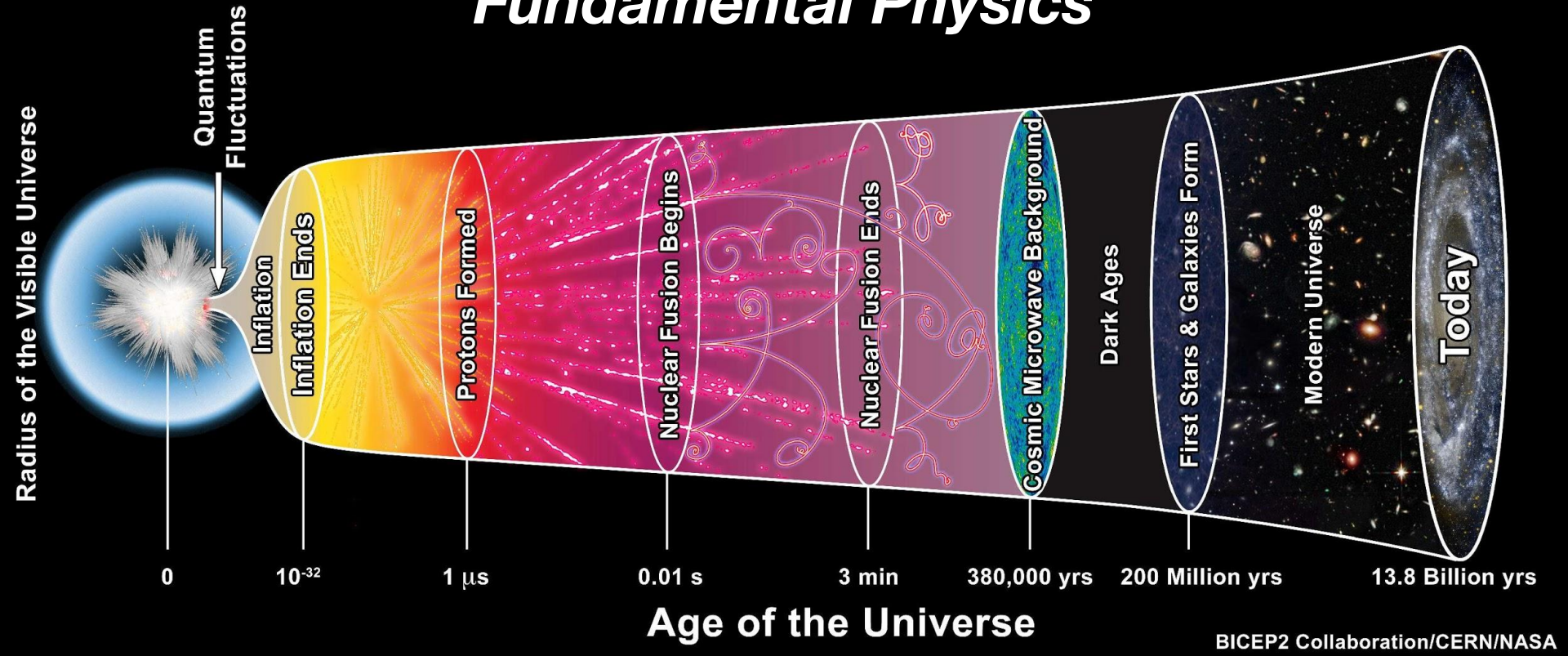
The CMB Probes Cosmology and Fundamental Physics



Inflation

- Rule out and test simplest models of Inflation
- Measure the ***Energy-scale of Inflation (~10^{16} GeV)***

Neutrinos

- Detect or rule out the production of any new ***light relic particle species***
- Measure structure growth to detect the ***sum of the neutrino masses***

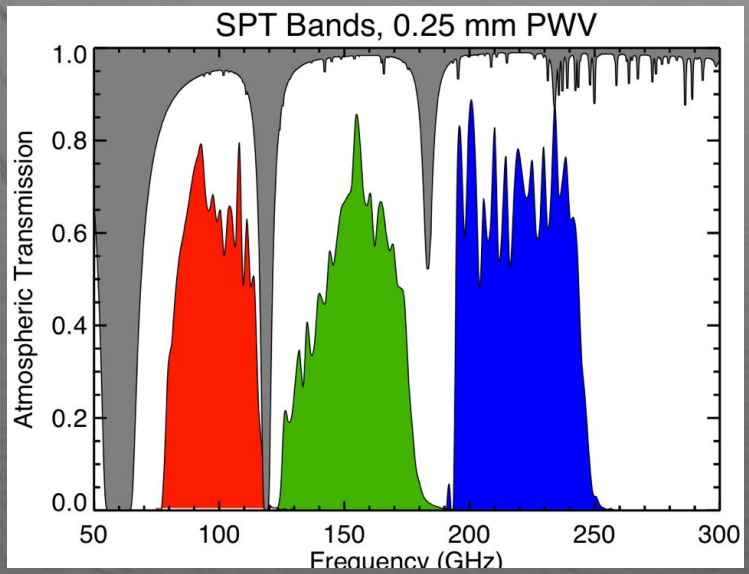
Dark Energy

- Use CMB as back-light to measure evolution of structure via lensing and Sunyaev-Zel'dovich effect
- ***Tests of gravity and the nature of dark energy***

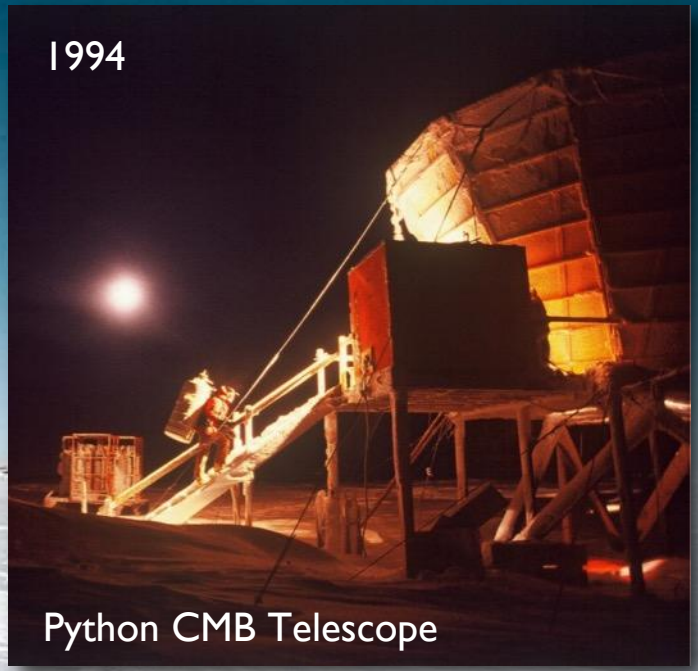
The South Pole is the Best Place in the World to Observe the CMB

South Pole Environment

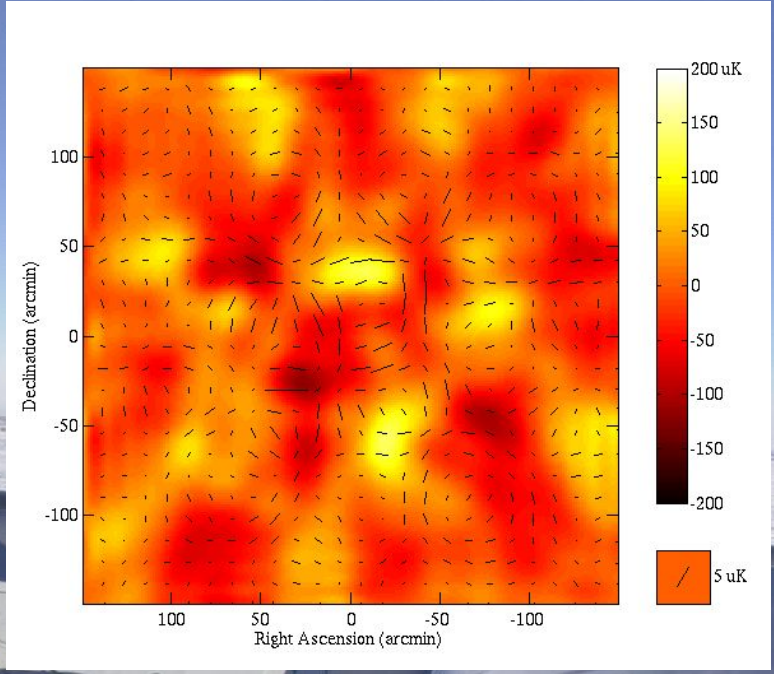
- **High Altitude (~10,000 ft)**
- **Extremely Dry**
  - Precipitable water vapor in winter is ~4x less than Chile, ~6x less than Hawaii
- **Stable Atmosphere**
  - During 6-month night, the sky is ~30-100x more stable than in Chile



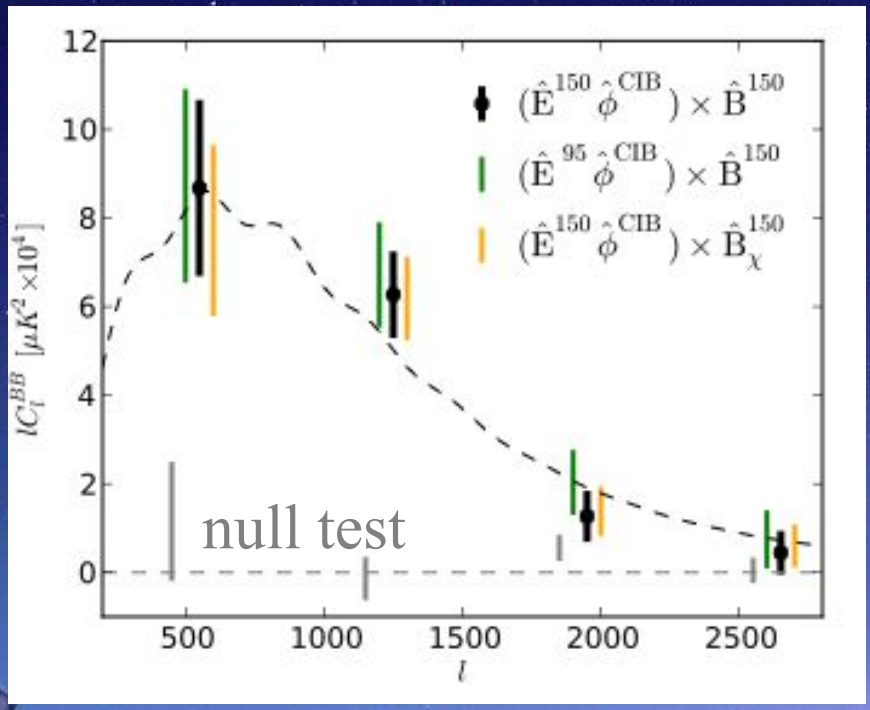
South Pole CMB efforts started in 1980's



CMB polarization first detected in 2002, at South Pole

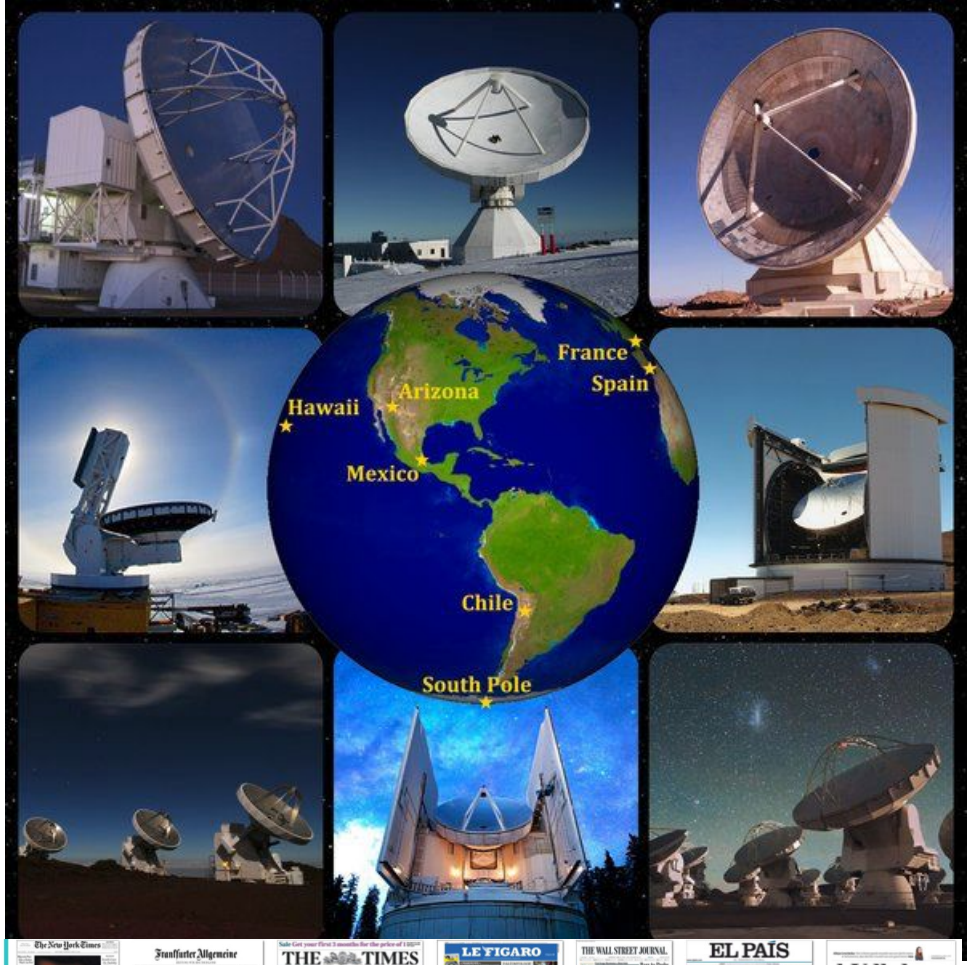


CMB B-mode Polarization first detected in 2013, at South Pole



SPT participation in Event Horizon Telescope

France Cordova
NSF Director



CMB Lessons Learned

Experience has taught us how to build and operate experiments at the South Pole:

- BICEP lineage of experiments (BICEP1, BICEP2, KECK, BICEP3, BICEP-Array) have operated continuously for past 14 winter seasons (2006-current)
- South Pole Telescope (SPT-SZ, SPTpol, SPT-3G) has operated continuously for past 13 winter seasons (2007-current)
- Made possible by logistical support for infrastructure and construction at South Pole Station!


Early Nov 2006
Dark Sector Lab
(Before South Pole Telescope)

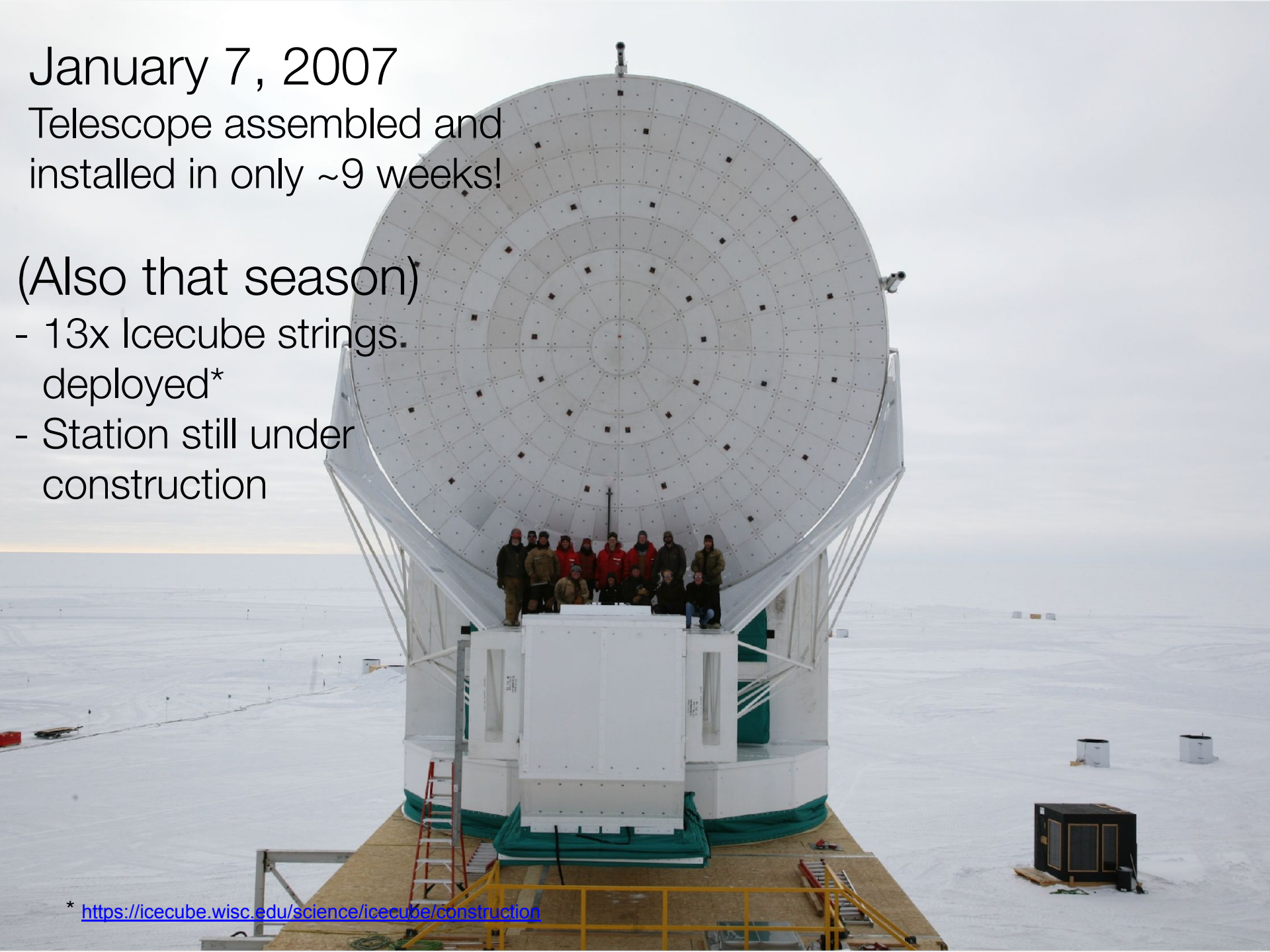

Nov. 22 2006
Assembling SPT primary mirror
backing structure


Early Dec. 2006
Aligning SPT mirror panels
under a wind tent


Jan. 4 2007
MANTIS
Installing SPT primary mirror on
telescope mount

January 7, 2007

Telescope assembled and installed in only ~9 weeks!



