Pre-supernova neutrinos

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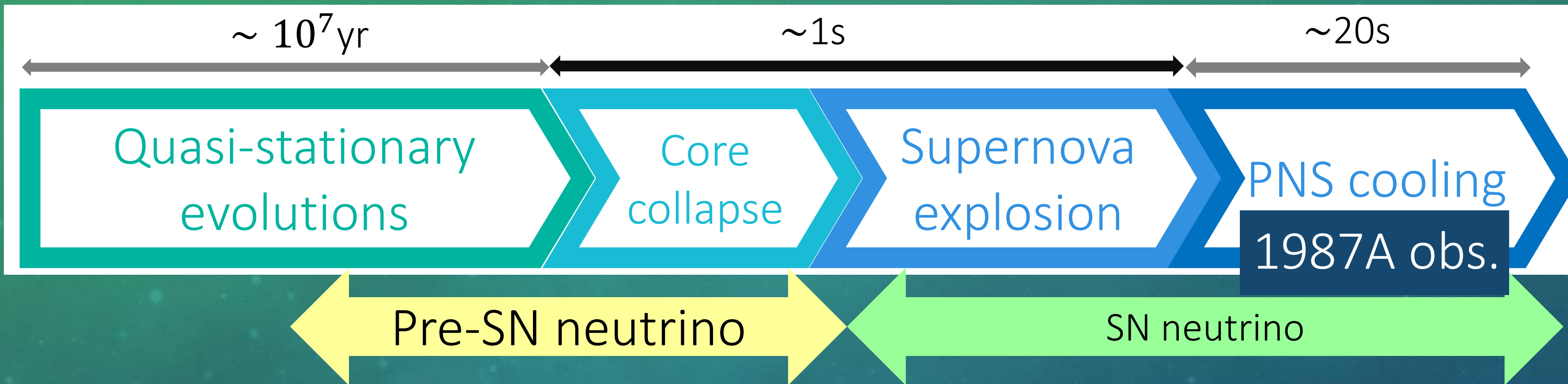
NEUTRINO 2020

Massive star evolution & ν emissions



Pre-SN neutrinos

✓ νs emitted from SN progenitors before core bounce

✓ important factor for stellar evolution

νs can freely escape a stellar core and cool down it

✓ typical average energy: ~ a few MeV ≈ detection threshold

Observation of pre-SN νs has come into view !!

➡ Odrzywolek 2004 first pointed out

Importance of pre-SN ν observation

✓ SN alarm

- pre-SN νs are emitted before SN

✓ Proof of stellar evolution theory

- convection property
- nuclear burning process ➡ shell burning Yoshida 2016
- progenitor type

