The third annual conference
of Multimessenger Astrophysics
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EHIME UNIVERSITY

X-ray spectroscopy of accretion disk & jets in Galactic microquasars

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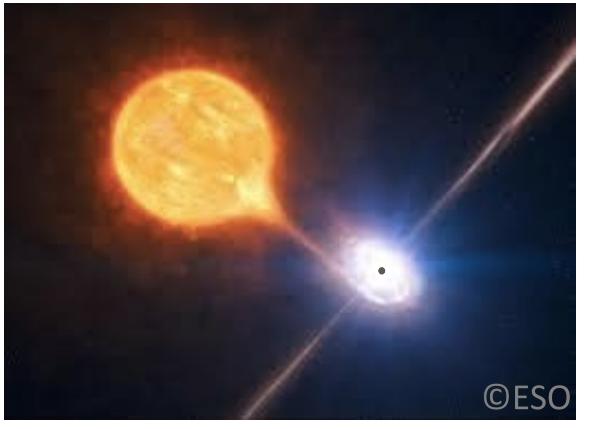

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Chris Done, Maxime Parra, Yoshihiro Ueda,
Toshihiro Takagi, Miyu Uenishi, Marina Yoshimoto,
and more…

Outline

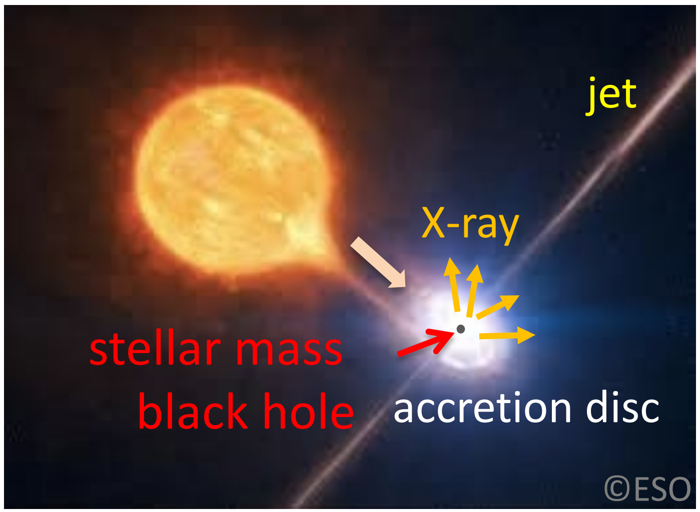
1. Broad-band X-ray spectroscopy of accretion flows in Galactic microquasars

2. XRISM High-resolution X-ray spectroscopy of the microquasar SS 433: Ni production in the vicinity of the compact object?

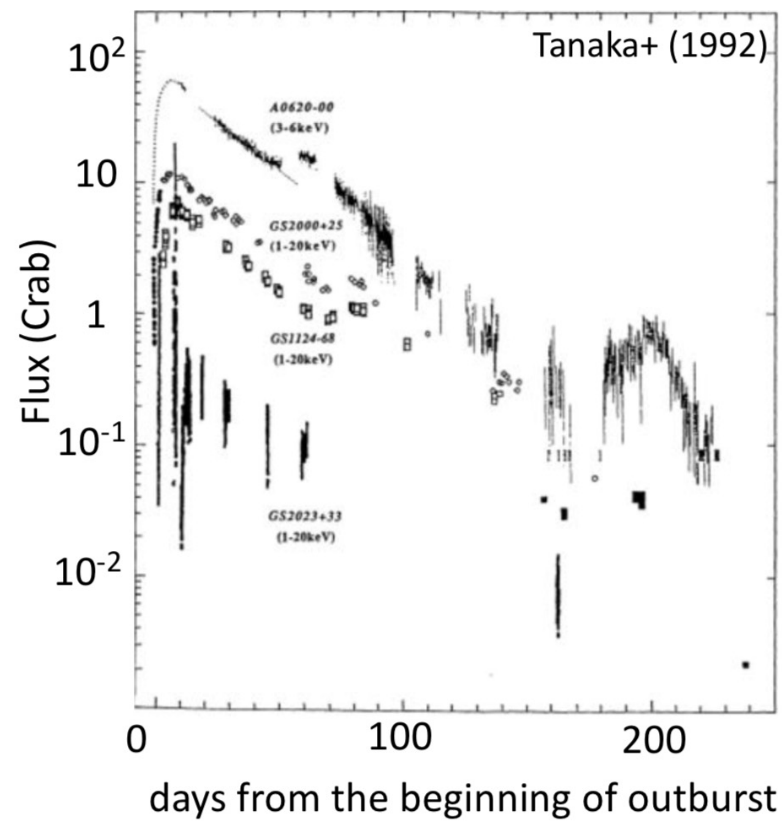
XRISM

c: JAXA

Microquasars (X-ray binaries with jets)



light curves of BH X-ray binaries



Most sources found so far are transients,
increasing the X-ray flux
by ~several orders of magnitude
in their outbursts

Best laboratories to study the evolution of black hole accretion flows and outflows over a wide range of mass accretion rates

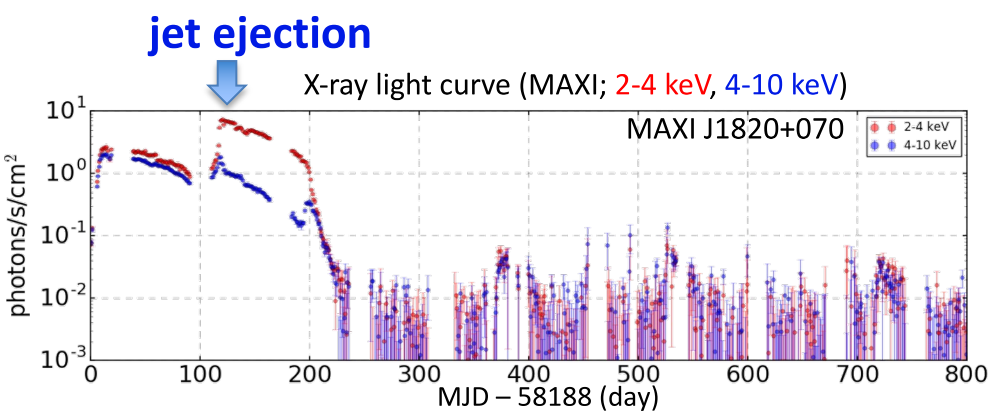
Also important in terms of particle acceleration

