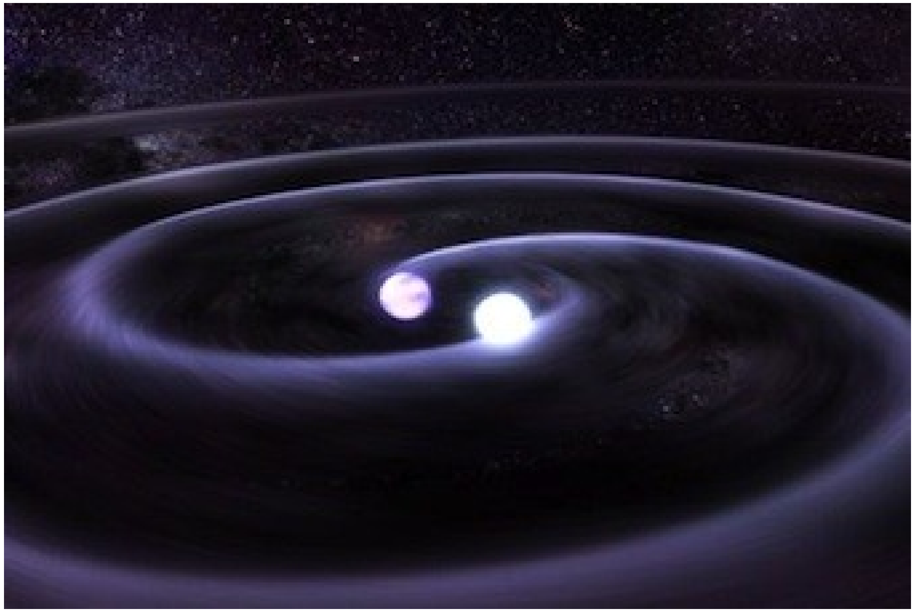
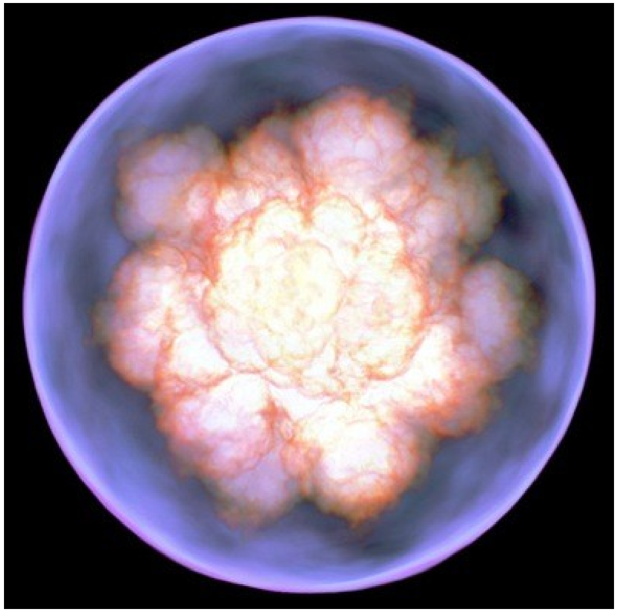
SPH simulation of double white dwarfs merger
for investigating progenitor models of SNe Ia

Yushi Sato(1), Naohito Nakasato(2), Ataru Tanikawa(3), Keiichi Maeda(4), Izumi Hachisu(1), Ken'ichi Nomoto(5)

(1)University of Tokyo, (2)University of Aizu, (3)RIKEN, (4)Kyoto University, (5)Kavli-IPMU





2014/7/8 @ RIKEN

Today's my talk is organized as ...

Introduction

↓

Methods

↓

Results

↓

Discussion

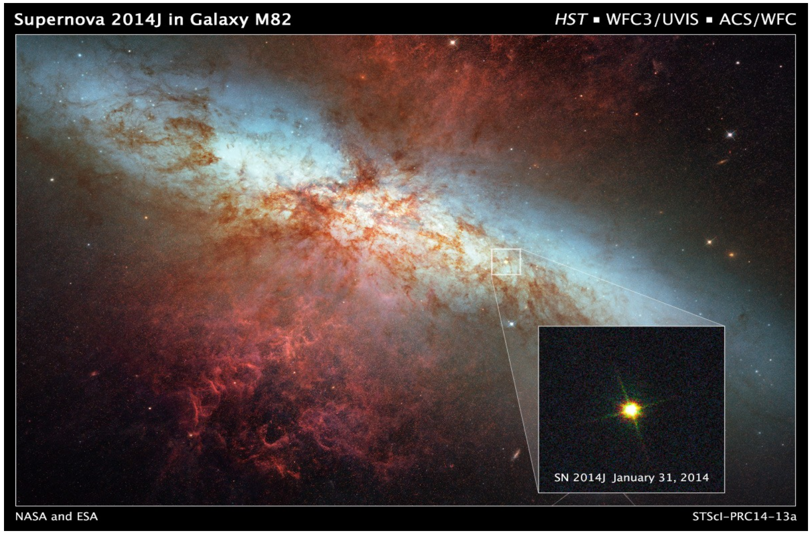
↓

Summary

Introduction

Type Ia Supernovae

- Explosion of WD in binary system
- Cosmological standard candle
- Major souces of iron group elements



SN 2014J

Image Credit: NASA, ESA, A. Goobar (Stockholm University), and the Hubble Heritage Team (STScI/AURA)

⇩

Very important for studying evolution of the Universe!

