CMB Polarization Experiments: Status and Prospects

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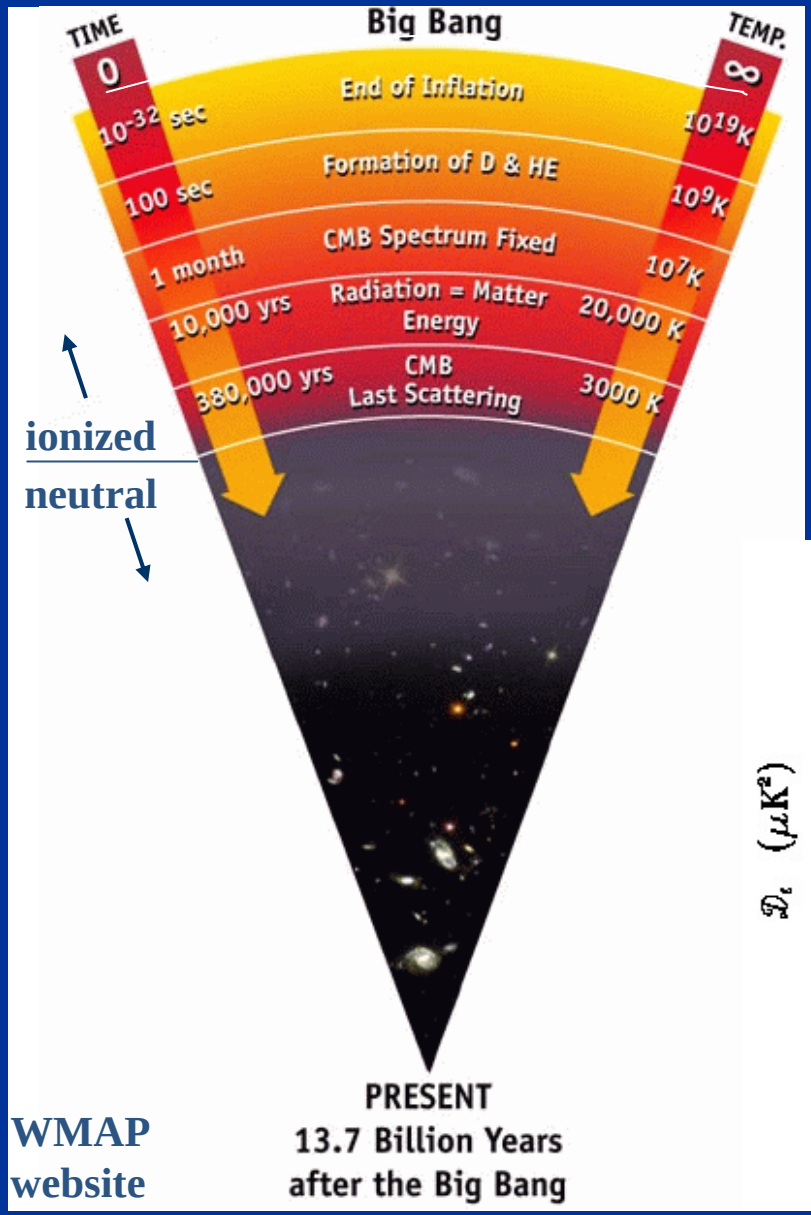
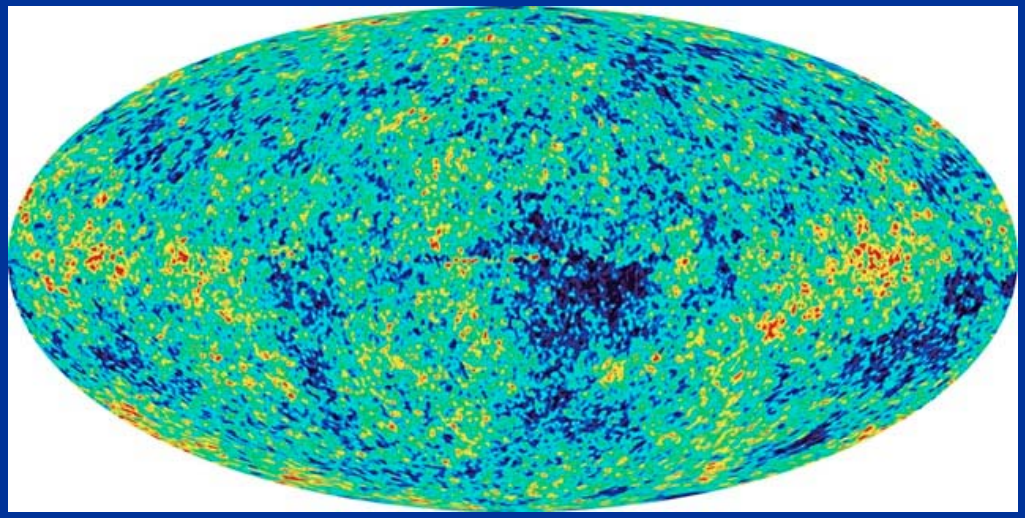
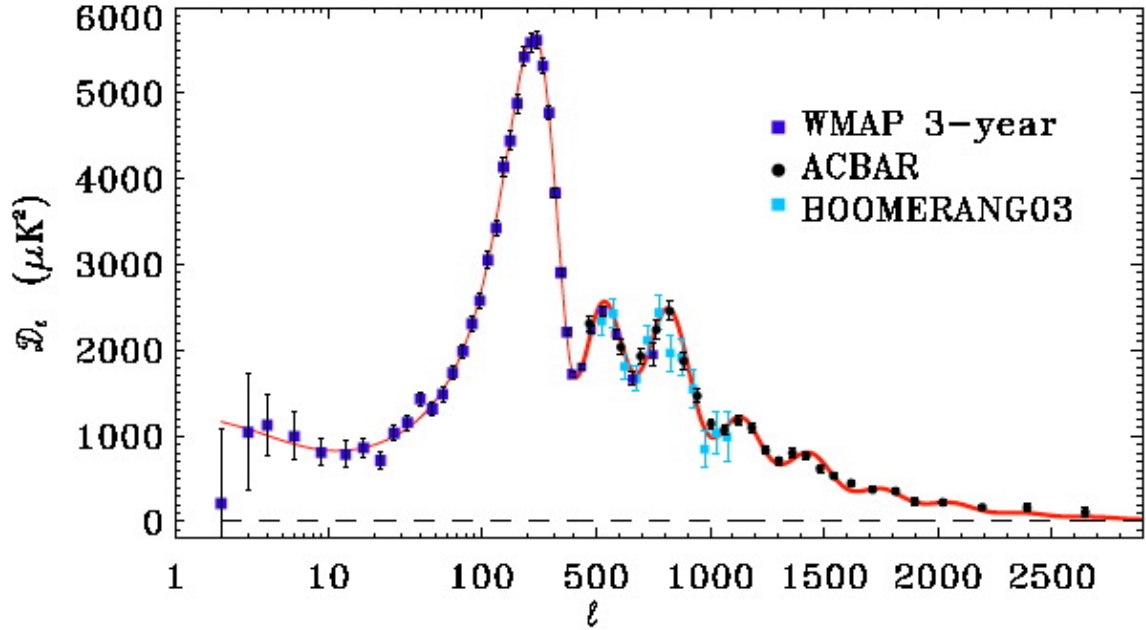
Remaining questions in fundamental Cosmology

- Spectral index of the initial perturbations, or the "n_s-1" parameter (Planck)
- Primordial non-Gaussianity (Planck)
- adiabatic vs. isocurvature perturbations (Planck)
- *Deviation from flatness* (Planck)
- The nature of Dark matter (sCDMS, …)
- The nature of Dark energy: the "w" parameter (*JDEM, LSST,…*)
- Primordial gravitational wave: the Tensor/Scalar ratio "*r*"
- Finite neutrino mass and its effects in cosmology

Cosmic Microwave Background

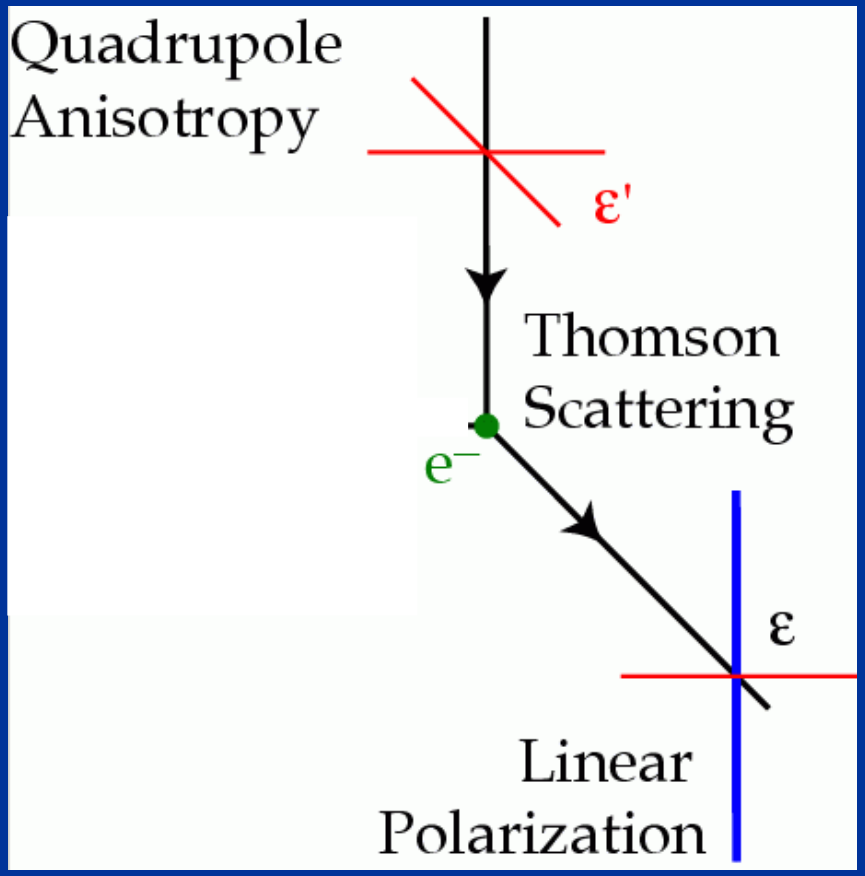






WMAP website

CMB is polarized. Why?



