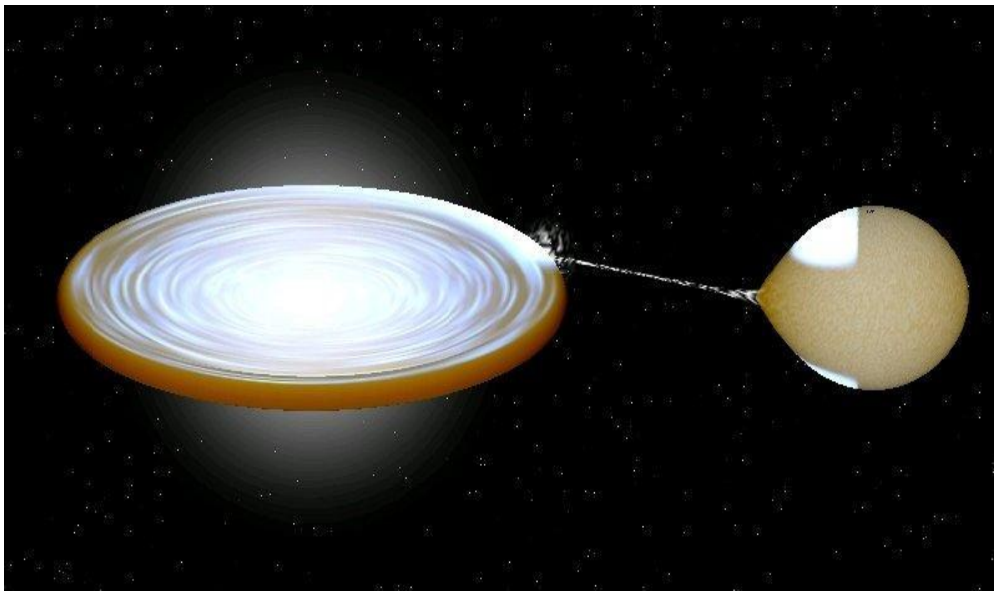
On the nature of the optical emission in low-mass X-ray binaries

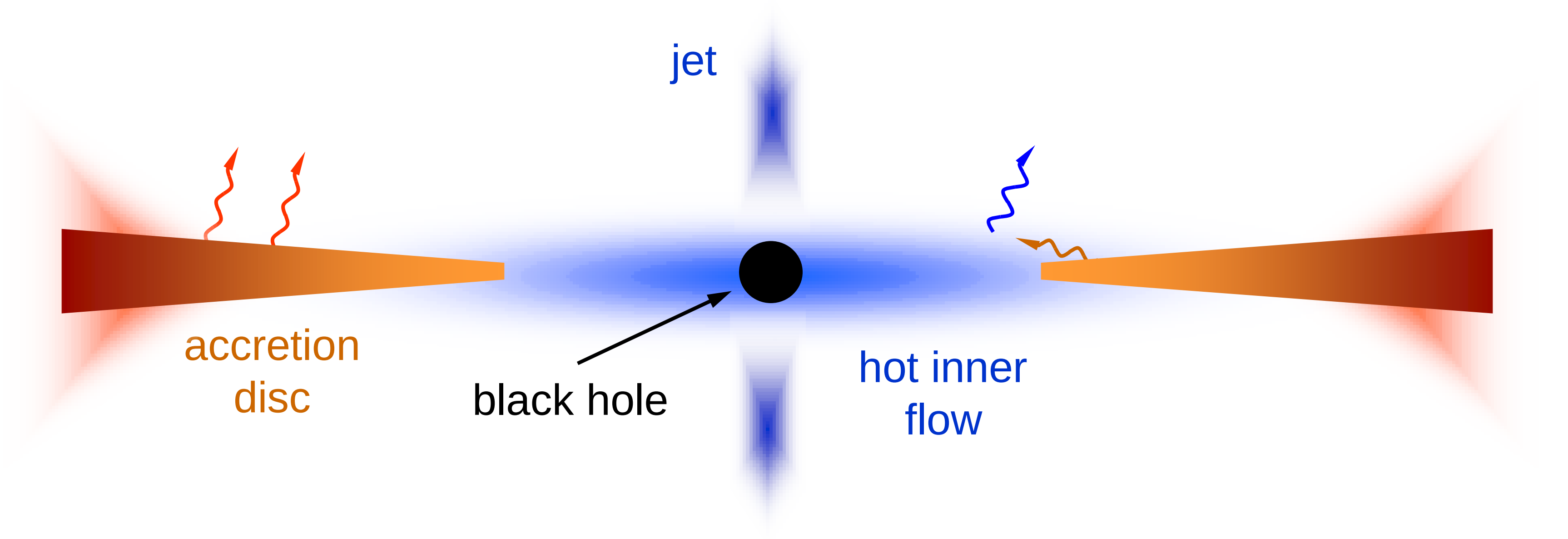


Alexandra Veledina
Juri Poutanen
Indrek Vurm

ESAC, Madrid, Spain
30 November 2011

For details see:
Poutanen & Vurm 2009 , ApJ, 690, L97
Veledina, Poutanen & Vurm 2011, ApJ, 737, L17

