Toward multi-messenger observation of core-collapse supernovae from simulations of the central engine

Nakamura et al. 2016 MNRAS, ArXiv: 1602.03028

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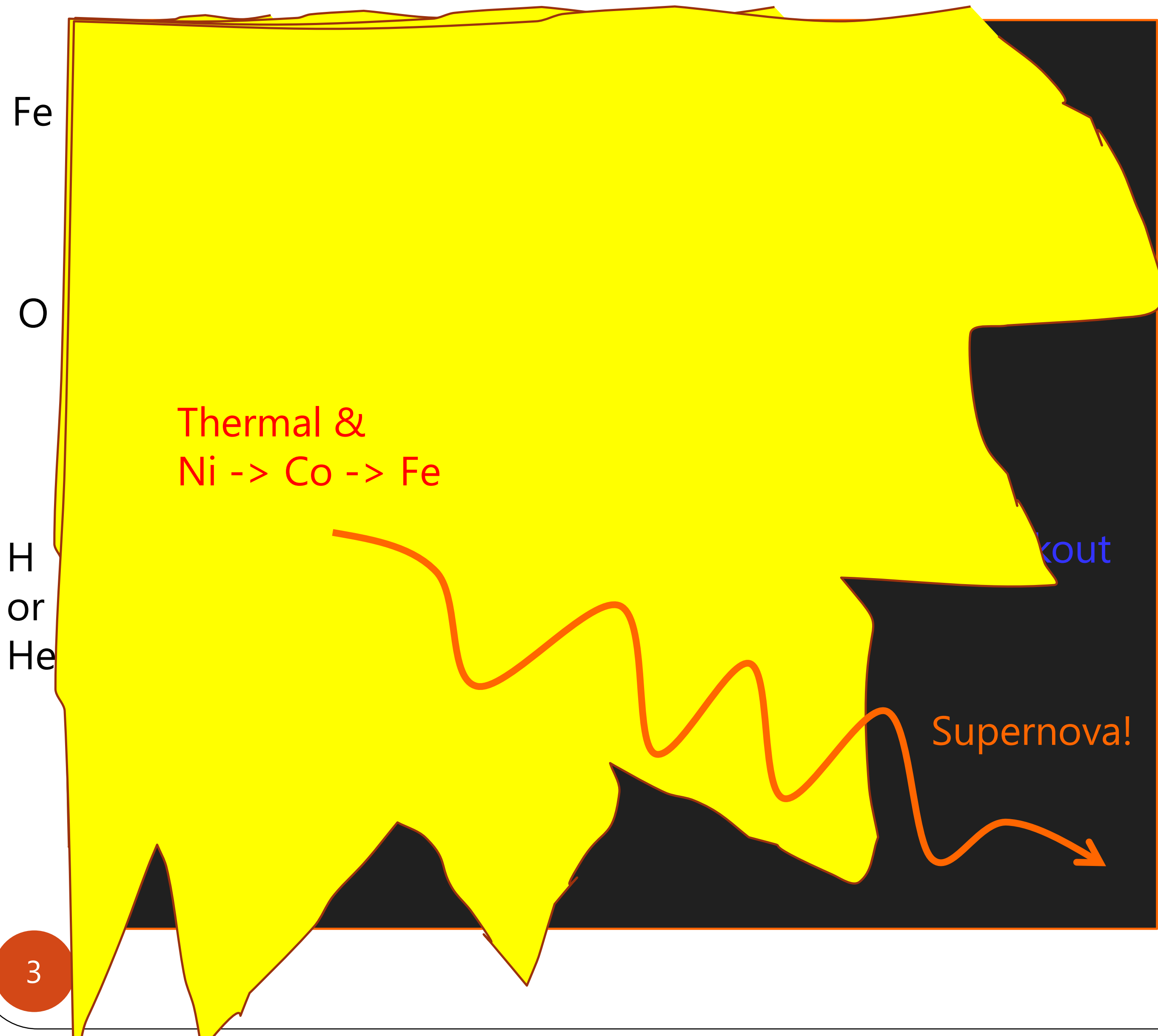
Next Galactic Supernova!

Features

- Rare:
  ~1 in 100 years
- Rich information
  neutrino, gravitational wave, photon
  progenitor's property

To maximize the benefit of such a rare event,
we should consider strategy for the observation
based on supernova simulations.

