Emission of compact jets powered by internal shocks

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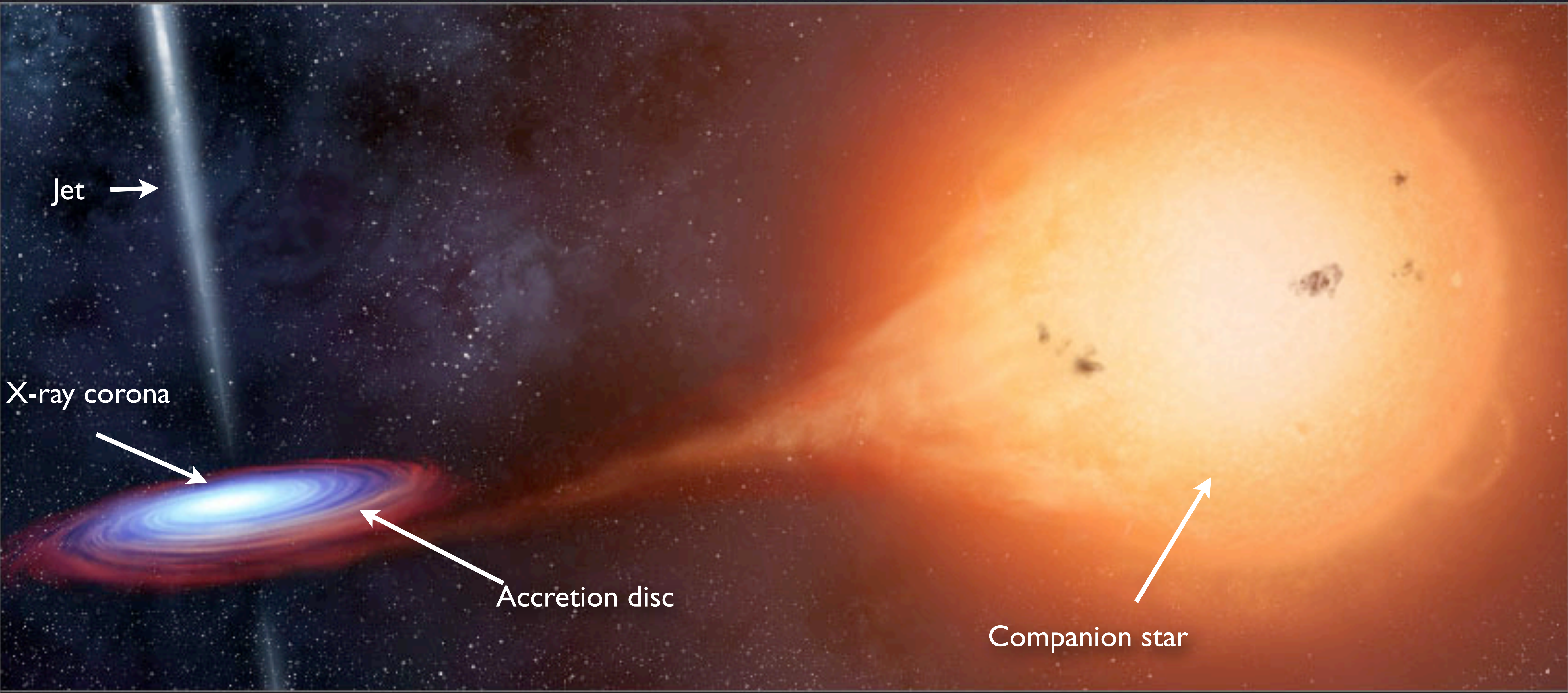
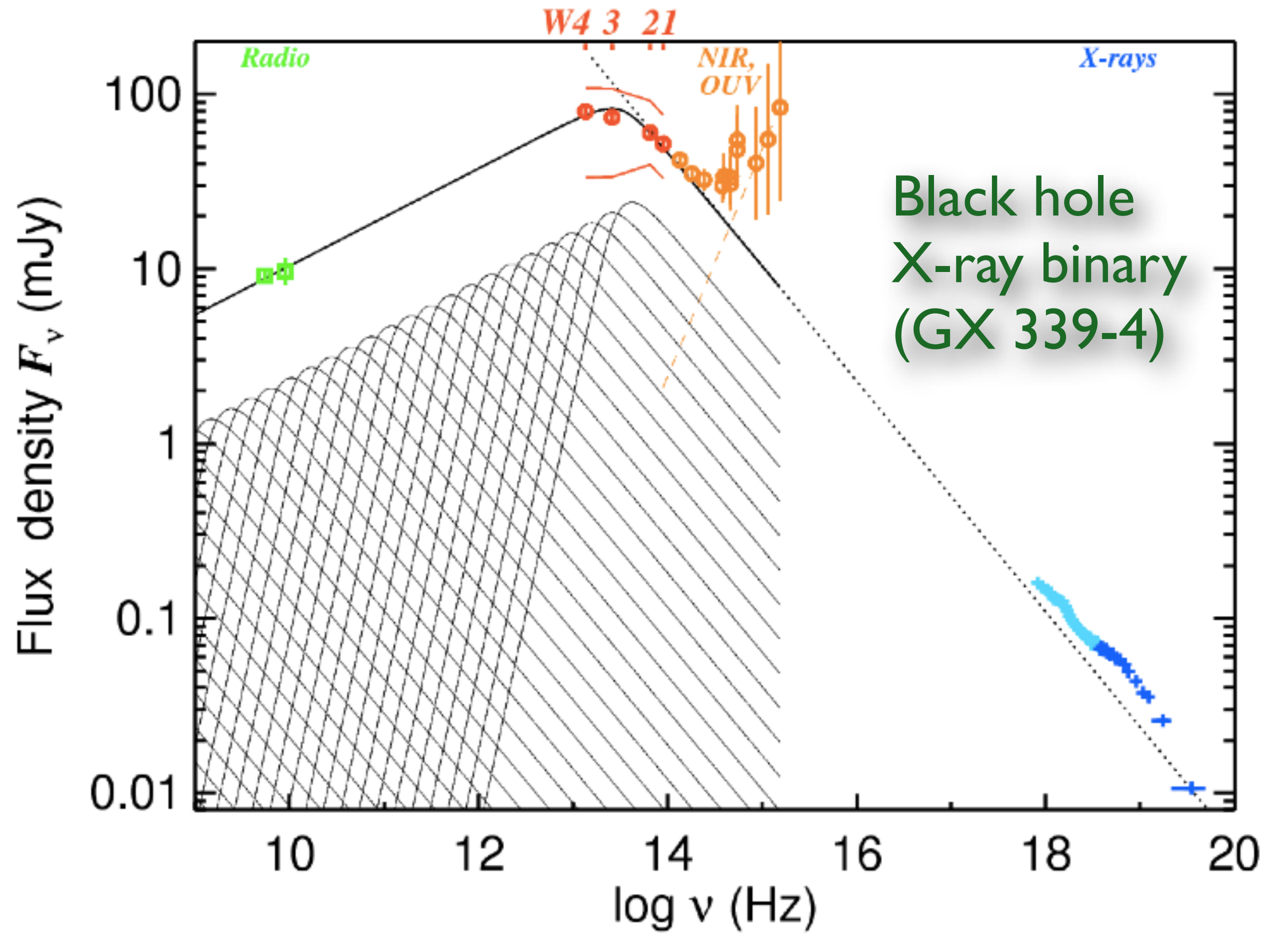
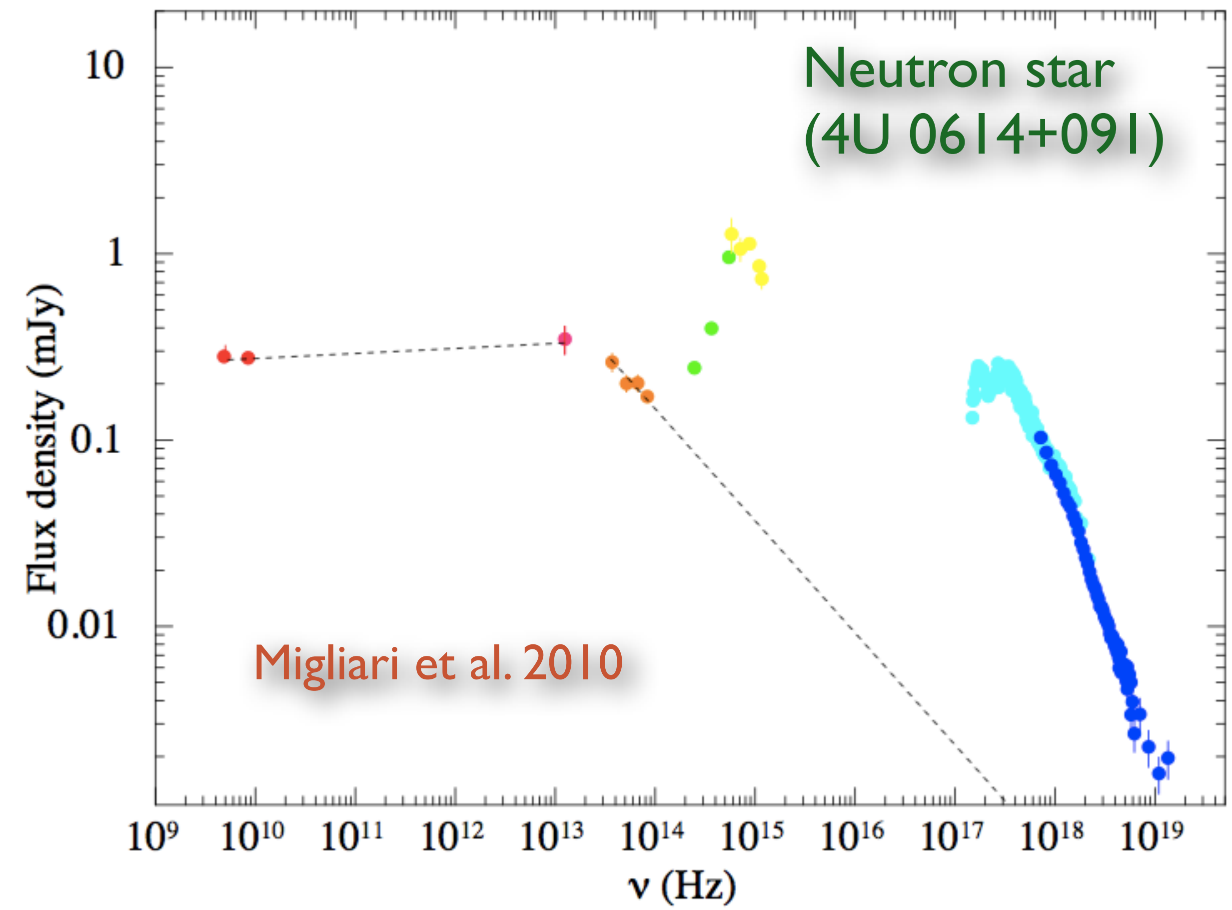


