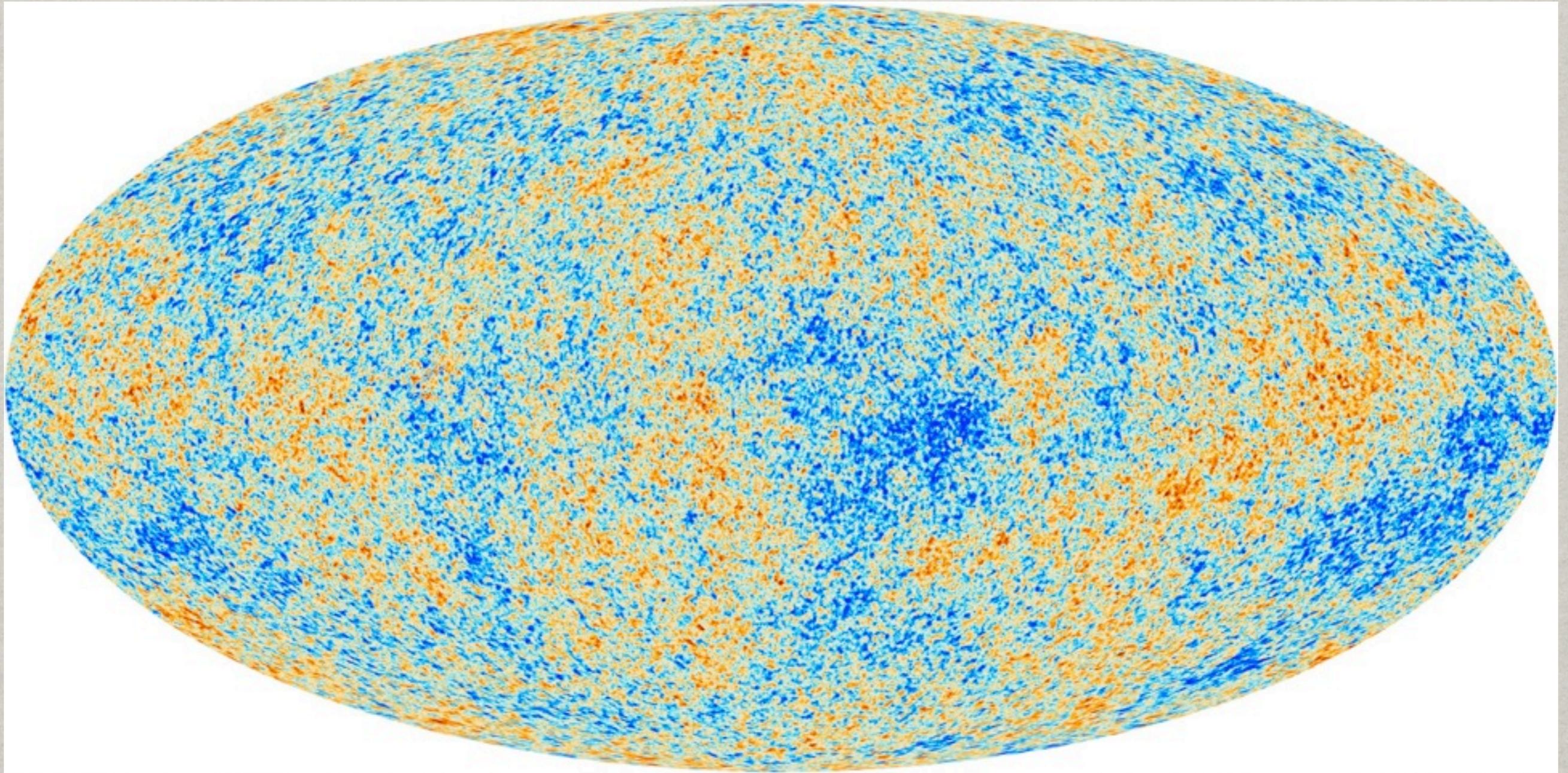
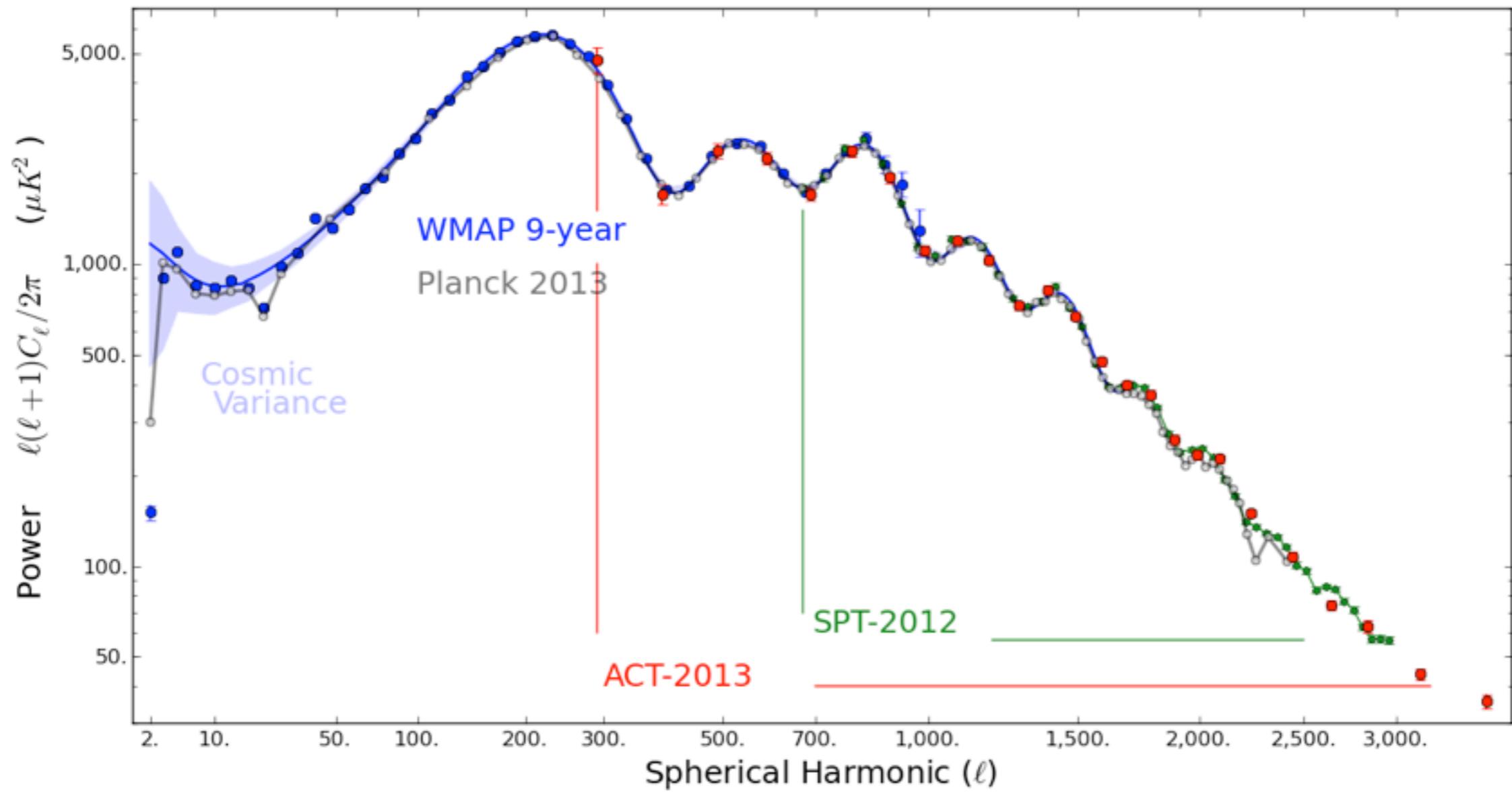


