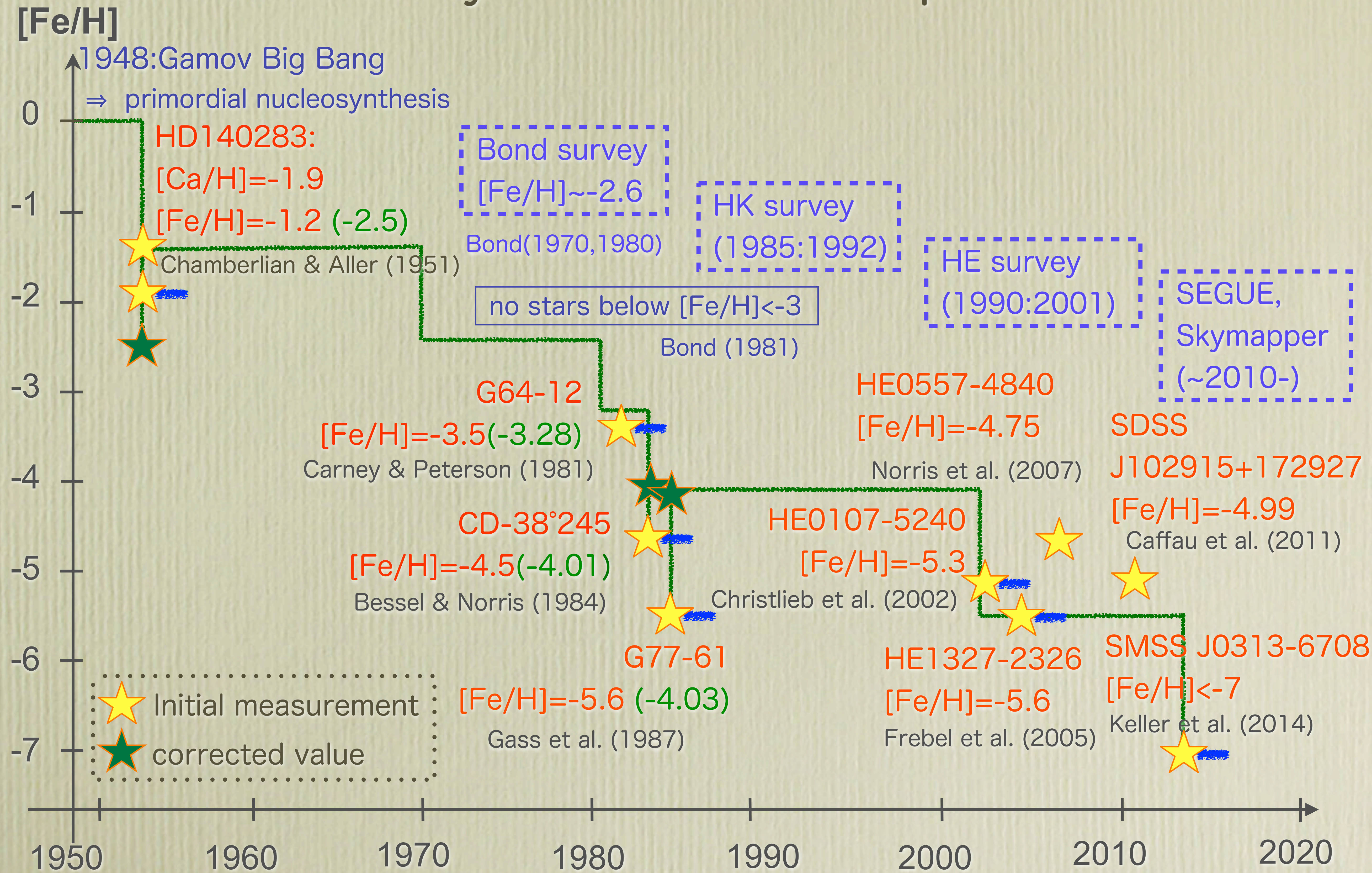
Core-collapses supernova explosions in binary systems as a probe into Pop. III stars

Takuma Suda（RESCEU, U-Tokyo）

Collaborators:
Takayuki Saitoh (Kobe U)
Yuuki Moritani (Kavli IPMU, U-Tokyo)
Toshikazu Shigeyama (RESCEU, U-Tokyo)

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.