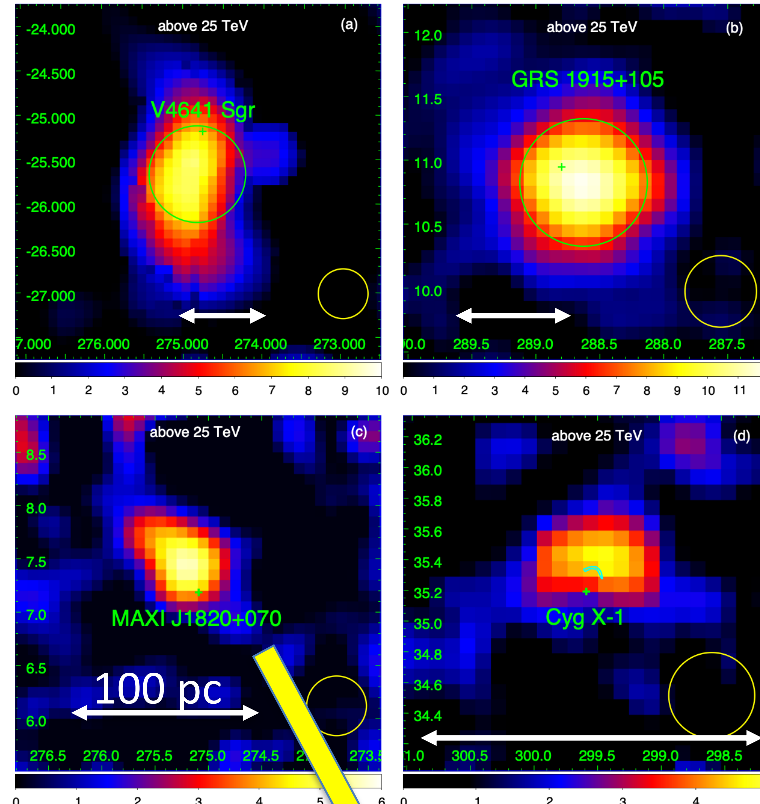
BH X-ray binaries with jets (microquasars) are ultra-high-energy gamma-ray emitter?

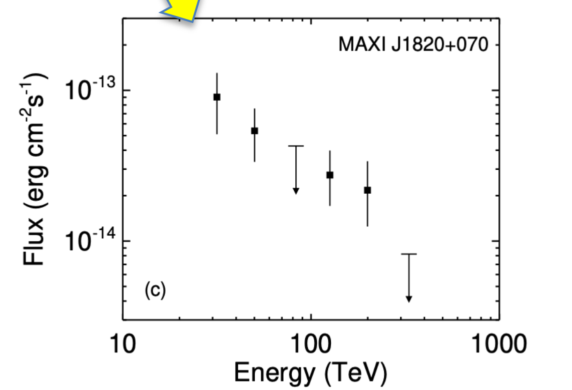
LHAASO and HAWC detected extended (~10-100 pc) ultra-high-energy (1-100 TeV) diffuse emission around several microquasars.
→ Efficient producers of PeV cosmic rays ?

But...

Relativistic large-scale jets are only seen in a very limited period.
Can they provide the large-scale high energy gamma-ray structure??





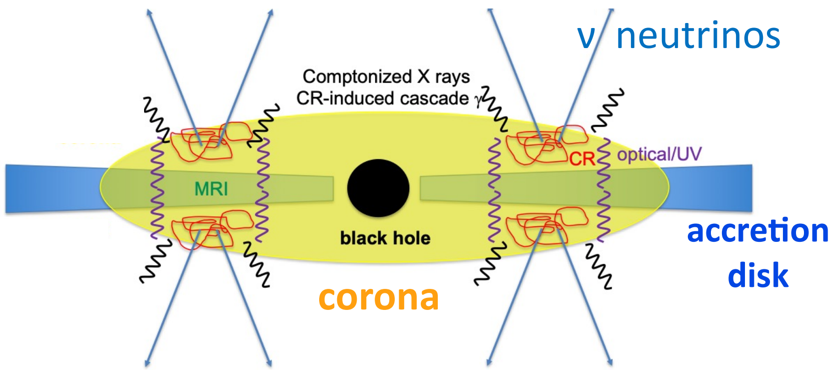


LHAASO Collaboration (2024)

How much energy is produced from the central source?
X-ray studies are important!

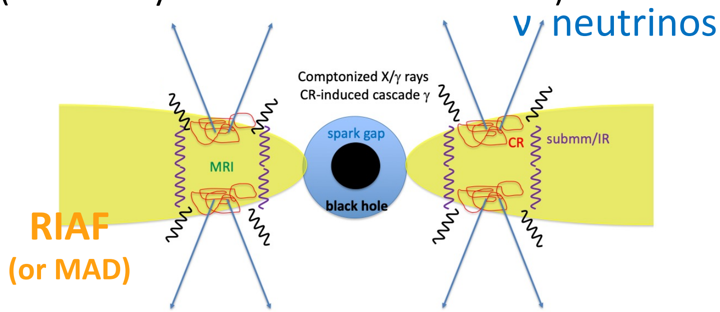
Hot plasma around BH as a source of high energy neutrino