THE STATE OF  
MICROWAVE  
BACKGROUND  
POLARIZATION

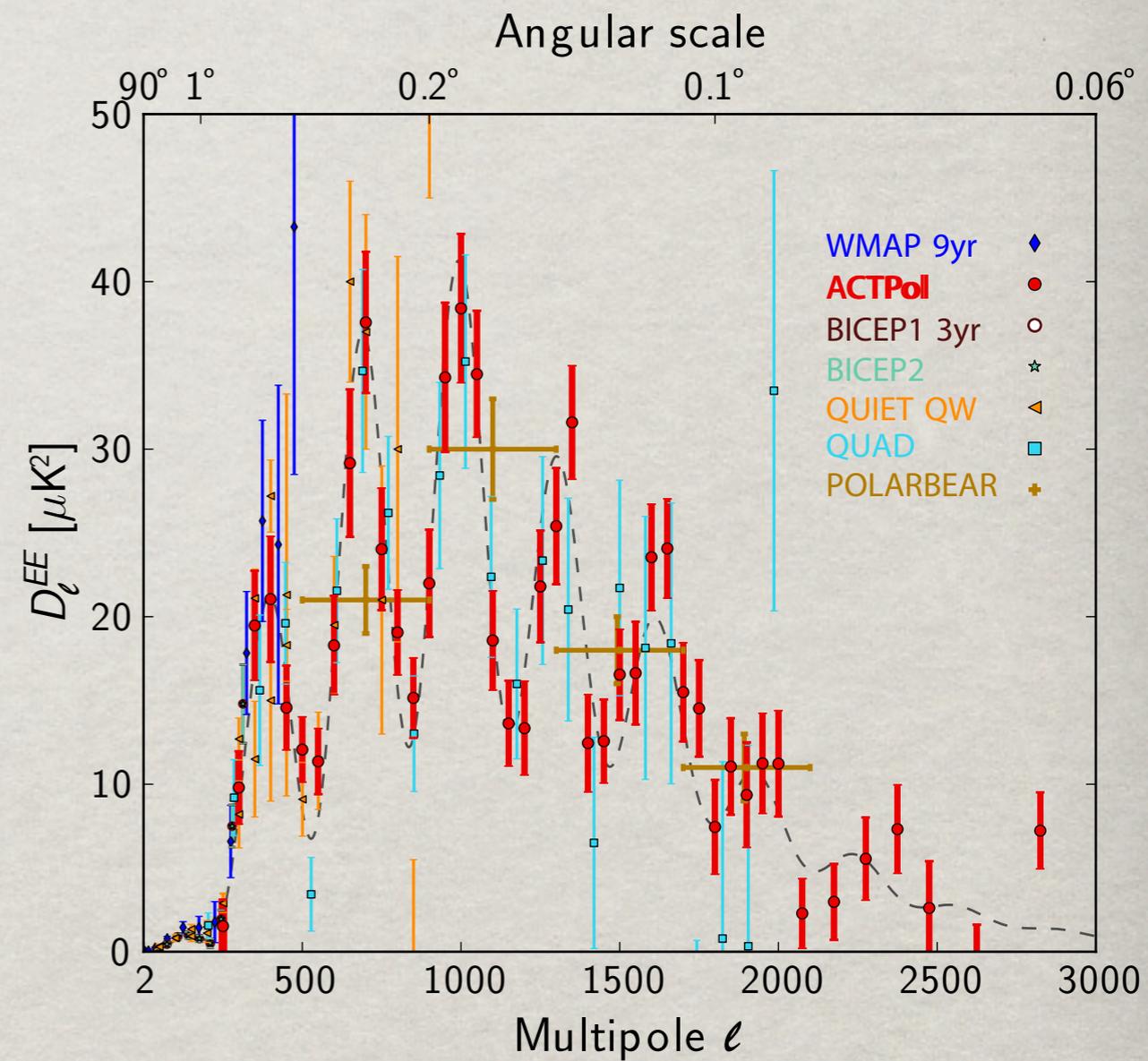
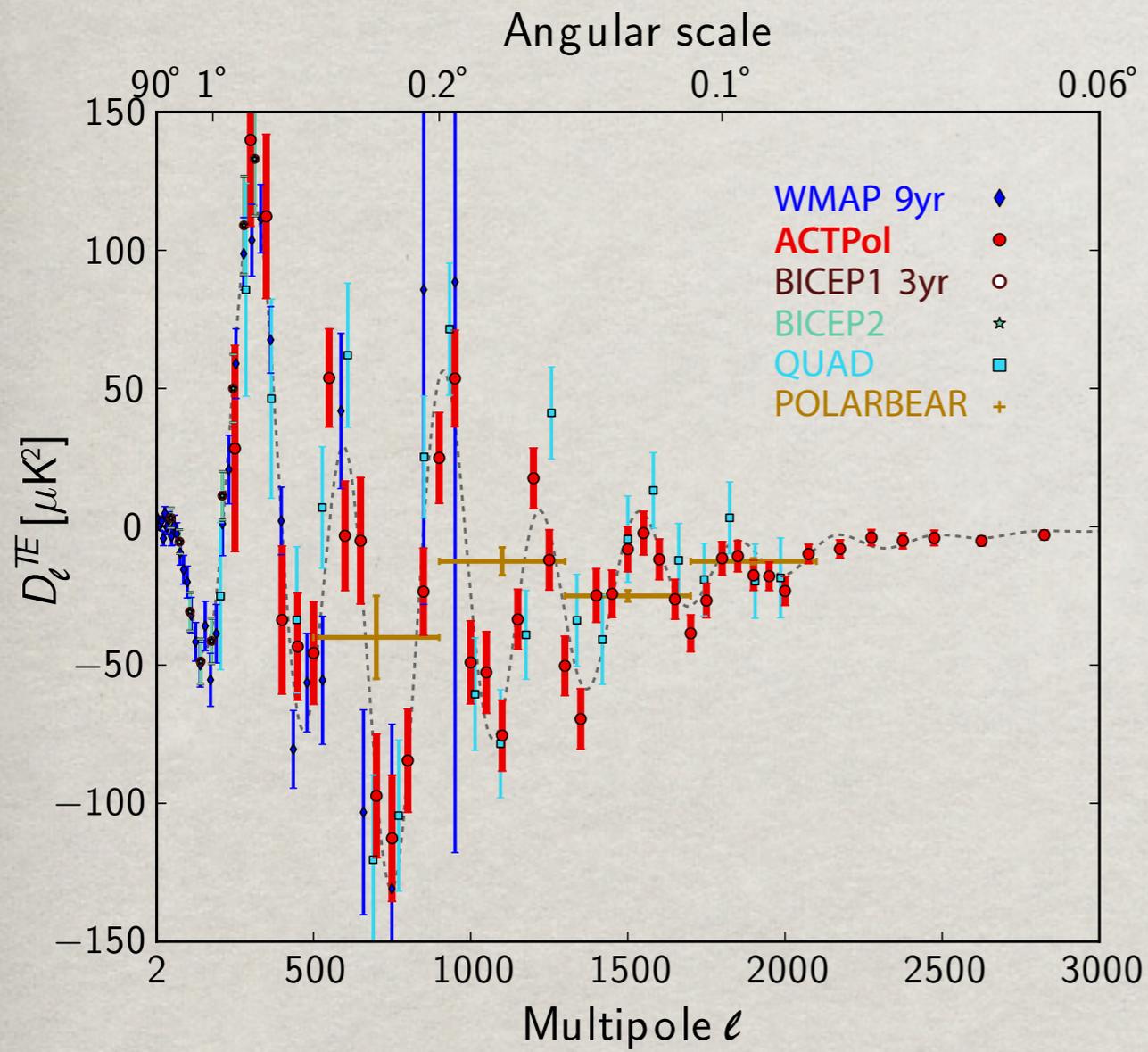
ARTHUR KOSOWSKY  
UNIVERSITY OF PITTSBURGH