  ➡ distinction between ECSN & FeCCSN progenitors Kato 2015
- EOS

✓ Neutrino physics

- mass hierarchy ➡ Kato 2017, Guo 2019

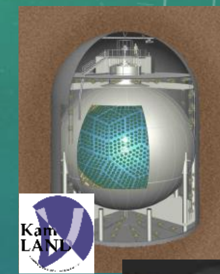
Outline of calculation methods

Stellar evolution calculation
➡ ν emission

1. emission

ν

ν



3. detection

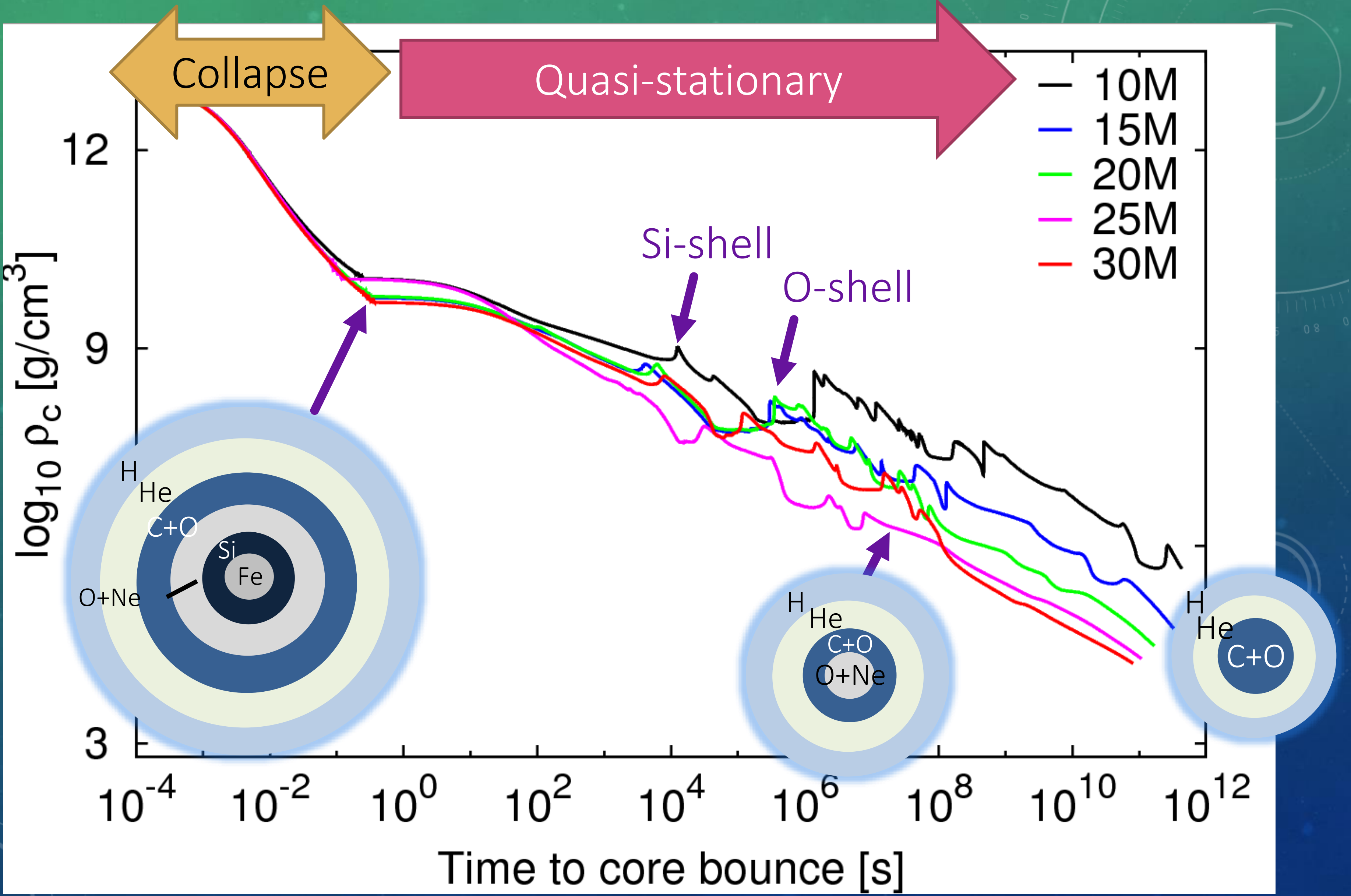
Estimation of ν events
@ detectors

2. propagation

ν oscillation

➡ calculation of ν flux on the Earth

Results of stellar evolution calculations



Yoshida 2019/ Nagakura 2014

Important ν Emission processes

✓ For $\bar{\nu}_e$

- pair annihilation $e^- + e^+ \rightarrow \nu_e + \bar{\nu}_e$

(・plasmon decay $\gamma^* \rightarrow \nu_e + \bar{\nu}_e$ for ECSN progenitor)

