Radioactive isotopes as power sources in the late-time evolution of core-collapse supernova light curves

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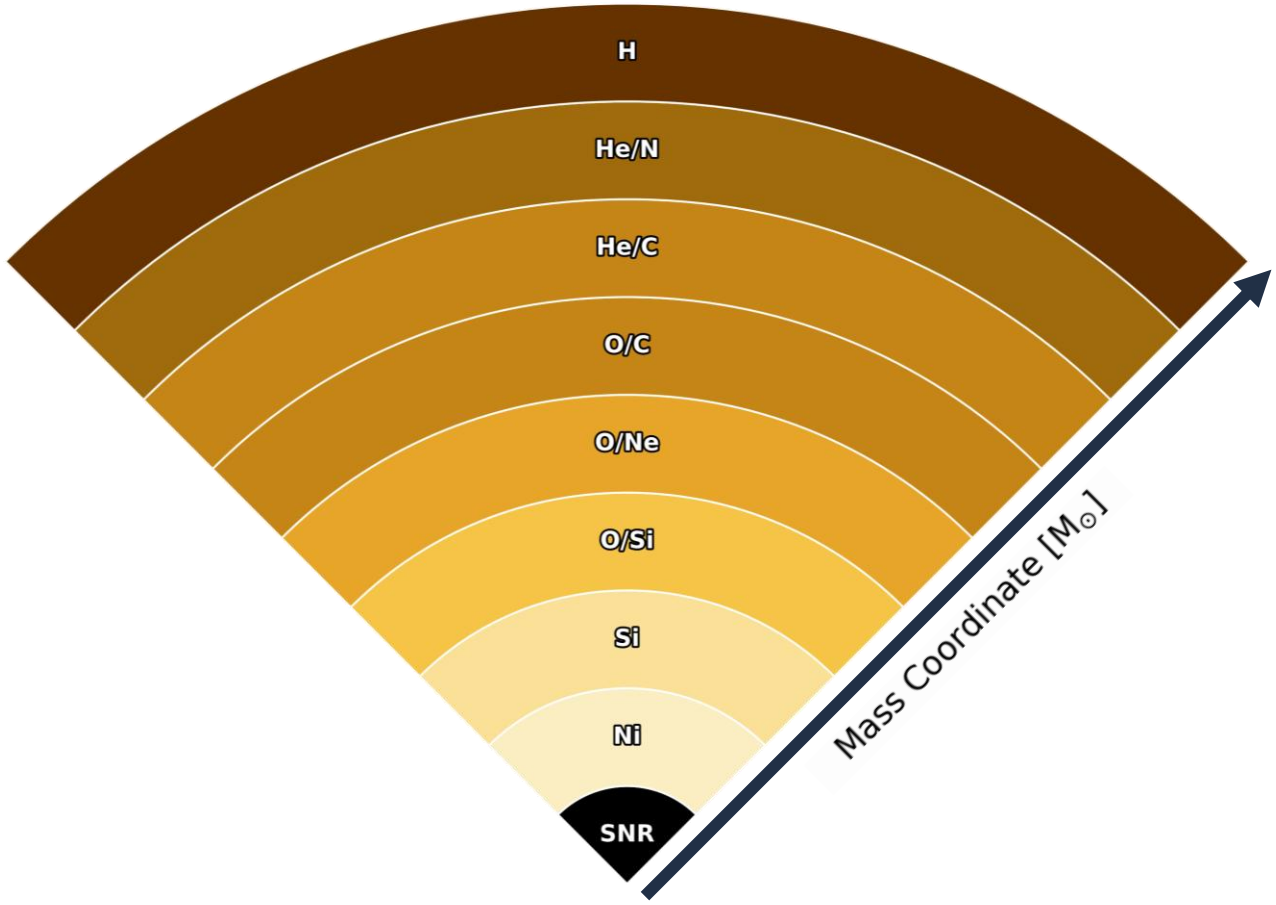
Introduction: Core-collapse supernovae from massive stars

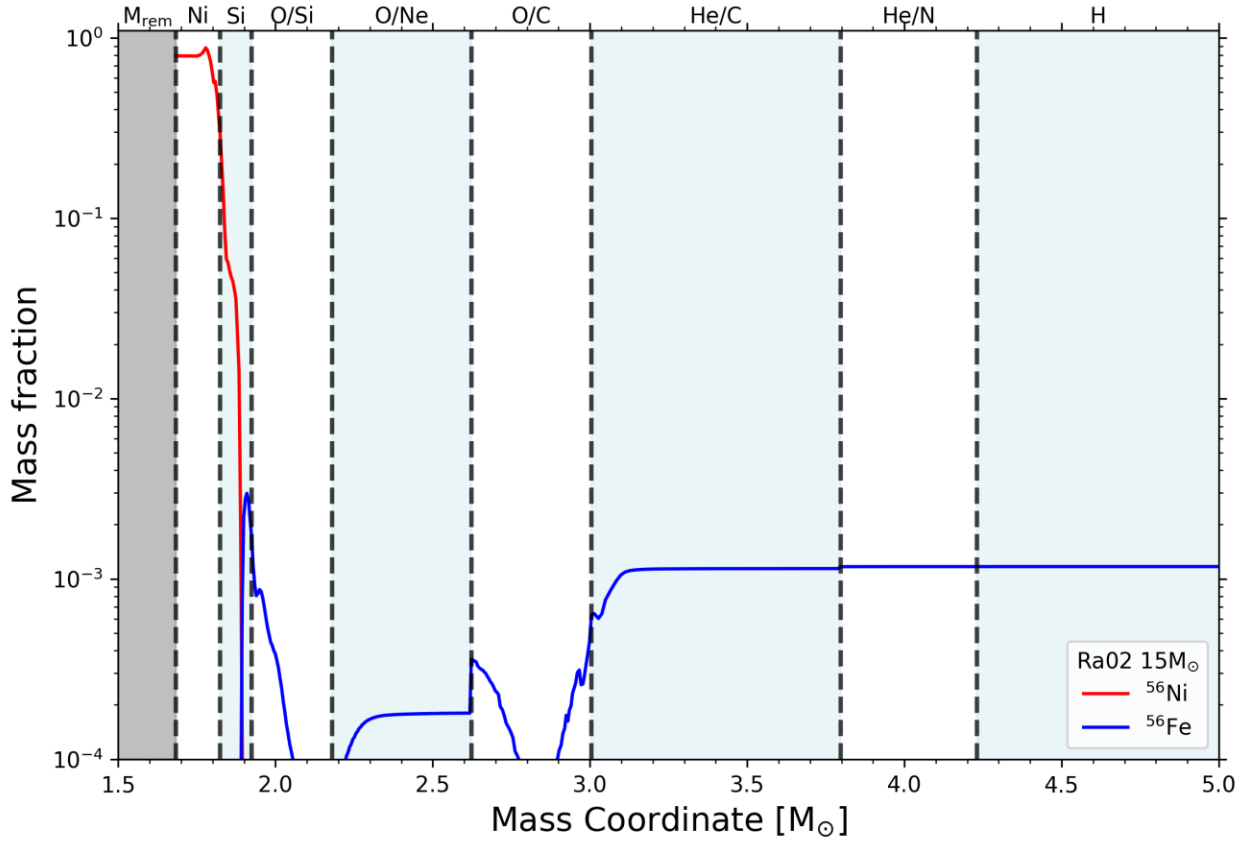
- Core-collapse supernovae originate from stars $M_{ZAMS} > 9\ M_{\odot}$
- The light curves are powered by different radioactive isotopes, providing insight into the explosion and the progenitor

- Goals:
  - More constrained isotopic ratios for long-term predictions
  - Explosion mechanism and progenitor constraints

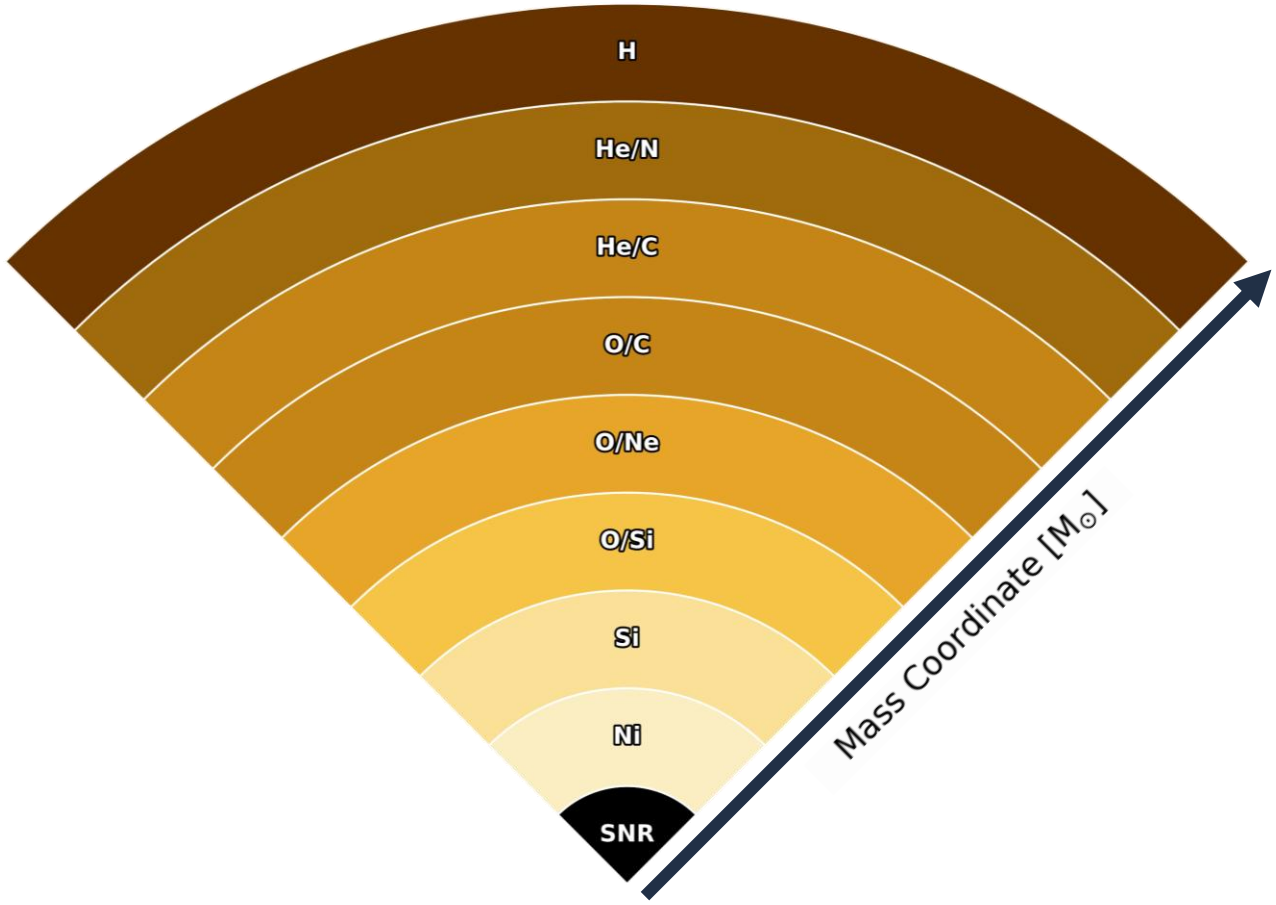
- Current problem: No available observations for several thousand days
- Long term predictions can be made based on well constrained isotopic ratios
- LSST may provide crucial data for more direct analysis?

