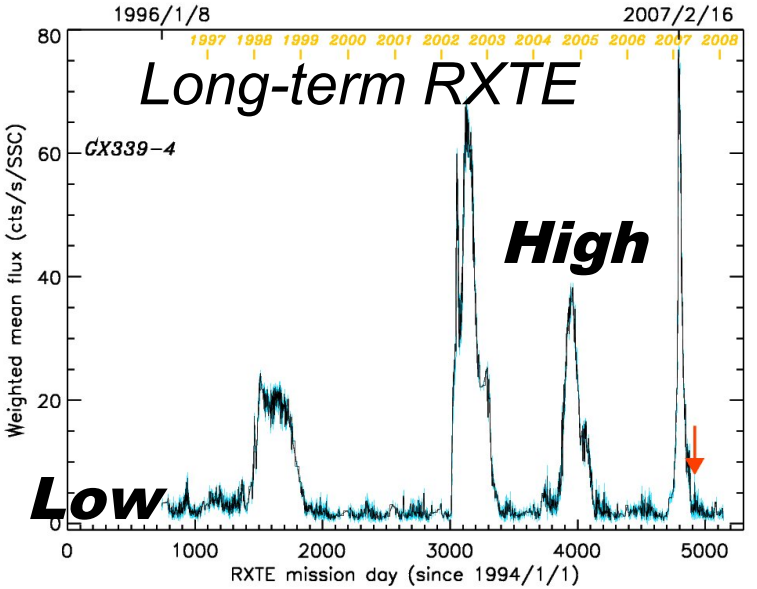
Rapid Optical/X-ray flux correlations in the low/hard state of GX 339-4

Poshak Gandhi
(RIKEN, Japan)

K. Makishima, A. Kubota (Japan)
A.C. Fabian, T. Marsh, V. Dhillon (UK)
M. Durant, T. Shahbaz (Spain)
J. Miller (USA)
H. Spruit (Germany)

Timing studies of GX 339-4

- One of the strongest BH candidates
  M>6 M_{sun} (Hynes+03)
  d~8 kpc (Zdziarski+04)
  Faint companion (R>21; Shahbaz+01)



- - X-ray low: optically-bright;
    high flaring (~10 ms)
  - X-ray high: optically-dim (low flaring)
  - Very high, Intermediate, Quiescent

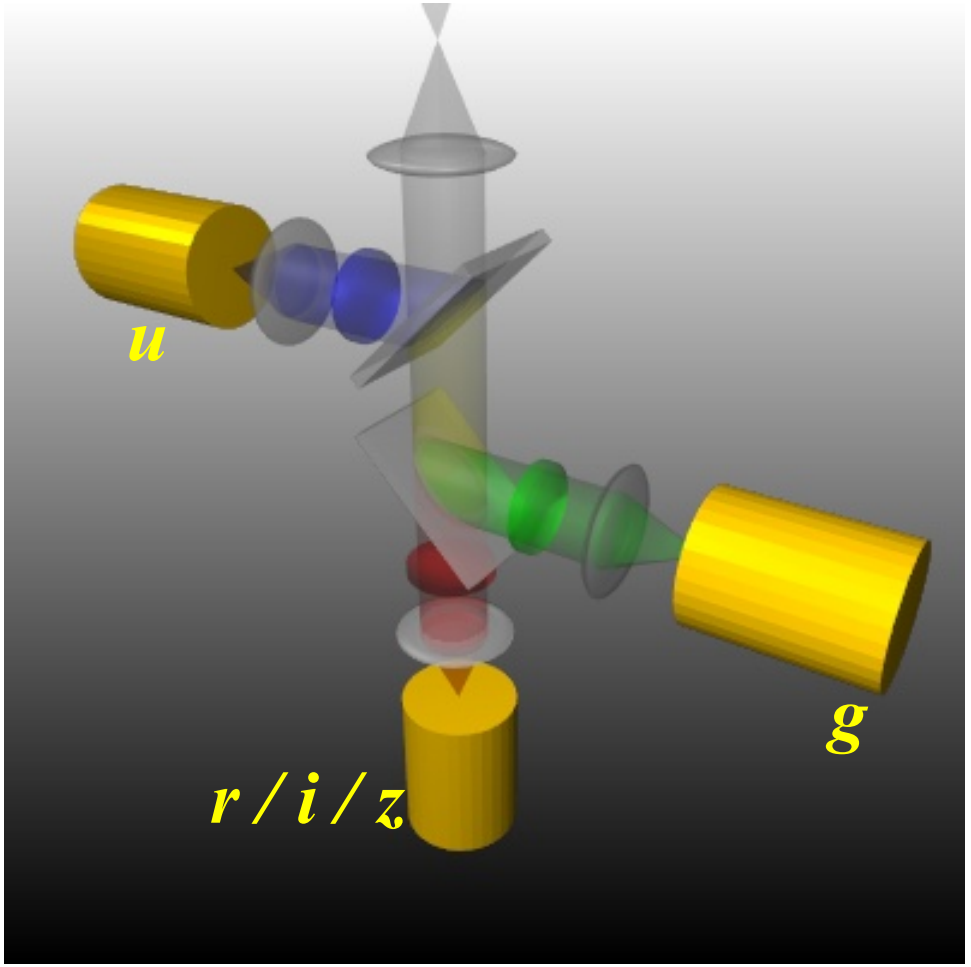
- Extensive timing studies (e.g. Dunn+08, Nowak+98, Homan+05…), but only a few simultaneous with rapid optical (Makishima+86, Motch+83)

