
Accreting black holes
in X-ray binaries
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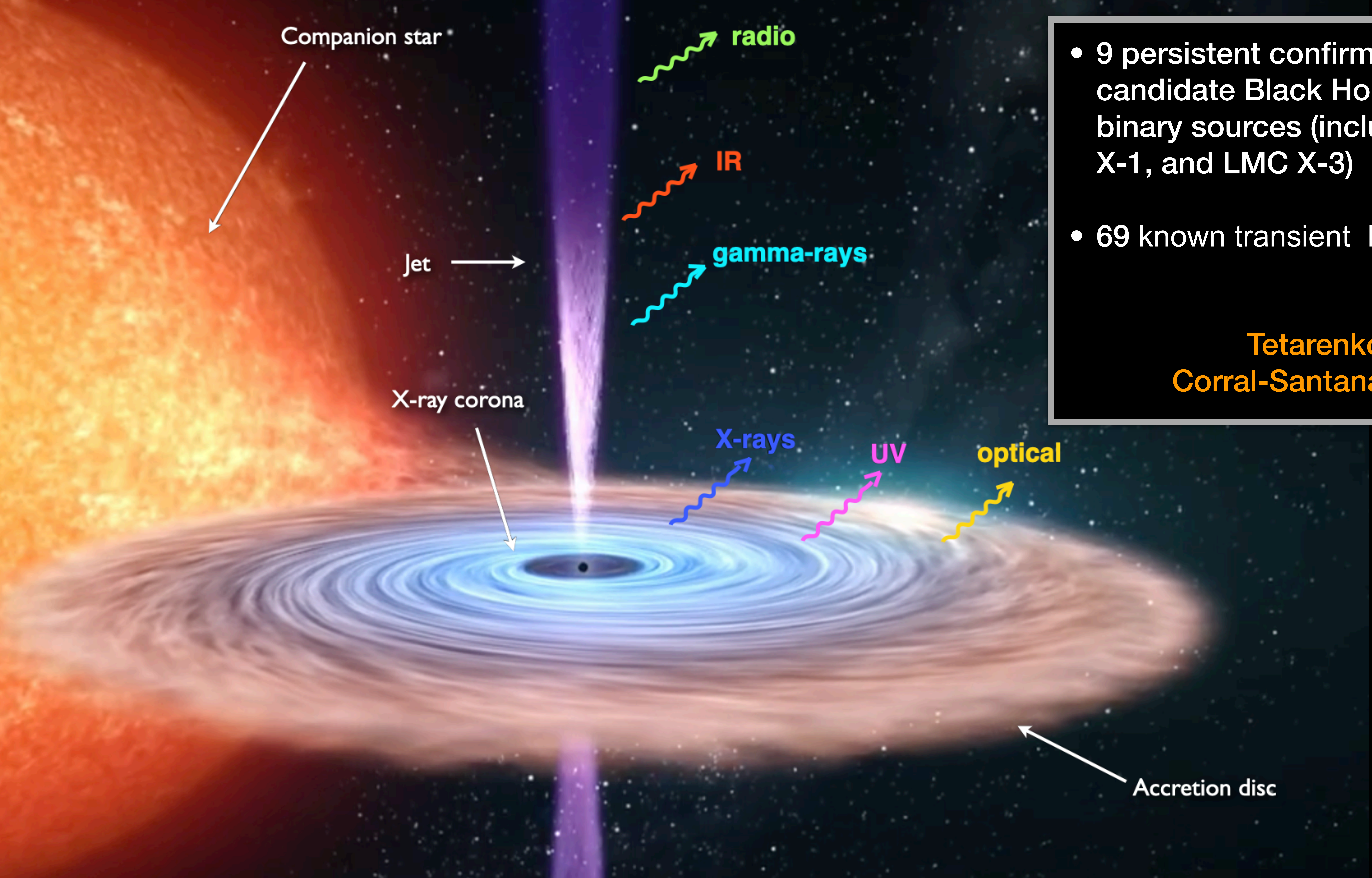
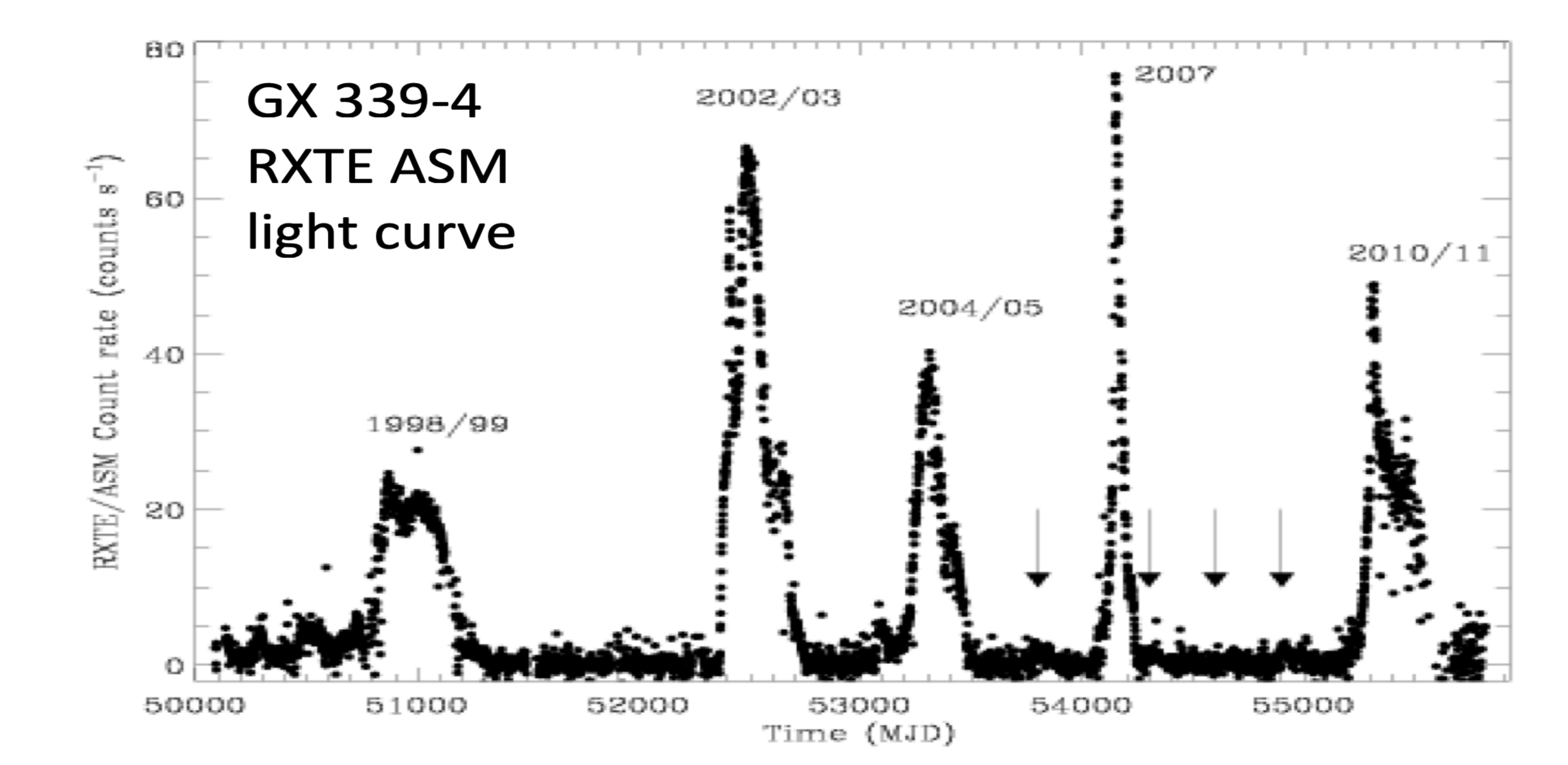


- 9 persistent confirmed or candidate Black Hole X-ray binary sources (including LMC X-1, and LMC X-3)
- 69 known transient BH sources

