Review: "Evidence for an aspherical Population III supernova explosion inferred from the hyper metal-poor star HE 1327−2326"

2020/06/23, Sho Nishijima

Colloquium

Today's paper

- **Title**
  Evidence for an aspherical Population III supernova explosion inferred from the hyper metal-poor star HE 1327−2326
- **Authors**
  Rana Ezzeddine, Anna Frebel, Ian U. Roederer, Nozomu Tominaga, Jason Tumlinson, Miho Ishigaki, Ken'ichi Nomoto, Vinicius M. Placco, and Wako Aoki
- **Journal**
  ApJ 876 97, 2019
- **ADS**
  https://ui.adsabs.harvard.edu/abs/2019ApJ...876...97E/abstract

Outline

1. Background
2. Previous work
3. This work

Background

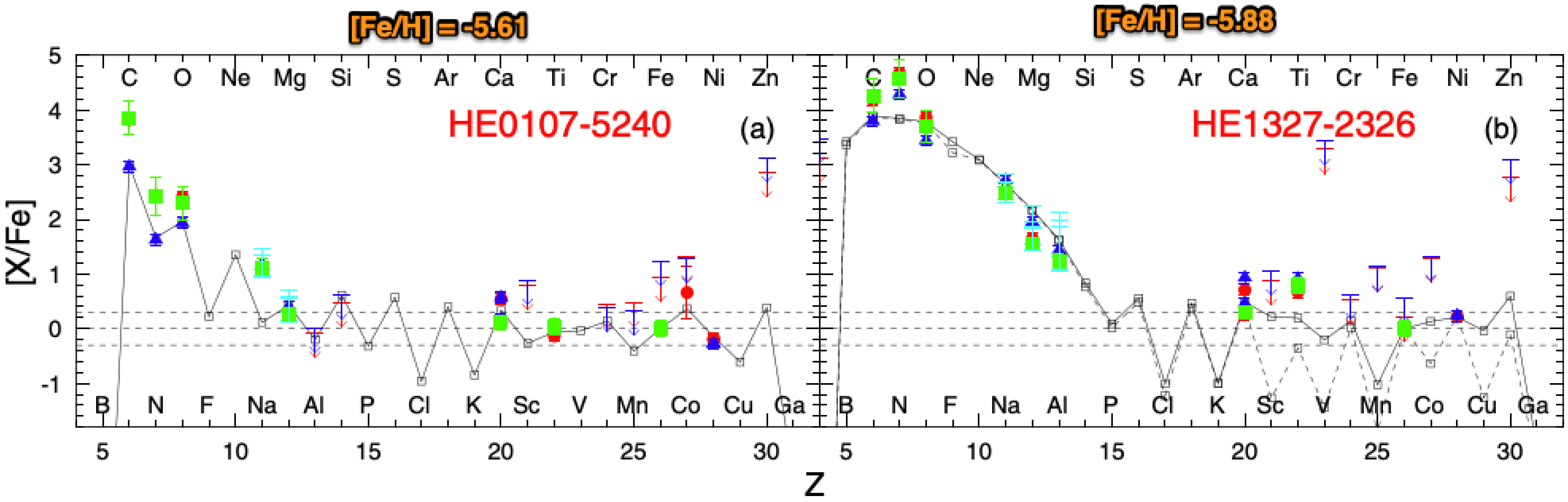
We can know about First stars from ultra metal-poor stars

- First stars formed from primordial gas, mostly H and He.
- Second-gen stars formed from mixture of ejecta of First SNe explosion and primordial gas. ([Fe/H]<-3.0)
    - Especially, ultra-metal poor (UMP) stars with $[\mathrm{Fe/H}] < -4.0$ are likely formed from gas enriched by individual first-SNe events (Frebel+ 2015; Hartwig+ 2018)
- Intersteller medium became homogeneous after cycles of those. (-3.0<[Fe/H]<-2.5) (Argast+ 2000; Tumlinson 2006)