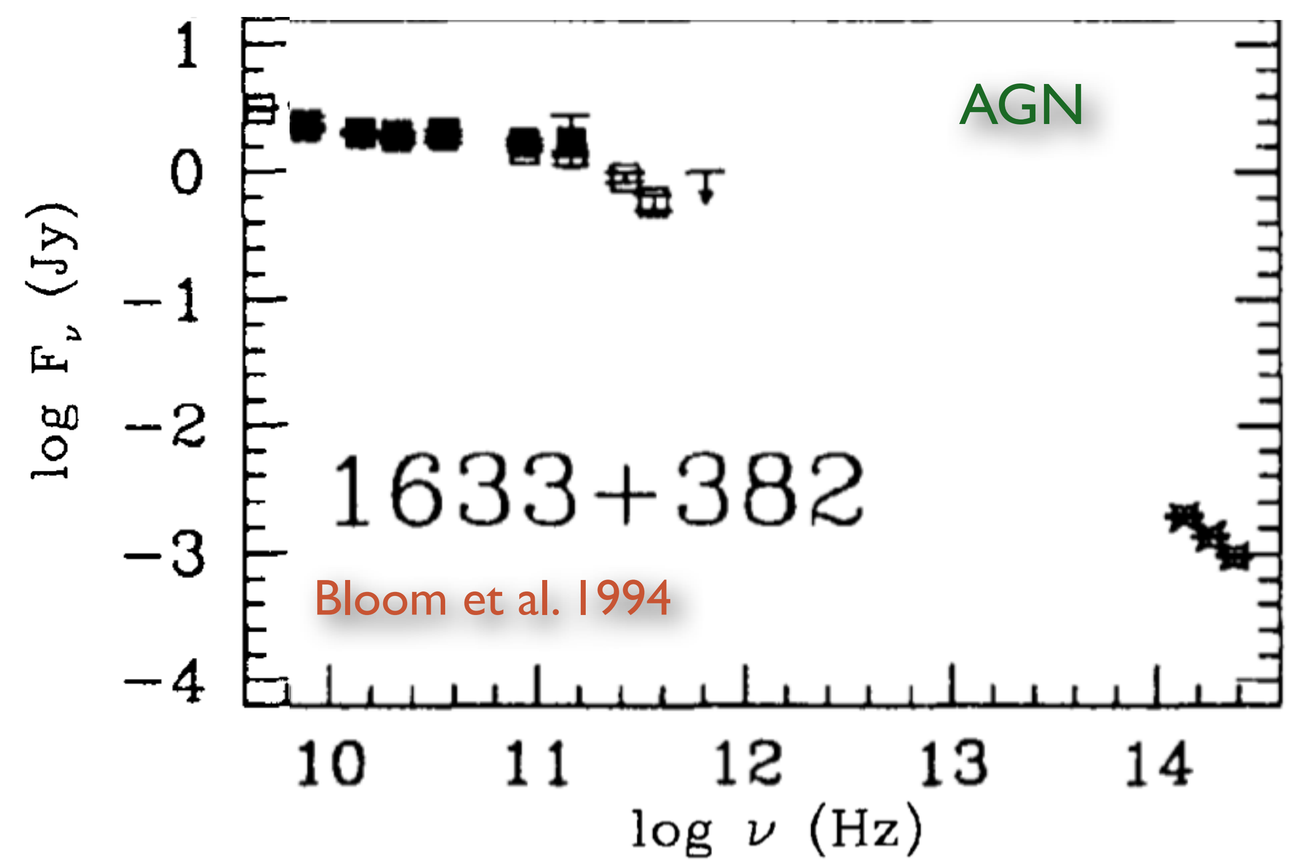
Observed Spectral Energy Distribution of Compact Jets



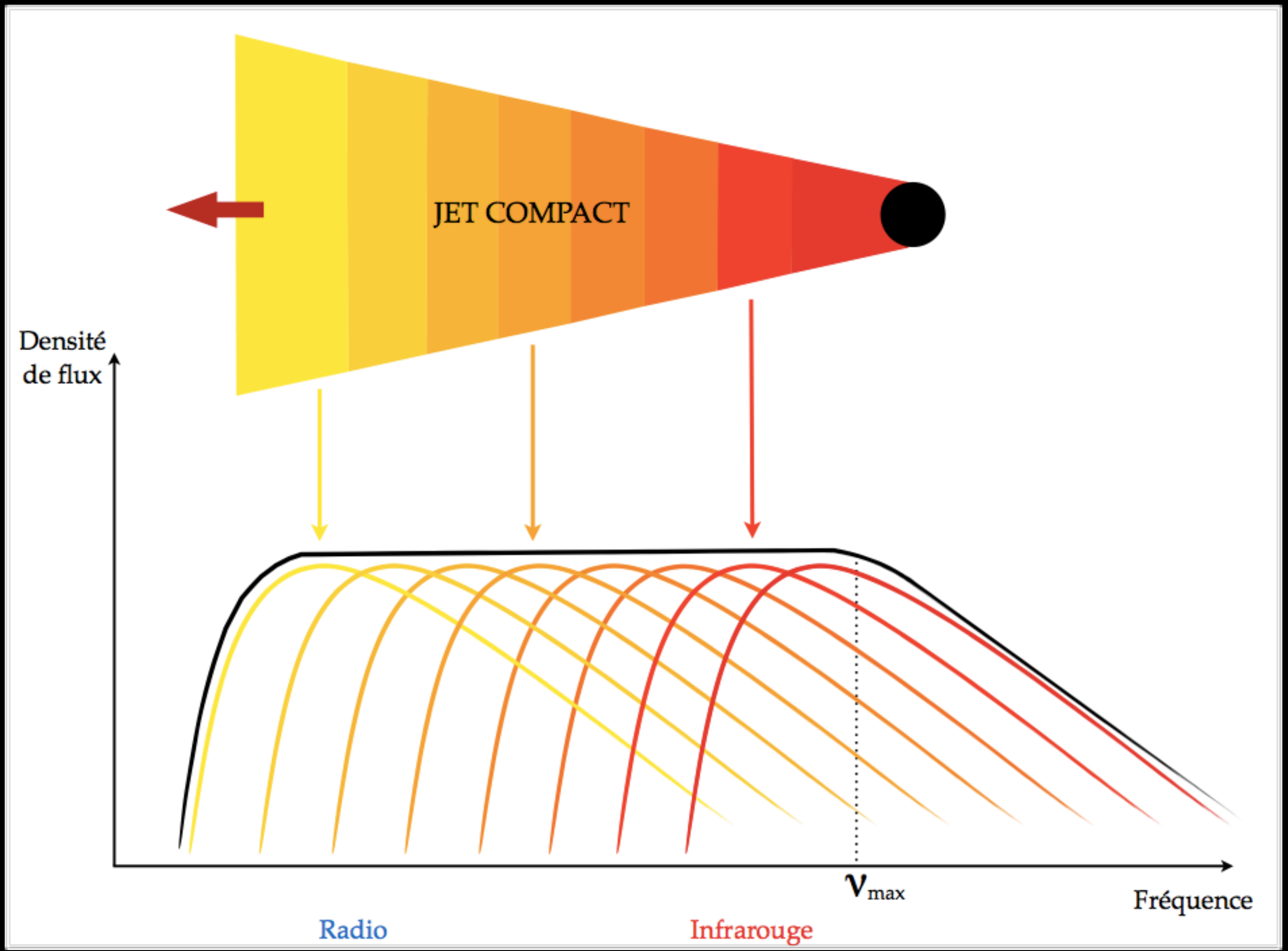
Gandhi et al. 2011

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





Standard conical jet emission model (Blandford & Koenigl 1979)



M. Coriat

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

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

Energy losses neglected:

$\Rightarrow$ constant specific internal energy:

$$\tilde{\epsilon}(z) = \tilde{\epsilon}_0$$

$$B^2 \propto n \propto E_{\rm int} \propto V^{-1} \propto r^{-2}$$

$$F_\nu \propto \nu^\alpha \;\Rightarrow\; \alpha_{\rm thick} = 0$$

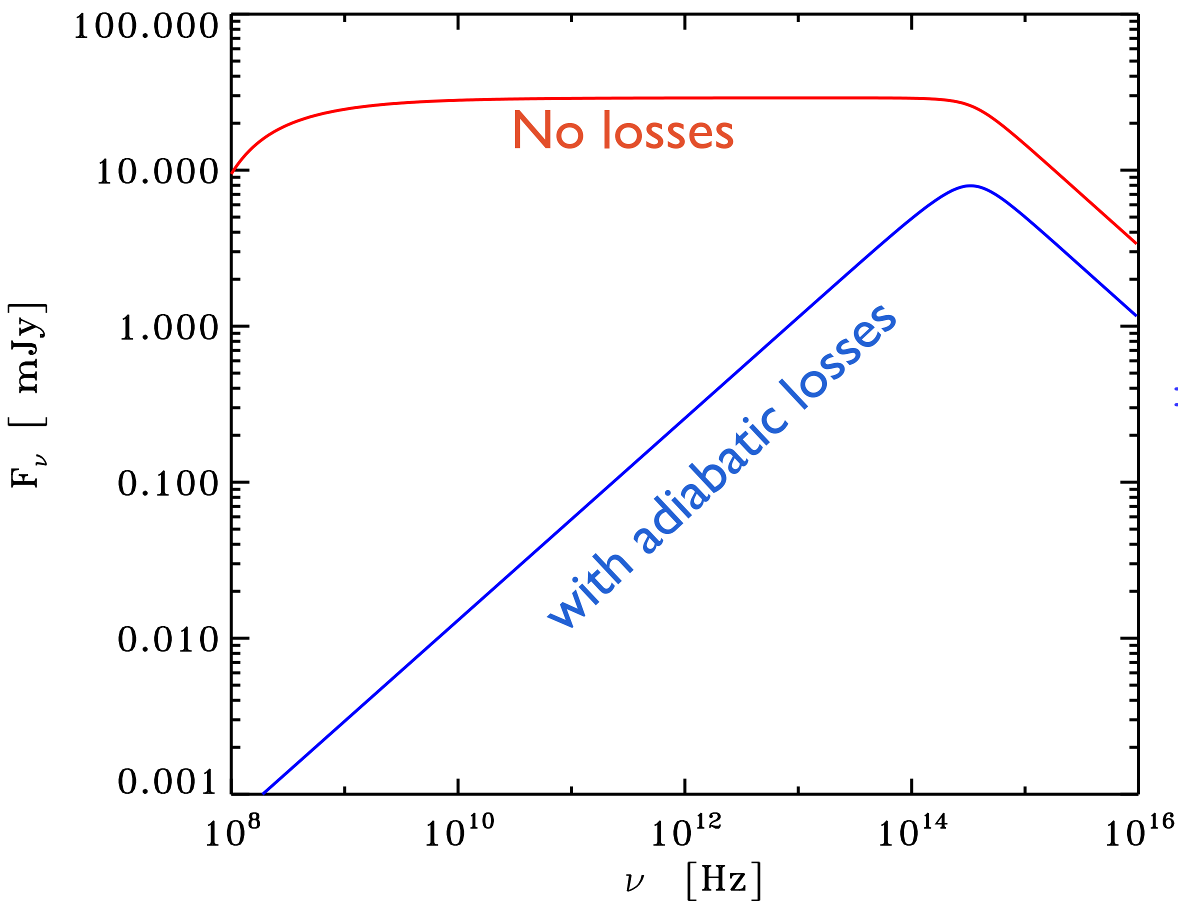
$$\alpha_{\rm thin} = \frac{1-p}{2}$$

What about adiabatic expansion losses ?

