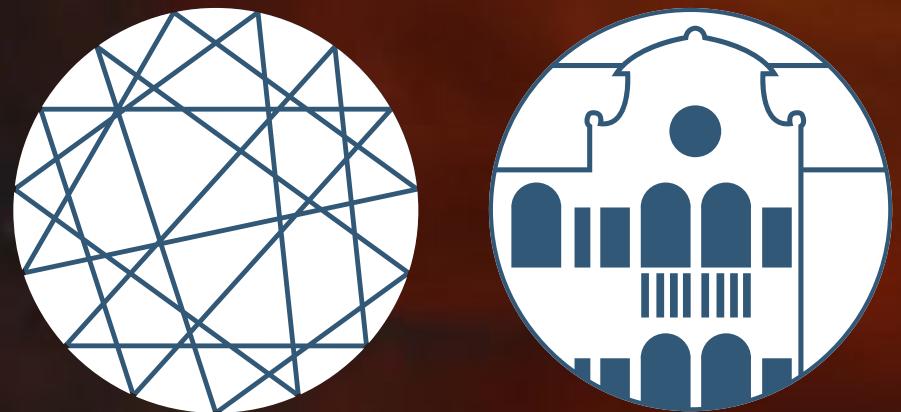


# Inconsistencies among different types of analyses

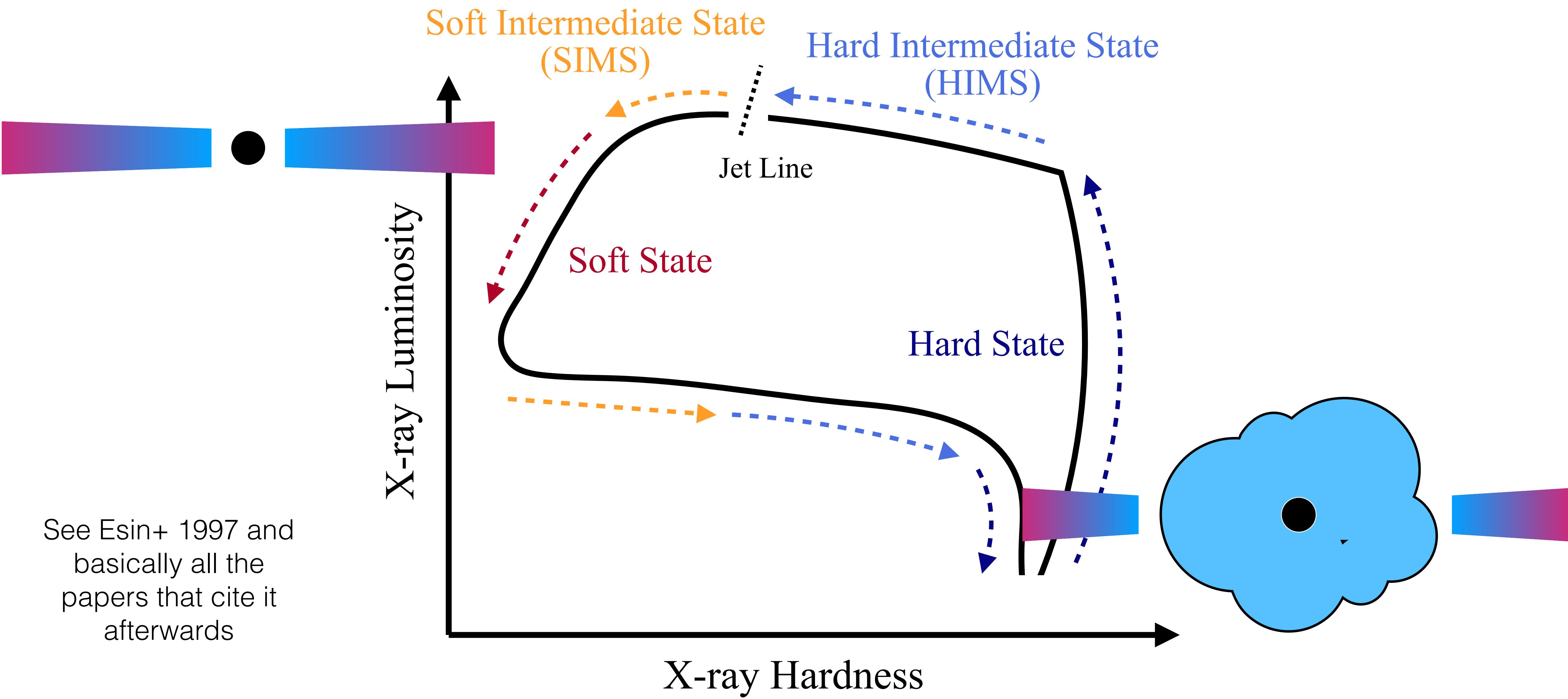


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Scuola Universitaria Superiore Pavia

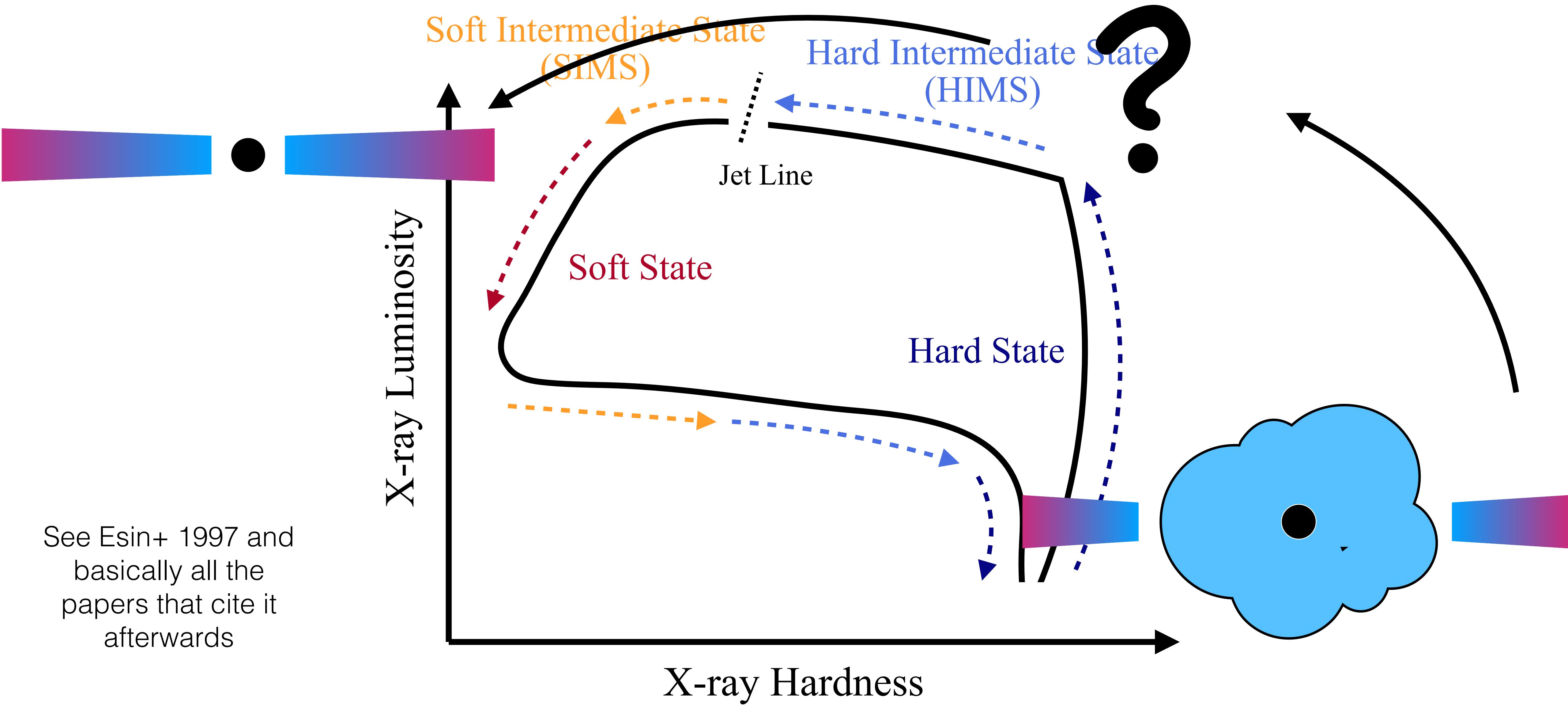
Guglielmo Mastroserio

# Evolution during the outburst on the HID



# Evolution during the outburst on the HID

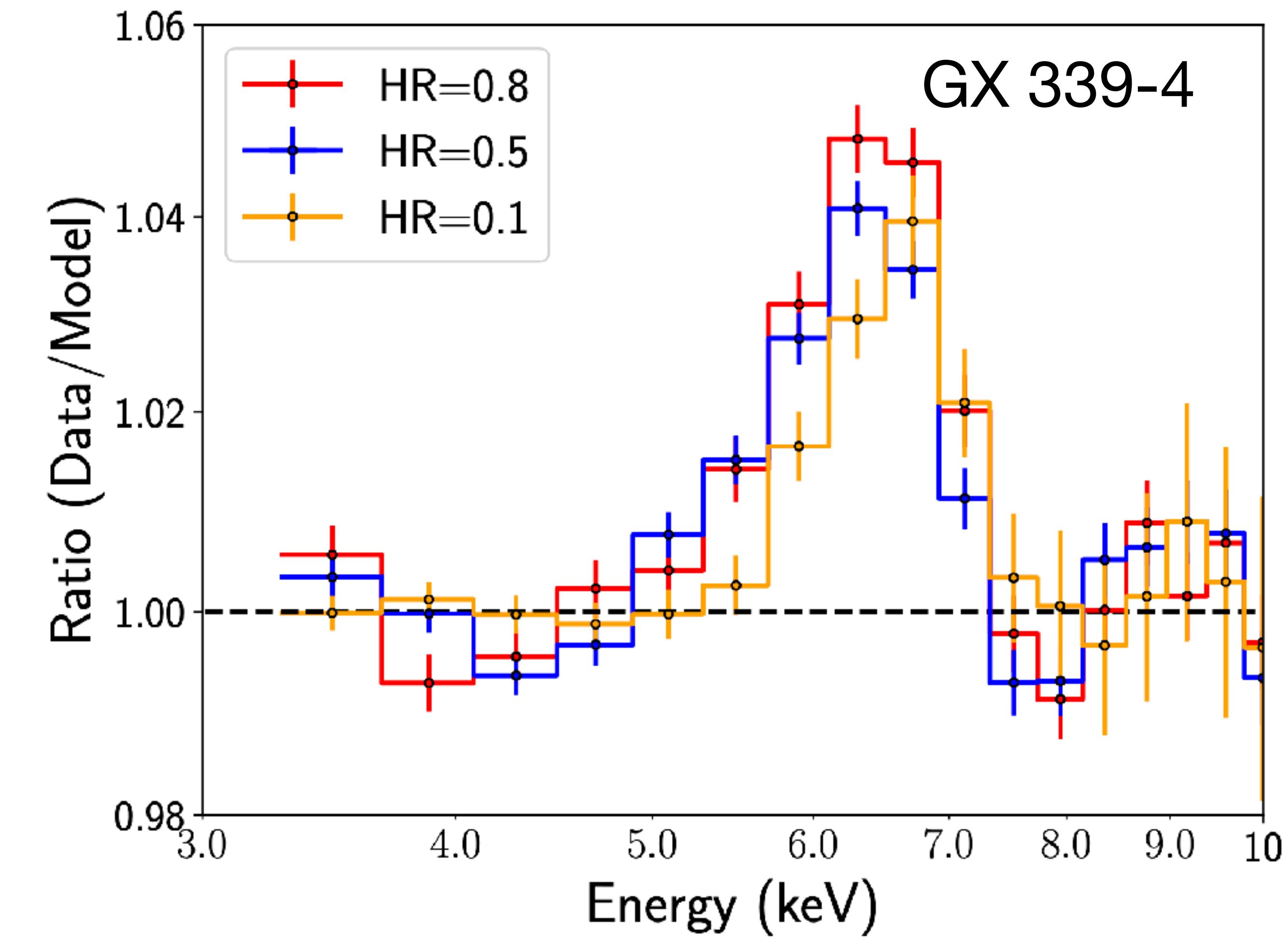
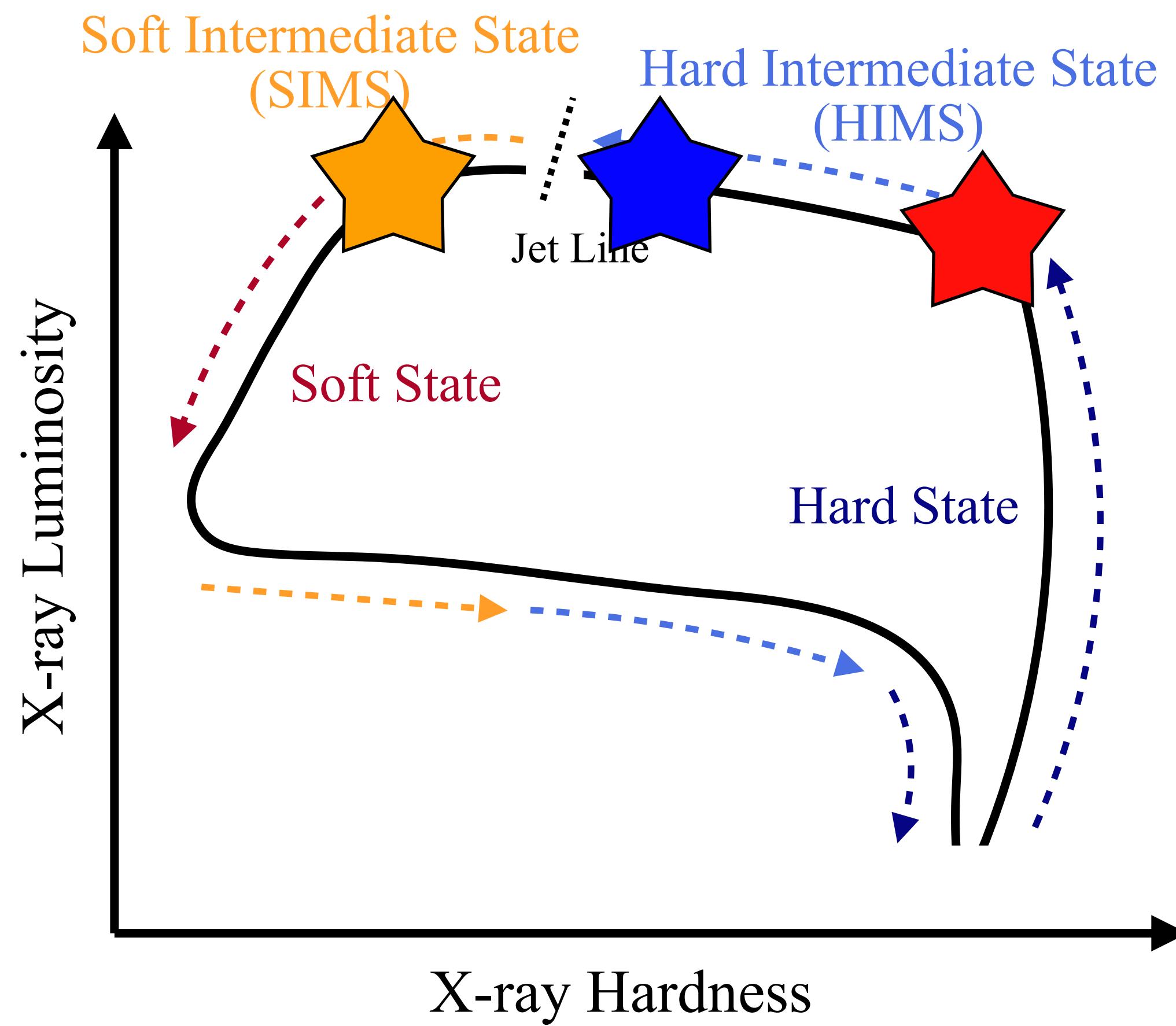
What happens during the transition?



# Energy spectrum features: Iron K $\alpha$ line

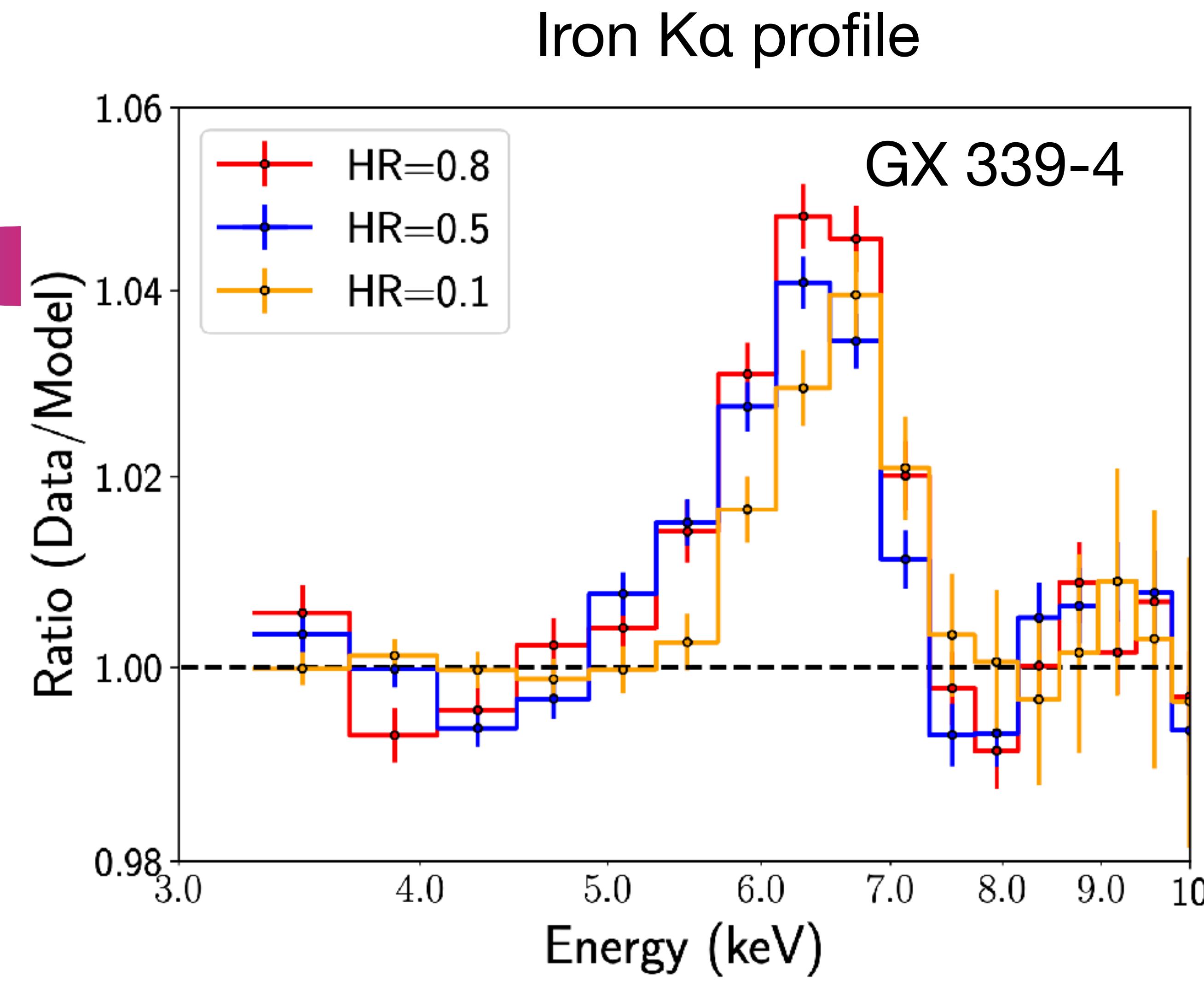
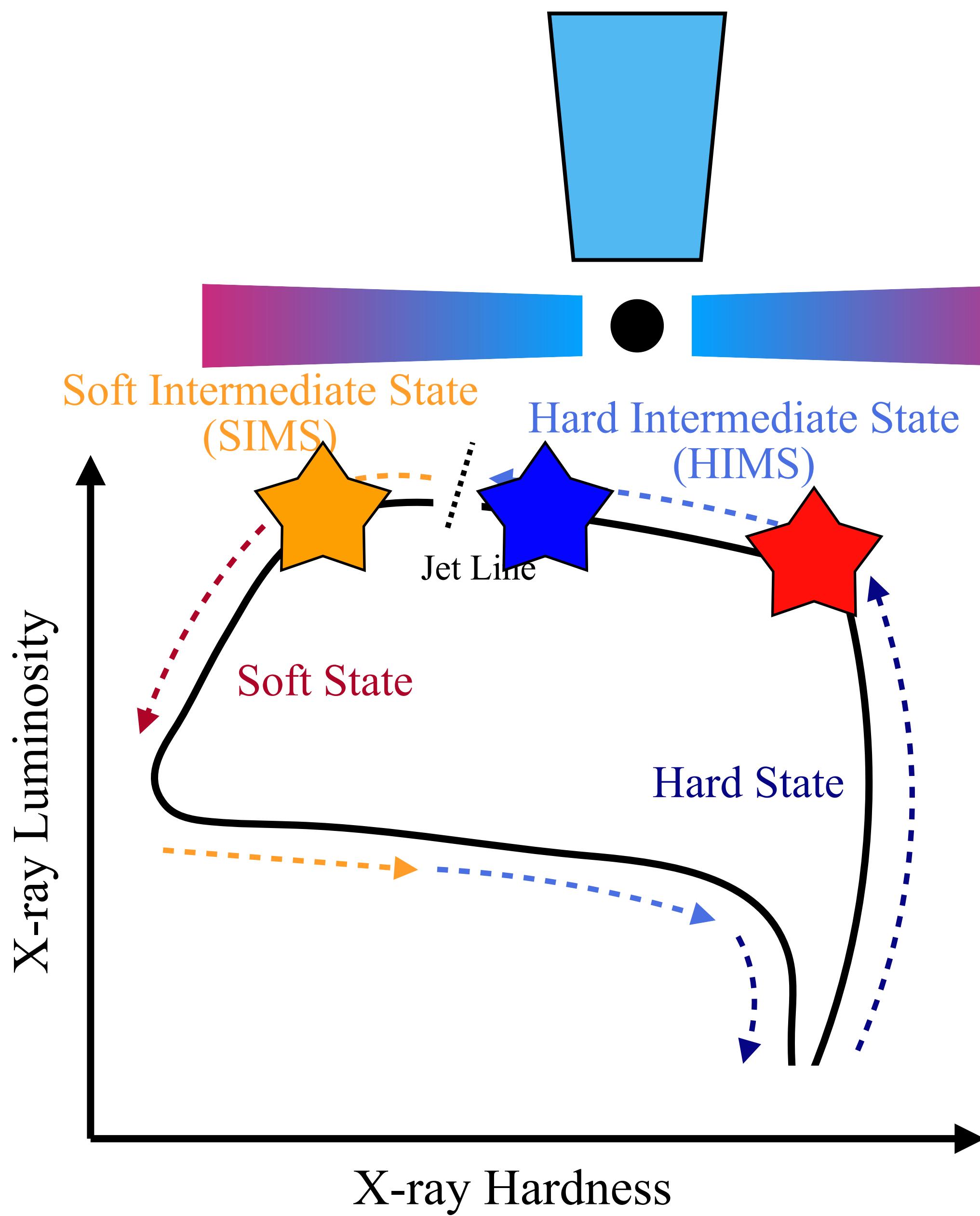
# Observables — Energy spectrum

Iron Ka profile

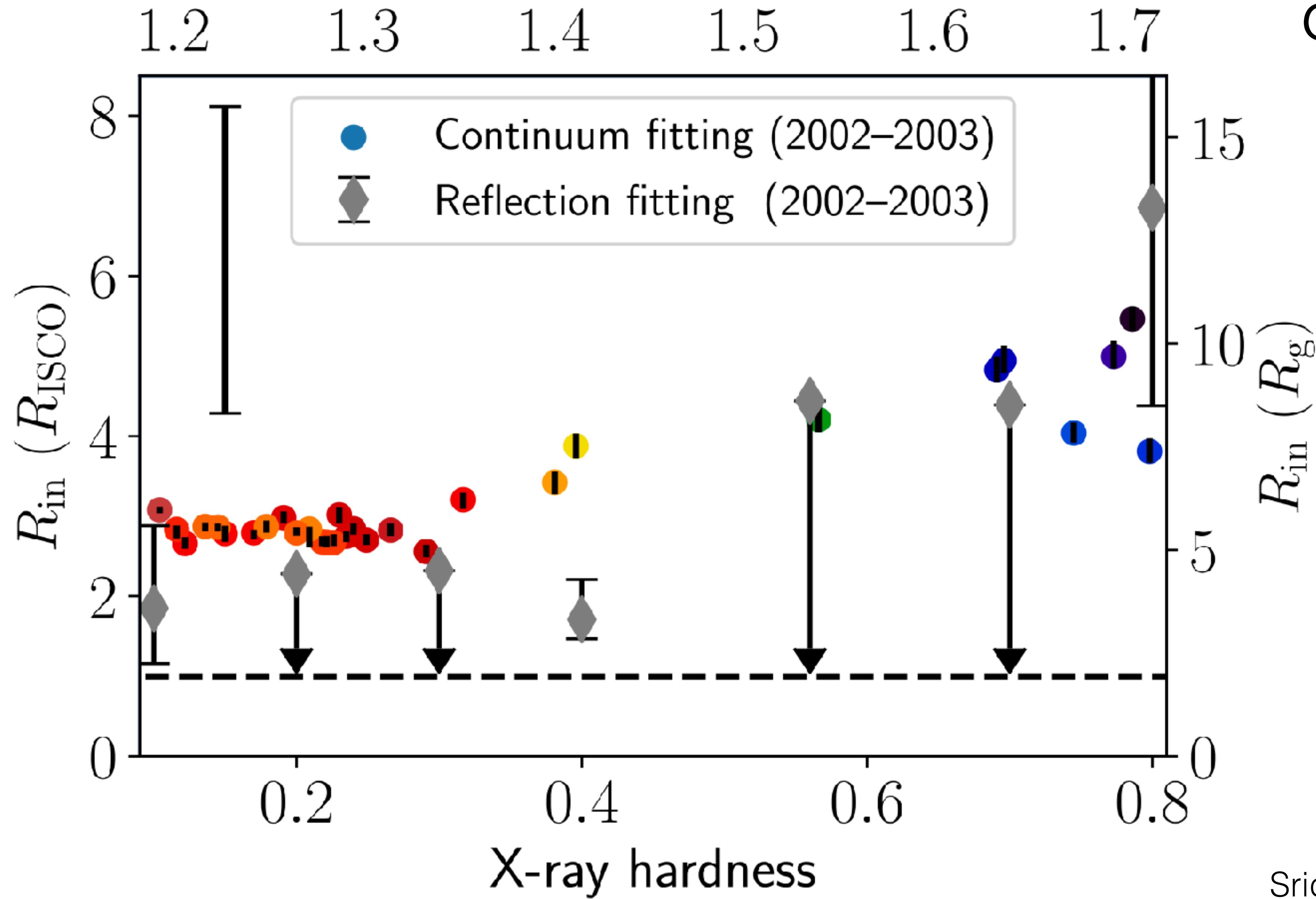


Sridhar+ 2020, and also Garcia+ 2015, 2016; Miller 2007;  
Ross+2007; McClintock+2011; Kulkarni+2011; Gou+ 2011

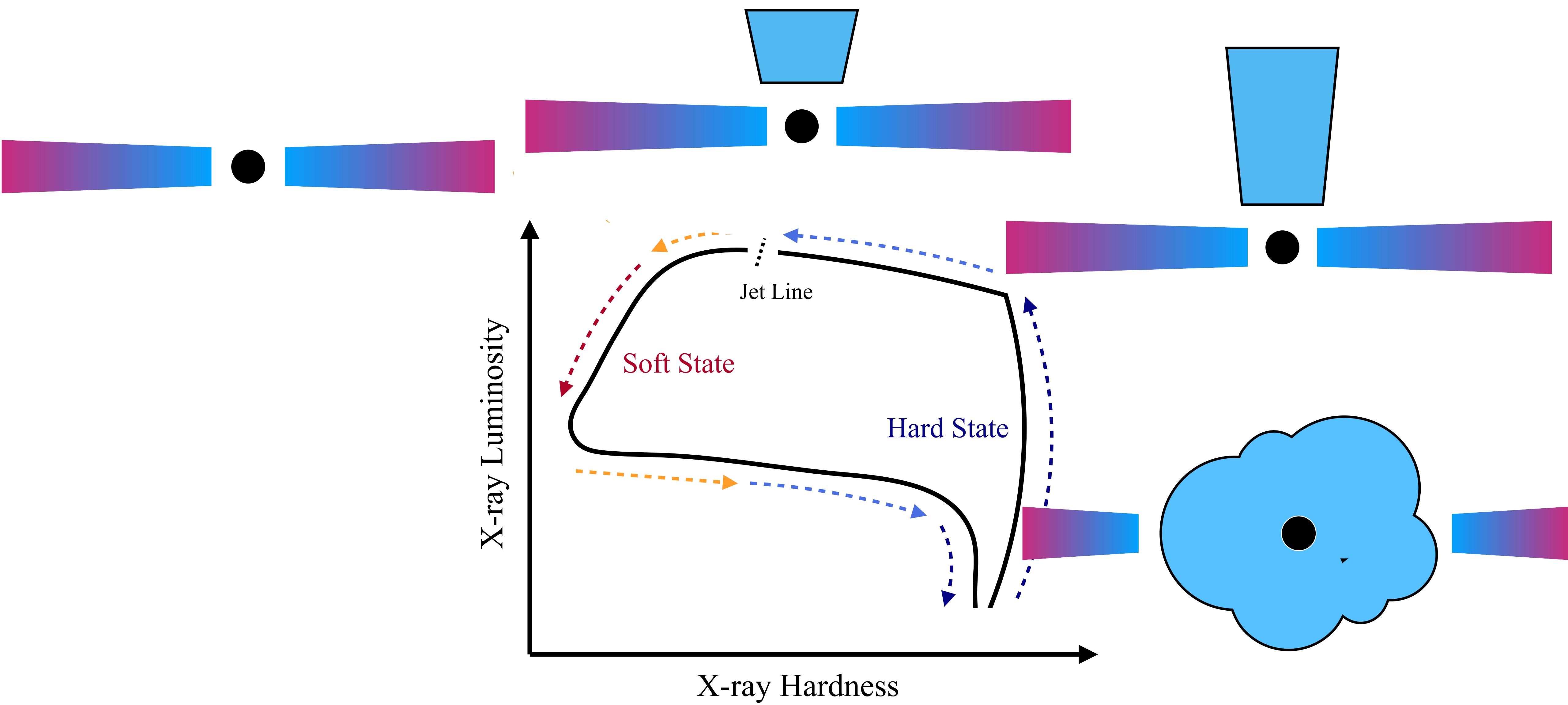
# Observables — Energy spectrum



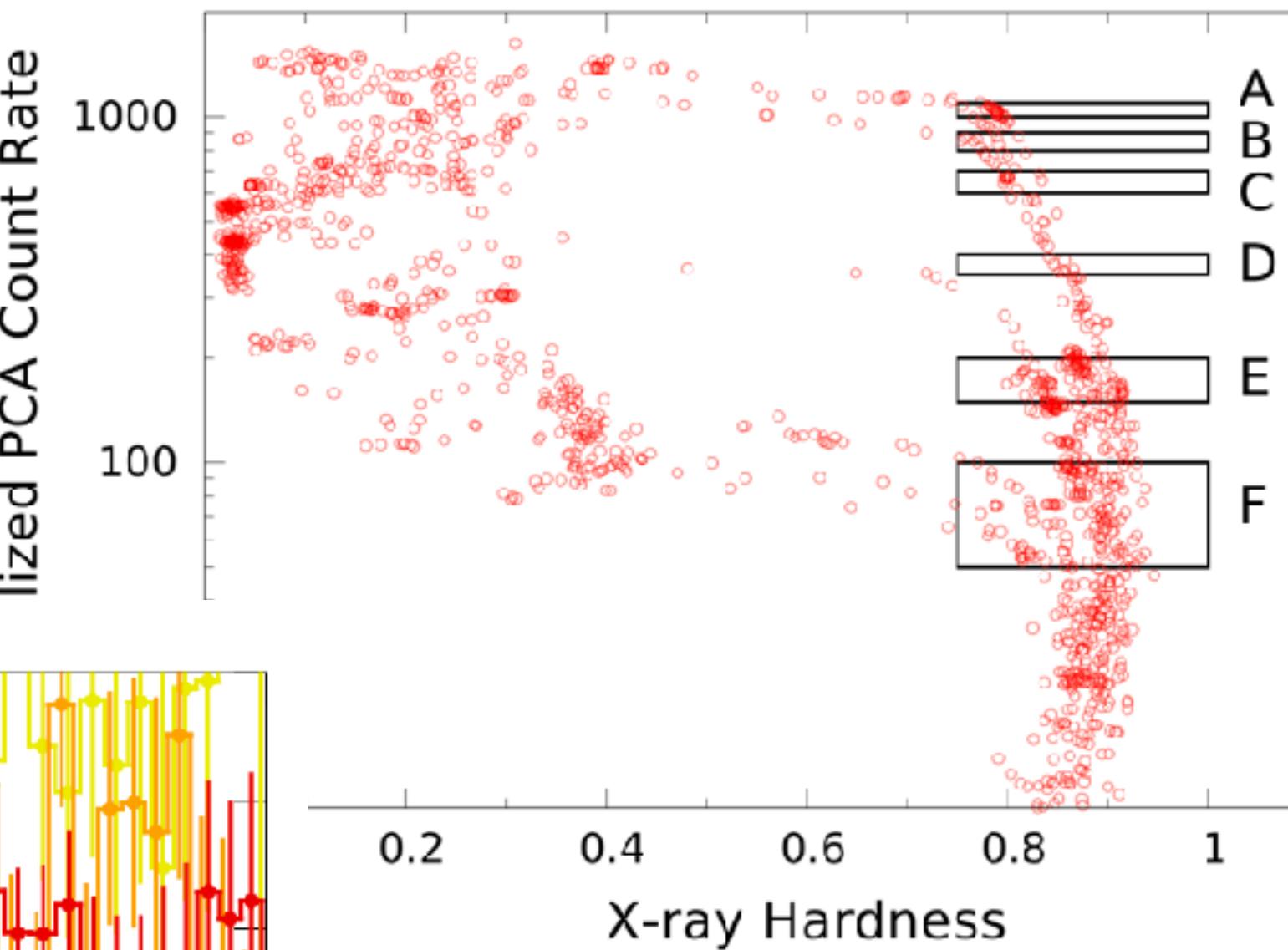
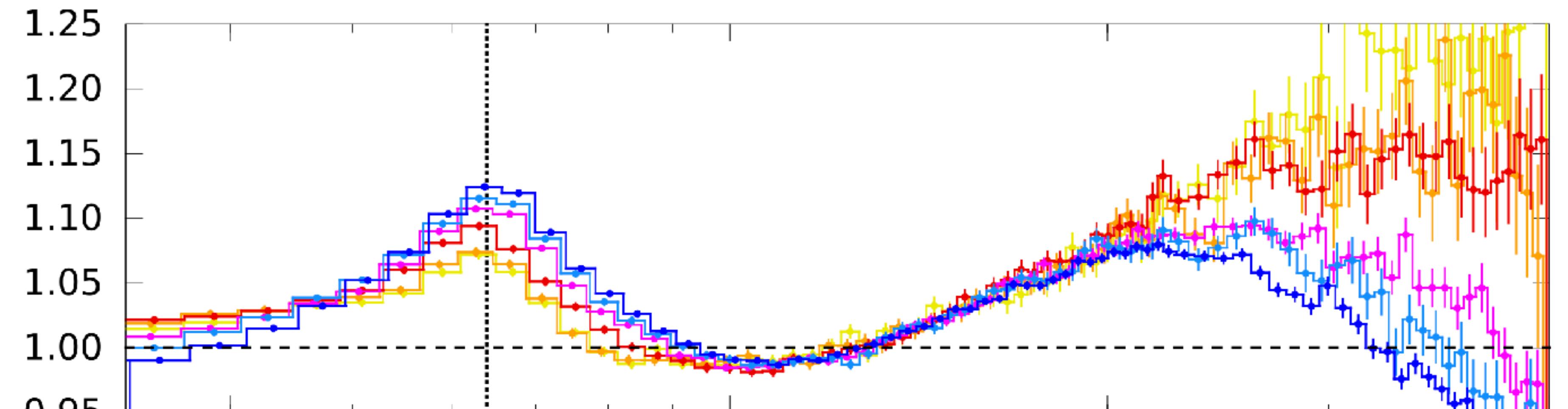
Sridhar+ 2020, and also Garcia+ 2015, 2016; Miller 2007;  
Ross+2007; McClintock+2011; Kulkarni+2011; Gou+ 2011

$f_{col}$ 

# Evolution during the outburst



Data/Model Ratio



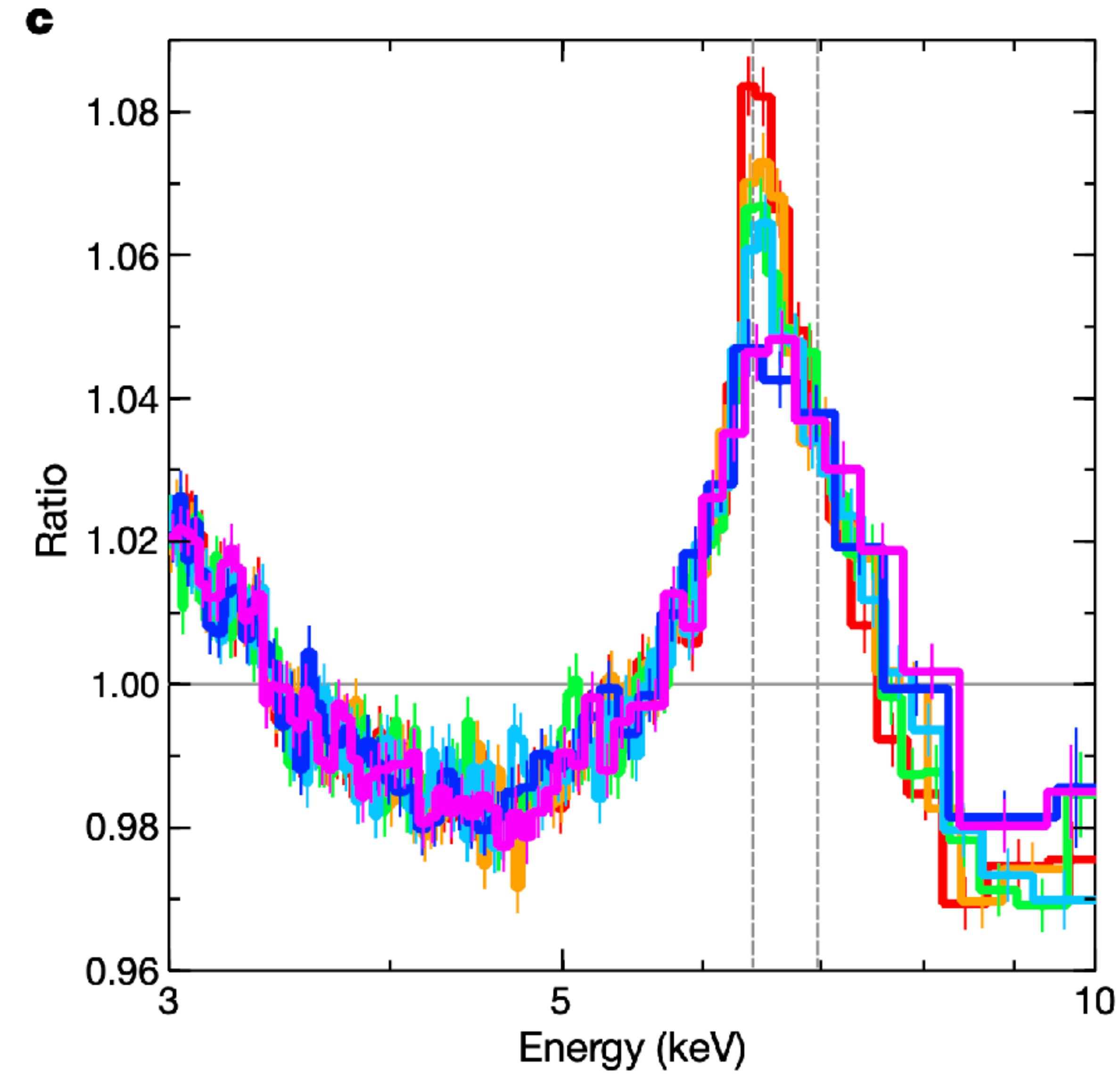
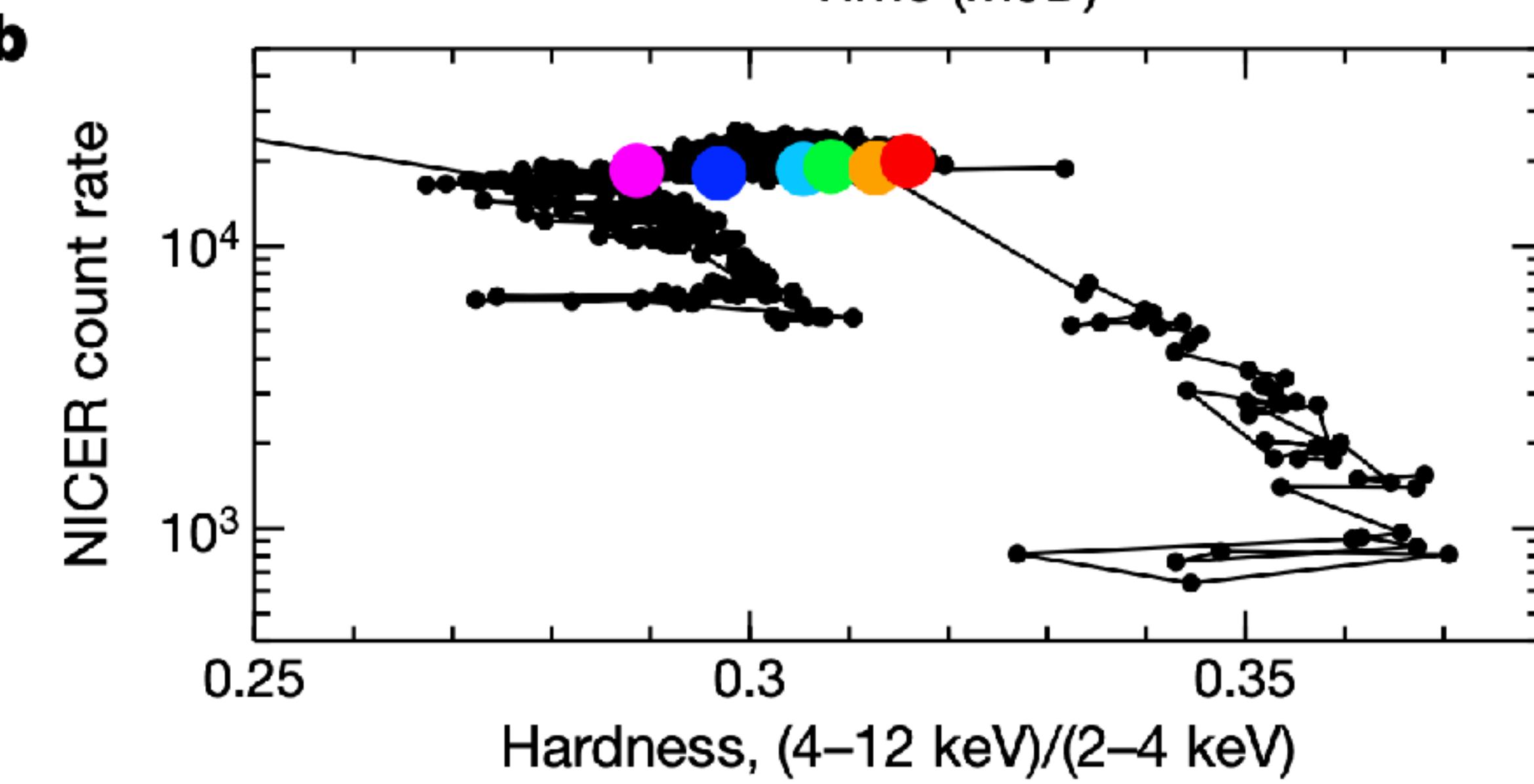
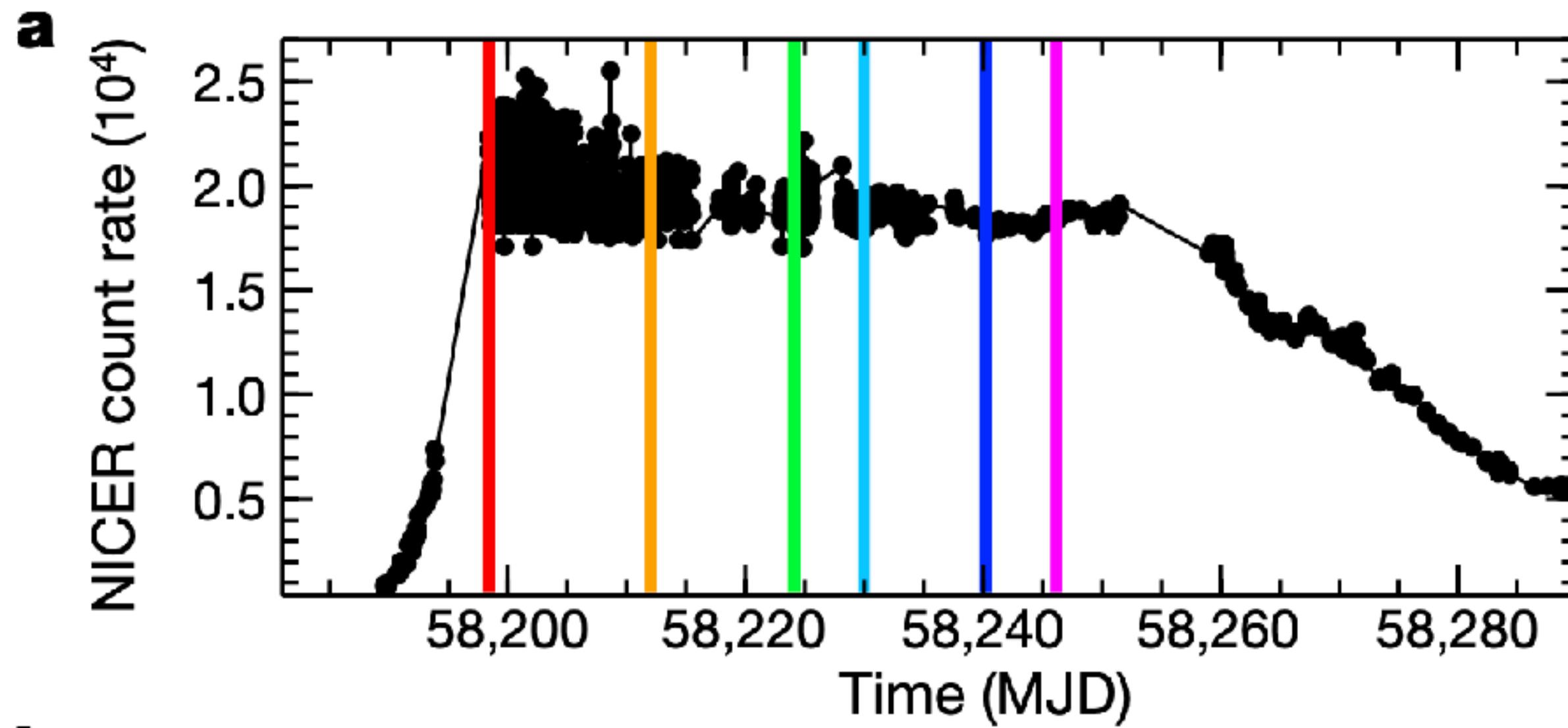
Garcia+2015

Spec A (17.3%  $L_{\text{Edd}}$ )  
Spec B (14.2%  $L_{\text{Edd}}$ )  
Spec C (11.9%  $L_{\text{Edd}}$ )  
Spec D (7.9%  $L_{\text{Edd}}$ )  
Spec E (3.9%  $L_{\text{Edd}}$ )  
Spec F (1.6%  $L_{\text{Edd}}$ )

