Astronomy and Astrophysics Advisory Committee Meeting
National Science Foundation, February 25, 2019

NSF/OPP Astrophysics Program and Budget Update

Dr. Vladimir Papitashvili

Program Director, Antarctic Astrophysics & Geospace Sciences

Office of Polar Programs

Directorate for Geosciences


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


U.S. Amundsen-Scott South Pole Station
2.9 km elevation above sea level
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1/1/2019
~10 m/year, ~1.1-km since Amundsen & Scott arrivals in 1911/1912
South Pole Markers Line
1/11/1912

Antarctic Neutrino Astrophysics

U.S. Antarctic Program

National Science Foundation

- IceCube Neutrino Observatory: 8+ years of observations

  $272M MREFC Project, 2002-2010; current M&O support (2016-2021; $7M/year) and science awards (~$3M/year) - jointly funded by GEO/OPP and MPS/Physics.
  Lead PI: Francis Halzen, Univ. of Wisconsin-Madison and IceCube Collaboration (46 institutions in 12 countries)

- Askaryan Radio Array (ARA) concept for GZK neutrino studies (5 testbed stations) 2013-2019
  Jointly funded by OPP & PHY (~$350K/year)
  Lead PI: Albrecht Karle, Univ. of Wisconsin (Collaboration of 5 institutions in 2 countries)

- Antarctic Ross Ice-Shelf ANtenna Neutrino Array (ARIANNA) concept for GZK neutrino studies (7 testbed stations) 2010-2019
  Jointly funded by OPP & PHY (~$175K/year)
  Lead PI: Steven Barwick, Univ. of California-Irvine

Σ ~ $10.5M/year

Antarctic Astronomy & CMB Astrophysics

U.S. Antarctic Program

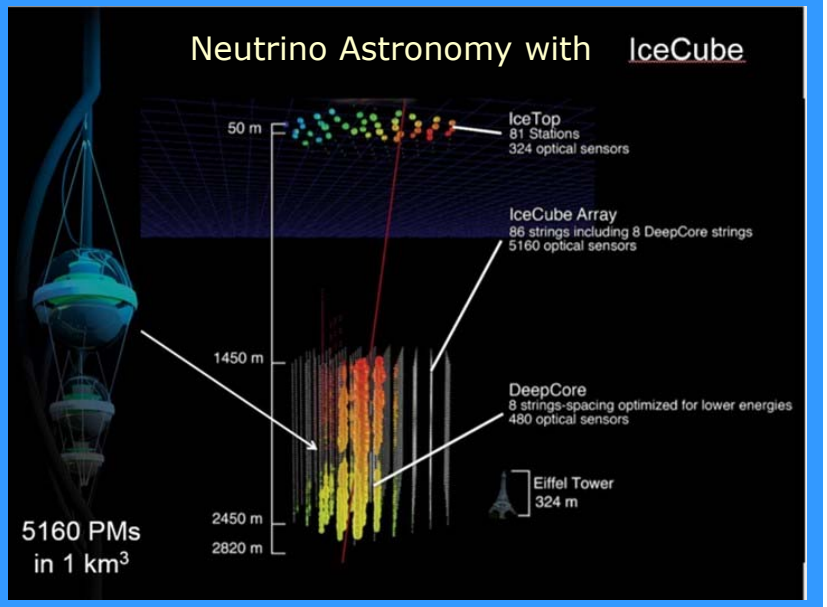
National Science Foundation

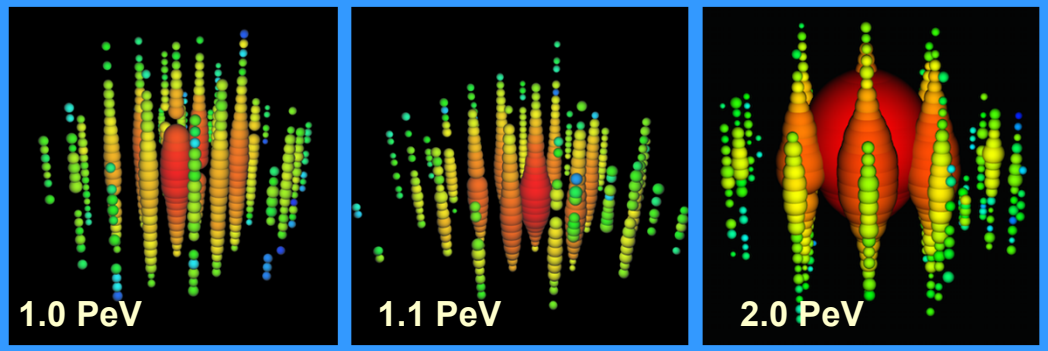
- South Pole 10m CMB Telescope (SPT) 12+ years of observation
  2007-2019 Jointly funded by OPP & MPS/PHY/AST (~$2.7M/yr)
  Lead PI: John Carlstrom, University of Chicago & SPT collaboration
  (2 National Labs and 10 institutions in 3 countries)
- Background Imager for Cosmic Extragalactic Polarization - BICEP
  Array of up to 50cm aperture telescopes 13+ years of observation
  2006-2019 Jointly funded by OPP/PHY/AST (~$1.5M/year)
  Lead PI: John Kovac, Harvard University & BICEP Collaboration
  (9 institutions in 4 countries)
- HEAT – TeraHertz Robotic Telescope at Ridge A (4.1 km elevation)
  6 years of observations (2011-2016, removed from Antarctica in
  January 2019) Jointly funded by OPP & AST ($250K/year)
  Lead PIs: Craig Kulesa (University of Arizona) and Michael Ashley
  (University of New South Wales, Australia)

  Σ ~ $4.5M/year
- NASA Long-Duration Balloon Program at McMurdo 1990–2019
  56 science payloads launched, 7 OPP co-funded, 90% astrophysics

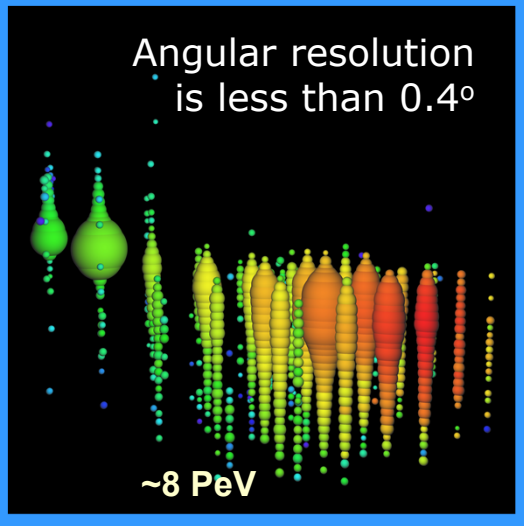
A New Window on the Non-Thermal Universe!