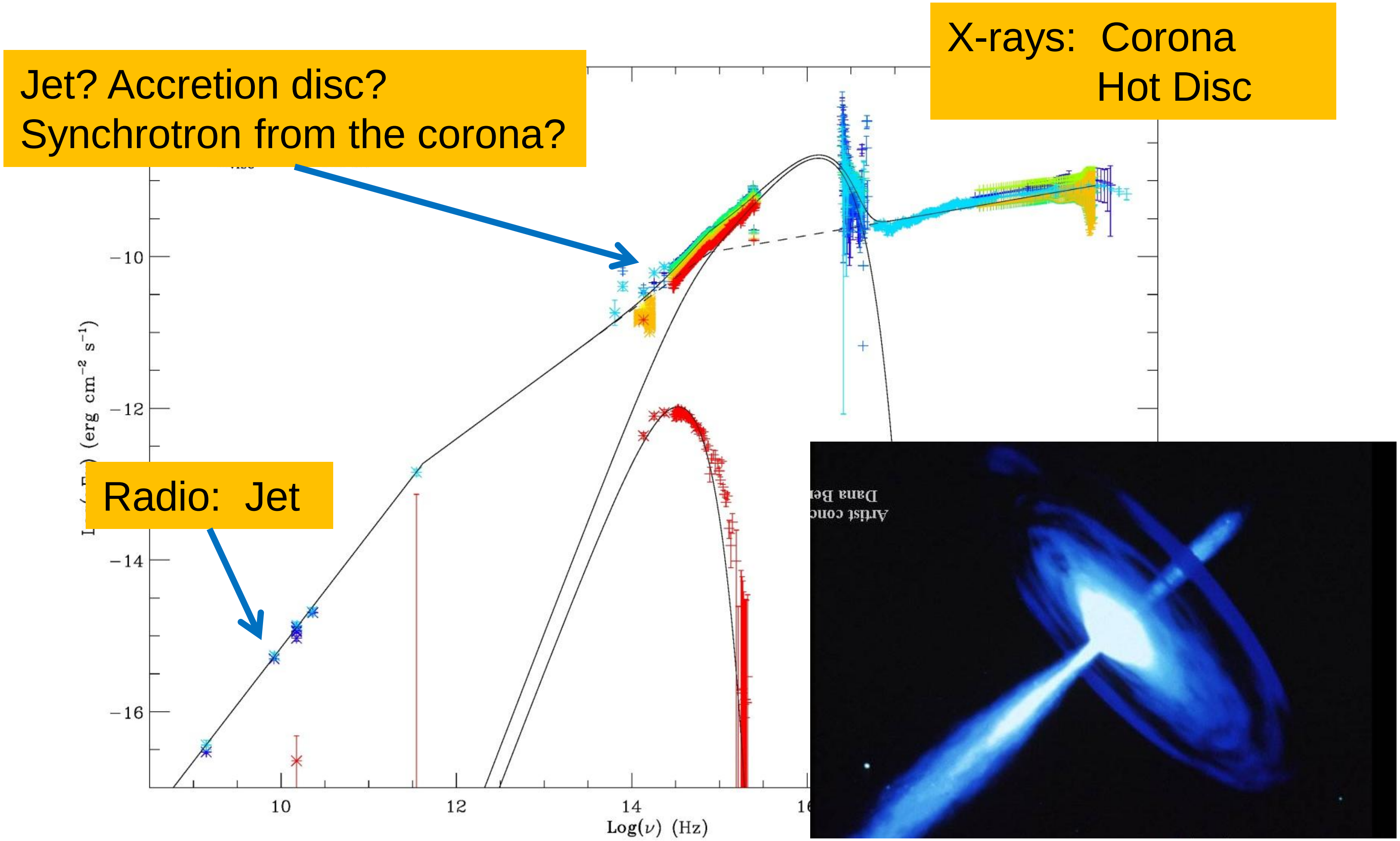
Geometry



Zdziarski & Gierlinski, 2004

OBSERVATIONS

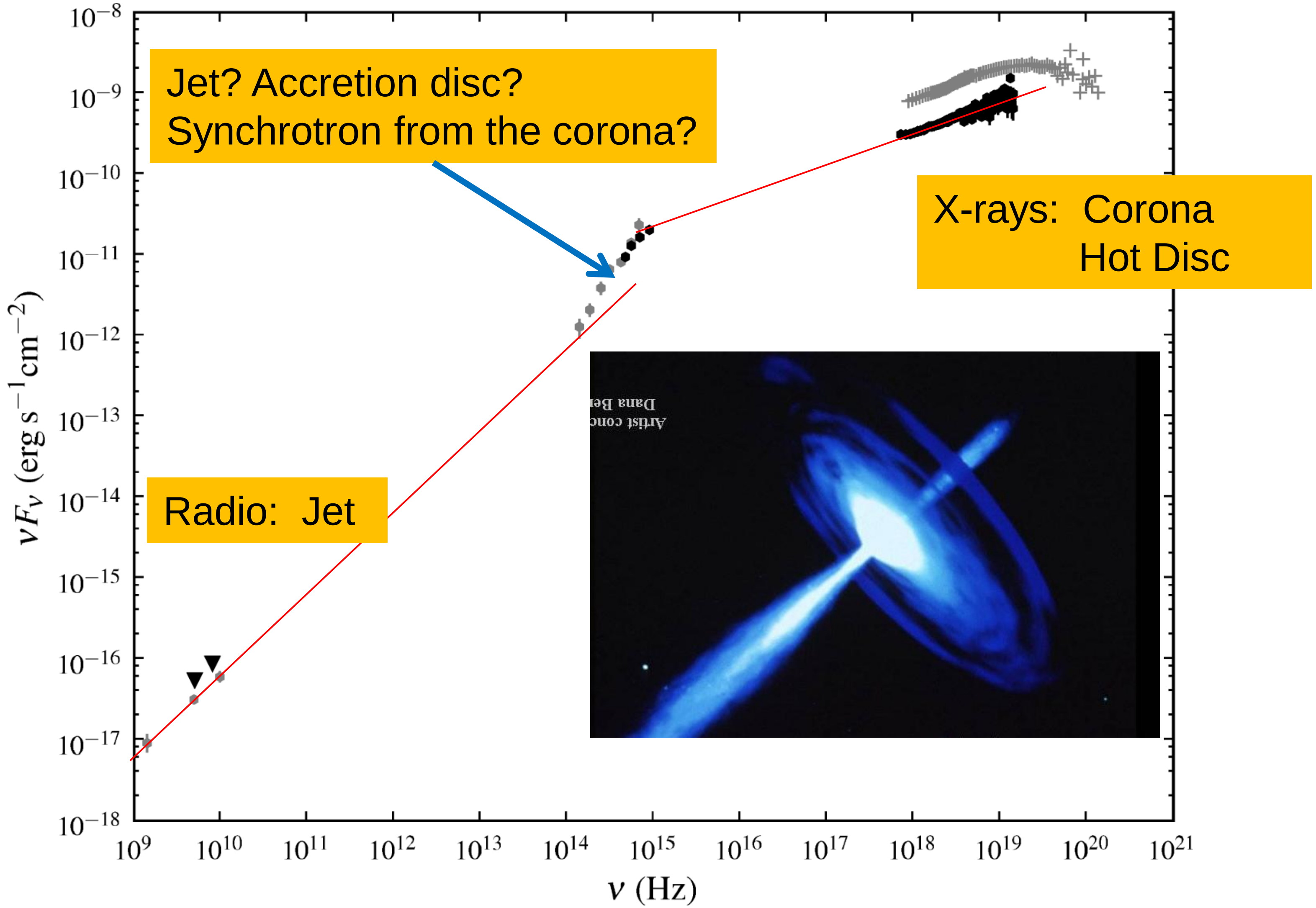
Broadband spectra of LMXBs



XTE J1118+480

Chaty et al. 2003

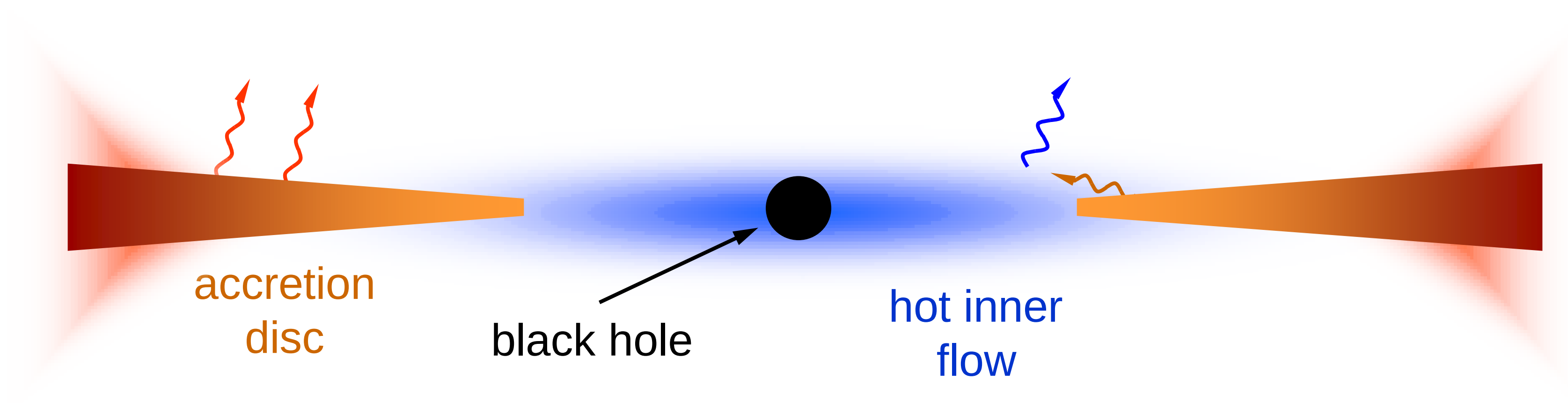
Broadband spectra of LMXBs



Swift J1753.5-0127

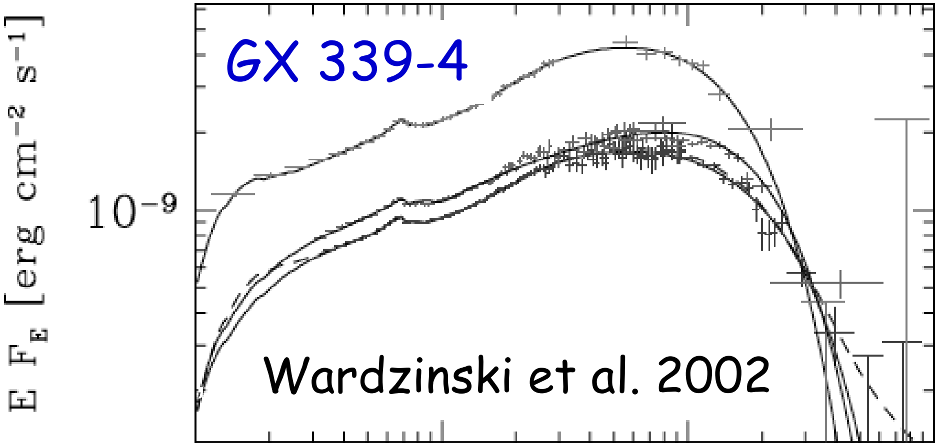
Cadolle Bel et al. 2007, Durant et al. 2009

