# BICEP:

The John Robinson Gravitational Wave Background Telescope

Fundamental Physics with CMB
UC Irvine, 24 March 2006

# TEAM BICEP


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** = PI
* = Co-I

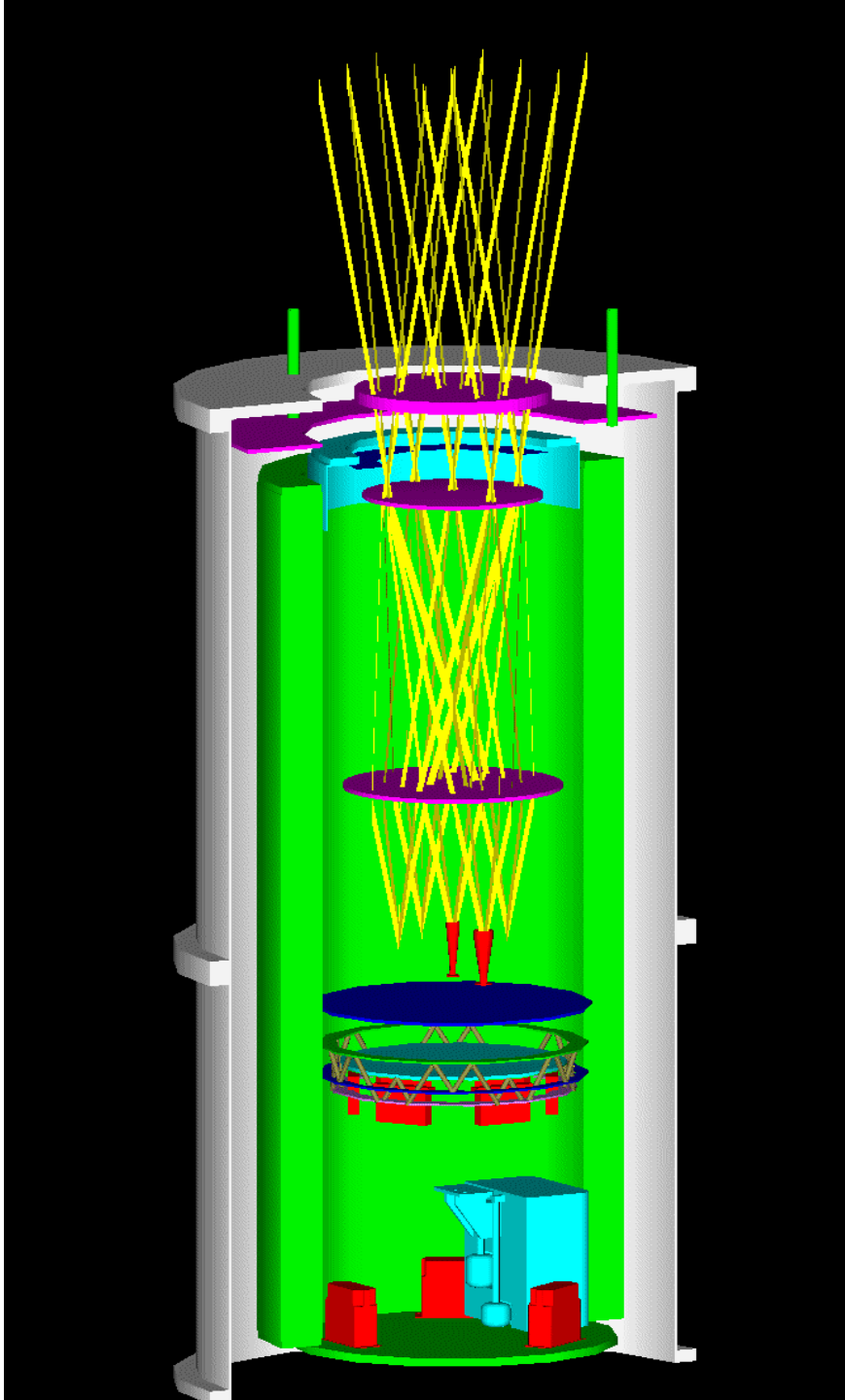


NSF

United States Antarctic Program — National Science Foundation

# BICEP receiver

- Wide-field refractor:
  - All-cold optics: 2 lenses + filters
    - HDPE lenses (C.D. Dowell)
    - Teflon AR coated (C.L. Kuo)
  - 25cm -> 0.95°, 0.63° FWHMs
  - 17° FOV, high throughput
  - Low instr-pol, cross-pol
  - Flat, telecentric focal plane
  - Cf. EPIC, SPIDER



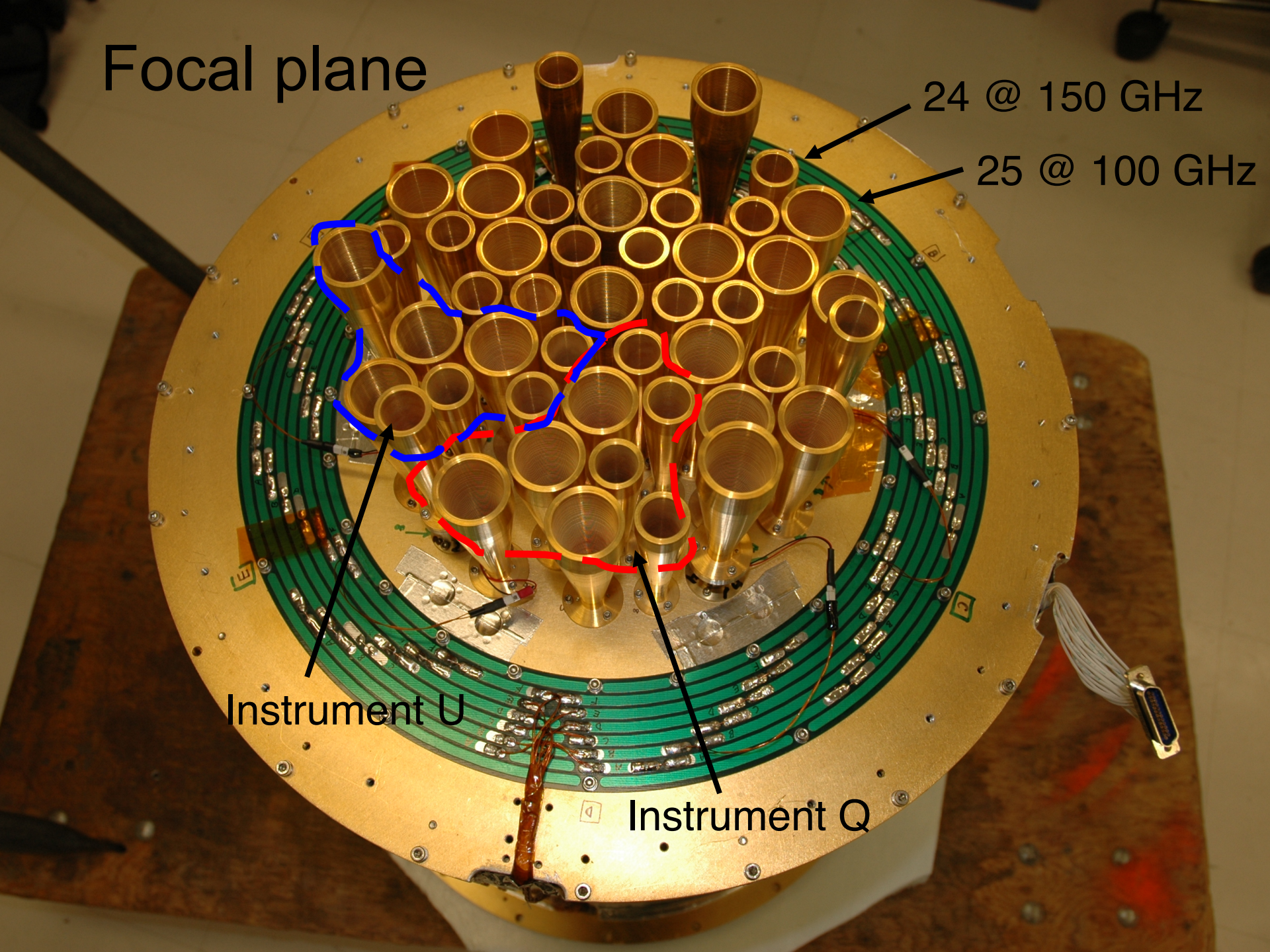
# BICEP focal-plane insert

Trussed structure + vacuum-gap isolate 4K feeds from 250 mK filters, PSBs (Planck/JPL style)

