Astronomy and Astrophysics Advisory Committee Meeting
National Science Foundation, January 23, 2020

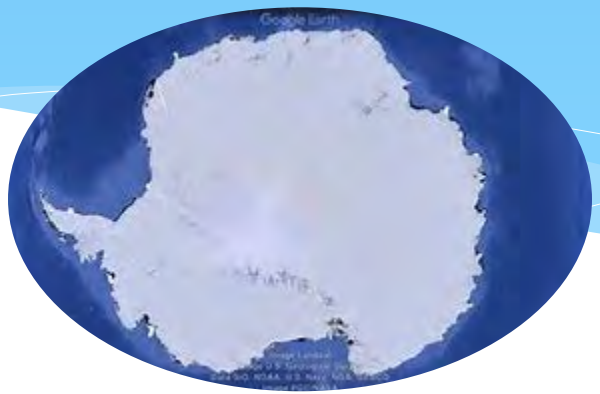
NSF/OPP Astrophysics Program and Budget Update

Dr. Vladimir Papitashvili

Program Director

Antarctic Research Facilities for Astrophysics

Office of Polar Programs, NSF/Directorate for Geosciences



www.nsf.gov

www.usap.gov

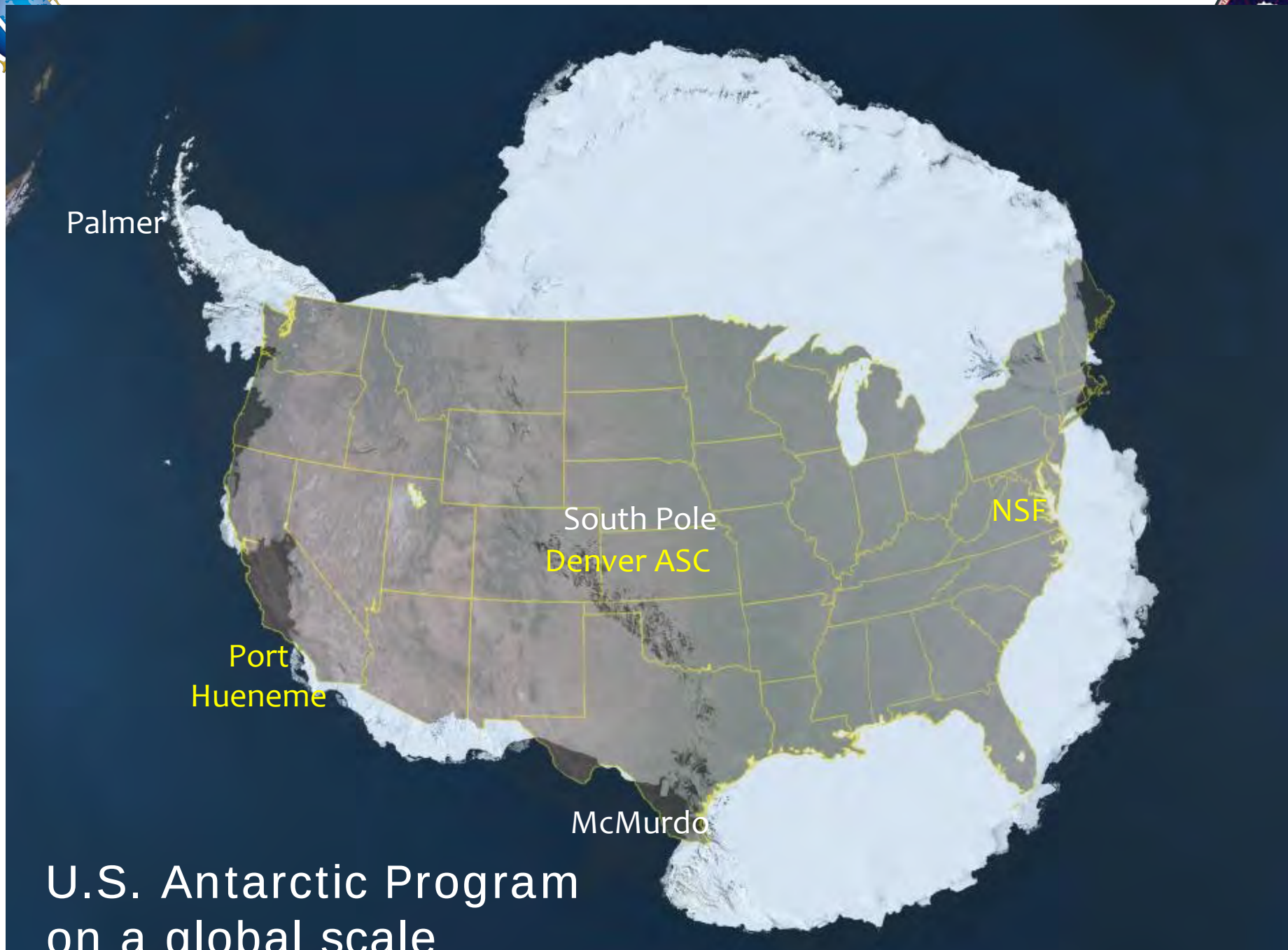
Astrophysics from Antarctica

Antarctic Treaty System defines Antarctica as all of the land and ice shelves south of 60°S latitude

- ✓ Signed December 1, 1959 by 12 countries (IGY participants, 1957-1958)
- ✓ Entered into force in 1961… many nations joined… now 53 members

Important Antarctic Treaty Provisions:

- ➢ Antarctica shall be used for peaceful purposes only (Art. I)
- ➢ **Freedom of scientific investigation in Antarctica and cooperation toward that end … shall continue (Art. II)**
- ➢ **Scientific observations and results from Antarctica shall be exchanged and made freely available (Art. III)**
- ➢ The treaty does not recognize, dispute, nor establish territorial sovereignty claims; no new claims shall be asserted while the treaty is in force (Art. IV)

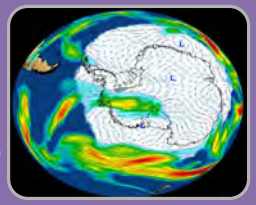


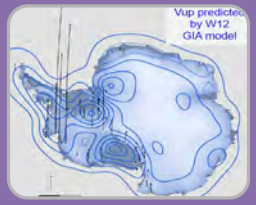
U.S. Antarctic Program on a global scale

NSF/GEO/OPP Antarctic Science Programs

Ocean

Atmosphere





Earth sciences

Integrated System Science

Glaciology

Organisms and Ecosystems

Astronomy, Astrophysics, and Geospace

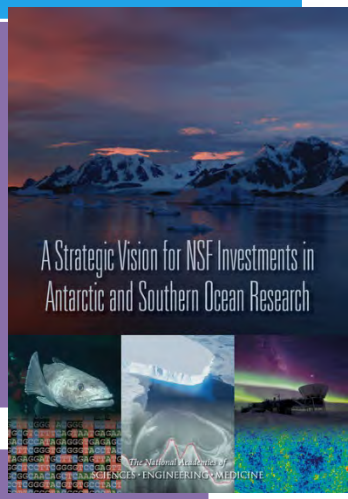
Instrumentation and Facilities

NAS/NRC Report (2015): Strategic Science Priorities

Changing ice sheets

WAIS ice mass loss and sea level rise

How much, how fast?



