The Sudbury Neutrino Observatory (SNO) and the new SNOLAB

Our Cosmic Address

Our sun is one of 400 billion stars in the Milky Way galaxy, which is one of more than 100 billion galaxies in the visible universe.

Art McDonald
Queen’s University, SNO Institute Director
Sudbury City Council, June 13, 2007
With the **Sudbury Neutrino Observatory (SNO)** and the new **SNOLAB** we have great new scientific opportunities in Neutrino Physics, Cosmology and Astrophysics at the lowest radioactivity underground site in the world.
Why Go Underground?

- Other astronomers go to the tops of mountain peaks or up in satellites to observe the heavens...

- We go deep underground to exclude high energy particles (Cosmic Rays) from outer space that would otherwise make our detector glow like the Northern Lights. Neutrinos and Dark Matter particles pass through the rock unimpeded.

- By going deep underground and creating ultra-clean conditions, we can measure very rare processes (few events per year):
  - **NEUTRINOS from the SUN**
  - **DARK MATTER particles left over from the BIG BANG**
  - **VERY RARE RADIOACTIVE DECAY**, unobserved to date that will help us to understand how the Universe evolved and why we are all made of matter, rather than anti-matter.

- **SNOLAB**: the lowest radioactivity laboratory on Earth, the world’s scientists want to site 4 or 5 projects, each worth more than $10 million.
SNO: One million pieces transported down in the 3 m square mine cage and re-assembled under ultra-clean conditions.

Over 60,000 Showers to date and counting
In the midst of all this technology we should not forget the human element.

There was one exception on showers, where we carefully vacuumed and INCO built a special stainless steel rail car for clean transportation.
How to tell a neutrino from a hole in the ground

• Neutrinos, along with electrons and quarks are the basic building blocks of nature.

• They are produced in large numbers by the nuclear reactions that power the Sun and can pass through virtually anything, so we can use them to study the Sun in great detail.

• Using Canadian heavy water reserves and the best underground location in the world, SNO has determined that neutrinos have mass. That changes the laws of physics at the most basic level.

• SNO has also confirmed that the models of energy generation in the Sun are very accurate.

• We now know that Neutrinos do not have enough mass to be the Dark Matter Particles making up 25% of the Universe. So what are these Dark Matter Particles left over from the Big Bang? SNOLAB will be the best place in the world to study them…..
The SNO results have been very well received by the scientific community and have generated a large amount of further theoretical and experimental work.

For much of 2003, the three SNO papers occupied the top three places for citations of papers in all of physics. Over 3000 so far.

SNO is “Textbook science” changing the basic laws of physics:
See the latest Ontario and Alberta Grade 12 physics textbooks.

SNO has portrayed Sudbury & Canadian science very well internationally:

Science magazine, Discover magazine, American Inst. of Physics:
SNO results rated in top 2 scientific discoveries of 2002.

News articles on SNO have appeared in major newspapers all over the world: Globe and Mail, National Post, NY Times, Washington Post, The Guardian, CBC, CTV, Discovery and there was a full edition of ABC Nightline on SNO results.
A Canadian Success Story

Neutrino Mystery Solved

For physicists, 2002 may go down as the year of the neutrino. In October Raymond Davis Jr. of the University of Pennsylvania and Brookhaven National Laboratory shared a Nobel Prize for detecting solar neutrinos and discovering that the sun emits far fewer than expected of the Earth-shaking subatomic particles—a finding that exposed a serious flaw in our understanding of fundamental natural laws. Last spring, an international team of physicists conducted an elegant experiment that finally solved the enigma Davis had uncovered nearly 30 years earlier.

Standard models of how the sun shines tell us exactly how many neutrinos should be created by nuclear reactions in the solar core. Checking these models proved quite a challenge. Neutrinos are so light, they rarely pass right through Earth, but Davis managed to capture and count a few of them, an enormous underground detector. He was shocked: the found just one third as many as theory had predicted. Reported results have since confirmed the solar neutrino deficit. More recently, physicists at the Sudbury Neutrino Observatory in Ontario, Canada, and of the Super-K detector in Japan have provided possible explanations. Neutrinos are known to exist in three varieties, called flavors, each of which is associated with another subatomic particle. Until recently, physicists could effectively detect only one flavor, the electron neutrino. According to theory, that is the kind that should be generated by the nuclear fusion of hydrogen in the sun. Some physicists have speculated, however, that certain other neutrinos might transform on their way to the Earth into the other flavors, making them extremely difficult to find.

