The third annual conference of Transformative Research Areas (A),
"Multimessenger Astrophysics" (11/18–20, 2025)

Rapid variability in black-hole systems and our efforts for multi-wavelength observations

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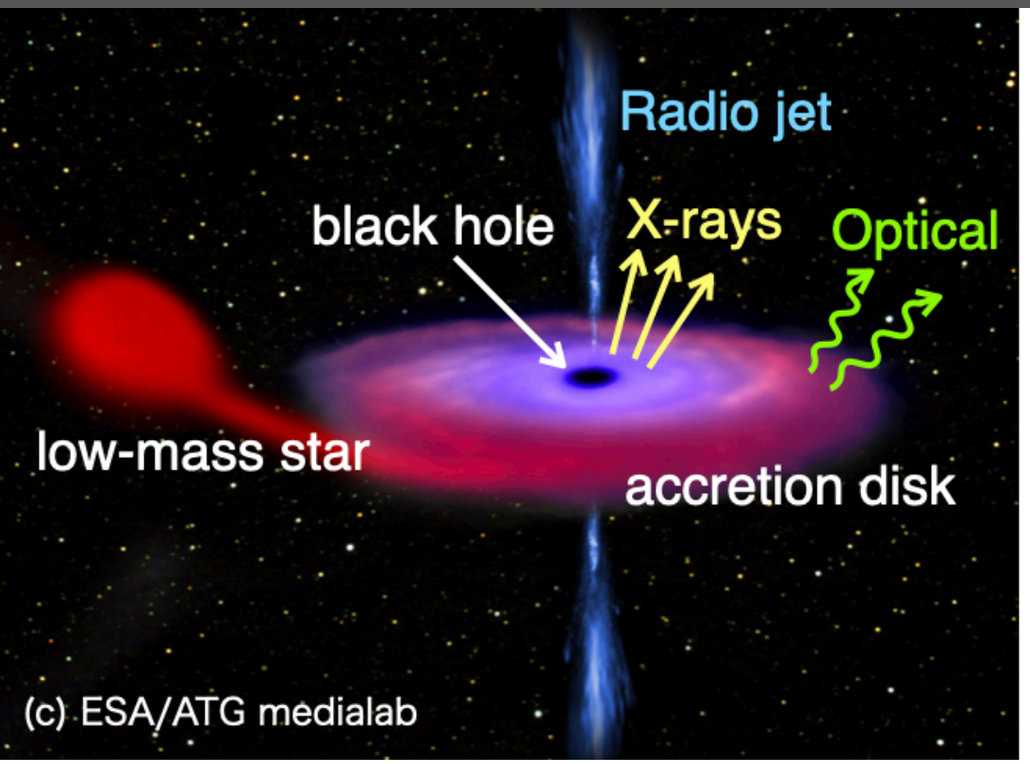
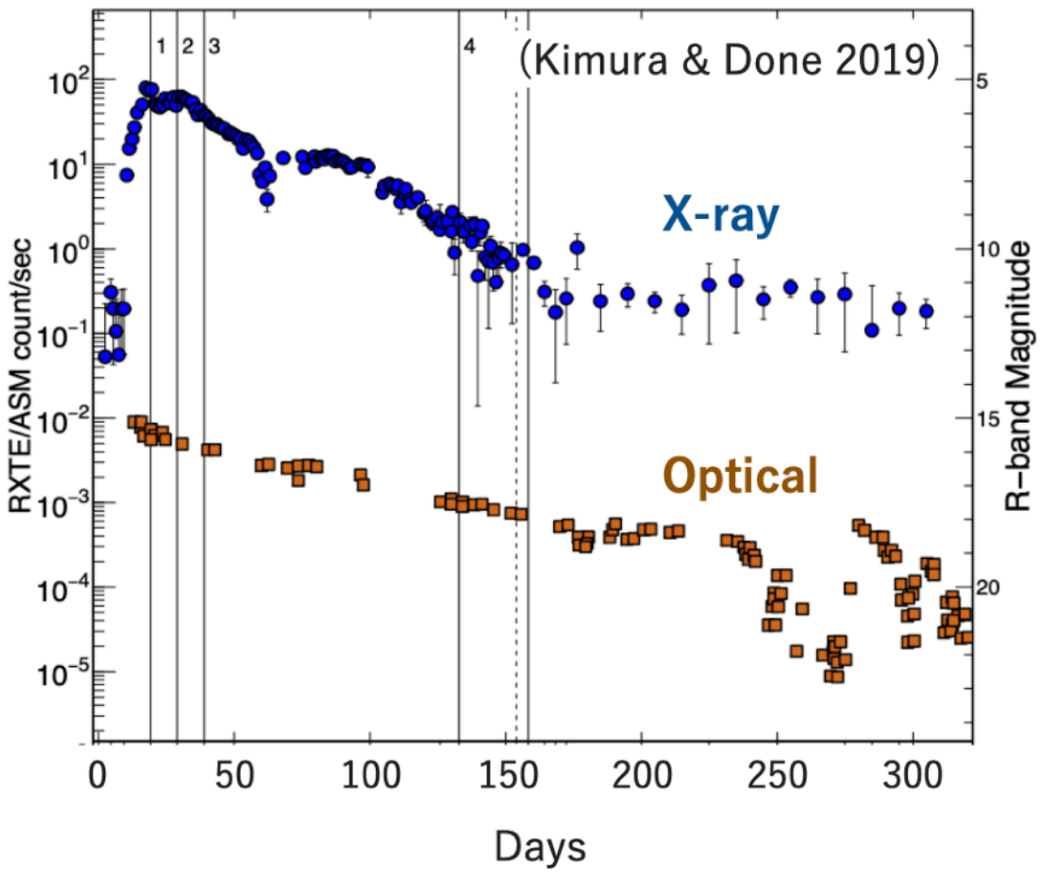
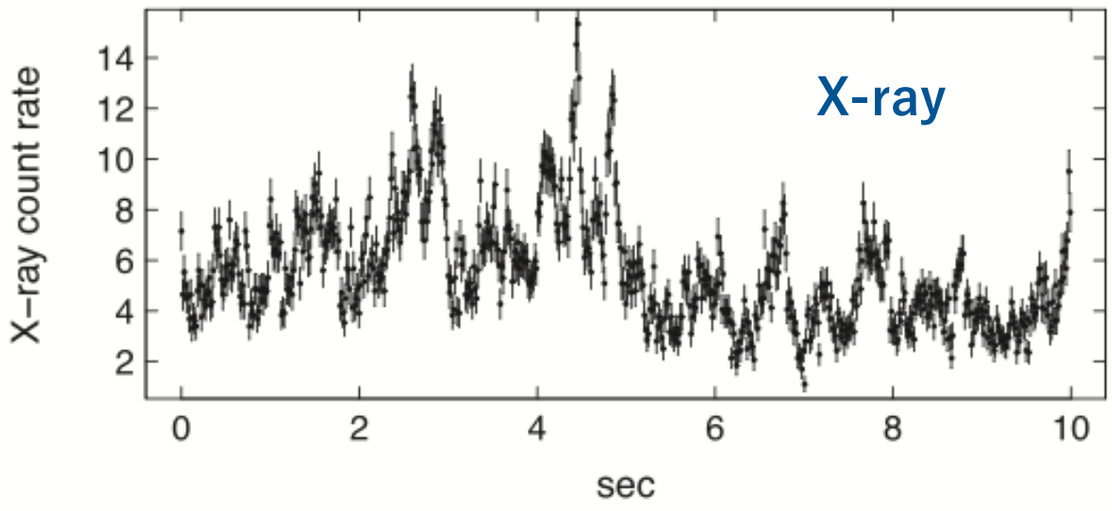
Makoto Uemura (Hiroshima University), Hiroyuki Maehara (Okayama Observatory),
Kenta Fujisawa (Yamaguchi University)