→ **Evidence on the first stars/SNe can be obtained from the chemical signatures of surviving low-mass, UMP stars with $[\mathrm{Fe/H}] < -4.0$ (Beers & Christlieb 2005)**

* $[\mathrm{A/B}] = \log_{10}\left(N_\mathrm{A}/N_\mathrm{B}\right)_\mathrm{star} - \log_{10}\left(N_\mathrm{A}/N_\mathrm{B}\right)$

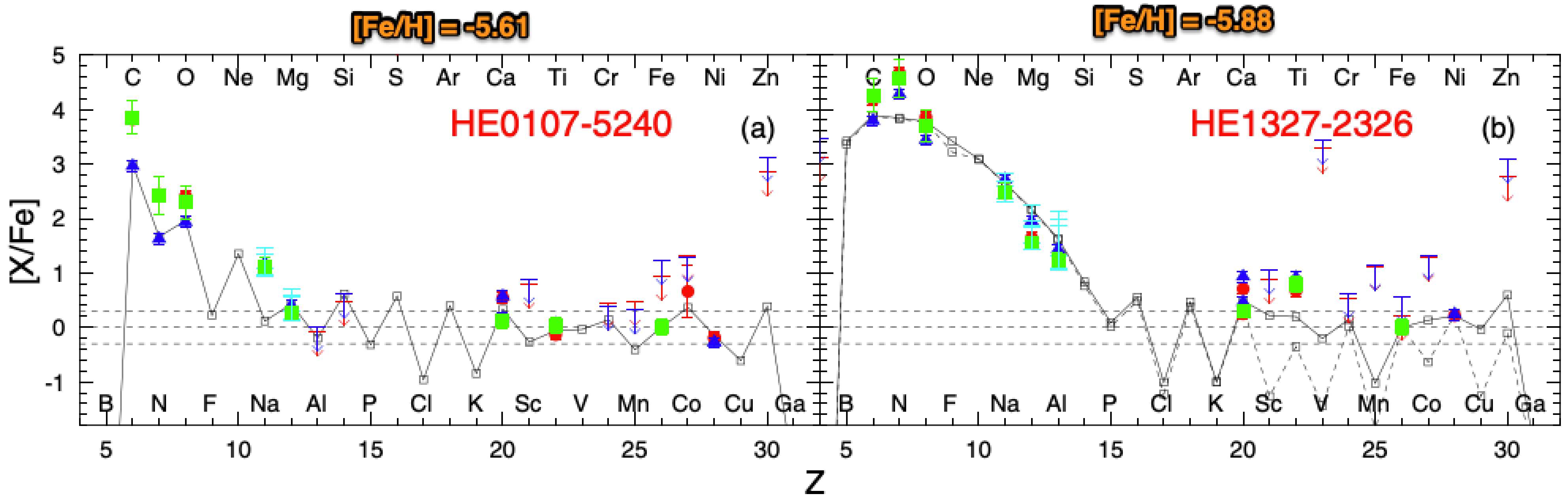
Abundance profiling



- Compare observed chemical abundance pattern to theoretical SNe nucleosynthesis yield

Fig: Tominaga+ 2014

Characteristics of MP star



- Fe-peak rich: $[\mathrm{Co}, \mathrm{Zn}/\mathrm{Fe}] > 0$
- α element rich: $[\alpha/\mathrm{Fe}] > 0$
- Light element rich: $[\mathrm{C}, \mathrm{N}, \mathrm{O}/\mathrm{Fe}] > 1$

→ **"What kind of SN explosion can reproduce these characteristic chemical abundance?"**

Fig: Tominaga+ 2014

Previous work

Difficulty of spherical explosion models

Spherical explosion model cannot produce those 3 characteristics at the same time

- Small energy:
  - cannot produce $[\mathrm{Co, Zn/Fe}] > 0$
- Large energy:
  - produce $[\mathrm{Co, Zn/Fe}] > 0$ (Nomoto+ 2013)
  - but high $[\mathrm{Fe/H}]$

