Section 8.
Mechanism of core-collapse supernovae

8.1 Core-collapse

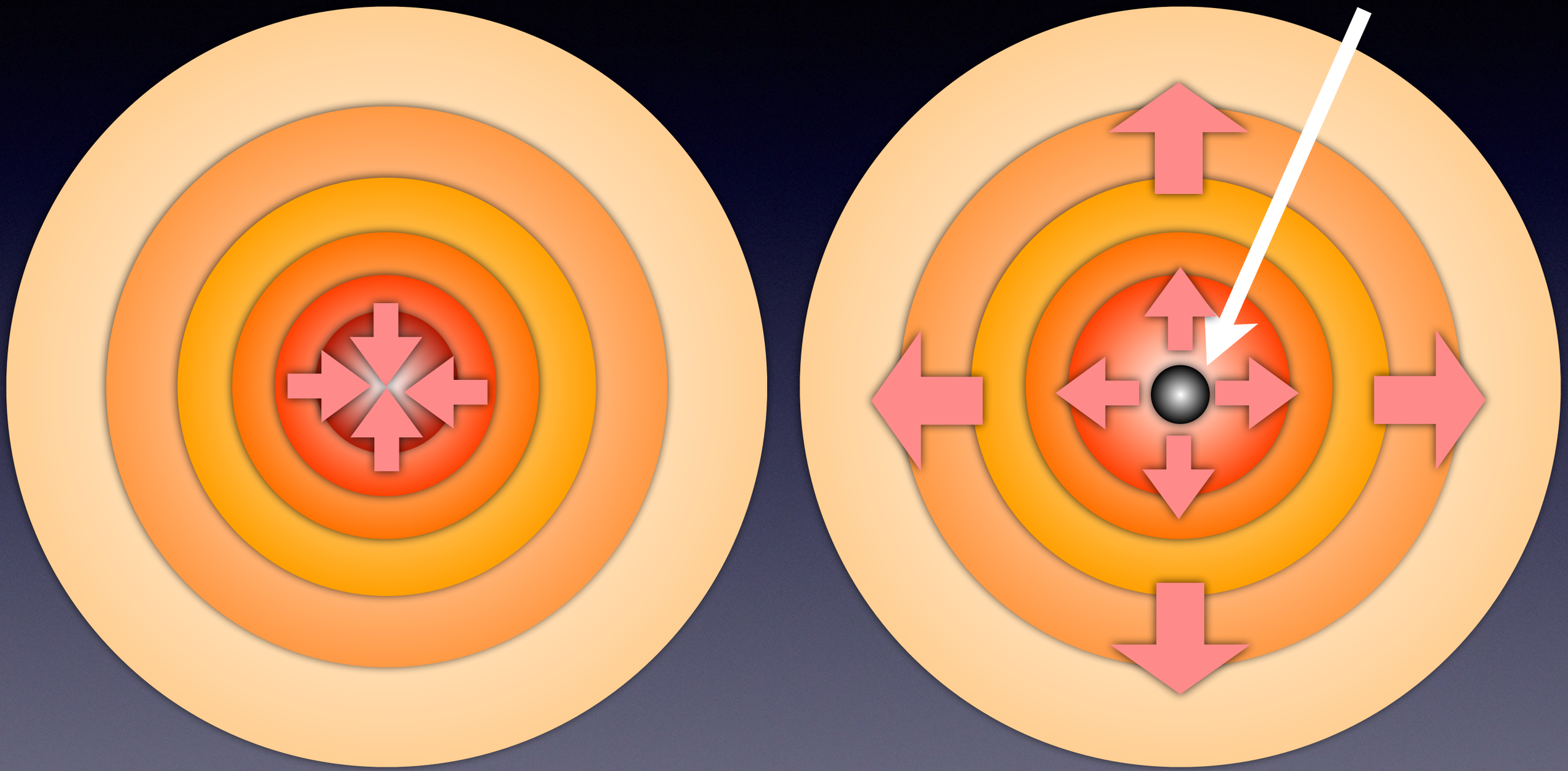
8.2 Mechanism of core-collapse supernovae

Goals of this lecture

- Standard properties of stars
  - Stellar structure and properties
  - Stellar evolution
- Origin of the elements in the Universe
  - Nucleosynthesis in stars and supernovae
  - Explosion mechanism of supernovae
- Topics in time-domain astronomy
  - Radiation from explosive phenomena
  - Multi-messenger astronomy

Collapse
(< 1 sec)

Neutron star
or
Black hole



Supernova!

What triggers the collapse of the star??