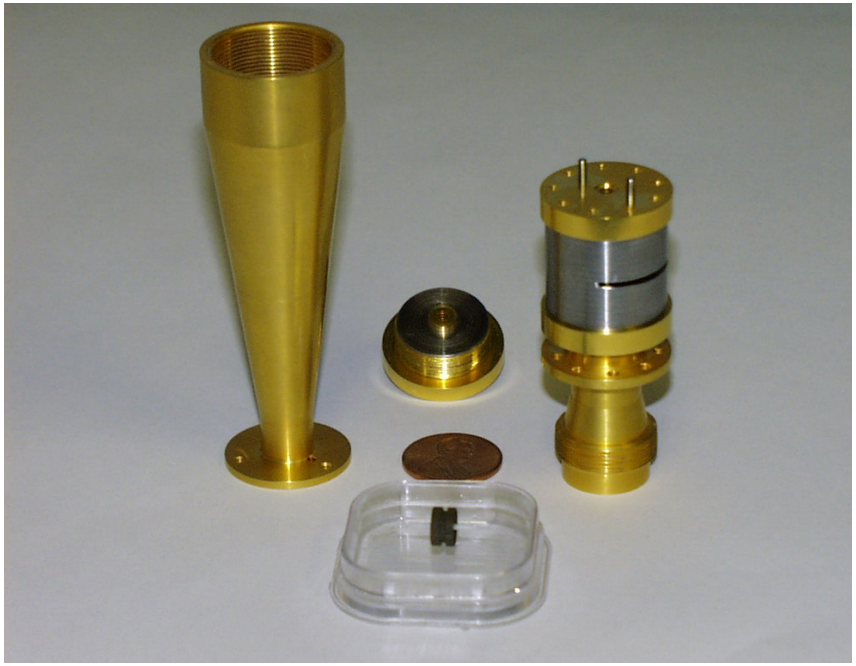
144 JFET pairs (SPIRE/JPL style)
fridge: 4He/3He/3He, 250mK, > 60 hours

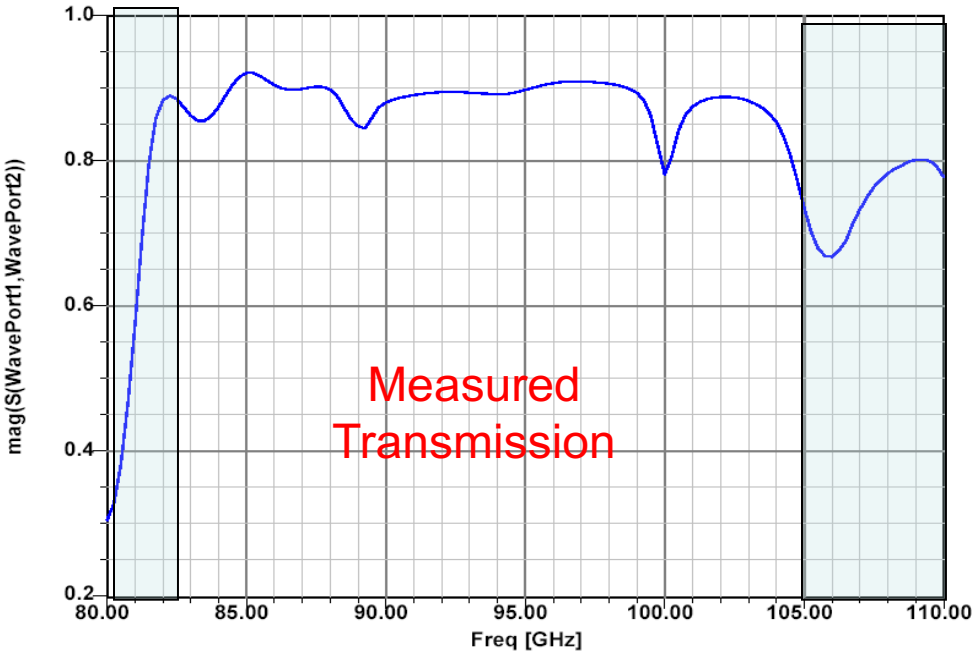
RF-sensitive components enclosed in 4K Faraday cage

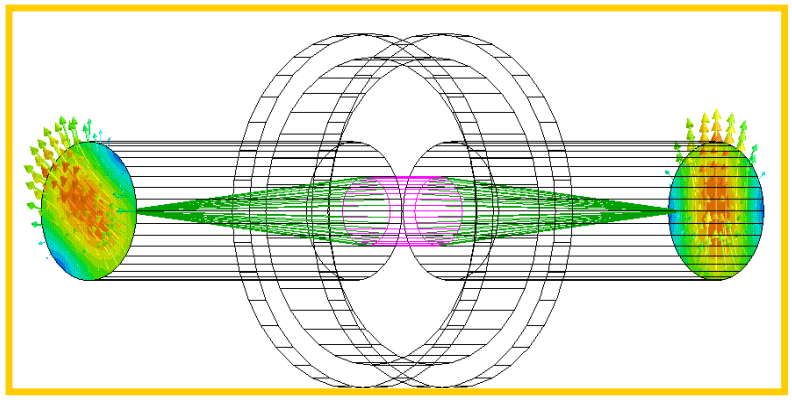
Look for: Ki Won Yoon (2006)…


Focal plane
24 @ 150 GHz
25 @ 100 GHz
Instrument U
Instrument Q

# Faraday Polarization Modulators





## Work of Brian Keating/UCSD

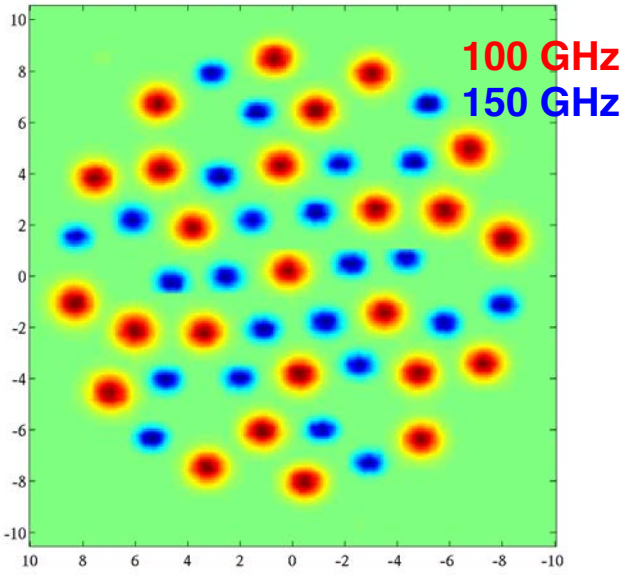
- All Solid State
- Rapid, efficient modulation +/- 45 deg
- >30 % Band-Width
- Installed in **6** out of **49** pixels for 2006

# Aug 04 - Oct 05: BICEP in California

- Fully integrated at Caltech, both indoors and outdoors
- BICEP telescope mount:
  - Vertex/RSI
  - 3 axis rotation
  - Fast AZ scanning:

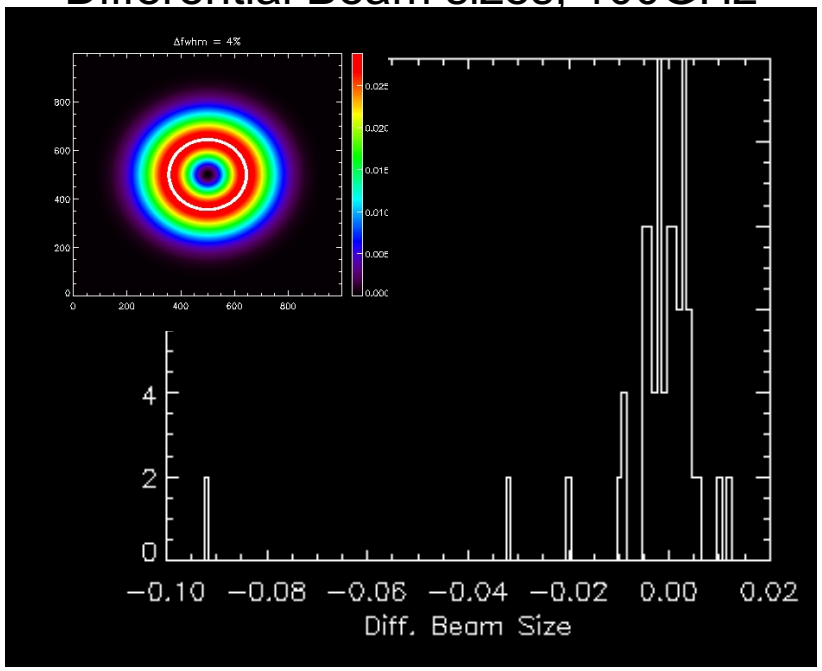
    up to 5 deg/sec !!
  - Low vibration
  - Pointing: < 20 arcsec
- Beam mapping:
  - Indoors: 50m far field
  - Chopped thermal source, wire grids