Planck Collaboration 2013



compilation courtesy M. Halpern



Naess et al. 2014 (Atacama Cosmology Telescope Collaboration)

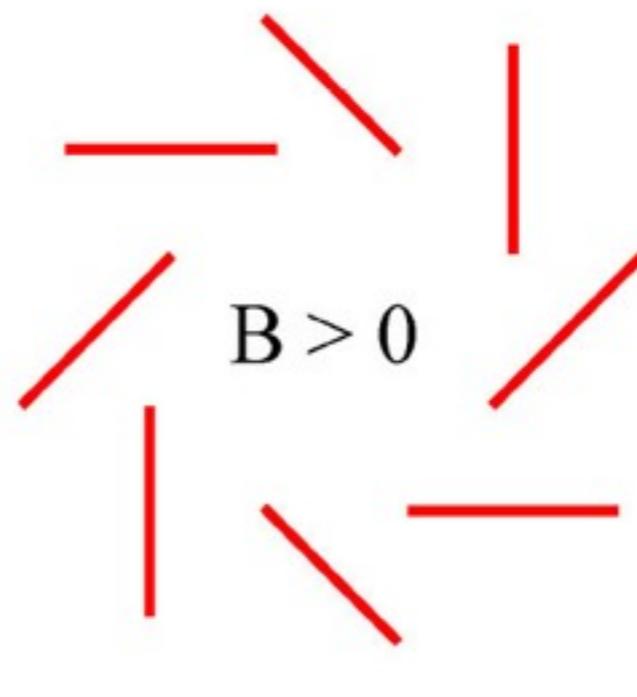
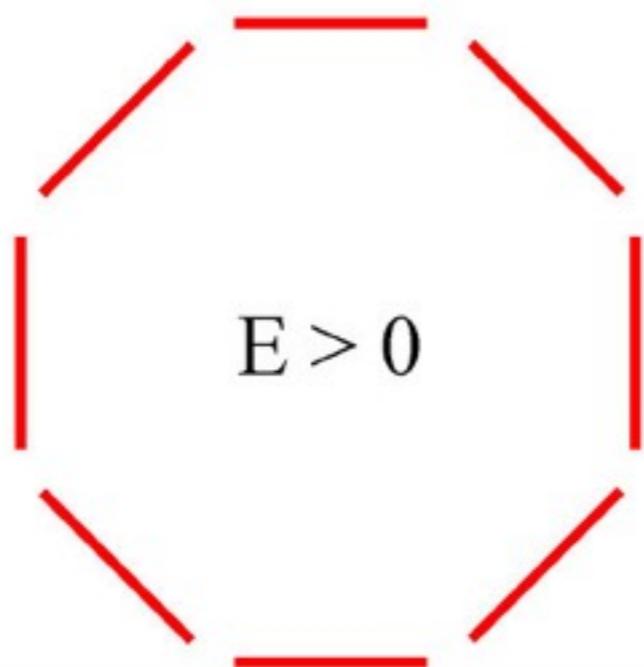
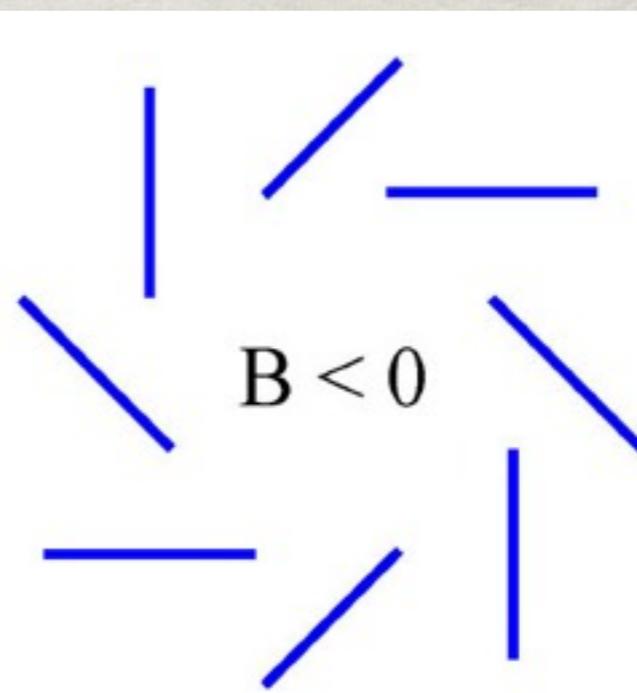
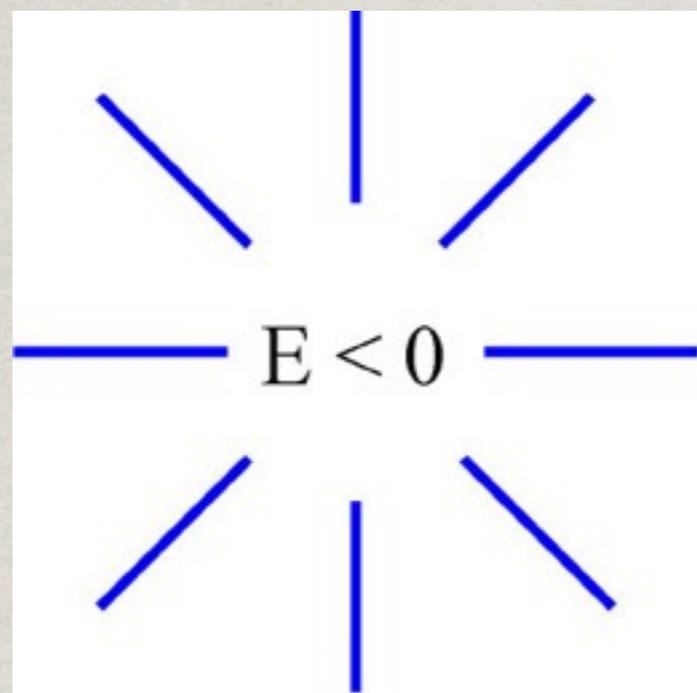
Linear polarization: 2x2 tensor with  
2 degrees of freedom (Q,U)