Models of progenitor

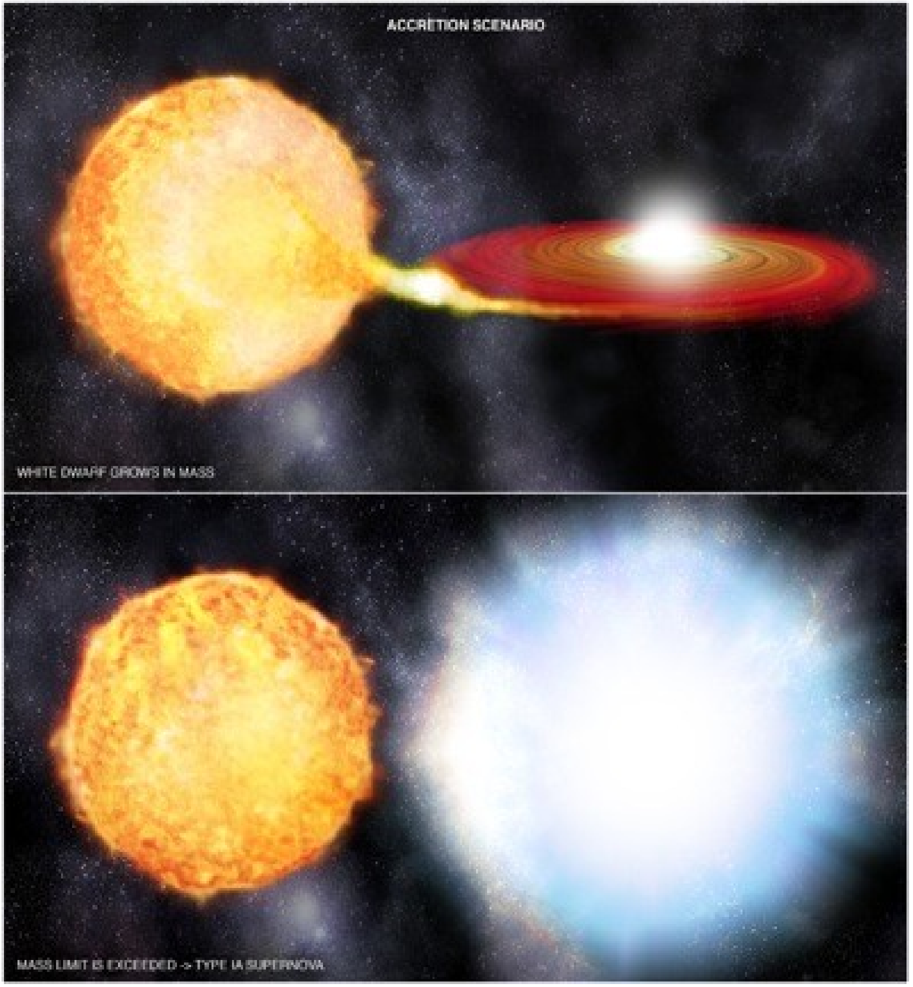


Illustration: NASA/CXC/M Weiss

or

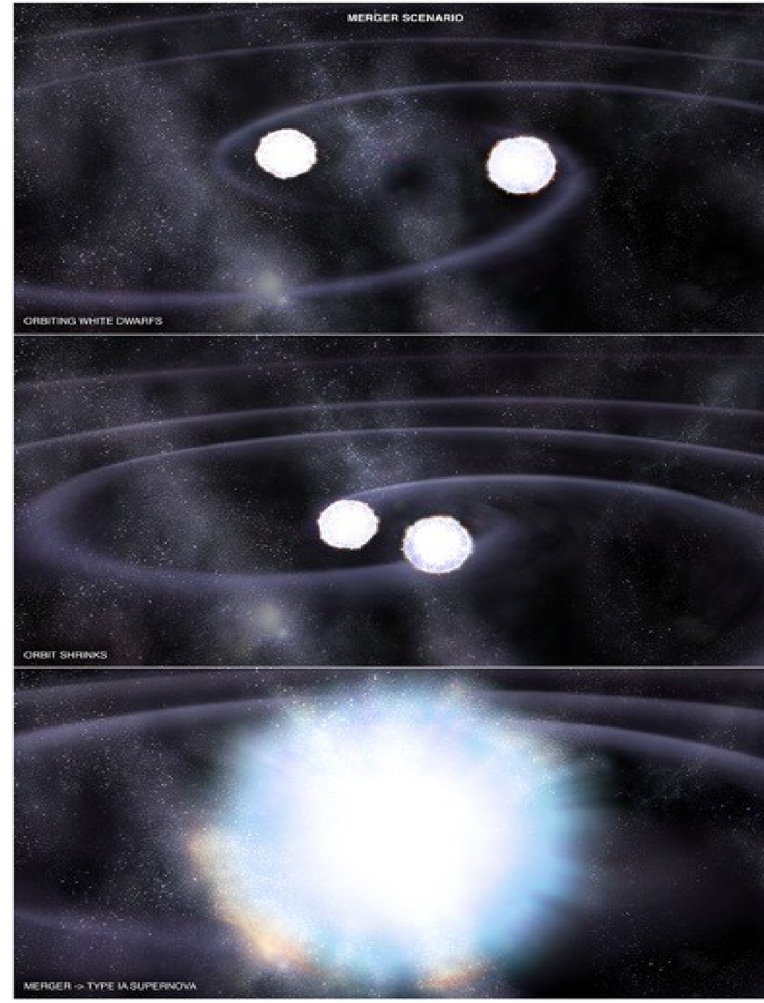


Illustration: NASA/CXC/M Weiss

Single Degenerate ?
(Whelan&Iben, 1973, ApJ, 186, 1007-1014)

Double Degenerate ?
(Webbink, 1984, ApJ, 277, 355-360)

Observational approaches

・Direct detection of companion before/after explosion
→ No certain detection (DD model)
(e.g. Schaefer&Pagnotta, 2012 Nature, 481, 164-166)

・Detection of interaction between ejecta and companion
→ No certain detection (DD model)
(e.g. Kasen, 2010, ApJ, 708, 1025-1031)

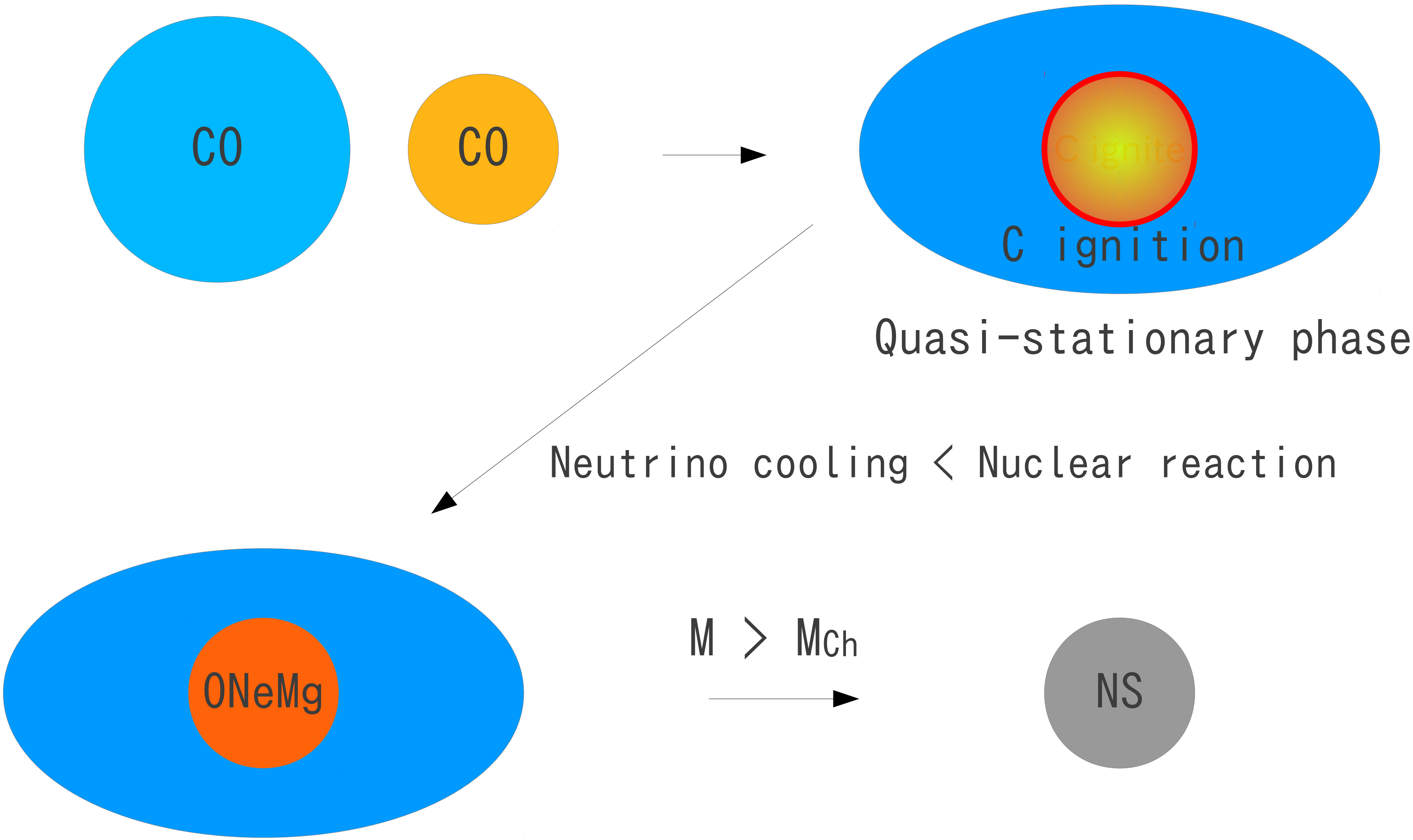
・Detection of signatures of CSM
→ Detected in some SNe Ia (SD model)
(e.g. Foley et al. 2012, ApJ, 752, 101)