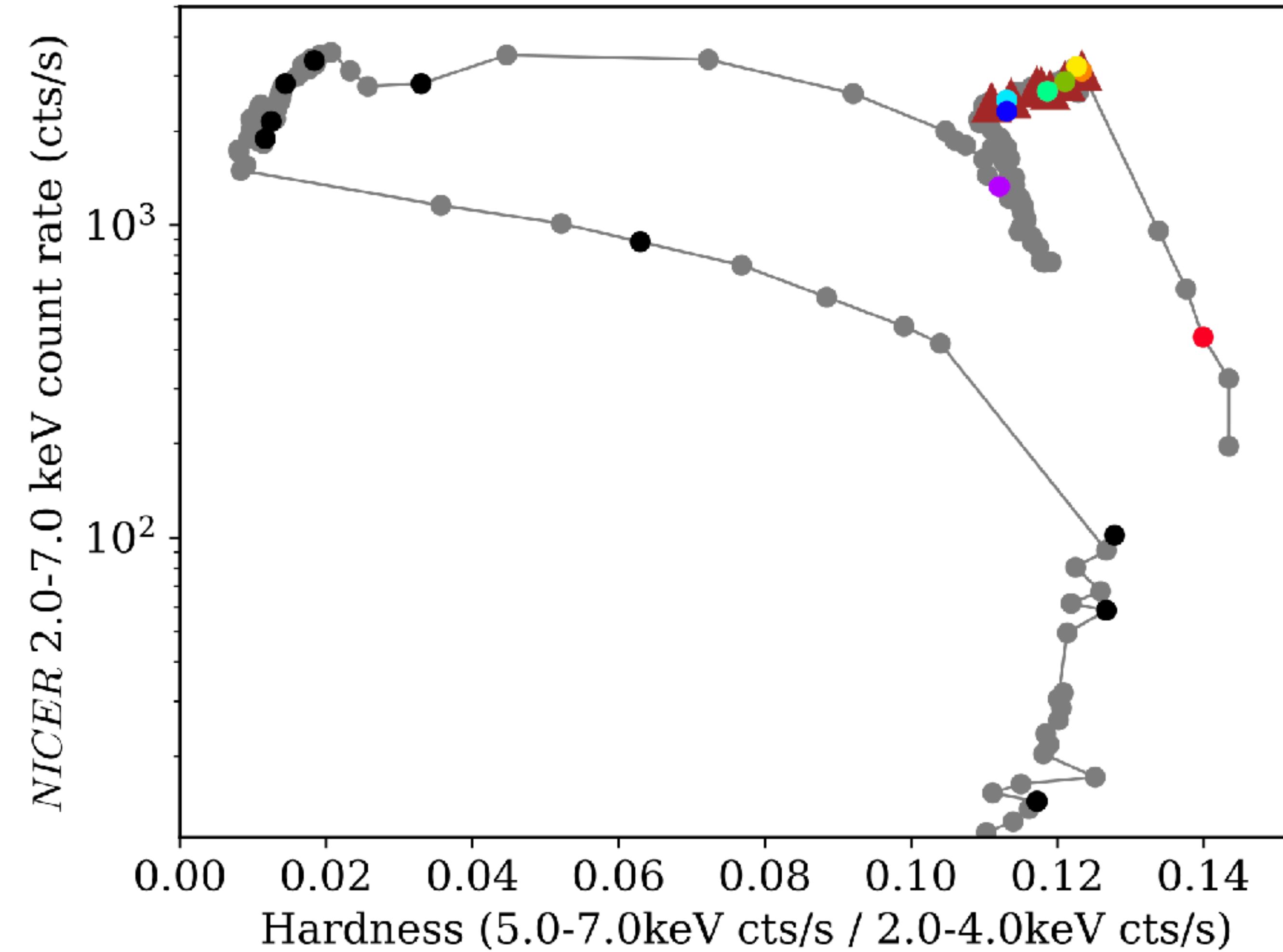
Energy spectrum feature:  
Iron K $\alpha$  line

**CAVEATS**

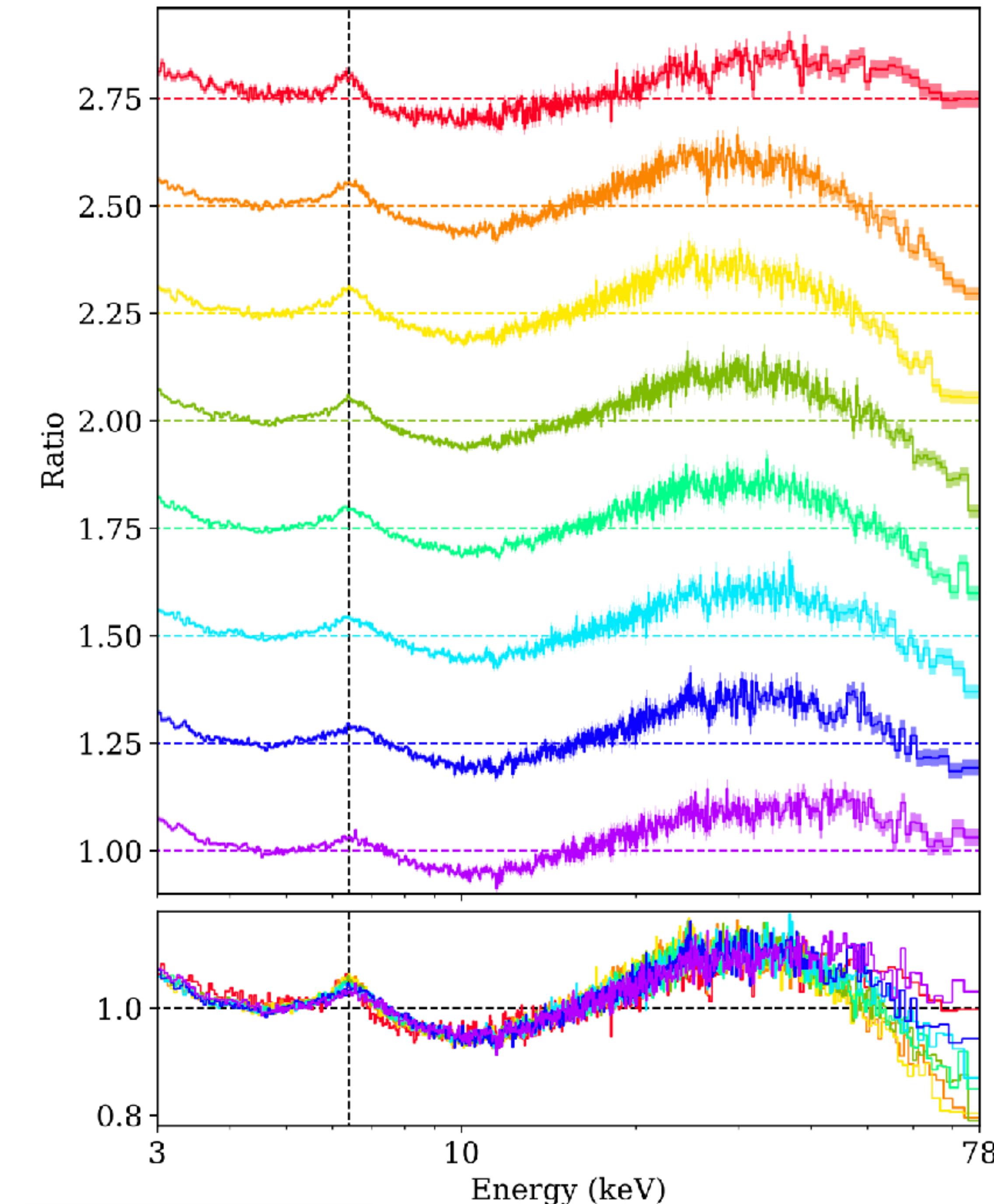
# Iron line in MAXI J1820+070



# Reflection spectrum in MAXI J1820+070

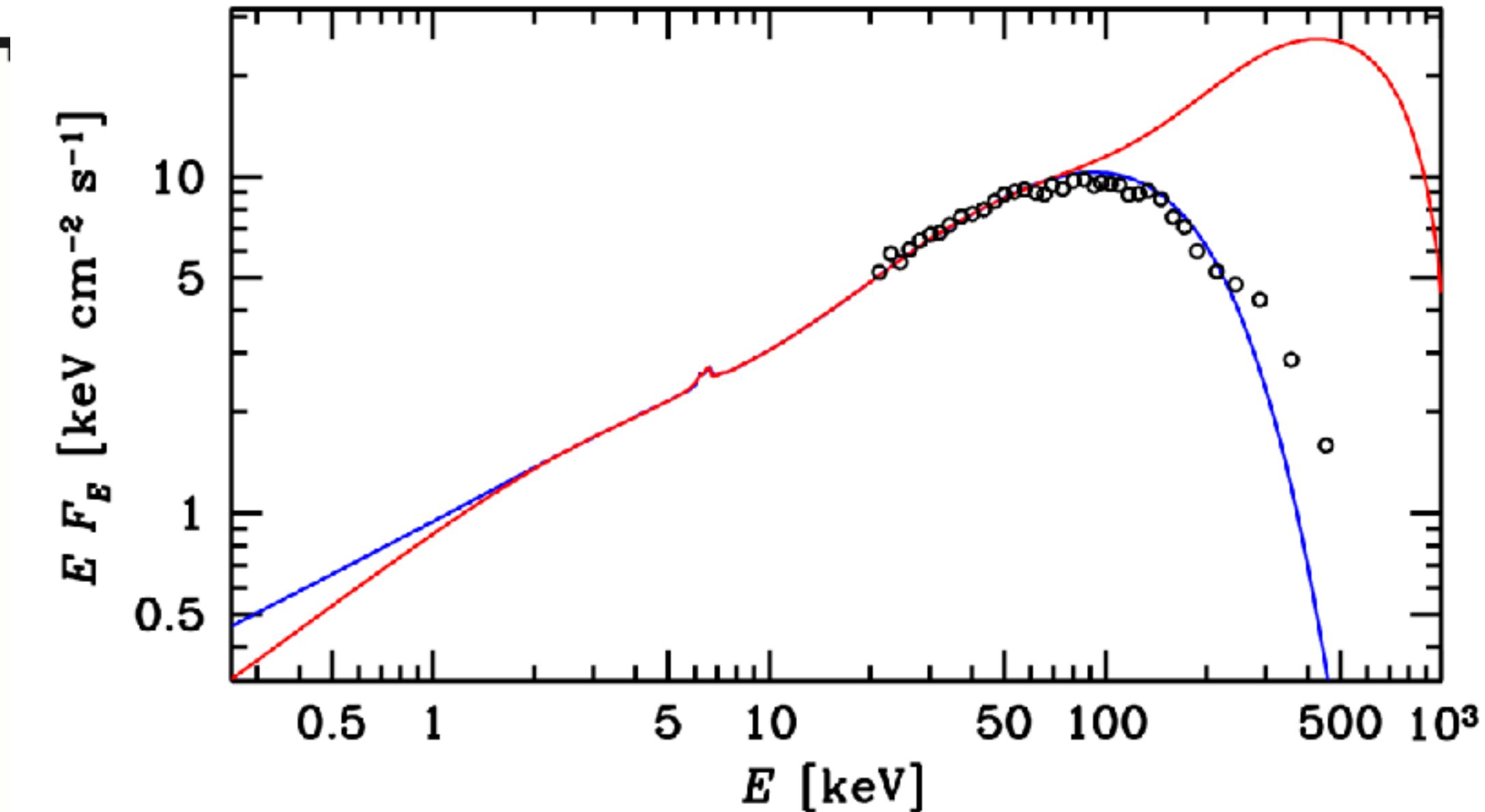
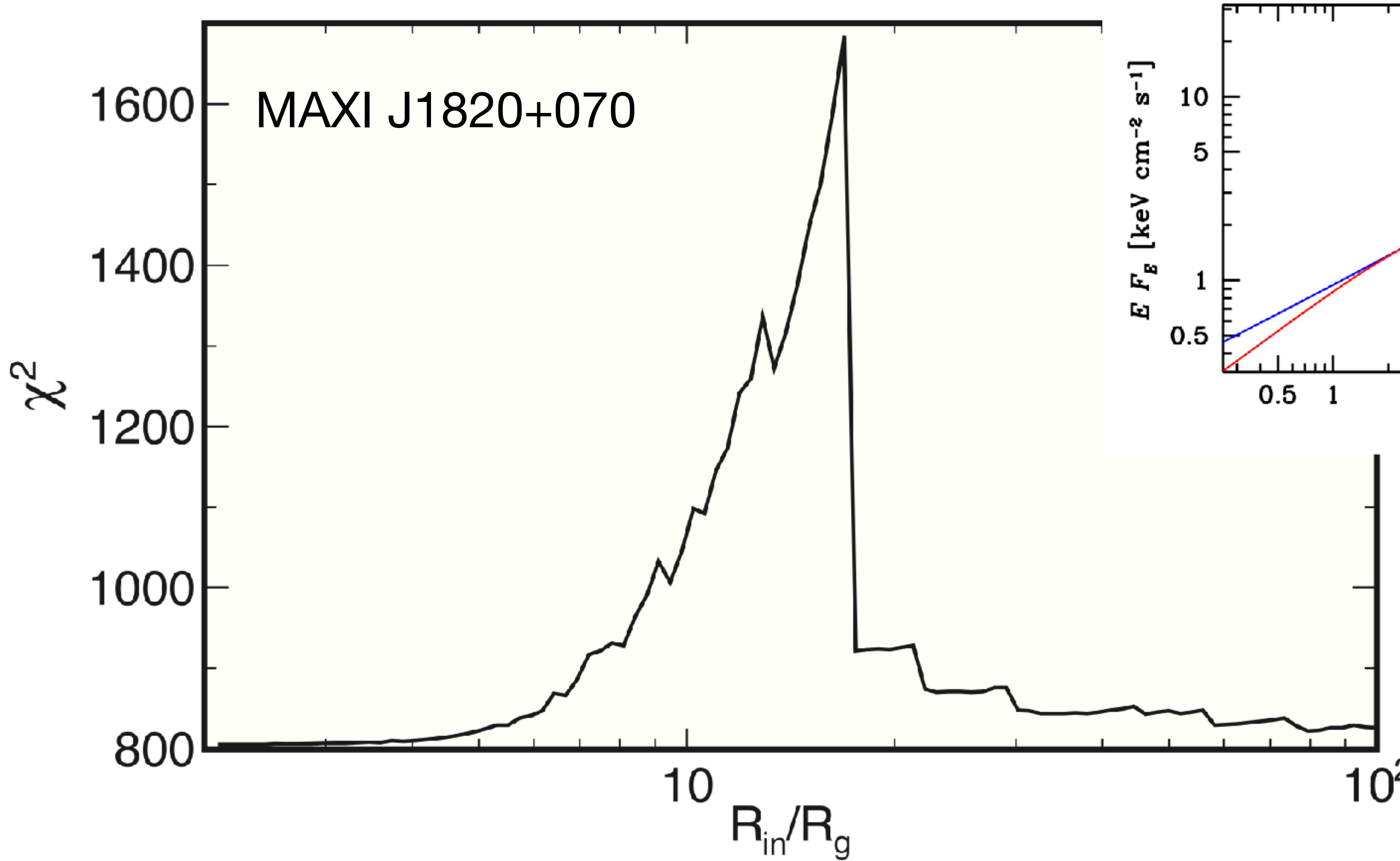


Buisson+ 2019

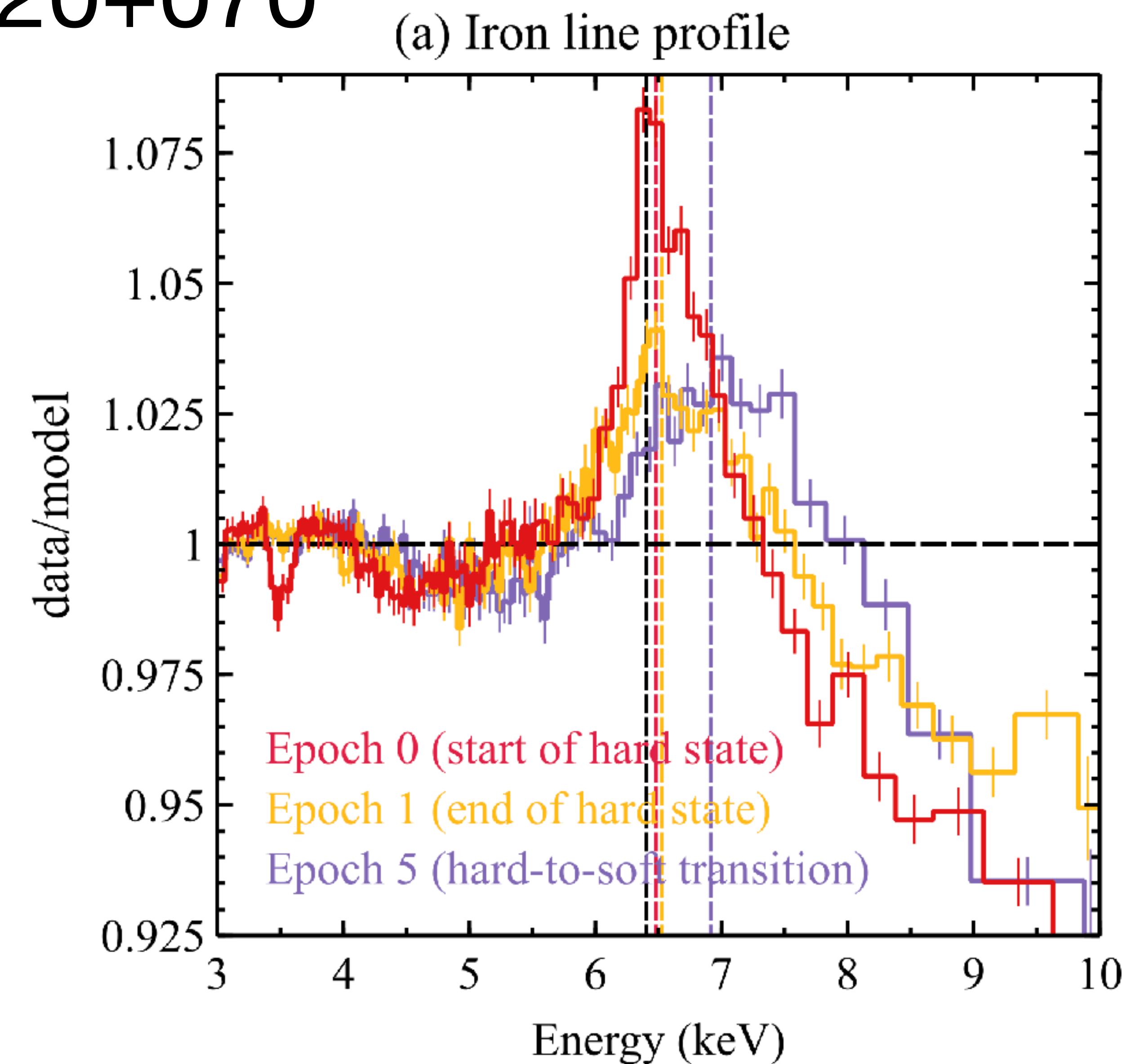
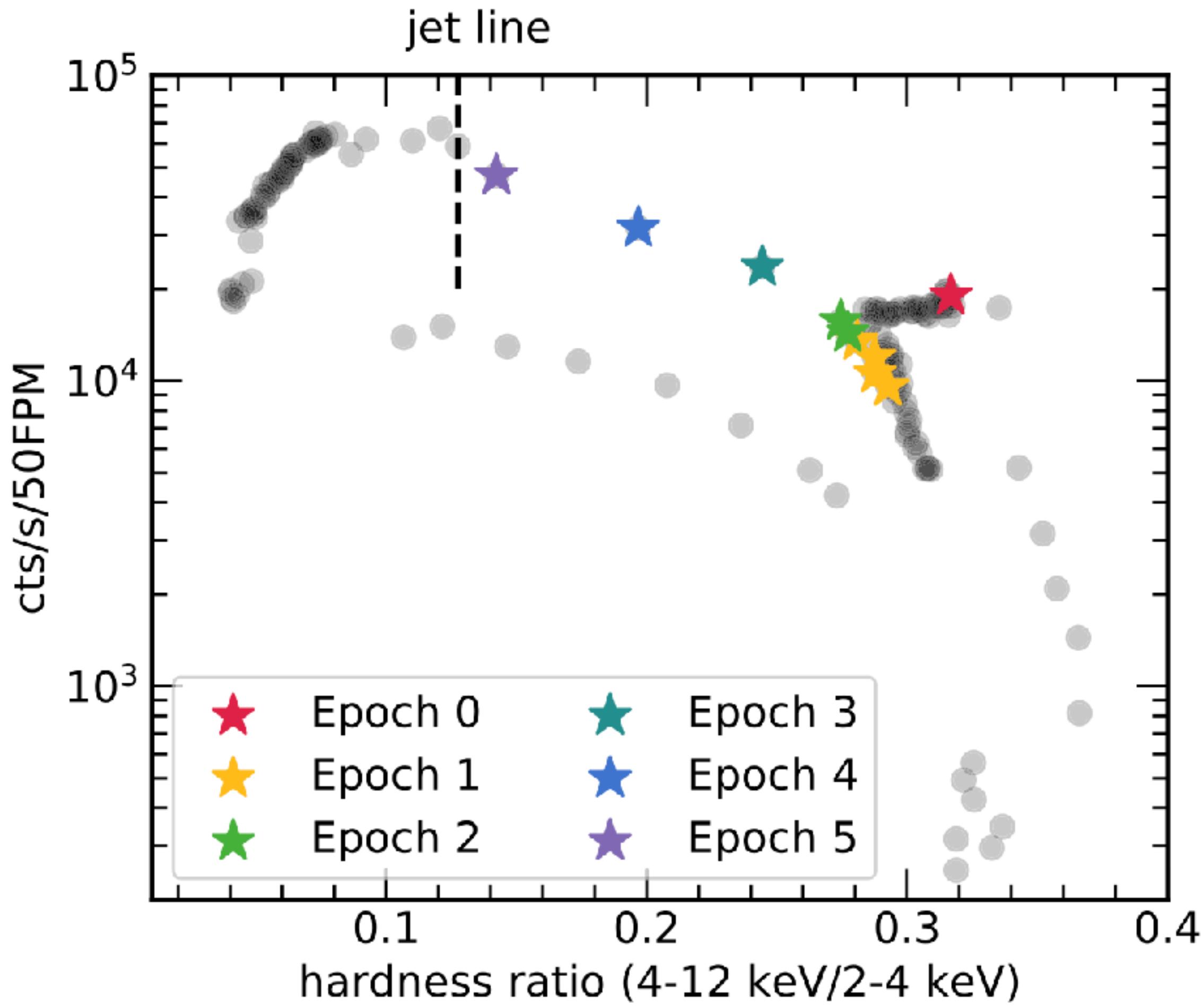


# Not an easy parameter space

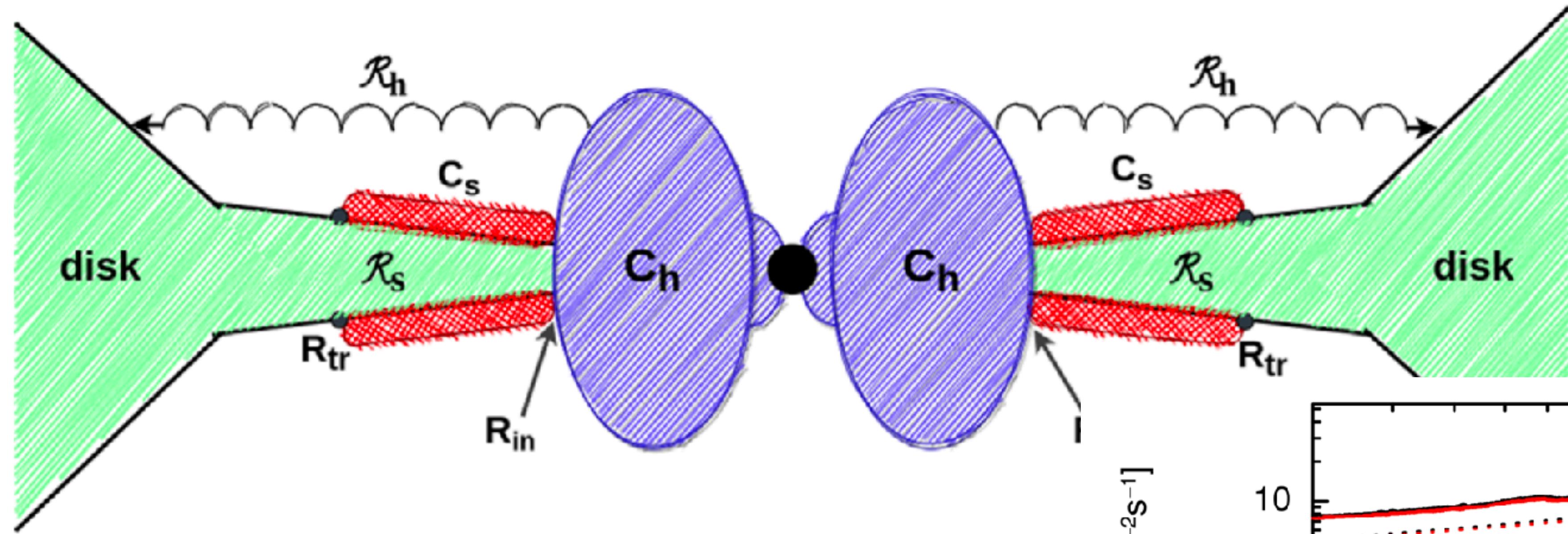
Fitting the energy spectrum with two reflection can lead to some degeneracies



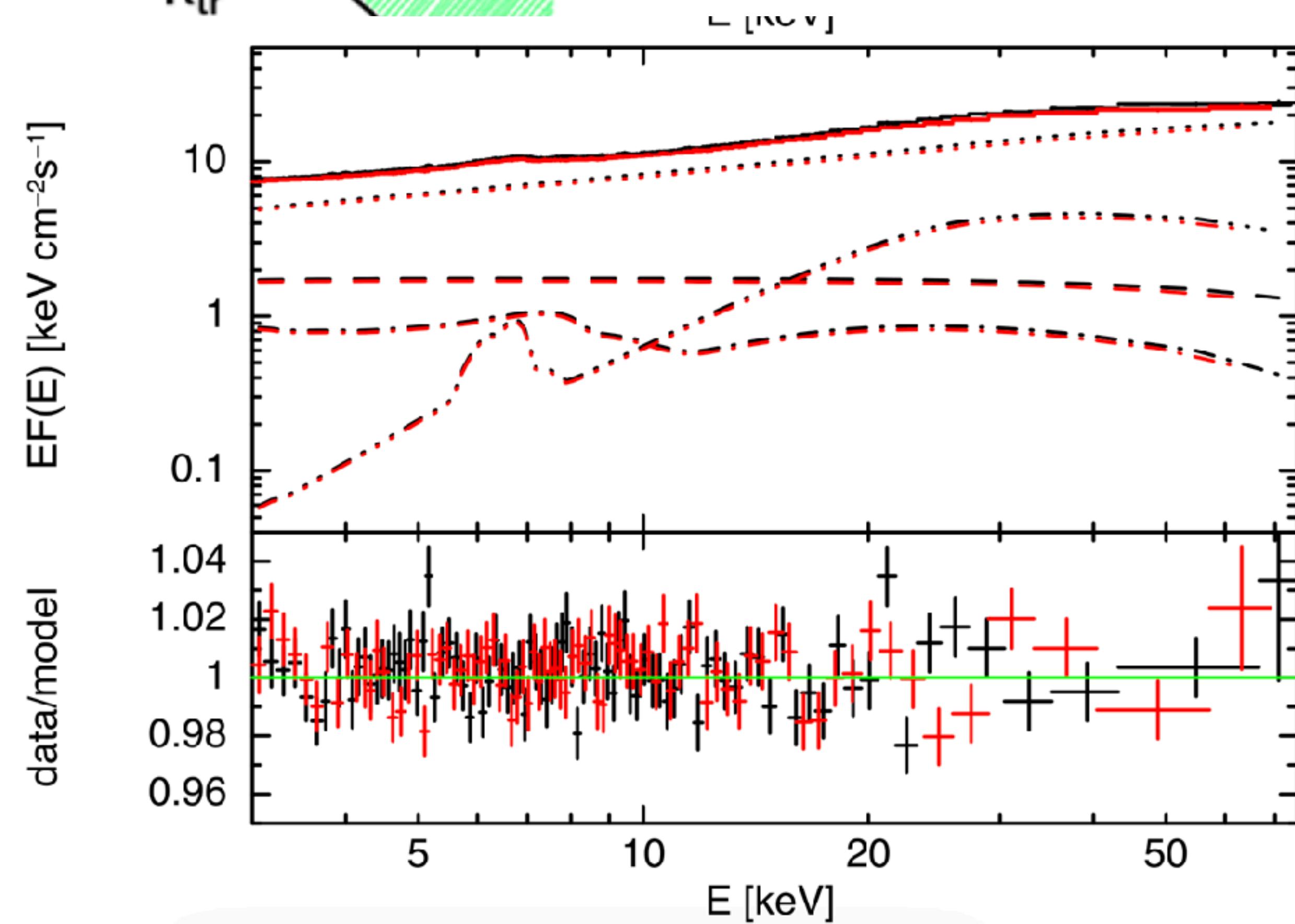
# Iron line during the transition in MAXI J1820+070



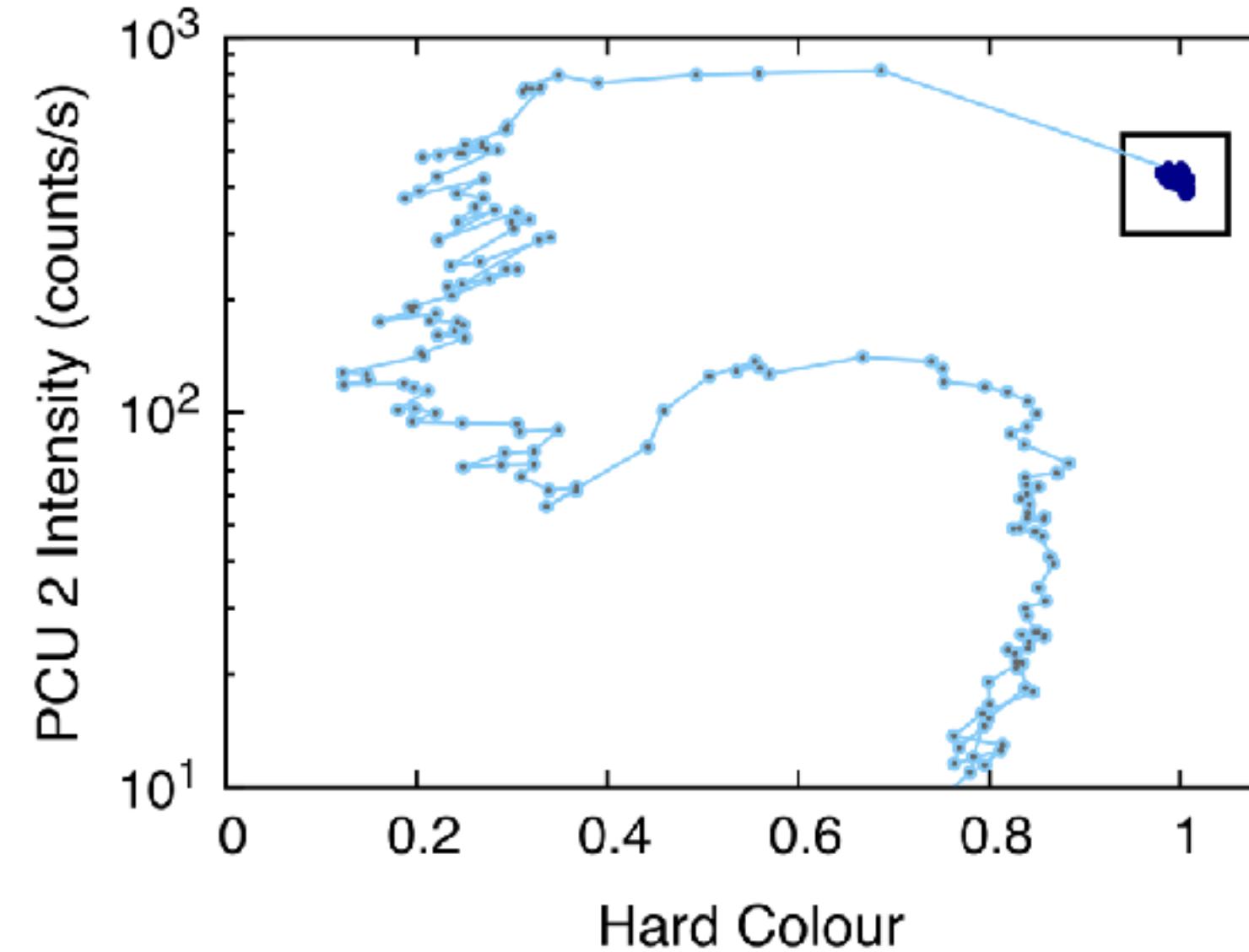
# Stratified corona



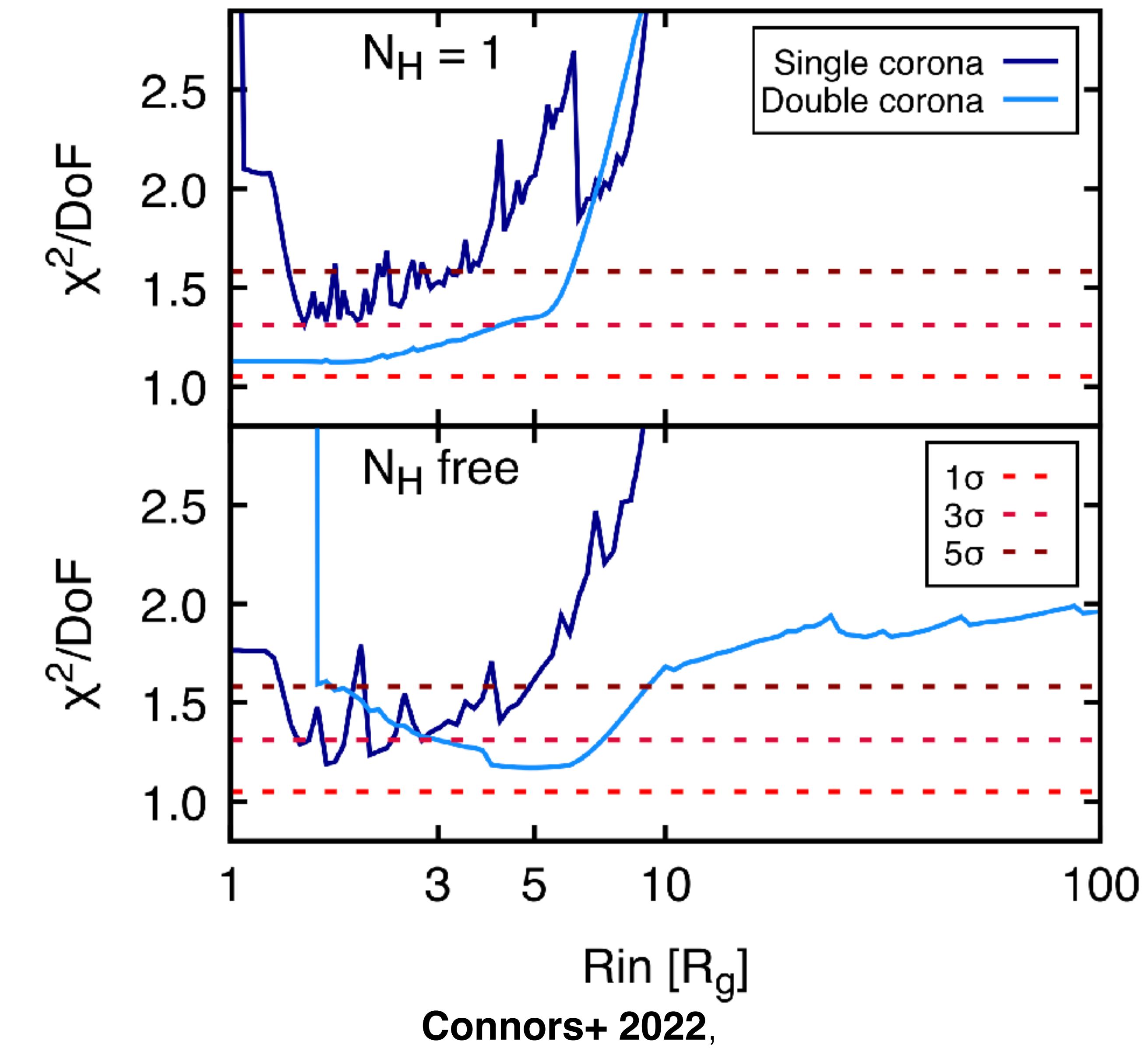
Two component corona produces  
two reflection spectra



# The case of XTE J1752-223



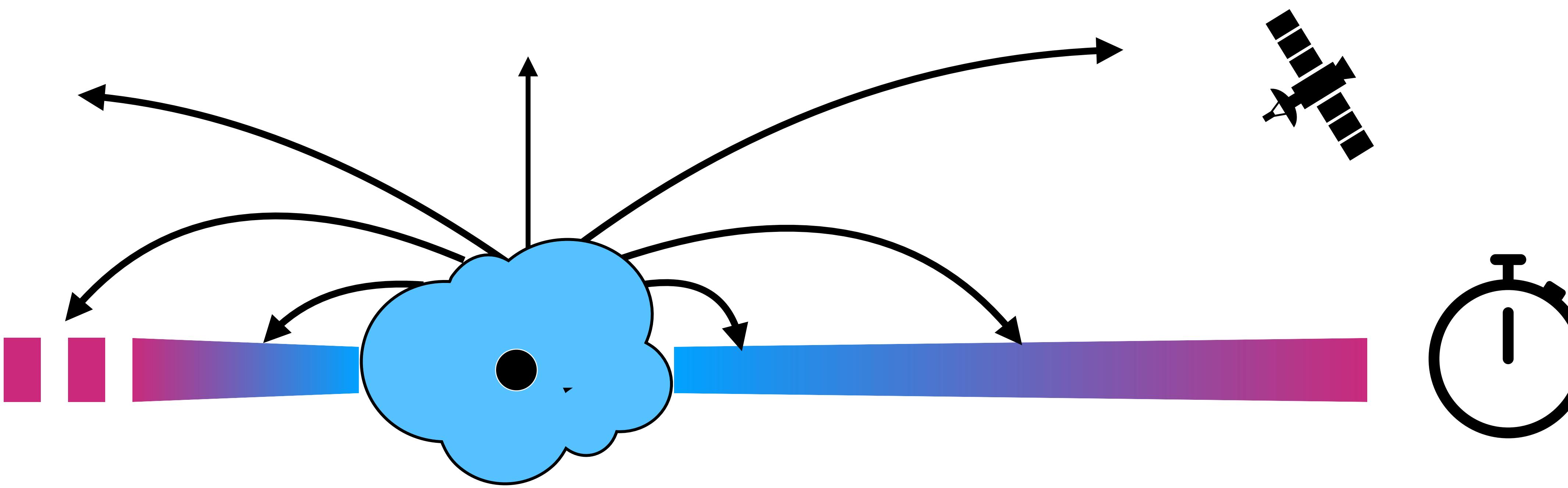
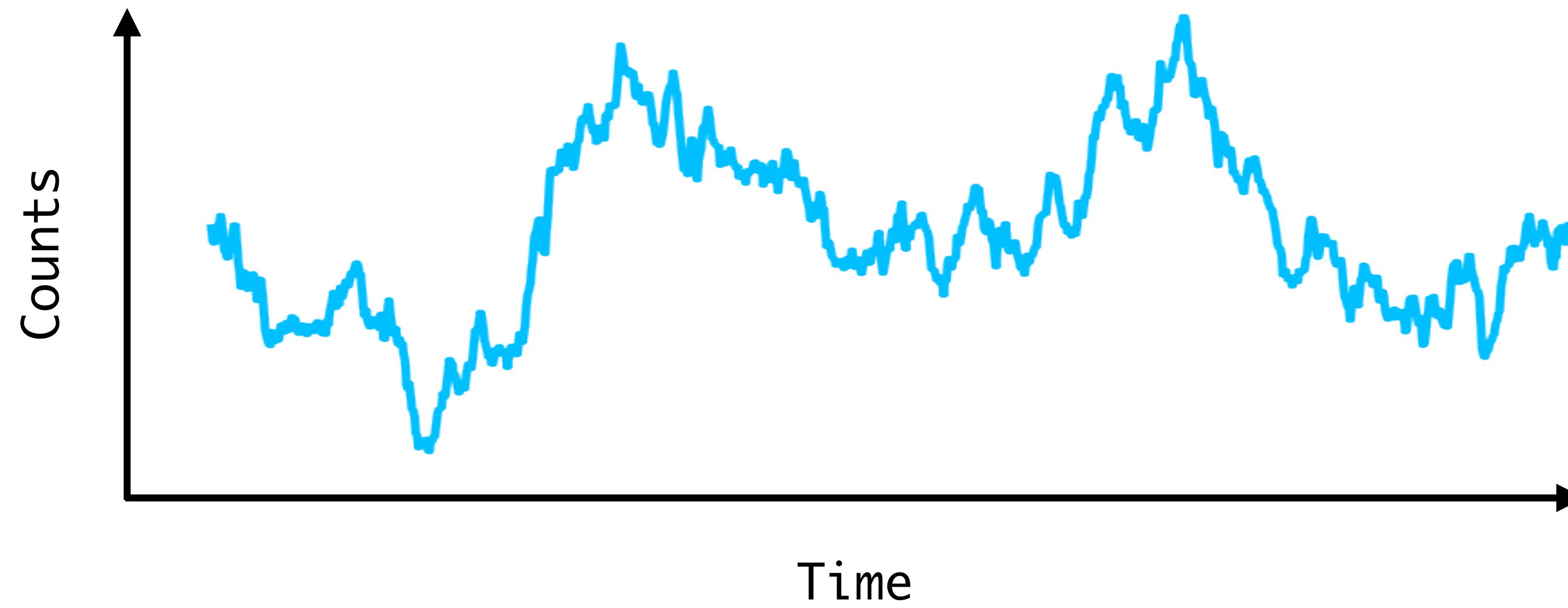
Spectral fit of the hard state with two comptonisation components seems to require the inner radius to be at the ISCO

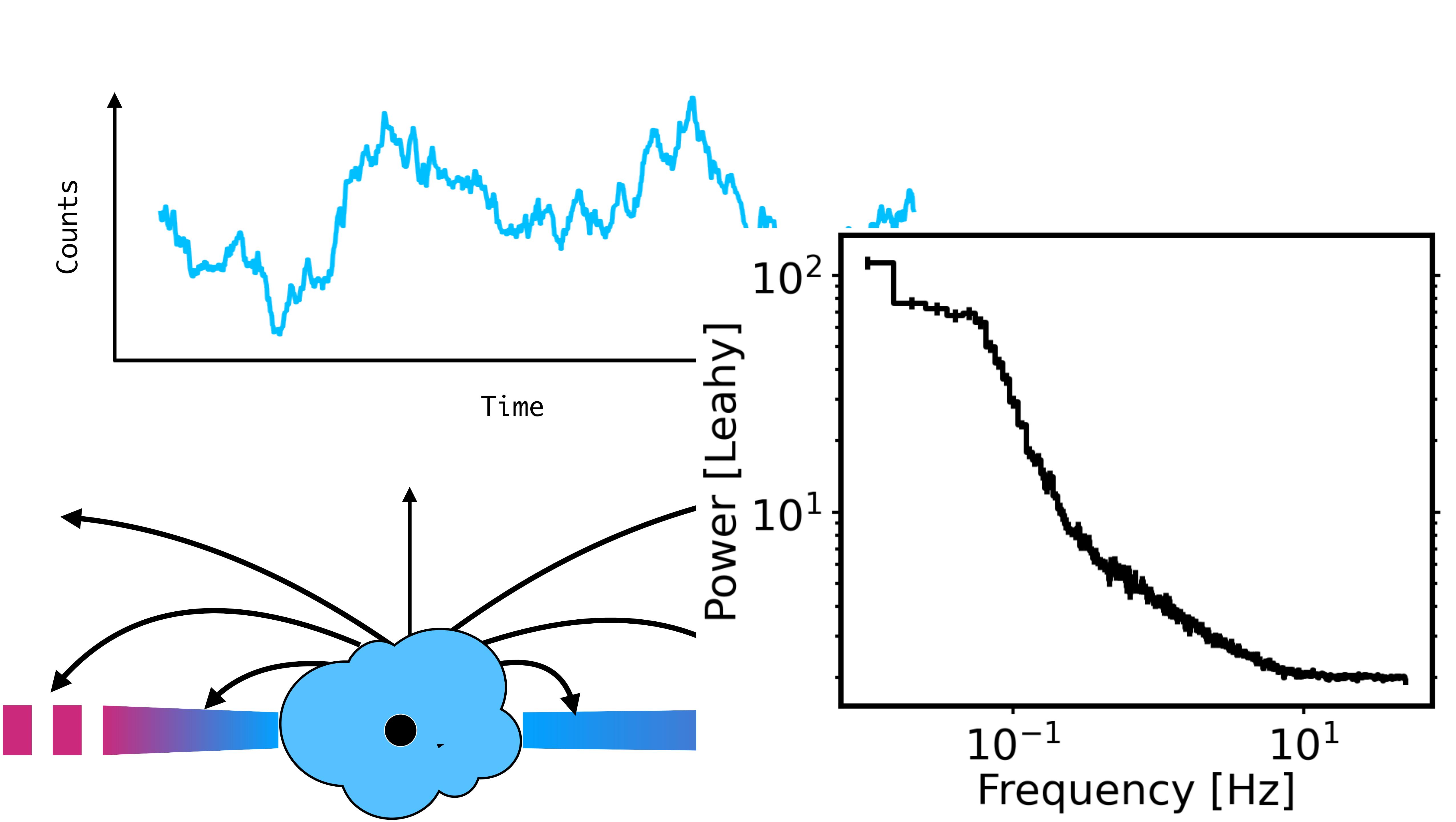


Connors+ 2022,

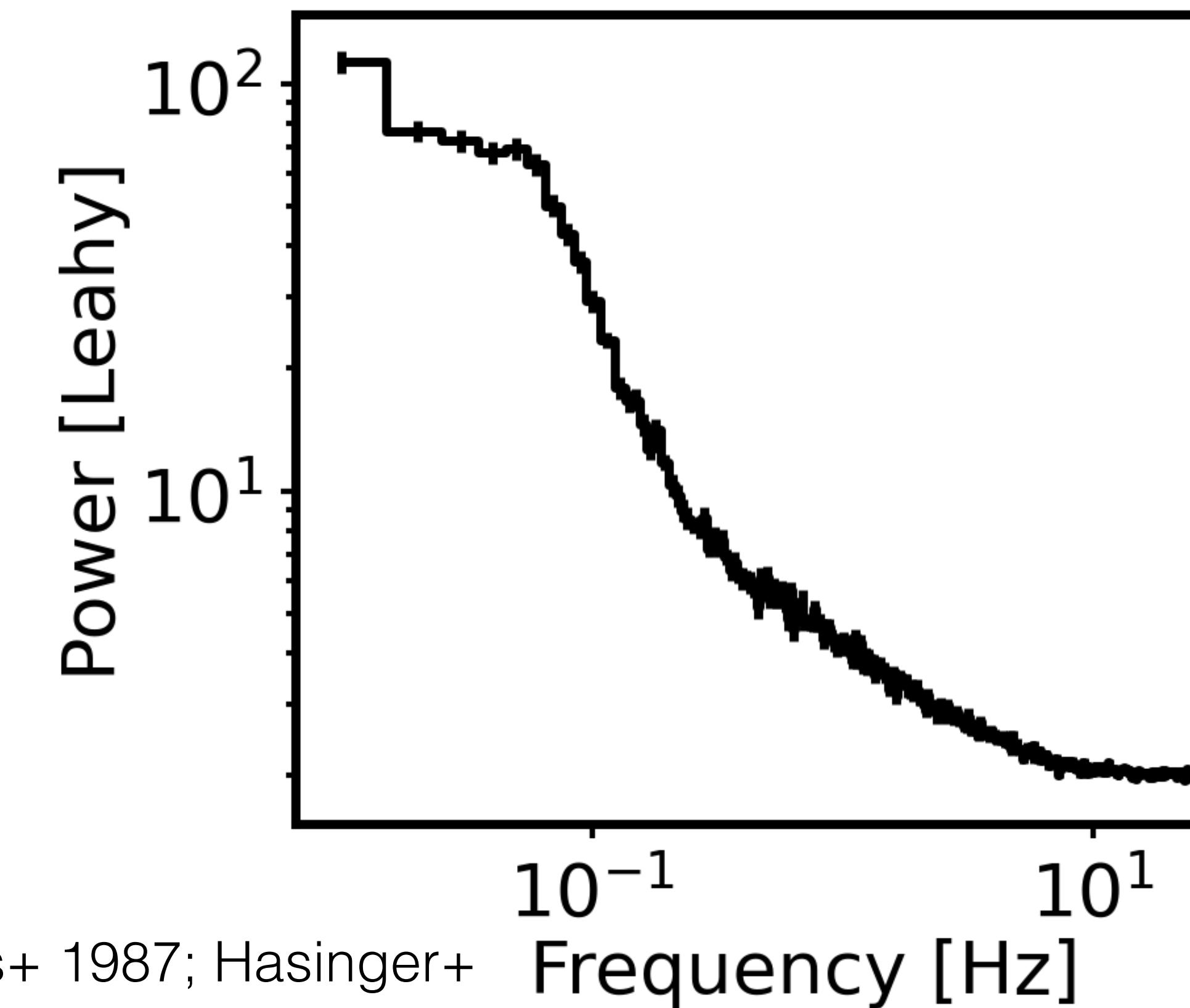
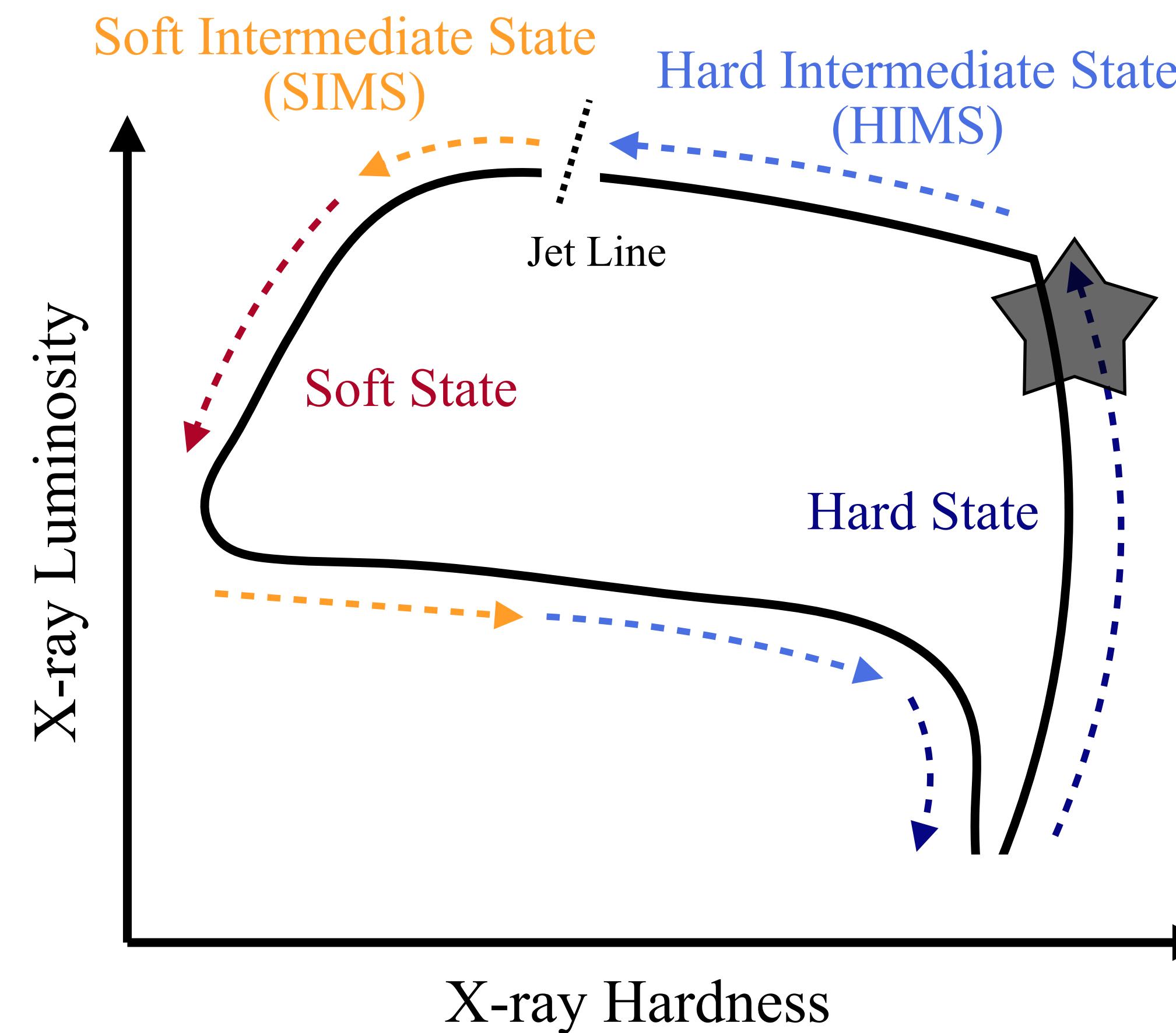
see also Garcia+ 2018 and Zdziarski+ 2021 on spectral fit of the same source

