Searching for CMB B-mode Polarization from the Ground

Clem Pryke – University of Minnesota

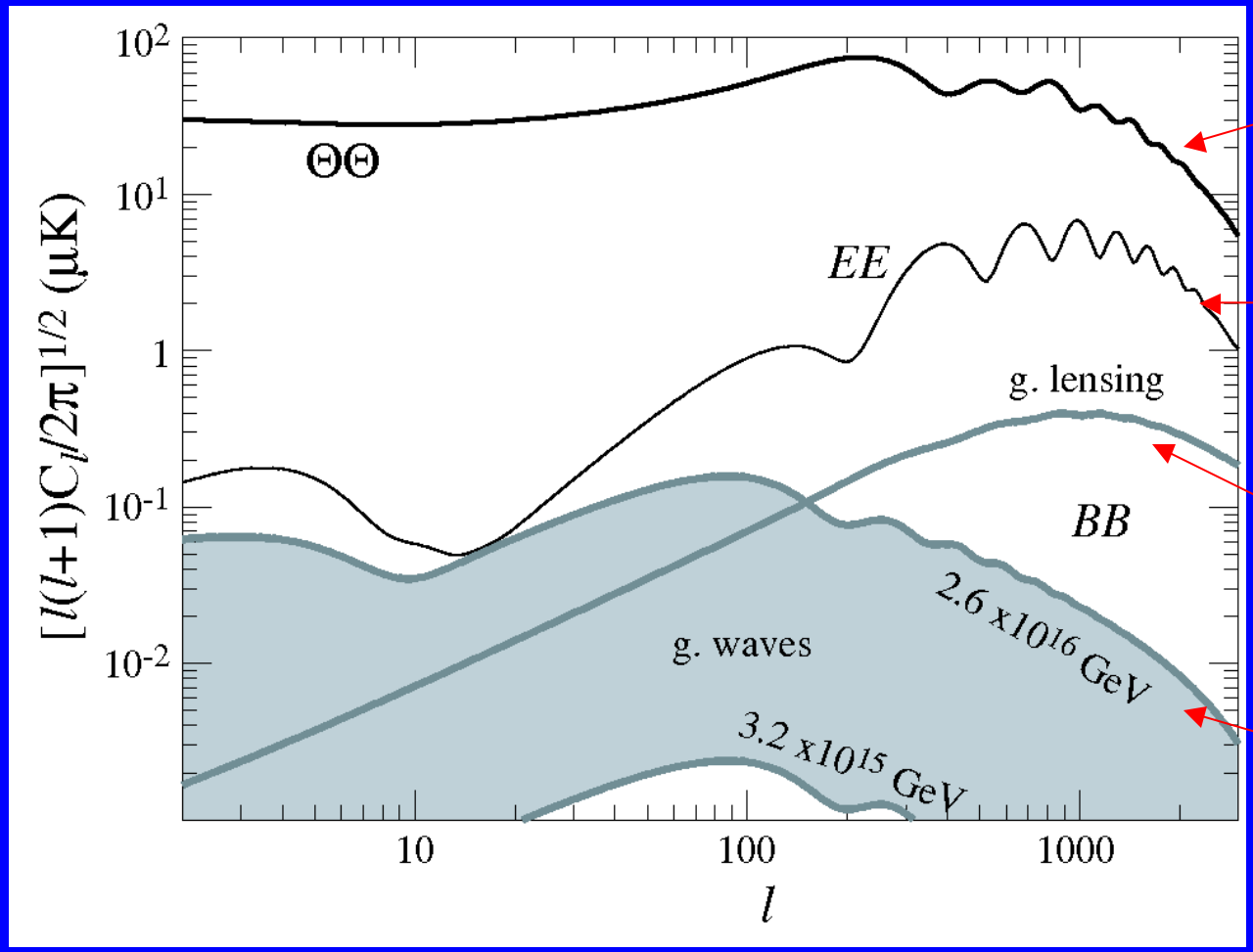
Pre-Plankian Inflation Workshop

Oct 3, 2011

Outline

- Review of CMB polarization and history of detection from the ground
- Current best results
- On-going experiments and their prospects

CMB Power Spectra



Temperature

E-mode Pol.

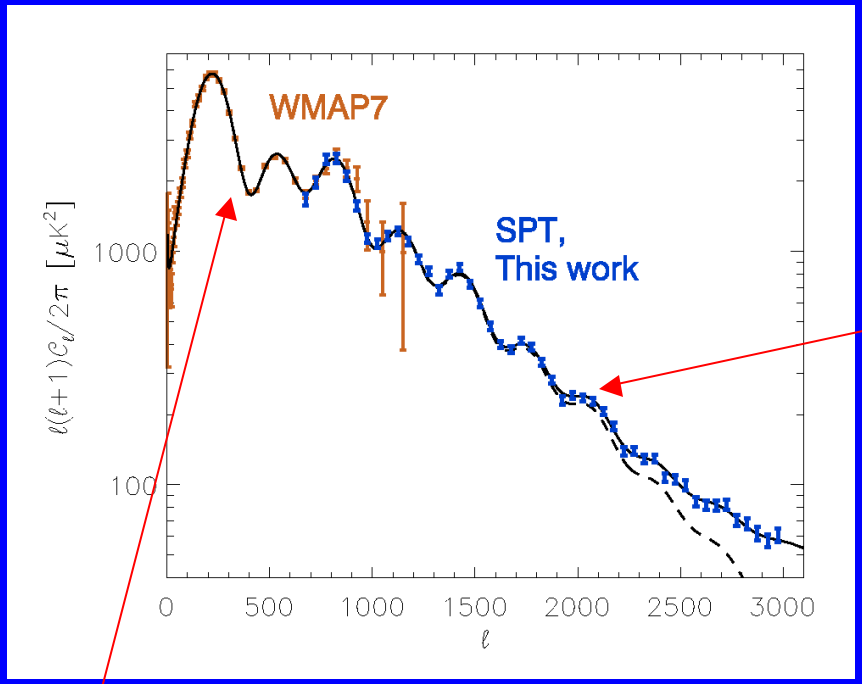
Lensing B-mode

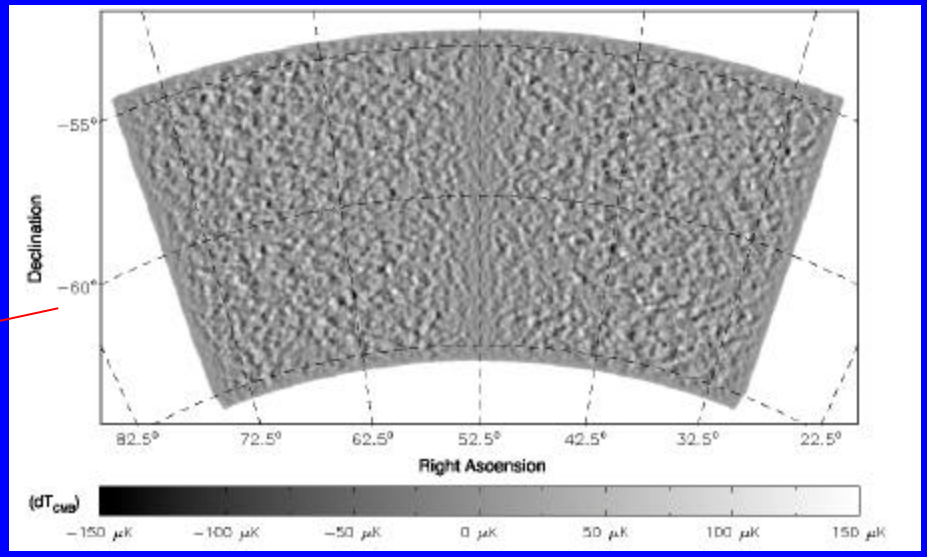
Inflation B-mode

Hu et al astro-ph/0210096

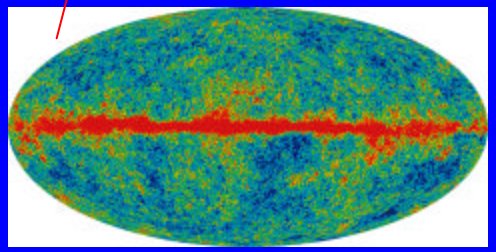
Log Scale! Enormous experimental challenge!

Existing Limit on Inflation from CMB Temp+

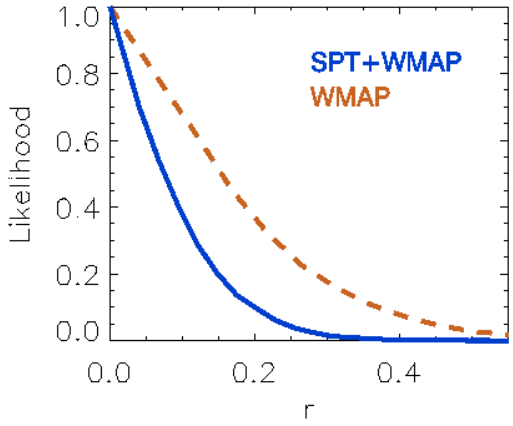


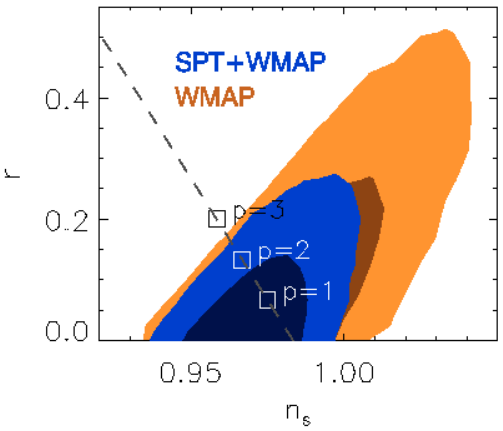


Keisler et al 1105.3182 sets limit r<0.17 from SPT+WMAP+H0+BAO

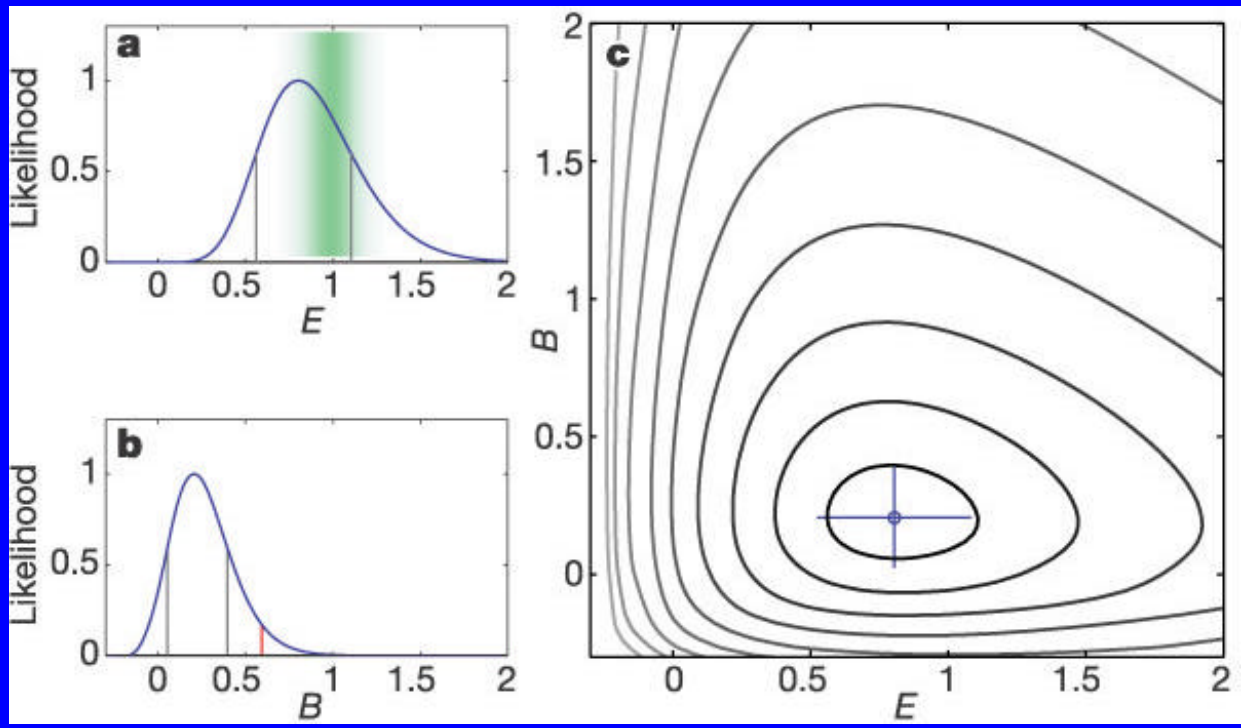


Sample variance limited
Need B-modes to go further!





DASI First Detection of CMB Pol. In 2002



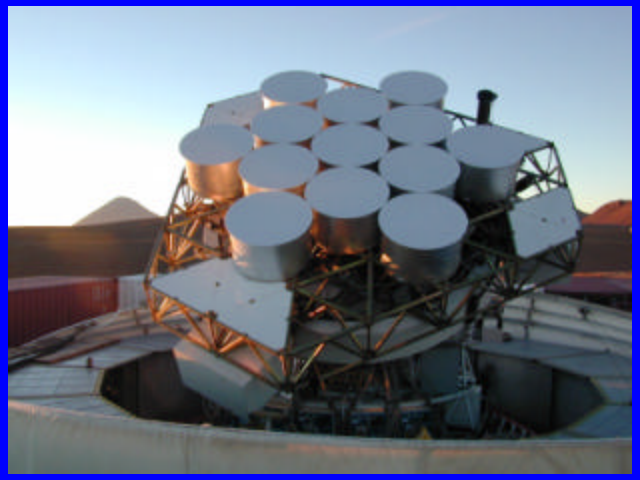
Kovac et al Nature 12/19/02

DASI showed CMB *has* E-mode pol.