Black-hole low-mass X-ray binaries



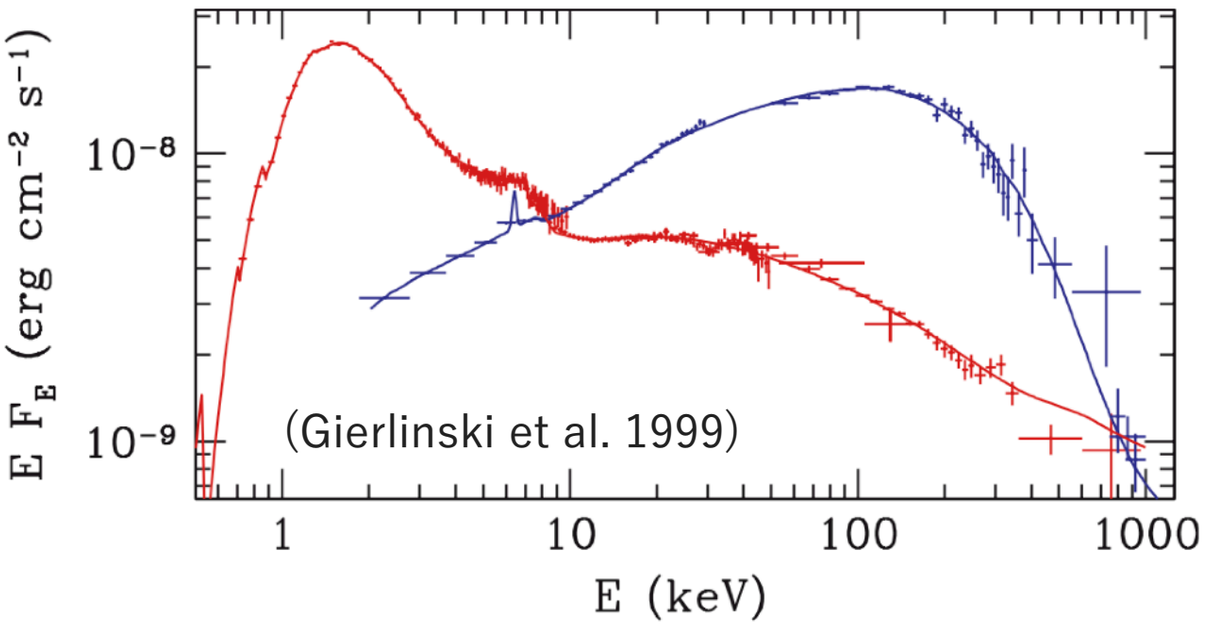
- Close binary system composed of a black hole and a low-mass star
- An accretion disk is formed around the black hole
- Show intermittent outbursts (sudden brightening of the disk) at multi-wavelengths
- Outbursts are triggered by thermal-viscous instability at the disk
- Sub-second flares during outburst



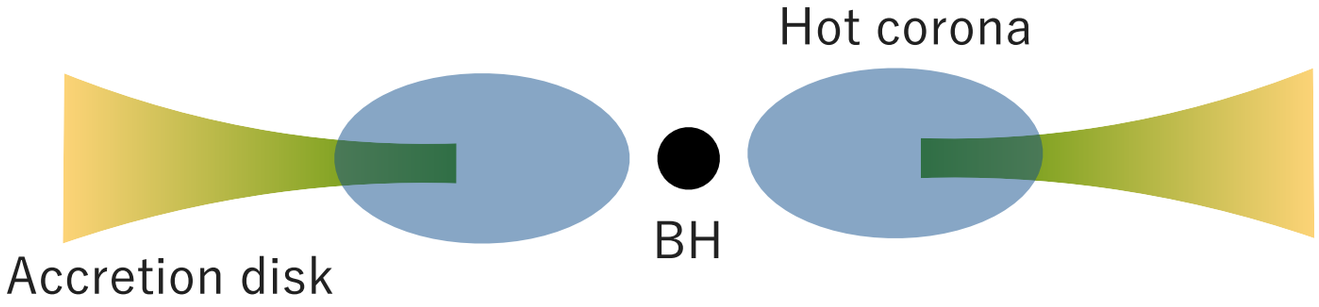


The origin of sub-second flares ?

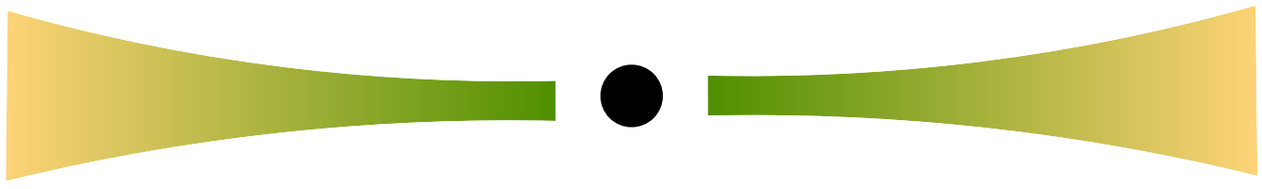
X-ray spectral transition & variability

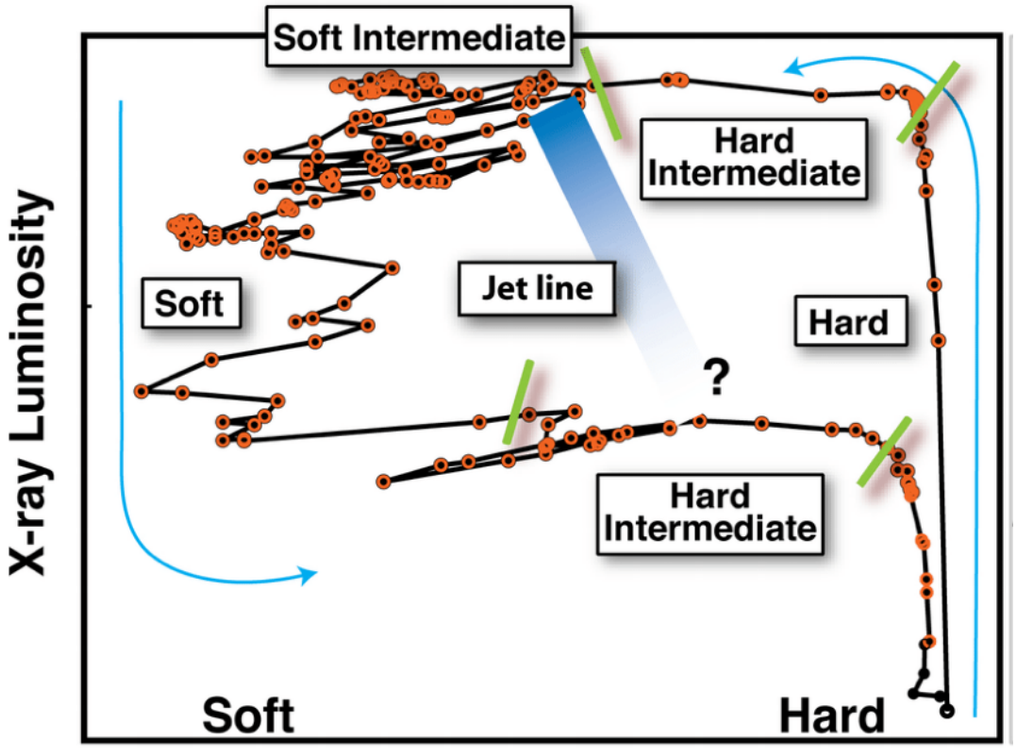


Blue: hard state



Red: soft state

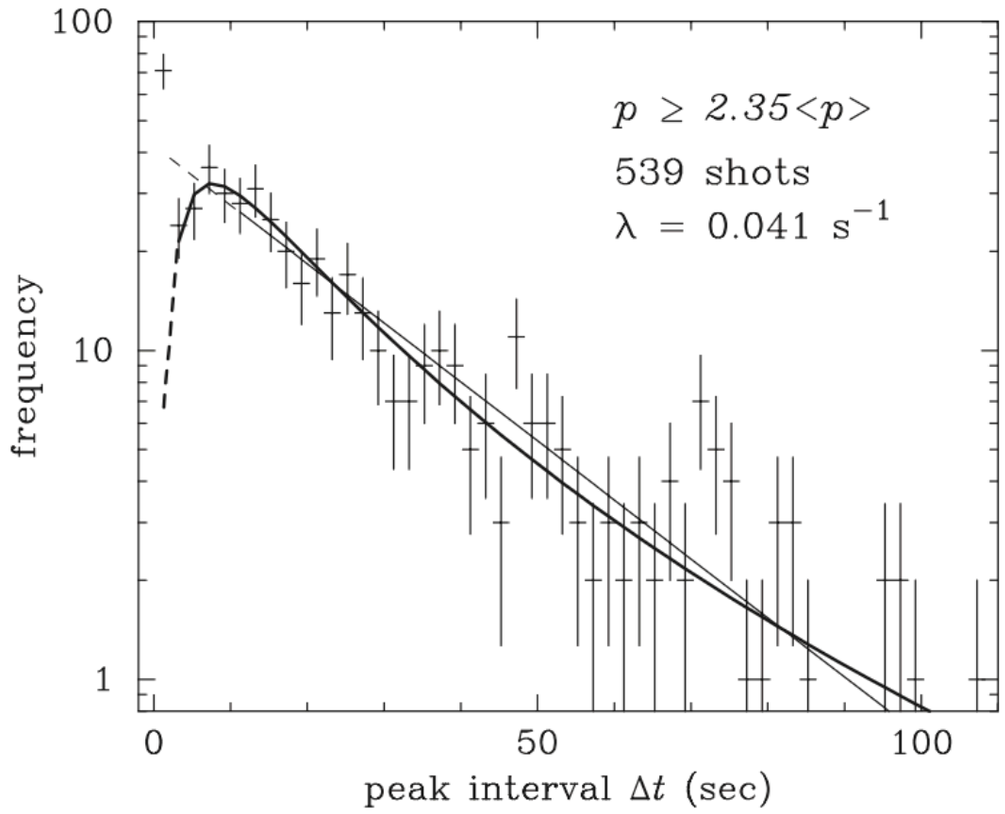




- **Sub-second variability is observable in the hard state.**
- Typically, the hard-to-soft state transition occurs around the outburst maximum.