Observations

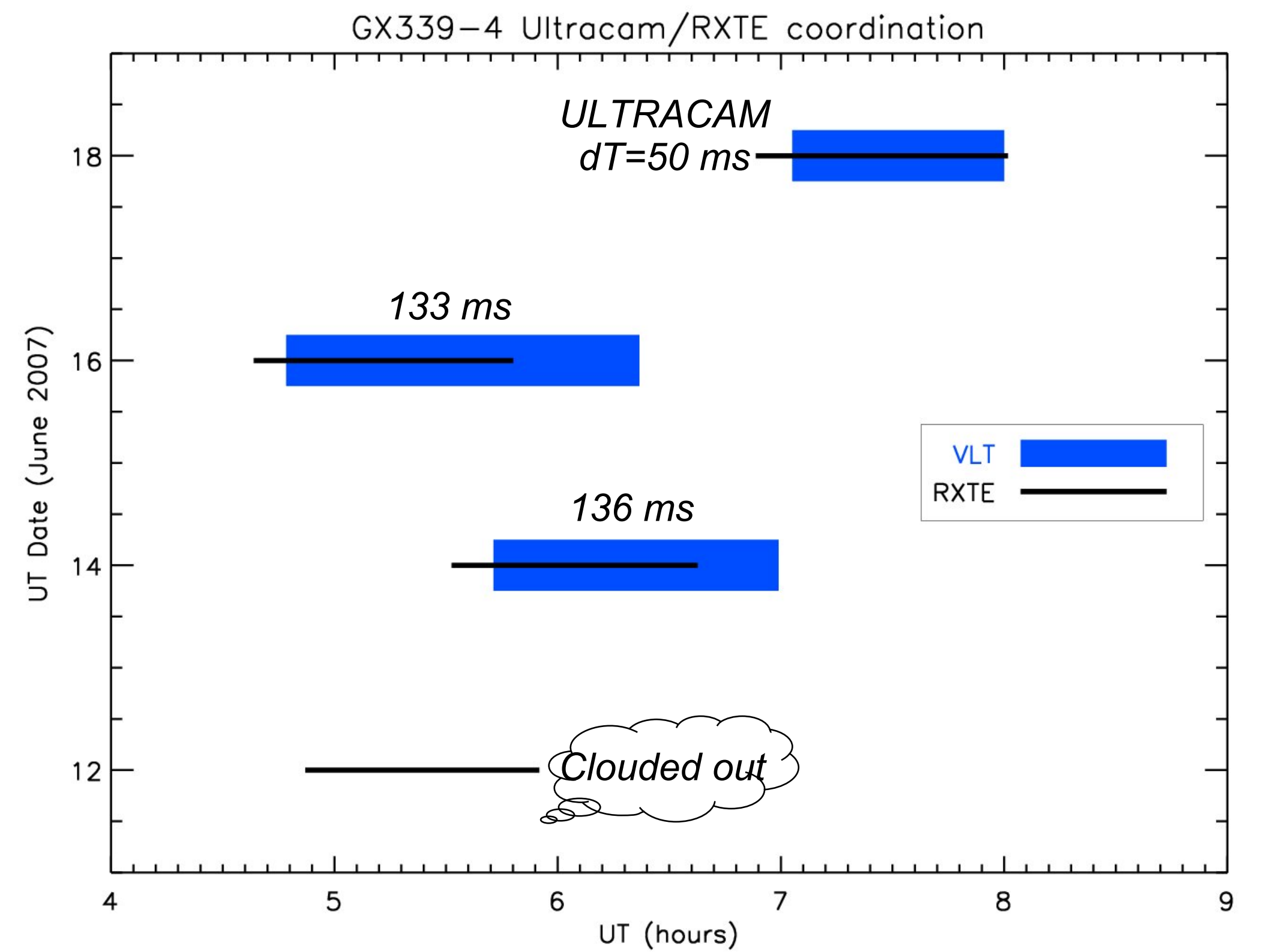
+

ULTRACAM:
ultra-fast, triple-beam CCD camera

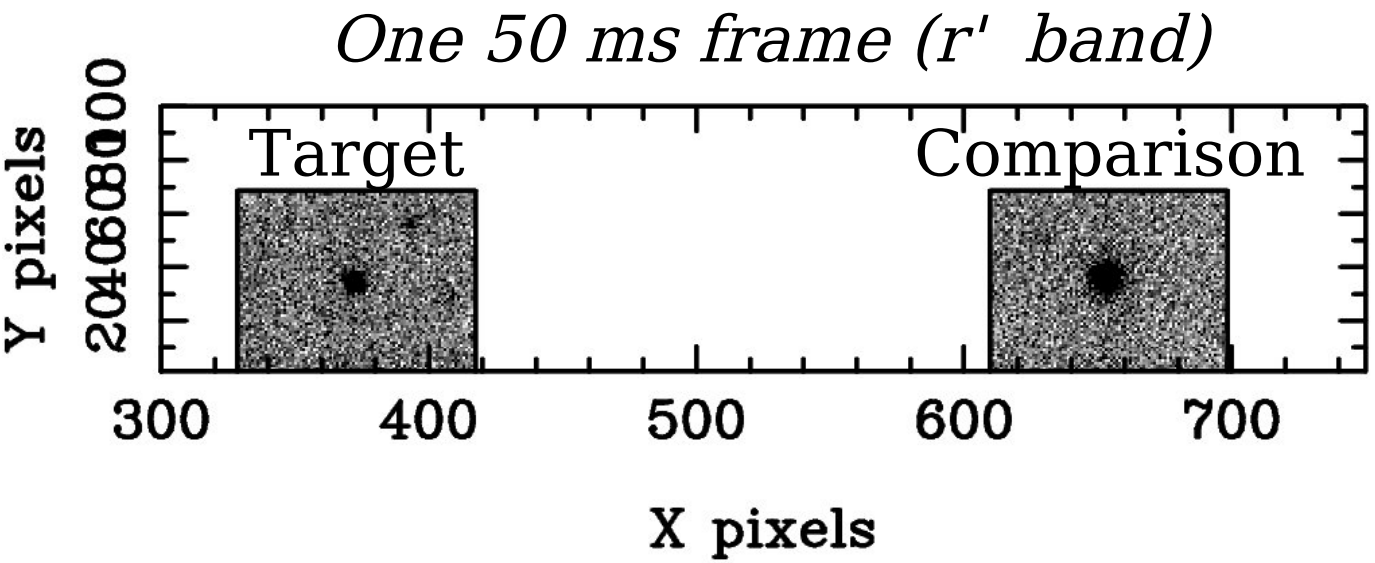
- light-weight camera
(visitor instrument on *WHT/VLT*)
- frame-transfer CCDs with
low dark current, dead-time
- speeds ~ 500 frames / sec
- 3 simultaneous optical filters
- absolute timing ~ 1 ms