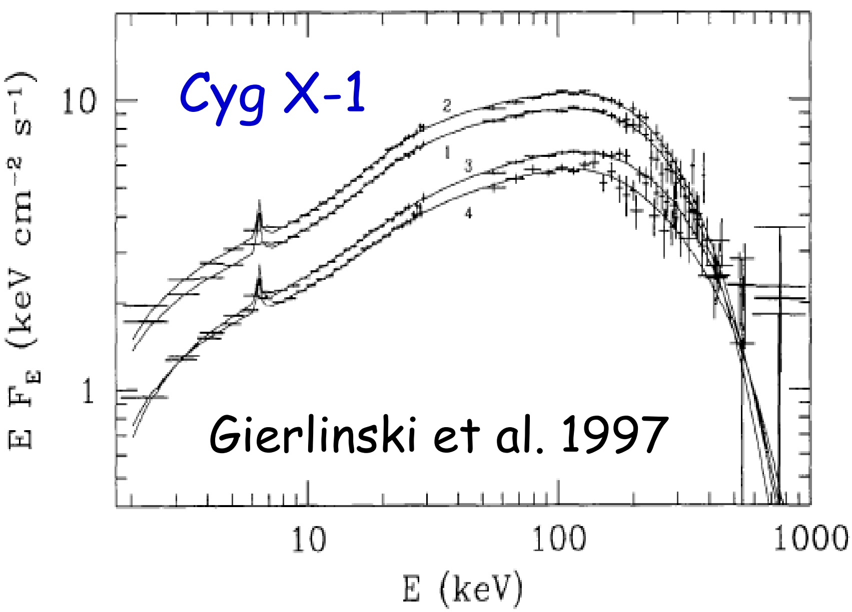
Geometry

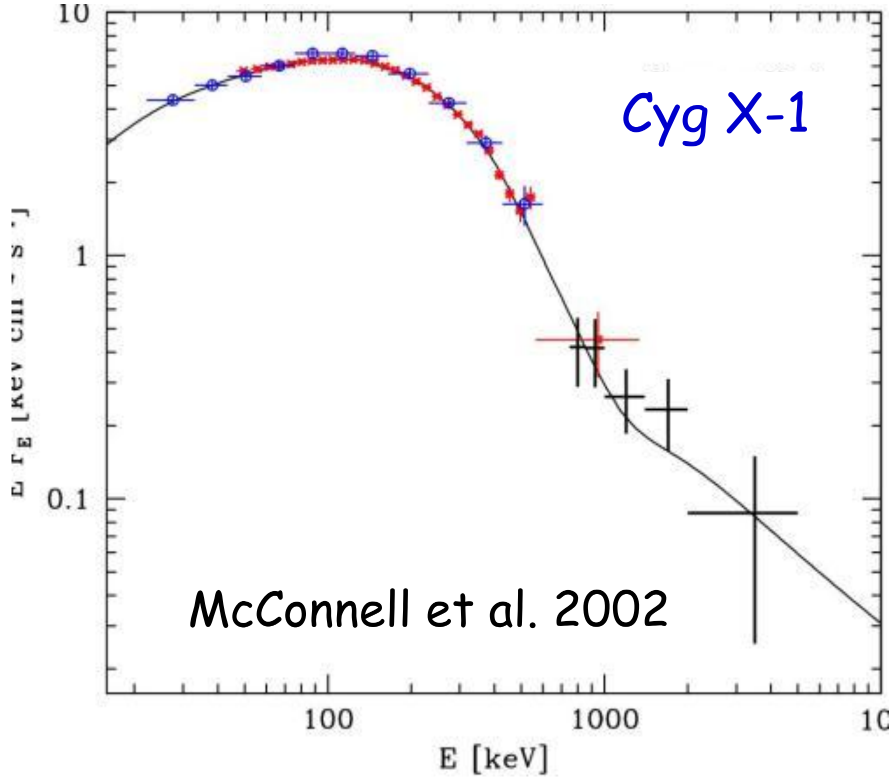


Zdziarski & Gierlinski, 2004

Thermal Comptonization in the hard state

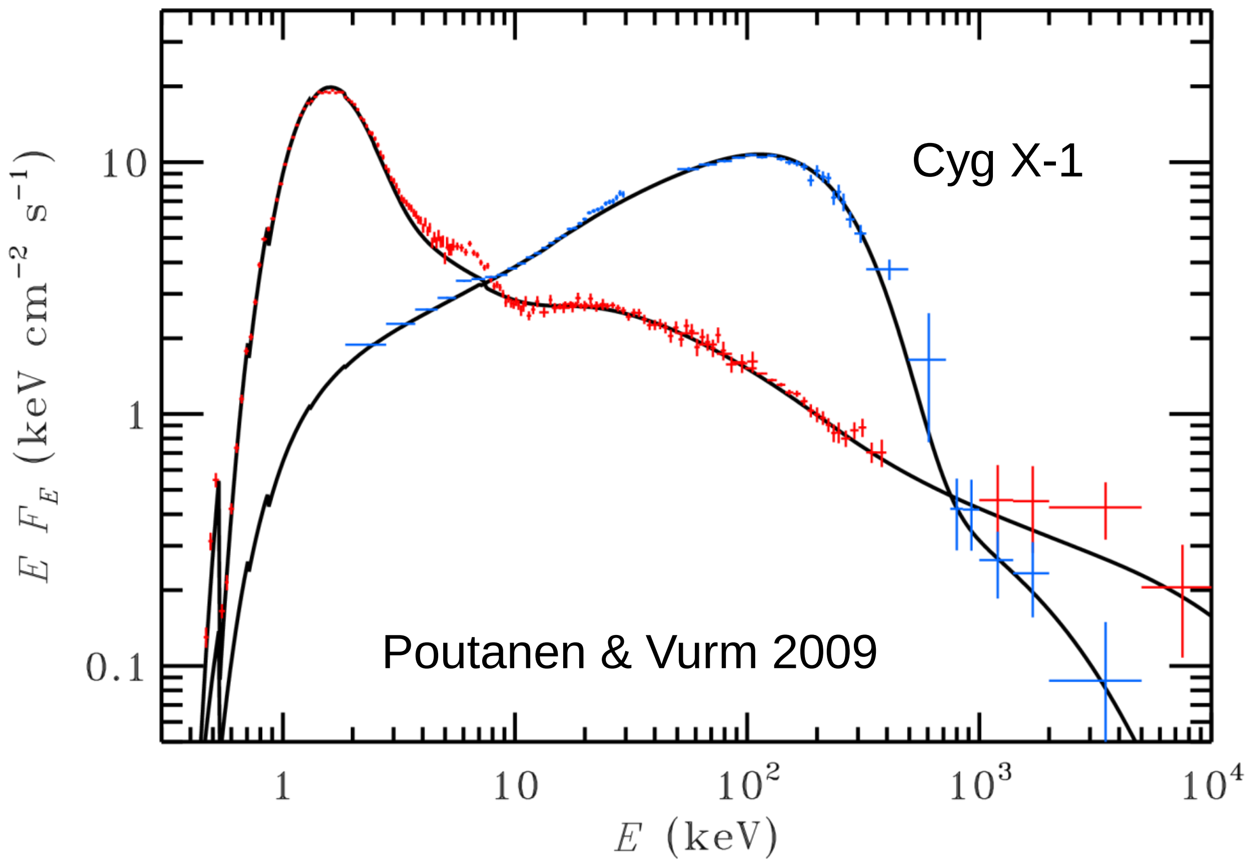






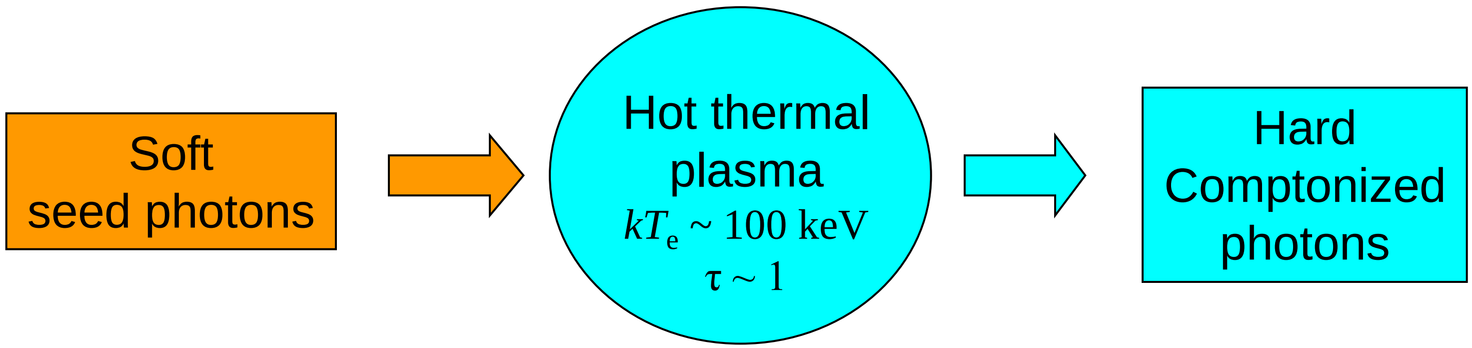
A weak non-thermal tail is present

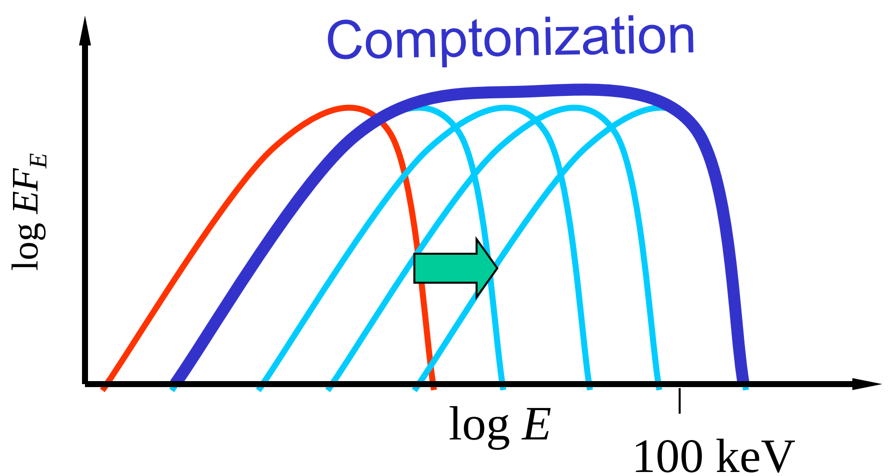
Spectral states: presence of non-thermal particles



Non-thermal tails are present in both hard and soft state

Hot thermal plasma – thermal Comptonization

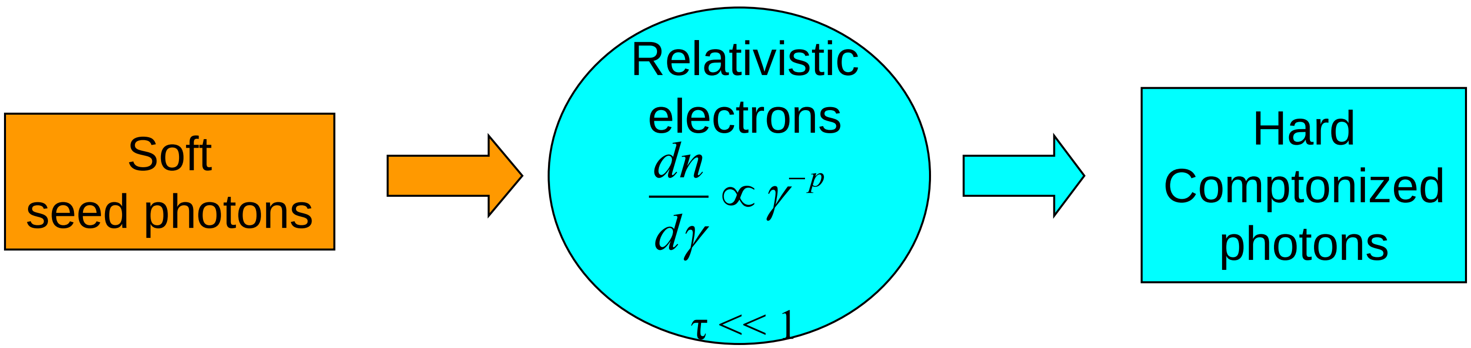


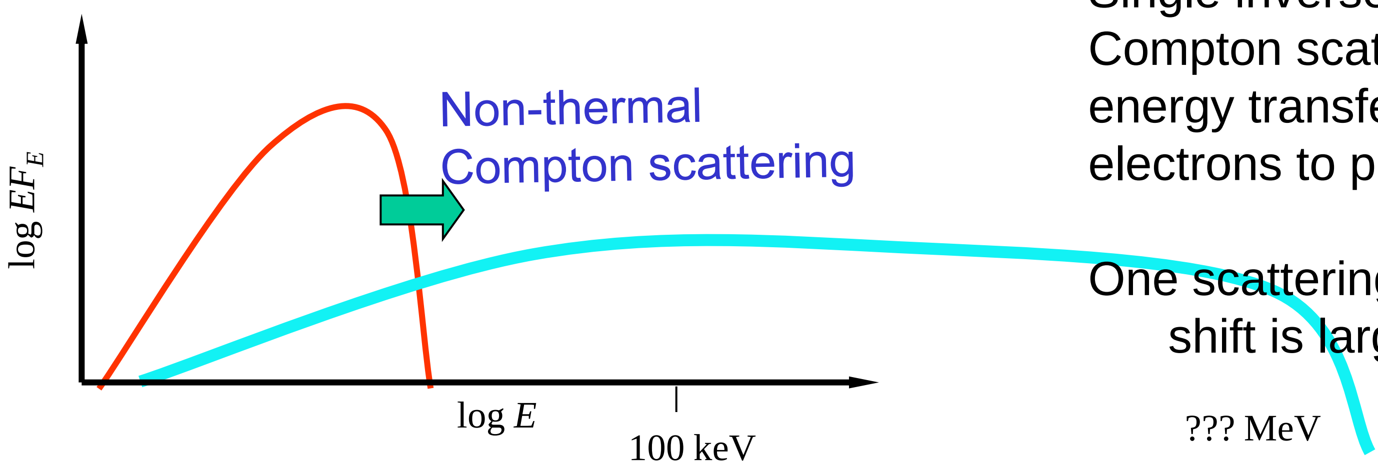


Multiple inverse Compton scattering: energy transfer from electrons to photons

Small energy shift in one scattering, but many scatterings

Relativistic non-thermal plasma – (single inverse) Compton scattering

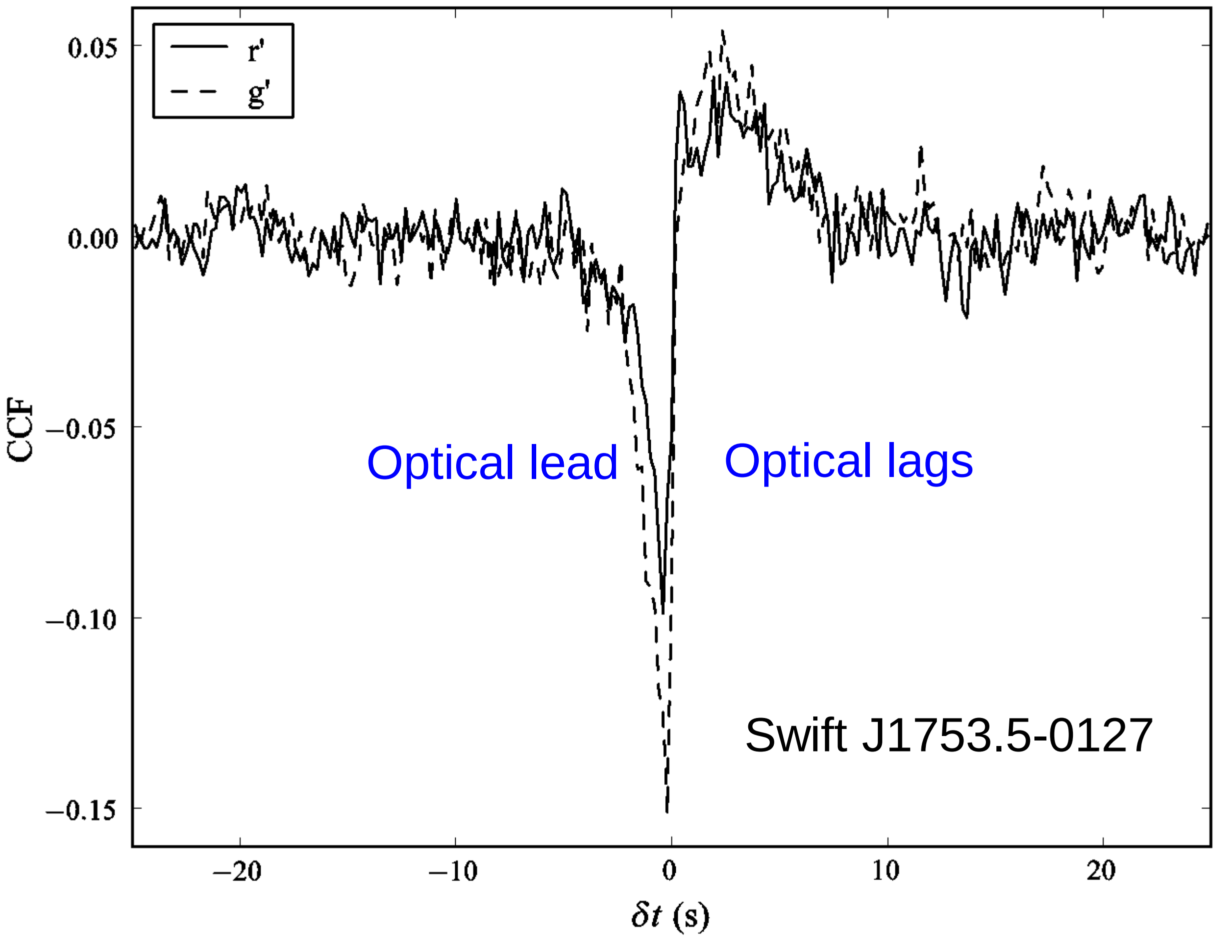




Single inverse Compton scattering: energy transfer from electrons to photons

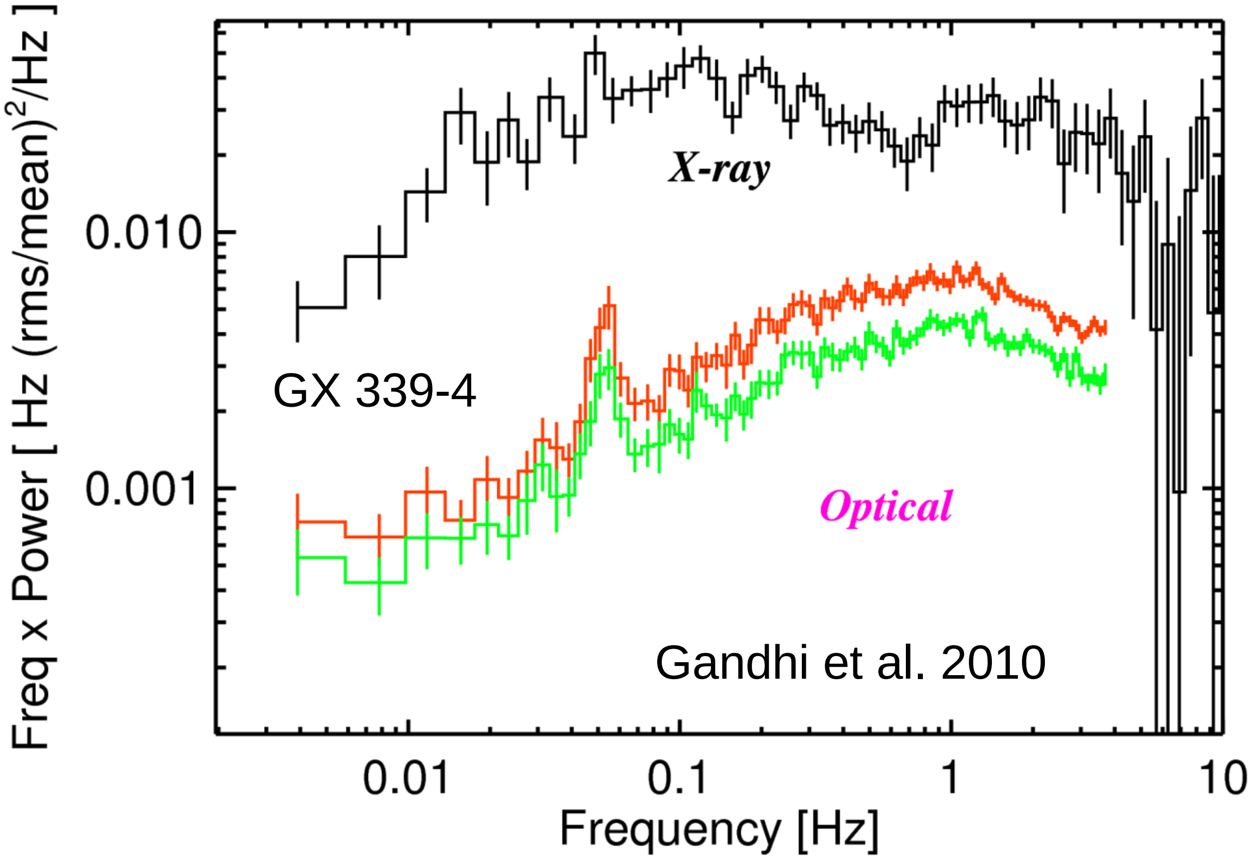
One scattering, but shift is large.

