Neutrinos from Presupernova Stars

Presuprenova neutrino events relating to the final evolution of massive stars,
PRD ***93****, 123012 (2016); arXiv:1606.04915*

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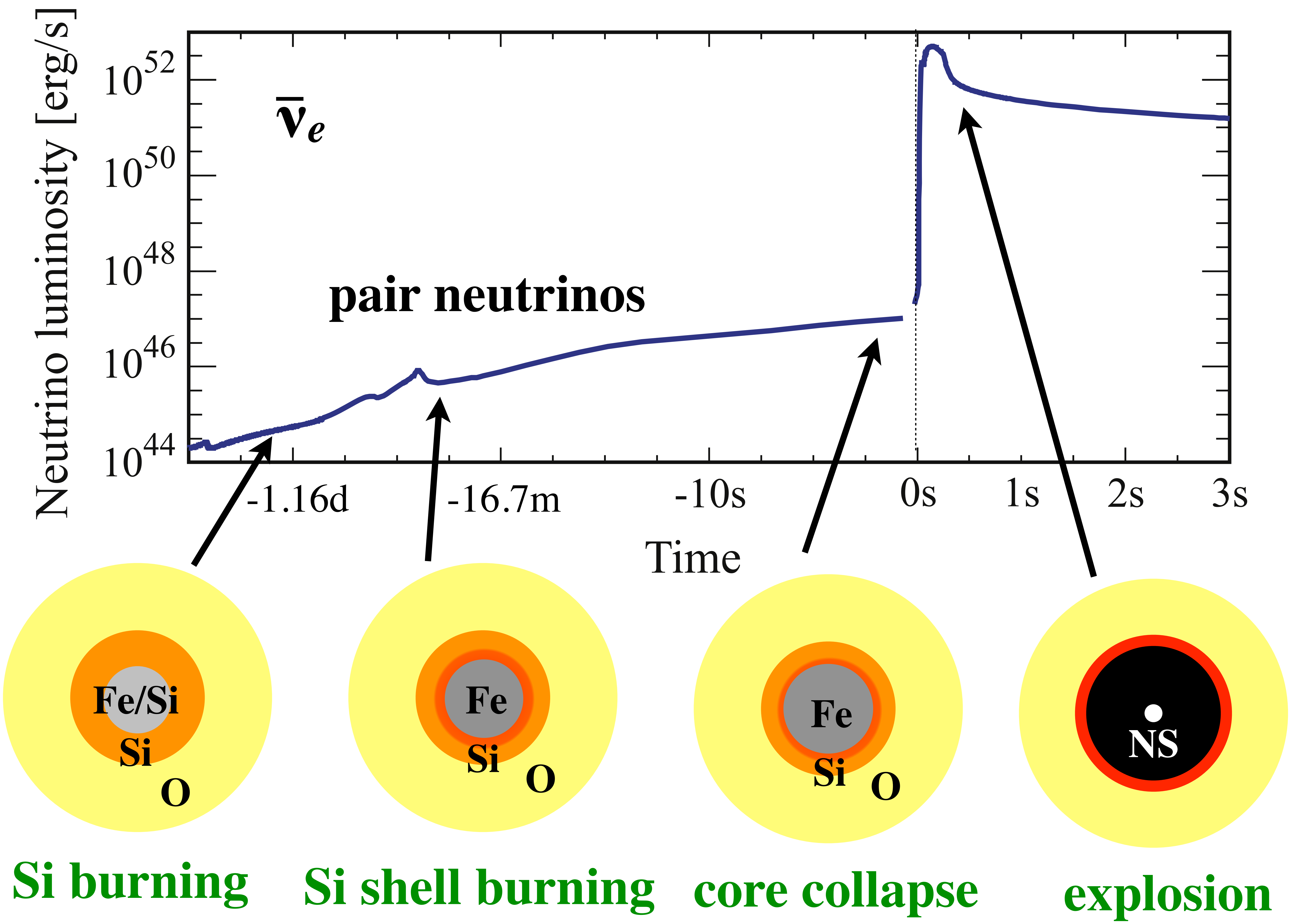
Neutrinos from Presupernova Stars



Asakura et al. (2016): fixed

- **PreSN neutrinos from a neighboring SN (at hundreds pc) are detectable.**
  e.g., Antares (150 pc), Betelgeuse (~200 pc)

(e.g., Odrzywołek et al. 2004; Misiaszek et al. 2006; Kato et al. 2015; Asakura et al. 2016; Yoshida et al. 2016; Patton et al. 2017; Kato et al. 2017)

Neutrinos from Presupernova Stars

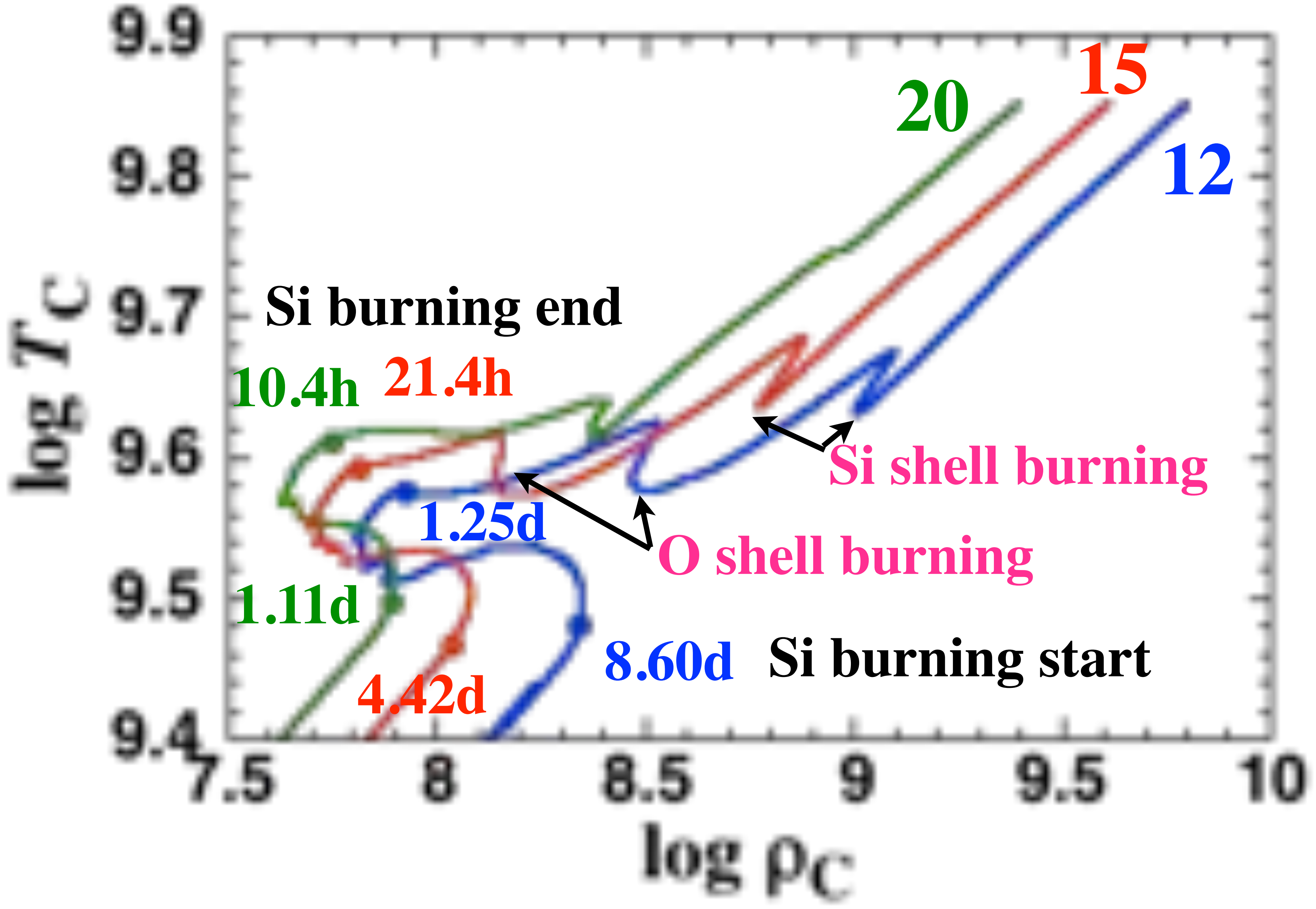
- Neutrino emission from Si burning until core-collapse
  - 12, 15, 20 $M_\odot$ star models
  - Neutrino emission through pair neutrino process
    - ➡ Neutrino spectrum evolution
  - Neutrino detection by current and future neutrino detectors

