Prospects for detecting gamma rays from r-process producing supernovae

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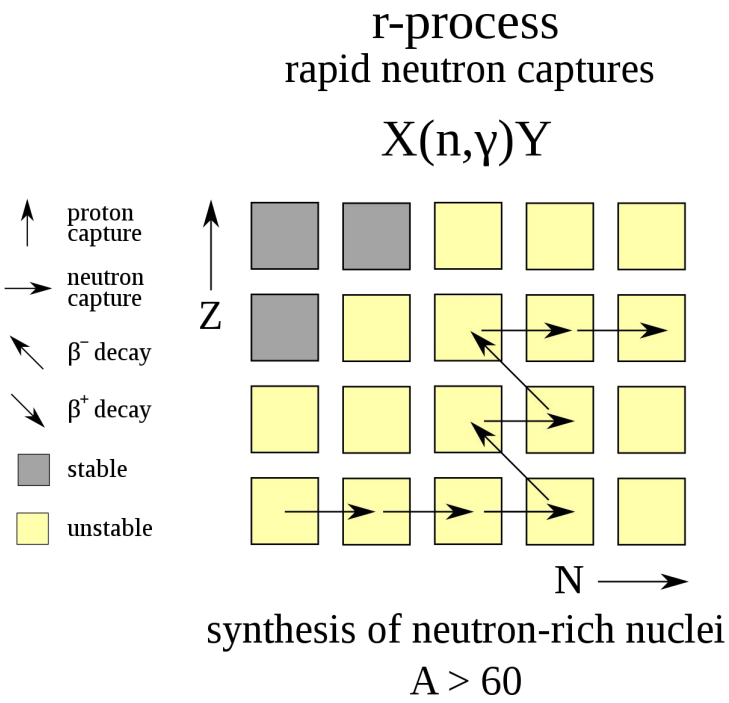
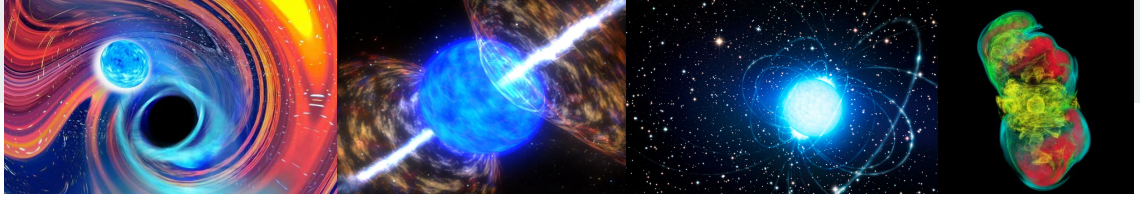
r-process

- Elements heavier than iron generally are synthesized in **astrophysical** sites via different processes.
- **R-process** (rapid neutron capture) is considered a major nucleosynthesis process responsible for forging heavy isotopes.