January 7, 2007

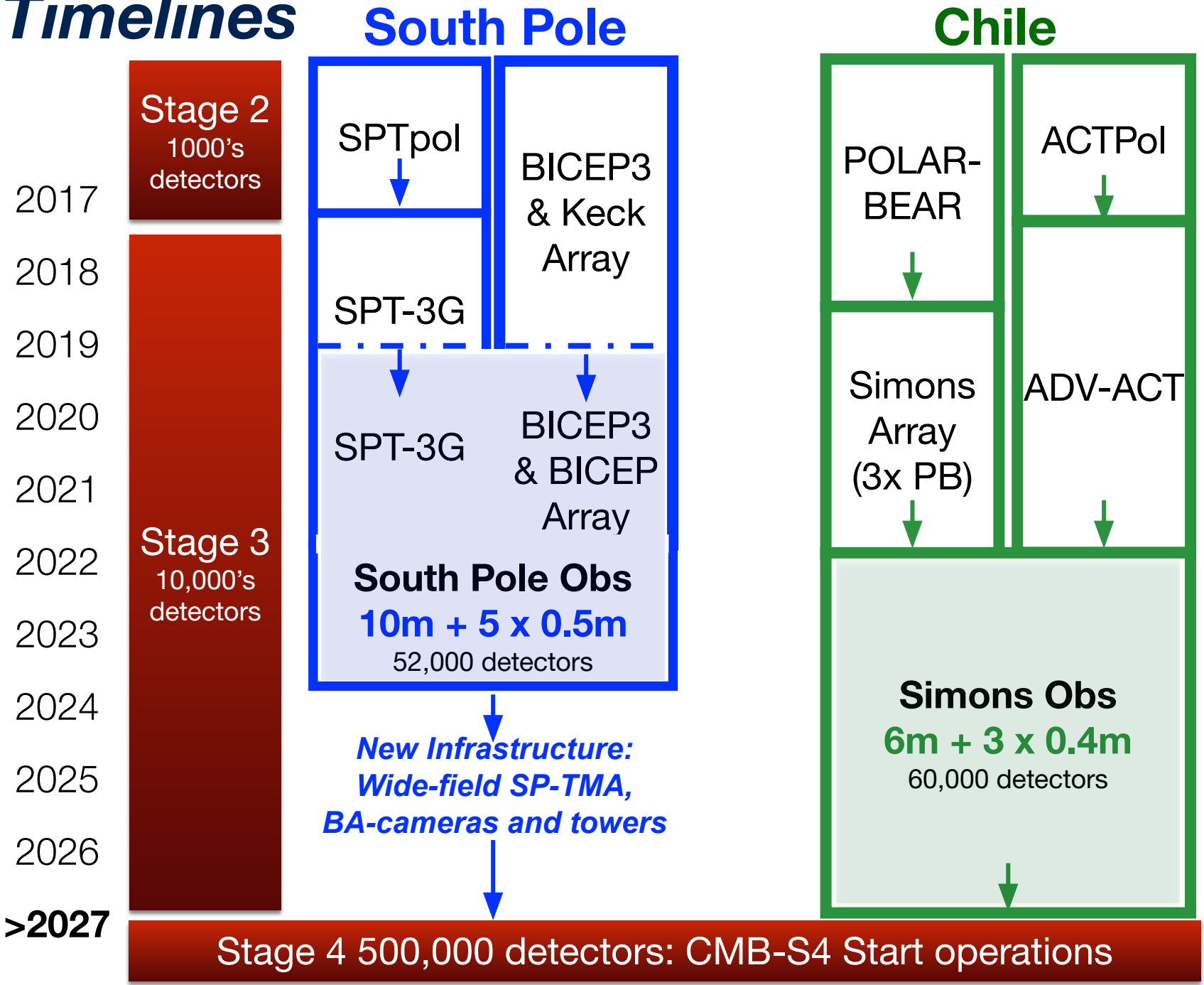
Telescope assembled and installed in only ~9 weeks!

(Also that season)

- 13x Icecube strings deployed*
- Station still under construction

* https://icecube.wisc.edu/science/icecube/construction

Timelines

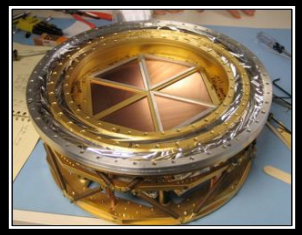

South Pole
Chile
Stage 2
1000's
detectors
Stage 3
10,000's
detectors
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
>2027
SPTpol
BICEP3
& Keck
Array
SPT-3G
SPT-3G
BICEP3
& BICEP
Array
South Pole Obs
10m + 5 x 0.5m
52,000 detectors
New Infrastructure:
Wide-field SP-TMA,
BA-cameras and towers
POLAR-
BEAR
ACTPol
Simons
Array
(3x PB)
ADV-ACT
Simons Obs
6m + 3 x 0.4m
60,000 detectors
Stage 4 500,000 detectors: CMB-S4 Start operations

The South Pole Telescope (SPT)

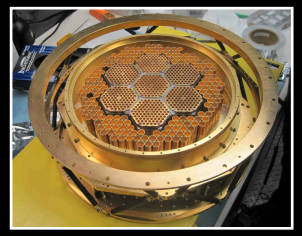
10-meter sub-mm quality wavelength telescope

100, **150**, **220** GHz and
1.6, **1.2**, **1.0** arcmin resolution

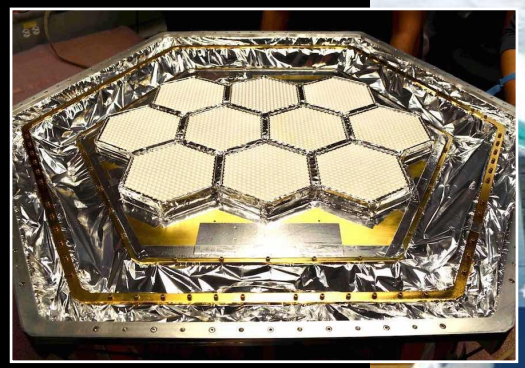
2007: SPT-SZ
960 detectors
100,150,220 GHz

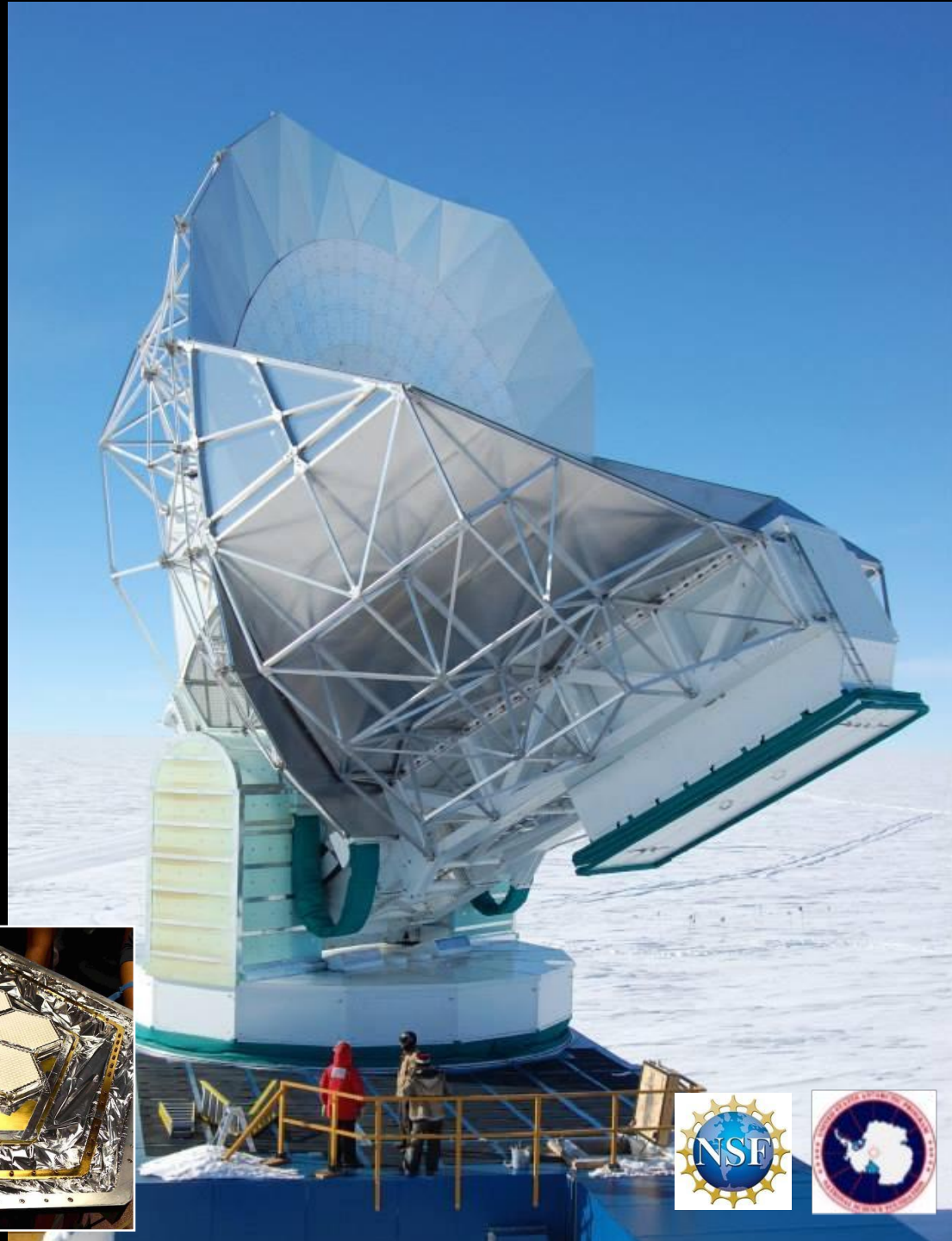


2012: SPTpol
1600 detectors
100,150 GHz
+Polarization

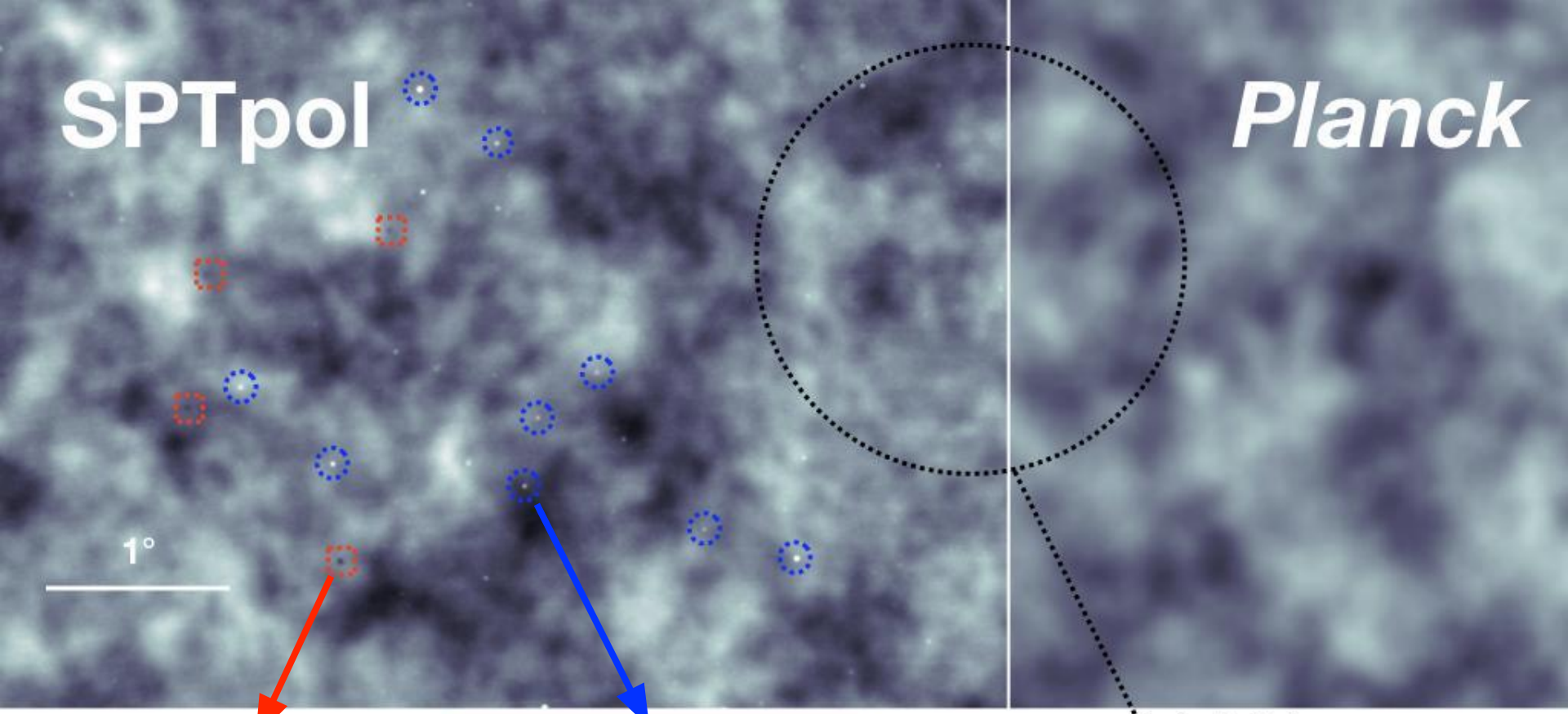


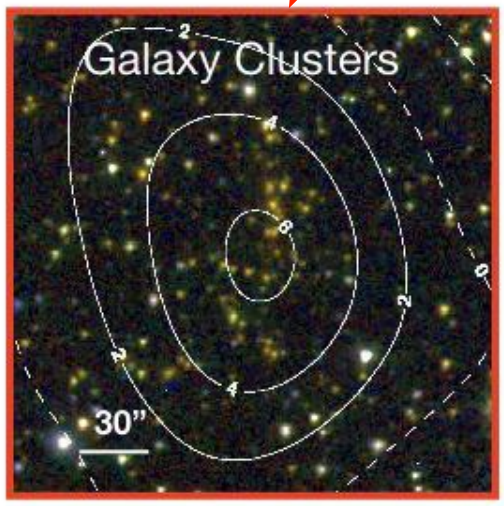
2017: SPT-3G
~16,200 detectors
100,150,220 GHz
+Polarization

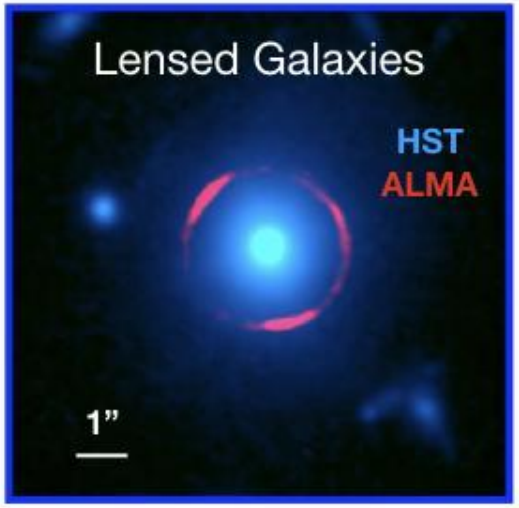


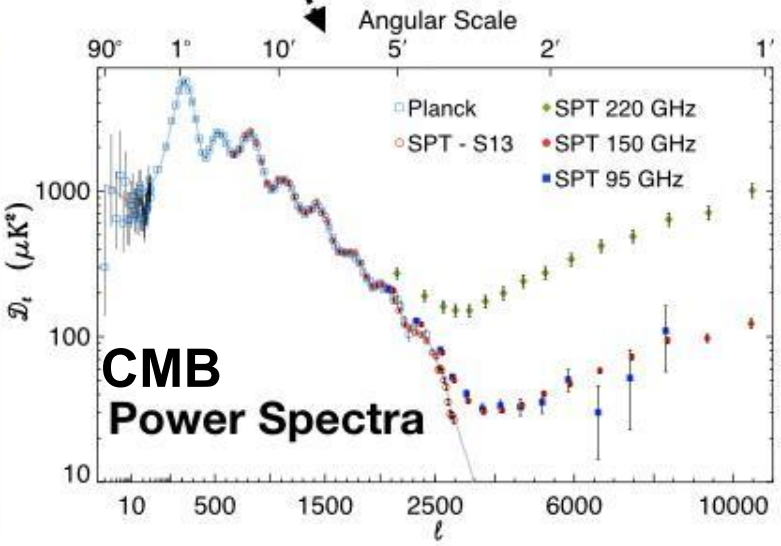



The SPT-3G Collaboration (July 2018)
~70 scientists (~half postdocs and students)
across ~20 institutions
Argonne NATIONAL LABORATORY
BERKELEY LAB
NIST
Fermilab
KICP
Kavli Institute
for Cosmological Physics
AT THE UNIVERSITY OF CHICAGO
Berkeley
University of California
Case
CASE WESTERN
RESERVE UNIVERSITY
McGill
Colorado
University of Colorado at Boulder
CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD
UCDAVIS
UNIVERSITY OF CALIFORNIA
THE UNIVERSITY OF
CHICAGO
LMU
LUDWIG-
MAXIMILIANS-
UNIVERSITÄT
MÜNCHEN
Harvard-Smithsonian
Center for Astrophysics
SLAC
NSF


SPTpol
Planck
1°

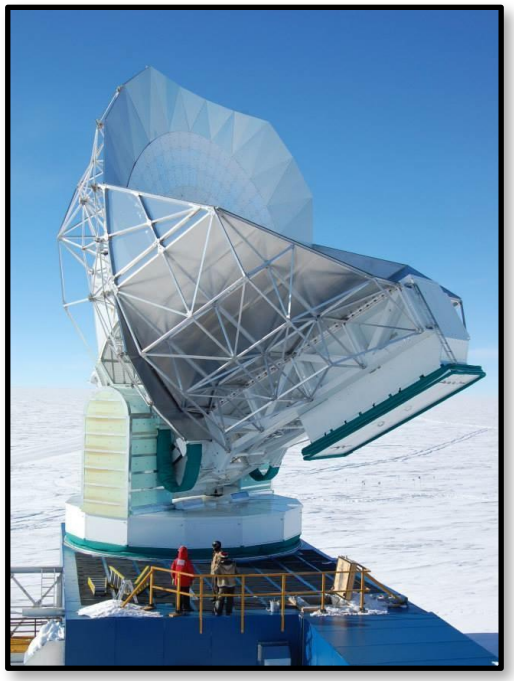

Galaxy Clusters
30"


Lensed Galaxies
HST
ALMA
1"

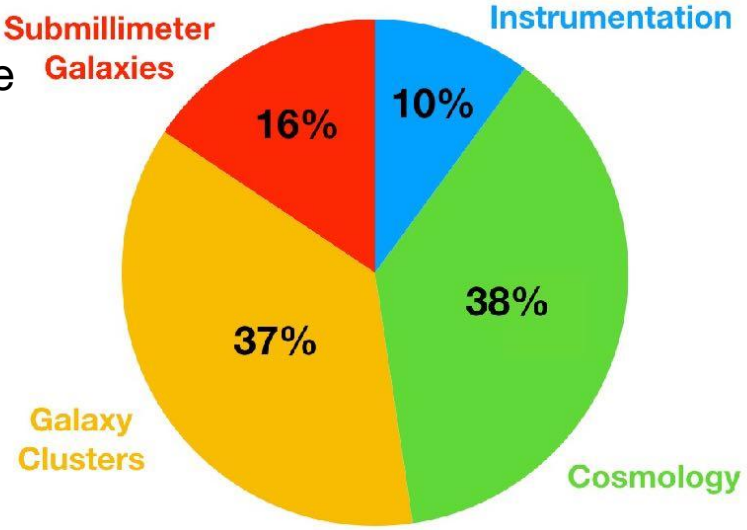

Angular Scale
90°
1°
10′
5′
2′
1′
Planck
SPT - S13
SPT 220 GHz
SPT 150 GHz
SPT 95 GHz
1000
100
10
$\mathcal{D}_\ell$ (μK^2)
CMB
Power Spectra
10
500
1500
2500
6000
10000
ℓ