# Timing features: Quasi Periodic Oscillations QPO



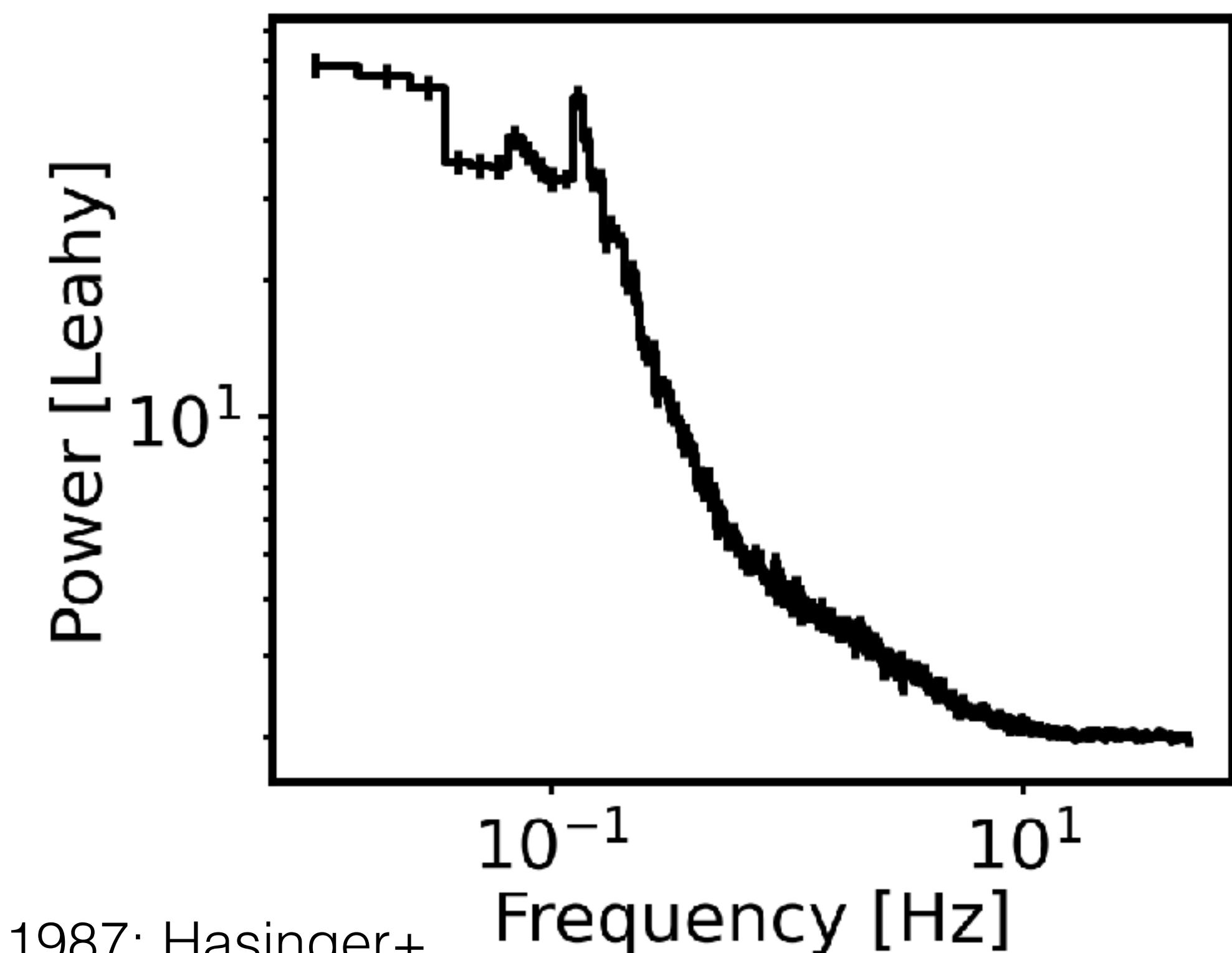
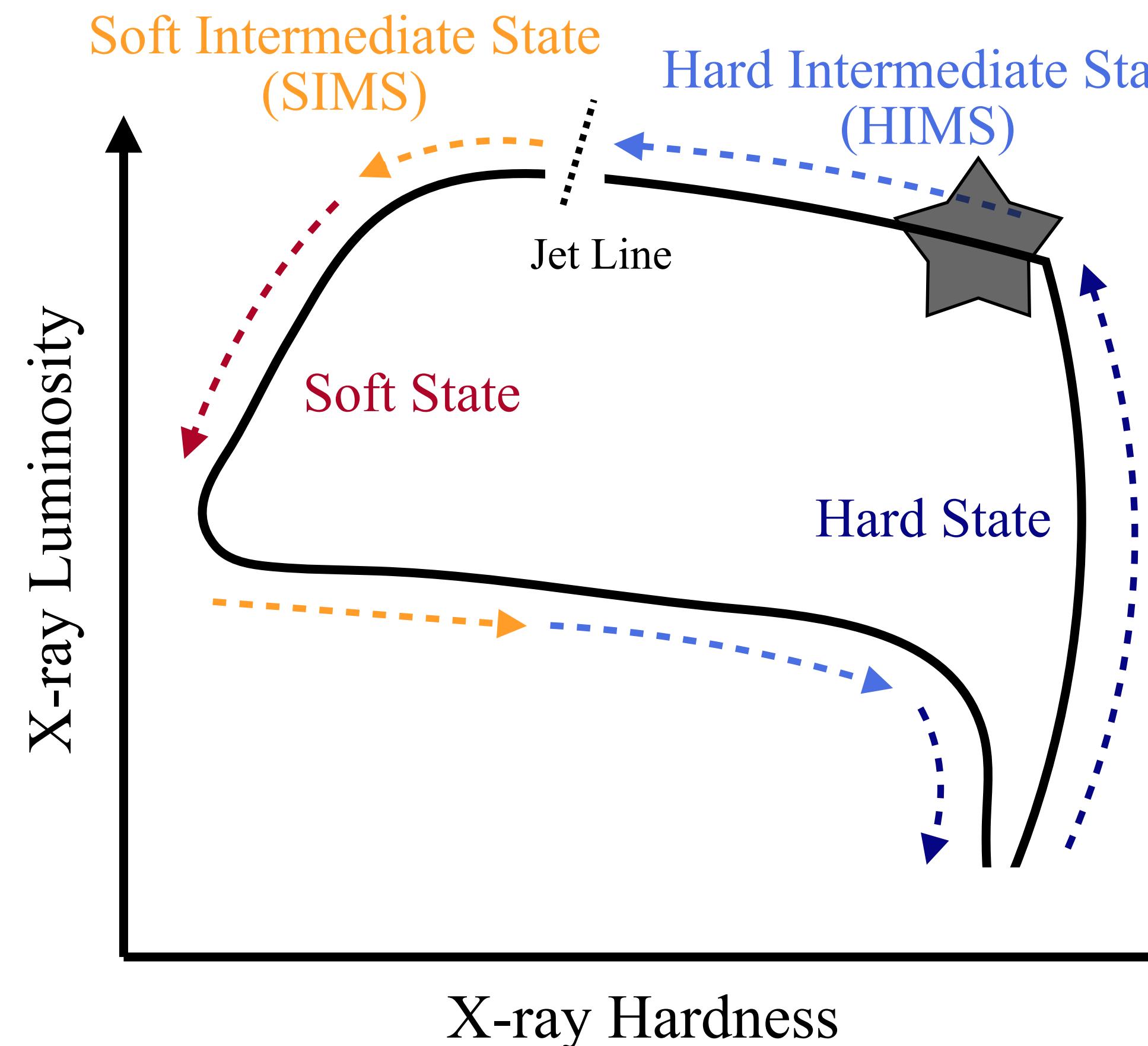


# Evolution of the variability during the outburst



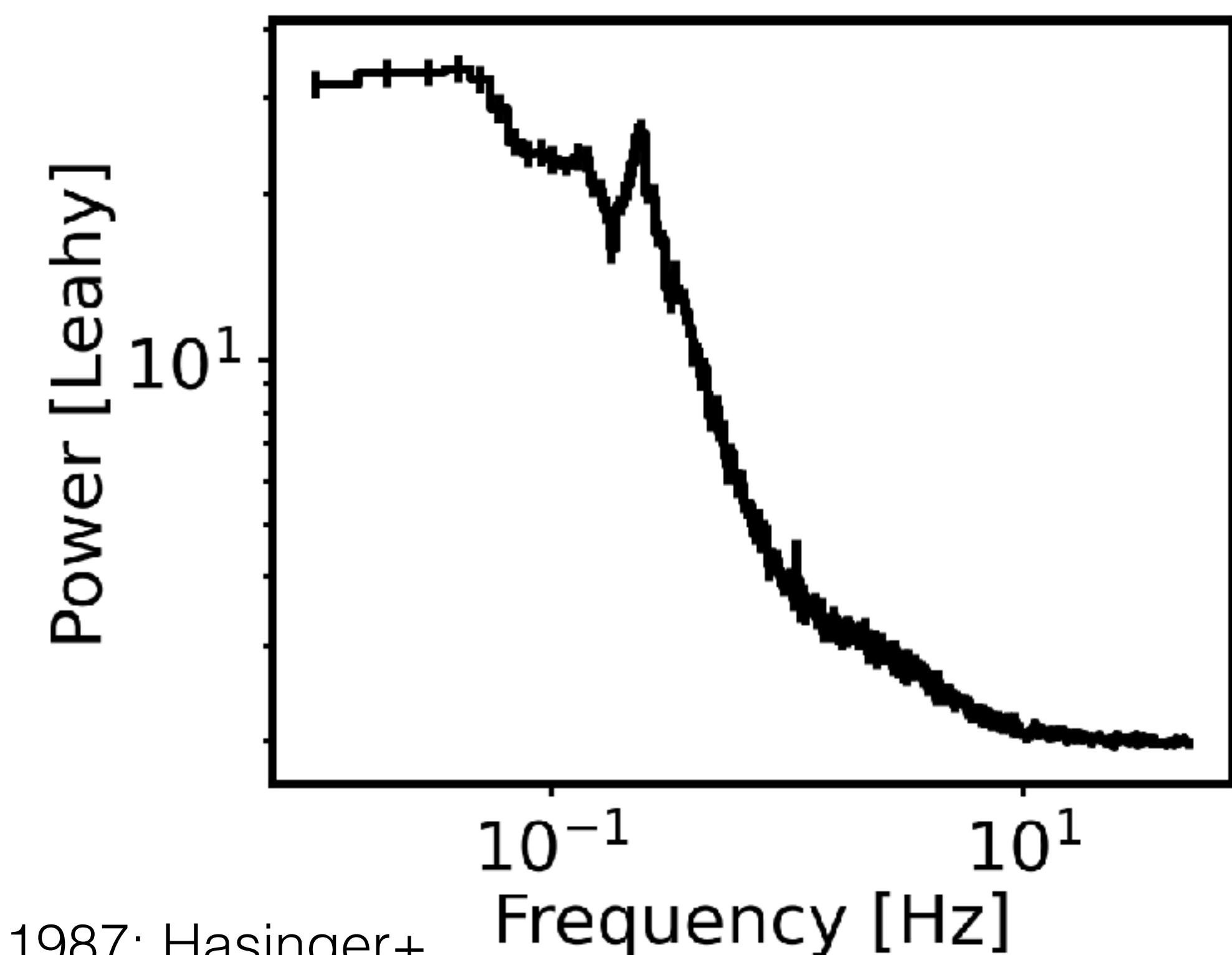
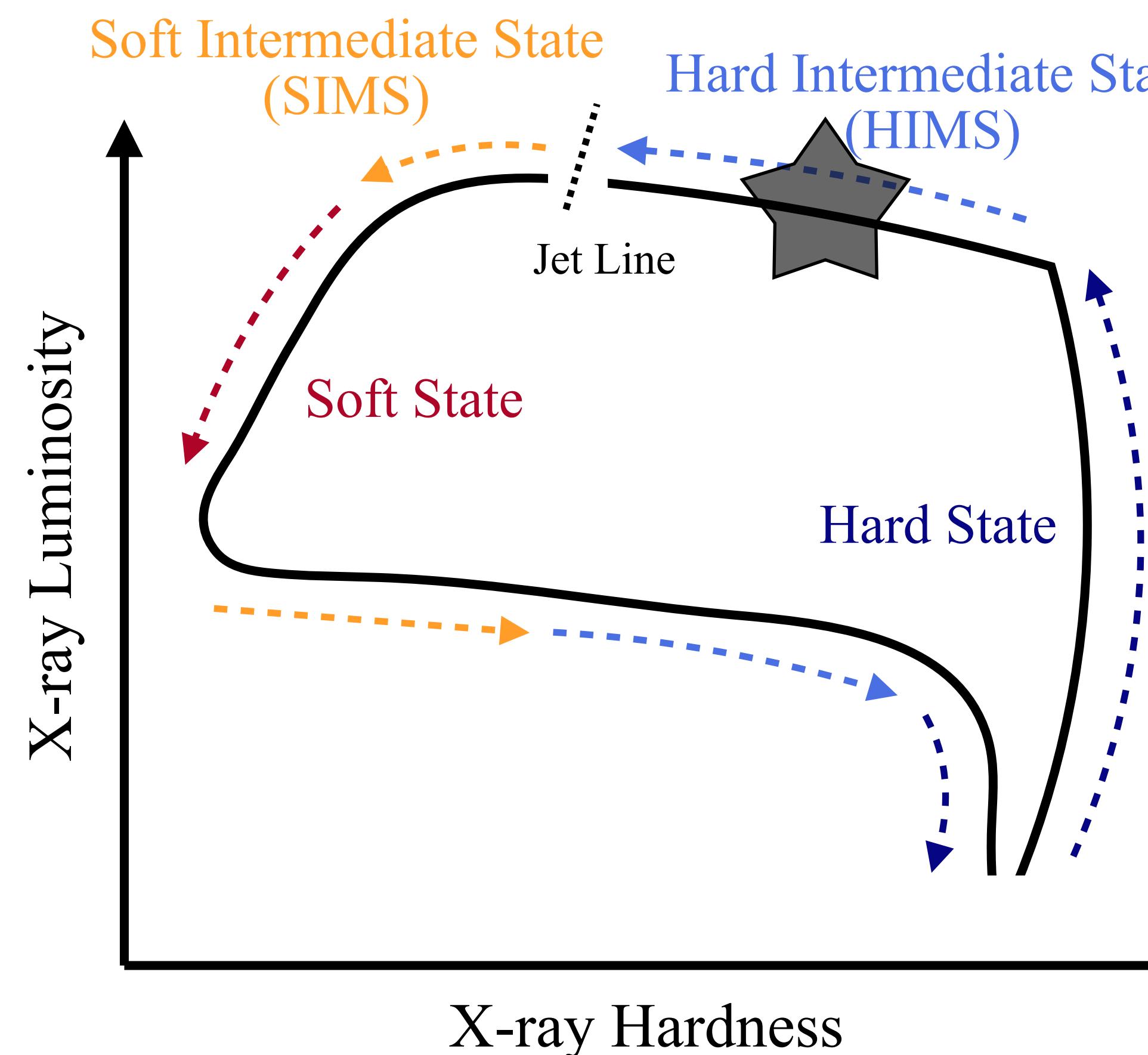
See e.g. **van der Klis+** 1985, 1986, 1987, etc.; Stella+ 1987, 1988; Wijers+ 1987; Hasinger+ 1988; Kylafis+ 1988; Miyamoto+ 1989 and many many more. Recent review Ingram+ 2020

# Evolution of the variability during the outburst



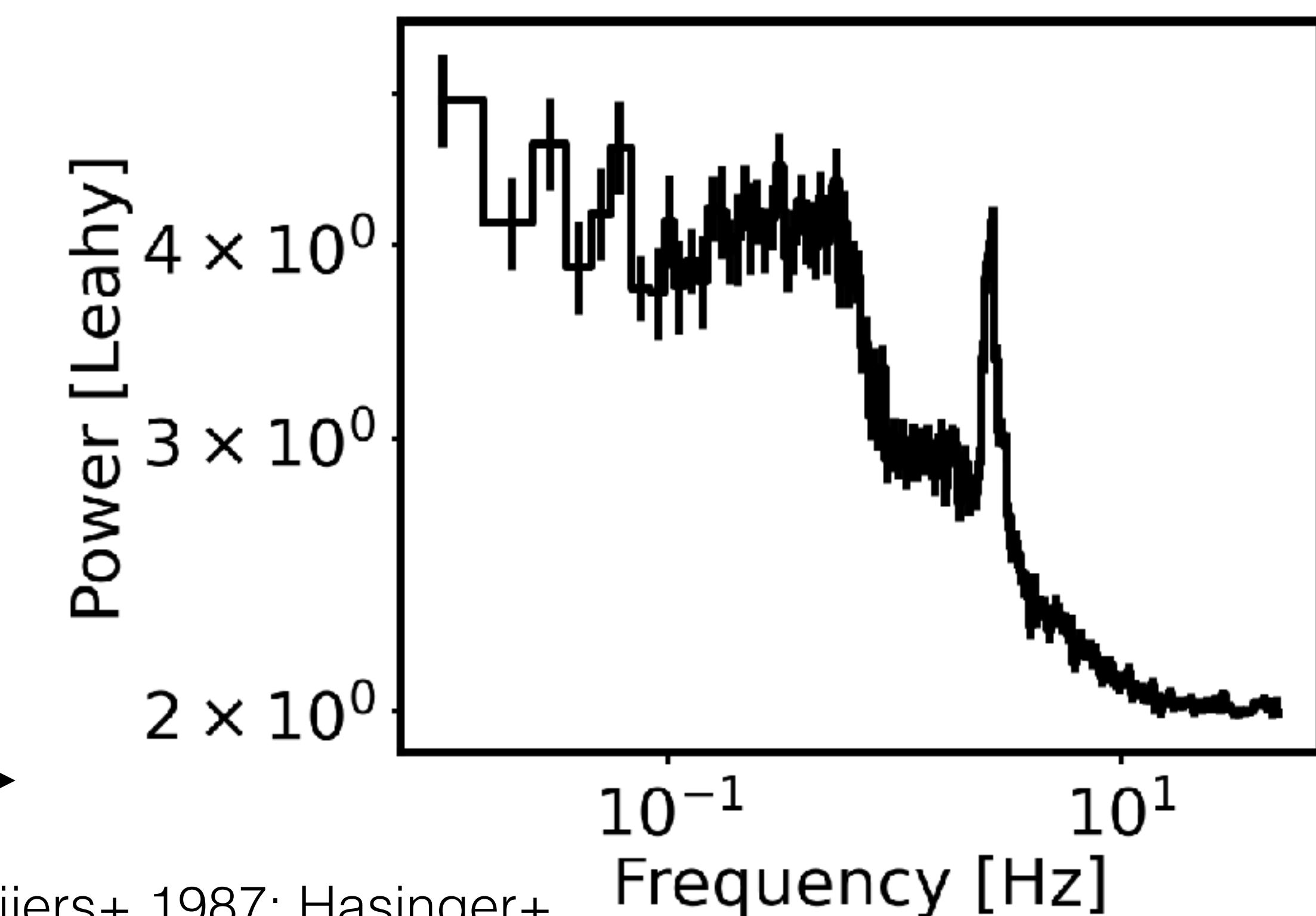
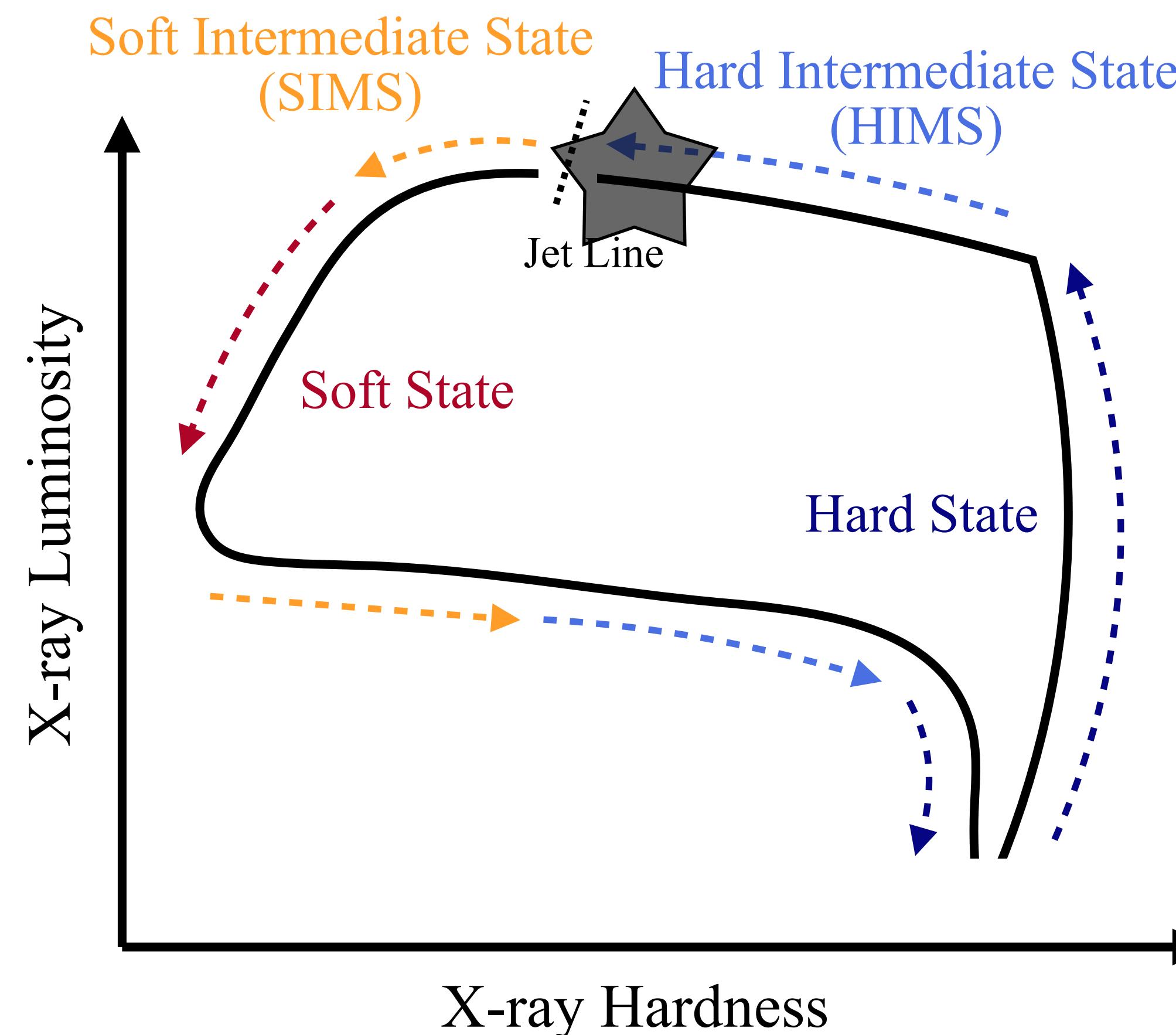
See e.g. **van der Klis+ 1985**, 1986, 1987, etc.; Stella+ 1987, 1988; Wijers+ 1987; Hasinger+ 1988; Kylafis+ 1988; Miyamoto+ 1989 and many many more. Recent review Ingram+ 2020

# Evolution of the variability during the outburst



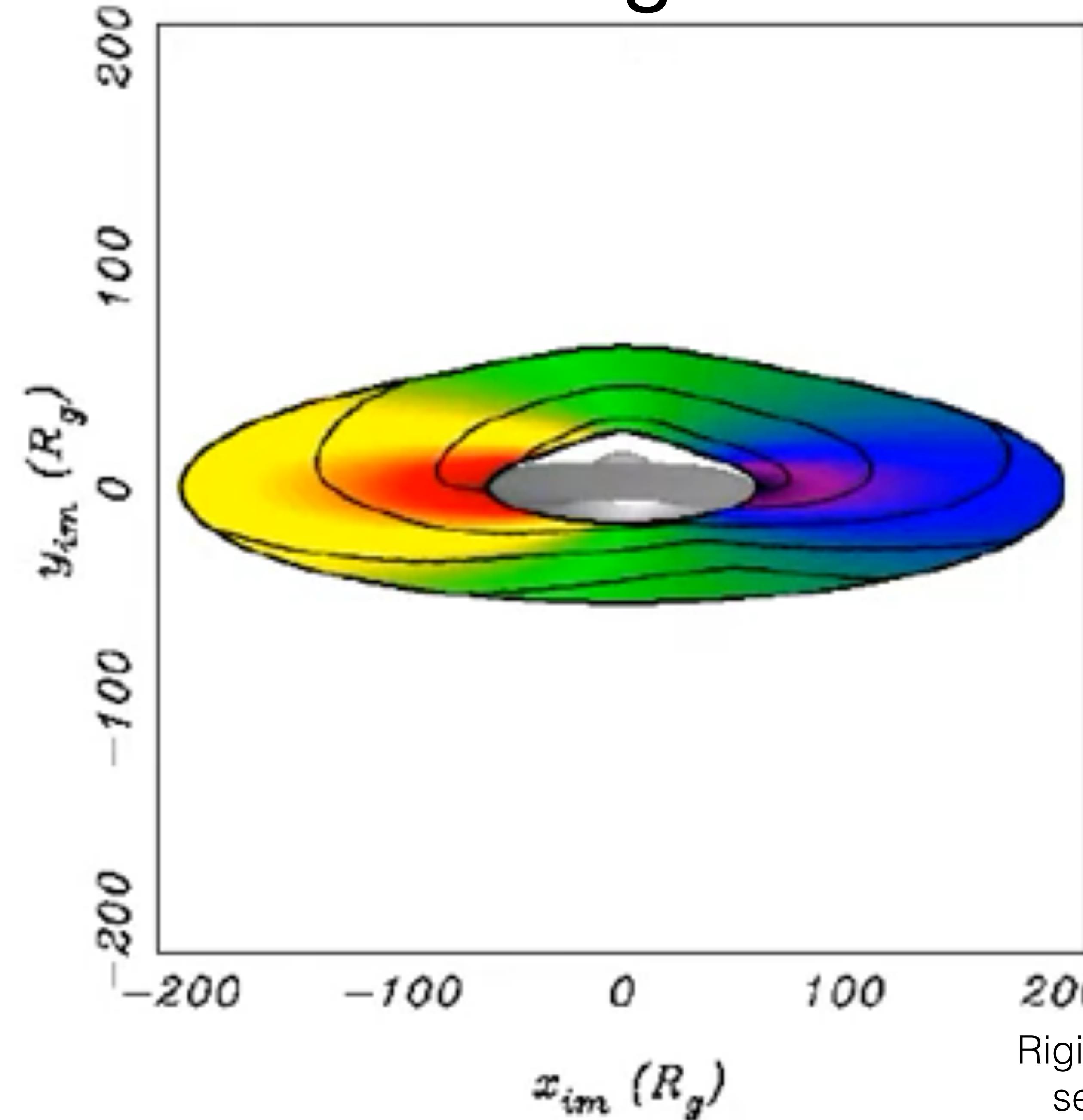
See e.g. **van der Klis+** 1985, 1986, 1987, etc.; Stella+ 1987, 1988; Wijers+ 1987; Hasinger+ 1988; Kylafis+ 1988; Miyamoto+ 1989 and many many more. Recent review Ingram+ 2020

# Evolution of the variability during the outburst



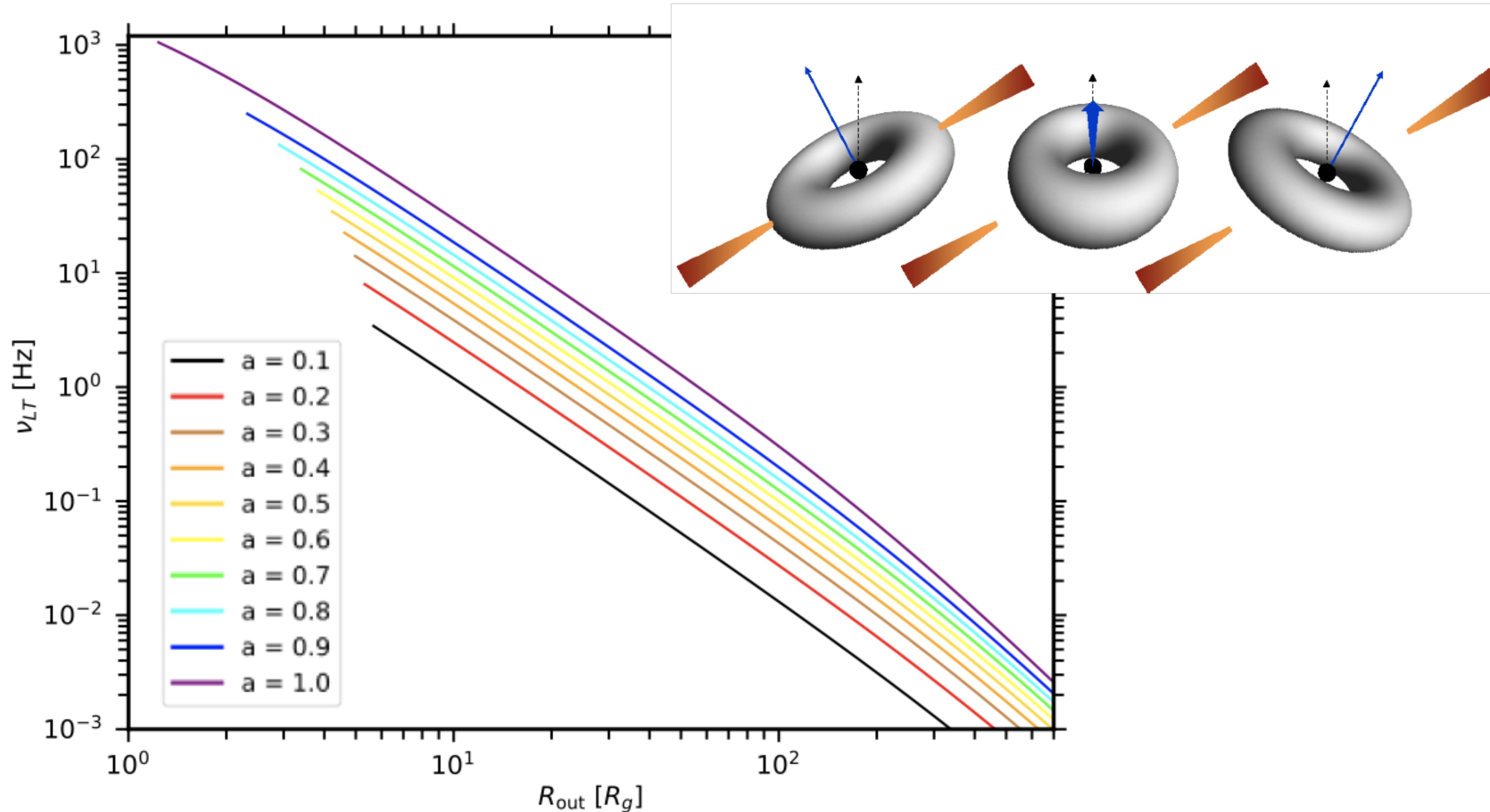
See e.g. **van der Klis+** 1985, 1986, 1987, etc.; Stella+ 1987, 1988; Wijers+ 1987; Hasinger+ 1988; Kylafis+ 1988; Miyamoto+ 1989 and many many more. Recent review Ingram+ 2020

# Lense Thirring Precession

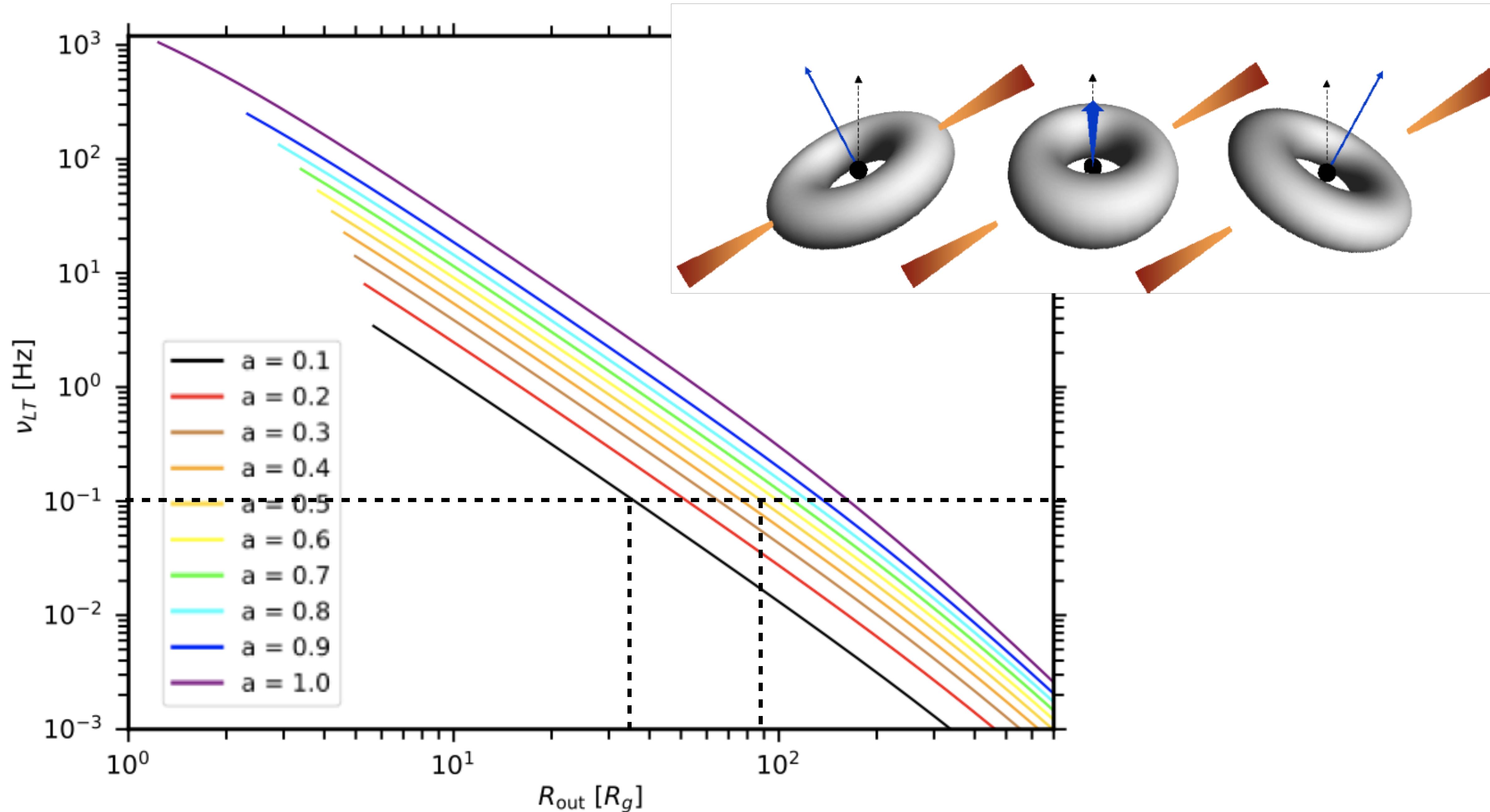


Rigid precession model: **Ingram+ 2009**  
see also Ingram+ 2020 for a review

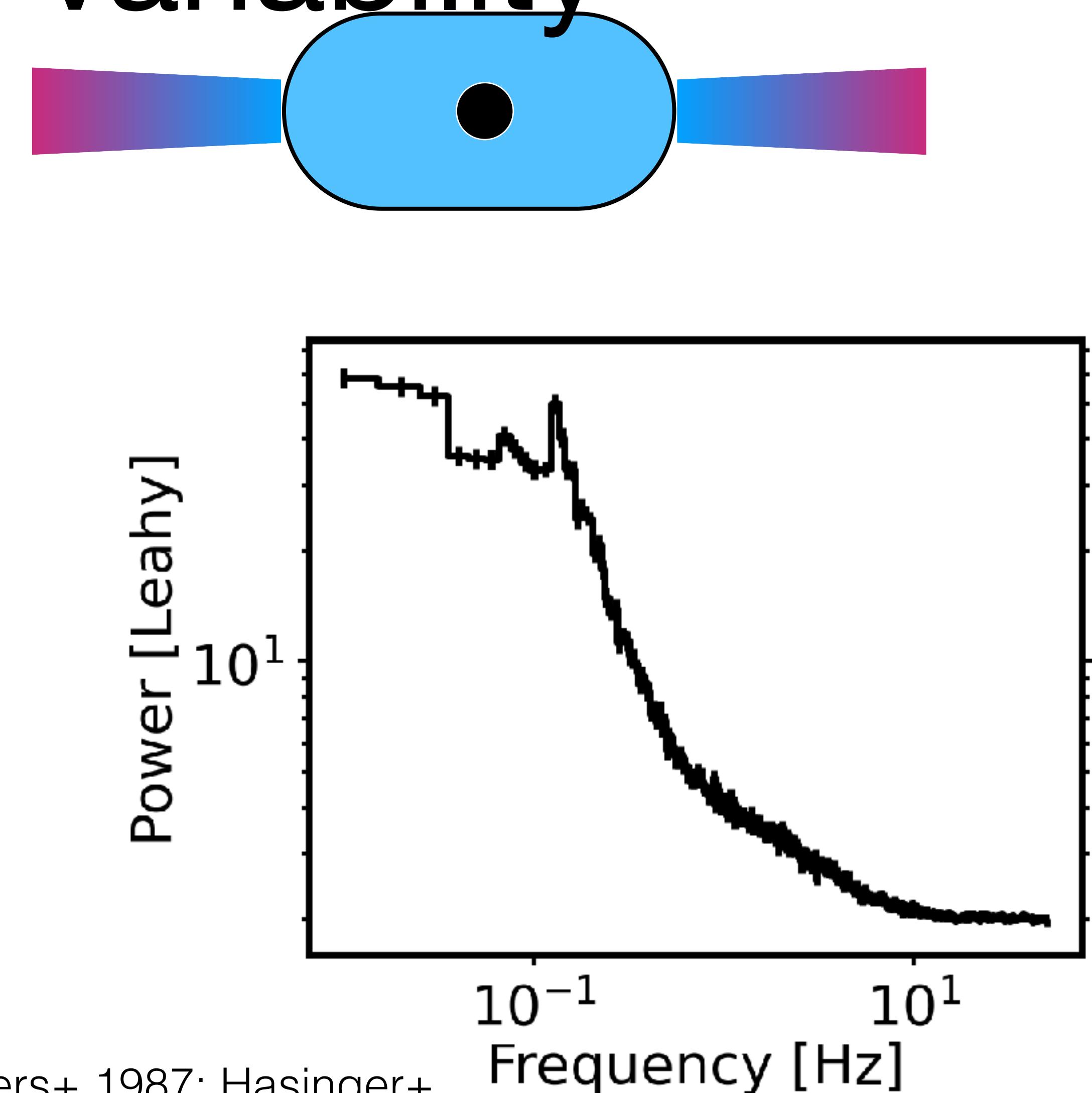
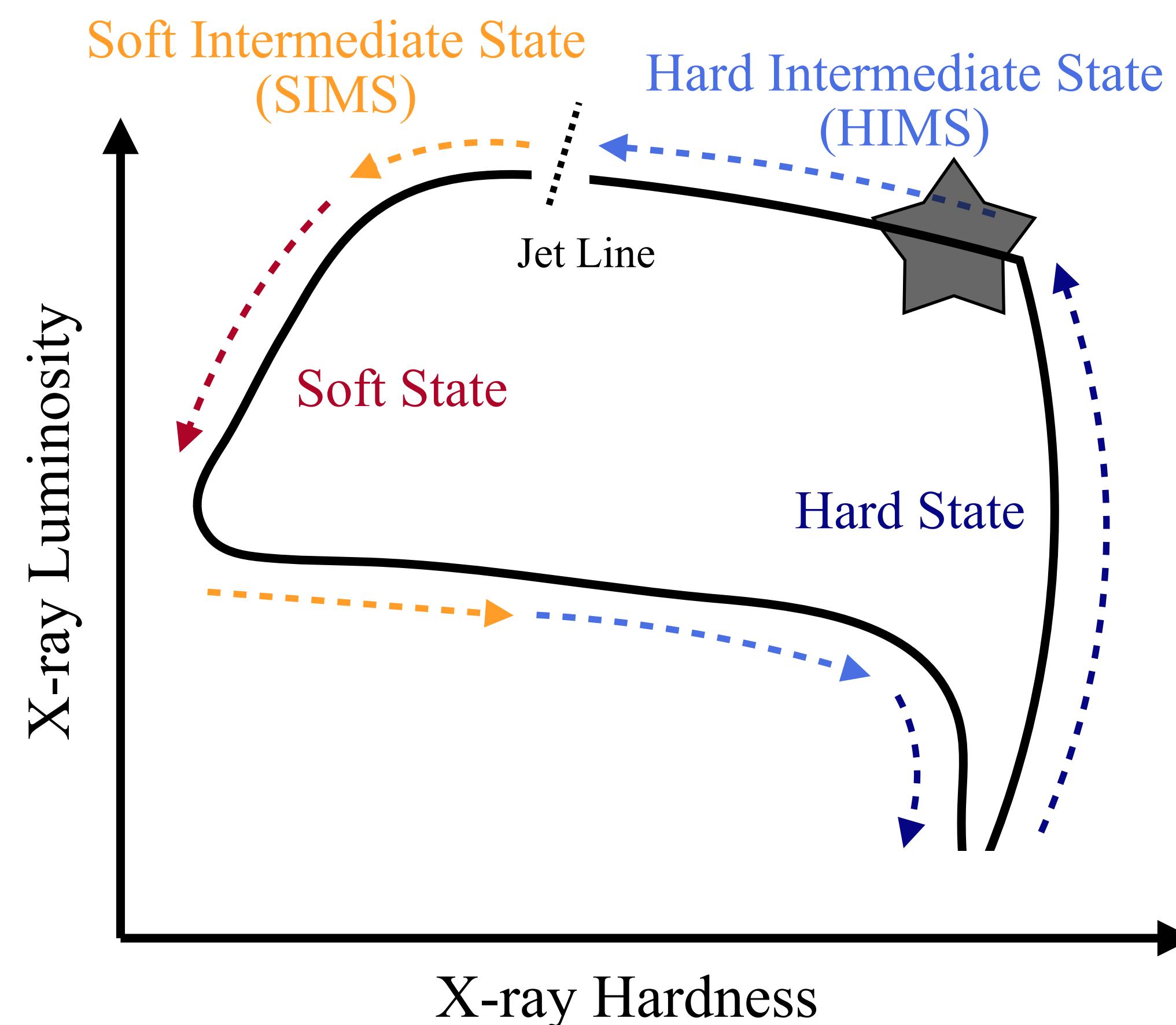
# Predictions from solid body precession



# Predictions from solid body precession

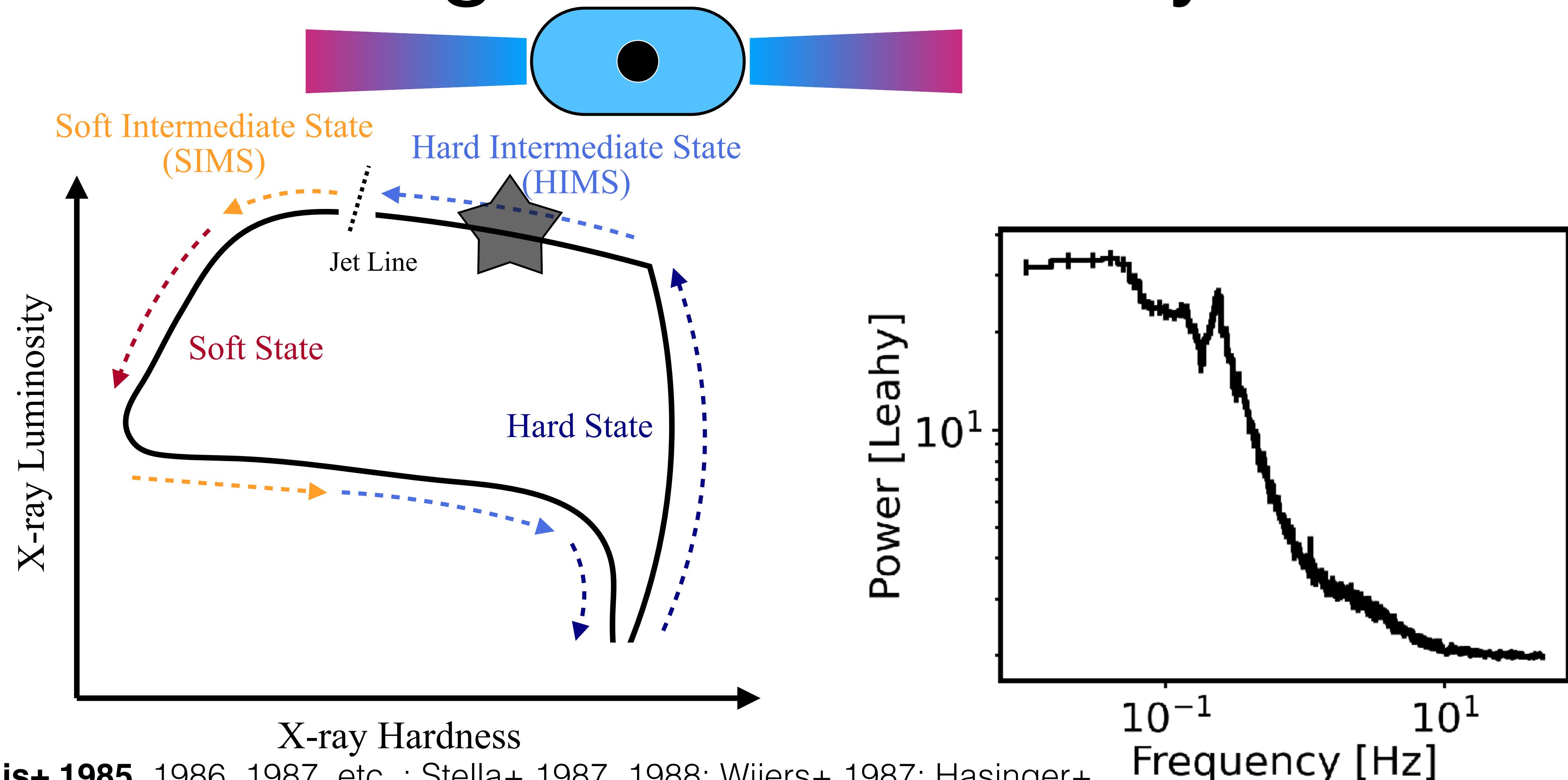


# Evolution of the corona according to the variability



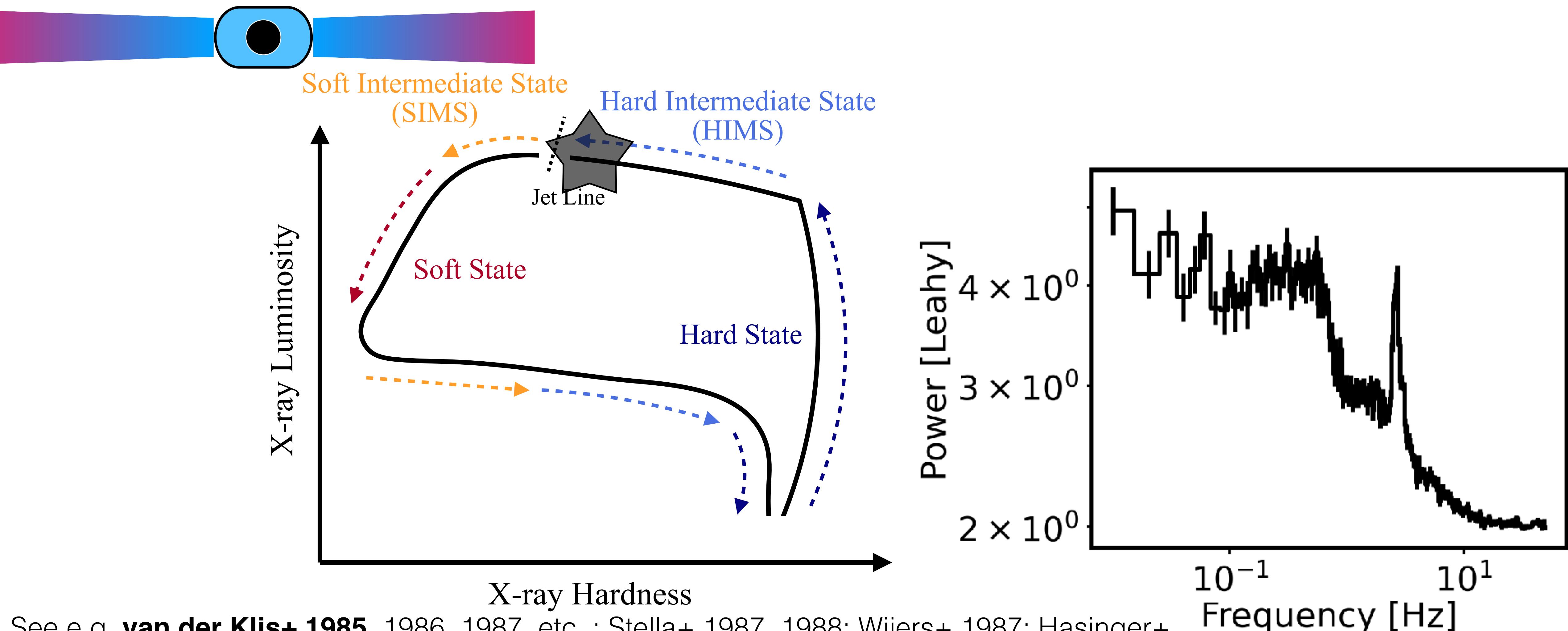
See e.g. **van der Klis+ 1985**, 1986, 1987, etc.; Stella+ 1987, 1988; Wijers+ 1987; Hasinger+ 1988; Kylafis+ 1988; Miyamoto+ 1989 and many many more. Recent review Ingram+ 2020