Antarctic biota: Evolution and adaptation

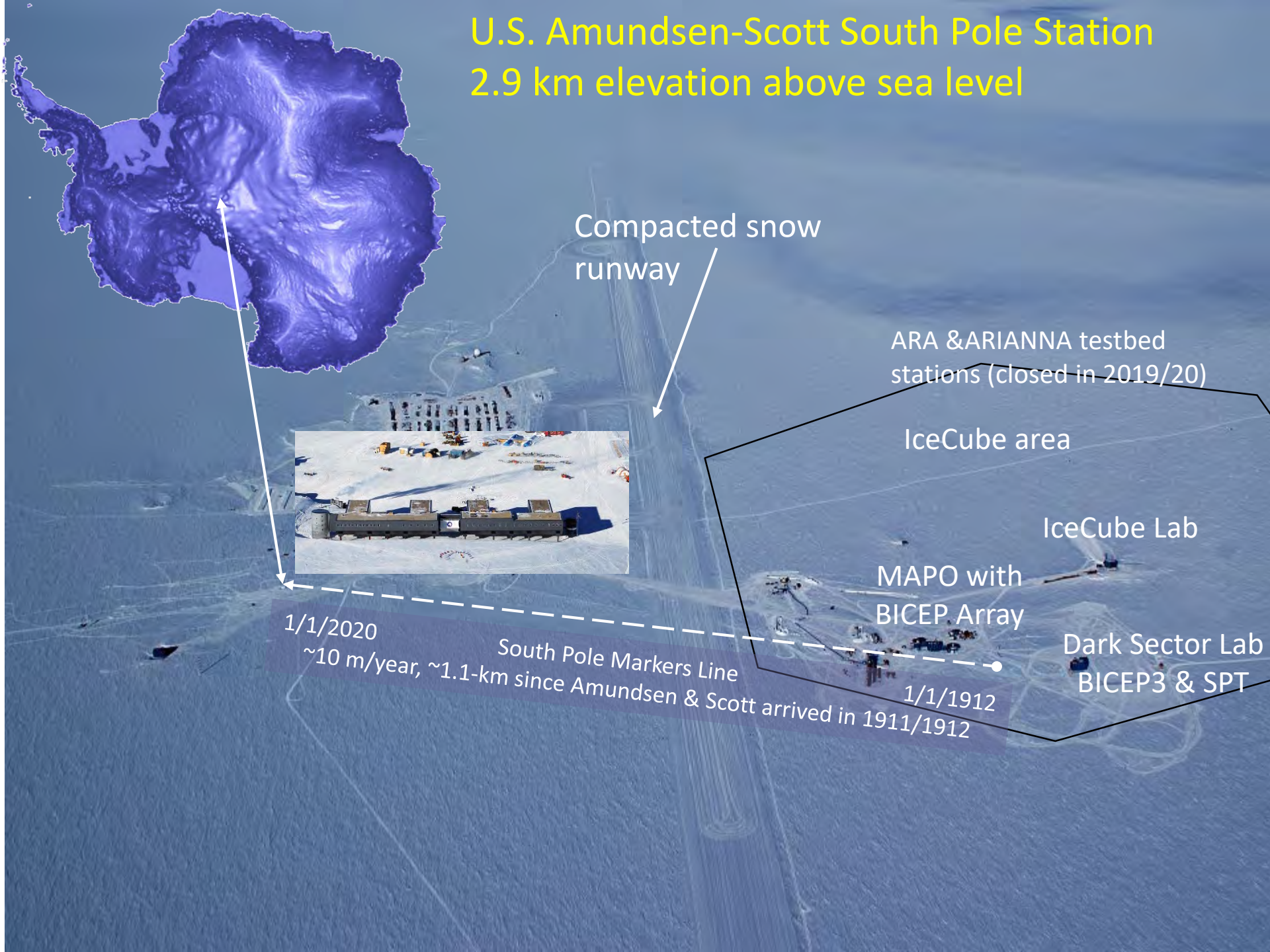
Decoding genomics/transcriptomics

NSF Big Idea: "Rules of Life"

How did the Universe begin?

Next generation cosmic microwave background program

NSF Big Idea: Windows on the Universe


U.S. Amundsen-Scott South Pole Station
2.9 km elevation above sea level
Compacted snow runway
ARA &ARIANNA testbed stations (closed in 2019/20)
IceCube area
IceCube Lab
MAPO with BICEP Array
Dark Sector Lab BICEP3 & SPT
1/1/2020
~10 m/year, ~1.1-km since Amundsen & Scott arrived in 1911/1912
South Pole Markers Line
1/1/1912

Summer Solstice above South Pole Station December 21, 2019

Photo: John Hardin

Antarctic Neutrino Astrophysics: ~$10.5M/year

- **IceCube Neutrino Observatory** **9+ years of observations**

  $272M MREFC Project, 2002-2010; M&O support (since 2008 to 2021; **$7M/year**) and science awards **(~$3M/year**) - jointly funded by GEO/OPP and MPS/PHY. Lead PI: Francis Halzen, University of Wisconsin-Madison and IceCube Collaboration (52 institutions, 12 countries) NSF provides ~60% of the total M&O support.

  IceCube Neutrino Observatory Upgrade **NSF $23M+$14M from non-NSF** partners, 2018-2023; PHY & OPP. Lead PI: Kael Hanson, University of Wisconsin and Collaboration (12 institutions in 4 countries) - **in progress**.

- **Askaryan Radio Array (ARA, closed)** concept for GZK neutrino studies, 2012-2019, 5 testbed stations; PHY & OPP, ~$350K/year; Lead PI: Albrecht Karle, Univ. of Wisconsin (Collaboration of 5 institutions, 2 countries).
- **Antarctic Ross Ice-Shelf ANtenna Neutrino Array (ARIANNA, closed)** concept for GZK neutrino studies, 2010-2019, 5 testbed stations, jointly funded by OPP & PHY (~$200K/year); Lead PI: Steven Barwick, University of California-Irvine.

Antarctic CMB Astrophysics: ~$5.3M/year

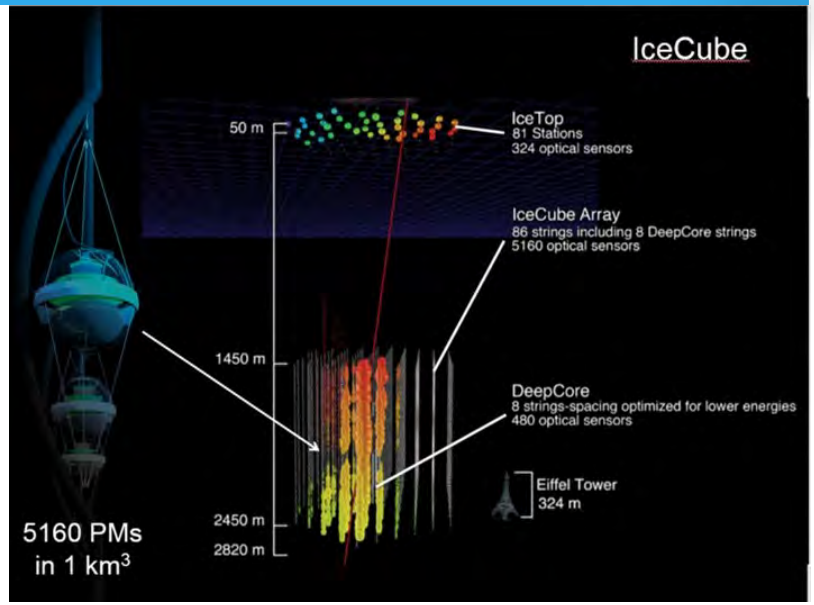
- **South Pole 10m CMB Telescope (SPT)** First light: February 2007, 13+ years of observations; jointly funded by OPP & MPS/PHY/AST (~$2.7M/year); Lead PI: John Carlstrom, University of Chicago & SPT collaboration (2 National Labs and 10 institutions, 3 countries).
- **BICEP – Background Imager for Cosmic Extragalactic Polarization** First light: February 2007, 14+ years of observations, currently array of five ~50-cm aperture CMB telescopes; funded by OPP/PHY/AST & OIA/MRI (~$2.6M/year); Lead PI: John Kovac, Harvard University & BICEP Collaboration (9 institutions, 4 countries).