Breadth of SPT results

>200 science or technical publications* and ~10,000 citations

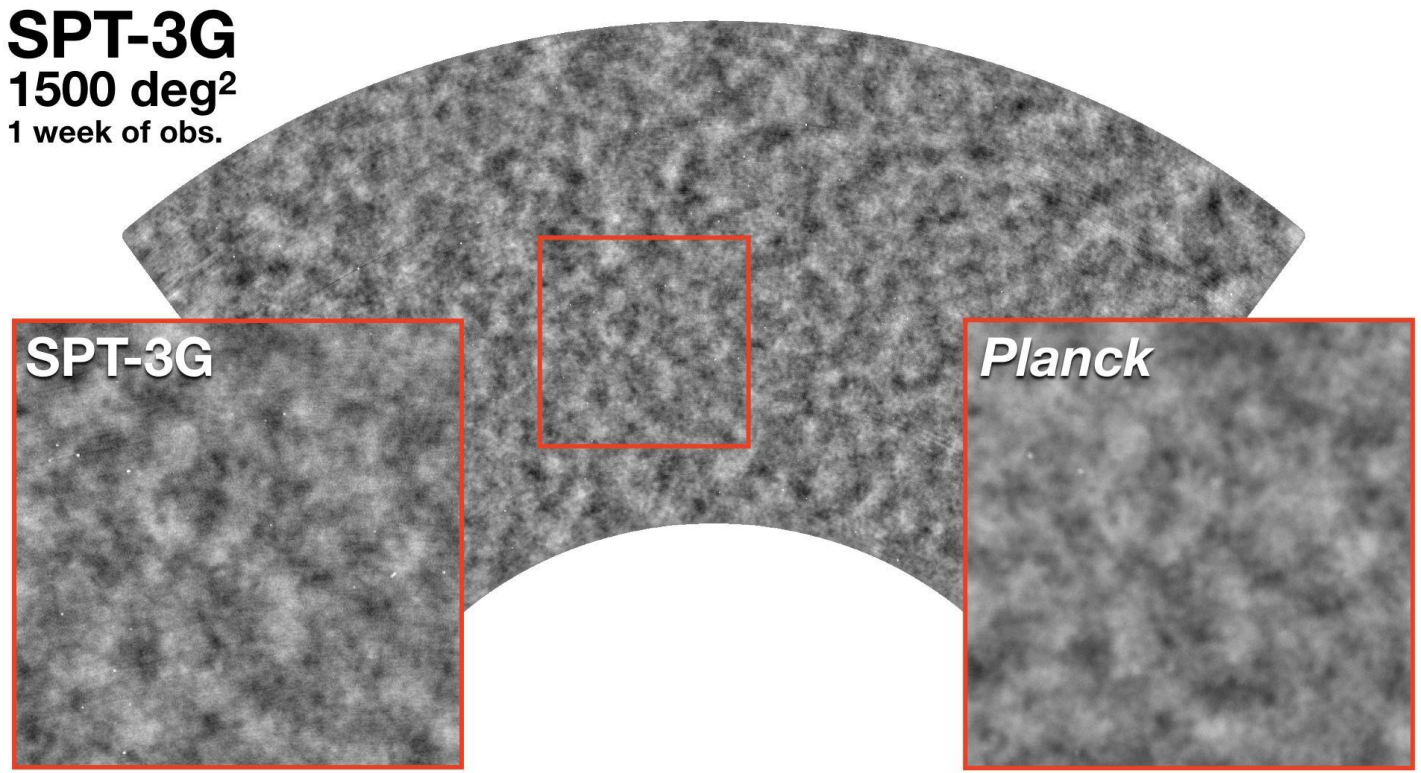


- **CMB anisotropy:** Power spectra and cosmological parameters
- **CMB B-Modes:** First detection of lensing B-mode polarization; demonstrating of de-lensing
- **CMB lensing**: power spectra; cross-correlations; cluster-lensing mass calibration
- **Sunyaev-Zeldovich (SZ):** Diffuse kinematic and thermal SZ effect constraints: bi-spectrum, pairwise kSZ, patchy reionization
- **Galaxy Clusters:** First SZ discovery clusters, SZ cluster catalog and cosmology
- **High-Redshift Galaxies**: Discovered population of lensed dusty star forming galaxies
- Participating in the **Event Horizon Telescope**
- much more…



*For publications see pole.uchicago.edu

SPT-3G Observing Plans (Now - 2023)



- During 2019 season, SPT-3G was operating at full projected sensitivity
  - Over 1500 deg^2 survey field, get to better than Planck satellite sensitivity with < 1-week of data
- Through 2023 winter season:
  - Continue 1500 deg^2 survey (will be >10x deeper than SPT-SZ survey)
  - Continue participation in EHT observations

Stage 2

Stage 3

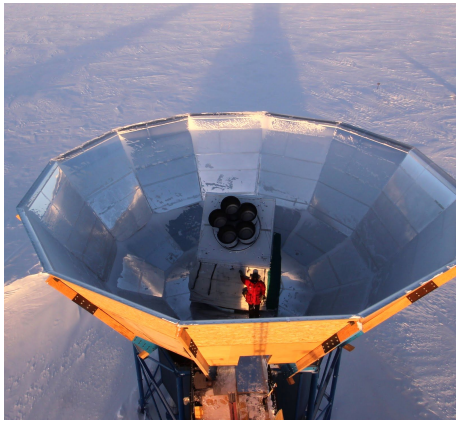
BICEP2
(2010-2012)

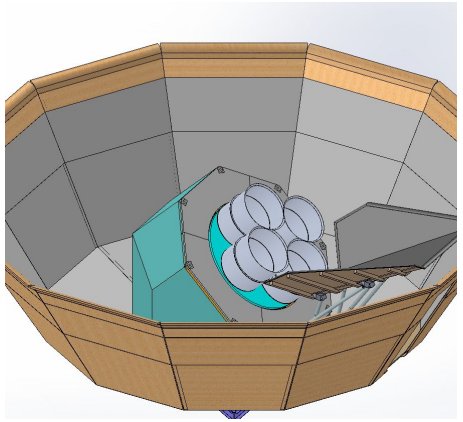
Keck Array
(2012-2019)

BICEP3
(2015-)

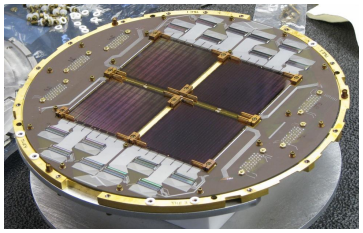
BICEP Array
(2020-)

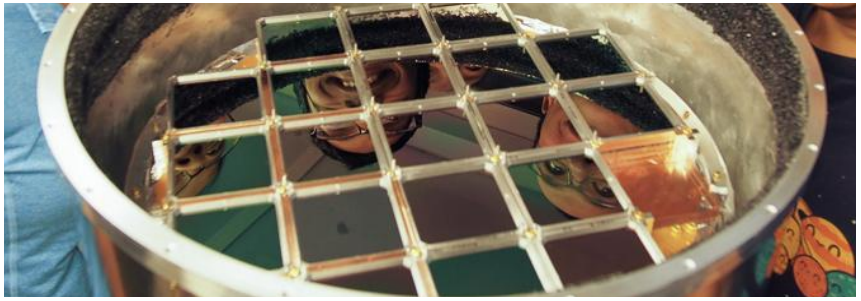
Telescope and Mount



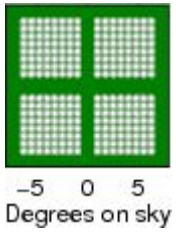


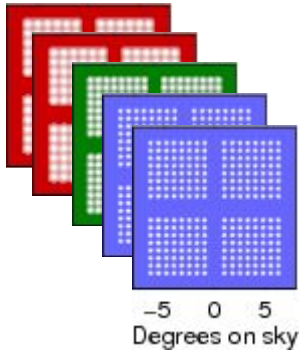
Focal Plane

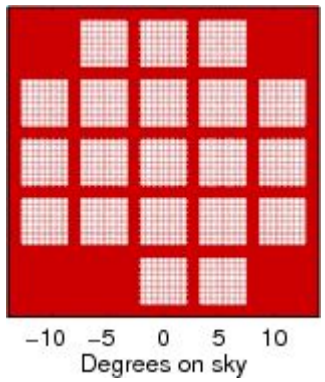


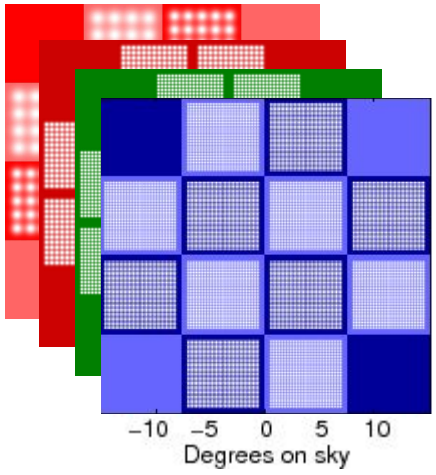


Beams on Sky

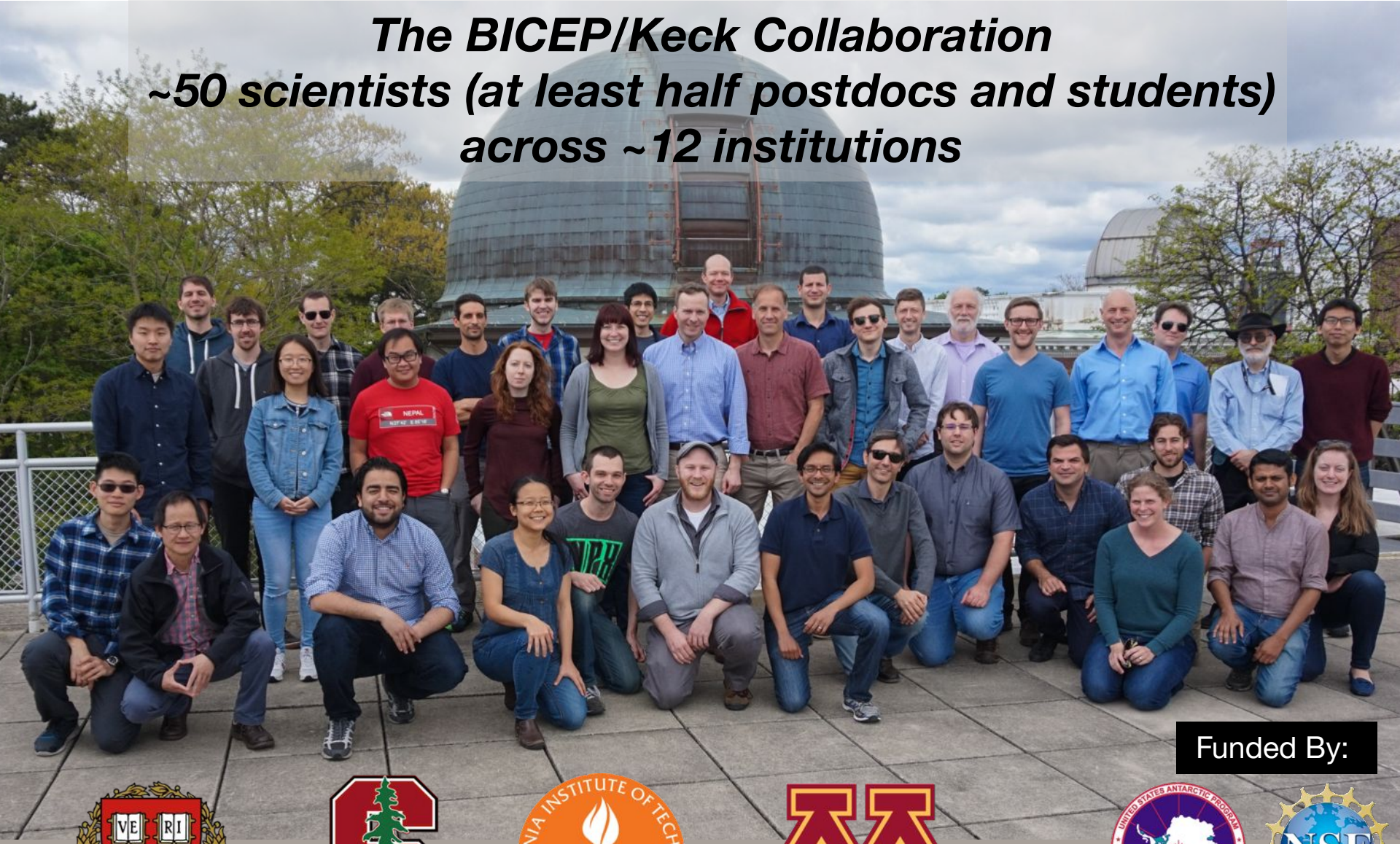








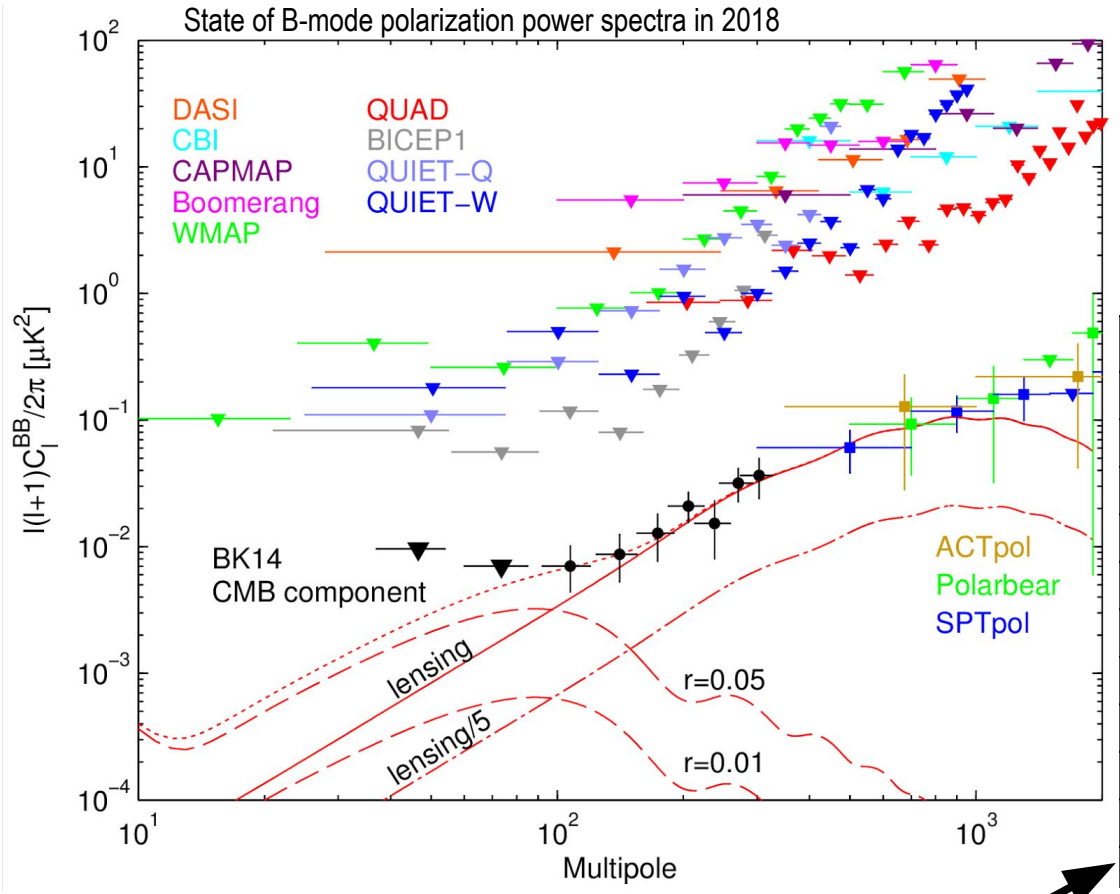
The BICEP/Keck Collaboration
~50 scientists (at least half postdocs and students) across ~12 institutions

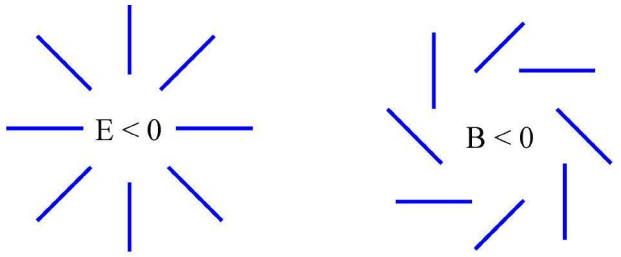


Funded By:

BICEP-Keck Constraints on Inflation to Date

r = tensor to scalar ratio, i.e. amplitude of inflationary gravitational-wave background



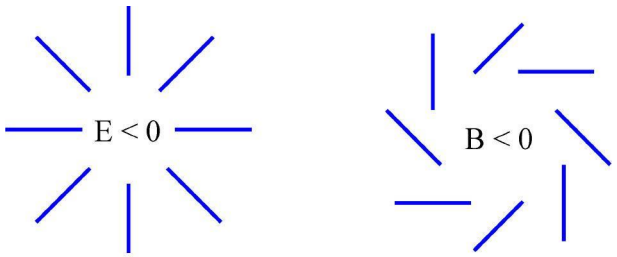


Published B-Mode Sensitivity to r				
Experiment	**Year**	**Bands [GHz]**	**σ(r)**	
DASI	2004	26…36	7.5	
BICEP1 2yr	2009	100, 150	0.28	
WMAP 7yr	2010	30…60	1.1	
QUIET-Q	2010	43	0.97	
QUIET-W	2012	95	0.85	
BICEP1 3yr	2013	100, 150	0.25	
BICEP2	2014	150	0.10	
BK + Planck	2015	150 + Planck	0.034	
BK14	2015	95, 150 + P	0.024	Pole
ABS	2018	150	0.7	Chile
Planck	2018	30...353	~0.2	
BK15	2018	95,150,220 + P	0.020	
BK17	2019?	95,150,220 + P	0.010 (est)	

South Pole has 30x tighter constraints than best ground-based result from Chile!

BICEP-Keck Constraints on Inflation to Date

r = tensor to scalar ratio, i.e. amplitude of inflationary gravitational-wave background



BICEP-Keck (Pole) has 30x tighter constraints than best ground-based result from Chile!

