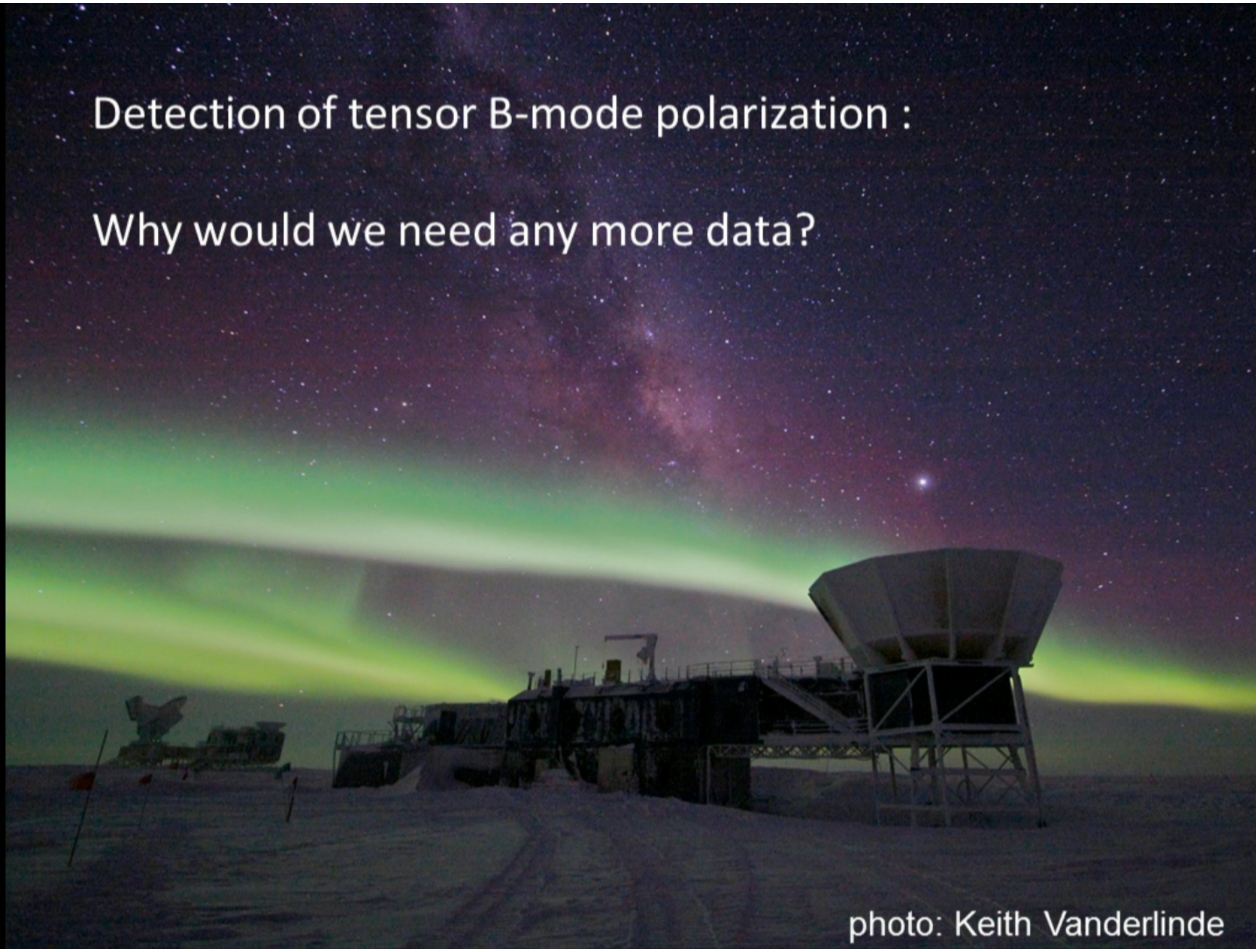
Title: Prospects for Future Measurements

Date: Apr 04, 2014 11:30 AM

URL: http://pirsa.org/14040122

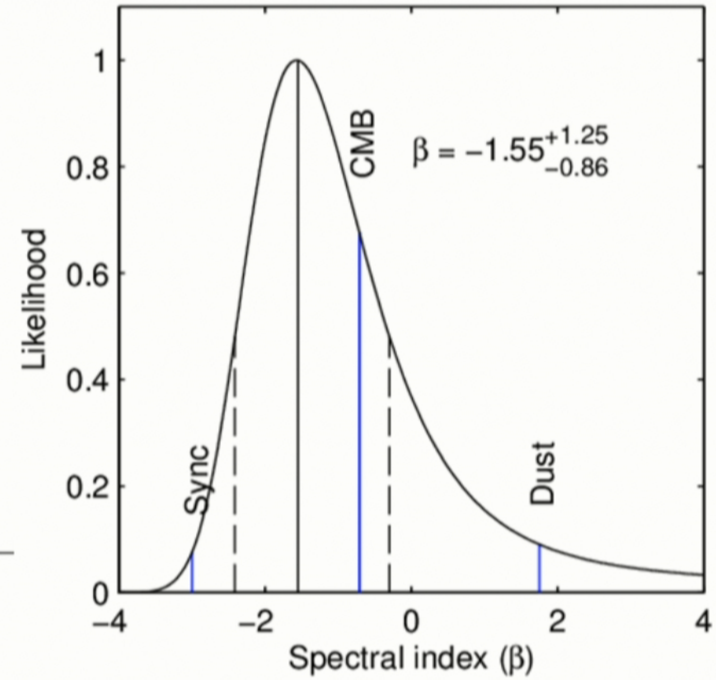
Abstract:


Detection of tensor B-mode polarization :
Why would we need any more data?
photo: Keith Vanderlinde

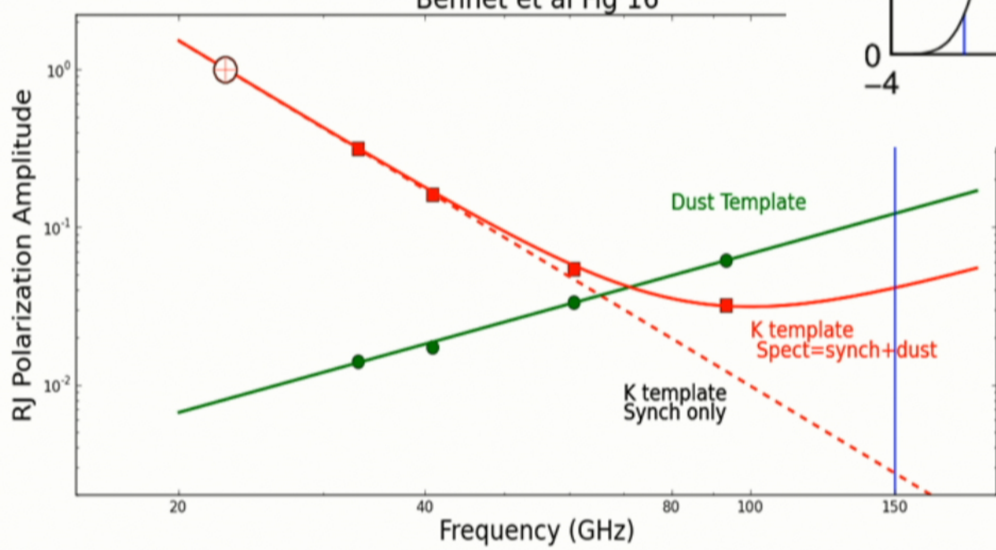
If the measured r angular-spectrum leads to any surprising physics, it is crucial to establish beyond any doubt that the signal originates in the CMB.

There are not good enough templates for polarized synchrotron or polarized dust emission. Data would help.

Direct r-detection at more wavelengths than two would help.



Bennet et al Fig 16

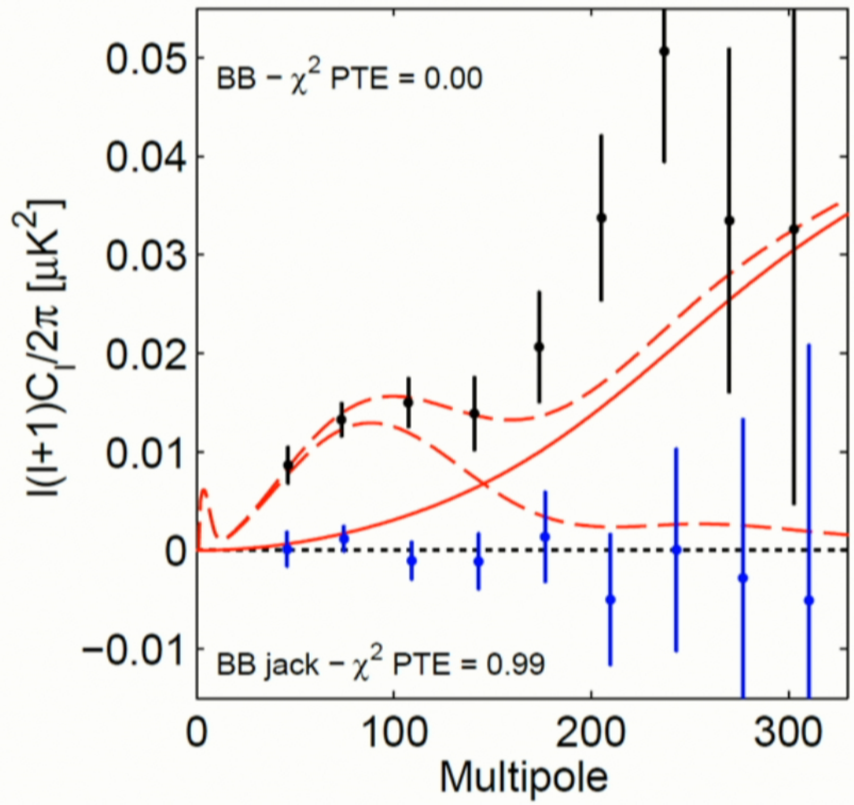


The WMAP synchrotron template is dust-contaminated by the Bicep2 frequency.

Is the shape of the BB power spectrum unambiguously due to tensor-modes?

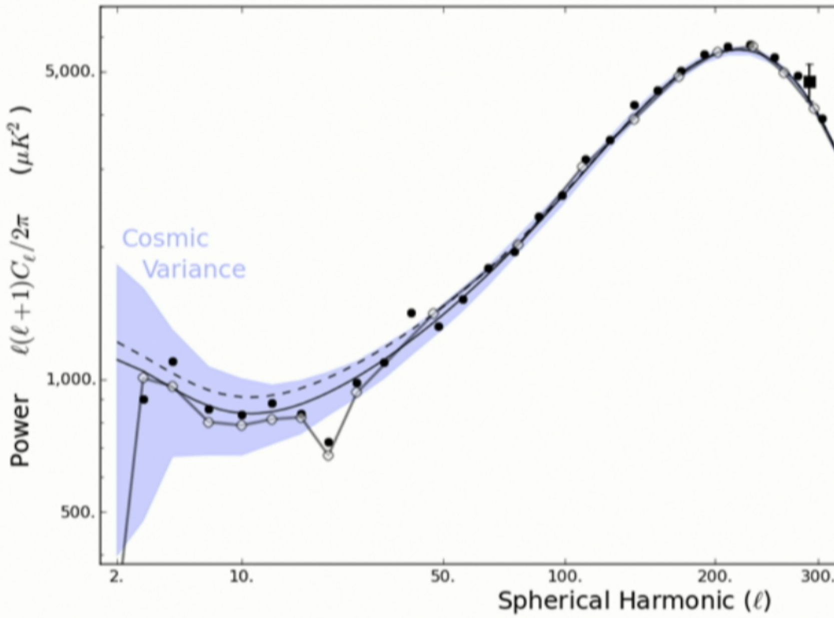
Measurements with higher resolution in ℓ will help.
Detection of the re-ionization bump at $\ell \sim 10$ would be decisive.

Good measurements of EE at higher angular frequencies can lead to calculation of the lensing conversion of EE to BB at all angular scales, and thus to a cleaner spectrum at the largest angular scales

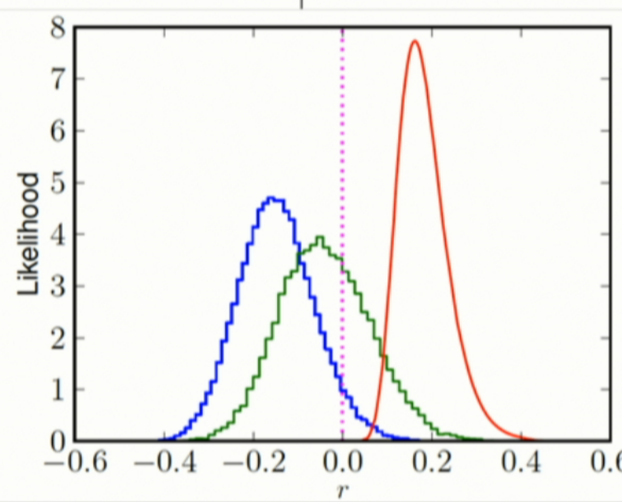


Is the deficit in TT at large angular scales cosmic variance or a hint of new physics?

Measuring EE and TE gives us access to more modes, which might reduce the ambiguity.