Pressure work against external medium as flow expands in conical geometry

$$d\tilde{W} = Pd\tilde{V} = (\gamma_a - 1)m\tilde{\epsilon}\frac{d\tilde{V}}{\tilde{V}} \simeq \frac{2m\tilde{\epsilon}}{3}\frac{dR}{R}$$

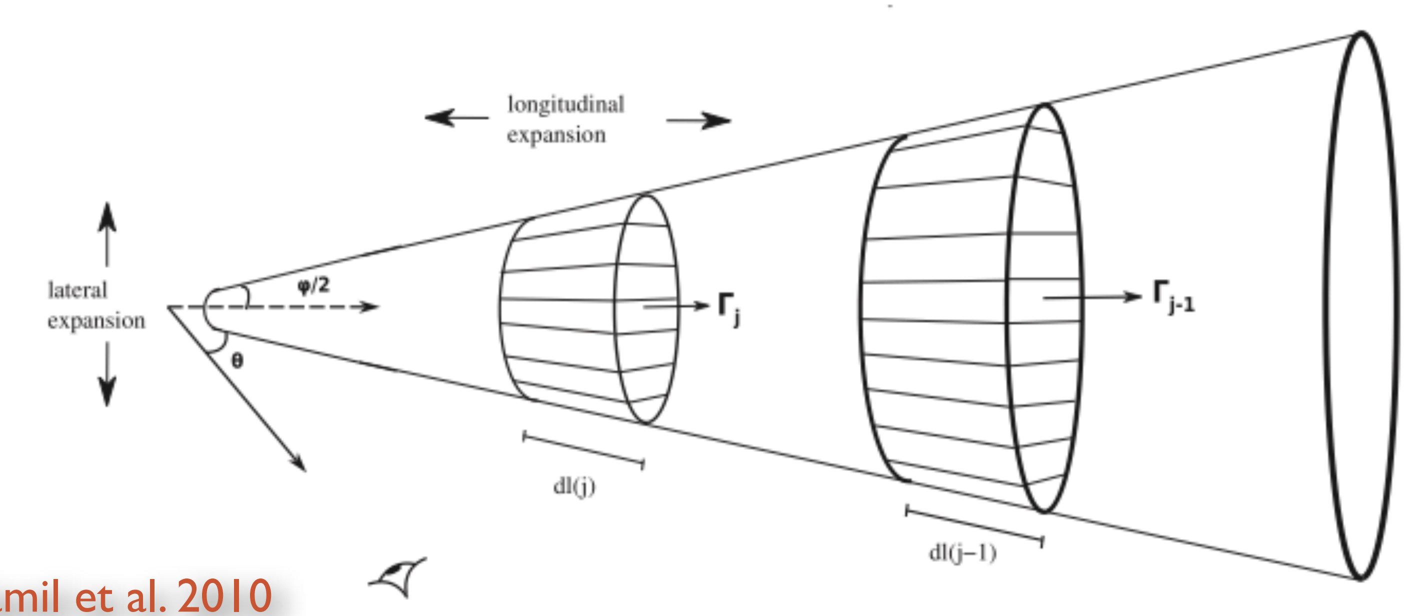
$\Rightarrow$ Specific internal energy decreases: $\tilde{\epsilon} \propto R^{-2/3}$



$$\Rightarrow \alpha_{\rm thick} = \frac{2p+13}{4p+18} \simeq 0.65$$

Spectrum is strongly inverted : need to compensate for losses

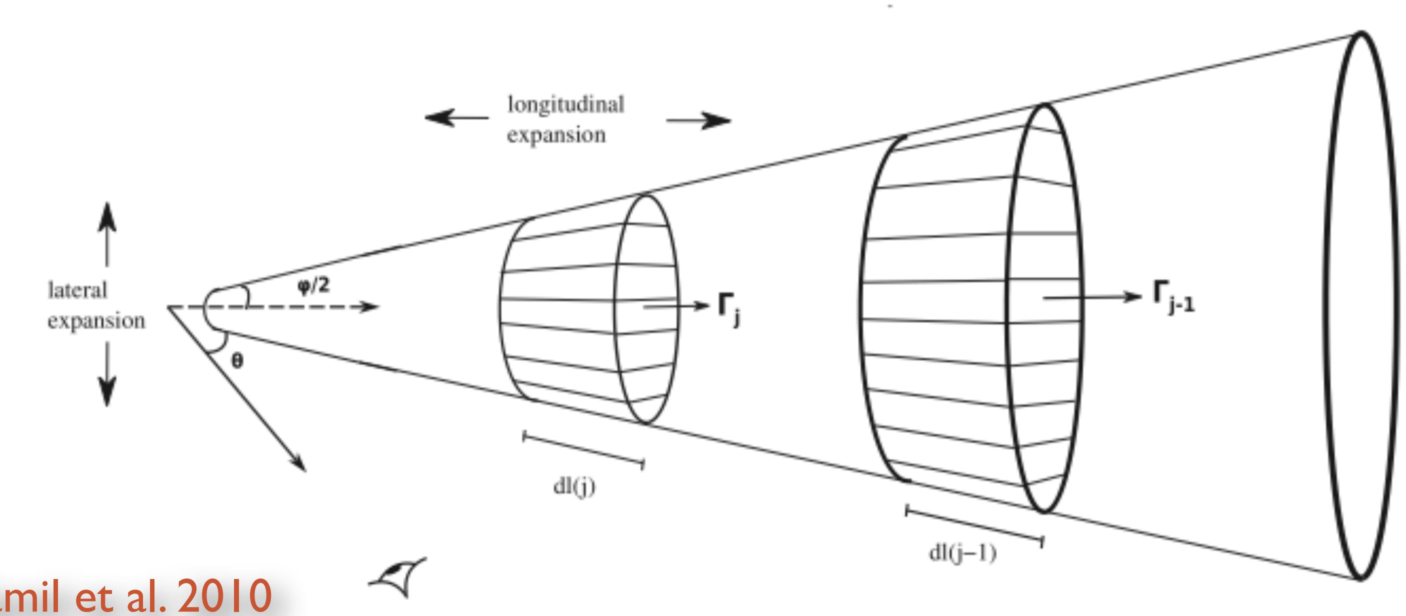
Internal shock model



Jamil et al. 2010

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

Internal shock model



Jamil et al. 2010

- Jet= ‘shells‘ ejected a time intervals ~ t_{dyn} with randomly variable velocities
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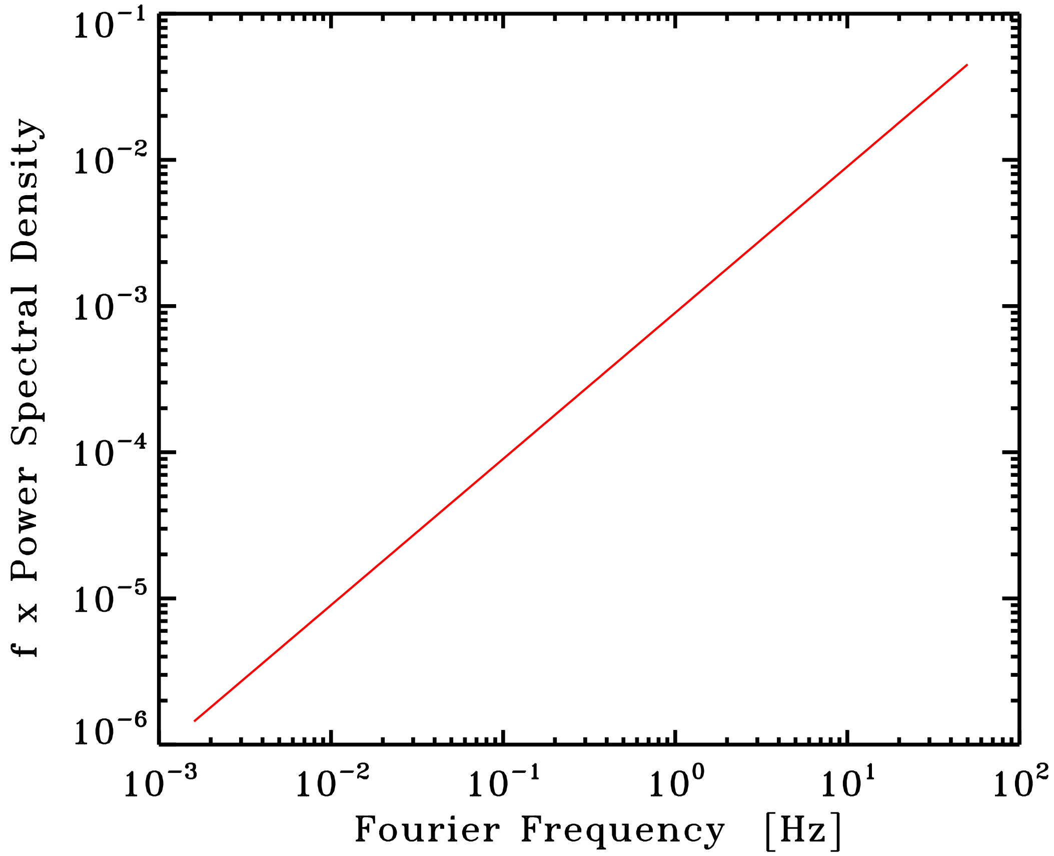
- Velocity fluctuations of smaller amplitudes and longer time-scales merge (and dissipate) at larger distances

- Aim: study how results depend on the properties of Fourier PSD of fluctuations

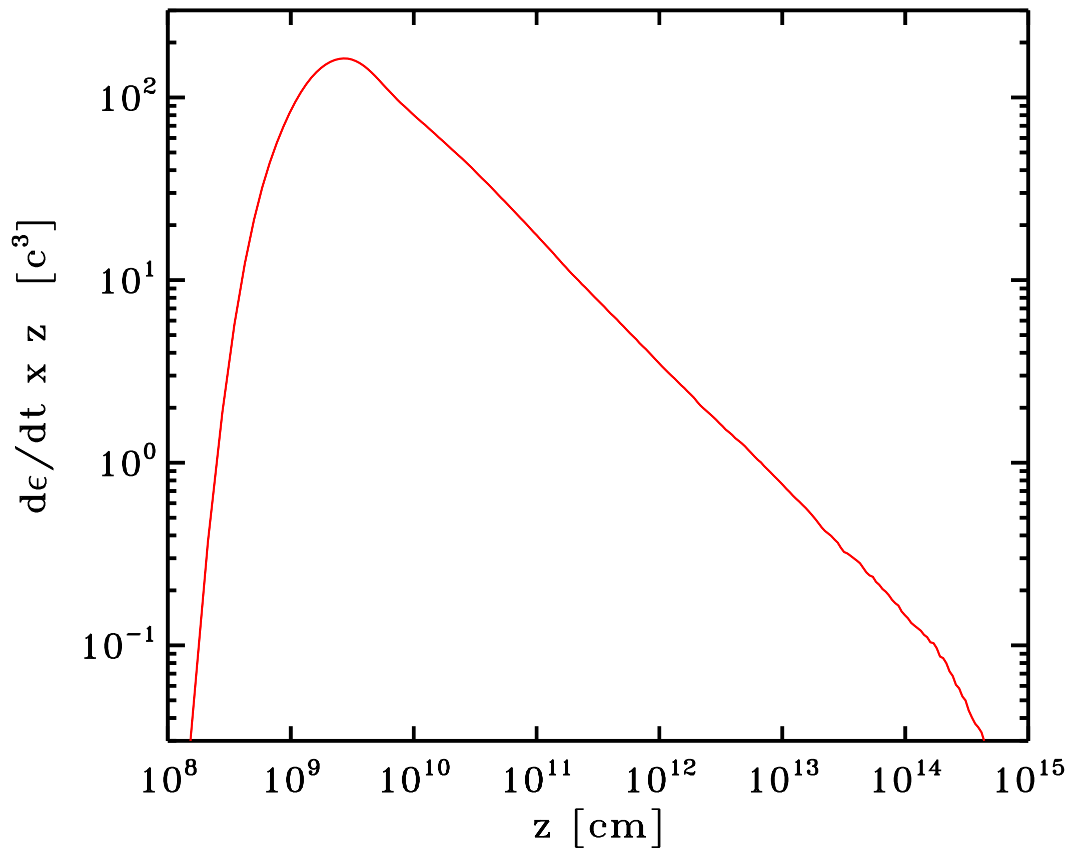
- Combining two approaches:
  - Monte-Carlo simulations
  - Analytical/Semi-analytical model