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BK15	2018	95,150,220 + P	0.020
BK17	2019?	95,150,220 + P	0.010 (est)

BICEP-Array Deployment in Summer 19-20

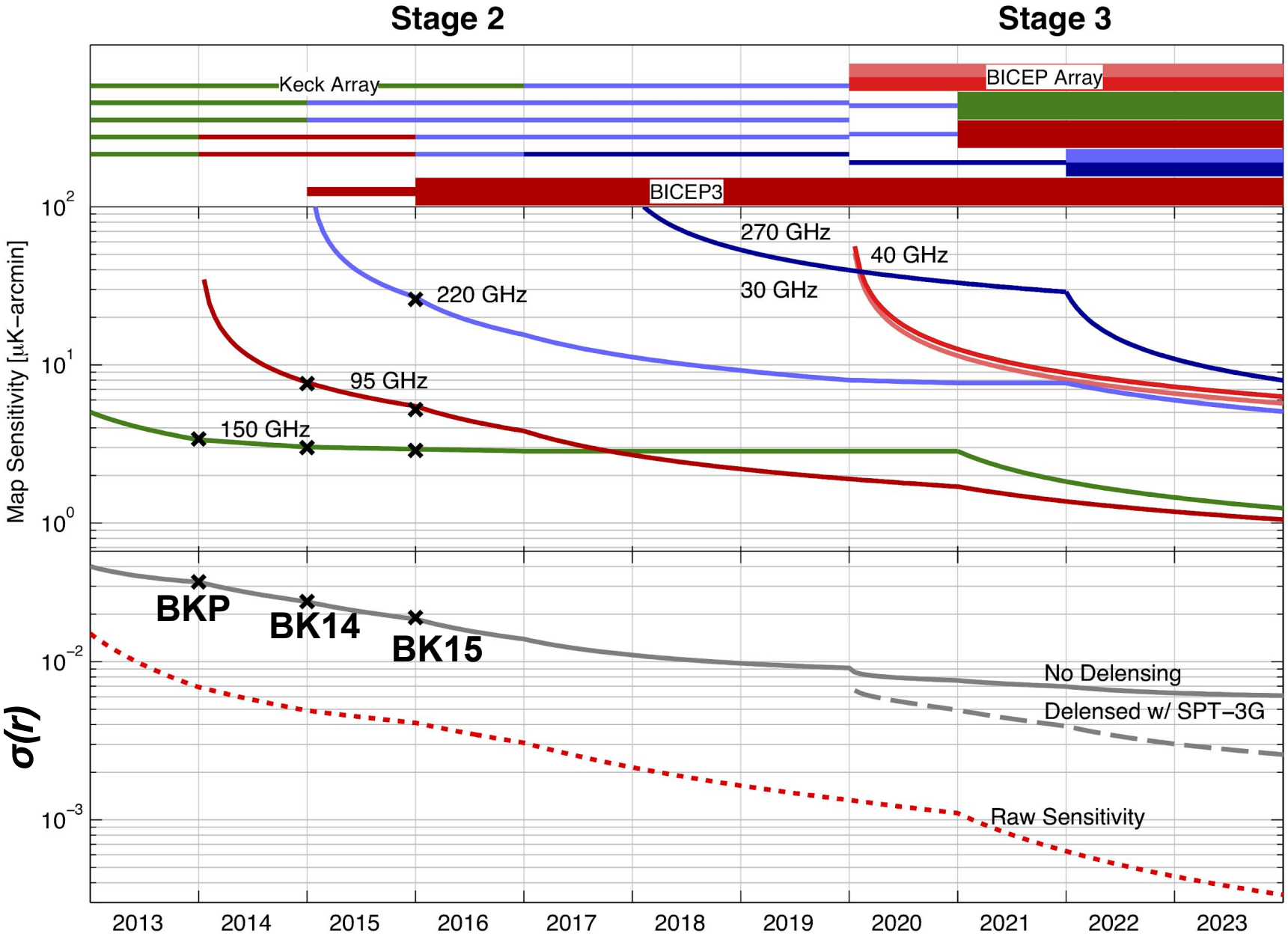
Nov 2019:
Lifting new telescope mount onto DASI tower

Dec 2019:
New BA receiver

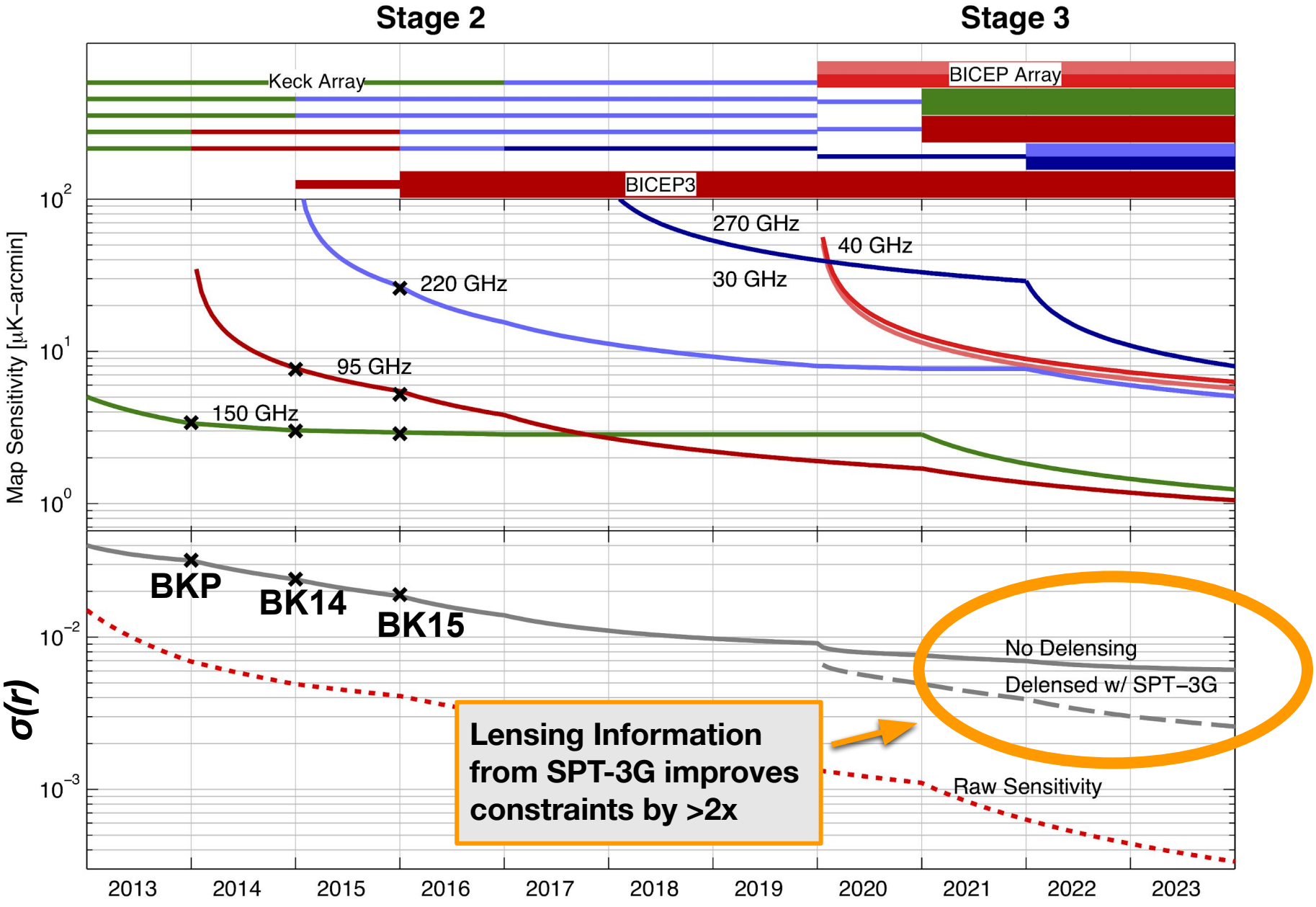
Dec 2019:
Installing new telescope mount

Jan 2019:
Successful BA deployment!

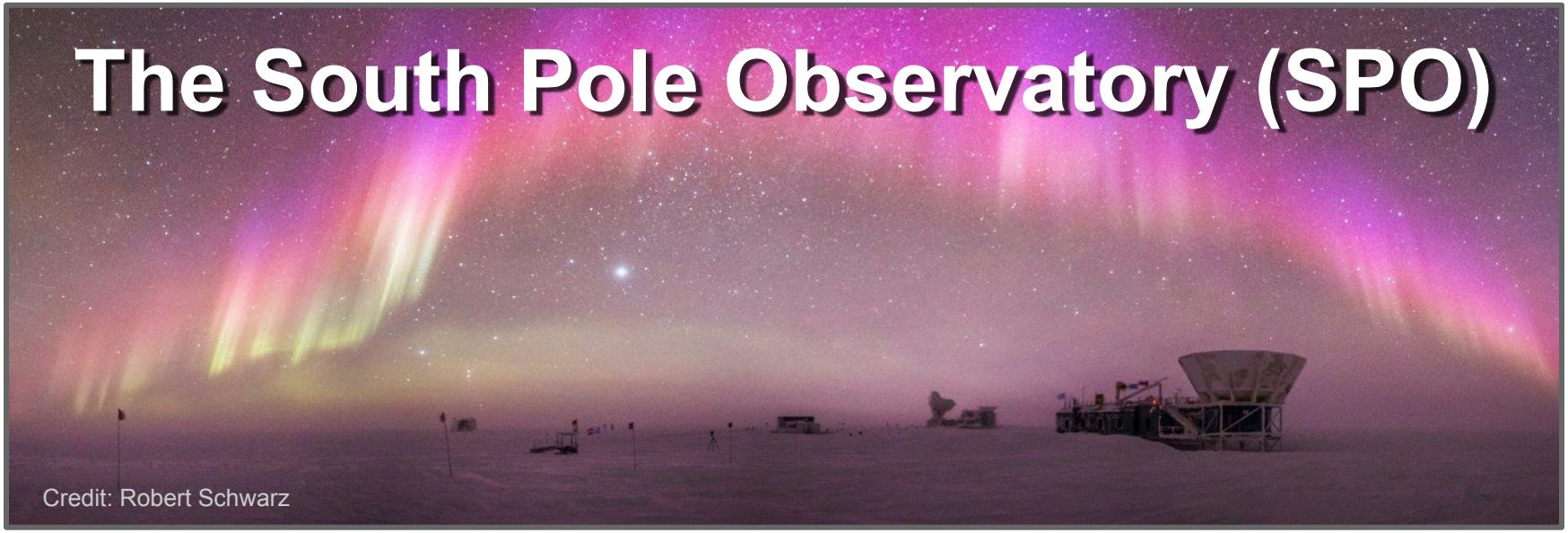
BICEP/Keck-SPT-3G Projected Inflation Constraints



BICEP/Keck-SPT-3G Projected Inflation Constraints



The South Pole Observatory (SPO)



- SPO is a new entity to guide the development of the combined South Pole CMB program for producing the highest science return
- SPO builds on existing collaboration between the BICEP/Keck and SPT programs, increasing coordination of their Stage 3 activities.
- SPO serves as an umbrella organization, coordinating ongoing projects and leading new initiatives for infrastructure and science.
- SPO and the SPT and BICEP/Keck South Pole CMB projects are committed to support CMB-S4 by freely sharing the data and lessons learned from ongoing and new Stage 3 observations needed for S4's design, and by continuing to develop the infrastructure and methods CMB-S4 will need.

What is SPO?

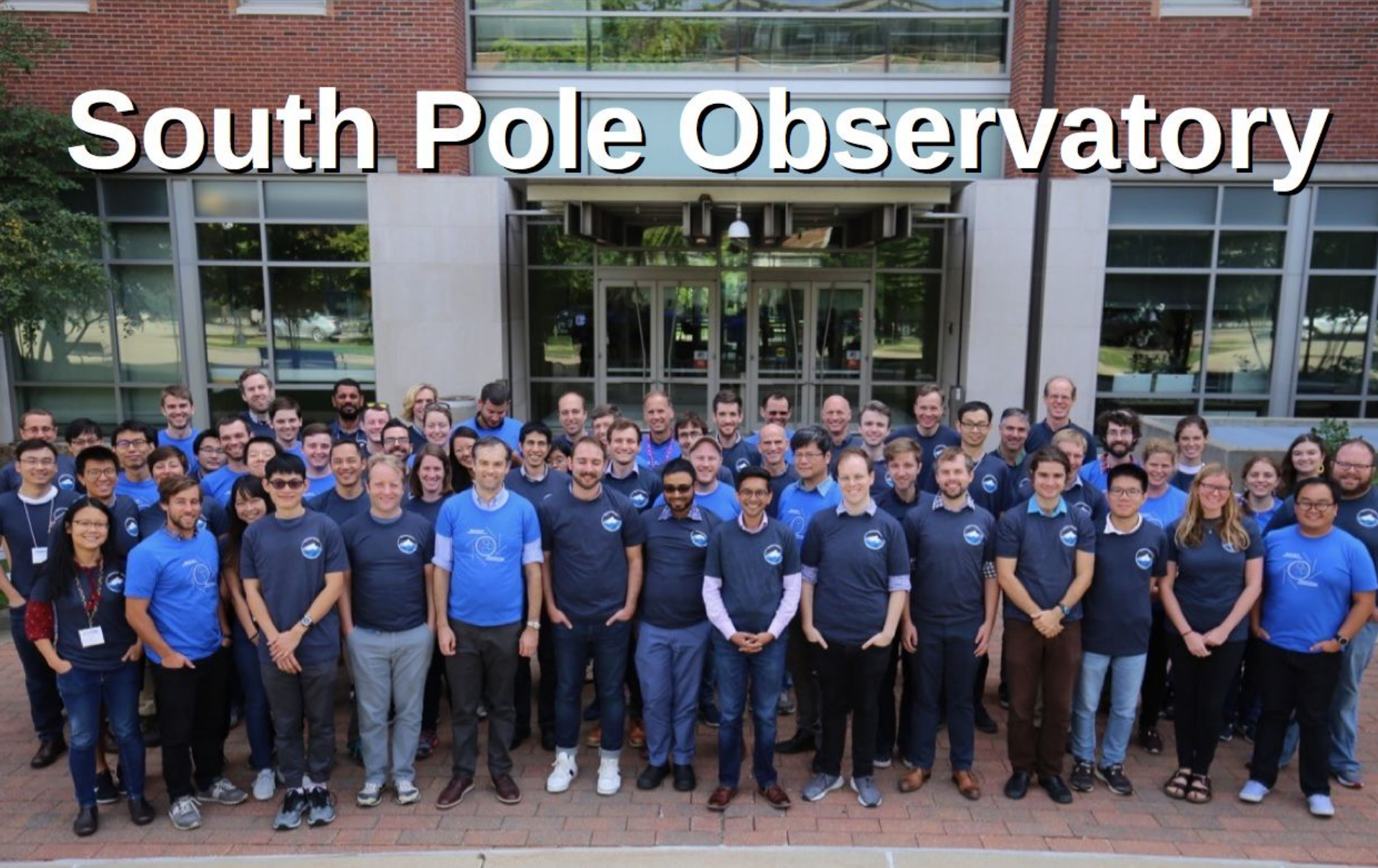
From an LOI to the CMB-S4 leadership:

“We are increasing the coordination of the South Pole CMB program through the formation of a South Pole Observatory (SPO), which will serve as an umbrella organization for the continuing South Pole Stage 3 experiments into the next decade. The SPO will build upon the current MOU between the BICEP/Keck and SPT programs by establishing a formal entity to guide the development of the combined South Pole CMB program for producing the highest science return. These developments and the observational results will continue to benefit CMB-S4.”

Opportunities for involvement may include:

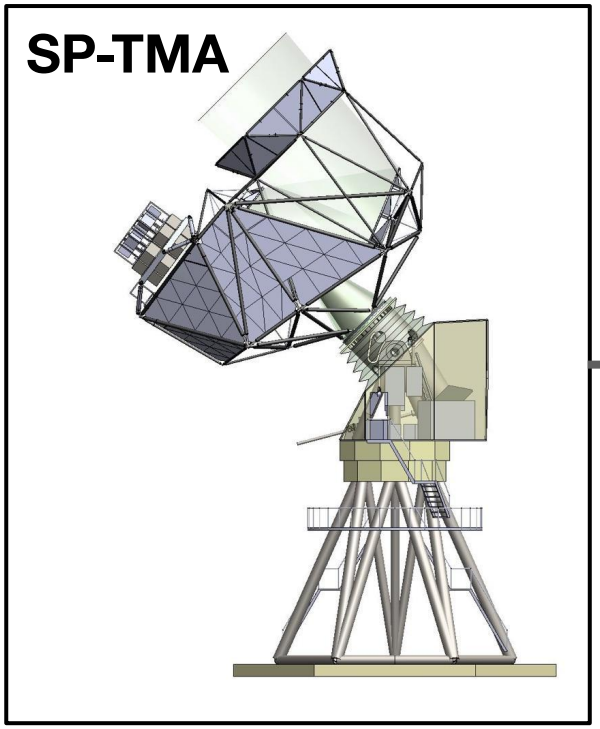
Contributions to infrastructure at Pole (see JC’s talk next)

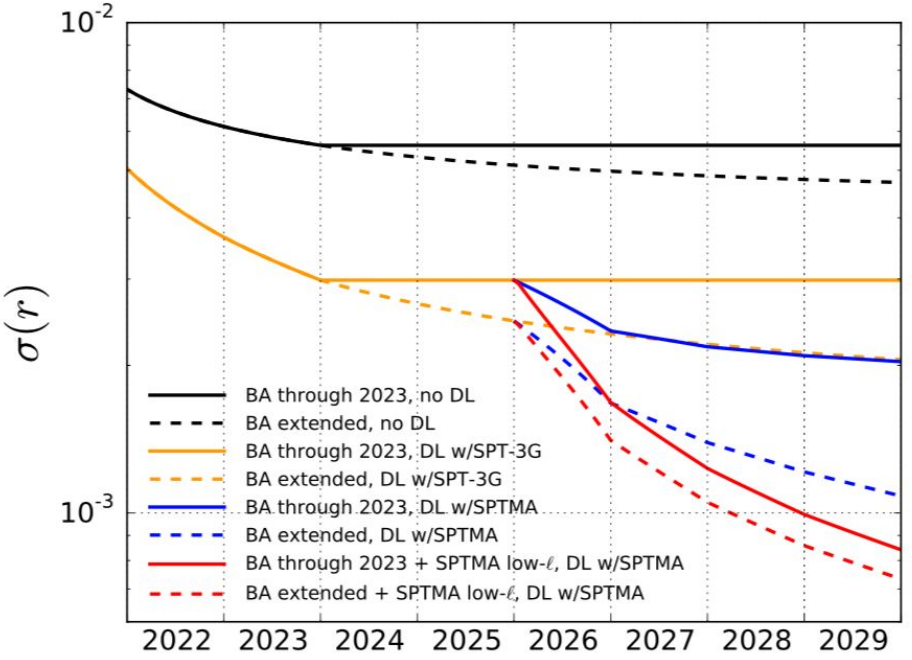
South Pole Observatory

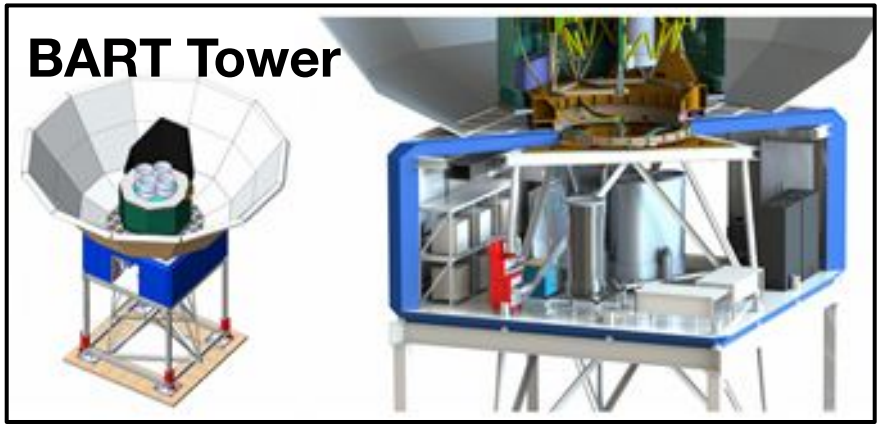


Inaugural SPO Workshop
UIUC Oct. 3-4 2019

The South Pole Observatory (SPO)







