Optical/Infrared — X-ray (rapid) variability of X-ray binaries

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Martin Durant
Vik Dhillon
Tom Marsh
Kazuo Makishima
Stephane Corbel

Andy Fabian
Dave Russell
Piergiorgio Casella
Julien Malzac
Sera Markoff

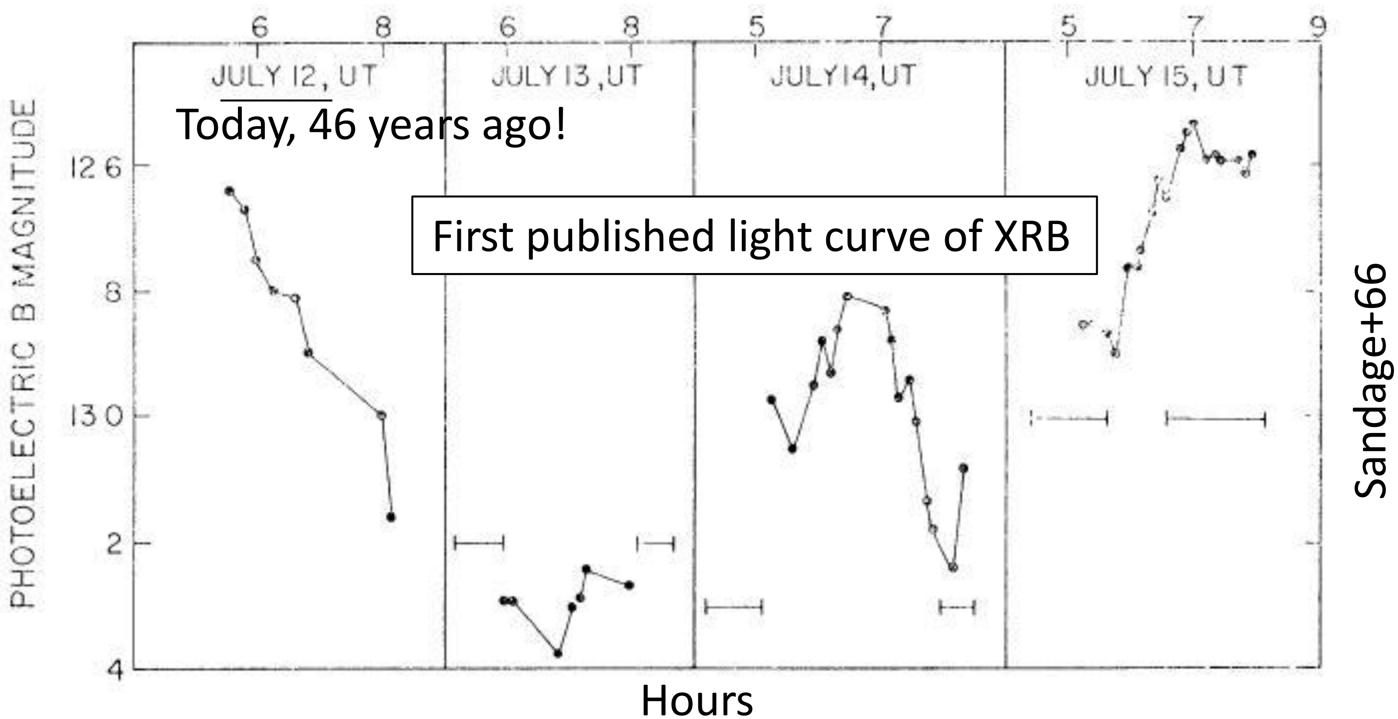
and others …

XRB variability: discovery

- 1962 – Giacconi+62: Discovery of Sco X-1
- 1966 – Discovery of first Optical/infrared (OIR) counterpart

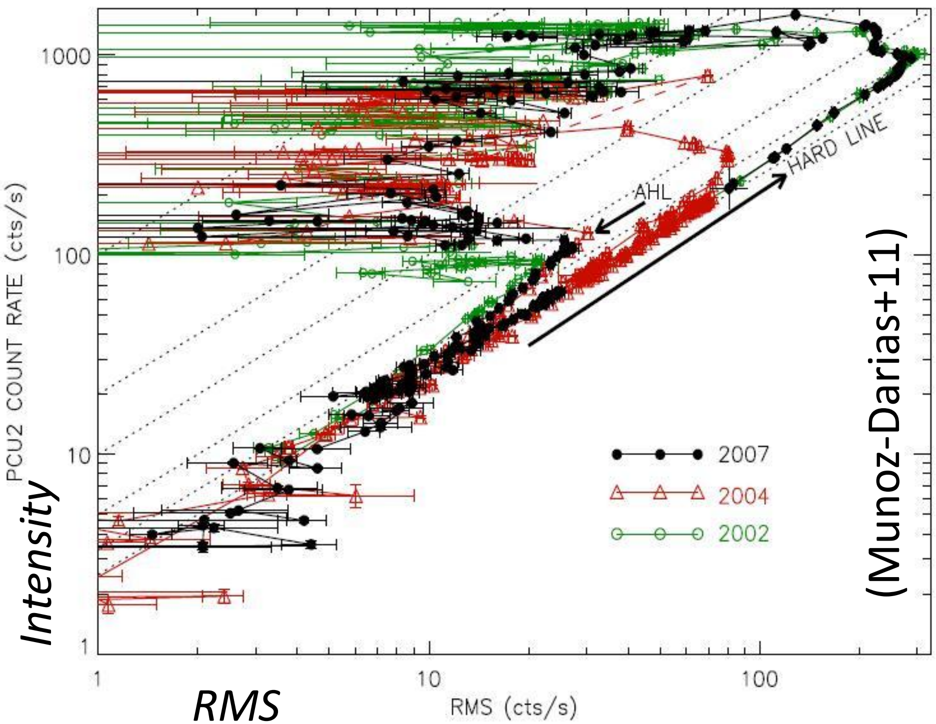
  AND (Sandage+66)

  Discovery of variability of an XRB, Sco X-1



Variability is a key characteristic of accretion

X-rays:



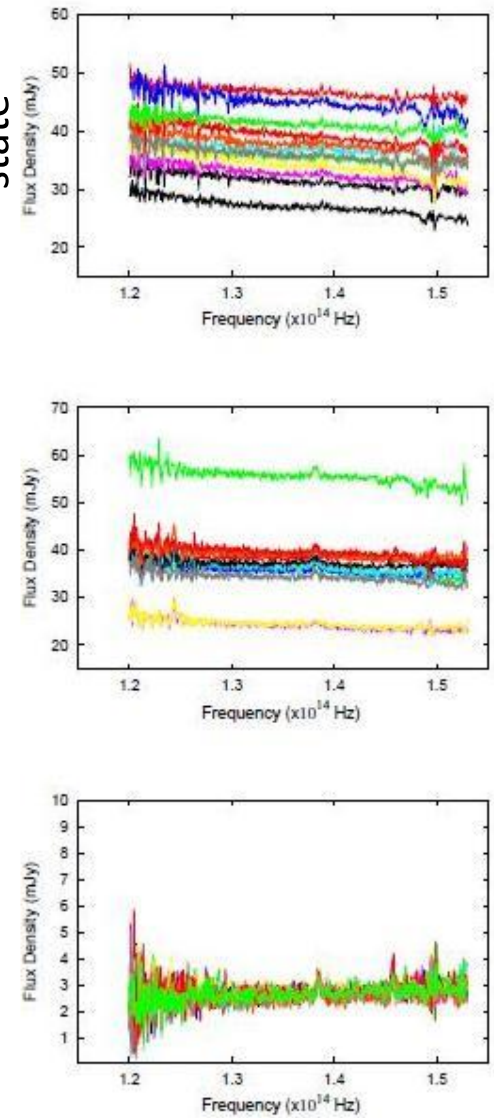
(Munoz-Darias+11)

Near-Infrared:

Hard state

Hard

Soft

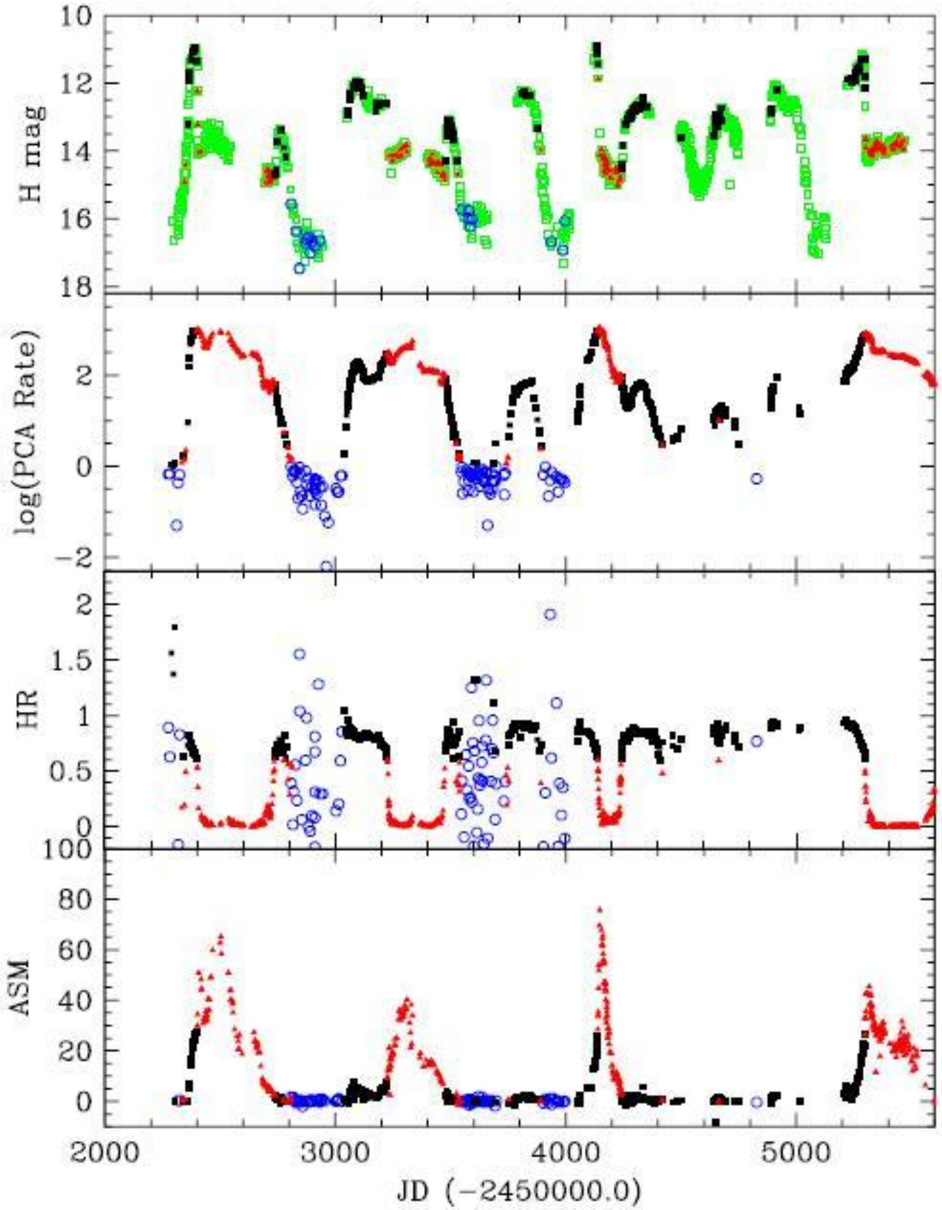


(Rahoui+12)

All data on **GX 339-4**

Variability on long timescales

A decade of OIR/X Monitoring of GX 339-4



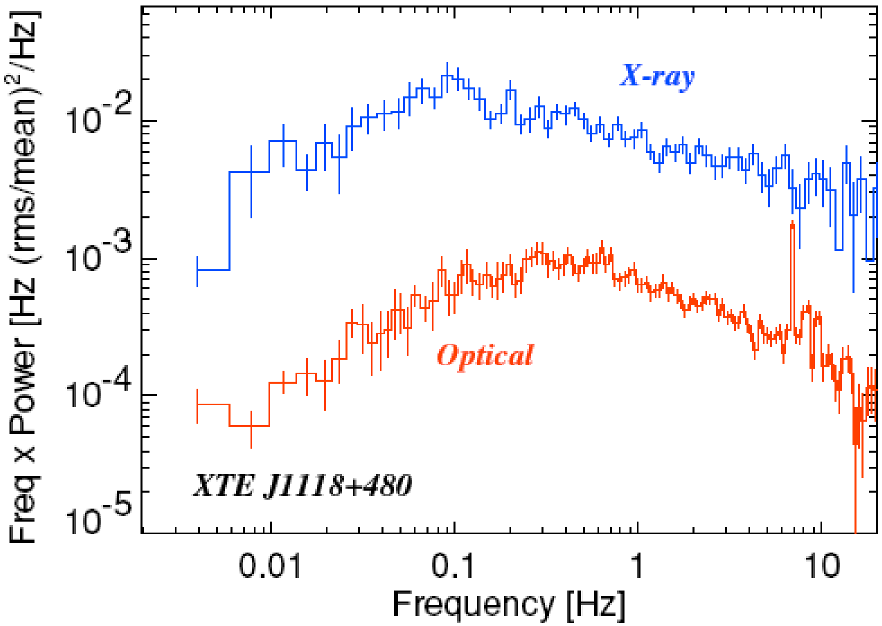
Near-IR

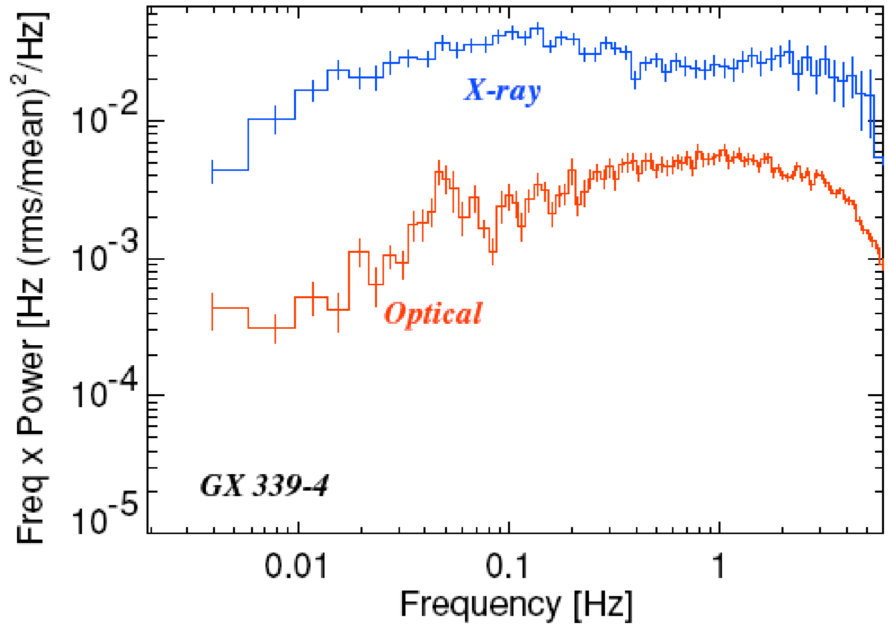
X-ray

X-ray

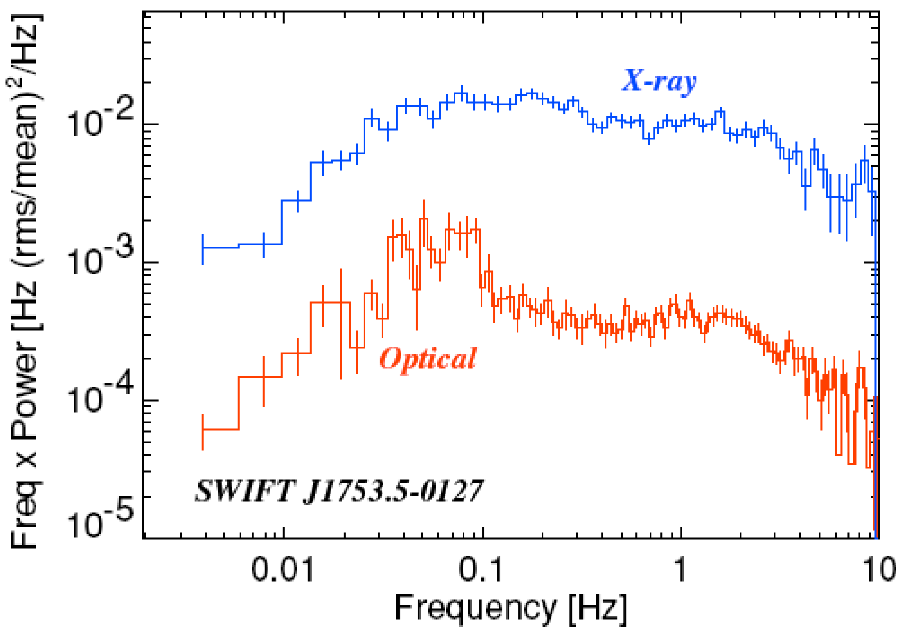
(Buxton+12)

Variability on short timescales





Band limited noise power over >3-4 decades in Fourier freq.



X-ray: XTE/PCA

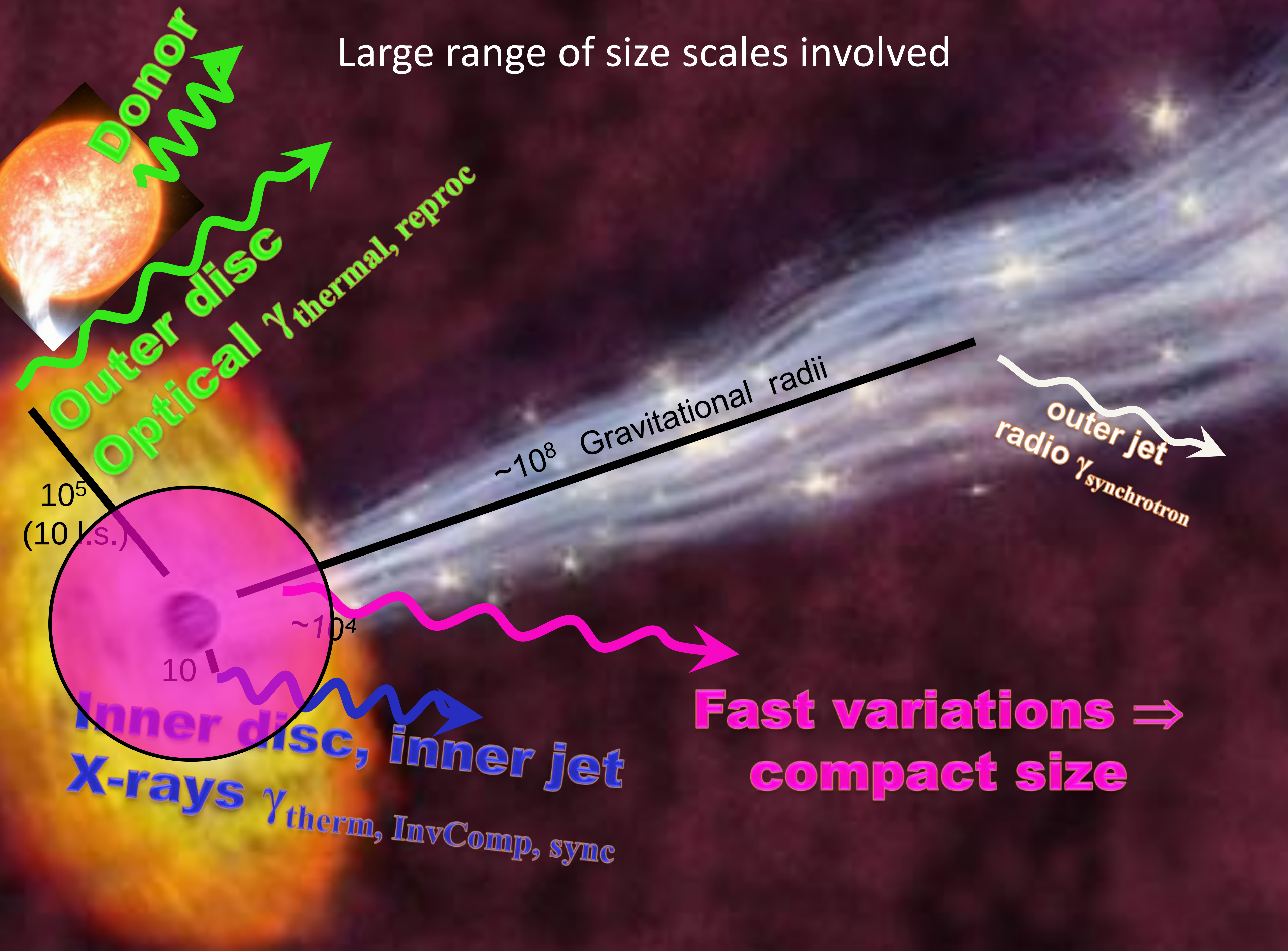
Optical: Either r' or g' or white

(Gandhi 2009)

Going beyond X-ray timing: Key issues

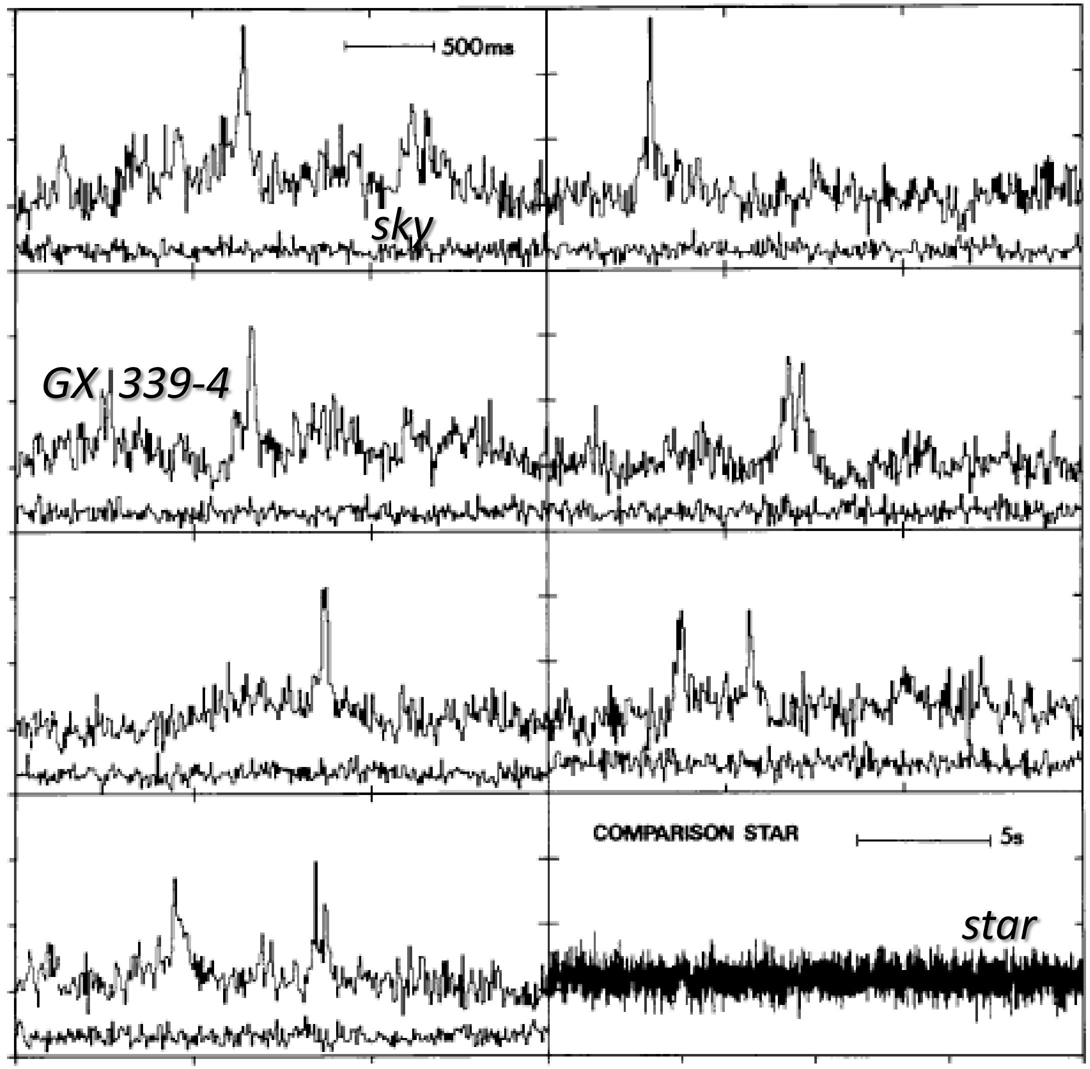
- How fast can (should) we go?
- How can we use multi-wavelength variability to disentangle observed radiative components?
- What is underlying driver of variations at different wavelengths, and how are they connected?
- Hope to constrain key physical parameters and understand acceleration processes.

