The 1st Conference of Polish Society on Relativity

29 June – 4 July 2014, Spała, Poland

Primordial gravitational waves at gates of a new era

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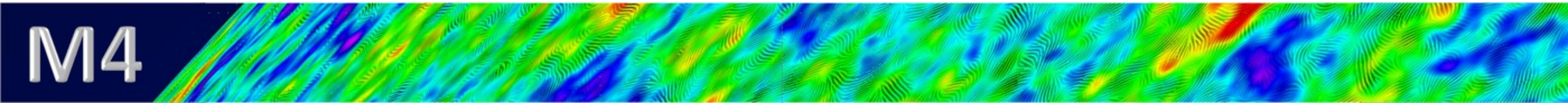

March 2014 – BICEP2 team announced the detection of polarization B modes in CMBR

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NATURE | NEWS

Gravitational-wave finding causes 'spri in physics

Big Bang findings would strengthen case for multiverse and all but Universe'.

Ron Cowen

21 March 2014

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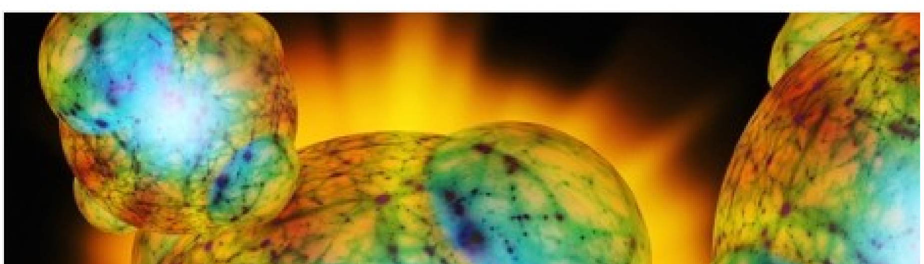

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Gravitational waves discovery: 'We have a first tantalising glimpse of the cosmic birth pangs'

Ian Sample explains the importance of the discovery of primordial gravitational waves, dating back to the big bang, while eminent physicists and astronomers react to the news

Ian Sample

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The Observer, Saturday 22 March 2014 22.27 GMT

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March 2014 – BICEP2 team announced the detection of polarization B modes in CMBR

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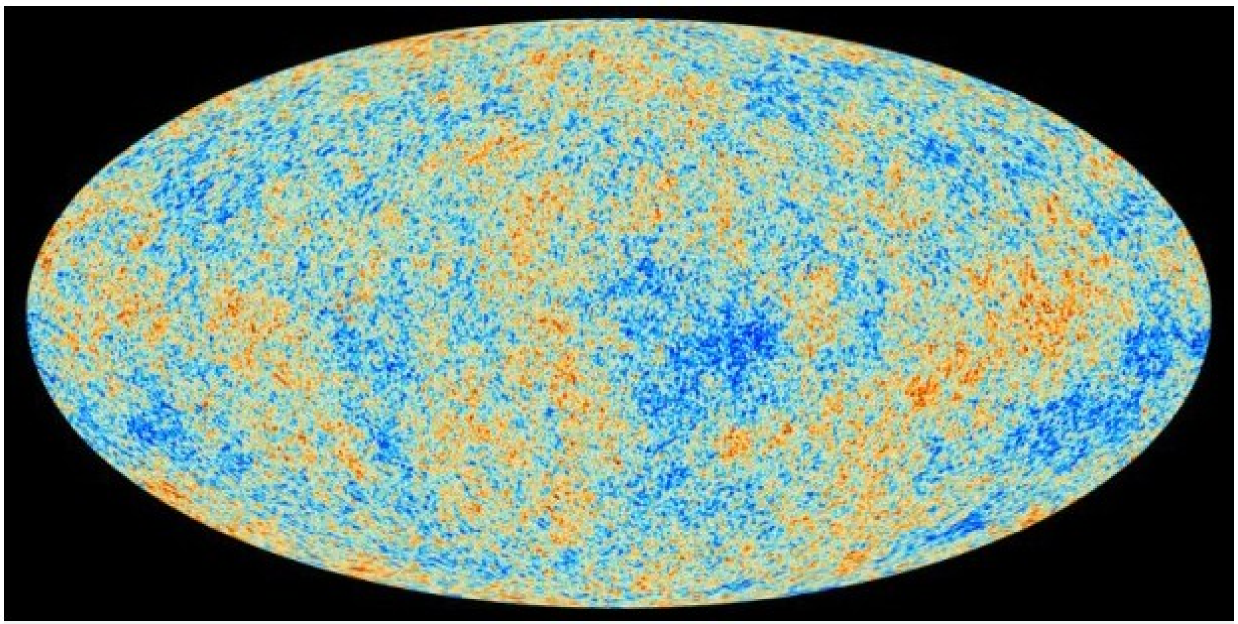
Odkryto fale grawitacyjne - ostatni brakujący element teorii względności Einsteina

Piotr Stanisławski 17.03.2014 17:29

A A A



Zdjęcie przedstawia promieniowanie tła obserwowane przez teleskop Planka (Fot. Nature News)

Po bozonie Higgsa odkryliśmy kolejny element, który dopełnia naszą wiedzę o

Najczęściej czytane

1. 7 najdziwniejszych prototypów pojazdów wojskowych
2. W ciągu 50 sekund przestraszysz się, zdziwisz i nauczysz trochę
3. 6 przykładów najczęstszych oszustw na Facebooku i garść
4. Stephen Hawking: Sztuczna inteligencja może być największym
5. Obrazek dnia: zbliża się wypożyczanie filmów na polskim

Inflation

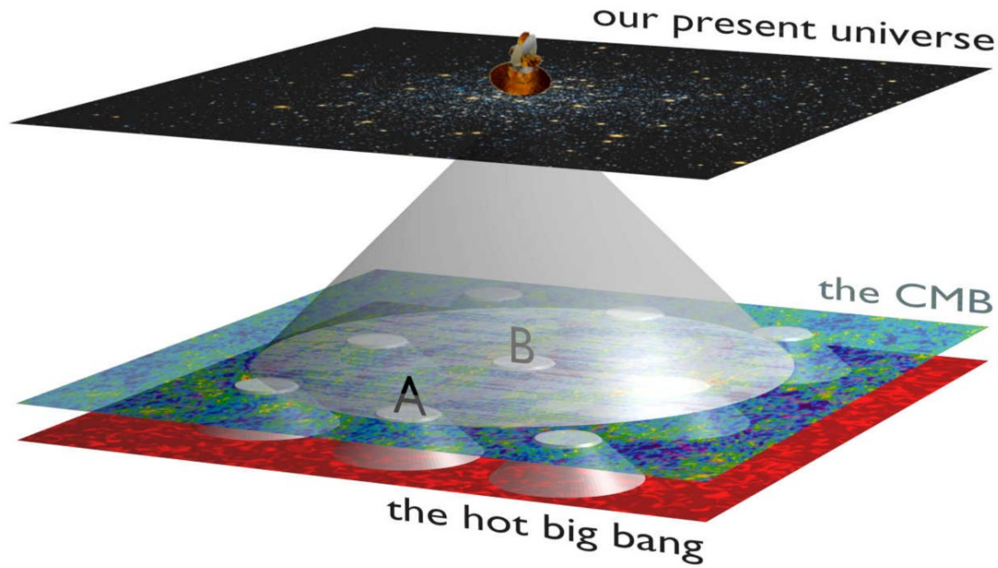
not only solves old conceptual problems of Big Bang

