CMB Polarization with BICEP2 and Keck Array

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IAU Symposium 288:

Astrophysics From Antarctica

Beijing, 30 August, 2012

BICEP → BICEP2 →Keck-Array

BICEP1 (2006 – 2008)
30cm refractor
96 NTD bolometers (same kind as Planck)
Best published limits on r from B-modes – r<0.72

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

Keck-Array (2011 – 2015)
5 BICEP2 like receivers
2500 TES bolometers
5x faster than BICEP2

BICEP/Keck Approach to Inflation Detection:

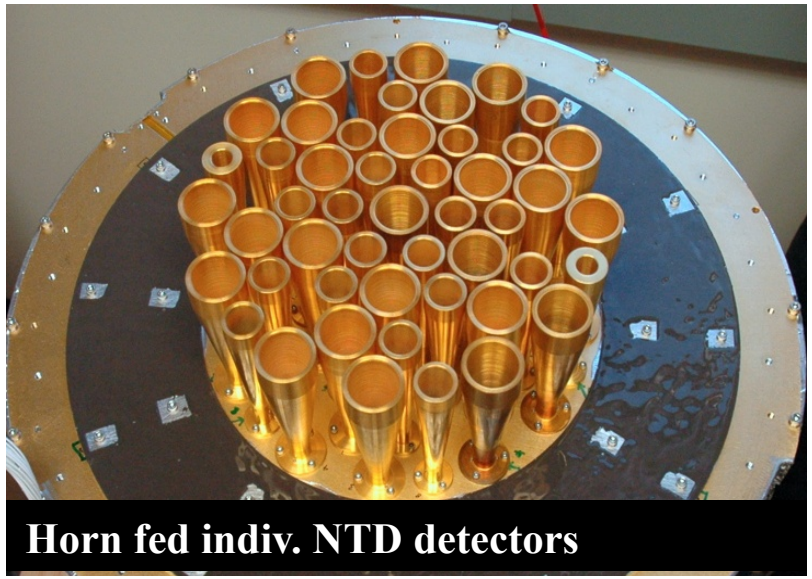
As we've heard there is the possibility of a Nobel prize grade scientific discovery if one can get enough sensitivity/fidelity – our approach is fast/targeted:

- 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=80 bump
- Observe the cleanest sky at the "sweet spot" frequency of 150GHz until B-modes detected
  - Cosmological or otherwise!
    - Then go multi frequency…

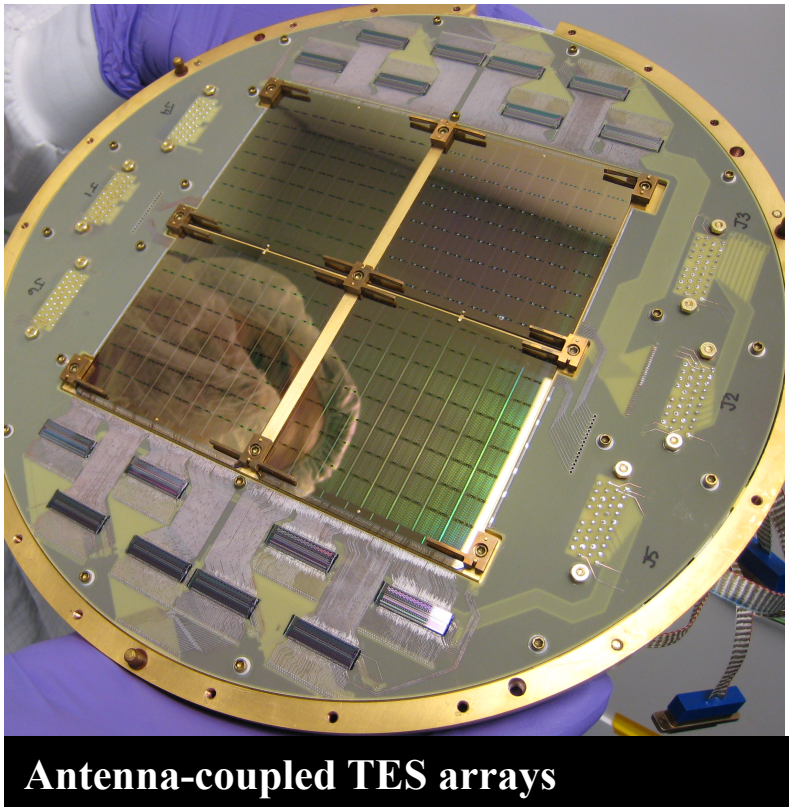
Why observe from the South Pole?

- 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

Switch to monolithic focal plane technology:



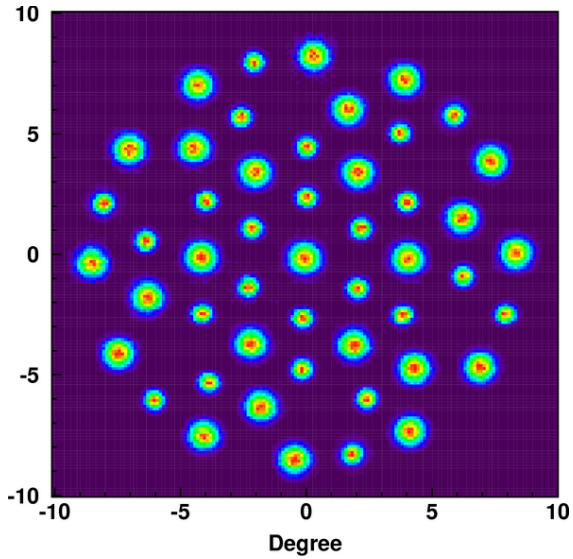
Horn fed indiv. NTD detectors

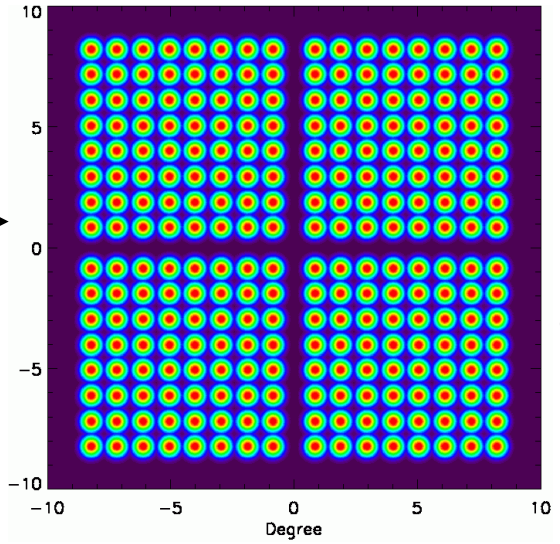


Antenna-coupled TES arrays

BICEP1

48
150 GHz
detectors

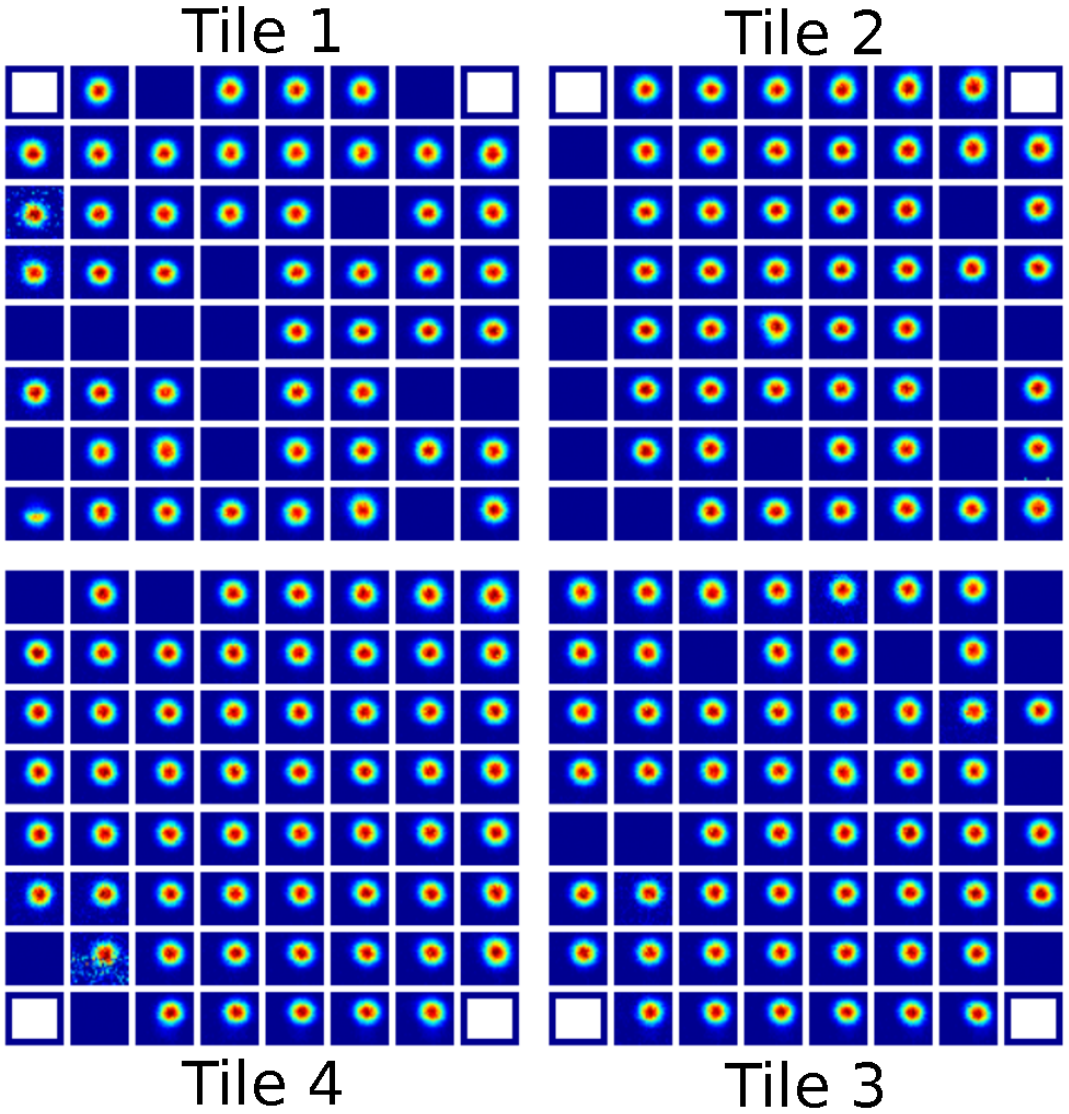




BICEP2

512
150 GHz
detectors

BICEP2 Beam Maps



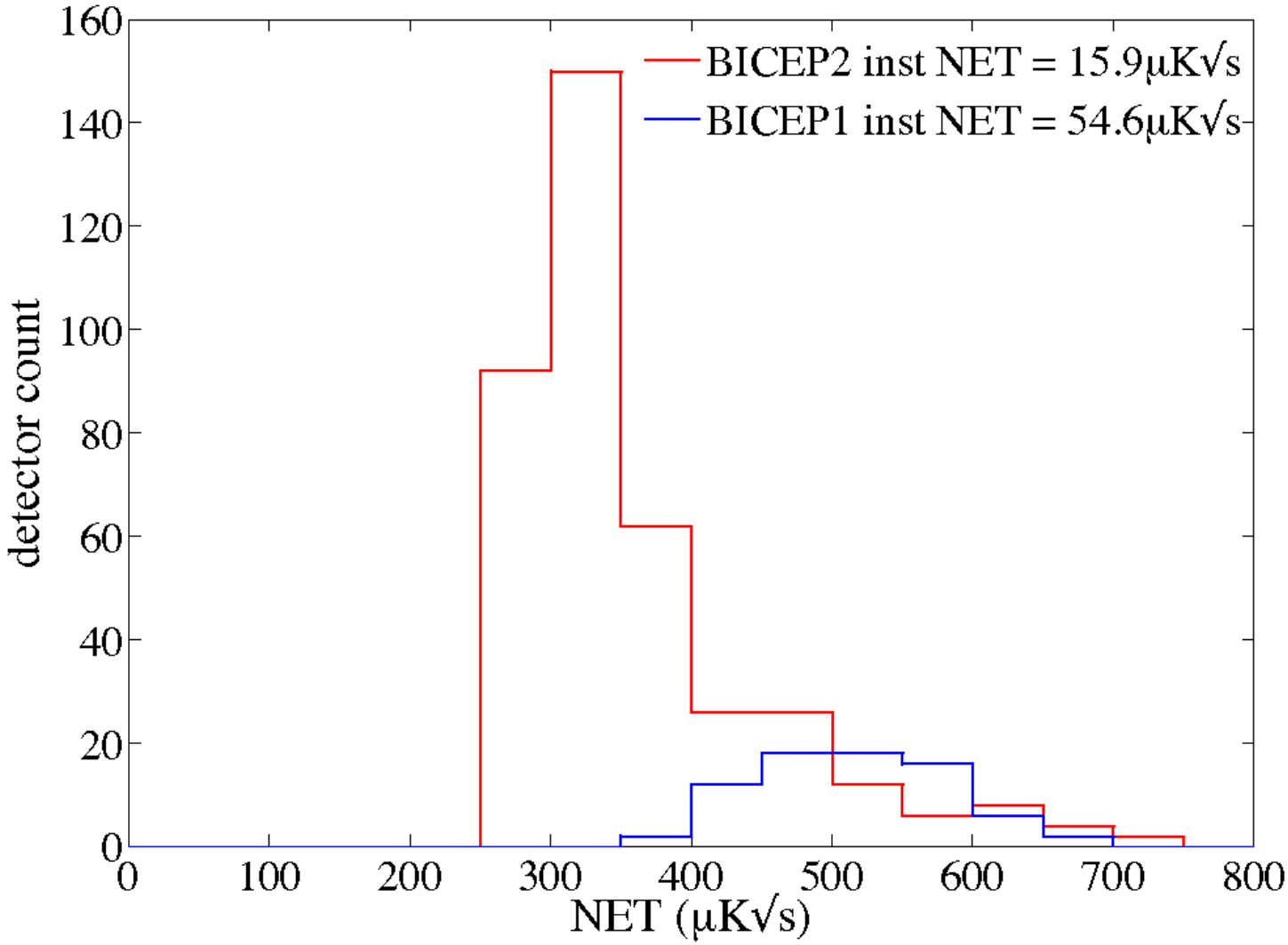
From Ogburn
SPIE 2012

- As usual imperfect detector yield…

Basically how it works…

- Bolometer temperature coupled to intensity of incoming radiation from small "spots" on the sky
  - Whole telescope scans in azimuth sweeping this set of pencil beams across the sky. Then step in el and repeat.
- Detectors arranged in co-located orthogonal pairs
  - By differencing pairs measure linear polarization at some angle on the sky
- By using known polarization angles bin the pair difference timestream into a grid of pixels appropriately to make Q/U maps
  - Then take the Fourier transform of the maps, convert Q/U to E/B and bin to make power spectra
- Also run signal and noise simulations to understand biases and offsets resulting from complete experimental process

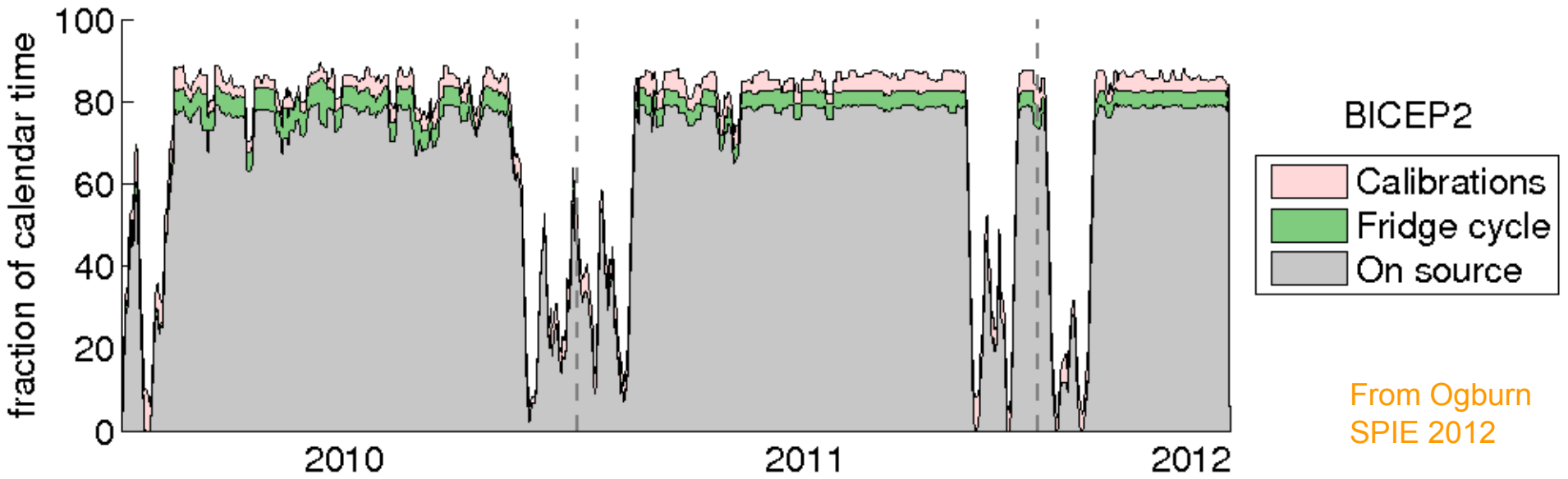
BICEP2 Proven On Sky Sensitivity



J. Brevik

Factor 12 better than BICEP1!

