



P45 High-resolution X-ray astrophysical search for r-process nucleosynthesis signatures from Galactic binary neutron-star mergers

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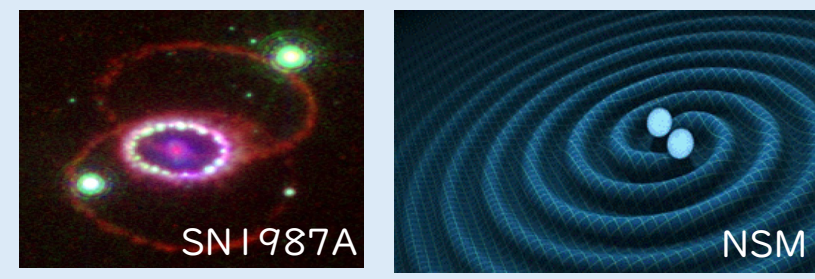
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Abstract: Binary neutron star mergers (NSMs) are widely considered r-process nucleosynthesis sites, as suggested by infrared observations of kilonovae and by the gravitational-wave event. Unstable heavy nuclei produced via the r-process later decay, emitting nuclear gamma rays along with internal conversion X-rays. The flux of a single merger is far below the sensitivity of existing observatories. Detectability, however, becomes plausible if we focus on emission from r-process nuclei with Myr-scale decay times synthesized in multiple NSMs (like in globular clusters or the nuclear stellar cluster), tracing the integrated merger history over their decay time. In this presentation, we introduce an astronomical survey strategy using the recent high resolution X-ray observatory XRISM.

1. Where is r-process nucleosynthesis site?

Neutron rich environment in the universe

- Birth of neutron stars (NS): core-collapse supernovae
- Death of neutron stars: binary NS mergers (NSMs)



-- NSMs represents lower Y_e environment than SNe

(Lattimer & Schramm 1974, Metzger et al. 2010, Wanajo et al. 2011)

We focus on NSMs as r-process site / kilonova

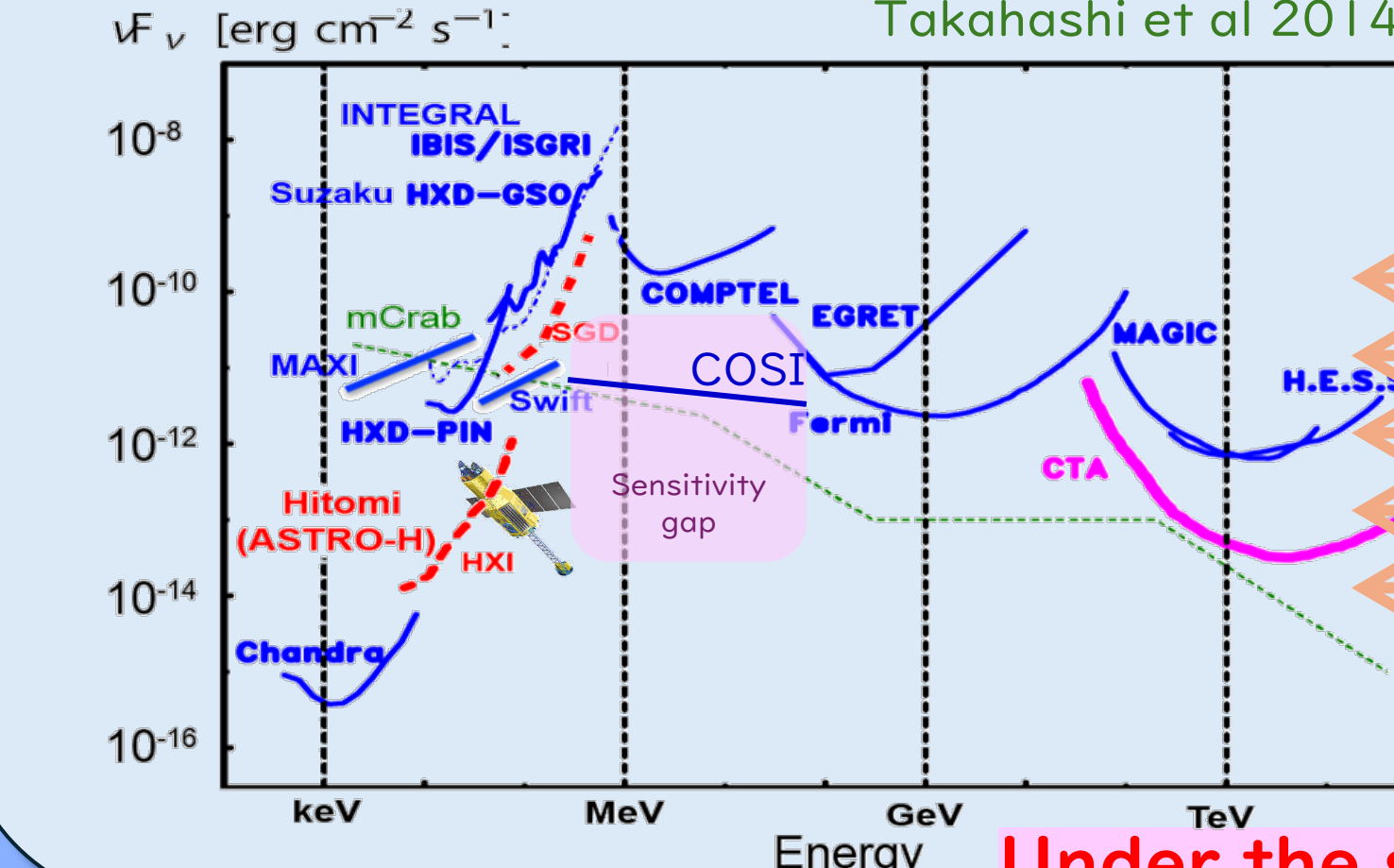
- Observational hint of r-process nucleosynthesis in IR GRB 130603B (Tanvir et al. 2013), GW170817 (Villar et al. 2017)

