

# A Brief History of Foregrounds: From Pigeon Poop to the Dust that Ate the Nobel Prize

Bruce Partridge

[bpartrid@haverford.edu](mailto:bpartrid@haverford.edu)

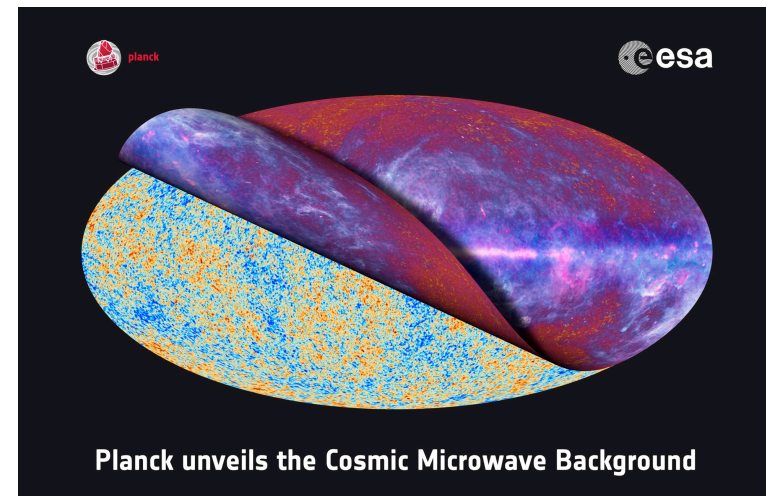
# General Remarks

For CMB studies, *everything* is a foreground

Emphasis of this meeting on *astrophysical* foregrounds (fixed and unchangeable), but I will be more inclusive

From the beginning, foregrounds have concerned CMB observers, but **which foregrounds** dominated has changed

My presentation will be an informal history of which foregrounds worried us and what we did about them



# 1964: Penzias and Wilson

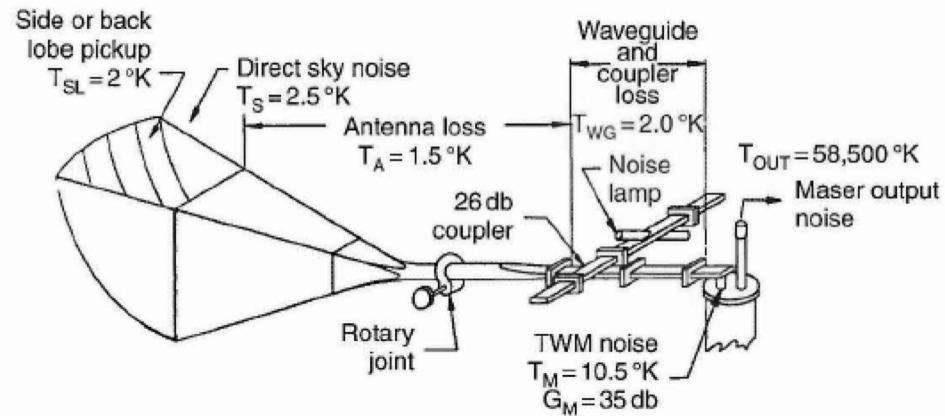
They found “an excess antenna temperature of 3.5 K”

Much of their one-page paper was showing that the “excess” was ***not foregrounds***

“Foregrounds” included any source of emission in front of their detector

They considered:

- man-made radio emission
- emission from the Galaxy
- atmospheric emission
- pick-up from the ground
- emission from the walls of their horn antenna
- “deposits” – by pigeons – in the horn (hence the temporary unit of “milli-dungs”)