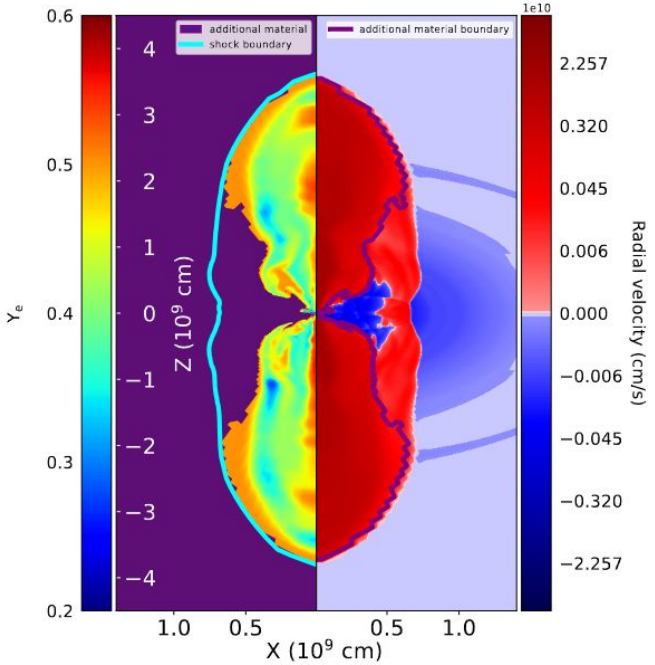




Sites for r-process

- **GW170817** confirms **Neutron Star Mergers (NSM)** as r-process sites.
- **NSM might not be the only r-process site since it requires delay.** It might be unable to explain the observed decrease in the Eu/Fe ratio (Côte et. al 2019)
- Other candidates include:
  - **Neutron Star-Black Hole Mergers** (e.g. Surman et al. 2008)
  - **Collapsar** (e.g. Popham et al. 1999)
  - **Magnetar** (e.g. Patel et al. 2025)
  - **Magneto-Rotational Supernovae** (Nishimura et al. 2015)

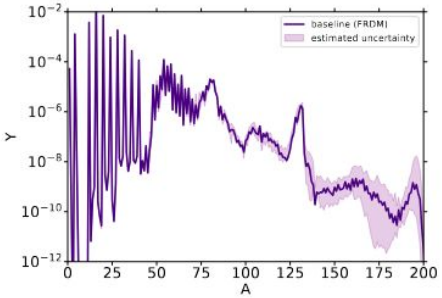
What are Magneto-Rotational SNe?

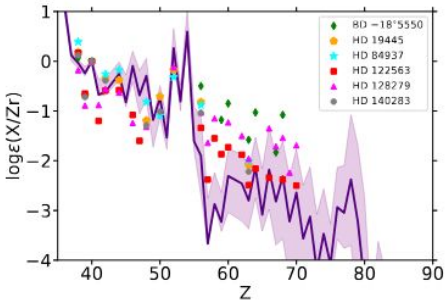


Liu et.al 2025 (in prep)

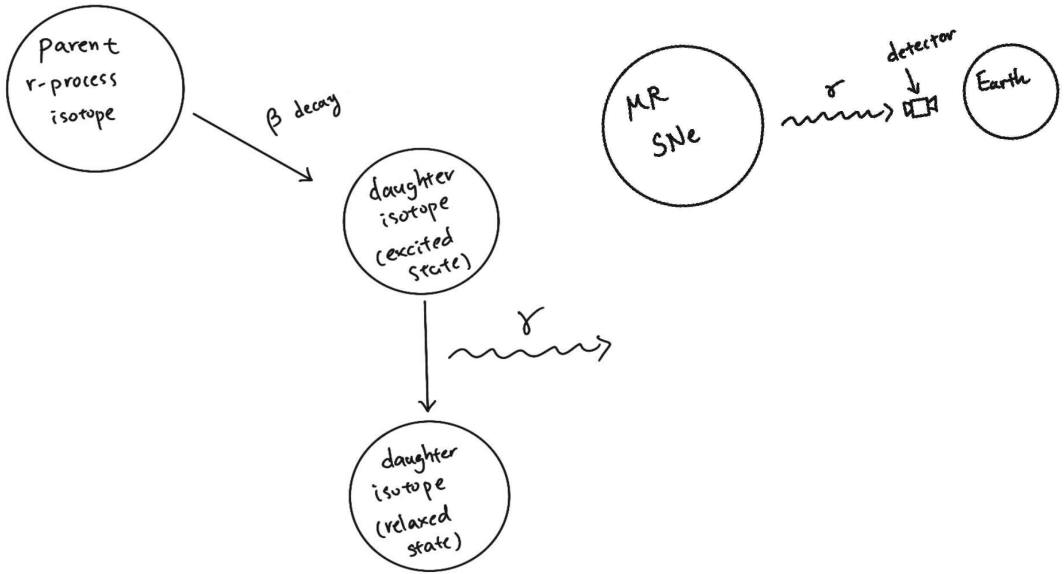
- **Magneto-Rotational SuperNovae** (MR-SNe) are **energetic supernovae that have high (10^{12}G) magnetic fields.**

