Recent Results from the IceCube Neutrino Observatory

Chris Weaver for the IceCube Collaboration Lake Louise Winter Institute—February 20, 2015







Messenger Particles



- Cosmic Rays are charged, and so don't travel in straight paths
- Gamma Rays have straight paths, but can be easily attenuated
- Neutrinos have straight paths and pass through nearly everything

Image courtesy NASA Johnson Space Center

Air Showers



- Many high energy neutrinos come from our own atmosphere
- Muons are produced at the same time
- These form a background when one tries to study astrophysical neutrinos (or gamma rays)

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The IceCube Collaboration

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 University of Alberta–Edmonton
 University of Toronto

USA

Clark Atlanta University Drexel University Georgia Institute of Technology Lawrence Berkeley National Laboratory Michigan State University **Ohio State University** Pennsylvania State University South Dakota School of Mines & Technology Southern University and A&M College Stony Brook University University of Alabama University of Alaska Anchorage University of California, Berkeley University of California, Irvine University of Delaware University of Kansas University of Maryland University of Wisconsin-Madison-University of Wisconsin-River Falls Yale University

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University of Adelaide, Australia

University of Canterbury, New Zealand

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Detector actually ~2 km below

Haley Buffman & Jamie Yang. IceCube/NSF

Detector Hardware



Detection Principle

Schematic of an IceCube 'String'



- Energetic particles produce
 Cherenkov light in the ice
- Modules detect photons
 - Good linearity from single photon to several hundred photon level
- Absorption length for light is long (~90m) but scattering length is shorter (~25m)

Selecting Neutrinos





- Two approaches:
 - Select events with an interaction vertex in the detector, and no visible entering particles (starting events)
 - Select events which have passed through the Earth, but may enter the detector after interacting (through-going events)

All-Flavor, All-Sky with Starting Events



- <u>Phys. Rev. Lett. 113, 101101</u>: Analysis of starting events depositing >60 TeV or more using 3 years of data, observes events up to ~2 PeV
- $\bullet\,$ Mostly ν_e charged current and neutral current interactions, mostly sensitive in the southern sky
- Clear excess over background (5.7 σ), no clear clustering on the sky

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Northern Sky Through-going Events



- (Paper in internal review) Analysis of through-going events from the northern sky using 2 years of data— v_{μ} charged current only, >1 TeV
- Excess over atmospheric background of 3.7σ
- Signal looks similar in different channels and different parts of the sky

Neutrino Oscillation $2\Delta \ln L$ Earth T2K 2014 [NH] IceCube 2014 [NH] 3.8 MINOS w/atm [NH] SK IV [NH] 3.6 90% CL contours $\begin{vmatrix} \Delta m_{32}^2 \\ \circ & \circ \\ \circ &$

 <u>arXiv:1410.7227</u>: Disappearance analysis of ~10 GeV-100 GeV atmospheric V_{μ} with 3 years of data

2.4

2.2

2.0

0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70

 $\sin^2(\theta_{23})$

Atmospheric

Neutrinos

• Obtains $\sin^2(\theta_{23}) = 0.53^{+0.09}_{-0.12}$ and $|\Delta m^2_{32}| = 2.72^{+0.19}_{-0.20} \times 10^{-3} \text{eV}^2$ for the normal hierarchy.

Detector

1 2 3

 $-2\Delta \ln L$

0

Neutrino Oscillation



- <u>arXiv:1410.7227</u>: Disappearance analysis of ~10 GeV-100 GeV atmospheric ν_µ with 3 years of data
- Obtains sin²(θ_{23}) = $0.53^{+0.09}_{-0.12}$ and $|\Delta m^2_{32}| = 2.72^{+0.19}_{-0.20} \times 10^{-3} eV^2$ for the normal hierarchy.

WIMP Annihilation

- arXiv: 1406.6868: Analysis of arrival directions of V_{μ} to look for correlation with the expected signature of WIMP annihilations in the Galactic halo
- Used I year of data, events with energies from ~100 GeV to 10 TeV



Summary

- For astrophysical neutrinos IceCube sees:
 - A consistent diffuse flux in all detection channels
 - No clear association with known sources
- Also lots of work in other areas:
 - Neutrino oscillations
 - Dark matter
 - Supernovae
 - Monopoles

Questions?

Point Sources Muon Neutrinos



- <u>arXiv:1406.6757</u>: Analysis of through-going events from the whole sky ν_µ and µ using 4 years of data
- No significant features observed (post-trial p-values of 0.23 and 0.44 for the best points on the sky pre-trial)

Point Source Sensitivity/Limits



All-Flavor, All-Sky with Starting Events



- <u>Phys. Rev. D 91,022001</u>: Extends analysis of starting events down to ~I TeV, using 2 years of data
- Astrophysical spectrum seems to continue down to a few TeV



• <u>arXiv: I502.03376</u>: Used 3 years of starting events with energies >35 TeV



• (Paper in internal review): Using 4 years of through-going v_{μ} from the northern hemisphere



Energy Resolution for Muons