$p + \bar{\nu}_e \rightarrow n + e^+$
$(E_{th,\nu} = 1.8$ MeV$)$

➡ Neutrino events

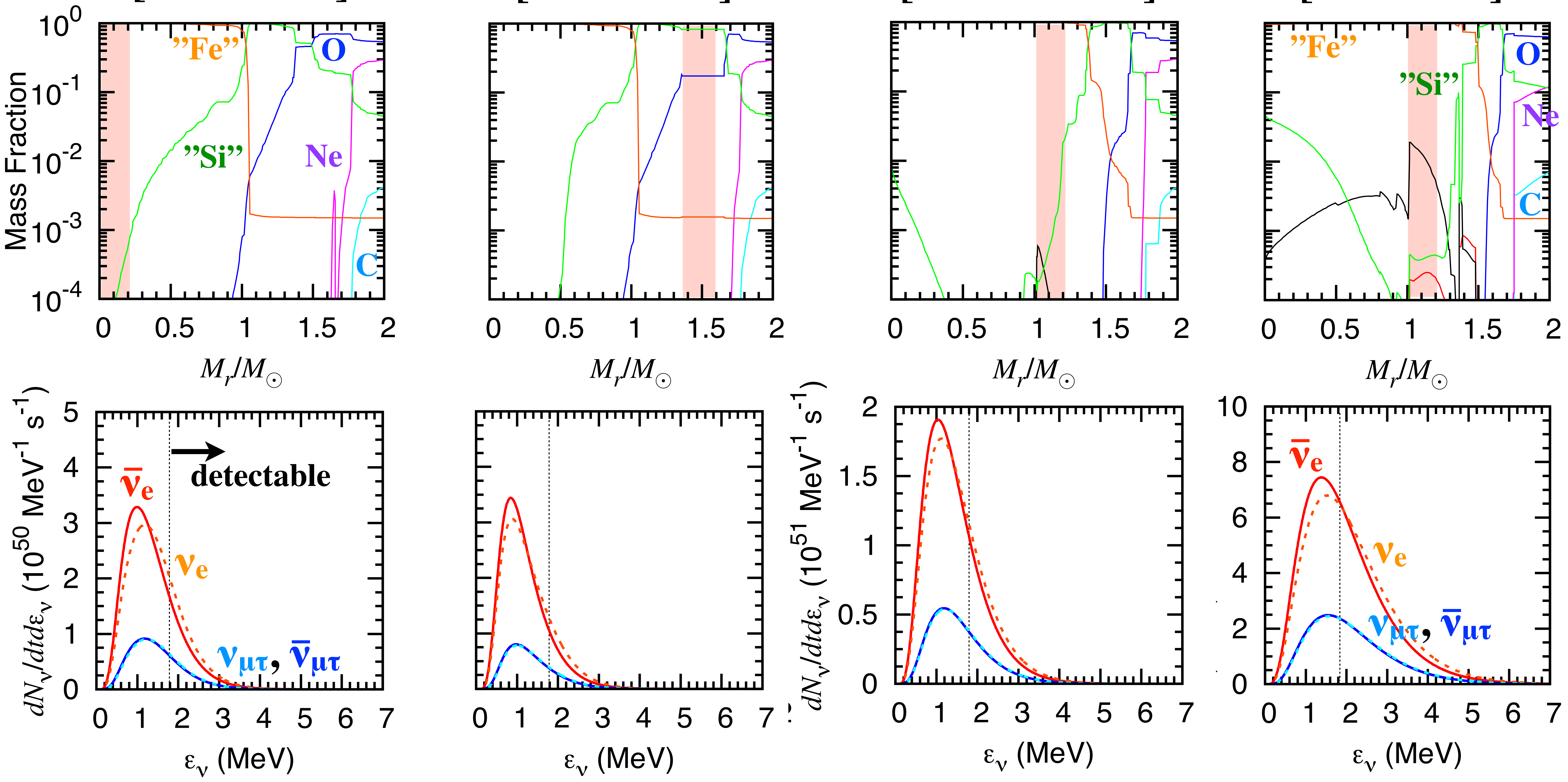
➡ SN alarm

➡ Stellar interior observations



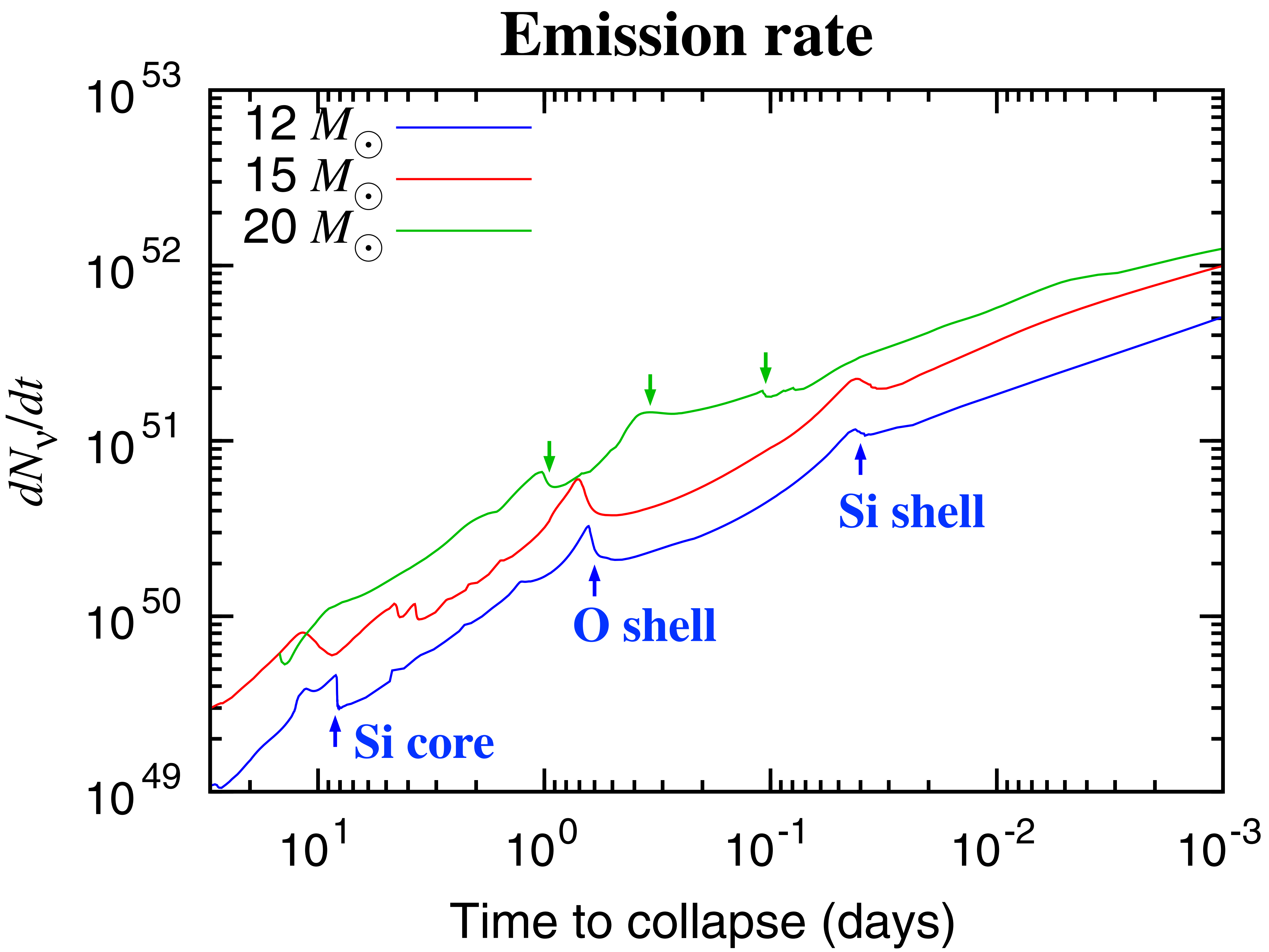
Final Evolution of a $15M_\odot$ Star and Neutrino Spectra

