NEUTRINO ASTRONOMY
MEASURING THE SUN’S CORE

Based on J.H. Davis, Phys. Rev. Lett. 117 (2016) 211101

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NEUTRINO ASTRONOMY

- In order to do astronomy with neutrinos we need to be able to work out where they are coming from in the sky.
- Interested in two cases: supernova neutrinos and solar neutrinos.
- If a supernova goes off in our galaxy and we detect its neutrinos, can we work out where in the galaxy it happened?
- **Can we use neutrino directionality to probe the sun’s core?**
DETECTION OF NEUTRINOS

- I will focus on water Cherenkov detectors such as Super Kamiokande (SK).

- Very large detectors such as SK mean that it is possible to obtain large statistics even though neutrinos interact weakly.

- They are good for solar and supernova neutrinos and they have directional sensitivity for incoming neutrinos.
DETECTION OF SOLAR NEUTRINOS

• An MeV-energy neutrino scatters elastically off an electron.

• The electron emits Cherenkov light, which is observed by photomultiplier tubes.

$$\nu + e^- \rightarrow \nu + e^-$$

In $\text{H}_2\text{O}$  
Emits Cherenkov Light
DETECTION OF NEUTRINOS

- The elastic scattering cross section is strongly forward-peaked for MeV-scale neutrinos, especially for higher recoil energies.
- Hence the electron after scattering will point back towards the original direction of the neutrino.

THE ANGULAR RESOLUTION OF NEUTRINO DETECTORS

- Unfortunately the actual resolution is much worse, since the electron scatters in the water multiple times. Hence the observed electron direction is only weakly correlated with the incident neutrino direction.

- This multiple scattering contributes almost all of the angular resolution, and is well-understood due to calibration data.

CASE STUDY: SUPERNOVA POINTING WITH NEUTRINOS

• Since the multiple-scattering of the electron is well-known, we can reconstruct the supernova direction.

• Obtain a simple approximate formula for the angular resolution for SN pointing:

\[ \delta \theta \approx \frac{25^\circ}{\sqrt{N_s}} \]

FIG. 4: Angular distribution of \( \bar{\nu}_e p \rightarrow ne^+ \) events (green) and elastic scattering events \( \nu e^- \rightarrow \nu e^- \) (blue) of one simulated SN.

SOLAR NEUTRINOS

- Solar neutrinos are produced via fusion reactions occurring in the Sun’s core.
- The solar core has a radius of 20% to 25% of the solar radius.
- Their energies and fluxes depend on the fusion reactions in which they are created.
WHERE ARE 8B NEUTRINOS PRODUCED IN THE CORE?

- Different fusion reactions should occur at different positions within the core.
- We focus on 8B neutrinos, which are predicted to be produced in a spherical region located at 5% of the solar radius from the core centre.

MAXIMUM LIKELIHOOD ANALYSIS – GENERATING SIGNAL DISTRIBUTIONS

• We need to generate the distribution of electrons in a water Cherenkov detector, given an assumption on the neutrino distribution in the solar core.

• Start by generating initial angles of the neutrinos as they arrive at Earth, given a distribution in the core:

[Diagram showing the Sun, 8B production region, Neutrino, and Earth]
• Combine the initial distribution of neutrinos, the differential cross section of electron-nu scattering and the distribution of electron multi-scattering in the detector.

• Repeat this process for different initial neutrino distributions within the solar core.
The spectra are only just distinguishable above statistical noise.

Poisson uncertainty is roughly $\sqrt{31000} = 176$. 

Difference between profiles is about 200 events per bin.

Spectra of electrons from neutrino scattering assuming different values of $R_{SB}$

2000 kton years exposure

MAXIMUM LIKELIHOOD ANALYSIS – GENERATING SIGNAL DISTRIBUTIONS
MAXIMUM LIKELIHOOD ANALYSIS - RESULTS

95% confidence contours

20 years for Super Kamiokande

4 years for a 500 kilo-tonne experiment

CONCLUSION

• We can use solar neutrino experiments as telescopes of the solar interior.

• Super Kamiokande has 20 years of data so can already constrain the solar neutrino production region to be within the solar core.

• A 500 kton experiment, perhaps Hyper Kamiokande, could do much better, but it would need to keep background levels as small or smaller than for Super Kamiokande.