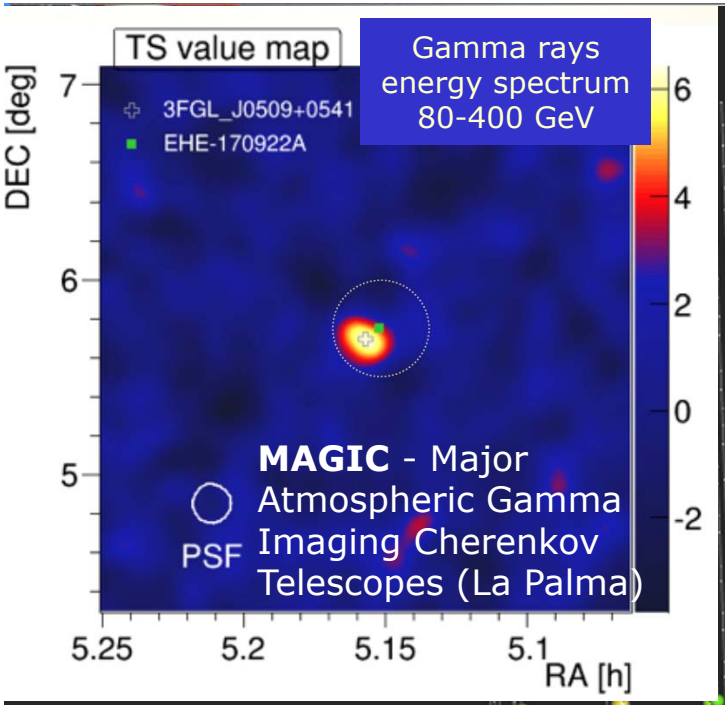
- IceCube was completed in 2010 as a discovery machine - to search for very high energy neutrinos created in the most extreme cosmic environments.
- 2013: ICNO discovered first high energy (100–10 PeV TeV) cosmic neutrinos - over 100 events currently collected… robust statistics!
- Sep 22, 2017: IceCube issued an alert 170922A upon pinpointing an extra-galactic neutrino (~0.3 PeV) source within 0.1° of the flaring blazar TXS 0506+056.





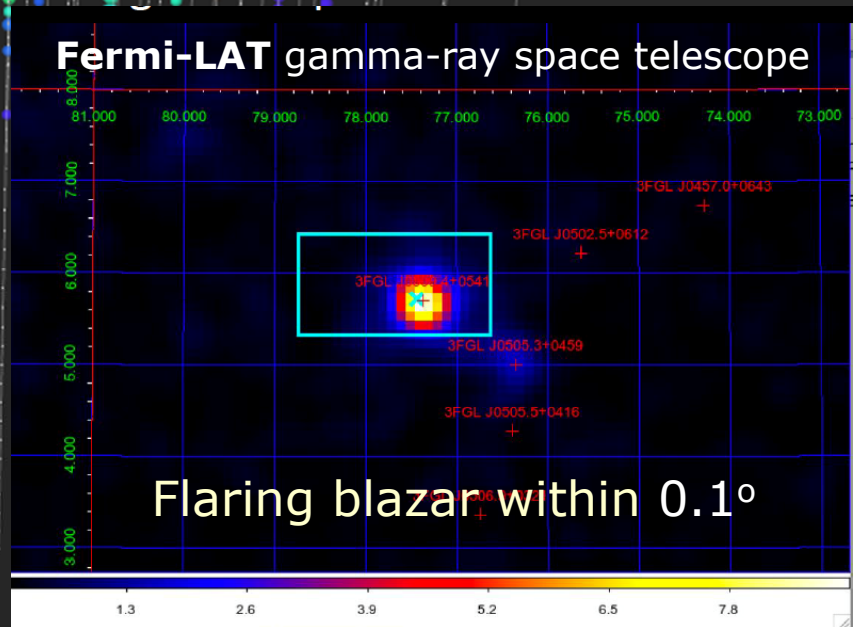
Total energy measurements, all flavors, all sky





IceCube 170922
290 TeV

4 in Top 10 stories of 2018 by http://www.sciencenews.org



July 12, 2018
NSF Press Release 18-050
Neutrino observation points to one source of high-energy cosmic rays

ICNO mid-scale size upgrade

Title: IceCube Gen2 Phase 1: an IceCube extension for precision neutrino physics and astrophysics (funded by PHY & OPP in 2018 for 60 months)

