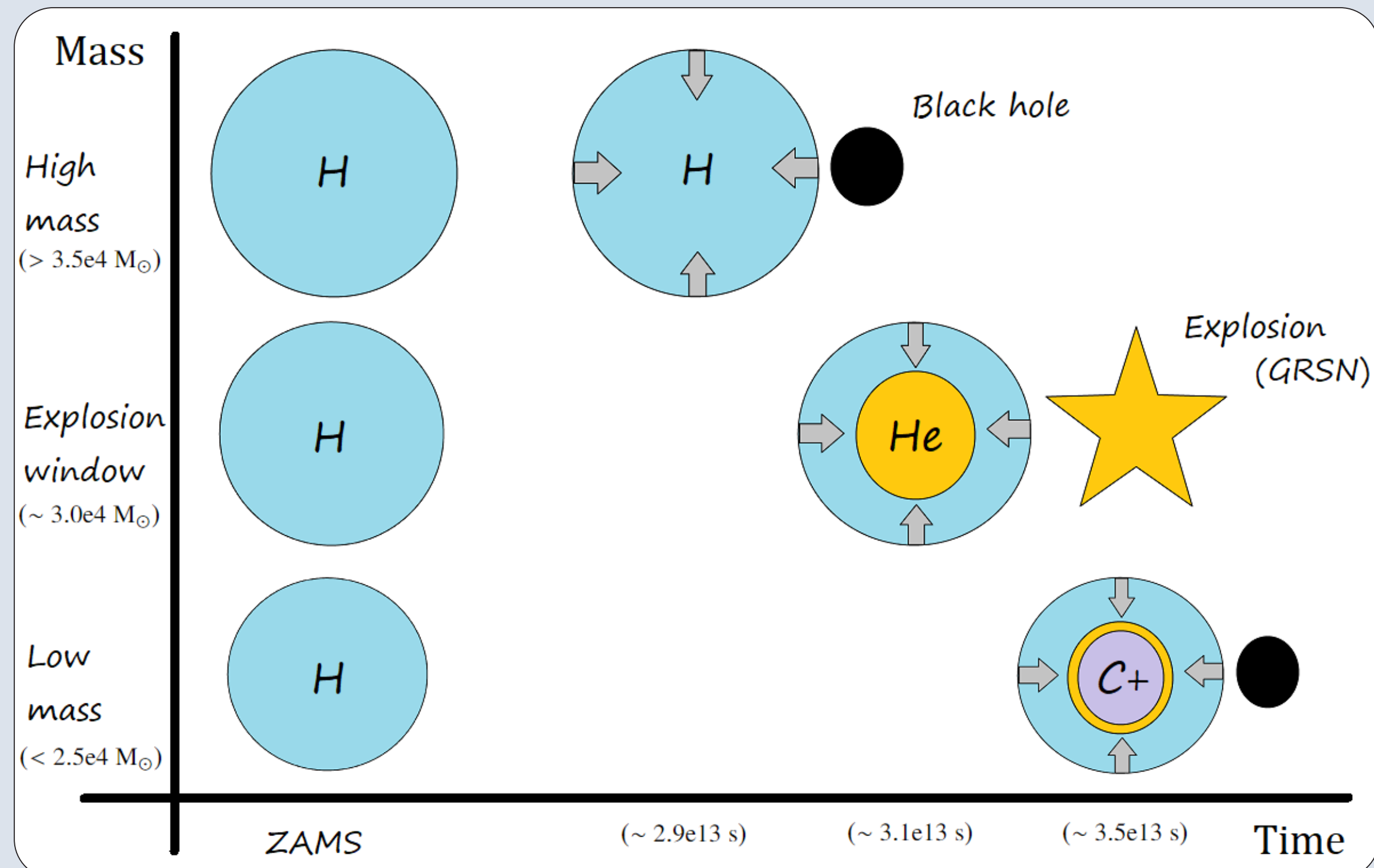


## Background



- Early universe SMBHs exist<sup>1</sup>.
- Whence?
- Direct collapse?
  - ◊ Local FUV radiation.
  - ◊ DM-baryon streaming.
  - ◊ Cold turbulent inflows.
- A supermassive star forms.
- It collapses to a SMBH seed.
- Testable?
  - GRSN<sup>2-5</sup>.