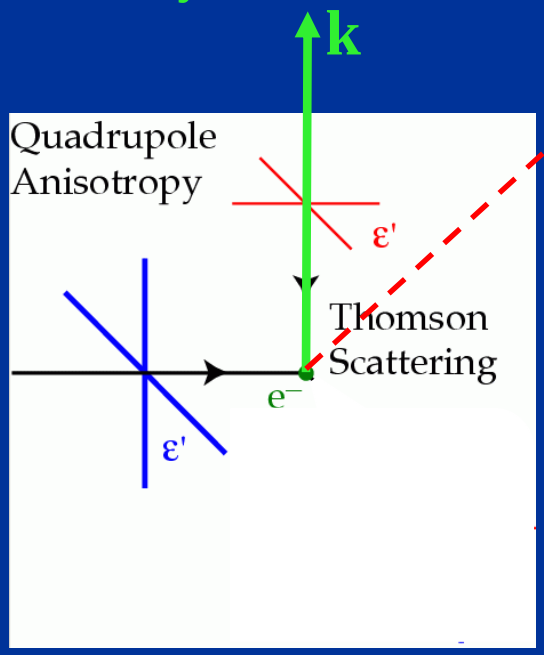
From W. Hu

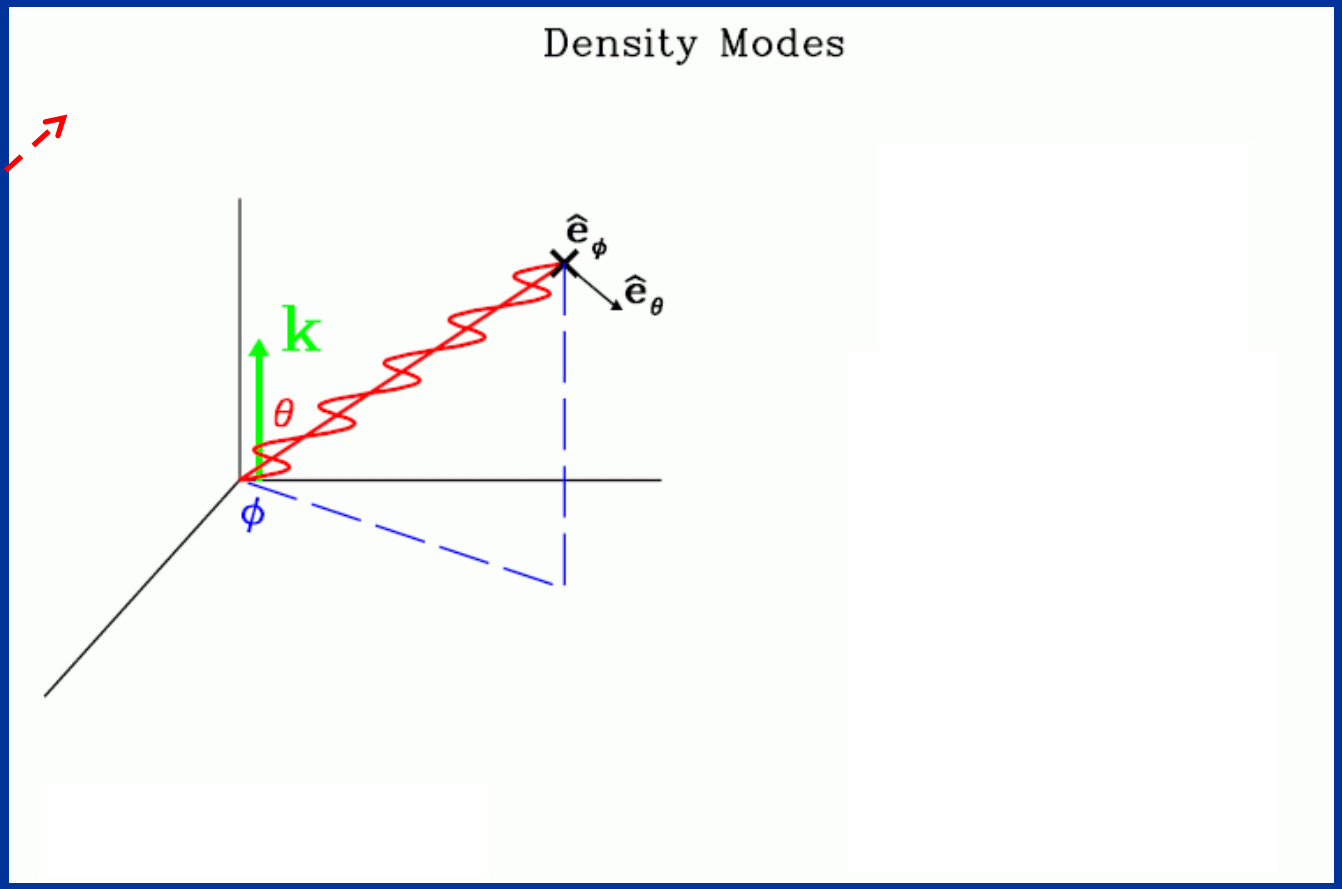
- Induced by quadrupole through Thomson scattering (in the rest frame of the electron)
- *Generated only at the ionized/neutral interface (completely ionized: no anisotropy; completely neutral: no electrons to scatter)*

B-mode is forbidden *for density perturbations*

(Seljak& Zaldarriaga, 1997; Kamionkowski et al., 1997)

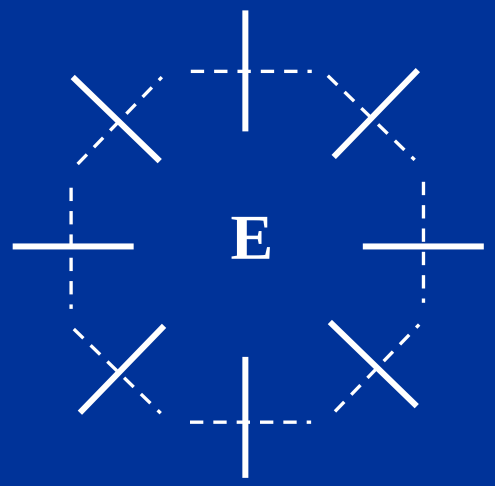
Planar Fourier density mode

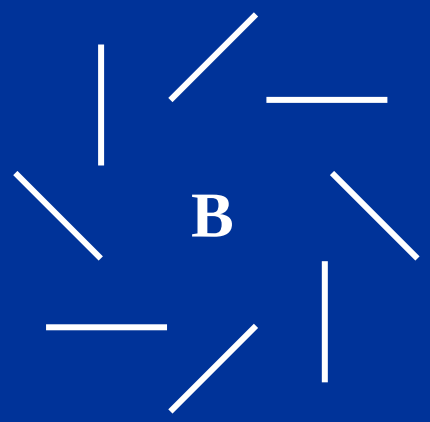




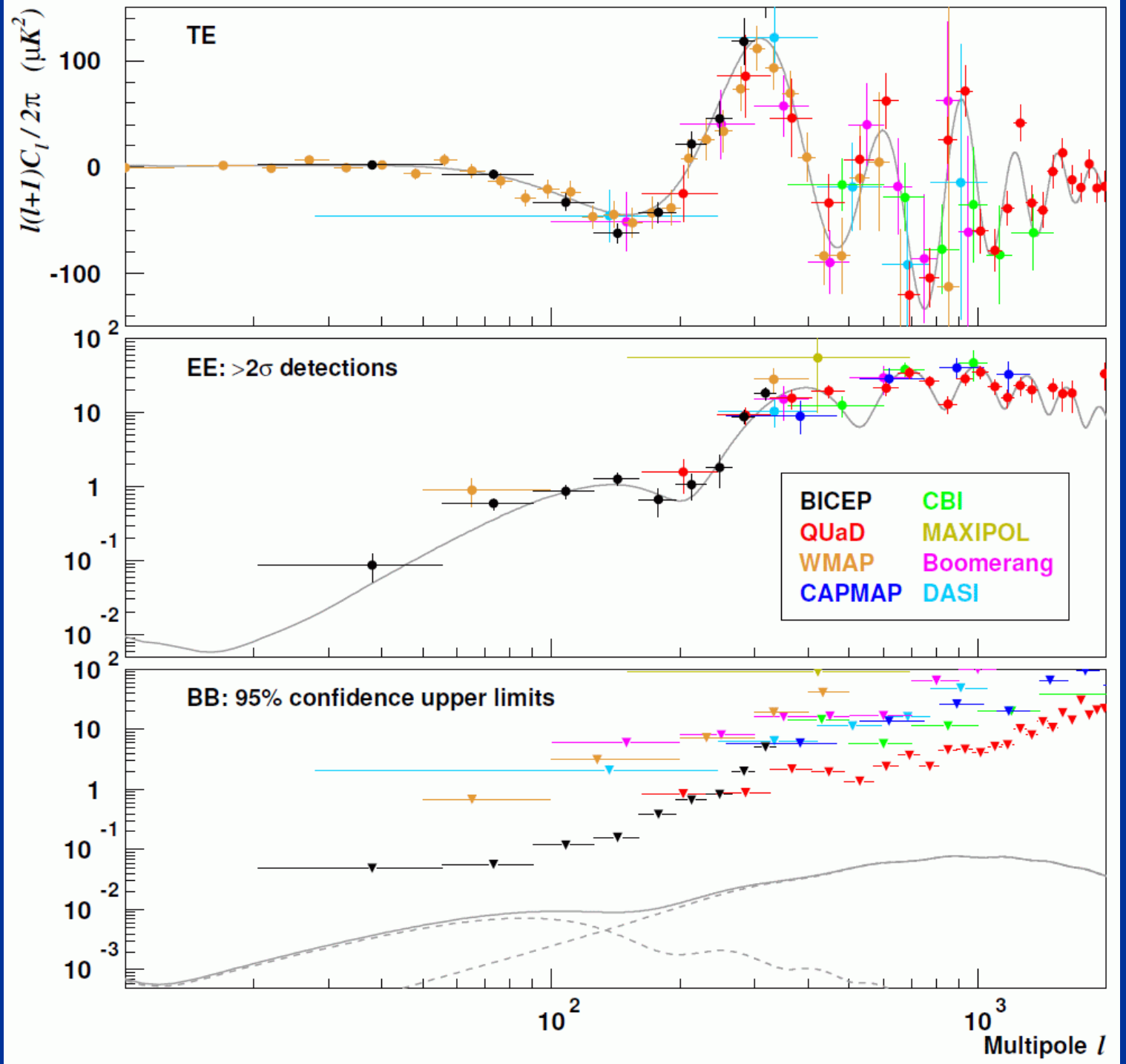
Seljak & Zaldarriaga

E-mode and B-mode





- Polarization fields can be linearly decomposed to E and B mode
- E-mode polarization is perpendicular/parallel to the direction of modulation
- B-mode polarization is oriented at 45° to the direction of modulation
- Linear, scalar perturbation cannot generate B-mode polarizations
- No Cosmic Variance



Chiang and the BICEP Team

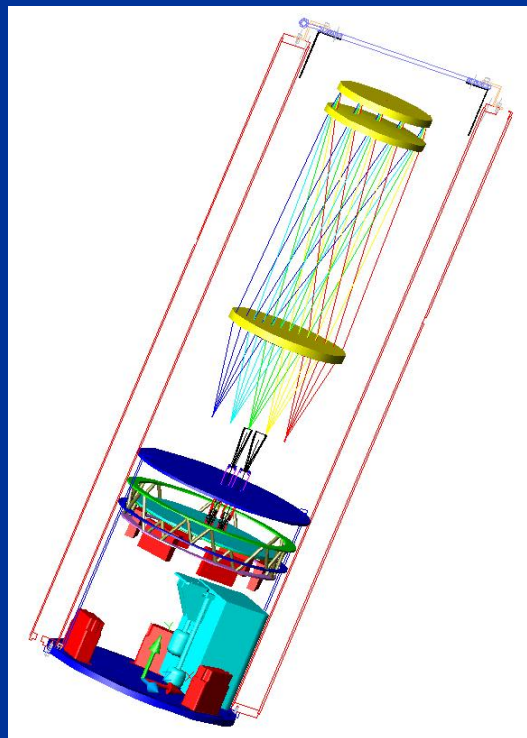
Global experimental efforts searching for *B*-mode