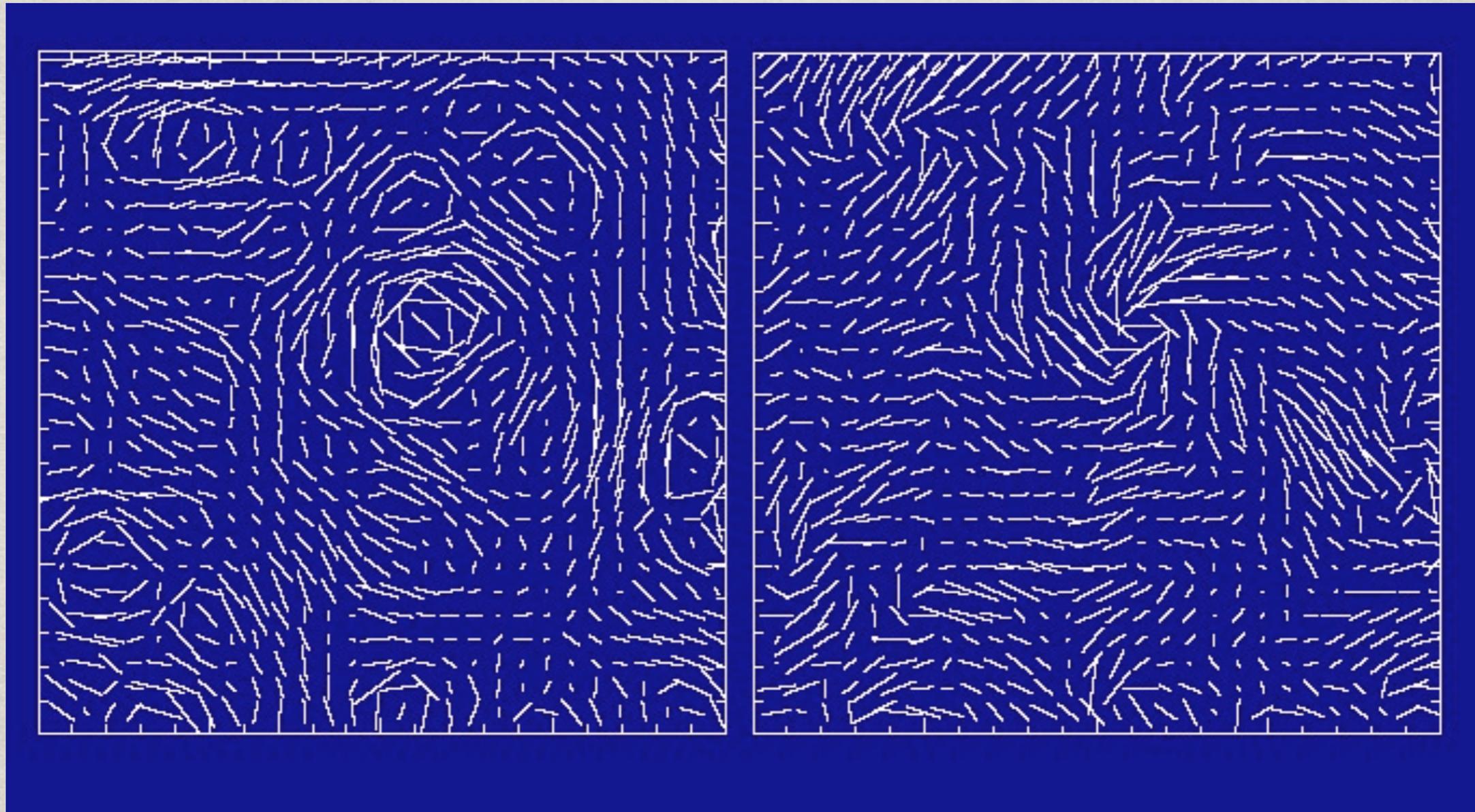
Expand polarization field in 2 tensor spherical harmonics:  
“E-mode” and “B-mode”

Kamionkowski, Kosowsky, Stebbins PRD 1997; Seljak and Zaldarriaga PRD 1997

E-mode: parity even      Scalar (density) perturbations

B-mode: parity odd      Other stuff





Which is E-mode and which is B-mode?

courtesy W. Hu

What makes B-mode polarization?

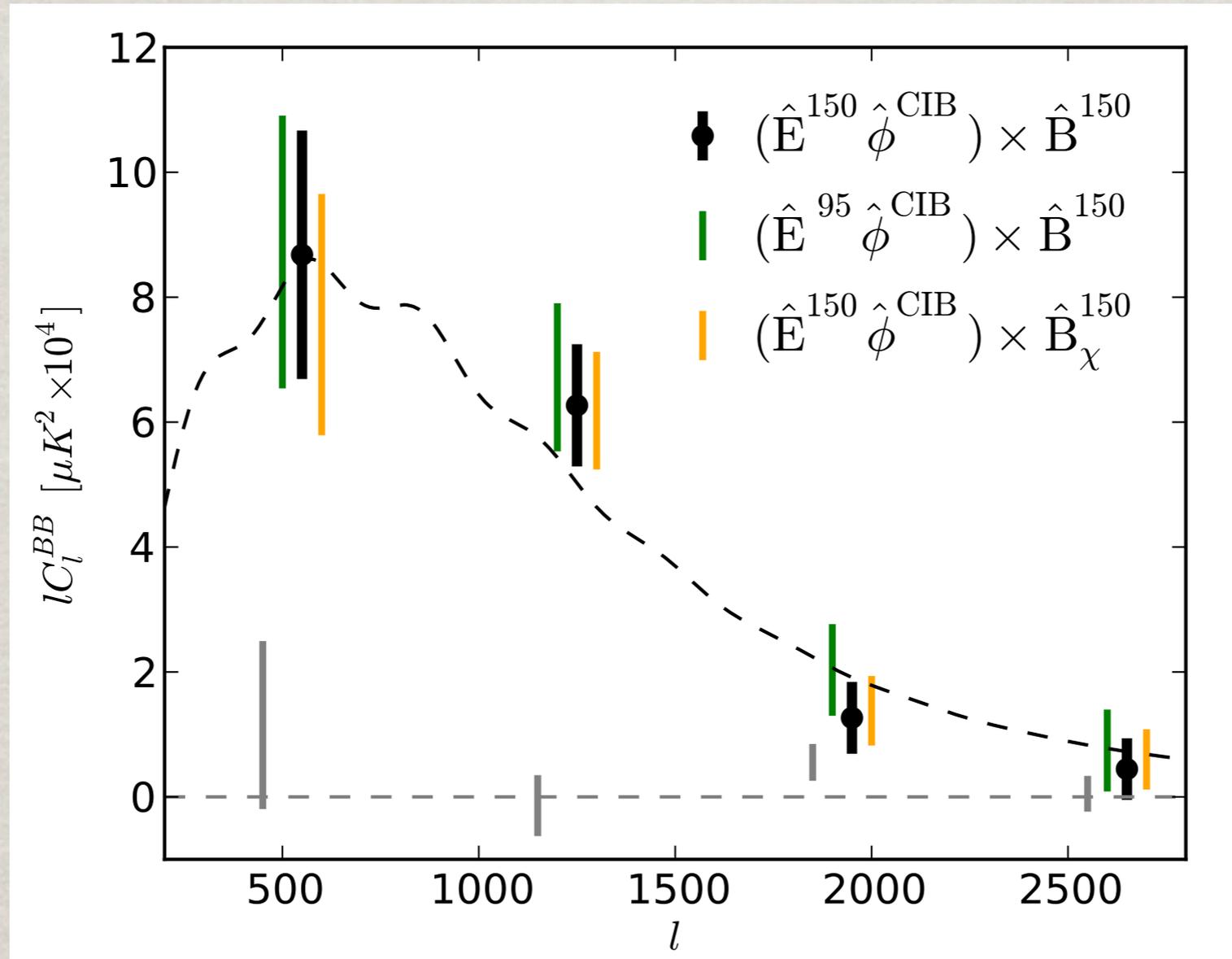
Primary perturbations:  
vector or **tensor** perturbations