Last year preliminary evidence from the Sudbury and Super-K detectors showed tentative hints of such neutrino transformations but with limited statistical significance. Then in April, physicists working at Sudbury announced the results of a challenging new study that compared the total flux of all three neutrino types with the flux of the electron-neutrino stream. The data showed conclusively that the bulk of the neutrinos had transformed to one or both of the other flavors, known as muon-neutrinos and tau-neutrinos. “We observed clearly that there are significantly more than just electron-neutrinos arriving,” says Art McDonald, project director at Sudbury. The results imply that contrary to physicists’ assumptions, neutrinos are not massive; otherwise, such transformations would not be possible. That finding is forcing researchers to recast the standard model of physics, which describes the interactions of all the fundamental particles in the universe. “This is the first major advance of the model in more than 20 years,” says Kevin Lesko, a physicist at the Lawrence Berkeley National Laboratory in California. More energy detectors would also account for some of the invisible matter thought to hold galaxies and galaxy clusters together. “Neutrinos are a mystery that we are just beginning to understand,” Lesko says.

—Mike Weisskopf

Discover magazine – January 2003
Solving the Solar Neutrino Problem

The Sudbury Neutrino Observatory has solved a 30-year-old mystery by showing that neutrinos from the sun change species en route to the earth.

By Arthur B. McDonald, Joshua R. Klein and David L. Wark

Building a detector the size of a 10-story building two kilometers underground is a strange way to study solar phenomena. Yet that has turned out to be the key to unlocking a decades-old puzzle about the physical processes occurring inside the sun. English physicist Arthur Eddington suggested as early as 1920 that nuclear fusion powered the sun, but efforts to confirm critical details of this idea in the 1960s ran into a stumbling block: experiments designed to detect a distinctive by-product of solar nuclear fusion reactions—ghostly particles called neutrinos—observed only a fraction of the expected number of them. It was not until last year, with the results from the underground Sudbury Neutrino Observatory (SNO) in

Or our web site: www.sno.phy.queensu.ca
Recognition for participants in the SNO project

- Benjamin Franklin Medal in Physics
- Order of Canada
- NSERC - John C. Polanyi Prize to entire SNO team
- NSERC – Gerhard Herzberg Gold Medal
- Canadian Association of Physics Gold Medal
- 7 Honorary Degrees to SNO scientists
- 3 Fellows of the Royal Society of Canada
- Tom Bonner Prize of the American Physical Society
- Russia – Bruno Pontecorvo Prize
- UK – Rutherford Medal
- 1 Fellow of the UK Royal Society
- 5 Fellows of the American Physical Society
- Membership in the US Academy of Science

- 7 Canada Research Chairs including one soon at Laurentian
- Over 130 Graduate degrees (Ph. D and M. Sc.)
- Training for over 400 undergraduates
- Development of a highly skilled workforce: over 30 workers in Sudbury
Economic Impact

- Over $150 million expended to date, including over $120 million capital construction and over $30 million operating costs.

- Over 30 full-time jobs in a high-tech enterprise with the prospect for future increases as SNOLAB develops.

- Future operating budget of over $6 million per year for 15 to 20 years at least.

- Future SNOLAB experiments involving 4 or 5 major projects with over 60 international participants each and capital construction in excess of $10 million each: Significant local economic impact.

- Name recognition of Sudbury across the world in association with the highest level of achievement in science and technology.

- A strong education program in partnership with Laurentian University and other Sudbury institutions.

- A strong outreach program in partnership with Science North.
What will we study with SNOLAB experiments?

With SNOLAB experiments we intend to measure topics as fundamental as we did with the original SNO experiment:

**SNO+ (existing SNO detector with heavy water replaced with liquid scintillator for more light output):**

- Neutrinos from the Earth: Why is it 40 degrees at the 6800 ft level?
- Lower energy neutrinos from the Sun to understand it in more detail.

**PICASSO, DEAP/CLEAN, LUX, SUPER-CDMS:**

- What are the DARK MATTER PARTICLES making up 25% of the Universe and fundamental to its evolution?

**EXO, MAJORANA, SNO+:**

- Neutrino-less Double Beta Decay (a very slow, rare radioactivity):
  Why is our Universe mainly made of MATTER? Where is the anti-matter?

**HALO, SNO+:**

- Neutrinos from collapsing stars: Supernovae.
Initial Suite of Experiments

Cube Hall: 1 or 2 of 2008: DEAP/CLEAN 2009: PICASSO-III 2009: LUX (1 ton Xe)

SNO Utility Rm: Now: PICASSO-IB (2kg)

SNO Control Rm: 2007: DEAP-1

SNO Cavern: 2008/9: SNO+

Future: HALO

Cryopit: 1 or 2 of DEAP/CLEAN LUX Large EXO, CLEAN 1-ton GERDA/MAJORANA


Shows Existing SNO area

Phase 1: Excavated, in use in 2008

Phase 2: Funding complete soon, Occupied in early 2009
THANK YOU SUDBURY!

We greatly appreciate the strong support we have received from all of the Sudbury community over many years.

You have helped greatly to make all of this possible.

We look forward to working with you for many years in the future to make SNOLAB another local and international success for all of us.