Section 10.
Mechanism of core-collapse supernovae

10.1 Core-collapse

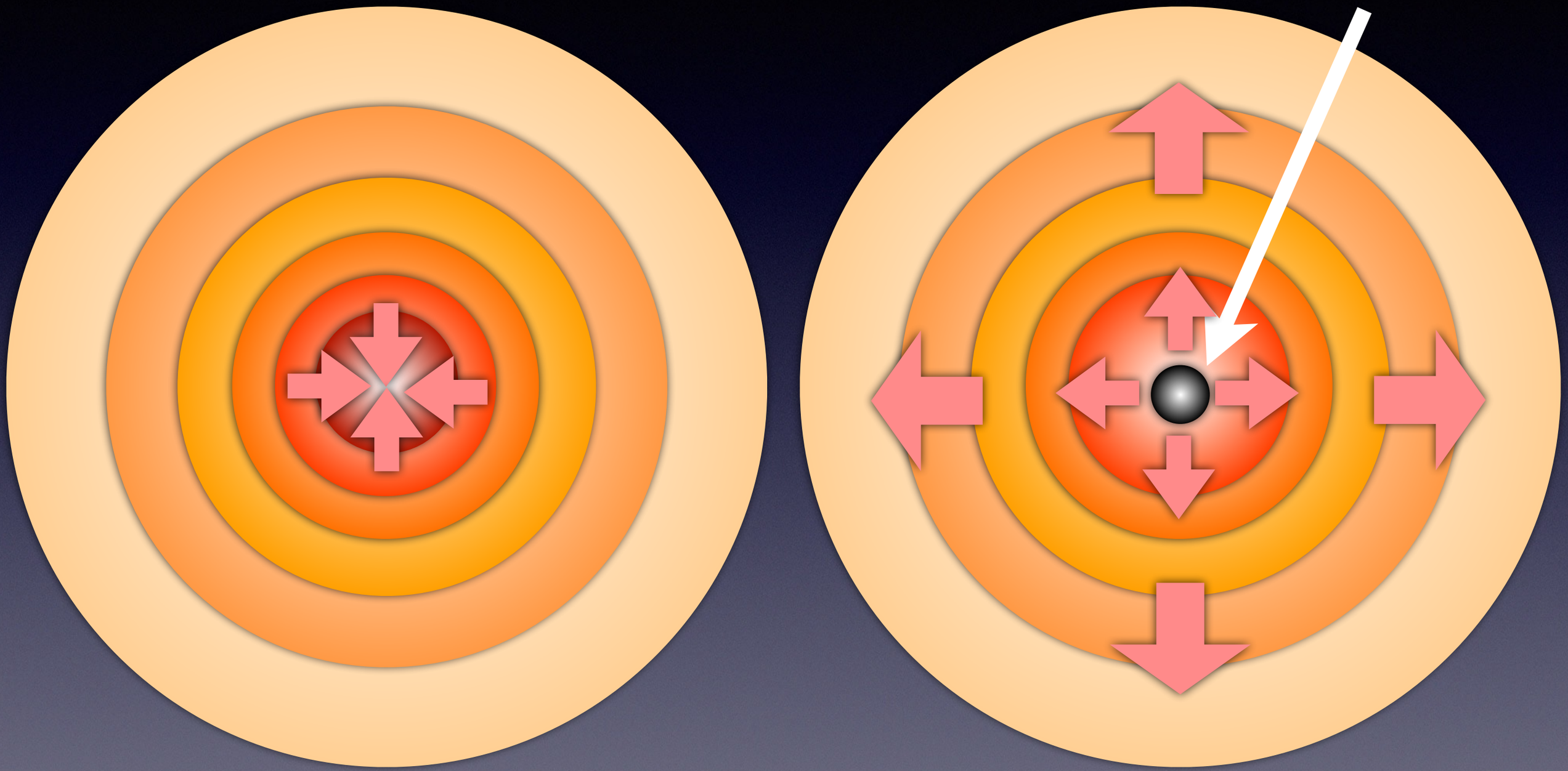
10.2 Mechanism of core-collapse supernovae

Let's understand these questions with the words of physics

- Why are stars so luminous?
- Why do stars show $L \sim M^4$?
- Why do stars evolve?
- Why does the destiny of stars depend on the mass?
- Why do some stars explode?
- Why don't normal star explode?
- Why does stellar core collapses?
- Why is the energy of supernova so huge?
- …

Collapse
(< 1 sec)

Neutron star
or
Black hole



Supernova!

What triggers the collapse of the star??