# Evolution of the corona according to the variability



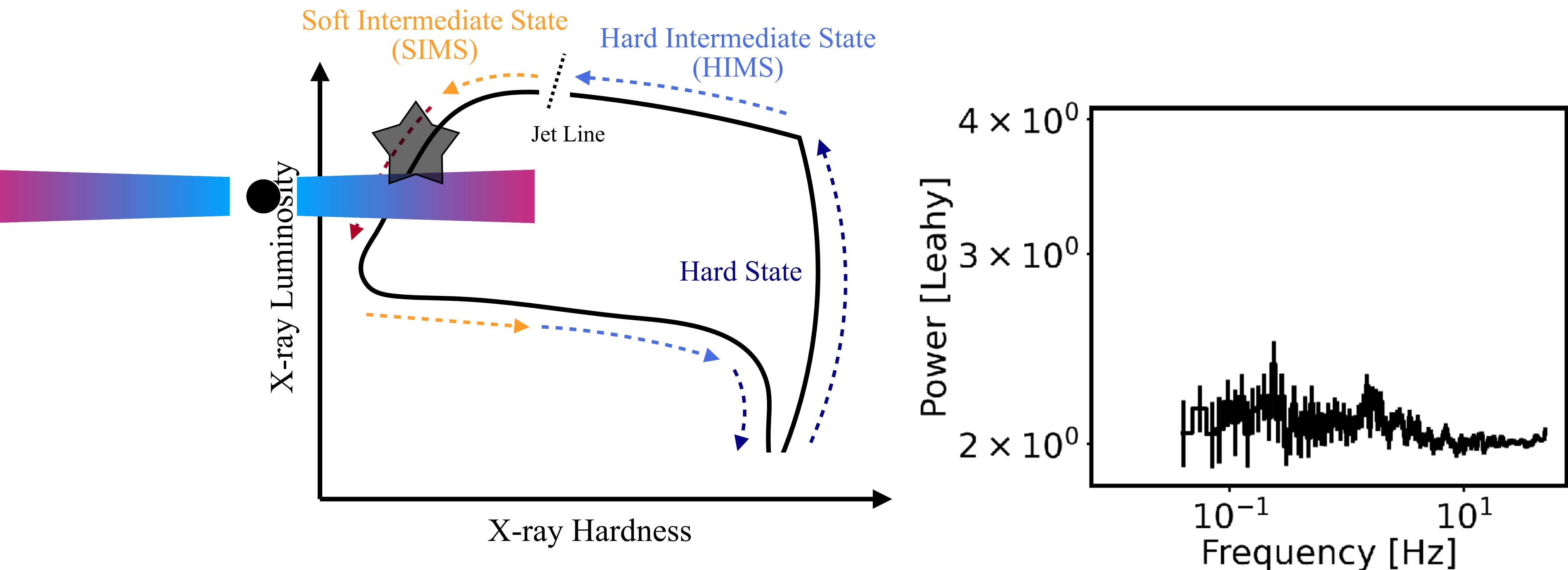
See e.g. **van der Klis+ 1985**, 1986, 1987, etc.; Stella+ 1987, 1988; Wijers+ 1987; Hasinger+ 1988; Kylafis+ 1988; Miyamoto+ 1989 and many many more. Recent review Ingram+ 2020

# Evolution of the corona according to the variability

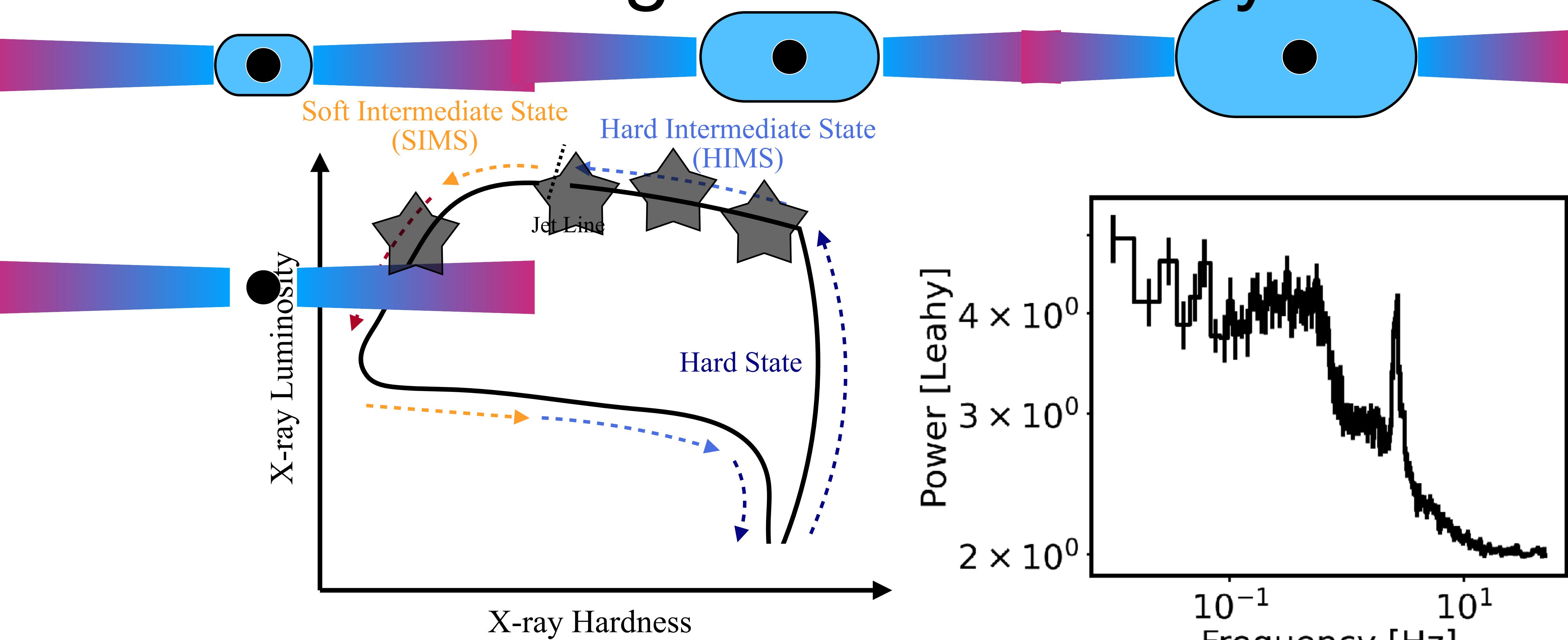


See e.g. **van der Klis+** 1985, 1986, 1987, etc.; Stella+ 1987, 1988; Wijers+ 1987; Hasinger+ 1988; Kylafis+ 1988; Miyamoto+ 1989 and many many more. Recent review Ingram+ 2020

# Evolution of the corona according to the variability



# Evolution of the corona according to the variability

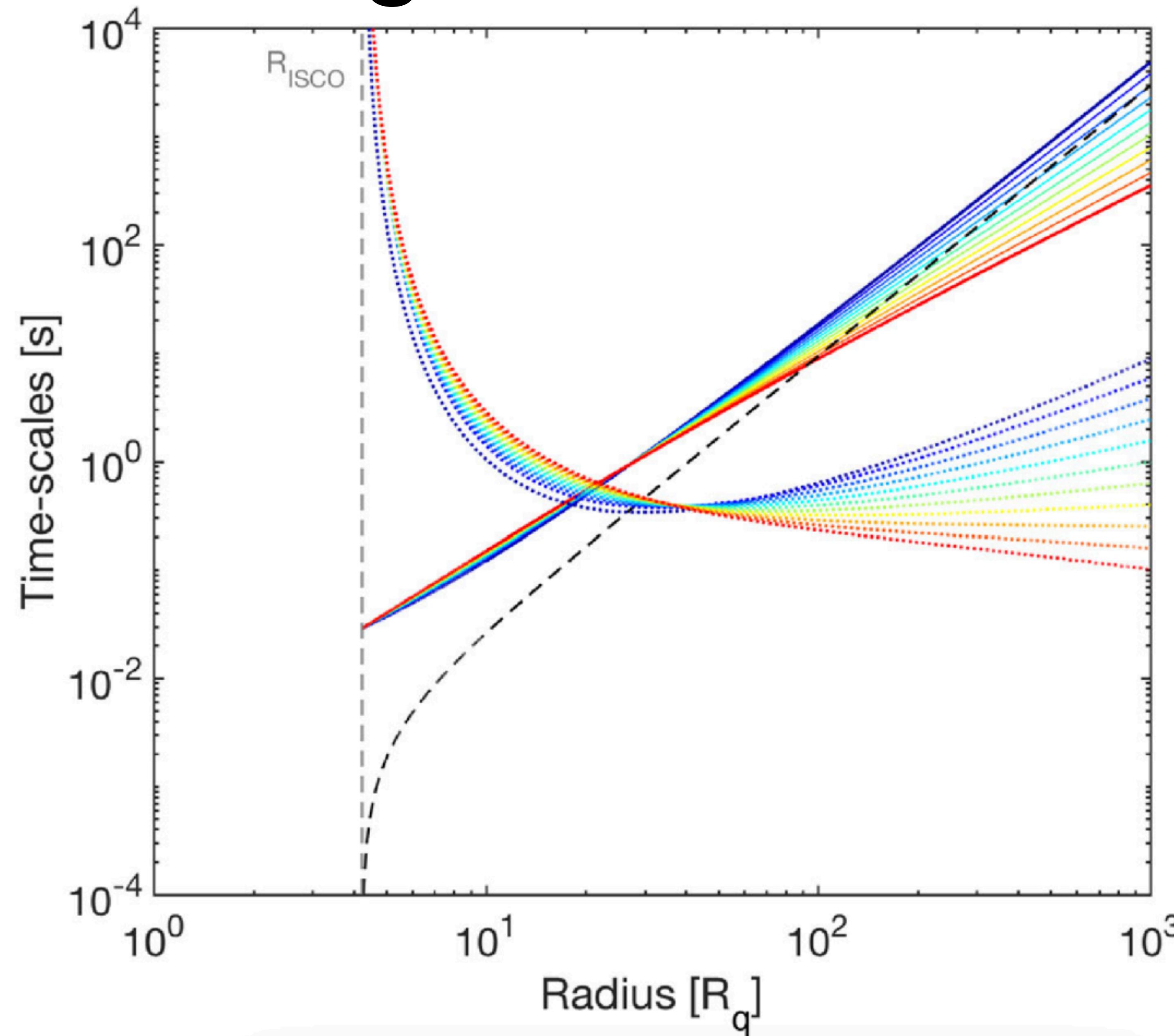


See e.g. for models: Stella & Vietri 1998, 1999; Psaltis+2000; Fragile+ 2001; Ingram+ 2009; Fragile+2012; Bollimpalli+ 2023, 2024

# **Timing features: Quasi Periodic Oscillations QPO**

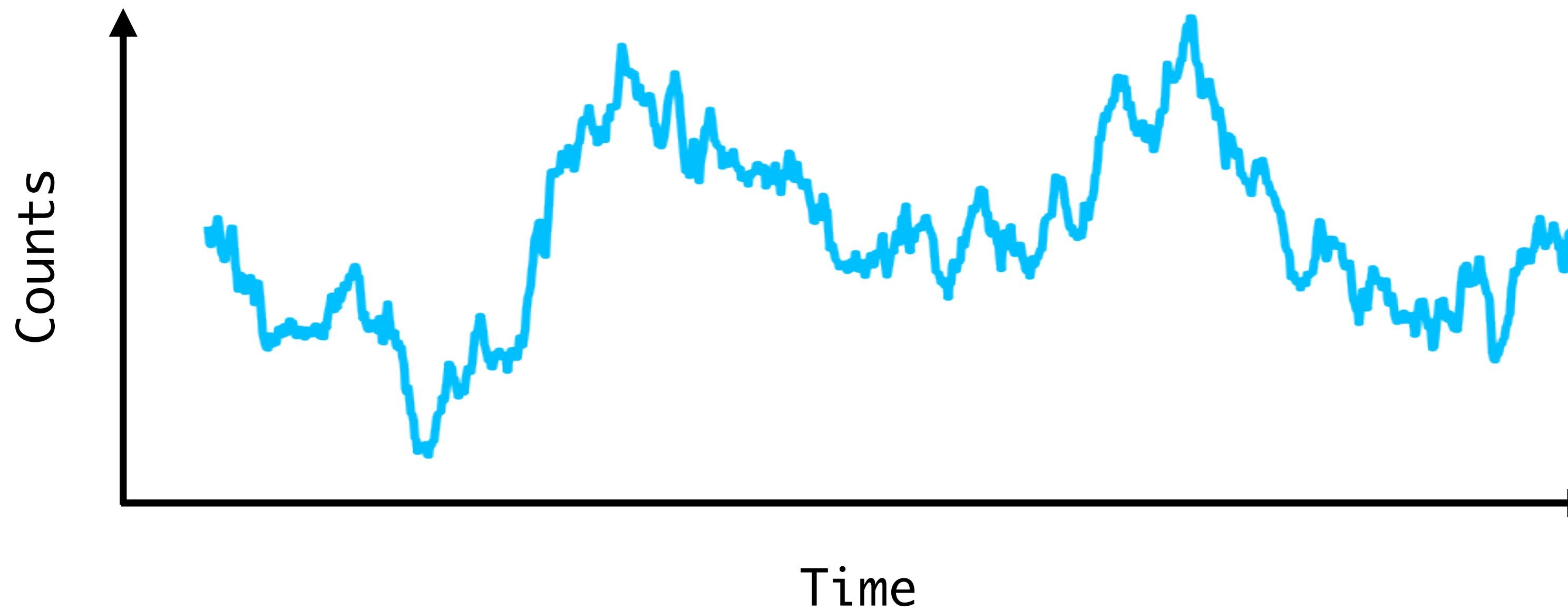
**CAVEATS**

# Alignment time



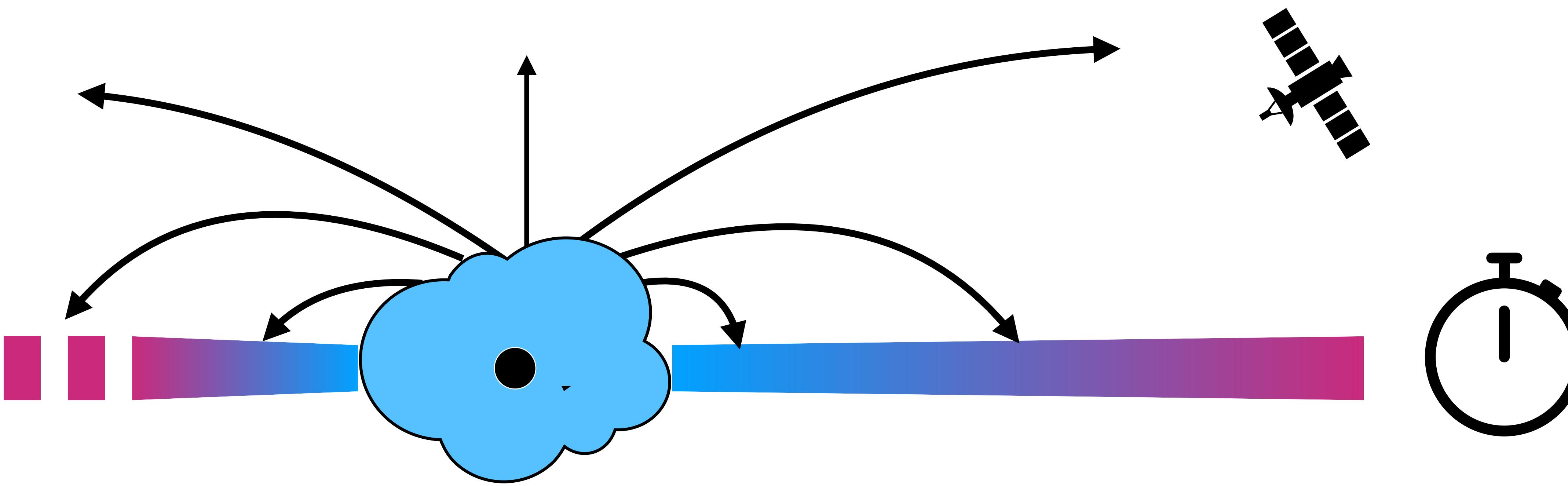
# Spectral-Timing features: X-ray time lag

# Timing analysis

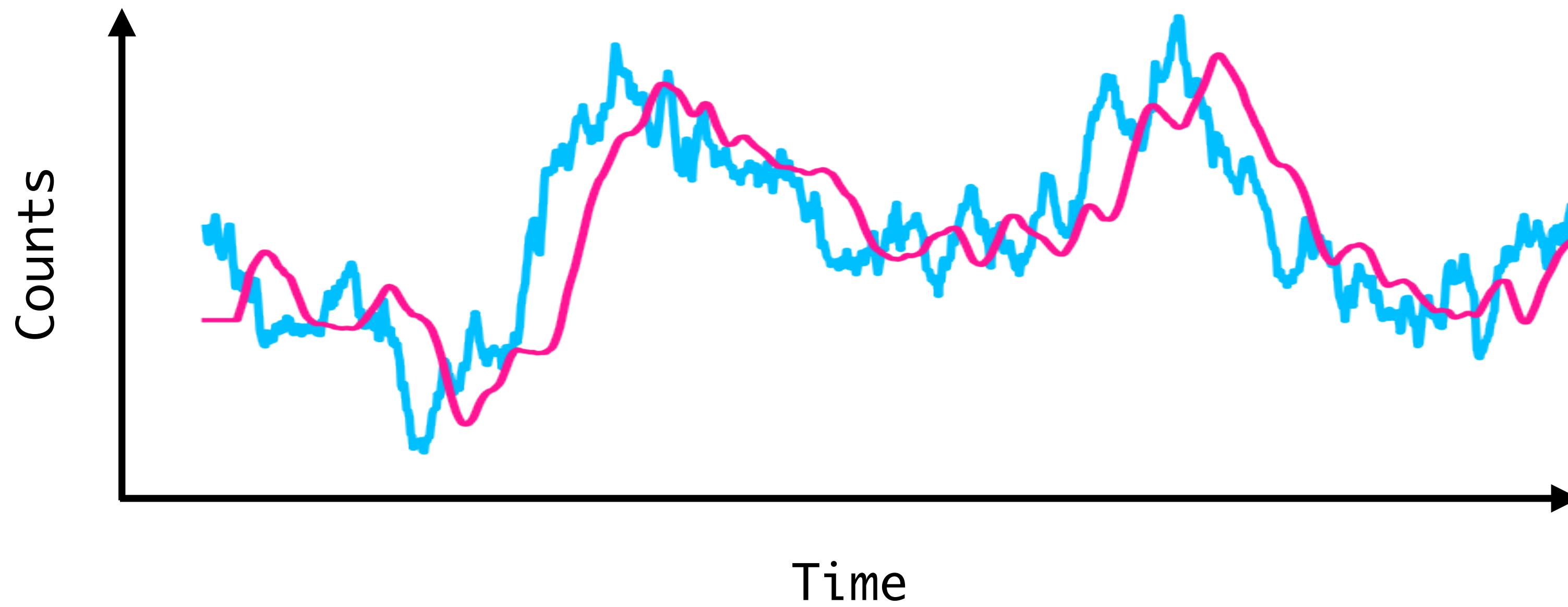


# Simulated light curve

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



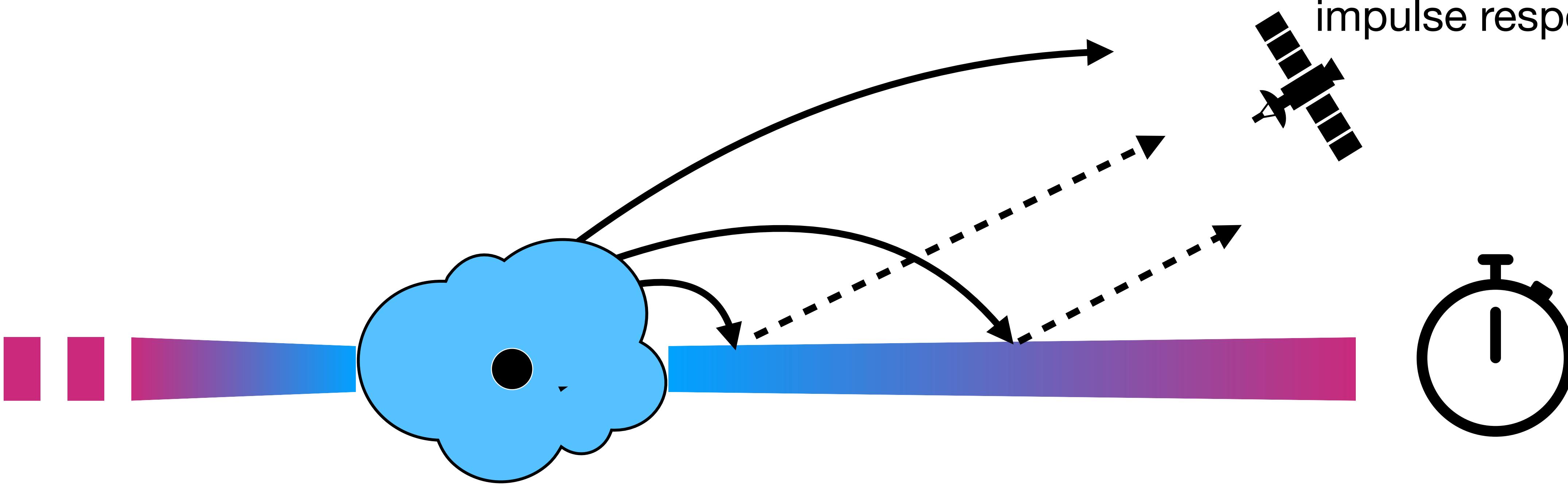
# Timing analysis



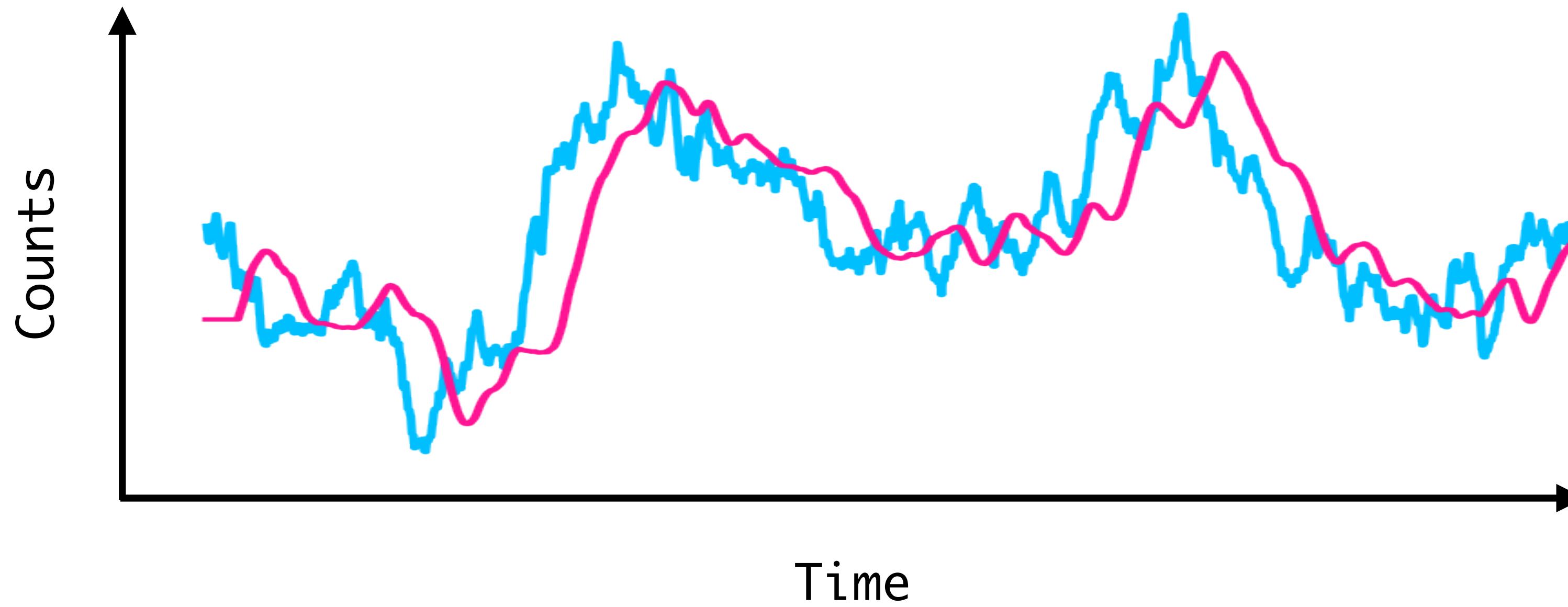
# Simulated light curve

**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



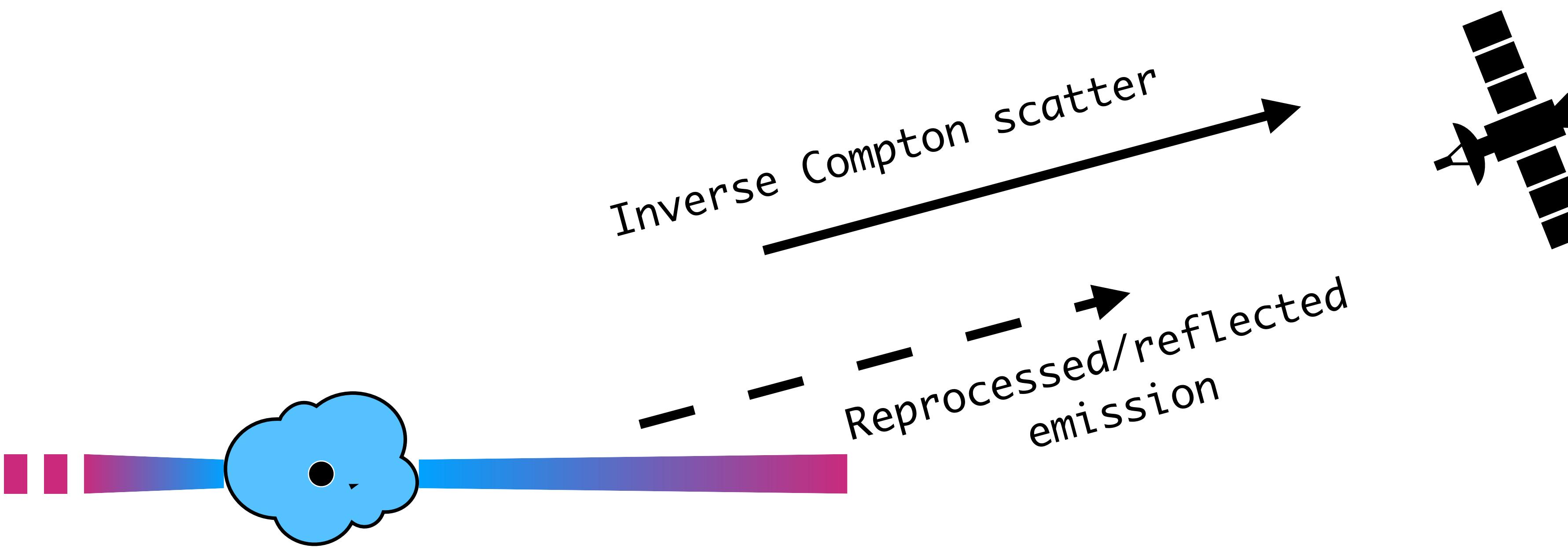
# Timing analysis



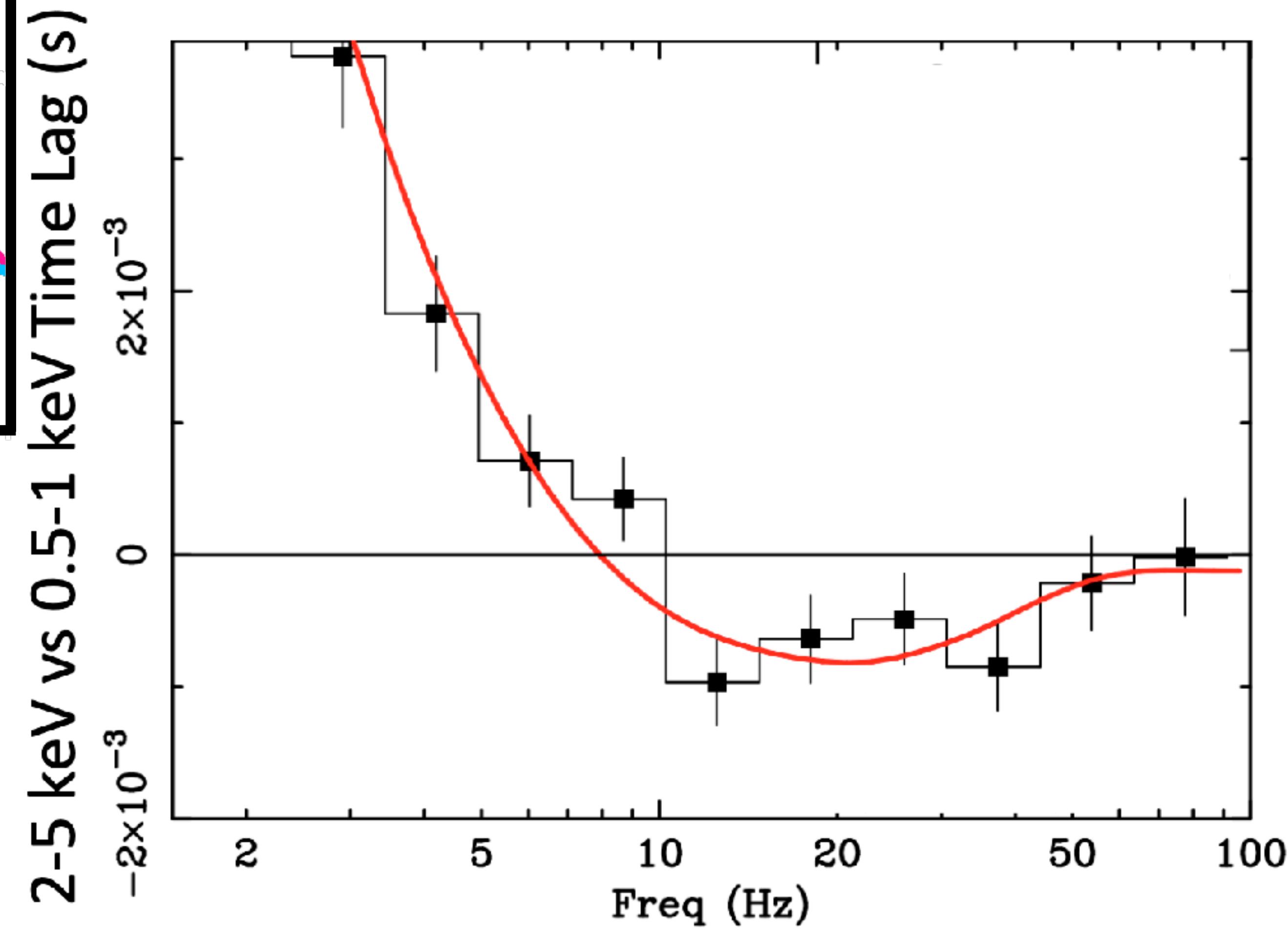
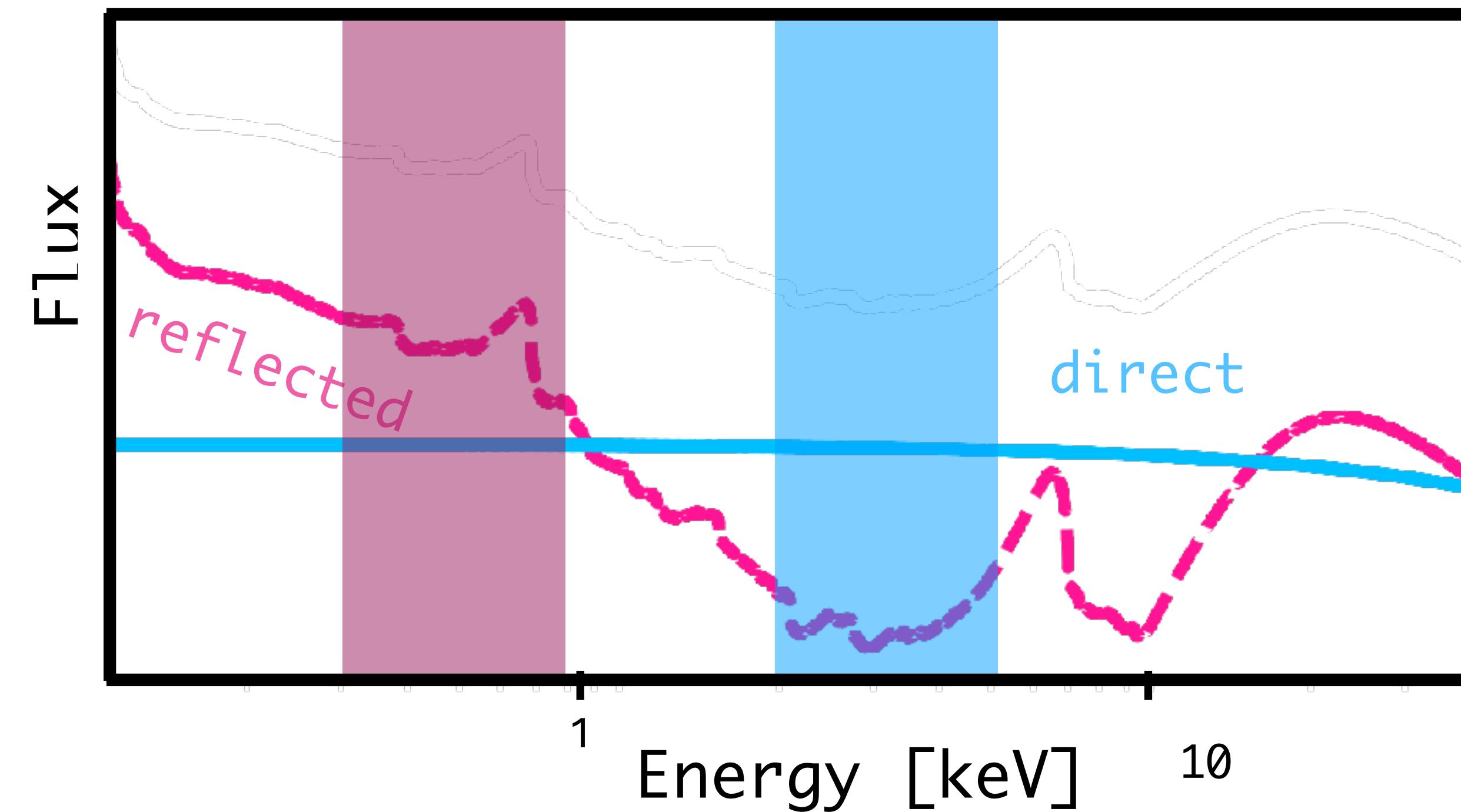
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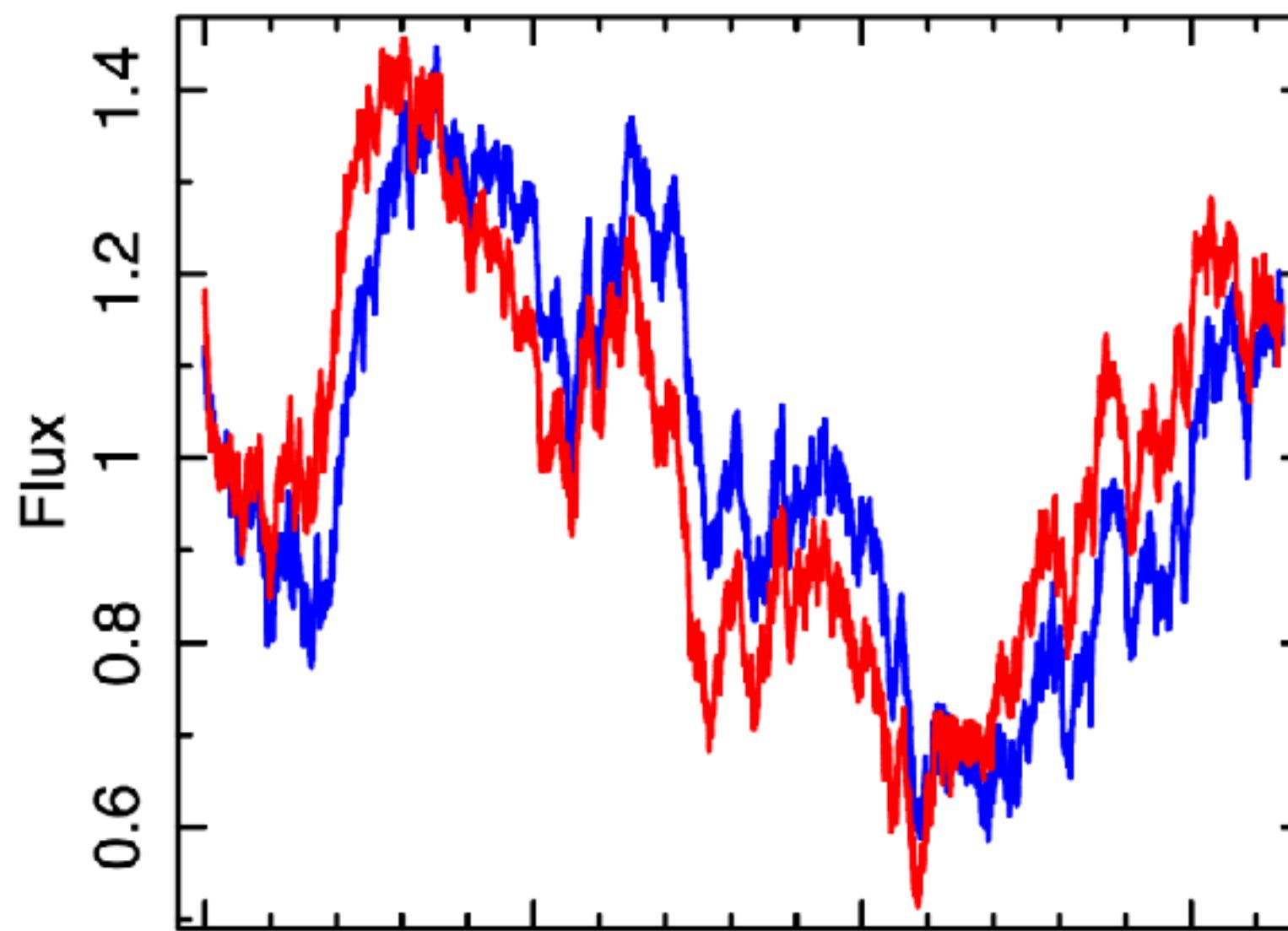
# Time lags in Black Hole Binaries



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

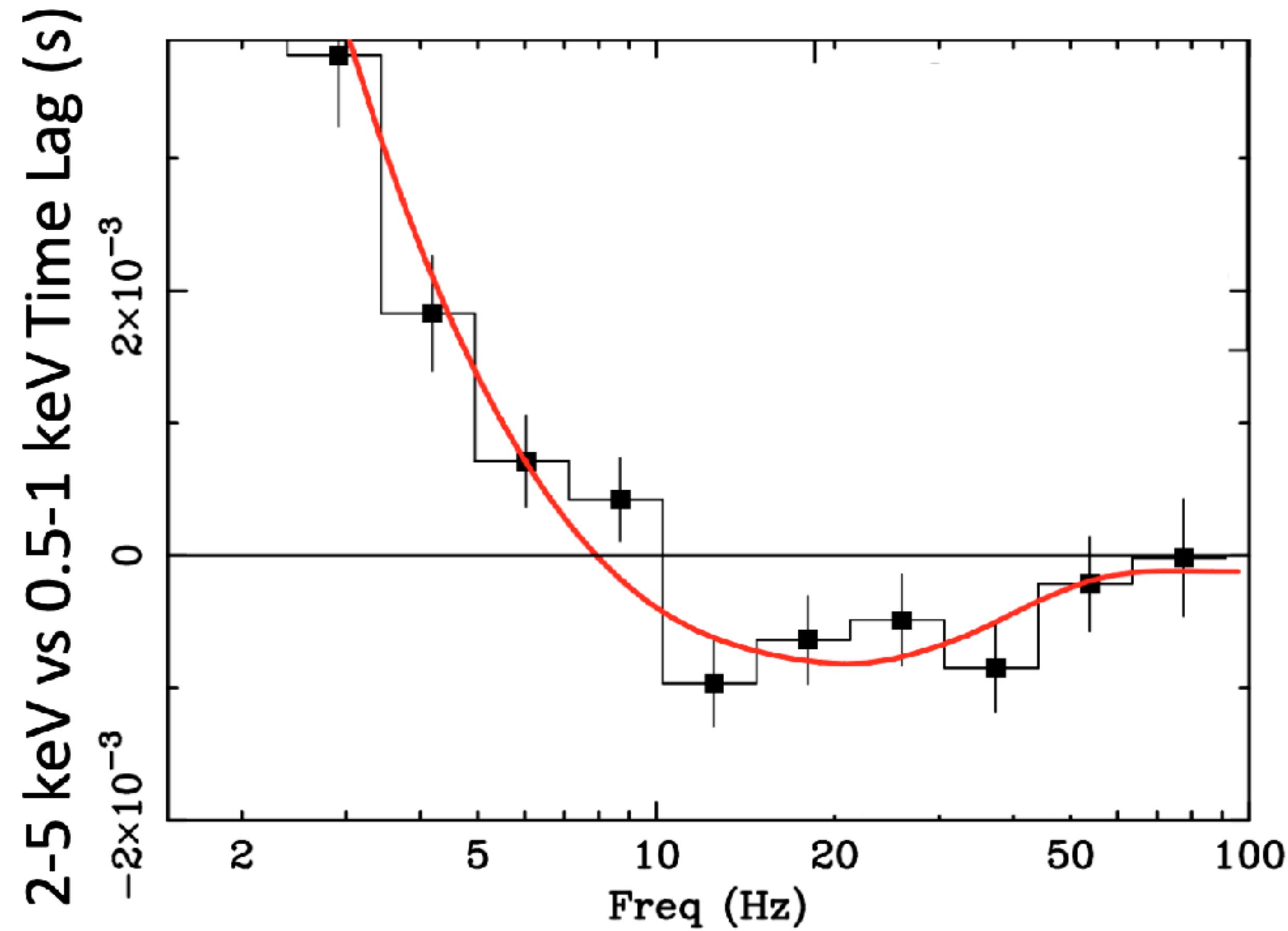
# Time lags in Black Hole Binaries



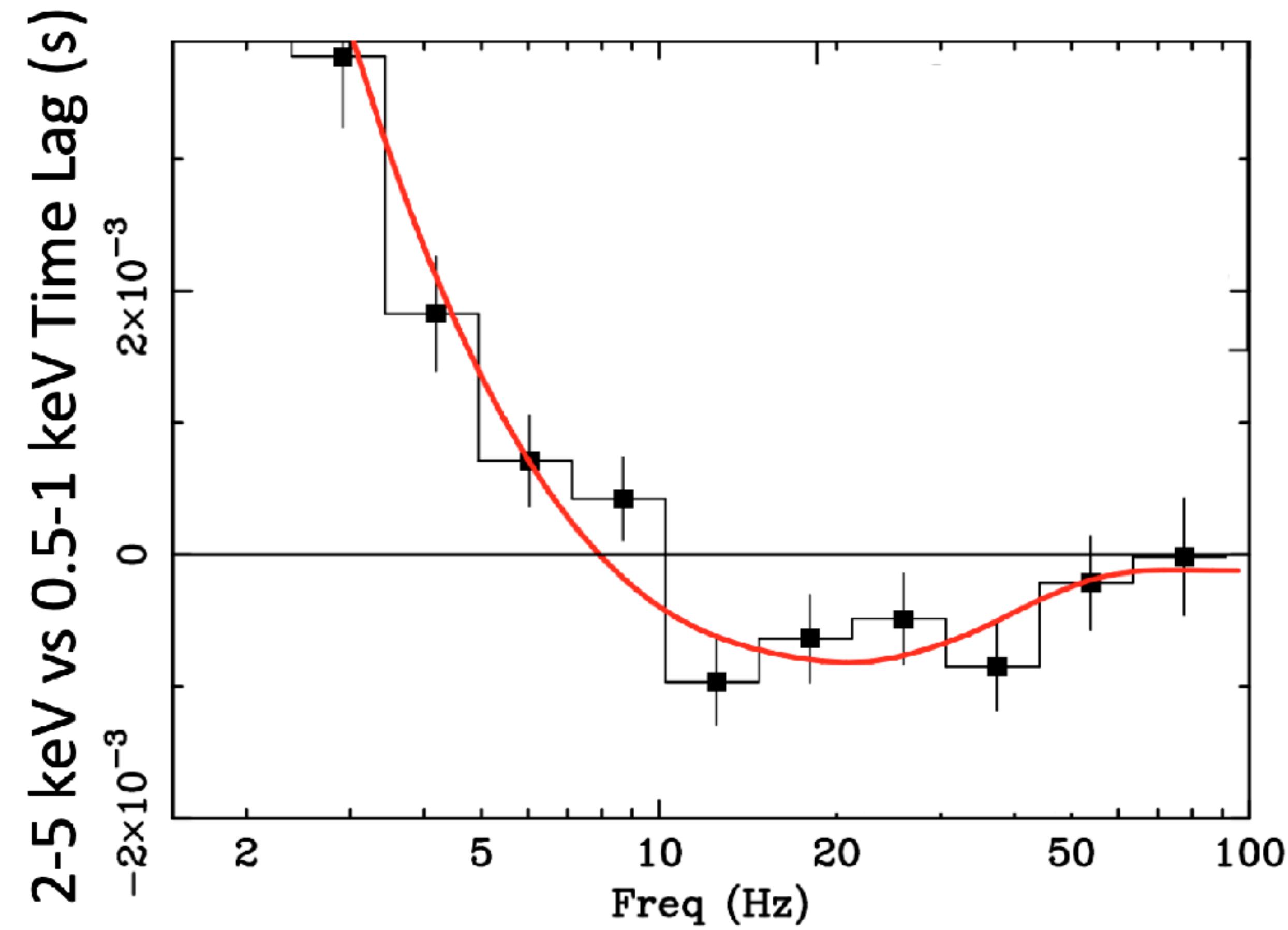
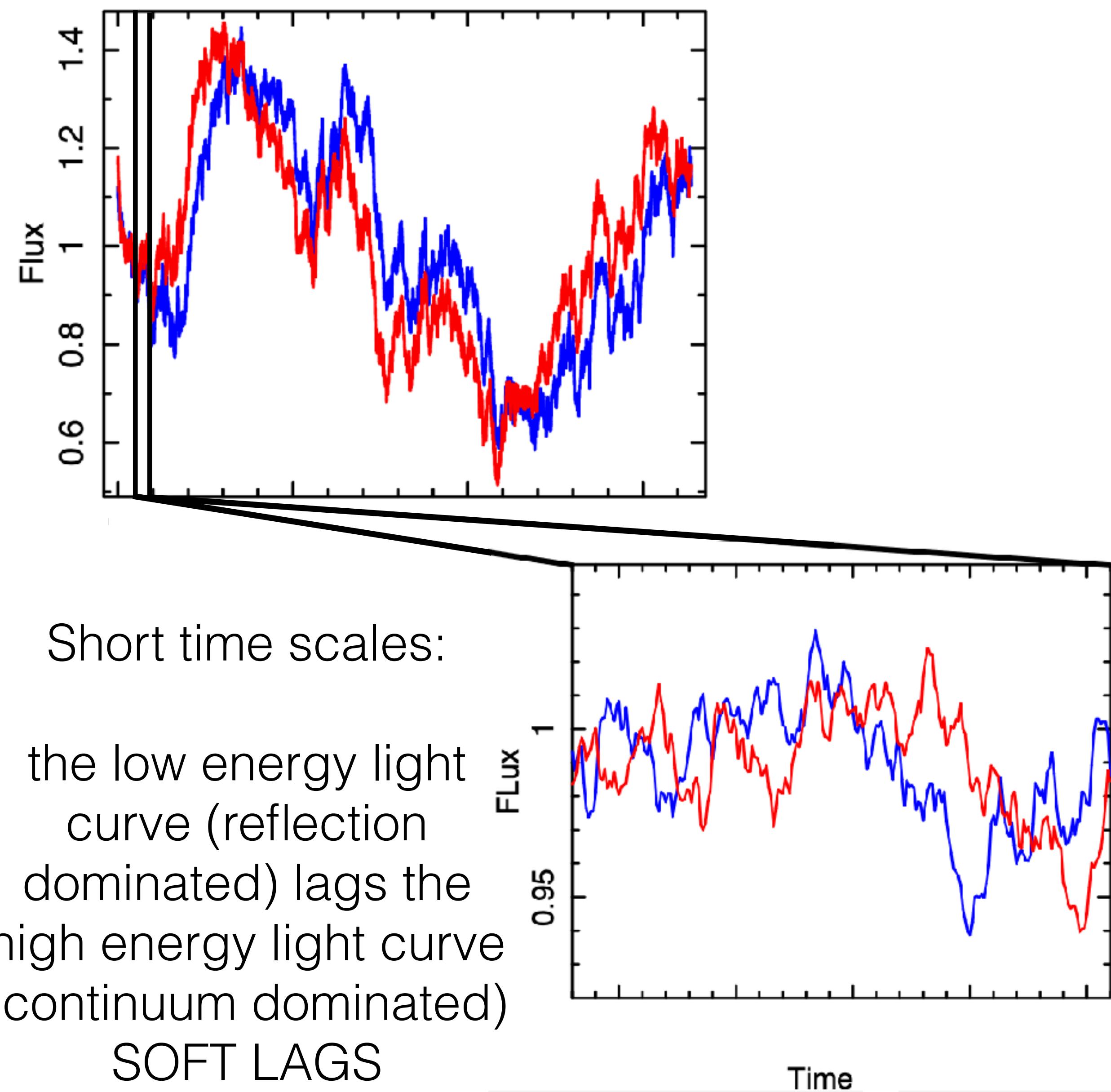
Time