- These explosions have **jets** where the **r-process could take place.**



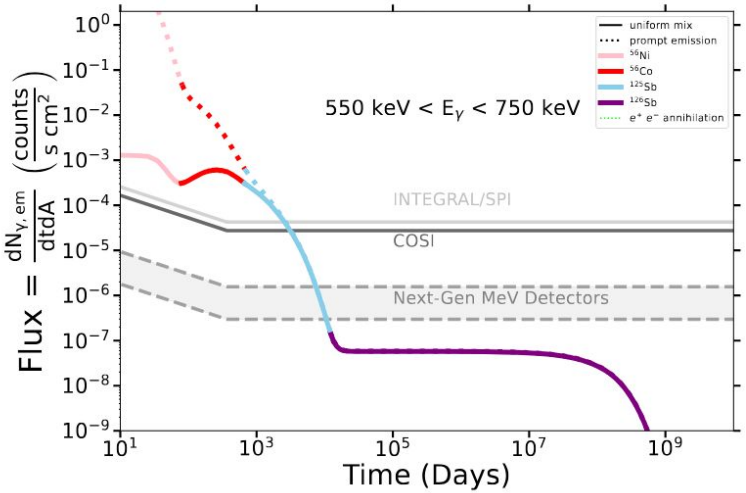


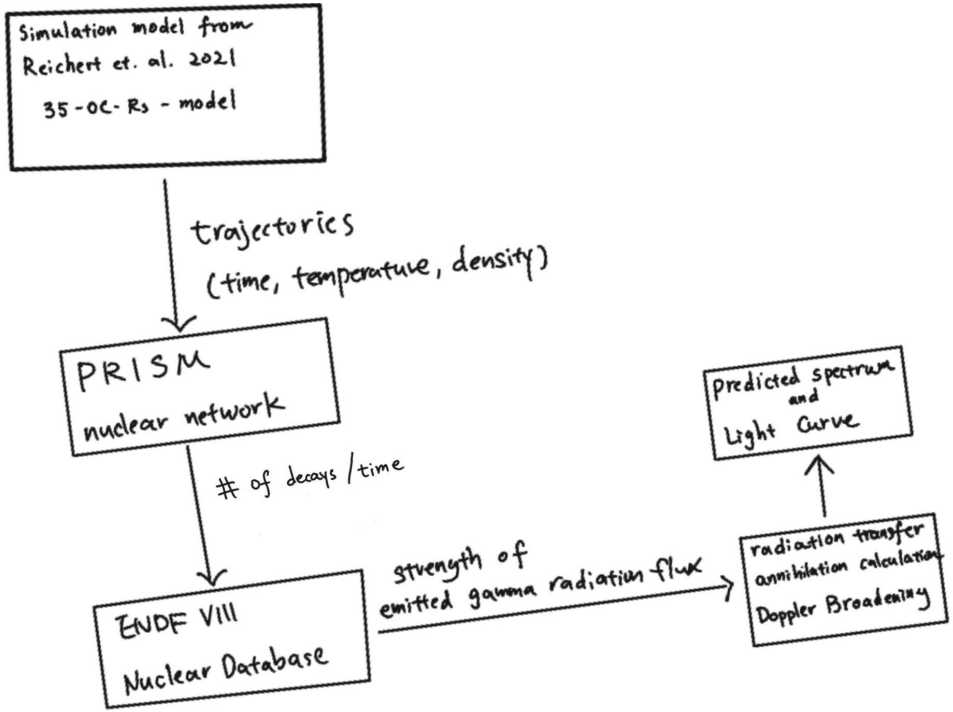
Beta decay related gamma signal from the r-process as a direct probe



- The beta decay daughters of the freshly synthesized r-process isotopes will sometimes **gamma-decay** and release a **photon**.
- This gamma radiation is a **direct probe of nucleosynthesis**.
- **With proper instruments, we might be able to observe these gamma signals**

