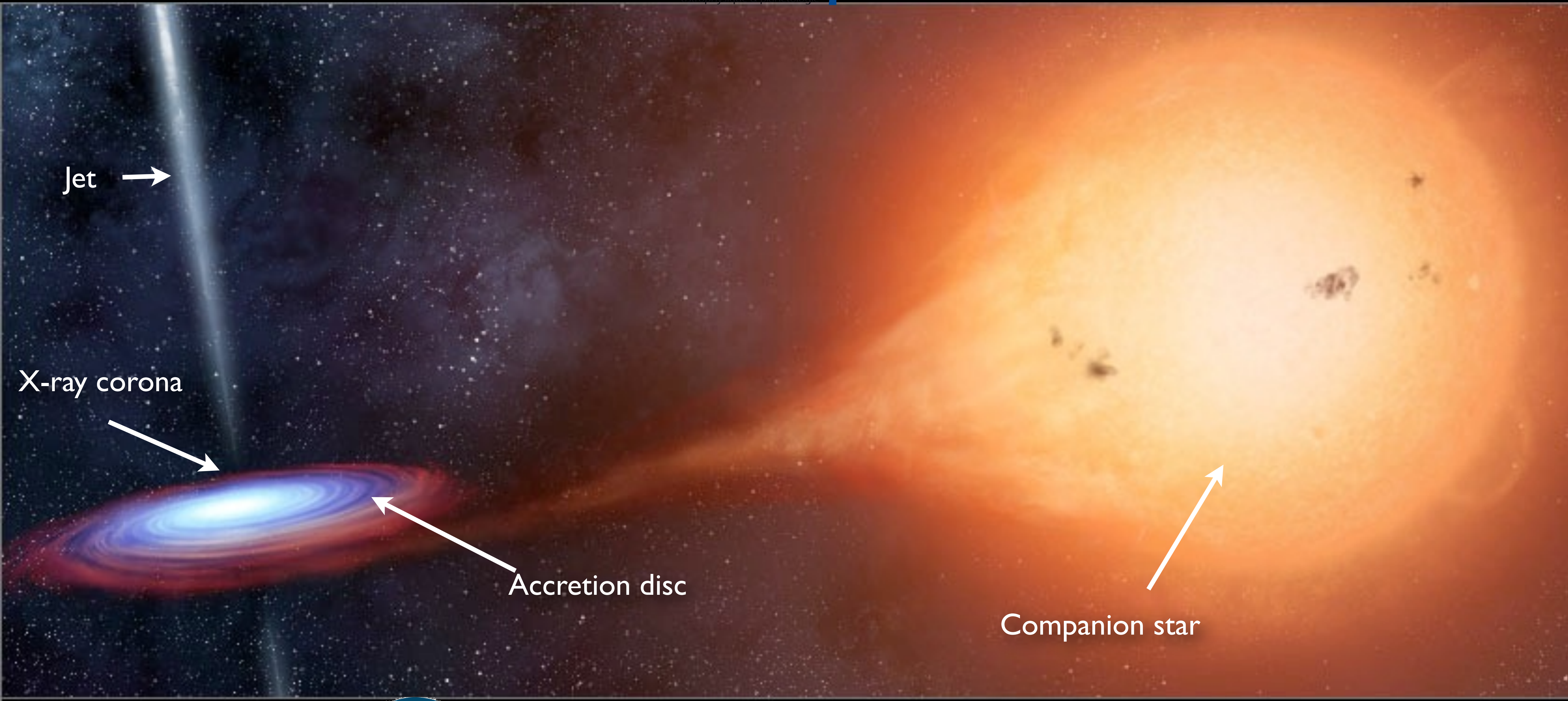
An internal shock model for the emission of compact jets in X-ray binaries

Julien Malzac
irap



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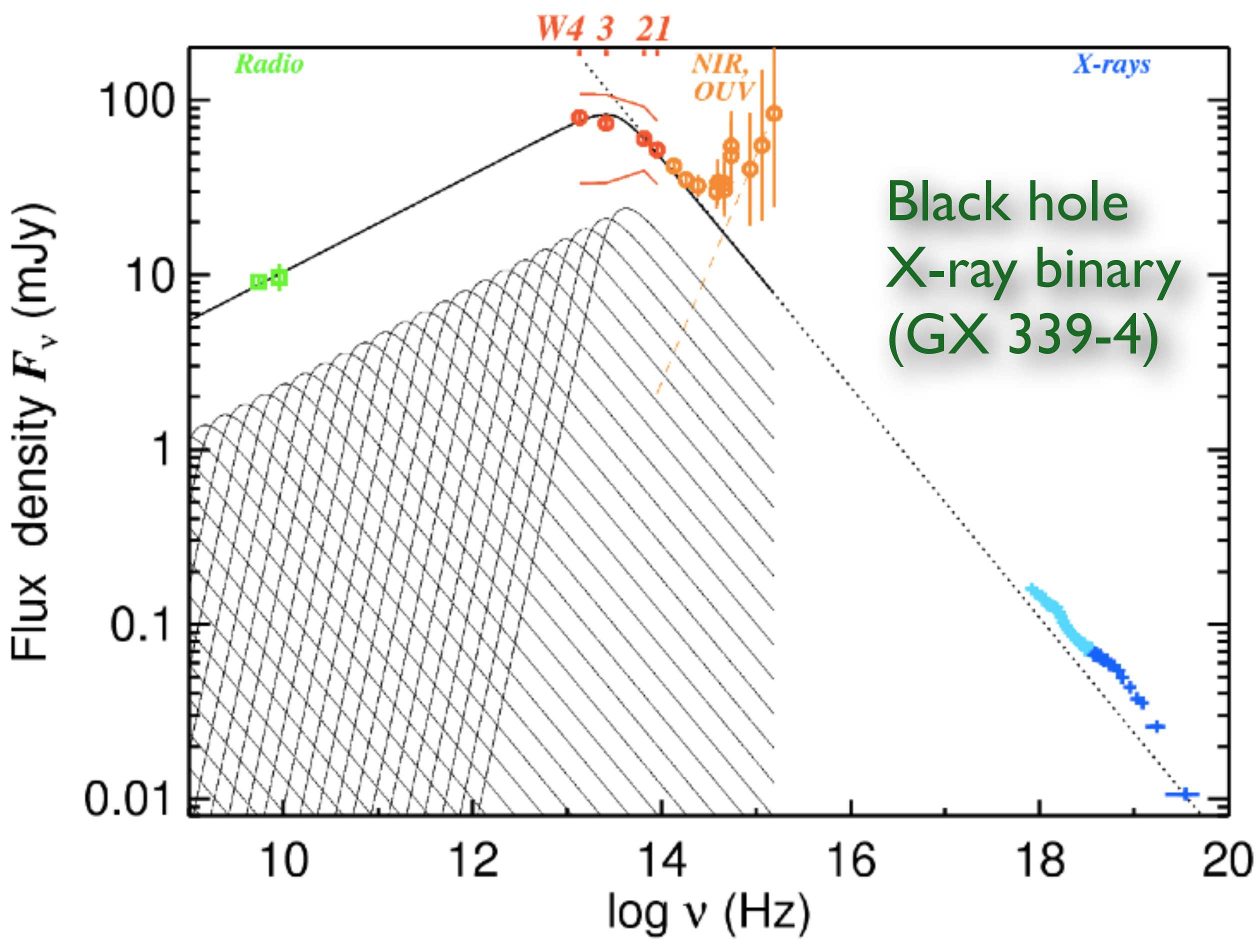
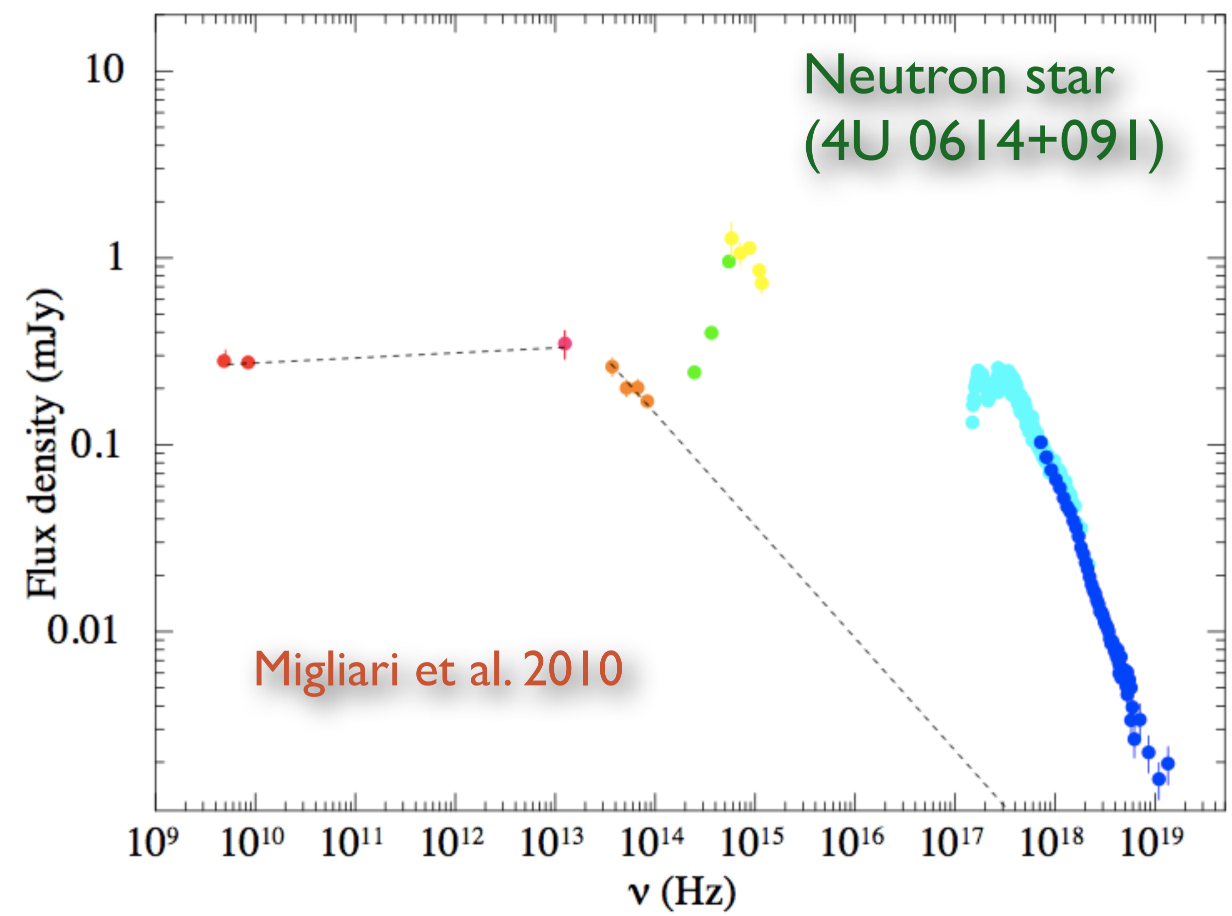
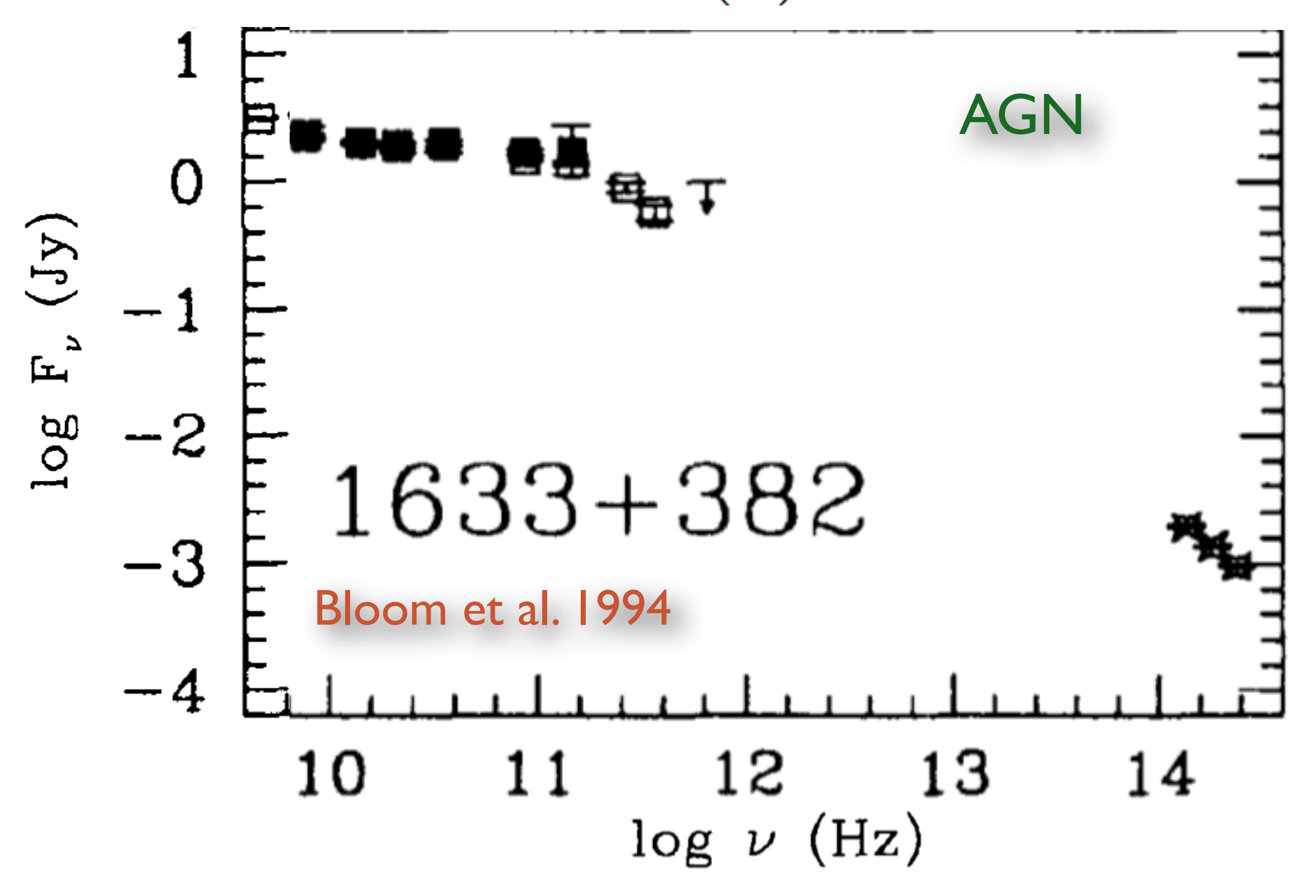
Observed Spectral Energy Distribution of Compact Jets



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...