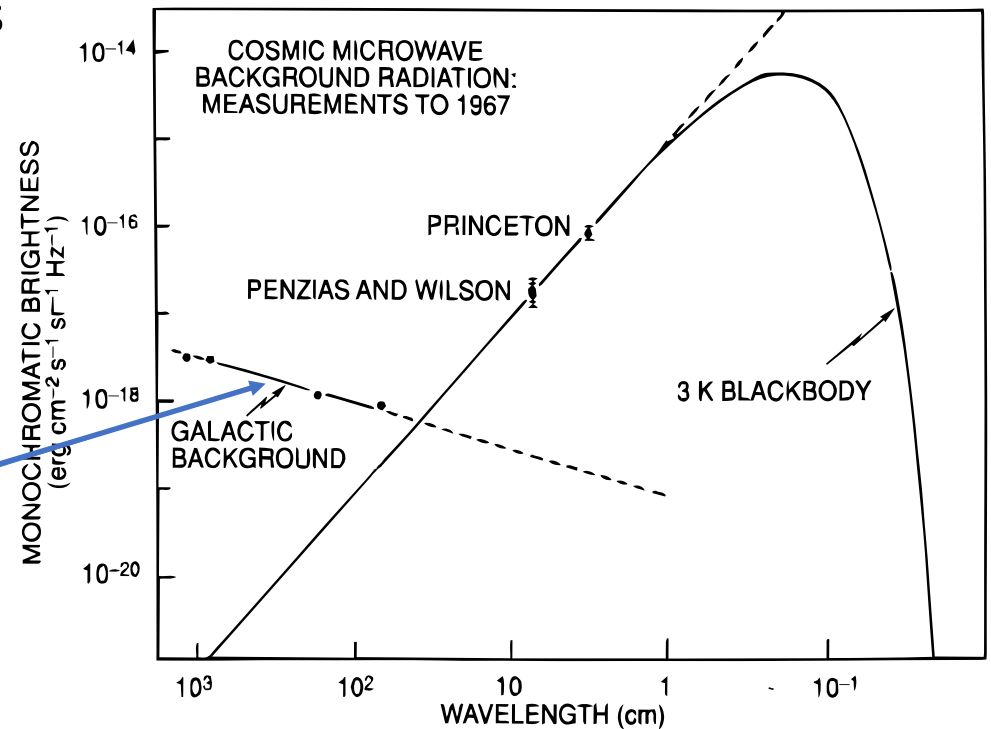
# 1965: Roll and Wilkinson

Design eliminated some foregrounds  
Measured atmosphere

Result  $T = 3.0 \pm 0.5$  K

-- and this astonishing graph

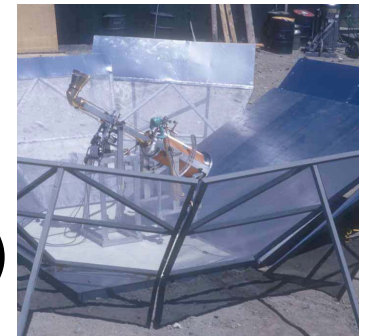
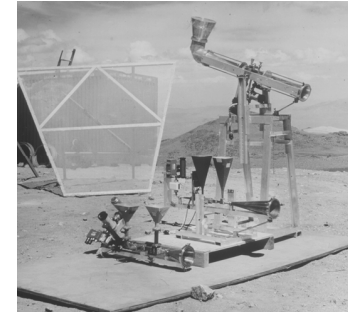
Note that a key foreground  
(Galaxy) was explicitly included, and  
shown to be negligible



# 1967-8 The Next Step – Co-ordinated, Multi-Frequency Measurements

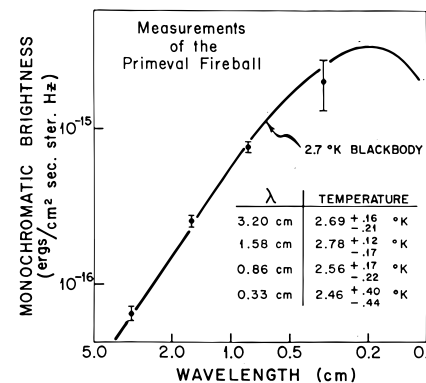
Explicit attention to foregrounds, especially *atmosphere*

- high, dry site
- improved measures of remaining atmospheric emission
- better control of emission from the ground
- used same horn for sky and cold load measurements
- apparatus kept fixed
- attention to instrumental “foregrounds” (cold load walls; reflector)



These three papers:

- no mention of astrophysical foregrounds
- established black-body spectrum (not  $\nu^2$ )