- β^-decay $(Z, A) \rightarrow (Z+1, A) + e^- + \bar{\nu}_e$

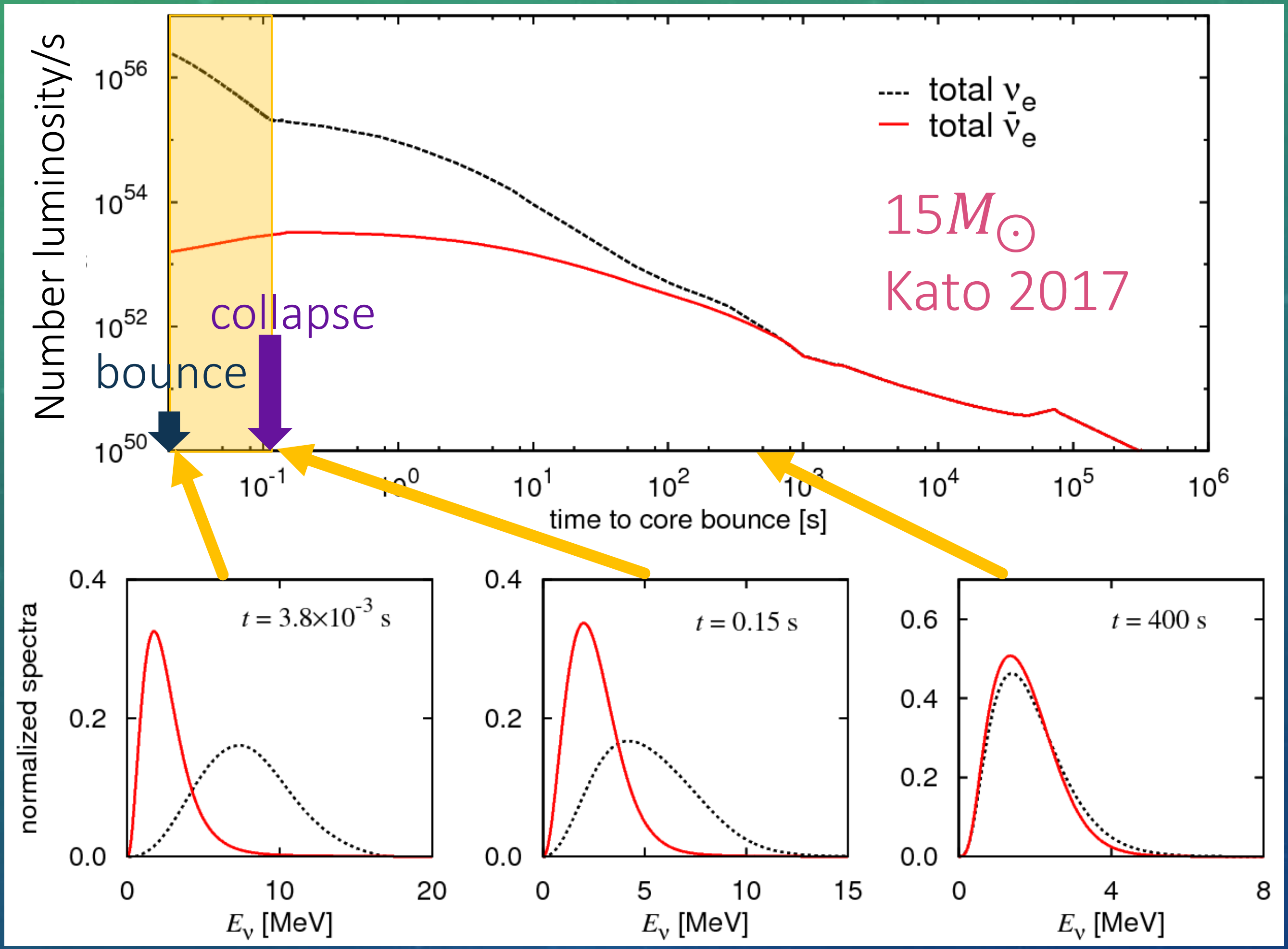
✓ For ν_e

- EC on free protons $e^- + p \rightarrow n + \nu_e$
- EC on heavy nuclei $(Z, A) + e^- \rightarrow (Z-1, A) + \nu_e$