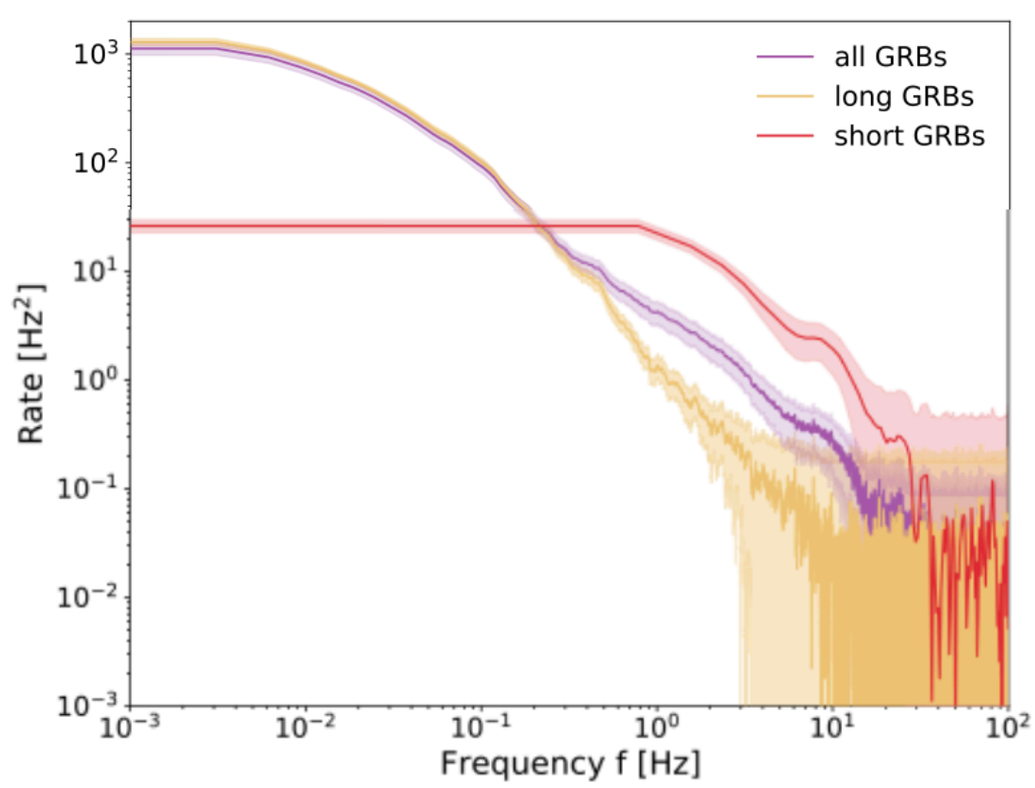
Relation to other types of objects

- Sub-second flares in BHBs and GRBs share common properties.



The distribution of intervals between flares is log-normal.

(Negoro & Mineshige 2002)



The PSD has a broken power-law shape.

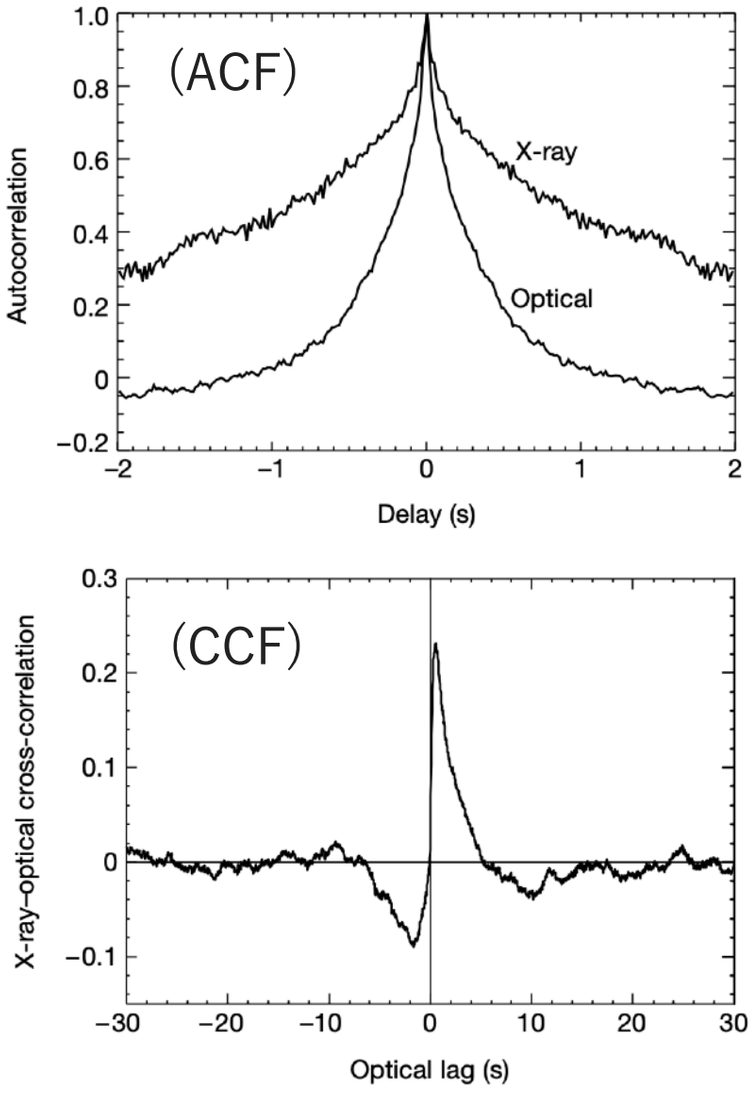
(Done et al. 2007; Magnus et al. 2025)

Universal physics underlying BHBs and GRBs ??

Purposes of our proposed research

I want to know the physics underlying sub-second flares in black-hole systems (BHBs or GRBs) !

→ Desirable to obtain ****simultaneously observed**** multi-wavelength/multi-messenger data.



(Kanbach et al. 2001)

Problems

- Should prove synchrotron emission is dominant by multi-wavelength SEDs and light curves
- Are ACF and CCF the same over all flaring events? Do we have to perform analyses for each flare?
- Many works focus only on period analyses.. Need to extract other properties.

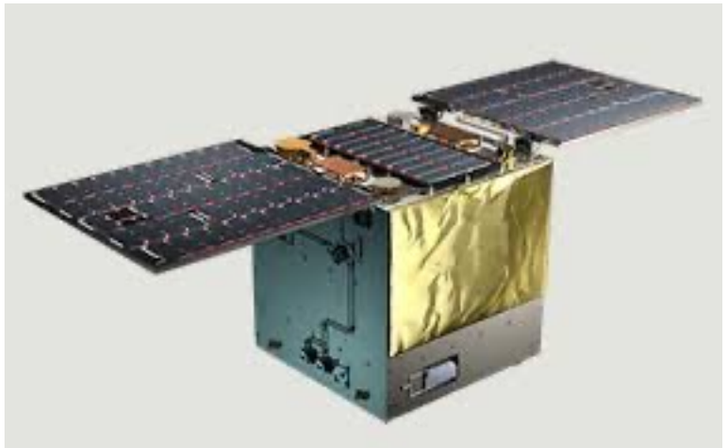
Difficult to collect simultaneously observed multi-wavelength data..

Establish an automatic observation network to accelerate our research !

Purposes of our proposed research

学術変革A・公募研究「突発天体の可視光高速観測の自動化：ブラックホール天体固有の物理現象の解明」(~~2024.4 — 2026.3~~) 2025.4 — 2027.3

Swift・MAXI・KOYOH

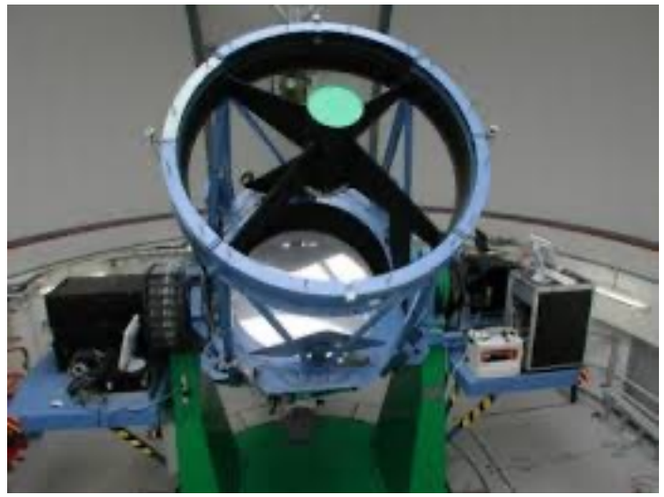


Develop alert systems !