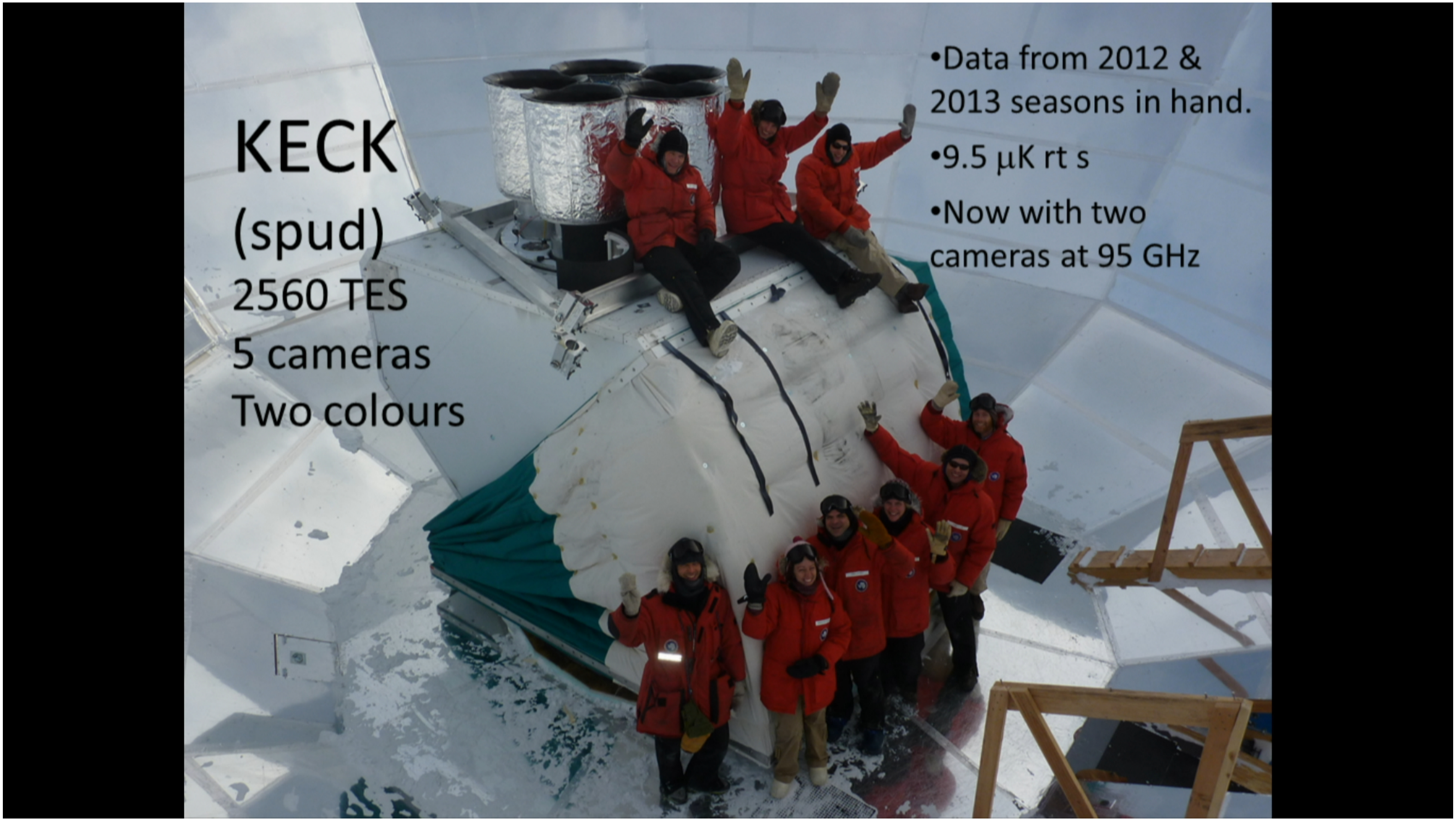


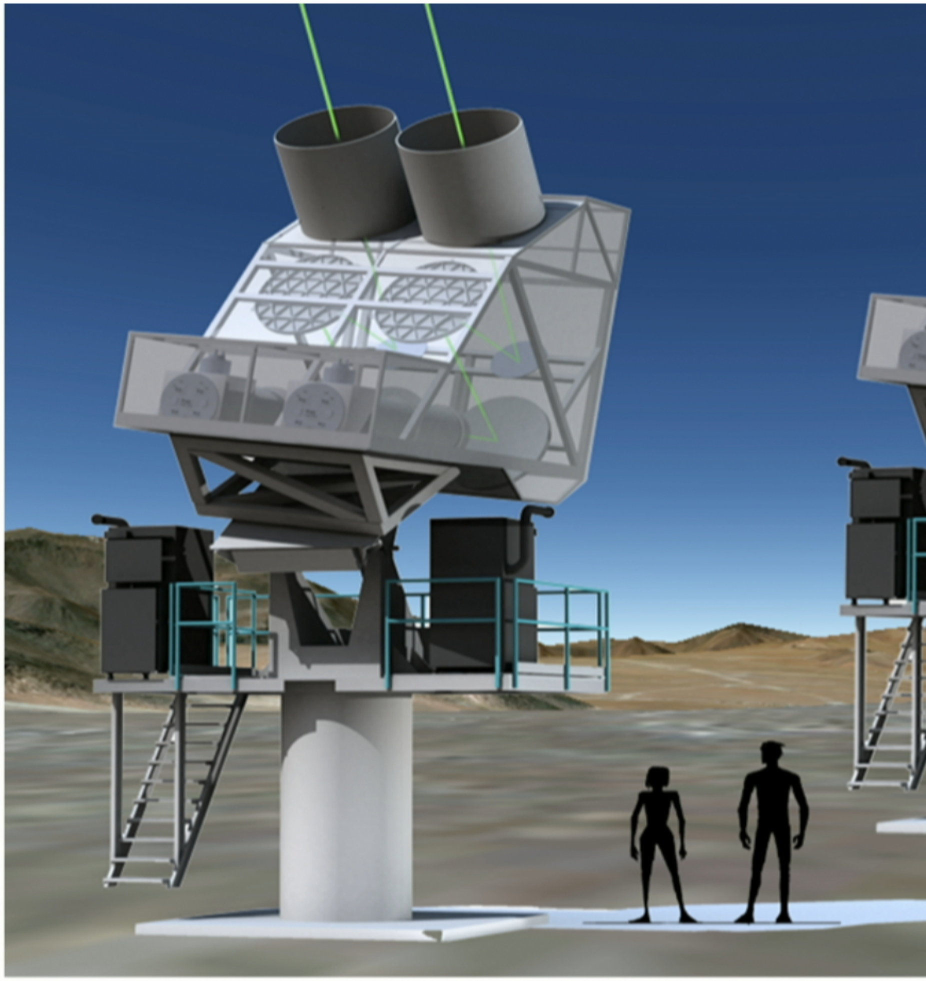
Smith et al.

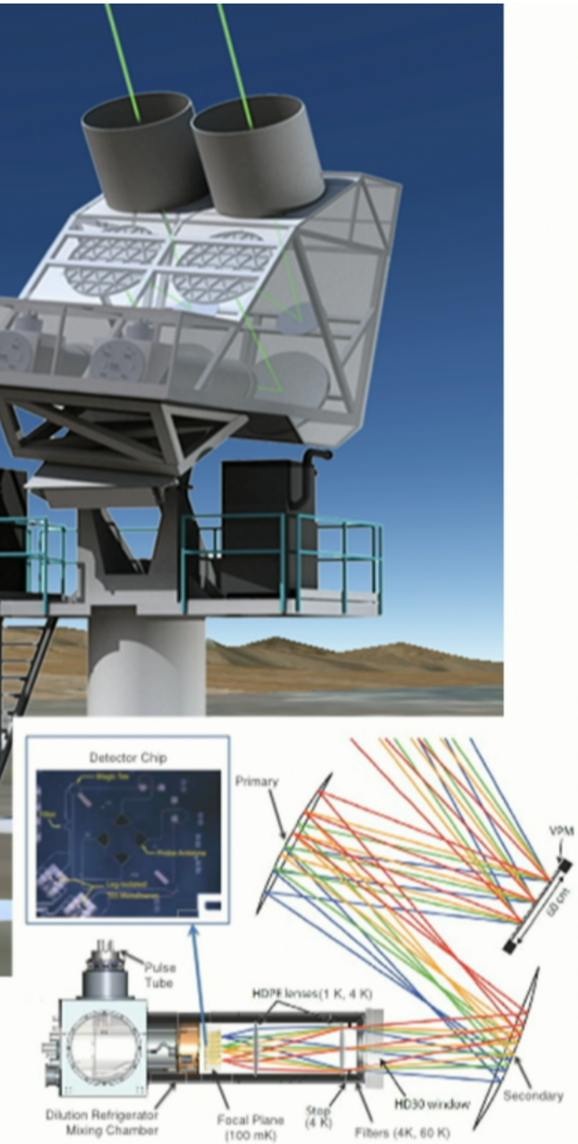


There are a lot of CMB polarization experiments already under way or very far along.

- ACT (ACTpol, Advanced ACT, ABS)
- Bicep3 & Keck
- CLASS
- Ebex
- Piper
- Pixie
- Planck
- Polarbear
- South Pole Telescope (SPTpol, SPT3g, ..)
- Spider


KECK
(spud)
2560 TES
5 cameras
Two colours
•Data from 2012 & 2013 seasons in hand.
•9.5 μK rt s
•Now with two cameras at 95 GHz



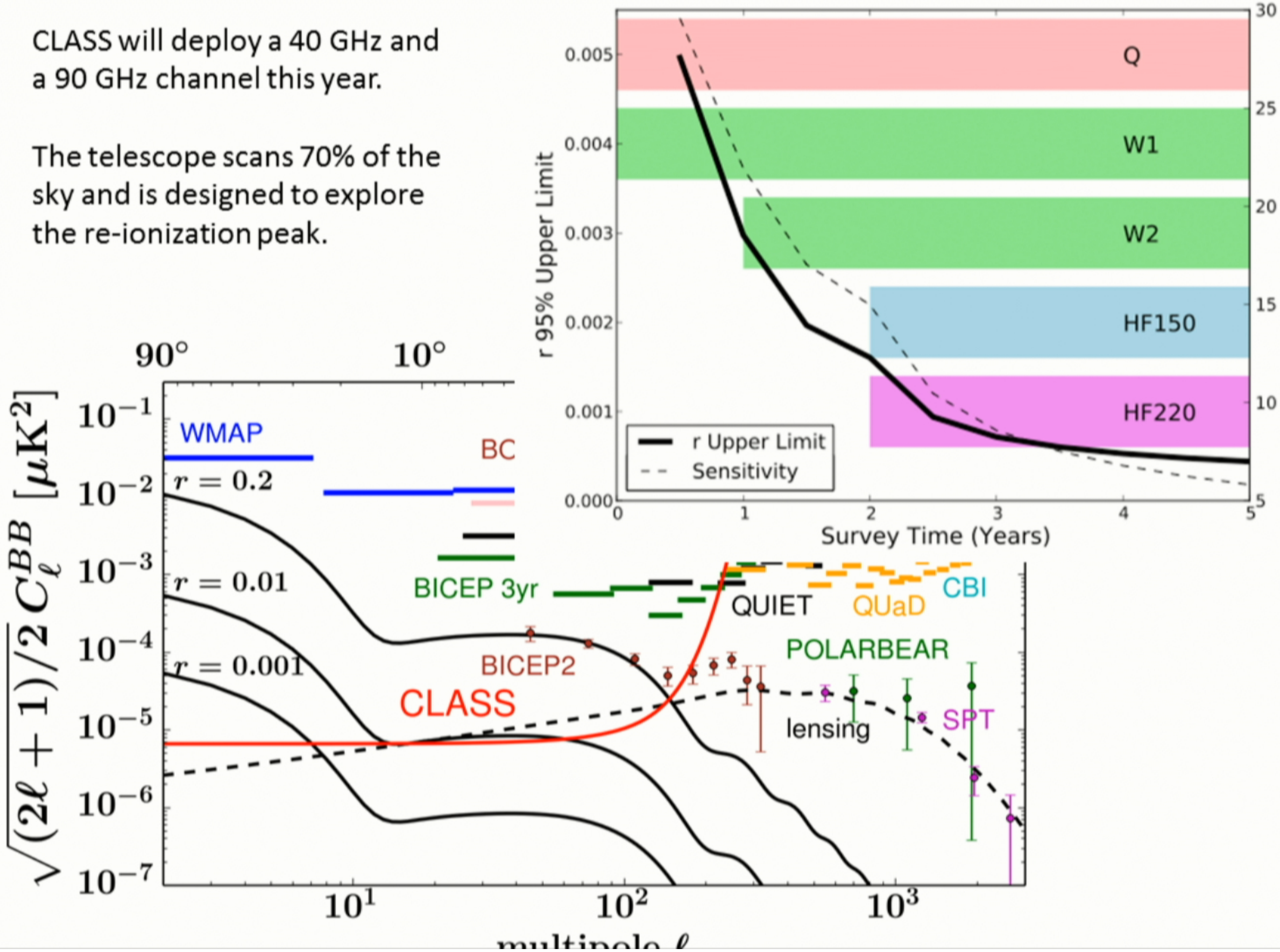


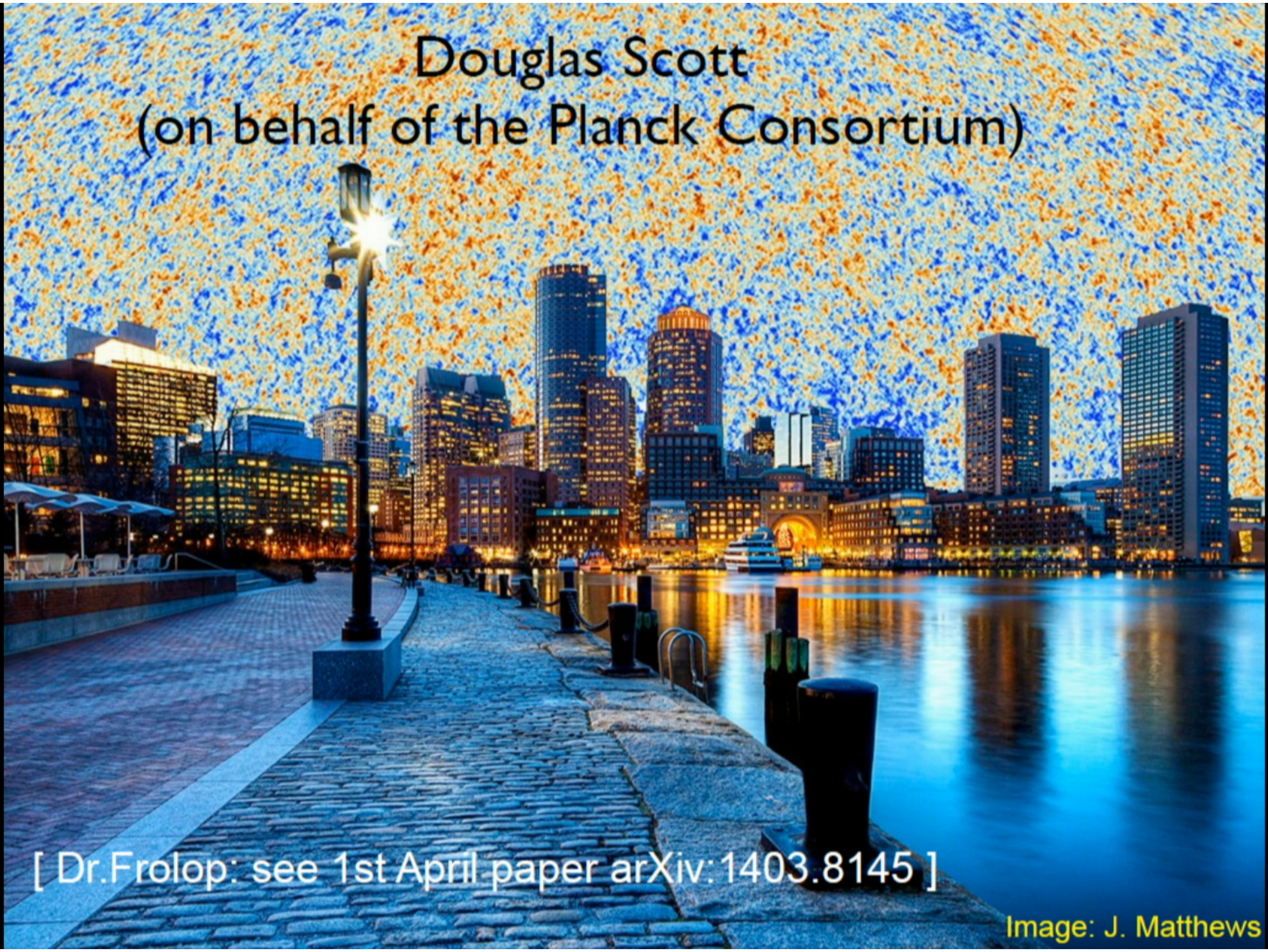
CLASS: Four colour large angular scales

To begin operation end of 2014

CLASS will deploy a 40 GHz and a 90 GHz channel this year.