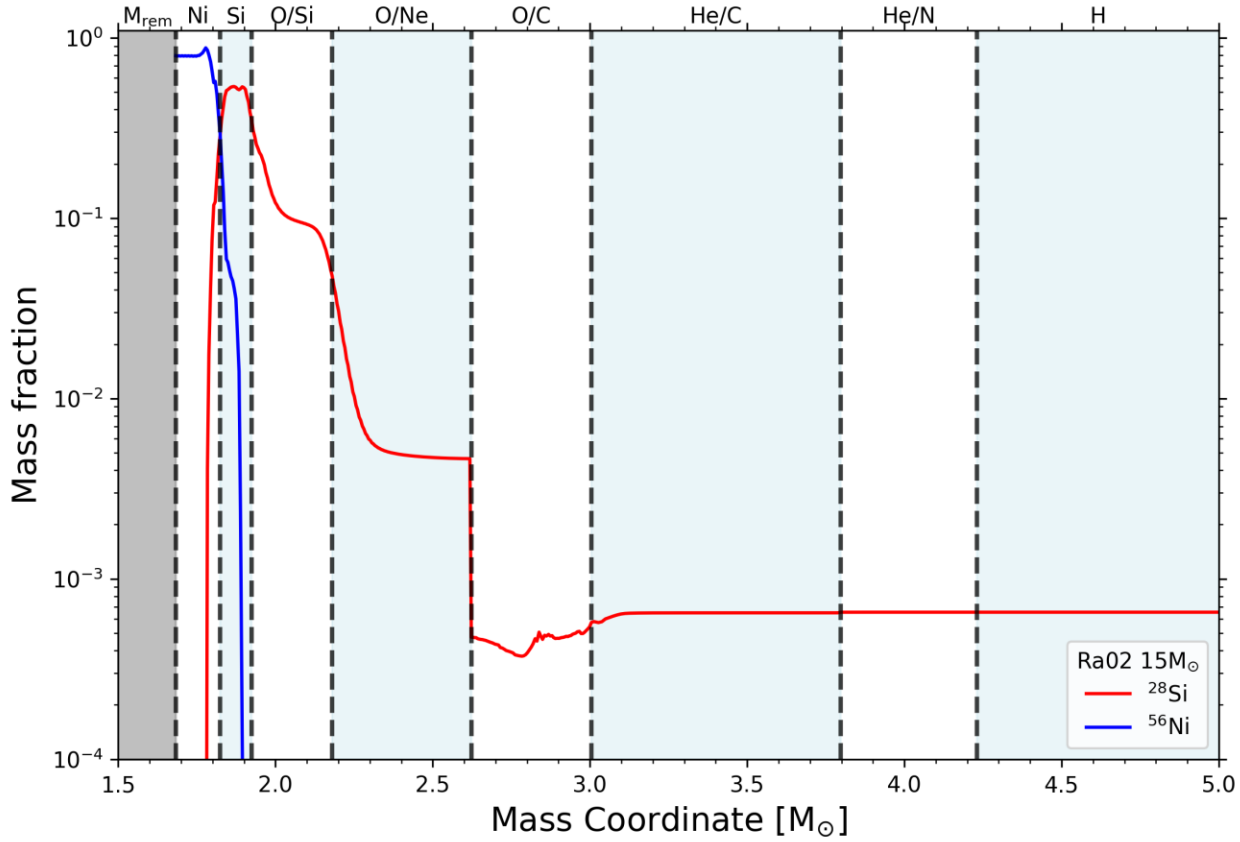
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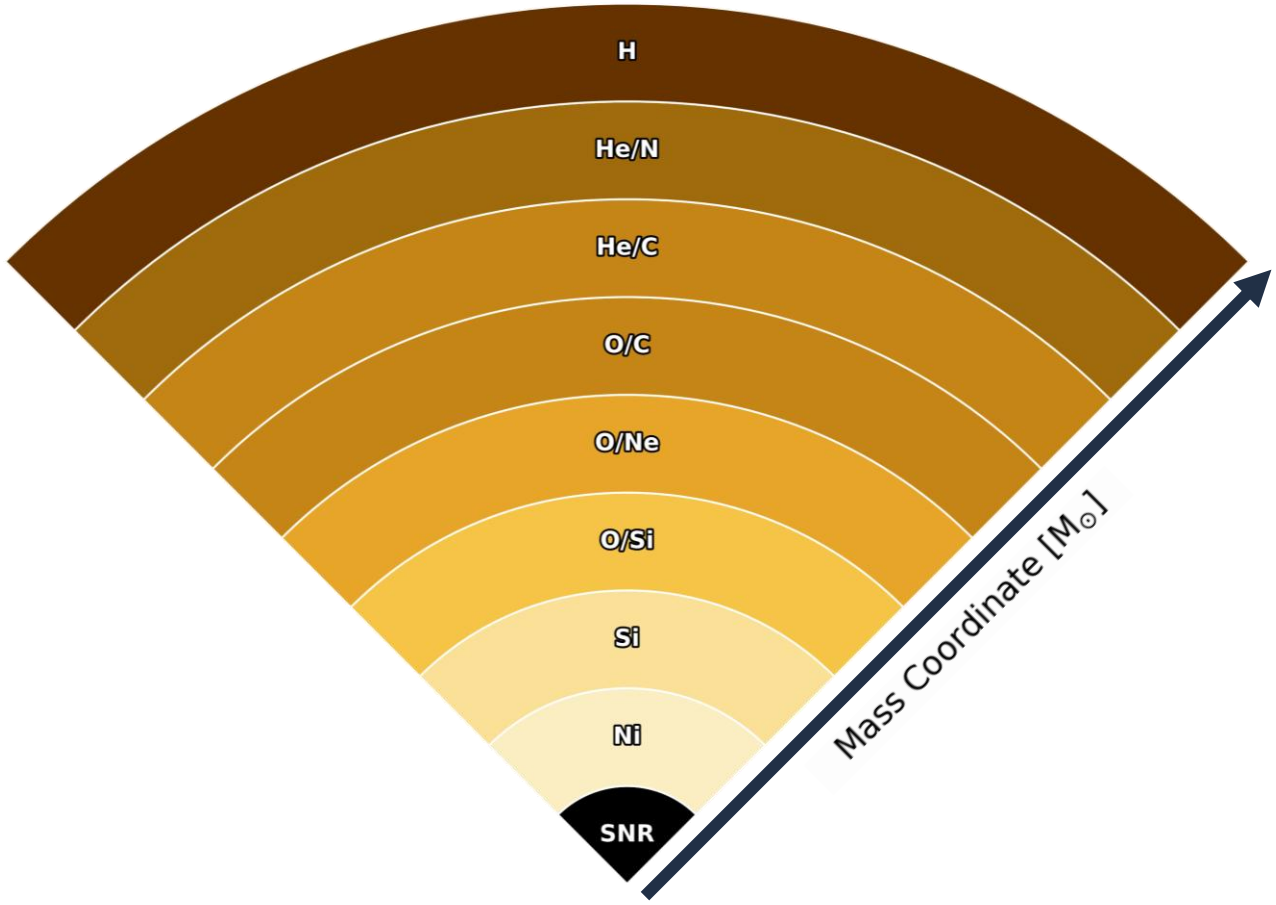


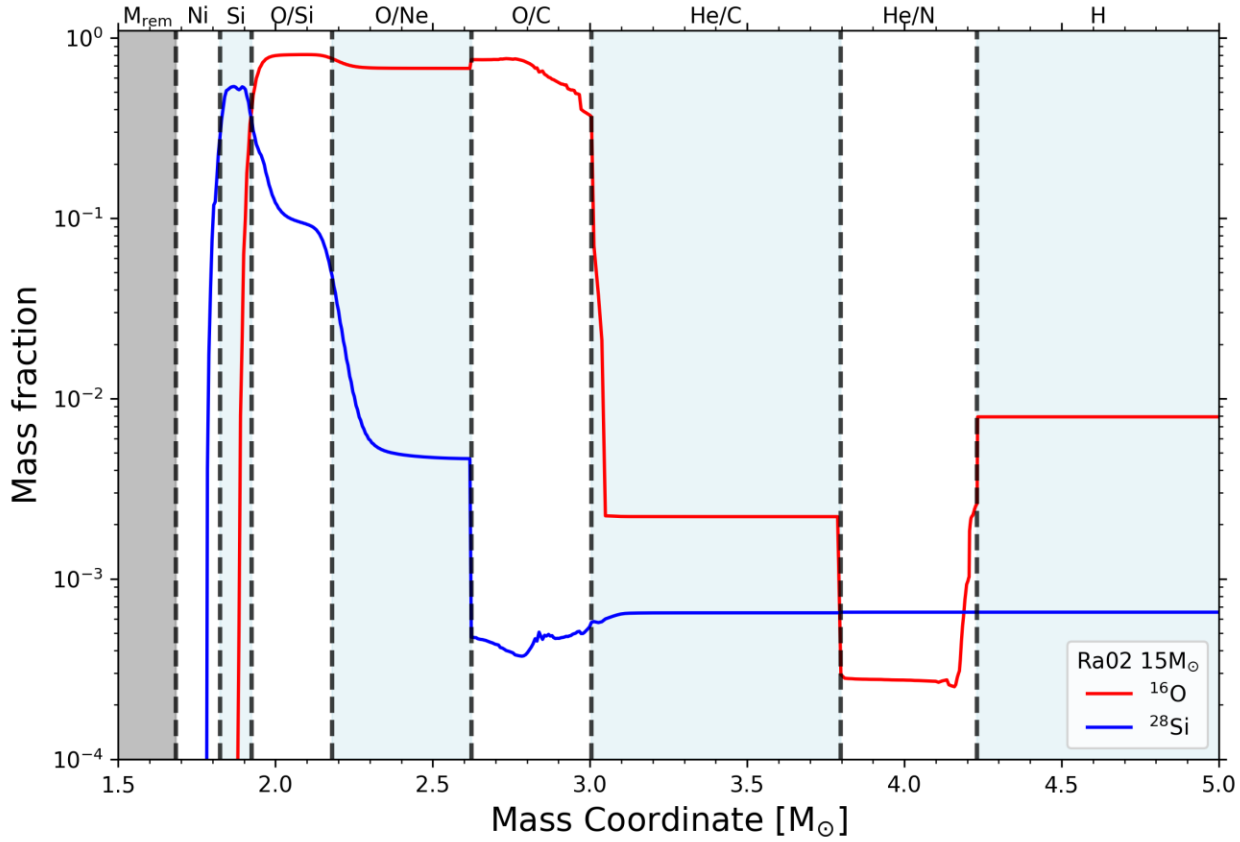
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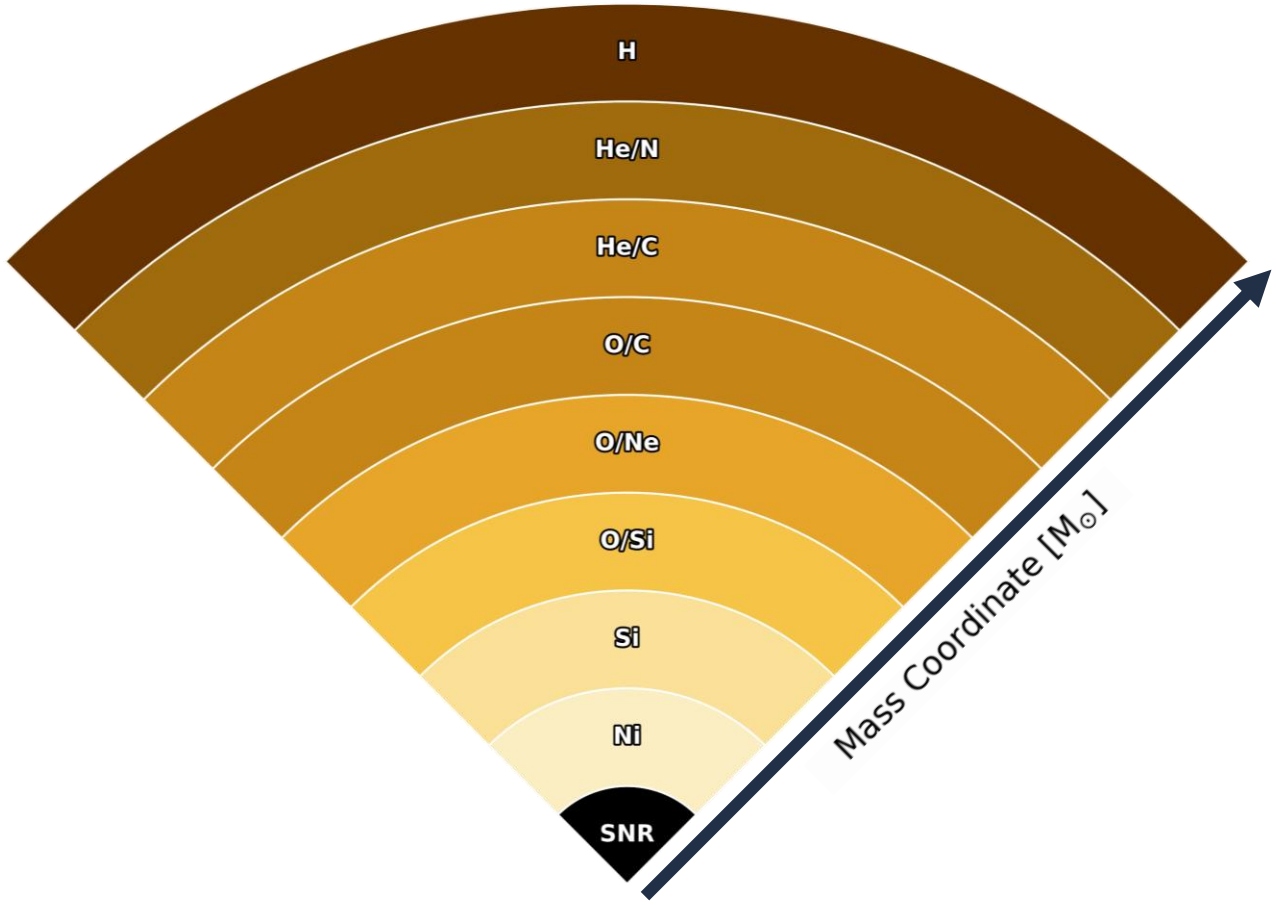


