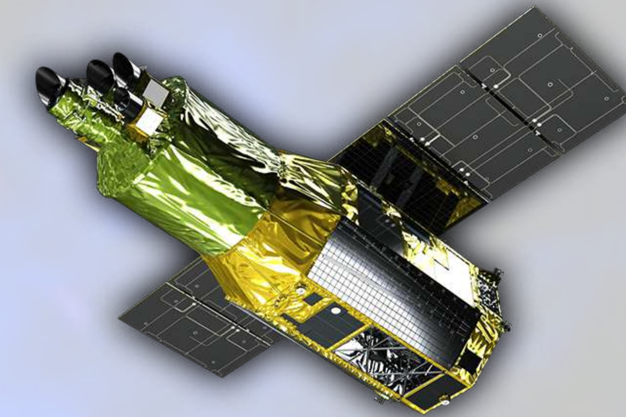


XRISM衛星による
粒子加速研究の展望
(超新星残骸 + α)

鈴木寛大 (Hiromasa Suzuki)

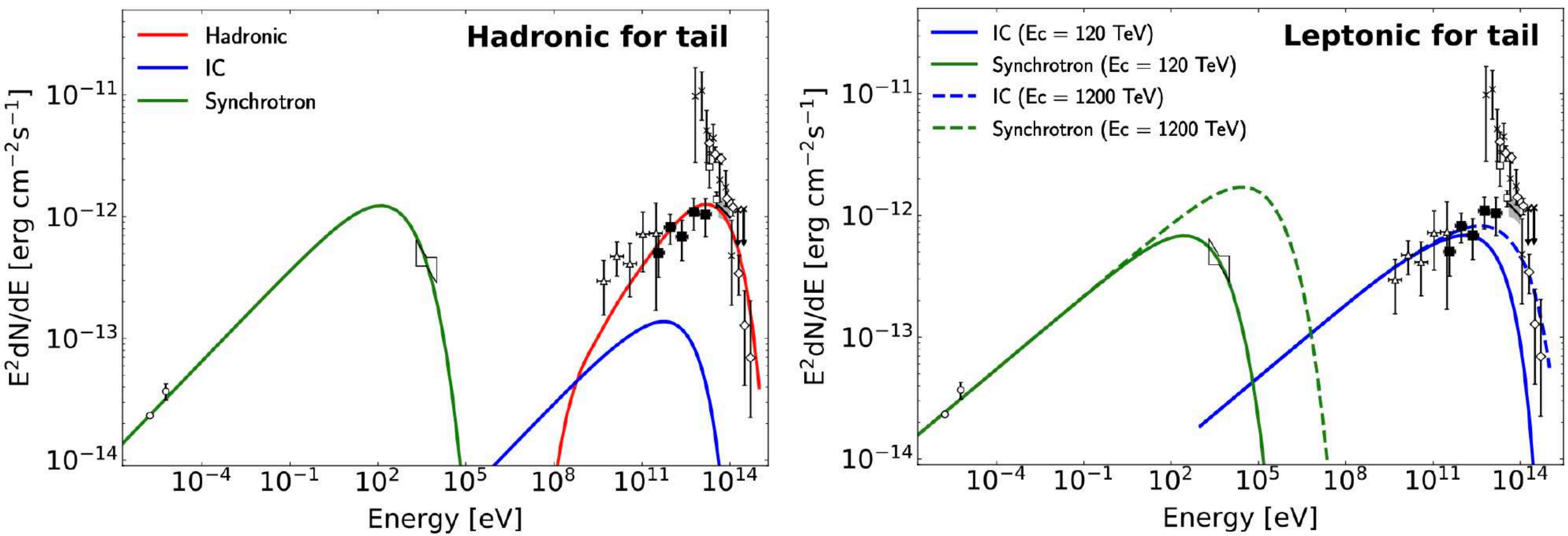
ISAS/JAXA

Image from
Zhao et al. 2016

X-ray observations in the context of particle acceleration physics

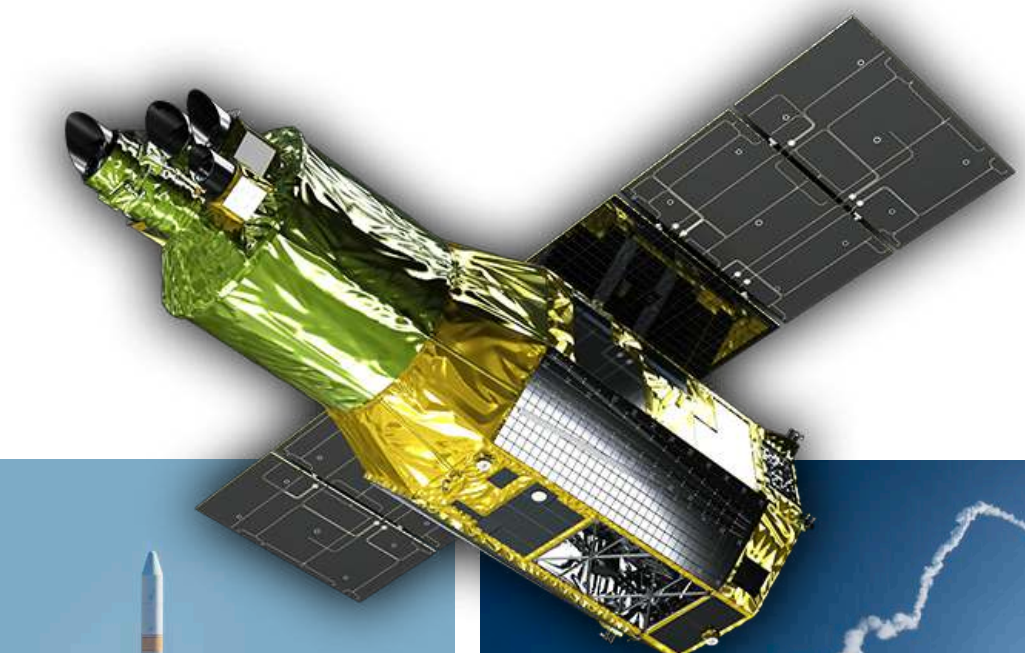
- **Probe to accelerated particles**
  - synchrotron emission of TeV electrons (around max. E in many cases) or non-thermal brems. of supra-thermal electrons
- **Probe to acceleration environments**
  - thermal properties of shock-heated plasma (temperatures, density, ionization state, metal abundances)
  - shock velocity from proper motion or Doppler shift of known line emission

Supernova remnant G106.3+2.7 (MAGIC collaboration 2022)



X-ray astronomical satellite XRISM

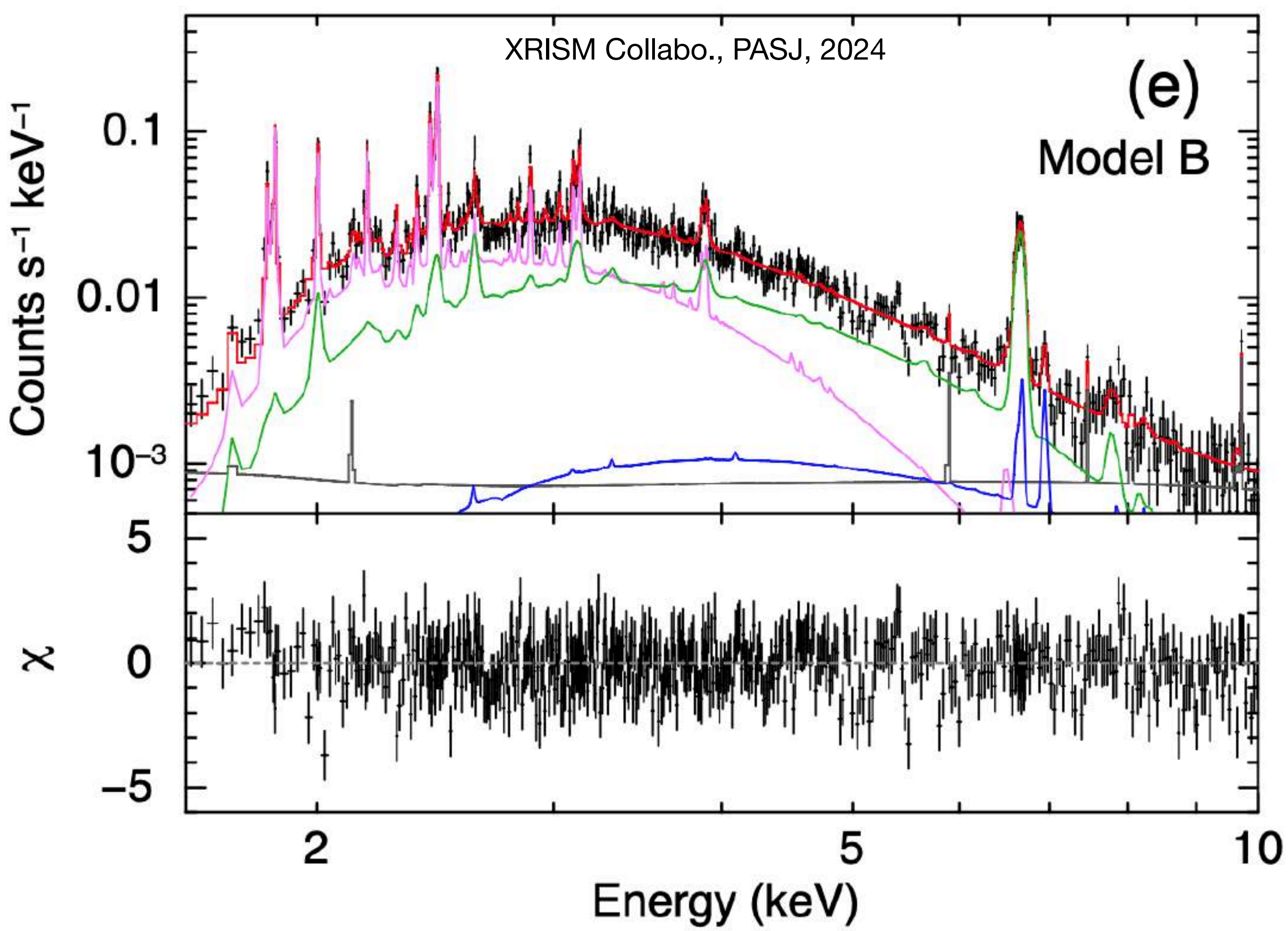
- Launched from Tanegashima, Japan in Sep. 2023
- Instruments: high-resolution spectrometer “Resolve” & large field-of-view CCD imager “Xtend”
  - **Resolve**:
    - ΔE < 5 eV @6 keV
    - currently sensitive for E = ~1.8–12 keV
  - **Xtend**:
    - imaging spectroscopy for 38’x38’ field of view
    - sensitive for E = 0.5–12 keV



