Supernova Neutrino Detection via CEνNS

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Introduction

Core Collapse SuperNova (CCSN) are the terminal point in the evolution of massive stars($M > 8M_\odot$) and are widely considered to be the site of nucleosynthesis of nuclei heavier than Iron. Neutrinos play an important role in this process and are responsible for powering the explosion. They also cause gradual neutronization of the stellar plasma and are responsible for carrying away the gravitational binding energy of the resulting proto-neutron star thereby contributing to its cooling. Hence a study of supernova neutrinos can provide important information on the processes of stellar evolution and nucleosynthesis. It can also serve as an early warning system for multi-messenger studies of supernova explosions(SNEWS).

As of date, neutrinos from CCSN have only been detected from SN1987A. Three detectors observed a total of 24 neutrinos in this explosion. With the improvement in detector technologies since then and the demonstration of neutrino detection via Coherent Elastic Neutrino Nucleus Scattering (CEνNS) we expect to observe many more neutrinos from supernova explosions in the galactic neighbourhood. This manuscript estimates the number of supernova neutrino events detectable by in Si, Ge and $PbWO_4$ detectors, considering Coherent Elastic Neutrino Nucleus Scattering (CEνNS).

CEνNS cross section

CEνNS is a neutral current process in which neutrino of any flavour scatters off a nucleus causing the nucleus to recoil. The cross section for this interaction is given by:

$$\frac{d\sigma}{dE_{nr}} = \frac{G_F^2}{8\pi} Q_W^2 M |F(q)|^2 \times \left[2 - \frac{2E_{nr}}{E_\nu} + \left(\frac{E_{nr}}{E_\nu}\right)^2 - \frac{ME_{nr}}{E_\nu^2}\right] \quad (1)$$

where G_F is the Fermi coupling constant, E_ν & E_{nr} the neutrino energy and nuclear recoil energy respectively, M the mass of the target nucleus, $F(q)$ its form factor and Q_W is the weak nuclear charge ($\propto$ N, the neutron number). The main advantage of CEνNS comes from its large cross-section compared to IBD, allowing for use of smaller detectors.

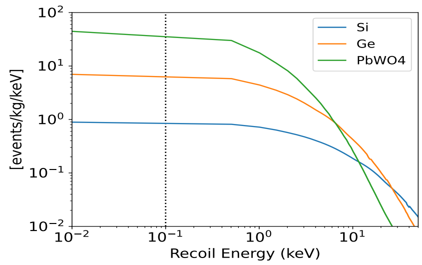

FIG. 1: Differential cross section of CEνNS for different nuclei

Supernova Neutrinos

The entire Supernova neutrino emission lasts about 20 seconds, and is divided into three phases [1, 2]. Starting from the bounce of the core at $t = 0$, the peak of electron neutrinos marks the neutronization burst, and occurs just after the bounce. The burst is caused by electron capture on nucleons freed by the shock wave propagating through the core. The burst is followed by an accretion phase during which charged current production of $\nu_e, \bar{\nu}_e$ is accompanied by thermal production of all

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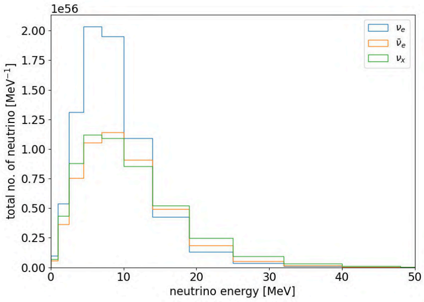

FIG. 2: Supernova neutrino spectra integrated till 18s for all neutrino flavours

TABLE I: Estimated counts in different detectors for M_{det} = 10kg and thresholds $(E_{nr})_{th}$

Detector	$(E_{nr})_{th} = 10eV$	$(E_{nr})_{th} = 100eV$
Si	50	49
Ge	212	183
$PbWO_4$	611	557

other flavours(ν_x). The accretion phase eventually stops, and the resulting proto-neutron star enters a cooling phase, emitting its gravitational binding energy through thermally produced neutrinos of all flavours.

Event Rate

The differential event rate as a function of the recoil energy is evaluated as follows:

$$\frac{dR}{dE_{nr}} = \frac{M_{det}}{M(4\pi d^2)} \times \sum_{i=\nu_e,\bar{\nu}_e,\nu_x} \int_{E_{min}}^{\infty} \frac{d\sigma}{dE_{nr}} f_i(E_\nu) dE_\nu \quad (2)$$

where M_{det} is the mass of detector, d is the distance to supernova explosion, E_{min} is the minimum energy a supernova neutrino must have to produce a nuclear recoil of E_{nr} and $f_i(E_\nu)$ is the differential spectra of ith neutrino flavour.

Due to the weakness of the interaction and the masses involved, the nuclear recoil energies are in keV range and require very sensitive and low-noise detectors. Most such detectors currently in use have a threshold $\sim$ 100 eV with future detectors being planned to reach as low as 10eV. Hence, we calculate the total counts from a supernova explosion considering these thresholds.

The results are presented in table I for the red-giant Betelgeuse located 196pc from earth, and expected to be the next star in milky-way to undergo supernova explosion. Figure 3 shows a contour plot of expected counts for 100eV threshold on E_{nr} for different detector masses and source distances. Further analysis involving detector sensitivities and energy response is being performed. Statistical significance of the time series and spectral reconstruction is also being studied.

References

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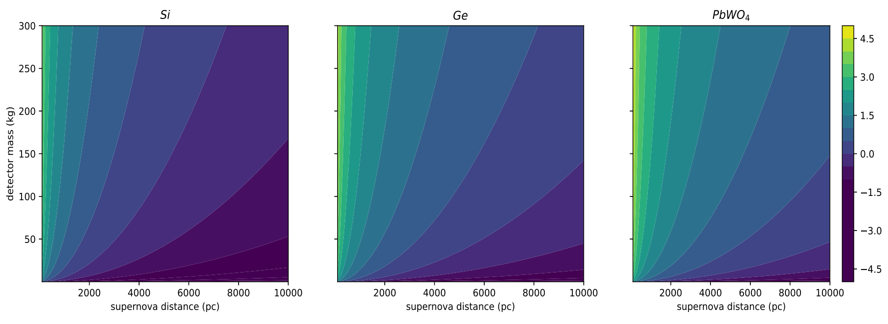

FIG. 3: Contour plot of counts for different detector masses(y-axis) and supernova distance(x-axis) in 3 detector materials