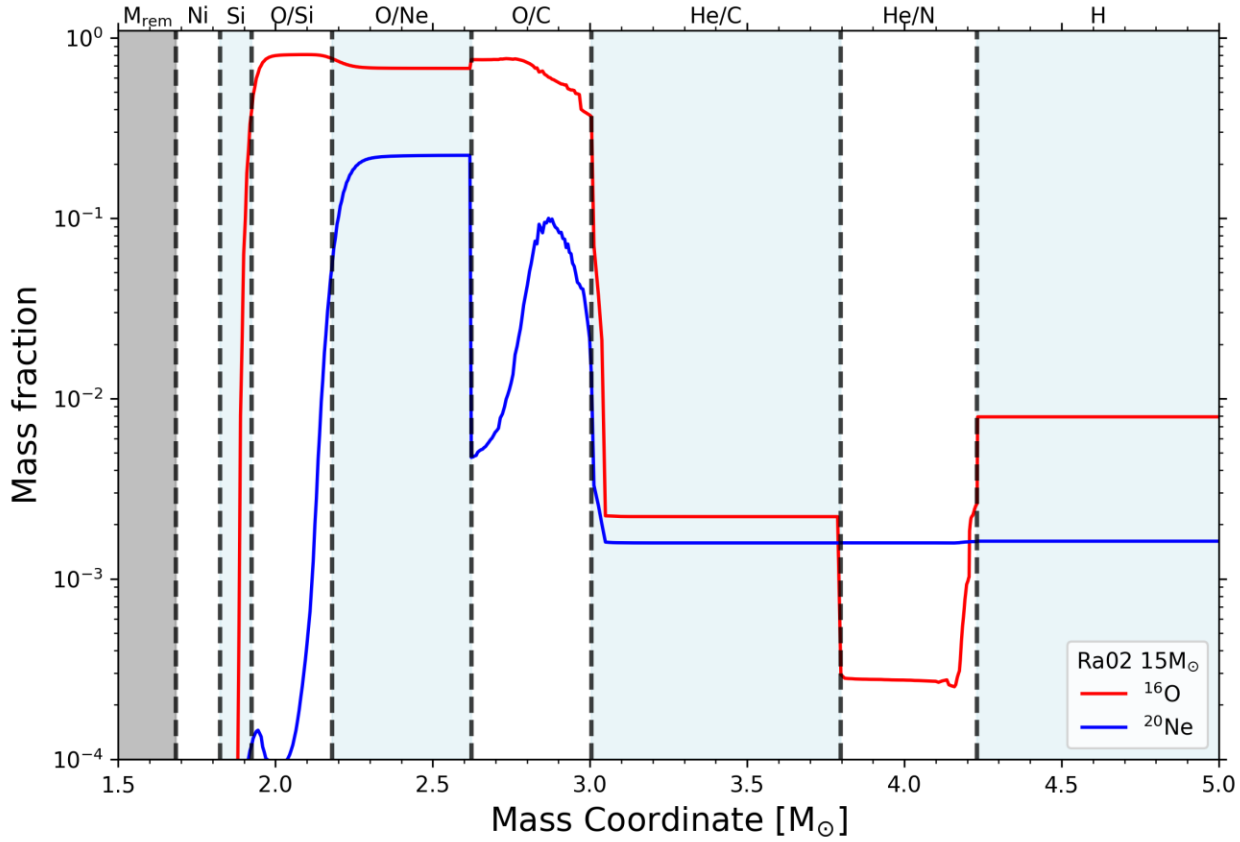
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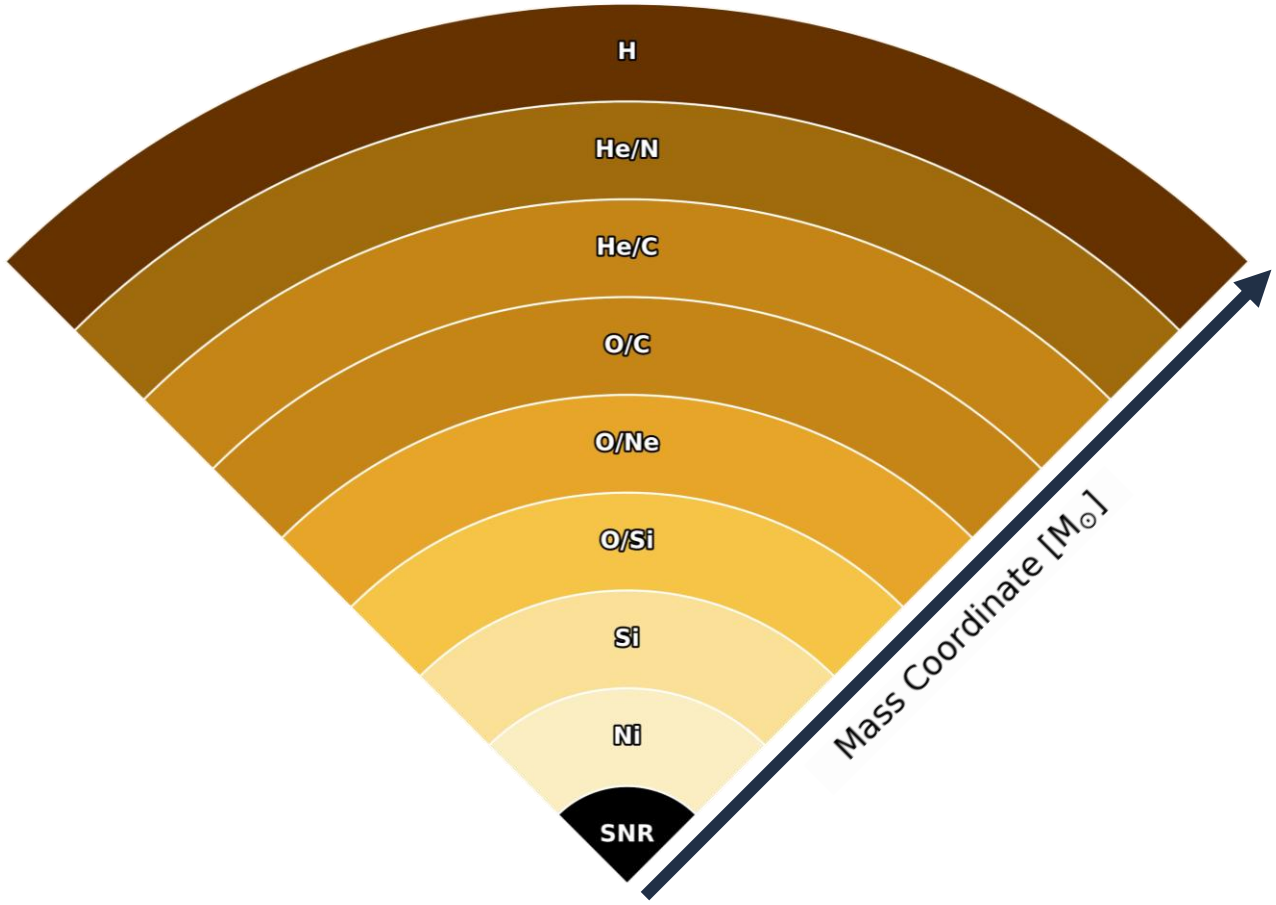