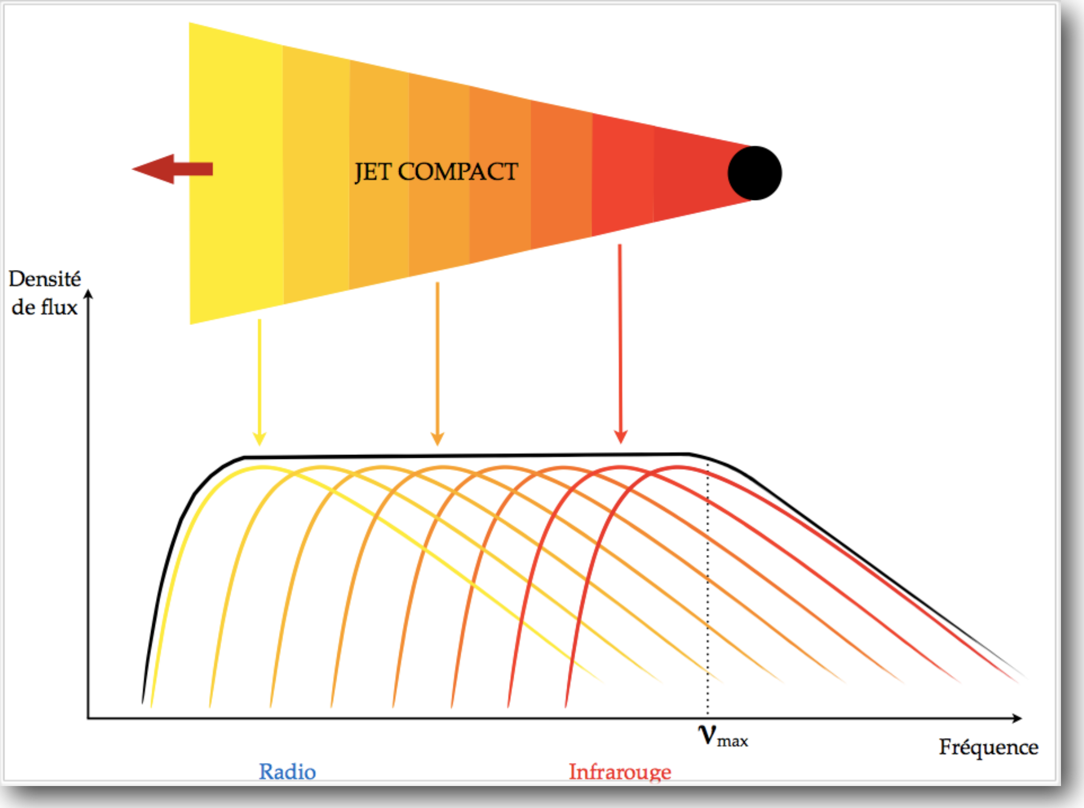


Standard conical jet emission model (Blandford & Koenigl 1979)

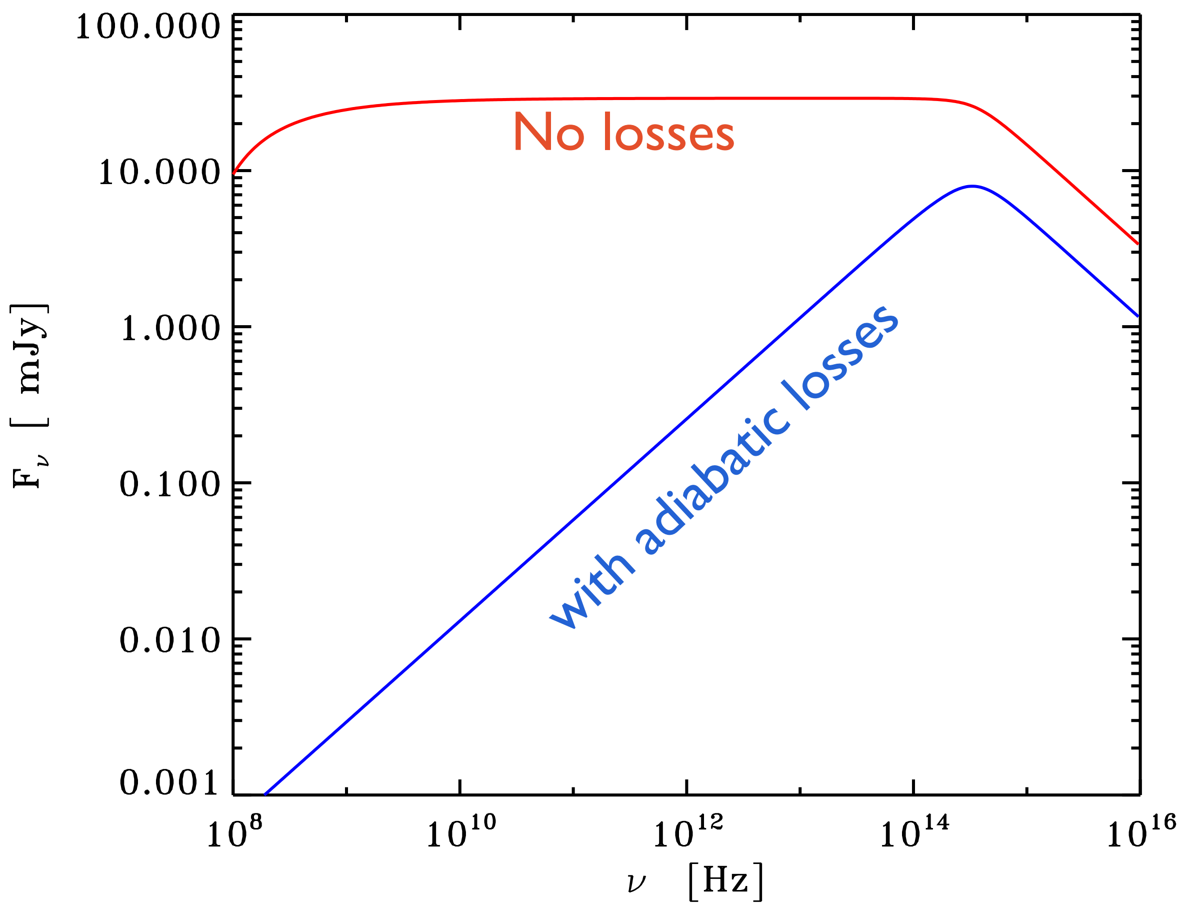
- Synchrotron radiation from a population of relativistic leptons travelling down the jet

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

- Energy losses neglected

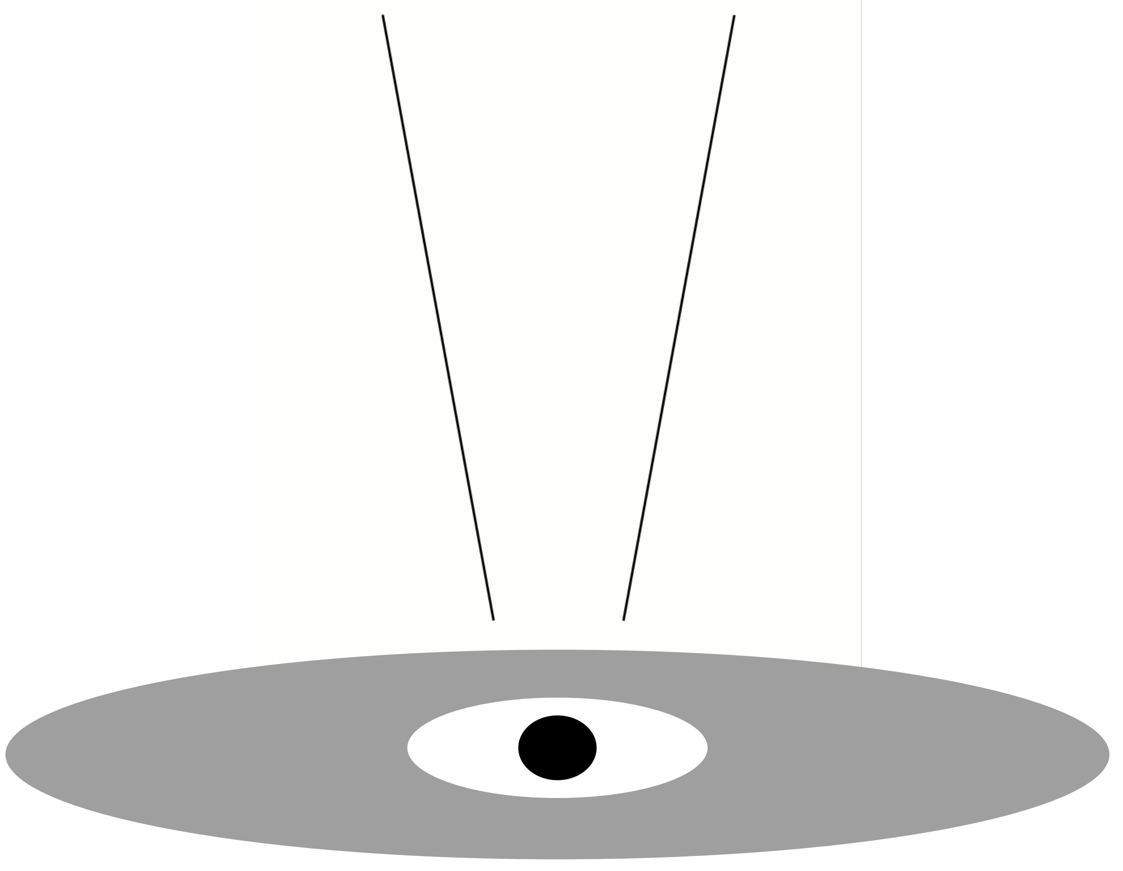


(M. Coriat)



Adiabatic expansion energy losses:
- ➡ strongly inverted SED
- ➡ need to compensate for losses