Response to white noise fluctuations

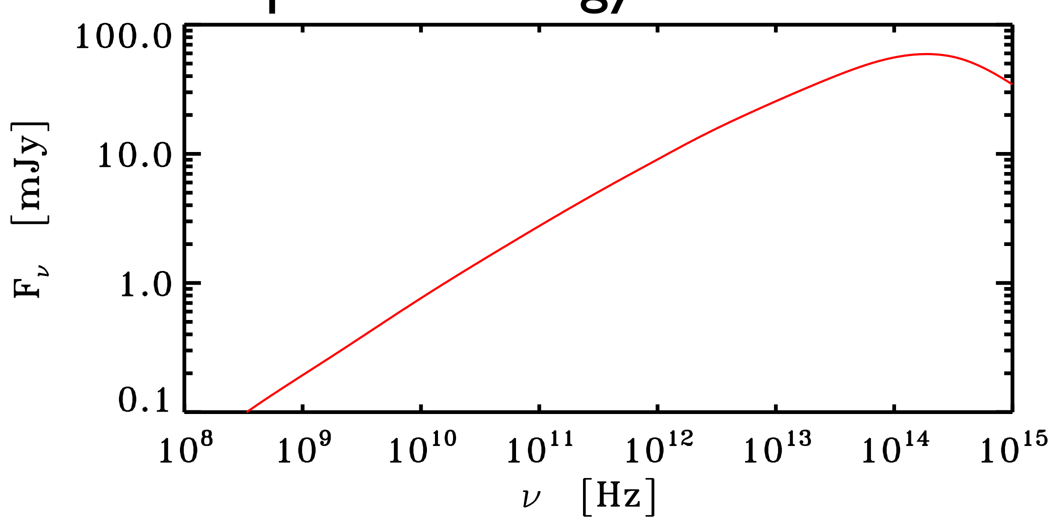
PSD of Lorentz factor fluctuations



Dissipation profile

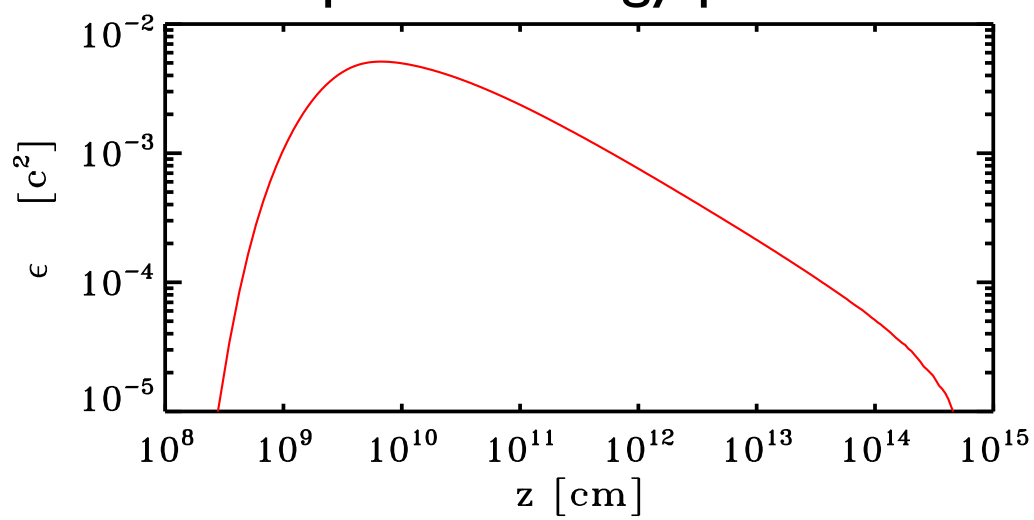


Spectral energy distribution



$$\Rightarrow \alpha_{\rm thick} = \frac{2p+13}{4p+18} \sim 0.65$$

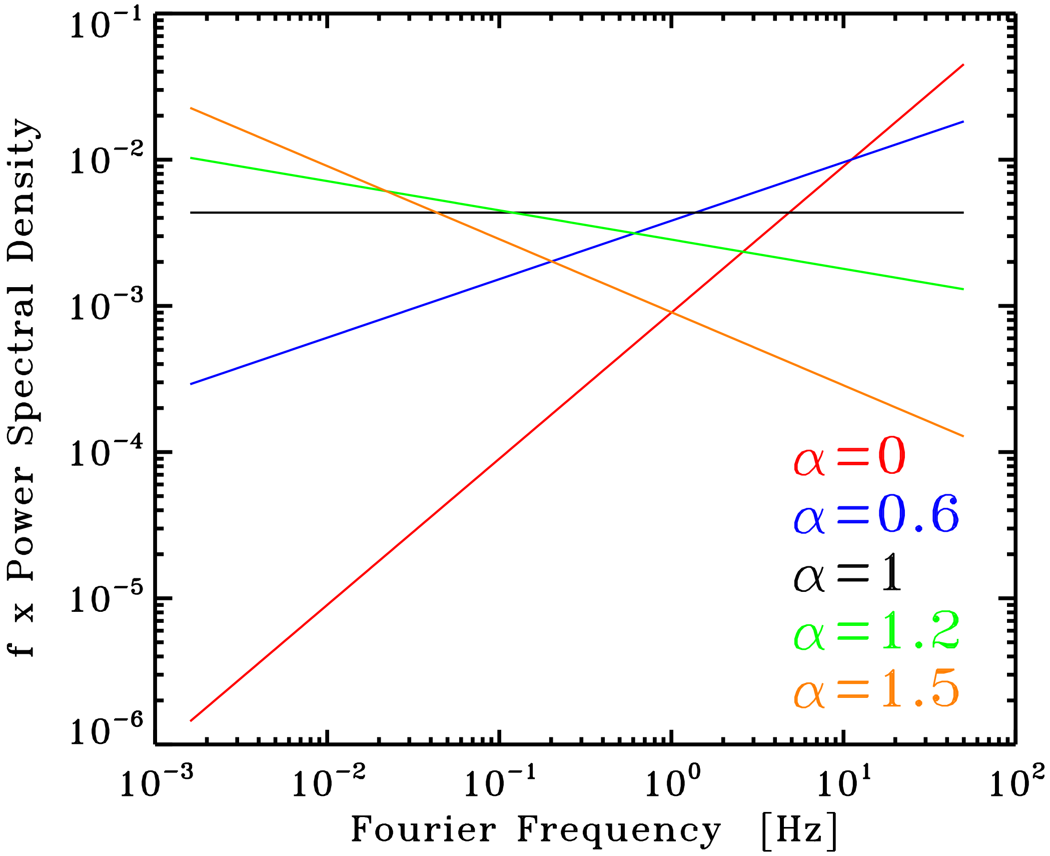
Specific energy profile



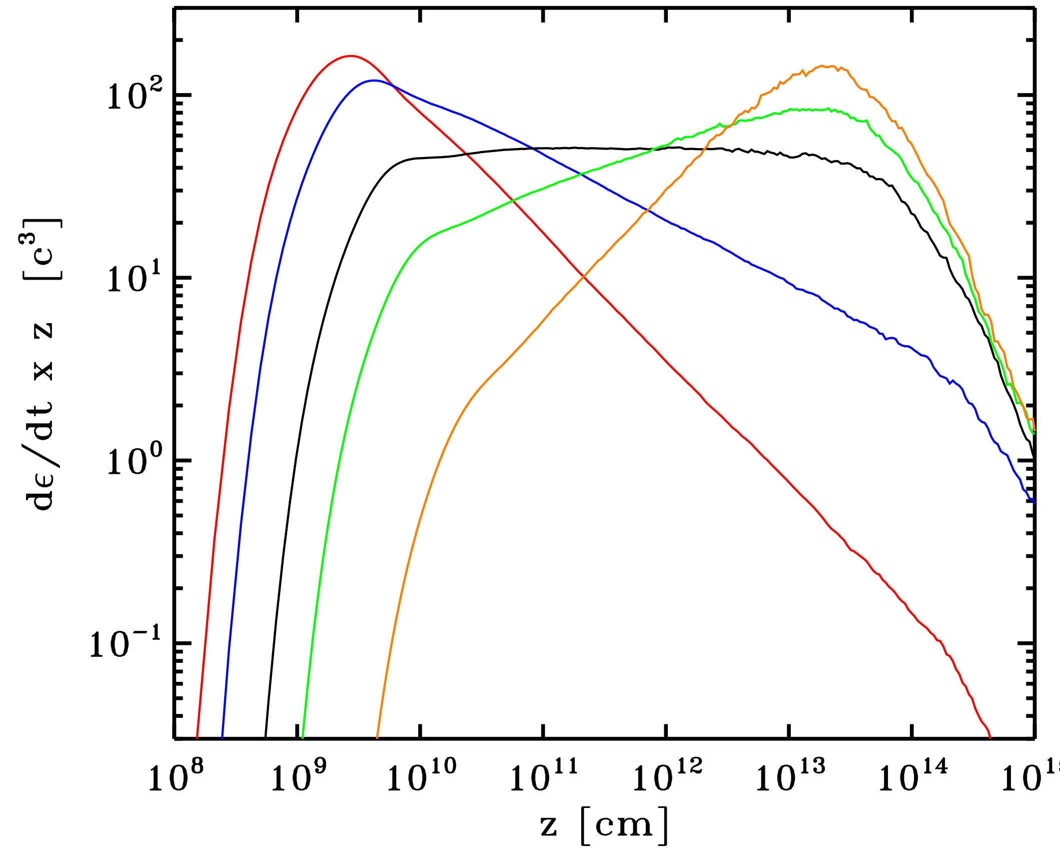
$$\tilde{\epsilon} \propto z^{-2/3}$$

$$P(f) \propto f^{-\alpha}$$

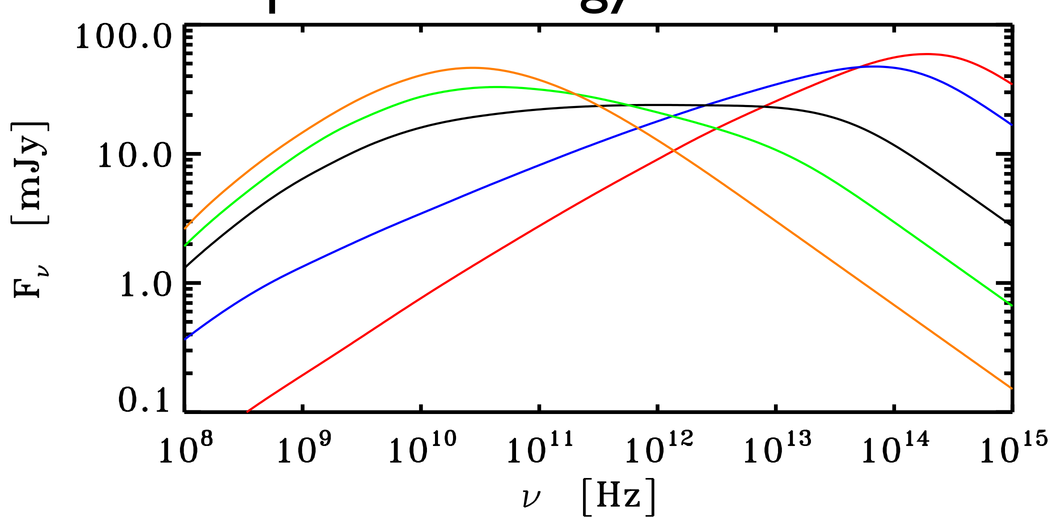
PSD of Lorentz factor fluctuations



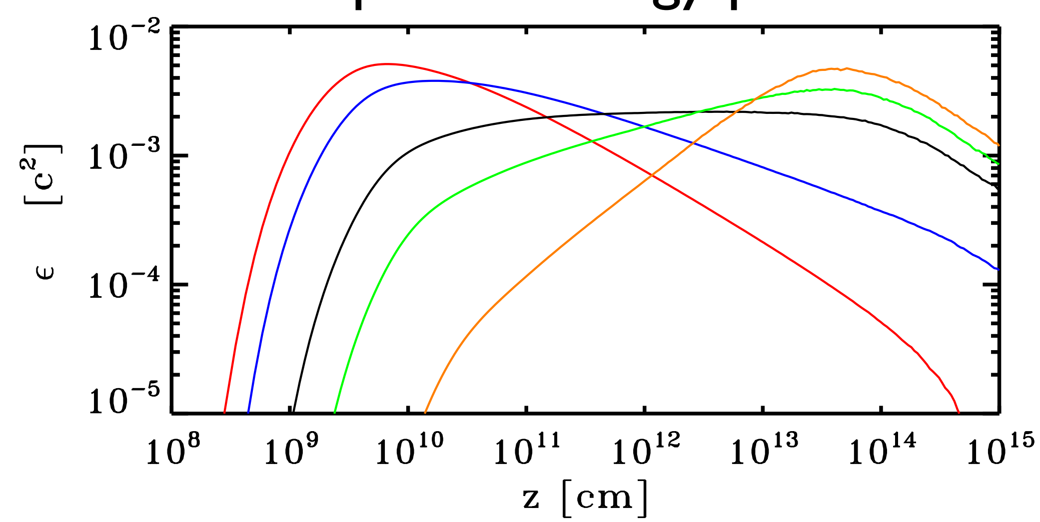
Dissipation profile



Spectral energy distribution



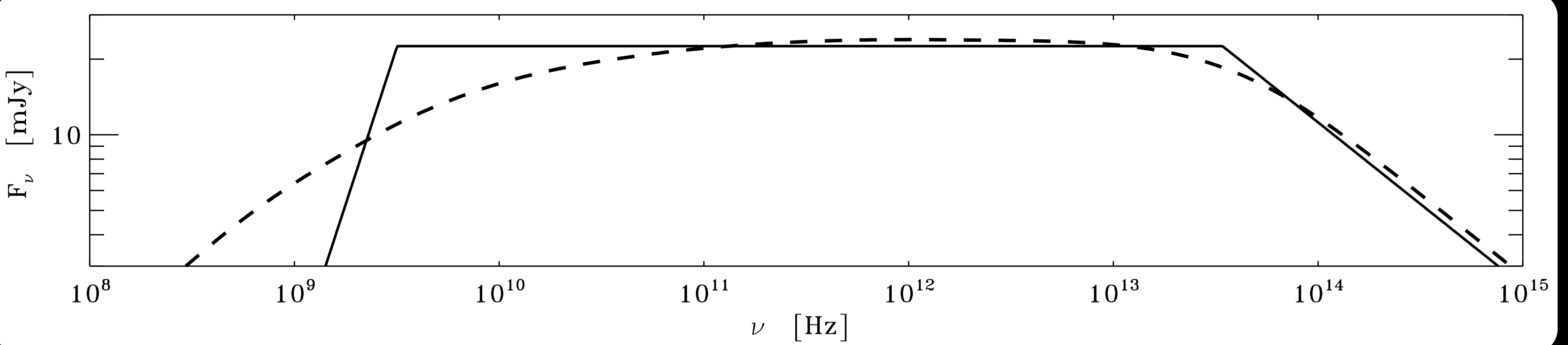
Specific energy profile



$$\Rightarrow \alpha_{\rm thick} = \frac{(2p+13)(1-\alpha)}{4p+18-\alpha(10+2p)}$$

$$\tilde{\epsilon} \propto z^{-\frac{2(1-\alpha)}{3-\alpha}}$$

