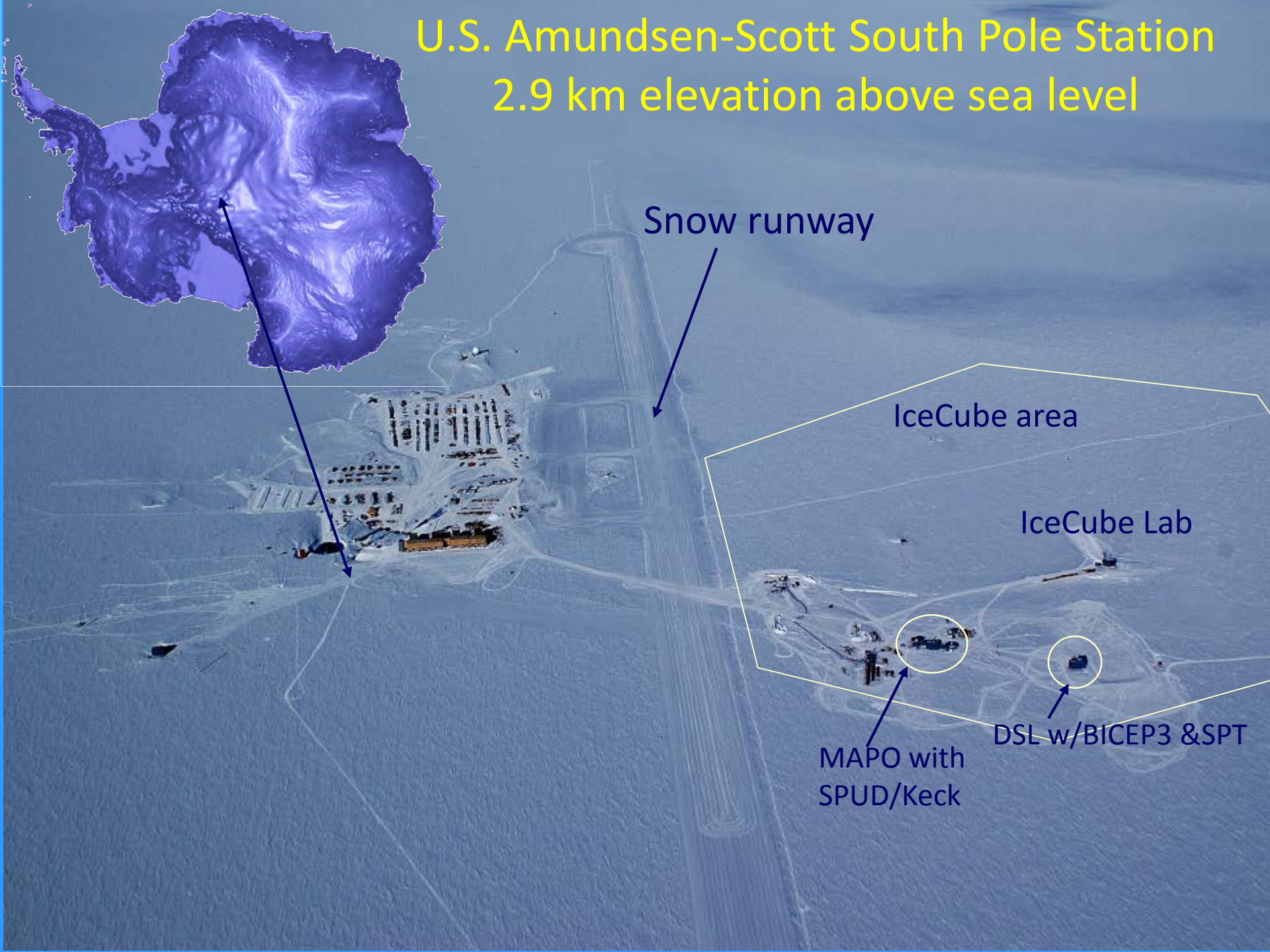
Astronomy and Astrophysics Advisory Committee Meeting
October 27, 2016

Astronomy and Astrophysics in Antarctica

Resent Results and Discoveries

Vladimir Papitashvili, Program Director
Antarctic Astrophysics & Geospace Sciences


U.S. Amundsen-Scott South Pole Station
2.9 km elevation above sea level
Snow runway
IceCube area
IceCube Lab
DSL w/BICEP3 &SPT
MAPO with
SPUD/Keck

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

Snow runway

IceCube area

IceCube Lab

2016 **South Pole Markers line** **~1957**

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

MAPO with SPUD/Keck

Antarctic Astronomy & Astrophysics projects

U.S. Antarctic Program

National Science Foundation

- **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).

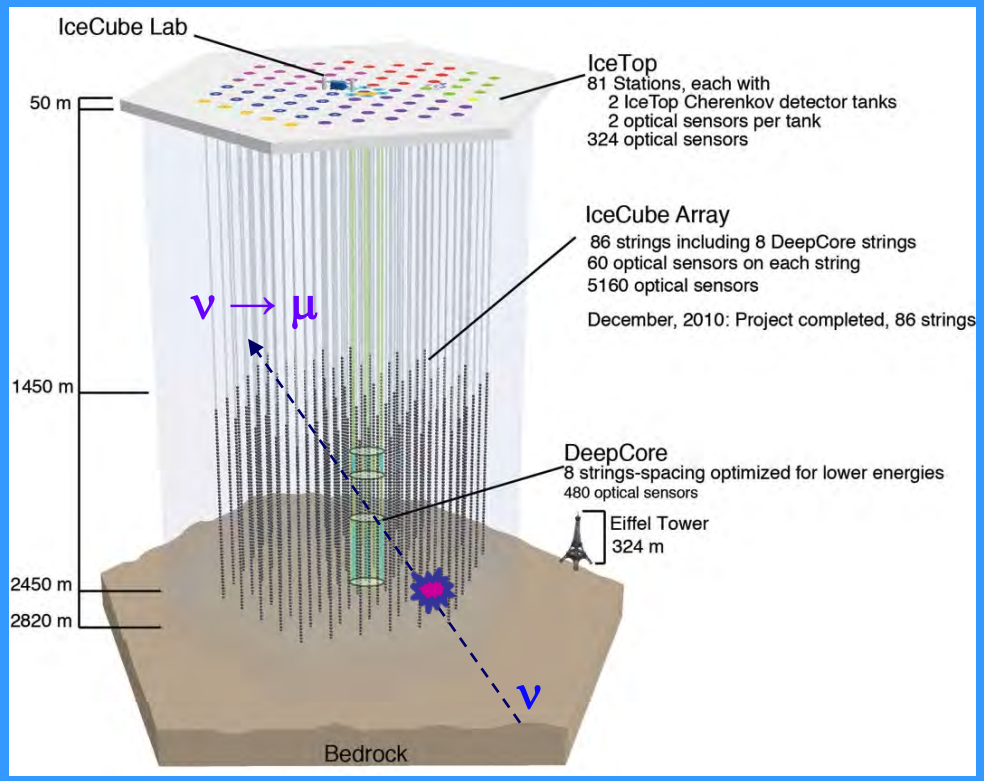
PLR & PHY - IceCube Neutrino Observatory

