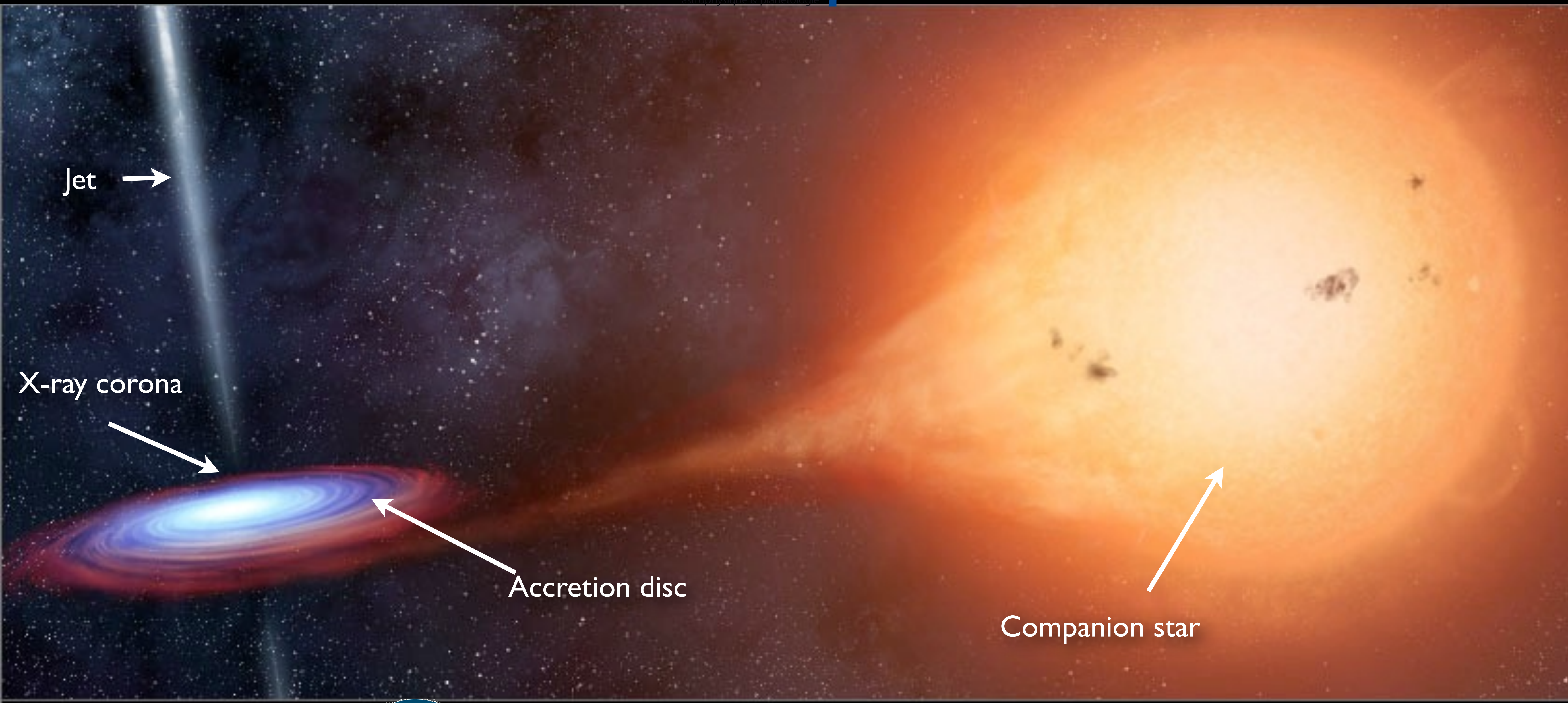
Compact jets in X-ray binaries

Julien Malzac
irap



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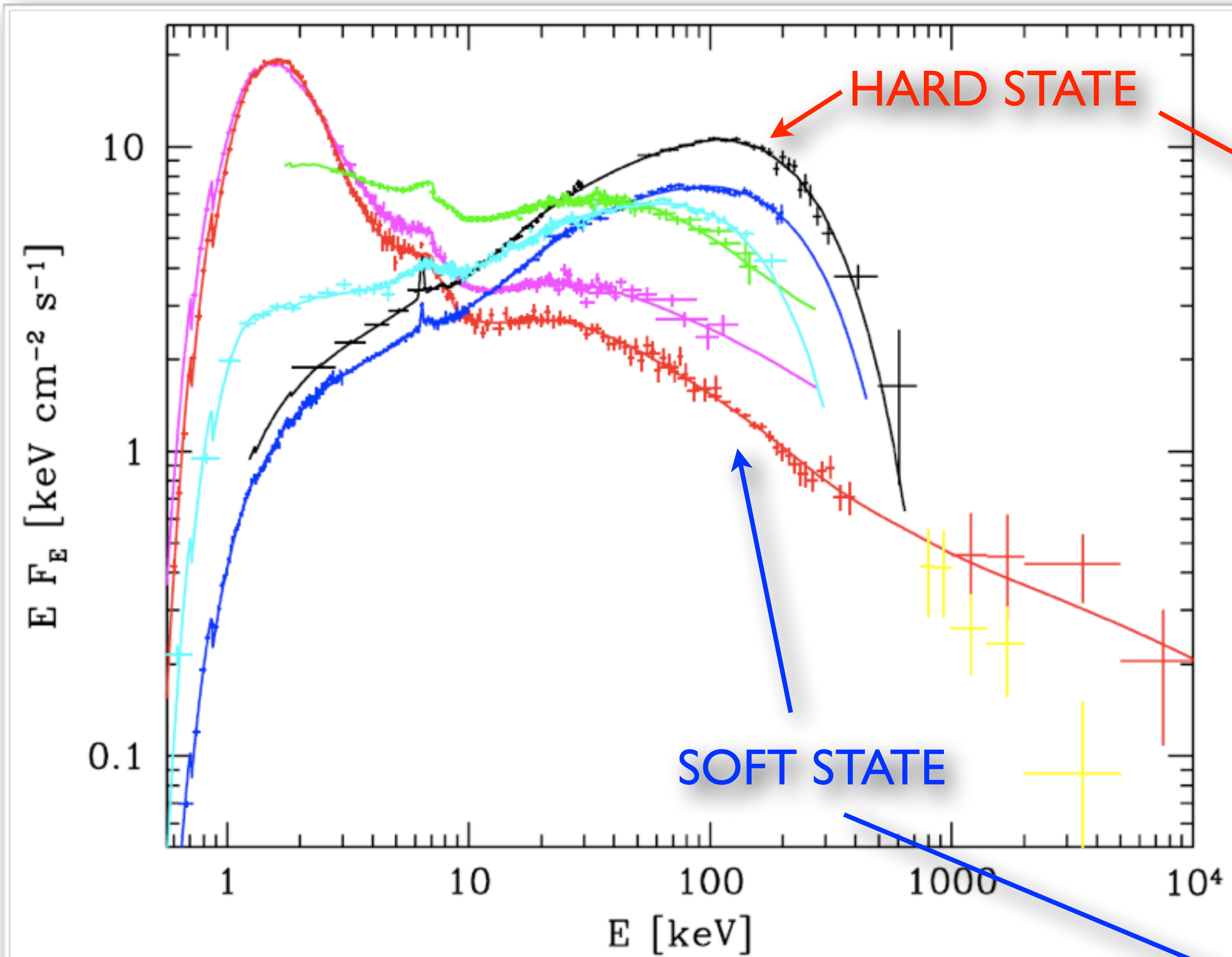
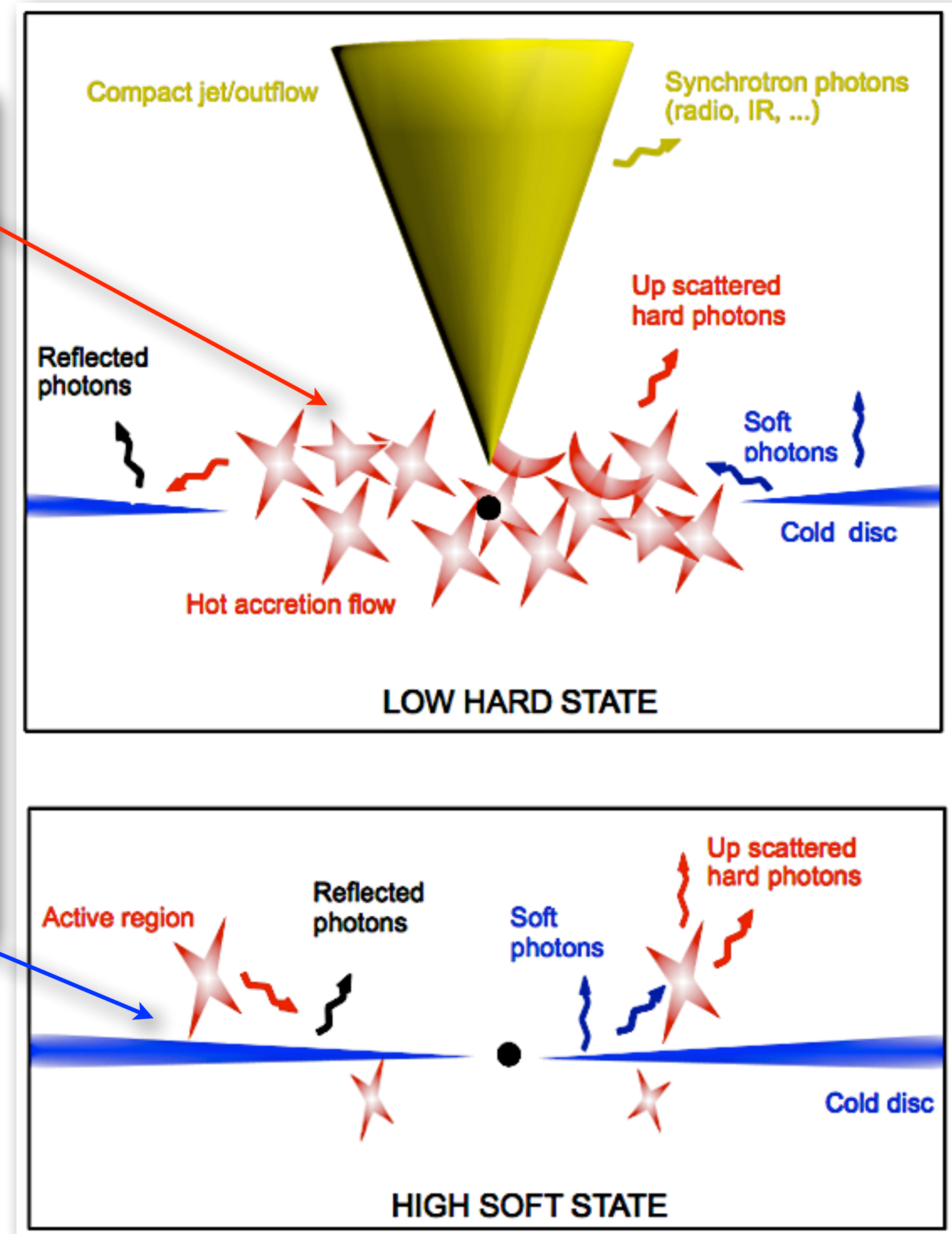
X-ray Spectral states of BH binaries

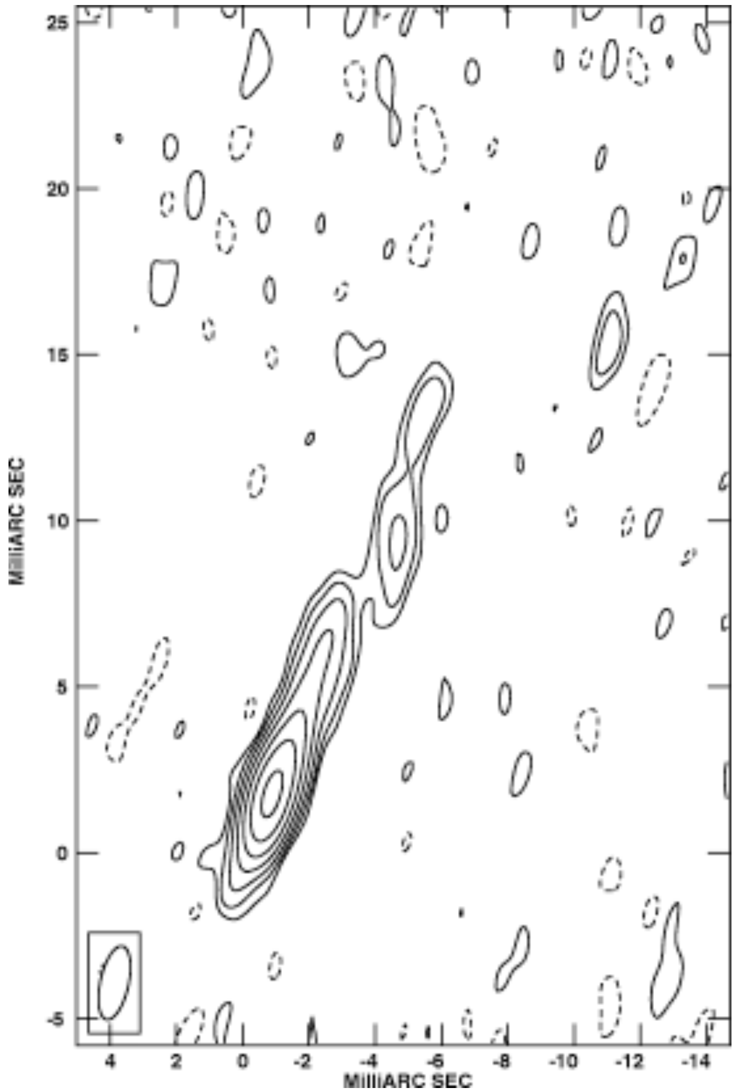


Zdziarski et al 2003

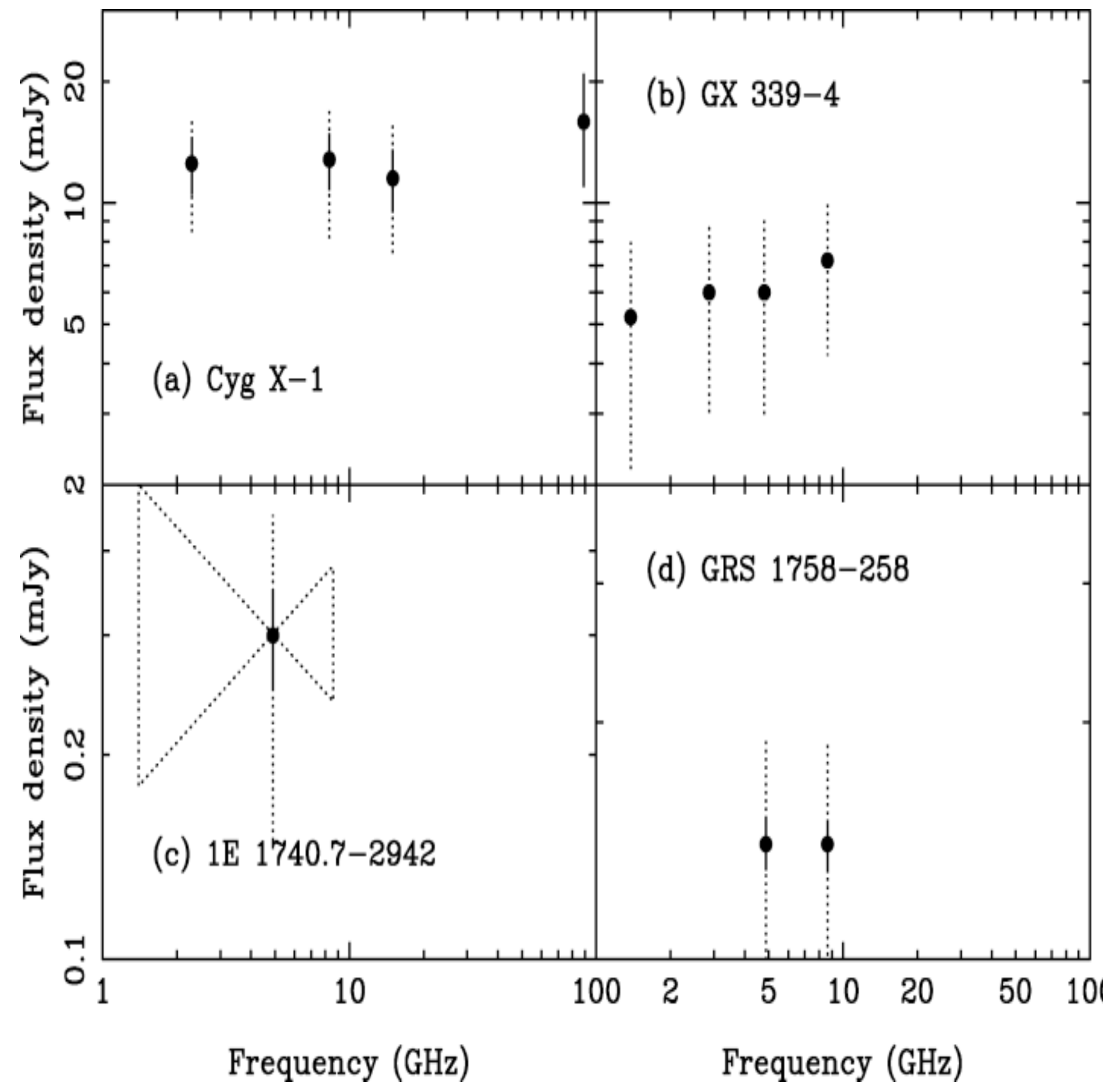


Esin et al. 1997; Poutanen et al 1997; Done et al. 2007

Evidence for compact radio jets in XRBs in the hard spectral state



Cygnus X-1
(Stirling et al. 2001)



