

J1913.2+0512

XRISM/Xtend detection of diffuse X-ray emission in the "inner cavity" region around SS 433

Hiromasa Suzuki (Univ. of Miyazaki)

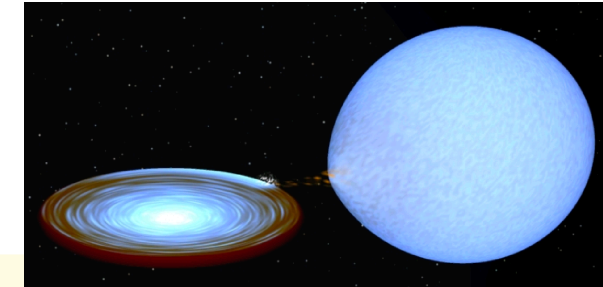
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- ☆ Microquasars as a new class of PeVatrons
- ☆ XRISM X-ray astronomy satellite
- ☆ Previous results on V4641 Sgr
- ☆ X-ray emission from the "inner cavity" of SS 433/W50
- ☆ Summary & Future plan

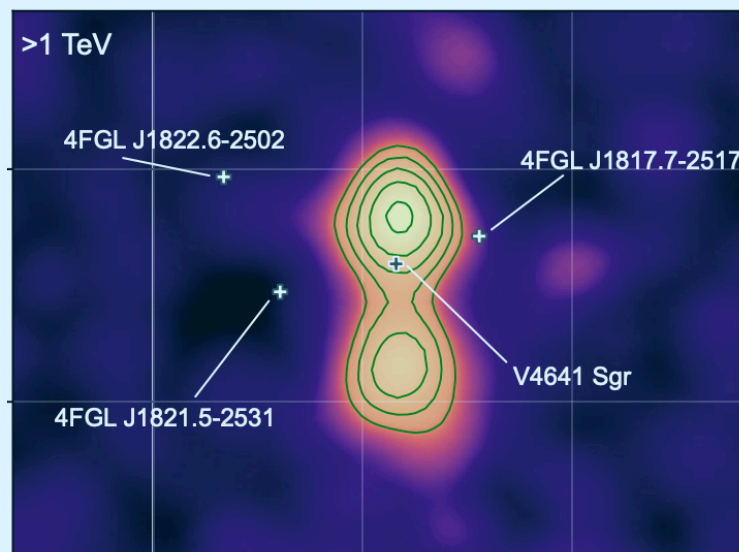
Microquasars as a new class of PeVatrons



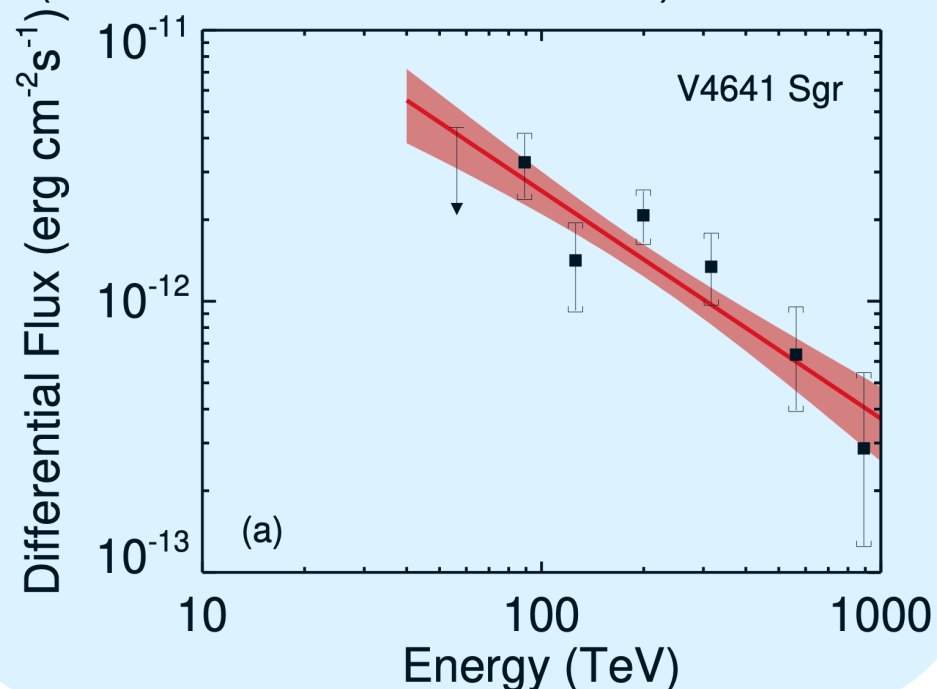
- Gamma-ray emission above 100 TeV found recently
- X-ray obs. are important for understanding accel. physics



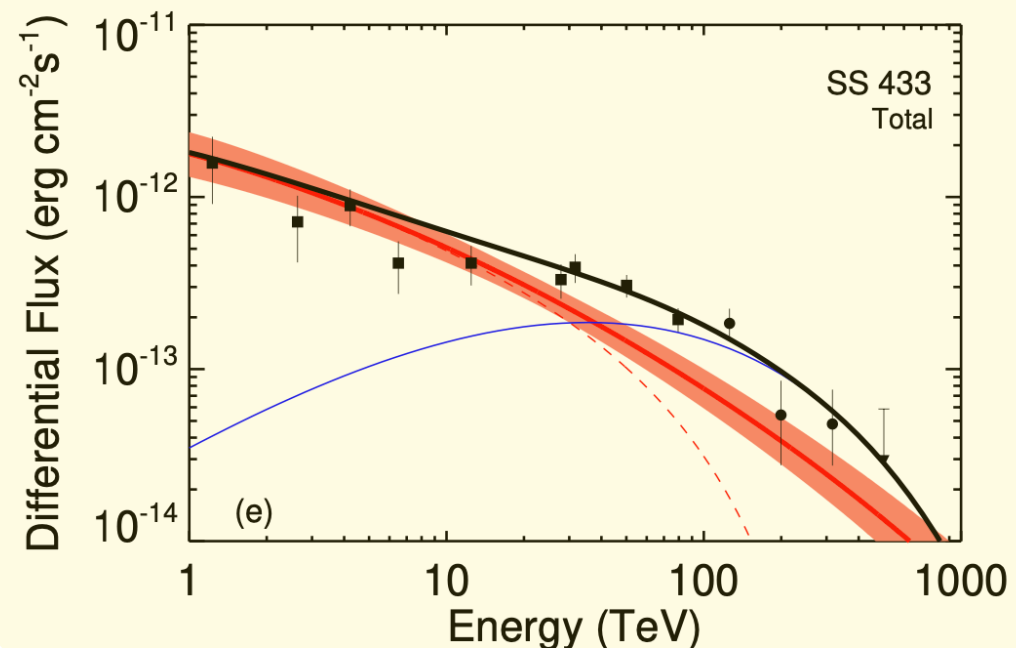
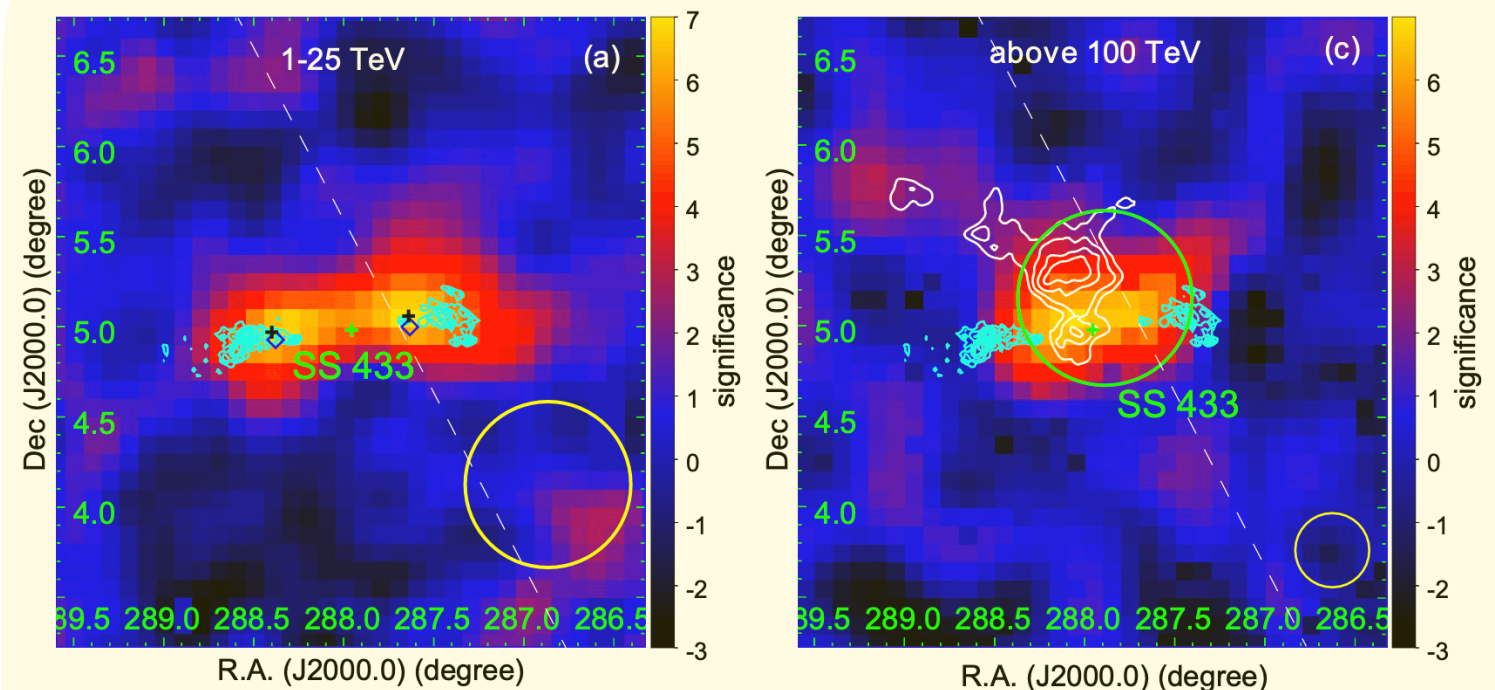
V4641 Sgr by HAWC (Alfaro et al. 2024)



V4641 Sgr by LHAASO (LHAASO Collaboration 2025)



SS433/W50 by LHAASO (LHAASO Collaboration 2025)



XRISM X-ray astronomy satellite

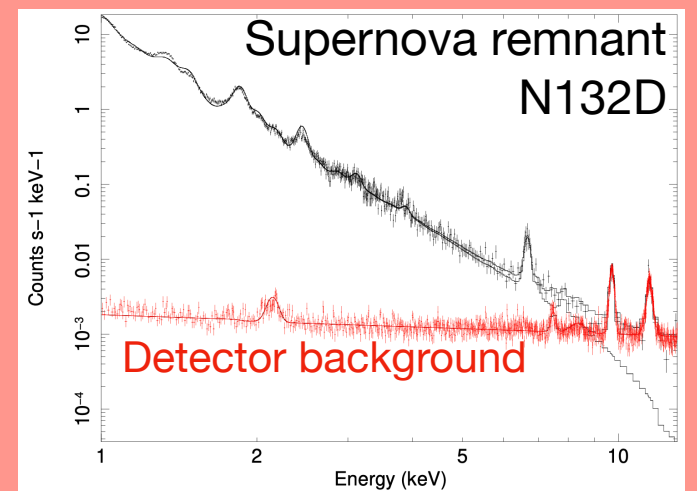
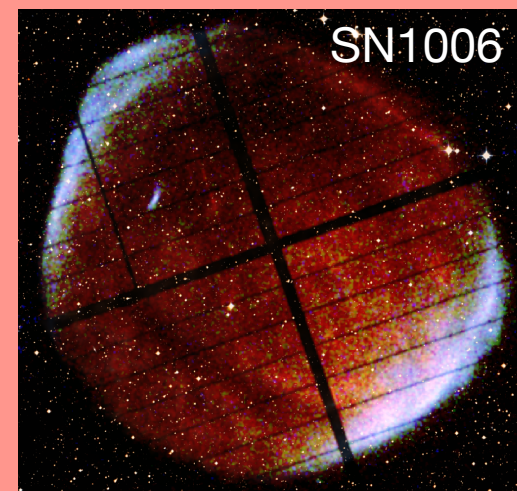
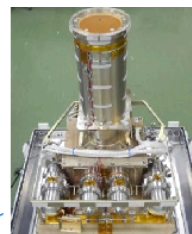


- In operation from 2024
- Strength: high-resolution X-ray spectroscopy ("Resolve")
- **But, also good at high-sensitivity, large field-of-view observations ("Xtend")**
- A few XRISM members + collaborators have been working on **faint diffuse emission which could not be detected previously**

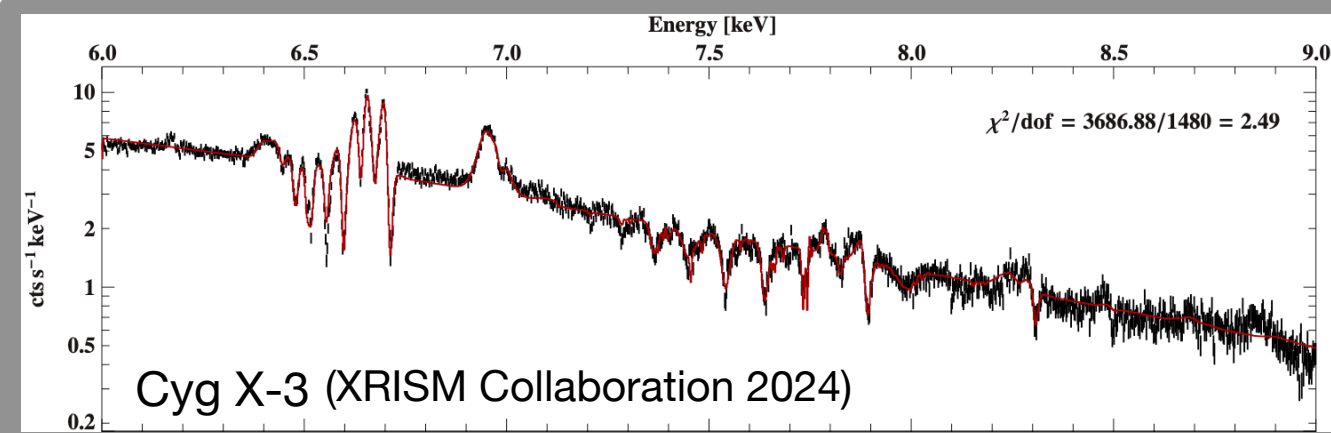
X-ray mirrors



X-ray CCD camera "Xtend"

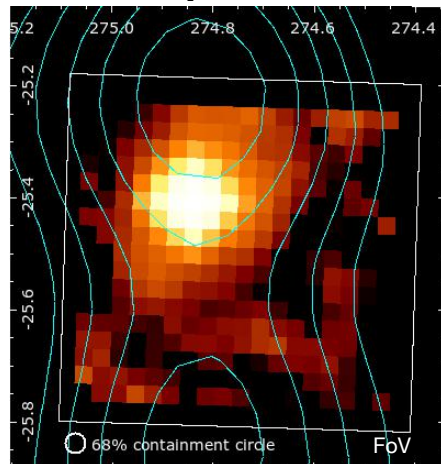


Microcalorimeter "Resolve"

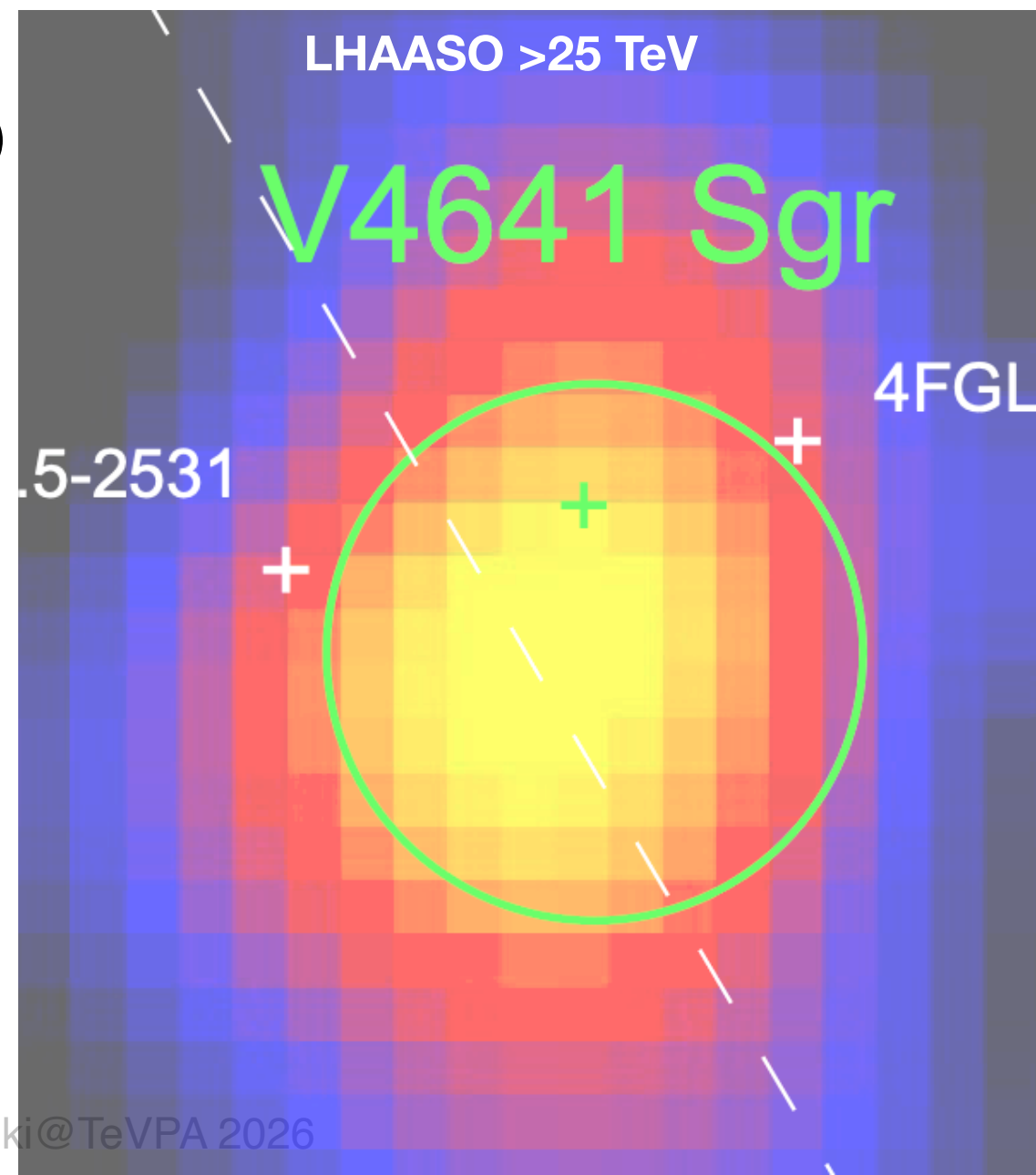
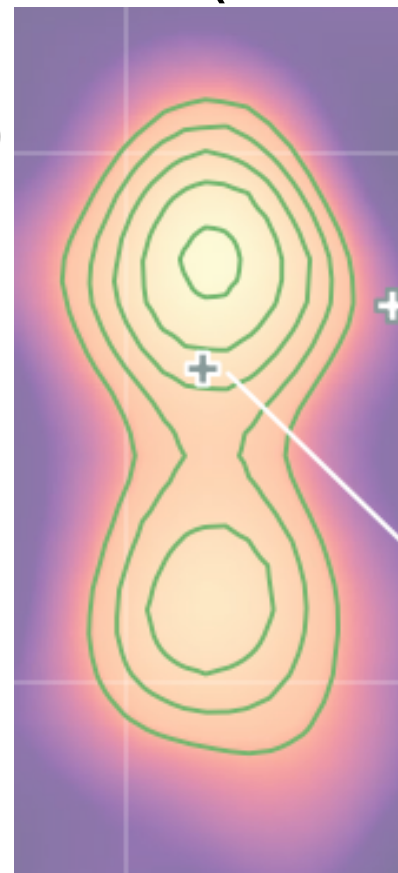