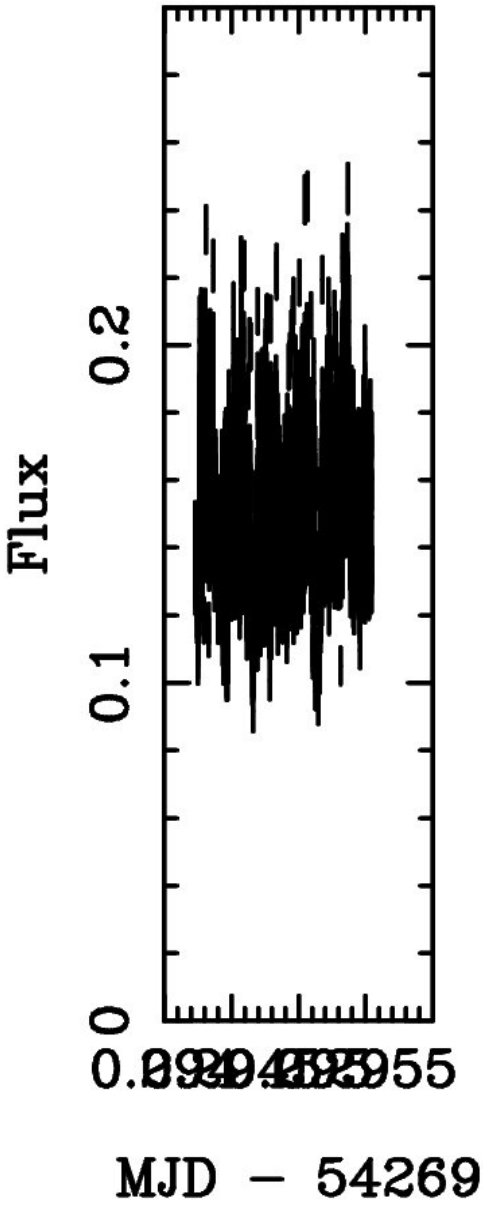


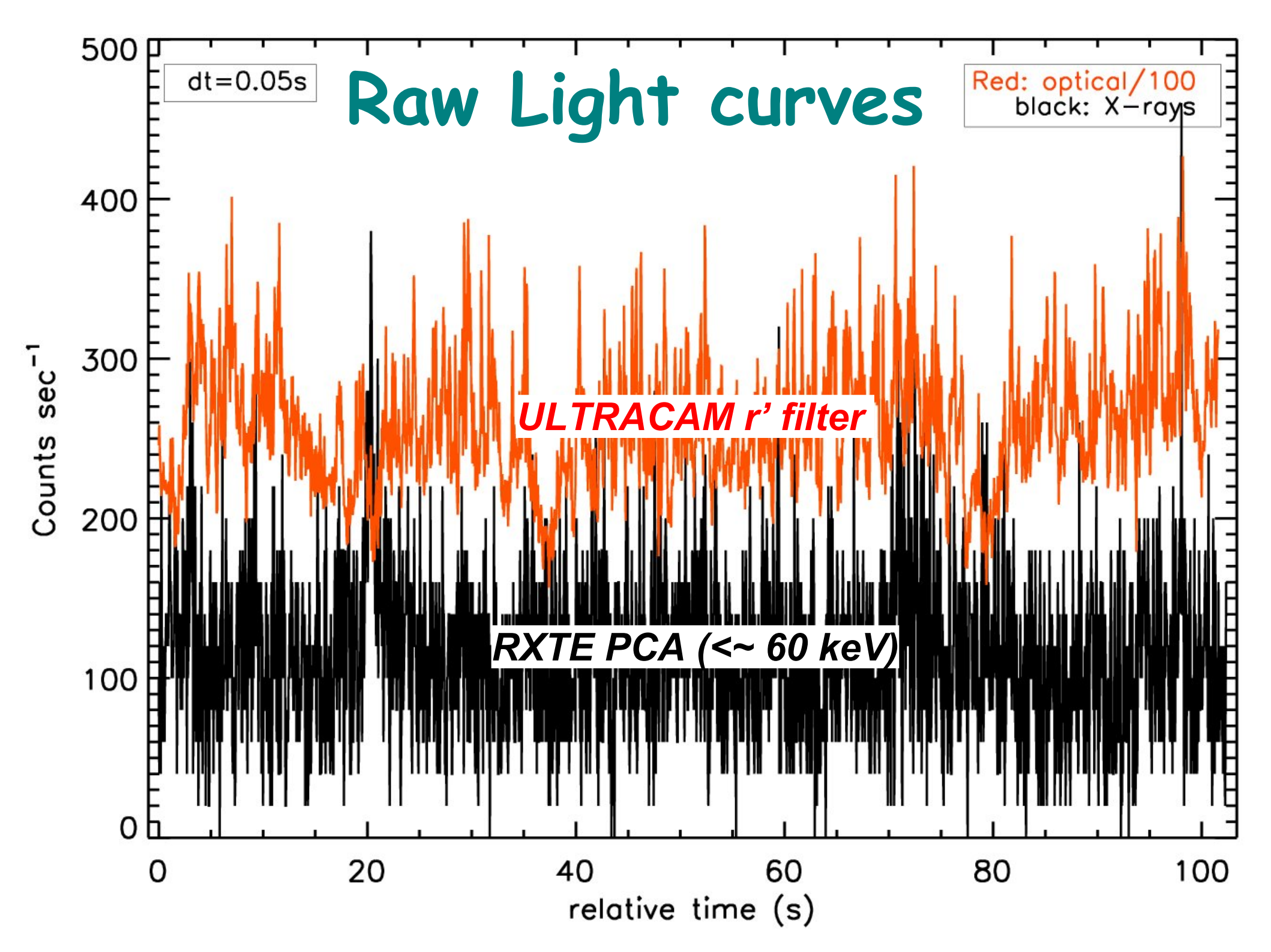
http://www.shef.ac.uk/physics/people/vdhillon/ultracam/


GX339−4 Ultracam/RXTE coordination
ULTRACAM
dT=50 ms
133 ms
136 ms
Clouded out
VLT
RXTE
UT Date (June 2007)
UT (hours)
18
16
14
12
4
5
6
7
8
9