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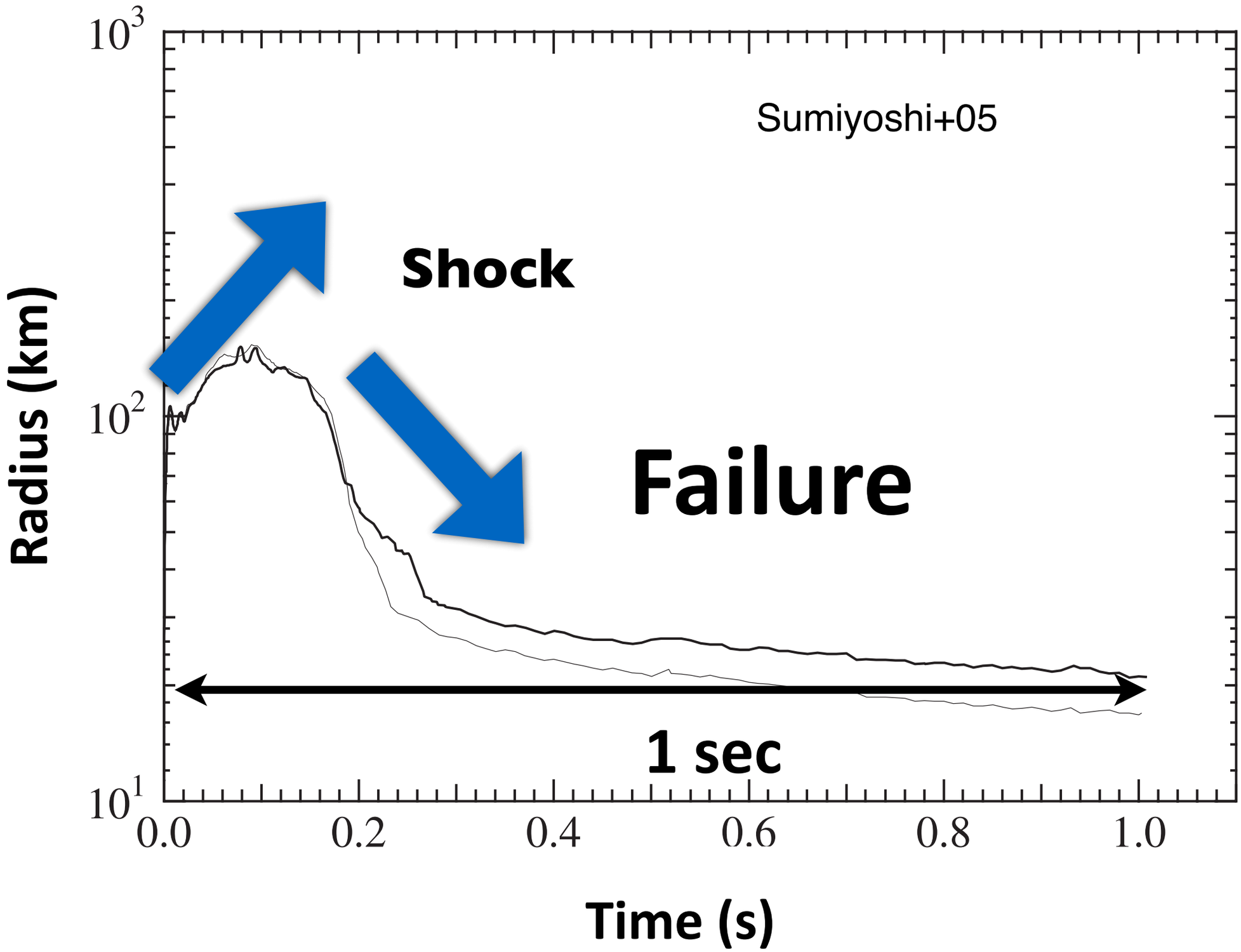
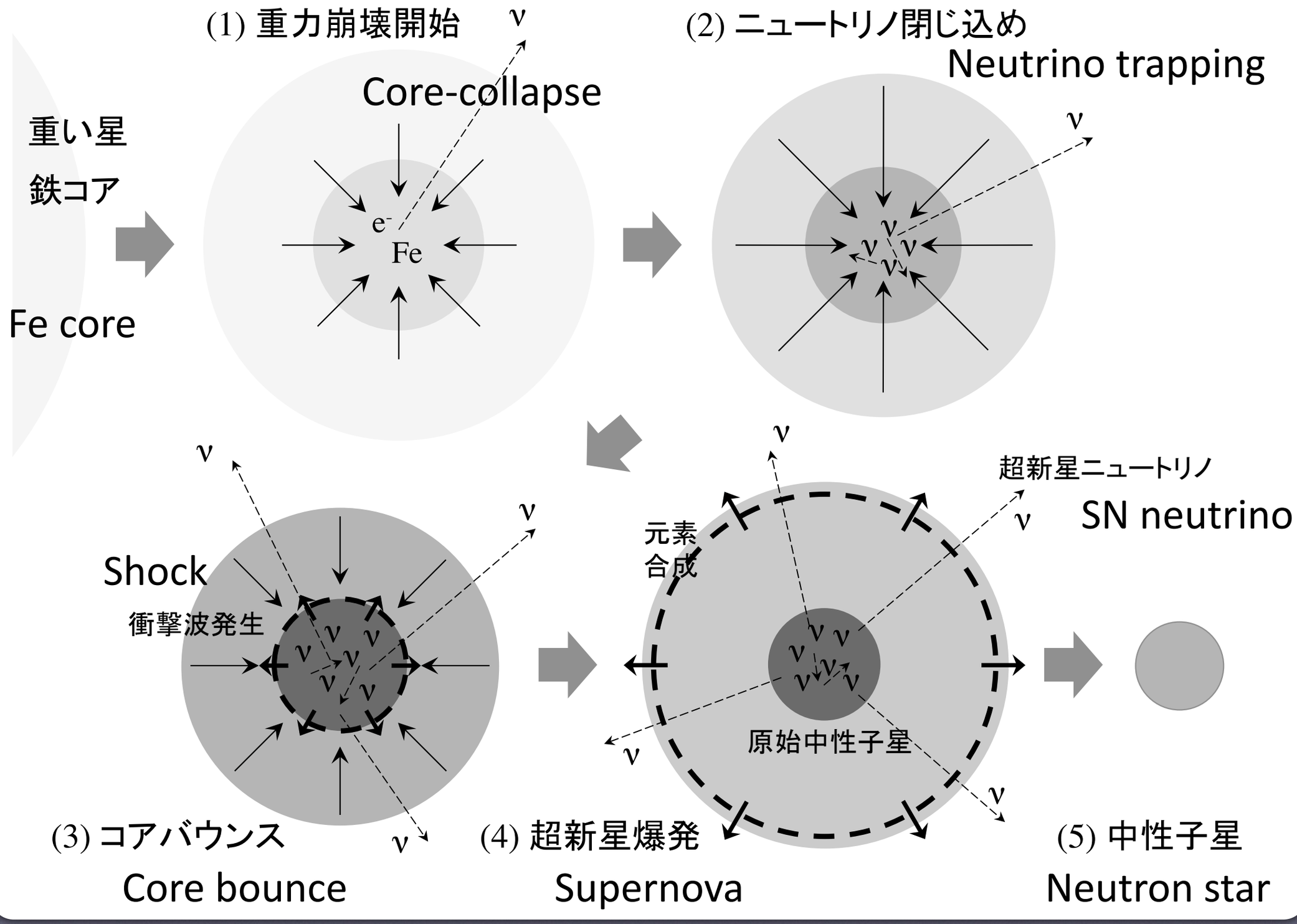
Results of simulations (1D)