- ~10 ksec XRISM observation revealed diffuse X-ray emission (> 4.5 sigma) around the central source
- Prompted XMM, Chandra, and NuSTAR observations (by K. Mori, N. Tsuji, all accepted/performed!) [N. Tsuji's talk yesterday](#)

XRISM (4.0–5.5 keV)



HAWC (> 1 TeV)

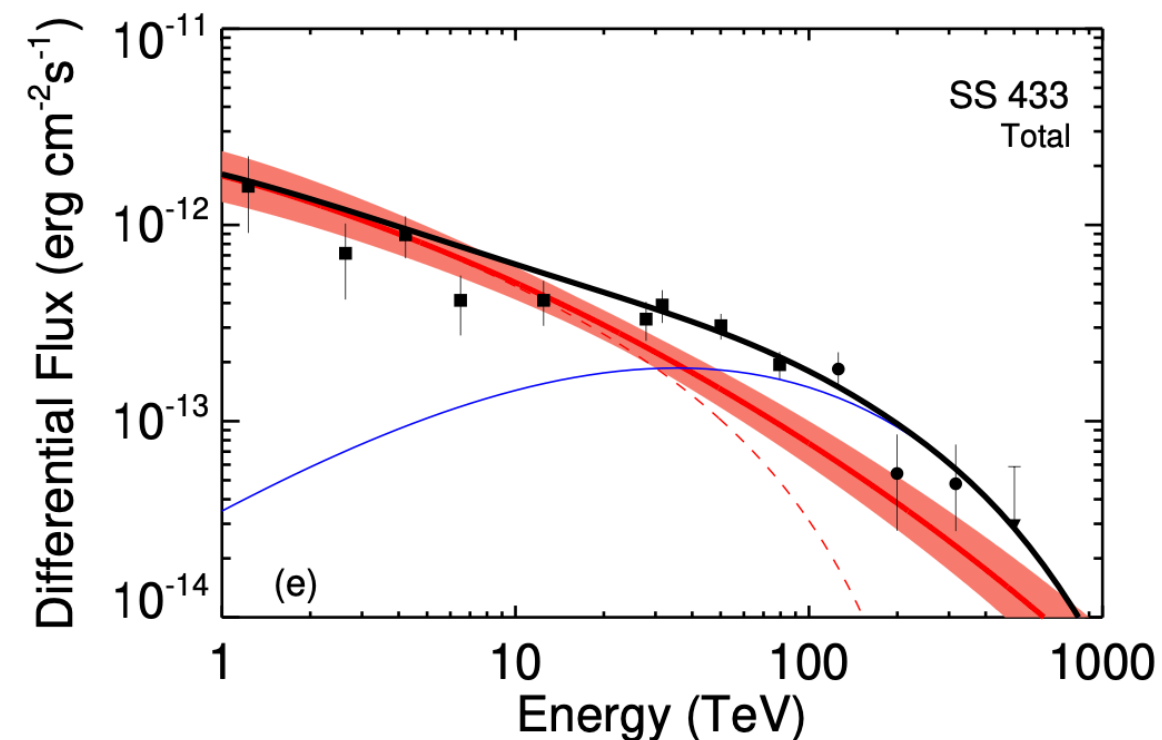
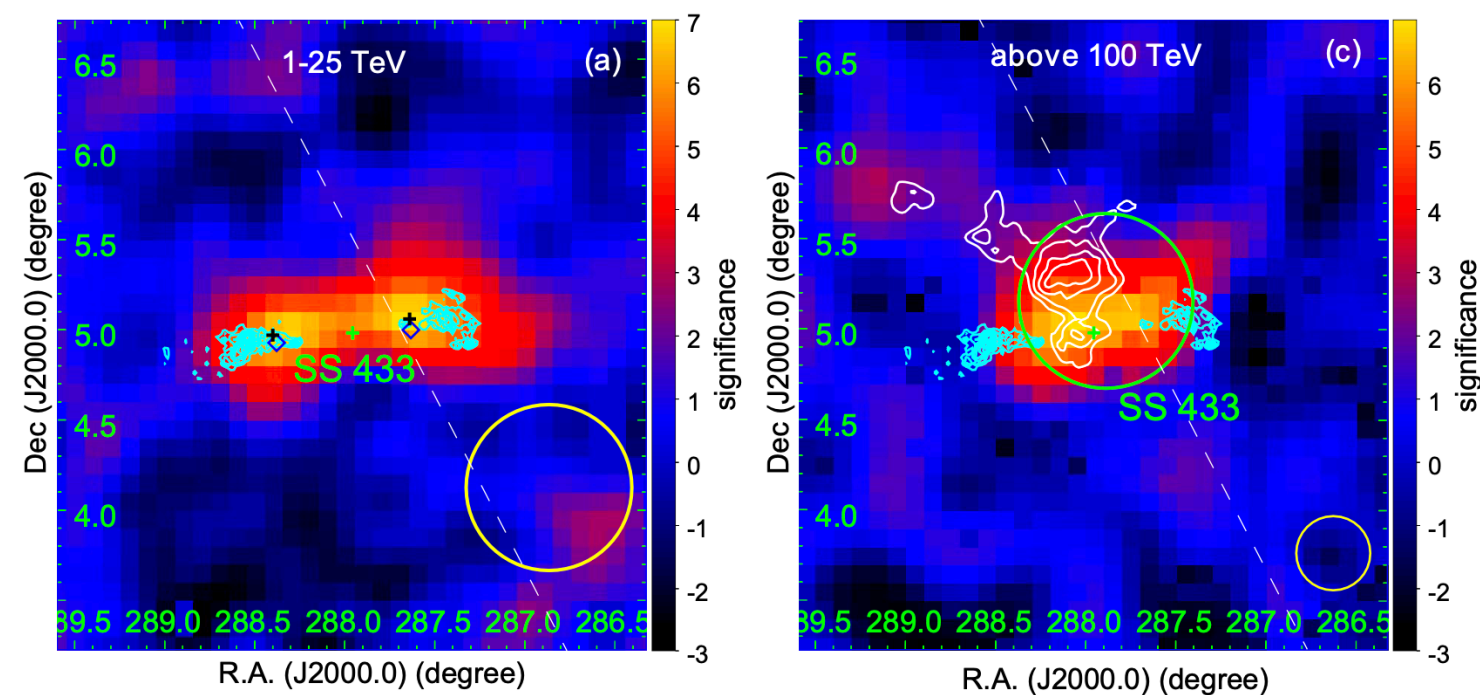


SS 433/W50: persistent super-Eddington microquasar

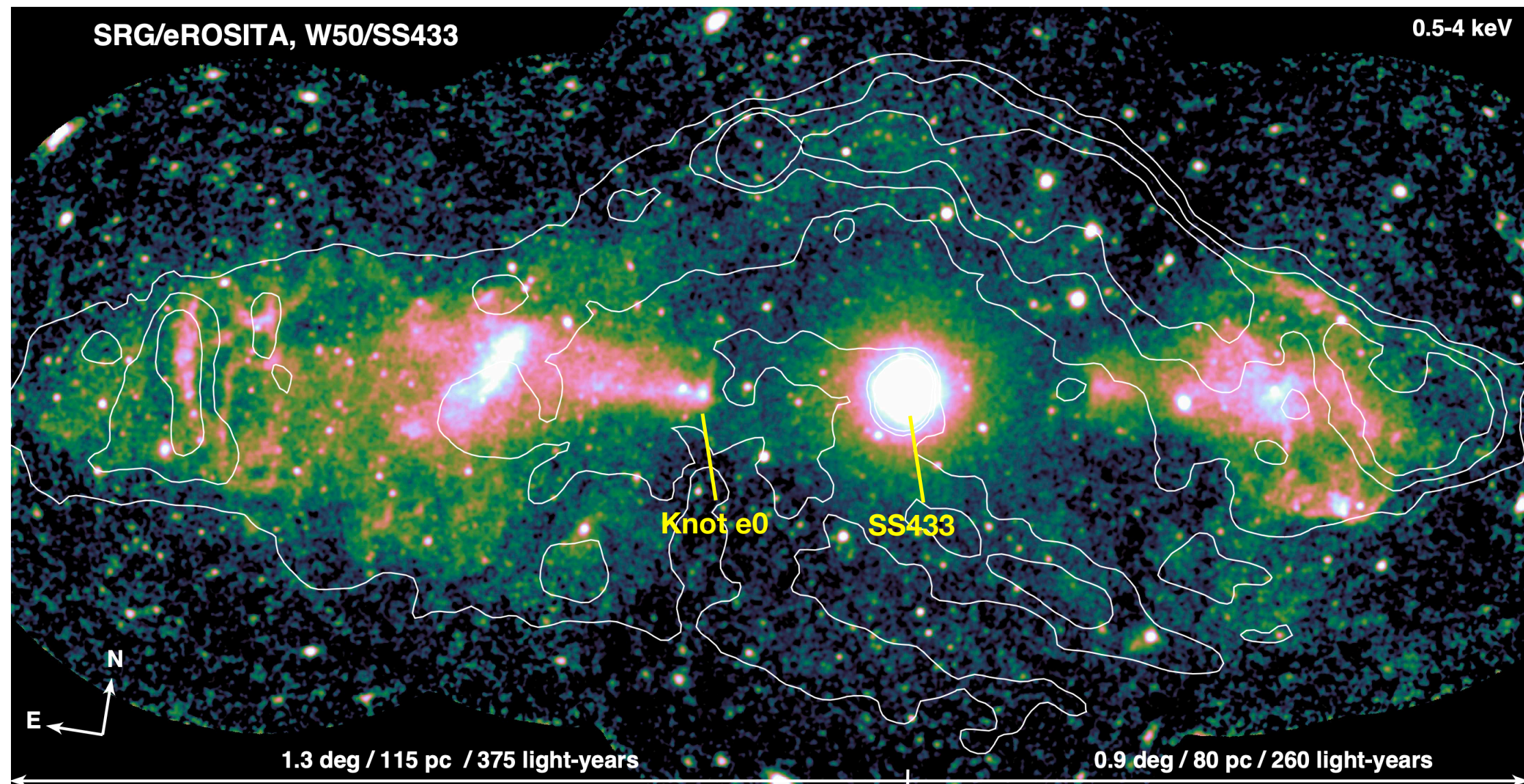


- 2nd brightest microquasar in sub-PeV
- Persistent super-Eddington luminosity
- Extended (bipolar) TeV emission
- Sub-PeV emission around center?

SS433/W50 by LHAASO (LHAASO Collaboration 2025)

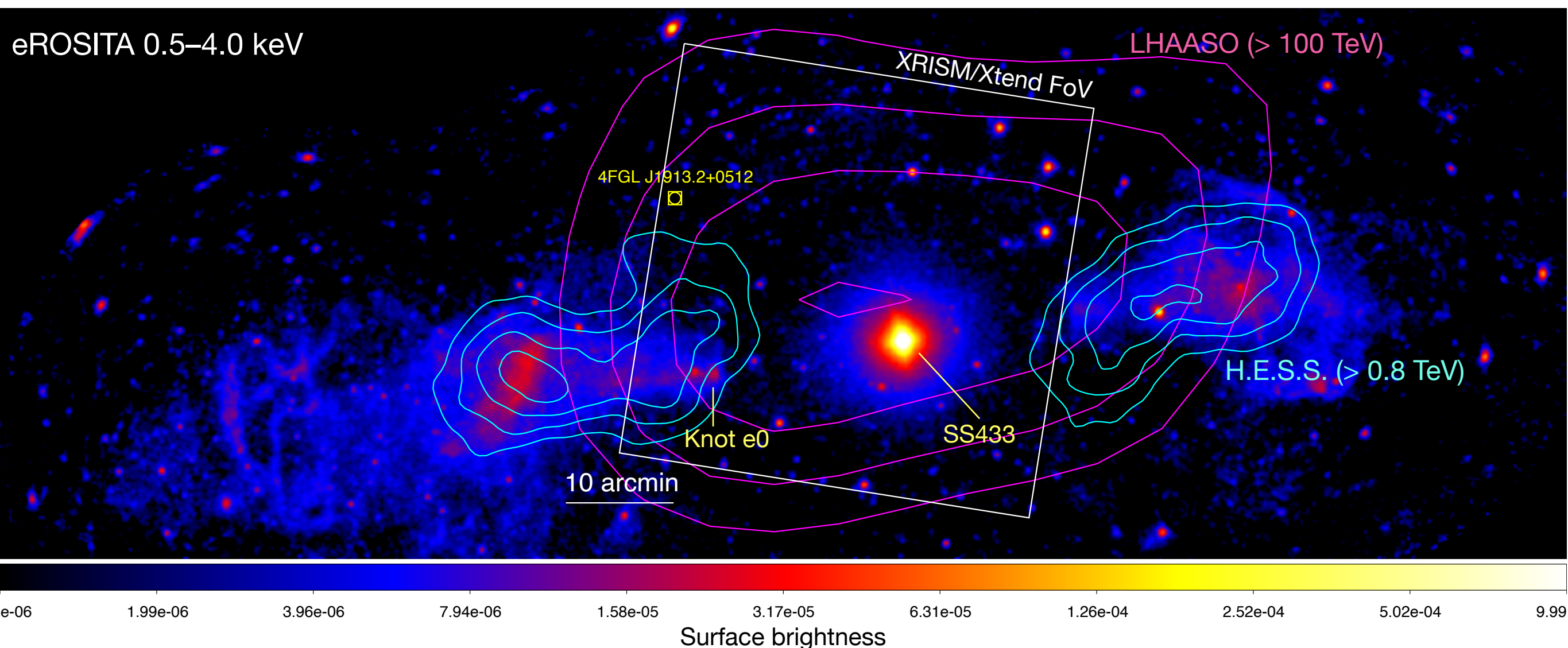


- What is happening in between SS 433 and X-ray jets?
- "inner cavity" or "dark flow" by eROSITA paper (Sunyaev et al. 2025)



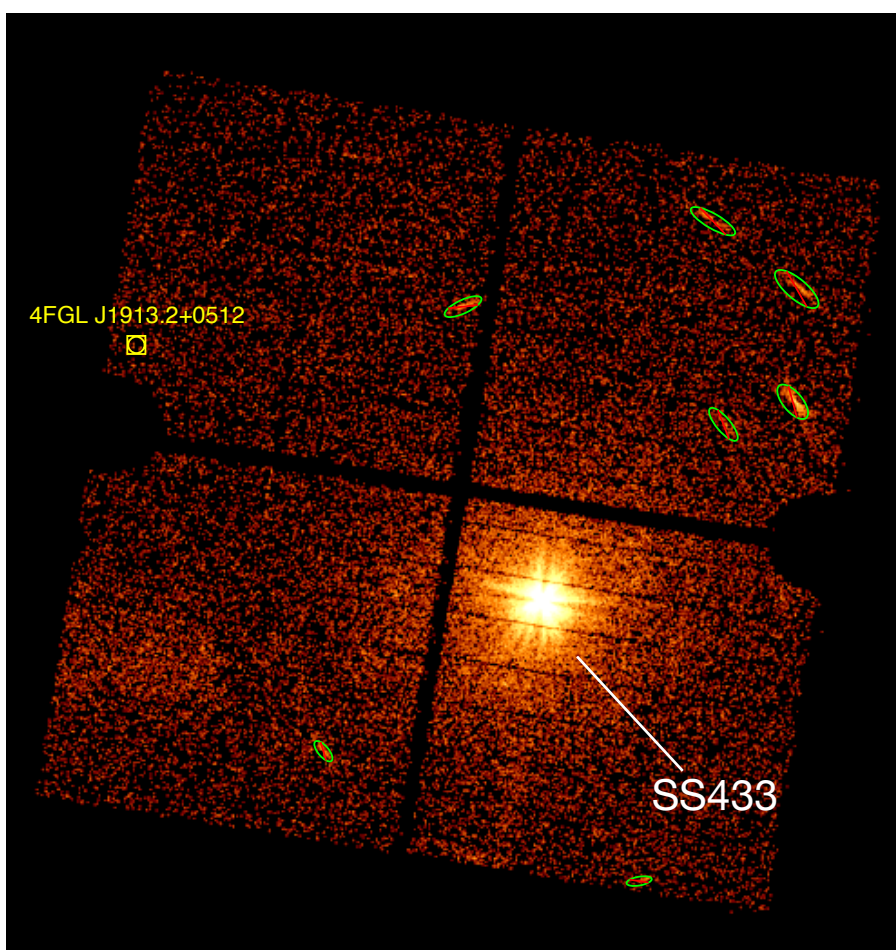
Sunyaev et al. 2025

- What is happening in between SS 433 and X-ray jets?
- "inner cavity" or "dark flow" by eROSITA paper (Sunyaev et al. 2025)
- **XRISM Xtend covered this region (not intentionally!)**