Seimei@Okayama (High-speed optical photometry with TriCCS)

Build an automated observation system !

Kanata@Hiroshima (NIR photometry)



Radio Interferometer @Yamaguchi

Analyses of multi-wavelength data !

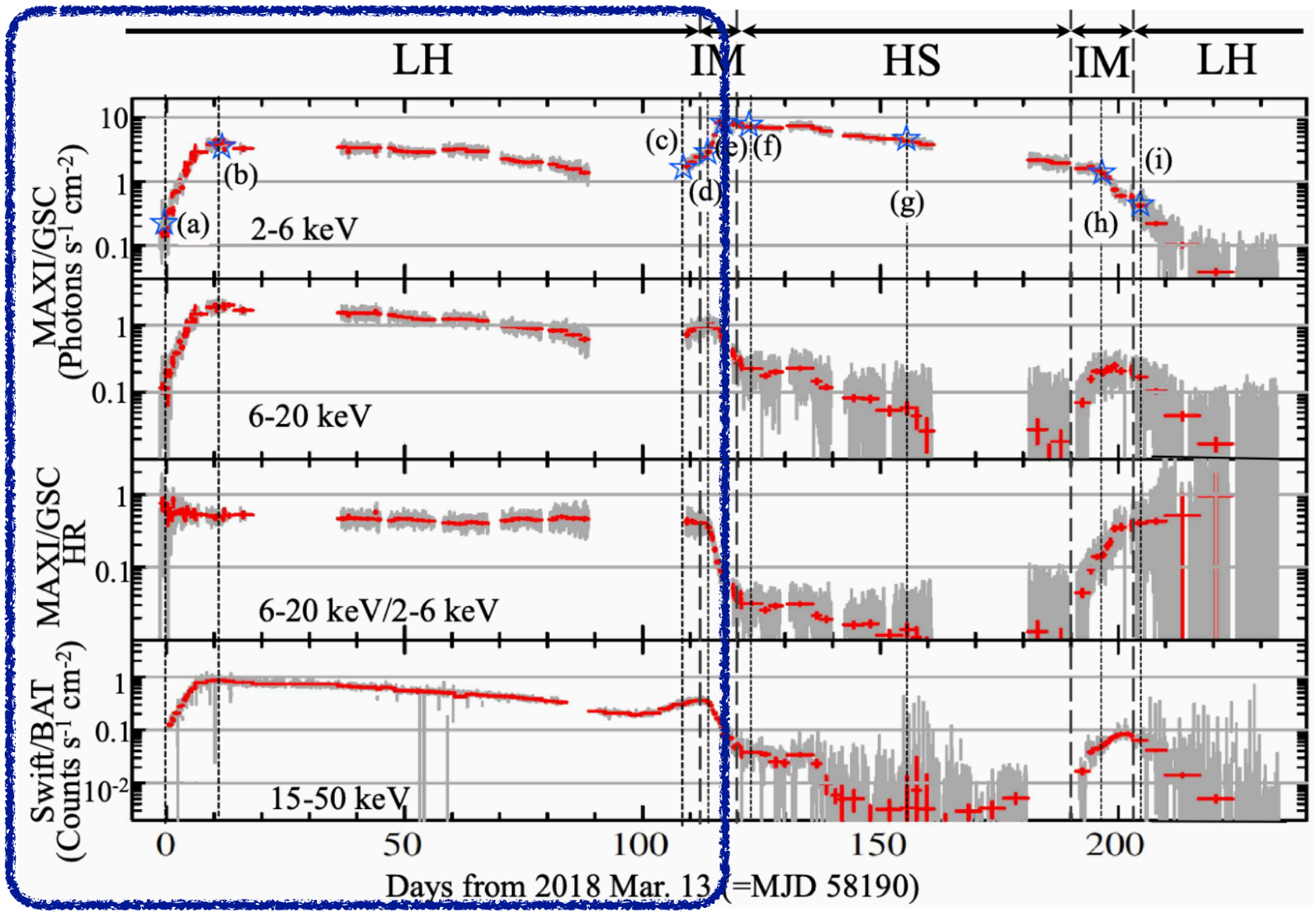
Pre-stage (This talk)

- **Publish previously obtained data**
- **Formulate strategy**

Data analyses of two black-hole binaries

(Kimura et al. 2025, PASJ, 77, 61; Otsuka et al. in prep.)

MAXI J1820+070 = ASASSN-18ey



(Shidatsu et al. 2019)

- Entered an outburst in 2018
- Very bright during outburst in X-ray (10^{-7} ergs/s/cm^2) and optical (12 mag)
- **The hard state lasted for ~100 days !**

↓

Best target for studying sub-second variability.

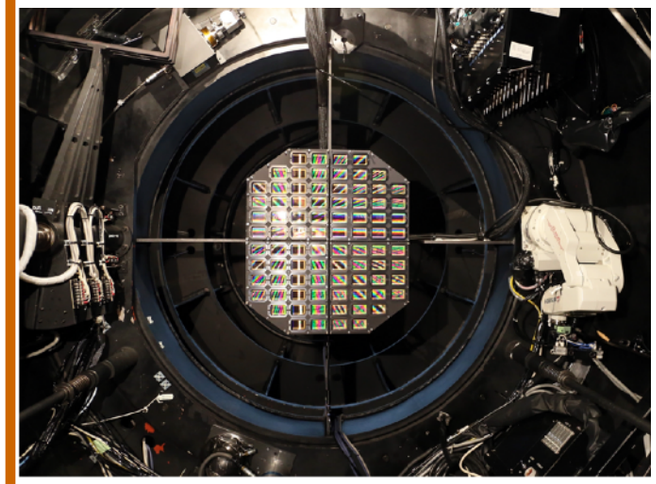
We obtained NICER (X-ray) & Tomo-e Gozen (Optical) light curves.

Observations

NICER (X-ray)

- 0.2—12.0 keV
- High time resolution (Absolute timing precision of < 300 ns)
- Mount on ISS
- Long-term monitoring
- Large effective area: ~1900 cm^2 at 1.5 keV

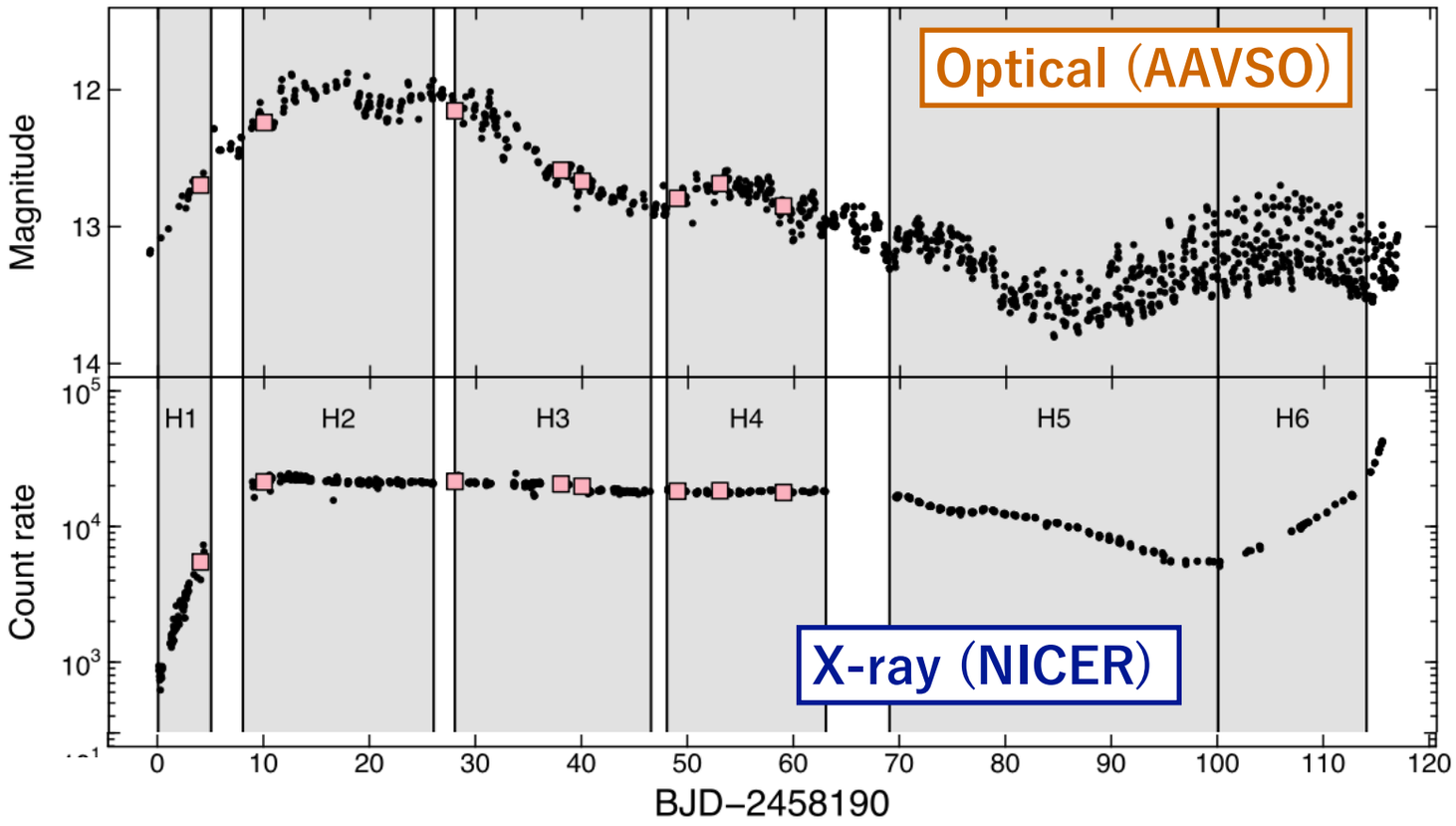
Tomo-e Gozen (Optical)