NASA-funded LDB Program:

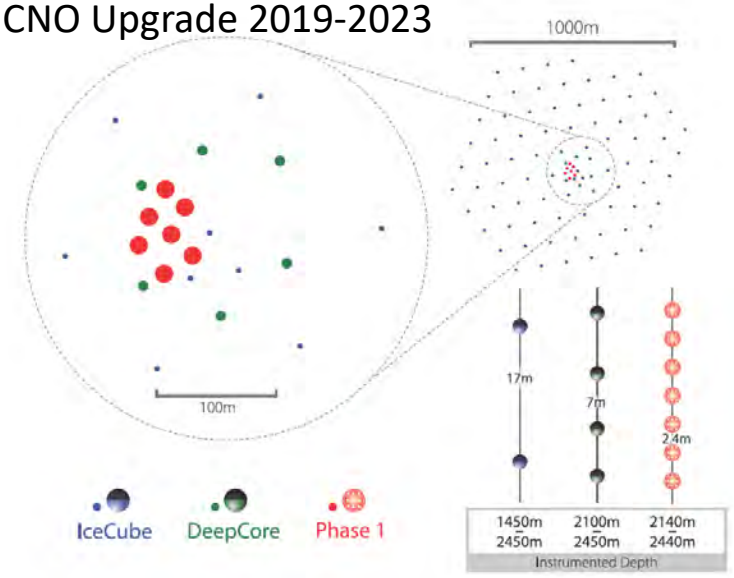
- Long Duration & Superpressure Balloons launched from McMurdo 1990–2020 57 science payloads (including 7 co-funded by OPP, ~90% are astrophysics payloads (OPP provides local logistics)

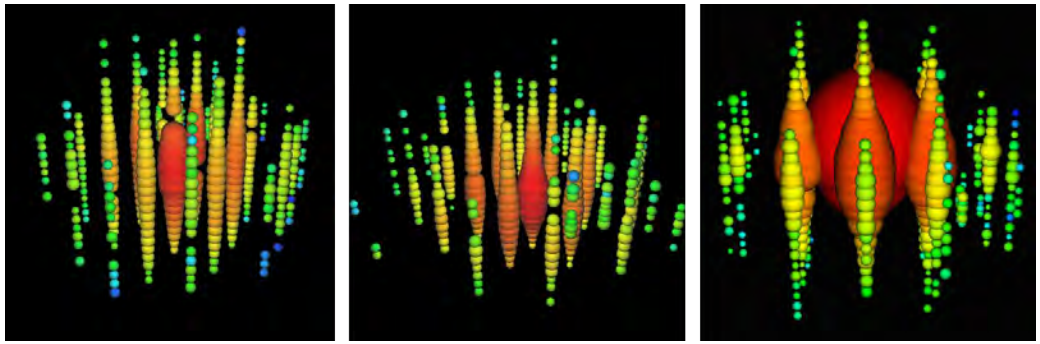
IceCube Neutrino Observatory (ICNO) managed by OPP & PHY

- IceCube was completed in 2010 as a discovery instrument - built to search for very high energy neutrinos created in most extreme cosmic environments.
- 2013: ICNO discovered first high energy (100 Tev –10 PeV) cosmic neutrinos - over 100 high-energy events are currently collected providing robust statistics for science analyses!
- 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.



ICNO Upgrade 2019-2023

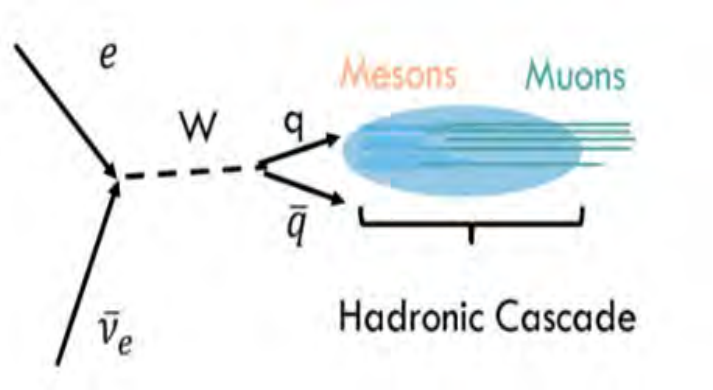


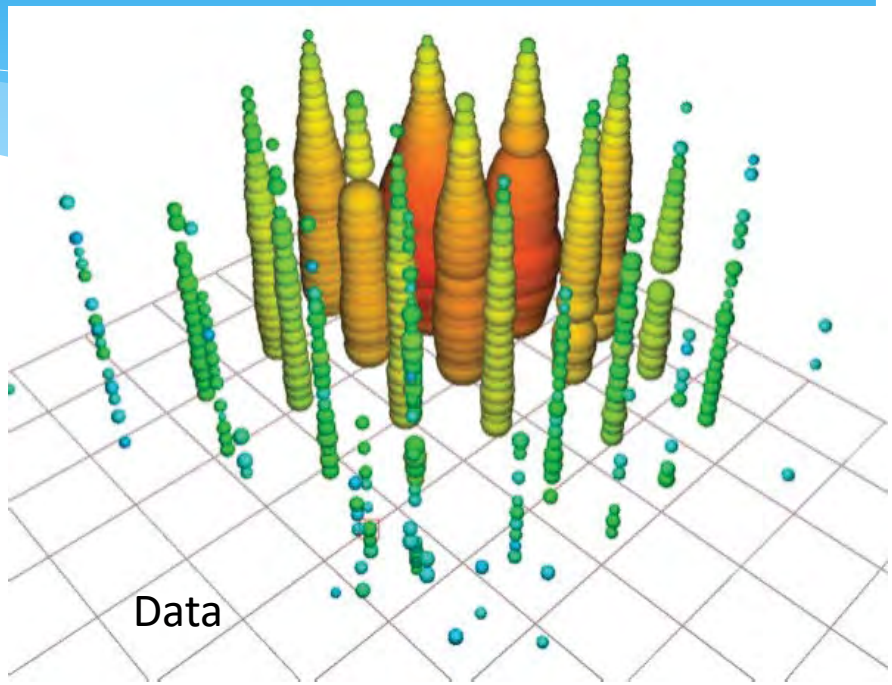


Bert 1.0 PeV Ernie 1.1 PeV Big Bird 2.0 PeV

IceCube science results update

A possible Glashow resonance event:
anti-n_e + atomic electron → real W meson at E_n = 6.3 PeV





