The IceCube Neutrino Telescope
Marcos Santander
Outline

- What’s the universe made of?
- What are neutrinos?
- Why are they special?
- How can we use them to explore the Universe?
- IceCube
- Some results
Building blocks for the universe

Proton $p^+$

Neutron $n$

Electron $e^-$

![Galaxy Image]

- Atoms 4.6%
- Dark Energy 72%
- Dark Matter 23%

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Beta decay

Tritium (1,2) → Helium-3 (2,1) → Electron

Number of electrons

Energy

- Observed spectrum of energies
- Expected electron energy
- Endpoint of spectrum
Why neutrinos?

Helium-3 (2,1)

Tritium (1,2)

Electron

(Anti) neutrino

Wolfgang Pauli (1930)
Nobel Prize 1945
Searching for the neutrino: the cool way
Searching for the neutrino: the OK way

Reines & Cowan experiment (Project Poltergeist)
Nobel Prize for Reines in 1995
Using neutrinos for astronomy: the Sun

Davis (Nobel Prize 2002)
Neutrino come in 3 *flavors*, and *oscillate*
Using neutrinos for astronomy: the Sun

The Sun as seen in neutrinos (Super-Kamiokande detector)
Using neutrinos for astronomy: Supernovae
Energy (eV)

- $10^{-3}$ eV (meV)
- $10^0$ eV
- $10^3$ eV (keV)
- $10^6$ eV (MeV)
- $10^9$ eV (GeV)
- $10^{12}$ eV (TeV)
- $10^{15}$ eV (PeV)
- $10^{18}$ eV (EeV)
- $10^{20}$ eV (ZeV)

**Observation**
- Ground based telescopes
- Chandra
- Fermi
- IACTs
- Kascade
- Auger

**Experimentation**
- AMO
- XFEL
- Bevatron
- LHC

**No data**
Discovery of cosmic rays

Discovery: 1912
Nobel prize: 1936


V. Hess 1912
Kolhörster (1913/4)
Discovery of cosmic rays

Discovery 1912
Nobel prize 1936

V. Hess, On observations of penetrating radiation during seven balloon flights
Physik. Zeitschr. XIII, 1912
Early debates on cosmic rays

NY Times, 10/29/1926

NY Times, 12/31/1932
CR spectrum and air showers

Knee

\[ E_{CM} \sim \sqrt{2E_p m_t} \]

99 years later...

Los Alamos Science 25 (1997)
Origin of cosmic rays... discovered?

Fermi telescope closes in on mystery of cosmic ray acceleration

In all directions of the sky, cosmic rays rocket through space with incredible speed. These "rays"—which mostly consist of protons—are some of the most energetic particles in the universe. For nearly 100 years, they have also been some of the most enigmatic. Now, a new result from the Fermi Gamma-ray Space Telescope’s Large Area Telescope collaboration offers insight into how the universe accelerates these particles to such high energies. The high-energy cosmic rays appear to be coming from supernova remnants, the dying remains of exploded stars; the new result reveals the spatial distribution of this emission in one particular supernova remnant.

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Origin Of Cosmic Rays: VERITAS Telescopes Help Solve 100-Year-Old Mystery

These findings were published in the Nov. 1 online issue of the journal Nature, and are being featured today in a press conference at the Fermi Science Symposium in Washington, DC.

Reference
- Nuclideothermics
- Supernova
IceCube Collaboration

10 countries
36 institutions
~260 collaborators
Working principle

\[ \nu_\ell \rightarrow \ell^\pm \]

Cherenkov radiation

\[ W^\pm \]

Charged current interaction

\[ \nu_\ell \]
\[ \nu_\ell \]

Neutral current interaction

\[ Z^0 \]

\[ \nu > c \text{ (in ice)} \]
The IceCube detector

- 86 strings
- 5160 DOMs
- 17 m vertical spacing
- 125 m between strings

Digital Optical Module
Getting to the Pole
South Pole
Drilling the ice
IceCube configurations
IceCube configurations

IC-1
04-05 Season
IceCube configurations

IC-9
05-06 Season
IceCube configurations

IC-40
07-08 Season
IceCube configurations

IC-59
08-09 Season
IceCube configurations

IC-79
09-10 Season
IceCube configurations

IC-86
10-11 Season
Muon event in IceCube

Muon – IC 40 data
~0.7° resol

Run 110261 Event 350001
Tue Jan 29 09:44:39 2008
Big cosmic ray shower
IceCube Moon shadow

![Diagram showing cosmic ray flux and Moon shadow]
Cosmic rays as seen with IceCube

- ~$10^{-3}$ anisotropy observed in the South
- Good match to observations in the North

arxiv/1005.2960
Atmospheric neutrinos
Neutrinos from Gamma Ray Bursts

Vela Satellite (1960s)
Point sources of neutrinos

- Nothing significant so far!
Neutrinos from Dark Matter

[Graph showing neutrino production cross-section vs. neutralino mass, with various experiment lines and shaded regions indicating experimental sensitivities.]
- So... No neutrino sources so far, but stay tuned!