EHIME UNIVERSITY

Multi-messenger Astrophysics through Collaboration
Among Different Observatories (MMA-CADO)
Aug. 30, 2026

XRISM Meets SS 433: Revealing the Dynamics and Propagation of the Jets

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（Ehime Univ.）

on behalf of XRISM collaboration

Collaborators:
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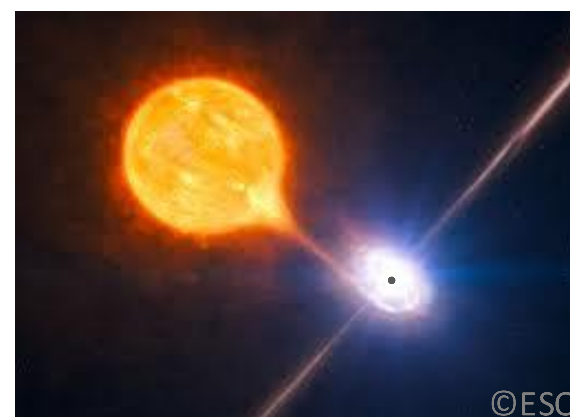
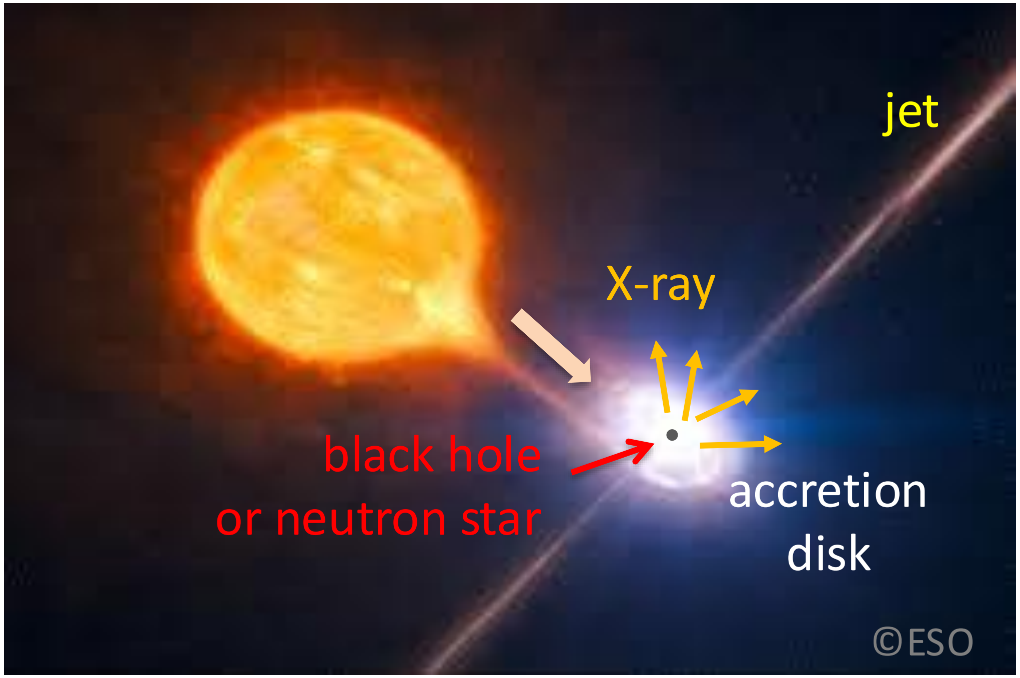
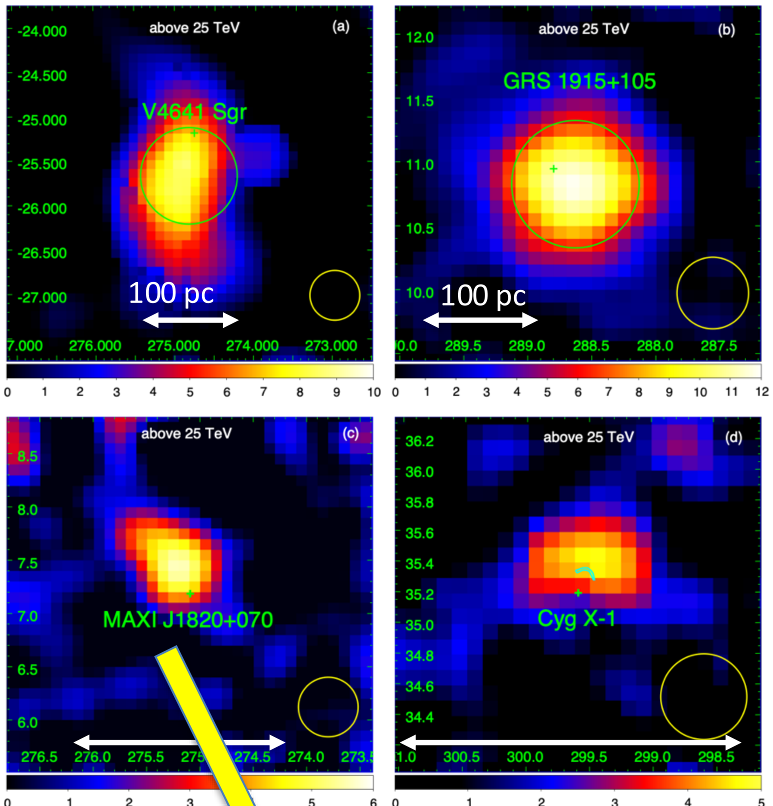


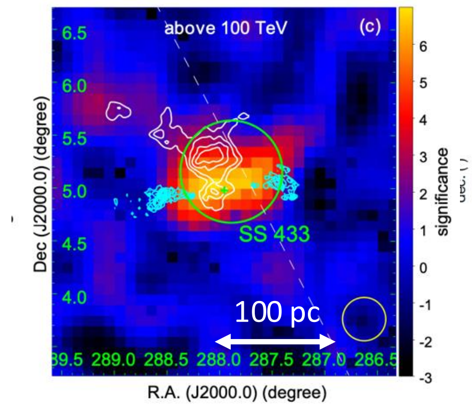
Microquasars
(= X-ray binaries with jets)



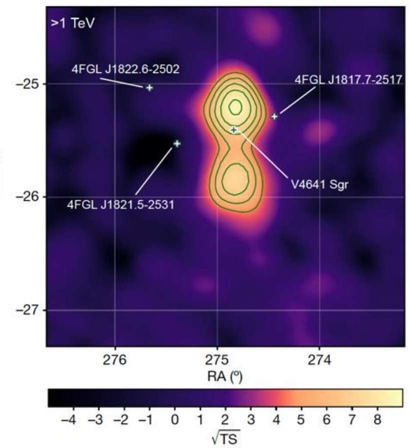
- X-ray binaries = close binary system with an accreting stellar-mass black hole (BH) or neutron star (NS) + a donor star
- Many of microquasars host a BH but some host a NS

Microquasars are efficient cosmic-ray accelerators?

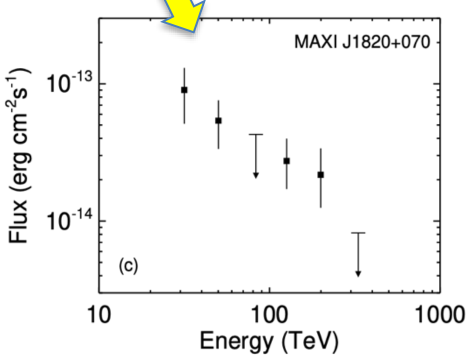




LHAASO Collaboration (2025)