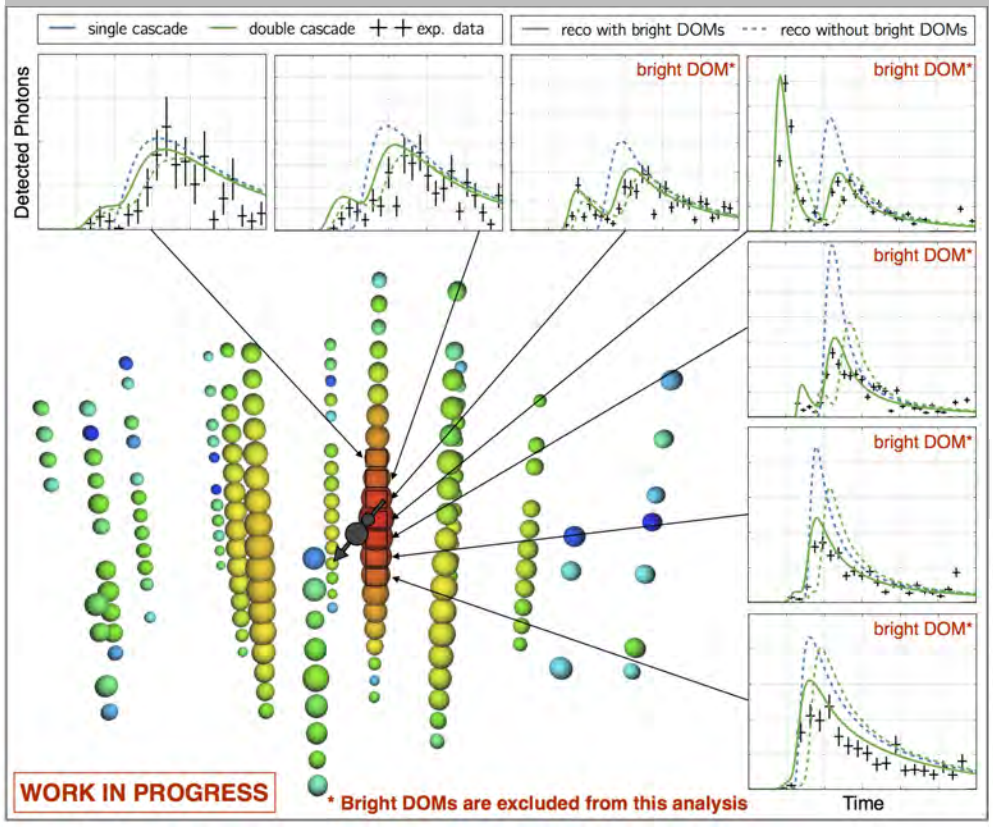
- ✓ About 5 years (2012-2016) of data are analyzed - one event is found at Glashow bin!
- ✓ It is brighter than all IceCube PeV events even only partially-contained.

- Partially-contained PeV search
- Event's deposited energy: **5.9±0.18 PeV**
- With the detector efficiency 93%, the resonance energy is 6.3 PeV

January 2020; with J. Whitmore

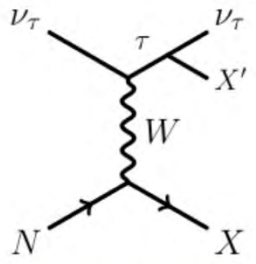
IceCube science results update

First cosmic ~300 TeV *tau* neutrino in IceCube

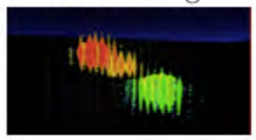


tau decay length: 50m per PeV

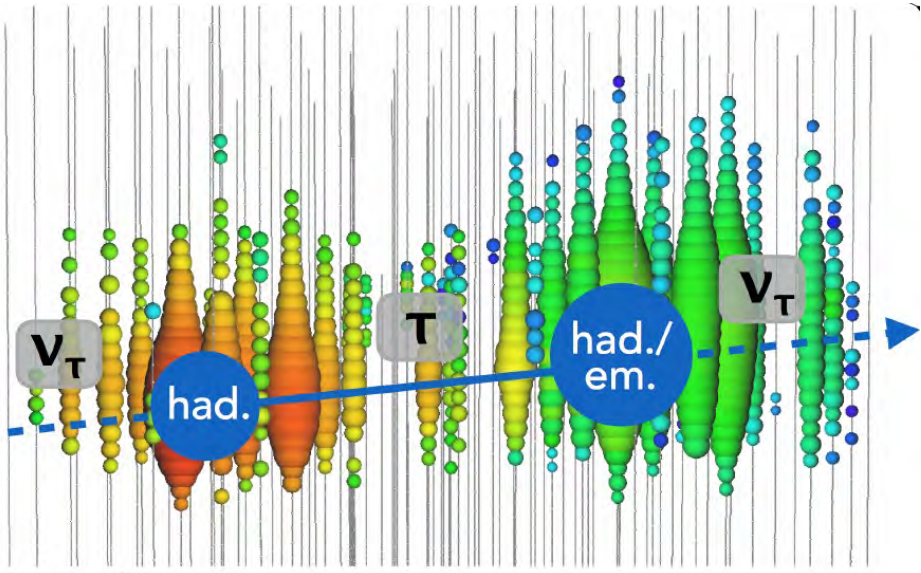
Charged-current (CC) neutrino interactions are required to determine the flavor of the interacting neutrino. *Tau* neutrinos become distinguishable from other flavors above a few hundred TeV, when the cascade from the tau neutrino CC interaction becomes resolvable from the cascade from the *tau* lepton decay.



double bang*



tau production and decay

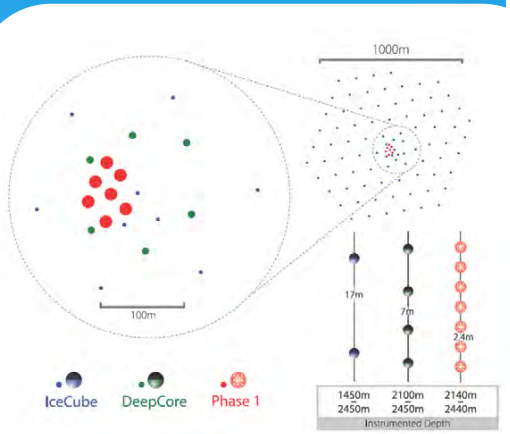


S(ICRC2017)973

ICNO Mid-Scale Upgrade Award's objectives:

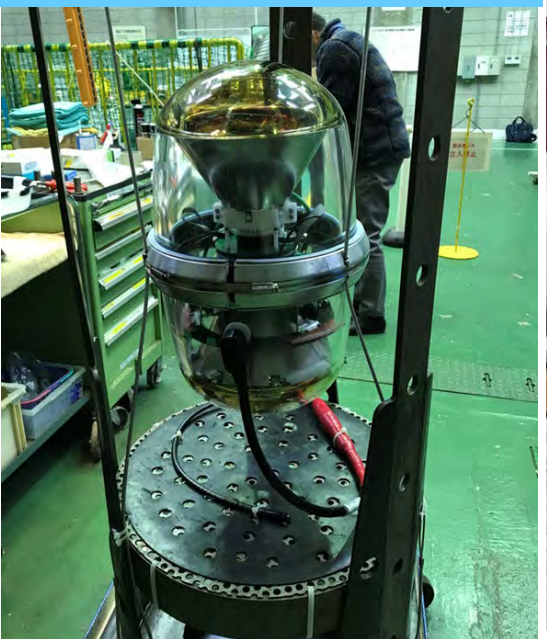
- ✓ Tau neutrino appearance on cosmic baselines
- ✓ The unitarity of the PMNS matrix
- ✓ Neutrino oscillations and sterile neutrino

ICNO Mid-Scale Upgrade Progress – South Pole, December 2019



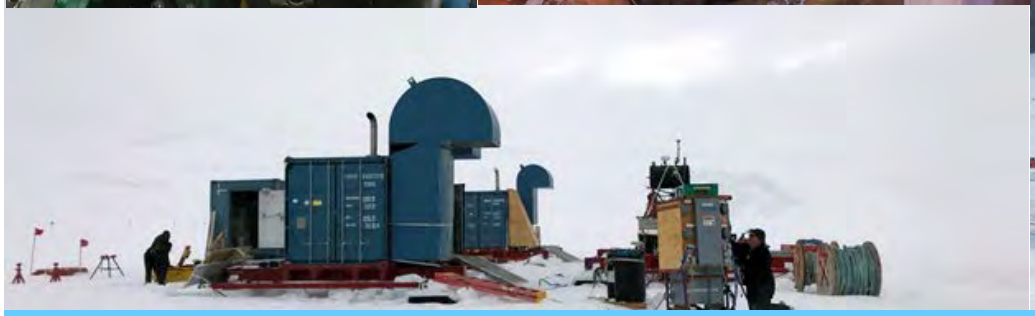
Enhanced Hot Water Drill (above), water tanks and drill towers (below)

