U.S. Antarctic Program

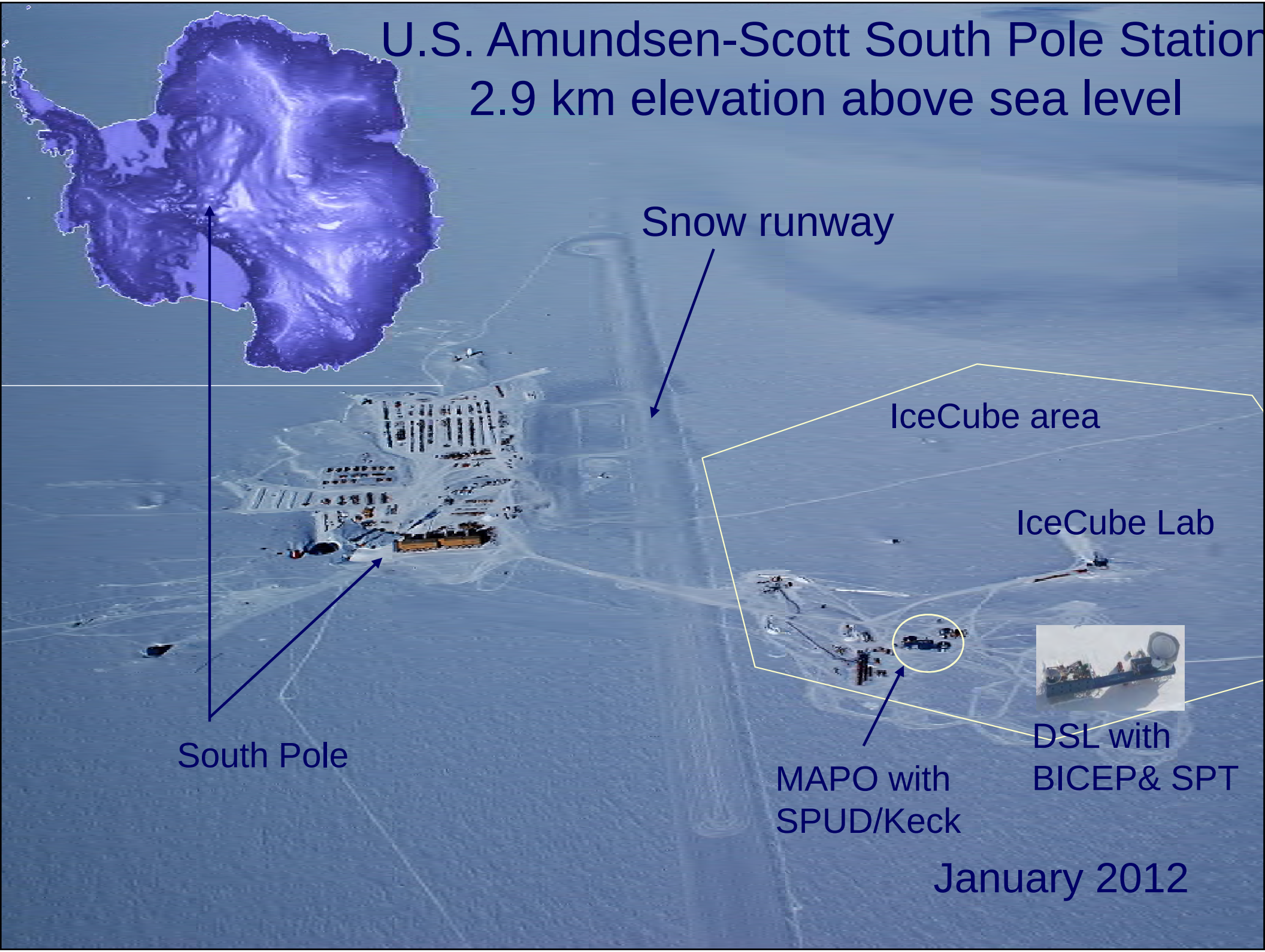
National Science Foundation

Astronomy and Astrophysics Advisory Committee Meeting
May 11, 2012

Astronomy and Astrophysics in Antarctica

Resent Results and Discoveries (a handout)

Vladimir Papitashvili, Program Director
Antarctic Aeronomy & Astrophysics


U.S. Amundsen-Scott South Pole Station
2.9 km elevation above sea level
Snow runway
IceCube area
IceCube Lab
South Pole
MAPO with
SPUD/Keck
DSL with
BICEP& SPT
January 2012

NSF/OPP Antarctic Astronomy & Astrophysics

- **IceCube Neutrino Observatory** (MREFC Project completed; M&O and science are underway) PI: Francis Halzen, Univ. of Wisconsin-Madison, and IceCube Collaboration of 39 institutions
- **South Pole Telescope (SPT)** (10-m dish sub-mm telescope) PI: John Carlstrom, Univ. of Chicago, and SPT collaboration of 7 institutions
- **Gravitational Wave Background (small aperture) Telescopes BiCEP 1&2 and SPUD/Keck receivers array** PIs: Andrew Lange (deceased), John Kovac (Harvard University), Clem Pryke (University of Minnesota), Jamie Bock (Caltech/JPL), and Chao-Lin Kuo (Stanford University)
- **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)
- **NASA Long-Duration Balloon Program at McMurdo**