The telescope scans 70% of the sky and is designed to explore the re-ionization peak.



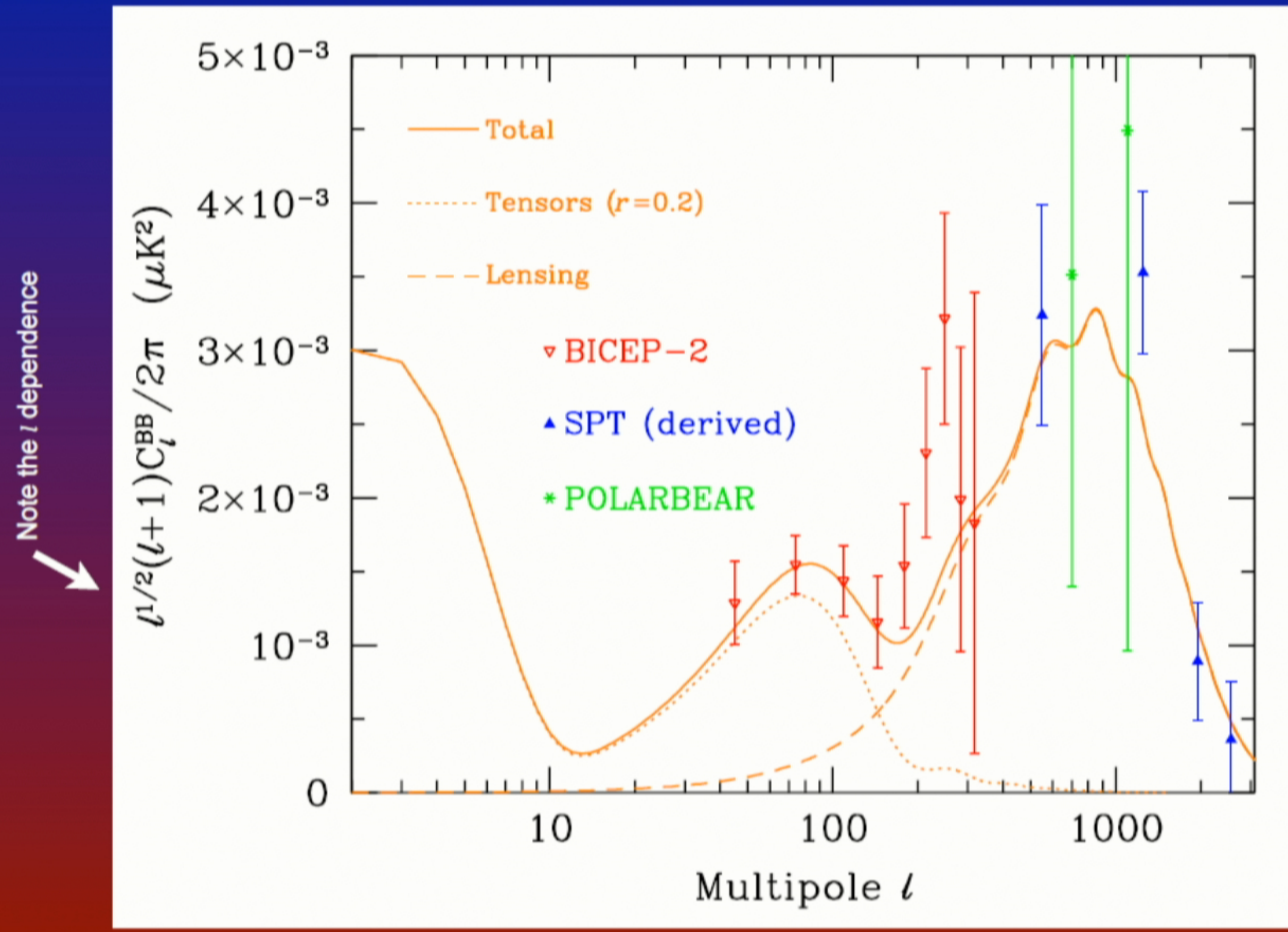

Douglas Scott
(on behalf of the Planck Consortium)
[Dr.Frolop: see 1st April paper arXiv:1403.8145]
Image: J. Matthews

Planck results so far

- 2 surveys, no polarization (+WP+Highl)
- Good fit to 6 parameter model
- r<0.11 in 7 parameter fit
- r<0.26 in 8 parameter fit (including running)
- But first 30 multipoles a little low
- Also hemispheric asymmetry at large scales

- Coming: 5 surveys (HFI), 8 surveys (LFI) including polarization

Current BB summary



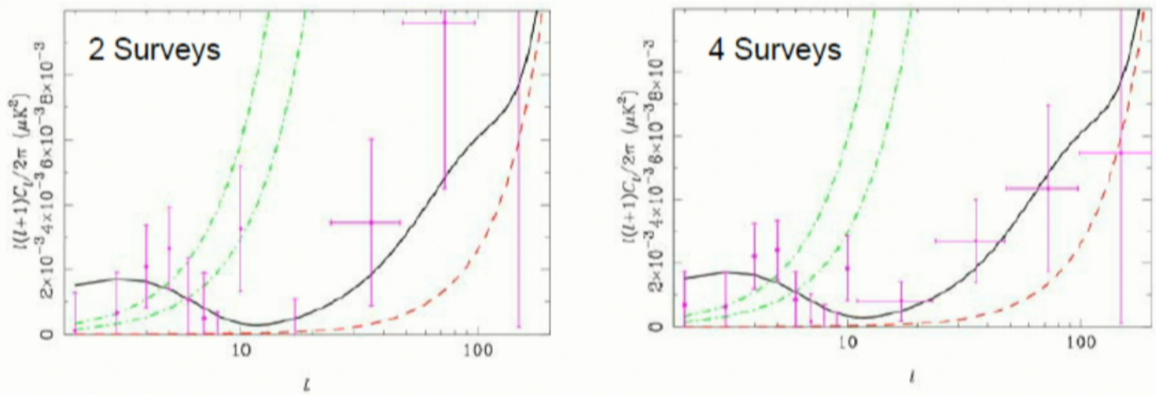


***Figure 2**: The purple points show the results of B-mode recovery from Planck with two sky surveys (left) and four sky surveys (right). An input value of $r = 0.05$ has been assumed in these simulations. The black lines show the theoretical B-mode spectrum. The dot-dashed green lines show the instrumental noise spectra for two and four surveys. The dashed red lines show the B-mode signal from lensing of E-modes by intervening large-scale structure. A detection of a B-mode with $r \sim 0.05$ is marginal with two sky surveys but statistically highly significant with four sky surveys.*

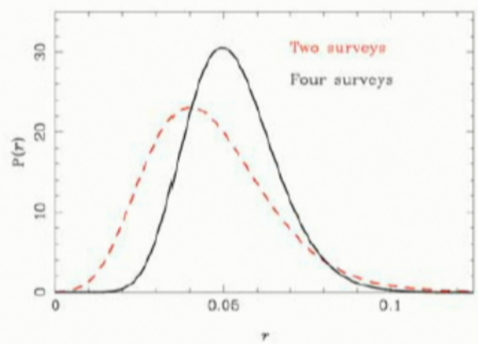
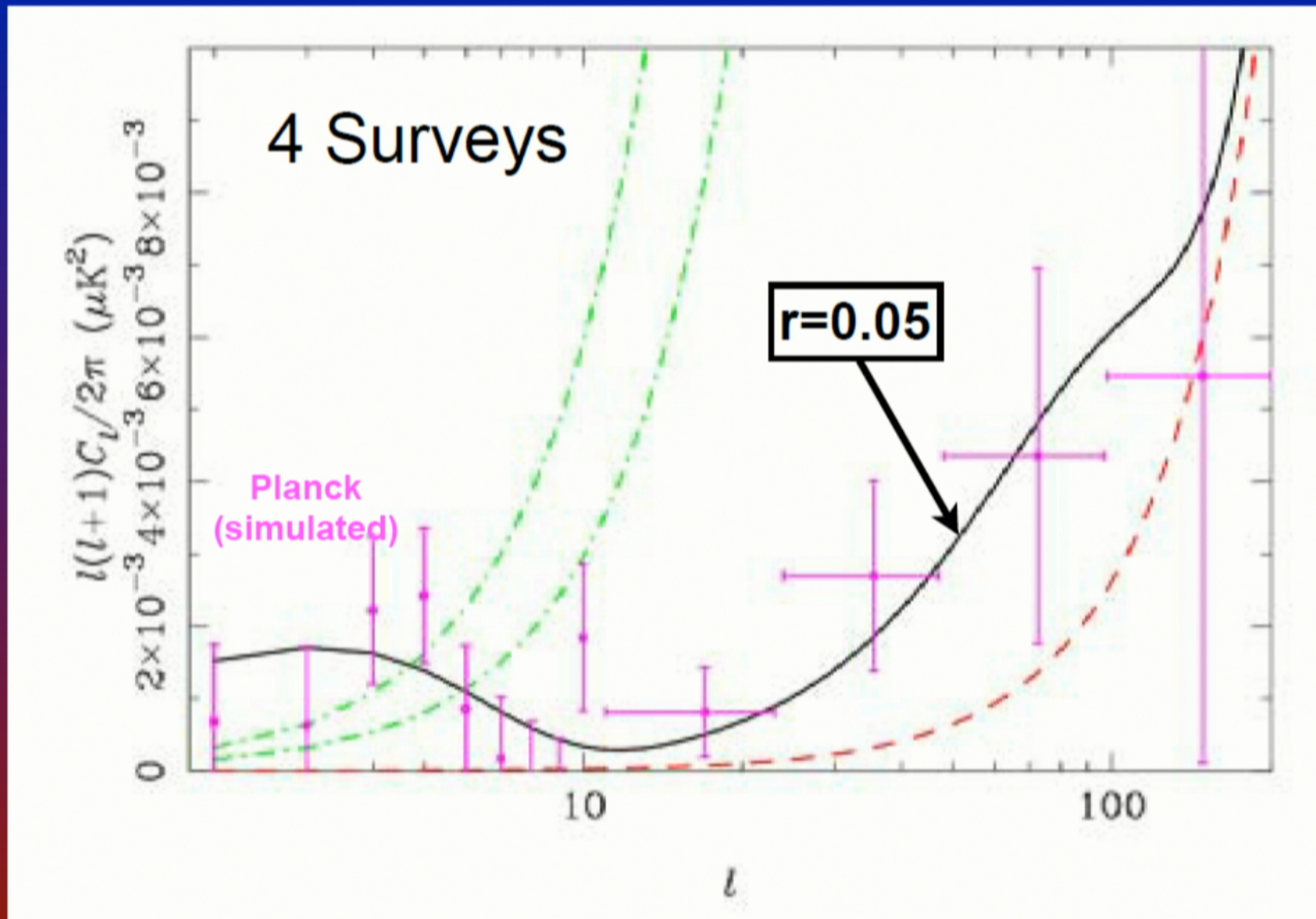


***Figure 3**: Marginalised likelihoods for the tensor-scalar ratio, r, for two Planck sky surveys (red dashed line) and four Planck sky surveys (black solid line). The theoretical 1σ sensitivity limit is $r \sim 0.01$ for Planck with 4 sky surveys (see Table 1) making Planck competitive with the most sensitive ground based and sub-orbital experiments.*



Polarization data release expected in October

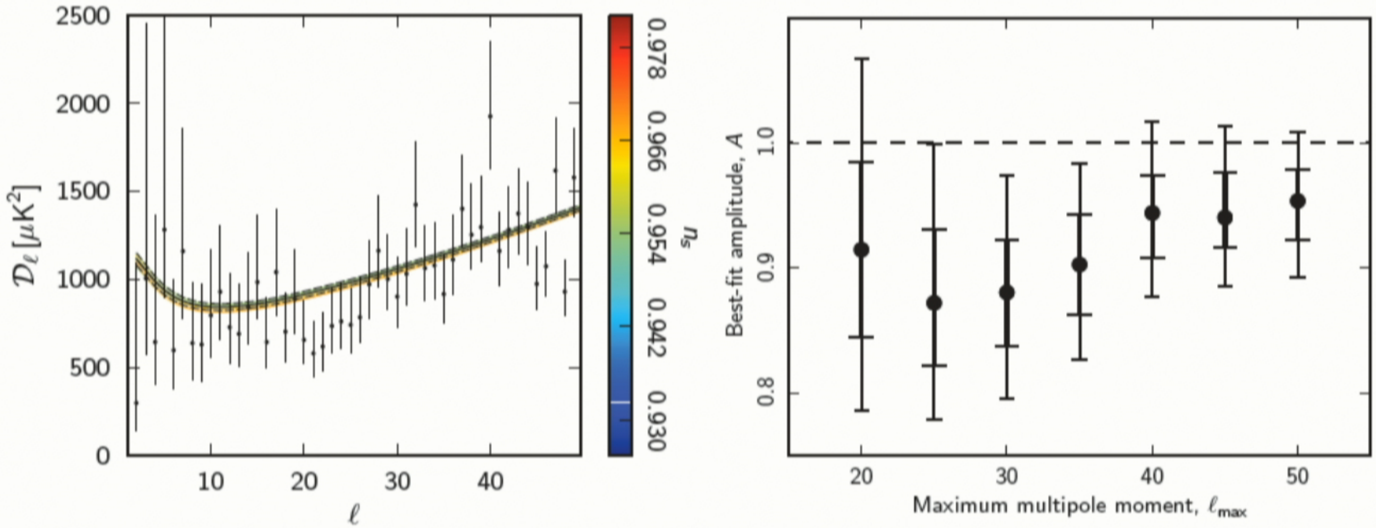


Fig. 39. *Left*: *Planck TT* spectrum at low multipoles with 68% ranges on the posteriors. The "rainbow" band show the best fits to the entire *Planck*+WP+highL likelihood for the base ΛCDM cosmology, colour-coded according to the value of the scalar spectral index n_s. *Right*: Limits (68% and 95%) on the relative amplitude of the base ΛCDM fits to the *Planck*+WP likelihood *fitted only to the Planck TT likelihood* over the multipole range $2 \le \ell \le \ell_{max}$.