New D-Egg DOMs



ICNO Mid-Scale Upgrade Progress
South Pole, December 2019

IceCube team at South Pole



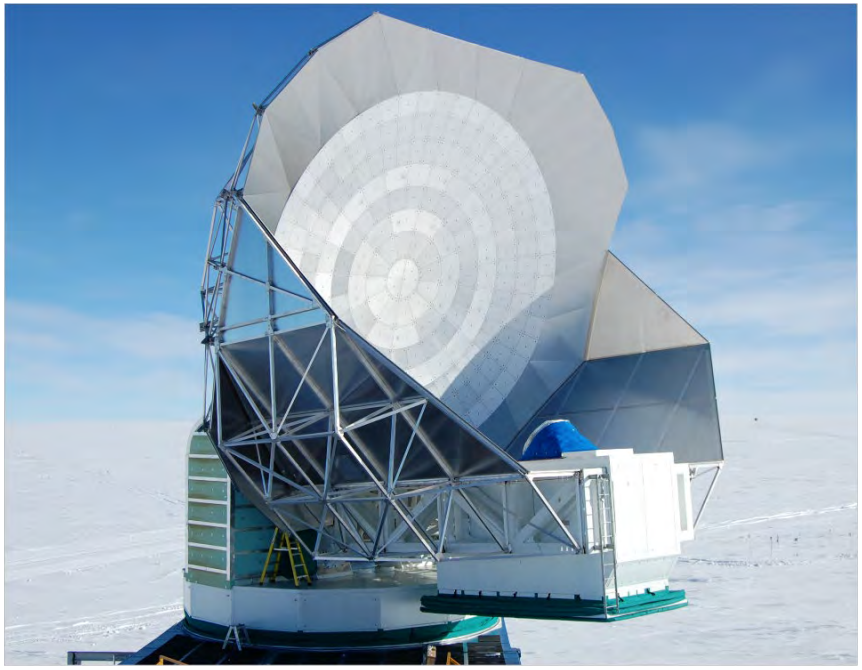
IceCube Power Plant and Generators at McMurdo

Merry Christmas from the team at McMurdo to IceCube Project. The Generators are loaded and scheduled to be transported to the pole on SPOT-3

The South Pole Telescope Program

Three Cameras, ~200 Scientific and Technical Papers, ~10,000 Citations.

- *over 30 papers and 500 citations in the last year alone*



First Generation: SPT-SZ

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

Second Generation: SPTpol

- 2012-2017
- 1536 detectors, 2 bands, polarization
- 500 deg^2 survey to 5 uK-arcmin

Third Generation: SPT-3G

- 2018 - 2023
- 16,000 detectors, 3 bands, polarization
- Largest CMB focal plane currently fielded
- Observing at full power and high efficiency
- 1500 deg^2 survey to ~2 uK-arcmin by 2023

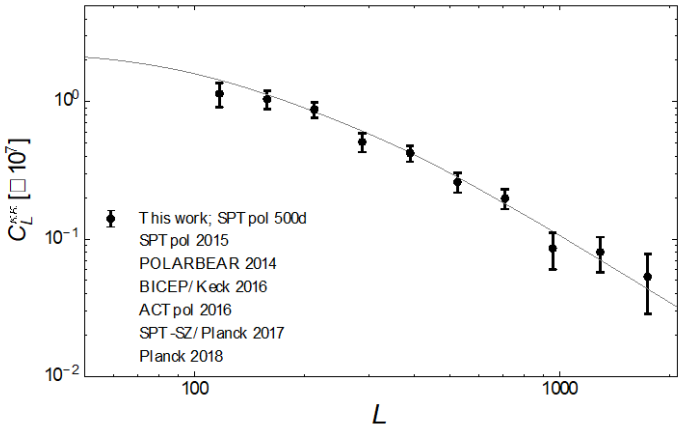
Future: South Pole Observatory (SPO)

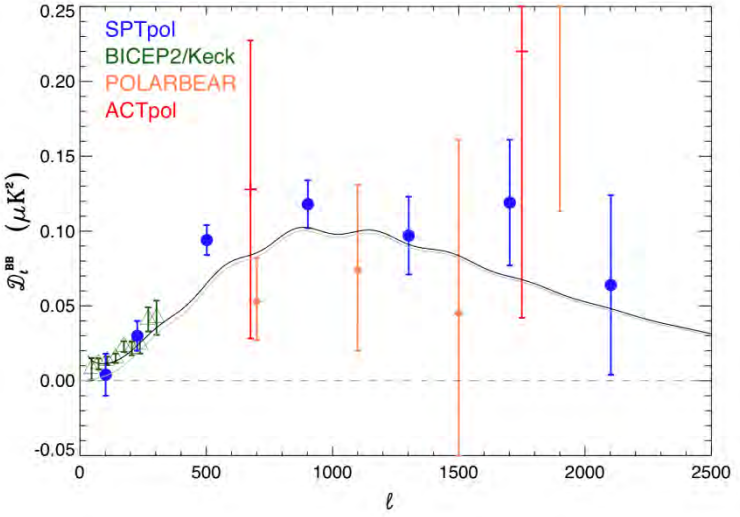
- SPO officially established in October 2019 as an umbrella organization for continuing South Pole CMB experiments into the next decade
- CMB-S4 Program envisions a new large-aperture (~5m) telescope at South Pole

The South Pole Telescope Program

SPT publications span many sub-fields of astronomy and physics

- Temperature and polarization power spectra and cosmological parameters.
- Diffuse kinematic and thermal SZ effect constraints: bispectrum, pairwise kSZ, duration of reionization.
- **CMB lensing: power spectra; cross-correlations; cluster CMB lensing mass calibration.**
- First SZ discovery of galaxy clusters, SZ cluster catalog and cosmology.
- Discovered population of high-redshift lensed dusty star-forming galaxies.
- **First detection of B-mode polarization; B-mode de-lensing; BB power spectrum.**
- Pioneering the new field of mm-wave transient surveys.
- Participating in the Event Horizon Telescope (see next slide).
- and much more…





SPT 2019 Highlight: First EHT Results

- ✓ 2017 observations with 8 telescopes in the EHT network, including the SPT, led to the biggest science story of the year at least!
- ✓ The Breakthrough Prize awarded all 347 EHT collaborators, including 13 SPT team members.
- ✓ First result from the M87 galaxy, but results from the Milky Ways black hole Sgr A* coming soon!

nature

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NEWS · 10 APRIL 2019

Black hole pictured for first time – in spectacular detail

The Event Horizon Telescope's global network of radio dishes has produced the first-ever direct image of a black hole and its event horizon.