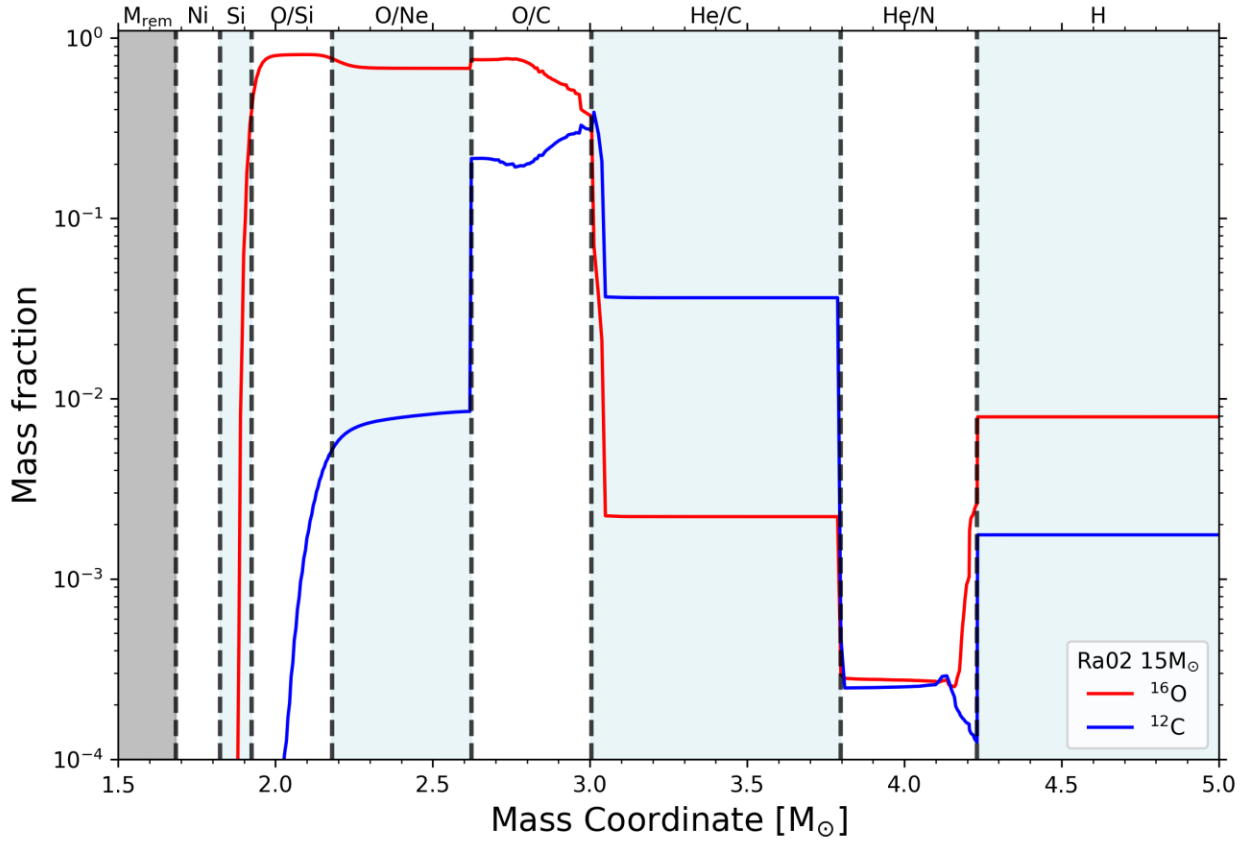
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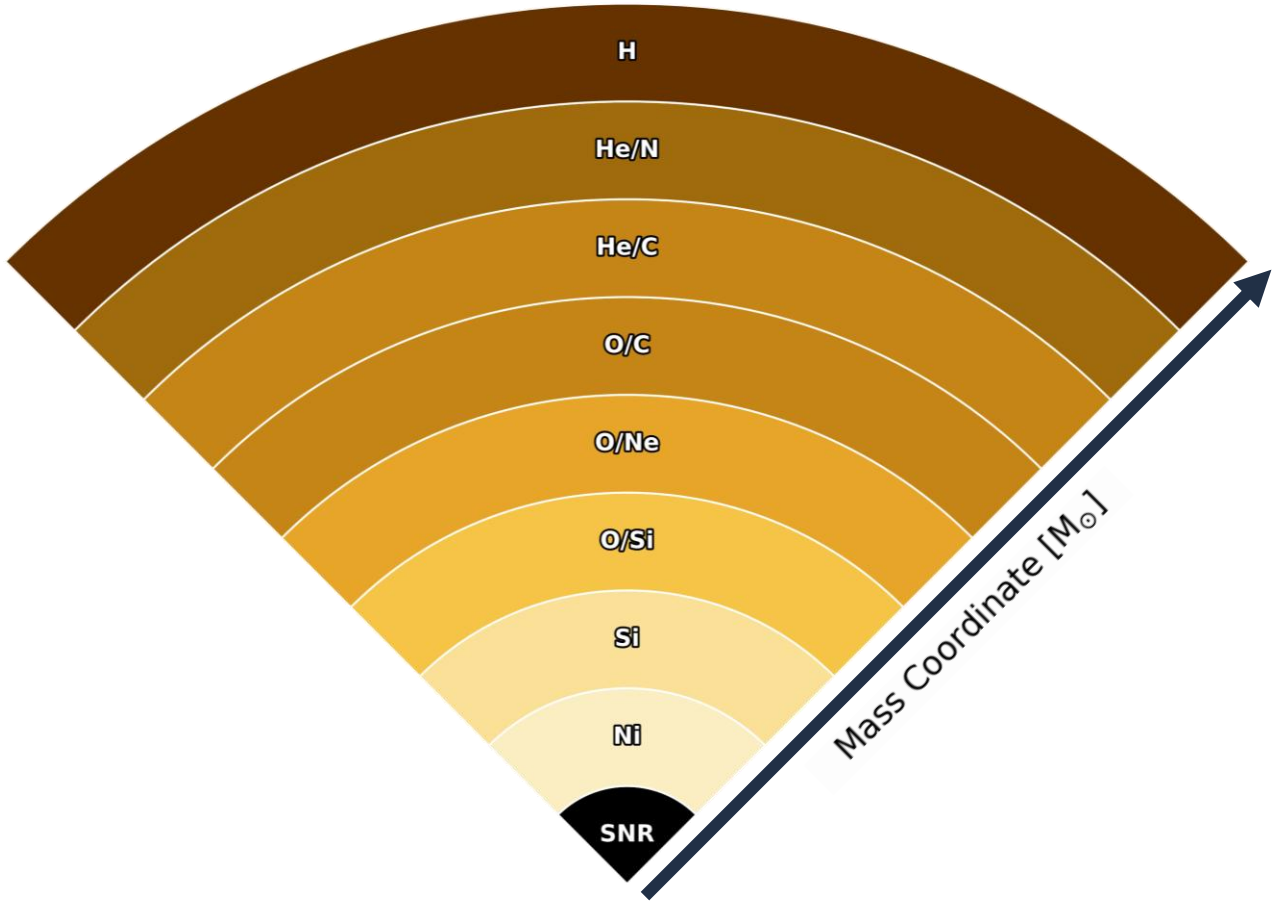


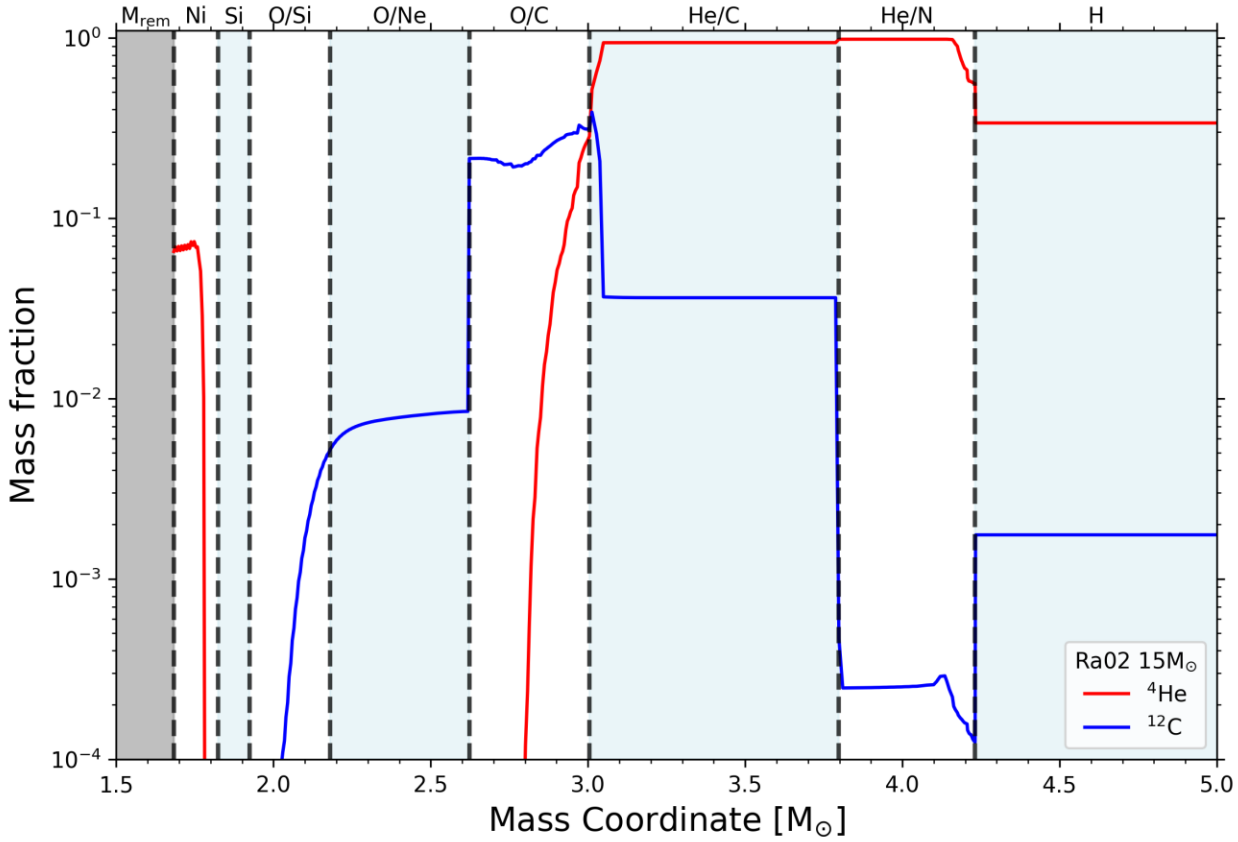
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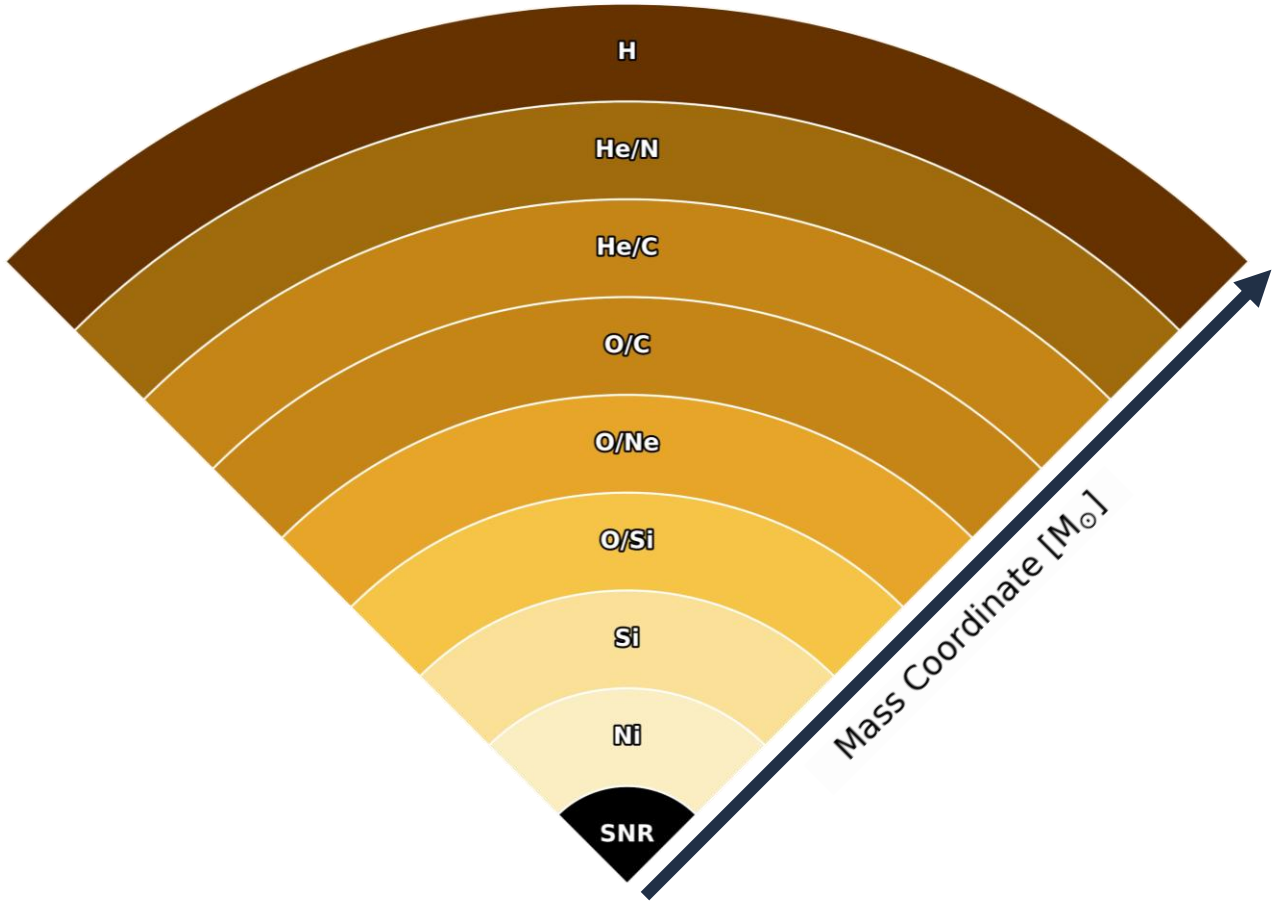