Optical/X-ray cross-correlation



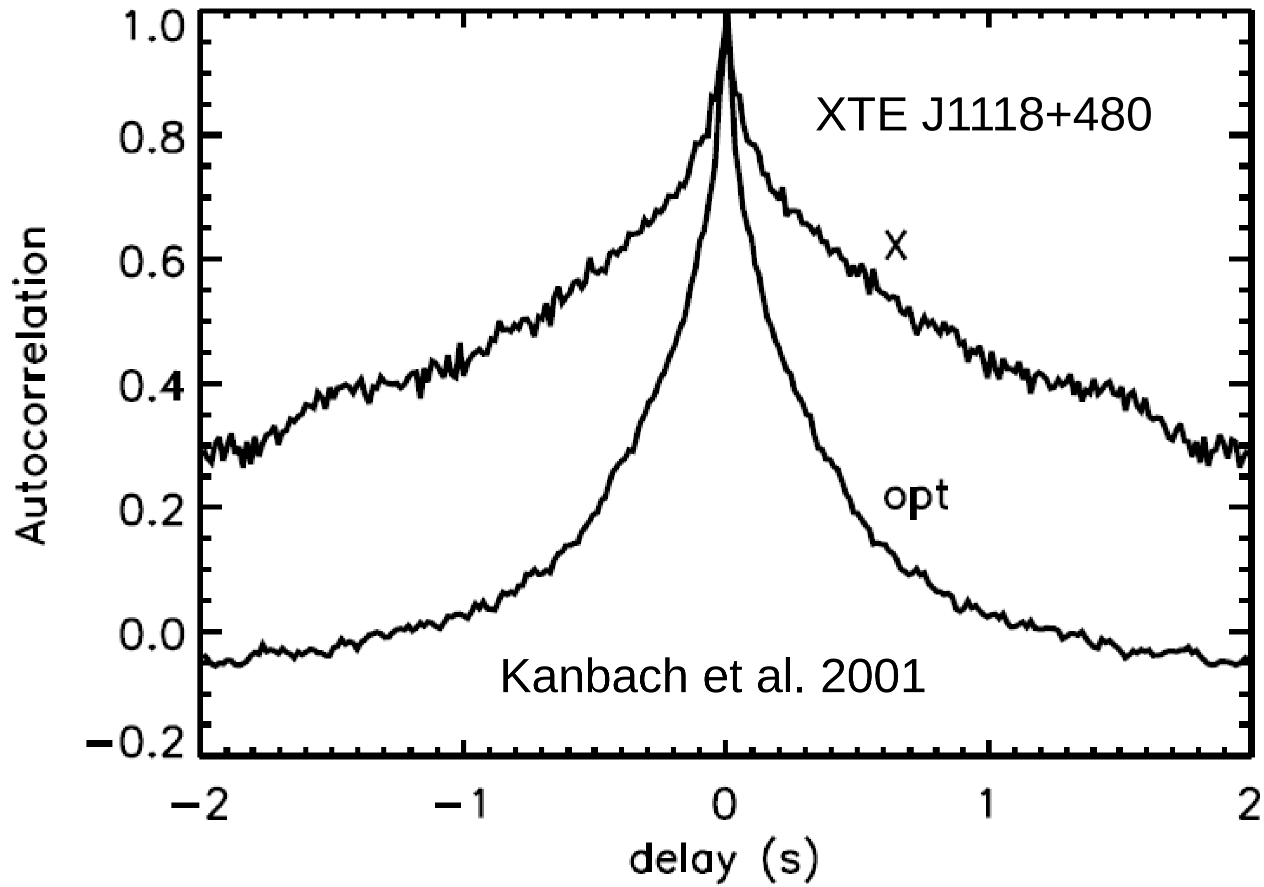
Durant et al. 2010

Power Density Spectrum



Optical varies faster than X-rays
➔ cannot be produced far away (e.g. in a jet)

Autocorrelation functions



Optical varies faster than X-rays
➔ cannot be produced far away (e.g. in a jet)

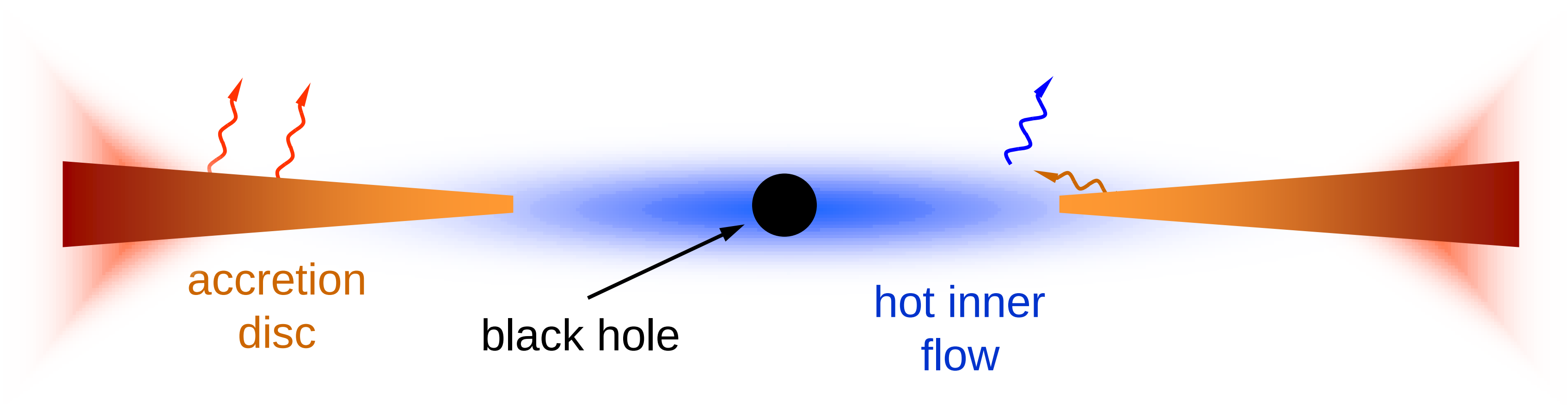
Observational aspects

- Spectrum: non-thermal high-energy tails suggest presence of non-thermal particles

- Timing: mysterious shape of the cross-correlation function, optical varies faster than the X-rays

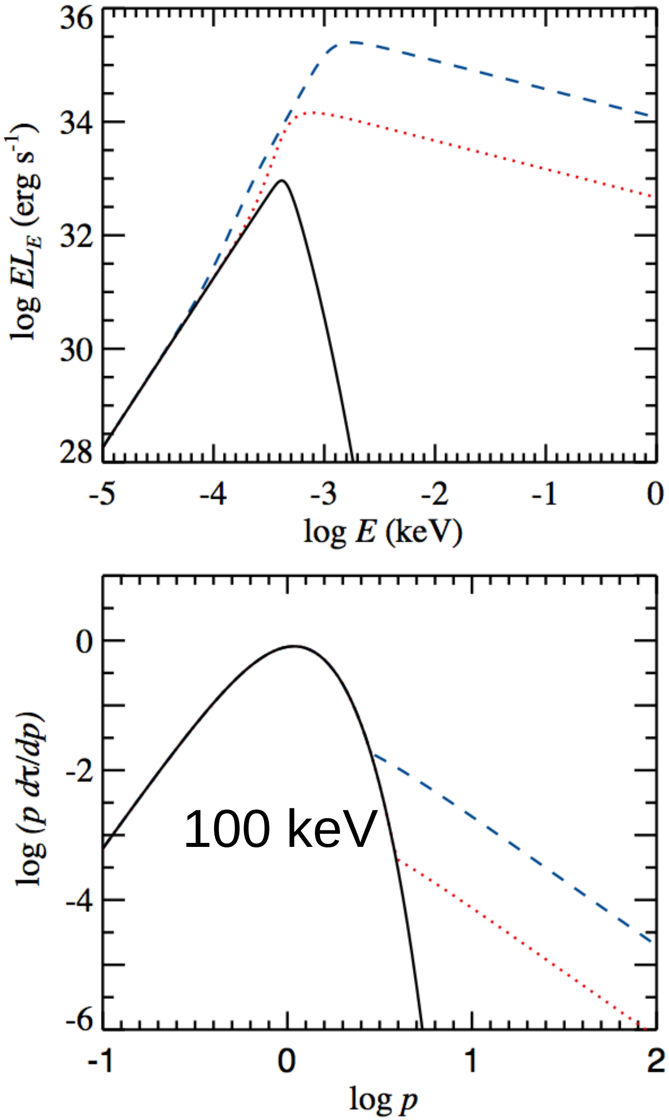
MODELING

Geometry



Zdziarski & Gierlinski, 2004

Synchrotron in hybrid plasma



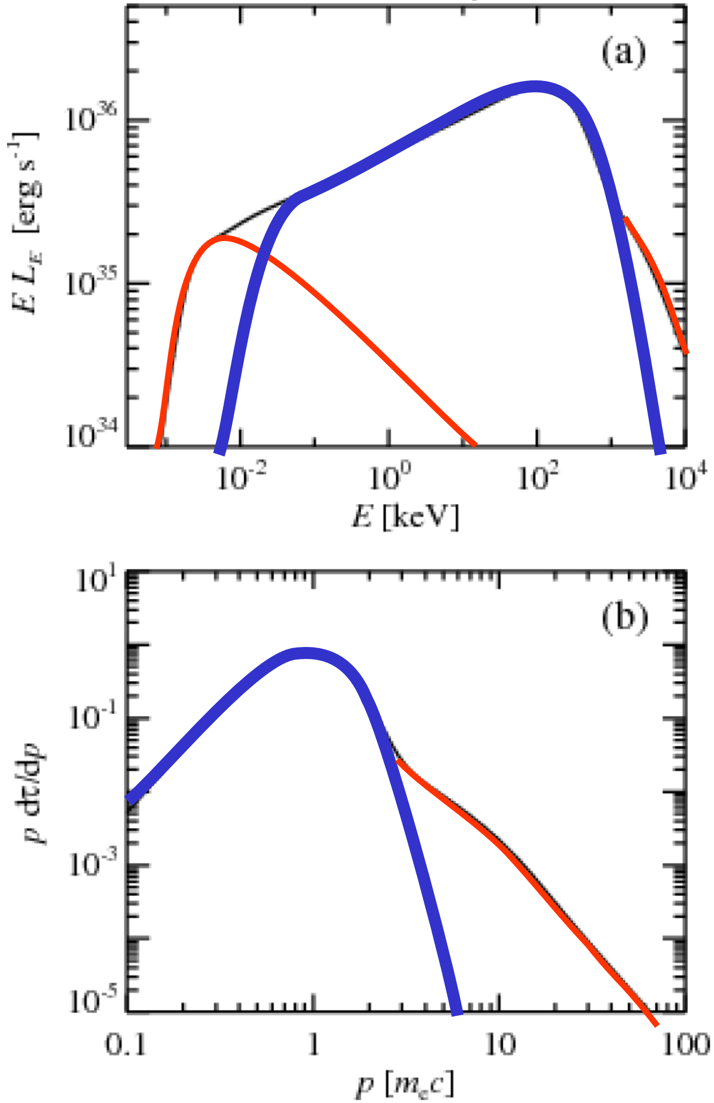
Hybrid electrons, 1% energy in the non-thermal component