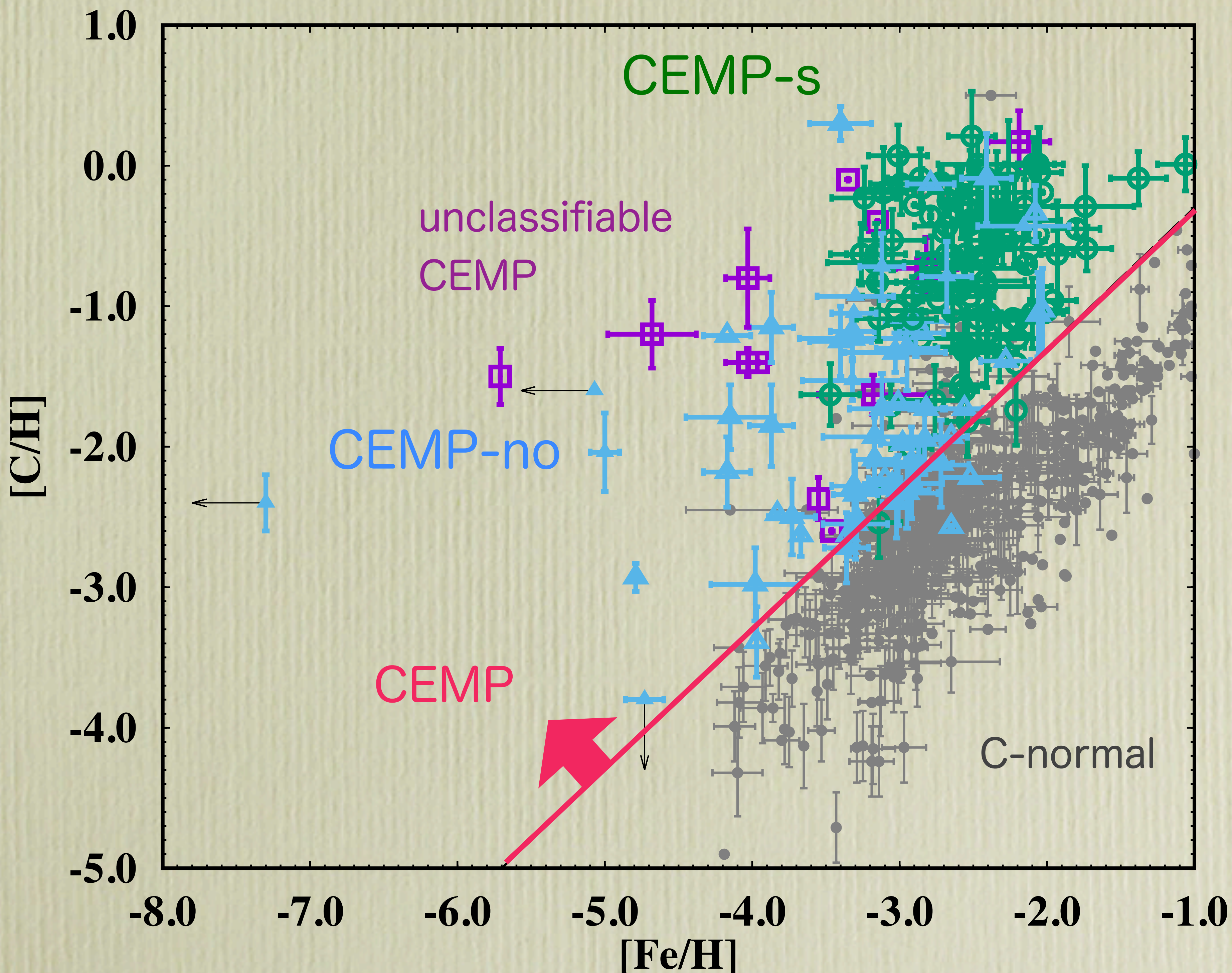
History of Search for Pop. III



Origin of Extremely Metal-Poor (EMP) Stars

☆Carbon-Enhanced Metal-Poor (CEMP) stars

☆> 20 % for [Fe/H] < -2 with [C/Fe] ≧ 0.7



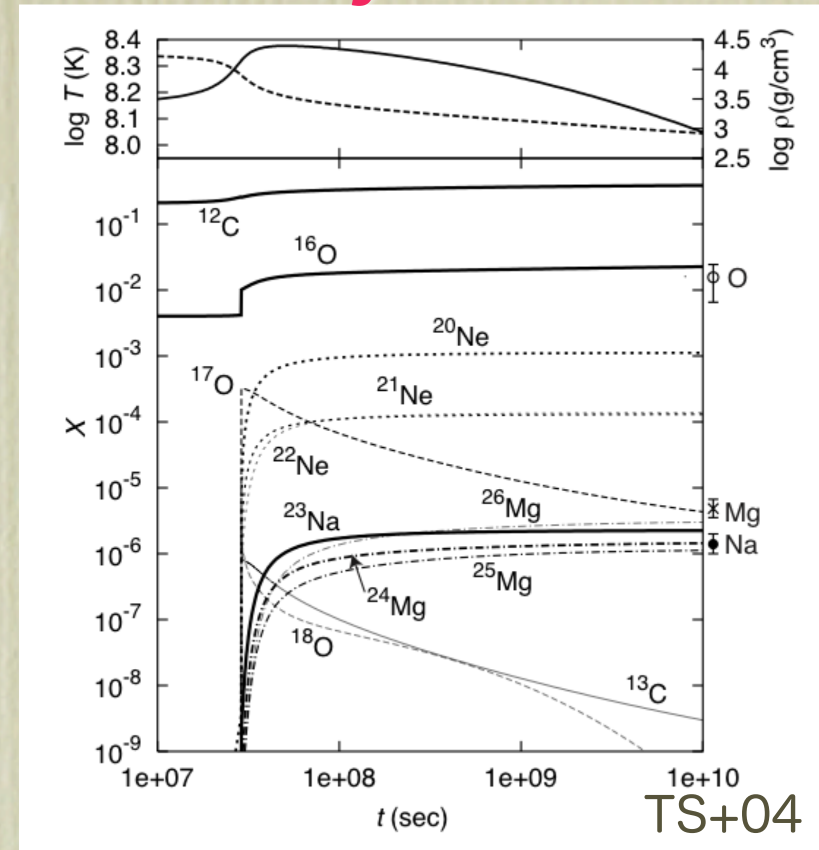
See also discussions by Aoki+07, Bonifacio+15, Yoon+16, Matsuno+17, etc.

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

Proposed Scenarios for the Origins of CEMP Stars

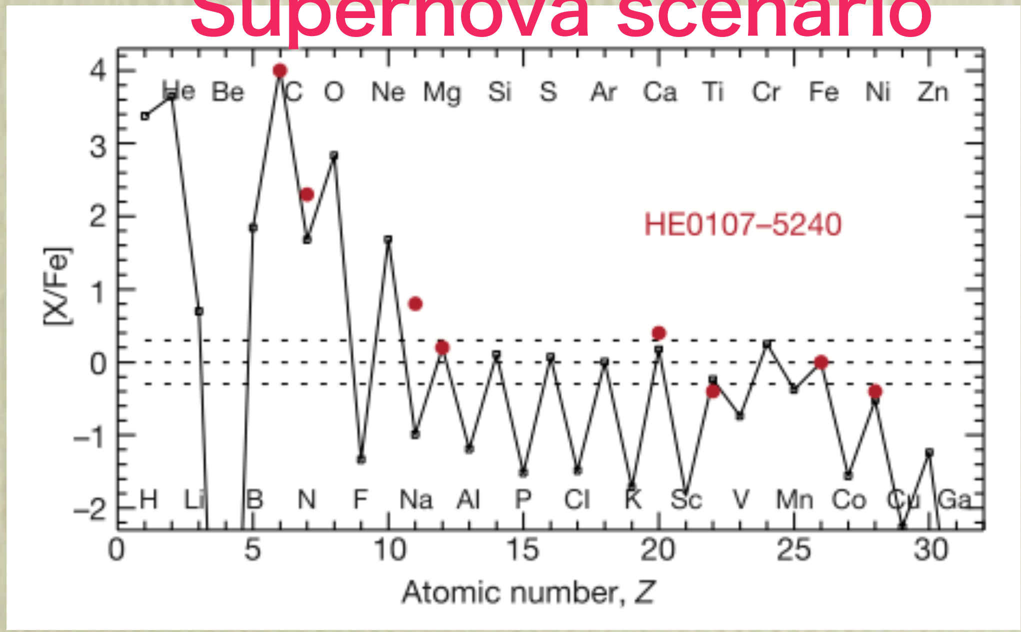
- Origin of EMP stars
  - Star formation from the gas influenced by SNe.
- Origin of CEMP stars
  - **Binary**: Mass transfer from AGB stars in binary systems (TS+04)
    - CEMP-s stars are thought to belong to binary systems (Lucatello+05).
  - **Supernova**: Star formation from gas affected by peculiar supernovae in the earliest generation of massive stars (Umeda+03, Limongi+04)
    - Abundance patterns are well reproduced by mixing and fallback models.
  - **Rotating stars**: Star formation affected by massive fast-rotating stars (Meynet+06)
    - Abundance patterns are well reproduced by rotational mixing.