Section 10.
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10.1 Core-collapse

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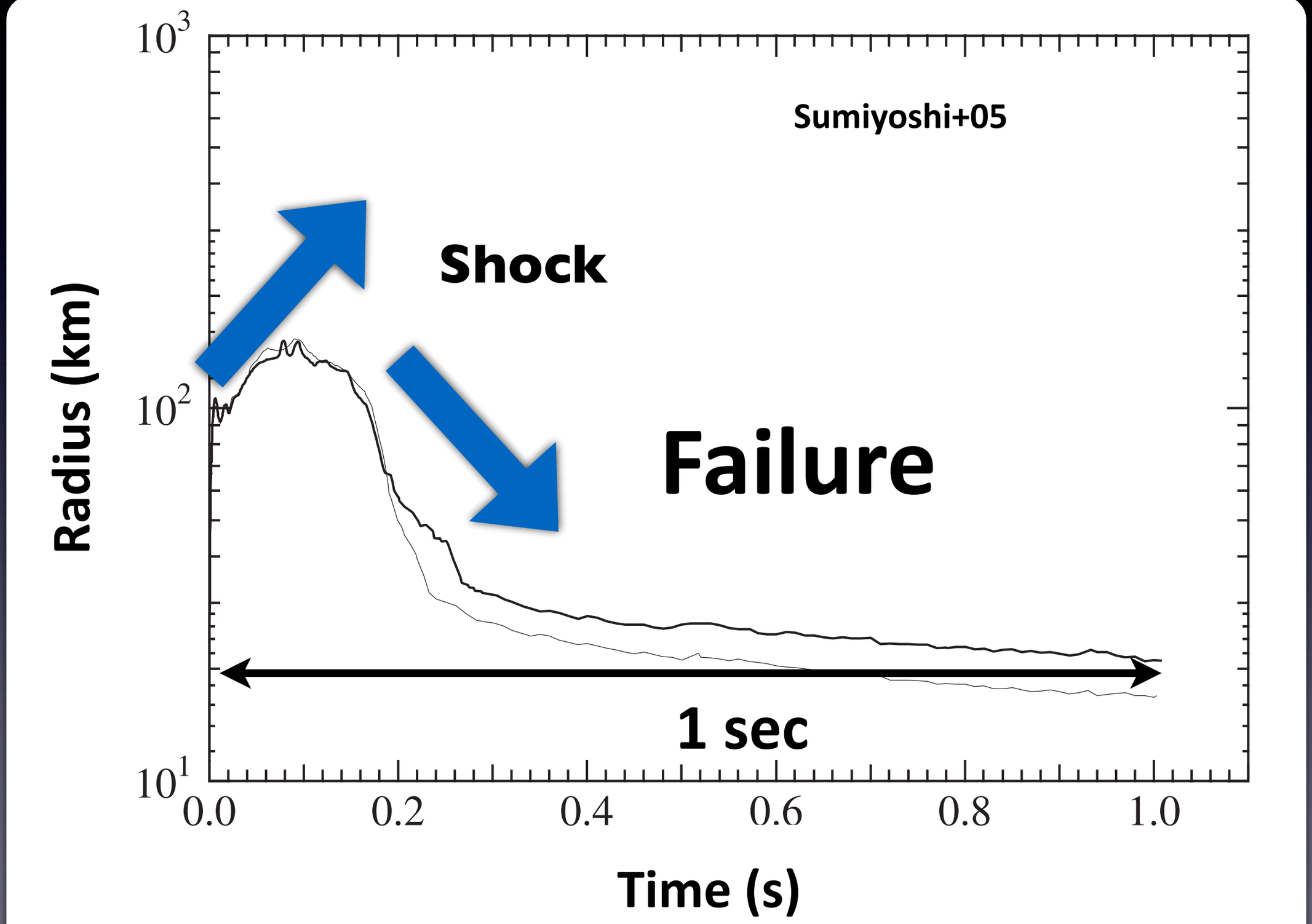
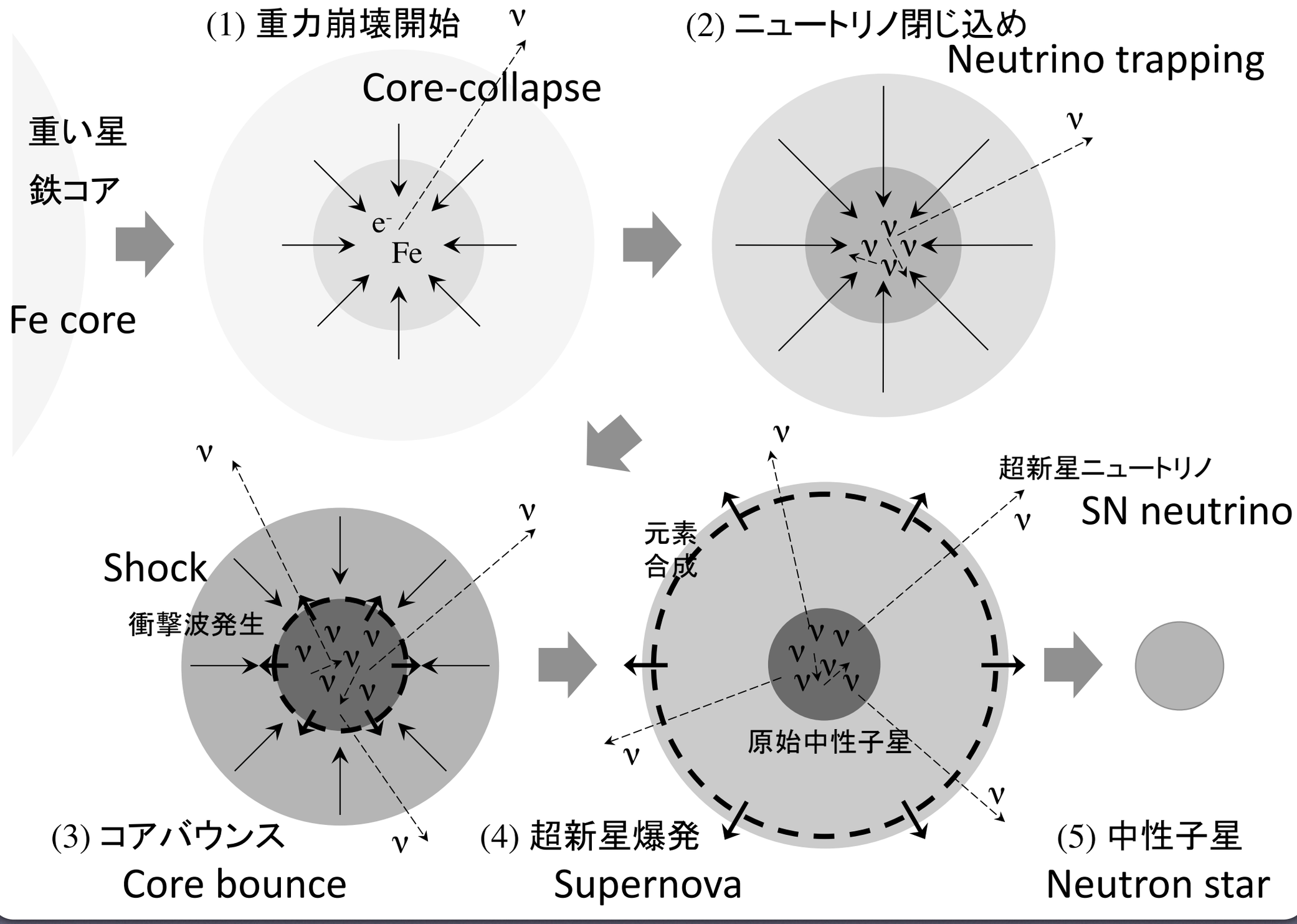
Results of simulations (1D)