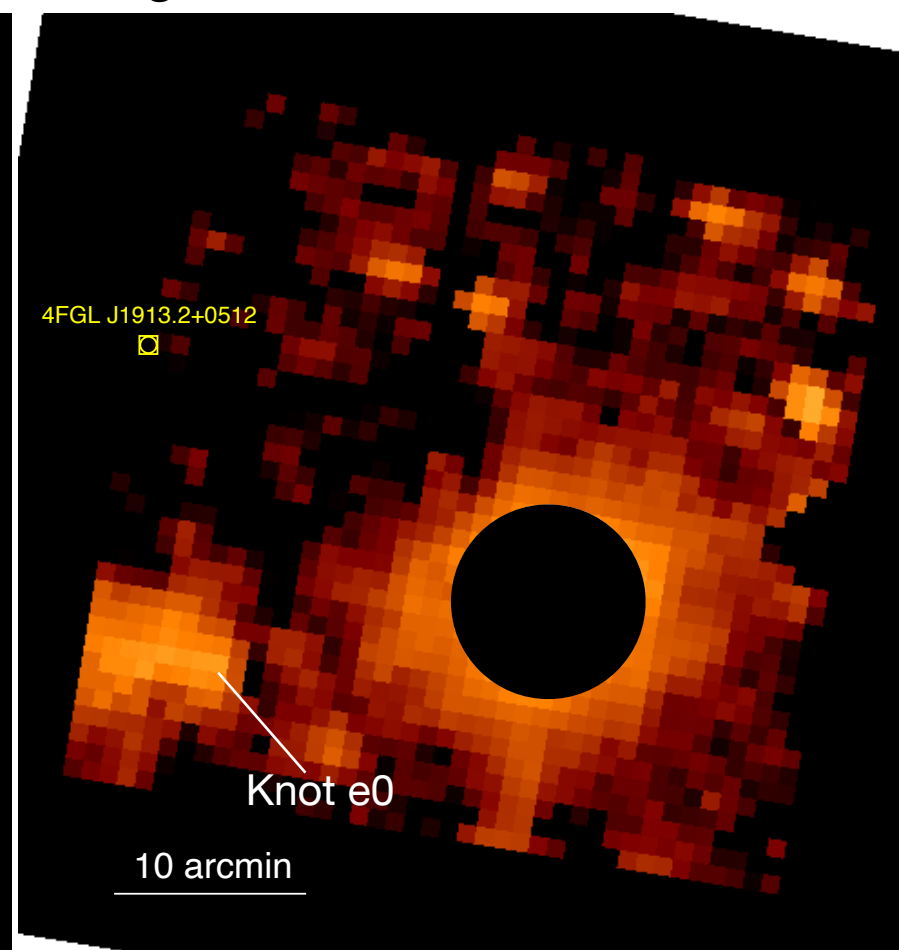


- XRISM observation revealed **diffuse X-ray emission within ~20 pc of SS 433**
- XRISM flux is consistent with the previous XMM upper limit (Kayama D. thesis, 2023)
 - on the order of 10^{-15} erg s $^{-1}$ cm $^{-2}$ arcmin $^{-2}$

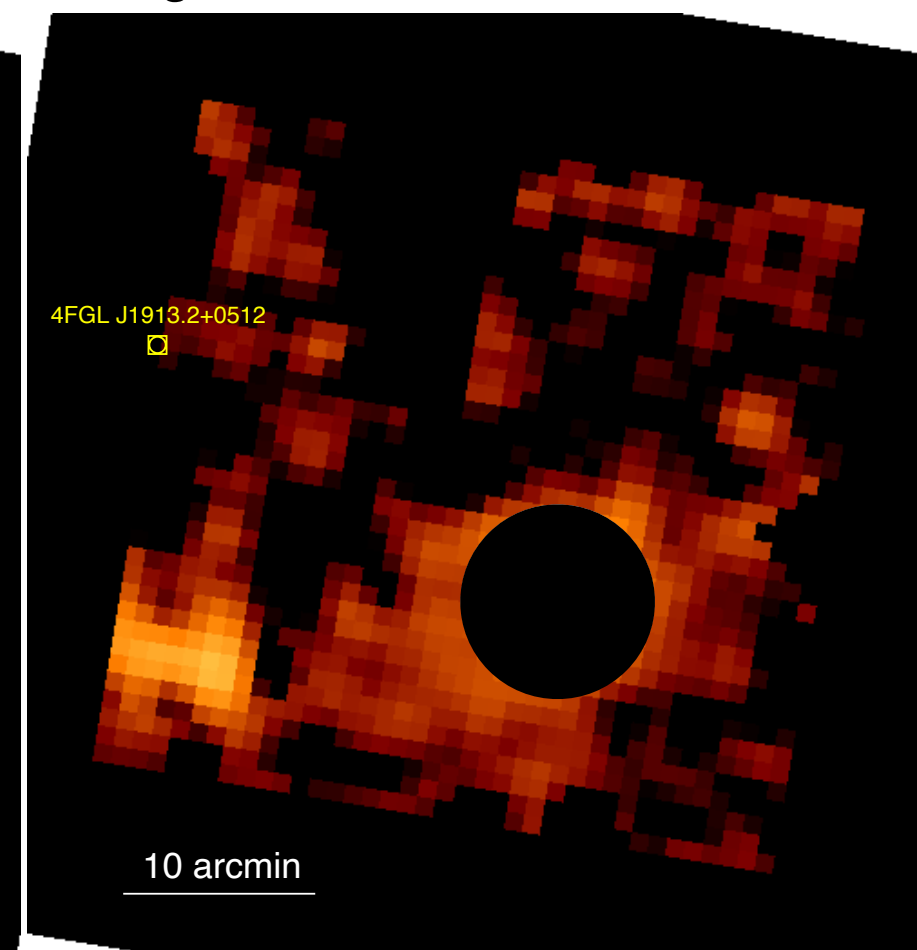
XRISM/Xtend (1.0–2.0 keV)



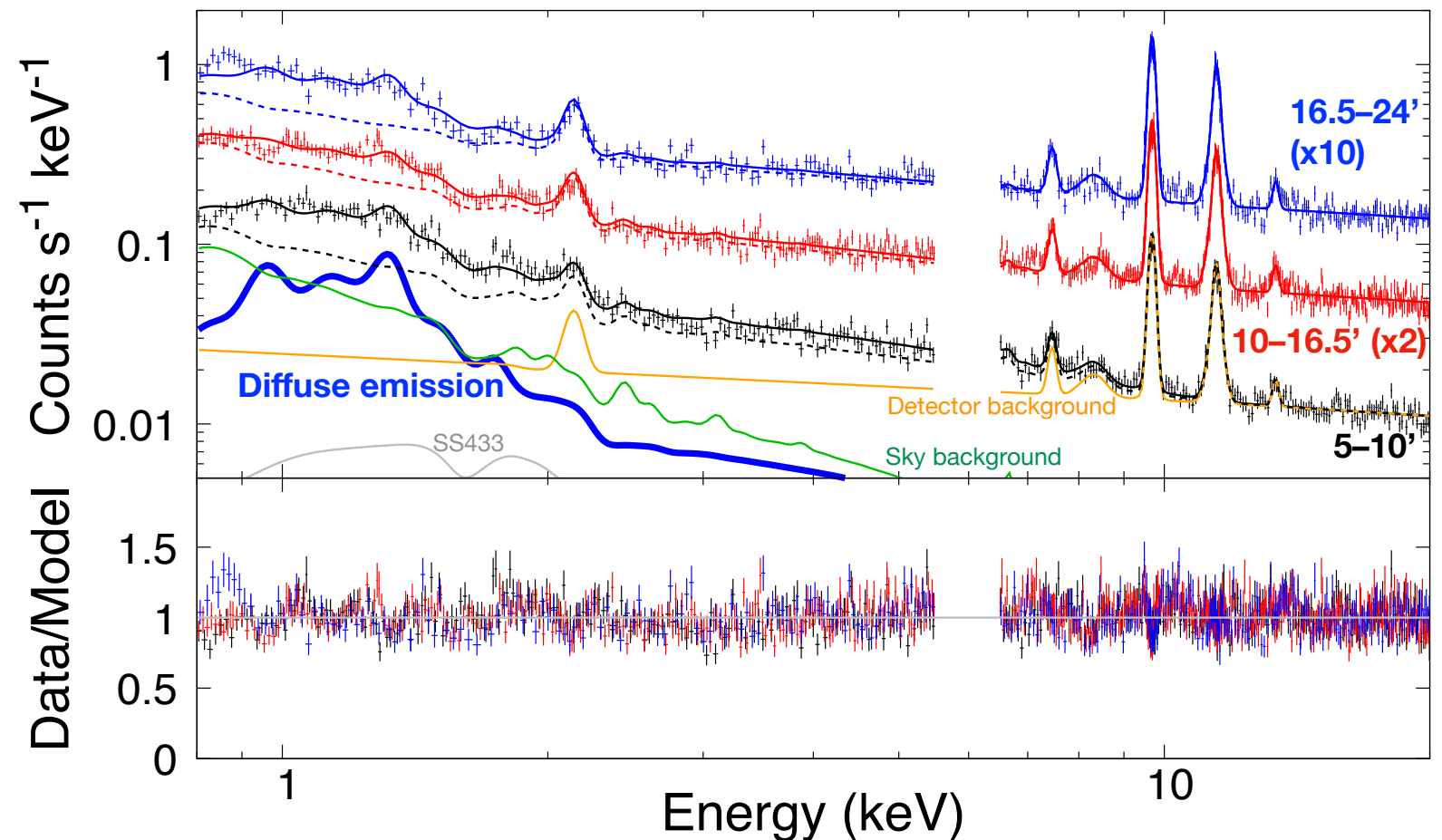
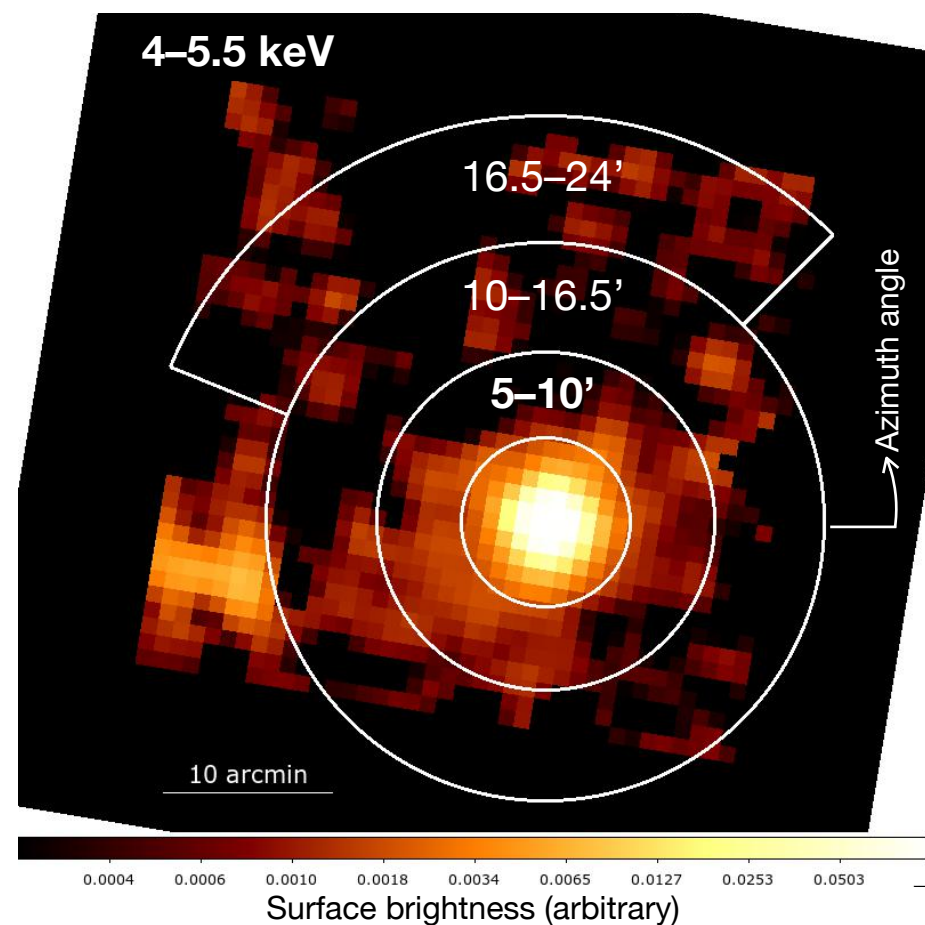
XRISM/Xtend (1.0–2.0 keV),
background-subtracted



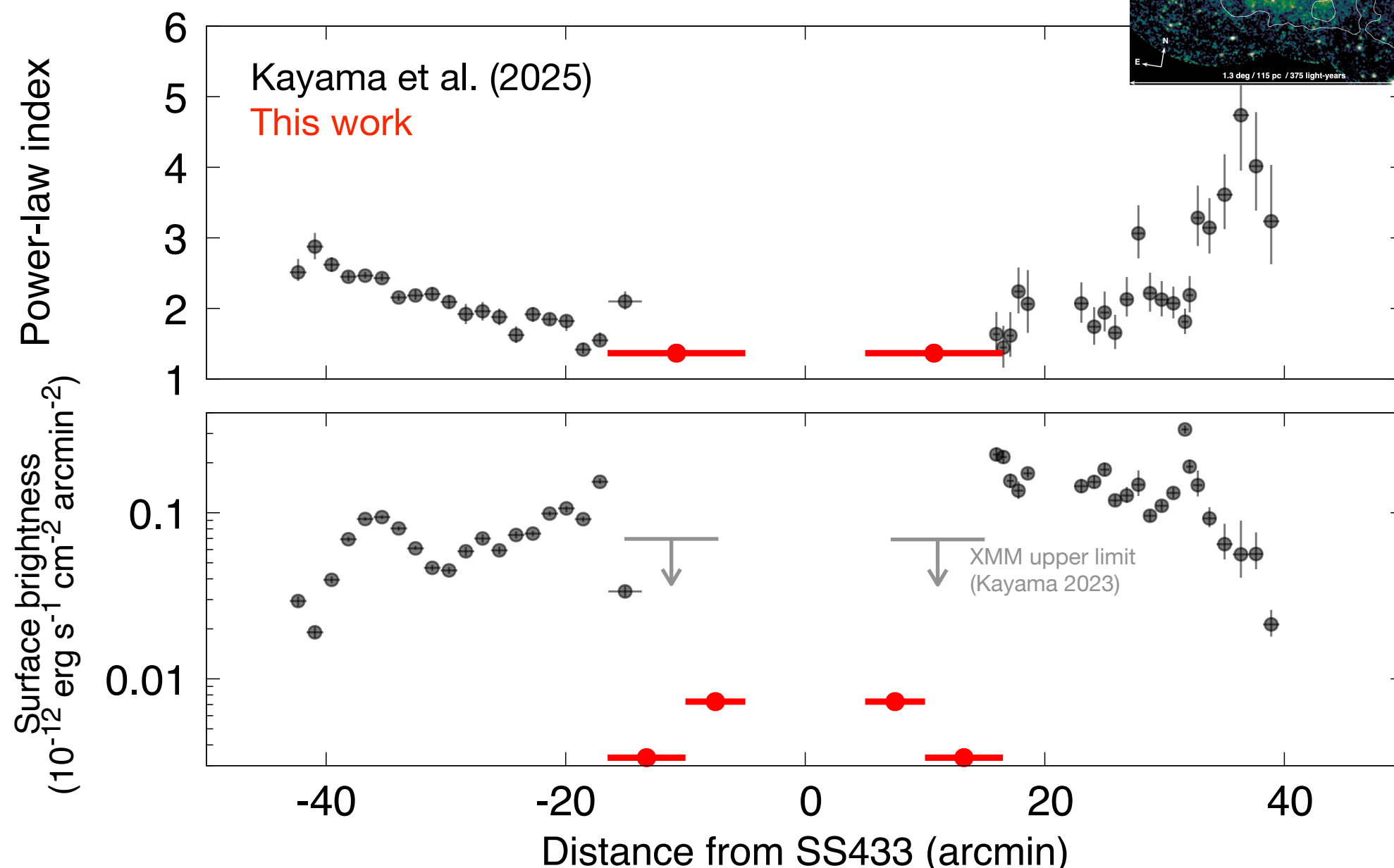
XRISM/Xtend (4.0–5.5 keV),
background-subtracted



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 - on the order of 10^{-15} erg s $^{-1}$ cm $^{-2}$ arcmin $^{-2}$
- The diffuse spectrum is explained with **thermal (~ 0.3 keV) + power-law ($\Gamma \sim 1.3$)** (hard to determine the shape precisely because it is mostly below background)