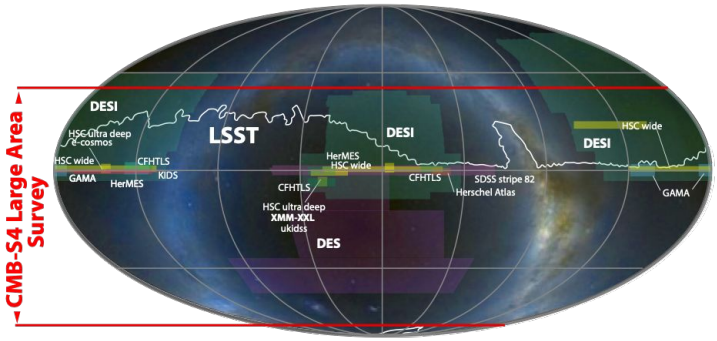
SPO leading efforts to continue improvements on infrastructure and CMB science at Pole:

- SP-TMA (NSF-MSIP submitted)
- BICEP-Array Receiver Towers (BART)

Overview of Future Vision (~8 slides)

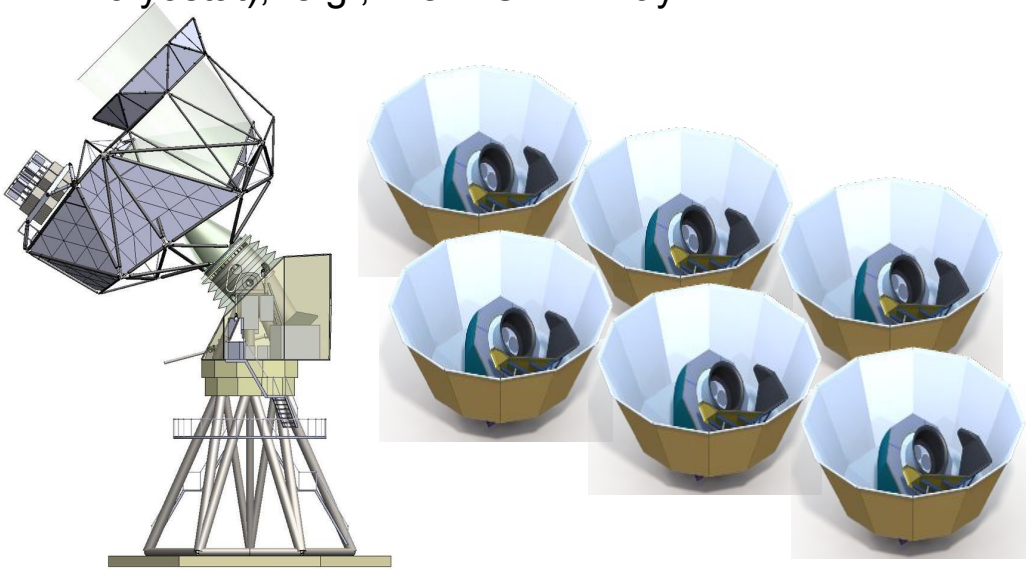
CMB-S4 Reference Design:
Nested ultra-deep narrow survey and deep wide surveys

Ultra-deep "r" survey with 18 x 0.55m small refractor telescopes targeting ≥ 3% of sky with 150,000 detectors over 8 bands and a dedicated de-lensing telescope with 120,000 detectors, 7 yrs.

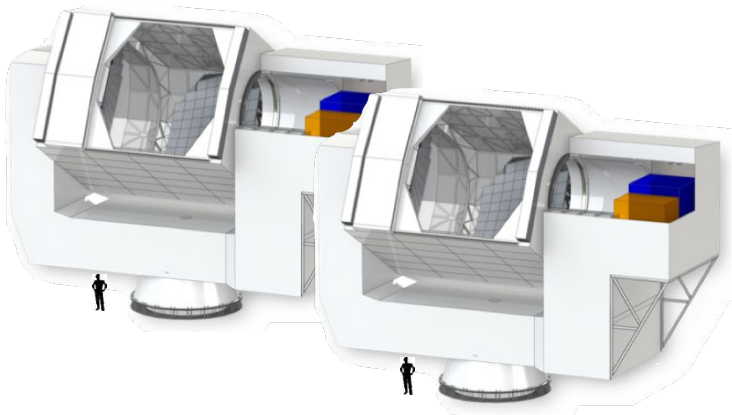


Deep-wide N_{eff} and Legacy Survey with 2 x 6m telescopes targeting ~60% of sky with 240,000 detectors over 6 bands, 7 years.

South Pole: 1x 5m de-lensing "LAT" telescope, 18 x 0.55m small "SAT" telescopes (3 per cryostat), e.g., like BICEP Array

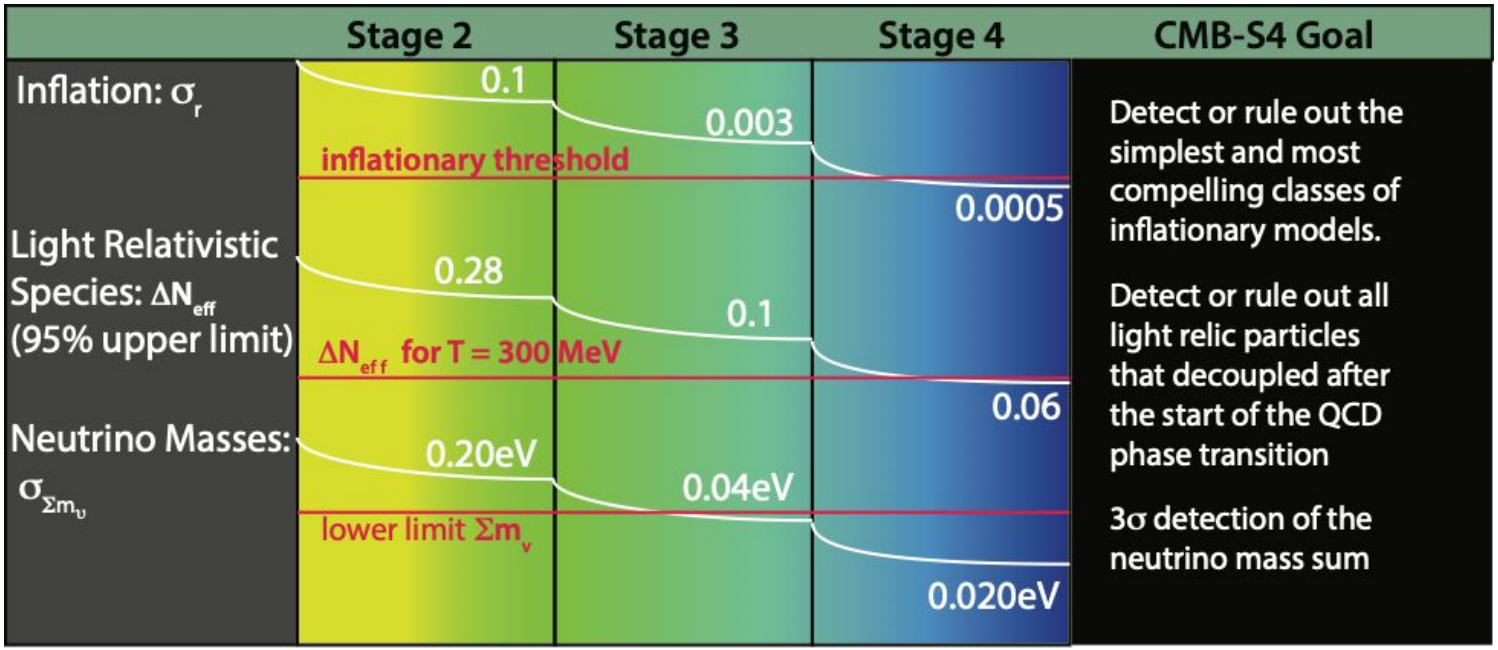


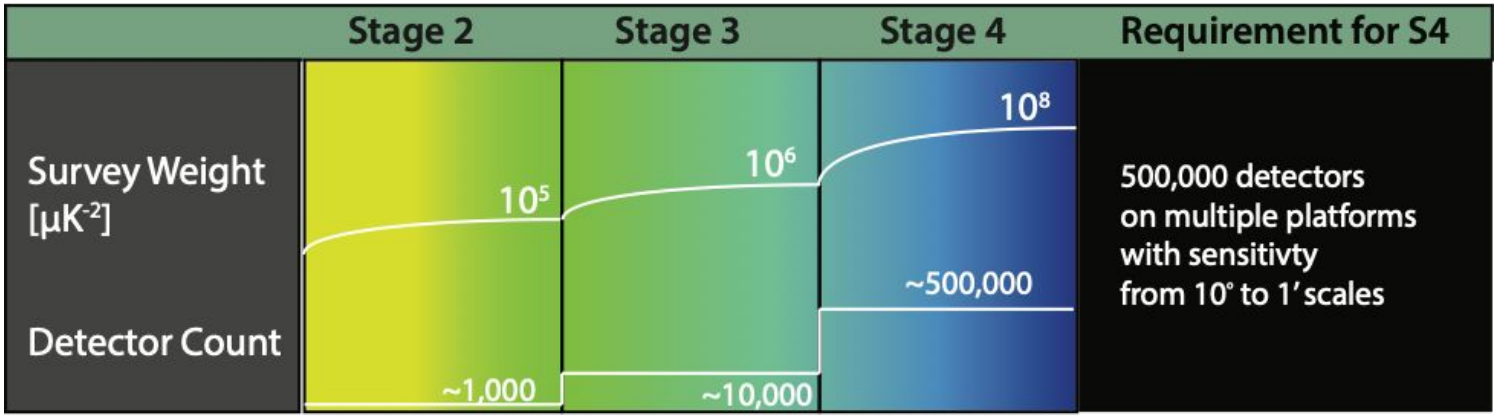
Chile: 2x 6m large telescopes, e.g., like Simons Obs.



CMB-S4 Science Thresholds

CMB-S4 Science Book:
arxiv:1610.02743

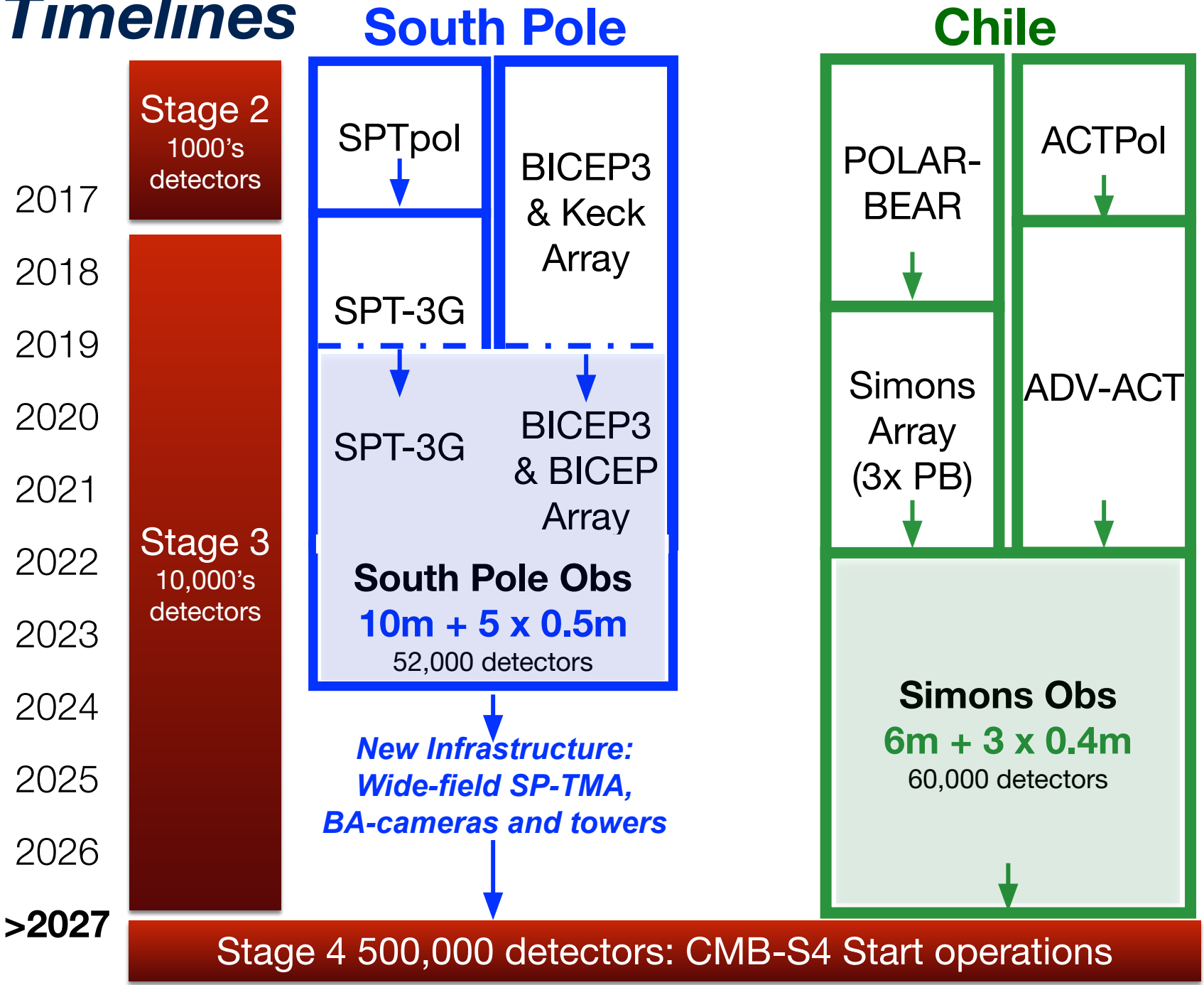




CMB-S4 Trajectory

- **2014**: Recommended by Particle Physics Project Prioritization Panel (P5)
- **2015**: NAS/NRC report calls out CMB-S4 as a strategic priority for Antarctic Science
- **2017:** DOE & NSF sponsored CMB-S4 Concept Definition Task Force (CDT report) enthusiastically accepted by AAAC
- **2018:** *Official* Collaboration established and elections held
- **2018:** Integrated Project Office (IPO) started
- Decadal Survey Report (focus of Dec 2018 annual review) posted July 9, 2019
- CMB-S4 Decadal Input White Paper submitted July 10, 2019
- CMB-S4 project established:
  - Achieved DOE Critical Decision CD-0 for a Major Item of Equipment (MIE) project on July 26, 2019
  - Awarded NSF MSRI-RI Design and Development grant to help us get on the Major Research Equipment & Facilities Construction (MREFC) track, started Oct 1, 2019
- **Anticipated Schedule:**
  - 2024 - NSF MREFC
  - 2028 - DOE CD-4 - Start of Operations

Timelines


South Pole
Chile
Stage 2
1000's
detectors
Stage 3
10,000's
detectors
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
>2027
SPTpol
BICEP3
& Keck
Array
SPT-3G
SPT-3G
BICEP3
& BICEP
Array
South Pole Obs
10m + 5 x 0.5m
52,000 detectors
New Infrastructure:
Wide-field SP-TMA,
BA-cameras and towers
POLAR-
BEAR
ACTPol
Simons
Array
(3x PB)
ADV-ACT
Simons Obs
6m + 3 x 0.4m
60,000 detectors
Stage 4 500,000 detectors: CMB-S4 Start operations

CMB Fieldwork: Overview

- SPT Operations
- BICEP Array (BA) Operations
  - Raising of MAPO building
  - BA Receiver Towers (BART)
- SP-TMA
  - New wide-field survey telescope
- CMB-S4
  - New lab building (similar to MAPO in scale)
  - New SAT receiver towers

SPT Fieldwork: Overview

- Maintenance and operations to support SPT-3G, EHT observations through end of 2023 winter season
- In addition to continued EHT observations, in 23-24 austral summer, proposing the installation of new “SPT4” camera:
  - Complimentary science goals to CMB-S4, including (e.g.): Sunyaev-Zel’dovich effect, high-redshift star-forming galaxies, proto-clusters, integral-field spectrometer for intensity mapping, etc.

SPT Fieldwork: Activities

- Summer 20-21, 21-22, 22-23:
  - Activities:
    - Typical SPT maintenance and re-supply (e.g., oil and grease for telescope motors, gears, bearings; regular computer, compressor maintenance; etc.).
    - Winter-over training for SPT-3G and EHT observations.
    - MAPO summer (and winter) machinist.
  - 17-personnel total. No ASC support beyond minimal cargo (~6,000 lbs).
- Winter 20-23:
  - Support SPT-3G and EHT observations.