Our Science Goal:

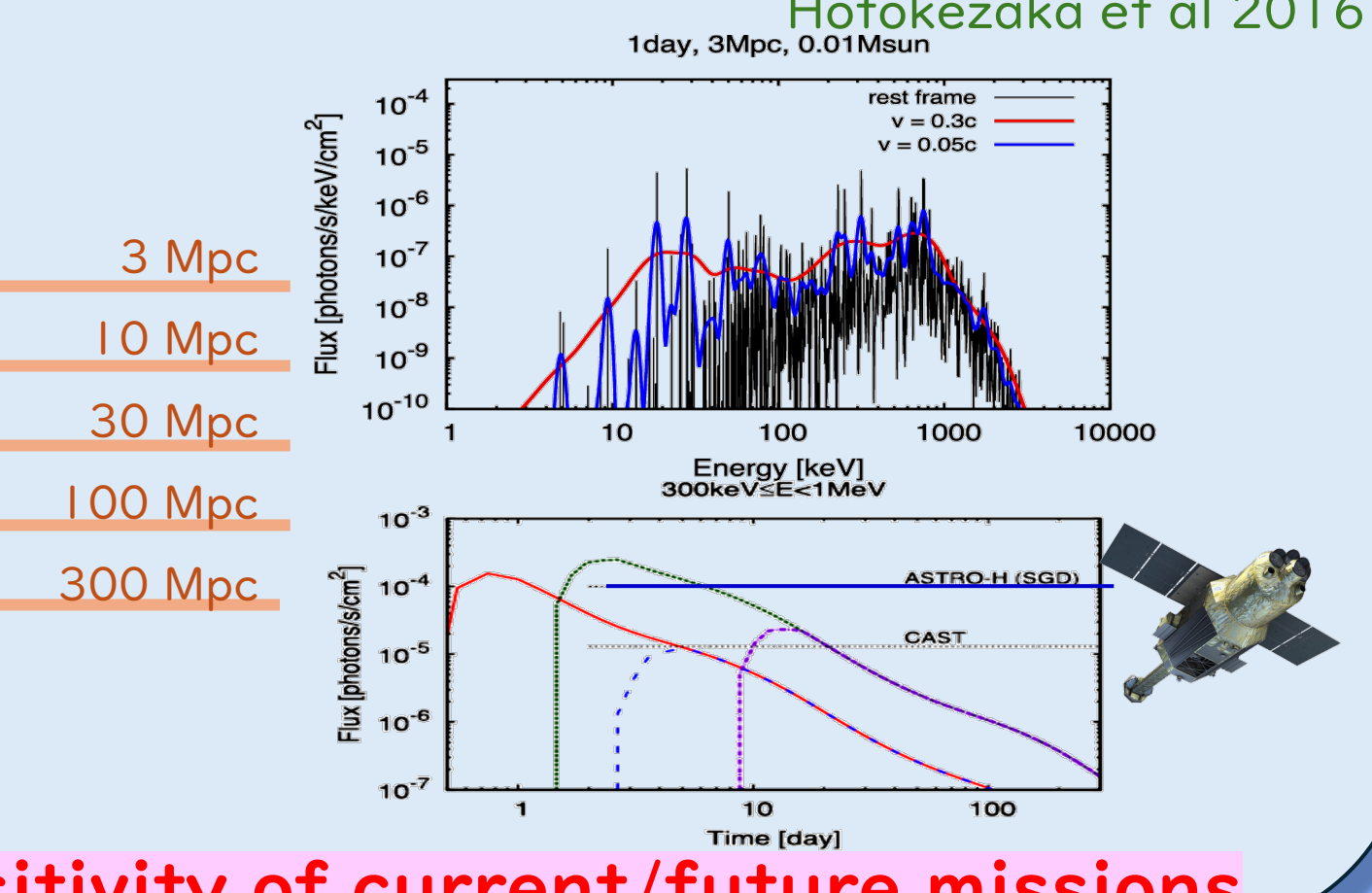
- Search for direct emission from unstable r-process nuclei in X-ray to Gamma-ray bands.