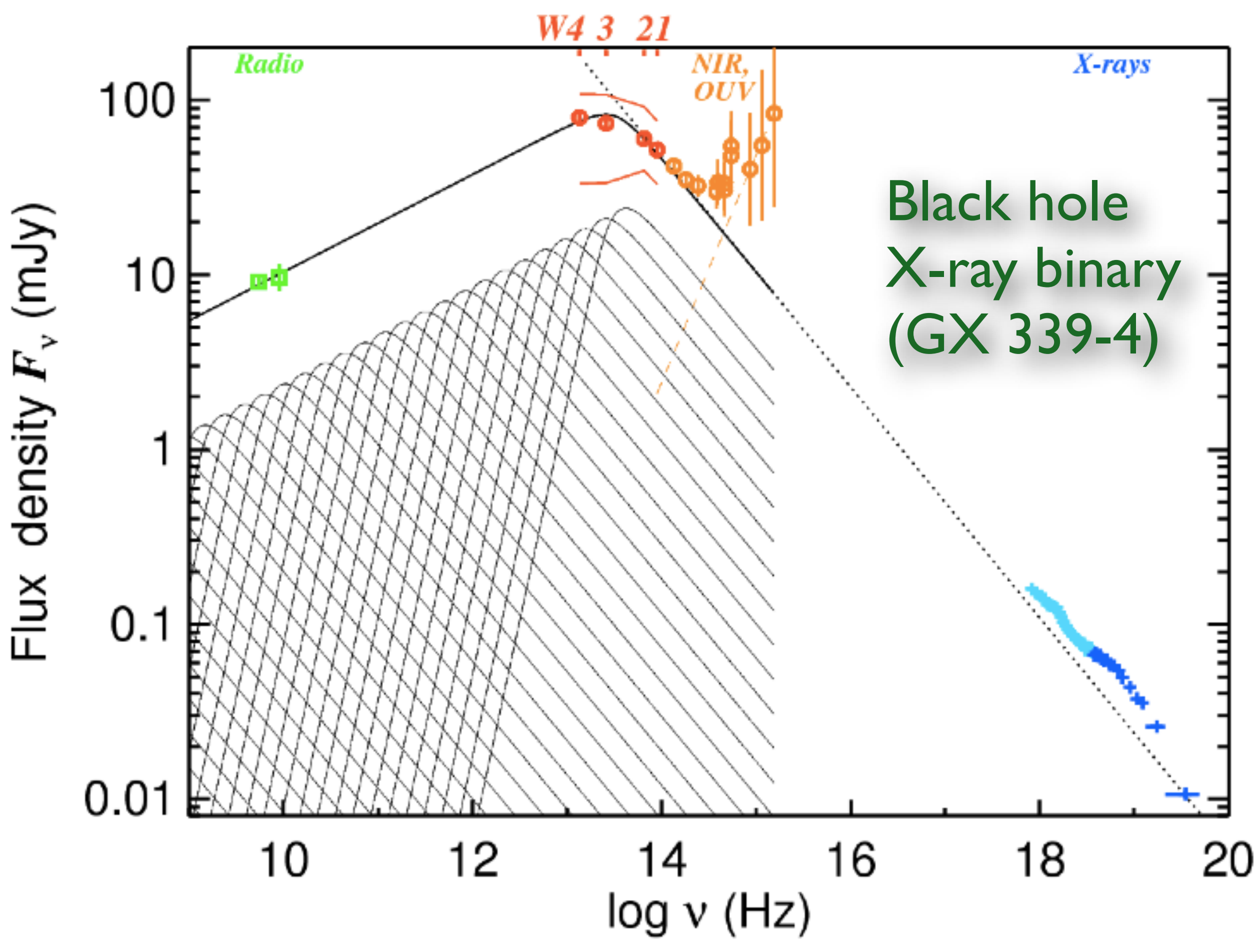
Flat/inverted radio spectra

(Fender 2001)

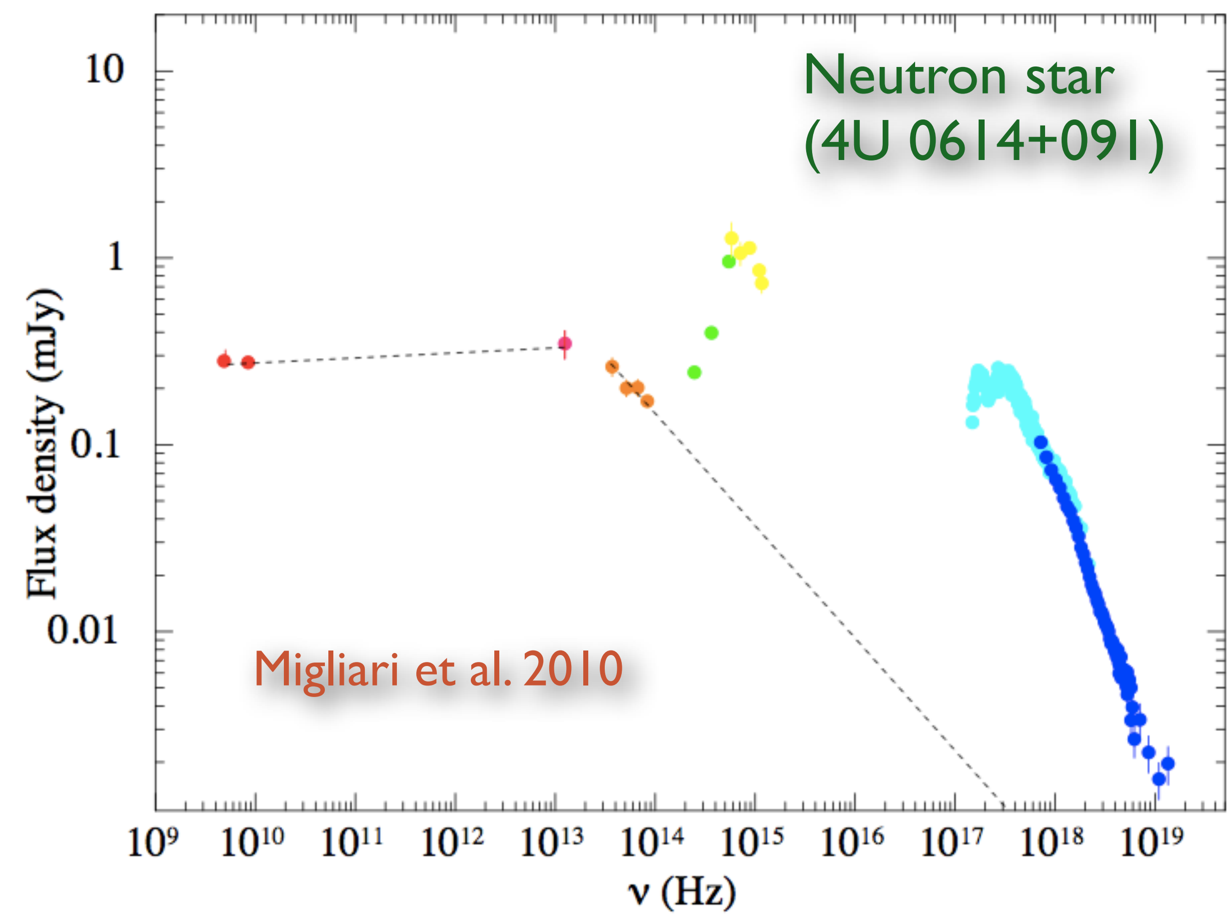
- Jet Lorentz factor $\Gamma = \left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}} \sim 1.5 - 3$
- Jet kinetic power > X-ray luminosity
- Jet half-opening angle ~ a few degs
- Radio emission quenched in soft state

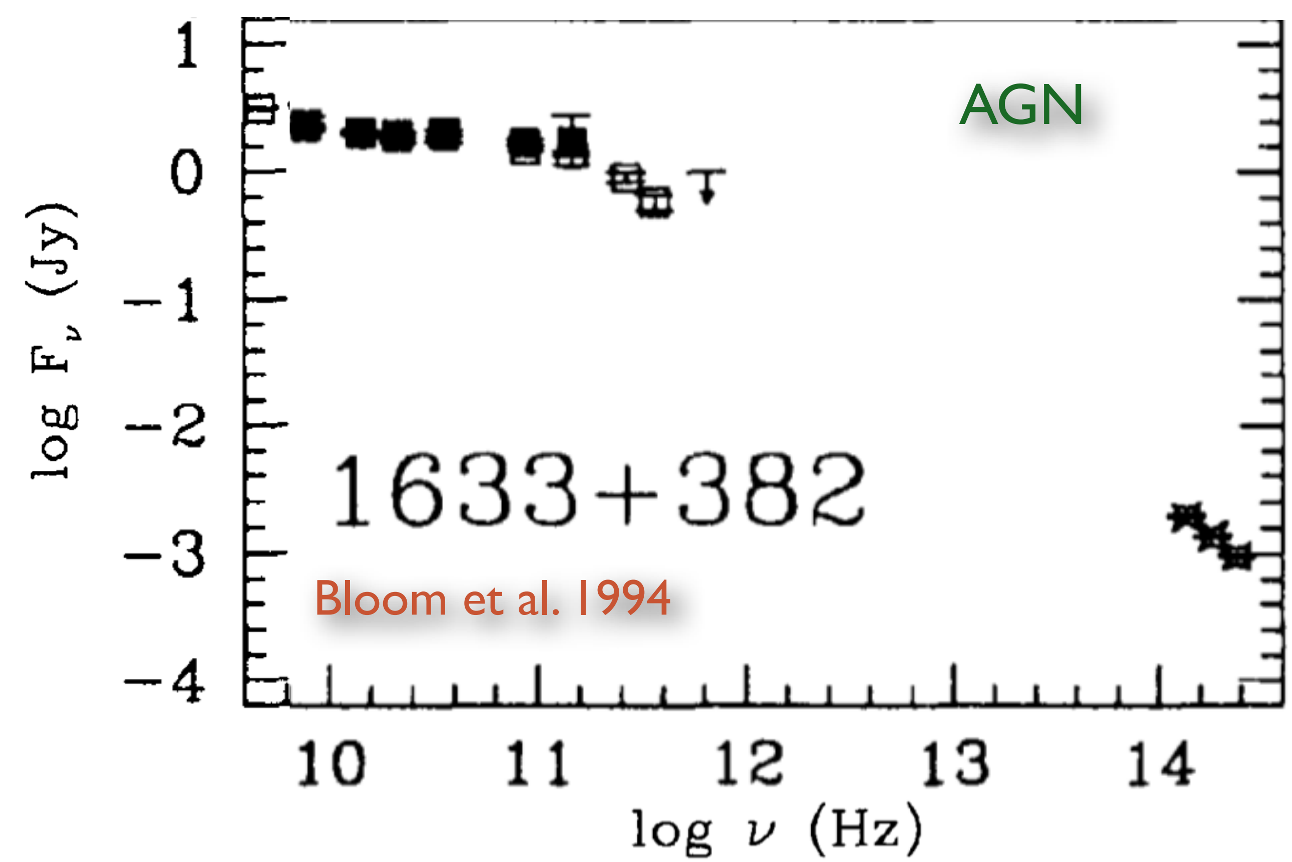
(Gallo et al. 2004)

Observed Spectral Energy Distribution of Compact Jets



Gandhi et al. 2011
see also Corbel & Fender 2002, Chaty et al. 2011; Rahoui et al 2012; Corbel et al. 2013; Russell et al. 2013...



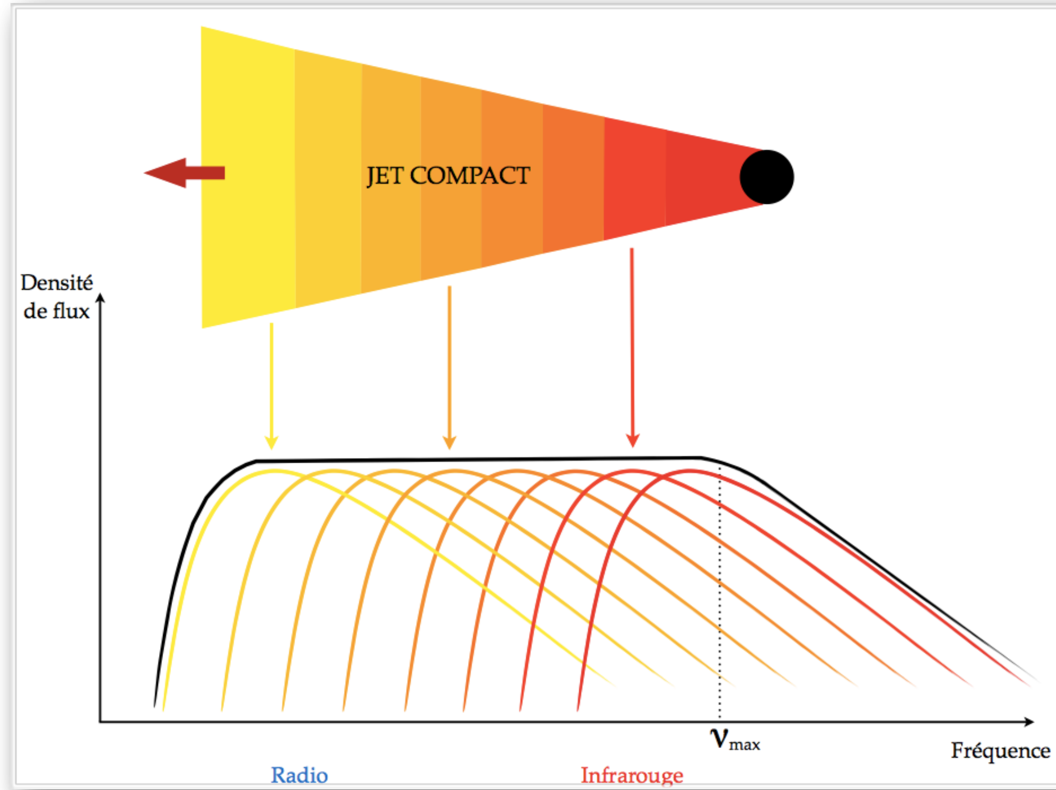


Standard conical jet emission model (Blandford & Koenigl 1979)