20-21, 21-22, 22-23 Summer

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Project's Name		Types/items of fieldwork	Southbound cargo projection		Projected Population Profile (max per day in a half-month)							Total per season		Power & Bandwidth	
Work Item number		Enter here what is absolutely needed (in black) for the subject season, "good to be accomplished" (in blue), or what the project envisions (in red - even not yet funded activities)	Weight (lbs)	Cubic Feet	Nov 1-15	Nov 16-30	Dec 1-15	Dec 16-31	Jan 1-15	Jan 16-31	Feb 1-15	Total Team (not Σ left)	Self-Ticketers	kW	GB/day
		A-379-S Cargo and Population Total	6,000	0	4	7	9	9	10	10	10	17	0	60	125
SPT A-379-S	1	Winter-over relief and continued observing			2	3	3	3				3			
	2	Telescope and SPT-3G receiver maintenance	4,000			3	3	3	2	2	1	5			
	3	EHT maintenance and training	1,200						2	2	2	2			
	4	Winter-overs and training					2	2	5	5	5	5			
	5	MAPO Machine Shop	800		2	1	1	1	1	1	2	2			

SPT Fieldwork: Activities

- Summer 23-24:
  - Activities: Decommission SPT-3G camera. Install new “SPT4” camera. SPT telescope and EHT maintenance. MAPO machine shop.
  - 30-personnel total, 16,500 lbs cargo. Similar (but smaller) to SPT-3G 2016-17 deployment season.
- Winter 24:
  - Support SPT4 and EHT observations
- Summer 24-25:
  - Activities: SPT4 receiver improvements and maintenance. SPT telescope and EHT maintenance. MAPO machine shop. 24-personnel. 6,000 lbs cargo.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Project's Name		Types/items of fieldwork	Southbound cargo projection		Projected Population Profile (max per day in a half-month)							Total per season		Power & Bandwidth	
Work Item number		Enter here what is absolutely needed (in black) for the subject season, "good to be accomplished" (in blue), or what the project envisions (in red - even not yet funded activities)	Weight (lbs)	Cubic Feet	Nov 1-15	Nov 16-30	Dec 1-15	Dec 16-31	Jan 1-15	Jan 16-31	Feb 1-15	Total Team (not Σ left)	Self-Ticketers	kW	GB/day
23-24 Summer															
		A-379-S Cargo and Population Total	16,500	0	6	14	14	14	16	14	13	30	0	60	125
	1	SPT-3G Decommissioning	500		4	6						6			
	2	SPT4 camera deployment	10,000			4	8	8	8	6	4	12			
	3	EHT maintenance and training; Telescope Maintenance	5,200			3	3	3	2	2	2	5			
SPT	4	Winter-overs and training					2	2	5	5	5	5			
A-379-S	5	MAPO Machine Shop	800		2	1	1	1	1	1	2	2			
24-25 Summer															
		A-379-S Cargo and Population Total	6,000	0	4	8	14	14	16	14	12	24	0	60	125
	1	Winter-over relief and Telescope maintenance			2	3	3	3				3			
	2	SPT4 receiver maintenance	4,000			4	8	8	8	6	3	12			
	3	EHT maintenance and training	1,200						2	2	2	2			
	4	Winter-overs and training					2	2	5	5	5	5			
SPT	5	MAPO Machine Shop	800		2	1	1	1	1	1	2	2			

BICEP Array Fieldwork: Overview

- Completion of the BICEP Array by 2022
  - 3 additional receivers
    - These are the model for CMB-S4 SATs
- BICEP Array operations 2022-2027(+)
  - Require shift to BART to allow MAPO raise
- After MAPO raise and shift to BART1, proposing to re-use original BICEP Array mount for BART2
  - Commissioning 2024-25 with receivers that will be CMB-S4 SAT prototypes
  - Provides a realistic ramp-up for CMB-S4 construction, integration, and commissioning schedule.

BICEP Array Fieldwork: Overview

BICEP Array Fieldwork: Overview

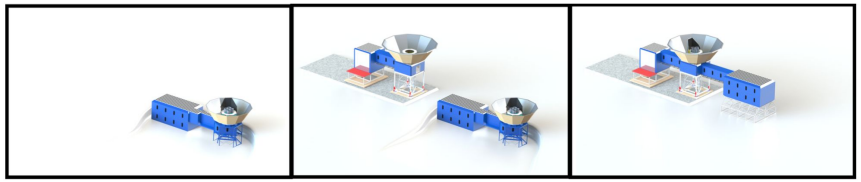
BICEP Array Fieldwork: Overview

BICEP Array Replacement Tower (BART) precedes MAPO raise:

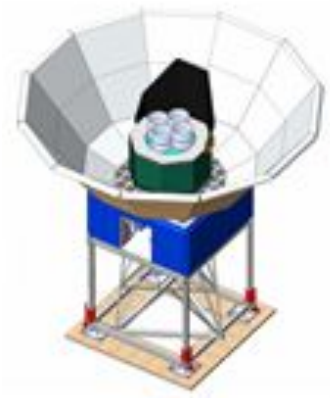
- Allows Stage 3 science to proceed through 2022-2027
- meets a long-recognized, urgent facility need
  - Aligns with DS planning since 2008, 2015 NRC *Strategic Vision* report, 2017 design charrette
  - 2019 SPO MSRI-1 feedback: “The proposed upgrade of MAPO with BART is essential to the support of compelling future CMB science at South Pole and must be carried out soon.”

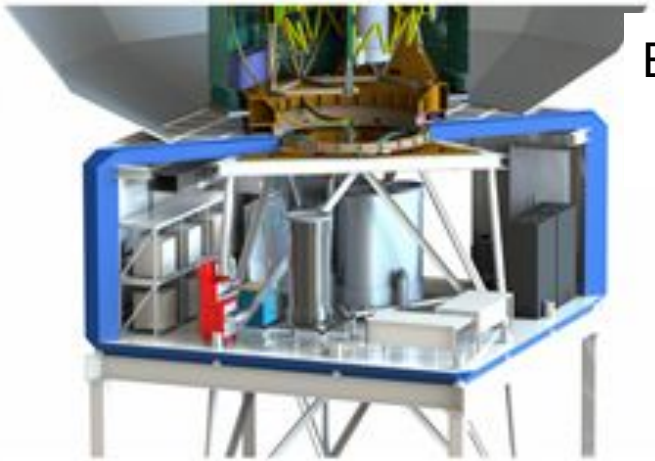
MAPO 1995

MAPO 2019



BART Deployment Sequence





BART detail: tower, shield, mount

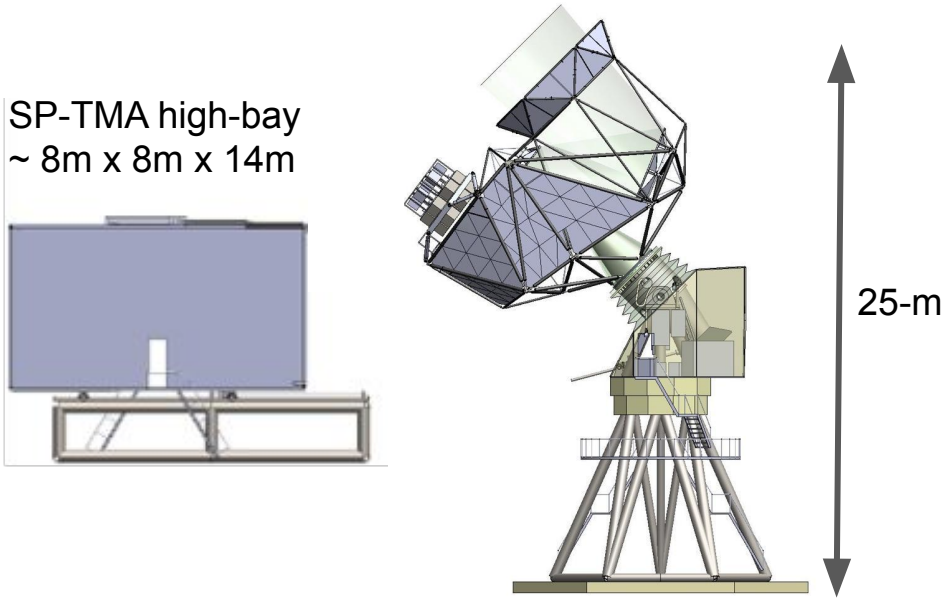
- designed/costed in detail in 2019 SPO MSRI
- Compatibility with S4 SATs, while enabling Stage 3 science program

BICEP Array Fieldwork: Activities

- Summer 2020-21:
  - Activities: BICEP Array BA2, BA3 receiver deployment, install BART1 icepad.
  - BICEP Array operations continue each year below
  - 24 personnel total, 22k lbs cargo. Smaller than 2019-20
- Summer 2021-22:
  - Activities: BA4 receiver installation, BART1 tower/mount installation
  - 29 personnel total, 100k lbs cargo. Construction similar to Nov/Dec 1999.
- Summer 2022-23:
  - Activities: BICEP Array shifts operation to BART1, recycle original tower, recover original mount and set footers for BART2 (MAPO raise underway)
  - 21 personnel total, 18k lbs cargo. Smaller than any recent year
- Summer 2023-24:
  - Activities: BART2 tower/mount installation, connection to (raised) MAPO
  - 19 personnel total, 93k lbs cargo, includes re-use of first BA mount
- Summer 2024-25:
  - Activities: install receivers on BART2, could be CMB-S4 prototype SATs
  - 20 personnel total, 23k lbs cargo

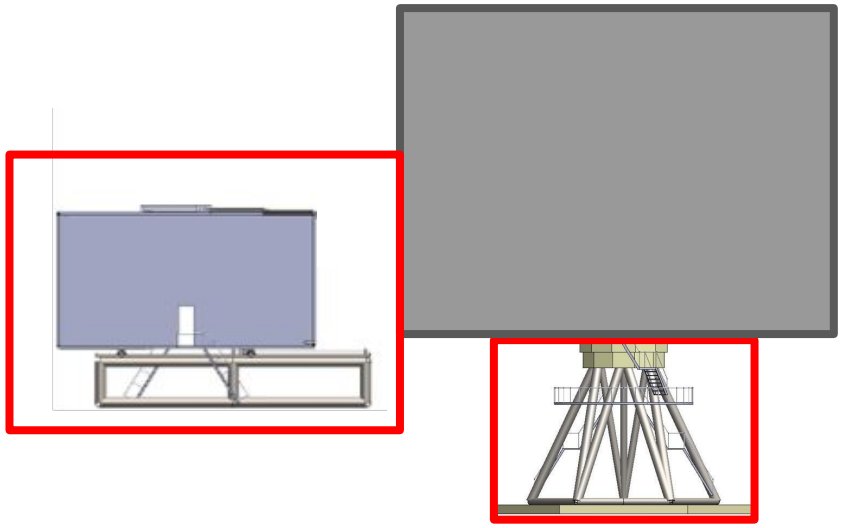
SP-TMA Fieldwork: Overview

- SP-TMA: NSF-MSIP proposal submitted to build a new wide-field survey (5-meter diameter) telescope with 20x field of view of SPT
  - Mapping Speed (Sensitivity) ~ Field of View ~ Detectors
  - Enables next step in CMB sensitivity at South Pole
- SP-TMA is of similar weight and size to SPT, and would follow a similar deployment schedule.
  - 22-23 Season: Install icepads (for telescope foundation)
  - 23-24 Season: Assemble telescope foundation and high-bay / control-room
  - 24-25 Season: Assemble SP-TMA telescope and commissioning receiver



SP-TMA Fieldwork: Activities

- Summer 22-23:
  - Icepad installation: 2-person ASC dozer crew for 2-months
- Summer 23-24:
  - 11-people total
  - Significant cargo total (720,000 lbs)
  - Assemble telescope foundation: 4-person ASC crew for 2-months
  - High-bay assembly: 5-person ASC crew for 3-months

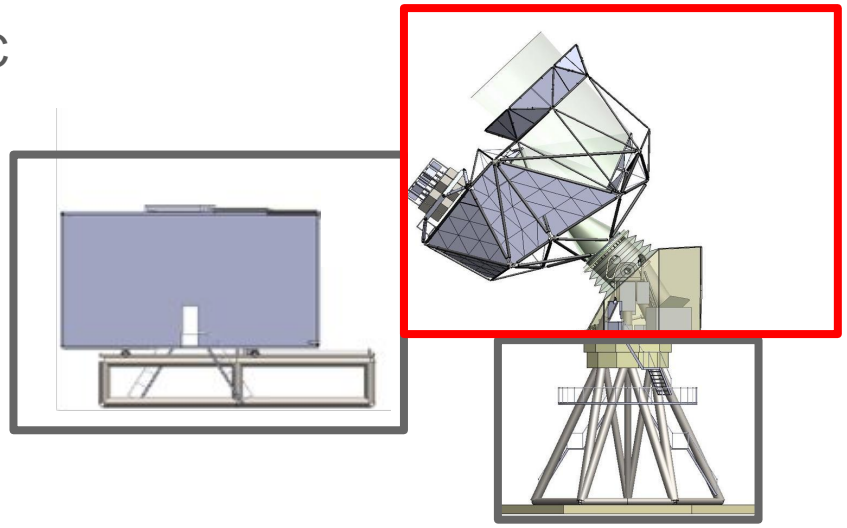


23-24 Summer

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Project's Name		Types/items of fieldwork	Southbound cargo projection		Projected Population Profile (max per day in a half-month)							Total per season		Power & Bandwidth	
Work Item number		Enter here what is absolutely needed (in black) for the subject season, "good to be accomplished" (in blue), or what the project envisions (in red - even not yet funded activities)	Weight (lbs)	Cubic Feet	Nov 1-15	Nov 16-30	Dec 1-15	Dec 16-31	Jan 1-15	Jan 16-31	Feb 1-15	Total Team (not Σ left)	Self-Ticketers	kW	GB/day
		A-379-S Cargo and Population Total	720,000	0	7	9	11	11	9	8	8	11	0	20	0
SPT/TMA A-379-S	6	Fly in TMA foundation materials	330,000												
	7	TMA foundation construction				4	4	4	4			4			
	8	Traverse in 3 TMA mirrors (ea. 4000 kgs including packaging), 1 azimuth bearing assembly	60,000				2	2				2			
	9	Fly in TMA High Bay materials	330,000												
	10	TMA High Bay Assembly			7	5	5	5	5	8	8	5			

SP-TMA Fieldwork: Activities

- Summer 24-25:
  - 17-people total
  - Significant cargo total (462,000 lbs)
  - TMA Telescope assembly: 8-person ASC crew for 3-months
  - Test and install commissioning camera (with ~20,000 detectors)
- Winter 25:
  - Two person winter-over crew for commissioning camera observations.



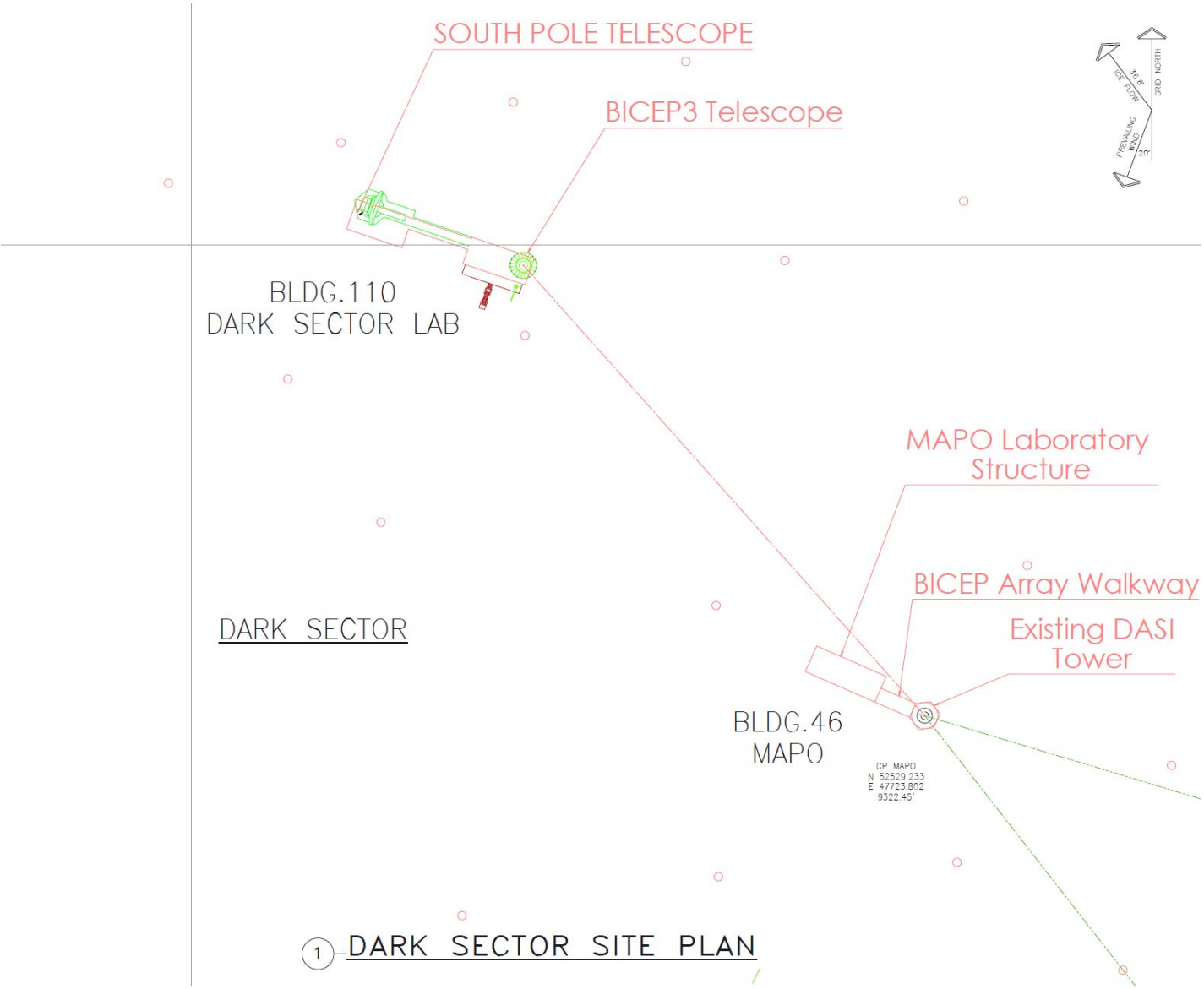
24-25 Summer

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Project's Name		Types/items of fieldwork	Southbound cargo projection		Projected Population Profile (max per day in a half-month)							Total per season		Power & Bandwidth	
Work Item number		Enter here what is absolutely needed (in black) for the subject season, "good to be accomplished" (in blue), or what the project envisions (in red - even not yet funded activities)	Weight (lbs)	Cubic Feet	Nov 1-15	Nov 16-30	Dec 1-15	Dec 16-31	Jan 1-15	Jan 16-31	Feb 1-15	Total Team (not Σ left)	Self-Ticketers	kW	GB/day
		A-379-S Cargo and Population Total	462,000	0	2	12	12	14	16	17	17	17	0	60	120
SPT/TMA A-379-S	6	Fly in TMA Telescope materials	440,000												
	7	TMA Assembly				10	10	10	12	12	12	12			
	8	TMA Telescope Commissioning						2	2	3	3	3			
	9	Fly in TMA Camera equipment	22,000												
	10	TMA Camera Commissioning			2	2	2	2	2	2	2	2			

CMB-S4 Fieldwork

- CMB-S4 will re-use SPO-led infrastructure built at Pole including: SP-TMA, MAPO, and BART towers.
  - New CMB-S4 cameras expected to be deployed on these facilities after 2025 season
- In addition, CMB-S4 will need 4x additional “SAT” towers, including a new laboratory building to support integration of new CMB-S4 cameras.
  - The above will closely follow MAPO-BART tower infrastructure and configuration (see later slides), while adding new receiver/support capacity
  - 23-24 Season:
    - Install icepads for new lab building: 1 person ASC dozer crew for 2-months
    - Ship SAT-3 tower and lab building materials: 255,000 lbs cargo
  - 24-25 Season:
    - Install icepads for SAT towers 4-6
    - Install SAT-3 tower: 5-person ASC crew for 2-months
    - Assemble new lab building: 10-person ASC crew for 3-months
    - 15 personnel total, 105,000 lbs of cargo