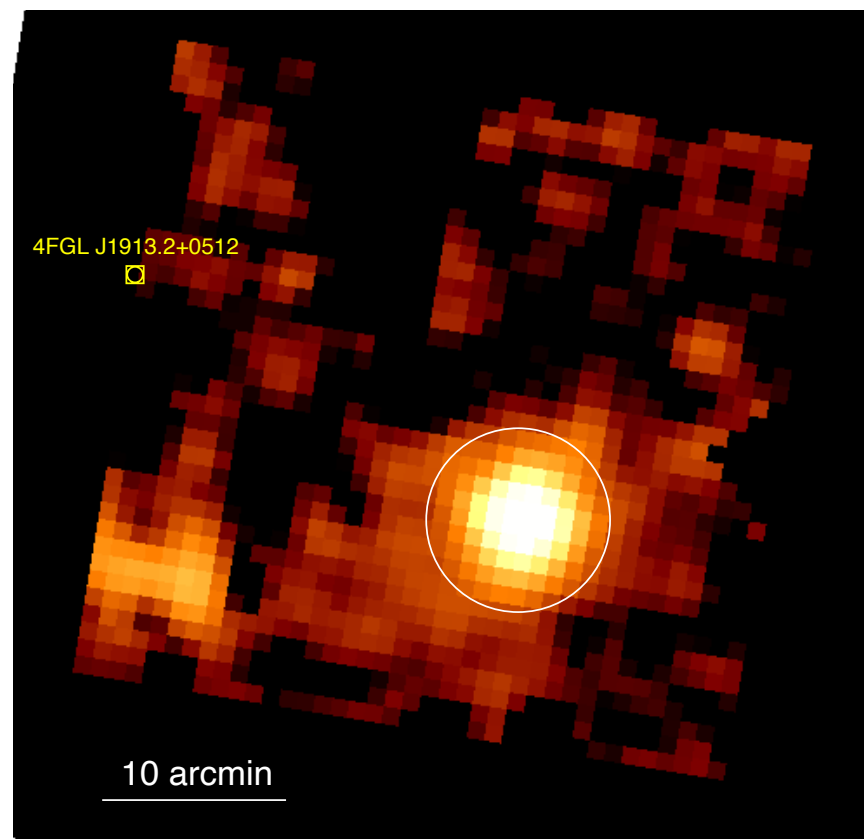


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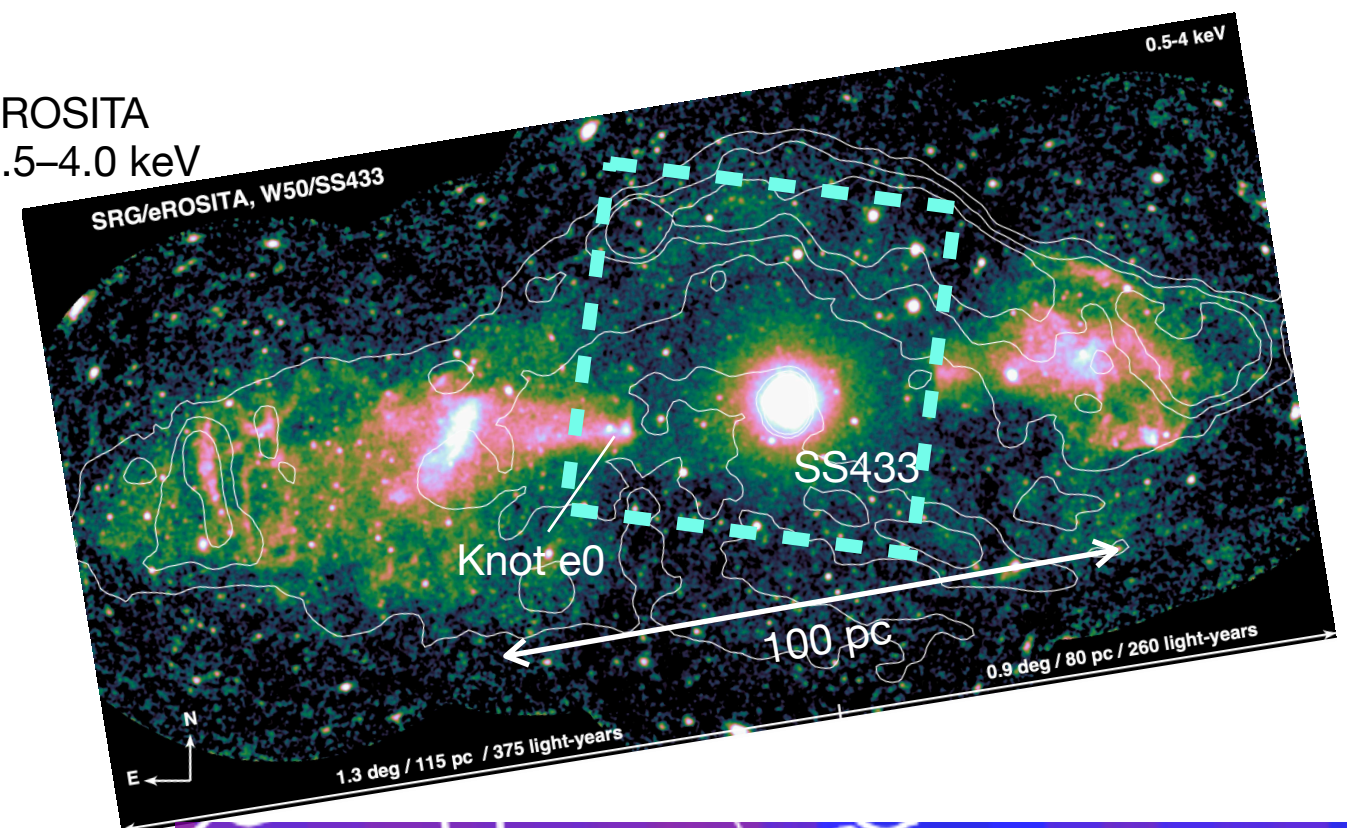


- XRISM observation revealed diffuse X-ray emission within ~ 20 pc of SS 433
- XRISM flux is consistent with the previous XMM upper limit (Kayama D. thesis, 2023)
- Similar to the sub-PeV distribution?? (...but note that XRISM cannot resolve point sources)

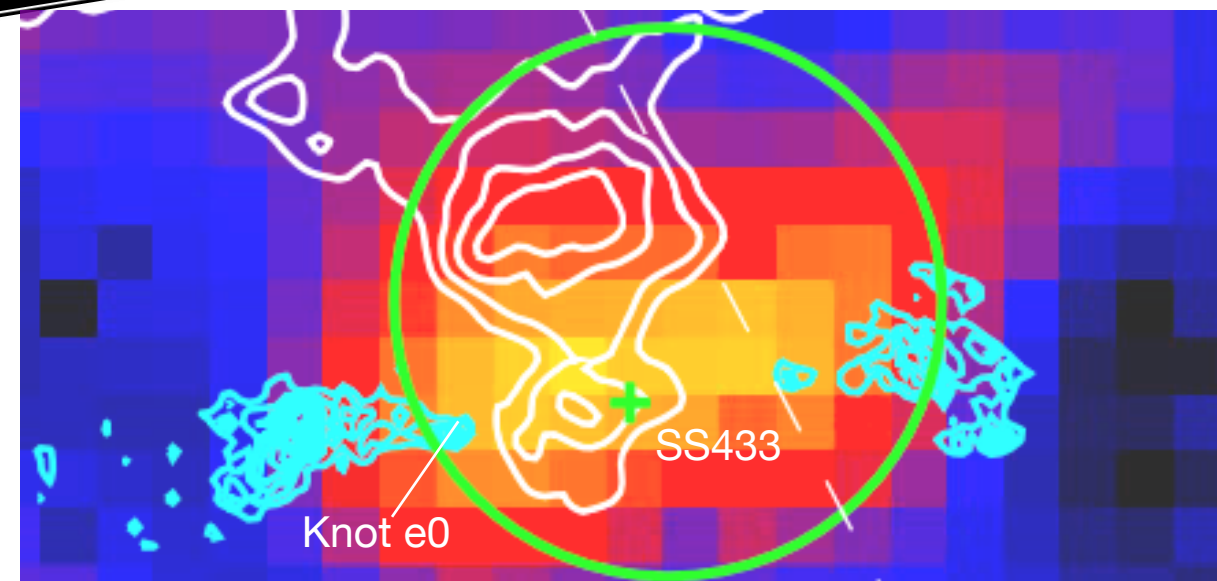
XRISM Xtend background-subtracted image (4.0–5.5 keV)



eROSITA
0.5–4.0 keV



LHAASO
> 100 TeV



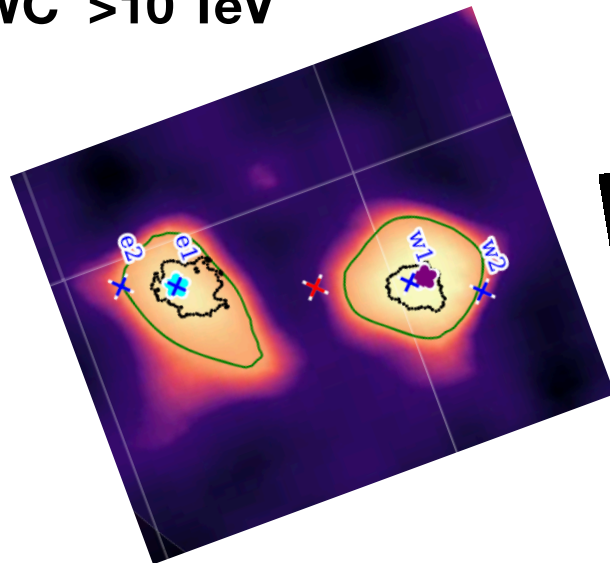
SS 433/W50: origin of the diffuse X-rays

Suzuki et al. in prep.

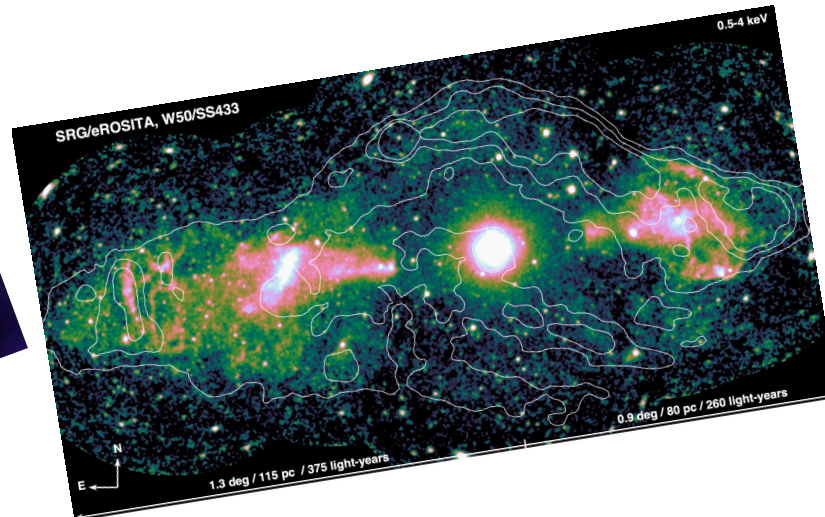


EAST & WEST JETS

HAWC >10 TeV



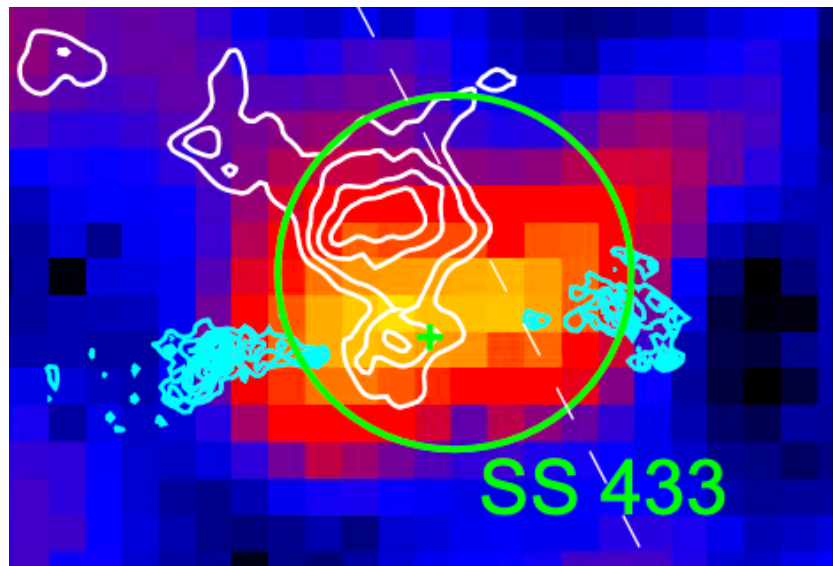
eROSITA 0.5-4.0 keV



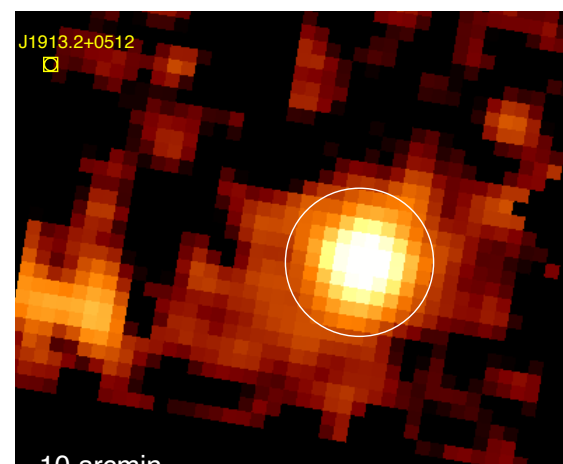
- Jet termination shocks
- GeV–TeV electrons & protons

CENTER

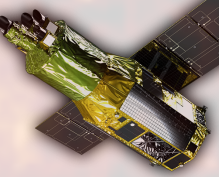
LHAASO >100 TeV



Xtend 4.0–5.5 keV



- Some unidentified processes which dissipate jet energy (internal shocks? recollimation shocks?)
- PeV electrons & protons