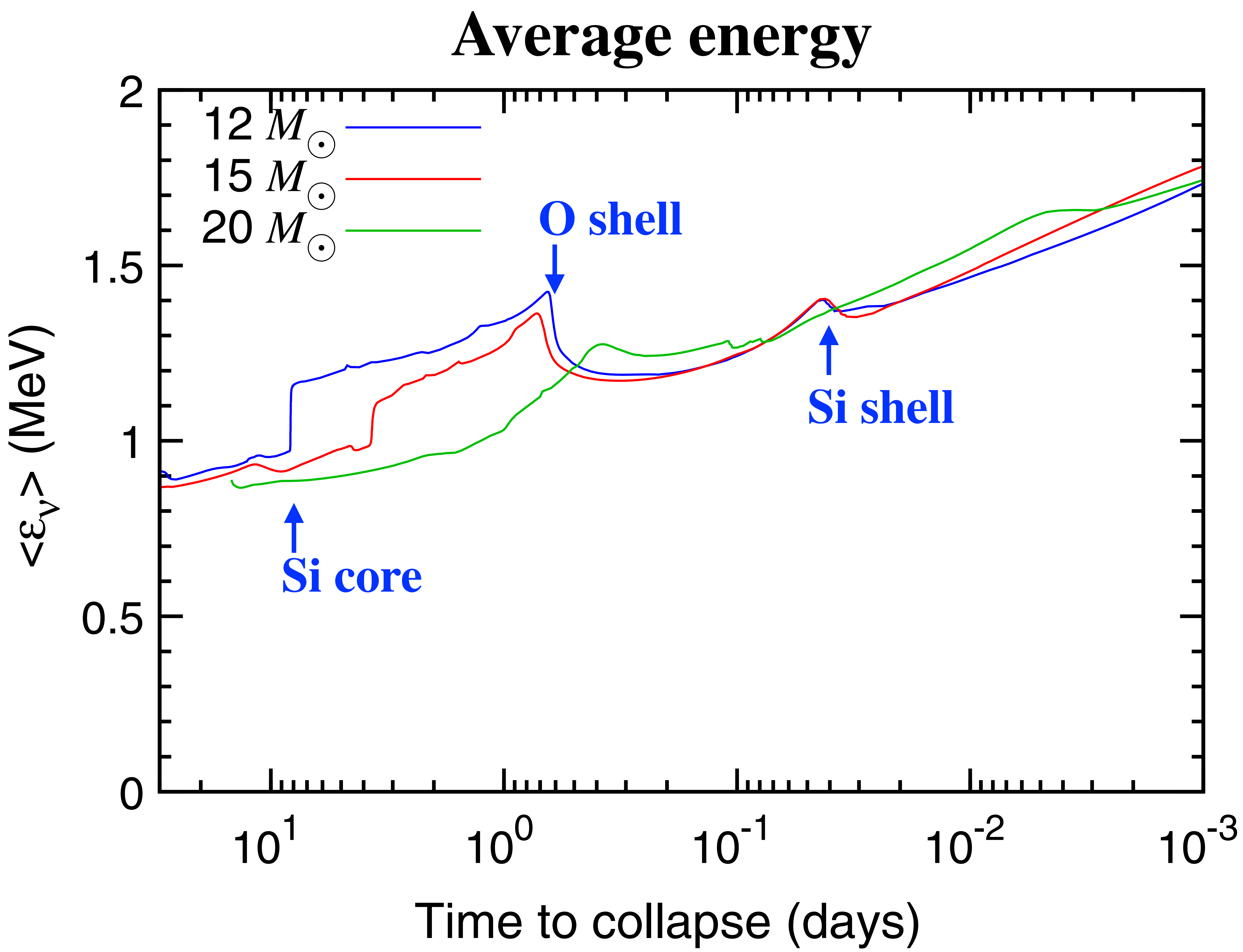
$(\log T_C, \log \rho_C) =$	**Si core burning end**	**O shell burning**	**Si shell burning**	**Core collapse**
	(9.60, 7.90)	**(9.57, 8.24)**	**(9.66, 8.85)**	**(9.81, 9.46)**
	[20.1 hours]	**[9.78 hours]**	**[23.8 minutes]**	**[0 minutes]**