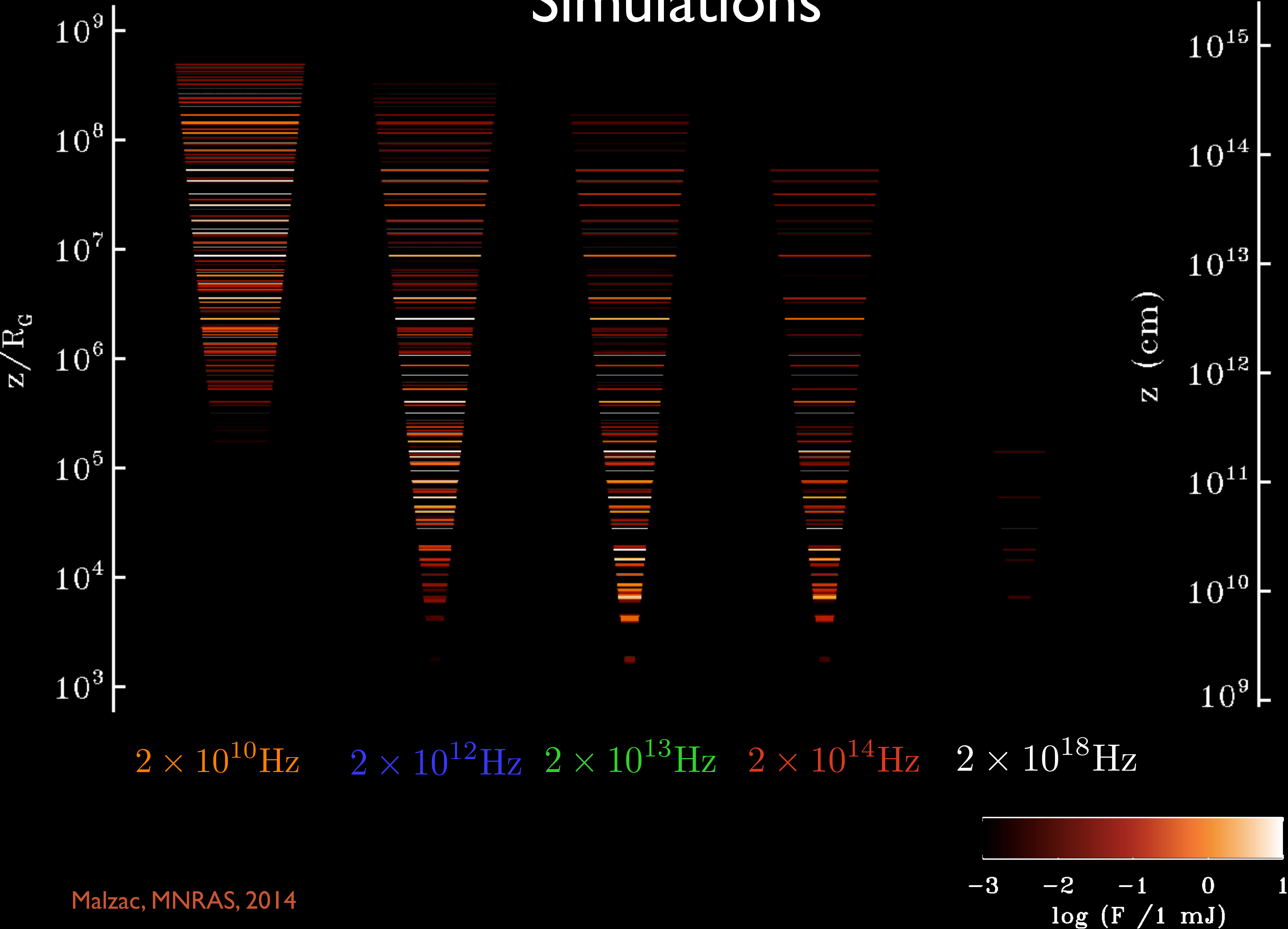
Internal shock model



- 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

Malzac 2013, 2014

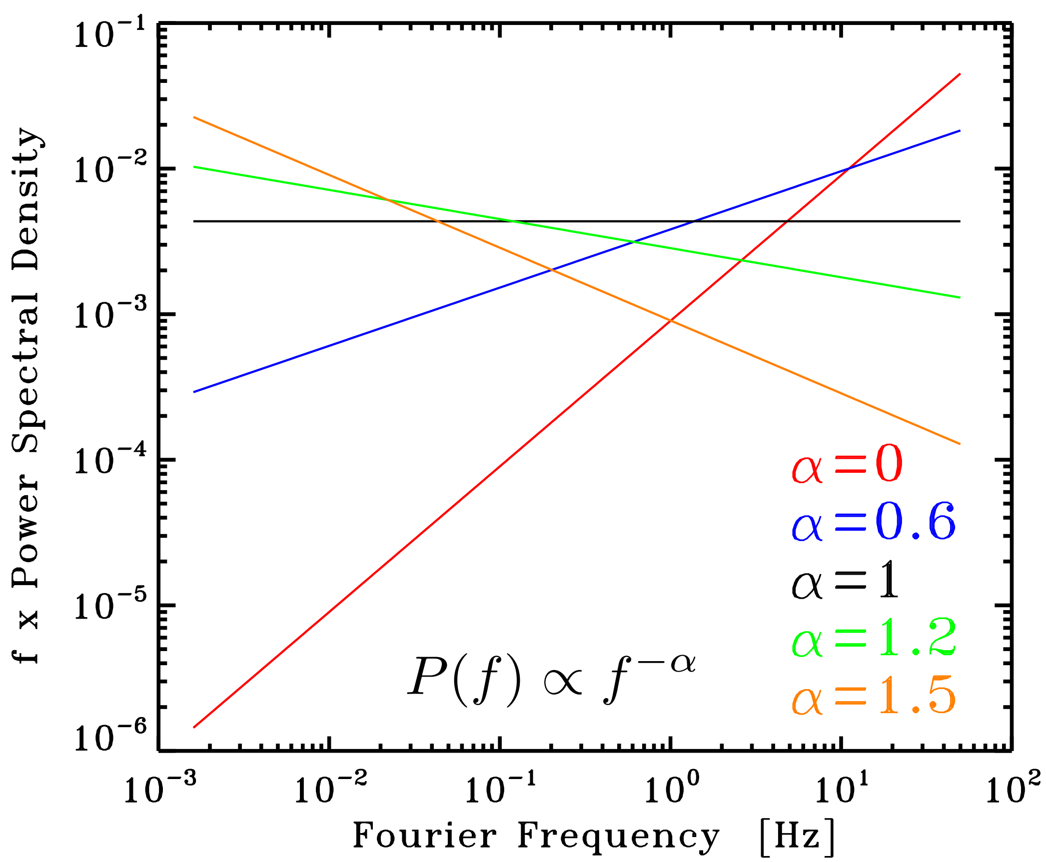
Simulations



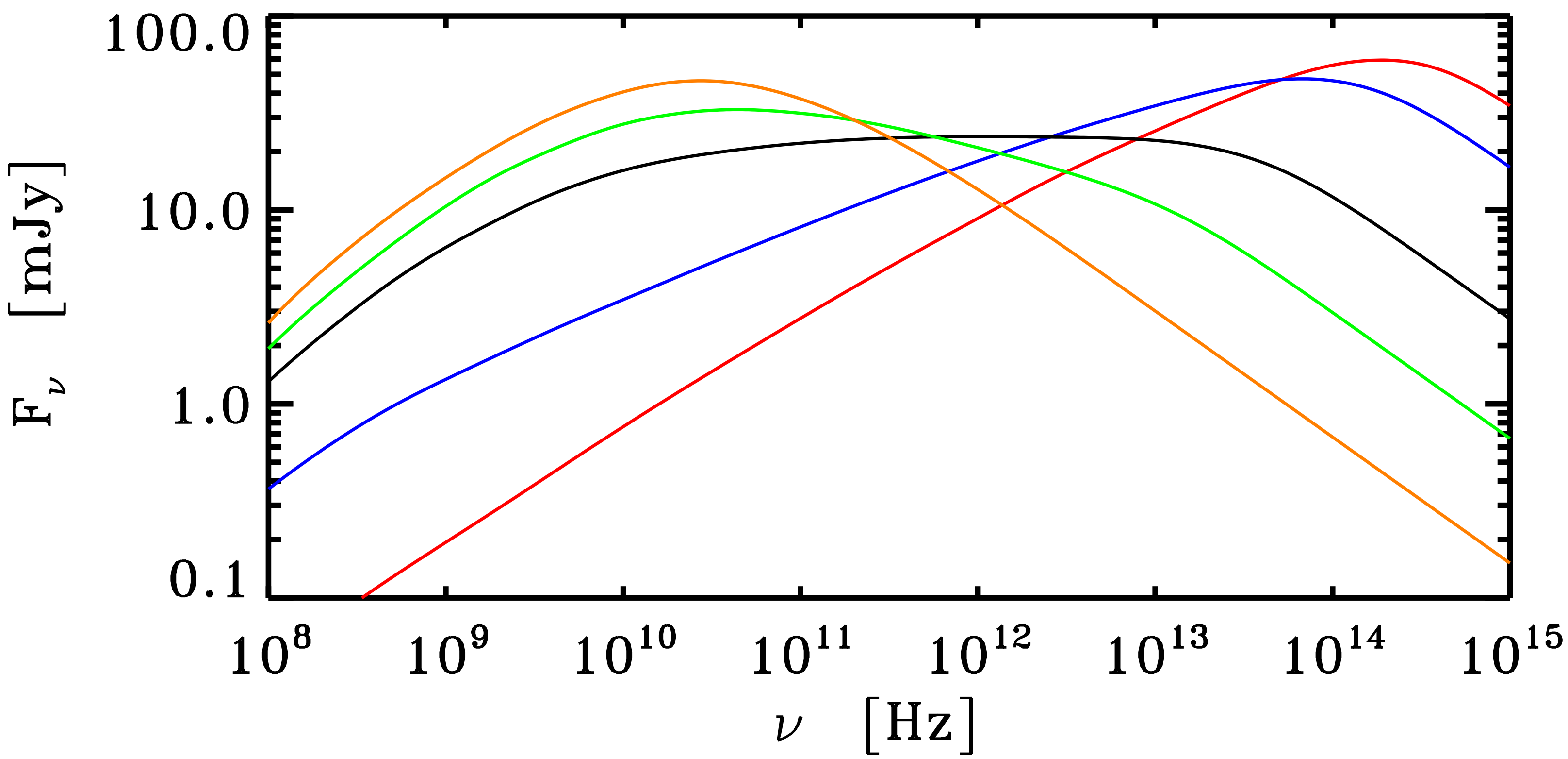
Malzac, MNRAS, 2014

Can shock dissipation balance energy losses ?

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



PSD of Lorentz factor fluctuations



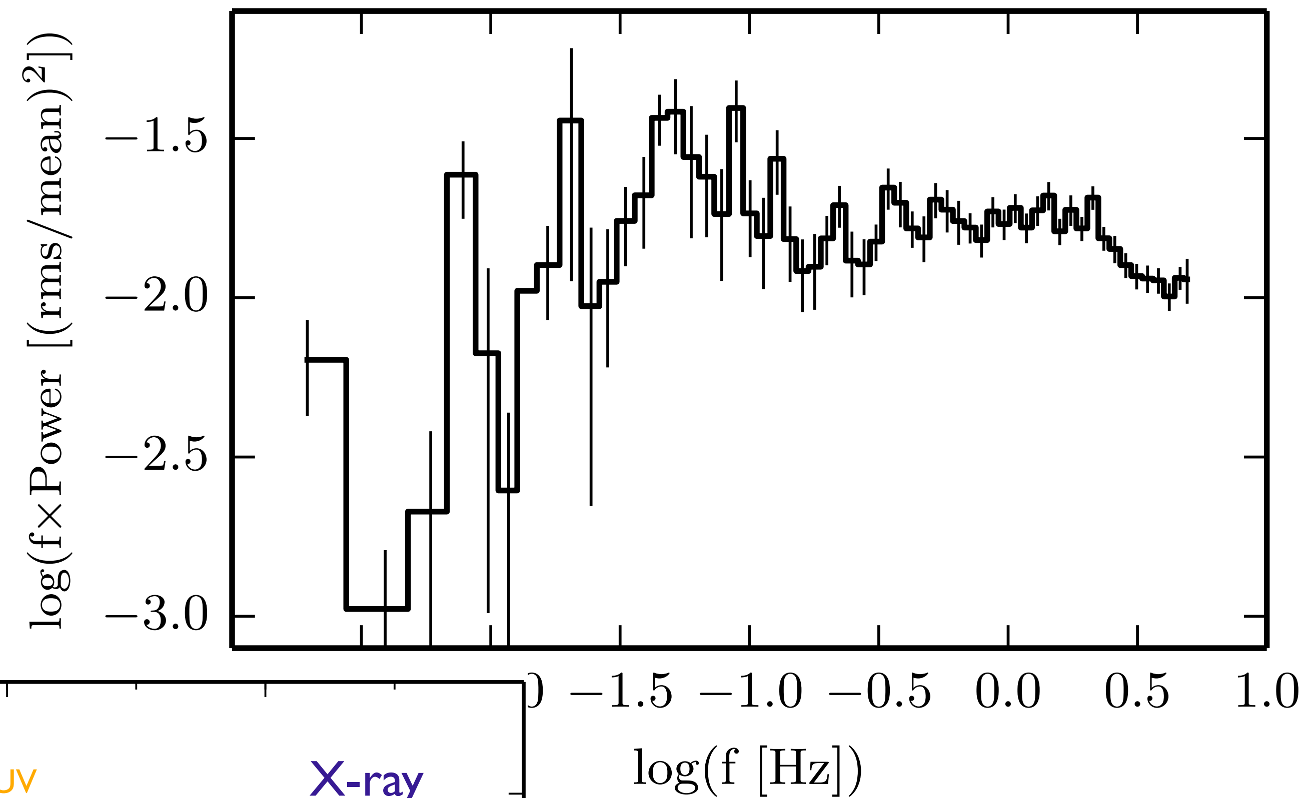
Spectral energy distribution

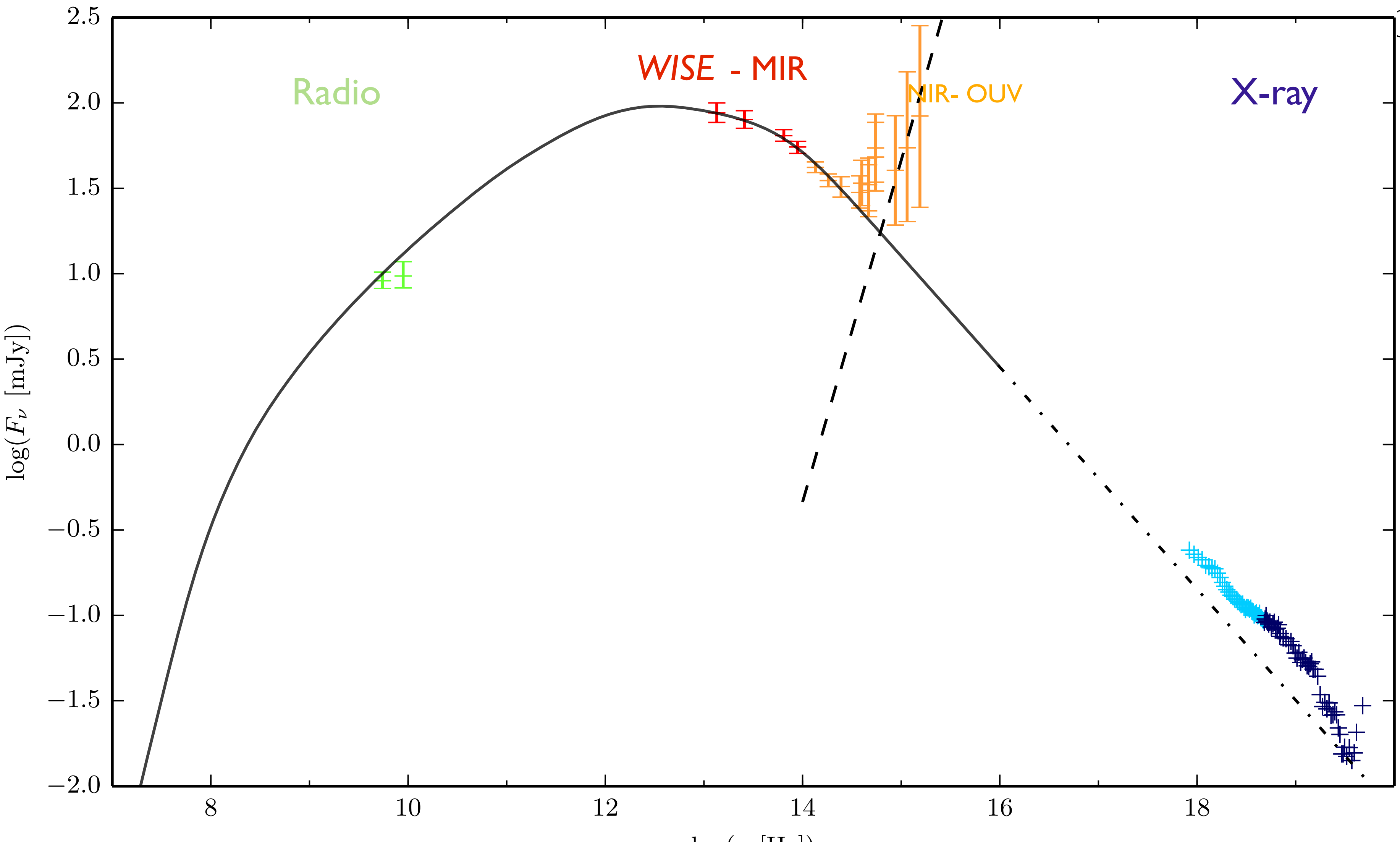
➡Flat radio-IR spectra produced for flicker noise Lorentz factor fluctuations

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 fluctuation





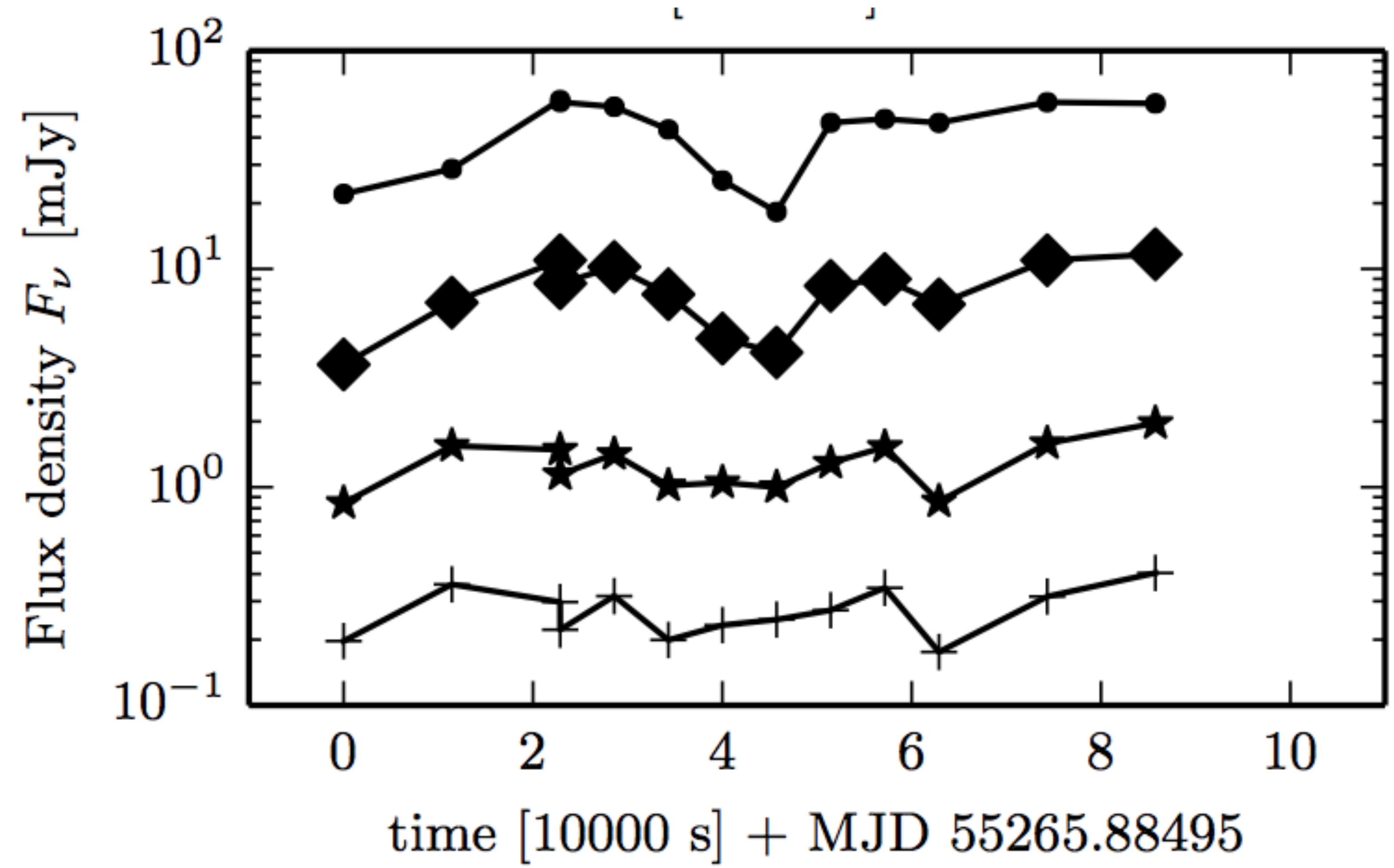
Jet SED

Drappeau, et al. MNRAS, 2015

Observation

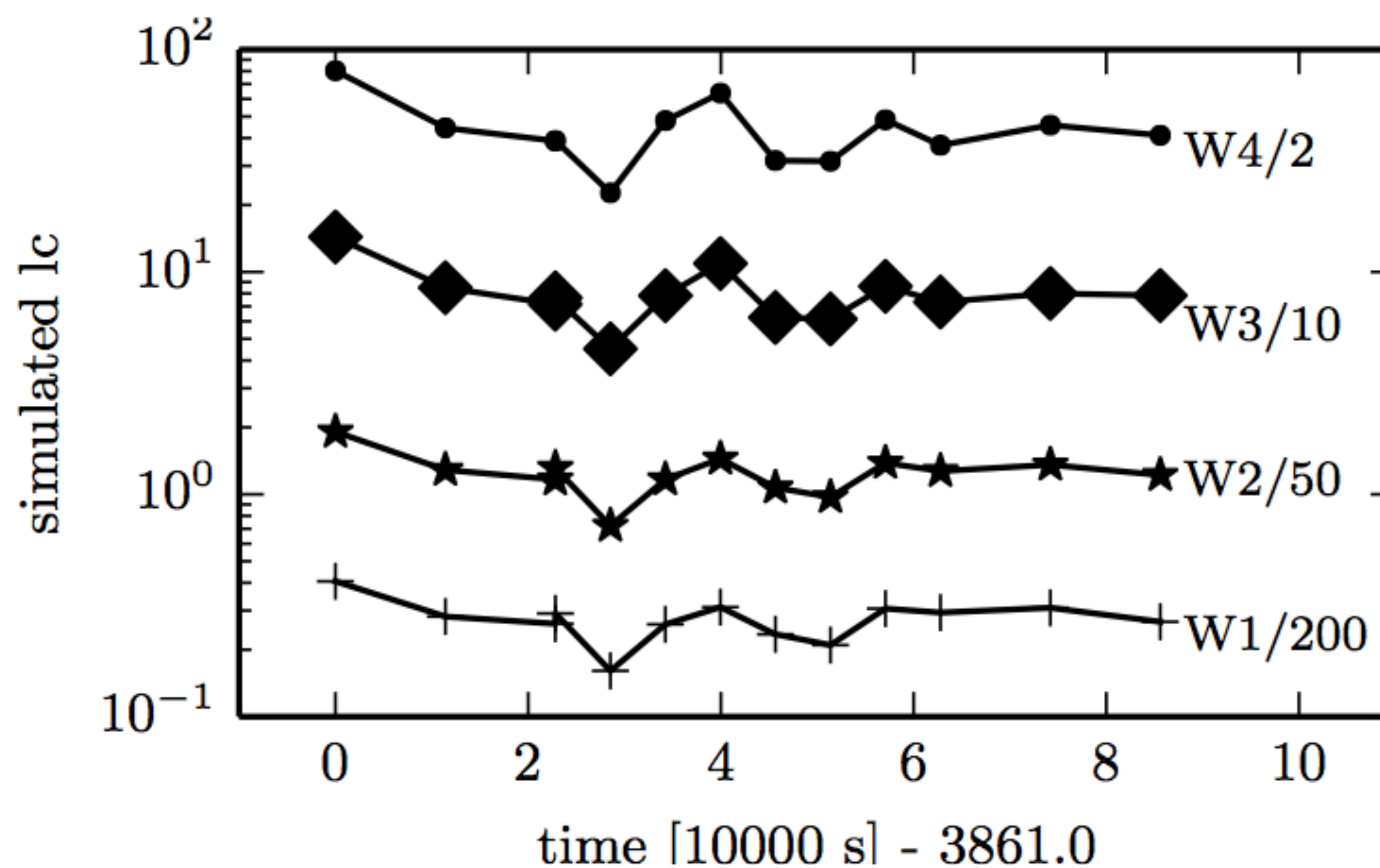
Observed NIR light curves

(Gandhi et al. 2011)