Large range of size scales involved



Fast variations

C. Motch et al.: Fast Optical Activity of GX 339-4



30 years ago! (Motch+82, 83, 85; Fabian+82; Makishima+86, Steiman-Cameron+90…)

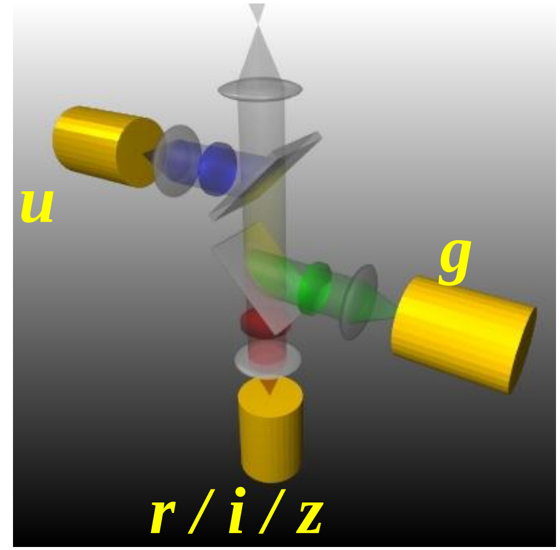
Rapid optical flickering ‘movies’ of X-ray binaries

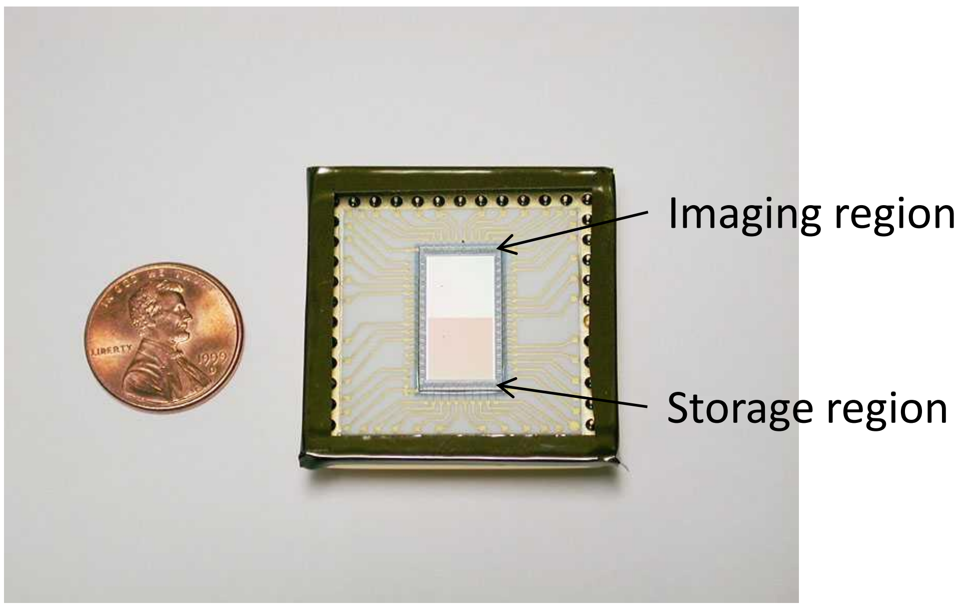
50 ms time resolution

GX 339-4 2007 hard state (Gandhi+08…10)

ULTRACAM:
ultra-fast, triple-beam CCD camera

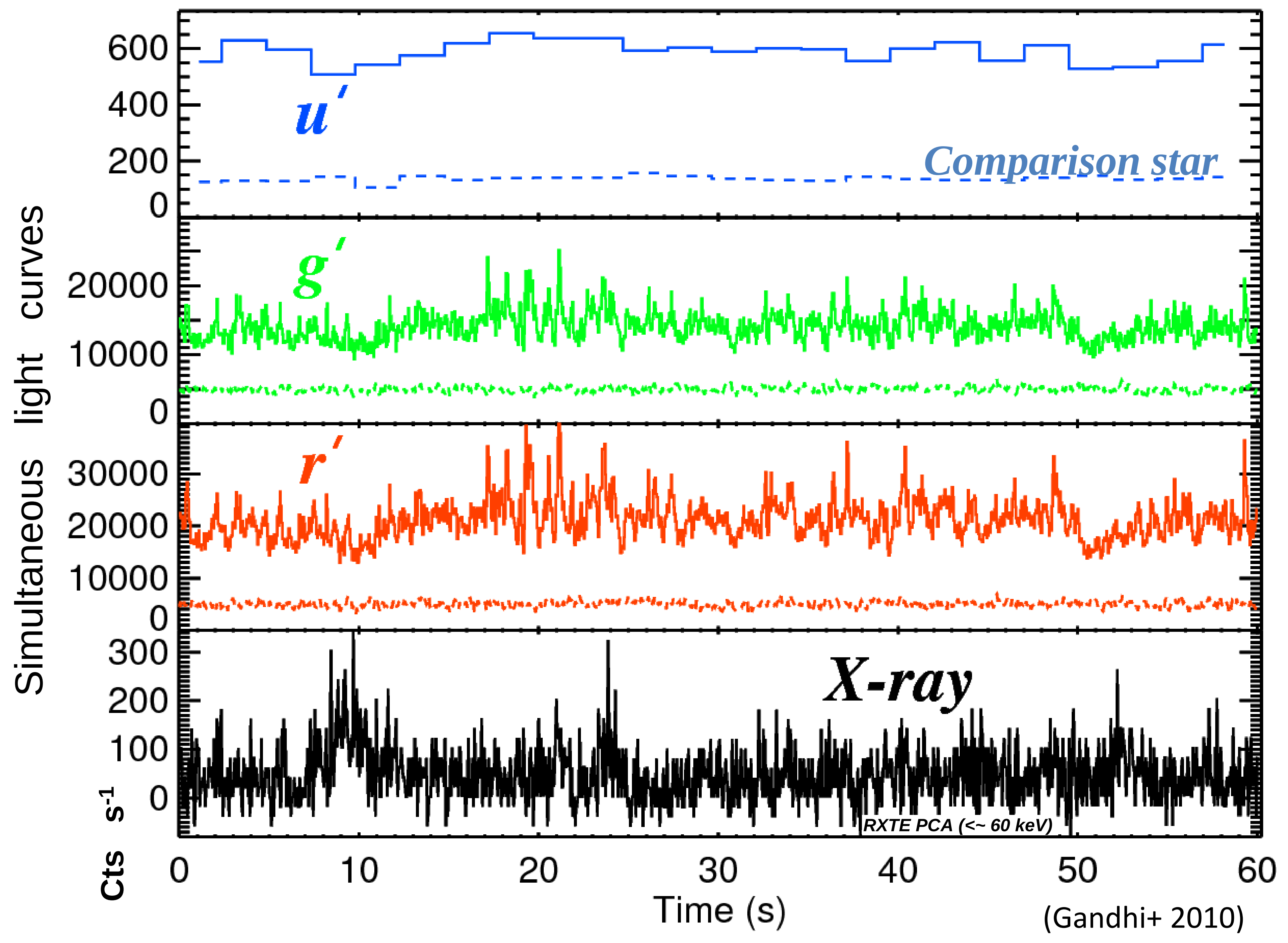
- Frame-transfer CCDs with negligible dead-time
- Speeds ~ 500 frames / sec
- Simultaneous imaging in three beams



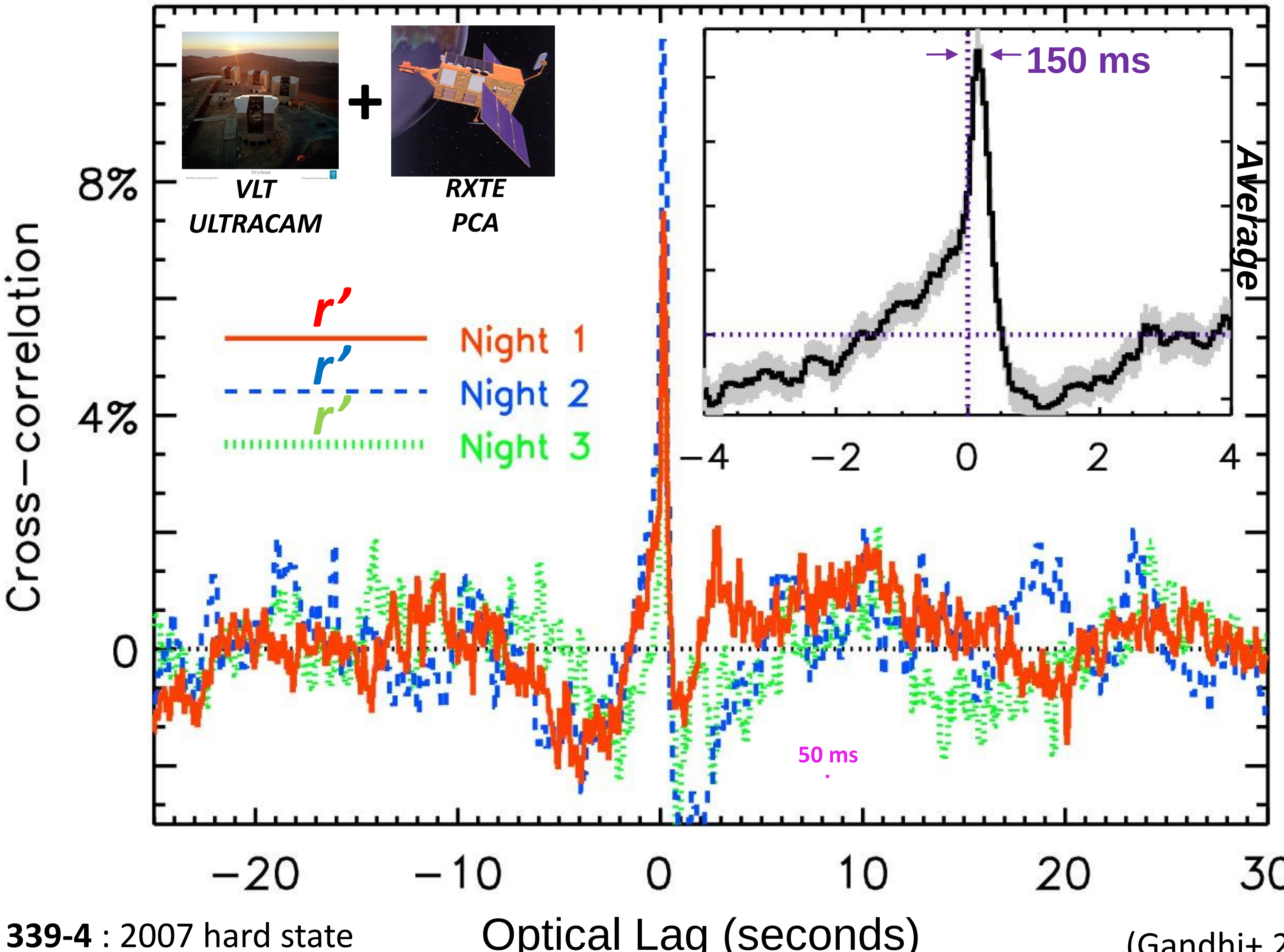


ULTRACAM @VLT

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


u′
Comparison star
g′
r′
X-ray
RXTE PCA (<~ 60 keV)
Simultaneous light curves
Cts s-1
Time (s)
(Gandhi+ 2010)

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



GX 339-4 : 2007 hard state

(Gandhi+ 2008)

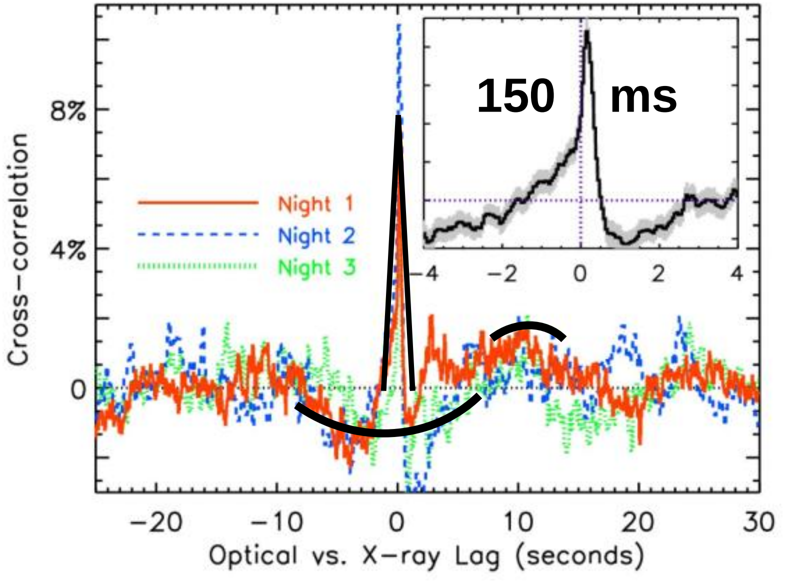
Optical/X-ray coherence and lags

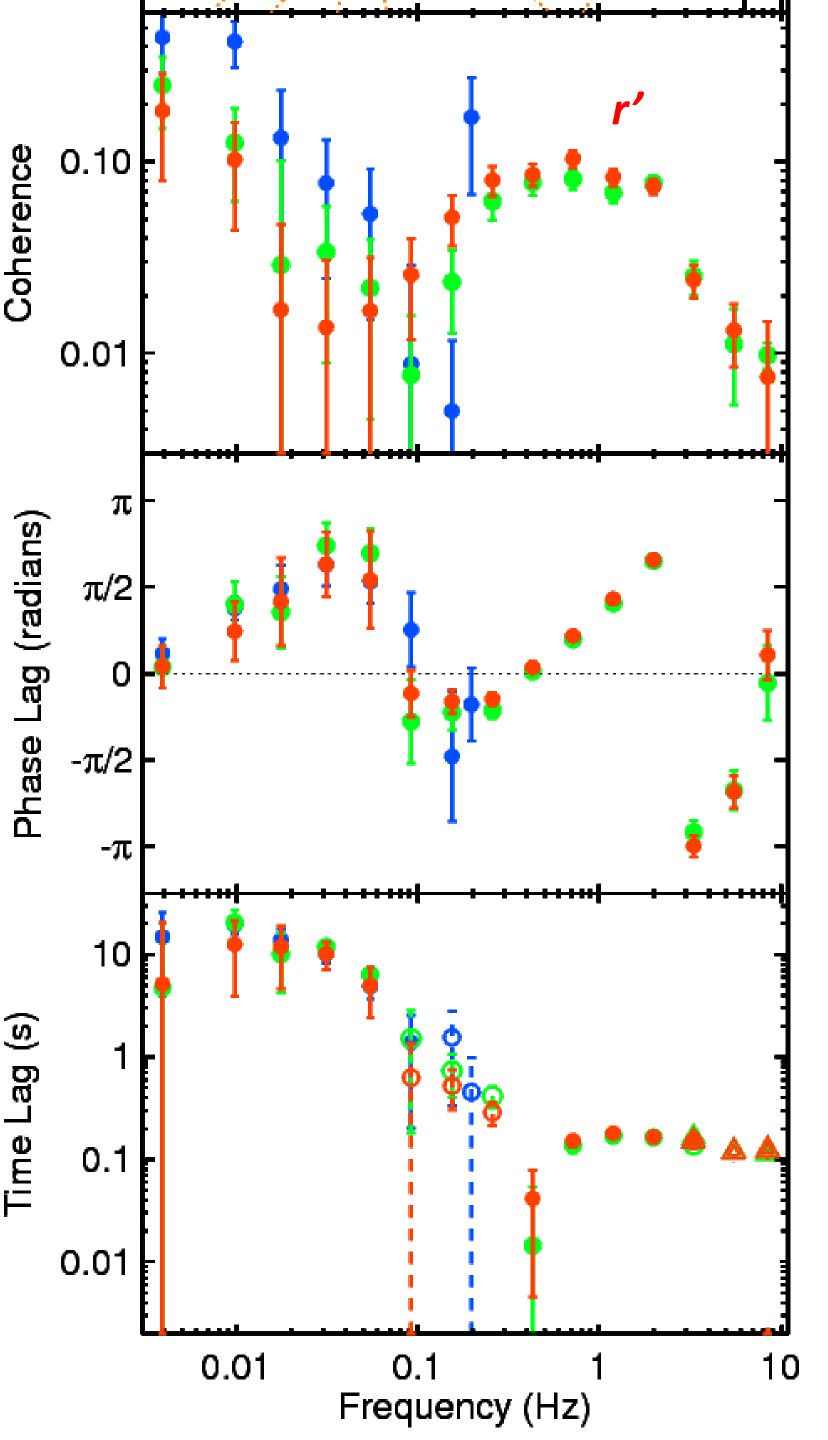
$$\text{Coherence} = \frac{|\langle X^* O\rangle|^2}{\langle|X^2|\rangle\langle|O^2|\rangle}$$

$$\text{Phase lag} = \arg(X^* O)$$

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

(Gandhi+ 2010)





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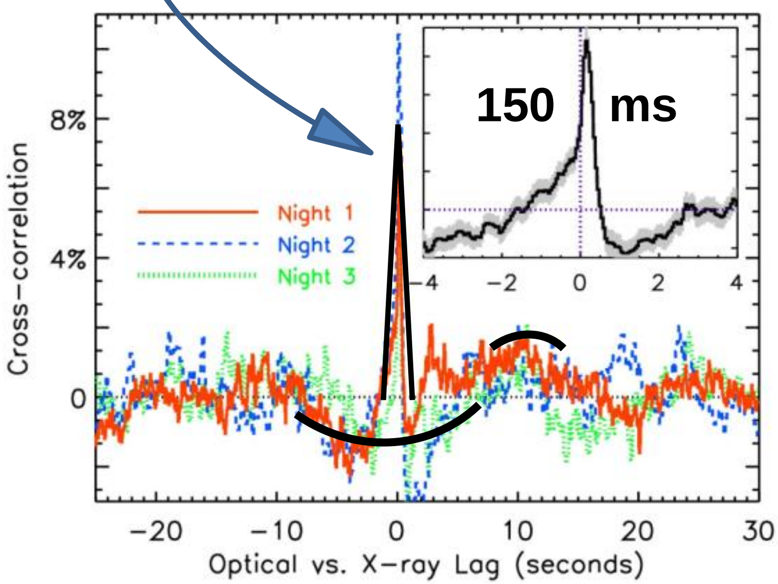
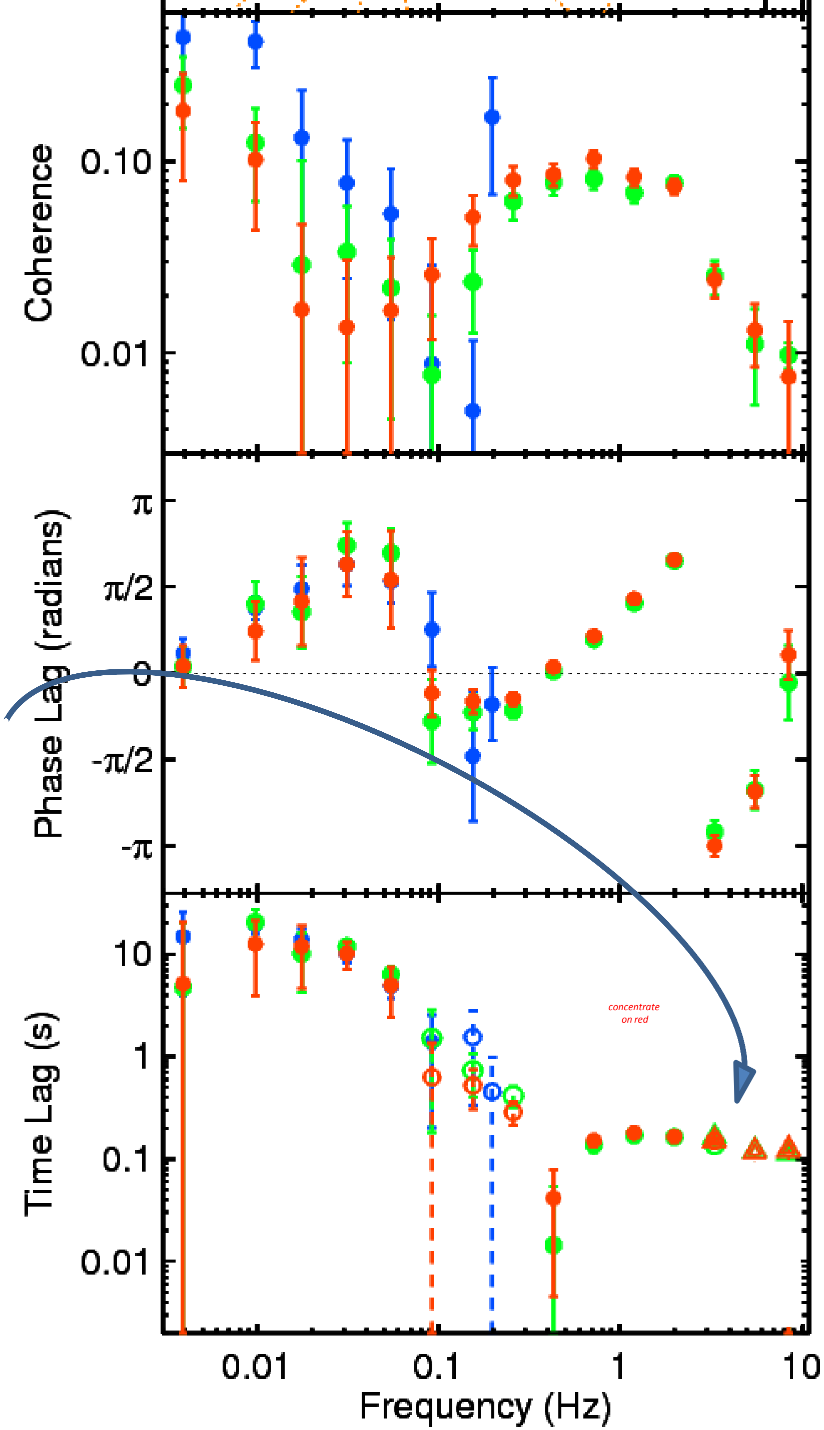
(Gandhi+ 2010)