- BICEP, BICEP2, Keck Array
- POLAR-1, POLAR Array
- ABS
- POLARBEAR
- QUIET-I, QUIET-II
- SPTpol, ACTpol
- Ballooning: SPIDER, EBEX
- Satellite: Planck

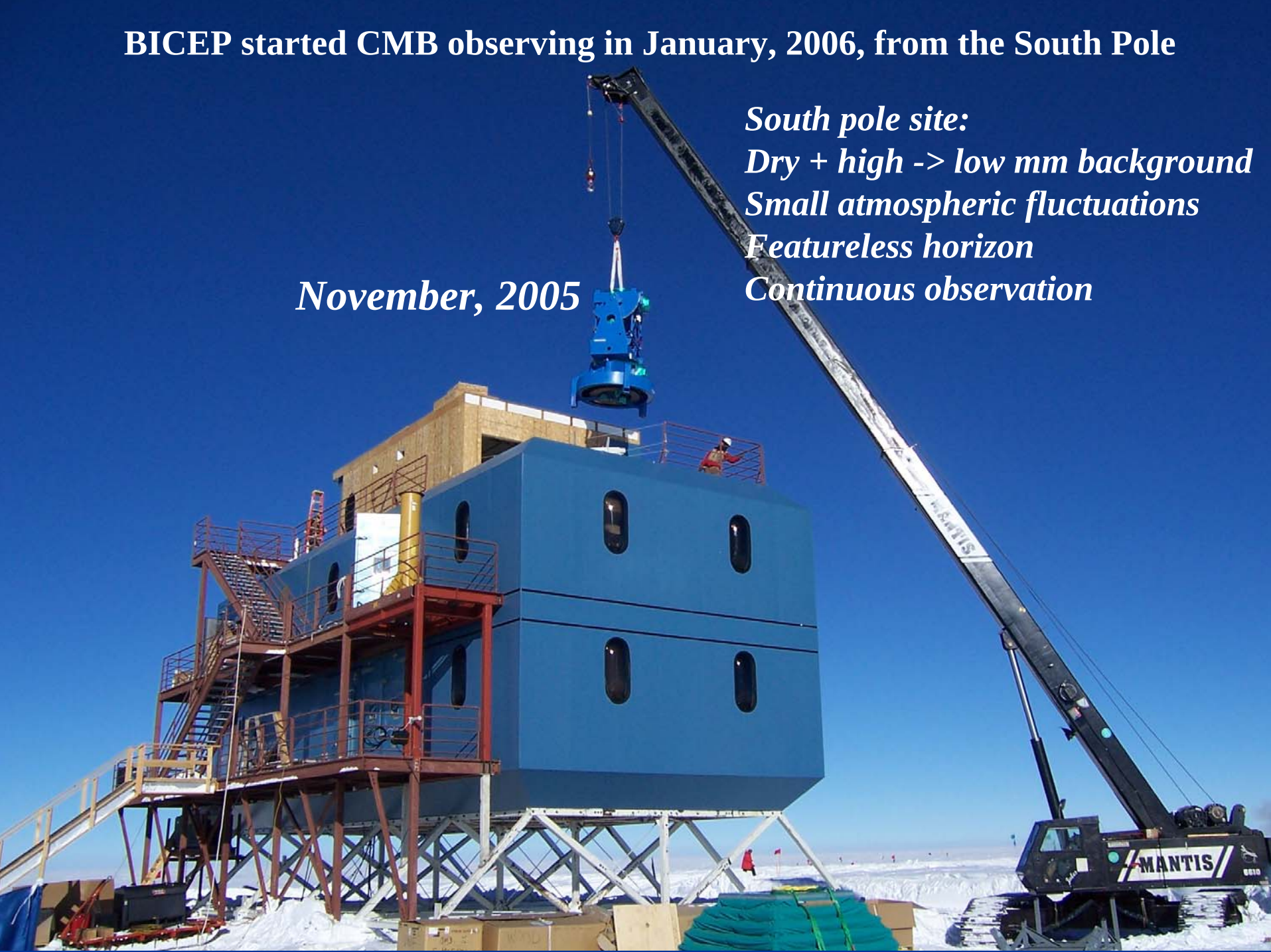
- ~20 cm primary aperture (30 cm window)
- Refractive wide-field optics (@ 4 K - excellent stability)
- Detector cooled to 0.25 K
- ~20° FOV

- 0.7° (150 GHz) and 1.0° (100 GHz) resolutions
- 49 feeds / 98 polarization-sensitive bolometers at 250 mK

B I C E P



BICEP started CMB observing in January, 2006, from the South Pole



November, 2005

South pole site:
Dry + high -> low mm background
Small atmospheric fluctuations
Featureless horizon
Continuous observation

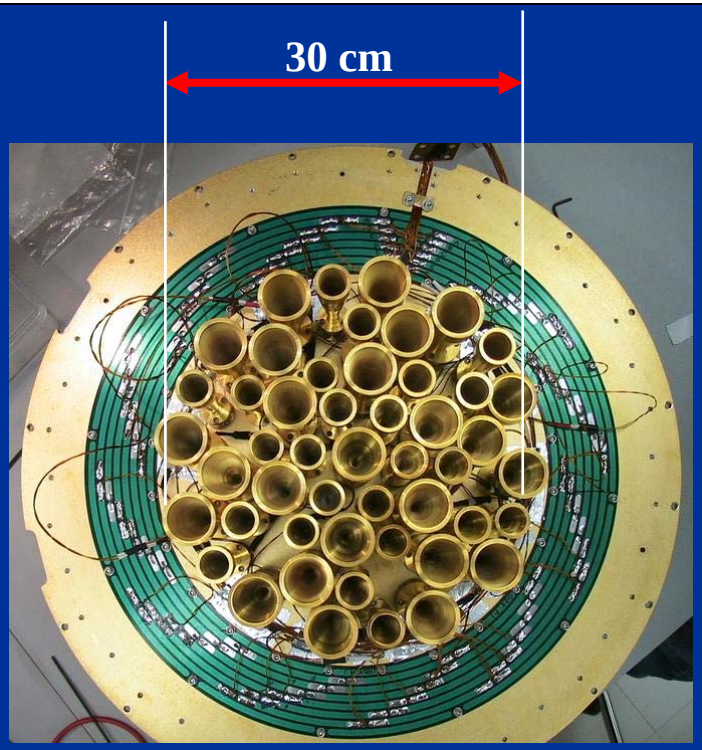
Bolometric Polarimeters

The state-of-the-art:

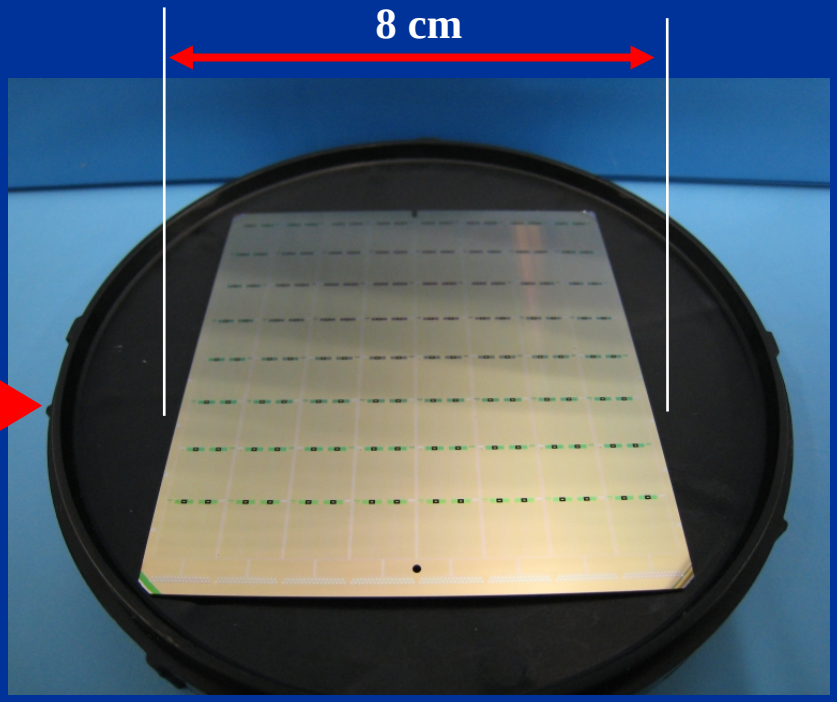
- Co-locating dual-polarization polarimeter
- High optical efficiency, wide band
- Extremely stable
- Nice beam/band
- Low polarization artifacts
- *Discrete elements: feeds, filters, detectors*

The future:

- To integrate all these components on a Si wafer → mass production
- Higher packing density
- TES enables SQUID multiplexed read-out