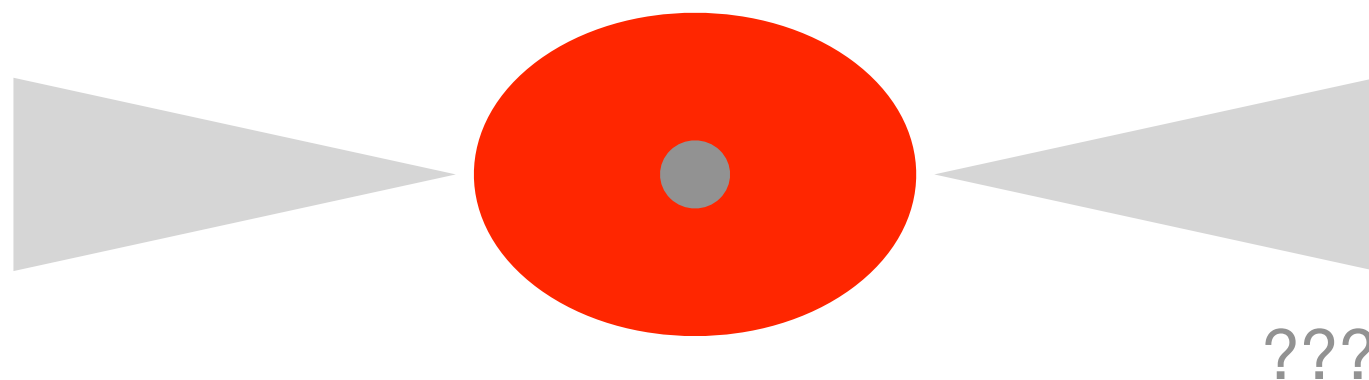


EAST & WEST JETS



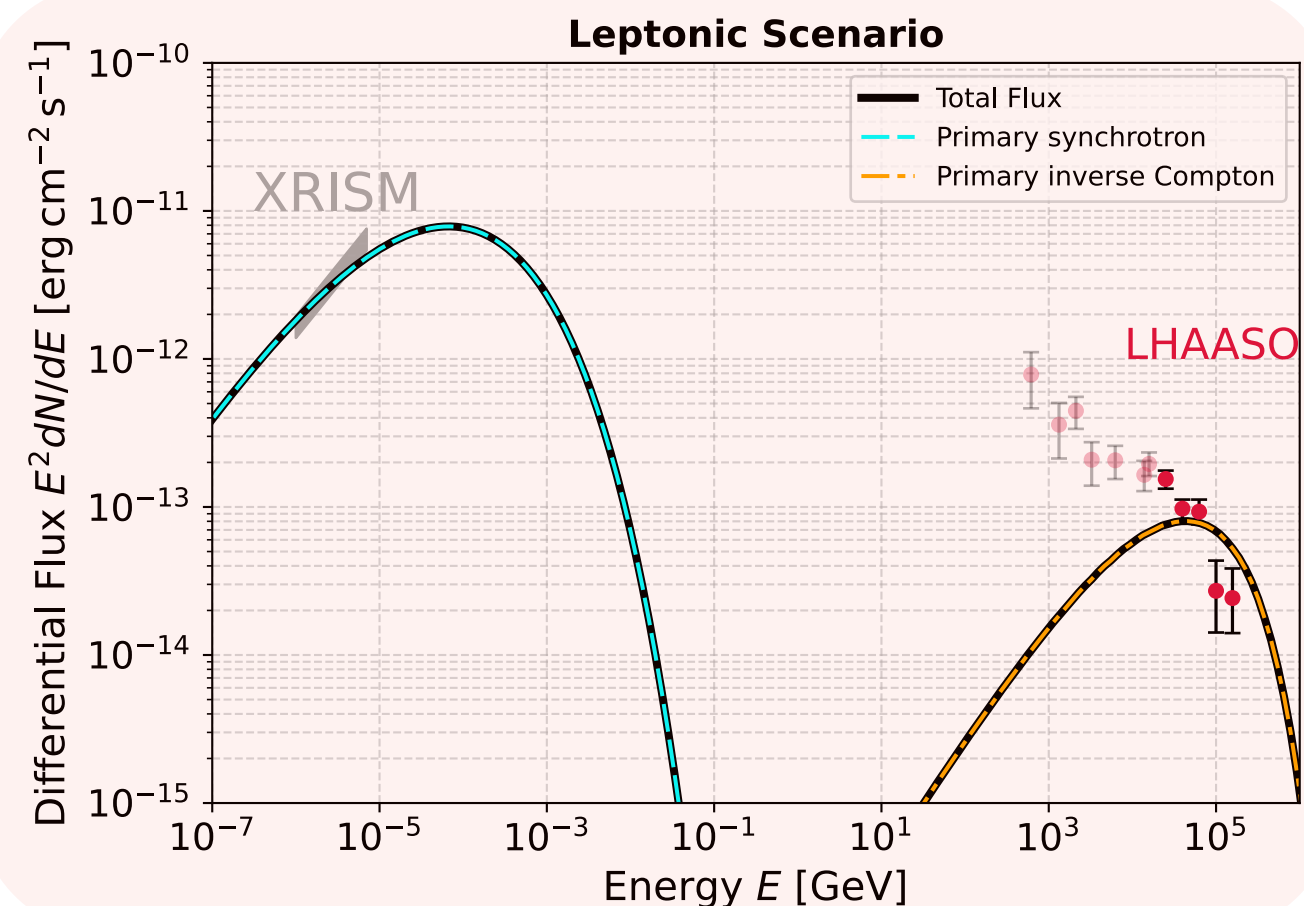
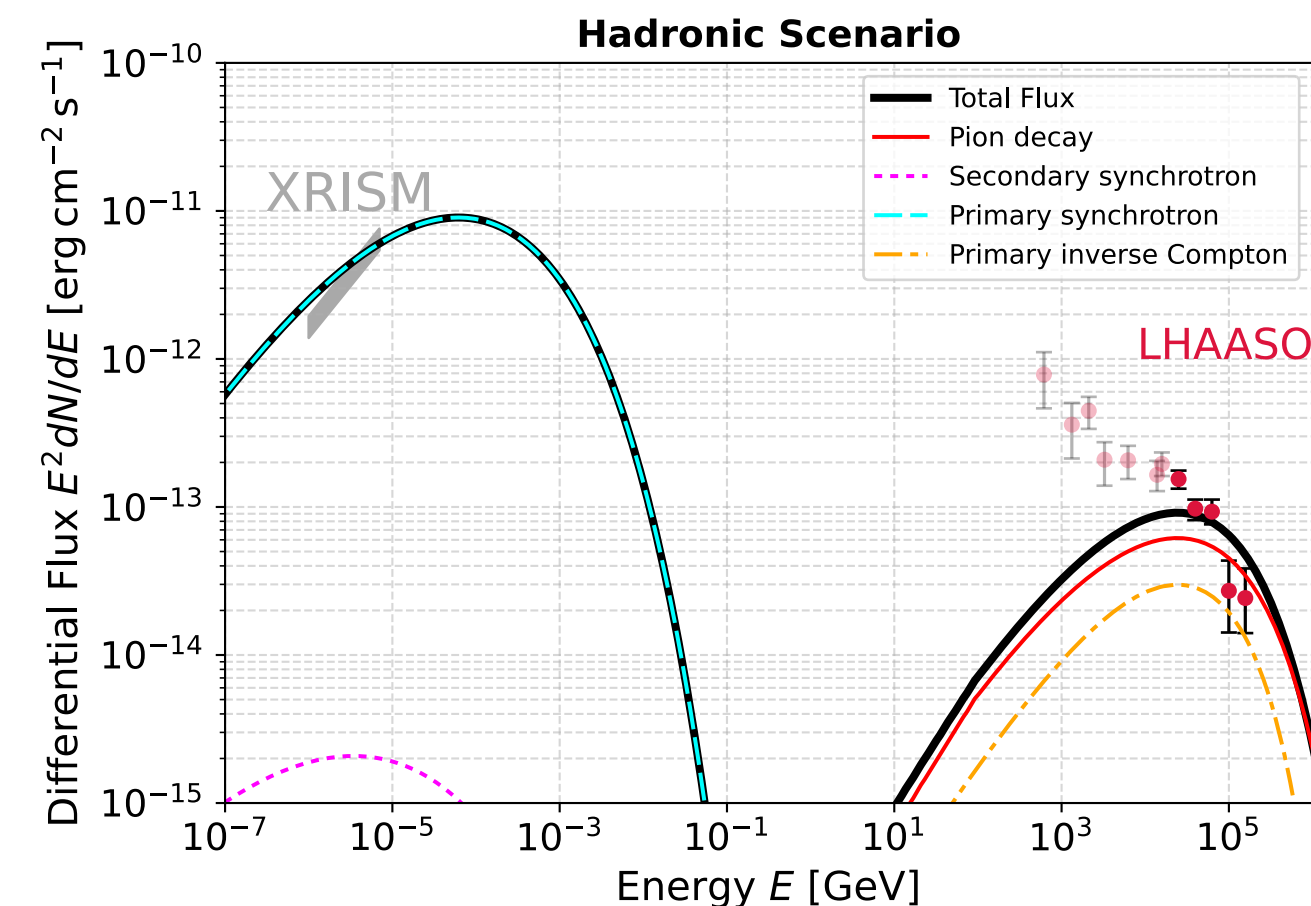
- Jet termination shocks
- GeV–TeV electrons & protons

CENTER



- Some unidentified processes which dissipate jet energy (internal shocks? recollimation shocks?)
- PeV electrons & protons

- If diffuse X-rays & LHAASO sub-PeV source are of the same origin...
Leptonic scenario is more feasible:
 - hard X-ray spectrum smoothly explains sub-PeV data
 - required electron energy budget ($L_e \sim 7 \times 10^{35} \text{ erg s}^{-1}$) is reasonable
- <40 TeV gamma-rays maybe from the outer X-ray jet regions (another component)



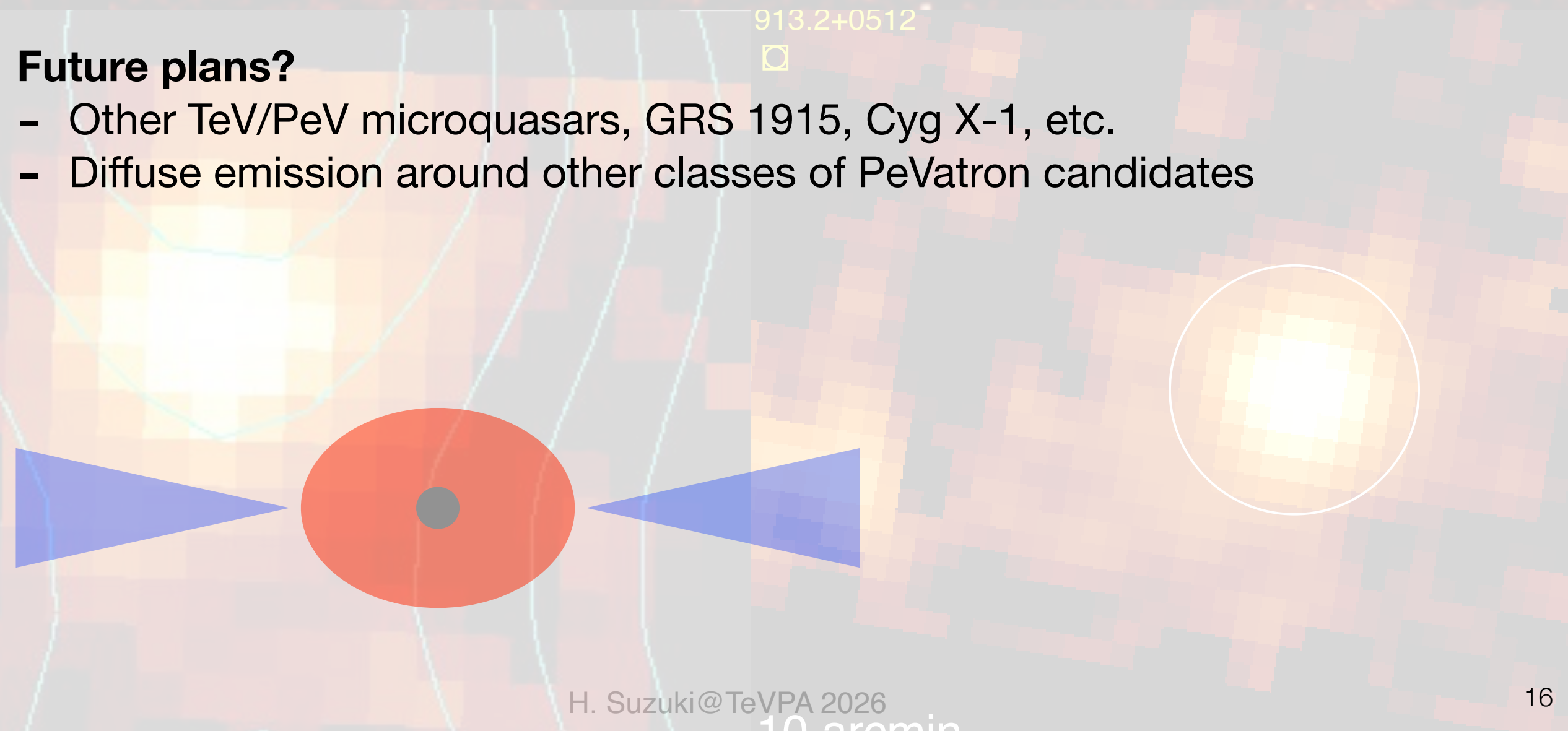
X-rays from acceleration sites tell us about the acceleration physics

XRISM/Xtend observation of SS 433/W50

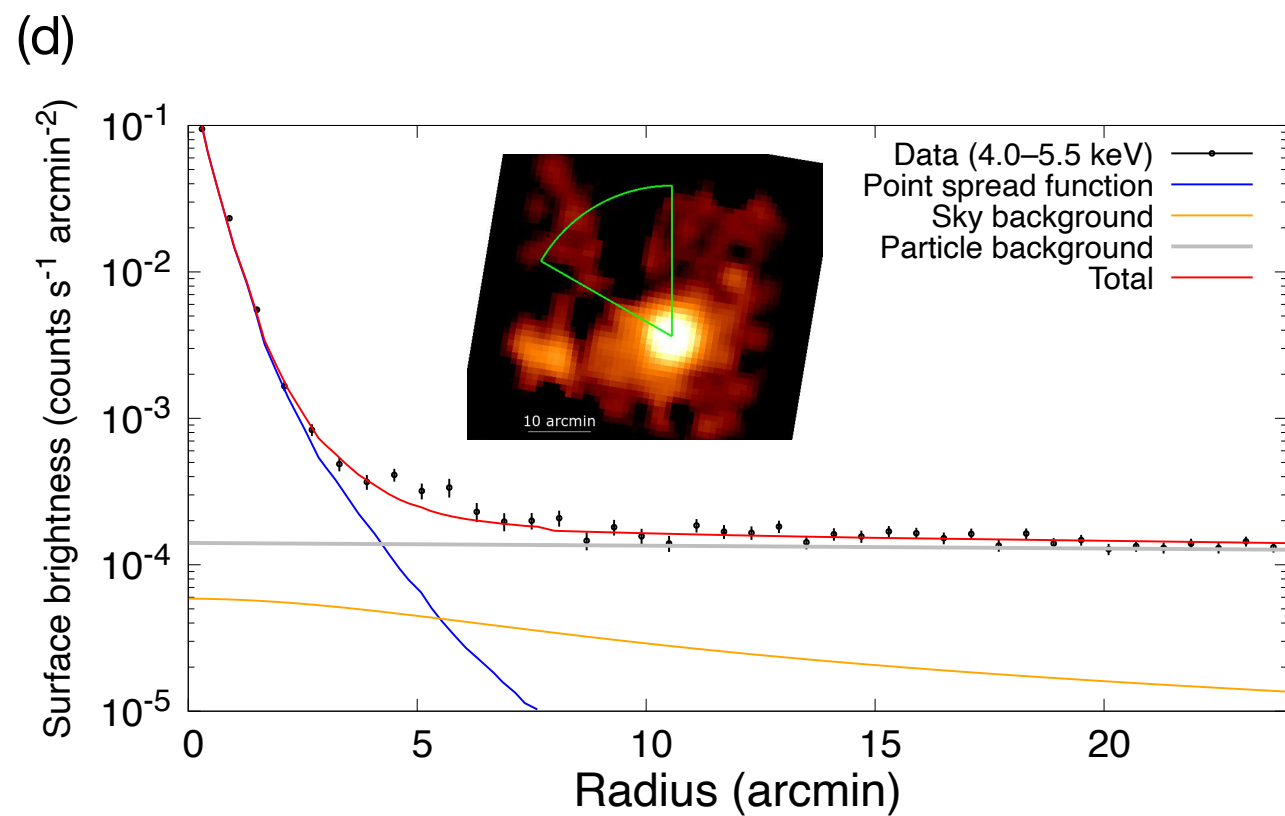
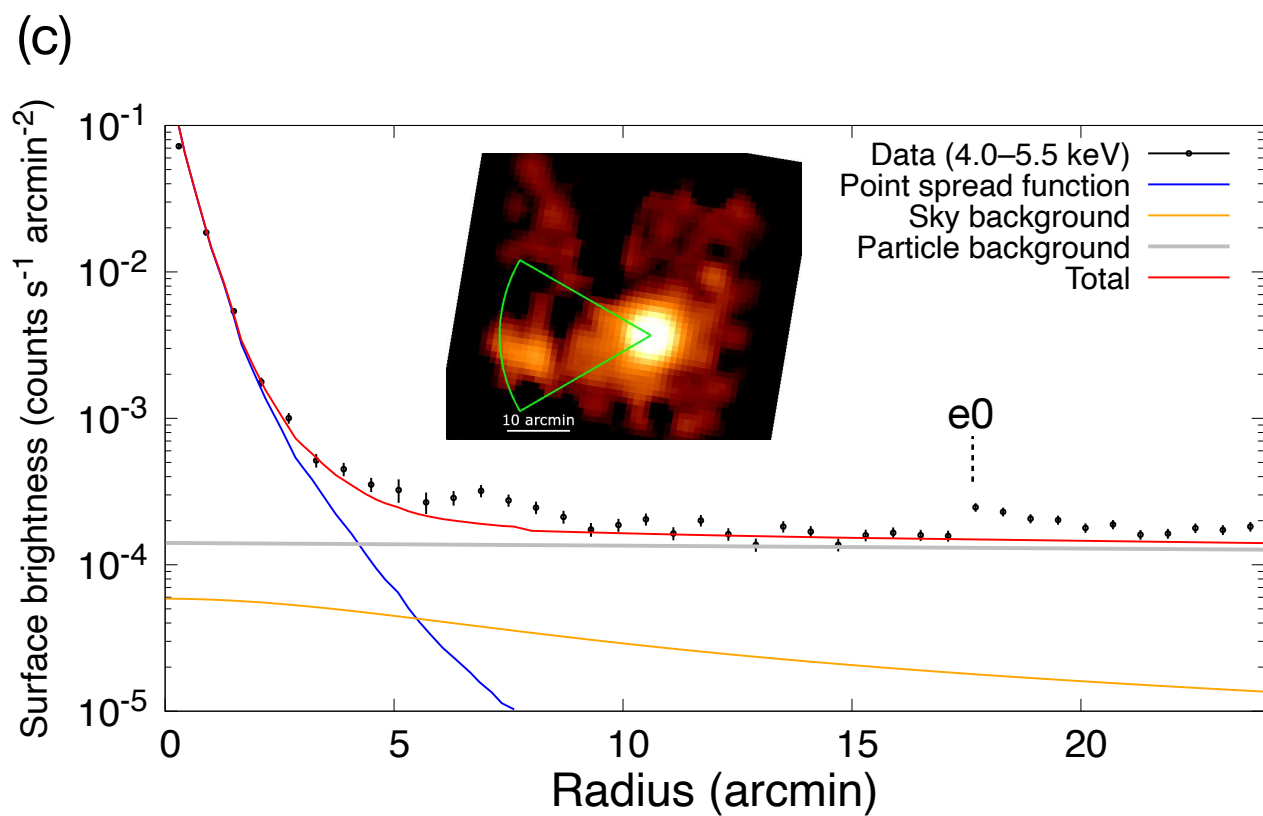
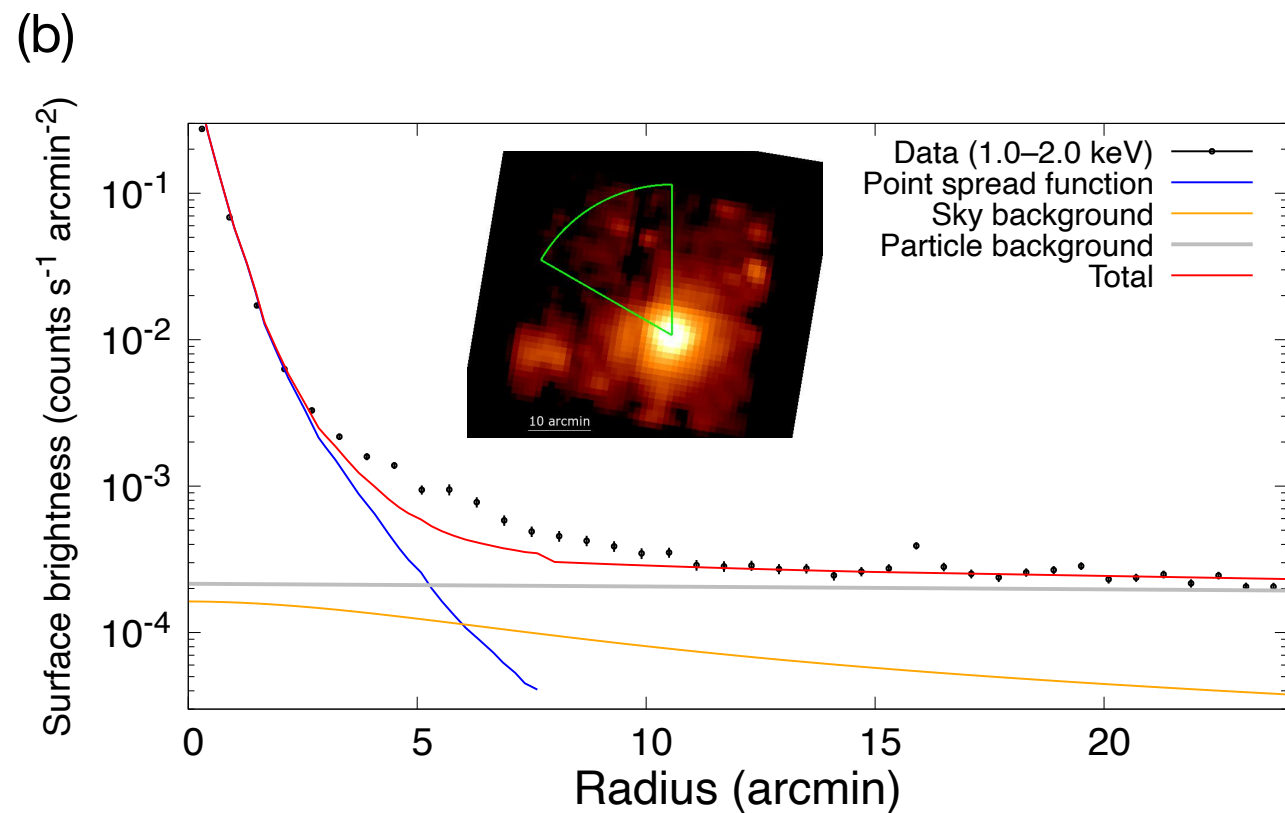
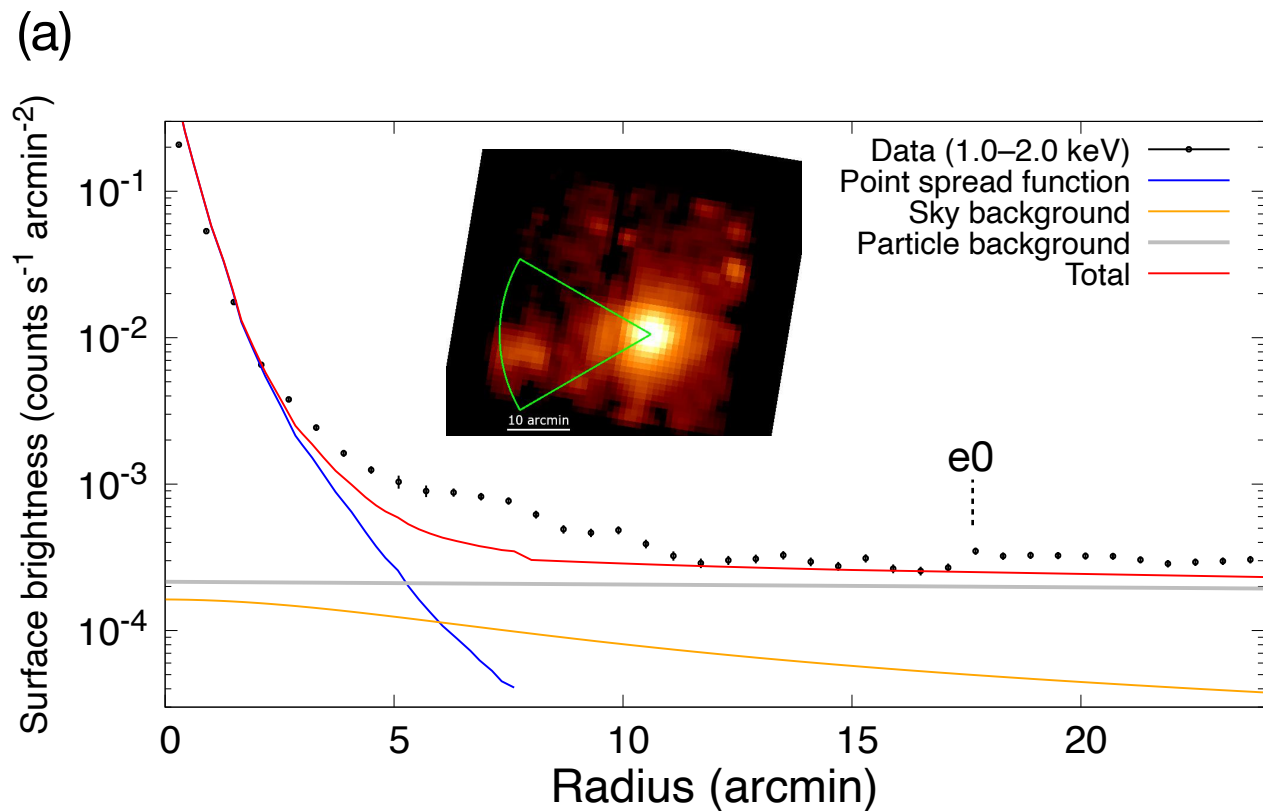
- Diffuse X-rays around ~ 20 pc of SS 433 ("inner cavity") were found
- Different from the TeV distribution (and possibly similar to PeV)
- Interpretation: unidentified energy dissipation processes produce X-rays, which also produce PeV particles. Leptonic scenario is more feasible