Fast component





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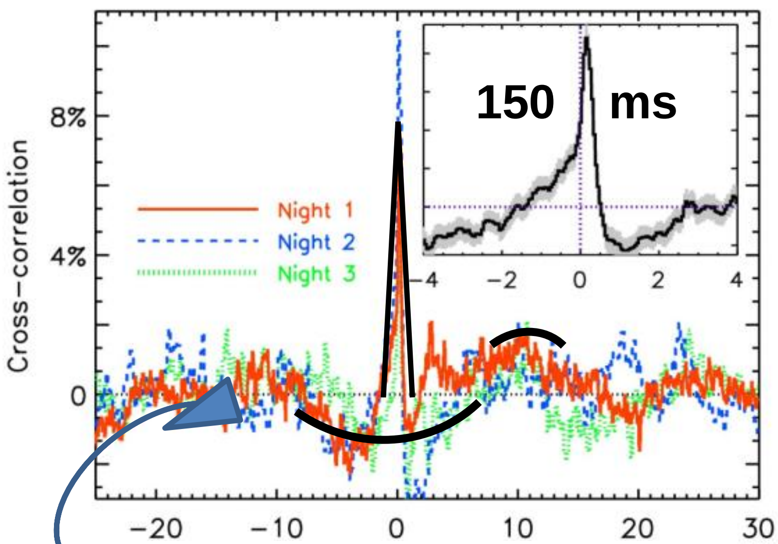
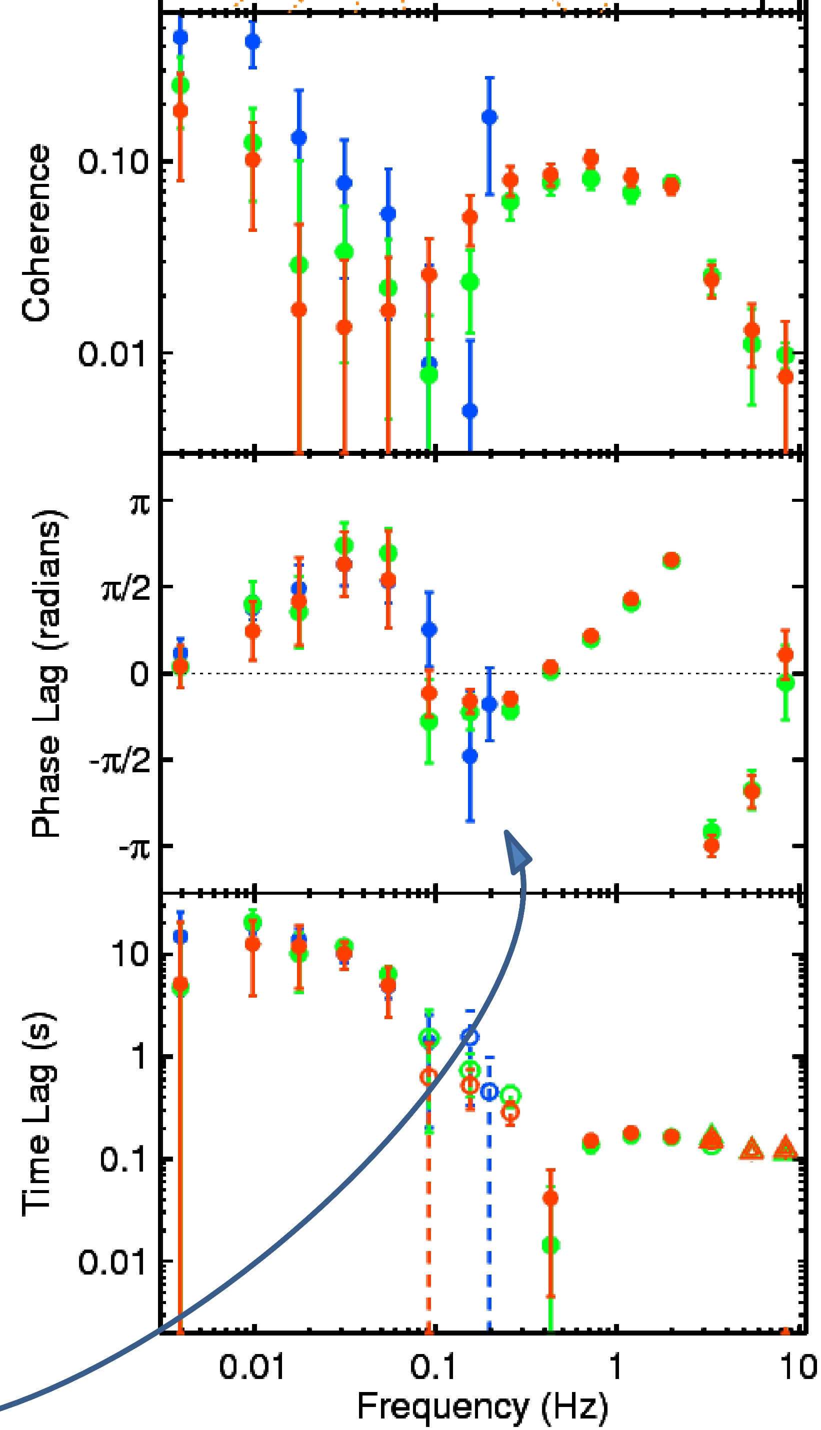
(Gandhi+ 2010)

Fast component



Intermediate negative component



Optical/X-ray coherence and lags

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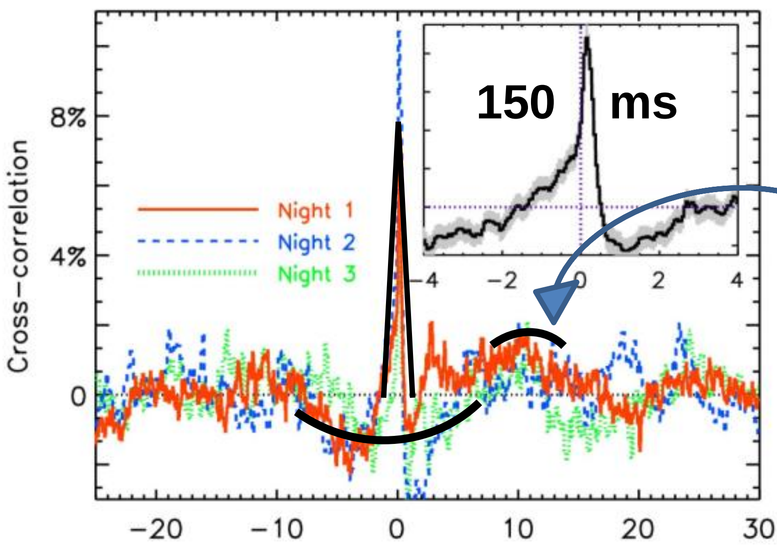
$$\text{Phase lag} = \arg(X^* O)$$

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

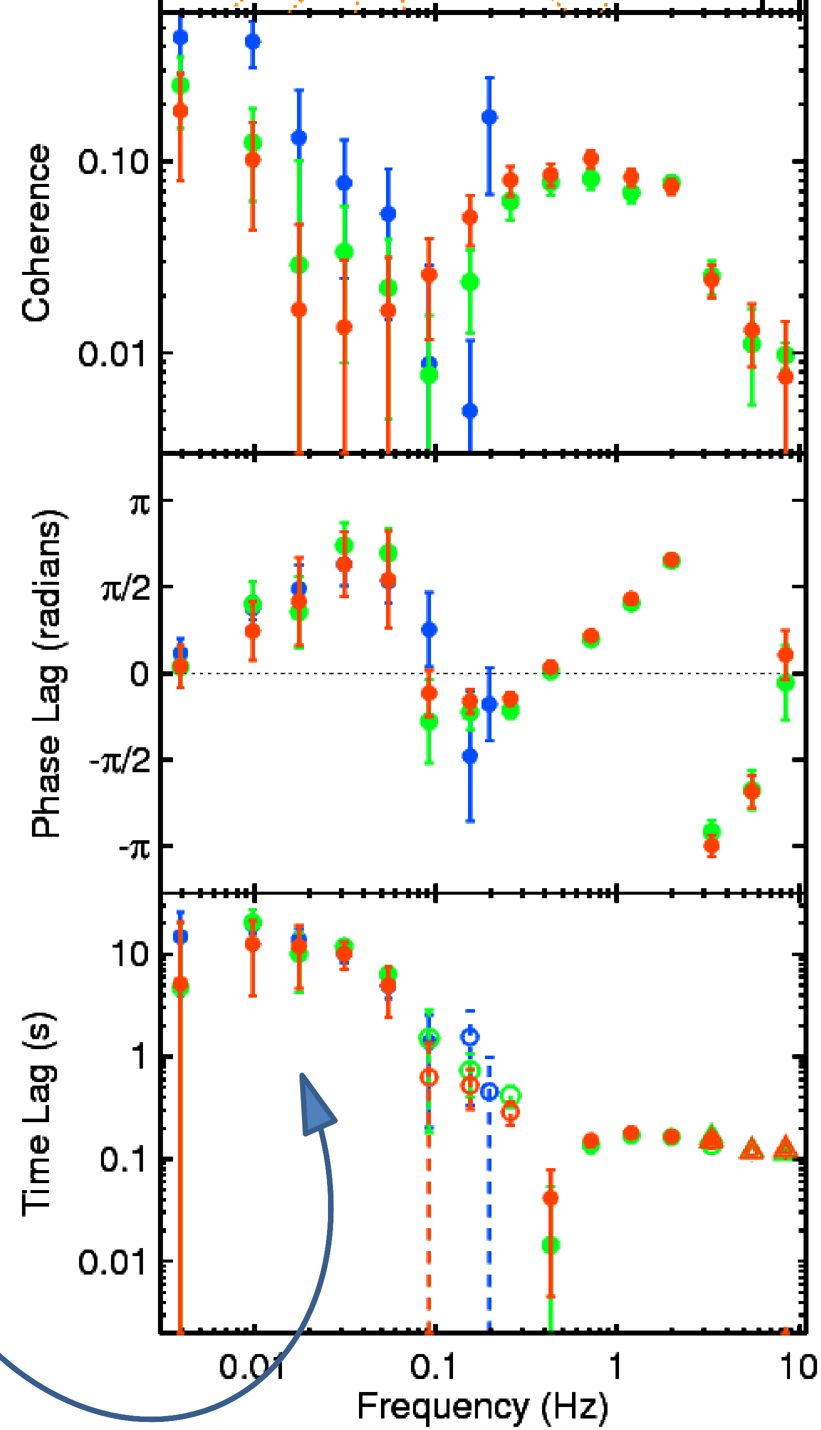
(Gandhi+ 2010)

Fast component



Slow

Intermediate negative component



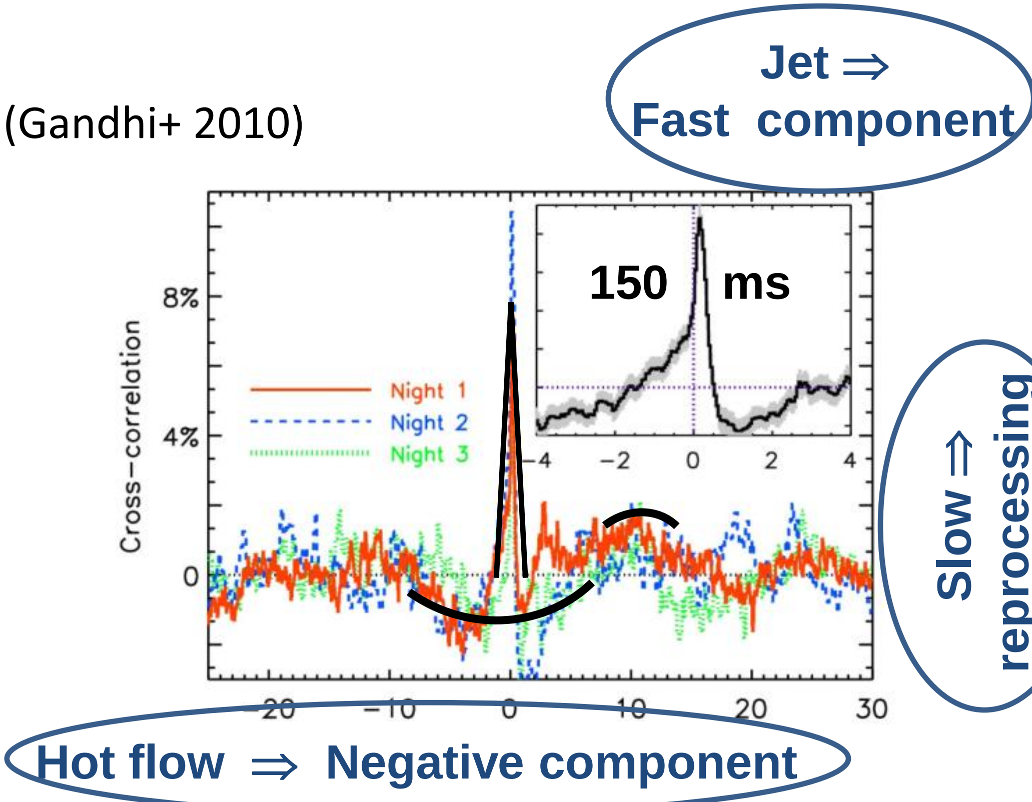
Optical/X-ray coherence and lags

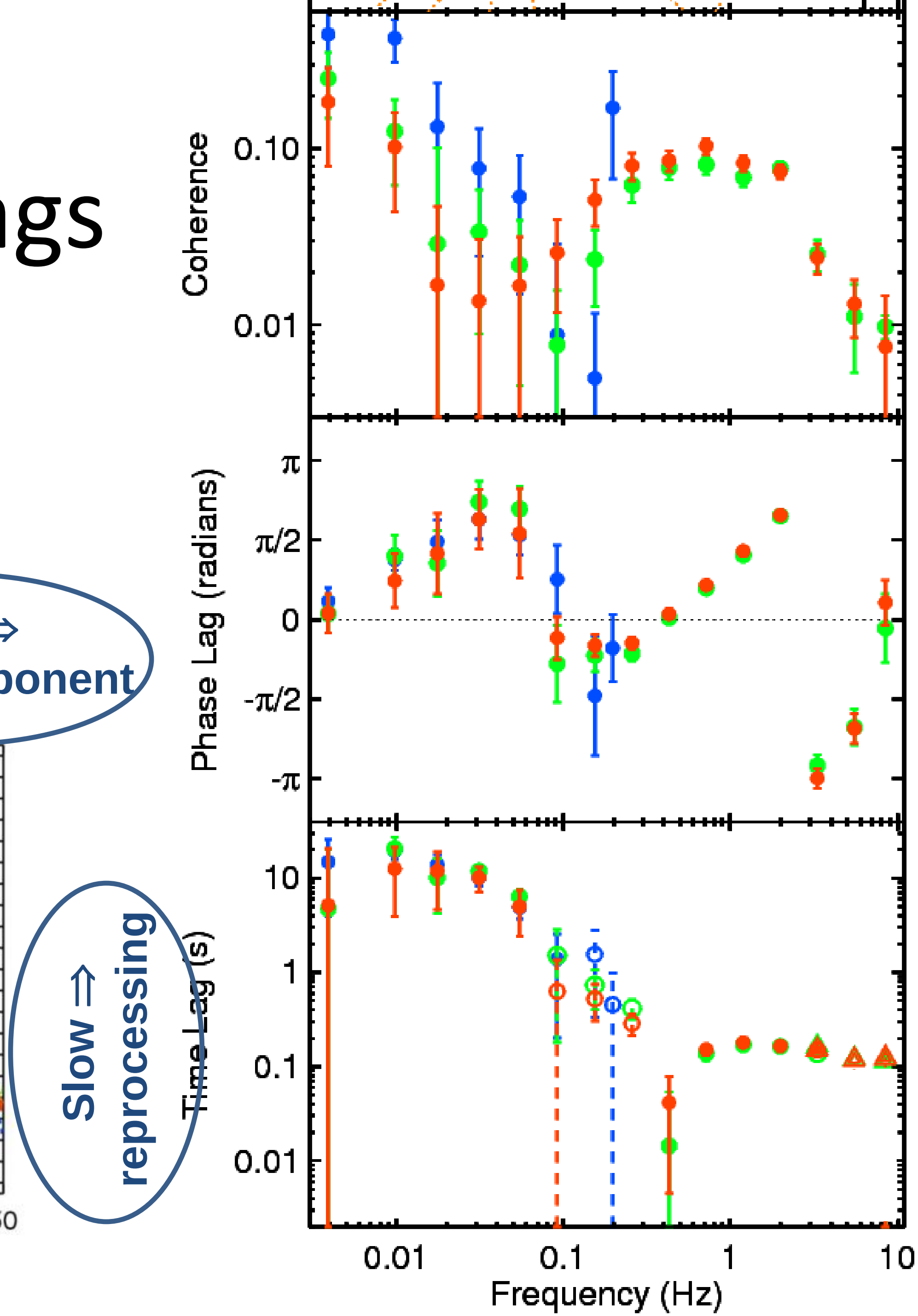
$$\text{Coherence} = \frac{|\langle X^{*} O\rangle|^{2}}{\langle|X^{2}|\rangle\langle|O^{2}|\rangle}$$

Phase lag = arg $(X^{*}\,O)$

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

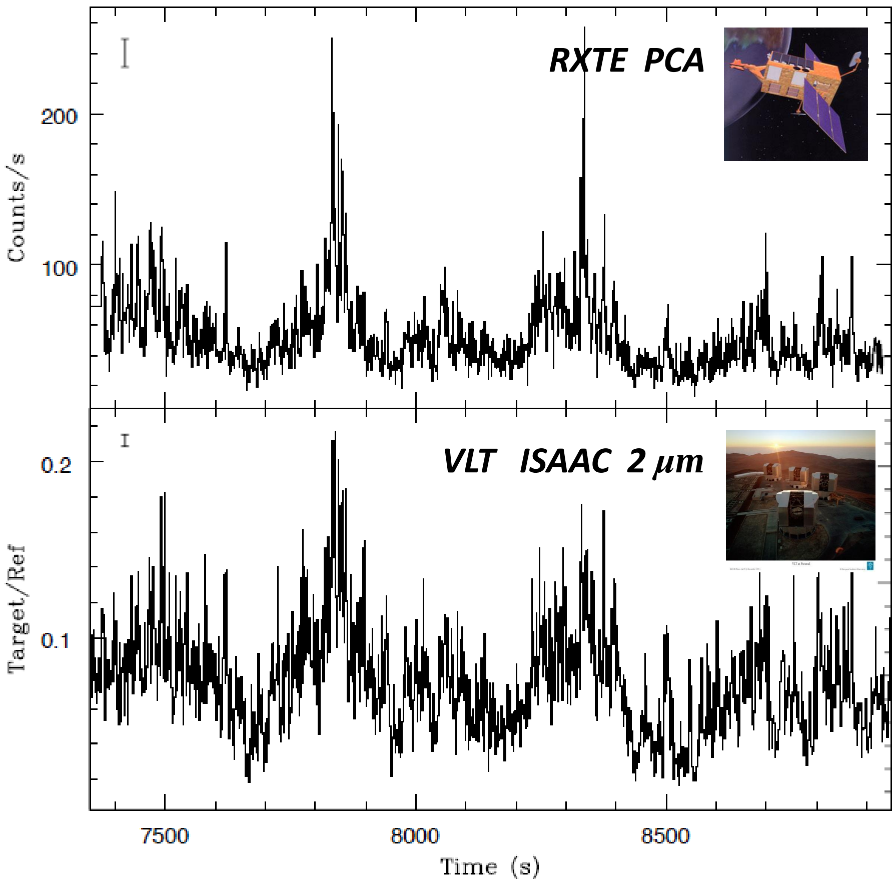
(Gandhi+ 2010)