Binary scenario



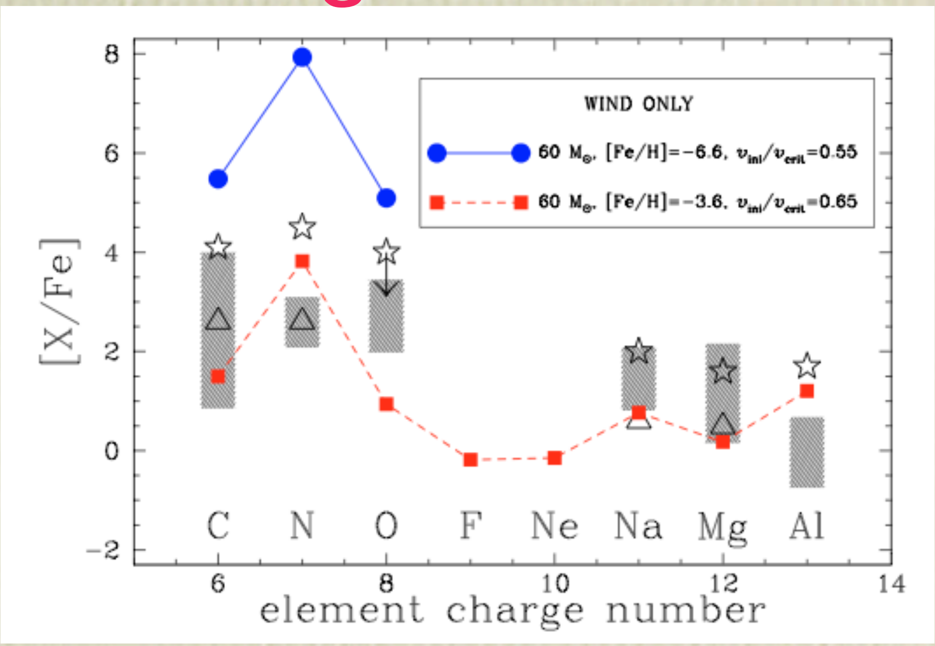
TS+04

Supernova scenario



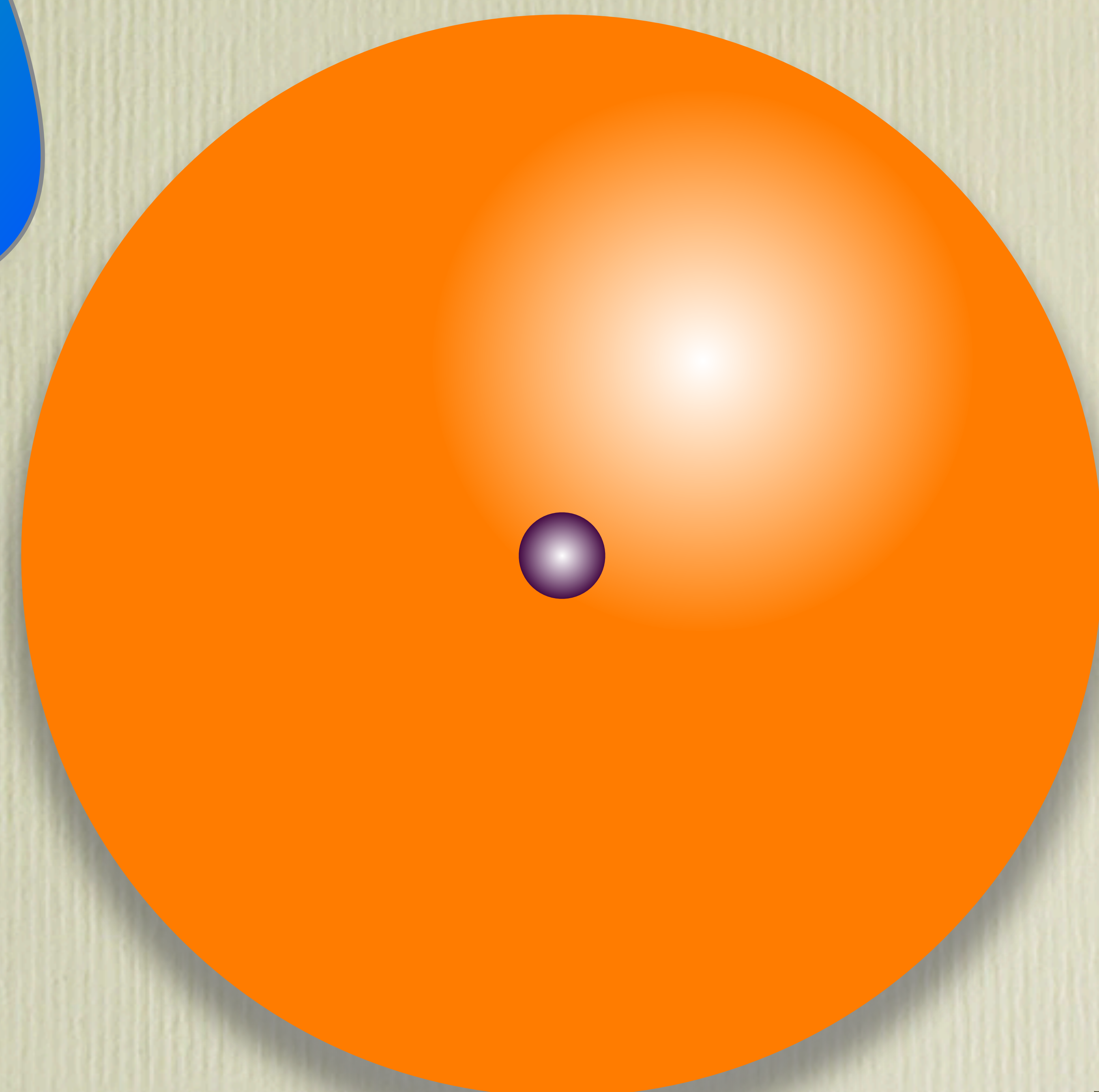
Umeda+Nomoto03

Rotating star scenario



Meynet+06

Supernova binary scenario



- ⭐ 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).

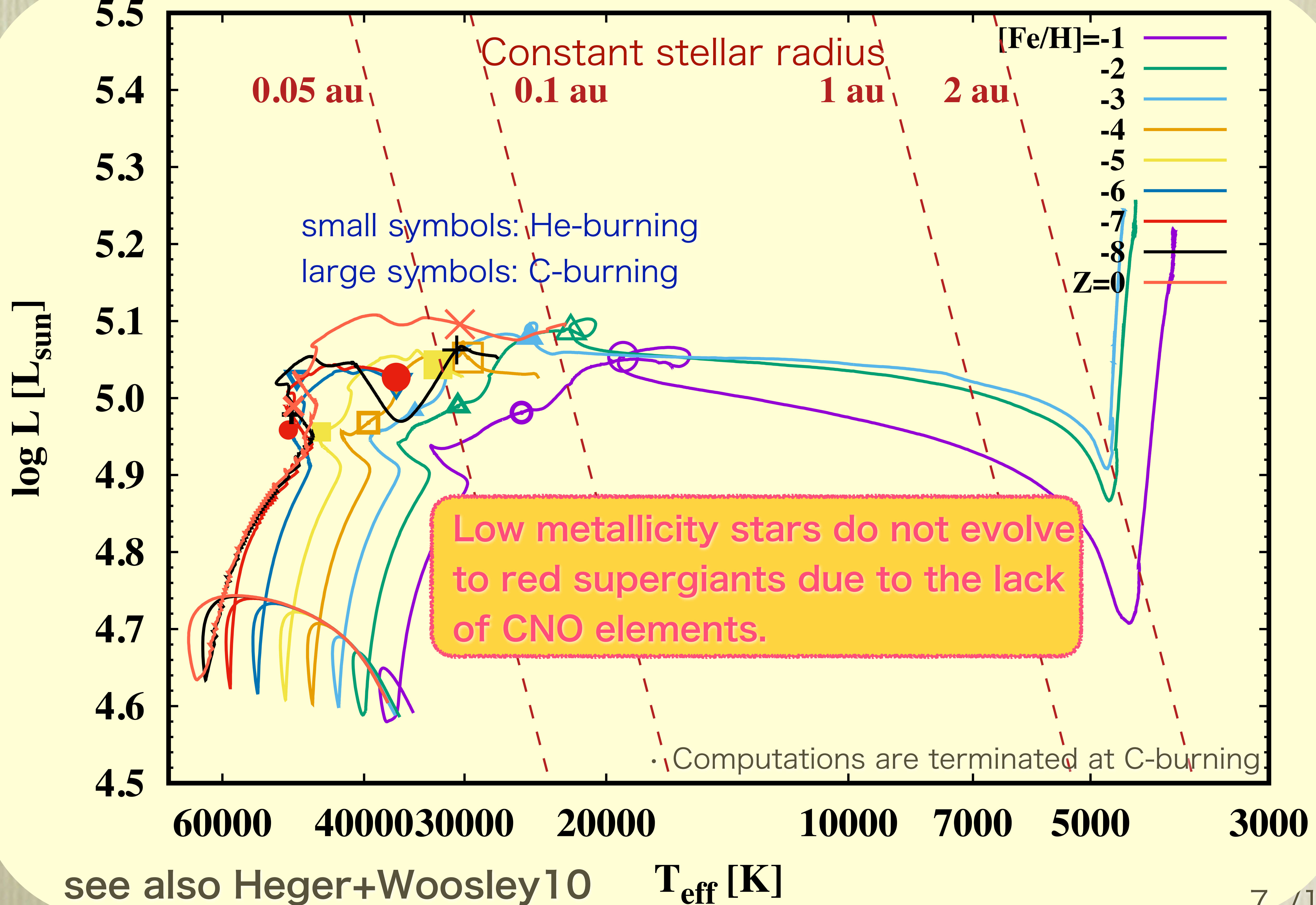
Simulations of SN binary scenario

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

- Binary system: 20 $M_\odot$ + 0.8 $M_\odot$
- Separation : ~0.05 au (~10 $R_\odot$) or ~0.1 au (~20 $R_\odot$)
- Num. of particles: ejecta: ~16M, companion: ~1M

- Previous studies on the stripping by the collisions of supernova ejecta
  - Ia: Marietta+00: PPM
  - Ia: Pakmor+08: GADGET
  - Ia: Pan+12: FLASH
  - II: Hirai+14: yamazakura, massive + massive
  - Ibc: Rimoldi+16: Gadget-2