Why do stars finally explode?

Why is it difficult to reproduce explosions?

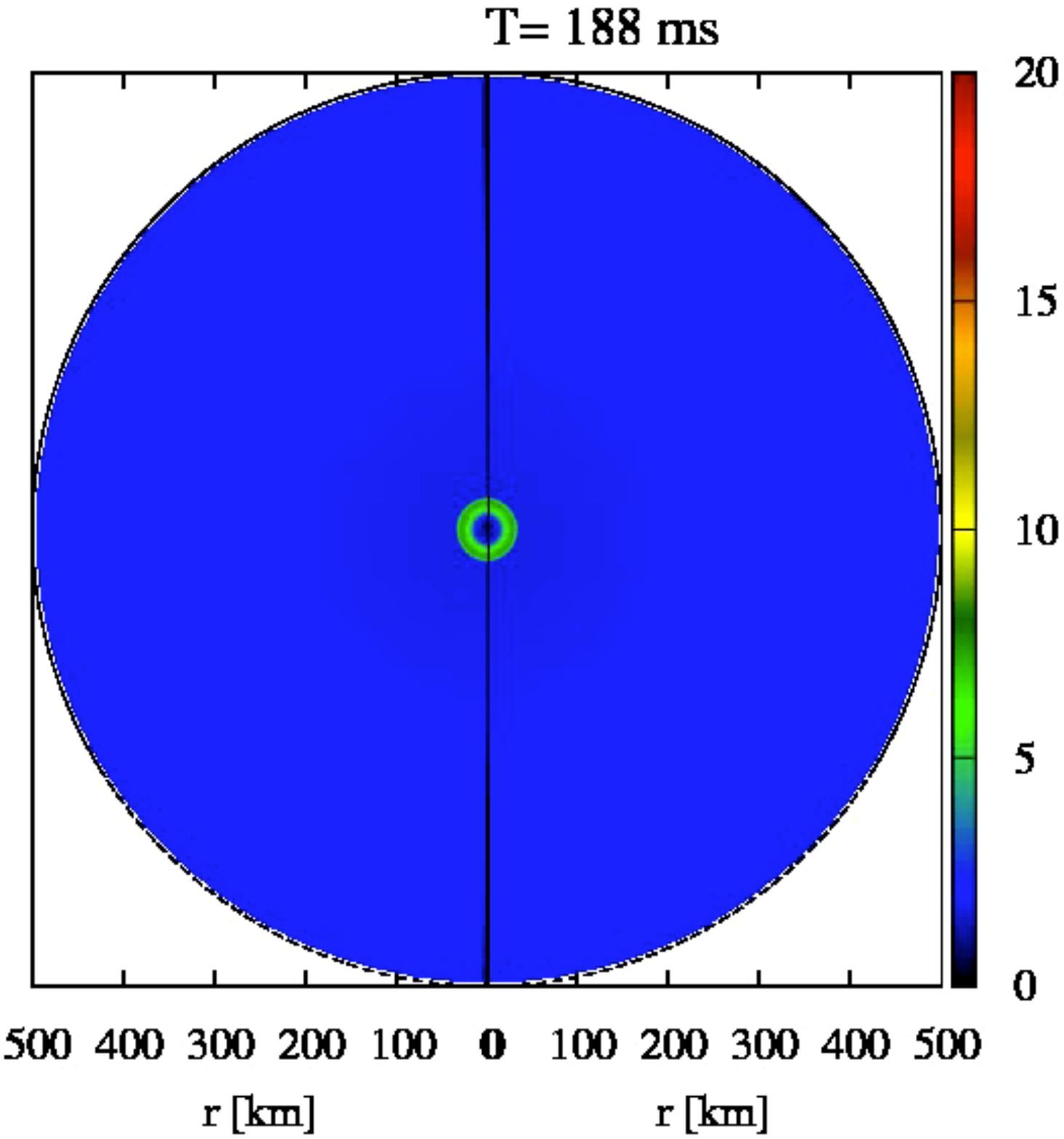