⬇

Imply the contribution from both models

Accretion Induced Collapse

(e.g. Saio & Nomoto, 1985, A&A, 150, L21)



SPH simulation of WDs merger

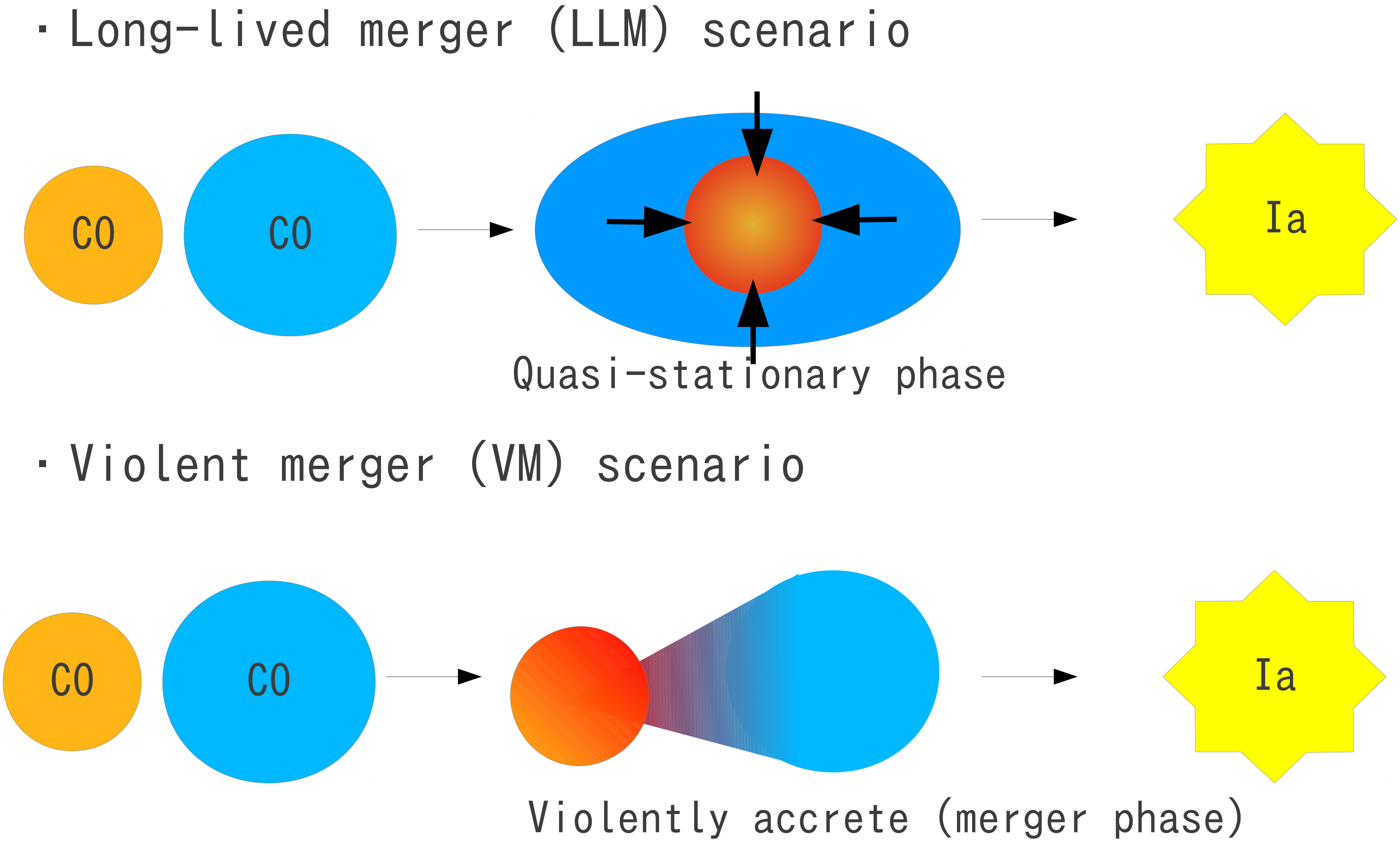
・e.g. Yoon et al. 2007, MNRAS, 380, 933-948
(0.9+0.6M_{sun}, 2×10^5)

Long-lived merger ··· explode **after** merger and accretion

・e.g. Pakmor et al. 2010, Nature, 463, 61-64
(0.9+0.9M_{sun}, $\sim2\times10^6$)

Violent merger ··· explode **at** merger

→ Imply possibility SNe Ia from WDs mergers


· Long-lived merger (LLM) scenario
CO
CO
Ia
Quasi-stationary phase
· Violent merger (VM) scenario
CO
CO
Ia
Violently accrete (merger phase)

The conditions for SNe Ia from WDs merger

LLM scenario ・・・

Carbon burning does not ignite on surface in quasi-stationary phase ＋ Total mass exceeds Chandrasekhar mass (M_{ch})