IceCube Neutrino Observatory

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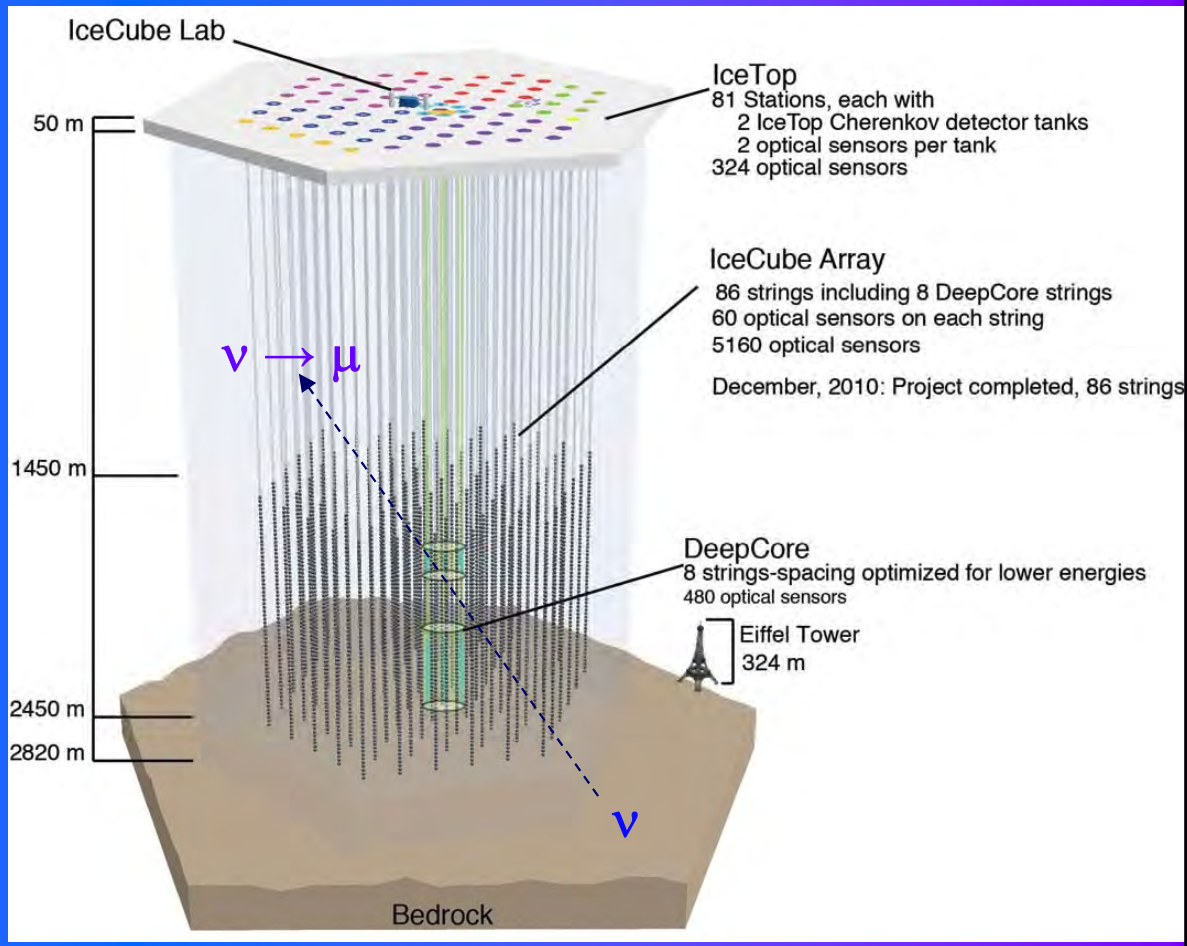
(jointly supported by NSF's OPP/ANT and MPS/PHY)

Recent Accomplishments

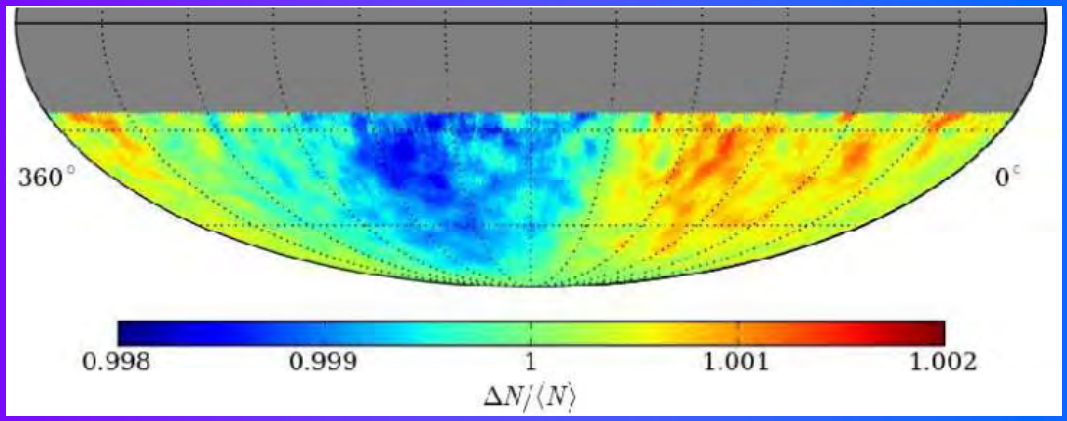
- Univ. of Wisconsin successfully completed the ice drilling and deployment of all 86 strings in December 2010
- ICNO operations and scientific research are fully underway
- New window on the Universe is now open!