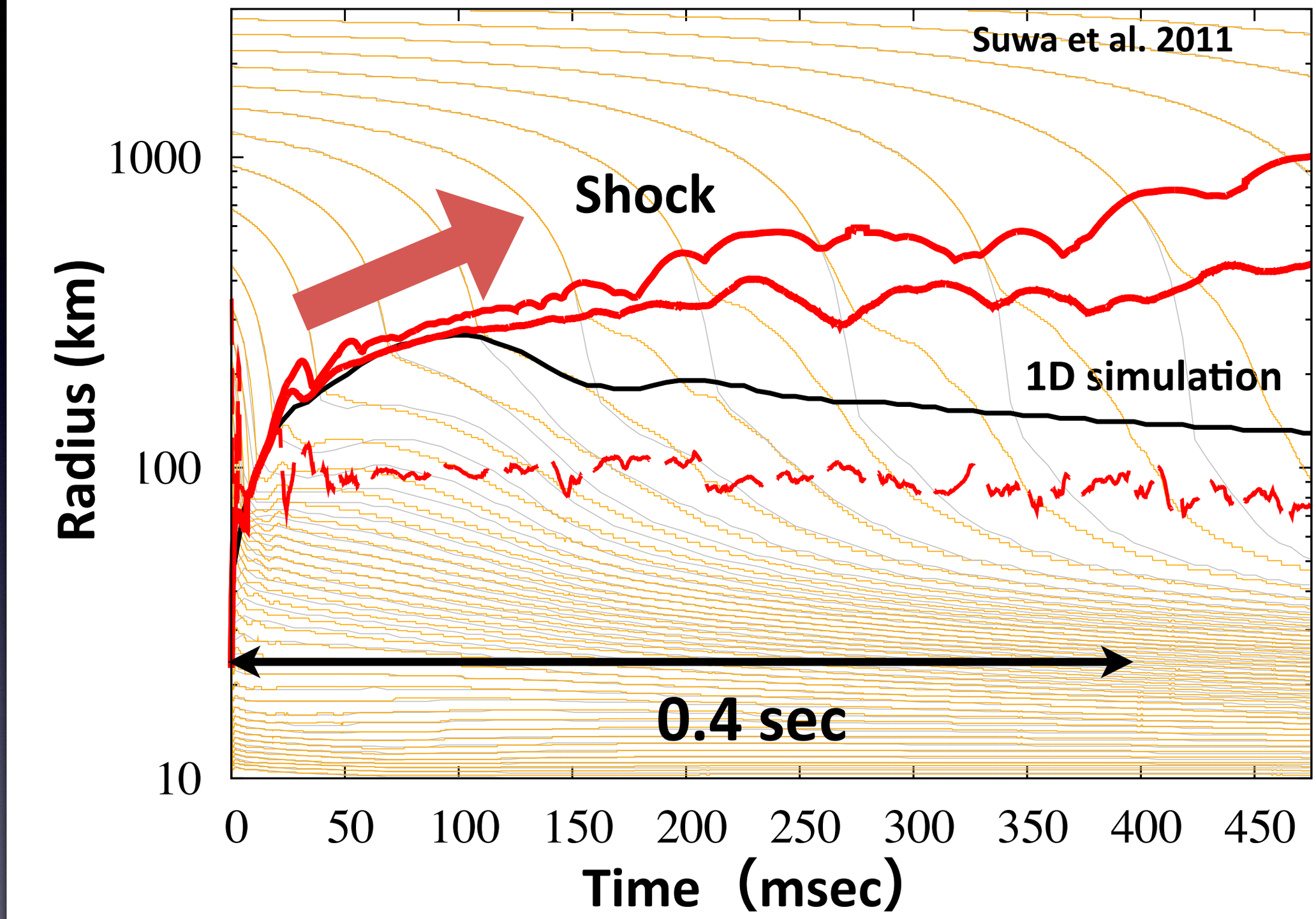
(C) 原子核から読み解く超新星爆発の世界

住吉光介さん著 (Kosuke Sumiyoshi)