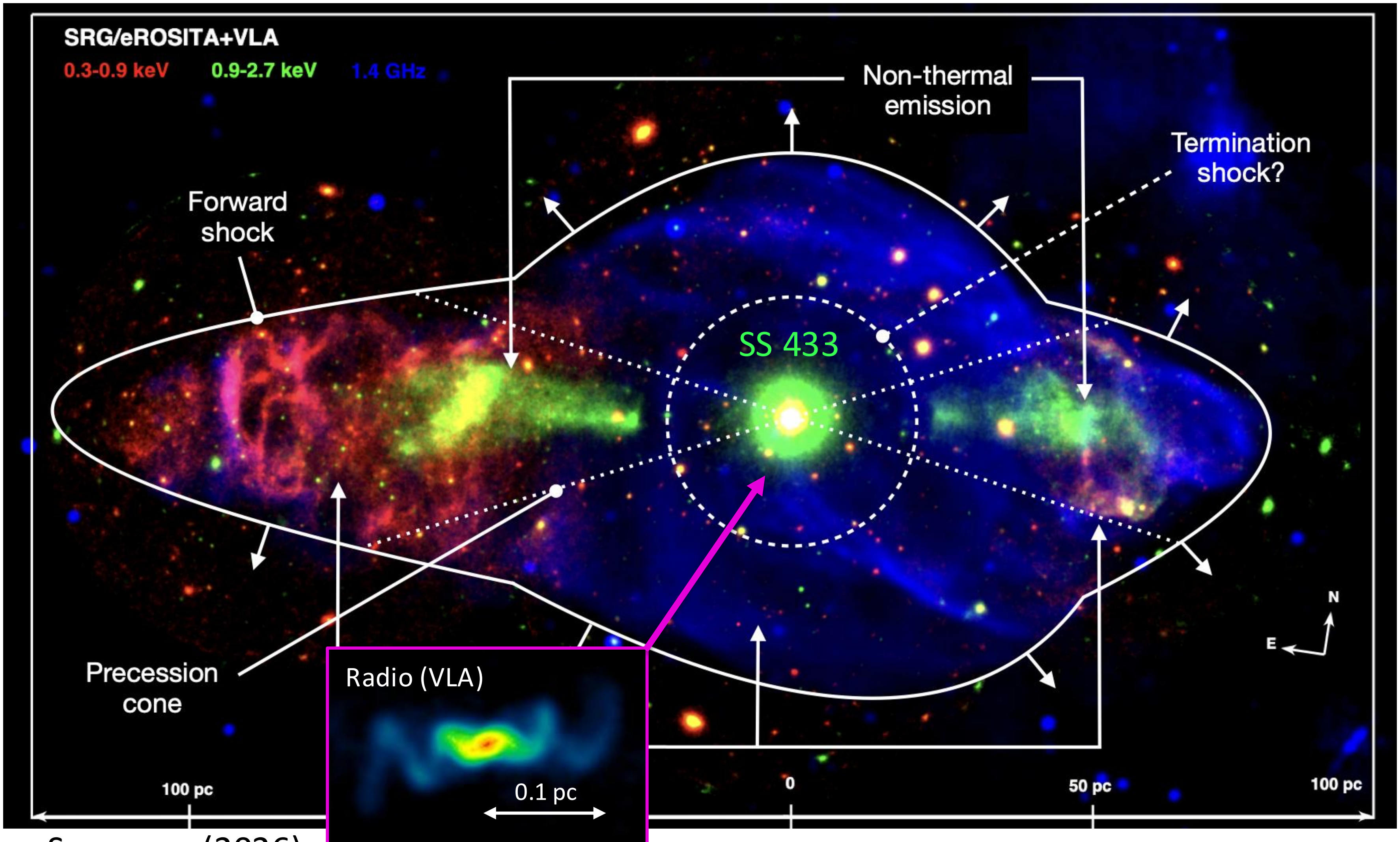
HAWC, V4641 Sgr
(Alfaro+ 2024)



Ultra-high-energy (up to sub PeV)
diffuse emission extending over ~10-100 pc
in several microquasars, including SS 433
→ **Efficient producers of PeV cosmic rays?**

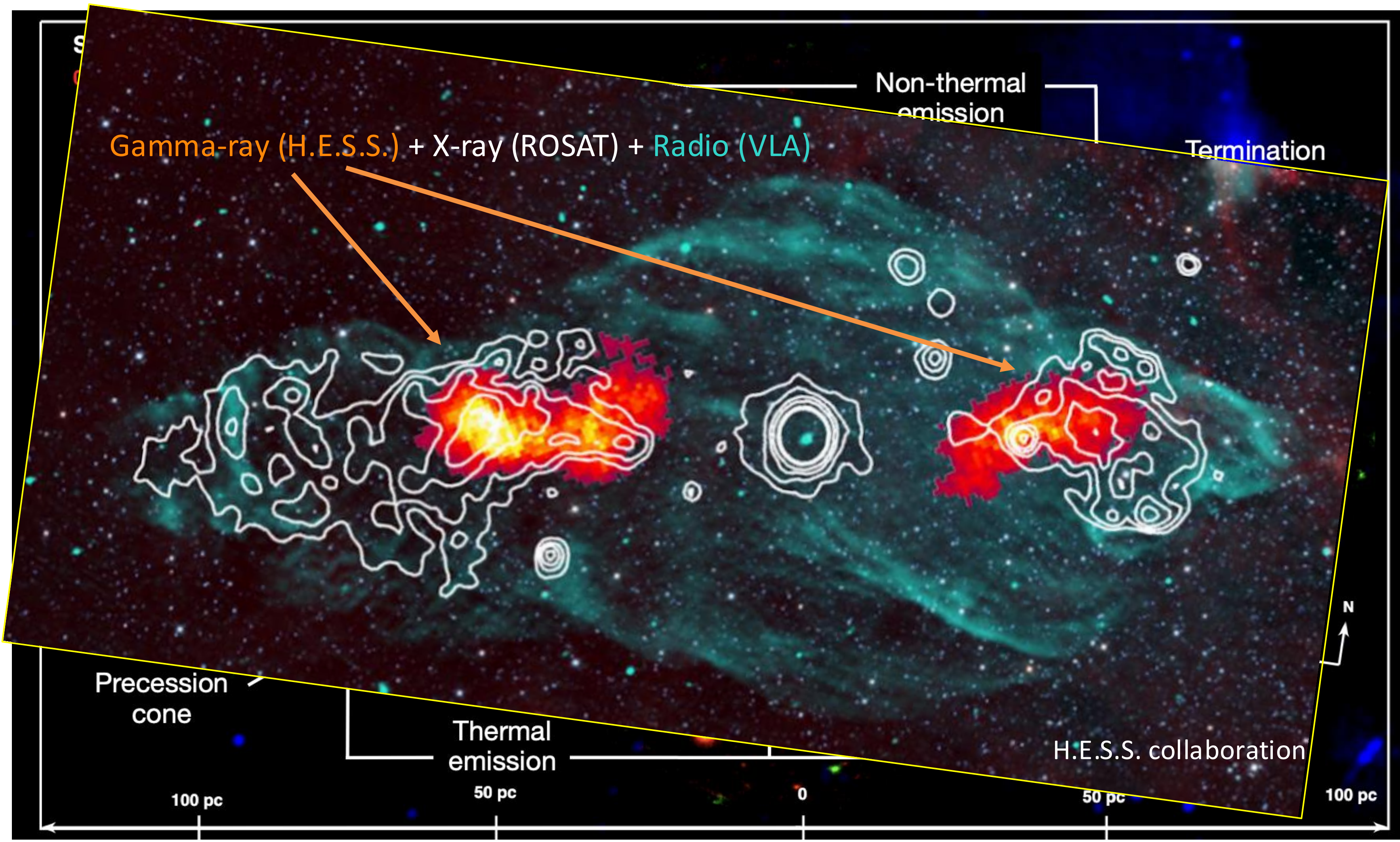
Particle acceleration via jet - ISM interaction??

SS 433 + W50 (Manatee nebula)



Sunyaev+ (2026)

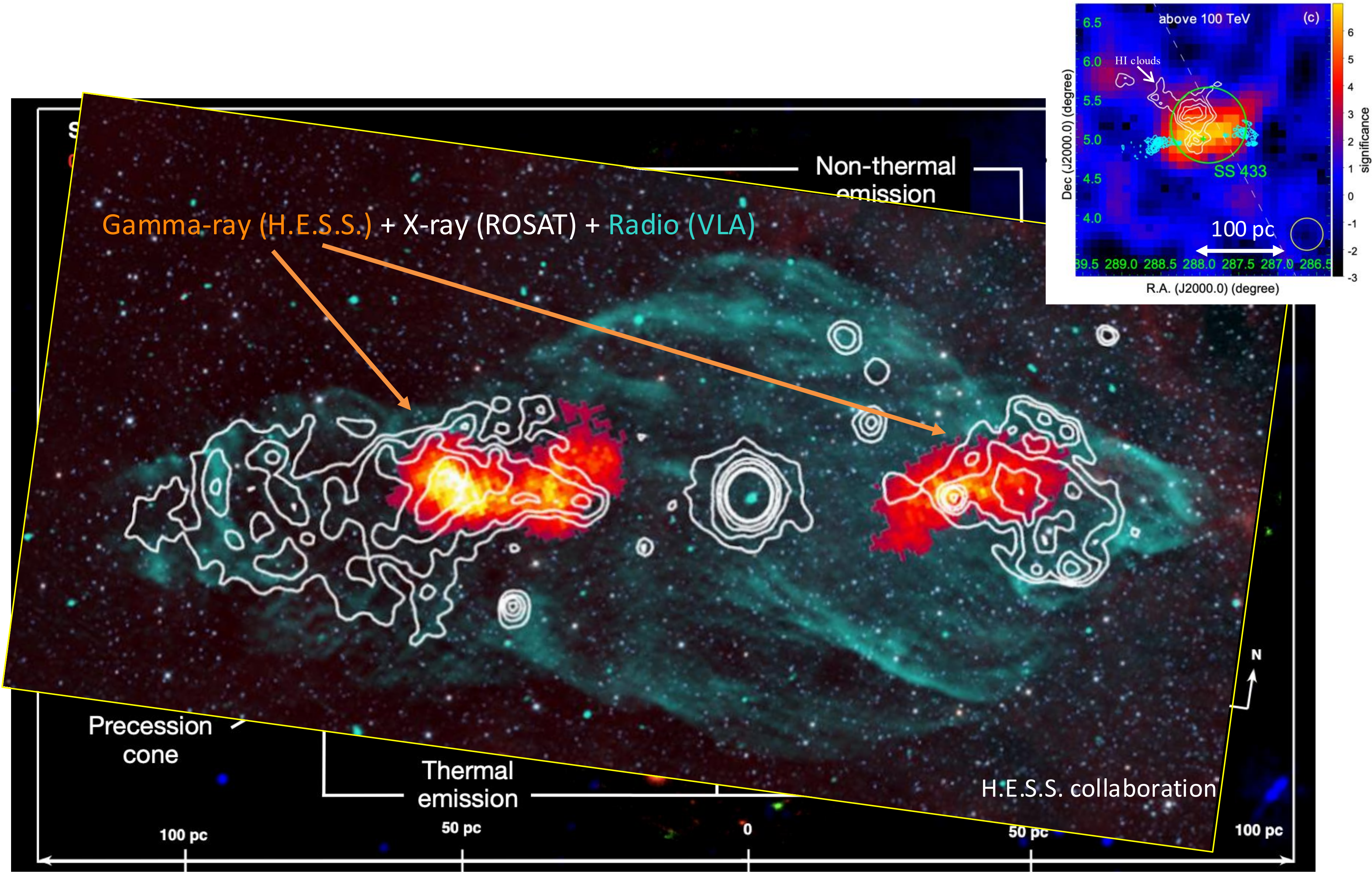
SS 433 + W50 (Manatee nebula)