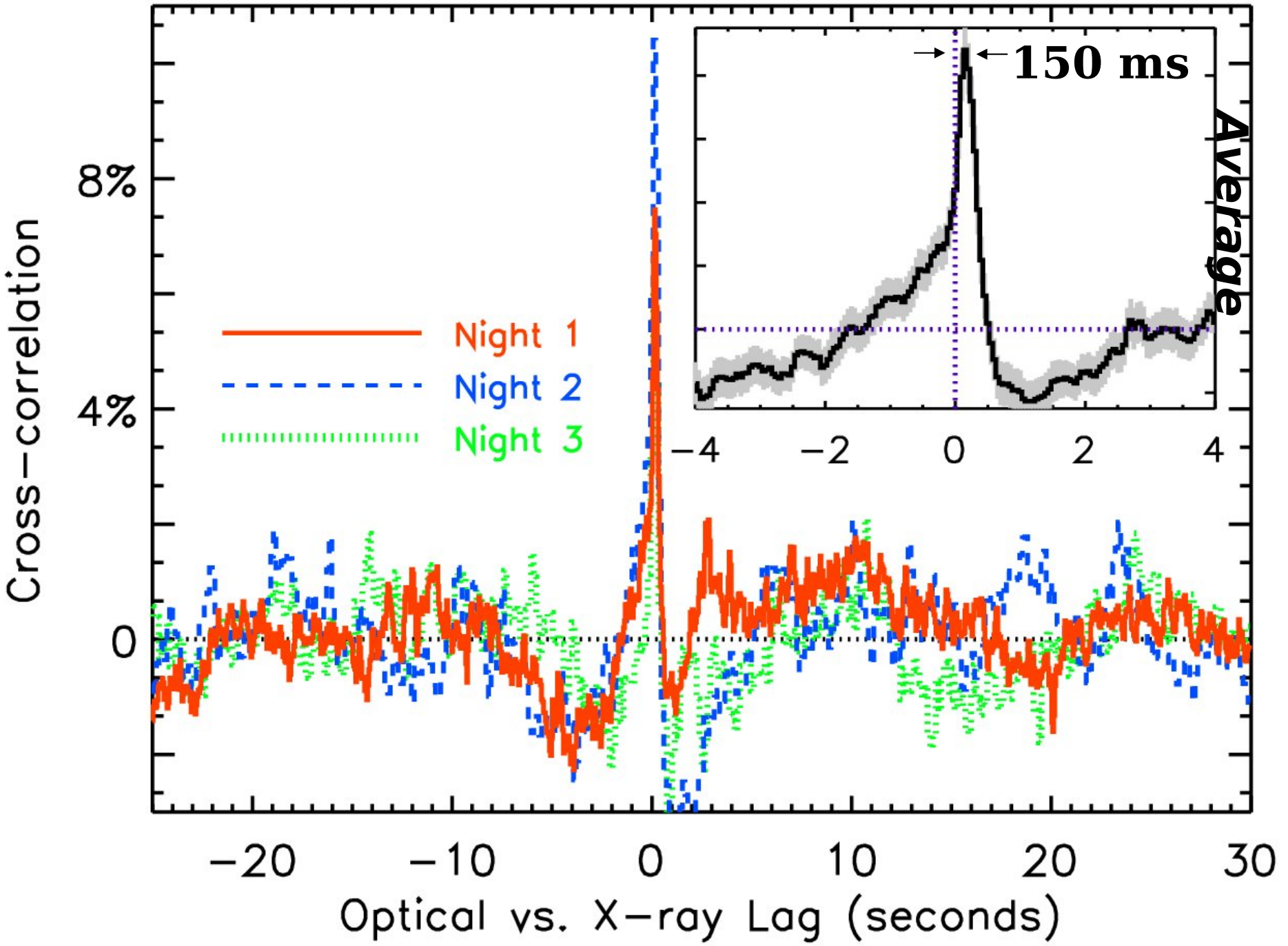
Observations



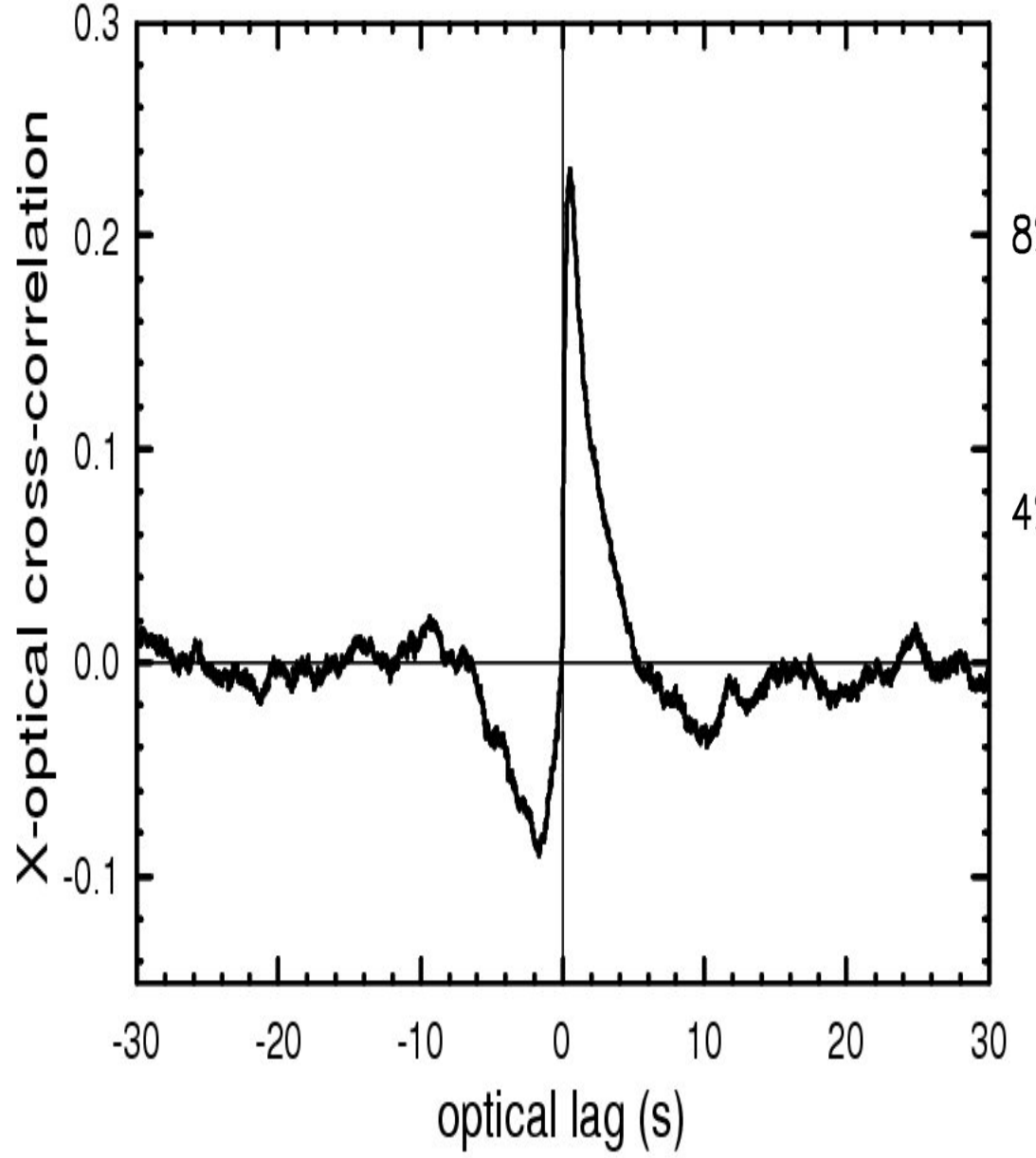


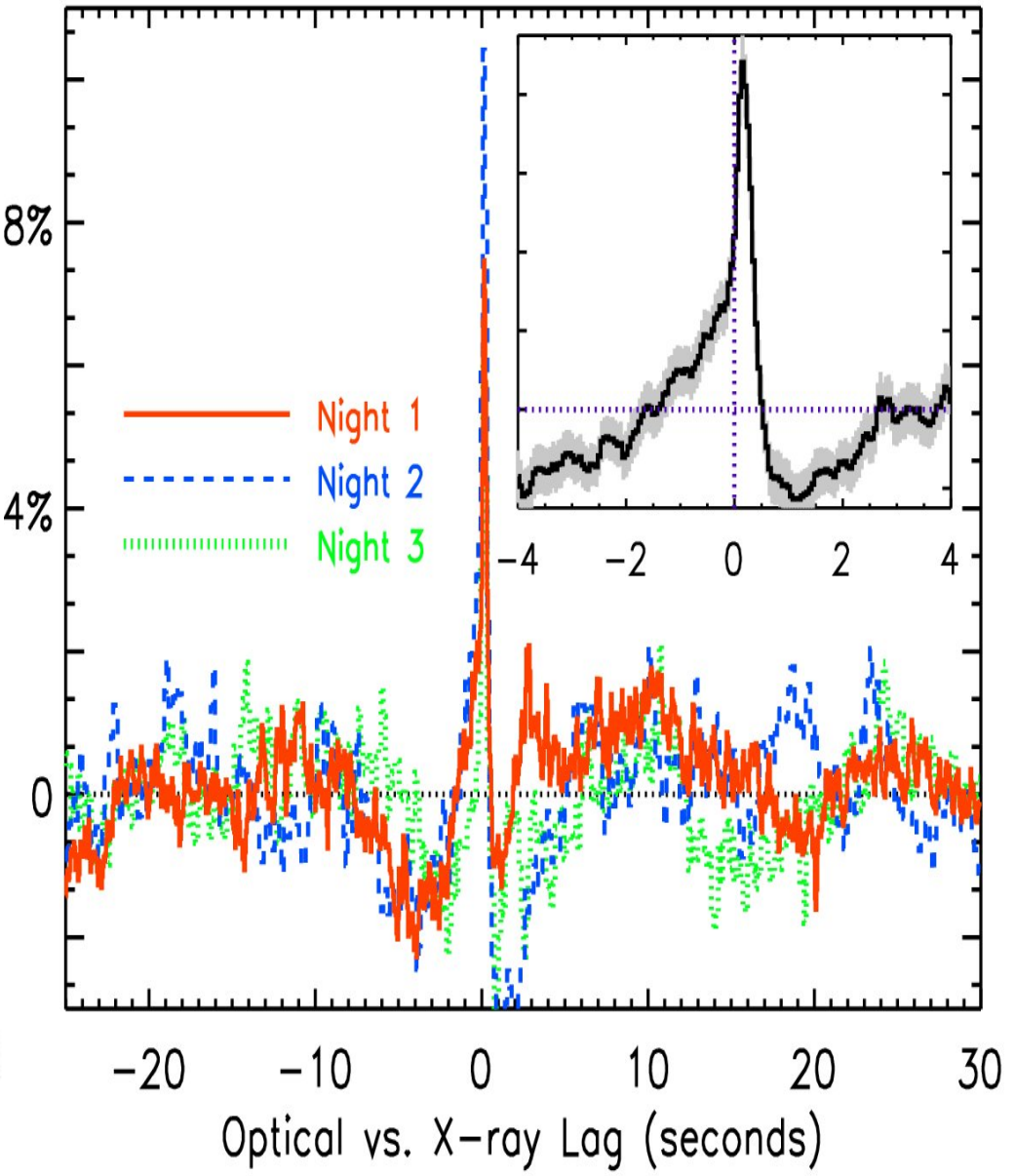

Raw Light curves
dt=0.05s
Red: optical/100
black: X-rays
ULTRACAM r' filter
RXTE PCA (<~ 60 keV)
Counts sec^{-1}
relative time (s)
0
100
200
300
400
500
0
20
40
60
80
100