S20.0 ENTROPY
LEA VELOCITY
Time = -168.0 ms
Radius = 500.00 km
(C) A. Burrows

Suwa et al. 2011



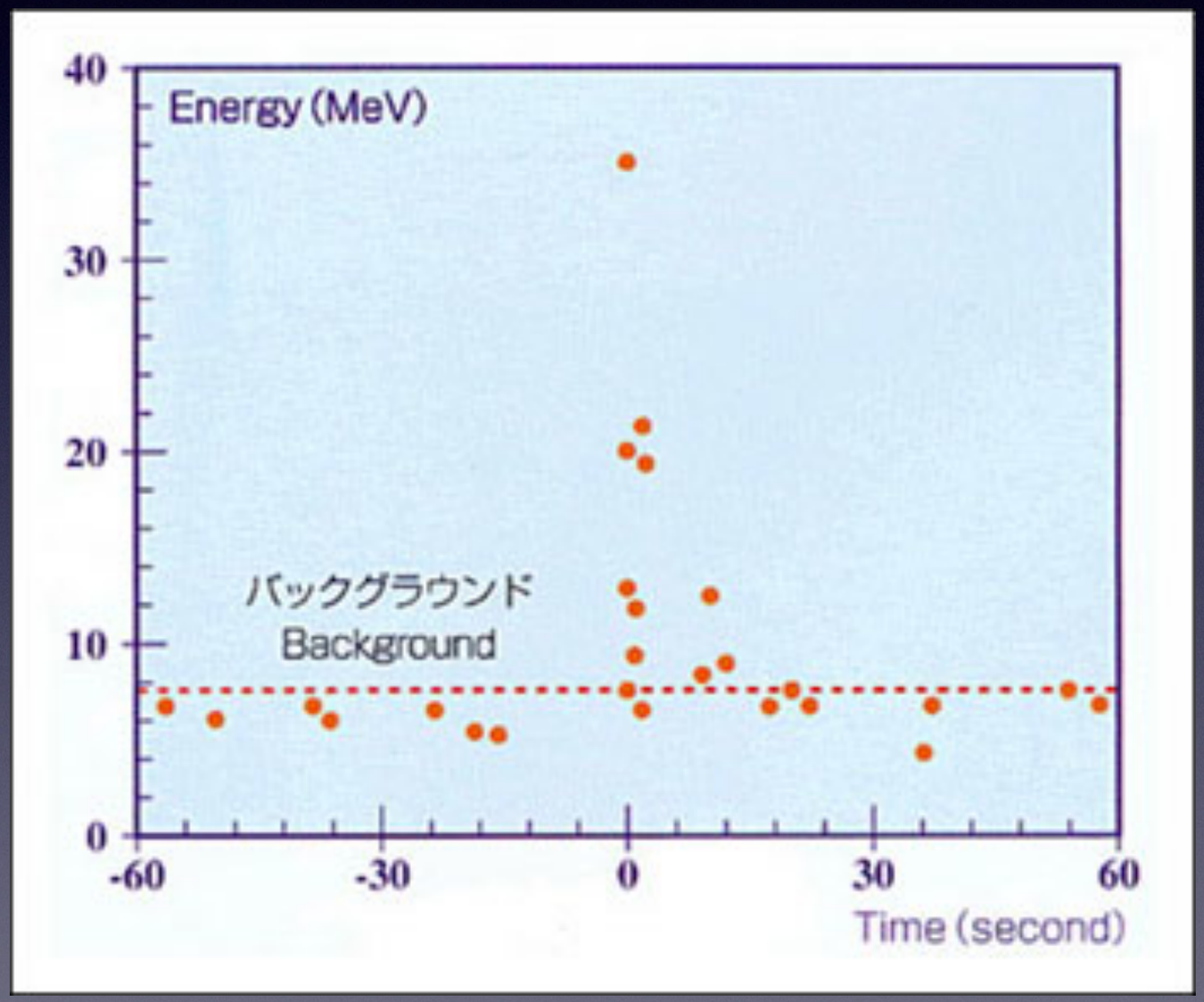


E ~ 10^{50} erg (smaller than observations by 1 order of magnitude)

