U.S. Antarctic Program

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Astronomy and Astrophysics Advisory Committee Meeting
January 25, 2018

Astronomy and Astrophysics in Antarctica

Resent Results and Discoveries

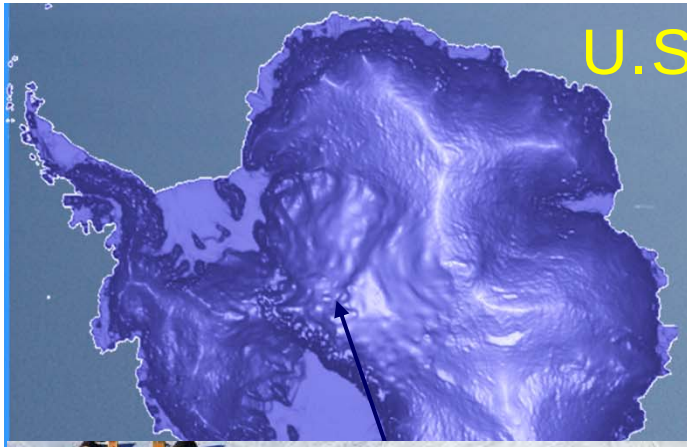
Dr. Vladimir Papitashvili

Program Director, Antarctic Astrophysics & Geospace Sciences

Head of Antarctic Sciences Section (Acting)


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

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



Snow runway

ARA testbeds

IceCube area

IceCube Lab

DSL w/BICEP3
& SPT

2018 **South Pole Markers Line** **1912**

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

MAPO with
BICEP Array

Antarctic Astronomy & Astrophysics

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- **IceCube Neutrino Observatory** $272M MREFC Project, 2002-2010; current M&O ($7M/year) and science (up to $3M/year) - jointly funded by GEO/OPP and MPS/PHY. Lead PI: Francis Halzen, Univ. of Wisconsin-Madison and IceCube Collaboration (46 institutions in 12 countries) 7+ years of observations
- **Askaryan Radio Array (ARA) concept for GZK neutrino studies** (5 testbed stations) 2013-2018 OPP & PHY $350K/year Lead PI: Albrecht Karle, Univ. of Wisconsin (Collaboration of 5 institutions in 2 countires)
- **Antarctic Ross Ice-Shelf ANtenna Neutrino Array (ARIANNA) concept for GZK neutrino studies** (7 testbed stations) 2010-2018 OPP & PHY $180K/year Lead PI: Steven Barwick, Univ. of California-Irvine
- **South Pole 10m CMB Telescope (SPT)** First light: February 2007 Lead PI: John Carlstrom, Univ. of Chicago and SPT collaboration (2 National Labs and 10 institutions in 3 countries) OPP/PHY/AST $2.7M/year 11 years of observations
- **Background Imager for Cosmic Extragalactic Polarization - BICEP Array of small (50-cm) aperture CMB telescopes** First light: February 2006 Lead PI: John Kovac (Harvard University) and BICEP Collaboration (9 institutions in 4 countries) OPP/PHY/AST $1.5M/year 12 years of observations
- **HEAT – TeraHertz Robotic Telescope at Ridge A** (4.1 km elevation) Lead PIs: Craig Kulesa (Univ. of Arizona) and Michael Ashley (Univ. of New South Wales, Australia) 2011-2017 OPP & AST $250K/year 7 years of observations
- **NASA Long-Duration Balloon Program at McMurdo** (1990 – 2017; 54 payloads)

OPP & PHY - IceCube Neutrino Observatory

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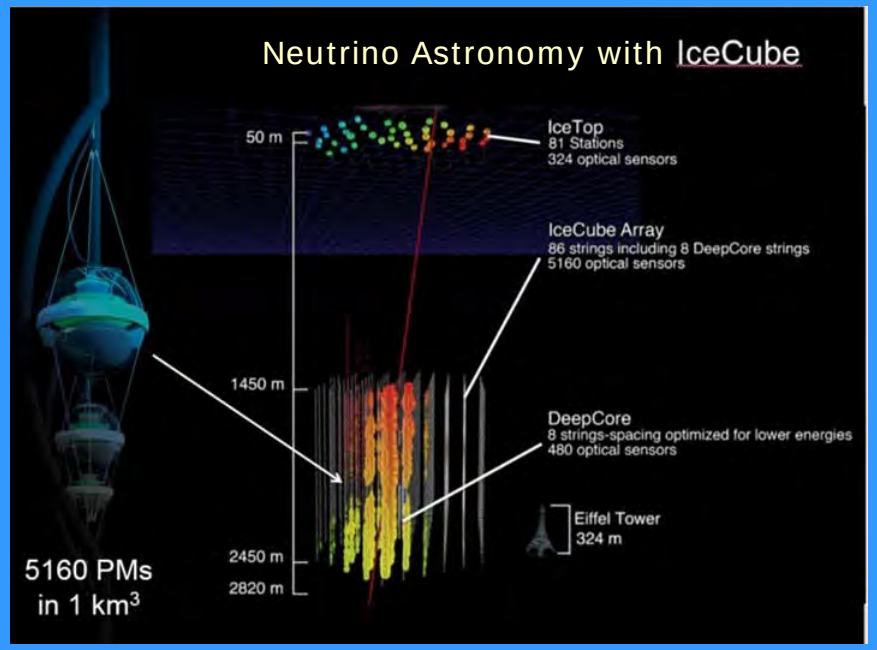
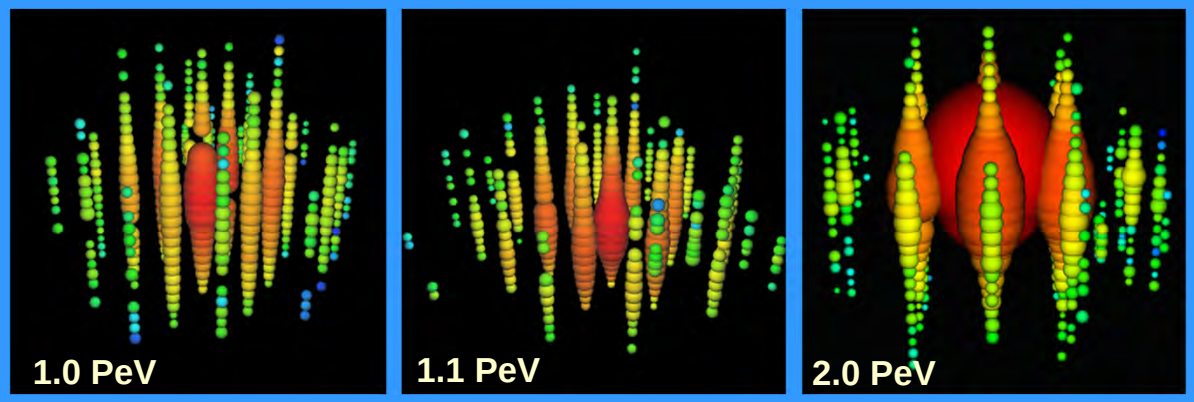
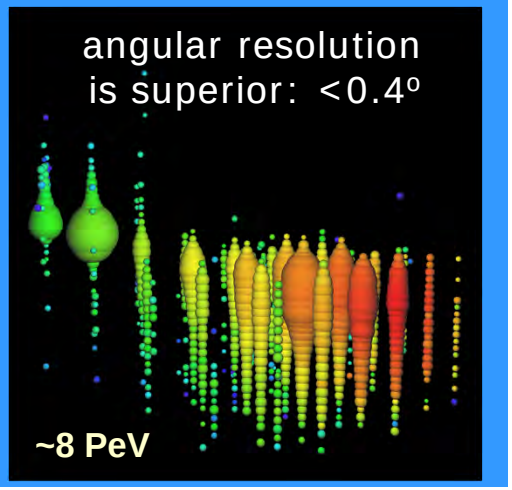
A new window is open on the non-thermal Universe!