Why do stars finally explode?

Why is it difficult to reproduce explosions?

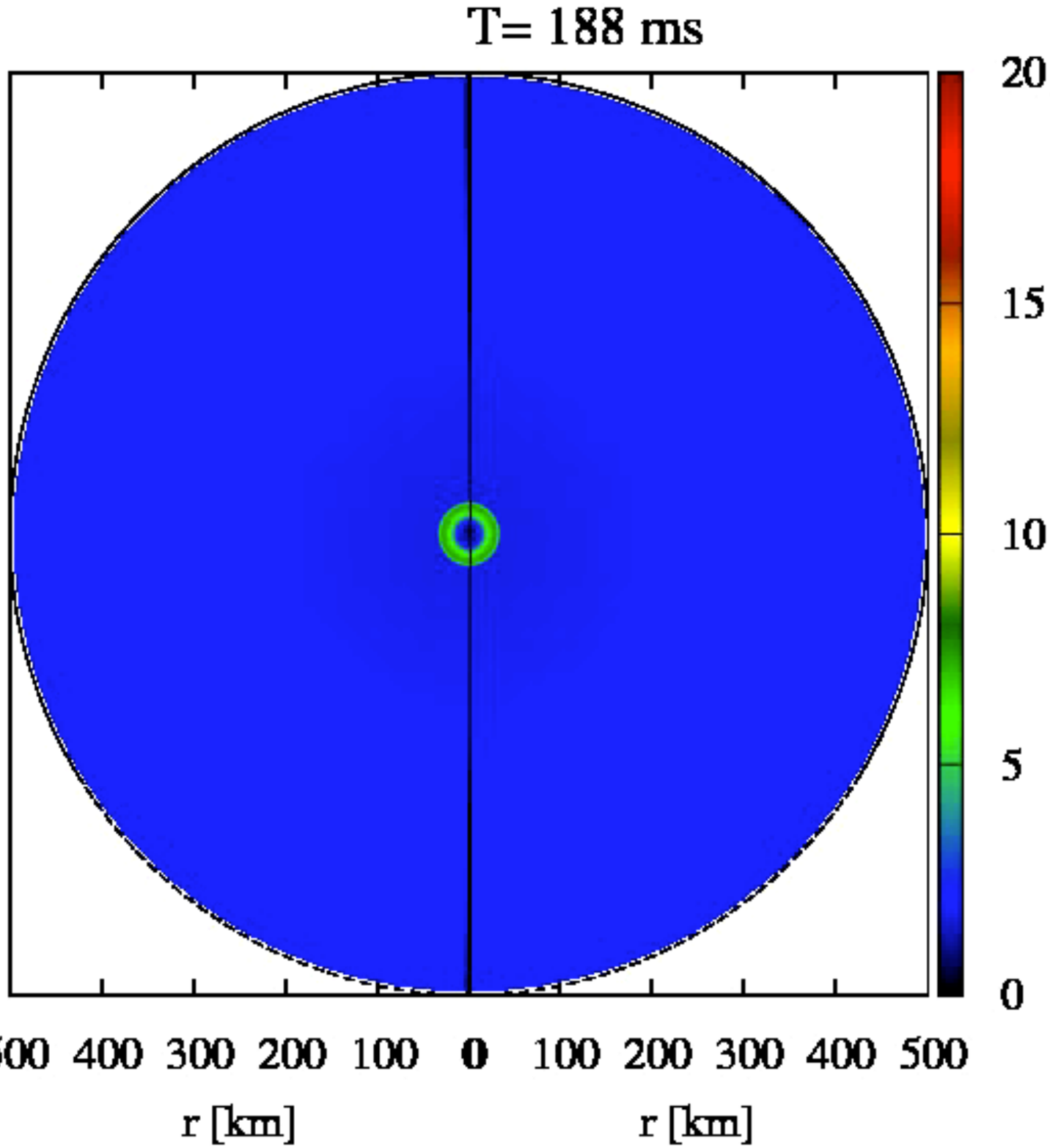


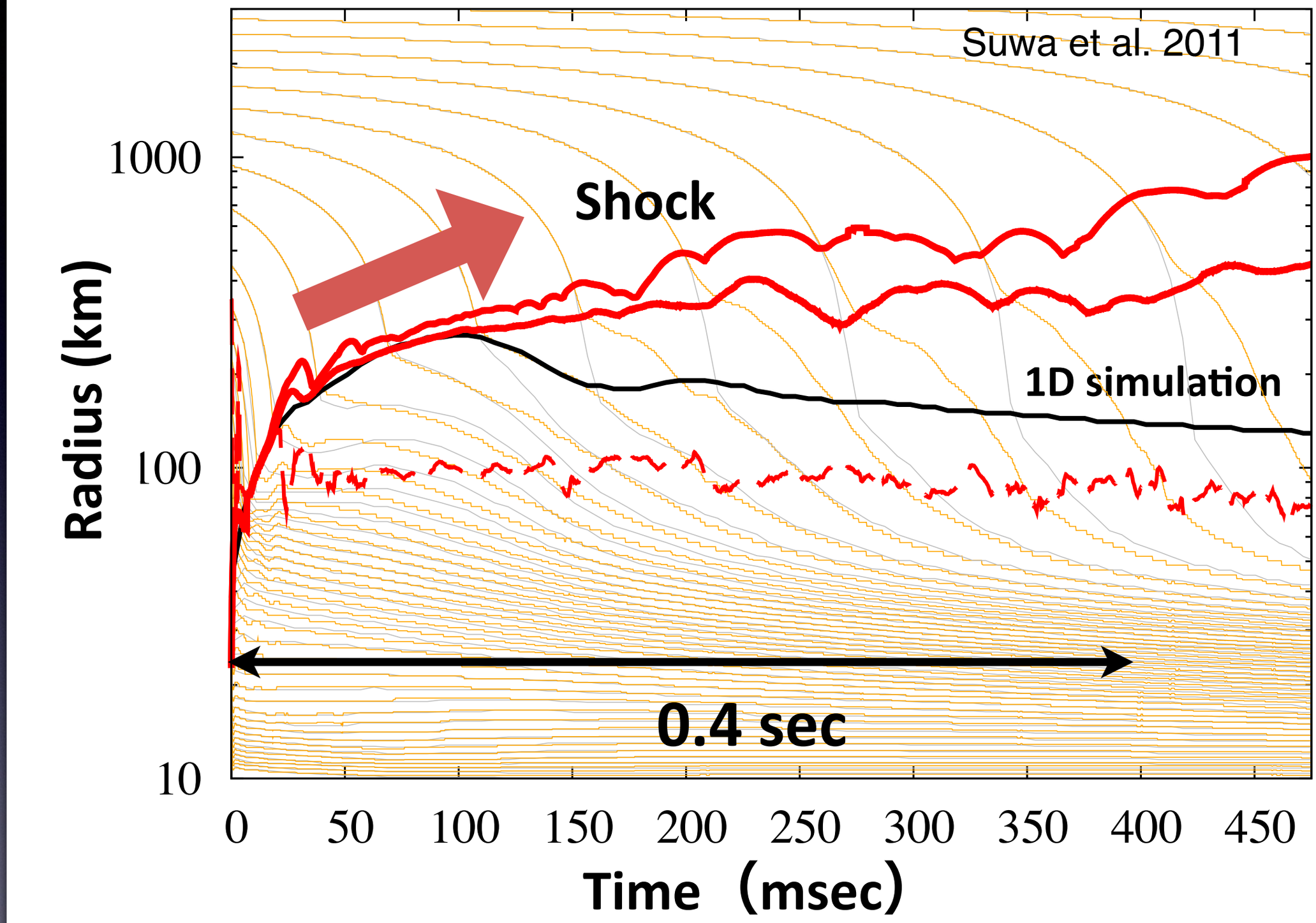
(C) 原子核から読み解く超新星爆発の世界