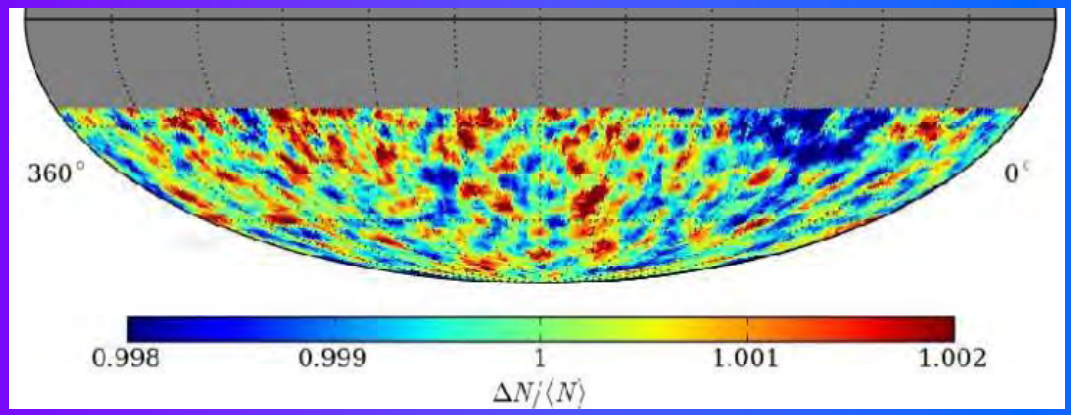
IceCube occupies a volume of one cubic kilometer. Here all 86 strings of optical modules are depicted deployed deep in the South Pole's ice sheet. The IceTop modules are deployed at the snow surface, comprising an array of sensors to detect cosmic ray air showers. This surface array is used to veto some IceCube muon detections and to conduct research on high-energy cosmic rays.

IceCube Collaboration Recent Results

Anisotropy in the arrival direction distributions of Cosmic Rays

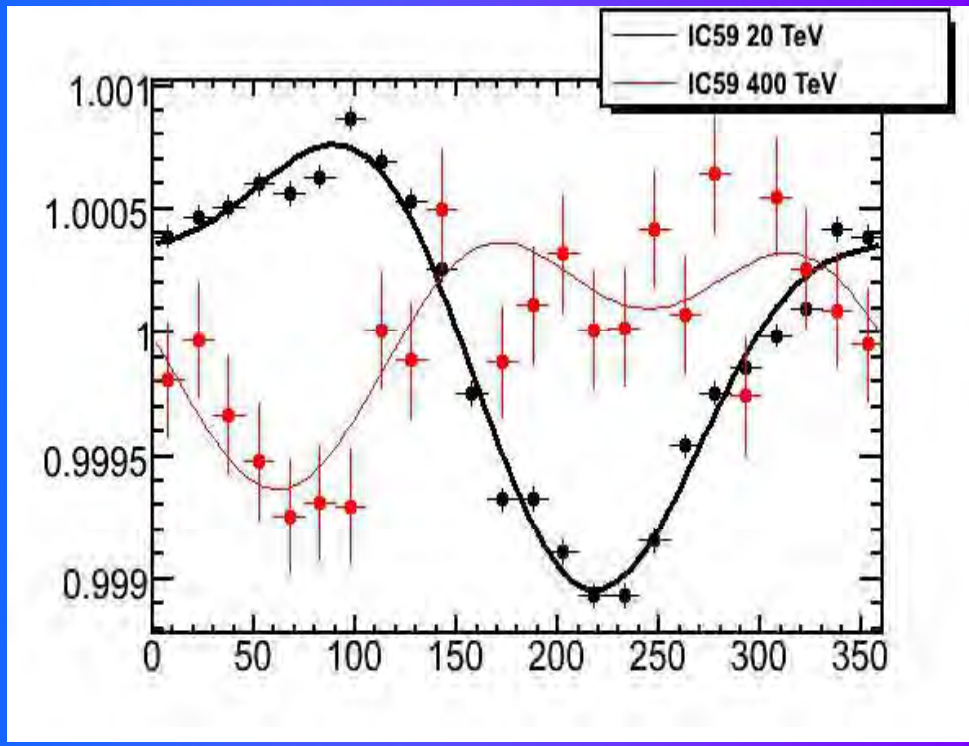


Relative intensity map in equatorial coordinates for cosmic rays of the 20-TeV sample



Relative intensity map in equatorial coordinates for cosmic rays of the 400-TeV sample

The ICNO has observed for the first time in the Southern Sky anisotropy of cosmic rays arrival on multiple angular scales from a few degrees to larger scales