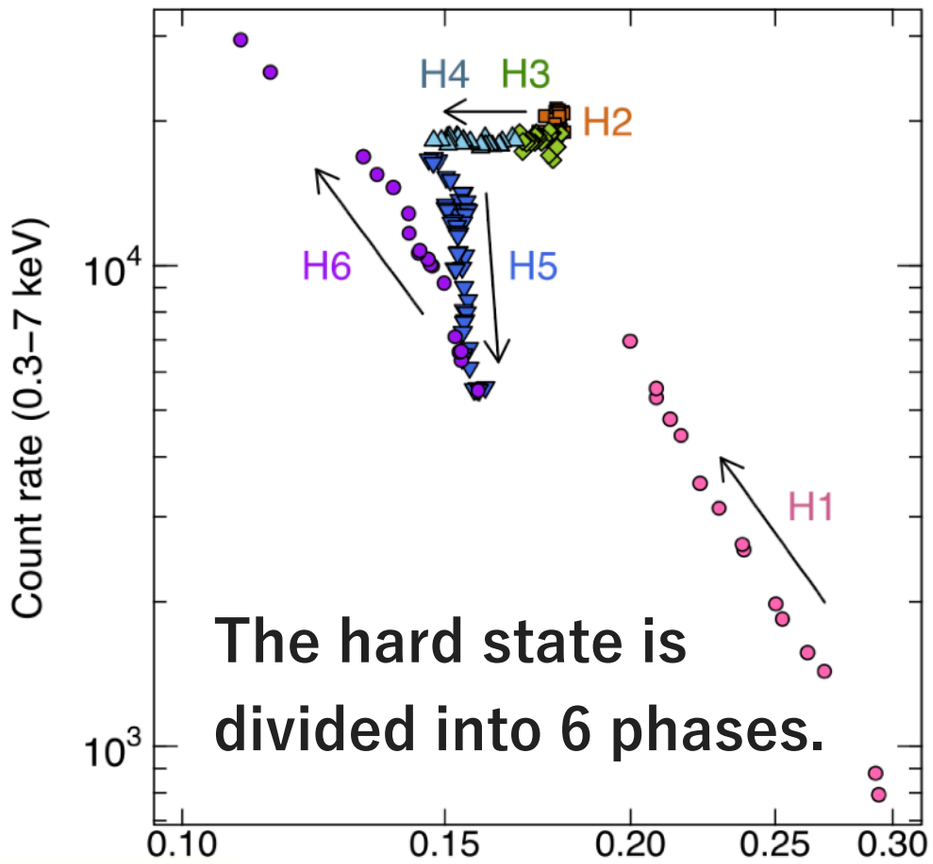


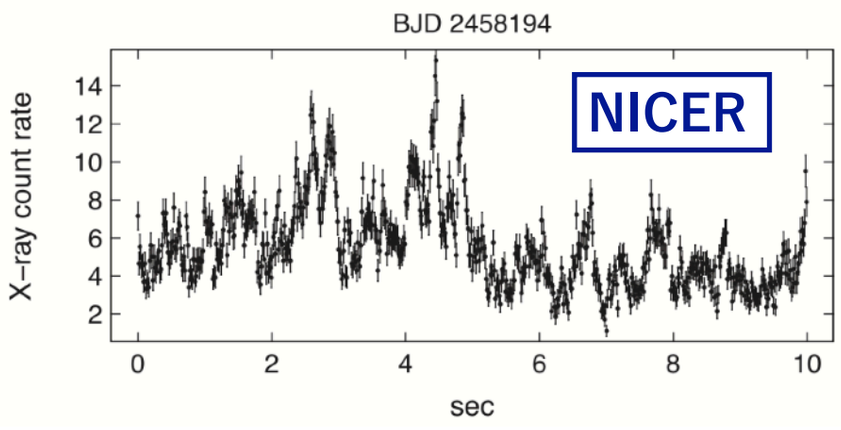
- 400—700 nm
- Absolute time accuracy of 0.2 ms
- Mount on the 1.05-m Kiso Schmidt telescope
- Wide-field video survey (2 fps with a FOV of 20 deg^2 with 84 chips of CMOS)
- **160 fps (max)** in partial-frame

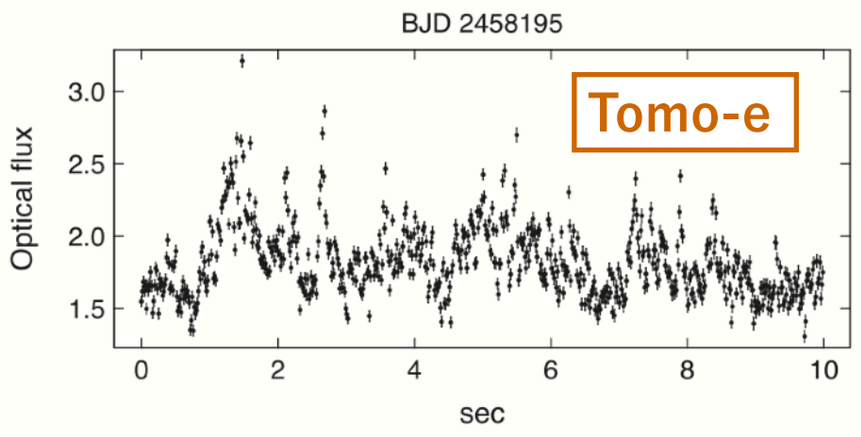
- NICER monitored MAXI J1820+070 during the 2018 outburst.
- We observed MAXI J1820+070 by Tomo-e Gozen with 67 fps on 8 days. (Not completely simultaneously, but on the same date as observed by NICER)

Overall light curves during the hard state









- We detected sub-second variability in X-ray and optical.

Method of shot analyses

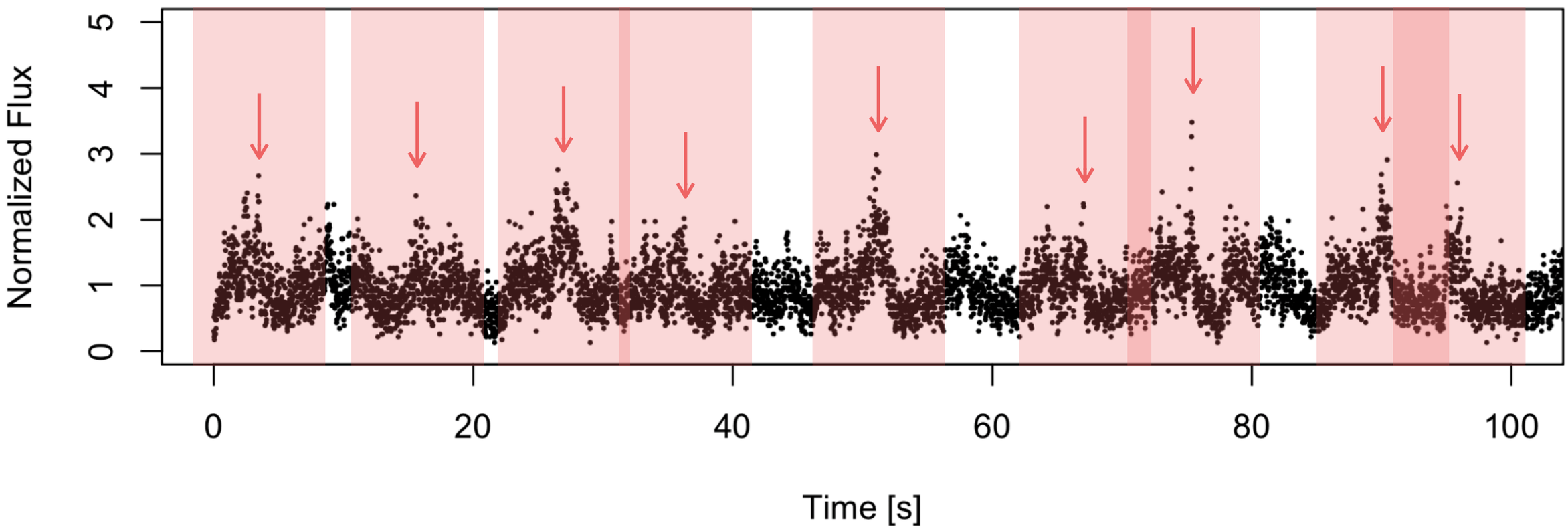
- Create an averaged flare profile (= shot) **per date** by extracting many flares from light curves and superposing them (Negoro et al. 1994).