(Cayrel+ 2004, Woosley+ 1995)

→ **Needs aspherical effects?**

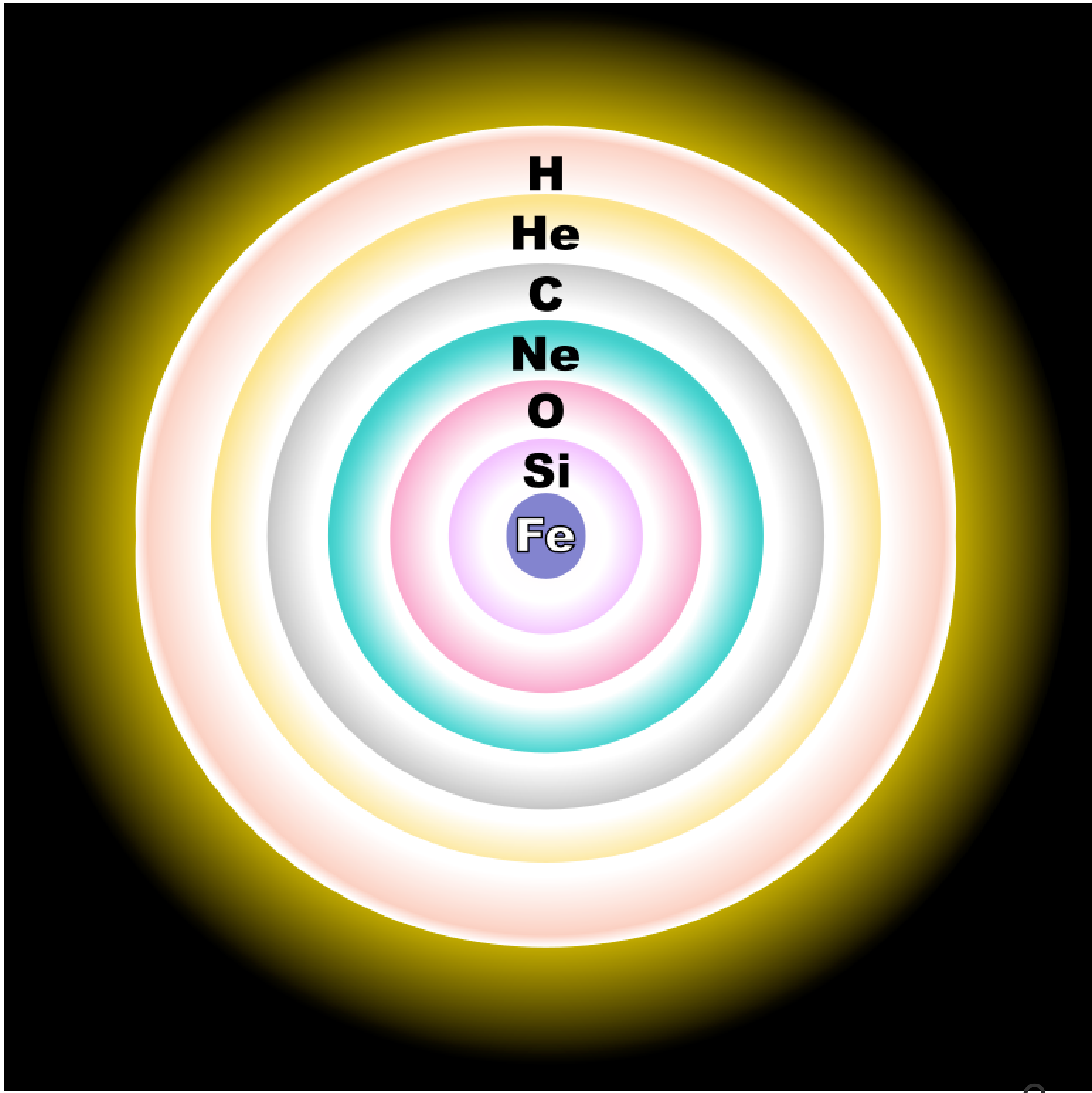


Fig: II型超新星 - Wikipedia

Mixing & Fallback Model was developed

“mixing and fallback” (MF) SNe model was developed (Umeda & Nomoto 2002) and it can mimic 2 different mechanisms:

- (a) Faint quasi-spherical MF SNe
  - Rayleigh–Taylor instability (Joggerst+ 2009, 2010)
- (b) Aspherical bipolar jet SNe
  - Jet-like explosion (Tominaga+ 2007, Tominaga 2009)

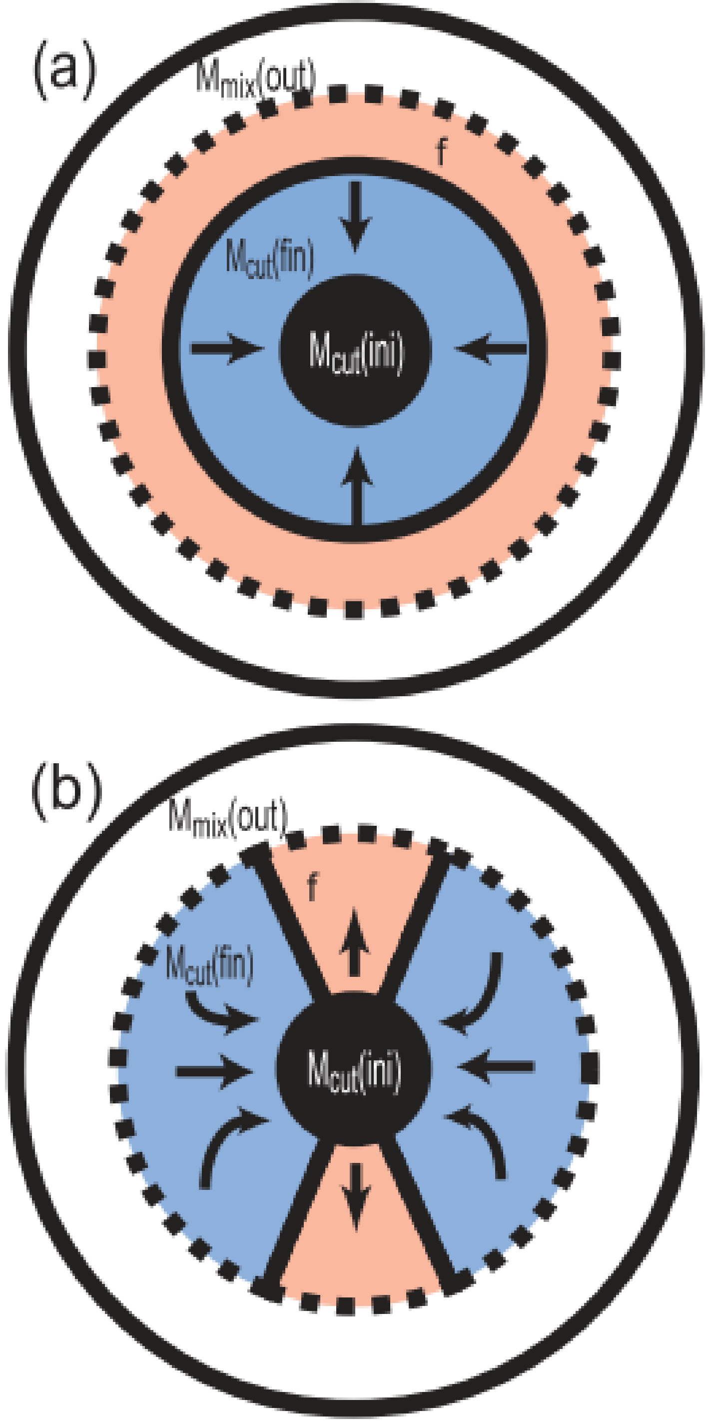
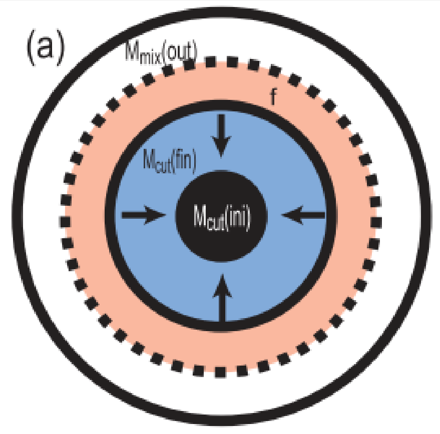
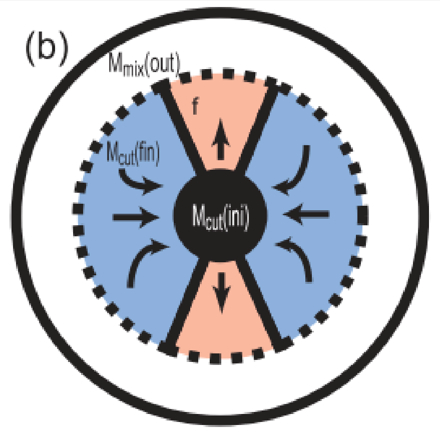