2. Can we search for r-process gamma-rays?

Gamma-ray Sensitivities



Expected flux from NSMs

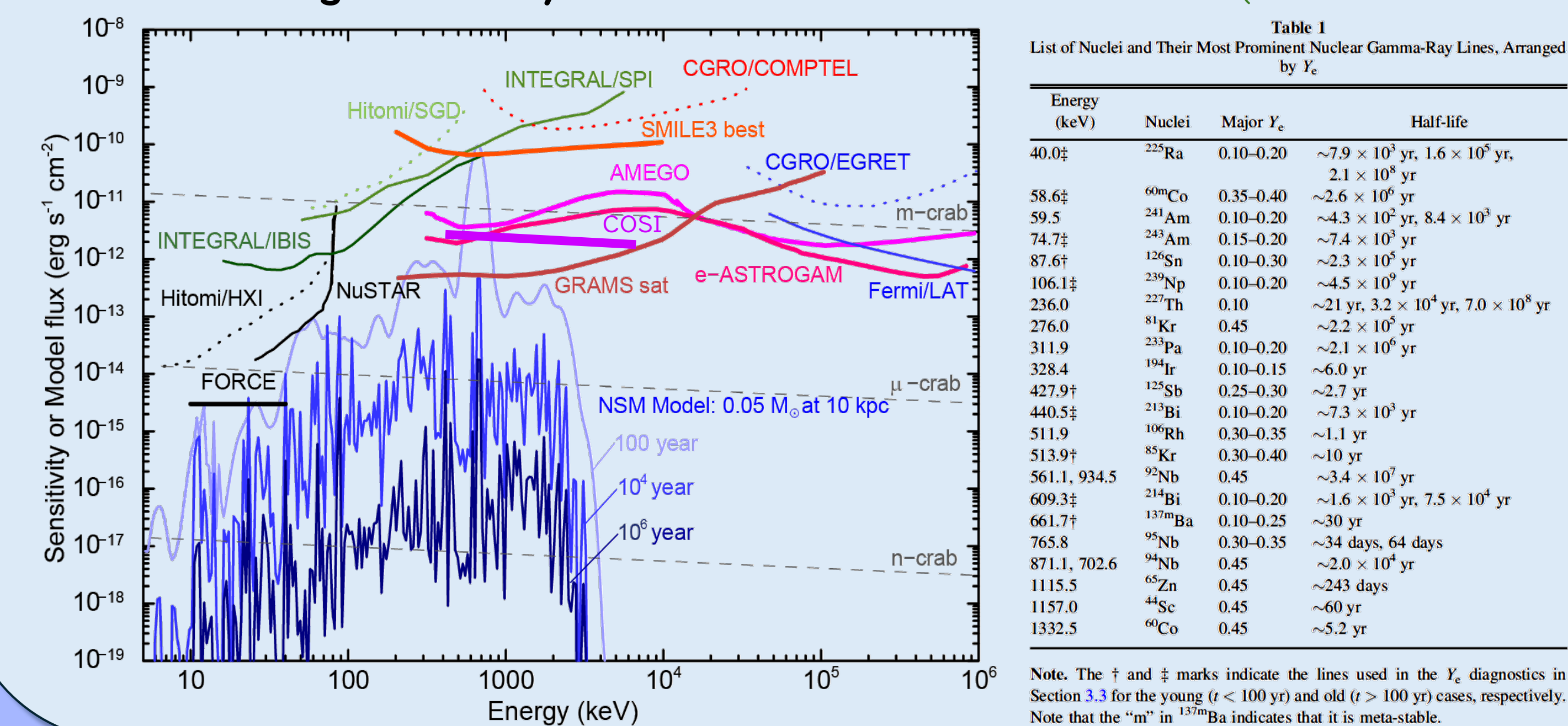


Under the sensitivity of current/future missions.

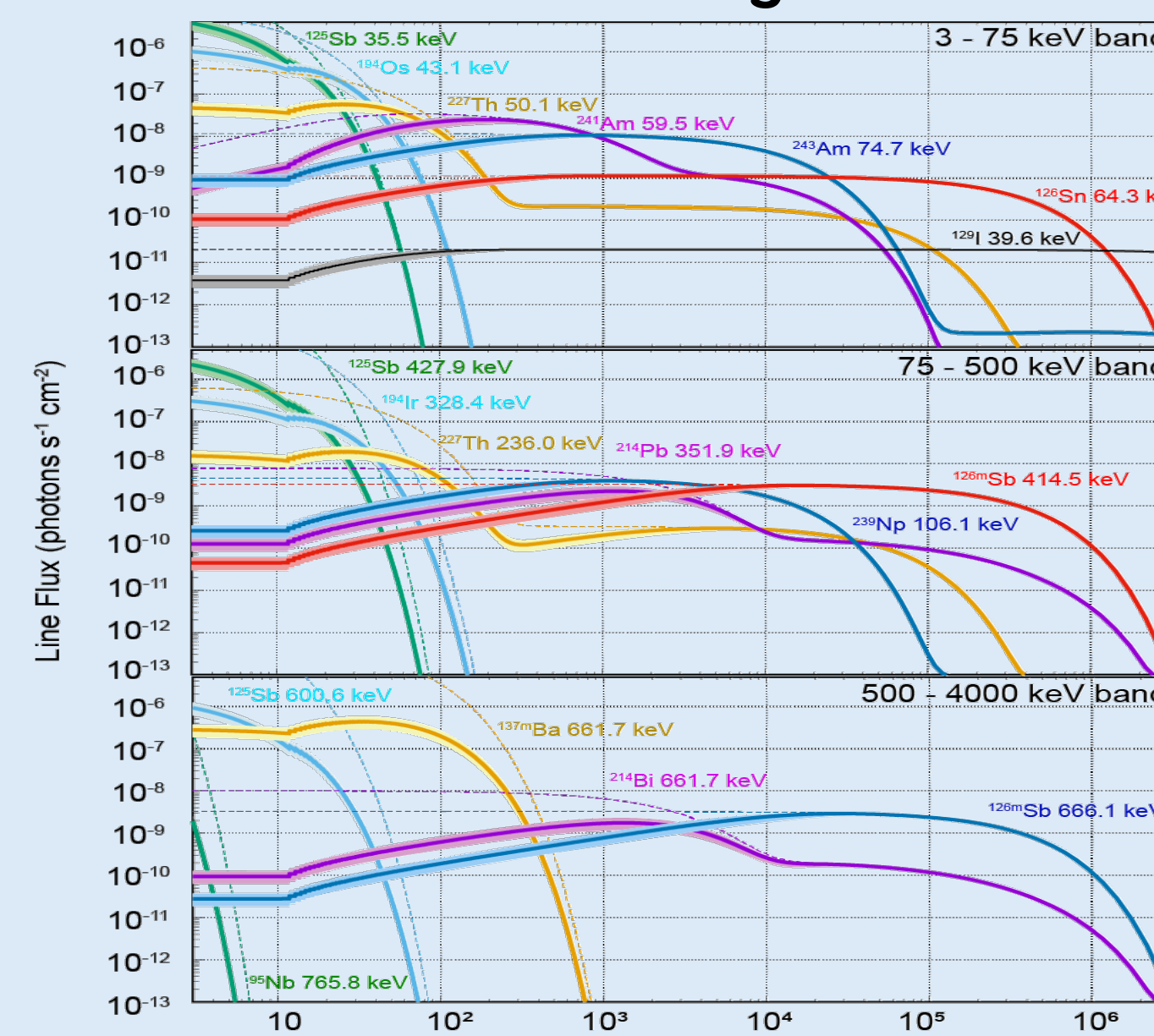
3. What information can we obtain using r-process gamma-rays from Galactic NSM Remnants?

