Constraining the energy growth timescale of a core-collapse supernova explosion by explosive nucleosynthesis products

Ryo Sawada, Keiichi Maeda (Department of Astronomy, Kyoto University)

The explosion mechanism of core-collapse supernovae (CCSNe) is one of the unsolved issues in astrophysics. Focusing on the explosion timescale, we succeeded to constraint on the explosion mechanism;

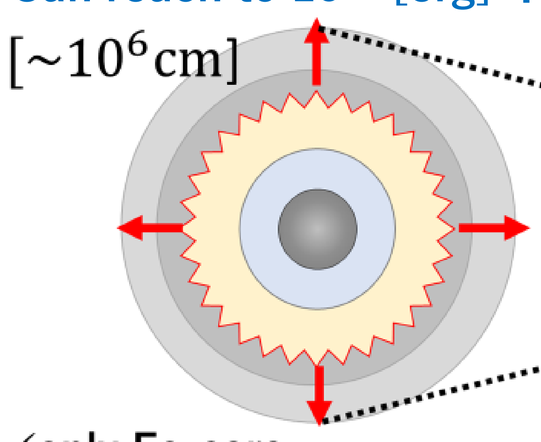
'slow' explosion mechanism ($t_{\rm grow} \gtrsim 1000$ ms) would never explain the obs. of CCSNe

ab-initio v.s. artificial explosion

ab-*initio* calculation

(Takiwaki+ 2014, Nakamura+ 2016)

Can reach to 10^{51} [erg] ?

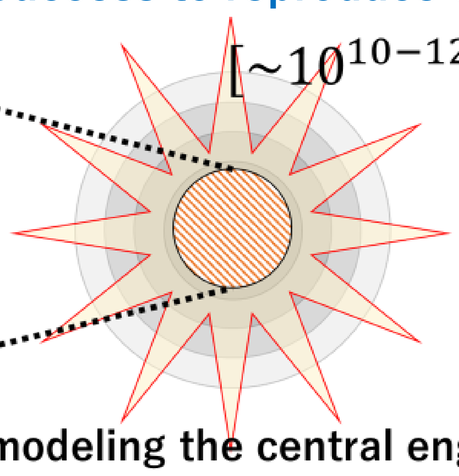


✓only Fe-core

Artificial explosion simulation

(Sukhbold+ 2016, Woosley+ 1995)

Success to reproduce obs.!!