- Synchrotron radiation from a population of relativistic leptons travelling down the jet

$$n_e(\gamma_e) \propto \gamma_e^{-p}$$

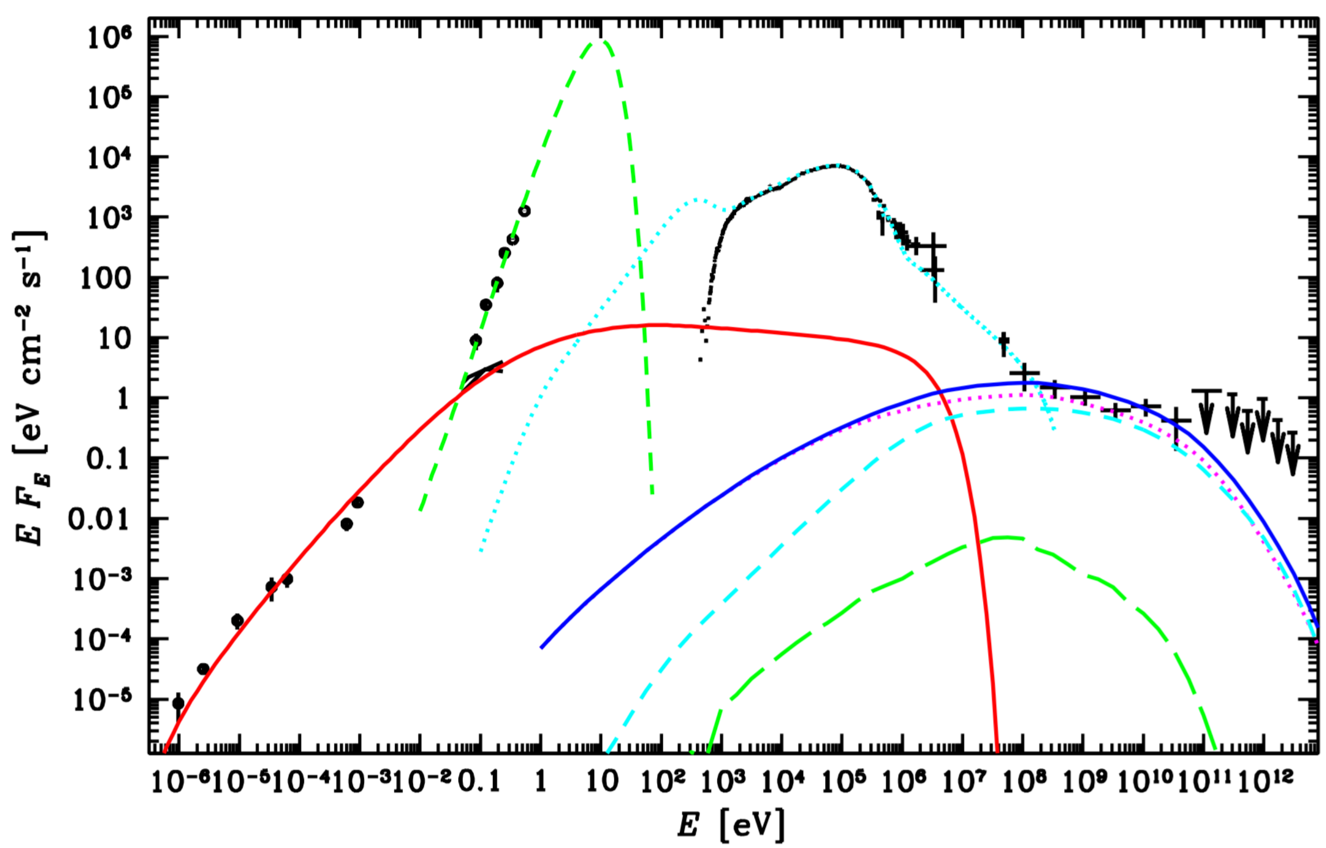
- Energy losses neglected



(M. Coriat)

- Most detailed version of the model also includes IC emission

Zdziarski et al. 2014, 2016



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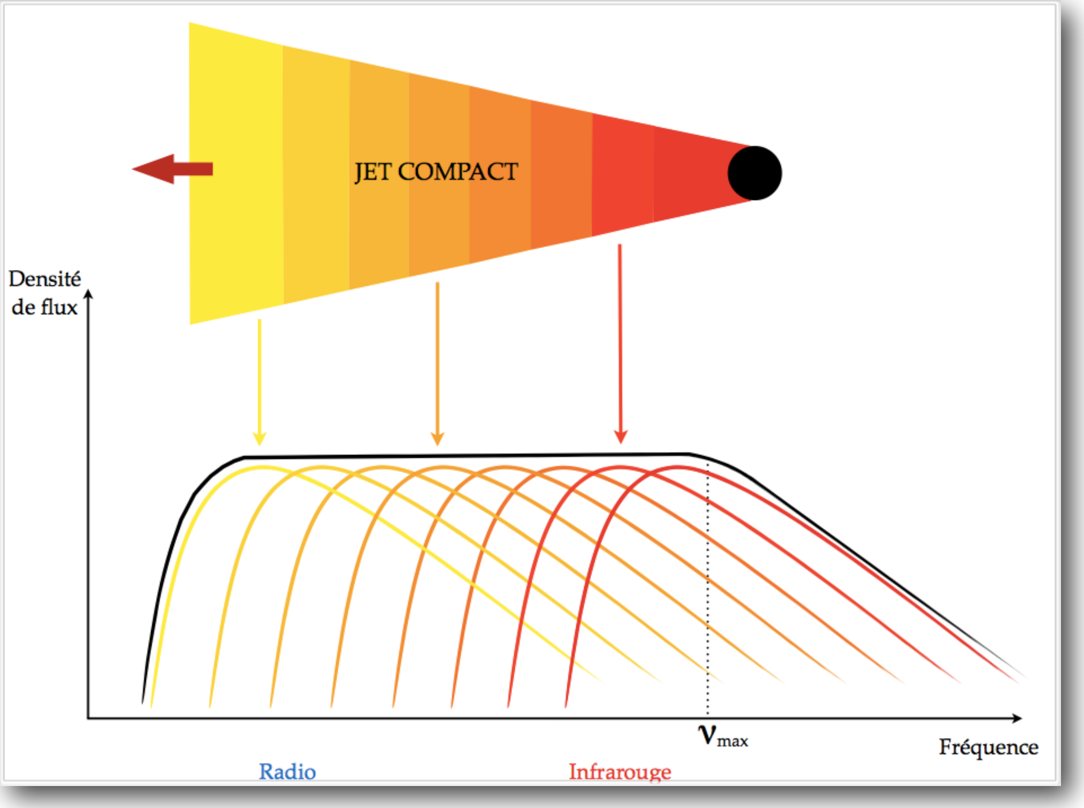

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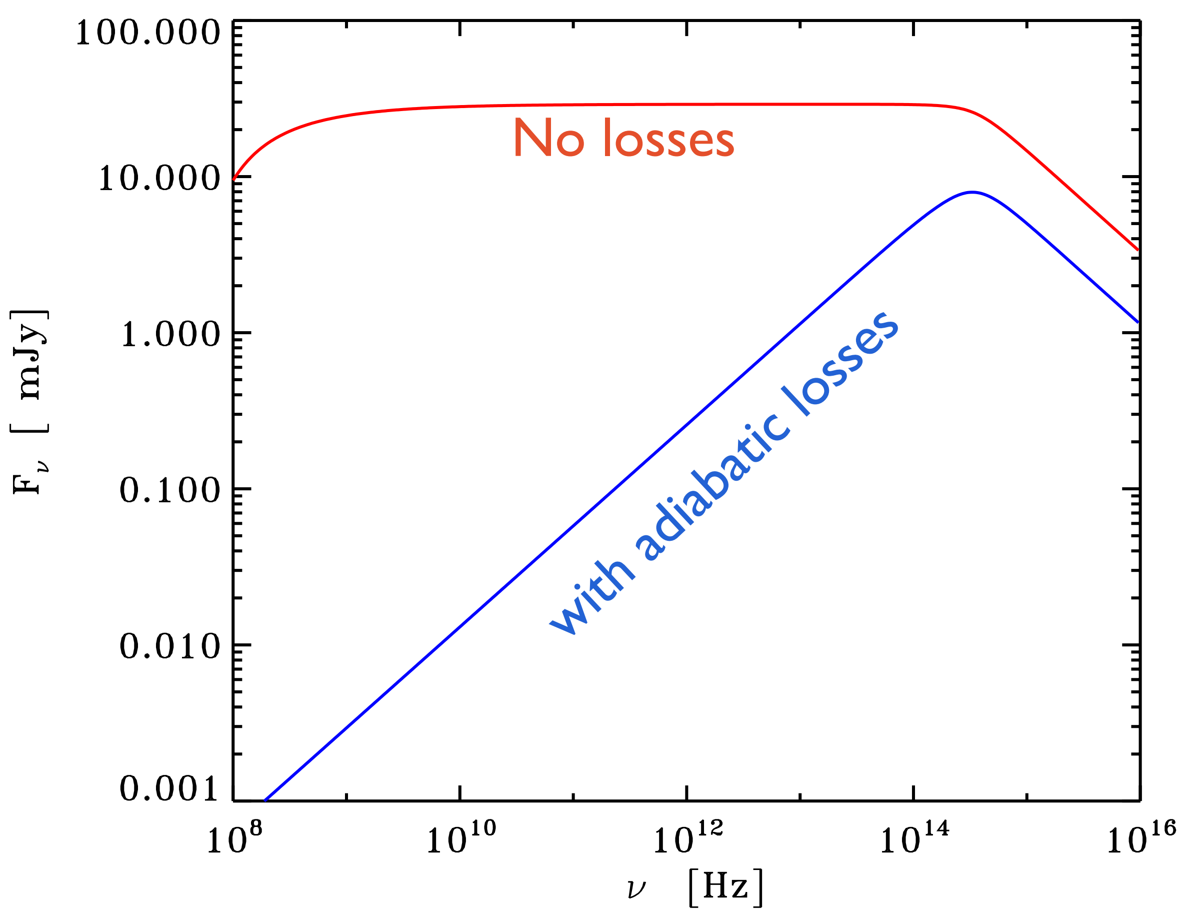
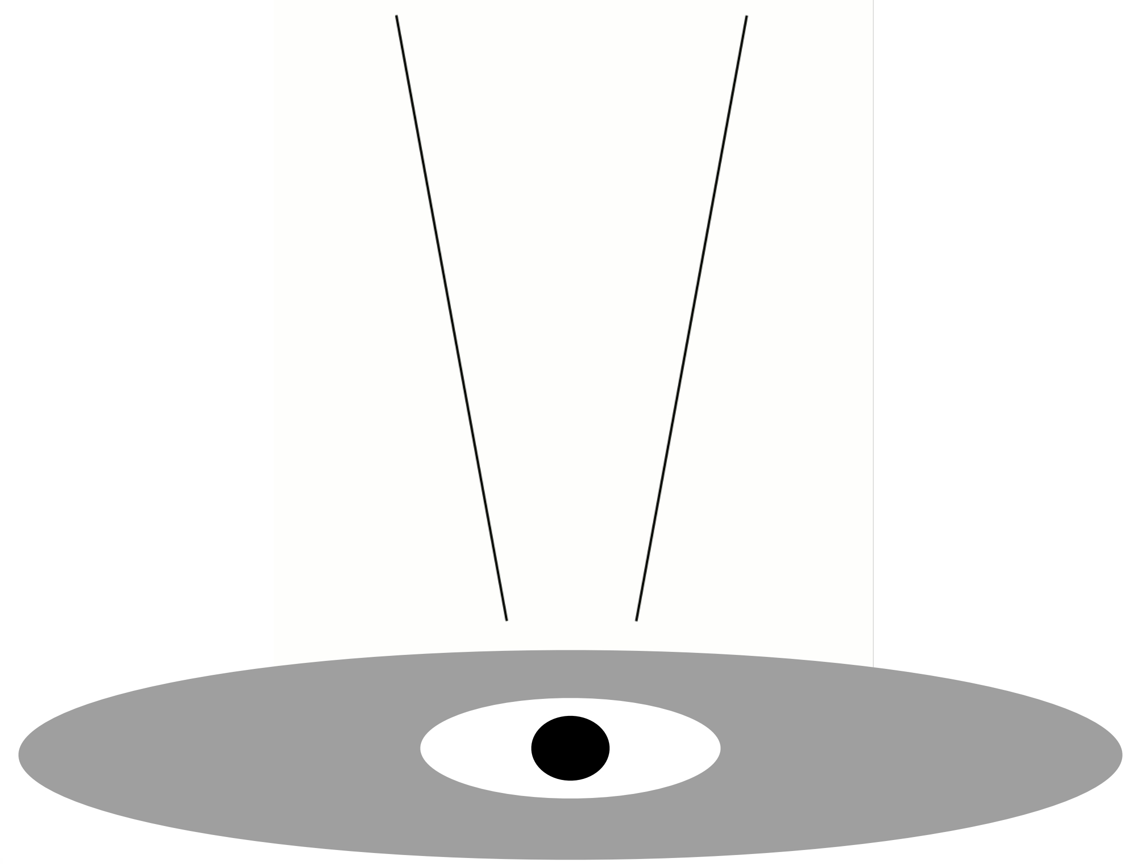


Adiabatic expansion energy losses:

➡ strongly inverted SED

➡ need to compensate for losses

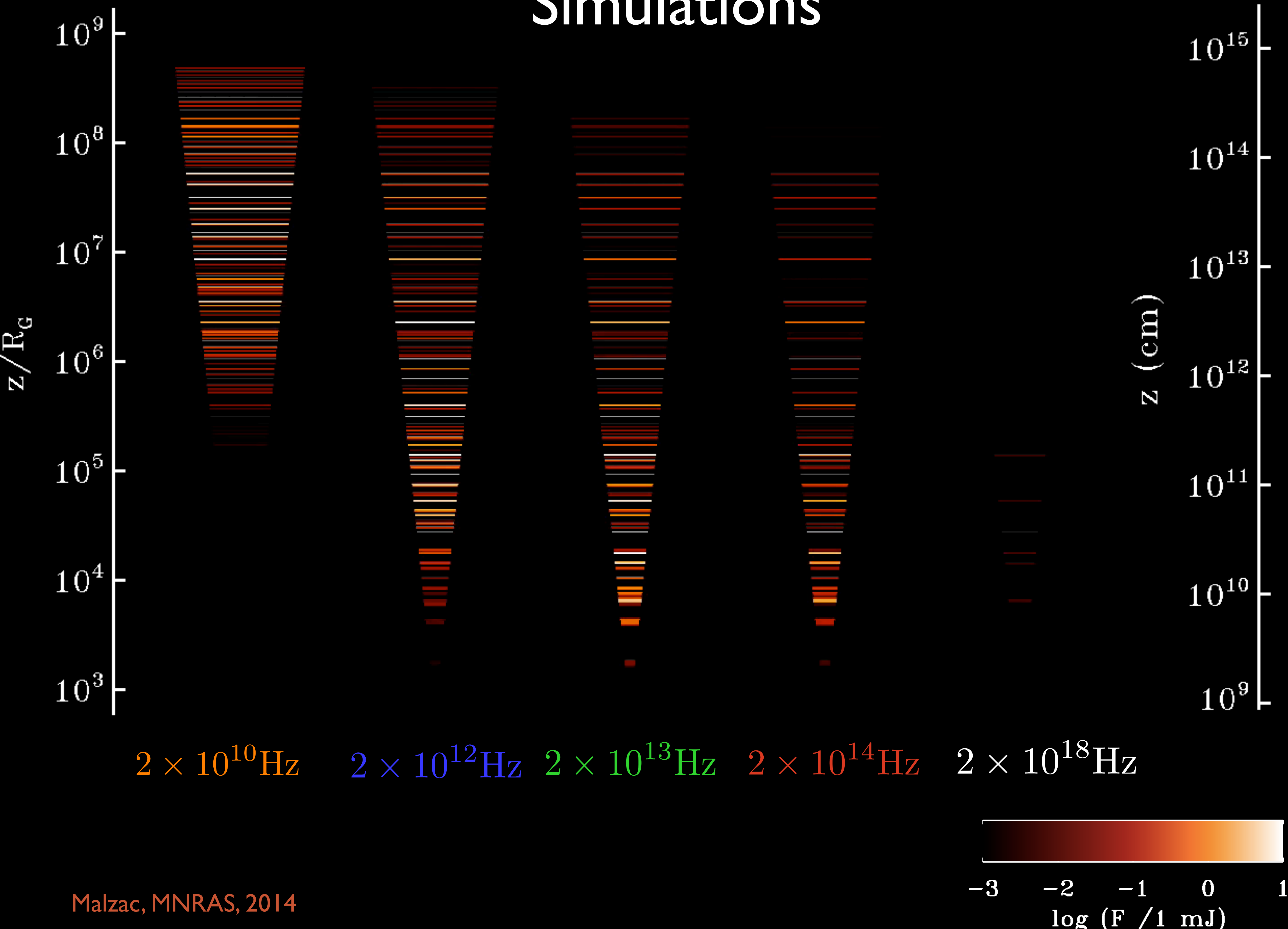
Internal shock model



- Jet= ‘shells‘ ejected a time intervals ~ t_{dyn} with randomly variable Lorentz factors
- Faster shells catch up will slower shells and collide
- Shocks, particle acceleration, and emission of synchrotron radiation
- Hierarchical merging process