Idea) Search for long-lifetime r-process nuclei of NSM remnants in our Galaxy. (Wu et al. 2019, Wang et al. 2020, Terada et al. 2022)

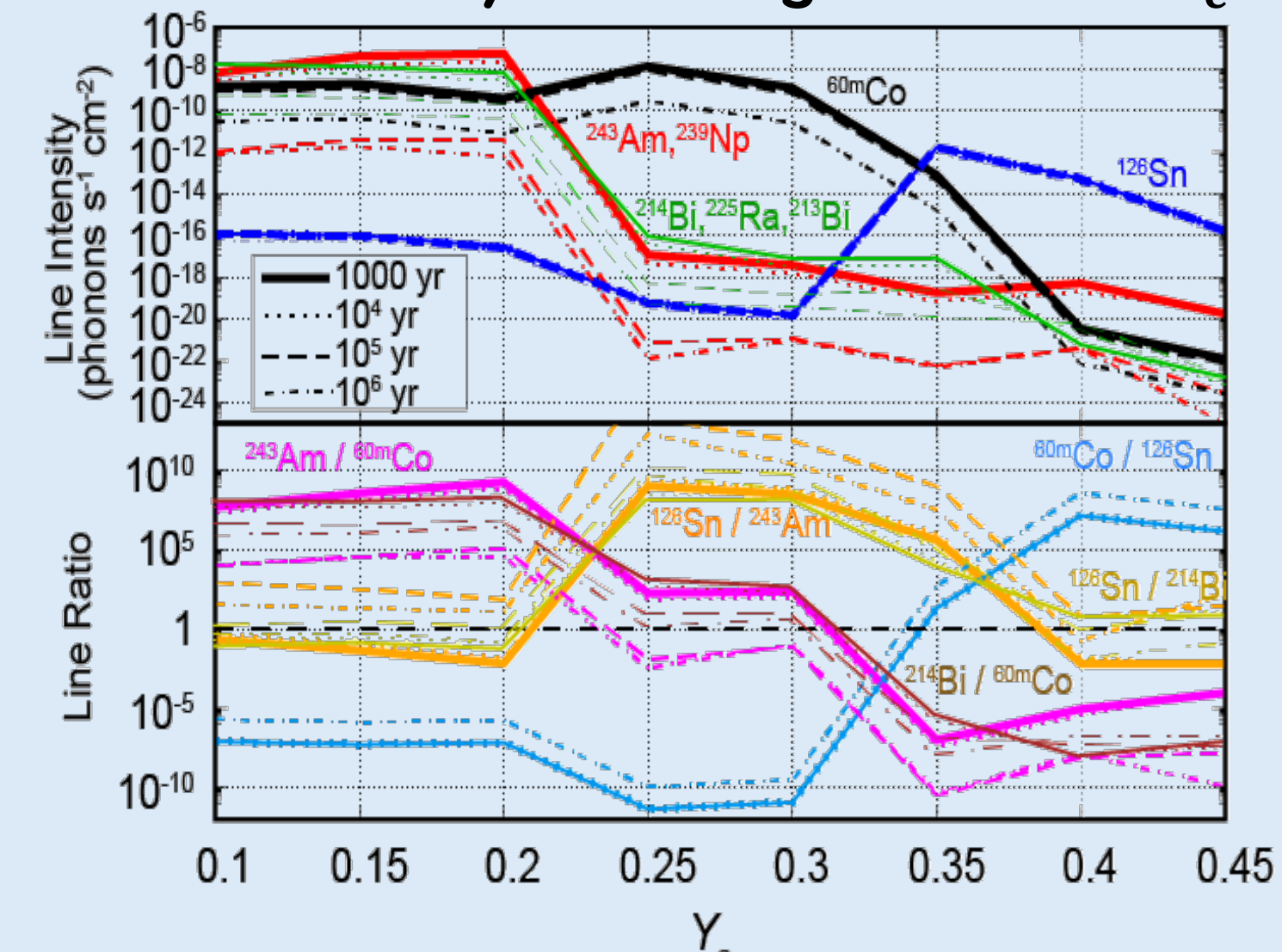
Estimation of gamma-rays from Galactic NSM Remnants (Terada et al. 2022)



Time evolution of gamma lines



Gamma-ray line diagnostics of Y_e



Nuclear gamma lines provides the age and Y_e , if we can measure gamma-ray spectra.