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



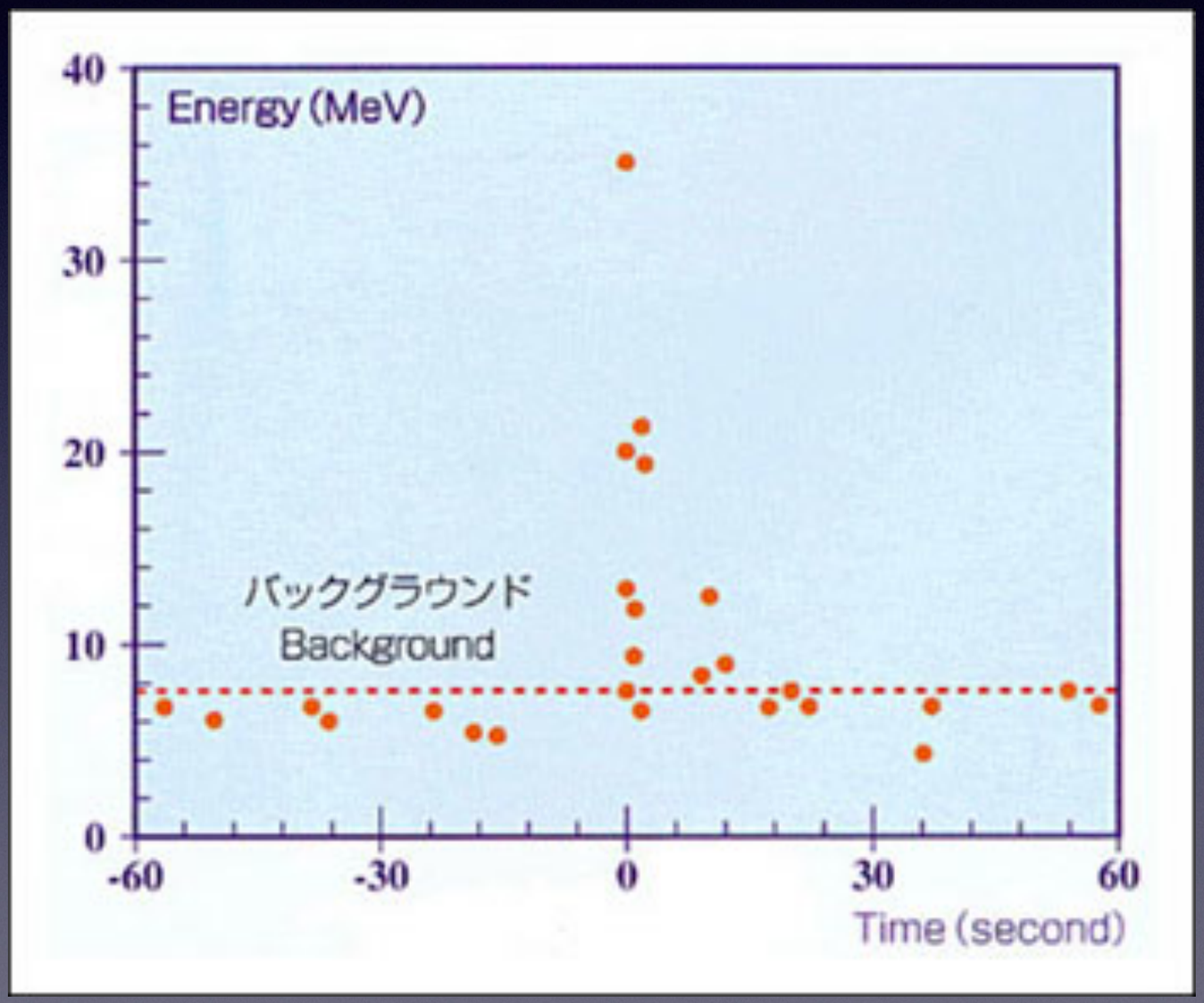


E ~ 10^{50} erg (smaller than observations by 1 order of magnitude)