Tetarenko et al. 2016
Corral-Santana et al. 2016

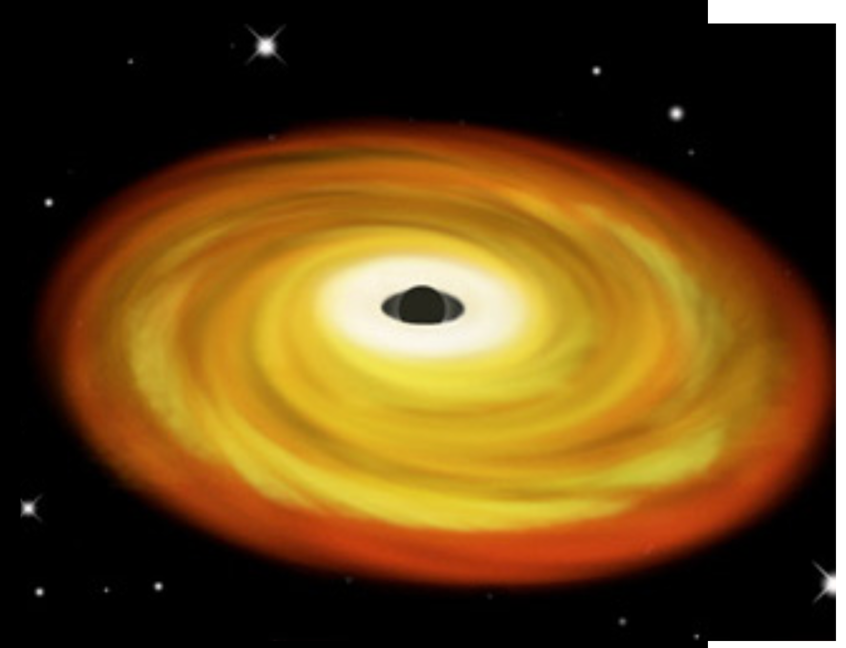
Outbursts

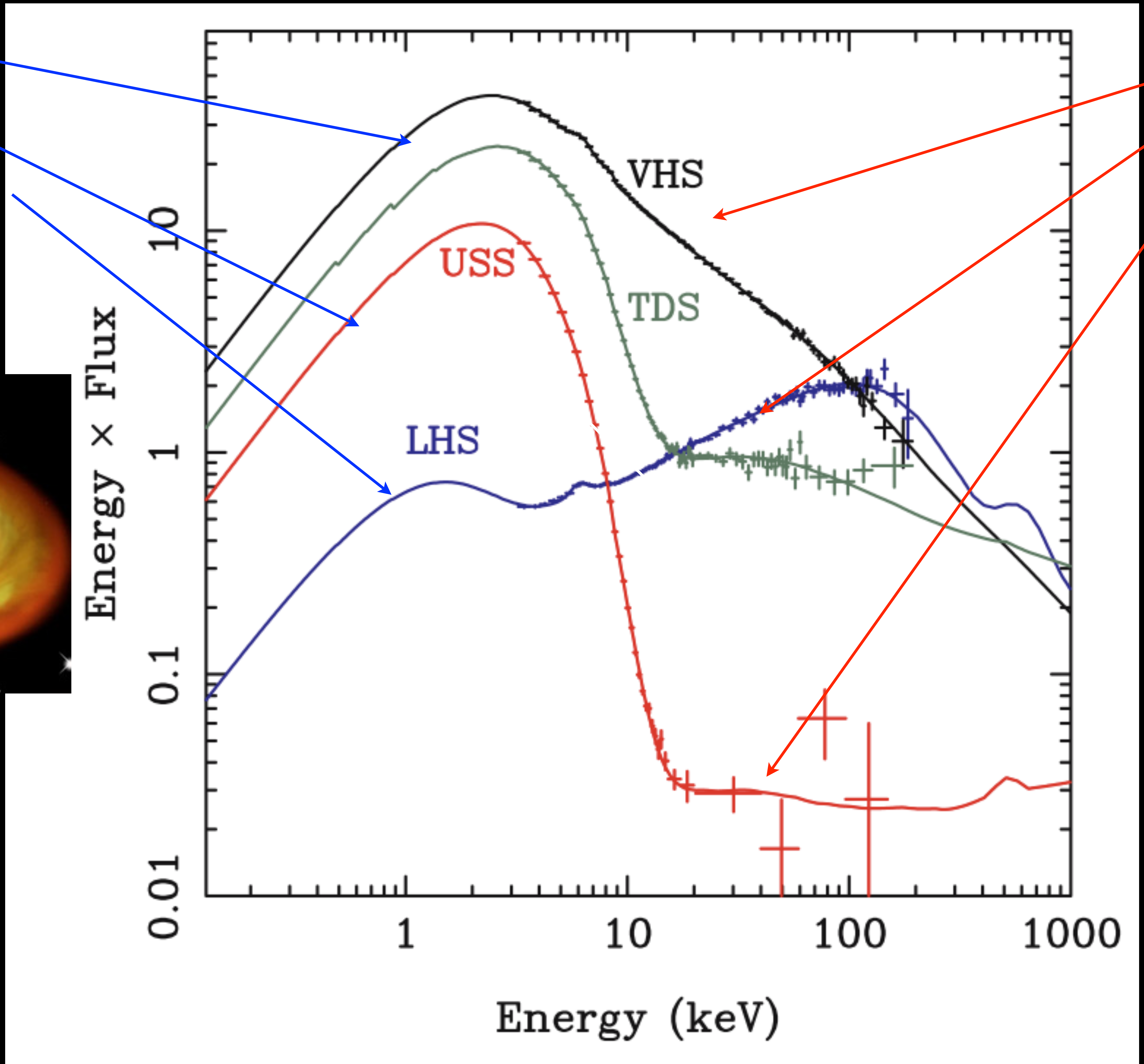


GX 339-4
RXTE ASM
light curve
2002/03
2007
2010/11
2004/05
1998/99
RXTE/ASM Count rate (counts s^{-1})
Time (MJD)
0
20
40
60
80
50000
51000
52000
53000
54000
55000

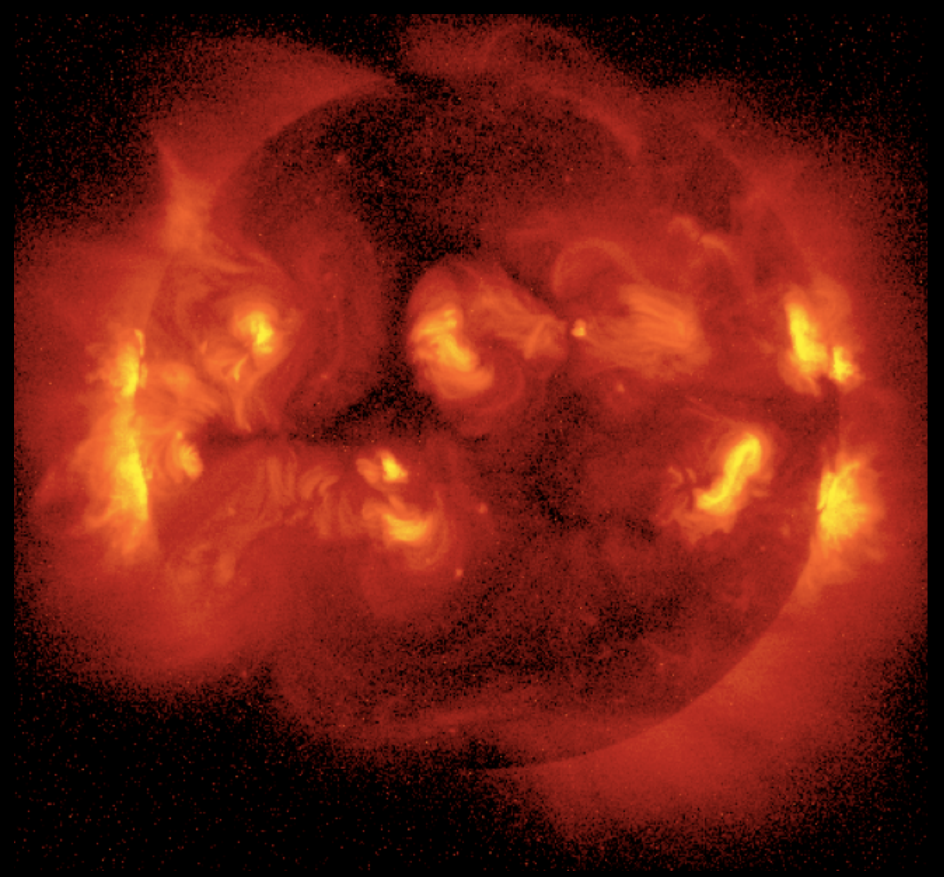
High energy spectra of BH X-ray binaries

Thermal emission: accretion disk





Non-thermal emission: ‘the corona’



