Multiwavelength rapid timing of X-ray binaries

Martin Durant
Andy Fabian
Piergiorgio Casella
Vik Dhillon
Jon Miller

Elena Mason
Kazuo Makishima
Julien Malzac
Tom Marsh
Tariq Shahbaz
What is the source of the optical power of X-ray binaries?

Gandhi et al. (2008) ESO press release 36/08

Illustration: L. Calçada
Comparison to blackbody optical reprocessing model

Reprocessed emission

\[ \propto f(\text{incident flux, area of reprocessor}) \]

**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).
Speedy aperiodic optical variations in X-ray binaries

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

(target: sky)

(GX 339-4: Motch+82)

(V404 Cyg: Uemura+02)

(XTE J1118+480: Kanbach+01)
1. GX 339-4

Classic BH binary transient:
- $M > 6 \, M_{\text{sun}}$ (Hynes+03);
- $d \sim 7-9 \, \text{kpc}$ (Zdziarski+04);
- $i > 45 \, \text{degs}$ (Munoz-Darias+08);
- microquasar (e.g. Gallo+05);
(Summary: Shidatsu+11).
ULTRACAM (on the VLT): ultra-fast, triple-beam CCD camera

- Frame-transfer CCDs with negligible dead-time
- Speeds ~ 500 frames/sec
- Beam splitters => 3 filter simultaneous imaging

http://www.shef.ac.uk/physics/people/vdhillon/ultracam/
1. GX 339-4

$\Delta T = 50 \text{ ms}$
Simultaneous light curves

RXTE PCA (<~60 keV)

Comparison star

X-ray (ΔT=50 ms)
Optical and X-ray simultaneous timing

GX 339-4: 2007 low/hard state

2.5 s resolution, ~1 h of data
New fast red component in CCF?

2.5 s resolution, ~1 h of data

GX 339-4: 2007 low/hard state
Sub-second X-O Cross Correlation Function (CCF)

Optical Lag (seconds)

50 ms resolution, ~1 h of data (x3)

50 ms resolution, ~1 h of data (x3)

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

Average

Cross-correlation

8%

4%

GX 339-4 : 2007 low/hard state

Optical Lag (seconds)

VLT + RXTE PCA

Night 1

Night 2

Night 3

1σ

50 ms resolution, ~1 h of data (x3)

(Gandhi+ 2008)
2. Swift J1753.5-0127

- Galactic halo BH transient
- Very short period ~ 3h (Zurita+08)
- Lives in the low/hard state
- Radio weak source

\[ \Delta T = 39 \text{ ms} \]

Animation: binsim
Swift J1753.5-0127

X-ray

(Durant+08)
Asymmetric and complex optical/X-ray cross-correlation functions in X-ray binaries

**GX 339-4: Gandhi et al. 2008**

**Swift J1753.5-0127: Durant et al. 2008**

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

All X-ray data: RXTE PCA
1. Small time delay, sharp positive response

![Graph showing correlation between optical lag and time delay with a peak at 150 ms and a 1σ deviation.](image)
2. Anti-correlation

GX 339-4: Gandhi et al. 2008

Swift J1753.5-0127: Durant et al. 2008

XTE J1118+480: Kanbach et al. 2001

All X-ray data: RXTE PCA
3. Small optical coherence times

Auto Correlation Function
(Poisson corrected)

**Optical (r’, g’, u’)**

**X-rays (PCA)**

**Optical ACFs narrower than X-ray ACF for two sources**
4. How much reprocessing is expected?

All sources in low/hard state with \( \frac{L_x}{L_{\text{Edd}}} \sim 0.01 \)

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\[ M_V (\text{mag}) \]
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\[ \log \left[ \Sigma = \left( \frac{L_x}{L_{\text{Edd}}} \right)^{1/2} P_{\text{hr}}^{2/3} \right] \]
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“Canonical” reprocessing
(van Paradijs & McClintock 1994)
Speedy optical variability: scales and power

- Fastest flares have timescales $\sim 20$-$100$ ms.
  
  \[ R \sim 10^4 \text{ km} \sim 10^3 R_G \]

- Brightness temperature
  
  \[ T_B \sim 10^7 \text{ K} \]

- Equipartition
  
  \[ B > 10^4 \text{ G} \]
Models for XTE J1118+480

- Merloni+00  
  Magnetic corona
- Esin+01  
  Advection flow (ADAF)
- Markoff+01  
  Pure jet
- Malzac+04  
  Magnetic ‘reservoir’ jet + corona
- Yuan+05  
  ADAF+jet
- Veledina+11  
  Synchrotron-self-Compton+reprocessing

Optical (cyclo)synchrotron.
Interaction between components.
RMS spectrum optical and X-ray slopes differ, suggesting two different components (Gandhi+10).
B field dissipation $\iff$ anti-correlation

Release of coronal $B$ energy density $\Rightarrow$ optical cyclosynchrotron

(Gandhi+10)
Jet $\leftrightarrow$ positive correlation

Time delay of 150 ms $\Rightarrow$ ↑ jet optical (cyc)syn, at

1. $5000 \, R_G$ @ lightspeed, or

2. $50 \, R_G$ @ $v_{Alvenic}$, for jet poloidal field perturbations on times $\sim$ tens $\times \, t_{dynamical}$ $\sim$ 100 ms; (Livio+03; Malzac+04)
Outer disc $\leftrightarrow$ slow positive correlation

Slow delay on $\sim$seconds time lag
$\Rightarrow$ Positive Opt/X CCF due to reprocessing on outer disc

(Gandhi+10)
Inferences from CCF characteristic times

Positive correlation delay =>
    perturbation delay from disc/corona to jet

Slow positive correlation delay => constrain reprocessing in outer disc

Anti-correlation time => size of corona/hot flow and/or strength of X-ray flaring episodes.

(Gandhi+10)
Swift J1753.5-0127: Weak positive CCF and faint jet

Strong jetted sources have sharp positive correlation (Gandhi+10)
Complex optical/X-ray correlations

Models outnumber sources!

GX 339-4: Gandhi et al. 2008

Optical vs. X-ray Lag (seconds)
Neutron star binaries

X-ray: Optical Cross-Correlation Function (CCF)

- SWIFT J1753
- Sco X-1
- Cyg X-2
- GX 339-4

Optical Delay (s)
IR : clean probe of jet?

Corbel & Fender 2002
Infrared variability

GX 339-4  2008 low/hard state

X-rays/XTE

Infrared/VLT/ISAAC

IR lag 100 ms

2nd orbit
3rd orbit
1st orbit

(Casella+10, Gandhi+11 submitted)
Summary

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

• Optical not reprocessed simply.

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

Multi-wavelength timing gives independent, quantitative constraints on accretion on a wide range of timescales.