Method





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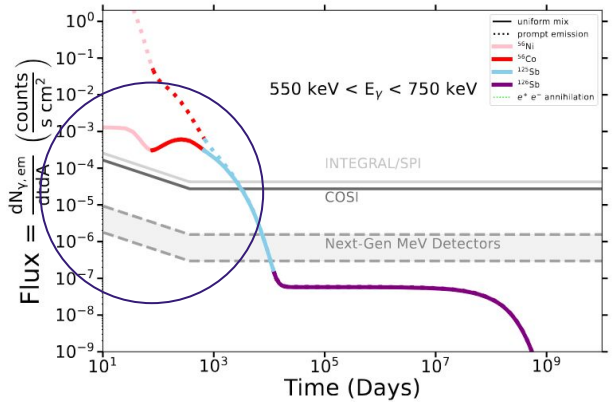
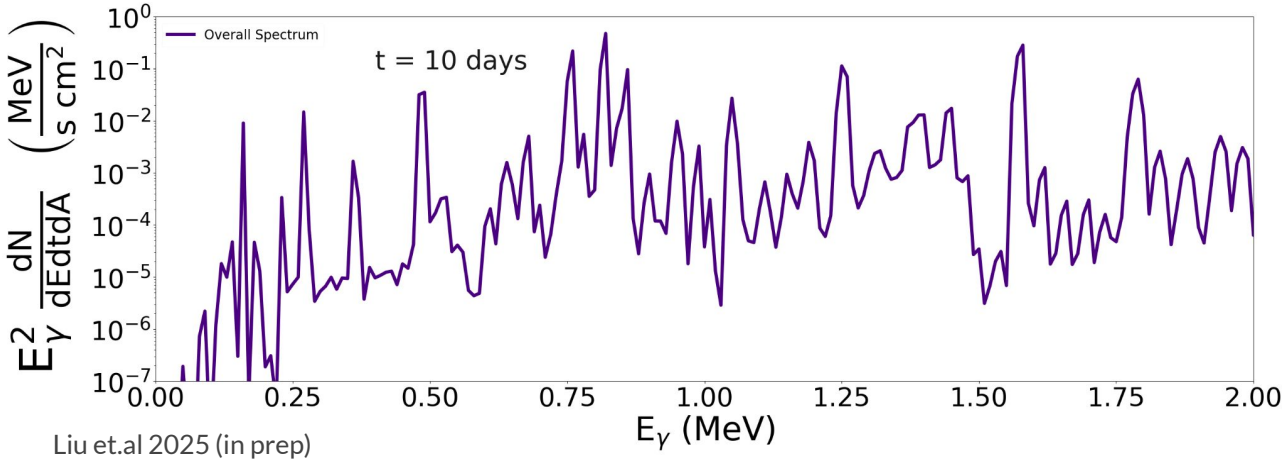
Future event signal



- I want to **predict what will the gamma signal looks like** if a **MR supernova event** occurred in **our galaxy** (**progenitor distance = 10 kpc**).
- Also, I am interested in finding **features that could be observed by current and planned gamma ray telescopes**.
- These features will correspond to specific isotopes.

- The **overall spectrum** from nuclear decays for an MR-SNe at 10kpc.

Spectrum at 10 days



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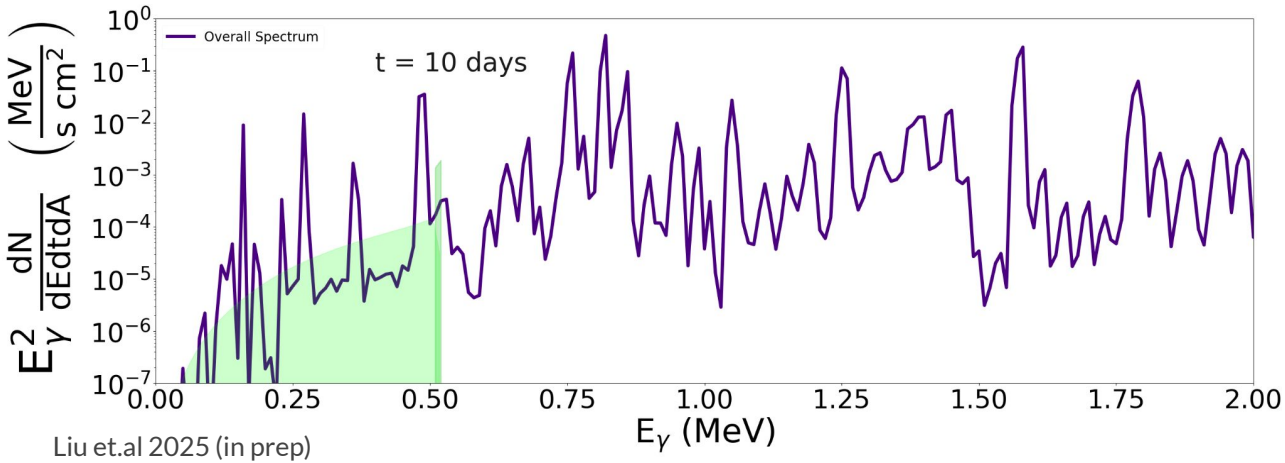