The projections of both maps onto the right ascension are shown

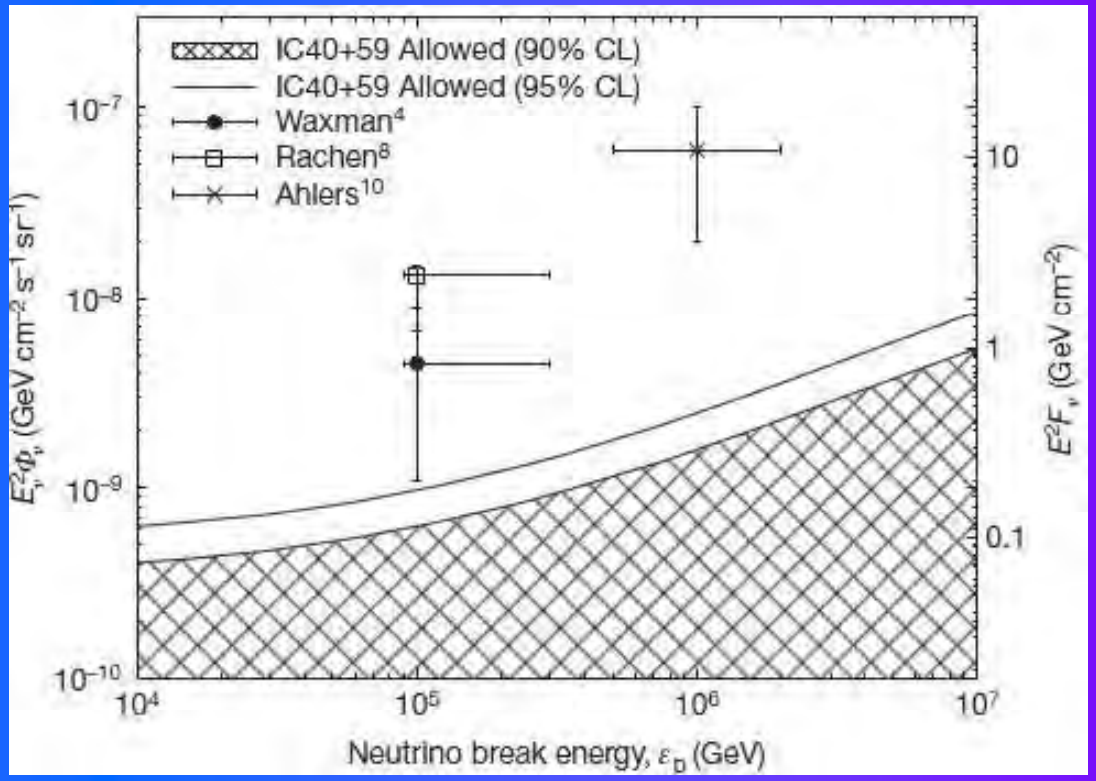
Nature (10.1038/nature11068) April 19, 2012

An absence of neutrinos associated with cosmic-ray acceleration in γ-ray bursts

The IceCube Collaboration reported about a search for neutrinos possibly emitted from 300 gamma ray bursts (GRBs) that occurred between May 2008 and April 2010 and detected by the SWIFT and Fermi satellites.

It was found that an upper limit on the flux of energetic neutrinos associated with GRBs is at least a factor of 3.7 below the model prediction.

This implies either that GRBs are not the only sources of cosmic rays with energies exceeding 10^9 GeV or that the efficiency of neutrino production is much lower than has been predicted.



Compatibility of some models of cosmic-way fluxes with observations. The cross-hatched area shows the 90% confidence allowed values of the neutrino flux versus the neutrino break energy in comparison to model predictions.