PI: Kael Hanson, Univ. of Wisconsin & 7 institutions of 4 countries

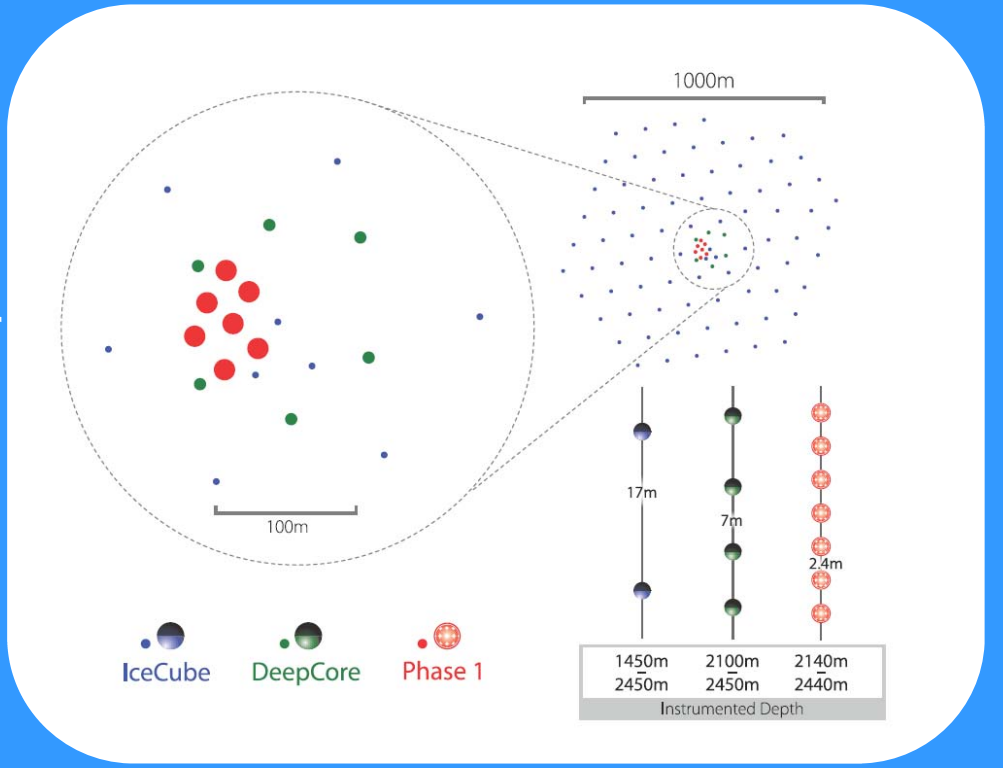
NSF: $24M Other U.S. & Non-U.S. institutions: $14M in-kind

Additional 7 strings (each 100+ DOMs) in the center of DeepCore Array

Main Science Objective: Multimessenger Astrophysics - A new Window on the PeV Universe

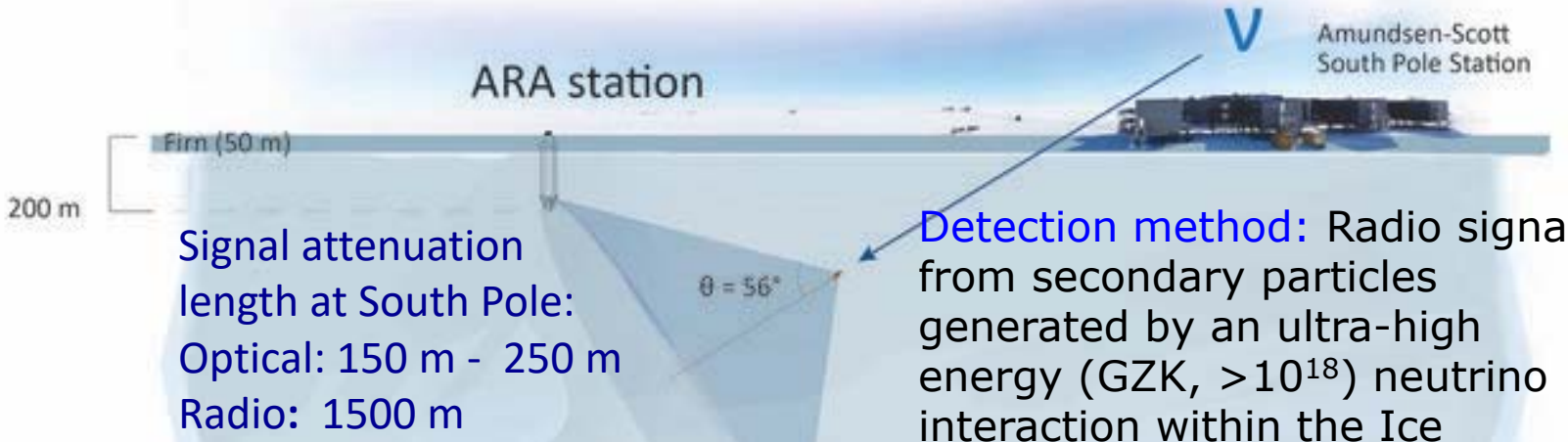
Main Science Topics:

- ✓ Tau neutrino appearance and the unitarity of the PMNS matrix
- ✓ Neutrino oscillations, sterile neutrino, and indirect dark matter
- ✓ Improving IceCube's capabilities for neutrino astronomy:
  - Tau neutrino appearance on cosmic baselines
  - Neutrino astronomy with high-energy cascades



OPP & PHY – Askaryan Radio Array concept

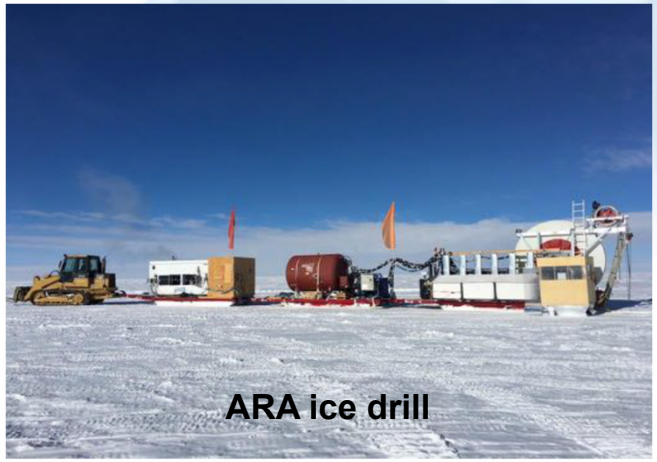
Radio detection of neutrinos complements optical techniques at very high energies