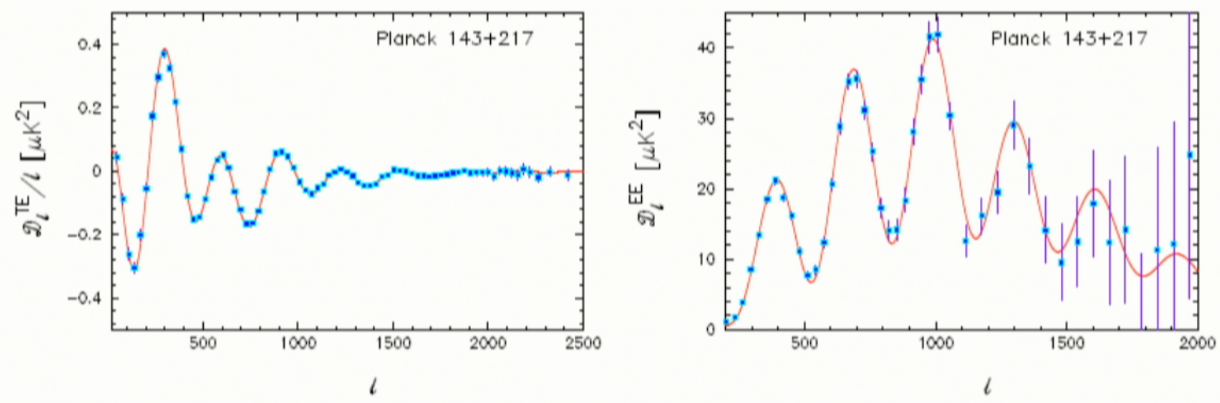


Fig. 11. *Planck TE* (left) and *EE* spectra (right) computed as described in the text. The red lines show the polarization spectra from the base ΛCDM *Planck*+WP+highL model, *which is fitted to the TT data only*.

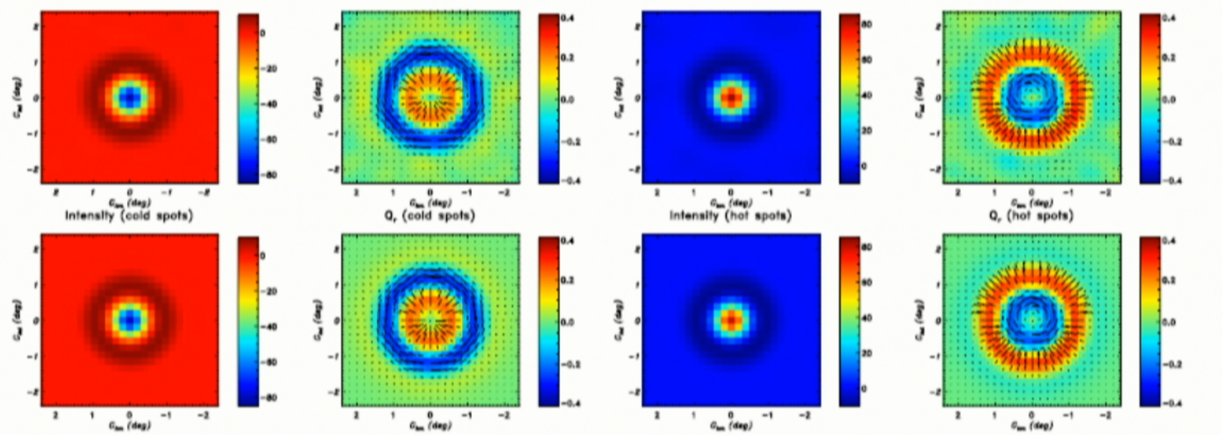
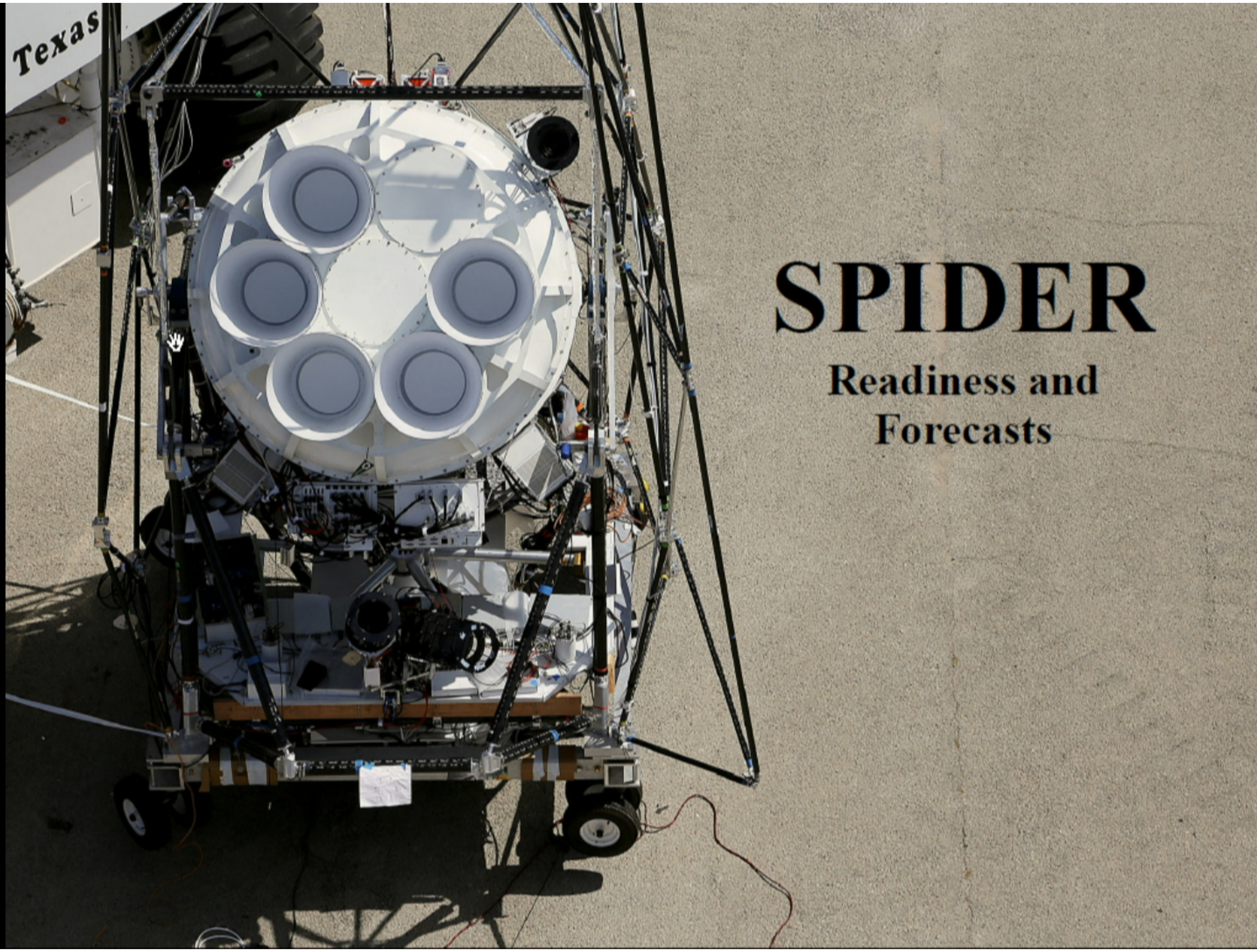
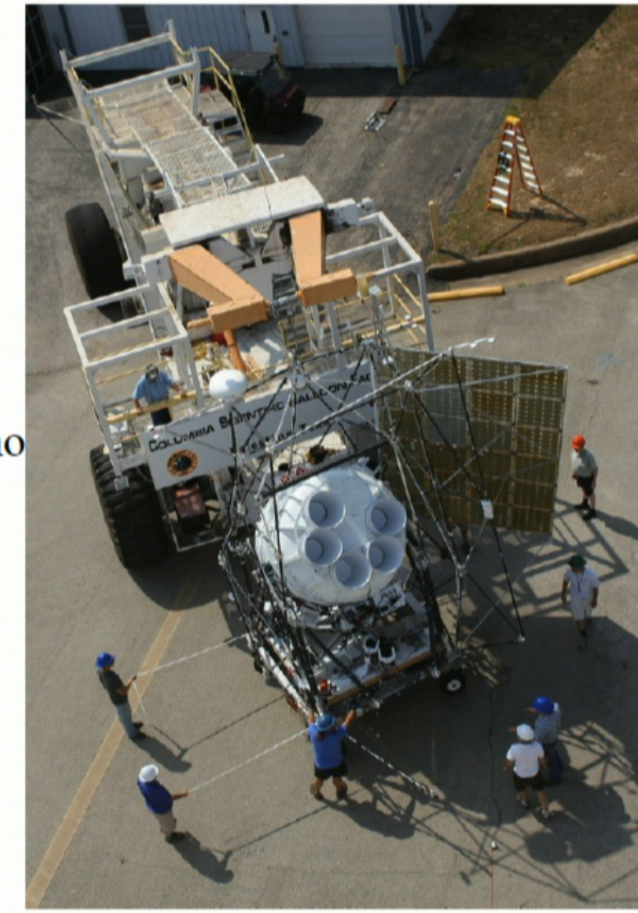


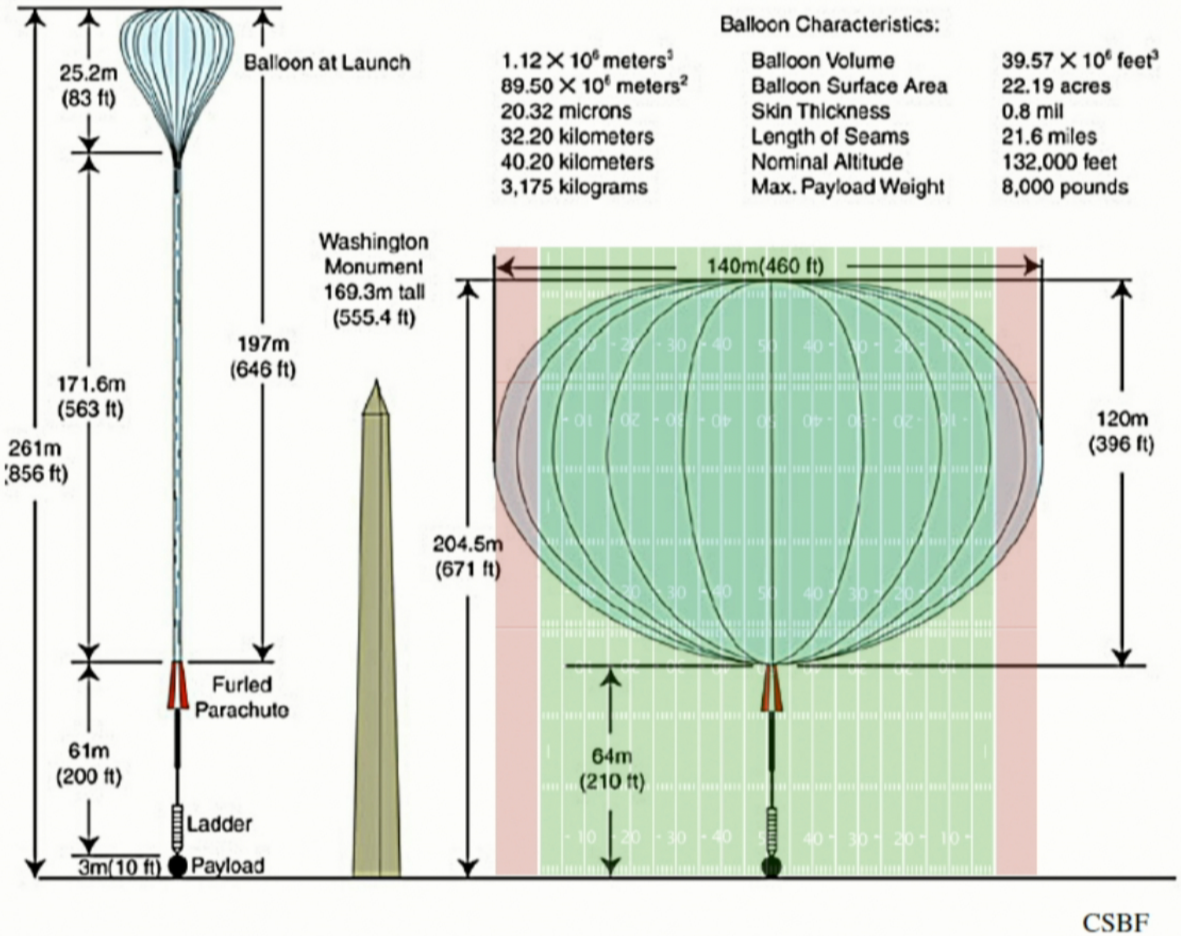
Fig. 27. Stacked maps of the CMB intensity I and polarization Q_r at the position of the temperature extrema, at a common resolution of 30 arcmin. Maps are displayed for CMB temperature cold spots (left) and hot spots (right) for the *Planck* CMB estimates (top row) and for the ΛCDM*Planck* best fit model prediction (bottom row).


Texas
SPIDER
Readiness and
Forecasts

SPIDER

- A balloon borne polarimeter
- Will map the cleanest 8% of the full sky.
- Six telescopes 3/3 at 90/150 GHz
  - Approximately 2300 detectors
- Half degree resolution. $\ell = 10 - 300$
- Science goals:
  - Precisely determine the amplitude of B mo
- Palestine, June 4 – August 28.
- Two science flights: planned 2013/2015
- Integrated and **deployed** Sep 2013
- Gov't shutdown eliminated the 2013/14 season in Oct 2013
- (Two science flights: 2013/2015)++



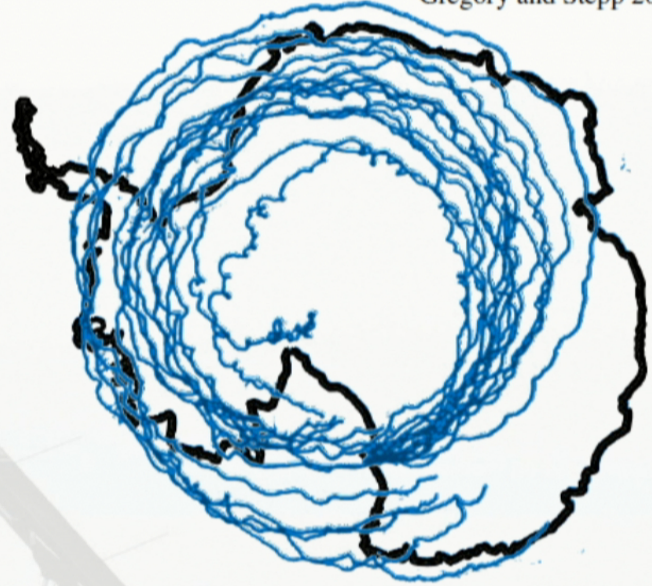


Balloon Characteristics:
1.12 X 10^6 meters^3 Balloon Volume 39.57 X 10^6 feet^3
89.50 X 10^6 meters^2 Balloon Surface Area 22.19 acres
20.32 microns Skin Thickness 0.8 mil
32.20 kilometers Length of Seams 21.6 miles
40.20 kilometers Nominal Altitude 132,000 feet
3,175 kilograms Max. Payload Weight 8,000 pounds
Balloon at Launch
25.2m
(83 ft)
171.6m
(563 ft)
261m
(856 ft)
197m
(646 ft)
Furled
Parachute
61m
(200 ft)
Ladder
3m(10 ft)
Payload
Washington
Monument
169.3m tall
(555.4 ft)
140m(460 ft)
204.5m
(671 ft)
120m
(396 ft)
64m
(210 ft)
CSBF

Steve Benton – **The Boss** letting go of *Blastpol* 2012

Long Duration Ballooning

Gregory and Stepp 2004

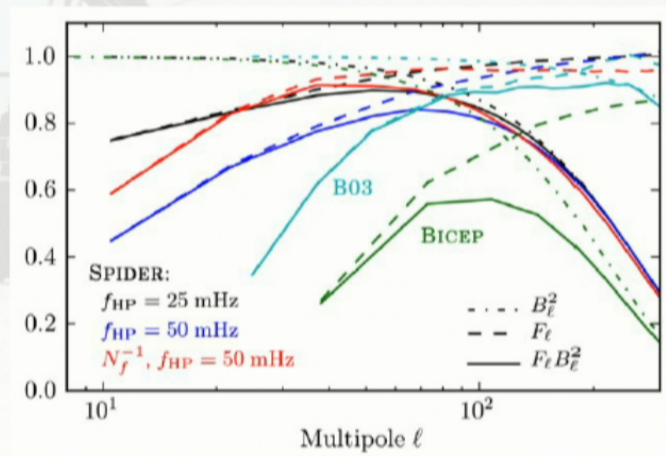


Why Ballooning? Access to space.

