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

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Timing studies of GX 339-4

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

- X-ray low: optically-bright; high flaring ($\sim 10$ 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)
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
\(dT=50\text{ ms}\)

133 ms

136 ms

Clouded out
Observations

One 50 ms frame (r' band)
Raw Light curves

- RXTE PCA (<~ 60 keV)
- ULTRACAM r' filter

Red: optical/100
black: X-rays

dt=0.05s

Counts sec^{-1}

relative time (s)
Cross Correlation Function (CCF)

![Graph showing cross correlation function with optical vs. X-ray lag (seconds)]

- Night 1
- Night 2
- Night 3

150 ms

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

(Kanbach et al. 2001)
Light curve flares and dips follow CCF.
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 $\sim 10 \ GM/c^2$ or less (Reis talk; Tomsick+08, Miller+06)

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

\[ \downarrow \]

*magnetic energy release in coexistent jet / disk / corona*
Jet $\rightarrow$ positive CCF? 

1. X-ray flare 
2. Increased coronal heating/disc evaporation 
3. Jet poloidal field responds on timescales $\sim$ tens $\times$ $t_{\text{disk}}$ (dynamical) $\sim$ 100 ms. 
   - Synchrotron emission by accelerated particles during this period $\Rightarrow$ positive CCF part. 
4. Rapid radiative cooling following acceleration $\Rightarrow$ steep optical CCF fall-off
X-ray heating => anti-correlated CCF ?

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

1. release of stored coronal B energy density => \[ \downarrow \] coronal synchrotron
2. disk evaporation => \[ \downarrow \] 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)
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.