accretion disk corona



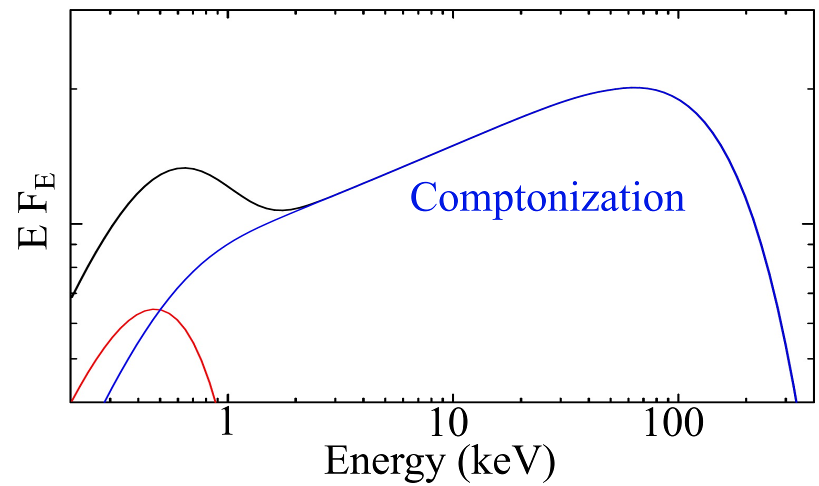
CR: Cosmic ray
MRI: magneto rotational instability

RIAF
(radiatively inefficient accretion flow)



Murase & Stecker 2022

Essential parameters of hot plasma (such as the T, τ, size) can be determined from broad-band X-ray spectra



Compared with AGN, microquasars:

- are located much closer to us and become very bright in X-rays

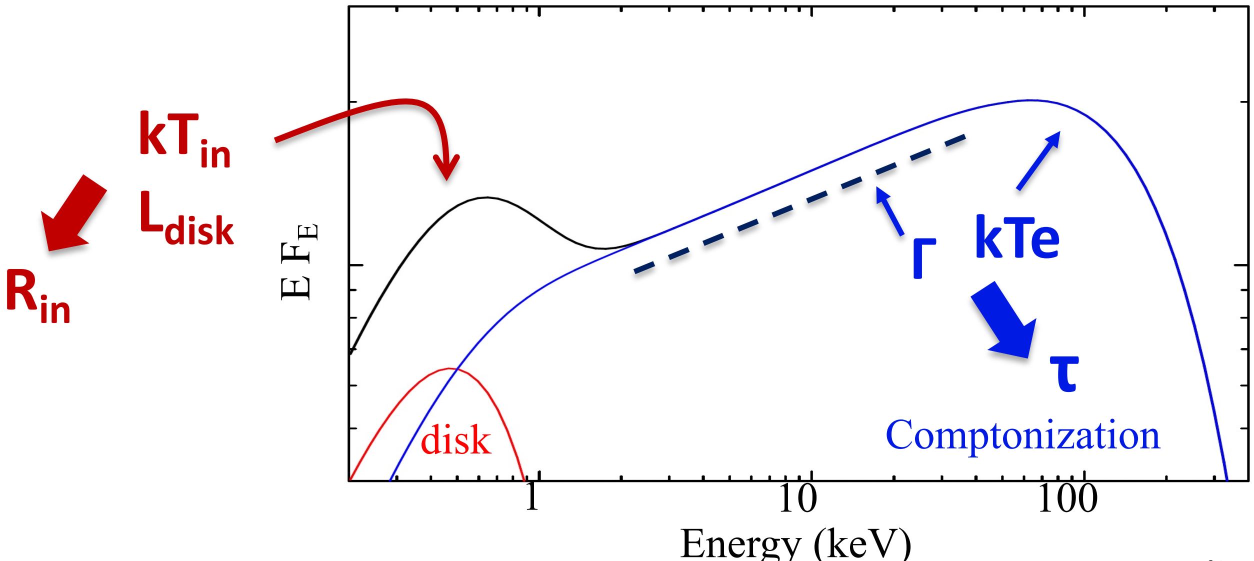
→ **We can get data with very good statistics!**

- vary Lx on much shorter time scales

→ **We can probe the evolution of hot plasma over a wide range of mass accretion rate**

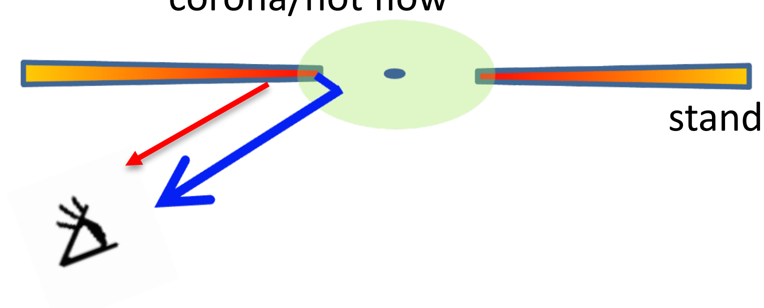
Broad-band X-ray spectrum in microquasars

Essential parameters of hot plasma (such as the T, τ, size) can be determined from broad-band X-ray spectra