Application to black hole binaries



$P(f) \propto 1/f \quad \text{for} \quad 10^{-3} < f < 50 \quad \text{Hz} \qquad \text{rms} = 30\%$

$P_{kin} = 0.01 L_{\rm E}$, $\Gamma = 2$, $\phi_j = 1^o$, + equipartition

Malzac 2013

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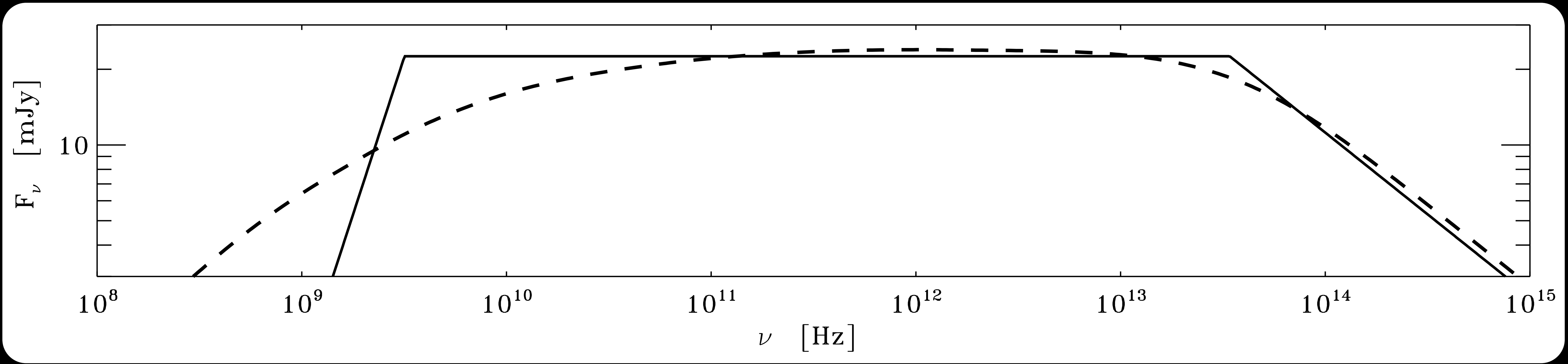


$P(f) \propto 1/f$ for $10^{-3} < f < 50$ Hz   rms $= 30\%$

$P_{kin} = 0.01 L_{\rm E}$, $\Gamma = 2$, $\phi_j = 1^o$, + equipartition

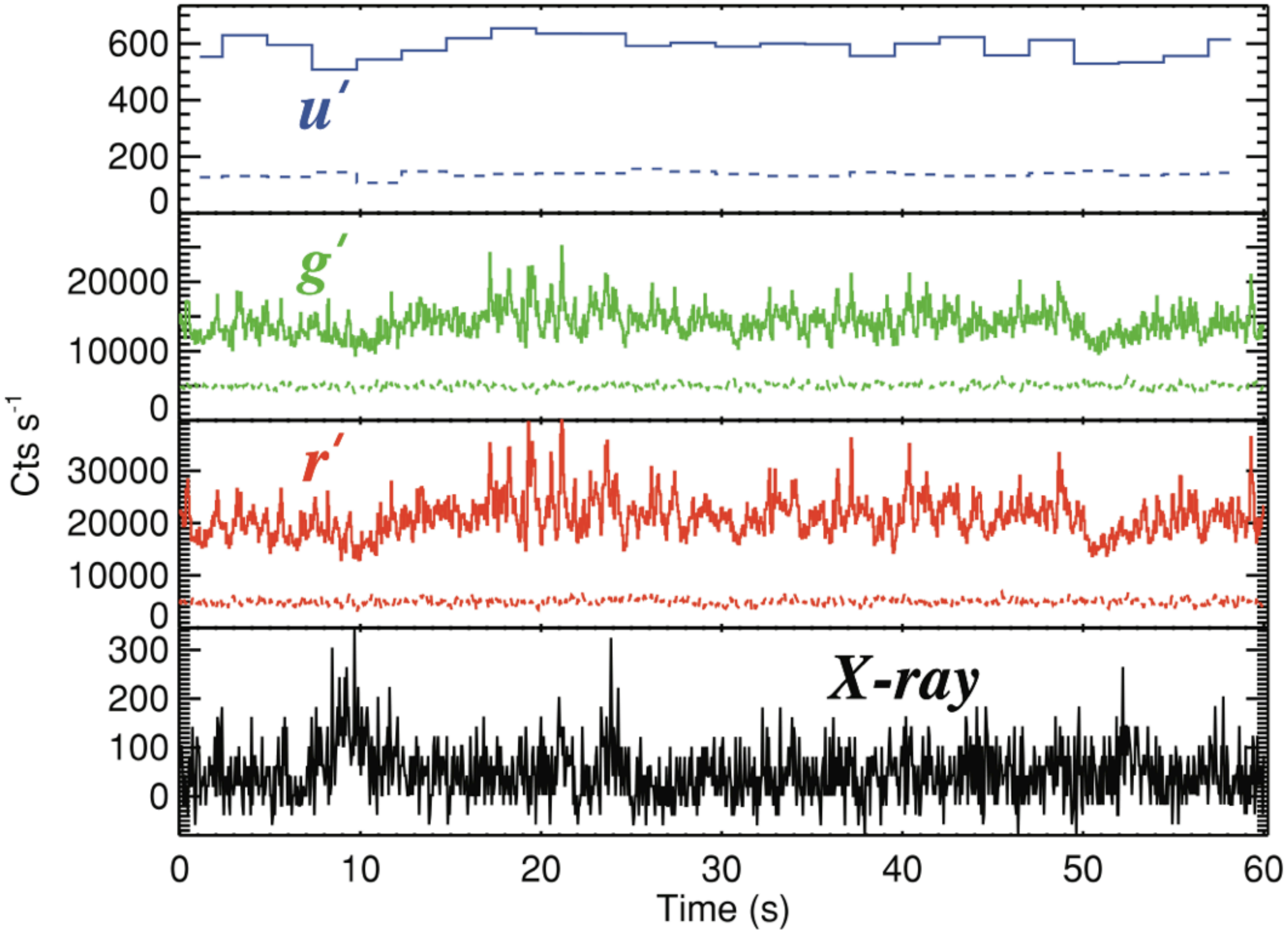
- Base of emitting region: $z_0 \sim 10^{10}\,\mathrm{cm}$
- Magnetic field at base: $B_0 \sim 10^4$ G
- Flux of flat component: $F_{v0} \simeq 84 \frac{\delta^2}{D^2_{\rm kpc}}$ mJ
- High frequency break: $\nu_T \simeq 2 \times 10^{13}\,\mathrm{Hz}$
- Low frequency break: $\nu_s \simeq 1\,\mathrm{GHz}$