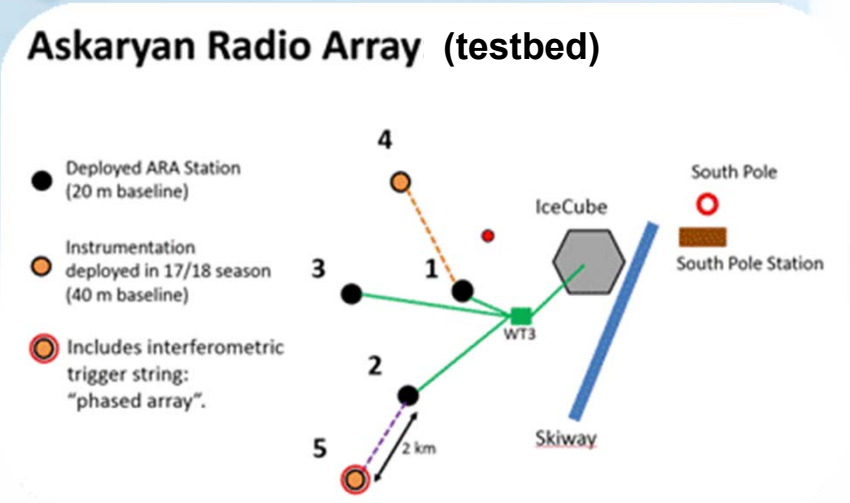


Signal attenuation length at South Pole:
Optical: 150 m - 250 m
Radio: 1500 m

Detection method: Radio signal from secondary particles generated by an ultra-high energy (GZK, $>10^{18}$) neutrino interaction within the Ice

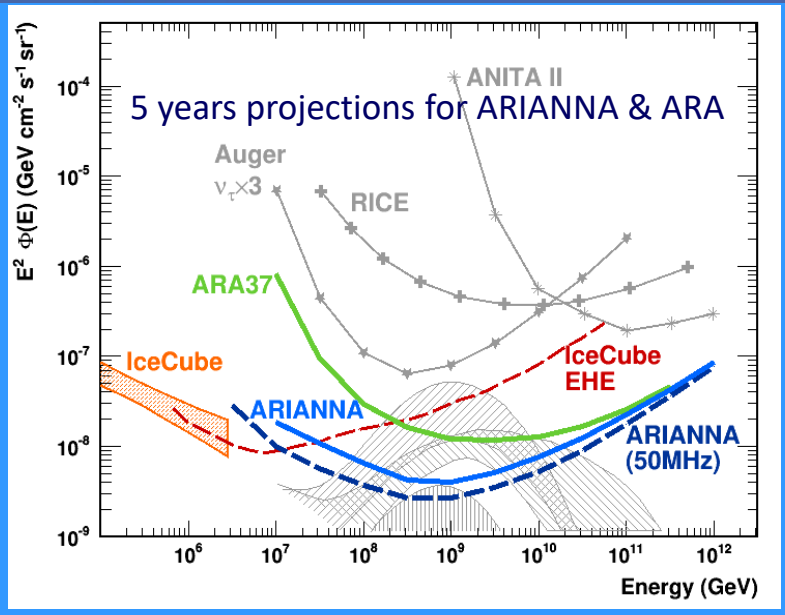
Concept: Full ARA array (37 stations, 200 km^2) will reach required sensitivity at the energies above 100 PeV

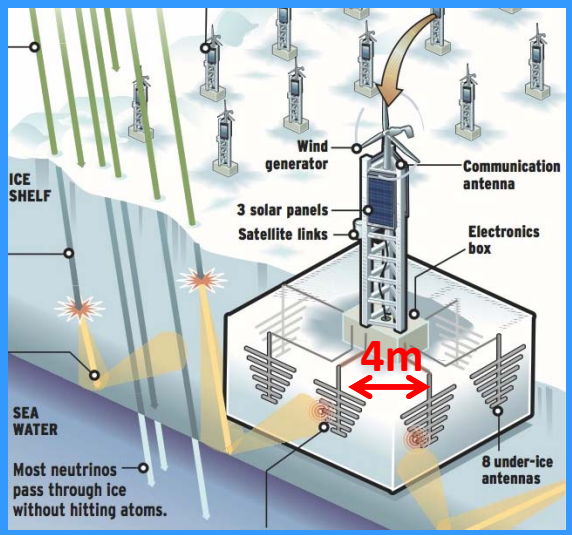

ARA ice drill



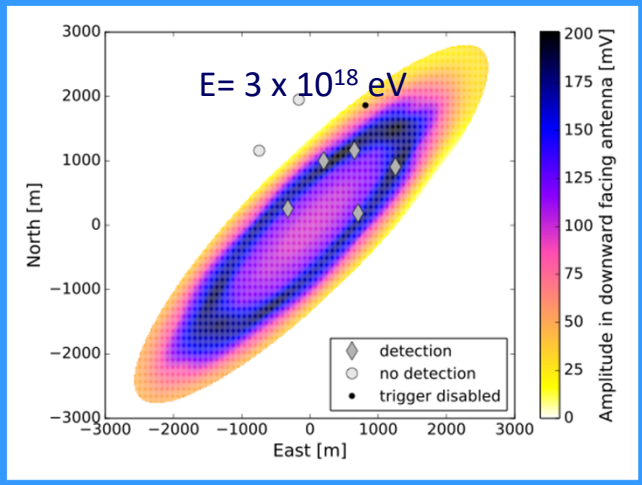
OPP & PHY - ARIANNA Concept

- 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
- Same as ARA's radio detection method that additionally includes measurements of a signal reflect from the water surface under the Ross Ice Shelf.
- Currently testing two ARIANNA stations at the South Pole Station – to compare with ARA data.





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



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

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

The South Pole Telescope Program

U.S. Antarctic Program

National Science Foundation

Three Cameras, ~200 Papers on a Vast Array of Subjects, ~10,000 Citations.

