超新星連星による初代星探査

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Kakenhi (C)「連星系での超新星爆発の影響を受けた星の熱進化」

TS, T. R. Saitoh, Y. Moritani, & T. Shigeyama, in prep.

Origin of Extremely Metal-Poor (EMP) Stars

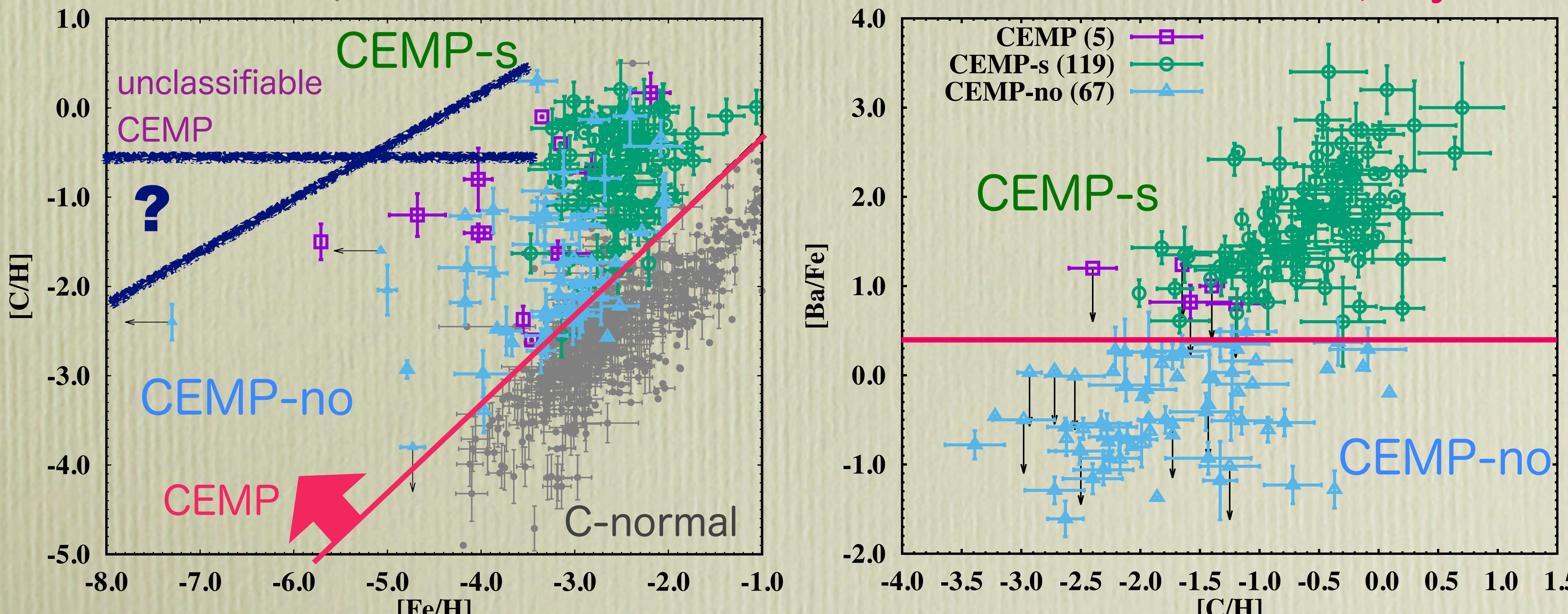
- common in Extremely Metal-Poor (EMP) stars
  - > 20 % for [Fe/H] < -2 with [C/Fe] ≧ 0.7
- divided into subclasses
  - CEMP-s (s-process) [Ba/Fe] ≧ 0.5
  - CEMP-no (no s-proces) [Ba/Fe] < 0.5
    - lower and higher CEMP-no (Bonifacio+15)
  - CEMP-r (r-process), CEMP-r/s (s+r), etc.

- Possible origins

I) CEMP-s and no come from binary mass transfer

II) CEMP-no from supernova models (Umeda+02)

III) CEMP-no from rotating massive stars (Meynet+06)



See also discussions by Aoki+07, Bonifacio+15, Yoon+16, etc.

Data taken from SAGA database (TS+08,11,17, Yamada+13)

IS HE 0107−5240 A PRIMORDIAL STAR? THE CHARACTERISTICS OF EXTREMELY METAL-POOR CARBON-RICH STARS

2004, ApJ, 611, 476

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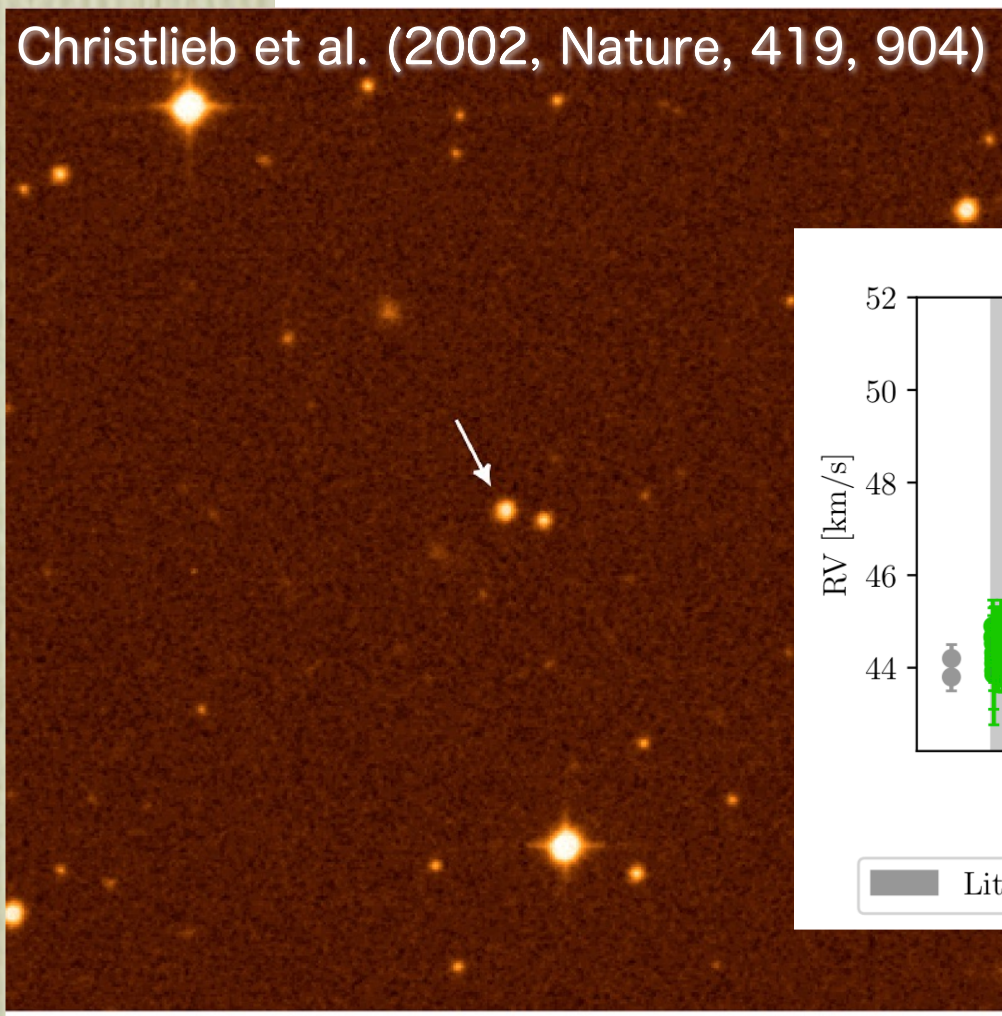
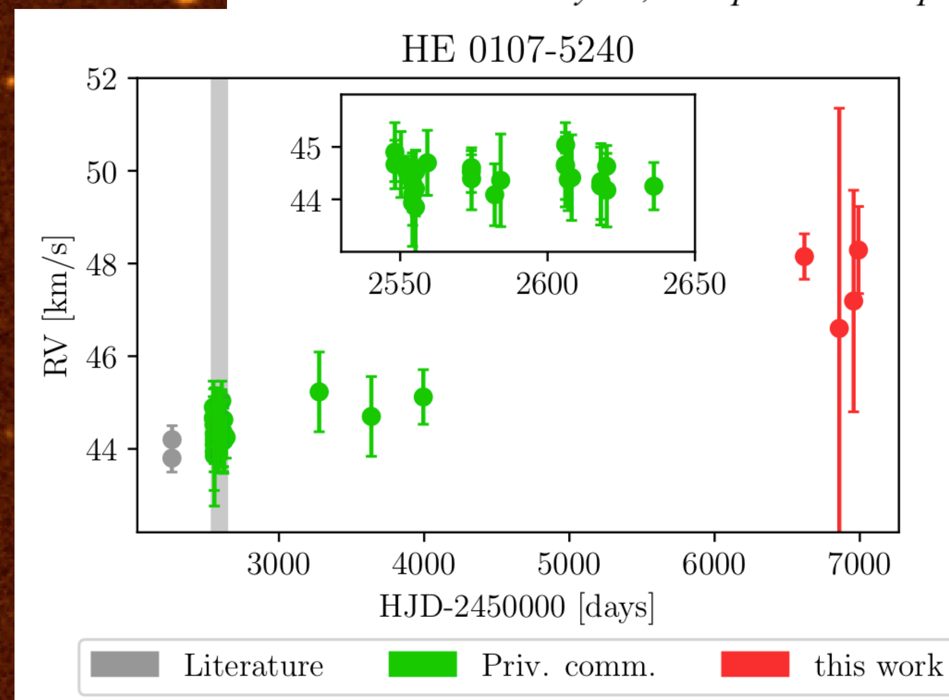
Christlieb et al. (2002, Nature, 419, 904)