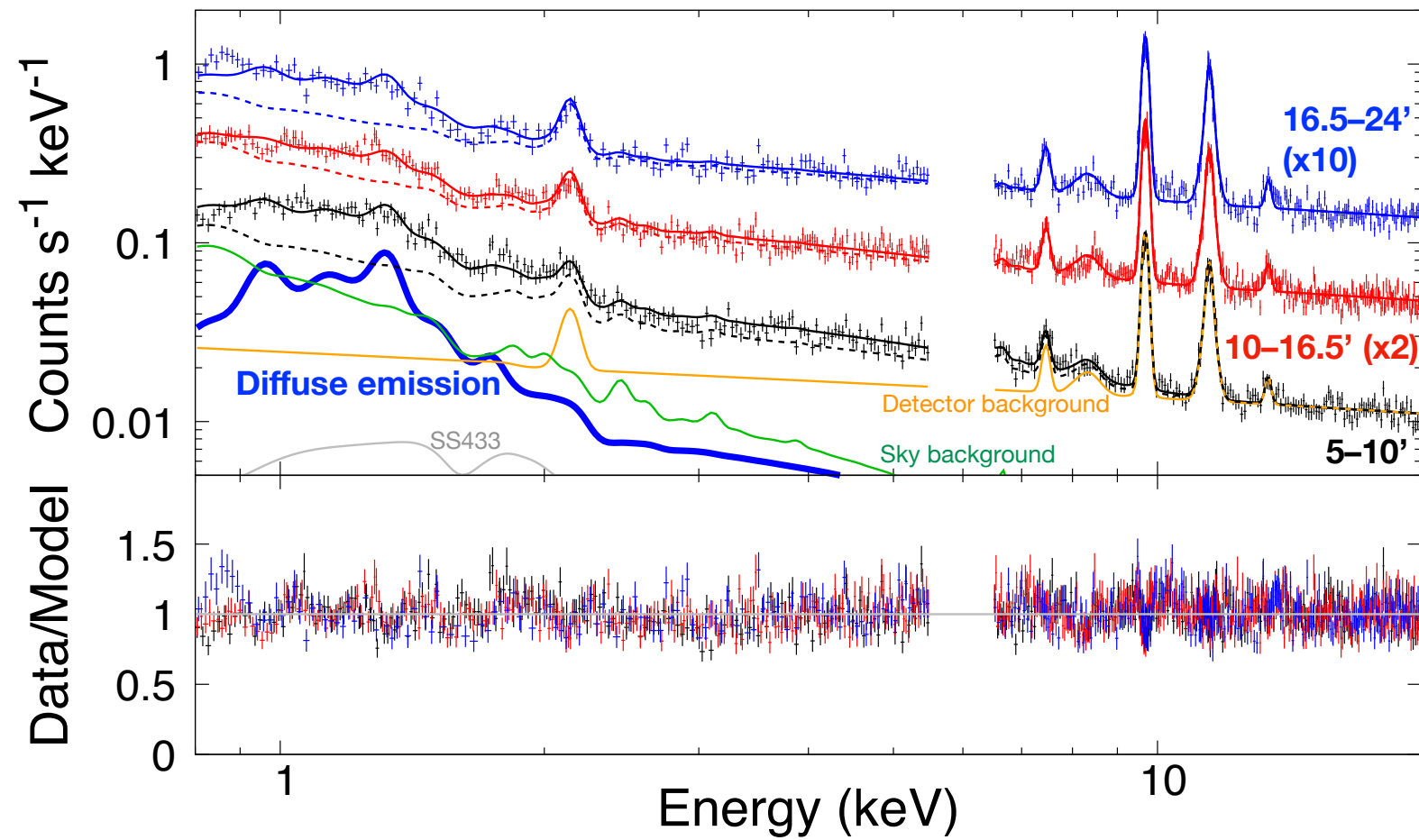
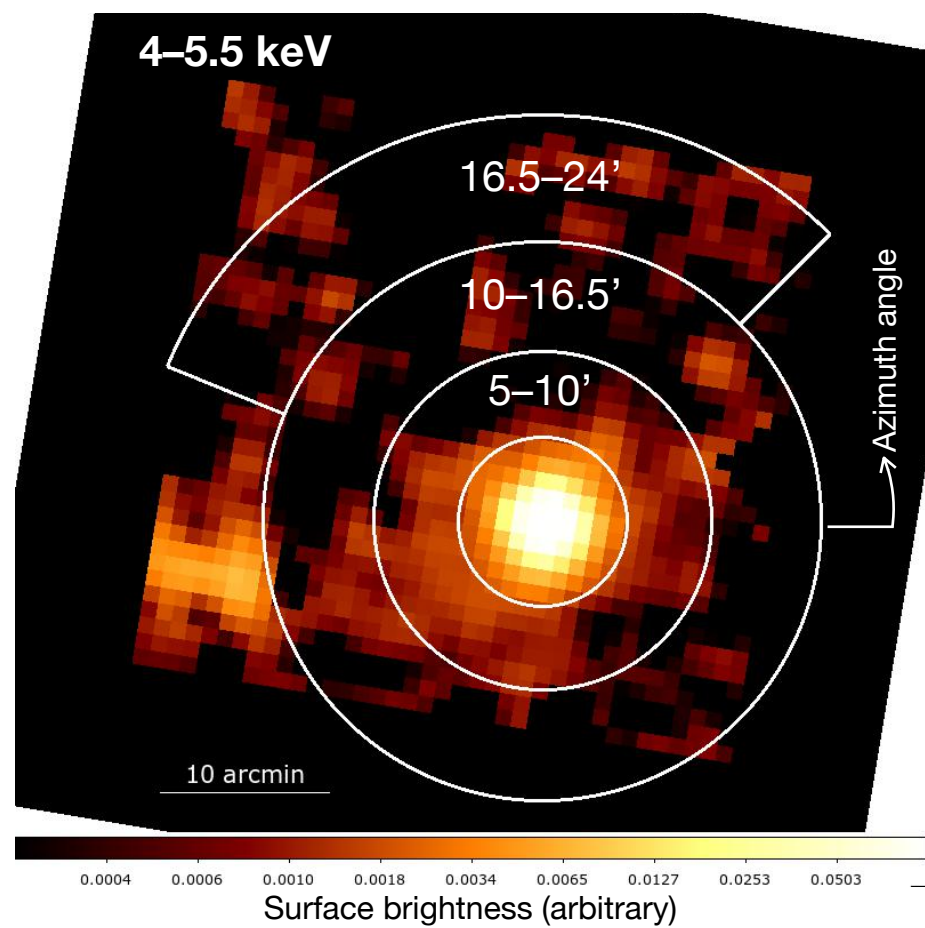
Future plans?

- Other TeV/PeV microquasars, GRS 1915, Cyg X-1, etc.
- Diffuse emission around other classes of PeVatron candidates

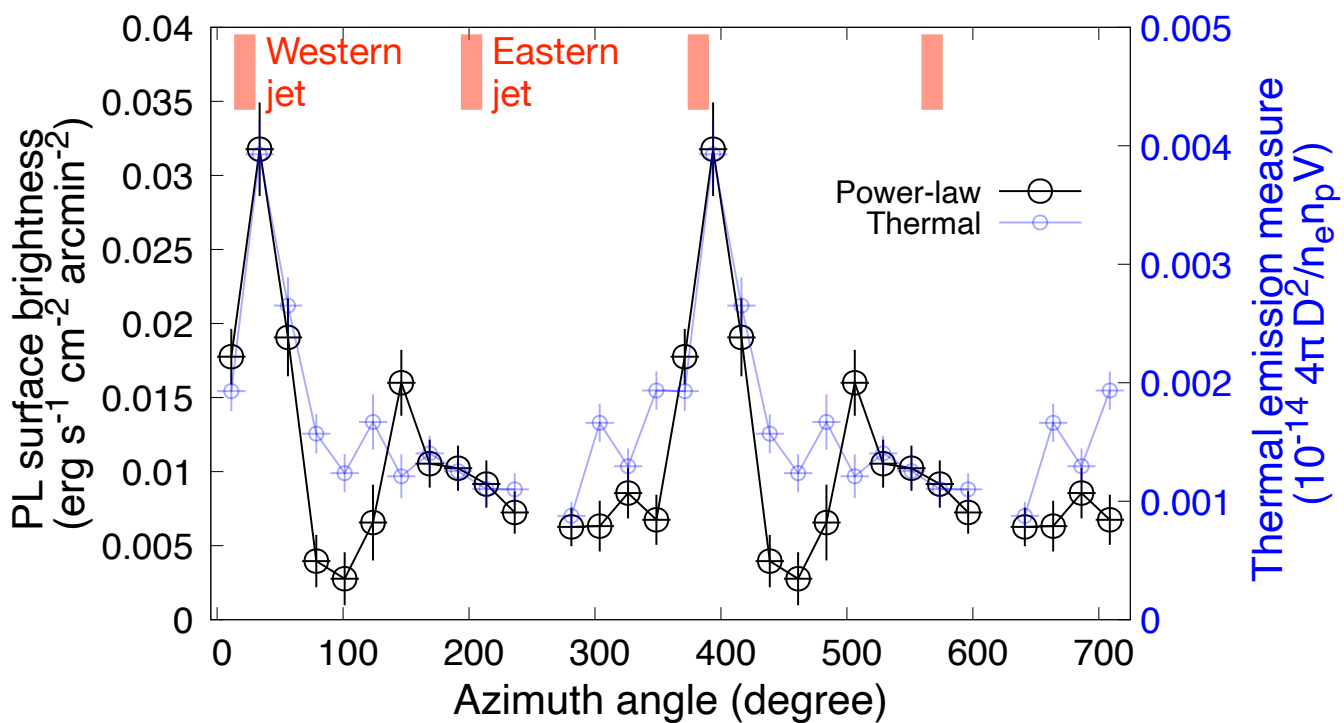


c.f.

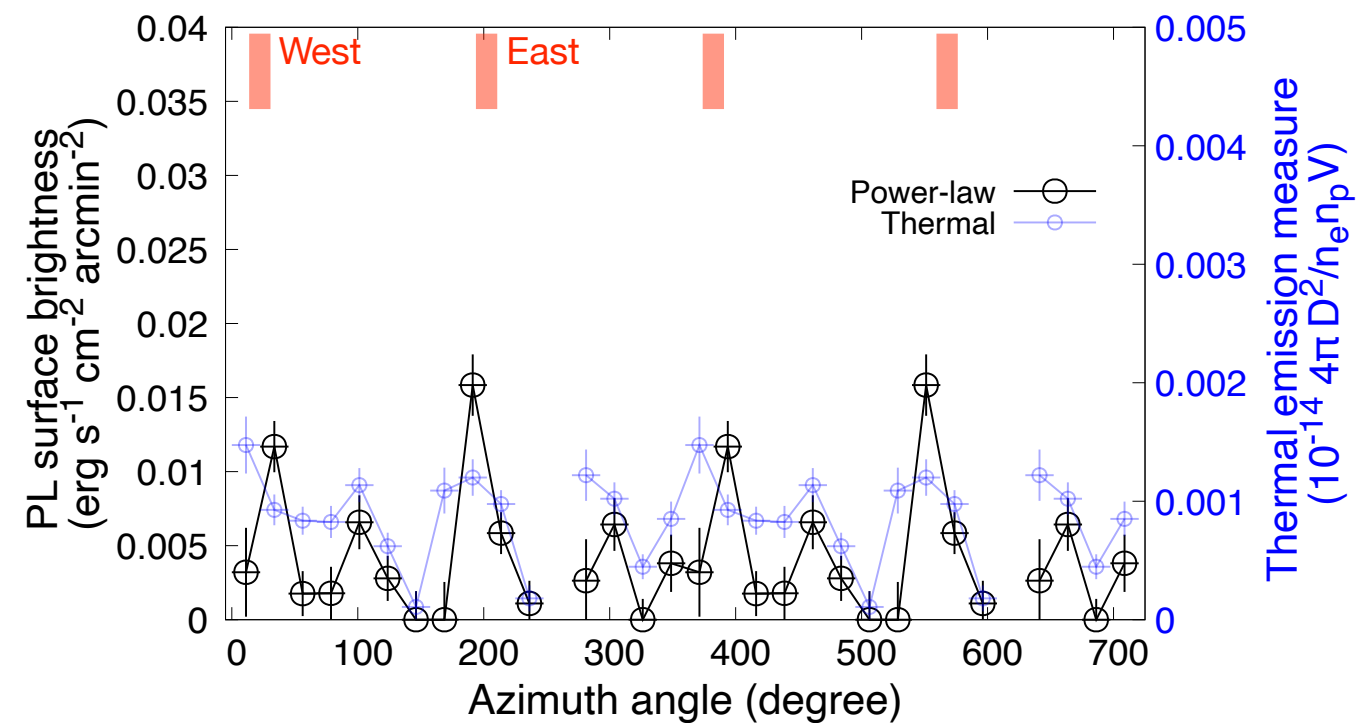




(a) 5–10 arcmin from SS433



(b) 10–16.5 arcmin from SS433



- Excess hard component confirmed with spectroscopy (> 9 sigma)
- Hard component can either be thermal (apec) or non-thermal (power-law)
- Required jet luminosity will be...
 - If non-thermal (= accel. electrons), $\sim 10^{37-38}$ erg s $^{-1}$ (~ 0.01 – 0.1 x Eddington L.)
 - If thermal (= shock-heated plasma), $\sim 10^{39}$ erg s $^{-1}$ ($\sim$ Eddington L.)