# Measuring beam match…



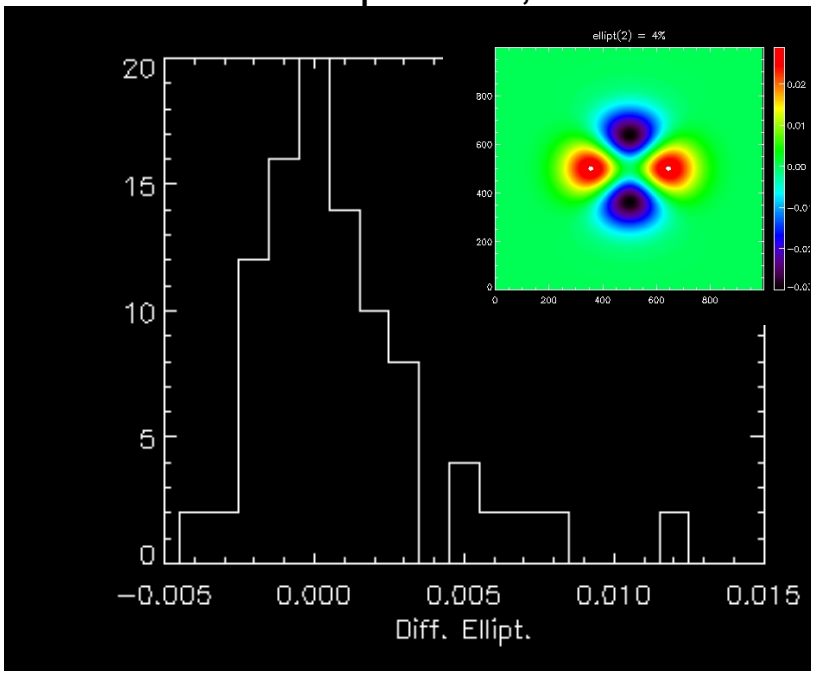

- beams mapped in highbay to ~-30dB
- Ongoing work:
  - Beam parameters characterized for each feed/PSB pair (H.C. Chiang)
  - SPECs for pairwise match of FWHM, ellipticity driven by simulations of measuring B (at level of r=0.1) (N. Ponthieu)

Differential Beam sizes, 100GHz




SPEC: 1.1%

Differential ellipticities, 100GHz




SPEC: 2.7%

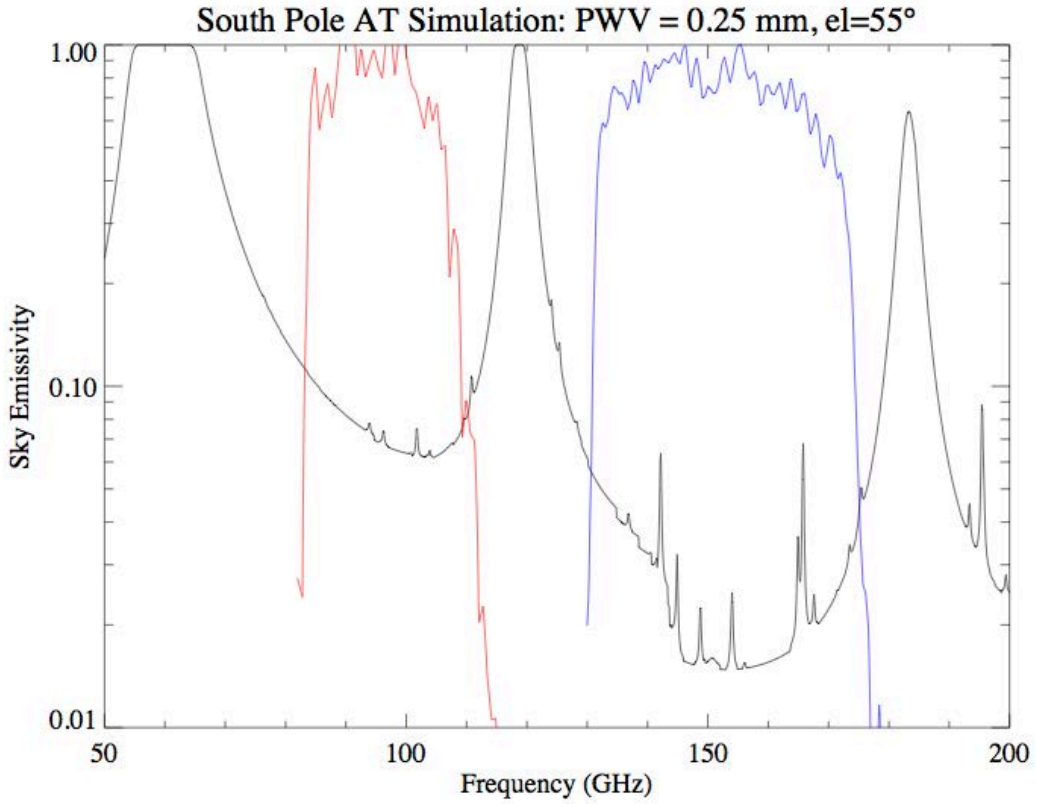
# Measuring spectral match…

- Measured before shipping with CWRU and UCSD polarizing FTS's (E. Bierman)
- Important for foreground removal
- Gain match from atmosphere (K. Yoon)…

$$\nu_0 = \frac{\int \nu F[\nu]\, d\nu}{\int F[\nu]\, d\nu}$$

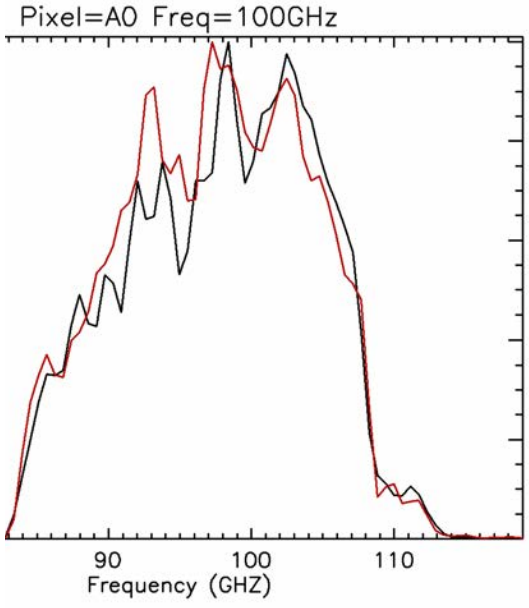
$$B_{eff} = \frac{\left(\int F[\nu]\, d\nu\right)^2}{\int F^2[\nu]\, d\nu}$$

| Band | "100 GHz" | "150 GHz" |
|---|---|---|
| Band Center | 97.7 GHz | 151.8 GHz |
| Bandwidth | 24.4 GHz (25.0%) | 42.9 GHz (28.3%) |




**-well-matched** pair

ı $\nu_0$ mismatch 1-3%)



# 14 Oct 05: To the South Pole…

# 17 Nov 05: safe arrival

15 Nov - 15 Dec 05:
Building a new observatory…

# 29 Nov 2005: BICEP lifted home

# Dec 05: Assembling and Installing the BICEP receiver


# Jan 06: A working instrument:

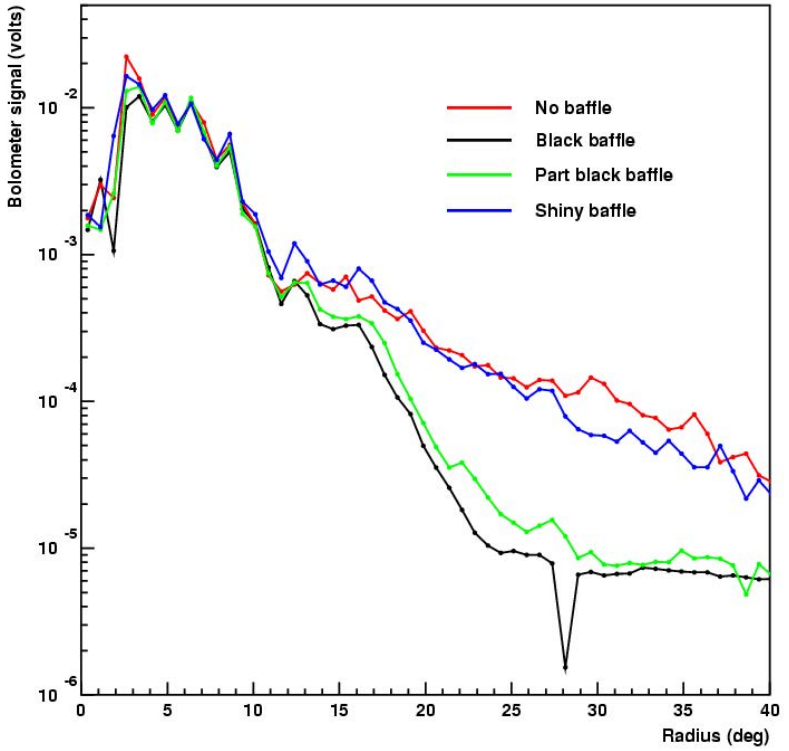
Dr. Erik Leitch:
You *WILL* fund science

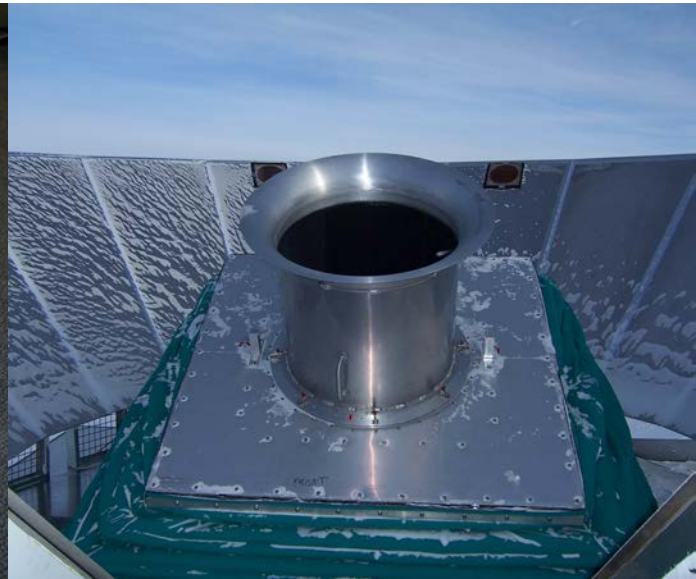
Senator McCain:
How can I get one of those T-shirts?