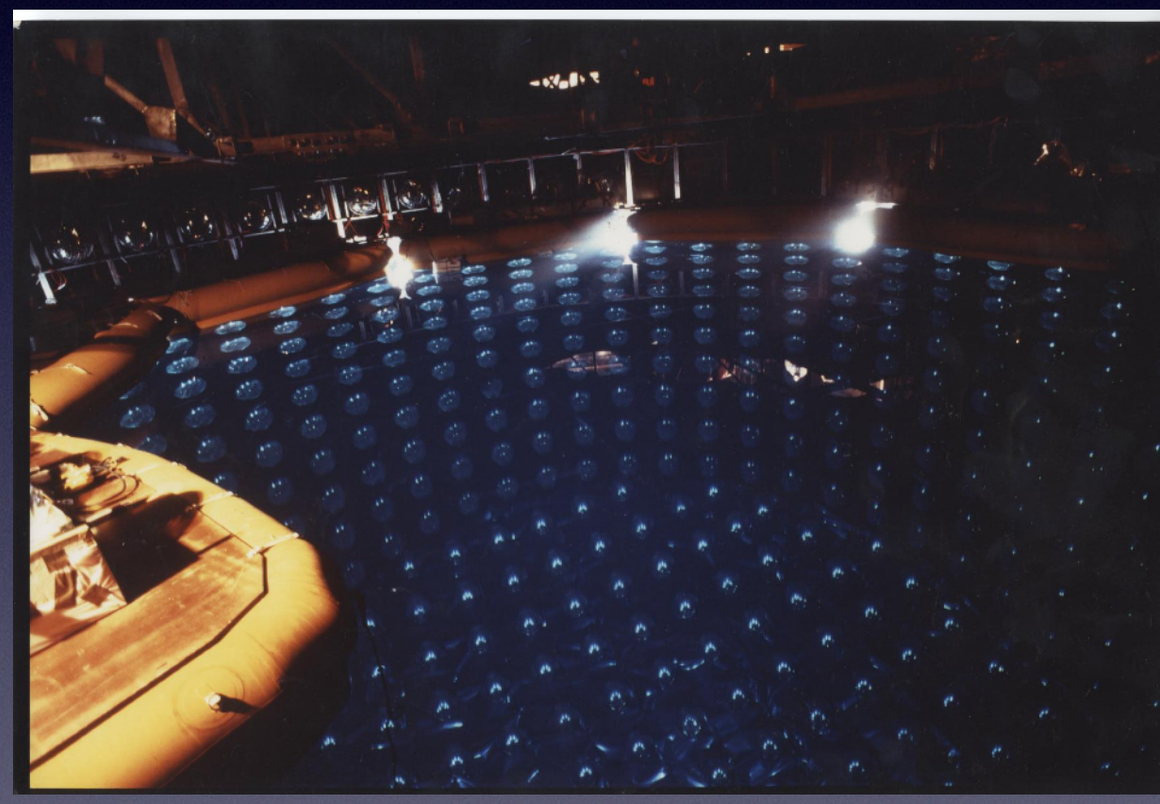
One of the biggest mystery in modern astrophysics

SN 1987A (in Large Magellanic cloud, 50 kpc)

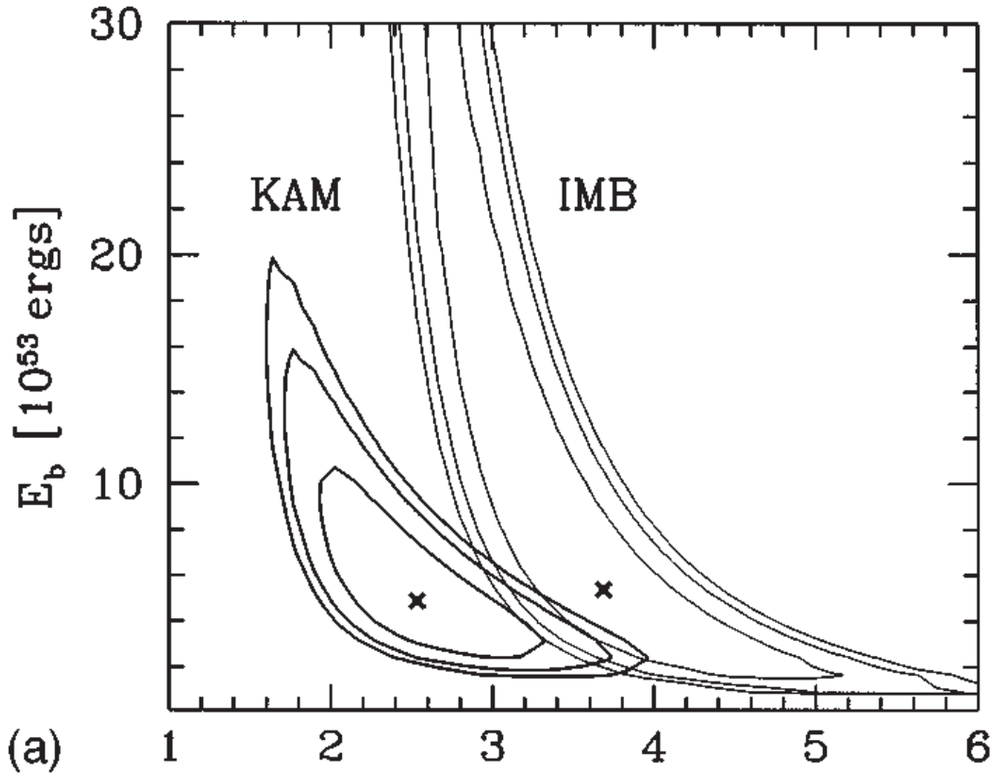
Neutrino detection From SN 1987A



Kamiokande



(C) ICRR



Jegerlehner et al. 1996

E_{nu} ~ 10^{53} erg!!
=> Foundation of neutrino-driven mechanism

*** Observed energy**
(anti electron neutrino) x 6

Assignment 4

Kamiokande detected 11 neutrino events from SN 1987A.
By this fact, estimate total neutrino energy
that SN 1987A released