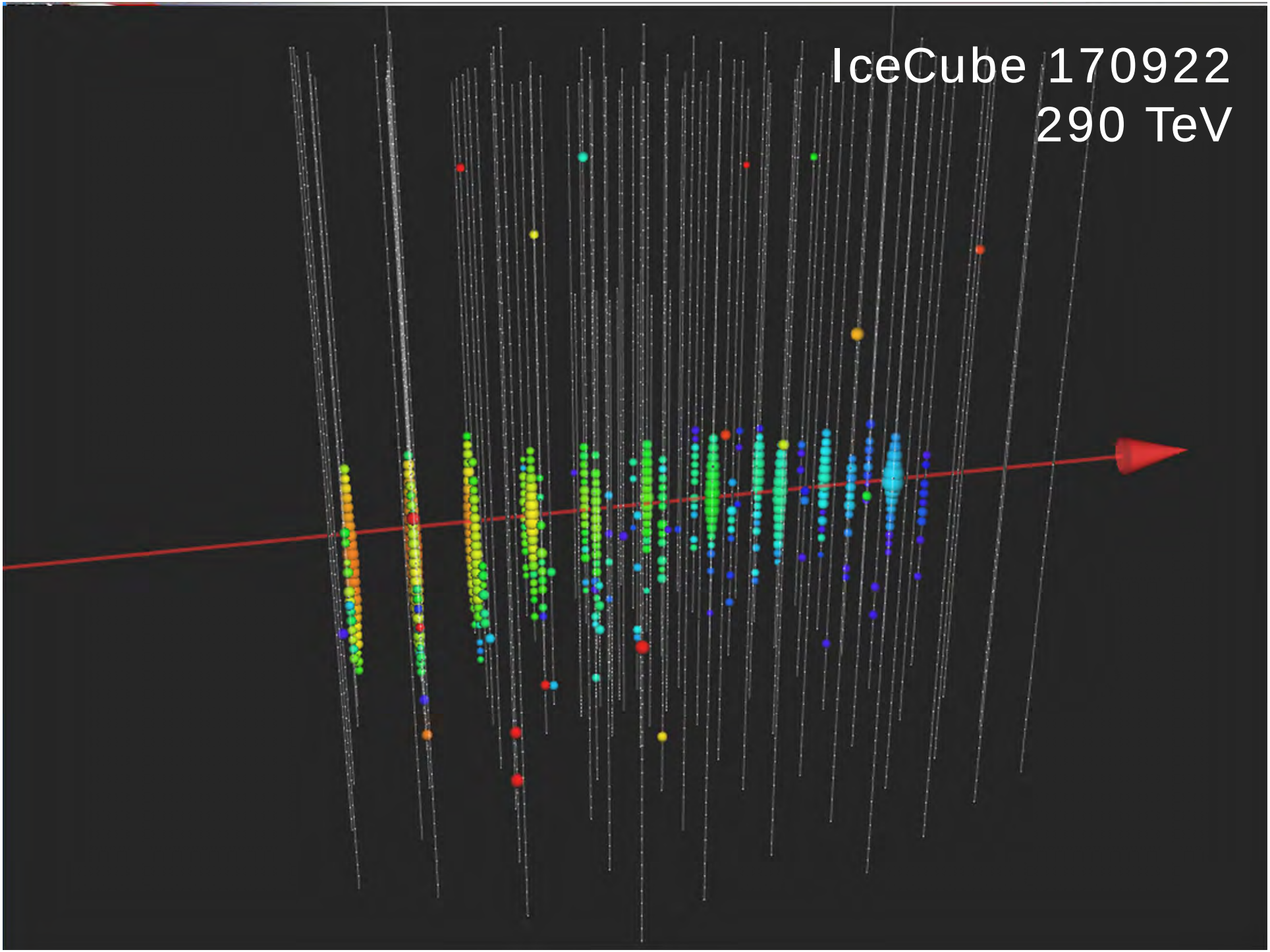
- **IceCube was completed in 2010** to search for very high energy neutrinos created in the most extreme cosmic environments
- **2013:** Discovery of first high energy (>30 TeV) cosmic neutrinos (currently over 150 events: robust statistics!)
- **Sep 22, 2017:** IceCube issued an alert 170922 upon detecting the cosmic neutrino (~0.3 PeV) within 0.1° of the flaring blazar 3FGL_J0509+0541