**INFLATION!**

Secondary fluctuations:  
**lensing** (deflection), birefringence (rotation)

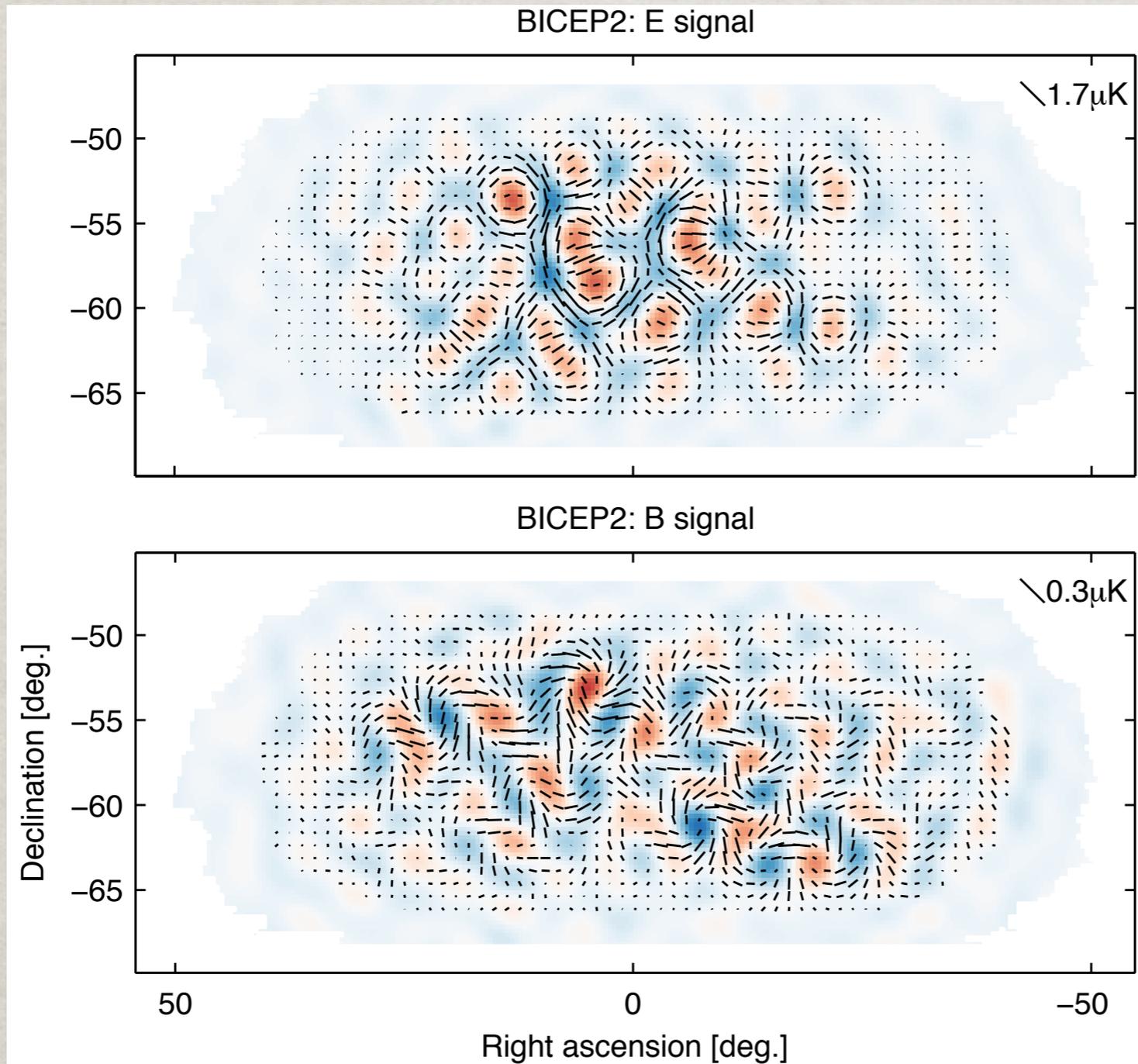
**Large-scale structure**

# B-mode Polarization: First Detection!

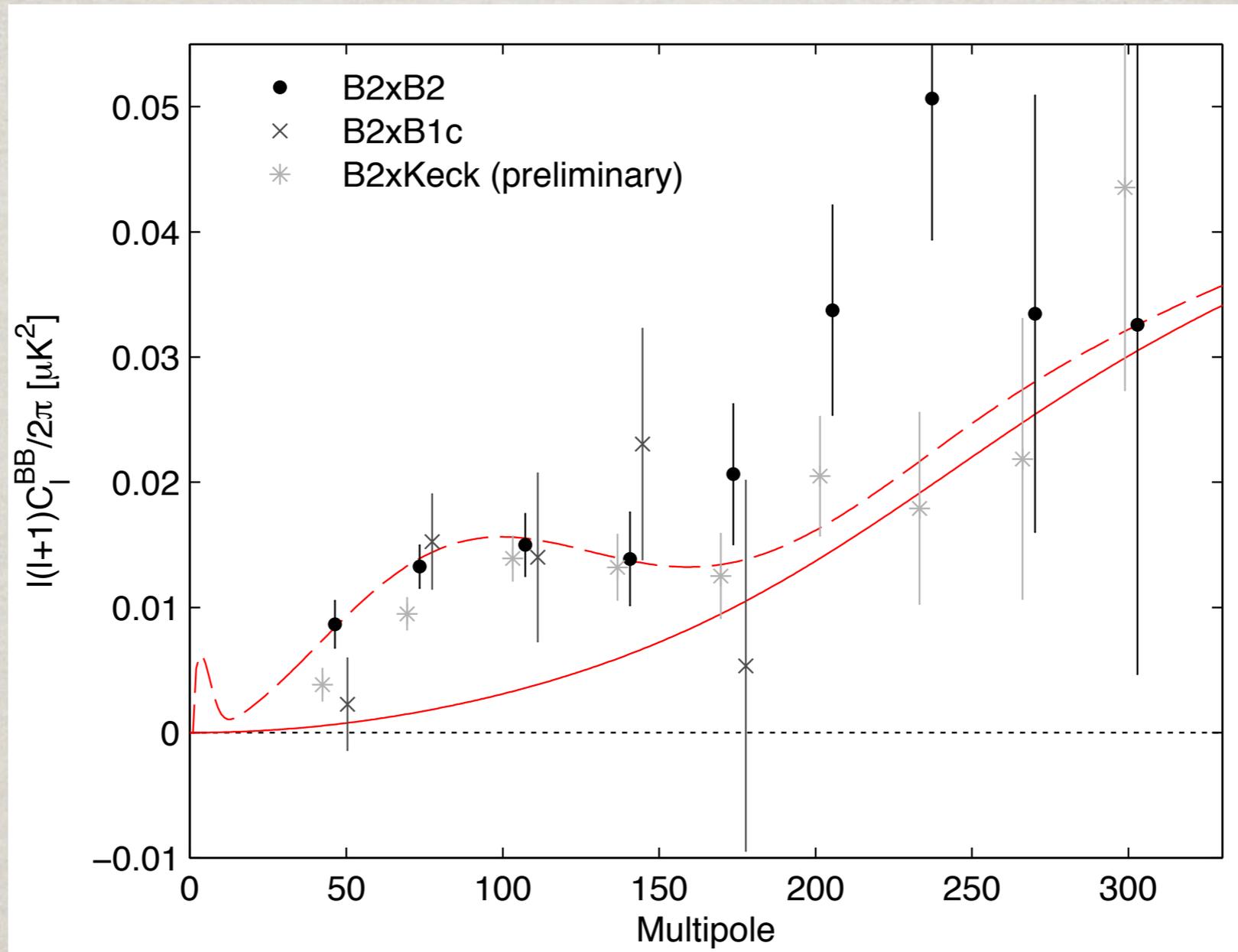