Hybrid electrons, 0.01% energy in the non-thermal component

Thermal electrons, 100 keV

Synchrotron can be the main source of seed photons for Comptonization

Synchrotron Self-Compton mechanism in hybrid plasma

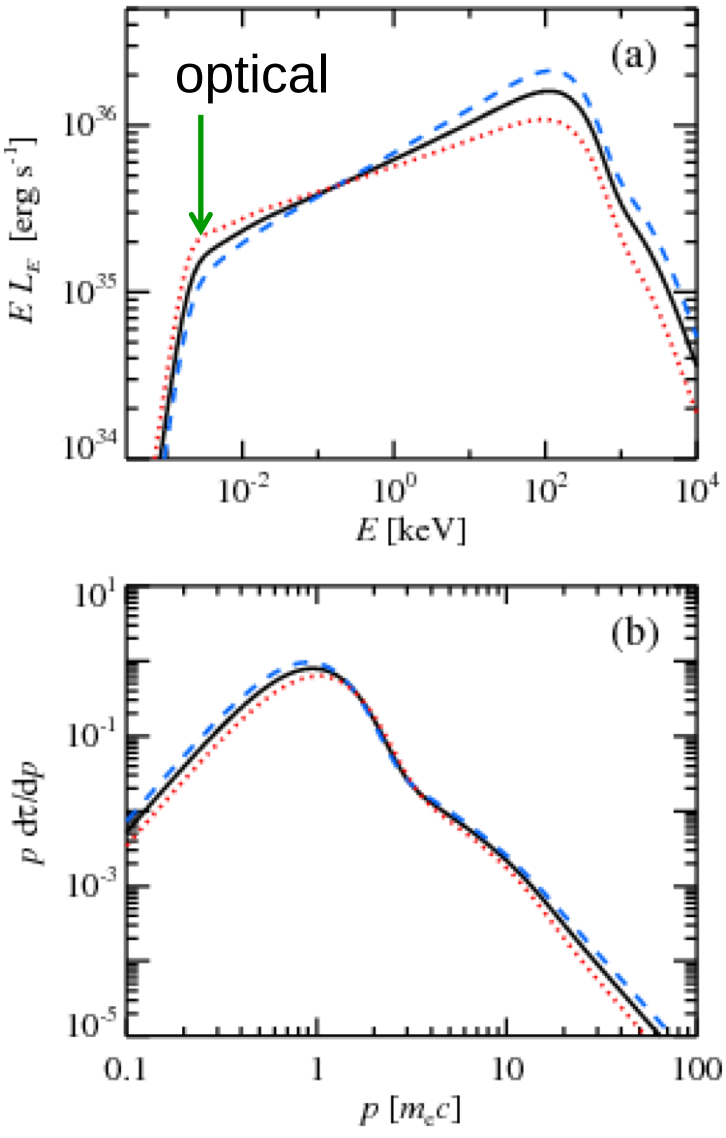


$R = 9\times10^{7}\,cm$

$\tau = 1.0$

$B = 3\times10^{5}\,G$

Synchrotron Self-Compton mechanism in hybrid plasma



$R \propto \dot{m}^{-4/3}$ (Rozanska & Czerny 2000)

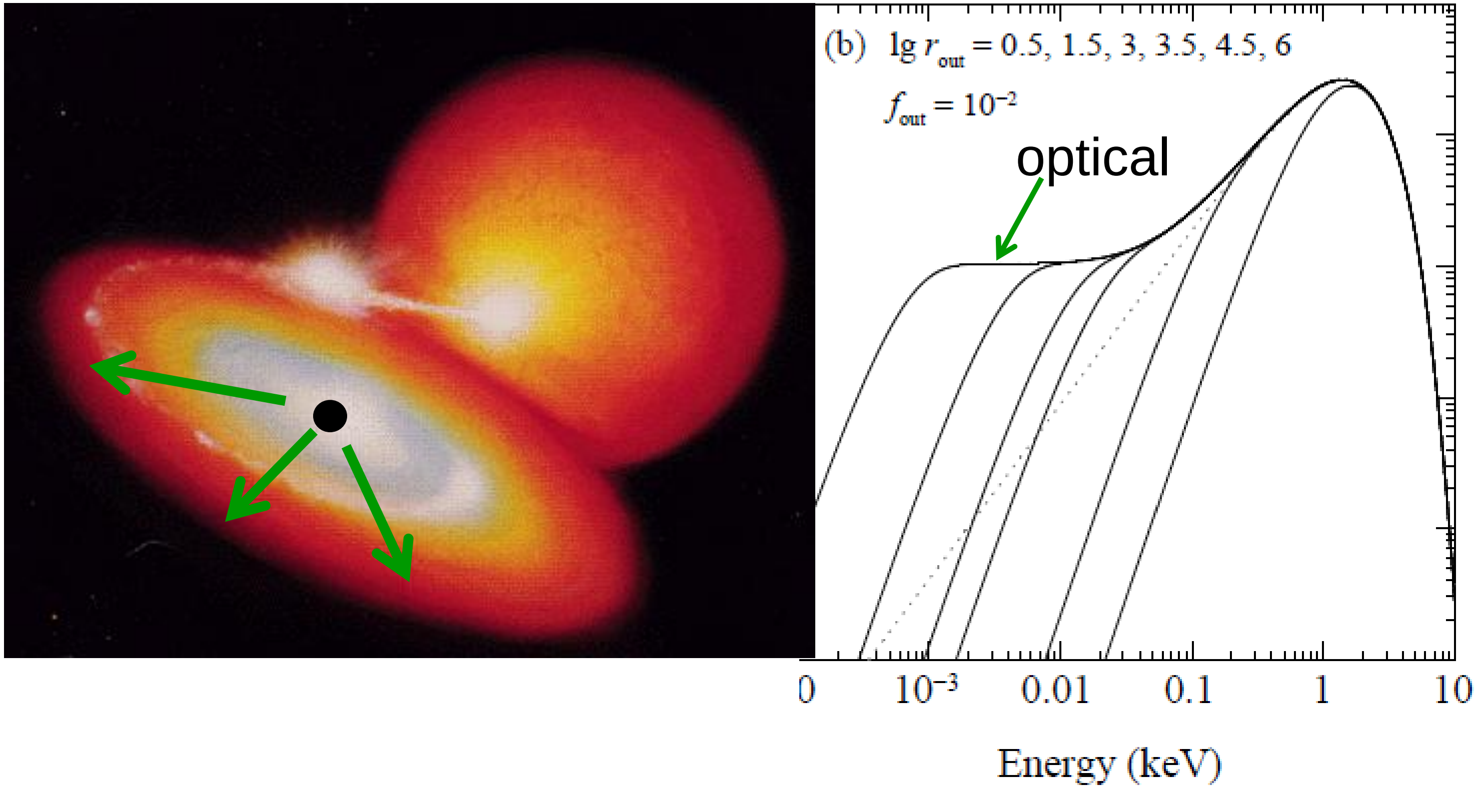
$L \propto \dot{m}$

$\tau \propto \dot{m}$

$B = const$

The optical and the X-rays are anticorrelated

Irradiated discs



Gierlinski et al. 2009

Light-curves

X-rays $x(t)$

Synchrotron $s(t) \propto -x(t)$

Irradiated disc $d(t) \propto \int_{-\infty}^{t} x(t')r(t-t')dt'$

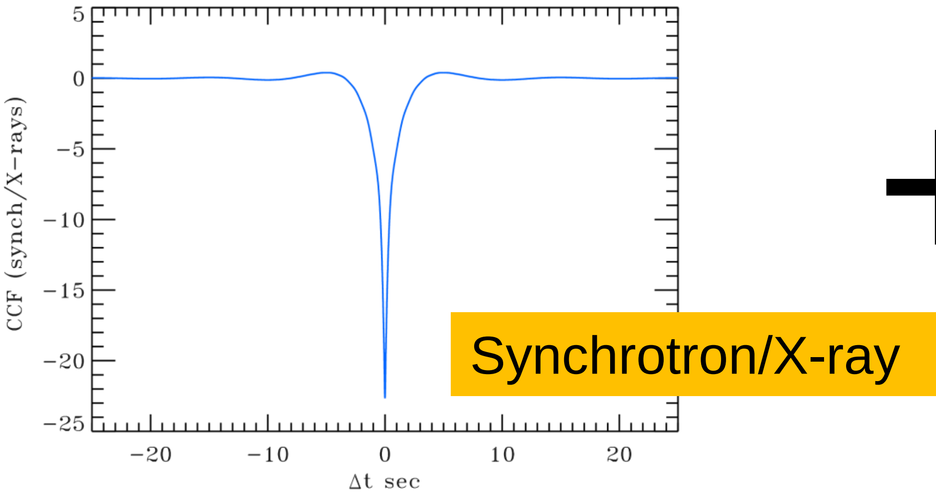
Optical $o(t) \propto -x(t) + r_{ds} \int_{-\infty}^{t} x(t')r(t-t')dt'$

Main parameters: r_{ds} and $r(t)$

Optical/X-ray cross-correlation

$$CCF(t) = -\underbrace{\int_{-\infty}^{+\infty} x(t')x(t+t')dt'}_{ACF_X} + \underbrace{r_{ds}\int_{-\infty}^{+\infty} x(t')dt' \int_{-\infty}^{t+t'} x(t'')r(t+t'-t'')dt''}_{Irradiated\ disc}$$

Optical/X-ray cross-correlation



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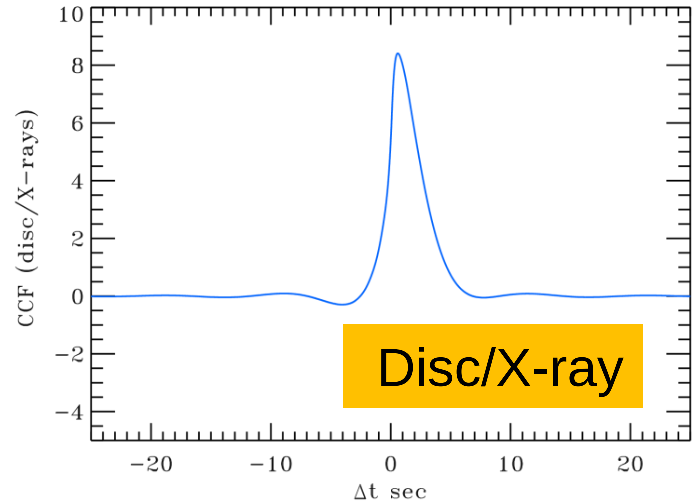