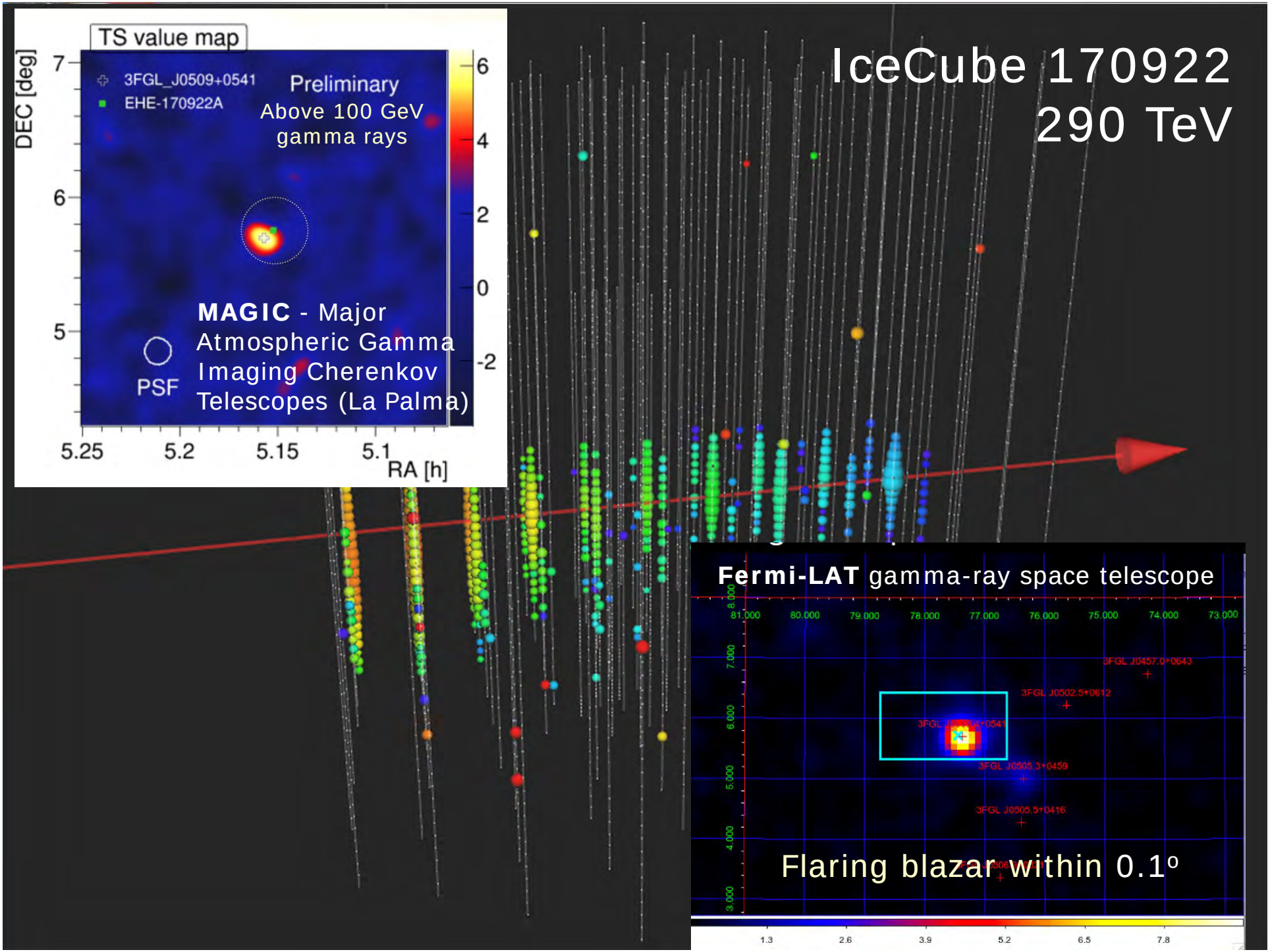




Total energy measurements, all flavors, all sky




IceCube 170922
290 TeV


TS value map
3FGL_J0509+0541
EHE-170922A
Preliminary
Above 100 GeV
gamma rays
PSF
MAGIC - Major Atmospheric Gamma Imaging Cherenkov Telescopes (La Palma)
DEC [deg]
RA [h]
IceCube 170922
290 TeV
Fermi-LAT gamma-ray space telescope
3FGL J0457.0+0643
3FGL J0502.5+0612
3FGL J0505.3+0459
3FGL J0505.5+0416
Flaring blazar within 0.1º

IceCube – Major Results so far!

- Energy density of neutrinos in the non-thermal Universe is the same as in gamma-rays.
- Observed neutrinos demonstrate that proton accelerators are essential for understanding the non-thermal Universe.
- Evidence for dark sources below 100 TeV because accompanying photons from neutral pion decay are not observed.
- Multimessenger astronomy follows the IceCube 170922 alert.
- Discovery of a very large attenuation length for Cherenkov light; thus, a detector ten times of the current cubic-km volume can be built and instrumented similar to IceCube.

http://icecube.wisc.edu

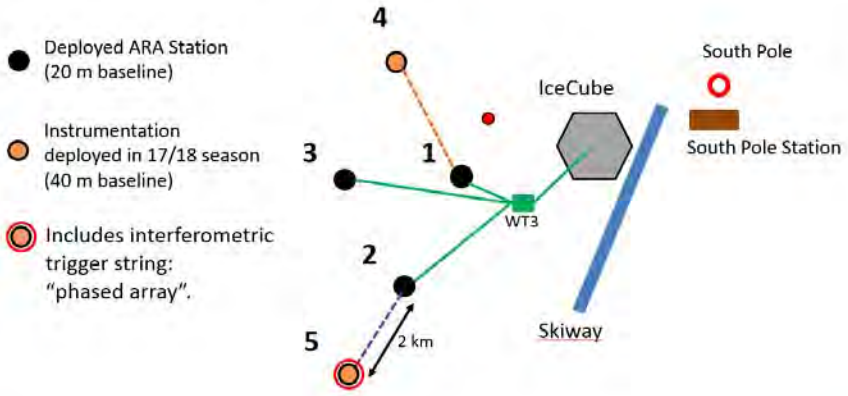
Radio detection of neutrinos complements optical techniques at very high energies