(1) Determine the time interval of flares (2*t_int)

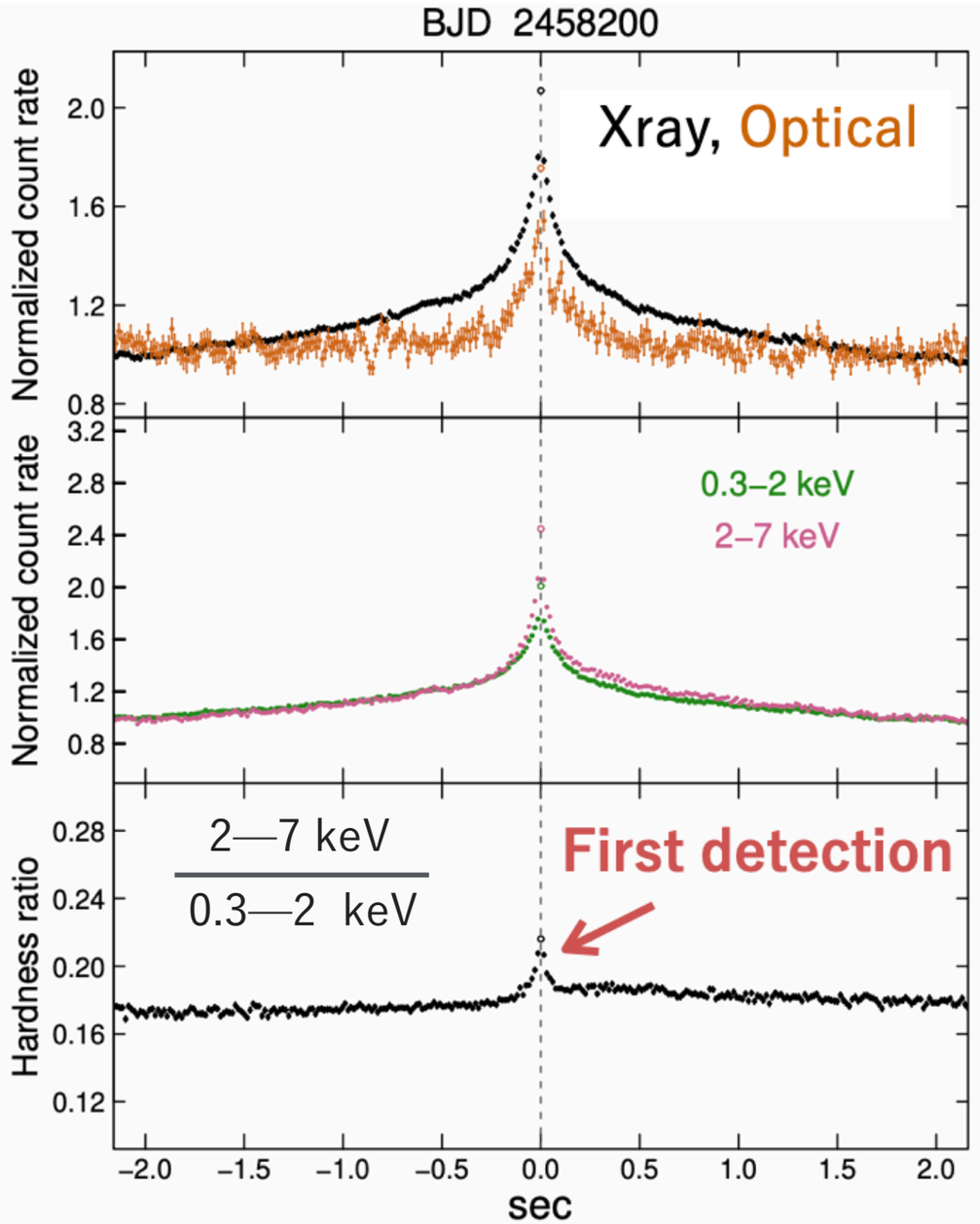
(2) Search the time of maximum flux (t_p) in a window with the length of t_int by shifting the window

(3) Extract the light curve in $t_p - t_{int} < t < t_p + t_{int}$

(4) Superpose flares by centering them with t_p and take averaged flux in each time bin.



X-ray & optical shot profiles per date



- X-ray flares had a duration of ~0.2 s.
- Optical flares were narrower than X-ray flares.
- The spectrum became harder after the flare.
- **The abrubt increase of the hardness at the center of flares was detected for the first time !**

- The shot properties changed with time (see Kimura+25 for the detail).

Origin of X-ray flares

- The flare amplitude was the largest at the onset of the outburst.
- Flares faded at the hard-to-soft spectral transition.

→ **The source is “hot corona” (ADAF-like region).**

- There are two timescales:

(1) >1 s: Fading tail of flares & spectral hardening after the fading of flares

(2) ~0.2 s: Steep flaring & accompanied abrupt spectral hardening

→ (1) **Viscous timescale at the inner disk edge**

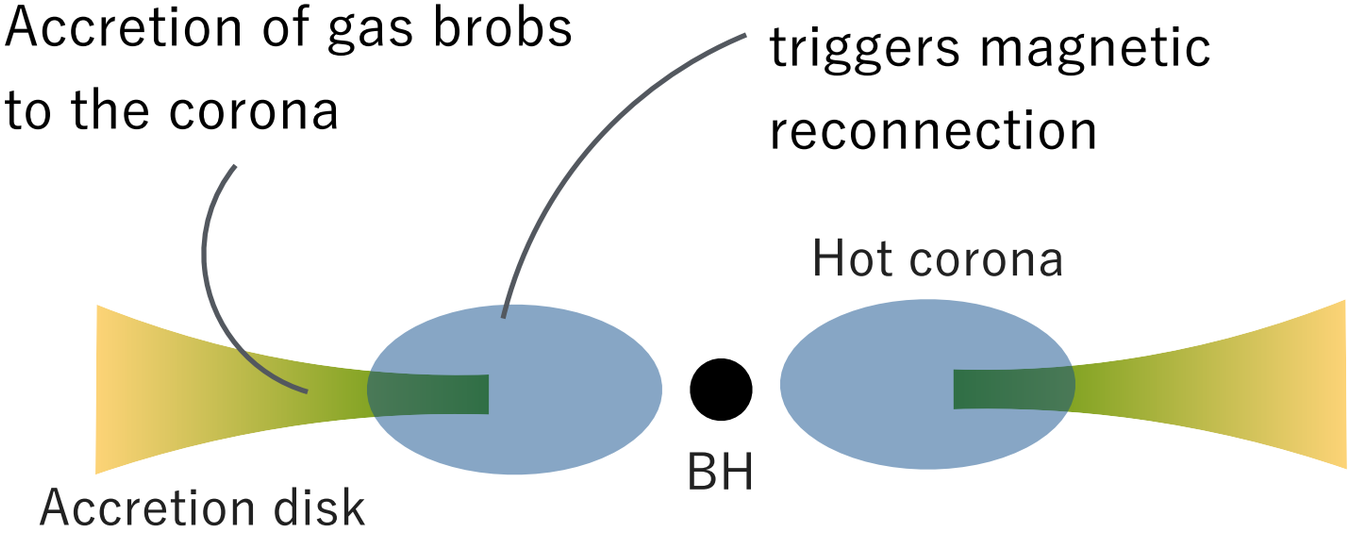
(2) **Dynamical timescale**

Amplifying hard X-ray emission !

Hot electrons and protons

Deposited energy triggers magnetic reconnection

Accretion of gas brobs to the corona



Magnetic activity is the key ?