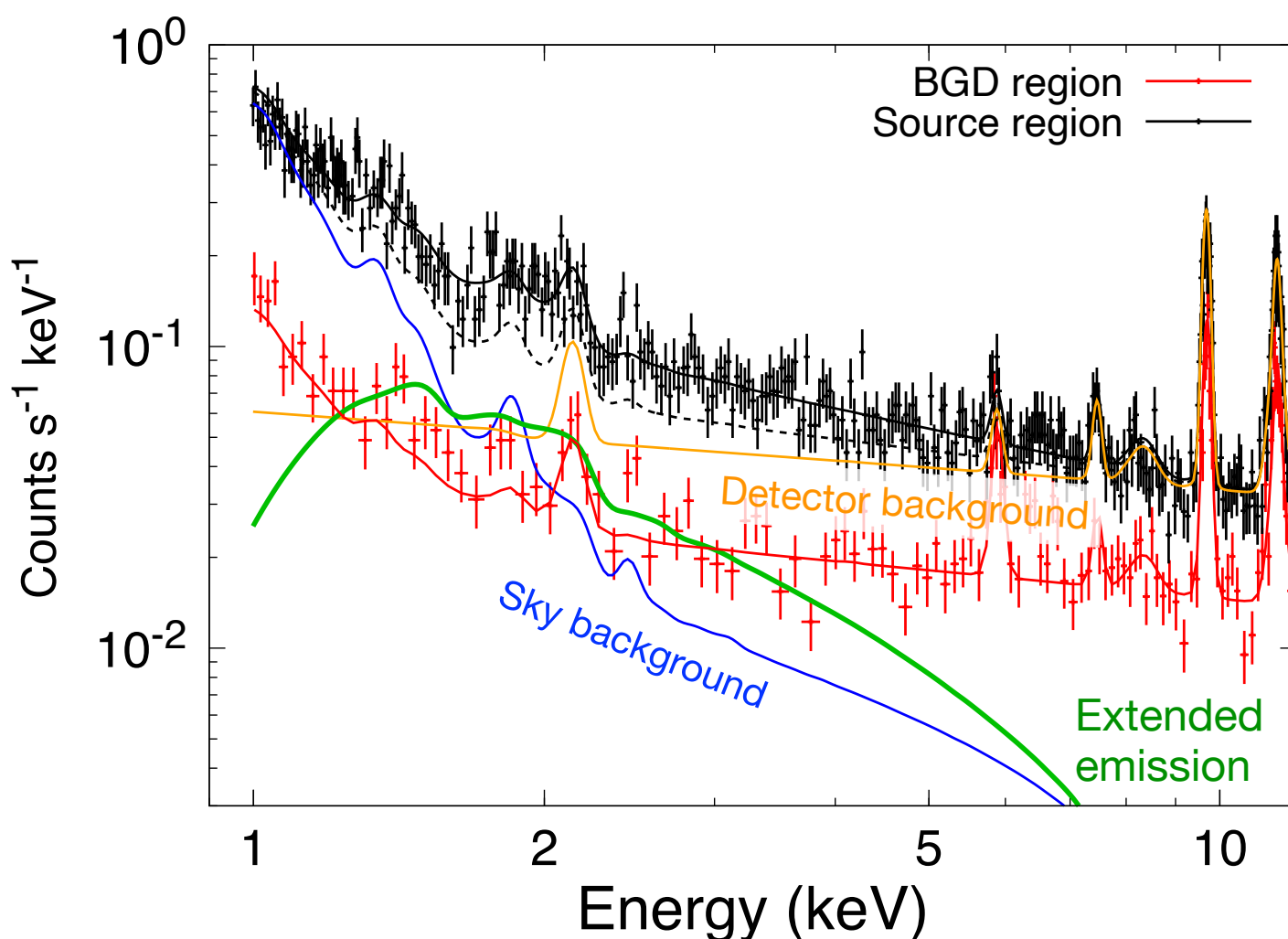


Table 1. Best-fit spectral parameters of the extended emission.

**Non-thermal
(Power-law)**

N_H (10^{22} cm $^{-2}$)	1.8 ± 0.5
Power-law index	2.4 ± 0.3
Power-law flux (2–10 keV) (10^{-15} erg s $^{-1}$ cm $^{-2}$ arcmin $^{-2}$)	7.8 ± 0.9
Integrated power-law flux (2–10 keV) ^a (10^{-12} erg s $^{-1}$ cm $^{-2}$)	4.3 ± 0.5
C -stat./d.o.f.	4190.1/3658

Thermal (apec)

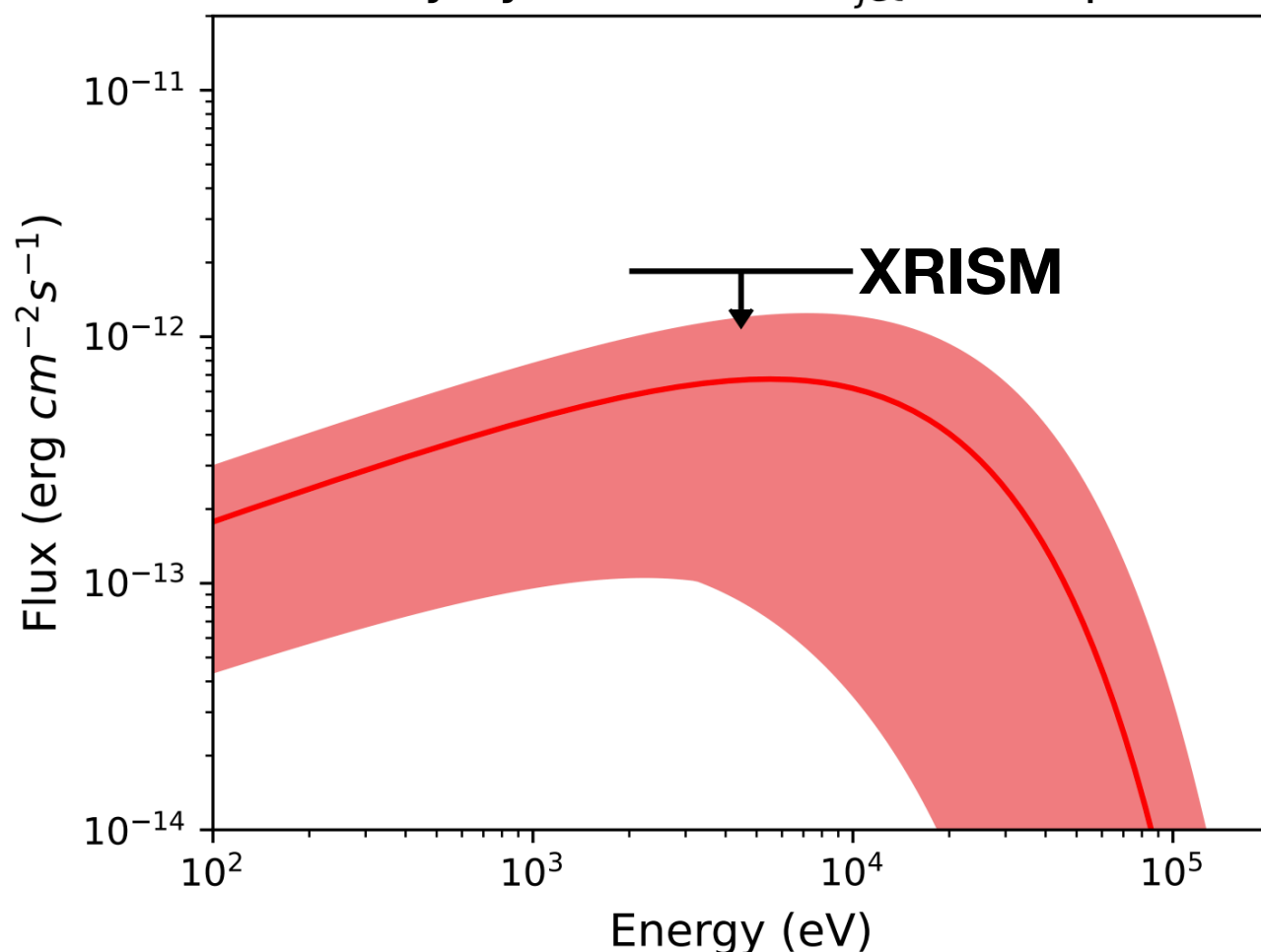
N_H (10^{22} cm $^{-2}$)	1.5 ± 0.4
kT_e (keV)	3.2 ± 0.7
$n_e n_p V$ (10^{58} cm $^{-3}$)	1.3 ± 0.2
C -stat./d.o.f.	4192.3/3658

V4641 Sgr: origin of the diffuse X-rays

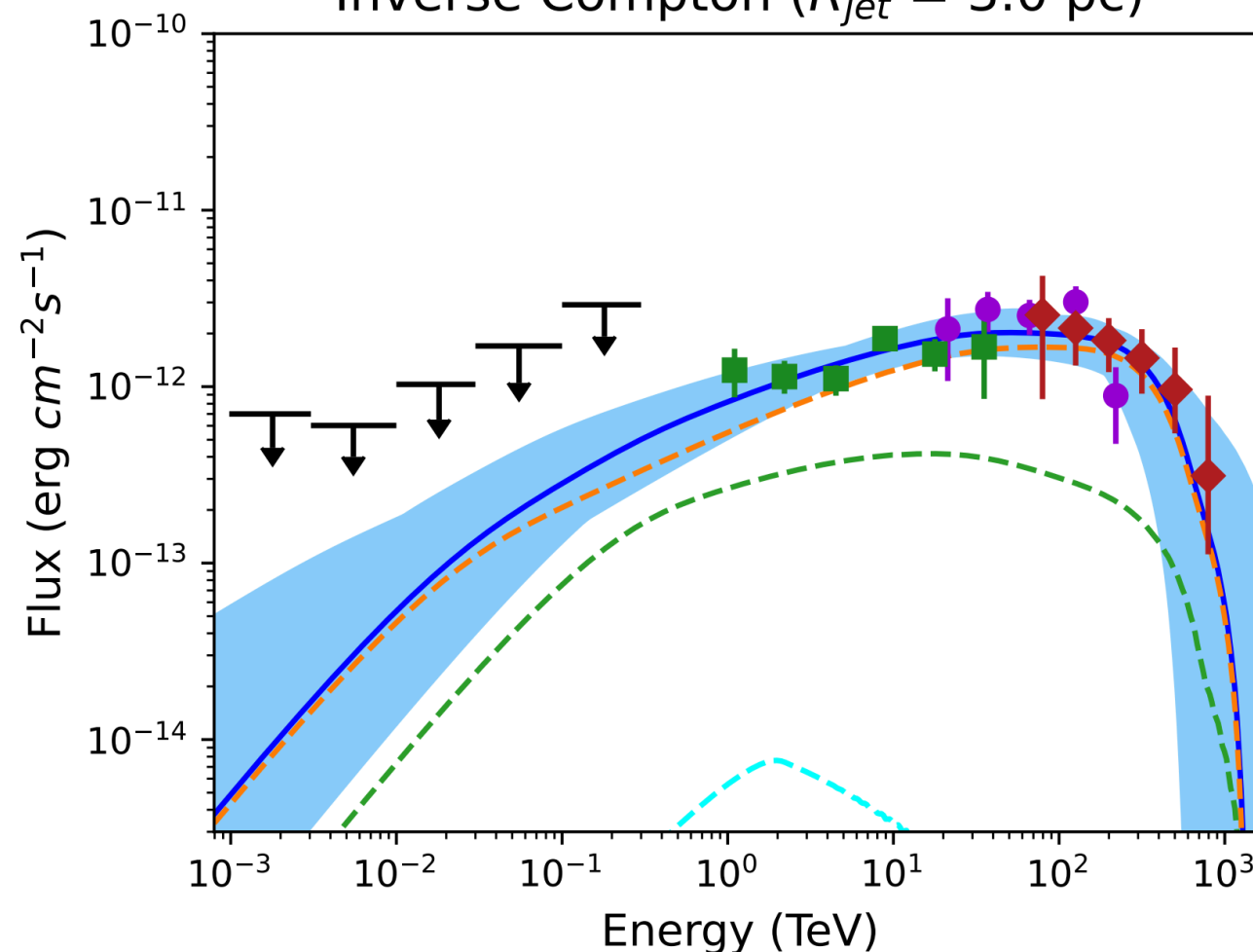


- Diffuse X-rays: electrons near V4641 Sgr or shock-heated plasma, probably unrelated to the HAWC gamma-ray data
- Hard sub-PeV spectrum implies hadronic origin
- But recent theoretical studies suggest leptonic interpretations (e.g., shear acceleration in jets), which is also consistent with the detected X-rays

X-ray synchrotron ($R_{jet} = 3.0$ pc)



Inverse Compton ($R_{jet} = 3.0$ pc)



Wan et al. 2026

Kayama doctoral thesis 2023

4.3 X-ray Emission between SS 433 and Innermost Knots

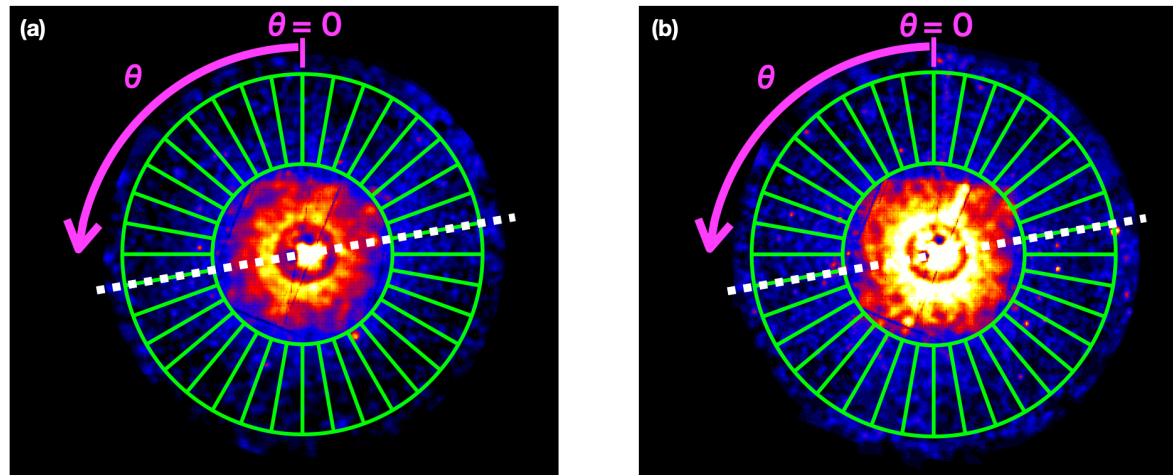


Fig. 4.7: X-ray combined images in the energy band (a) 0.5–1.5 keV and (b) 2.0–7.0 keV obtained with *XMM-Newton*. The flux extract regions for measurement of the X-ray emission around SS 433 are overlaid with a green pie. The origin and circumferential direction of θ as defined as noted with a magenta line. The white dashed lines indicate the jet precessional axis. Note that the exposures are corrected.

Xtend fluxes (translated to $< 1e-14$ erg s $^{-1}$ cm $^{-2}$ arcmin $^{-2}$) are well below (consistent with) the UL (7–8e-14) claimed by Kayama 2023

Based on these results, we estimate the upper limit flux of the jet-originated emission in this region from the combined X-ray images of the *XMM-Newton* observations. We measured the count rate within a width of ± 1 bins around the axis, corresponding to the jet precessional angle of $\sim 20^\circ$. The X-ray count rates within these regions are 6.3×10^{-2} counts s $^{-1}$ and 6.9×10^{-2} counts s $^{-1}$ for the eastern and western jets, respectively, in the 0.5–10.0 keV energy range. The upper limit count rates of the total W50-originated X-ray emission are estimated as 2.0×10^{-2} counts s $^{-1}$ and 2.9×10^{-2} counts s $^{-1}$ for the eastern and western jets, respectively, after subtracting the contribution of the sky and particle background. Several authors detected the X-ray emission from the SS 433 jet at a distance of $\leq 10^{15}$ cm from the jet base (e.g., Migliari, Fender, and Méndez, 2002; Namiki et al., 2003; Migliari et al., 2005). The spectrum is well fitted with a power law with a photon index of $\Gamma = 1.40$ and an interstellar absorption with a column density of $N_H = 1.31 \times 10^{22}$ cm $^{-2}$ (Namiki et al., 2003). Assuming the same model and parameters, the estimated upper limits of the surface brightness for the eastern and western jets are 6.7×10^{-14} ergs cm $^{-2}$ s $^{-1}$ arcmin $^{-2}$ and 8.4×10^{-14} ergs cm $^{-2}$ s $^{-1}$ arcmin $^{-2}$, respectively in 0.5–7.0 keV the energy.