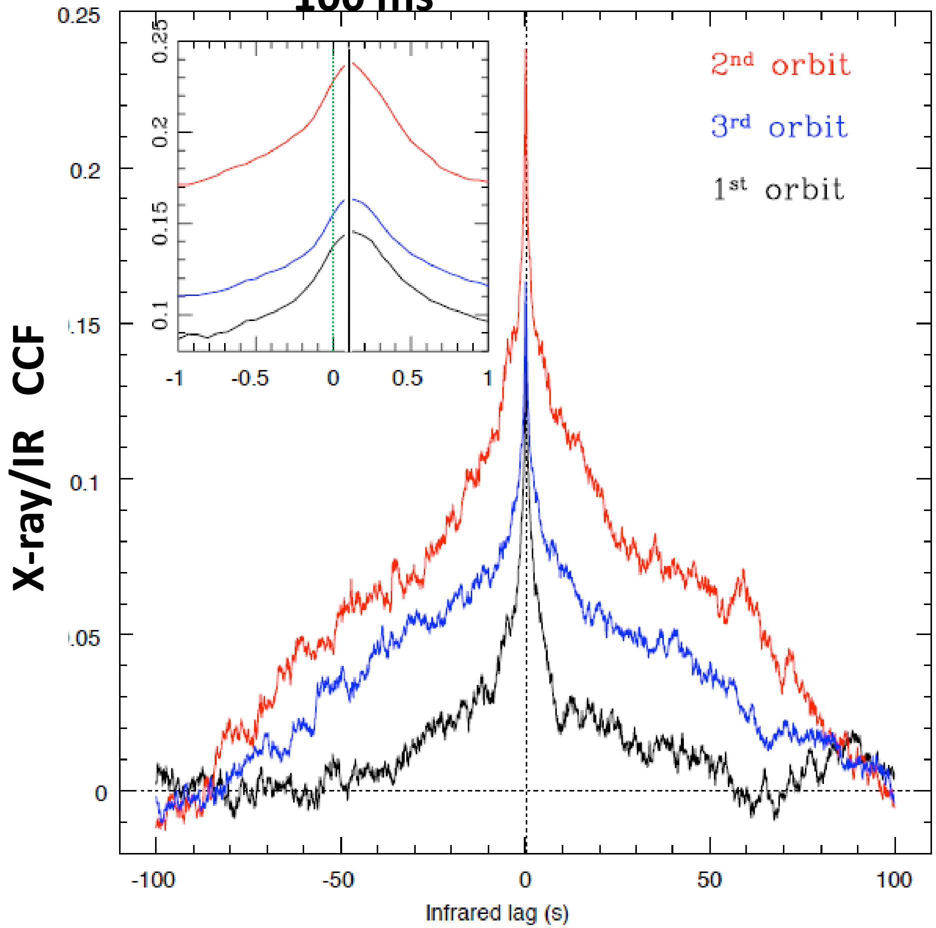


Near-IR (jet) also delayed by ~100 ms

2008 hard state

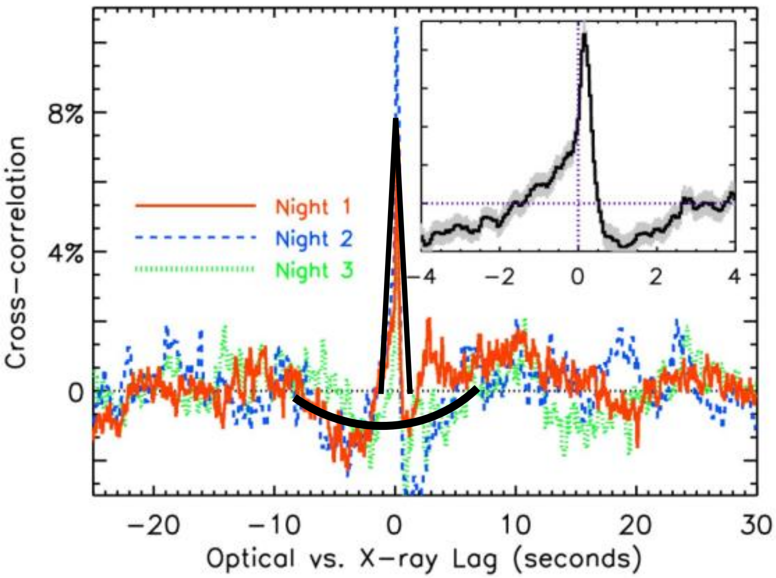


IR lag
100 ms

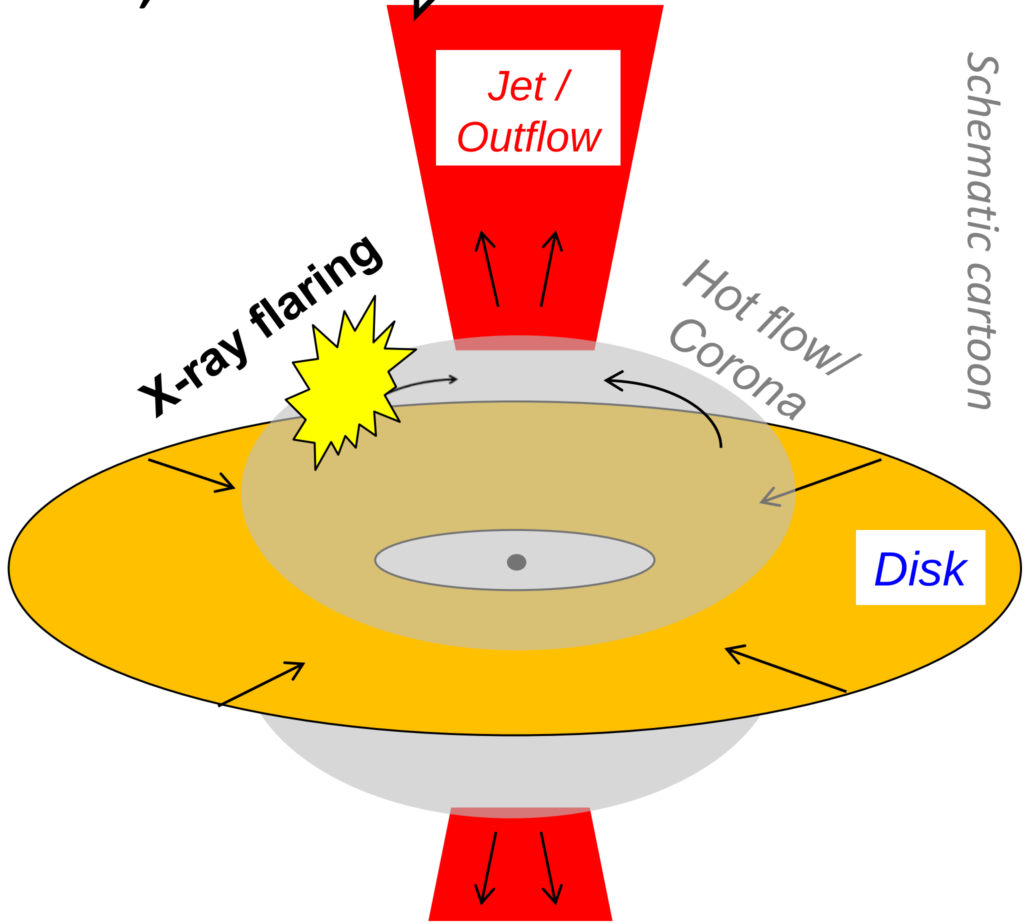


(Casella+10)

Hot flow ⇨ -correlation, Jet ⇨ +correlation



(Gandhi+10)

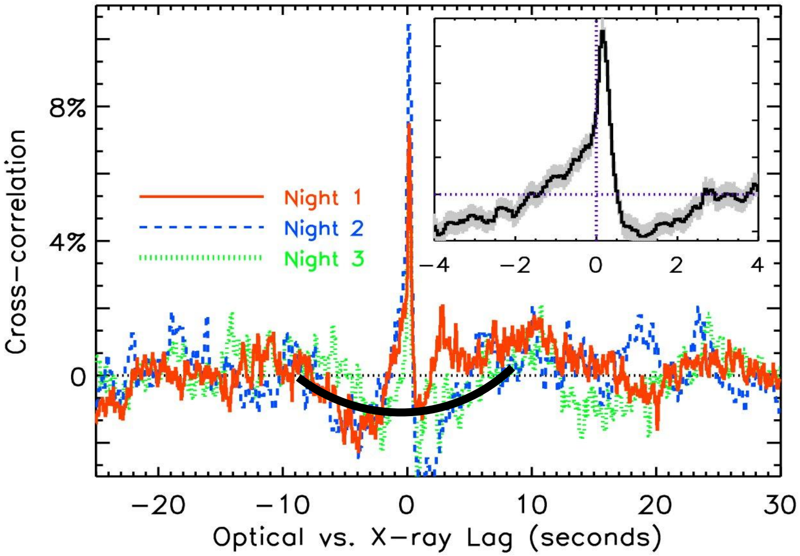


Coronal X↑ ⇨ B↓ ⇨ O↓ ⇨ ………ΔT……… Jet O↑

ΔT=150 ms => jet optical (cyclo)synchrotron emission at 5000 R_G

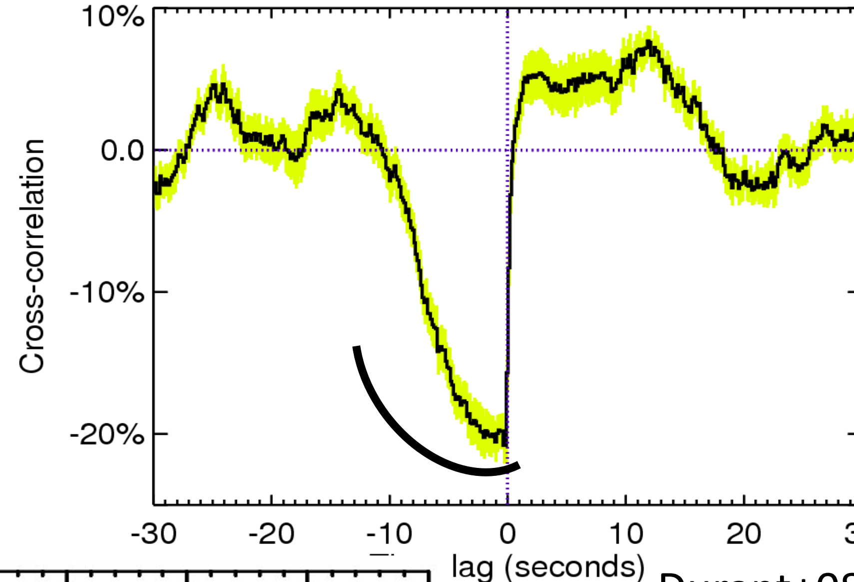
O/X cross-correlation functions in X-ray binaries

GX 339-4

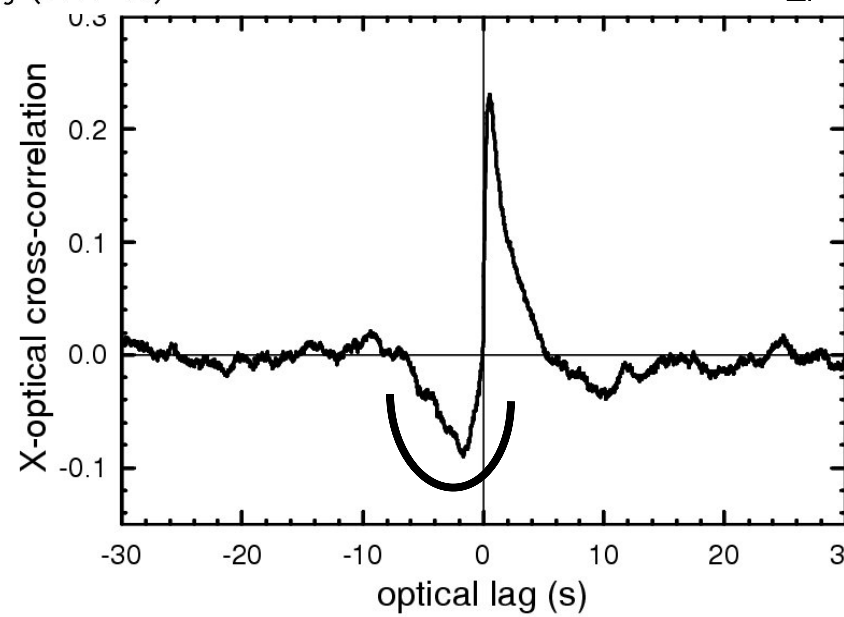


Gandhi+08, 10

Swift J1753.5-0127

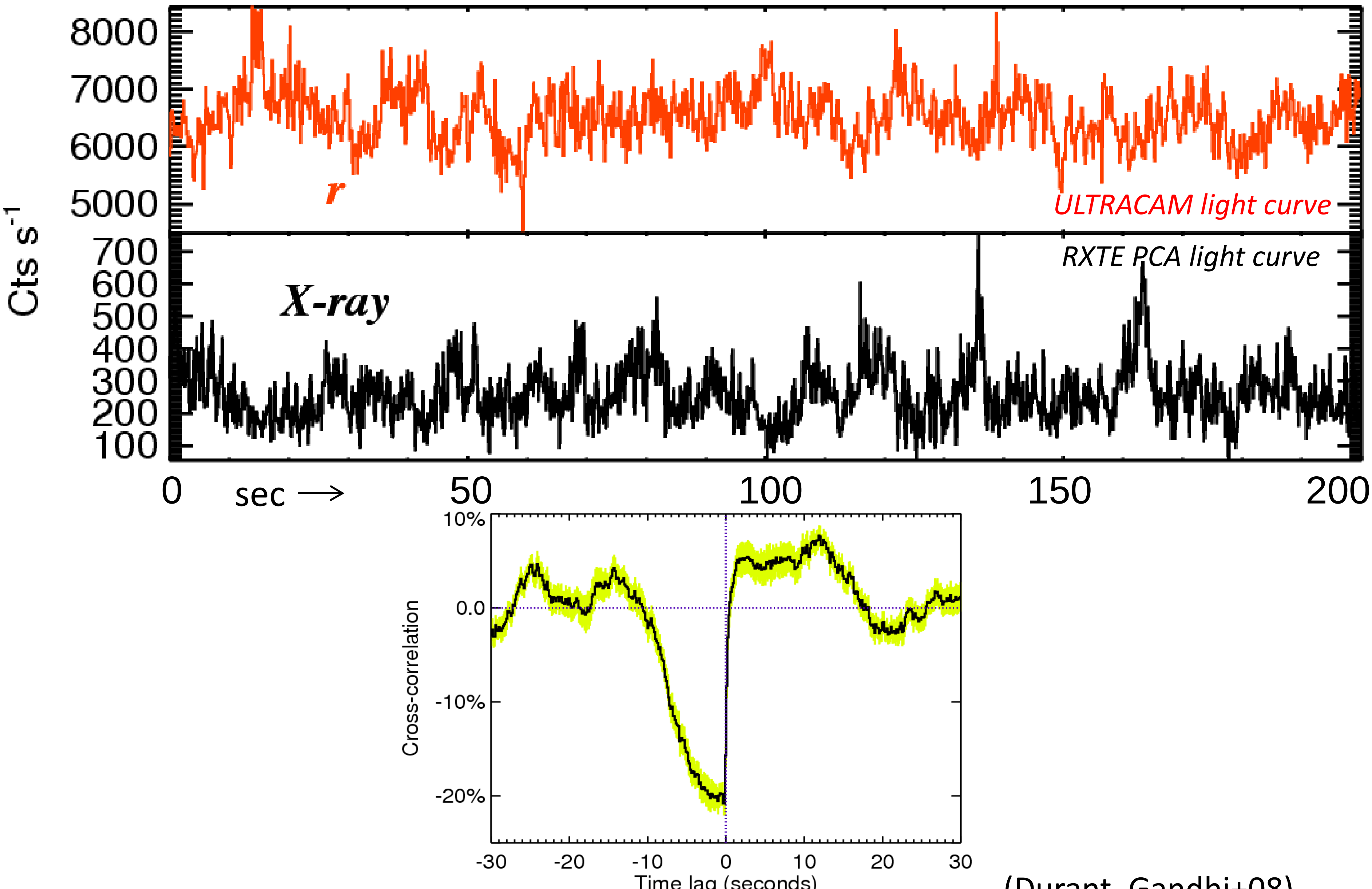


Durant+08, 09
Hynes+09



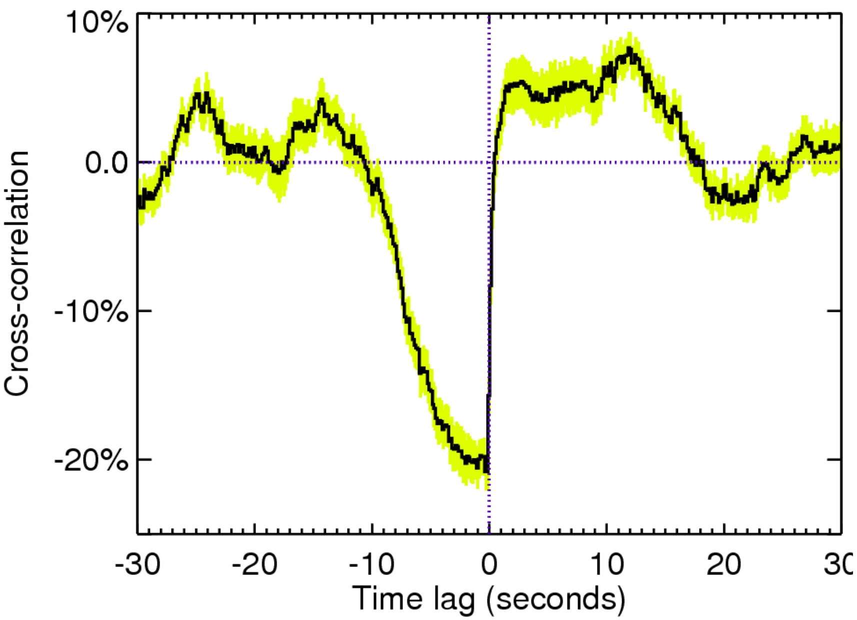
XTE J1118+480:
Kanbach+01,
Hynes+03

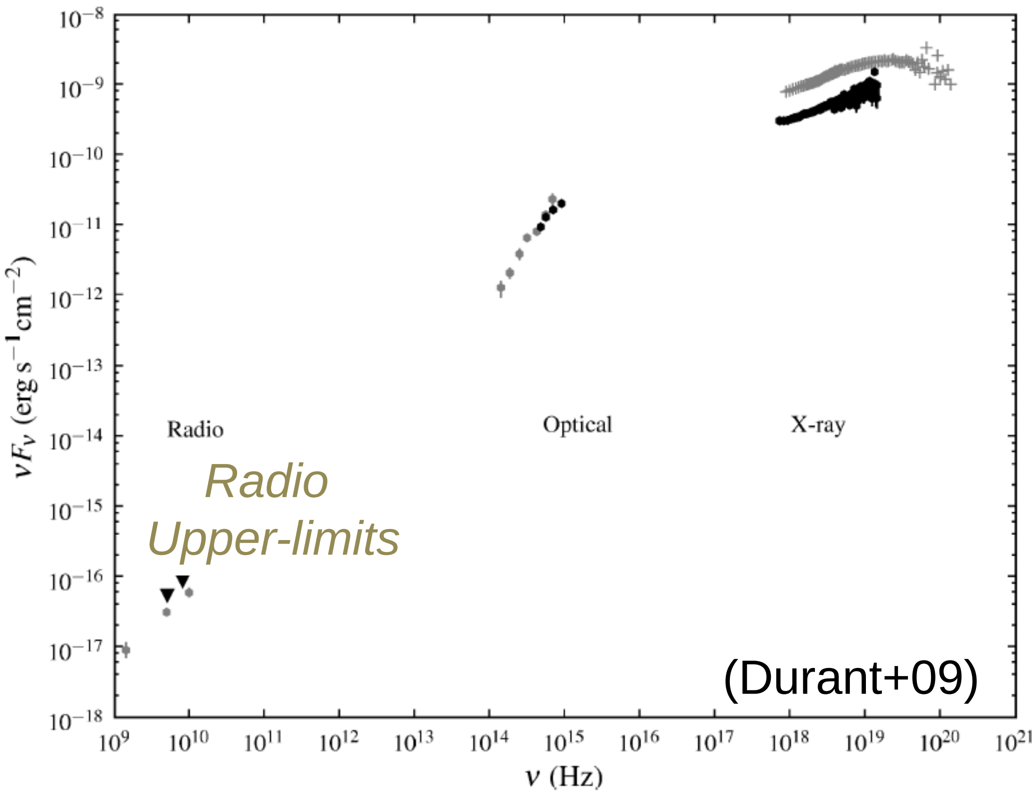
Swift J1753.5-0127

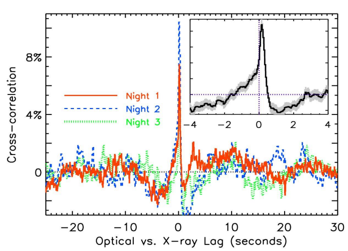


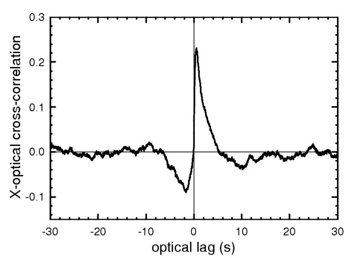
(Durant, Gandhi+08)

Swift J1753.5-0127:
Weak positive CCF and faint jet



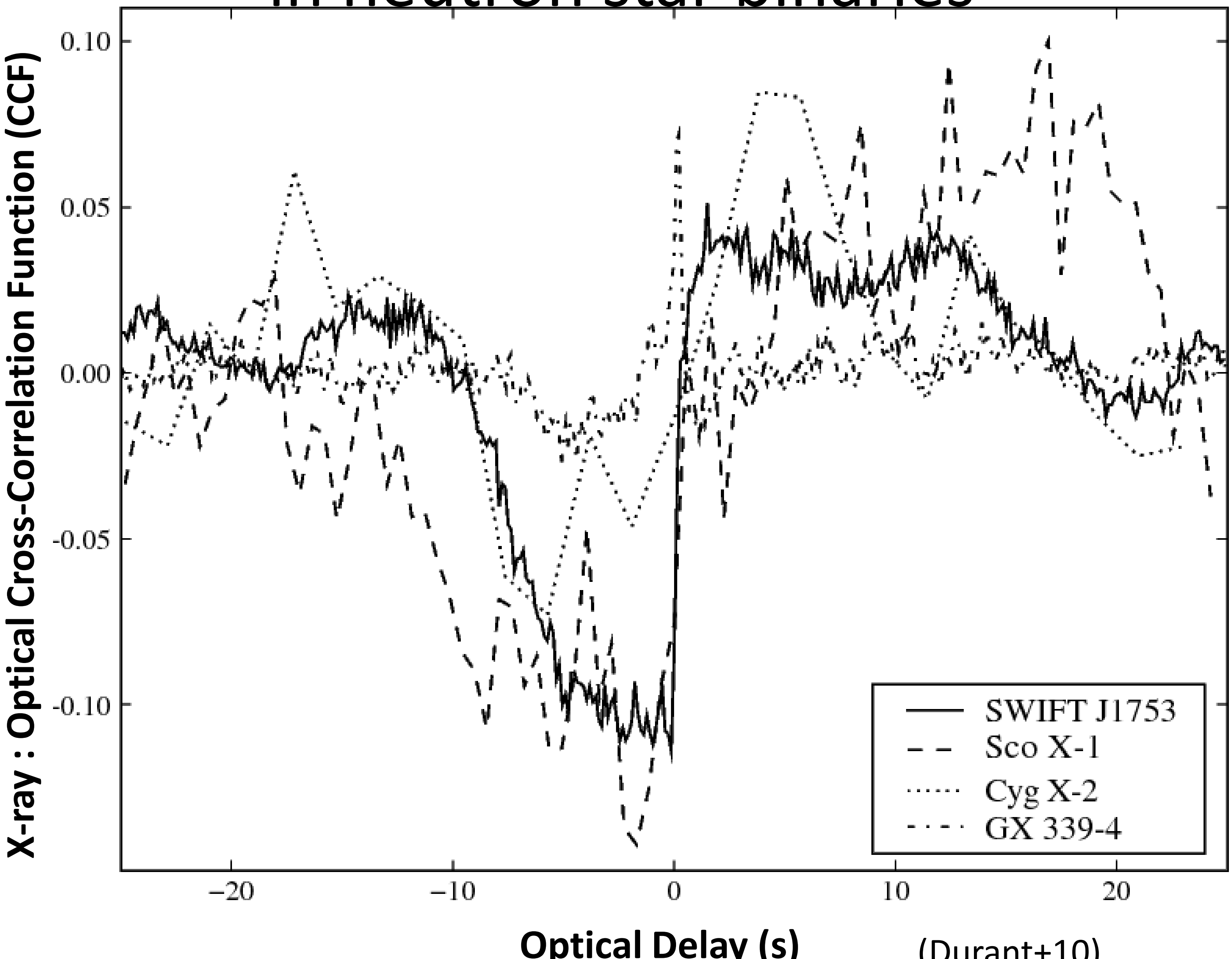






← Strong jetted sources have sharp positive correlation (Gandhi+10)