South Pole Telescope

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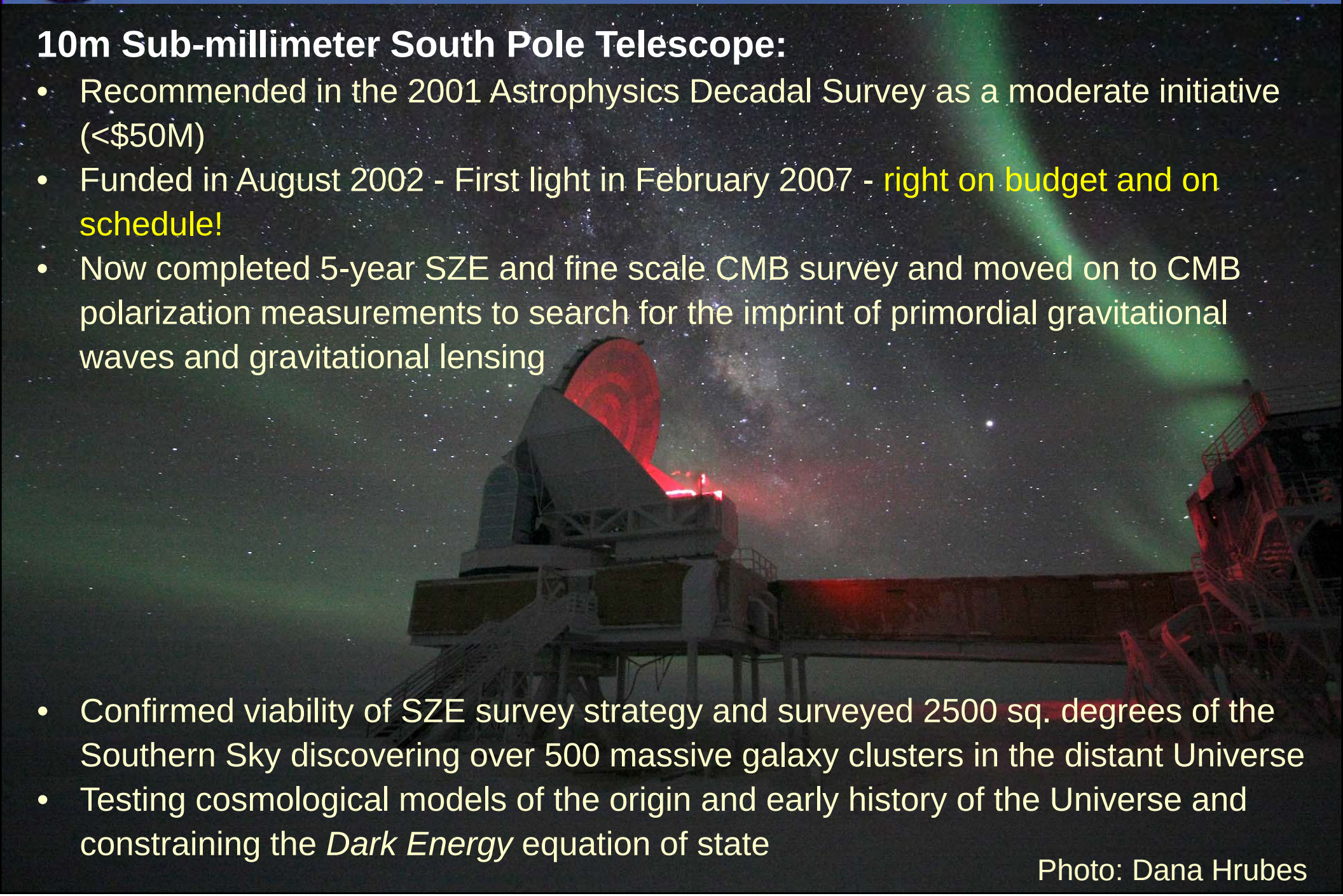
10m Sub-millimeter South Pole Telescope:

- Recommended in the 2001 Astrophysics Decadal Survey as a moderate initiative (<$50M)
- Funded in August 2002 - First light in February 2007 - right on budget and on schedule!
- Now completed 5-year SZE and fine scale CMB survey and moved on to CMB polarization measurements to search for the imprint of primordial gravitational waves and gravitational lensing



- Confirmed viability of SZE survey strategy and surveyed 2500 sq. degrees of the Southern Sky discovering over 500 massive galaxy clusters in the distant Universe
- Testing cosmological models of the origin and early history of the Universe and constraining the *Dark Energy* equation of state

Photo: Dana Hrubes

SPT Recent Results and Discoveries

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First clusters discovered via their SZ signature
Staniszewski et al., ApJ, 701, 32, 2009

Cluster spatial profiles measured to the virial radius
Plagge et al., ApJ, 716, 1118, 2010

First detection of secondary CMB anisotropy and cosmological implications
Lueker et al., ApJ, 719, 1045, 2010
Shirokoff et al., ApJ, 736, 61, 2011
Reichardt et al., ApJ subm *(arXiv:1111.0932)*

First mm-wave detection of Cosmic Infrared Background (CIB) anisotropy
Hall et al., ApJ, 718, 632, 2010

Discovery of high-redshift, strongly lensed dusty galaxies
Vieira et al., ApJ, 719, 763, 2010
Greve et al., ApJ submitted (under review)

First SZ cluster catalog and cosmological constraints
Vanderlinde et al., ApJ, 722, 1180, 2010
Benson et al., ApJ subm *(arXiv:1112.5435)*
Reichardt et al., ApJ subm *(arXiv:1203.5775)*

Redshift estimation, optical and X-ray properties of SPT SZ-selected clusters
High et al., ApJ, 723, 1736, 2010
Zenteno et al., ApJ, 734, 3, 2011
Andersson et al., ApJ ,738, 48, 2011

Discovery of the two most massive z>1 clusters
Brodwin et al., ApJ, 721, 90, 2010
Foley et al., ApJ, 731, 96, 2011

Testing ΛCDM with massive, high-redshift clusters
Foley et al., ApJ, 731, 96, 2011
Williamson et al., ApJ, 738, 139, 2011

Most sensitive measurement of the CMB power spectrum damping tail - improved cosmological constraints; inflation tests, number of neutrinos
Keisler et al., ApJ, 743, 28 2011

First public data release of SPT maps and tools
Schaffer et al., ApJ, 743, 90, 2011

First CMB constraints on the duration & timing of the reionization of the Universe
Zahn et al., ApJ submitted *(arXiv:111.6386)*

High confidence measurement of the power spectrum of gravitational potential from CMB lensing
van Engelen et al., ApJ submitted *(arXiv: 1202.0546)*

Correlation of SPT mass maps reconstructed from CMB lensing with Galaxy surveys
Bleem et al., ApJ submitted *(arXiv:1203.4808)*

First weak mass lensing calibration of SZ selected clusters
High et al., ApJ, submitted

Discovery of a extreme star forming "classic" cooling flow cluster at z = 0.6… the strongest cooling flow known
McDonald et al. *Nature*, submitted

These initial results are only from a small portion of the survey – the best is yet to come!