Multi-Messenger Astronomy of CCSNe



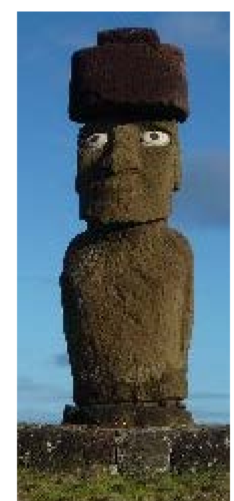
Multi-messengers

GW and ν

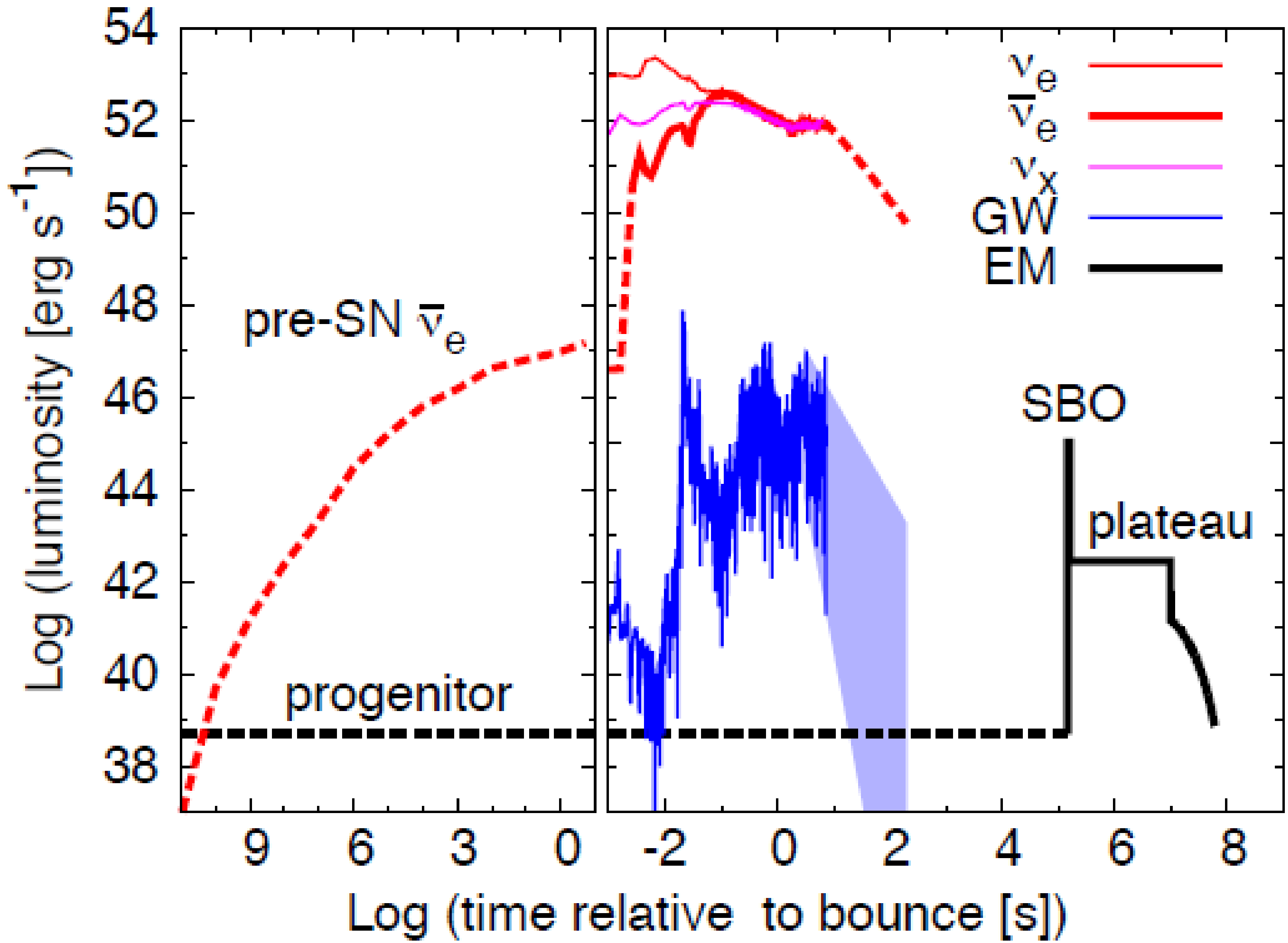
Nucleosynthesis
(Ni synthesis)