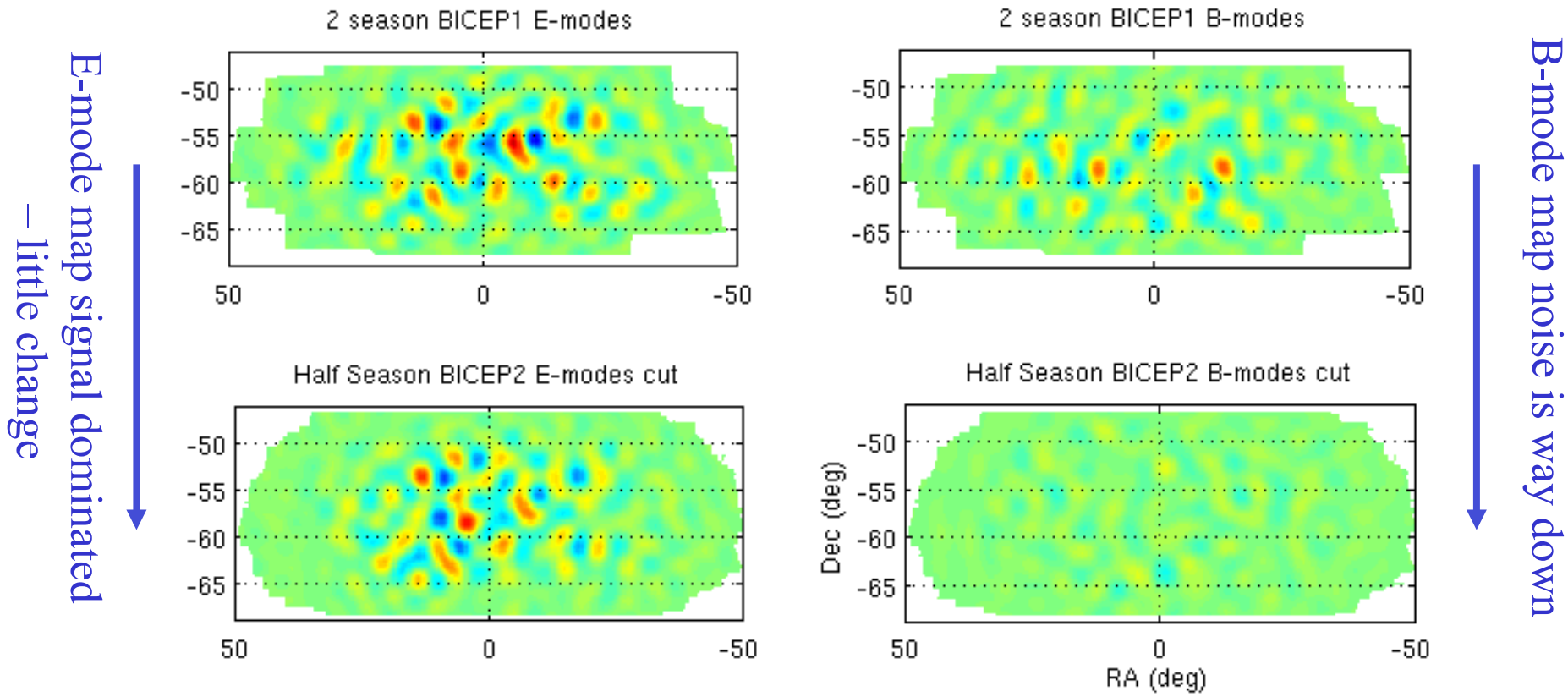
BICEP2 Observing Efficiency



From Ogburn SPIE 2012

- During winter observing season "grinds away" relentlessly
  - Over 12,000 hours of data already in the can…

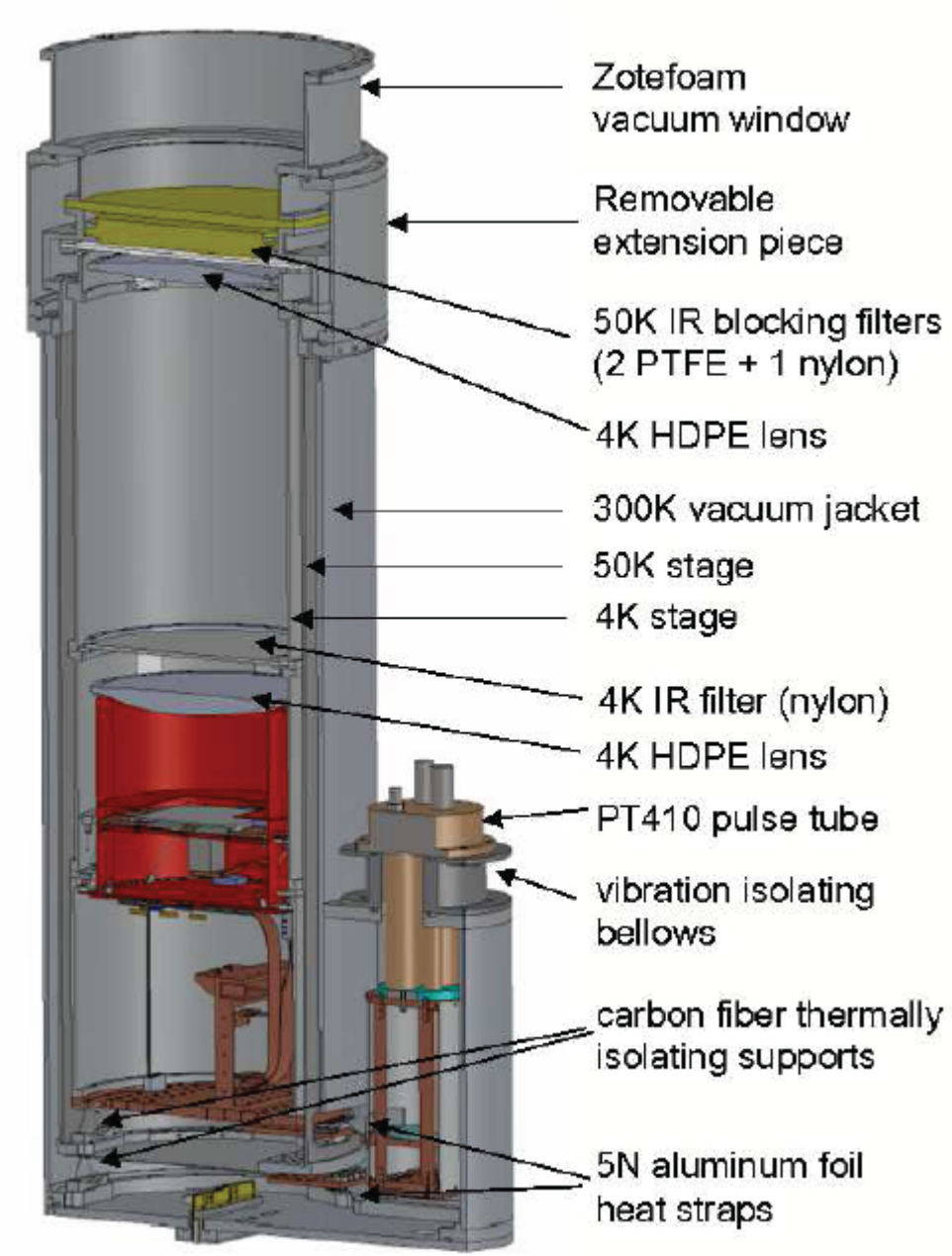
BICEP1 vs BICEP2 E/B Maps



- Using only half a season of data BICEP2 B-mode maps show far lower B-mode power than BICEP1
  - These maps *are* a B-mode limit many times better than BICEP1's
- 2.7 seasons of BICEP2 data already in the can! (and under analysis)