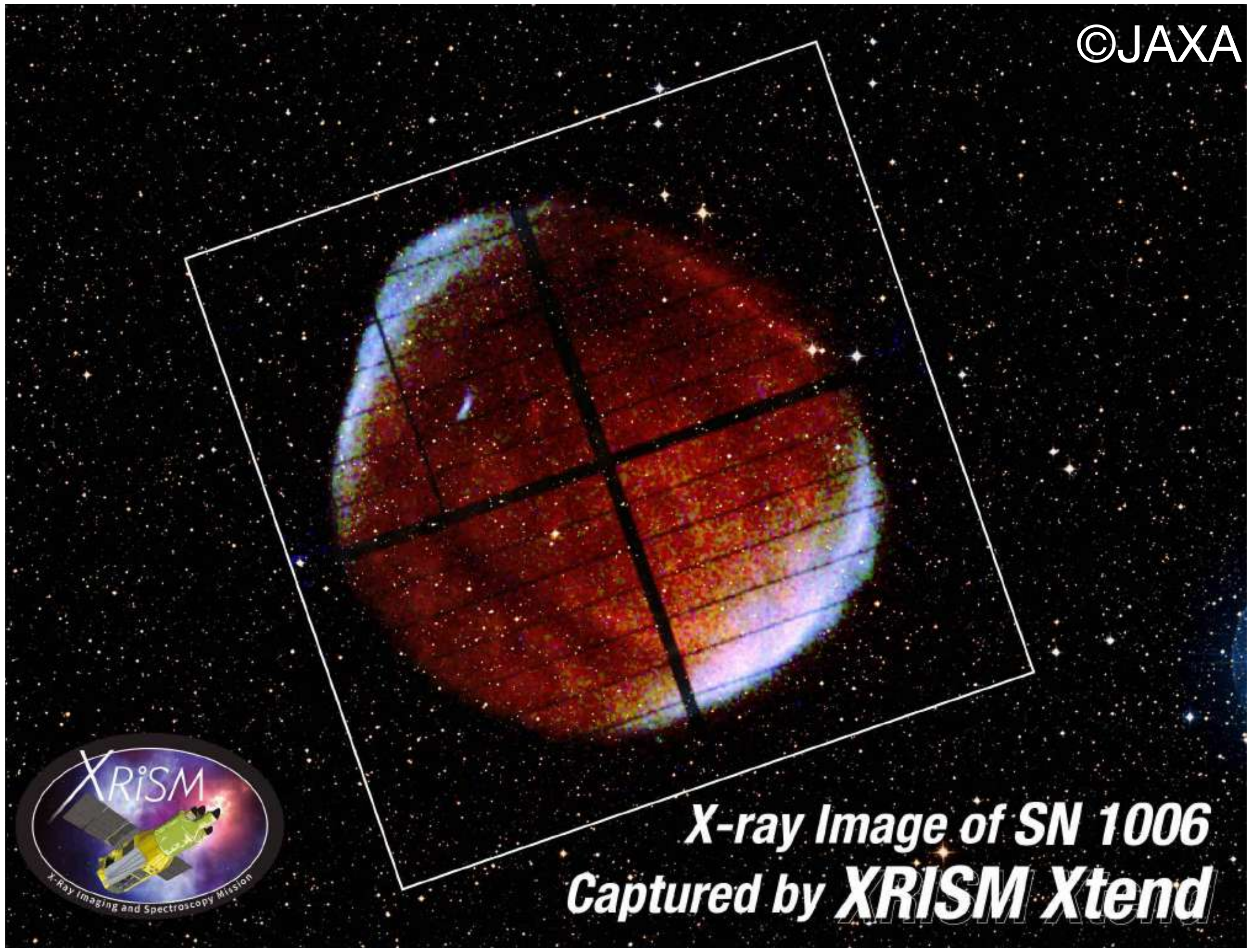
Status of XRISM

- Performance is pretty well (except for sensitivity at < 1.8 keV of Resolve)
- Three papers published, several under revision/preparation
  - Supernova remnant N132D (PASJ)
  - Active galactic nucleus in NGC4151 (ApJL)
  - High mass X-ray binary Cygnus X-3 (ApJL)

Resolve spectrum of supernova remnant N132D



Xtend image of supernova remnant SN1006



Particle acceleration physics with XRISM

- XRISM's primary target is X-ray "line" emission = (mostly) thermal particles
- But we can access particle acceleration physics via …
  - **widths of lines from shock-heated plasma**
  - lines stimulated by non-thermal particles
    - **neutral iron lines (6.4 keV)** … traces MeV protons
    - dielectric recombination lines
  - **hard (non-thermal) tail in broad-band spectrum**
  - **faint diffuse emission around acceleration sites** … traces particle diffusion
  - … potentially more

- Which accelerators are suitable for studies with XRISM ?
  - supernova remnants
  - Galactic center
  - microquasar (black hole binary with jets)
  - pulsar wind nebulae

Note: almost no results about particle acceleration physics from XRISM came out yet ! (basically all items above are challenging !)

Observations of supernova remnants as famous particle accelerators: line widths

- XRISM has observed several bright supernova remnants (N132D, Cas A, Tycho, Kepler, …)
- in general, we see high-reso. S, Ar, Ca, Fe lines
- line width —> ions' thermal motion = downstream thermal energy
  —> particle acceleration efficiency

Shimoda et al. 2022

X-ray line diagnostics of ion temperature at cosmic ray accelerating collisionless shocks

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[8]Institute of Laser Engineering, Osaka University, 2-6 Yamadaoka, Suita, Osaka 565-0871, Japan
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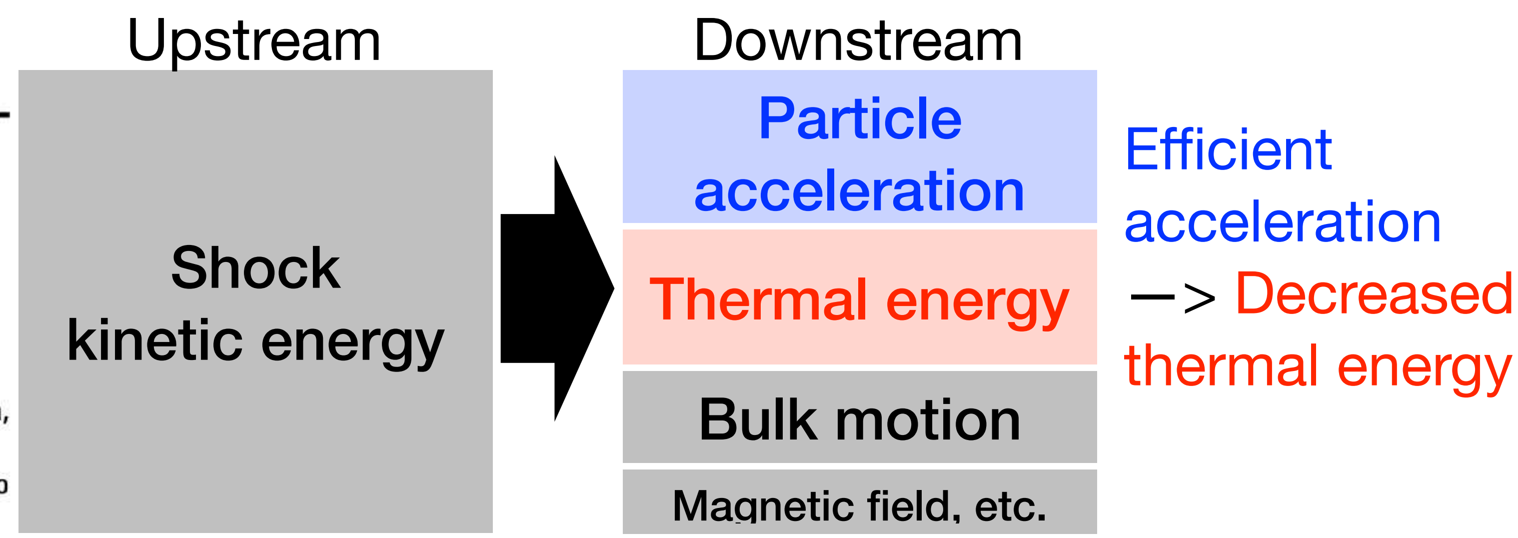
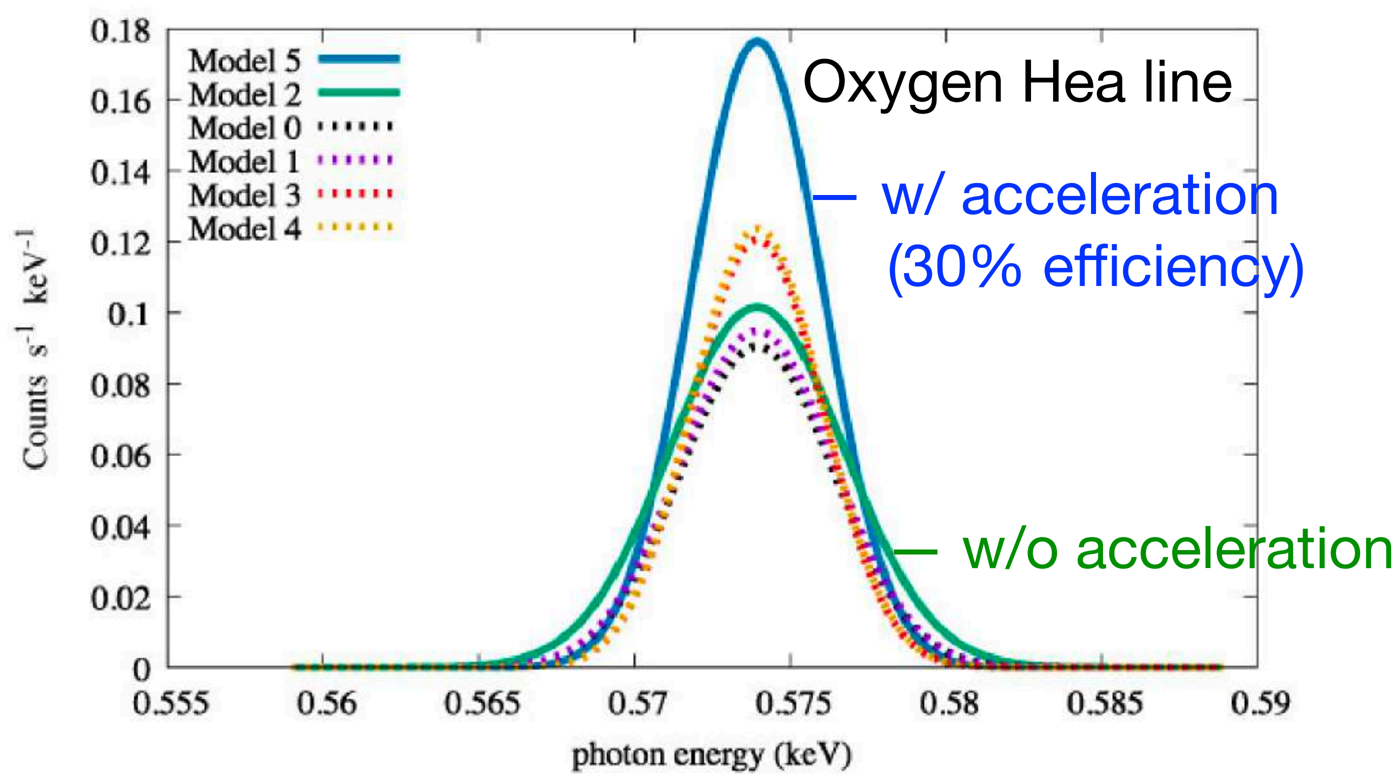
Abstract

A novel collisionless shock jump condition is suggested by modeling the entropy production at the shock transition region. We also calculate downstream developments of the atomic ionization balance and the ion temperature relaxation in supernova remnants





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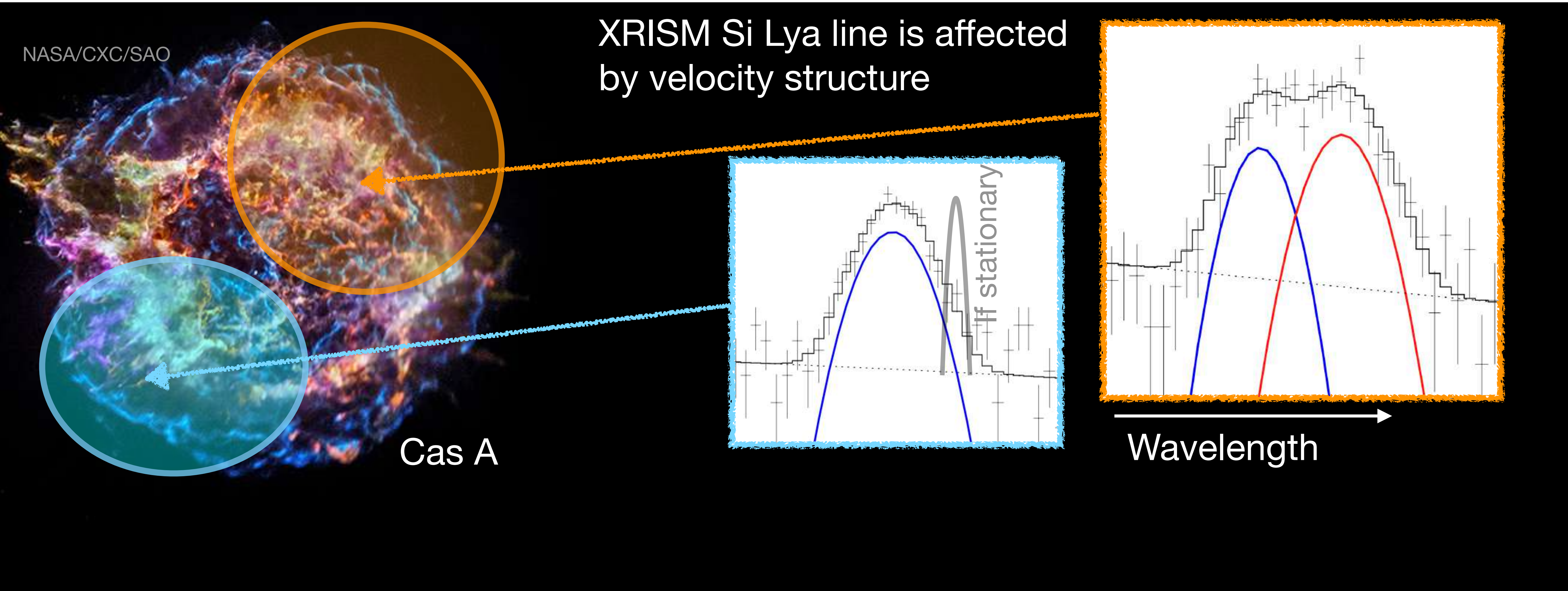
- in general, we see high-reso. S, Ar, Ca, Fe lines
- line width —> ions' thermal motion = downstream thermal energy
- **But, it's not so simple in reality…**
  - line width = (thermal motion) + (velocity dispersion)