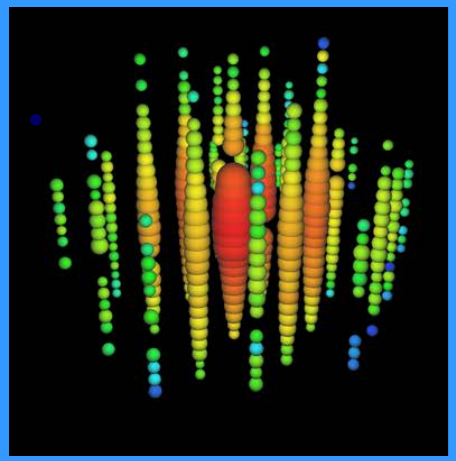
U.S. Antarctic Program

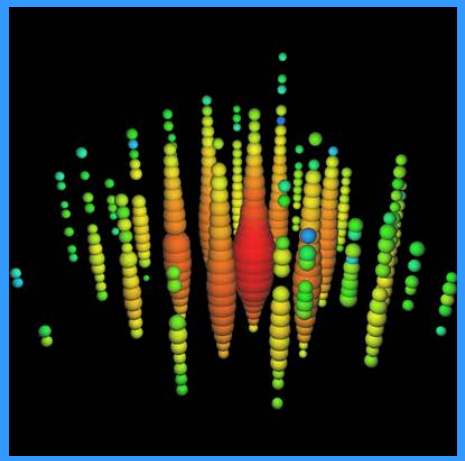
National Science Foundation

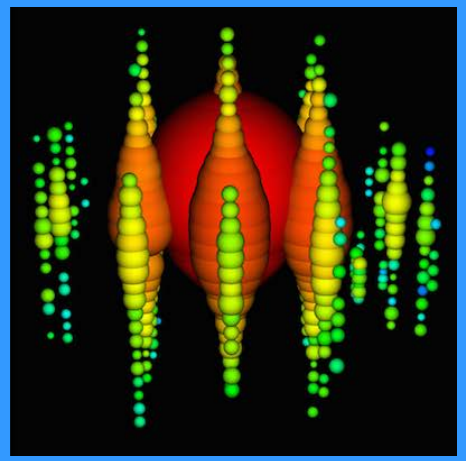
Building a new window on the Universe!

- 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.

PLR & PHY - IceCube Neutrino Observatory

Building a new window on the Universe!