(Machida & Matsumoto 2003; Mineshige et al. 1994)

Origin of optical flares

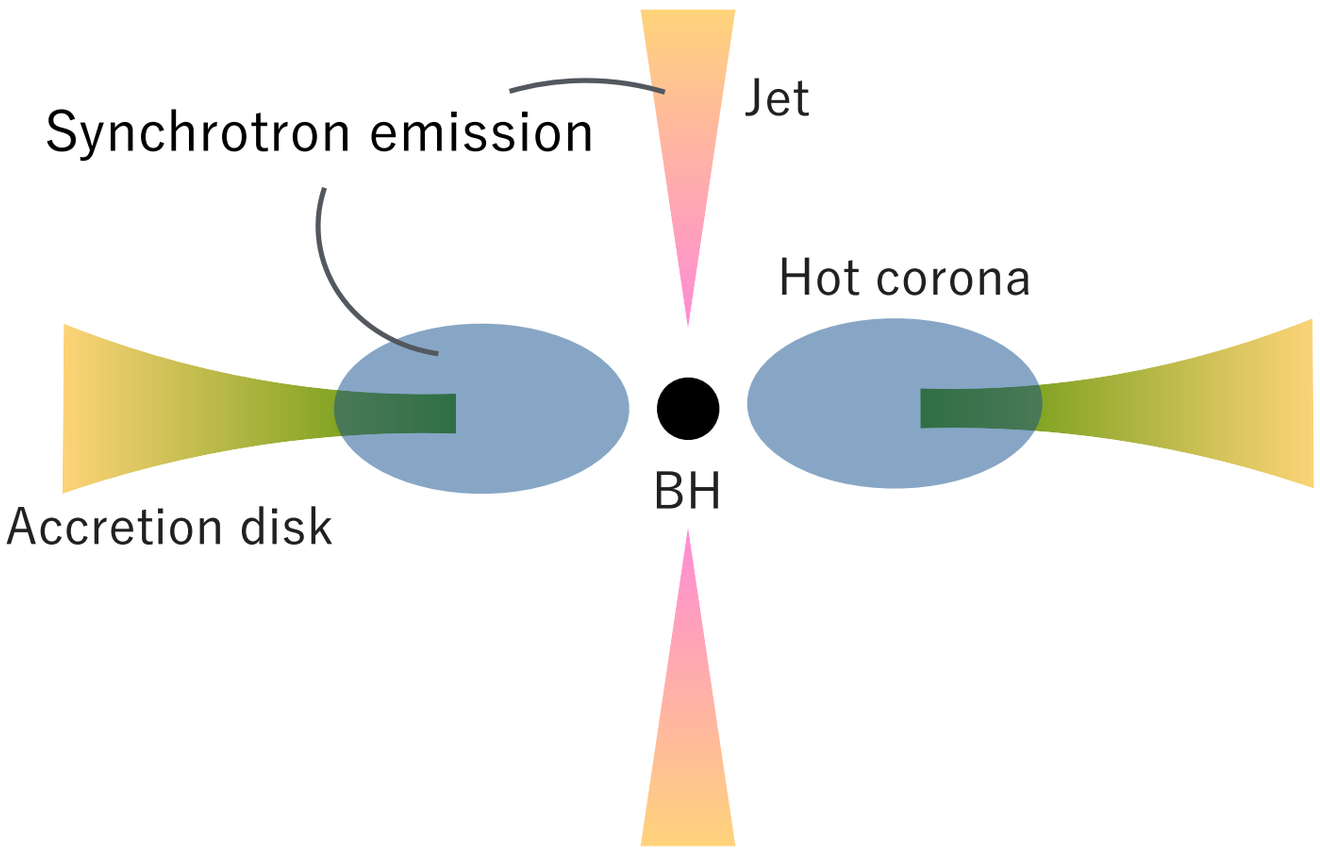
- Optical shots were narrower than X-ray shots.

→ ✕ X-ray reprocessing

○ **Synchrotron emission**

- Different time evolution between X-ray and optical shots.

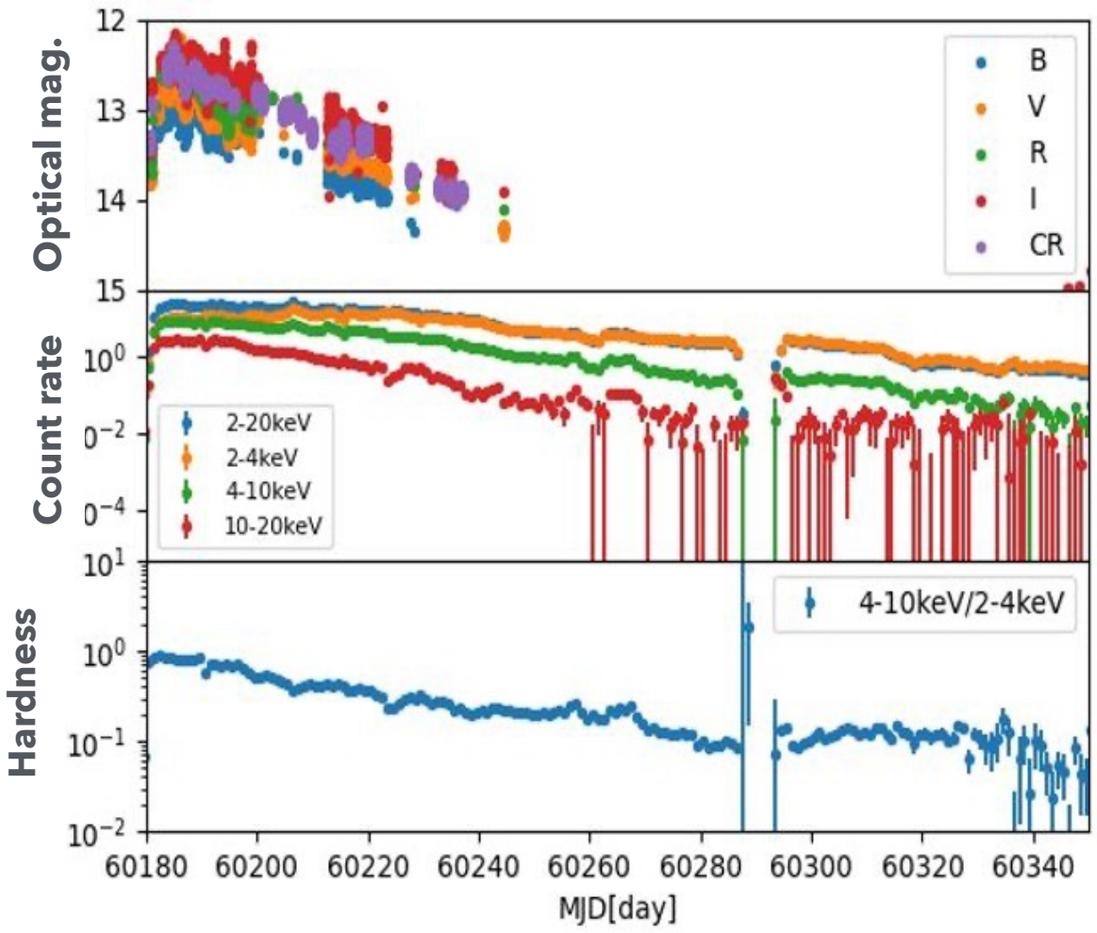
→ **Not only the emission from the hot corona but also the emission from the jet are related to the variability.**



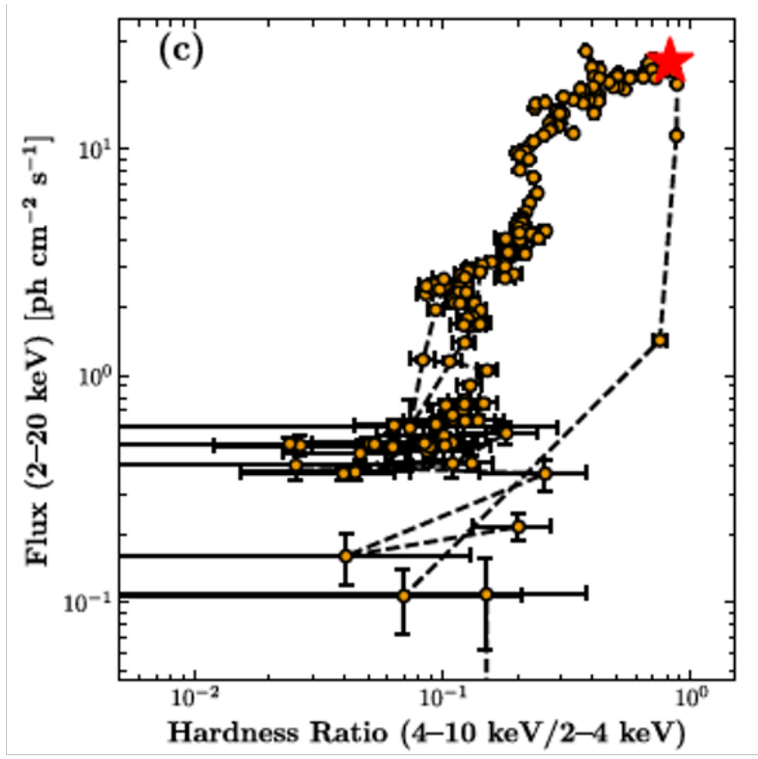
However, we missed the strong evidence of synchrotron emission. (No completely simultaneous data & multiwavelength SED)

(Kanbach et al. 2001; Veledina et al. 2011)