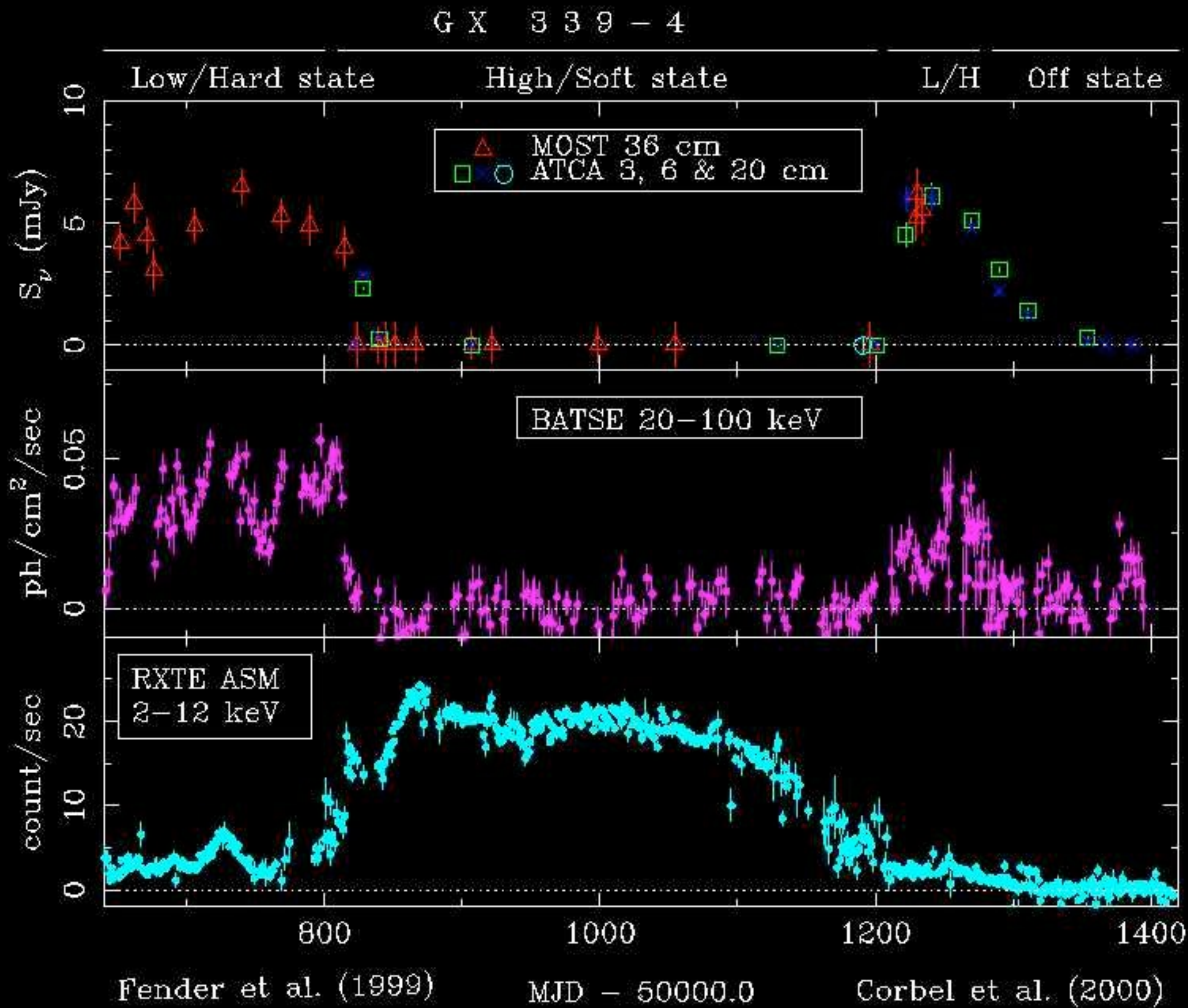
Simulation

Sample simulated light curves



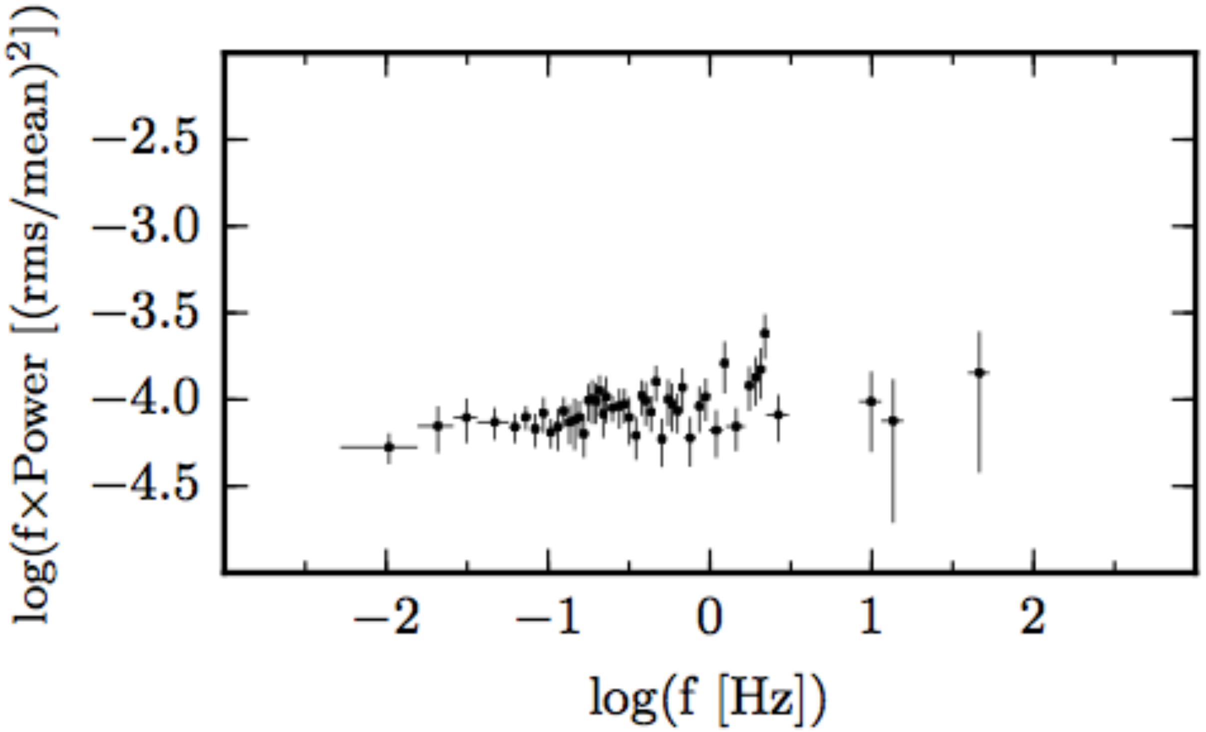
Drappeau et al., MNRAS 2015

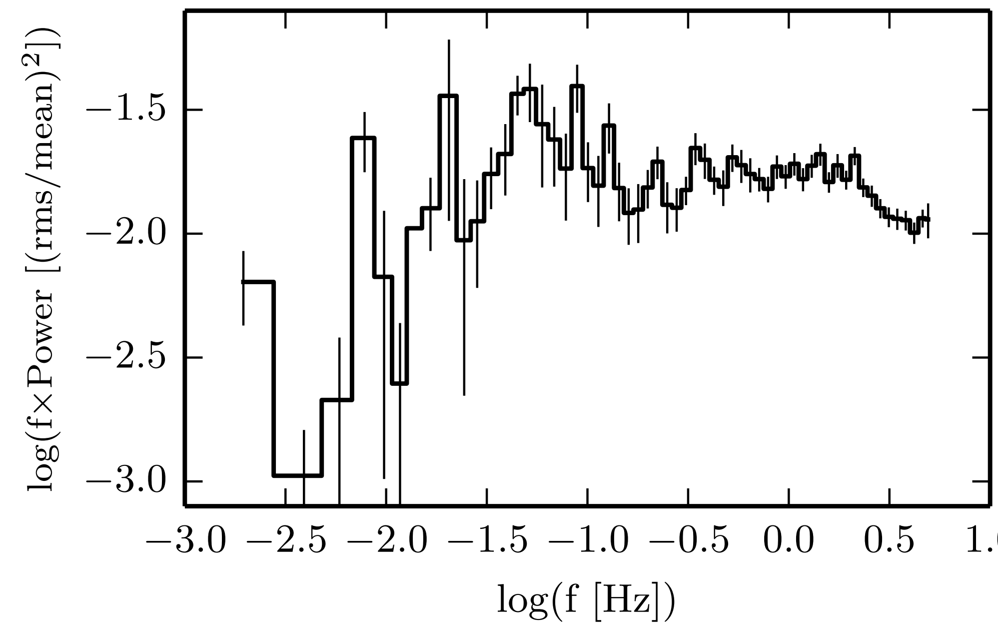
X-ray/Radio correlations



⇒ Jet quenched in the high soft state

A dark jet in the soft state ?



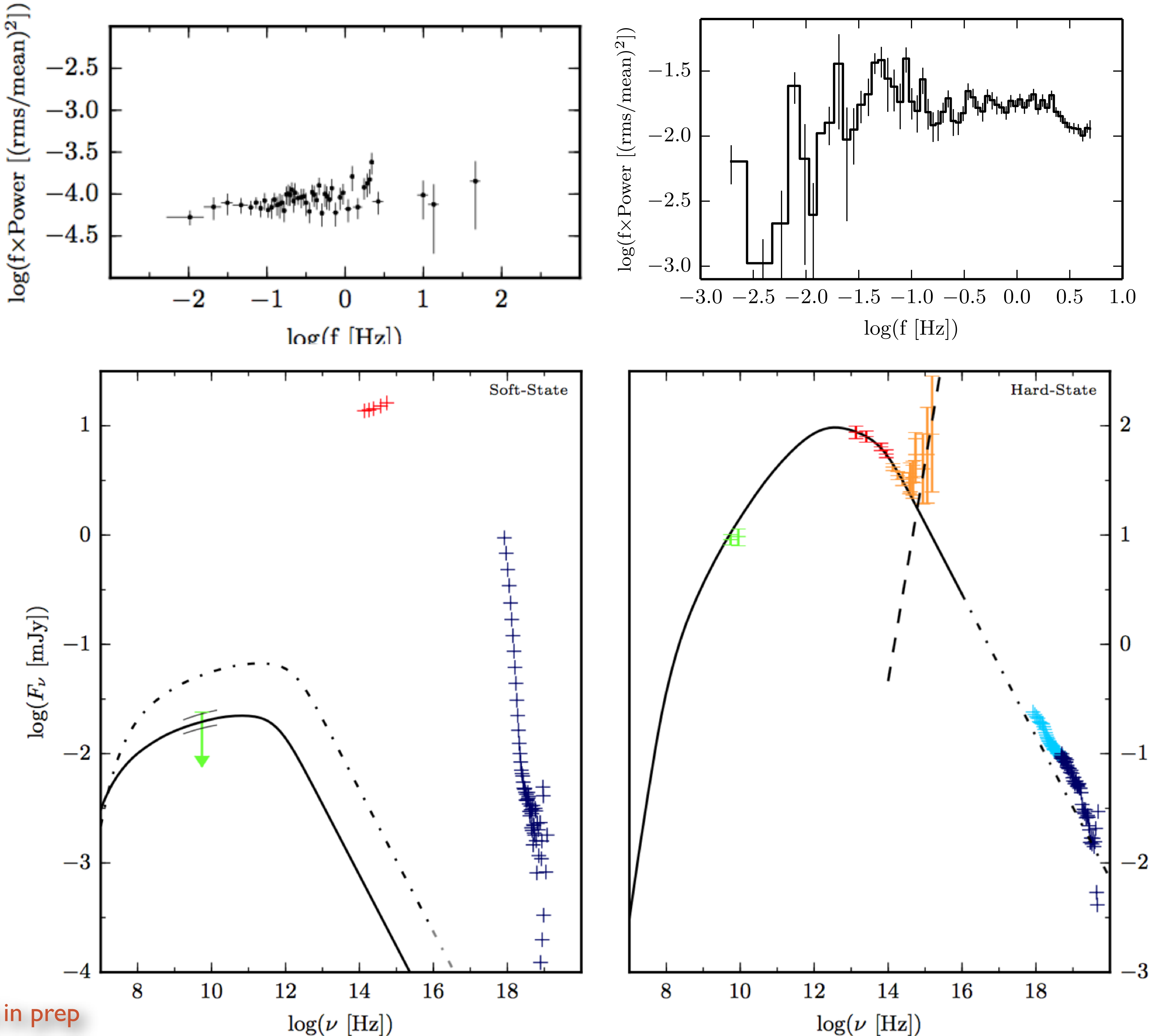


- Jet luminosity very sensitive to rms amplitude of fluctuations

- Disappearance of the jet in soft state associated to drop in X-ray variability ??