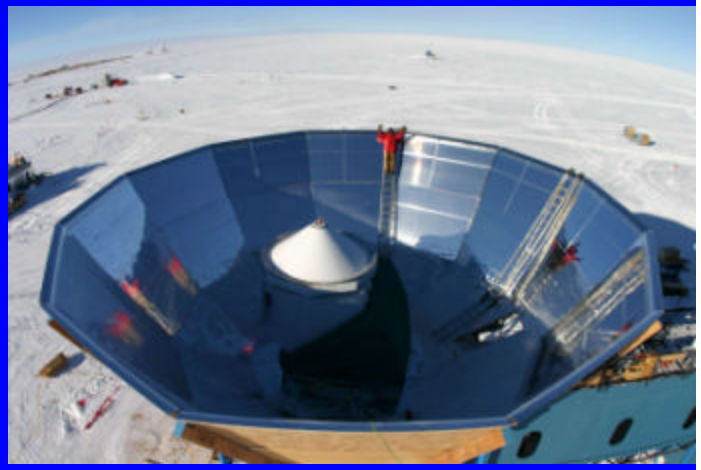
- B-mode was consistent with zero

Previous Experiments with CMB Pol Detections

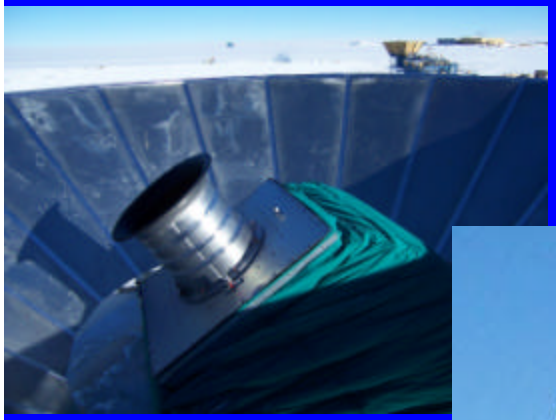
CAPMAP



CBI

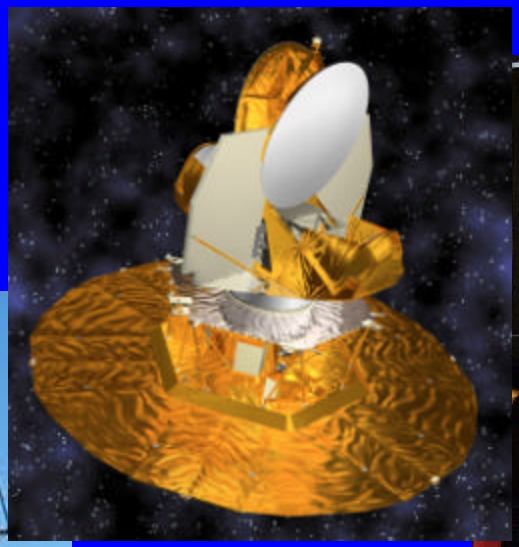


QUaD

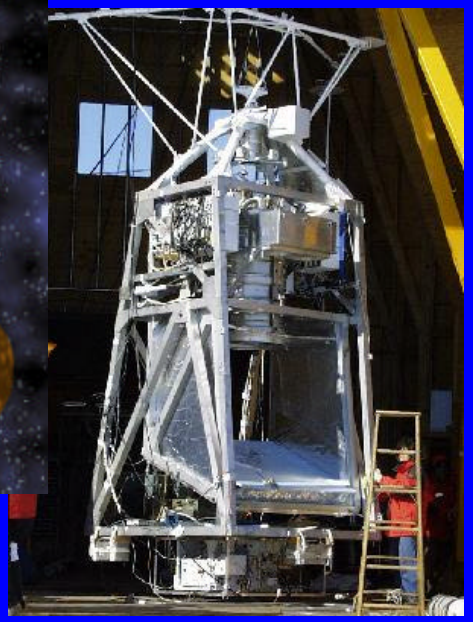


BICEP1

QUIET

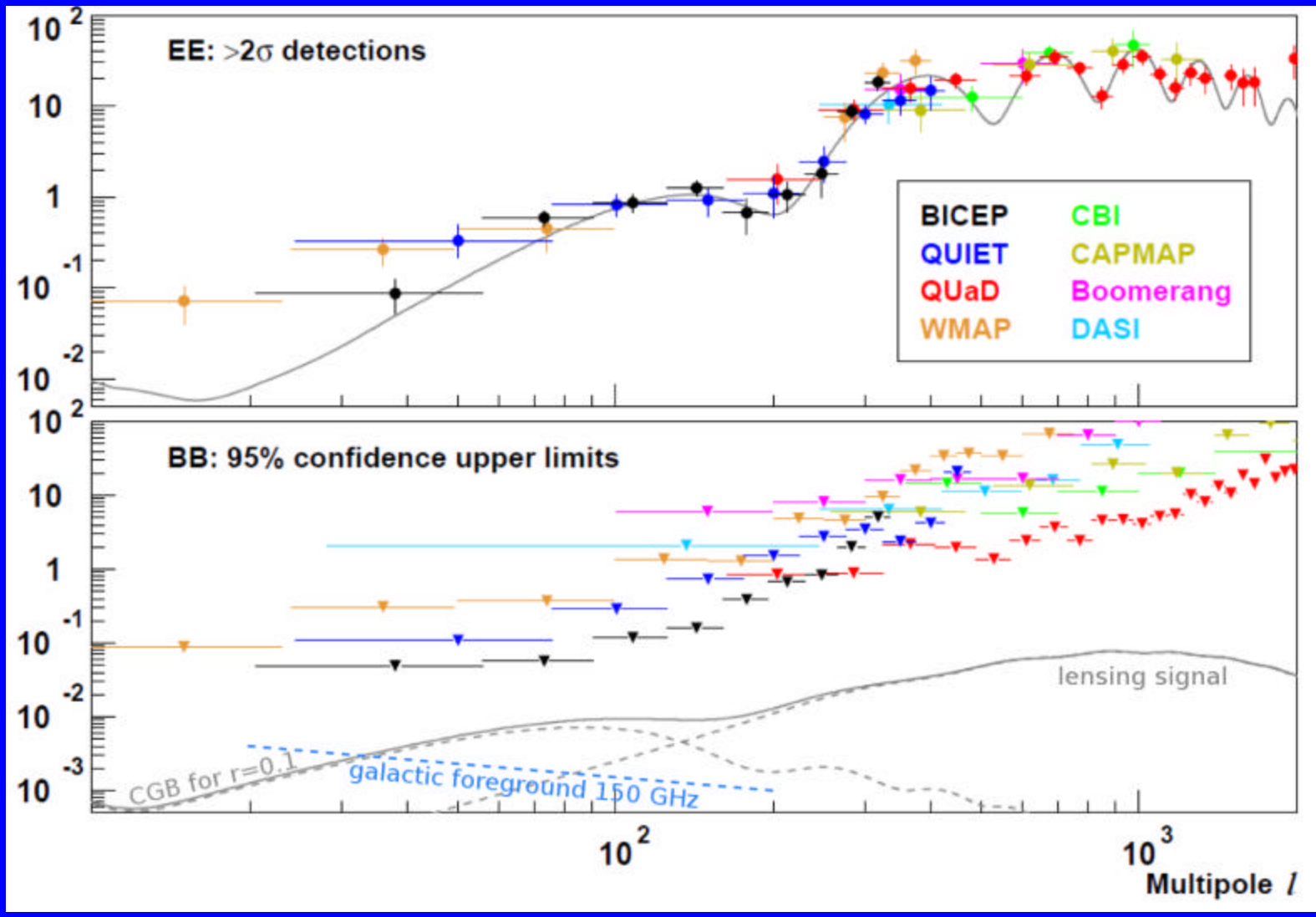


WMAP



BOOMERANG

Current Status of CMB Pol. Measurements



Chiang et al 0906.1181 fig 13 updated with QUIET results

BICEP1 sets best B-mode limit to date – r<0.72

Current/Future Experimental Efforts

- Orbital: Planck
- Sub-orbital: SPIDER, EBEX, PIPER
  - Assume already covered…

- This talk: Ground based experiments
  - Chile: POLARBEAR, ABS, ACTpol
  - Other: QUBIC, (QUIJOTE)
  - South Pole: SPTpol, BICEP/Keck-Array, POLAR1

- Many of these experiments are making claims of r limits around 0.02 – but which ones will really deliver?

ACTpol

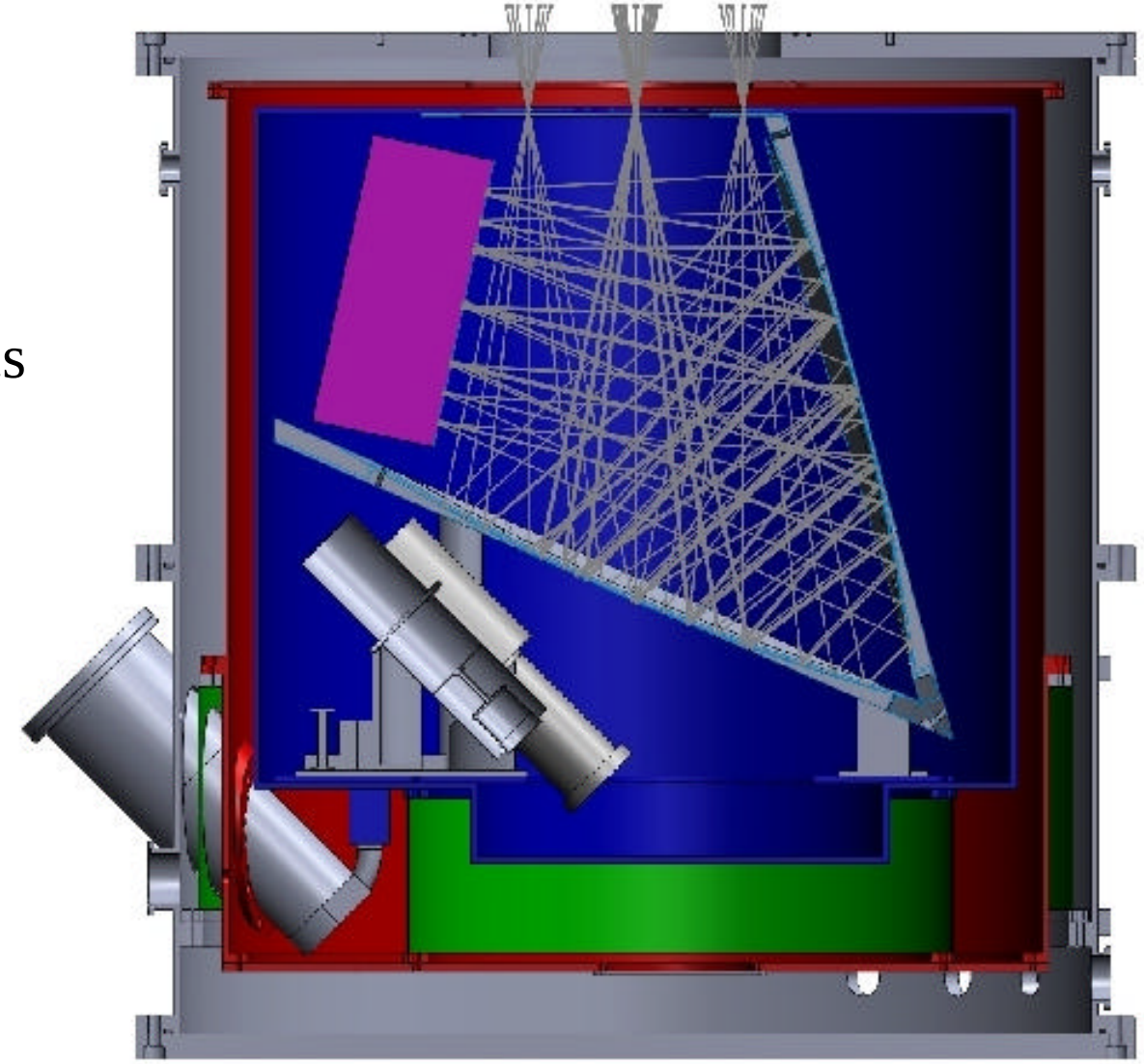
(Niemack et al., SPIE 2010)

- ACT is Existing 6m telescope
- Polarimeter being fabricated
- Deploy with 1 (of 3) arrays in first half 2012
- *Not* emphasizing gravity wave detection

Atacama **B**-mode **S**earch

- Smaller experiment
- 240 feeds at 150GHz
- 4 K all reflective optics
- 0.3 K detectors
- Mini telescope – 0.3m
- 1 cubic meter cryostat

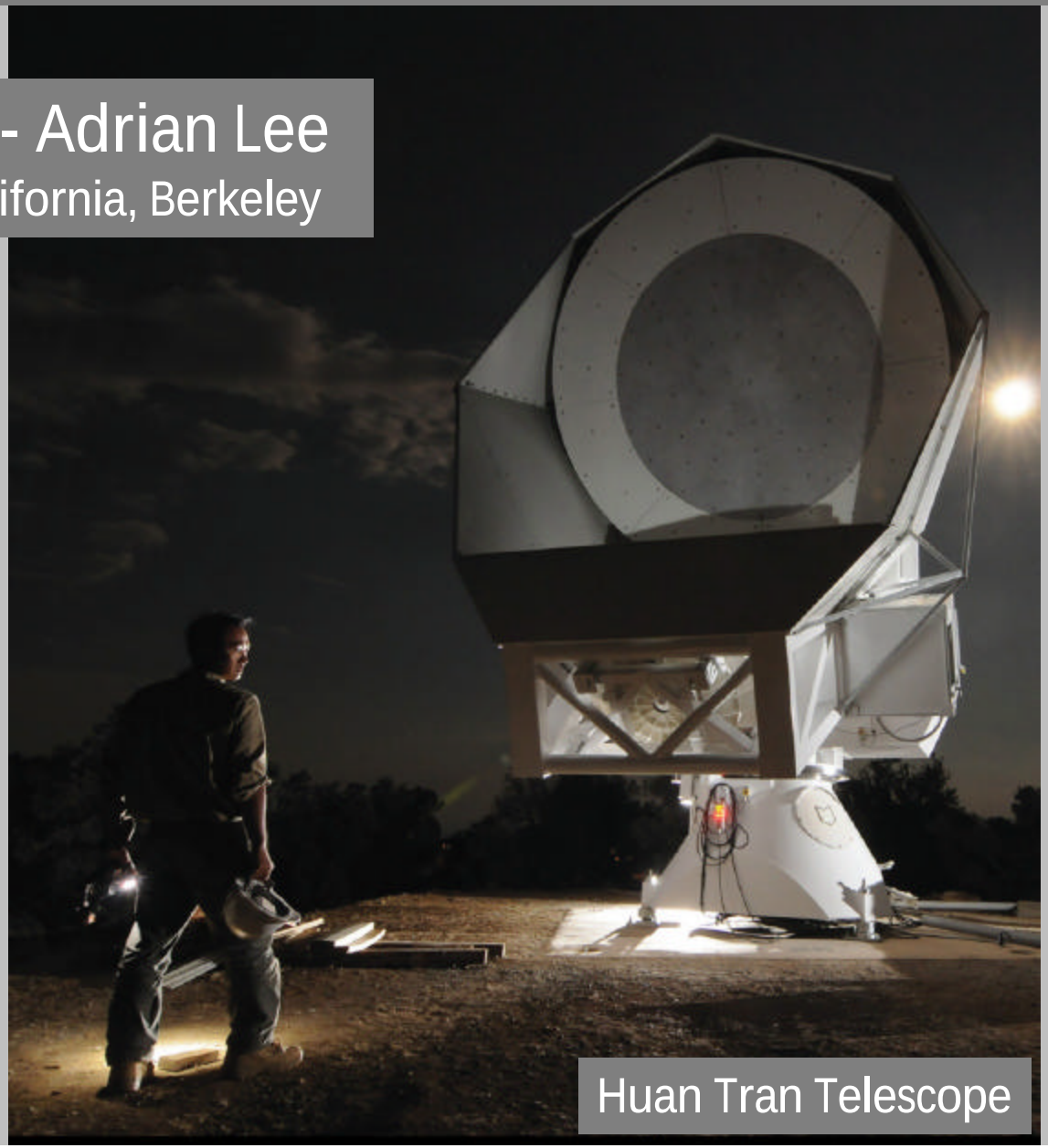
- r~0.03 depending on foregrounds etc.