Hot plasma:
- accretion disk corona
- hot accretion flow
- jet

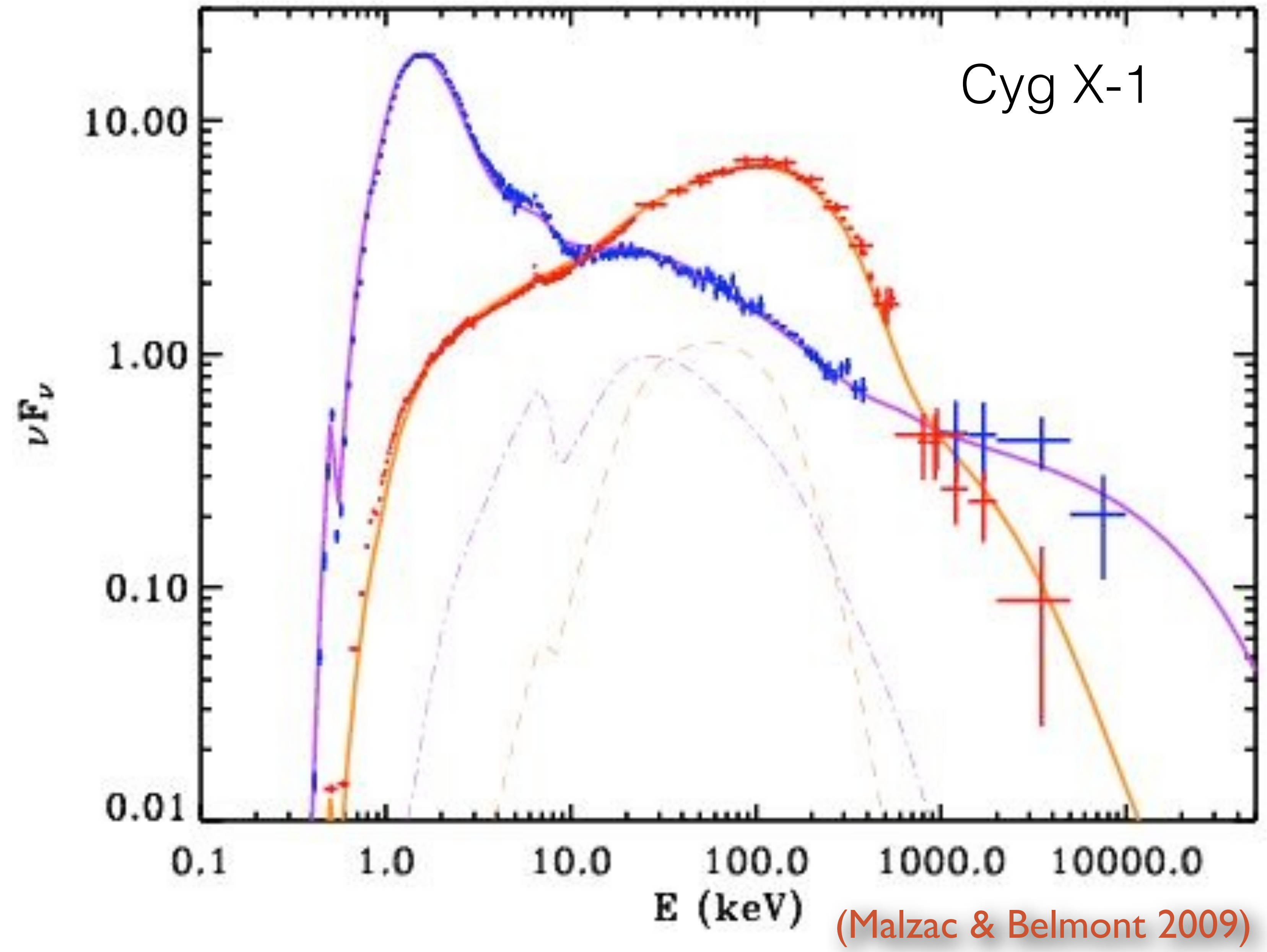
SOFT SPECTRAL STATE vs **HARD SPECTRAL STATE**

from Done et al. 2007

Emission above 200 keV

Emission in excess of thermal comptonization detected in several sources in hard state. (Mc Connell et 2002; Del Santo et al. 2008)

IC emission from non-thermal electrons in the corona (hybrid thermal/non thermal models) (Coppi & Poutanen 1998)

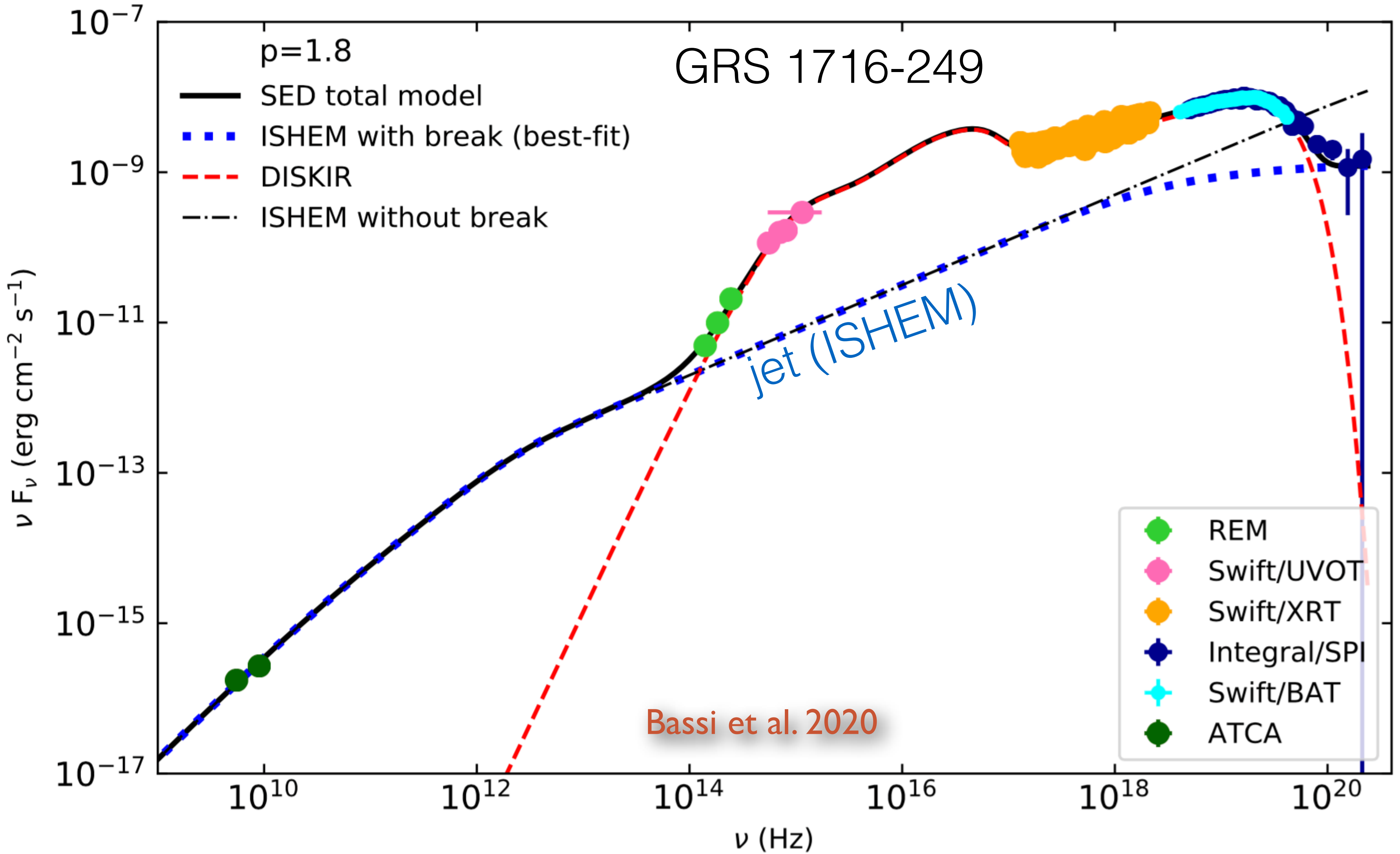


(Malzac & Belmont 2009)

INTEGRAL polarization measurements in Cyg X-1 suggests excess is strongly polarized (PD: 76%+/-15% above 230 keV).

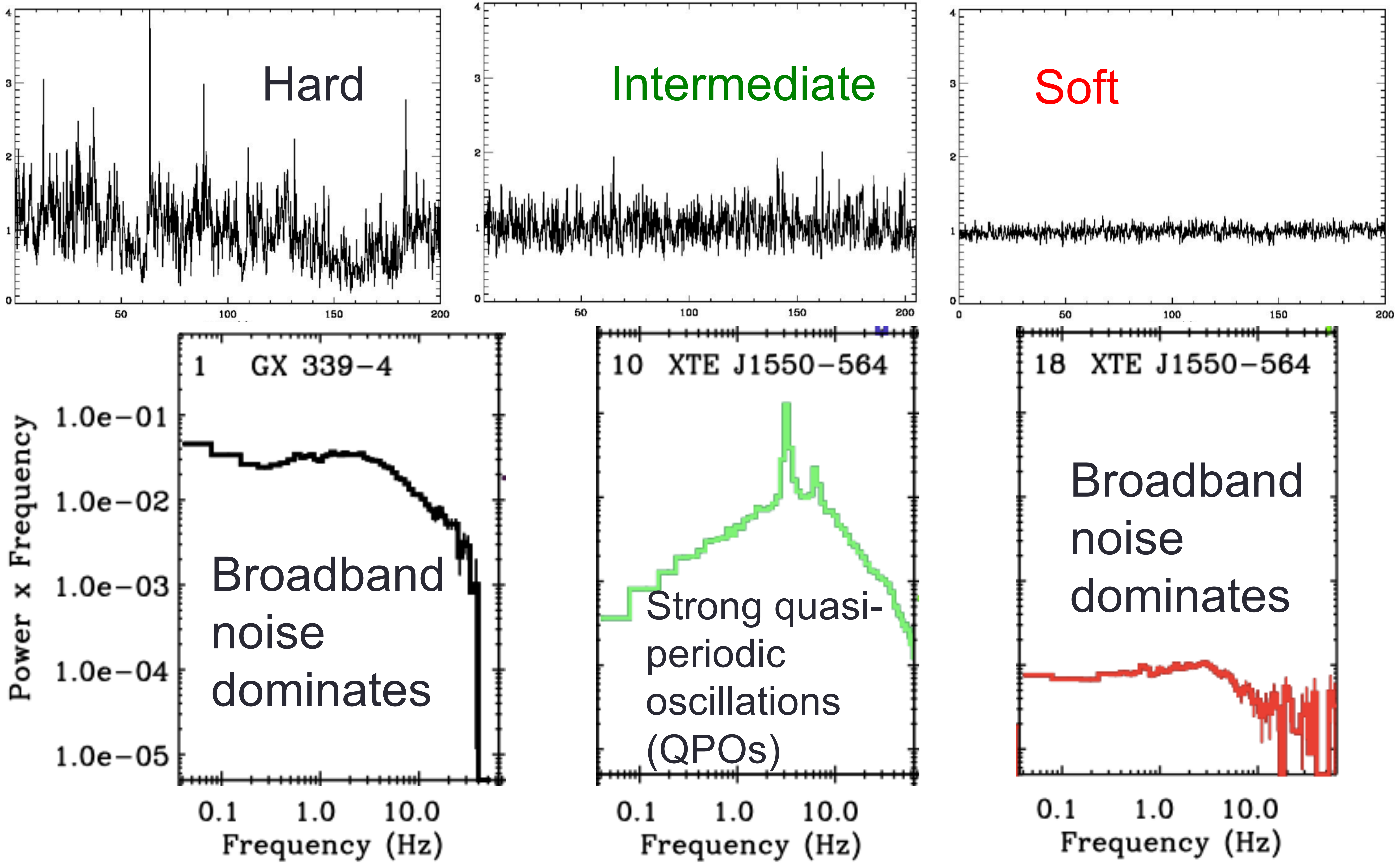
Jet synchrotron emission ?

