

Introduction to BICEP2 B modes results

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IN2P3-CNRS et Université de Paris-Sud 11

Rencontres de Moriond 2014 - Electroweak session

Outline

This short presentation was prepared on the spot to introduce to the audience the recent results from Bicep2, which were made public 2 days ago and in which the author has had no part (and hence should not get credit from!), and their context.

- CMB polarization
- why is it hard to measure
- The hunt for B modes
- Bicep2 & Keck array basics
- Results + some comments
- what about Planck 2013?

CMB polarization anisotropies

- CMB is (weakly) polarized
- polarization = vector field \Rightarrow use Stockes parameters Q and U
- decompose $Q + iU$ in the (spinned) spherical harmonics basis

$$Q + iU = \sum_{\ell m} \pm 2 a_{\ell m} \pm 2 Y_{\ell m}(\theta, \phi)$$

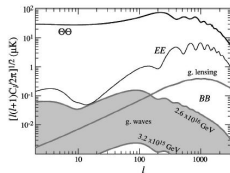
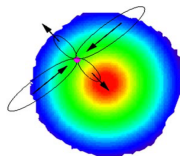
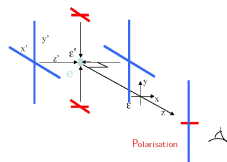
- transform into parity even (E) and odd (B) components :

$$\pm 2 a_{\ell m} = a_{\ell m}^E \pm i a_{\ell m}^B$$

- As for temperature, all information contained in variances C_{ℓ}^{XY} ($X, Y = T, E, B$)
- in general 6 power spectra but symetries $\Rightarrow C_{\ell}^{TB} = C_{\ell}^{EB} = 0$

CMB polarization

- Mechanism : temperature quadrupolar anisotropies + Thomson scattering on e
- Origins :
 - ▶ primordial tensor modes (GW) → B modes
 - ▶ plasma dynamics (correlation with temp. anisotropies) → E modes
 - ▶ late time re-ionisation ($z \sim 10$) → E modes (low ℓ)
 - ▶ gravitational lensing transforms (part of) E into B modes
- very low amplitude signals ($\sim 10^{-2} - 10^{-4}$ temperature)
- amplitude of primordial B modes power spectrum measures $r = A_t/A_s$ (\propto inflation energy scale)



B modes hunt

- ground-based :
 - ▶ South pole : SPTpol, Bicep1/2/3, QUBIC (Fr/It)
 - ▶ Atacama altiplano : ACTpol, ABS, Polarbear, Groundbird (Jap.)
- balloon-borne (at various stages)
 - ▶ EBEX
 - ▶ SPIDER
 - ▶ Piper
- (future) space projects : Core/Prism (ESA), Litebird (Jap.), Pixie (NASA)

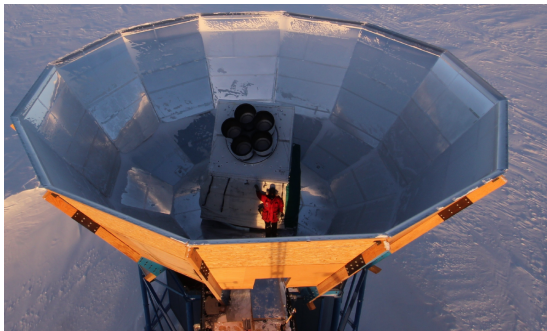
Measuring polarization

- ideal detector measuring only one polarization direction measures at orientation ψ :

$$m = I + Q \cos 2\psi + U \sin 2\psi$$

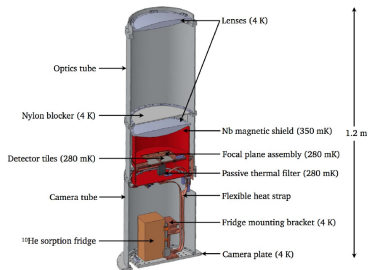
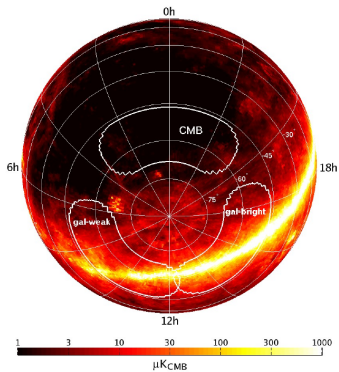
- to extract I,Q,U measurements one needs to combine several measurements of several detectors with different orientations
- arrangement by orthogonal pairs helps
- examples
 - ▶ Planck (1992-2014) : O(10) detectors in pairs with \sim orthogonal polarisation sensitivities + scan strategy to change orientation
 - ▶ Bicep : phase 1 (2007-2008) O(100) det. (Planck-like); phase 2 (2010-2012) O(500) det. ; phase 3 (Keck array, 2011-2016) O(2500) detectors in pairs, rotate all focal plane
 - ▶ SPTpol O(780x2) detectors , 90 and 150 GHz (lensing B modes first detection - 2013-)
 - ▶ Polarbear O(1200) detectors + half wave plate to modulate polarization (B modes from lensing, 2013-) version 2 with 2 freq. and O(7000) detectors in dev.
- avoid I to Q,U leakages due to systematics : gains, pointing, beam uncertainties
- main systematics for Bicep2 : pointing/beams