Long time scales:

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

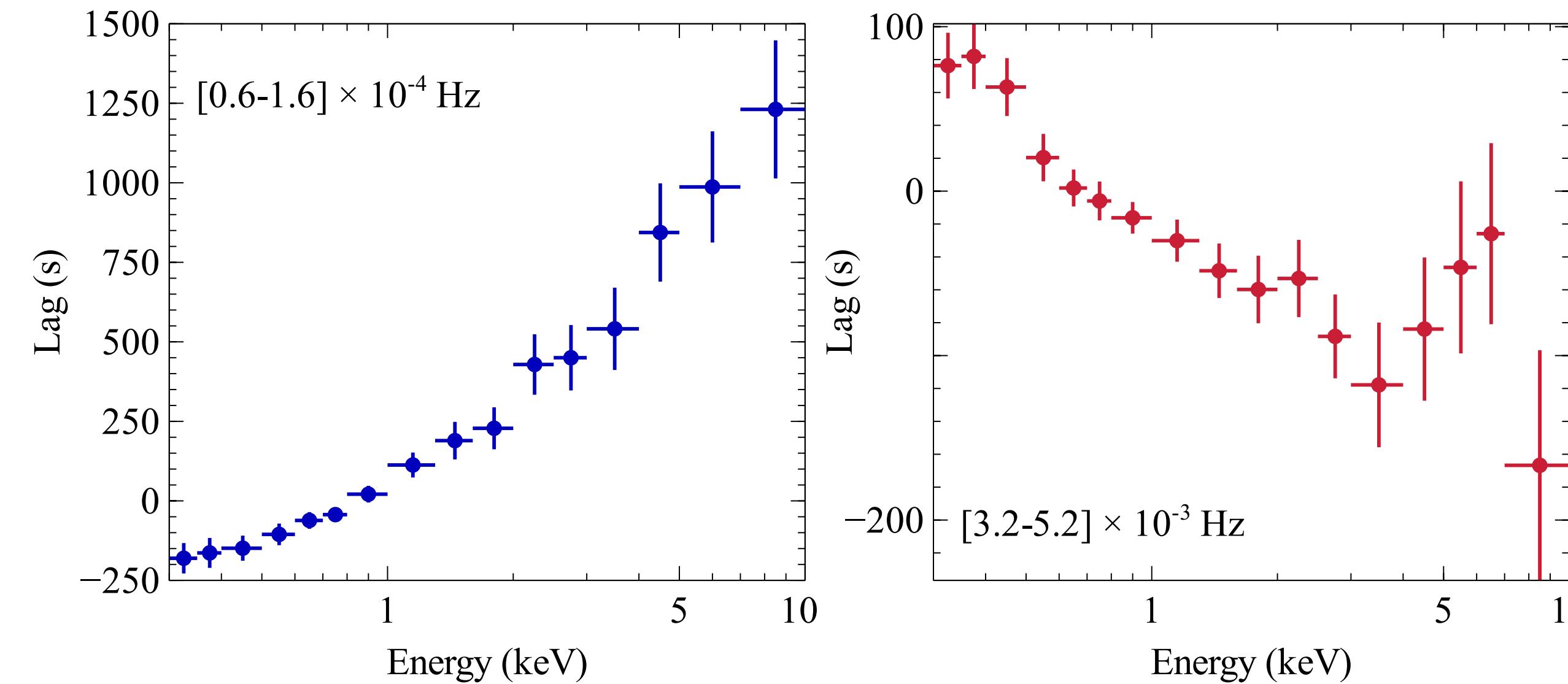
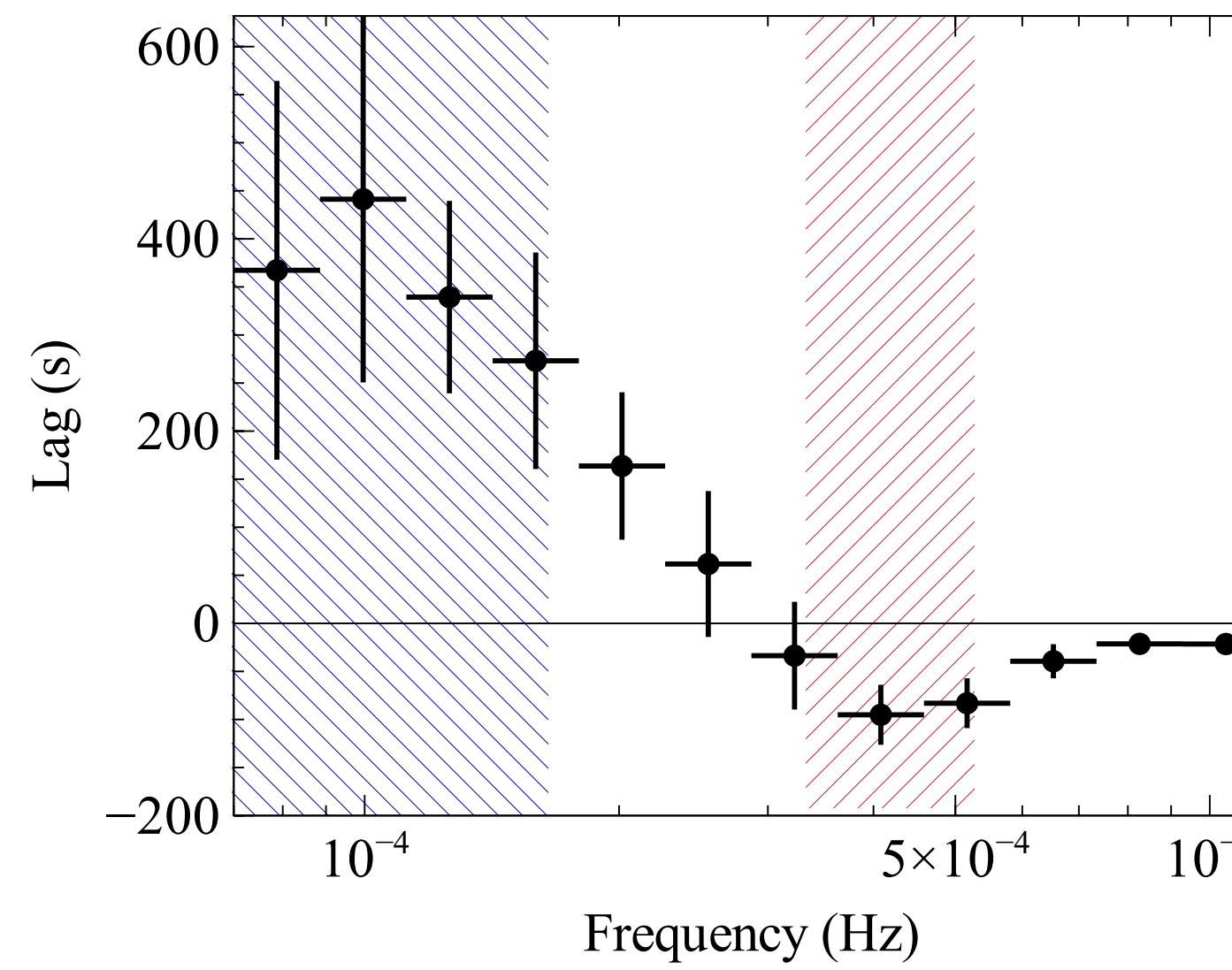


# Time lags in Black Hole Binaries

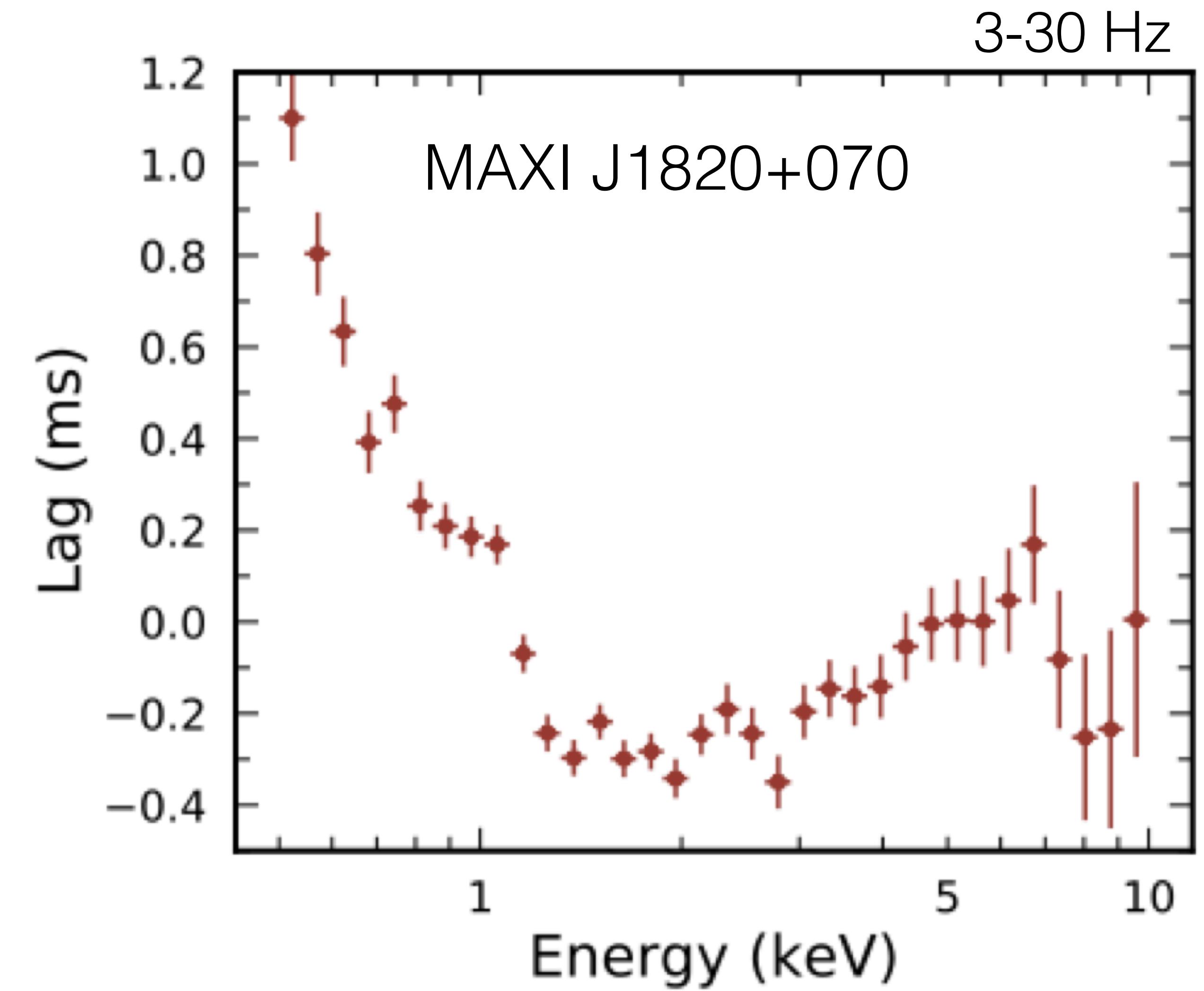
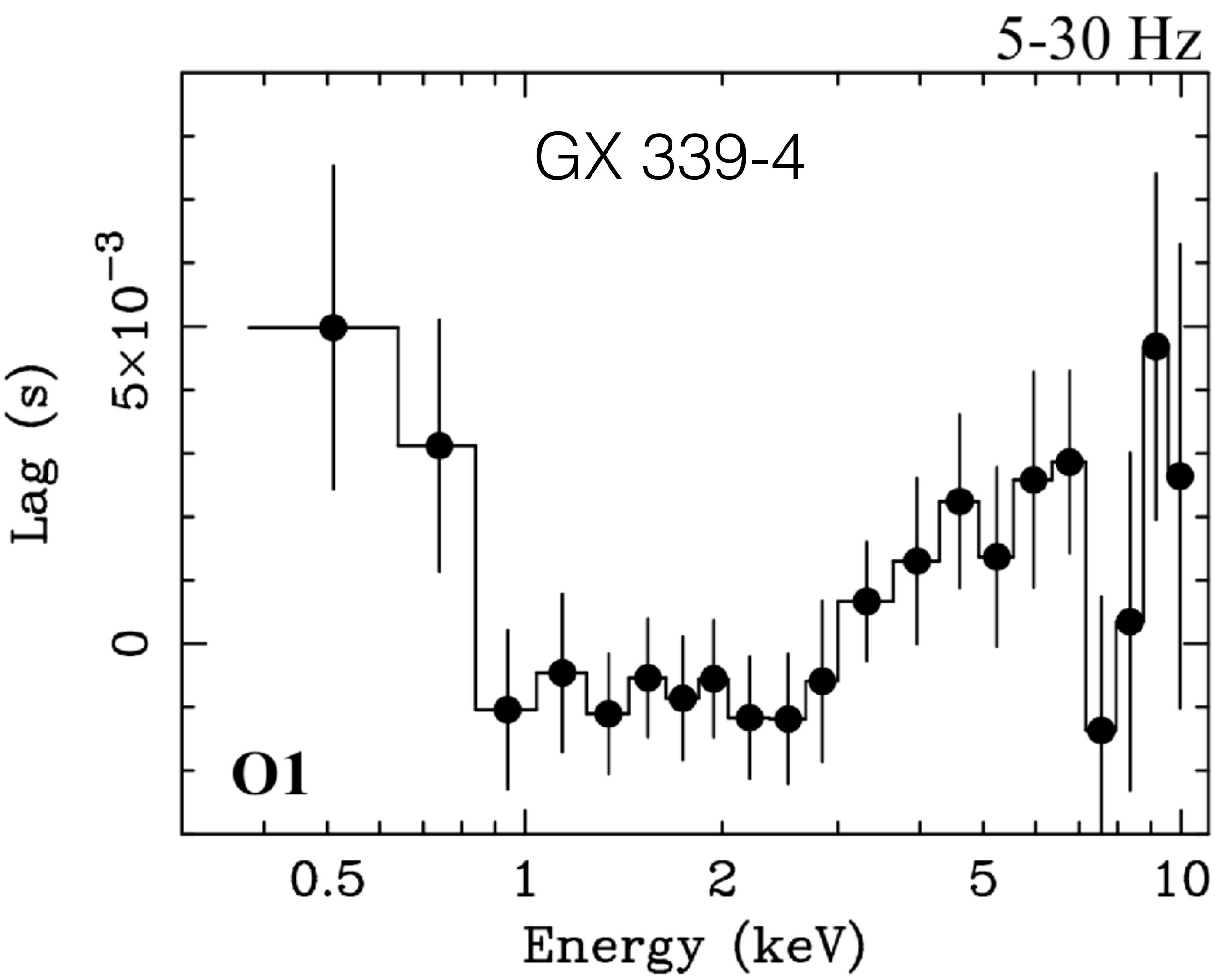


# Lag vs Energy

**AGN**  
Ark 564  
 $M \simeq 10^6 M_\odot$   
Kara+ 2013

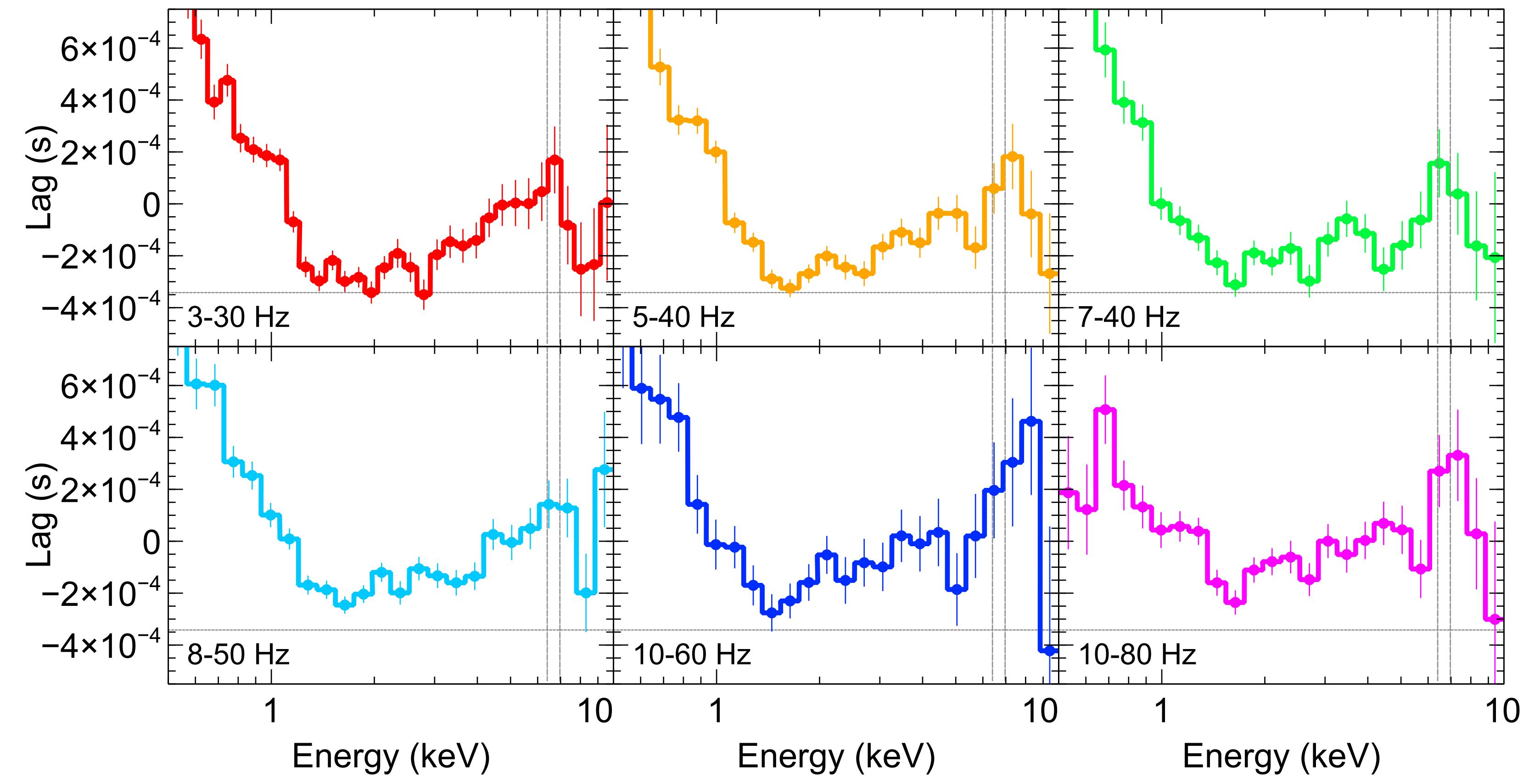
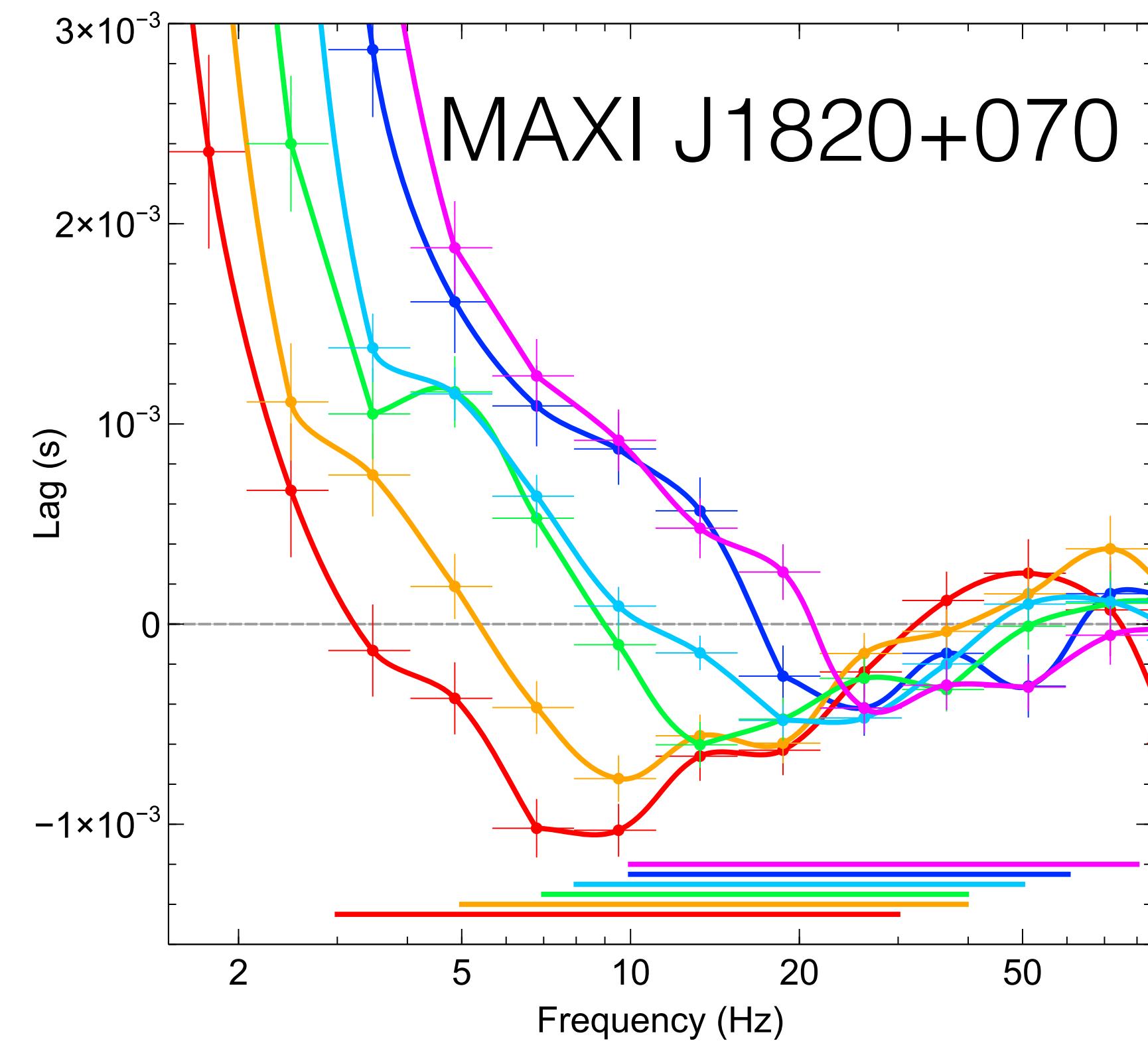


# Lag vs Energy

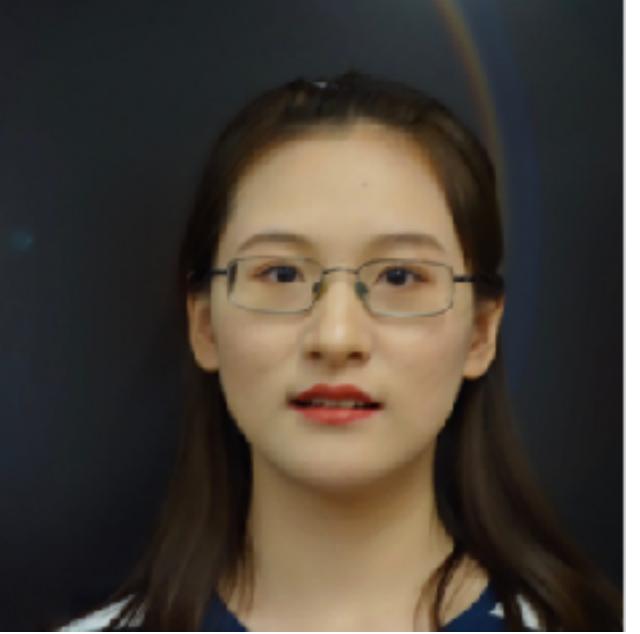


# Time lags in Black Hole Binaries

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

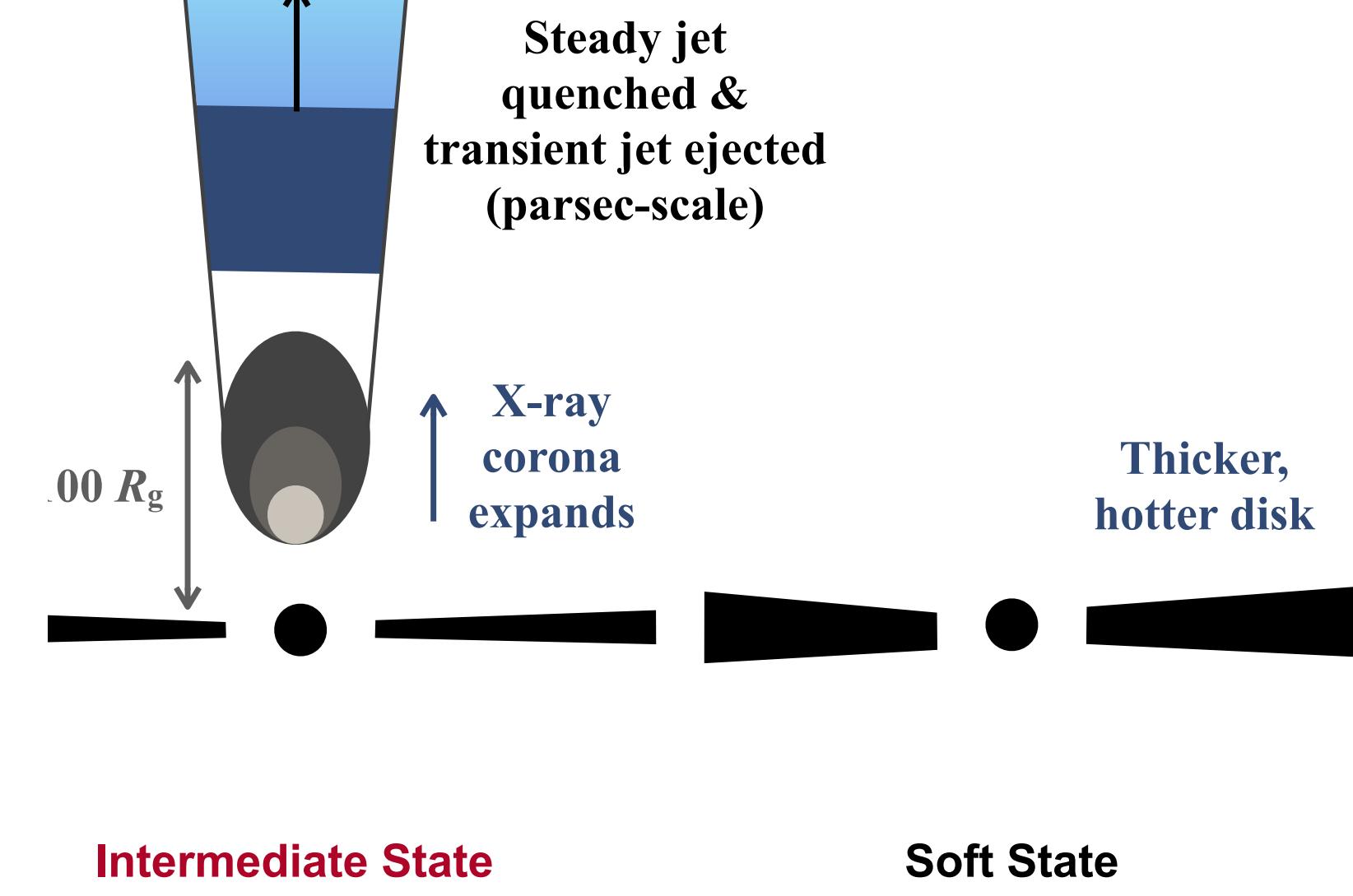
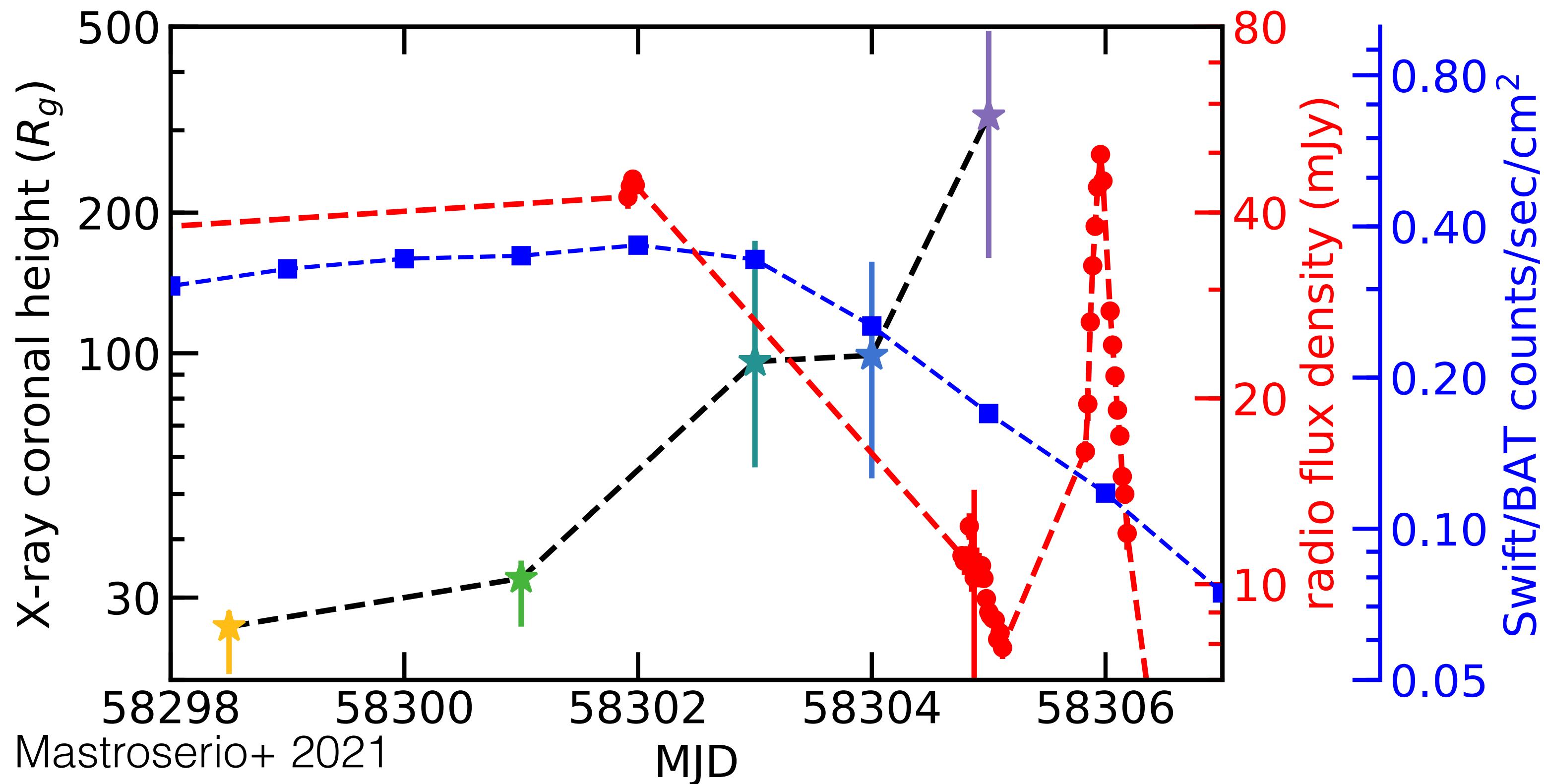
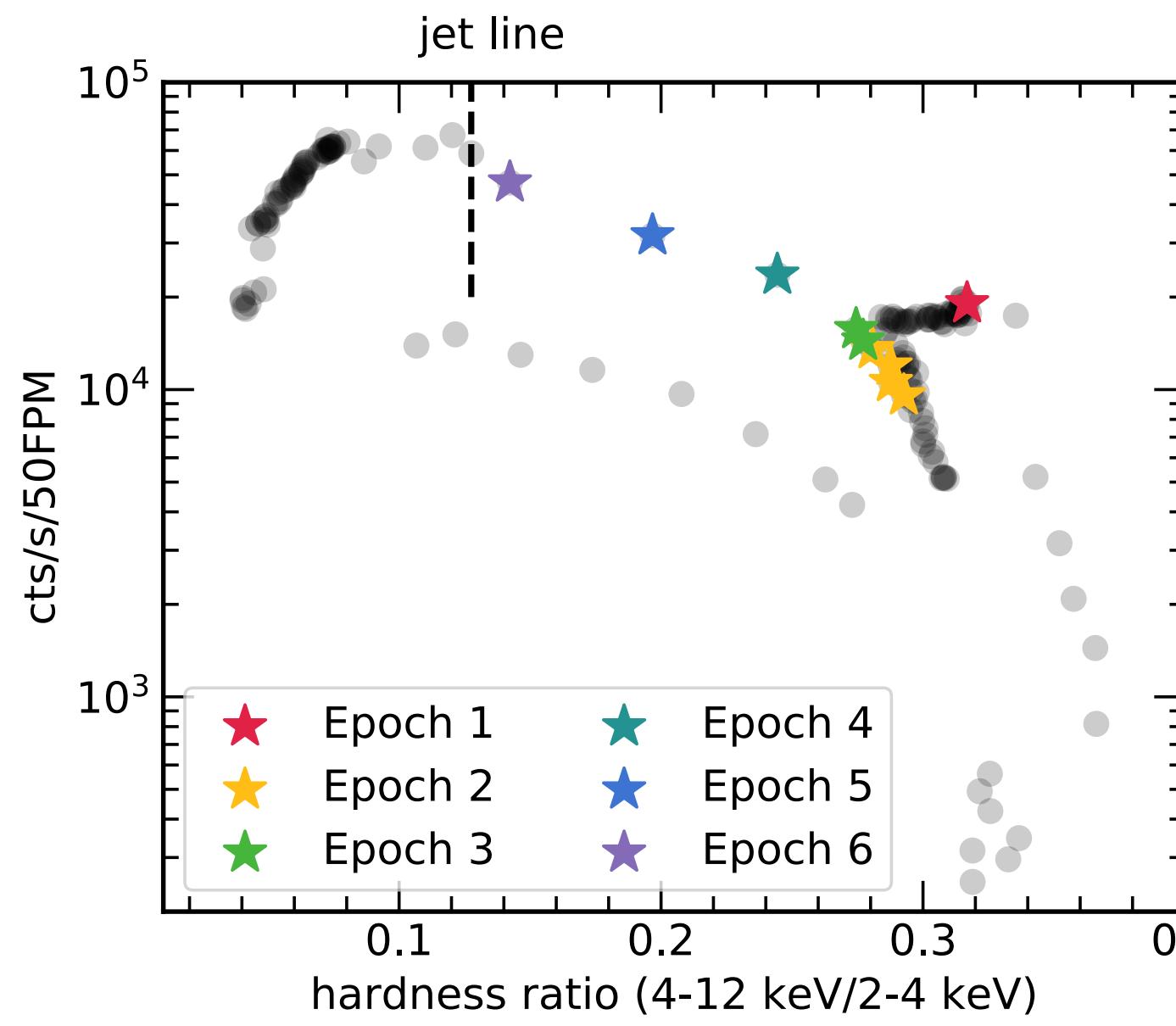


# MAXI J 1820+070

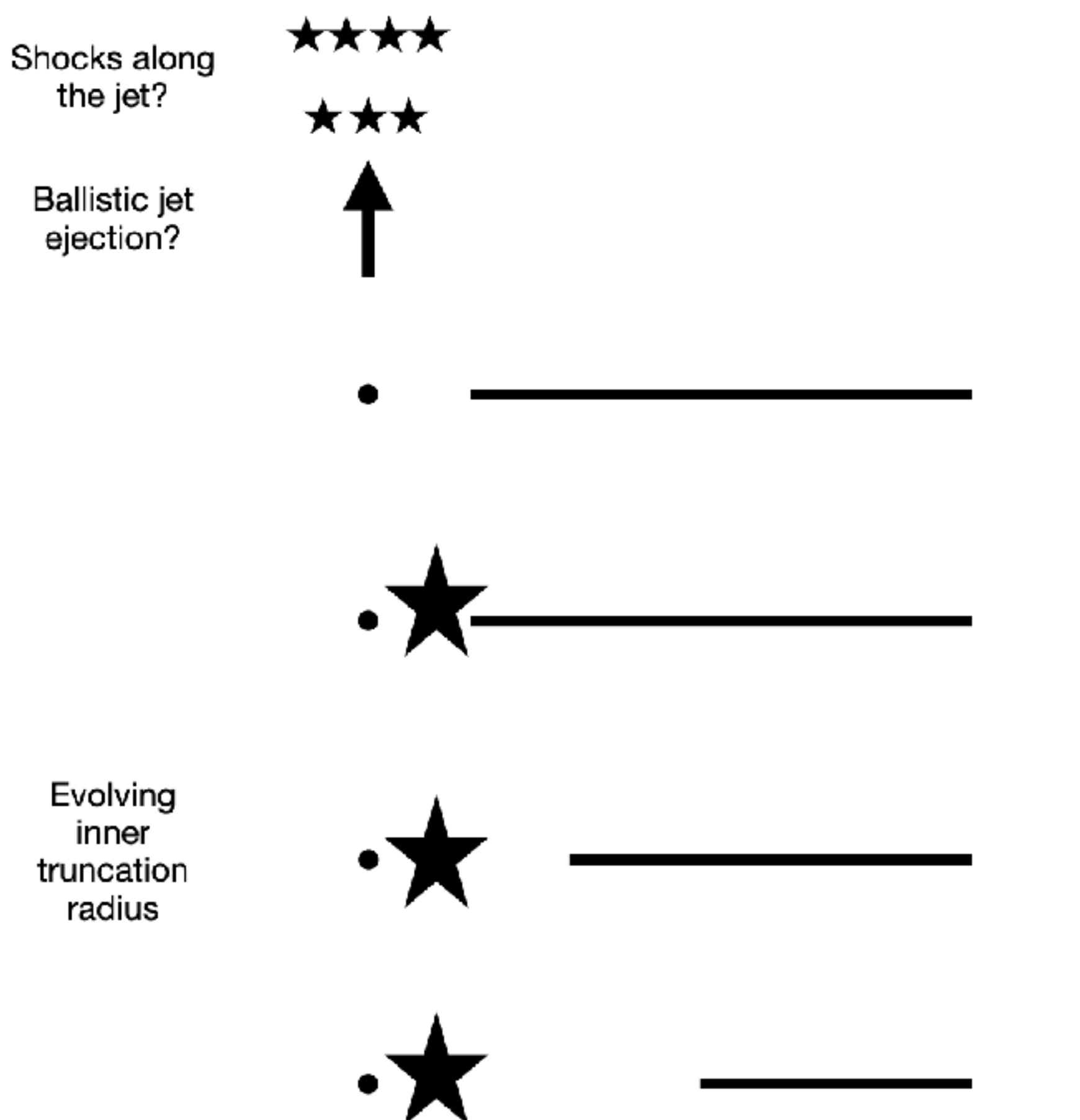


RESULT: The height of the lamppost source increase during the transition until the jet is launched

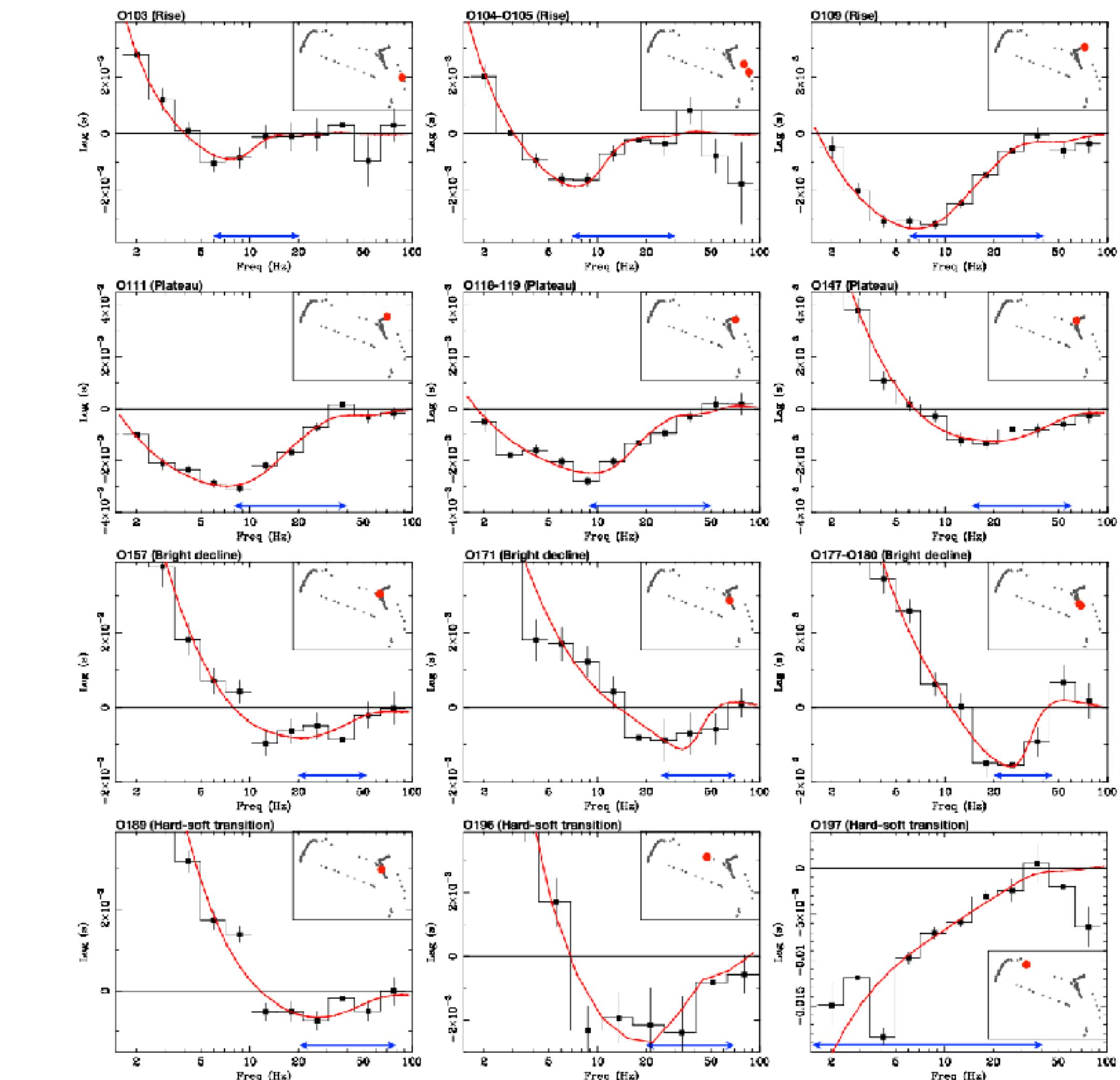
Jingyi Wang (MIT)



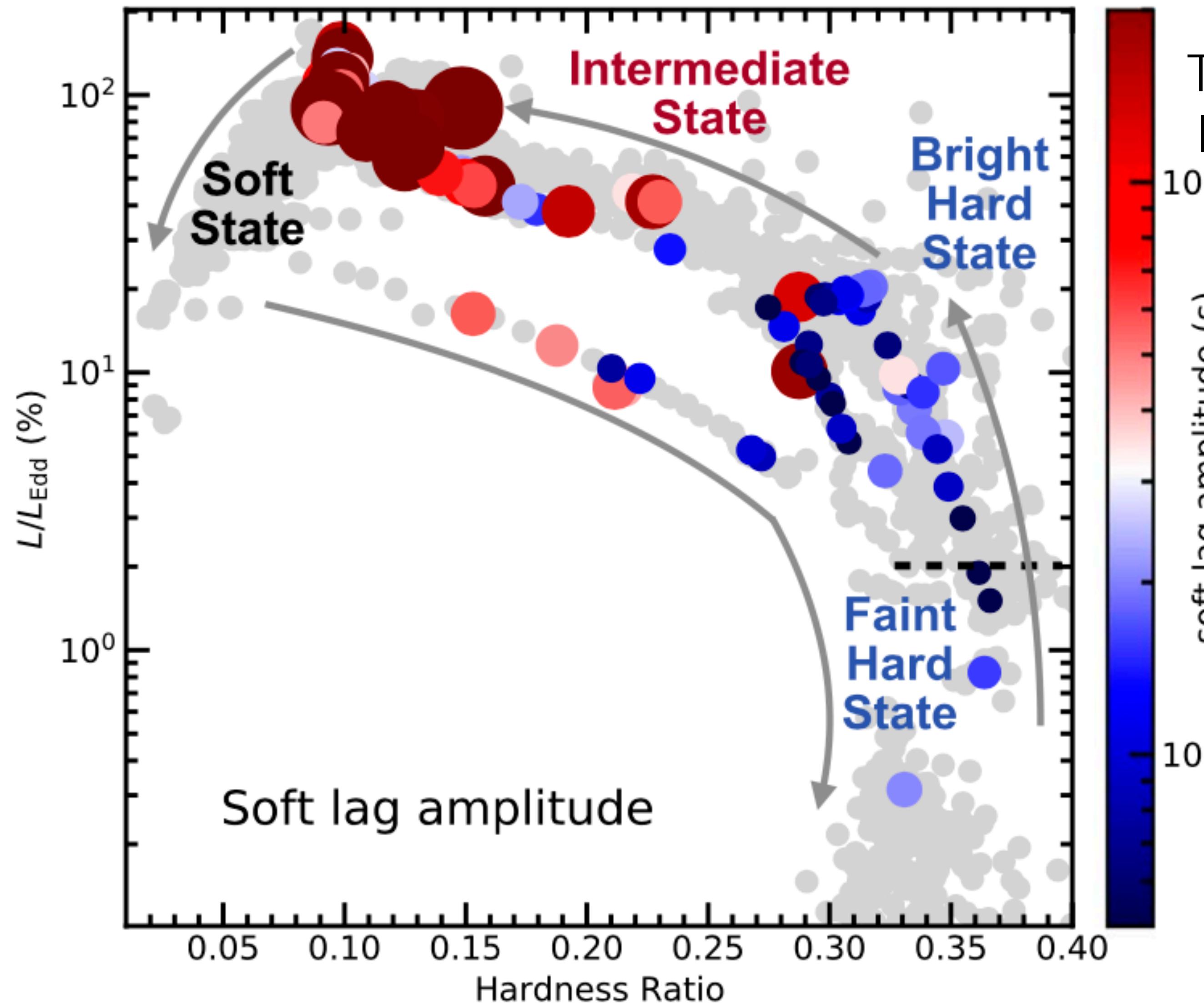
# Interpretation of the reverberation lags during the outburst