4. How can we search for r-process signals using astrophysical missions?

Gamma-ray band (0.5-5 MeV)

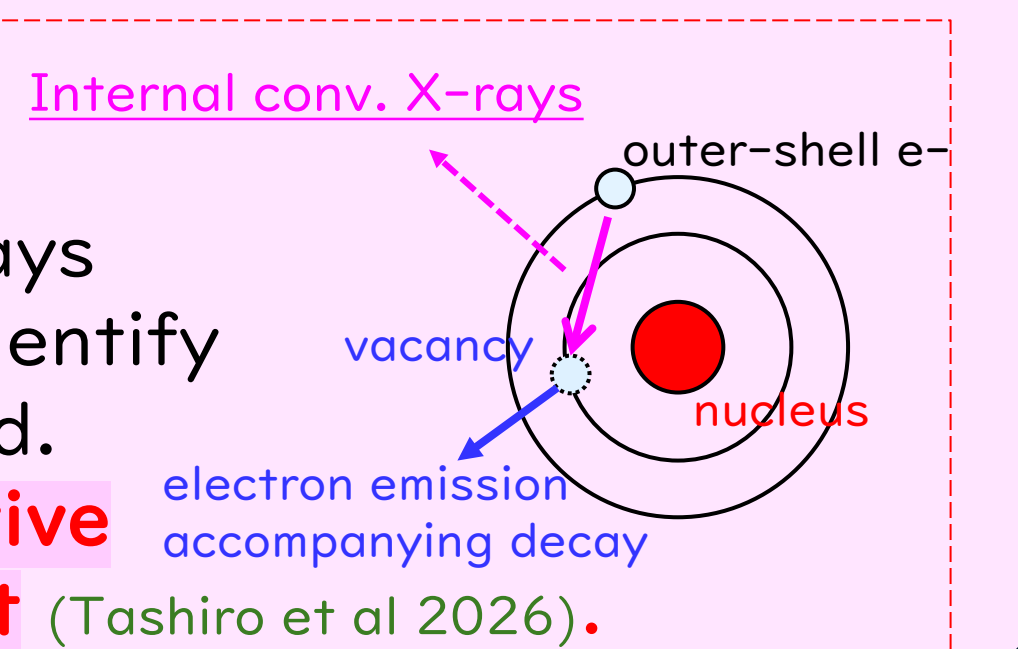
- Limited sensitivity in principle of detection
- Future missions may probe 100 - 1000 years old NSM remnants.
- We expect COSI (2027-) for detection.

Hard X-ray band (10-70 keV)

- Higher sensitivity with focusing optics.
- NuSTAR is active but below the sensitivity.
- HEX-P (US) and FORCE (Japan) could potentially detect signals. (Stephen et al 23, Mori et al. 23), but neither mission has been approved.

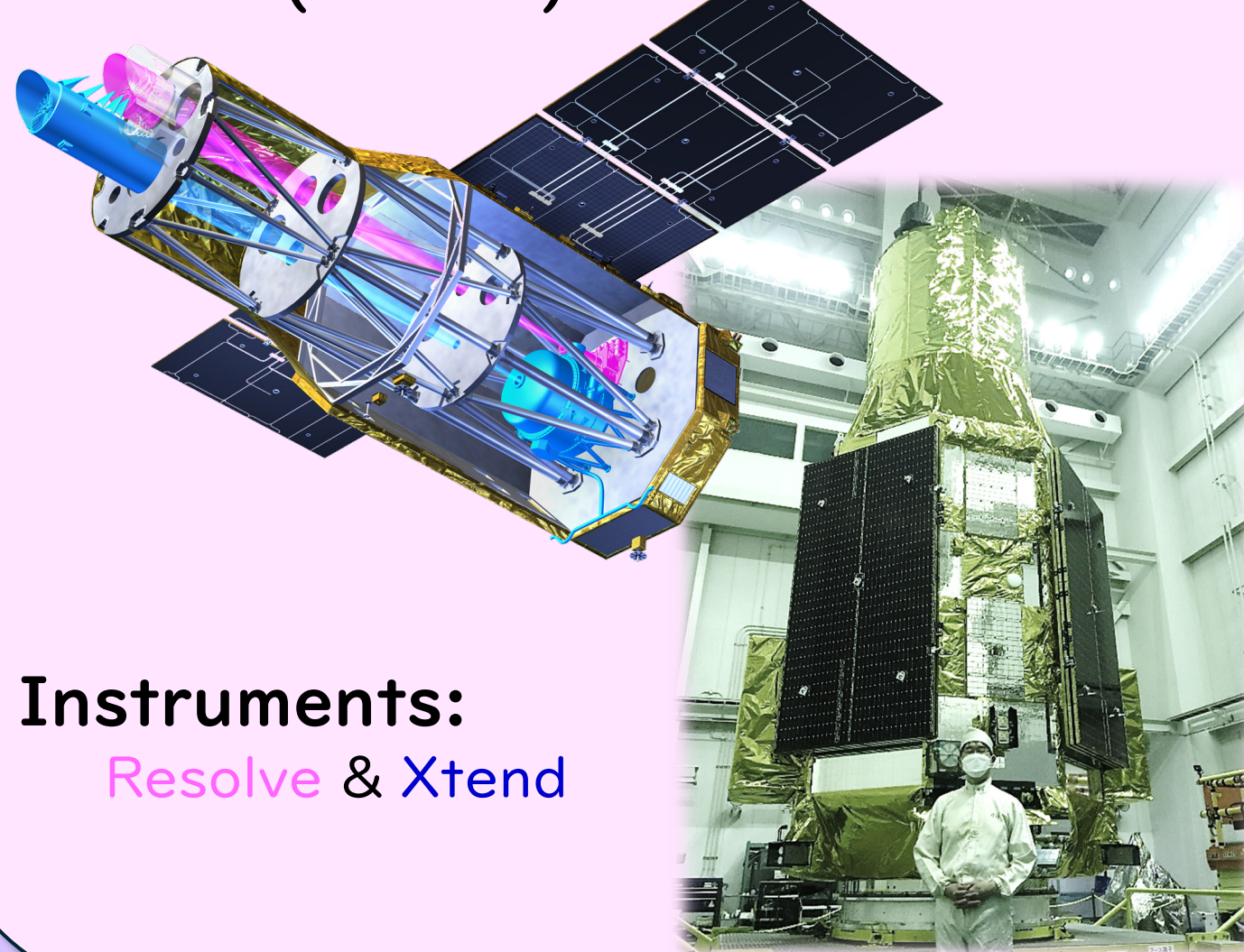
Soft X-ray band (2-10 keV)

- No gamma-ray lines
- Targeting internal conversion X-rays
- AXIS (US) survey could potentially identify signals (Koss et al 2025) but not approved.
- XRISM (Japan/US) is currently active and the strongest option at present (Tashiro et al 2026).