Above statements are not paper titles … they what papers are about… essence of results!

Inflationary Gravitational Waves Background

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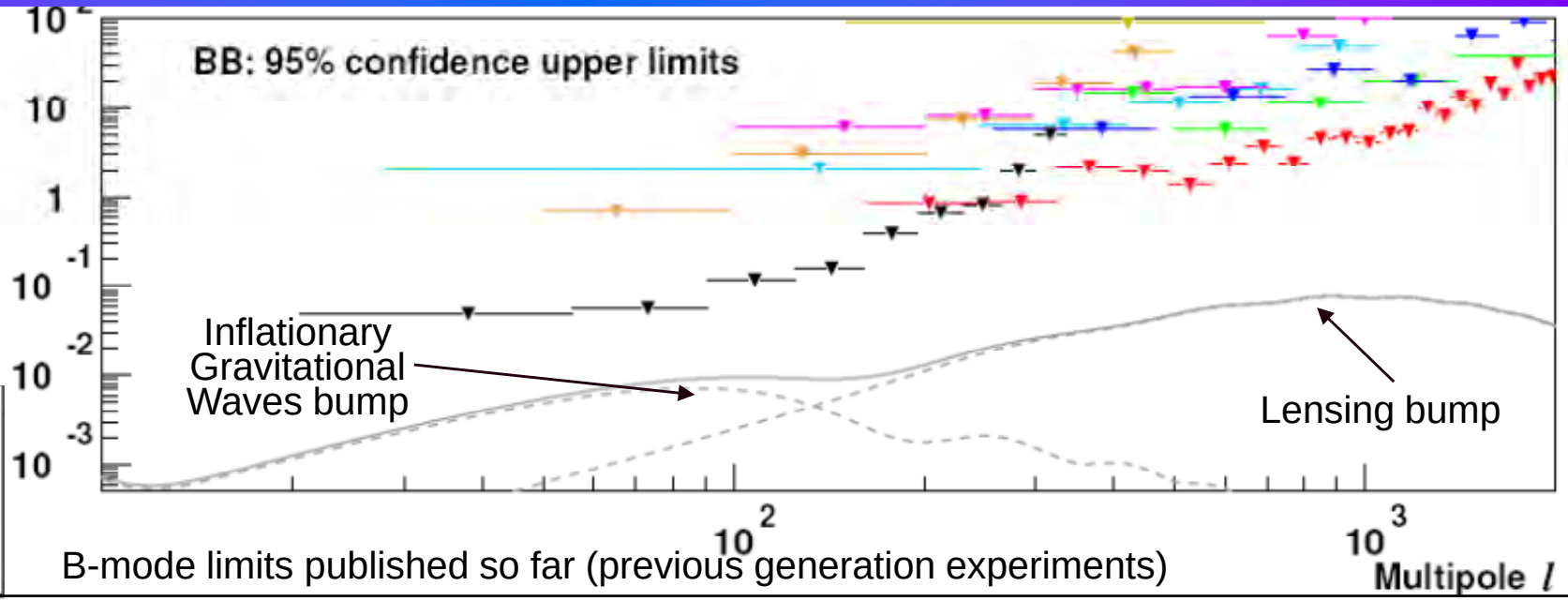
with 30-cm aperture telescopes

In 2005, the CMB Interagency Task Force set a target to detect the CMB polarization B-mode if $r > 0.02$

BiCEP-1 has the best published results to date (Chiang et al. ApJ 711, 1123, 2010):

- The measured CMB polarization E-mode spectrum was consistent with expectations from a ΛCDM model, and the B-mode spectrum was consistent with zero
- The tensor-to-scalar ratio derived from the BiCEP-1 B-mode spectrum observations was $r = 0.02^{+0.31}_{-0.26}$ or $r < 0.72$ at 95% confidence
- This was the first meaningful constraint on the Inflationary Gravitational Wave Background (IGWB) from B-modes – and still the best!