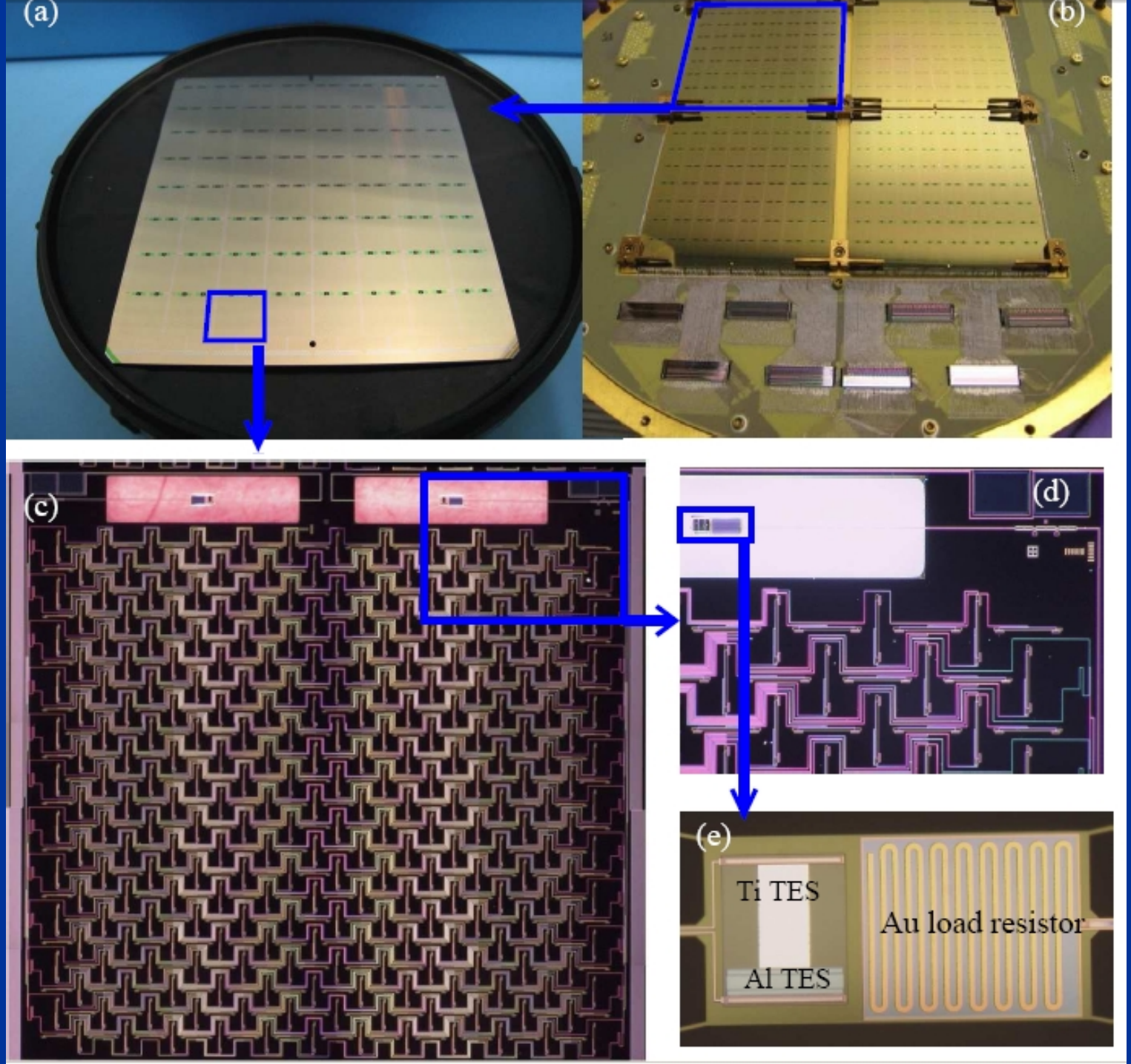


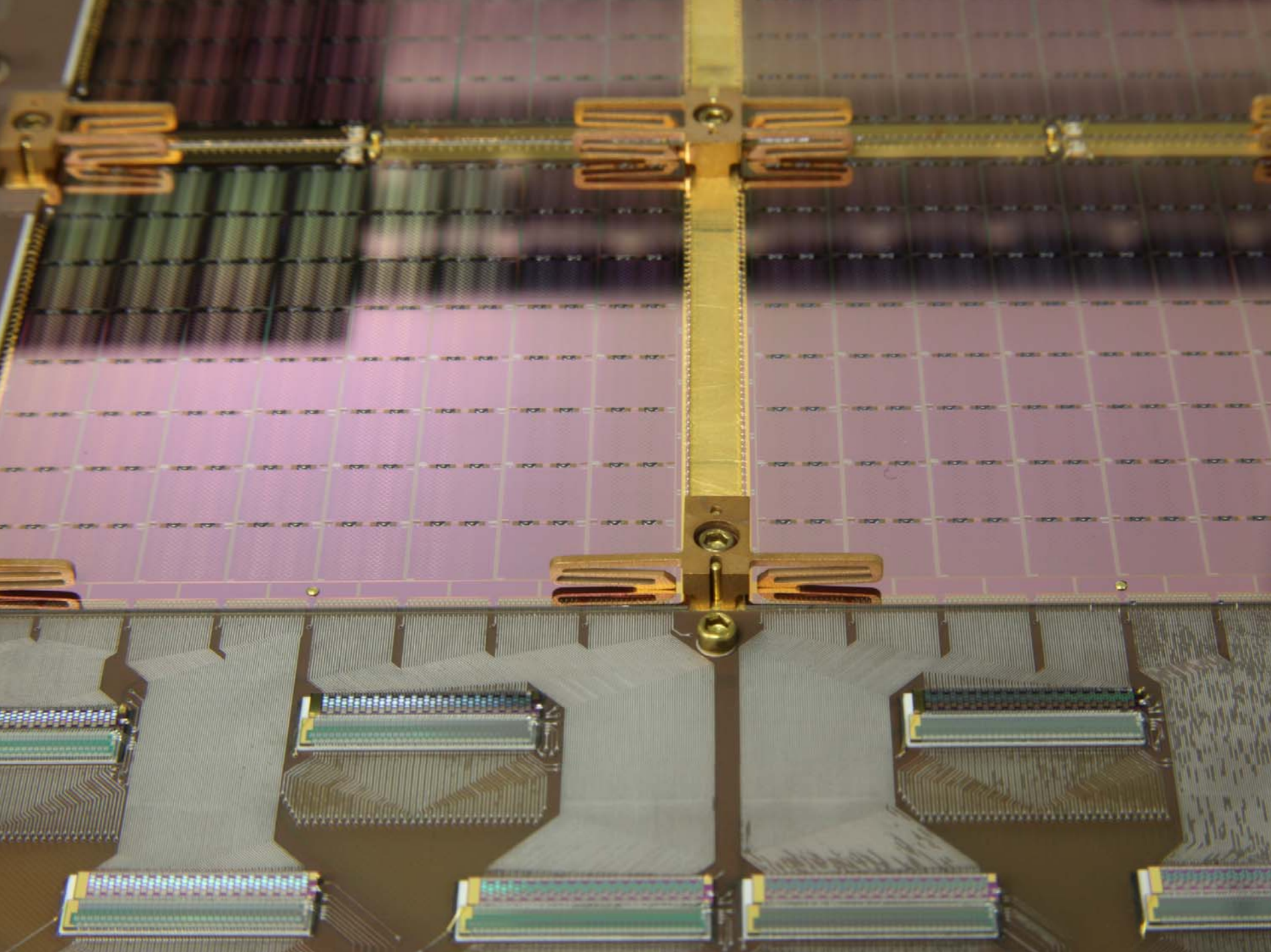
BICEP focal plane (98 detectors)



Antenna-coupled TES array (128 detectors)

New Detectors for the CMB





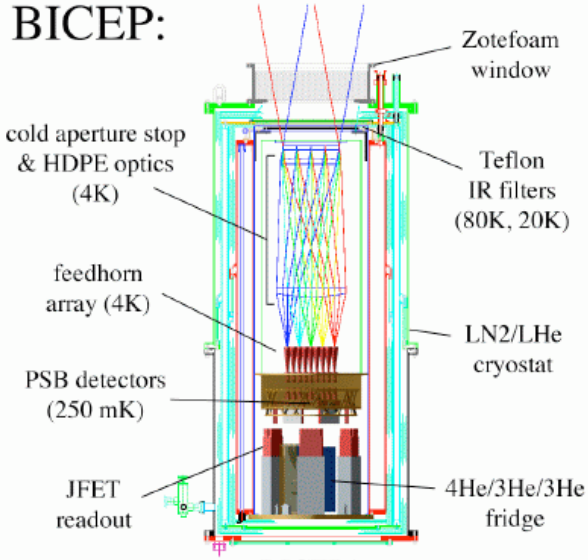
BICEP-BICEP2-Keck time line

- *All with small refractors (25cm) ; observing from the South Pole*

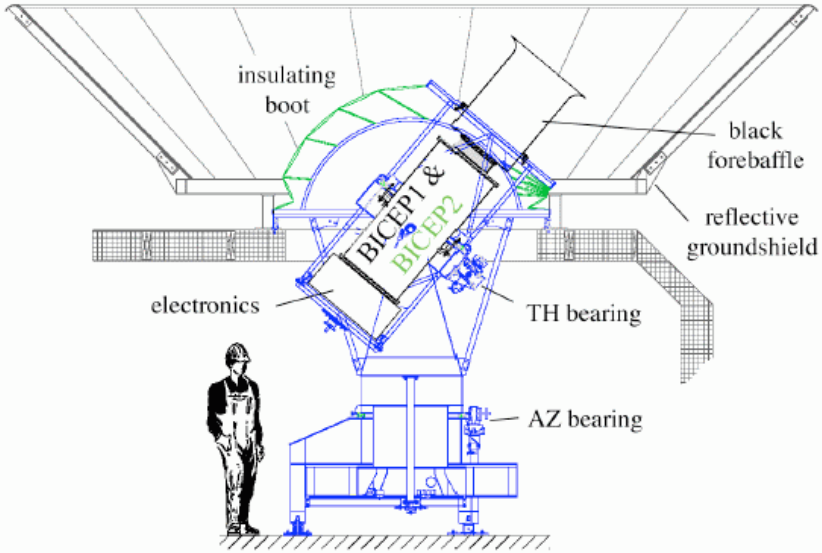
- BICEP (2005-2007) currently provides the best limit on B-mode
- BICEP2 (2009-) observing with x5 BICEP sensitivity
- Keck Array (scheduled 2010 -) under construction, x4 BICEP2 sensitivity

- *Will likely reach T/S ~< 0.03 by 2013*

BICEP:

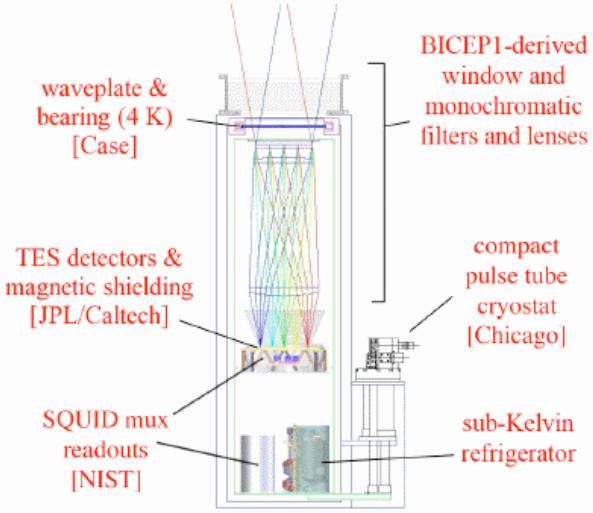


BICEP1

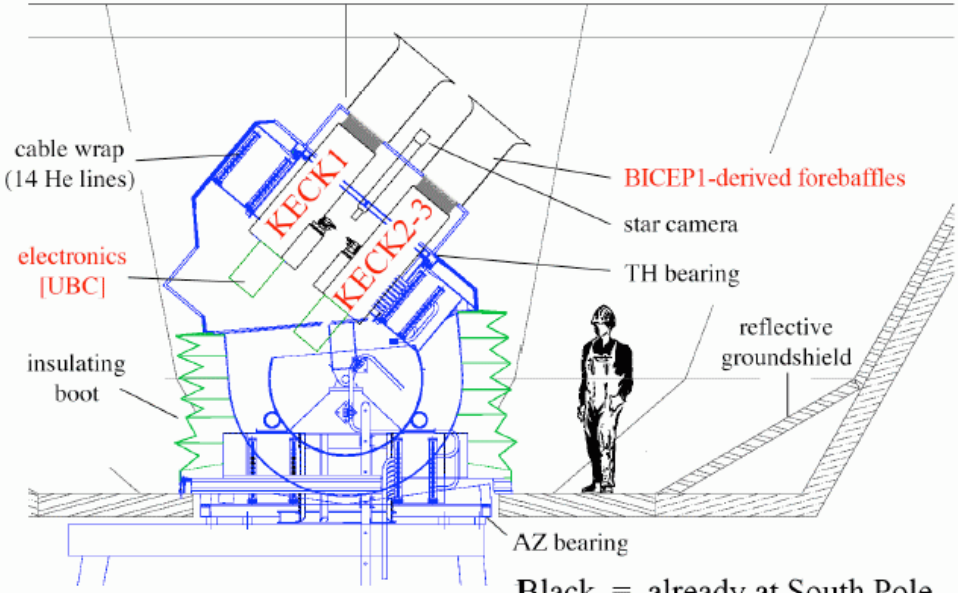


DSL BICEP platform (7500 lbs cap)