(Jourdain et al. 2012, Laurent et al 2012, but see Zdziarski et al. 2017, Bassi et al. 2020)



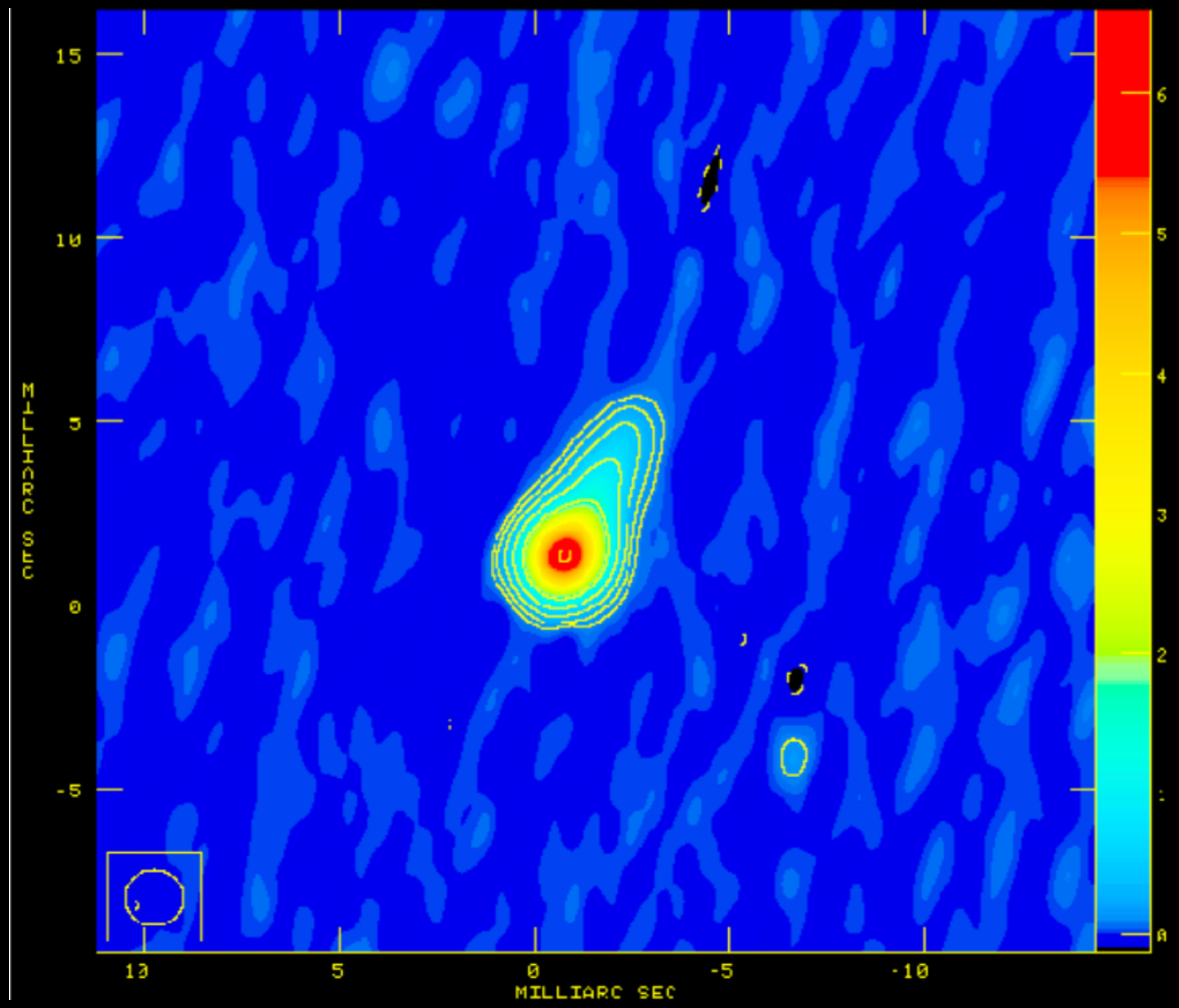
Bassi et al. 2020

Fast X-ray variability



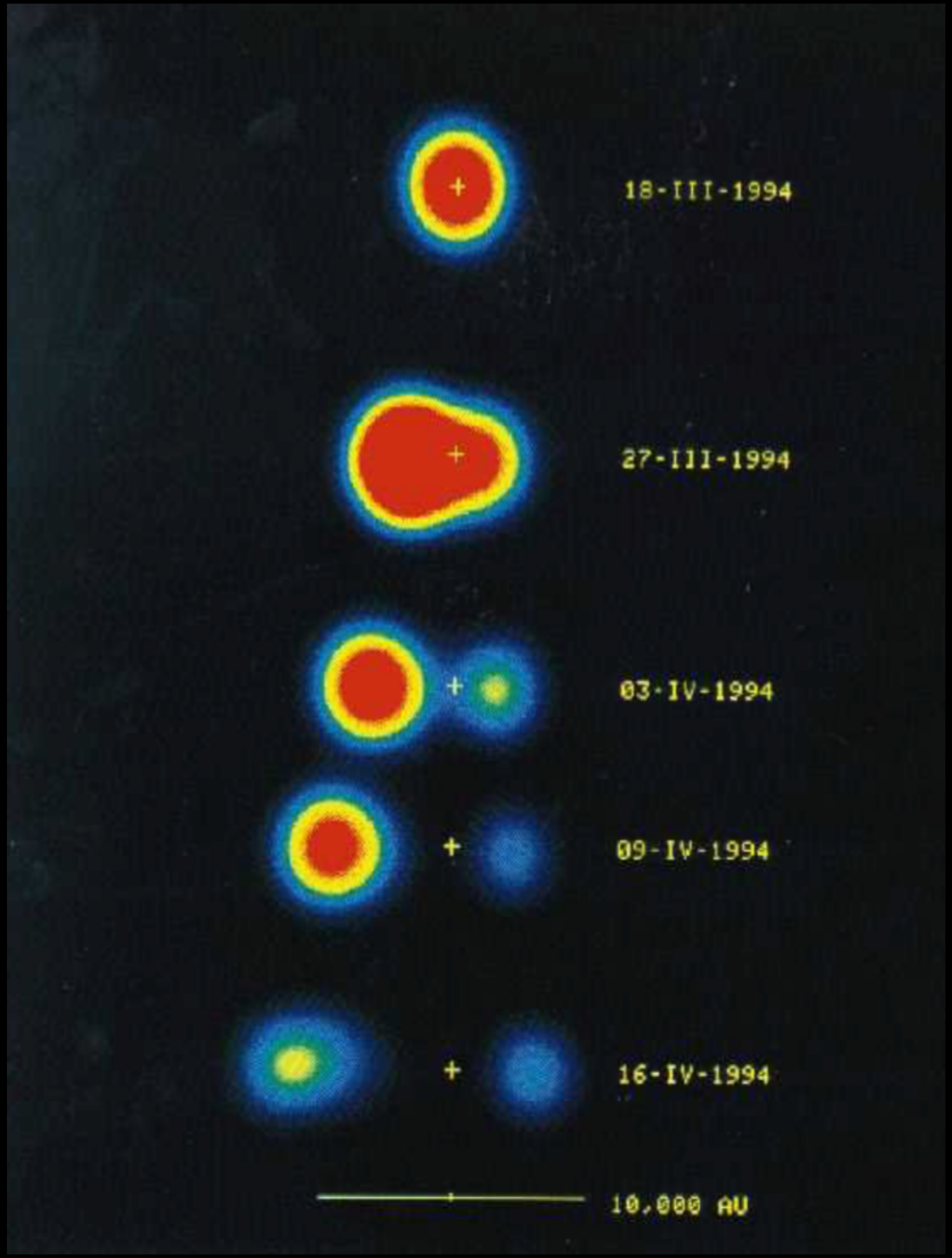
Radio jets

- Steady compact partially absorbed jets (mas scale)