Jamil et al. 2010; Malzac 2013, 2014

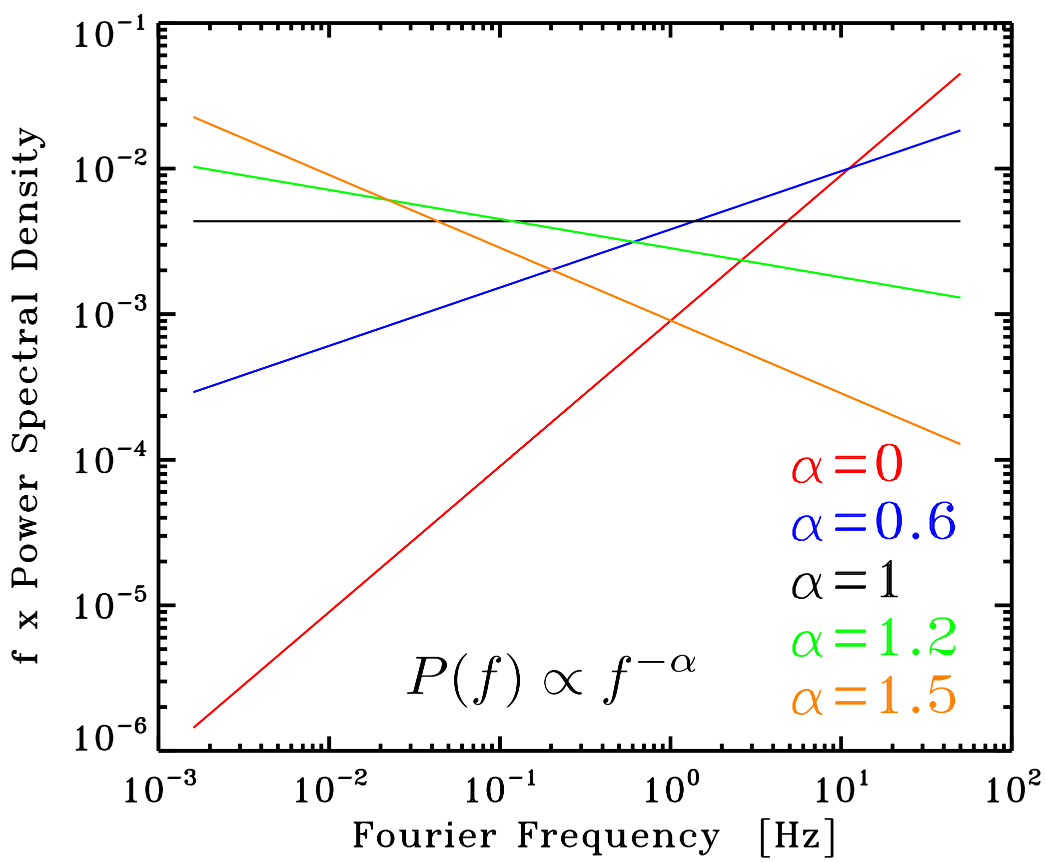
Simulations



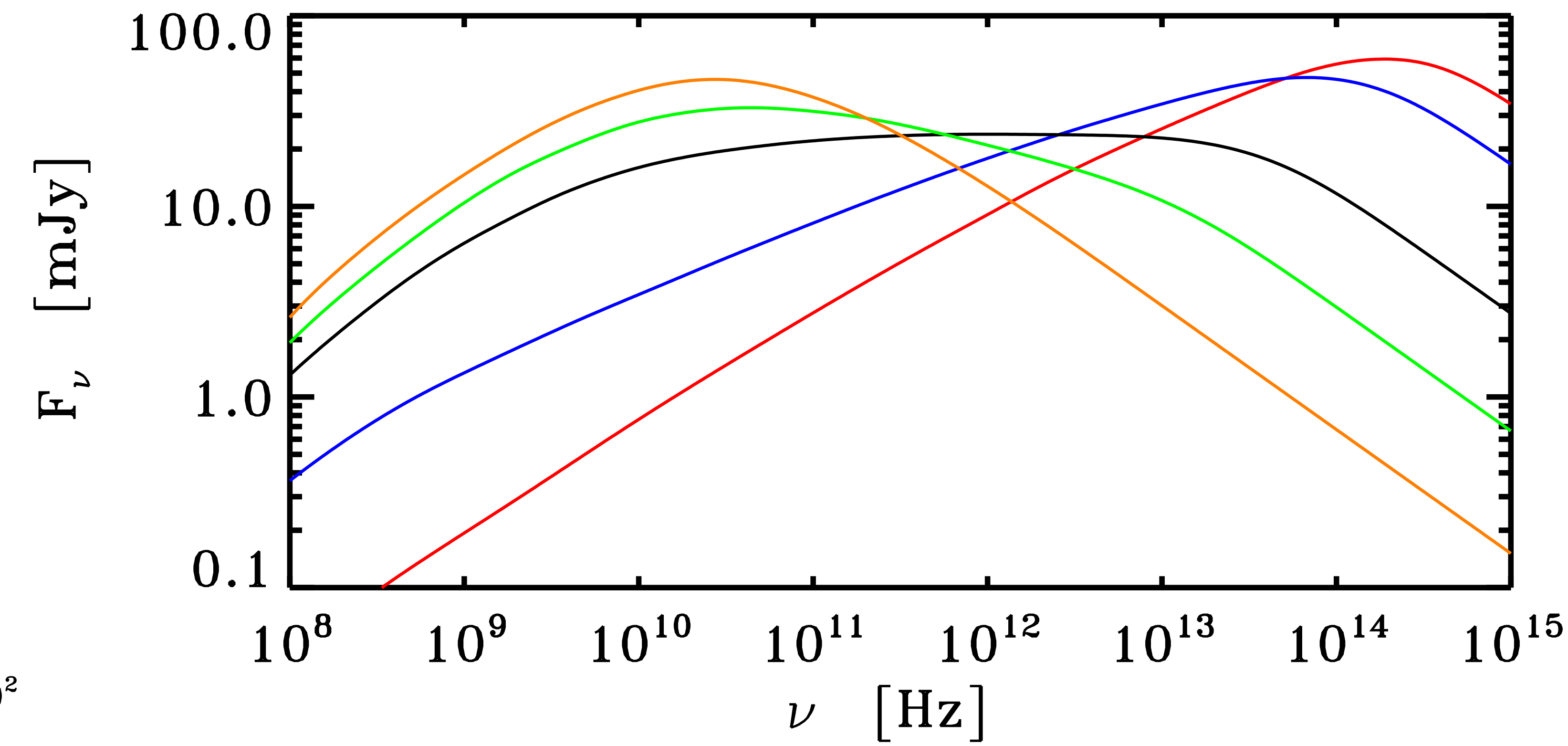
Malzac, MNRAS, 2014

Can shock dissipation balance energy losses ?

- Dissipation profile and SED sensitive to Fourier PSD of input Lorentz factor fluctuations



PSD of Lorentz factor fluctuations



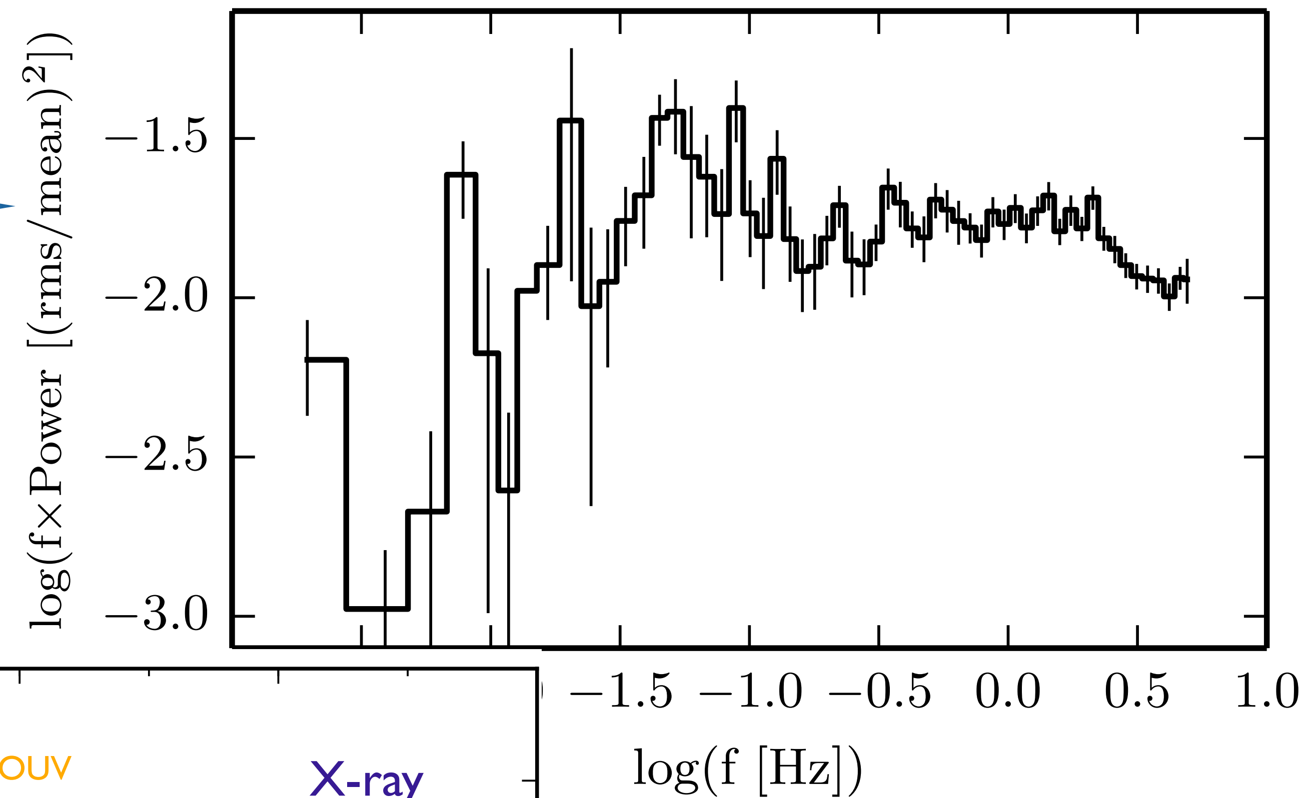
Spectral energy distribution

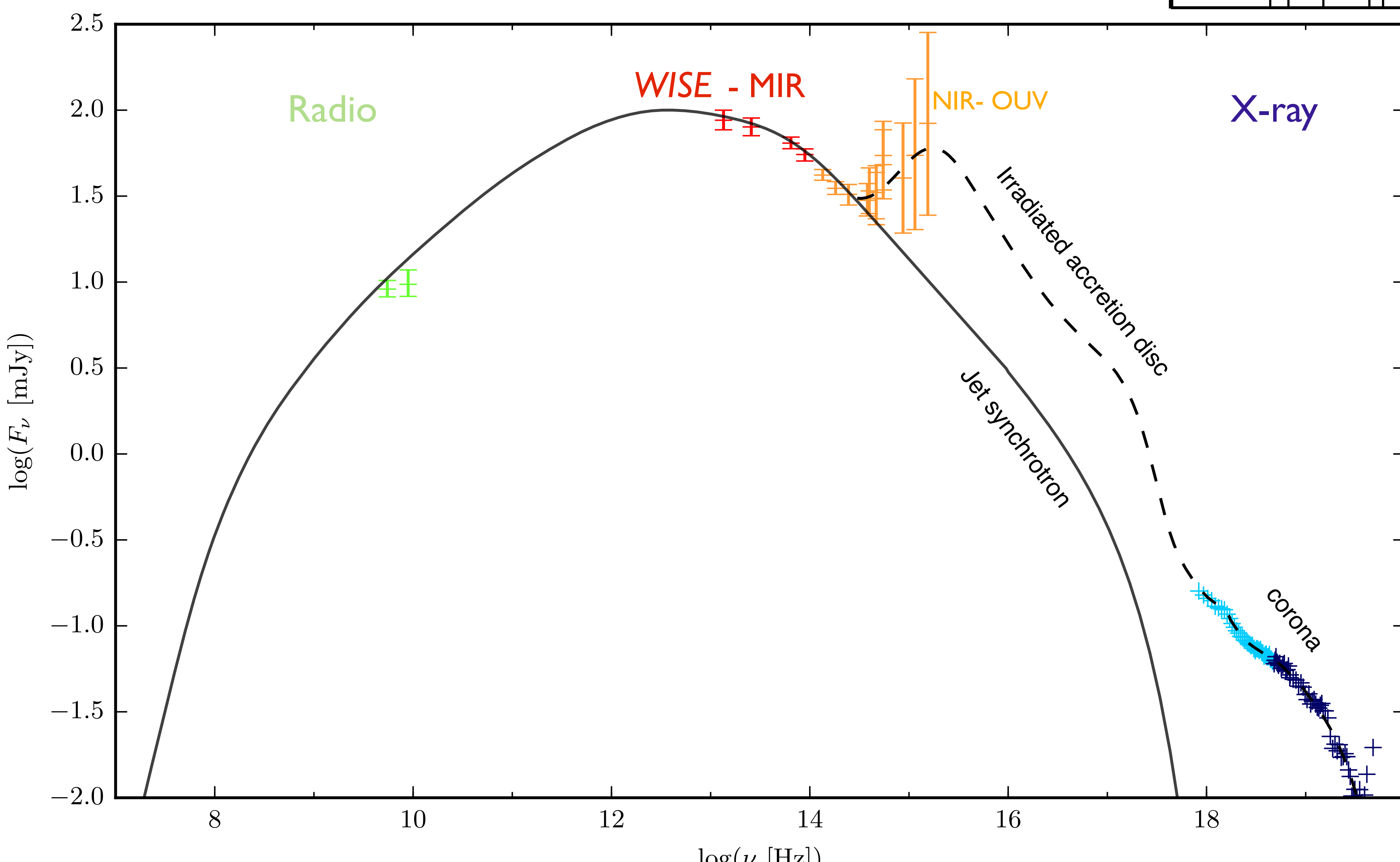
➡Flat radio-IR spectra produced for flicker noise Lorentz factor fluctuations