Cross Correlation Function (CCF)



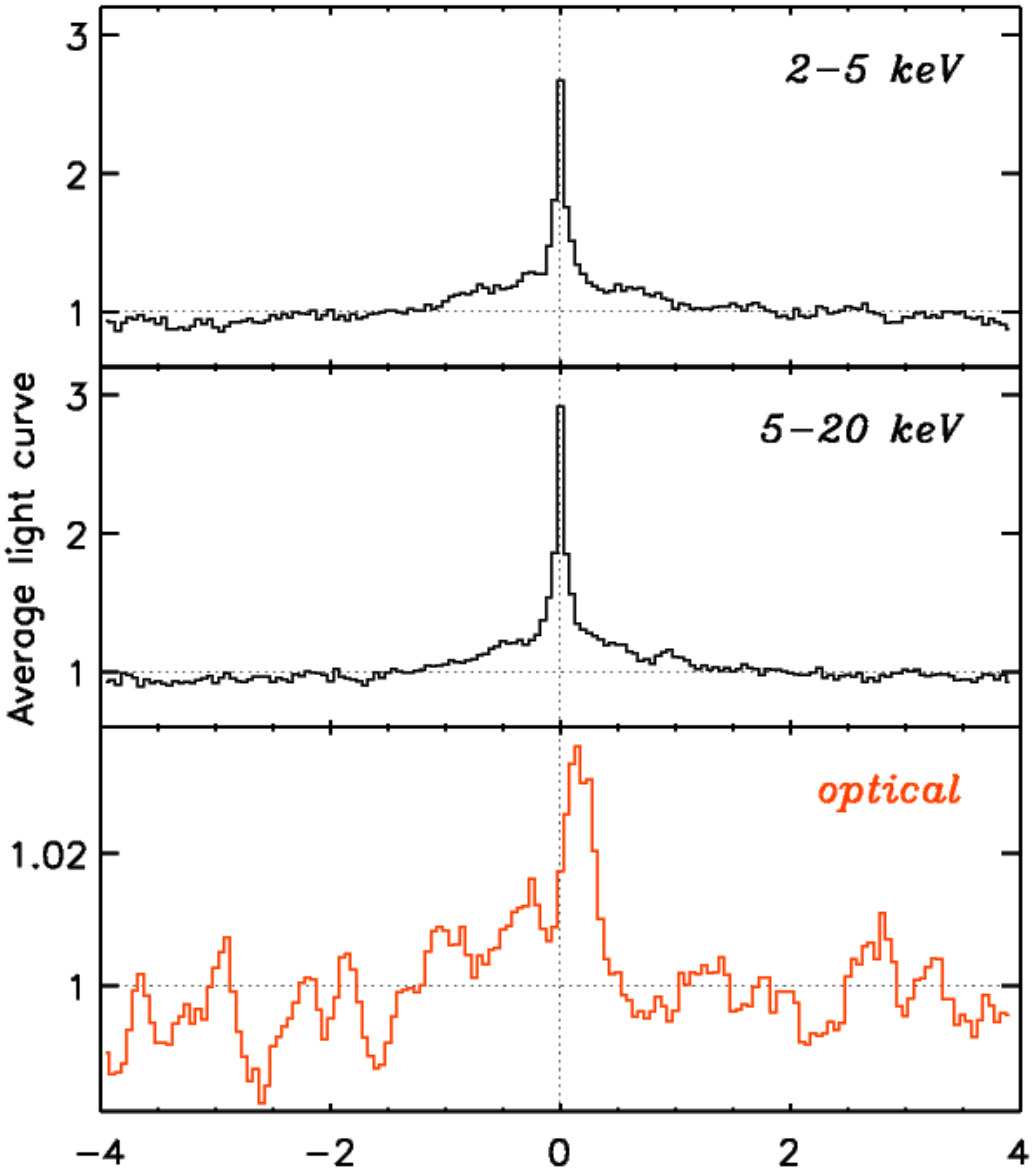
CCF: GX 339-4 vs. XTE J1118+480



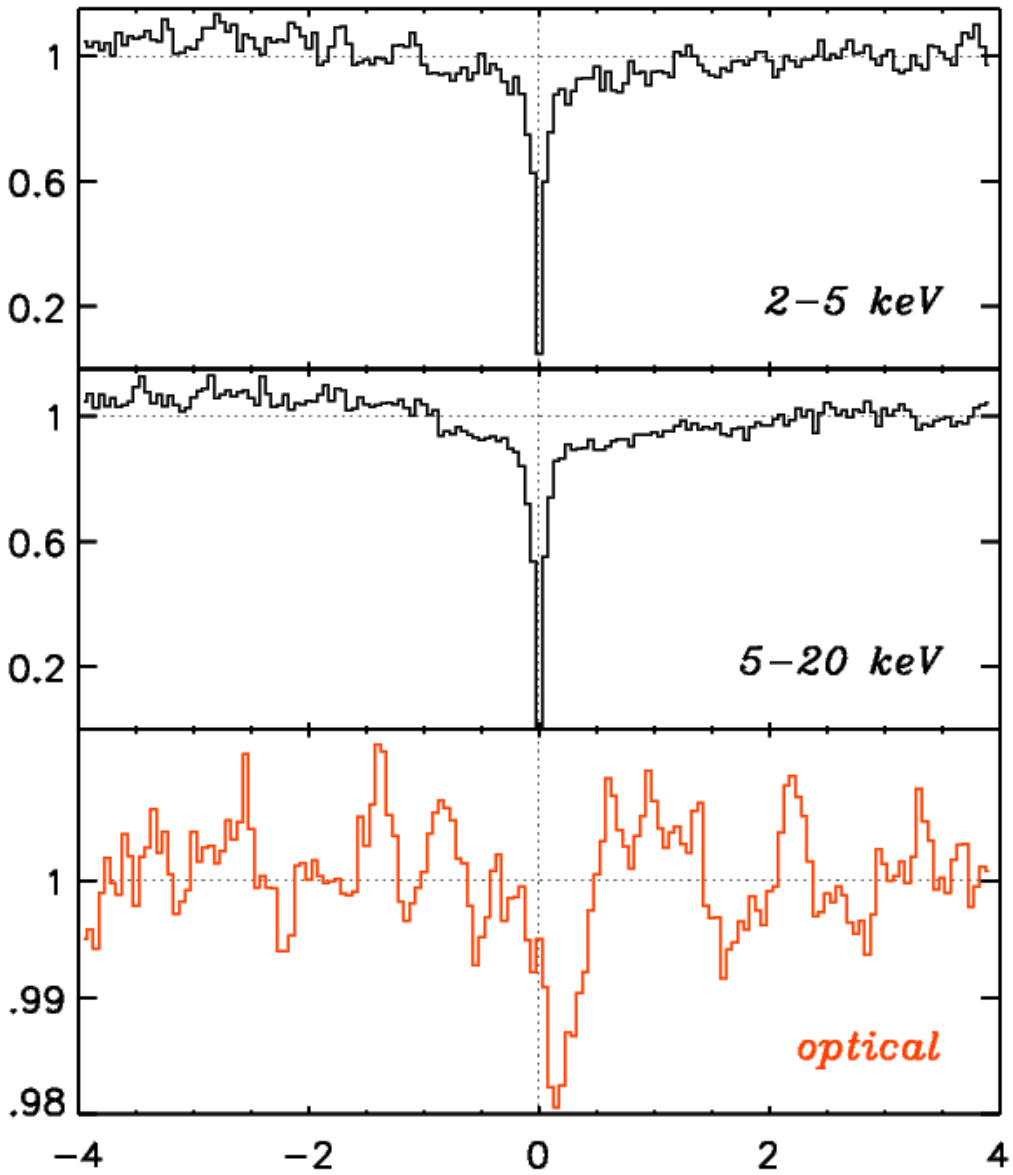


(Kanbach et al. 2001)

Light curve flares and dips follow CCF

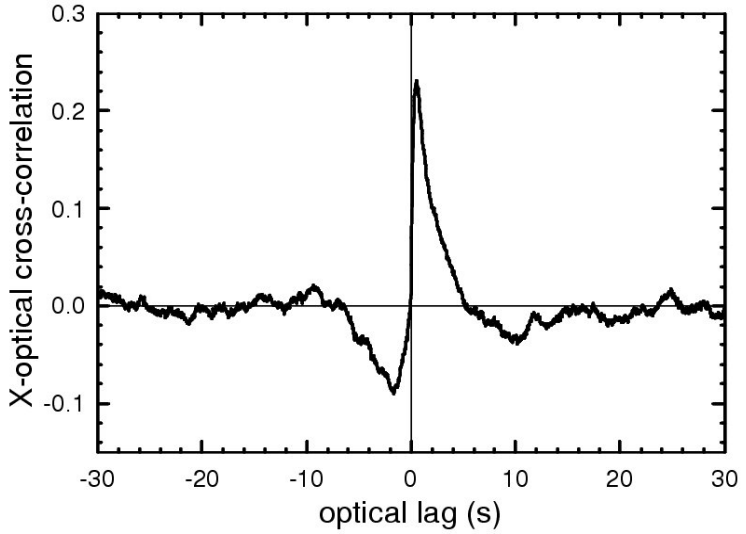


Around full-band X-ray flares (2xavg)



Around full-band X-ray minima (avg/2)