Signal attenuation length at South Pole:
Optical: 150 m - 250 m
Radio: 1500 m

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

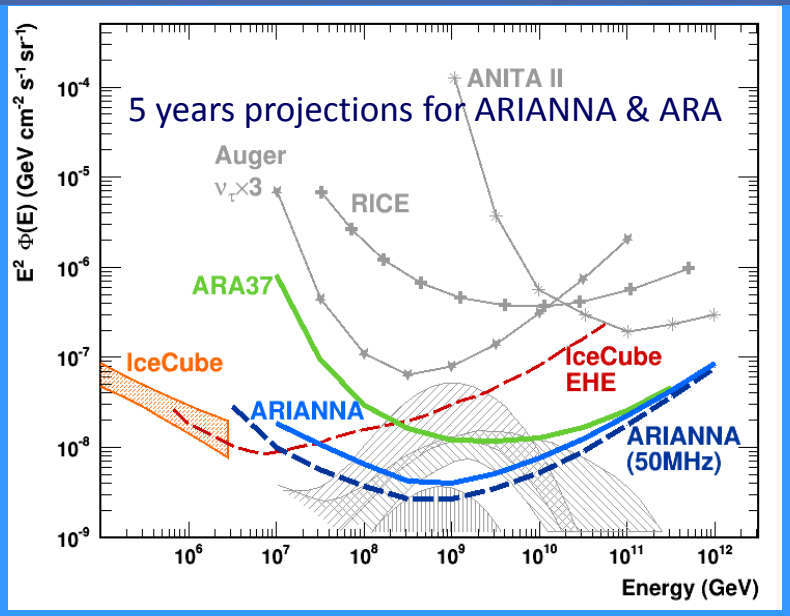
Full ARA array (37 stations, 200 km^2) will reach required sensitivity at the energies above 100 PeV

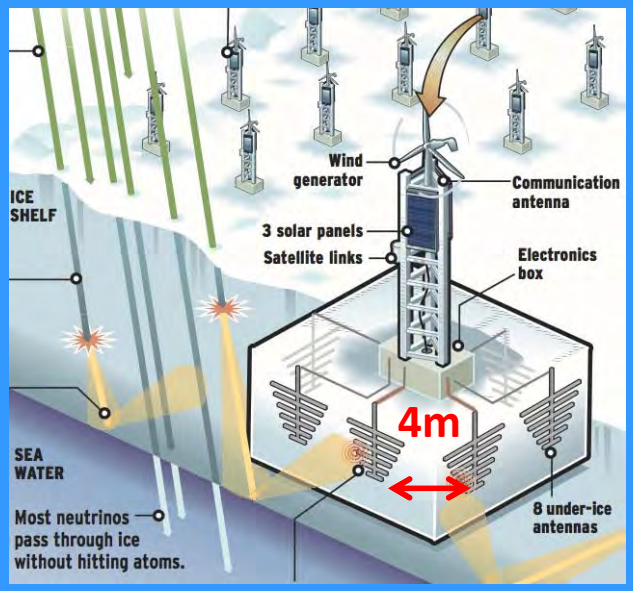
Askaryan Radio Array: 2017/18 upgrade



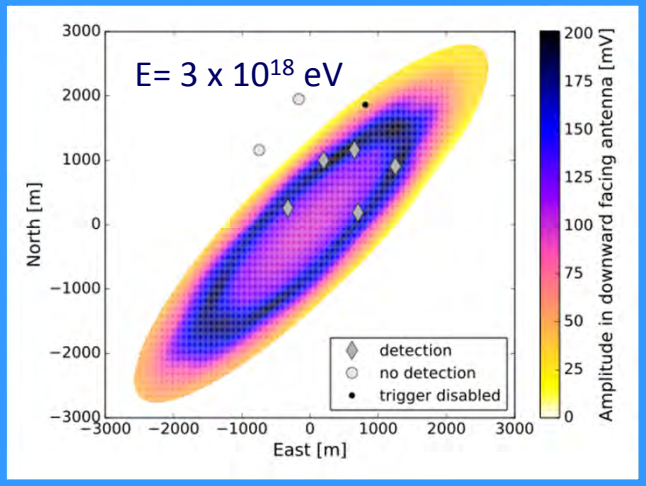
OPP & PHY - ARIANNA Concept

- An array of ~1000 autonomous stations on the snow surface in Antarctica to measure a flux of ultra-high energy (GZK) neutrinos from astrophysical sources.
- The array can make unique contributions to multi-messenger campaigns detecting high energy neutrinos generated by neutron star mergers.





7 stations in a hexagonal array, 1-km spacing; deployed over Ross Ice Shelf, ~100km south of McMurdo



First detection of the cosmic rays signal by the self-triggered, multi-station array

Radio detection of air showers with the ARIANNA experiment on the Ross Ice Shelf, Astroparticle Physics 90 (2017) 50-68, arXiv:1612.04473v2

SPT-3g upgrades in 2017/18 Season

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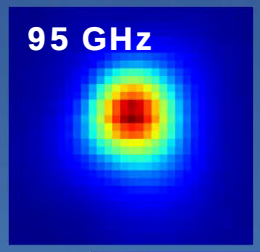
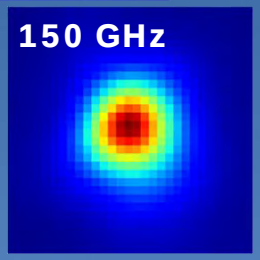
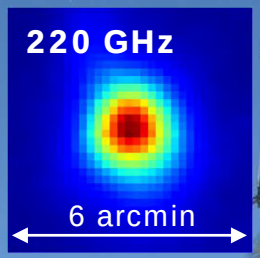