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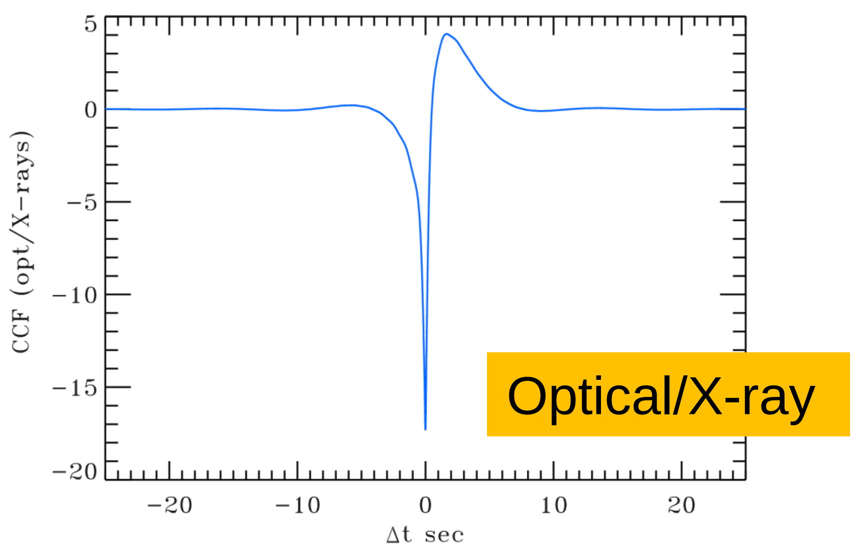
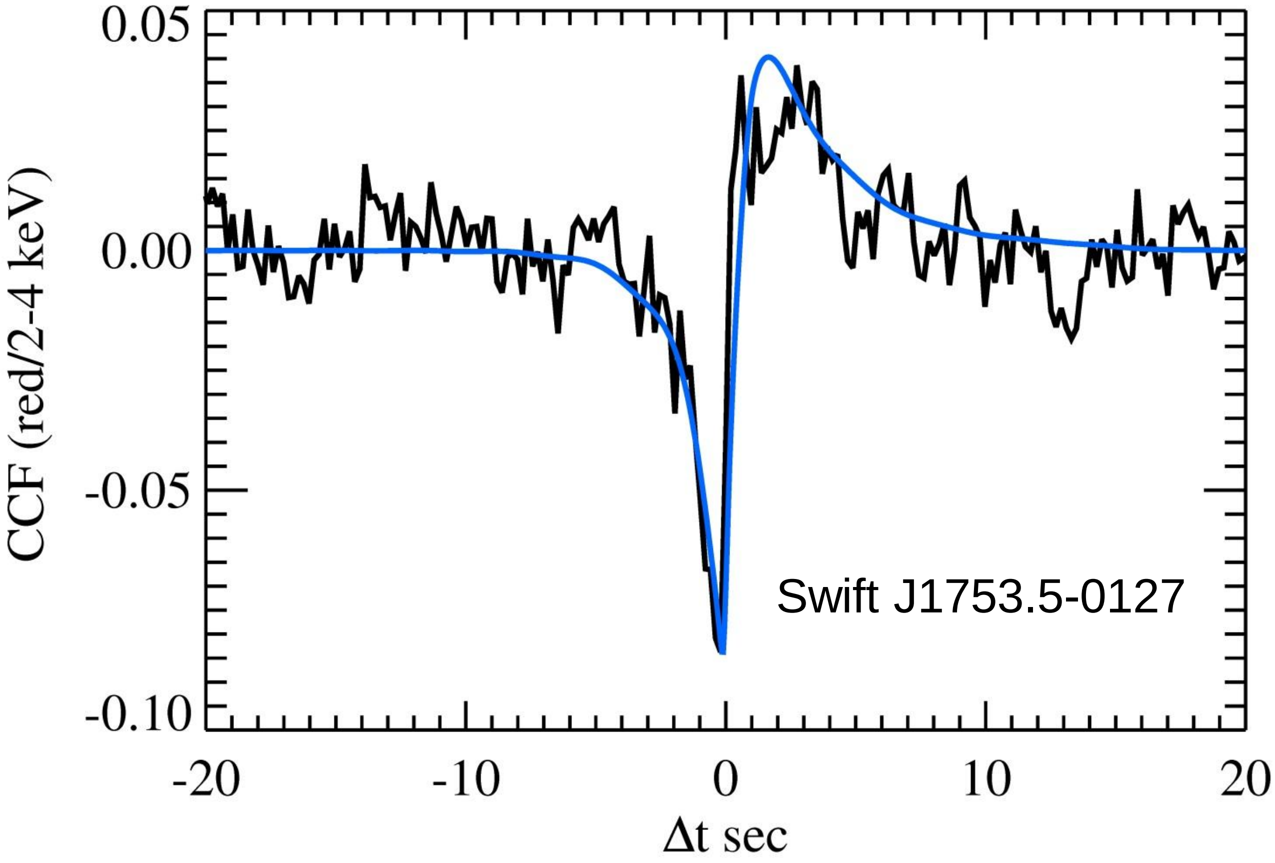


Comparison with the data



Data from Durant et al. 2010

Fourier images

X-ray $X(f)$

Synchrotron $S(f) \propto -X(f)$

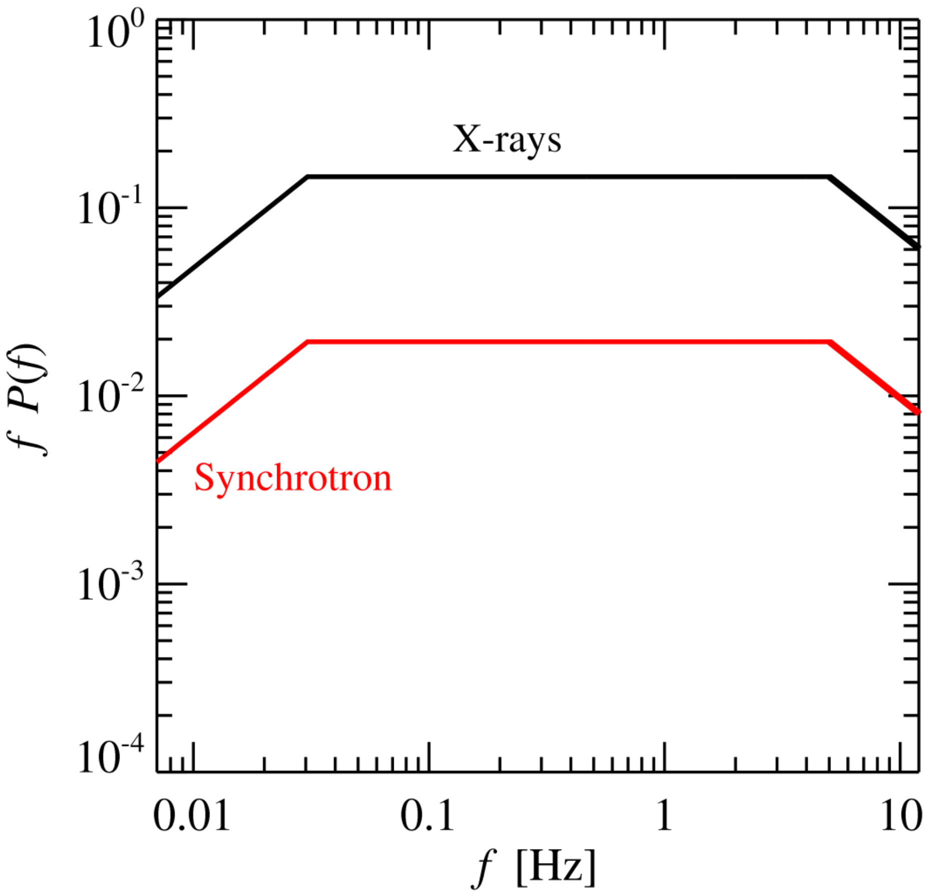
Irradiated disc $D(f) \propto X(f)R(f)$

Optical $O(f) \propto X(f)\left[-1 + r_{ds}R(f)\right]$

Power spectral density

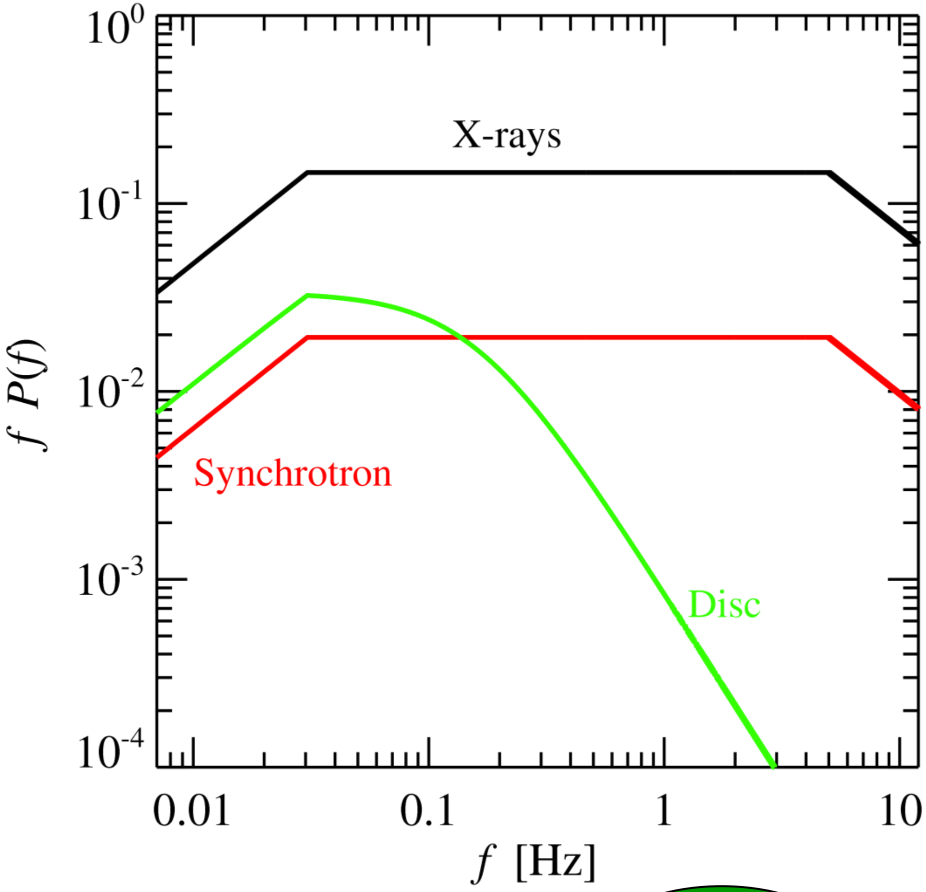
$$PSD_{opt}(f) \propto PSD_X(f)\left\{1 + r_{ds}^2 |R(f)|^2 - 2r_{ds}\,\mathrm{Re}\left[R(f)\right]\right\}$$

Power spectra



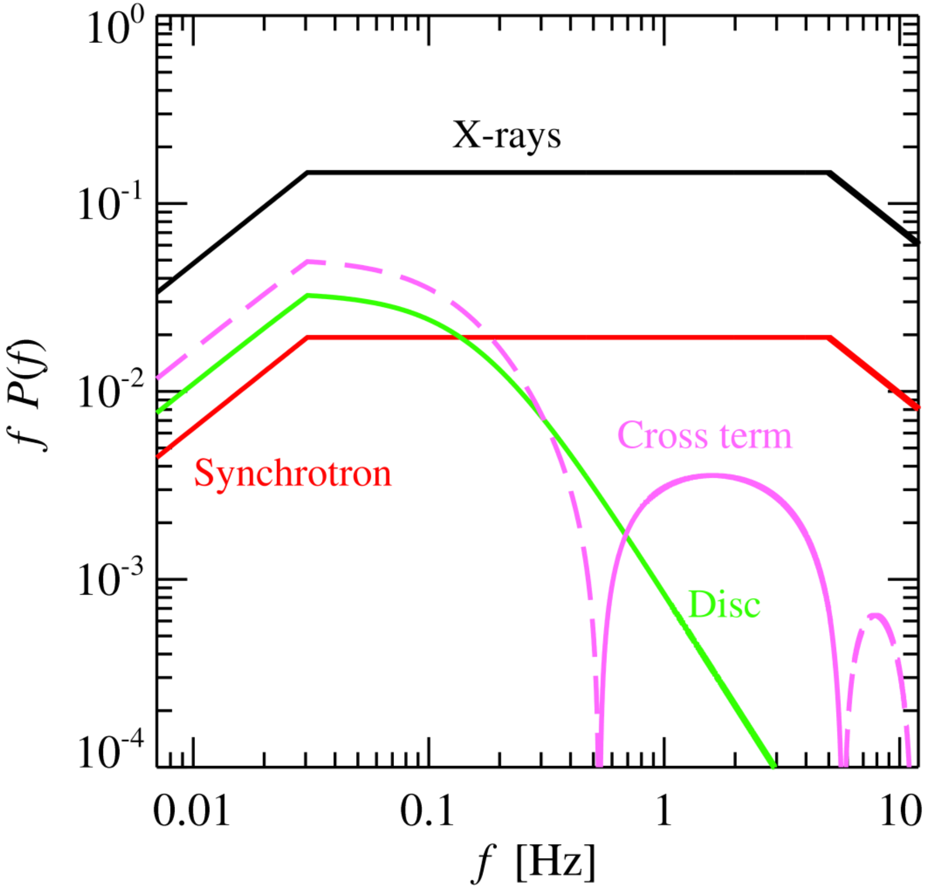
$$PSD_{opt}(f) \propto PSD_X(f)\left\{1 + r_{ds}^2 |R(f)|^2 - 2r_{ds}\,\mathrm{Re}[R(f)]\right\}$$