Keck Array

- Five "copies" of BICEP2 on the old DASI platform
  - 2500 TES detectors.
- Pulse tube coolers – no more liquid helium!
- 2011 season had 3 receivers, now running with 5 for 2012…



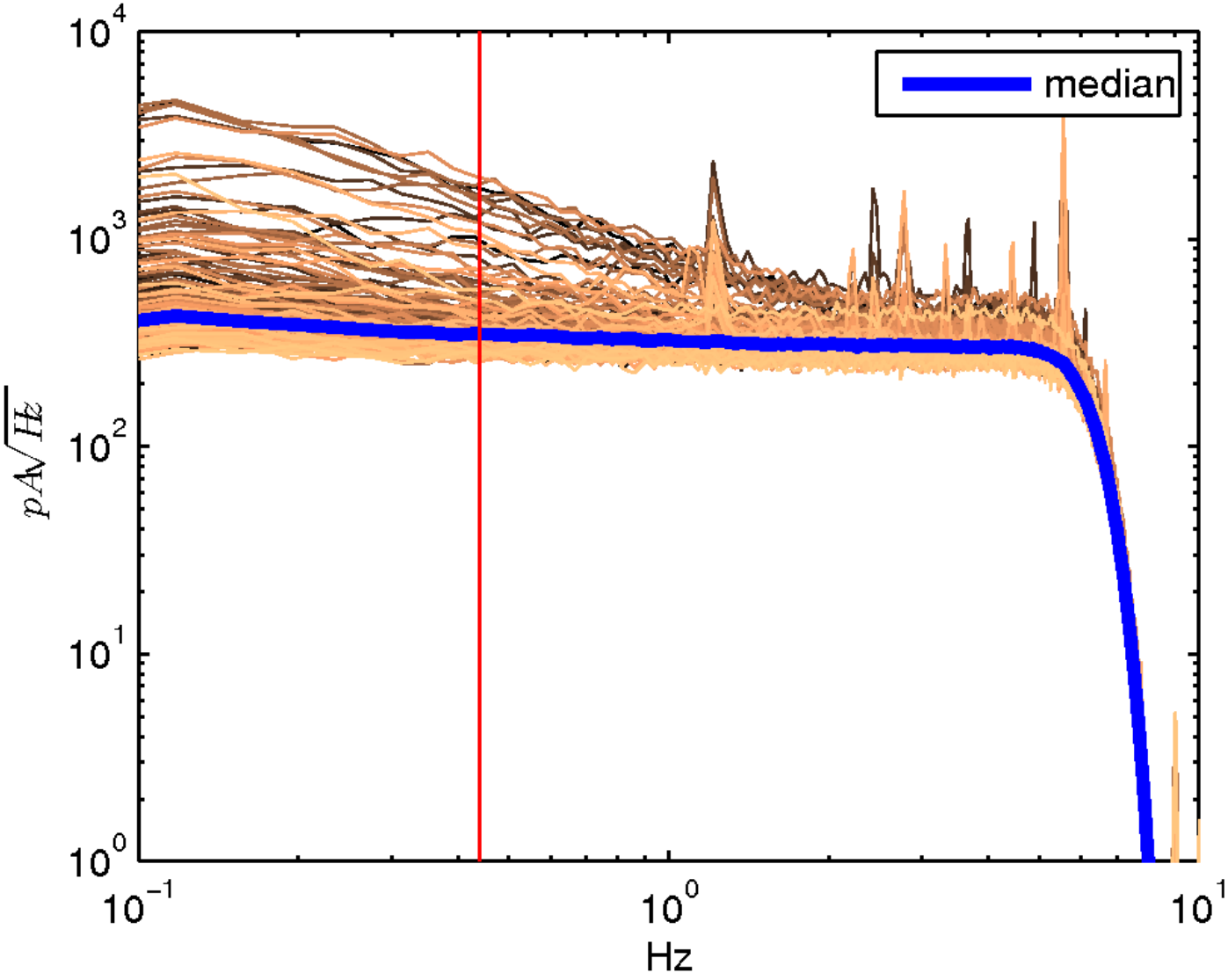
C. Sheehy
SPIE 2010

Keck in Feb this year

Tired and happy team with five working receivers!