Neutrino Emission Rate and Average Energy

- **$\bar{\nu}_e$ emission rate and average energy of 12, 15, and 20 $M_\odot$ stars**



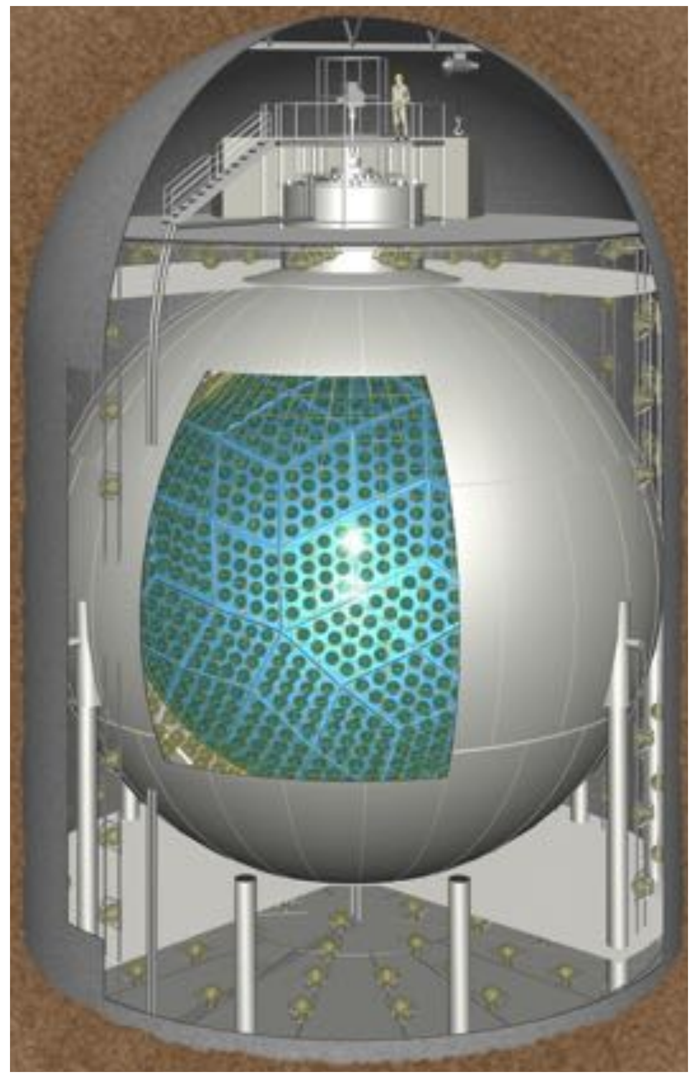


- **Neutrino emission rate and average energy**
  - ➡ **Increase with time**
  - ➡ **Temporal decrease during O and Si shell burnings**

Neutrino Observatories in the Next Decade

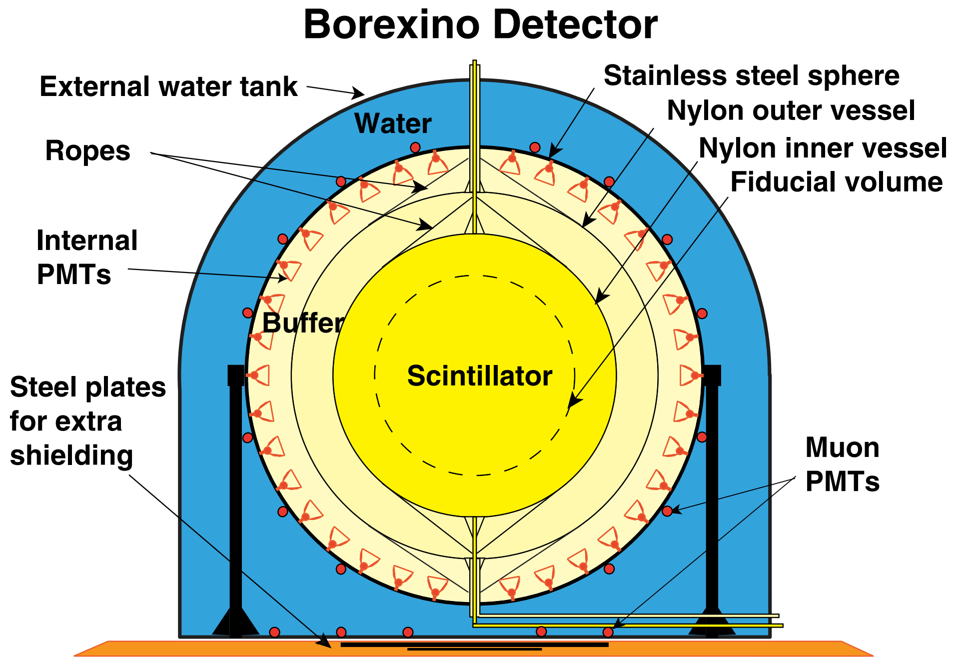
Liquid scintillation detector

KamLAND (1kt)