Sunyaev+ (2026)

SS 433 + W50 (Manatee nebula)

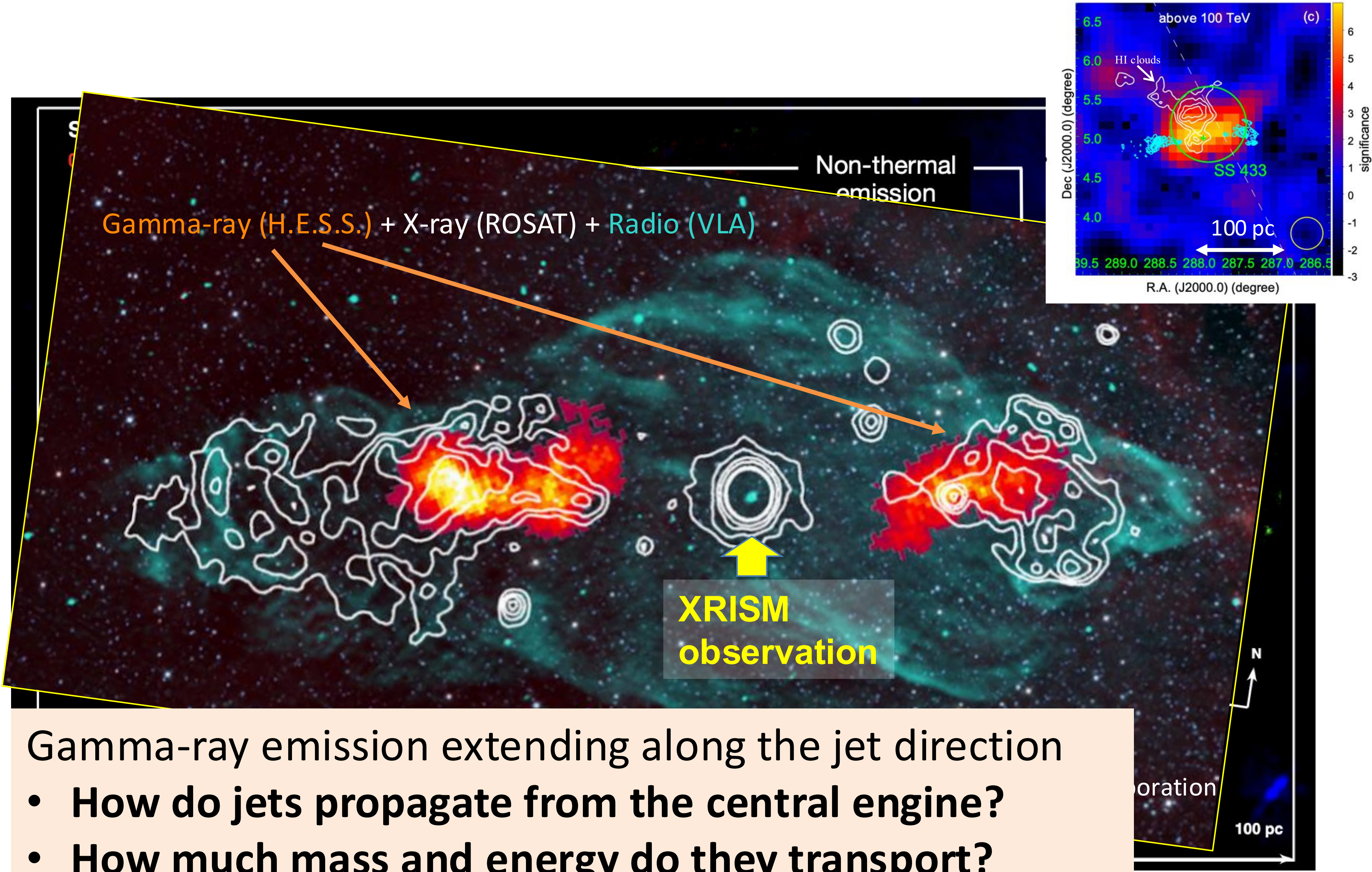
LHAASO
>100 TeV



Sunyaev+ (2026)

SS 433 + W50 (Manatee nebula)

LHAASO
>100 TeV



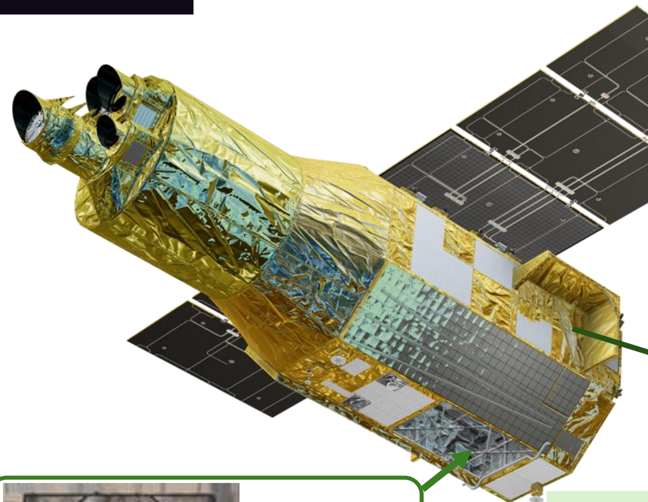
Gamma-ray emission extending along the jet direction

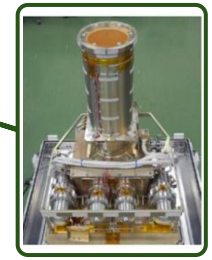
- **How do jets propagate from the central engine?**
- **How much mass and energy do they transport?**

XRISM X-Ray Imaging and Spectroscopy Mission

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

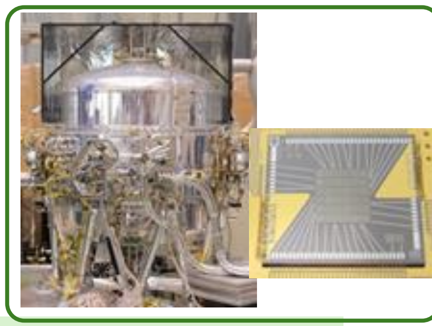
JAXA Japan Aerospace Exploration Agency





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

largest FoV among large X-ray satellites!
→ powerful to study diffuse sources

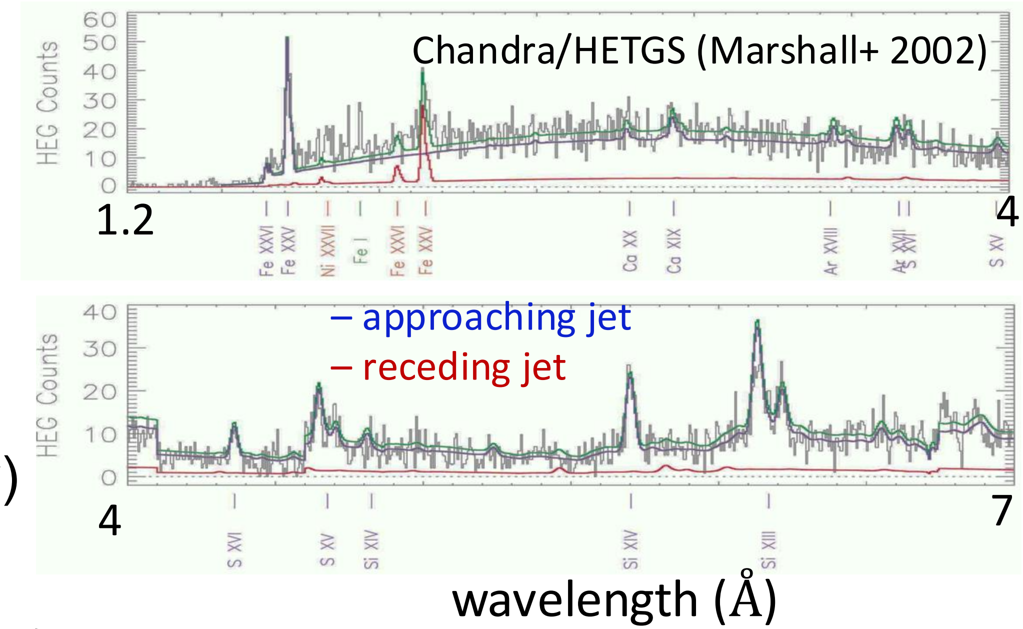


Resolve (X-ray microcalorimeter)
Energy range: 0.4 (1.7) -12 keV
ΔE ≦ 5 eV @ 6 keV
FoV: 2’.9 x 2’.9 (6 x 6 pixel)
Effective area: >=210 cm^2 @ 6 keV