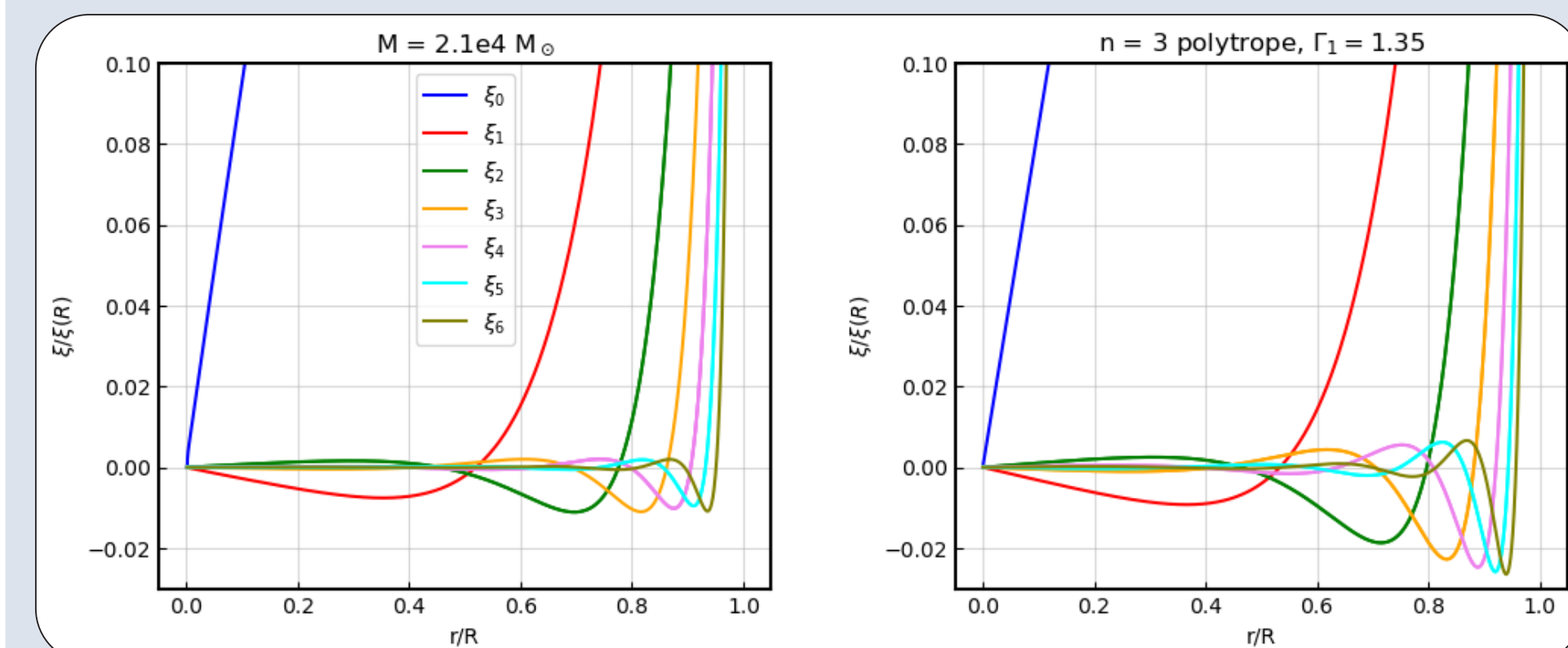
SMBH = supermassive black hole

GRSN = general relativistic instability supernova

## Methods: GR instability<sup>5</sup>

- Perturb EOM:  $\xi \propto e^{i\omega t}$ .
- Iterative solution to determine  $\xi_i$ :