※Here, $M_{Ch} = 1.38 M_{sun}$

VM scenario ・・・

Carbon burning dynamically occurs at merger phase

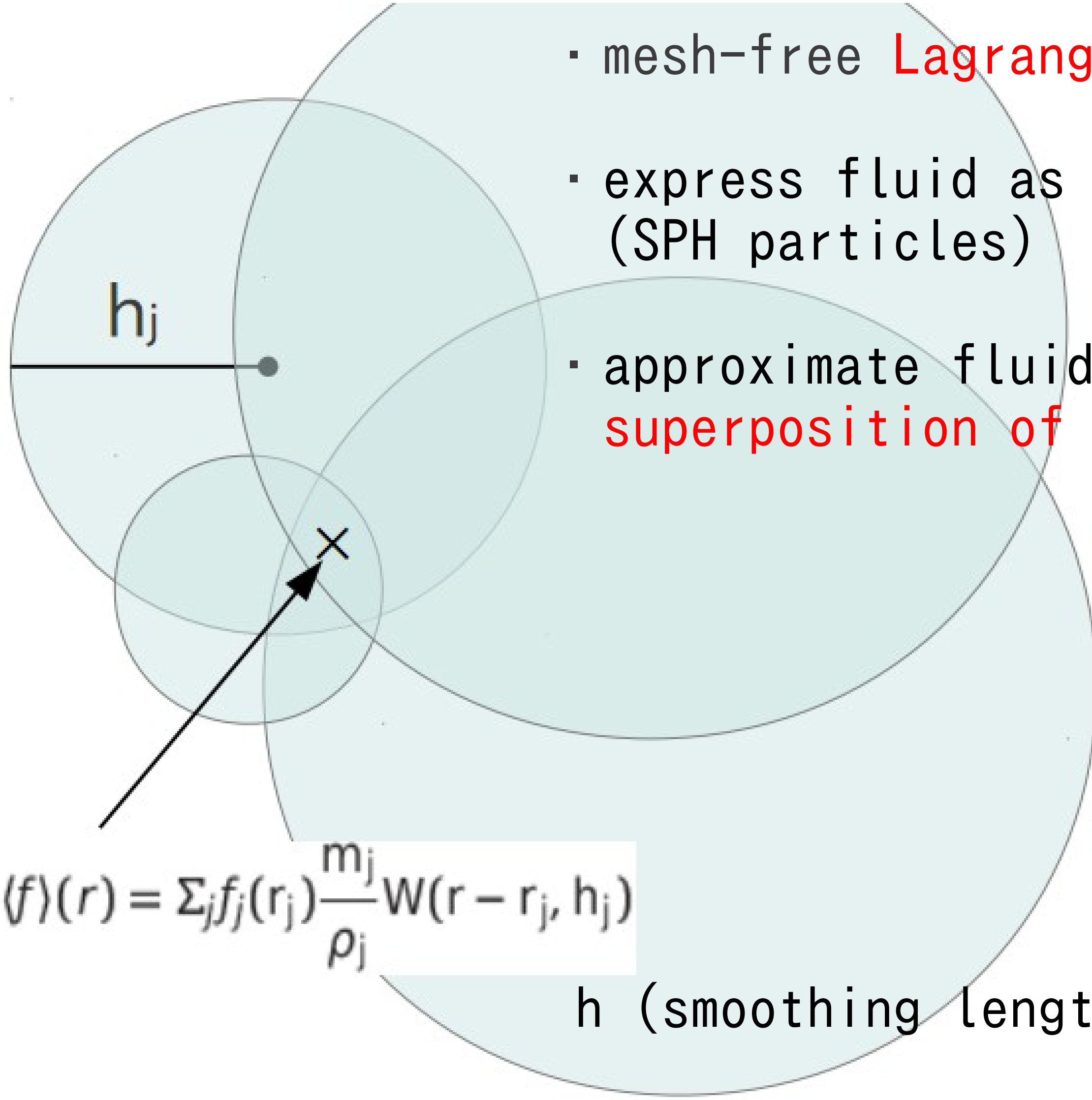
→ What's mass range satisfying the above conditions?

Implementing SPH simulation of CO WDs merger over wide mass range

Methods

Smoothed Particle Hydrodynamics (SPH)

- mesh-free Lagrangian method
- express fluid as a set of discrete elements (SPH particles)
- approximate fluid's physical quantity as superposition of SPH particle's



$$\langle f \rangle(r) = \Sigma_j f_j(r_j)\frac{m_j}{\rho_j}W(r - r_j, h_j)$$

h (smoothing length)･･･size of particle

W (kernel function)･･･distribution of particle

Simulation setup

Code : Nakasato et al. 2012, arXiv1206.1199

Gravitational calclation : Oct tree method

EOS : Timmes & Swesty, 2000, ApJS, 126, 501

Nuclear reaction : Not included

Artificial viscosity : Monaghan, 1992, ARA&A, 30, 543-574

Initial condition : Dan et al. 2011, ApJ, 737, 89

Mass range : 0.5～1.1Msun(0.1Msun)

Composition : C 50%, O 50%

Particle number : 10k, 50k, **100k**, 500k(/Msun) (k=1,024)
→ for confirming numerical convergence

Results

Example of simulation

Mass ・・・ 1.1+0.9 M_{sun}

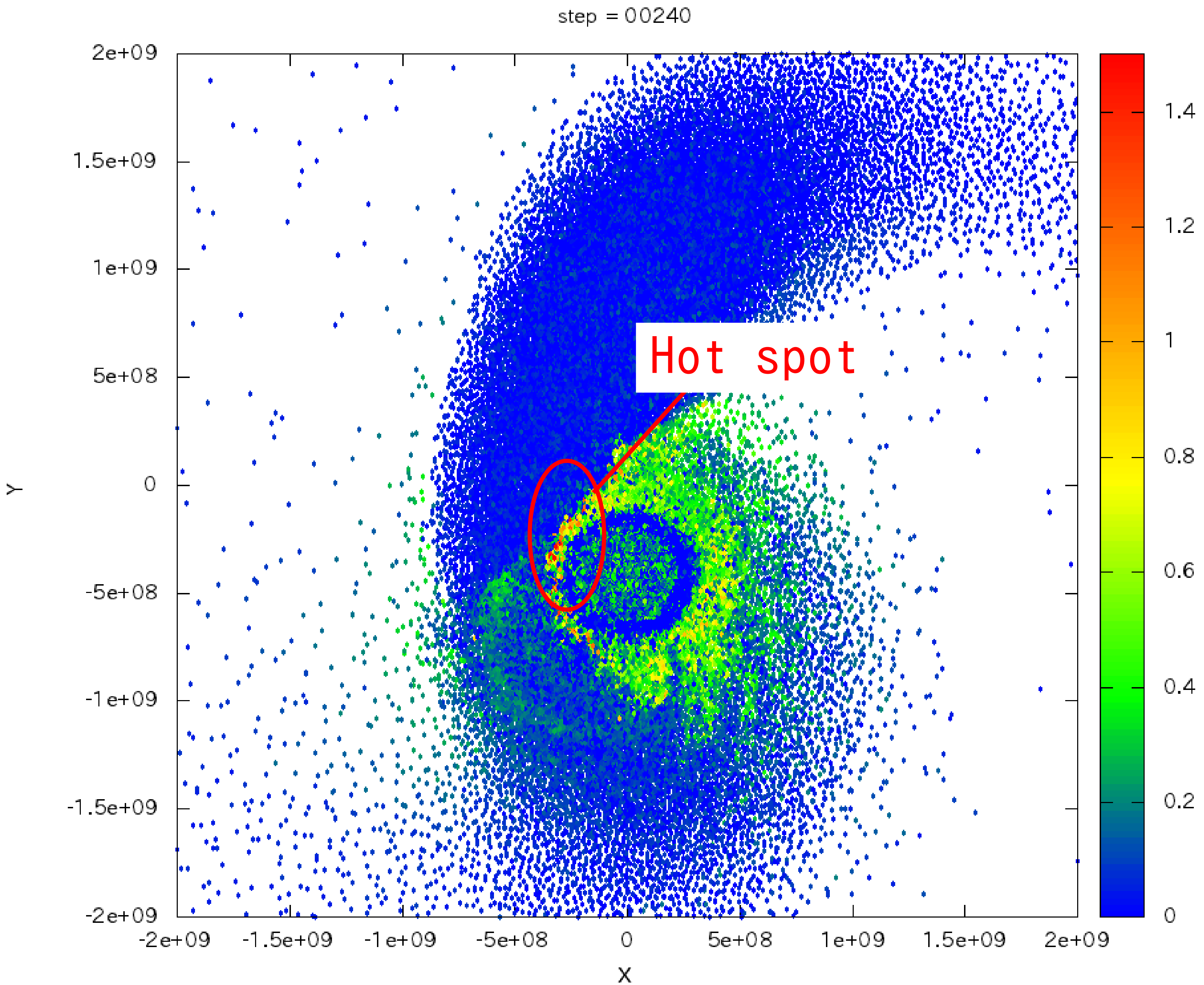
Particle number ・・・ 500k/M_{sun}

Color ・・・ temperature(10^9K)