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

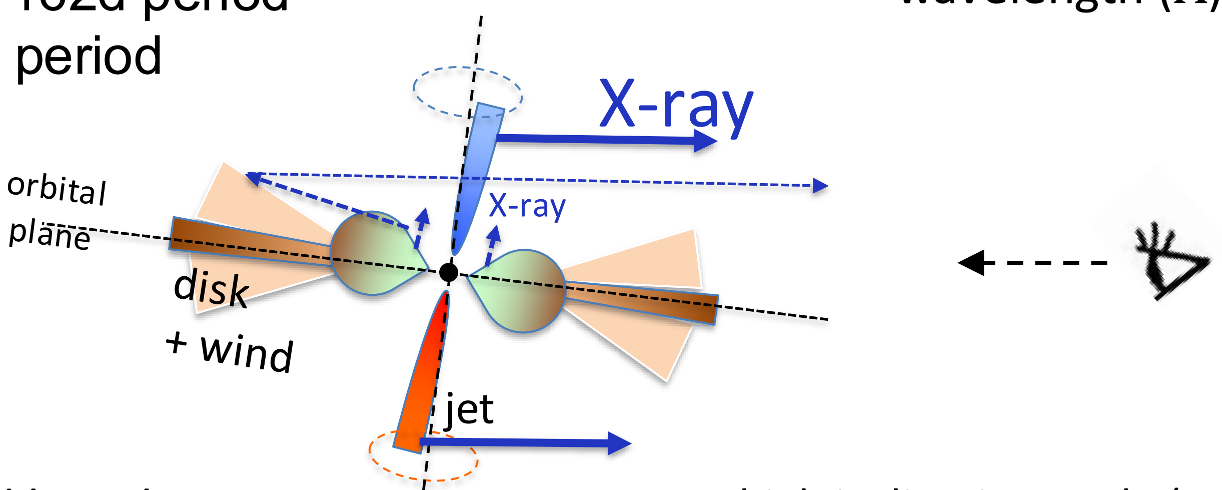
SS 433
(central source)

The X-ray spectrum is dominated by thin thermal plasma emission from **persistent bipolar jets**



Doppler shifts (line-of-sight velocity) of jet emission lines varies with

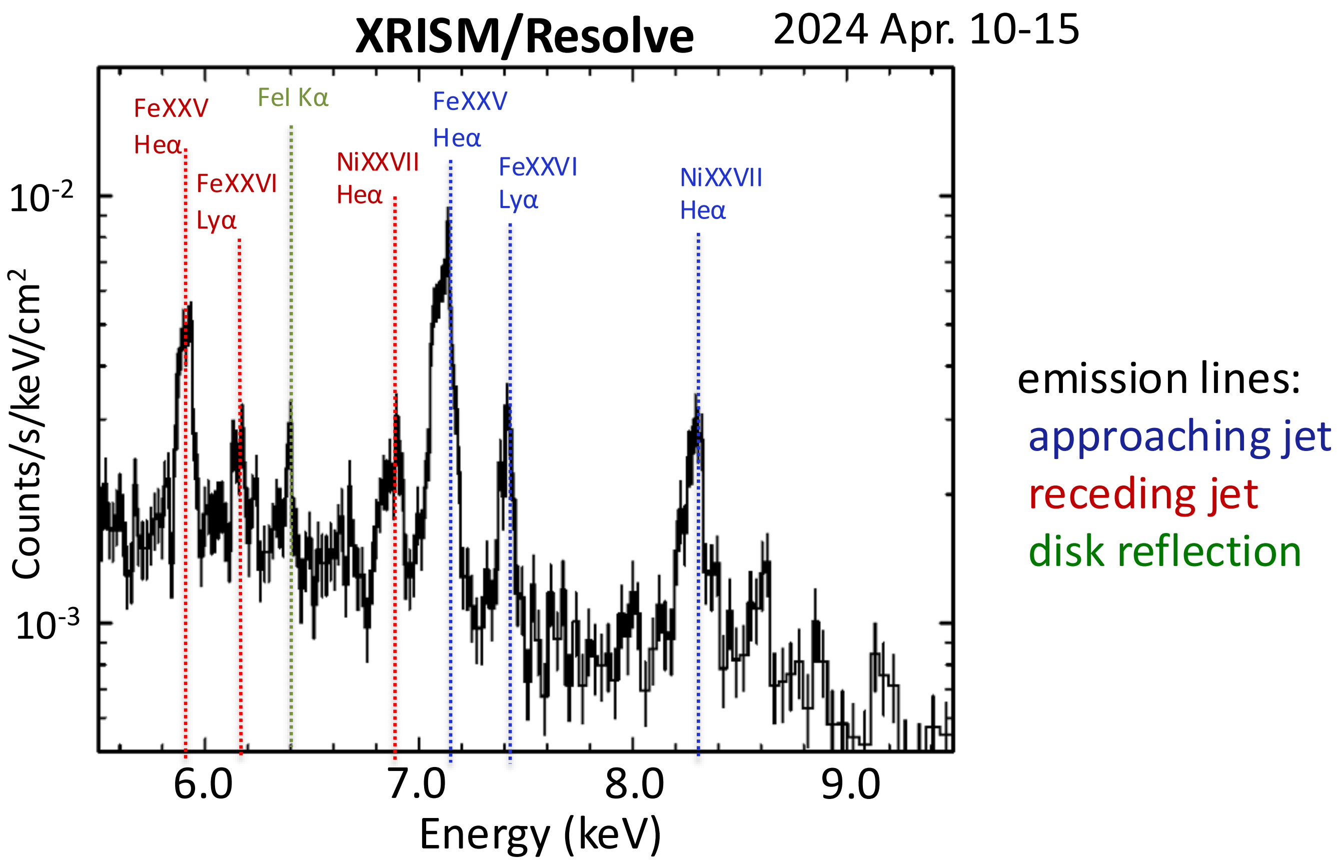
- precession: ~162d period
- nutation: ~6d period