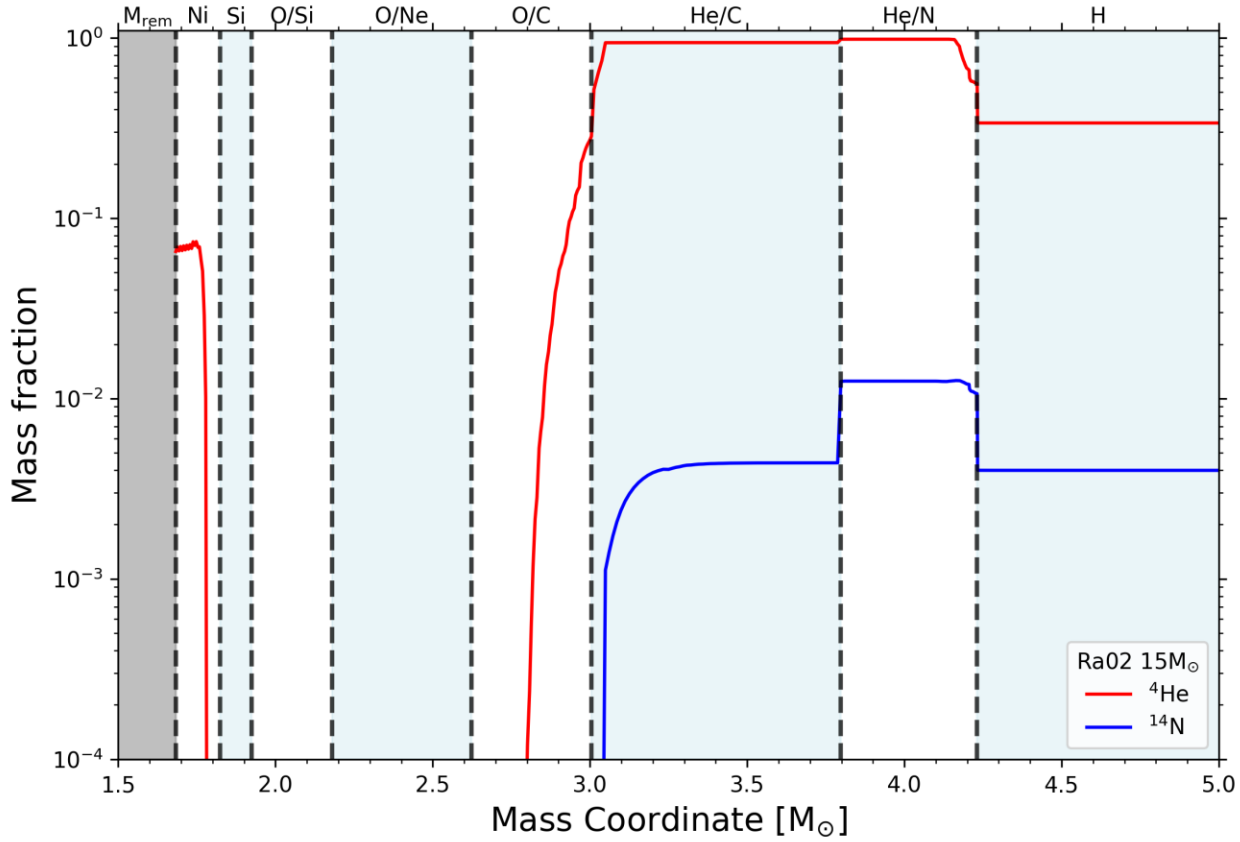
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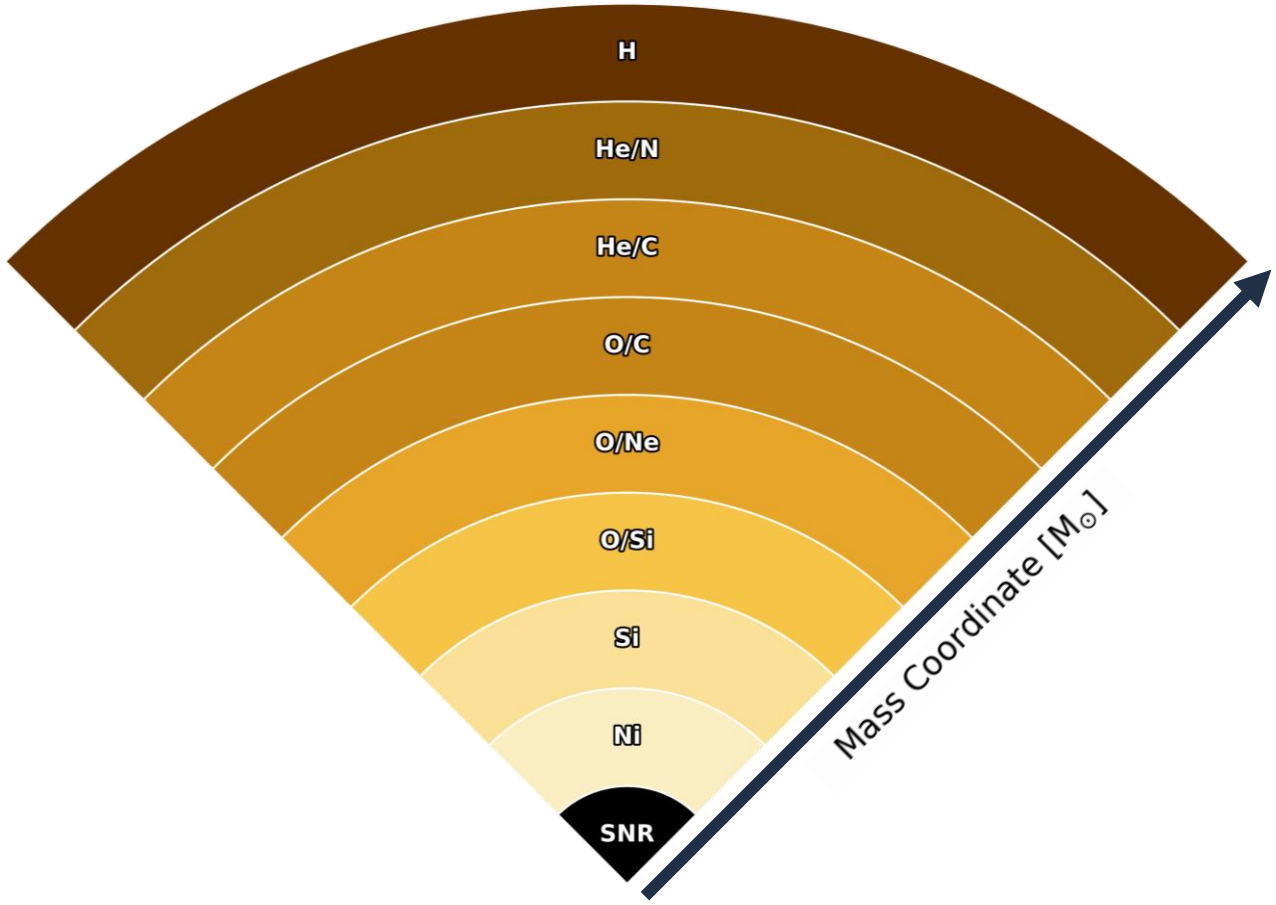


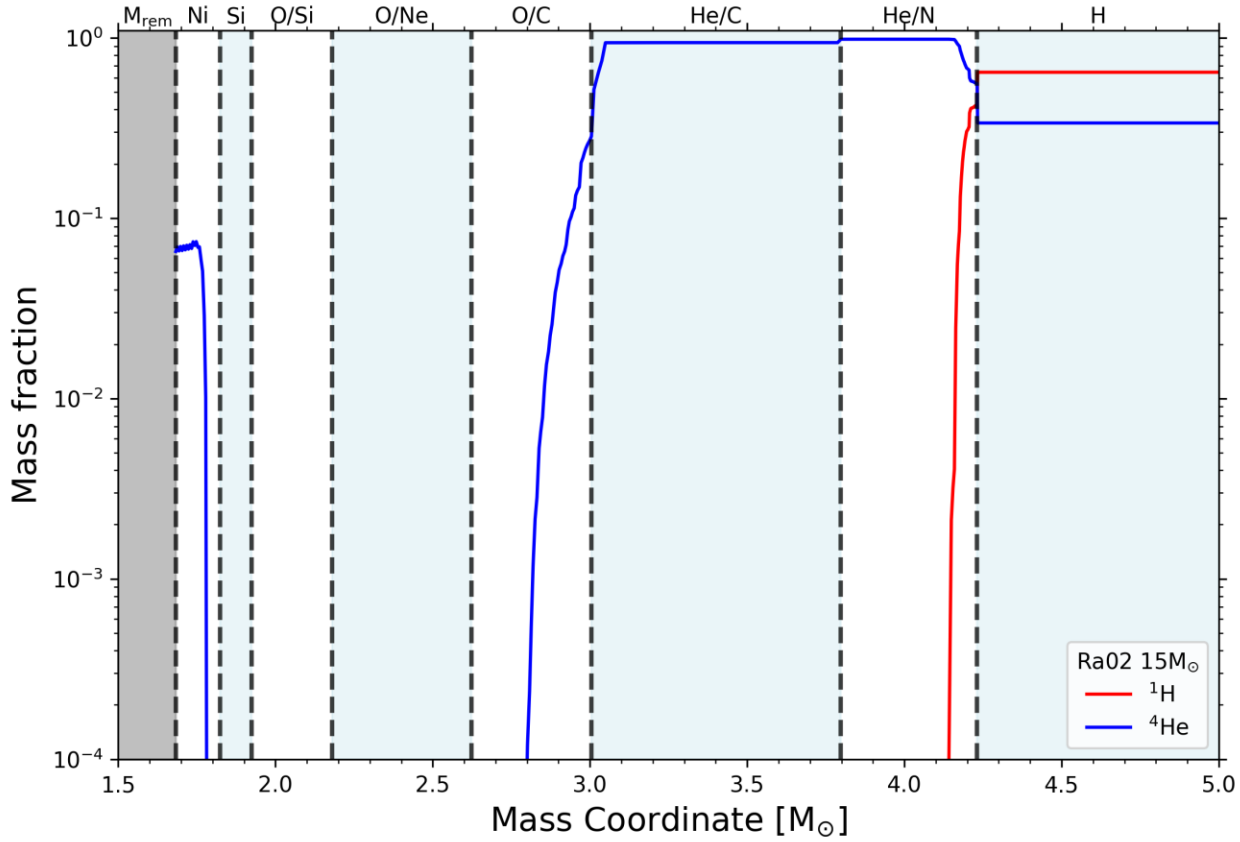
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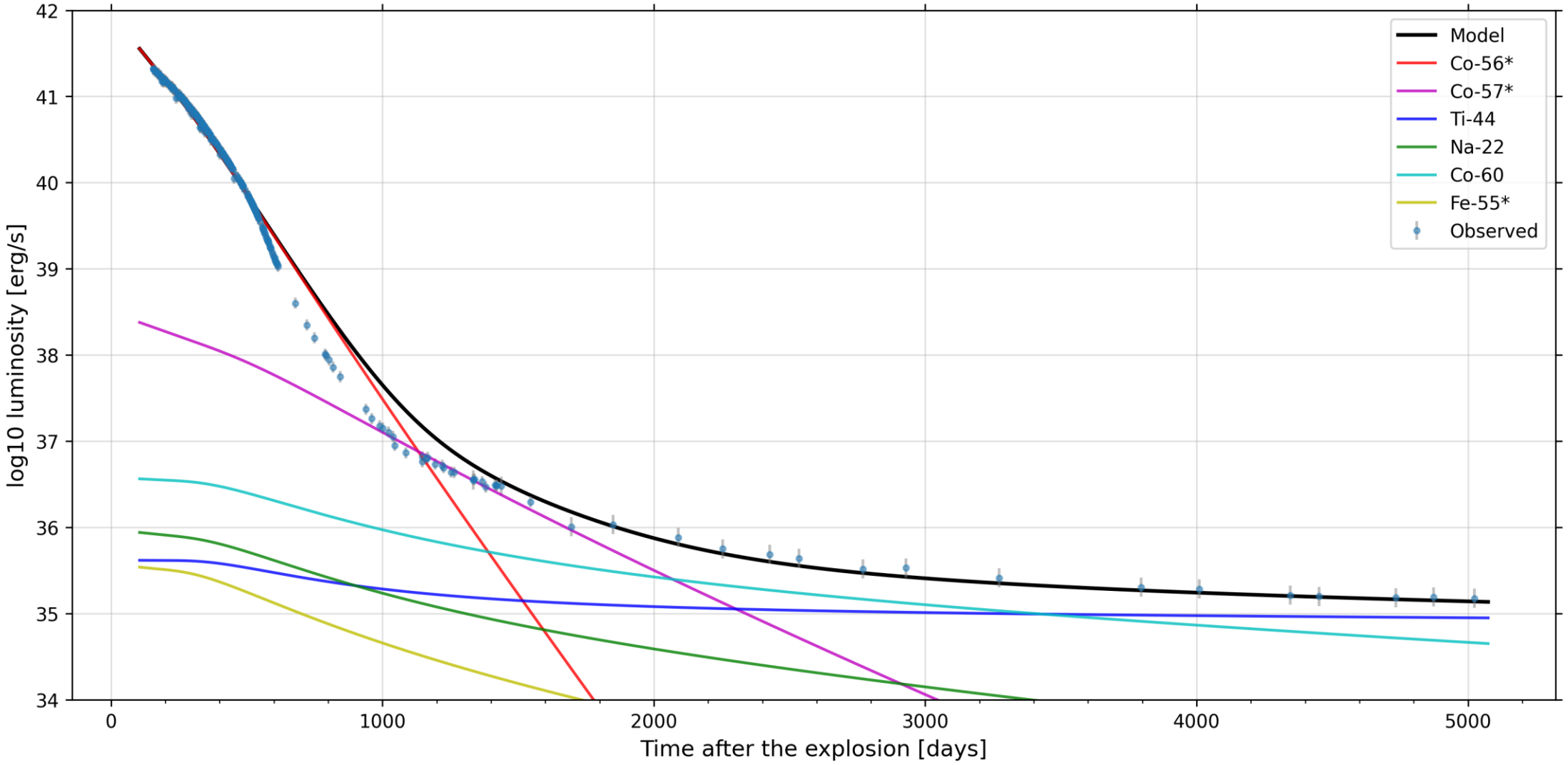