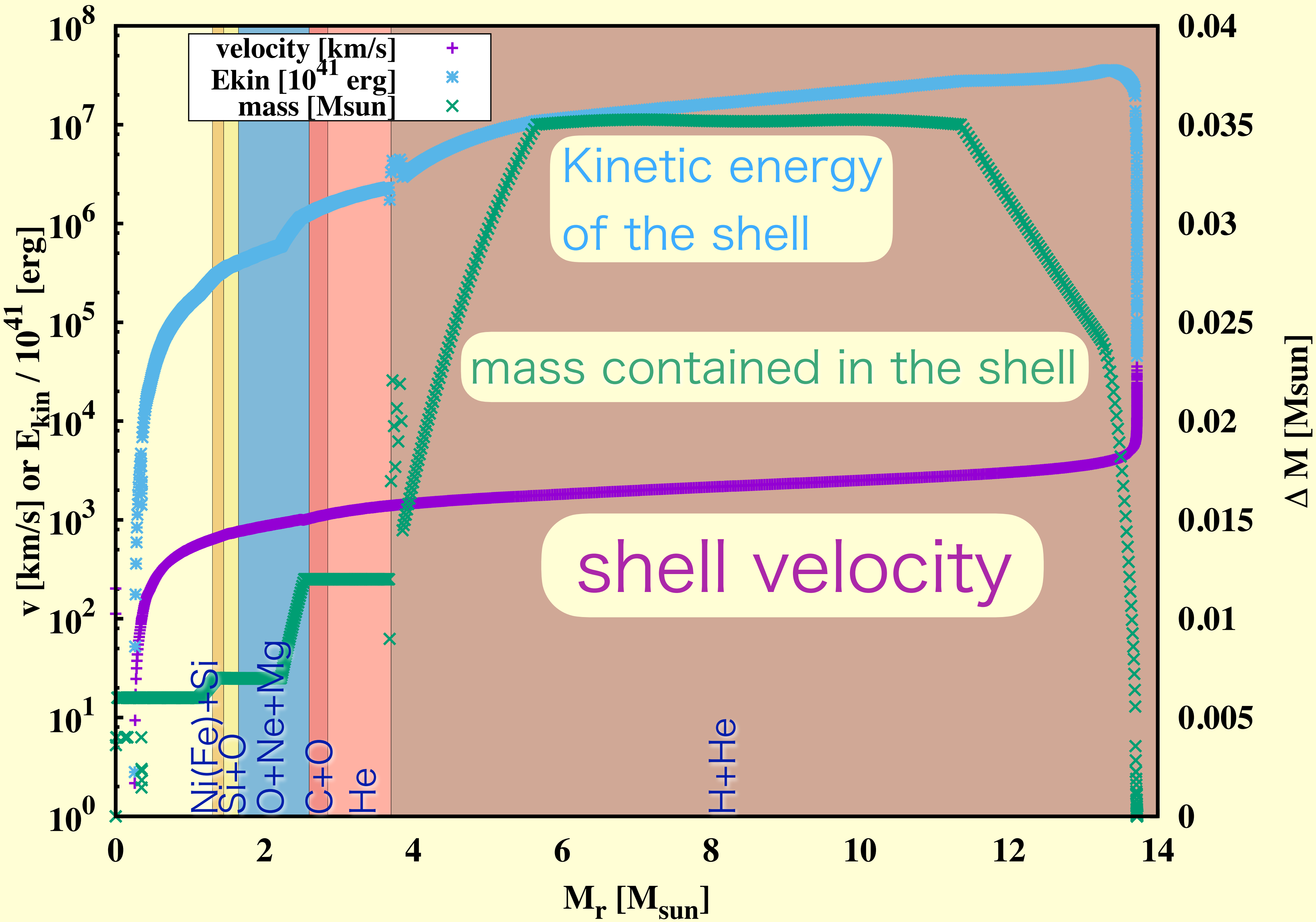
Evolution of 20 M⊙ Stars



see also Heger+Woosley10

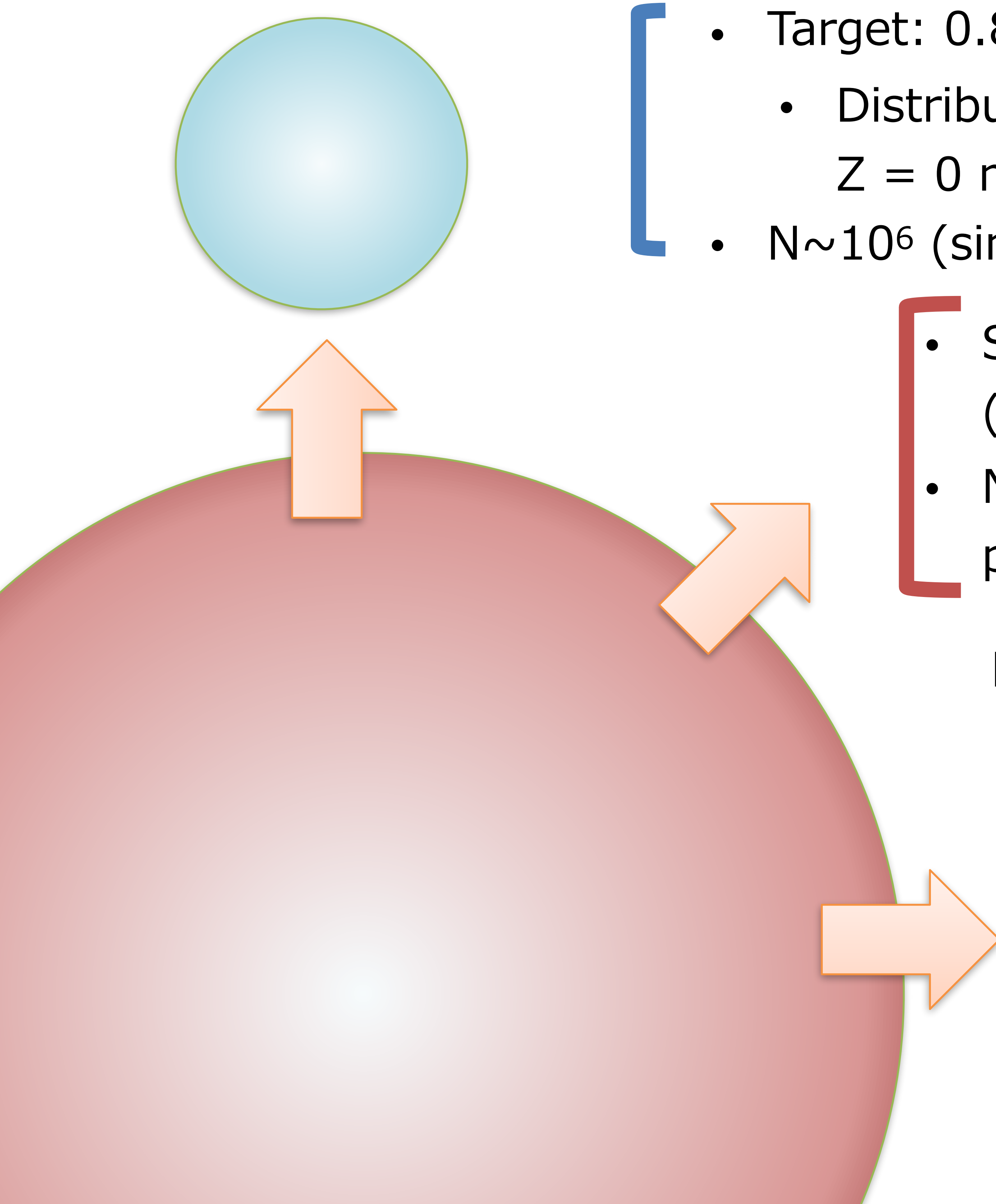
SN ejecta of H15[_2] models

Shigeyama+90 prescription based on Heger+10 models



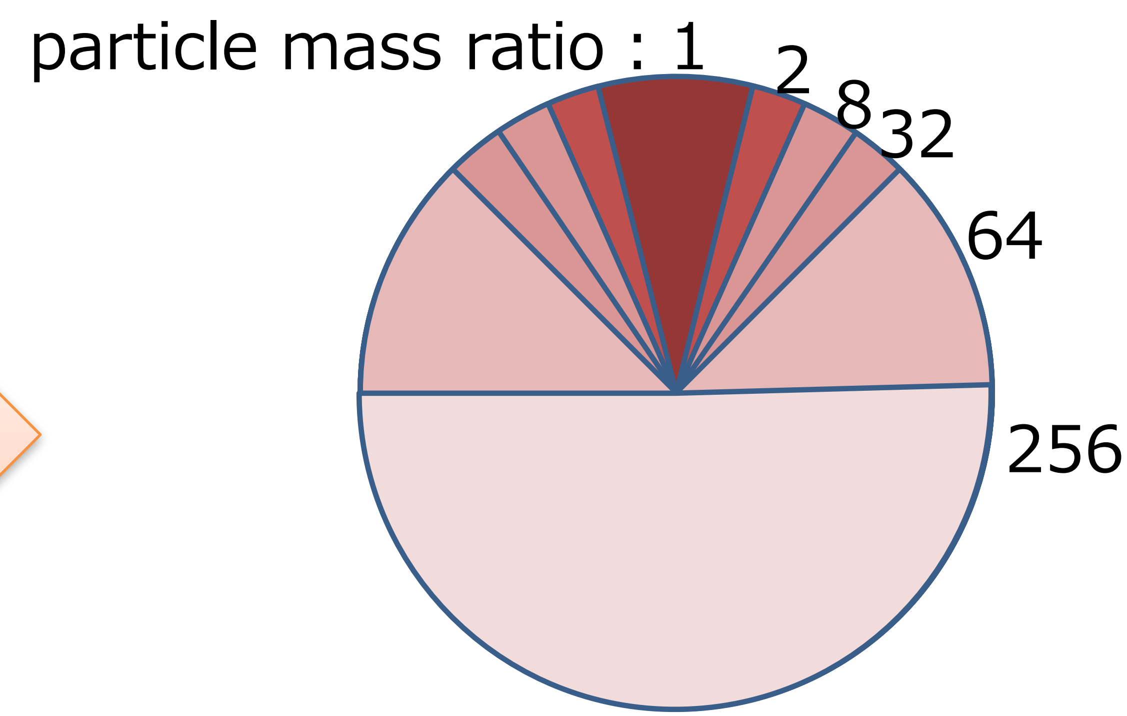
