Coordinated multi-wavelength rapid timing of X-ray binaries

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Marting Durant

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Andy Fabian
Julien Malzac
Jon Miller

What is the source of the optical power of X-ray binaries?

Comparison to blackbody optical reprocessing model

Reprocessed emission

$\propto$

f(incident flux, area of reprocessor)

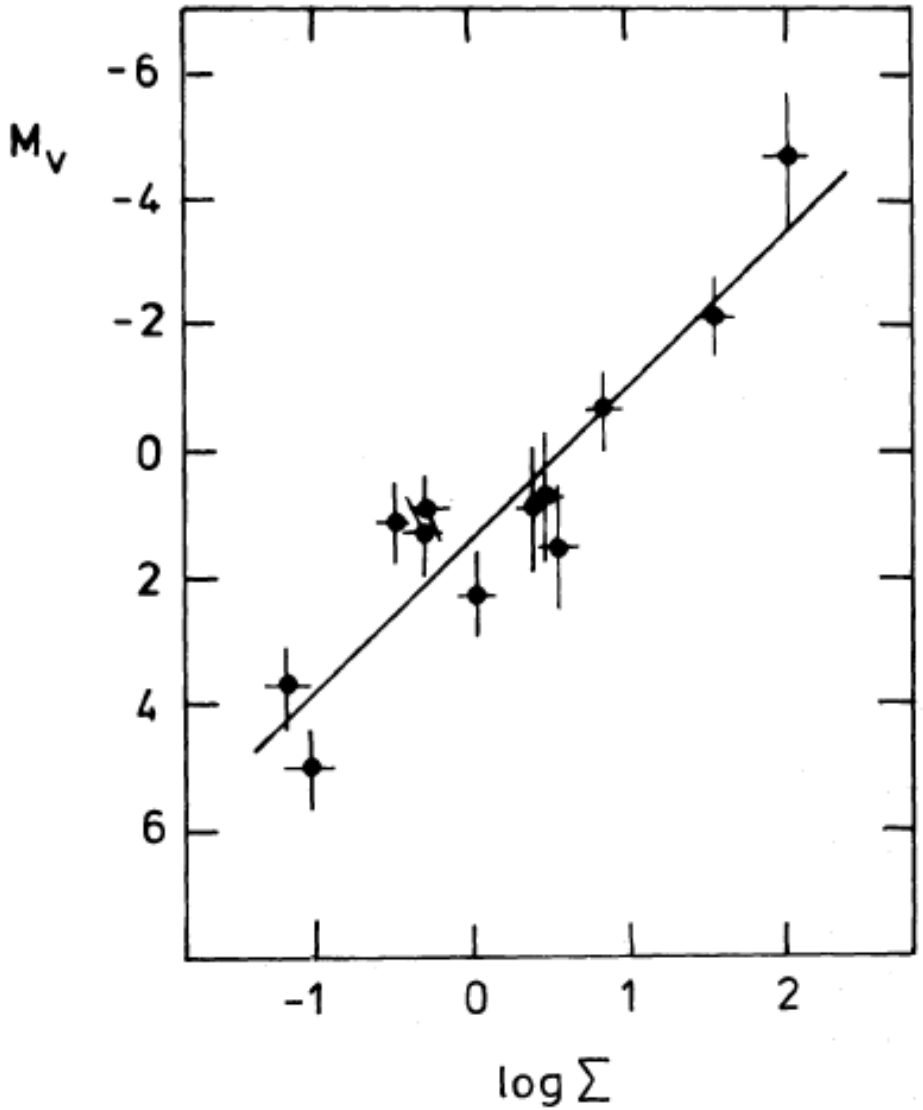
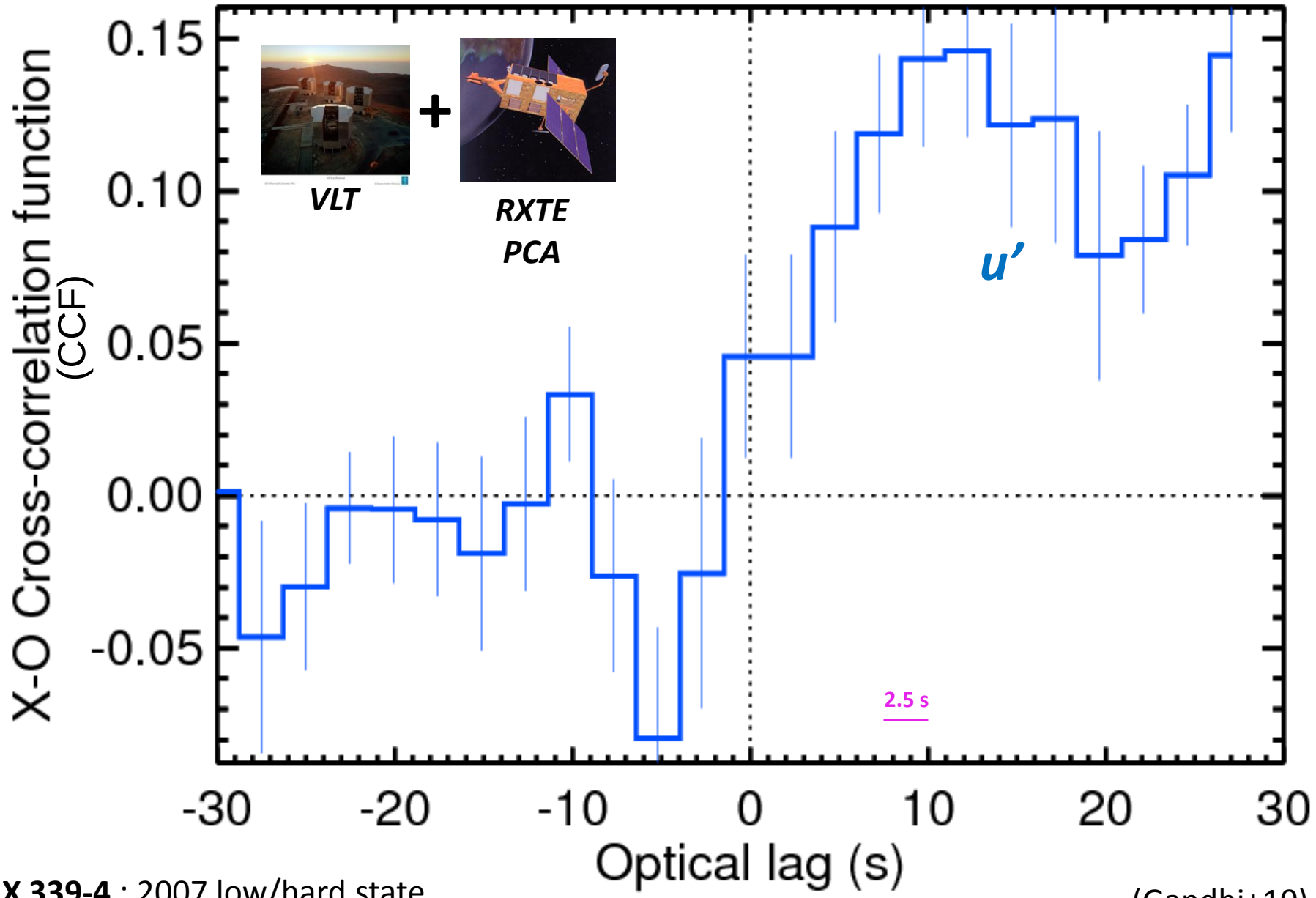


Fig. 2. Relation between the absolute visual magnitude M_V and $\Sigma = (L_X/L_{Edd})^{1/2}\ (P/\ 1\text{hr})^{2/3}$. The straight line represents the least-squares fit (see text)

(van Paradijs & McClintock 1994)

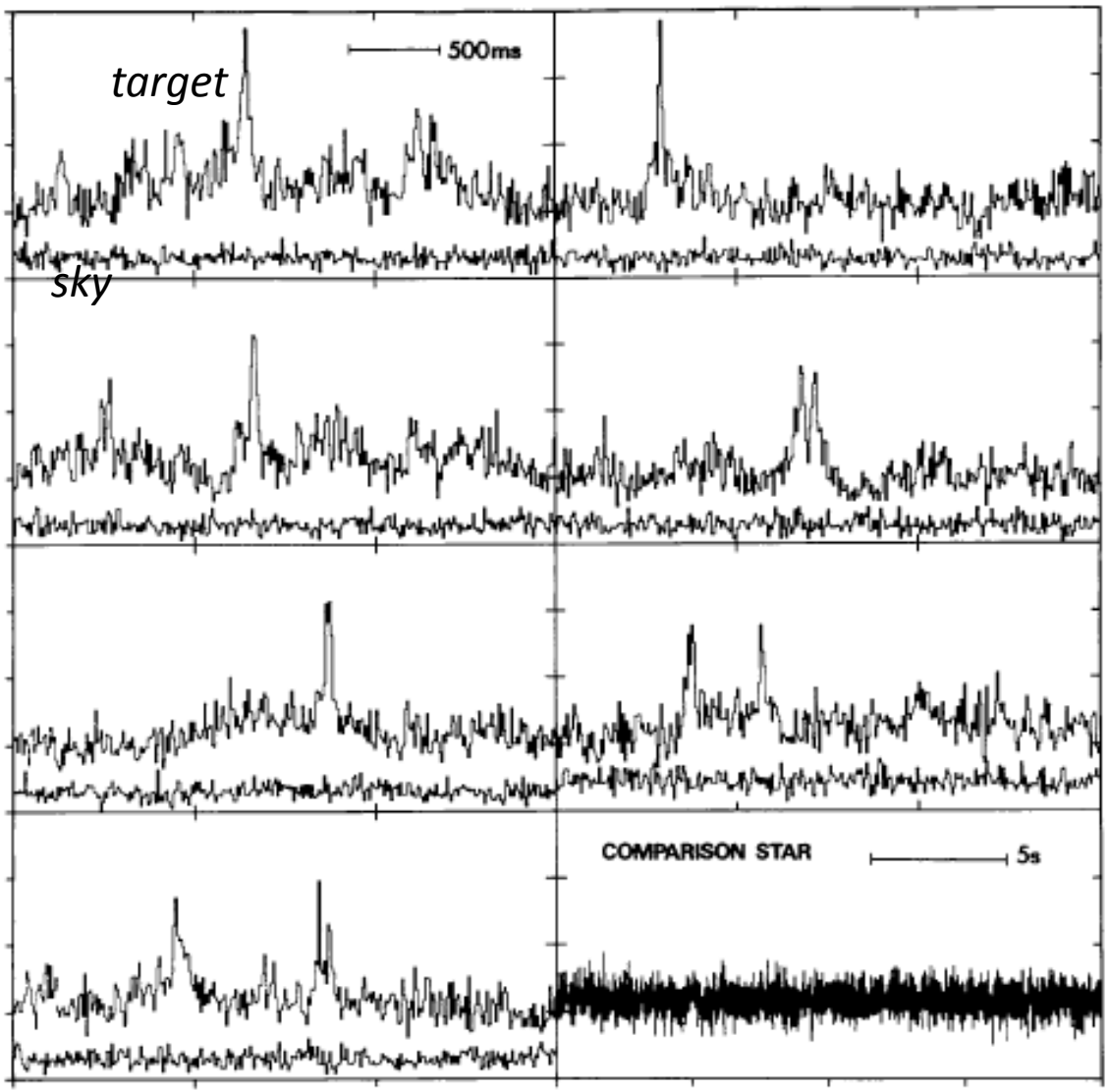
Optical and X-ray simultaneous timing



GX 339-4 : 2007 low/hard state

(Gandhi+10)

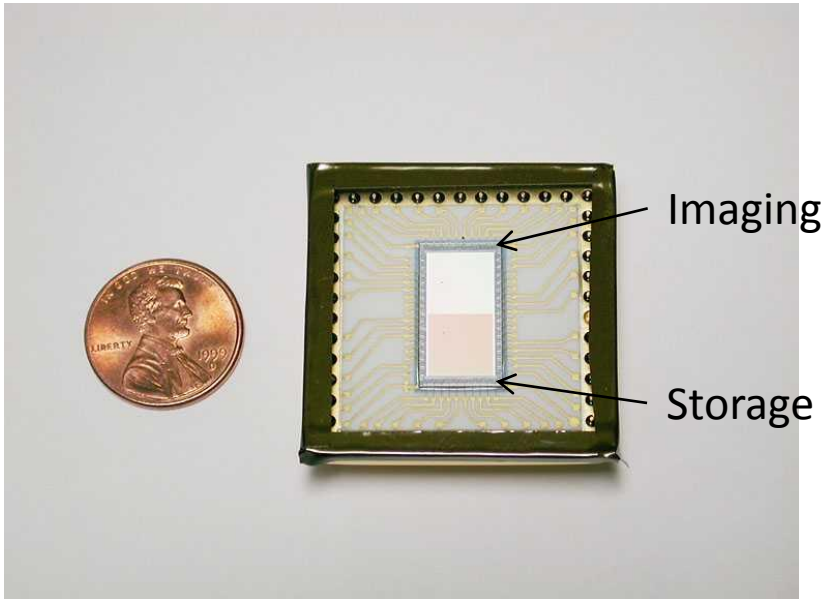
Speedy optical variations in X-ray binaries

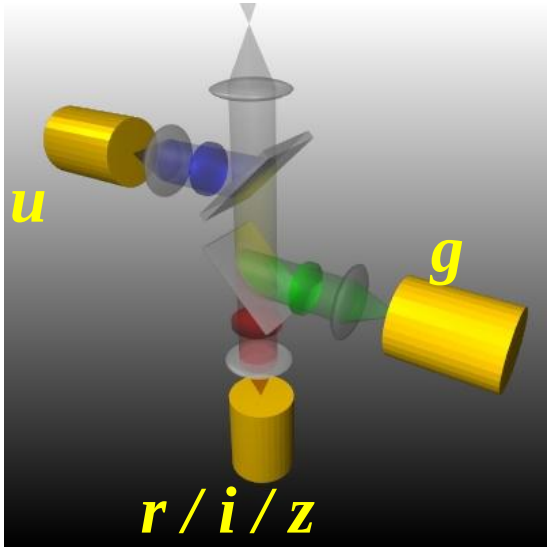


(***GX 339-4***: *Motch+82*)

ULTRACAM:
ultra-fast CCD camera

- Frame-transfer CCDs with small dead-time
- Speeds up to ~ 500 frames / sec
- Triple beam camera (3 simultaneous filters)