# 1990 – COBE FIRAS

Exquisite attention to systematics

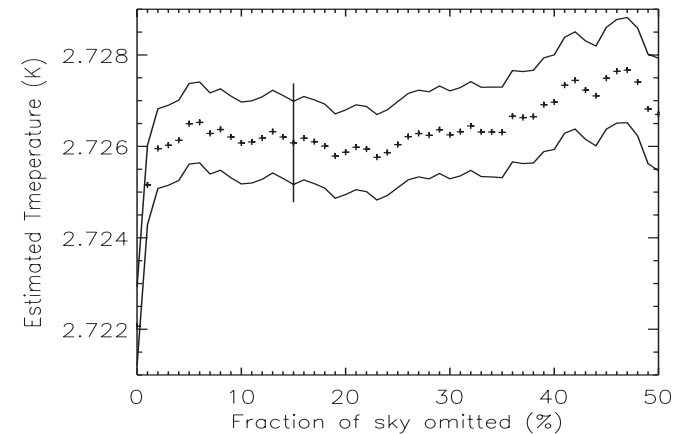
Null signal using adjustable cold load

Main limit on accuracy: fidelity of cold load

Astrophysical foregrounds not even mentioned  
in first paper (Mather et al., 1990)

But by 2009 (Fixsen et al.), zodi, proxies  
for Galactic emission, and line emission  
all considered (7 templates fitted)

-- yet a Galactic mask was still necessary at  $\sim 2\sigma$



**Figure 2.** Crosses are the CMB temperature estimation for a given fraction of the brightest part of the sky excluded. The lines are the nominal  $+1\sigma$  and  $-1\sigma$  limits. The error bar is the adopted value and uncertainty inflated for the excess  $\chi^2$ .

# 2011 -- The Puzzle of Arcade

Measured  $T_0$  at 3 & 10 GHz (Fixsen et al. 2011; Seiffert et al. 2011)

-- made “expected” corrections for Galactic synchrotron & free-free, extragalactic sources....

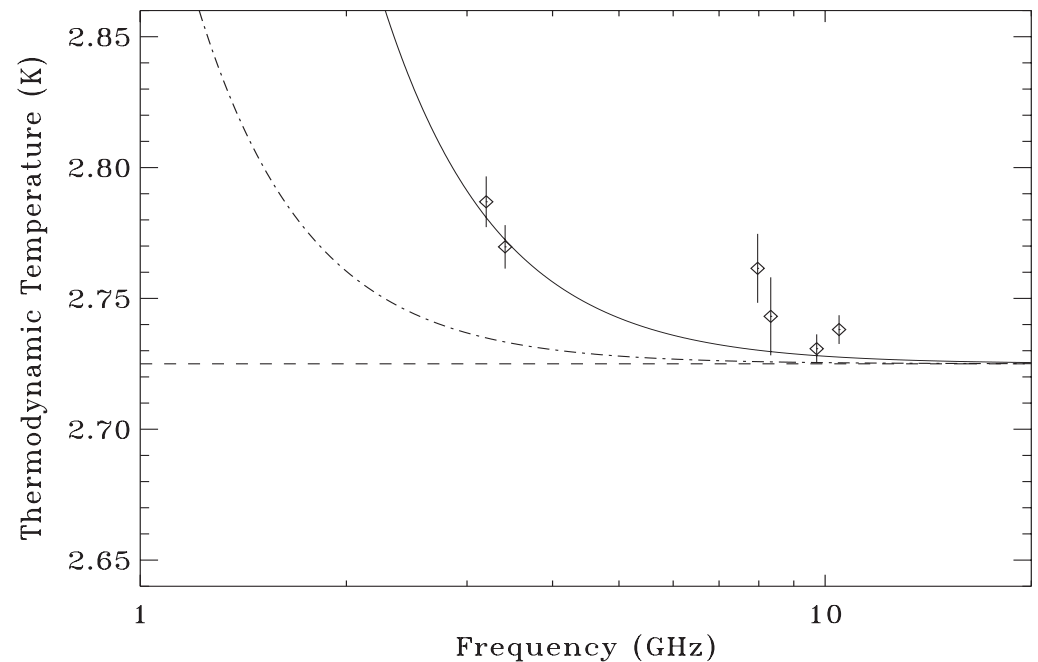
-- still unexplained ?