Configuration with ASURA code

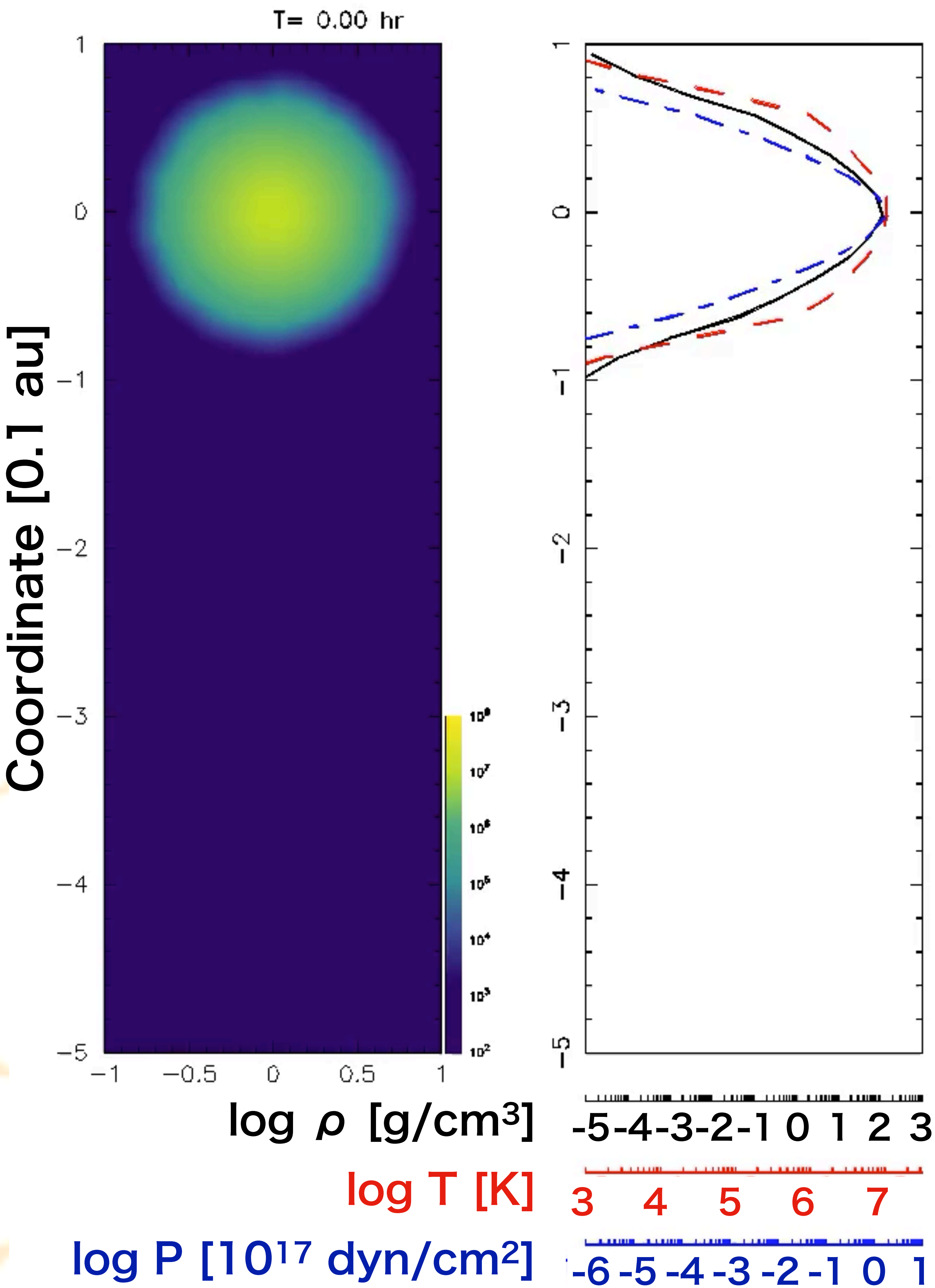
Saitoh+08



- 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 & Woosley (2010) (15,20,25 $M_\odot$)
- N~7x10^6 (reduced the number of particles for offset collision)