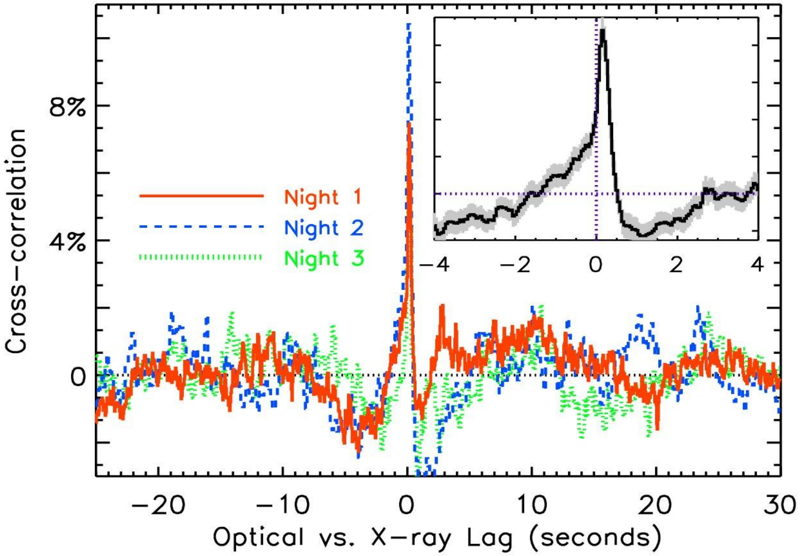
Negative CCF component also more prominent in neutron star binaries



(Durant+10)

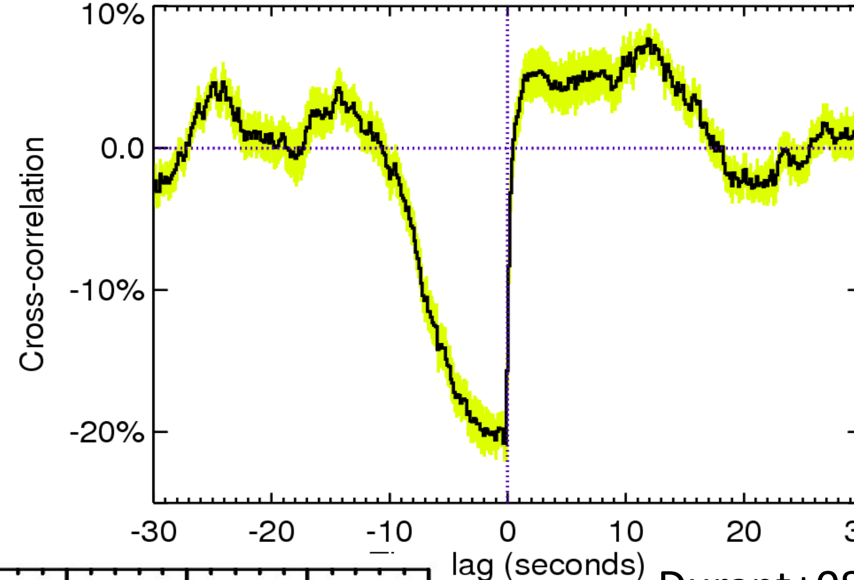
Strong jet/disk/hot flow connection in XRBs

GX 339-4

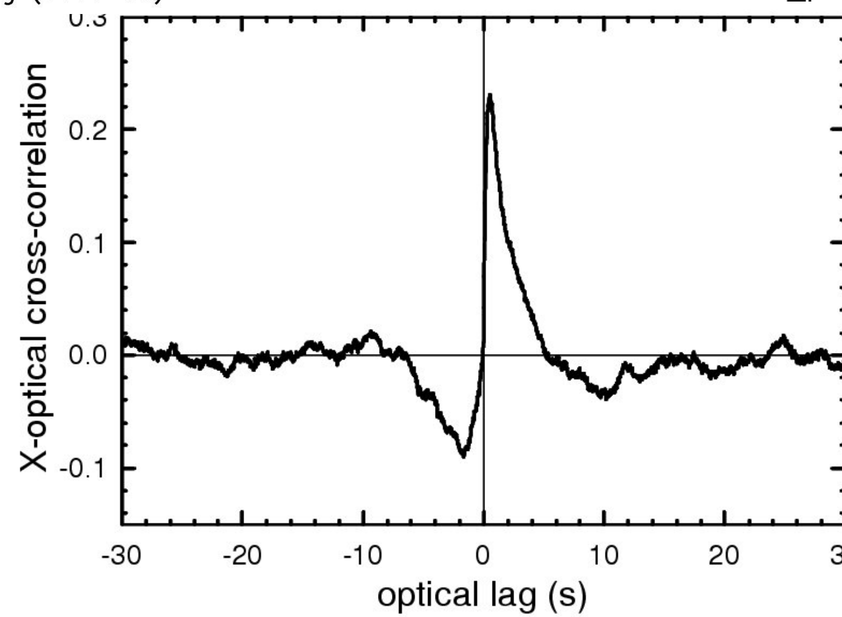


Gandhi+08, 10

Swift J1753.5-0127

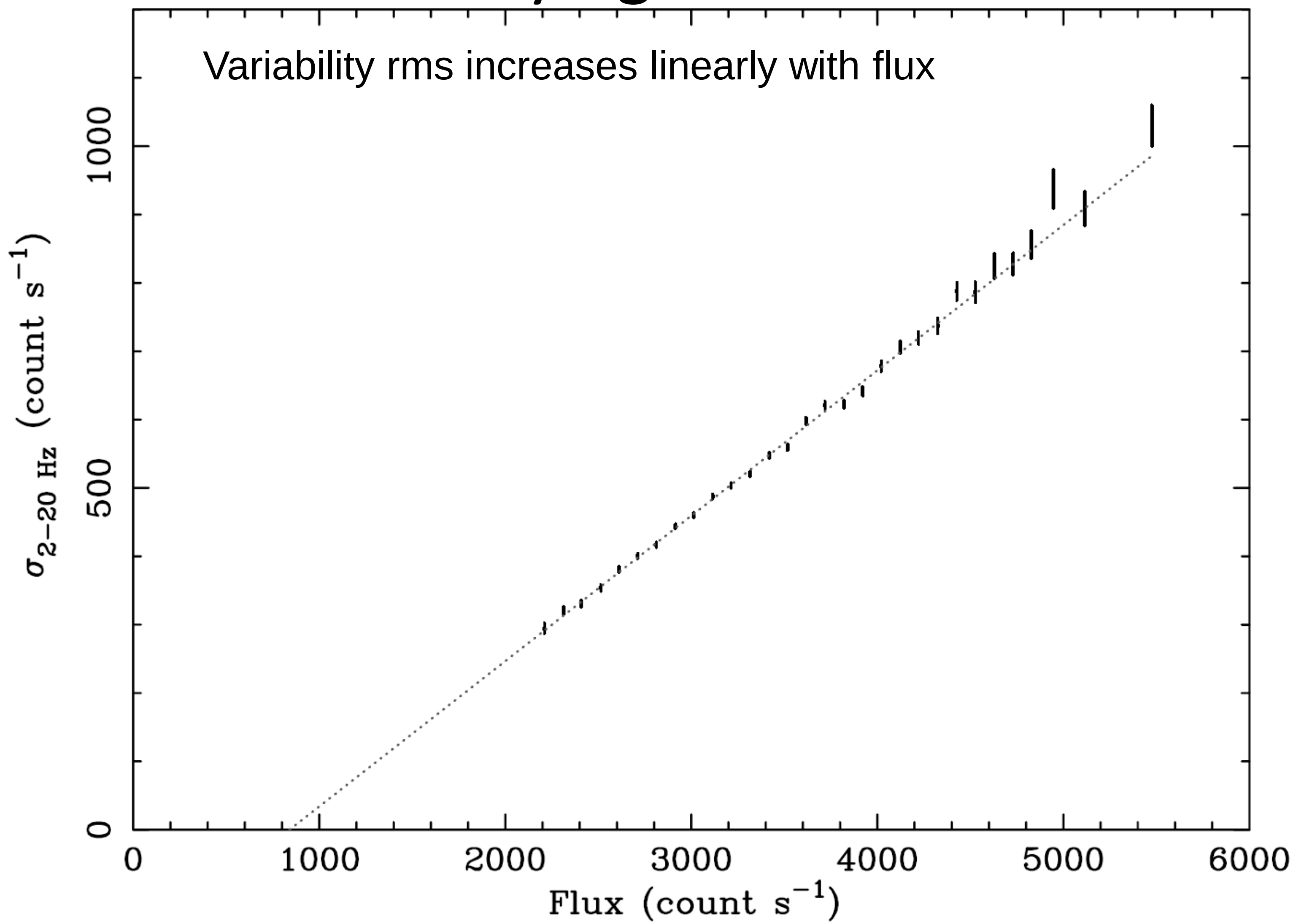


Durant+08, 09
Hynes+09



XTE J1118+480:
Kanbach+01,
Hynes+03

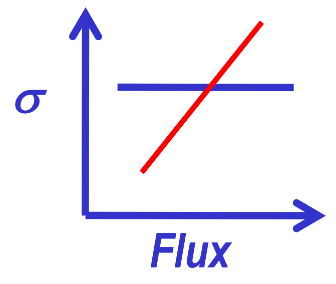
rms-flux relation: connections between underlying variations



Stochastic variability cannot be local and additive (Uttley+ 01…05)

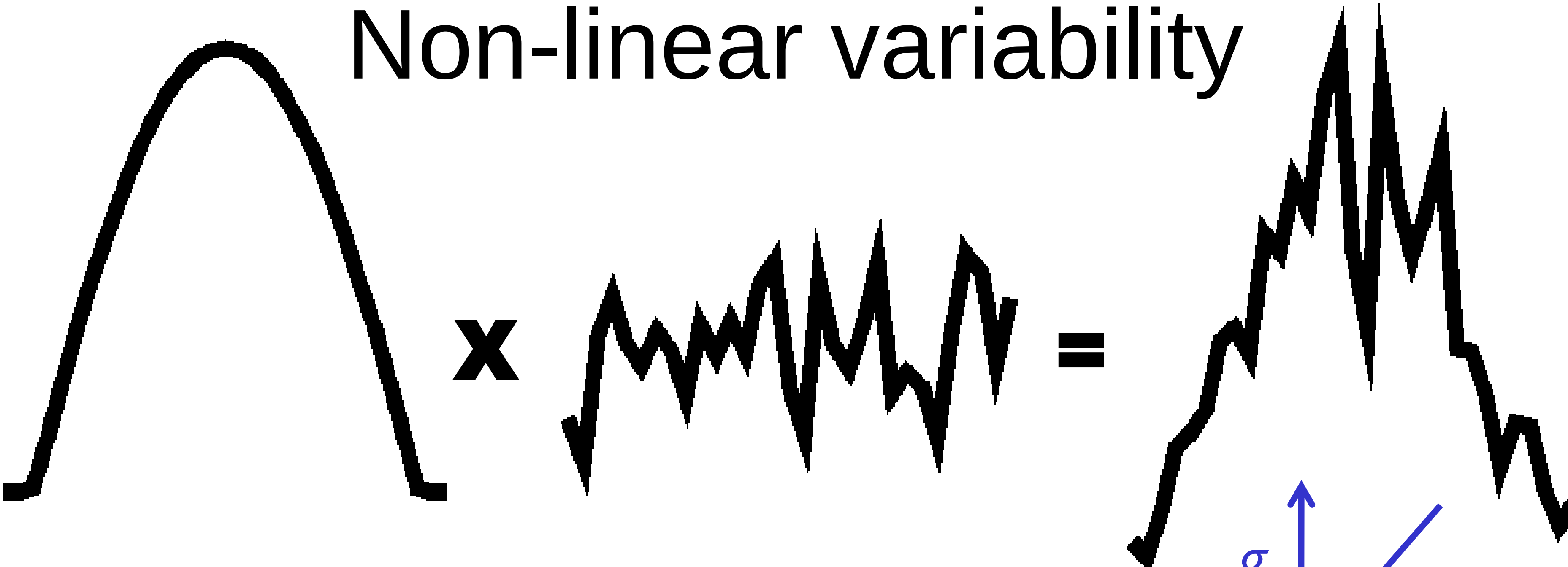
Additive shot models

Superposition of independent shots
=> Equal variability power at all fluxes

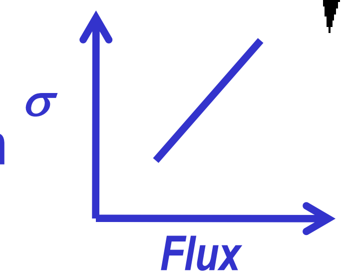


Ruled out in X-rays (Uttley+…)

Non-linear variability

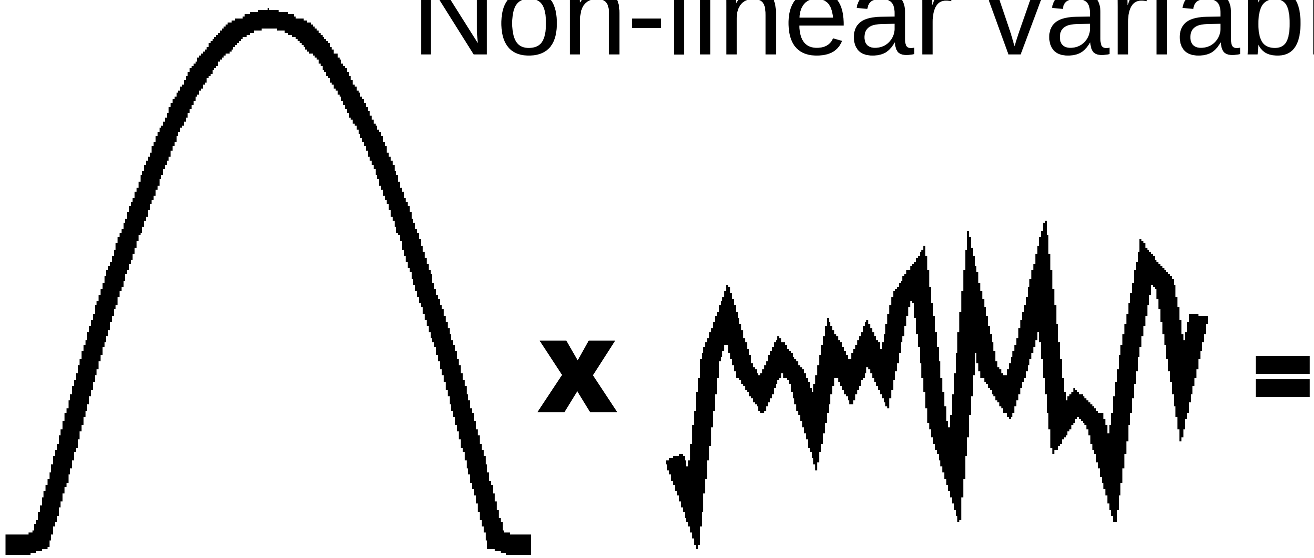


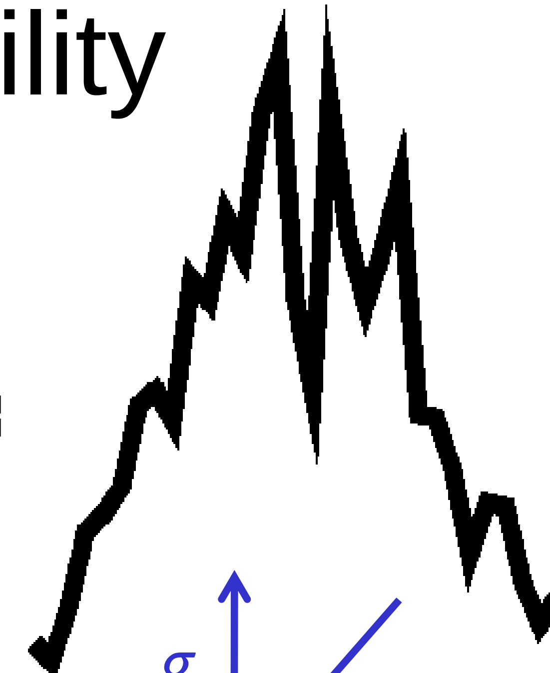
Multiplicative coupling rather than additive superposition



(Lyubarskii 97, Misra 00, King+04, Titarchuk+07, Zhang 07)

Non-linear variability





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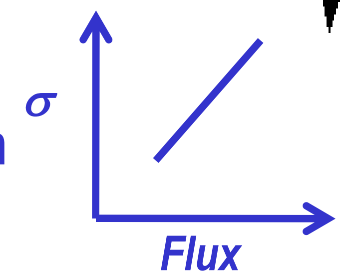
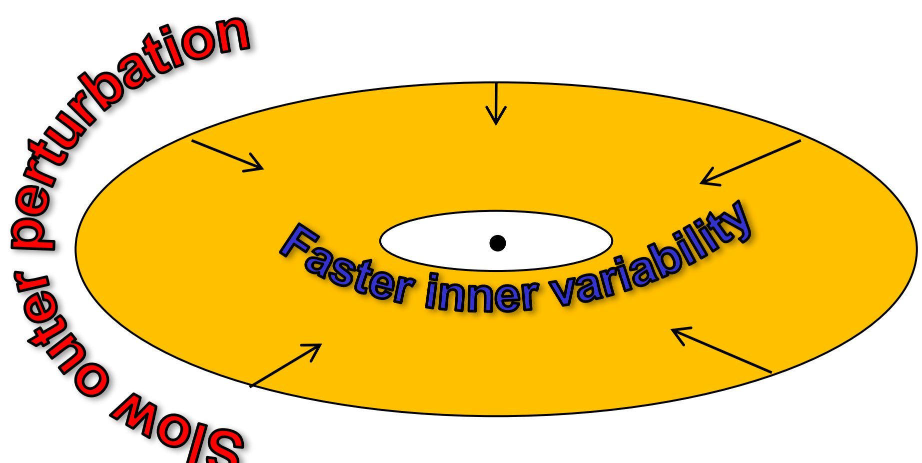


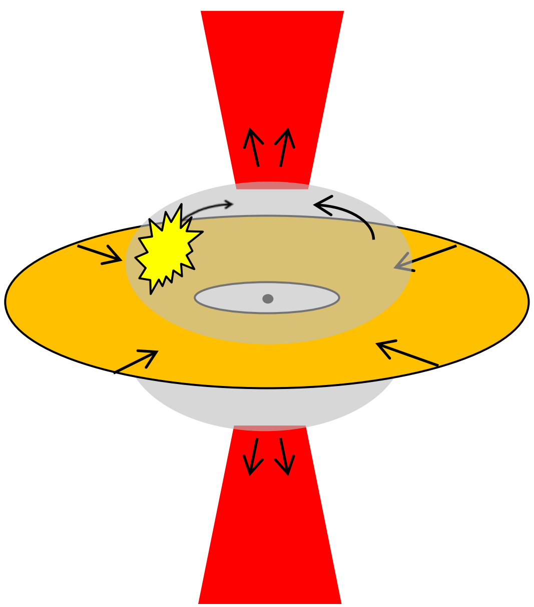
Driven by accretion rate perturbations propagating in (Lyubarskii 1997)



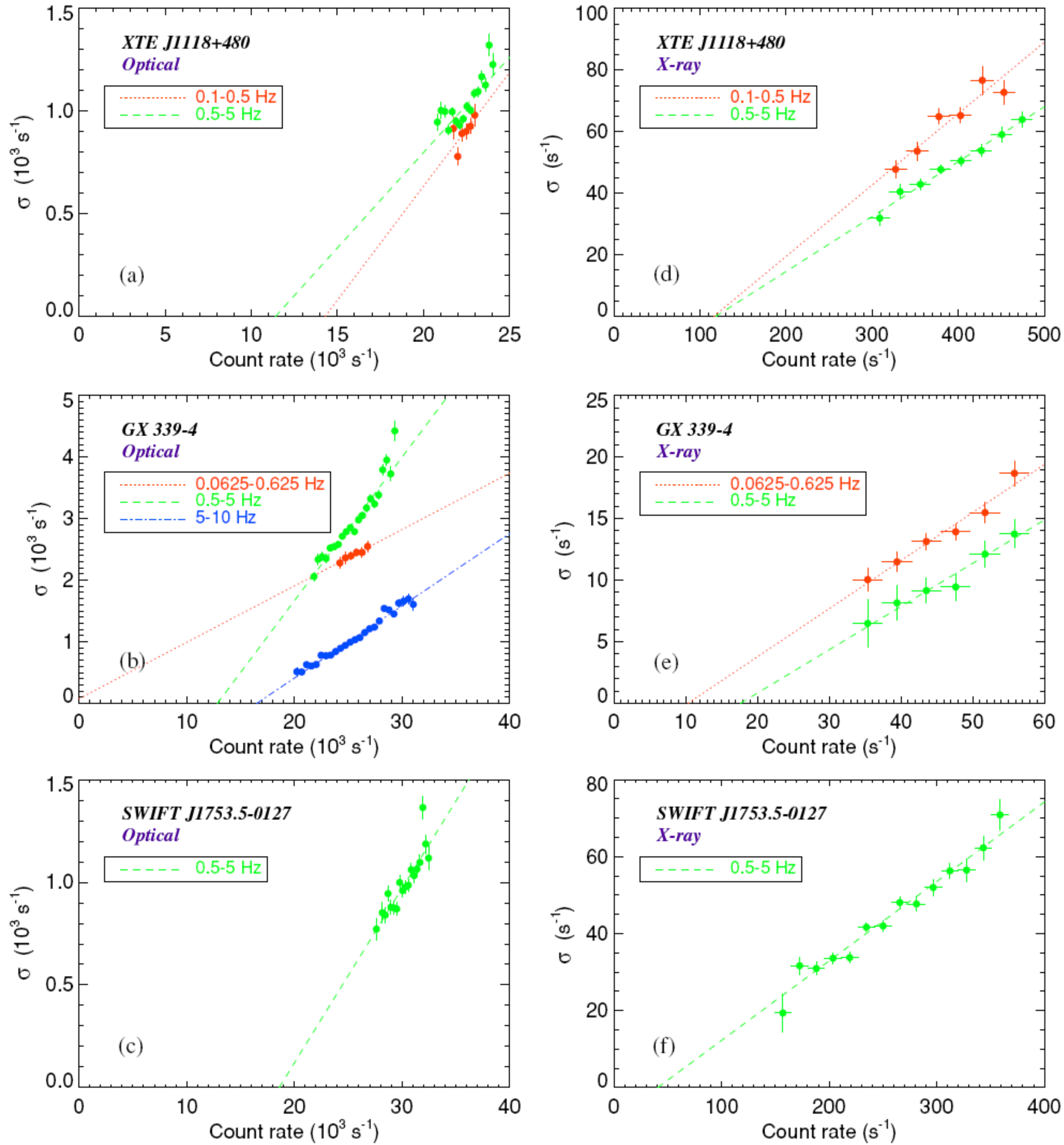
Optical **rms-flux relation in several binaries**