Power spectra



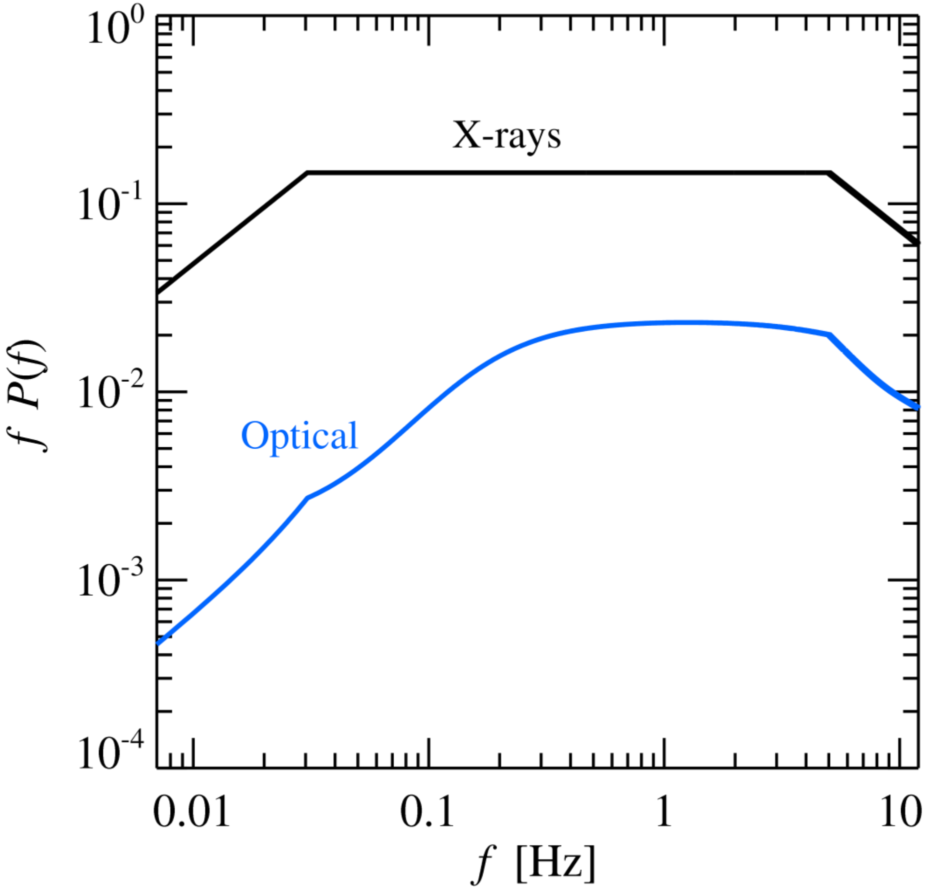
$$PSD_{opt}(f) \propto PSD_X(f)\left\{1 + r_{ds}^2 |R(f)|^2 + 2r_{ds}\,\mathrm{Re}[R(f)]\right\}$$

Power spectra



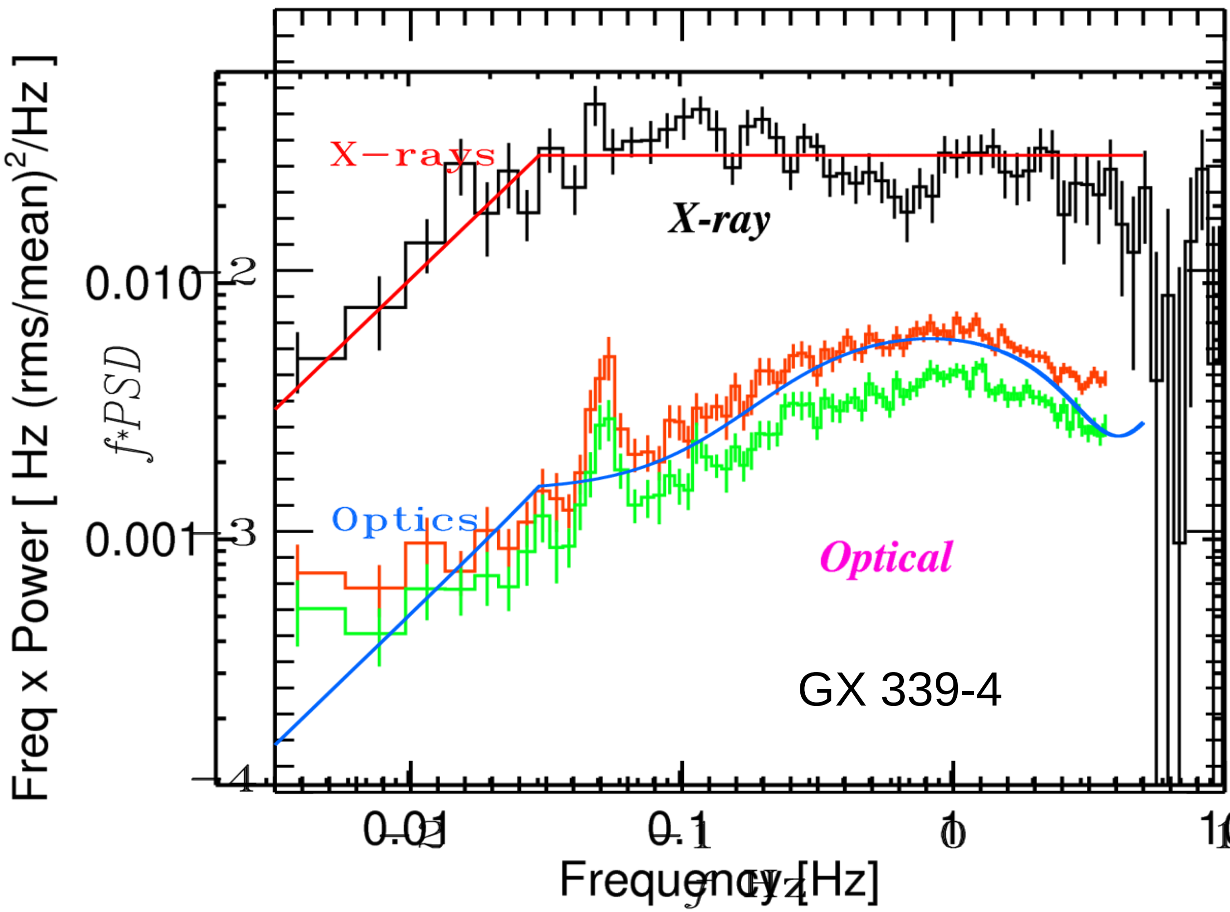
$$PSD_{opt}(f) \propto PSD_X(f)\left\{1 + r_{ds}^2 |R(f)|^2 - 2r_{ds}\,\mathrm{Re}[R(f)]\right\}$$

Power spectra



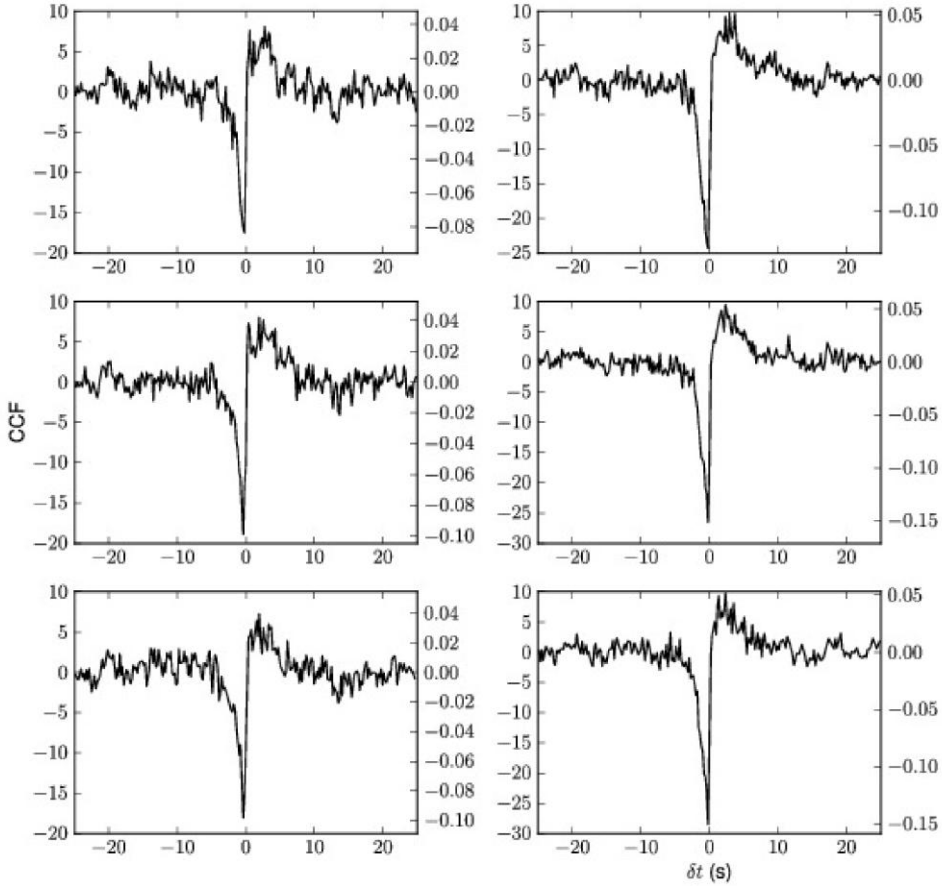
$$PSD_{opt}(f) \propto PSD_X(f)\left\{1 + r_{ds}^2 |R(f)|^2 - 2r_{ds}\,\mathrm{Re}[R(f)]\right\}$$

