News from the Sudbury Neutrino Observatory

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Abstract. The Sudbury Neutrino Observatory (SNO) has now completed neutrino detection with 1,000 tonnes of heavy water situated 2,000 meters underground in INCO's Creighton Mine near Sudbury, Ontario. During the first two phases of the experiment, SNO showed that neutrinos change flavour on their way to earth and accurately measured the solar neutrino oscillation parameters. Besides this, SNO was also able to use the data of these first two phases for other analyses. In particular, it recently set a limit on the Solar hep Reaction and the diffuse Supernova background. The third and final phase of operation uses an array of neutron detectors to independently observe the Neutral Current reaction of solar neutrinos on deuterium. Data analysis of this phase is in progress. In this paper, I discuss the latest results of the first two phases of the SNO experiment and report on the operation and calibration of the SNO detector during the it's final phase.

1. The three phases of SNO

The Sudbury Neutrino Observatory (SNO) [1] uses 1000 tonnes of pure heavy water to detect solar neutrinos. It is only sensitive to $^8\text{B}$ (and the much less numerous hep) neutrinos. The following three detection reactions are used:

- (CC) $\nu_e + d \rightarrow p + p + e^-$
- (NC) $\nu_x + d \rightarrow p + n + \nu_x$
- (ES) $\nu_e + e^- \rightarrow \nu_e + e^-$

The charged current (CC) reaction is sensitive only to electron neutrinos, while the neutral current (NC) reaction is sensitive to all active neutrino flavours ($x = e,\mu,\tau$) above the energy threshold of 2.2 MeV. The elastic scattering (ES) reaction is sensitive to all flavours as well, but with reduced sensitivity to $\nu_\mu$ and $\nu_\tau$.

The observed CC and ES reactions are observed by detecting the Cherenkov light produced by the electrons in the final state. The NC reaction is observed through the detection of the neutron in the final state of the reaction, using three different methods. These three methods distinguish the three operational phases of the SNO experiment.

In the first phase of SNO, neutrons of the NC reaction were detected from the Cherenkov light produced by the 6.25 MeV gamma ray emitted in neutron capture on deuterium. SNO observed a significant difference between the CC- and NC neutrino flux, which provided first evidence for neutrino flavour transformation [2].
In the second phase of SNO, two tonnes of salt (NaCl) was added to the heavy water. The neutrons were then captured predominantly by $^{35}\text{Cl}$, resulting in the emission of multiple gamma rays. The resulting Cherenkov light patterns are generally more isotropic than those from CC reactions, which allowed the statistical separation of NC and CC reactions. The larger cross-section and greater energy release for neutron capture on $^{35}\text{Cl}$ than on H enhanced the sensitivity to the NC signal in the salt phase. One of the most significant results from this phase is the precise determination of the total active solar neutrino flux, in excellent agreement with the predictions from solar models [3].

In the third and final phase of SNO, which ended in November 2006, the neutrons produced by the NC reaction were observed by an array of $^3\text{He}$-filled proportional counters, made from ultra-low radioactivity [4]. This breaks the covariance between the detection of the CC and NC events. Also the measurement of the NC signal has a very different set of systematic uncertainties compared to previous phases. The analysis of the data of this phase is still ongoing.

The $^3\text{He}$ array has been calibrated by mixing a small amount of the short-lived isotope $^{24}\text{Na}$ into the heavy water. As the $^{24}\text{Na}$ emits a 2.75 MeV gamma in its decay, it has a relatively high probability of photo-disintegrating the deuteron. This creates a source of neutrons similar to the neutrons produced by neutrino interactions, especially with respect to their geometrical geometrical distribution, allowing a precise calibration of the detector.

2. The measurements of the high(er) energy neutrino spectrum in SNO

Using data collected during the first operational phase of SNO, a search has been made for neutrinos from the hep reaction in the Sun and from the diffuse supernova neutrino background (DSNB) [5]. For the hep neutrino search, two events are observed in the effective electron energy range of $14.3 \text{ MeV} < T_{\text{eff}} < 20 \text{ MeV}$ where 3.1 background events are expected. After accounting for neutrino oscillations, an upper limit of $2.3 \times 10^4 \text{ cm}^{-2}\text{s}^{-1}$ at the 90% confidence level is inferred on the integral total flux of hep neutrinos. For DSNB neutrinos, no events are observed in the effective electron energy range of $21 \text{ MeV} < T_{\text{eff}} < 35 \text{ MeV}$ and, consequently, an upper limit on the electron neutrino component of the DSNB flux in the neutrino energy range of $22.9 \text{ MeV} < E_\nu < 36.9 \text{ MeV}$ of $70 \text{ cm}^{-2}\text{s}^{-1}$ is inferred at the 90% confidence level. This is an improvement by a factor of 6.5 on the previous best upper limit on the hep neutrino flux and by two orders of magnitude on the previous upper limit on the electron neutrino component of the DSNB flux.

3. Conclusions

SNO stopped taking data in November 2006 and the analysis of the third and final phase of SNO is still ongoing. In addition, an analysis combining the data from the first two phases aimed at lowering the energy threshold of the CC spectrum is in progress. These analyses are expected to provide an improved overall accuracy for the measurement of the neutrino oscillation parameters, in particular the oscillation angle $\theta_{12}$. A paper on atmospheric neutrinos seen in SNO is also being prepared.

References

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