KECK:



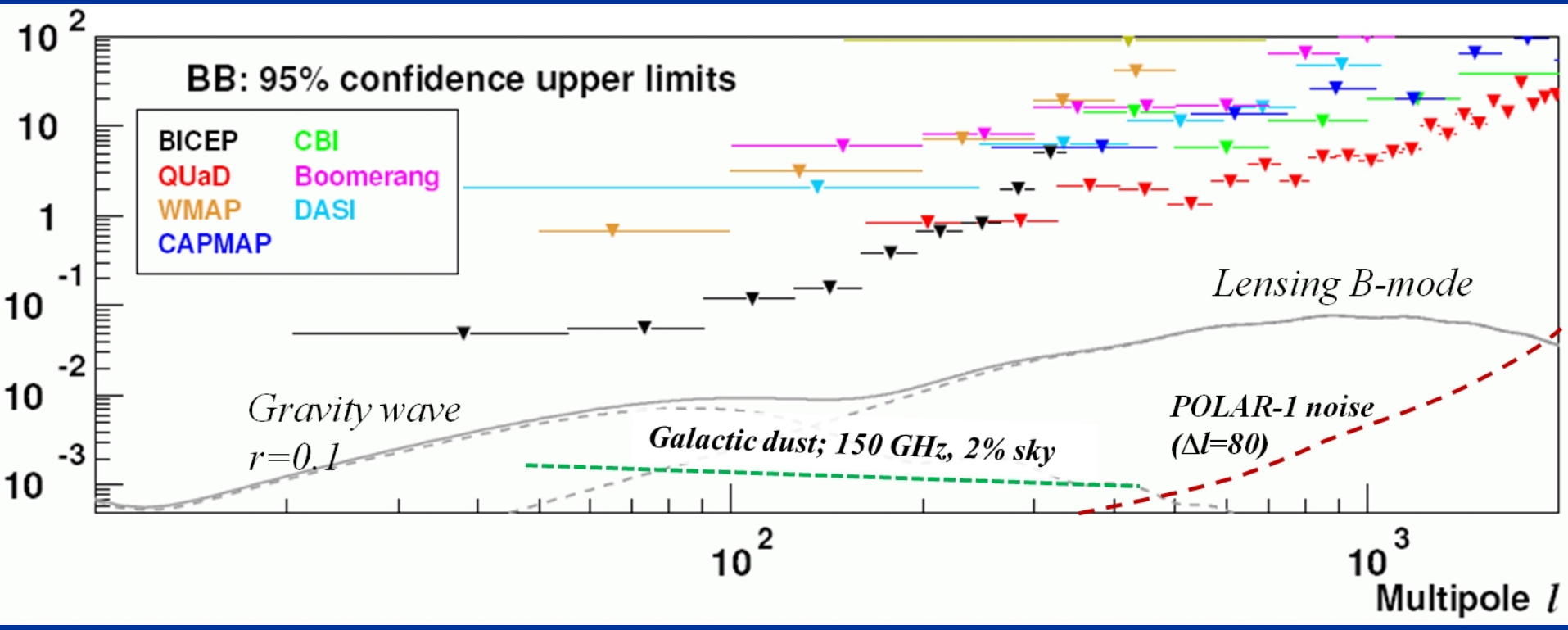
KECK1,2,3



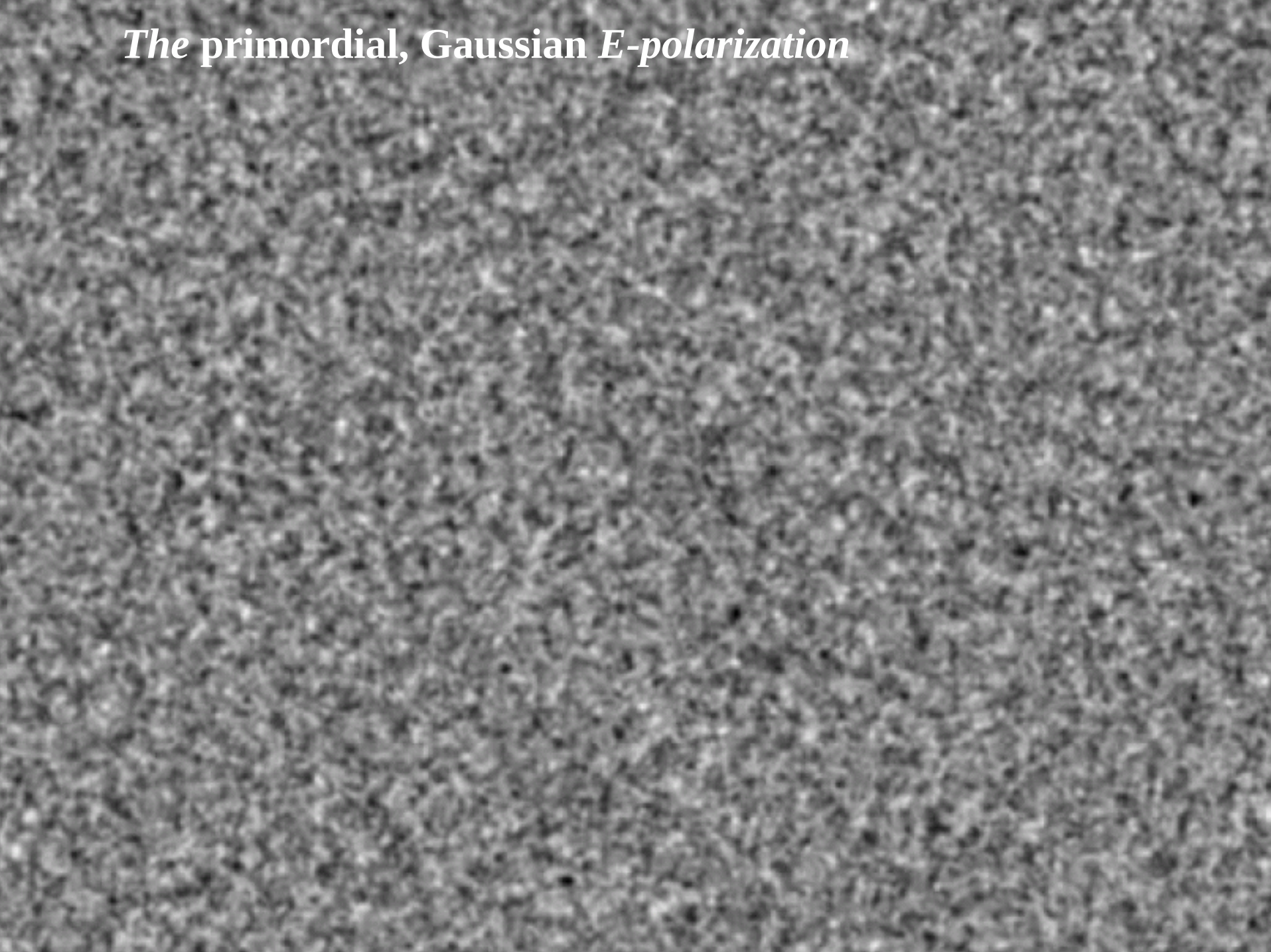
DASI tower (100,000 lbs cap)