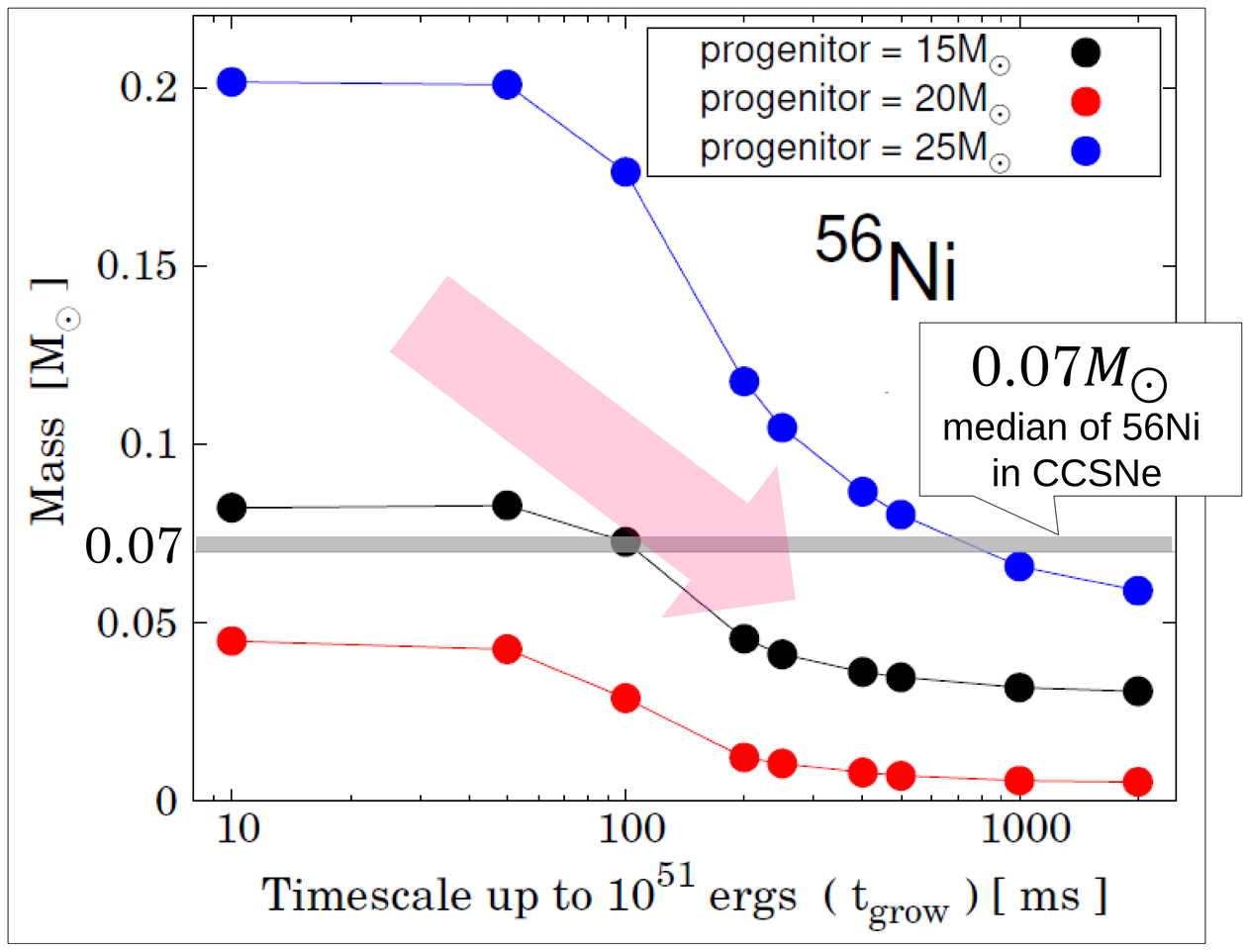
✓modeling the central engine

$t_{\rm grow}$: timescale up to 10^{51}[erg]

suggest 'slow' explosion $[t_{\rm grow} \gtrsim 1{\rm s}]$ ⟷ assuming instant explosion $[t_{\rm grow} \lesssim 100{\rm ms}]$

inconsistent

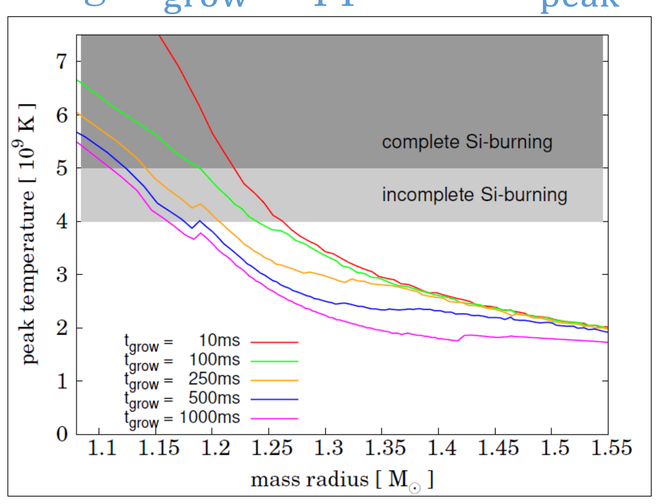
Constraint from 56Ni



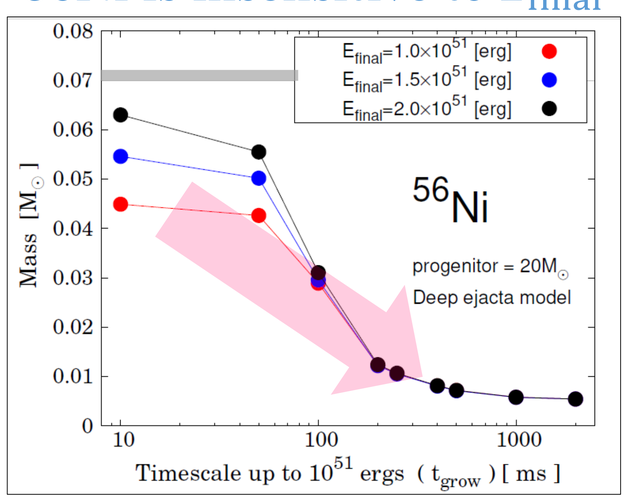
plot : the maximally allowed amount of synthesized isotopes

→ should exceed $0.07M_\odot$, but 'slow' can not !

Because large $t_{\rm grow}$ suppresses $T_{\rm peak}$



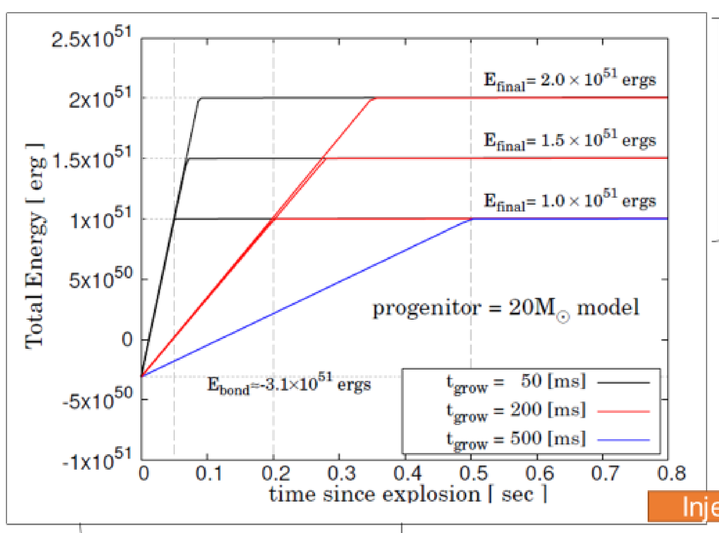
And 56Ni is insensitive to $E_{\rm final}$