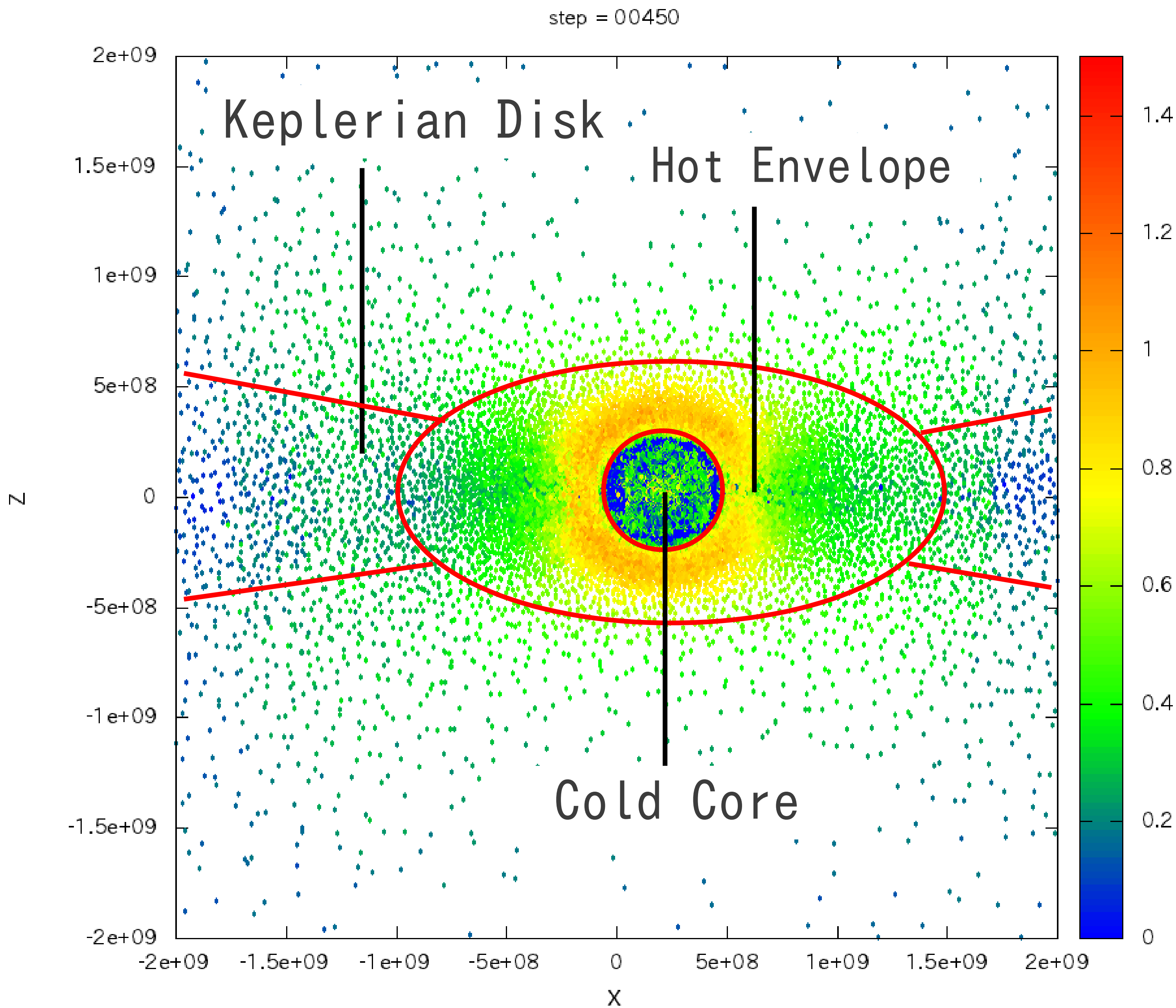
orbital plane

meridional plane

Structure in merger phase (VM scenario)



Structure in quasi-stationary phase(LLM scenario)



Criteria for Carbon burning in each scenarios

in merger phase (for VM scenario)

Carbon burning time scale < Dynamical time scale

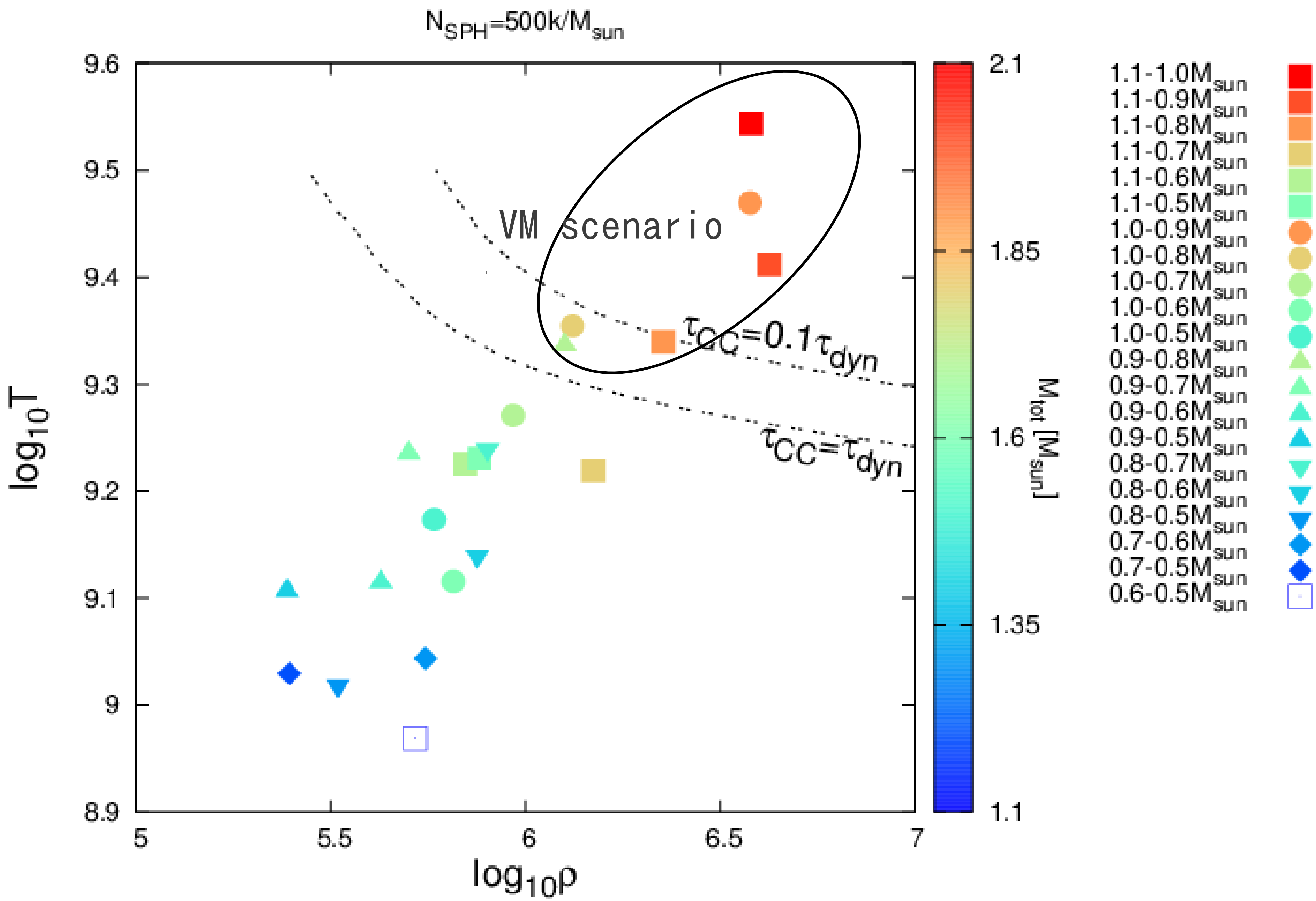
(Nomoto, 1982b, ApJ, 257, 780-792)

in quasi-stationary phase (for LLM scenario)