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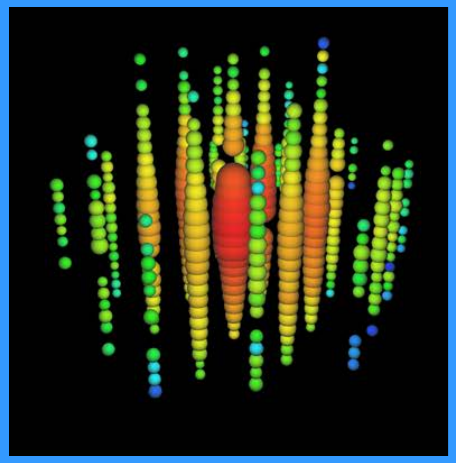
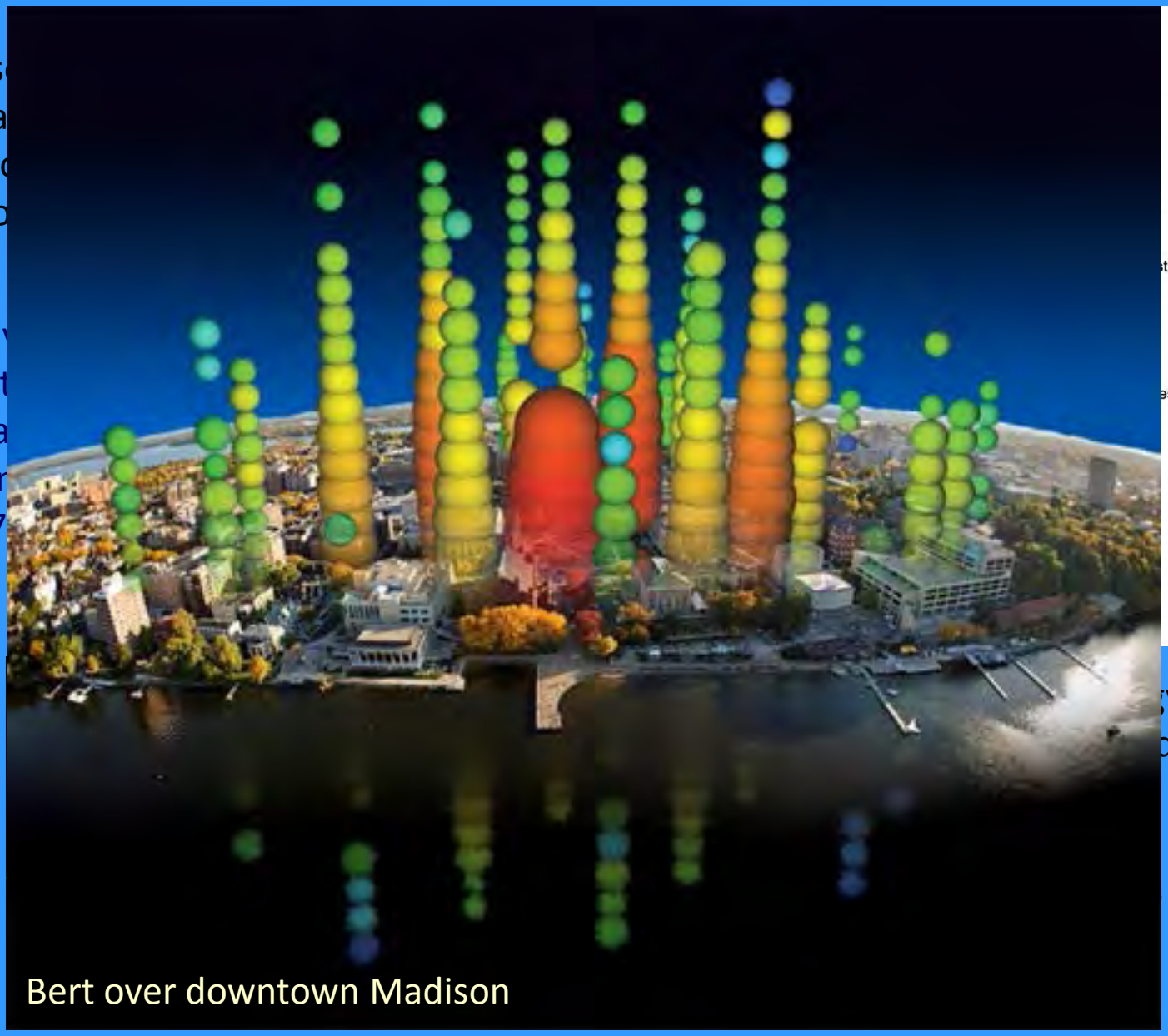
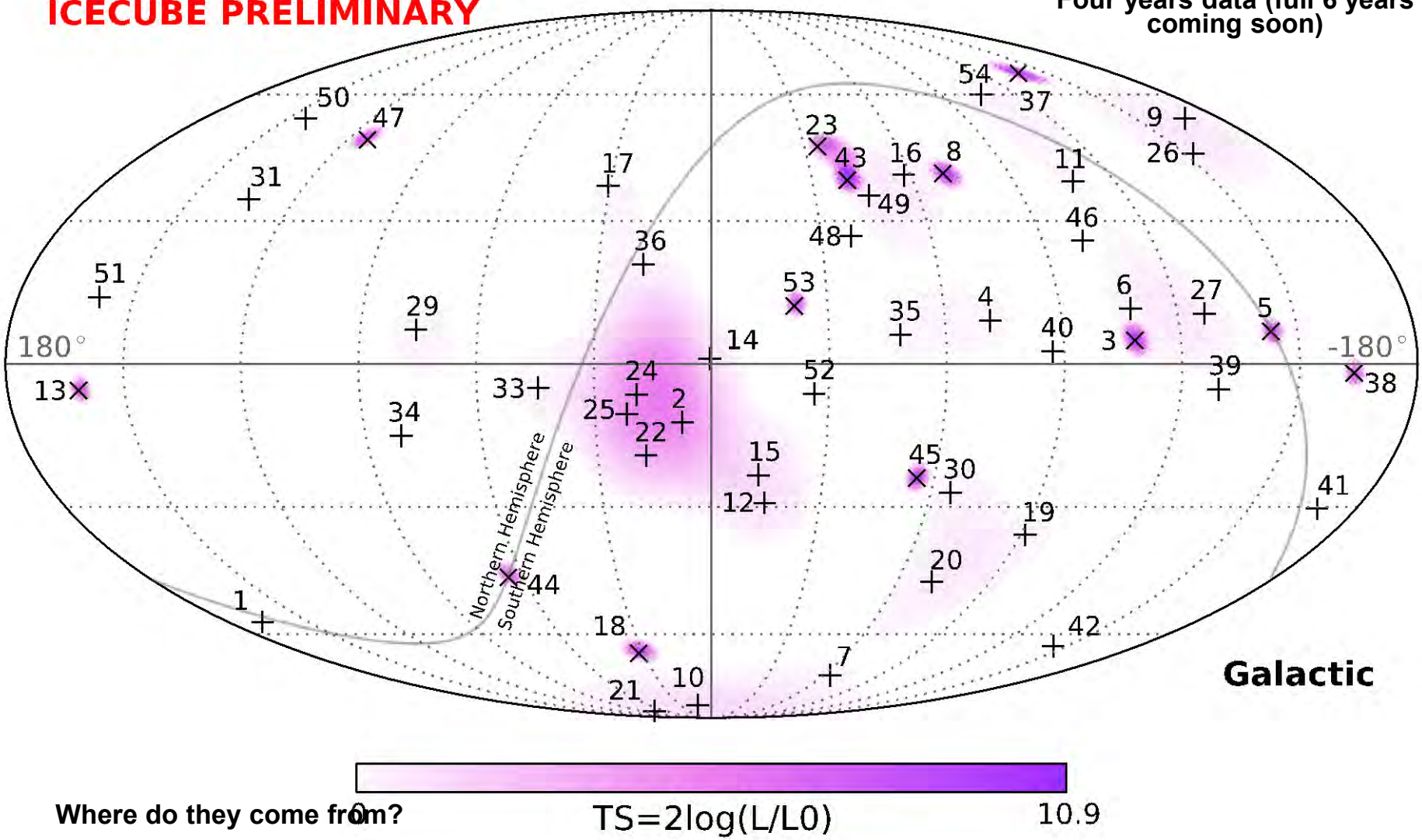
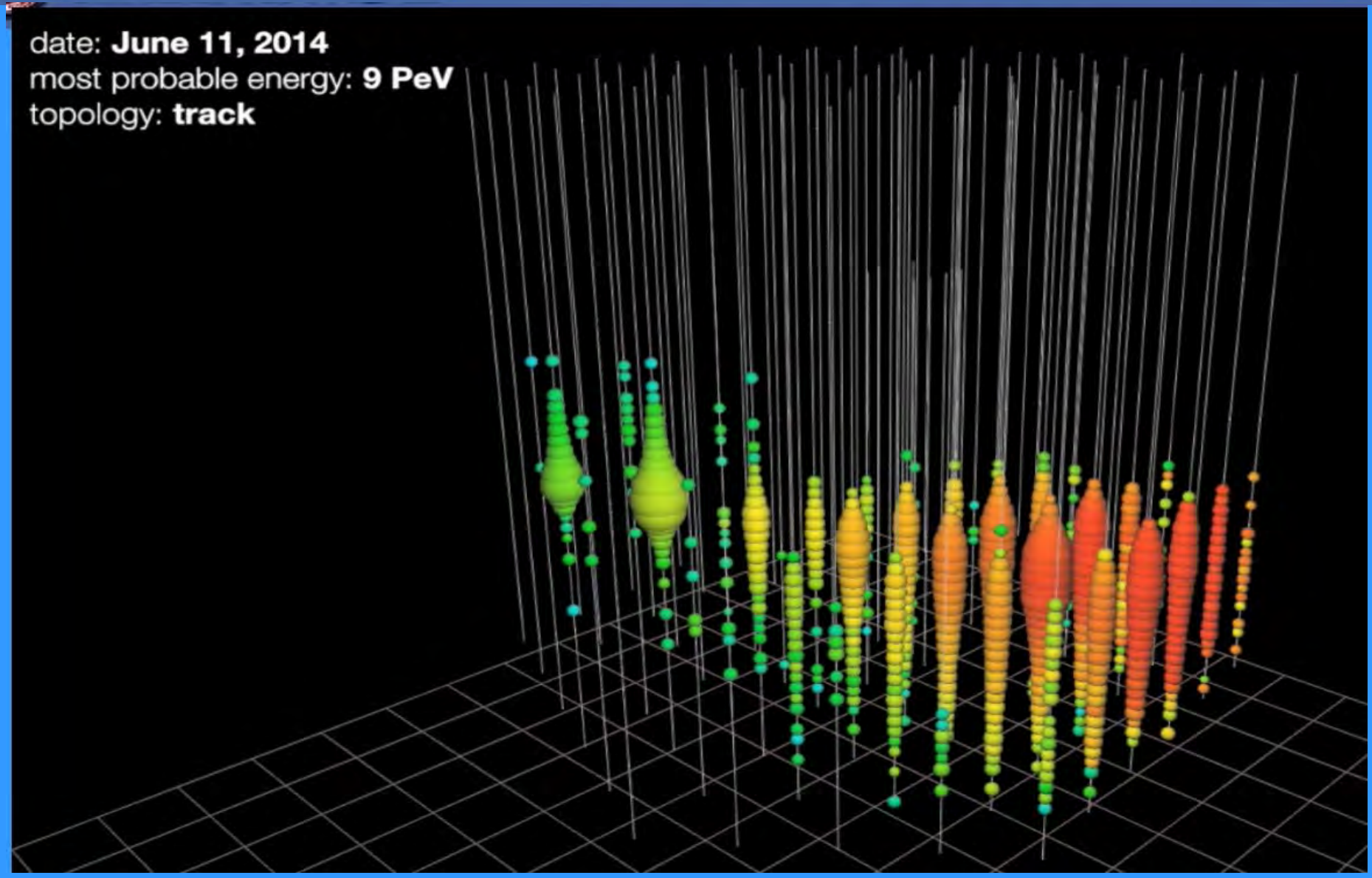




Bert over downtown Madison


ICECUBE PRELIMINARY
Four years data (full 6 years coming soon)
180°
-180°
Northern Hemisphere
Southern Hemisphere
Galactic
TS=2log(L/L0)
0
10.9
Where do they come from?