Astronomers capture first image of a black hole

National Science Foundation and Event Horizon Telescope contribute to paradigm-shifting observations of the gargantuan black hole at the of distant galaxy Messier 87

"All the News That's Fit to Print"

The New York Times

Late Edition

VOL. CLXVIII ... No. 58,294 NEW YORK, THURSDAY, APRIL 11, 2019 $3.00

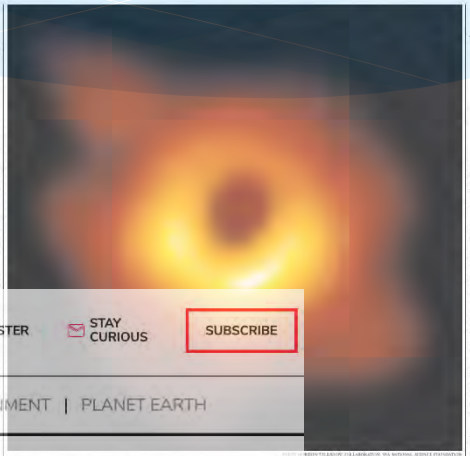
Migrants Pour Into a System That's 'on Fire'

U.S. Border Could Be at a Breaking Point

Israelis Lean On Stability With Leader

Netanyahu Is Symbol of Cherished Security

By DAVID M. HALBFINGER



Scientists captured a view of a black hole at the heart of a galaxy known as Messier 87, some 55 million light-years away from Earth.

Discover

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Story of the Year: Humanity's First Look at a Black Hole

#1 in our top science stories of 2019.

By Korey Haynes | December 31, 2019 4:00 PM

Peering Into Light's Graveyard: The First Image of a Black Hole

Linked Antennas Turn Earth Into Telescope

WINNERS OF THE 2020 BREAKTHROUGH PRIZE IN LIFE SCIENCES, FUNDAMENTAL PHYSICS AND MATHEMATICS ANNOUNCED

A Total of $21.6 Million Awarded for Breakthroughs in Creating the First Image of a Black Hole, Determining the Biological Basis of Obesity, and Discoveries in the Biochemistry of Pain Sensation, Among Other Major Achievements.

2020 Breakthrough Prize in Fundamental Physics Awarded to 347 Members [listed at the bottom of this page] of the Event Horizon Telescope Collaboration.

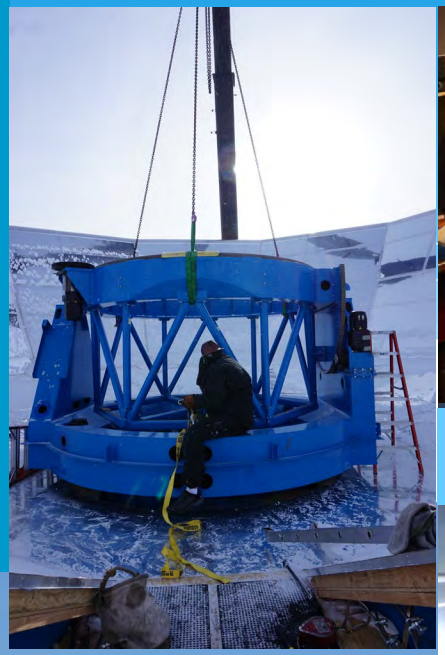
Deep CMB field observations from South Pole

BICEP Array - Hardware upgrade in 2019/2020:

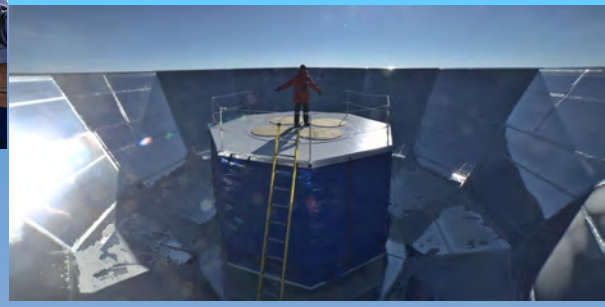
- New mount for FOUR receivers is deployed
- One BICEP receiver (30/40 GHz) is installed.

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

With the SPT-3G delensing effort of the B-mode signal, plans are to reach $\sigma(r)<0.004$ by the of end of 2021, and maybe $\sigma(r) \sim 0.002$ by 2023



BICEP Team (above) and New Mount (left and below). Photos: Nathan Precup



South Pole Telescope (SPT-3g: 16,000 detectors)