BiCEP-2 has already run for 2 years with sensitivity 10x higher than BiCEP-1



B-mode limits published so far (previous generation experiments)

BiCEP-1 *vs.* BiCEP-2 E/B Maps

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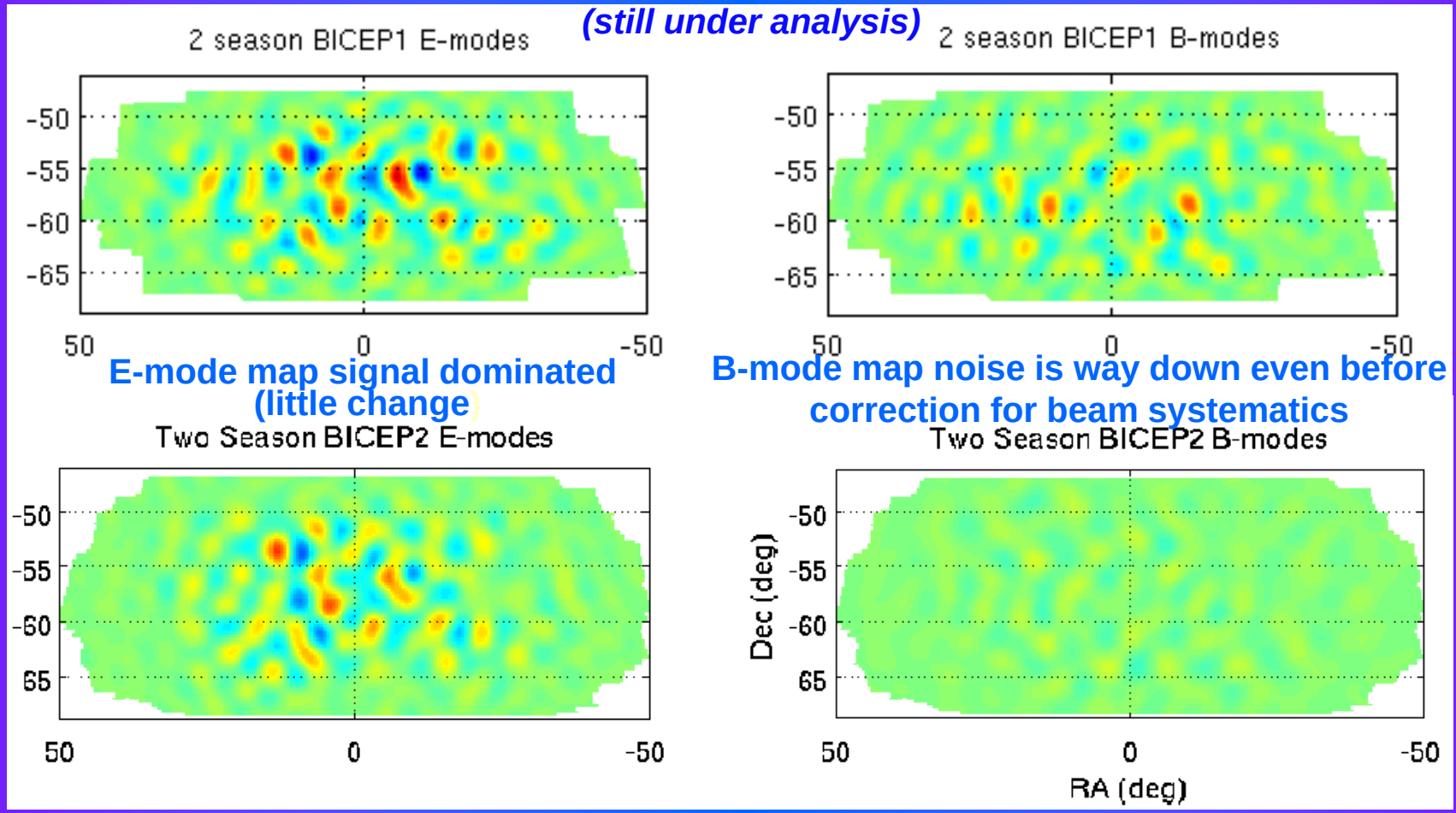
These *preliminary* BiCEP-2 maps correspond to a limit $r < 0.1$ at 95% confidence *(still under analysis)*



E-mode map signal dominated (little change)

B-mode map noise is way down even before correction for beam systematics

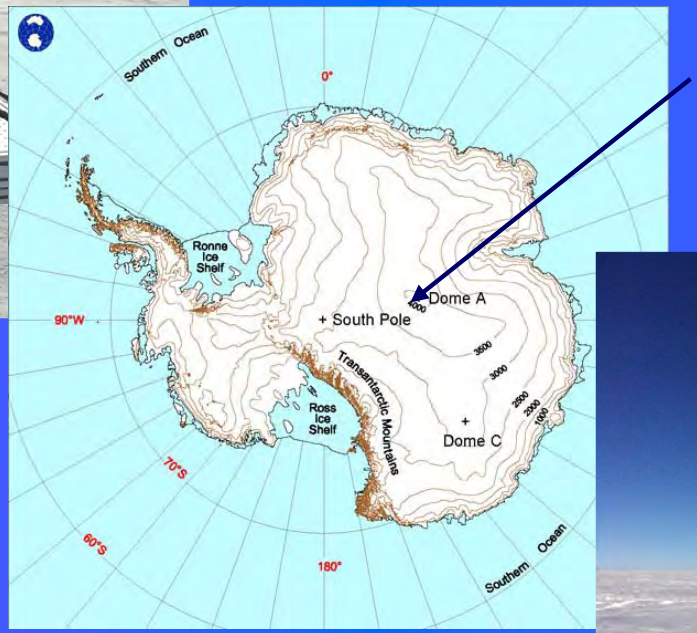
SPUD/Keck array of three (five) small aperture receivers began observations in February 2011 (2012) with enough sensitivity at 150 GHz to reach the Task Force limit in 2014.