T, ρ, Y_e, X_i are necessary for calculation of ν emission

Odrzywoleck 2004/2007/2009, Kato 2015, Guo 2016, Patton 2017a

Typical lightcurve and spectrum



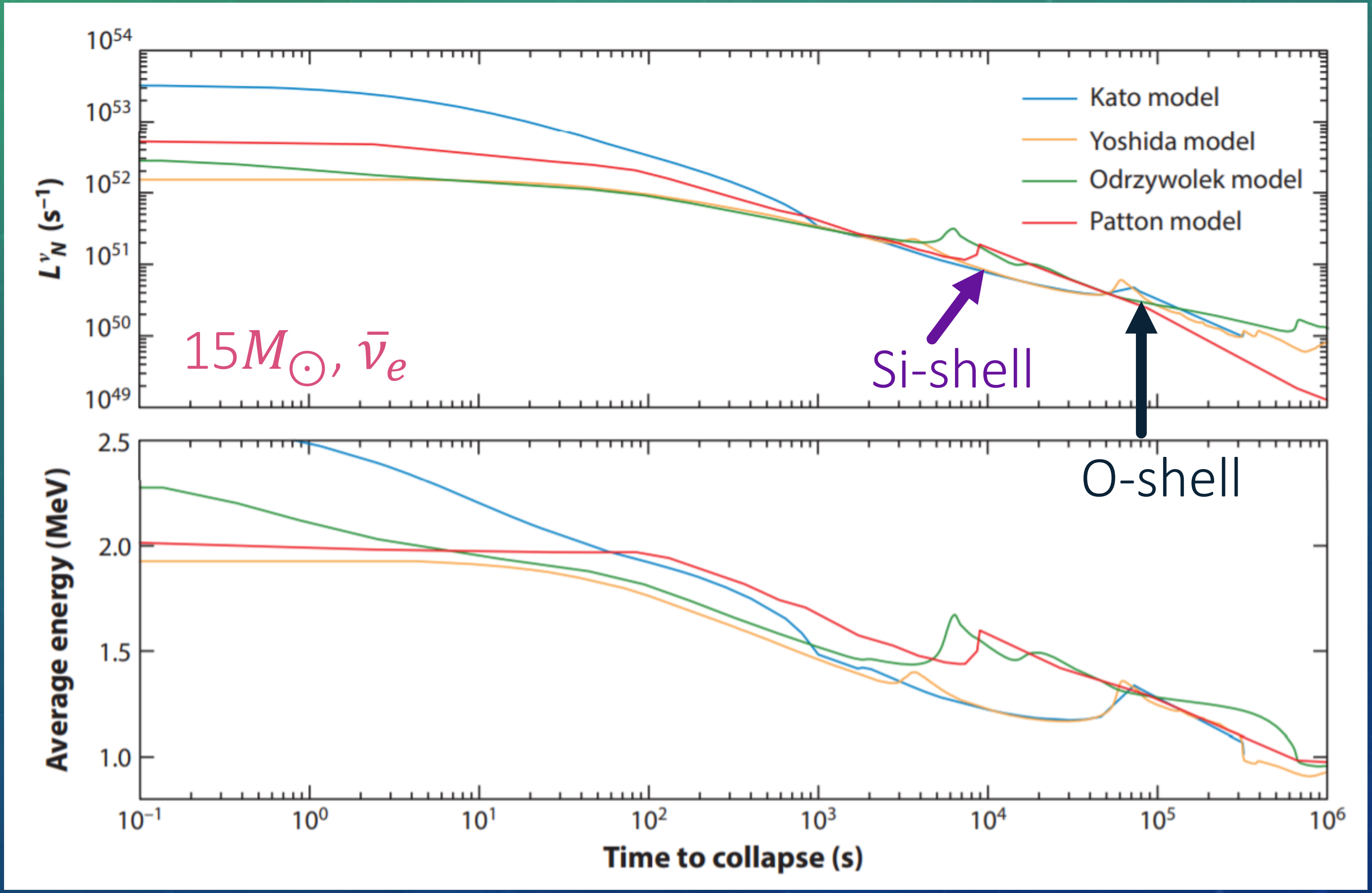
✓ $\bar{\nu}_e$: ~10^{53}/s, ν_e: ~10^{56}/s