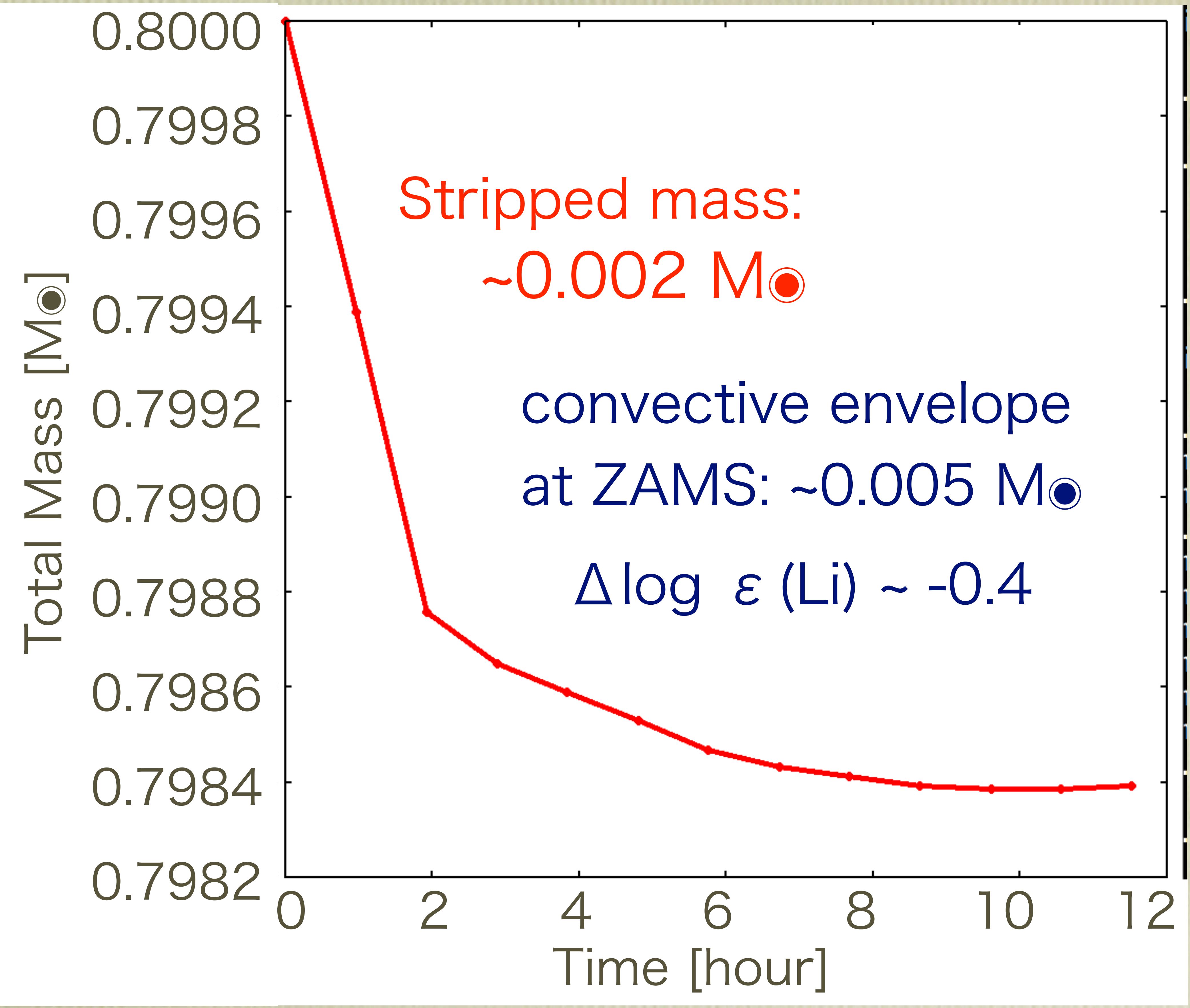


Simulation Result

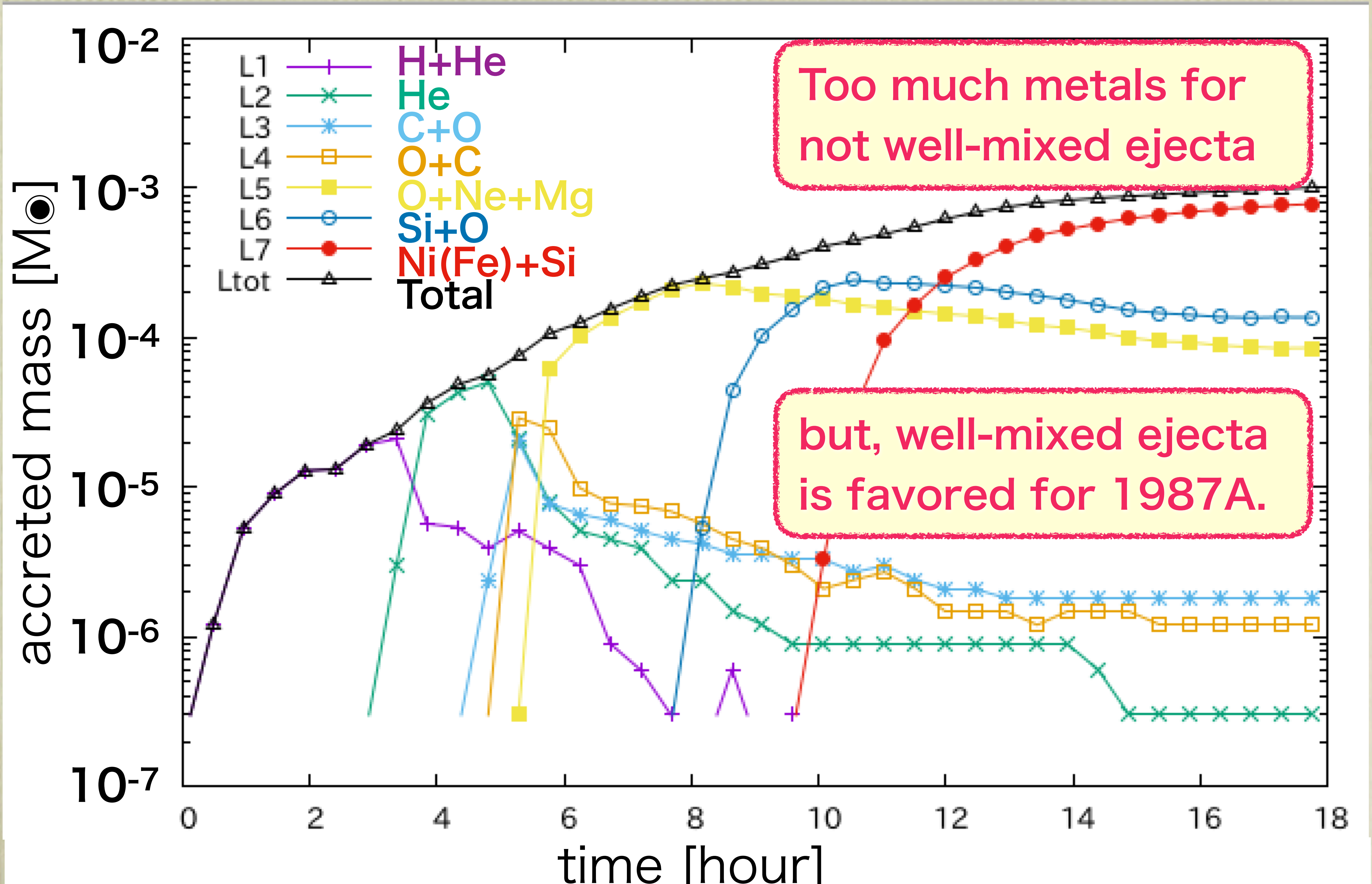
- $M_1 = 15M_\odot$ 主星質量
- $M_2 = 0.8M_\odot$ 伴星質量
- $a = 0.1$ au 連星間距離
- $t = 0$-20 hours 計算時刻