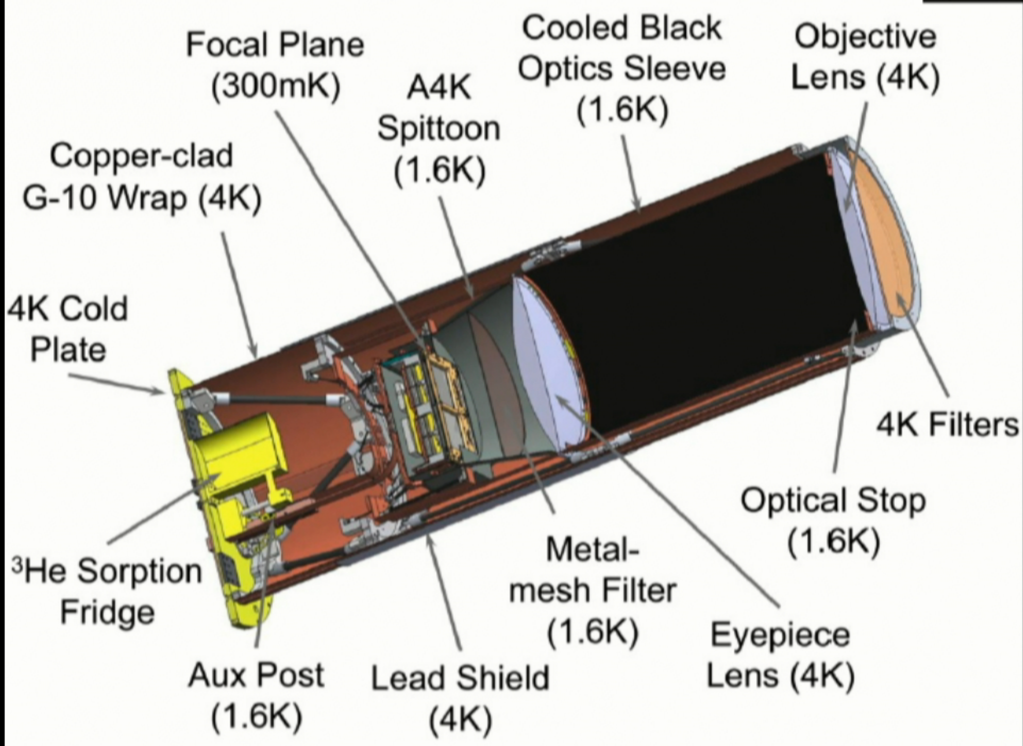
- Fidelity to large angular scales.
- Wider frequency windows.
  - Water vapor makes >150 GHz difficult
- Space-like loading (NET).

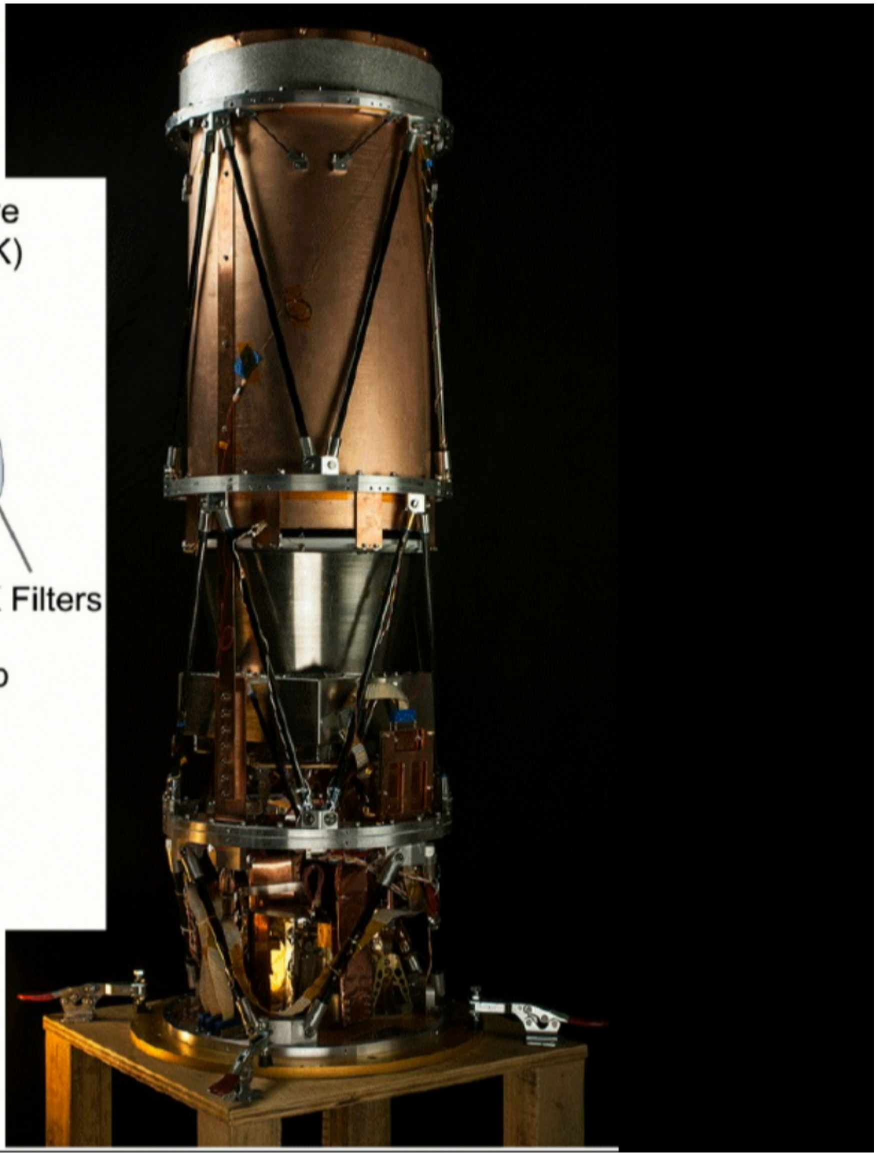
At what price?

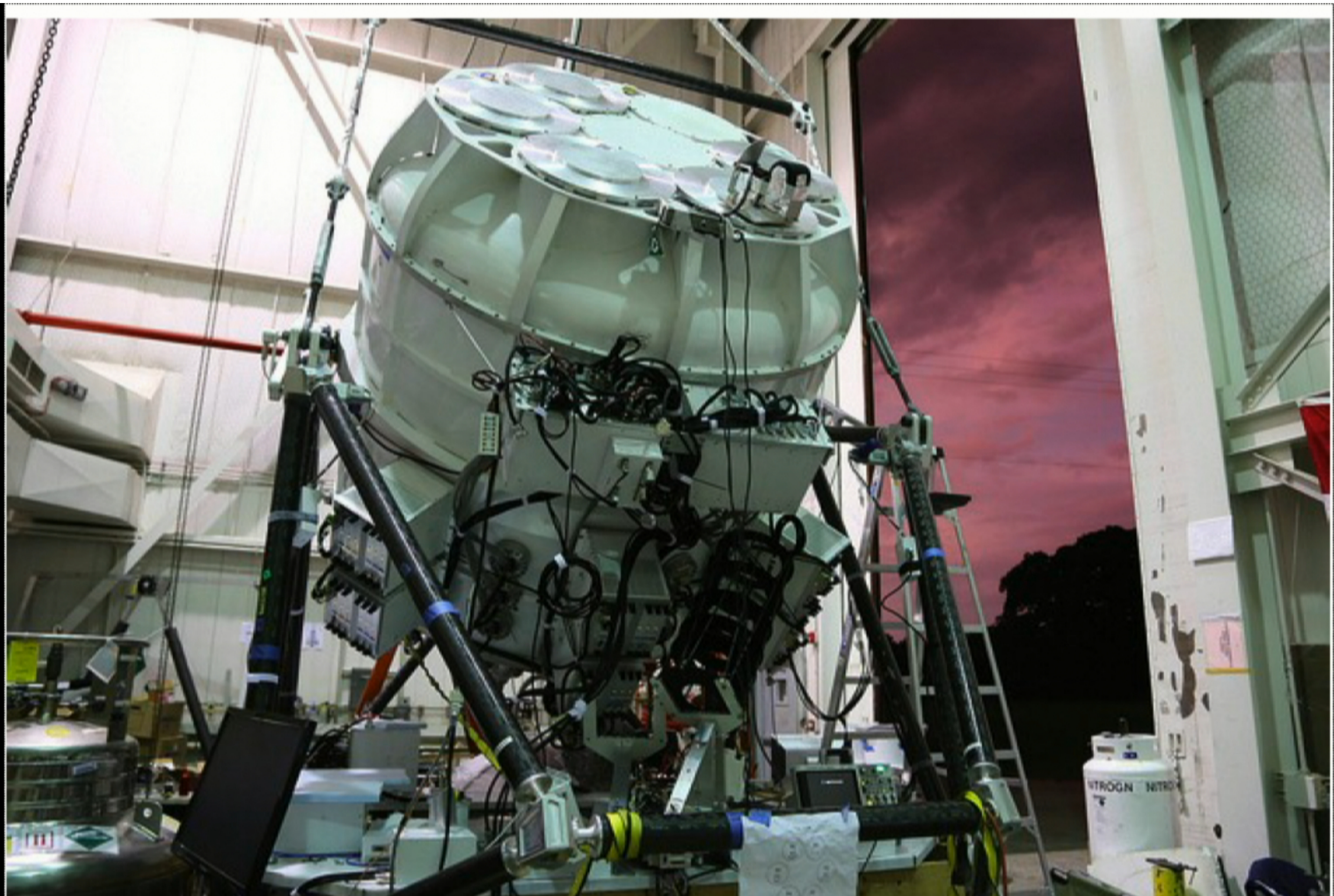
- Mass, power, automation
- Risky recovery
- Narrow, and scarce, flight windows
- (Exposure to Congressional whim)