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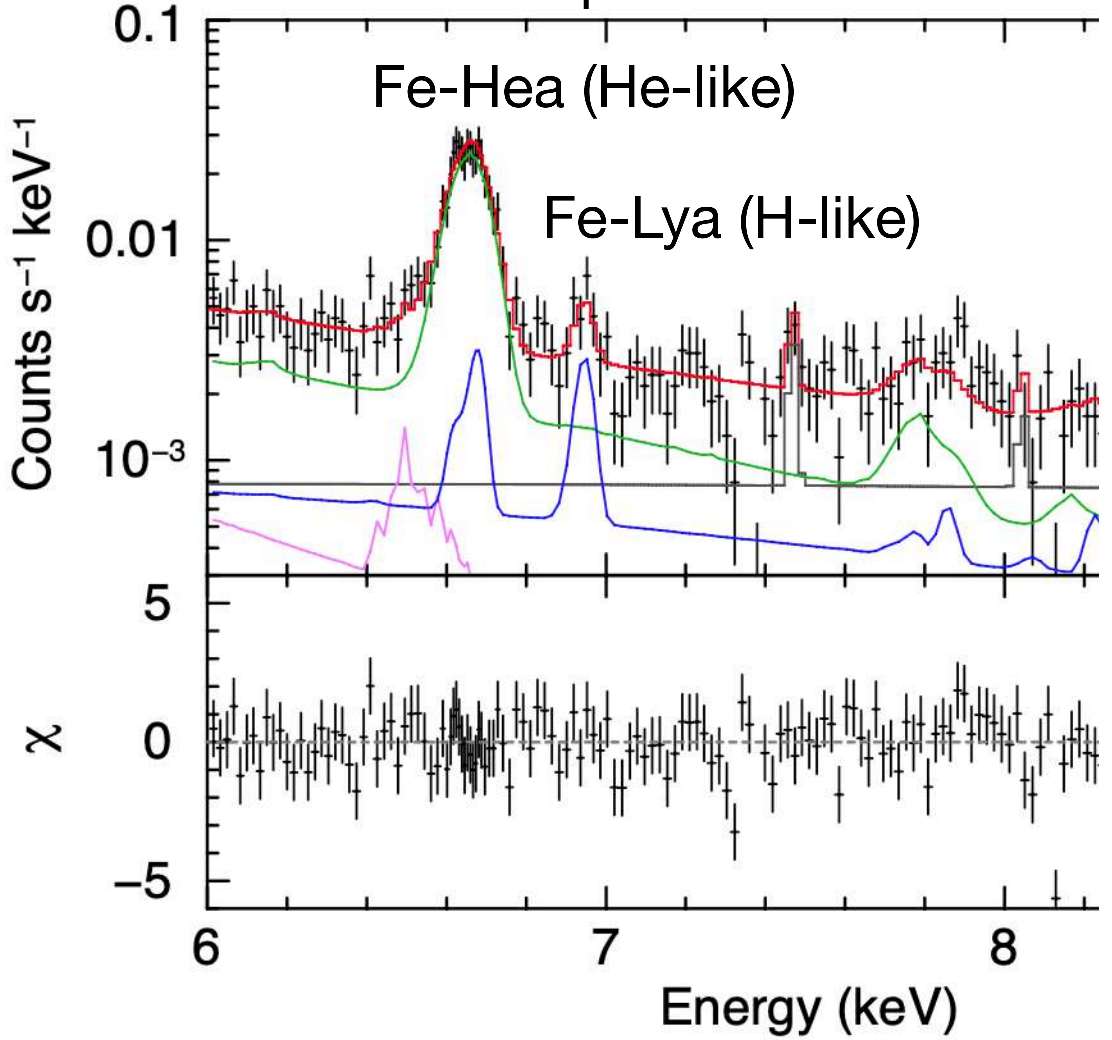
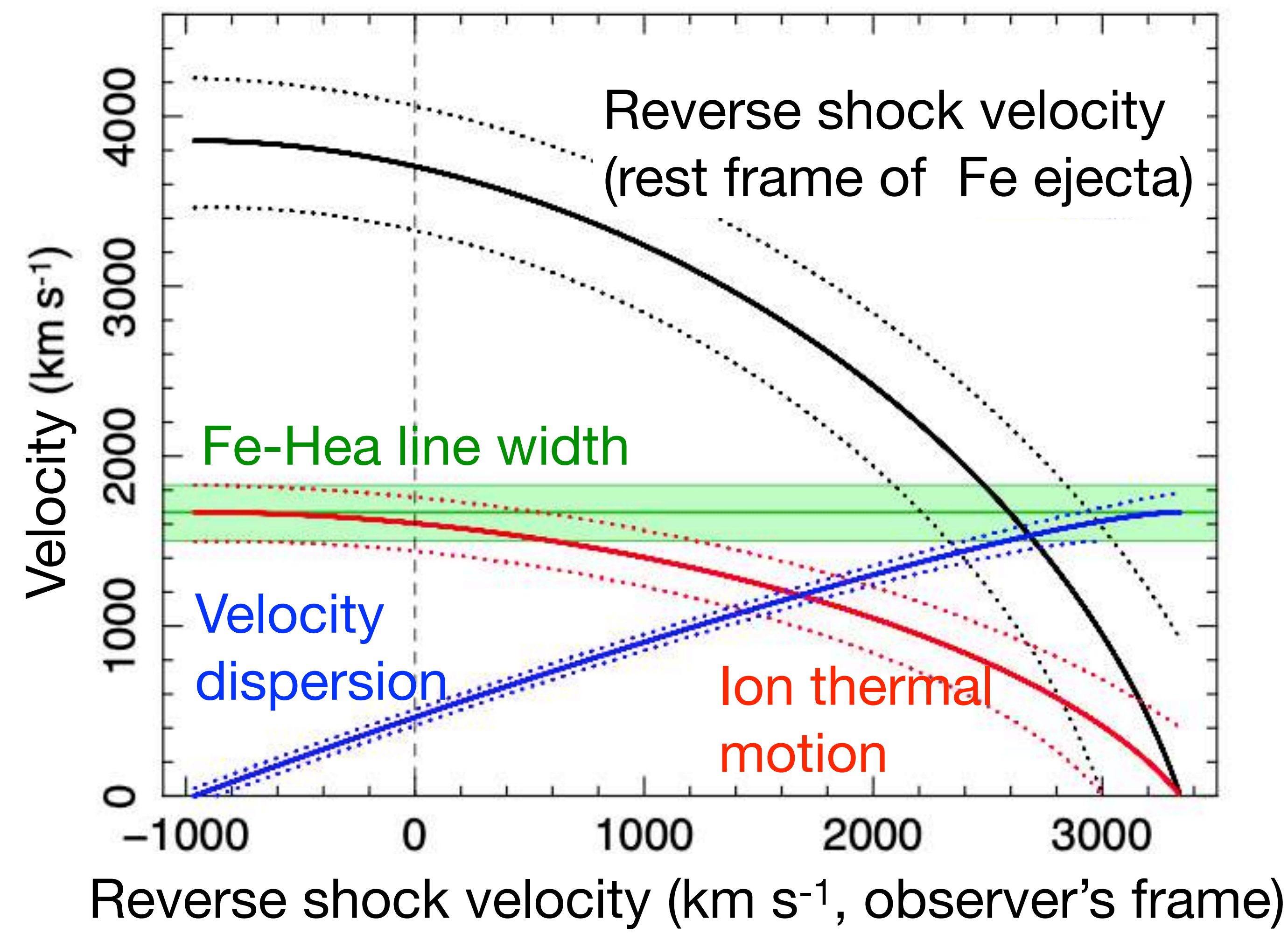
- line width —> ions' thermal motion = downstream thermal energy
- **But, it's not so simple in reality…**
  - line width = (thermal motion) + (velocity dispersion)
  - N132D observations: hard to constrain contribution of particle acceleration