5. High-resolution X-ray spectral search with XRISM

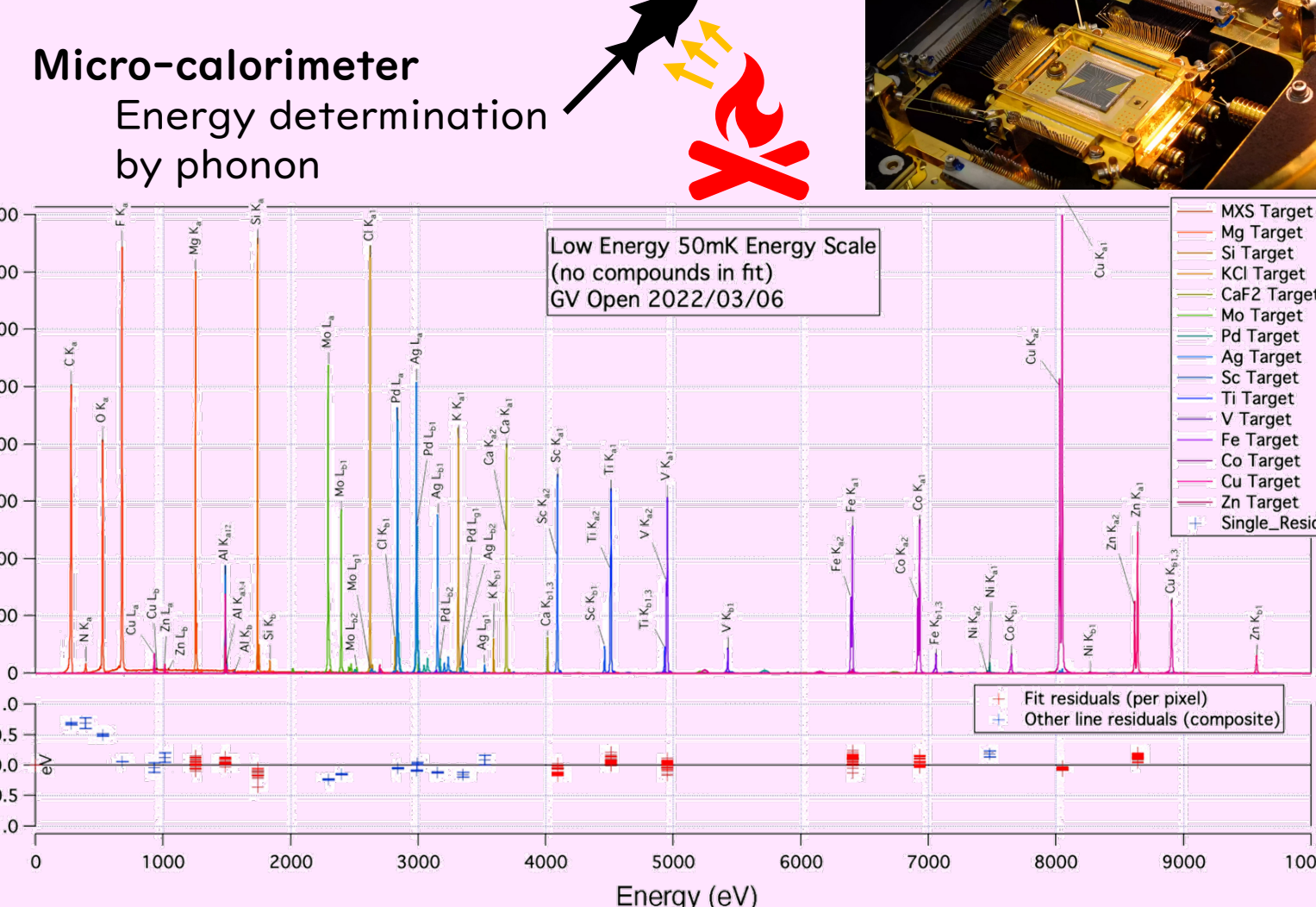
XRISM (2023-)



