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

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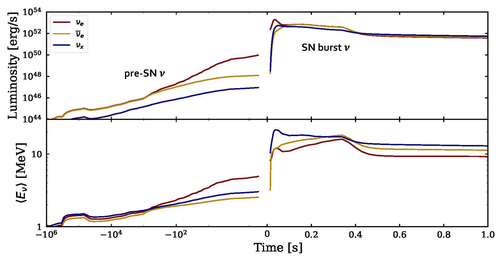
Pre-SN Neutrinos

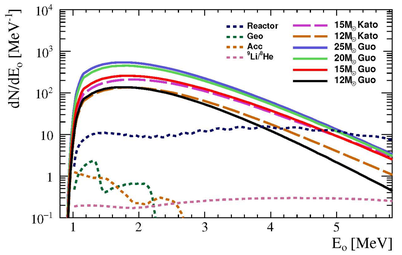
- ~MeV neutrinos emitted from the massive stars days before the core collapse
- Less energetic and smaller luminosity compared with SN burst neutrinos
- Detectable for nearby galactic progenitors
- Serve as early-warning signal for the imminent SN explosion
- Probe to the late-time evolution of massive stars



pre-SN neutrino model from *Kato et al, Astrophys. J. 848, no. 1, 48 (2017)*
SN burst neutrino model from *Nakazato et al, Astrophys. J. Suppl. 205 (2013) 2*

Detection

- Observable in liquid scintillator (LS) detectors due to its low energy threshold, e.g. JUNO with 0.2 MeV detected energy threshold
- ***Inverse beta decay (IBD)*** is the golden channel with distinguishable prompt-delayed coincidence signals
- ***Neutrino-electron elastic scattering*** with single signal could also be detected, suffering from large background.
- The number of observable events depends on the neutrino mass ordering (*NO* or *IO*).

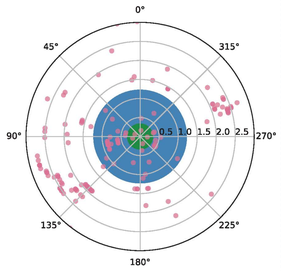


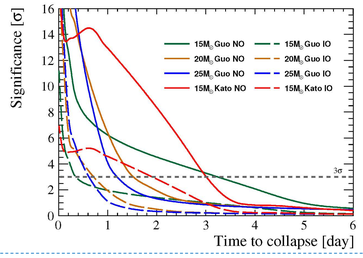
Observable IBD events in a JUNO-like LS detector over the last one day before collapse with toy MC simulation. Background events are from JUNO collaboration *An et al, J. Phys. G 43 (2016) 030401*

Sensitivity

Take a JUNO-like LS detector with 20 kiloton fiducial mass as the example:

- Pre-SN events could be monitored with IBD candidates to give the early warning of the subsequent CCSN.
- With a 3σ significance required, progenitors within 1.23 kpc in the optimal scenario and 0.34 kpc in the worst scenario could be alerted.

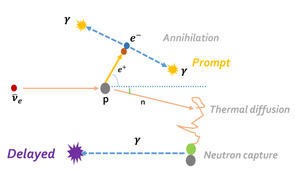




Assumed a progenitor of $15M_\odot$ at 0.2 kpc, the warning could be sent out at 3σ significance,

- 3.2 day before the collapse with NO
- 0.3 day before the collapse with IO

Pre-SN Pointing

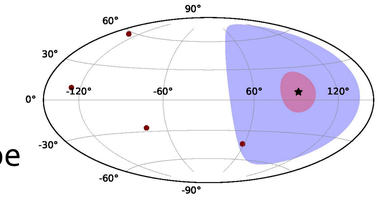


After the pre-SN is warned, the cumulated pre-SN IBD events with position and neutron vertex could be used to reconstruct SN direction in LS detectors:

$$\vec{d} = \frac{1}{N}\sum_{i=1}^{N}(\vec{x}_{e^+}^{\,i} - \vec{x}_n^{\,i})$$

Assumed a progenitor of $25M_\odot$ at 0.2 kpc with NO:

- The uncertainty of the reconstructed SN direction is around 70° at 68% confidence level.
- The limited number of galactic massive stars could be constrained a lot with pre-SN pointing information.



For more details, please find our paper

arXiv:2003.03982

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