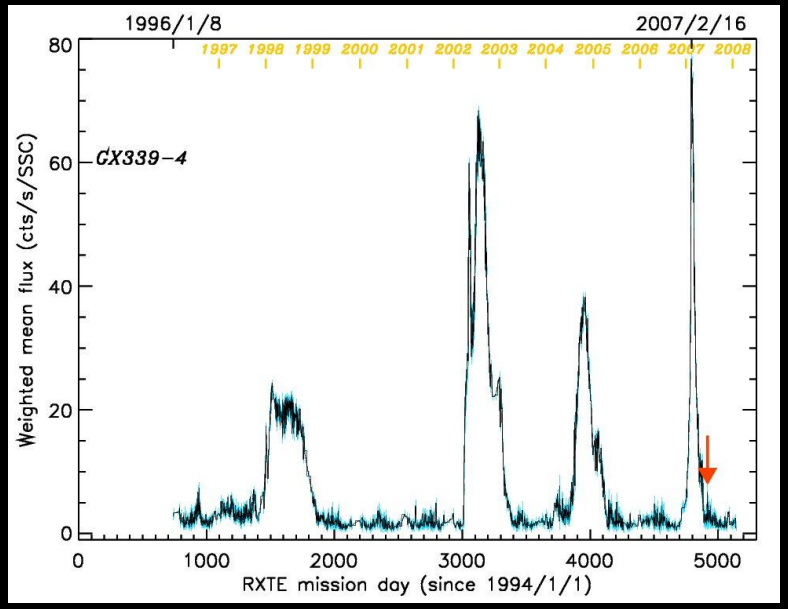
ULTRACAM Mounted on Visitor Focus of MELIPAL

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

ULTRACAM @VLT

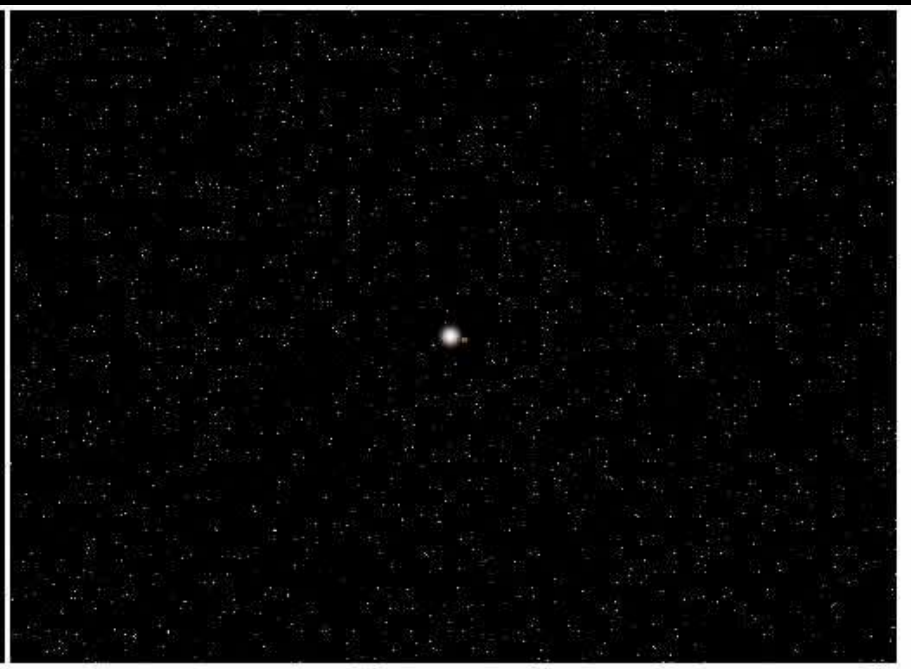
http://www.shef.ac.uk/physics/people/vdhillon/ultracam/

GX 339-4

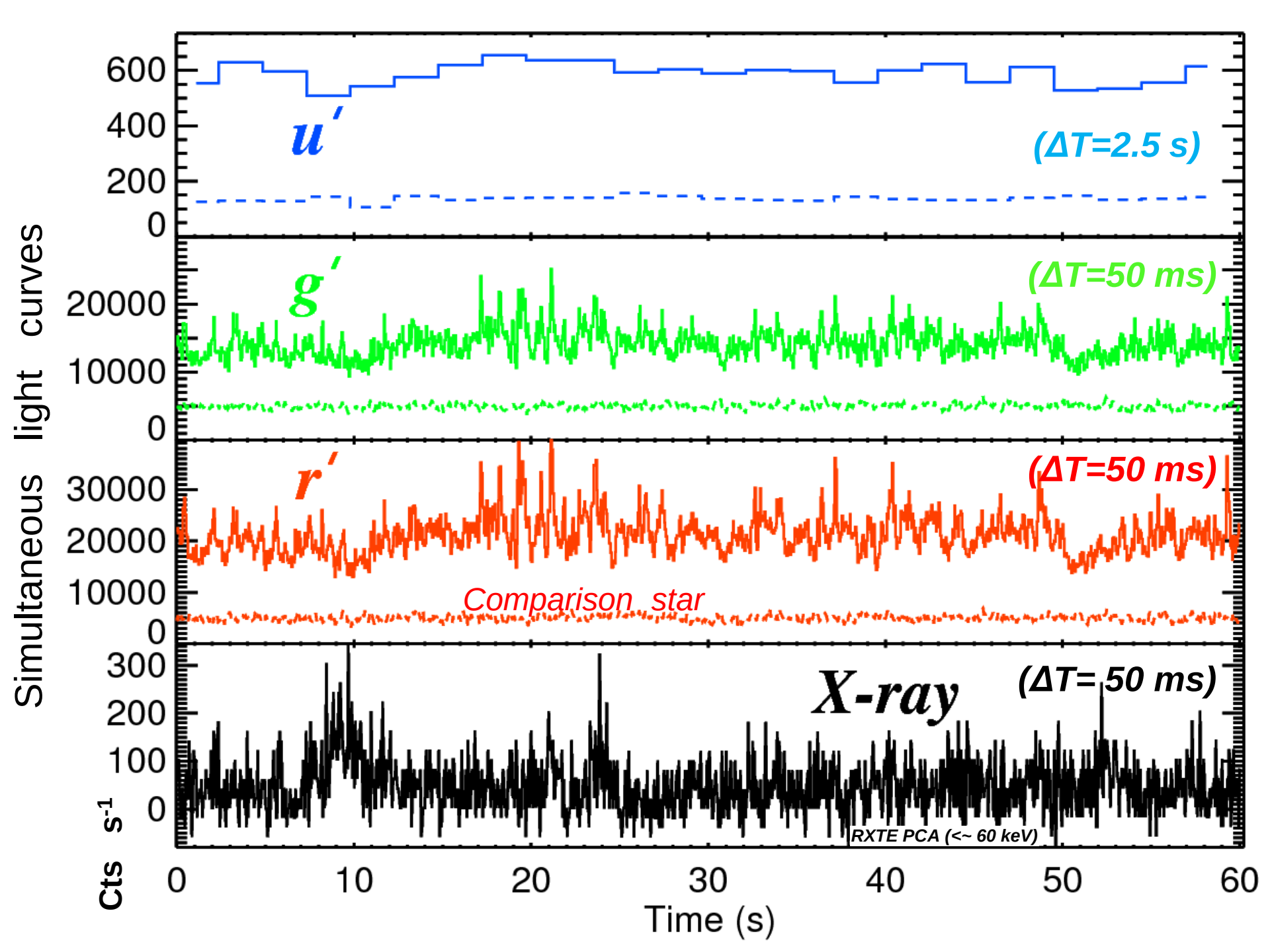


ΔT=50 ms

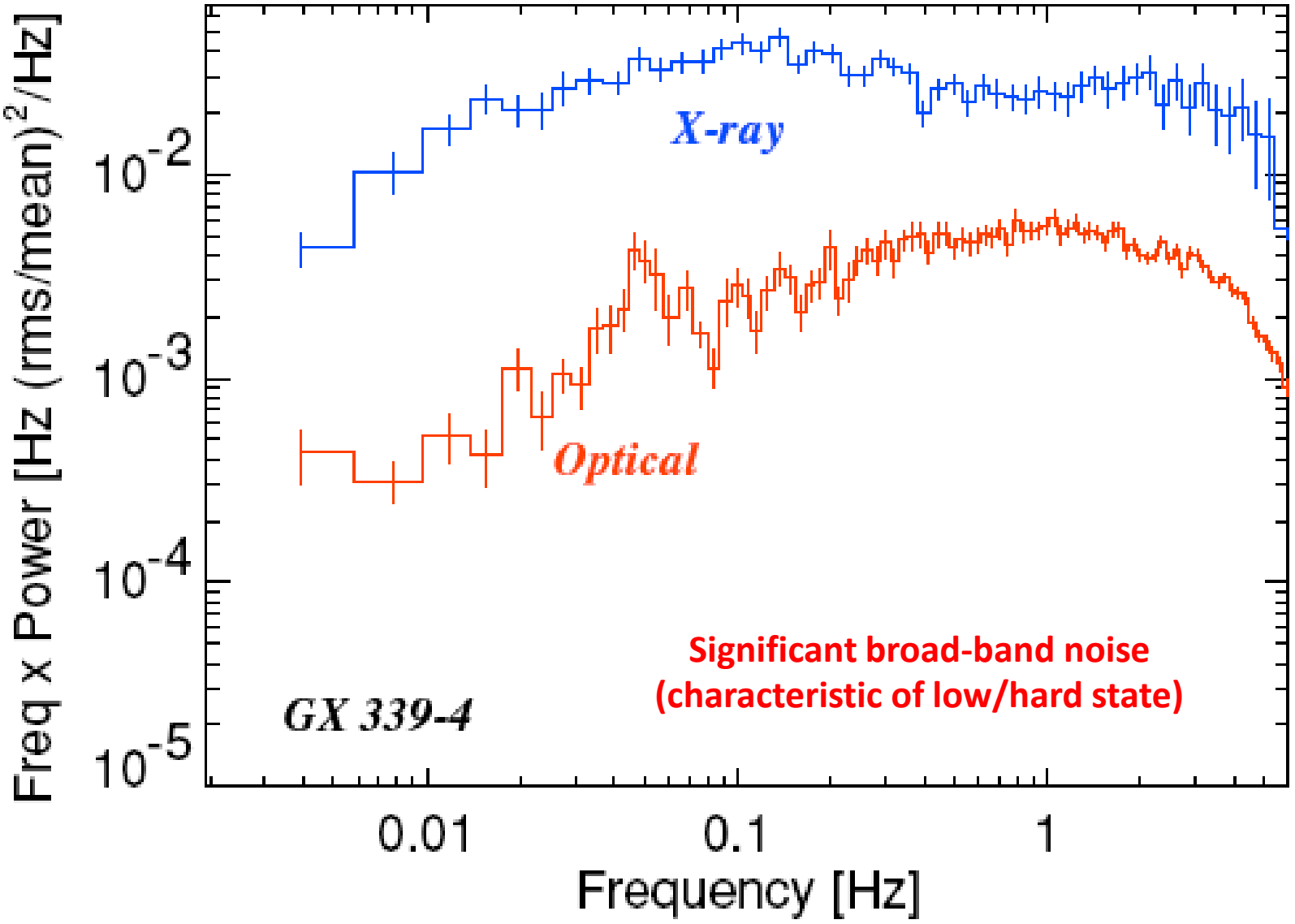
ULTRACAM



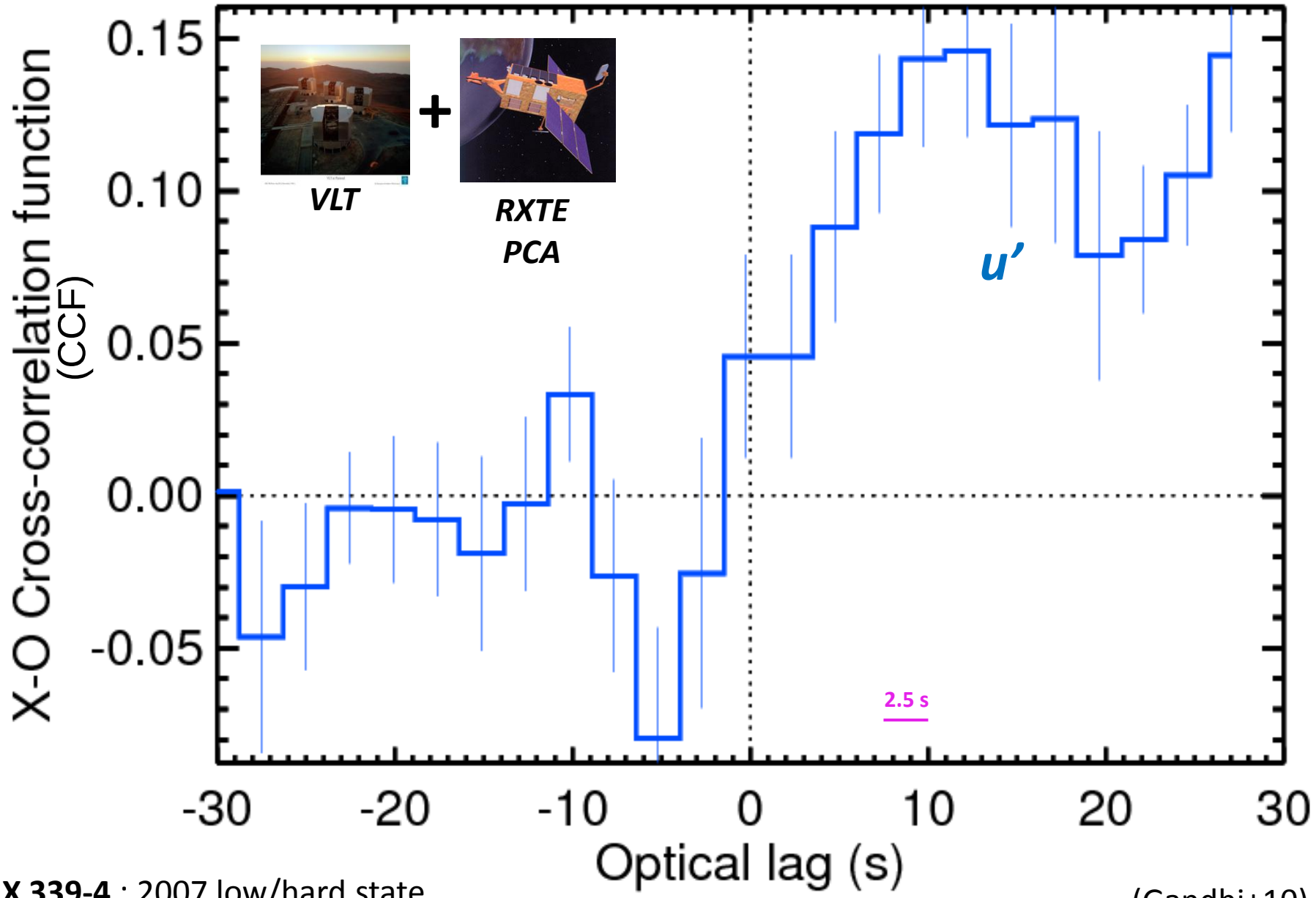
Animation: binsim


Simultaneous light curves
u′
(ΔT=2.5 s)
g′
(ΔT=50 ms)
r′
(ΔT=50 ms)
Comparison star
X-ray
(ΔT= 50 ms)
RXTE PCA (<~ 60 keV)
Cts s-1
Time (s)
600
400
200
0
20000
10000
0
30000
20000
10000
0
300
200
100
0
0
10
20
30
40
50
60