XRISM Collaboration, 2024

N132D Fe-K spectrum with XRISM



Fe-Hea line width of N132D



Observations of supernova remnants as famous particle accelerators: line widths

XRISM
X-Ray Imaging and Spectroscopy Mission

- XRISM has observed several bright supernova remnants (N132D, Cas A, Tycho, Kepler, …)
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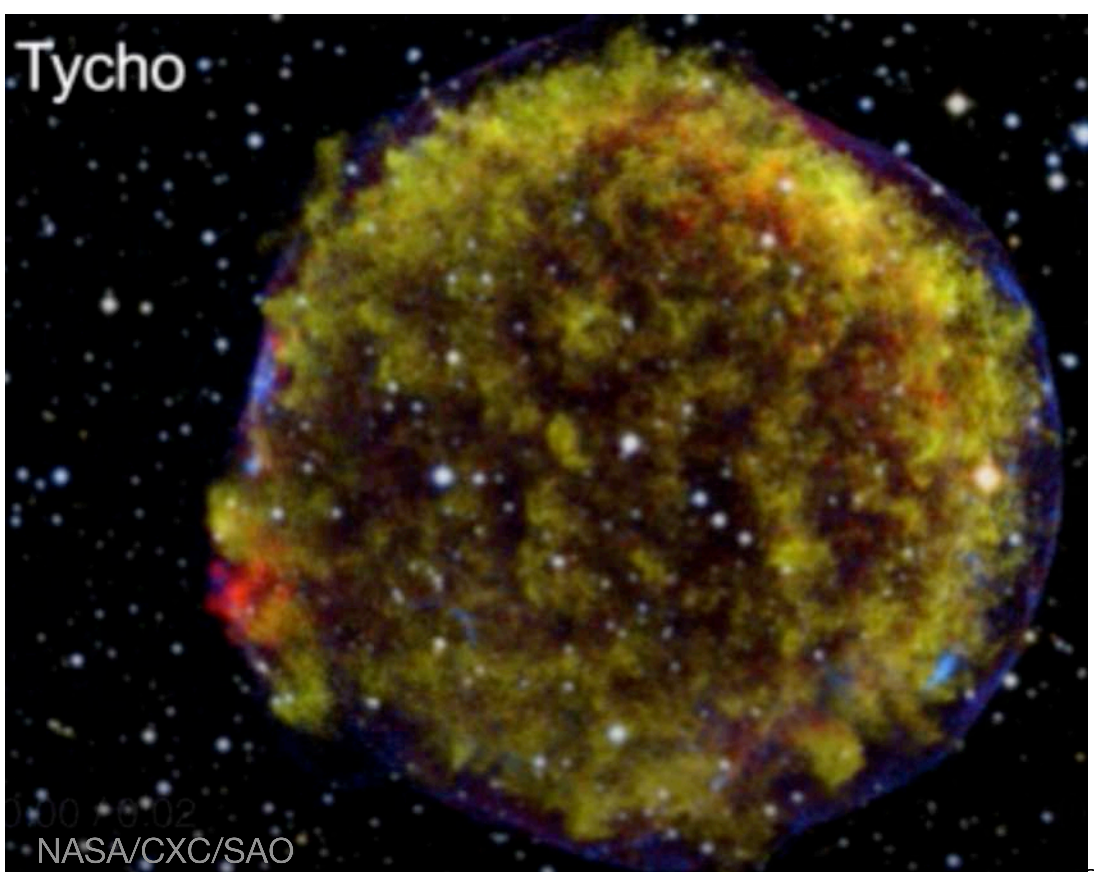
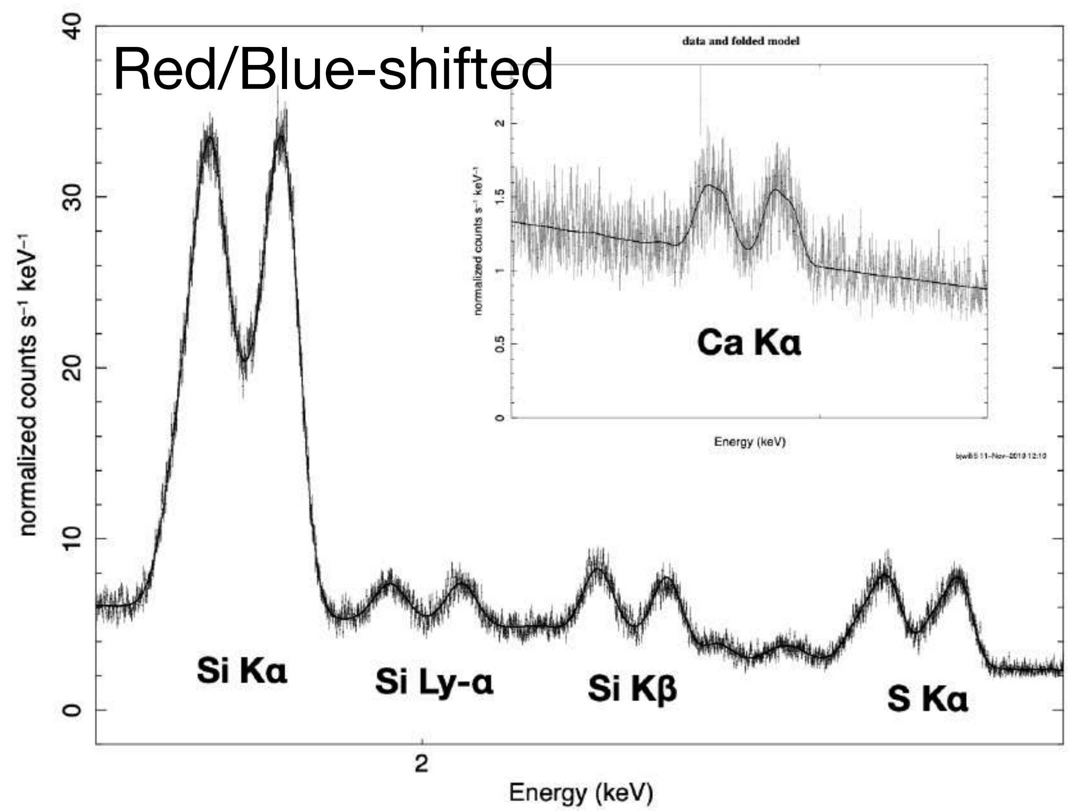
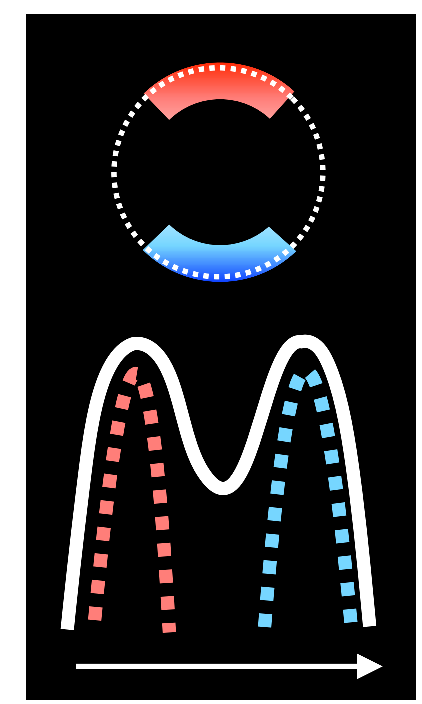
- line width —> ions' thermal motion = downstream thermal energy
- **But, it's not so simple in reality…**
  - line width = (thermal motion) + (velocity dispersion)

- Good targets to determine velocity dispersions ?
  - Symmetric supernova remnant: Tycho? (observed)
  - Focus on a rim: RCW 86 (planned to be observed)



Simulated spectrum at the center of Tycho





Observations of supernova remnants as famous particle accelerators: line widths

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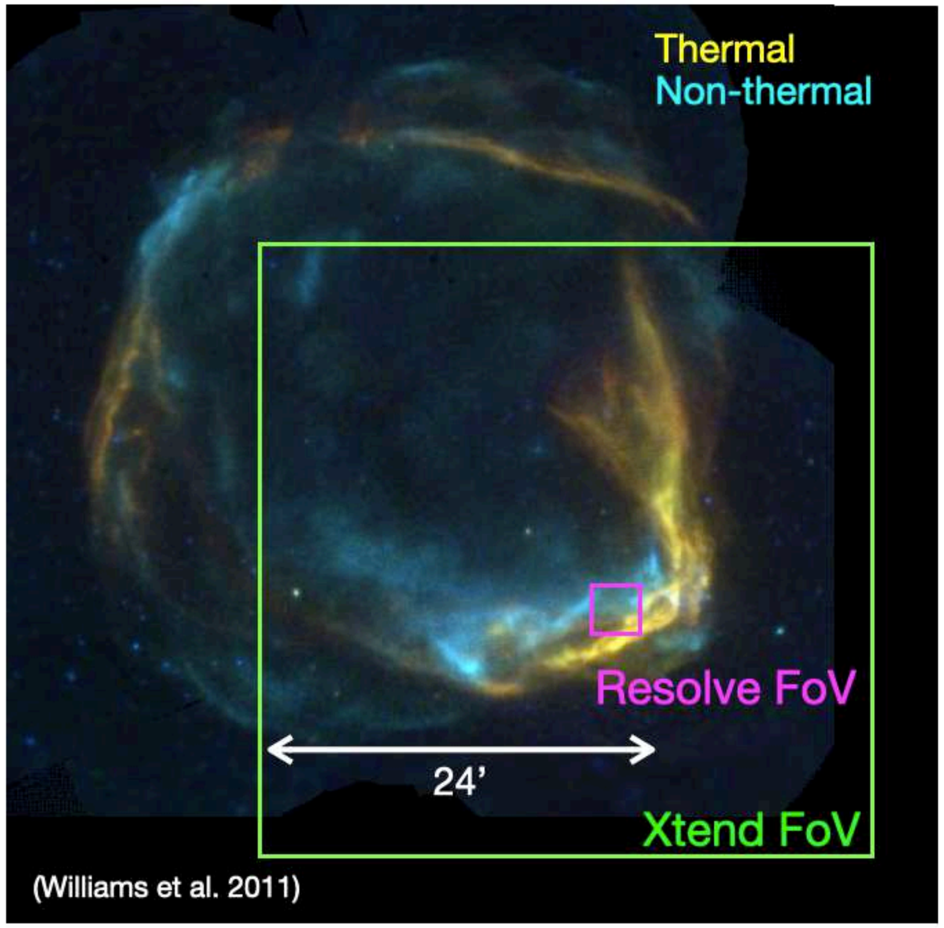
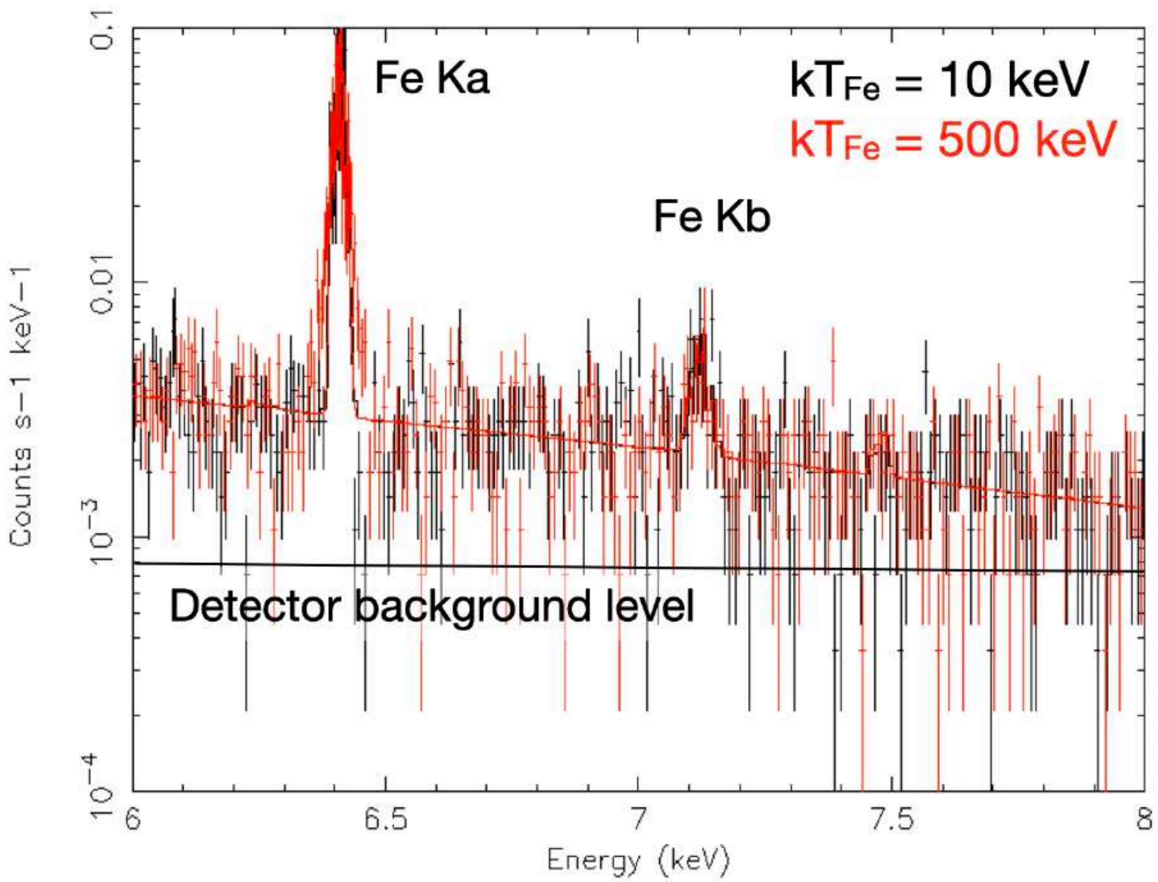
  - Symmetric supernova remnant: Tycho? (observed)
  - Focus on a rim: RCW 86 (planned to be observed)

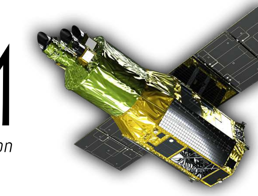
(b) X-ray view of RCW 86



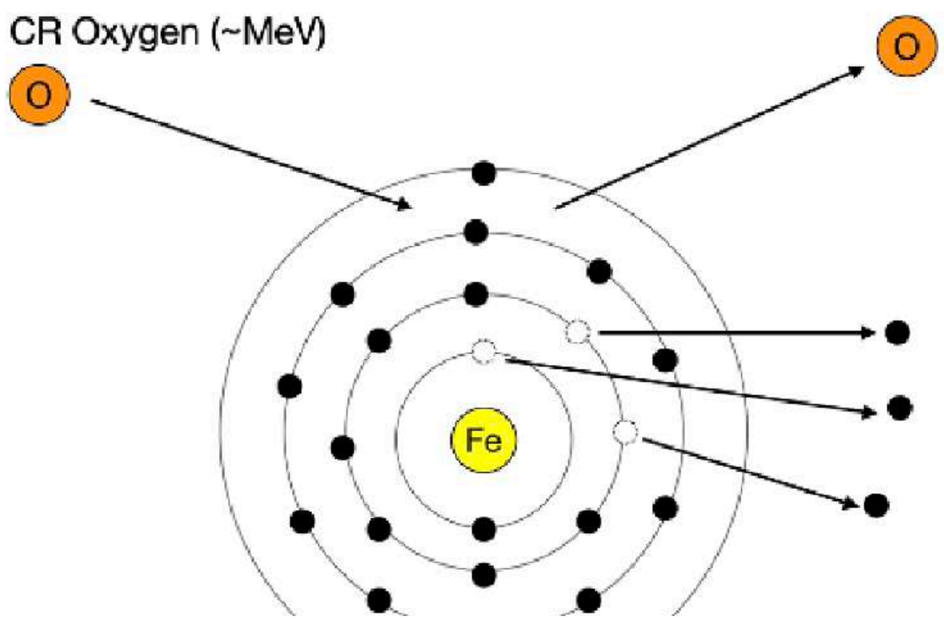
(a) Simulated Resolve spectra of RCW 86 (FoV)