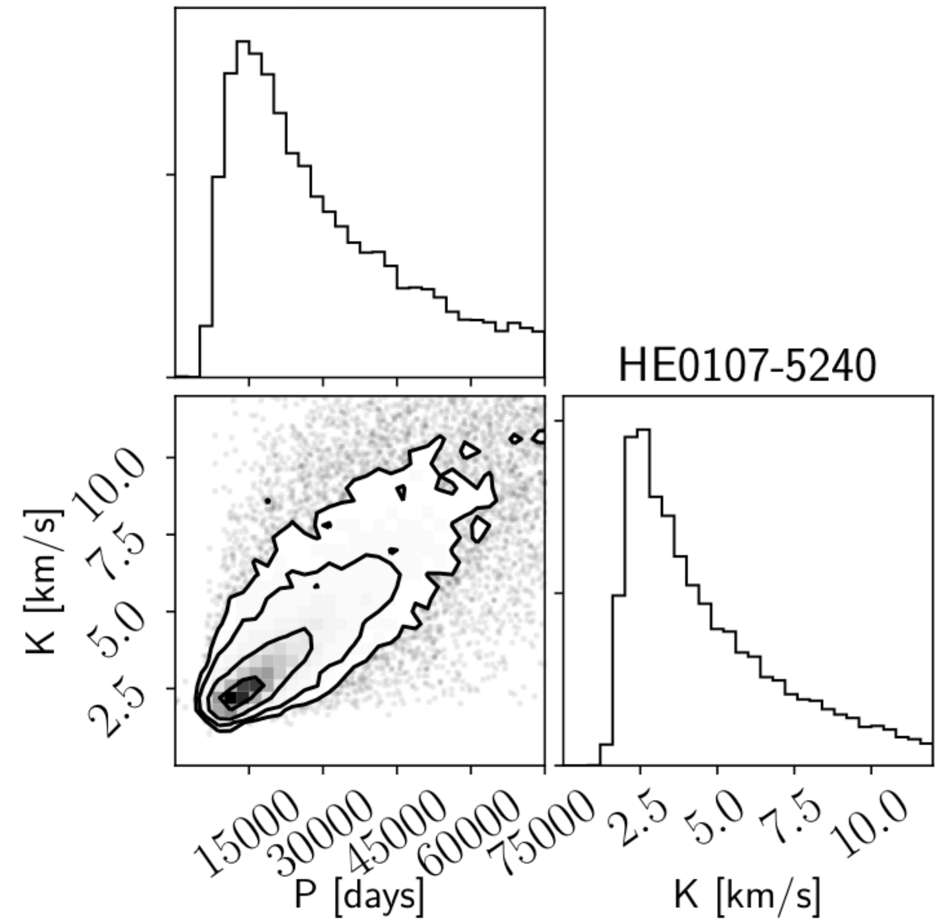


The Very Metal-Deficient Star HE 0107-5240

ESO PR Photo 25a/02 (30 October 2002)

Arentsen+, arXiv:1811.01975

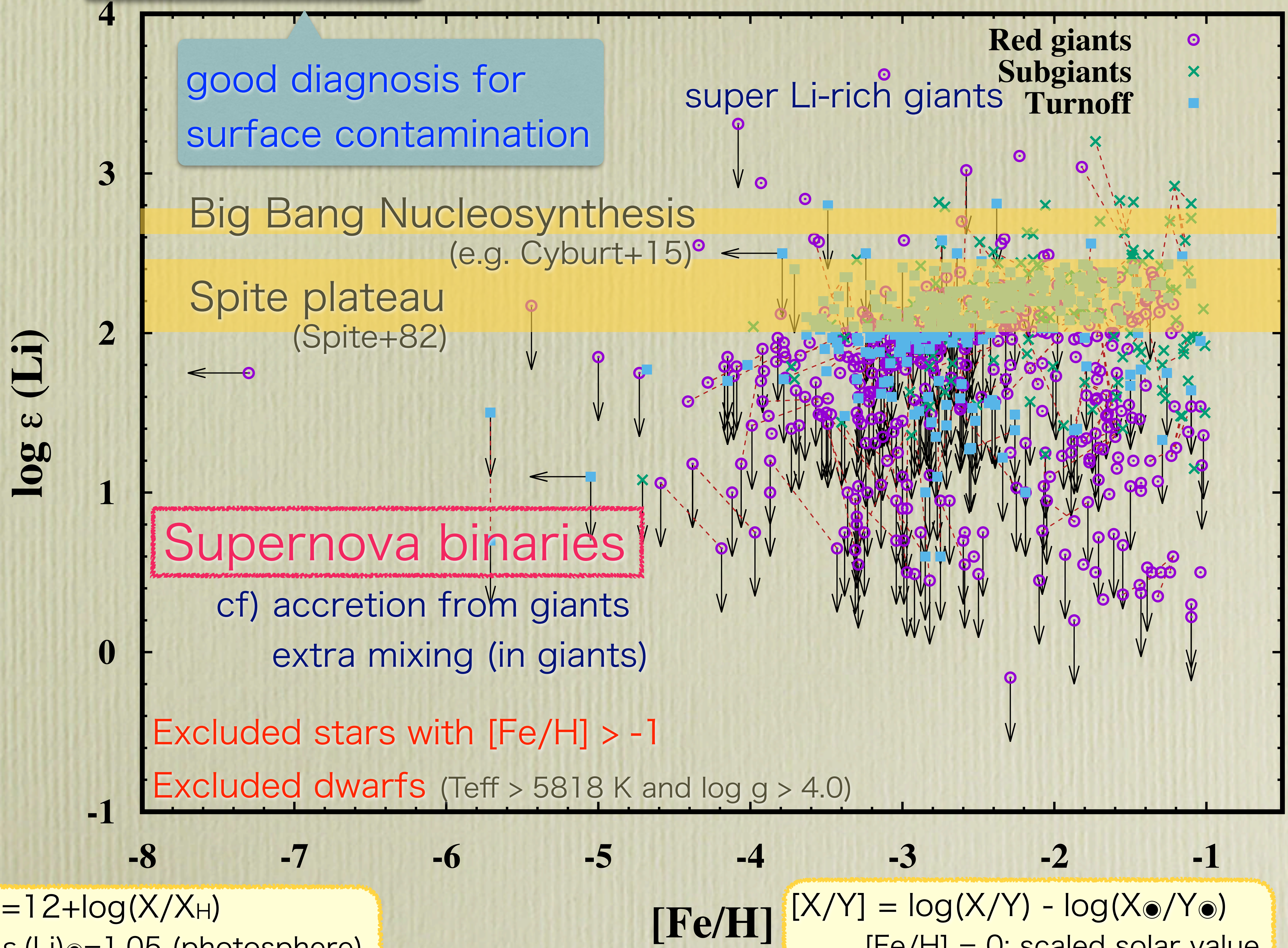




chemically evolved companion, which
ed in the binary, we rely on the results
sics. Nucleosynthesis in a helium-flash
ved, allowing us to explain the origin in
enrichments and to discuss the abundances of *s*-process elements. From th
that HE 0107−5240 has evolved from a wide binary (of initial separation ∼20 AU) with a primary of initial mass in the range 1.2–3 $M_\odot$. On the assumption that the system now consists of a white dwarf and a red giant, the present binary separation and period are estimated at ≃34 AU and a period of ≃150 yr, respectively. We also conclude that the abundance distribution of heavy *s*-process elements may hold the key to a satisfactory understanding of the origin of HE 0107−5240. An enhancement of [Pb/Fe] ≃ 1–2 should be observed if HE 0107−5240 is a second-generation star, formed from gas already polluted with iron-group elements. If the enhancement of main-line *s*-process elements is not detected, HE 0107−5240 may be a first-generation secondary in a binary system with a primary of mass less than 2.5 $M_\odot$, born from gas of primordial composition, produced in the big bang, and subsequently subjected to surface pollution by accretion of gas from the parent cloud metal-enriched by mixing with the ejectum of a supernova.