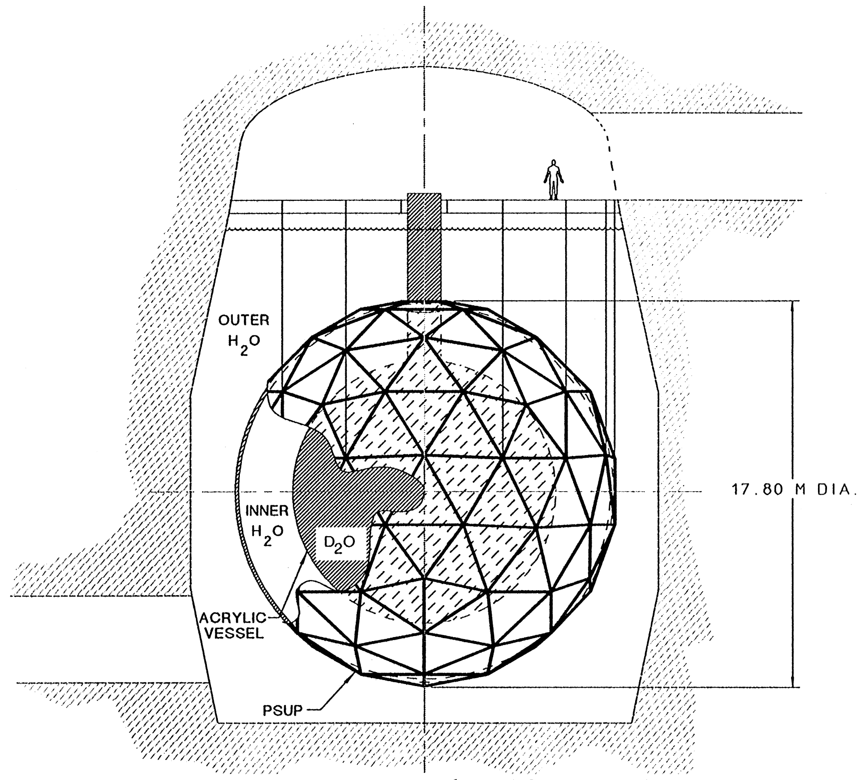
(c) KamLAND Collaboration

Borexino (278t)



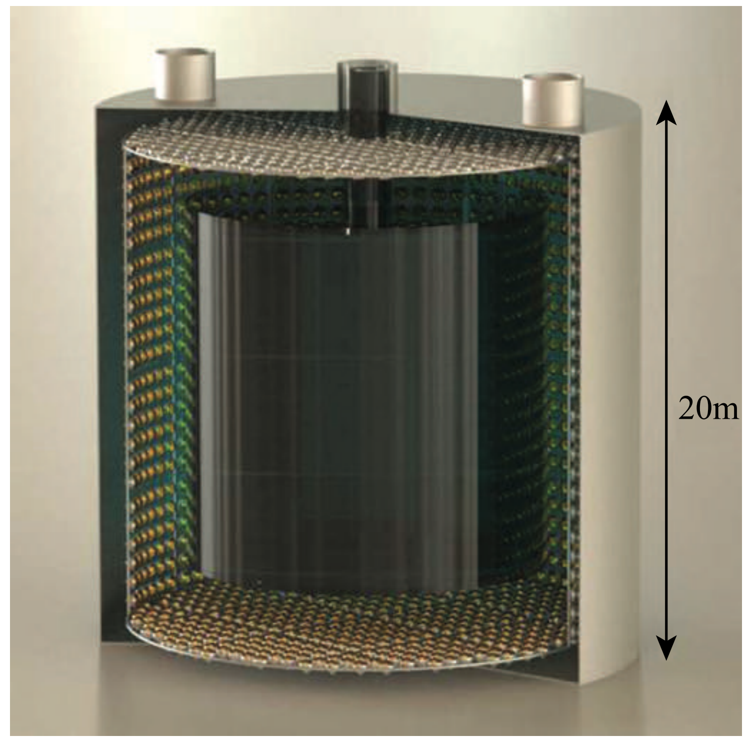
Bellini et al. (2014)

SNO+ (780t)



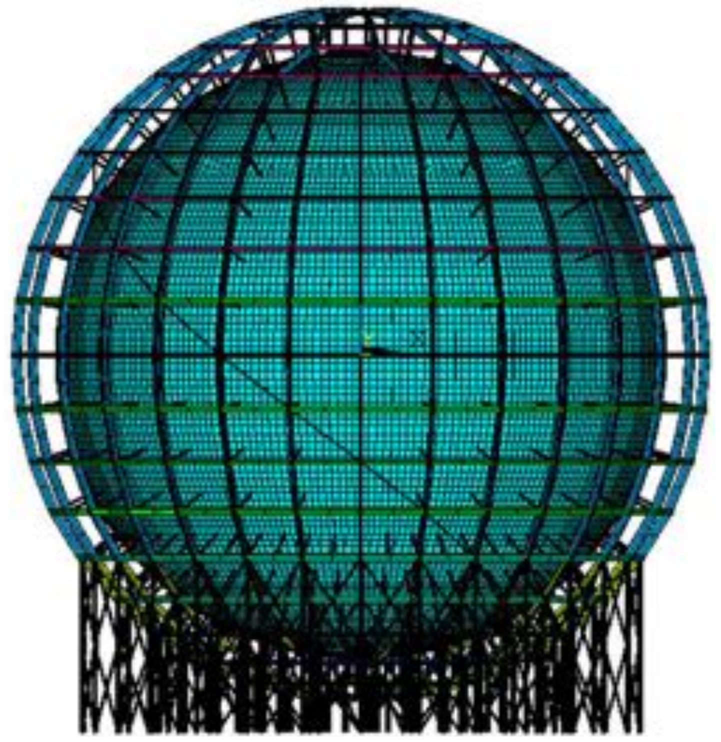
Boger et al. (2000)

Jinping (2kt)



Beacom et al. (2017)

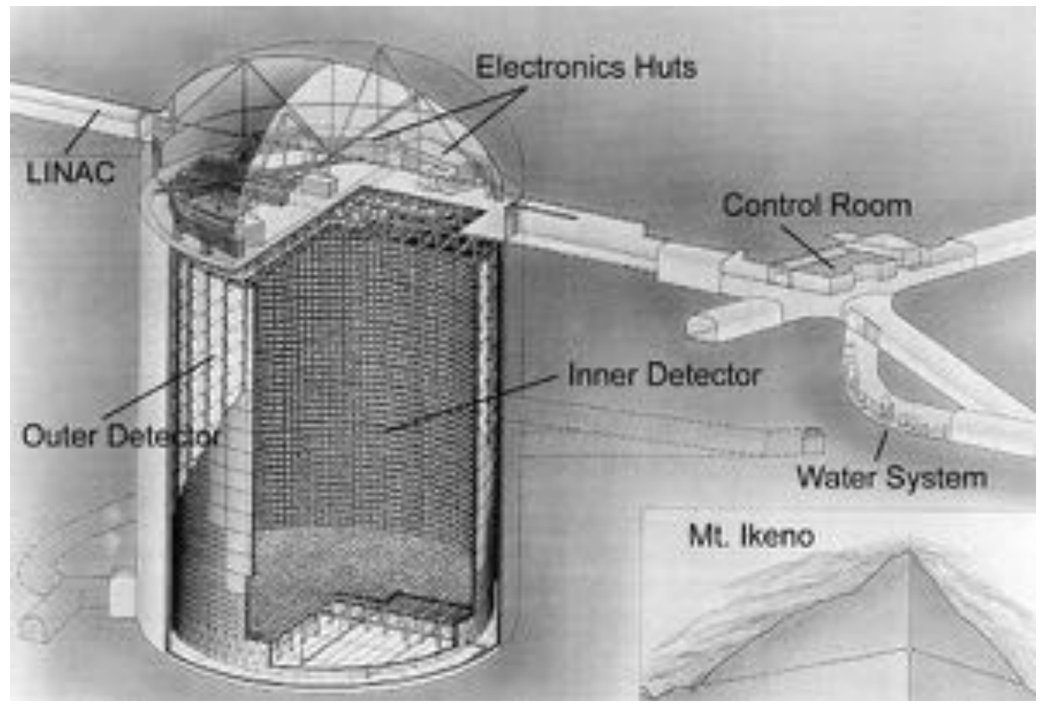
JUNO (20kt)