Malzac 2013

Fast Jet Variability

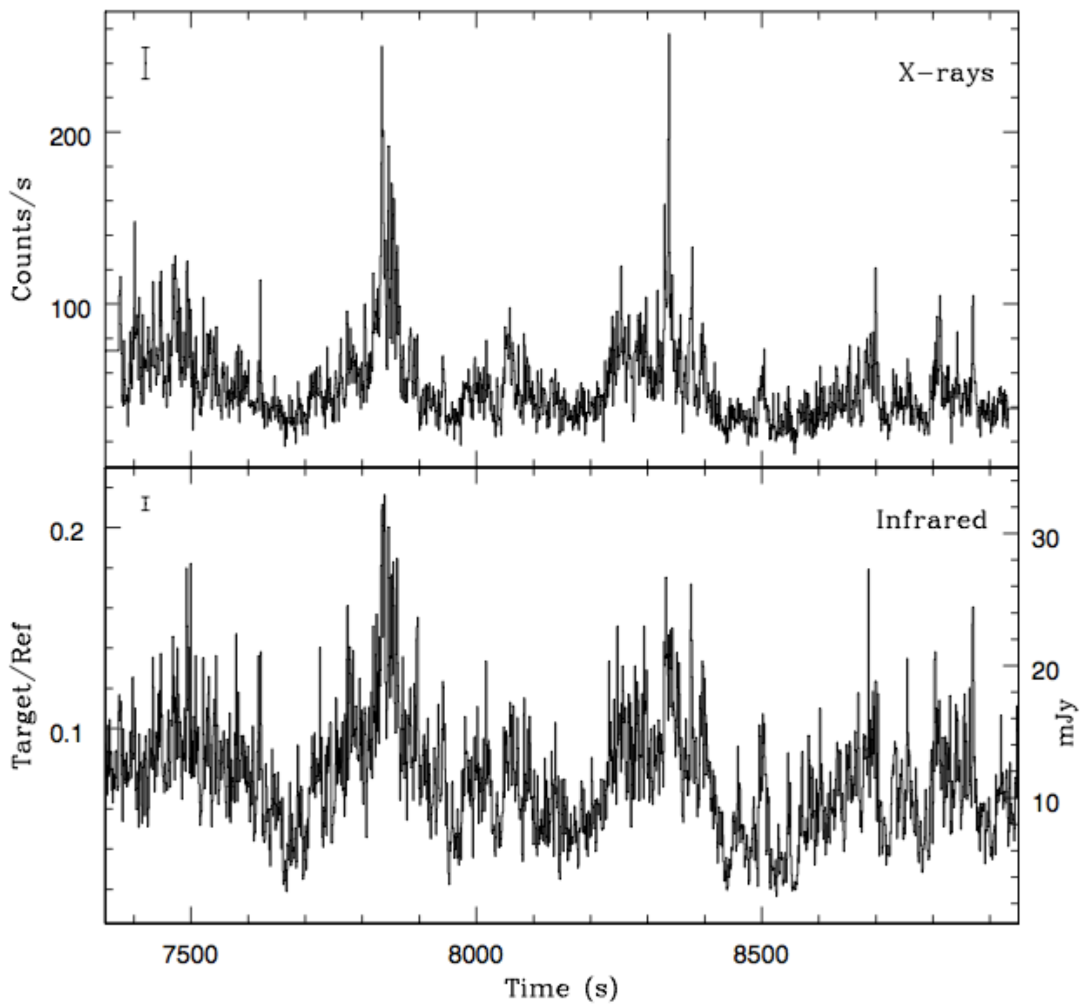
Observations of GX 339-4

Optical



Gandhi et al. 2010

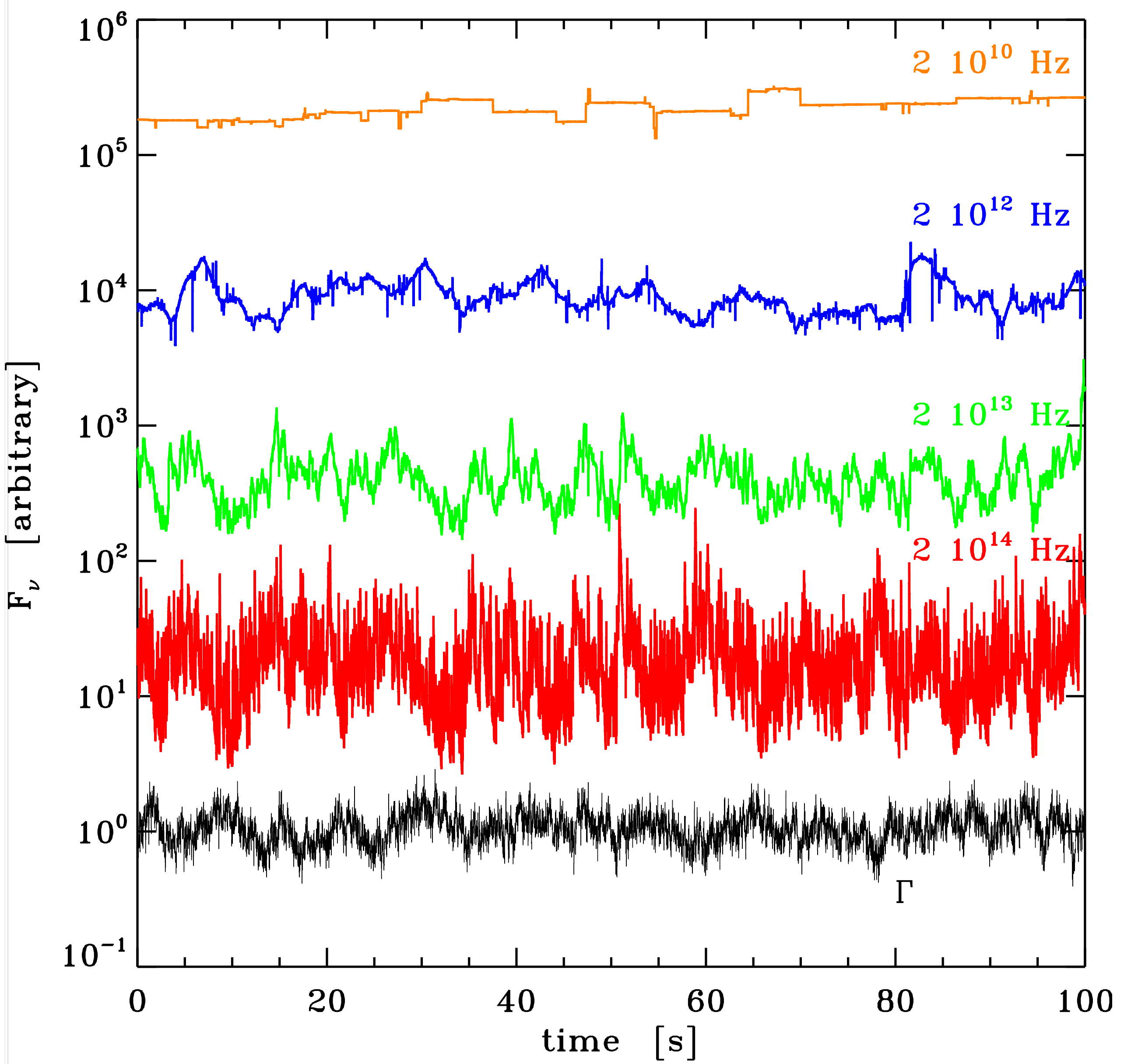
Infrared

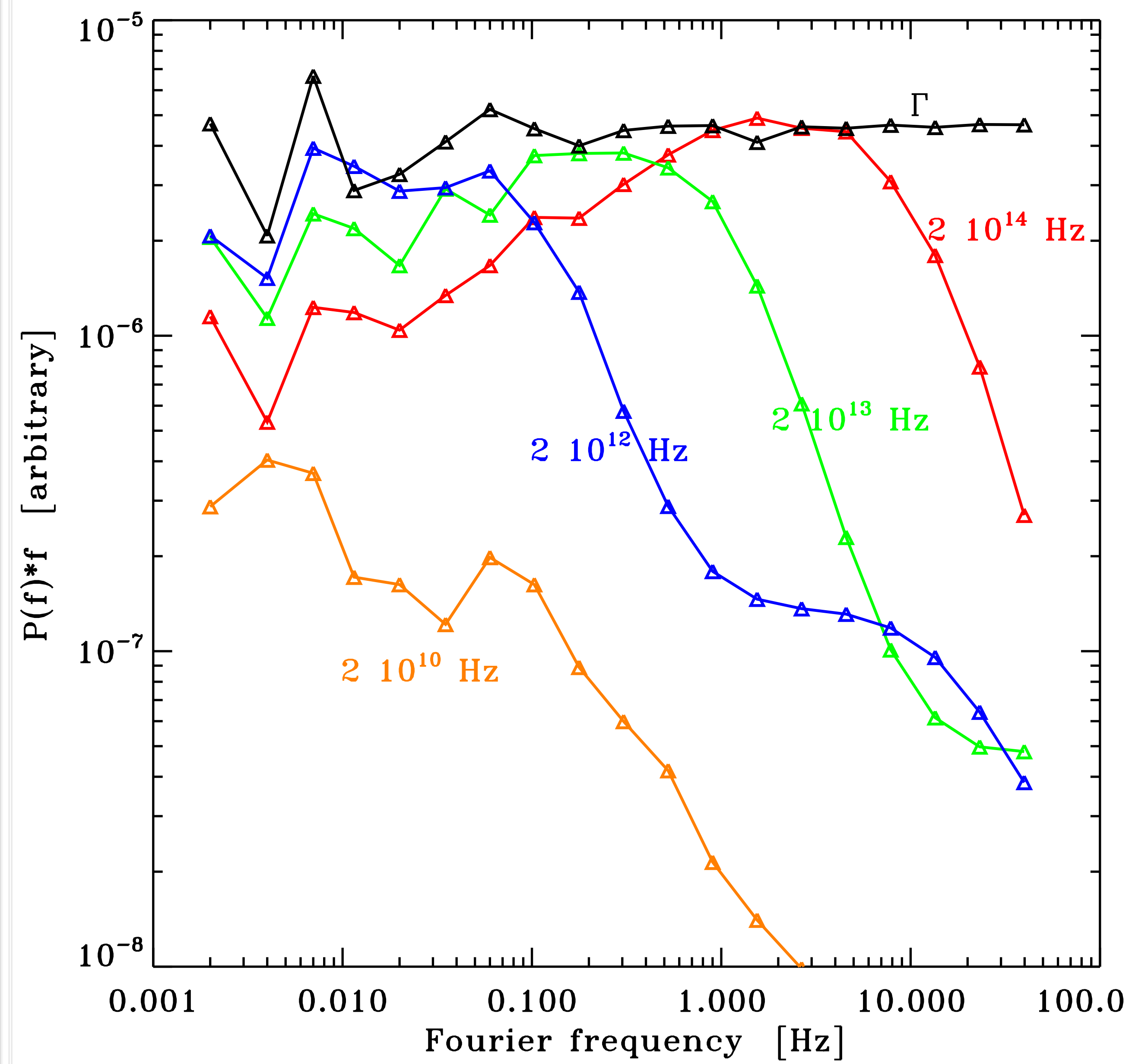


Casella et al. 2010

Fast Jet Variability

Model