Shock breakout

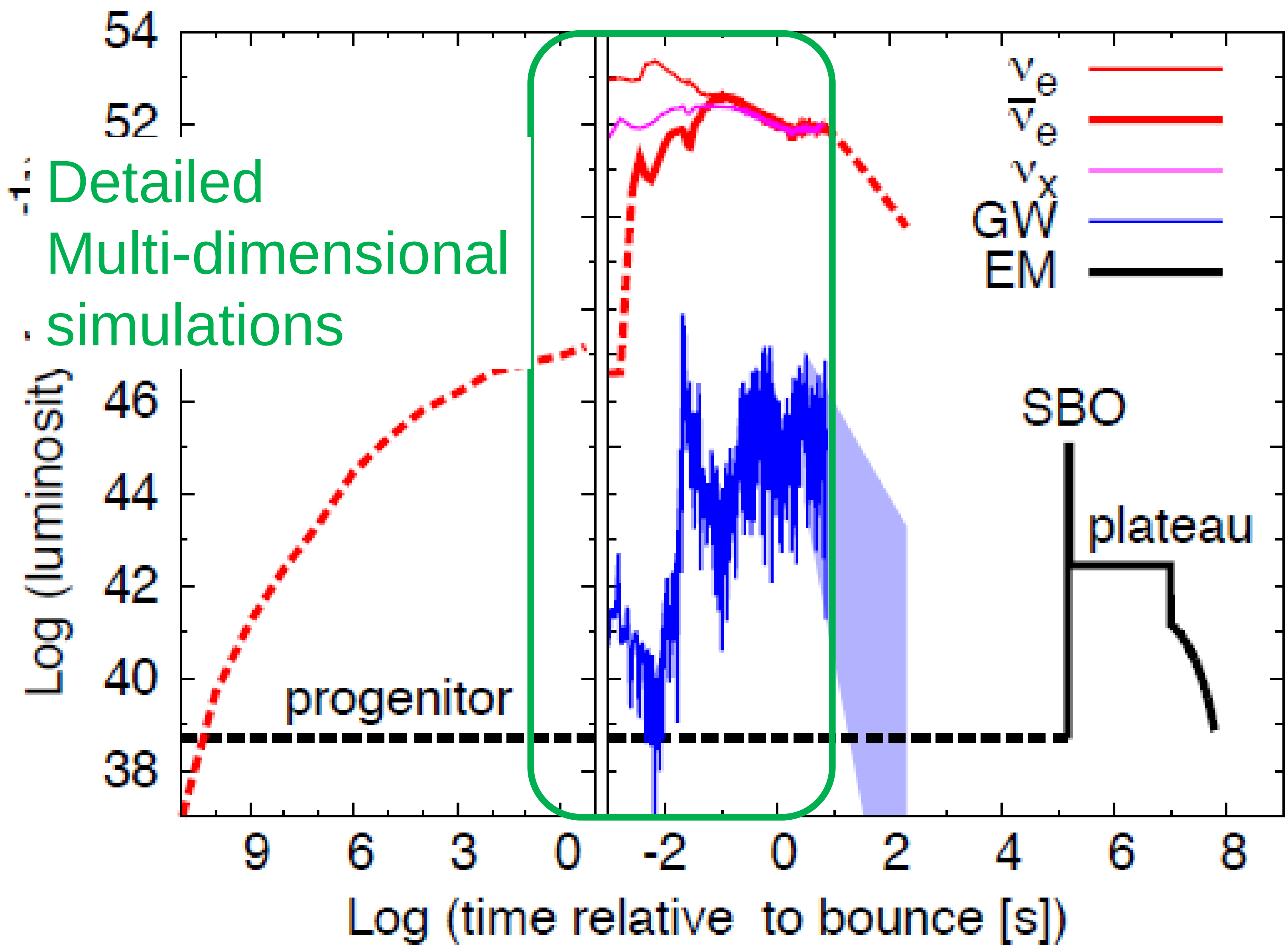
Supernovae



Summary of emitted messengers



Summary of emitted messengers



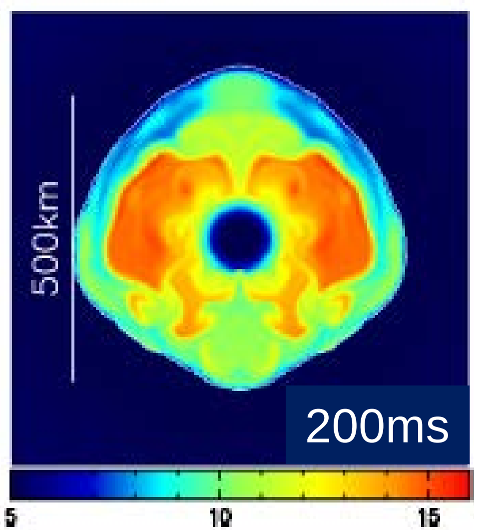
From 1D to 3D

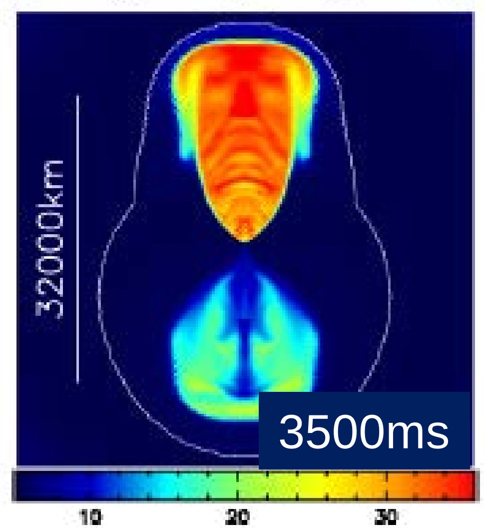
Supernova Modeling

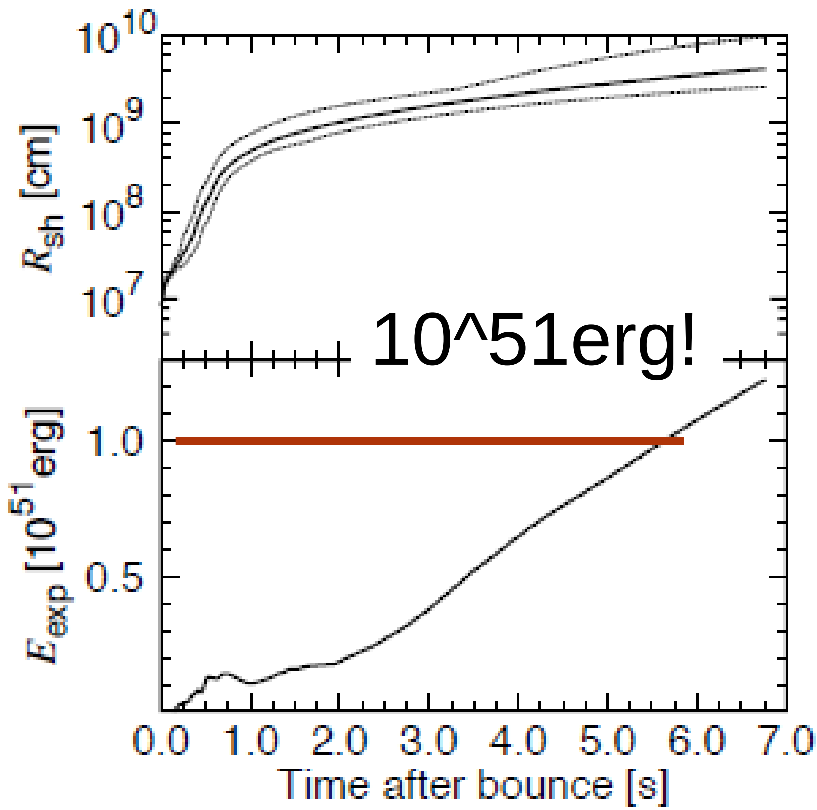
	Time Scale	Neutrino	GW	Photon	Problem
1D	~100s	○	△	○	Phenomenological Explosion
2D	~10s	◎	○	○	Axi-Symmetric
3D	~1s	◎	◎	×	Short time

Neutrino and GW can be calculated in ~1s.
For photon, long term simulation is necessary b.c. amount of explosion energy and Ni mass is not determined in such a short period.