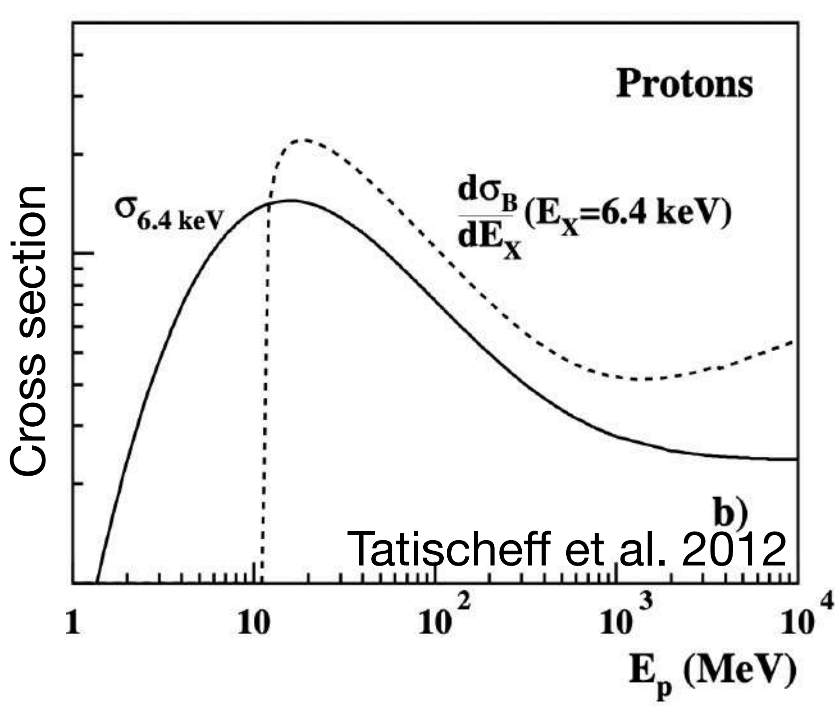


Observations of supernova remnants as famous particle accelerators: neutral iron lines



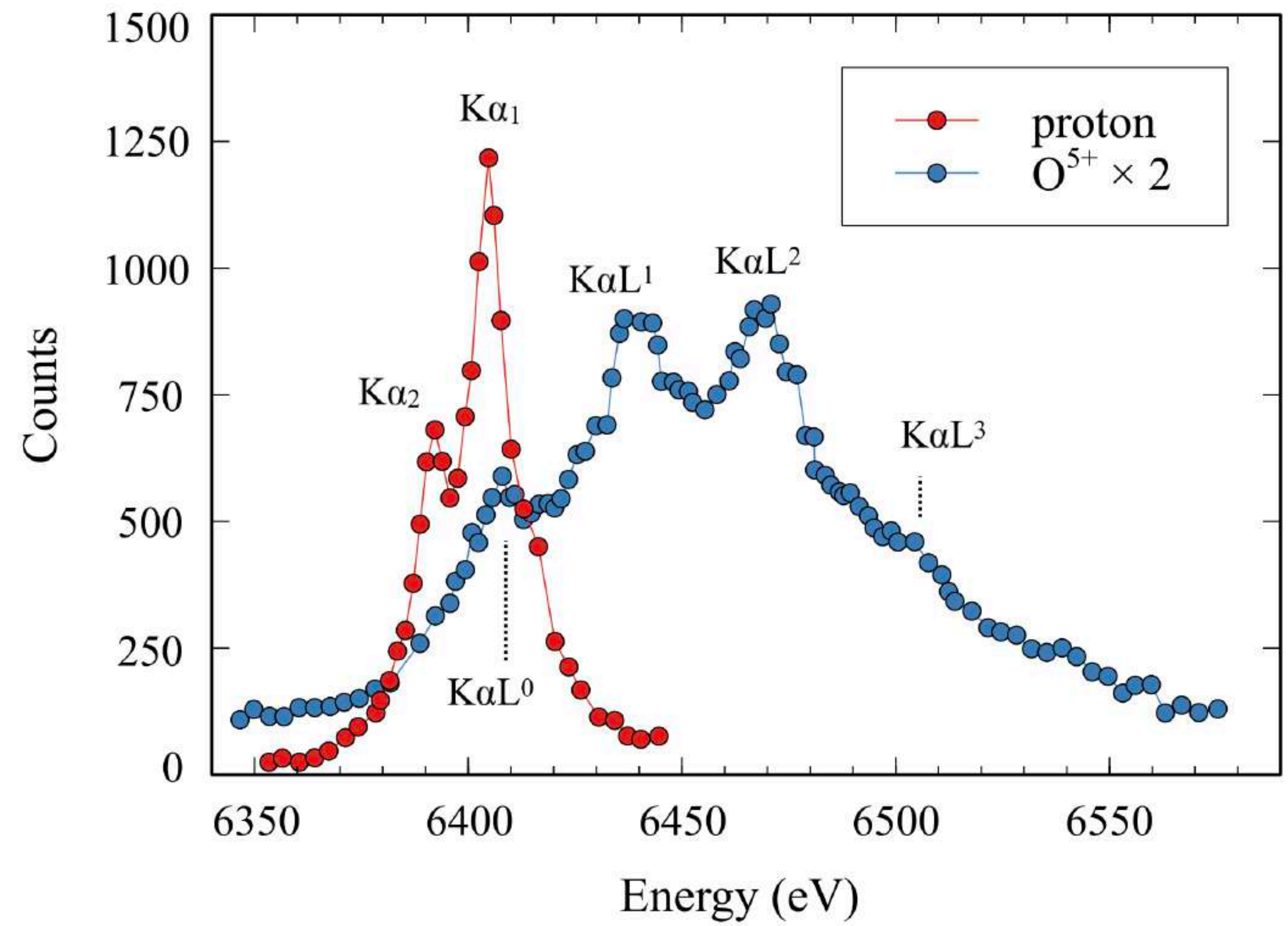
- Neutral iron lines are stimulated by ~MeV protons (low E cosmic rays)
- and multiple-ionization lines may be enhanced by accelerated heavy ions
- difficulties: lines probably too weak for XRISM Resolve
  - not found with XRISM until now



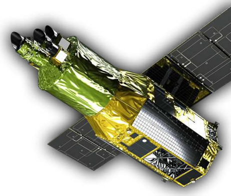


Tatischeff et al. 2012

Okon et al. 2020

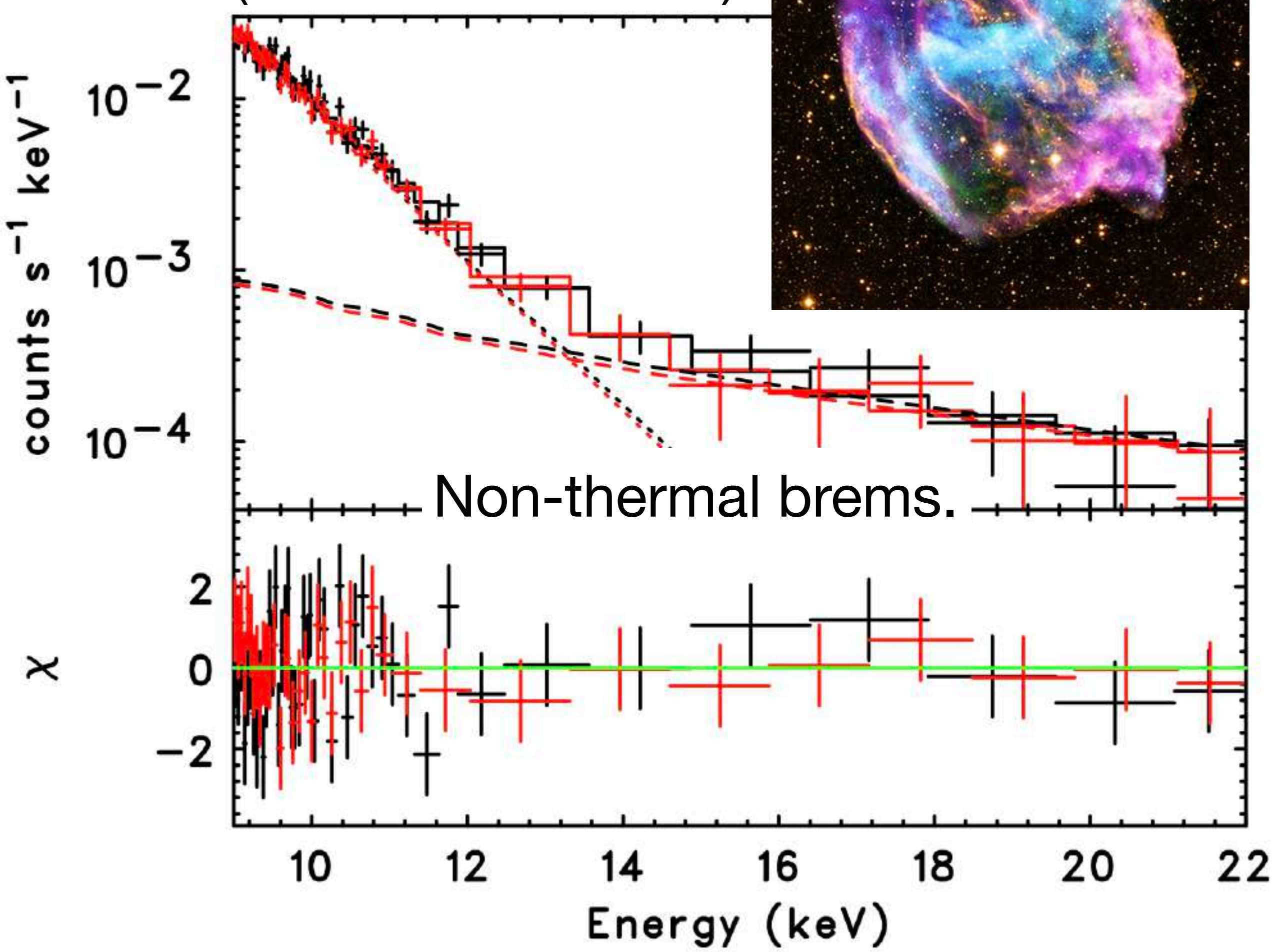


Observations of supernova remnants as famous particle accelerators: hard tail, diffuse emission

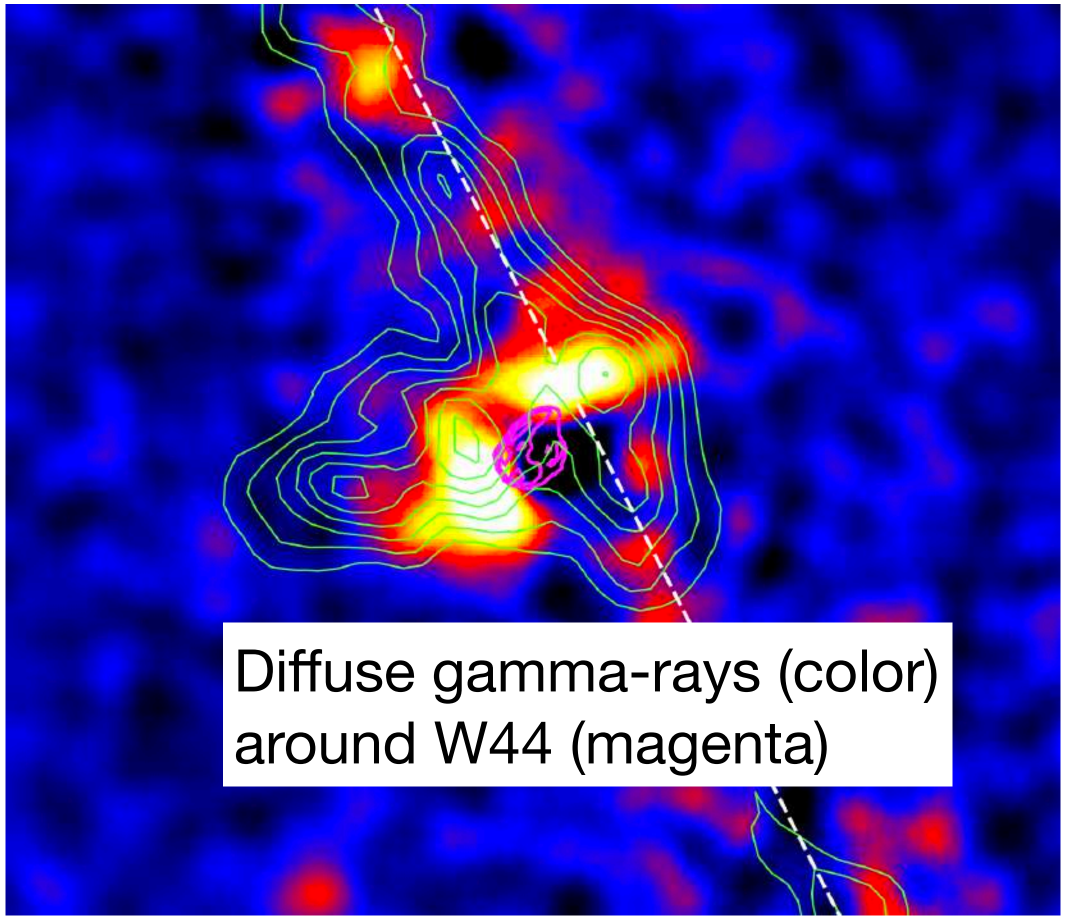


- High-reso. X-ray spectroscopy → precisely determine thermal properties → constrain hard tail: synchrotron/non-thermal brems.
- Diffuse X-ray emission which traces escaping high-energy particles
  - secondary electrons from interacting protons
- Probably feasible, but yet to be investigated with real data of XRISM