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- The **overall spectrum** from nuclear decays for an MR-SNe at 10 kpc.
- **Electron-positron annihilation radiation:** Positrons are from: $^{56}Co \rightarrow {}^{56}Fe + e^+ + \nu$.

  e^+e^- pairs form positronium:
  - **Para- positronium (singlet state, 2γ)**
  - **Ortho- positronium (triplet state, 3γ)**

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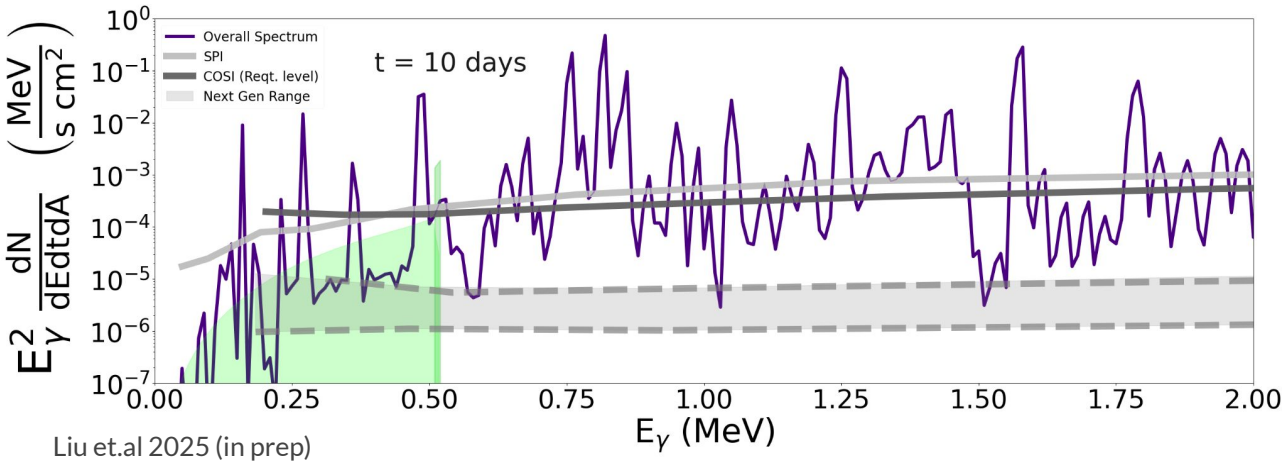

Liu et.al 2025 (in prep)

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  e^+e^- pairs form positronium:
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  - Ortho- positronium (triplet state, 3γ)
- **Detector sensitivities**:
  - SPI (current, out of service 2025)
  - COSI (planned in 2027)
  - GRAMS/AMEGO etc (Next-Generation detectors)