Power spectra



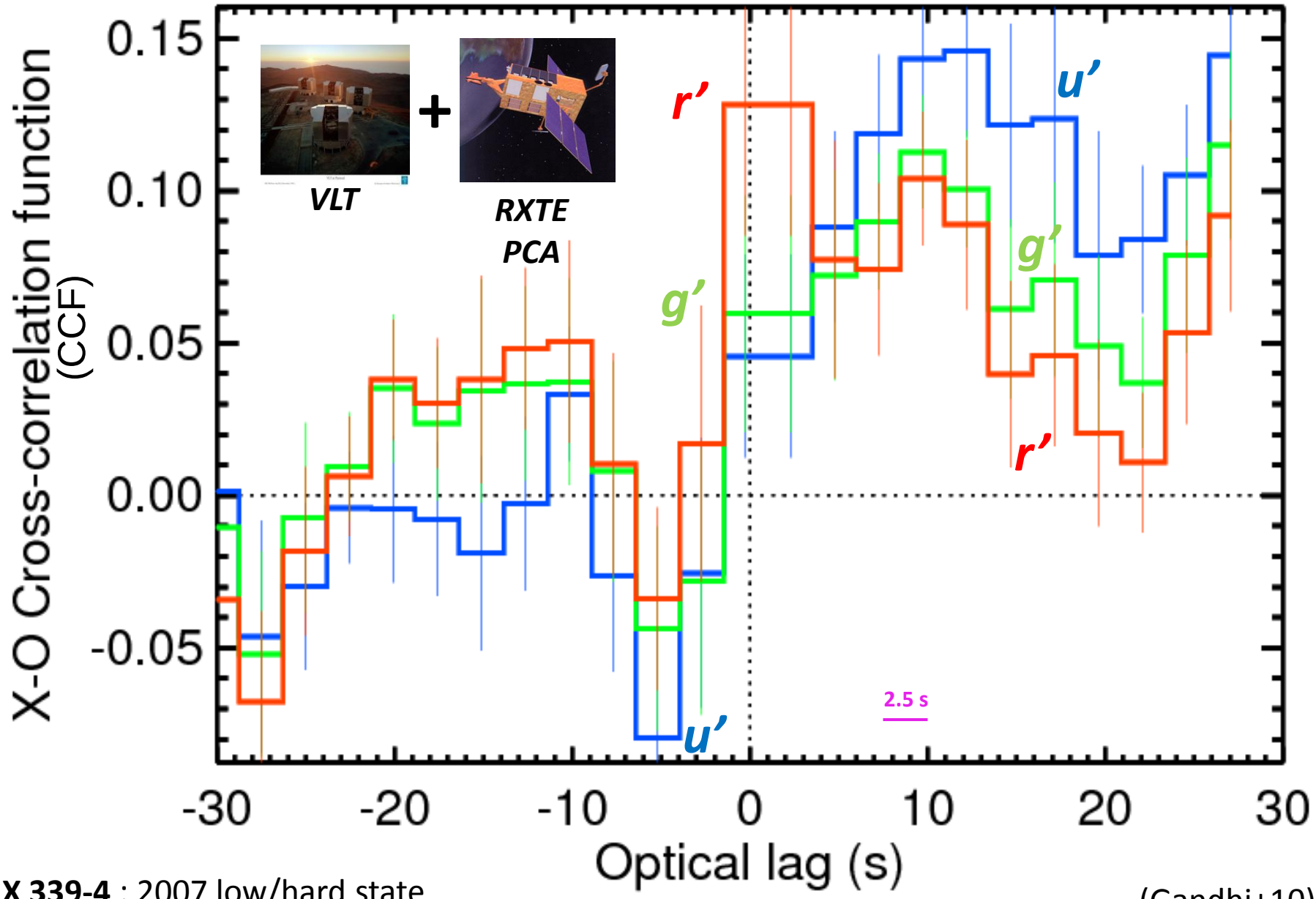
Optical and X-ray simultaneous timing



GX 339-4 : 2007 low/hard state

(Gandhi+10)

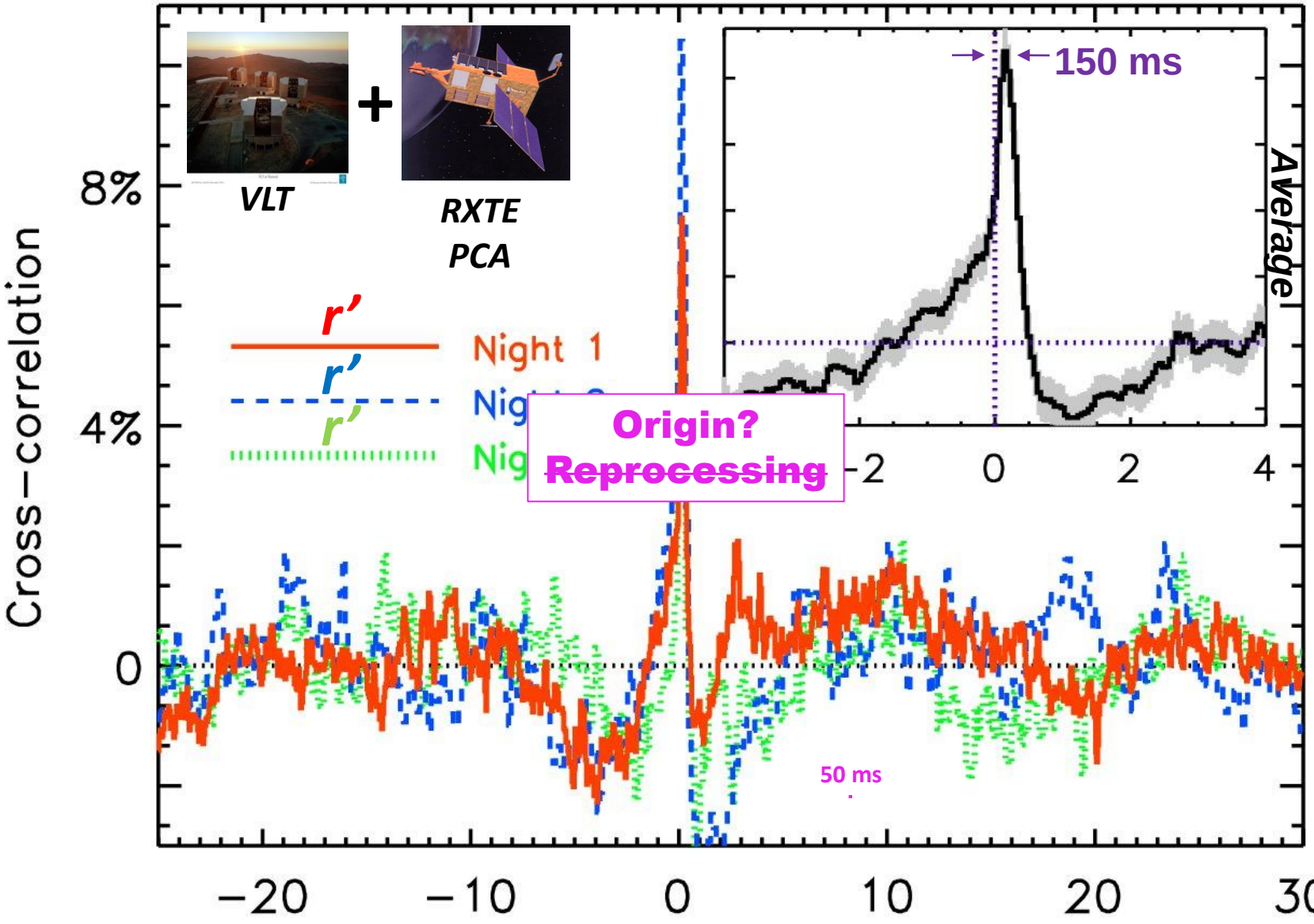
New fast red component in CCF?



GX 339-4 : 2007 low/hard state

(Gandhi+10)

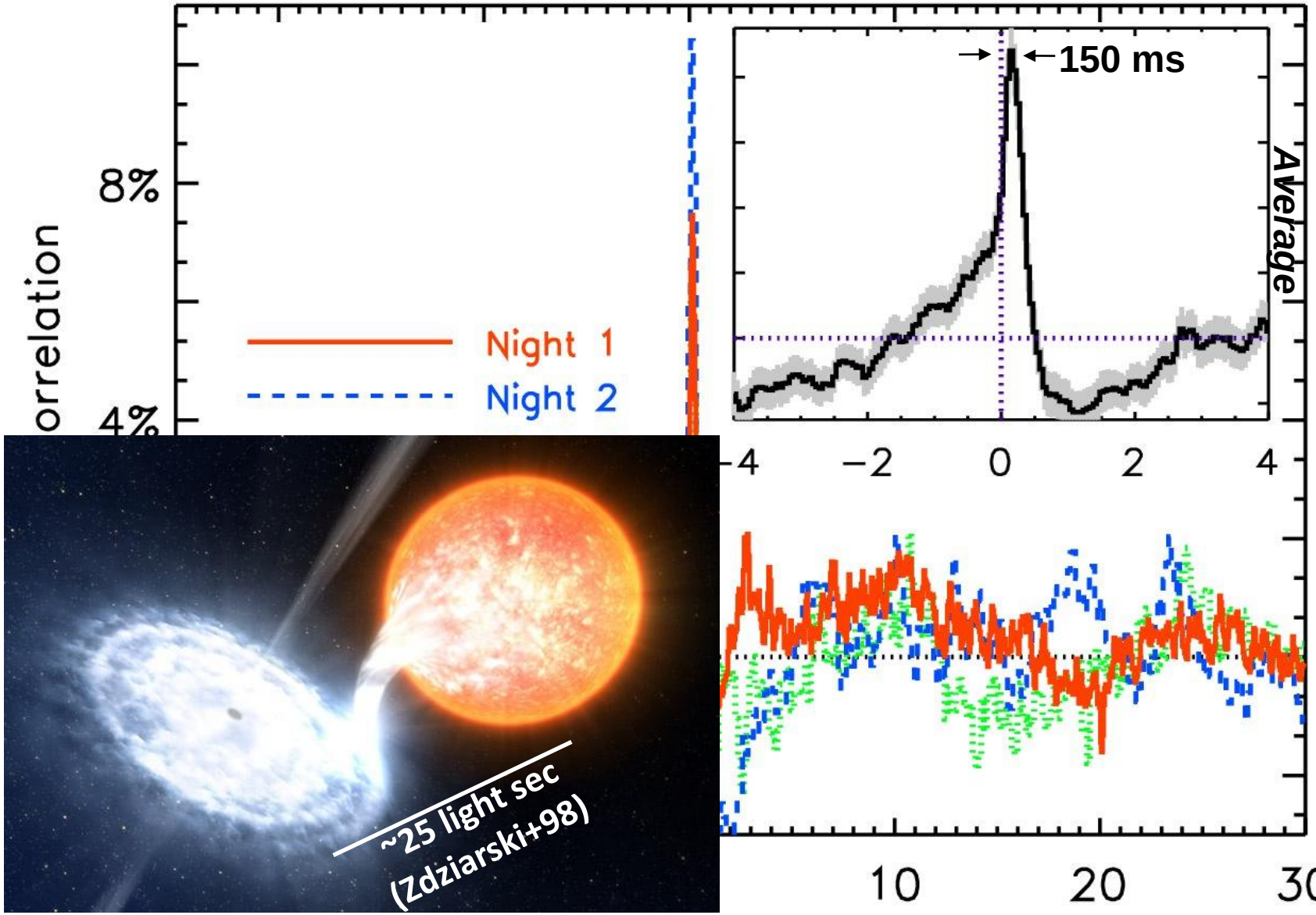
Sub-second X-O Cross Correlation Function (CCF)



GX 339-4 : 2007 low/hard state

(Gandhi+ 2008)

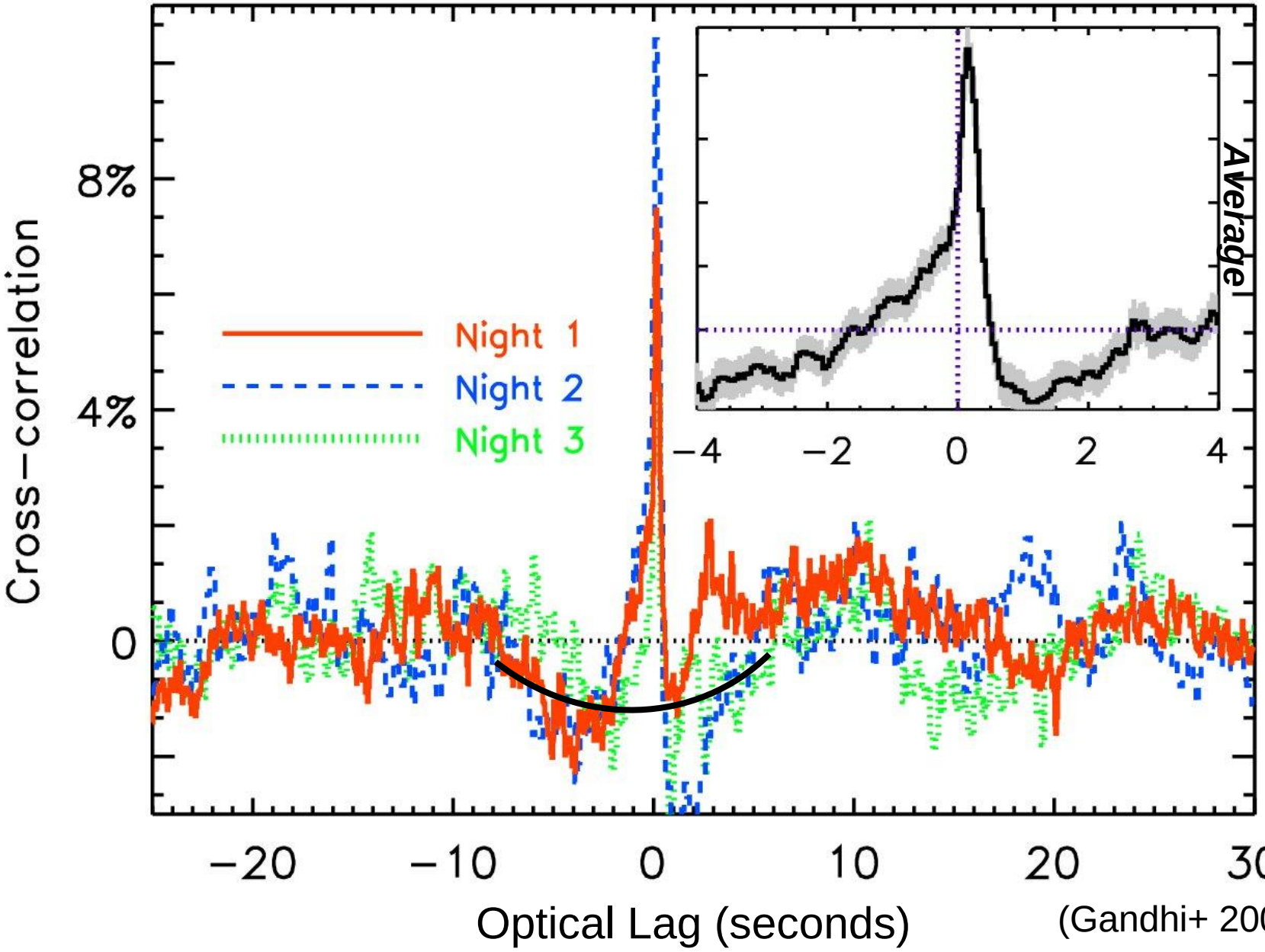
1. Small time delay



Optical Lag (seconds)