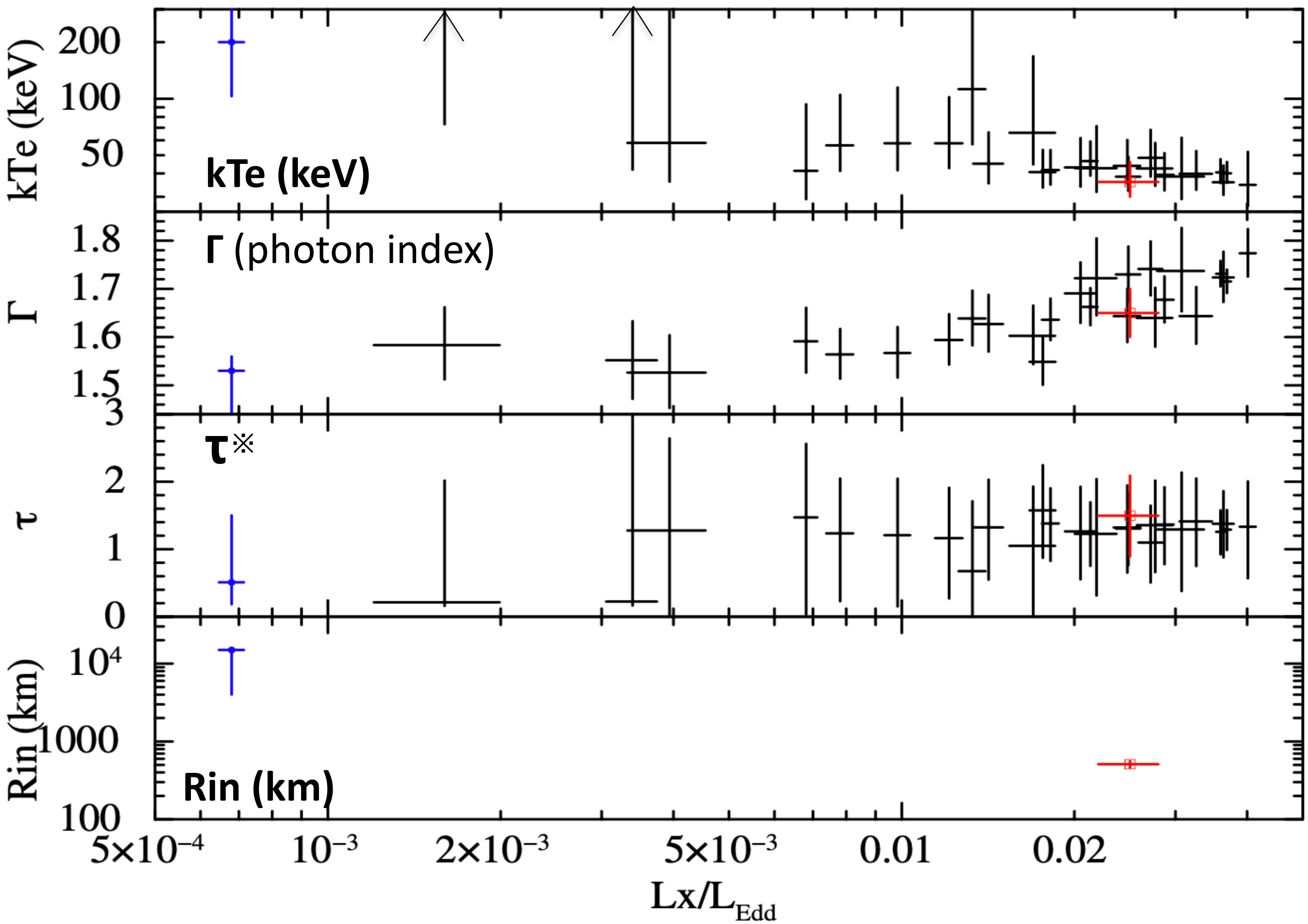


Compton y
$= 4\, kT_e/m_ec^2 * \max(\tau, \tau^2)$

(low/hard state)



Evolution of the plasma properties with Lx

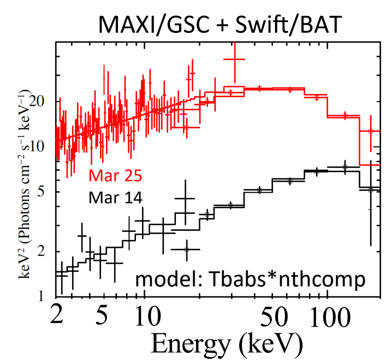


+ MAXI/GSC + Swift/BAT(survey)

+ Swift/XRT + Swift/BAT(event)

+ Swift/XRT + INTEGRAL/IBIS-ISGRI + optical + UV

※ spherical geometry is assumed



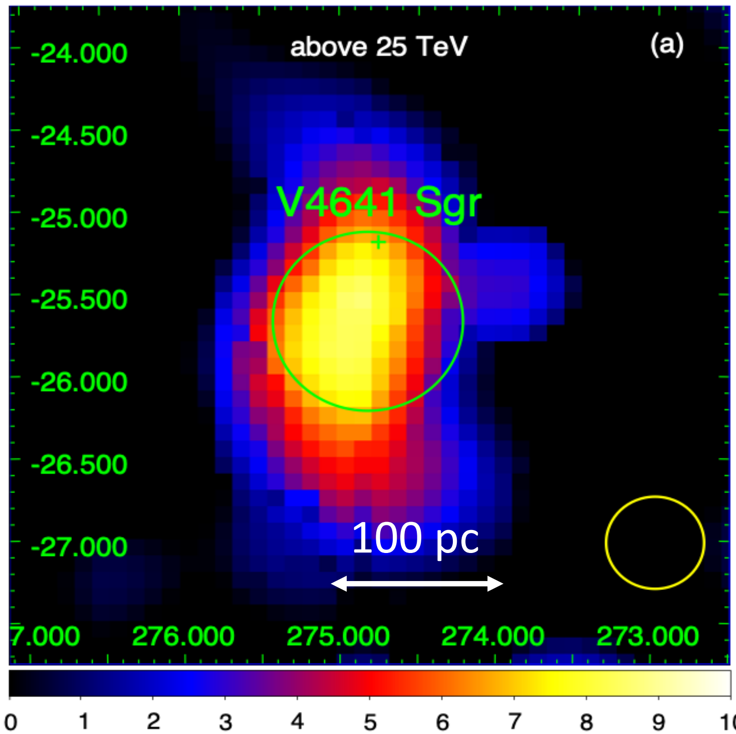
MAXI J1820+070, hard state in 2018-2019

(Shidatsu+ 2018, 2019, Yoshitake & Shidatsu+ 2022, 2024, Özbey Arabacı+ 2022)