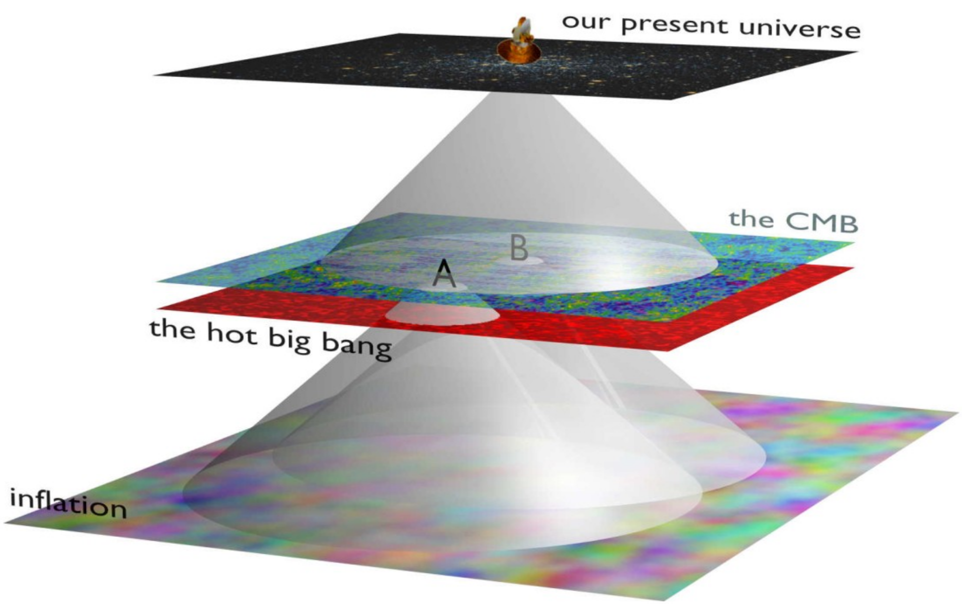
* horizon

* flatness

* monopole

it makes predictions !





Ammount of inflation necessary for solving *horizon problem* is sufficient for solving *flatness* and *monopole* problems too

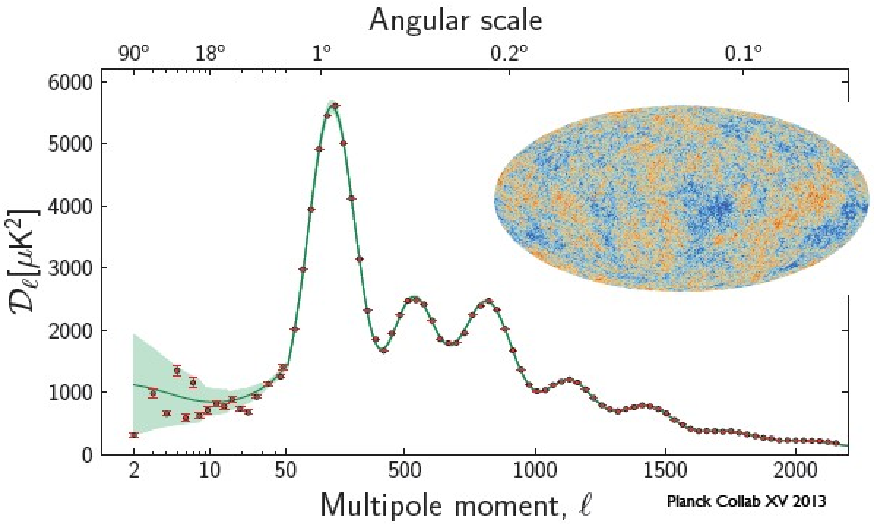
Credits: Yi Wang https://inspirehep.net/record/1222779/plots

Inflation

not only solves old conceptual problems but
makes predictions !

Most of them confirmed !

Planck

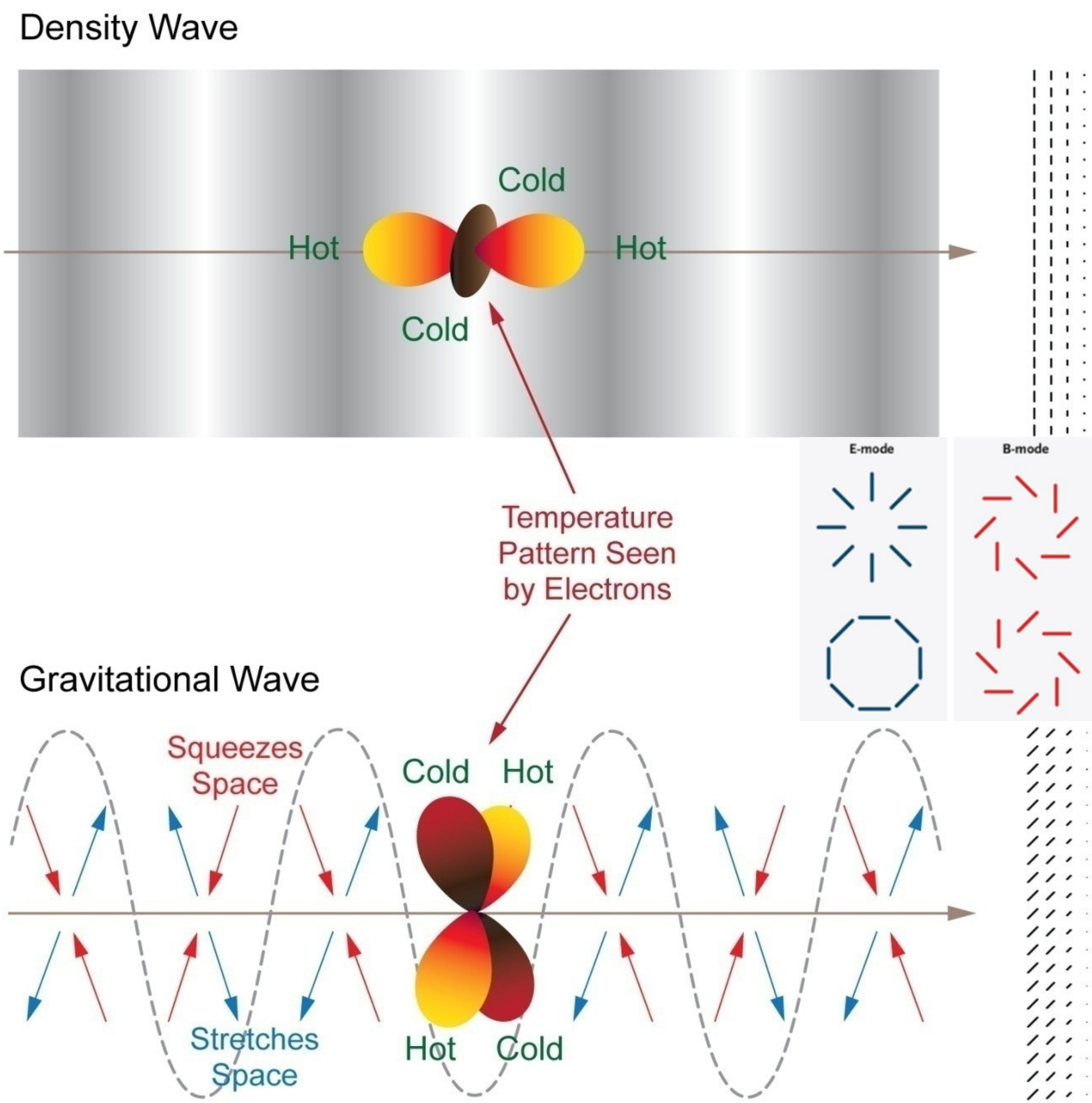


Primordial fluctuations

•**adiabatic** – can sustain acoustic oscillations (acoustic peaks predicted)
•**nearly Gaussian** – as a result of amplification of initial Gaussian quantum fluctuations (some small degree of non-Gaussianity expected due to physical processes)
•**nearly scale invariant** – should deviate slightly from the Harrison-Zeldovich $n_s = 1$
– should be lower (Planck 2013 $n_s = 0.9690 \pm 0.0089$)
•CMBR anisotropies should be not only due to density perturbations but also due to **primordial gravitational waves**

