A Black Hole X-ray Binary at ~100 Hz:
Rapid Multiwavelength Timing of MAXI J1820+070 with HiPERCAM and NICER

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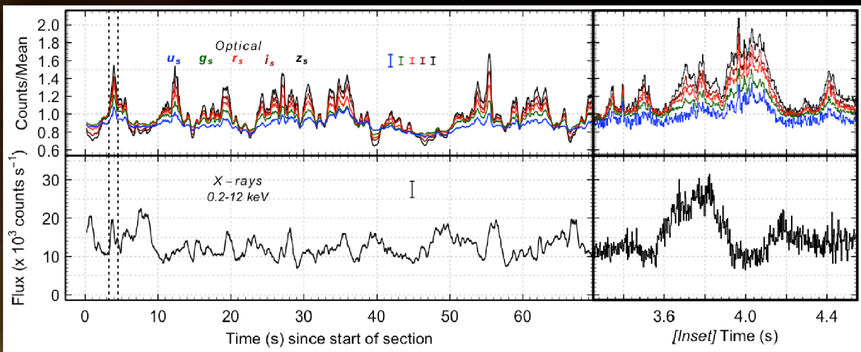
Abstract

Rapid, multiwavelength observations of the Low Mass X-ray Binary black hole MAXI J1820+070 have revealed startling activity at hitherto unprecendented timescales. Data from HiPERCAM/GTC at frame rates over 100 Hz in five optical bands show intense red flaring activity (factor of two) over a broad range of timescales, down to ~10ms. Using X-ray data from NICER/ISS, cross-correlations find a prominent anti-correlation on timescales of ~seconds, as well as a narrow, wavelength-dependent sub-second correlation at a lag of ~+165 ms (optical lagging X-rays). These are consistent with an inner accretion flow and jet base within 5000 Gravitational radii. This is the first time such a study has been done at this time resolution, and these novel results allow constraints on internal shock jet stratification models.

Intro

The origin of optical emission in LMXBs is generally considered to be a mixture of processes, including, e.g., X-ray reprocessing (King & Ritter 1998), synchrotron radiation from a jet (Markoff et al. 2001; Malzac 2018), and/or an accretion flow (Fabian et al. 1982, Veledina et al. 2011). Fast timing observations can probe the interactions between these components and give important insight into the structure of the accretion flows. But such observations are challenging, and only a handful of sources have been observed using strictly simultaneous rapid multiwavelength timing. Here, simultaneous optical/X-ray timing results of J1820 from 2018 April 17 during its hard state, carried out by the new HiPERCAM and NICER detectors at an unprecedented time resolution.



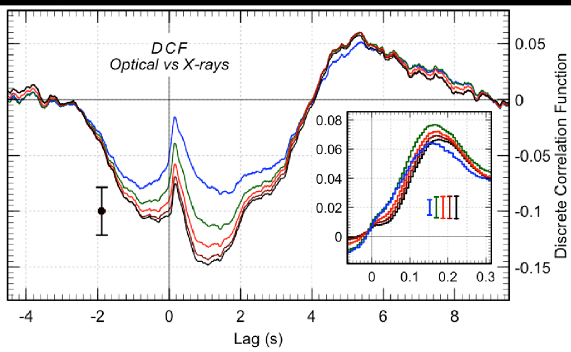


Fig. 1: Optical (top) and X-ray (bottom) lightcurves, binned with a moving average function over 150 points (0.5 seconds). The optical bands are Super *ugriz* filters (blue/green/red/dark red/black respectively). Representative error bars on individual time bins are shown. Note the rapid flaring and extreme variability of the source.

Fig. 2 Inset of the lightcurve, shown by the dashed lines. Note how red the flares are, and the short time scale of some of the fastest flares - e,g, down to 10ms long at 3.96s.

Fig. 3 Optical vs X-ray Discrete Correlation Function (a positive lag denotes optical emission lagging X-rays) created from averaging 30s segments of data. The colours denote which optical band is cross-correlated with X-rays. Top-to-bottom around 0s lag, the order of the bands is *u* - *z*, in order of wavelength. **Inset:** The same, but constructed from 2s segments. Note the wavelength dependence of the peak (See Fig. 4 and 6).

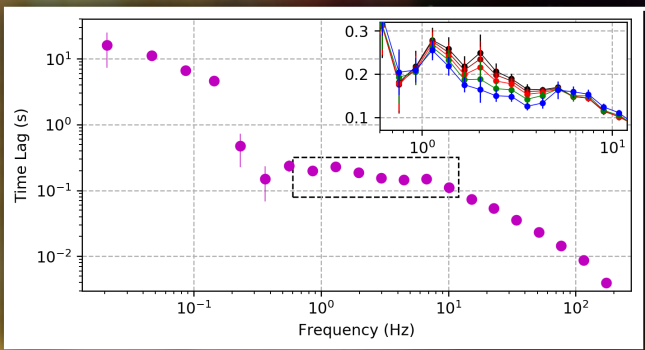


Fig. 4
Time lags created by Fourier analysis; lags here are optical lagging X-rays, and all lags are assumed to be positive. This reveals a 'plateau' in the time lags between 0.3 - 10 Hz, consistent with the peak seen in the correlation function. Plotting for every band (Inset) shows a striking wavelength dependence.

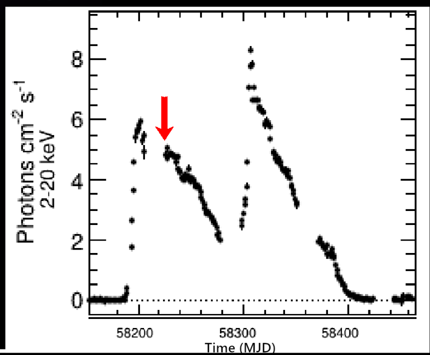


Fig. 5
X-ray lightcurve from MAXI, showing the evolution of the outburst of J1820. Our observation was carried out at the point shown by the red arrow, just after the peak in the hard state.

Wavelength Dependency

Wavelength-dependence of such a lag has never been seen before at such magnitude. Synchrotron emission from internal shocks within a relativistic jet could be an explanation. Emission from this zone is expected to be optically-thin, but this is likely only true on average; shocks between relativistic shells of plasma would emit in optical/IR wavelengths, dependent on velocity shear. Assuming material travelling at *c*, this 165ms lag corresponds to a maximum distance of roughly 4650 gravitational radii. An optical lag of 0.1 light-seconds appears to be common in hard state LMXBs (Kanbach et al. 2001, Gandhi et al.2008; 2017) and is likely to be constraining the elevation of the first plasma acceleration zone above the black hole

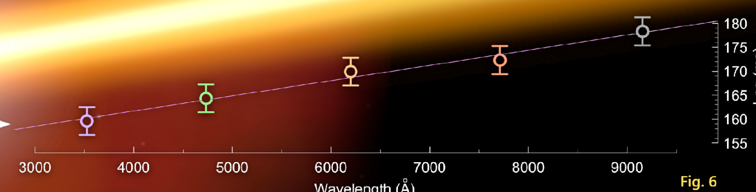


Fig. 6
Peak lags of the sub-second correlation.

Conclusions

MAXI J1820+070 was the brightest LMXB transient in 2018, and studies of its multiwavelength emission, including the richness of information available on millisecond timescales, will undoubtedly continue to prove valuable. It increasingly seems that time and length scales are similar across LMXBs (e.g. GX 339-4 and V404 Cyg). Testing this trend through analysis of future LMXB sources should prove most interesting; tests that, with this newest generation of telescopes, we now have the ability to carry out better than ever before.

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