Li Problems

fragile element
burn at 2.5x10⁶ K



$\log \varepsilon(X) = 12 + \log(X/X_H)$

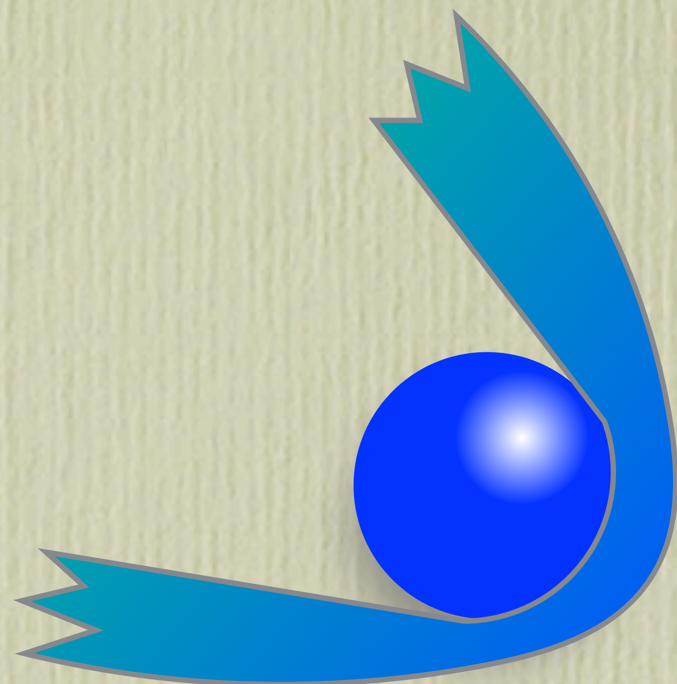
- $\log \varepsilon(\mathrm{Li})_\odot = 1.05$ (photosphere)
- 3.26 (meteorite)

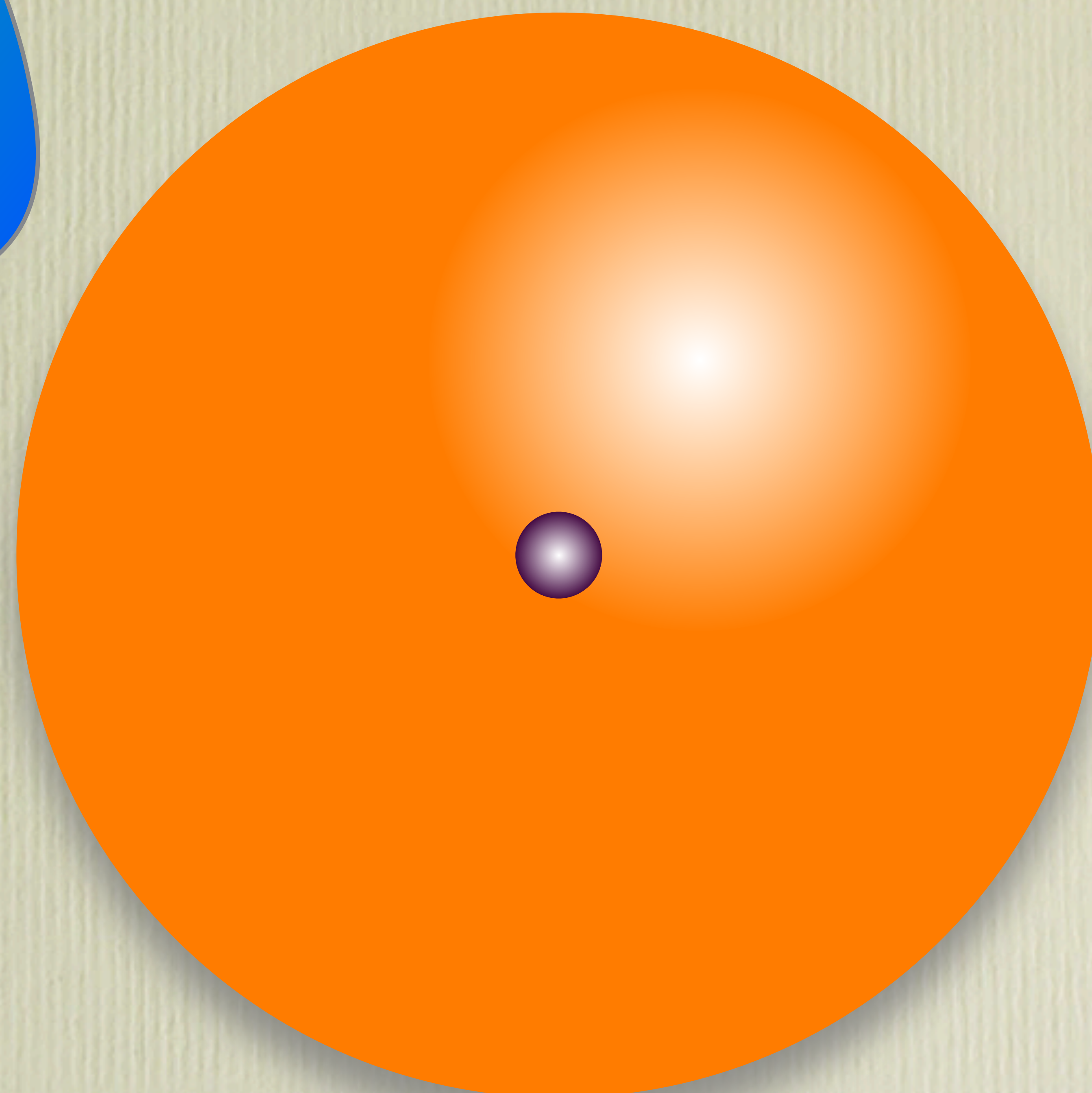
$[X/Y] = \log(X/Y) - \log(X_\odot/Y_\odot)$