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Relevant isotopes

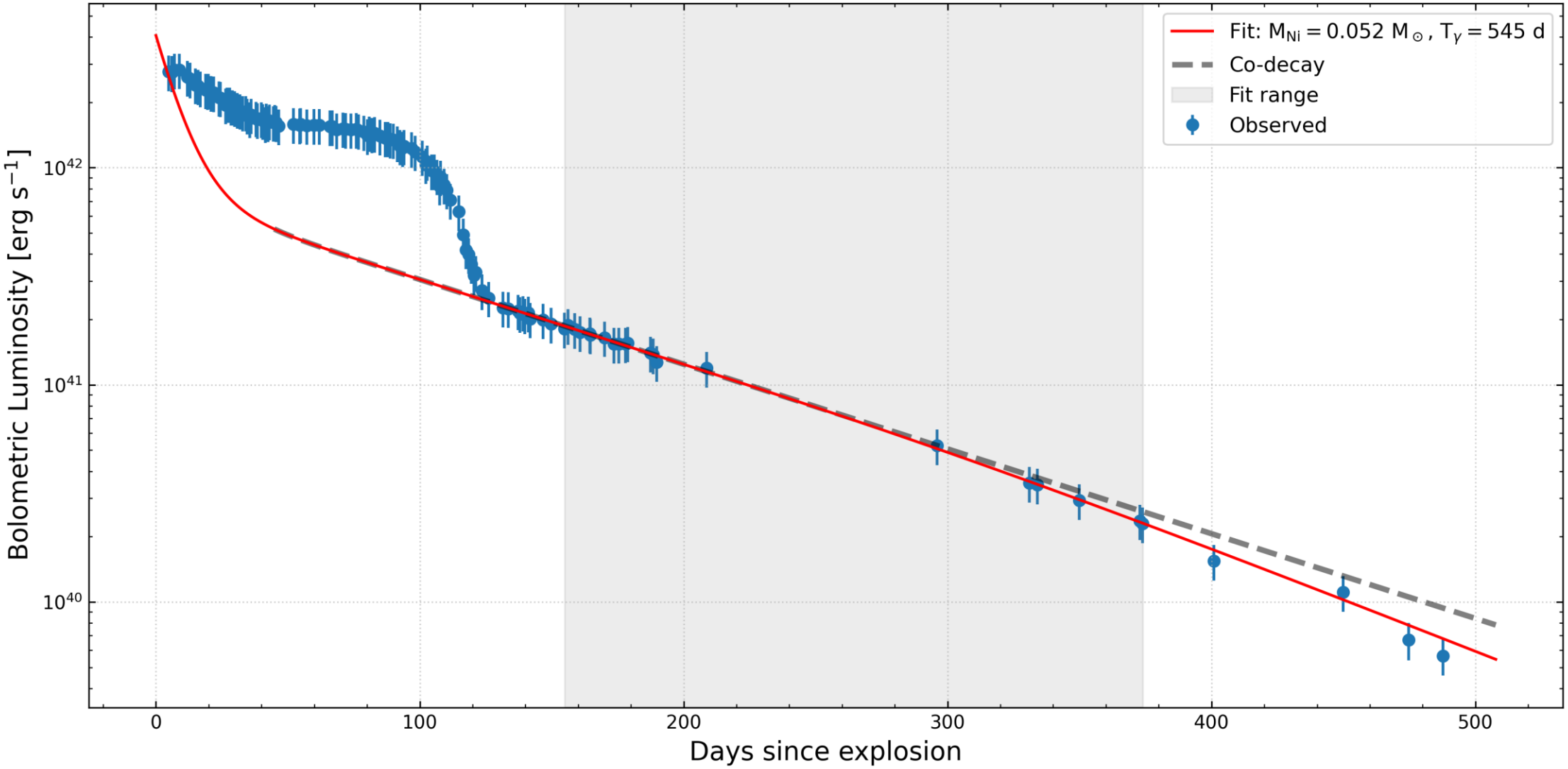


Methods

- Calculate modelled light curves for the plateau phase (up to ~110 days) with a hydrodynamic model called **HYPERION** *(Limongi et al. 2020)*
- Obtain isotopic abundances by fitting the late stage observations (after the ^{56}Ni dominated phase) of SN1987A and SN1993J *(Seitenzahl et al. 2014, Pignatari et al. 2025)*
- **Develop a pipeline connecting theoretical and observational approaches for both light curves and stellar nucleosynthesis**
- Compare the data with 1D CCSNe models from 7 different sets
  [Rauscher et al. (2002), Pignatari et al. (2016), Ritter et al. (2018), Limongi & Chieffi (2018), Sieverding et al. (2018), Lawson et al. (2022), Falla et al. (2025)]

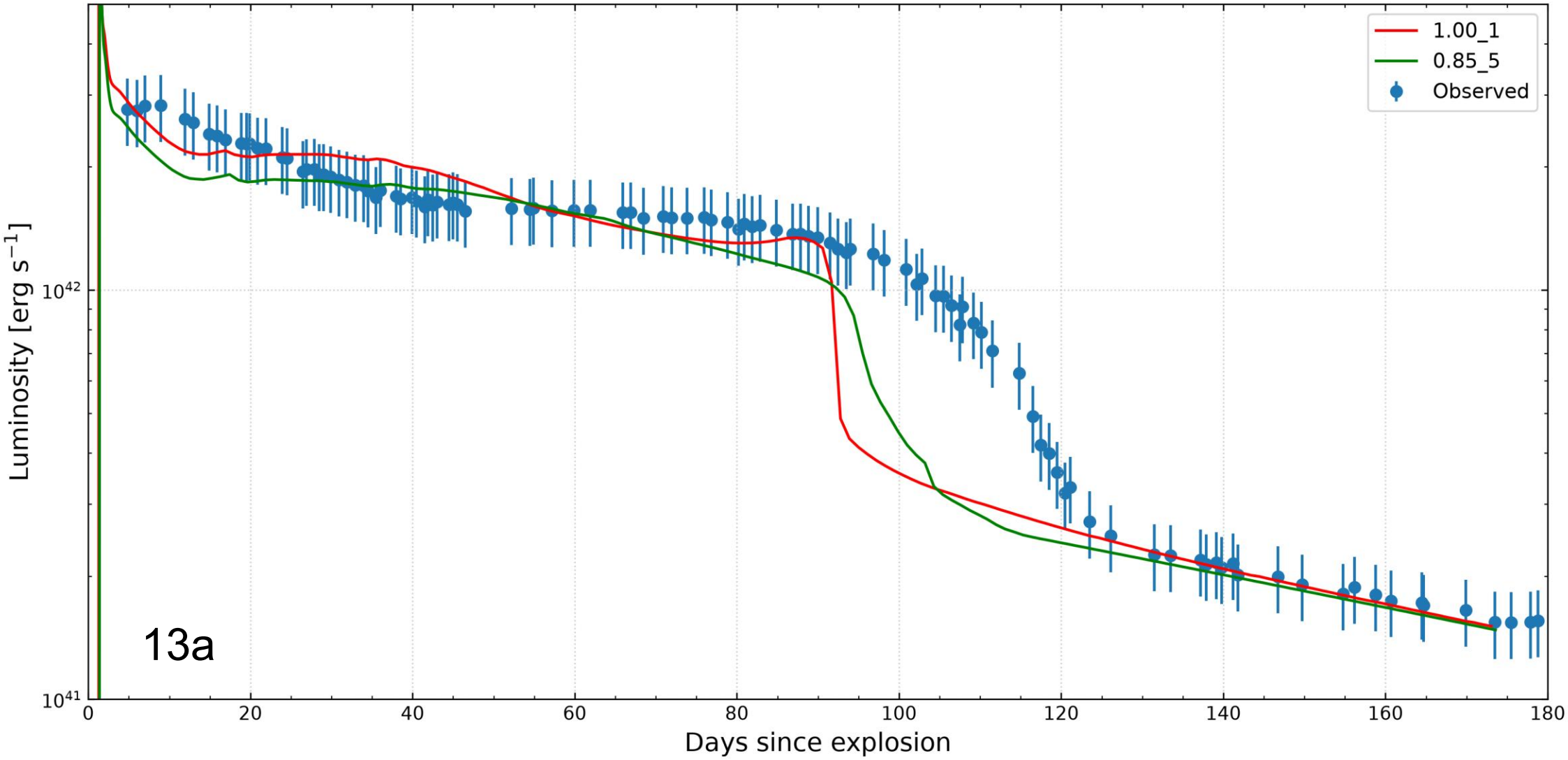
- Observations for 10 CCSNe:
  - 6 from the Open Supernova Catalogue (OSC)
  - 3 from the Las Cumbres Observatory (LCO) collaboration
  - 2 from Konkoly RC80
  - 1 From Baja RC80