✓ $\langle E_{\bar{\nu}_e} \rangle$: ~3 MeV, $\langle E_{\nu_e} \rangle$: ~8 MeV @ core bounce

c.f. SN neutrinos: ~ 10^{58}/s , ~a few tens of MeV

Theoretical uncertainties

Stellar models / Neutrino reactions / Nuclear composition



Odrzywoleck 2010, Yoshida 2016, Kato 2017, Patton 2017a

Estimation of ν events (IBD)

✓ν oscillation: vacuum + MSW

$$F_{\bar{\nu}_e}(E_\nu, t, d) = pF^0_{\bar{\nu}_e}(E_\nu, t, d) + (1-p)F^0_{\bar{\nu}_x}(E_\nu, t, d)$$

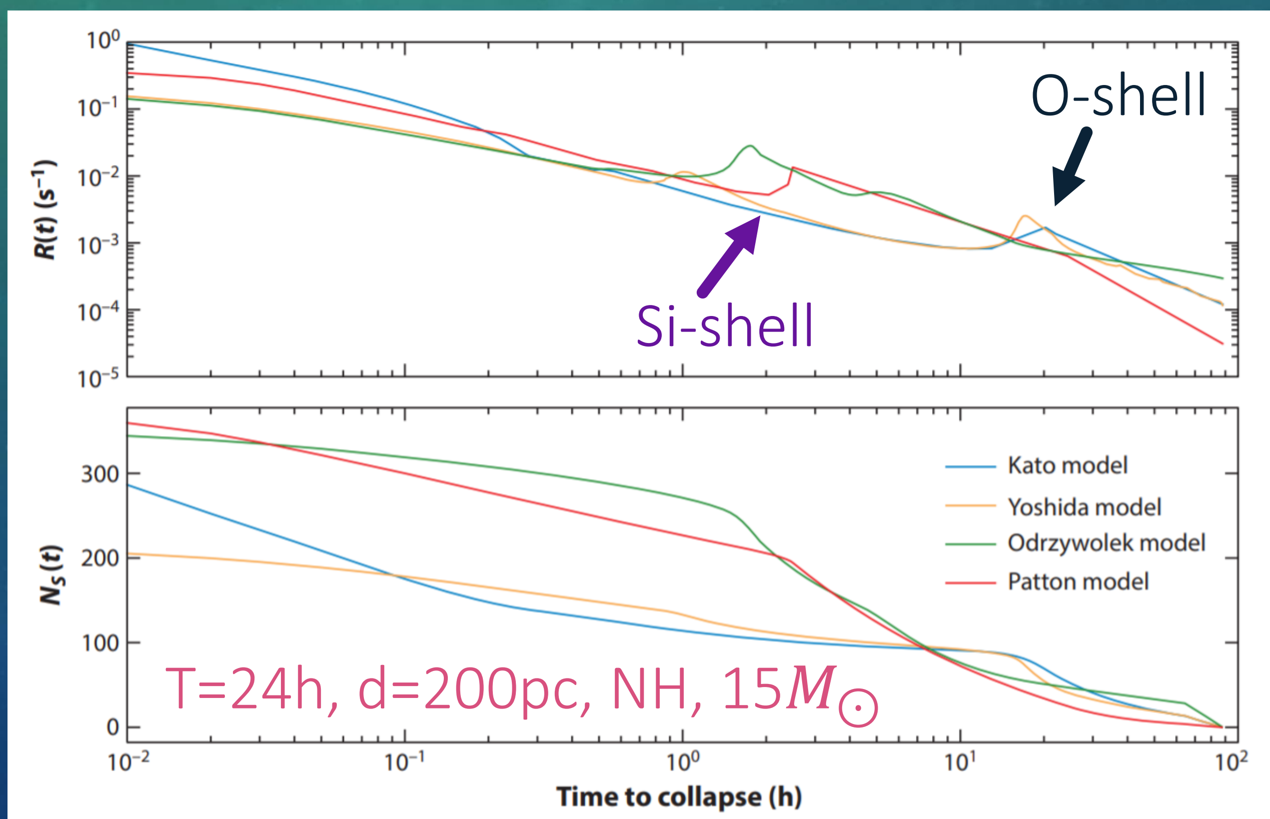
✓IBD events @JUNO

$$R(t,d) = N_P \int F_{\bar{\nu}_e}(E_\nu, t, d)\sigma(E_\nu)\epsilon(E_\nu)\mathrm{d}E_\nu$$

$$\langle N_s(t,d)\rangle = \int_t^{t+T} R(t', d)\mathrm{d}t'$$