Malzac, MNRAS, 2013

Jet Lorentz factor fluctuations driven by accretion flow variability which is best traced by X-ray light curves

Fourrier PDS of X-ray light curve
=
Power spectrum of Lorentz factor fluctuations

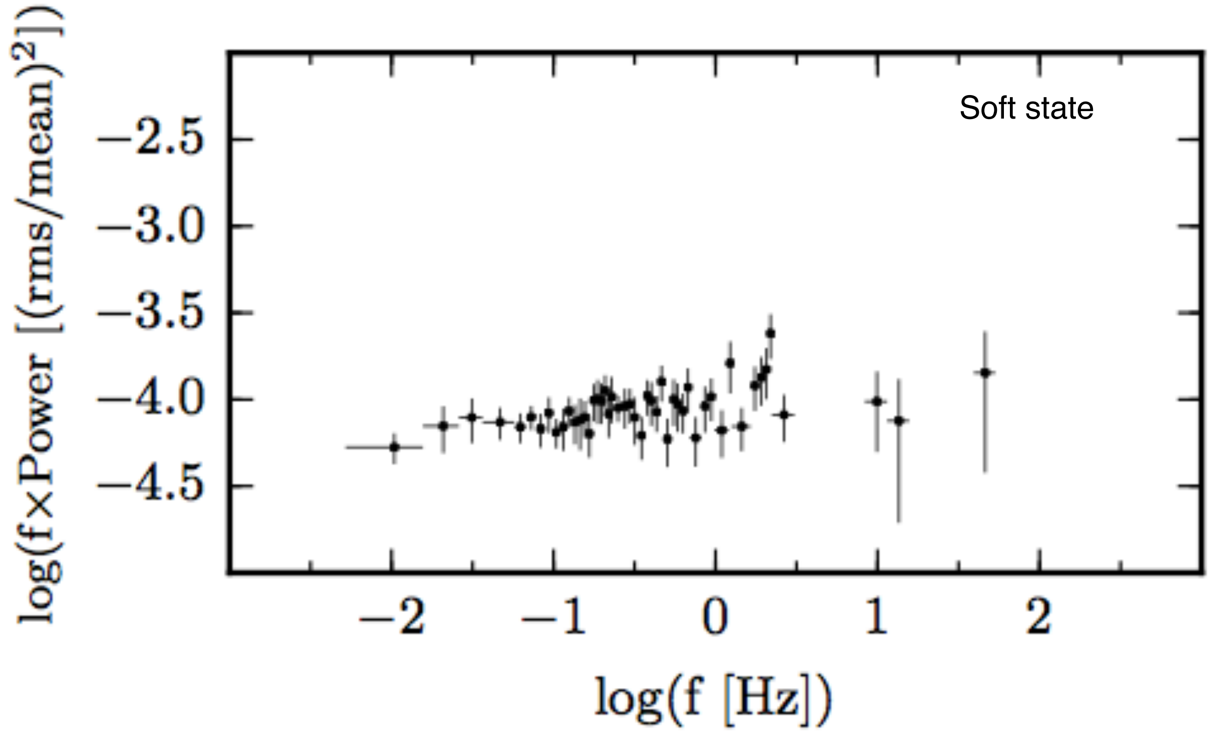


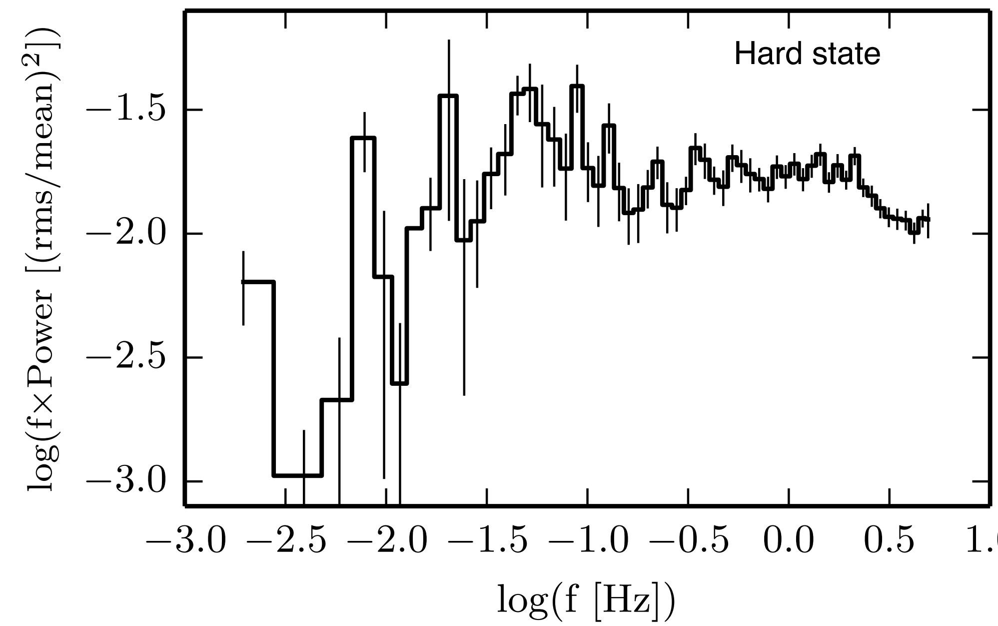


Jet SED

Drappeau, et al. MNRAS, 2015

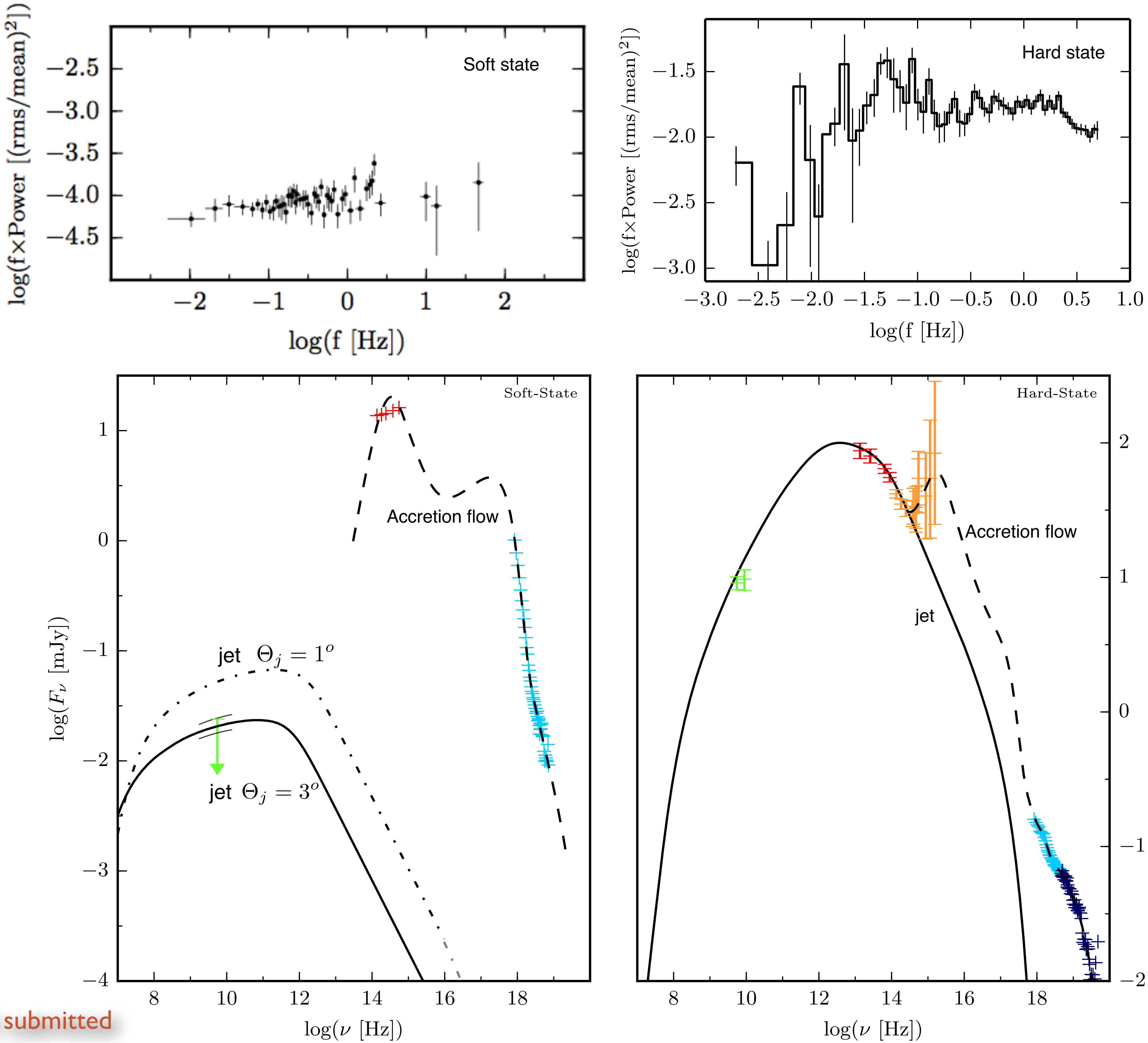
A dark jet in the soft state ?





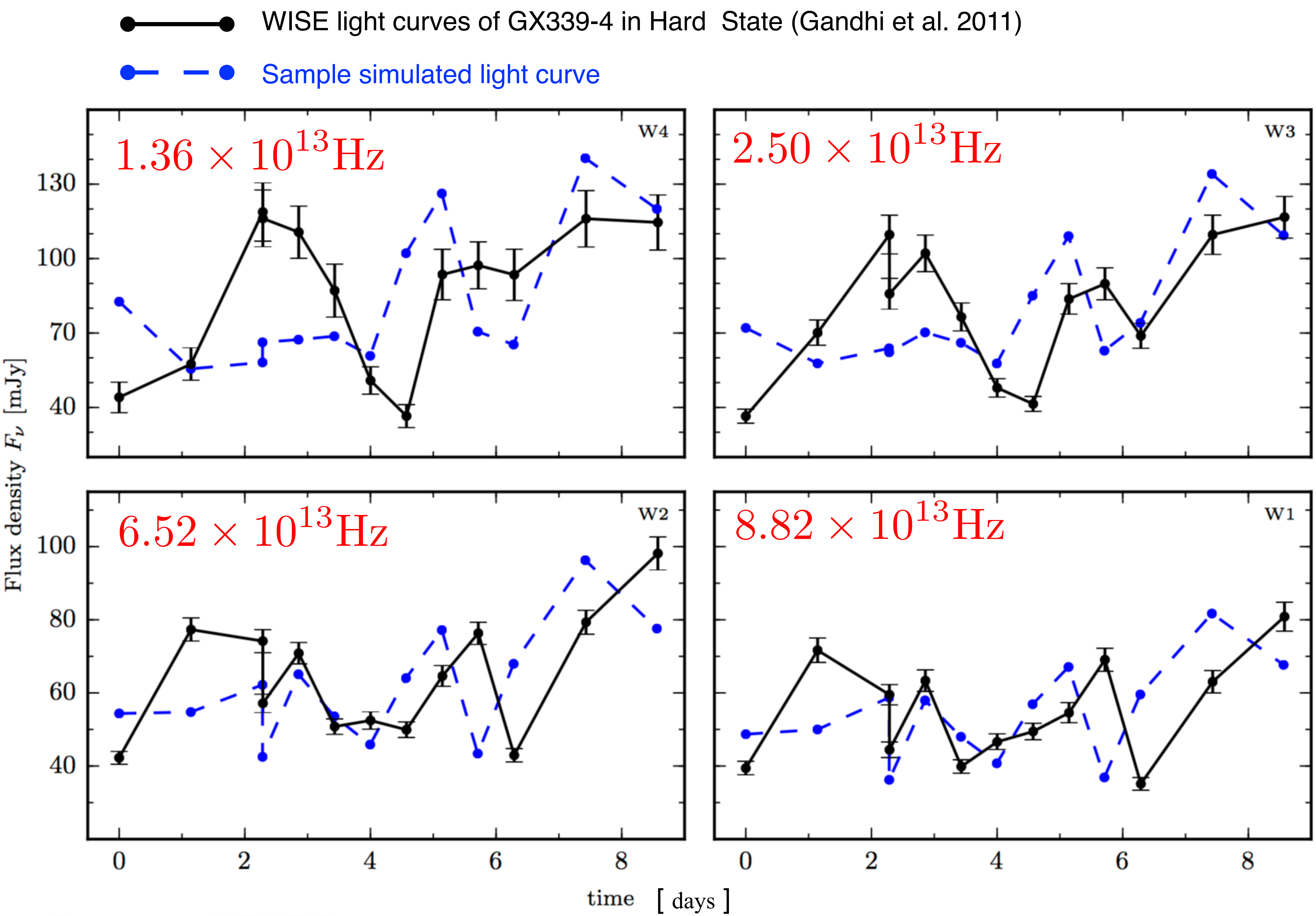
- Jet luminosity very sensitive to rms amplitude of fluctuations
- Disappearance of the jet in soft state associated to drop in X-ray variability ??
- Jet with same kinetic power as in hard state but radiatively inefficient ??

A dark jet in the soft state ?