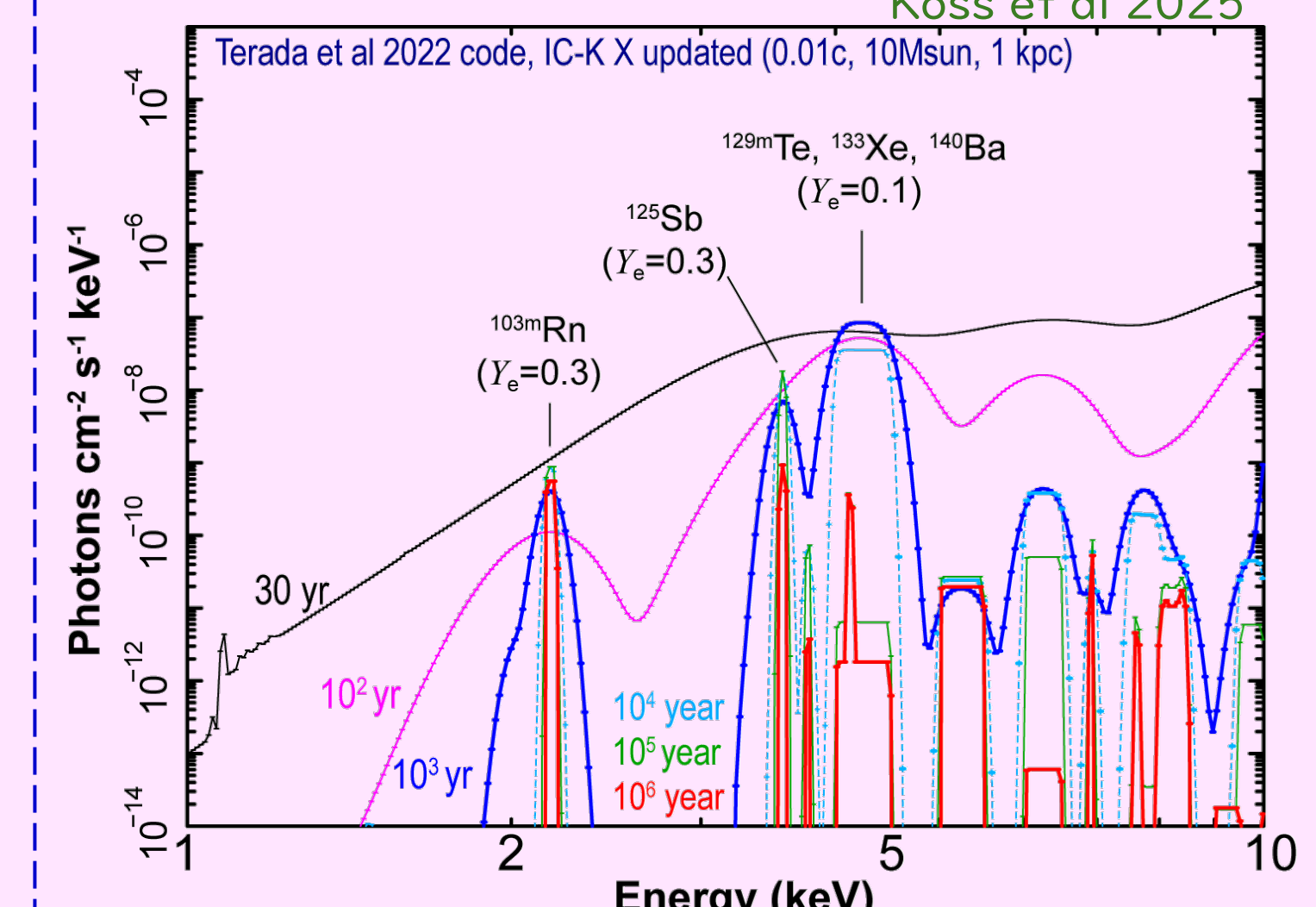
Instruments:

Resolve & Xtend

Parameters	Resolve	Xtend
X-ray Mirrors	Conically approximated Wolter I optics (203 nested shells)	
Focal Length	5.6 m	
Angular Resolution	1.3 arcmin (HPD)	1.4 arcmin (HPD)
Detector Technology	X-ray micro calorimeter	X-ray CCD
Effective Area	180 cm ² @ 6 keV	310 cm ² @ 6 keV
Field of View	3.1 × 3.1 arcmin ²	38.5 × 38.5 arcmin ²
Energy Range	0.3 (1.7) - 12 keV	0.4 - 13 keV
Absolute Energy Scale	≤ 1 eV (1.7-12 keV) ≤ 0.3 eV (5.4-9 keV)	-
Energy Resolution	4.5 eV FWHM @ 6 keV (H)	180 eV @ 6 keV, EOL
Non-X-ray Background	7 × 10 ⁻⁴ c/s/keV/array	≤ 1 × 10 ⁻⁶ c/s/keV/arcmin ² /cm ² in 5-12 keV
Time resolution	5 μs (M/M), 80 μs (L)	4 s (full window), 0.5 s (1/8 window)
Timing Accuracy	≤ 1 ms (absolute)	-



IC X-rays exp. from NSM Remnants

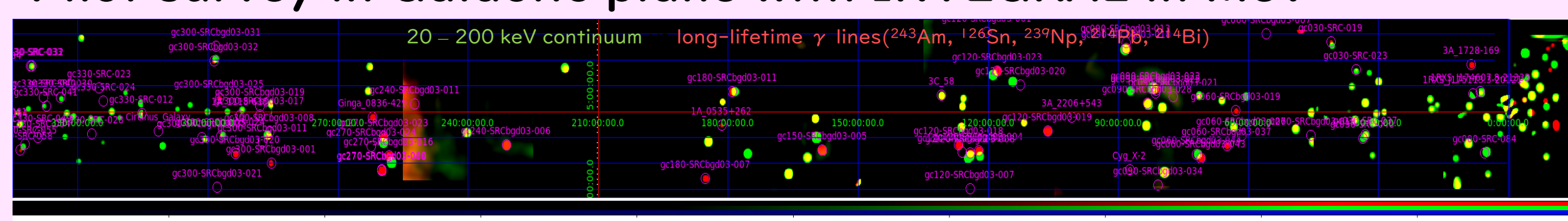


High resolution spectroscopy in 2-10 keV → best instrument for IC X-ray search.

6. Which object should we search?

XRISM : Pointing observatory (not suitable for wide area survey)
→ we should define the target position.

Pilot survey in Galactic plane with INTEGRAL in MeV



→ no candidates found.

