Rapid Optical/X-ray timing of black hole binaries: correlated and non-linear variability

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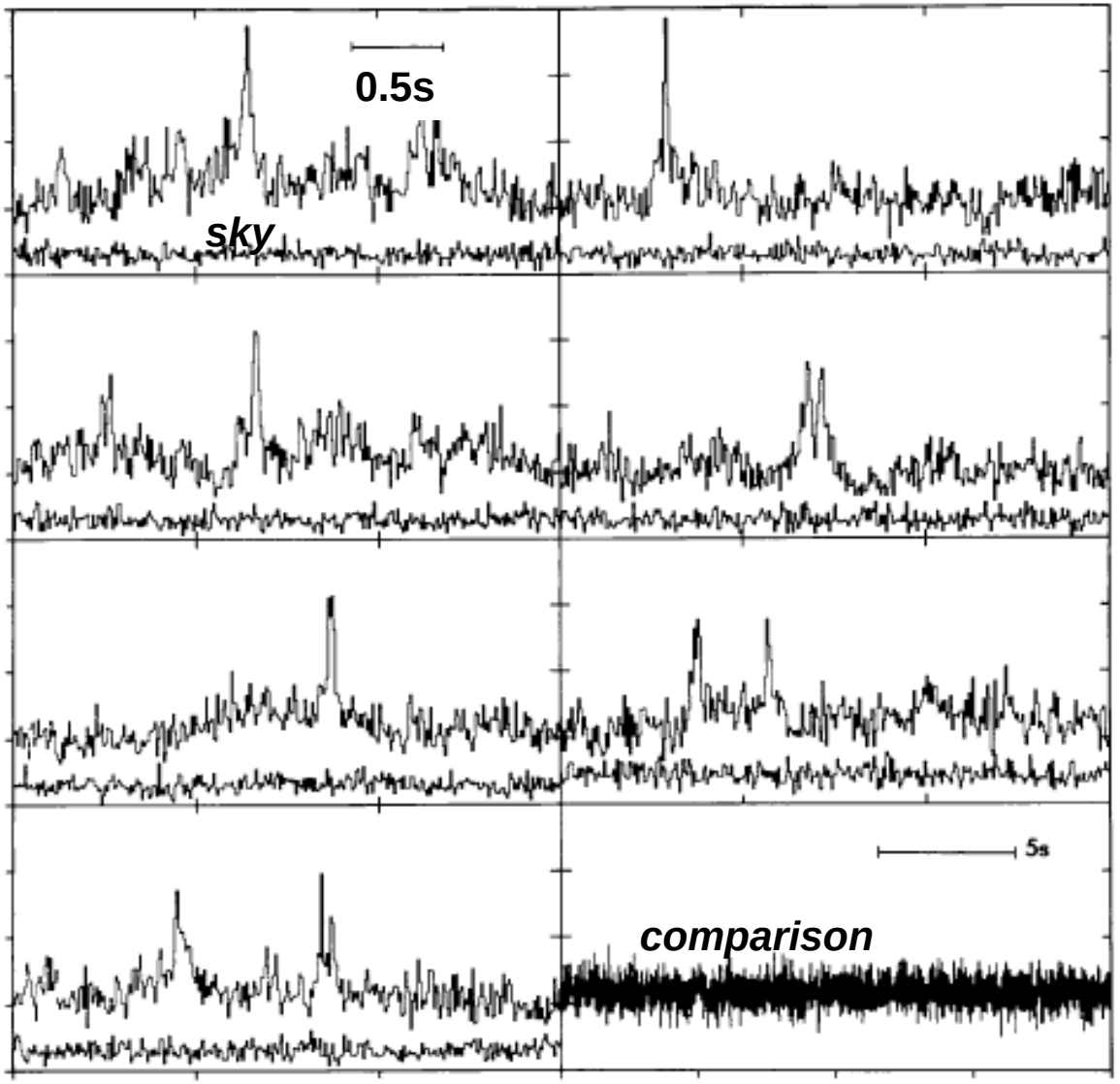
J.M. Miller (USA)
H.C. Spruit (Germany)

Optical power of X-ray binaries

Optical timing

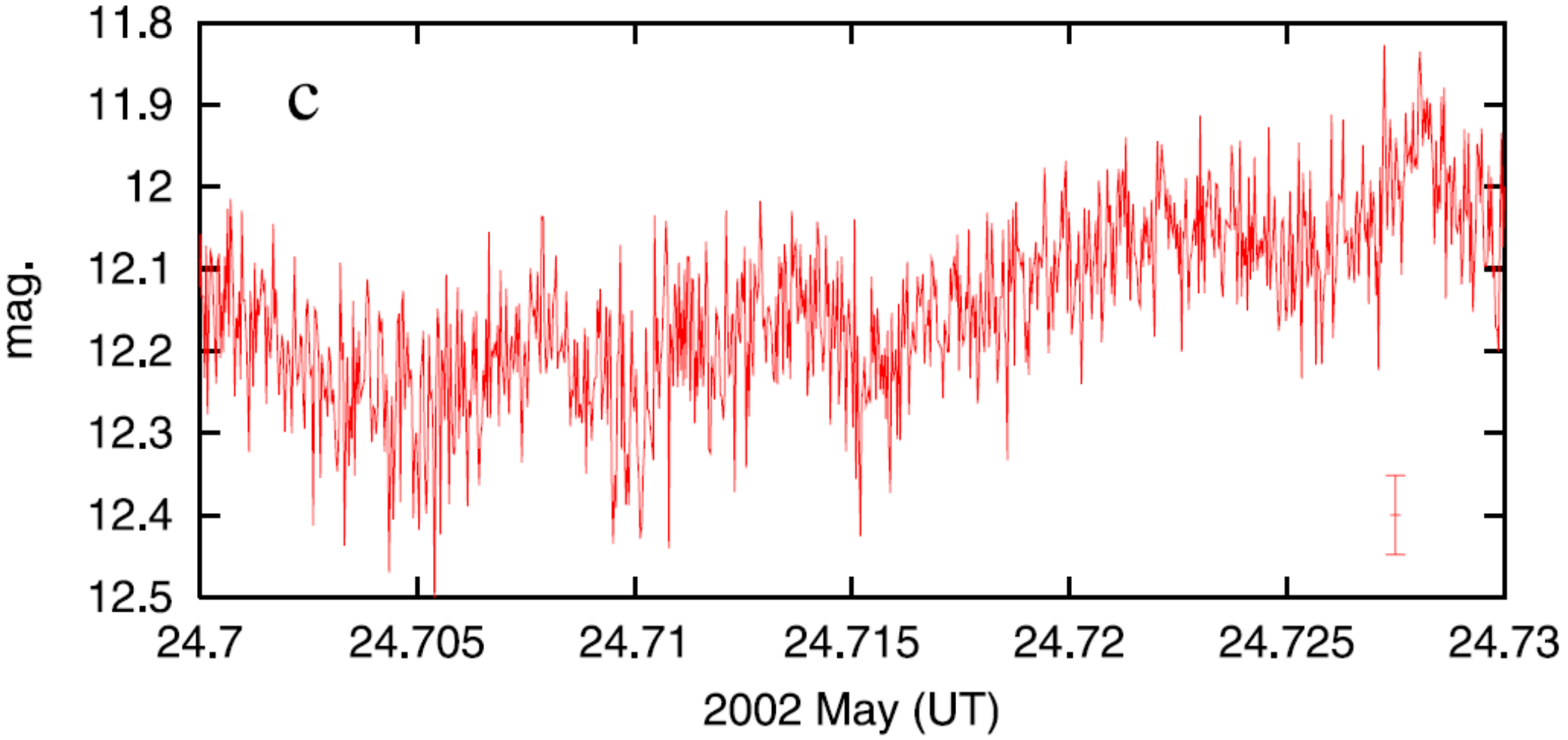
Early indications:
but not followed up, nor fully understood



(GX 339-4: Motch et al. 1982)

Optical timing

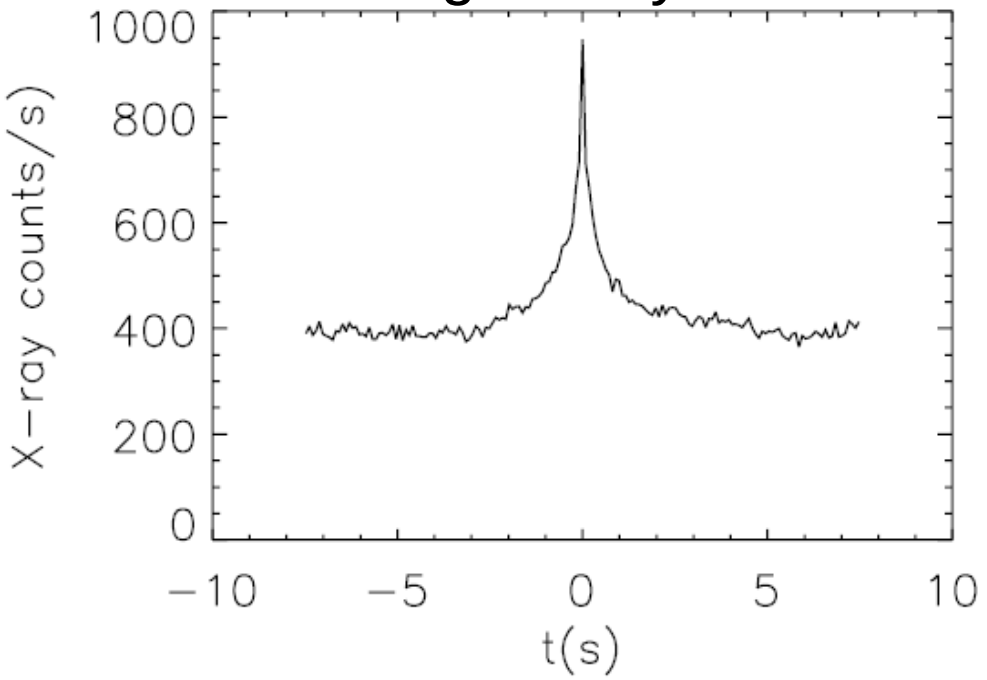
V4641 Sgr:



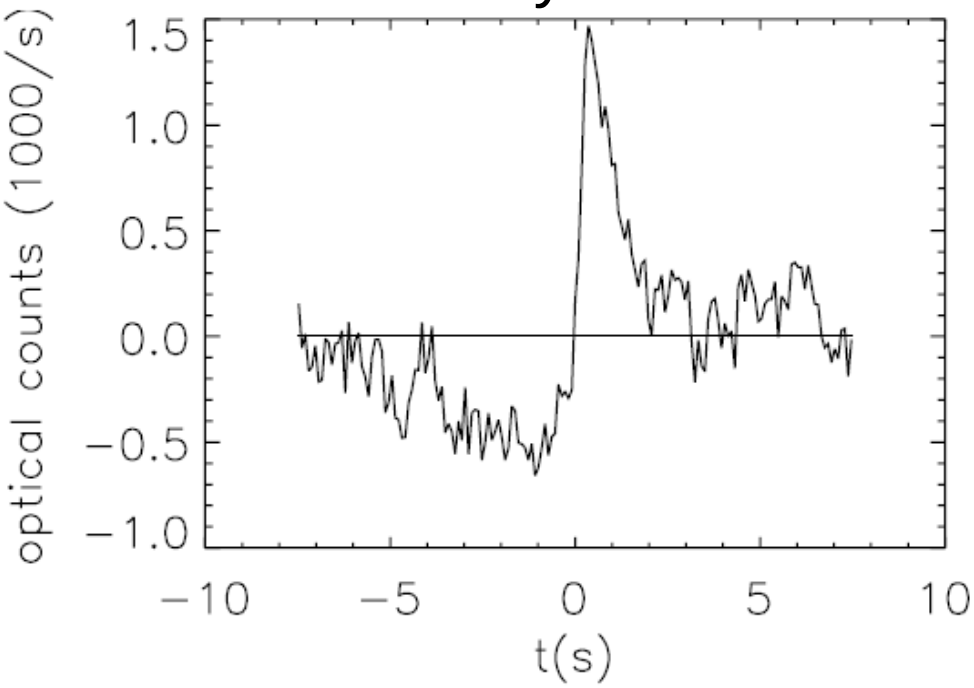
(Uemura et al. 2002)

XTE J1118+480

Average X-ray flares

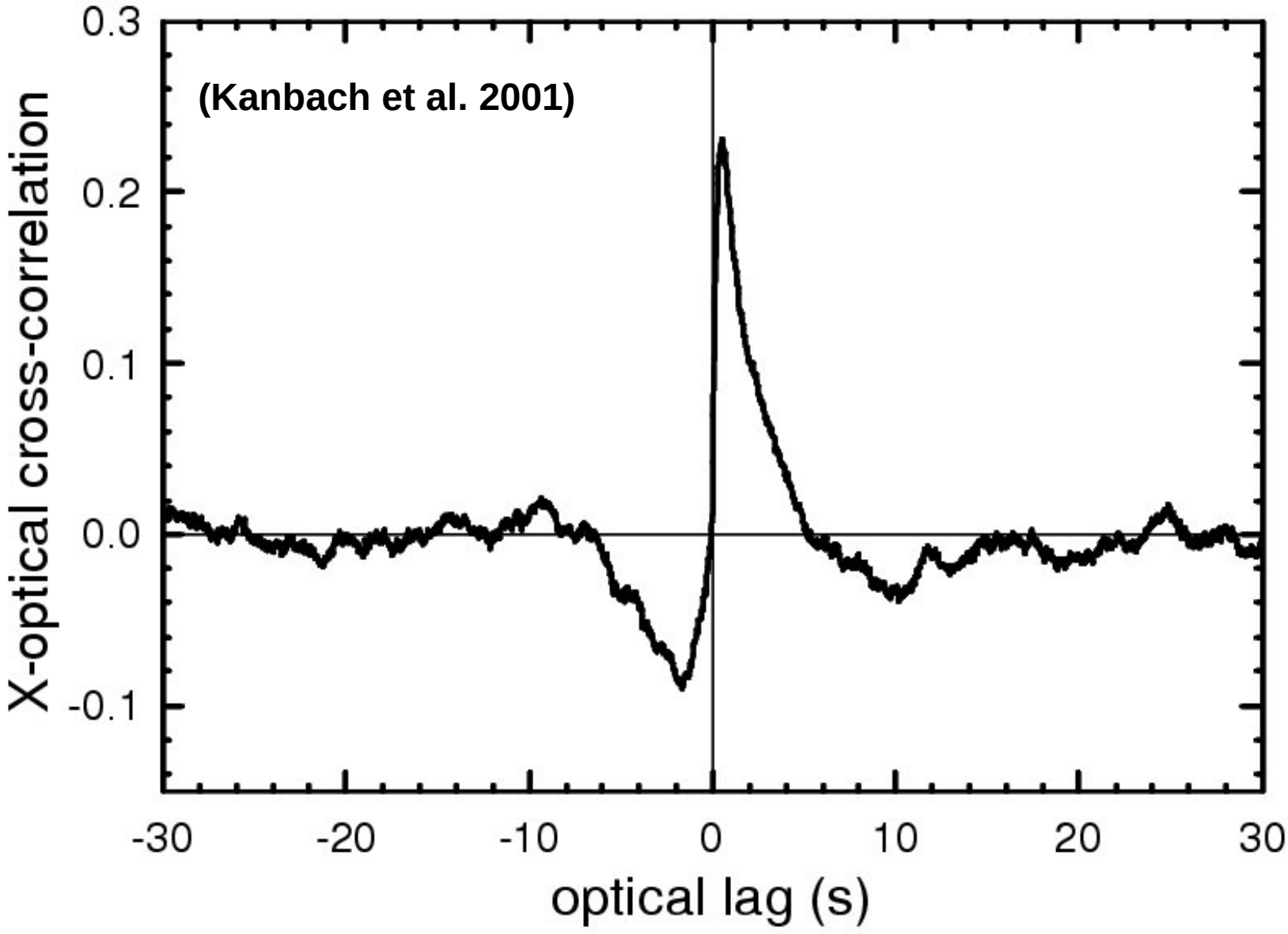


Average optical around X-ray flares

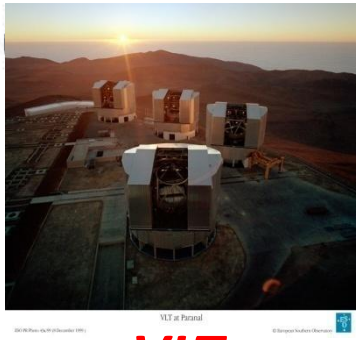


(Kanbach et al. 2001, Spruit et al. 2002)

XTE J1118+480



Our observations



VLT

+

RXTE

1. *GX 339-4*
2. *Swift J1753.5-0127*

ULTRACAM:
ultra-fast, triple-beam CCD camera

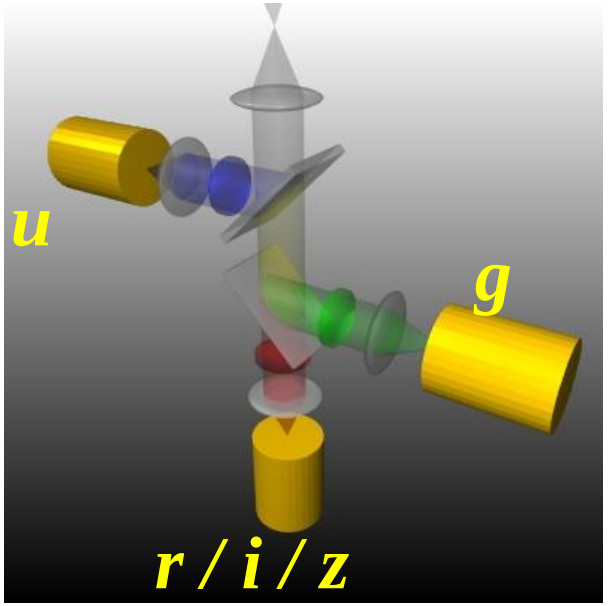
- Light-weight camera
(visitor instrument on *WHT/VLT/NTT*)