Black = already at South Pole
Green = deploying this year
Red = this proposal

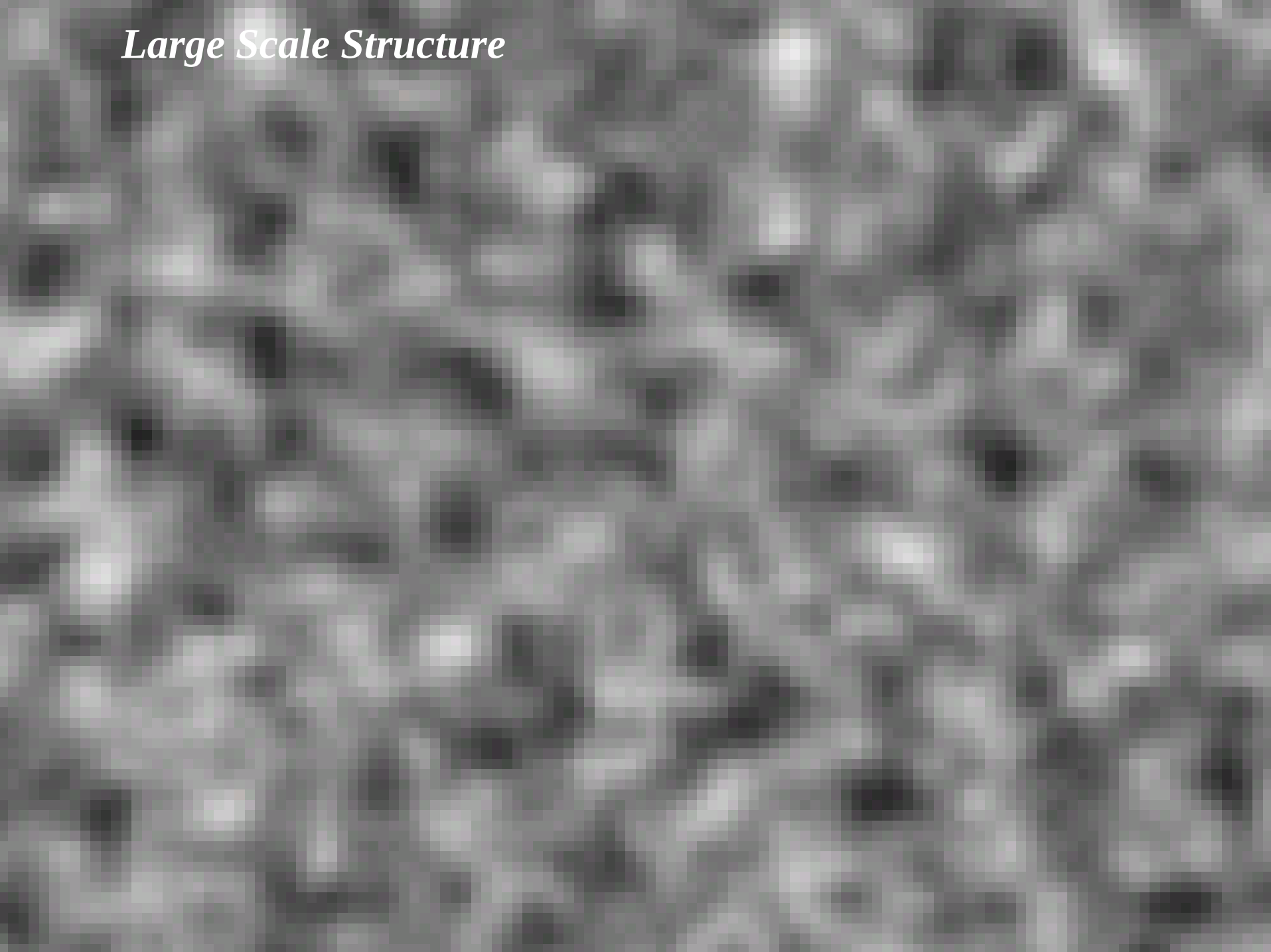
The B-mode polarization

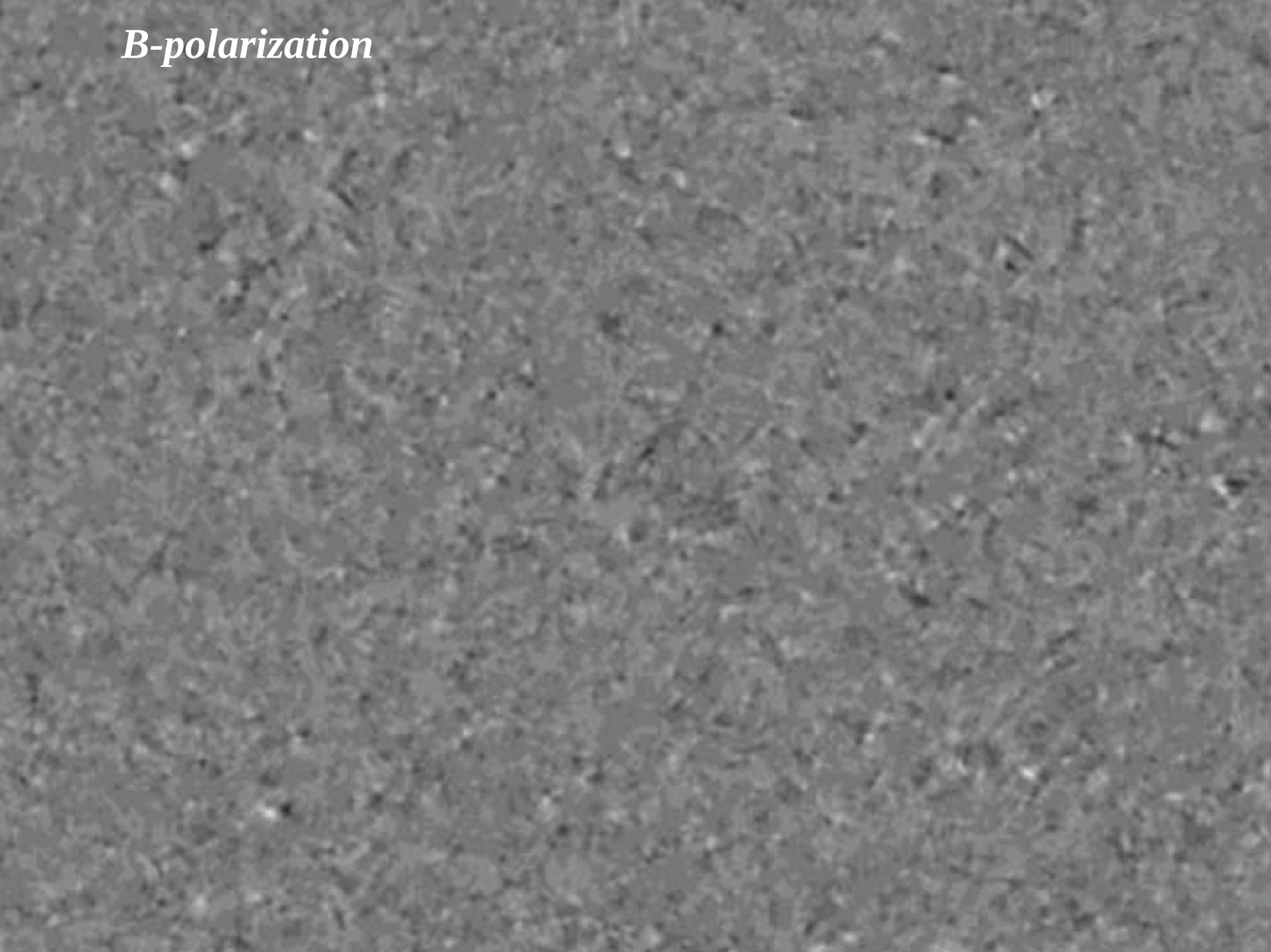


* The gravity wave signal down to *r~0.02* is likely reachable in the next 5 years (e.g. Keck Array, QUIET-II)
* *The prospect for lensing/de-lensing calls for big projects – 100× the current speed*


The primordial, Gaussian *E-polarization*

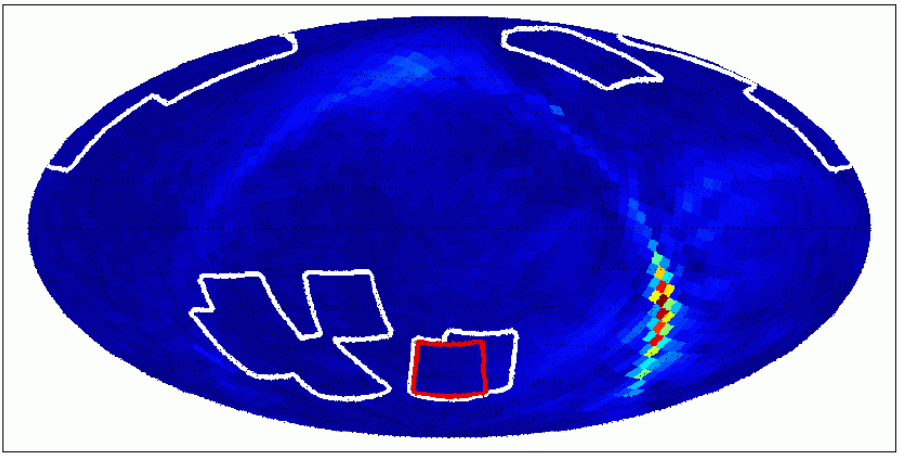
Large Scale Structure




B-polarization

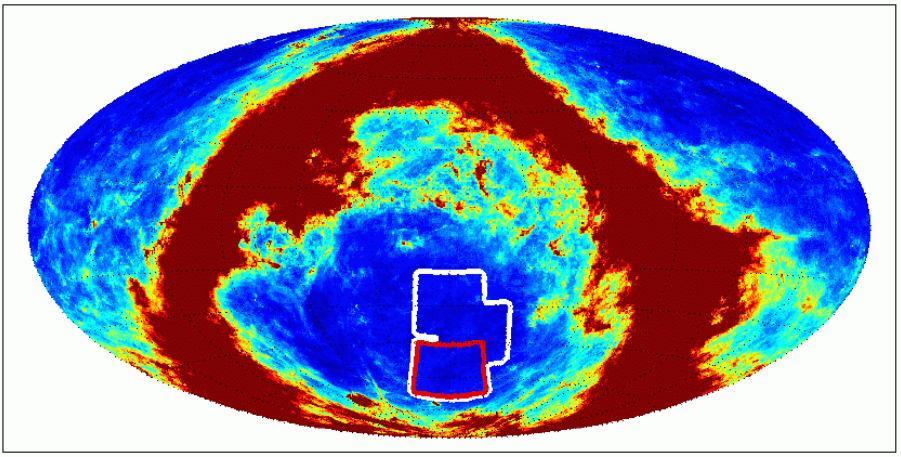
Astronomical Foregrounds

WMAP K–band P @ 150GHz (assuming index −3.0)