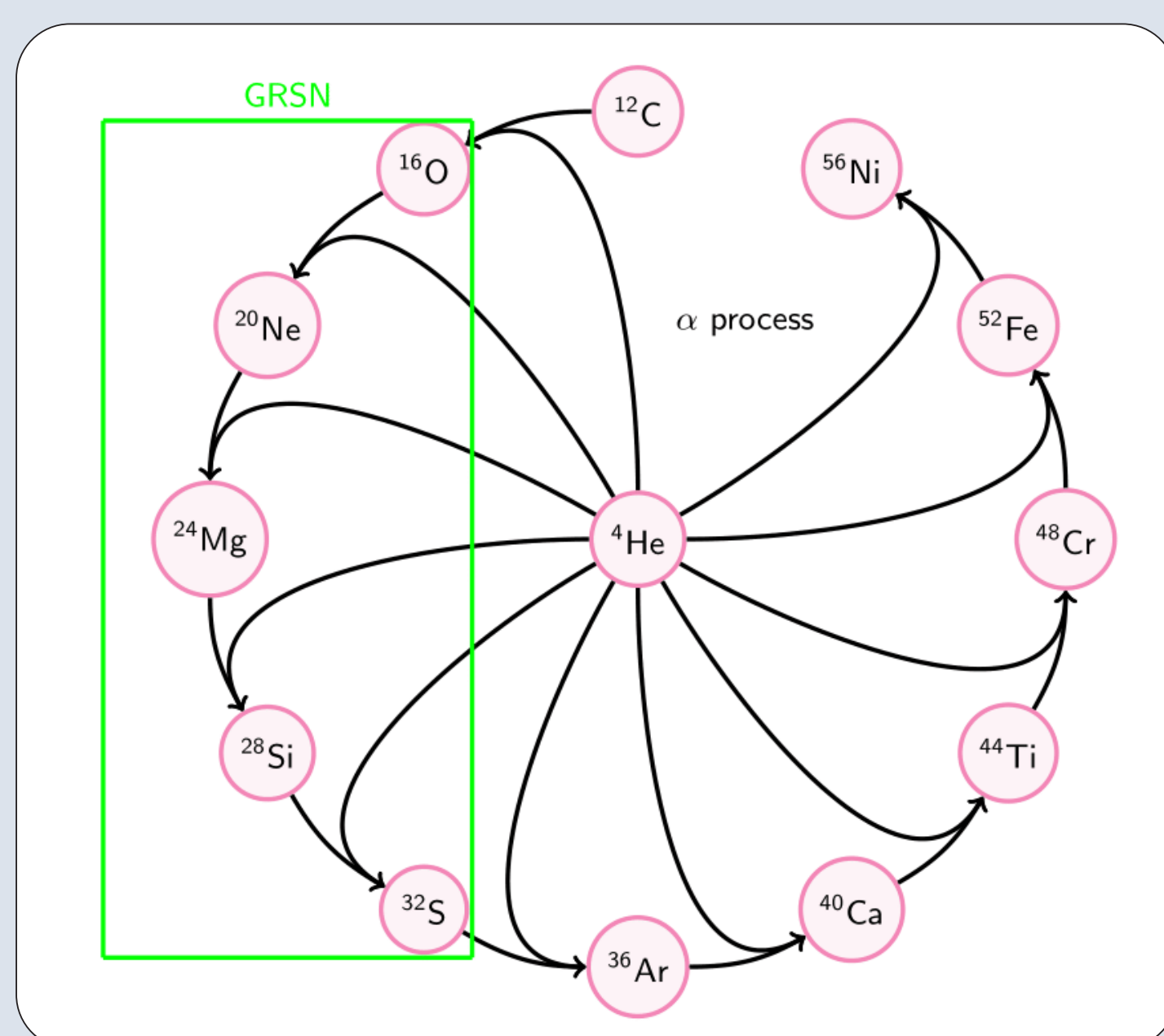
Star is unstable  $\Leftrightarrow \omega_0^2 < 0$



- Codes employed: HOSHI (stellar evolution), HYDnuc (GR hydro), SNEC (lightcurve)