Swift J1727.8-1613 (My student Otsuka-kun's work)



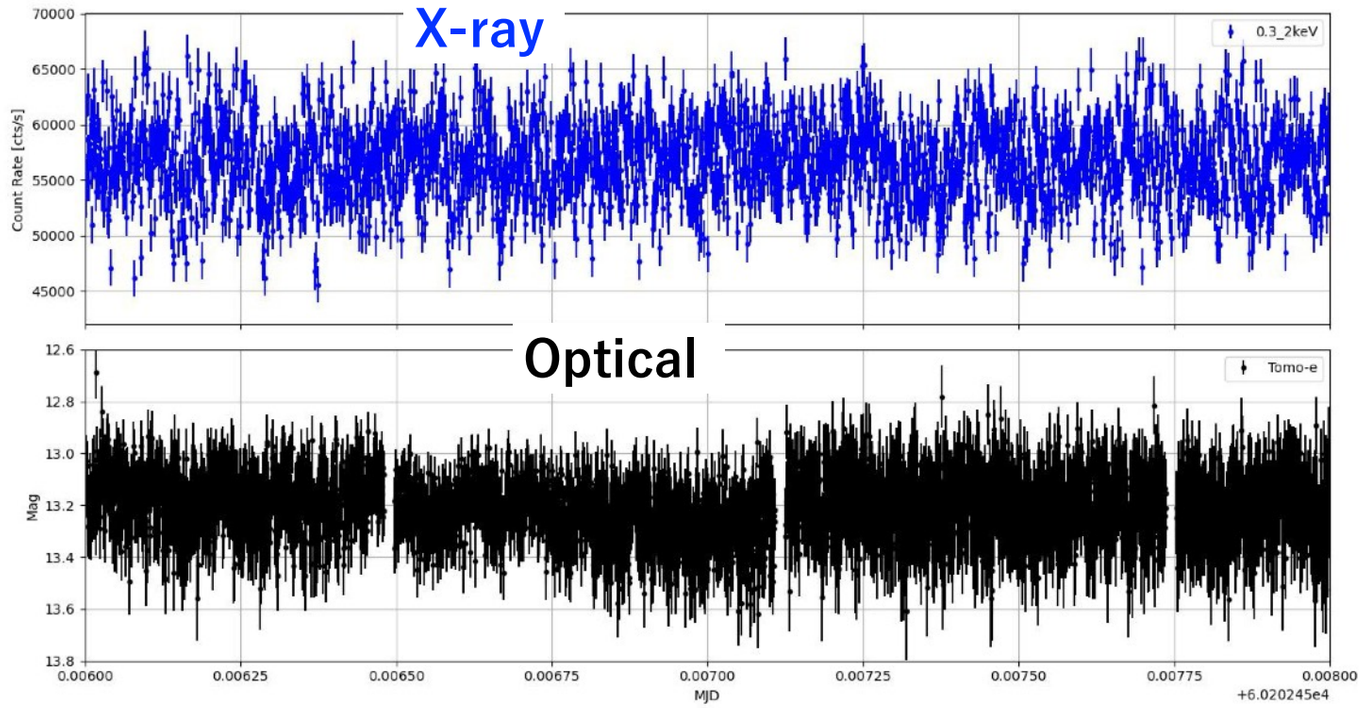
(Shui et al. 2024)



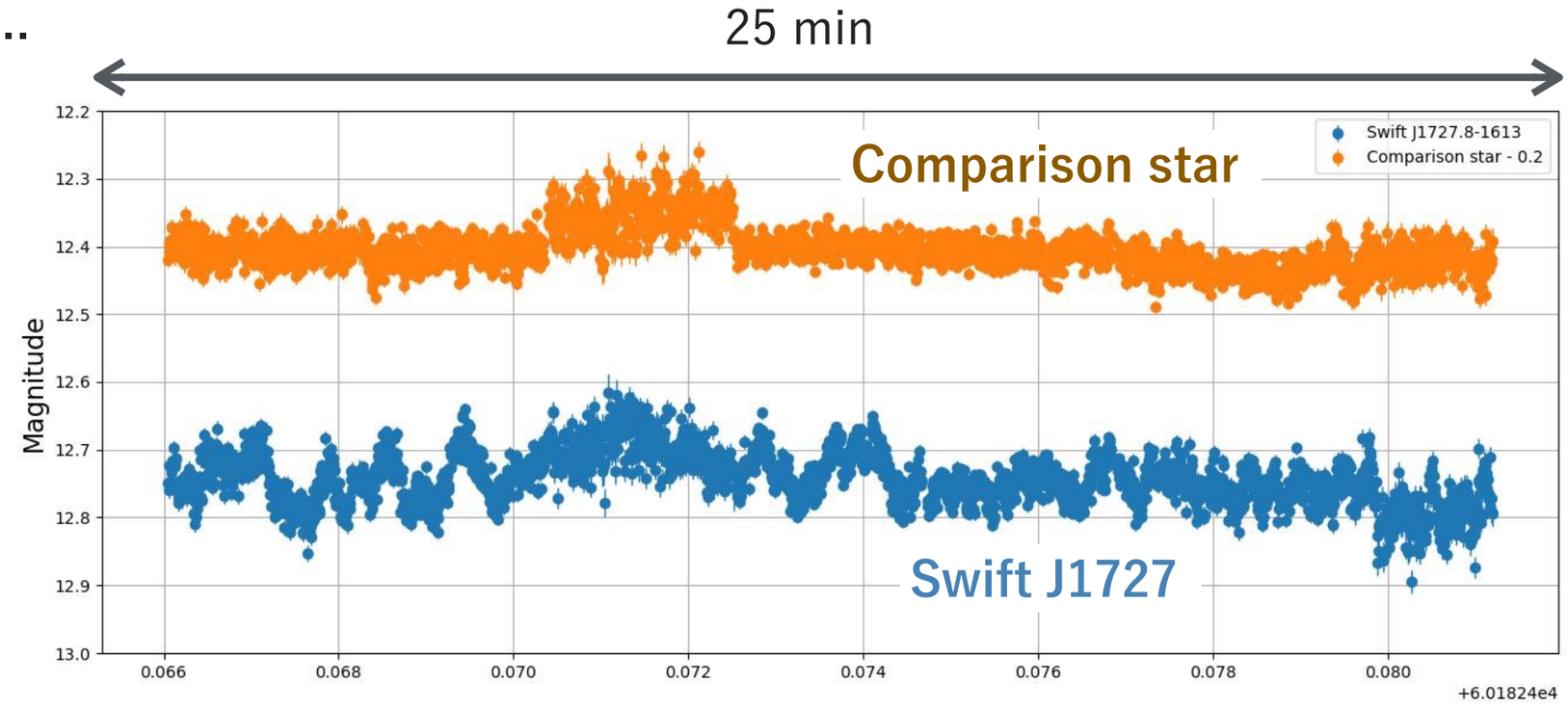
- Entered an outburst in 2023
- Very bright during outburst in X-ray (3 x 10^{-8} ergs/s/cm^2) and optical (12 mag)
- **Failed outbursts ?**
- **We obtained Tomo-e Gozen & TriCCS data at the early phase.**

Simultaneous X-ray & optical observations ?

- We successfully obtained NICER & Tomoe-Gozen simultaneously observed light curve ! However, no significant variations in optical..



- We detected rare optical variations on minute scales from TriCCS data, but no simultaneous X-ray data..



Towards automatic observations

Dr. Maehara developed the automete observing system !

Seimei Automated Observing SYSTEM

obs_id	object	R.A.	Decl.	Inst.(exp_id)	Start (UT)	End (UT)	Priority	flg_done
NO DATA								

KOOLS obs. request form TriCCS obs. request form

Purchased the cloud sensor -> better weather focasts !

I'm now developing an alert system.

(Email the information of the object name, coordinates, and brighteness)

```
=== ATel ===
ATel 17491: EP251020a: Einstein Probe detection of an X-ray transient associated with the galaxy nucleus of LEDA 962438
https://www.astronomerstelegram.org/?read=17491
Candidates: ['EP251020a']
Coordinates: RA 2:17:31.20, Dec -11:44:45.60
[Brightness]
Optical:
  None
X-ray:
  None
Radio:
  None
```

Summary

- To identify the physical mechanism of subsecond variability in black-hole systems, we need multi-messenger/multi-wavelength data.
- We are planning to establish automatic observations of high-energy transients on Seimei telescope at Okayama Observatory.
- Shot analyses are useful for investigating the detailed properties of X-ray and optical flares; however, we still need light curves that are completely simultaneously observed in X-rays and optical.
- My student is analyzing multi-wavelength data of Swift J1727. Perhaps HXMT took observations completely simultaneously with TriCCS ??
- The cloud sensor has been delivered, and we are currently developing alert systems.

Please email to mariko-kimura@se.kanazawa-u.ac.jp if you have questions or comments !

Thank you very much for your attention !