Idea) Targeting old system hosting multiple NSMs

Globular clusters : ~160 objects
(10⁵⁻⁶ stars, 10³ BHs, 10³ NSs, 10⁴ WDs)

Nuclear stellar cluster (single object)
(10⁷ stars, 10⁴ BHs, 10³⁻⁴ NSs)



Feasibility / rough estimation

- Target Selection of Globular Clusters
- NS → millisecond pulsar (MSP), LMXB → NSMs
- Number of MSP (N_{MSP}): $\propto$ Gamma-ray flux

Best Gamma-ray globular clusters in 4th Fermi/LAT catalog for Data Release 2

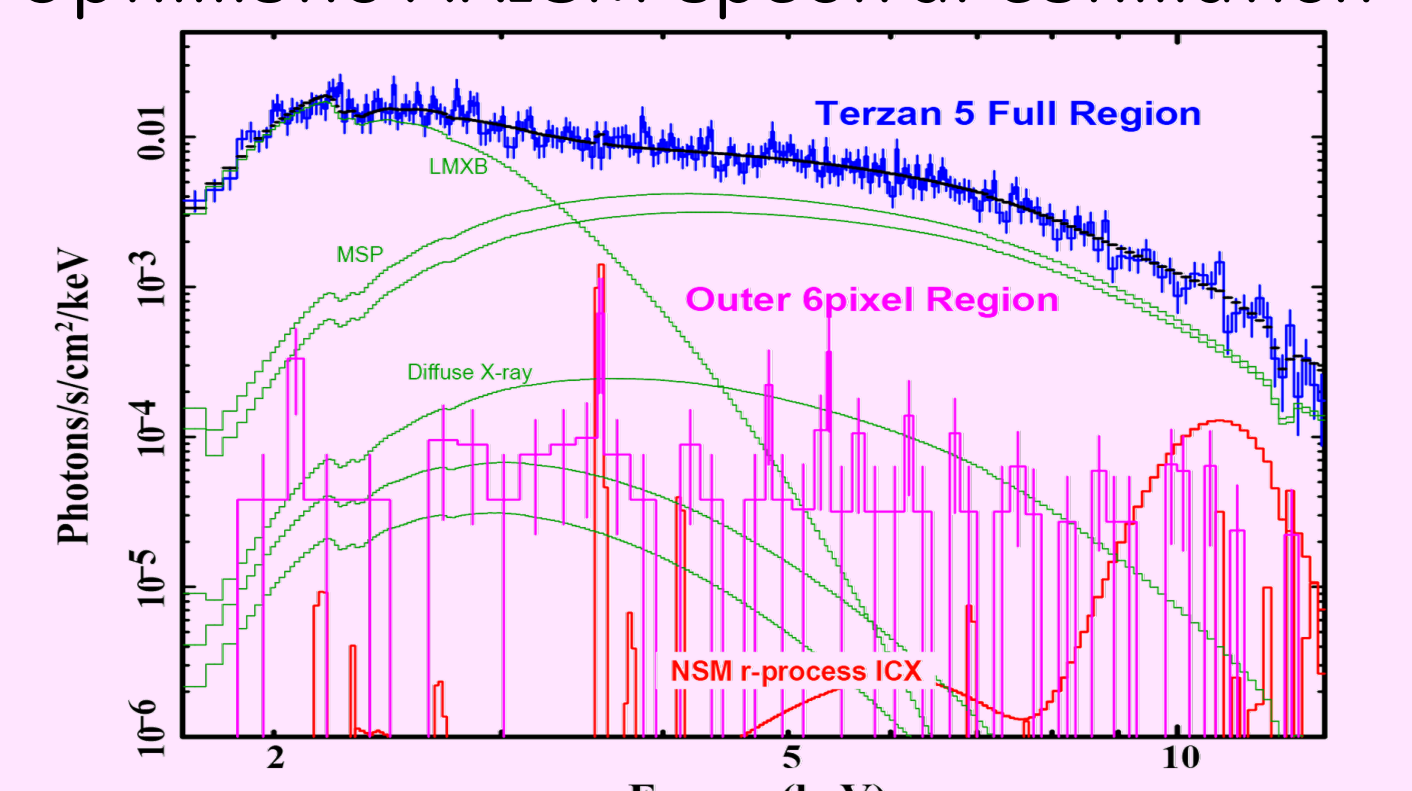
GC name	0.1500 GeV Flux (10 ⁻¹² erg/s/cm ²)	$N_{\text{MSP}}^{\text{detected}}$	$N_{\text{MSP}}^{\text{estimated}}$	d (kpc)
Terzan5	80.5 ± 1.4	39	317 ± 123	6.9
47Tuc	17.8 ± 0.4	27	29 ± 12	4.5
NGC 6715	2.6 ± 0.5	none	157 ± 69	26.8
NGC 6441	13.6 ± 0.6	7	151 ± 69	11.6
NGC 6388	16.5 ± 0.6	none	134 ± 52	9.9
NGC 6316	12.3 ± 0.7	none	110 ± 43	10.4

- Number of NSMs (N_{NSM}) : no detail estimation if we adopt evolutionary simulation for Open cluster,

Table 2: Estimation of NSM numbers in the best three globular clusters.

GC name	total Mass	NS number	MSP number	NSM number
Terzan5	2 × 10 ⁶ M _⊙	800-1,000	60-330	50-300
47Tuc	7 × 10 ⁵ - 10 ⁶ M _⊙	270 - 380	16-23	12-17
NGC 6441	2 × 10 ⁶ M _⊙	540 - 760	30-200	23-110

Optimistic XRISM spectral estimation



→ 3σ detection with 250 ks exposure (limiting N_{NSM} for NSM evolution)

- NSC could be more promising, as gravitationally confined obj. by SMBH.

We continue target selection & feasibility studies for XRISM observation.

If you have comments/questions, please contact us, terada@mail.saitama-u.ac.jp