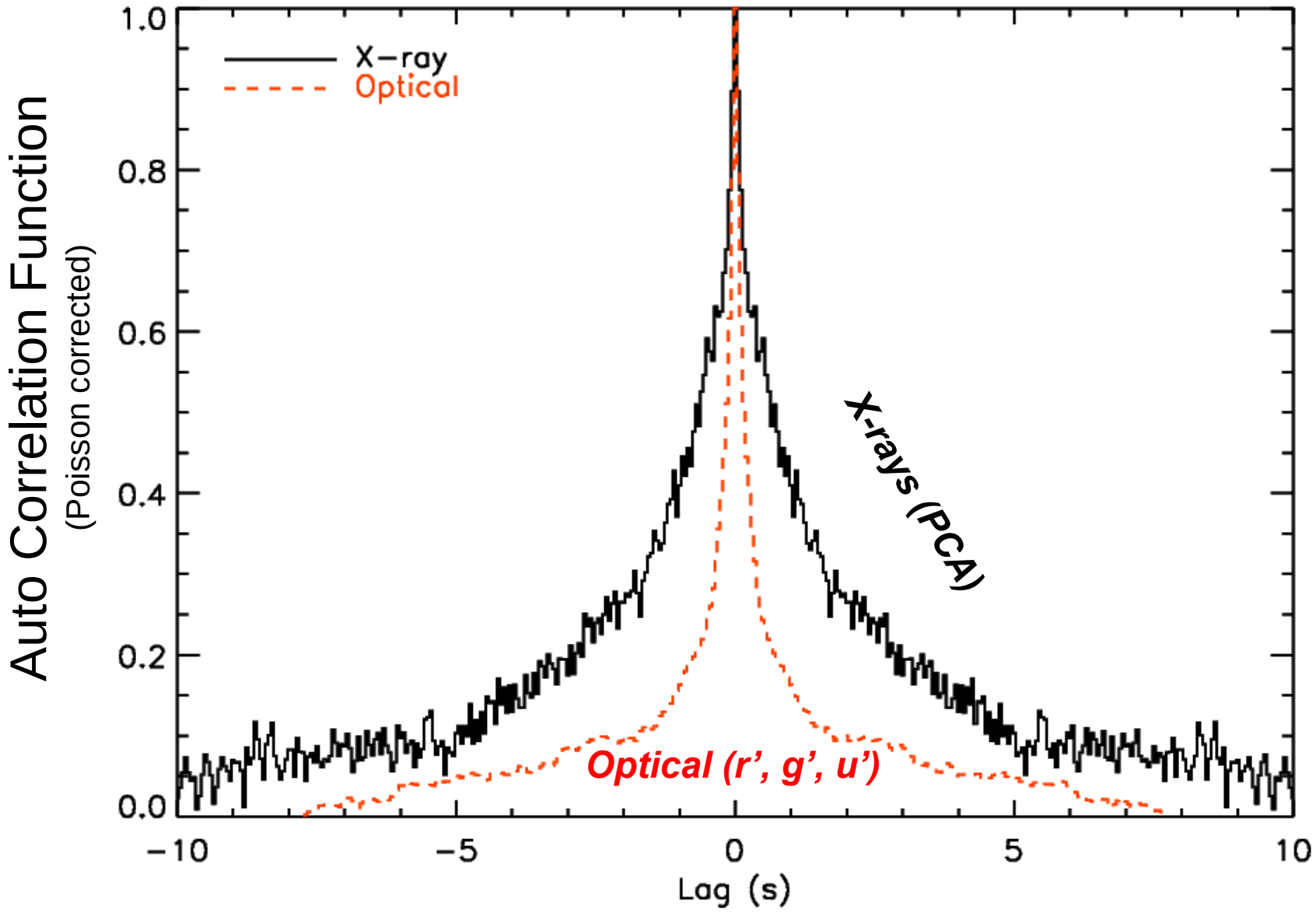
(Gandhi+ 2008)

2. Anti-correlation



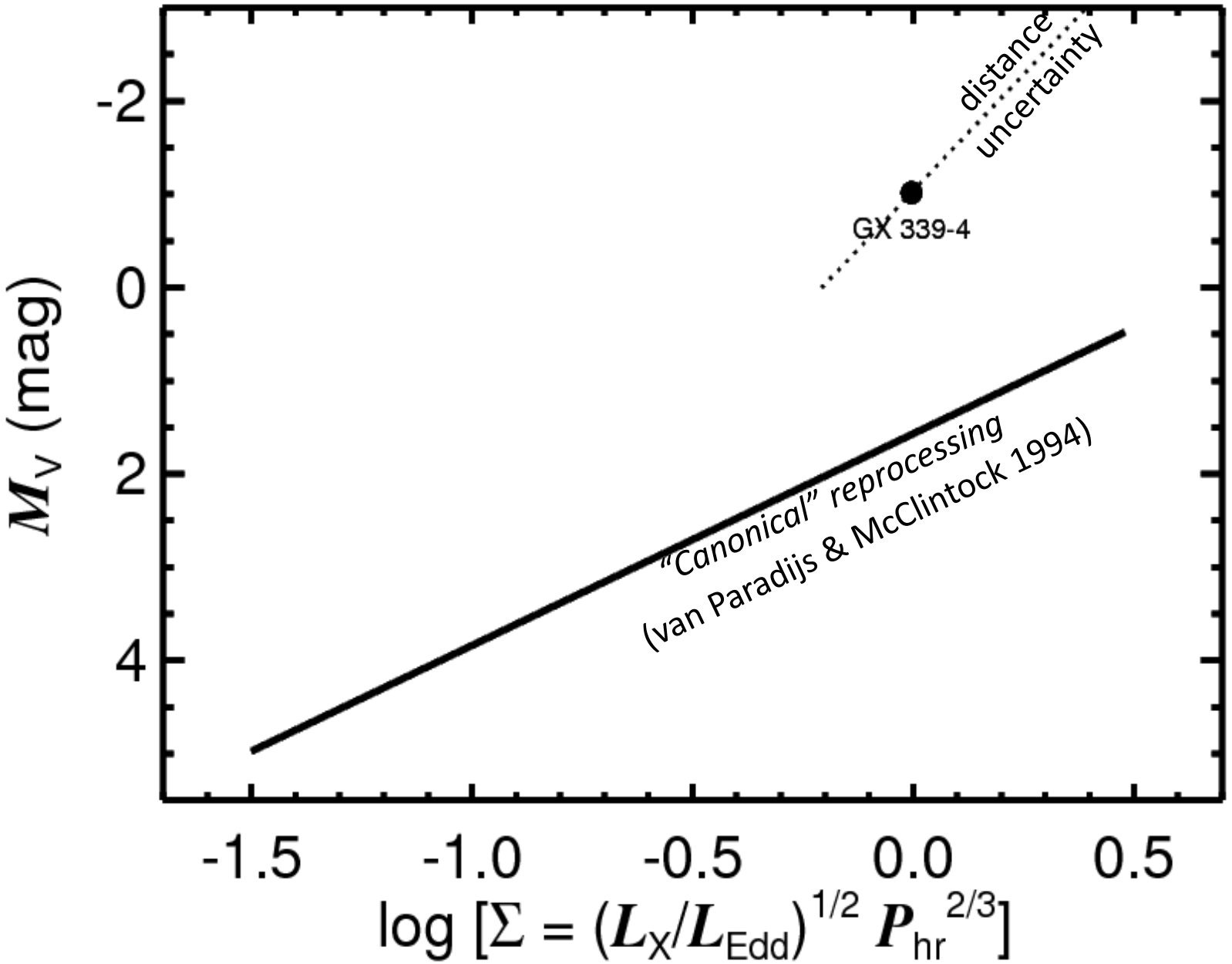
(Gandhi+ 2008)

3. Small optical coherence time



Optical ACF narrower than X-ray ACF

4. How much reprocessing is expected?



Speedy optical variability: scales and power

- Fastest flares have timescales <~ 20-50 ms.

  => R <~ 10^4 km <~ 10^3 R_G

- Brightness temperature

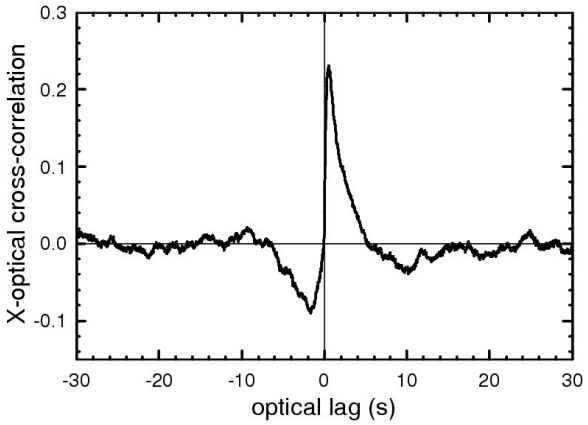
  => T_B >~ 10^7 K

⇨ Optical (cyclo)synchrotron.

- Equipartition

  => B > 10^4 G

Models for XTE J1118+480



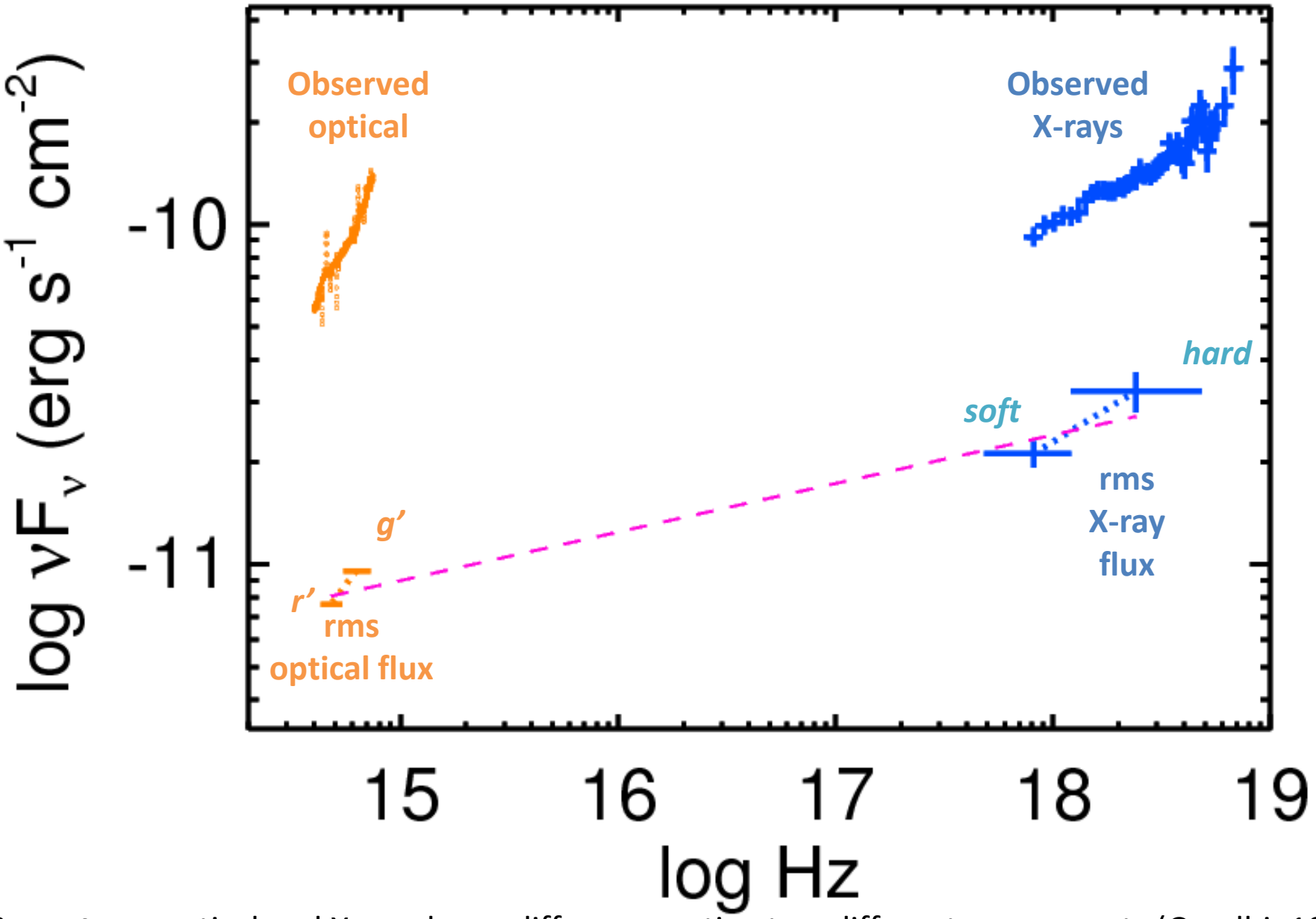
⇨ Optical (cyclo)synchrotron.

⇨ Interaction between components.

- Merloni+00 *Magnetic corona*
- Esin+01 *Advection flow (ADAF)*
- Markoff+01 *Pure jet*
- Malzac+04 *Magnetic 'reservoir' jet/corona*
- Yuan+05 *ADAF+jet*

…

GX 339-4: Two separate components? Or one?



RMS spectrum optical and X-ray slopes differ, suggesting two different components (Gandhi+10).