- You can assume the same numbers for all the flavors (6 flavors).
- protons in water are main reactor (Cross section σ ~ 10^{-41} cm^2)
- Effective volume of Kamiokande 2 kton
- Distance to the LMC is 50 kpc

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

レポート課題 4

カミオカンデで11イベントのニュートリノが観測された。
このことから、SN 1987Aがニュートリノとして放出した
総エネルギーを概算せよ

* すべてのフレーバーのニュートリノが同数放出されたと仮定して良い
* 主な反応は水分子中の陽子 (反応断面積$\sigma \sim 10^{-41}$ cm^2)
* カミオカンデの有効体積 2 kton
* 大マゼラン雲までの距離 50 kpc

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

Summary: Core-collapse supernovae

- **Core-collapse**
  - Triggered by electron capture and photo dissociation
- **Explosion mechanism**
  - Core-collapse => Bounce => Shock stalled => neutrino heating
  - Neutrino detection from SN 1987A
  - Detailed mechanism is not yet solved
- **Explosive nucleosynthesis**
  - 56Ni => heating source of supernova

Thermodynamics

Electromagnetism

Classical mechanics

Statistical mechanics

Astrophysics

Hydrodynamics

Quantum mechanics

Relativity

Nuclear physics

Appendix

Timescales of core-collapse supernovae

Core-collapse **Bounce** **Shock revival** **Breakout**

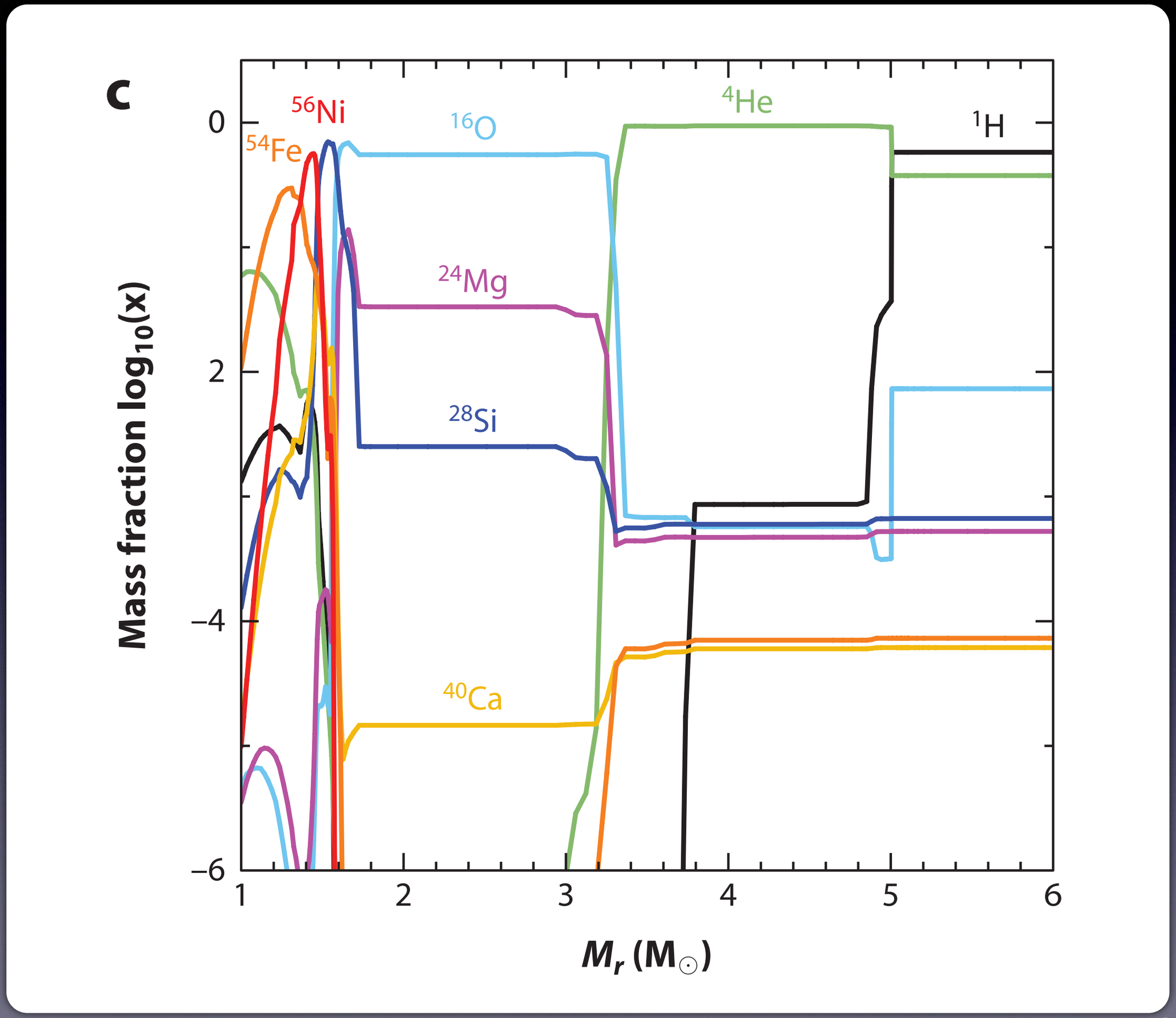
~0.1 sec **~0.1-1 sec** **~1 day (~10^5 sec)**