Drappeau et al. submitted

IR Variability

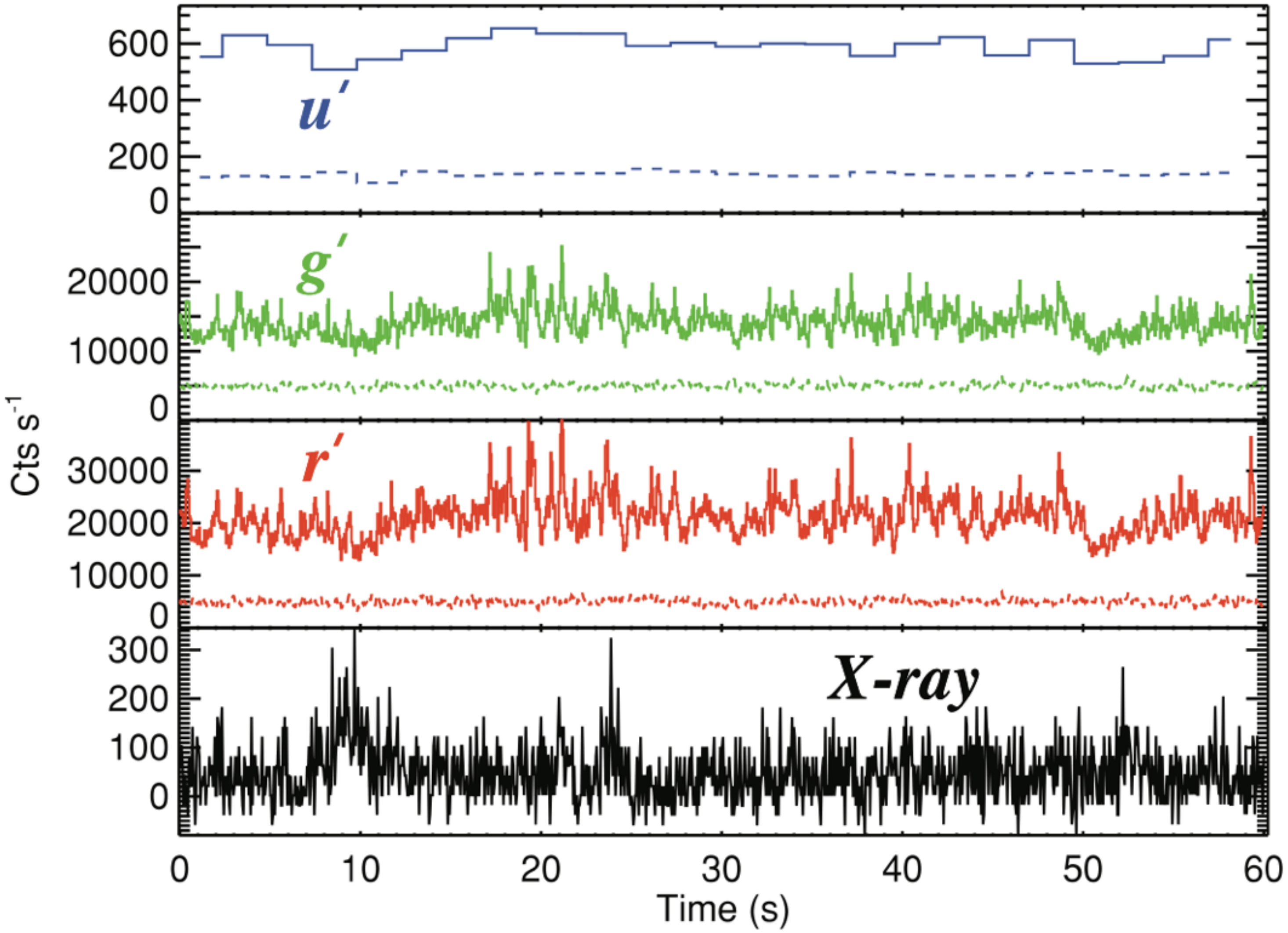


Drappeau et al., MNRAS 2015

Fast OIR Variability

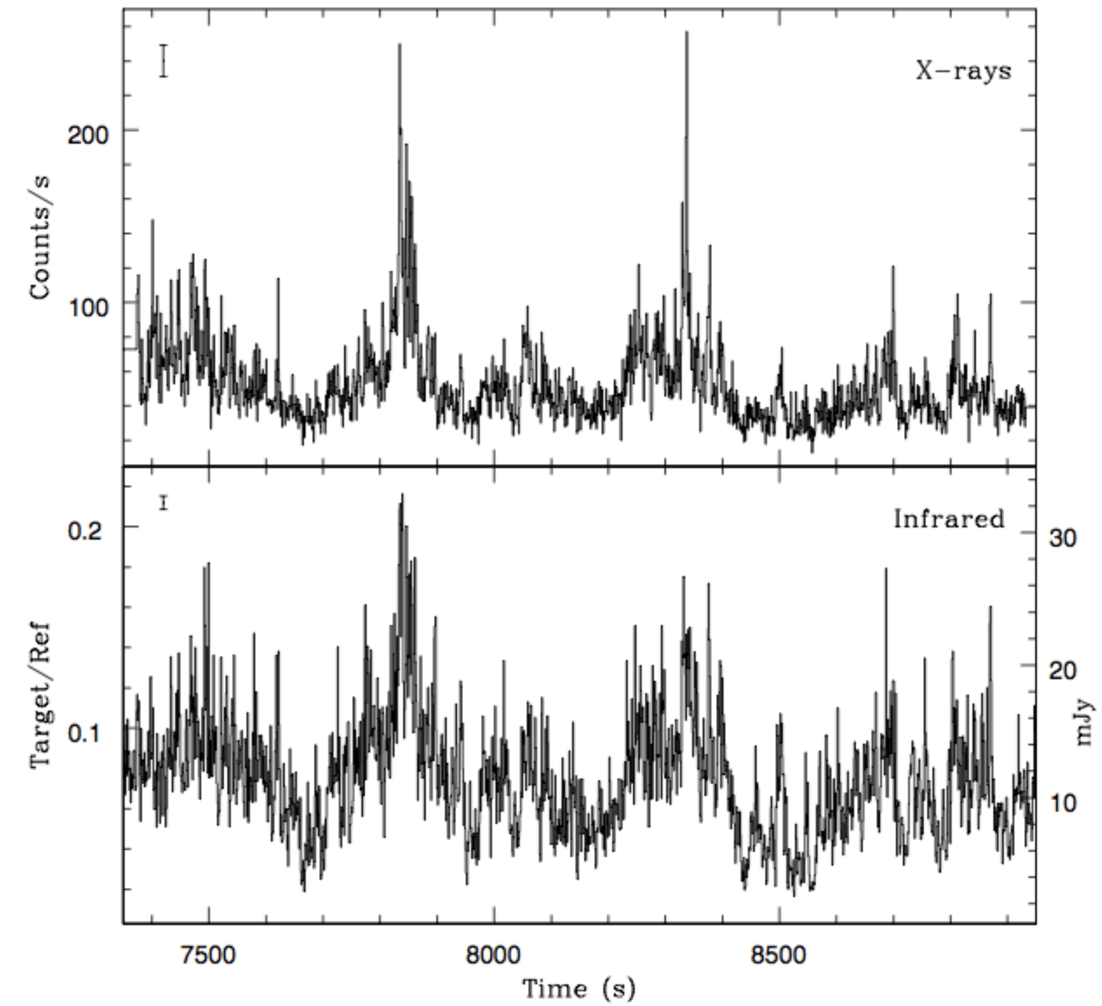
Observations of GX 339-4

Optical



Gandhi et al. 2010

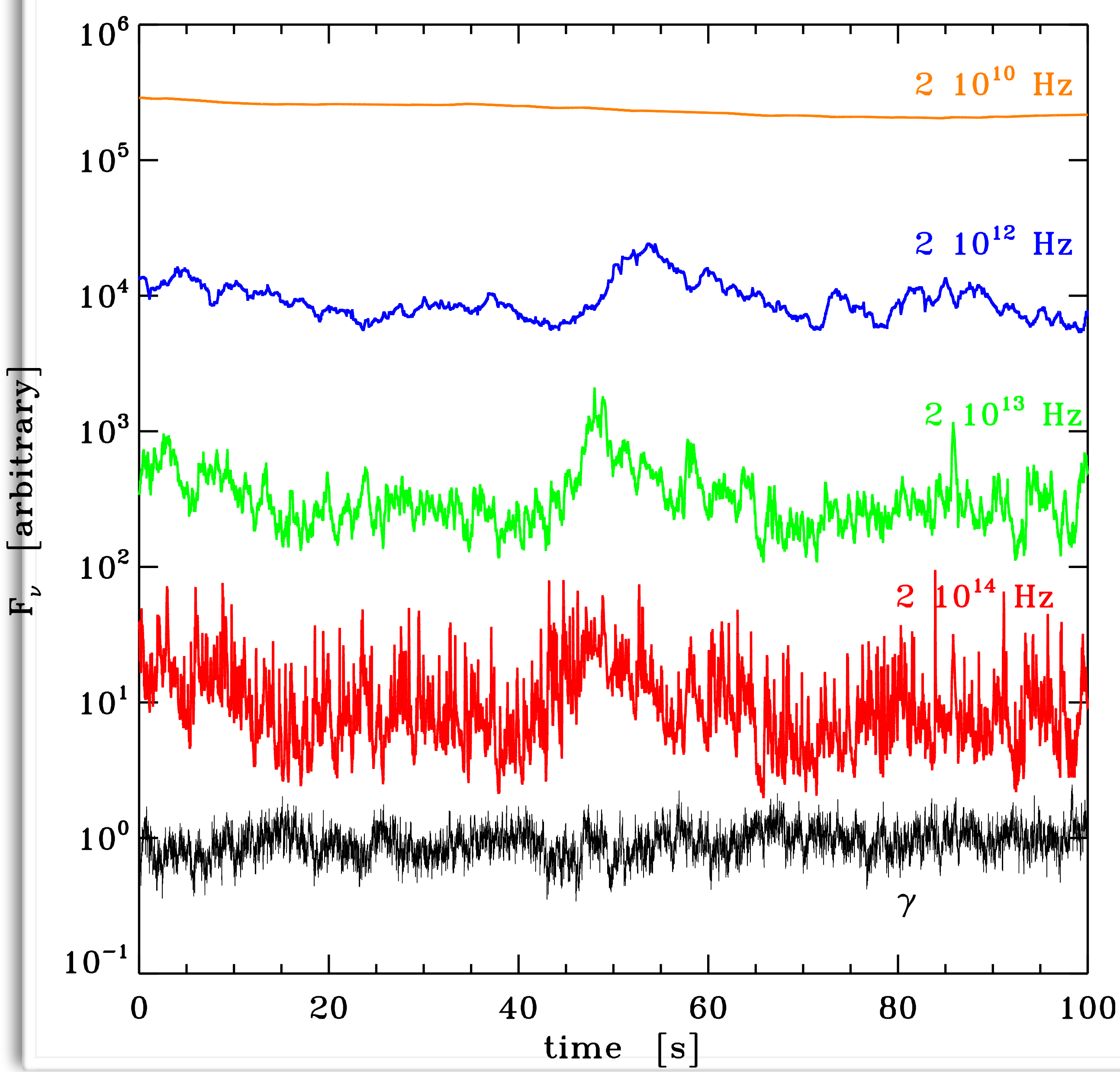
Infrared

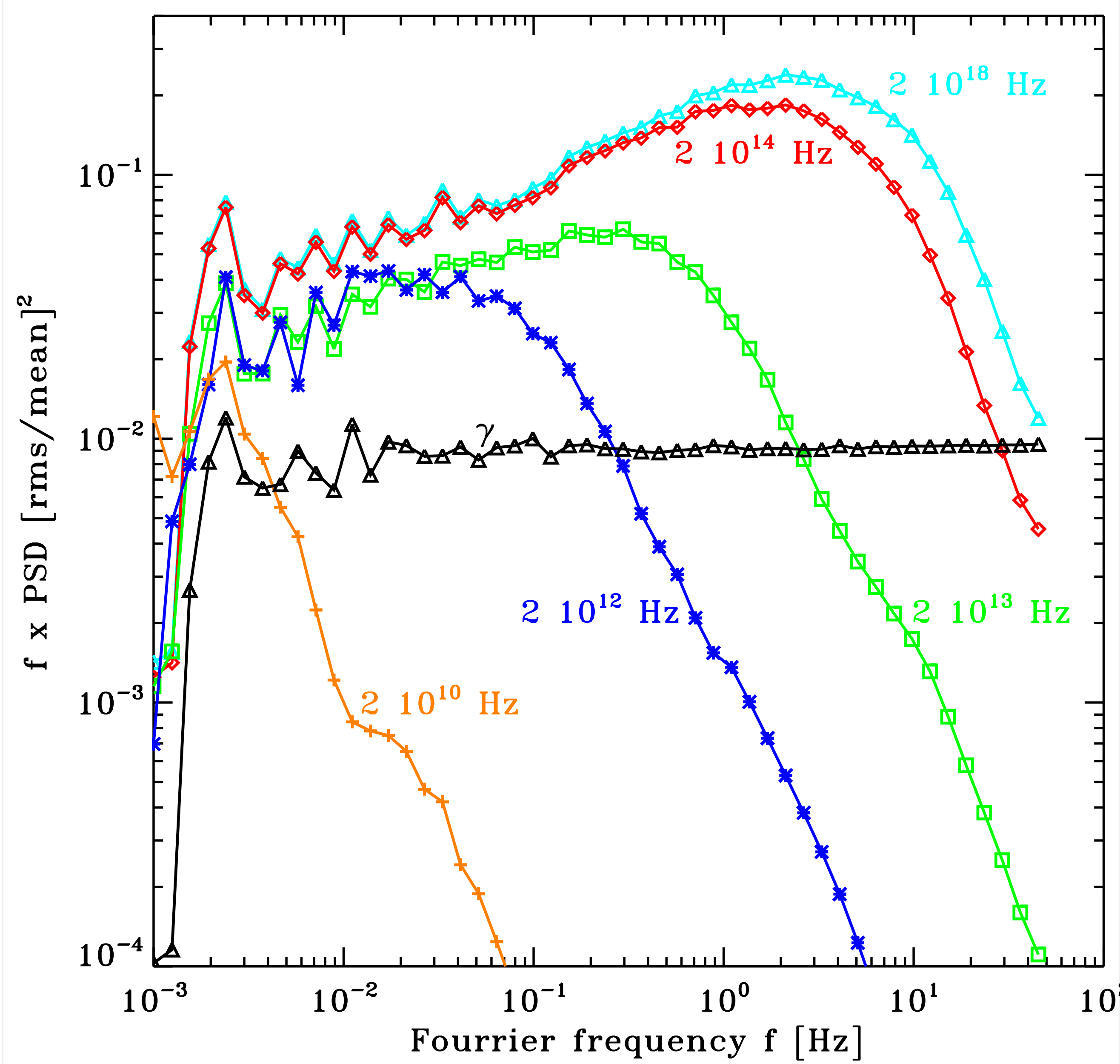


Casella et al. 2010

Fast Jet Variability

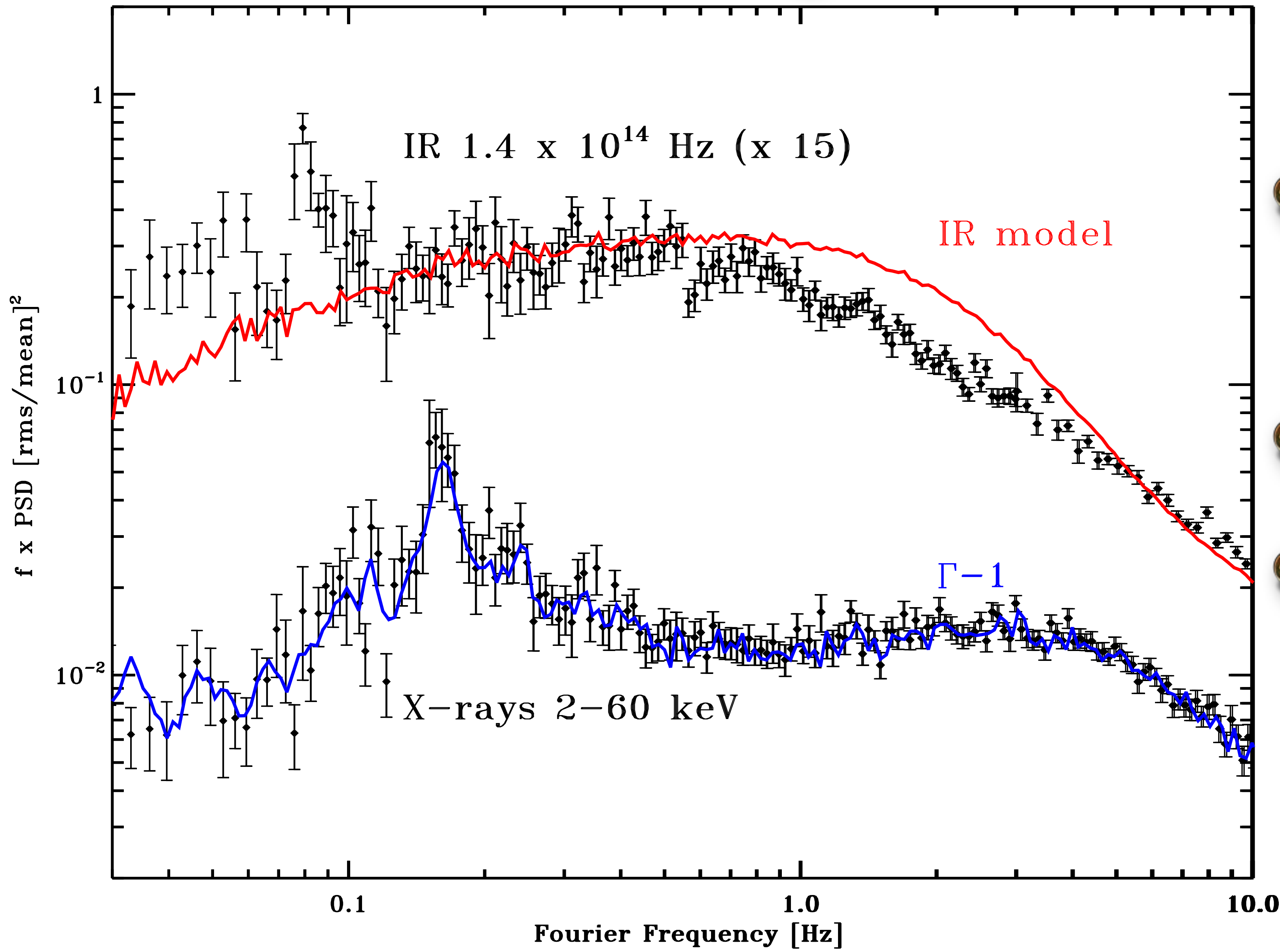
Internal shock model





Malzac, MNRAS, 2014

IR timing data of GX 339-4: First QPO detected in Infrared



- Simultaneous IR / X timing data with VLT/ISAAC and RXTE (Kalamkar et al. 2016)
- IR rms ~ X-ray rms ~ 20 %
- IR QPO @ ~0.08 Hz
  X-ray QPO @ ~0.16 Hz

- Internal shock model predicts similar shape of IR PSD but model fractional rms amplitude larger by factor of ~4. Additional constant component from disc or jet ?
- Model lacks IR QPO.