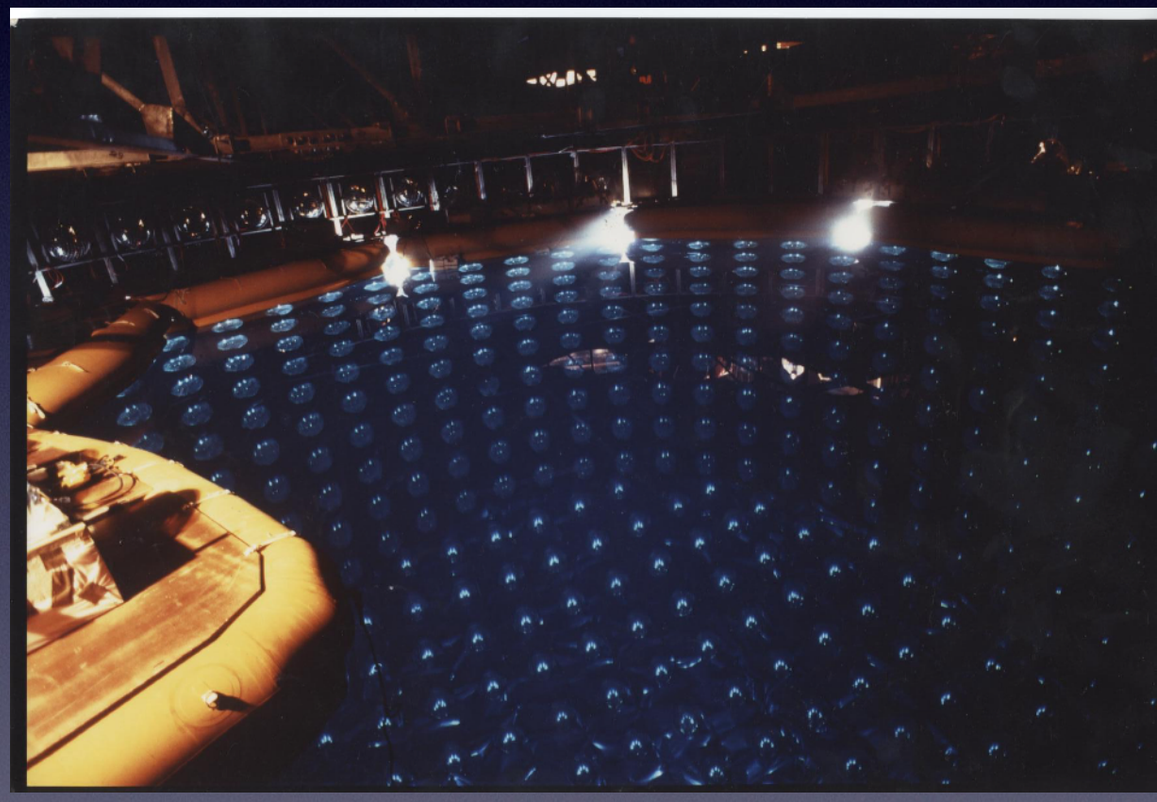
One of the biggest mystery in modern astrophysics