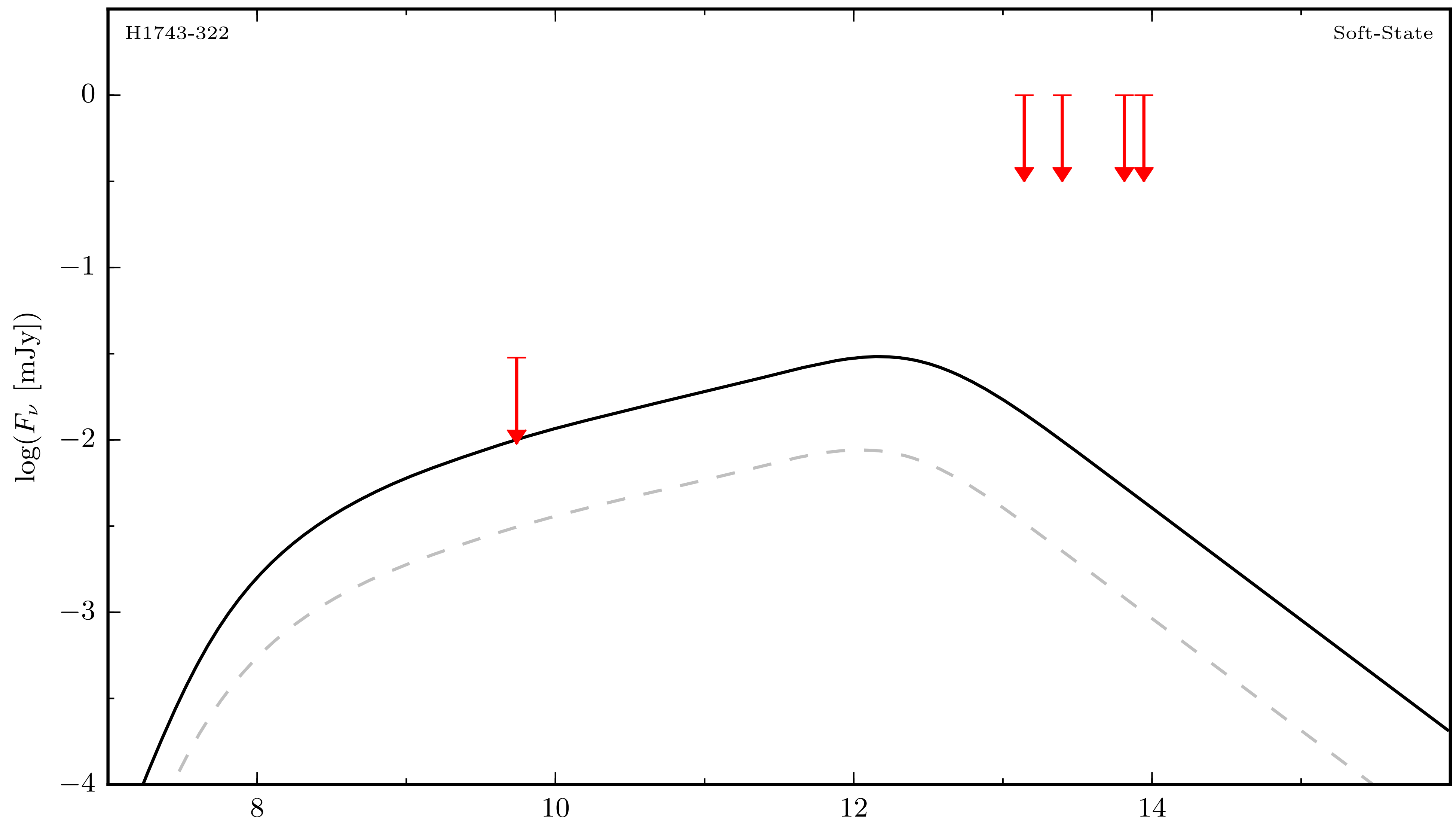
- Jet with same kinetic power as in hard state but radiatively inefficient ??

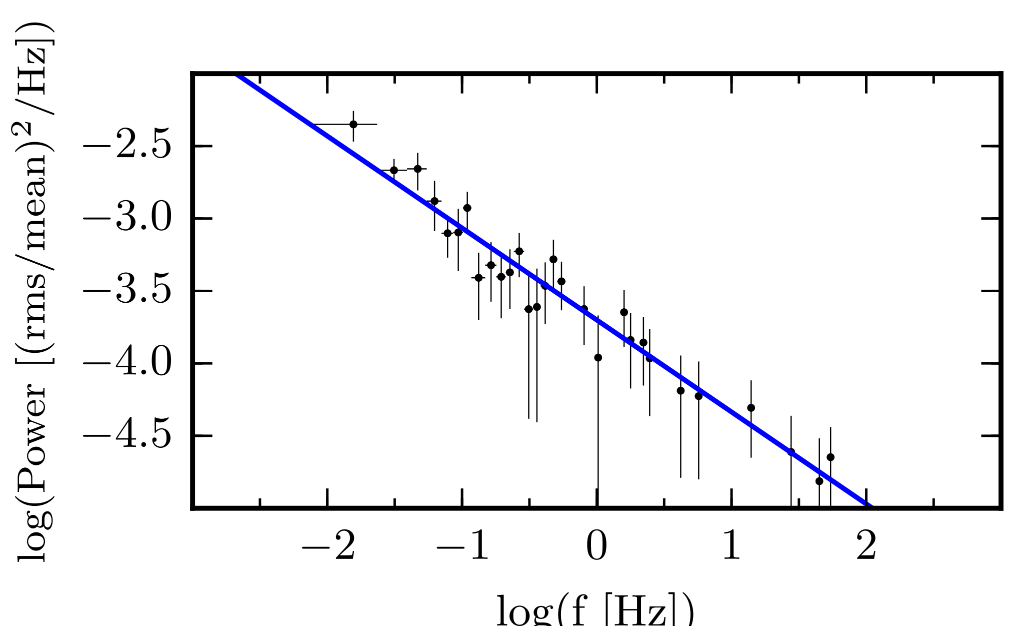
A dark jet in the soft state ?