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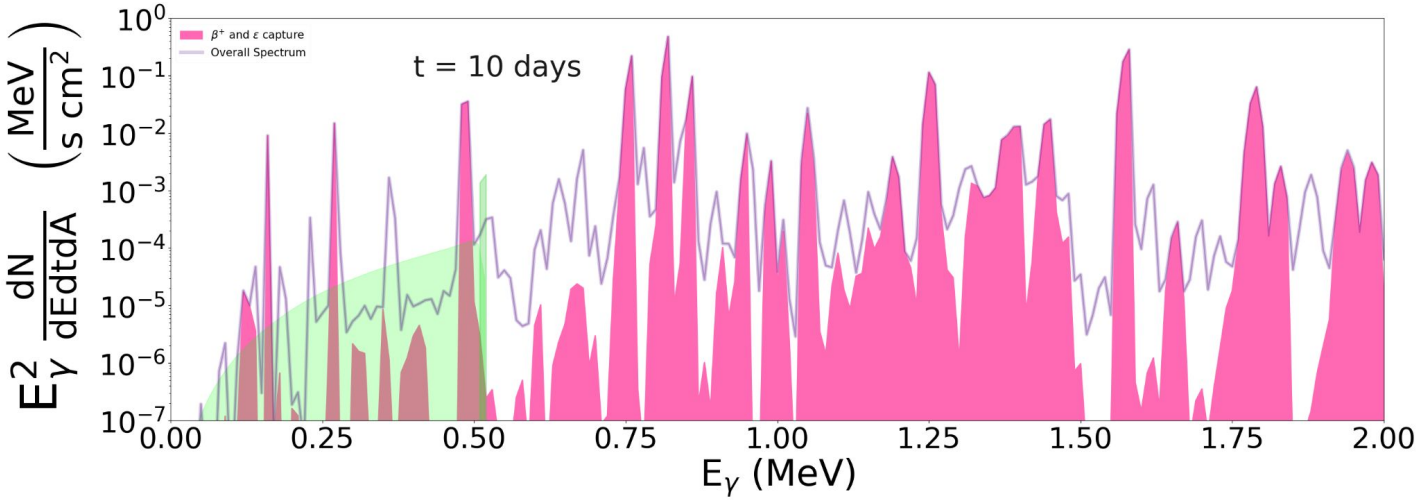

- **Pink Region**: Signals that are contributed by **beta plus decay or electron capture. These isotopes come from explosive burning and are also expected from regular core-collapse event (such as ^{56}Ni or ^{56}Co).**

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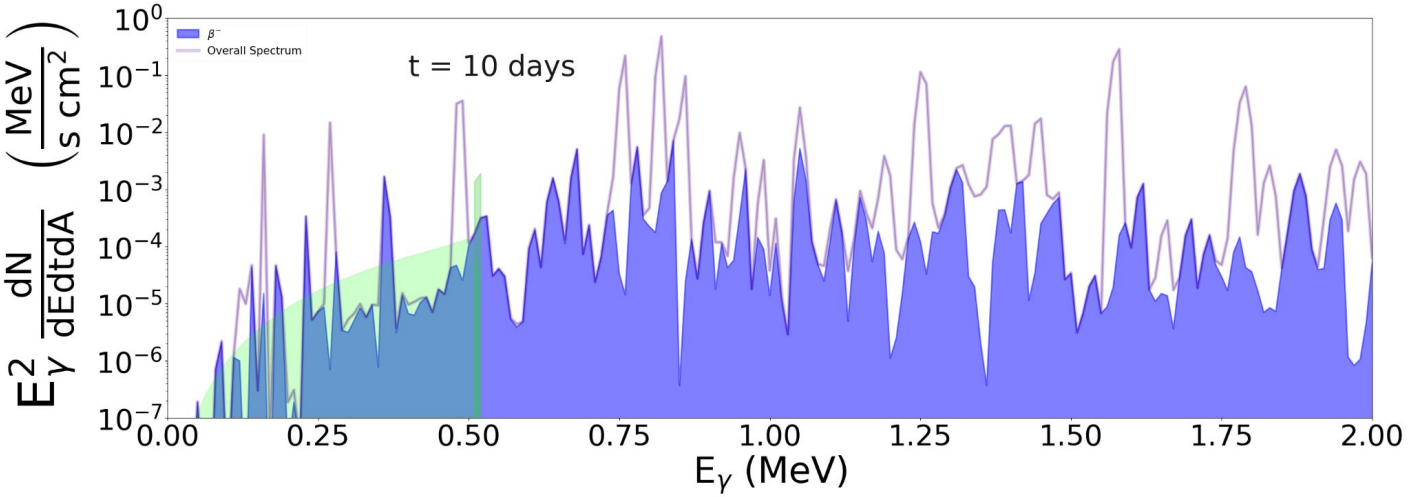