NSF NIST JHU PRINCETON UNIVERSITY UBC CITA ICAT Ministerio de Educación Gobierno de Chile CONICYT

POLARBEAR: Polarization of Background Radiation

Slides from - Adrian Lee
University of California, Berkeley



Huan Tran Telescope

POLARBEAR Collaboration

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Daniel Flanigan
William Holzapfel
Jacob Howard
Zigmund Kermish
Adrian Lee P.I.
Marius Lungu
Mike Myers
*Haruki Nishino
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Erin Quealy
Christian Reichardt
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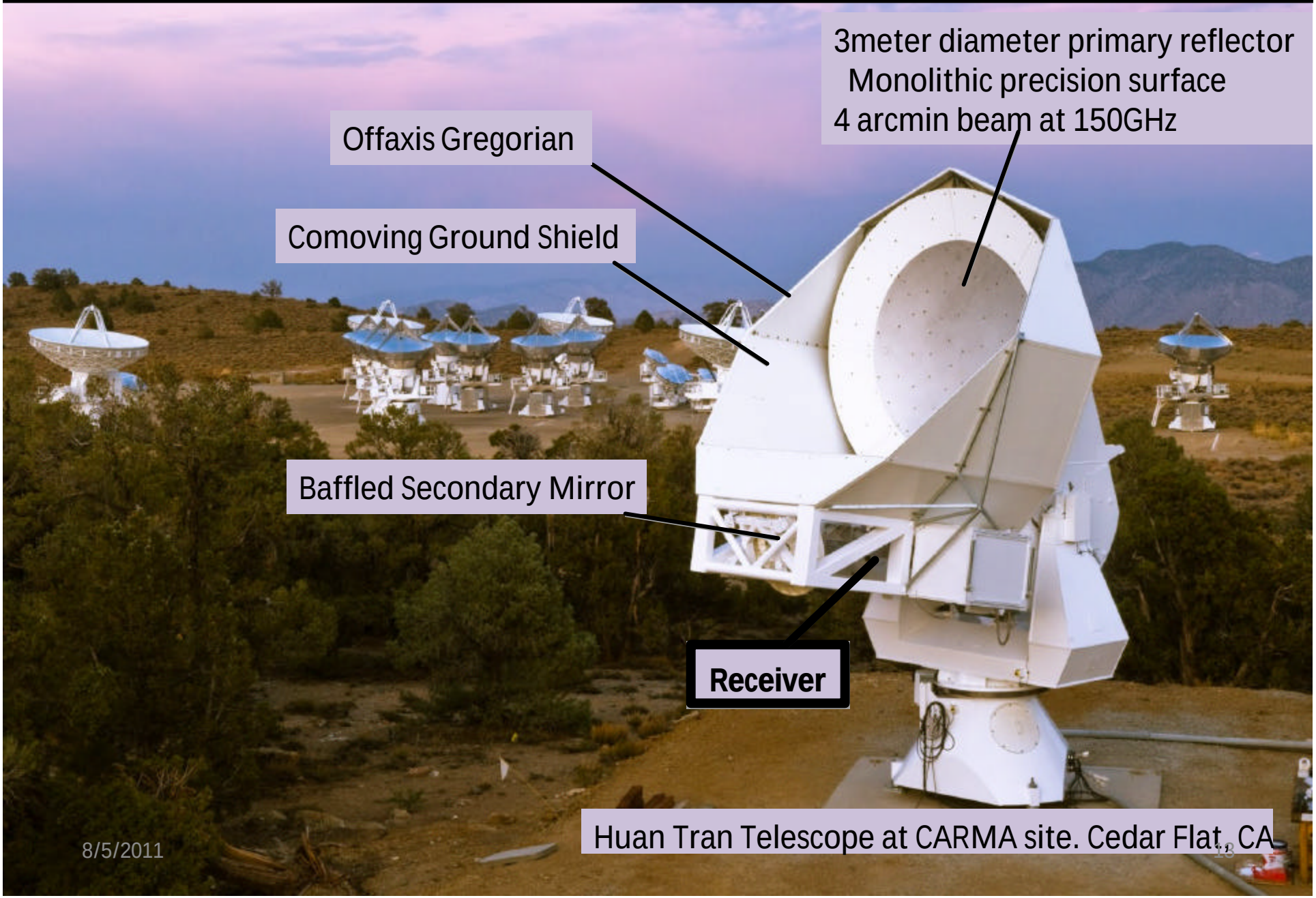
Cardiff University
Peter Ade
Will Grainger
Carole Tucker

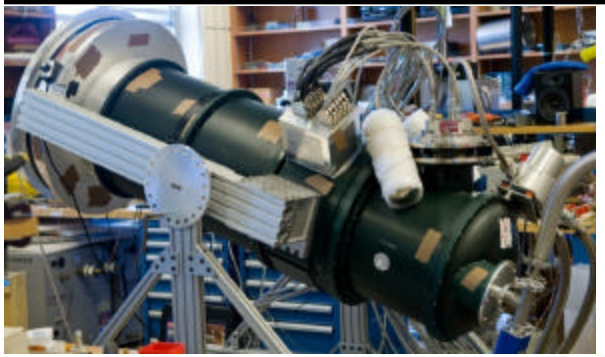
POLARBEAR-I is funded by NSF AST-061839

Huan Tran Telescope

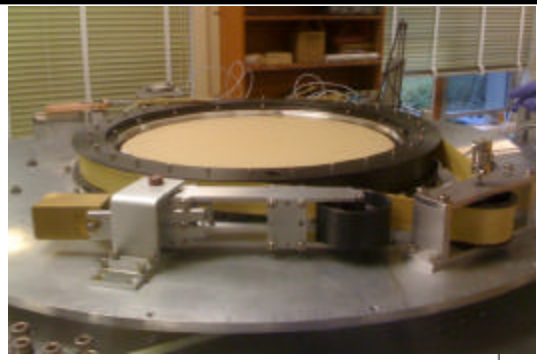


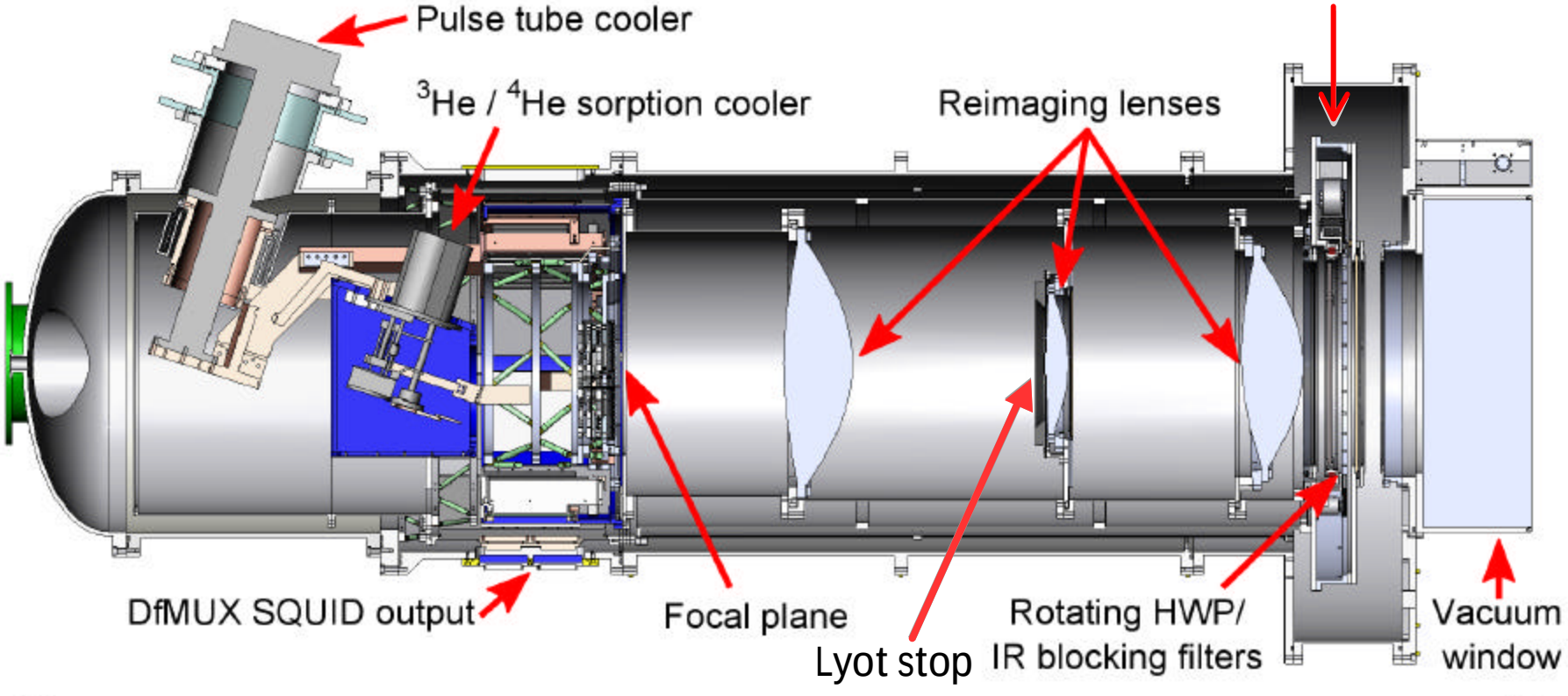
Huan Tran Telescope at CARMA site. Cedar Flat, CA

