X-ray and Optical-NIR Observations of Black Hole Binaries

Nobuyuki Kawai, Katsuhiro Murata, Yuichiro Tachibana, Kotaro Morita, Ryosuke Itoh (Tokyo Tech), Hitoshi Negoro (Nihon Univ.), Satoshi Nakahira (RIKEN)

The MAXI Team
Kumiko Morihana (Nagoya U.), Takahiro Nagayama (Kagoshima U)
Black Hole Binary (high mass)

- Black Hole: $>3-20 \ M_{\text{sun}}$
- Stellar wind
- Only a few known in the Galaxy
- Cyg X-1, Cyg X-3, SS433(?)
- High-mass star: $10-20 \ M_{\text{sun}}$
Black Hole Binary (low mass)

- Black Hole
  - >3–20 $M_{\text{sun}}$
- Low-mass star
  - 0.1–1 $M_{\text{sun}}$
- Roche Lobe overflow

- mostly transient ("X-ray nova")
- ~1/year new BHB discovered
Figure 3: X-ray light curves of four bright black-hole X-ray novae. The observed X-ray fluxes are shown in units of the Crab Nebula intensity in the energy band separately indicated for each source. The dotted curve for A0620-003 is from Elvis et al. (1975), and the dots with vertical error bars are from Kaluzienski et al. (1977b). The GS 2000-251 data (open circles) are from Tsunemi et al. (1989) and Takizawa (1991). The GS 2023-338 data (thick vertical bars, which indicate actual large flux excursions) are from Tanaka (1992a). The GS/GRS 1124-684 data (open squares) are from Kitamoto et al. (1992) and Ebisawa et al. (1994).
Anatomy of an accreting black hole

Advection dominated flow + corona

Inverse Compton radiation
(seed photon: disk/cyclotron)

optically thick disk

Blackbody radiation
\( kT_{\text{in}} \approx 0.1-1 \) keV

innermost stable circular orbit

3 \( r_g = 6GM/c^2 \)

jet

Synchrotron/SSC
X-ray spectrum of a black hole binary

- Total disk emission
- Comptonized emission from disk corona or Synchrotron/SSC from jet
- Blackbody from each ring
Monitor of All-Sky X-ray Image

- Mission started August 2009
- Ops approved until Mar 2021
- Real-time link ~70%
- “MAXI 10-Year” Symposium planned in Fall 2019
Scans with Slit + Slats collimator

ISS rotation

Celestial sphere

160 deg

1.5 deg (FWHM)

3.0 deg (at bottom)

1-dimensional position sensitive detector

proportional counter

X-ray CCD

Operating in equatorial region

Particle background rate
Optical/NIR emission from Low-mass X-ray binaries

- Thermal emission from the X-ray irradiated disk and/or the companion
- Synchrotron emission from the jet
- Cyclotron emission (or Comptonized —) from ADAF

may constrain the system geometry and dynamics, and provide information on accretion and radiation processes
Fig. 1. (a) The MAXI/GSC 2–8 keV and 8–20 keV light curves, hardness ratio between 8–20 keV and 2–8 keV, and the 15–50 keV Swift/BAT light curve, from top to bottom. Black points indicate data with time resolution (∼ 92 minutes), and red points are binned data. (b) Top: the zoomed 2–8 keV (black) and 15–50 keV (red) light curves around the first hard-to-soft state transition indicated in panel (a) by a vertical line in green. The second order Bézier curves (solid lines) and its knots (circles) are superposed on the data. Middle and bottom: the ratios of the data to the Bézier curve. Errors in all panels represent 1σ confidence intervals.

MAXI J1535–571

⇔ X-ray light curves

Hardness-Intensity Diagram (HID) ↓

2.3 Energy spectra

We extracted time-averaged MAXI/GSC spectra of MAXI J1535–571 from the 109 binned time points (defined in Section 2.2). The derived spectra were fitted with the standard X-ray emission model for black hole X-ray binaries: a disk blackbody emission and its Comptonization, absorbed by cold interstellar medium. We adopted the multi-color diskbb model (Mitsuda et al. 1984), and convolved it with simpl (Steiner et al. 2009) in which a fraction of the input seed photons are redistributed by Comptonization into a power-law form. The interstellar absorption was expressed by the TBabs model, referring to the solar-abundance table given by Wilmset al. (2000). Because simpl is a convolution model, the energy band used in the spectral fitting was extended down to 0.01 keV and up to 100 keV. The spectral analysis was carried out with XSPEC version 12.9.1, and the errors represent 90% confidence limits.

In the fitting, the absorption columns density was fixed at $N_H = 2.6 \times 10^{22}$ cm$^{-2}$, a value which was favored by essentially all the spectra. When the 2–8 keV vs 8–20 keV ratio is less than 0.22, we fixed $\Gamma$ at 2.40, a typical value during the soft state (McClintock & Remillard 2006), because the...
Follow-up observation with IRSF 1.4 m telescope

Near-infrared

- J (1.2μm), H (1.6μm), Ks (2.3μm)
- less dust extinction than optical and UV
- galactic plane source such as MAXI J1535-571

Sutherland observatory in South Africa

- Southern Hemisphere
- MAXI J1535-571

Observations

- Sep 6—17: Kumiko Morihana, Takahiro Nagayama
- Sep 28 — Oct 2: Katsuhiro Murata, Ryosuke Itoh
MAXI J1535–571: 2-color flux (H vs. J)
MAXI J1535–571: NIR flux properties

• **Variable on three time scales**
  - Slow gradual rise ($\tau \geq 10$ ks)
  - Intermediate variation ($\tau \sim 3$ ks) at plateau
  - Rapid variation ($\tau<20$s)

• **Slow and rapid variations share common properties**
  - Rapid var. amplitudes scales with total flux
  - Similar colors
  - Redder when brighter
    - $\rightarrow$ suggest existence of underlying stable blue component

• **Intermediate variation is different**
  - Redder when brighter in J-H, small amplitude in J band
  - Little change in H-Ks color
Rapidly variable component on color-color diagram

- Consistent with either irradiated disk or synchrotron emission above cooling break with $A_V \approx 10$
- "redder when brighter" difficult for irradiated disk
Possible broad-band SED

- Synchrotron emission from jet
- Irradiated inner and outer disk (diskir)
- X-ray Comptonized Disk emission

\[ \nu F_\nu \text{ (erg/cm}^2\text{s)} \]

Frequency (Hz): \(10^{11} \rightarrow 10^{19}\)
Conclusion

• Continuous 3-color (J,H,Ks) photometry with 17s sampling revealed flux and color variations on three different timescales: $\tau \geq 10$ ks, $\tau \approx 3$ ks, $\tau < 20$ s

• Slow ($\tau \geq 10$ ks) and rapid ($\tau < 20$ s) components may have common origin

• “Redder when brighter” variation can be explained by the combination of a variable red component (synchrotron jet?) and a stable blue component (irradiated disk?)