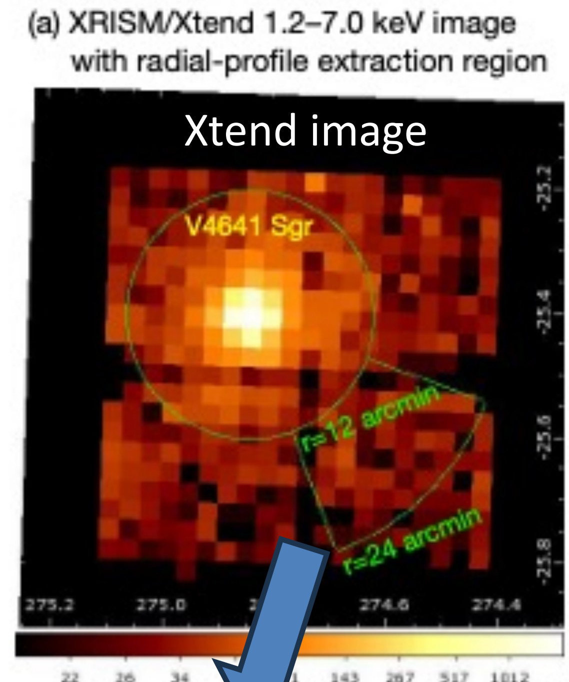
See Samuel's poster for the AGN NGC 4151

Diffuse X-ray emission
around microquasar V4641 Sgr

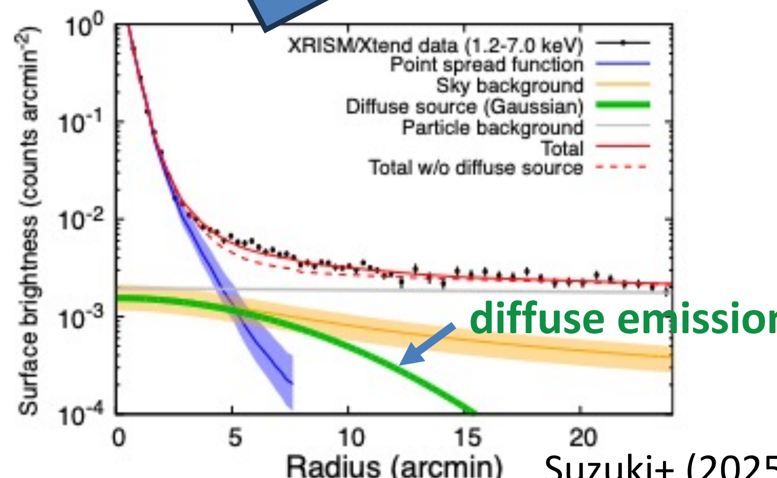
X-ray (XRISM/Xtend)



Ultra high energy (>1 TeV) gamma-rays have been detected (LHASSO Collaboration 2024, Nature)



exposure ~10 ks



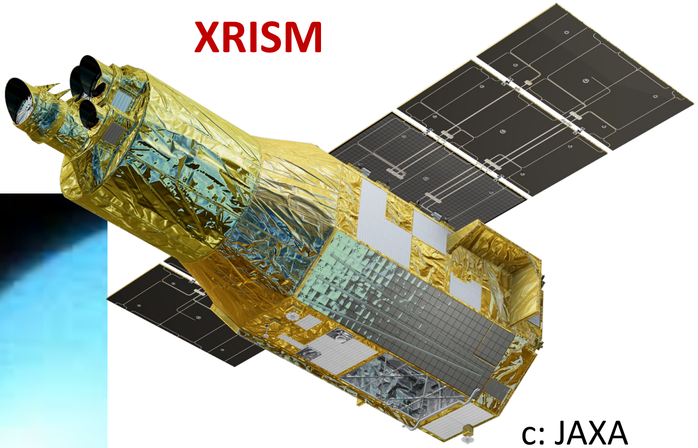
Suzuki+ (2025)

Extended X-ray emission was detected using XRISM's wide-field X-ray CCD Xtend!

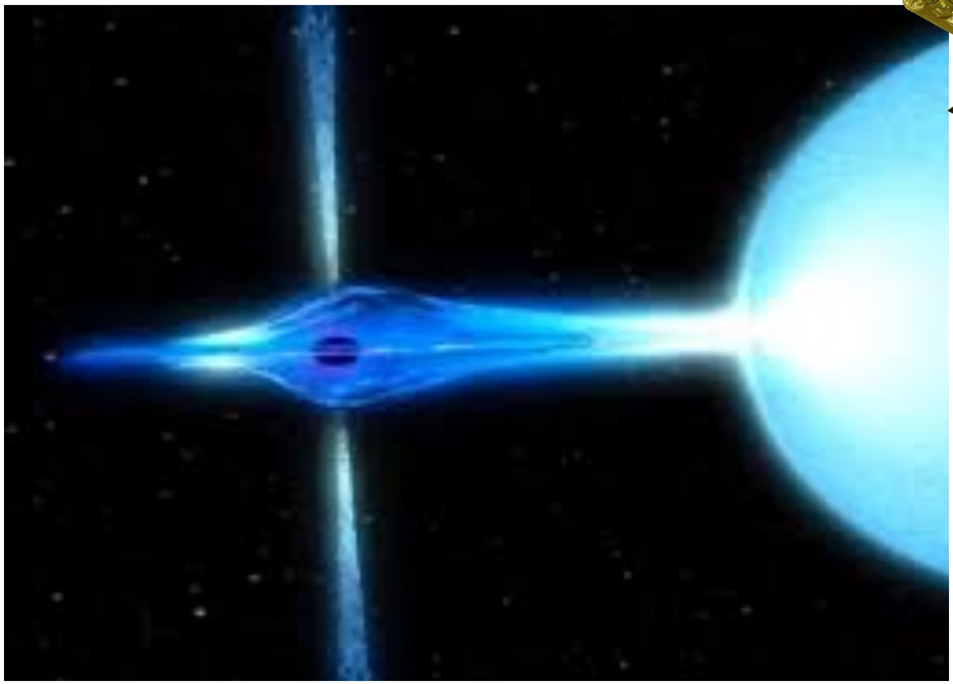
- further NuSTAR + XMM observations (PI: K. Mori)
- XRISM/Xtend observations of other sources:
  SS 433 (Suzuki+ in prep), GRS 1758-258 (AO-2) etc.