South Pole Observatory and CMB-S4 Site Planning: 2020-2021

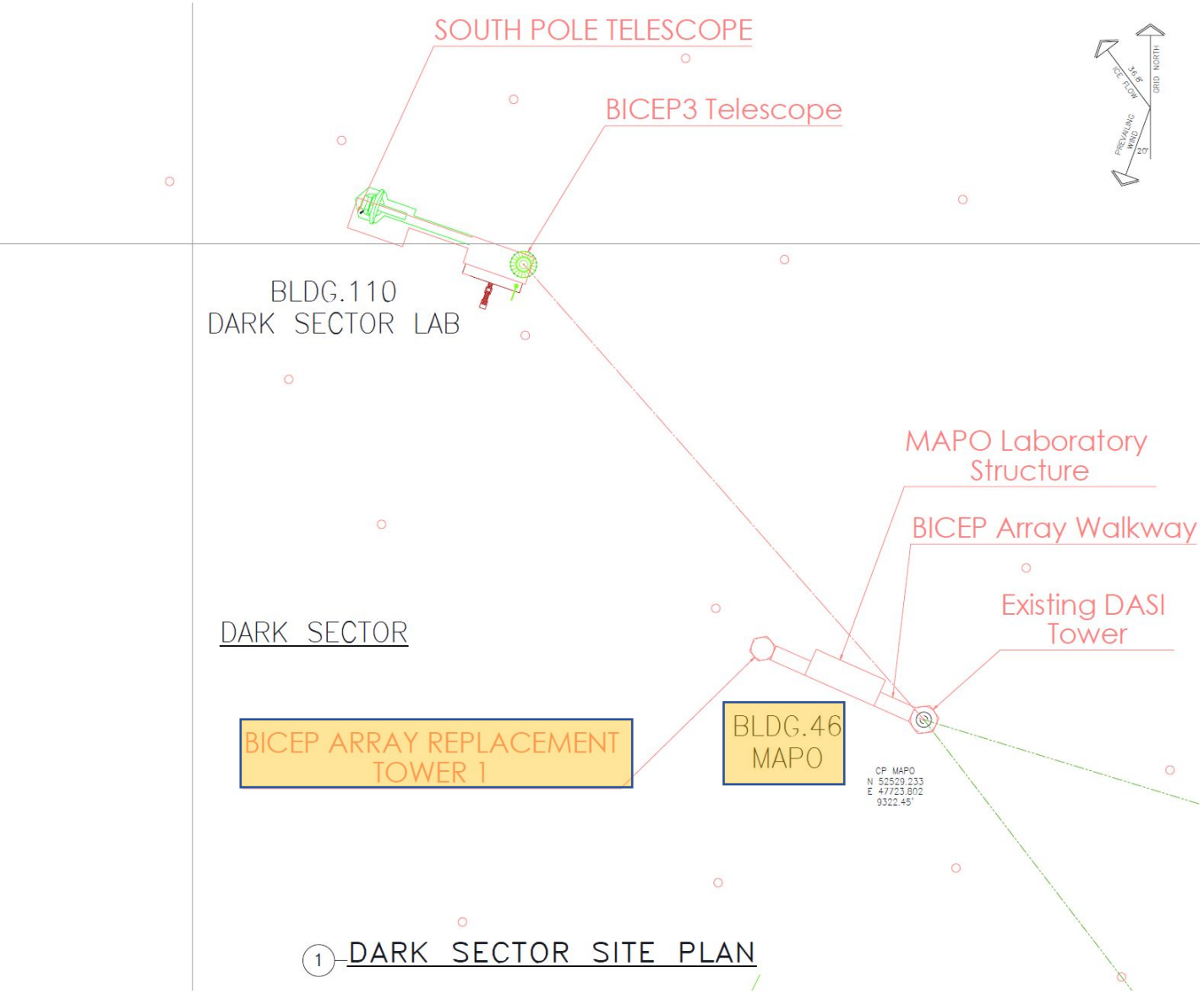


Infrastructure / Deployments

BART 1 Ice Pad

BICEP Array receivers #2 & #3

South Pole Observatory and CMB-S4 Site Planning: 2021-2022



Infrastructure / Deployments

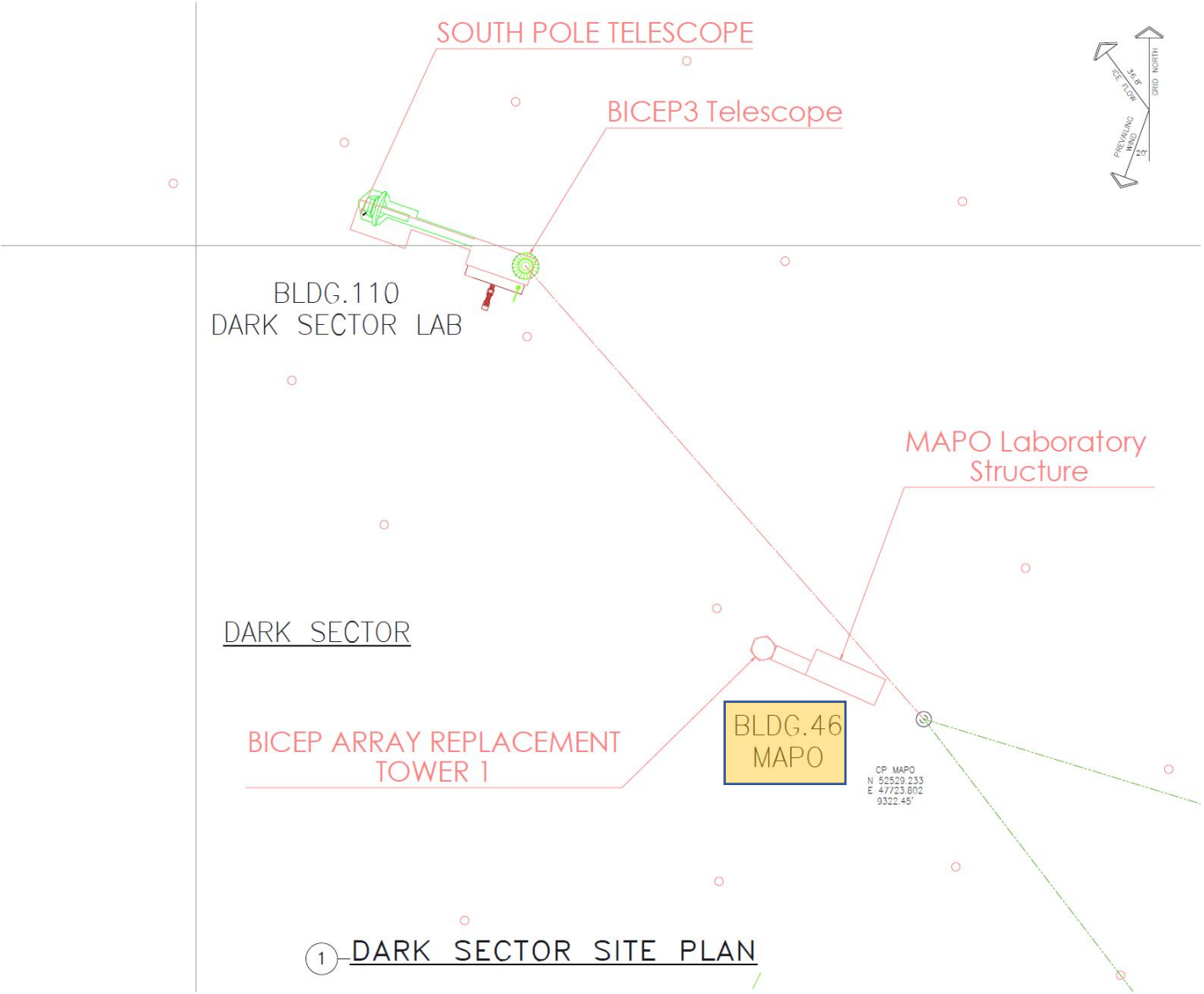
MAPO Raise (option 1)

BART 1

BICEP Array receiver #4

SPT 3G M&O

South Pole Observatory and CMB-S4 Site Planning: 2022-2023



Infrastructure / Deployments

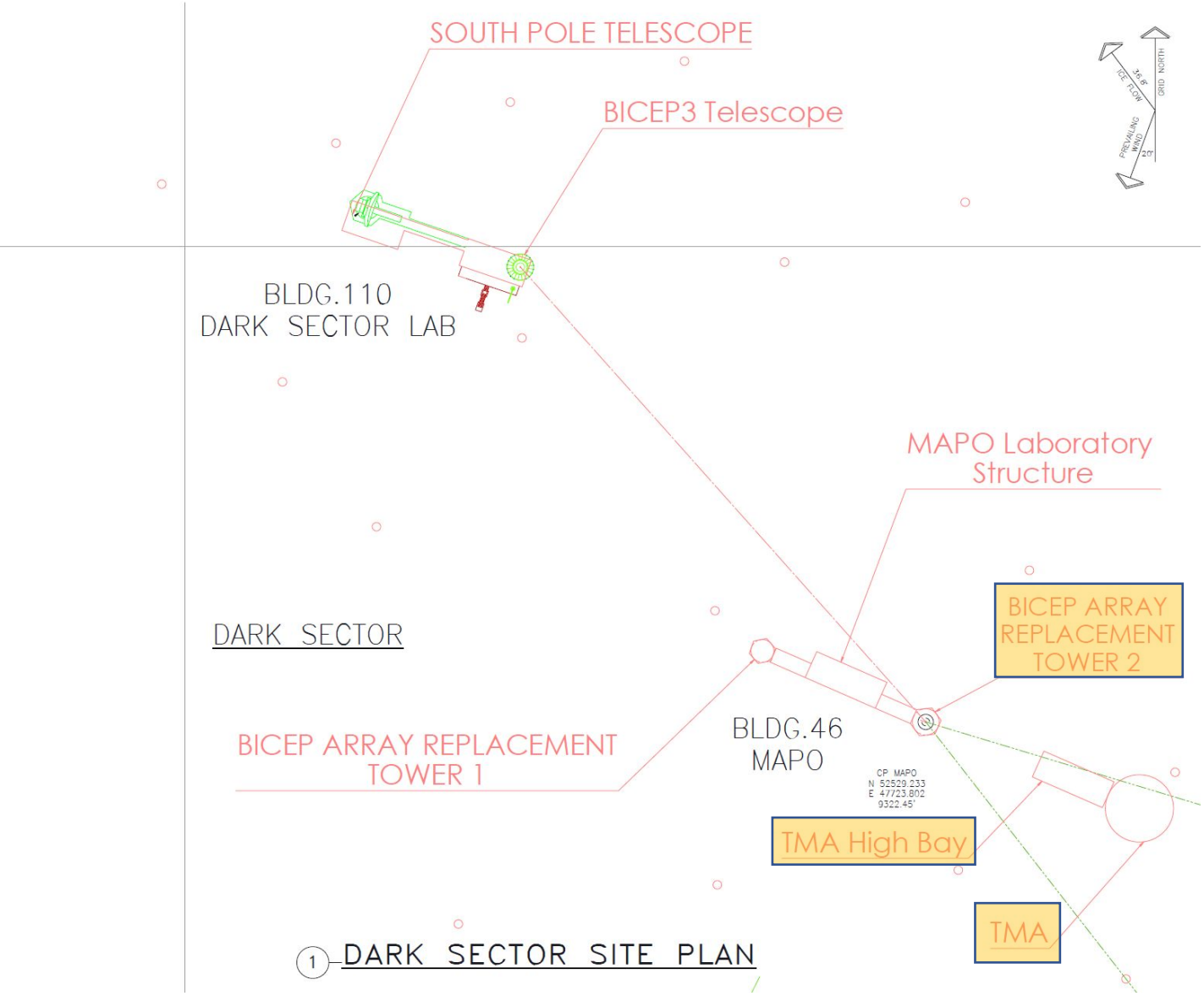
MAPO Raise (option 2)

BA Transfer to BART

SPT 3G M&O

TMA Ice Pads

South Pole Observatory and CMB-S4 Site Planning: 2023-2024



Infrastructure / Deployments

TMA Foundation

TMA High Bay

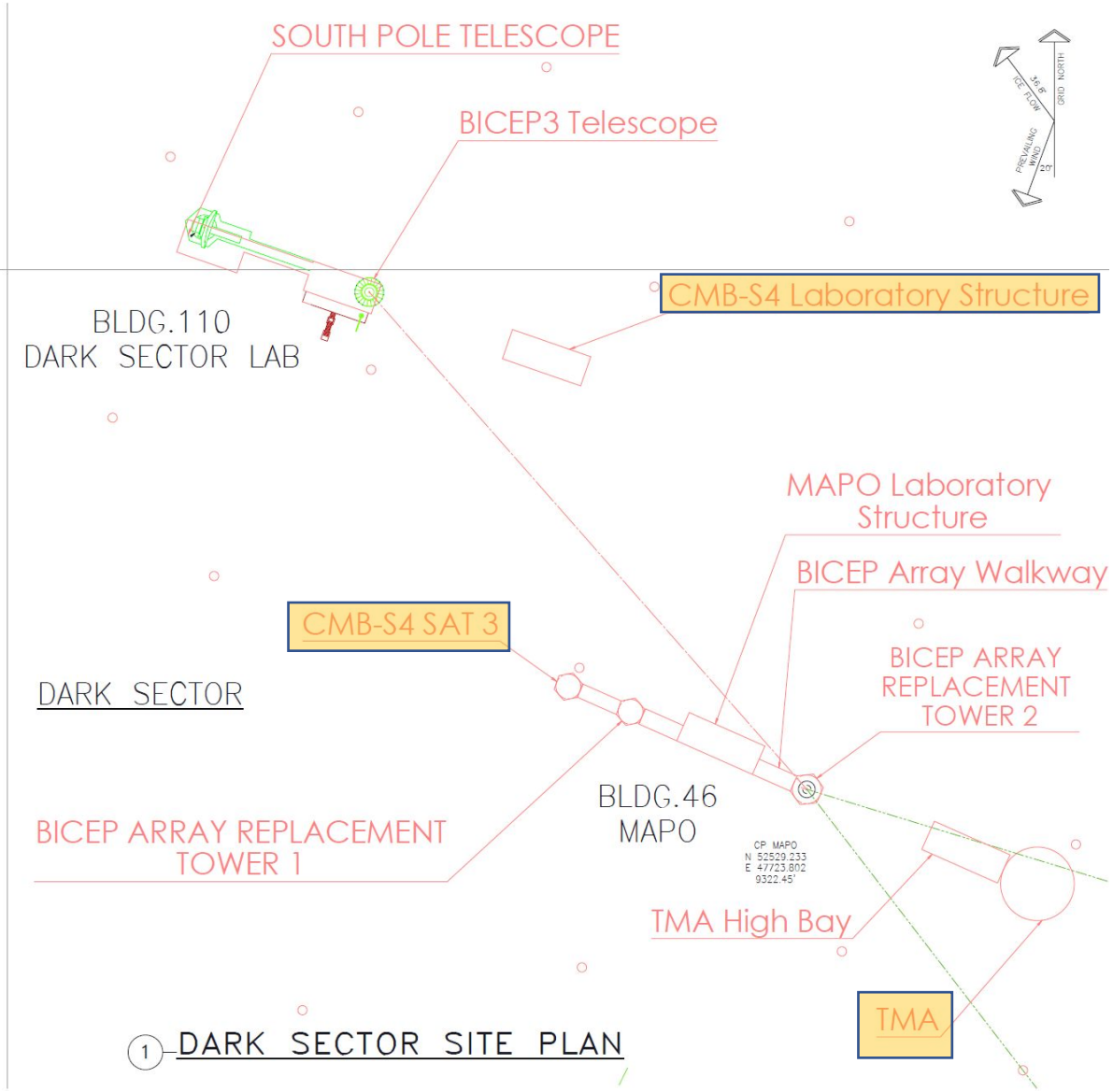
BART 2

SPT4 Receiver

CMB-S4 Lab Snow Pad

CMB-S4 Tower #3 Snow Pad

South Pole Observatory and CMB-S4 Site Planning: 2024-2025



Infrastructure / Deployments

TMA Telescope and Comm Cam Deployment

CMB-S4 SAT Tower #3

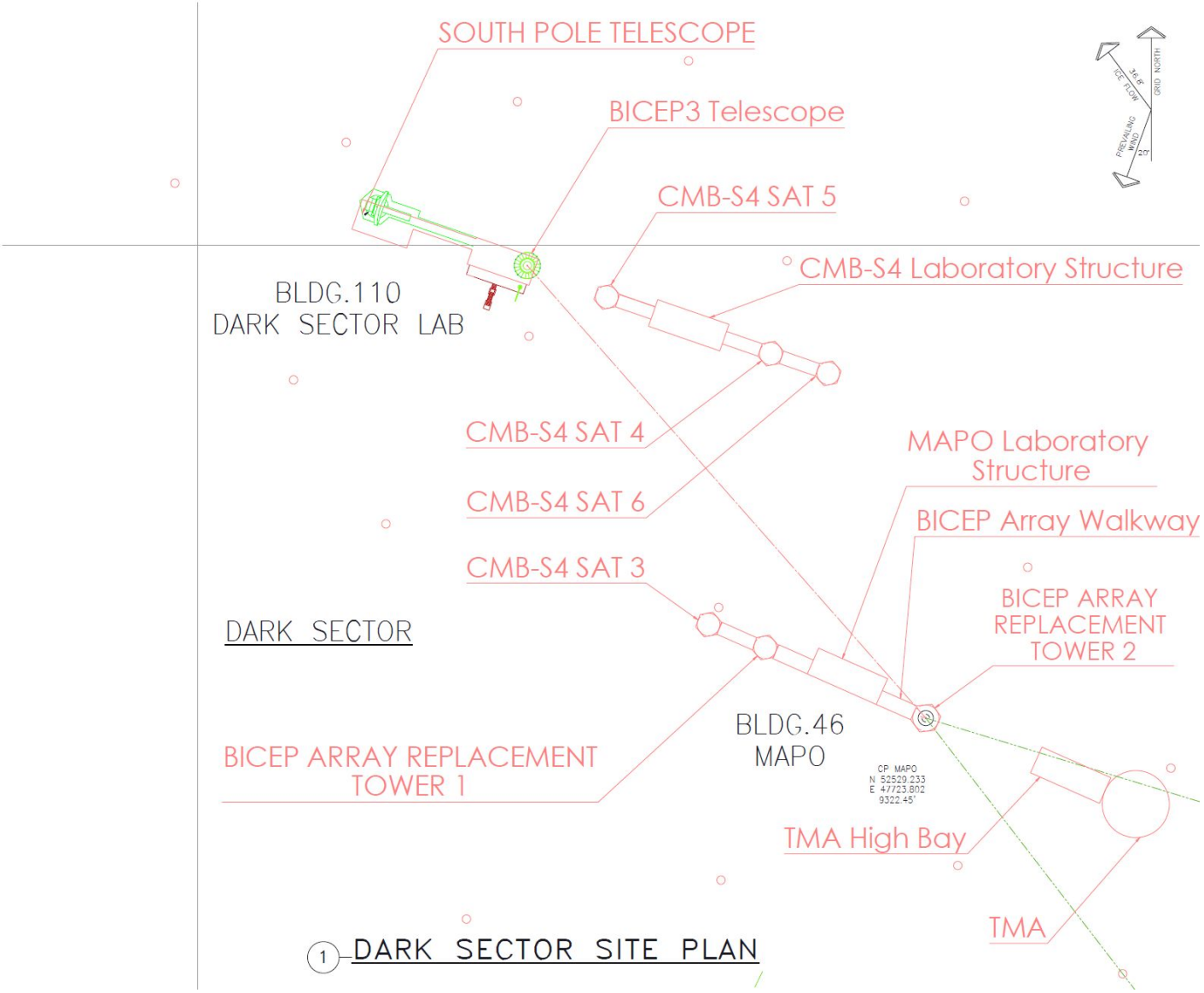
CMB-S4 Laboratory

BA Deployment to BART #2

SPT4 Operations

CMB-S4 SAT Snow Pad #4, #5, #6

Final CMB-S4 Site Configuration



Power and Bandwidth Overview, SPO projects

	Power	Bandwidth	Operating
2020-2021	140 kW	285 GB/day	BA + SPT-3G
2021-2022	140	405	BA + SPT-3G
2022-2023	140	405	BA + SPT-3G
2023-2024	165	480	BA + SPT4
2024-2025	250	850	BAx2 + SPT4 + TMA
2026-2035(?)	450	2-7 TB/day	SPT4 + CMB-S4

Thank you!