Comparison with the data



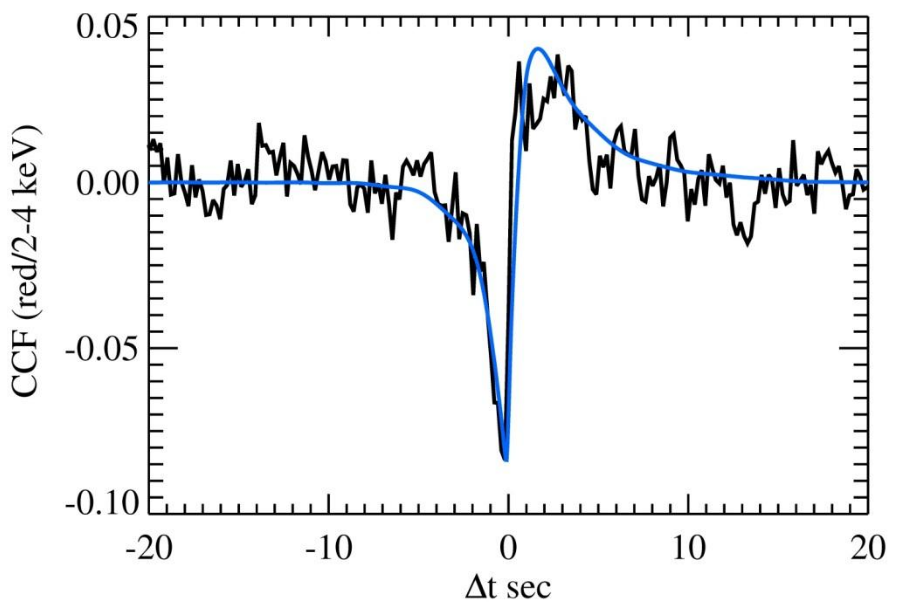
Gandhi et al. 2010

Examples

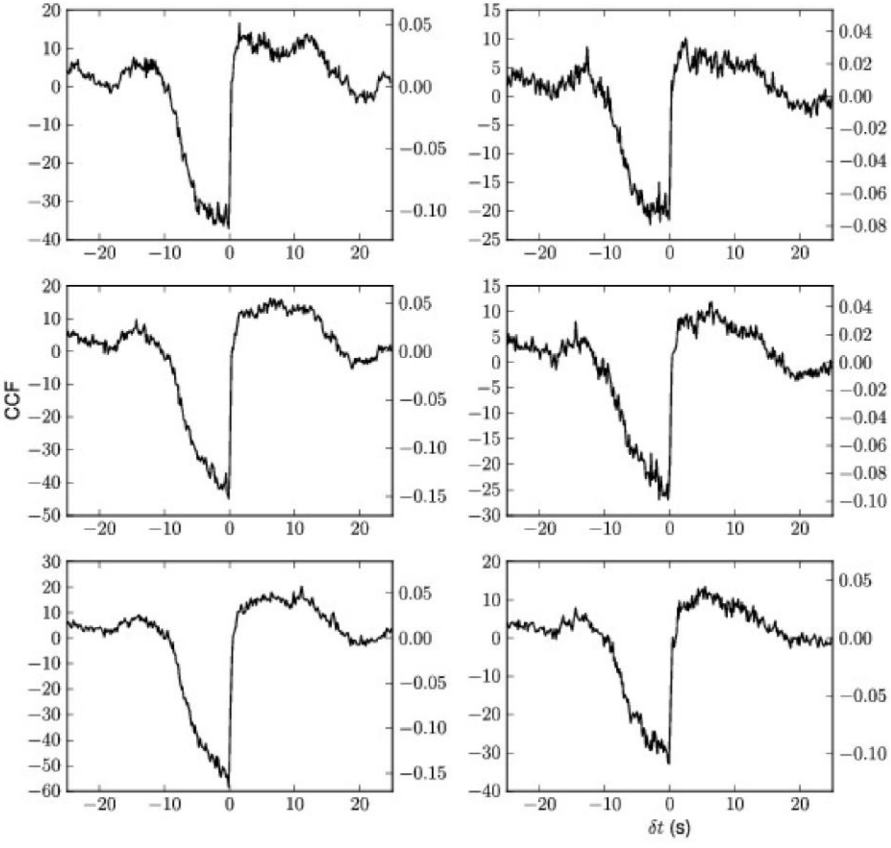


Durant et al. 2010

Swift J1753.5-0127

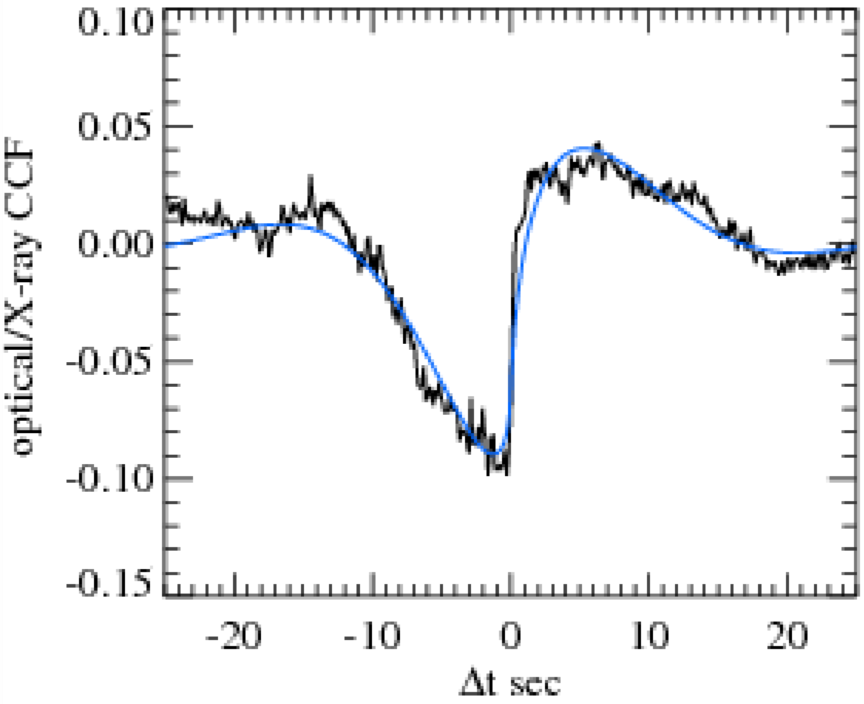


Examples

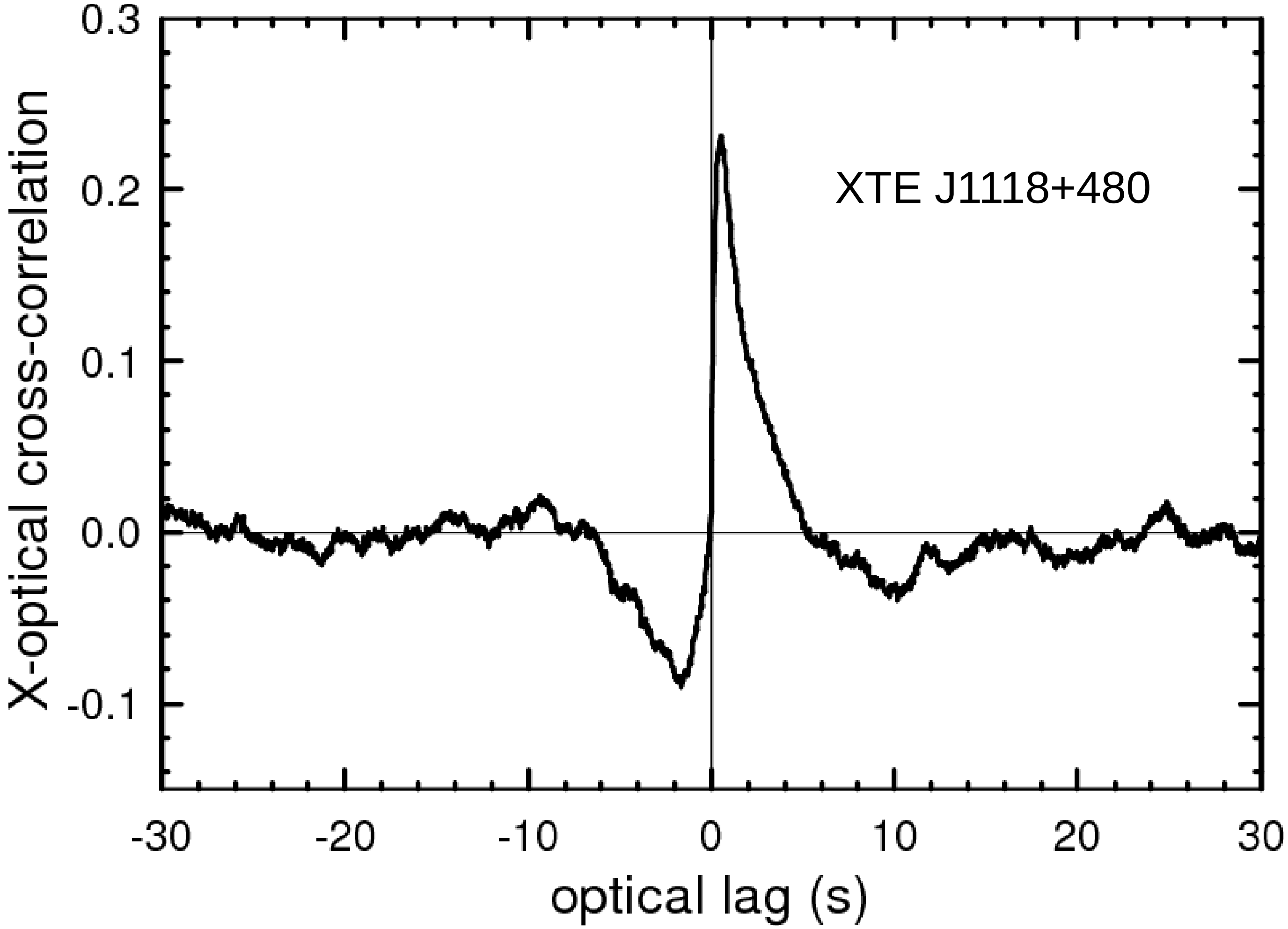


Durant et al. 2010

Swift J1753.5-0127

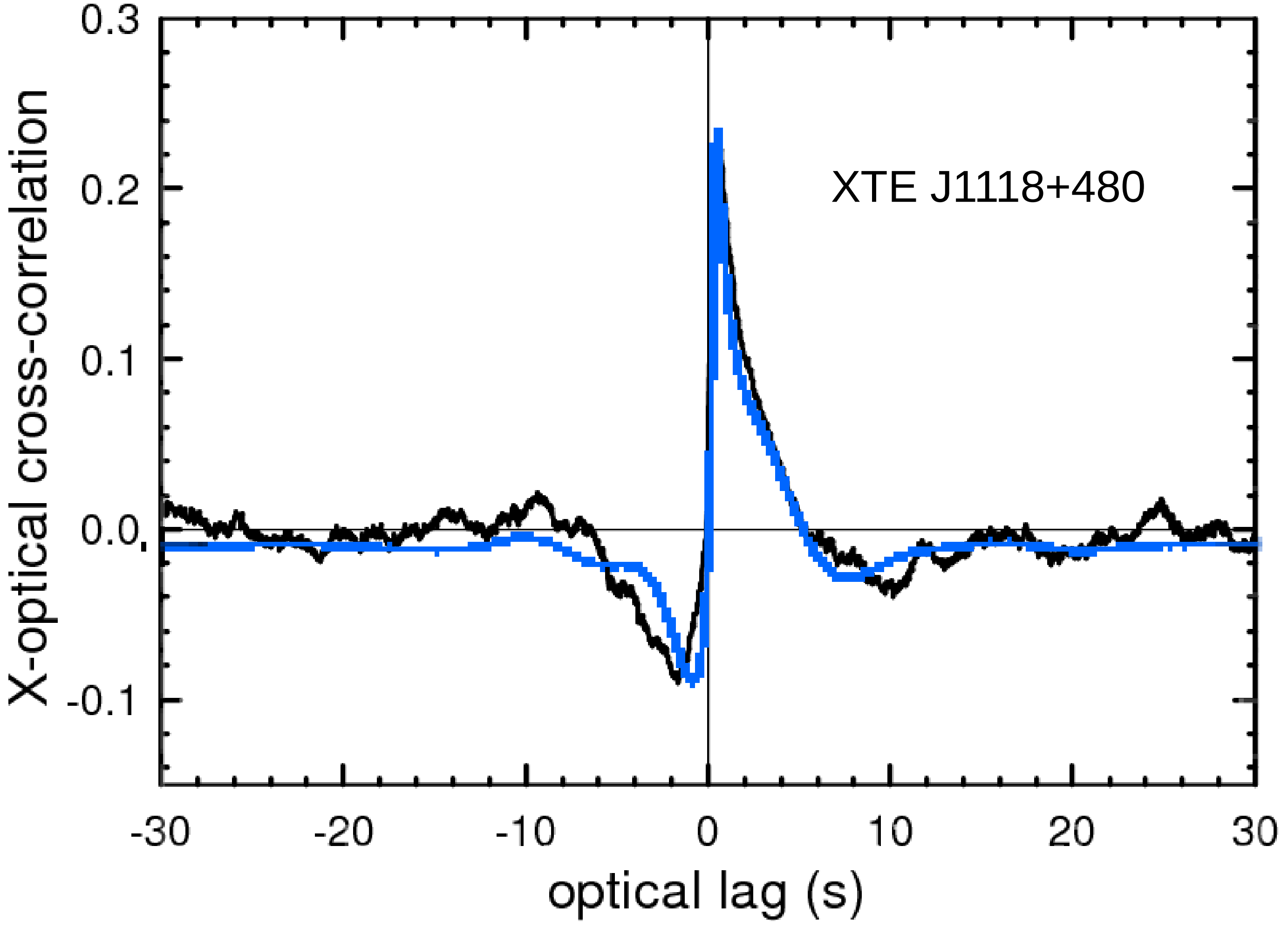


Examples



Kanbach et al.2001

Examples



Kanbach et al.2001

Conclusions

- Synchrotron radiation of non-thermal particles contributes to the optical energy band
- The optical/X-ray CCF is explained by joint contribution of the synchrotron + irradiated disc emission
- The interplay of the two components explains fast optical variability (narrow ACF or, equivalently, bump at high frequencies of the PDS)