Keck at Sunset – March this year

Keck Timestream Noise

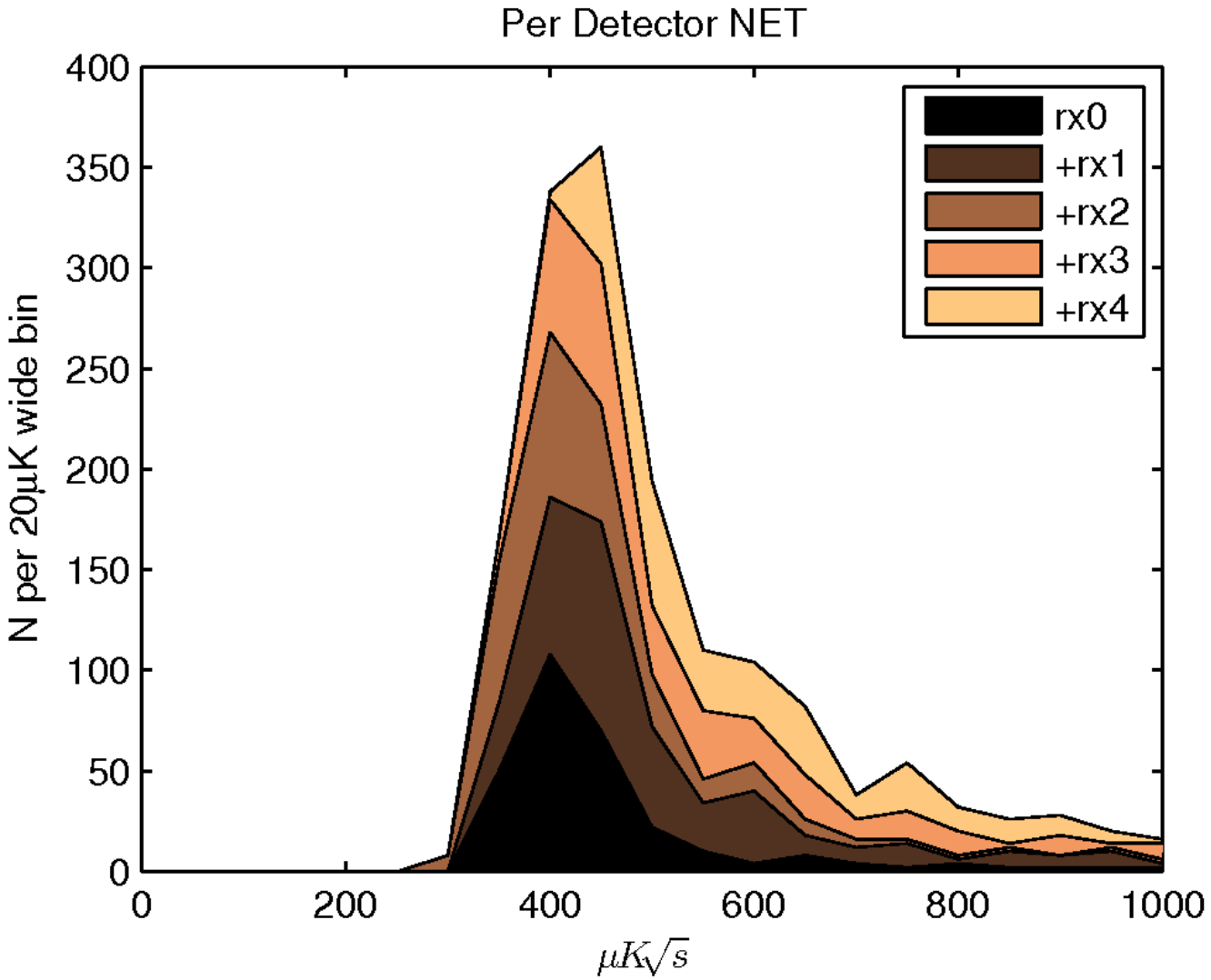


From Kernasovskiy SPIE 2012

- Atmospheric emission is largely unpolarized
  - cancels out in pair difference

Core B2/Keck Team in March

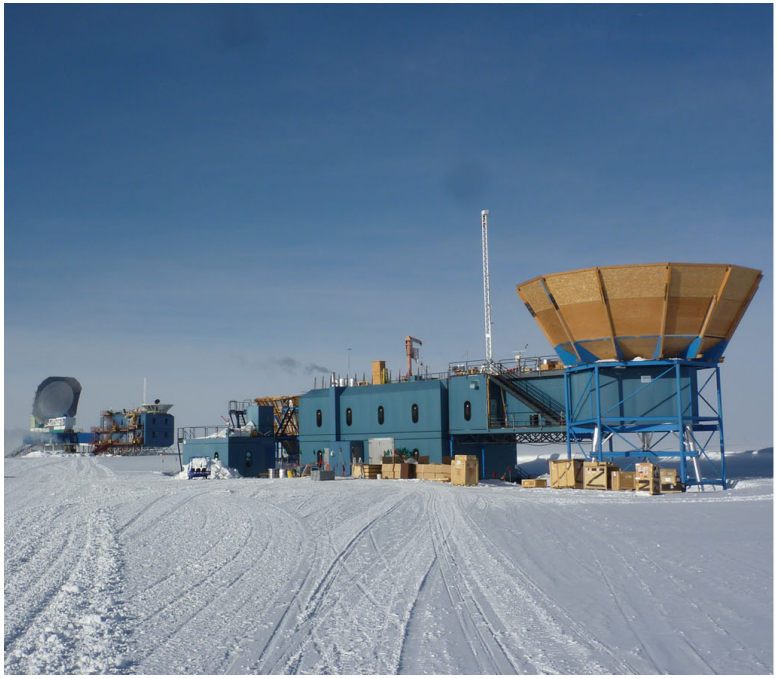
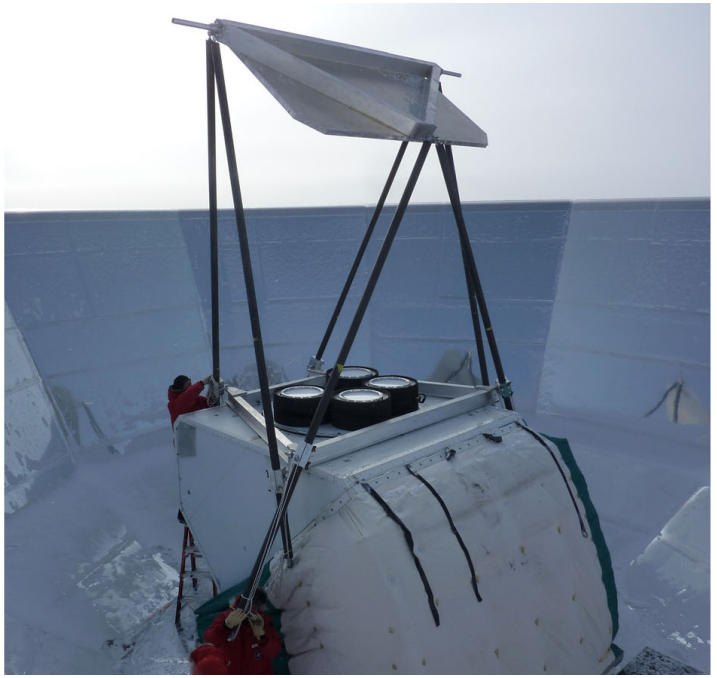
Keck On Sky Sensitivity



From Kernasovskiy SPIE 2012

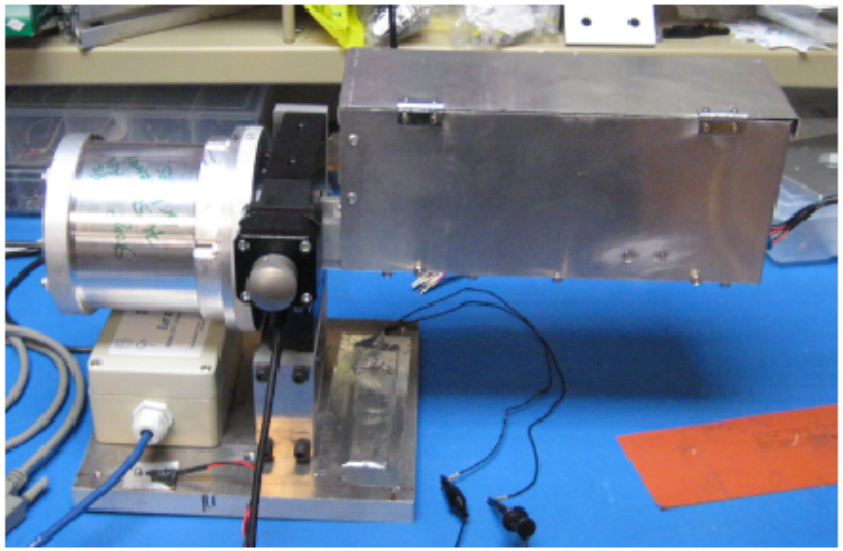
- Some room for improvement per detector – but a huge number of detectors – array sensitivity 11.5 uK √s !

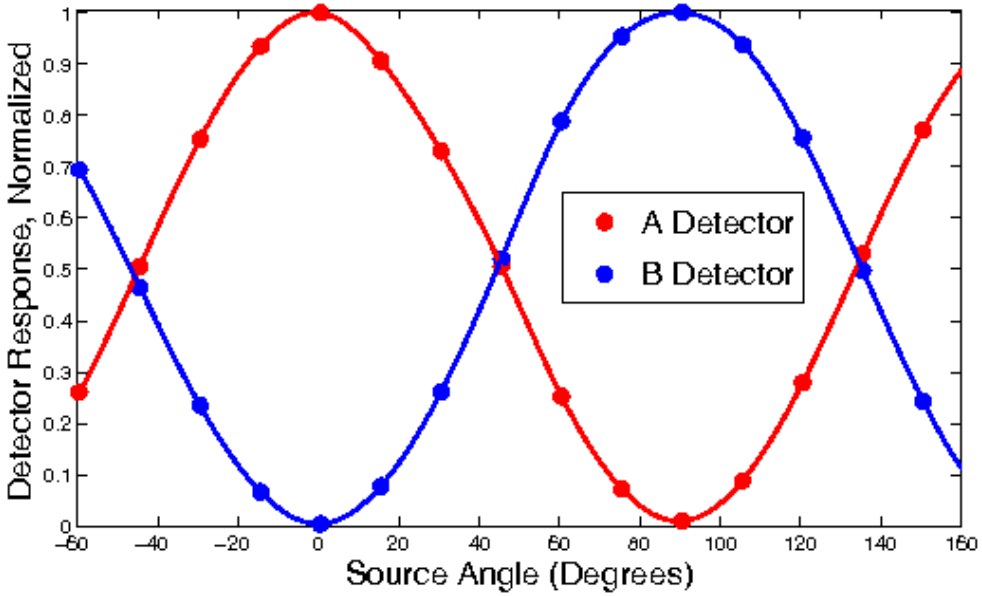
Source Calibrations


- Source on mast 200m away – which is far field!
- Telescope in shield (and can't tilt down anyway) – use 45 degree flat mirror to redirect beams
  - attached to front of telescope mount using carbon fiber rods