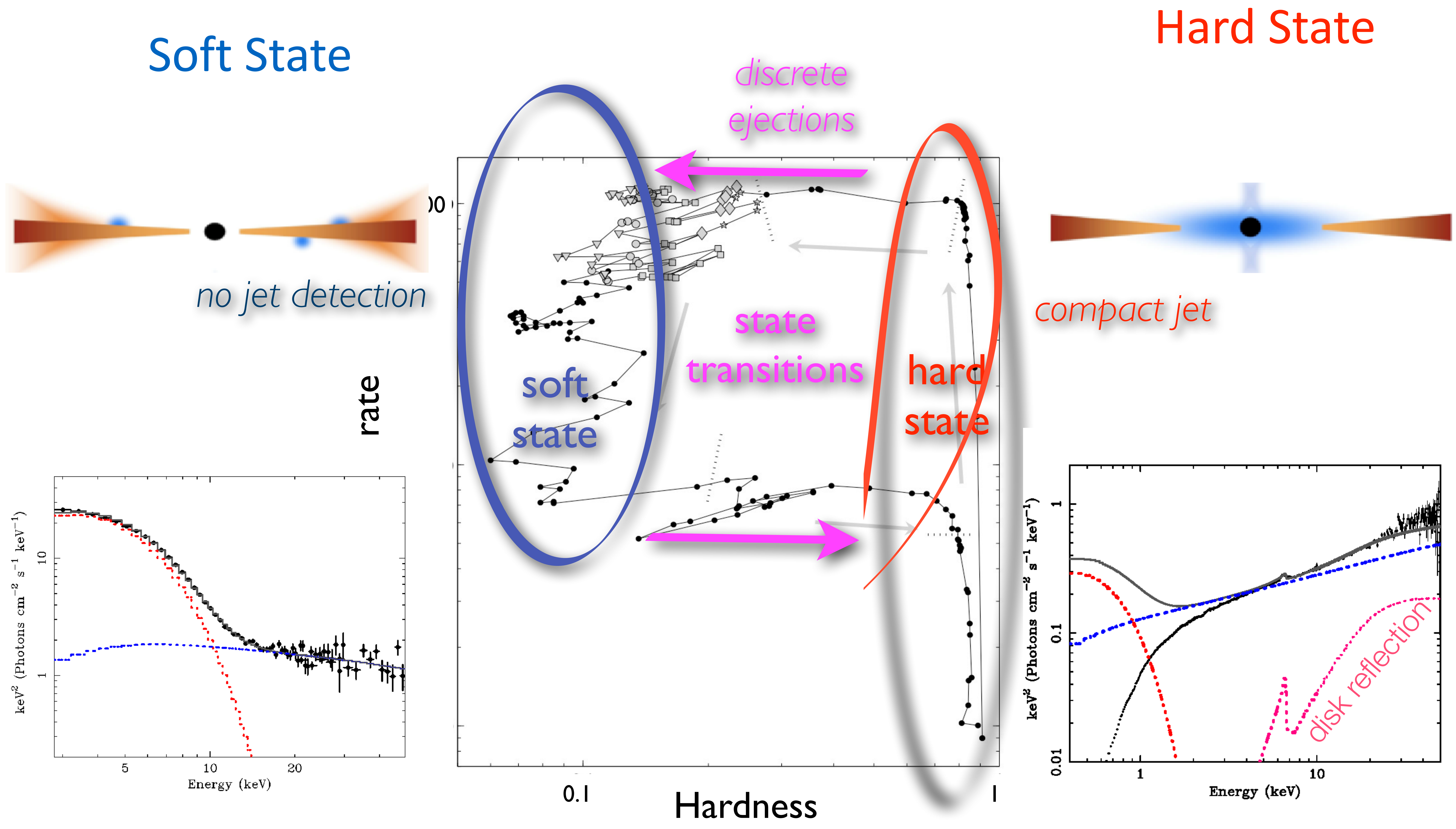
(Stirling et al. 2001)

- Discrete ejections (superluminal,balistic)

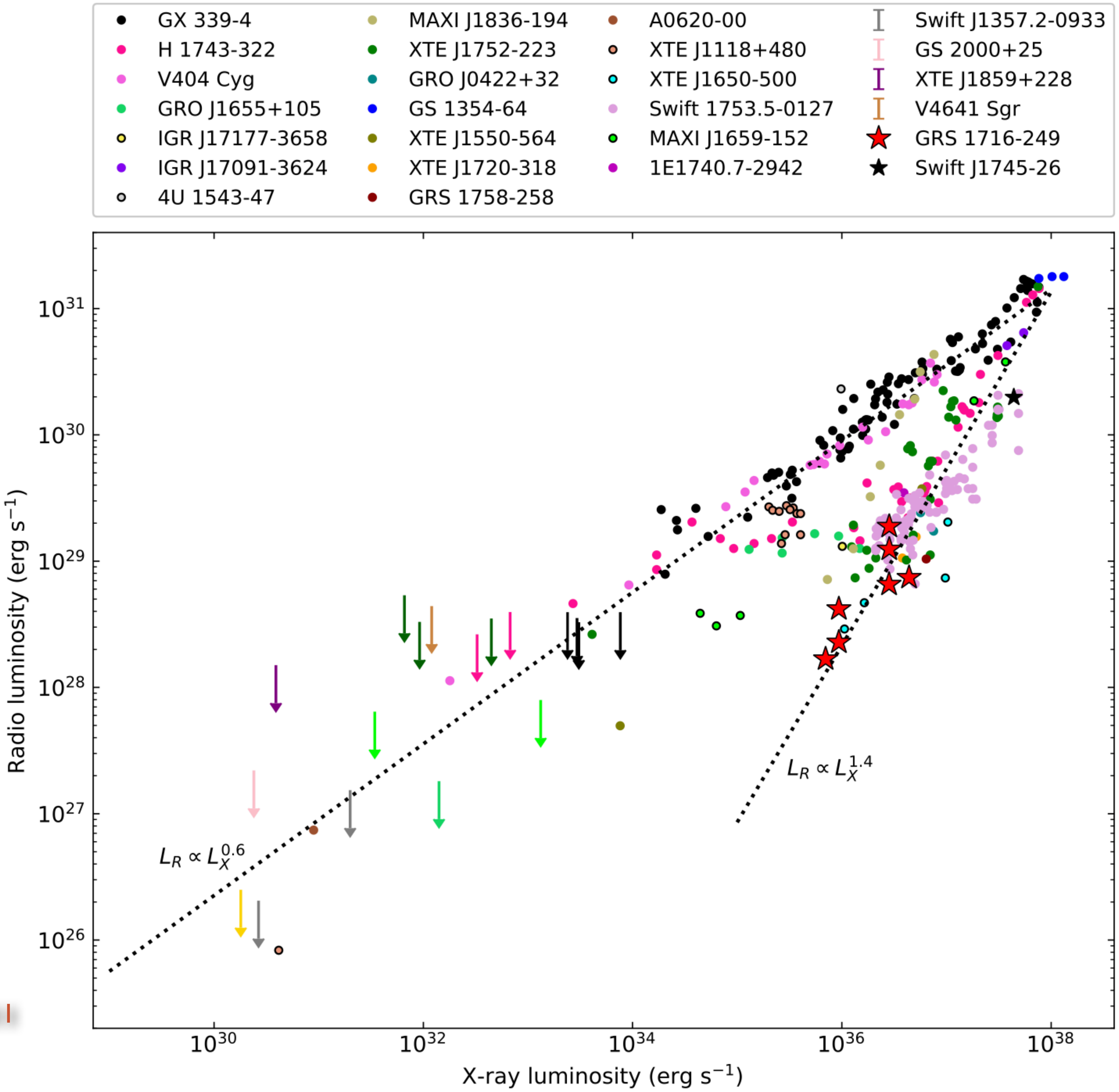


(Mirabel et al. 1994)

Spectral evolution during outbursts of BHBs



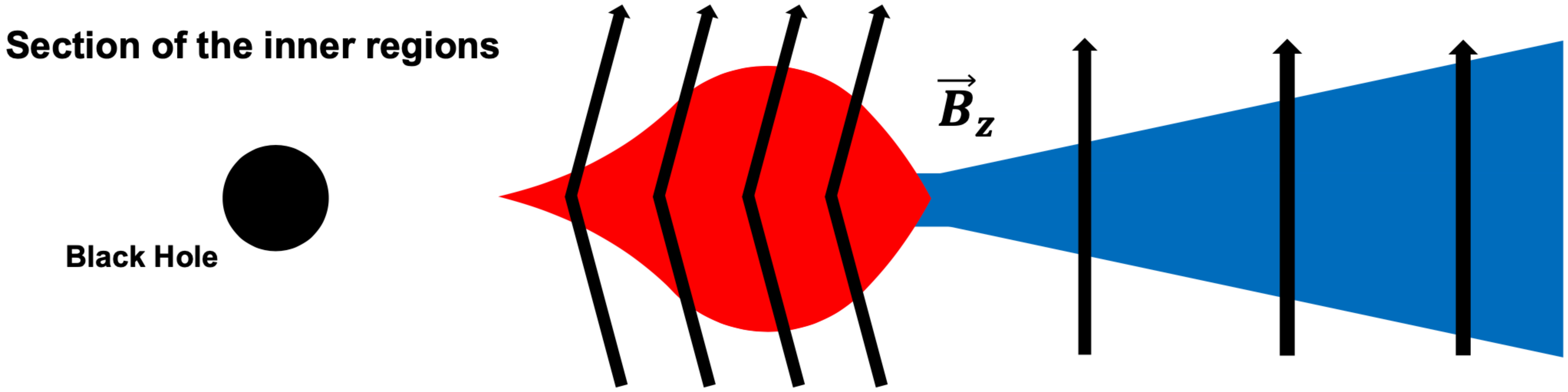
Radio X-ray correlation



Corbel et al. 2003; Gallo et al. 2003; Coriat et al. 2011

JED+SAD model :
a magnetised accretion-ejection structure

Jet Emitting Disc / Standard Accretion Disc



Ferreira+ 06,22
Petrucci+ 08, 13
Marcel+18ab,19,20,21
Marino+21
Barnier+22

Jet Emitting Disk

- Self similar MHD solutions **(Ferreira 1997)**
- **Supersonic accretion speed**
- Optically thin
- Hot