First Generation:
The SPT-SZ Camera

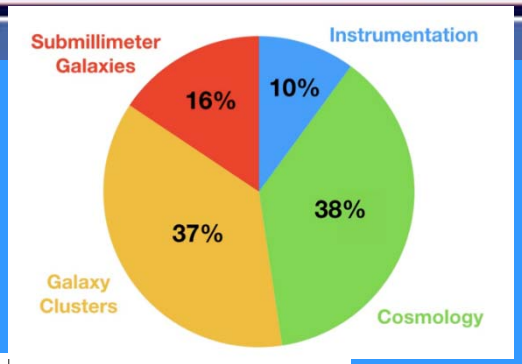
- 2007-2011
- 960 detectors, 3 bands
- 2500 deg^2 survey to 18 μK-arcmin

Second Generation:
The SPTpol Camera

- 2012-2016
- 1536 detectors, 2 bands, polarization sensitivity
- 500 deg^2 survey to 5 μK-arcmin

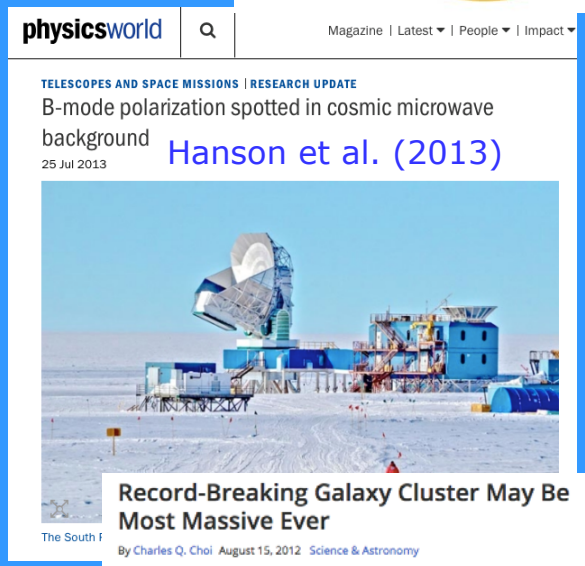
Third Generation:
The SPT-3G Camera

- See next slide



SPT publications and citations span many sub-fields of astronomy and physics.

SPT citations by subject


physicsworld

Magazine | Latest | People | Impact

TELESCOPES AND SPACE MISSIONS | RESEARCH UPDATE

B-mode polarization spotted in cosmic microwave background

25 Jul 2013

Hanson et al. (2013)

SPT discoveries include some of the most extreme objects in the Universe and have had lasting impacts on the fields of cosmology, galaxy clusters, and high-redshift galaxies.


Record-Breaking Galaxy Cluster May Be Most Massive Ever

By Charles Q. Choi August 15, 2012 Science & Astronomy

McDonald et al. (2013)

Artist's impression of the galaxy at the center of the Phoenix Cluster, which is forming about 740


Massive Primordial Galaxies Found Swimming in Vast Ocean of Dark Matter

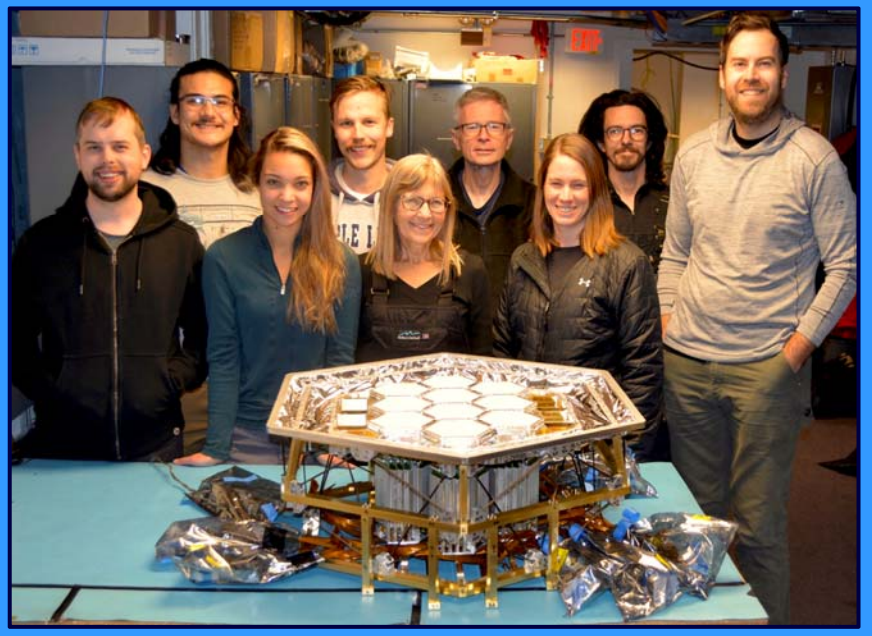
Credit: NRAO/AUI/NSF; D. Berry

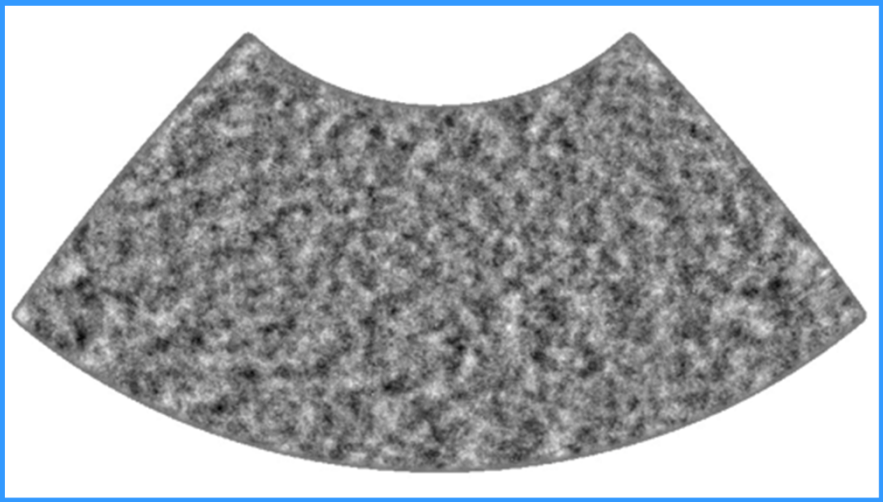
Marrone et al. (2018)