- [Fe/H] = 0: scaled solar value
- -3: 1/1000 of solar

Supernova binary scenario

Massive Pop III star

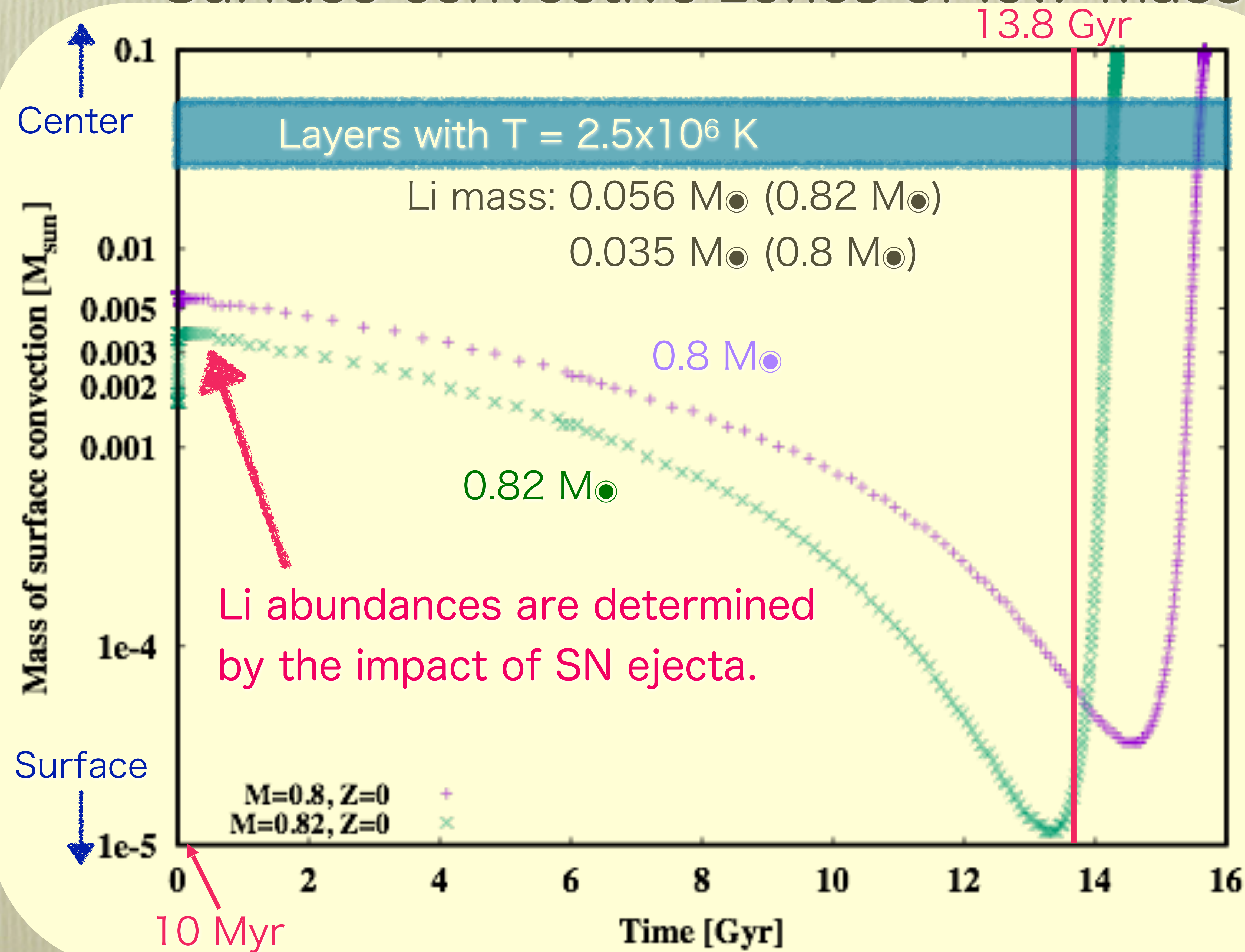




Low-mass Pop III companion

- ☆ Stripping of surface layers
- ☆ Accretion of SN ejecta
- ☆ Binary separation has to be small enough.
- ☆ Evolution to red supergiants (>~ 5 au) will inhibit this scenario (cf. Marigo+01, Heger+10, Kinugawa+14).

Surface convective zones of low-mass



Simulations of SN binary scenario

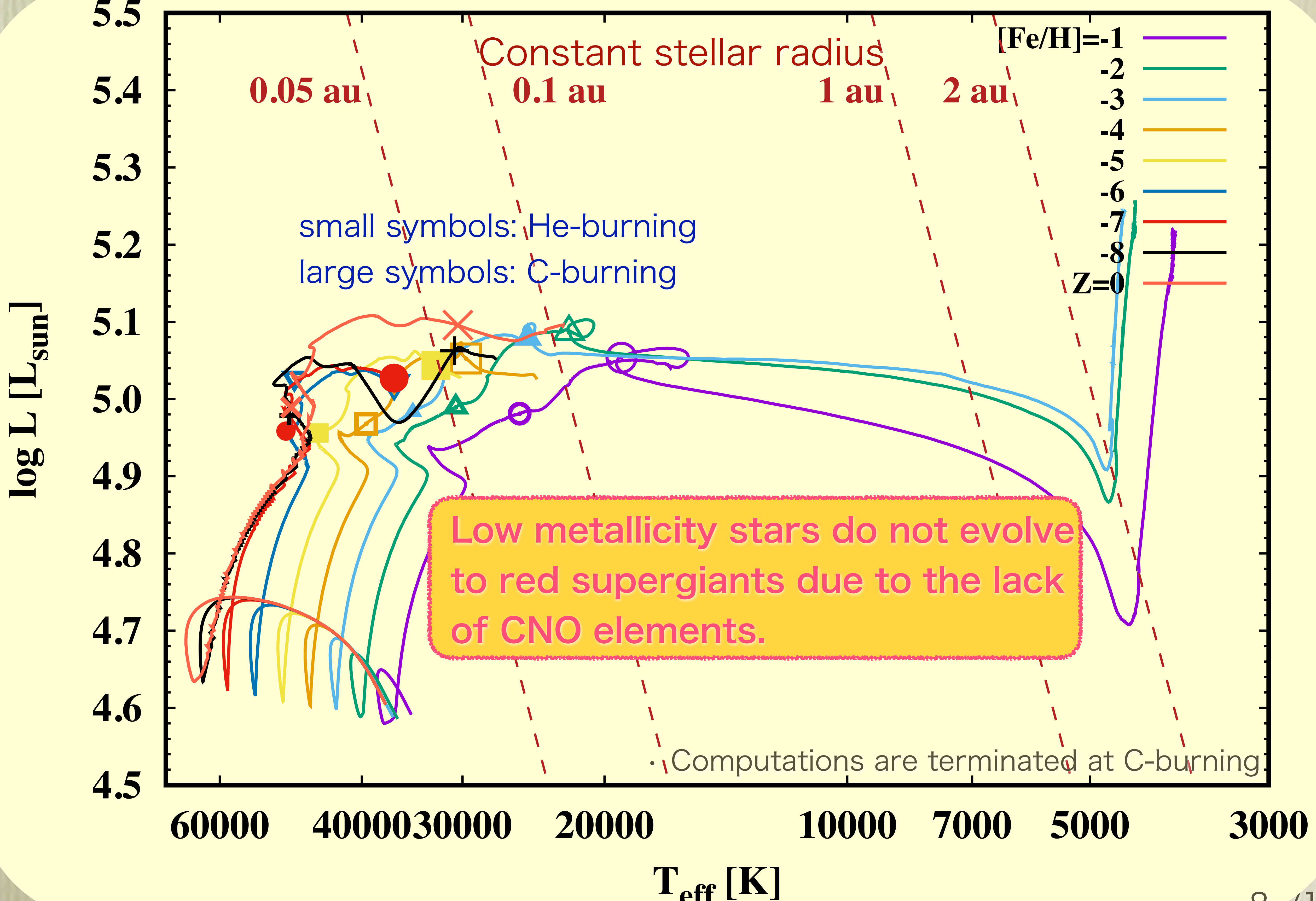
- Stellar evolution models: 1D hydrostatic (Suda+10)
- Supernova explosion models: SN1987A (Shigeyama+90)
- SPH simulations: ASURA code (Saitoh+08)

- Binary system: 15 $M_\odot$ + 0.8 $M_\odot$
- Separation : ~0.1 au (~20 $R_\odot$)

- Previous studies on the collisions of supernova ejecta
    - Ia: Marietta+00: PPM
    - Ia: Pakmor+08: GADGET
    - Ia: Pan+12: FLASH
    - II: Liu+13: GADGET, Wolf-Rayet stars
    - II: Hirai+14: yamazakura, massive + massive

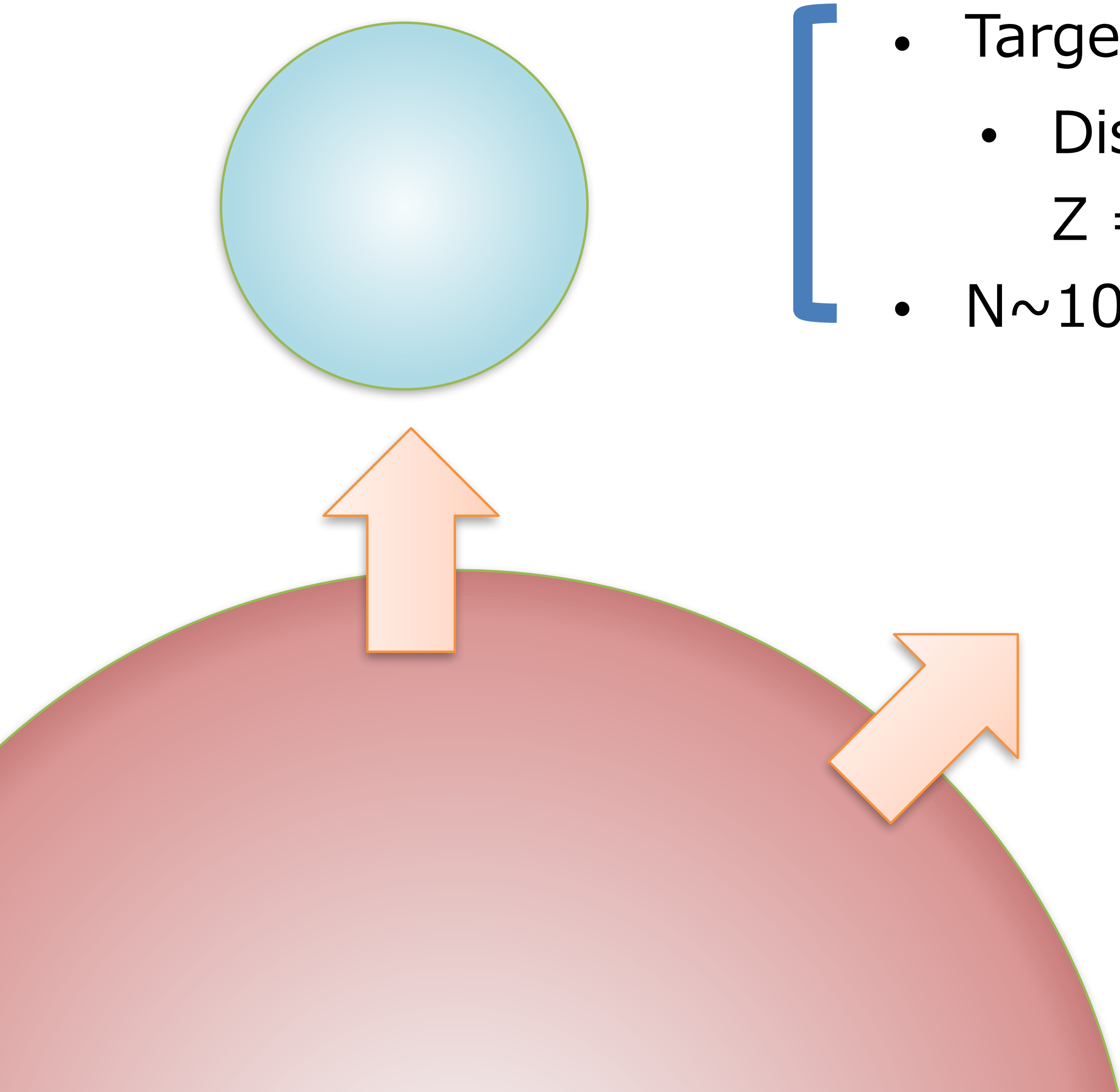
see also Heger+Woosley10 and T. Yoshida-san's talk