} **Even at high $\dot{m}$**

—> hot comptonizing medium

Standard Accretion Disc

- From **(Shakura & Sunyaev, 1973)**
- Optically thick
- Geometrically thin
- Cold ~1 keV

—> soft thermal emission

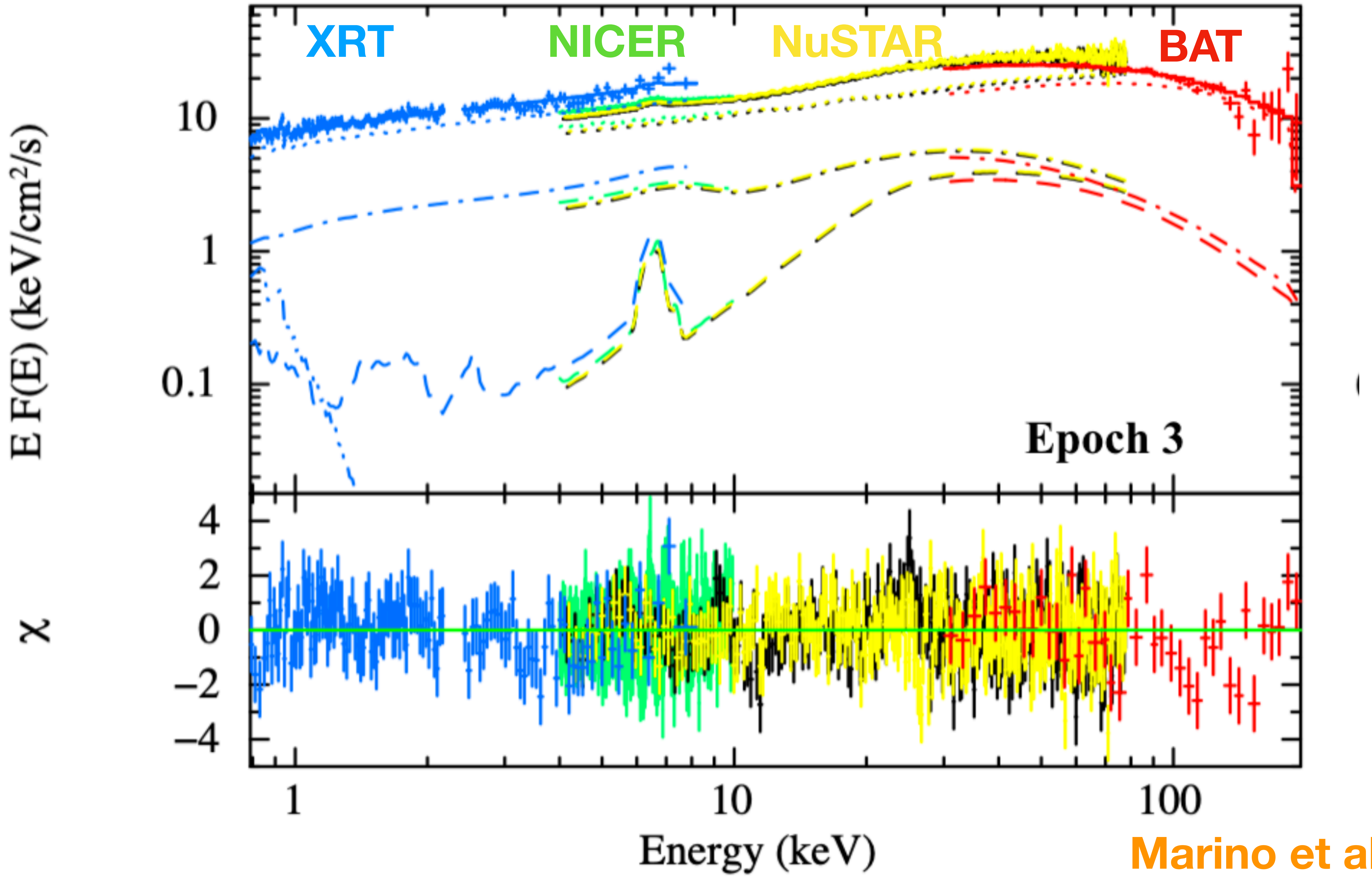
- **Calculation of steady state thermal structure and spectral energy distribution**
- **Comparison to spectral data (XRBs, AGN)**

Best fit JED/SAD solution of MAXI J1820+070 spectral data

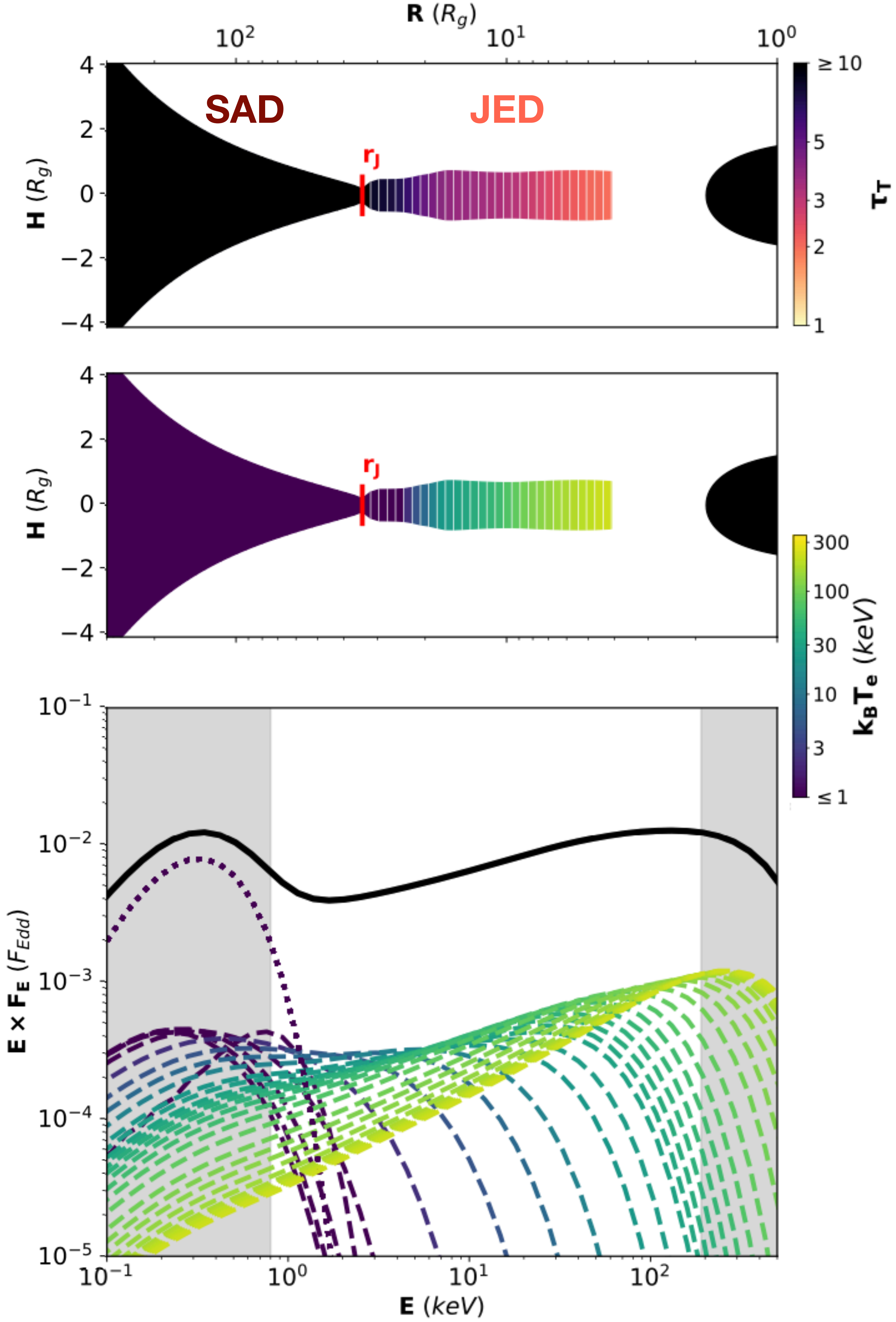
$$M_{BH} = 10\, M_{\odot}, \quad \dot{M}_0 c^2 = 2.36\, L_{Edd},$$

$$m_s = 1.243, \quad \alpha_v = 0.1$$

$$R_J = 44.8\, R_g, \quad R_i = 4\, R_g, \; R_o = 10^5\, R_g$$



Marino et al. 2021



What about timing ?