⇓

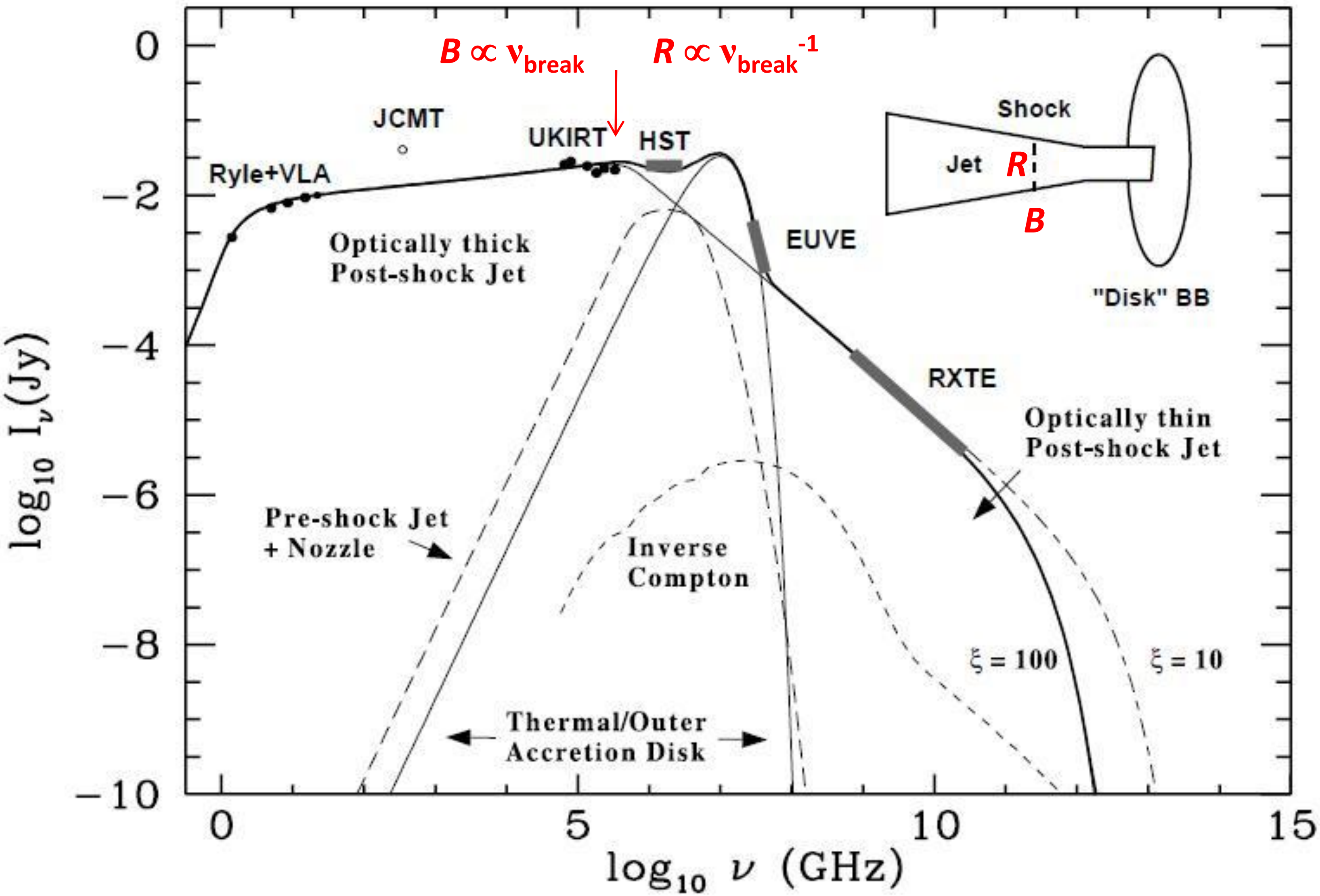
optical variability cannot arise from random shocks



(Gandhi 2009)



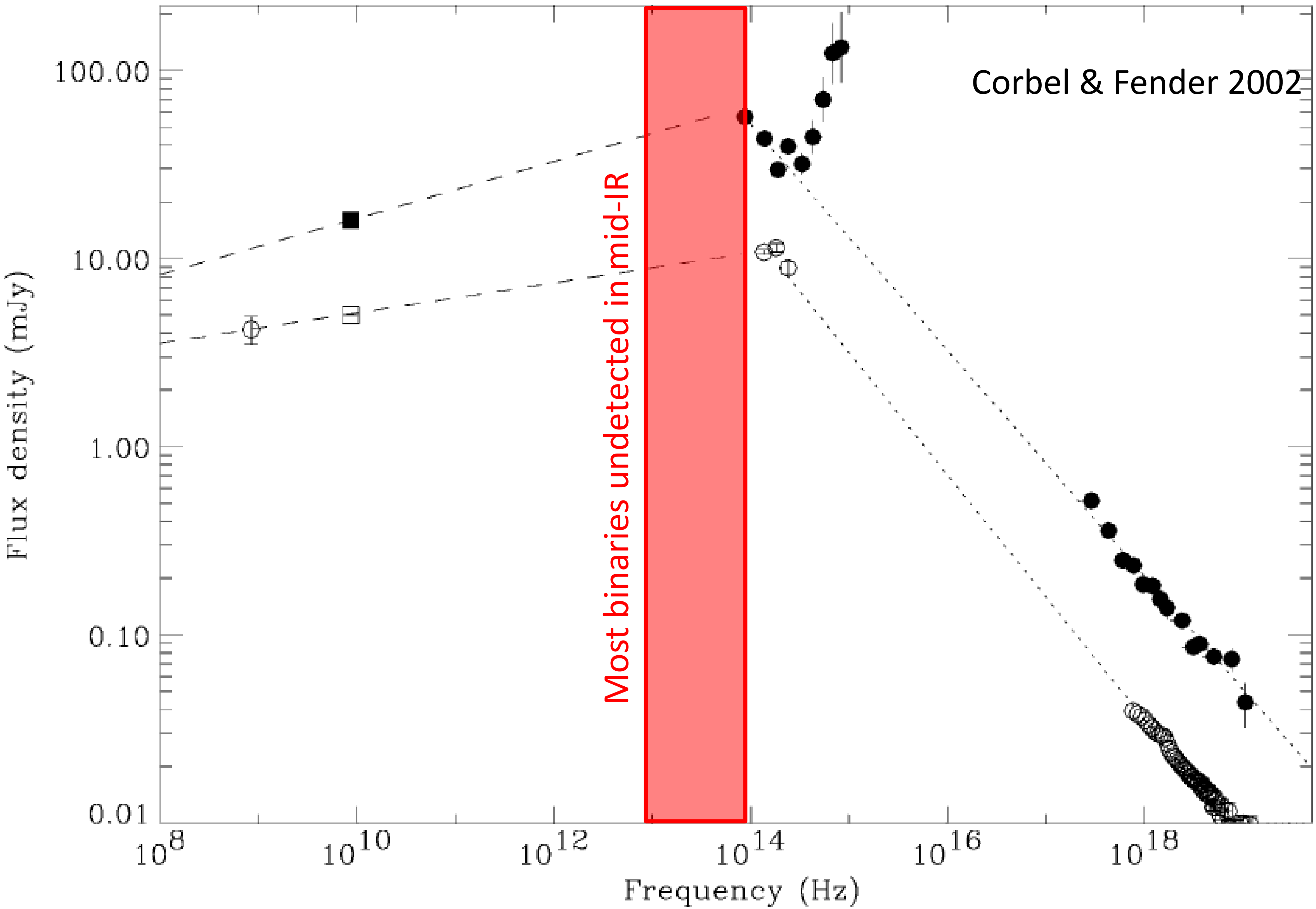
Constraining inner jet physical conditions



(Blandford & Koenigl 1979, Falcke+95, Chaty+11)

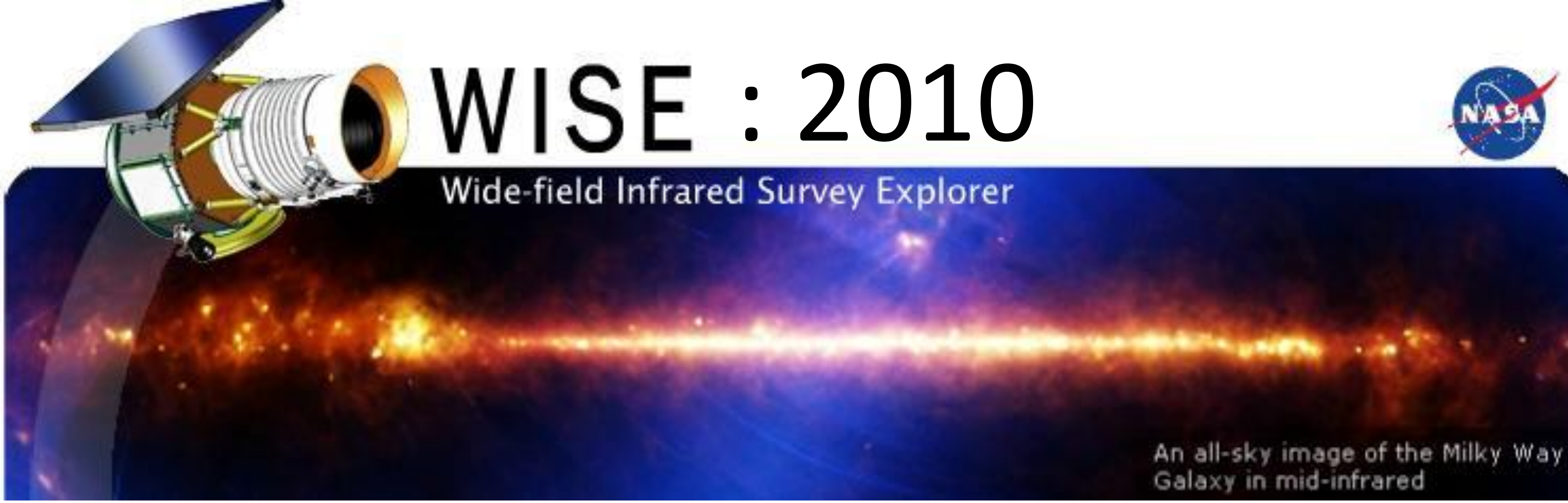
(Markoff+01)

GX 339-4: broadband constraints

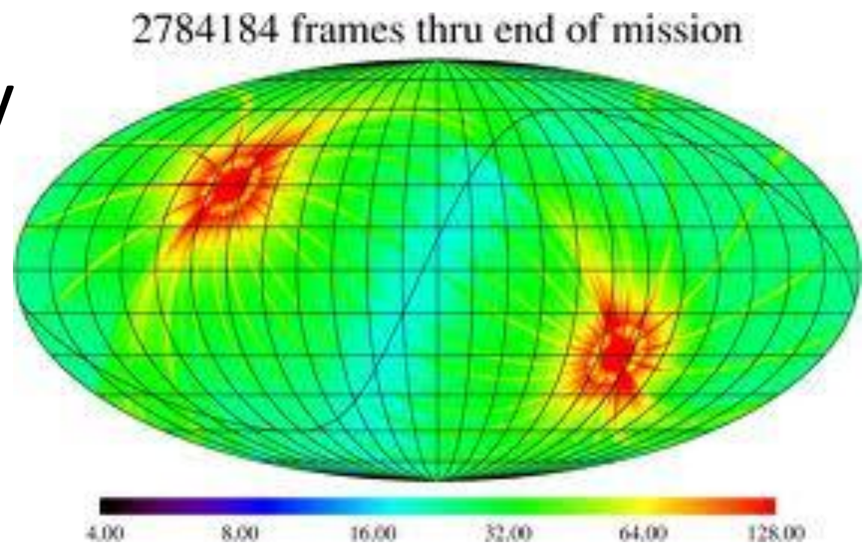


(Reported detections: cf. **Rahoui** talk: Cyg X-1; **Migliari+10**: 4U 0614; **Russell+12**: MAXI J1836)

WISE : 2010



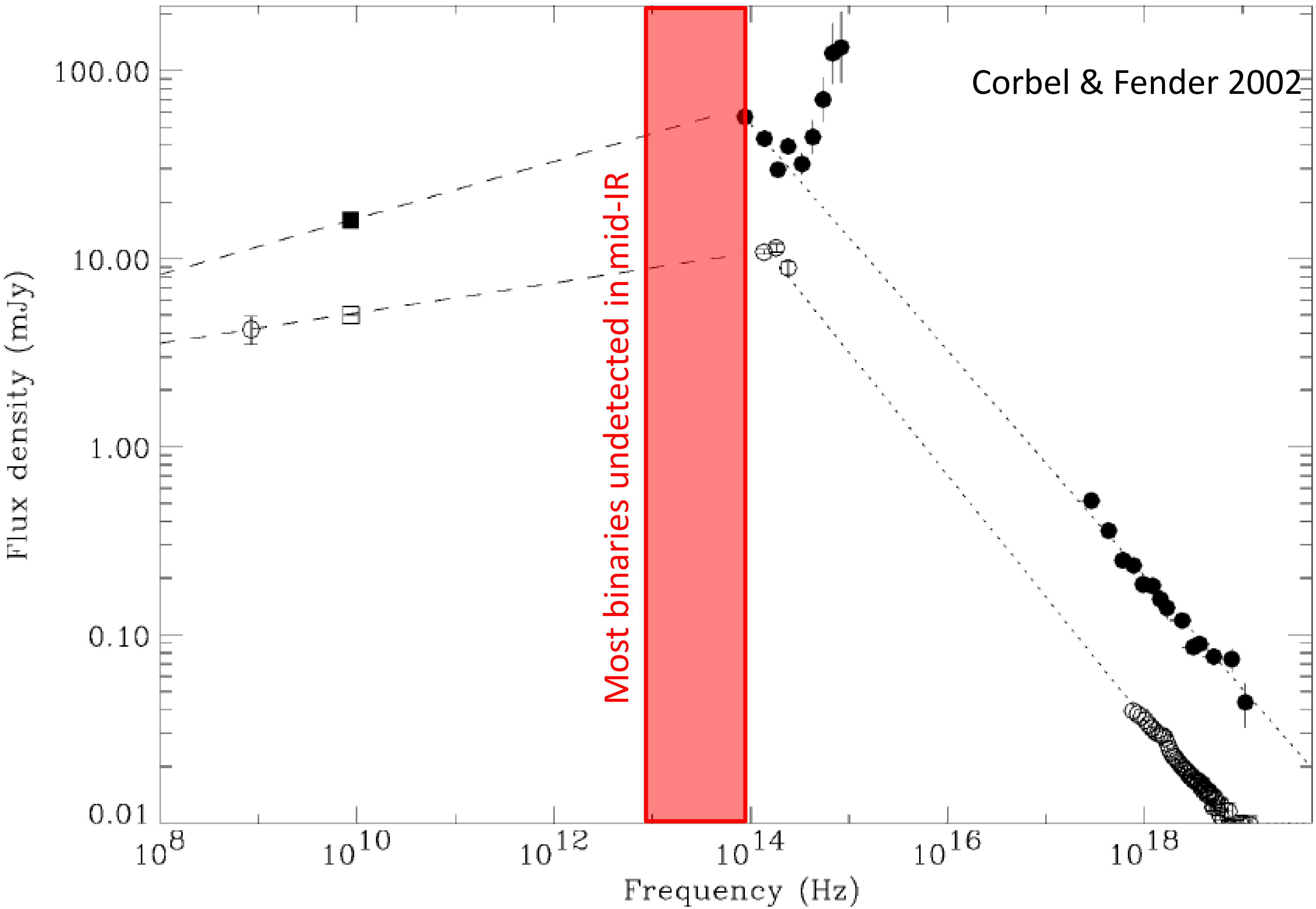
- Deepest IR all sky survey
- 3, 4, 12, 22 μm cameras
- Simultaneous in all four bands.



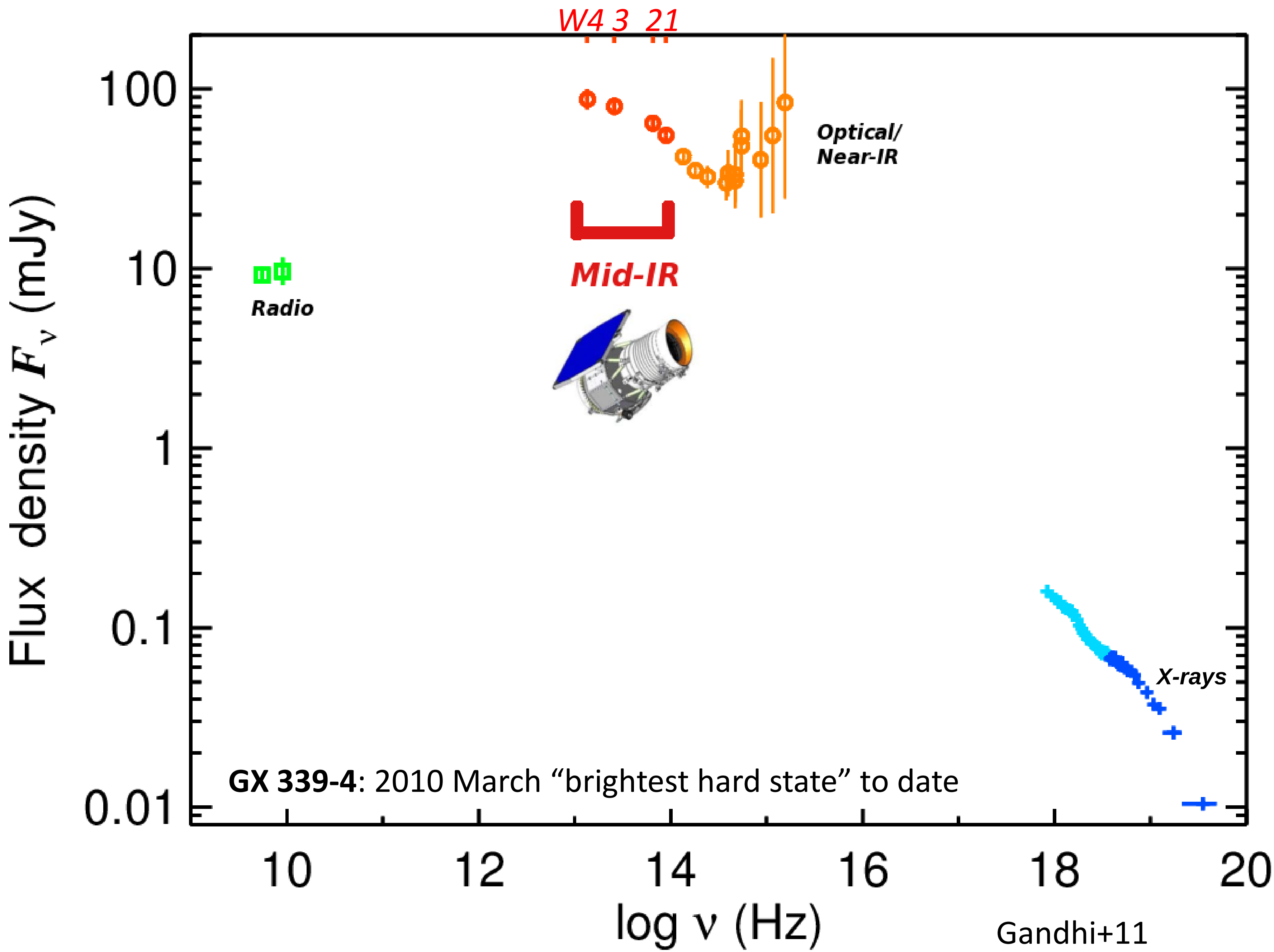
Sky coverage

Wright+10

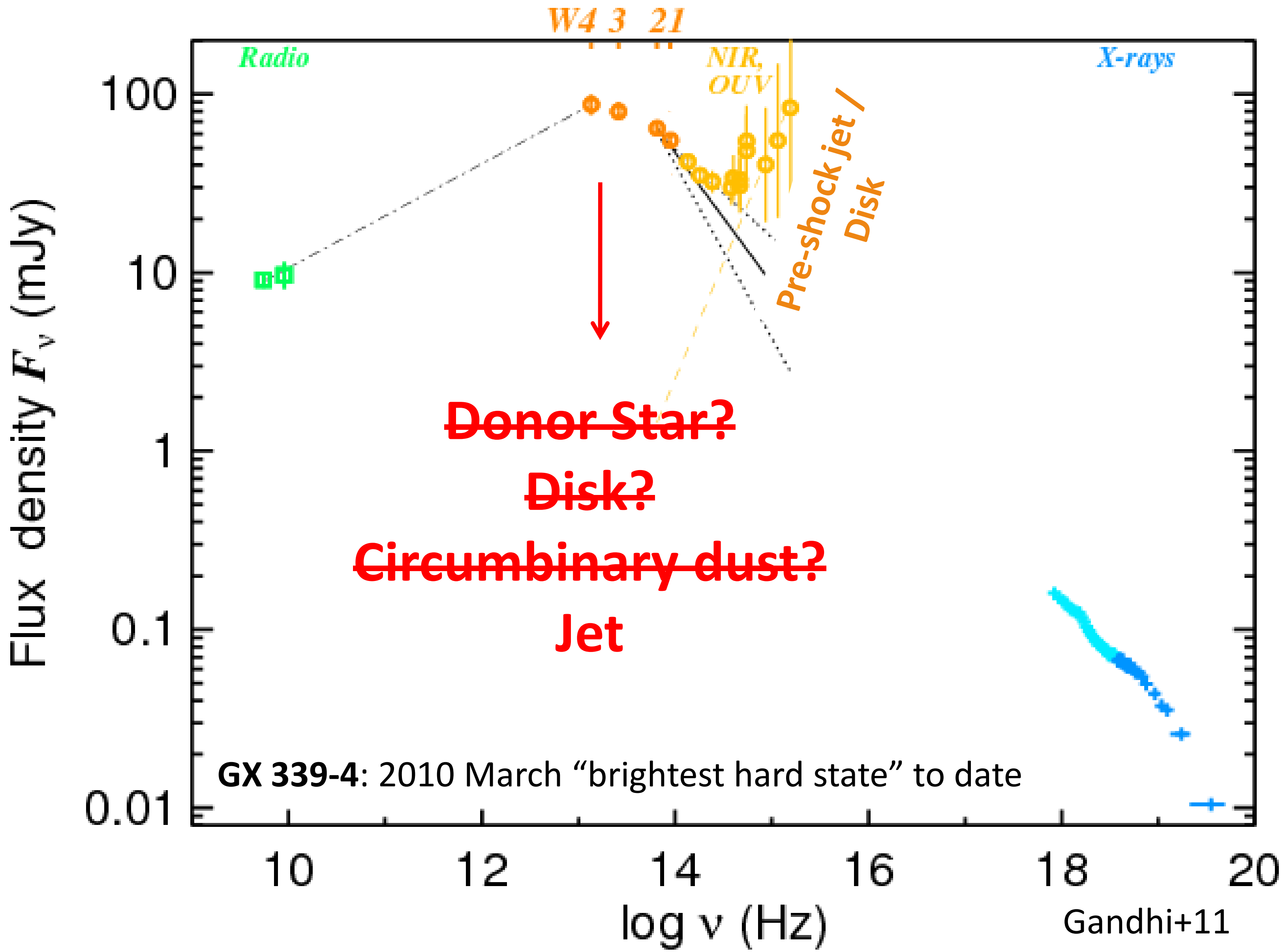
GX 339-4: broadband constraints



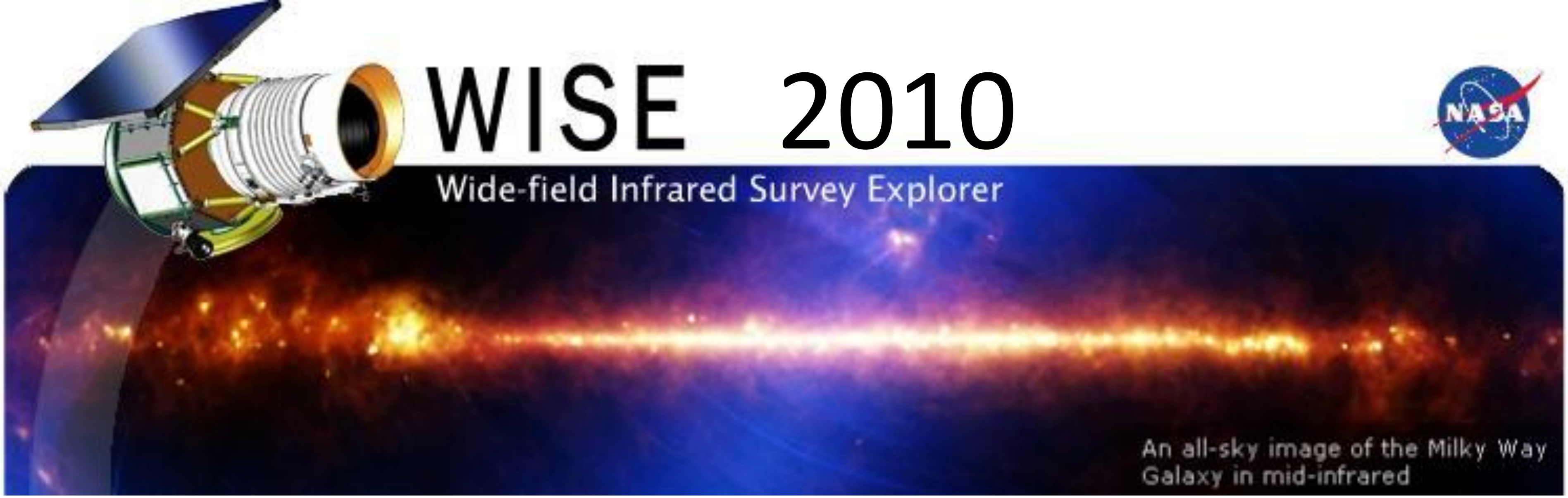
(Reported detections: cf. **Rahoui** talk: Cyg X-1; **Migliari+10**: 4U 0614; **Russell+12**: MAXI J1836)