2. High-resolution X-ray spectroscopy of SS 433

XRISM



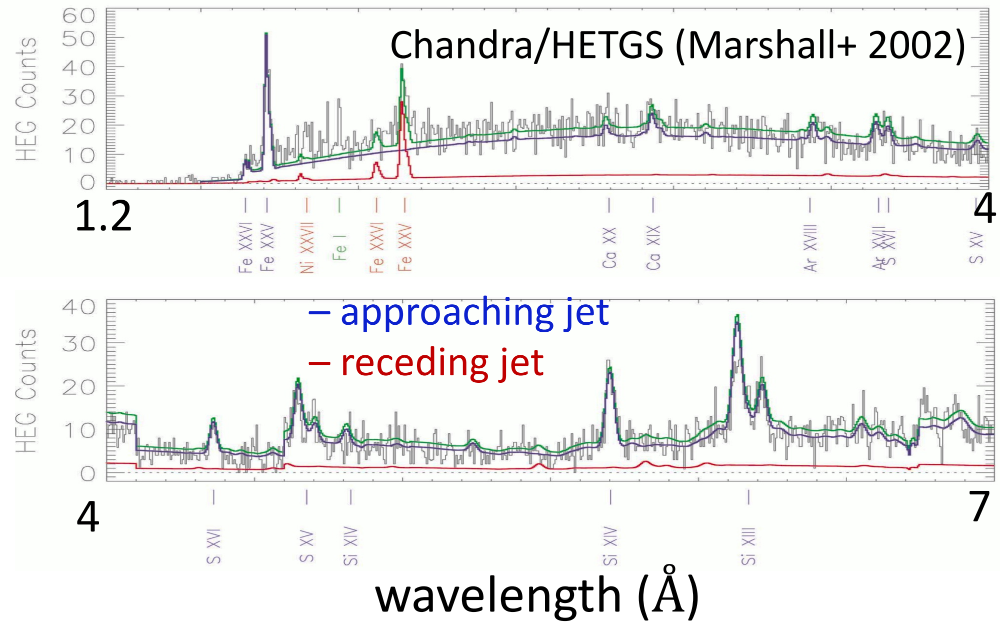
c: JAXA



SS 433

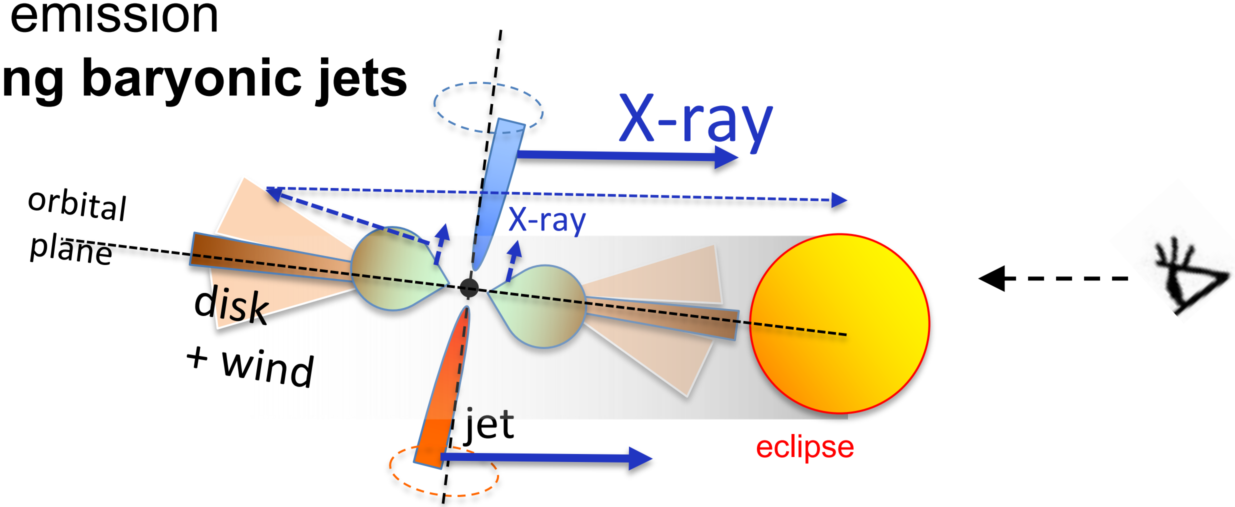
a unique Galactic microquasar with

- persistent supercritical accretion (L_{UV} ~ 1e40 erg/s)
- persistent bipolar baryonic jets with a ~162-day precession and nodding motions



high inclination angle (~78 deg)
-> inner disk is obscured

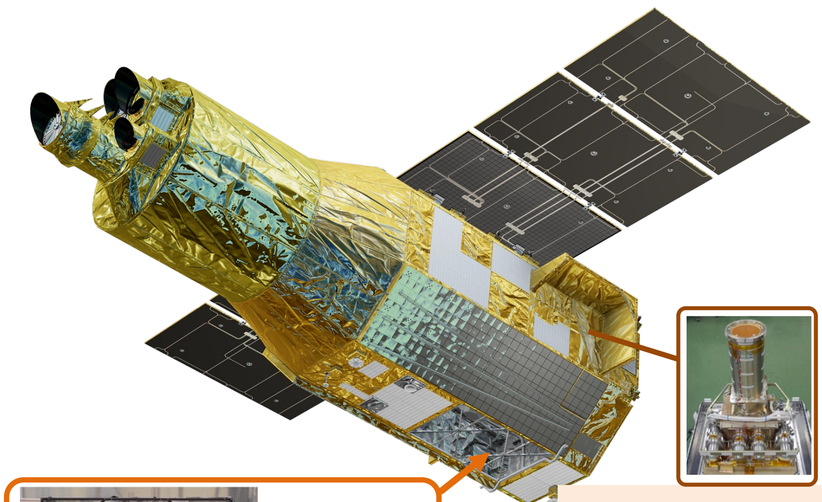
the X-ray spectrum is dominated by thin thermal plasma emission from **bipolar, precessing baryonic jets**