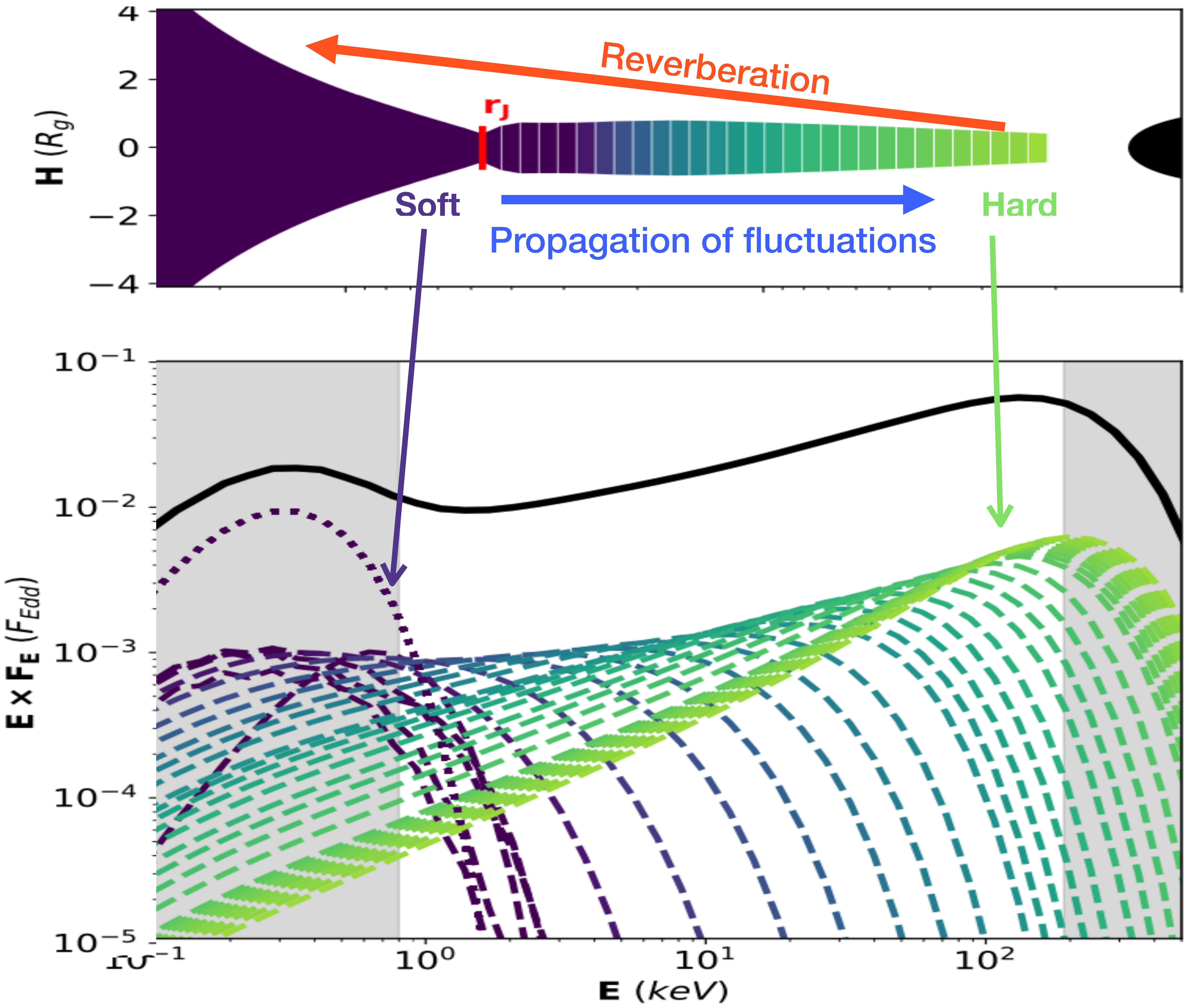
Simultaneous timing observations of MAXI J1820+070 with NICER

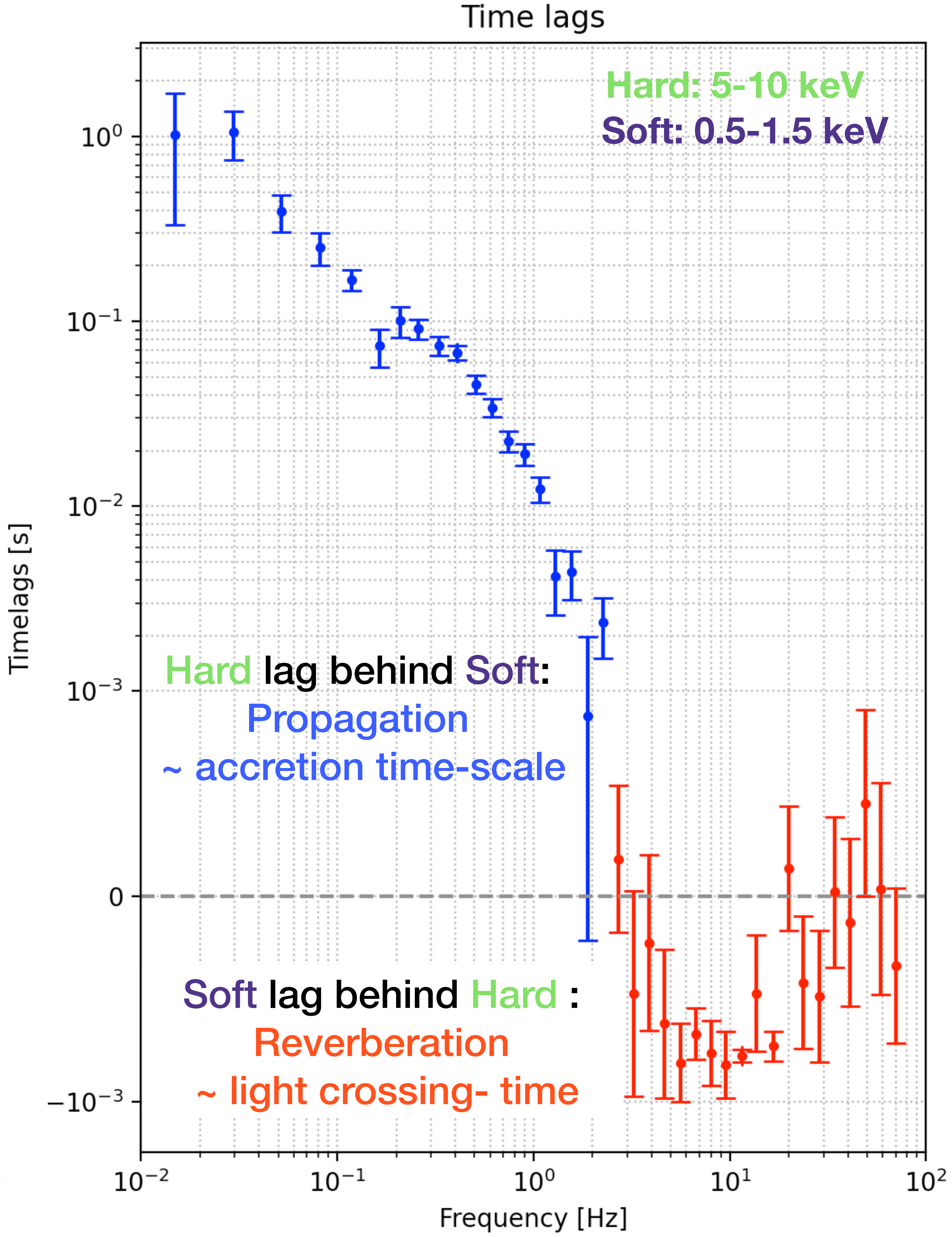
Kawamura et al. 2022

Propagating fluctuations model of variability

Accretion flow fluctuations propagate inward, modulated at faster times scales at smaller R (Lyubarskii 1997)

Lags in JED-SAD





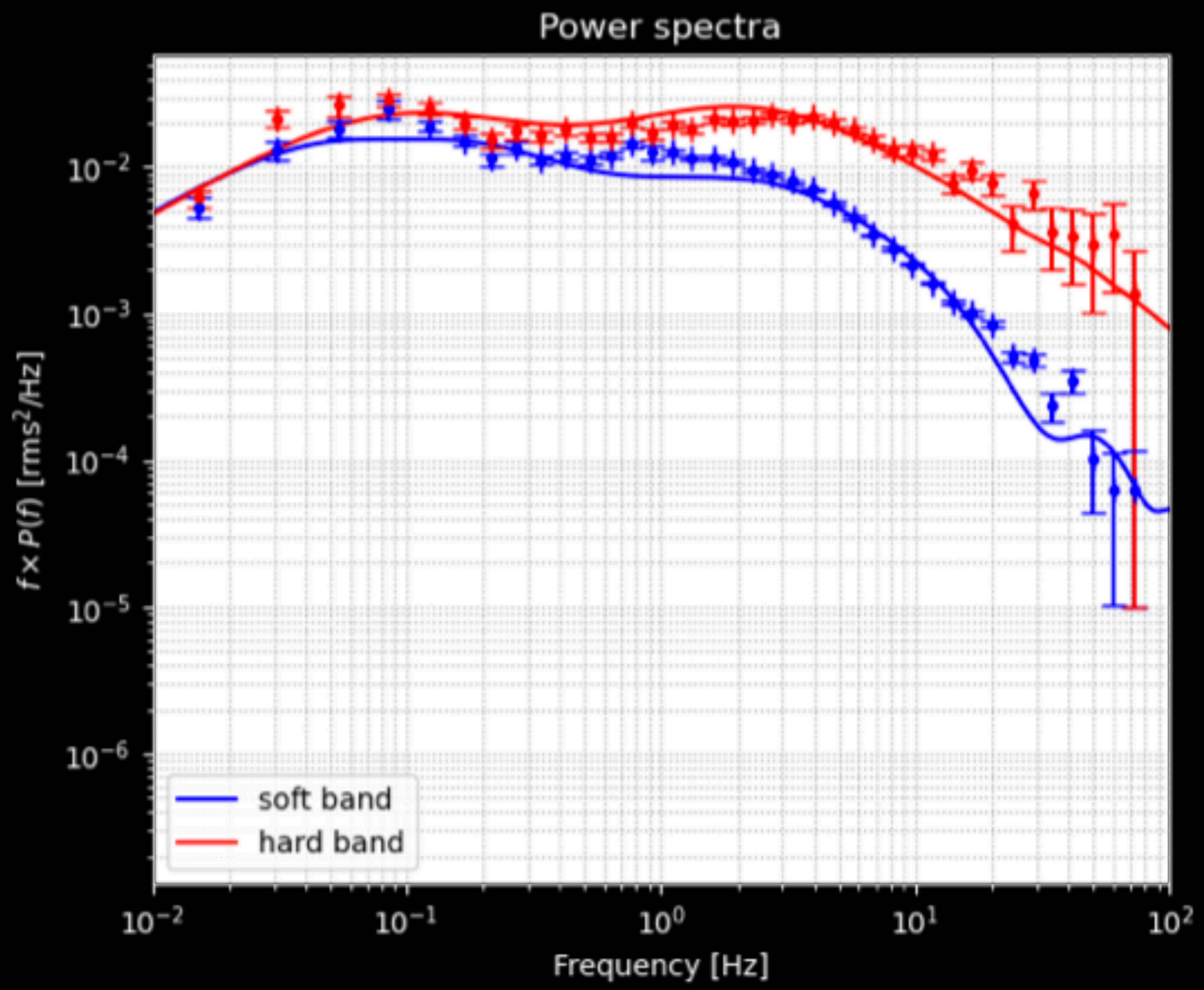
Time-dependent vesion of the JED+SAD model: comparison to data