POLARBEAR-I Receiver

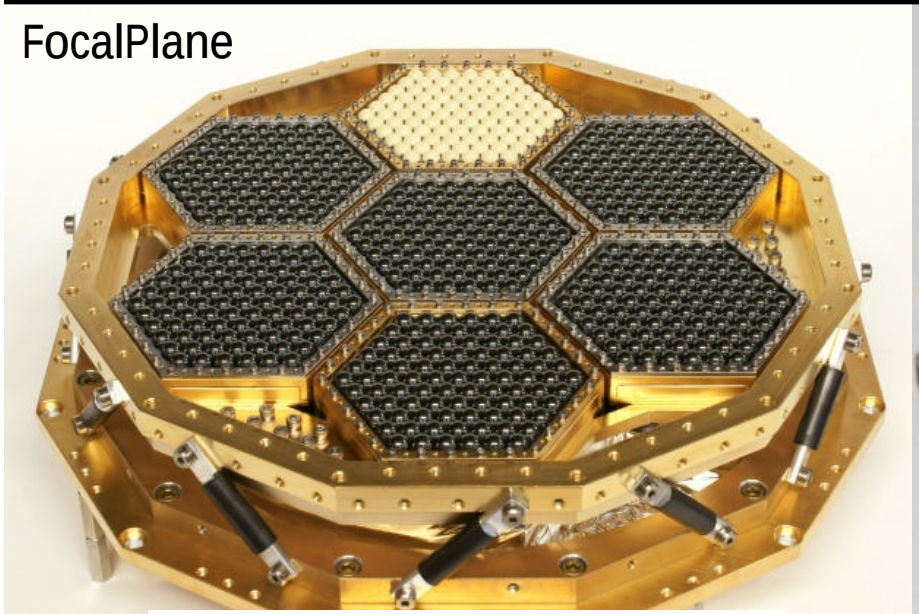


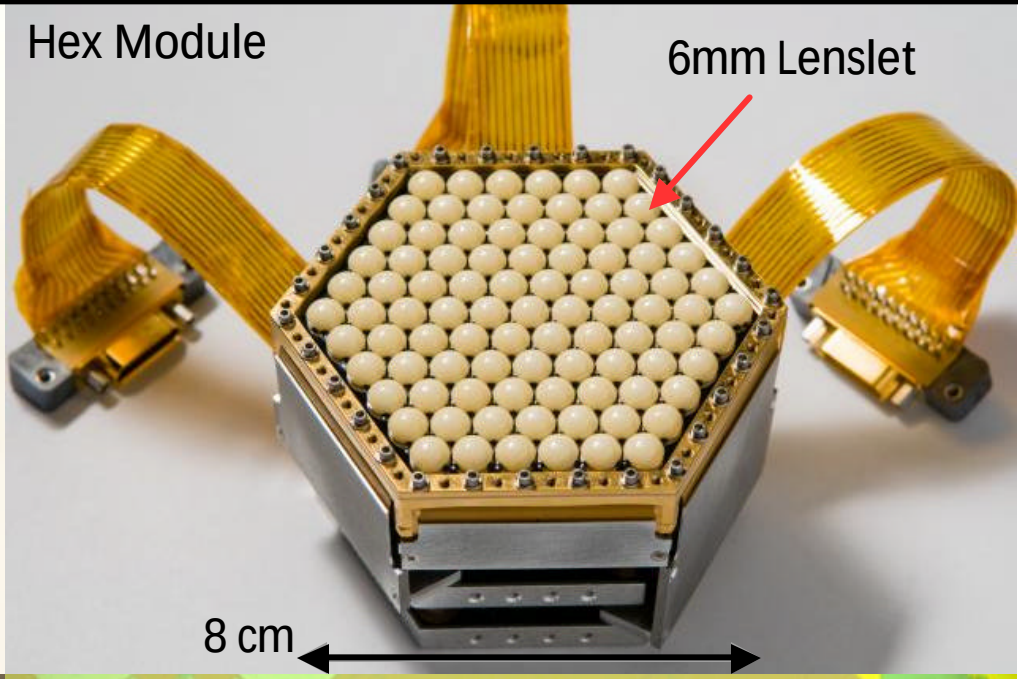
HWP

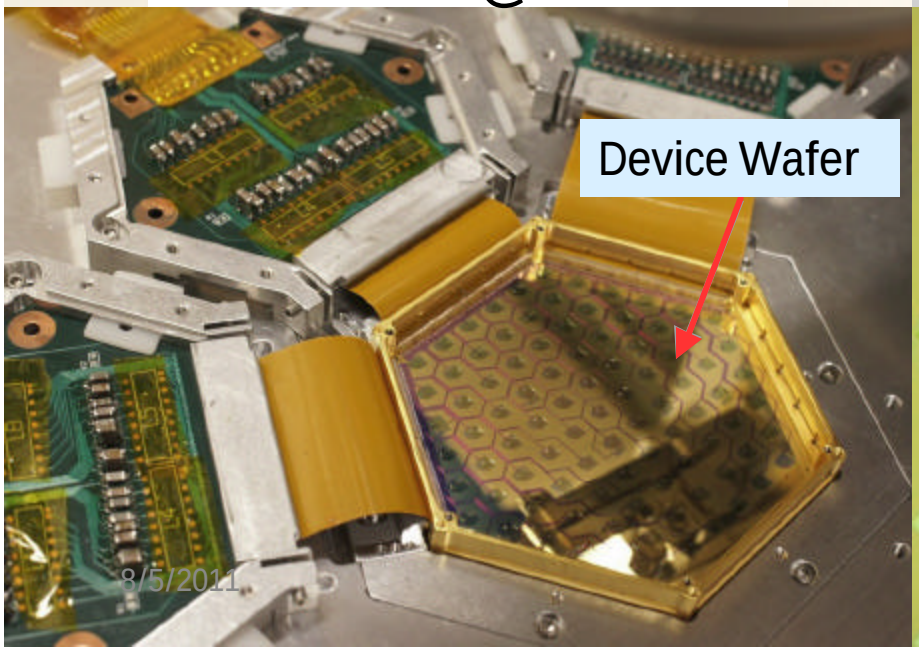


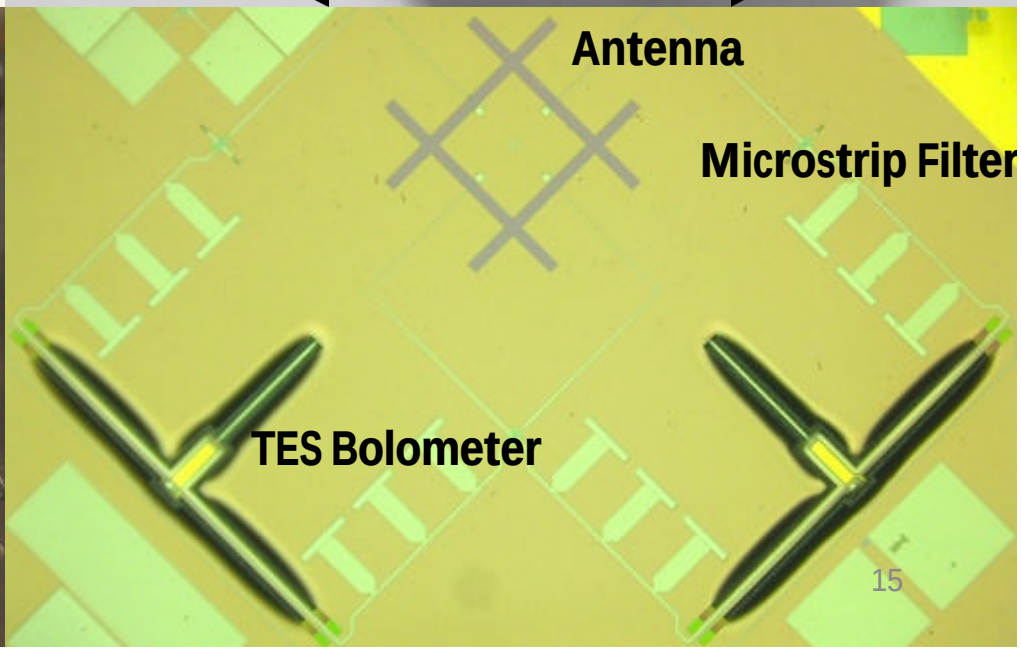


POLARBEAR-I Focal Plane



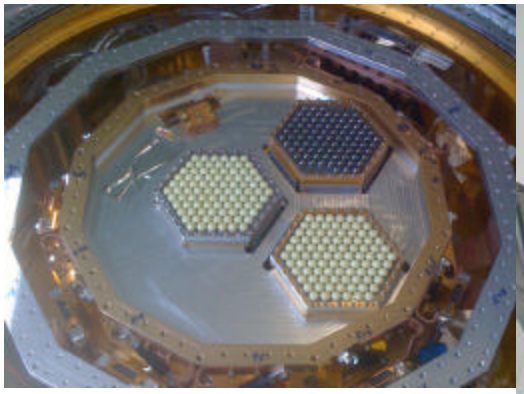


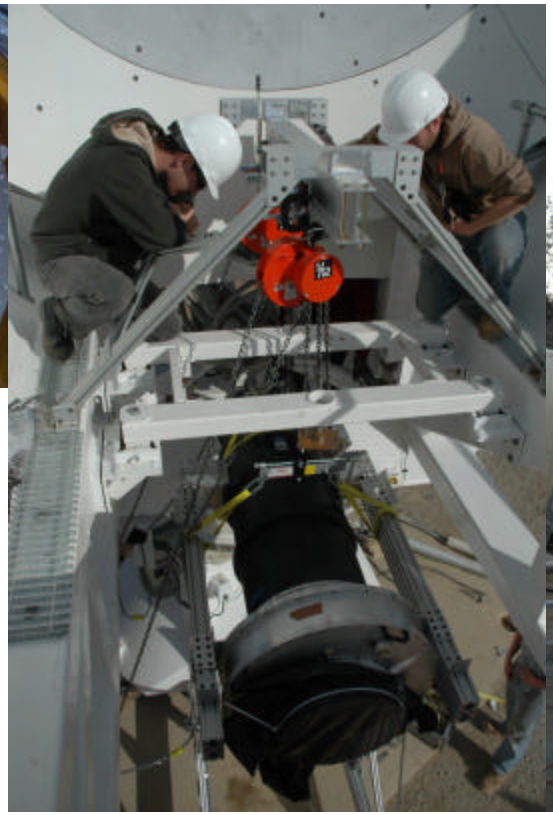




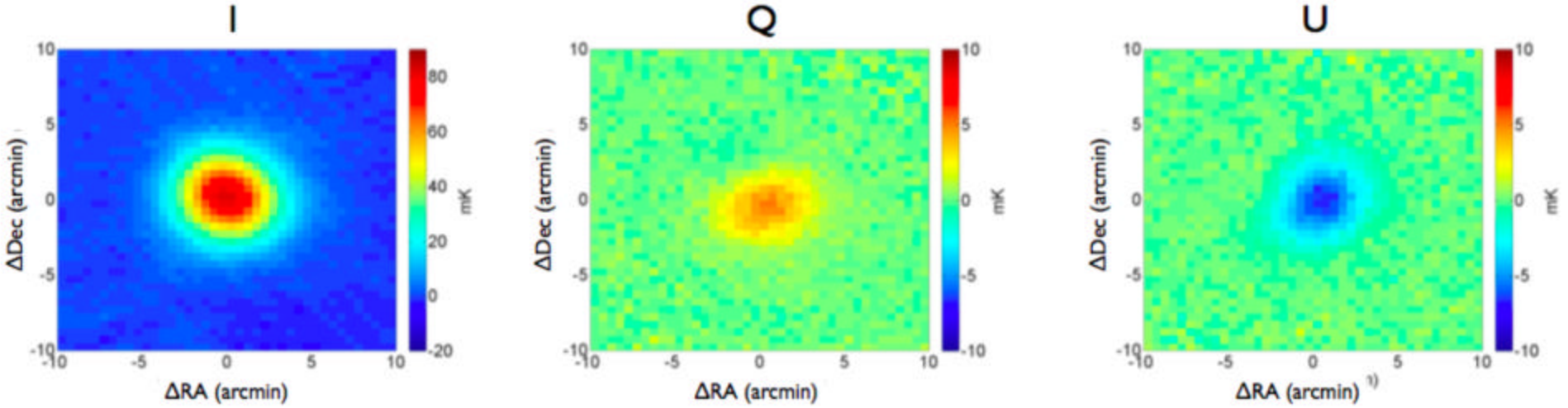
POLARBEAR Engineering Run

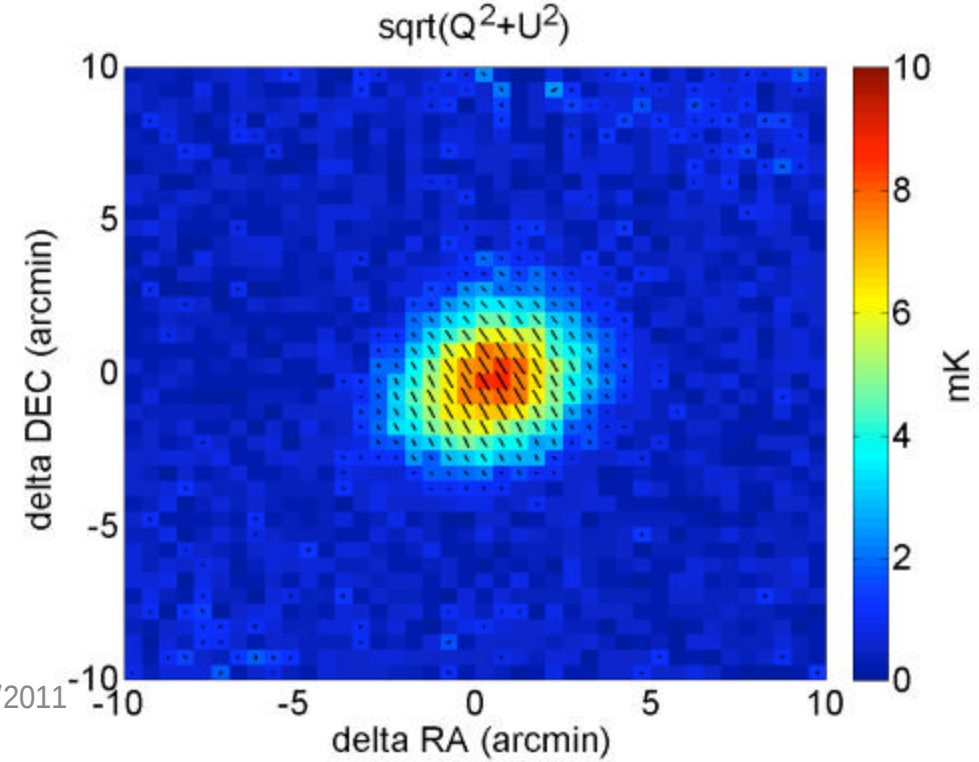
POLARBEAR-I Engineering Run
2010 Cedar Flat, CA





POLARBEAR Tau-A Measurements





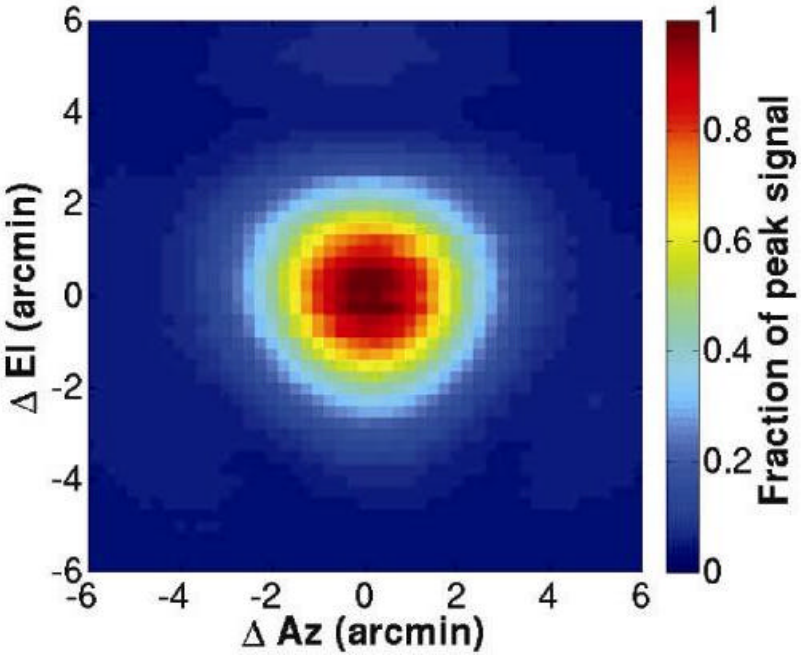
Pol. Magnitude and angle agree with Aumont et al., A&A 514 A70 (2010)

2 hours of data

POLARBEAR Detector Sensitivity

- Receiver (end-to-end) efficiency of 46%
- Implies detector efficiency of 71%
- Engineering run noise limited by Cedar Flat sky temperature
- Projected NET_{PIXEL} = 340 $\mu K_{CMB} \cdot \sqrt{s}$ in Chile

POLARBEAR Beam Properties

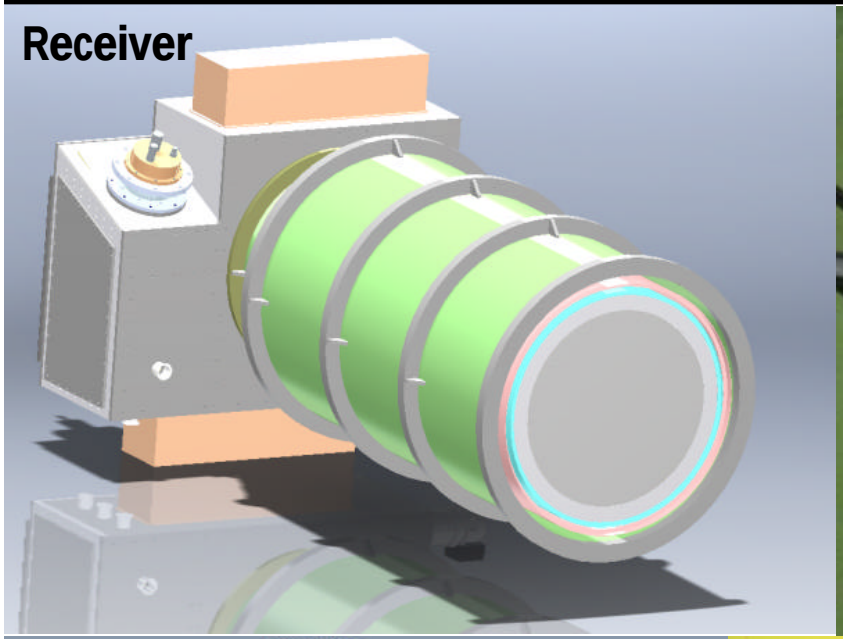


Co-added map of Jupiter

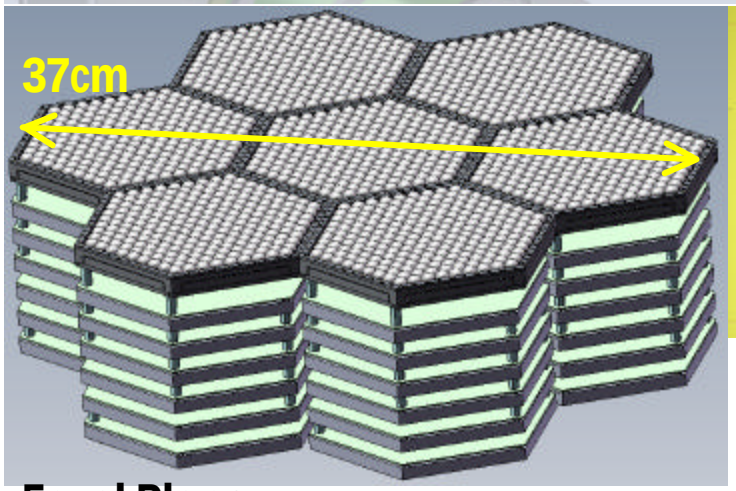
Effect	Measured (Eng. run)	Required for r = 0.025*
Differential Pointing	0.41”	1.1”
Differential Ellipticity	0.5%	2.9%
Differential Beam Size	0.4%	1.5%