Lensing foreground is confidently expected around the $r = 0.02$ level. Galactic foreground is projected at a similar or higher level. In case a signal is detected, a phased switchover to other frequencies is already in progress to determine if the signal is galactic or cosmological.

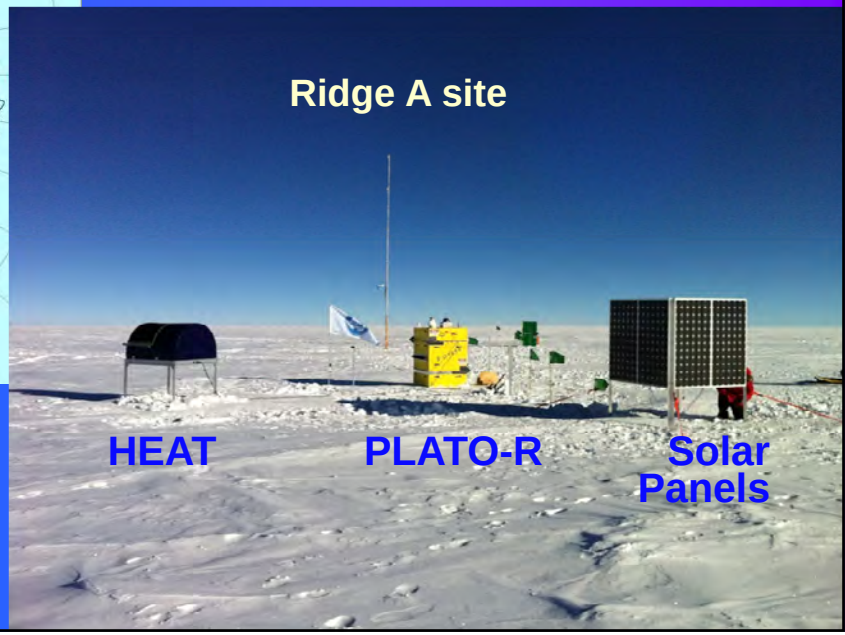
HEAT - TeraHertz Robotic Telescope at Ridge A

Joint project between the U.S. (Univ. of Arizona; HEAT telescope) and Australian (U. of New South Wales, PLATO-R power module) scientists

- **Funded by NSF and Commonwealth of Australia in July 2010 through June 2014**
- **Deployed by the U.S. Antarctic Program at Ridge A (East Antarctic Plateau, 4.1 km elevation) in January 2012**



Ridge A – 200 km south of Chinese station Kunlun at Some A



- **Currently operational observing winter Southern Sky: http://mcba11.phys.unsw.edu.au/~plato-r/**

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Long-Duration Ballooning from McMurdo, Antarctica

August 1988 – First MoA signed between NASA and NSF

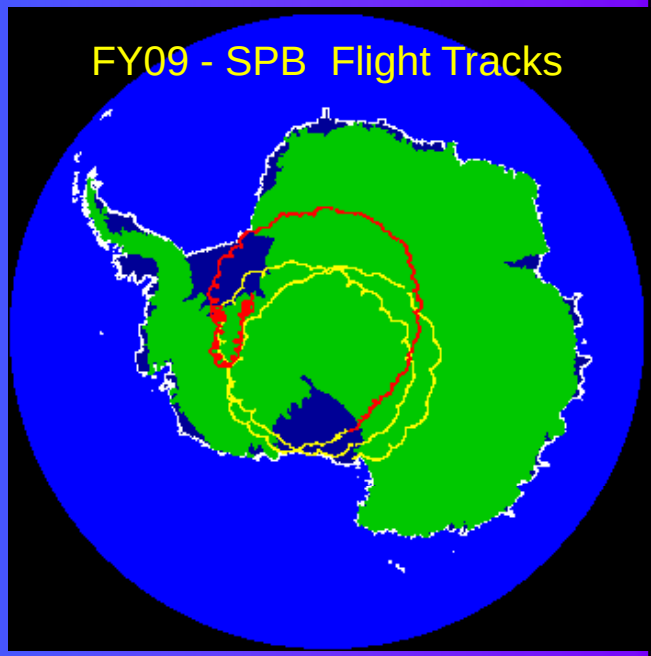
- One LDB launch every other year beginning in Jan 1990
- 22 long-duration balloon payloads flown from McMurdo between 1990 and 2003 **(~1.7 flights per year)**

Sep 2003 – Second MoA signed between NASA and NSF (expired March 31, 2009)

- Two launches per years beginning in December 2003
- 15 long-duration balloon payloads flown from McMurdo between 2003 and 2009 **(~2.5 flights per year)**

April 2009 – Third MoA signed between NASA and NSF (expiring March 31, 2014)

- Three launches per years, including Super-Pressure Balloons
- 10 balloon payloads flown between 2009 and 2012 **(~3.3 flights per year)**



CREAM: Longest LDB flight in 2008/2009 - 52 days 2 hours (3 circumnavigations)

Total 47 LDB and SPB launches over 22 years