Complementarity of Supernova Neutrino Detector Technologies

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1 Preamble

There exists a variety of neutrino detection technologies that will hopefully be operating when the next galactic supernova explodes. While all of these detectors will observe the neutrino signal, each will contribute unique information. In this exercise, we will simulate the expected neutrino signal from various technologies and identify the advantages for each.

2 SNOwGLoBES

In this exercise, we will use the SuperNova Observatories with `GLoBES` (`SNOwGLoBES`) package [1]. `SNOwGLoBES` is an open-source program and is available for download at `http://www.phy.duke.edu/~schol/snowglobes/download.html`.

`SNOwGLoBES` uses the predicted flux from a given supernova model and calculates the expected signal rate in a detector, taking into account the various cross sections for the specific detector material, the detector mass, and the resolution for the experimental setup.

`SNOwGLoBES` is already installed on the virtual machine available through CGWAS. Open the terminal and type: `cd snowglobes/snowglobes`

3 Simulating the supernova signal

On July 10, 2025, a supernova explodes at the centre of our galaxy (10 kpc from Earth). We will simulate the expected neutrino signal in each of the different detector targets.

To produce the signal files with `SNOwGLoBES`, run the supernova.pl script. The script is run by specifying the flux model, target, and detector configuration. The available fluxes are in the `fluxes/` directory, the available targets are listed in the `channels/` directory, and the available detector configurations are in the `detector_configurations.dat` file. We consider the Livermore flux model [7] and will run 3 different configurations: the expected signal from water, argon, and scintillator. The `wc100kt15prct` detector configuration is for a metric 100 kiloton water detector with 15% photocoverage, which represents how well the photodetectors are able to view the light produced in the neutrino interaction. The `ar17kt` configuration is a liquid Argon detector with a mass of 17 kilotons. The `scint50kt` configuration is a liquid scintillator detector with 50 kilotons of target mass. All of the SNOwGLoBES flux models assume the supernova is 10 kpc away. The combinations to run are summarized in Table 1. An example of how to run the script for the Livermore model with a water target is:

```
./supernova.pl livermore water wc100kt15prct
```

Table 1: `SNOwGLoBES` configurations to be simulated

Model	Target	Detector Configuration
livermore	water	wc100kt15prct
livermore	argon	ar17kt
livermore	scint	scint50kt

4 Reading the output files

The scripts will write output files for both the interaction rates and the smeared detected rates to the `out/` directory. The names of the output data files have the format `model_channel_detector_events_(smeared)_(unweighted).dat` where the smeared files take detector resolution into account and the unweighted files do not take the relative abundance of the target types into account (we will ignore the unweighted files in this activity). Inside the data file there will be two columns. The first is the neutrino energy (detected energy) in GeV for the unsmeared (smeared) files, and the second column is the total number of events in that energy bin.

Exercise 1: Use your favourite plotting program and plot one of the data files. For example, try plotting the detected neutrino rate as a function of energy for the IBD channel of a scintillation detector using the Livermore model. The information for this is contained in the `livermore_ibd_scint50kt_events_smeared.dat` file.

5 Comparing signals from different detector technologies

Let's look at the neutrino signal we would expect if SN2025CGWAS were to occur. In the year 2025, many next-generation neutrino experiments are proposed to be operating. For our water Cherenkov example, we will consider the Hyper-Kamiokande [2] detector, a 1 megaton water experiment proposed for construction in Japan. For the scintillator signal, we will look at Juno [5], a 20 kiloton experiment proposed to be built in China. Finally, for Argon we will use DUNE (formerly LBNE) [4], a 40 kiloton liquid argon experiment proposed to be built in the United States.

Exercise 2: Plot the neutrino signal as a function of energy in Hyper-Kamiokande. Plot each smeared interaction channel separately (there should be 15 channels for water) and scale for the mass of Hyper-Kamiokande. What is the dominant channel that is detected in a water Cherenkov experiment? What neutrino type takes part in this reaction?

Exercise 3: Repeat exercise 2 for DUNE and JUNO. What are the dominant reaction channels for each detector? Which neutrinos participate in the dominant channels?

Exercise 4: To get the total number of events for each channel, you can sum together all of the energy bins. The script `make_event_table.pl` does this and writes out the total number of events for a given model, target, and detector configuration to the terminal screen. This script takes the same arguments as `supernova.pl`, so to run the total expected rate from a water target using the Livermore model, we would type:

```
./make_event_table.pl livermore water wc100kt15prct
```

You will see the calculated number of events for each reaction channel, the total neutral current (NC) and elastic scattering (ES) events, and the total summed number of events for all reactions.

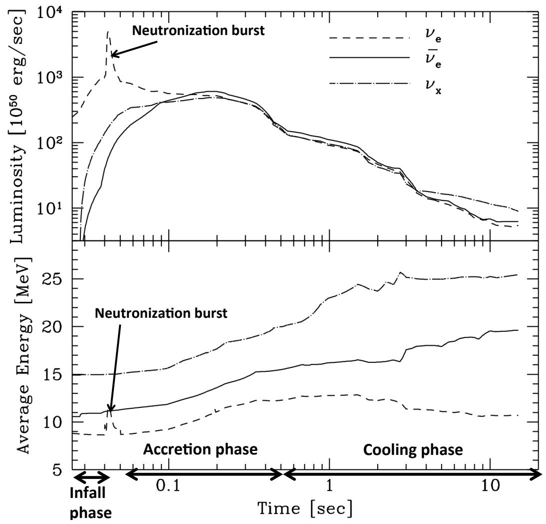

Figure 1: Neutrino events as a function of time for the Livermore model

Run `make_event_table.pl` for water, argon, and scintillator. After scaling by target mass, which detector has the largest total number?

Exercise 5: Now let's look at the supernova neutrino signal in time, rather than energy. Figure 1 shows the neutrino luminosity as a function of time for the Livermore flux model. This morning we talked about four phases of the supernova explosion process: infall, neutronization, accretion, and cooling. Using the results from the past exercises and Figure 1, which detectors are best suited to measure each phase? What is the advantage of measuring the neutral current reaction on Carbon, as will be done with the liquid scintillator experiments?

References

[1] `http://www.phy.duke.edu/~schol/snowglobes/`

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[5] Yu-Feng Li. Overview of the Jiangmen Underground Neutrino Observatory (JUNO). *Int. J. Mod. Phys. Conf. Ser.*, 31:1460300, jan 2014.

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