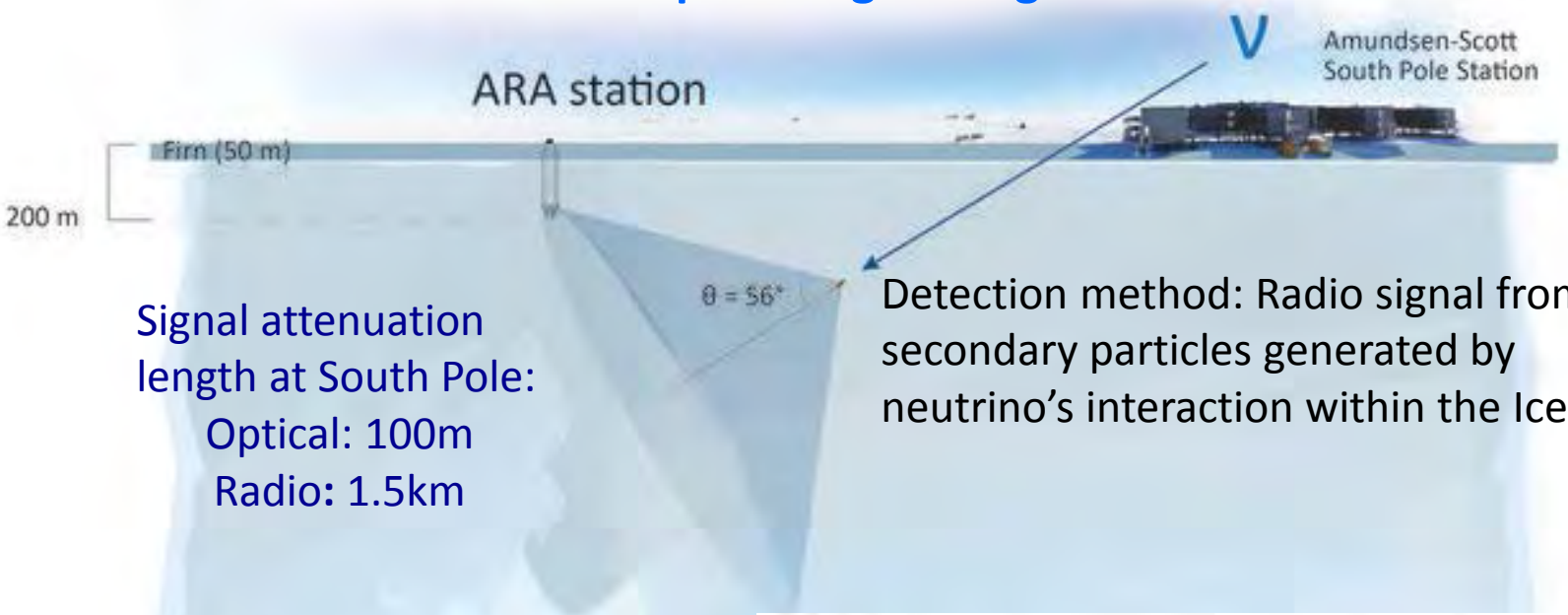
IceCube - highest energy event!



http://icecube.wisc.edu

PLR & PHY – Askaryan Radio Array

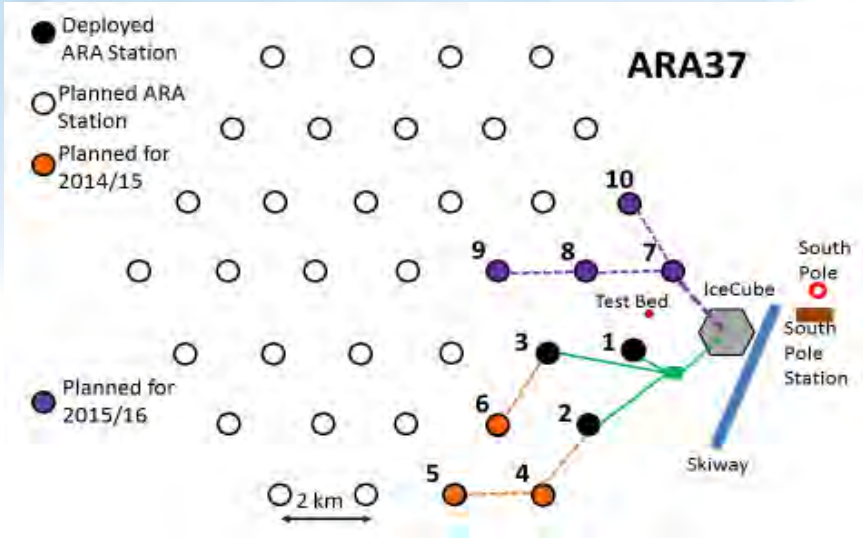
Radio detection of neutrinos complement optical technique at high energies



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

Detection method: Radio signal from secondary particles generated by neutrino's interaction within the Ice