-- see Dowell & Taylor 2018

Need to sort out before sensitive spectral measurements (e.g. of  $\gamma$ )

See Paddy Leahy’s earlier talk;  
repeat need for careful **zero-level** measurements

-- synchr. is smooth but so are  $\gamma$  &  $\mu$



# Isotropy Measurements

Many local and instrumental sources of foregrounds cancel out since measurements are differential

But need for  $10^3$  or  $10^4$  increase in sensitivity requires attention to both

- fluctuations in local foregrounds (e.g., clouds)
- remaining instrumental systematics

And ***astrophysical foregrounds*** were soon a central concern



# Canceling Local Foregrounds, by Design

Differential measurements

Same zenith angle

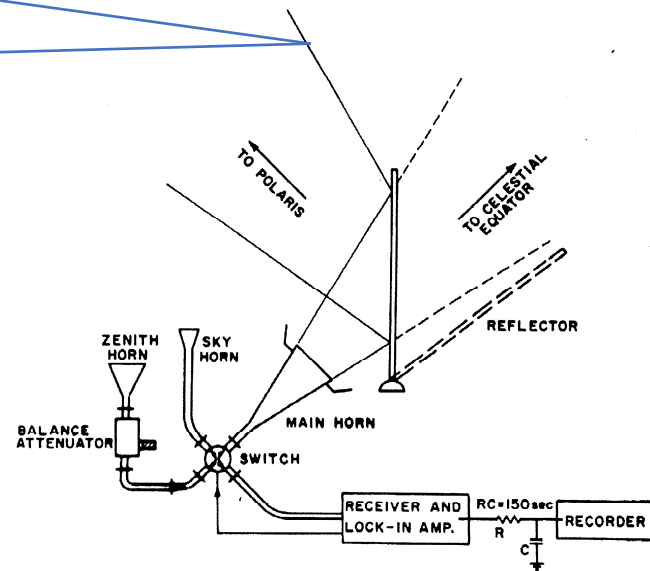
Attention to diurnal effects

Calibration (“Is it even on?”)

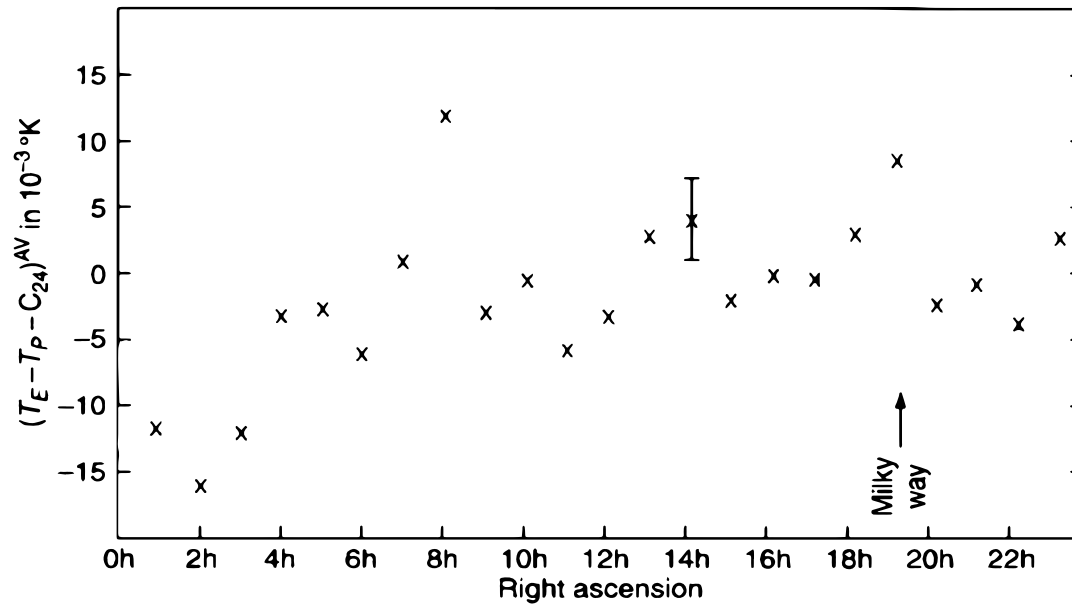
And of course, ground screens, etc.

The Princeton “flapper” --

reflector, with NCP as  
periodic reference (P = 5 min; not  
a wise choice)



# Results of the Isotropometer, 1967



Unconvincing detection of Galactic emission; no clear evidence of dipole  
Atmospheric noise dominated

# An Automated Isotropometer, 1967

Dominant foreground: *atmosphere*

Hence go to dry and sunny spot  
(not New Jersey)