An et al. (2015)

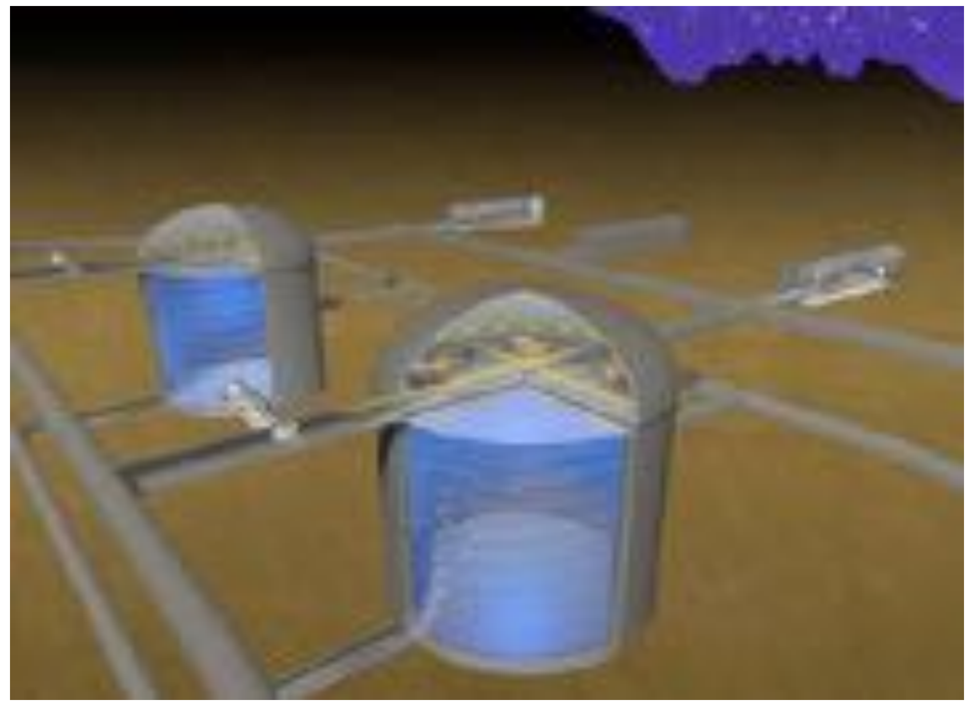
Water Cherenkov detector

Super-Kamiokande (22.5kt)



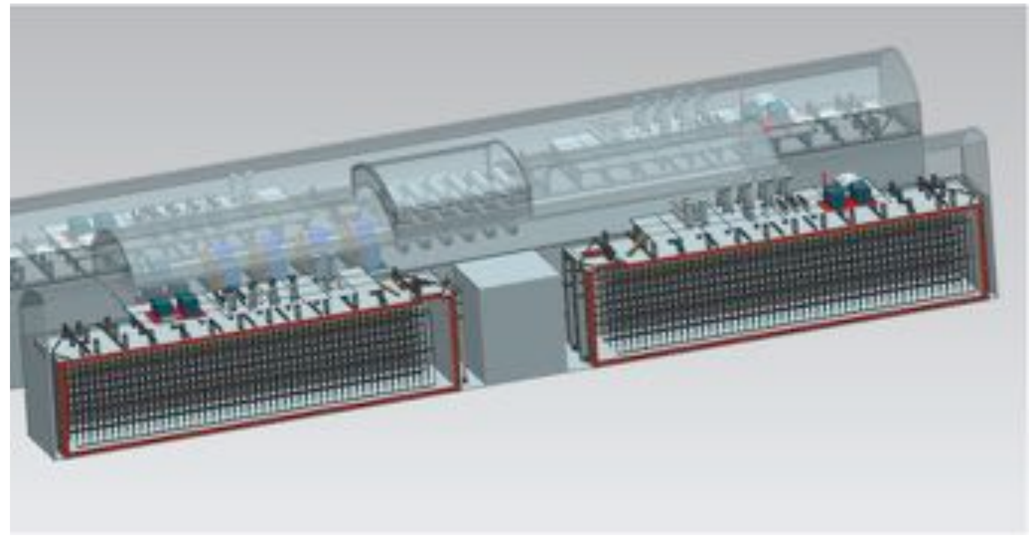
Fukuda et al. (2003)

Hyper-Kamiokande (380kt)



(c) Hyper-Kamiokande Collaboration

Liquid Ar detector

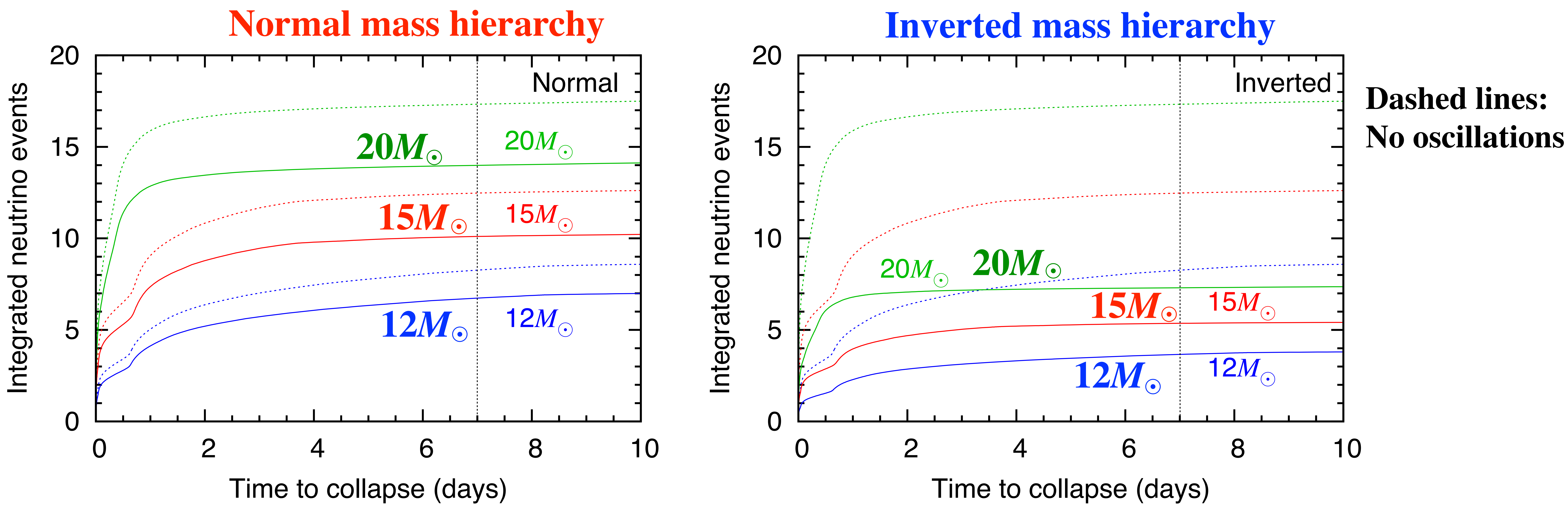


DUNE (40kt)