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

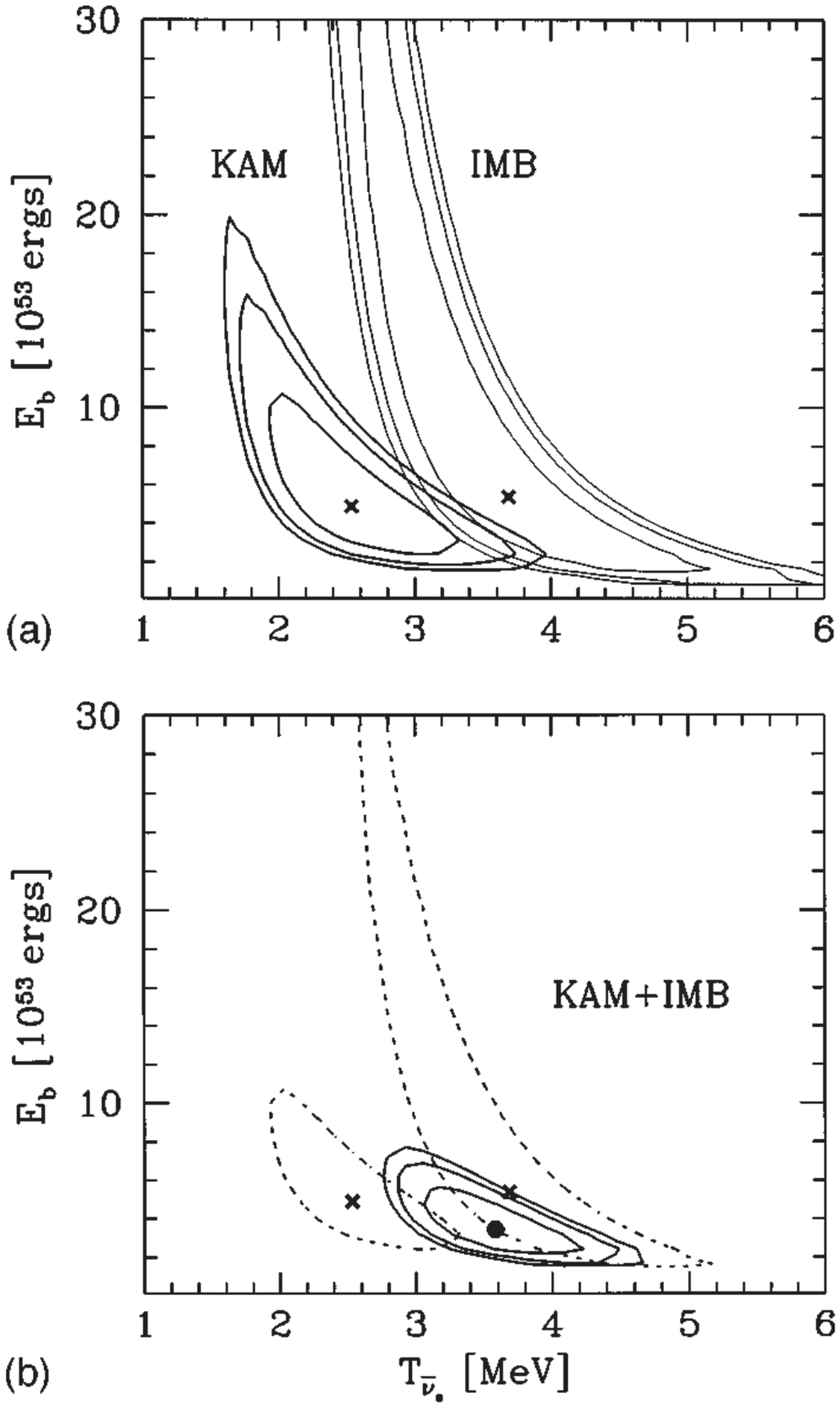
Neutrino detection From SN 1987A



Kamiokande



(C) ICRR



E_{nu} ~ 10^{53} erg!!

=> Foundation of neutrino-driven mechanism

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

Jegerlehner et al. 1996