- Frame-transfer CCDs with
negligible dark current, dead-time

- Speeds ~ 500 frames / sec

- 3 simultaneous optical filters

- Absolute timing ~ 1 ms



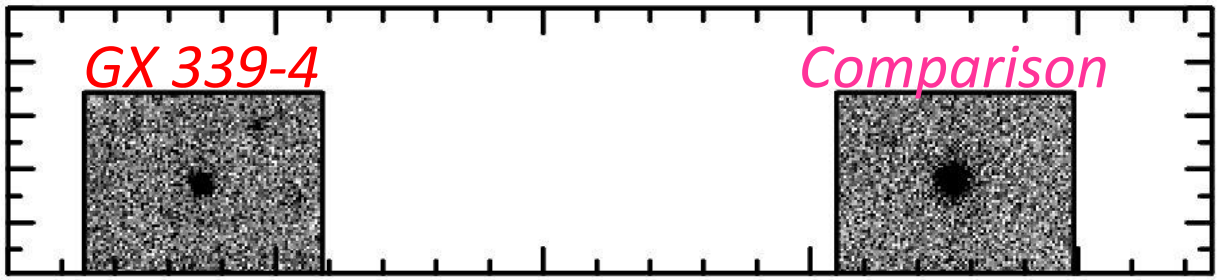
ULTRACAM Mounted on Visitor Focus of MELIPAL

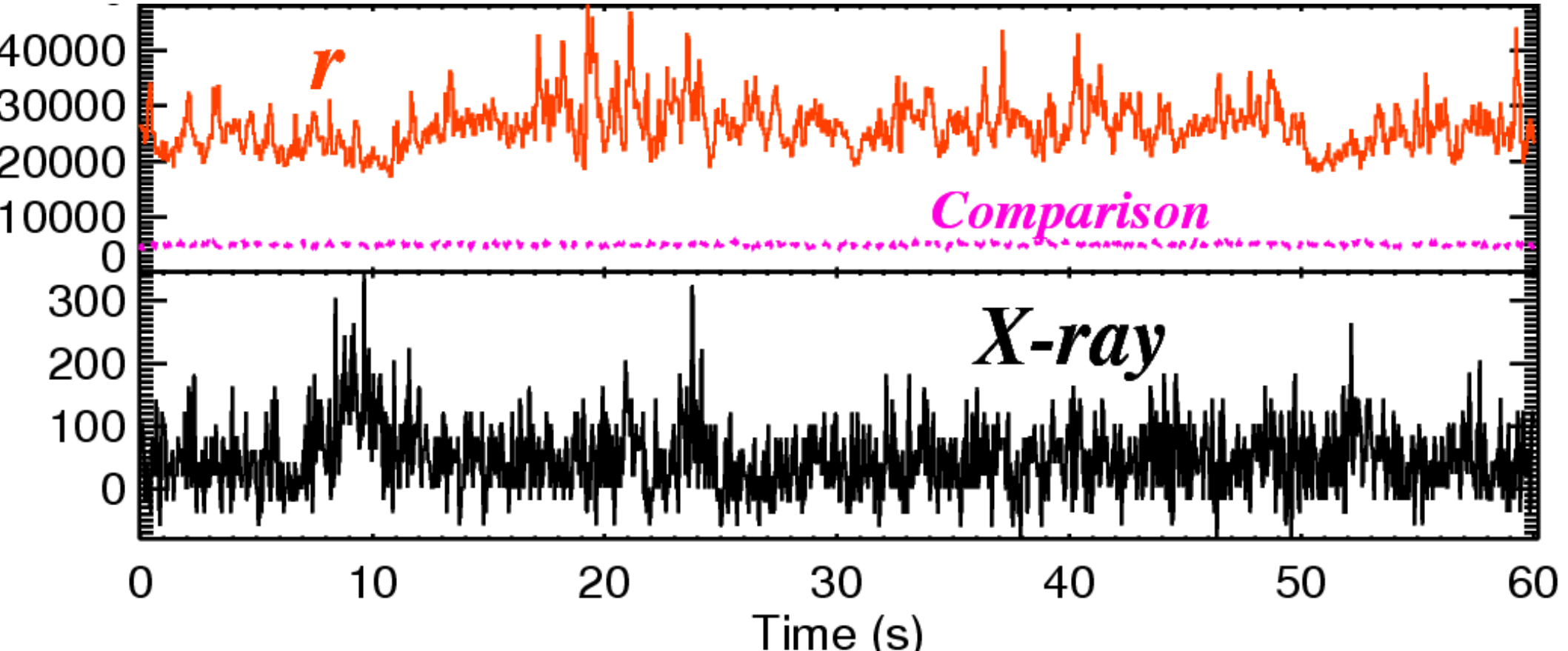
ESO PR Photo 19a/05 (9 June 2005) ©ESO

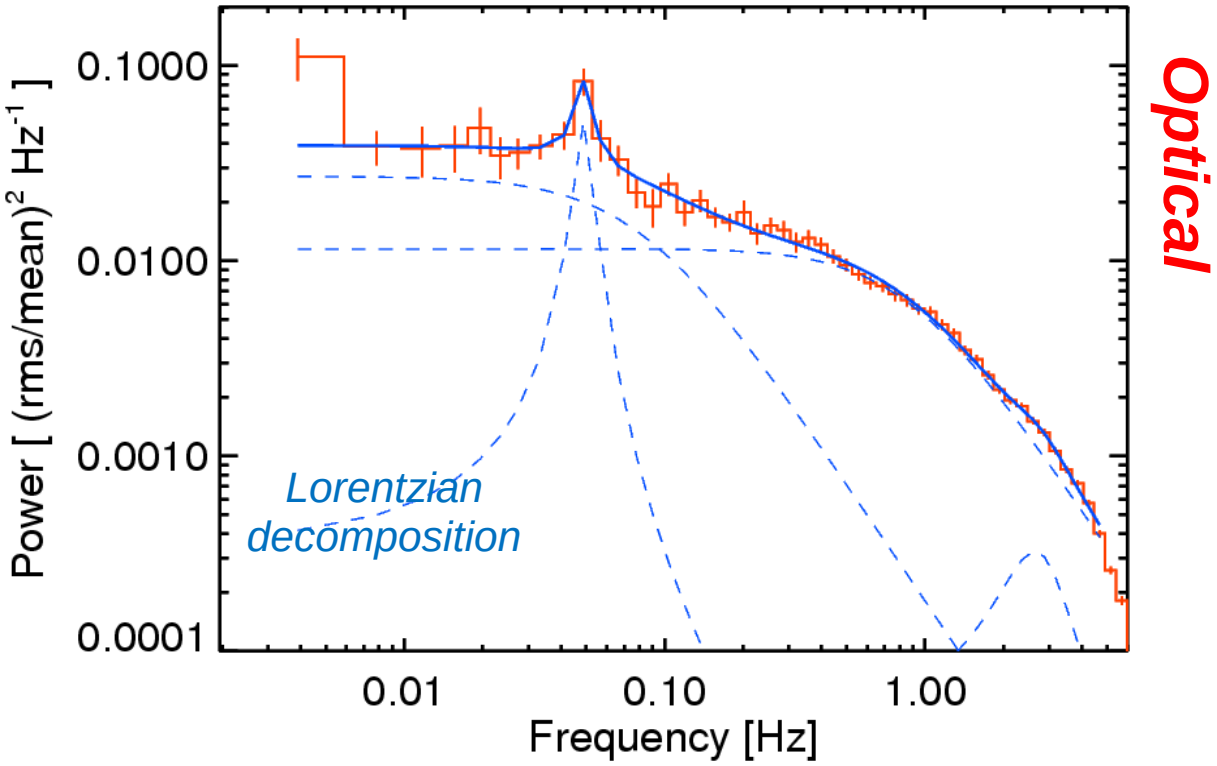
http://www.shef.ac.uk/physics/people/vdhillon/ultracam/

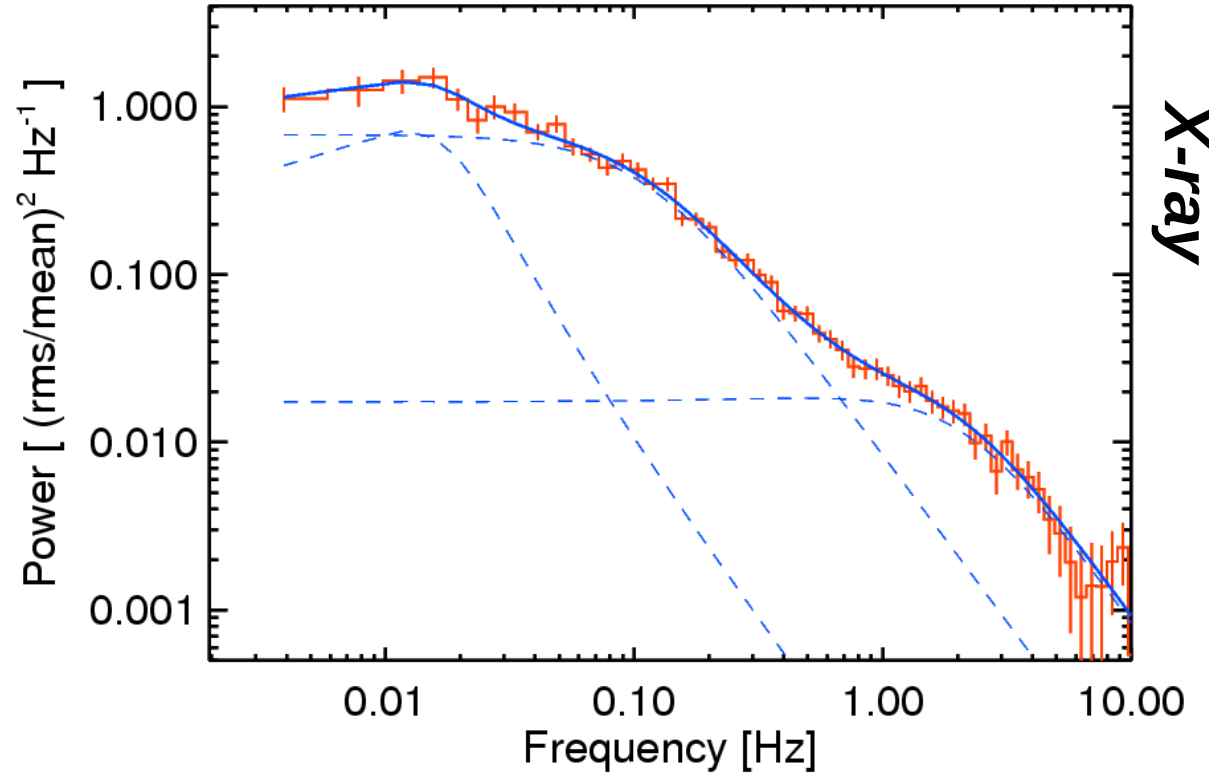
Observations

50 ms ULTRACAM frame (r' band)