Evolution of 20 M⊙ Stars



Configuration with ASURA code

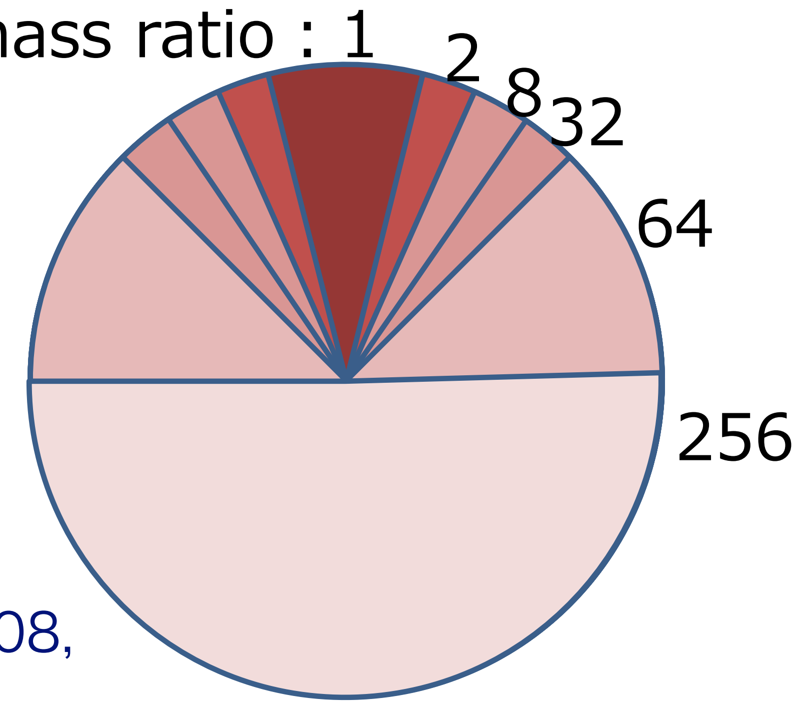
Saitoh+08



- Target: 0.8 $M_\odot$ with R=0.64 $R_\odot$
  - Distribution of mass and temperature from Z = 0 models
- N~10^6 (sink particle in the center)

- Supernova: Heger & Wooseley (2010) (15,20,25 $M_\odot$)
- N~7×10^6 (reduced the number of particles for offset collision)