Our model



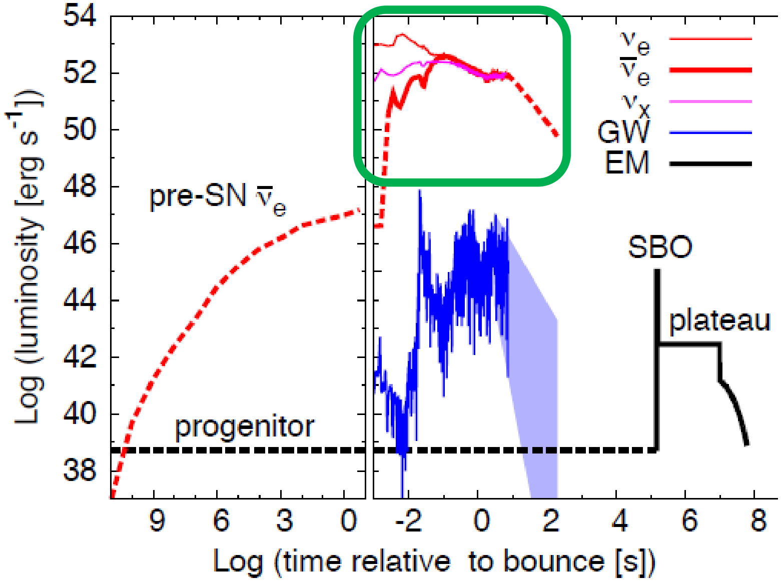


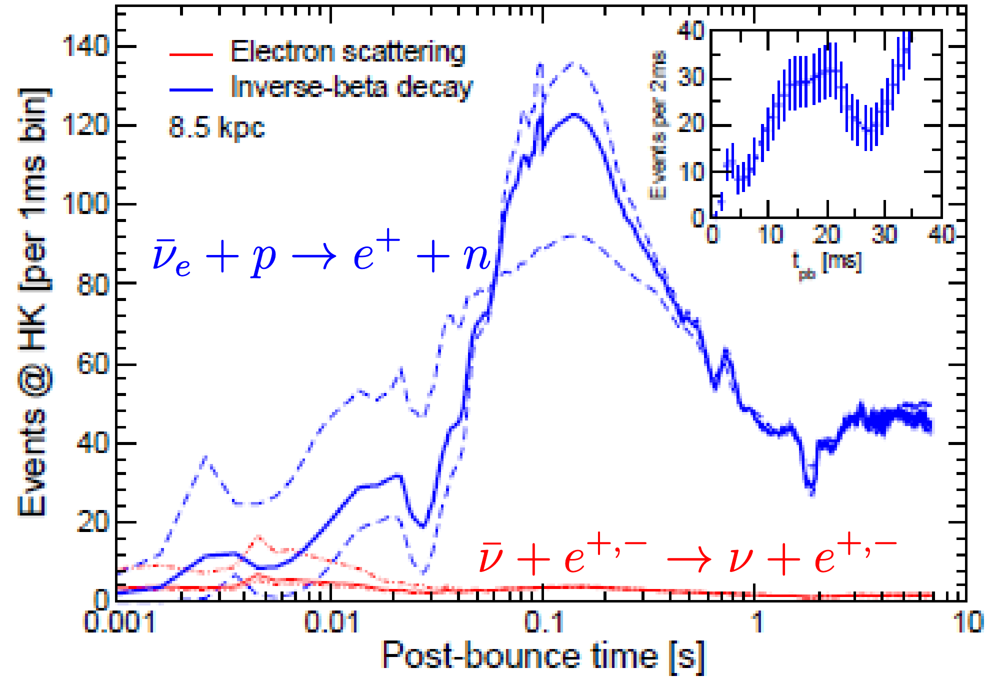


Evolution of Entropy,
Bipolar explosion is found.