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



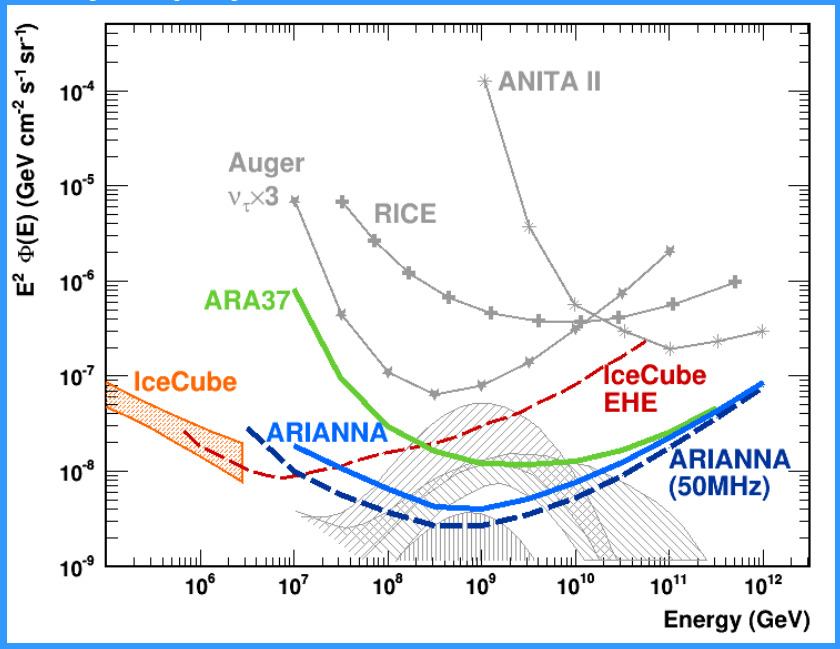
PLR & PHY - ARIANNA Concept

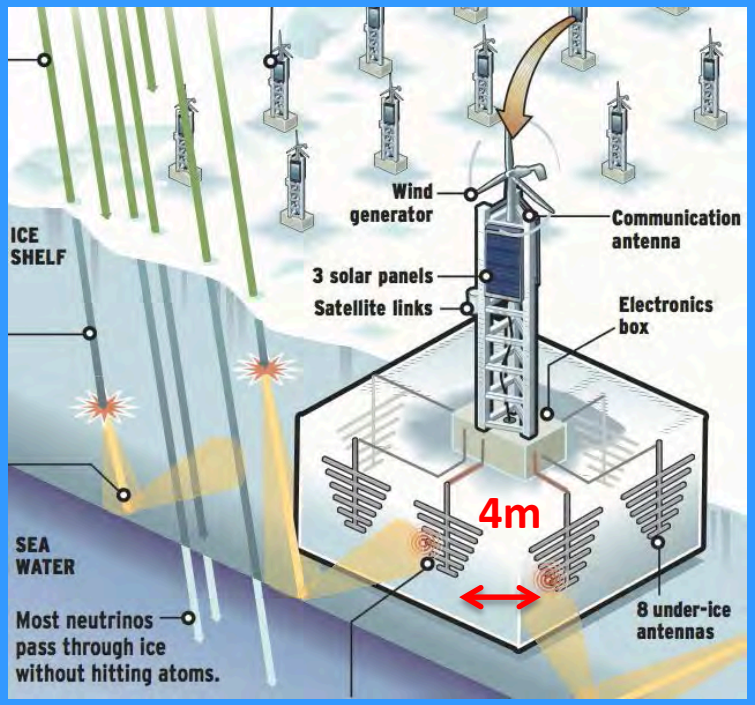
U.S. Antarctic Program

National Science Foundation

- 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

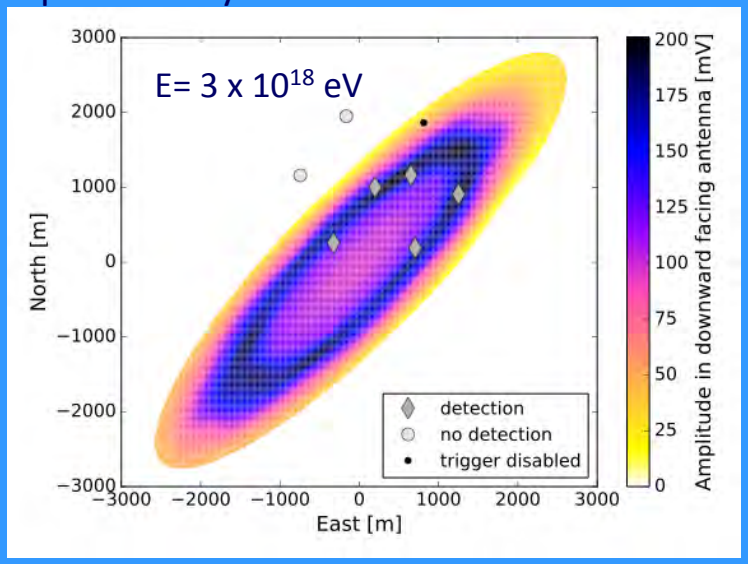
5 year projections for ARIANNA and ARA





7 stations in a hexagonal array, 1km spacing

preliminary



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

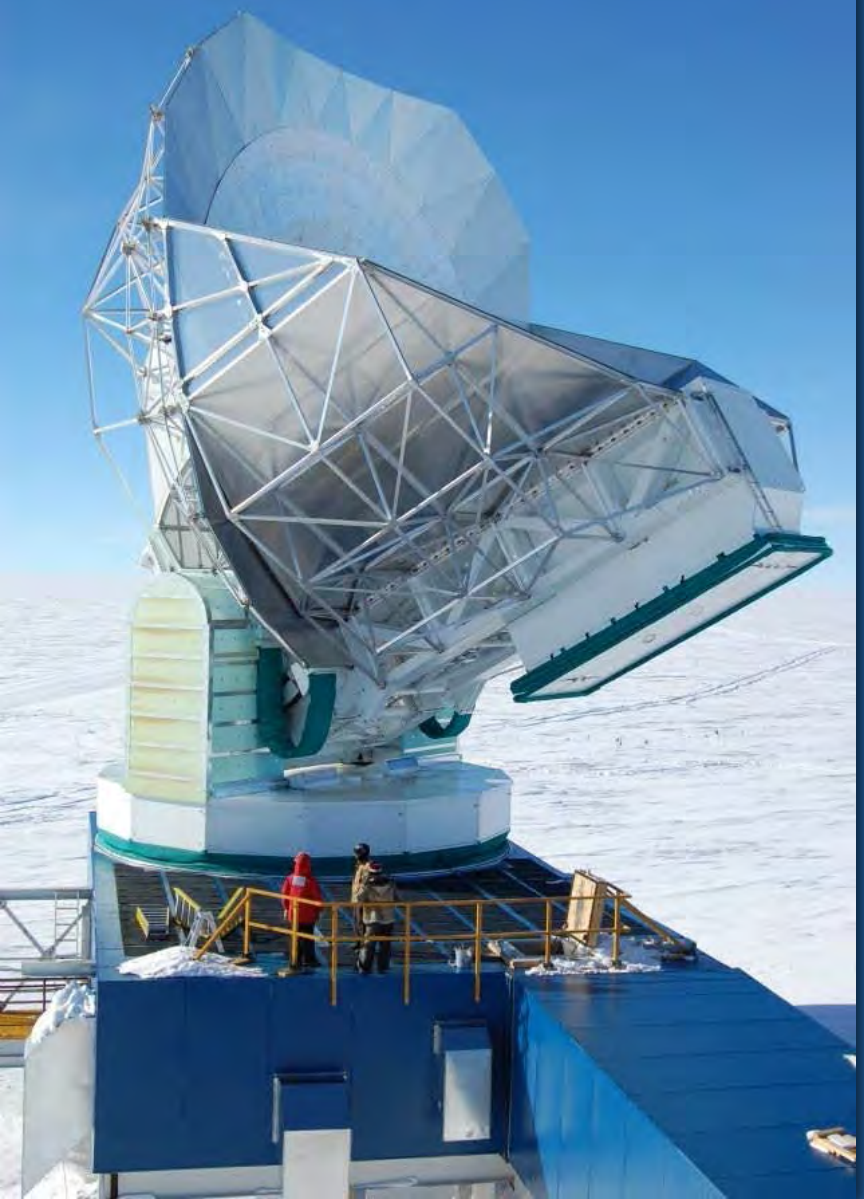
Deployed at Ross Ice Shelf, ~100km south of McMurdo

PLR, PHY, & AST - South Pole Telescope

U.S. Antarctic Program

National Science Foundation

http://spt.uchicago.edu/



- 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.