The Telescope

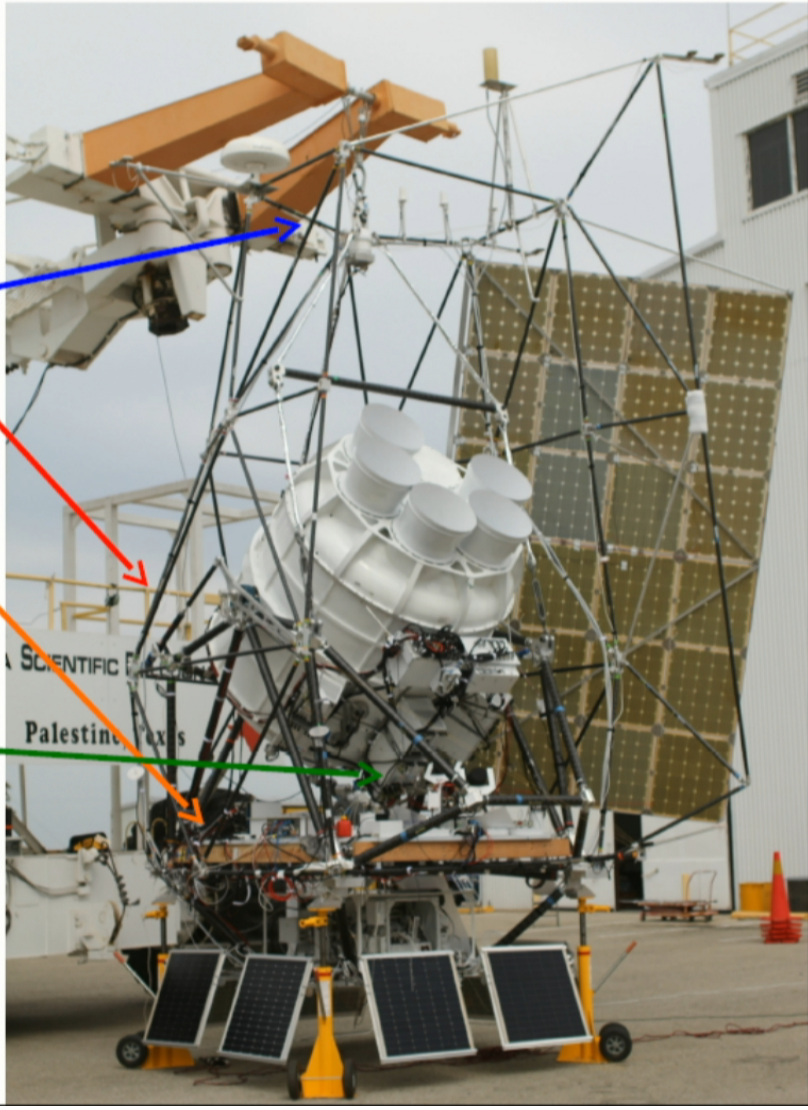




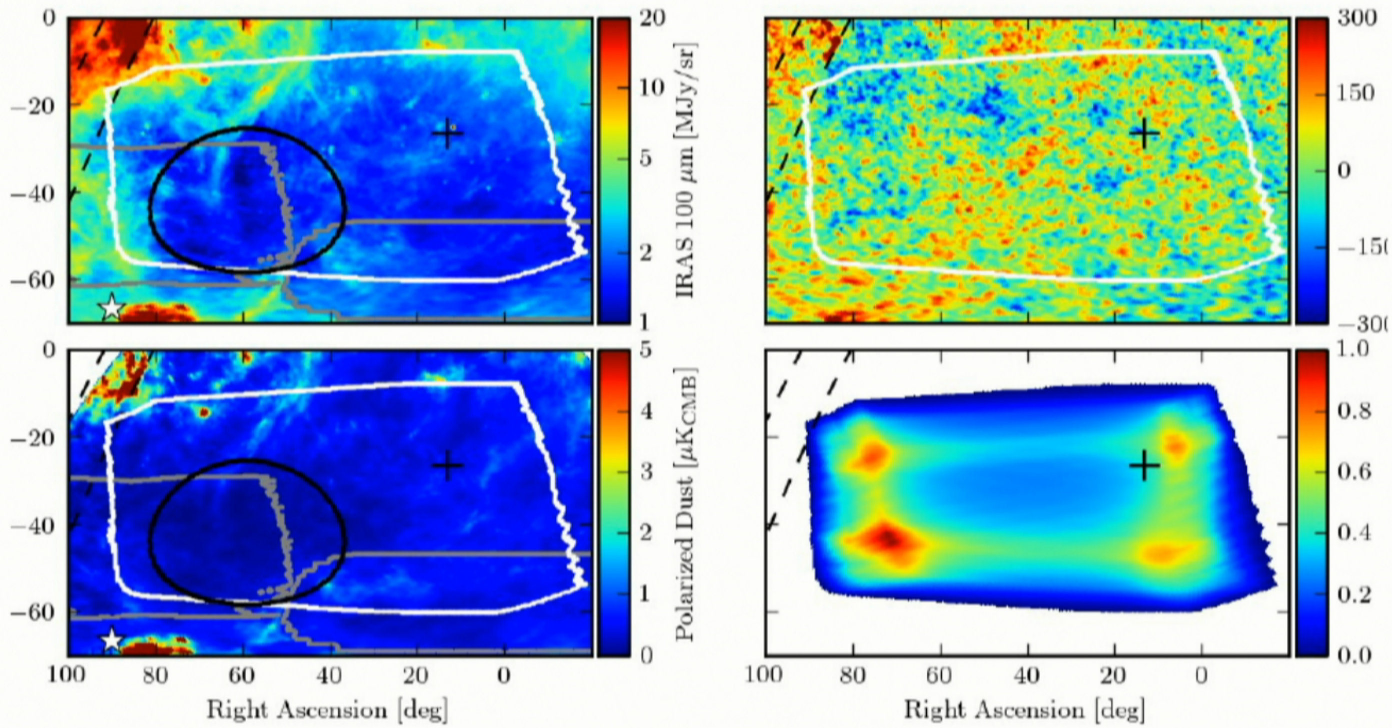

NITROGN

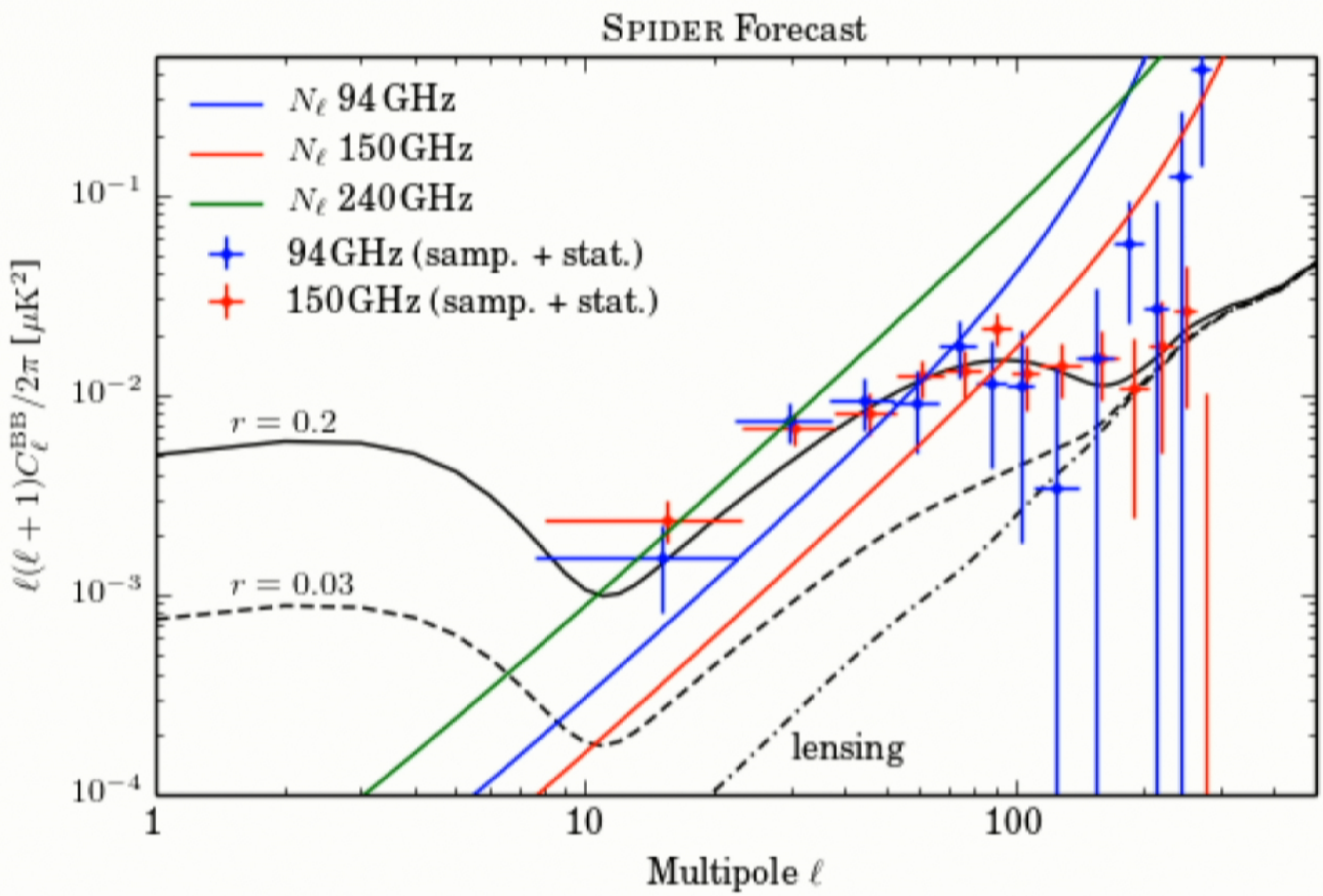
Pointing Control and Reconstruction

- Twin elevation drives
- Reaction wheel
- Pivot
- 3-axis gyros
- Differential GPS
- Magnetometer
- Pinhole sun sensors
- Orthogonal star cameras on rotating table to track objects
- Fixed boresight star camera
- Expect 1’ accuracy in flight, 6” post-flight



Spider's observing region
8% of the sky



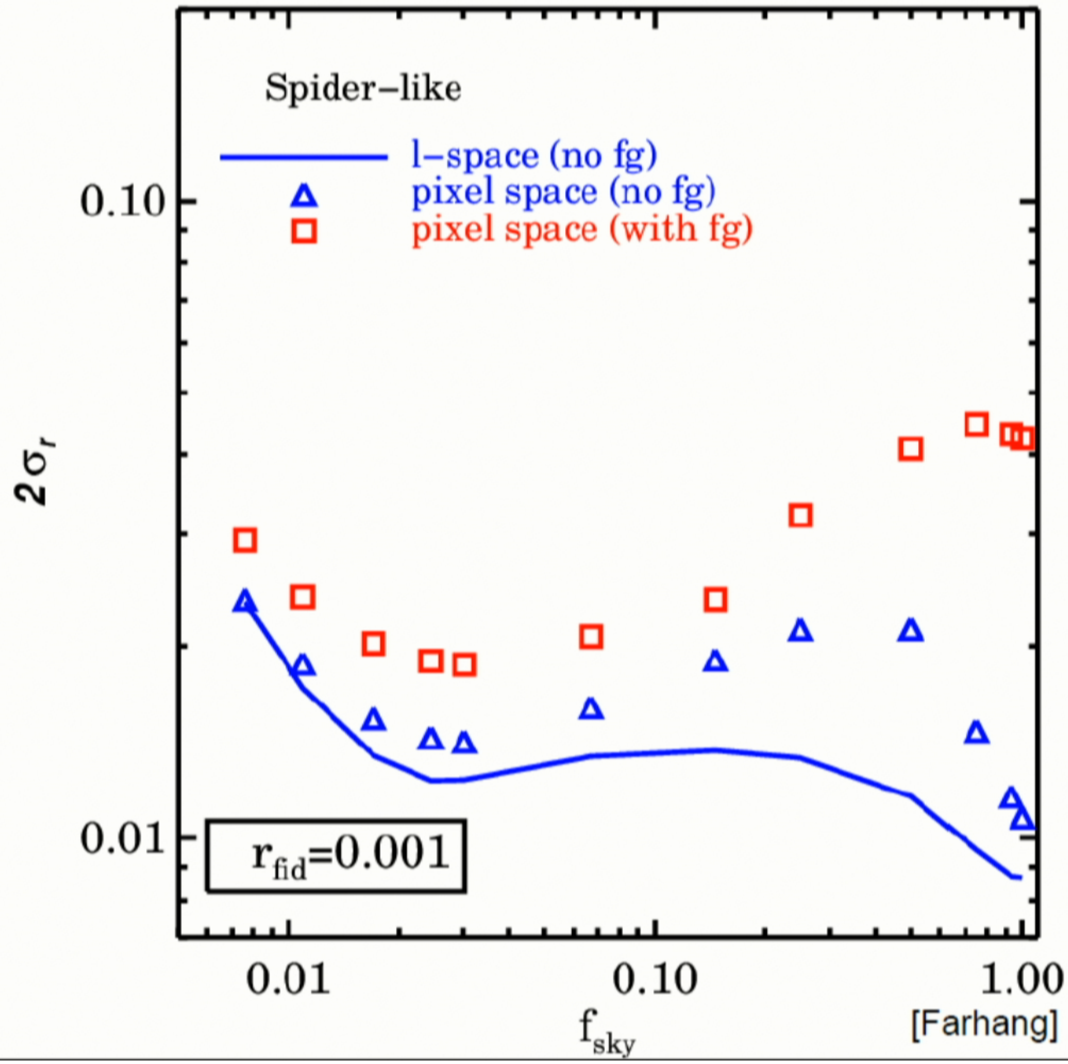

SPIDER Forecast
N_ℓ 94 GHz
N_ℓ 150GHz
N_ℓ 240GHz
94GHz (samp. + stat.)
150GHz (samp. + stat.)
$r = 0.2$
$r = 0.03$
lensing
$\ell(\ell+1)C_\ell^{BB}/2\pi$ [μK^2]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
1
10
100
Multipole ℓ

Pixel Space Direct Detection of r

$1\sigma < 0.01$ for Spider

Prefers ~3% of sky

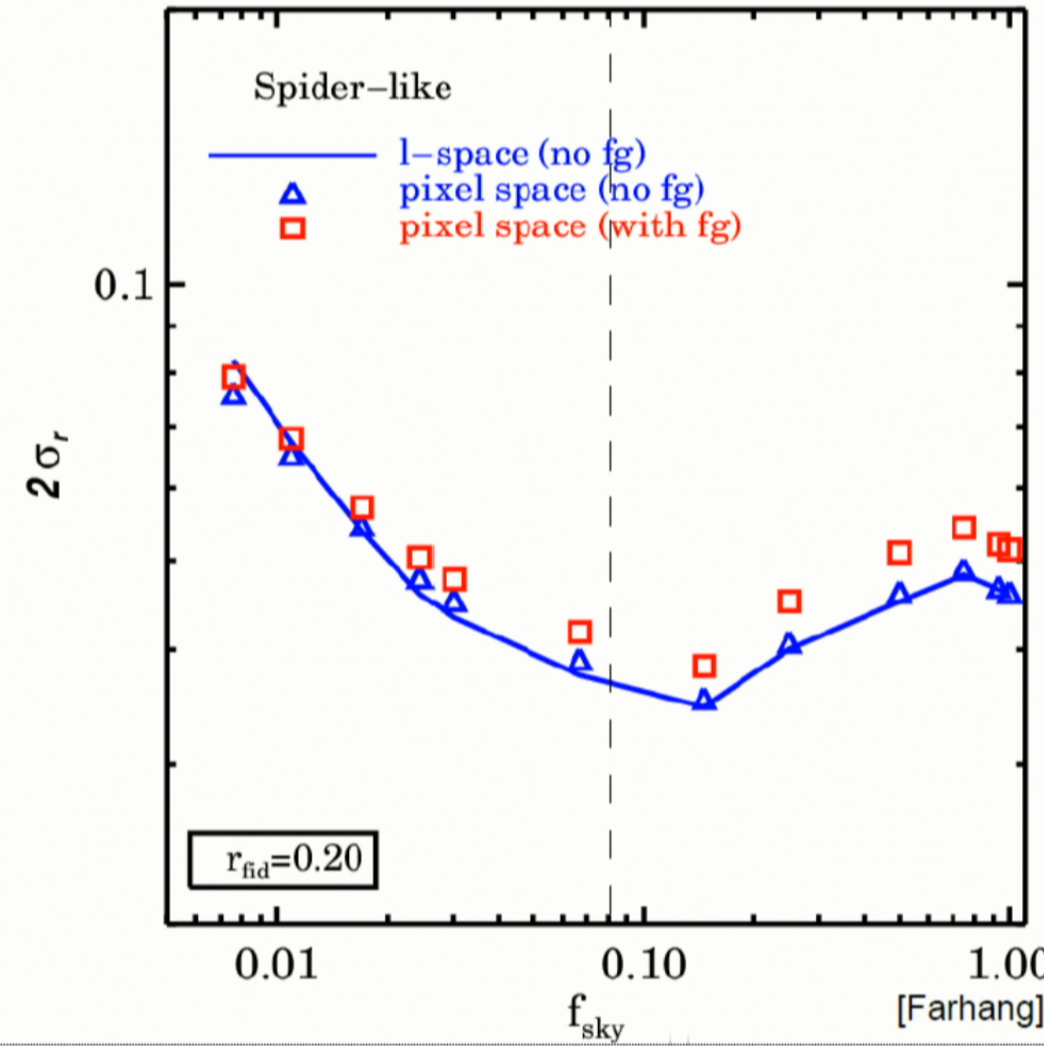
For tiny r (Our assumption pre-BICEP2)