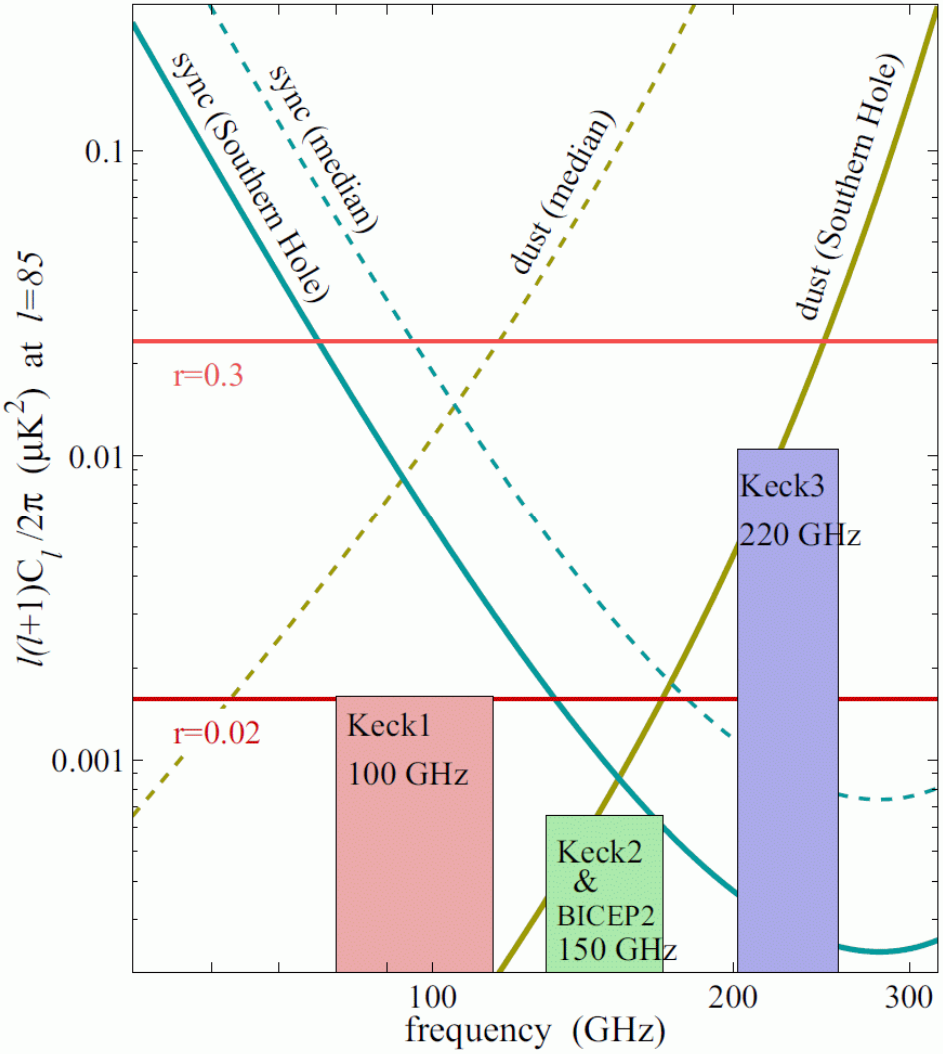


Color range 0 to 4μK

FDS Dust T @ 150GHz x 0.05



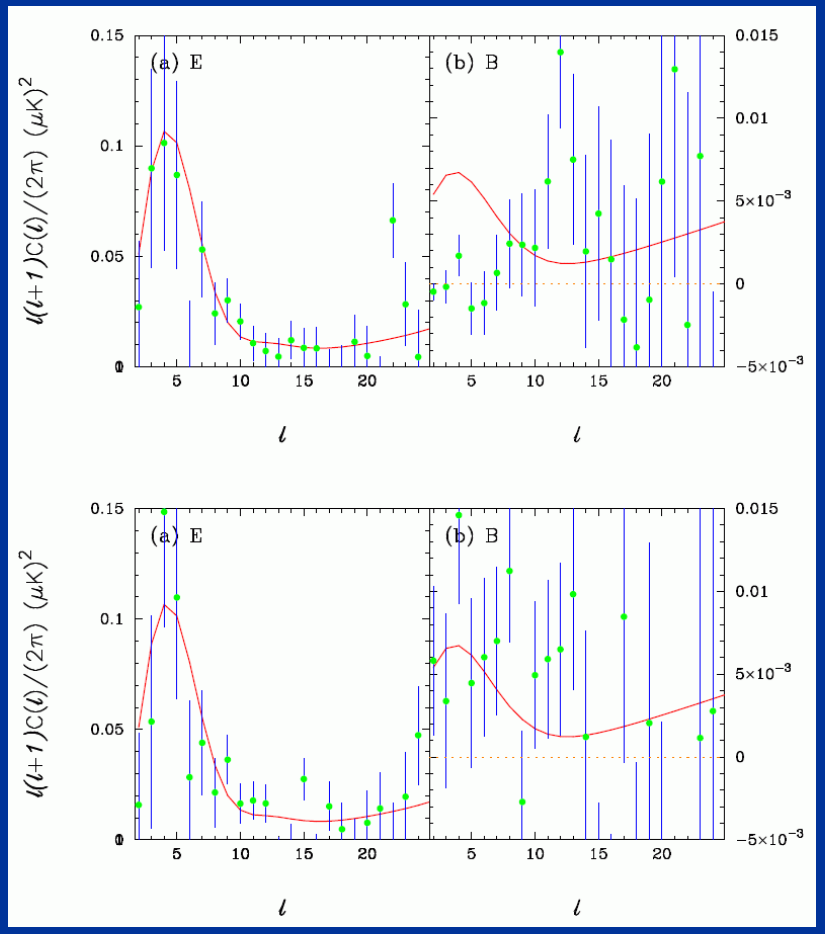
Color range 0 to 4μK



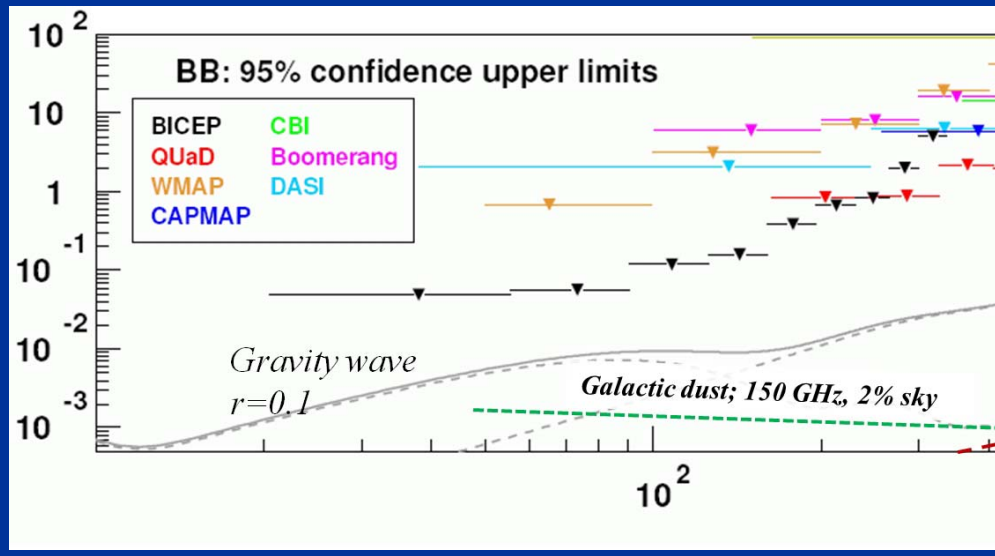
Kovac
and the
BICEP2/Keck Team

An important note on Planck vs ground in *B-mode* search

Planck

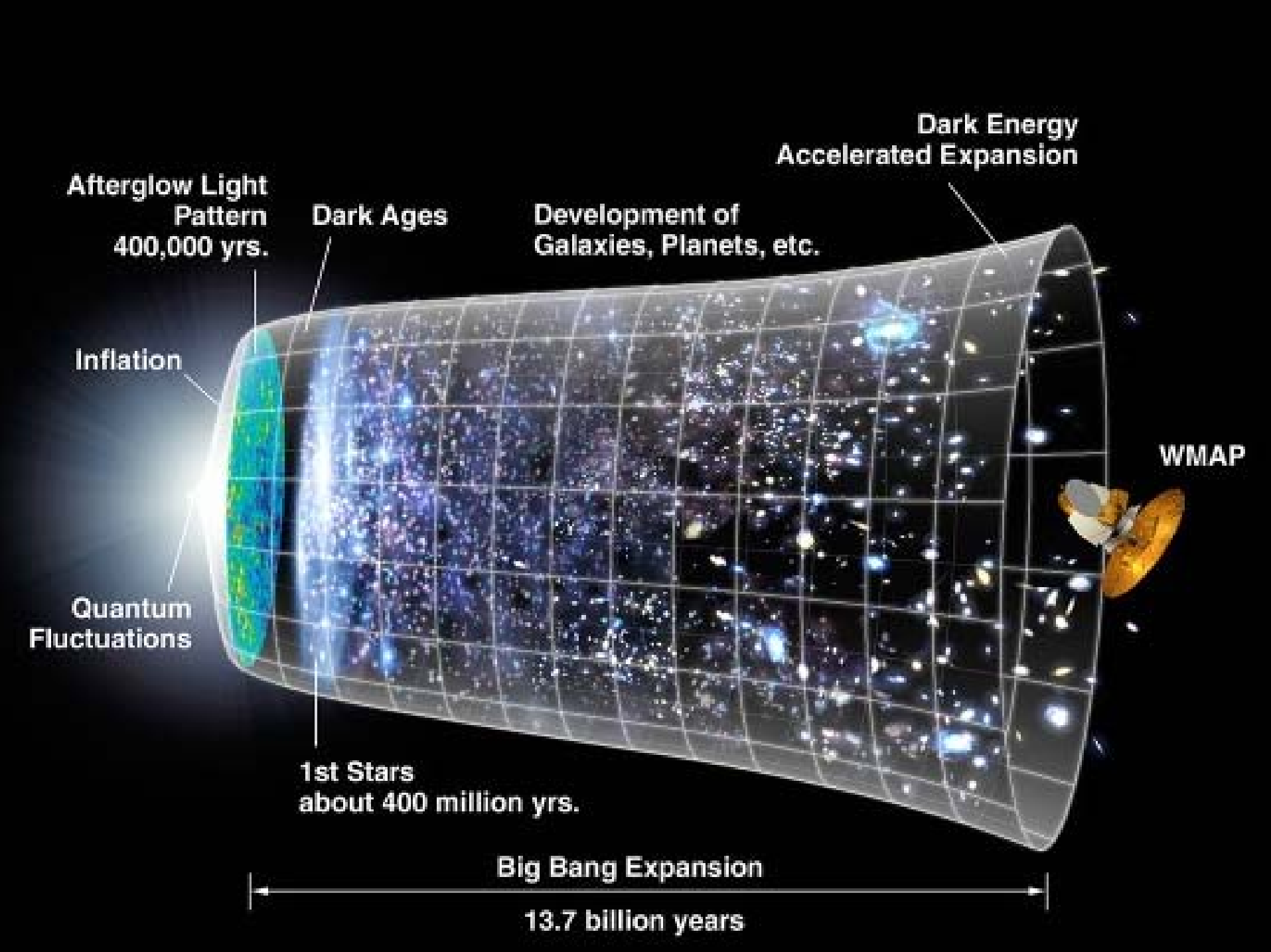


Efstathiou et al. 2009



Ground

Lensing *B*-mode


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

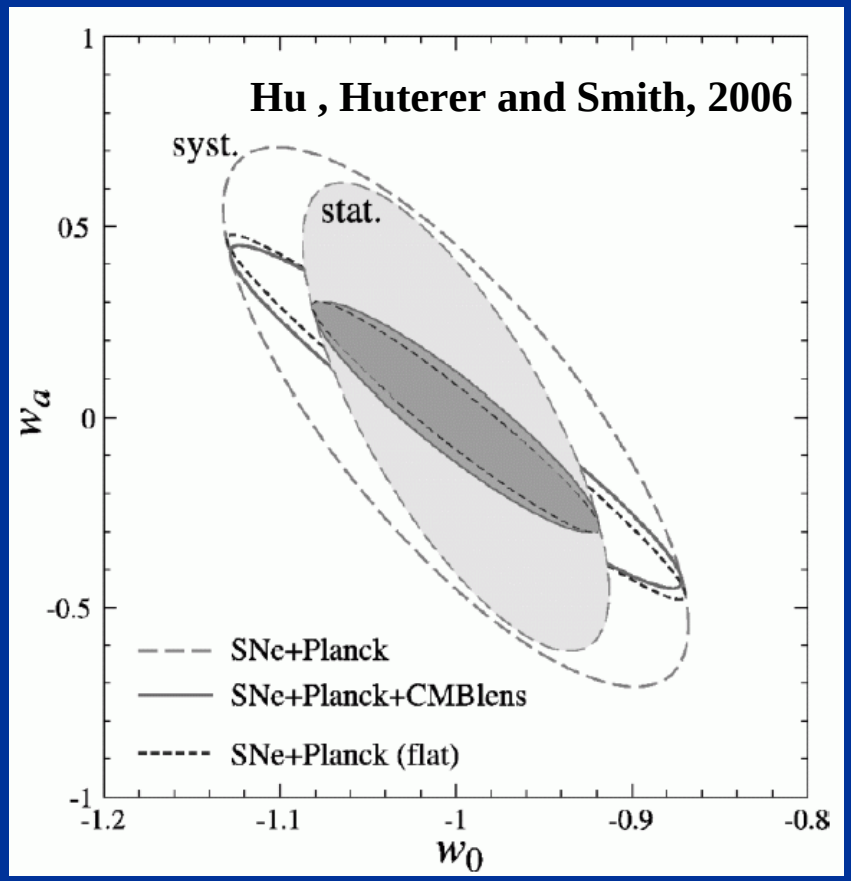
Lensing *B*-polarization is a LSS experiment

- Deep polarization measurements (4 μK rms) on 1.5% of the sky can significantly improve *Planck+SNAP* constraints on