Explosion Energy

Neutrino Observations



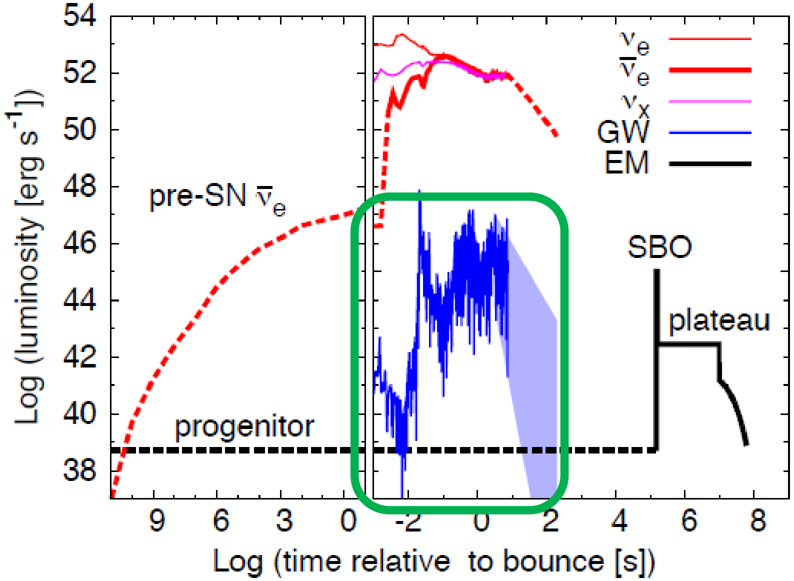


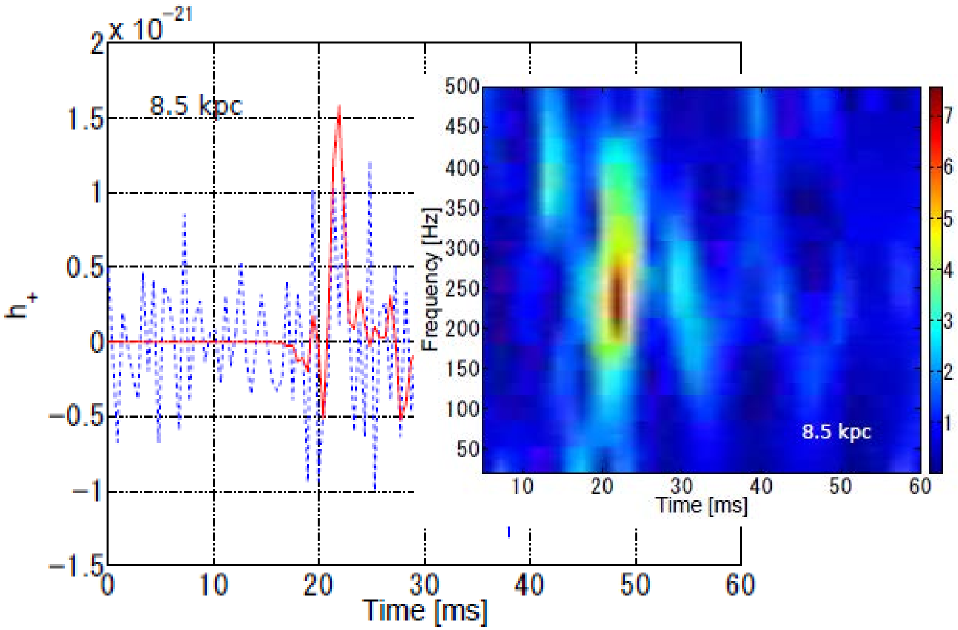
Using Hyper Kamiokande(740kton) or IceCube,

we detects neutrinos.

We can determine time and sky position

GW Observations





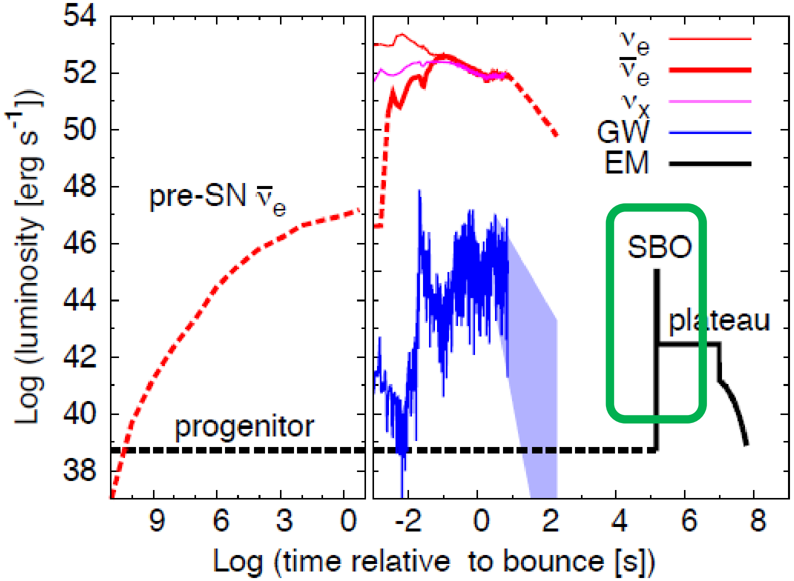
Even at the Galactic center, GW is not so distinct.

This Newtonian model may underestimate the amplitude.

With the help of ν observation, we can know the time of core-bounce.

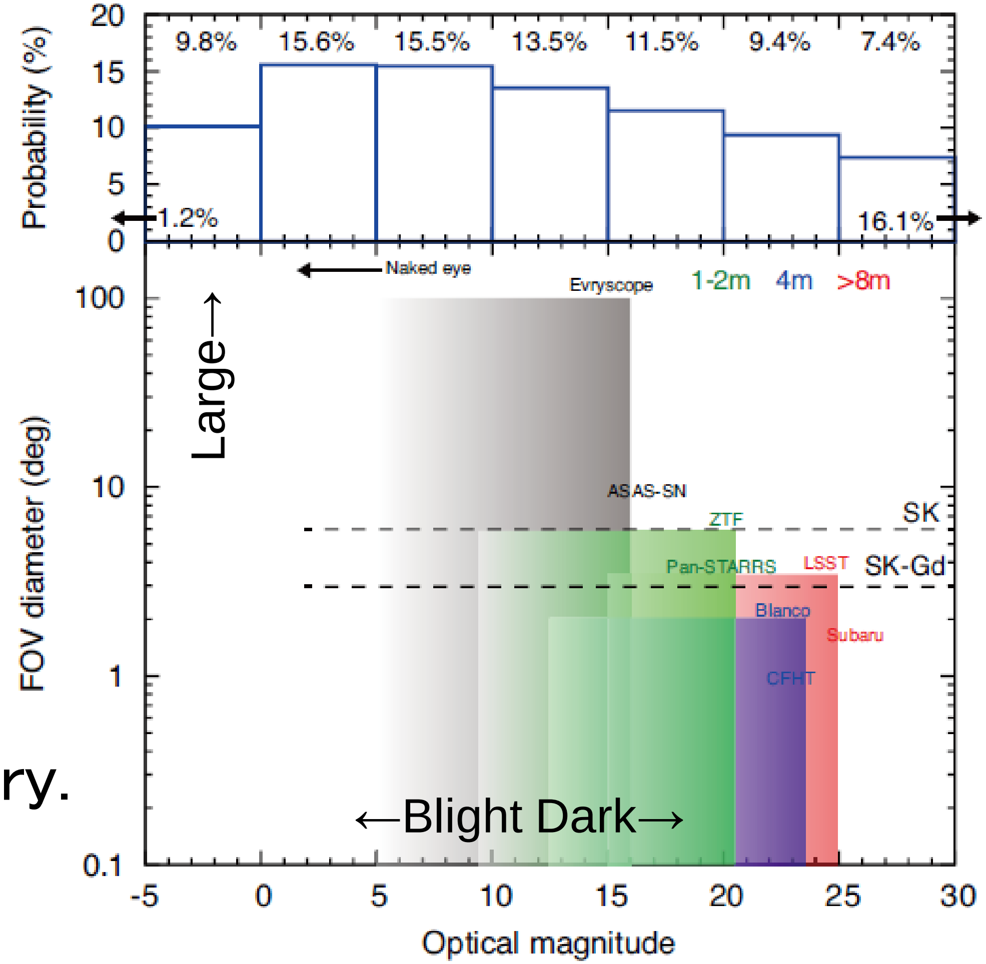
Focusing on that time (and frequency) domain, S/N become ~7.5.