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

Let’s **understand** these questions
with the word of physics

Knowing ≠ Understanding

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

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**

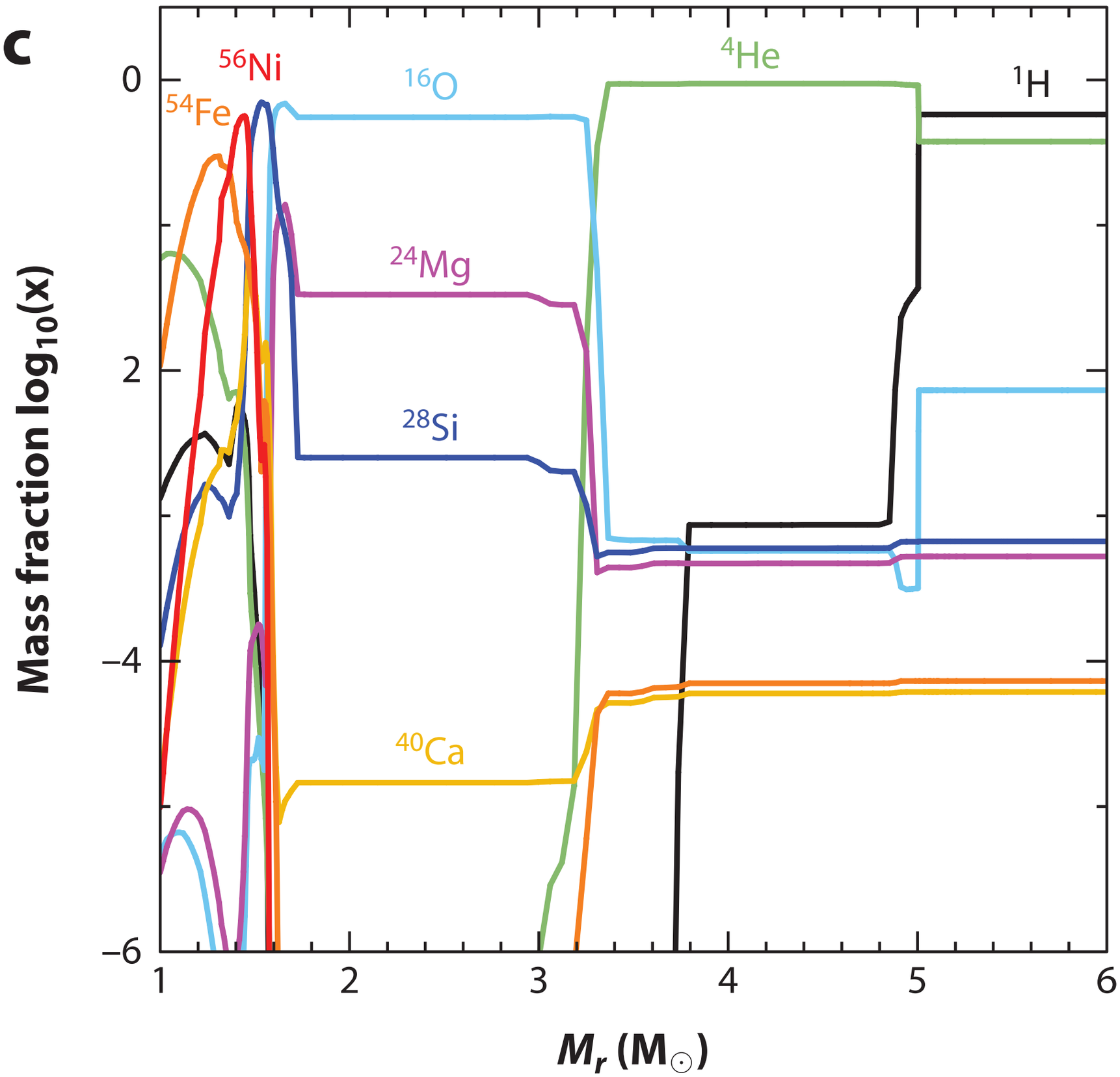
~0.1 sec ~0.1-1 sec ~1 day (~10^5 sec)