South Pole Telescope highlights

SPTpol: completed 4 year deep 500 deg^2 polarization survey, overlapping BICEP/Keck field:

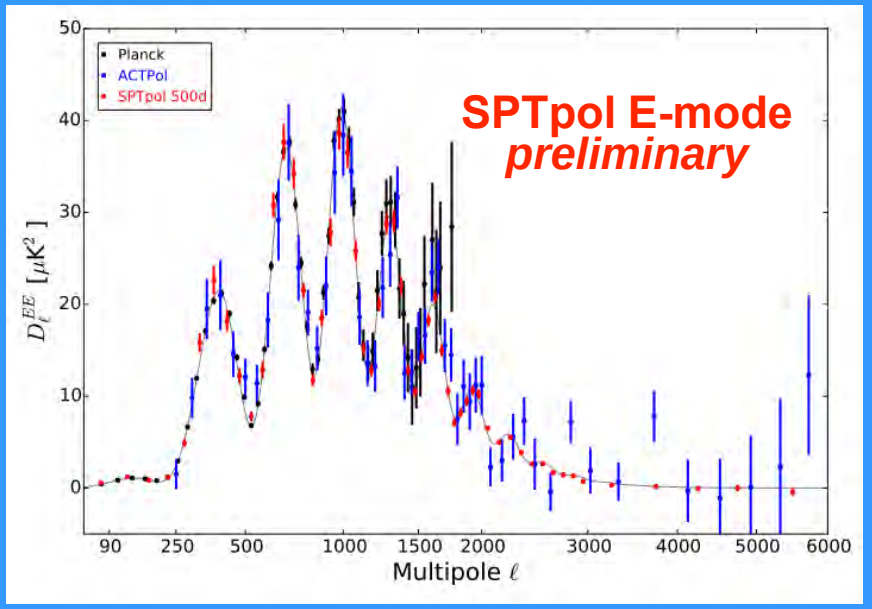
- Polarization angular power spectra to be submitted for publication imminently
- CMB-lensing analysis close behind
- Working on "de-lensing" analysis with BK team

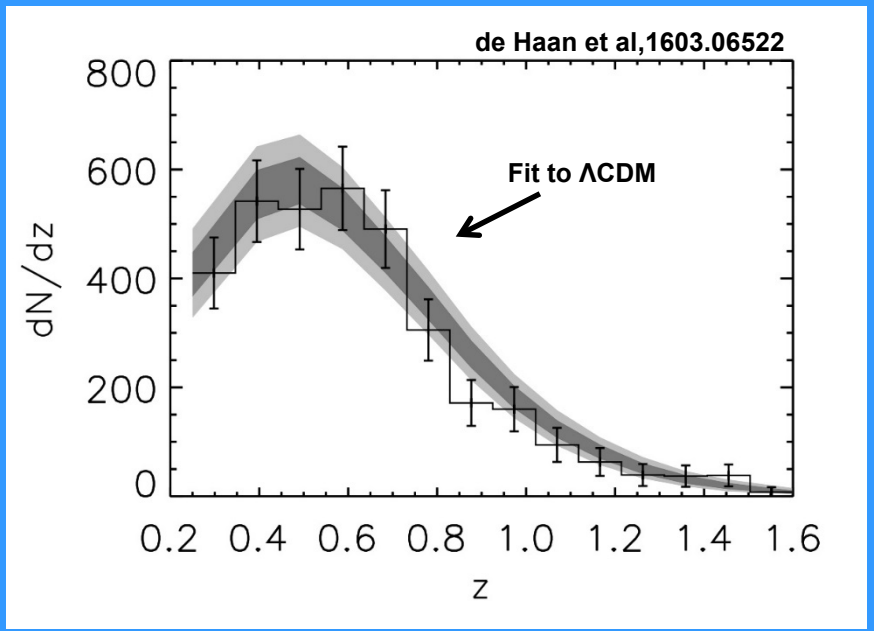
Selected recent SPT science highlights:

- 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:

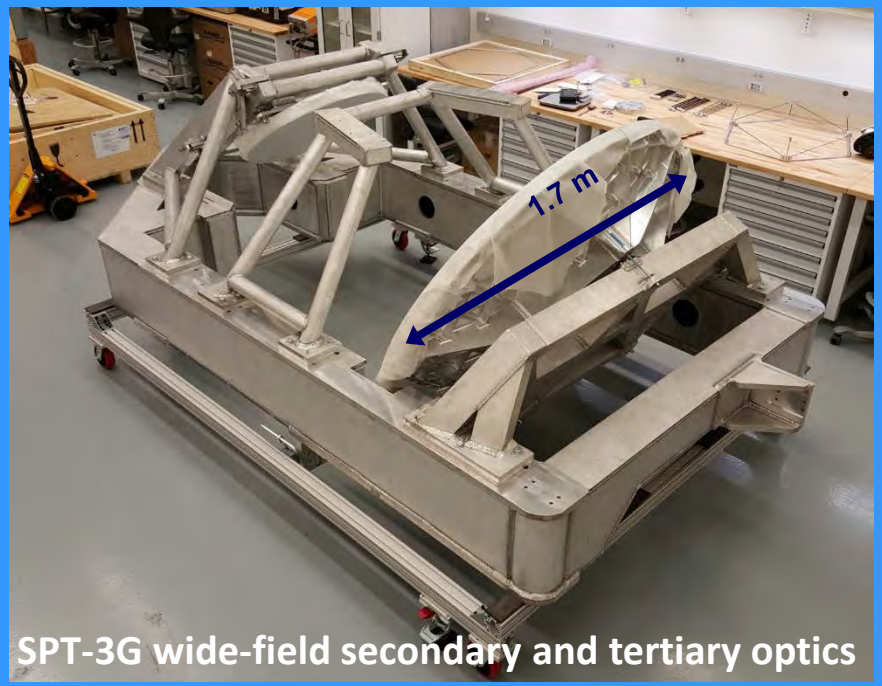
- 2016 highlights include so far: **CMB lensing tomography** (Giannantonio et l. 1507.05551), **detection of kSZE** (Soergel et al. 1603.03094), and **CMB-lensing shear and photo-z calibration** (Baxter et al. 1602.07384)