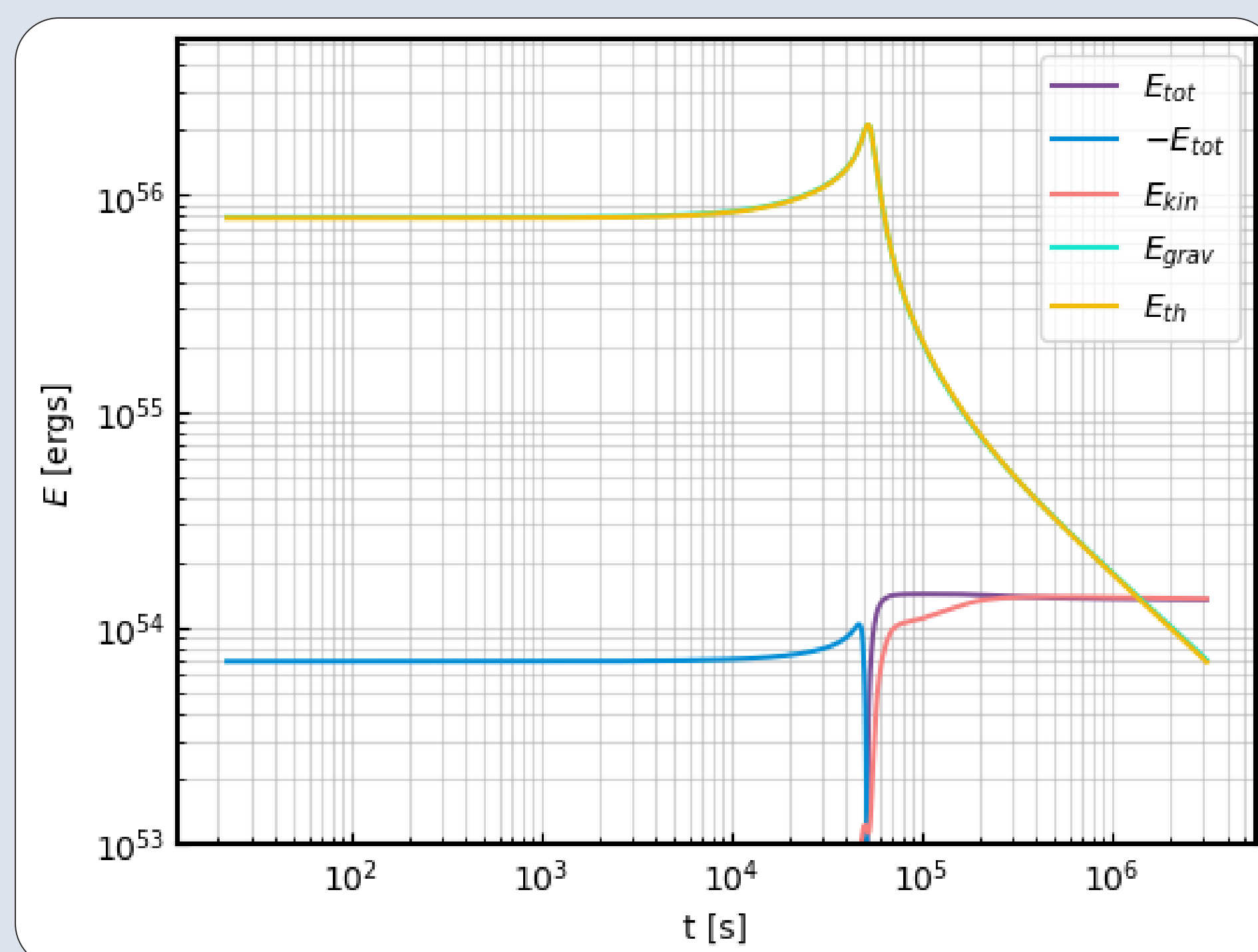
## Explosive $\alpha$ process

- $\alpha$  process does not usually power SNe.



- Requirements for  $\alpha$  process SN:  
Plenty of helium, sustained high temperature.

