Astronomy and Astrophysics in Antarctica
Recent Results and Discoveries

Vladimir Papitashvili, Program Director
Antarctic Astrophysics & Geospace Sciences
Where are we?

Snow runway

MAPO with SPUD/Keck

U.S. Amundsen-Scott South Pole Station
2.9 km elevation above sea level

IceCube Lab

IceCube area

MAPO with SPUD/Keck

DSL w/BICEP3 & SPT
Where are we?

U.S. Amundsen-Scott South Pole Station
2.9 km elevation above sea level

Snow runway

2016
South Pole Markers line
(~10 m per year; over 1 km since Amundsen & Scott arrivals in 1911/1912)

~1957

IceCube area

IceCube Lab

MAPO with SPUD/Keck

2016

 (~10 m per year; over 1 km since Amundsen & Scott arrivals in 1911/1912)
• **IceCube Neutrino Observatory** (MREFC Project completed in 2010; M&O and science jointly funded by GEO/PLR and MPS/PHY) Lead PI: Francis Halzen, Univ. of Wisconsin-Madison and IceCube Collaboration of 47 institutions in 12 countries; 6 years of observations.

• **Askaryan Radio Array (ARA) for GZK neutrino studies** (3-5 testbed stations) Lead PI: Albrecht Karle, Univ. of Wisconsin & collaboration of 4 groups.

• **Antarctic Ross Ice-Shelf ANtenna Neutrino Array (ARIANNA) for GZK neutrino studies** (7 testbed stations) Lead PI: Steven Barwick, Univ. of California-Irvine.

• **South Pole 10m CMB Telescope (SPT)** First light: February 2007 Lead PI: John Carlstrom, University of Chicago and SPT collaboration of 2 national labs and 10 institutions in 3 countries; 10 years of observations.

• **Background Imager for Cosmic Extragalactic Polarization BICEP1-3 and SPUD/Keck small aperture array** First light: February 2006 (11 years) Lead PI: John Kovac (Harvard) and BICEP Collaboration of 9 institutions in 4 countries.

• **HEAT – TeraHertz Robotic Telescope at Ridge A** (4.1 km elevation) PIs: Craig Kulesa (University of Arizona) and Michael Ashley (University of New South Wales, Australia) 2011-2016 (5 years of observations).

• **NASA Long-Duration Balloon Program at McMurdo** (1990 – current).
Building a new window on the Universe!

- IceCube was built to search for very high energy neutrinos created in the most extreme cosmic environments, opening a window to search for cosmogenic neutrinos.

- After analyzing three years of data (2011-2013), ICNO established the world’s best limit on an extragalactic flux of cosmogenic neutrinos with significance at 5.7 sigma.

- For example, ICNO results show that PeV-level Gamma Ray Bursts are not accompanied by PeV neutrinos.

IceCube - highest energy neutrinos ever recorded

From left to right, Bert, Ernie and Big Bird events with energies of 1.0, 1.1, and 2.2 PeV.
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Four years data (full 6 years coming soon)

Where do they come from?

TS = 2 log(L/L0) = 10.9
IceCube - highest energy event!

- Date: June 11, 2014
- Most probable energy: 9 PeV
- Topology: track

http://icecube.wisc.edu
Radio detection of neutrinos complement optical technique at high energies

Signal attenuation length at South Pole:
Optical: 100m
Radio: 1.5km

A full ARA array (200km^2) will reach required sensitivity at high energies (above 100 PeV)

Detection method: Radio signal from secondary particles generated by neutrino’s interaction within the Ice
PLR & PHY - ARIANNA Concept

- Explores energy window beyond the reach of IceCube
- Discover the sources of cosmic rays and learn how they evolve with time
- Exploits novel radio-based emission and Antarctic ice to lower costs

First Detection of Cosmic Rays signal by self triggered multi-station array

Preliminary analysis:

- $E = 3 \times 10^{18}$ eV

7 stations in a hexagonal array, 1km spacing

Deployed at Ross Ice Shelf, ~100km south of McMurdo
• 2001 Astrophysics Decadal Survey recommended 10m CMB South Pole Telescope as ‘moderate initiative’ <$50M

• Funded: August 2002; First light: Feb 2007 - right on budget and on schedule!

