The Final Evolution of Massive Stars Observed by Pre-Supernova Neutrinos

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Neutrinos from a Presupernova (PreSN) Star



Neutrino Observatories in the Next Decade



Super-Kamiokande 22.5kt water



Hyper-Kamiokande 380kt water



(c) Hyper-Kamiokande Collaboration

Neutrinos from a Presupernova (PreSN) Star

Neutrinos from preSN stars in neighbors (~200 pc)

KamLAND \longrightarrow A few to tens \overline{v}_e events

(e.g., Odrzywolek et al. 2004; Kato et al. 2015)

Future large liquid scintillator \longrightarrow Hundreds \overline{v}_e events (Kato et al. 2015) (e.g. JUNO; 20kton)

Detailed time evolution of neutrino events
 Observing the evidence for burning processes during the final evolution stage

This study

We investigate detailed time evolution of the neutrino emission from 12, 15, 20M_☉ preSN stars.

We investigate the time evolution of the neutrino events from preSN stars at *d* = 200 pc by current and future neutrino observatories and show the relations to the final evolution of preSN stars.

12, 15, 20*M*_o Star Models

M/M _o	<i>M</i> _f	M _{He}	M _{CO}	M _{Si}	M _{Fe}	Si-b (d)
12	10.6	3.52	1.82	1.52	1.38	8.60
15	12.3	4.66	2.74	1.65	1.50	4.42
20	14.3	6.86	4.64	2.11	1.44	1.11





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PreSN Neutrino Events by KamLAND and JUNO

• Neutrino events from preSNe at 200 pc by KamLAND (solid lines) $p + \bar{v}_e \rightarrow n + e^+ (E_{th,v} = 1.8 \text{ MeV})$

Detection efficiency ($\varepsilon_{s} = 0.64$; $\varepsilon_{live} = 0.903$) (Asakura et al. 2016)

~232, 347, 480 (normal), ~126, 180, 251 (inverted)

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PreSN Neutrino Events by Hyper-Kamiokande

Neutrino events by Hyper-Kamiokande (solid lines) p + v
 i → n + e⁺ M_{fiducial} = 380 kton; E_{th,v} = 4.79 MeV (E_{th,p} = 3.50 MeV)

(based on SK-IV; Sekiya et al. 2013)

~ 134, 250, 406 (normal), ~ 80, 146, 233 (inverted)

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

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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*

8 - 17 hours before collapse Decrease in the neutrino events

► Si core burning → O shell burning

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3σ level of high background (BG) → Reactor neutrino is considered.
BG events are estimated from An et al. (2016).

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Neutrino Events Revealing Burning Processes

• PreSN neutrino events *per 10 minutes* of the $15M_{\odot}$ model

About one hour before the explosion Decrease in the neutrino events
Ignition of Si shell burning

Observations of the time evolution of neutrino events could indicate the change of burning processes in the central region of an evolved star.

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Conclusions

We investigated the time evolution of the neutrino events by current and future neutrino observatories and showed the relations to the final evolution of the preSN stars.

• 12, 15, $20M_{\odot}$ preSN star models at d = 200 pc

- Expected neutrino events from a preSN star
 several tens neutrino events for KamLAND
 Hundreds neutrino events for JUNO and Hyper-Kamiokande
- Detailed time evolution of neutrino events from a preSN star
 Direct observation of the central region of an evolved star
 Decrease in the neutrino event rate
 - \rightarrow one day to the explosion \rightarrow O shell burning
 - \implies a few to one hour to the explosion \rightarrow Si shell burning
- Neutrino events from a preSN star could indicate the evidence for the change of burning processes in the central region of the star.