Optical/IR QPOs from jet precession

- X-ray low frequency QPO caused by Lense-Thirring precession of the hot accretion flow ?

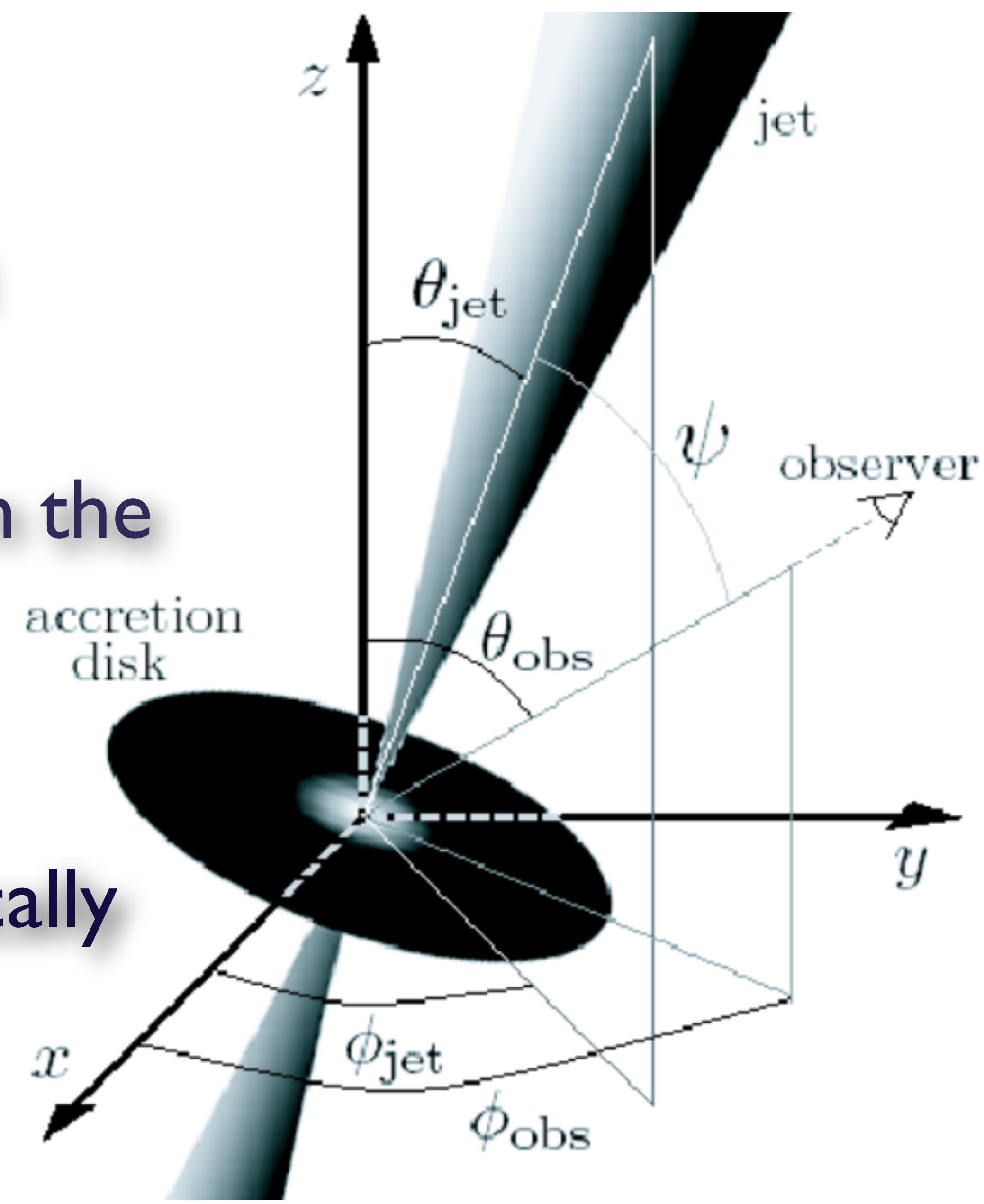
- If jet launched by the accretion flow, jet precesses with the hot flow

➡ modulation of synchrotron emission from the jet

- For a relativistic jets emitting in the optically thin regime, anisotropy is dominated by relativistic Doppler boosting:

$$F_{\nu,\mathrm{obs}} \propto \delta^{2-\alpha}$$

$$\delta = \left[\Gamma\left(1 - \beta\cos\theta\right)\right]^{-1}$$



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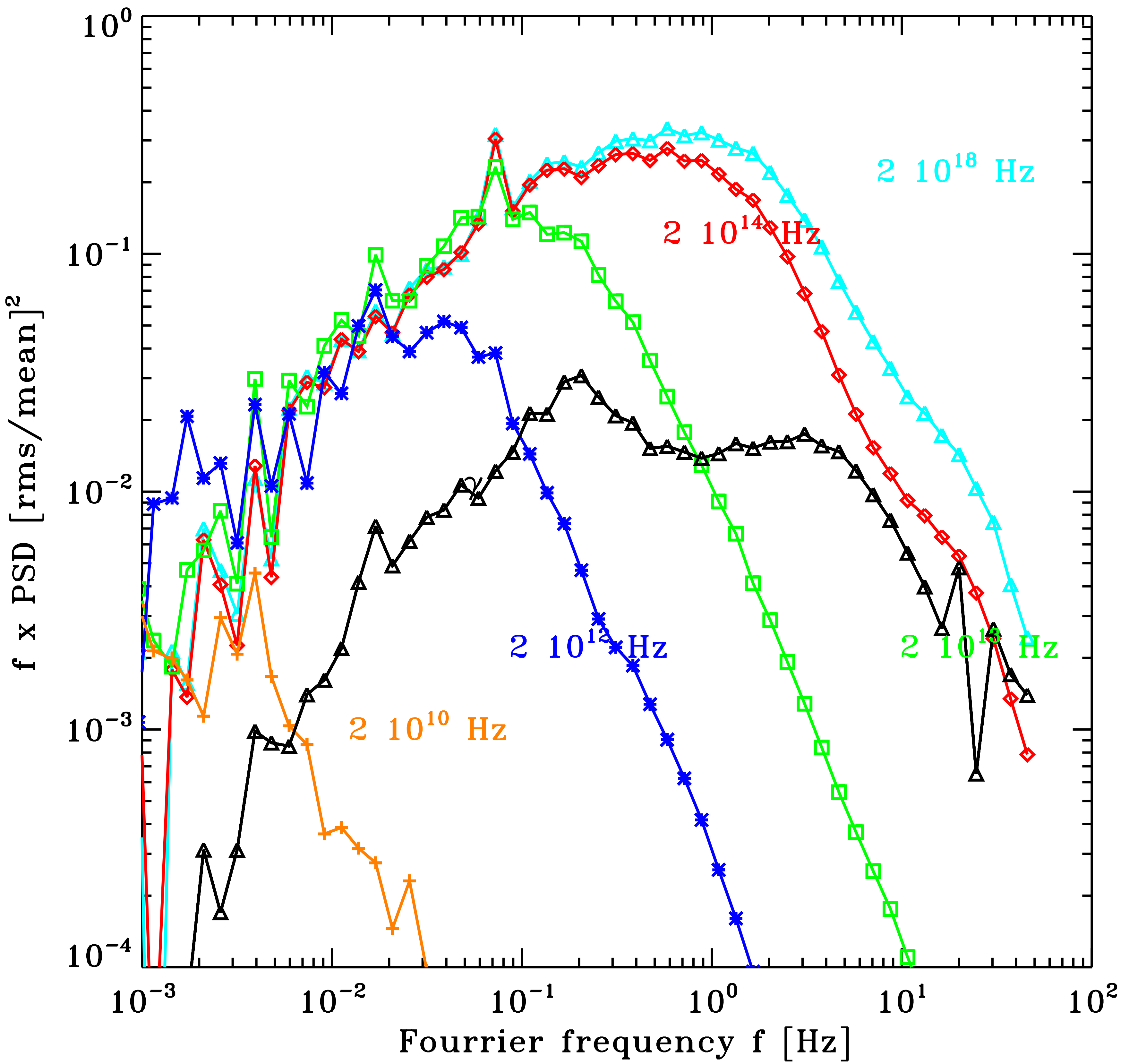
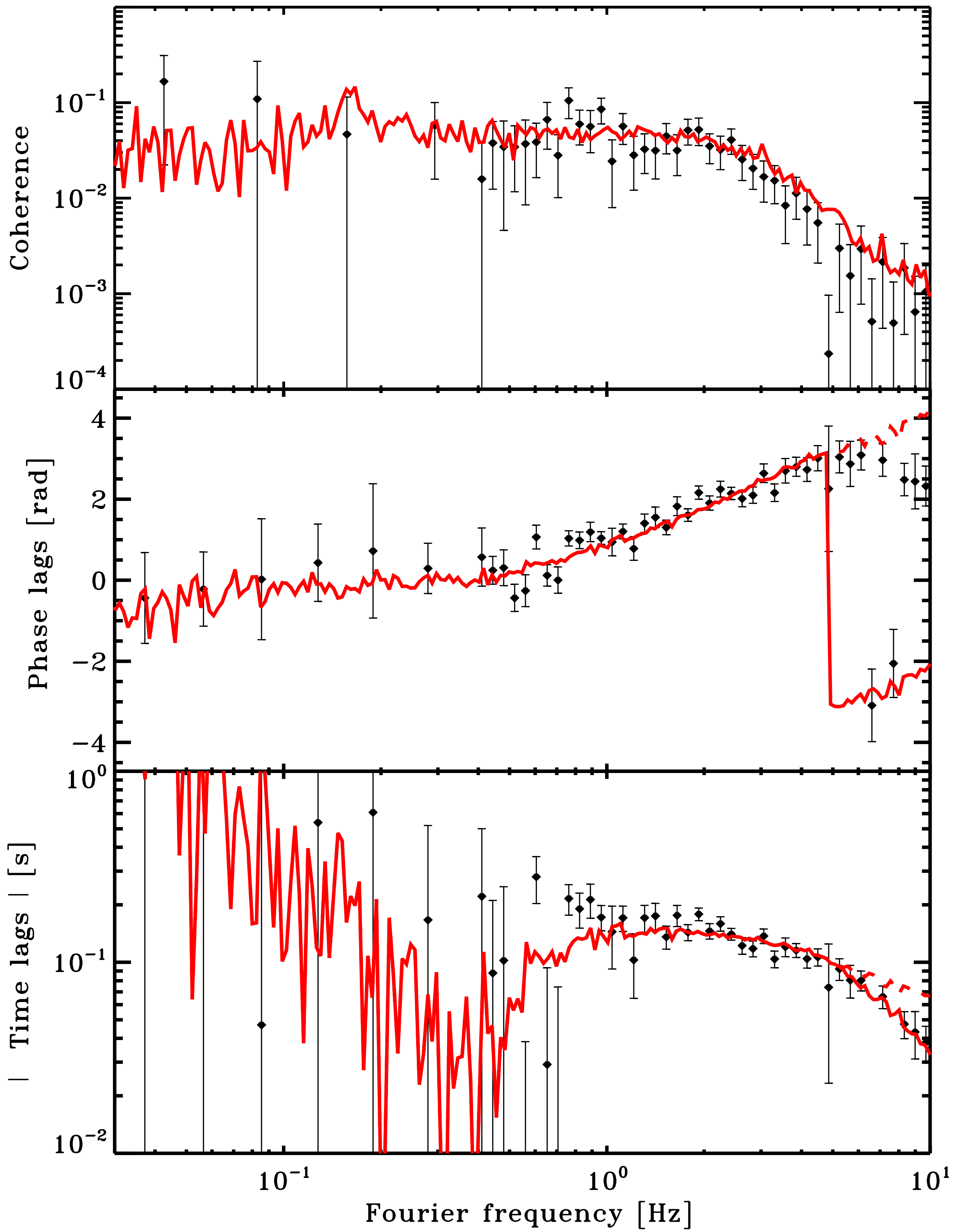


Fast IR /X-ray correlations in GX339-4



- IR vs X-ray Fourier coherence, and lags from Kalamkar et al. (2016) data

- Model:

- IR light curve from same model used for SED and IR PSD.

- X-ray light curve: $L_X(t) \propto \Gamma(t) - 1$

Conclusions

- Blandford and Koenigl model combined with internal shocks accounts for the canonical SED of compact jets (provided the PSD of the fluctuations is close to flicker noise)

- Possible connection between X-ray POWER spectrum and Radio-IR PHOTON spectrum.

- There might be powerful radiatively inefficient jets in soft states.

- Internal shock model predicts strong, frequency dependent, variability similar to that observed.

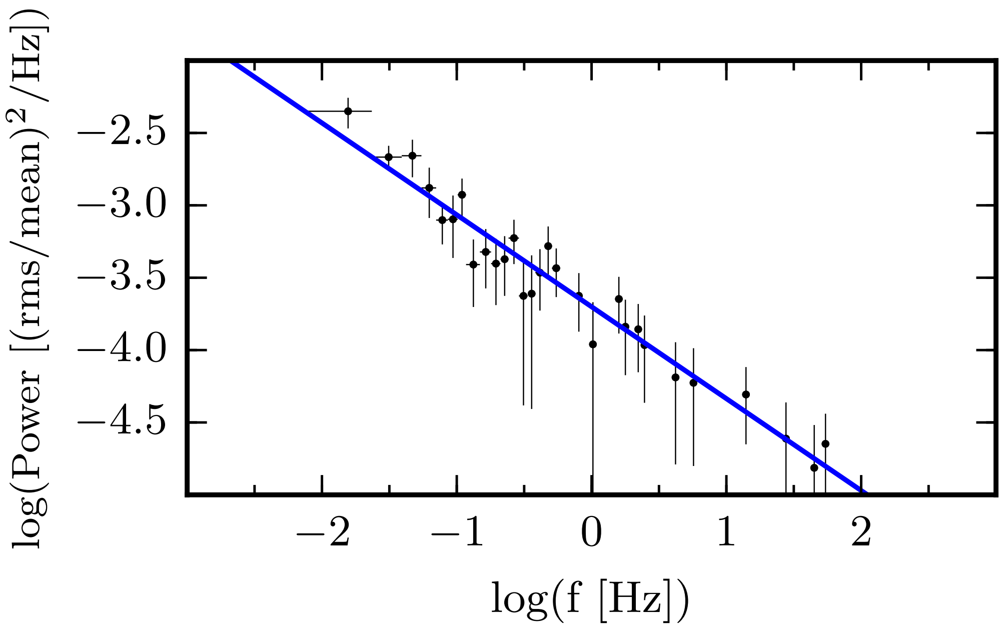
- Comparisons to data of GX339-4 suggest at least part of the IR variability produced in the jet.