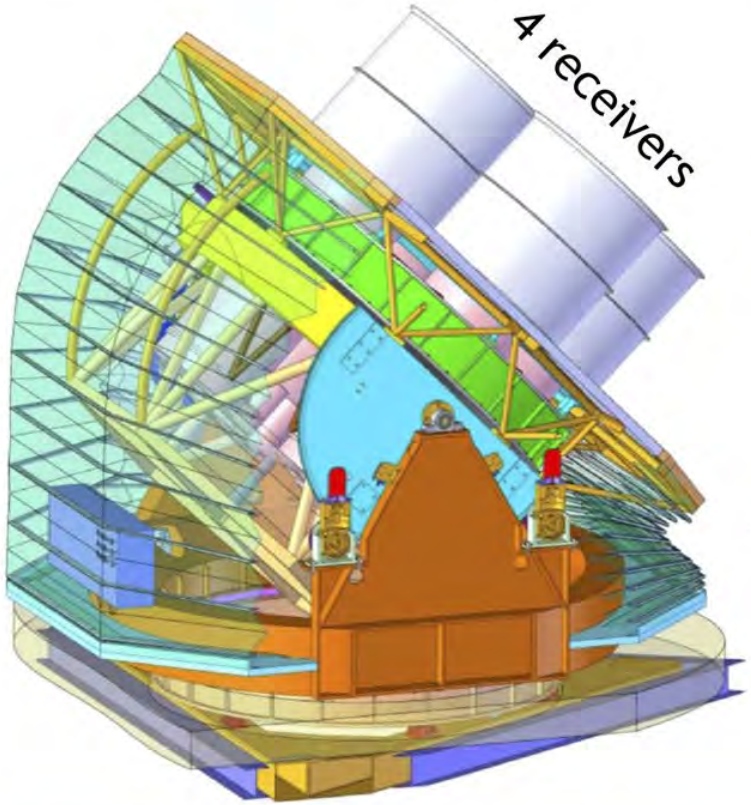
BICEP3, 500 detectors

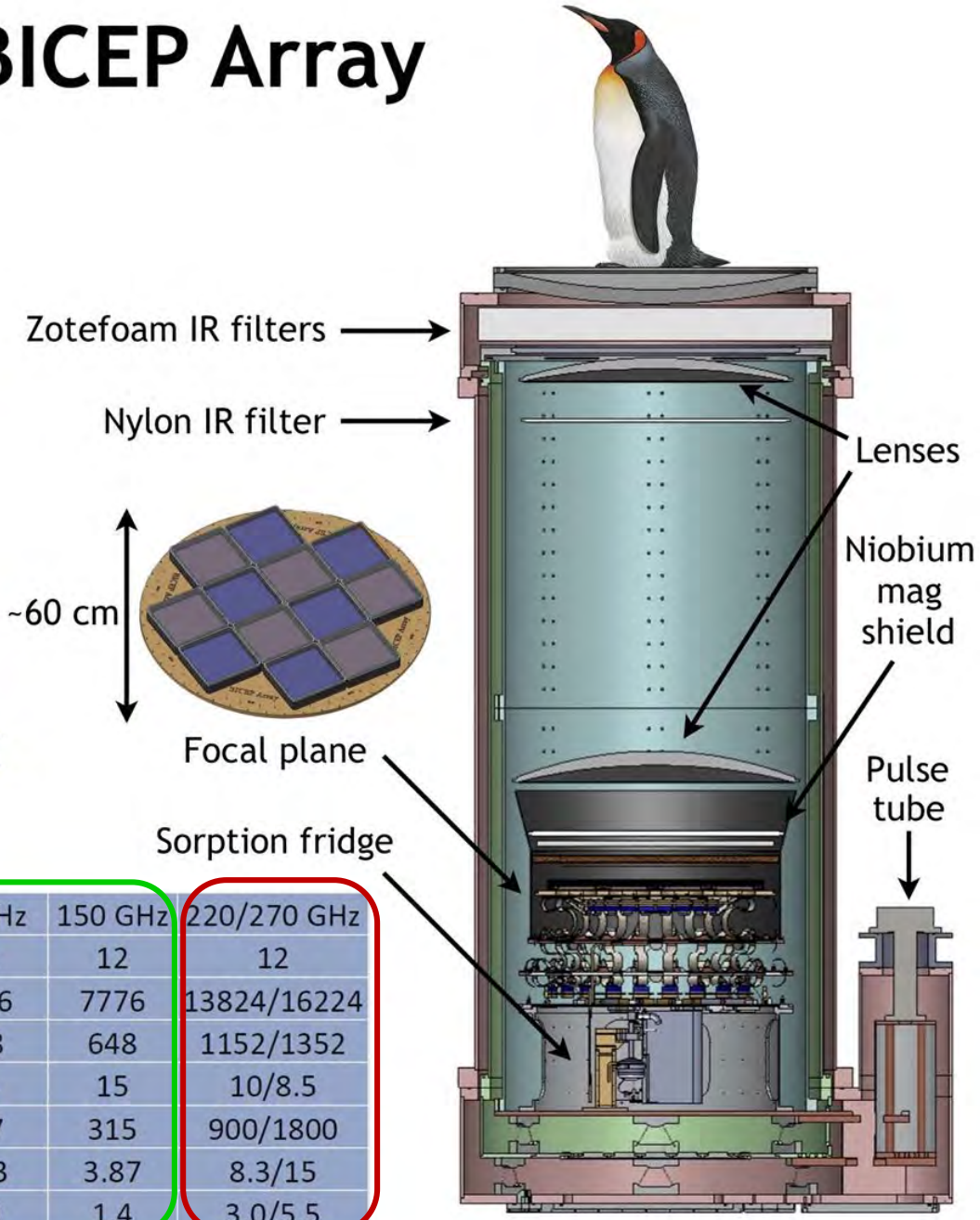
BICEP Array: in 2020 – one BA receiver, 30/40 GHz, ~500 detectors, and three old Keck receivers, 500 detectors each.

Thus, total 2,000 detectors on 2020
All four BA receivers in 2021

Total # of bolometers for Deep Field:
BICEP3 receiver: 2,500 bolometers
BICEP Array in 2021: ~30,000 bolometers

2019 onwards: BICEP Array





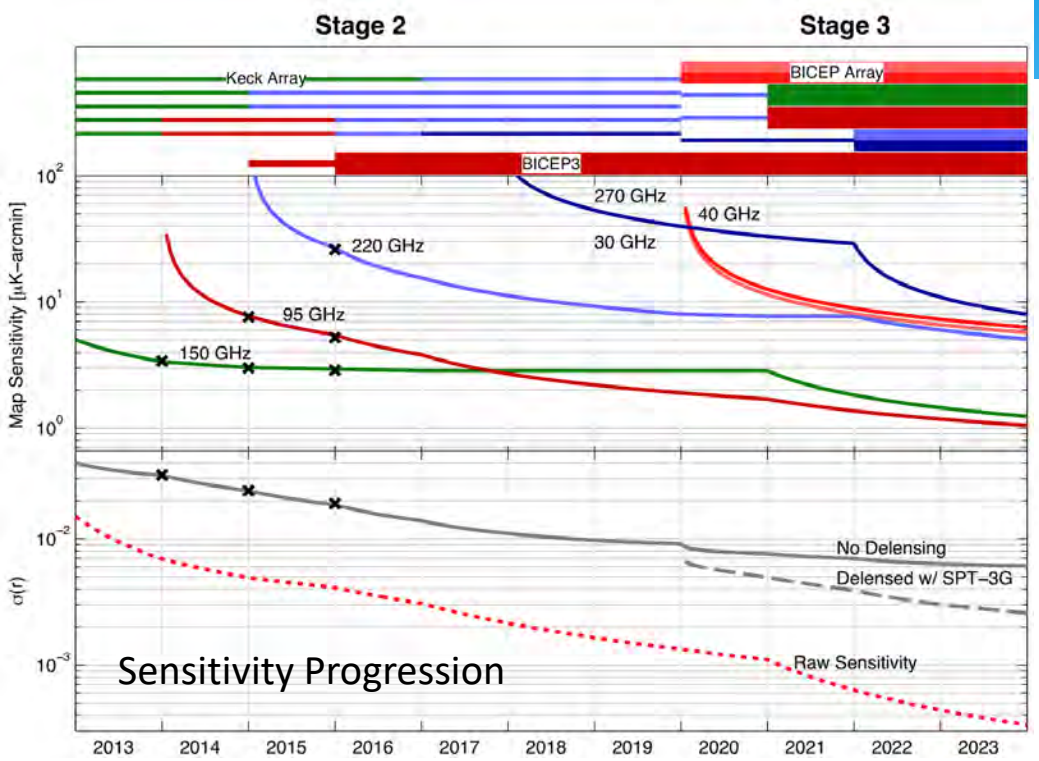
Frequency	30/40 GHz	95 GHz	150 GHz	220/270 GHz
Tiles	12	12	12	12
# Detectors	192/300	3456	7776	13824/16224
# Det/ Tile	32/50	288	648	1152/1352
Beam FWHM (arcmin)	76/57	24	15	10/8.5
NET per det (uK-rts)	268/334	267	315	900/1800
Instr. NET (uK-rts)	21/21	4.93	3.87	8.3/15
3-yr map depth (uK-arcmin)	7.5/7.5	1.9	1.4	3.0/5.5

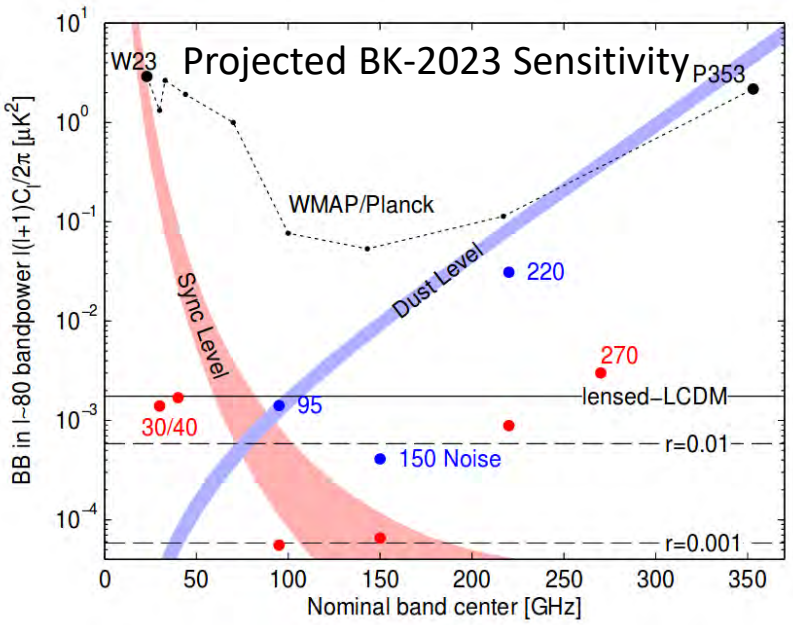
TDM-SQUID

RF-Multiplexed

BICEP program: CMB/B-modes & progress on σ(*r*)

http://bicepkeck.org





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
2016/18 BICEP/Keck + SPTpol delensing	σ(*r*) = 0.010	Two papers coming in 2020
2019/23 BICEP Array+SPT-3g delensing	σ(*r*) ~ 0.003	Forecast

Raw sensitivity of this experiment to primordial B-modes (i.e., with no foregrounds or lensing) is close to σ(r) ~ 0.002

It is all about components separation!