Automated device; left unattended

In a secure (very secure) location



# Canceling Local Foregrounds, by *Better Design*

Conklin and Bracewell 1967-9

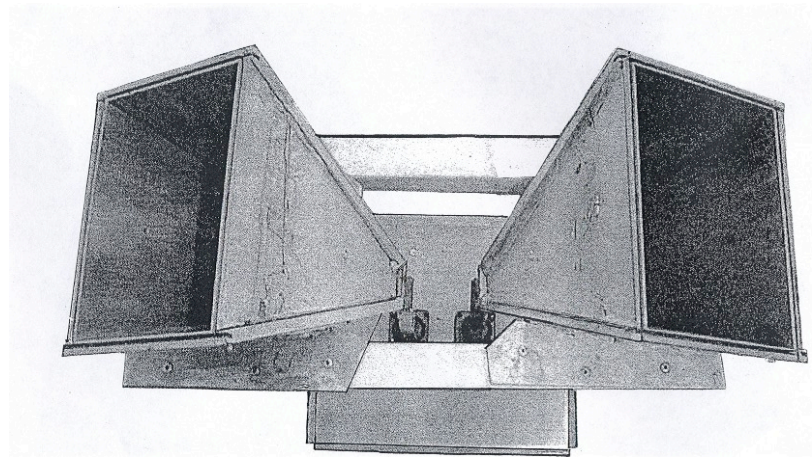
Differential measurements

Same zenith angle

Paired horn antennas

No moving parts

Design later adopted by Smoot  
for U2 and COBE projects and  
symmetrical design for WMAP



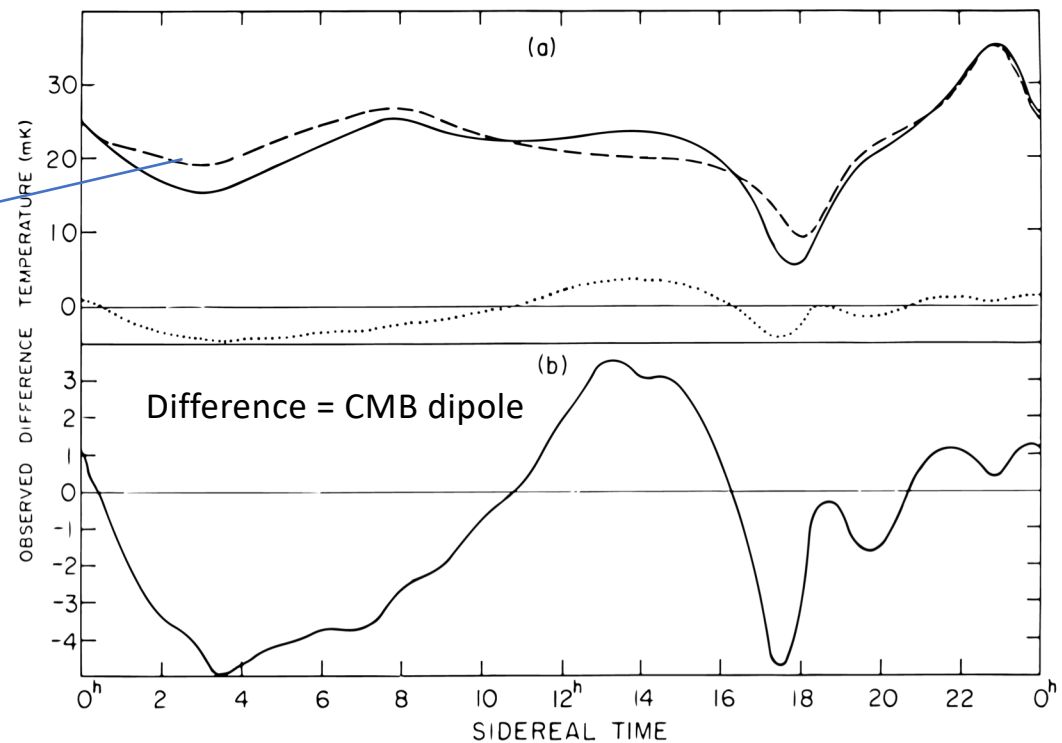
The first CMB experiment dominated by *astrophysical* foregrounds

# Conklin's Results, and Their Reception

From Conklin's thesis:

Impact of estimated  
Galactic emission very  
clear (dominates signal)

May have raised doubts  
about an actual detection  
of the dipole



# Rising above the Atmosphere: Balloons

Clearly dominant foreground – atmospheric emission

-- so observe above (most of) atmosphere and all water vapor

1971 – early attempt by Dave Wilkinson and

Paul Henry

-- an astronomical foreground dominates

# Rising above the Atmosphere: Balloons

1976 – Francesco Melchiorri, Paul  
Boynton, BP .... try again  
-- cheap beer dominates



Back to Astrophysical Foregrounds....