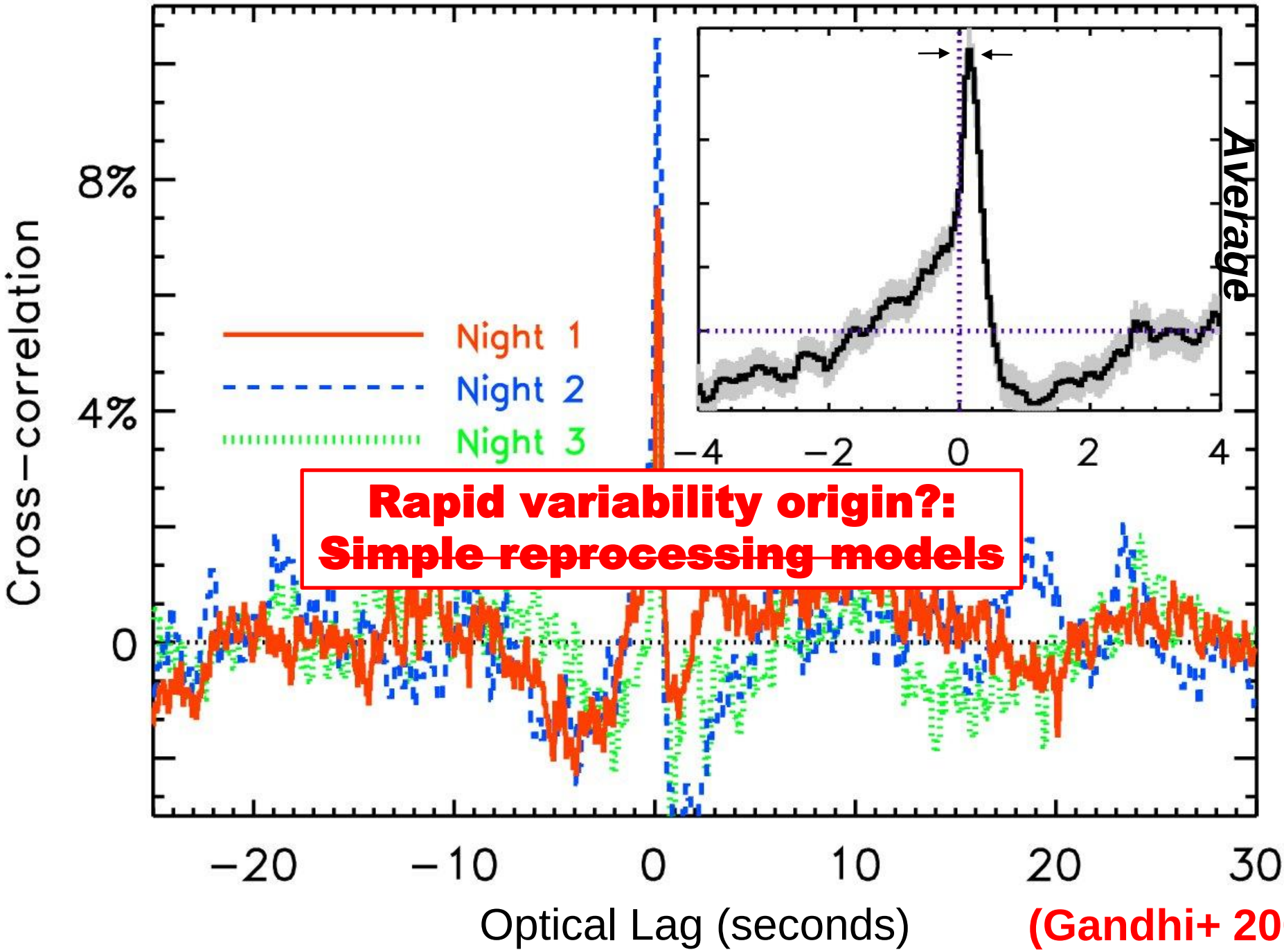




Power Spectra show

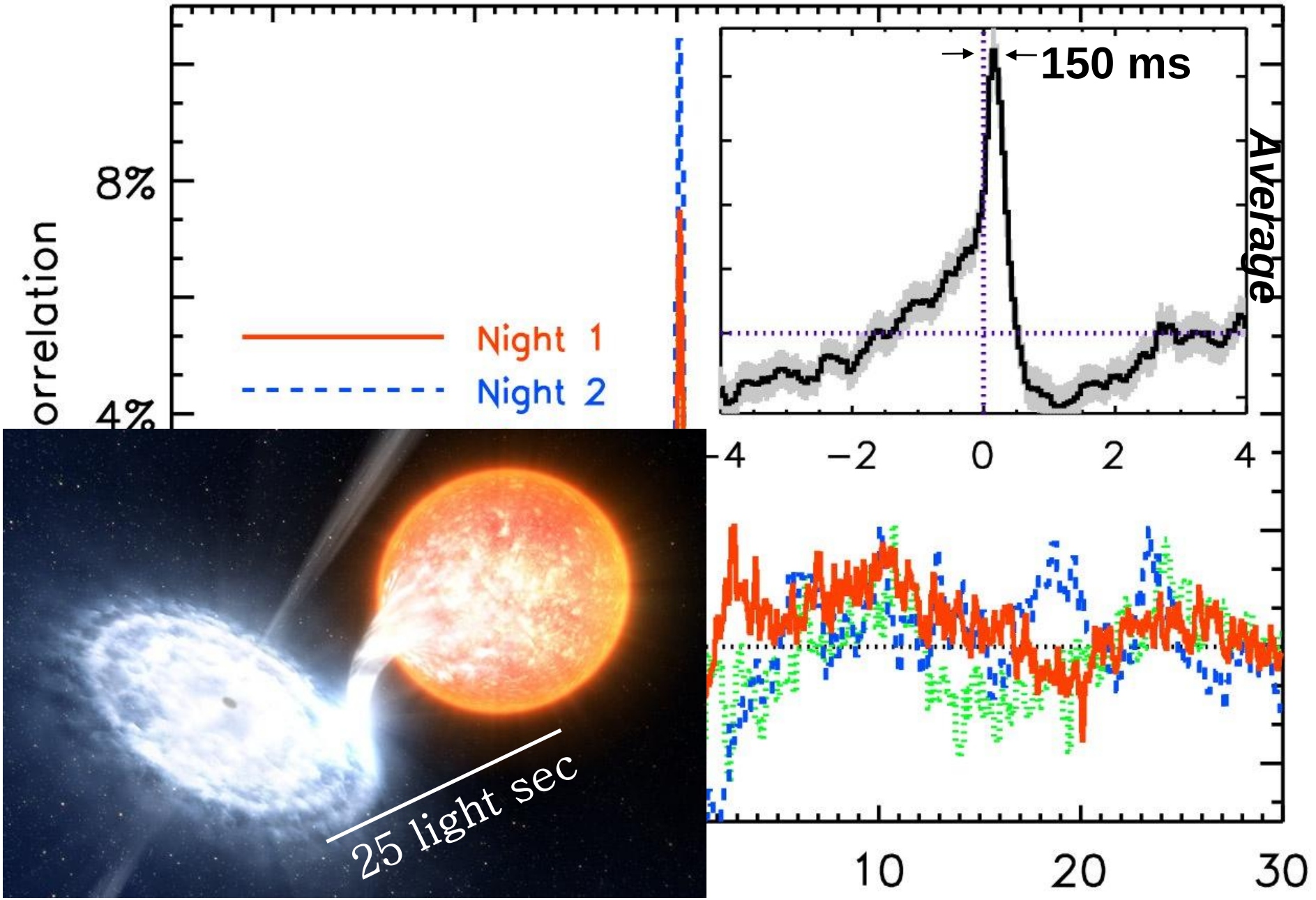
broad-band noise

X-O Cross Correlation Function (CCF)