Pixel Space Direct Detection of r

1σ ~ 0.017 for Spider

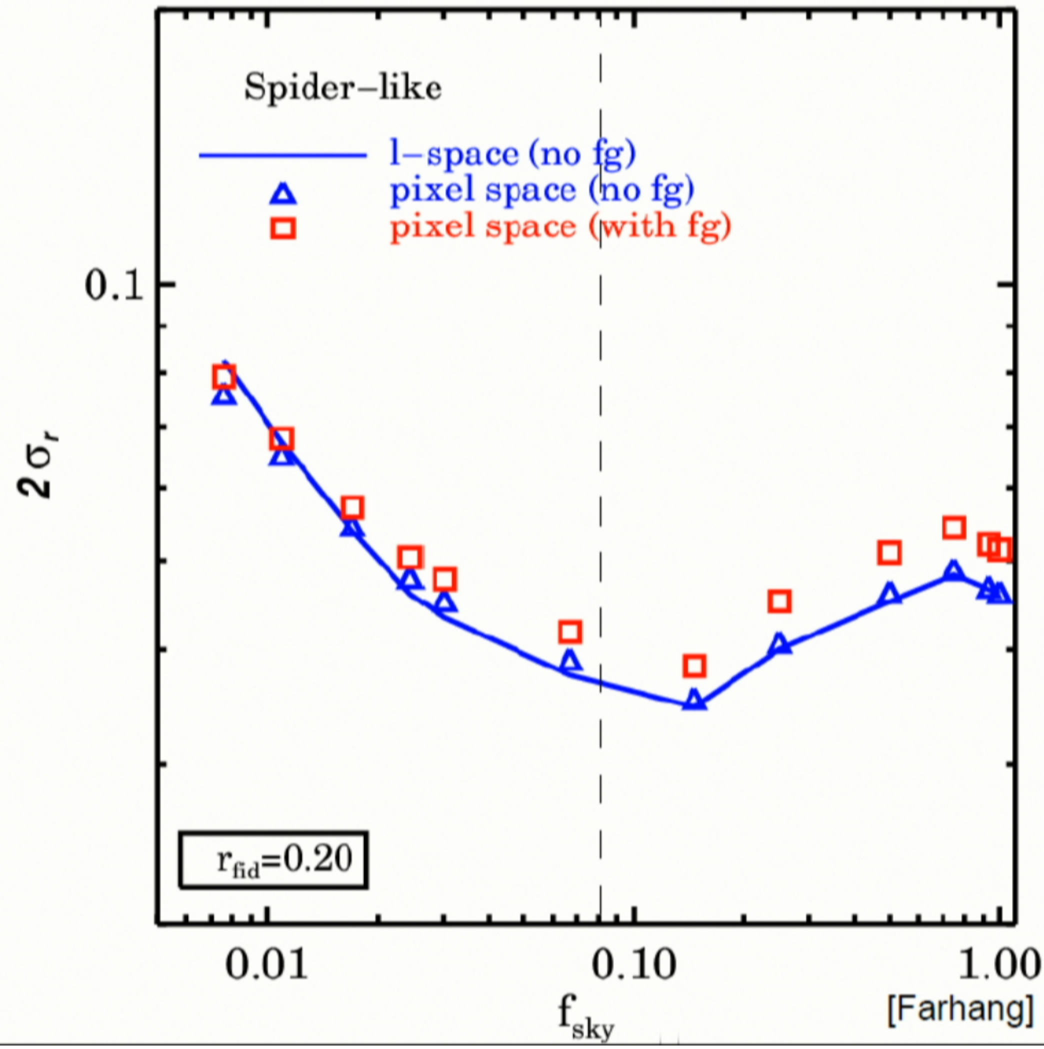
Excellent, *not* Overspeced!



Pixel Space Direct Detection of r

1σ ~ 0.017 for Spider

Excellent, *not* Overspeced!



SPIDER Collaboration

Caltech
J. J. Bock
J. A. Bonetti
B. P. Crill
O. Doré
J. P. Filippini
S. Golwala
W. Holmes
V. V. Hristov
P. V. Mason
L. Moncelsi
T. A. Morford
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A. Trangsrud
R. S. Tucker
A. D. Turner

Cambridge
C.J. MacTavish

Cardiff
P. Ade
C. Tucker

CWRU
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T. Montroy
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C.N. Clark
D.T. O'dea

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G. Hilton
C. Reintsema

Princeton
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A. Fraisse
A. Gambrel
J.E. Gudmundsson
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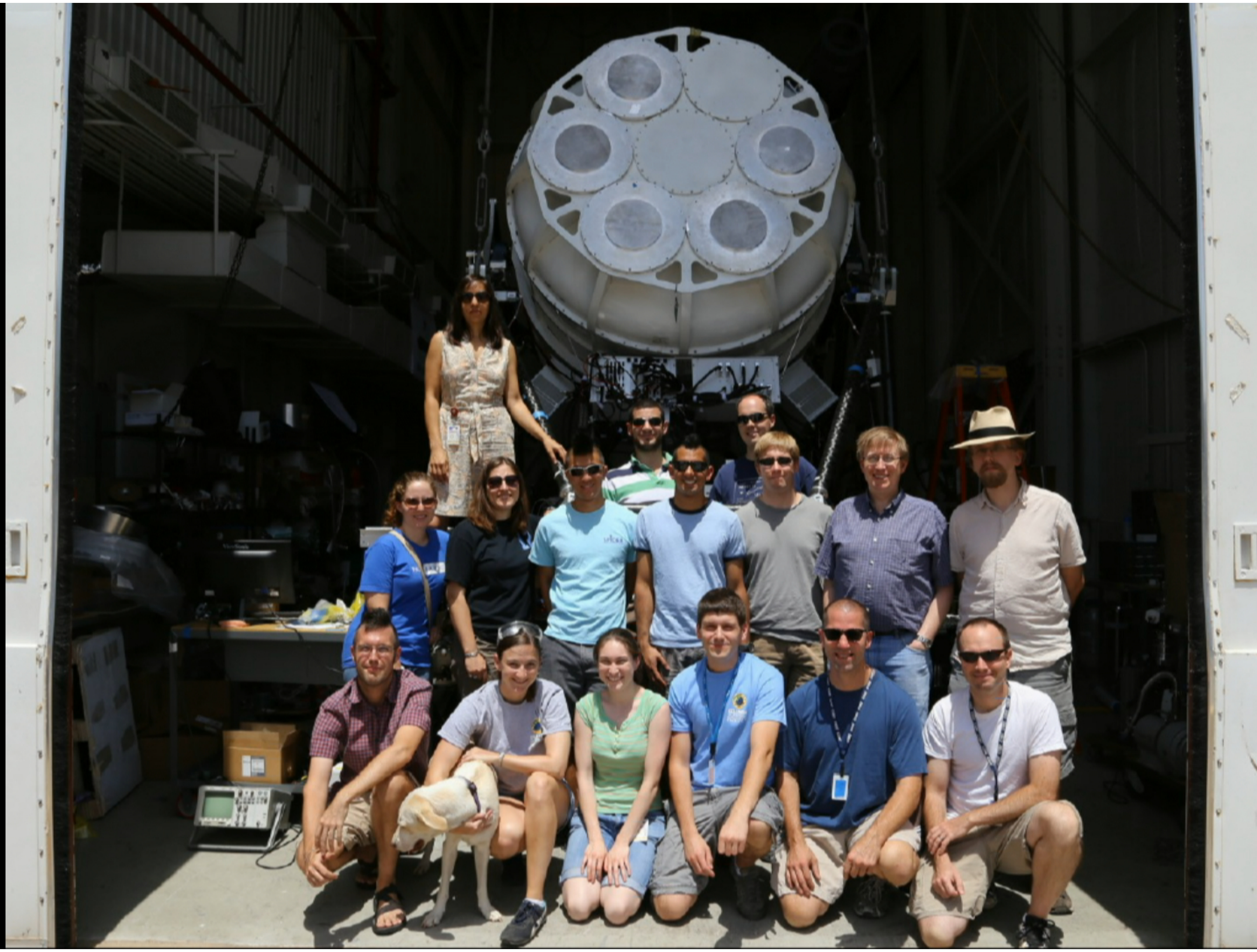
M. Halpern
M. Amiri
B. Burger
G. Davis
M. Hasselfield
D. Wiebe

UKZN
H.C. Chiang

U. Toronto/CITA
C.B. Netterfield
J.R. Bond
S.J. Benton
M. Farhang
L.M. Fissel
N.N. Gandilo
I. Padilla
J.A. Shariff
J.D. Soler

Stanford
K.D. Irwin
C.L. Kuo

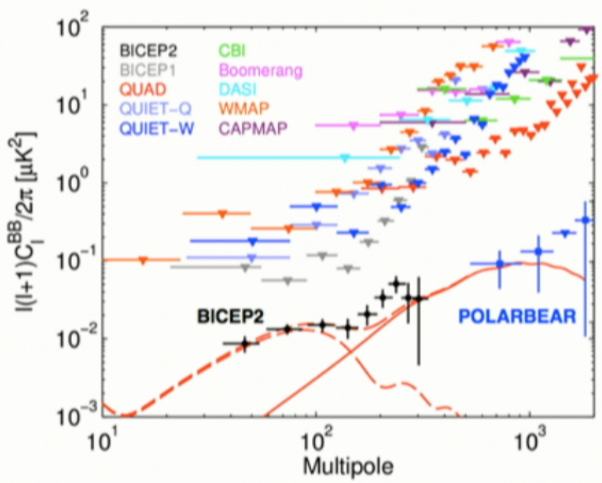


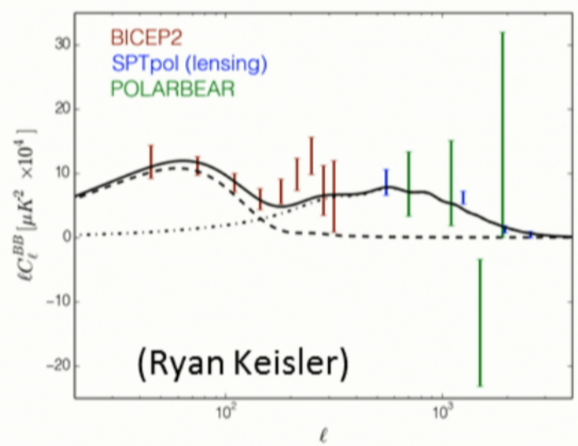
B-mode Science

- Inflation
  - r
  - n_s
    - Delensing
    - Large f_{sky}
- high-ell
  - LSS
  - Neutrino mass

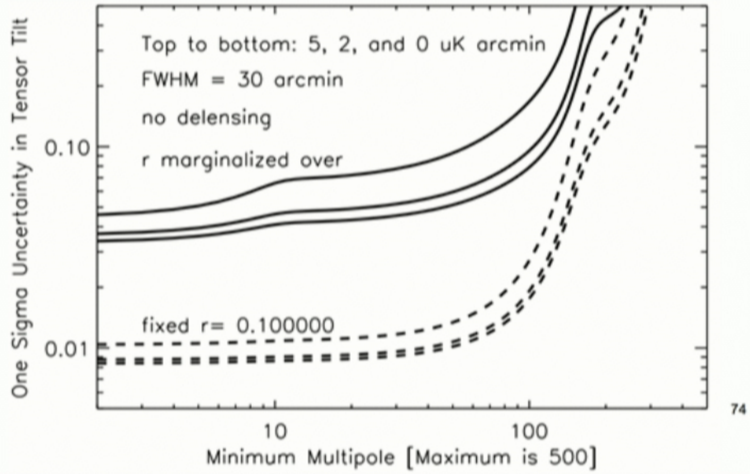
  → Big dish, deep.
  SPTpol/3g, POLARBEAR 2/Simons, ACTpol/adv
- Reionization
  - When - ell
  - how long - Δell
  - how big – amplitude

  → All sky, many colors
  PRISM, LiteBIRD, PIXIE





n_t



**Most optimistic forecast [full sky, white noise, no foreground]*

De-lensing is now crucial

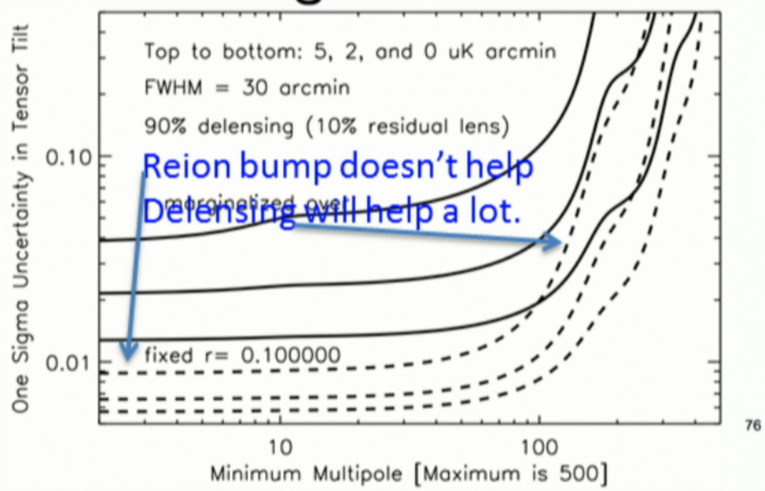


Figure: Komatsu
(Colloquium, Yukawa Institute for
Theoretical Physics, March 26, 2014)

- Without delensing, reducing noise beyond 5 uK-arcmin doesn't help.

PolarBEAR/Simons Array

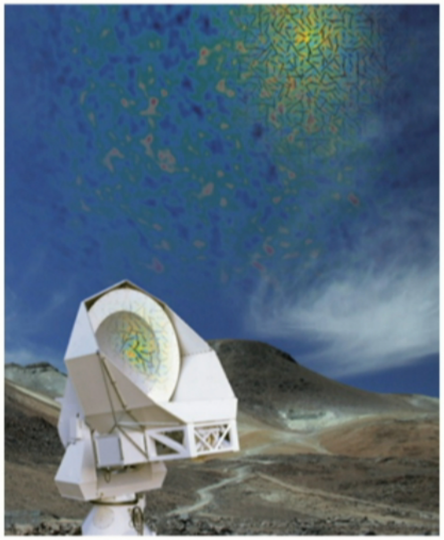
- PB1
  - One 3.5m Telescope
  - 1200 detectors
  - Already 6 uK-arcmin today.

