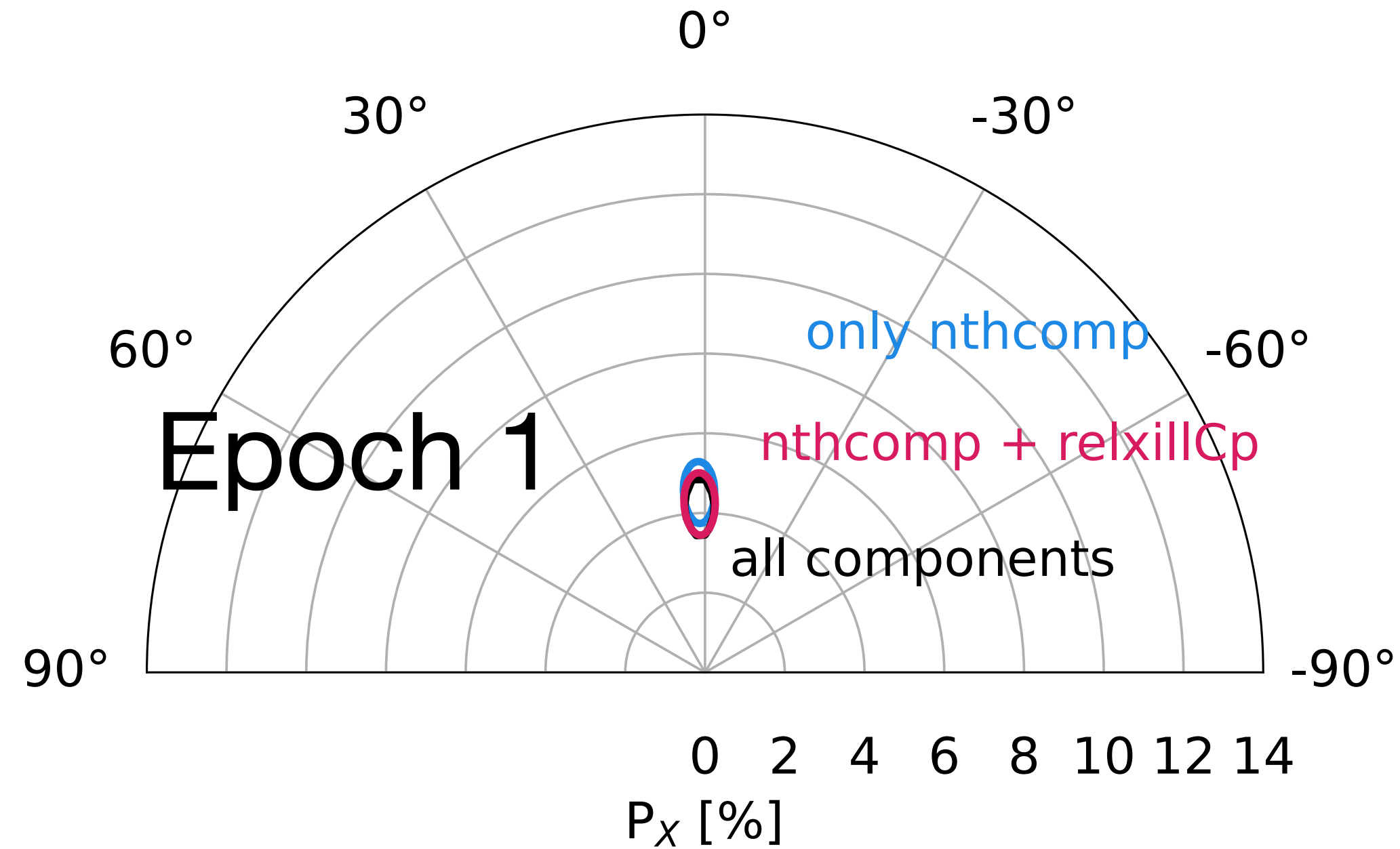


# Swift J1727.8-1613

Spectro-  
polarimetric fit of  
the 4 epochs

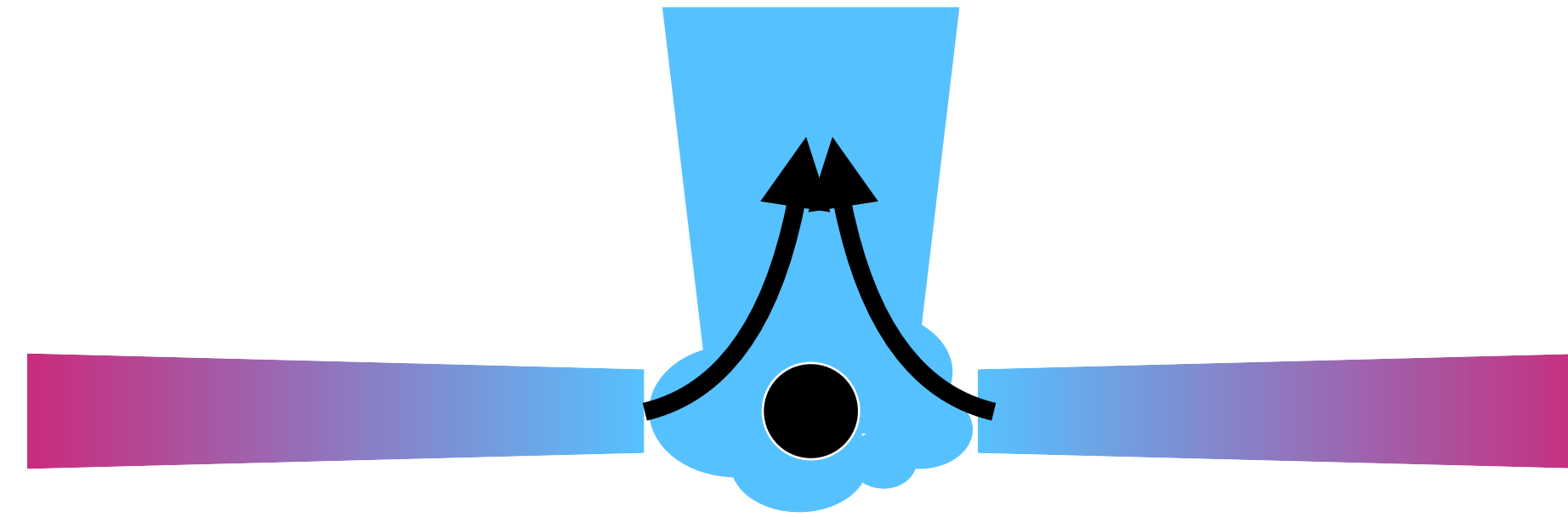


# Polarization by components



# Conclusions

The evolution of X-ray reverberation lag can be explained by an outflowing corona in the intermediate state



X-ray polarization detections point towards horizontally extended corona during the intermediate state