South Pole Telescope: Cross-correlation with infrared background (Herschel) reveals lensing signal

# Primordial B-mode Polarization: First Detection !?



BICEP2: Ade et al. 2014



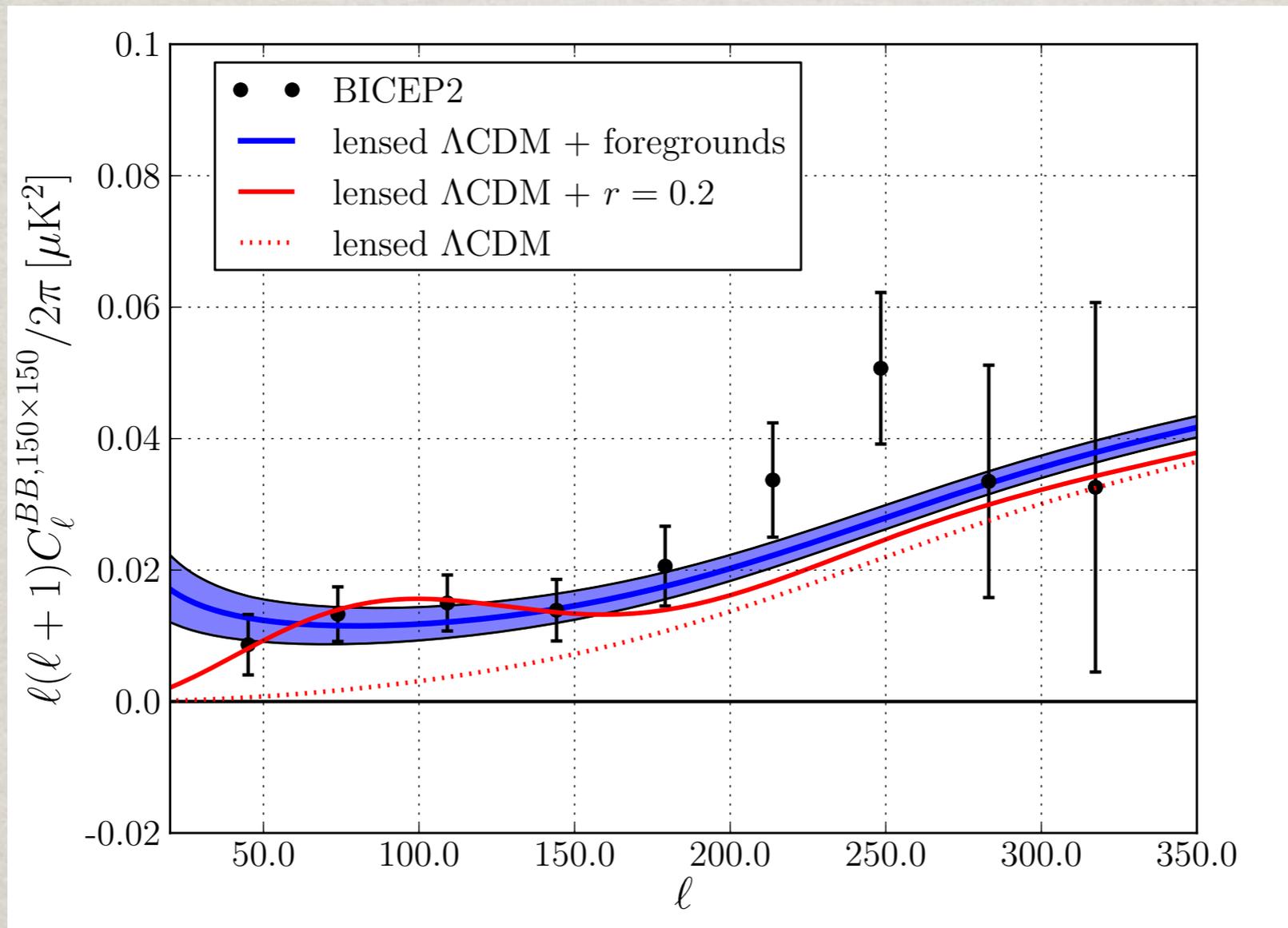
Model: Inflation tensor perturbations plus lensing