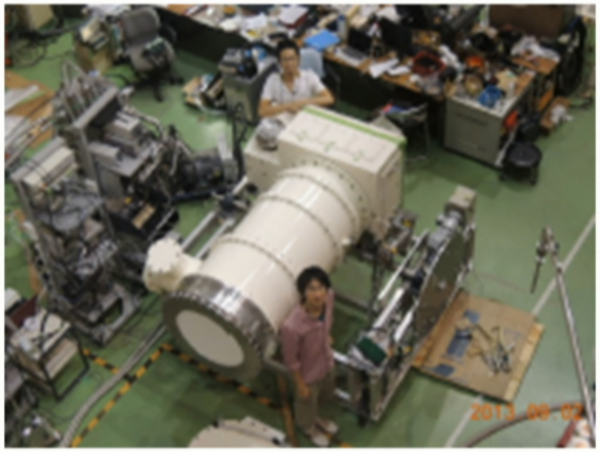
  Astro-ph/1403.2369 (high ell B-mode Power Spectrum)

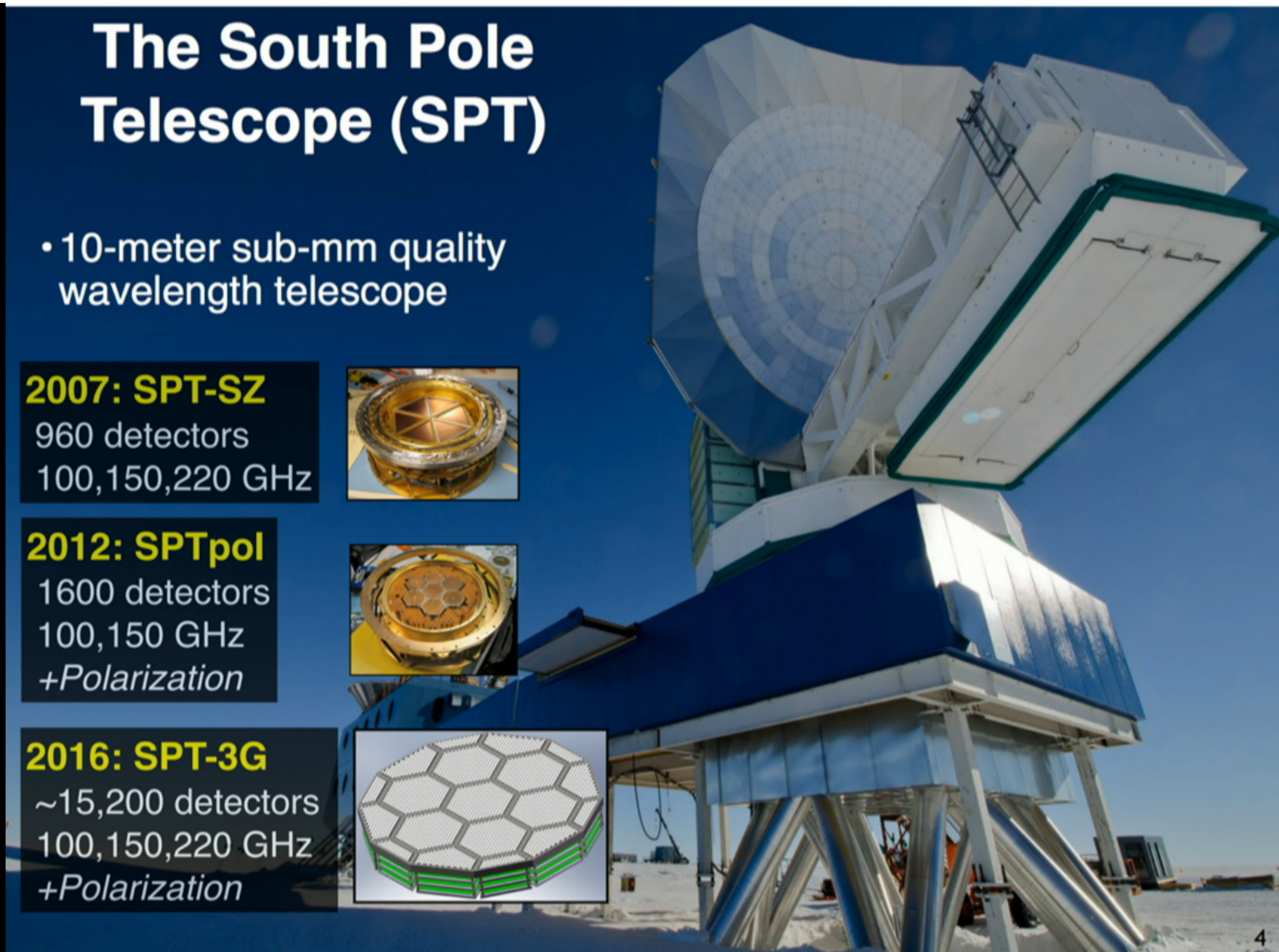
  Astro-ph/1312.6646 (CMB-only Lensing Spectrum)

  PRL **112**, 131302, Astro-ph/1312.6645 (CMB lensing x IR galaxies)

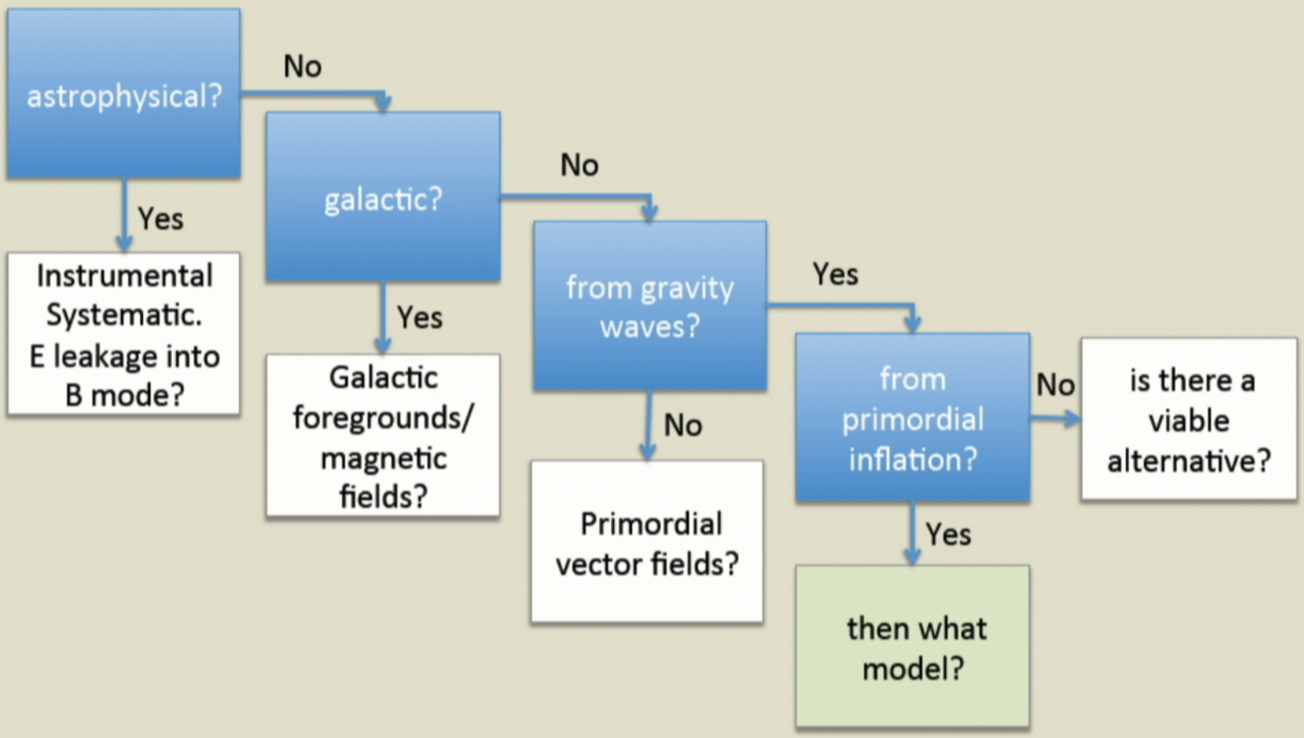
  → NEXT GOAL: POLARBEAR-1 explore r = 0.2 using 15° x 15 ° patches
- PB2
  - 1/3 of Simons
- Simons Array
  - Three 3.5m Telescopes
    - 30 < ell < 3000
  - 22,764 detectors
    - (dual color)
    - 7,588 at 95 GHz
    - 11,382 at 150 GHz
    - 3,794 at 220 GHz.
    - Digital fMUX readout + HWP
  - Resolution: 4' to remove lensing
  - Sky Coverage: Mid latitude => 80% of sky
  - Sensitivity: 23,000 total TES bolos






The South Pole Telescope (SPT)
• 10-meter sub-mm quality wavelength telescope
2007: SPT-SZ
960 detectors
100,150,220 GHz
2012: SPTpol
1600 detectors
100,150 GHz
+Polarization
2016: SPT-3G
~15,200 detectors
100,150,220 GHz
+Polarization
4

Is the BB bump:



From discussion with Liam McAllister

Rachel Bean, Cornell: Perimeter April 2014

If it is a result of inflation:

- If its large field inflation, is it $m^2\phi^2$?
- Are we seeing early times in slow roll? Was it preceded by old inflation? (Gott 82, Bucher, Goldhaber and Turok '95)
- Eternal inflation falsified by large $\Omega_k<0$, false vacuum eternal inflation falsified by large $\Omega_k<0$ (Guth and Namura'12, Kleban and Schillo'12)
- Can we discern the signature of modes at or just beyond the horizon?
  - Suppressed scalar power, boosted tensor modes, curvature?

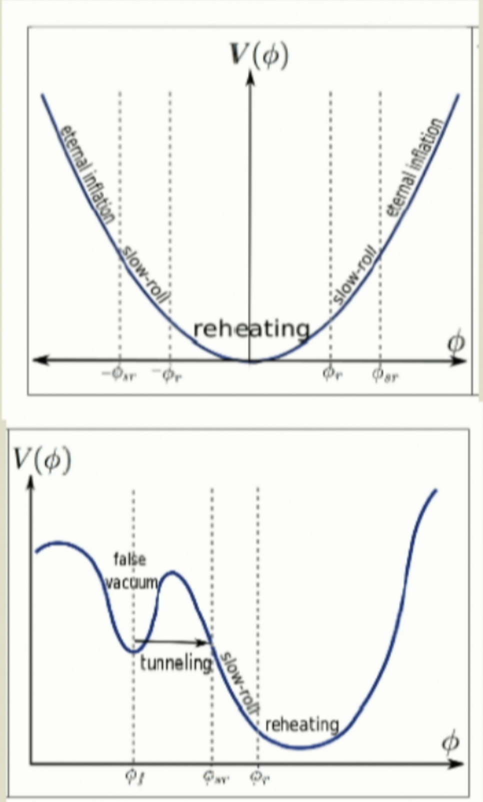


Fig: Kleban and Schillo 2012

Large scale structure's role

- Constraining the values and covariance for multi-dimensional parameter space $\{r, n_t, \alpha_s, n_s, \Omega_k\}$
  - r, n_t mainly dependent on CMB data –LSS can improve lensing extraction through cross correlation?
  - α_s, n_s, Ω_k and cov with r, n_t improved by addition of LSS power spectrum measurements along with small scale CMB

- Avoiding cosmic variance through correlating biased and unbiased estimators? (Seljak 2008)

Rachel Bean, Cornell: Perimeter April 2014

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Rachel Bean, Cornell: Perimeter April 2014

A summary comparison of Stage IV surveys

(based on publicly available data)

	DESI	LSST	Euclid	WFIRST-AFTA
Starts, duration	~2018, 5 yr	~2020, 10 yr	~2020, 7 yr	~2023, 5-6 yr
Area (deg^2)	14,000 (N)	20,000 (S)	15,000 (N + S)	2,000 (S)
FoV (deg^2)	7.9	10	0.54	0.281
Diameter	4 (less 1.8+)	6.7	1.3	2.4
Spec. res. $\Delta\lambda/\lambda$	3-4000 (N_{fib}=5000)		250 (slitless)	550-800 (slitless)
Spec. range	360-980 nm		1.1-2 μm	1.35-1.95 μm
BAO/RSD	20-30m LRGs/[OII] ELGs 0.6 < z < 1.7, 1m QSOs/Lya 1.9<z<4		~50m Hα ELGs Z~0.7-2.1	20m Hα ELGs z = 1–2, 2m [OIII] ELGS z = 2–3
pixel (arcsec)		0.7	0.13	0.12
Imaging/ weak lensing (0<z<2.)		15-40 gal/arcmin^2 5 bands 320-1080 nm	30-35 gal/arcmin^2 1 broad vis. band 550– 900 nm	68 gal/arcmin^2 3 bands 927-2000nm
SN1a		10^4-10^5 SN1a/yr z = 0.–0.7 photometric		2700 SN1a z = 0.1–1.7 IFU spectroscopy

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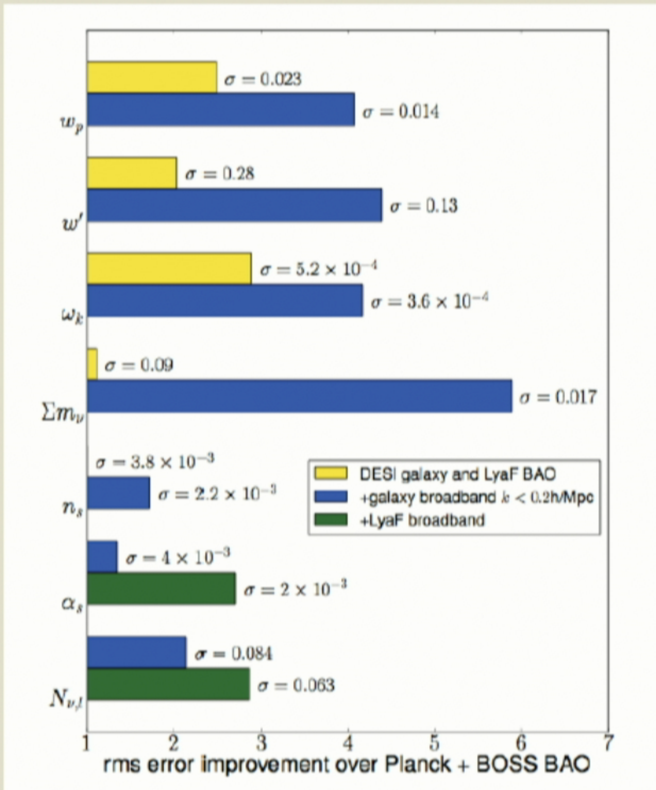
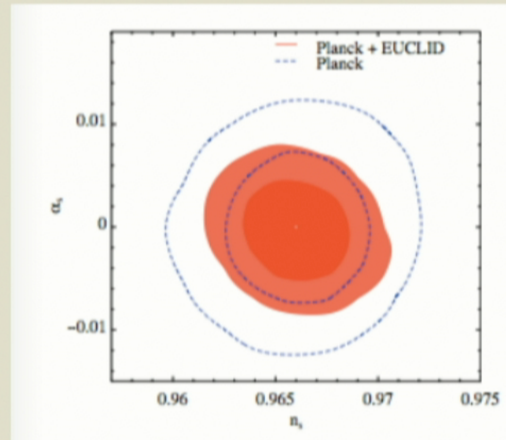
Potential improvements in inflationary constraints: DESI & Euclid





parameter	Planck constraint	Planck + Euclid
n_s	$0.966^{+0.003}_{-0.003}$	$0.966^{+0.002}_{-0.002}$
α_s	$-0.000^{+0.005}_{-0.005}$	$-0.000^{+0.003}_{-0.003}$
$\ln(10^{10} A_s)$	$3.078^{+0.009}_{-0.009}$	$3.077^{+0.006}_{-0.006}$
r	$0.128^{+0.018}_{-0.018}$	$0.127^{+0.019}_{-0.018}$

Amendola et al (Euclid) 2012 1206.1225
Levi et al (DESI) 2013 1308.0847

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Parting thoughts

- Tensor modes have spiced up an otherwise steadfastly standard universe

- While a pencil beam is being shone on large (but not yet horizon) scale tensor modes the cosmology space remains complex
  - $\{r, n_t, \alpha_s, n_s, \Omega_k\}$ plus observational degeneracies with relativistic and non-relativistic neutinos and dark energy.

- LSS and large and small scale CMB experiments will all play vital roles if we are to discern more about the nature of inflation.
  - Broadening scales over which primordial power spectrum sampled
  - break degeneracies with neutrino effects at small scales
  - Reducing the role of cosmic variance through correlation of biased and unbiased tracers
  - Providing alternate lensing signals with which to calibrate smaller scale BB.

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