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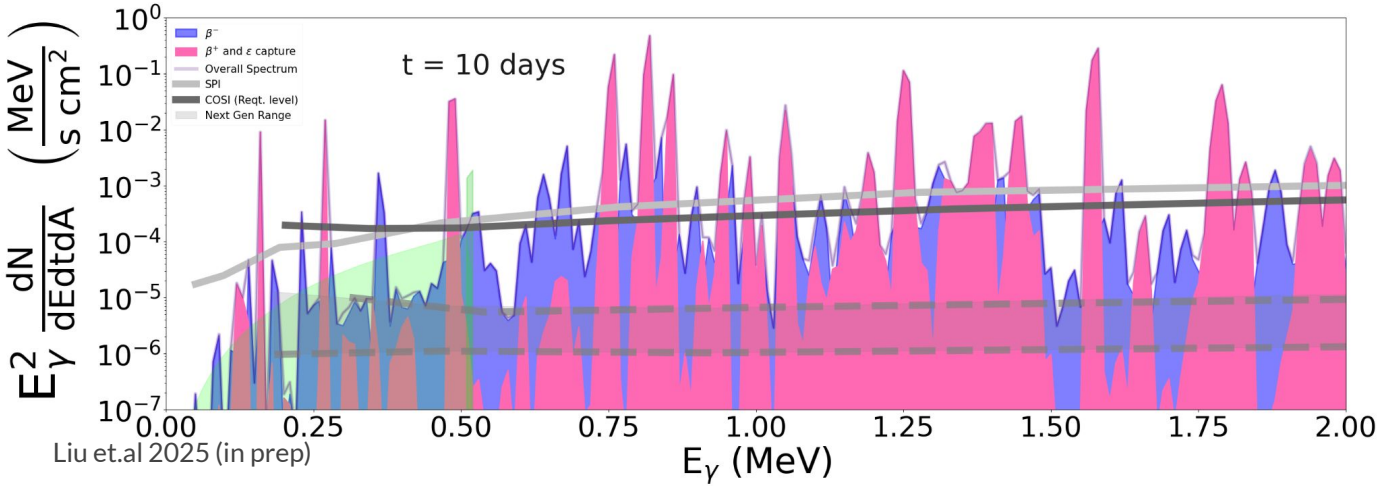
- **Blue Region**: **Signals that are contributed by beta minus decay.** This is the region we are interested in.

Spectrum at 10 days



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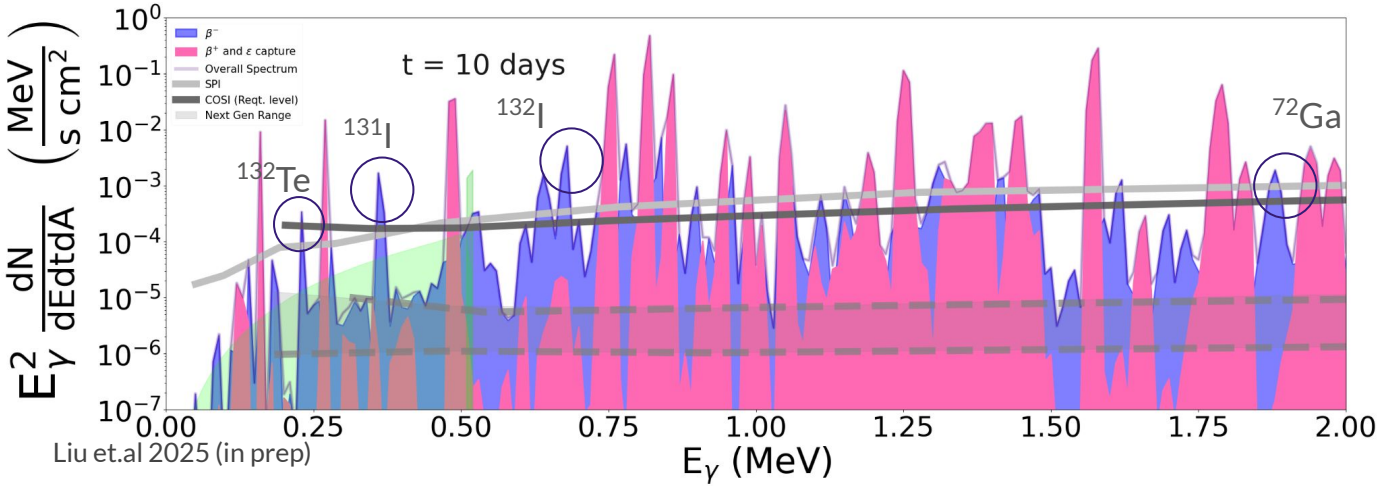