Bicep3/Keck array

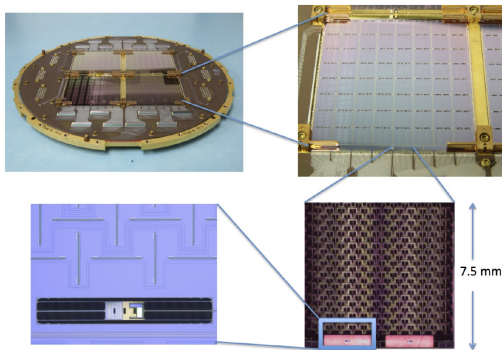


refractor optics (lenses)- observation at 150 GHz

Observations and instruments

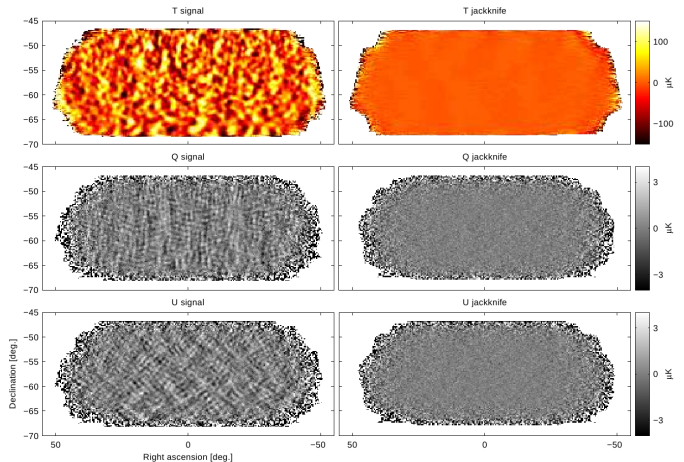


Detectors

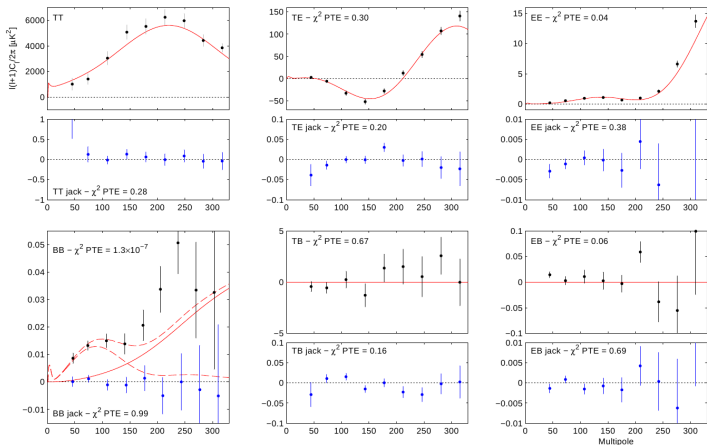


256x2 TES read-out by multiplexing SQUIDs (~ 300 mK)

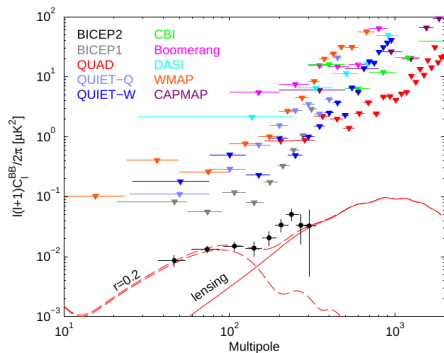
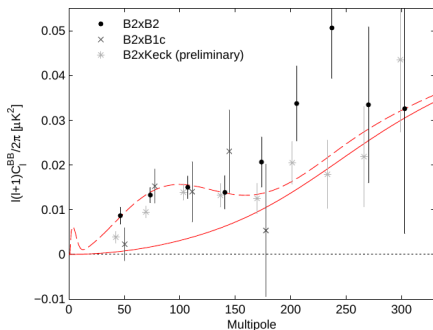
Sky maps



Power spectra



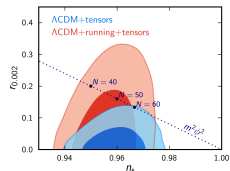
Power spectra (contd)



Summary + open questions

- something is here in BB at low ℓ
- big improvement wrt previous results!
- but foreground handling with model(s) (one freq. only observed) fixed amplitude - is this enough? (best model decrease r by .04)
- “moderately strong” tension with TT constraints (e.g. Planck 2013) $r < .11(95\%c.l.)$
- B modes add power in TT at low ℓ where WMAP/Planck see a deficit ... look for extensions (e.g. running n_s)??
- great, but not the final word on r maybe?

Planck 2013



Bicep2 2014