Polarization Angle and Efficiency

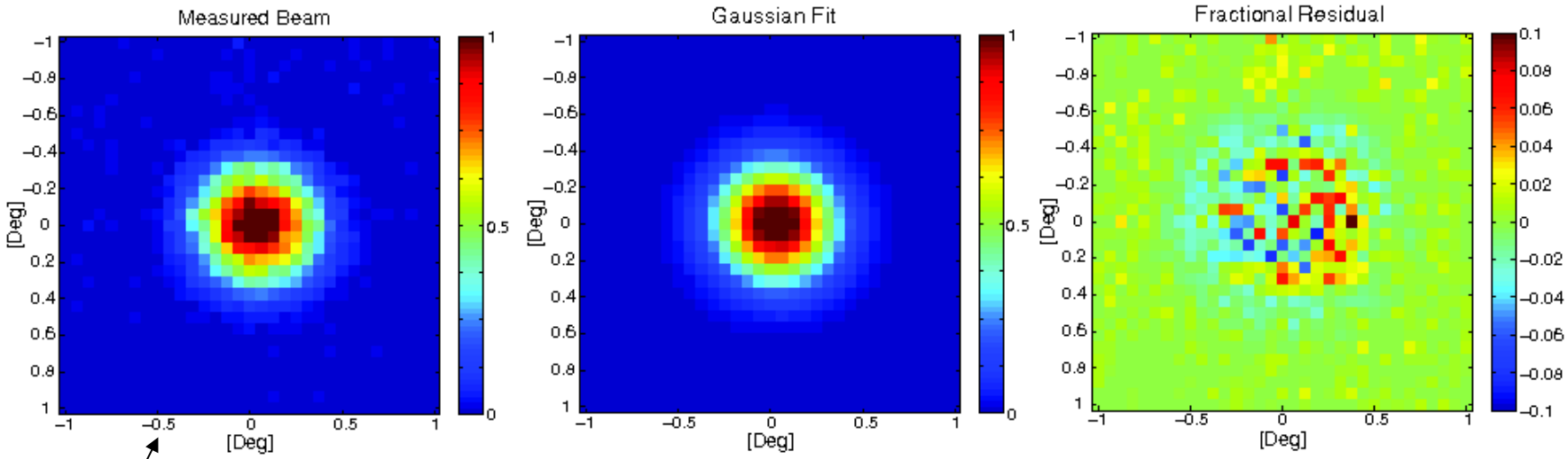




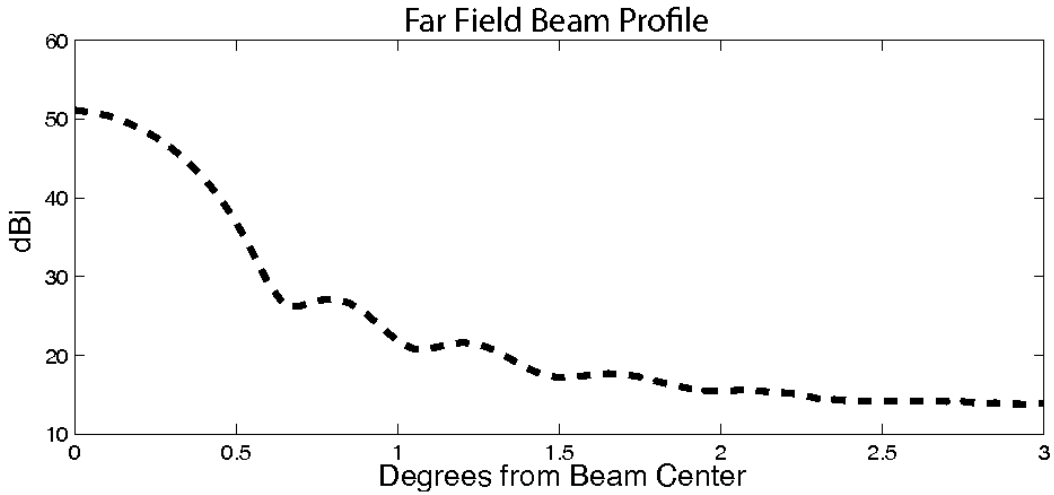
From Vieregg
SPIE 2012

- Amplified polarized broadband noise source mounted on rotating stage
- Used to measure detector sensitivity angle and polarization efficiency (cross polar response)

Beam Shape Measurements



Individual detector

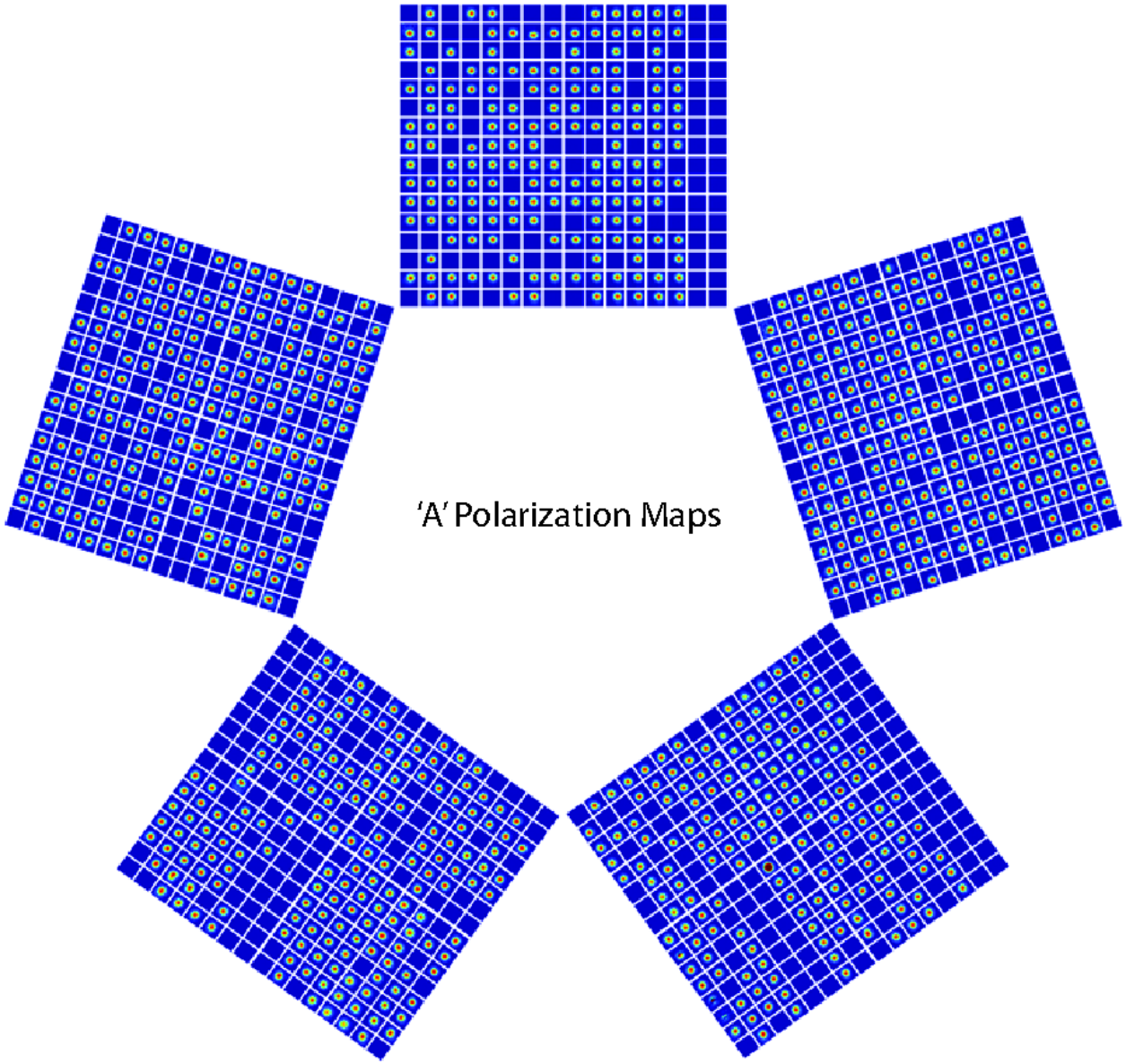


Averaged

From Vieregg SPIE 2012

- Using chopped thermal source (unpolarized)