Drappeau et al. in prep

Soft state of H1743-322



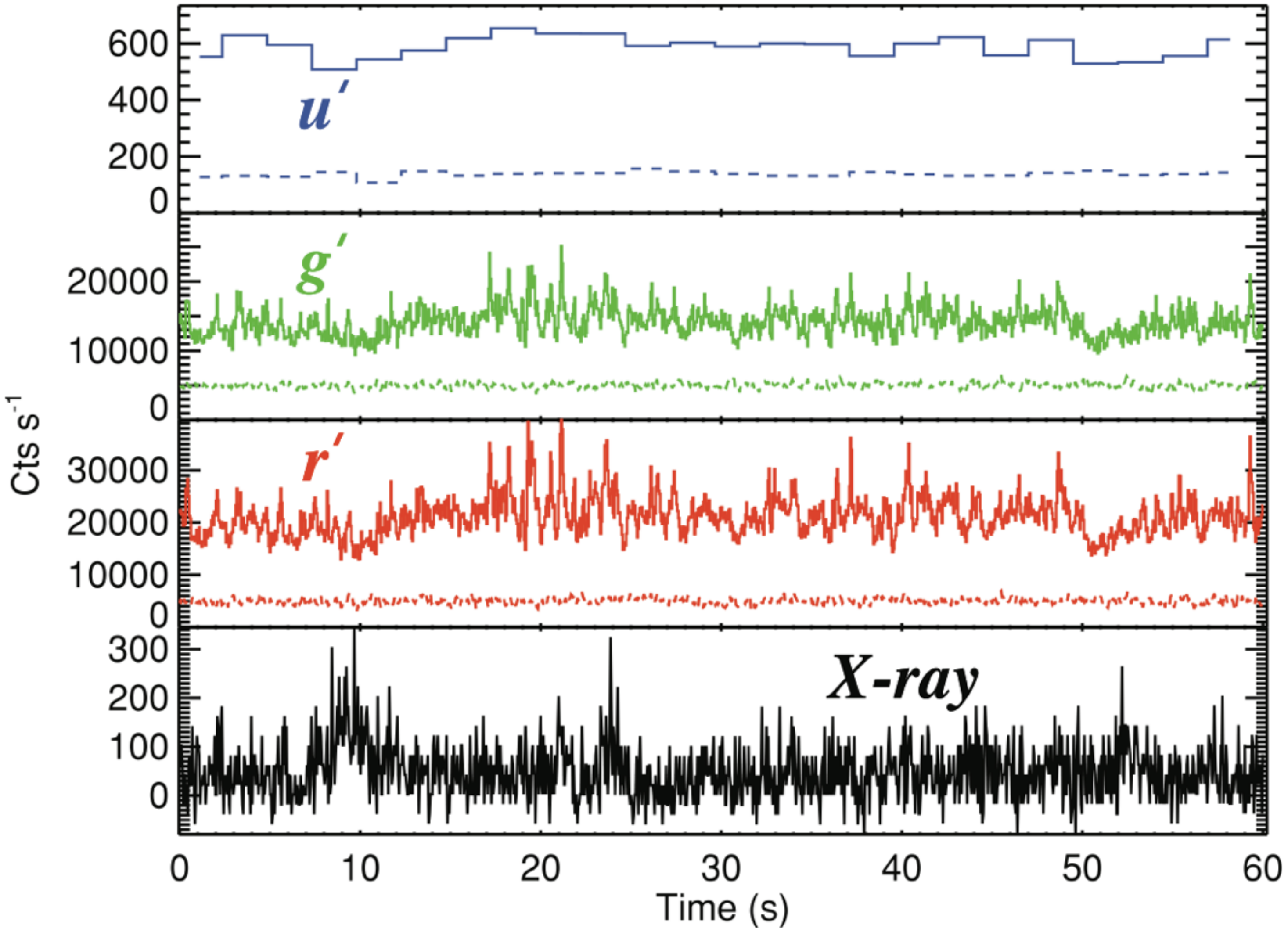


Drappeau et al. in prep

Fast Jet Variability

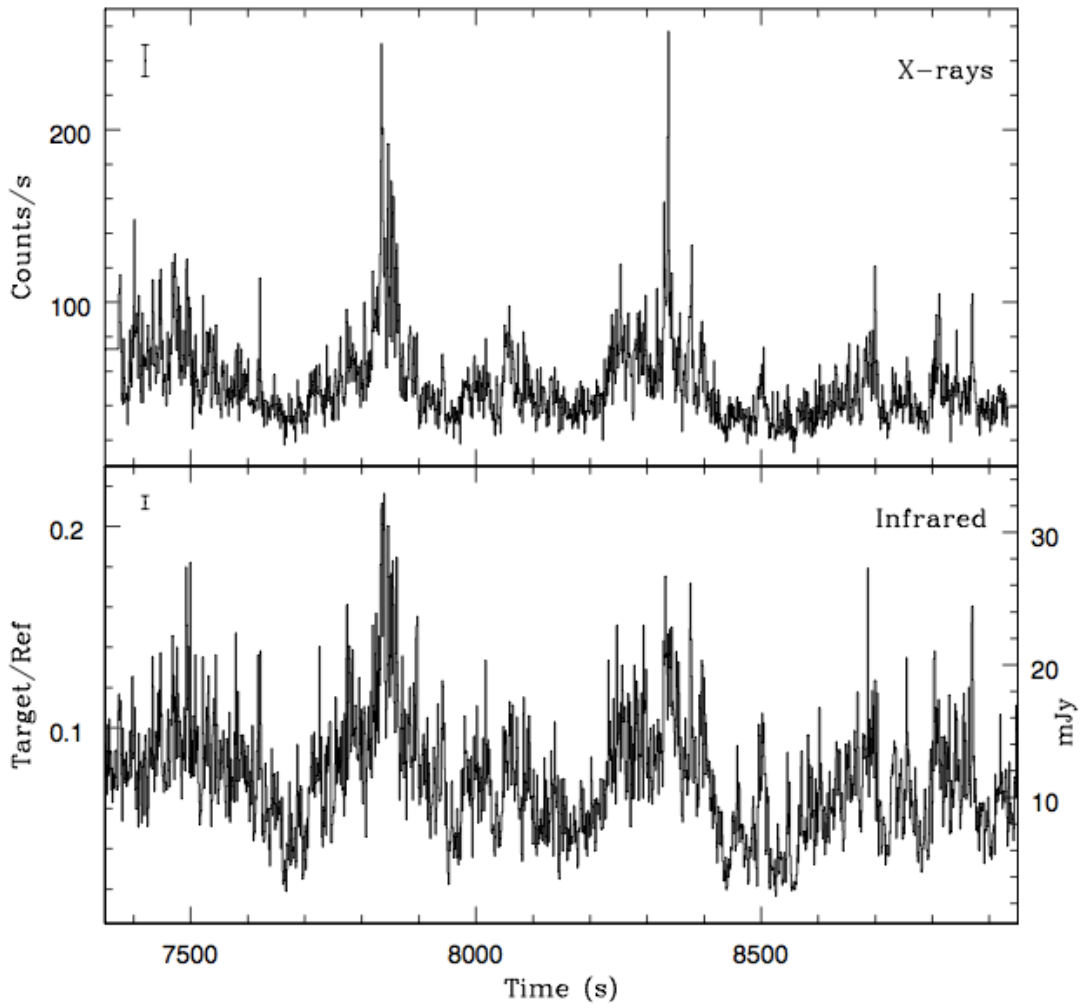
Observations of GX 339-4

Optical



Gandhi et al. 2010

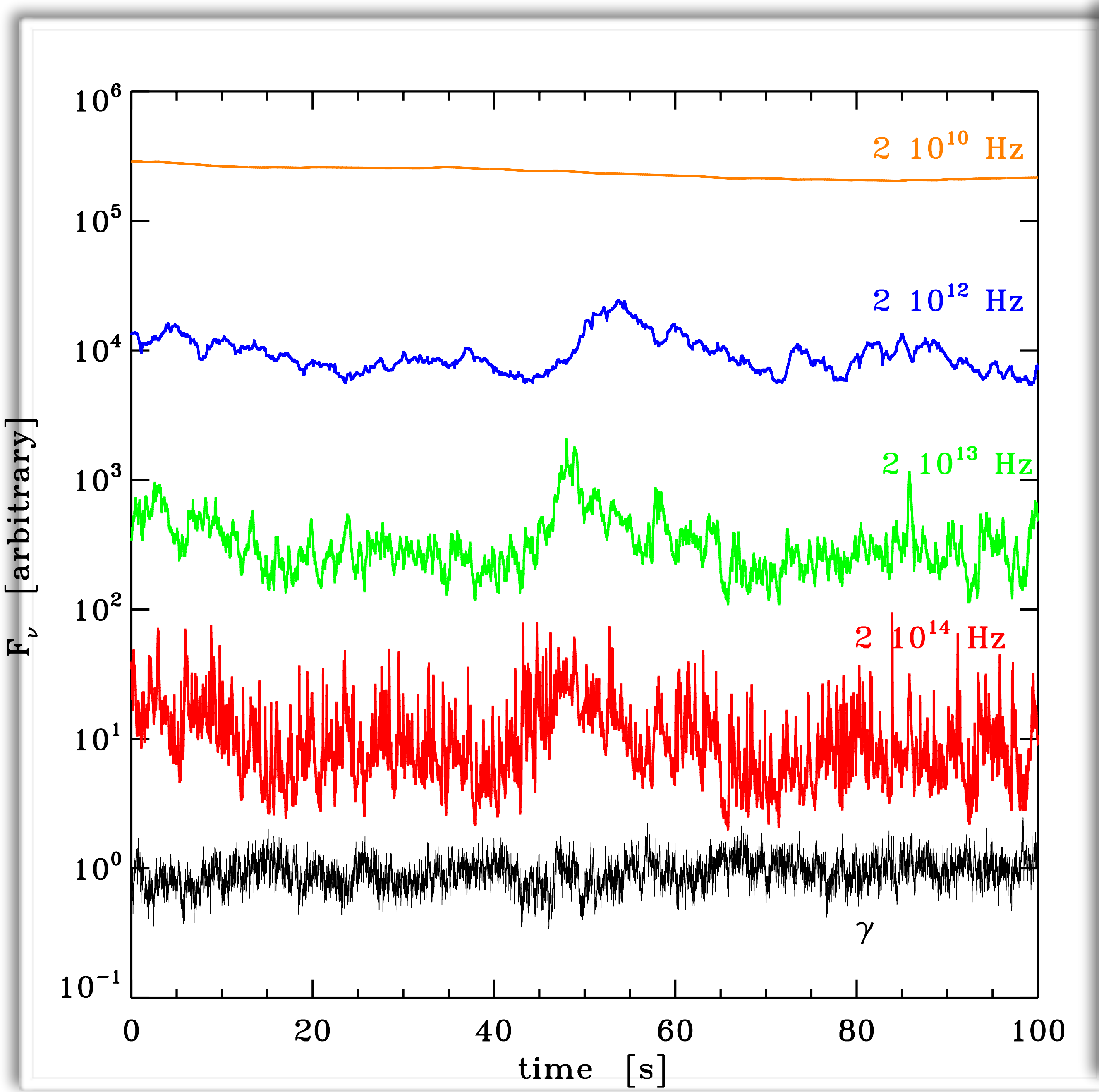
Infrared

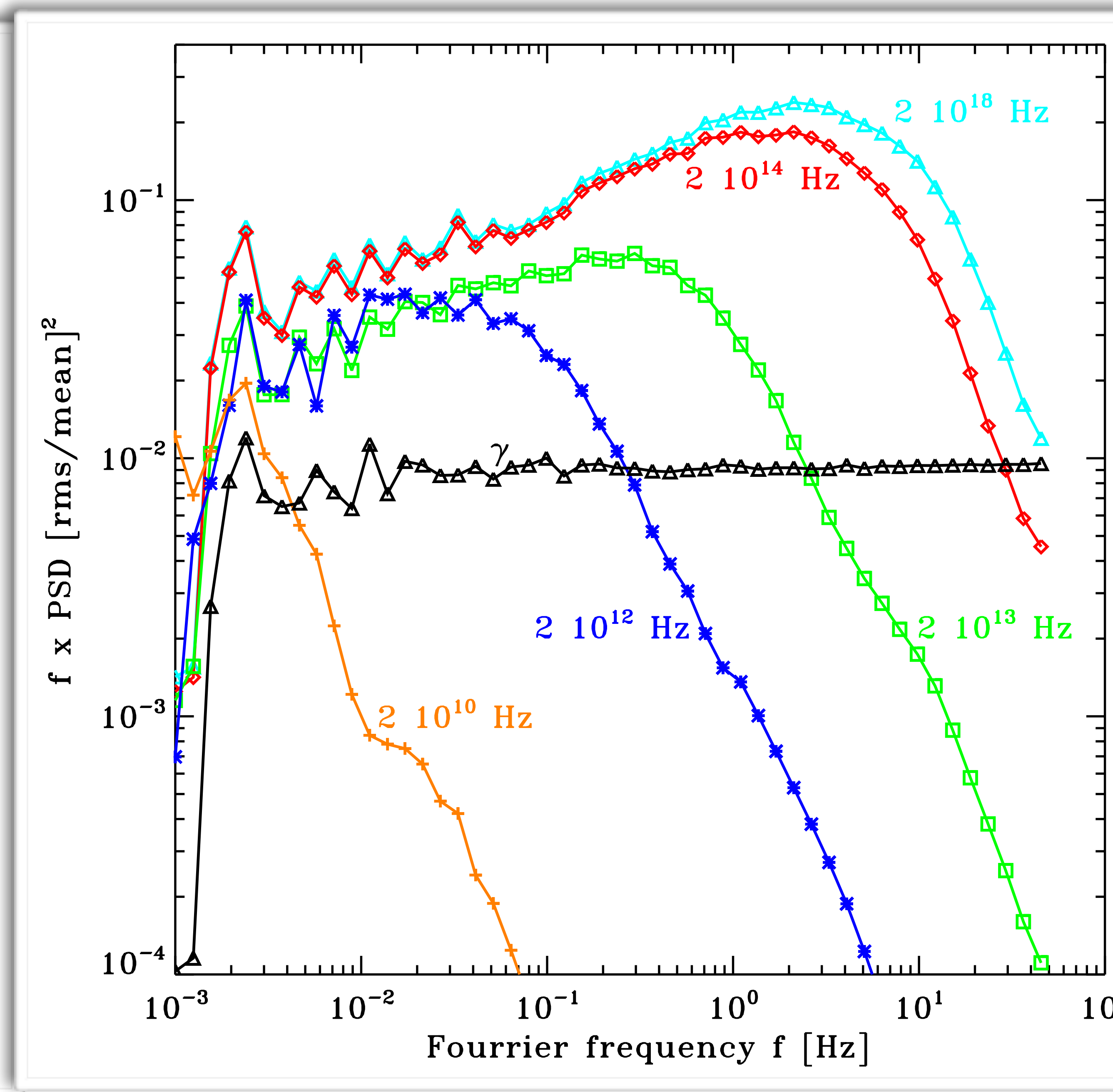


Casella et al. 2010

Fast Jet Variability

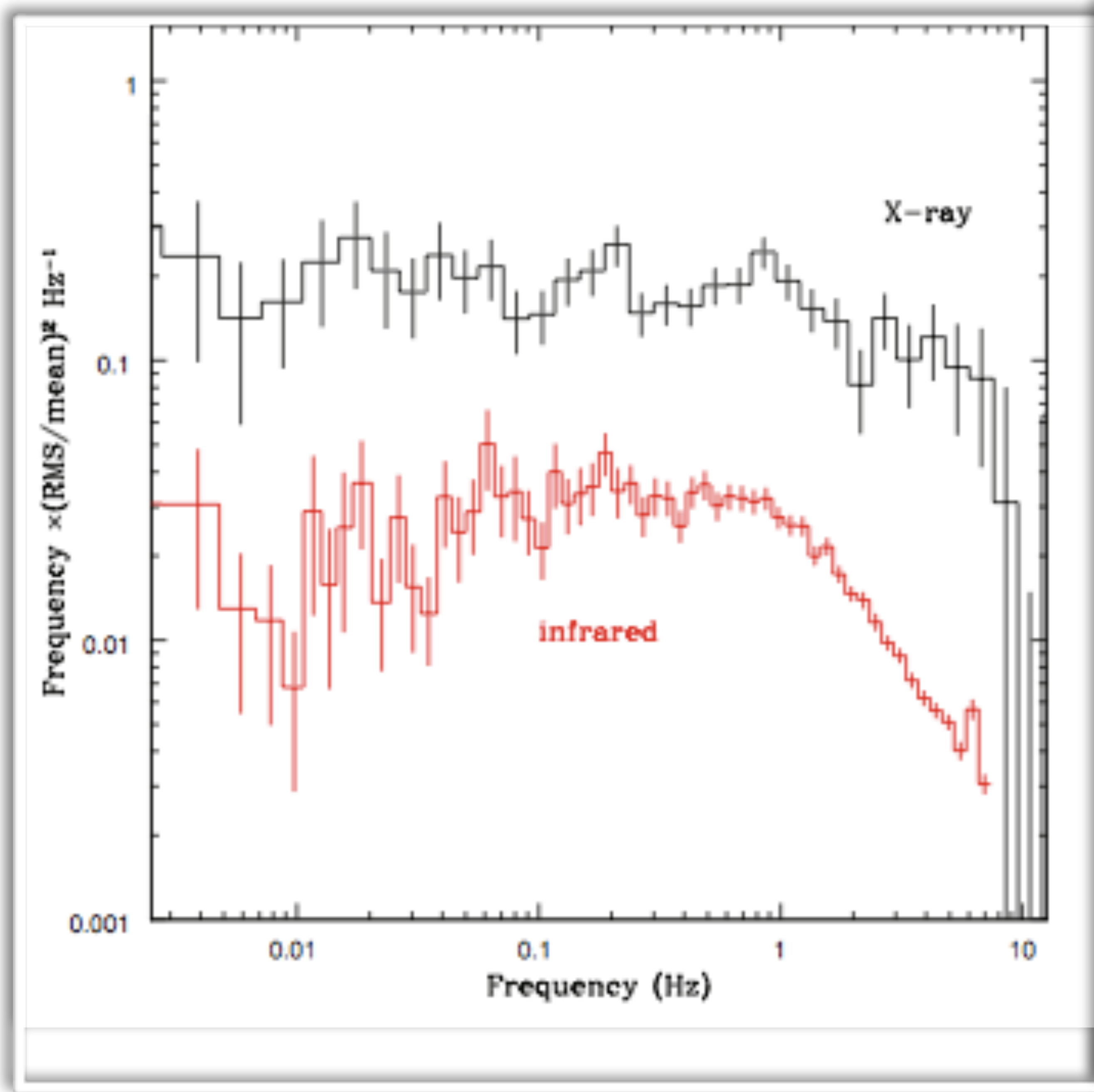
Model

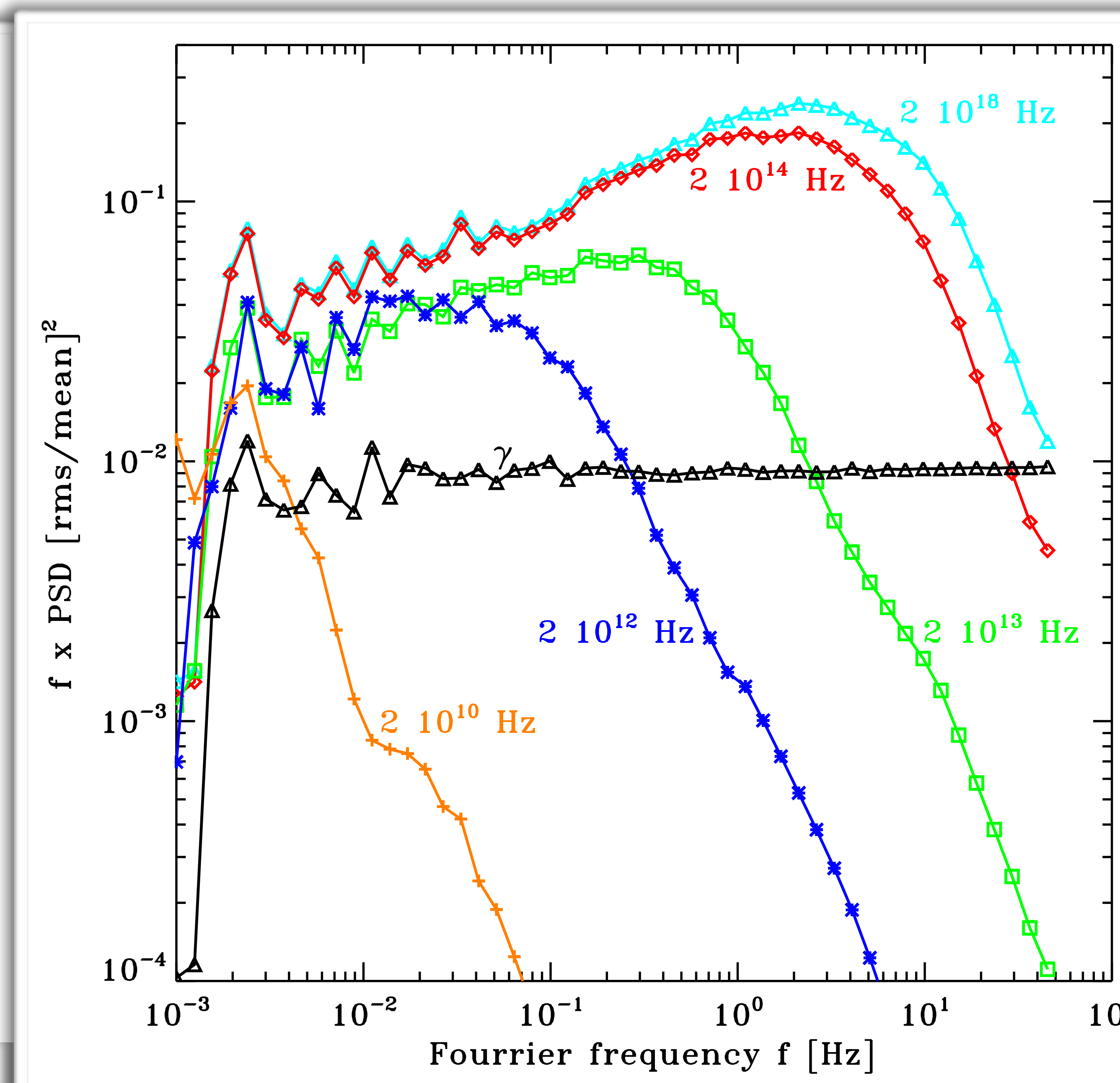