Event rate

Integrate event rate



SN alarm

SN rate: only once/century in our galaxy

➡ we must not miss the next near-by SN !

SNν detection will bring many important info.

➡ pre-SN ν detection will be a crucial notification

How far? How early? How well the direction pointing?

SNEWS 2.0

How far?

JUNO results

Poster #11 by Huiling Li

Kato 2020a (3 detectors)

Asakura 2016 (KamLAND)

Simpson 2019 (SK-Gd)

Li 2020 (JUNO)

NO, $15 M_{\odot}$

※ uncertainty: Pre-SN ν model / BG condition

Candidate stars

Given by S. Horiuch based on Nakamura 2016

Candidate stars

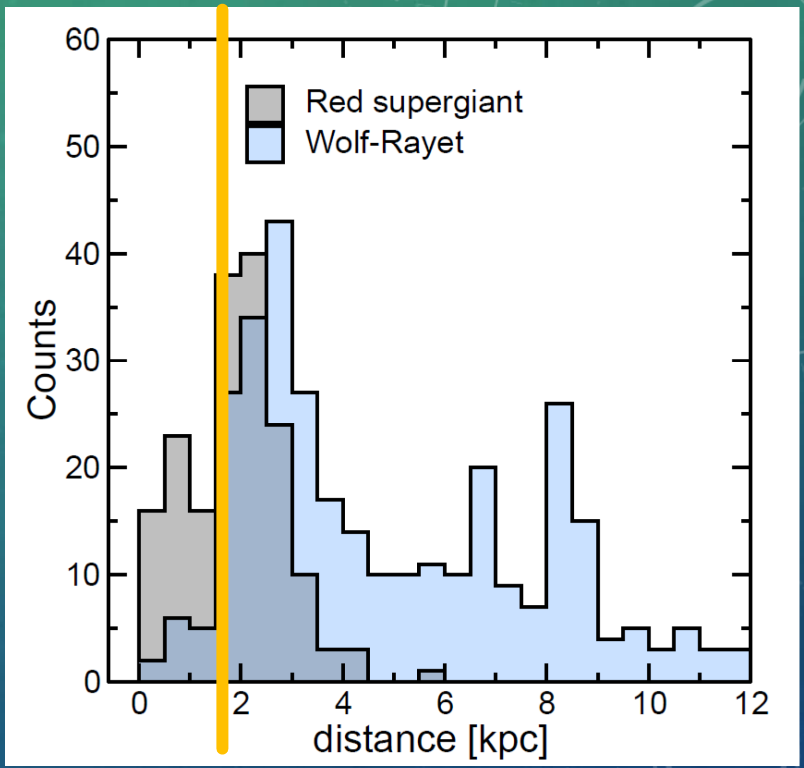
$\lesssim 40$ (d < 1kpc)