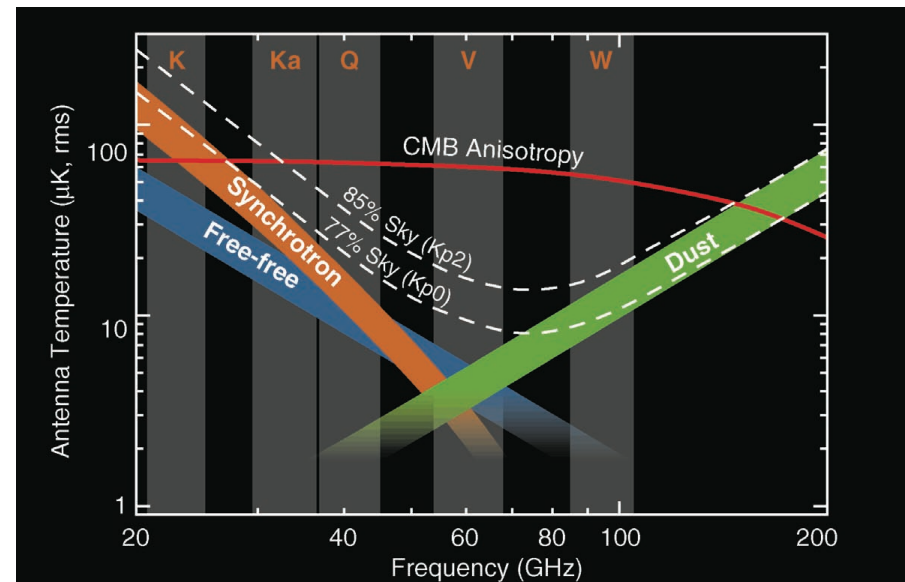


# Multi-Frequency – But Which Frequencies?

Debate initiated by Neil Brandt & Charles Lawrence, 1994

1. Emphasize frequency range of minimum foregrounds?  
-- then synchrotron, free-free and dust emission residuals must all be dealt with
2. Work in a regime where only a single component dominates  
-- and pay price of higher foreground

WMAP chose latter, possibly underestimating dust



# Polarization

Another leap of  $\sim 10^2$  in sensitivity required

New instrumental biases and “foregrounds”

Transition ***from instrumental to astrophysical foregrounds*** parallels the case for temperature anisotropies