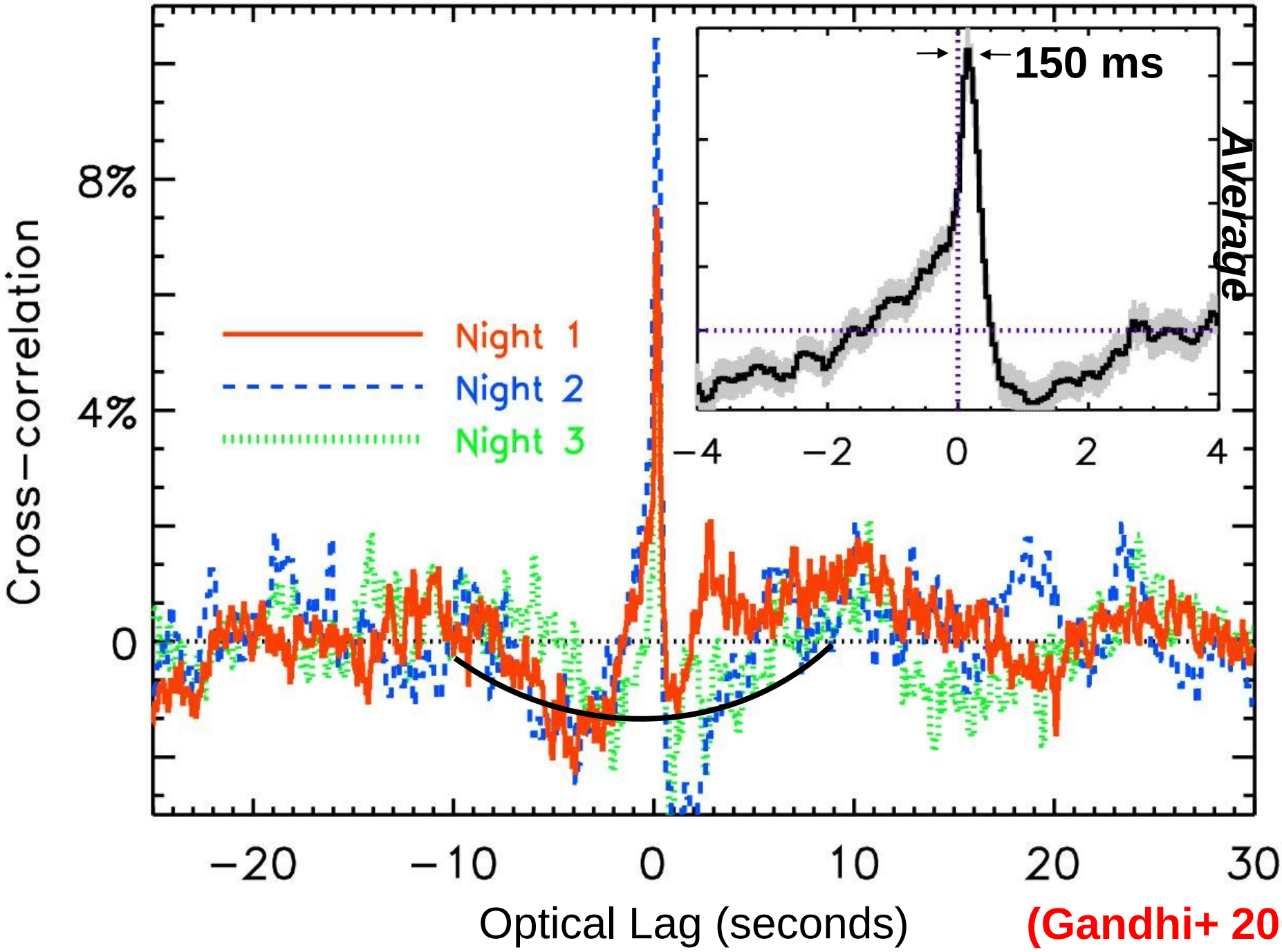
(Gandhi+ 2008)

1. Small time delay



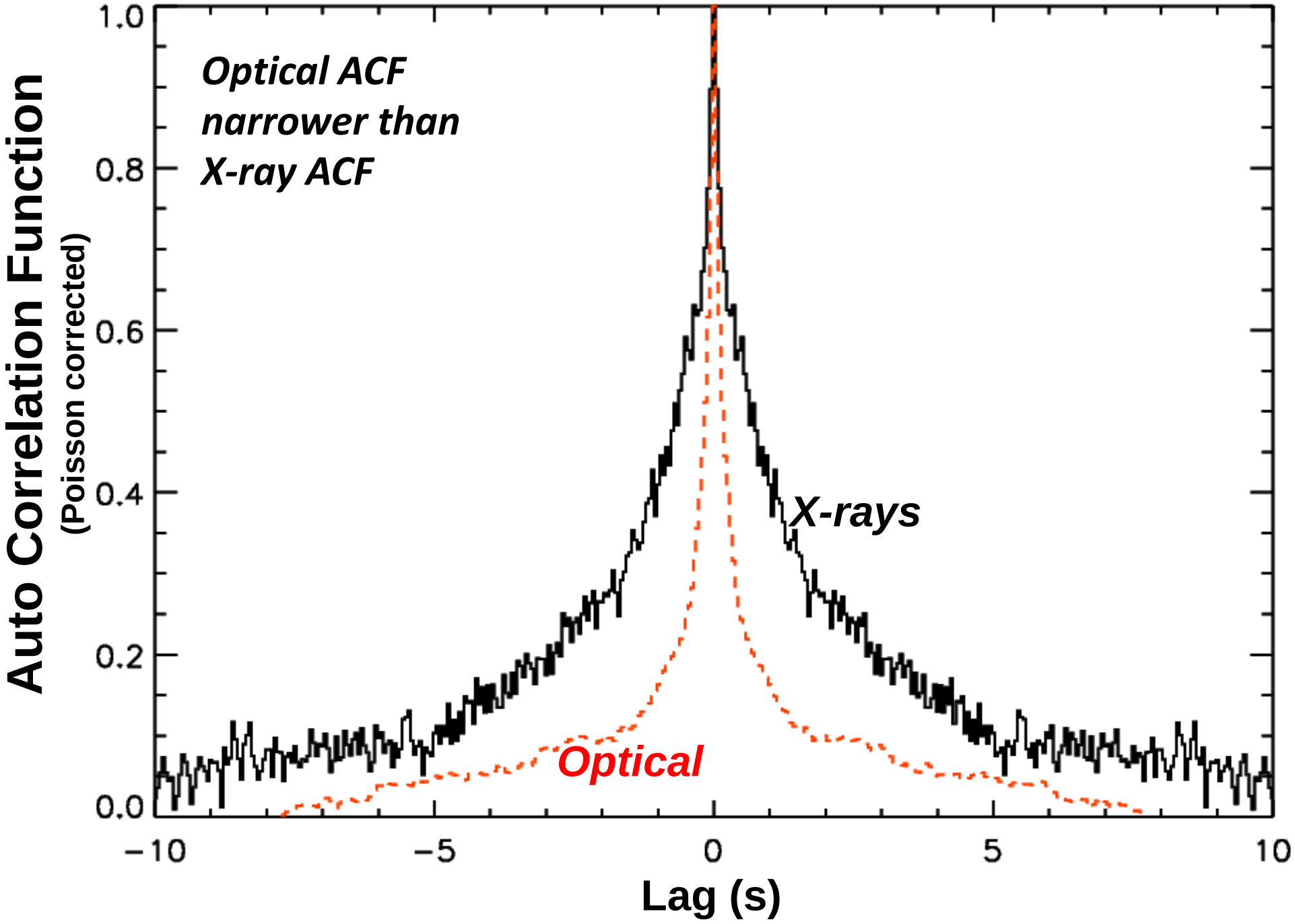
(Gandhi+ 2008)

2. Anti-correlation



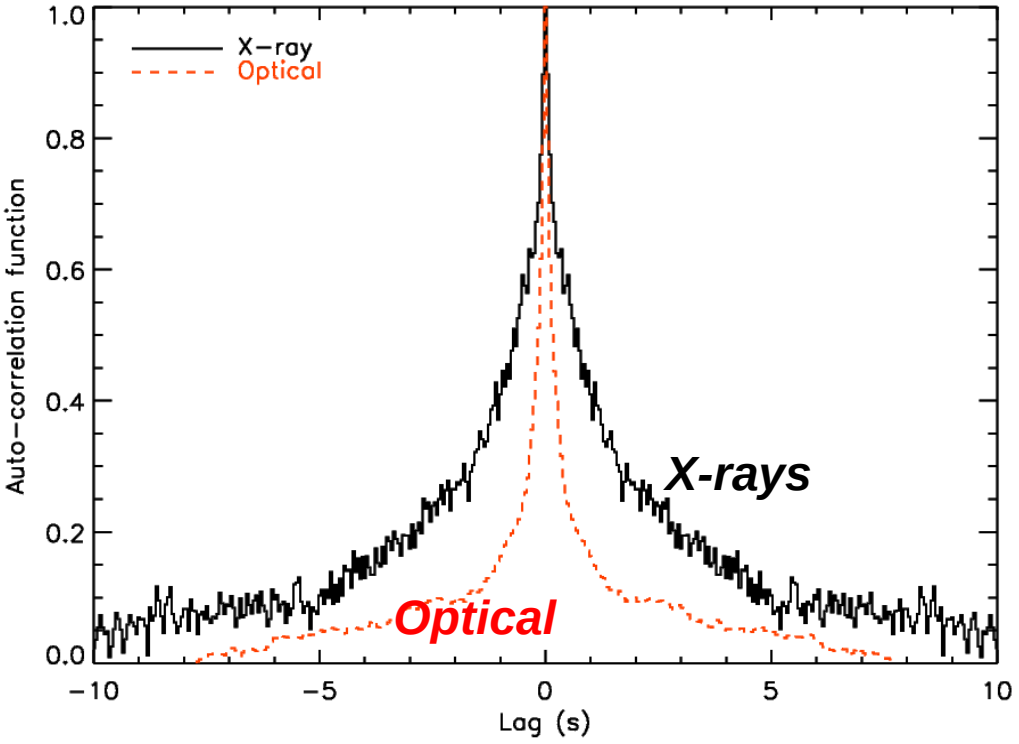
(Gandhi+ 2008)