7 Jan 06: congressional delegation of 25 tours BICEP

# Sidelobe characterization

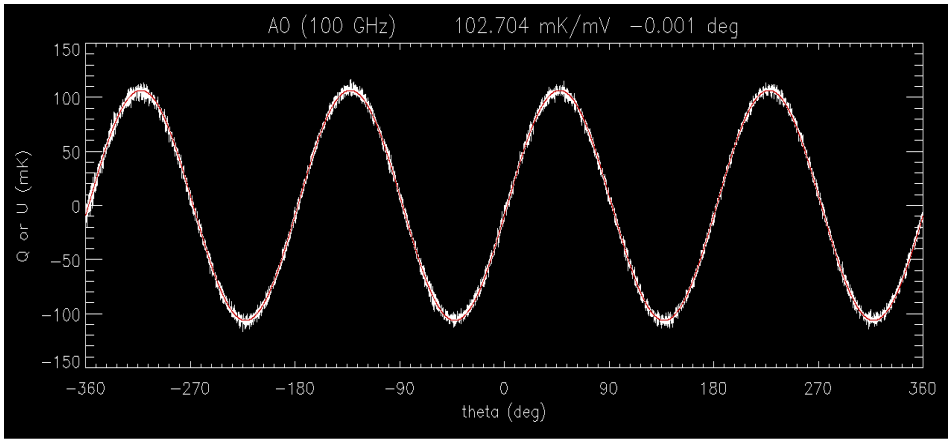
- Extremely clean optical design:
  - Unobstructed aperture
  - Black forebaffle
  - Reflective groundshield
- Sidelobes mapped in-situ using Gunn oscillators on 30’ mast
- Also, polarized thermal sources on groundshield edge
  - Very low ground pickup!

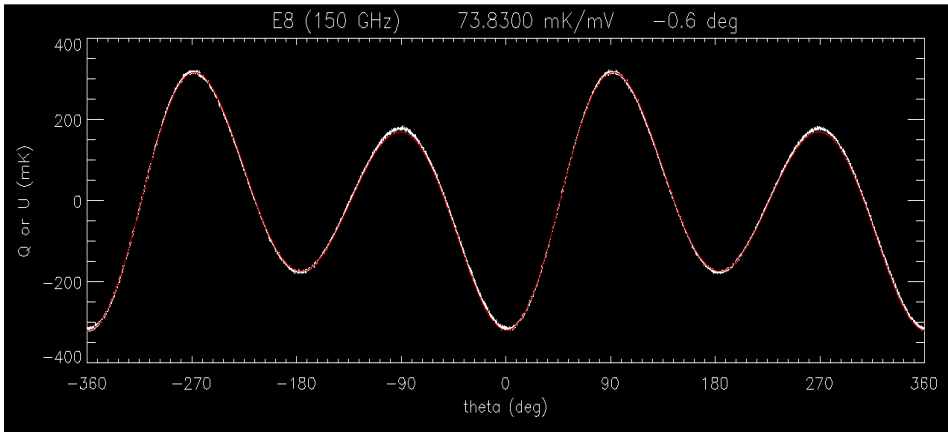


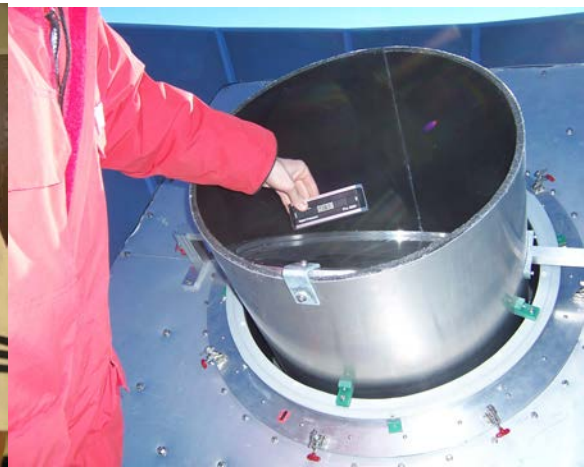



# Polarization calibrations

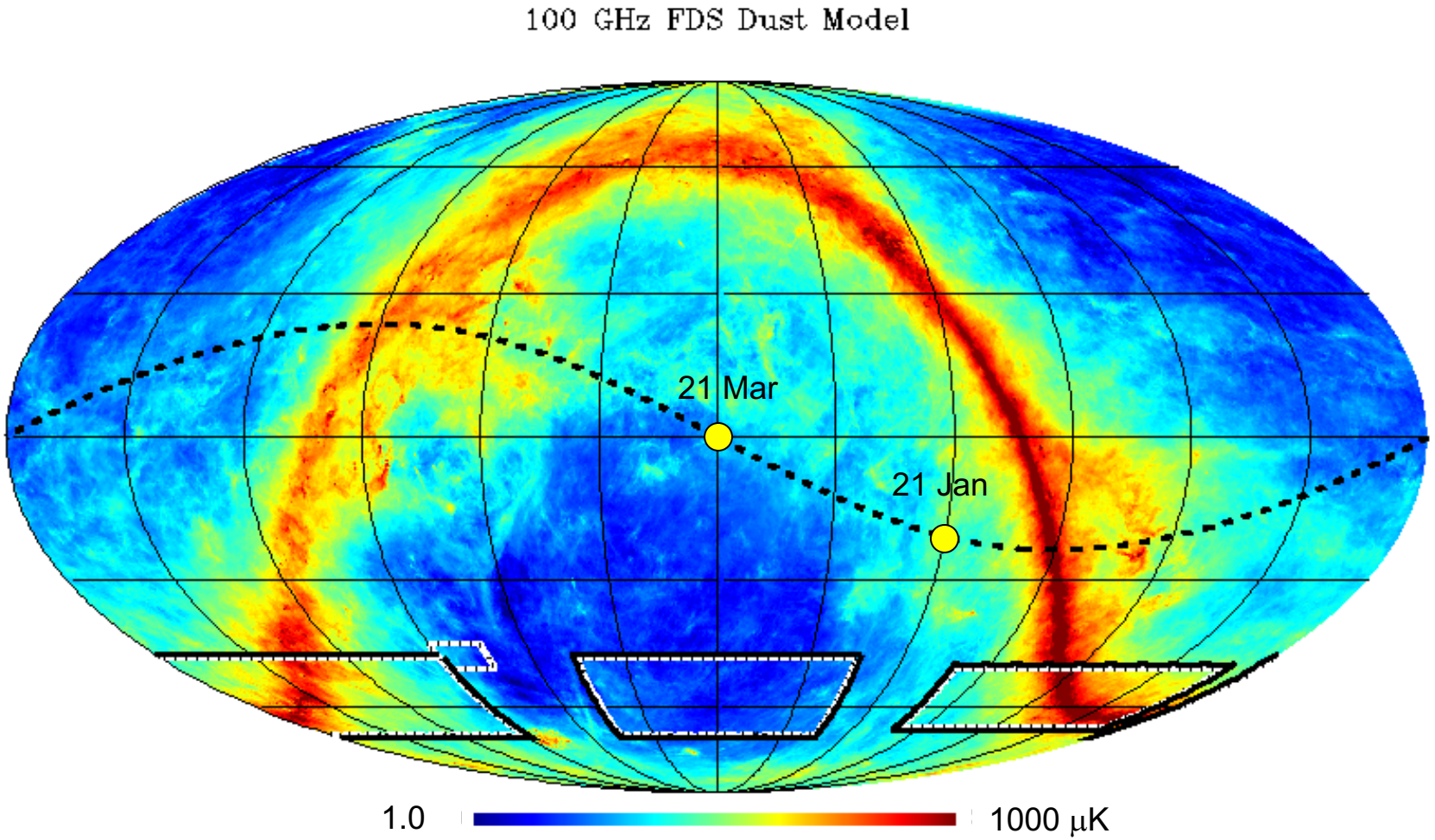
- **response angles**
  - No astronomical sources of known polarization angle
  - Measured with dielectric sheet calibrator to < +/- 0.3 degrees (Yuki Takahashi)
  - Spec: +/- 3.5 deg ~ B from r=0.1
- **cross-polar response**: measured using wire grids, near and far
- **gains**: matched using el-nods, stability checked with flash lamp