Hard State      Transition

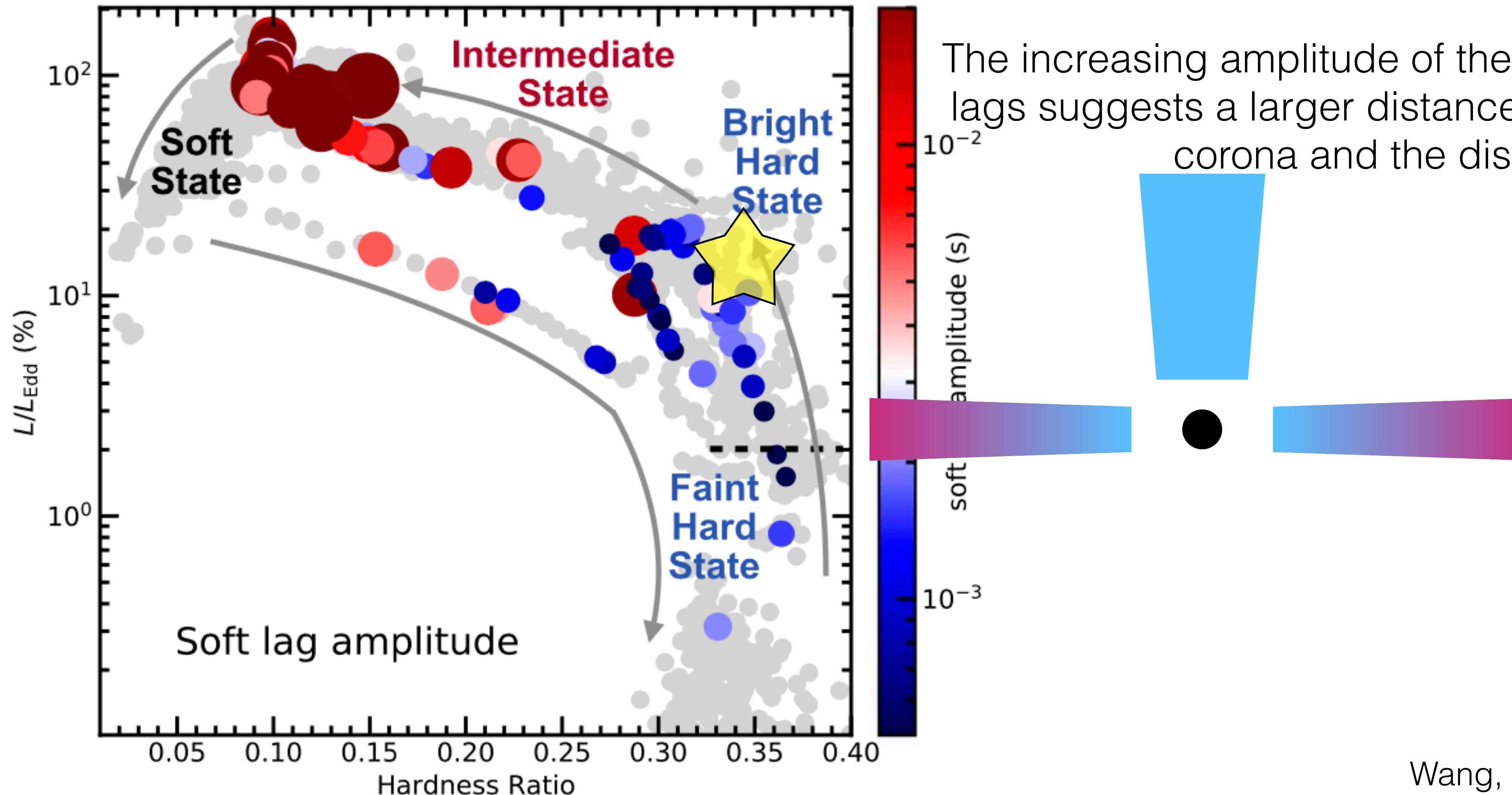


# Interpretation of the reverberation lags during the outburst

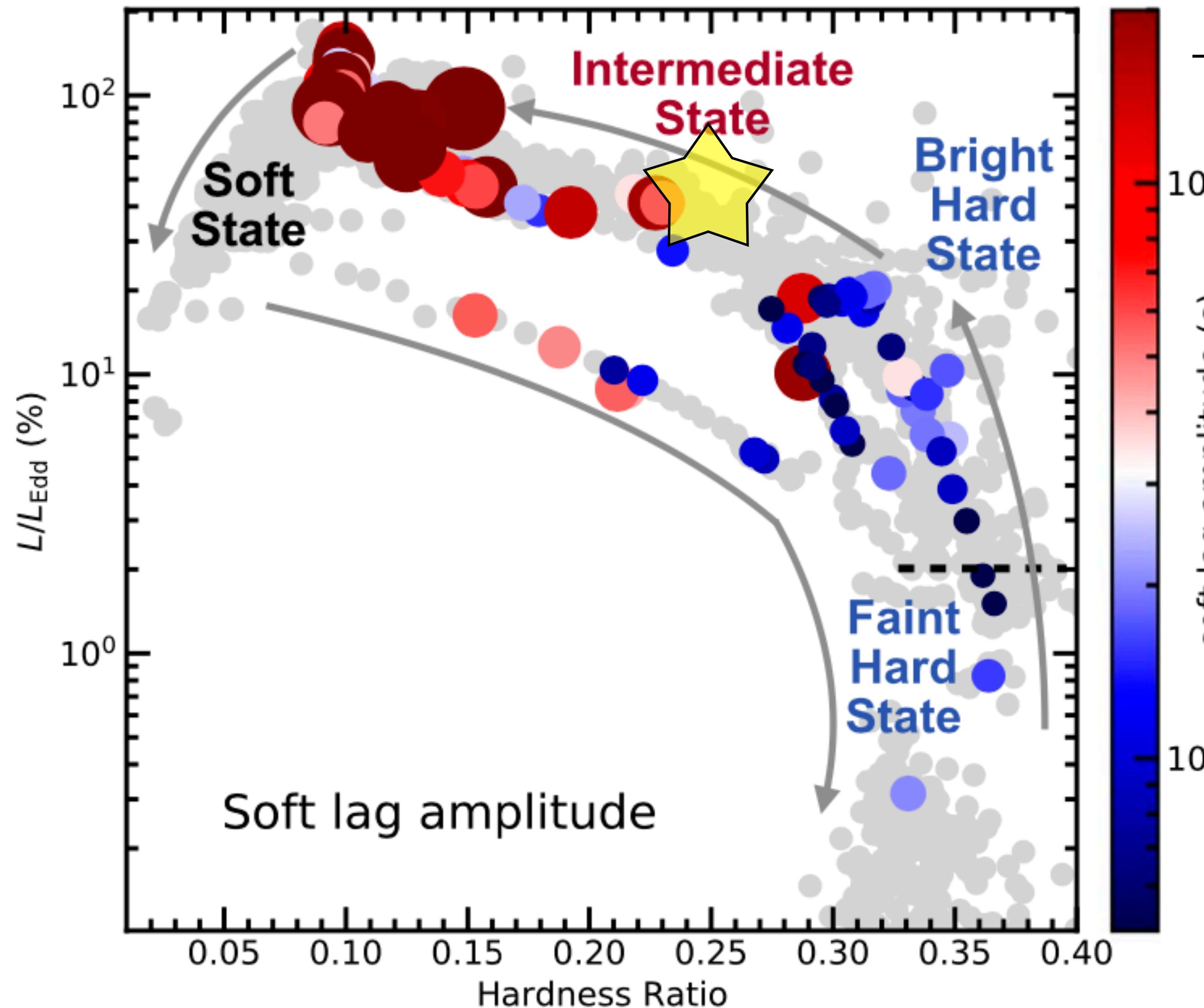


The increasing amplitude of the reverberation lags suggests a larger distance between the corona and the disk

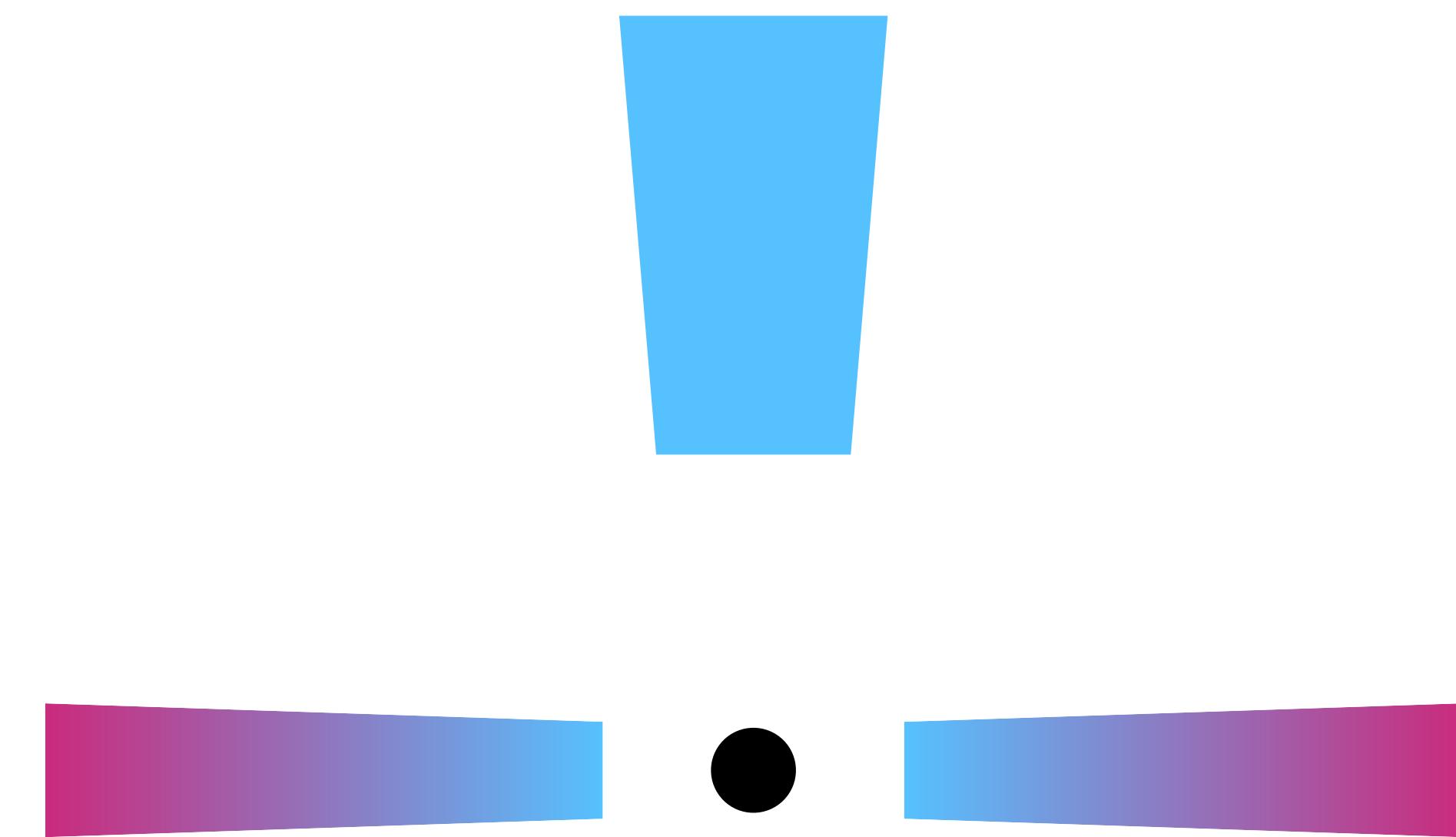
# Interpretation of the reverberation lags during the outburst



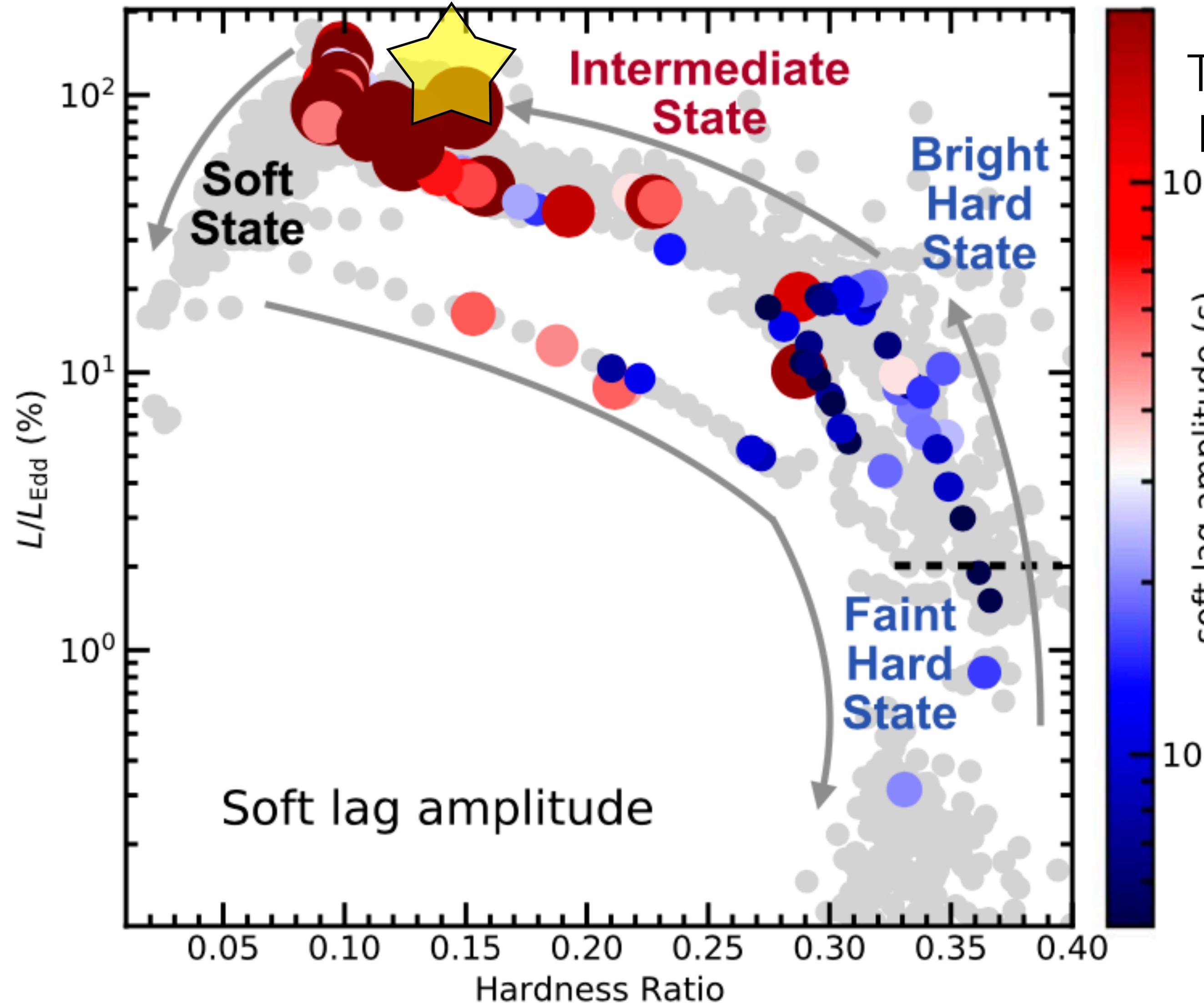
# Interpretation of the reverberation lags during the outburst



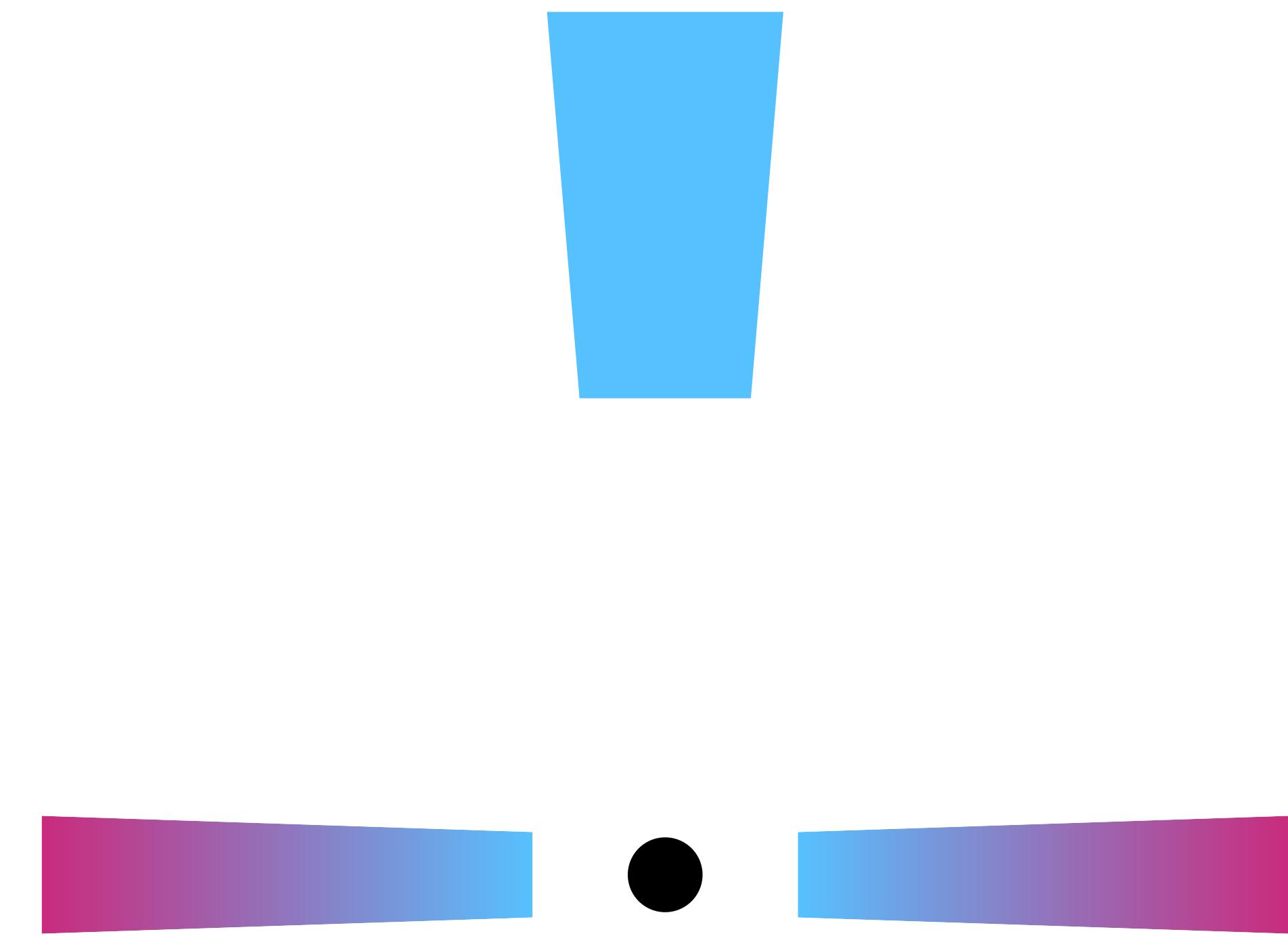
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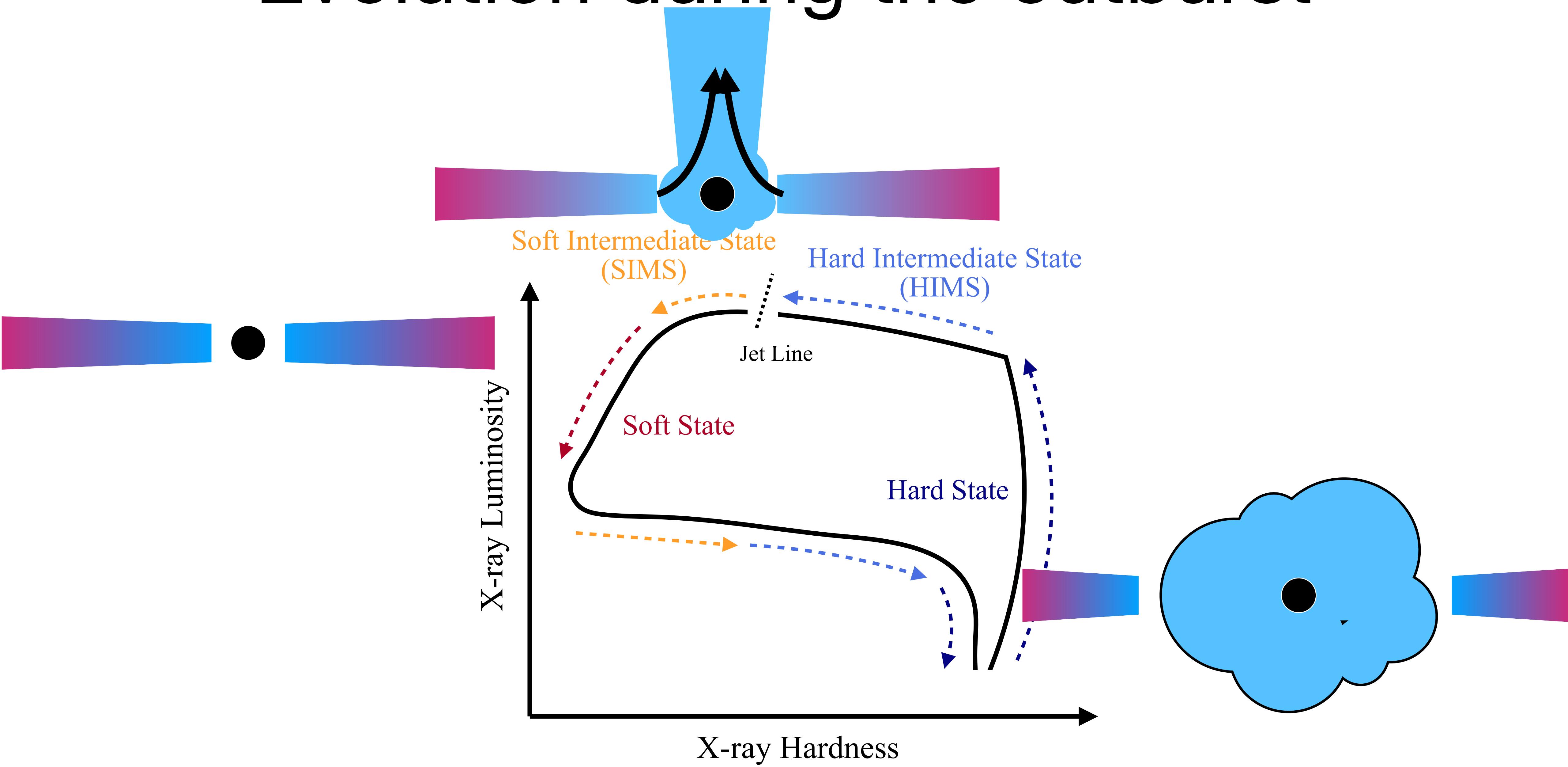
# Interpretation of the reverberation lags during the outburst



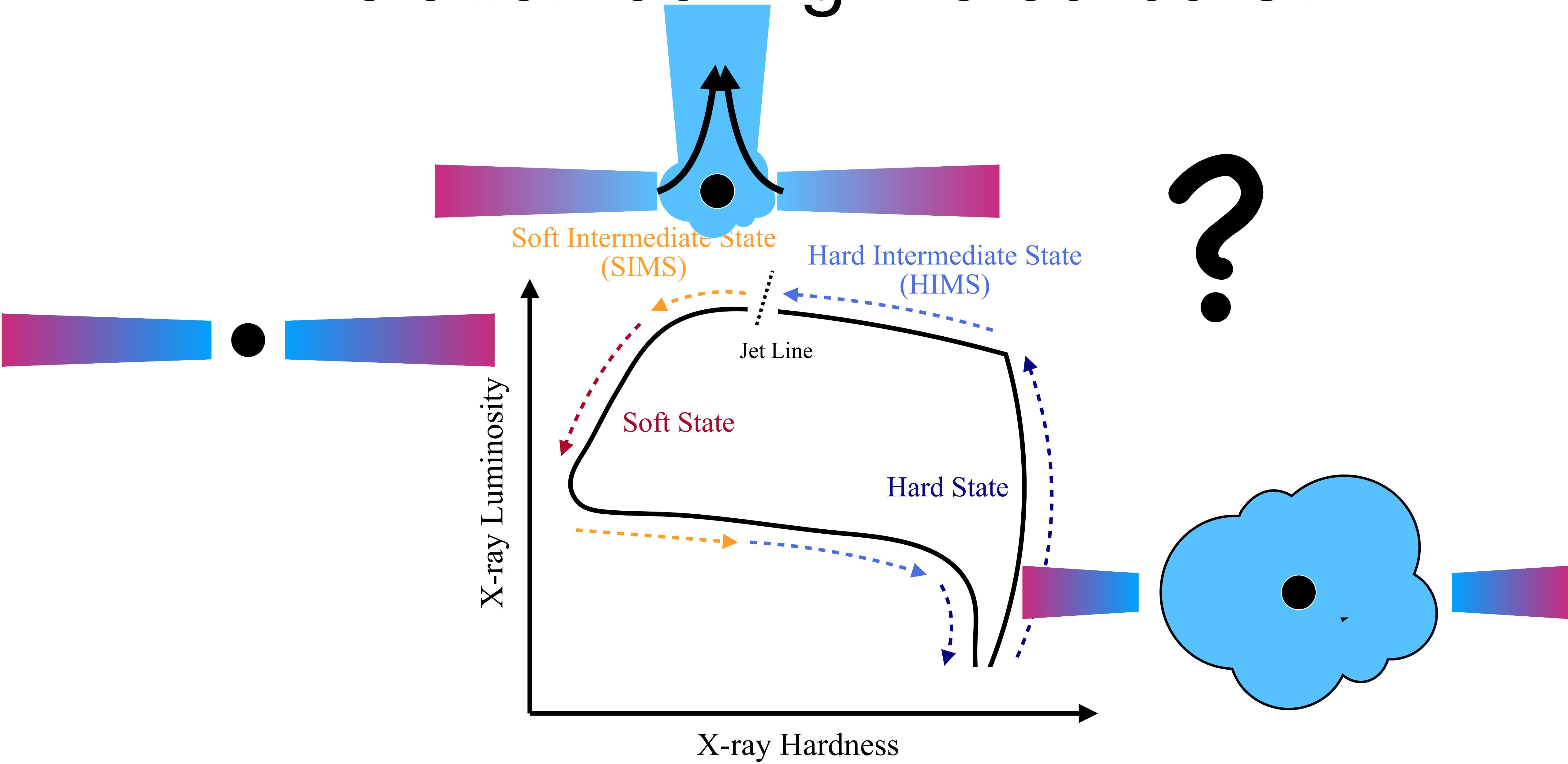
The increasing amplitude of the reverberation lags suggests a larger distance between the corona and the disk



# Evolution during the outburst



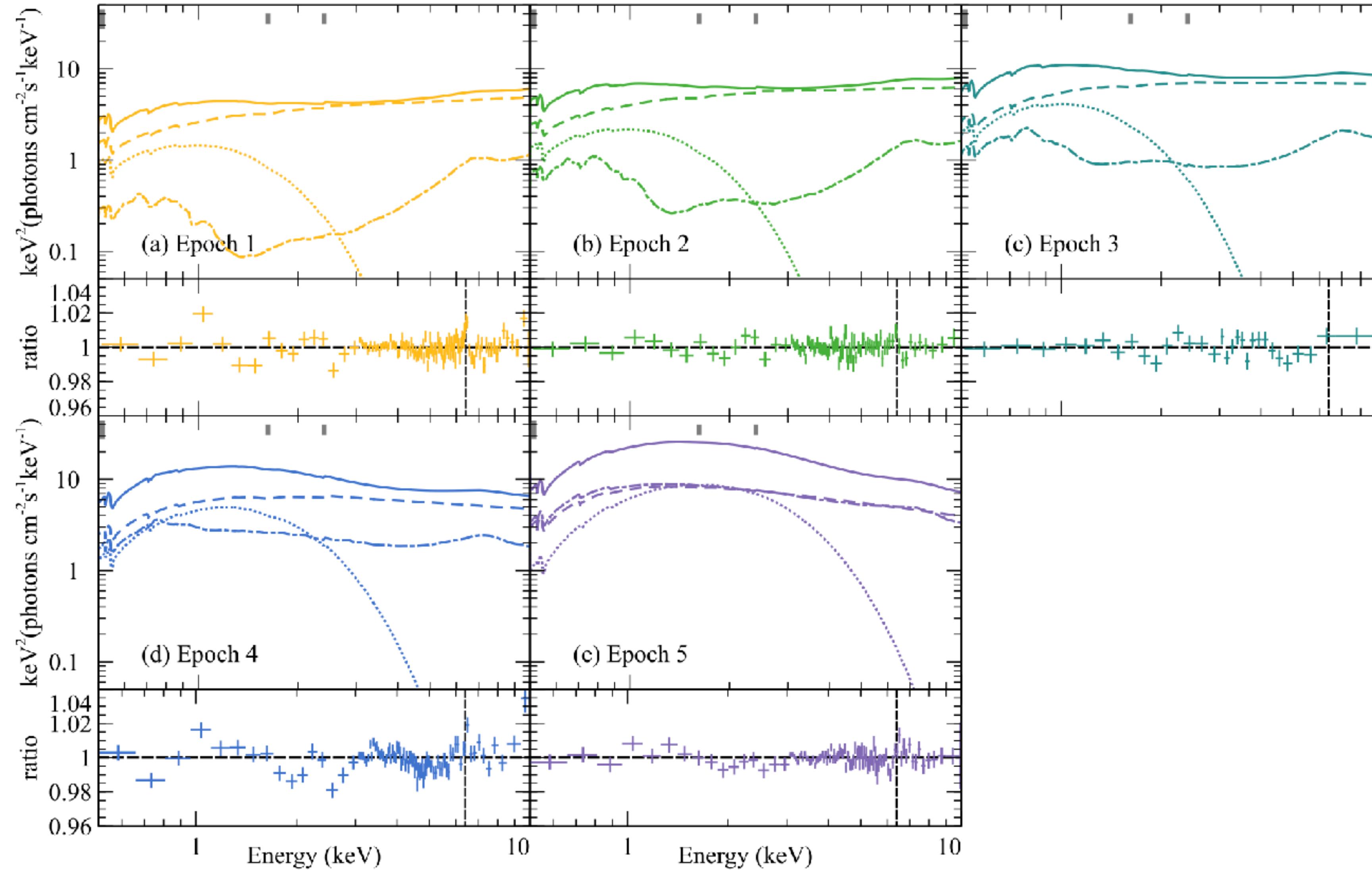
# Evolution during the outburst



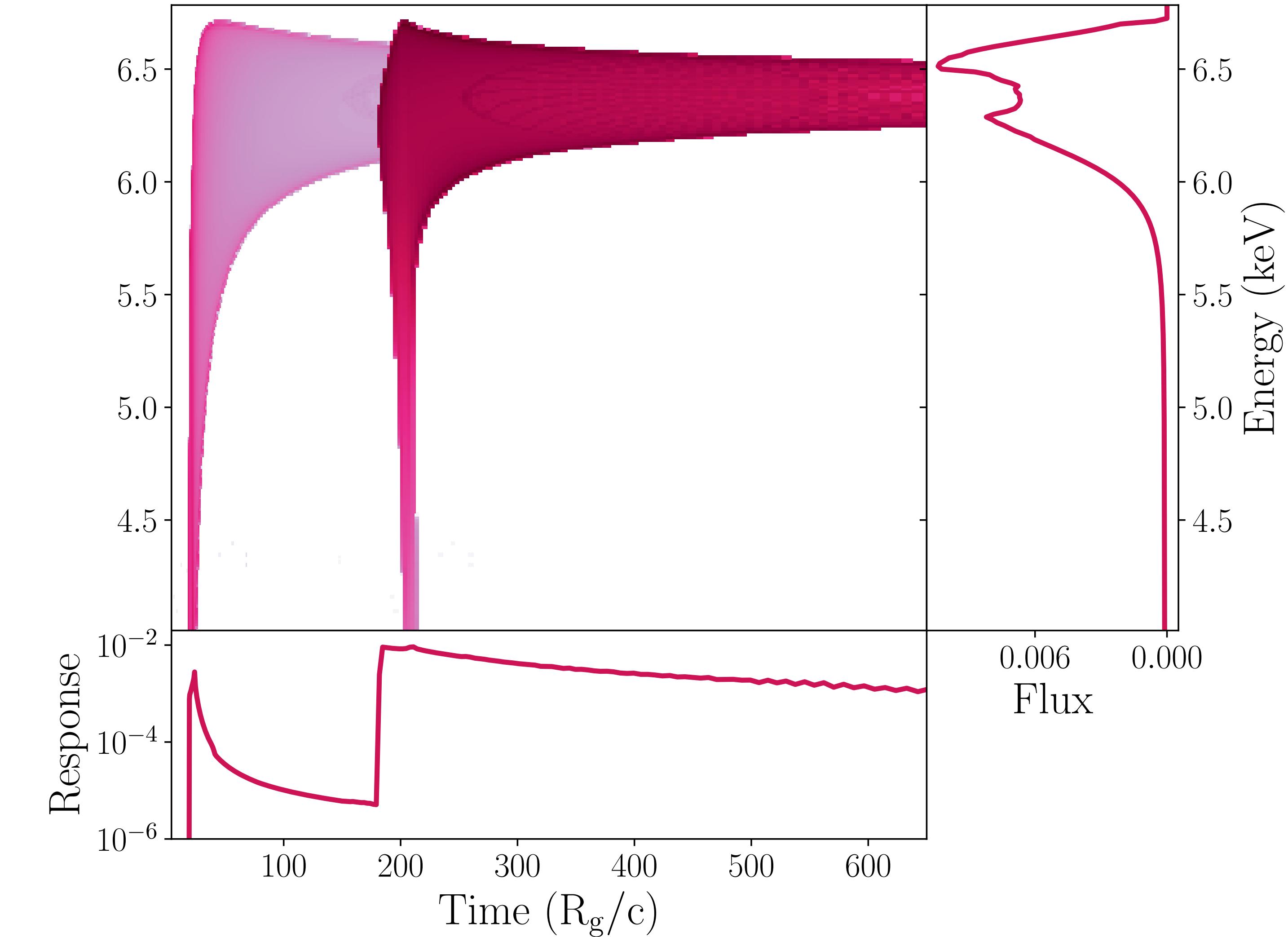
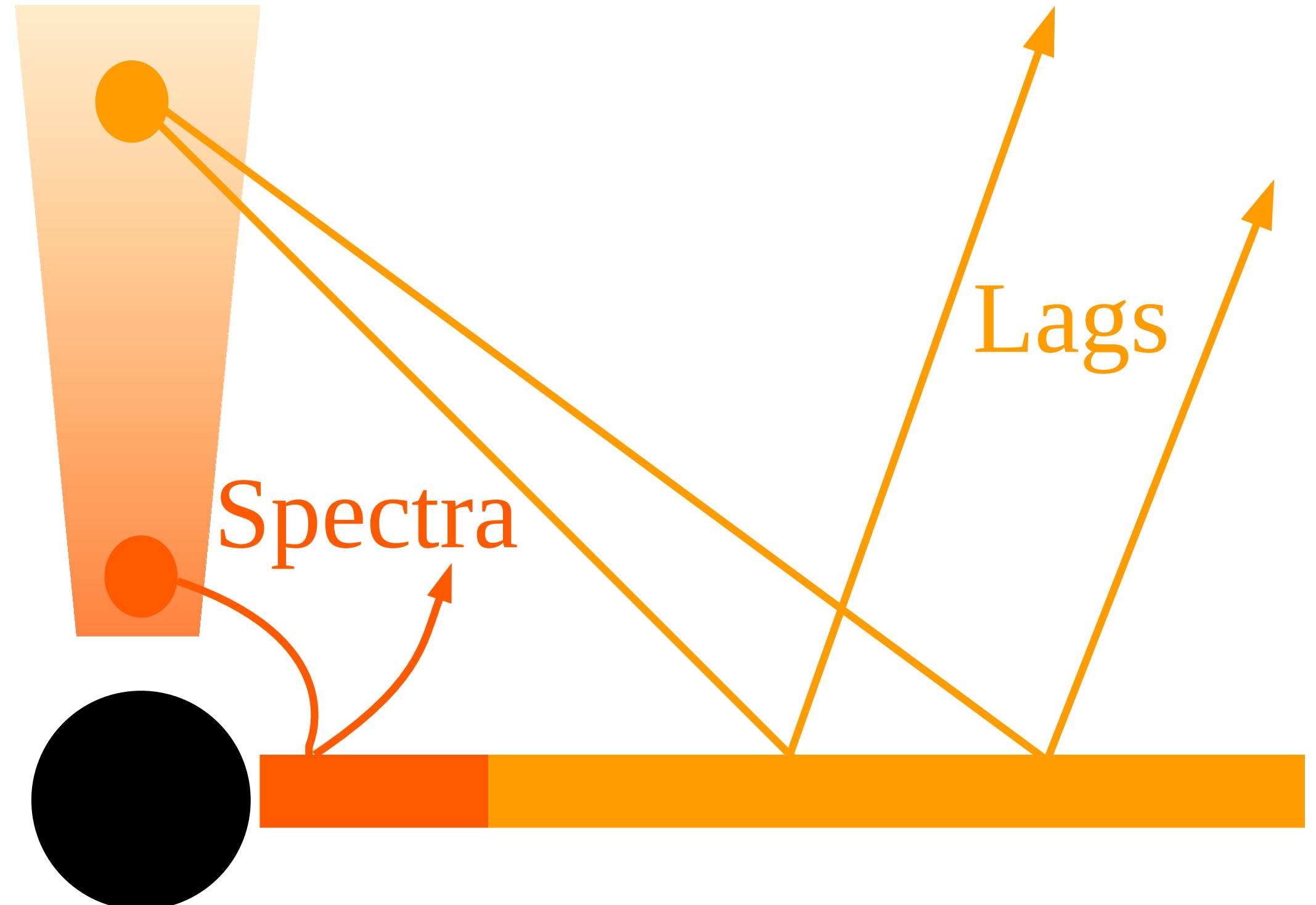
**Spectral-Timing features:  
X-ray time lag**

**CAVEATS**

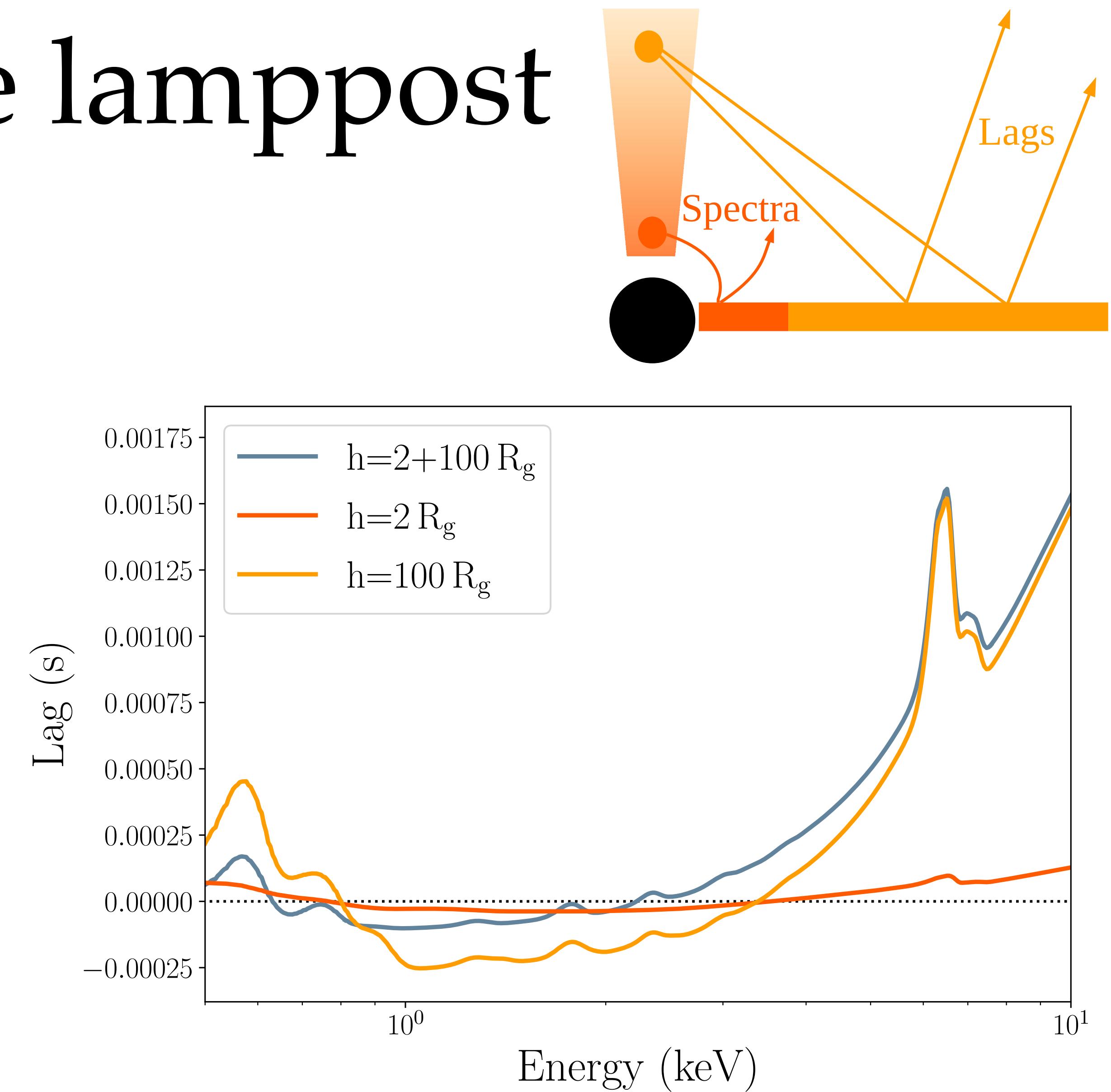
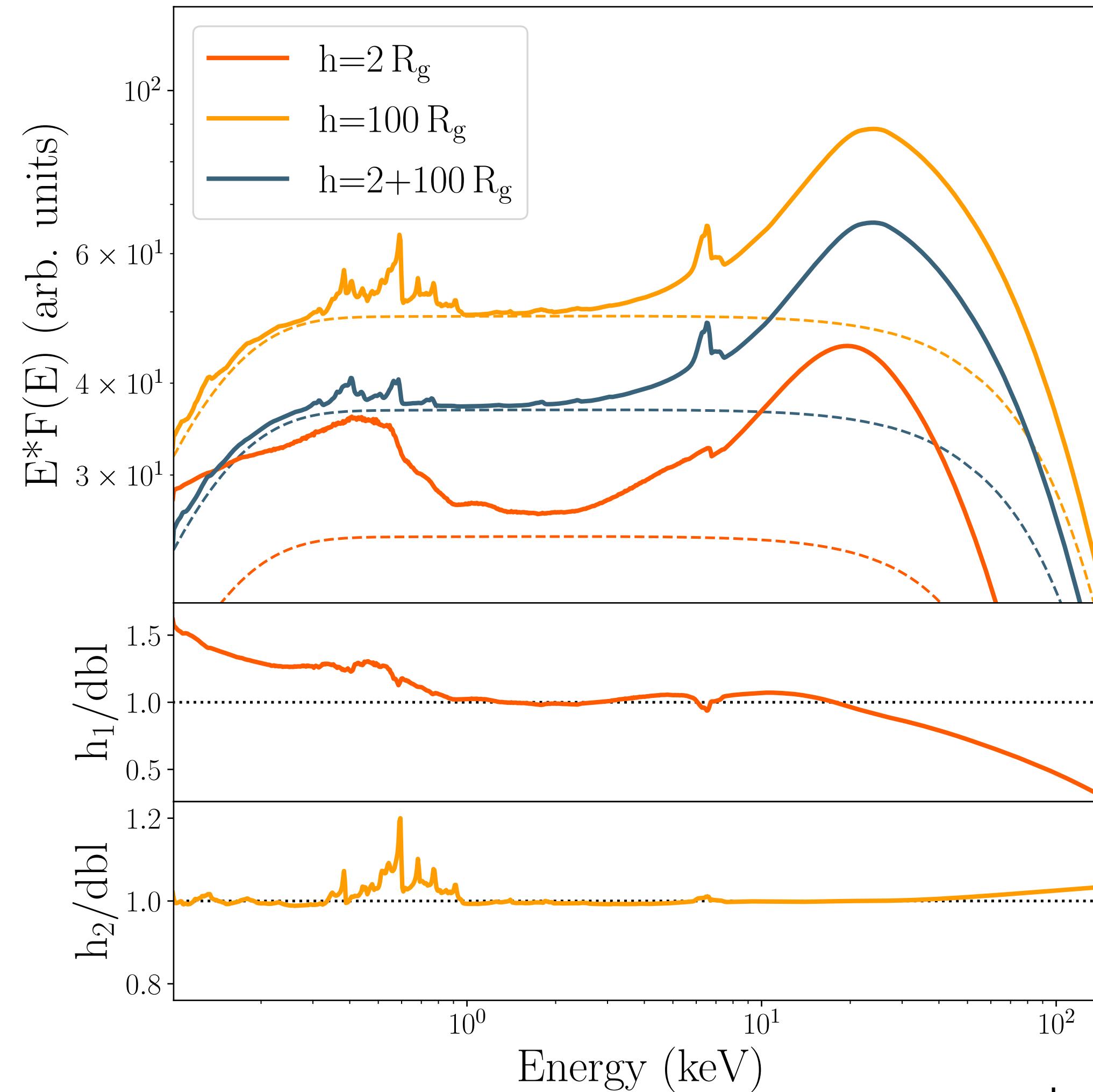
# Fitting simultaneously time averaged spectrum and lag energy spectrum doesn't work in MAXI J1820+070