Fig: Tominaga+ 2007

Jet-like explosion is favored on MP with -4.5<[Fe/H]<-3.0

	Picture	Characteristics
Faint, quasi-spherical		- Elements mixed before explosion - Low energy ($E \leqslant 10^{51}$erg) is required to the extensice fallback - Light elements & α elements are reproduced - But **Fe-peak is NOT enough bcause of weak energy**
Bi-porlar jet		- Density reduced artificially to mimic jet-like explosion - High energy enough to reproduce Fe-peak elements - Light elements & α elements are also reproduced

Umeda+ 2002, Tominaga+ 2007, Tominaga 2009, Nomoto+ 2013, Grimmett+ 2018

This work

How about HMP star with [Fe /H]<-5.0?

- They determine $[\mathrm{Zn/Fe}] = 0.80 \pm 0.25$ of hyper metal-poor (HMP) star, HE1327--2326, with $[\mathrm{Fe/H}] = -5.2$ for the first time
- The goal of this work is interpretation of new zinc abundance on such a metal-poor star

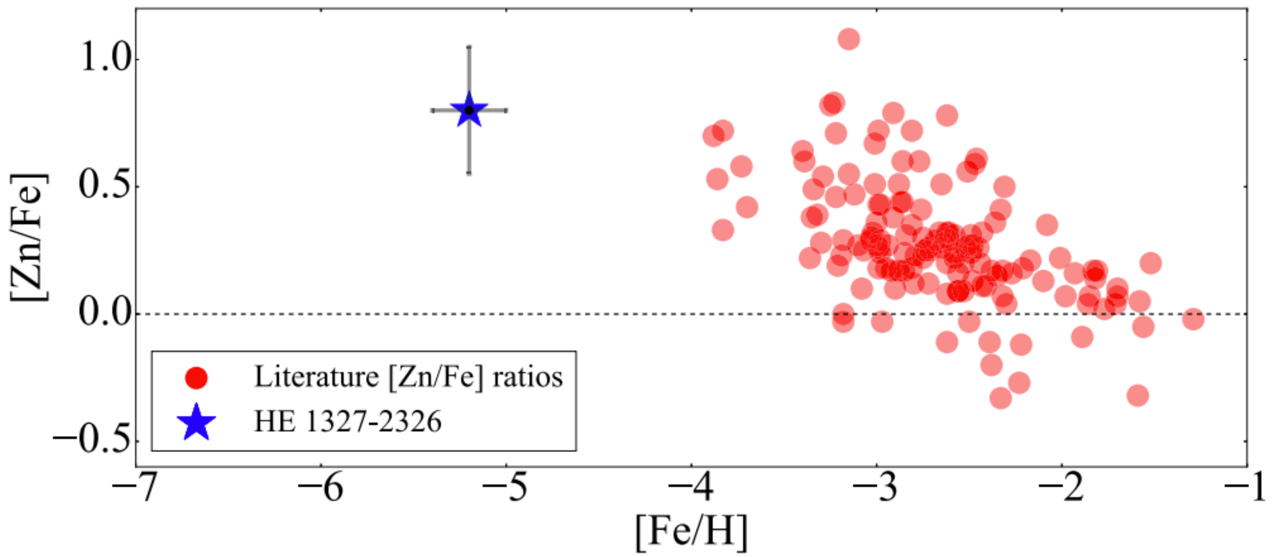


Fig: Tominaga+ 2007

Faint, quasi-spherical model

- Performed statistical fitting tests following Placco+ 2016
  - Grid has 16,800 models
    - mass: 10 -- $100 M_\odot$
    - energies: $(0.3$ -- $10) \times 10^{51}$ erg

$\rightarrow 27 M_\odot$ progenitor with 0.3×10^{51} erg explosion's yield is best fit(82%)
$\rightarrow$ **None of them matches high [Zn/Fe] abundance**