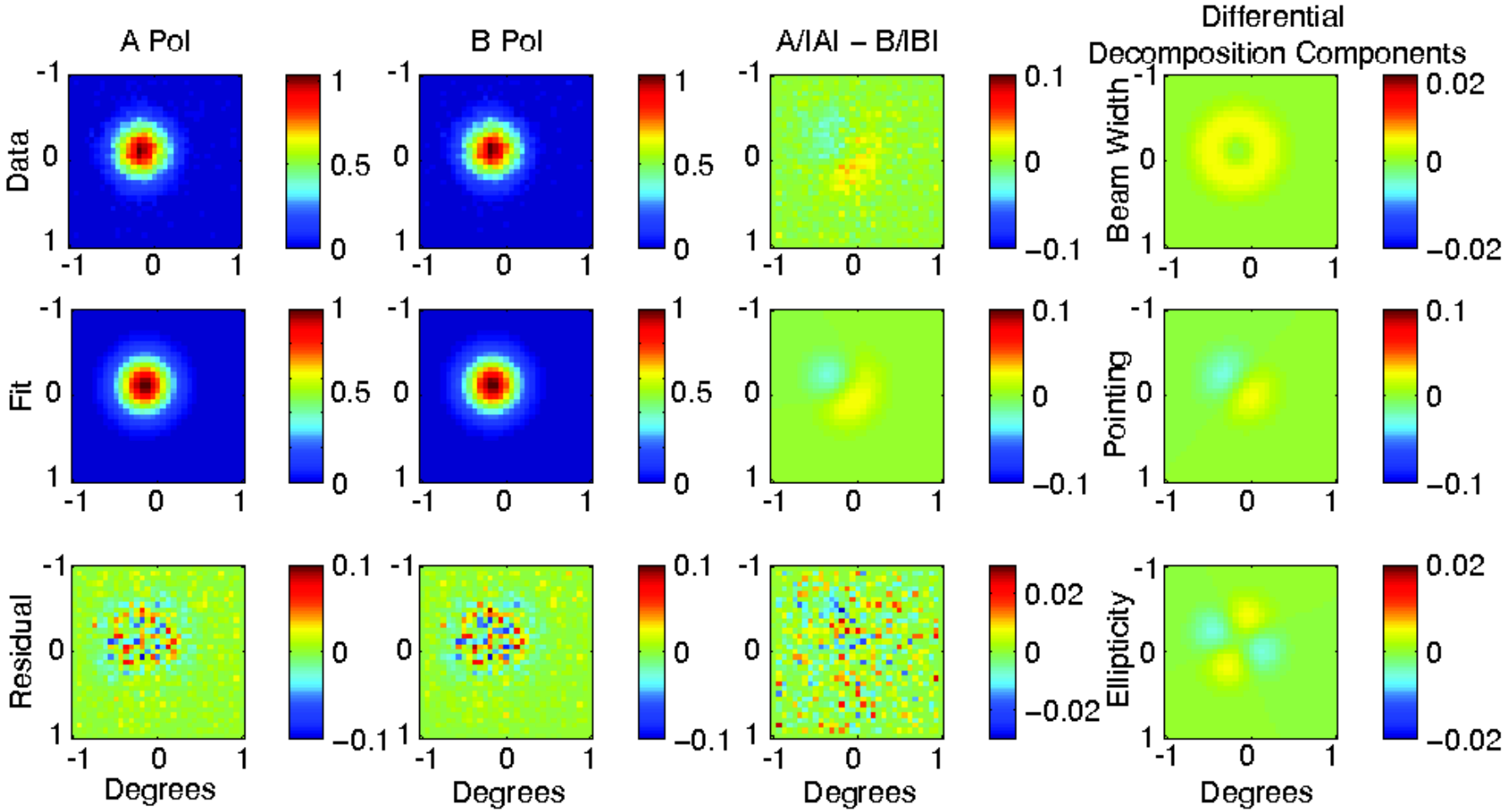
Keck has lots of Beams!



From Vieregg
SPIE 2012

- Illustration only – receiver fov's overlie

Beam Pair Differences Critical



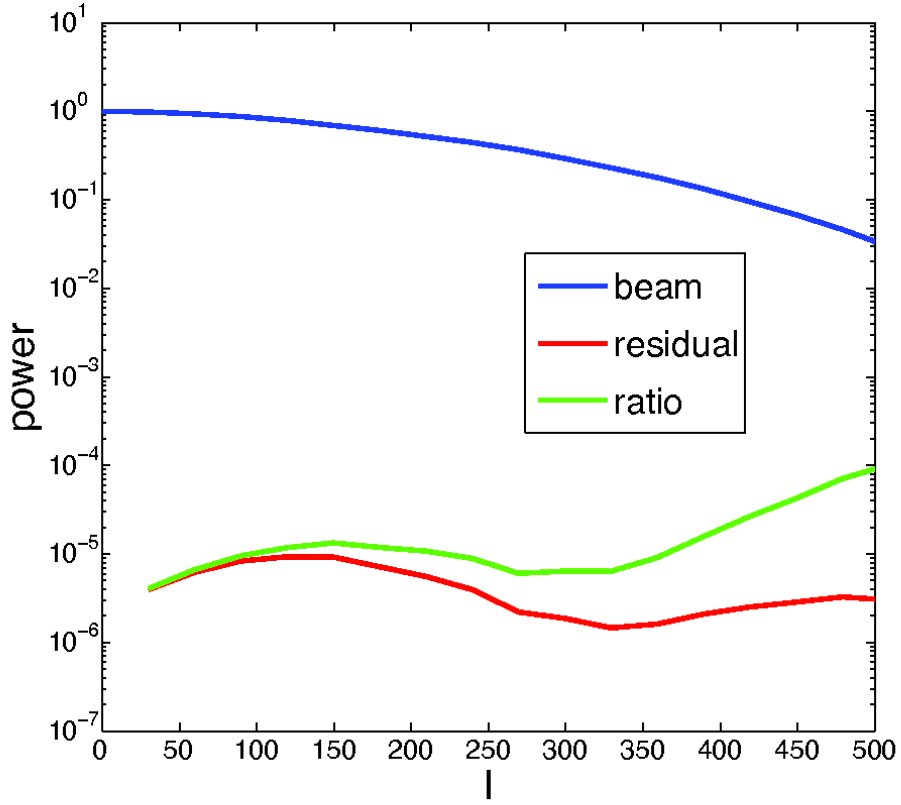
From Vieregg
SPIE 2012

- Centroid offset is the dominant effect

Beam Mismatch Mitigation

- Some mismatch components "naturally mitigate" due to observation strategy
  - Say centroid offset leaks grad(T) to +Q – reobserve later with array rotated by 180 and leaks to –Q and cancels out
  - We get a large benefit from this – but since fov is large compared to scan area overlap is not complete and cancellation is not perfect
- We are developing "deprojection" to remove contaminated modes in analysis
  - Calculate templates from T map and regress out of the pair difference timestream