RCW38 HII region "First Light" Image





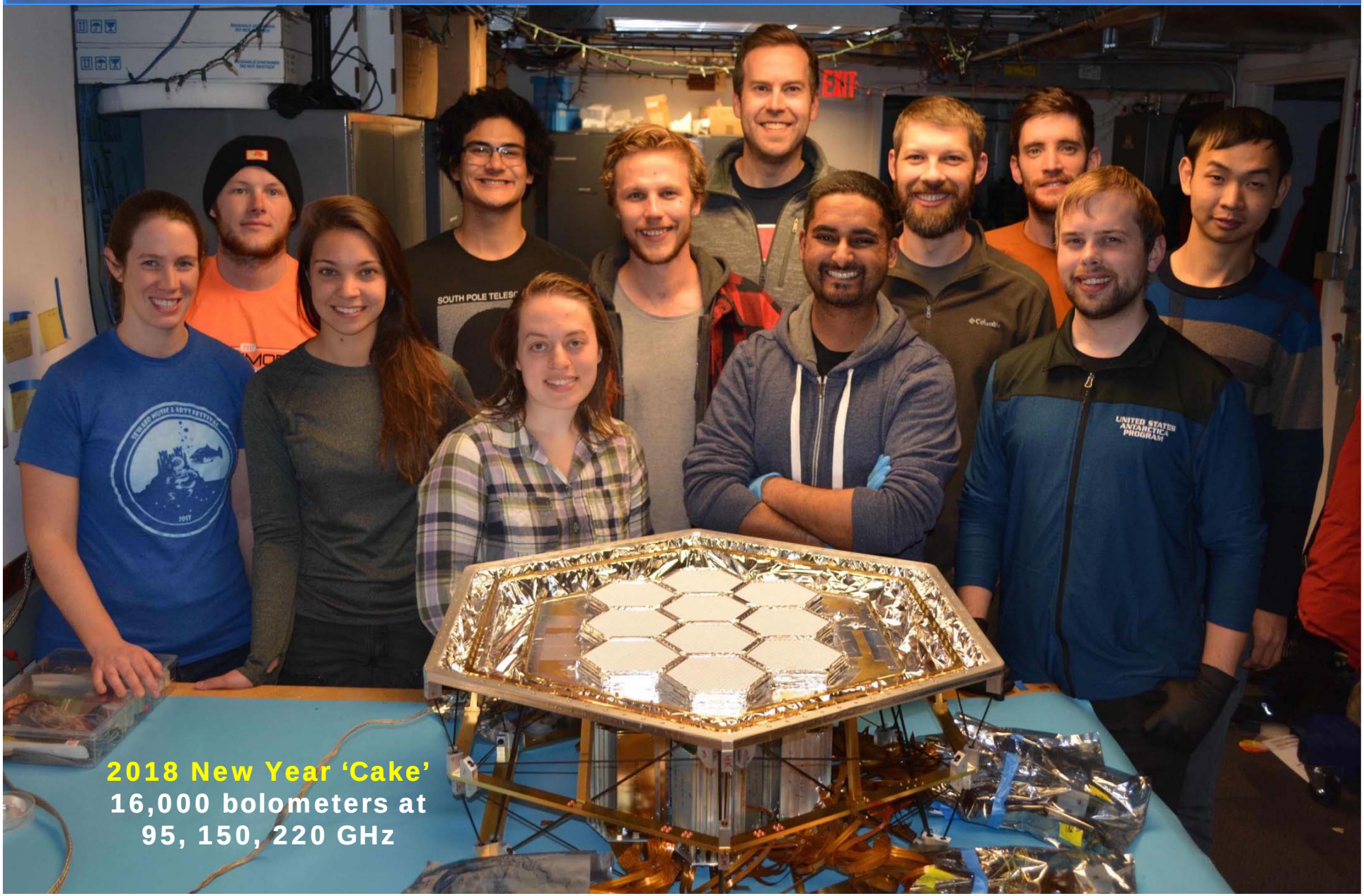
SPT-3g, December 2017:

- Improved detectors, SQUID readout electronics, AR coated lenses
- Inflation: De-lensing with BICEP Array
- Dark Energy, Neutrinos - Cross-correlation with DES survey
- New light Relic Particles
- tSZ, kSZ, high-z galaxies

http://pole.uchicago.edu

U.S. DEPARTMENT OF ENERGY

SPT-3g upgraded focal plane



2018 New Year 'Cake'
16,000 bolometers at 95, 150, 220 GHz

South Pole Telescope Highlights

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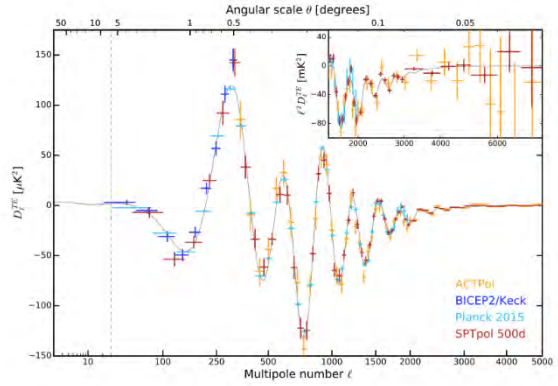
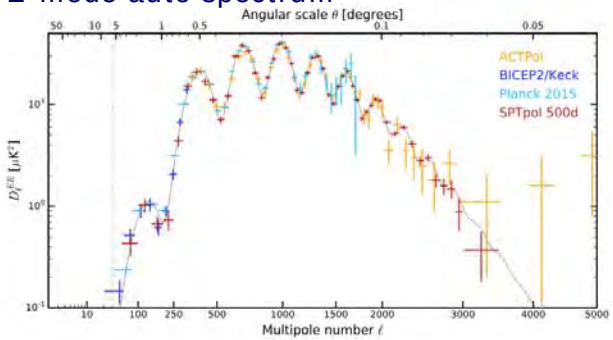
Polarized CMB power spectra from (almost) full 500-square-degree SPTpol data

- Most sensitive measurements to date of the EE and TE power spectra at l > 1050 and l > 1475, respectively (Henning et al., arXiv:1707.09353)

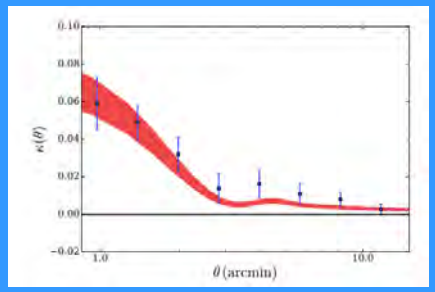
Temperature-E-mode correlation



E-mode auto spectrum



Calibration of Dark Energy Survey galaxy cluster masses with SPT lensing



Use CMB lensing from galaxy clusters to measure the mass of DES cluster sample (Baxter et al., arXiv:1708.01360)