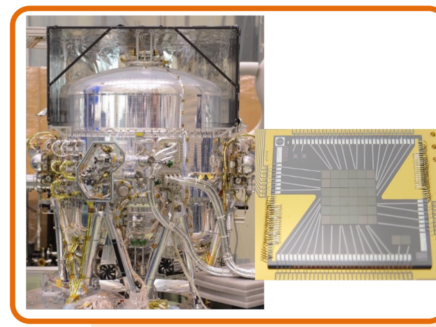
XRISM X-Ray Imaging and Spectroscopy Mission

official website (for researchers)
https://xrism.isas.jaxa.jp/research

2023 Sept. 7 Launch success!
2024 Feb. 8 Commissioning completed
→ PV obs. started
2024 late Aug. AO-1 obs. started
2025 Sep. Gate valve open operation
2025 Nov. AO-2 obs. start



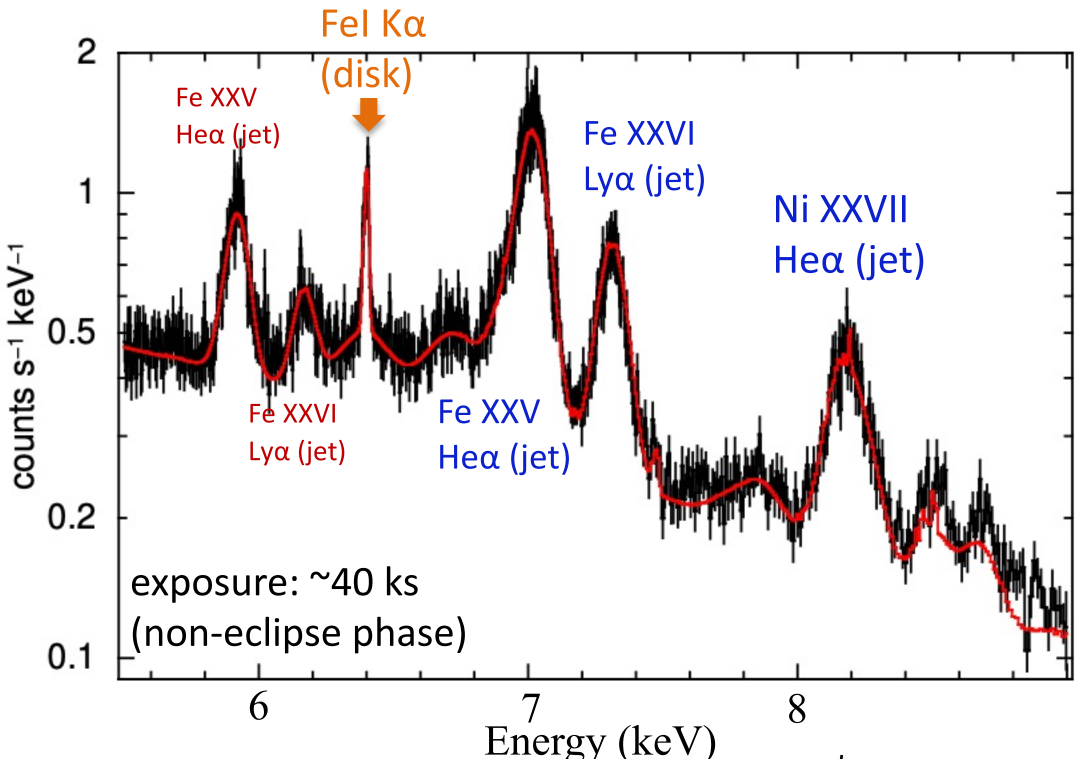
Xtend (X-ray CCD)
Energy range: 0.4-12 keV
ΔE: ~ 250 eV @ 6 keV
FoV: 38.5’ x 38.5’

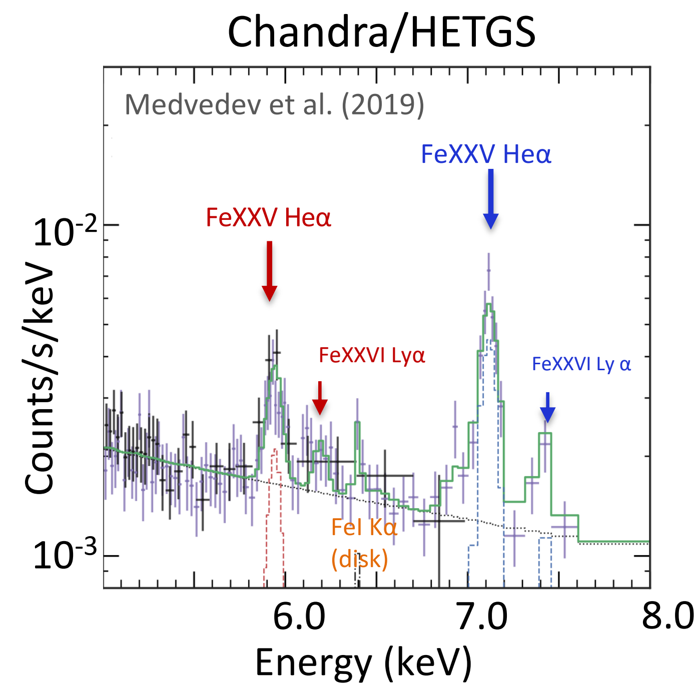


Resolve (X-ray microcalorimeter)
Energy range: 0.4 (1.7) -12 keV
ΔE ≦ 5 eV @ 6 keV
FoV: 2’.9 x 2’.9 (6 x 6 pixel)
Effective area: >=210 cm^2 @ 6 keV

10 x improvement in energy resolution and line detection sensitivity!!
-> best instrument to study line profiles