Example case: SN2017eaw



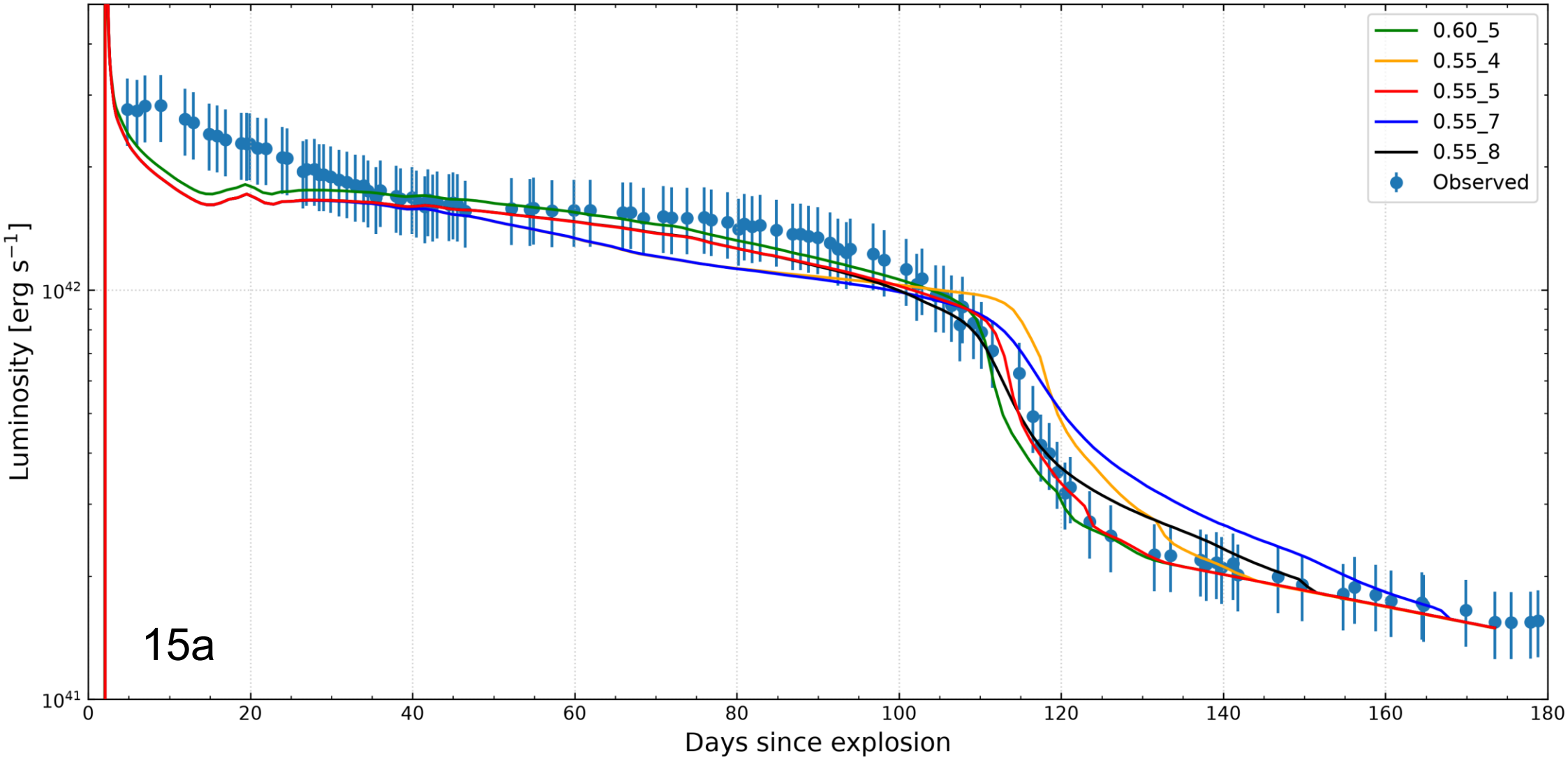
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Hydrodynamic modeling with HYPERION

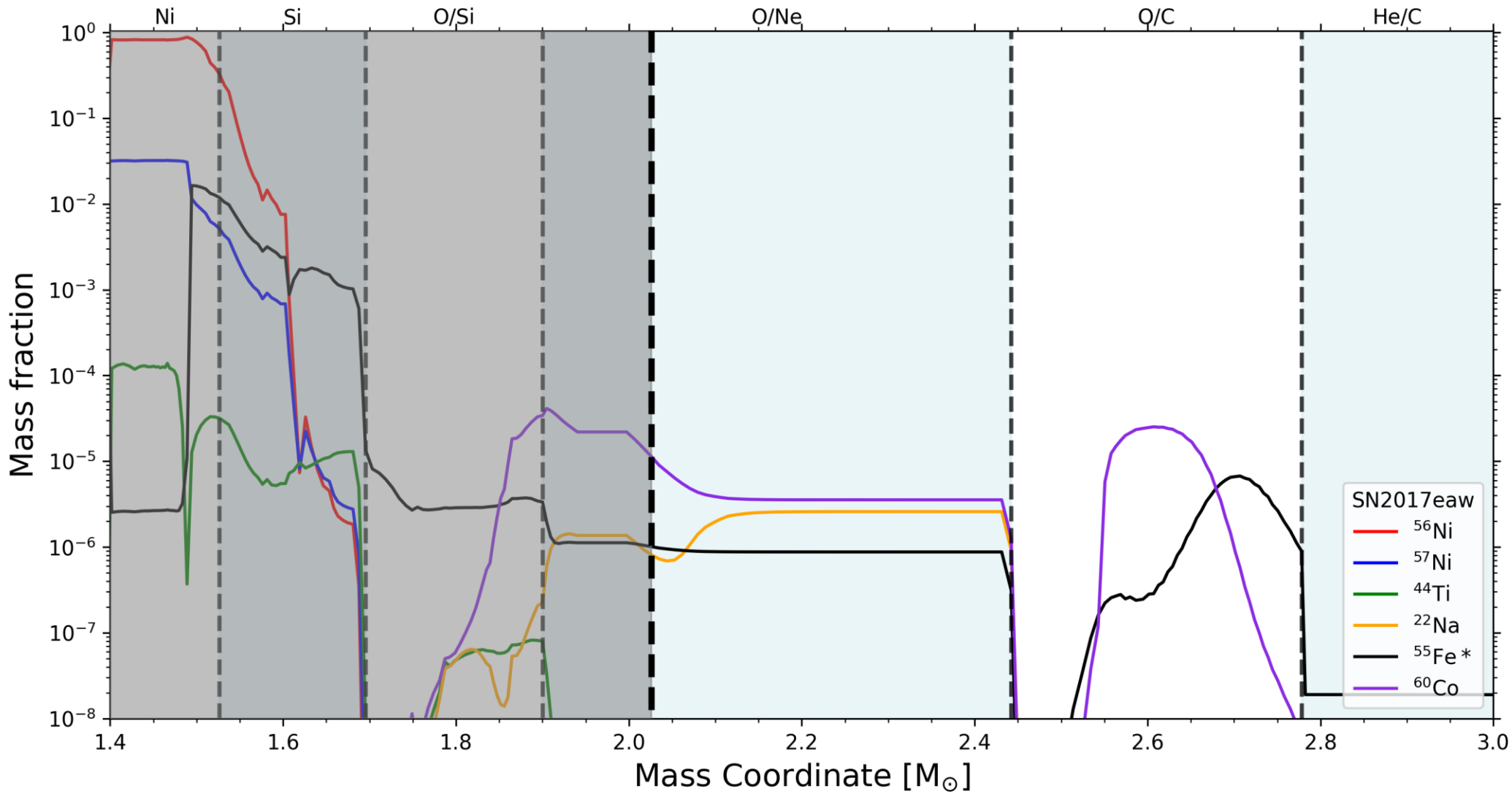


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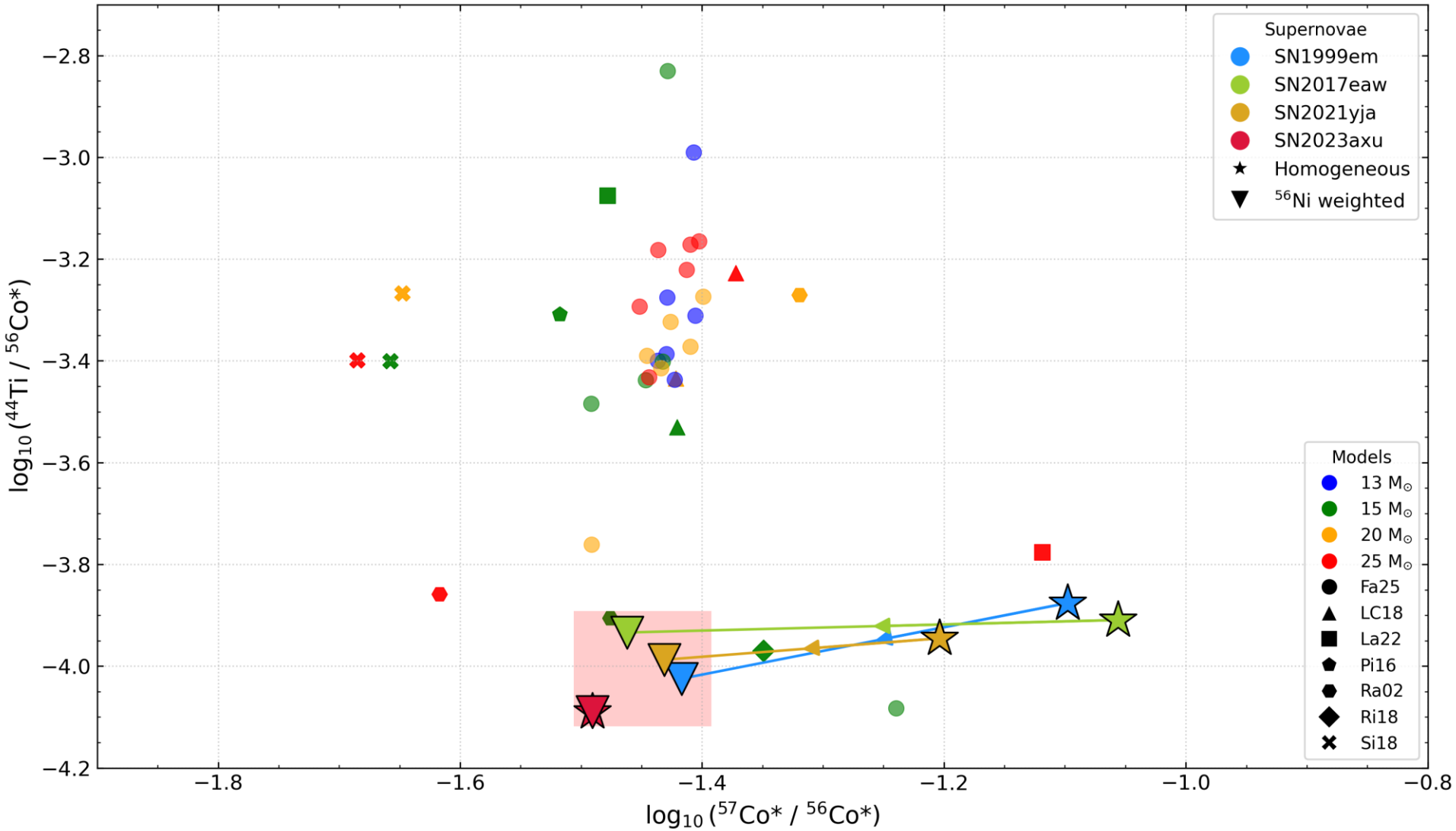
Hydrodynamic modeling with HYPERION