# IS THIS SIGNAL COSMOLOGICAL?

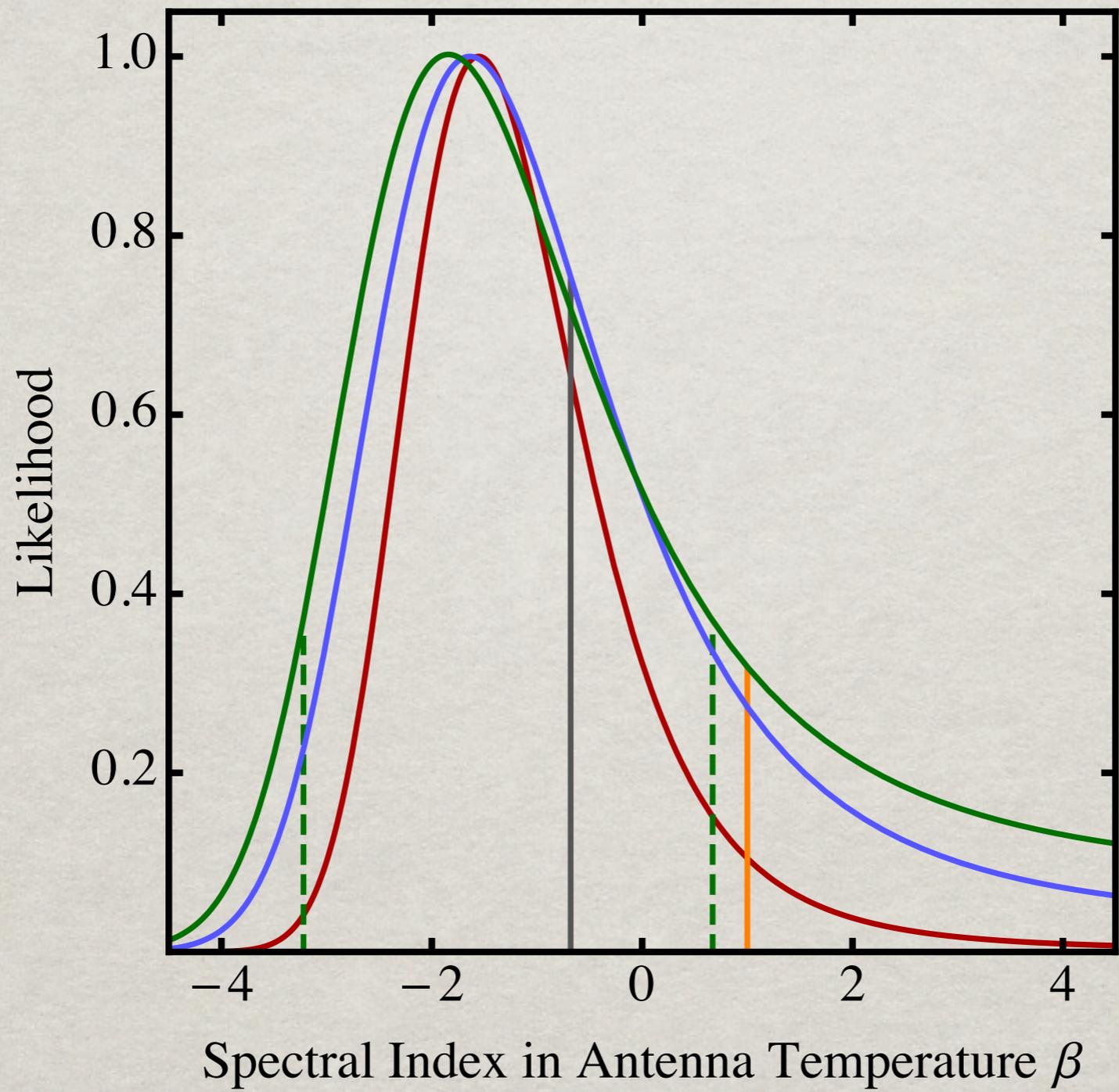
Caveat: BICEP2 measures in **1 frequency band**  
(150 GHz)

Models for galaxy polarization signal (dust, synchrotron),  
**but little published data at this frequency**

Planck: polarization data release scheduled for  
October 2014



Flauger, Hill, and Spergel 2014



# Early-Universe Inflation

Predicts initial **scalar** and **tensor** perturbations with  
**near scale-invariant power spectra**  
over at least **20 orders of magnitude in wavelength**

Scalar spectrum well measured: grows via gravity  
into large-scale structure

Tensor amplitude depends on **inflation energy scale**

$$E \propto r^{1/4}$$

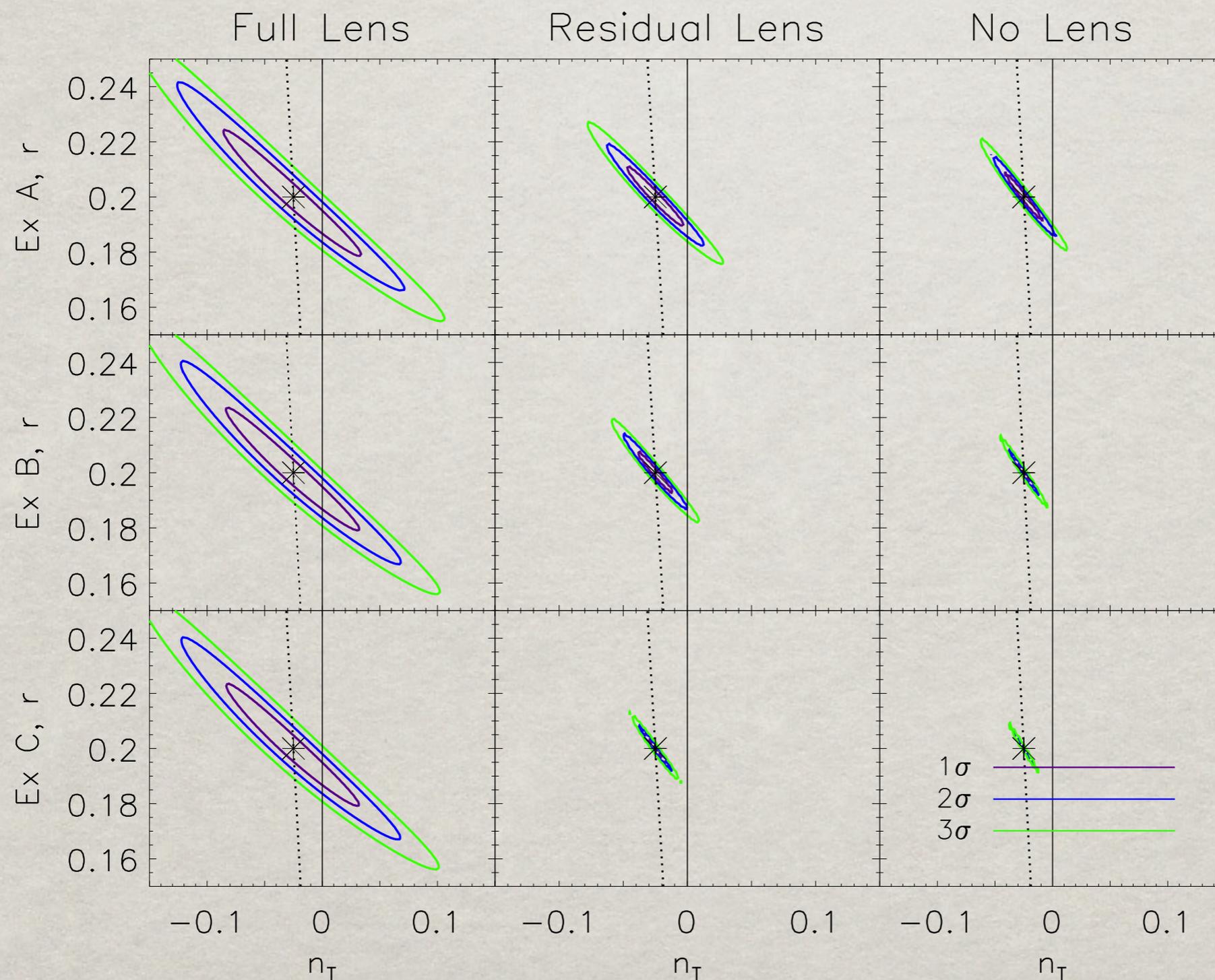
If BICEP2 signal is inflation tensor perturbations:

Inflation energy scale is  $2 \times 10^{16}$  GeV

## IF BICEP2 SIGNAL IS TENSORS:

1. Physics beyond Standard Model!
2. Energy scale around GUT scale!
3. Inflation is how visible universe began!
4. Gravity obeys quantum mechanics!

# Test of Inflation 1: $r = -8 n_T$



Ex C: 0.25  
muK arcmin,  
half sky

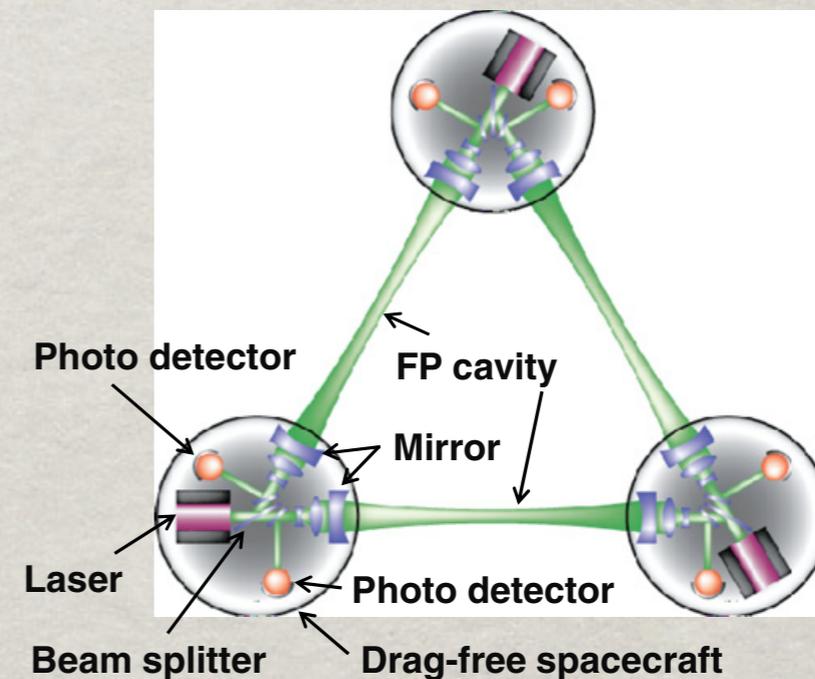
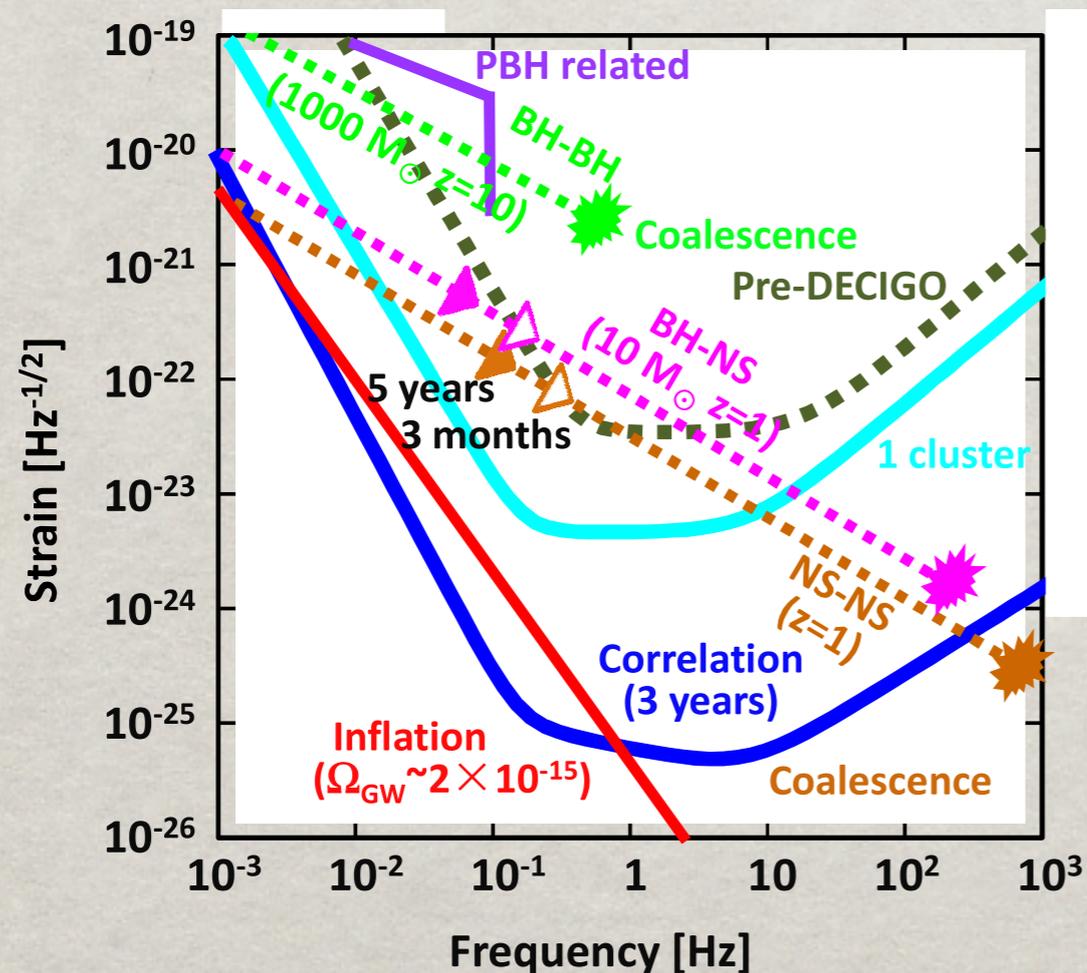
Caligiuri and Kosowsky,  
PRL 2014

# Test of Inflation 2: Tensor direct detection!

Turner PRD 1997; Caligiuri and Kosowsky PRL 2014

At frequency 0.1 Hz, proposed NASA Big Bang Observer detects at 100 sigma

Complication: confusion from white dwarf binary confusion limit



DECIGO:

Kawamura et al. CQG 2011

Will the next high energy physics breakthrough  
be from a space-based laser interferometer?