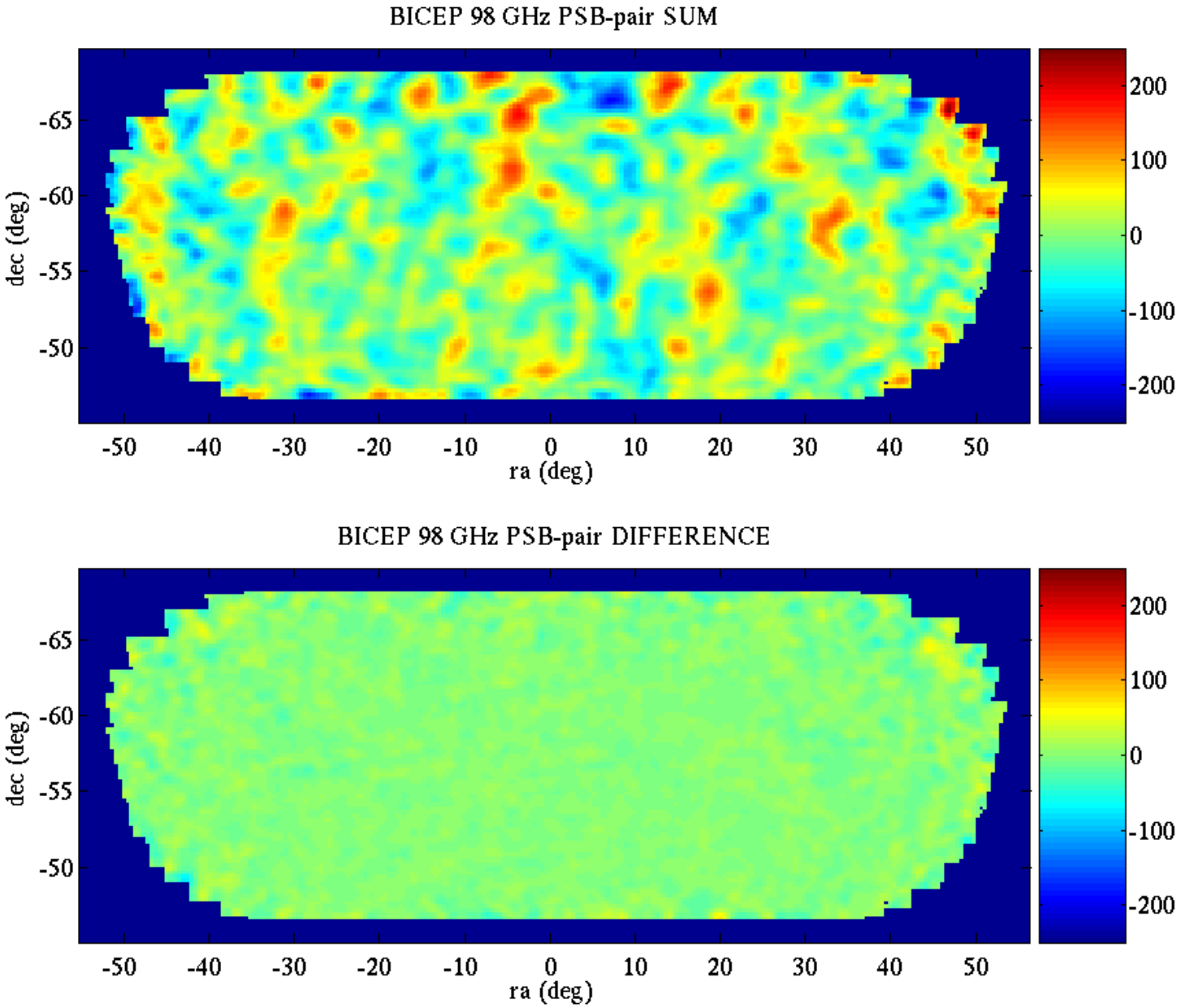
# BICEP field selection



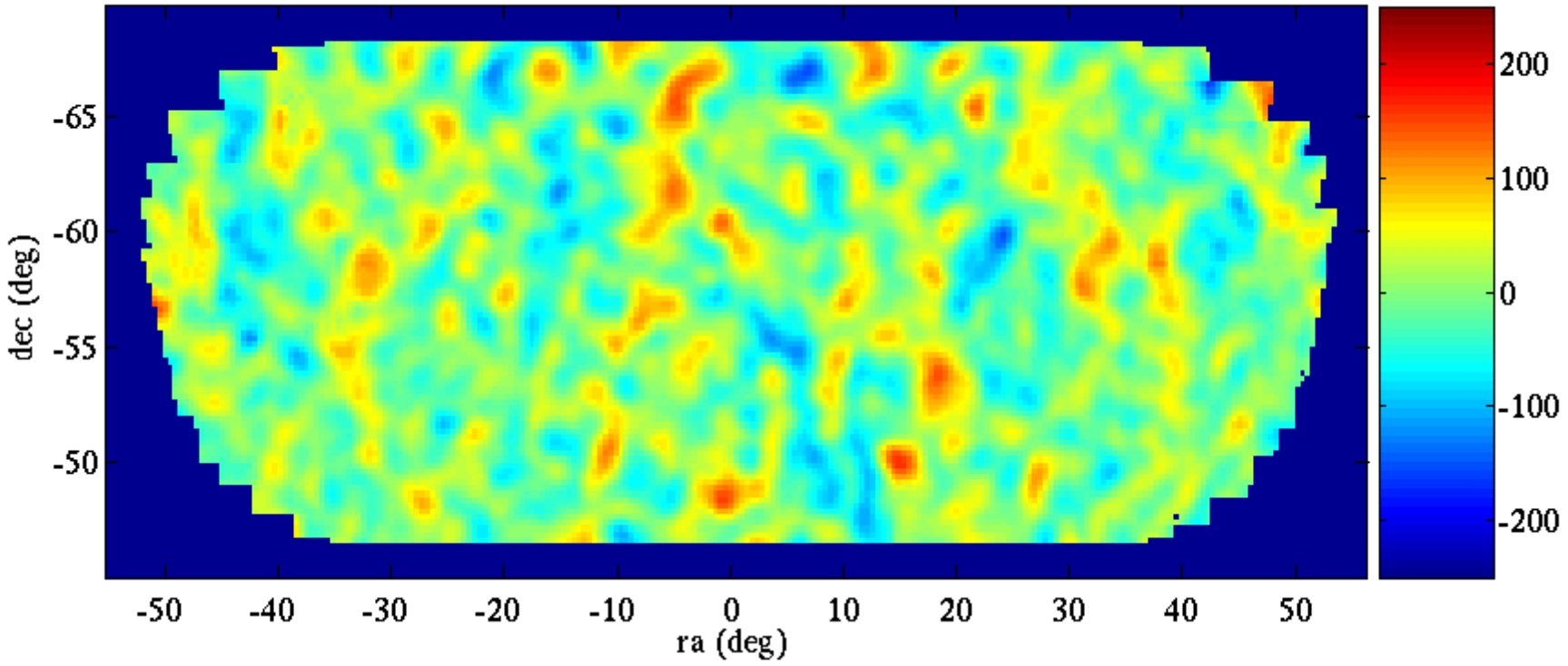
# CMB observing

- **48 hour** observing schedule:
  - 6 hours fridge cycle
  - 6 hours mapping trans-galactic field
  - 4 x 9 hours = 36 hours mapping CMB field
- Each **9 hour map**:
  - covers entire field at one of 4 boresight orientations
  - Consists of AZ scans: 75 degree span, 2.8 deg/sec
  - 22 scans (60 sec each), followed by calibration and 0.25 degree EL step
- Each **calibration**:
  - EL nod, 1 degree
  - Flash lamp on swingarm

