Towards a complete reconstruction of supernova neutrino spectra in future large liquid scintillator

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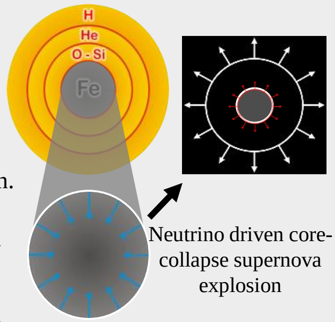
1. SN neutrino burst

- The spare SN1987A neutrino data provide us precious information on the total energy and average energy of the SN neutrinos. But details of the SN neutrino spectra are still unkown.
- Future large liquid scintillator detectors(e.g. JUNO) can give a high-statistics observation of supernova neutrino burst.
- The extraction of energy spectra of different flavor neutrinos will be helpful in understanding of SN neutrino production and flavor conversion as well as exploring the true explosion mechanism.



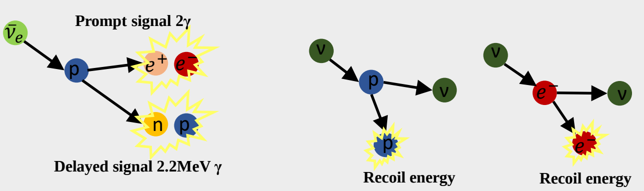
Neutrino driven core-collapse supernova explosion

Grav. binding energy $E_b \approx 3 \times 10^{53}$ erg
99% Neutrinos
1% Kinetic energy of explosion (1% of this into cosmic rays)
0.01% Photons, outshine host galaxy

2. Detection in LS

(IBD) $\bar{\nu}_e + p \to e^+ + n$

(pES) $\nu + p \to \nu + p$
(eES) $\nu + e \to \nu + e$

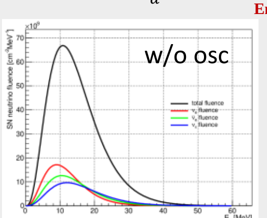


e.g. JUNO with 20kt LS can register ~5000 IBD, ~1000 pES and ~300 eES events with SN at 10 kpc.

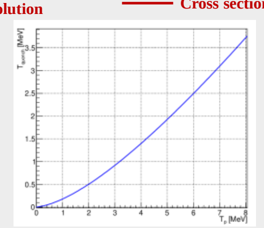
In a more realistic scenario (e.g. pES):

$$\frac{dN_{pES}}{dE_o} = N_p \sum_\alpha \int_0^\infty dT_q \cdot G(E_o; T_q, \delta_E) \int_{E_\alpha}^\infty \frac{dF_\alpha}{dE_\alpha} \cdot \frac{d\sigma_{\nu p}}{dT_p} dE_\alpha$$

Energy resolution   Cross section

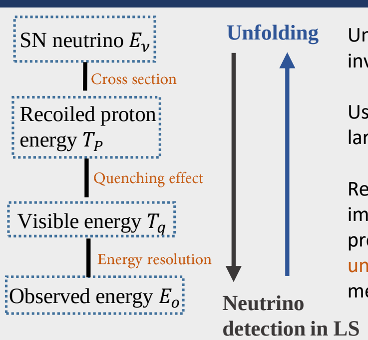


Analytical SN neutrino fluence



Quenching effect of protons in LS

3. SVD unfolding method



Unfolding belongs to the linear inverse problem:

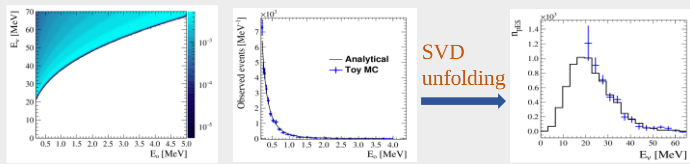
$$Ax = b \ \to x = A^{-1}b$$

Usually direct inverse result has large fluctuations and is unstable.

Regularization is usually implemented in the unfolding process to solve the problem. SVD unfolding method is one of these methods.

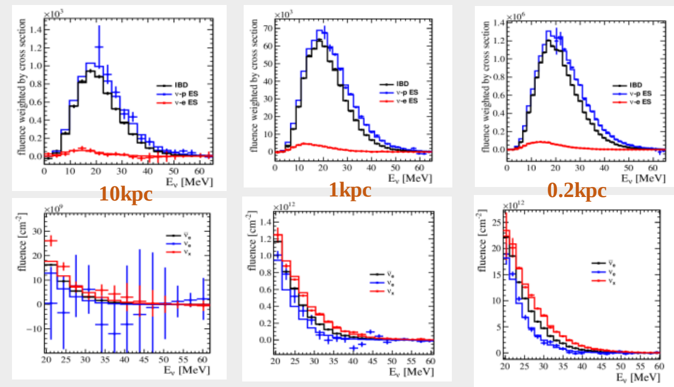
4. Reconstruction of energy spectra

SVD unfolding of pES channel for SN@10kpc



Response matrix   Observed spectrum   Unfolded spectrum

With all three unfolded spectra of IBD, pES and eES channels, simple bin-to-bin separation can extract the energy spectra of distinct flavor SN neutrinos. The more statistics of SN neutrinos detected, the more accurate flavor spectra can be obtained.



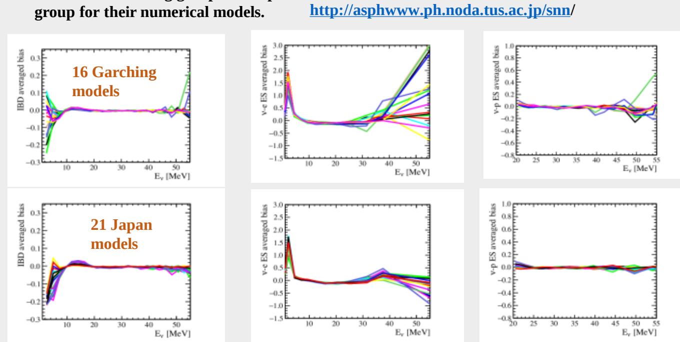
5. Unfolding with numerical models

Multiple Numerical models of SN neutrinos are tested with the same unfolding procedure. And the average bias is calculated as:

$$bias = \frac{1}{N}\sum_{k=1}^{N} \frac{n_k^{true}(E_\nu^i) - n_k^{unfolded}(E_\nu^i)}{n_k^{true}(E_\nu^i)}$$

500 times for each model

Thanks to Garching group and Japan group for their numerical models. http://mpa-garching.mpg.de/ccsnarchive/ http://asphwww.ph.noda.tus.ac.jp/snn/



6. Conclusion

- SVD unfolding method can be applied to reconstruct energy spectra of IBD, pES and eES channels in a more realistic senario.
- Energy spectra of different flavor SN neutrinos can be extracted with combining three spectra of IBD, pES and eES channels.

JUNO
NEUTRINO 2018 Heidelberg 4–9 June