Malzac, MNRAS, 2014

Fast Jet Variability



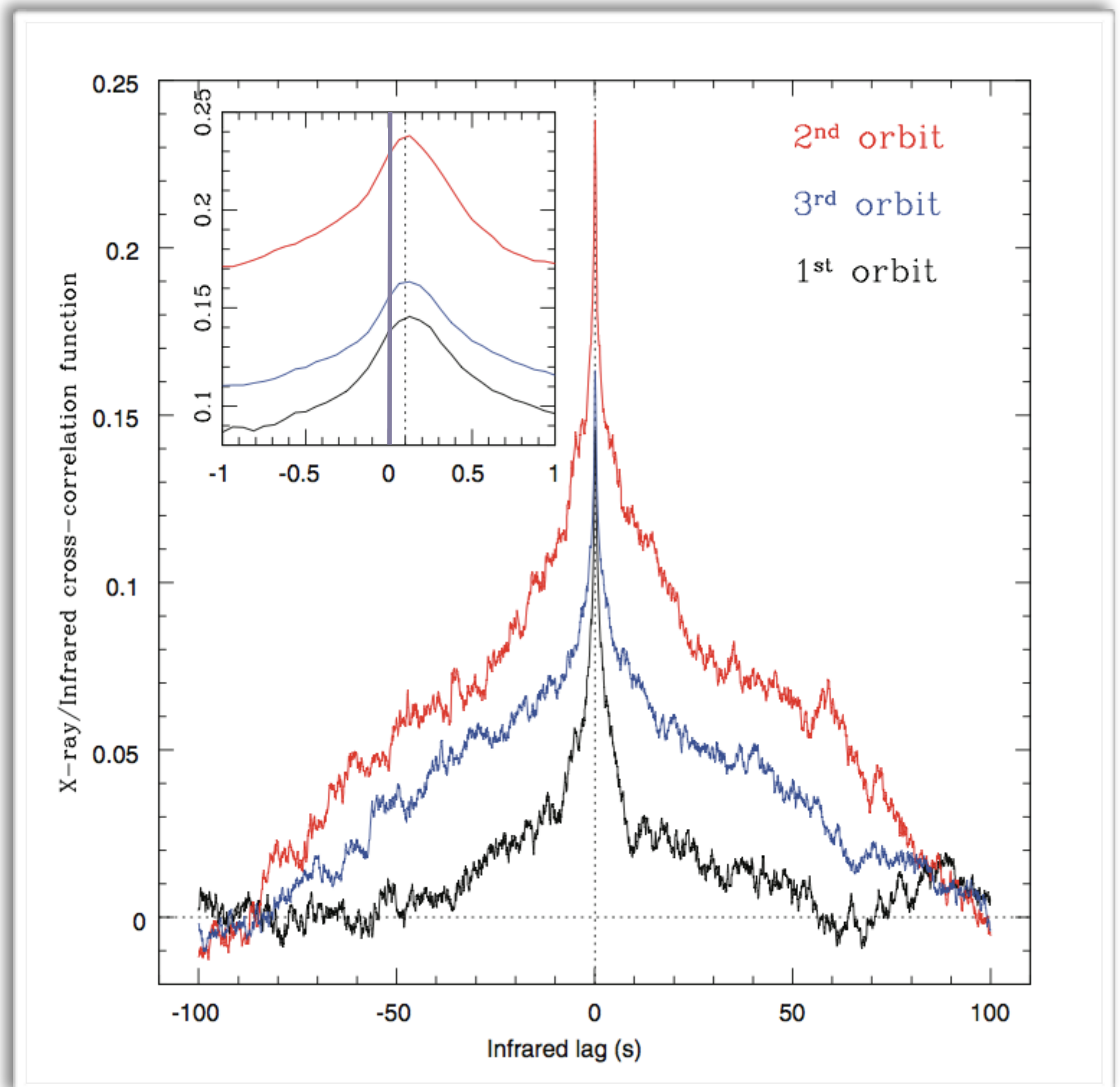


Casella et al. 2010

Malzac, MNRAS, 2014

IR /X-ray correlation

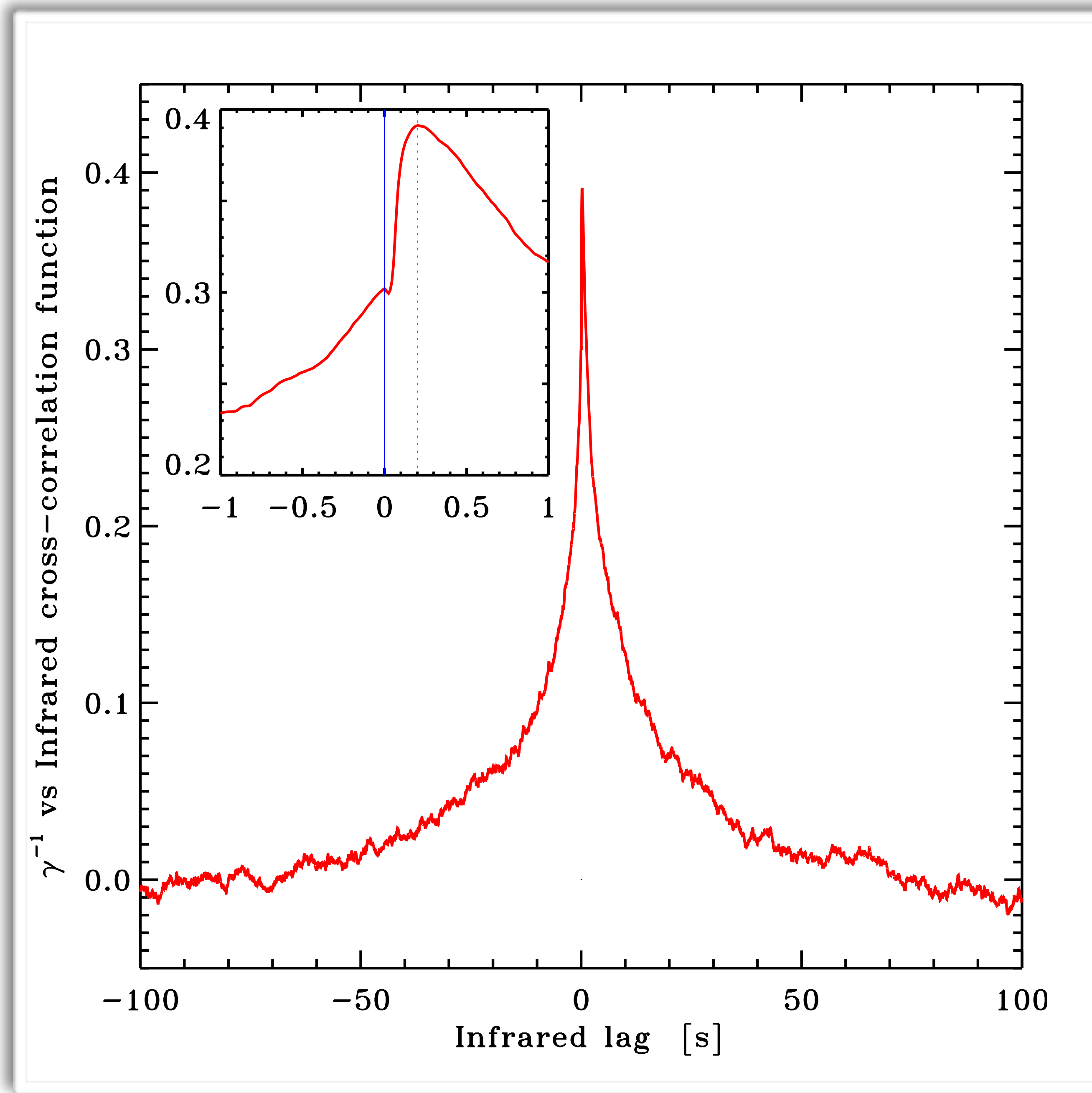
Observations



GX 339-4

Casella et al. 2010

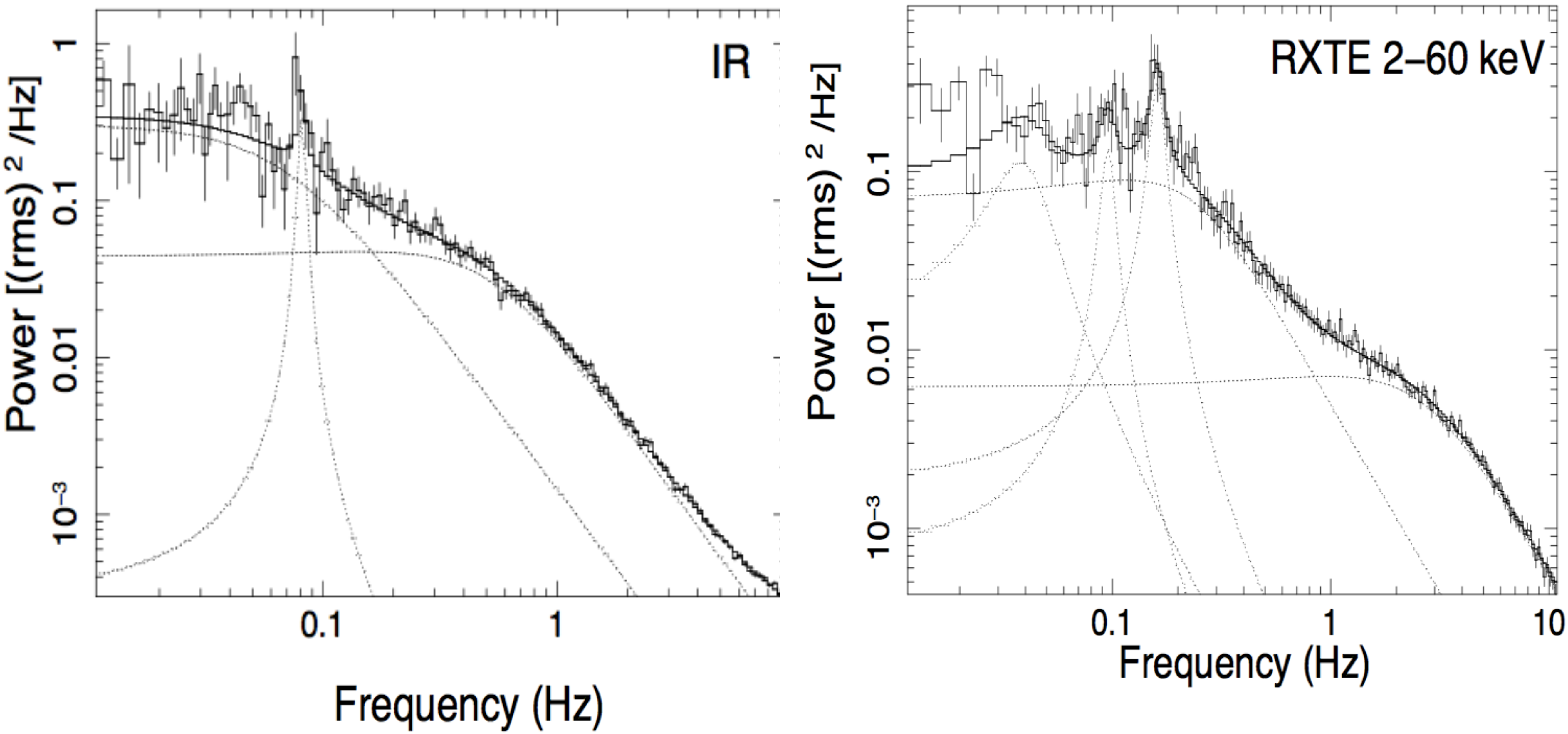
Simulation



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

Malzac 2014

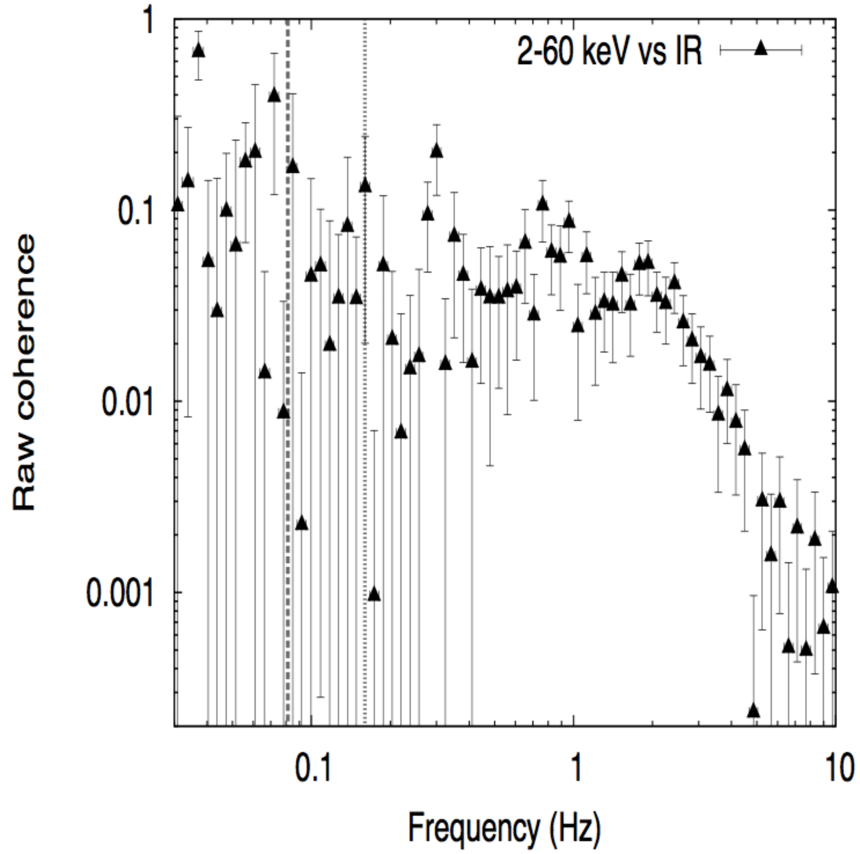
New fast IR timing data of GX 339-4: First QPO detected in Infrared