Density
Temperature
Pressure

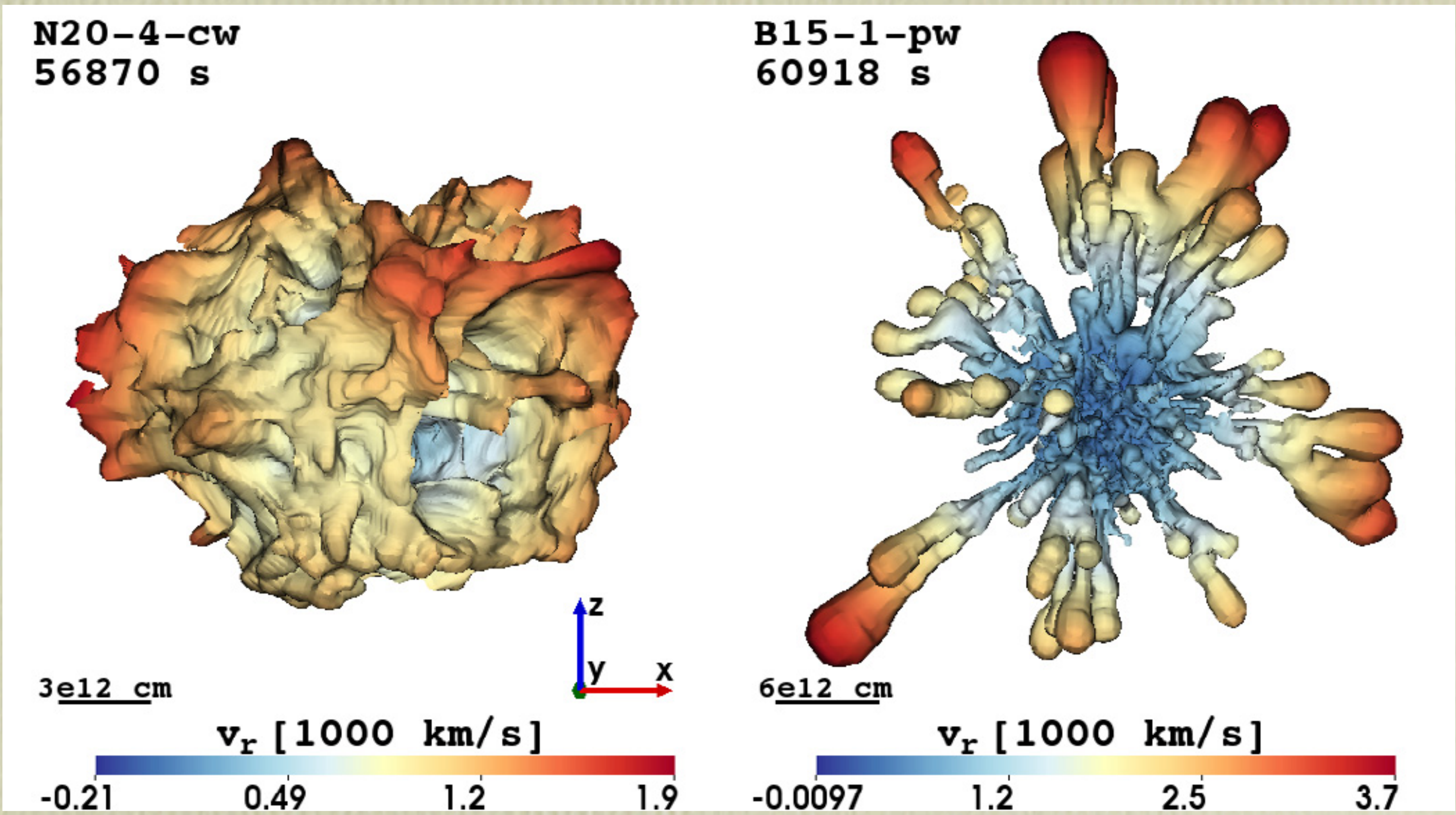
Stripped mass for the H15_2 model



Accretion of ejecta



Mixing of supernova ejecta

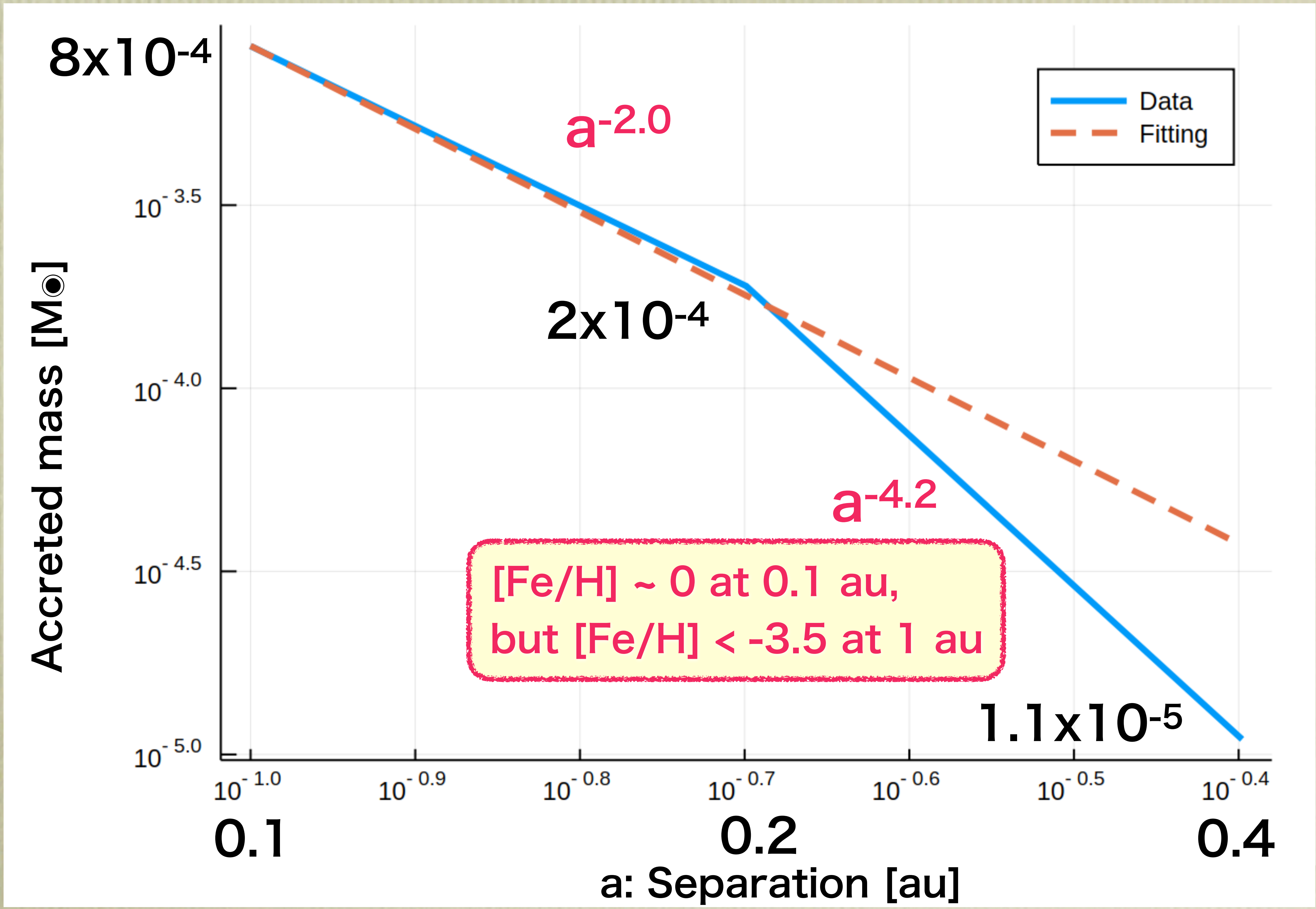


Wongwathanarat+15

Inhomogeneity and asymmetry develop during the explosion.

Preliminary result of

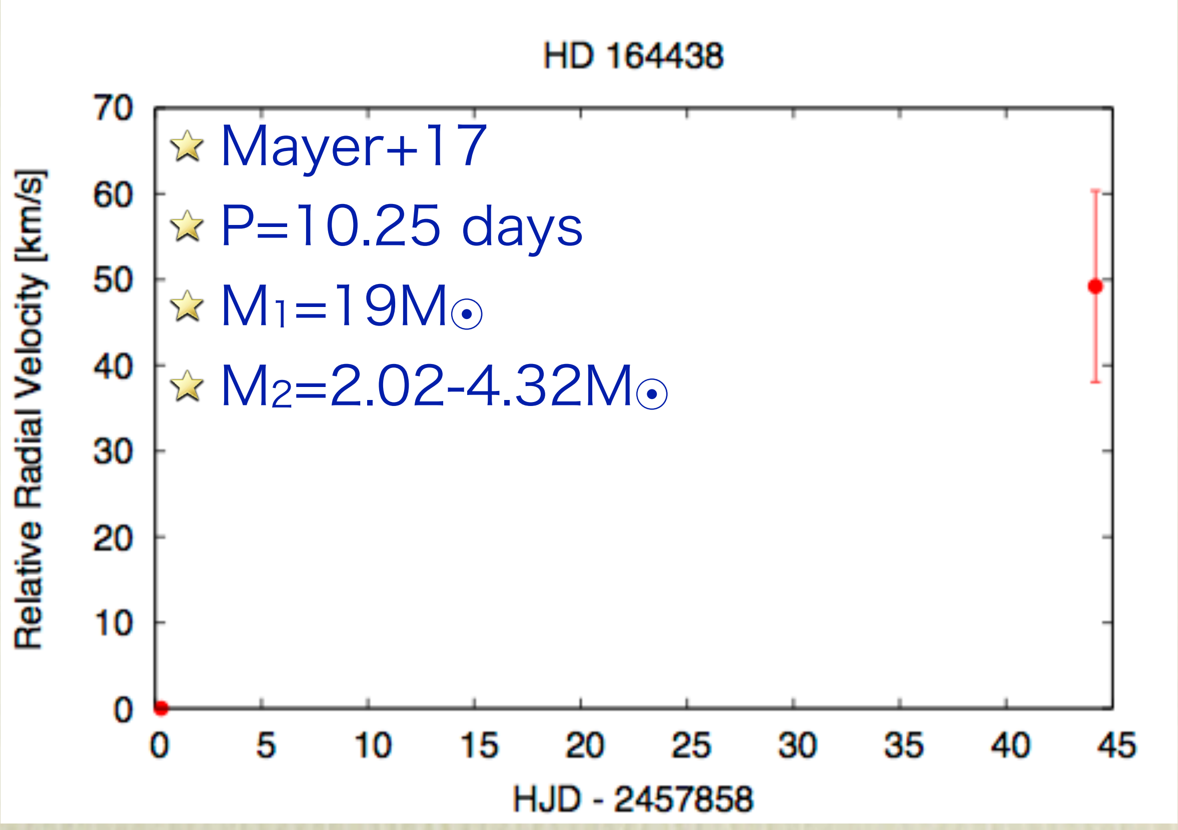
Dependence of accreted mass on separation

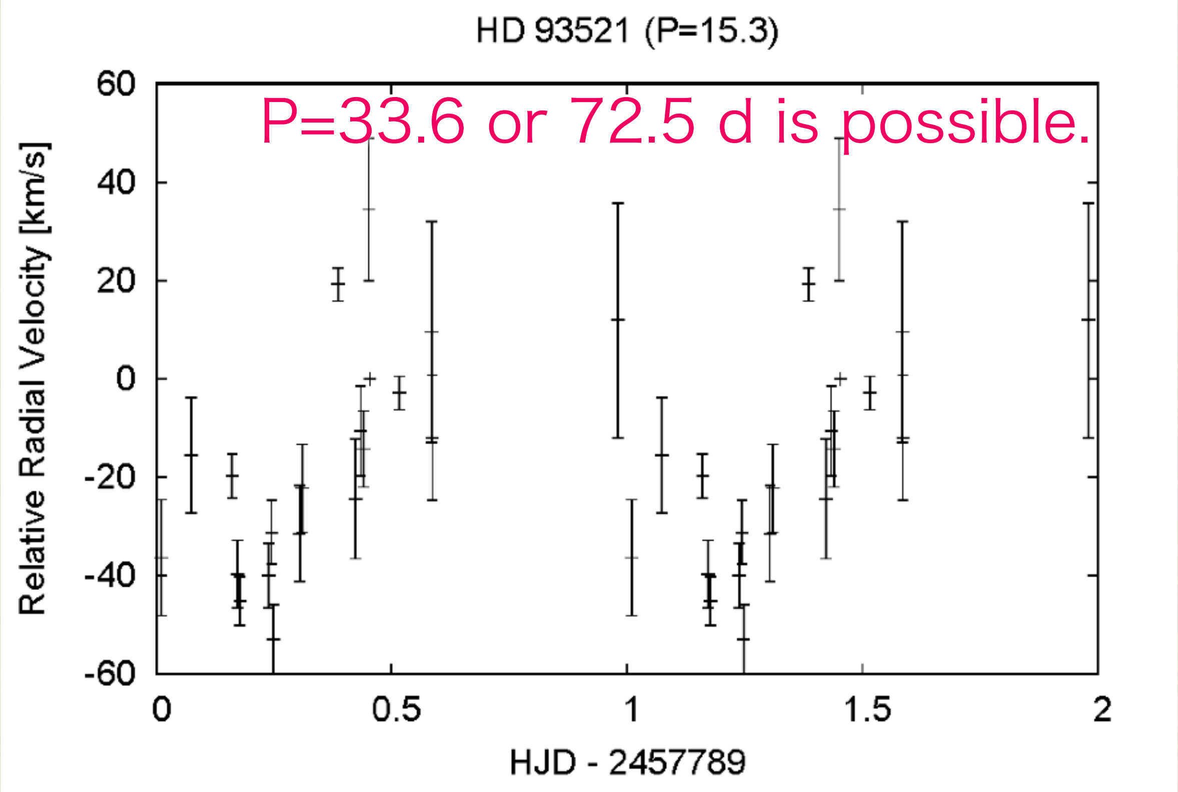


Observational Counterparts

- Massive Pop. III stars cannot survive until today.
  - Observational counterparts in nearby OB stars
- Radial velocity monitoring
  - MALLS on Nayuta telescope (Mid Res.)
    - 20 nights (16B-18B) + 3 nights (19A)
  - 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