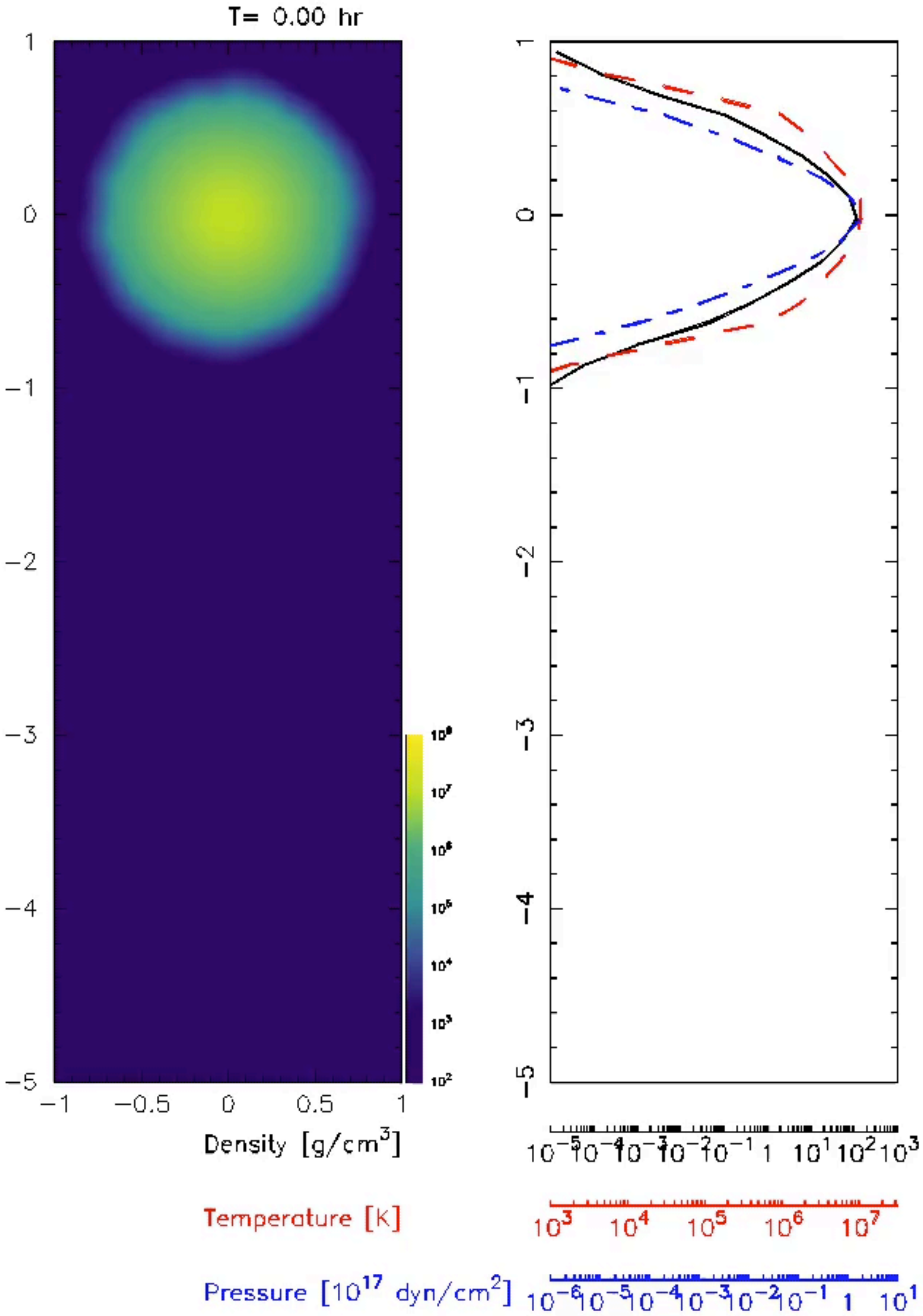
particle mass ratio : 1



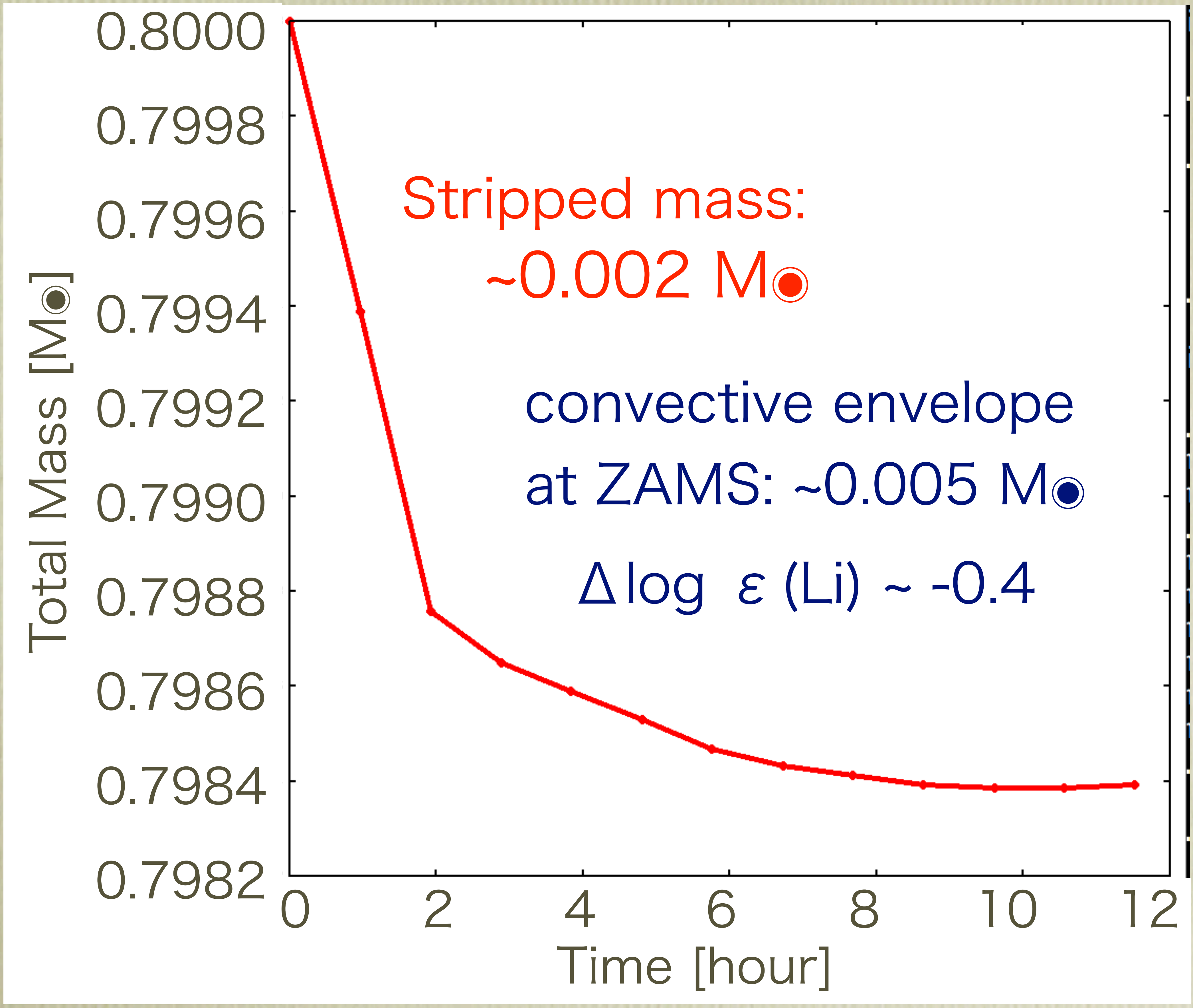
Model	N_{target}	N_{SN}	separation
H15	1,023,991	16,001,929	0.1 AU

Checked the consistency with Type Ia explosions by Pakmor+08, by confirming the total stripped mass of a companion star.

Result



Stripped mass for the H15 model

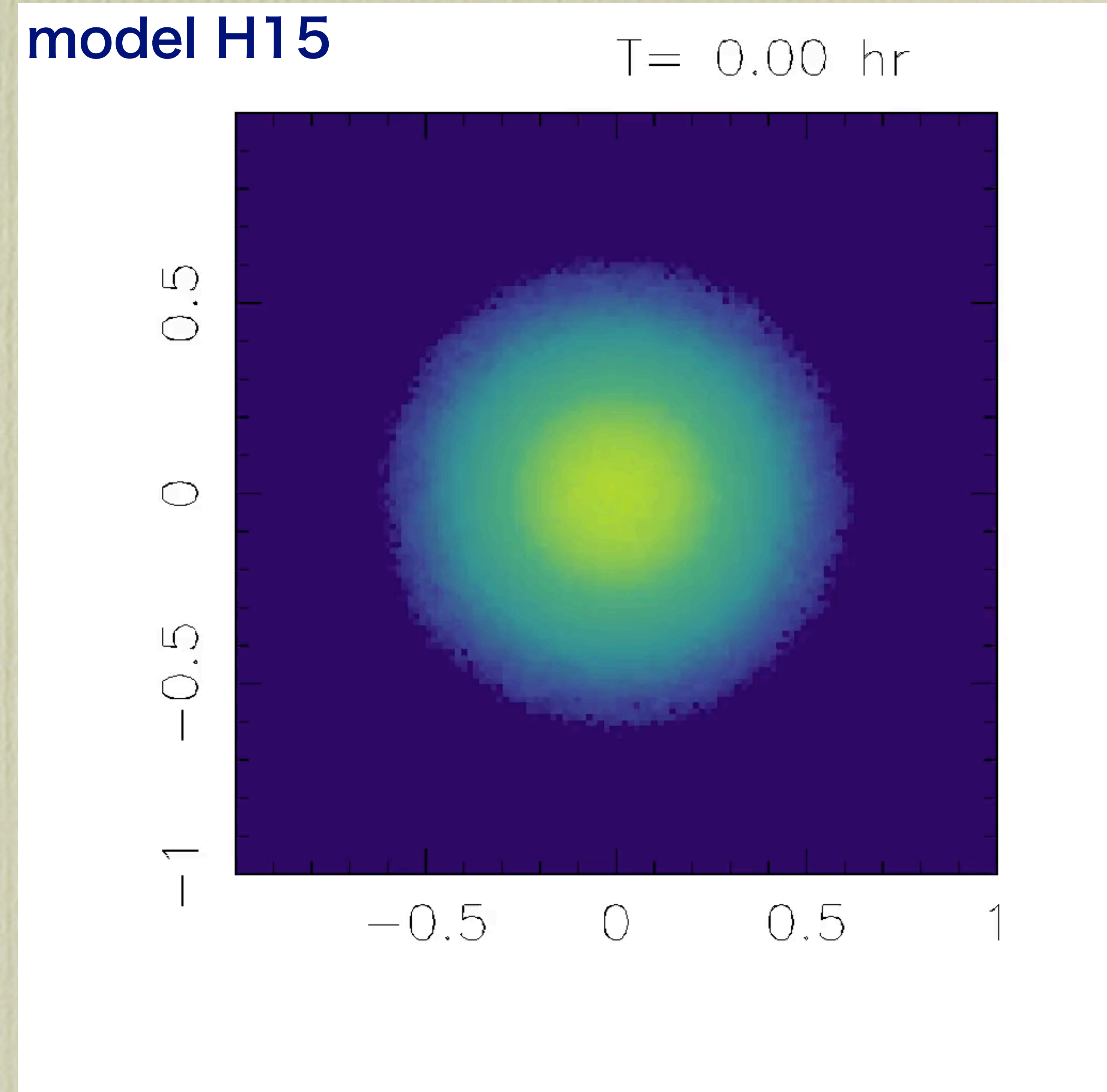


Impact of ejecta with a companion star

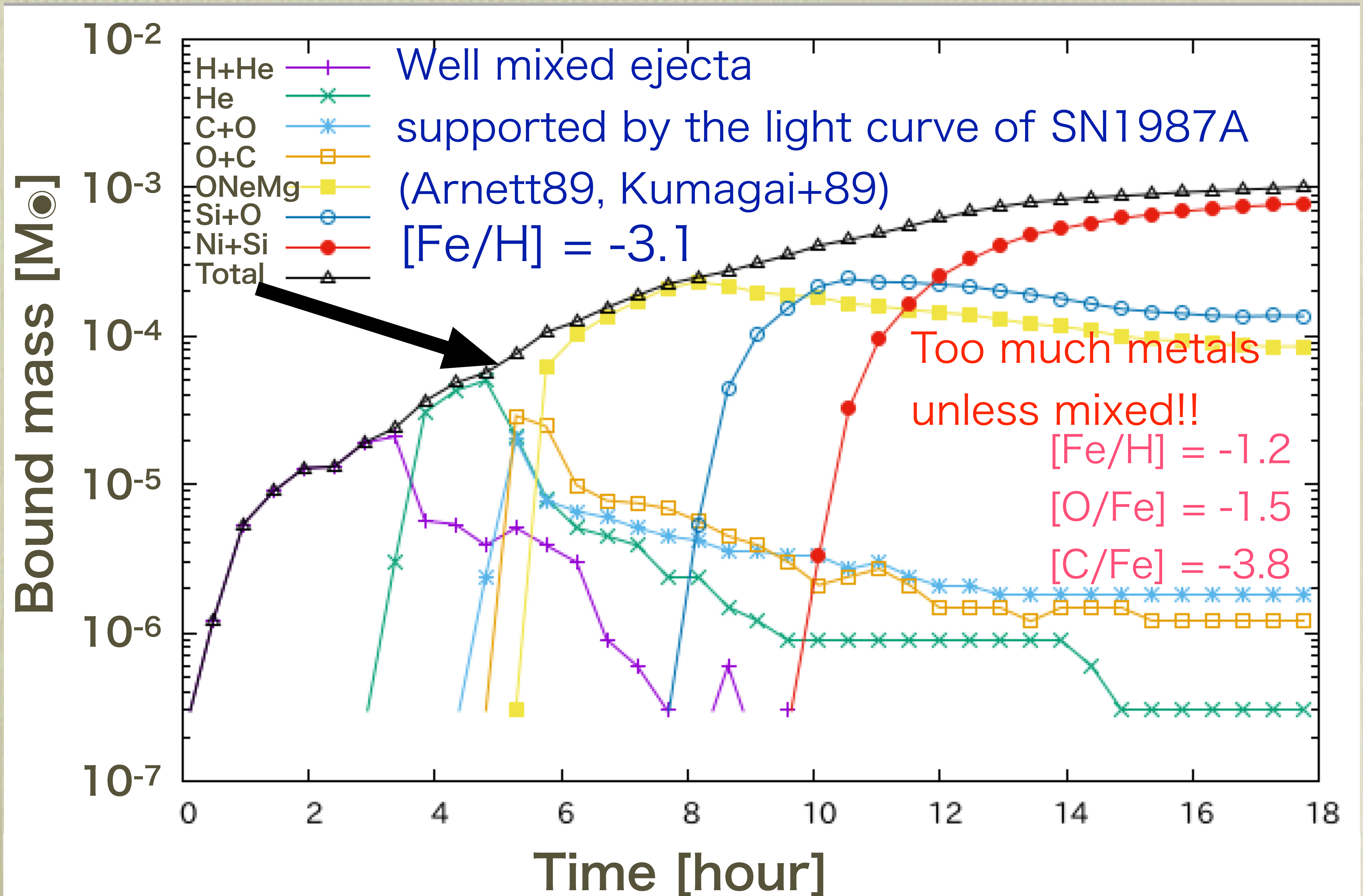
Particles w/ $E_{kin} + E_{grav} < 0$ are considered to accrete.