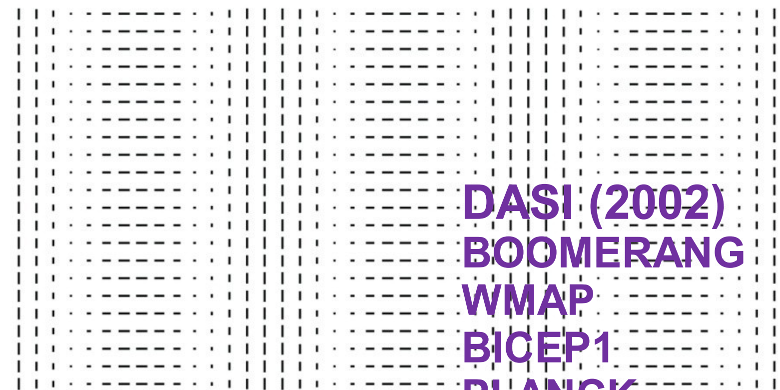
The last prediction – revealed by BICEP2

Quadrupole anisotropy in radiation field is necessary to produce net **polarization** via Thomson scattering



peak at 0.2^0
$l = 1000$

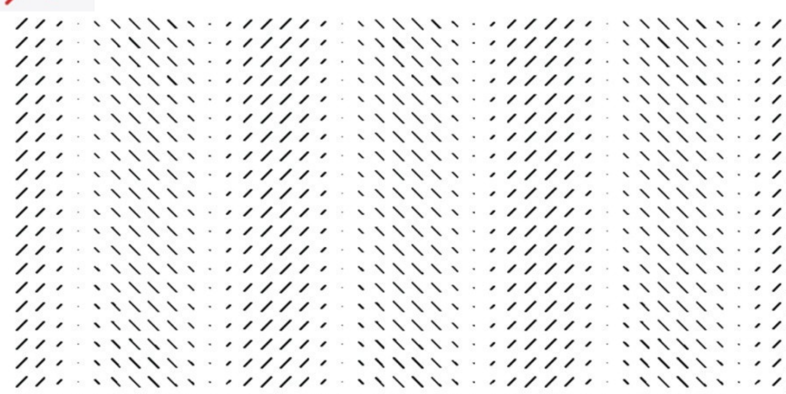
E-Mode Polarization Pattern



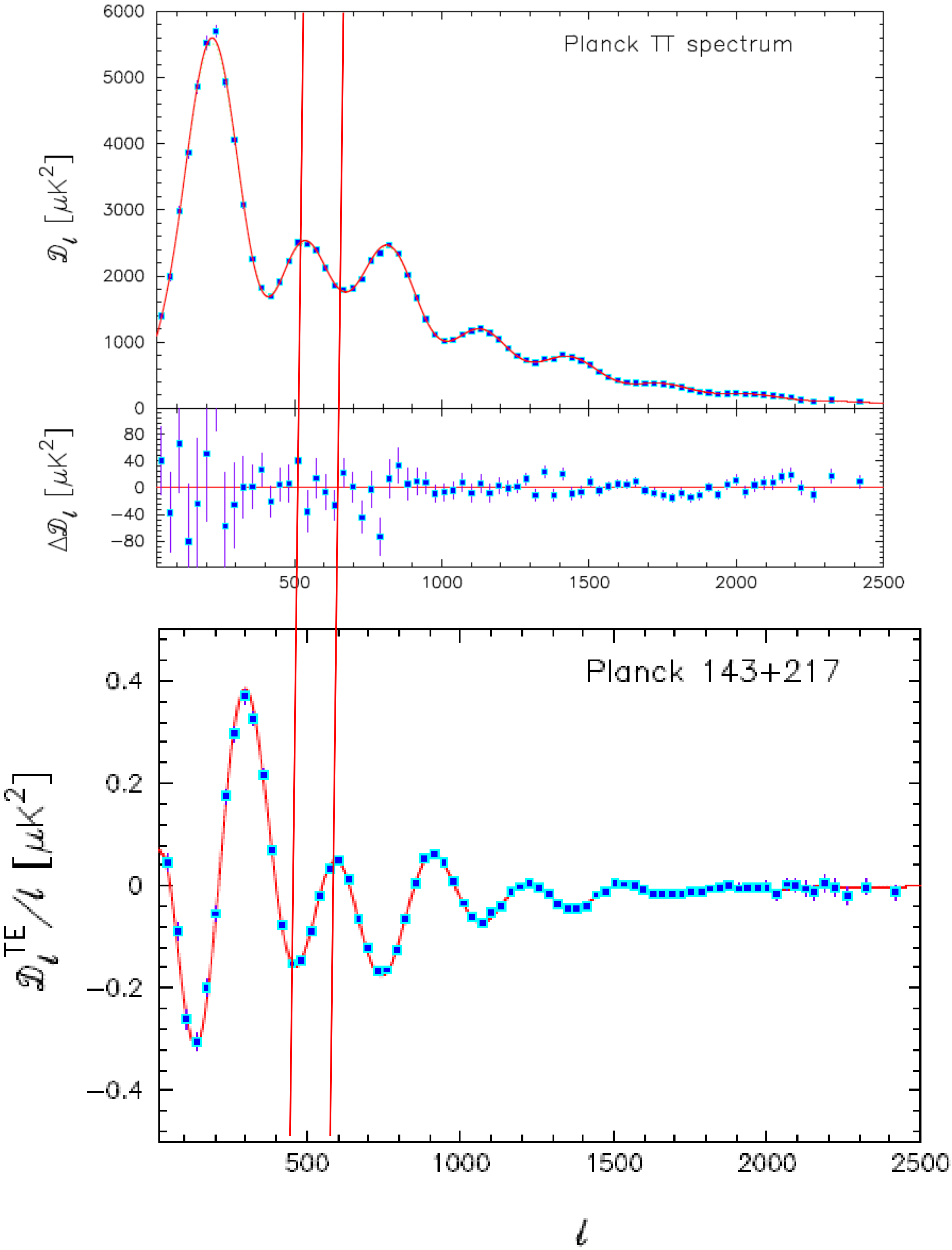
DASI (2002)
BOOMERANG
WMAP
BICEP1
PLANCK