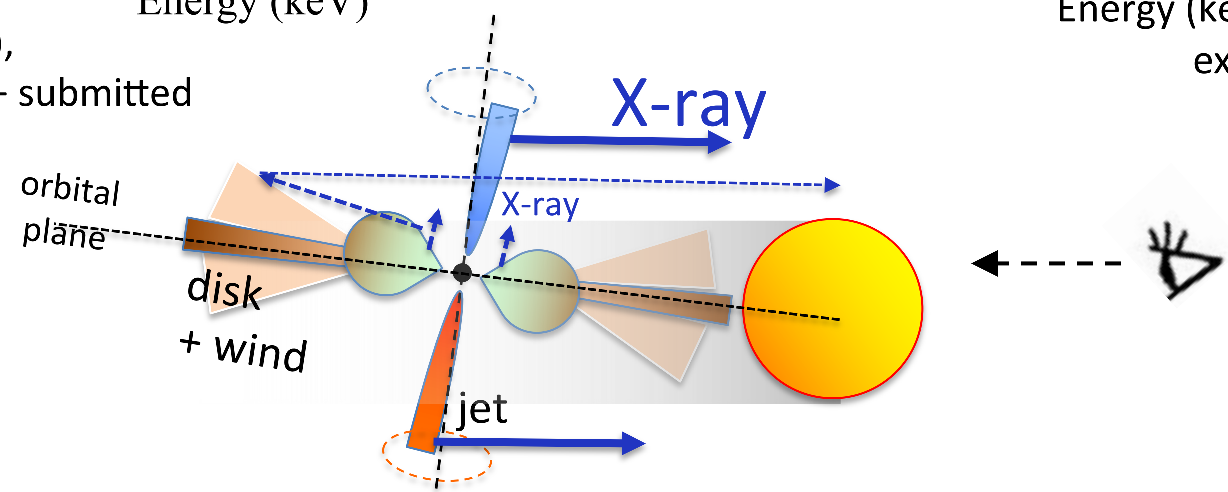
XRISM/Resolve spectrum



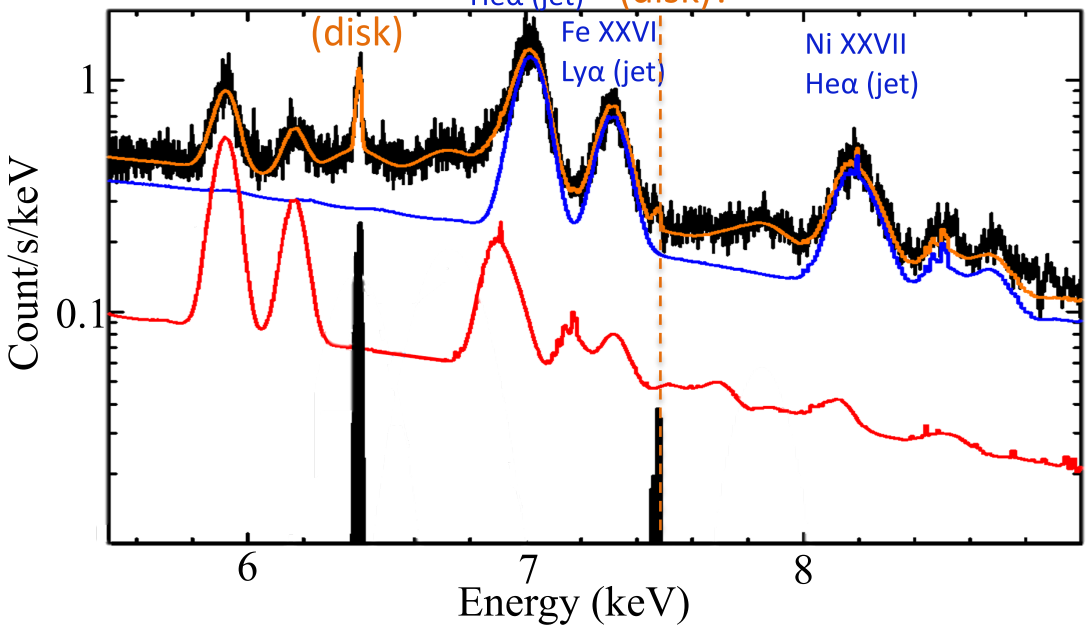


exposure ~ 40 ks

Shidatsu+ (2025),
Takagi, Shidatsu+ submitted



Ni/Fe abundance



Takagi, Shidatsu+ submitted

jet components (apec)

$$A_{\mathrm{Fe}} = 1.33^{+0.07}_{-0.08}$$
$$A_{\mathrm{Ni}} = 8.2 \pm 0.6$$
=> $A_{\mathrm{Ni}}/A_{\mathrm{Fe}} \sim 6$

neutral Fe & Ni lines (rdblur x Hölzer)

$$F_{\mathrm{NiI\ K\alpha}}/F_{\mathrm{FeI\ K\alpha}} \lesssim 0.018$$
=> $A_{\mathrm{Ni}}/A_{\mathrm{Fe}} \lesssim 3$

Note1: the same line broadening factor and shift were assumed.
Note2: $F_{\mathrm{NiI\ K\alpha}} / F_{\mathrm{FeI\ K\alpha}}$ ~ 0.05 for the solar abundance ratio (Medvedev+ 2018)

- Jet components give a **very high Ni abundance**
- **Ni/Fe abundance ratio** measured from the neutral lines is somewhat smaller than that from the jet components => nucleosynthesis in the vicinity of the compact object?? (as suggested by Medvedev+ 2018)

Further observation will be performed in the AO-2 period

Summary

- **broad-band X-ray spectroscopy** is important to get the essential information of hot accretion flow/corona (e.g., the electron temperature and the size)
- **multi-wavelength monitoring** is key to understand the energetics of accretion and outflow and their interactions as a function of the mass accretion rate
- XRISM/Resolve observation of SS 433 has revealed Ni overabundance and and possible creation of Ni around the compact object