partially affected by eclipse
X-ray emitting region: >~10^{12-13} cm

high inclination angle (~78 deg)
→ inner accretion disk is obscured

XRISM/Resolve data

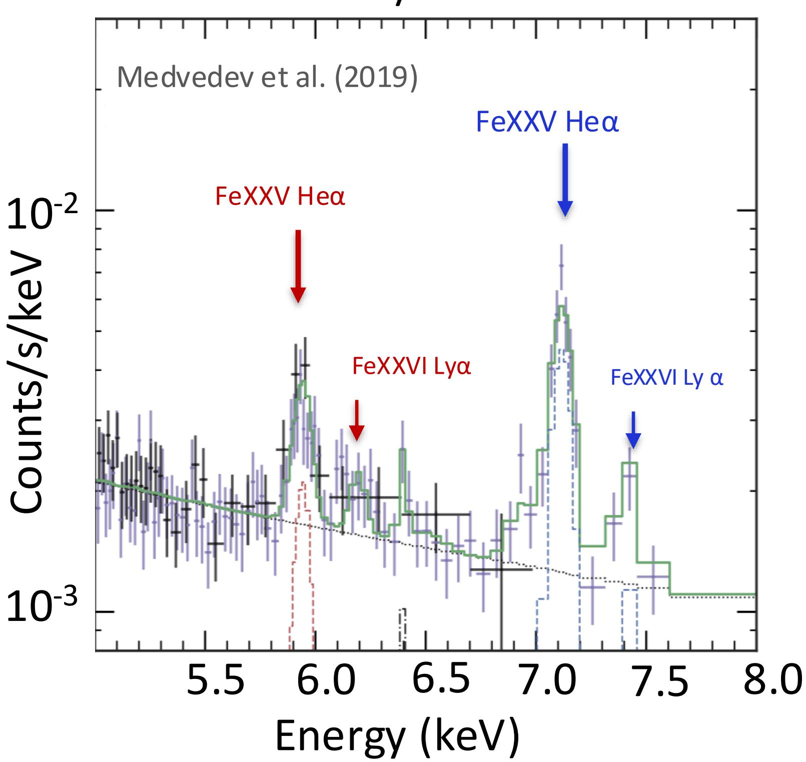


exposure: ~ 3.5 ks/snapshot

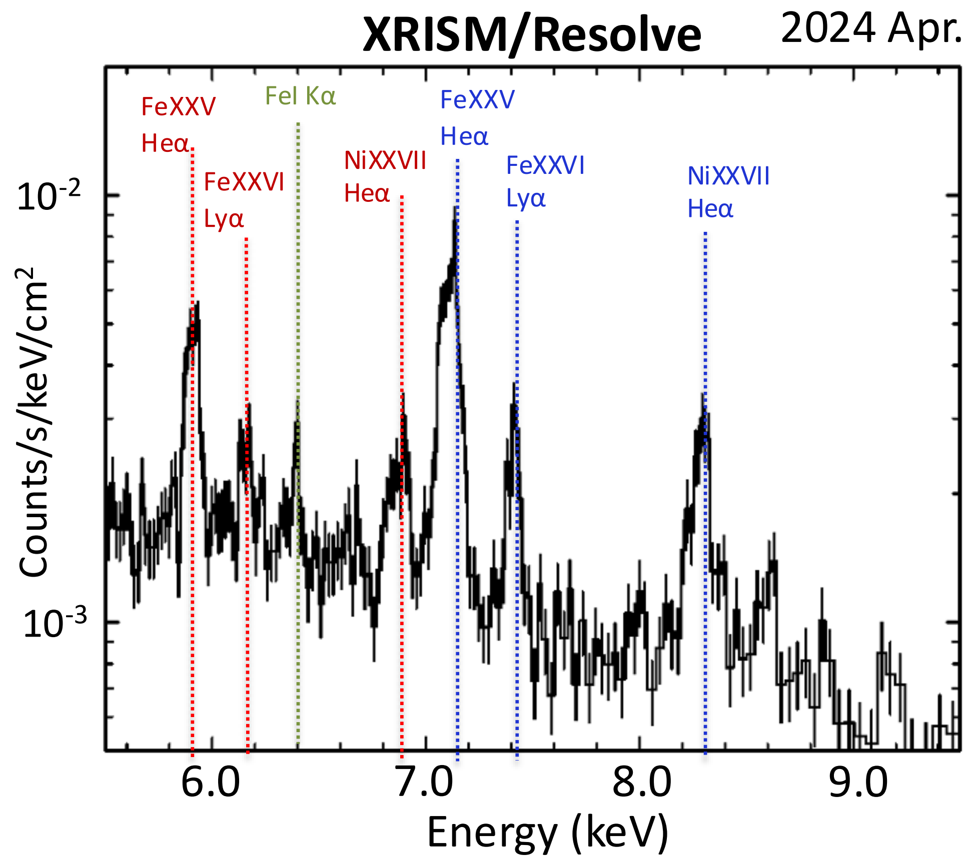
Broad lines from the precessing bipolar jets
+ a narrow FeI Ka line from the disk were detected

Shidatsu+ (2025), Takagi & Shidatsu+ (2026)

XRISM/Resolve data



exposure ~ 40 ks



exposure: ~ 3.5 ks/snapshot

Broad lines from the precessing bipolar jets
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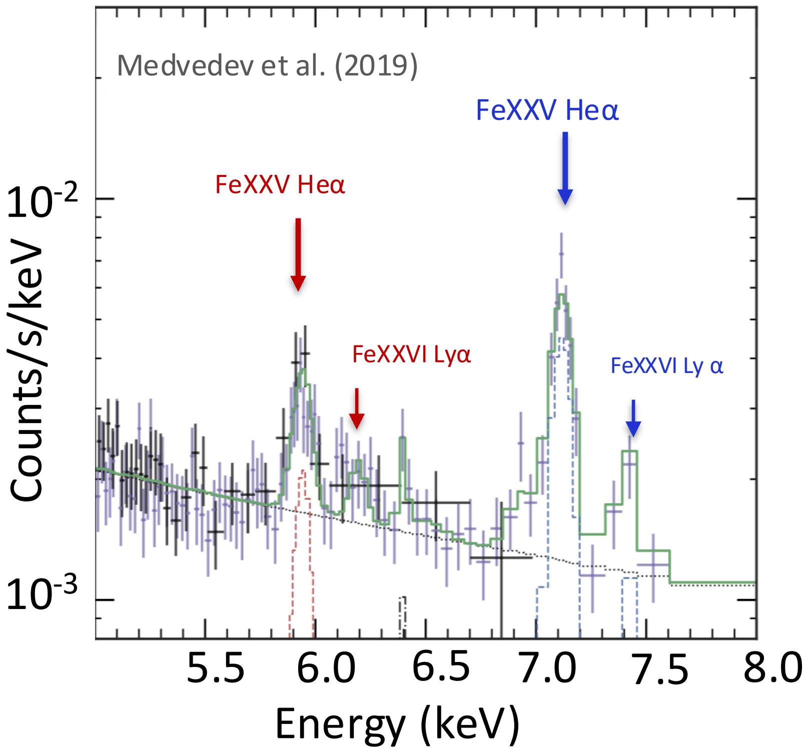
Shidatsu+ (2025), Takagi & Shidatsu+ (2026)