peaks at
$l = 80$
$l < 10$

B-Mode Polarization Pattern



http://bicepkeck.org/

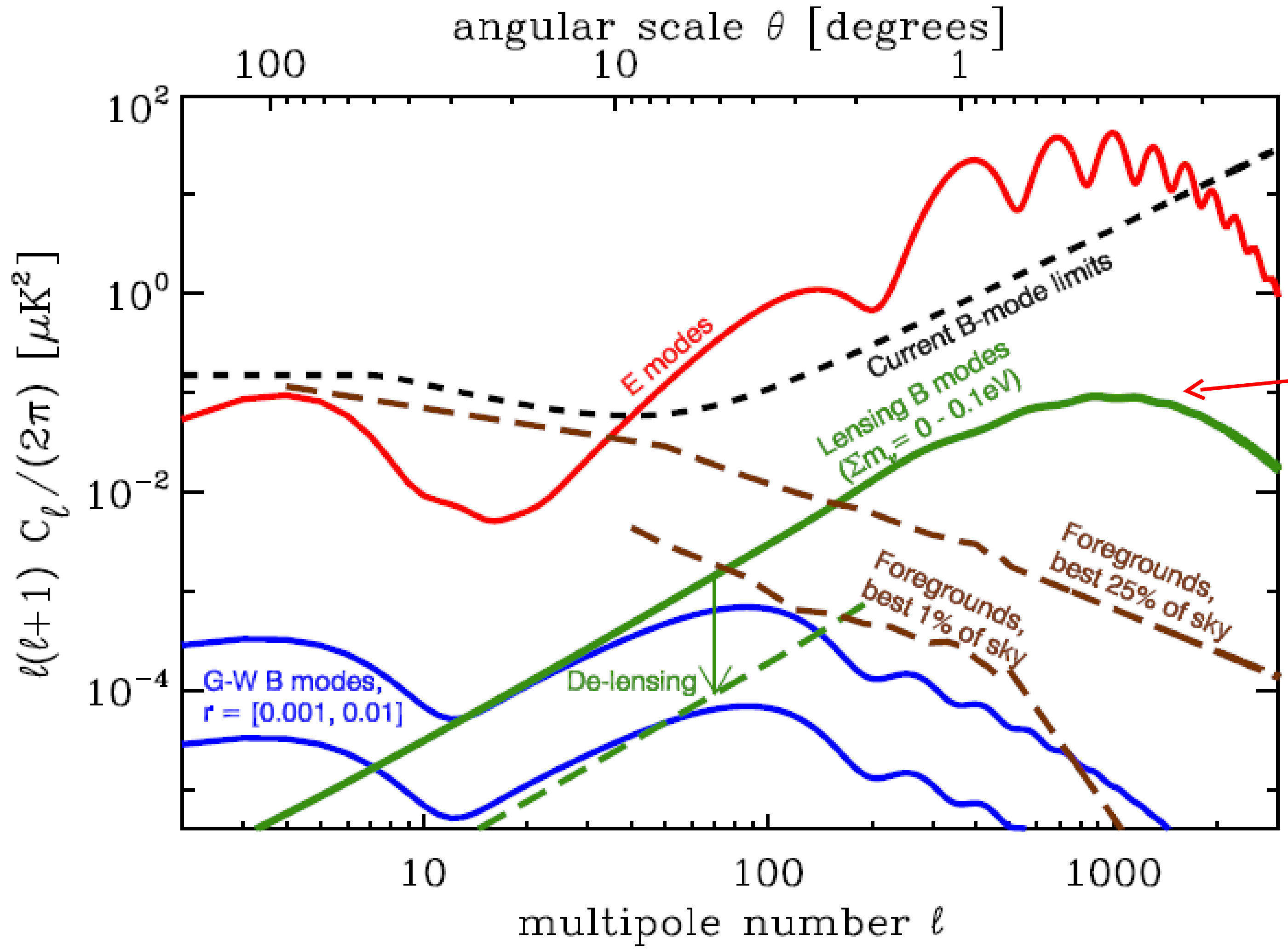


This curve needs 2 parameters to be fitted (A_s, n_s)

(anti) correlation predicted by
Coulson, Crittenden and Turok, PRL 73, 2390, 1994

With (A_s, n_s) fitted above this curve is an absolute prediction !

CMBR polarization



Seen by SPT 2013

BICEP 2

http://bicepkeck.org/

Selected for a Viewpoint in *Physics*
PRL **112,** 241101 (2014) PHYSICAL REVIEW LETTERS week ending 20 JUNE 2014

Detection of *B*-Mode Polarization at Degree Angular Scales by BICEP2

P. A. R. Ade,[1] R. W. Aikin,[2] D. Barkats,[3] S. J. Benton,[4] C. A. Bischoff,[5] J. J. Bock,[2,6] J. A. Brevik,[2] I. Buder,[5] E. Bullock,[7] C. D. Dowell,[6] L. Duband,[8] J. P. Filippini,[2] S. Fliescher,[9] S. R. Golwala,[2] M. Halpern,[10] M. Hasselfield,[10] S. R. Hildebrandt,[2,6] G. C. Hilton,[11] V. V. Hristov,[2] K. D. Irwin,[12,13,11] K. S. Karkare,[5] J. P. Kaufman,[14] B. G. Keating,[14] S. A. Kernasovskiy,[12] J. M. Kovac,[5,*] C. L. Kuo,[12,13] E. M. Leitch,[15] M. Lueker,[2] P. Mason,[2] C. B. Netterfield,[4,16] H. T. Nguyen,[6] R. O'Brient,[6] R. W. Ogburn IV,[12,13] A. Orlando,[14] C. Pryke,[9,7,†] C. D. Reintsema,[11] S. Richter,[5] R. Schwarz,[9] C. D. Sheehy,[9,15] Z. K. Staniszewski,[2,6] R. V. Sudiwala,[1] G. P. Teply,[2] J. E. Tolan,[12] A. D. Turner,[6] A. G. Vieregg,[5,15] C. L. Wong,[5] and K. W. Yoon[12,13]

(BICEP2 Collaboration)