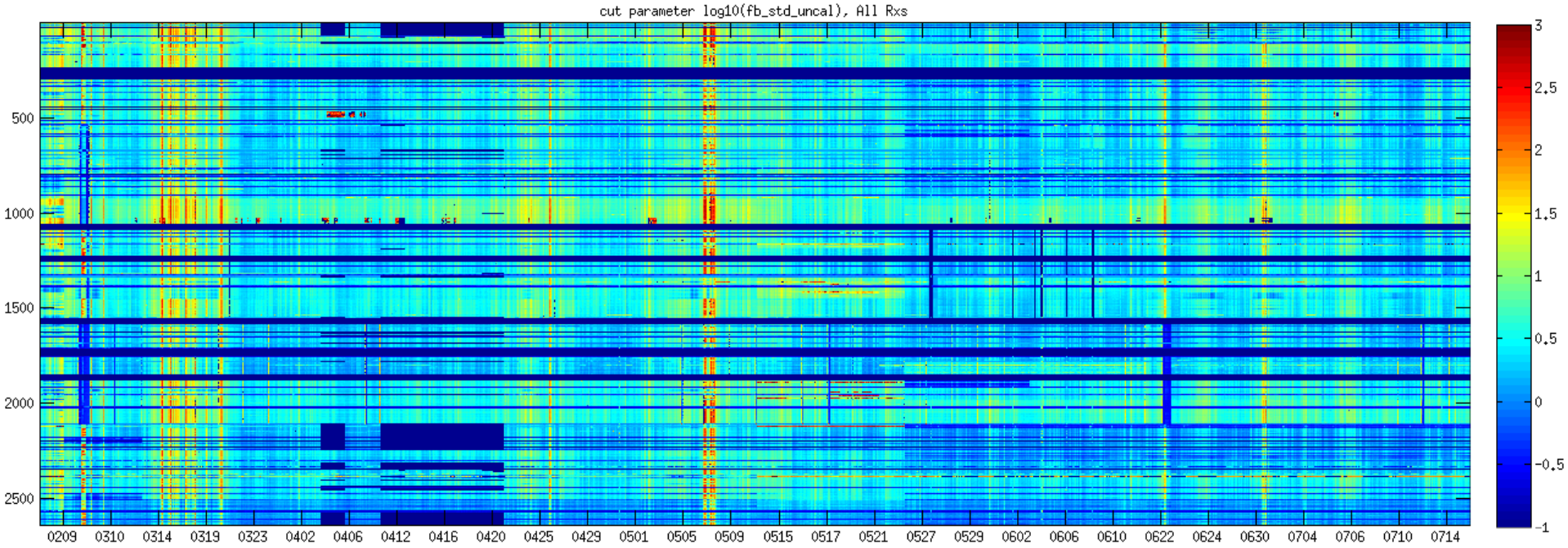
Unmodeled Residuals



From Vieregg SPIE 2012

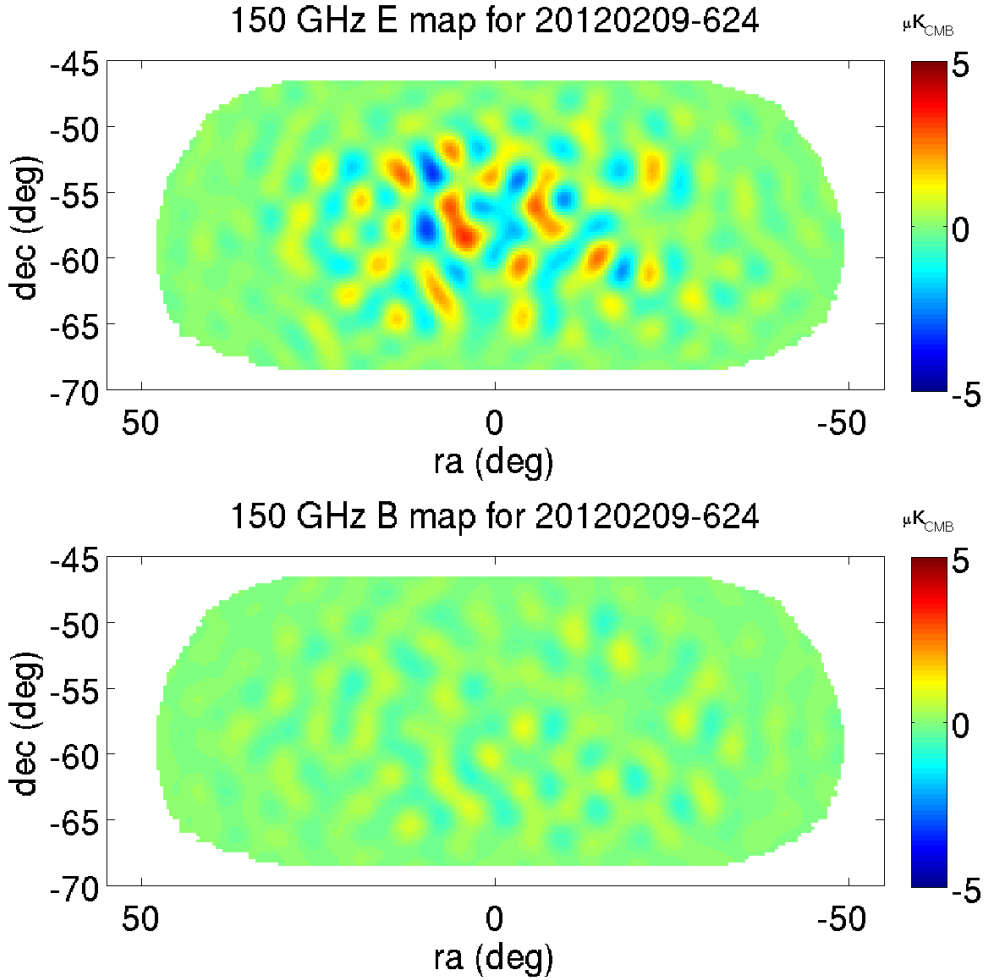
- Can only afford to deproject a limited number of modes (here up to elliptical Gaussian)
  - What then matters is the residual beyond that
- In this plot beammap s/n around r=0.01

Sophisticated Cut Framework



- Fully automatic data selection to remove data pathologies – both gross and subtle
  - Cuts made on many quantities at several levels of granularity (from per channel to per receiver)

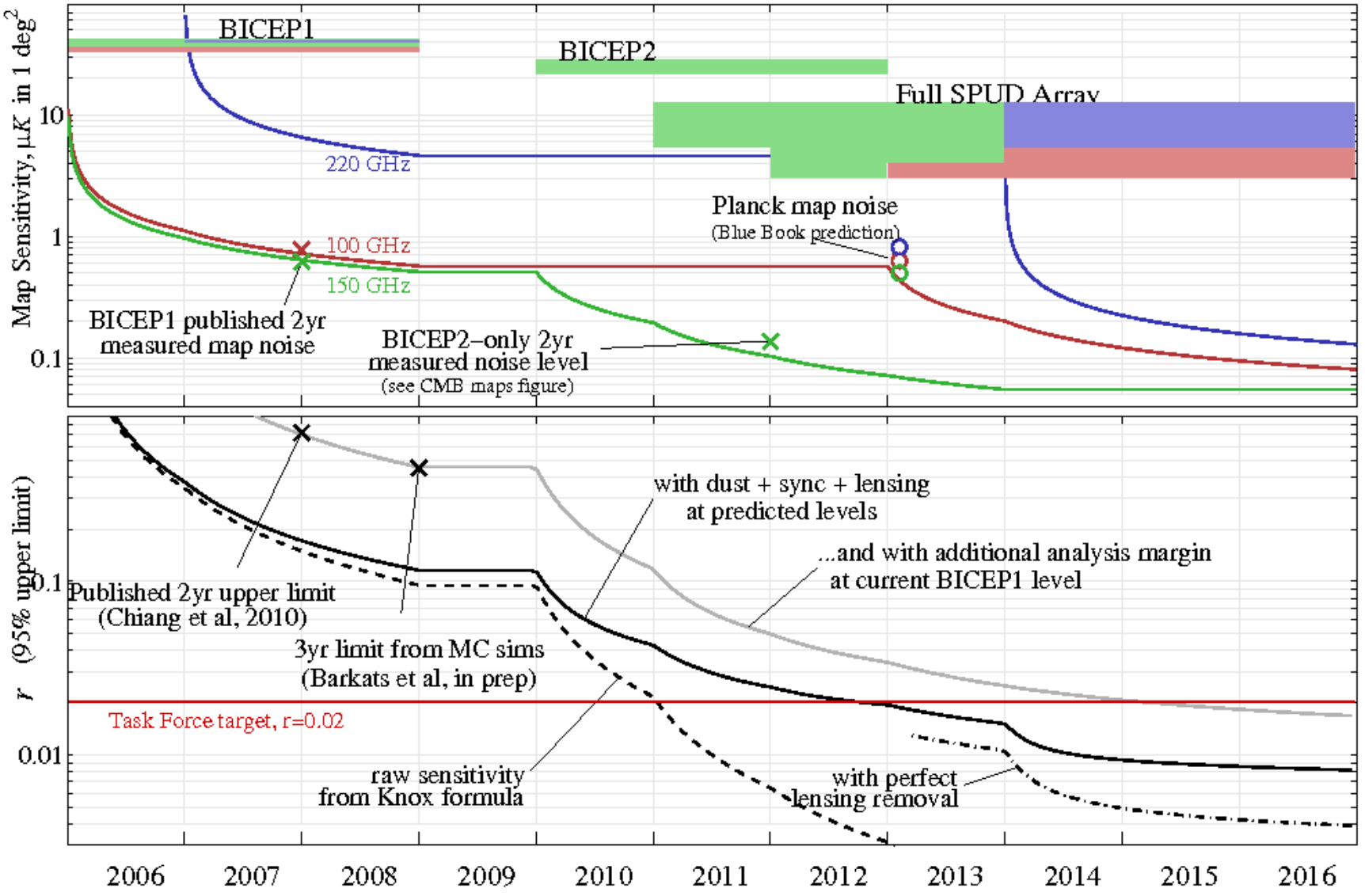
Preliminary Keck E/B Maps



Kernasovskiy

- Above is a few months of 2012 data
  - Array sensitivity around 11.5 uK √s

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



J. Kovac

We will detect B-mode!

– will then go multi frequency to determine if cosmological

Conclusions

- Inflation is the best cosmogenic theory we have
  - If we are lucky it left a specific detectable imprint in the B-mode polarization of the CMB
- So the race is on:
  - Many groups pushing hard and sensitivity improving rapidly.
  - BICEP2/Keck are leading the field…
  - 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/balloon