The SPT-3G Camera

Third Generation:
The SPT-3G Camera

- 16,000 polarization-sensitive detectors in 3 bands.
- Order-of-magnitude improvement over SPTpol and other 2015-era CMB cameras
- Maps a 3x larger region than SPTpol to full 4-year-survey SPTPol depths in 1 year.
- Currently surveying the final target sky field, a 1500 deg^2 region fully over-lapping the BICEP Array survey field (for de-lensing the B-mode signal).
- Final target map depth (2.2 μK-arcmin at 150 GHz) and observing strategy will enable breakthrough science in many areas, including new windows on the transient Universe and multi-messenger astrophysics.





http://pole.uchicago.edu

U.S. Antarctic Program

ALMA & SPT 2018 Highlight

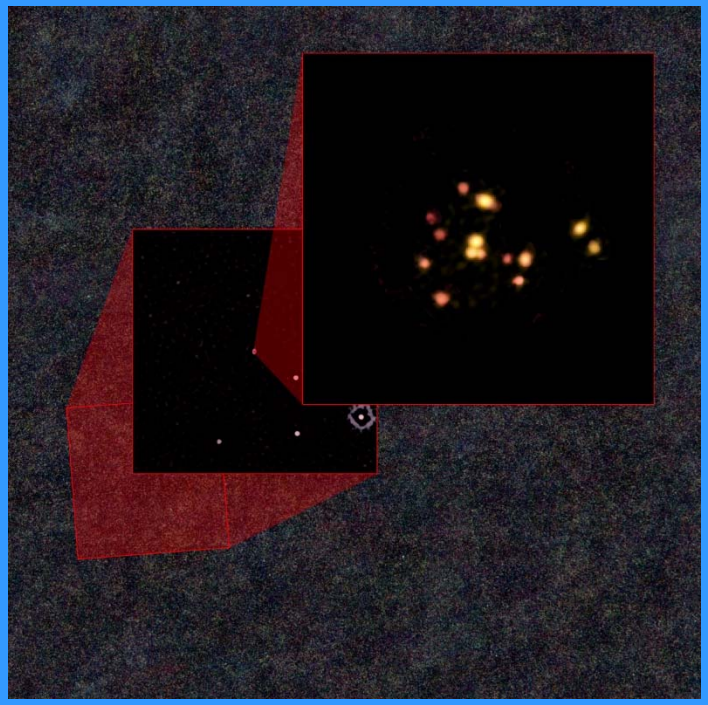
National Science Foundation

National Radio Astronomy Observatory

nature
International journal of science

Astronomers Witness Galaxy Megamerger
Cosmic pileup forging galaxy cluster in early Universe

T. Miller & S. Chapman et al. A massive core for a cluster of galaxies at a redshift of 4.3 (*Nature*, *556*, *pages 469-472*, *2018)*



Using the Atacama Large Millimeter/submillimeter Array (ALMA), an international team of scientists has uncovered a startlingly dense concentration of 14 galaxies that are poised to merge, forming the core of what will eventually become a colossal galaxy cluster.

Known as a protocluster designated as SPT2349-56, it is located approximately 12.4 billion light-years away and it was first discovered as a faint smudge of the mm-wavelength light in 2010 with the NSF's South Pole Telescope.

Current theory and computer models suggest that protoclusters as massive as the one observed by ALMA, however, should have taken much longer to evolve.

Zooming in to the galaxies discovered by ALMA that are evolving into a galaxy cluster.

The middle image -- a portion of a much-wider survey by NSF's South Pole Telescope -- uncovered the distant galactic source that was studied by ALMA to reveal the 14 galaxies.

The outer field is from data taken by the Hershel Space Observatory.

Credit: ALMA (ESO/NAOJ/NRAO), T. Miller & S. Chapman et al.; Herschel; South Pole Telescope; (NRAO/AUI/NSF) B. Saxton

Deep CMB field observing from South Pole

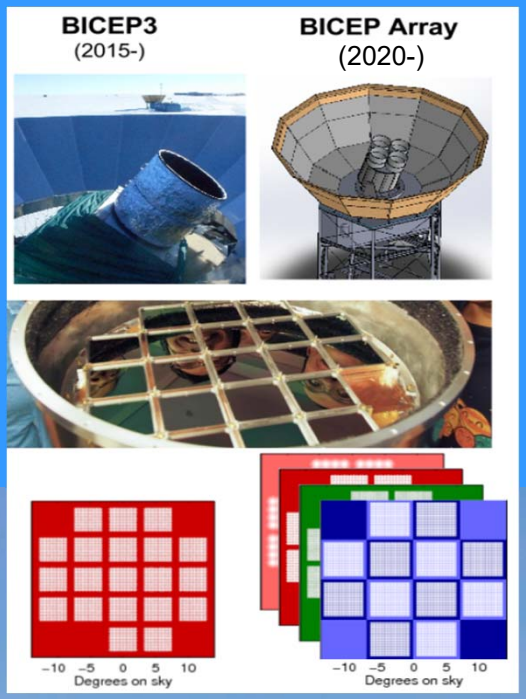
U.S. Antarctic Program

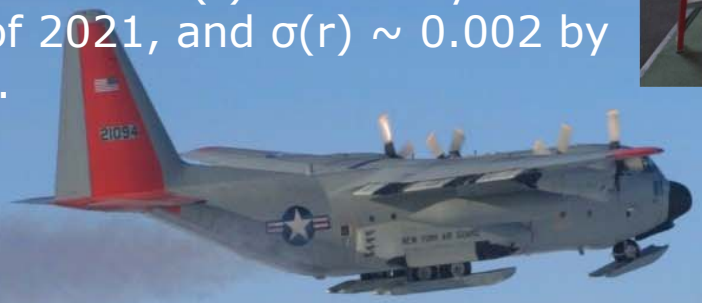
National Science Foundation

Keck Array - Hardware upgrades in 2018/19 included receivers optics with new hybridized focal plane.