*Requirements are relaxed when HWP, sky rotation included

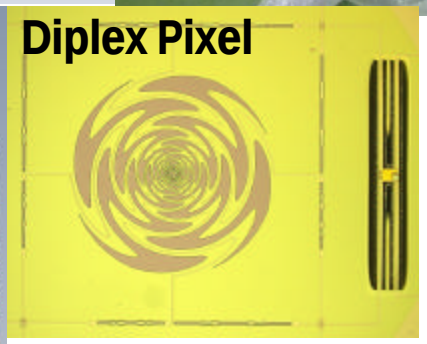
POLARBEAR-II Receiver

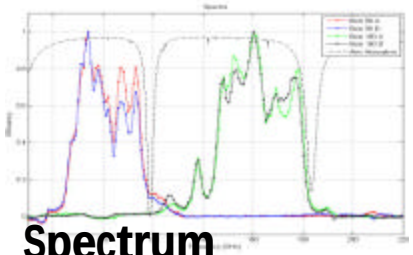


Receiver is being built at KEK Japan



Focal Plane

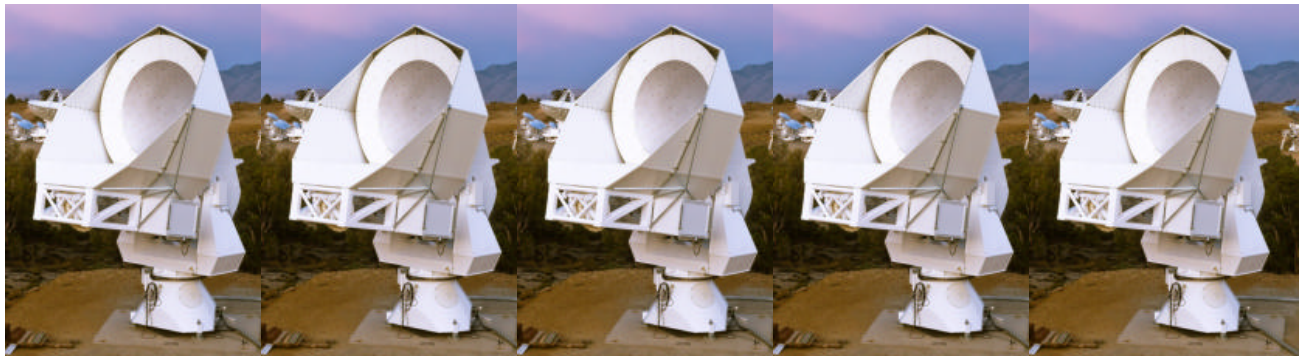




Spectrum

- Receiver Upgrade
- Focal Plane: Multichroic diplexed (90 & 150 GHz) pixel
- 1500 pixels / 6000 bolometers
- Detectors built at Berkeley
- KEK led project

POLARBEAR-Extended



- Investigating 3-6 telescopes at PB site in Chile
- Each telescope uses a PB-II type receiver

  (90/150 GHz or 150/220 GHz)
- Will produce high-quality lensing maps over a large fraction of the sky
- Overlap with optical surveys for cross-correlation science (BOSS, Herschel, etc)

Telescopes 2,3 fully funded by the James Ax Foundation at UCSD

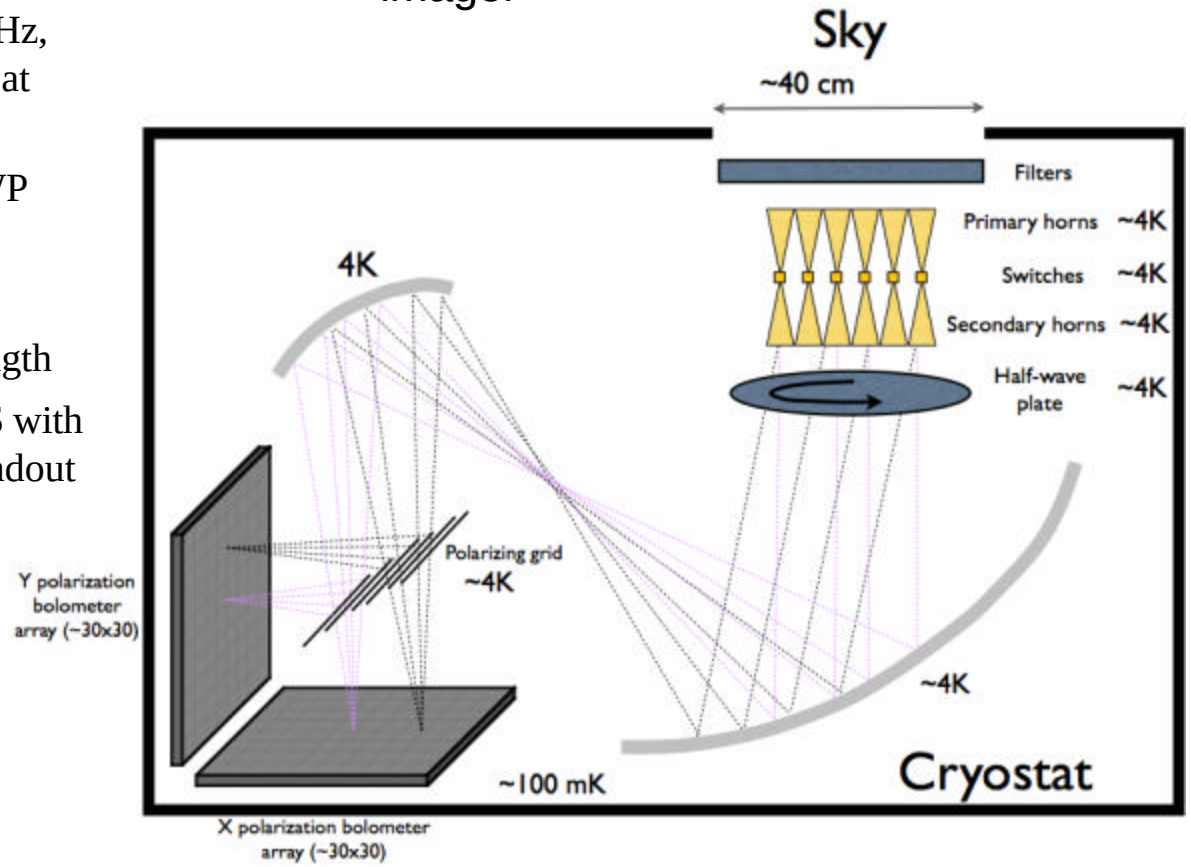
QUBIC: QU Bolometric Interferometer for Cosmology

? QUBIC Concept:

- Observe sky directly with 20x20 array of corrugated horn antennas
- Image fringe patterns on focal planes
- Frequency: 1st module150 GHz, 25% BW, total of 6 modules at 100, 150, 220 GHz
- Polarization modulation: HWP
- Horn FWHM: 14° FoV
- Optical combiner: off-axis Gregorian 300 mm focal length
- Detectors: 2x1024 NbSi TES with SQUID+SiGe ASIC mux readout

? Synthetic imager:

- Fringe superposition results in synthesized beam ~ 0.5° FWHM
- Scan sky with synthesized beam, make maps and power spectra as with an imager



QUBIC: QU Bolometric Interferometer for Cosmology

Team: APC, Brown, IAS, IRAP, CSNSM, Manchester, Milan, NUI, Richmond, Rome, UW-Madison

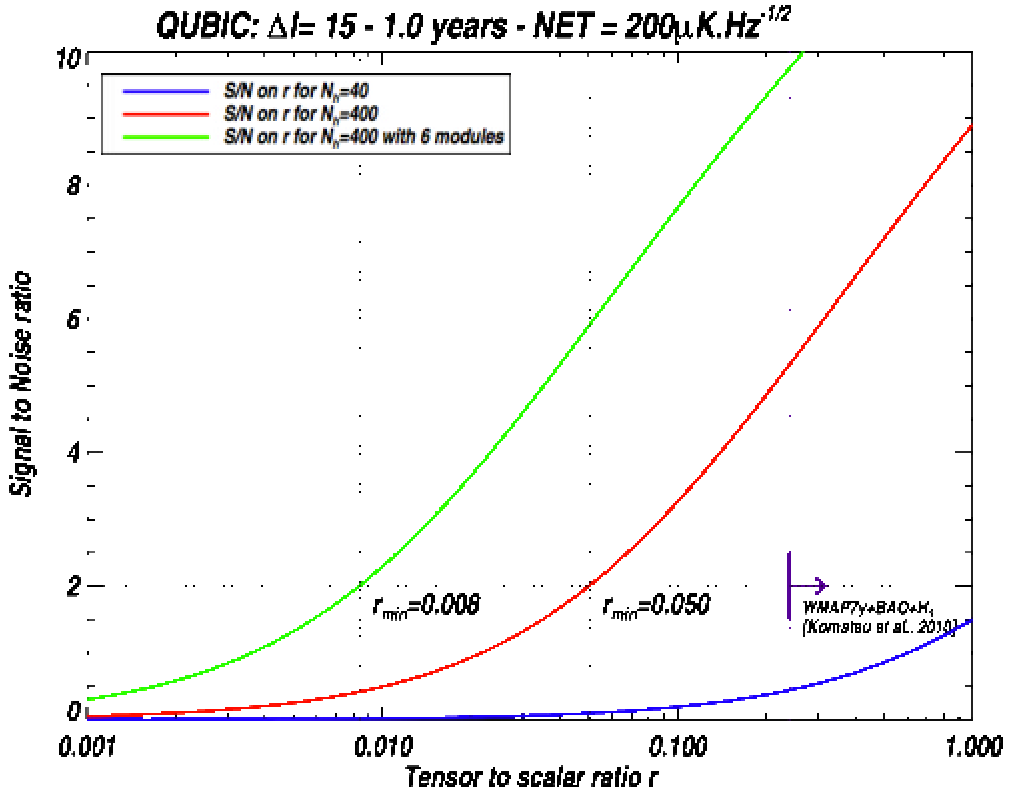
Deployment plan:

- 2011 Funded for first module
- 2011/12: R&D finalization of components
- 2013: 1st module integration, first light in lab
- 2014-...: 1st module observations from Dome C
- 2014-...: Other modules constructed and installed (100 GHz and 220 GHz)

Advantages – systematics:

- Views sky w/o mirrors or lenses
- Self-calibration: waveguide switches allow observation of calibration source with one pair of horns at a time; redundant baselines should measure identical visibilities.

arXiv:1010.0645
Astroparticle Physics 34 (2011) 705–71



SPTpol: CMB polarization *& Cluster Survey*

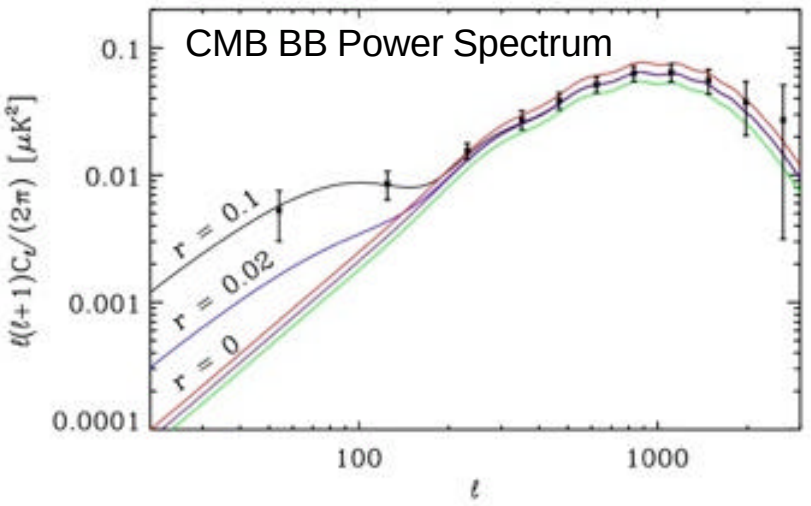
A 760 pixel polarimeter for the SPT, sensitive at 100 and 150 GHz

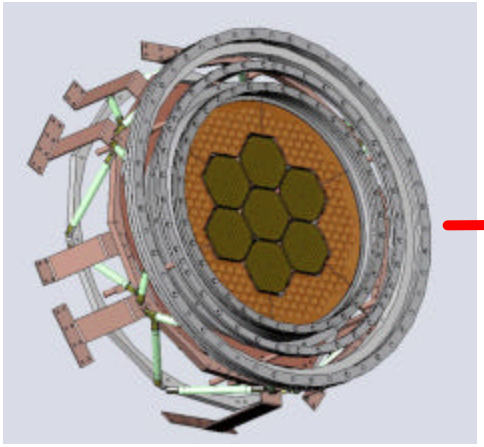
Will map 600 deg^2 to factor of 6x and 4x deeper than SPT-SZ at 100, 150 GHz

Designed for CMB Polarization, but ...

-should find ~1000 clusters

-catalog will go to lower mass and higher redshift than SPT-SZ survey

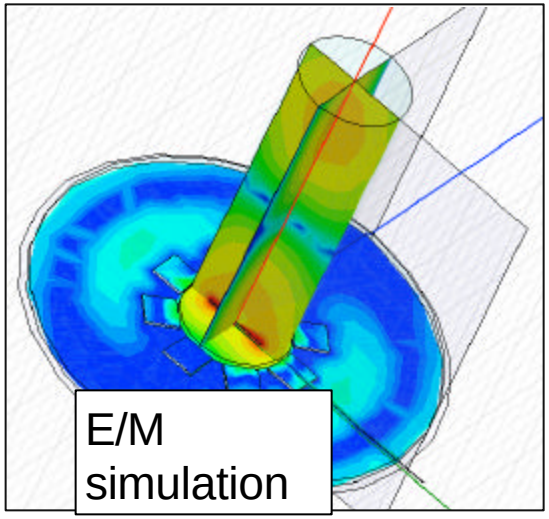


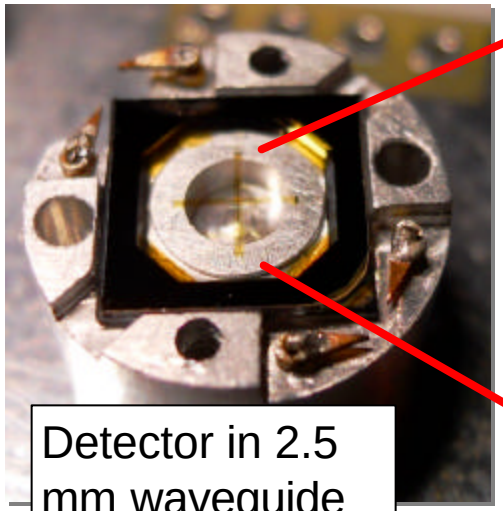


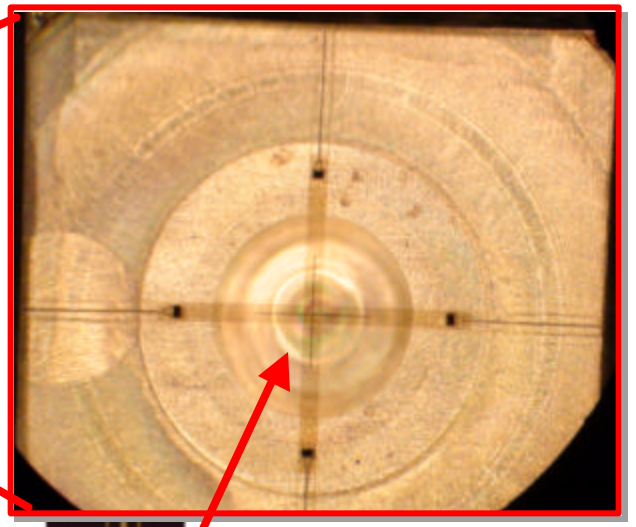
Abby Crites (U. Chicago)