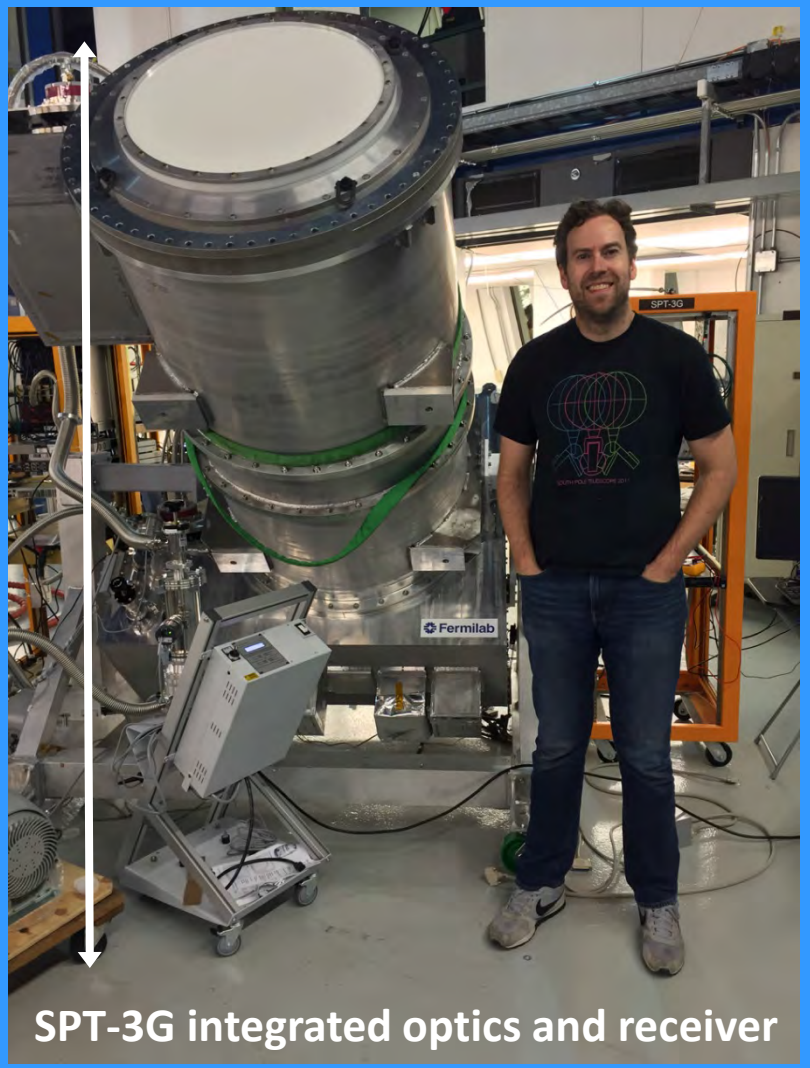


SPT upgrade with SPT-3G camera

- 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



SPT-3G integrated optics and receiver

PLR, PHY & AST - Observing from South Pole

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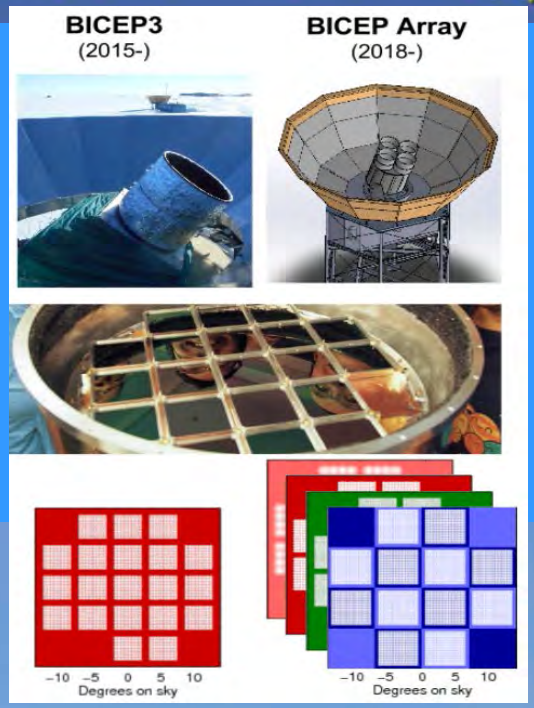
- SPT-3G 16,000 detectors and 3 frequencies would allow delensing to A_L=0.2 on f_{sky}= 2%
- BICEP3 + BICEP Array 35,000 detectors, 5 frequencies focusing on B-mode
- By 2018/2019, South Pole CMB telescopes will have ~50,000 detectors – first step to CMB-S4 program.



South Pole B-mode measurements lead progress on *r*

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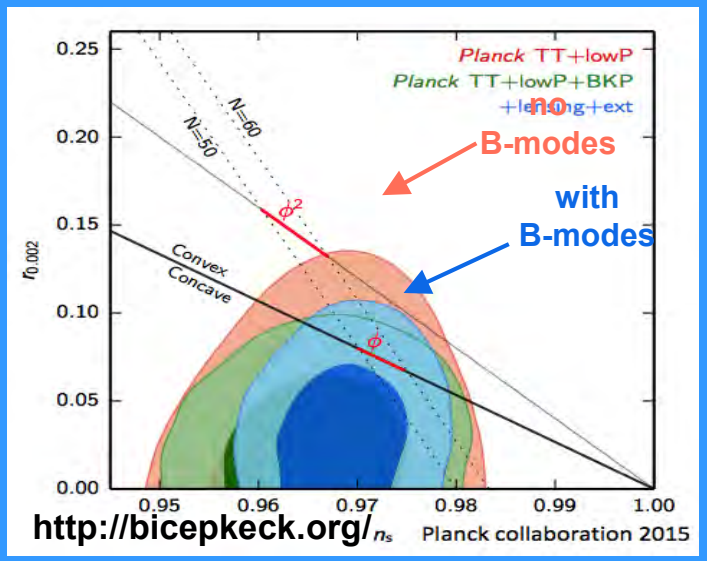
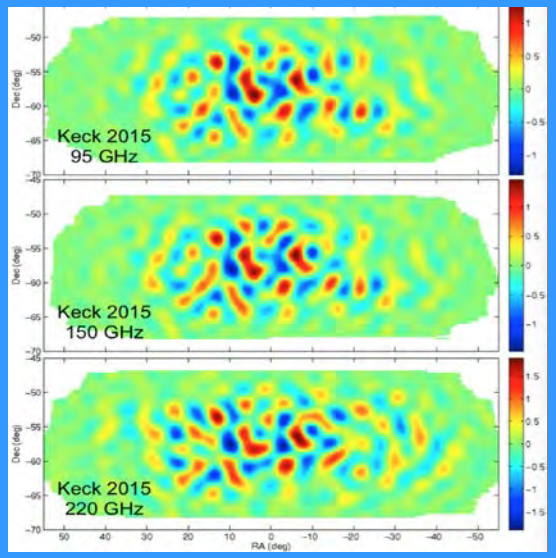
BKP raw sensitivity with no foregrounds or lensing: σ(*r*) = 0.006

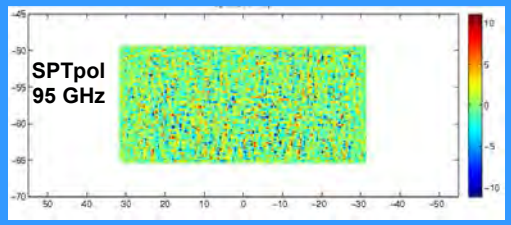
→ *it is all about component separation!*

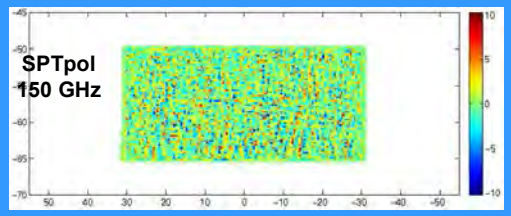




Deep degree-scale maps multiband for **foreground separation**

+





Deep high-resolution maps:
precision delensing

- BICEP/Keck-Planck analysis, deep 150 GHz B-modes to improve constraints on inflationary cosmology (left): σ(*r*) = 0.034 arXiv:1502.00612
- BK2014 data, deep 95 GHz improved *r* for B-modes: σ(*r*) = 0.024 arXiv:1510.09217
- BK2015, deep 220 GHz B-modes + SPTpol delensing: σ(*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 σ(*r*) < 0.005 by 2019