Full-scale CMB Stage 3 program replaces the Keck Array (95-270 GHz) with BICEP Array (next season 30 & 40, then 95, 150, 220 & 270 GHz) for the deep foreground separation.

With the SPT-3G delensing, plans are to reach σ(r)<0.004 by the of end of 2021, and σ(r) ~ 0.002 by 2023.





South Pole Telescope
(16,000 bolometers)

BICEP3

KECK Array of 5 receivers

Total number of bolometers:
BICEP3 + Keck Array: 6,000
BICEP3 + BICEP Array: ~35,000

will be replaced by BICEP Array of 4 receivers in 2020

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

U.S. Antarctic Program

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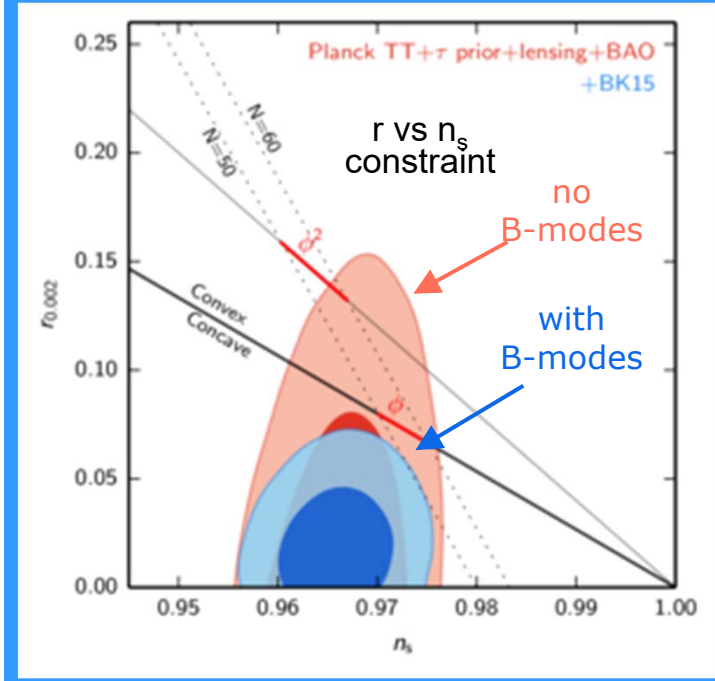
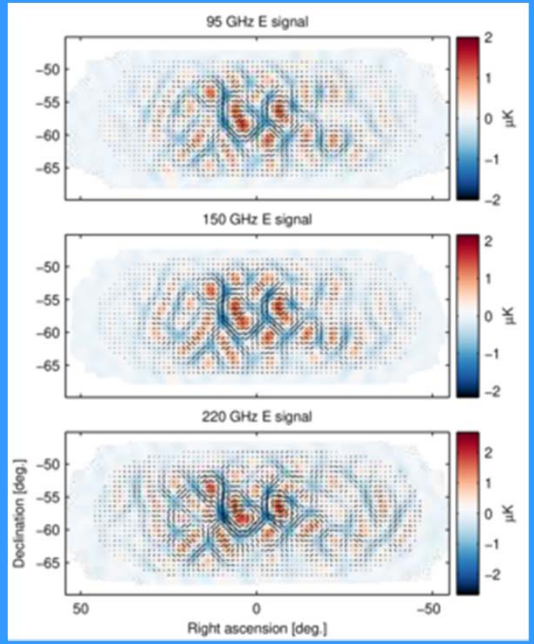
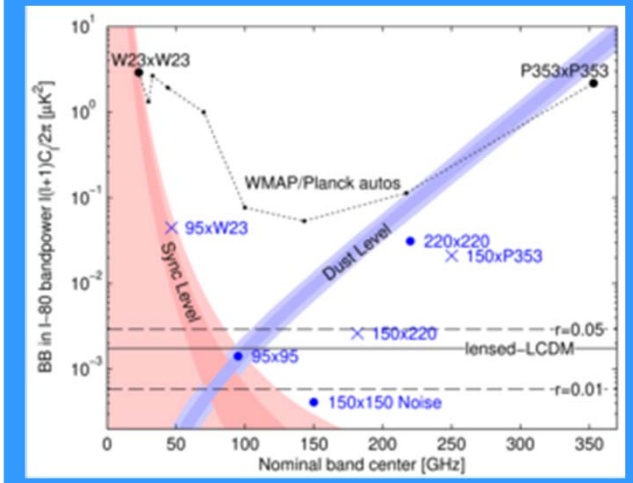
http://bicepkeck.org



Maps of degree angular scale *E*-modes ($50 < \ell < 120$)



Noise vs. frequency: Expectation values and noise uncertainties for the ℓ~80 *BB* bandpower in the BICEP2/*Keck* field.



BICEP/Keck/Planck analysis	σ(*r*) = 0.034	Phys.Rev.Lett. 114, 101301, 2015
2014 BICEP/Keck analysis adds 95 GHz	σ(*r*) = 0.025	Phys.Rev.Lett. 116, 031302, 2016
2015 BICEP/Keck analysis	σ(*r*) = 0.019	Phys.Rev.Lett. 121, 221301, 2018
2017 BICEP/Keck *plus* SPTpol delensing	σ(*r*) = 0.010	coming in 2019
2018/21 BICEP/Array+SPT-3g delensing	σ(*r*) ~ 0.004	forecast

Raw sensitivity of this experiment to primordial B-modes (i.e., with no foregrounds or lensing) is close to σ(r) ~ 0.006

It is now all about components separation!