# BICEP PSB pair SUM vs DIF maps

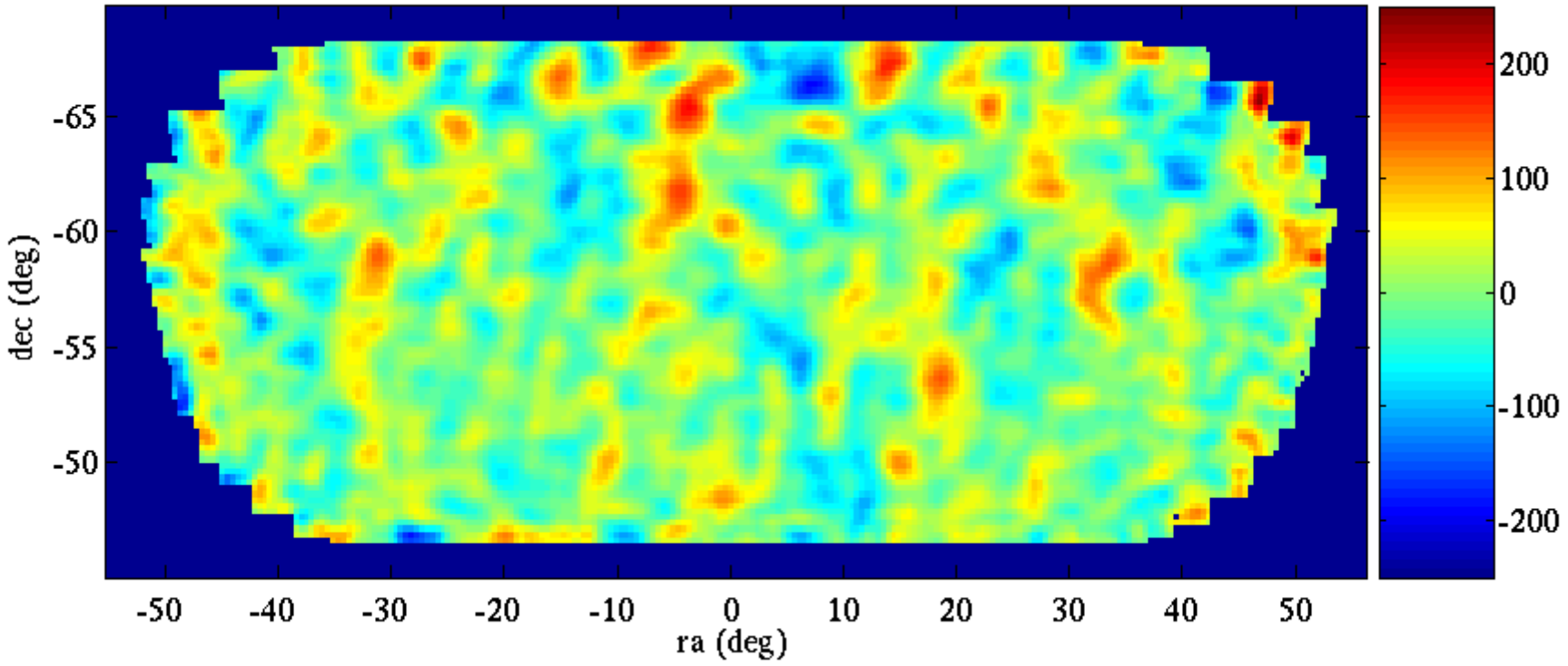


# WMAP 3yr



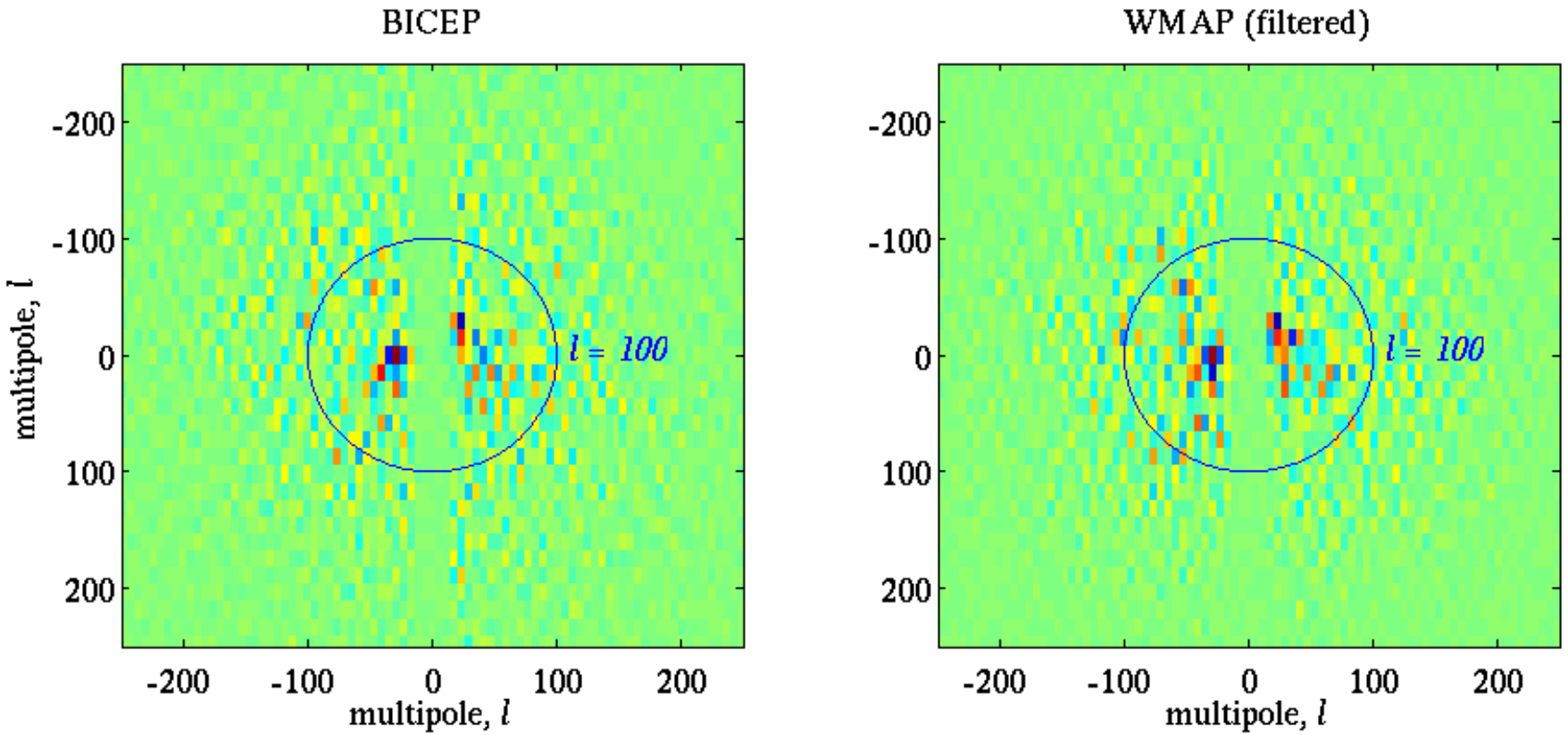

- 94 GHz (W-band)
- Filtered using the BICEP azimuth-scan strategy

# BICEP 9 day! (C.L. Kuo)

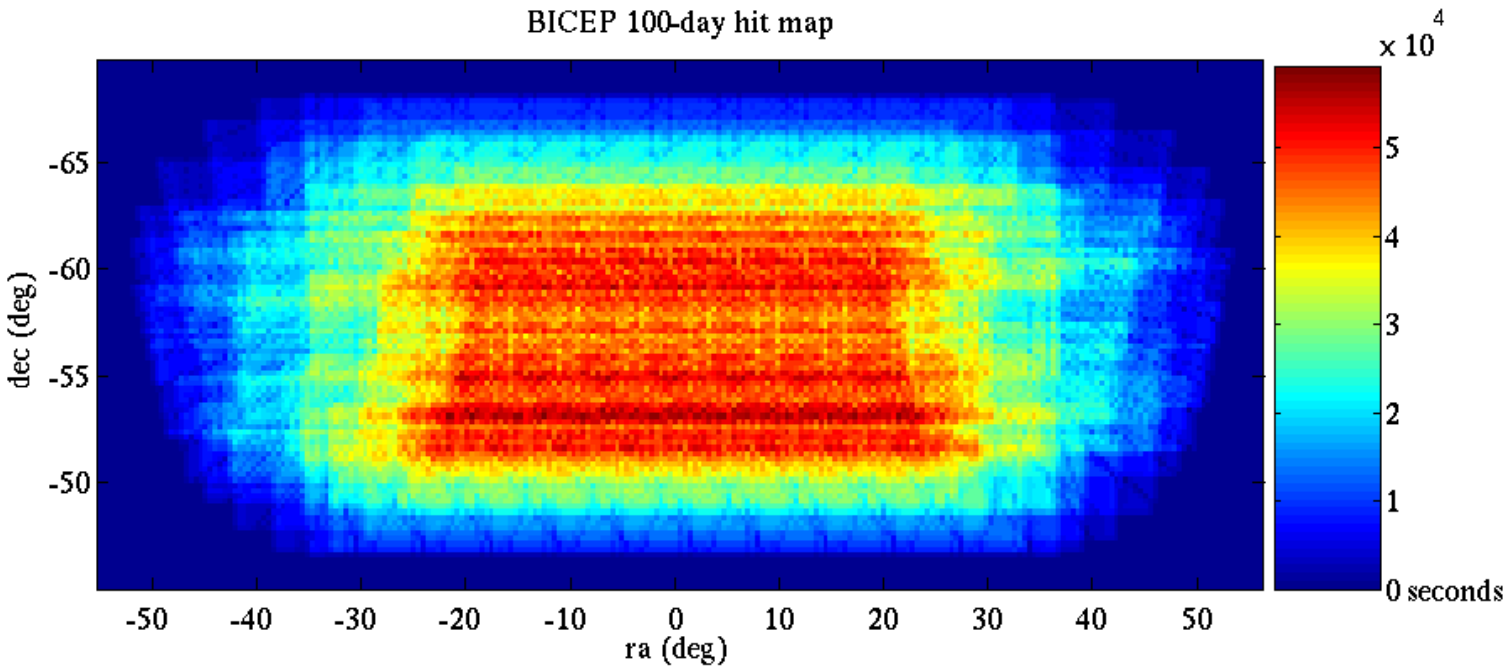



- Blind pointing: star camera + nominal radio model only
- Actual pointing model to be derived from galactic sources (WMAP?)
- Absolute calibration from WMAP