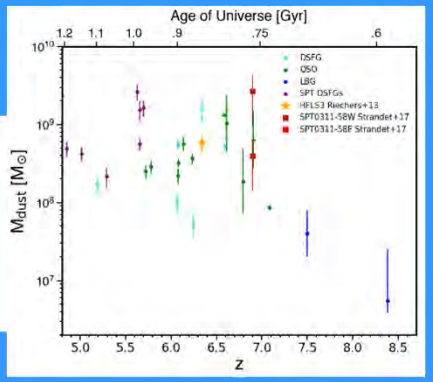
Marrone *et al. Nature, 2017*

LETTER

doi:10.1038/nature24629

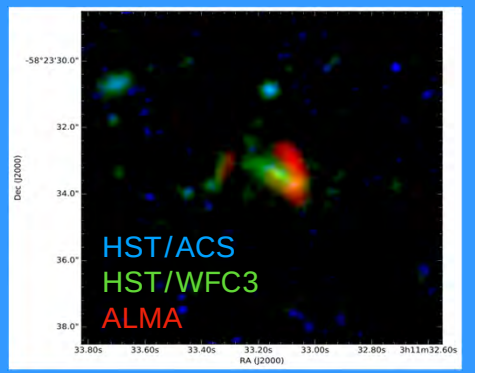
Galaxy growth in a massive halo in the first billion years of cosmic history

D. P. Marrone[1], J. S. Spilker[1], C. C. Hayward[2,3], J. D. Vieira[4], M. Aravena[5], M. L. N. Ashby[3], M. B. Bayliss[6], M. Béthermin[7], M. Brodwin[8], M. S. Bothwell[9,10], J. E. Carlstrom[11,12,13,14], S. C. Chapman[15], Chian-Chou Chen[16], T. M. Crawford[11,14], D. J. M. Cunningham[15,17], C. De Breuck[18], C. D. Fassnacht[19], A. H. Gonzalez[20], T. R. Greve[21], Y. D. Hezaveh[22], K. Lacaille[23], K. C. Litke[1], S. Lower[4], J. Ma[16], M. Malkan[24], T. B. Miller[15], W. R. Morningstar[22], E. J. Murphy[2,4], D. Narayanan[25], K. A. Phadke[4], K. M. Rotermund[15], J. Sreevani[4], B. Stalder[2,3], A. A. Stark[3], M. L. Strander[26,27], M. Tang[1] & A. Weiß[28]



… and SPT successfully participated in the first global [black hole] Event Horizon Telescope experiment in April 2017.

SPT 0311-58 The Highest Redshift submm galaxy at z=6.9
Two massive galaxies colliding 800M years after Big Bang



OPP, PHY & AST - Observing from South Pole

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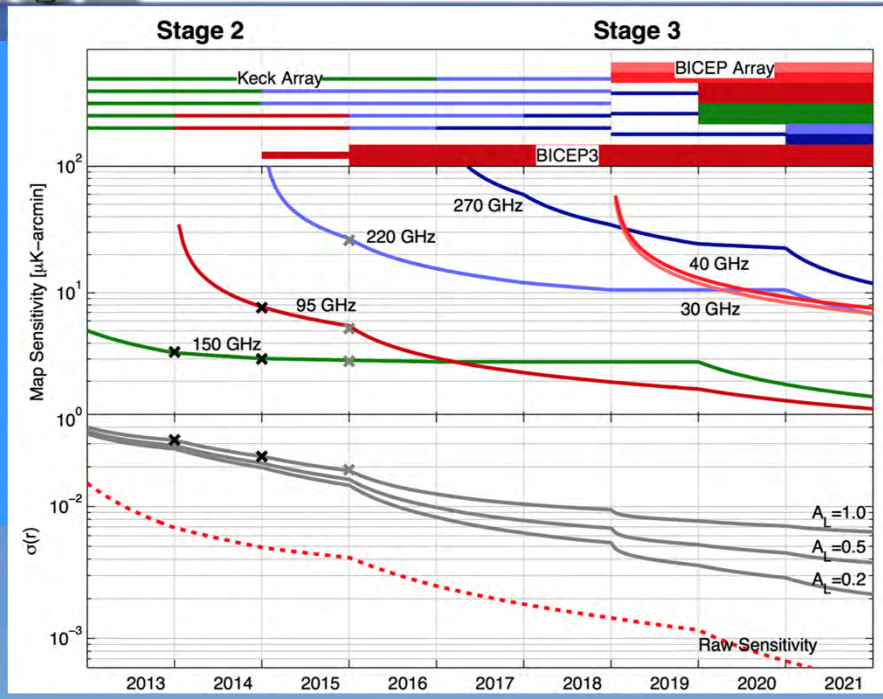
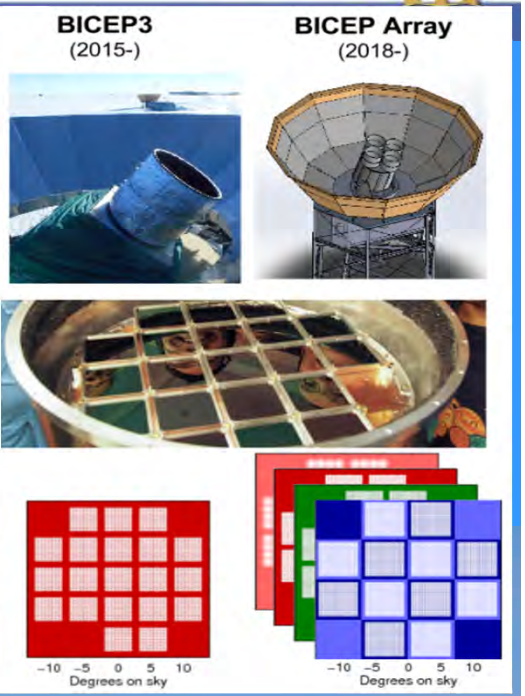
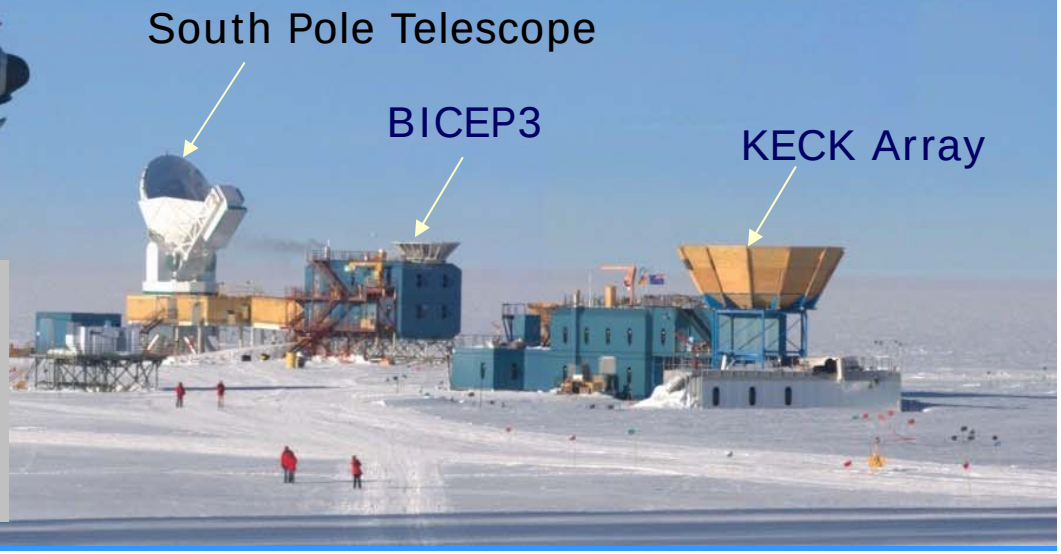
BICEP Array