3. Small optical coherence times

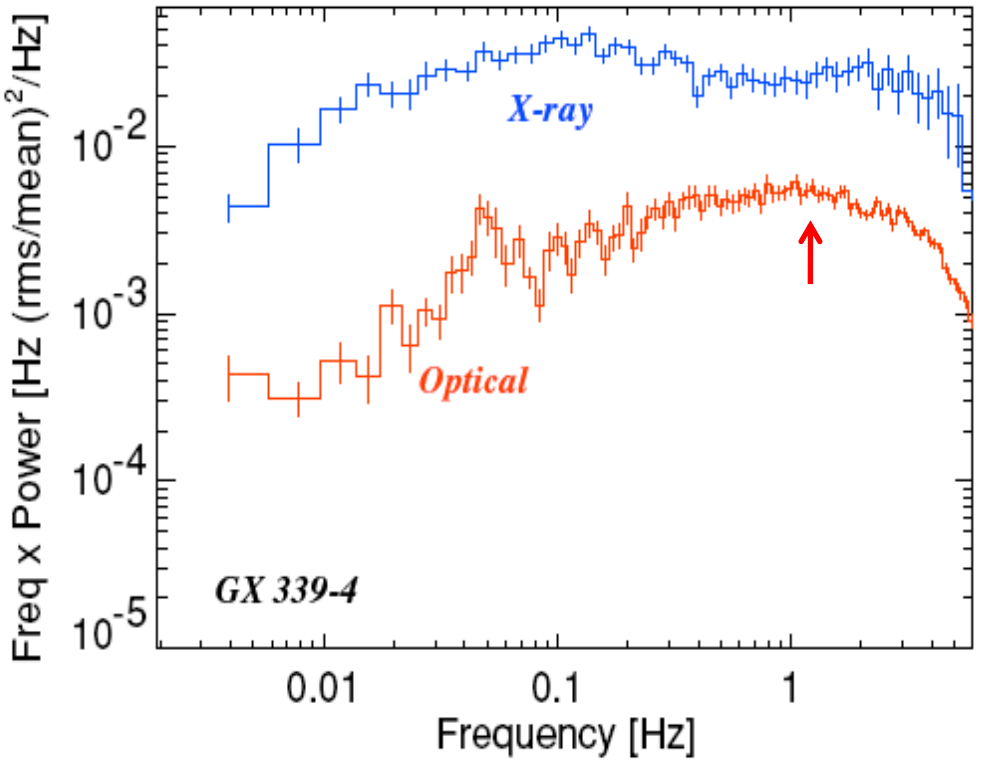


3. Small optical coherence times

Auto correlation functions

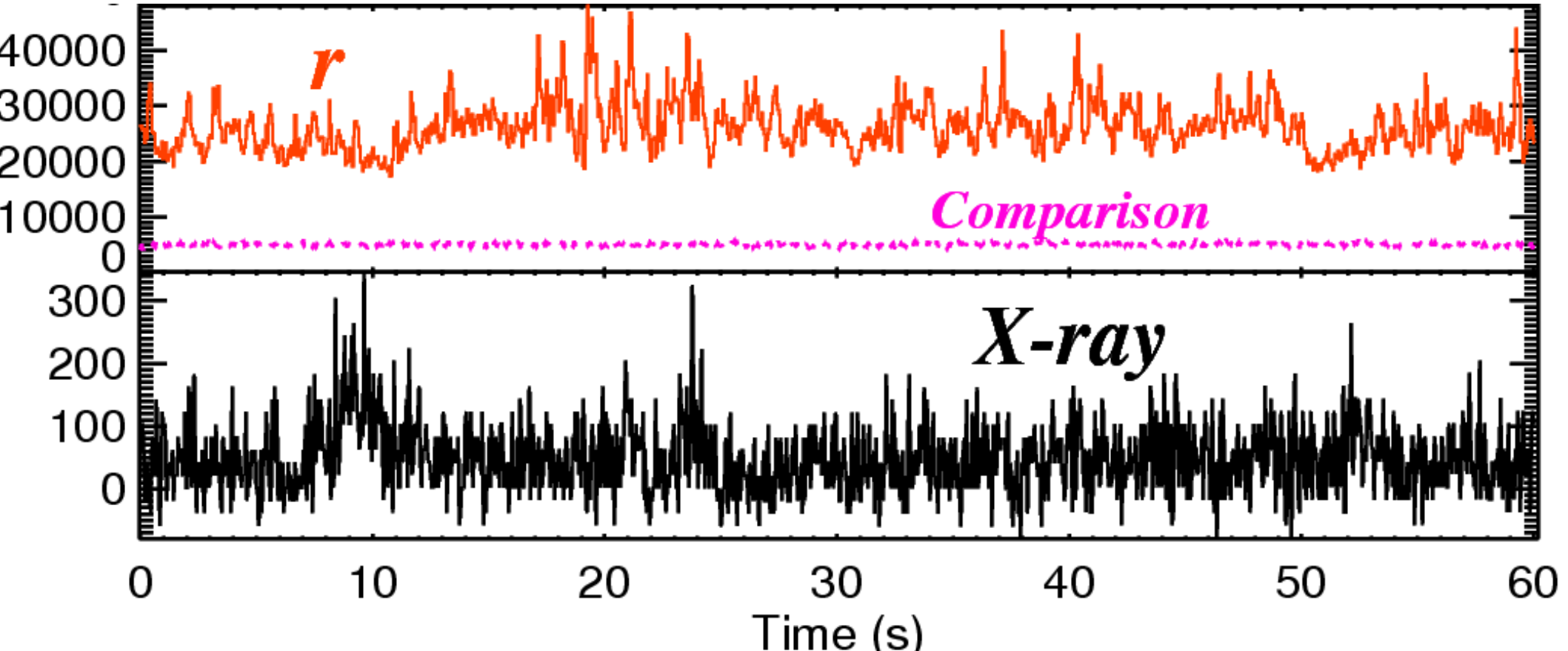


Power spectra

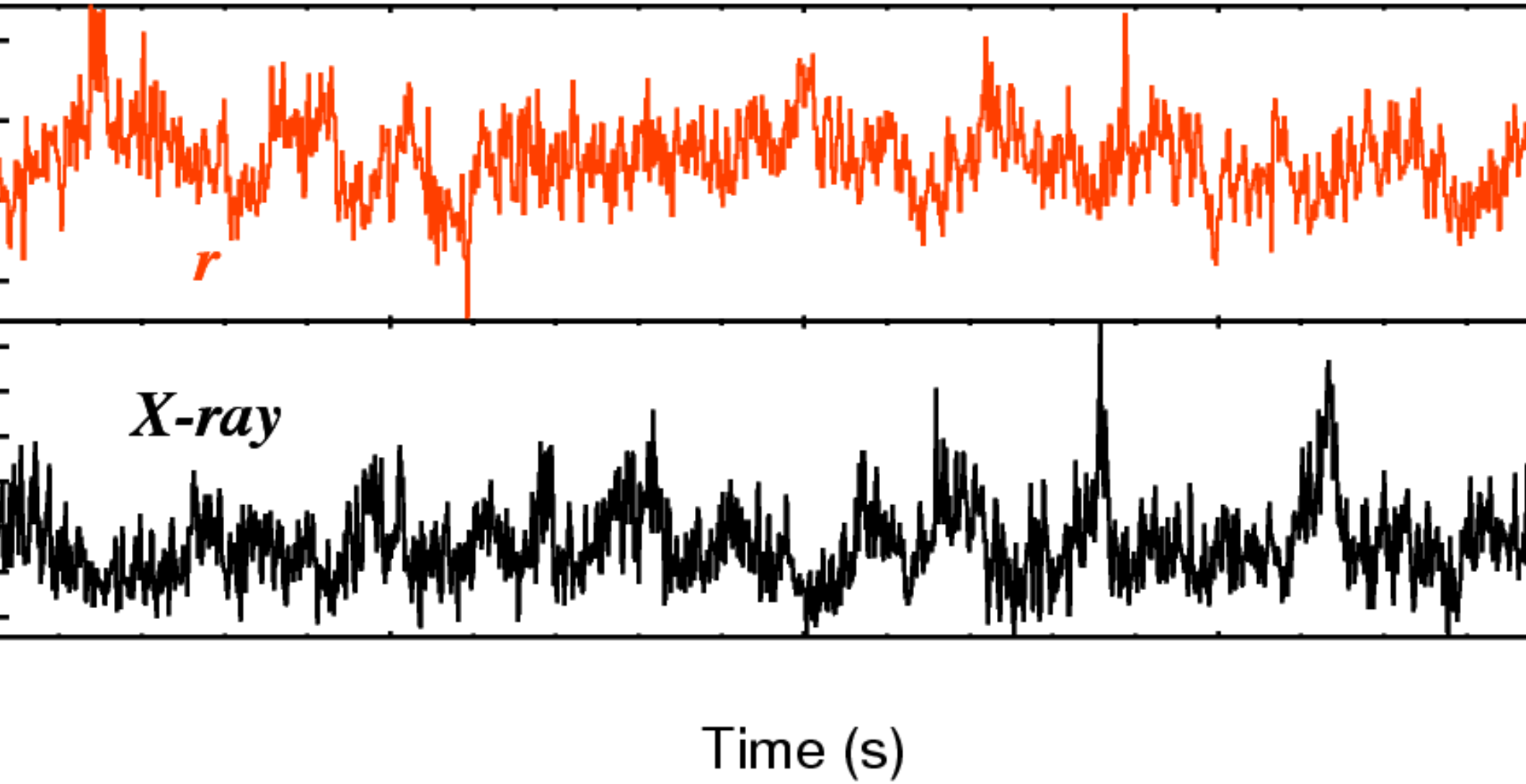


(rms² normalization: Belloni+90)