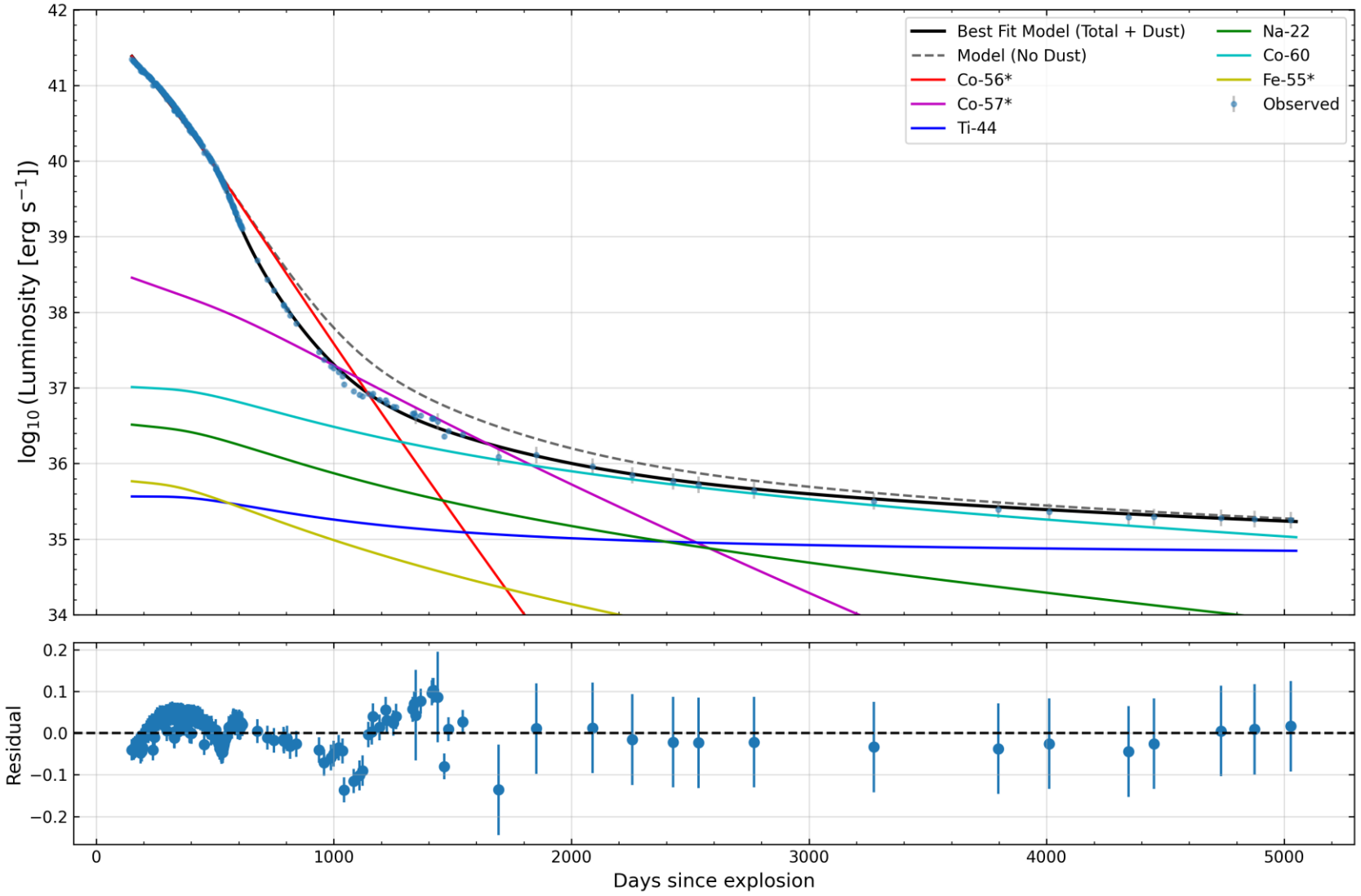
Ejecta structure



Isotopic ratios



Late-time light curve predictions



Summary and Preliminary Results

- 5 out of 10 events can be reproduced by the models so far
- From the 8 short light curves, 4 can be modelled with the current set of progenitors and 4 can be constrained for future development of PreSN models
- Isotope mixing is parametrized by two approaches, resulting in heavily different isotopic ratios

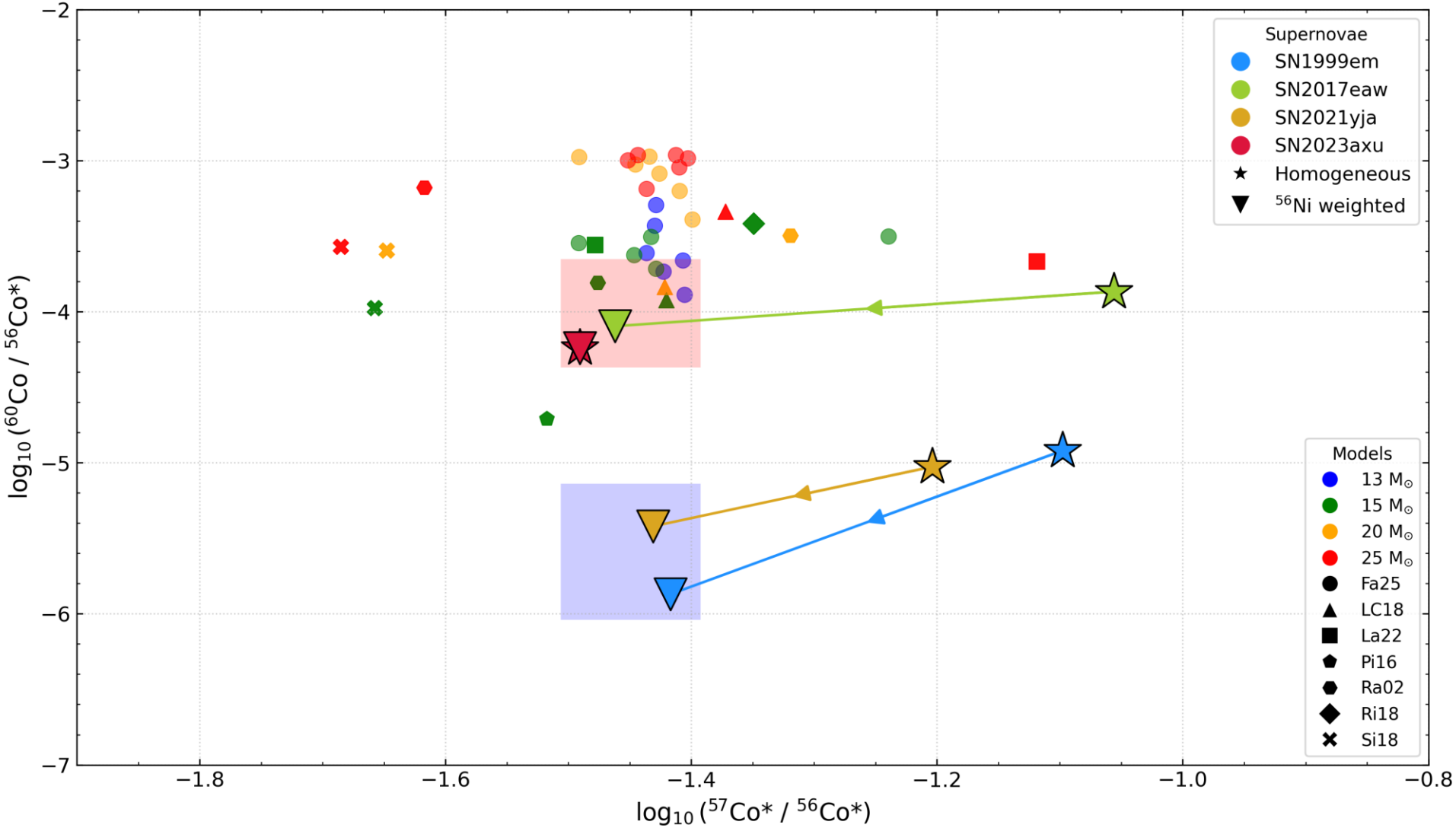
- The ratio of $^{44}Ti/^{56}Ni$ and $^{57}Ni/^{56}Ni$ can be well constrained
- For $^{60}Co/^{56}Ni$, two clusters can be identified related to the initial metallicity of the progenitors
- The case of ^{22}Na and ^{55}Fe due to high variability cannot be constrained
- With an upgraded Python code and the isotopic ratios further observations can be planned

Q & A



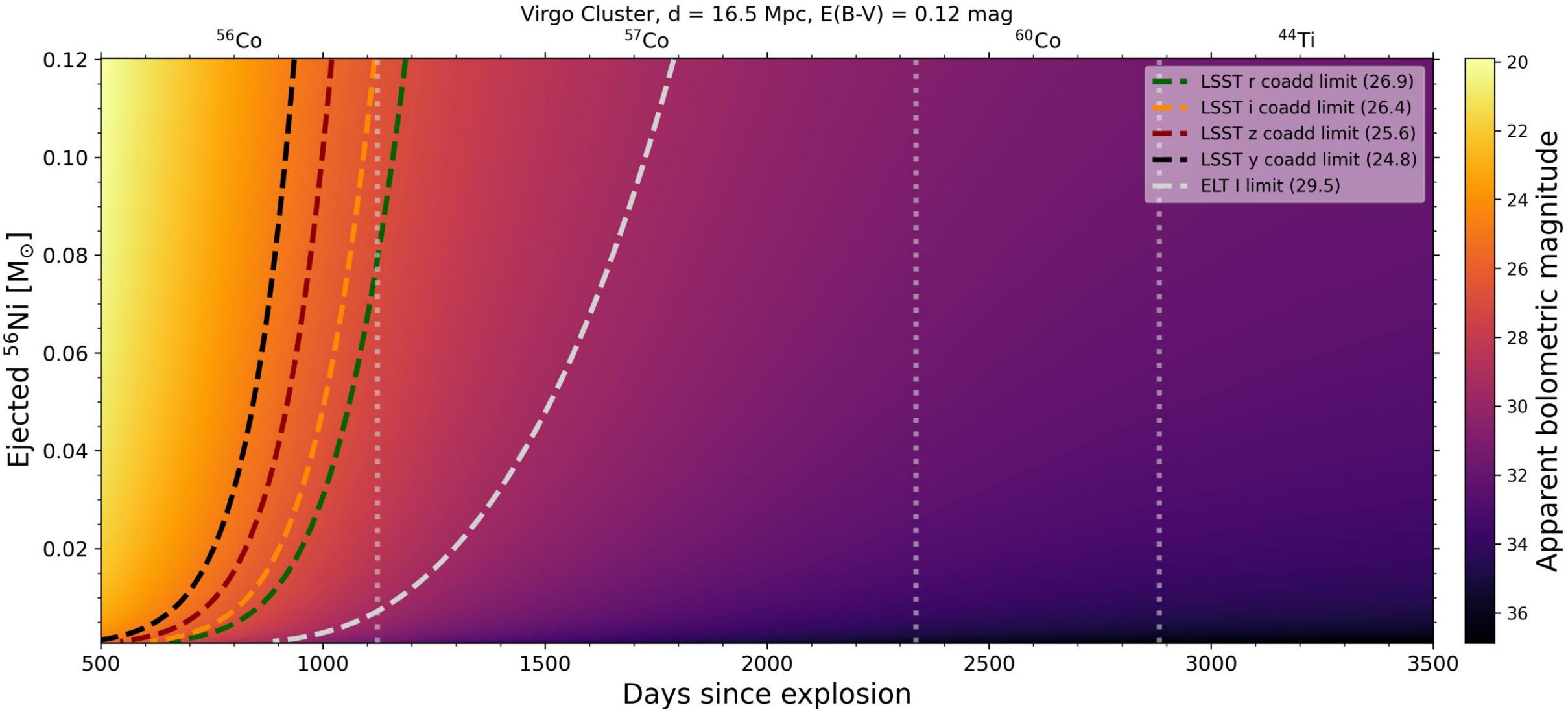
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Isotopic ratios



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Apparent magnitude predictions



Stellar 1D models

- Rauscher et al. (2002) [Ra02]

  (Rauscher, T., Heger, A., Hoffman, R. D., & Woosley, S. E., 2002, ApJ, 576, 323)
- Pignatari et al. (2016) [Pi16]

  (Pignatari, M., Herwig, F., Hirschi, R., et al., 2016b, ApJS, 225, 24)
- Ritter et al. (2018) [Ri18]

  (Ritter, C., Herwig, F., Jones, S., et al., 2018b, MNRAS, 480, 538)
- Limongi & Chieffi (2018) [LC18]

  (Limongi, M. & Chieffi, A., 2018, ApJS, 237,13L)
- Sieverding et al. (2018) [Si18]

  (Sieverding, A., Martínez-Pinedo, G., Huther, L., Langanke, K., & Heger, A., 2018, ApJ, 865, 143)
- Lawson et al. (2022) [La22]

  (Lawson, T. V., Pignatari, M., Stancliffe, R. J., et al. 2022, MNRAS, 511, 886)
- Falla et al. (2025) [Fa25]
  (Falla, A., Roberti, L., Limongi, M., & Chieffi, A., 2025, ApJ, 991, 21)