• Completed 5-yr SZE survey (2500 sq. deg) confirming viability of that strategy and discovering over 500 massive galaxy clusters in the distant Universe.

• Through the fine scale CMB survey, tested cosmological models of the origin and early history of the Universe.

• Constrained the *Dark Energy* equation of state and moved on to CMB polarization measurements to search for the imprint of primordial gravitational waves and gravitational lensing.

http://spt.uchicago.edu/
SPTpol: completed 4 year deep 500 deg$^2$ polarization survey, overlapping BICEP/Keck field:

- Polarization angular power spectra to be submitted for publication imminently
- CMB-lensing analysis close behind
- Working on “de-lensing” analysis with BK team

Selected recent SPT science highlights:

- Cosmological constraints from the 2500 deg$^2$ SZE survey (de Haan et al. 1603.06522).
- SPTpol search for orphan GRB afterglows; one candidate found (Whitehorn et al. 1604.03507): Opening new window on transient astronomy!

Active & growing SPT+DES collaborative analysis:

- 2016 highlights include so far: CMB lensing tomography (Giannantonio et al. 1507.05551), detection of kSZE (Soergel et al. 1603.03094), and CMB-lensing shear and photo-z calibration (Baxter et al. 1602.07384)
SPT upgrade with SPT-3G camera

- SPT upgrade from SPTpol 2-band, 1,600 detector camera to **SPT-3G 3-band, 16,000 detector camera** and new wide-field optics.
- SPT-3G camera is jointly funded by NSF and DoE
- Deployment - austral summer November 2016 - January 2017

SPT-3G wide-field secondary and tertiary optics

~2.5 meters

SPT-3G integrated optics and receiver
• SPT-3G 16,000 detectors and 3 frequencies would allow delensing to $A_L=0.2$ on $f_{\text{sky}}=0.02$
• BICEP3 + BICEP Array 35,000 detectors, 5 frequencies focusing on B-mode
• By 2018/2019, South Pole CMB telescopes will have $\sim$50,000 detectors – first step to CMB-S4 program.
South Pole B-mode measurements lead progress on $r$

**BKP raw sensitivity with no foregrounds or lensing:** $\sigma(r) = 0.006$

→ *it is all about component separation!*

- BICEP/Keck-Planck analysis, deep 150 GHz B-modes to improve constraints on inflationary cosmology (left): $\sigma(r) = 0.034$ [arXiv:1502.00612]
- BK2014 data, deep 95 GHz improved $r$ for B-modes: $\sigma(r) = 0.024$ [arXiv:1510.09217]
- BK2015, deep 220 GHz B-modes + SPTpol delensing: $\sigma(r) < 0.018$ paper in prep
- Uncertainty on $r$ will shrink as component separation improves with much deeper BICEP multiband maps with SPT3G delensing: estimate $\sigma(r) < 0.005$ by 2019

Deep degree-scale maps multiband for **foreground separation**

BKP raw sensitivity with no foregrounds or lensing: $\sigma(r) = 0.006$
• The 0.6m aperture High Elevation Antarctic Terahertz (HEAT) telescope operated robotically (2011-2016) at Ridge A summit, delivering spectroscopic data from 150 to 500 microns.

• Joint project of the U.S. and Australian scientists: Univ. of Arizona (HEAT telescope) and Univ. of New South Wales (PLATO-R power module)  
  
http://soral.as.arizona.edu/heat/
August 1988 – First MoA signed between NASA and NSF suggesting one LDB payload launch every other year beginning January 1990

Since 1990, total 52 LDB and SPB payloads have been flown from McMurdo (currently 3+ payloads per austral summer)

Three payloads are ready for the 2016/2017 season:

- Boron And Carbon Cosmic-rays in the Upper Stratosphere (BACCUS)
- Stratospheric Terahertz Observatory (STO)
- Antarctic Impulsive Transient Antenna (ANITA)
Thank you!

Questions?