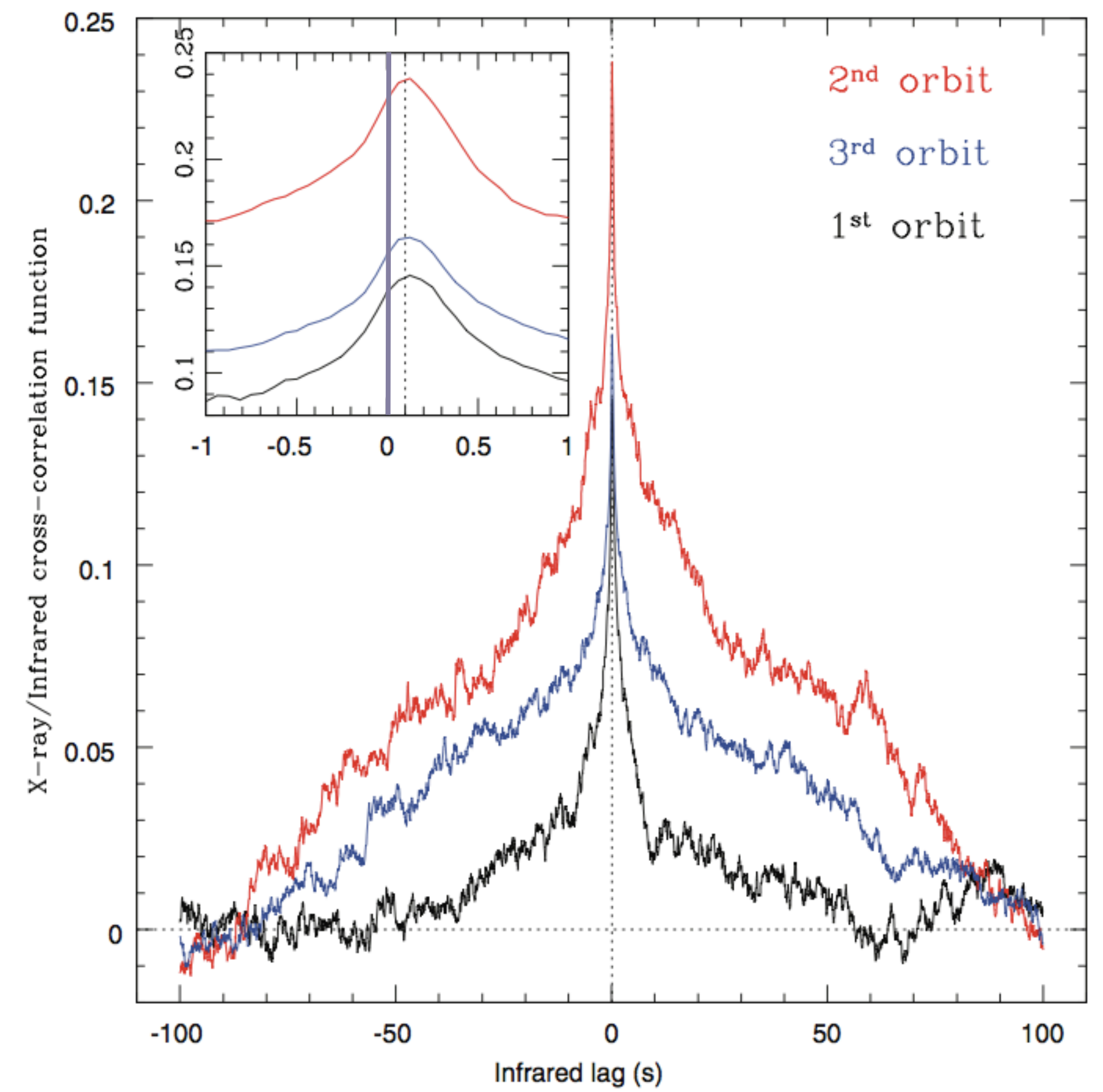




Malzac et al. in prep.

IR /X-ray correlation

Observations



GX 339-4

Casella et al. 2010

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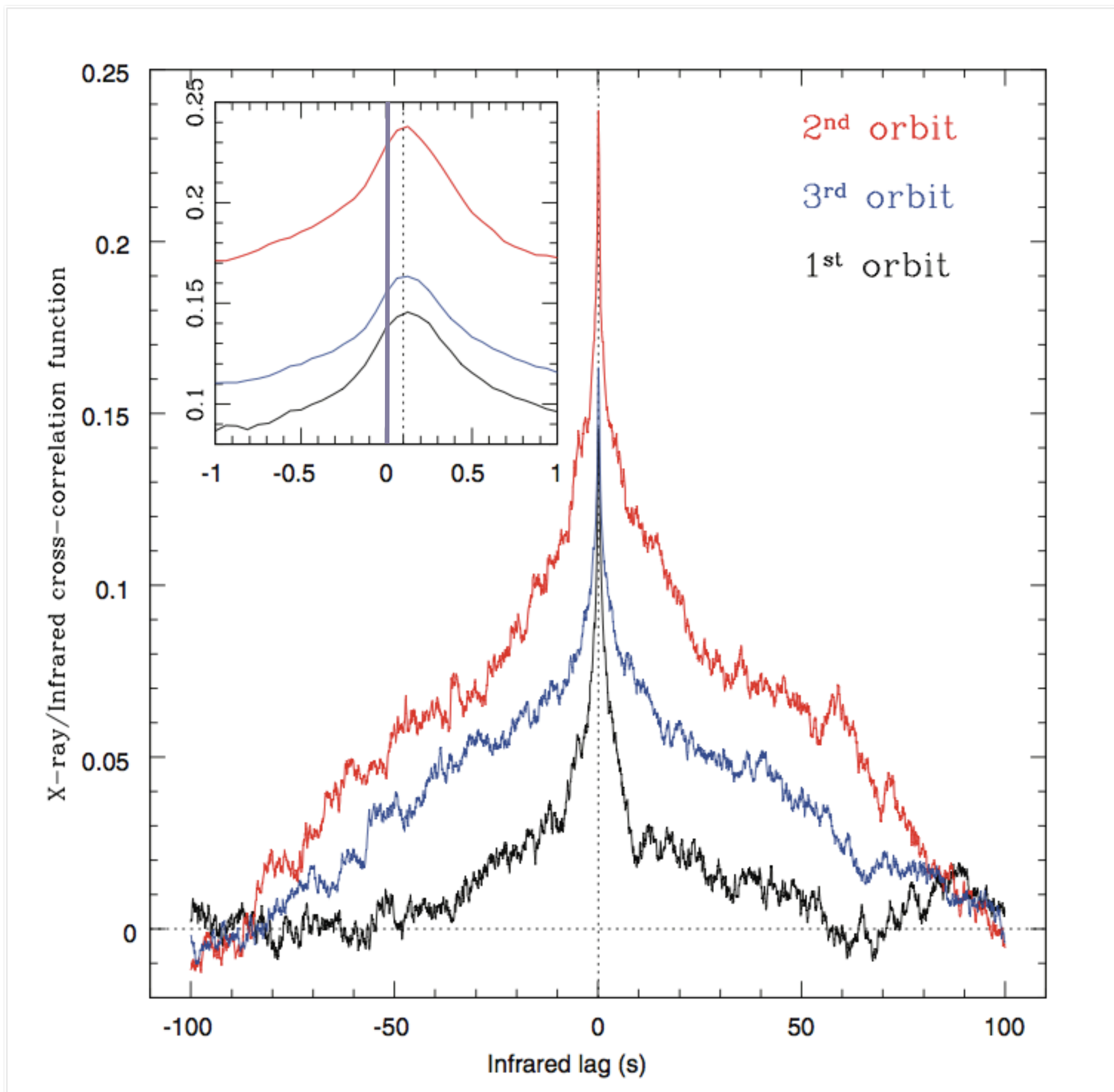
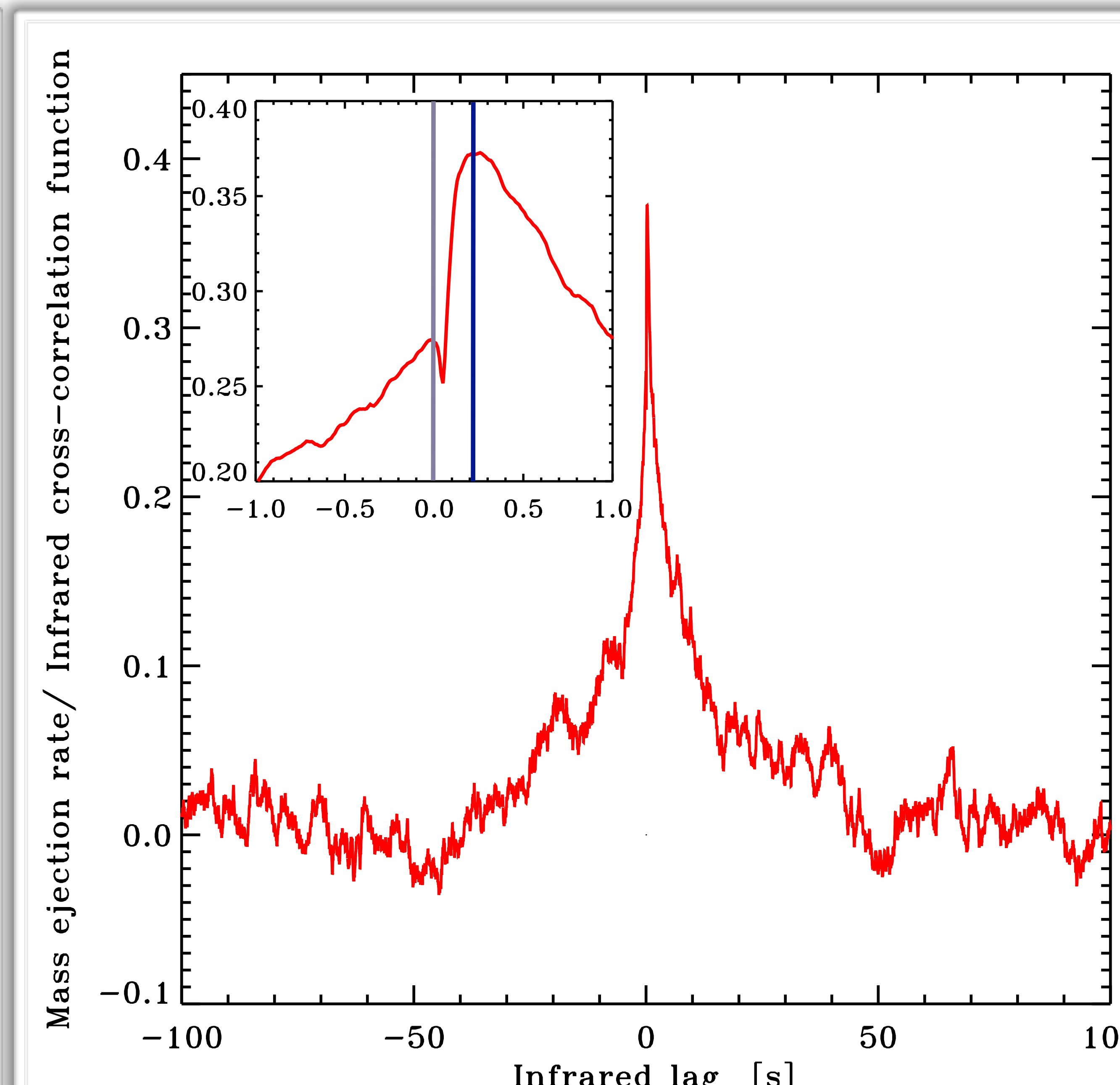