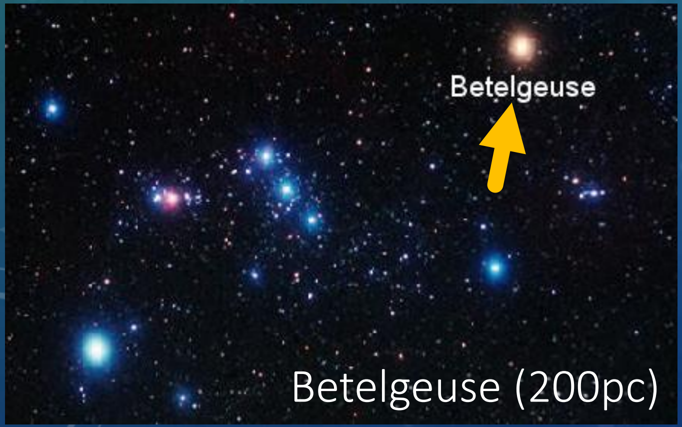
Their initial masses are highly uncertainty

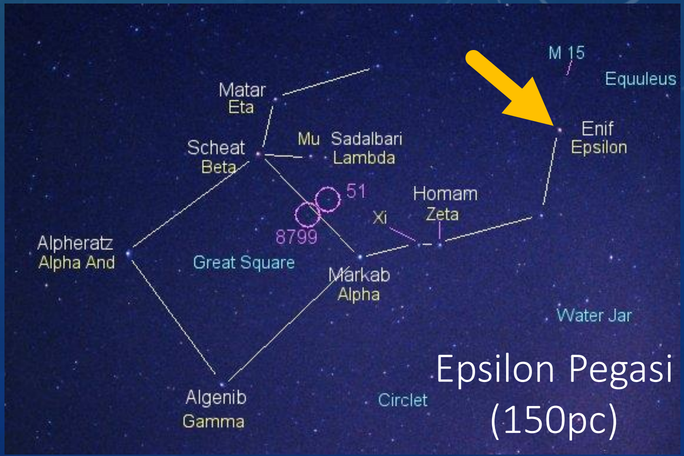
Suggestion of mass independent analysis

$(\varrho_c, T_c, Y_{ec}\ vs$ Pre-SNν lum.)

➡ Kato 2020b







How early?