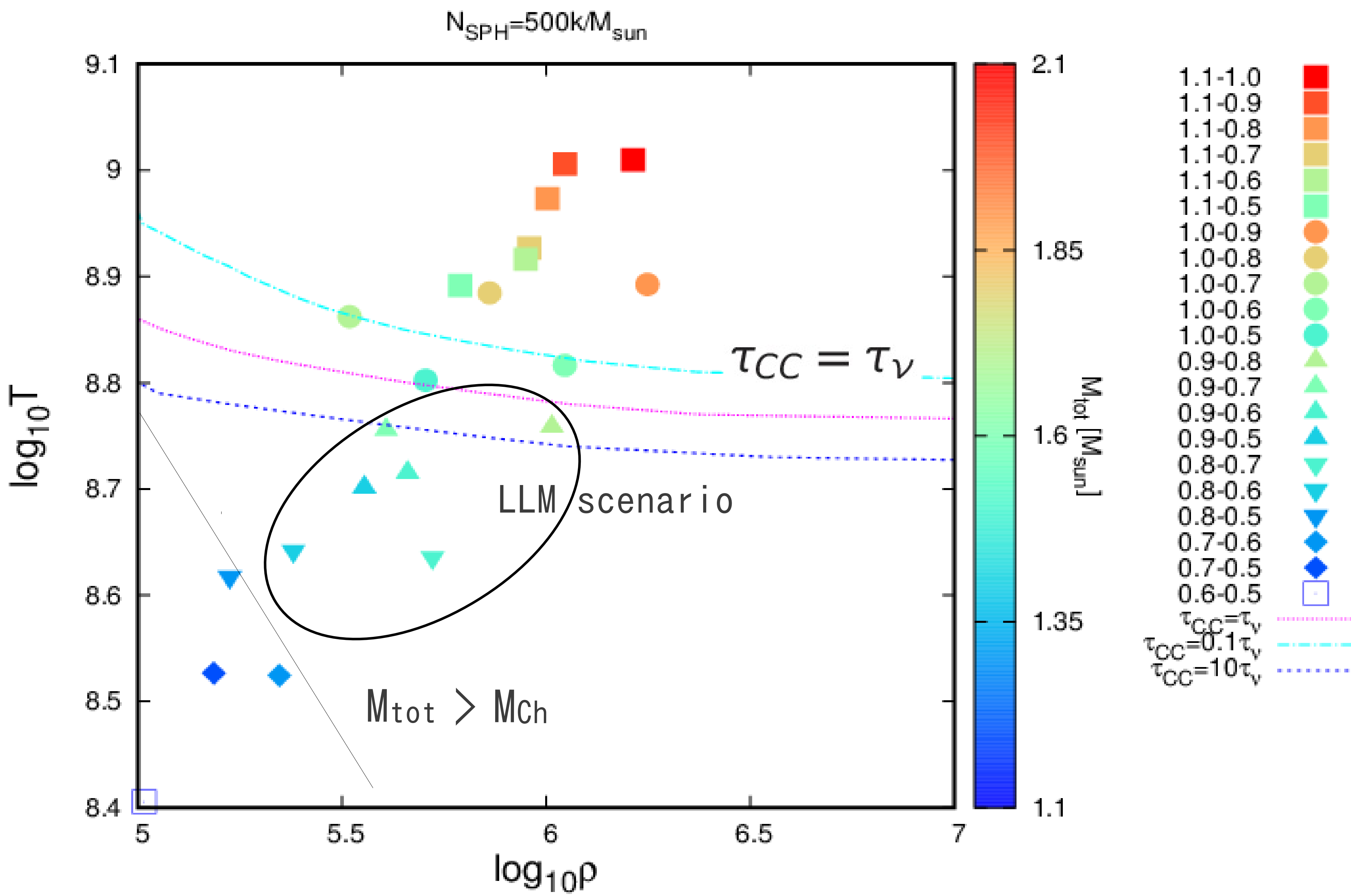
Carbon burning time scale < Neutrino cooling time scale

(Yoon et al. 2007, MNRAS, 380, 933-948)