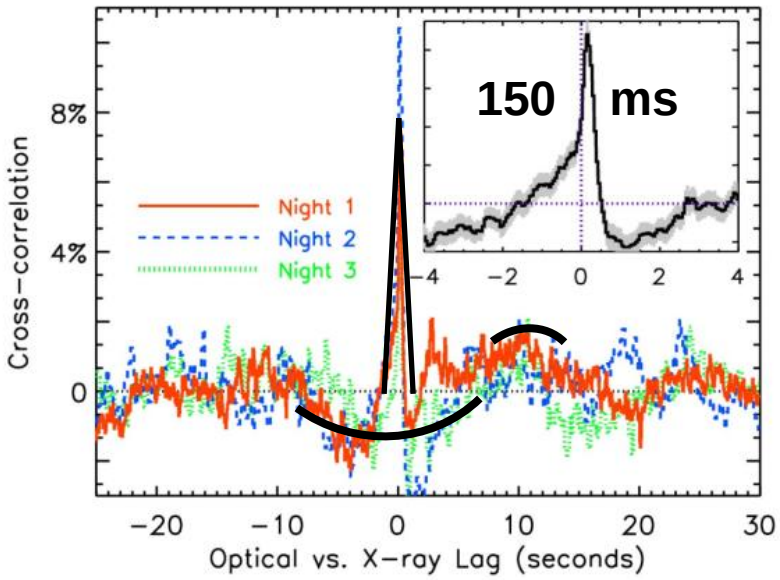
Optical/X-ray coherence and lags

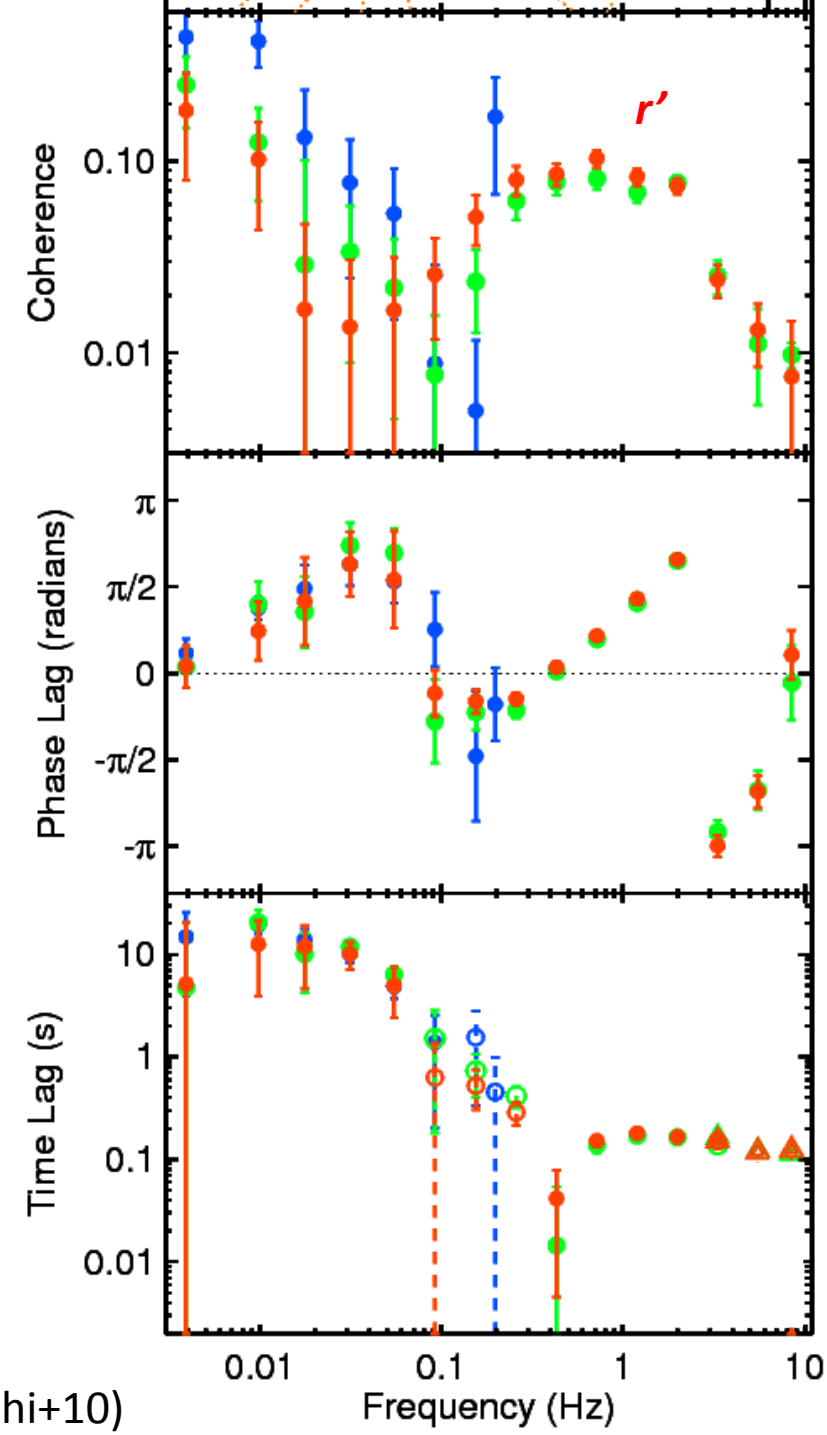
(e.g. Vaughan & Nowak 1997)

Coherence = $\frac{|\langle X^* O \rangle|^2}{\langle |X^2| \rangle \langle |O^2| \rangle}$

Phase lag = arg $(X^* O)$

Time lag = $\frac{\text{Phase lag}}{2\pi f}$





(Gandhi+10)

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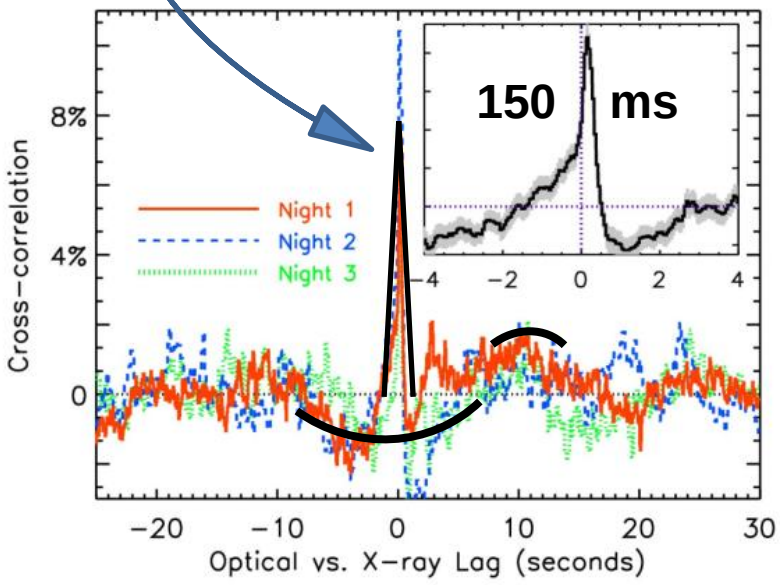
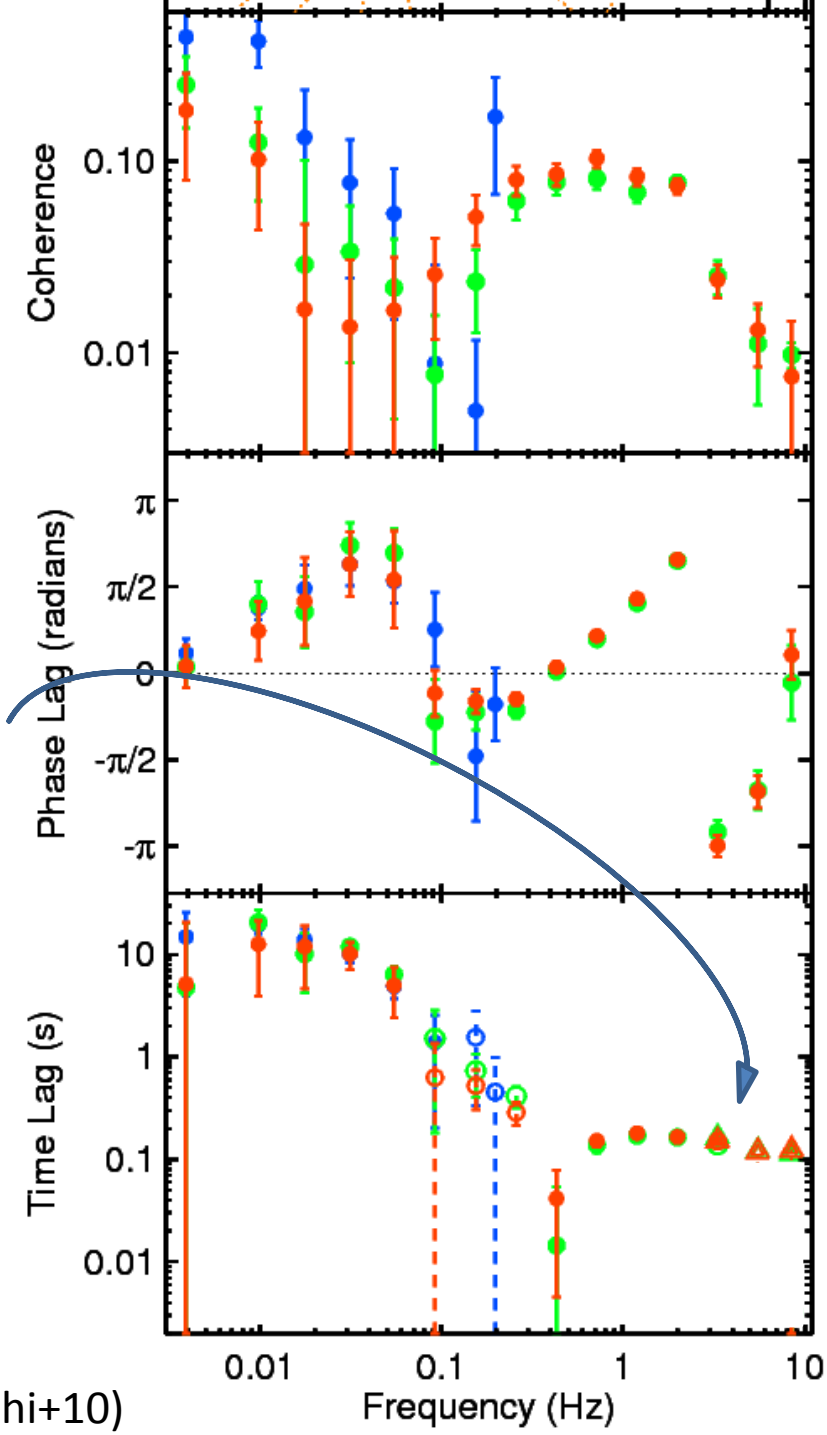
Fast component





(Gandhi+10)

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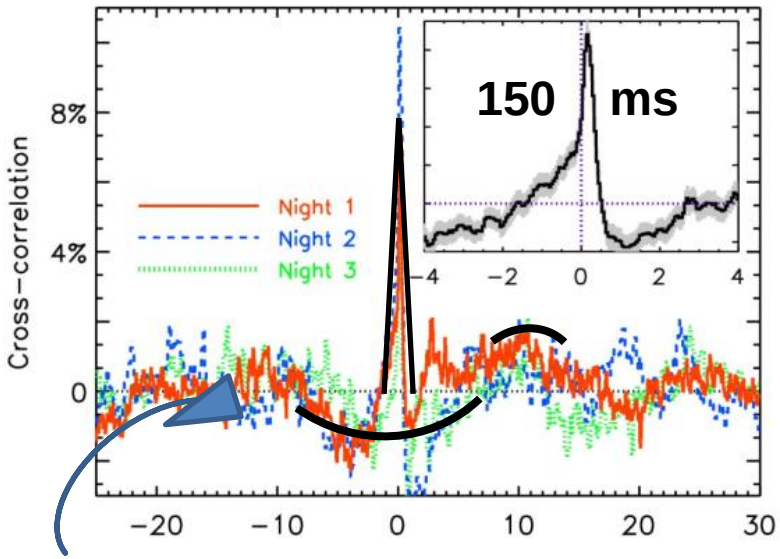
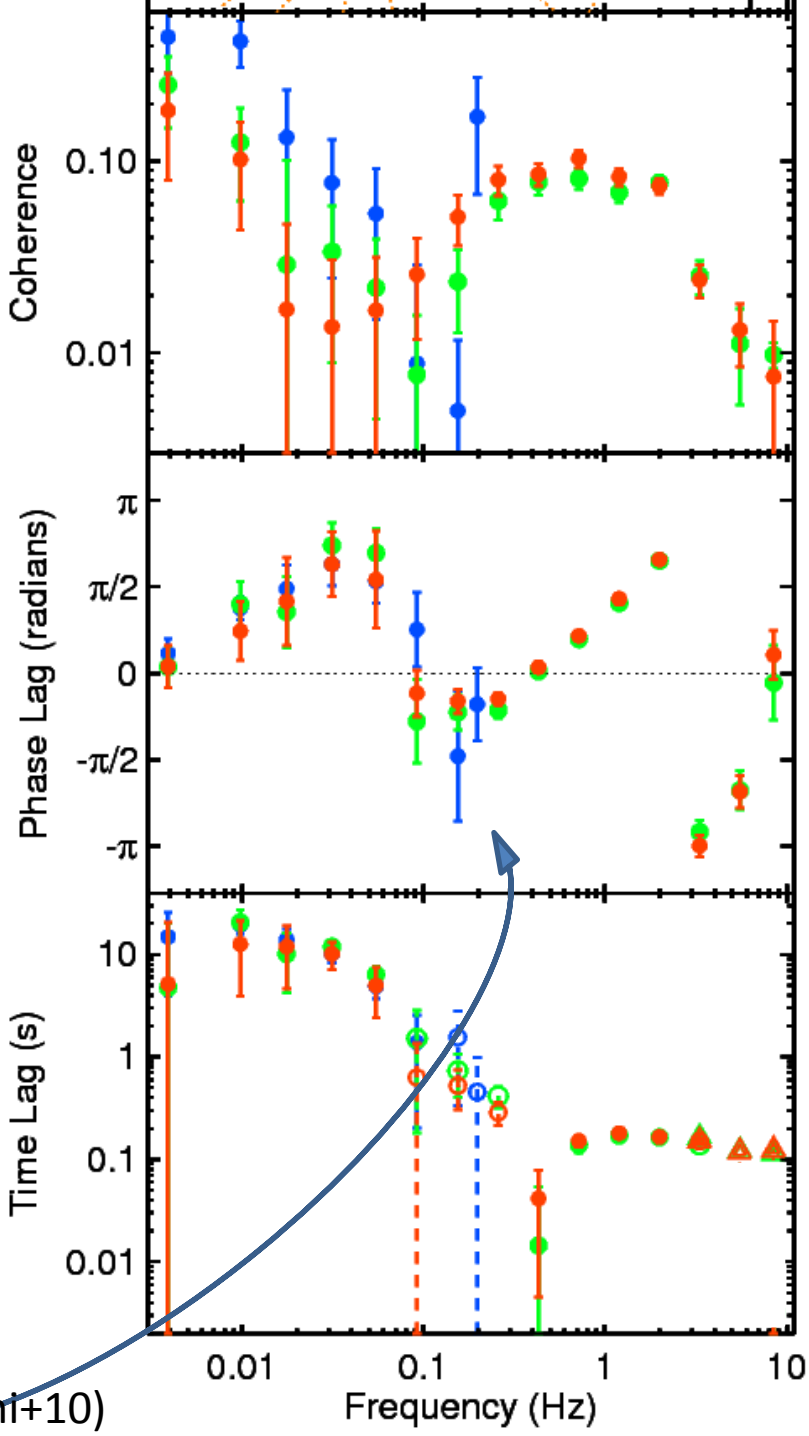