Kato 2020a, Asakura 2016, Simpson 2019, Li 2020

$15M_{\odot}$, d = 200pc, NO

※ uncertainty: Pre-SN ν model / BG condition

Quasi-stationary evolutions → Core collapse → SN

t=34-76hr

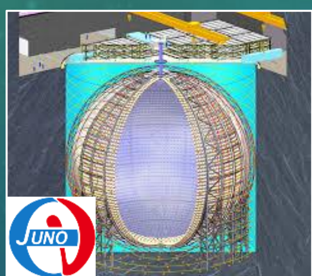
t=7.5-38hr

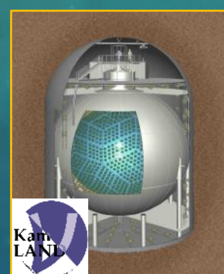
t=0.2-6.5hr

$t = 0$

~200ms ν burst

$\bar{\nu}_e$





t=a dozen hrs

300t-class Ar detector

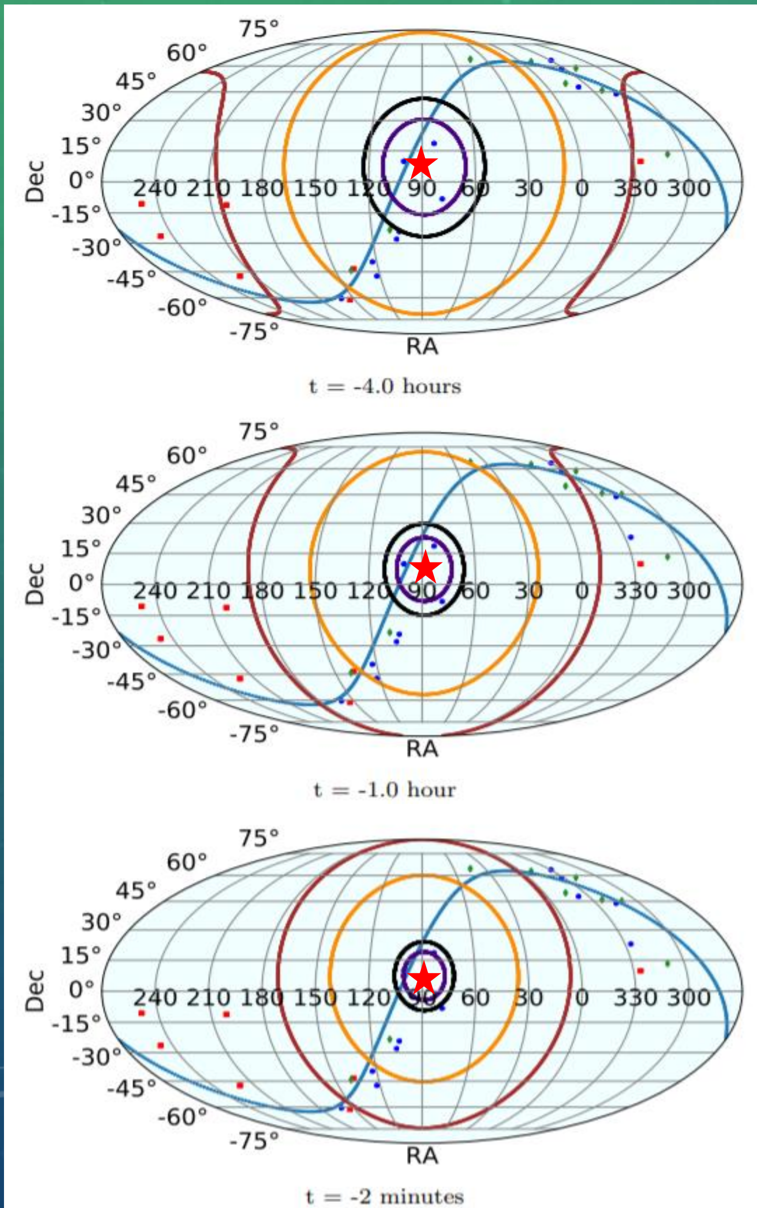
$\bar{\nu}_e \nu_e \nu_x$

t=a few mins

ν_e

DUNE: Kato 2017, Patton 2017b DM experiment: Raj 2020

How well the direction pointing?



t = -4.0 hours

t = -1.0 hour

t = -2 minutes

✓Anisotropy in IBD

✓Li-LS will make better

✓Reduced to a few candidates before a few hours

	LS		LS-Li	
Time to CC	68% C.L.	90% C.L.	68% C.L.	90% C.L.
4.0 hr	78.43°	116.17°	23.24°	33.98°
1.0 hr	63.92°	98.42°	15.47°	22.26°
2 min	52.72°	81.79°	11.63°	16.67°

Betelgeuse SN @ JUNO

Patton model, d=222pc, NH, $15M_{\odot}$

Li 2020, Mukhopadhyay 2020

Summary & Future prospects

Summary

✓New astronomical target: pre-SN νs
➡ Neutrinos emitted from SN progenitors

✓Pre-SN νs will provide us important info.
➡ SN alarm, Proof of stellar evolution theory, ν physics

Future prospects

✓Sensitivity of pre-SN νs to stellar uncertainties
overshooting parameter, metallicity, EOS etc..

✓Formation of combined alert system
multi-flavor analysis, follow-up pipeline etc...

Thanks for your listening!

ご清聴ありがとうございました！

Related posters

Poster #11 by Huiling Li

Early Warning from the Detection of Pre-supernova Neutrinos in Future Large Liquid-scintillator Detectors