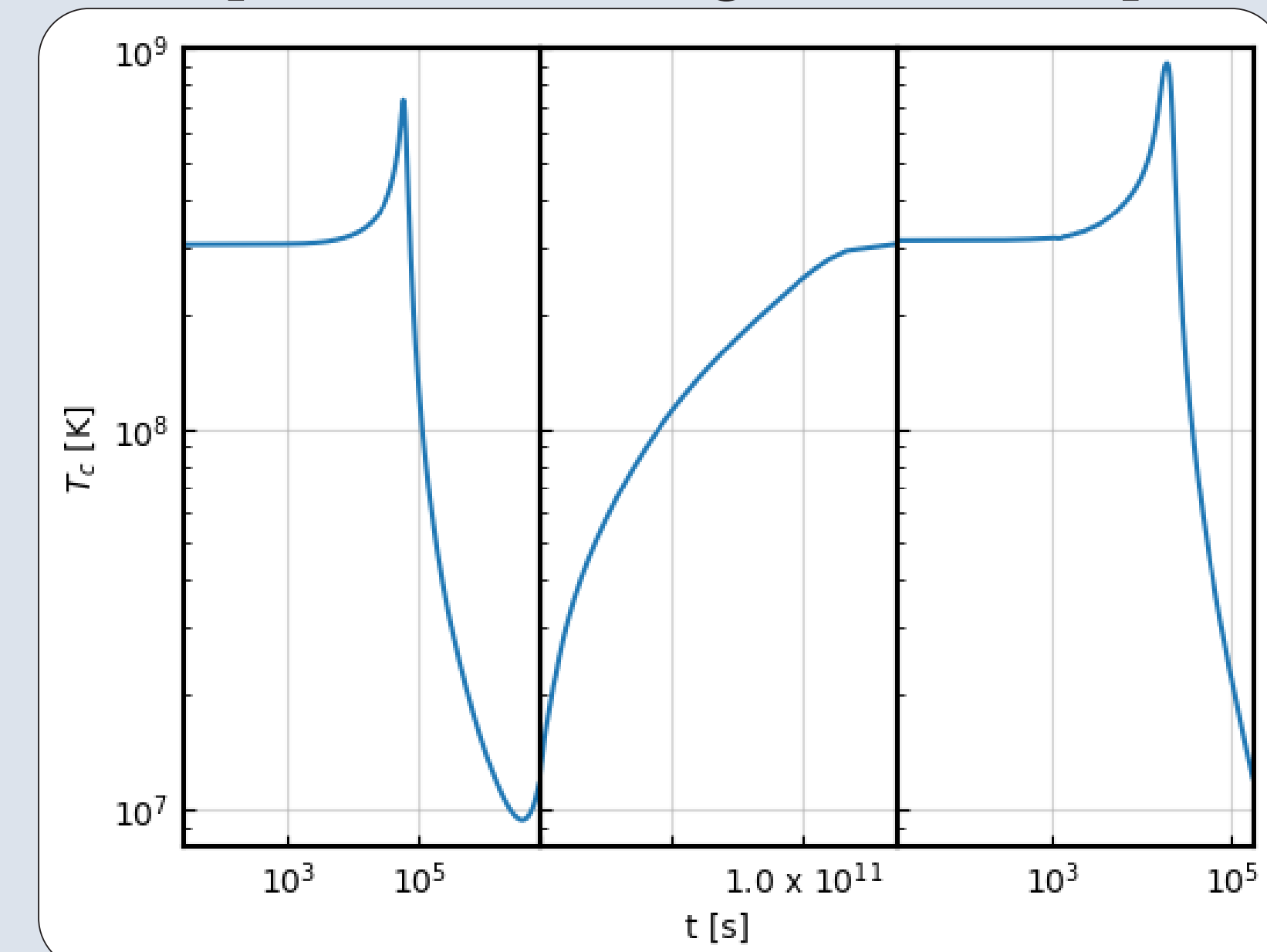
## GRSNe<sup>2-5</sup>



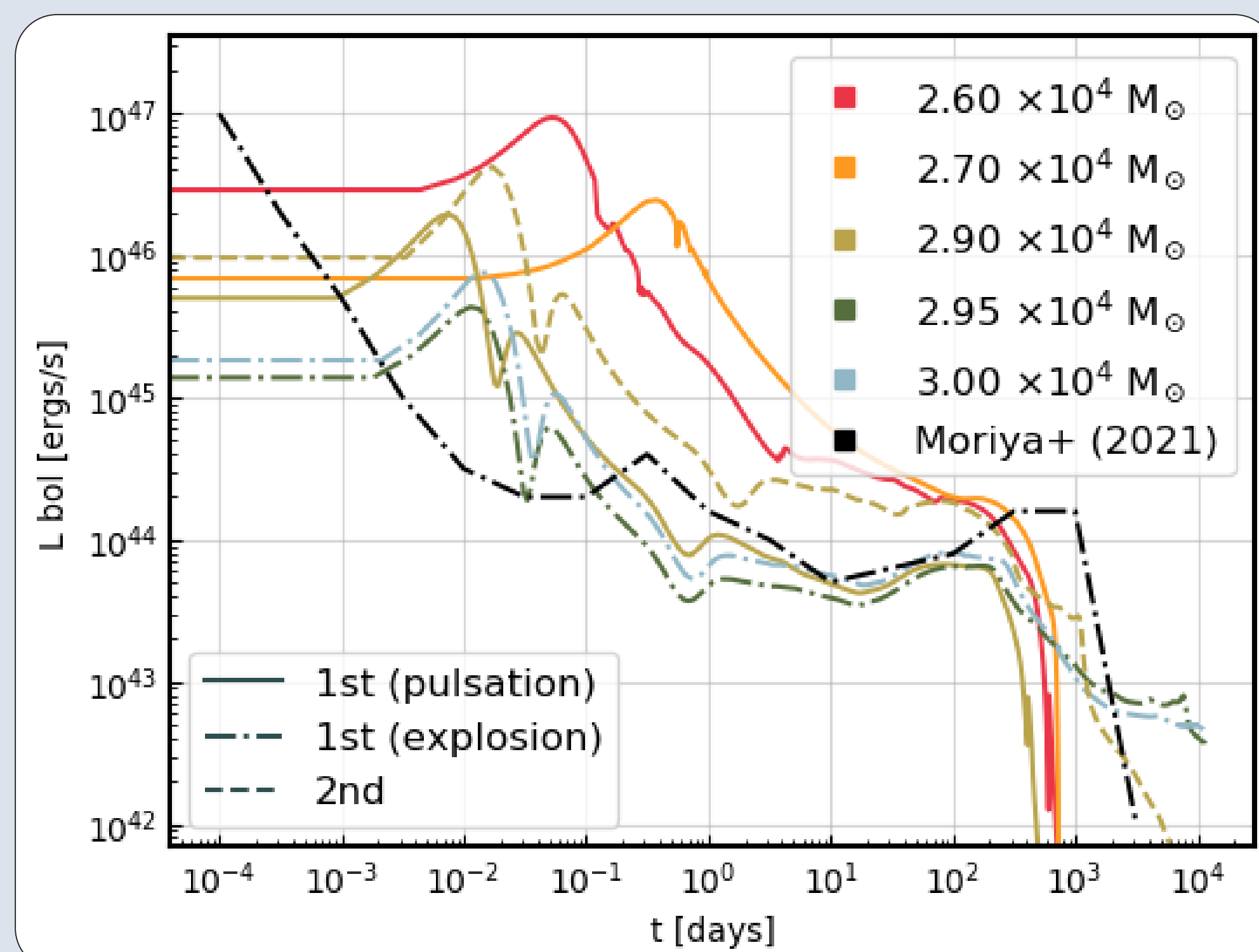
$E_{\text{exp}} = 10^{54}$  ergs!

## Pulsational GRSNe<sup>6</sup>

- Pulses only consume  $\sim 10\%$  of fuel (unlike PPISN).
- After KH contraction, pulses again.
- Second pulse reaches higher  $T_c \Rightarrow$  explosion.