W4 3 21
Flux density F_ν (mJy)
100
10
1
0.1
0.01
Optical/
Near-IR
Mid-IR
Radio
X-rays
GX 339-4: 2010 March "brightest hard state" to date
10
12
14
16
18
20
log ν (Hz)
Gandhi+11

Mid-IR emission from inner jet

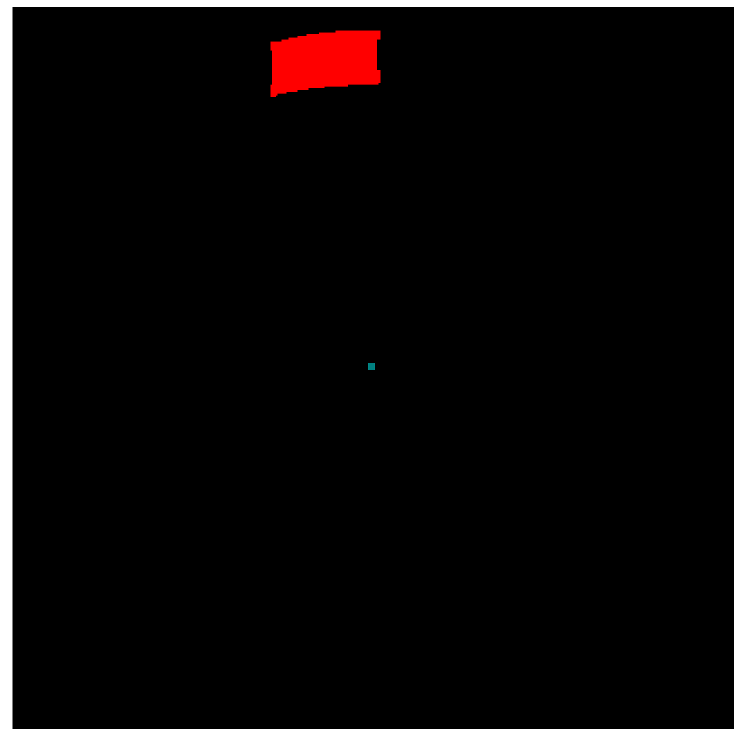


WISE 2010



- Every position scanned multiple times
- 95 min. orbit
- 11s scan cycle time
- 47' x 47' overlapping adjacent fields

Wright+10

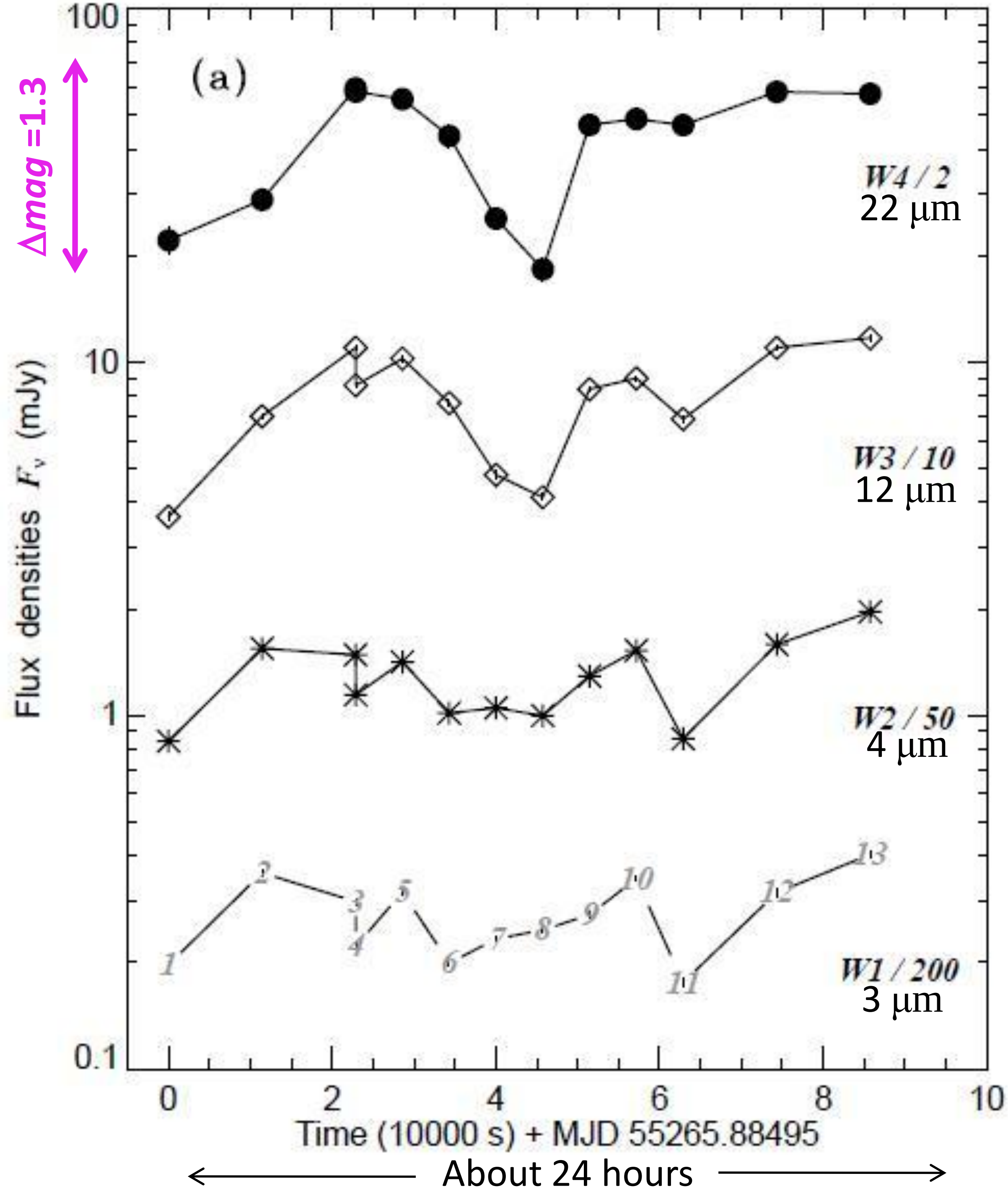


(Scan coverage)

GX 339-4 WISE variability

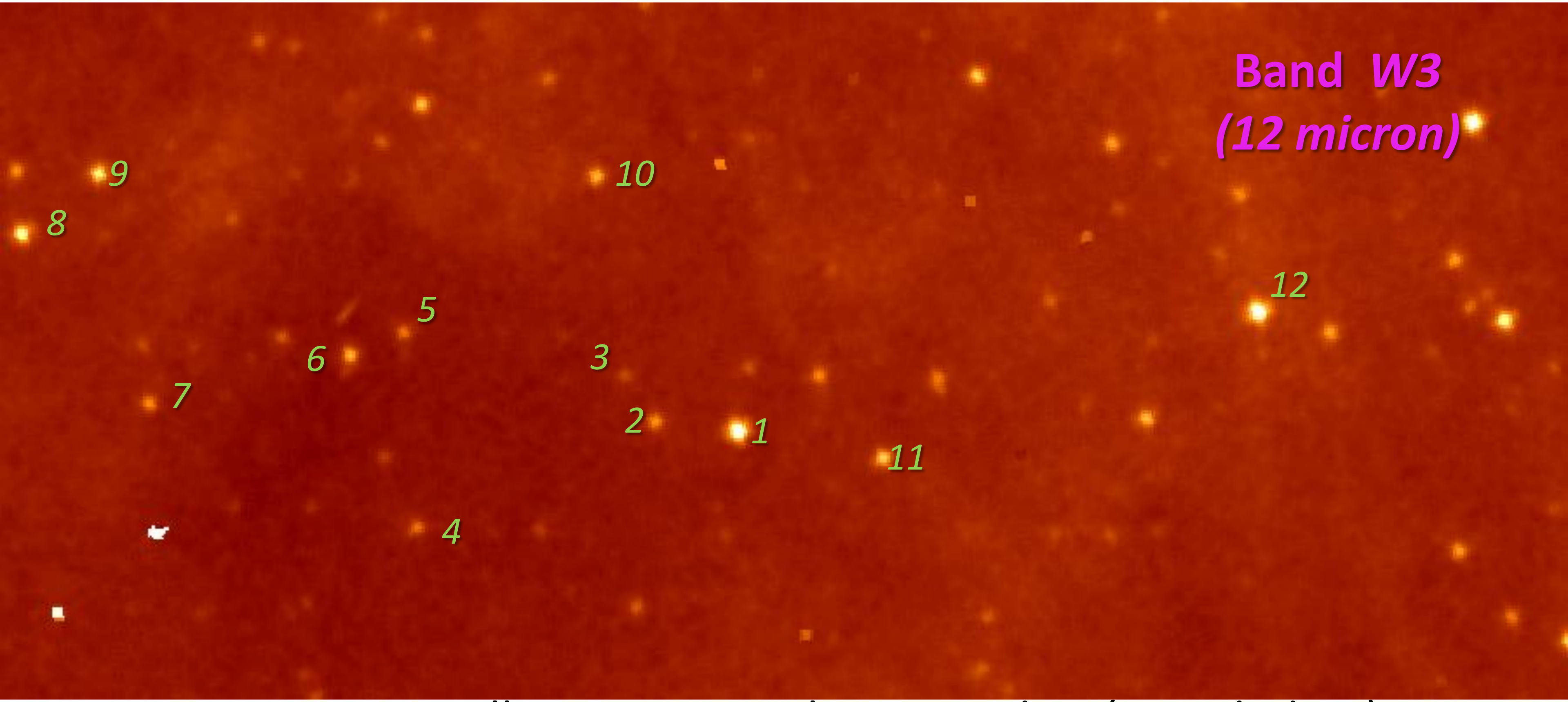
1. Very strong WISE variability (> 3 x)
2. Longer bands more variable
3. Bands not in-step

Gandhi+11



First mid-IR flickering of a black hole

Discover the black hole yourself!

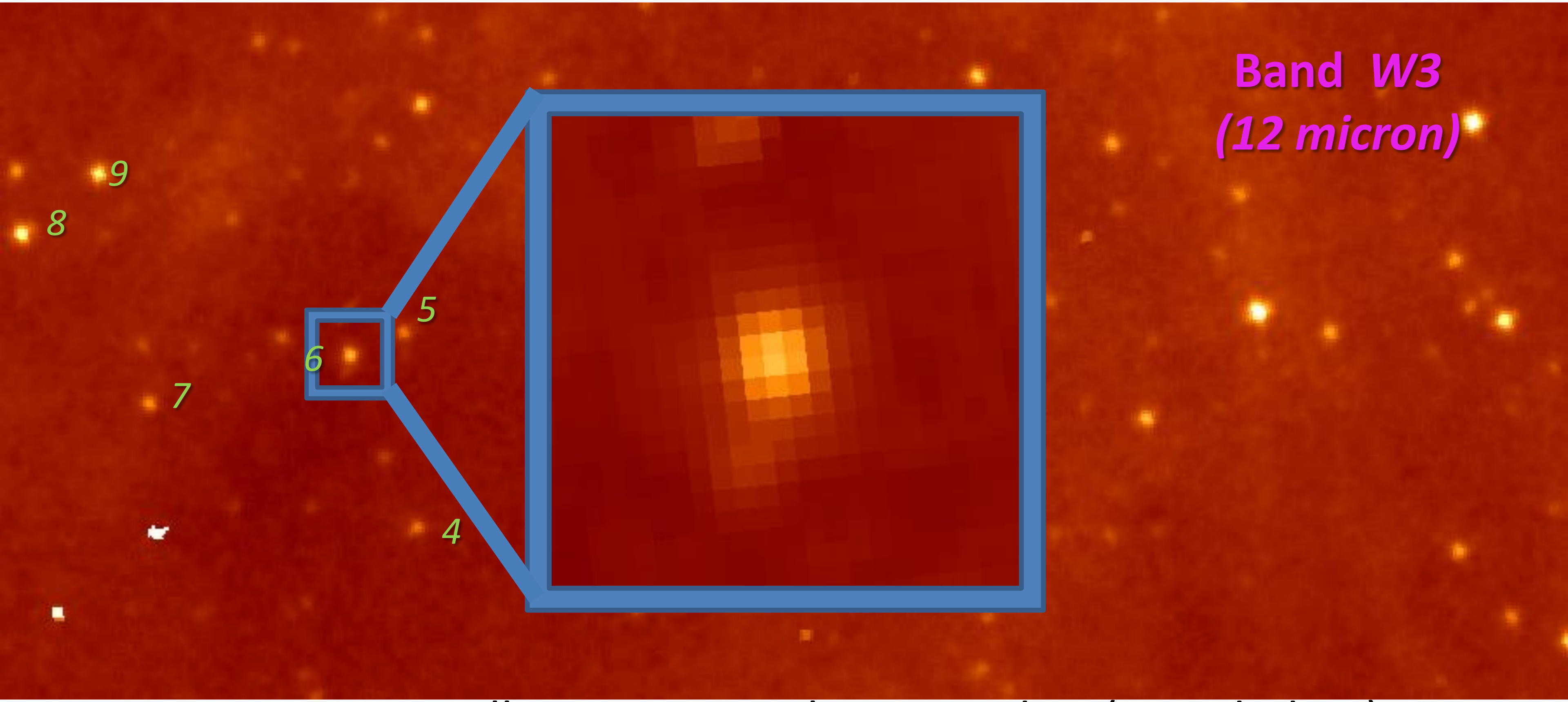


13 *WISE* satellite scans; total time ~1 day (speeded up)

GX 339-4: Gandhi+11

First mid-IR flickering of a black hole

Discover the black hole yourself!



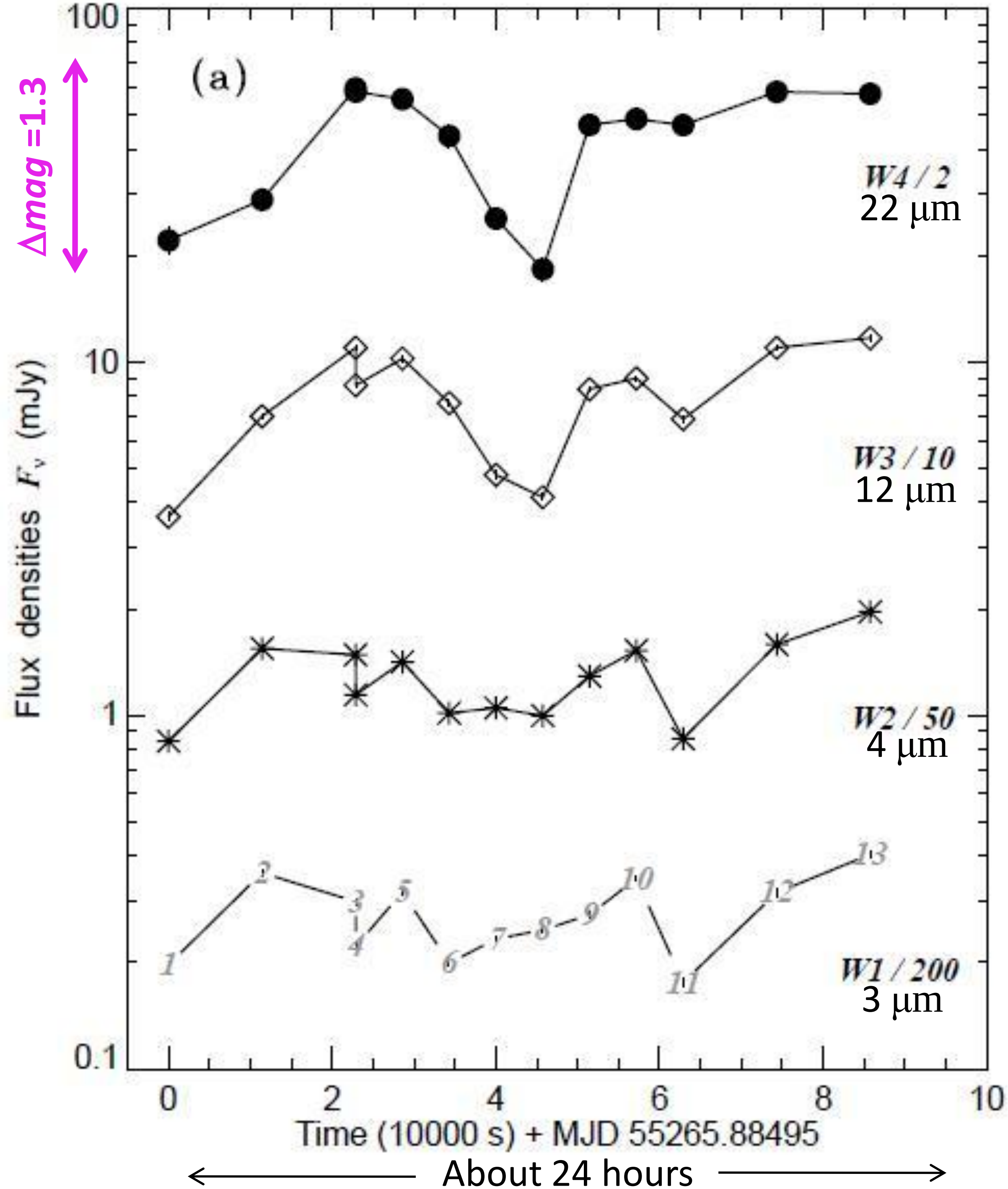
13 *WISE* satellite scans; total time ~1 day (speeded up)

