Rapid Optical/X-ray timing of black hole binaries: correlated and non-linear variability

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Optical power of X-ray binaries

Some sources show rapid direct optical variability (Suleimanov+ 2003). GX 339-4 ESO PR 2008

Artist: L. Calçada
Optical timing

Early indications: but not followed up, nor fully understood

(GX 339-4: Motch et al. 1982)
Optical timing

V4641 Sgr:

(Uemura et al. 2002)
XTE J1118+480

Average X-ray flares

Average optical around X-ray flares

(Kanbach et al. 2001, Spruit et al. 2002)
XTE J1118+480

(Kanbach et al. 2001)
Our observations

1. GX 339-4
2. Swift J1753.5-0127
ULTRACAM: 
ultra-fast, triple-beam CCD camera

- Light-weight camera (visitor instrument on WHT/VLT/NTT)
- Frame-transfer CCDs with negligible 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/
Observations

50 ms ULTRACAM frame ($r'$ band)

GX 339-4

Comparison

$r$

Comparison

X-ray

Time (s)
Power Spectra show broad-band noise in Optical and X-ray data. Lorentzian decomposition is used for spectral analysis.
X-O Cross Correlation Function (CCF)

Rapid variability origin?:
Simple reprocessing models

(Gandhi+ 2008)
1. Small time delay

Average Optical Lag (seconds) \( (Gandhi+ 2008) \)

\[ 150 \text{ ms} \]
2. Anti-correlation

![Graph showing cross-correlation over Optical Lag (seconds)]

(Gandhi+ 2008)

Average Optical Lag (seconds): 150 ms
3. Small optical coherence times

Optical ACF narrower than X-ray ACF

Auto Correlation Function (Poisson corrected)

Lag (s)

Optical

X-rays
3. Small optical coherence times

Auto correlation functions

Power spectra

(rms$^2$ normalization: Belloni+90)
GX 339-4: Simultaneous light curves
Swift J1753.5-0127: Simultaneous light curves

Time (s)
Complex optical/X-ray correlations

![Graph showing cross-correlation over time lag for Swift J1753.5-0127.](#)
Non-linear variability:

\[ \frac{df}{dt} \propto f \]

Random shot noise predicts constant \( \sigma \)

(Gandhi 2009)
Additive shots ruled out

Superposition of independent shots  =>

Ruled out in X-rays (Uttley et al. 2001...2005) and now optical (Gandhi 2009)
Non-linear variability

Perturbations must be \textit{coupled} together, rather than \textit{superposed}

\textbf{Interactions between multiple emission components}

(Lyubarskii 97, Misra 00, King+04, Titarchuk+07, Zhang 07)
X-ray binaries

(J. Orosz)
Simultaneous rapid optical/X-ray timing of X-ray binaries in low/hard state.

- Optical not reprocessed.

- Complex CCF => jet/corona/disk interaction

- X-ray and optical r.m.s. scales with flux => additive shots ruled out

Fast optical timing => interesting constraints on accretion and hot plasmas