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- **Blue Region**: Signals that are contributed by beta minus decay.
- For each feature in the gamma ray spectrum (binned by energy), we can use ENDF VIII nuclear data base to find the corresponding highest contributing isotope.
- Important isotopes at 10 days after explosion are: **^{132}Te , ^{131}I, ^{132}I (all are near-second peak isotopes).**

Time evolution

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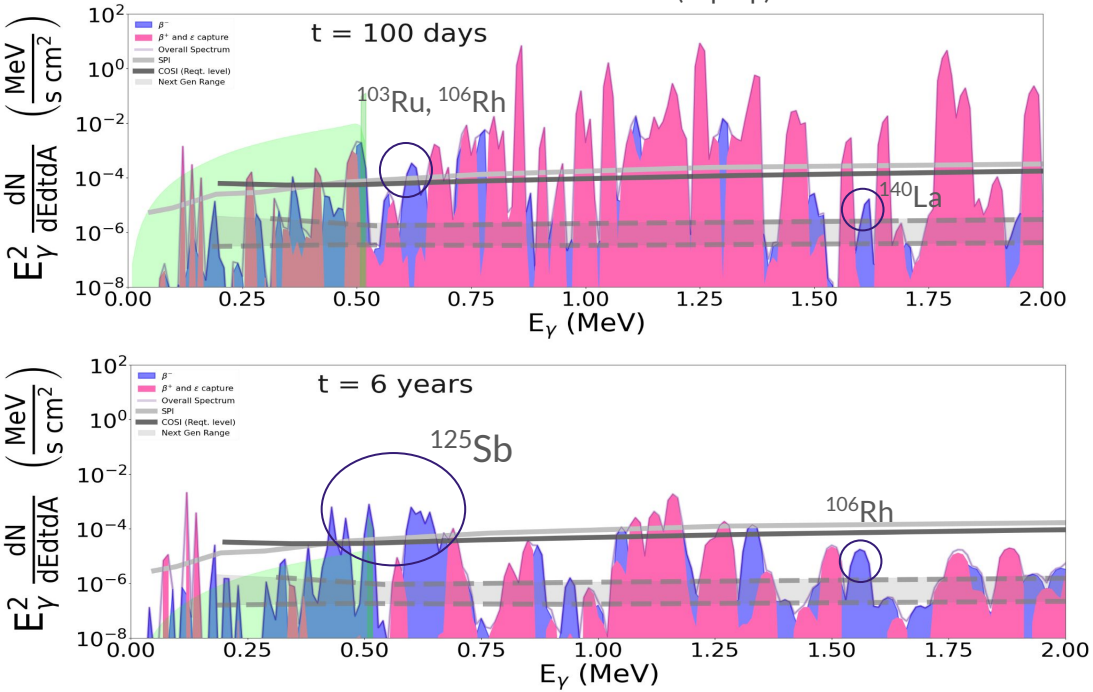

The same can be generalized for other times as well.

We identify **near second peak/weak r-process isotopes such as ^{103}Ru, ^{106}Rh, ^{125}Sb to be particularly interesting and could have a high possibility of being detected by instruments.**

Conclusion

-MR-SNe as a subtype of CCSNe may contribute to the Galactic inventory of heavy elements.

-The observation of gamma radiation from beta decays of newly synthesized unstable r-process isotopes would be a direct discovery of r-process formation in a supernova. Alternatively, the absence of such radiation could place a limit on the amount of element production from the r-process.

-Our findings suggest that if an r-process producing supernova event were to occur in our Galaxy, gamma-ray lines (^{131}I,^{132}I,^{132}Te^{125}Sb, ^{106}Rh, ^{103}Ru,) are above sensitivity levels of gamma-ray telescopes (SPI, COSI, next-generation detectors).