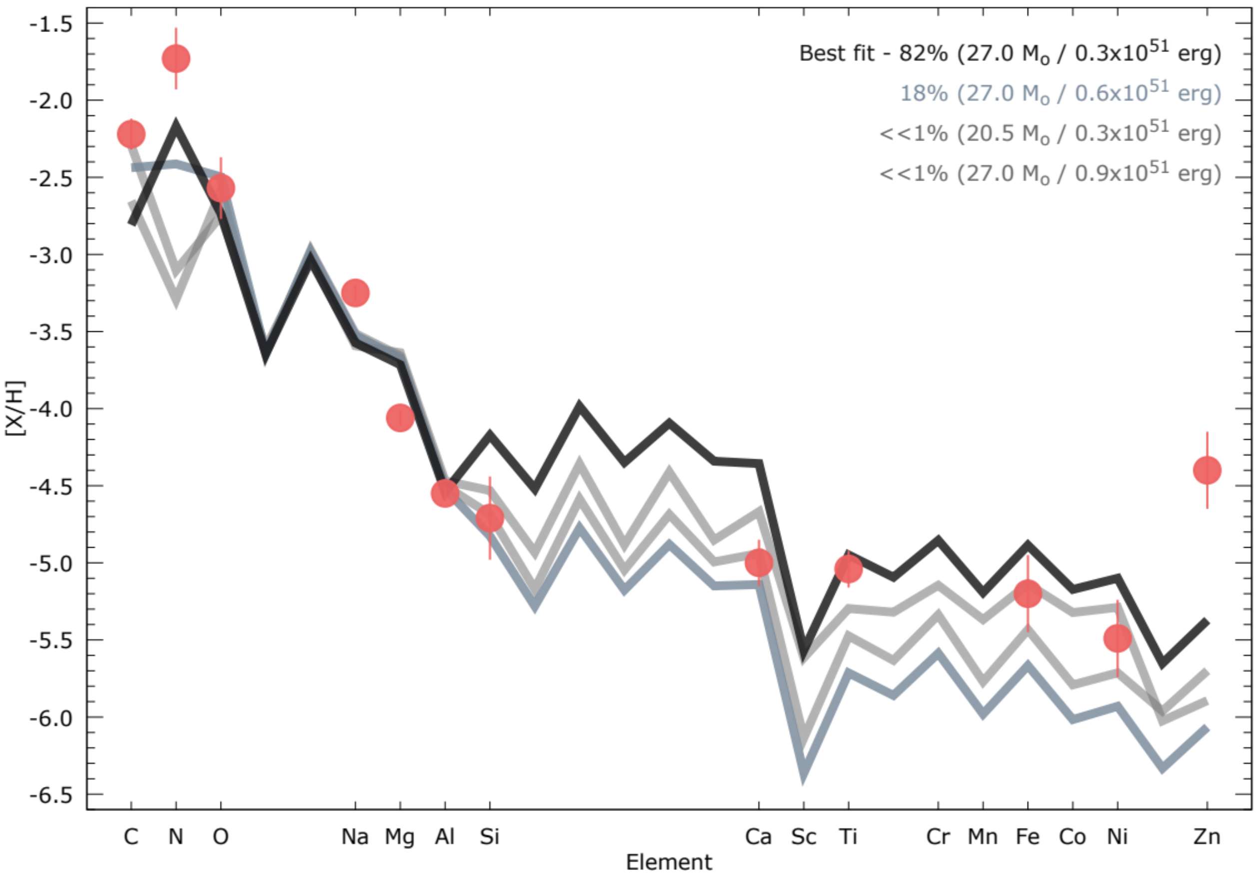


Fig: Ezzeddine+ 2019

Aspherical model

- Tominaga+ 2007
  - mass:20 -- $50 M_{\odot}$
  - energy:$(5$ -- $40) \times 10^{51}$ erg
  - density factor: 1/4 -- 1/2
- **Density modified MF model mimicking an aspherical explosion with bipolar-outflows in certain range of mass and higher energy**