XRISM/Resolve data

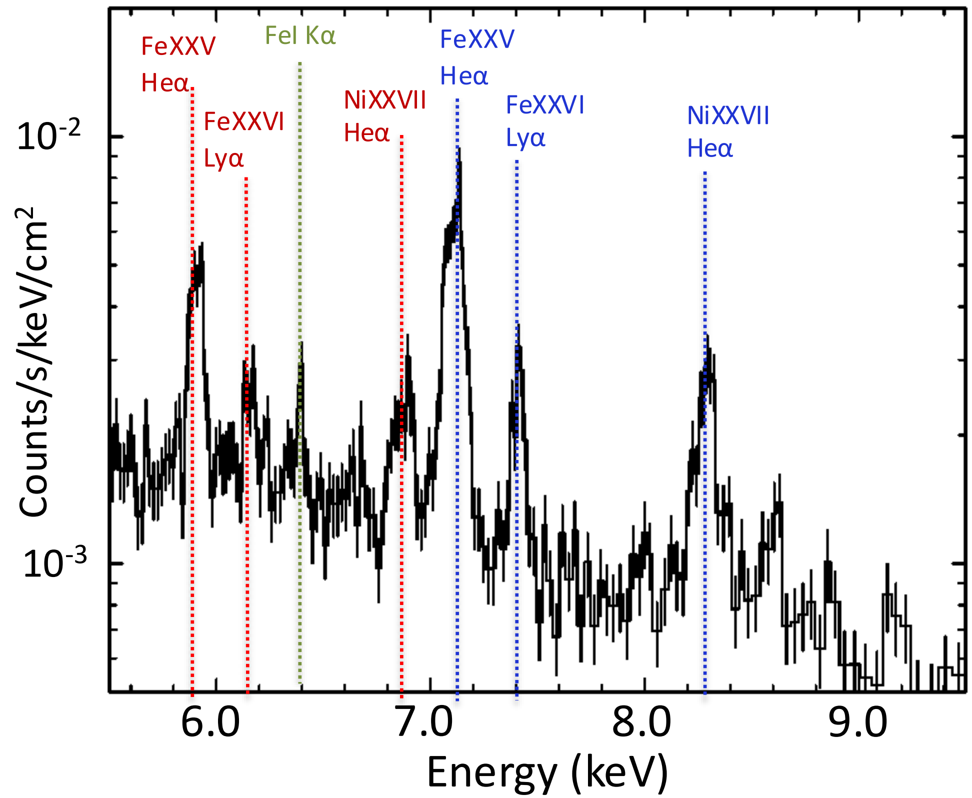
Chandra/HETGS



exposure ~ 40 ks

phase ID = 01

2024 Apr.



exposure: ~ 3.5 ks/snapshot

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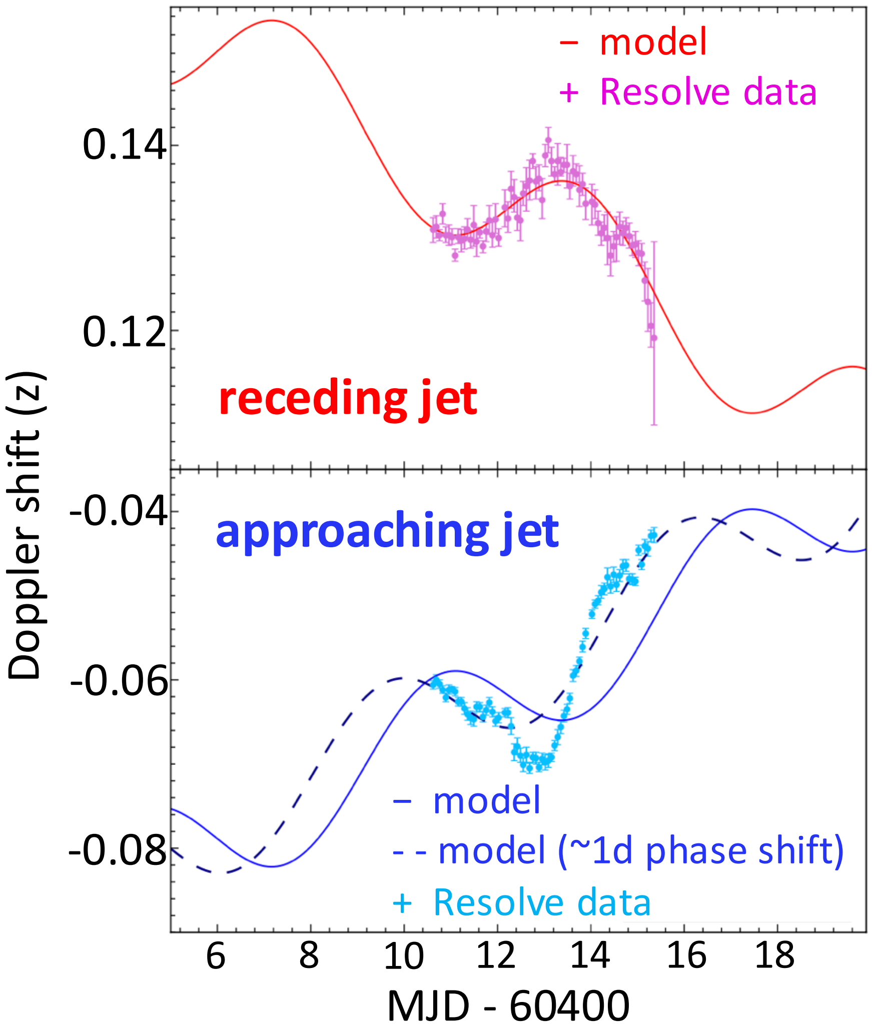
Shidatsu+ (2025), Takagi & Shidatsu+ (2026)

Time evolution of the Doppler shifts



Roughly follows the simple sinusoidal precession & nutation model for symmetric jets
(Gies+ 2002, Davydov et al. 2008; optical)

⇒ already accelerated to ~0.26c in the X-ray emitting region

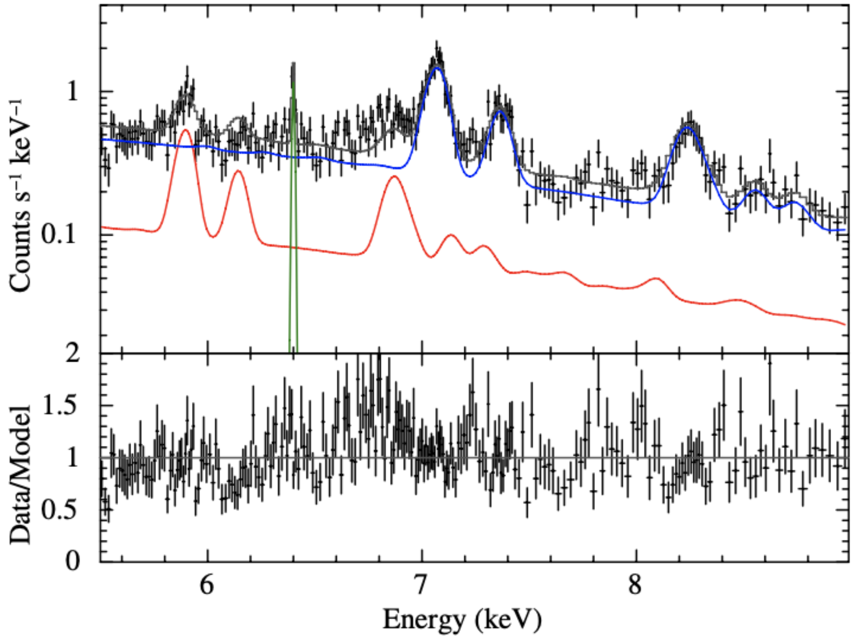
Sakai+ (2026),
Usuki & Shidatsu+ submitted to PASJ

But the model cannot fully reproduce the observed variations...

→ Asymmetric bipolar jets? (Different ejection angles and/or velocities?)

Geometry and Plasma properties of jets in the X-ray emitting region

XRISM/Resolve snapshot

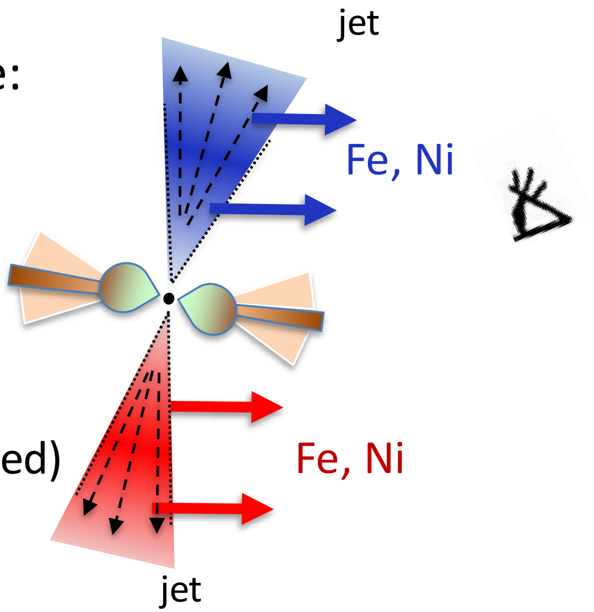


exposure: ~3.5 ks
(outside eclipse)

Jet parameters

plasma temperature:
kT = 7.2 ± 0.4 keV
velocity dispersion (line width):
σ = 1800 ± 200 km/s

jet opening angle:
θ ~ 1.6 deg
density:
n ~ 10^{11} /cm^3
kinetic power:
~10^{39} erg/s
(v ~ 0.26 c is assumed)

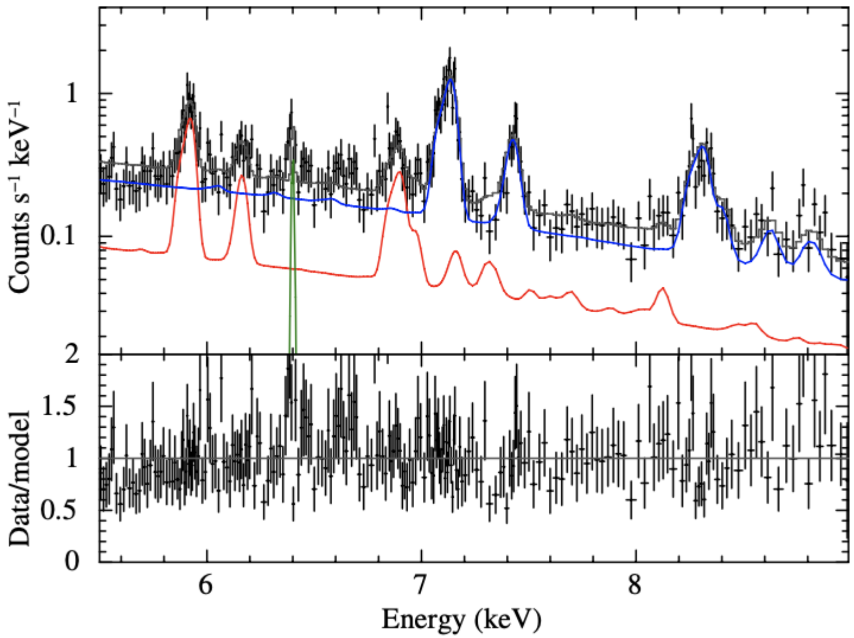


model
jet (blueshifted) + jet (redshifted) + disk reflection
↑ optically-thin thermal plasma

Shidatsu+ (2025)

Geometry and Plasma properties of jets in the X-ray emitting region

XRISM/Resolve snapshot



exposure: ~3.5 ks
(during eclipse)

Jet parameters

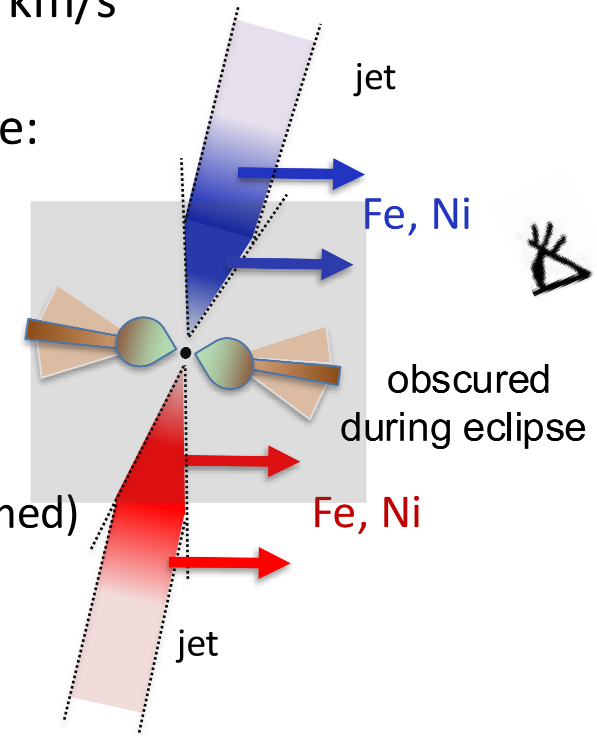
plasma temperature:
kT = 6.4 ± 0.4 keV

velocity dispersion (line width):
σ = 1000 ± 100 km/s

jet opening angle:
θ ~ 0.8 deg

density:
n ~ 10^{11} /cm^3

kinetic power:
~10^{39} erg/s
(v ~ 0.26 c is assumed)



model
jet (blueshifted) + jet (redshifted) + disk reflection
↑ optically-thin thermal plasma