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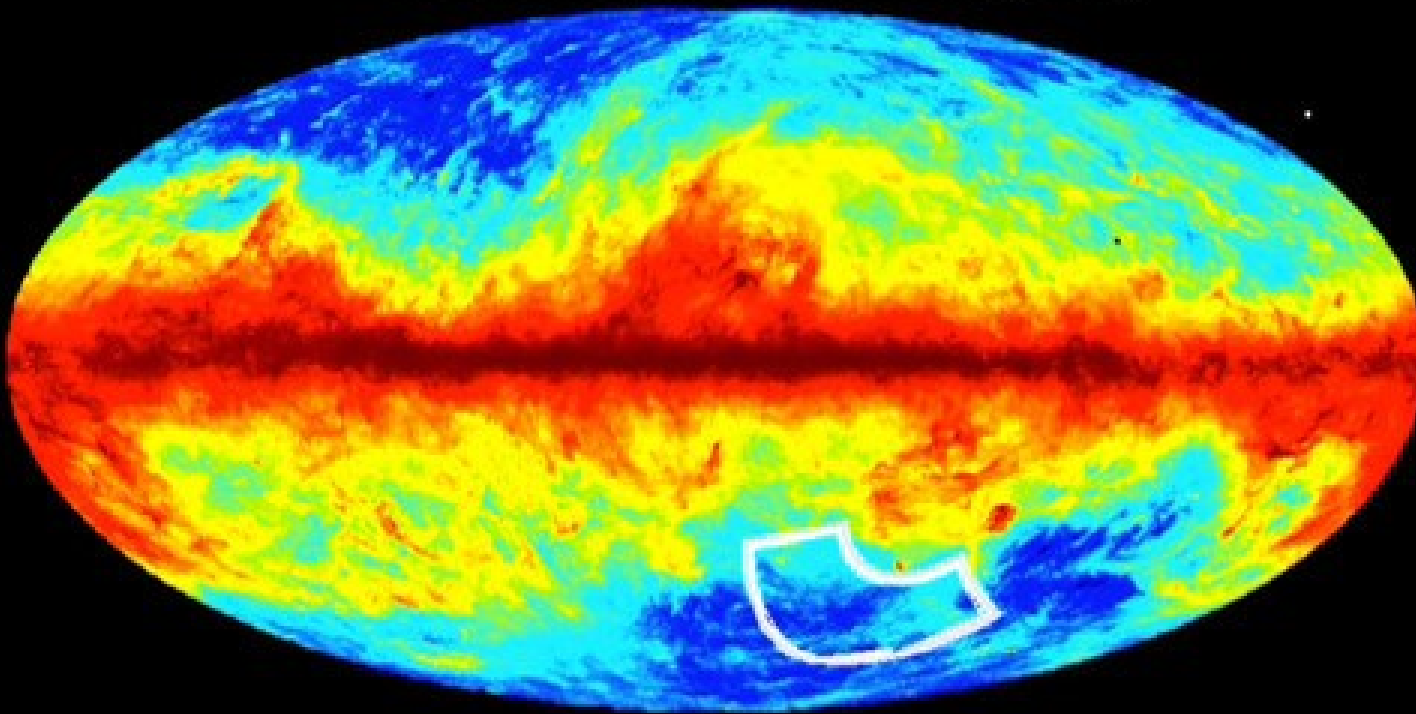
[6]*Jet Propulsion Laboratory, Pasadena, California 91109, USA*
[7]*Minnesota Institute for Astrophysics, University of Minnesota, Minneapolis, Minnesota 55455, USA*
[8]*Service des Basses Températures, Commissariat à l'Energie Atomique, 38054 Grenoble, France*

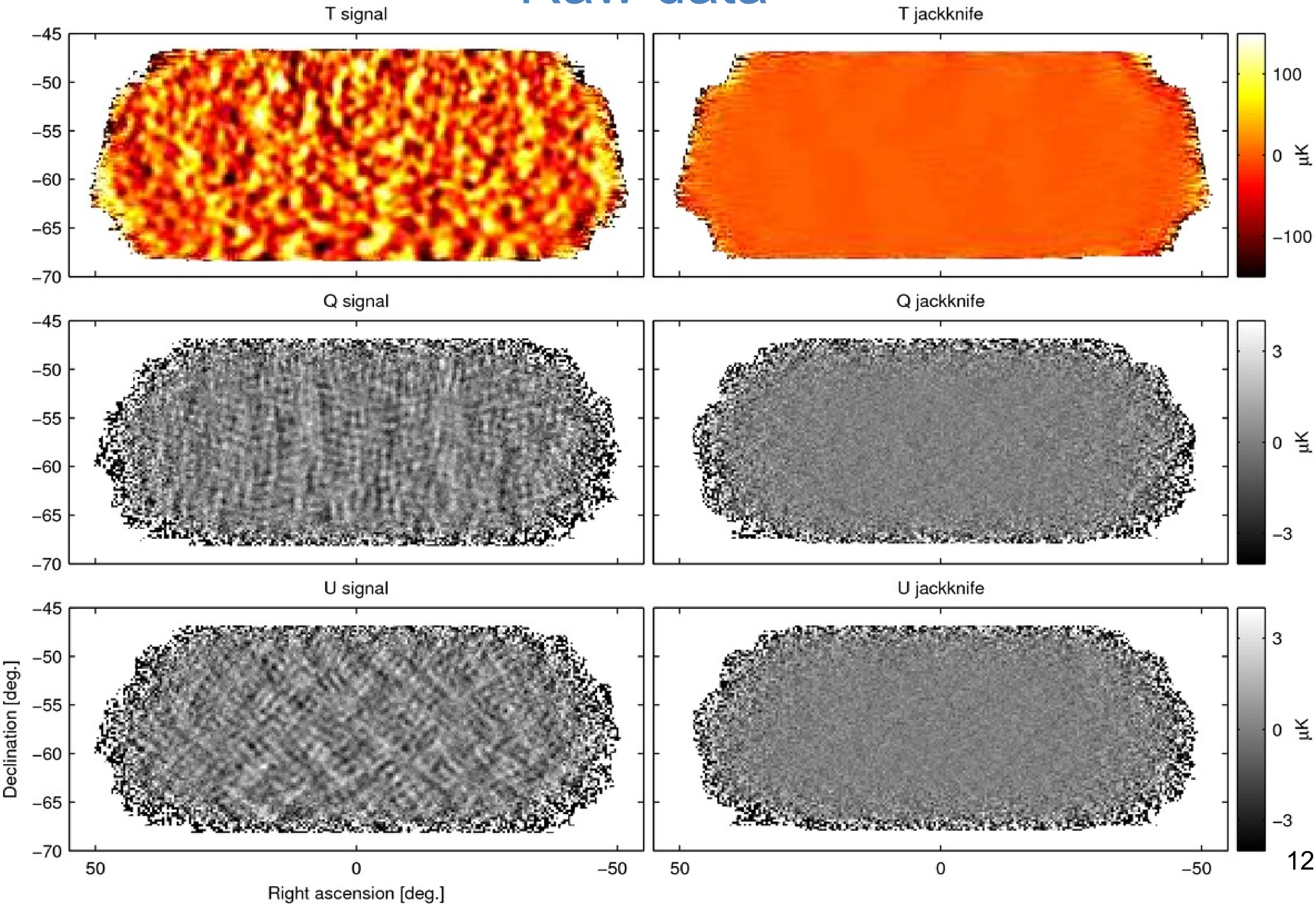
BICEP2 Experimental Strategy

- Observe the "Southern Hole" at 150 GHz
- a region of the sky exceptionally free of dust and radio emission from our galaxy