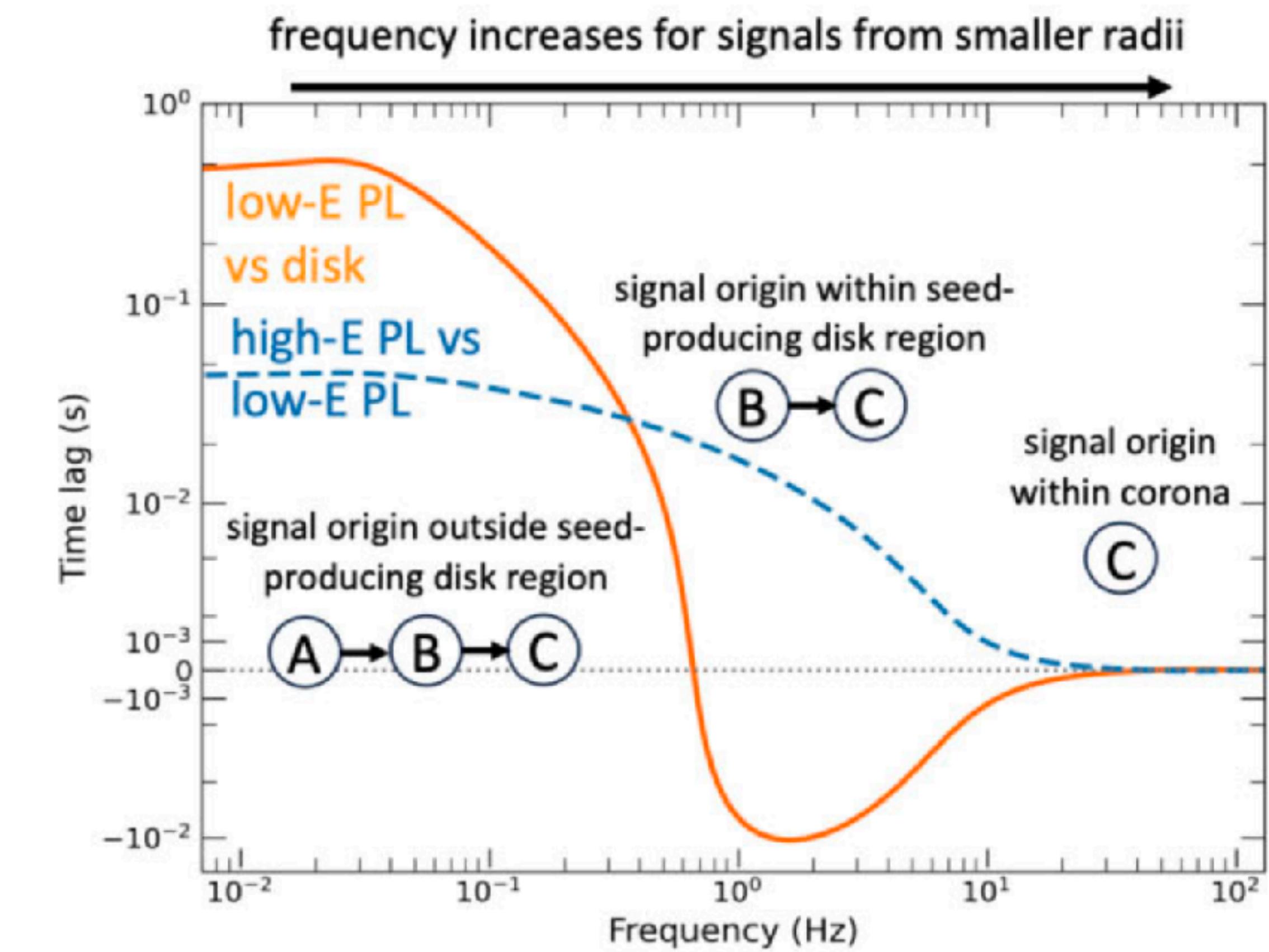
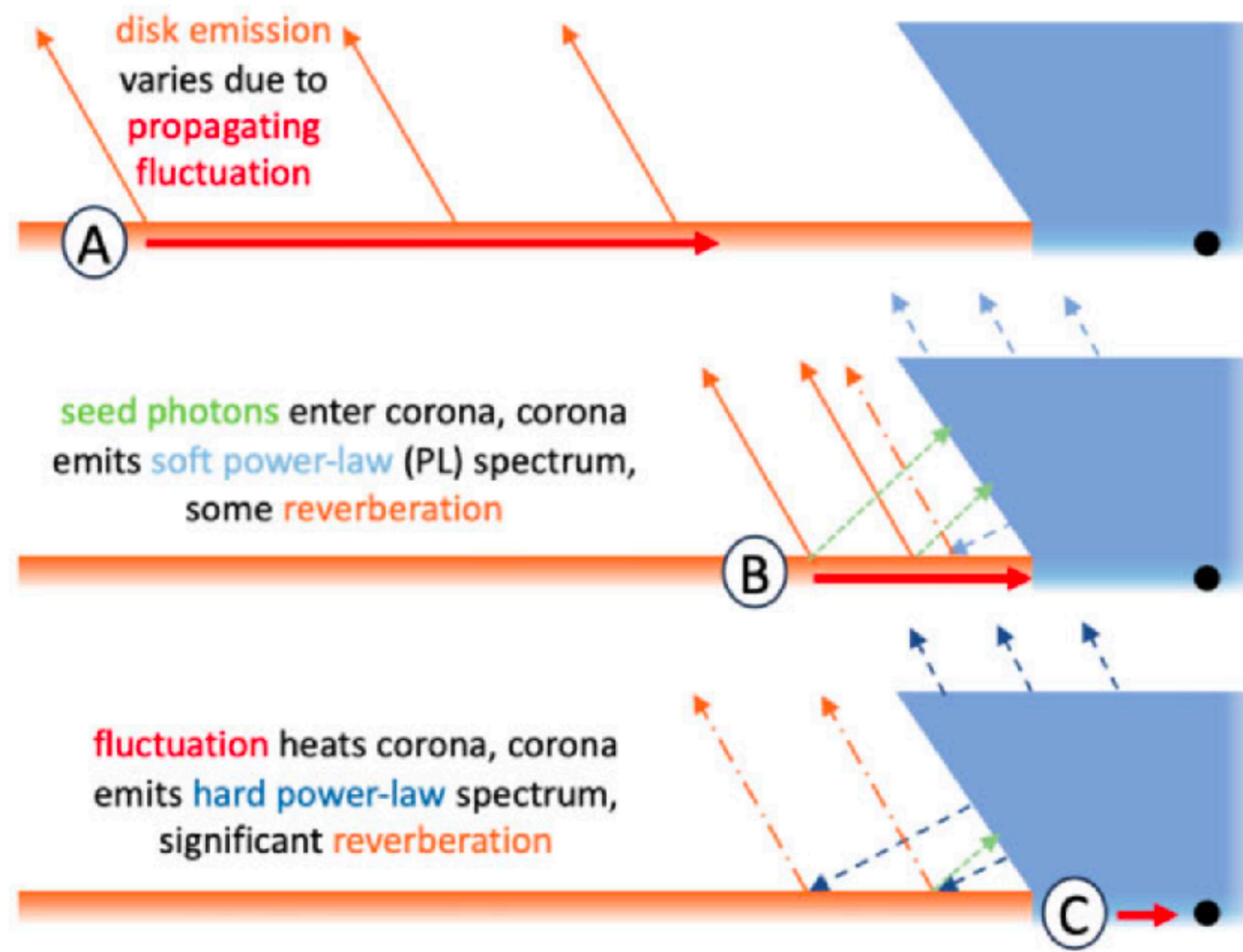
# Towards extended corona: double lamppost



# Towards extended corona: double lampost



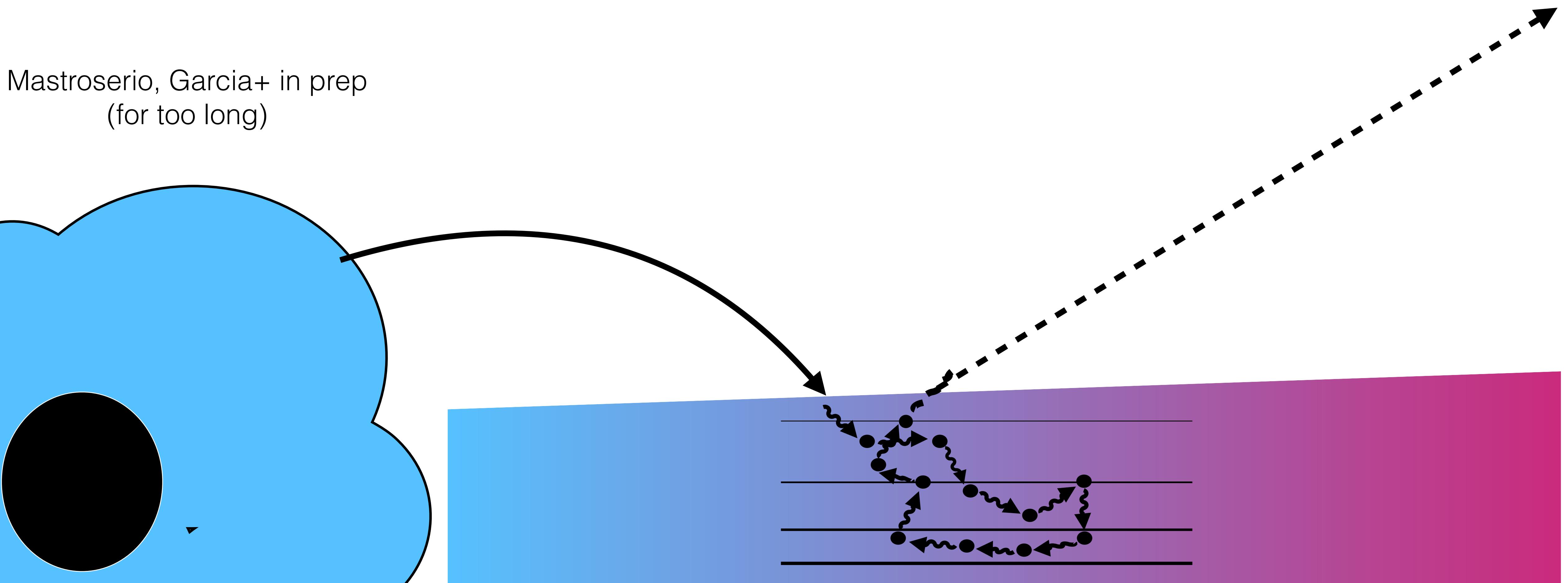
# X-ray reverberation without light crossing time delay



# Possible solutions

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

Mastroserio, Garcia+ in prep  
(for too long)



# X-ray Polarization

# 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

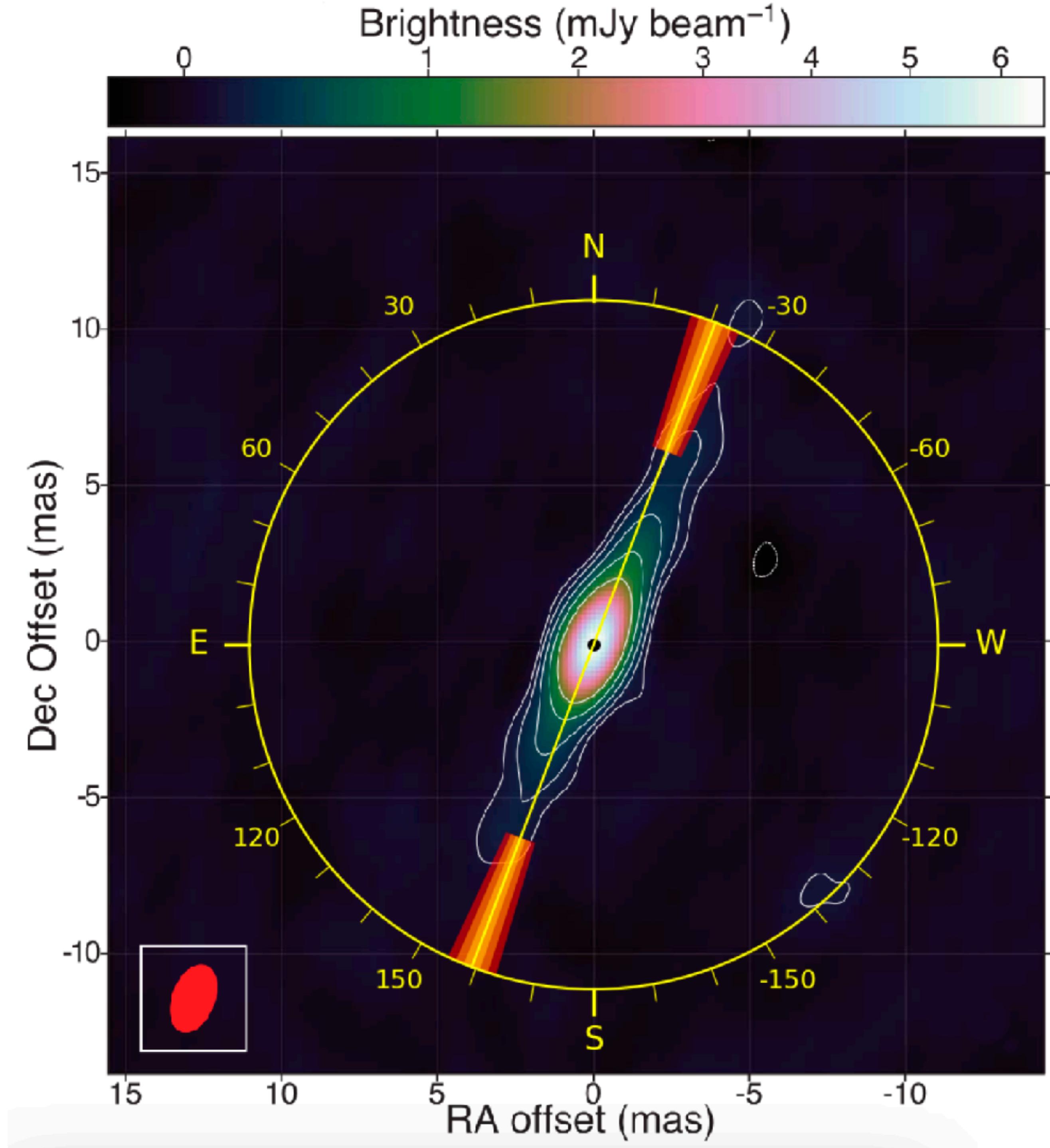
~3-4%

**Intermediate State**

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

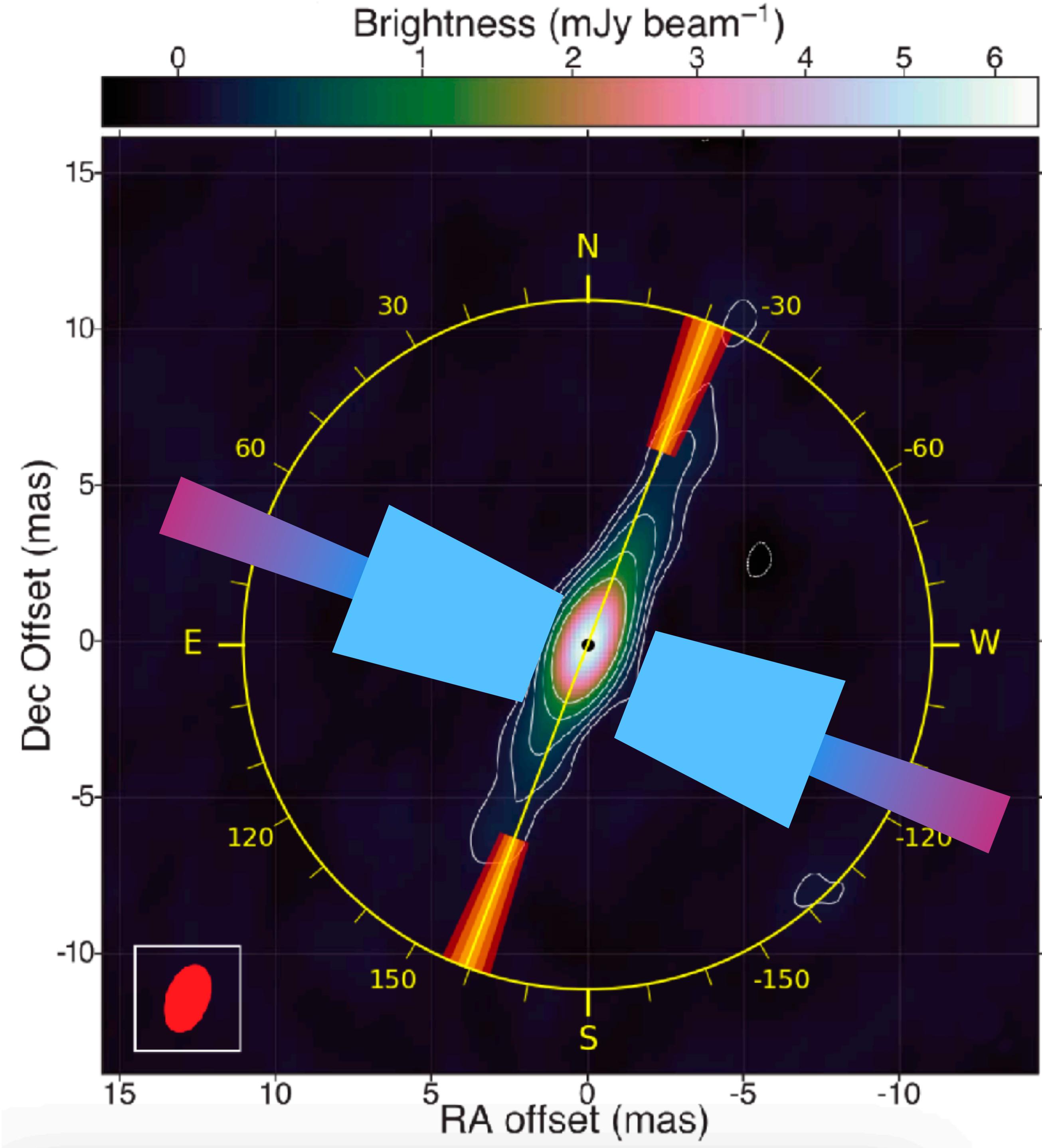
# Cygnus X-1

HARD state:  
4% polarization,  
aligned with the radio jet



# Cygnus X-1

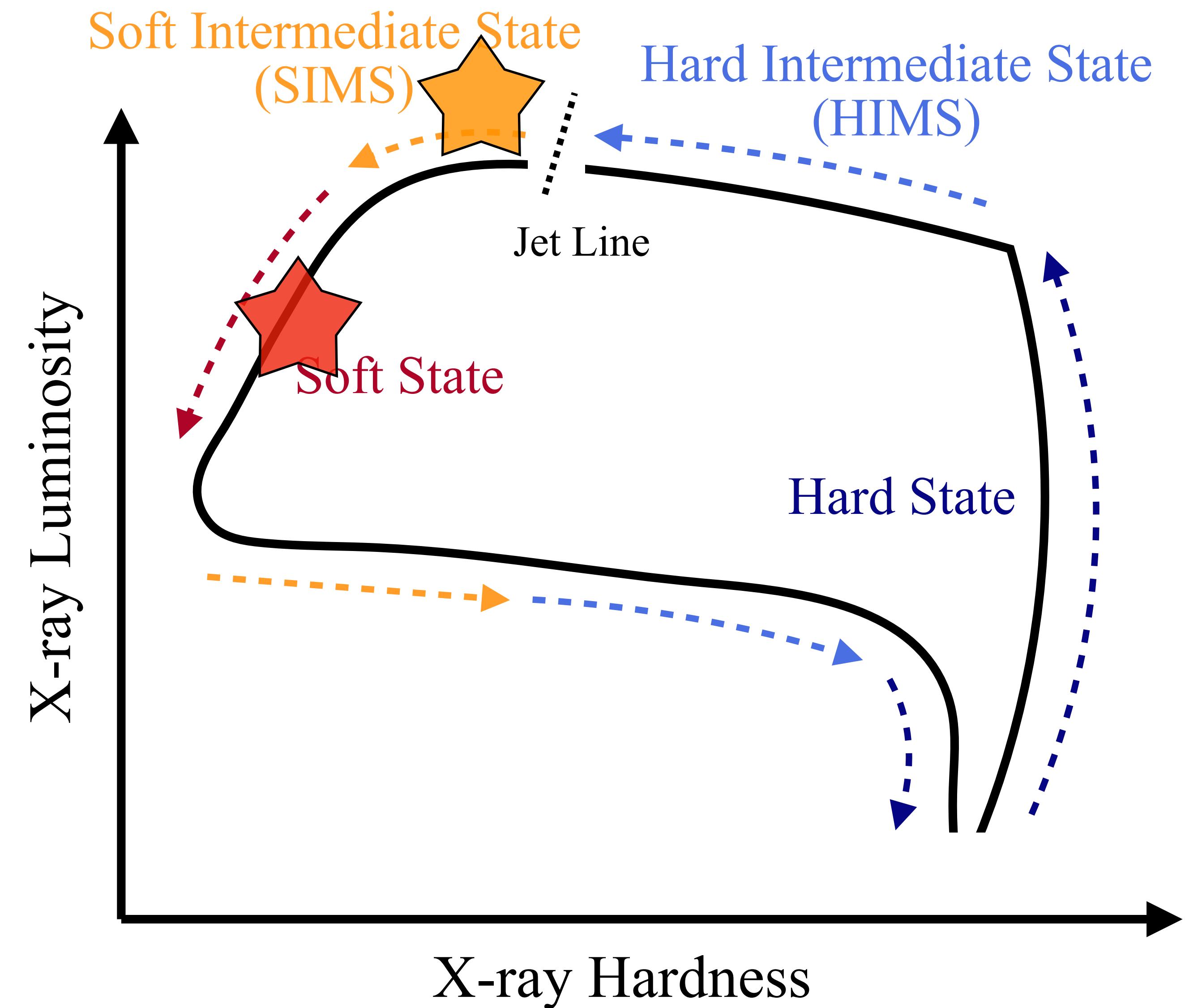
HARD state:  
4% polarization,  
aligned with the radio jet



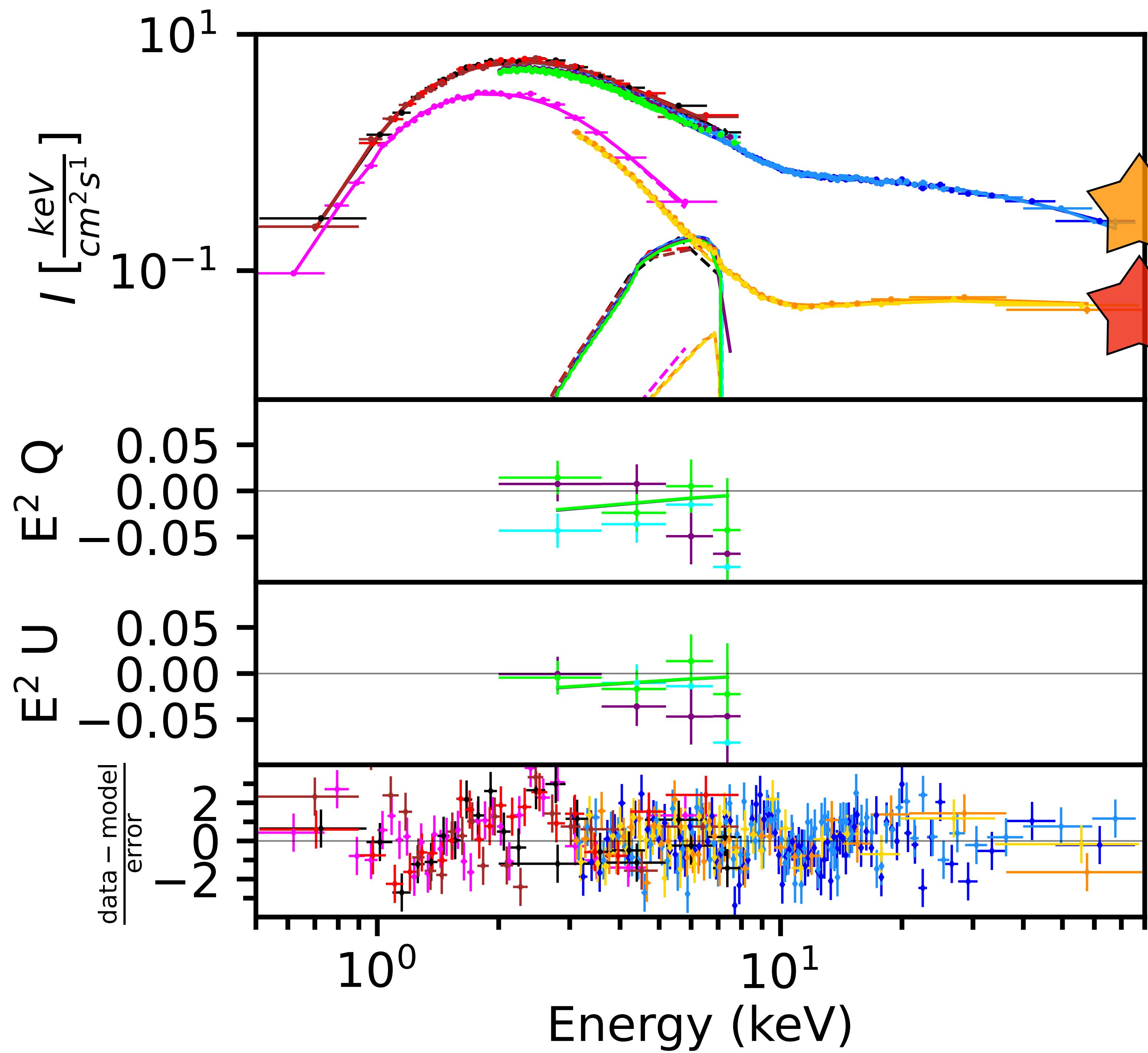
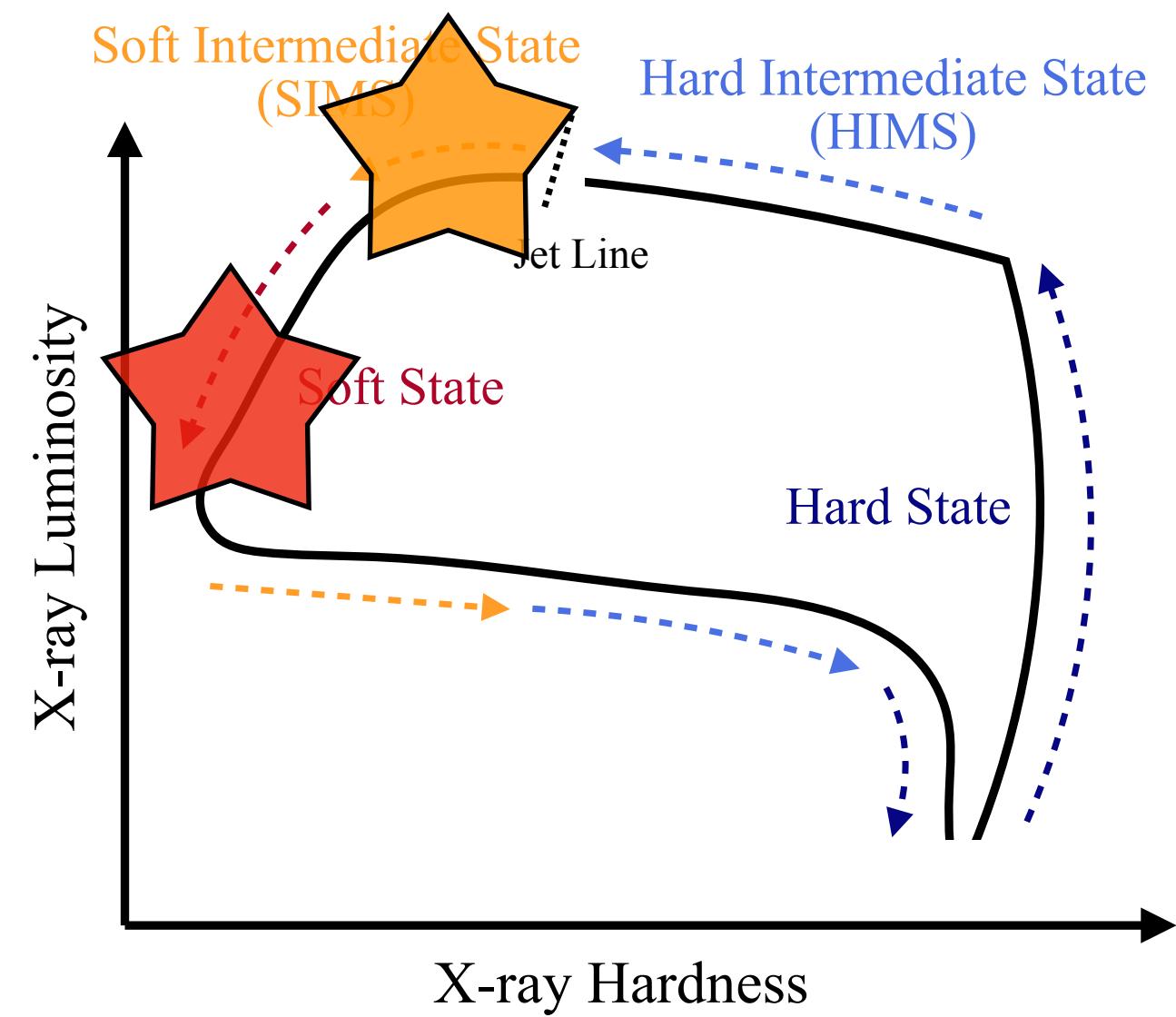
# GX 339-4 outburst 2023 HID

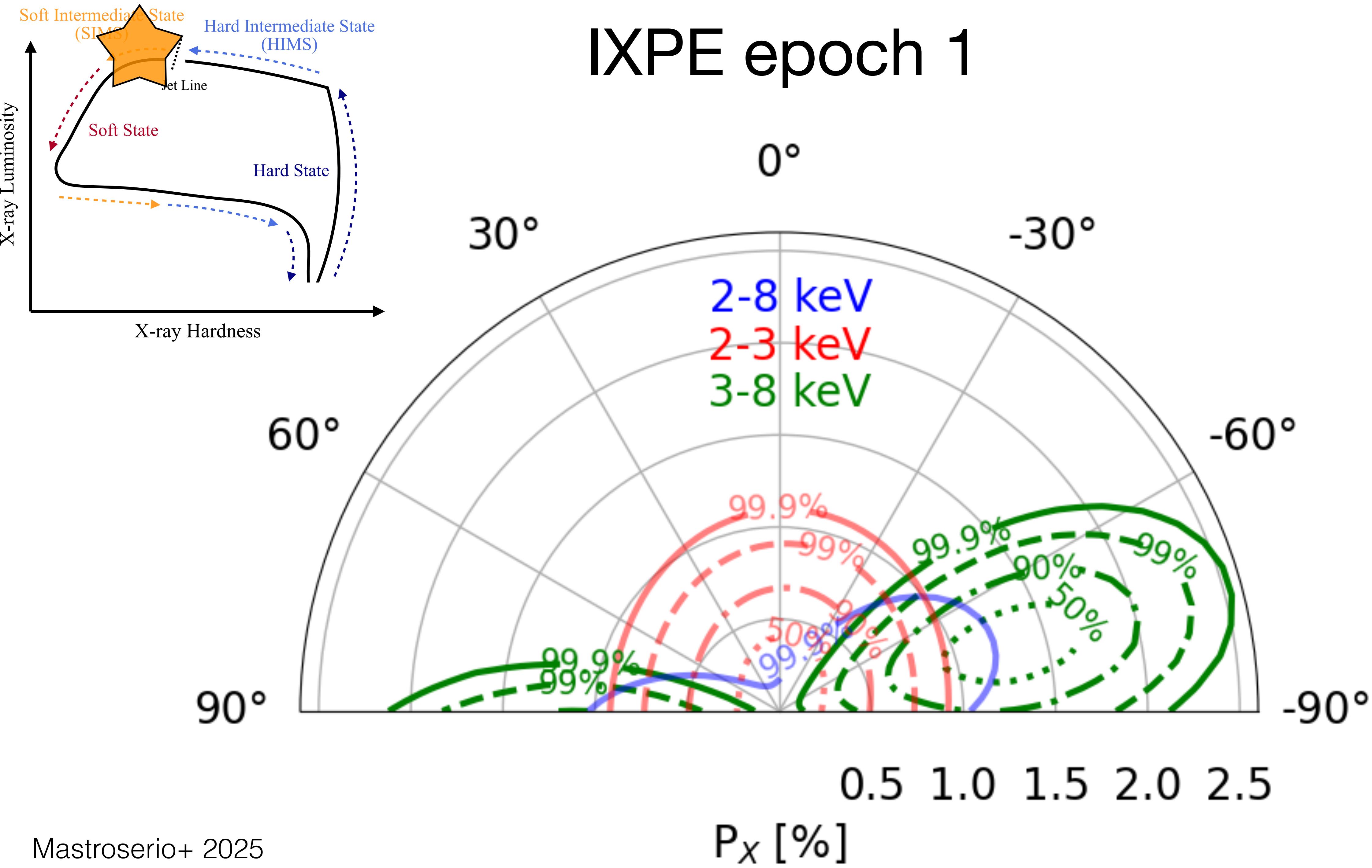
Epoch 1:  
soft intermediate state  
type-B QPO

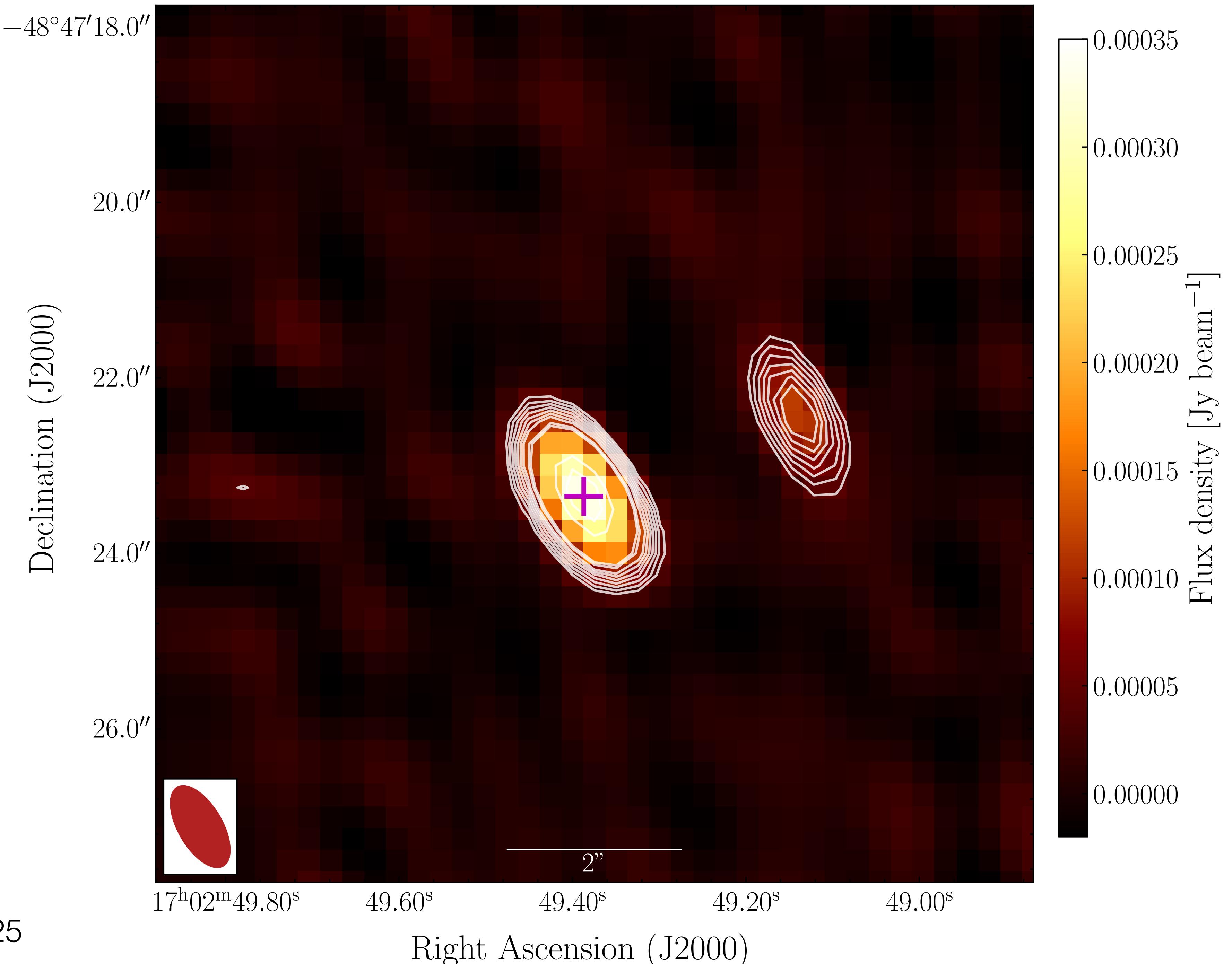
Epoch 2:  
soft state

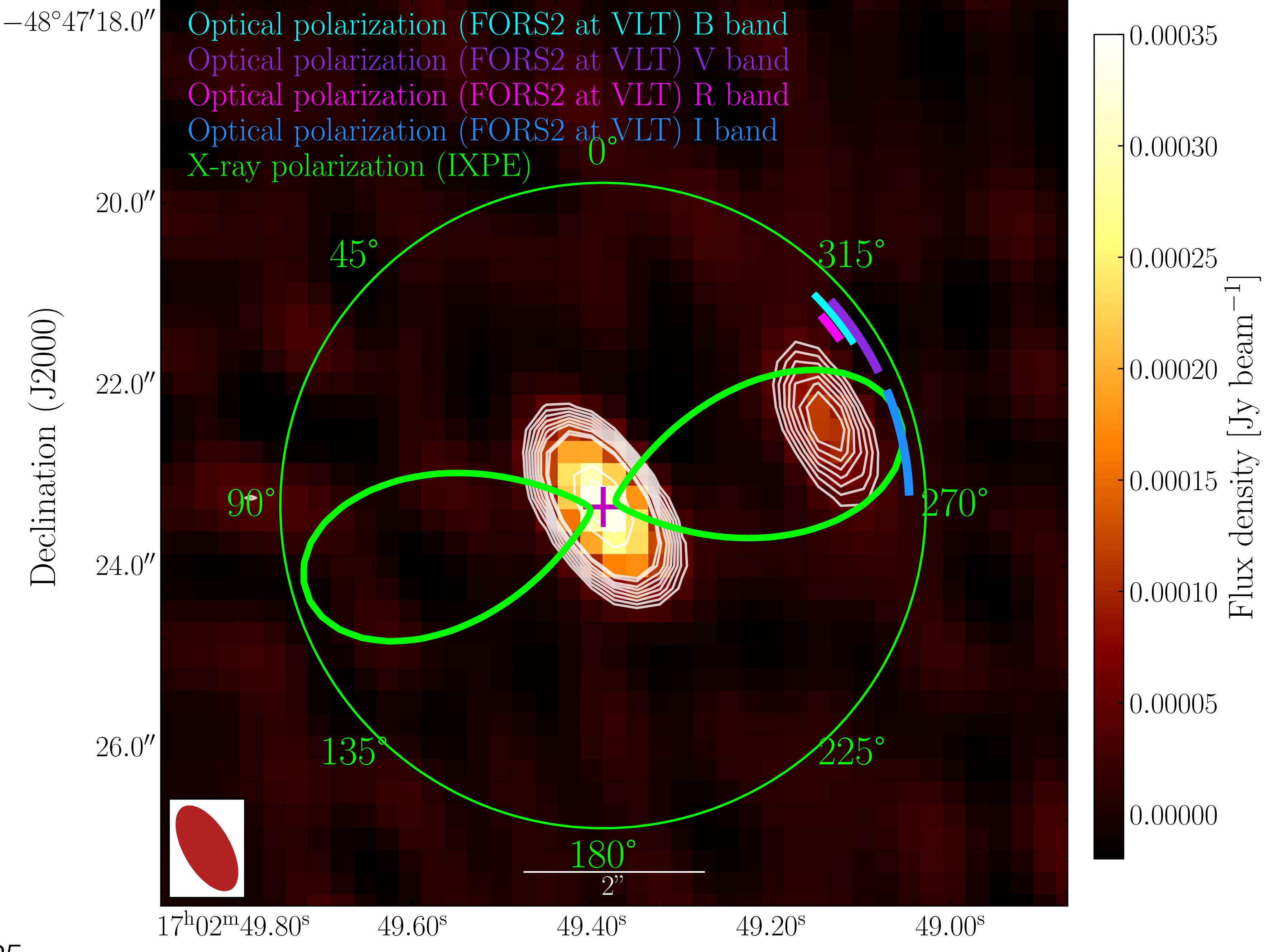


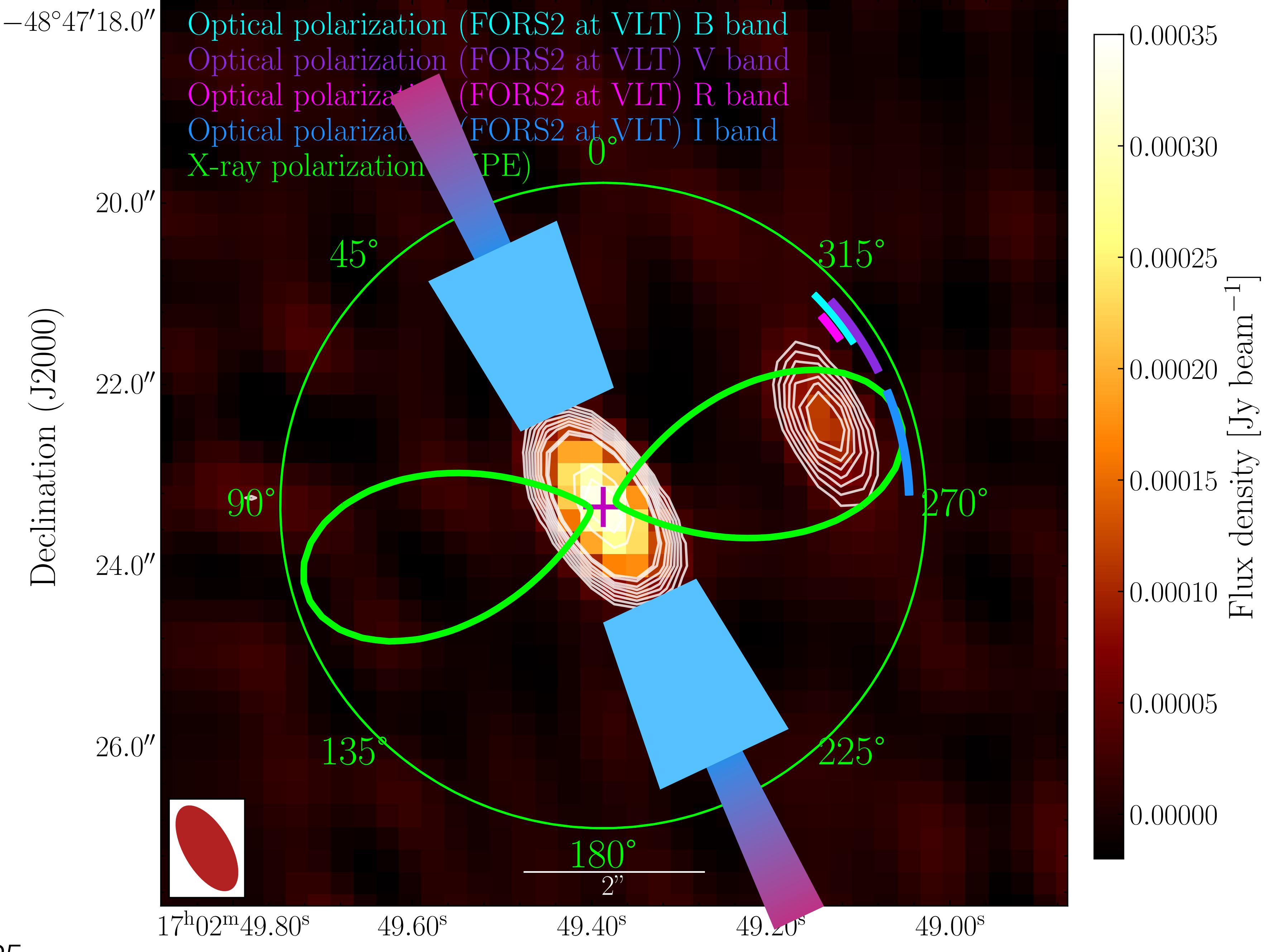
# Simultaneous fit of epoch 1 and epoch 2