Particle number 500k/M_{sun}
Judgement of nuclear burning in merger phase

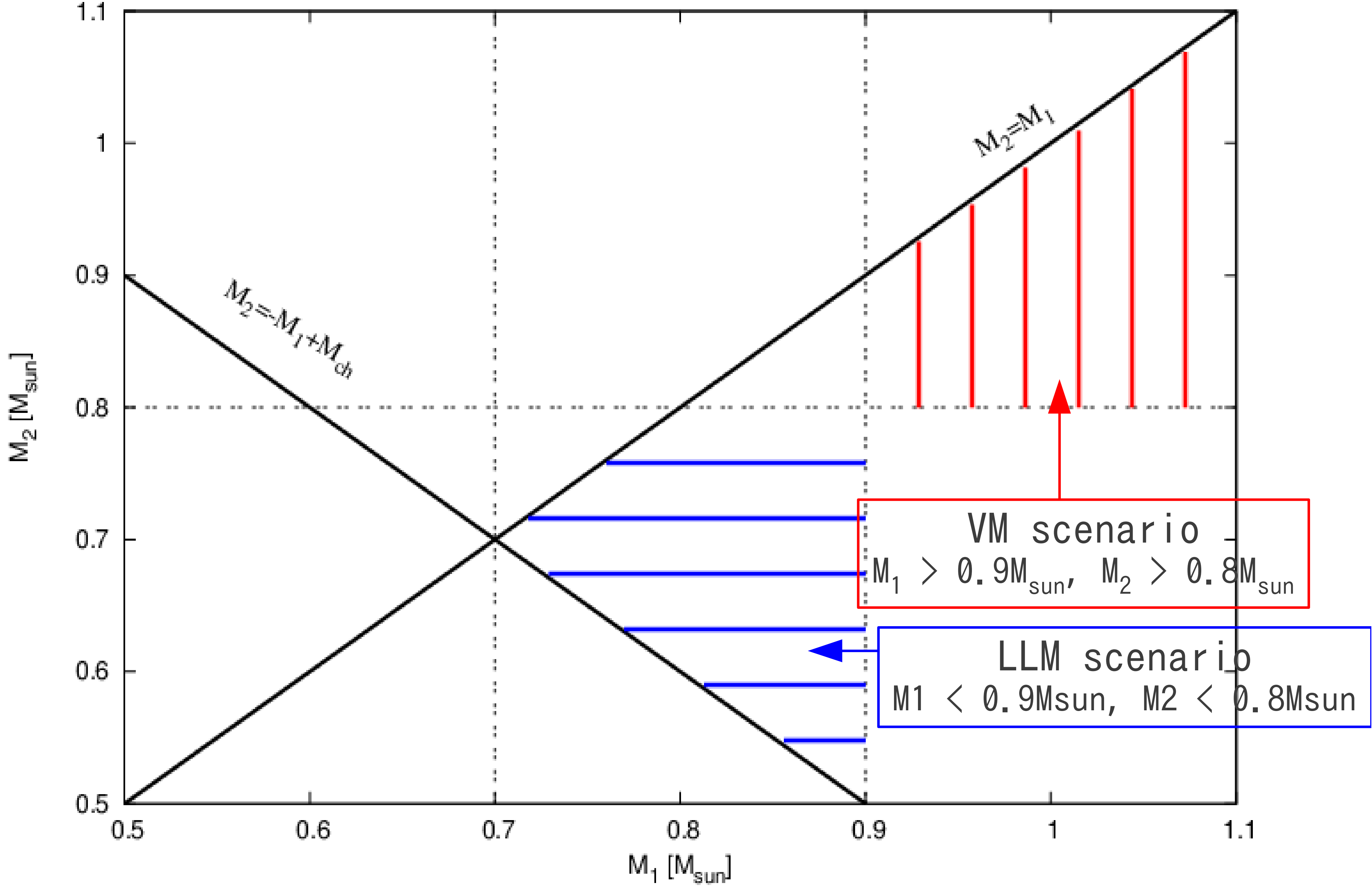


Particle number 500k/M_{sun}
Judgement of nuclear burning in quasi-stationary phase



Discussion

Mass range of double CO WDs for SNe Ia



Contribution of double WDs mergers (DD model)