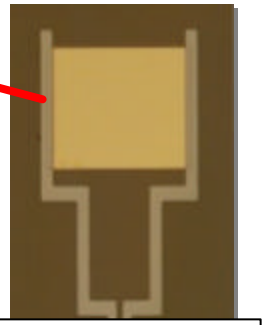
SPTpol 90 GHz Detectors (Argonne)

- Dipole absorbers in a waveguide
- Mo/Au TES Tc=0.500 K
- Assembled in individual holders with contoured feedhorns

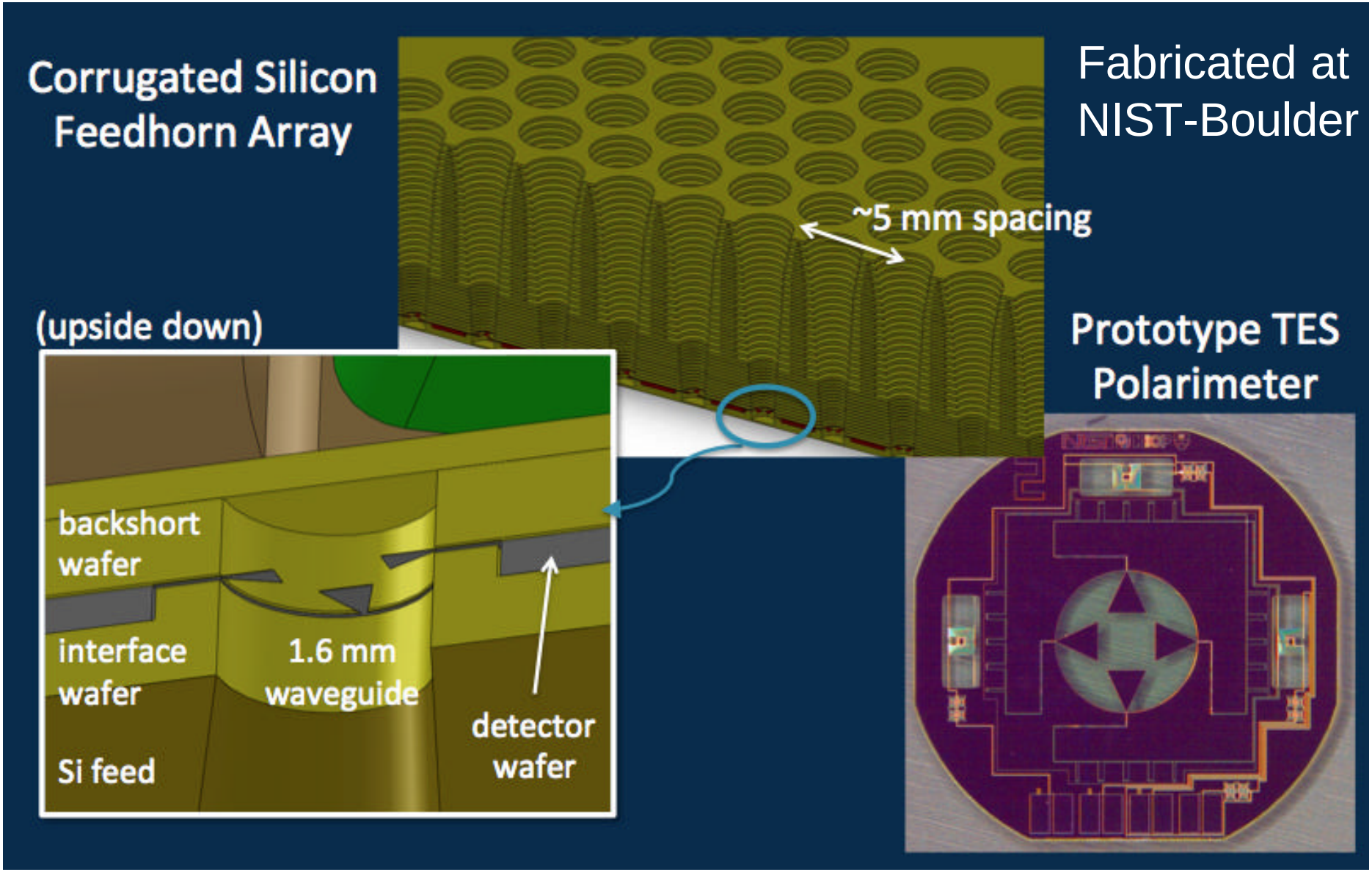








SPTpol 150 GHz Detectors (NIST)



BICEP1 - BICEP2 - Keck Program

BICEP1 (2006 – 2008)
Degree-scale polarimeter
96 NTD Ge bolometers
Best published limits on
Inflationary polarization

BICEP2 (2010 – 2012)
Same optics as BICEP1
512 TES bolometers at 150 GHz
10x faster than BICEP1

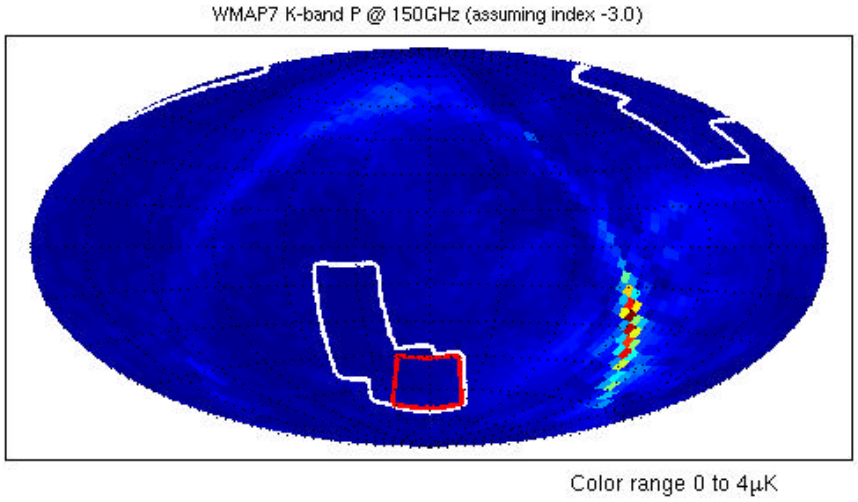
Keck-Array (2011 – 2015)
5 BICEP2 like receivers in 3 bands
2300 TES bolometers
>30x faster than BICEP1

BICEP/Keck Approach to Inflation Detection:

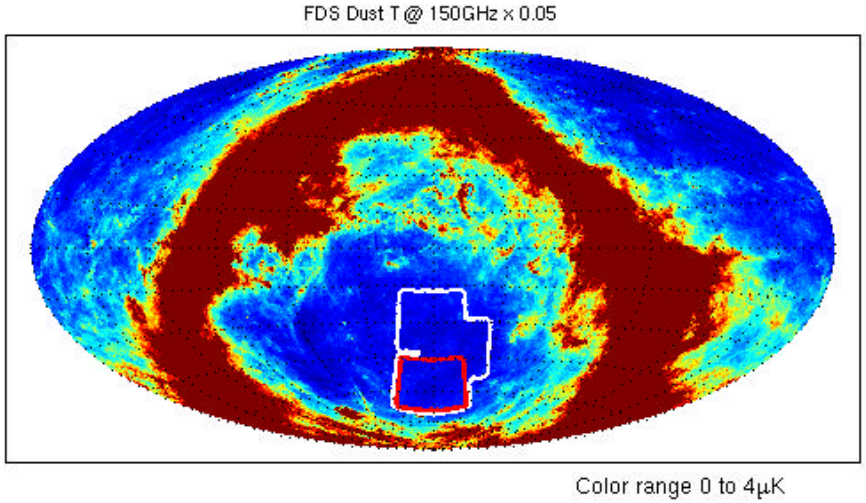
- Use small aperture - compact, cheap, mass-producible telescopes. (Single purpose)
- Observe relentlessly from the South Pole through the long Antarctic night
- Observe only the amount of sky needed to separate E/B-modes at l=90 bump
- Observe at the “sweet spot” frequency of 150GHz until B-modes detected
  - We estimate foregrounds equiv to around r=0.02 in our field

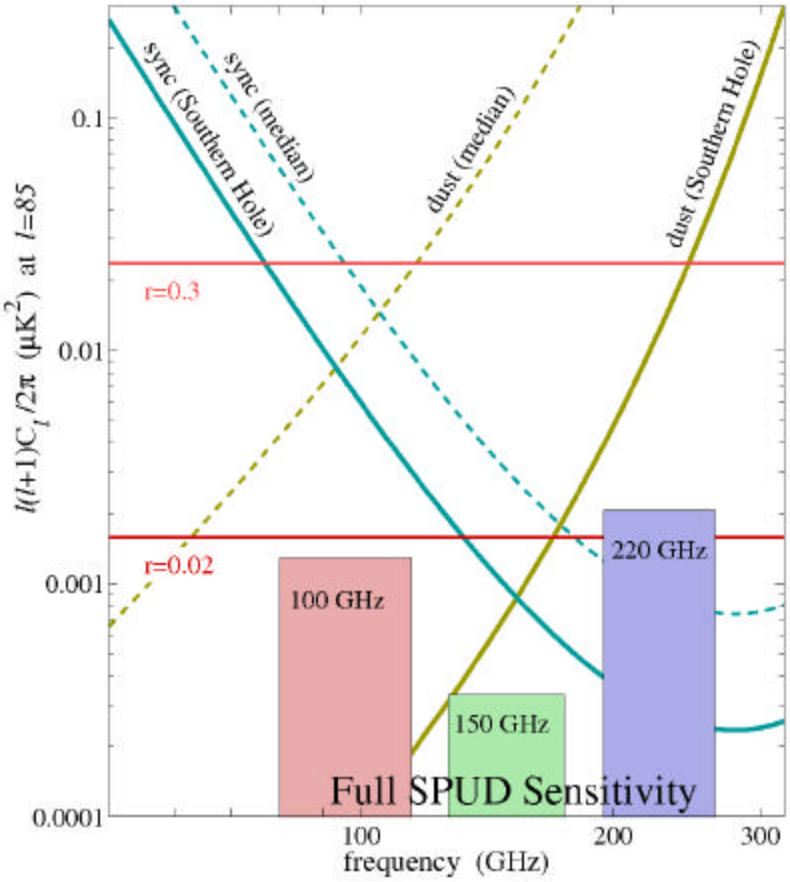
BICEP2/Keck Approach: Observe the Southern Hole at 150 GHz until you see B-modes – Cosmological or otherwise!

sync



dust



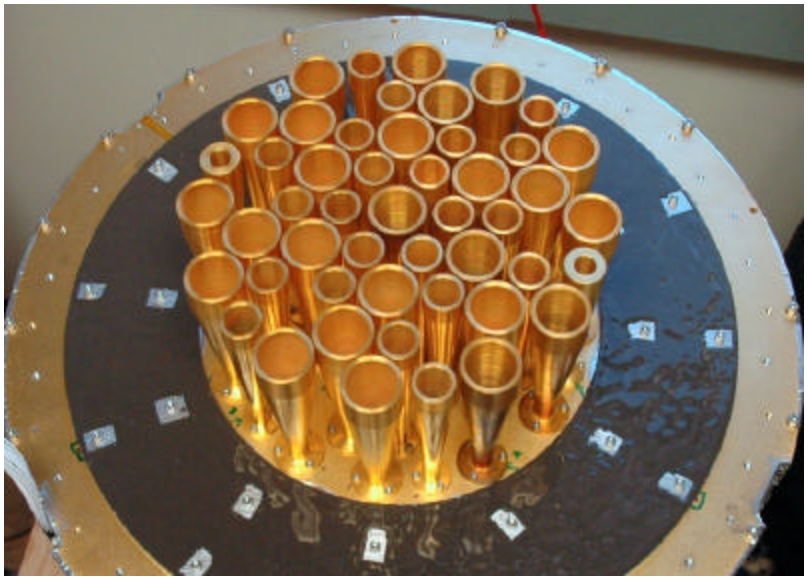


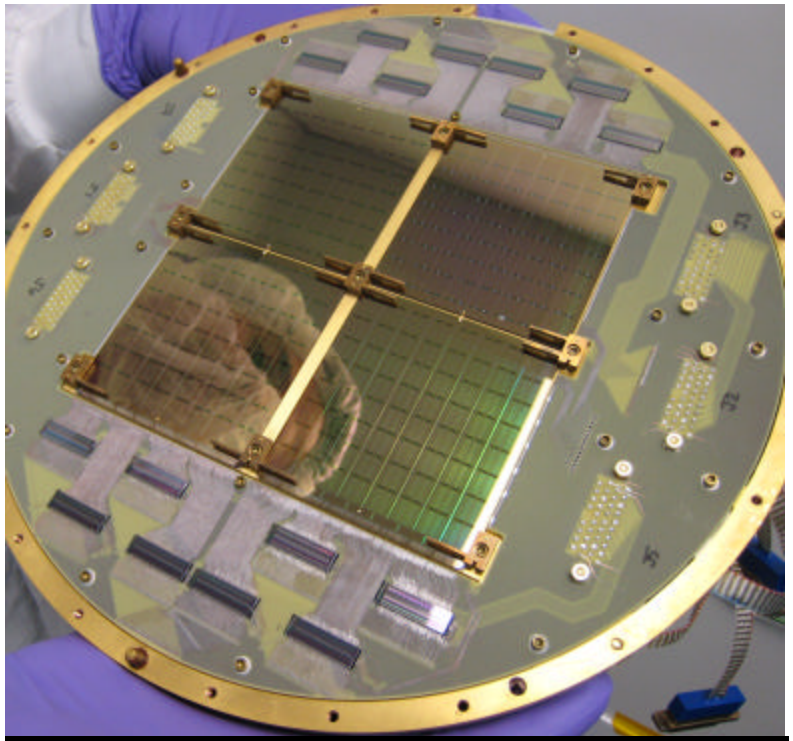
CP & John Kovac

Why observe from the South Pole?

- Extremely stable, dry atmosphere
  - Due to cold and altitude ~ 10,500 feet.
- Sun below horizon for 6 months
  - Install/upgrade in summer (day), observe in winter (night)
- Fantastic observing efficiency:
  - Best target region: “Southern Hole” observable 24/7
  - Easy access to telescope (!?)
  - Simple, low-cost (to us) logistics (!?)