GX 339-4

Casella et al. 2010

Simulation

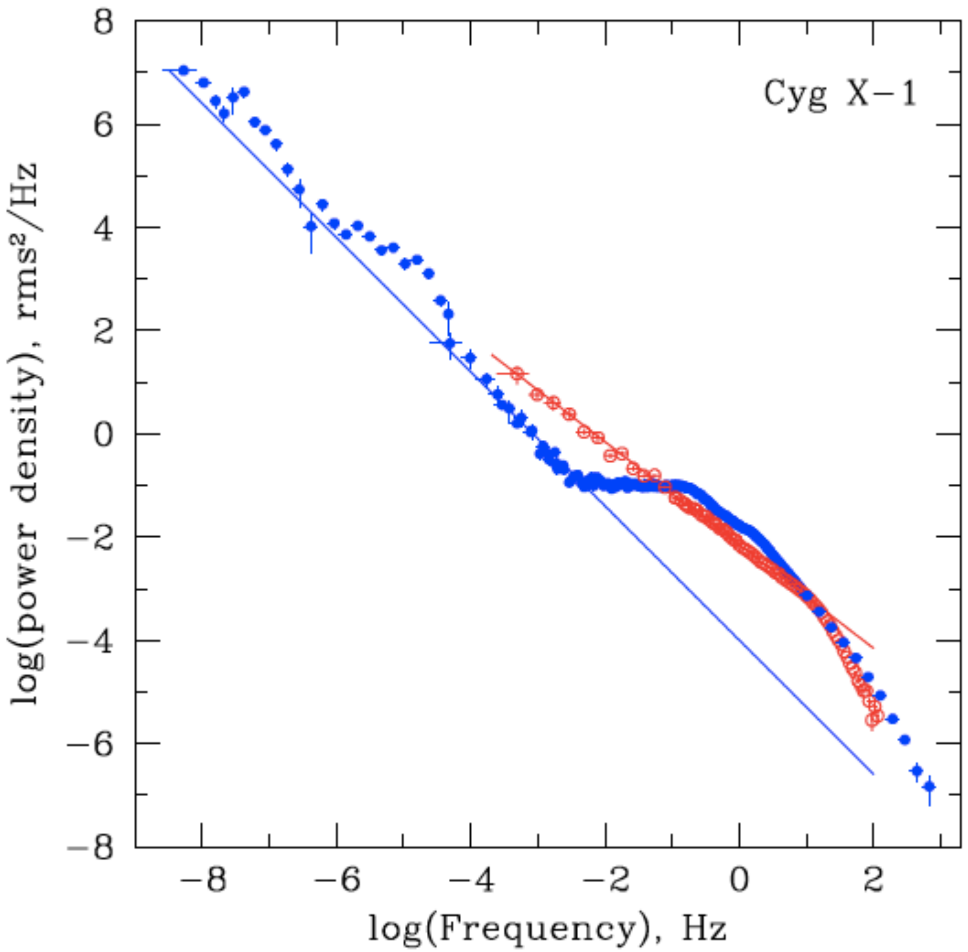


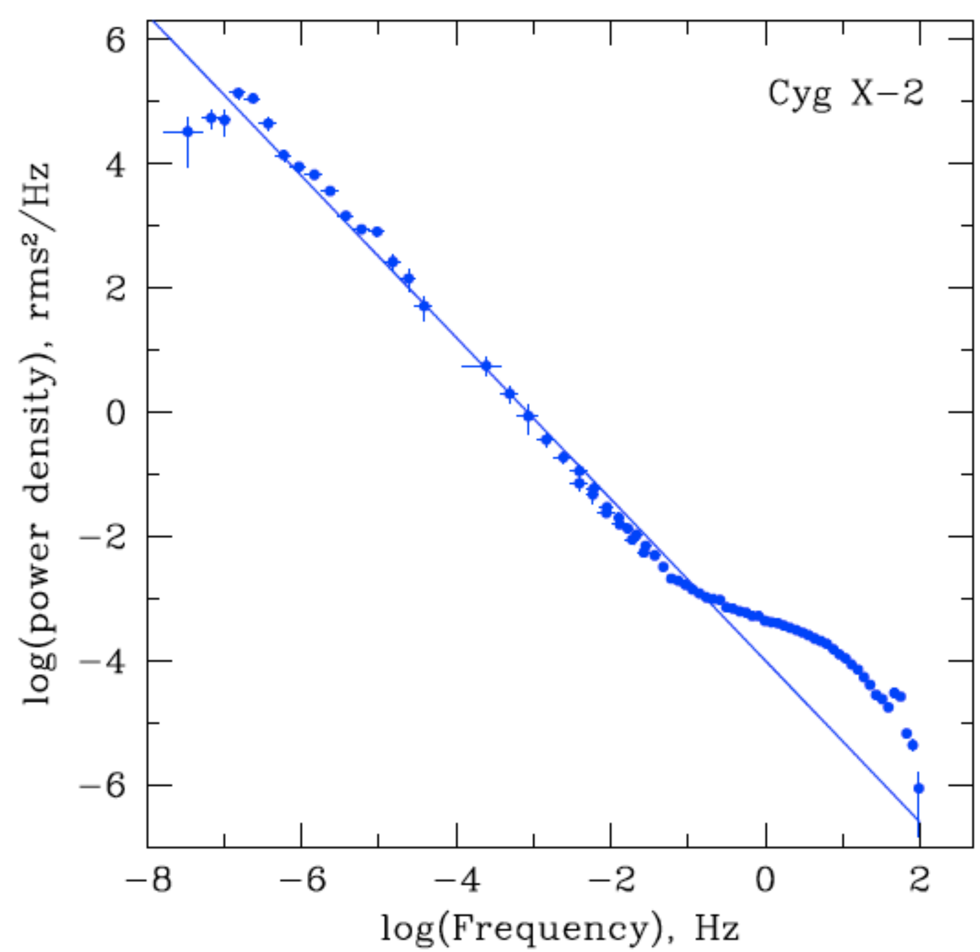
Assuming X-ray flux $\propto 1/\Gamma$

Malzac et al., in prep

Why flicker noise ?

- Accretion disks may produce 1/f noise (Lyubarskii 1997; King et al. 2004; Mayer & Pringle 2006)

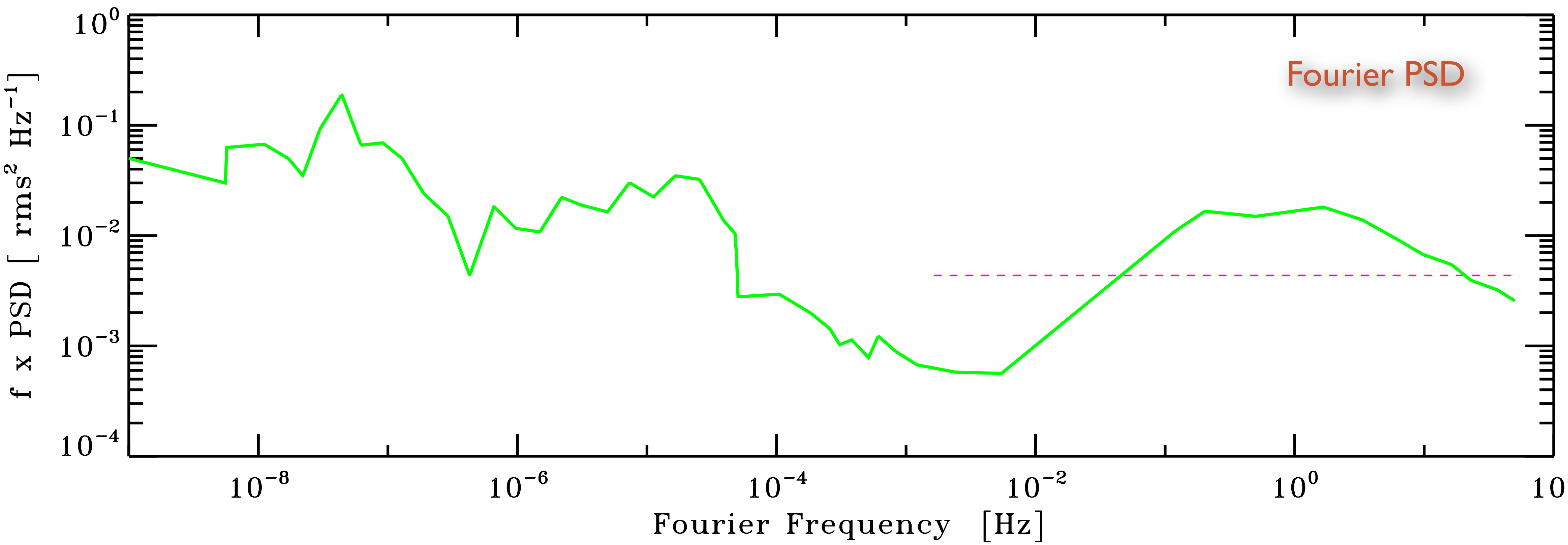


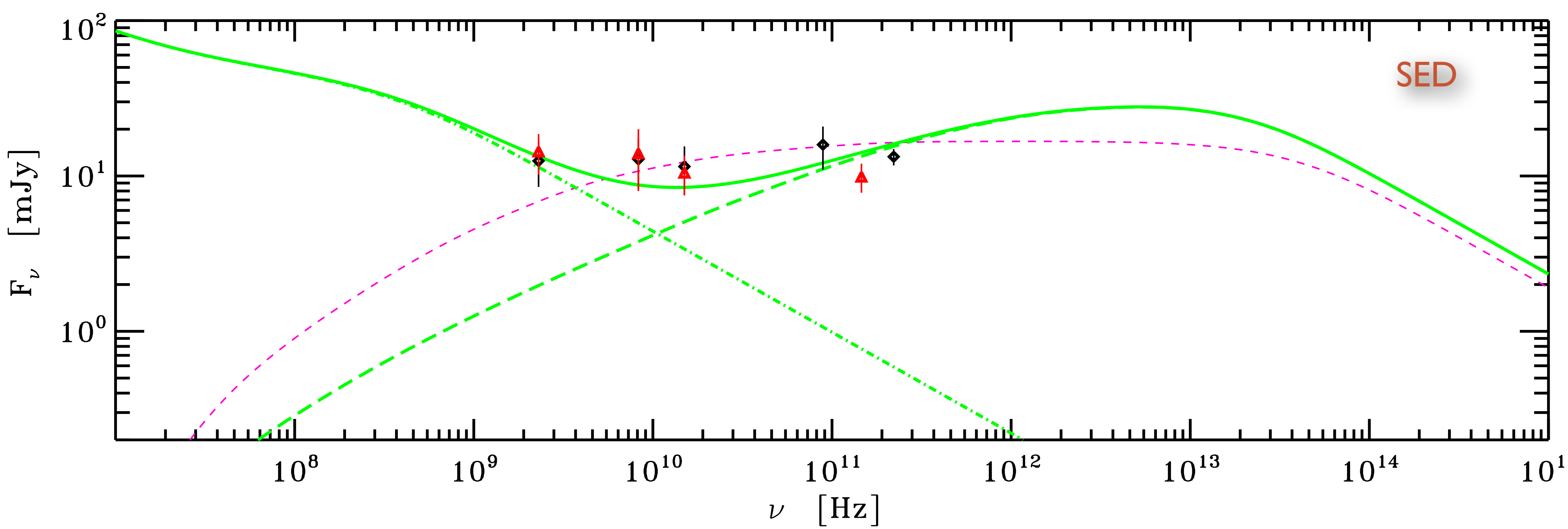


Gilfanov 2010

- X-ray power spectra of X-ray binaries close to flicker noise:
  $P(f) \propto f^{-1.3}$ at low frequencies
  + band limited (Lorentzians) at high frequencies in HS

Using observed X-ray PSD as input PSD of jet Lorentz factor fluctuations





Conclusions

- Internal shocks can account for the canonical SED of compact jets provided the power spectrum of injected fluctuations is close to $P(f) \propto f^{-1}$
- Internal shocks produce strong, frequency dependent, variability similar to that observed.
- Possible connection between X-ray POWER spectrum and Radio-IR PHOTON spectrum.

Thanks !