To Observe Shock Breakout

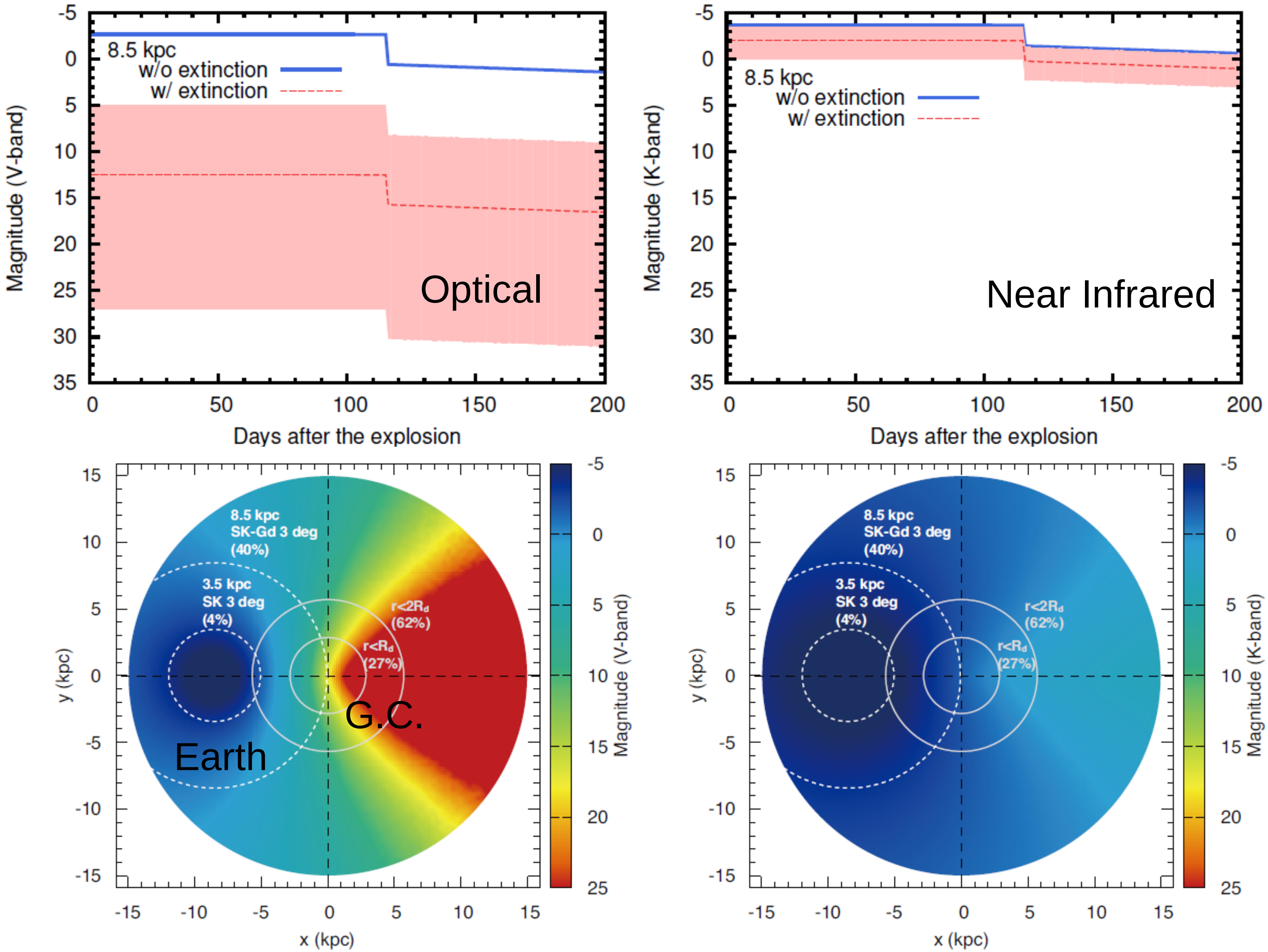


Not to miss SBO,

wide field of view is necessary.