Raw data

http://bicepkeck.org/



Polarization signal on maps

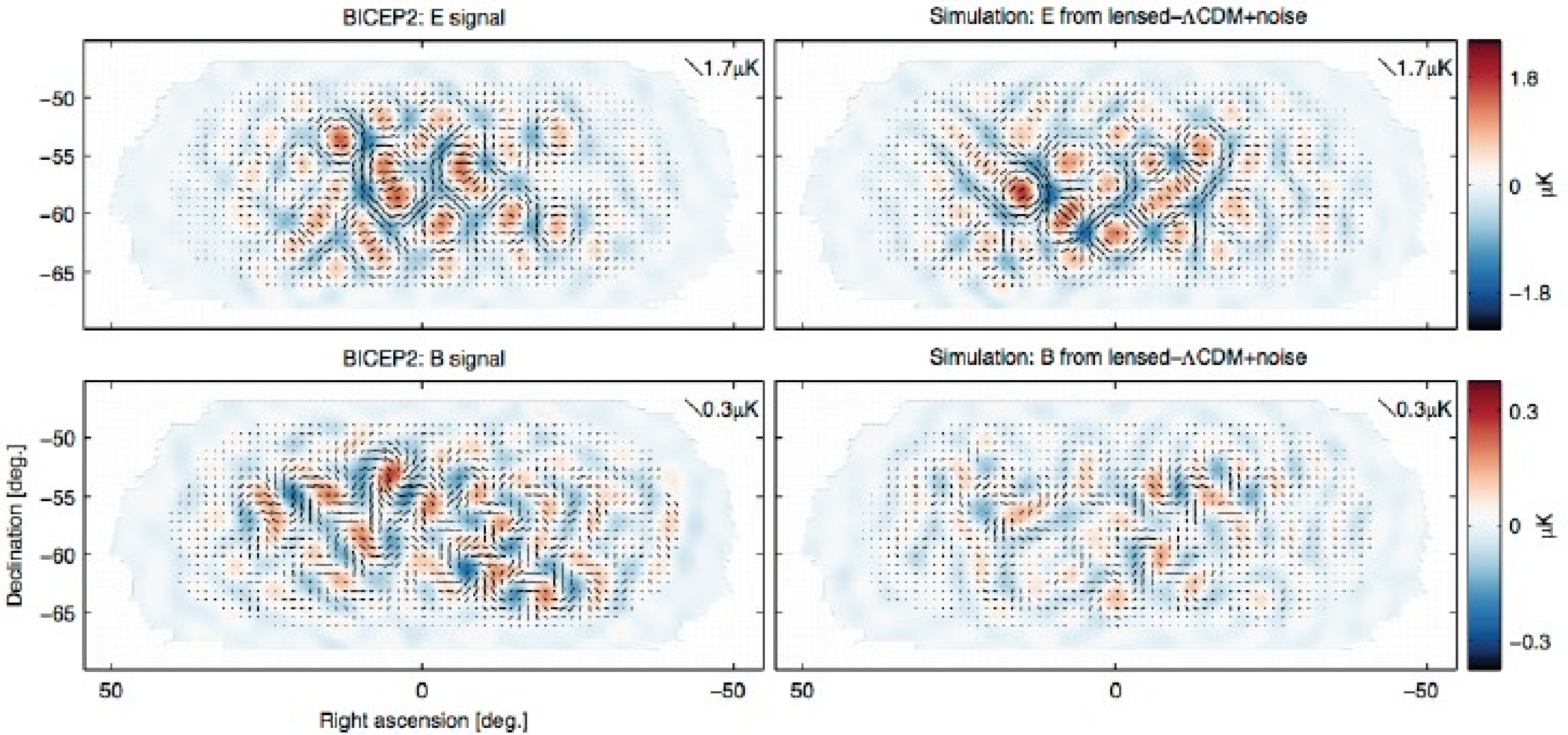
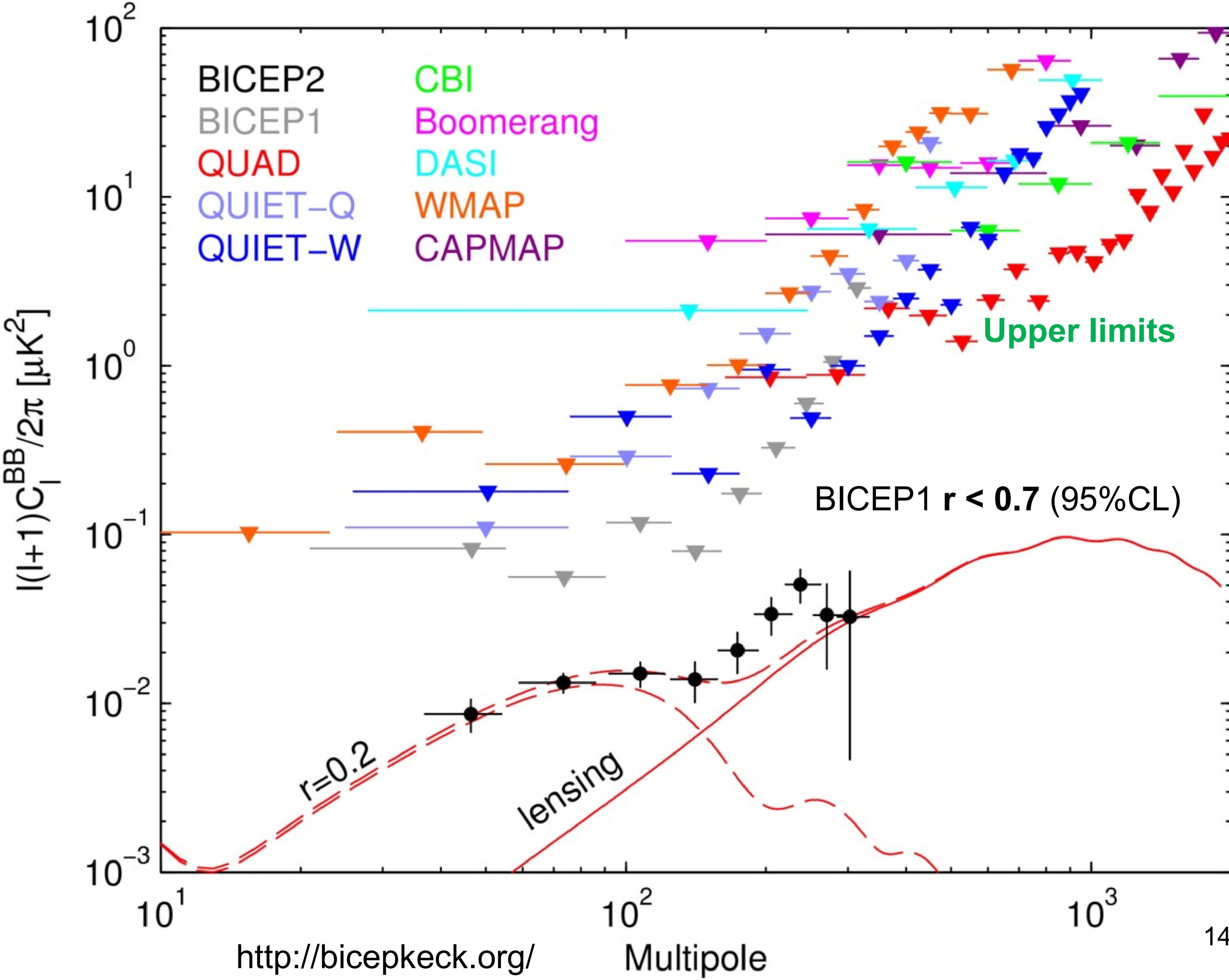


FIG. 3.— *Left:* BICEP2 apodized E-mode and B-mode maps filtered to $50 < \ell < 120$. *Right:* The equivalent maps for the first of the lensed-ΛCDM+noise simulations. The color scale displays the E-mode scalar and B-mode pseudoscalar patterns while the lines display the equivalent magnitude and orientation of linear polarization. Note that excess B-mode is detected over lensing+noise with high signal-to-noise ratio in the map ($s/n > 2$ per map mode at $\ell \approx 70$). (Also note that the E-mode and B-mode maps use different color/length scales.)