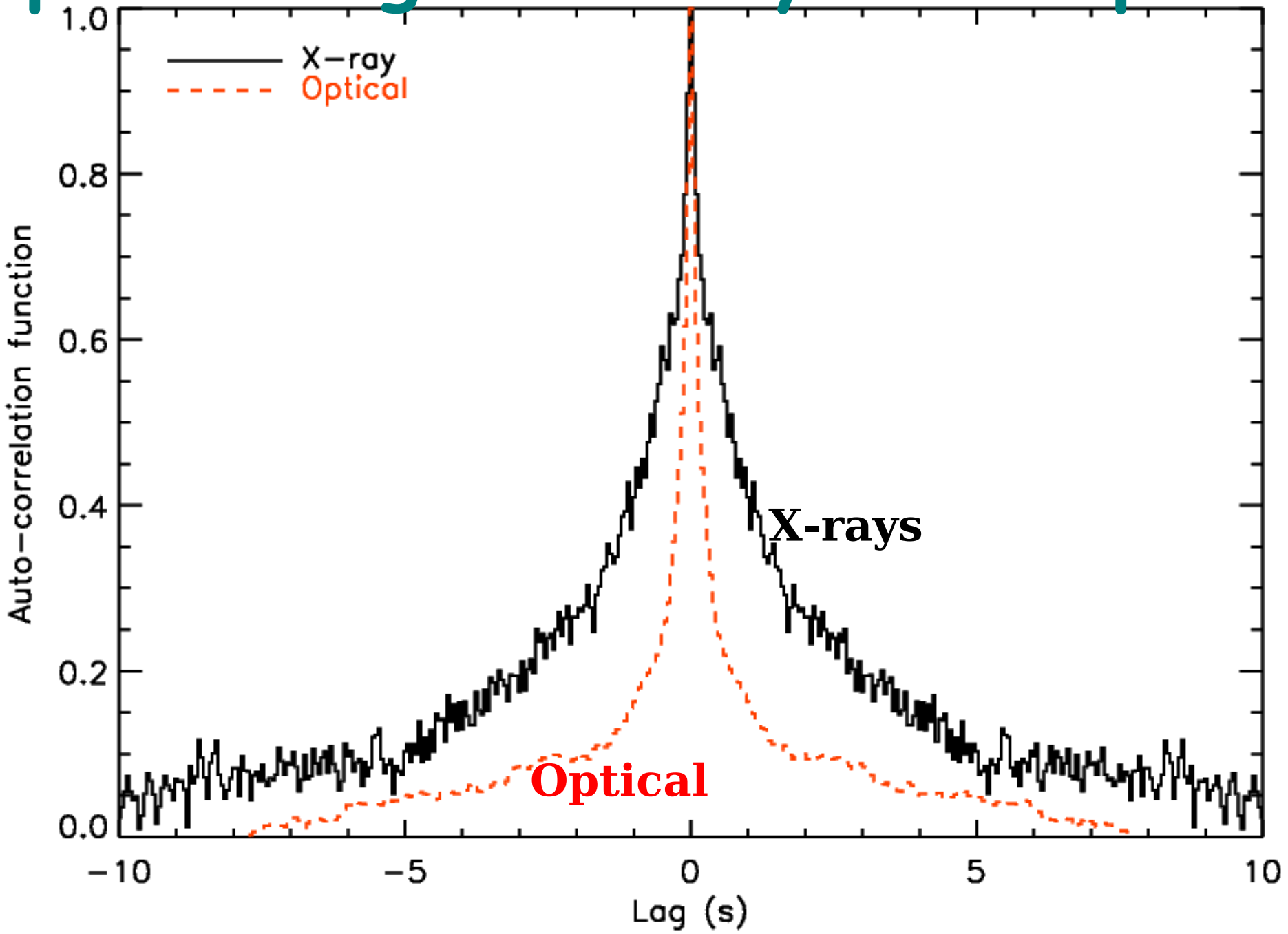
Models for XTE J1118+480



"The physical origin of the variability Is likely to be complicated."

- Esin+01 — *ADAF*
- Markoff+01 — *Pure jet*
- Merloni+00 — *Magnetic corona*
- Malzac+04 — *Common jet/corona reservoir*
- Yuan+05 — *ADAF+jet*
- …

Reprocessing of X-rays into optical?