W49B
(Tanaka et al. 2018)



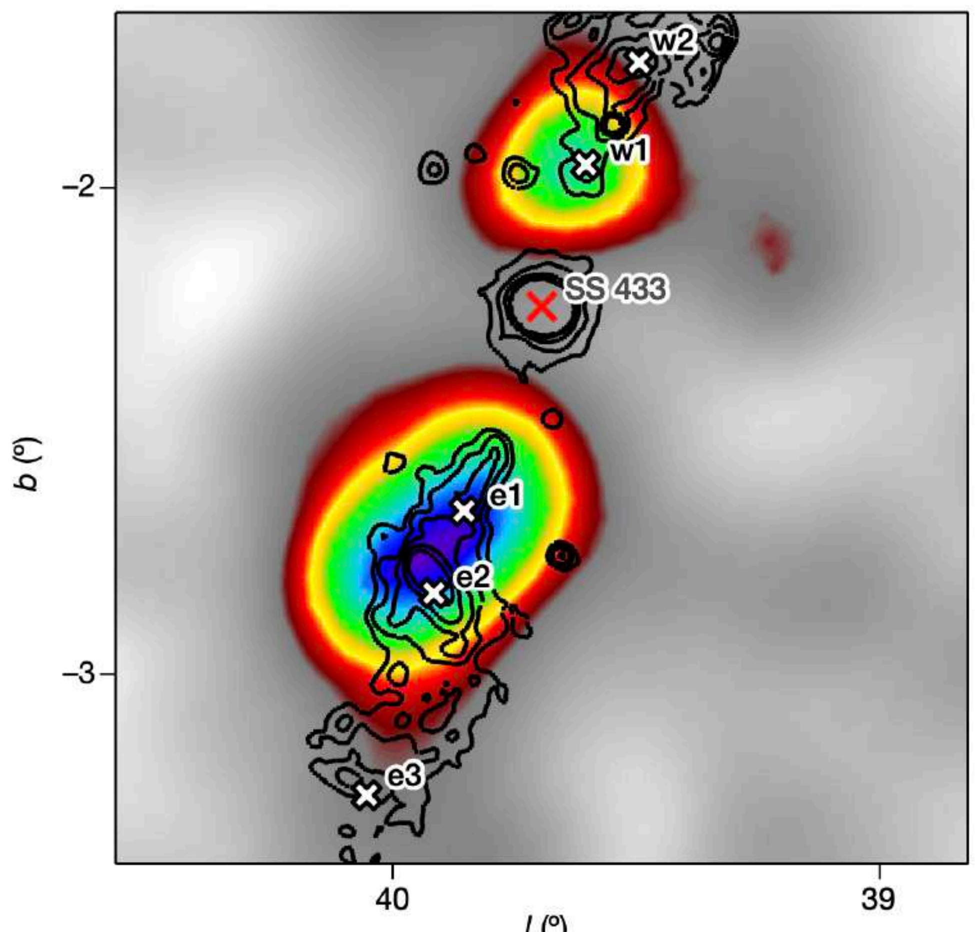
W44 (Uchiyama et al. 2012)



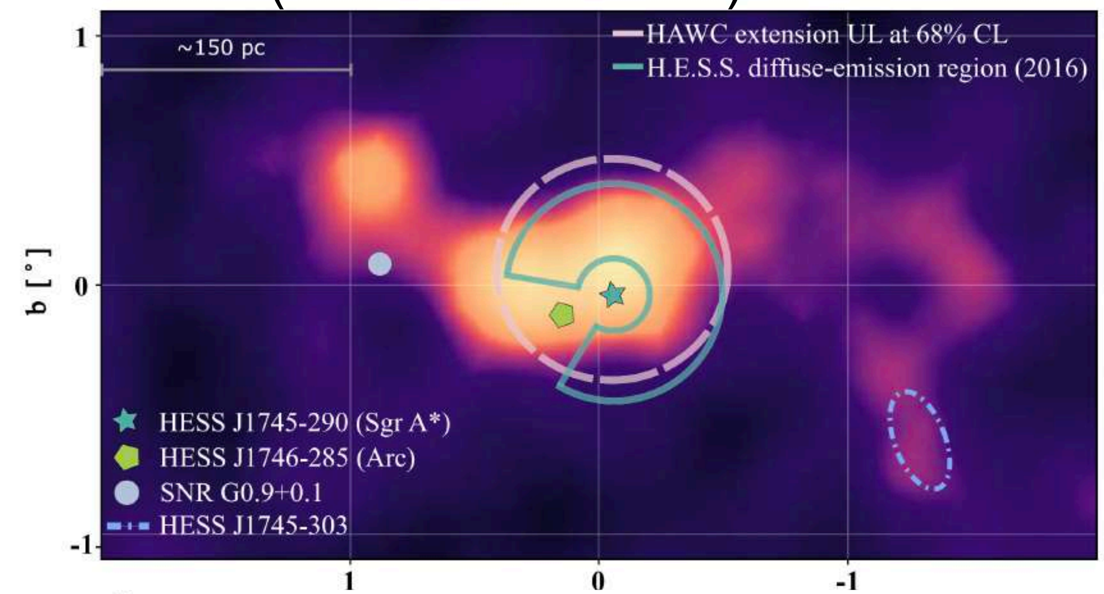
Other accelerators

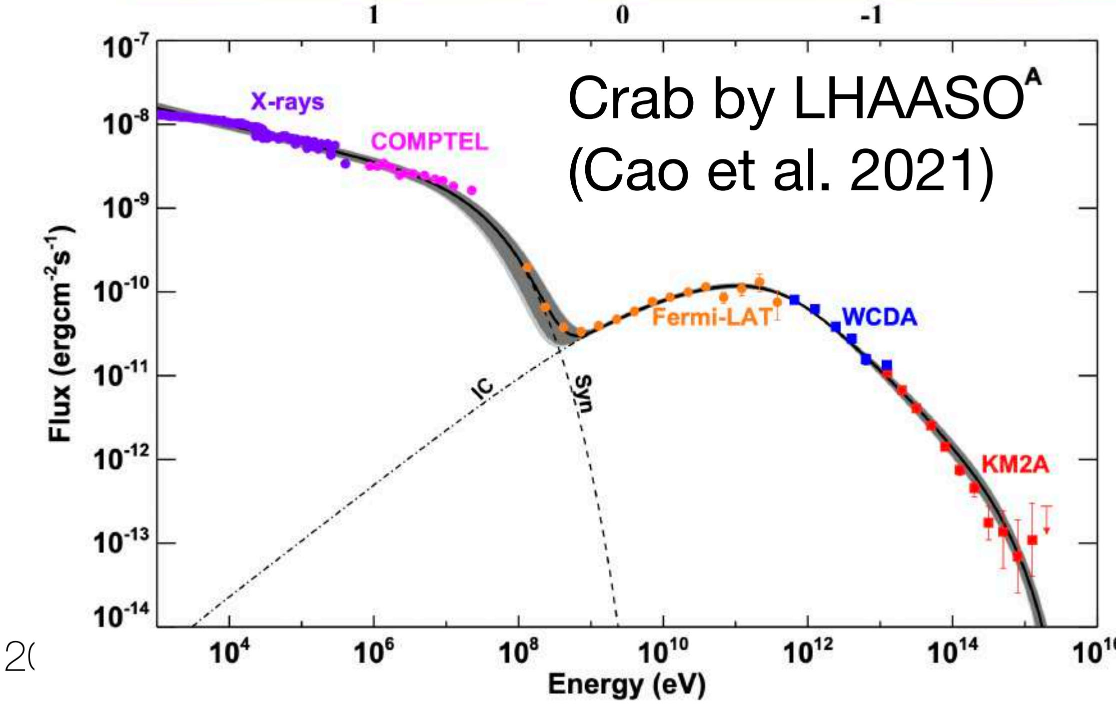
- Galactic center
  - neutral iron lines measured with XRISM, origin under investigation (low-E CRs?)
- Microquasar (black hole binary with jets)
  - several observed (SS433, Cyg X-1, GRS1915, V4641 Sgr)
  - diffuse emission around them? yet to be investigated
- Pulsar wind nebulae
  - thermal emission? —> progenitor, etc.
  - still only upper limits with XRISM (Crab, G21.5)

SS433 by HAWC
(Abeysekara et al. 2018)



Galactic center by HAWC
(Albert et al. 2024)



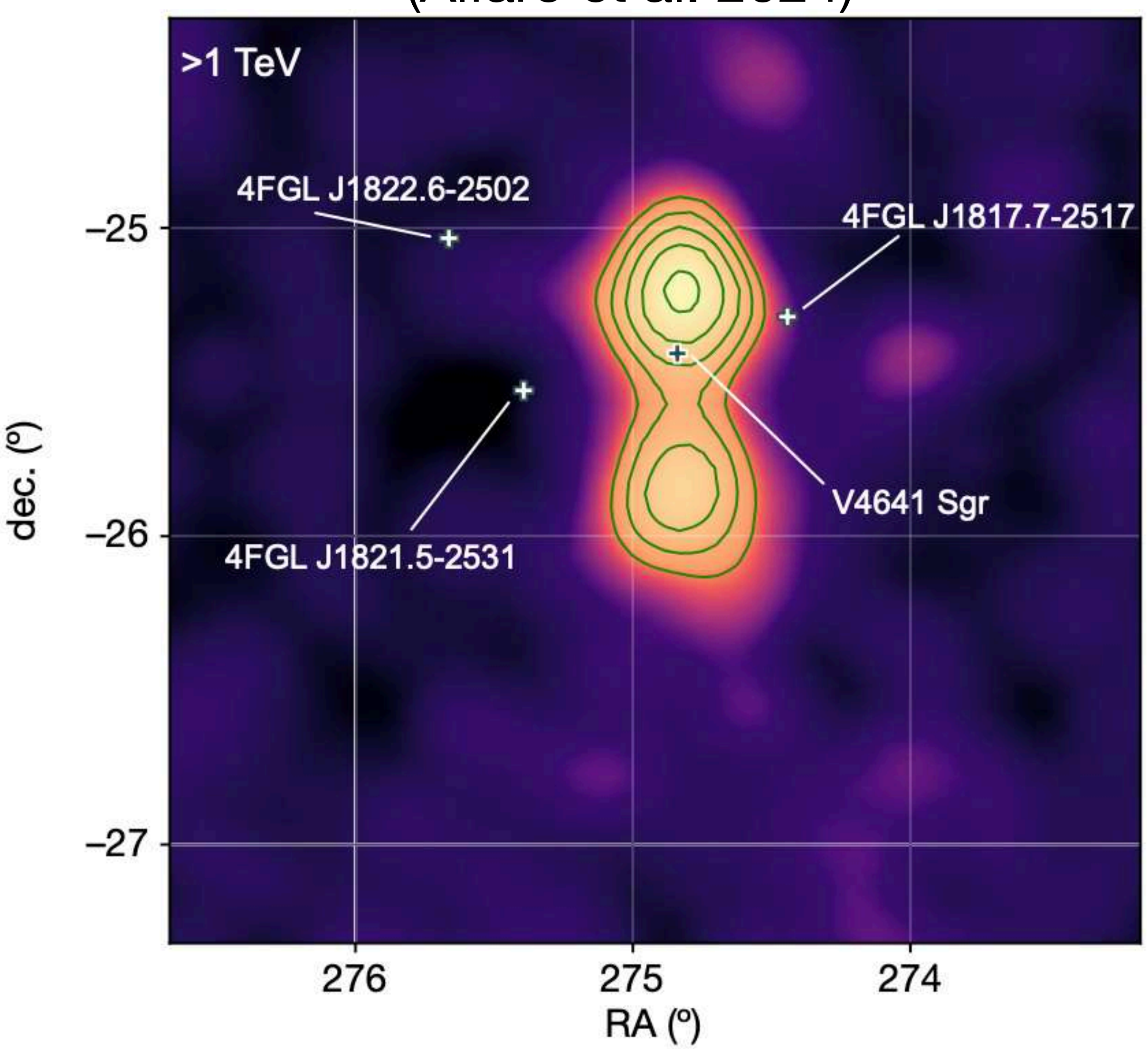


Crab by LHAASO[A]
(Cao et al. 2021)