http://bicepkeck.org/



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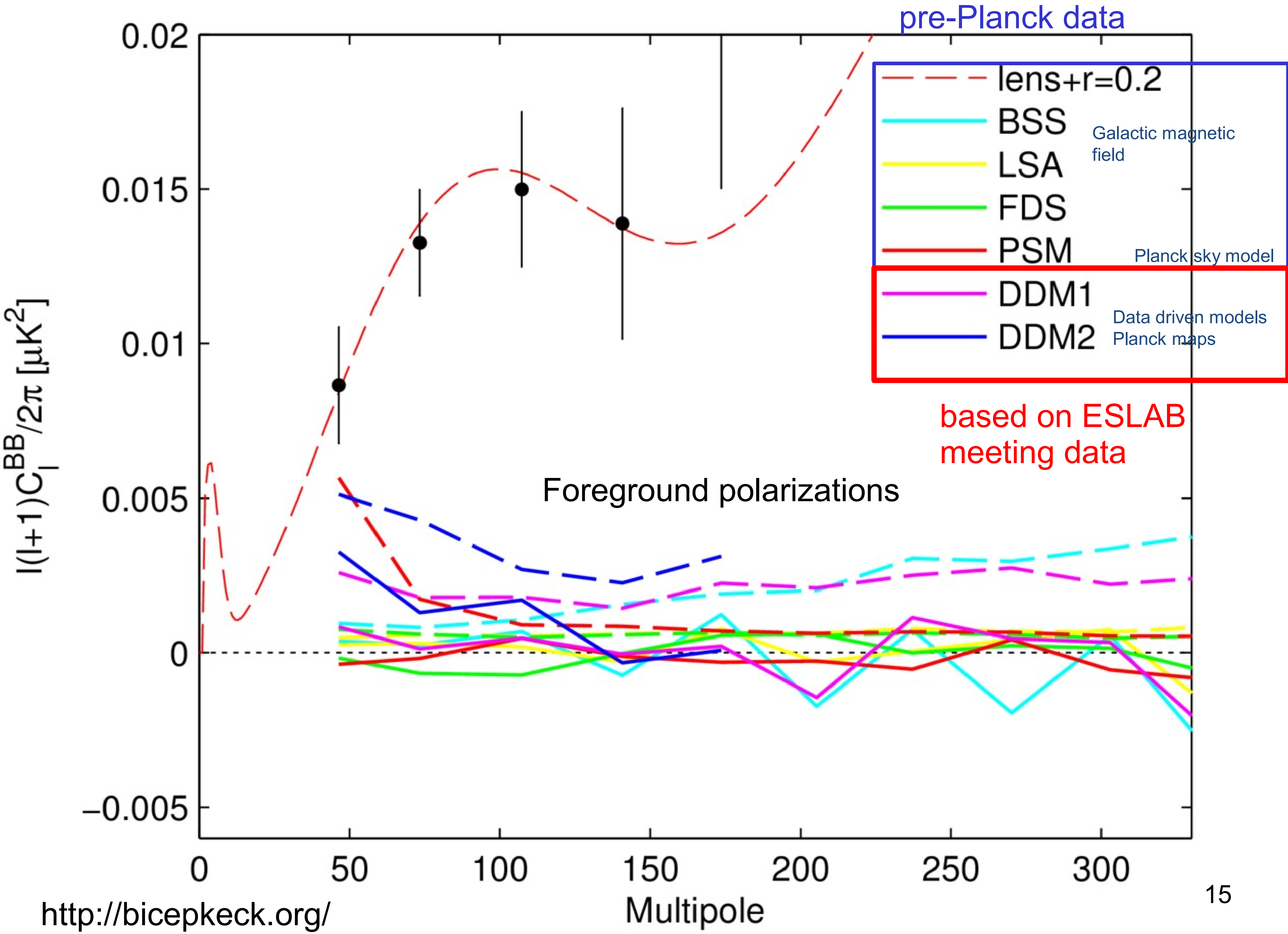

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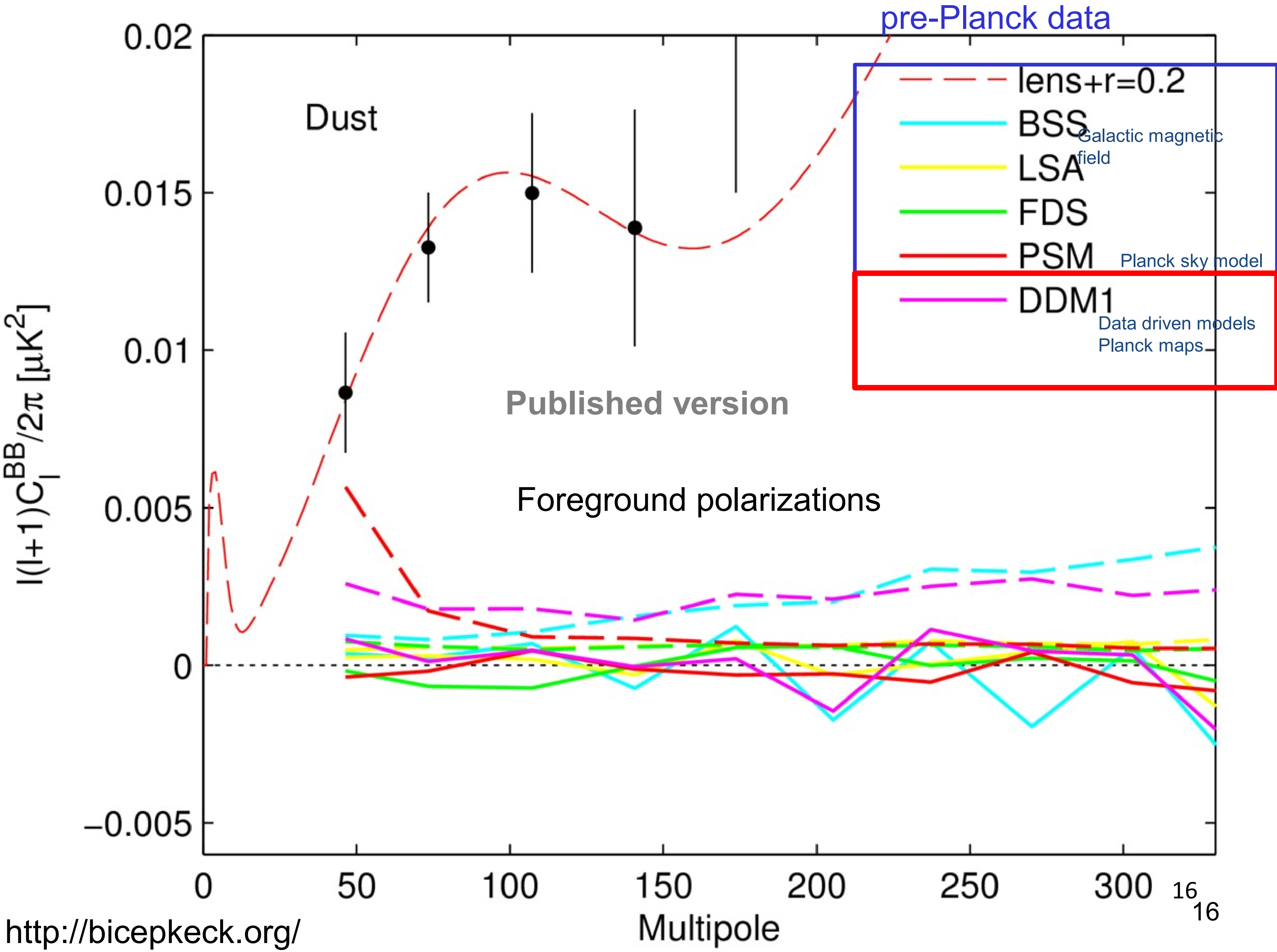