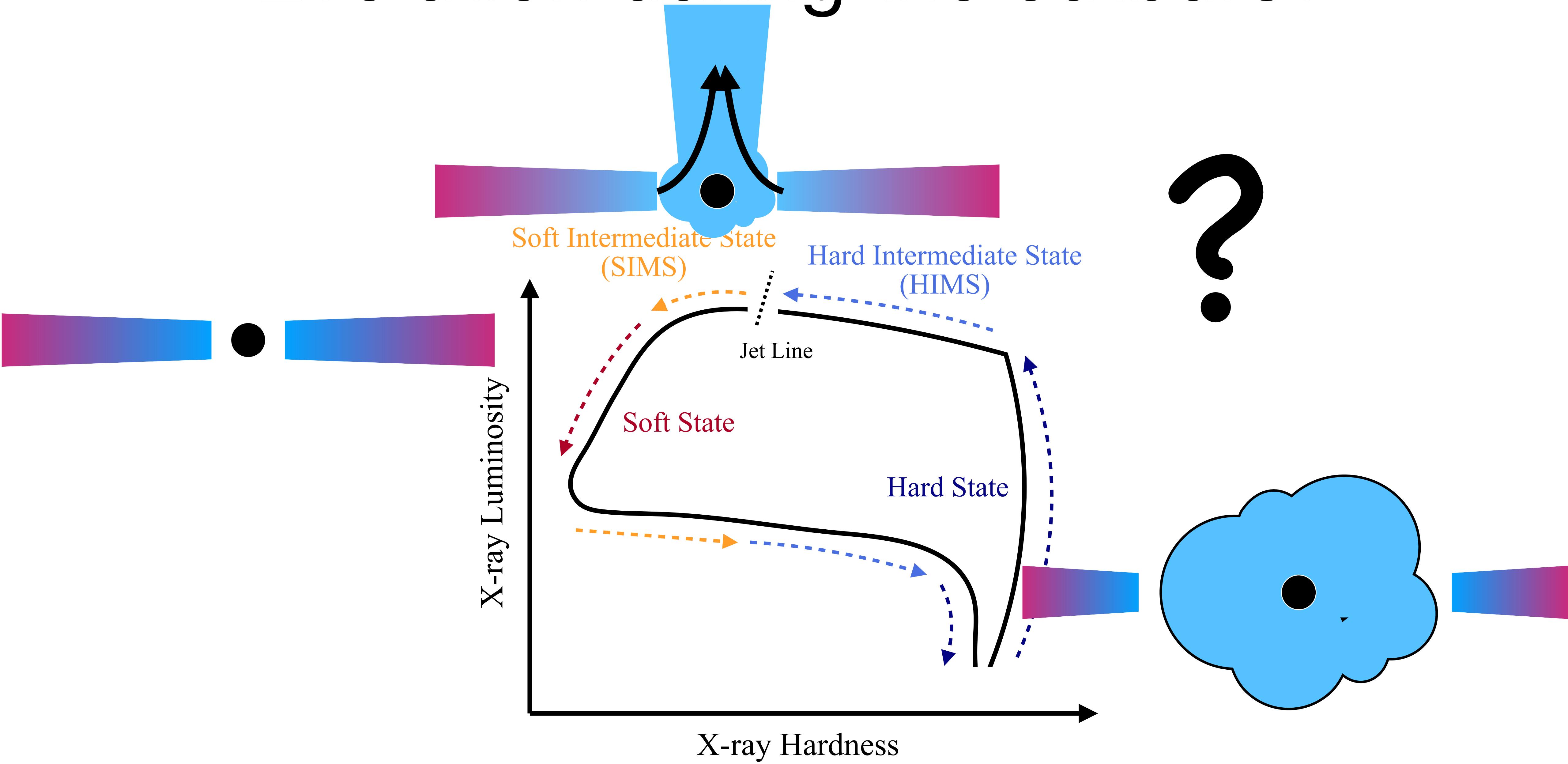




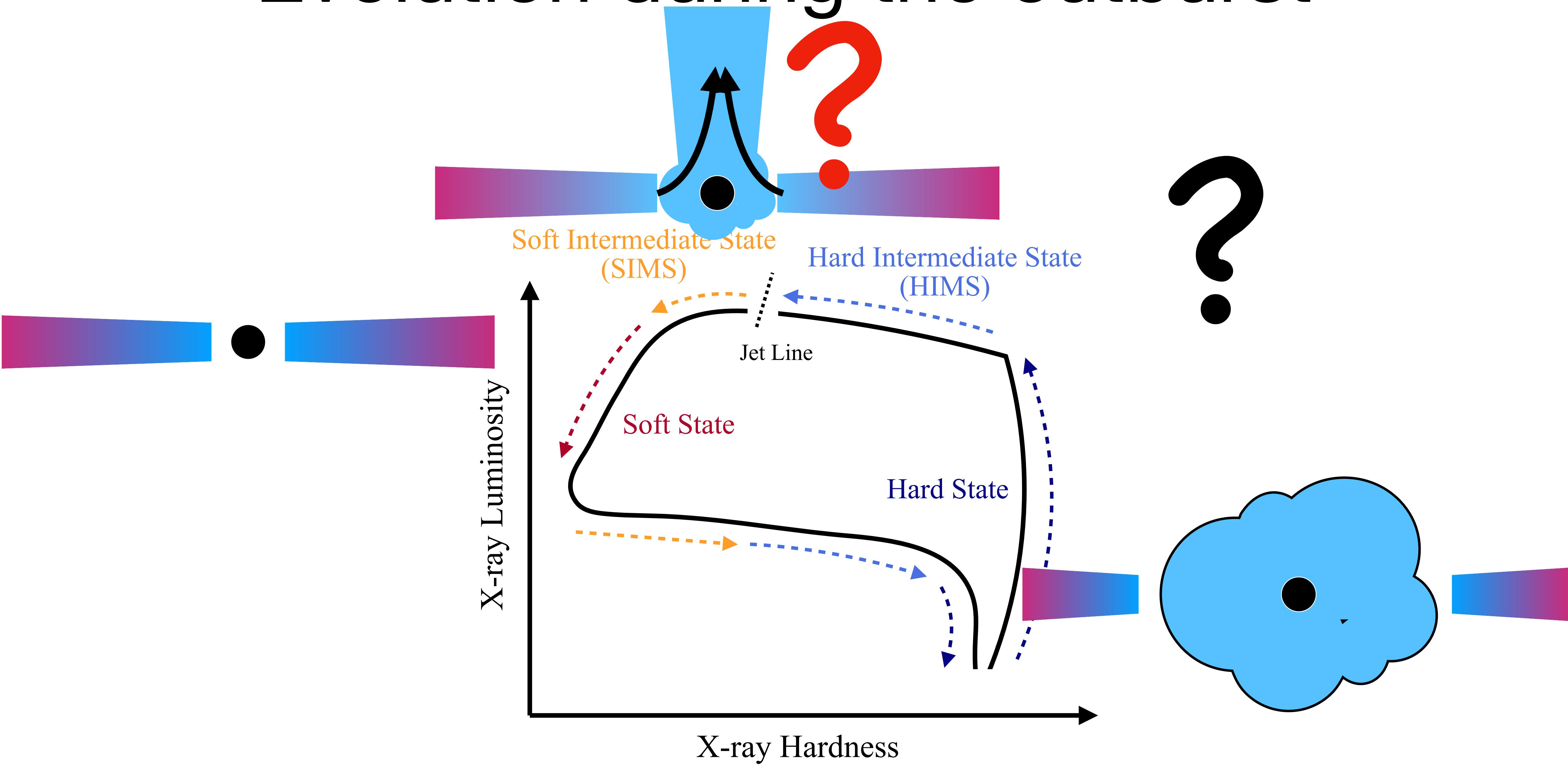




# Evolution during the outburst

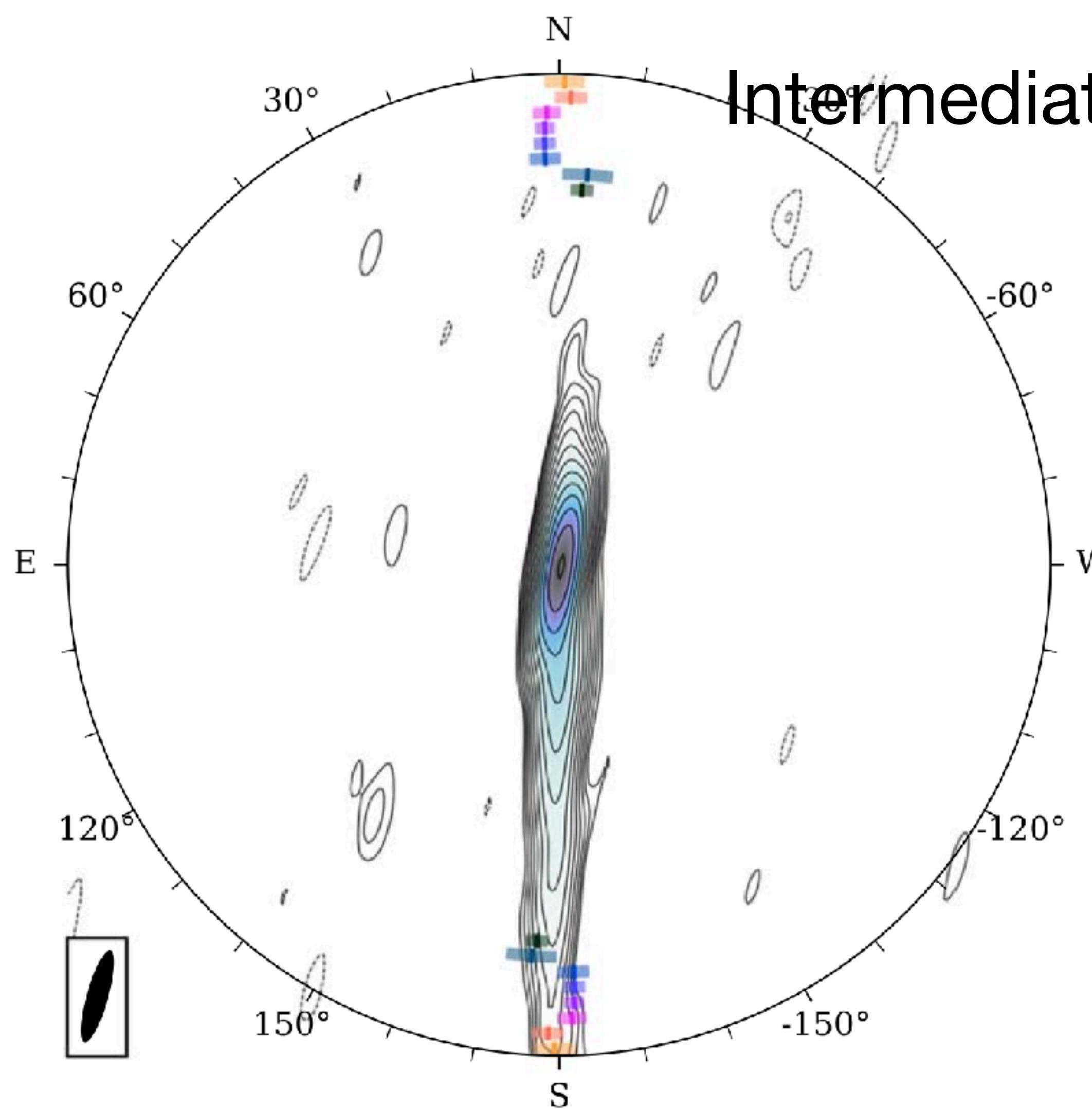


# Evolution during the outburst

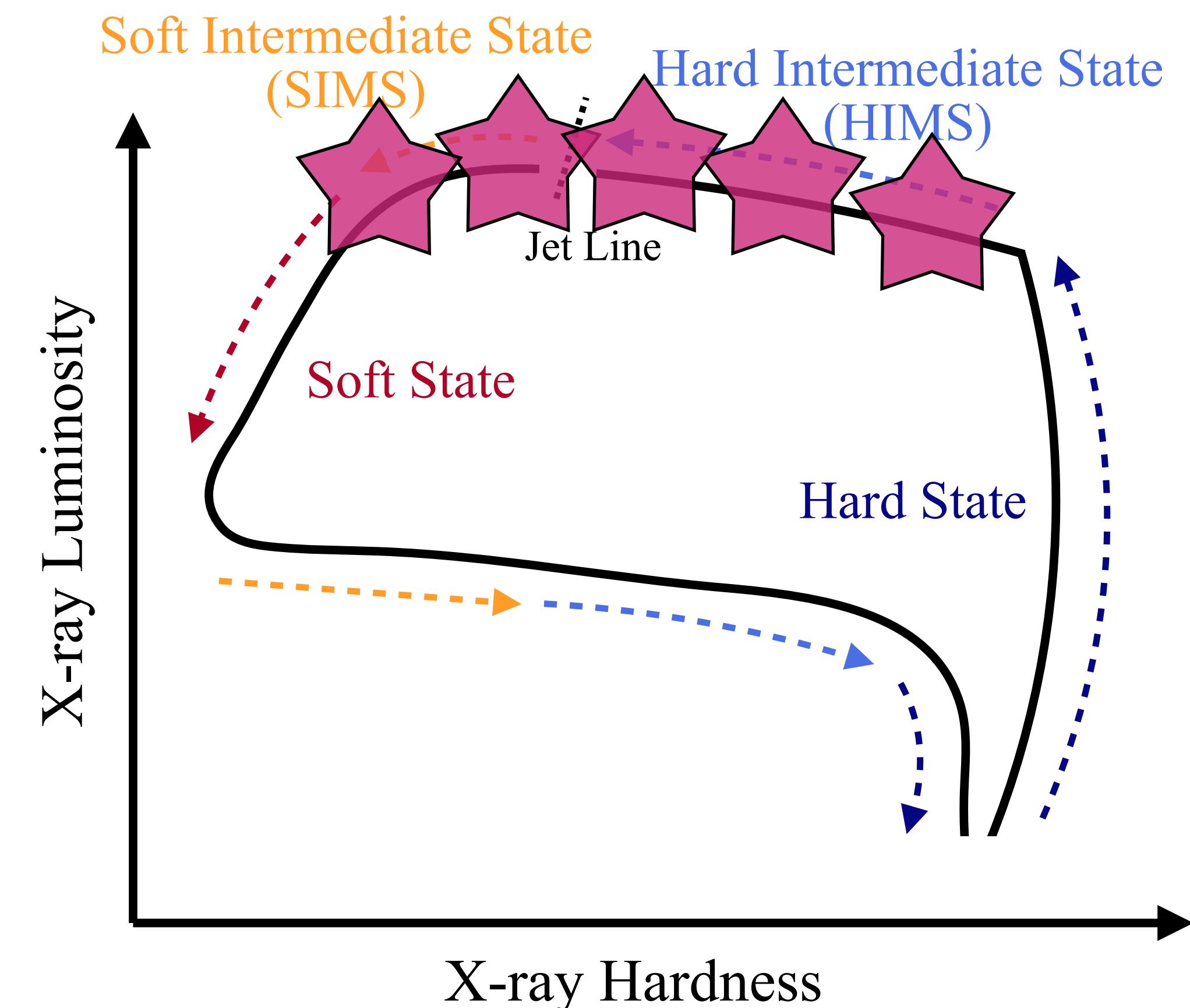


# Swift J1727.8-1613

Intermediate state: polarization aligned with the radio jet

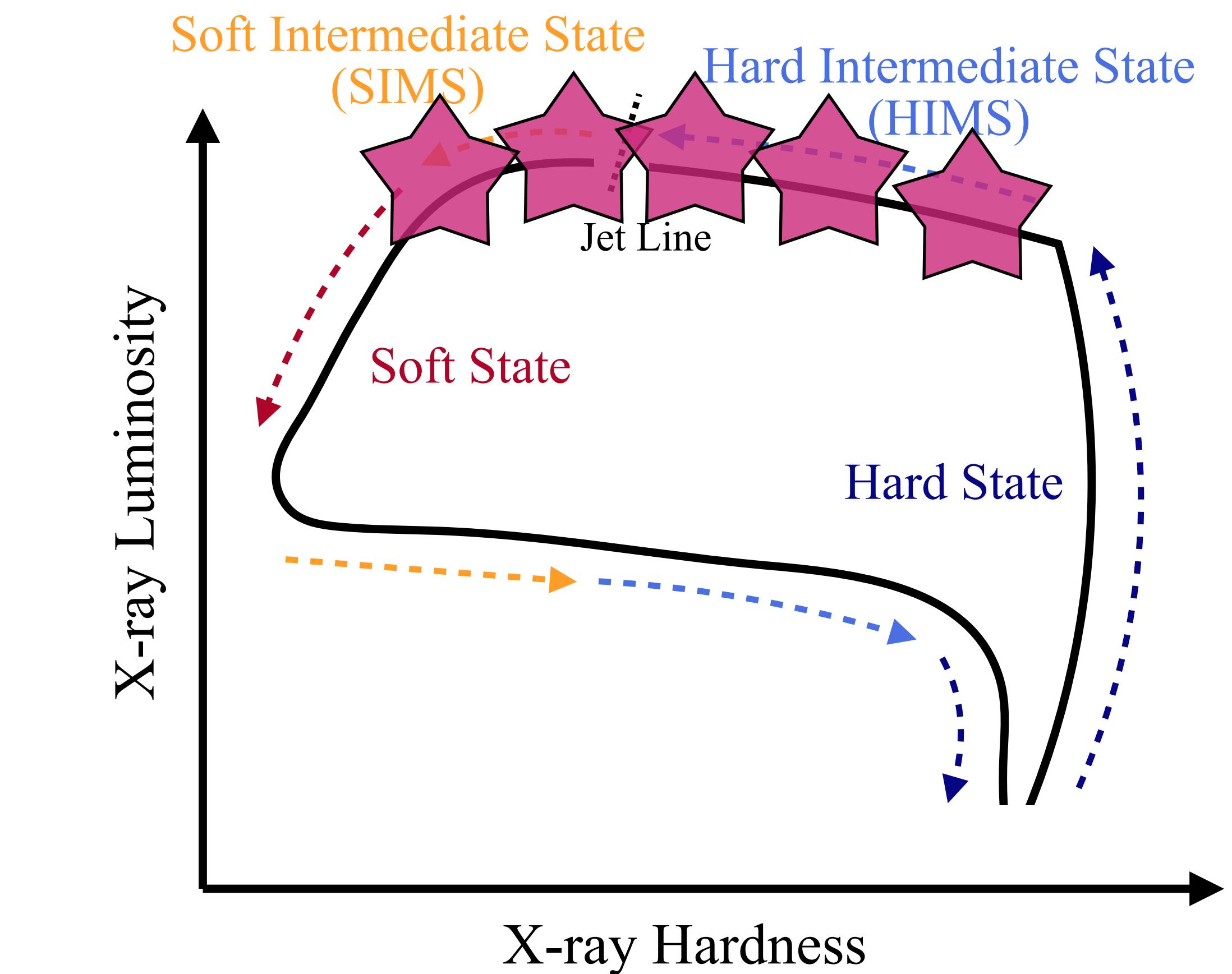
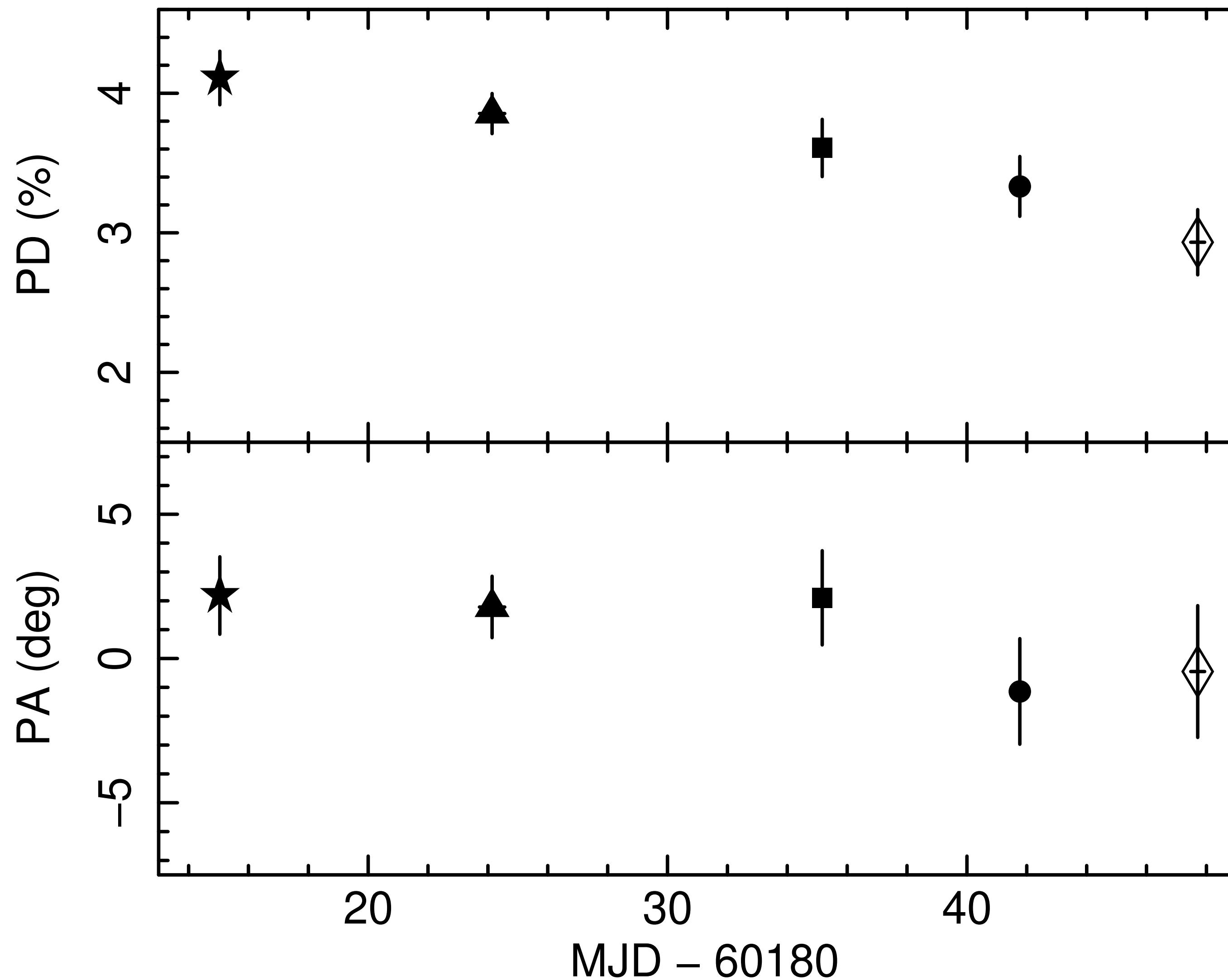


SMA (Sep 03)	IXPE (Sep 16/17)
SMA (Sep 04)	IXPE (Sep 27/28)
ATCA (Sep 28)	IXPE (Oct 04)
IXPE (Sep 07/08)	IXPE (Oct 10)



# Swift J1727.8-1613

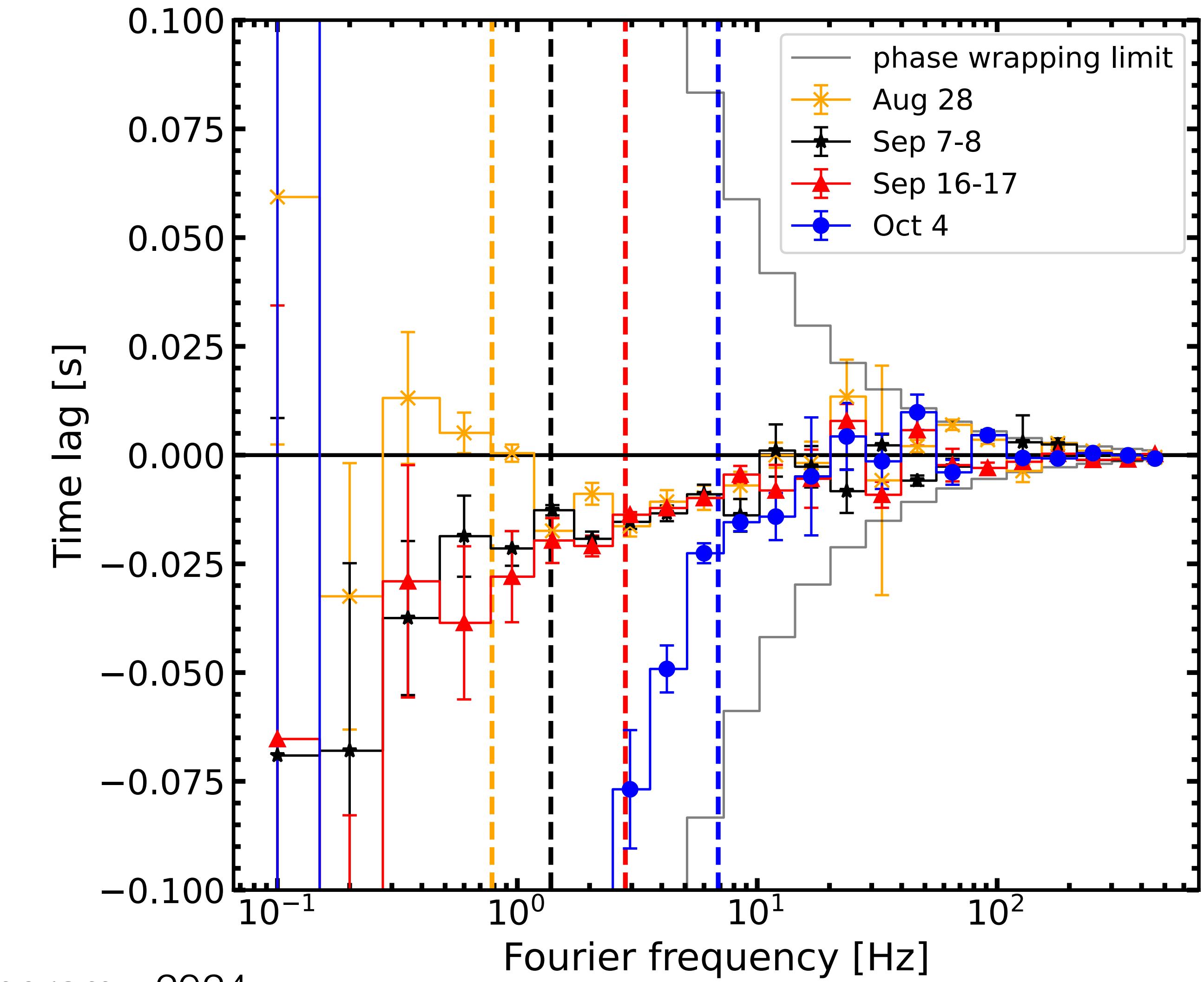
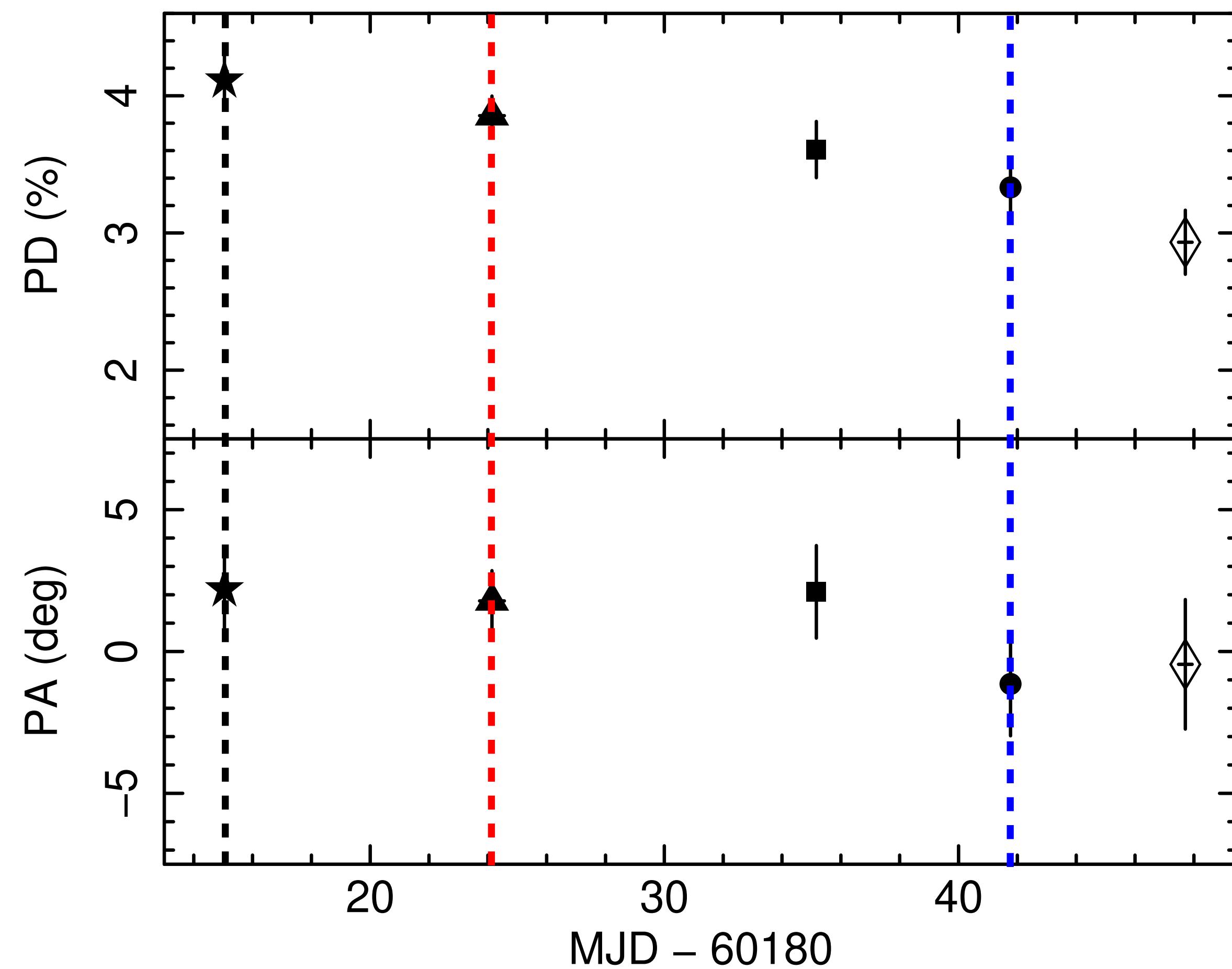
Polarization is almost constant during the outburst



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

# Swift J1727.8-1613

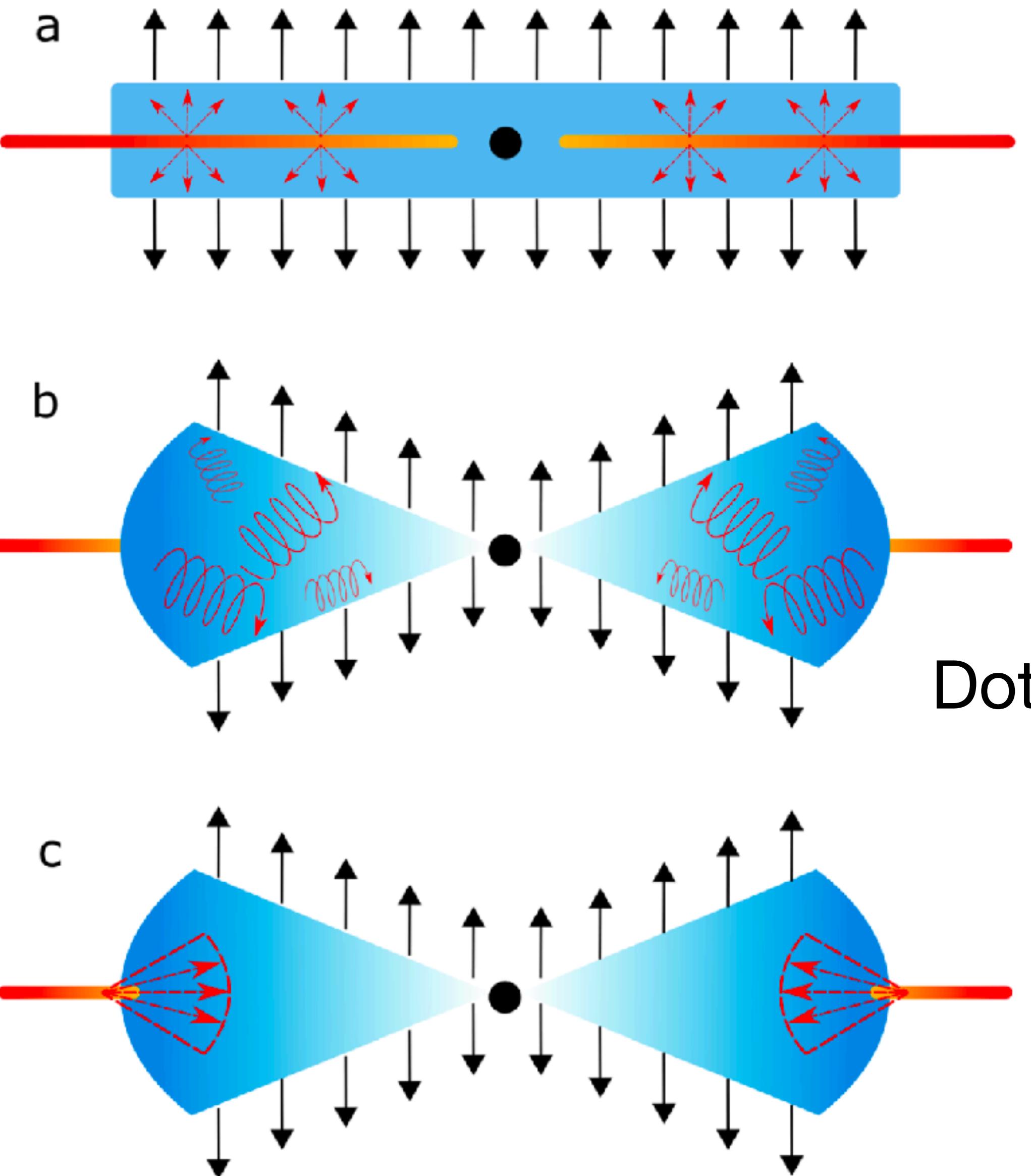
## Reverberation lags changes during the outburst



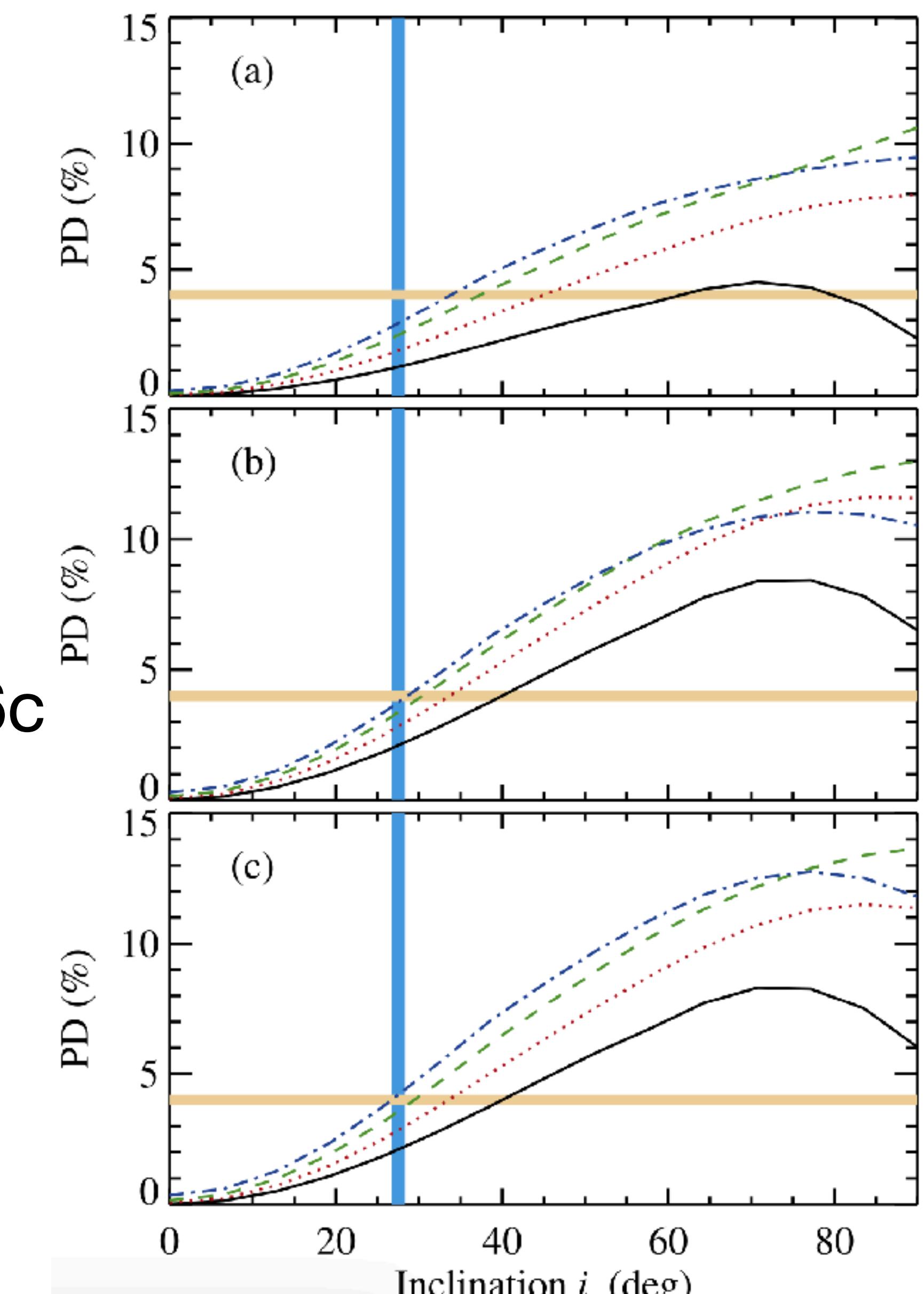
**X-ray Polarization**

**CAVEATS**

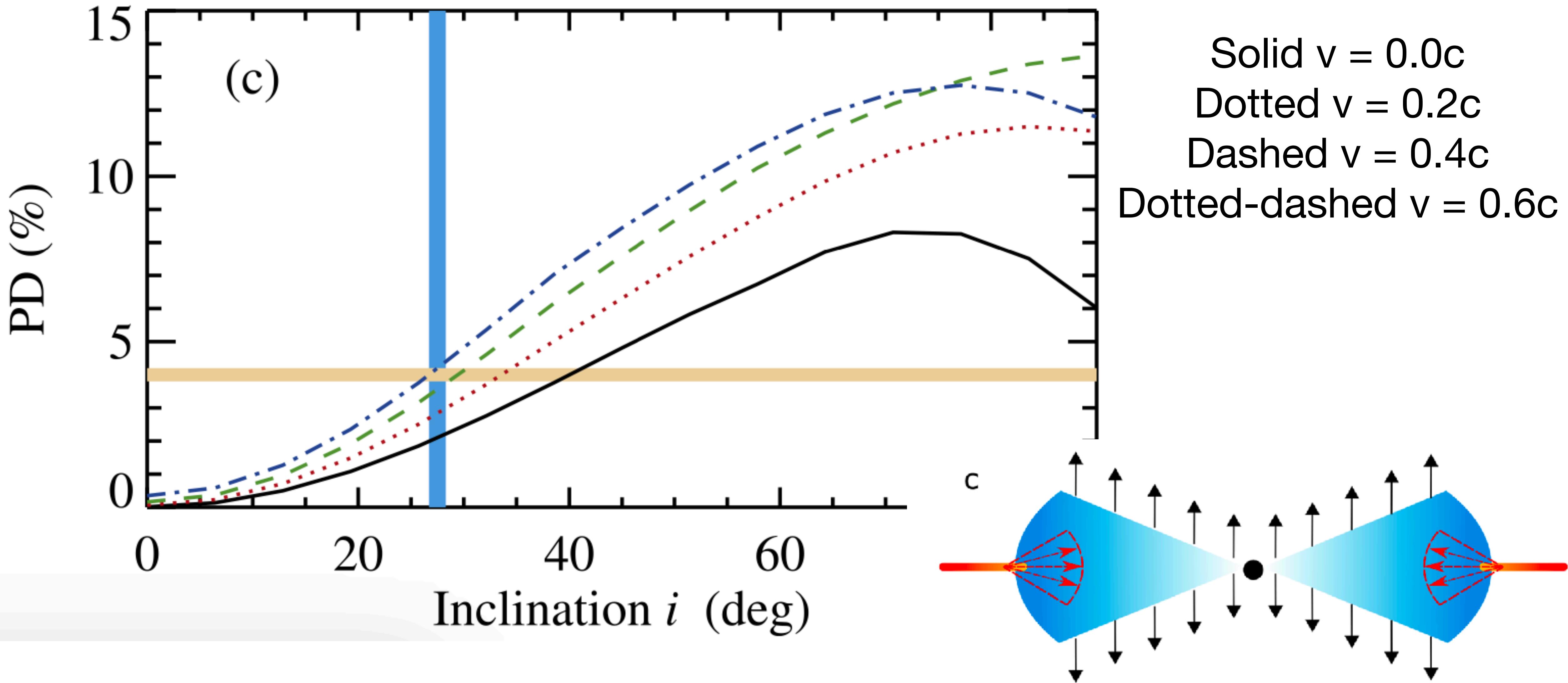
# (Very fast) outflowing corona



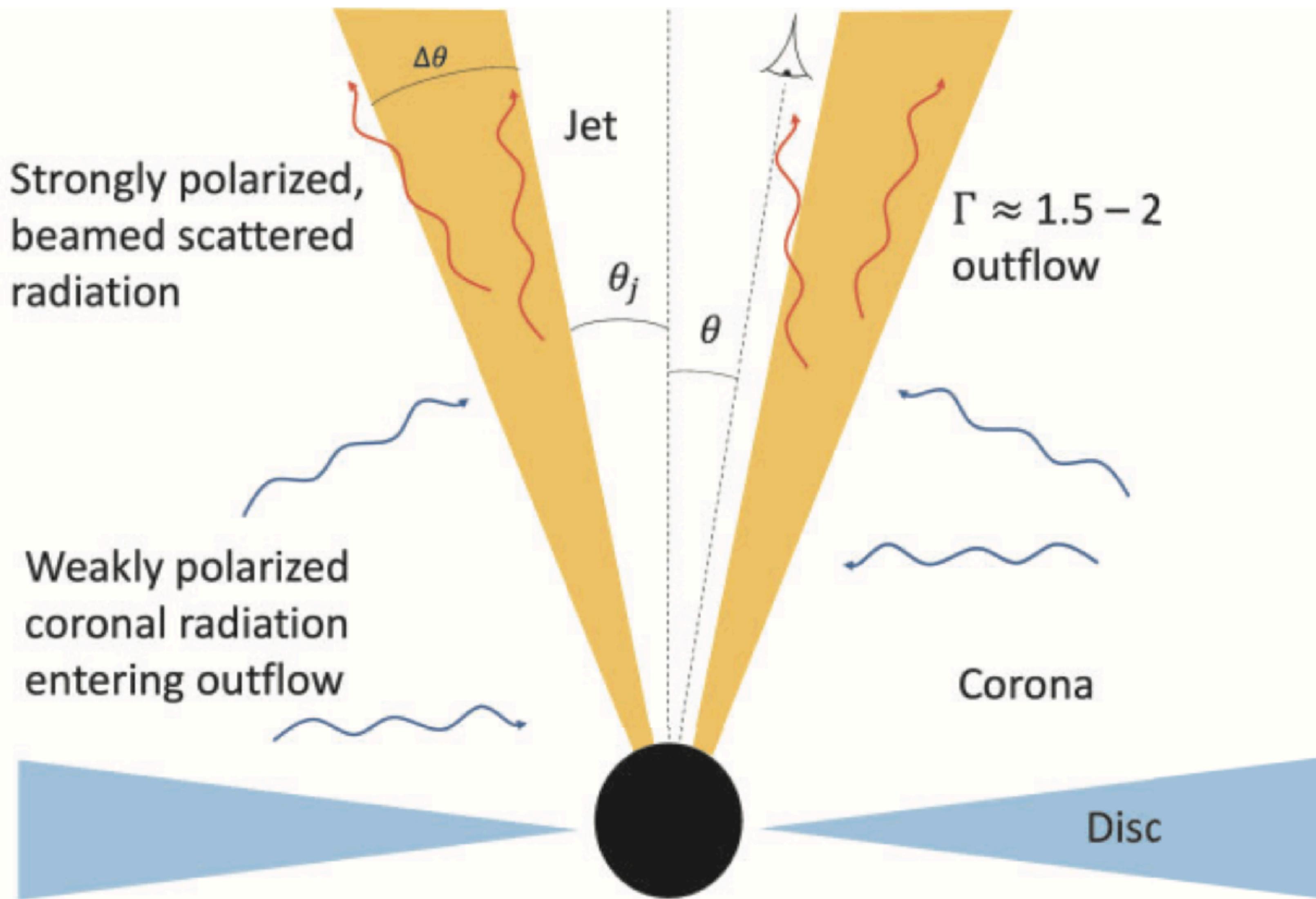
Solid  $v = 0.0c$   
Dotted  $v = 0.2c$   
Dashed  $v = 0.4c$   
Dotted-dashed  $v = 0.6c$



# (Very fast) outflowing corona

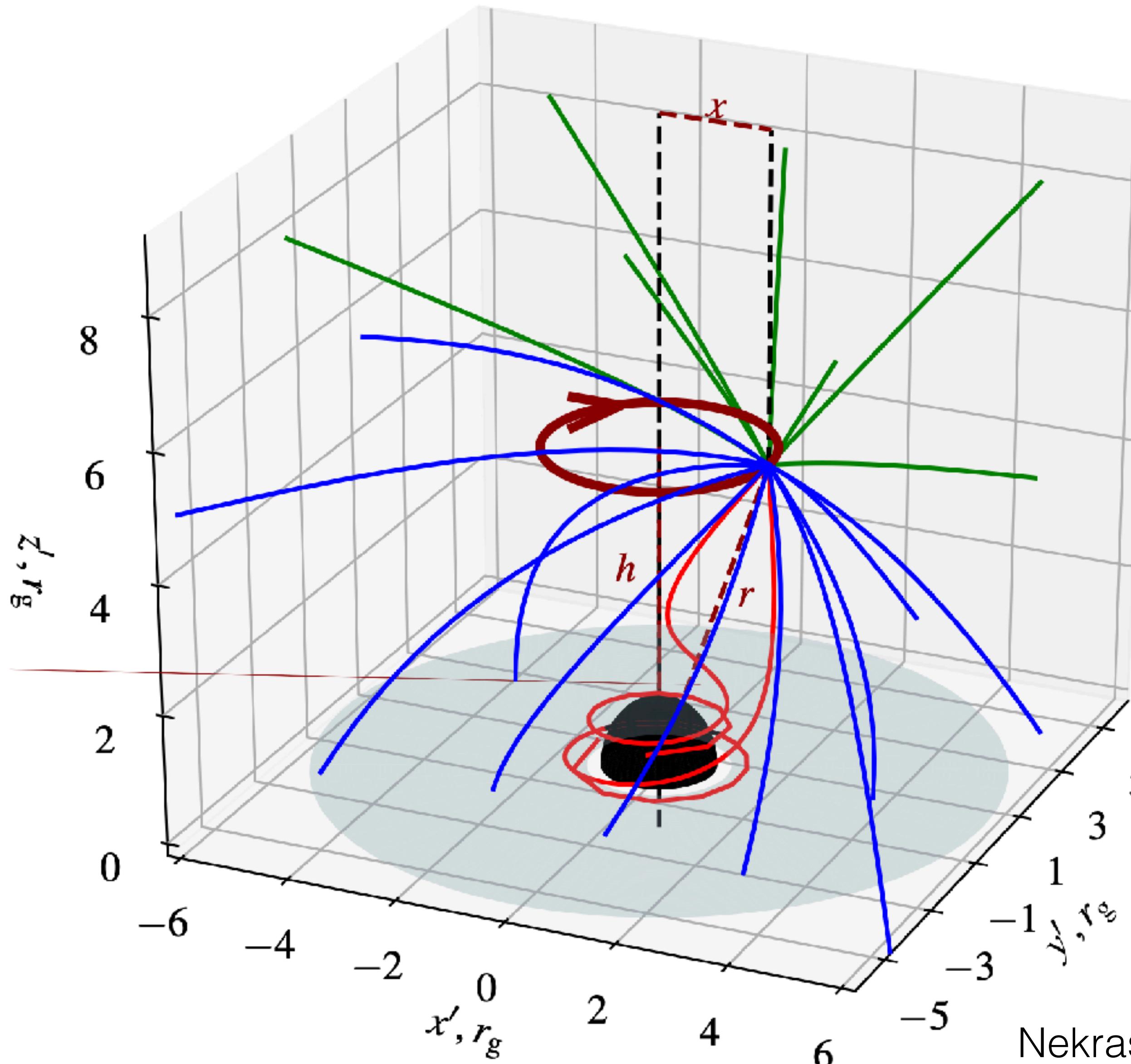


# Alternative models

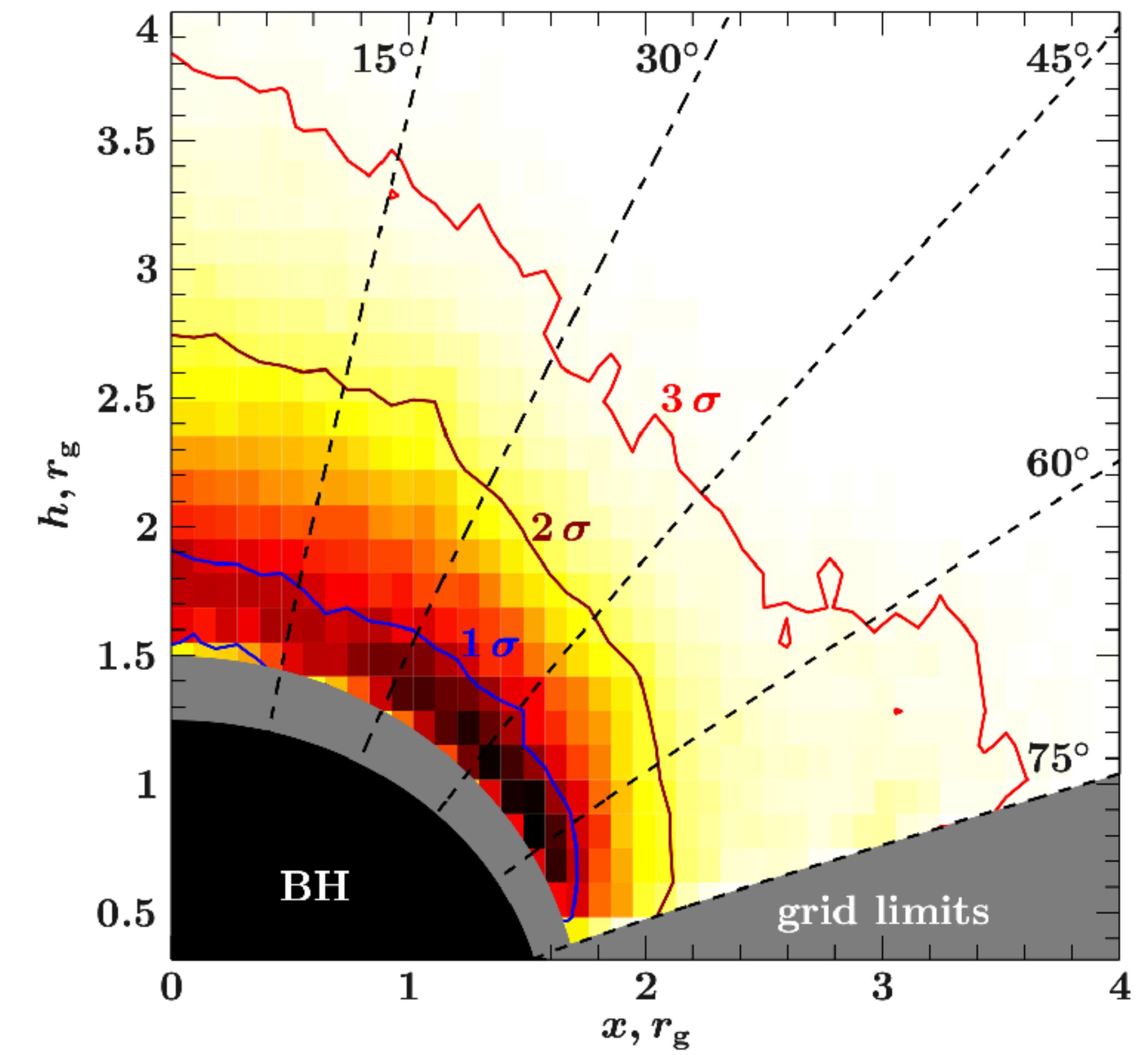


# Alternative models

Ring corona and the fit of ESO 033- G002

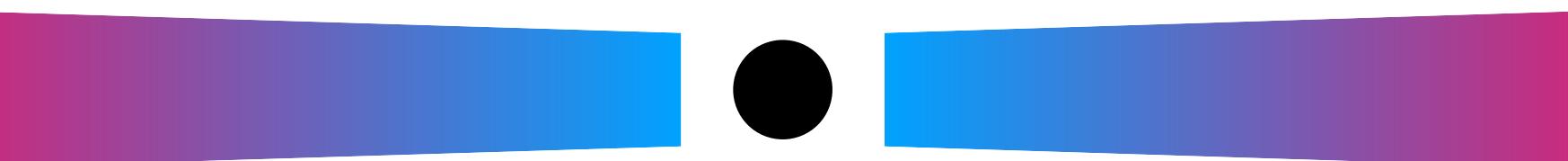


Nekrasov+ 2025

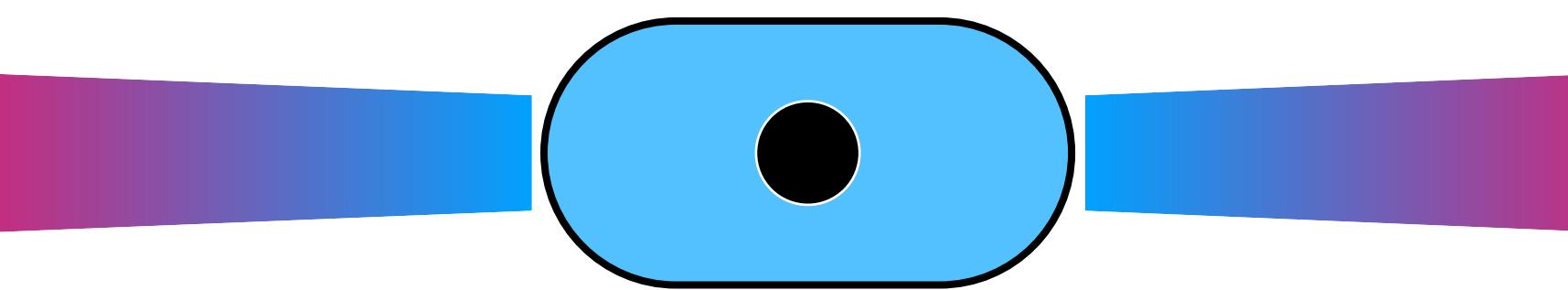


# Conclusions

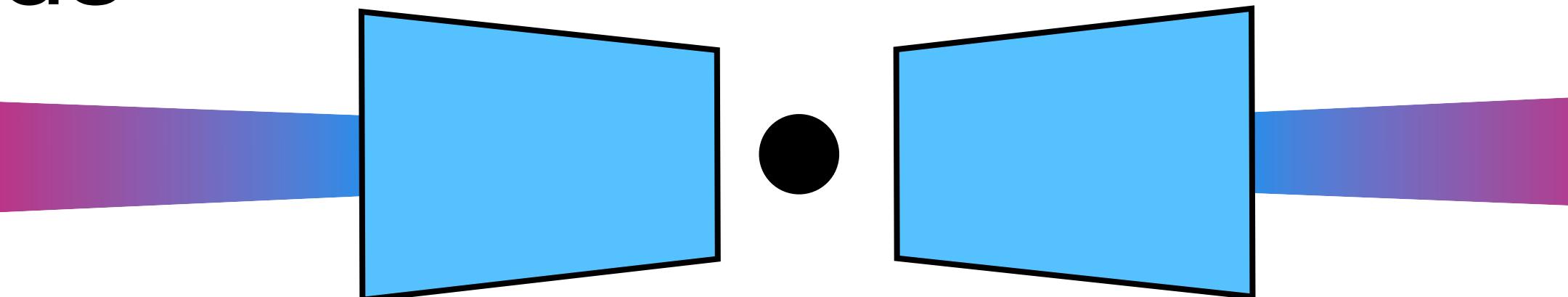
Iron line spectral fitting predicts vertical extension of the corona and not truncated disk in the hard state



QPO features suggest horizontal extension of the corona and truncated disk during the transition



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



# Conclusions

Iron line spectral fitting predicts extension of the corona and disk in the hard state

QPO features suggest truncation of the corona and truncated disk during the

transition between intermediate state

**Are we interpreting correctly  
our results?**