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



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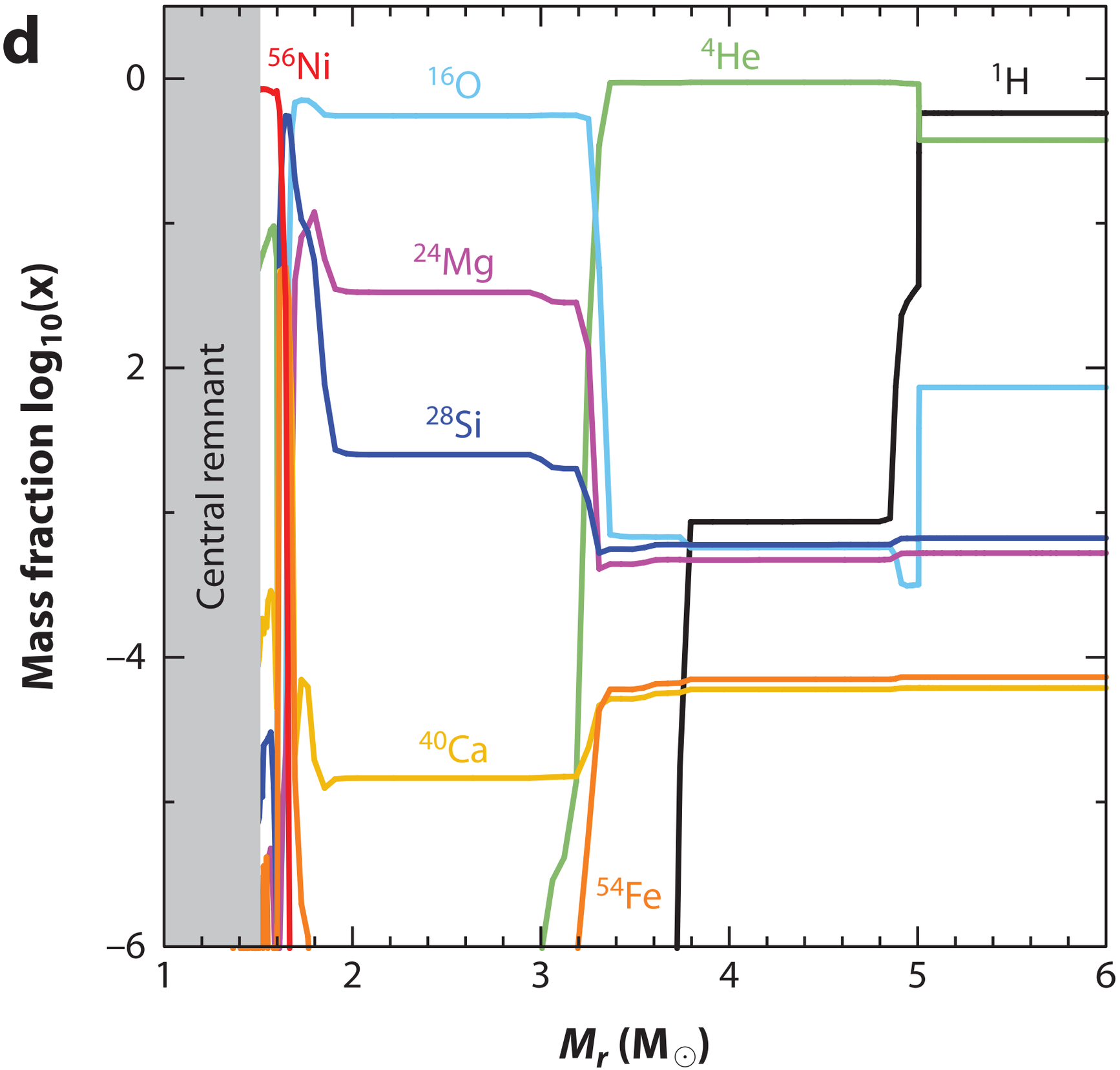
After



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