→$t_{\rm grow} \gtrsim 1000$[ms] is inconsistent with CCSNe for any progenitor masses and explosion energy

Nucleosynthesis by parametrizing expl.timescale

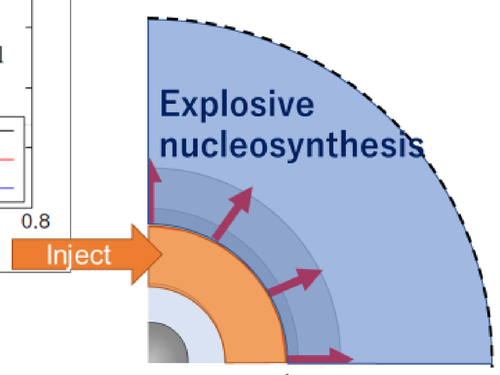
- **Model : Inject explosion energy linearly**



Parameter ① $E_{\rm final}$

Final energy of the explosion

$(1.0 - 2.0 \times 10^{51}{\rm ergs})$



Parameter ② $t_{\rm grow}$

timescale up to 10^{51} ergs $(10 - 2000$ ms$)$

↑ Boundary : Ye<0.48

calculation

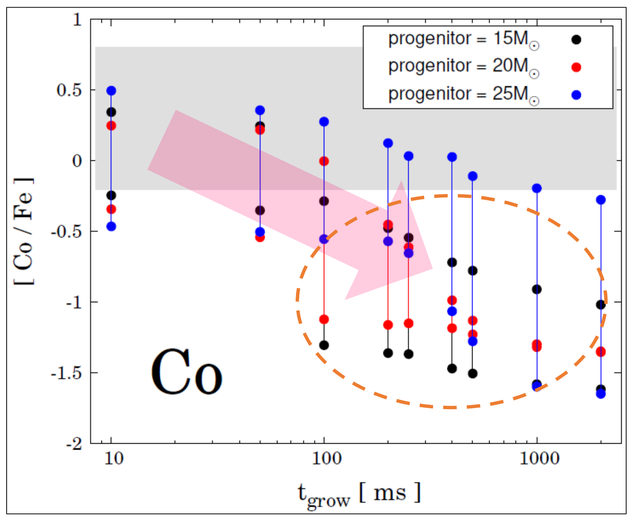
○Hydrodynamics :
- ✓ Newtonian
- ✓ EoS : Helmholtz
- ✓ 21-isotope α-reaction

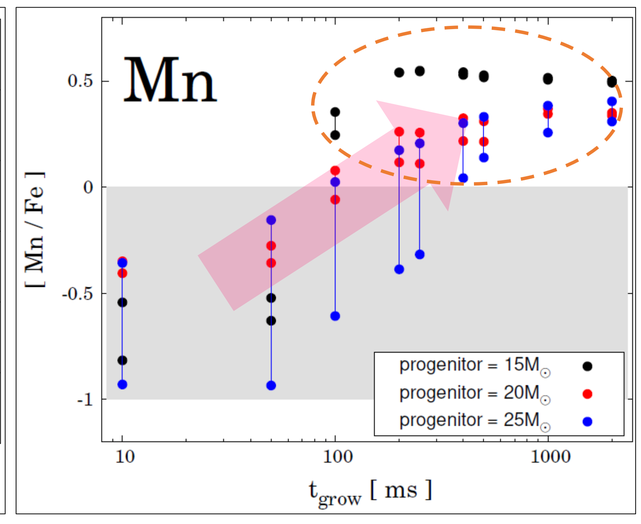
○ Nucleosynthesis :
- ✓ 640-isotopes reaction in post-process

Constraint from [X/Fe]*

∗ $\log_{10}({\rm X/Fe}) - \log_{10}({\rm X/Fe})_\odot$

The slow explosion model deviates from the obs. for "different direction" @ [Co,Mn /Fe]





- If change Ye ↑, $\rm Mn/Fe \approx {}^{55}Co/{}^{56}Ni \downarrow$, $\rm Co/Fe \approx {}^{59}Cu/{}^{56}Ni \downarrow$

(because ^{55}Co, ^{59}Cu = neutron excess!)

→ a better match would never be obtained in the 'slow' model, even if changing progenitor Ye.