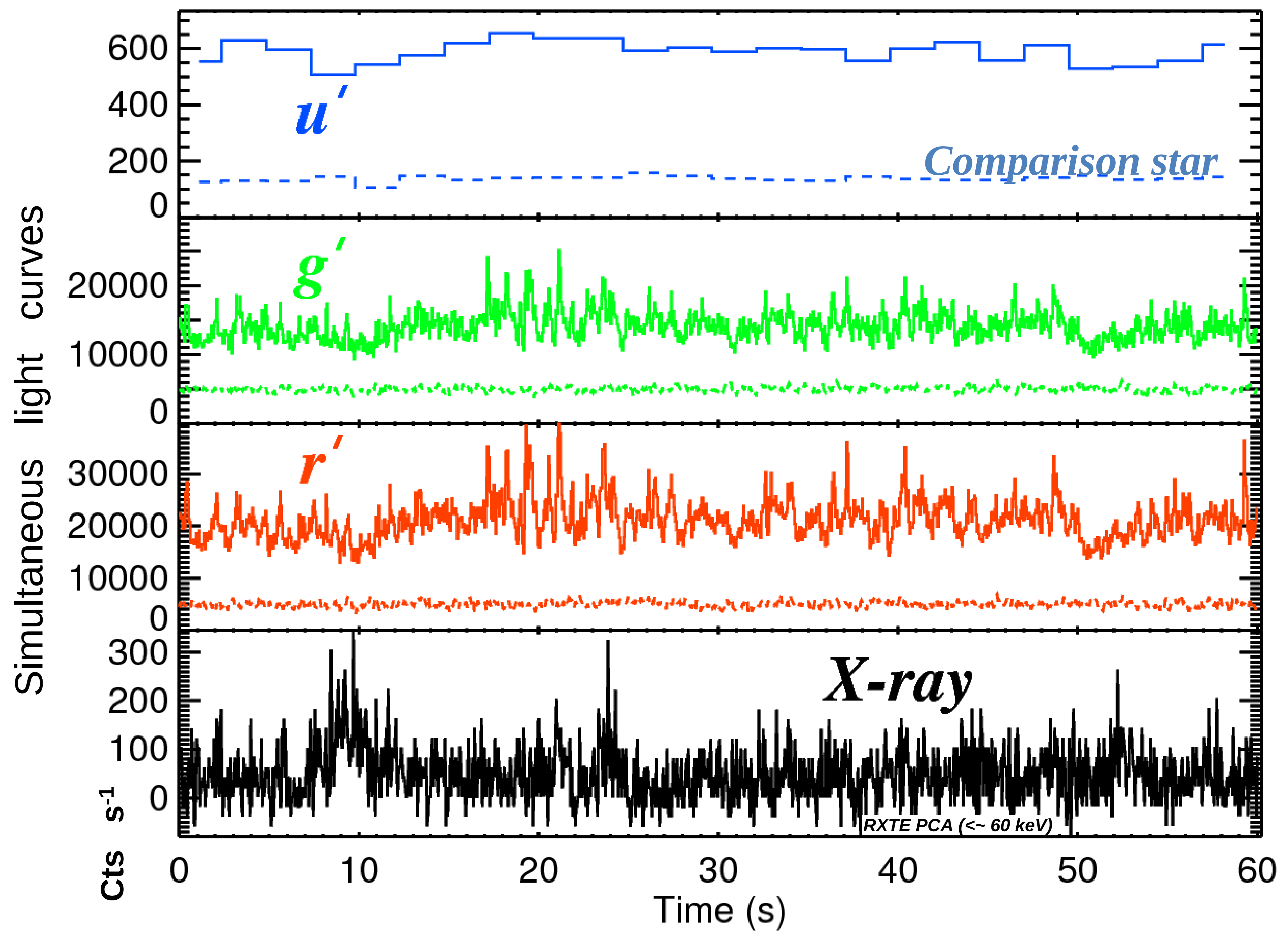
GX 339-4: Gandhi+11

GX 339-4 WISE variability

1. Very strong WISE variability (> 3 x)
2. Longer bands more variable
3. Bands not in-step

Gandhi+11



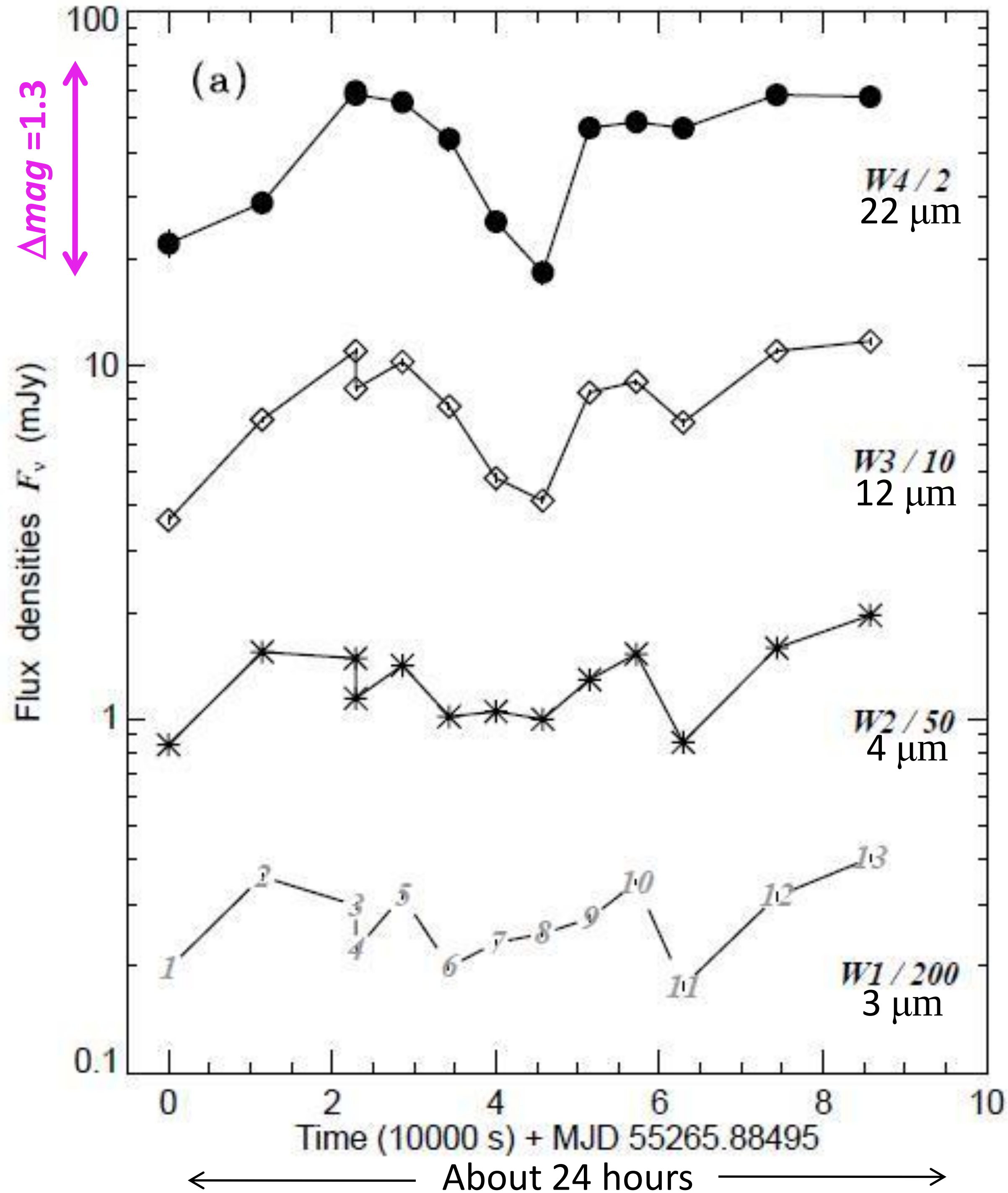


u′
Comparison star
g′
r′
X-ray
RXTE PCA (<~ 60 keV)
Simultaneous light curves
Cts s-1
Time (s)

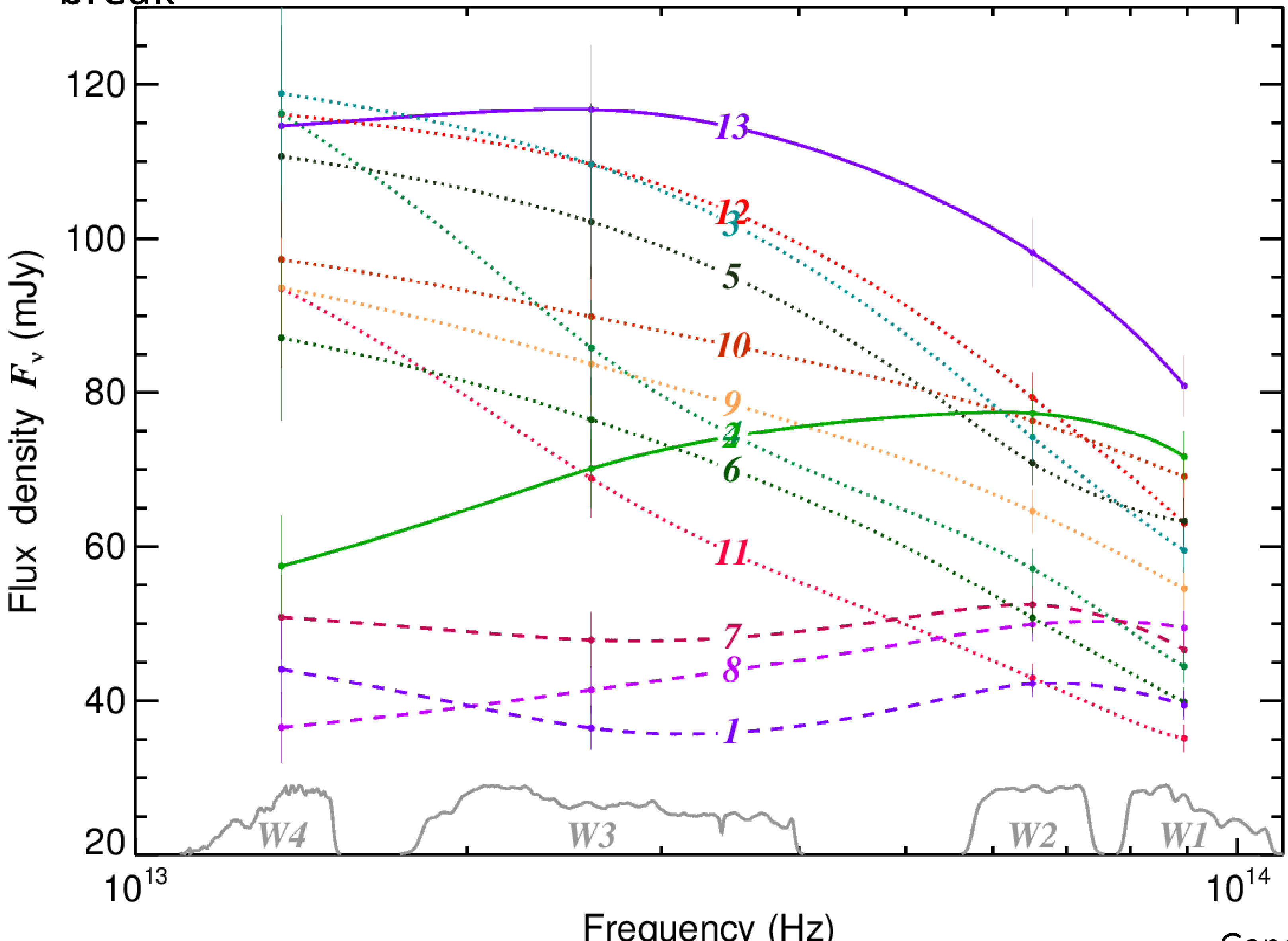
GX 339-4 WISE variability

1. Very strong WISE variability (> 3 x)
2. Longer bands more variable
3. Bands not in-step

Gandhi+11

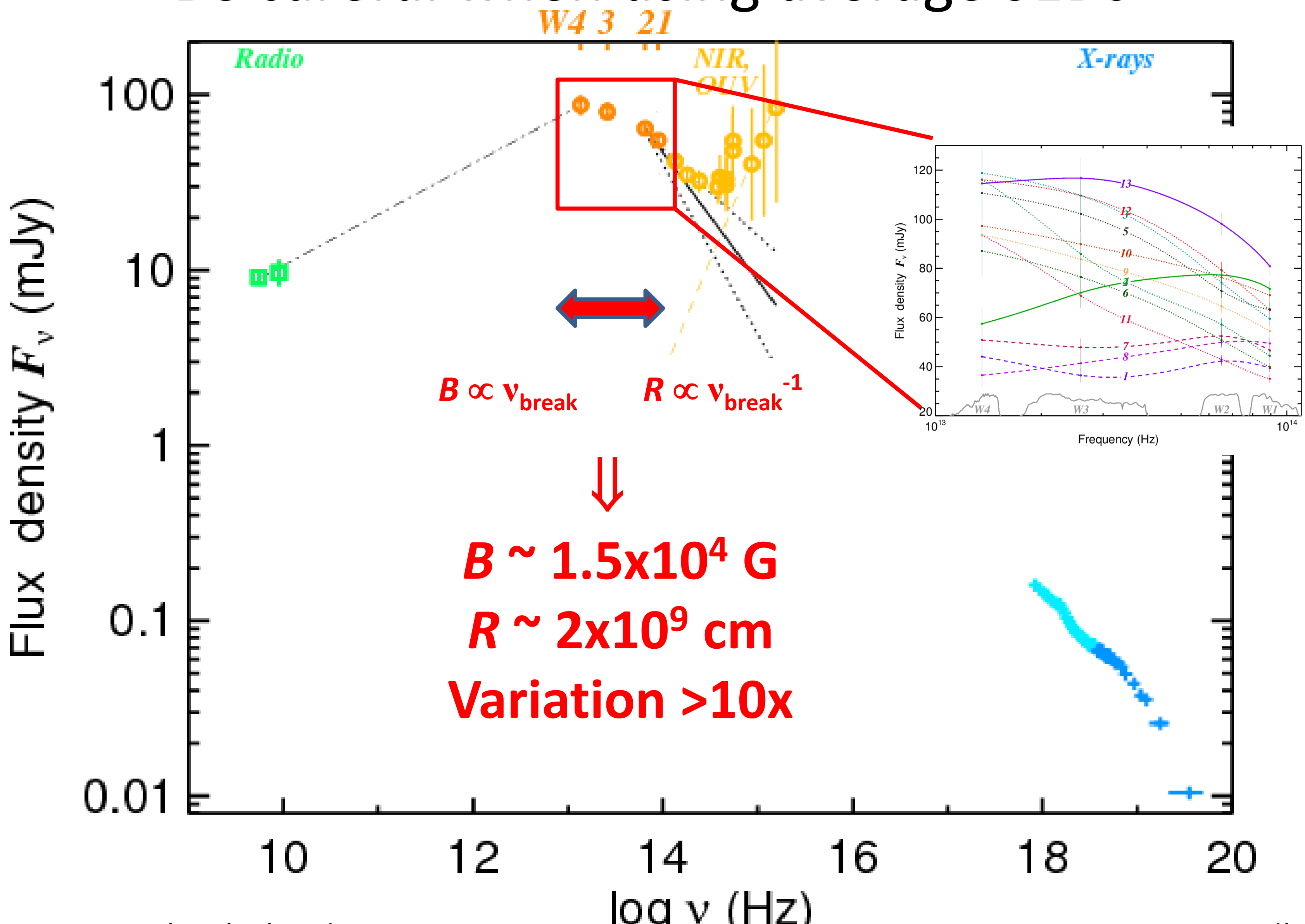


Time-resolved SEDs ⇒ ν_{break} moves over entire 3-22 μm+ range



Gandhi+11

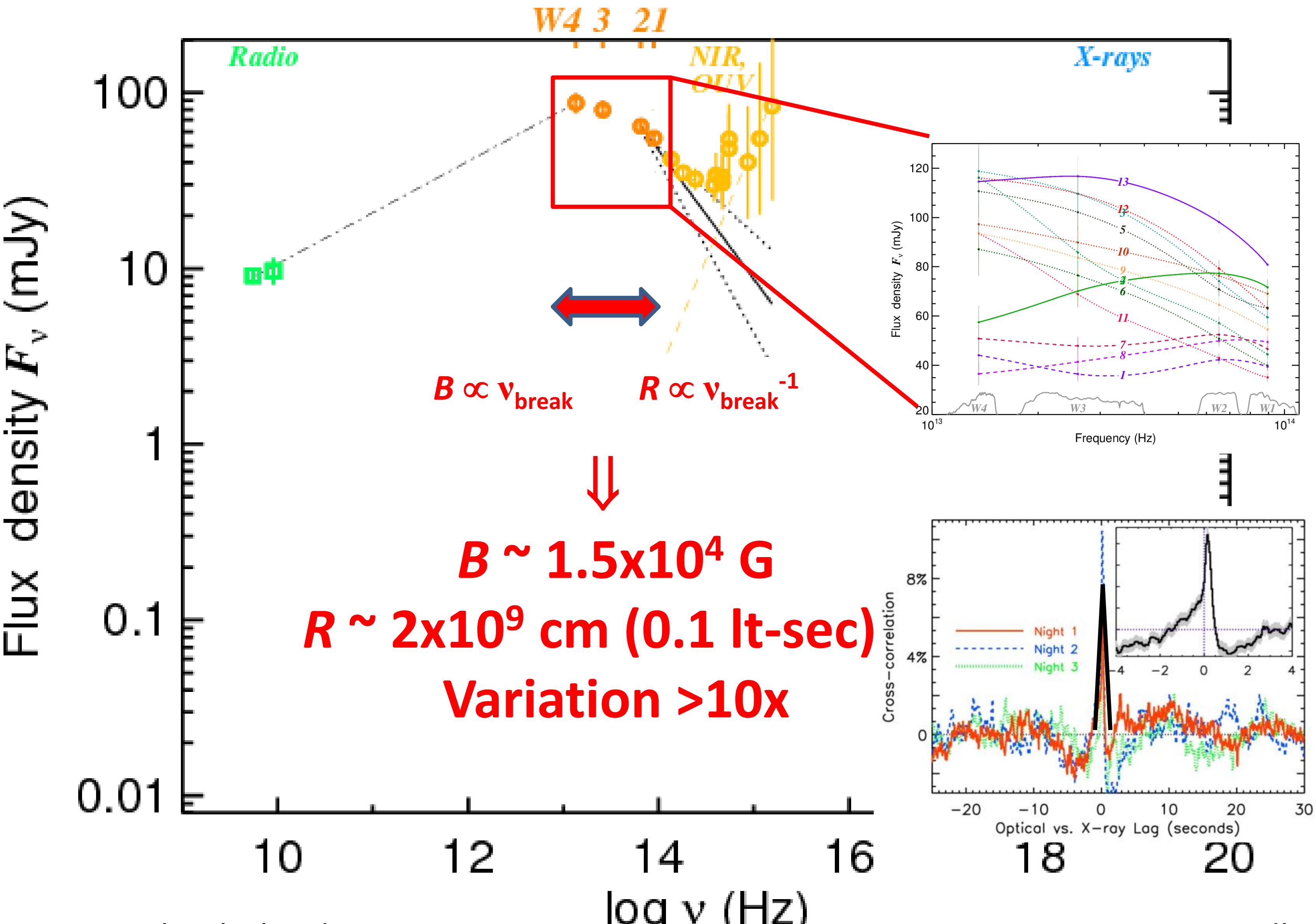
Strong and rapid changes in jet physical conditions: Be careful when using average SEDs



GX 339-4: 2010 bright hard state

Gandhi+11

Jet changes driven by accretion fluctuations?



$B \propto \nu_{break}$ $R \propto \nu_{break}^{-1}$

⇓

B ~ 1.5x10^4 G

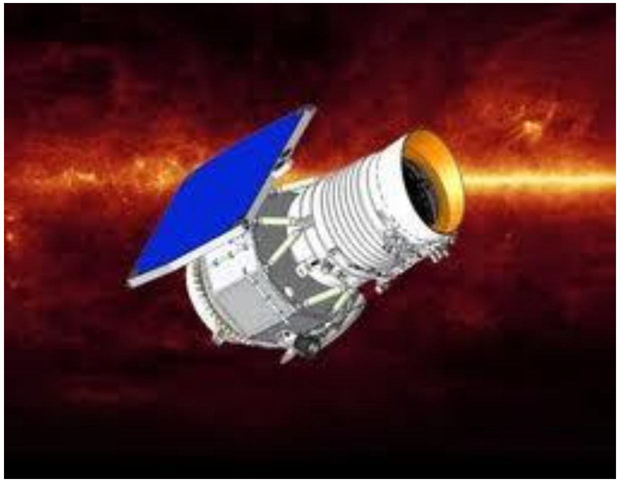
R ~ 2x10^9 cm (0.1 lt-sec)

Variation >10x

GX 339-4: 2010 bright hard state

Gandhi+11

Measure Mid-IR / X-ray correlation?



WISE : 2010 Jan-Oct

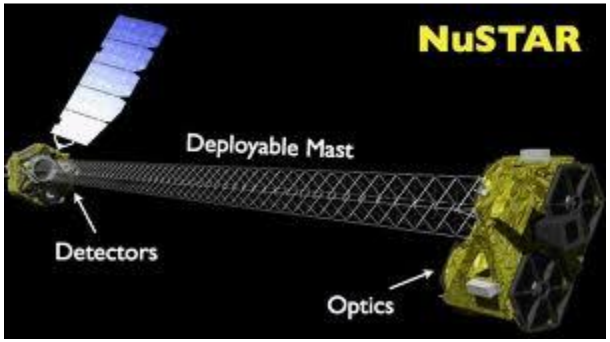
RXTE : 1996-2012

Unique monitoring capabilities:
- Simultaneous
- Broad band
- Rapid (~few sec) timescales

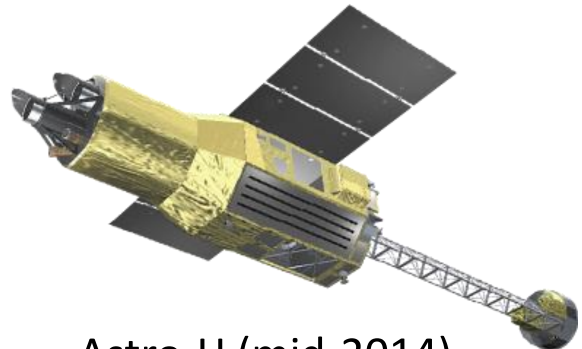
Rest in peace

Future of fast multi-λ variability

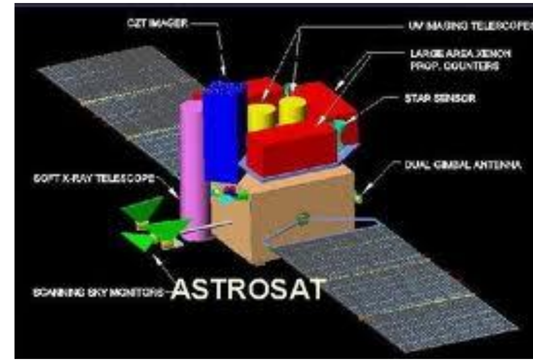
(The next 10 years: X-rays)



In orbit



Astro-H (mid-2014)



Launch? (sometime soon)

2022?

Athena ?

Future of fast multi-λ variability

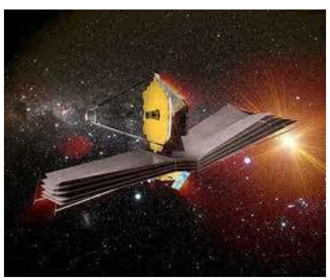
ULTRACAM/
ULTRASPEC

FORS HIT mode

Optical

SALTICAM

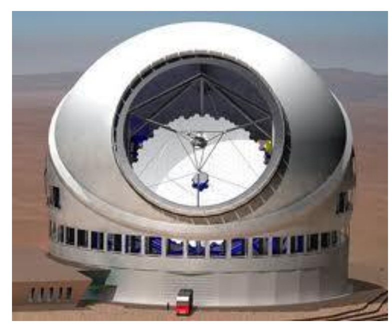
Infrared



JWST: 2018?
Stubby Hubble?

Spica: 2020?

TAO: 2022+?

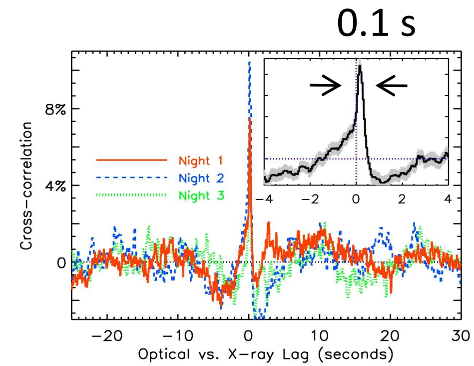


E-ELT/TMT: 2025+?

ISS ‘MAXI-style’
IR monitor??

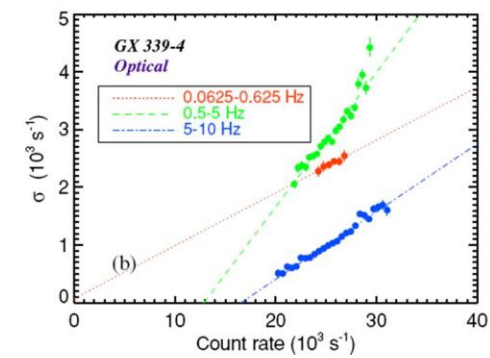
Summary

Going beyond X-ray timing: Key issues



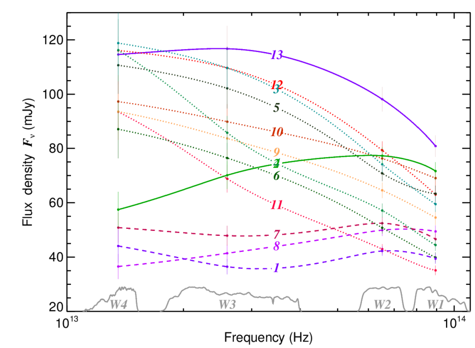
OIR timing gives quantitative constraints on inner accretion region complementary to X-ray timing.

- How fast should we go? **(<Fractions of a sec)**



- Multi-wavelength fluctuations disentangle observed radiative components **(CCF)**

- Probing connections between components **(rms-flux relation)**



- Constrain key physical parameters *B*, *R*, and monitor changes in them **(infrared)**