BICEP2: 10-fold increase in mapping speed:

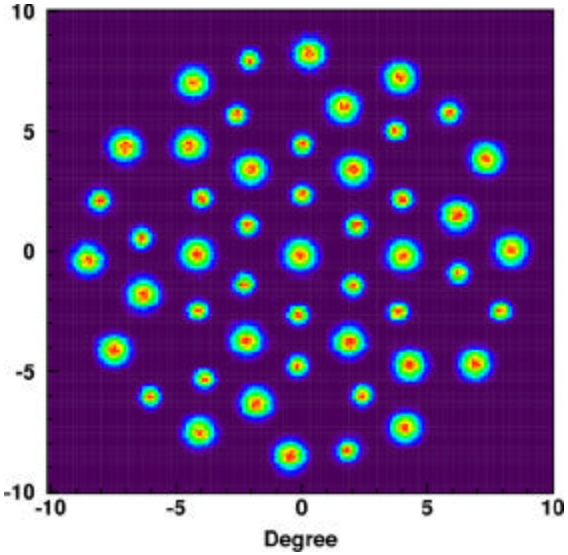


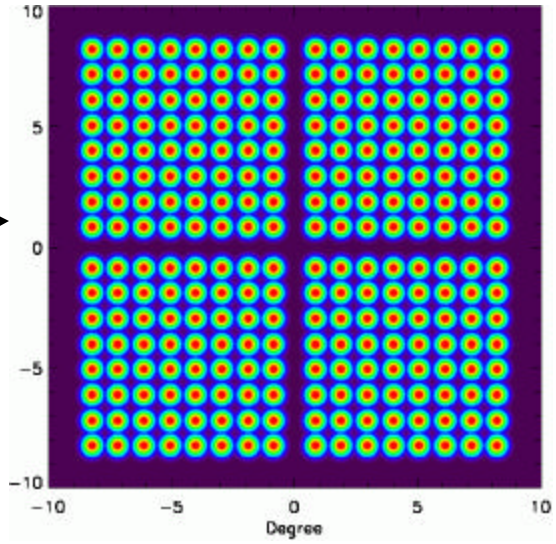


JPL : antenna-coupled TES arrays

BICEP1

48
150 GHz
detectors





BICEP2

512
150 GHz
detectors

Dec 2009:
Putting BICEP2 together in DSL

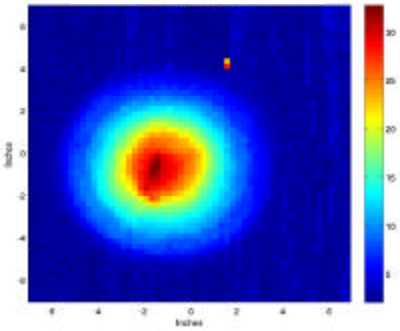
Justus Brevik

Precision Beam Mapping

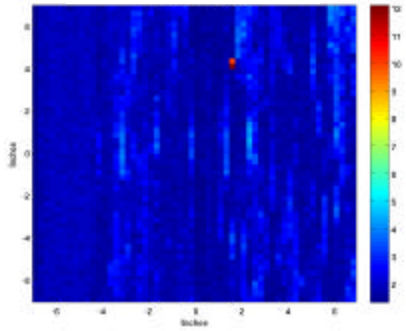
View toward station & mast source

Response to a Polarized Source

A Polarization

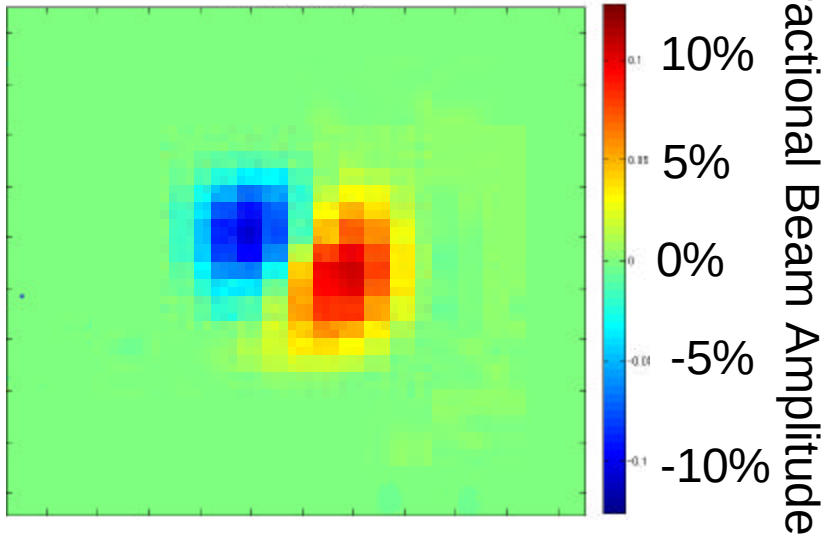


B Polarization



Response to an Unpolarized Source

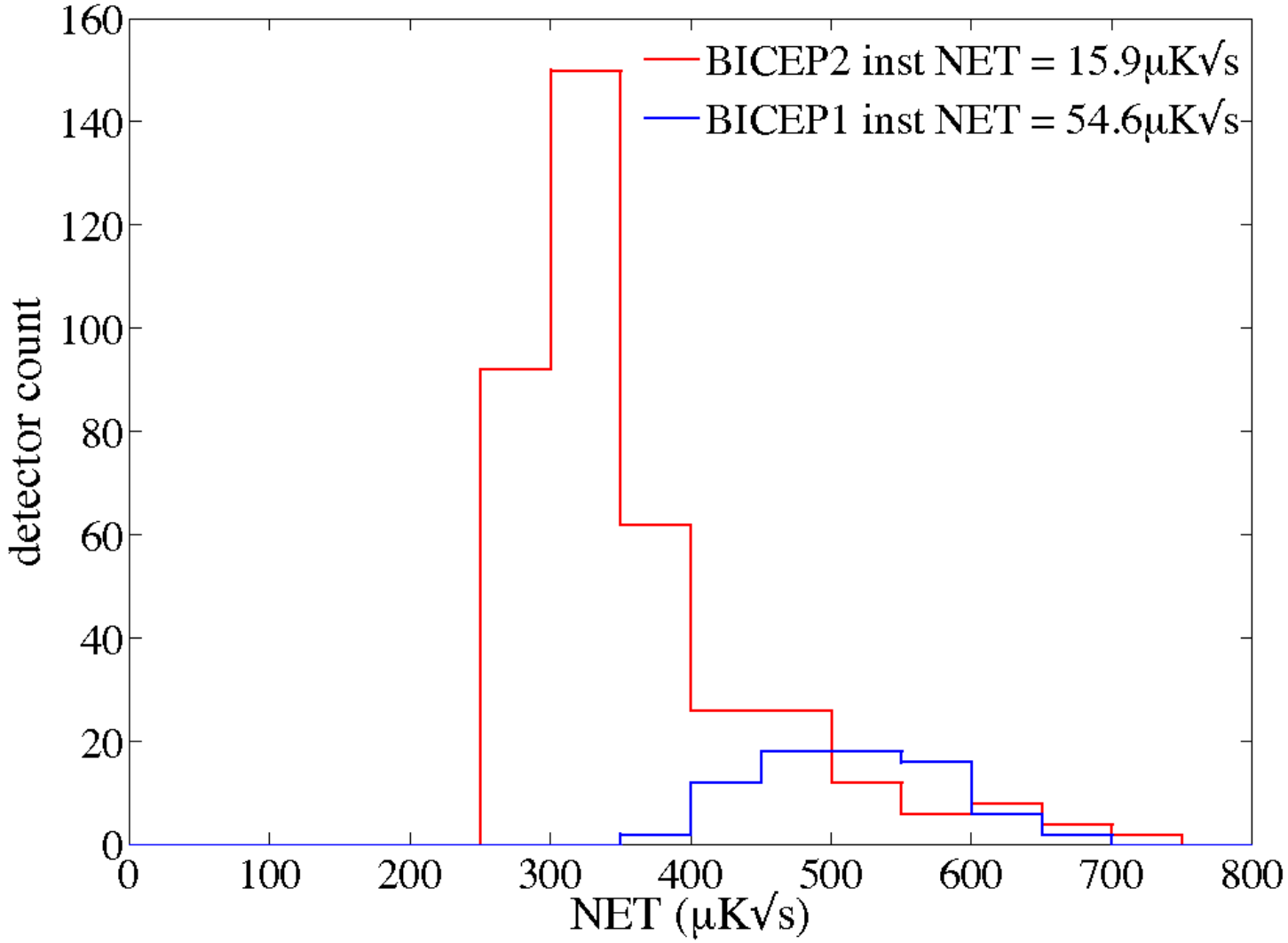
A-B Difference Map



Differential Pointing

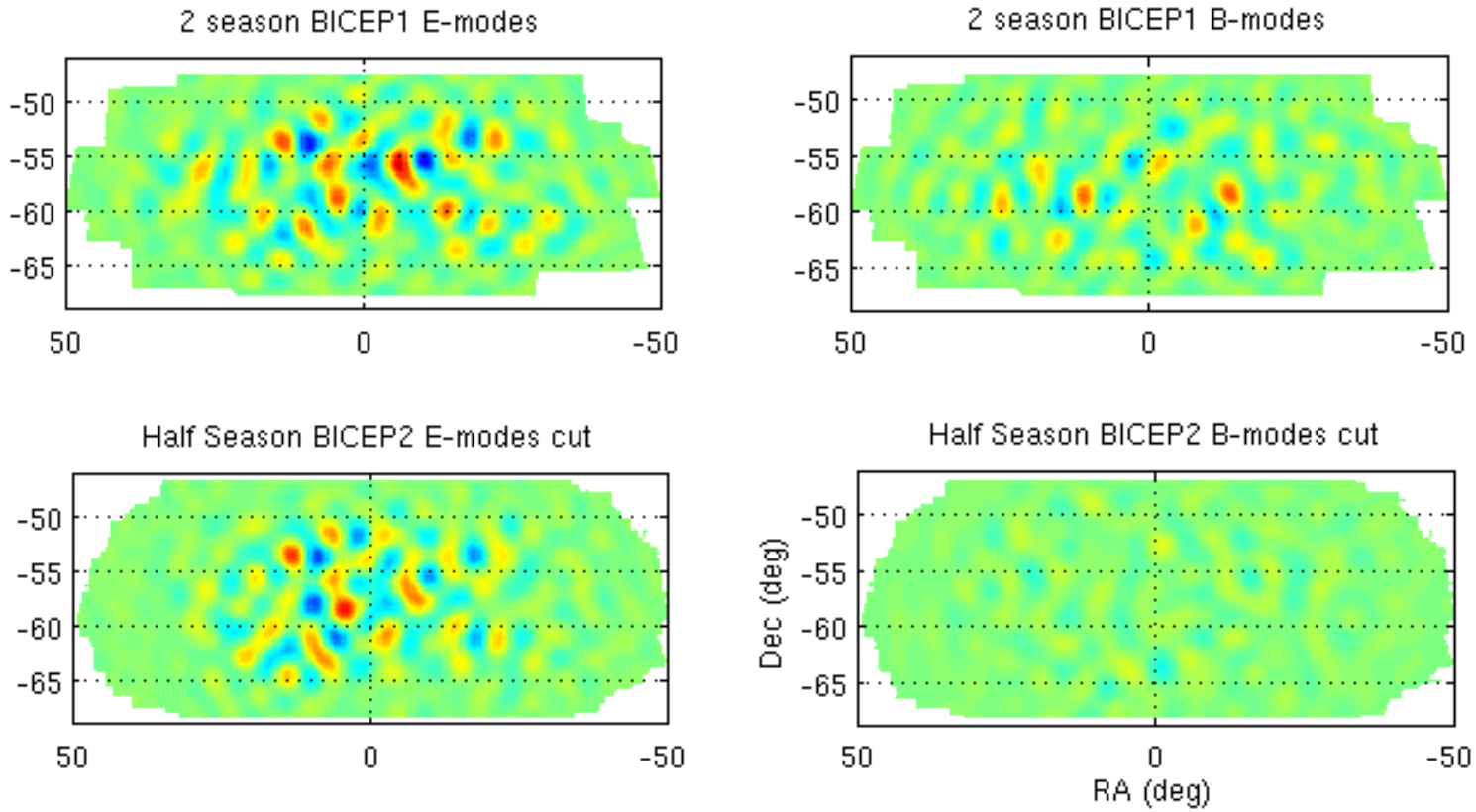
- From far-field maps of unpolarized sources
  - <u>knowledge is extremely good</u>
- 2’ pointing offset between A & B channels
- Heavily mitigated by “deck” rotation – further suppression in analysis

BICEP2 Proven On Sky Sensitivity



Factor 12 better than BICEP1!