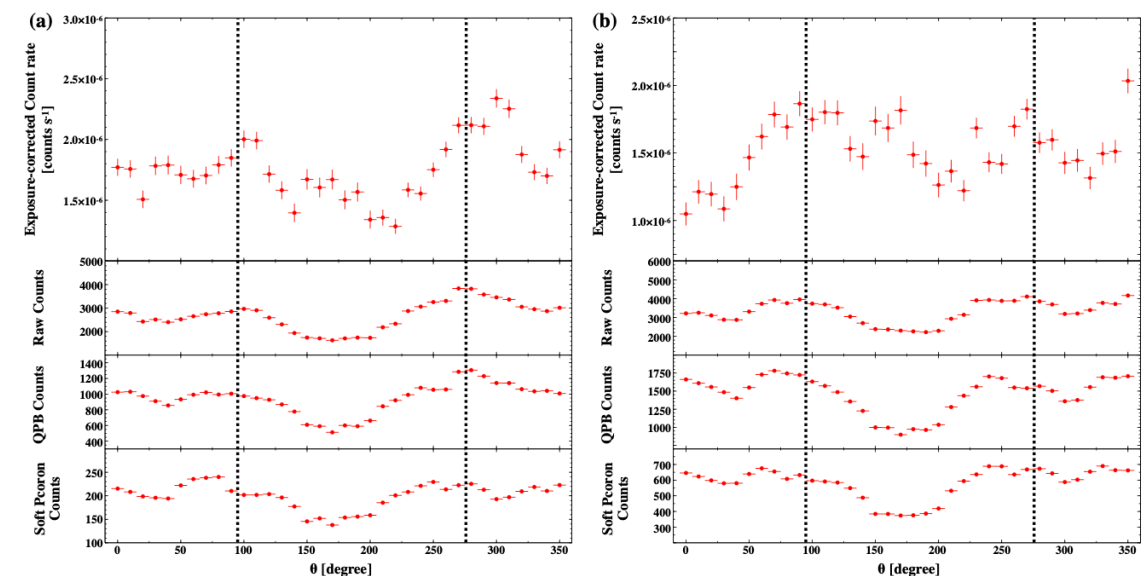
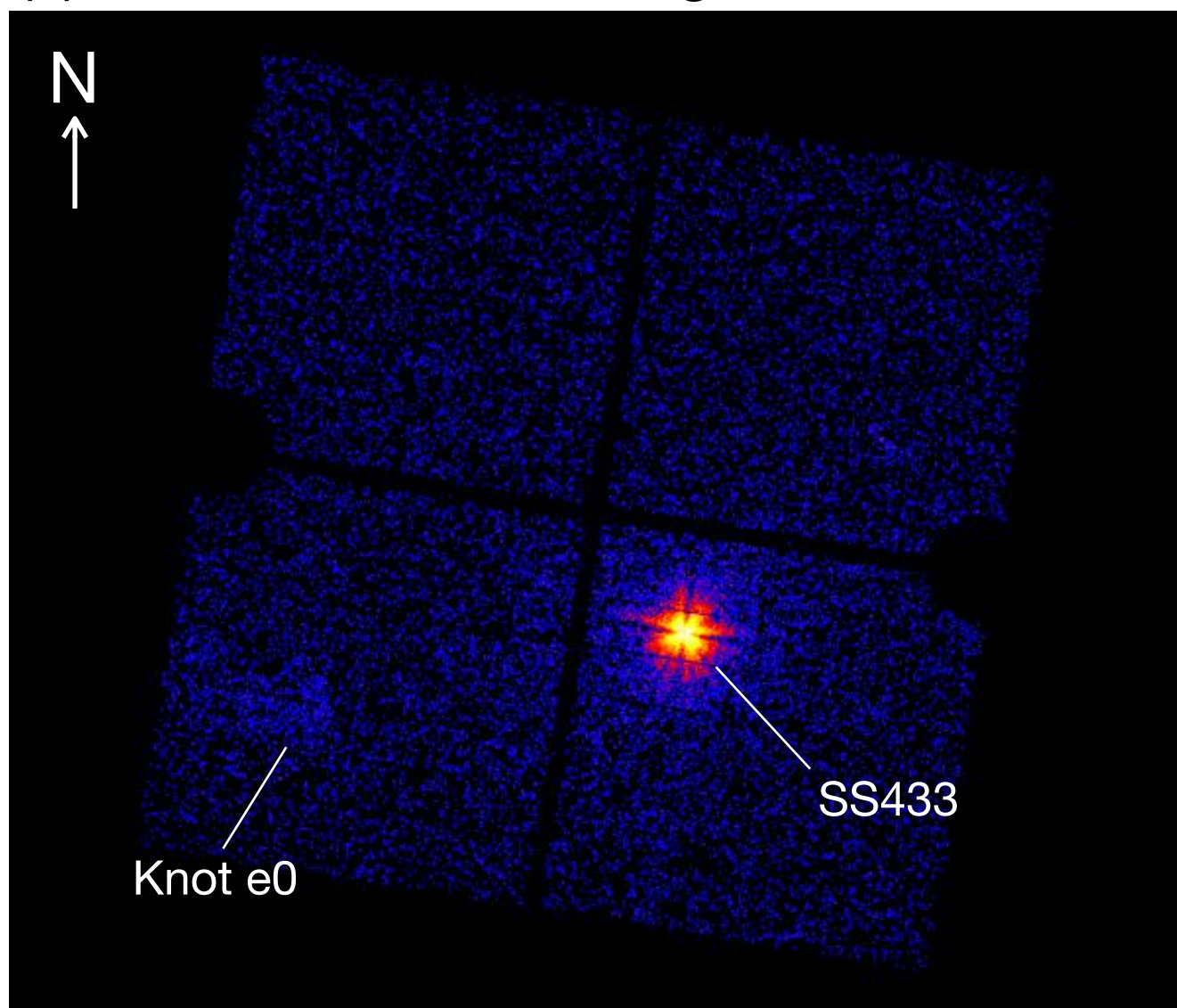
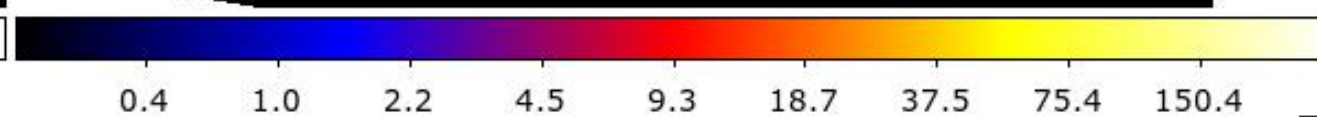
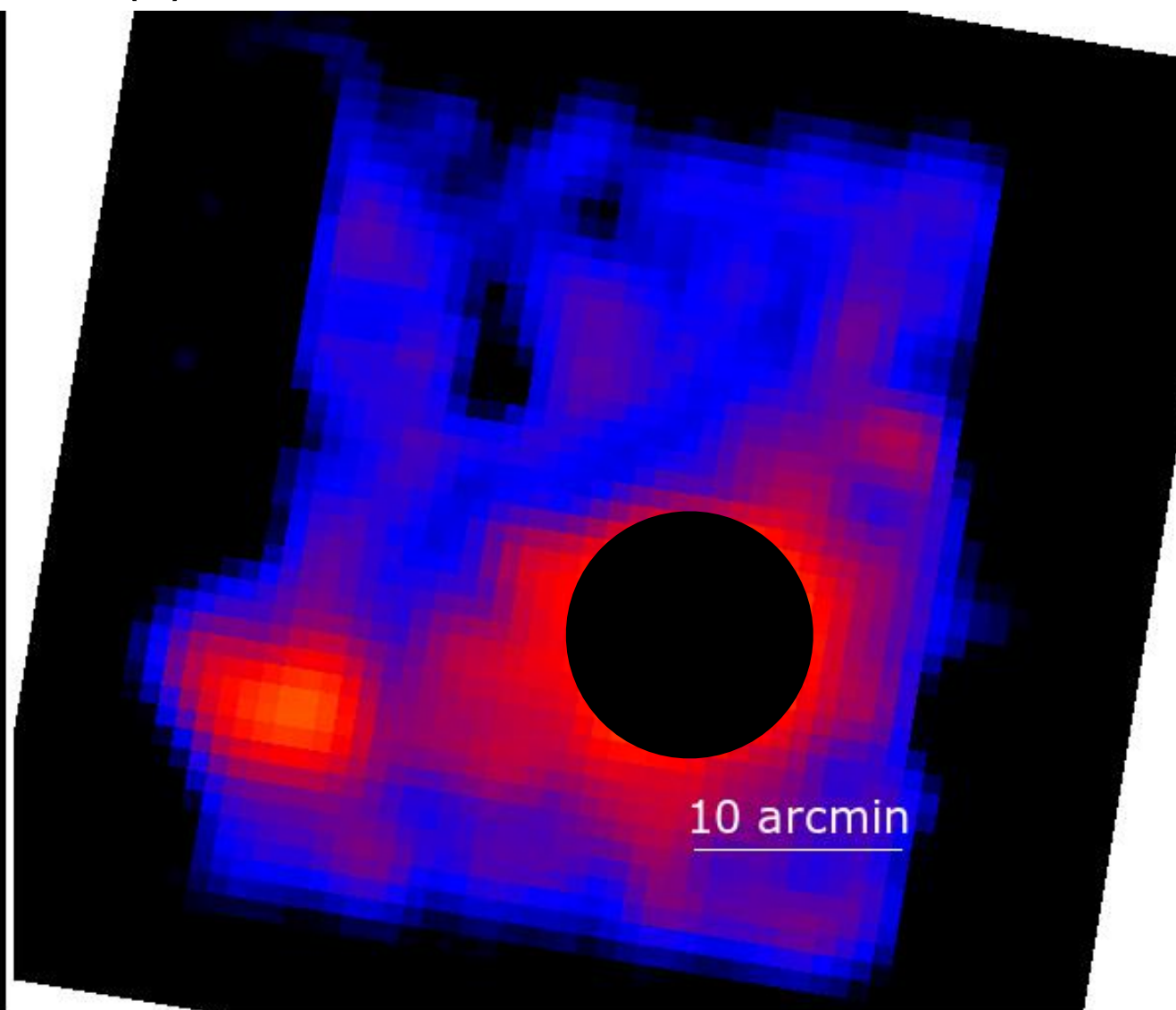


Fig. 4.8: Profiles in circumferential direction around SS 433 in the (a) low- and (b) high-energy band, as shown in figure 4.7. Each panel corresponds exposure-corrected count rate, raw counts, QPB counts, and soft proton counts from top to bottom, respectively. The dot lines indicate the position of the jet precessional axis.

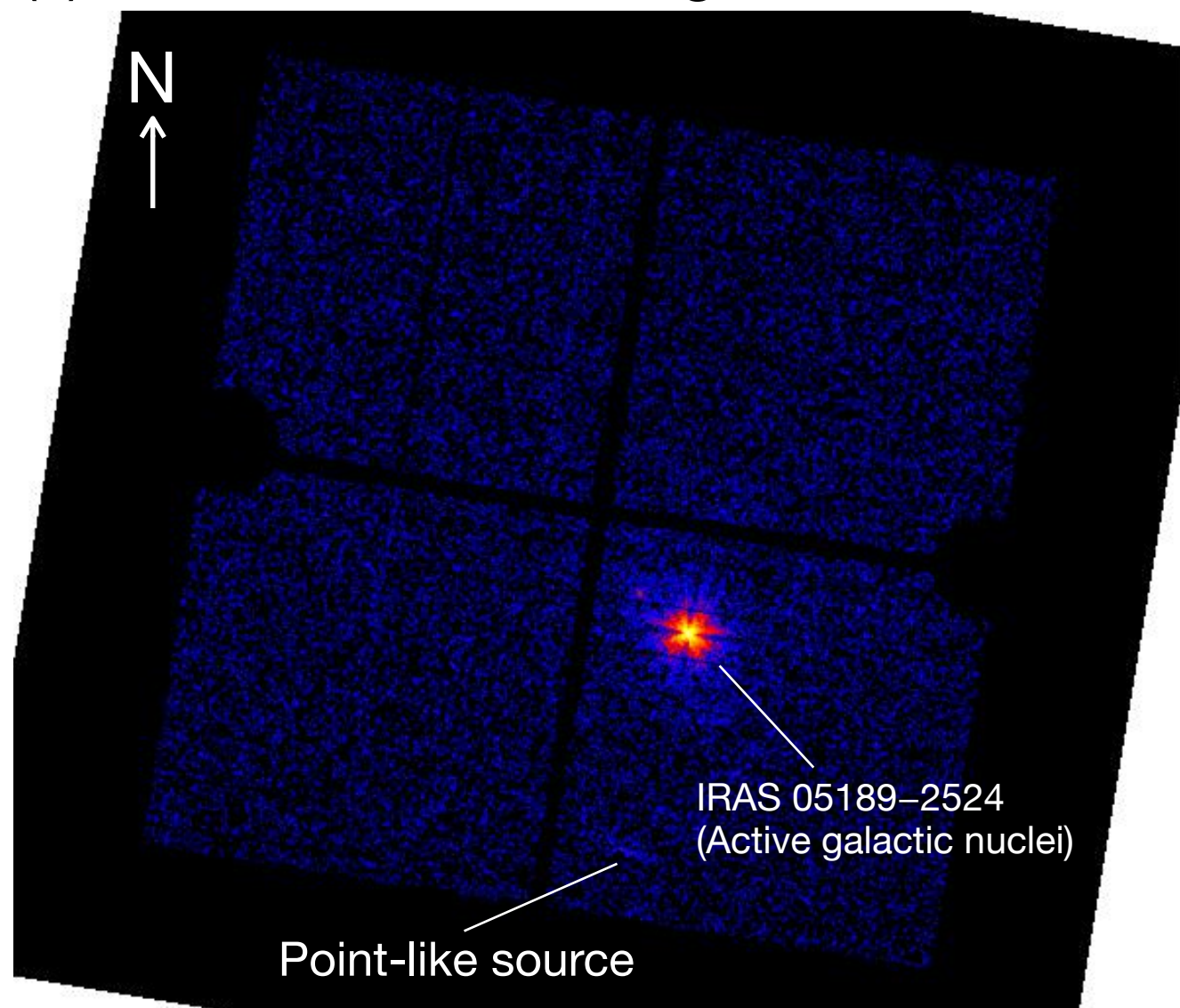
(a) Raw 4.0–5.5 keV image



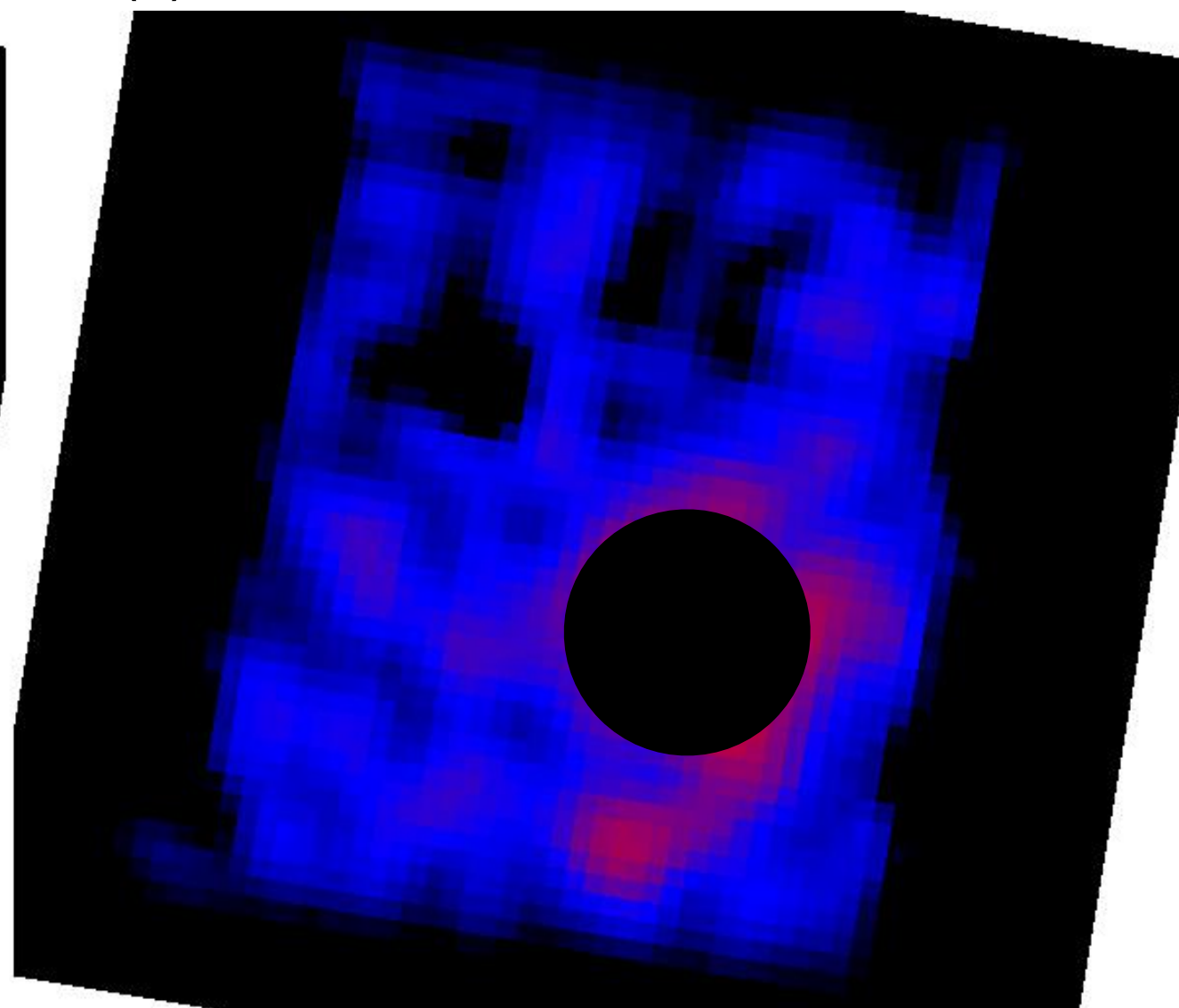
(b) NXB-subtracted, smoothed



(a) Raw 4.0–5.5 keV image



(b) NXB-subtracted, smoothed



0.028 0.085 0.2 0.42 0.88 1.8 3.6 7.2 14

1 2 4 9 19 37 75 151 301