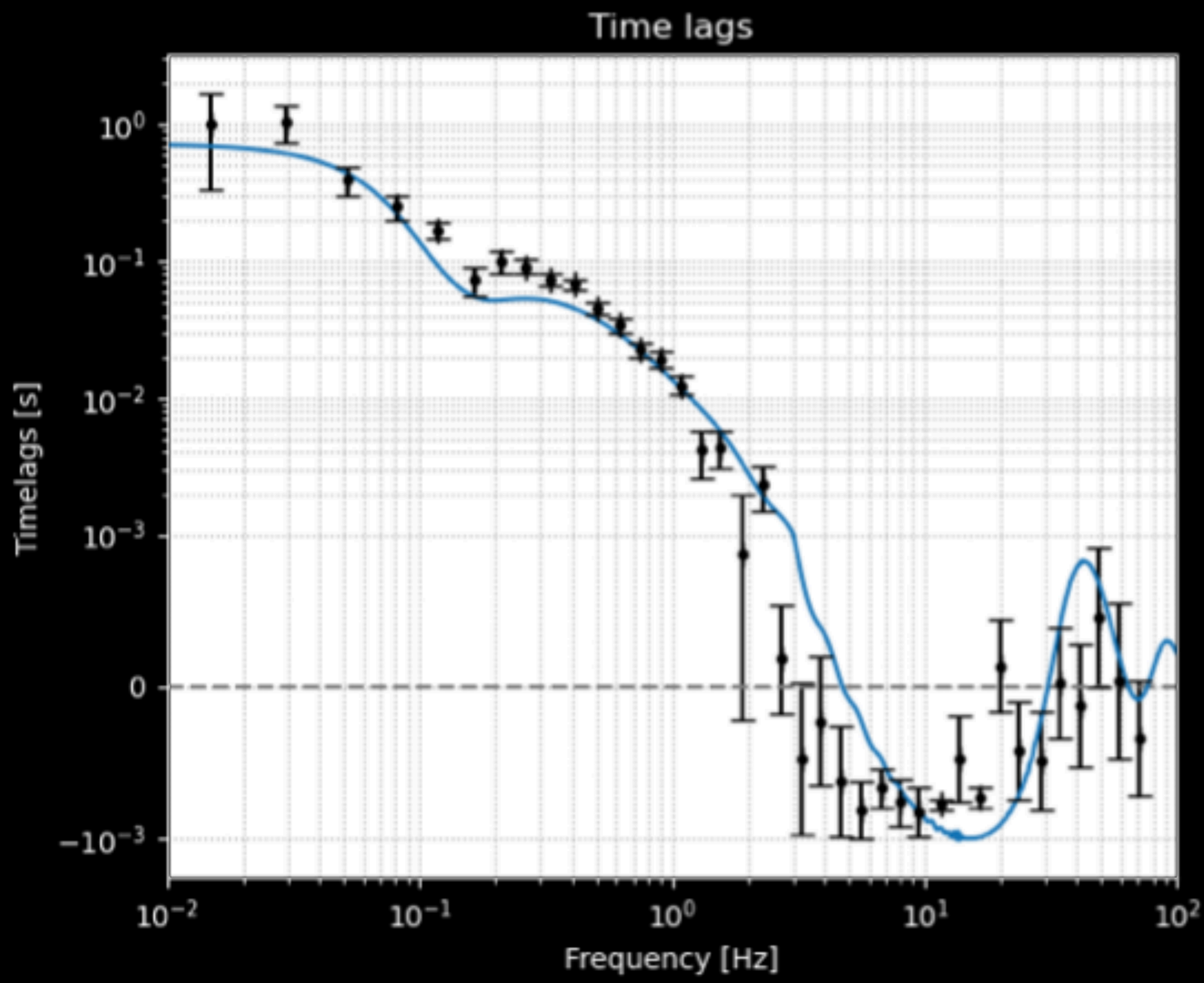
- The model makes it possible to reproduce simultaneously the timing AND spectral features of MAXI J1820+070

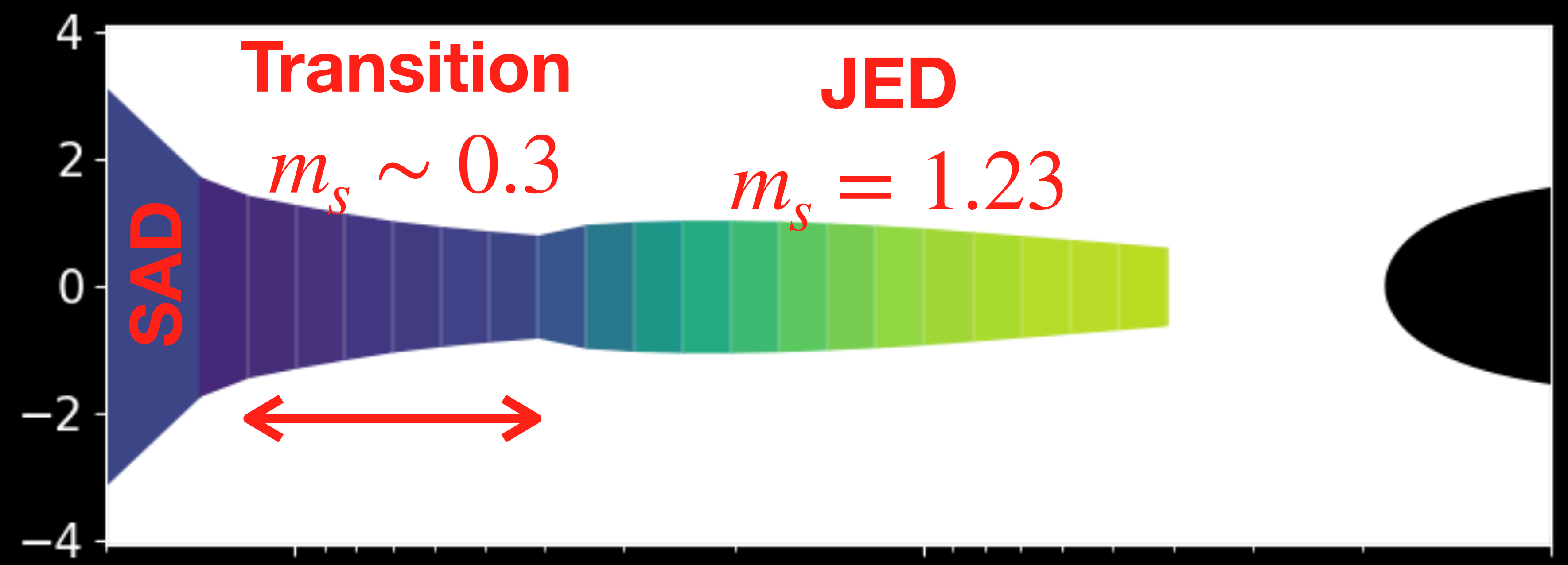
- This requires:

  ➡ an extended transition region between JED and SAD with intermediate properties (accretion velocity)

  ➡Most of the fluctuations injected at/around the transition region







Model required by timing data

Marino et al. 2021 spectral model

Malzac et al., in prep.

CONCLUSIONS

- Black holes X-ray binaries present a rich phenomenology which is far from being understood
- The JED+SAD is a physical model which can explain many of the observed features
- JED+SAD combined with propagating fluctuation model reproduces the main timing features of MAXI J1820+070 together with the spectral data
- The results suggest that ‘band-limited noise’ in X-ray power spectra observed in hard state originates mostly at or around the transition region between JED and SAD.
- The dynamics of this transition region which appears to be very unstable (see e.g. Spruit and Deufel 2001, Ferreira et al. 2022) requires further investigations.


GRAZIE !