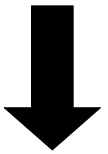


Possible scenario

- Radio observations => presence of jet during our low/hard state observation period (Tomsick+08)

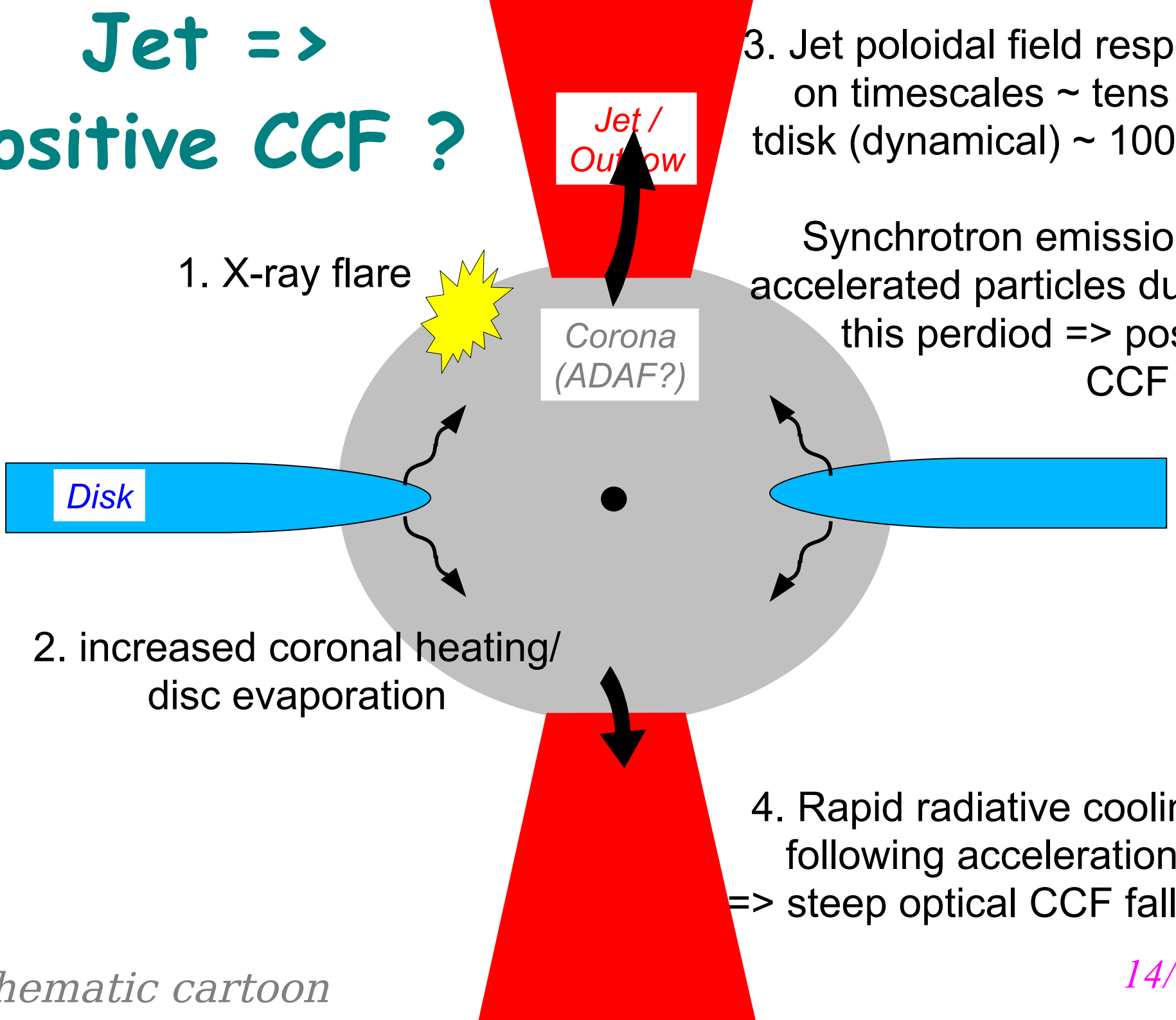
- X-ray spectroscopy (*Swift, XMM*) => disk extending to <~10 GM/c^2 or less (Reis talk; Tomsick+08, Miller+06)

- Models suggest optical due to cyclo-synchrotron emission (Fabian+82, di Mateo+99, Markoff+05 ...)



magnetic energy release in coexistent jet / disk / corona

Jet => positive CCF ?



1. X-ray flare

2. increased coronal heating/ disc evaporation

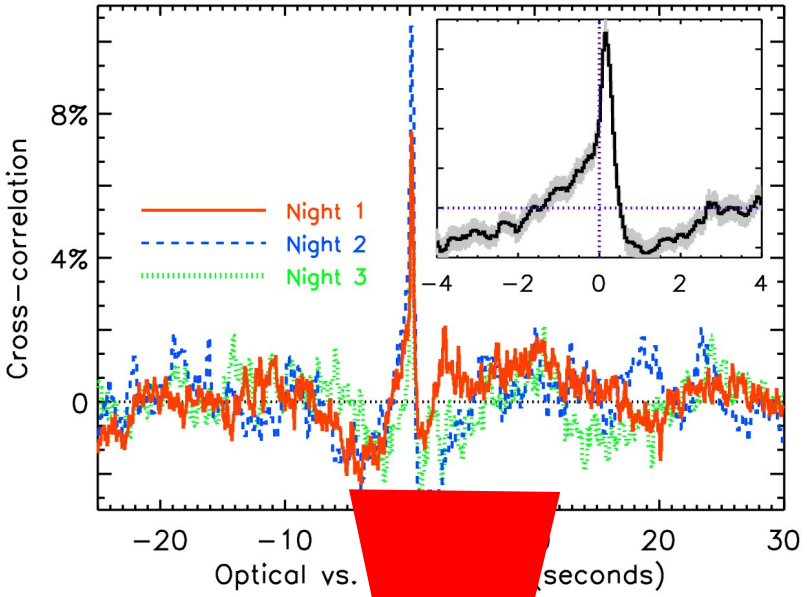
3. Jet poloidal field responds on timescales ~ tens x tdisk (dynamical) ~ 100 ms.

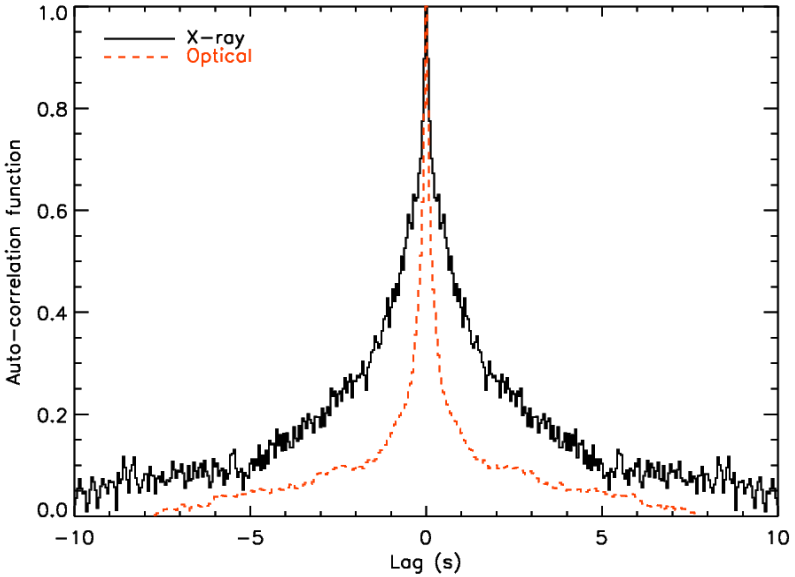
Synchrotron emission by accelerated particles during this perdiod => positive CCF part.