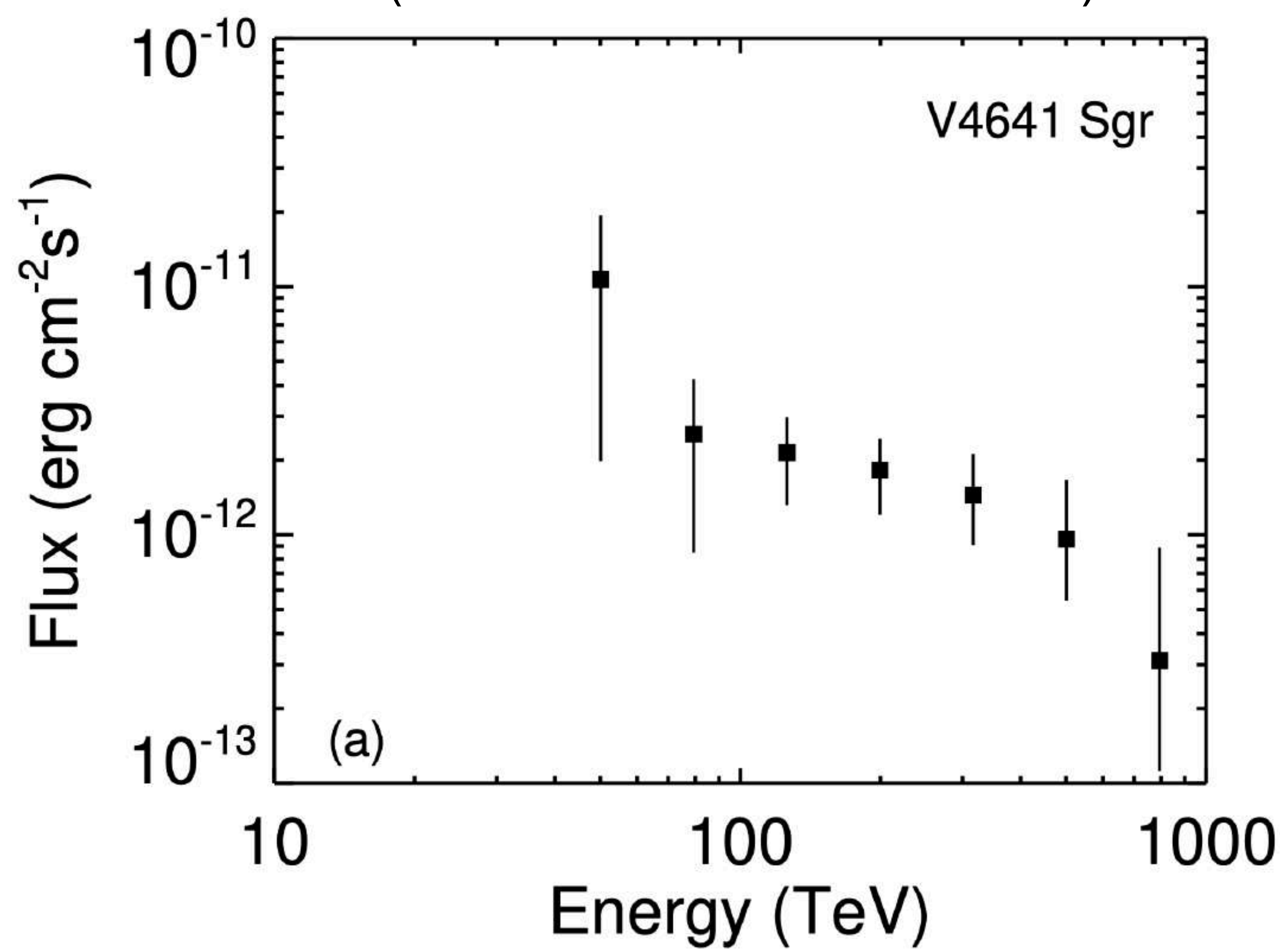
Other accelerators: Microquasar V4641 Sgr

- Observed with XRISM using “generic ToO” (used only for very rare events) because of the recent bursting activity (exposure: only ~12 ks)
- BH with ~6 solar mass, at ~6 kpc
- Recent gamma-ray detection by HAWC and LHAASO: 2nd case of PeV accelerating microquasars

V4641 Sgr by HAWC
(Alfaro et al. 2024)



V4641 Sgr by LHAASO
(LHAASO collaboration 2024)



Other accelerators: Microquasar V4641 Sgr

Suzuki et al. in prep.

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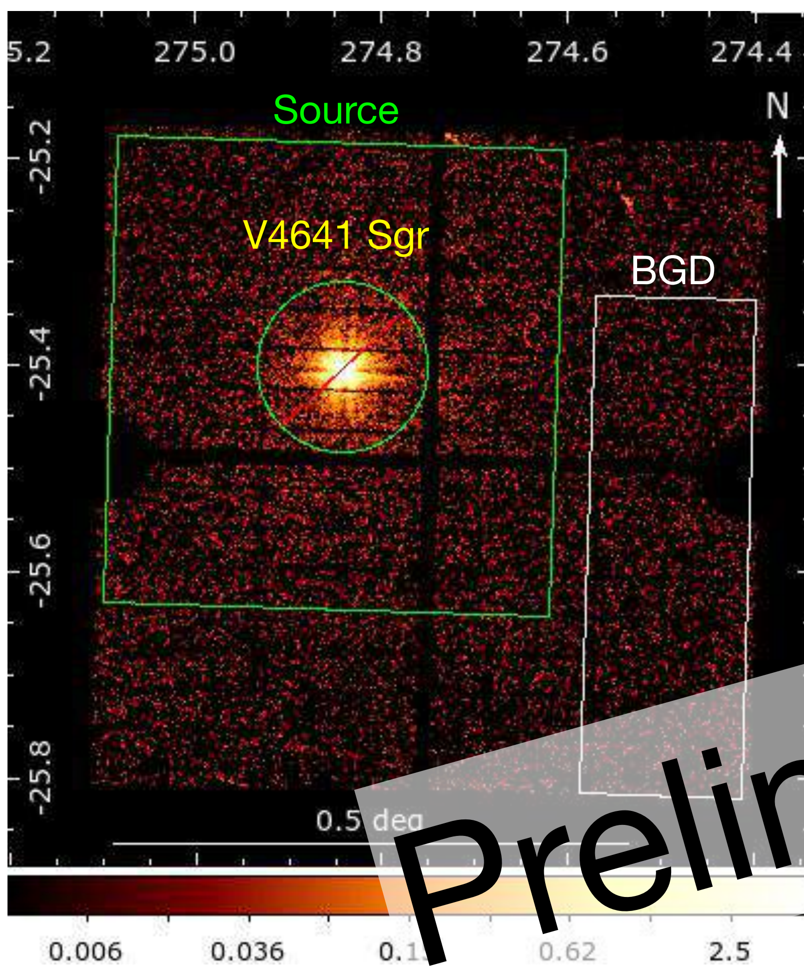
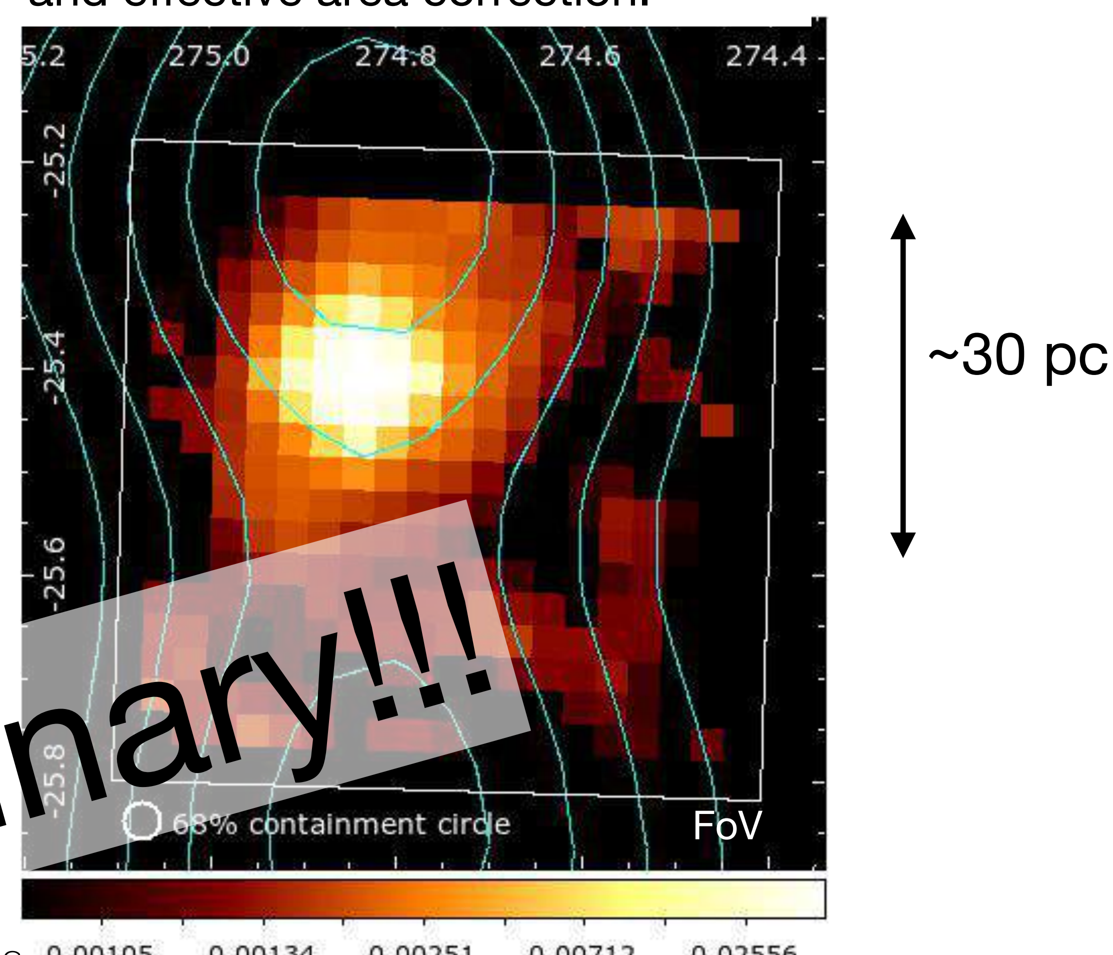
- Recent gamma-ray detection by HAWC and LHAASO: 2nd case of PeV accelerating microquasars
- XRISM Xtend image shows diffuse emission around V4641 Sgr
  → Acceleration site is probably close to V4641 Sgr (< 10 pc) while population of gamma-ray emitting particles is different

XRISM Xtend Raw image (1.2–7.0 keV)



After background subtraction and effective area correction.