Shidatsu+ (2025)

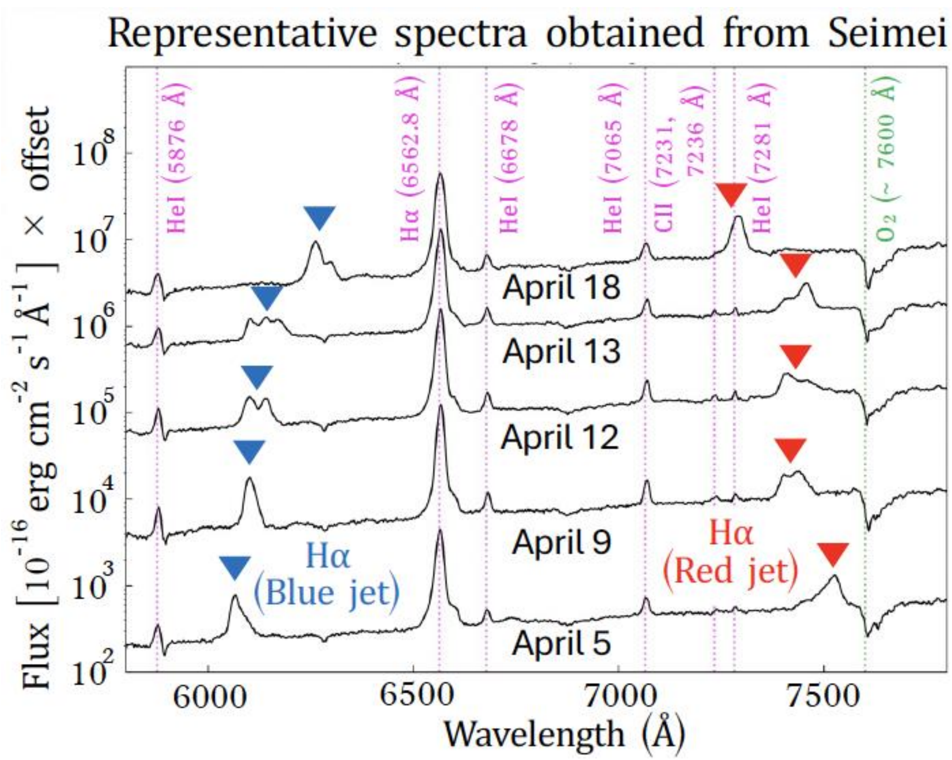
Optical spectroscopic monitoring

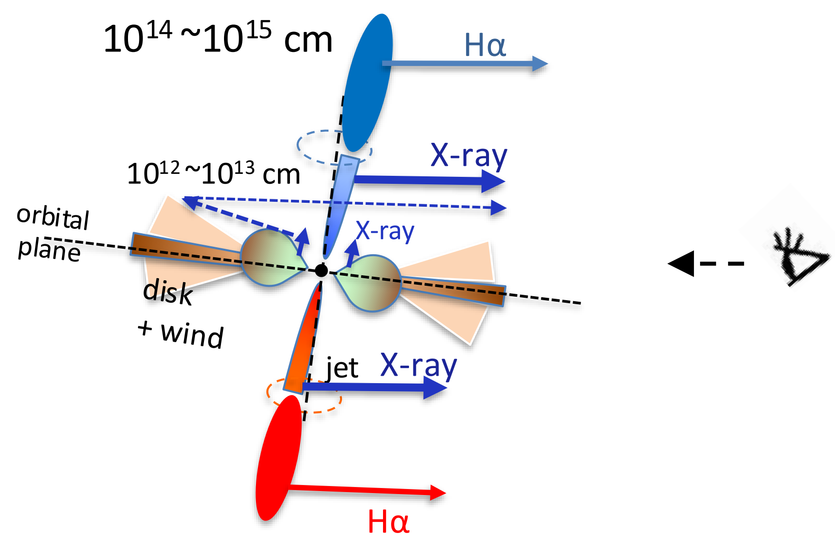
telescope: Seimei telescope (3.8m)

instrument: KOOLS-IFU

grism: VPH-blue (λ/Δλ ~ 500)

period: 2024 Apr. 5-18



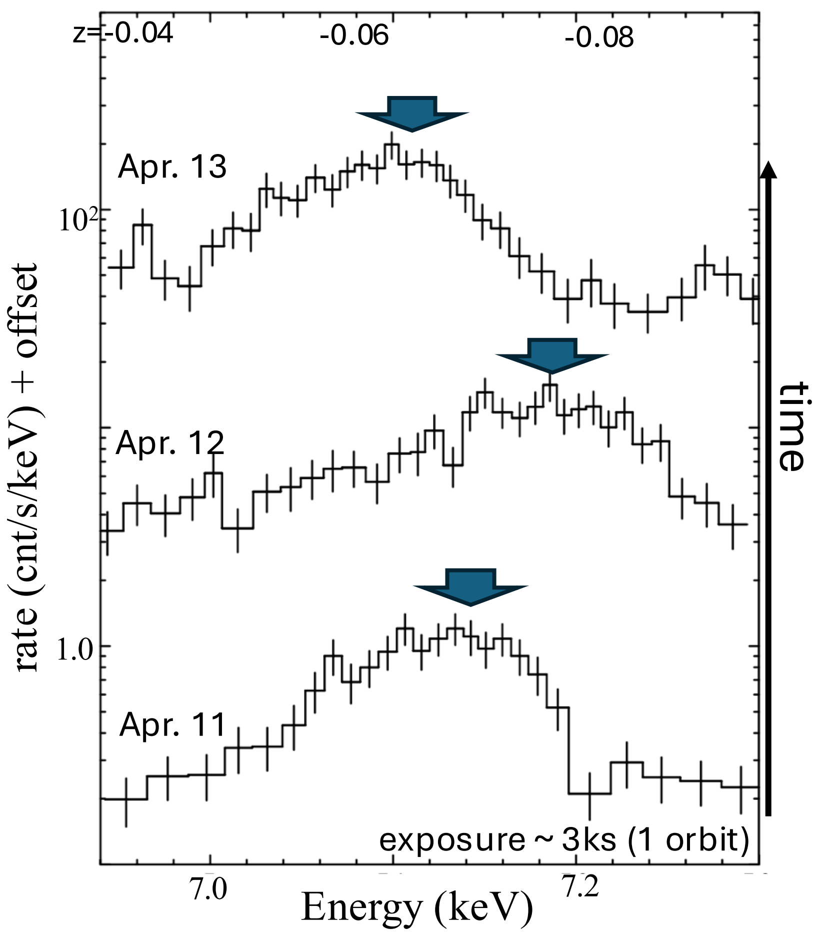


Sakai+ (2026), Usuki & Shidatsu+ submitted

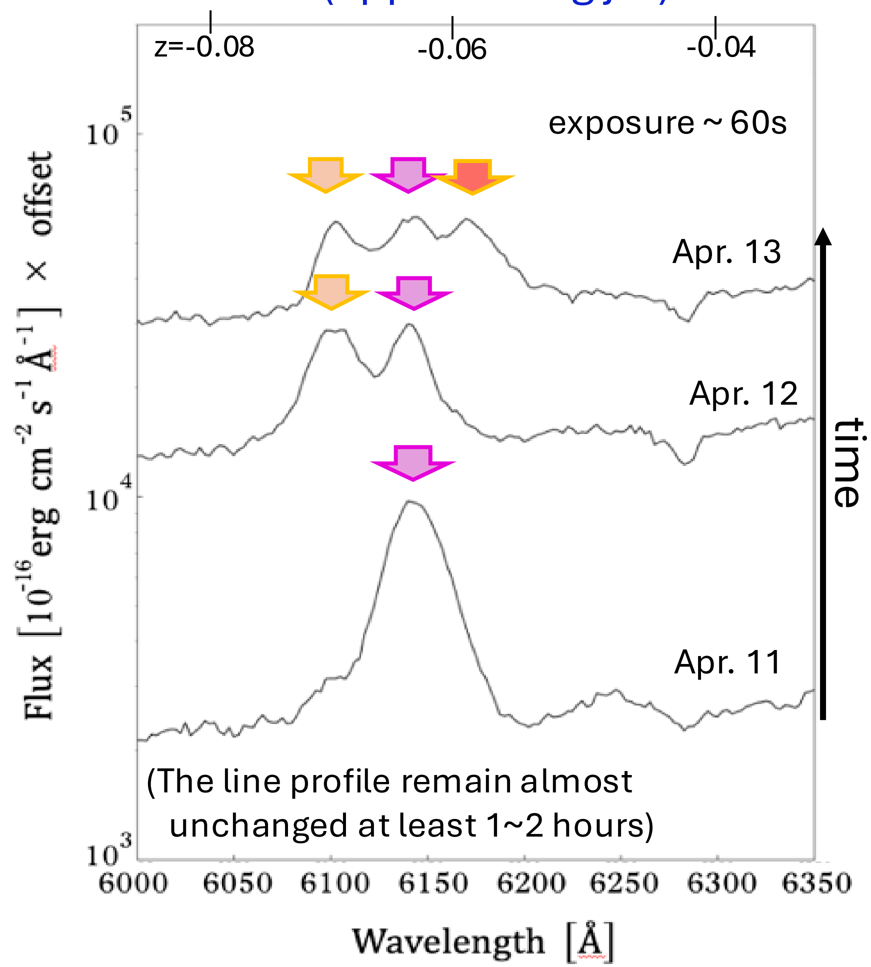
Comparison of emission lines in X-ray and optical bands