# Fourier plane comparison




- High-pass filter of sky and instrument 1/f preserves power at $\ell > 30$
- Modes lost to AZ-only scanning are localized to *v* axis of *uv* plane
- E/B mixing effects are also *uv* local
- No serious problems from AZ-only scanning…

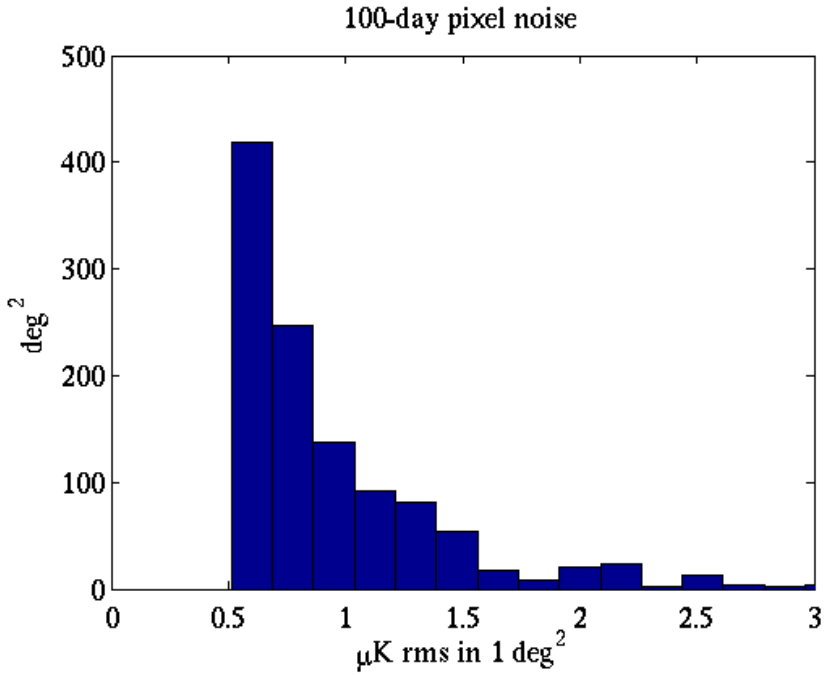



# Noise extrapolations…

- 1140 deg$^2$
- Apodized by large FOV

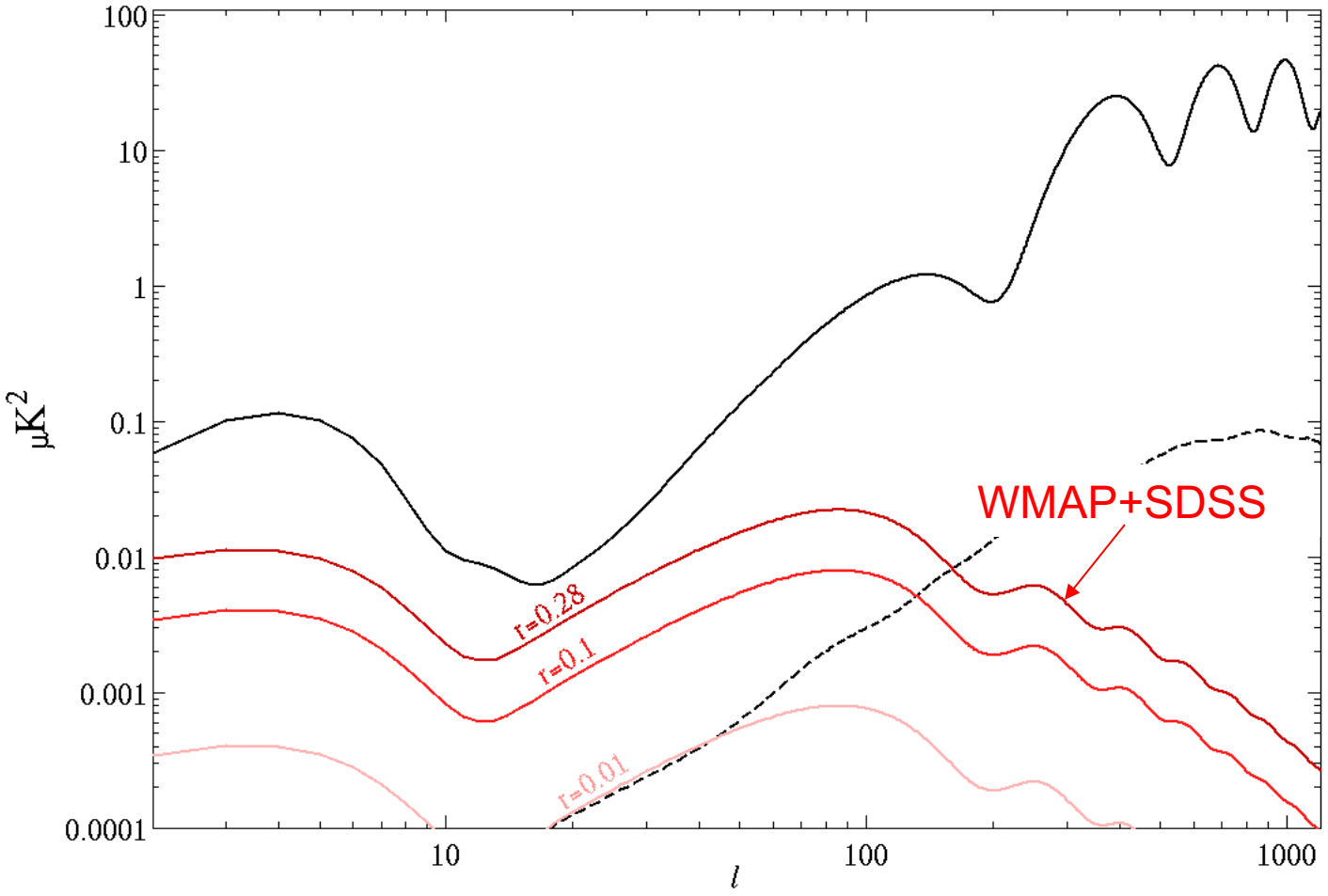
Assume 100 good-weather days

- At map center:
  0.51 μK rms in 1 deg$^2$



# How well could we do?

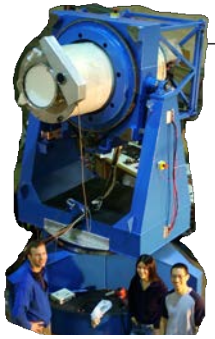
- Use actual coverage map, observing efficiency
- Assume no hit from systematics or foregrounds



# Sensitivity projections - buyer beware:

- Assumes no hit from systematics or foregrounds -

- 100 good weather days (~12 in the can so far)
  - Conservative guess for first season



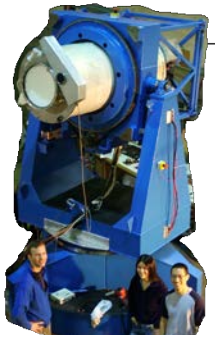
**BICEP 100-day**

# Sensitivity projections - buyer beware:

- Assumes no hit from systematics or foregrounds -

- 300 good weather days

  Reasonable guess for 2 - 3 seasons

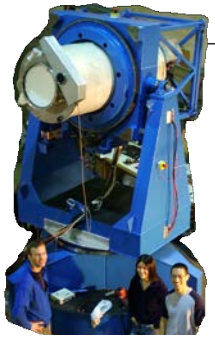


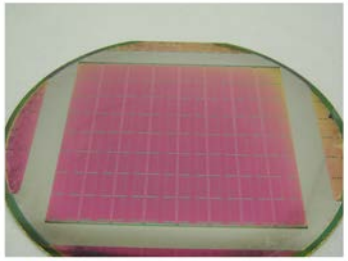
**BICEP 300-day**

# Sensitivity projections - buyer beware:

- Assumes no hit from systematics or foregrounds -

- BICEP-2 upgrade: antenna-coupled TES focal plane
  - 512 detectors at 150 GHz, 20 degree FOV



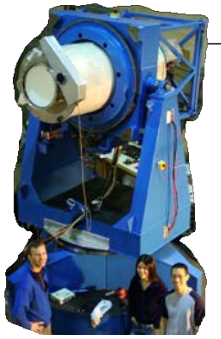


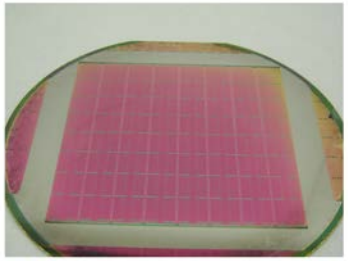
**BICEP 300-day** **BICEP-2**

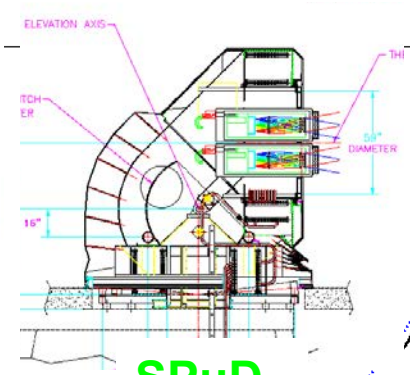
# Sensitivity projections - buyer beware:

- Array of co-pointed BICEP-2 style receivers
- One concept: “SPuD” SPider Upgrade to DASI:

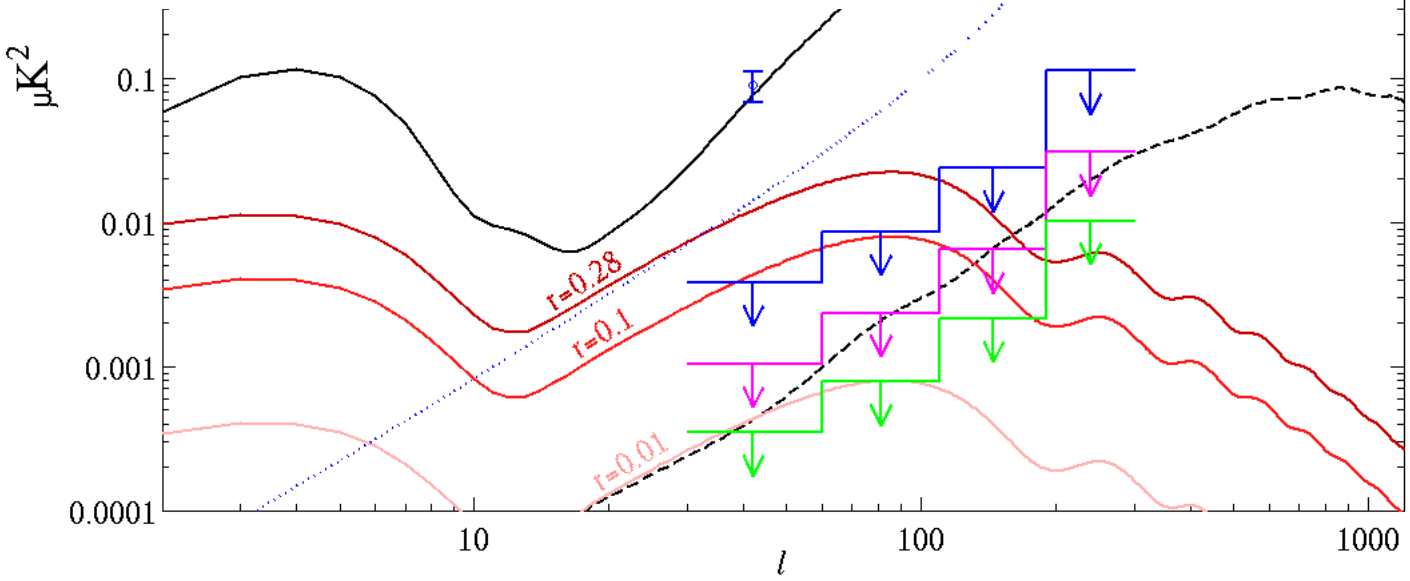
  2x100, 2x150, 1x220 GHz receivers share DASI & BICEP mounts





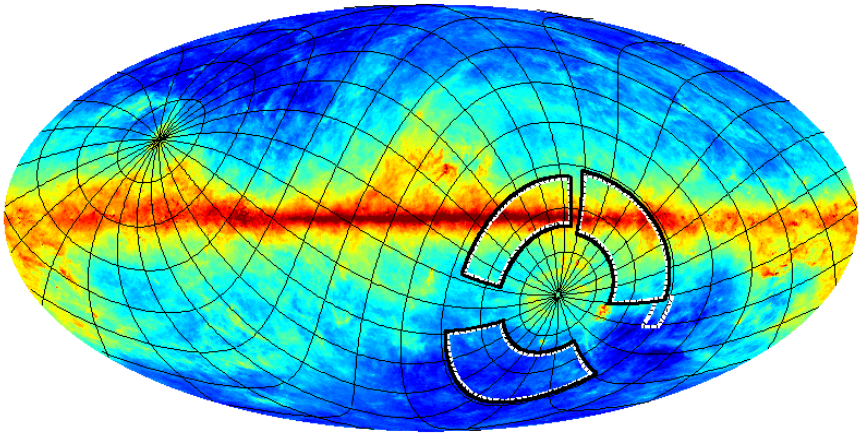



**BICEP 300-day** **BICEP-2** **SPuD**

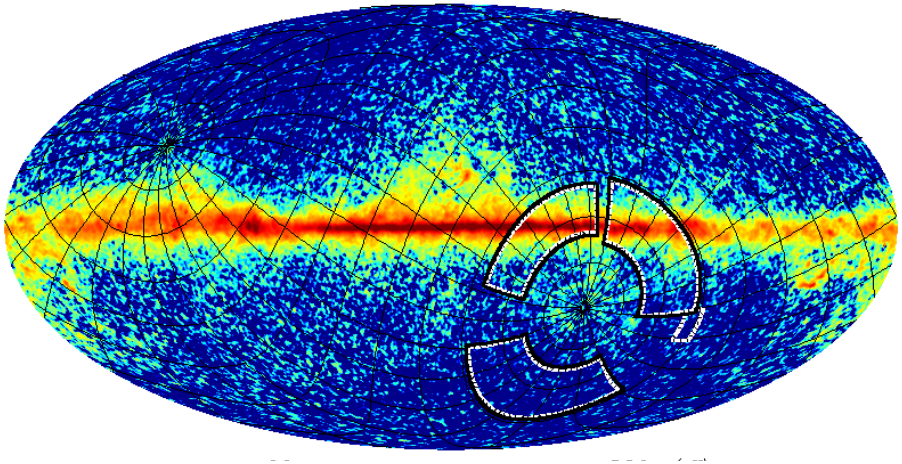


# Foregrounds…

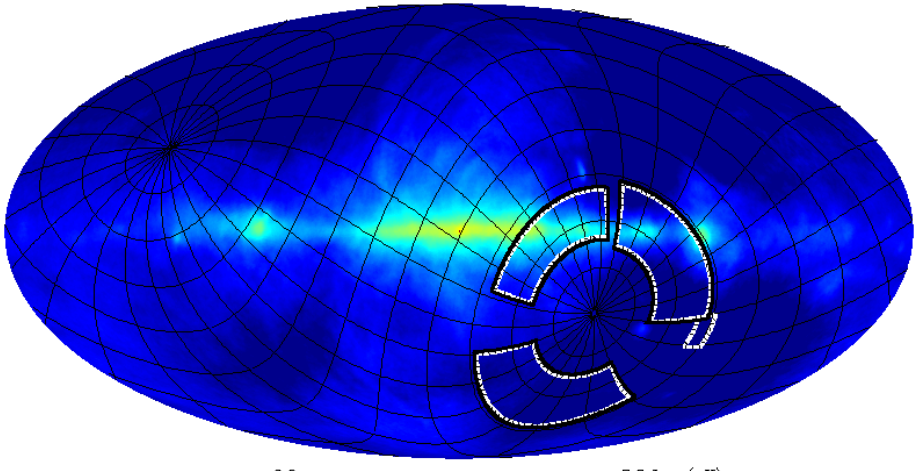
100 GHz FDS Dust Model



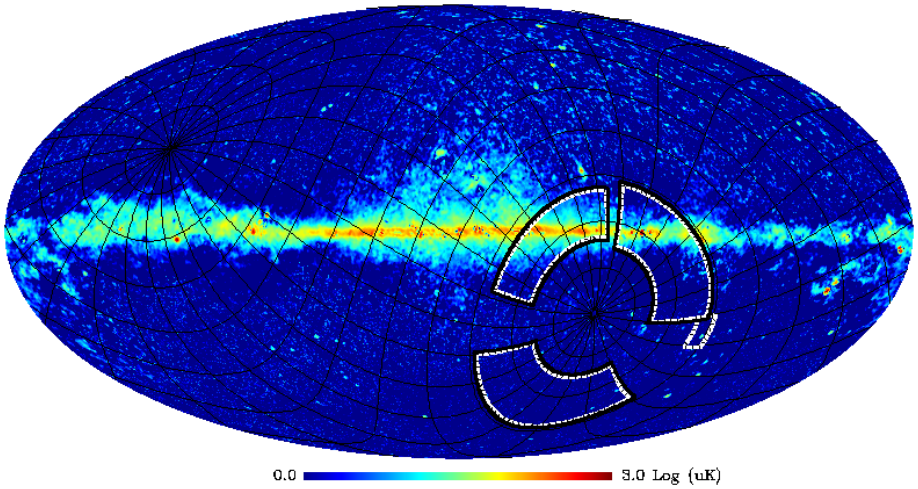
WMAP 3-yr W-Band MEM Dust



100 GHz Giardino Synchrotron Model



WMAP 3-yr W-Band MEM Synch



# Conclusions

- BICEP is the

  "John Robinson Gravitational Wave Background Telescope"

- BICEP is on the air right now!

- Over **next 6 months**, BICEP will teach us new things about:
  - Foregrounds: 90GHz and above in cleanest regions of sky
  - Large angular scales: what range is accessible from the ground with and without modulation
  - B-mode separation: gaining real experience with a well-characterized instrument
  - Inflation? (best current limit: $r < 0.28$)

# Stay tuned…

Photo: D. Barkats