## Light-curves<sup>4,6</sup>

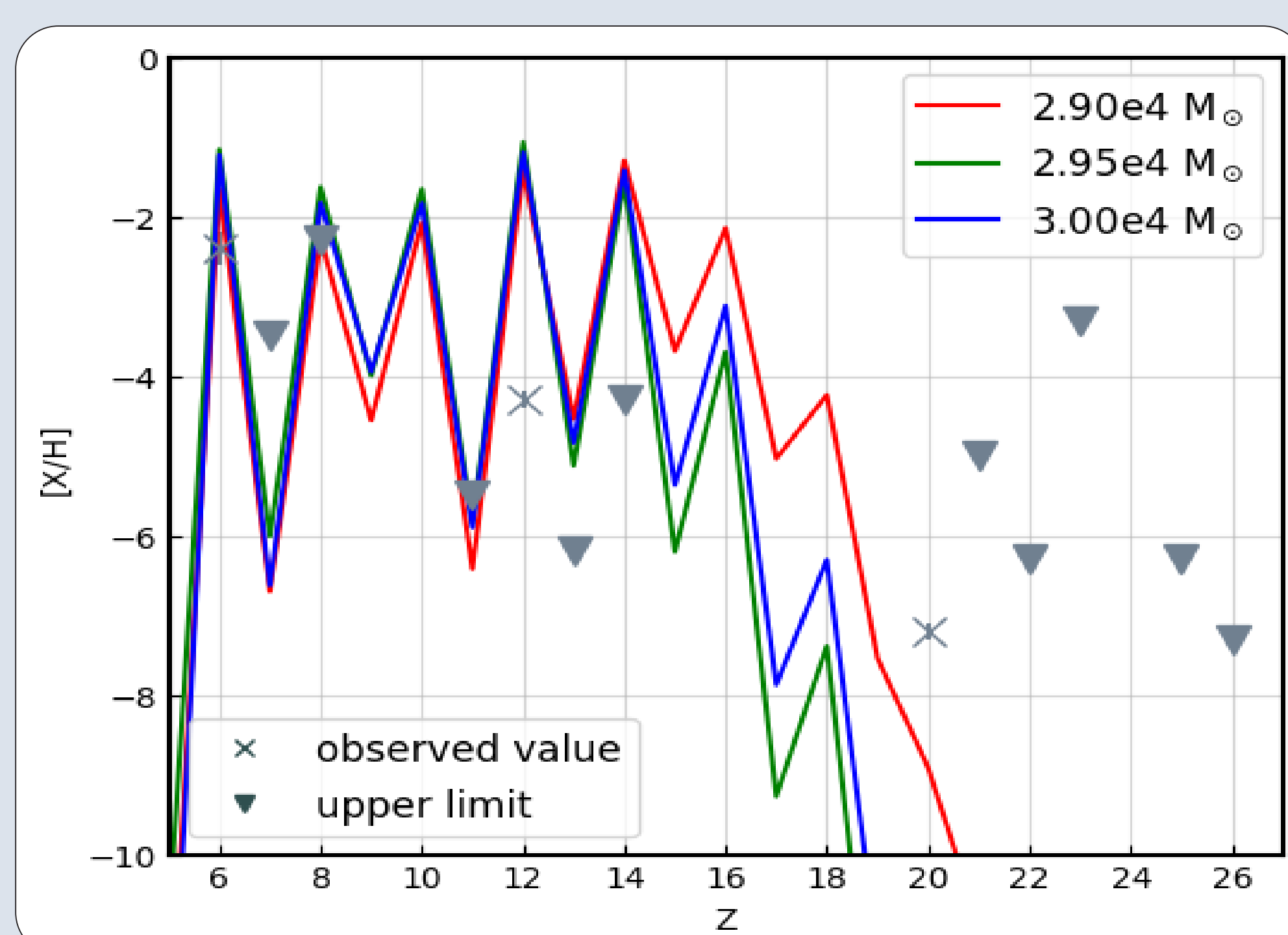


- Plateau phase  $\sim$  years rest frame
- Plateau phase  $\sim$  decades observer frame
- Moriya+(2021): visible to JWST @  $z = 15$
- Differentiable from galaxies if multiple bands
- Not yet including effects of interaction

## Future work

- PGRSNe as interacting SNe.
- CNO-rp GRSNe.
- Effects of rotation.
- Effects of KH instabilities (2D).

## Yields<sup>5,6</sup>



- No Fe
- Si and Mg rich
- Not a match for any observed metal poor stars
- Grey symbols shows Keller+ (2014)

## References

- <sup>1</sup>Wu X.-B., et al., 2015, Nature, 518, 512.
- <sup>2</sup>Chen K.-J., Heger A., Woosley S., Almgren A., Whalen D. J., Johnson J. L., 2014, ApJ, 790, 162.
- <sup>3</sup>CN, HU, Takahashi K., Yoshida T., Sumiyoshi K., 2021, MNRAS, 508, 828.
- <sup>4</sup>Moriya T. J., Chen K.-J., Nakajima K., Tomiyama N., Blinnikov S. I., 2021, MNRAS, 503, 1206.
- <sup>5</sup>CN, HU, Takahashi K., Yoshida T., Sumiyoshi K., 2022, accepted MNRAS, arXiv:2205.10493.
- <sup>6</sup>CN, HU, Takahashi K., in prep, 2022.