Intermediate negative component



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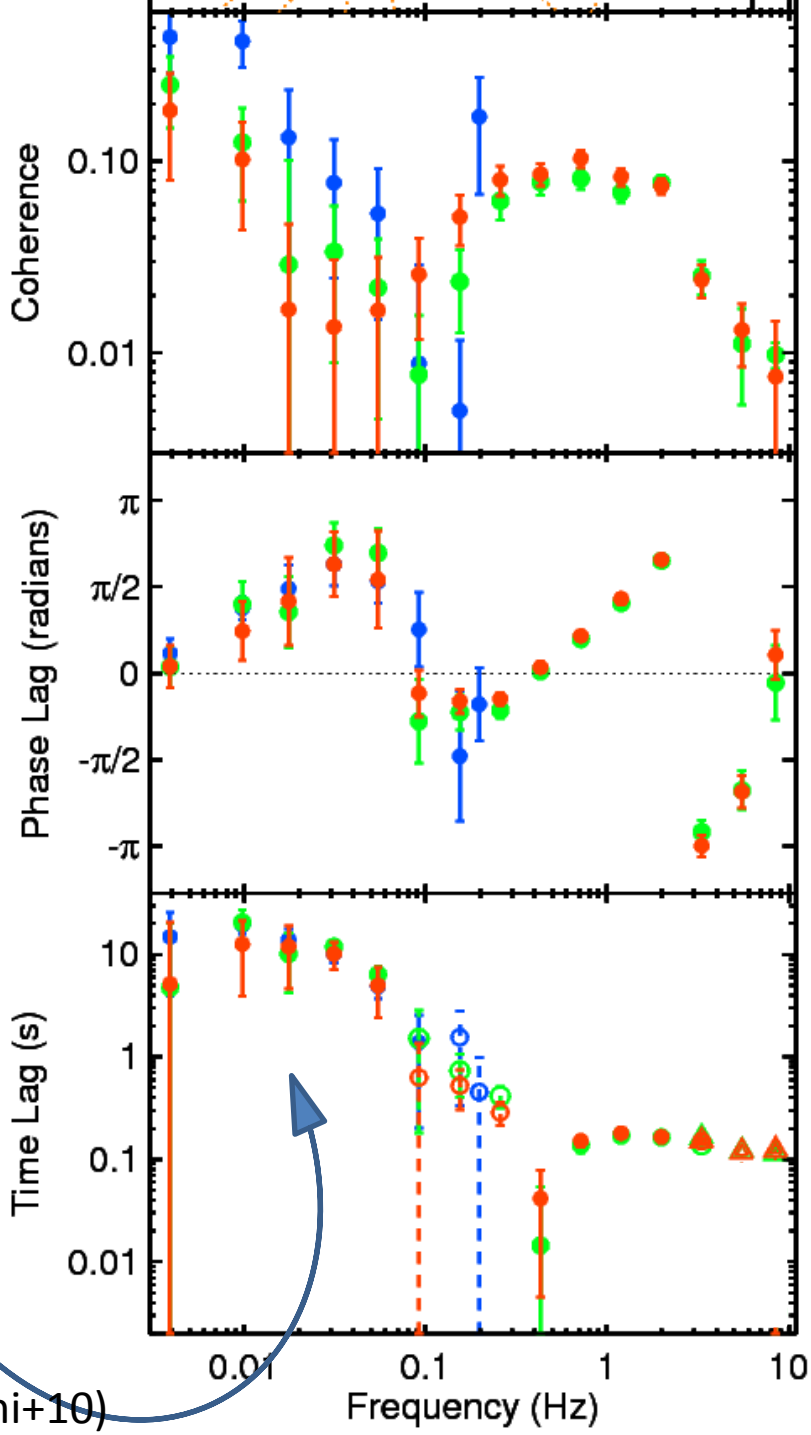
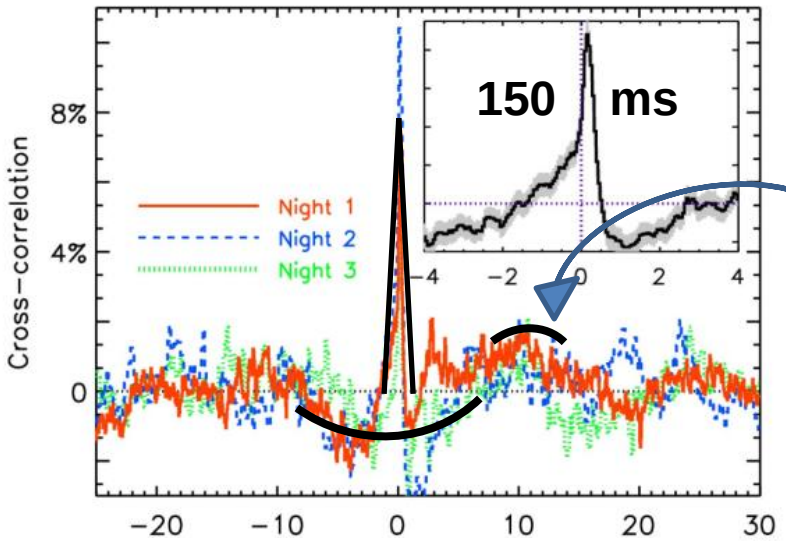


Fast component

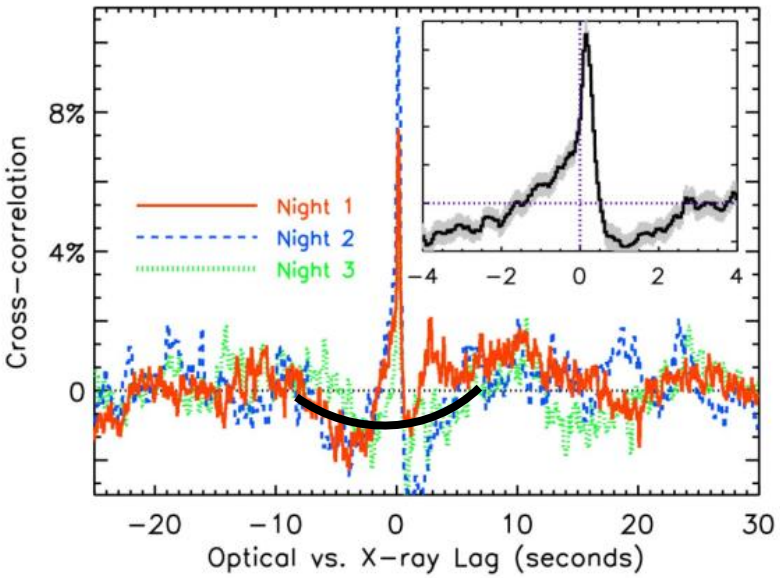


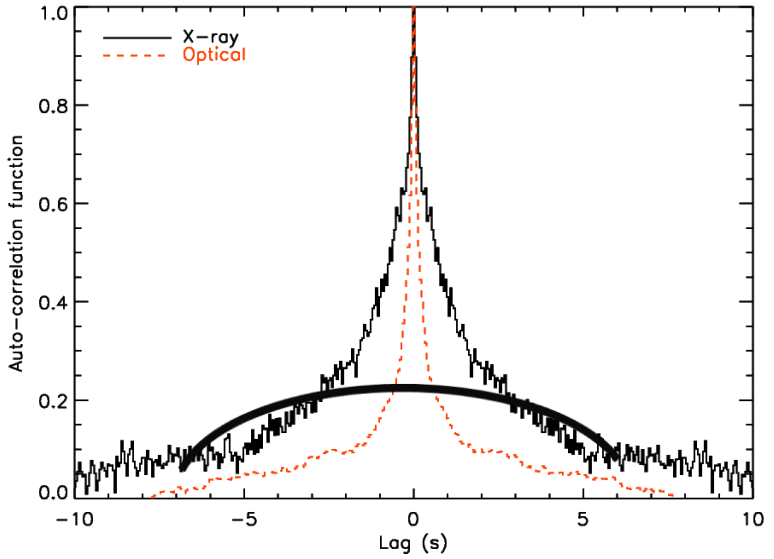
Intermediate negative component

Slow reprocessing

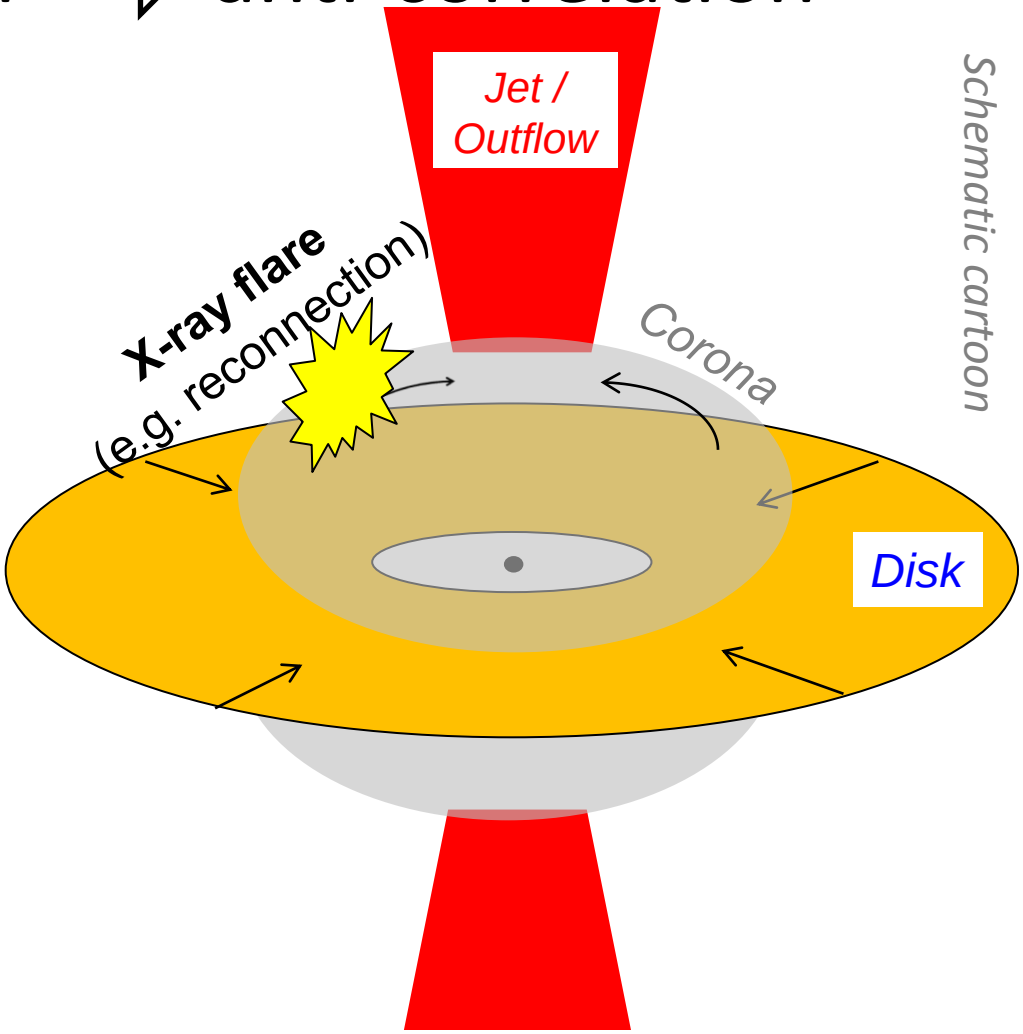
(Gandhi+10)

B field dissipation ⇨ anti-correlation





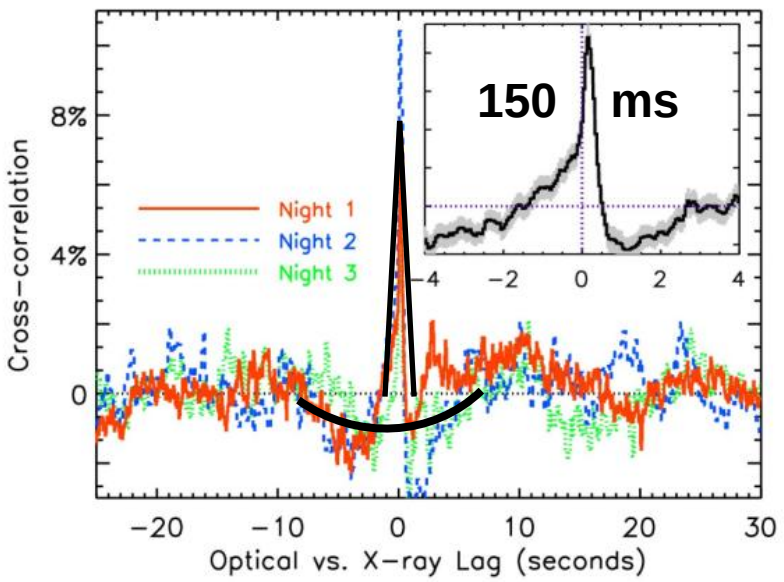
(Gandhi+10)