Usuki, Shidatsu+ submitted

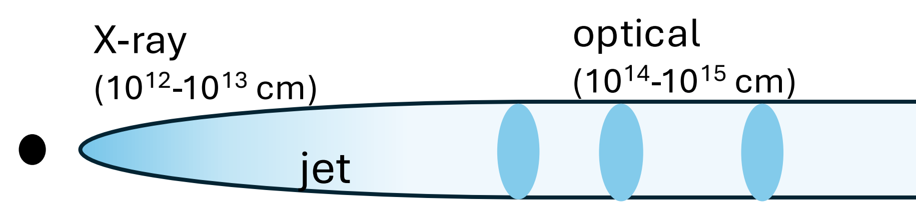
Fe XXVI Heα (approaching jet)



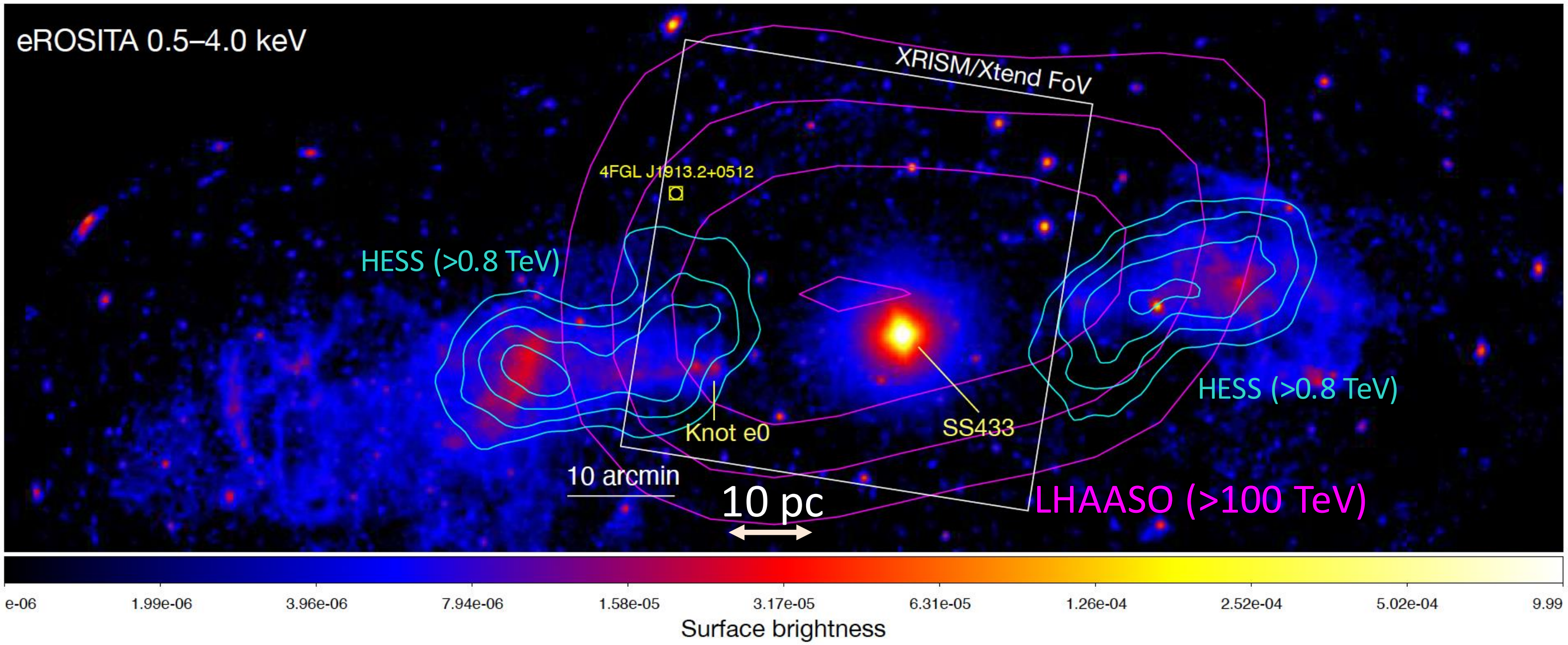
Hα (approaching jet)

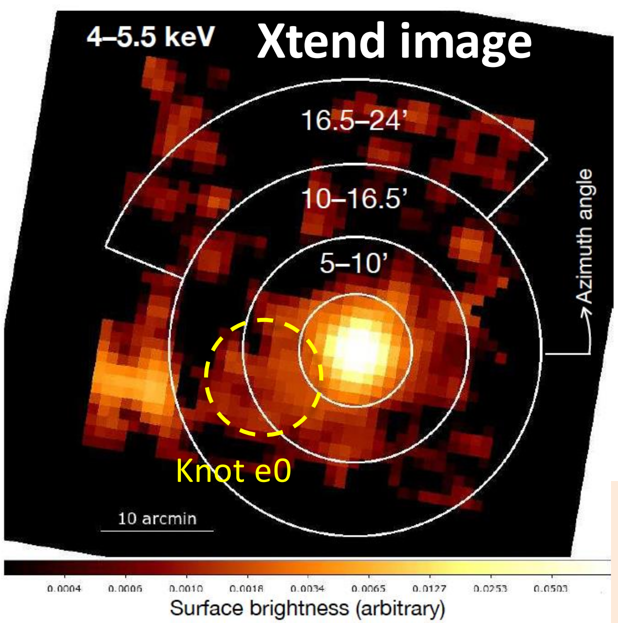


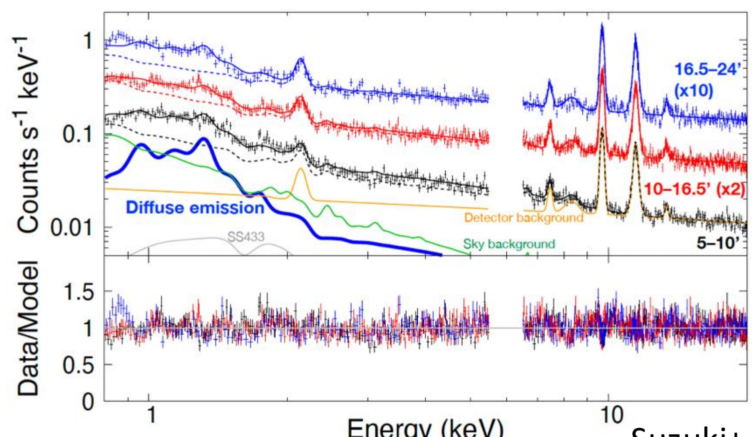
Jet plasma is homogeneous
in X-ray emitting region
but split into blobs in the optical region?



Diffuse X-ray emission

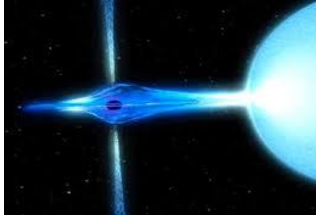






Suzuki+, submitted to ApJ

Diffuse emission was found in the inner cavity region
See talk by Hiromasa Suzuki on Sep. 1



Summary

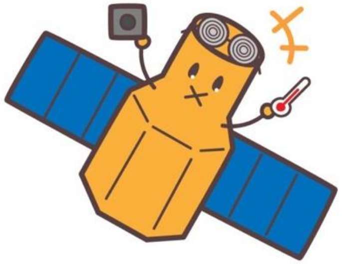
SS 433 is an ideal target for understanding the nature of microquasar jets and the mechanisms of particle acceleration.

XRISM/Resolve high-resolution spectroscopy
(combined with optical spectroscopic monitoring)
has significantly advanced our understanding of
the jet dynamics, spatial structure, and plasma propagation.

XRISM/Xtend wide-field imaging
has revealed diffuse emission between the central source
(the jet base) and the shock region.

Further XRISM observation is scheduled!

Special thanks to the team of the Grant-in-Aid for Transformative Research Areas (A) "The Creation of Multi-Messenger Astrophysics" for their kind invitation and support for this research.



credit: Higgstan