PLR & AST – HEAT: TeraHertz Robotic Telescope

U.S. Antarctic Program

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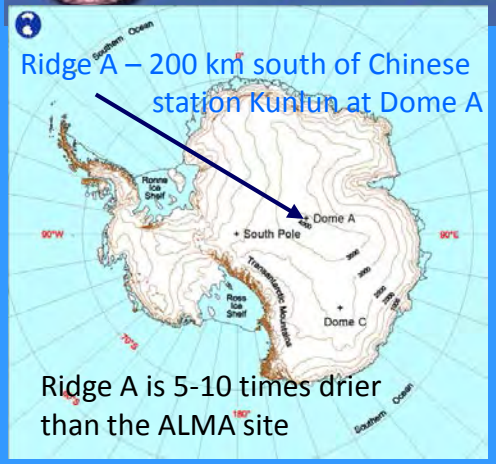
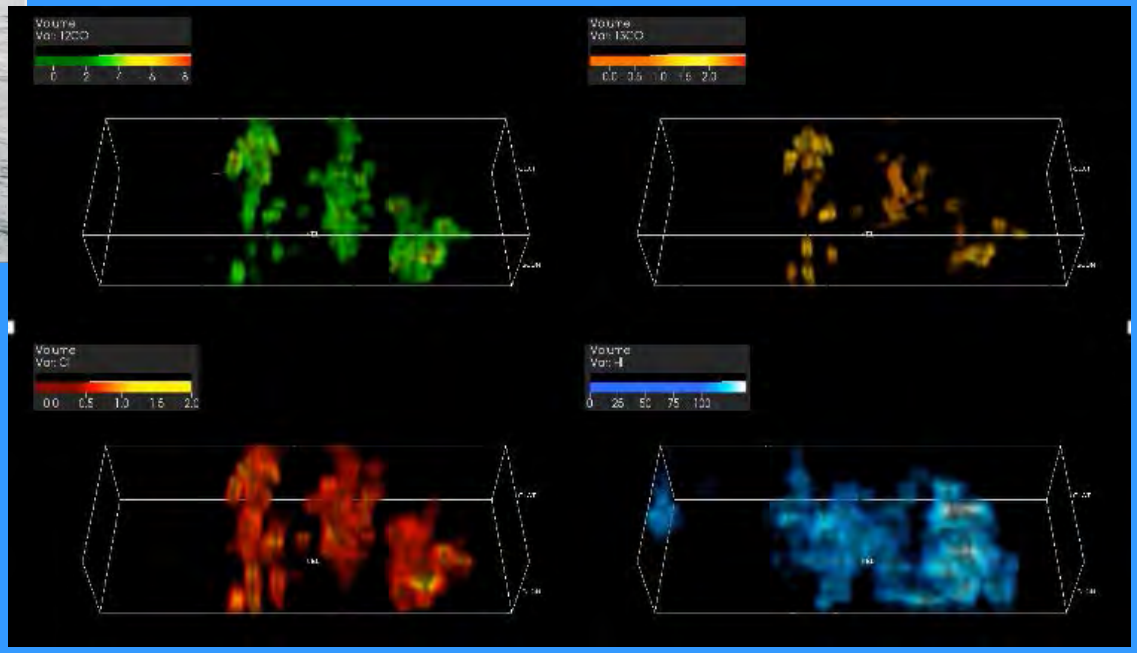
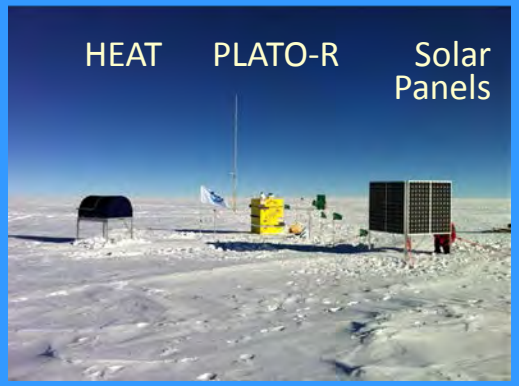


- The 0.6m aperture High Elevation Antarctic Terahertz (HEAT) telescope operated robotically (2011-2016) at Ridge A summit, delivering spectroscopic data from 150 to 500 microns.
- Joint project of the U.S. and Australian scientists: Univ. of Arizona (HEAT telescope) and Univ. of New South Wales (PLATO-R power module) http://soral.as.arizona.edu/heat/

HEAT's deep spectroscopic surveys (left) are finding pervasive, diffuse molecular clouds not seen in existing surveys of CO and HI (right).





Long-Duration Balloons, McMurdo, Antarctica

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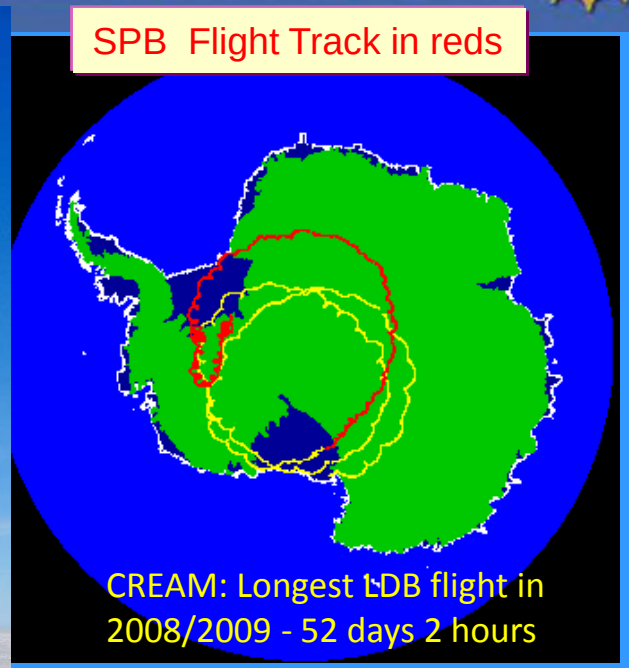

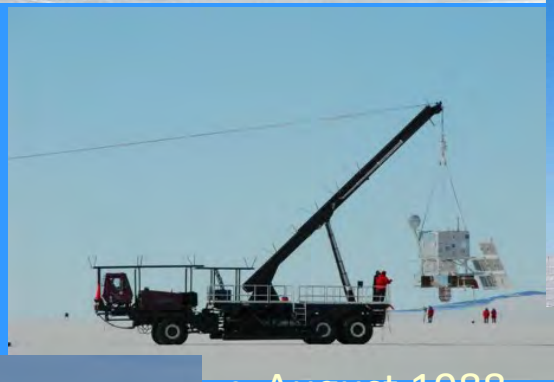

- August 1988 – First MoA signed between NASA and NSF suggesting one LDB payload launch every other year beginning January 1990
- Since 1990, total 52 LDB and SPB payloads have been flown from McMurdo (currently 3+ payloads per austral summer)
- Three payloads are ready for the 2016/2017 season:
- **Boron And Carbon Cosmic-rays in the Upper Stratosphere (BACCUS)**
- **Stratospheric Terahertz Observatory (STO)**
- **Antarctic Impulsive Transient Antenna (ANITA)**

U.S. Antarctic Program

Thank you!

National Science Foundation

Questions?