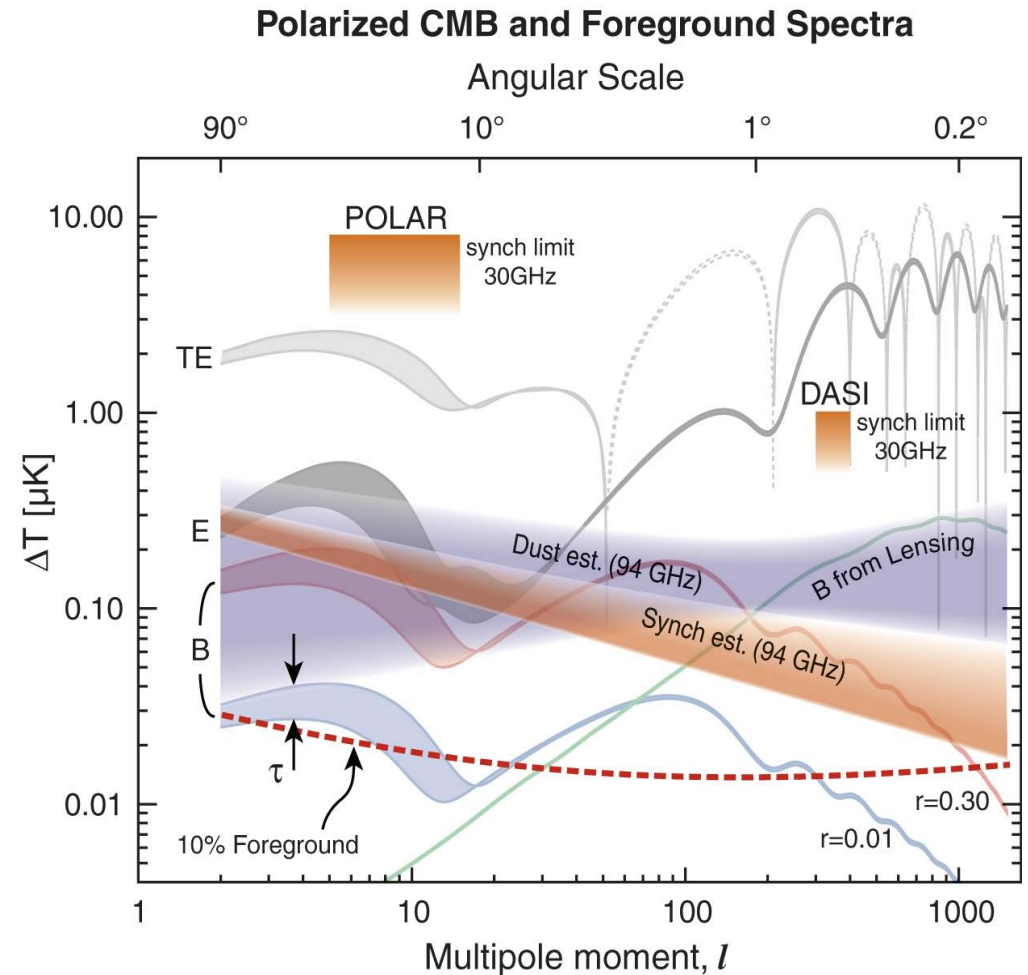
# Polarization

For TE & EE, can be managed:

$$(P/T)_{\text{sources}} < (P/T)_{\text{CMB}}$$

Problem is spatial variation of polarization and the unexpectedly high polarization fraction for dust emission

For BB, astrophysical foregrounds completely dominate



# WMAP -- Galactic Emission Dominates

Example: WMAP 3 year papers

-- on temperature maps,  $\frac{1}{2}$  of paper is devoted to foregrounds and component separation

-- for polarization maps,  $\sim 1/3$

-- and a separate paper by the 7 year release

Multi-frequency observations to control foregrounds

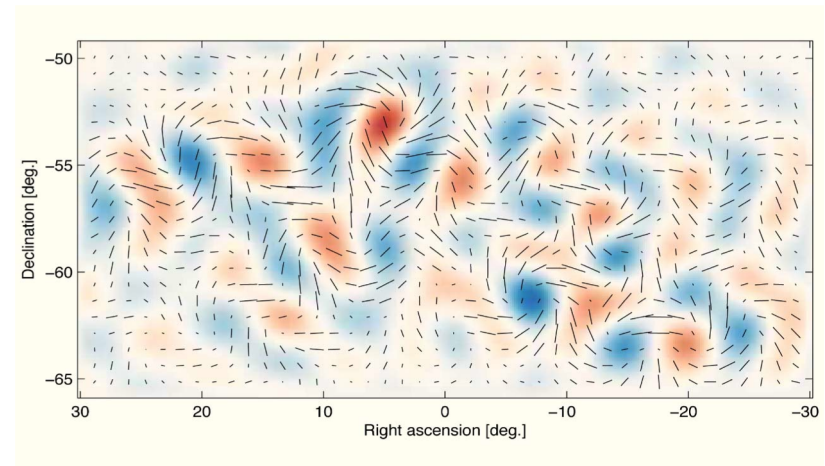
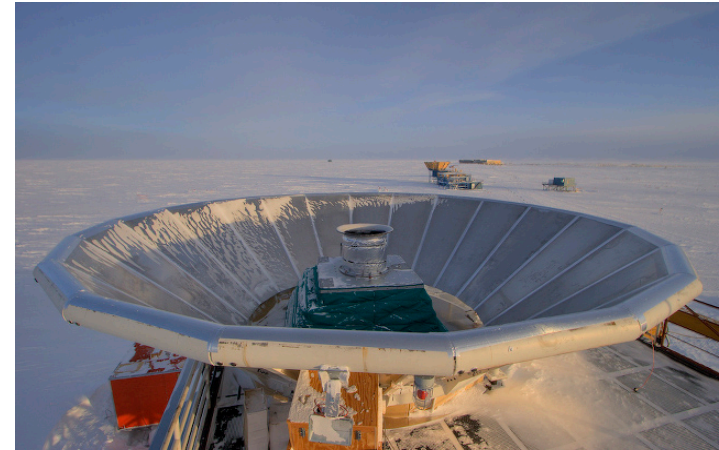
Masks and template fitting introduced for first time (I think)