Hardware upgrades in 2017/18 included BICEP3 optics and new 270 GHz frequency band

Full-scale CMB-S3 program: 6 bands, foreground control, and $\sigma(r)<0.003$ by 2021







- Projections above involve simple scaling from achieved published analyses, including all real-world performance hits.
- This method formed the basis for CMB-S4 forecasts in Science Book and CDT report.

BICEP/Keck data: B-modes & progress on *r*

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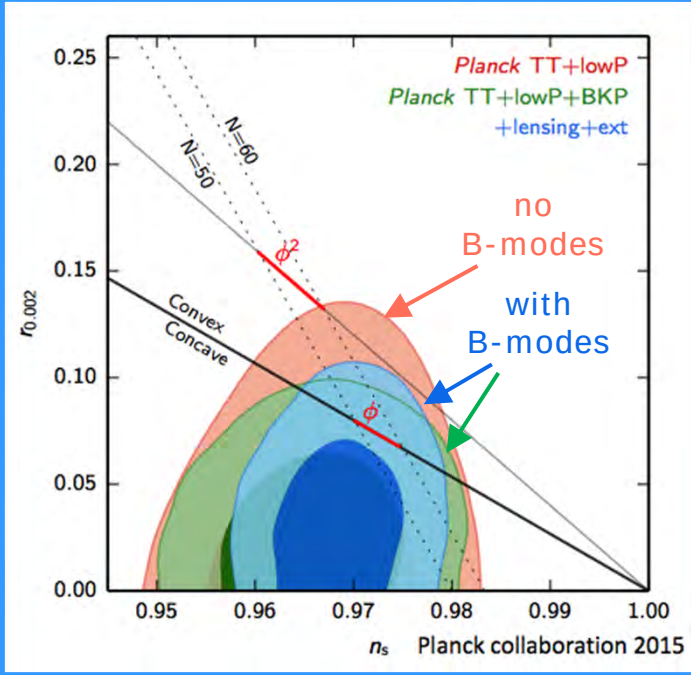
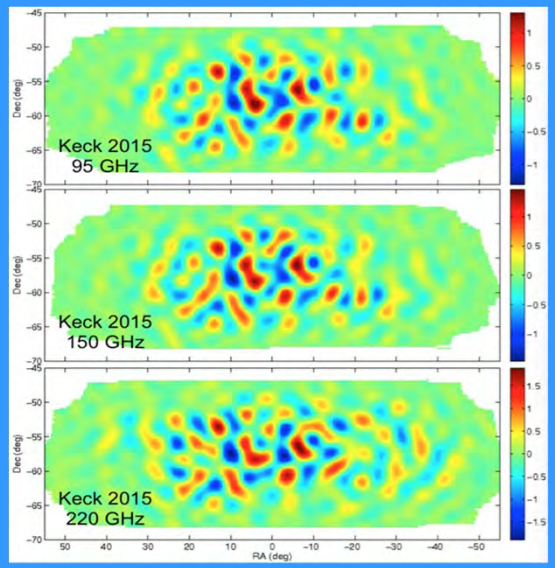
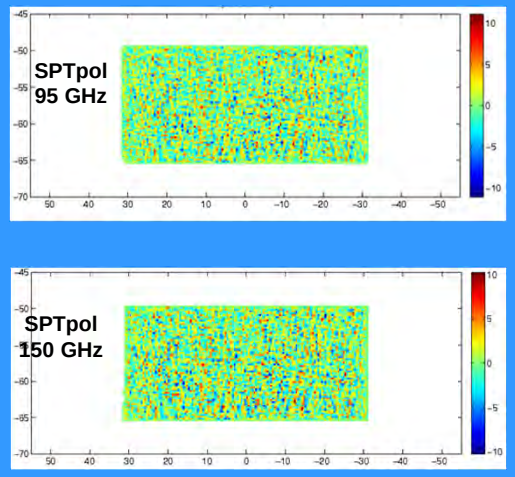
http://bicepkeck.org





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

+



Deep high-resolution maps:
precision delensing

• BICEP/Keck/Planck analysis (published Feb 2015)		σ(*r*) = 0.034	arXiv:1502.00612
• 2014 BICEP/Keck analysis adds 95 GHz		σ(*r*) = 0.025	arXiv:1510.09217
• 2015 BICEP/Keck analysis	expect	σ(*r*) = 0.019	coming next month
• 2017 BICEP/Keck *plus* SPTpol delensing	expect	σ(*r*) = 0.010	coming next year
• 2018-2021 BICEP/Array *plus* SPT-3g delensing		σ(*r*) ~ 0.003	forecast

Raw sensitivity of this experiment to primordial B-modes (i.e., with no foregrounds or lensing):
σ(r) = 0.006
It is now all about components separation!