Questions and Discussion

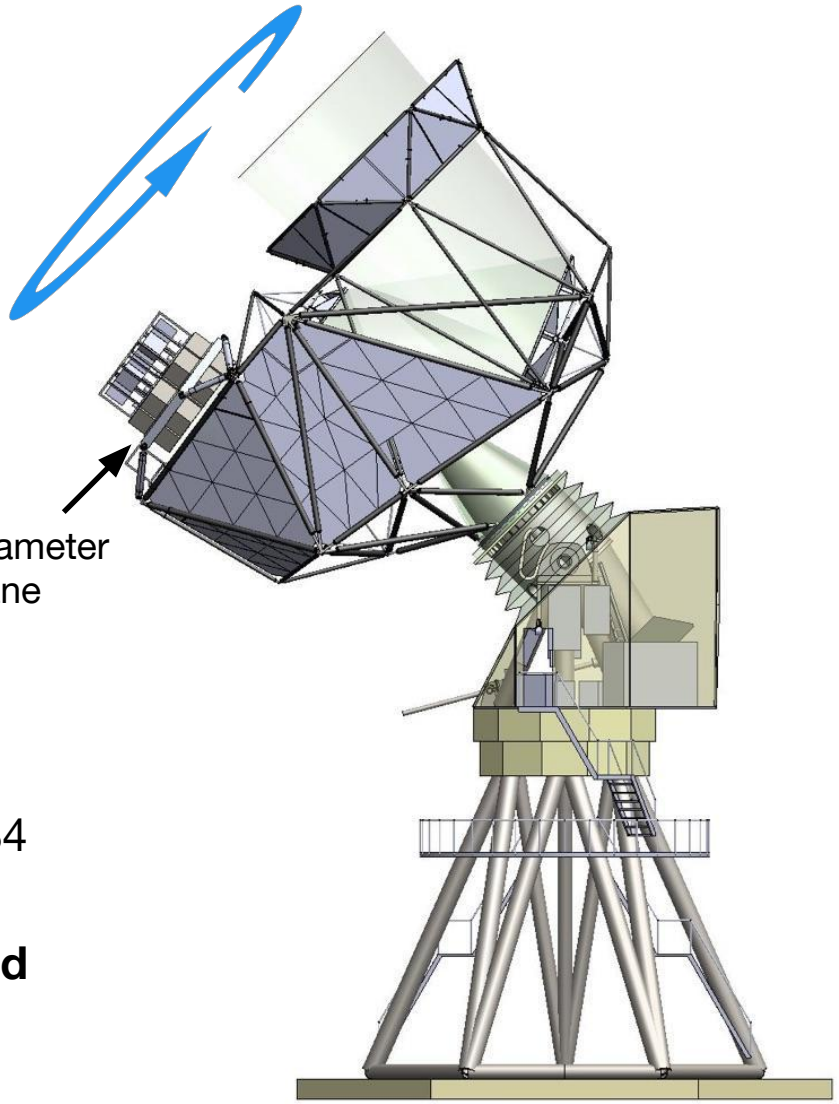
END

New high throughput South Pole telescope: Steve Padin Three Mirror Anastigmat design

Degree B-modes ***and*** arc minute resolution
with extremely high throughput.

For 5-m design:

- 100 deg^2 field of view, could support 424k/136k/63k Fλ pixels at λ=1/2/3mm
- Monolithic mirrors (low scattering)
- Boresight rotation for polarization modulation, characterization
- Comoving baffle (low pickup)
- 1.6’ resolution at 150 GHz



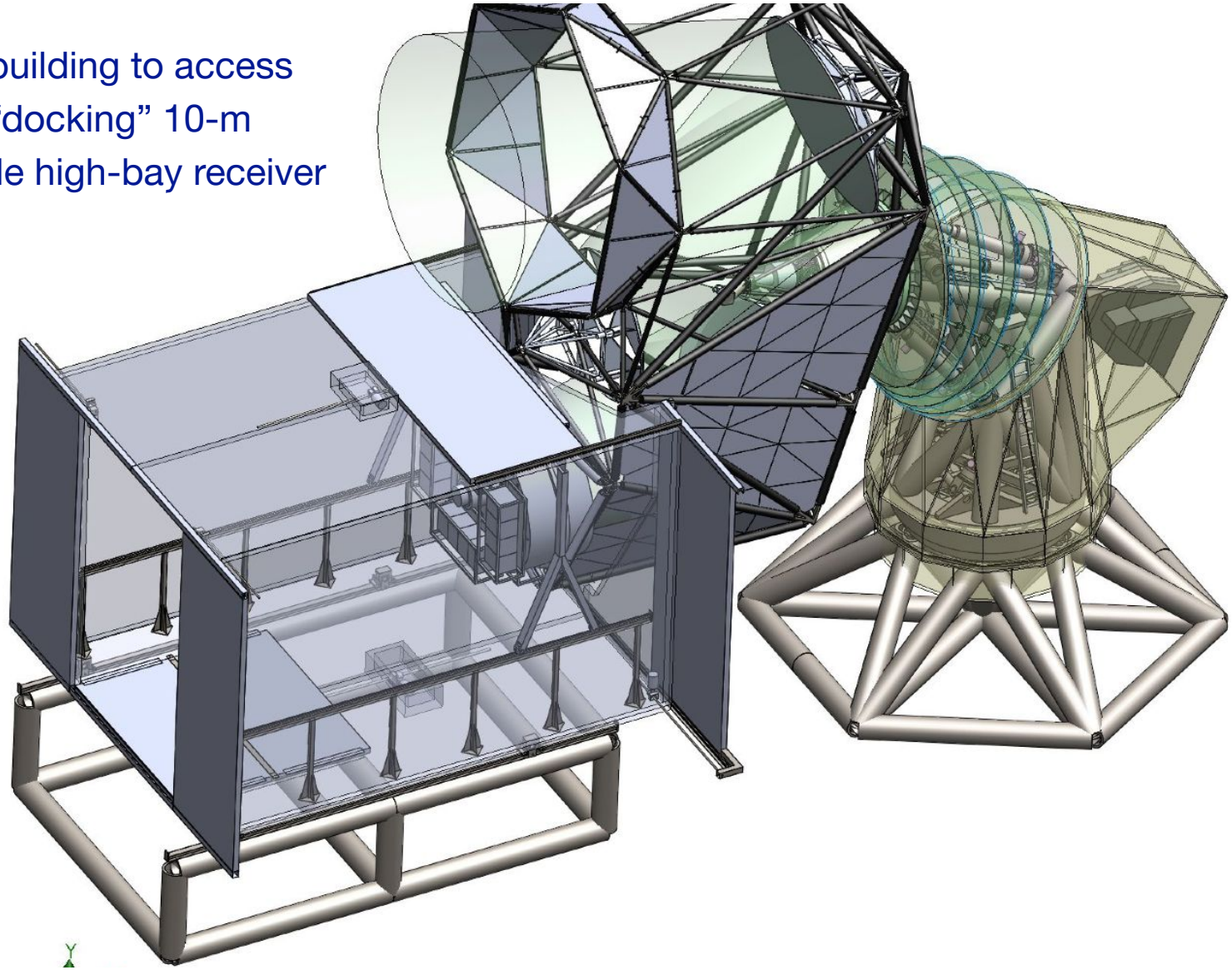
Designed compatible for South Pole and CMB-S4
(similar in cost and scope to 10-m SPT)

Now working to fully design and prototype and targeting 2024 deployment

Padin, Applied Optics, 57, 9, 2314 2018

New high throughput South Pole telescope: Steve Padin Three Mirror Anastigmat design

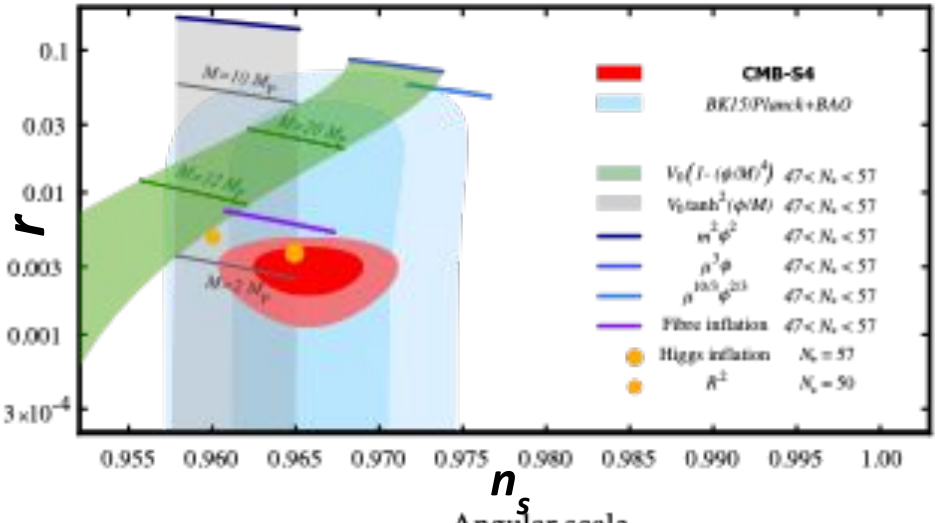
High-bay support building to access receiver similar to “docking” 10-m telescope to provide high-bay receiver access.



(figure not updated)

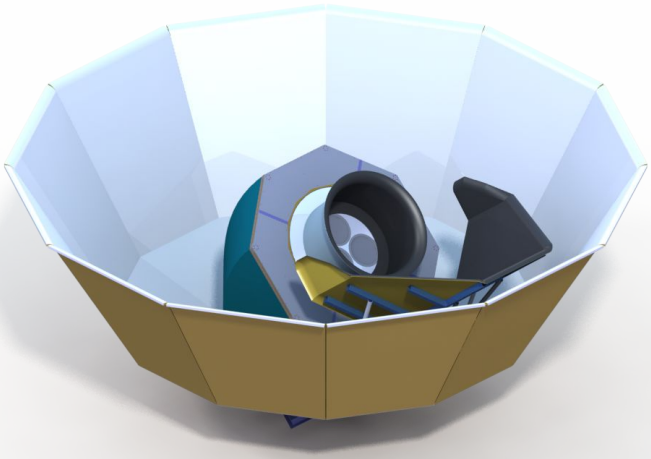
CMB-S4 Measurement of *r*

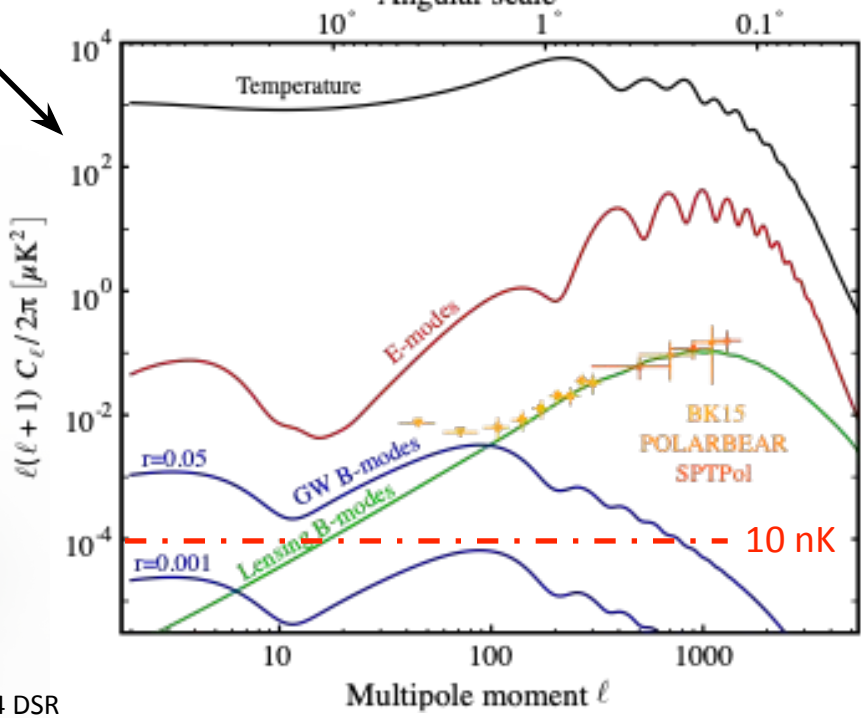
Goal: $r < 0.001$ at 95%, or detect $r = 0.003$ at high confidence



This means < 10 nK uncertainties at degree scales. Requires:

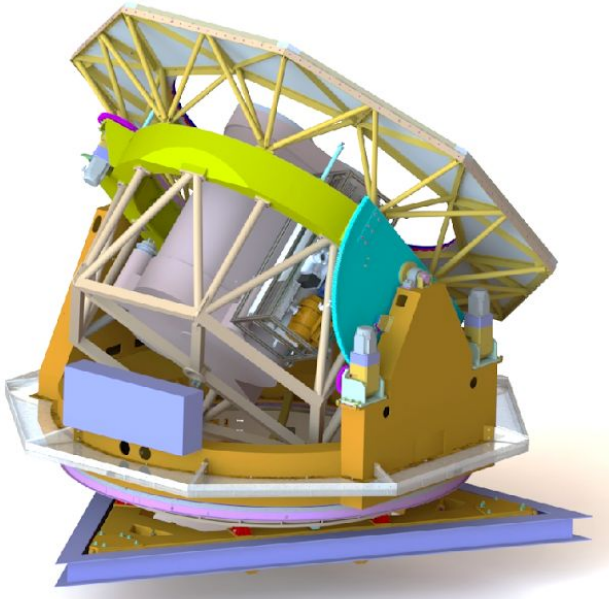
- Raw sensitivity
- Systematics control
- Foreground separation





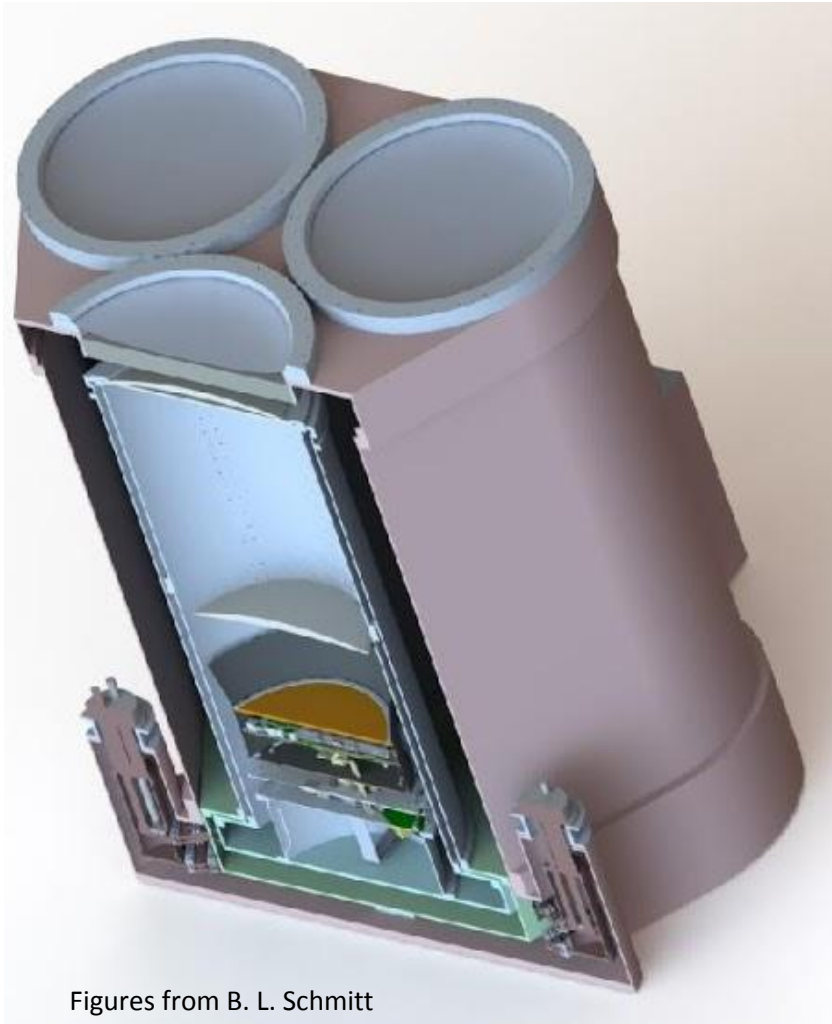
Figures from CMB-S4 DSR

CMB-S4 Small Aperture Telescopes



The S4 reference design for the SAT mounts, optics and shielding is modeled after Stage-3 BICEP3 and BICEP Array.

3 optics tubes inside a single cryostat



bands	lenses	field of view	min edge taper	modulation	detectors/ tube	tubes
SATs at South Pole, 12 tubes						
30 / 40	2x 55cm Al	29 ^{0}	-9.3 dB	scan	576	1
85 / 145	2x 55cm Al	29 ^{0}	-6.2 dB	scan	7056	4
95 / 155	2x 55cm Al	29 ^{0}	-8.4 dB	scan	7056	4
220 / 270	2x 44cm Si	29 ^{0}	-12.5 dB	scan	16884	3
				subtotals	107,676 detectors	

SATs in Chile, 6 tubes						
30 / 40	3x 55cm Al	35 ^{0}	-6.8 dB	scan	684	1
85 / 145	3x 44cm Si	35 ^{0}	-5.7 dB	HWP	6084	2
95 / 155	3x 44cm Si	35 ^{0}	-8.0 dB	HWP	6084	2
220 / 270	3x 44cm Si	35 ^{0}	-13.4 dB	HWP	16884	1
				subtotals	41,904 detectors	

Figures from B. L. Schmitt