  $\{w_0, w_a, \Omega_k, \sum m_\nu\}$,

$p_\Lambda = w\rho_\Lambda$

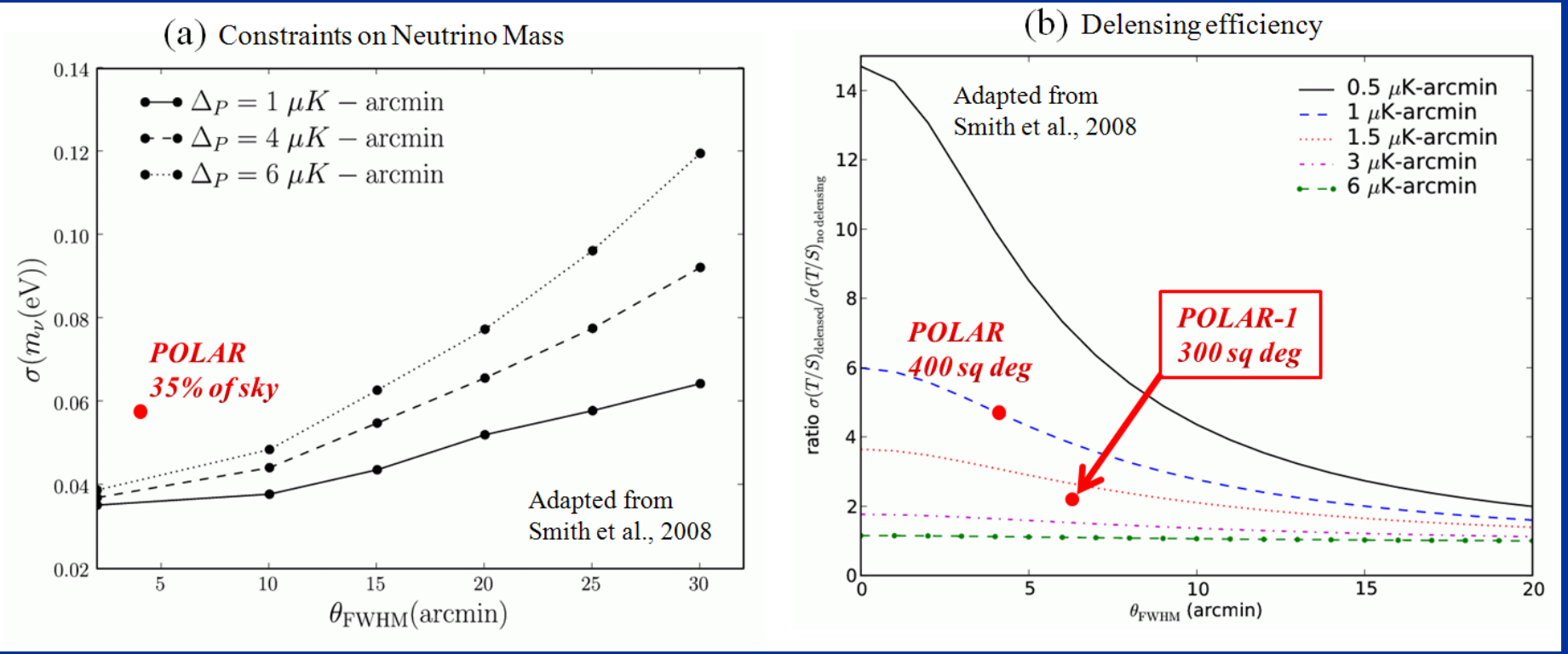
$w = w_0 + w_a(1-a)$



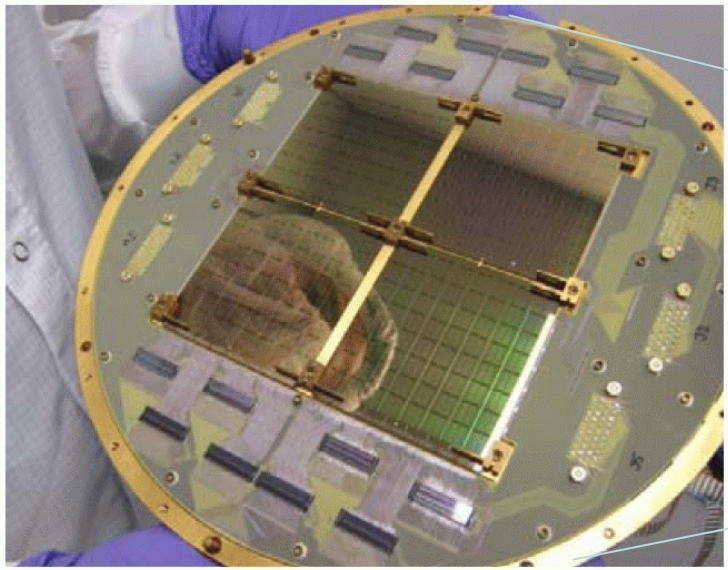
- There is a strong theoretical preference:

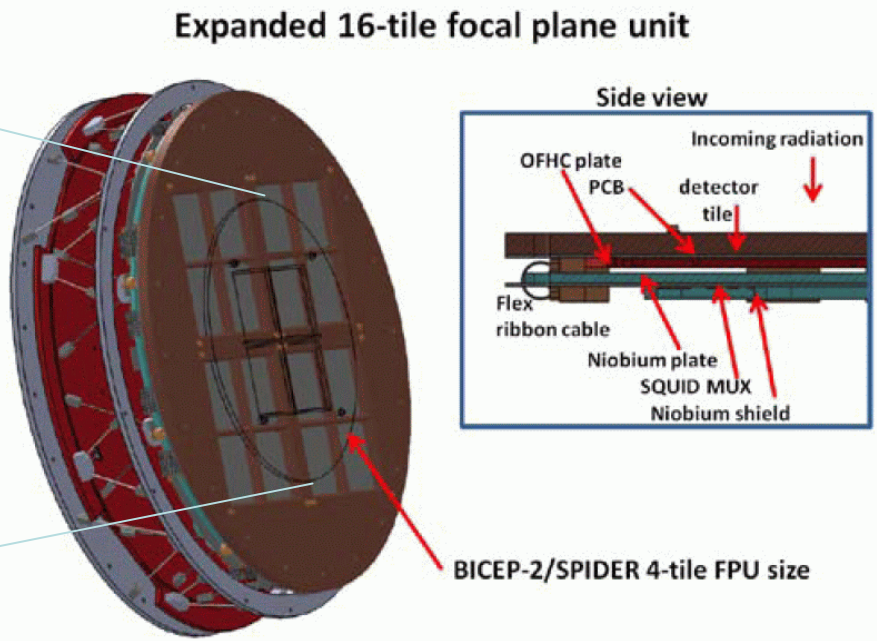
  $w_0 = -1$, $w_a = 0$, $\Omega_k < 10^{-4}$ → lensing *B* provides a constraint on $\sum m_\nu < 0.04$eV

Science with lensing/Prospect for de-lensing call for 5' experiments
→ larger telescopes and/or higher frequency



More, more and MORE!!!





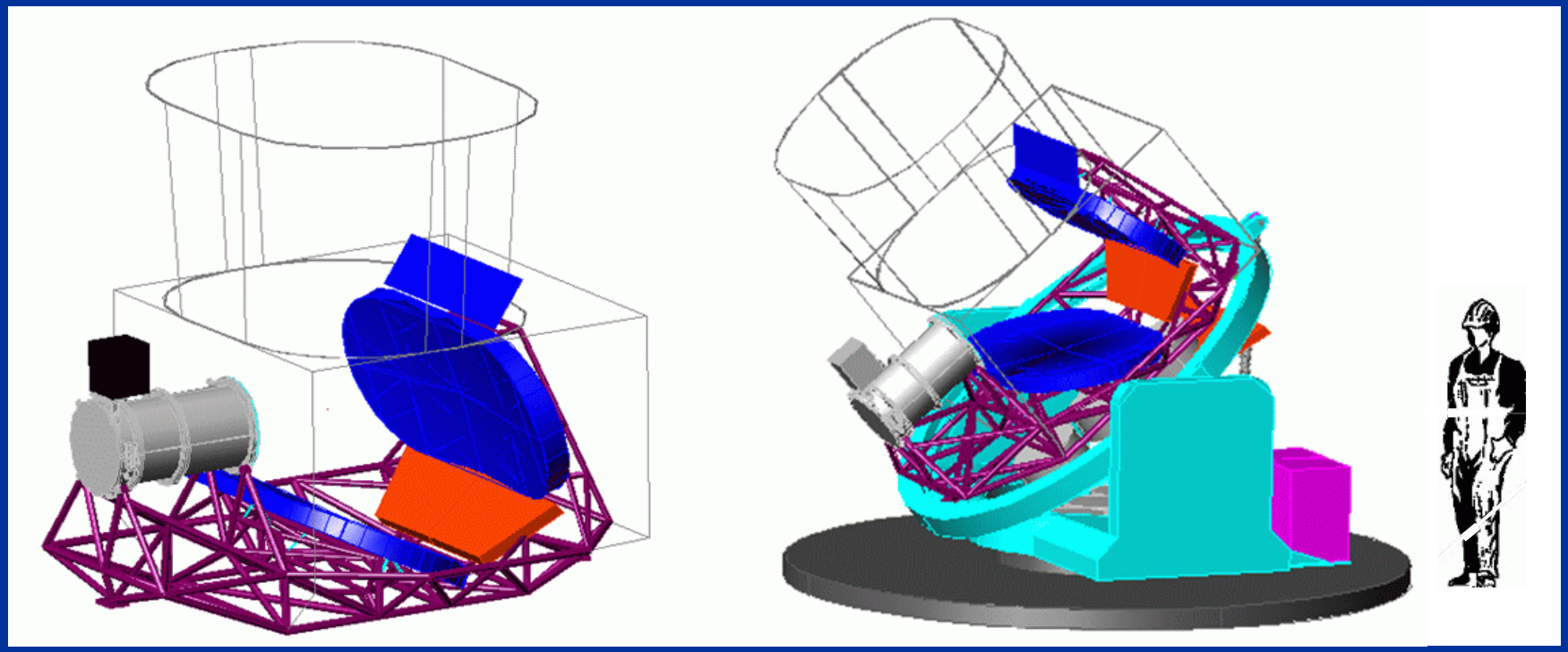
BICEP-2 and SPIDER
Focal plane, 512 detectors
(fielding 2009/2010)

Keck Array = BICEP-2 x 3
(fielding 2010/2011)

POLAR-1 Focal plane
4,608 detectors
(planned for 2012)

POLAR Array = POLAR-1 x 10

POLAR: 1.5–2 m Crossed-Dragone Reflectors



Parameters /Exp.	# of Tele-scopes	Aperture	Beam (FWHM)	Detector count	Frequency band(s)	Sky coverage	Year
POLAR-1 (this proposal)	**1**	**1.5 m**	**6'**	**2304×2**	**150 GHz**	**300 deg^2**	**2012**
POLAR	10	2 m	4'	2304×2×10	95, 150, 220 GHz	400/15000 deg^2	TDB

POLAR-1 = 1 telescope, POLAR Array = 10 telescopes