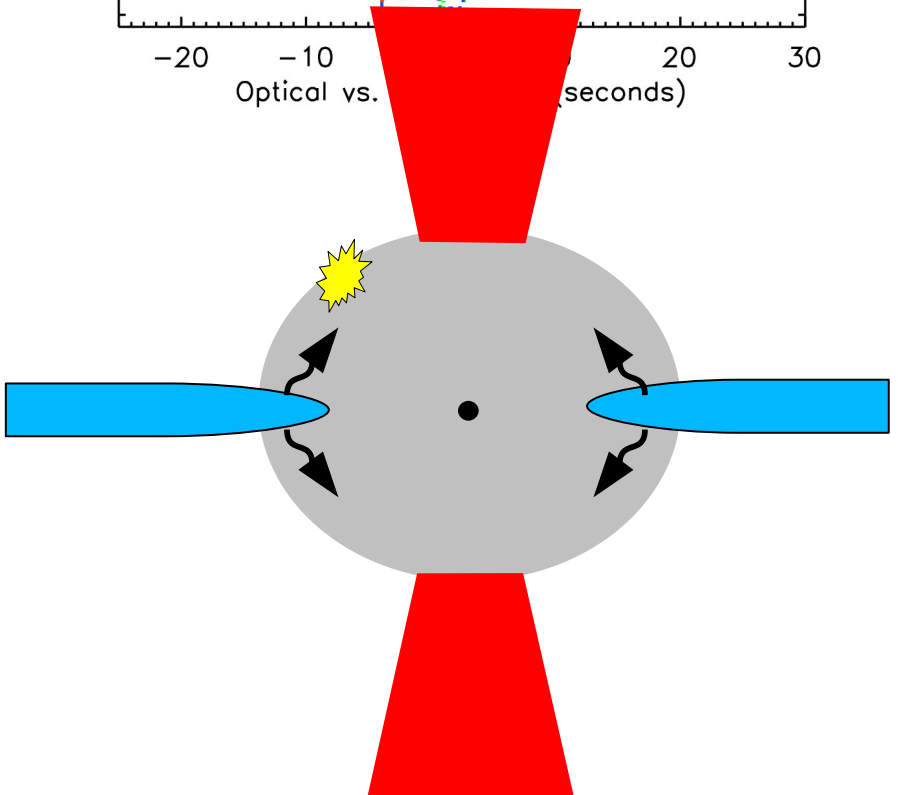
4. Rapid radiative cooling following acceleration => steep optical CCF fall-off

Schematic cartoon

X-ray heating => anti-correlated CCF ?





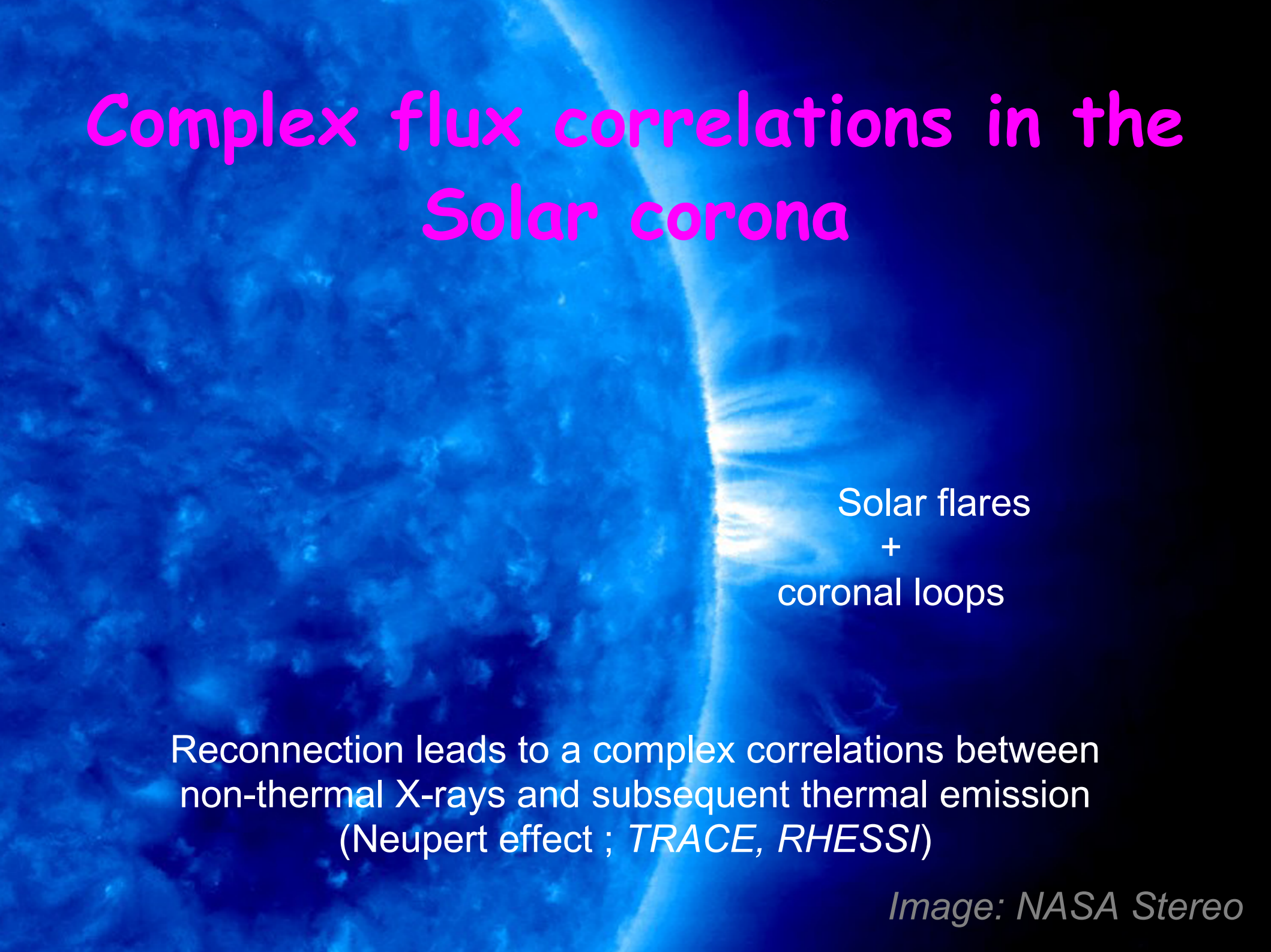


X-ray flare (e.g. reconnection) =>

1. release of stored coronal B energy density
   => ↓ coronal synchrotron

2. disk evaporation
   => ↓ disk emission

Complex flux correlations in the Solar corona



Solar flares
+
coronal loops

Reconnection leads to a complex correlations between non-thermal X-rays and subsequent thermal emission (Neupert effect ; *TRACE, RHESSI*)

Image: NASA Stereo

Summary

Observations:

- First simultaneous rapid optical/X-ray timing study of GX 339-4 in optically-faint low/hard state.
- Complex CCF has similarities with XTE J1118+480.

Model:

- Optical not re-processed. Synchrotron plausibly fits variable power.
- Perhaps jet responsible for positive CCF, corona for anti-correlation.

What next?:

- Prediction: CCF lag will evolve with prominence of jet.
- Optical polarimetry (especially rapid) detection will test synchrotron model.