SNe I

~

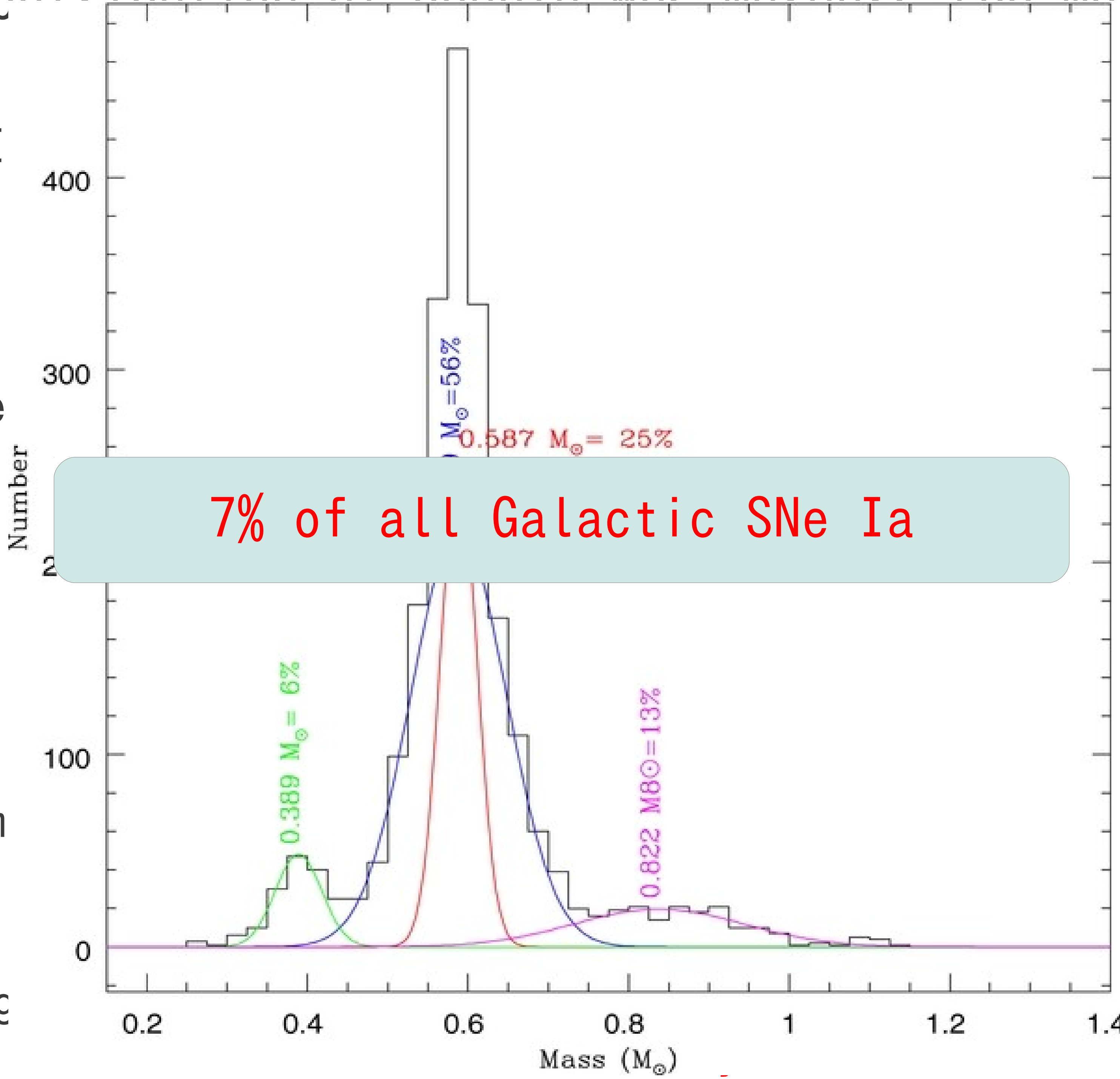
Merge

~

Mass

Assum

Merg

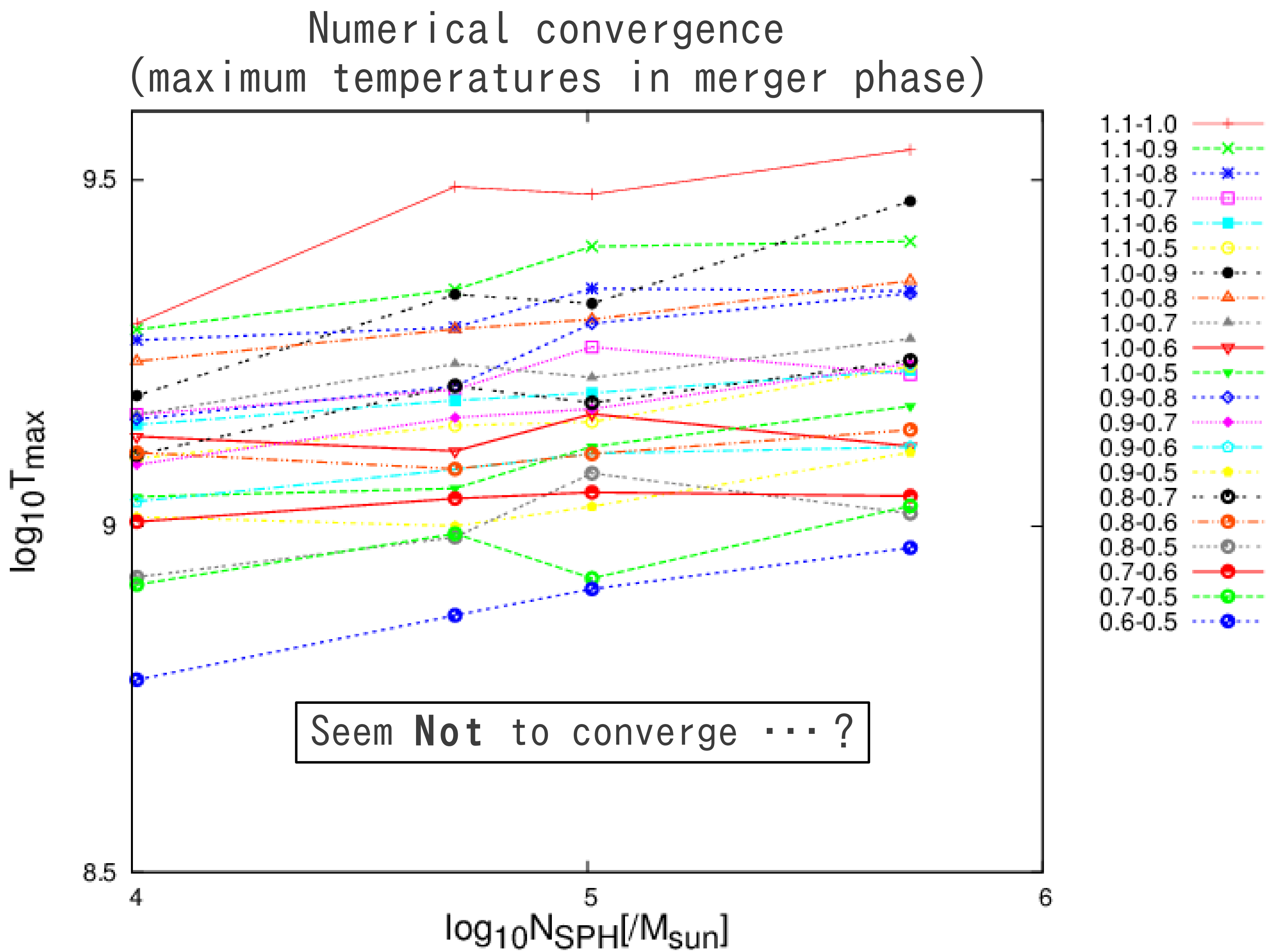


7% of all Galactic SNe Ia

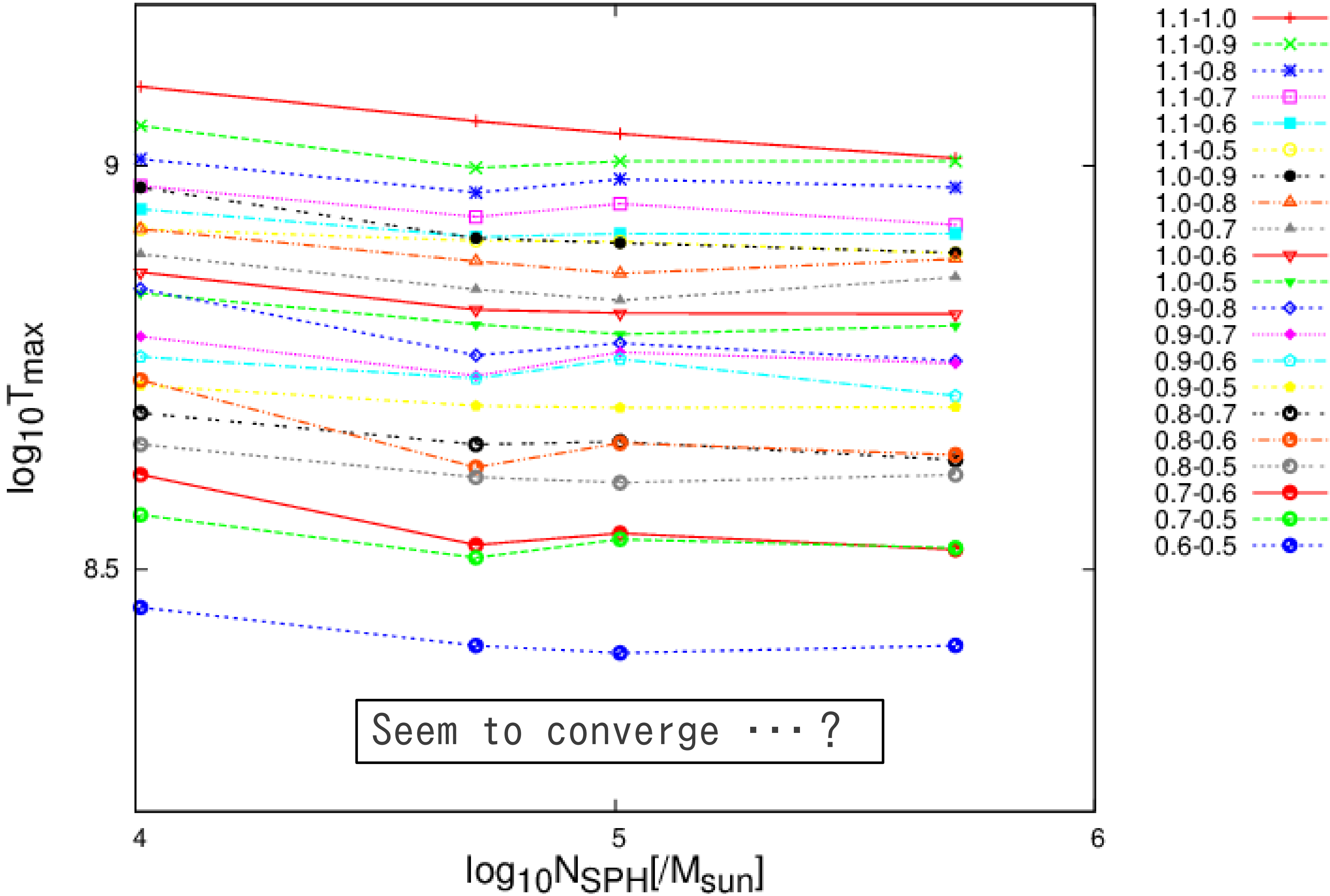
1)

)

SNe Ia


Numerical convergence
(maximum temperatures in merger phase)
9.5
9
8.5
4
5
6
log10Tmax
log10NSPH[/Msun]
1.1-1.0
1.1-0.9
1.1-0.8
1.1-0.7
1.1-0.6
1.1-0.5
1.0-0.9
1.0-0.8
1.0-0.7
1.0-0.6
1.0-0.5
0.9-0.8
0.9-0.7
0.9-0.6
0.9-0.5
0.8-0.7
0.8-0.6
0.8-0.5
0.7-0.6
0.7-0.5
0.6-0.5
Seem **Not** to converge ･･･?

Numerical convergence
(maximum temperatures in quasi-stationary phase)



Summary

Summary

- Implement SPH simulation of double CO WDs merger

- Investigate the mass range for SNe Ia
  and estimate contribution to Galactic SNe Ia

- Mass range is ・・・
  VM scenario $M_1 > 0.9M_{sun}$ and $M_2 > 0.8M_{sun}$
  LLM scenario $M_1 < 0.9M_{sun}$ and $M_2 < 0.8M_{sun}$ & $M_1+M_2 > M_{Ch}$

- Contribution from WDs mergers (DD model) is
  significantly small in our Galaxy
  → Other models (e.g. SD model) are more important

- Numerical convergence should be studied more carefully