- The yield of $25 M_{\odot}$ progenitor's exploding with $E = 5 \times 10^{51}$ergs is best match

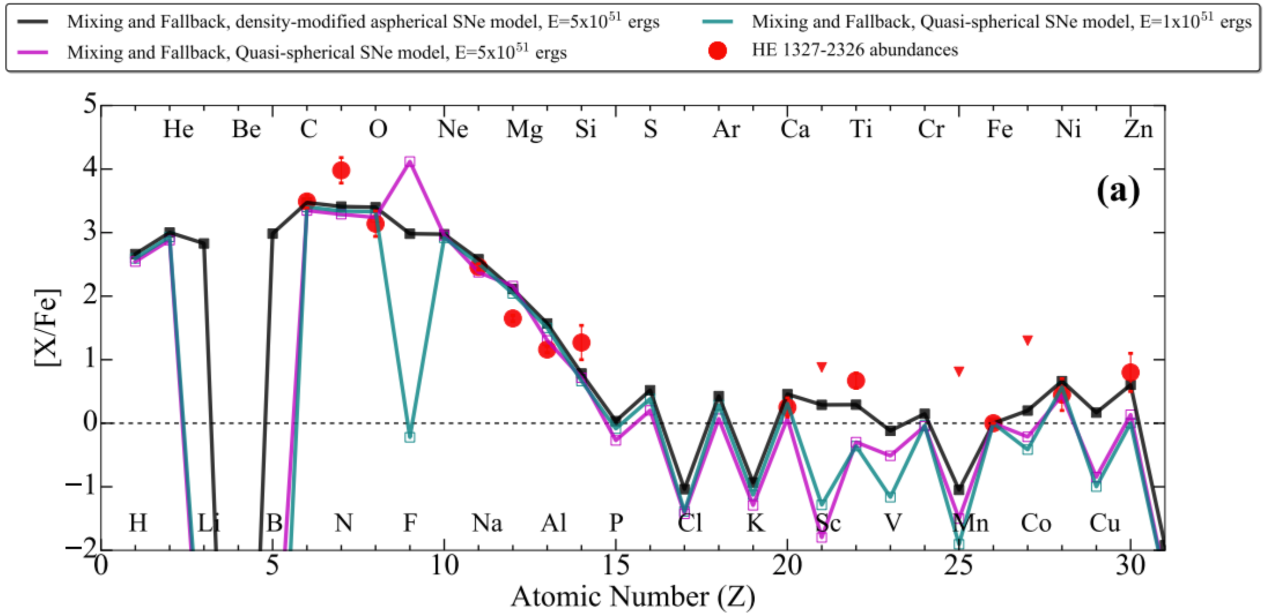


Fig: Ezzeddine+ 2019

Result

- Determine the abundance of Zn on HMP ($[\mathrm{Fe/H}] = -5.2$) star for the first time
- Found the yields of density-modified MF model mimicking aspherical SN explosion with bipolar outflow matches better than other models