Colored ejecta particles

- H+He
- He
- C+O
- O+C
- O+Ne+Mg
- Si+O
- Ni(Fe)+Si



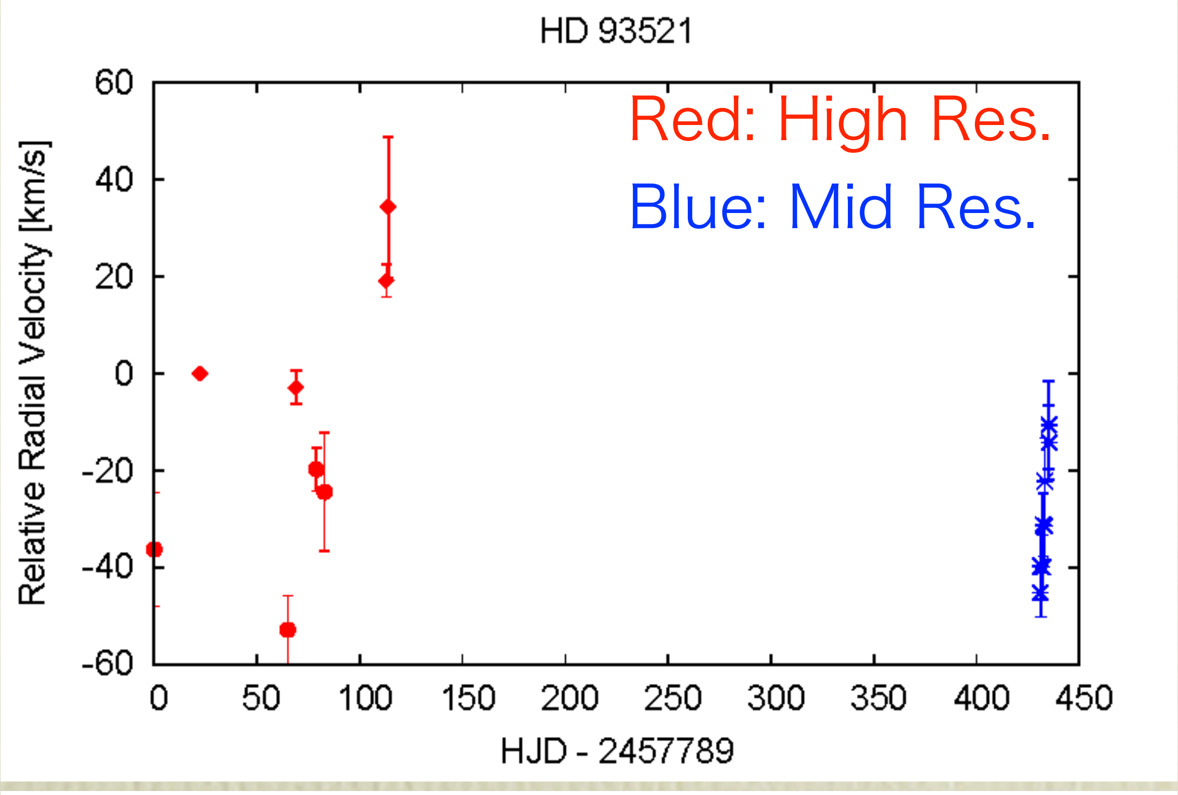
Accreted mass and composition

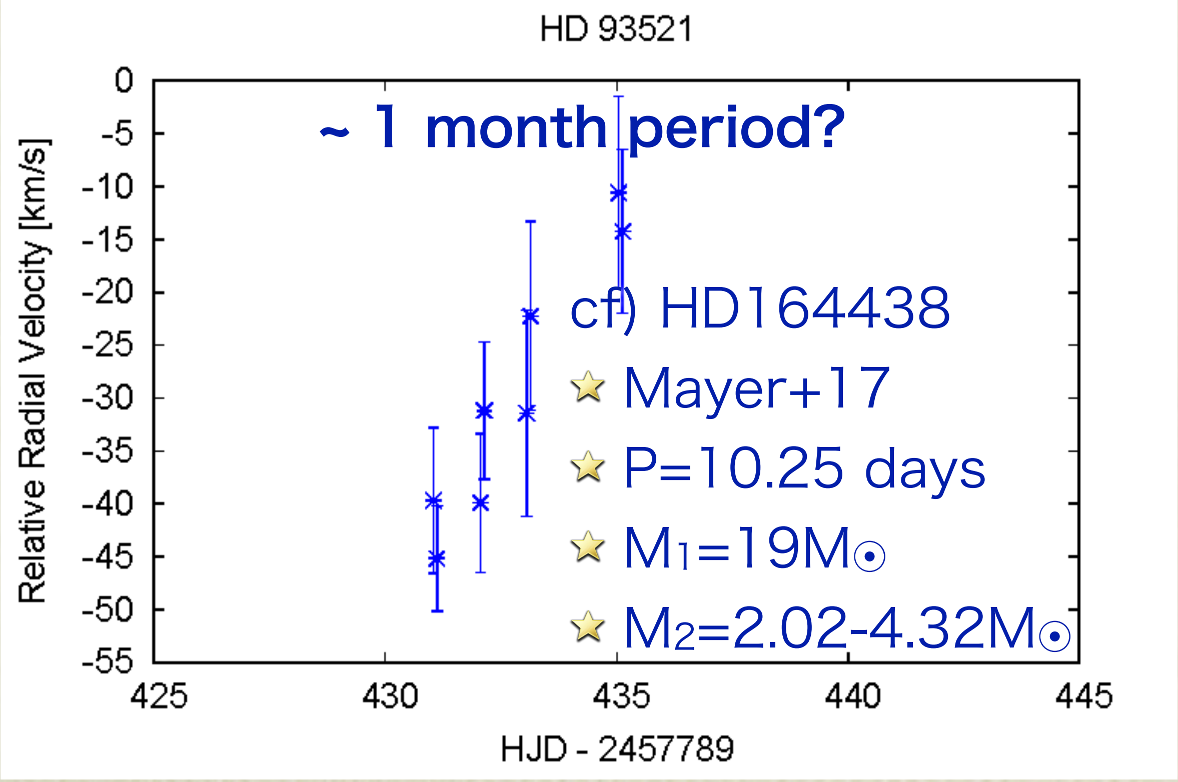


Observational Counterparts

- Massive Pop. III stars cannot survive until today.
  - Observational counterparts in nearby OB stars
- Radial velocity monitoring
  - MALLS on Nayuta telescope (Mid Res.)
    - 24 nights (16B-18B)
  - HIDES on Okayama (High Res.)
    - 17A: 6 nights
  - GAOES on Gunma Obs. (High Res.)
    - 2016/11/12-2017/2/4: 7 nights
- Target: Massive (+Low-mass) stars
  - OB stars from spectroscopic catalog (Skiff, 2009-2016) [64112 stars]
  - Exclude double-lined, eclipse, and visual binaries from >20 references [62940]
- Spectroscopic SB1 [62]
- brighter than 8 mag. [24]
- Dec. > -25° [14] -> 10 stars