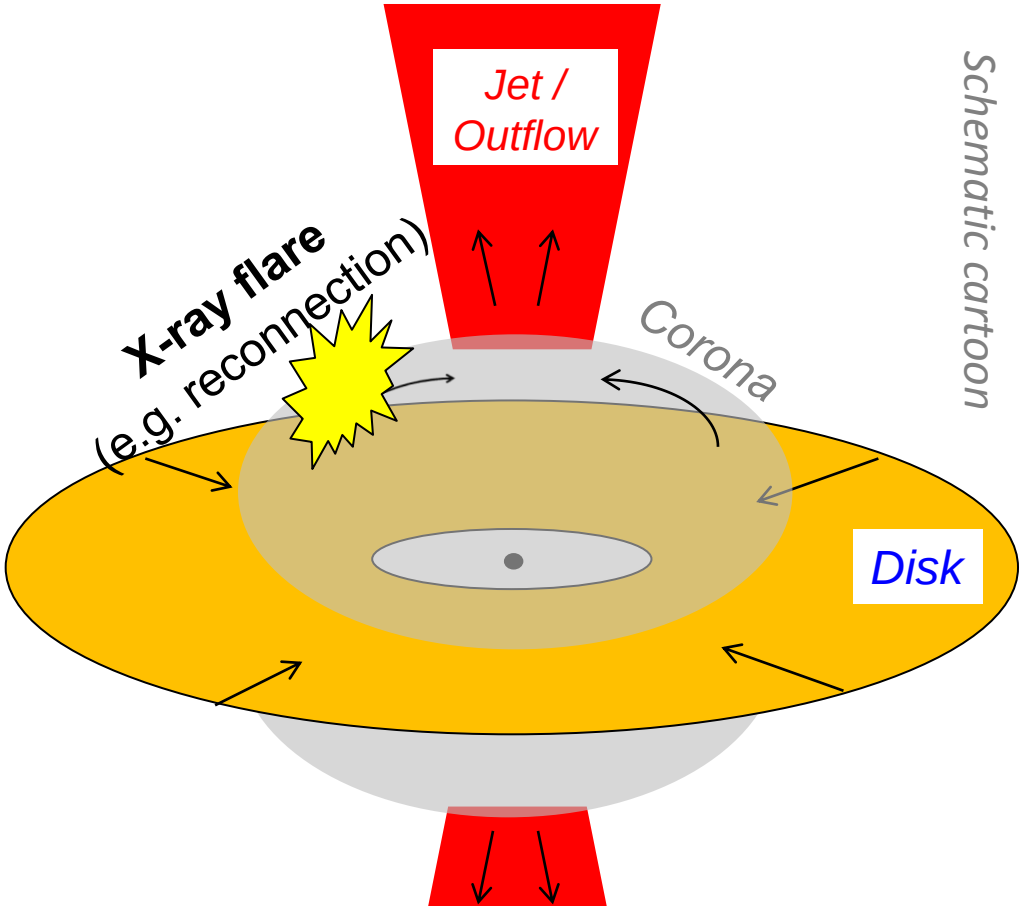
Release of <u>coronal</u> *B* energy density

⇒ ↓ optical cyclosynchrotron

Jet ⇨ positive correlation



(Gandhi+10)

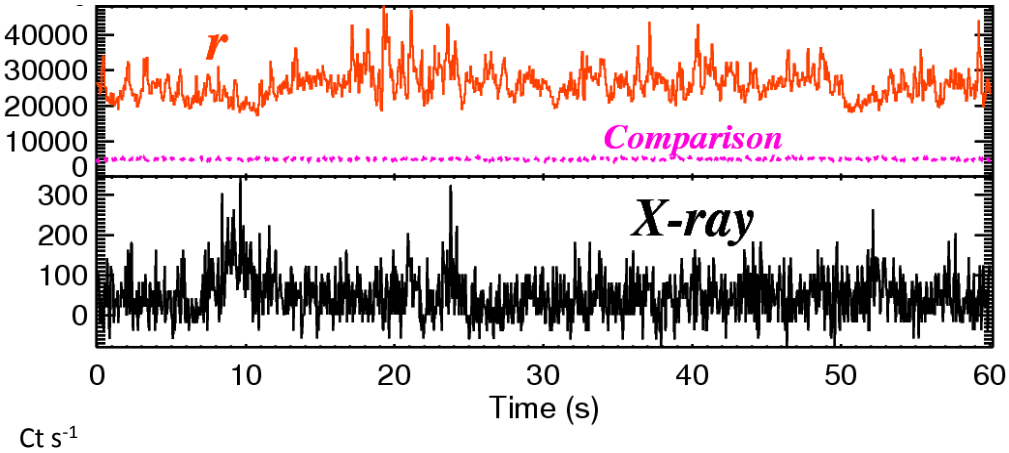


Time delay of 150 ms => ↑ jet optical (cyc)syn, at

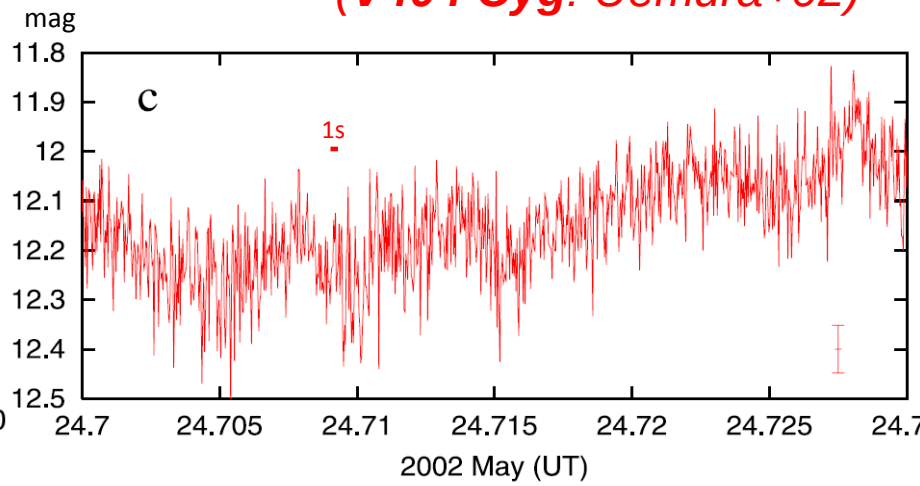
1. 5000 R_G @ lightspeed, or
2. 50 R_G @ $v_{Alvenic}$, for jet poloidal field perturbations on times ~ tens x $t_{dynamical}$ ~ 100 ms; (Livio+03; Malzac+04)

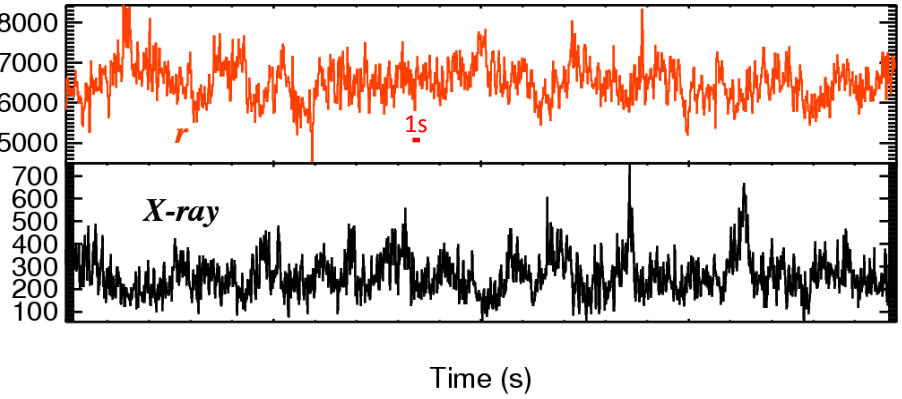
Speedy optical variations in X-ray binaries

*(**GX 339-4**: Gandhi+10)*

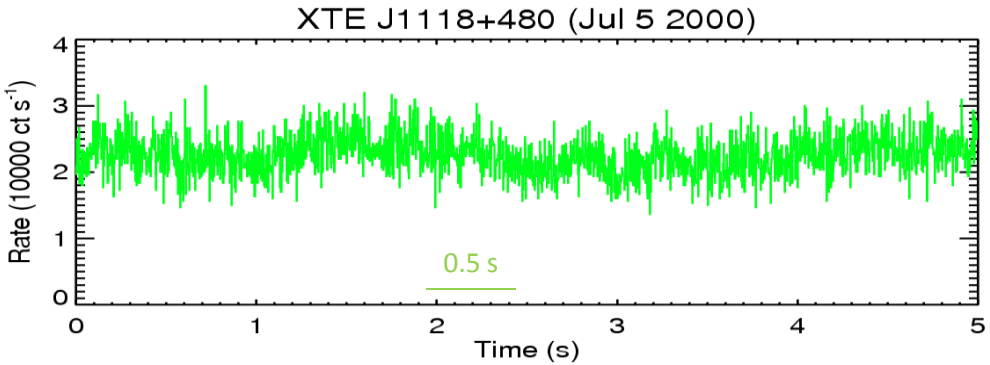


*(**V404 Cyg**: Uemura+02)*



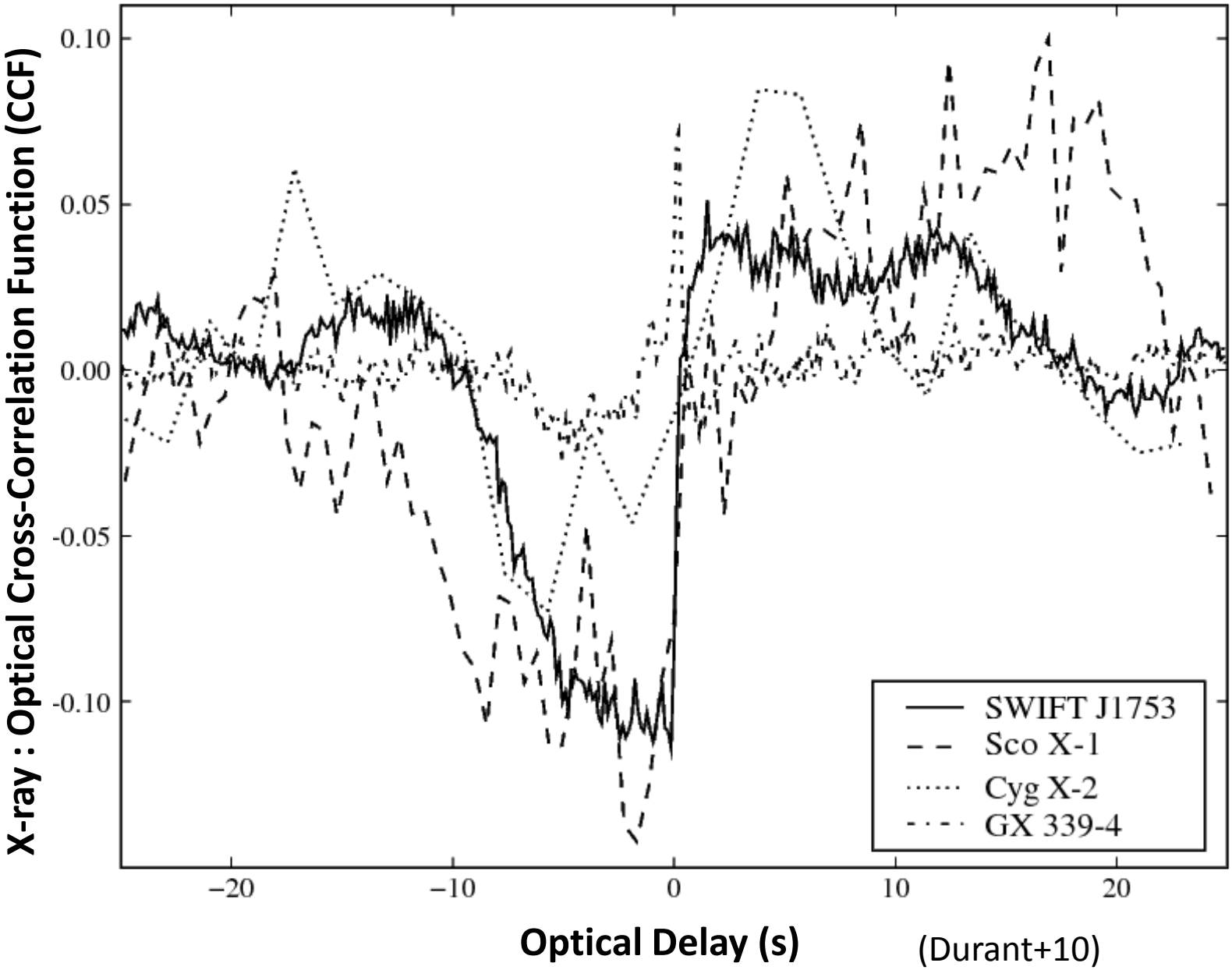


*(**Swift J1753.5-0127**: Durant+08)*



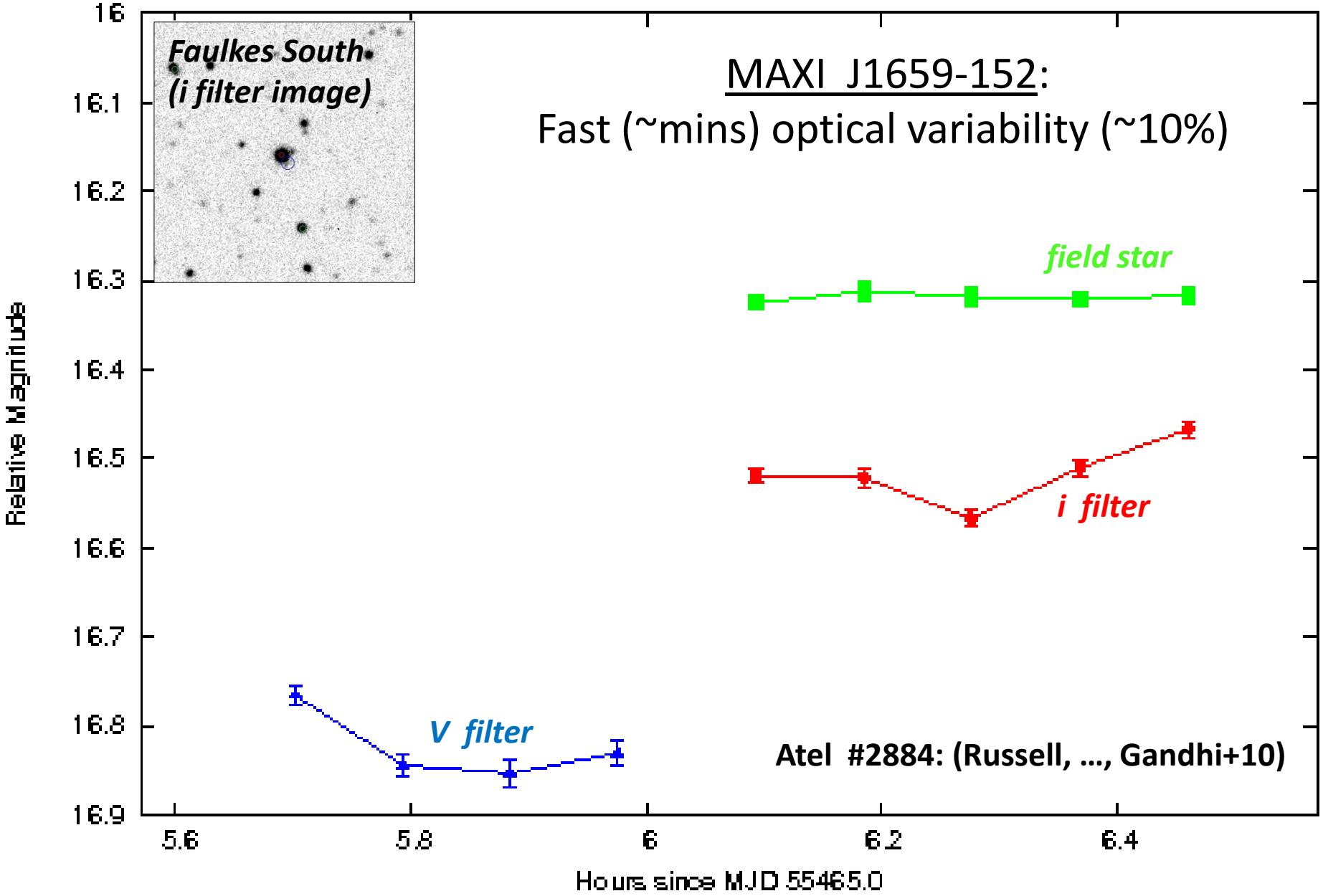
*(**XTE J1118+480**: Kanbach et al. 2001)*

Neutron star binaries also?