Shock breakout
t(breakout) = R(RSG)/v(SN)
~ $10^{14}/10^9$ ~ 10^5 sec
~ 1 day

R(RSG) ~ 1000 Rsun
~ 10^{14} cm

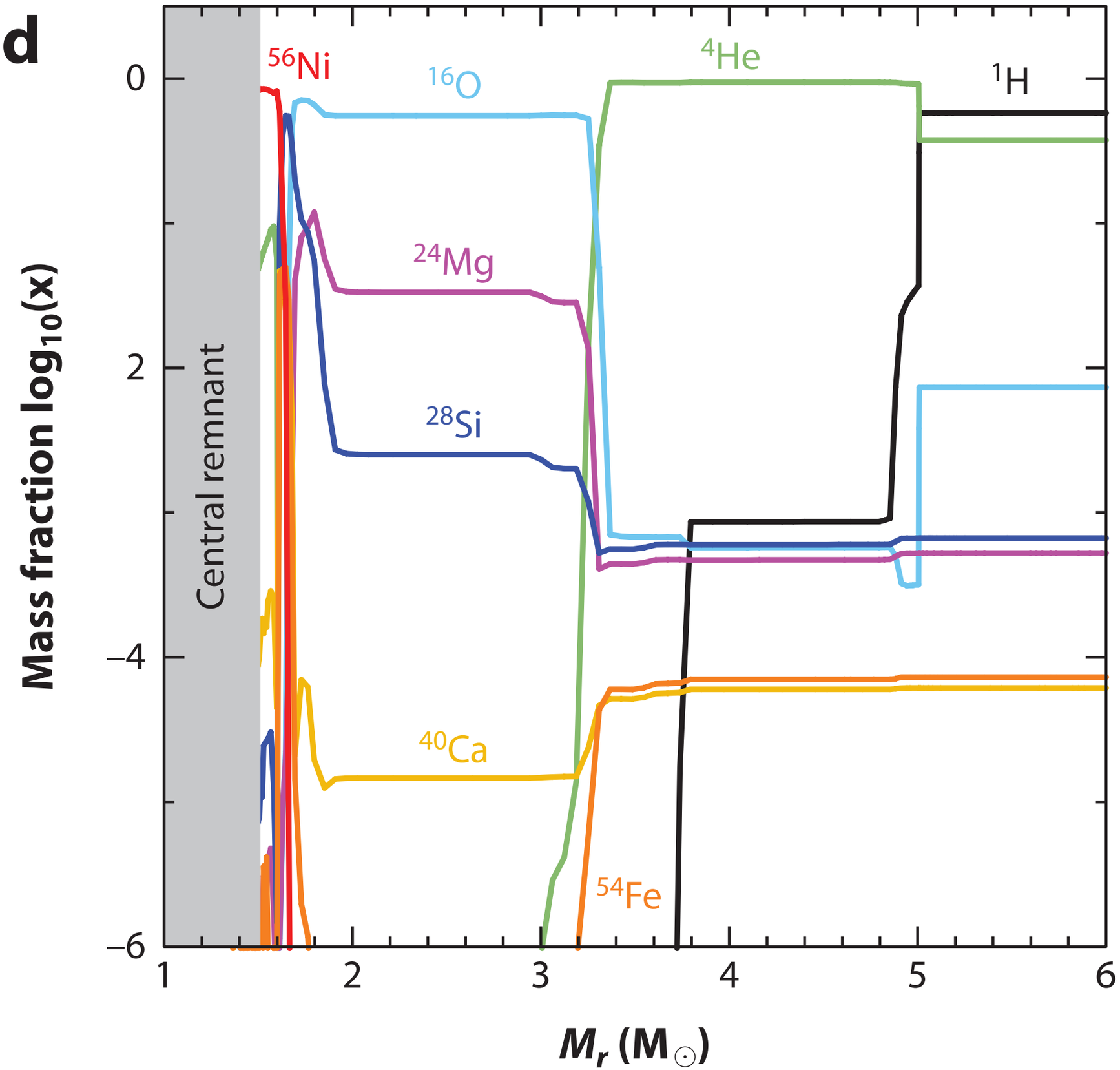
v(SN) ~ 10,000 km/s
(10^9 cm/s)

Before



Nomoto+13

After



Nomoto+13