Interpretation

- A high-velocity ejecta could facilitate carrying the SNe yields out of the parent host minihalo to enrich a neighboring minihalo.

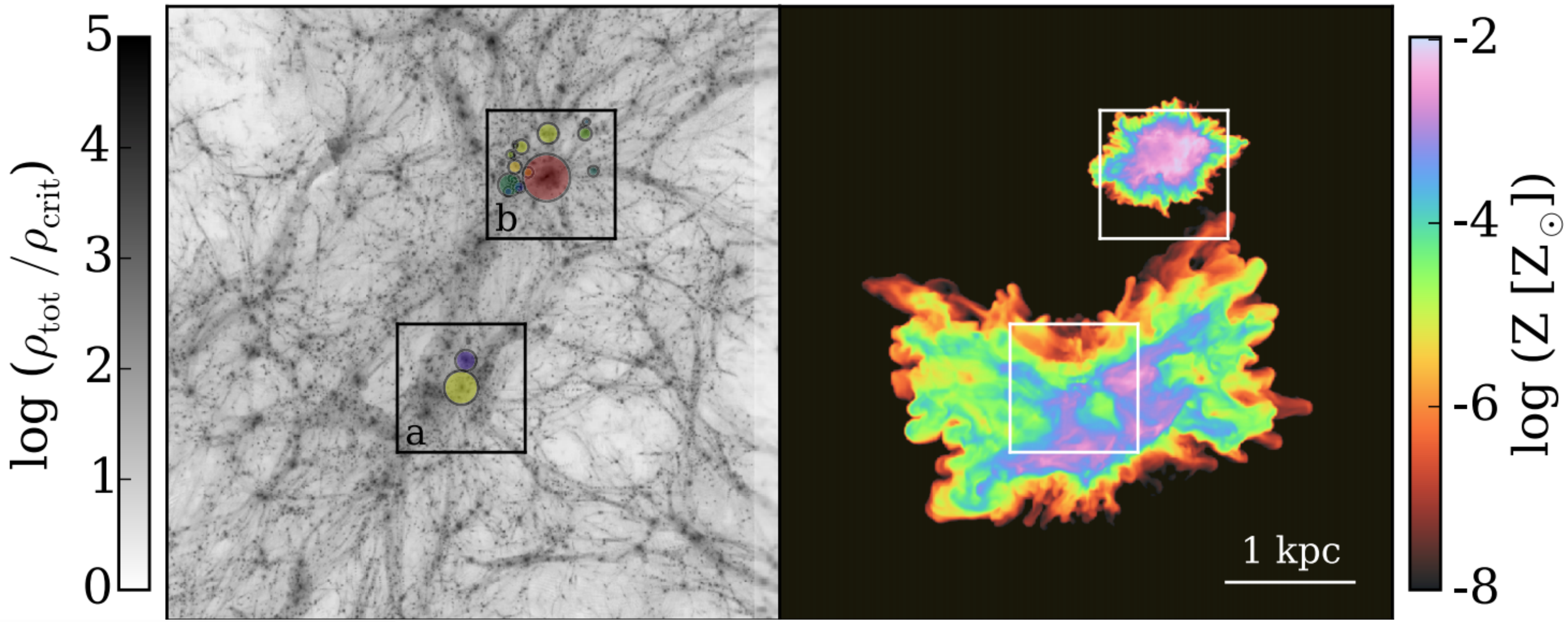


Fig: Smith+ 2015