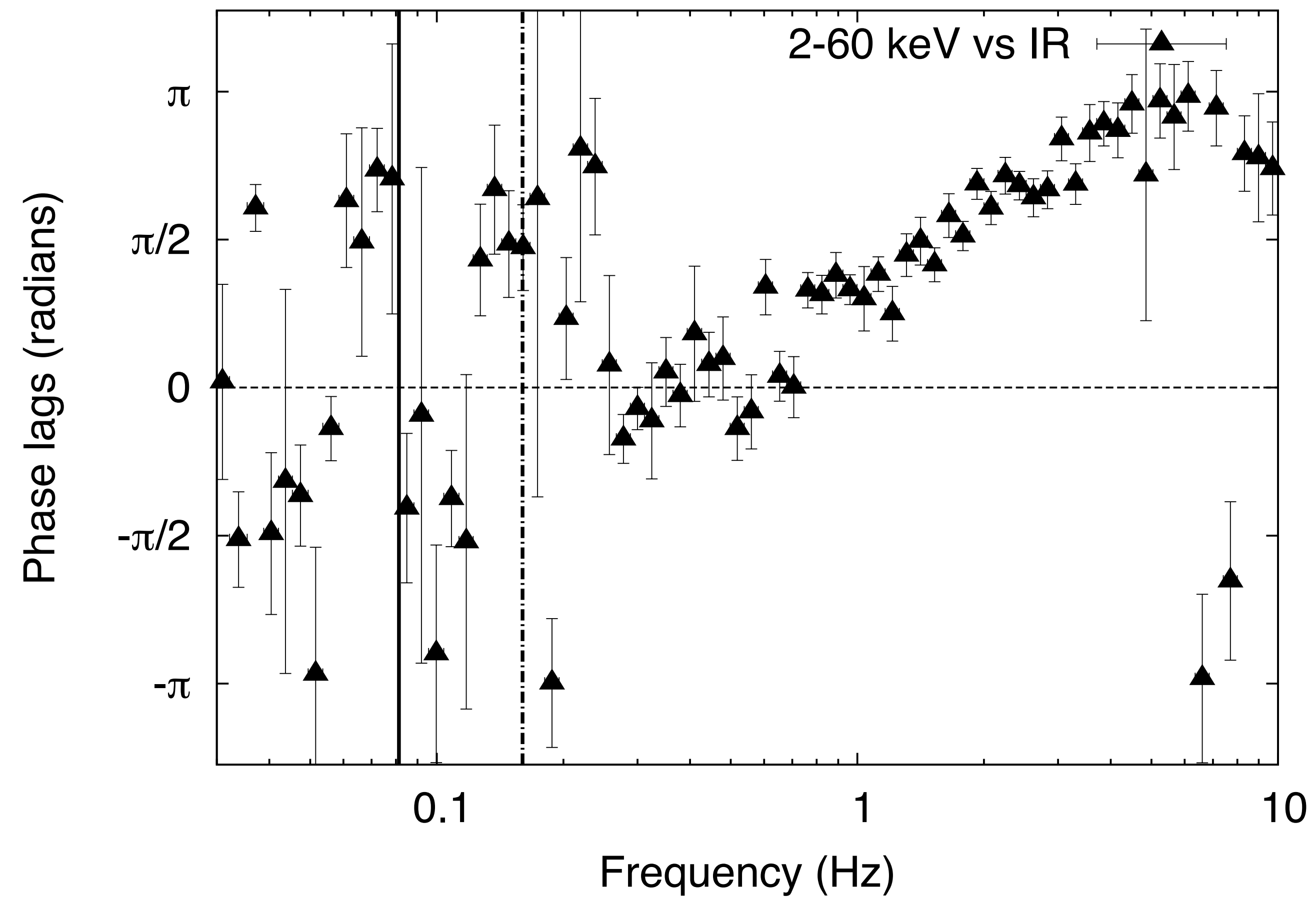


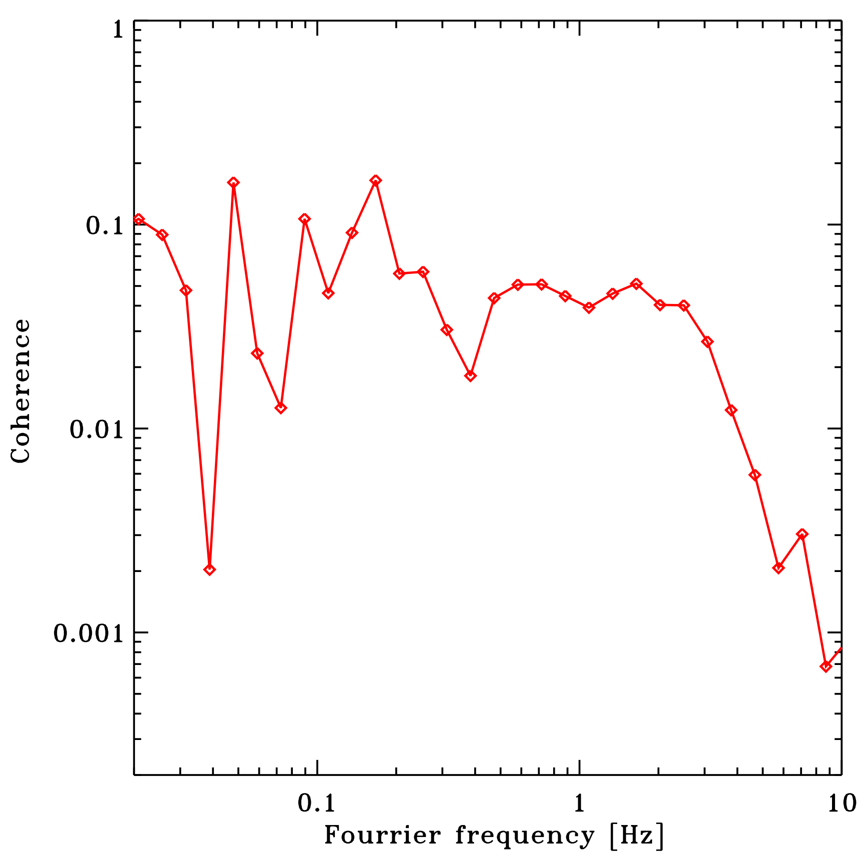
Kalamkar et al. 2015

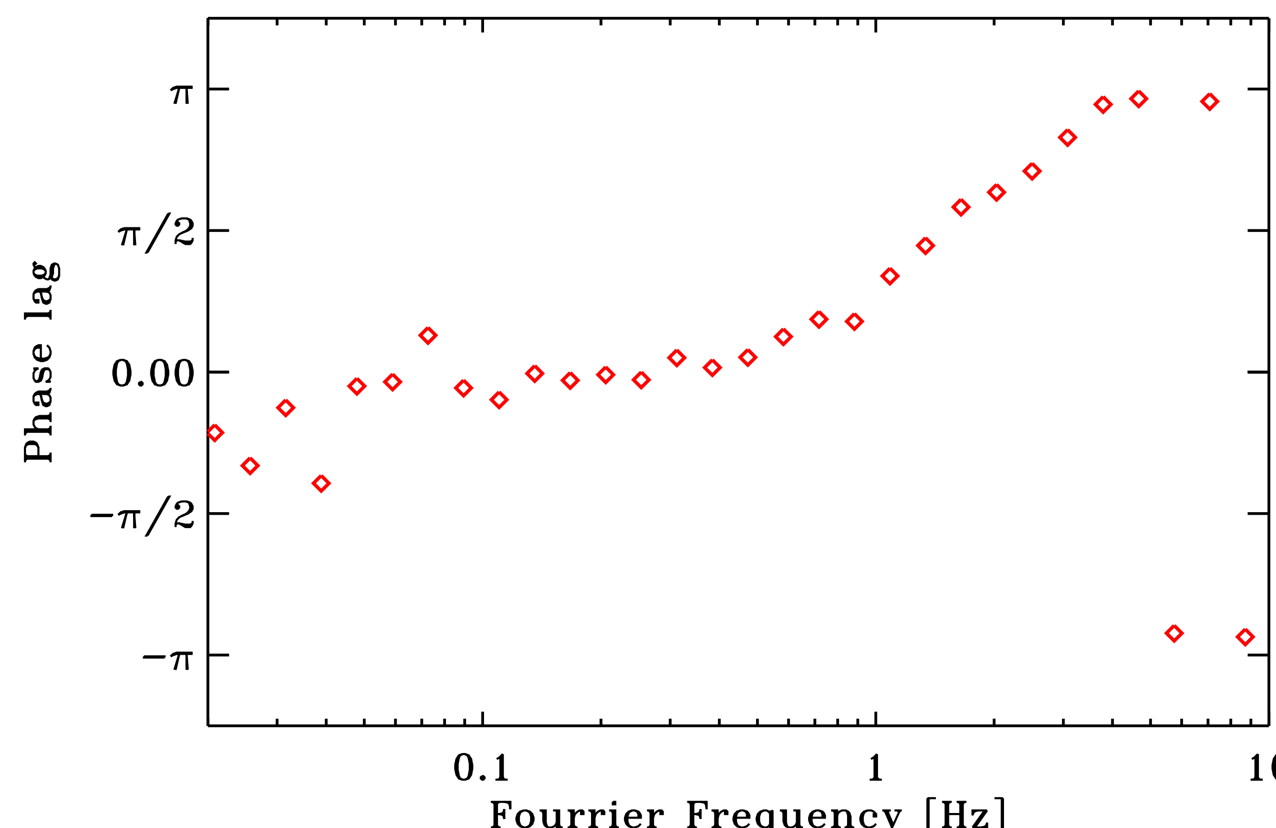
IR /X-ray correlations

Preliminary comparisons to IS model









Optical/IR QPOs from jet precession

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

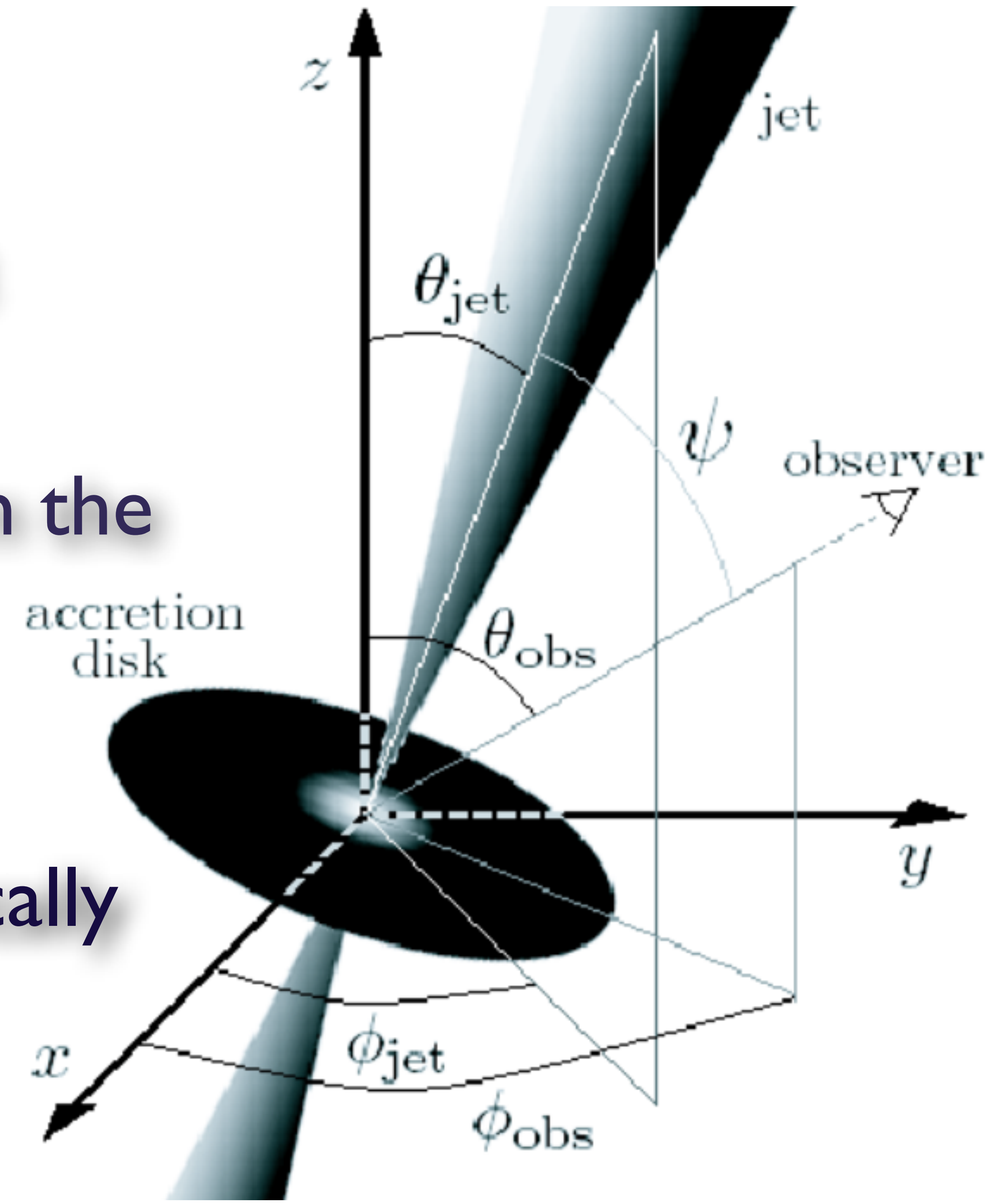
- If jet launched by the accretion flow, jet precesses with the hot flow

➡ modulation of synchrotron emission from the jet

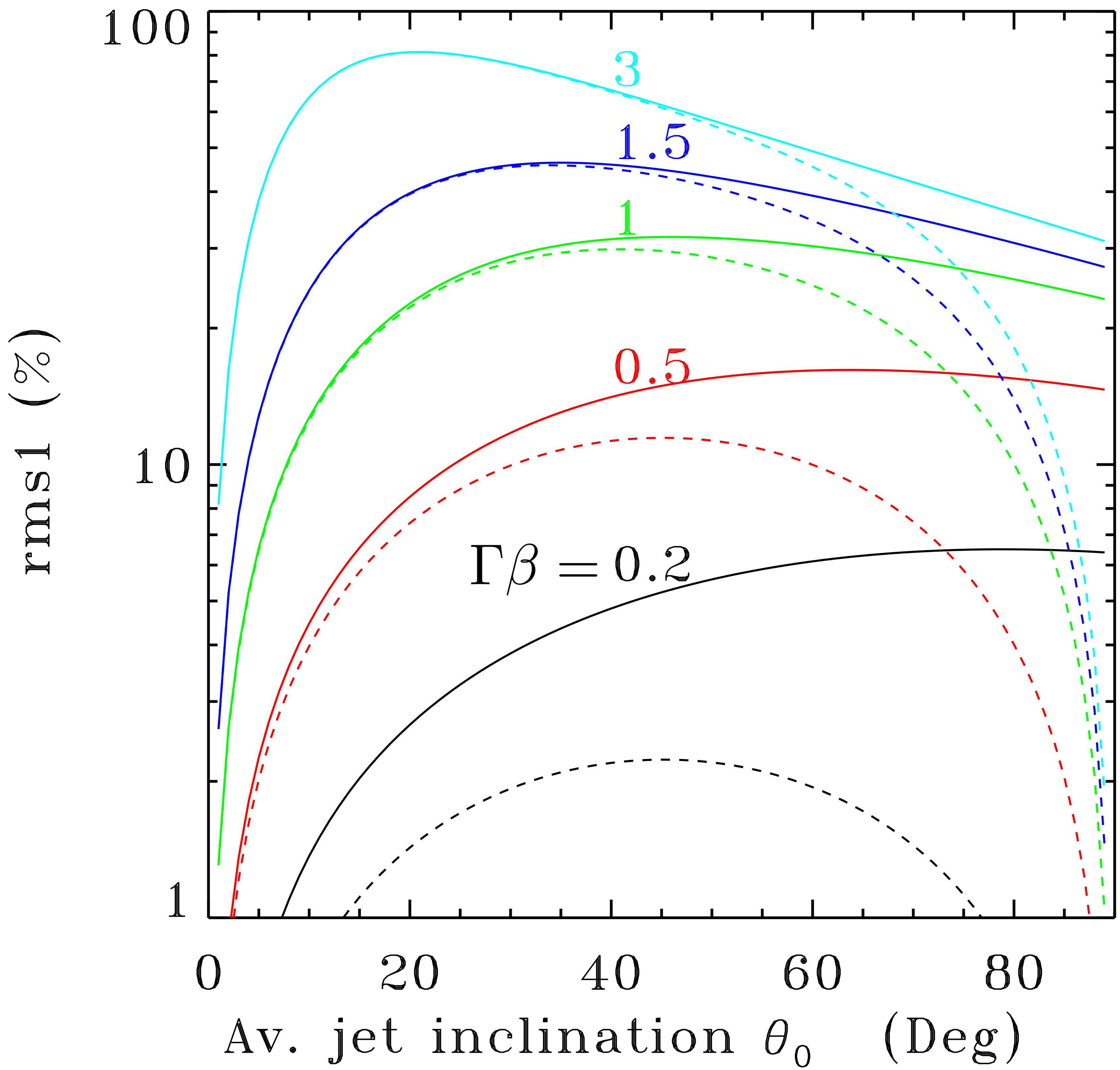
- For a relativistic jets emitting in the optically thin regime, anisotropy is dominated by relativistic Doppler boosting:

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

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

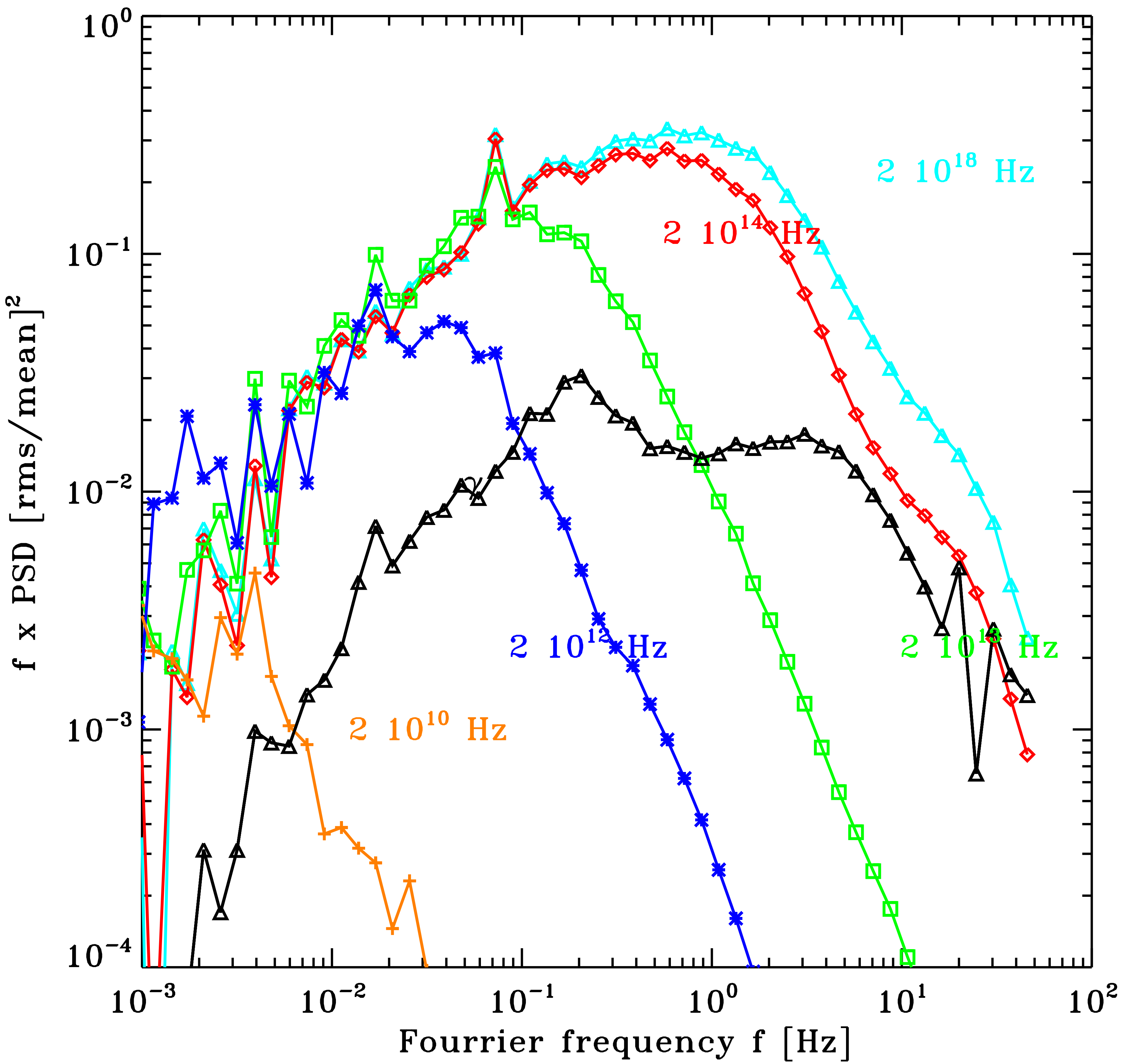


Optical/IR QPOs from jet precession



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

Optical/IR QPOs from jet precession



Conclusions

- Internal shock model predict strong, frequency dependent, variability similar to that observed.
- Possible connection between X-ray POWER spectrum
  and Radio-IR PHOTON spectrum.
- Comparisons to data suggest at least part of the IR and optical variability produced in the jet
- Opt/IR/X-ray correlations can unveil the dynamics of accretion and ejection physics.
- Need to combine accretion flow and jet models.

Thanks !