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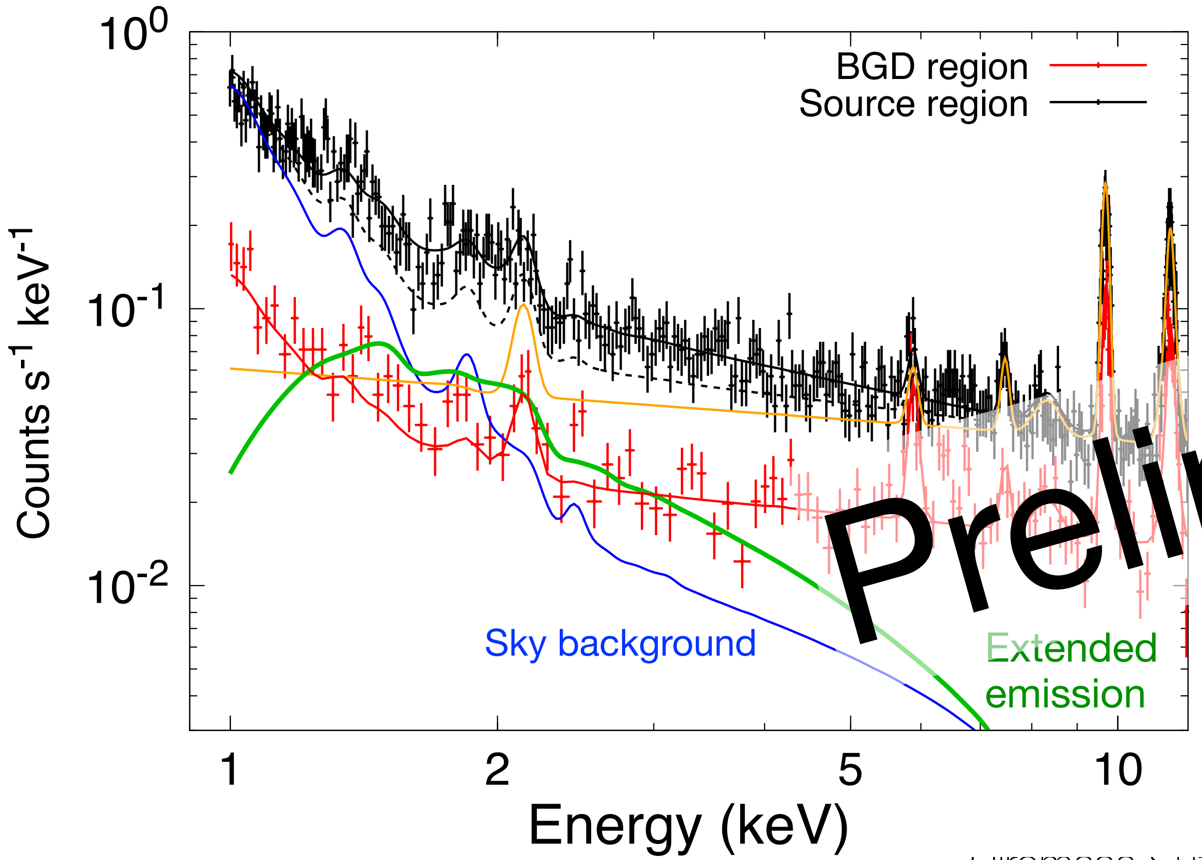
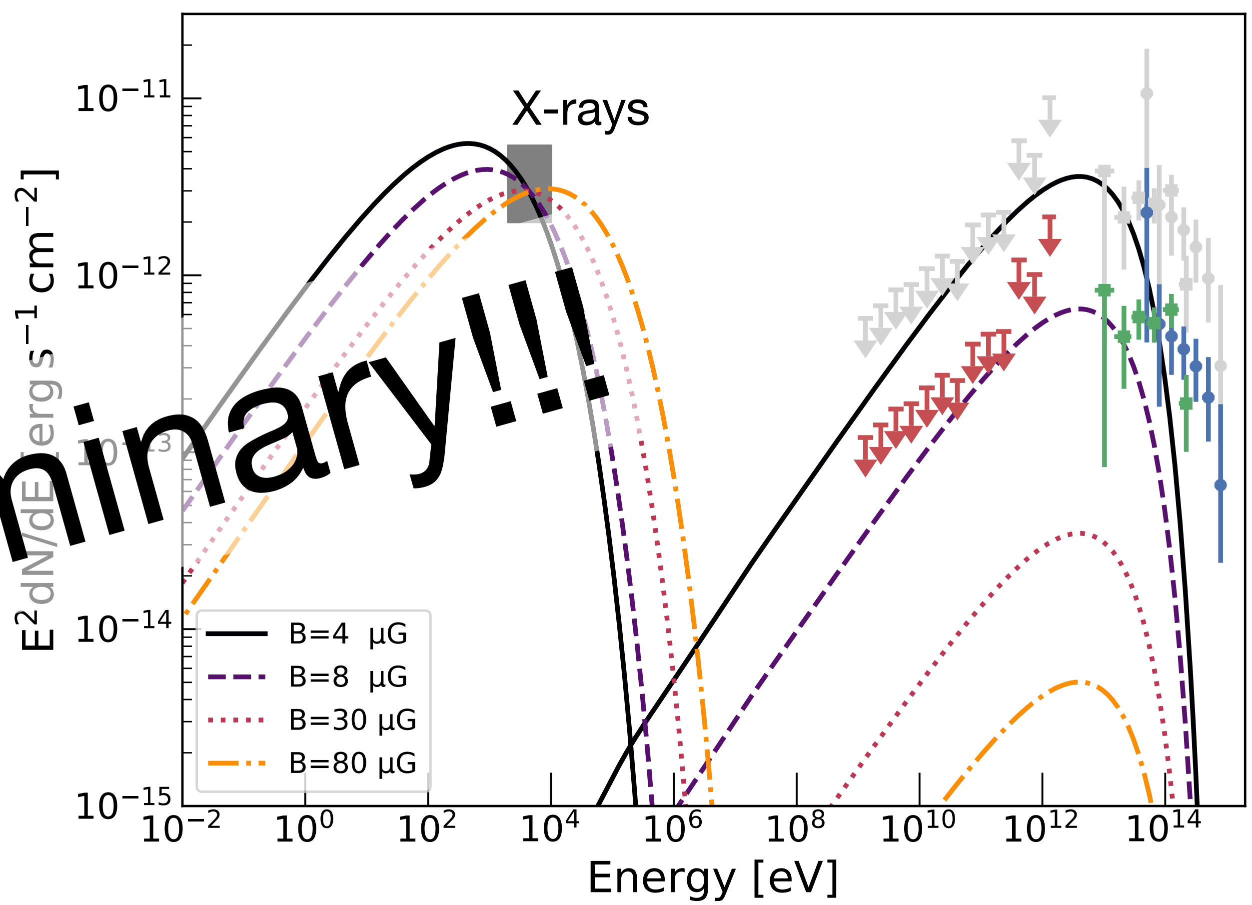
- BH with ~6 solar mass, at ~6 kpc
- Recent gamma-ray detection by HAWC and LHAASO: 2nd case of PeV accelerating microquasars
- XRISM Xtend spectrum: both non-thermal/thermal models can explain data
- If non-thermal, upper limit of inverse Compton gamma-rays obtained (gamma-rays are likely hadronic (very hard spectrum)) → B >~8 uG = enhanced from ISM values
- If thermal, jet luminosity ~1e39 erg s^{-1} (~Eddington luminosity) can explain data

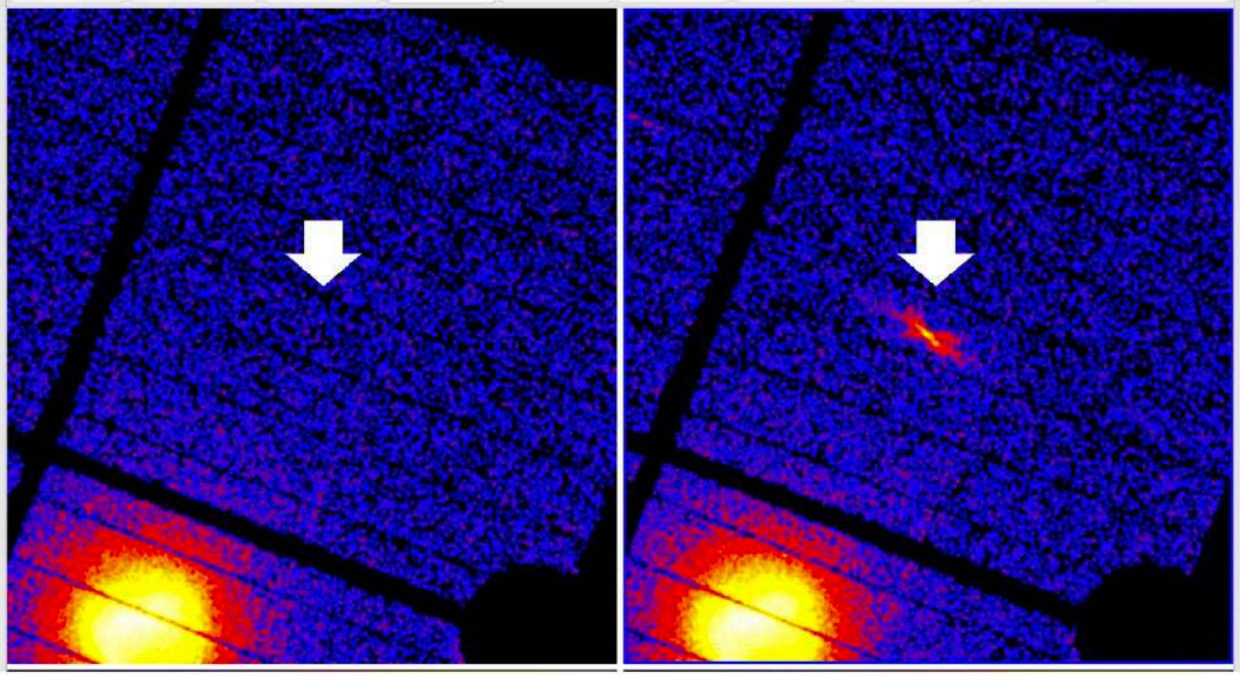


Upper limit of Inverse Compton gamma-rays



Contribution in time-domain astronomy: XRISM XTS (Xtend transient search) system

- 38’x38’ FoV of Xtend is used for transient-source search (semi-automatic system)
- Note: max. ~24h separation between observation and data acquisition (examination)



Tsuboi et al., Proc. SPIE, 2024

Figure 4. The Xtend images of AX J1910.7+0917 before (*left*) and after (*right*) the outburst reported as the ATel #16607 (see Table 1)

ATel#	Date	Type	Counterpart (species)	Time lag (hour)[†]
16532	2024-03-15	Stellar Flare	LP 593-21 (M dwarf binary)	168
16558	2024-03-28	Stellar Flare (?)	4XMM J190821.5+06585 (?)	36
16561	2024-03-31	Stellar Flare	SSTGLMC G335.2665-00.0151? (YSO candidate)	20
16592	2024-04-17	Stellar Flare	UCAC4 476-091023 (spectroscopic binary)	123
16607	2024-05-01	Outburst	AX J1910.7+0917 (NS HMXB)	67
16632	2024-05-28	Supernova	SN2024iss (Super Nova)	N/A[‡]
16652	2024-06-14	Stellar Flare	Cl Collinder 228 113 (spectroscopic binary)	91
16683	2024-07-02	Stellar Flare	MS Ser (BY Dra type variable)	19
16685	2024-07-03	Stellar Flare	MS Ser (BY Dra type variable)	15

[†] Time lag between the transient and the ATel submission.

[‡] Not triggered but followed up by XTS.

Summary & future prospects

- **Primary objective of XRISM is line emission from thermal plasma,** but we can study **particle acceleration via line/thermal properties** (although challenging)
  - line widths of shock-heated plasma
  - neutral iron lines stimulated by non-thermal particles
    } Resolve (spectrometer)
  - hard tail in broad-band spectrum
  - diffuse emission around acceleration sites
    } Resolve (spectrometer) & Xtend (CCDs)

- **Work in the near future …**
  - particle acceleration efficiency in supernova remnants (Tycho, RCW86, N132D, …)
  - hard tails in supernova remnants (W49B, Cas A, …)
  - diffuse emission around accelerators (supernova remnants? microquasars?)
    - V4641 Sgr: paper will be submitted soon
  - neutral iron lines in the Galactic center
  - Multi-messenger collaboration is under discussion:
    XRISM Xtend's large FoV (38'x38') & neutrino/GW alerts
    (ToO already doable but can be improved significantly)
- New ideas are welcome !!