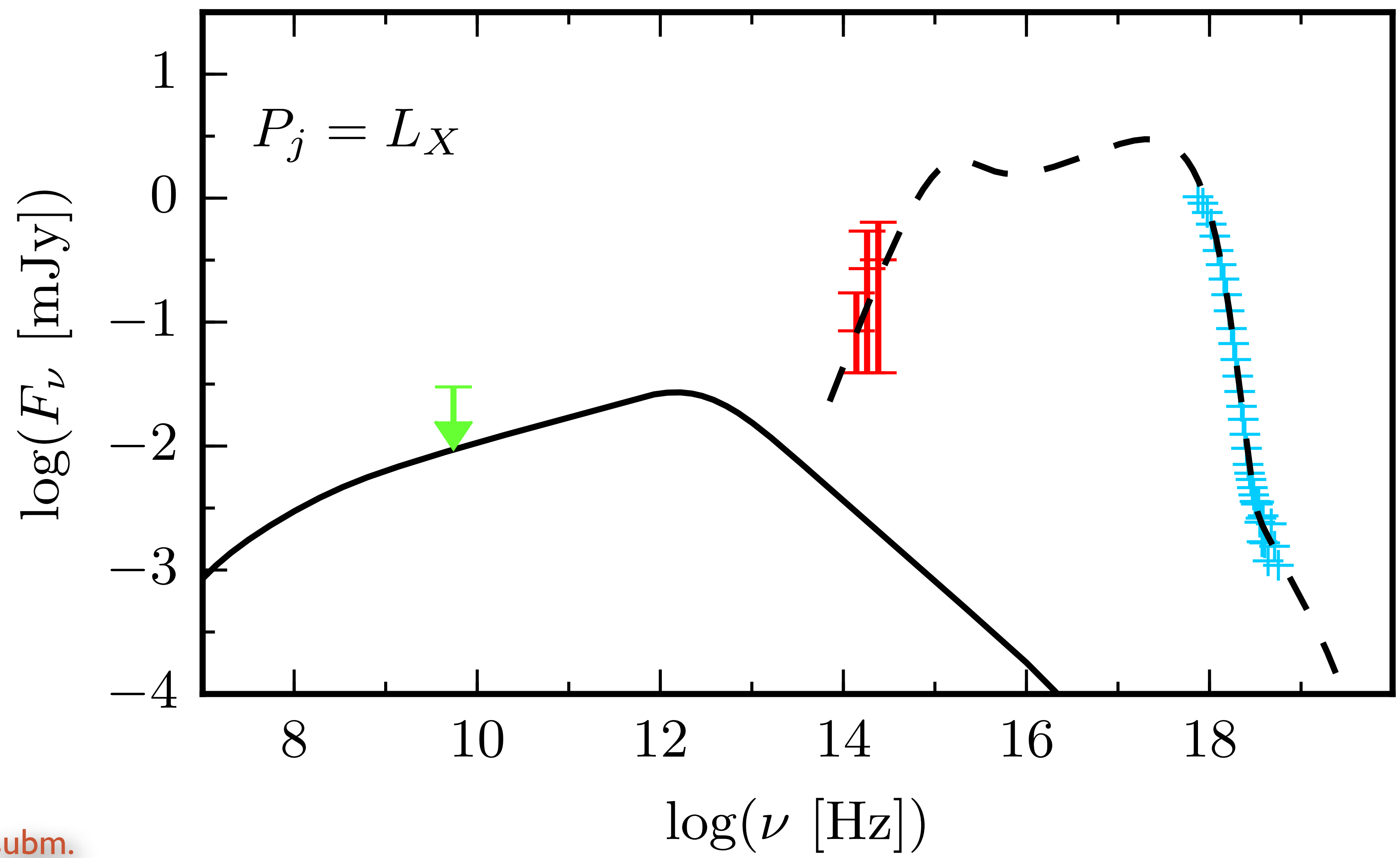
- IR QPO may be caused by jet precession.

- Opt/IR/X-ray correlations can unveil the dynamics of accretion and ejection physics. Need to combine accretion flow and jet models.

Thanks !

Soft state of H1743-322

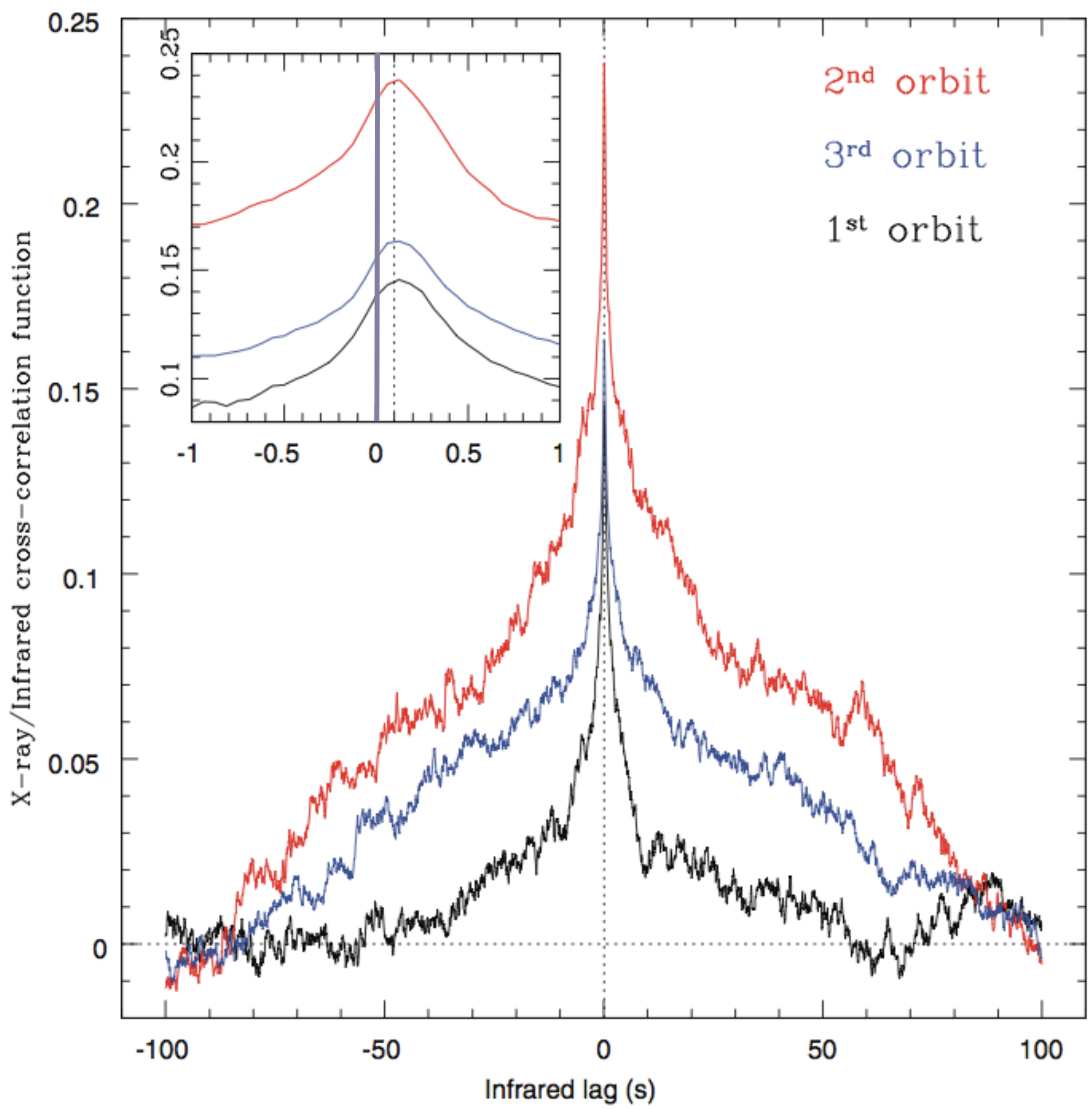




Drappeau et al. subm.

IR /X-ray correlation

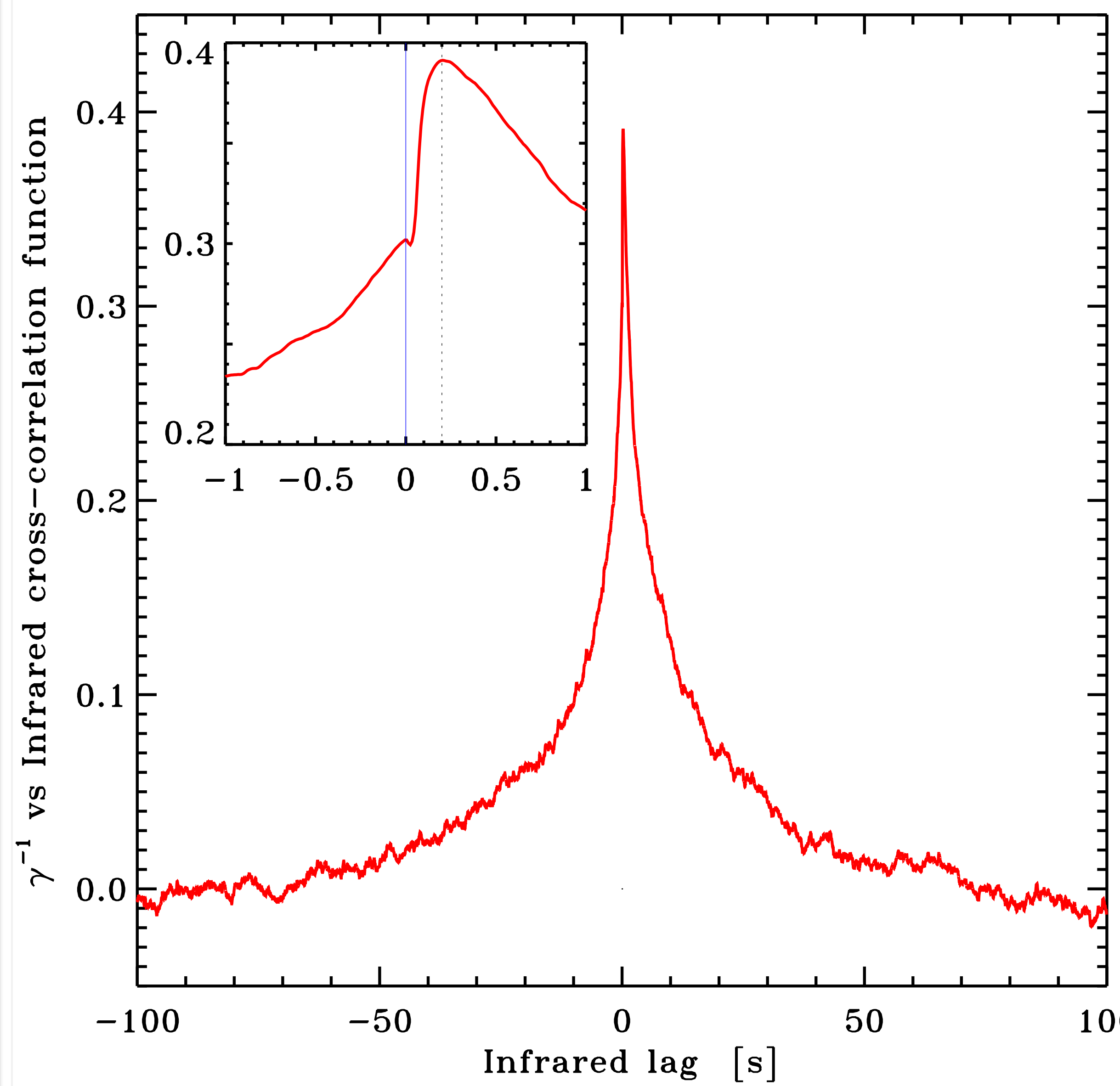
Observations



GX 339-4

Casella et al. 2010

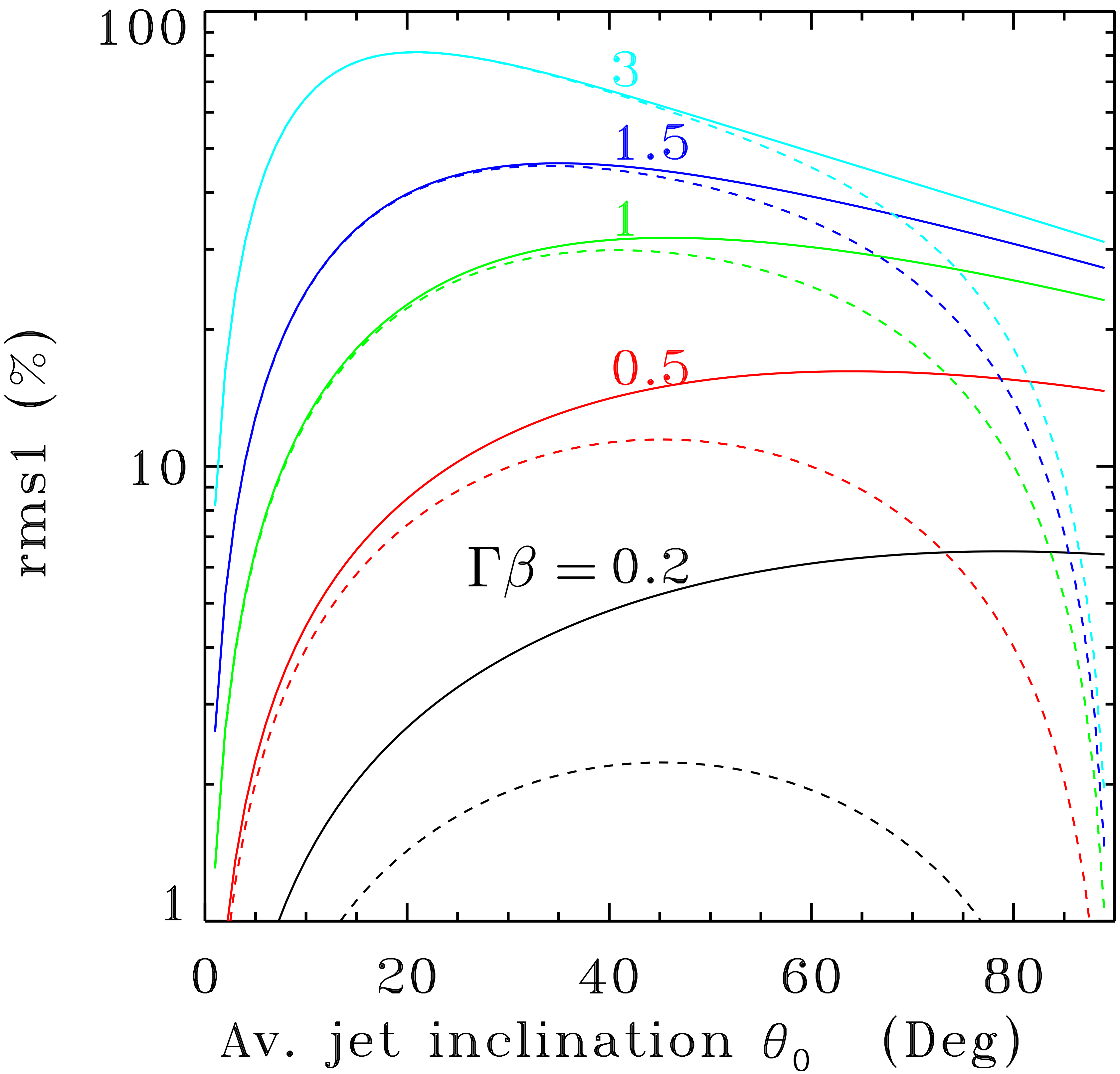
Simulation



Assuming X-ray flux $\propto 1/\Gamma$

Malzac 2014

Optical/IR QPOs from jet precession



Kalamkar et al. 2015, Malzac et al. in prep