Moritani, TS+ 2018, Stars and Galaxies, vol. 1



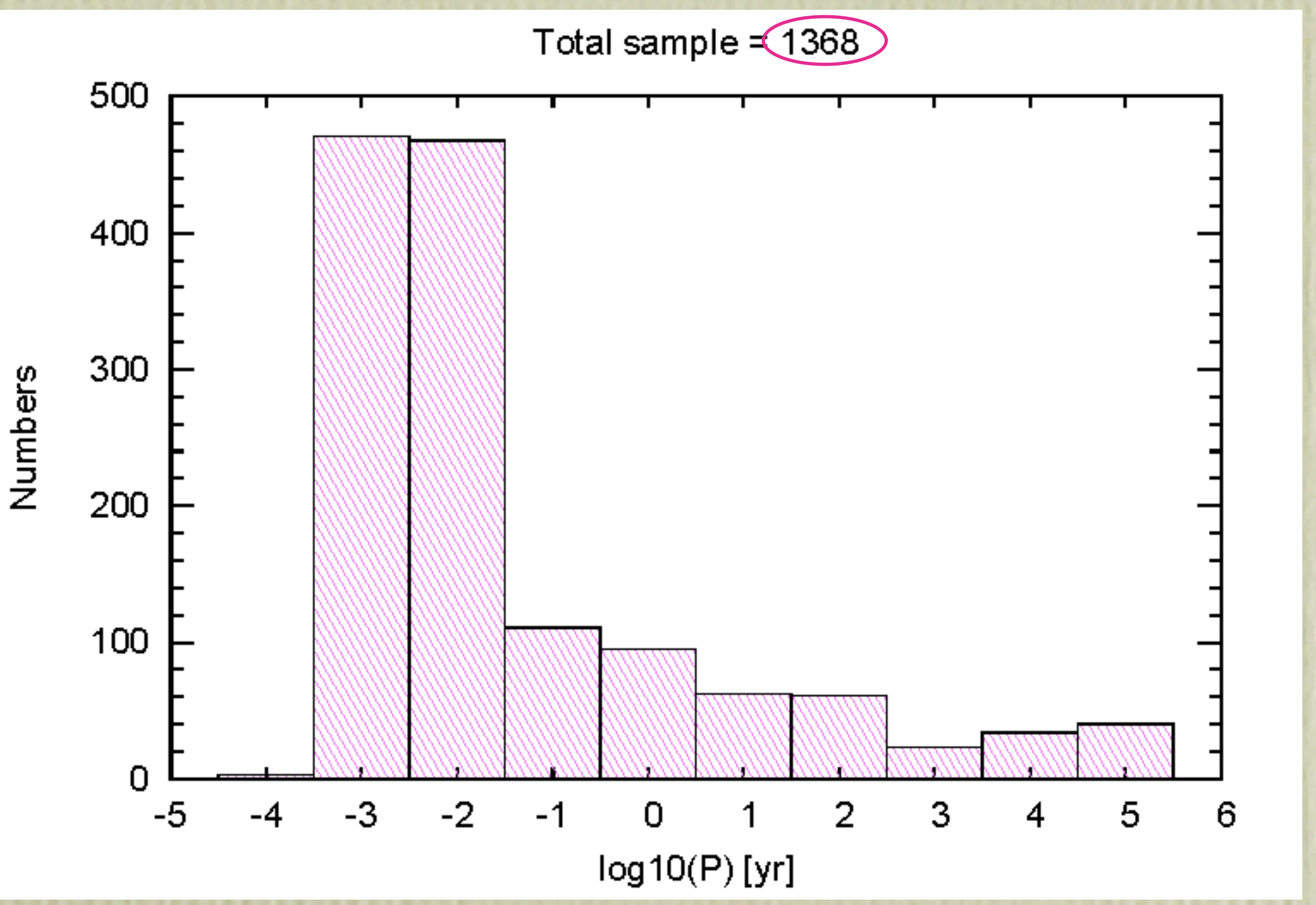


OB star binaries in literature

(excluding X-ray binaries)

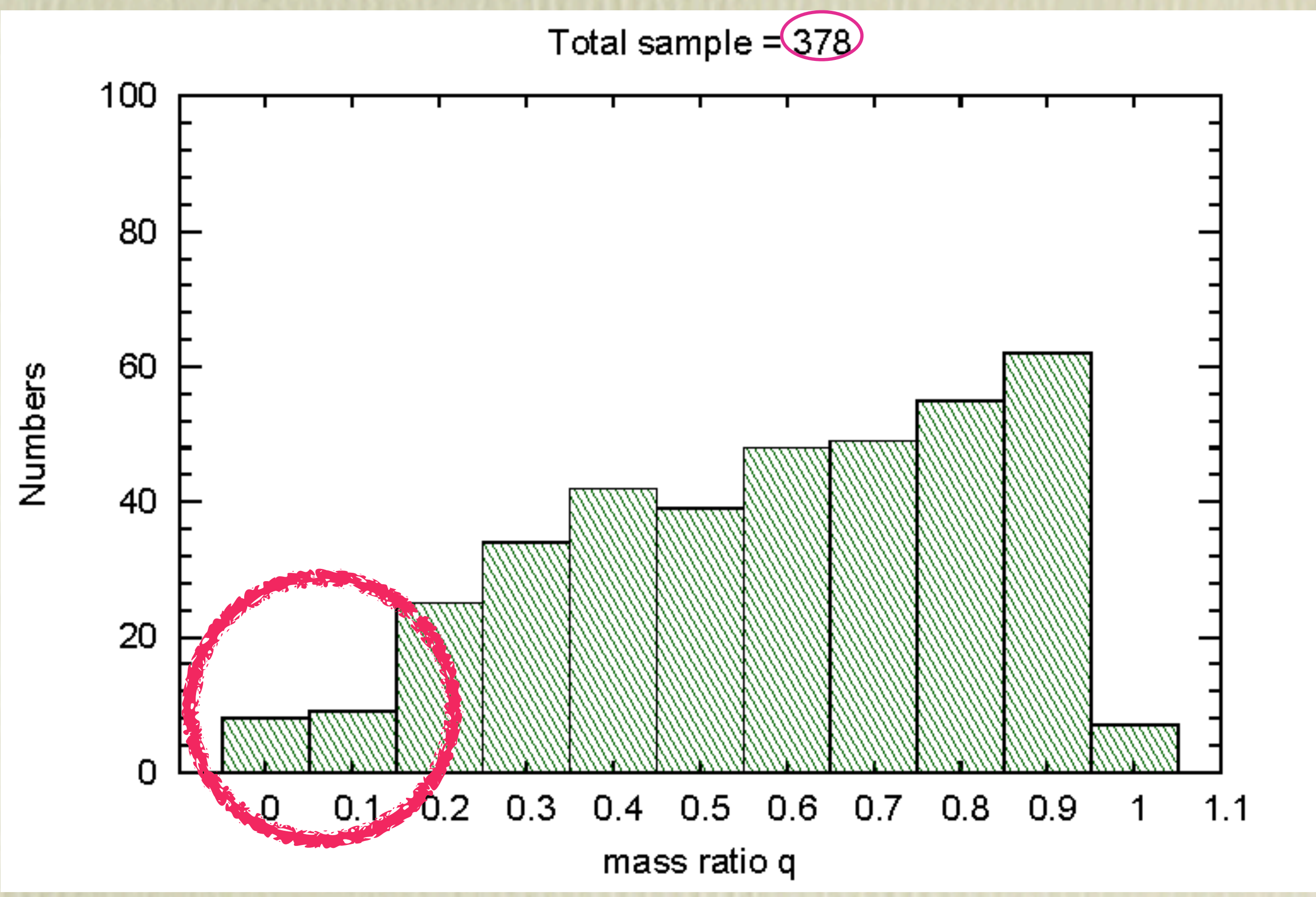
Observational counterparts in solar neighborhood

Orbital periods



* multiple systems are counted separately.

Mass ratios



* Most of them are derived in eclipsing or spectroscopic binaries.

Discussion and Summary

- We have added another scenario to explain the origins of known extremely metal-poor stars, e.g., supernova binary scenario.
- Lithium abundance might be indicators of Pop. III binaries consisting of massive + low-mass stars.
- Close binaries (~0.1 au) are likely to change the surface abundances (by stripping or accretion)
  - Li-normal hyper metal-poor stars
    - SMSS J0313, SDSS J0023, etc.
  - Li-depleted ultra metal-poor stars
    - SDSS J1029, etc.
- Binaries with large mass ratios should exist in the vicinity.
  - Connection with binary formation and gravitational waves
- Other topics: n-capture elements, triple system, CEMP, etc.