preliminary results for radial velocities

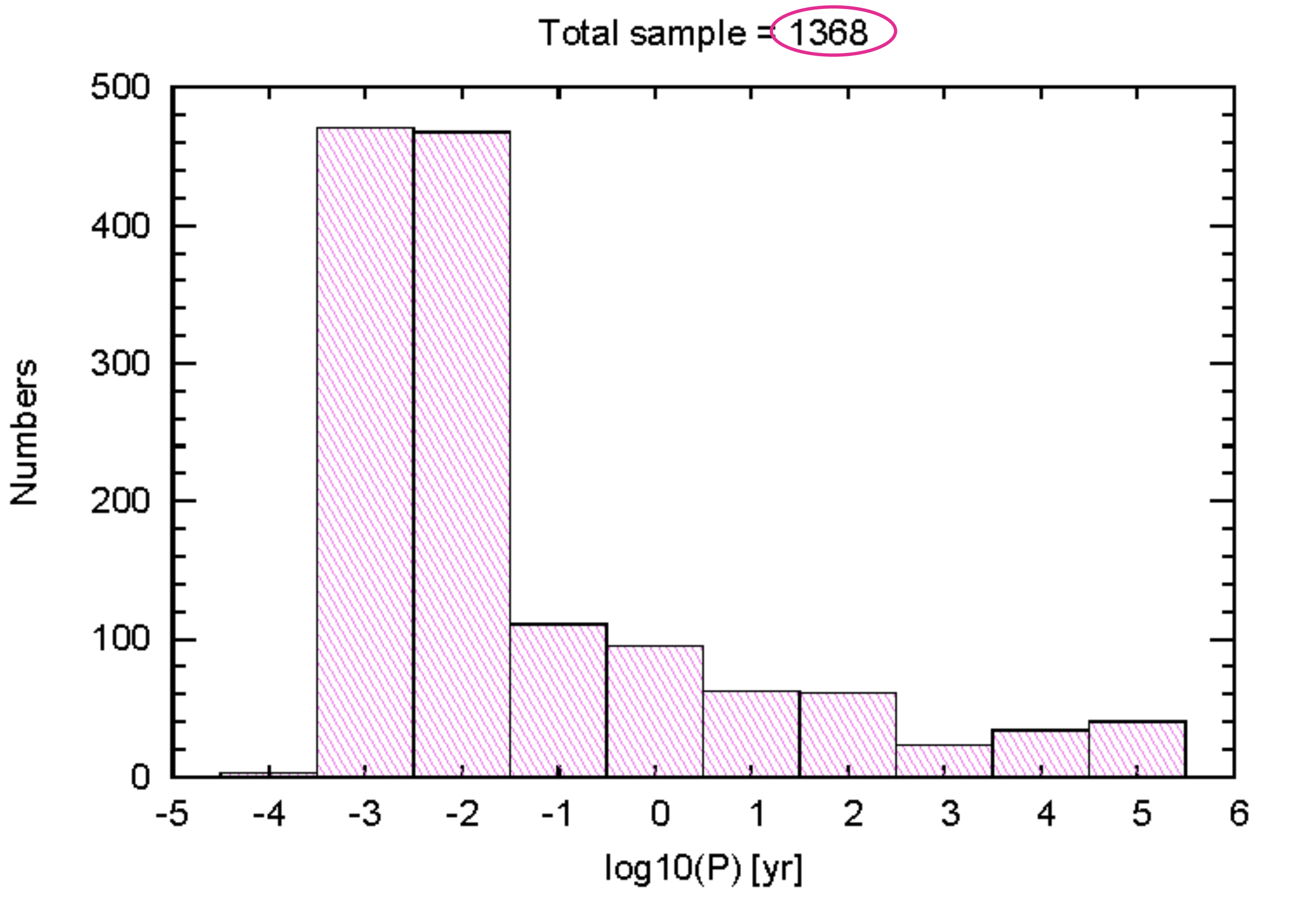




OB star binaries in literature
(excluding X-ray binaries)

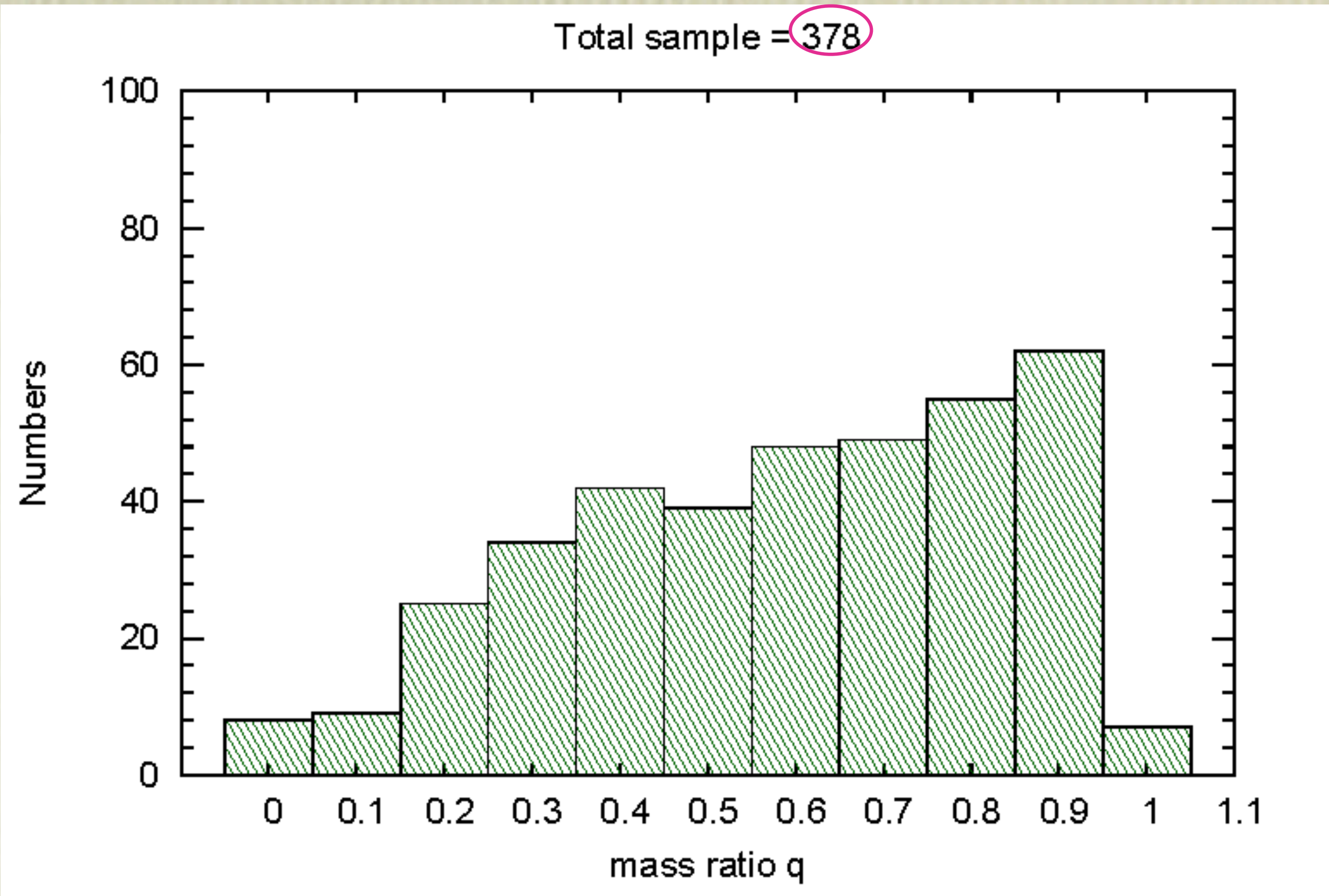
Observational counterparts in solar neighborhood

Orbital periods



* multiple systems are counted separately.

Mass ratios



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

Discussion and Summary

- This study adds another scenario for the origin of known extremely metal-poor (C-enhanced) stars.
  - combined scenarios with mixing & fallback or rotating massive stars?
- Accretion of ejecta is a key diagnosis for Pop. III binaries consisting of massive + low-mass stars.
  - Accretion of metals
  - Accretion of lithium (produced during SN)
- Binary separation of ~0.1 - 1 au is likely to change the surface abundances by stripping or accretion.
  - <u>Now computing the case for 0.8 au.</u>
- There should be observational counterparts of massive + low-mass star binaries in solar vicinity.
  - true for Pop. III case?