(Durant+10)

MAXI+optical



MAXI+optical: beyond simple identification

Disc timescales:

$$t_{\text{light-cross}} < t_{\text{dyn}} \sim t_z \sim \alpha t_{\text{th}} \sim \alpha (H/R)^2 t_{\text{visc}}.$$

(e.g. A. King)

ms ~ few seconds

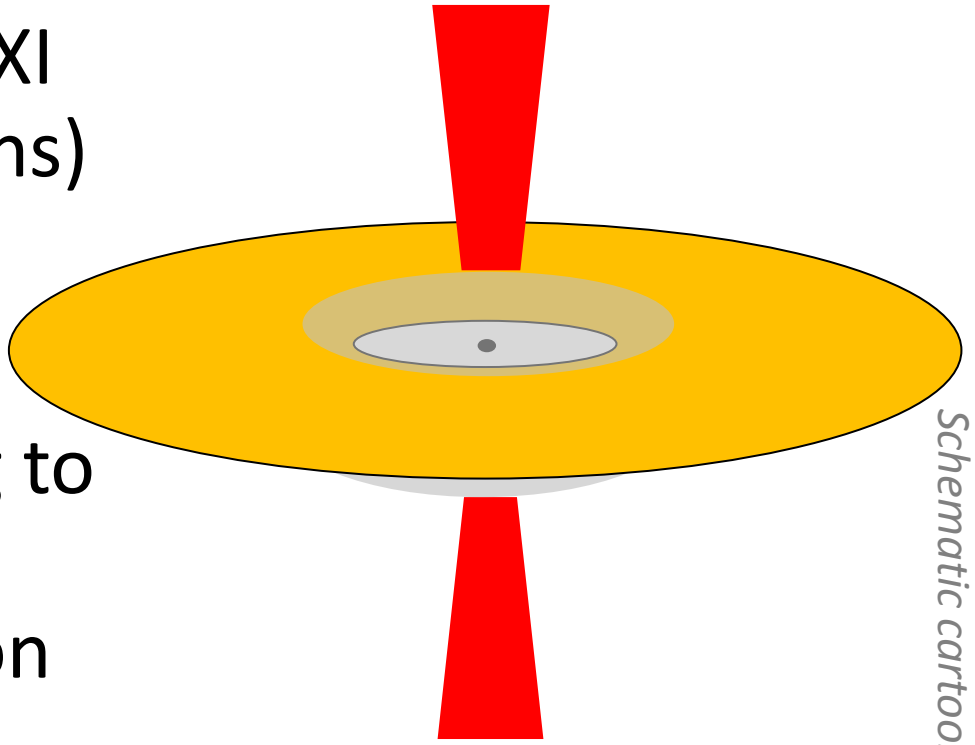
seconds ~ days

days ~ months

Coordinated optical/MAXI monitoring (ΔT=90 mins) over weeks/months

⇓

deconvolve reprocessing to constrain physical parameters of accretion components.



Schematic cartoon

Optical/X-ray coherence and lags

(e.g. Vaughan & Nowak 1997)

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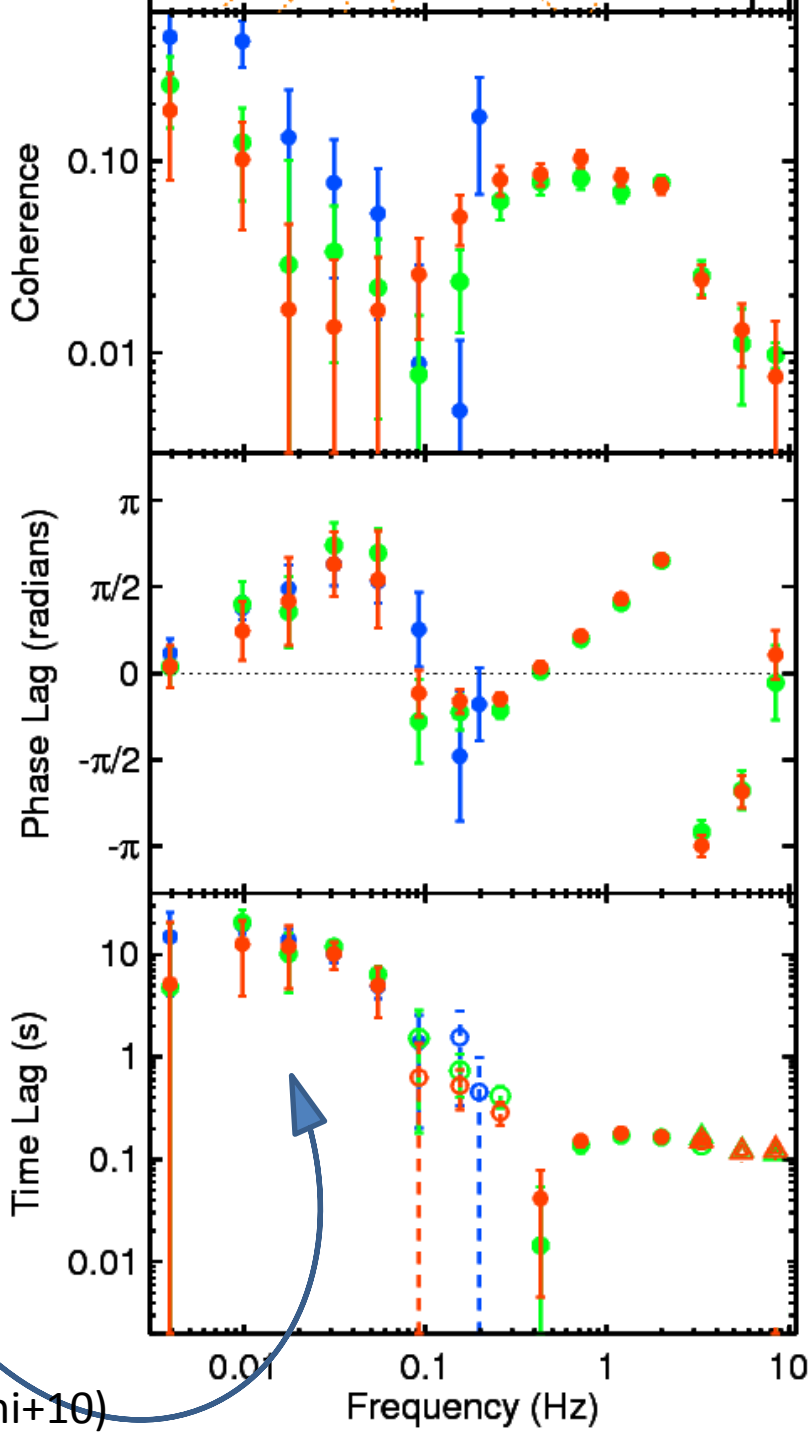
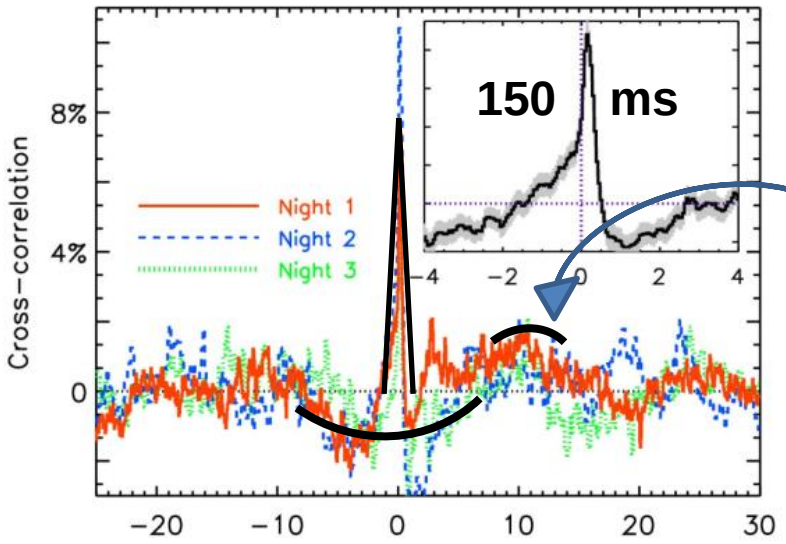


Fast component

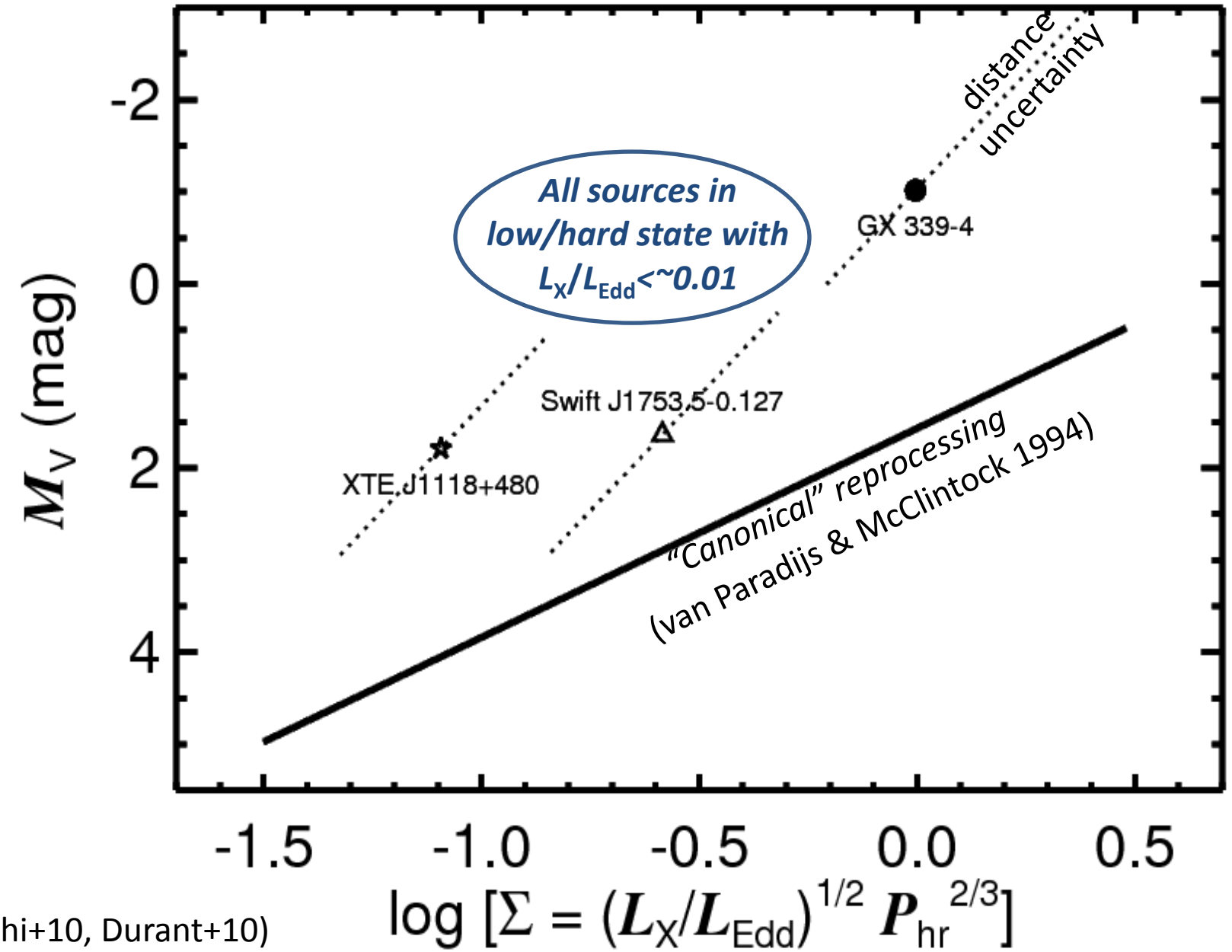


Intermediate negative component

Slow reprocessing

(Gandhi+10)

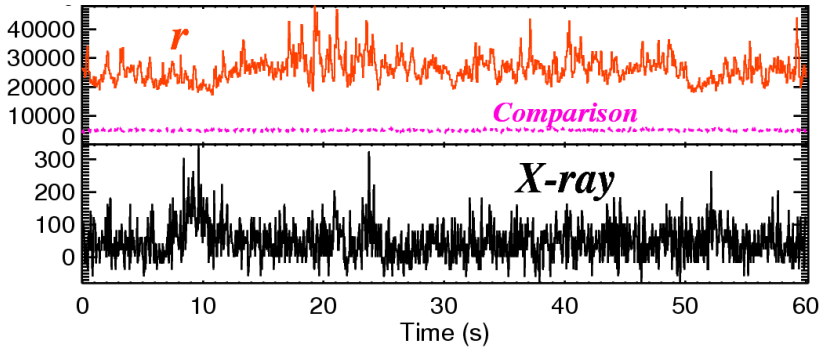
4. How much reprocessing is expected?

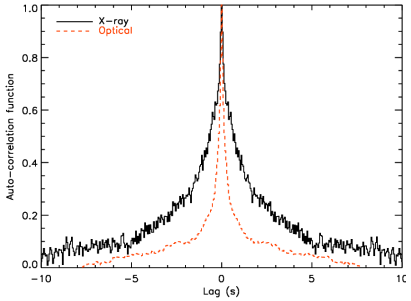


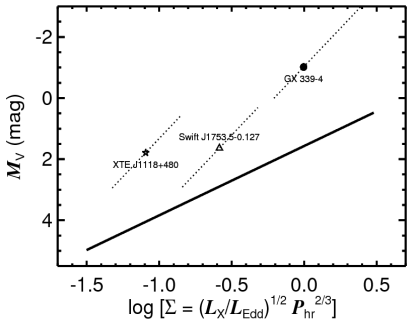
(Gandhi+10, Durant+10)

Summary

- Rapid optical flaring in low/hard state observations of several binaries.

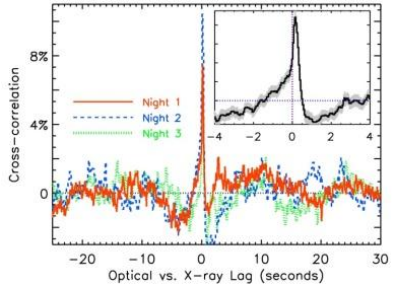






- Optical not reprocessed simply.

- Complex CCF
  => jet/corona/disk interaction.



- Optical timing gives complementary constraints on inner accretion processes.