Acciari et al. (2016)

PreSN Neutrino Events by KamLAND and JUNO

- **Neutrino events from preSN stars at 200 pc by KamLAND (solid lines)**
  $p + \bar{\nu}_e \rightarrow n + e^+$ ($E_{th,\nu}$ = 1.8 MeV)



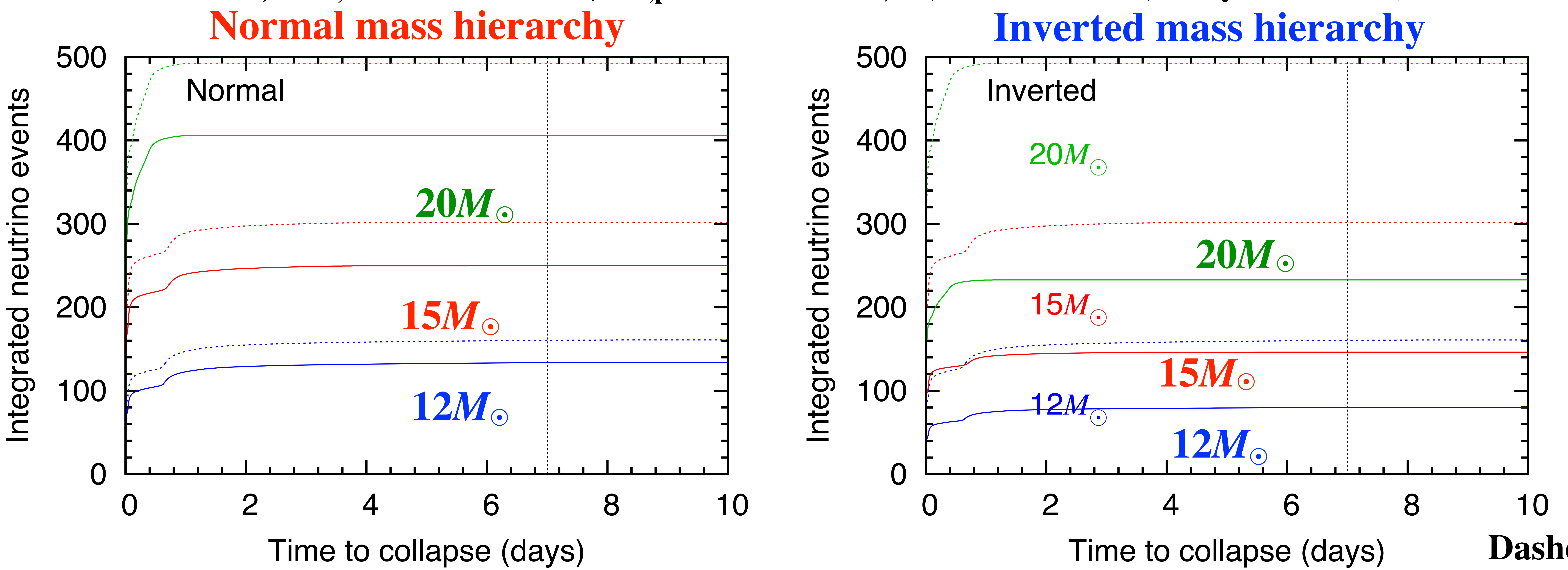
- **Neutrino ($\bar{\nu}_e$) events by KamLAND for one week before the explosion**
  → **~7, 10, 14 (normal), ~4, 5, 7 (inverted) for 12, 15, 20 $M_\odot$ star**
- **Neutrino ($\bar{\nu}_e$) events by JUNO (20 kton fiducial mass) for one week**
  → **~232, 347, 480 (normal), ~126, 180, 251 (inverted)**

PreSN Neutrino Events by Hyper-Kamiokande

- **Neutrino events by Hyper-Kamiokande (solid lines)**

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

  $M_{\mathrm{fiducial}} = 380$ kton; $E_{\mathrm{th},\nu} = 4.79$ MeV ($E_{\mathrm{th,p}} = 3.50$ MeV) (based on SK-IV; Sekiya et al. 2013)



Dashed lines: No oscillations

- **Neutrino ($\bar{\nu}_e$) events for one week before the explosion**

  → **~134, 250, 406 (normal), ~80, 146, 233 (inverted) for 12, 15, 20 $M_\odot$ star**