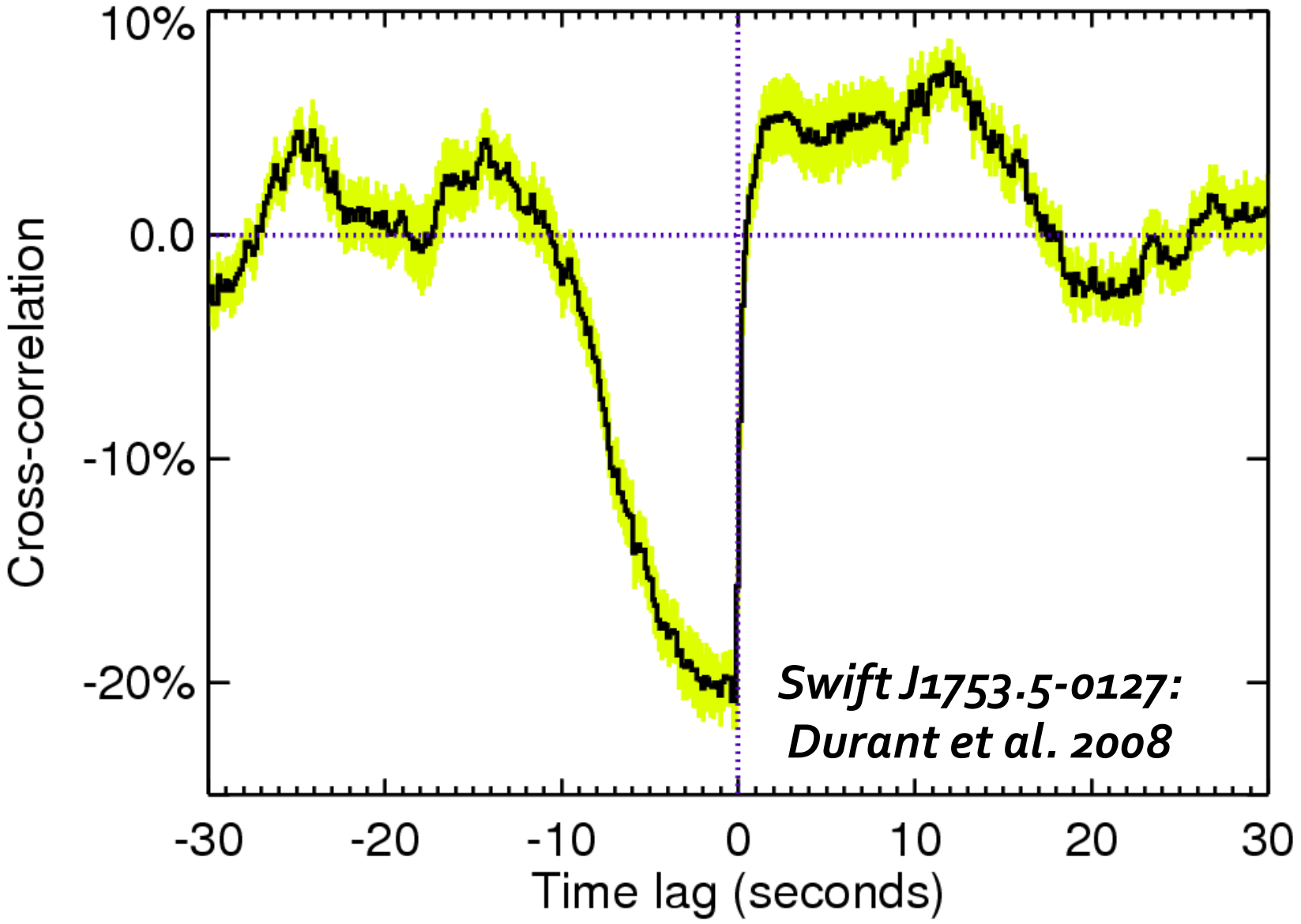
GX 339-4: Simultaneous light curves



Swift J1753.5-0127: Simultaneous light curves



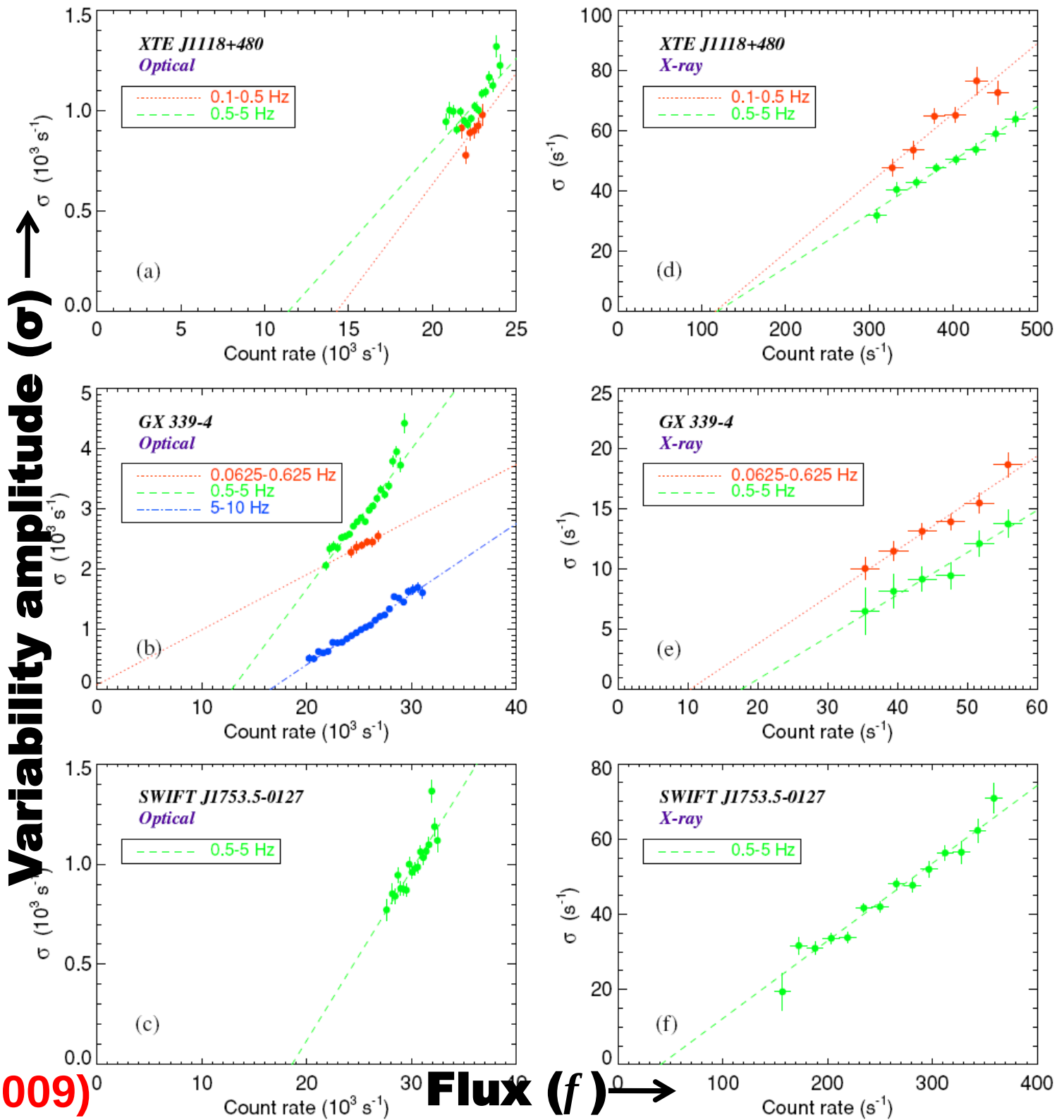
Complex optical/X-ray correlations



Non-linear variability:

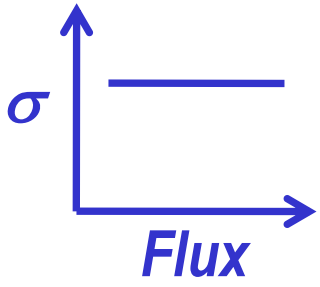
$$\frac{df}{dt} \propto f$$

Random shot noise predicts constant σ



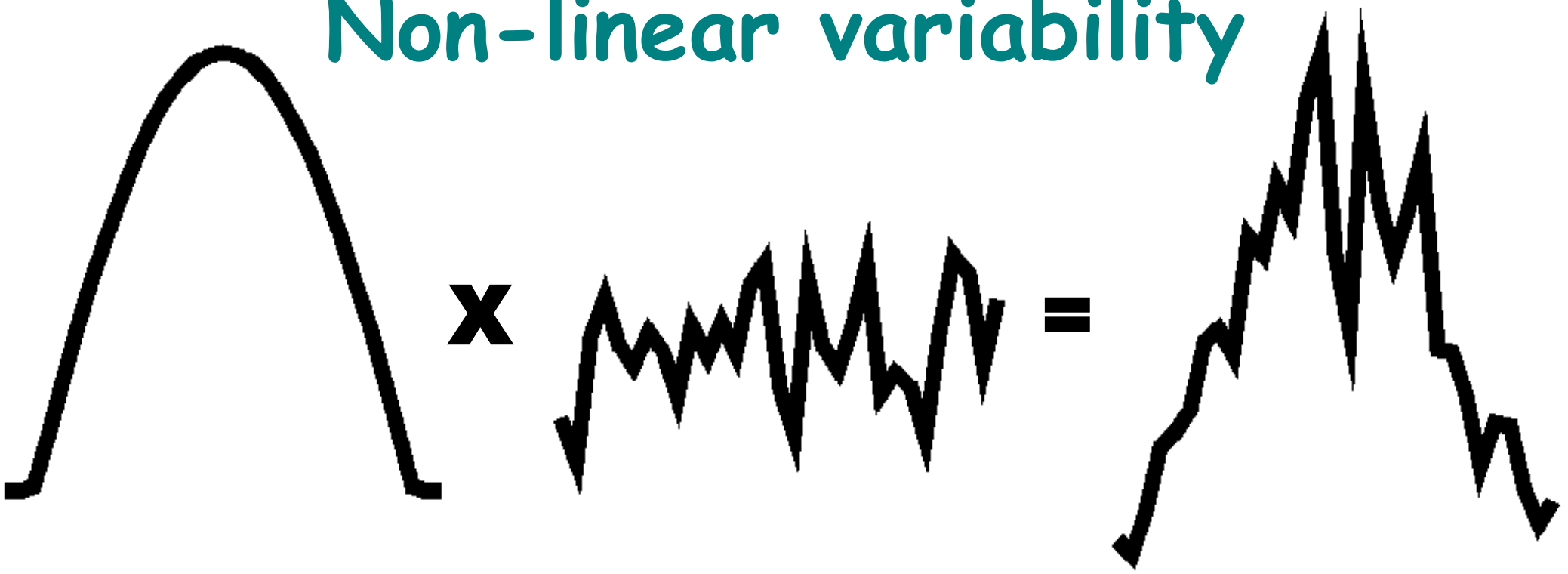
(Gandhi 2009)

Additive shots ruled out

Superposition of independent shots => 

Ruled out in X-rays (Uttley et al. 2001…2005)
and now optical (Gandhi 2009)

Non-linear variability

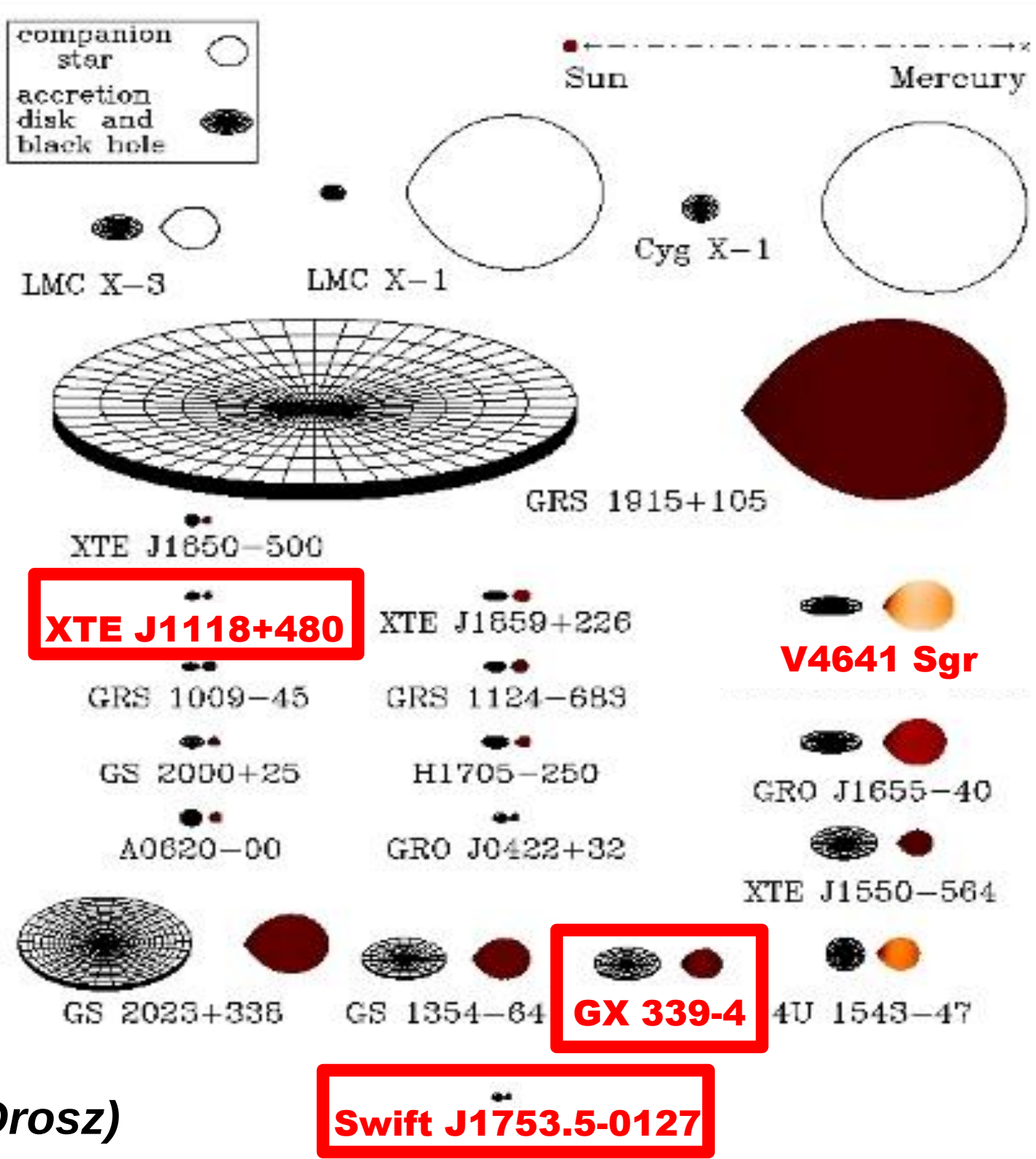


Perturbations must be ***coupled*** together, rather than *superposed*

⇓

Interactions between multiple emission components
(Lyubarskii 97, Misra 00, King+04, Titarchuk+07, Zhang 07)

X-ray binaries



(J. Orosz)

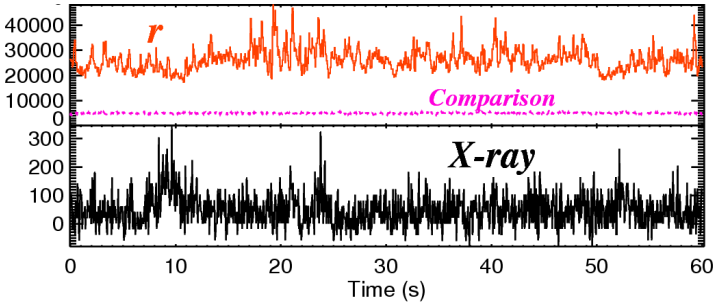
Summary

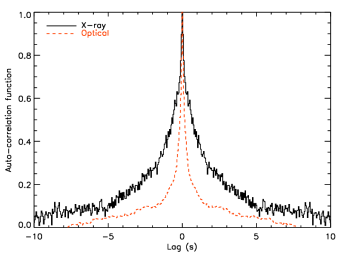
- Simultaneous rapid optical/X-ray timing of X-ray binaries in low/hard state.

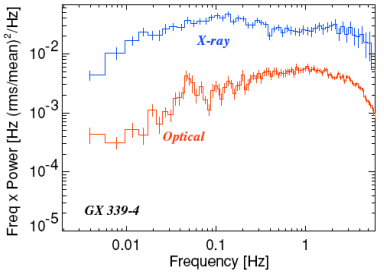
- Optical not reprocessed.

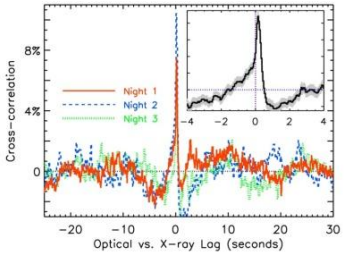
- Complex CCF
  => jet/corona/disk interaction

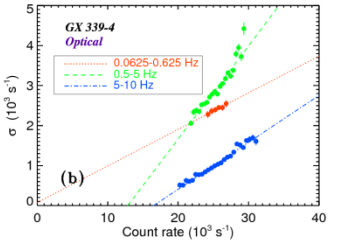
- X-ray and optical r.m.s. scales with flux
  => additive shots ruled out











Fast optical timing => interesting constraints on accretion and hot plasmas