Dust Extinctions

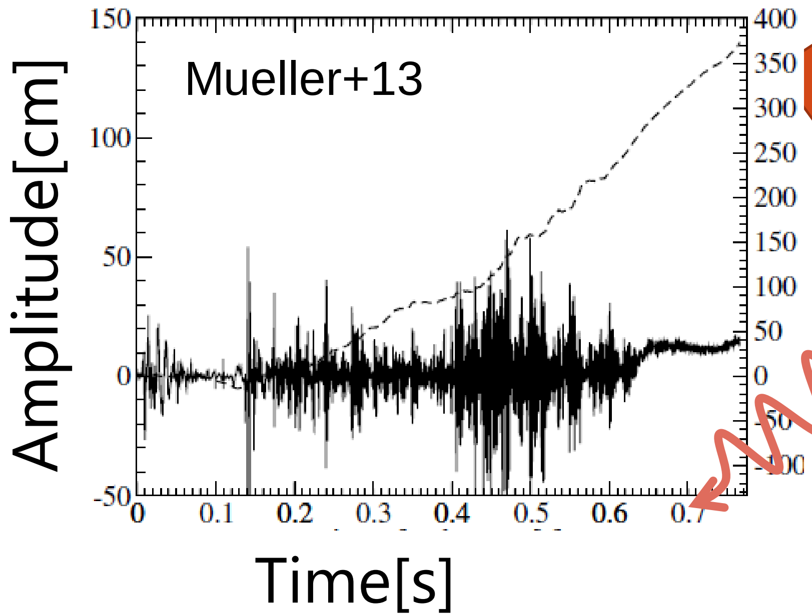


Summary

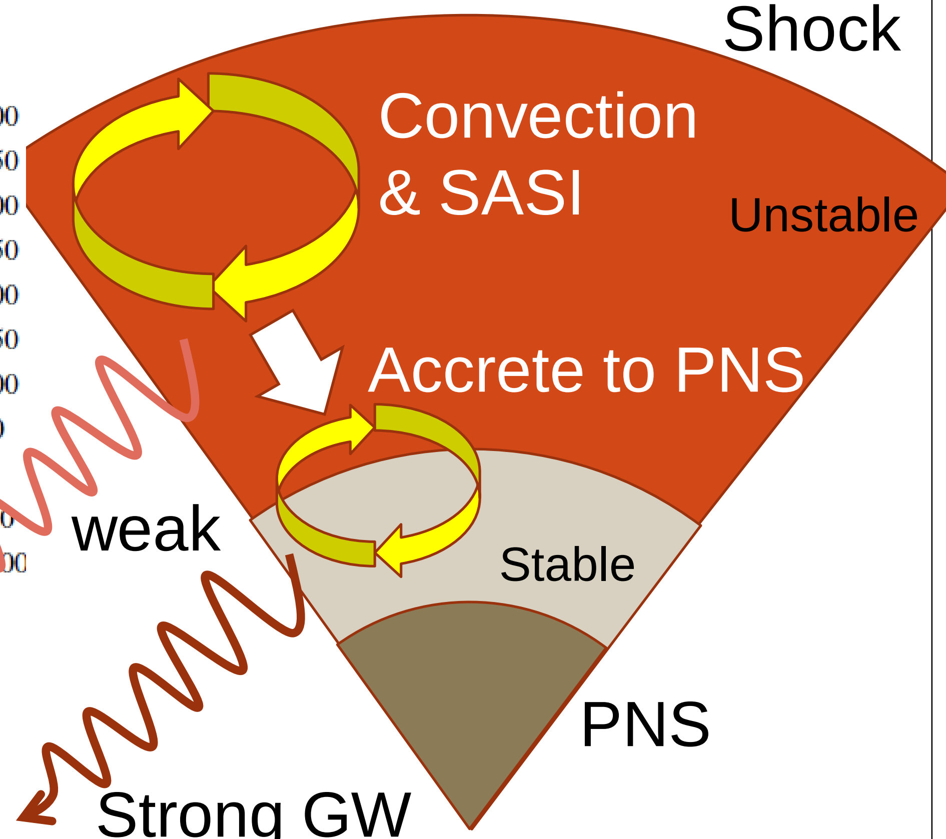
- For next Galactic Supernova we should do our best not to miss it.
- Neutrino plays important role:
  the precise timing and the rough sky position are determined.
- GW can be detected with the help of neutrino that can properly restrict time domain.
- 80% of SBO can be observed in optical telescope of wide field of view (FOV).
  Not to miss the rest 20%, near infrared telescope with wide FOV is necessary.

Gravitational Wave from Convection & SASI

Activity of convection and SASI is printed in the waveform of GW indirectly.