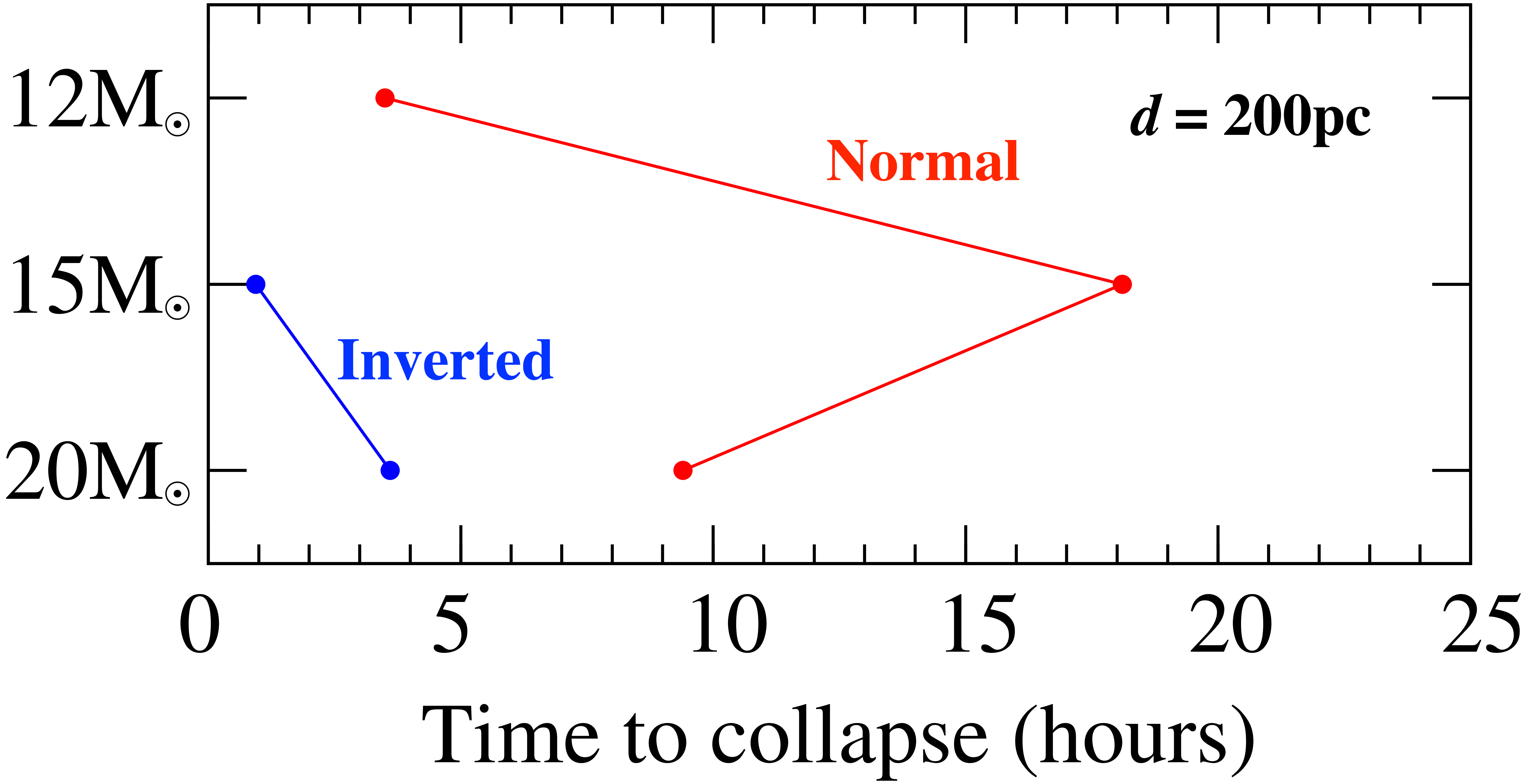
  Most of the events will be observed for one day before the explosion.

Supernova Alarm

- SN alarm using preSN neutrino events (Asakura et al. 2016; Yoshida et al. 2016)

  ➡ Three $\bar{\nu}_e$ events for 48 hours in KamLAND with $0.9 < \varepsilon_{positron} < 3.5$ MeV

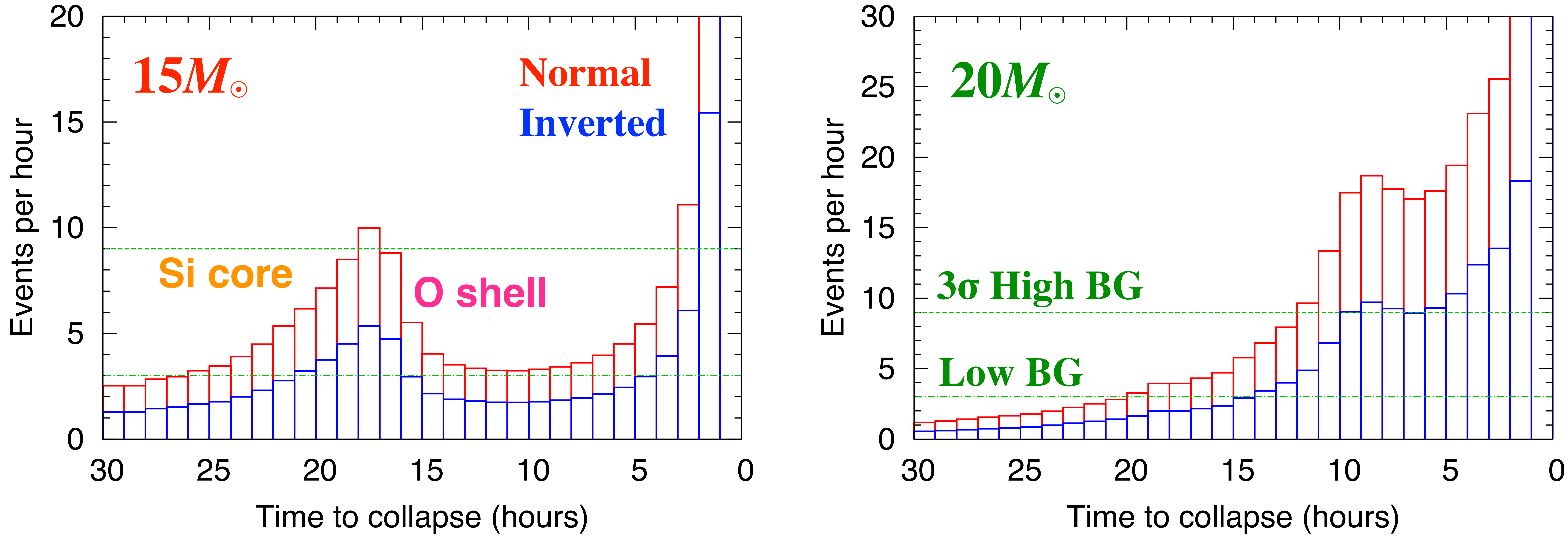
  → 3.7σ (2.1σ) detection significance in low (high) background (using the analysis in Asakura et al. 2016)



- SN alarm using preSN neutrino events could be possible in a few to ten hours before the explosion.
- SN alarm using preSN neutrinos will also be possible by SNO+, Jinping, JUNO.

Neutrino Events Revealing Burning Processes

- ~100 - 500 neutrino events for one week before the explosion by JUNO
  - ➡ Time evolution of preSN neutrino events *per hour*



- 3σ level of high background (BG) → Reactor neutrino is considered.
- 8 - 17 hours before collapse ➡ Decrease in the neutrino events
  - ➡ Si core burning → O shell burning

The central burning processes will be observed by neutrinos!

Summary

Neutrinos from neighboring preSN stars ($d \sim 200$ pc) will be detectable by neutrino observatories.

- **Emission rate of neutrinos from a preSN star**
  - ➡ **Increase with time and decrease by shell burnings**
- **Expected neutrino events from a preSN star**
  - ➡ **Several - tens neutrino events for KamLAND**
  - ➡ **Hundreds neutrino events for JUNO and Hyper-Kamiokande**
- **SN alarm by preSN neutrinos**
  - ➡ **A few - tens hours before SN explosion by KamLAND, SNO+, Jinping, JUNO**
- **Observation of final burning processes by neutrinos**
  - ➡ **Decrease in the neutrino event rate could be an evidence for O shell burning during the core-collapse**

Thank you for your attention!