Mid-Scale Research Infrastructure Award 1935892

Title: Mid-scale RI-1 (M1:DP): Consortium Proposal for CMB-S4 Design Development

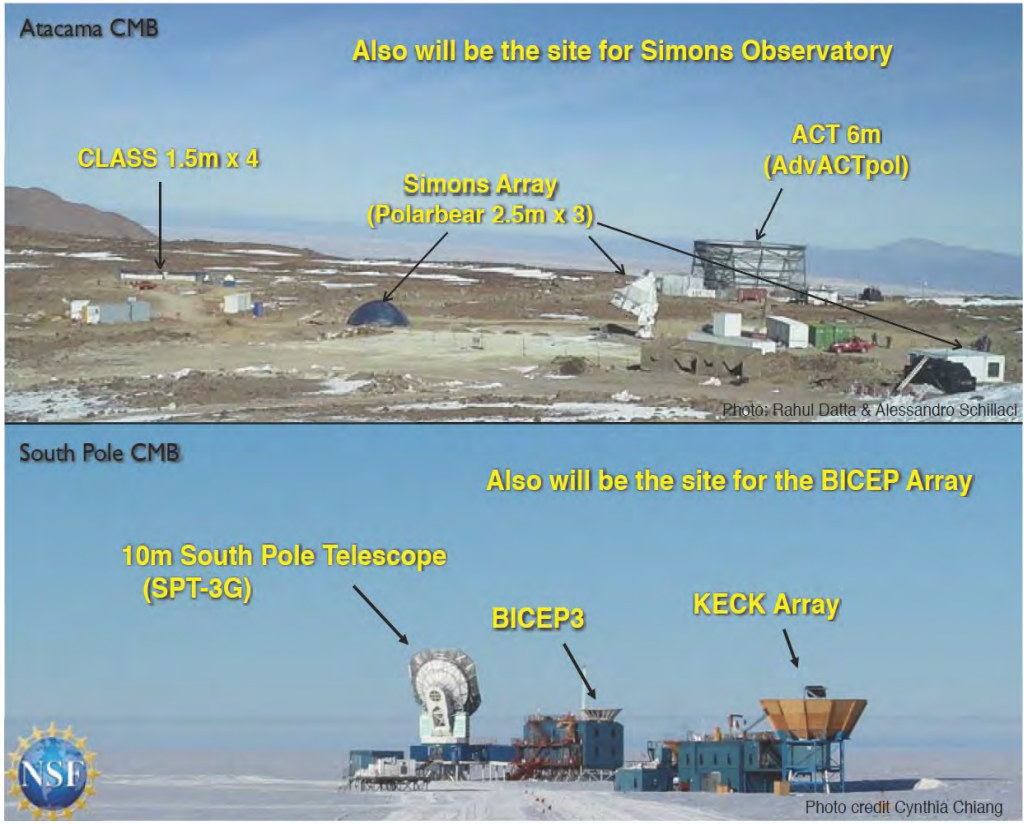
~$4M funded in October 2019 for 24 months (https://www.nsf.gov/awardsearch/)

PIs: John Carlstrom (U. Chicago), Julian Borrill (U. California–Berkeley), Jim Yeck (U. Wisconsin)

Main Objectives: Support an Interim Project Office (IPO) tasked with developing the CMB-S4 project through the Preliminary Design Phase. CMB-S4 aims to become a joint NSF/MREFC and DOE/MIE project.

Primary Research Infrastructure: Complex mm-wave telescopes equipped with state-of-the-art cryogenic superconducting detectors that will be deployed to the NSF's Amundsen-Scott Station at South Pole and to the high Atacama Plateau in Chile.

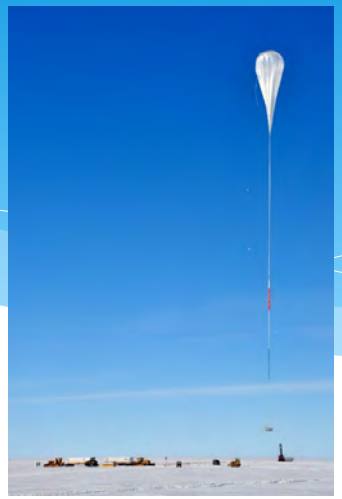
Intellectual Merit: CMB-S4 is the definitive ground-based project with enormous increase in sensitivity that will allow crossing critical thresholds to test Inflation, determine the number and masses of neutrinos, constrain possible new light relic particles, provide precise constraints on the nature of Dark Energy, and test general relativity on large scales.

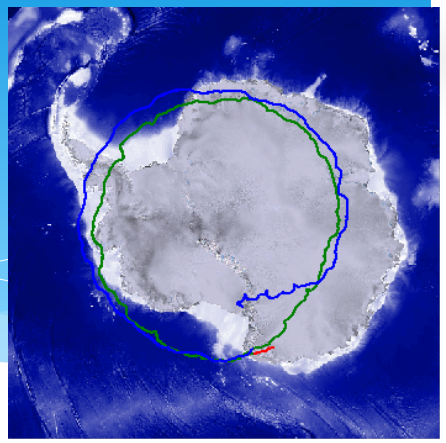


http://cmb-s4.org

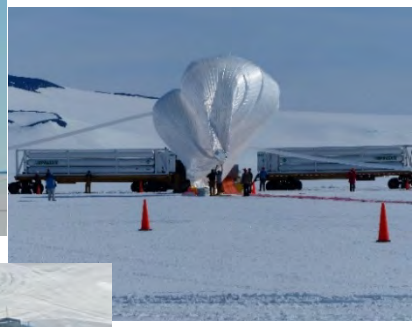
NASA Long-Duration Balloons Program
McMurdo, Antarctica

- 1988 – First MoA was signed between NASA and NSF, planning to launch **one (1) LDB payload every other year** beginning January 1990
- 30 years later - **total 57 LDB and SPB payloads** have been flown from McMurdo - in average TWO payloads per year!
- Over last 5 years, planning to launch 2-3 payloads per austral summer created logistical backlogs that significantly affected the overall USAP capabilities to support the Program.
- For example, the X-CALIBUR payload was launched in December 2018 – and retrieved from the Antarctic Plateau only in January 2020.
- During 2019-2020 austral summer, only two payloads were launched – SuperTIGER (two circumnavigations; 32 days; landed ~450 miles from McMurdo) and BLAST-TNG (the latter was terminated in ~24 hours; landed ~200 miles away).
- The longest LDB flight in Antarctica was with the CREAM payload in 2008/2009 - 52 days!





SuperTIGER flight
2019/2020 32 days



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

Antarctic Astrophysics – Budget Update

The OPP current annual science funding (excluding logistical support) for Antarctic Astrophysics is ~$9.0M, where ~$5M go to neutrino astrophysics; ~$4M go to astronomy & CMB-related projects.

The OPP co-funds almost all Antarctic astrophysical research projects together with MPS/PHY & AST science programs!

IceCube M&O and related projects (IceCube science, ARA, ARIANNA, etc.) are co-funded by OPP and PHY (50:50) since the IceCube MREFC project was completed at South Pole. The ICNO/Upgrade was funded by PHY/Mid-scale; OPP – logistics.

Thus, the combined annual spending for **Antarctic neutrino astrophysics** currently reached $10.5M. **In 2004-2019, OPP and PHY spent jointly ~$132M.**

Antarctic astronomy & CMB research are mostly funded by OPP. Since 2004, AST (PHY since 2012) helped to co-fund 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** currently reached $5.3M. **In 2004-2019, OPP, AST, and PHY spent jointly ~$105M.**

Thank you for your attention!

Questions?