The case of tau: first value 0.17, changed to 0.088 (better analysis & better modeling of foregrounds; tests for foreground residual; foreground model (esp. dust) still rough

# The BICEP/Keck Results and “Losing the Nobel Prize”

2014 BICEP2/Keck claim of  
primordial B modes  $r = 0.2$   
Highly sensitive – but single frequency,  
hence little control of foregrounds

Apparent B-mode signal in data

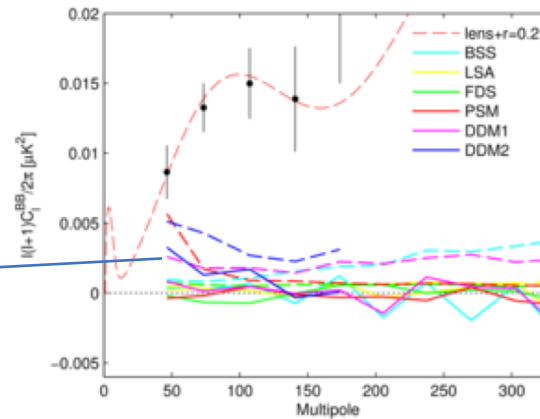


# The BICEP/Keck Results and “Losing the Nobel Prize”

Relied on preliminary Planck observations for estimate of Galactic dust emission

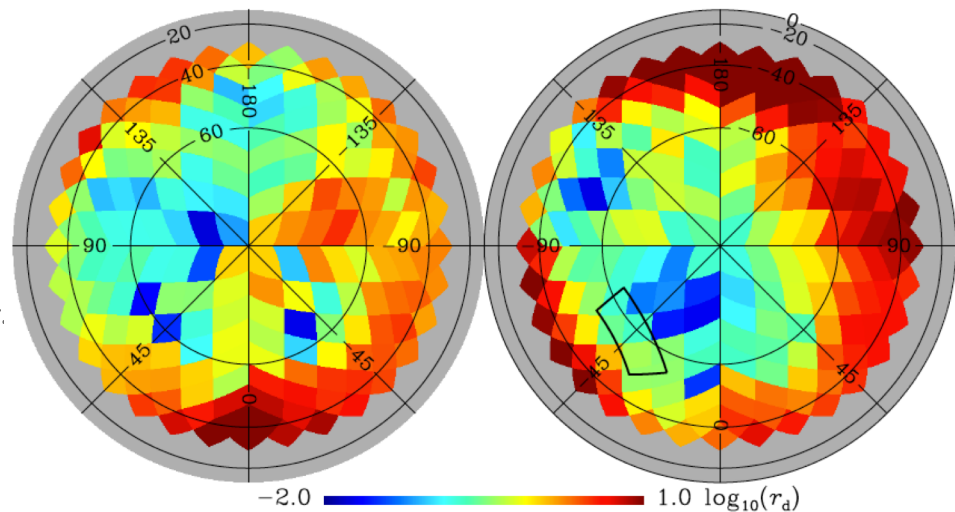
-- not good enough

In fact, dust emission largely explains the result



Later 2015 joint analysis:  $r < 0.13$

Even this has problems: frequency to frequency correlation



# Today's Problems

Newly relevant astrophysical foregrounds

- AME
- SZ signals
- lensing
- variability

New foregrounds complicate choice of frequencies

New instrumental biases

- and for ground-based projects, ground pick-up, atmosphere....are still problems

Even worse, ***interaction*** between systematics and foregrounds (e.g., bandpass mismatch)

# Planning for Future Observations

The value of ground-based surveys (for synch., AME, free-free)

-- e.g. C-BASS, S-PASS, QUIJOTE....

-- monopole (**zero-point**) measurements crucial

-- so is accurate polarization

**Multi-frequency** measurements required for any isotropy survey

-- e.g. LiteBIRD started with 6, now 15 (I think)

-- if number of bands is limited, must decide to work in sweet spot (foreground minimum) **or not**

Attention to **interaction** between instrumental systematics and foregrounds: e.g.

-- measure band passes, polarization angles and efficiencies with

precision before launch or deployment

-- devise and plan tests of these effects





# Polarized CMB and Foreground Spectra