Convection & SASI

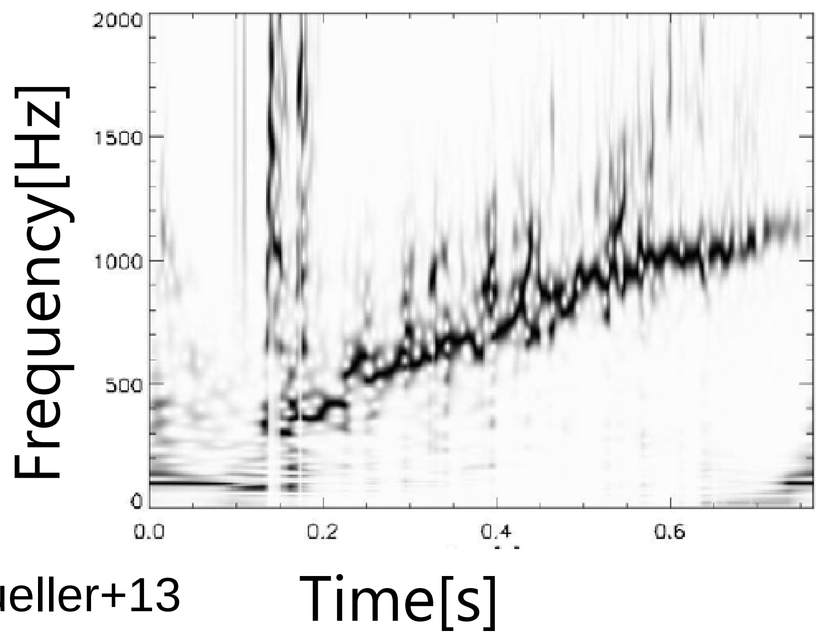


Observation of GW => Explosion mechanism

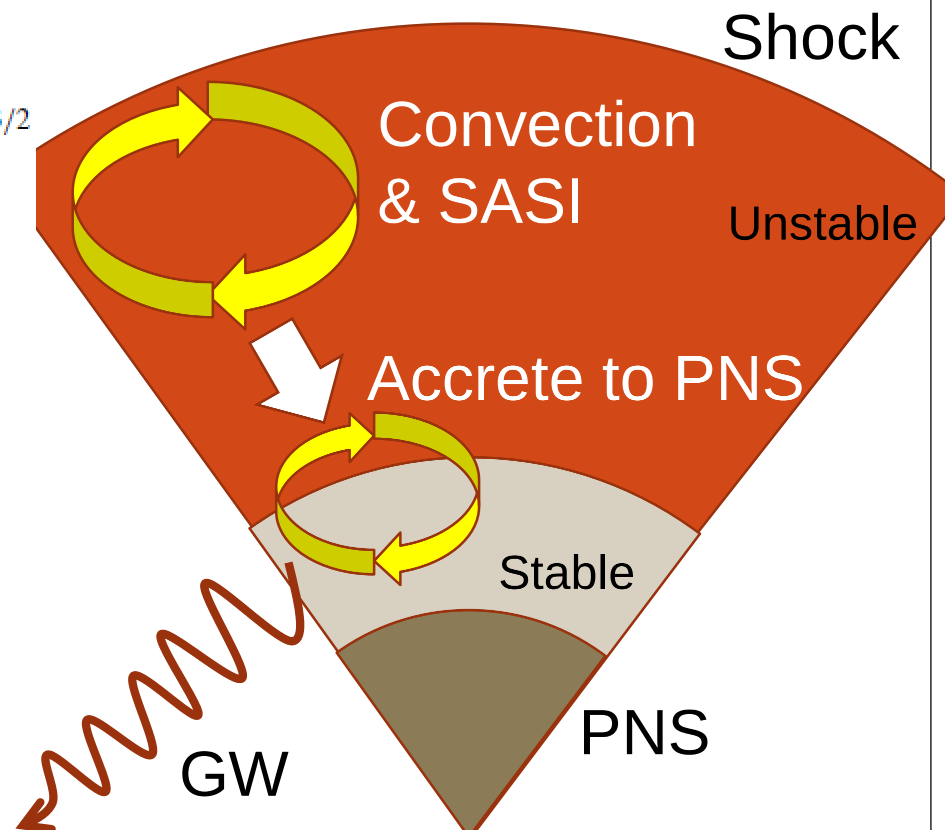
Gravitational Wave from Convection

Mass, radius and temperature of PNS determine the typical frequency.

$$f_p = \frac{N}{2\pi} = \frac{1}{2\pi}\frac{GM}{R^2}\sqrt{\frac{(\Gamma-1)m_n}{\Gamma k_b T}}\left(1-\frac{GM}{Rc^2}\right)^{3/2}$$



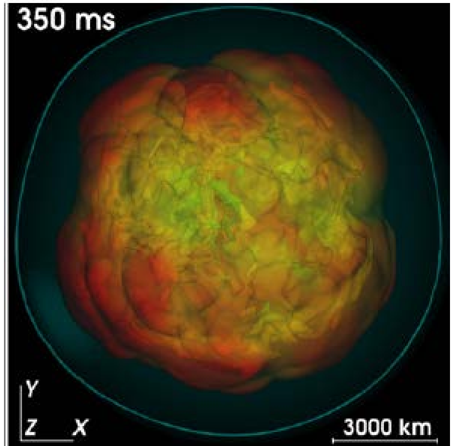
Mueller+13



Observation of GW => property of Proto neutron star

Explosion Models in 3D

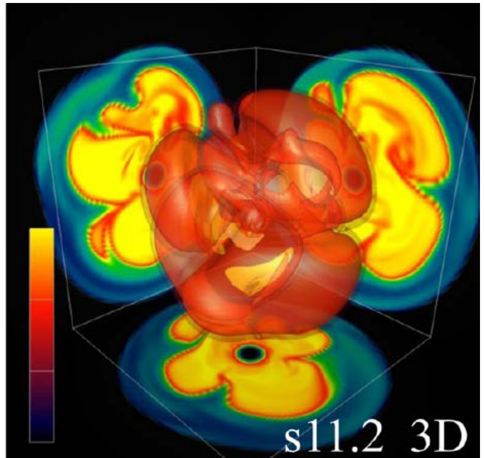
$M < 10M_s$



Melson+15
9.6 M_s
zero metal

Dilute outer layer
Only ν-heating

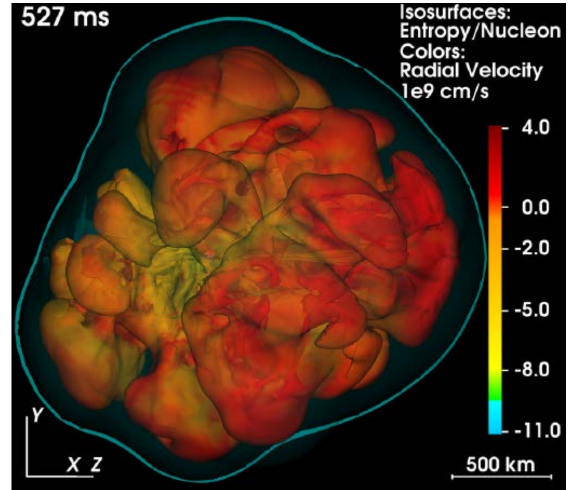
$M < 15M_s$



Horiuchi+14
11.2 M_s

ν-heating and convection

$M < 40M_s$



Melson+15
20.0 M_s

ν-heating, convection and SASI