OPP & AST – TeraHertz Robotic Telescope

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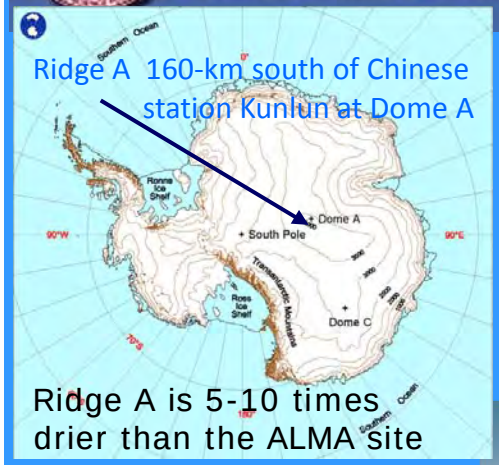
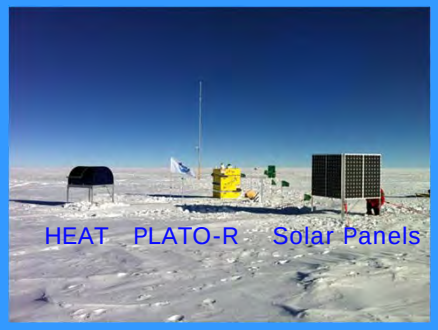
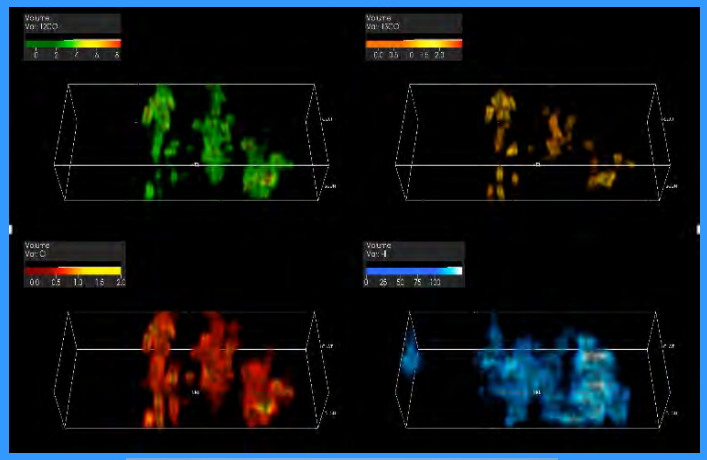


- The 0.6m aperture High Elevation Antarctic Terahertz (HEAT) telescope operated robotically (2011-2017) at Ridge A summit, delivering spectroscopic data from 150 to 500 microns.
- Joint project of the U.S. and Australian scientists: Univ. of Arizona (HEAT telescope) and Univ. of New South Wales (PLATO-R power module)

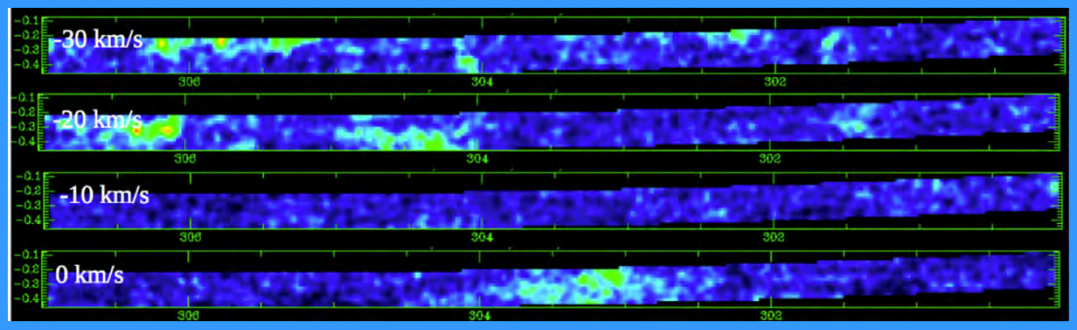
http://soral.as.arizona.edu/heat/



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



Studies of Atomic and Molecular Emissions from our Galaxy



NASA Long-Duration Balloons Program at McMurdo, Antarctica

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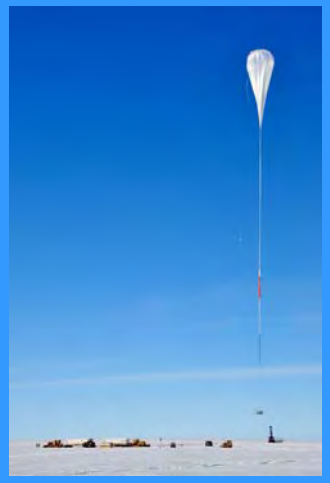
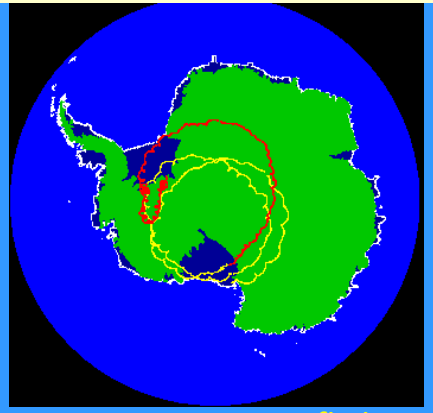
- 1988 – First MoA was signed between NASA and NSF, planning to launch **one (1) LDB payload every other year** beginning January 1990.
- 28 years later - total 54 LDB and SPB payloads have been flown from McMurdo.
- Recent pace of launches, 2-3 payloads per austral summer, created logistical backlog.
- Only one payload (SuperTIGER) was planned for the 2017/2018 austral summer season, but unfortunately the upper atmospheric vortex had not established at all, forcing cancelation for the season.



SPB Flight Track in reds



CREAM: Longest LDB flight in 2008/2009 - 52 days 2 hours

http://www.csbf.nasa.gov/antarctica/ice.htm

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Thank you!

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Questions?