OPP & AST – TeraHertz Robotic Telescope

U.S. Antarctic Program

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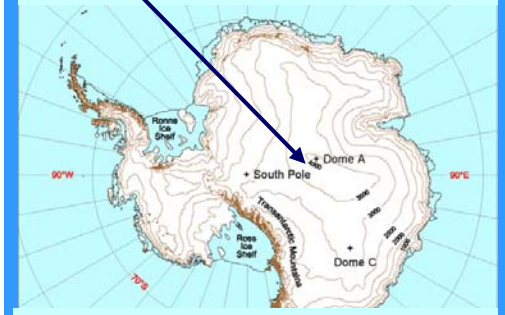
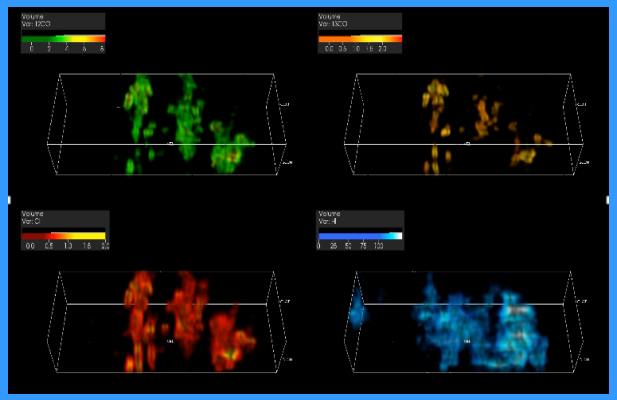
Ridge A - 160-km south of Chinese station Kunlun at Dome A



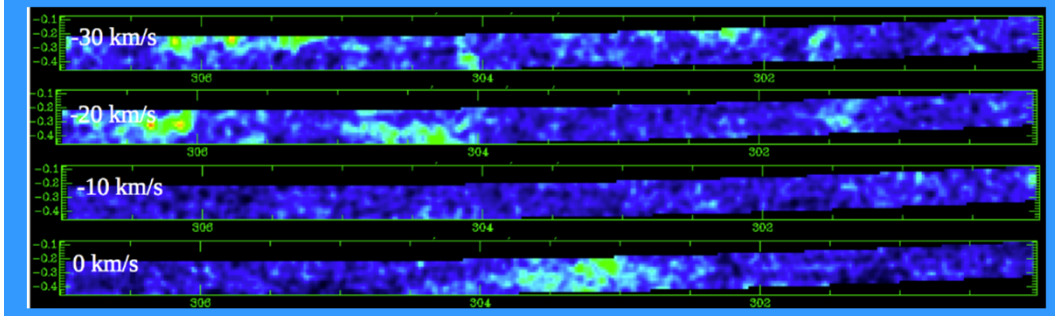
Ridge A is 5-10 times drier than the ALMA site

- The 0.6m aperture High Elevation Antarctic Terahertz (HEAT) telescope operated robotically at Ridge A summit, delivering spectroscopic data from 150 to 500 microns for 6 years (2011-2016).
- This was a joint project of the U.S. and Australian scientists: Univ. of Arizona (HEAT telescope) and Univ. of New South Wales (PLATO-R power module).
- The HEAT and PLATO-R were removed from Ridge A in January 2019.



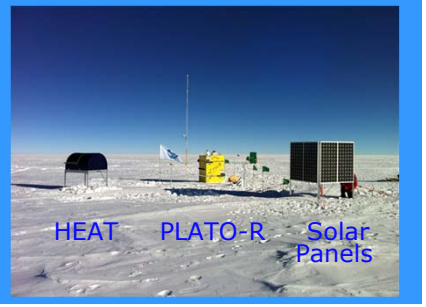
http://soral.as.arizona.edu/heat/

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

http://mcba11.phys.unsw.edu.au/~plato-r/



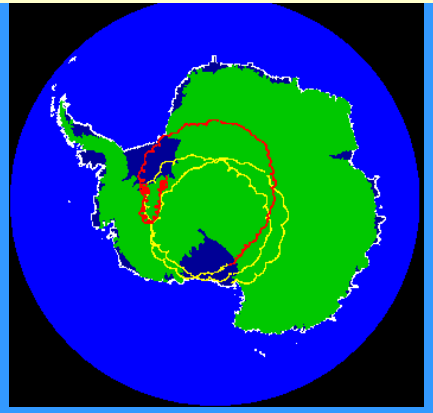
NASA Long-Duration Balloons Program at McMurdo, Antarctica

U.S. Antarctic Program

National Science Foundation

- 1988 – First MoA was signed between NASA and NSF, planning to launch one (1) LDB payload every other year beginning January 1990.
- 29 years later - total 56 LDB and SPB payloads have been flown from McMurdo - in average 2 payloads per year!
- In 2018-2019 austral summer season, only two payloads (SuperTIGER and X-Calibur, out of 3 planned) were flown, but both were terminated soon after being launched due to equipment failures. BLAST-TNG was stored on-site and will be launched in 2019-2020.

SPB Flight Track in reds



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

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

Antarctic Astrophysics – Budget Update

- Current annual spending for Antarctic Astrophysics is ~$9.0M, where ~$5M+ go to support neutrino astrophysics, and ~$4M+ to support astronomy & CMB-related projects.
- As previous slides show, almost all Antarctic astrophysical research projects were (and are!) co-funded with the MPS/PHY & AST science programs – thank you, friends!
- The IceCube M&O and related science projects (IceCube science, ARA, ARIANNA, etc.) were co-funded by OPP & PHY 50:50 since the IceCube MREFC project arrived to South Pole.
- Thus, the combined annual spending for Antarctic research in neutrino astrophysics reaches $10.5M. OPP and PHY spent jointly ~$120M in 2004-2018.
- Antarctic astronomy & CMB research were mostly funded by OPP. Since 2004, AST (PHY since 2012) helped co-funding some CMB projects. In 2018, the AST/MSIP & OPP/AAGS programs jointly co-funded 50:50 the latest BICEP Array award.
- Thus, the combined annual spending for Antarctic astronomy and CMB research is about $4.5M. OPP spent jointly with AST & PHY ~$100M in 2004-2018.

U.S. Antarctic Program

Thank you for your attention!

National Science Foundation

Questions?