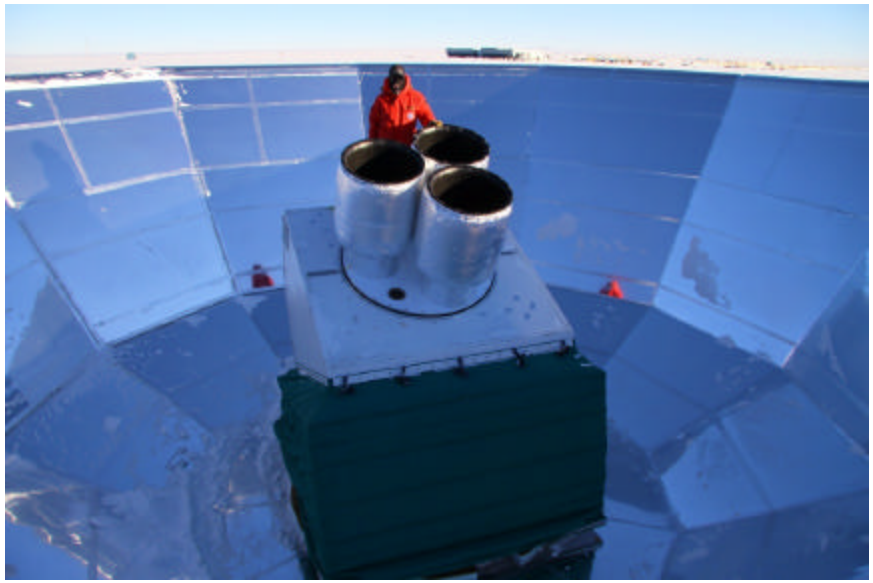
BICEP2 Prelim. E/B Maps



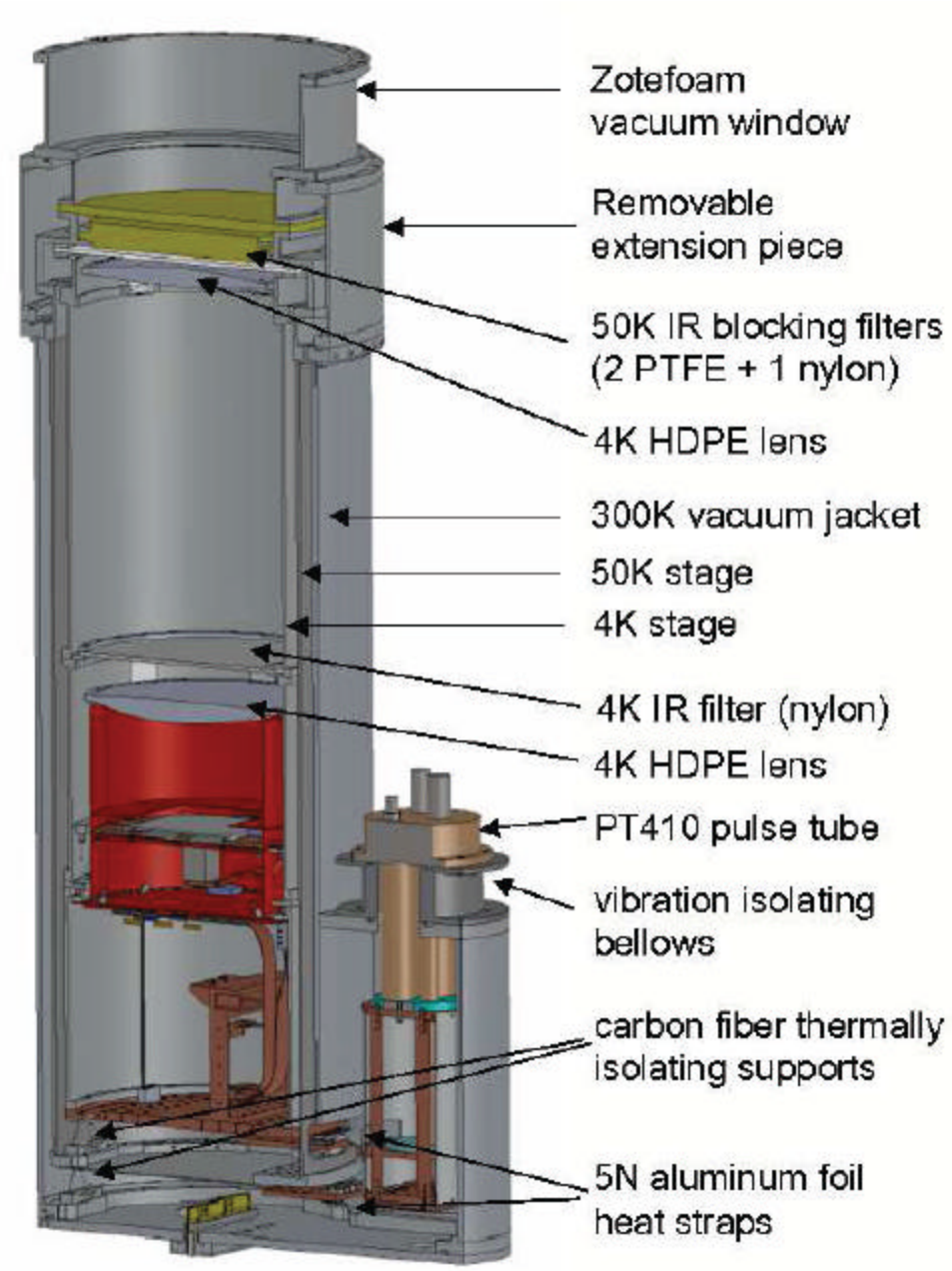
- Using only half a season of data BICEP2 B-mode maps already show far lower B-mode power than BICEP1
- 2 seasons of BICEP2 data already in the can! (and under analysis)

[Above are apodized maps filtered to 50 < ell < 120]

Keck Array

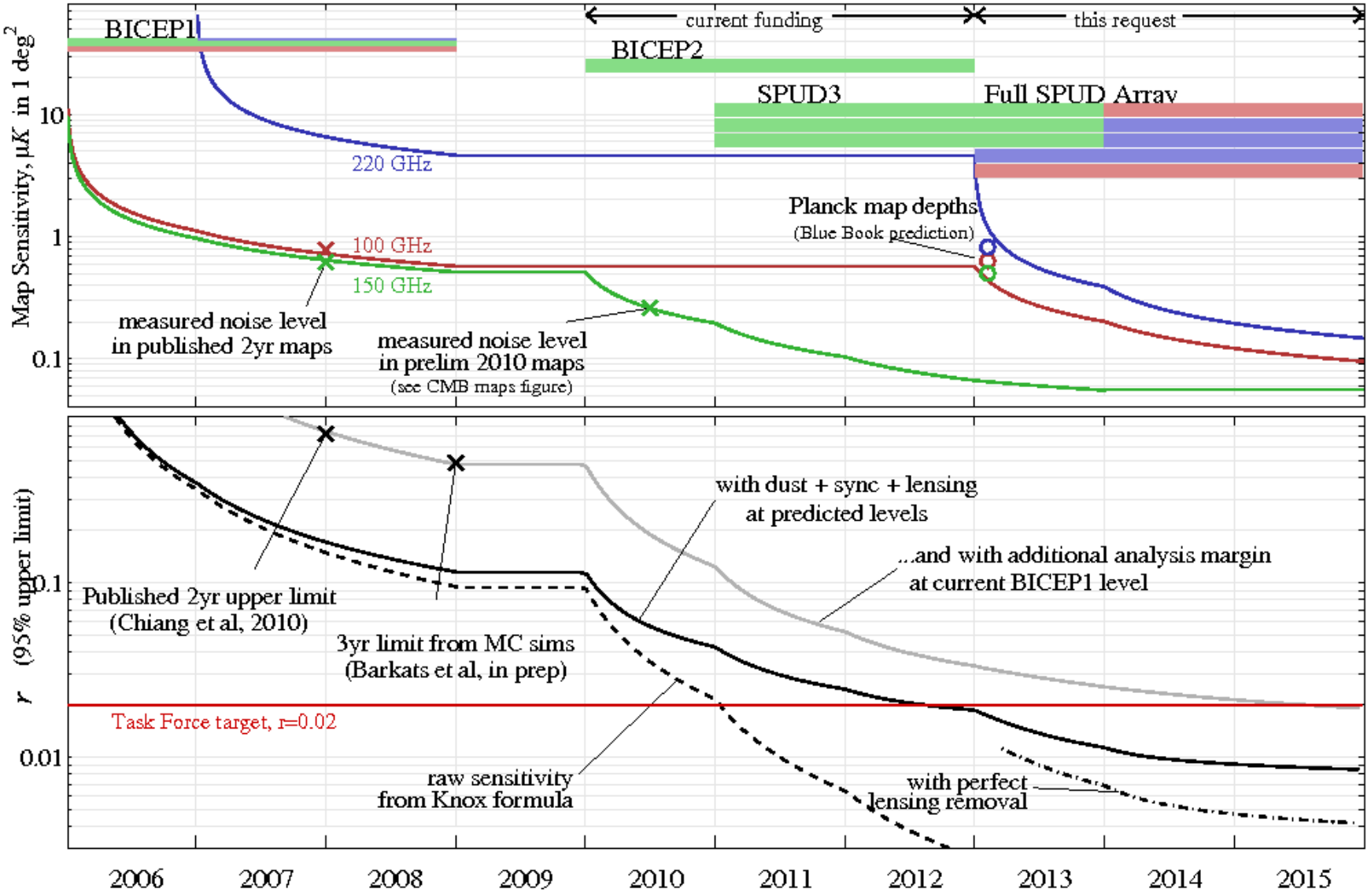


- Multiple copies of BICEP2 on the old DASI platform
- Pulse tube coolers – no more liquid helium
- 2011 season had 3 receivers, about to send 2 more



C. Sheehy

BICEP / Keck : map depth & sensitivity to *r*



We will detect B-mode

– will then go multi frequency to determine if cosmological

Beyond Keck: POLAR-1

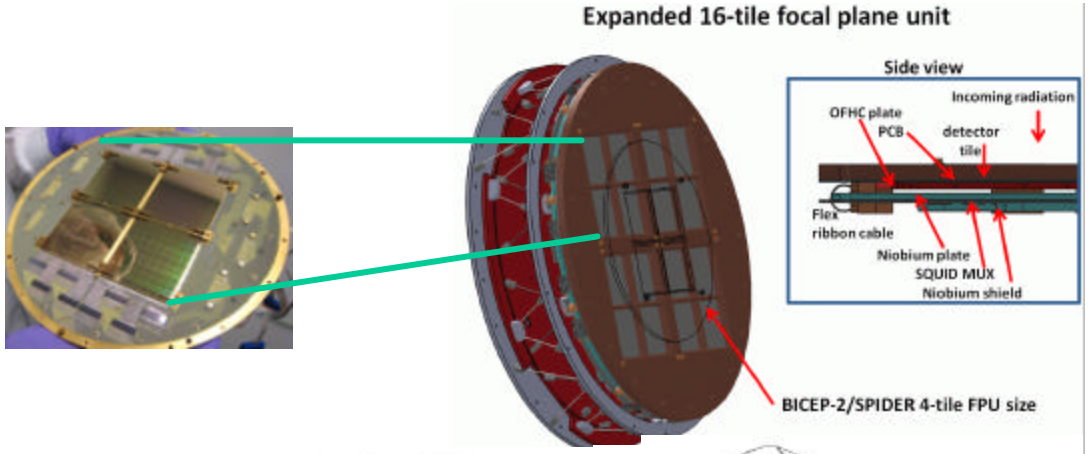
- a *very* high throughput CMB polarimeter

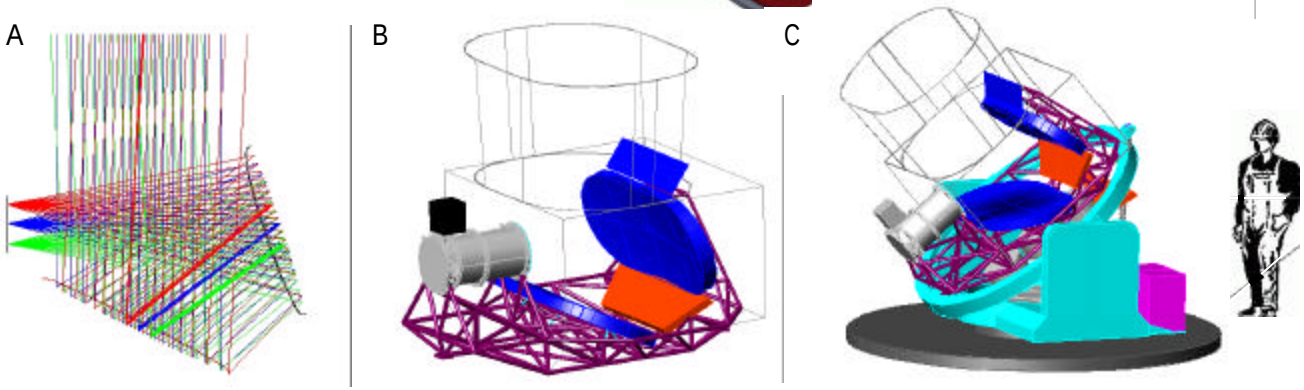
By 2013…

6,000 detector
focal plane

2m aperture
cross-Dragone
telescope

expectations:
r < 0.01
1.8 uK-arcmin
(300 deg^2 survey)





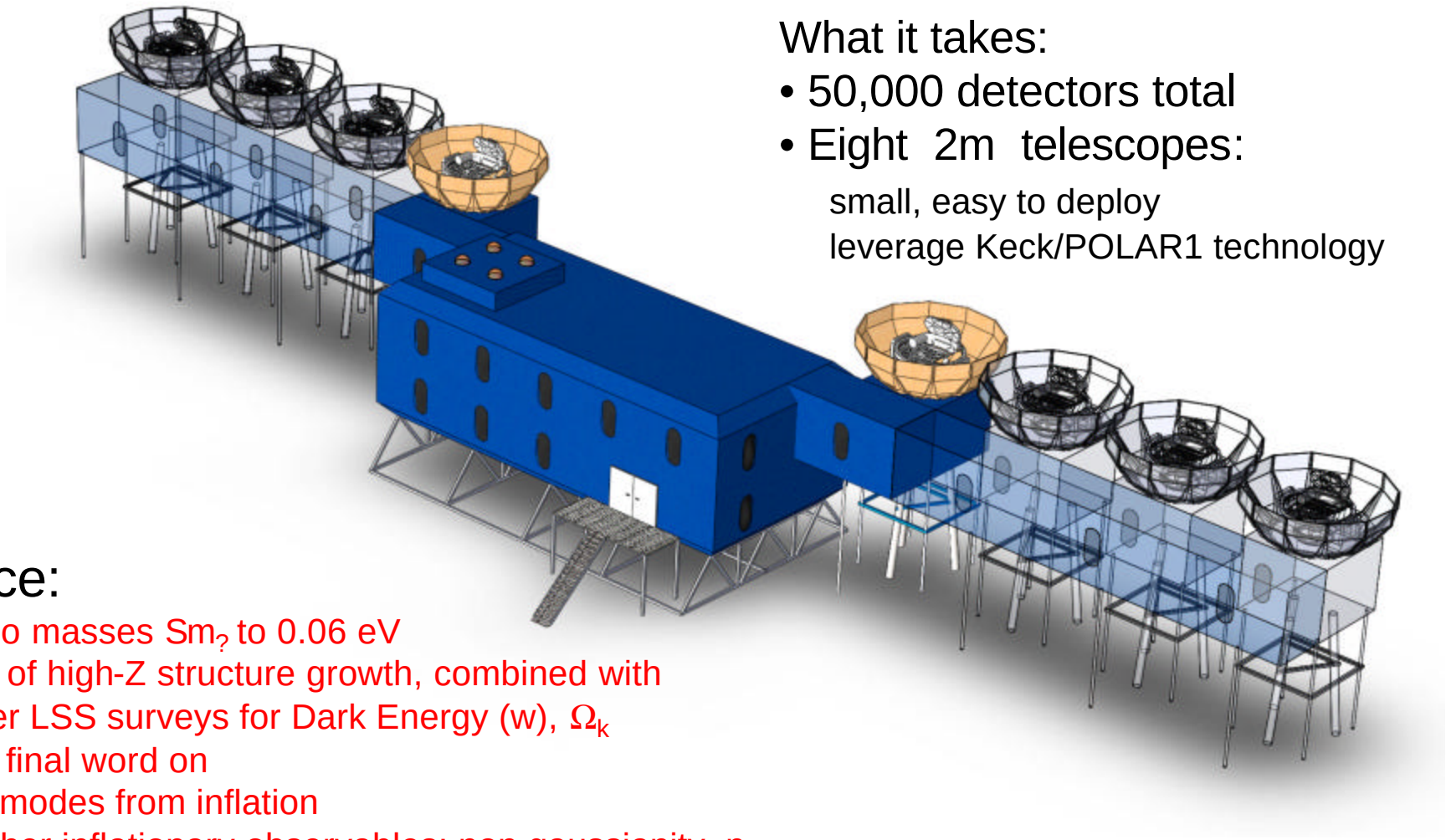
New science target: Lensing B-modes

- neutrino masses $Sm_?$
- evolution of Dark Energy
- curvature – pre-Inflationary relics

C. L. Kuo

POLAR1 is a pathfinder for a future array capable of doing

the definitive CMB Lensing Survey



What it takes:

- 50,000 detectors total
- Eight 2m telescopes:
  - small, easy to deploy
  - leverage Keck/POLAR1 technology

Science:

- neutrino masses $Sm_?$ to 0.06 eV
- survey of high-Z structure growth, combined with other LSS surveys for Dark Energy (w), Ω_k
- CMB's final word on
  - B-modes from inflation
  - Other inflationary observables: non-gaussianity, n_s

Conclusions

- Best current inflationary limit is set by CMB temperature measurements (WMAP+SPT) $r<0.17$
  - To go lower we need B-mode polarization
- So the race is on:
  - Several groups pushing hard and polarization sensitivity improving rapidly
  - Most experiments targeting the l=90 bump (observing smaller regions of sky)
  - If $r>0.02$ we should detect soon! (few year timescale)
  - If not then fighting galactic and lensing foregrounds will take years but probably can eventually get substantially lower – even from the ground