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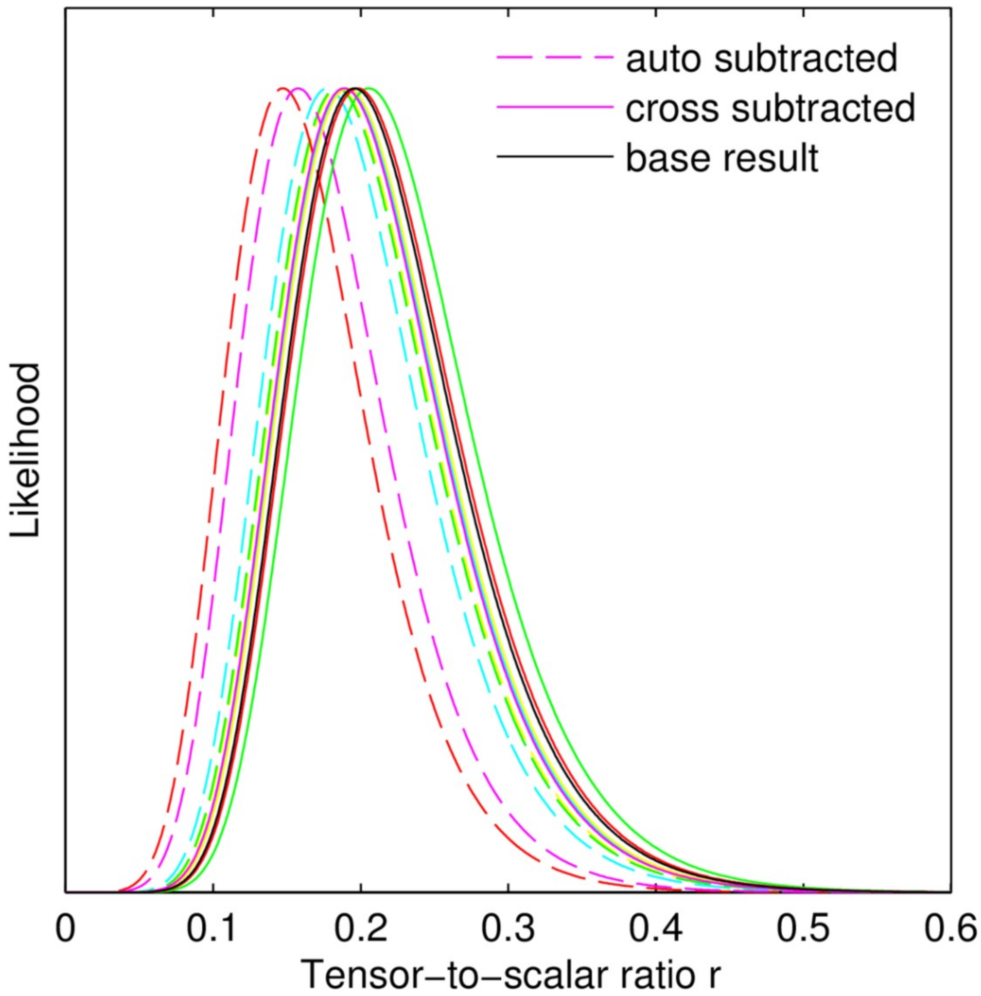
16

Tensor/Scalar ratio r



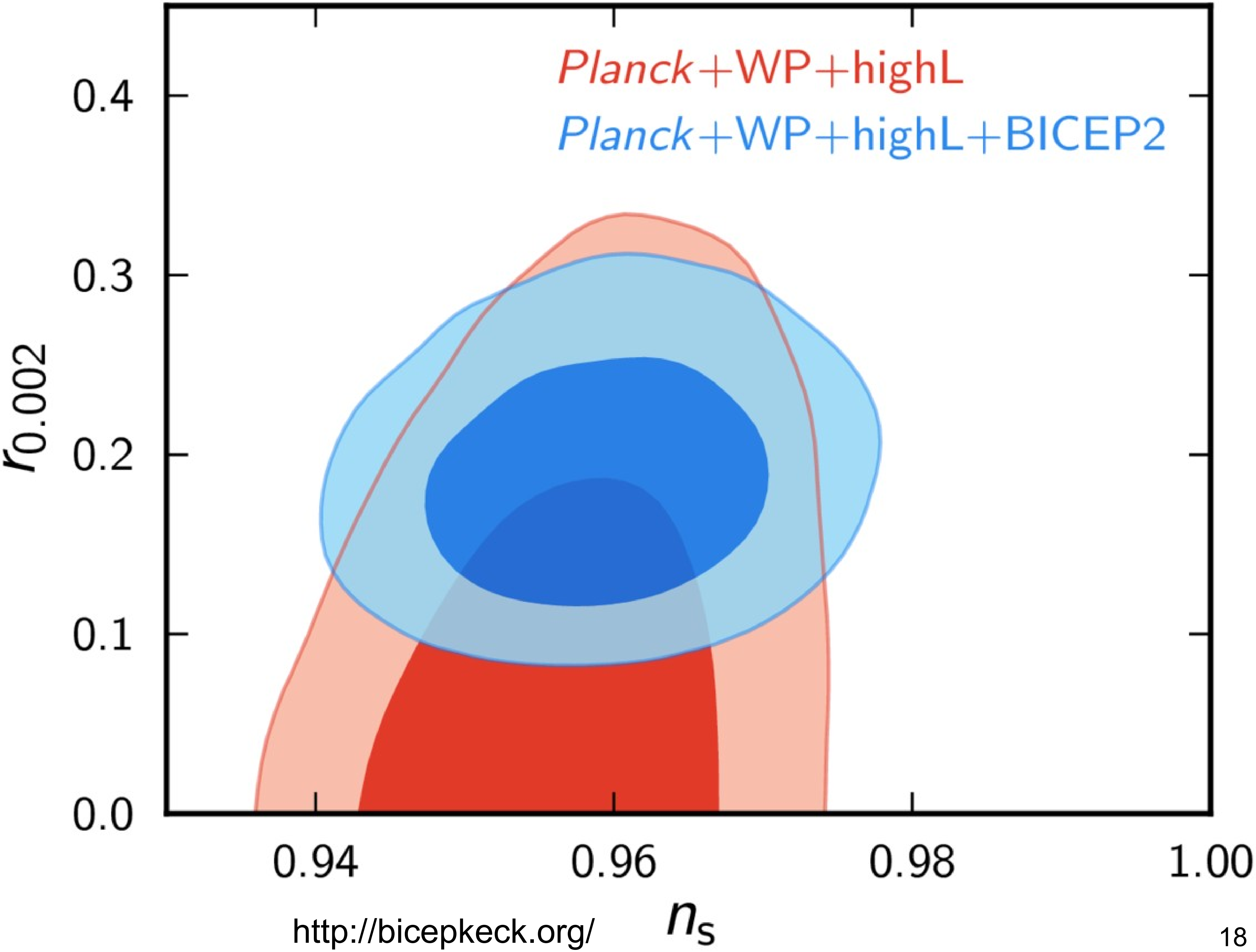
base result

$$r = 0.20^{+0.07}_{-0.05}$$

with subtracted backgrounds

r in
(0.15, 0.19) autocorr.
(0.19, 0.21) crosscorr.

http://bicepkeck.org/



http://bicepkeck.org/

Why is it so important?

$$\epsilon_1 \simeq \frac{1}{2M_{\rm Pl}^2}\left(\frac{V_\phi}{V}\right)^2$$

$$\epsilon_2 \simeq \frac{2}{M_{\rm Pl}^2}\left[\left(\frac{V_\phi}{V}\right)^2 - \frac{V_{\phi\phi}}{V}\right]$$

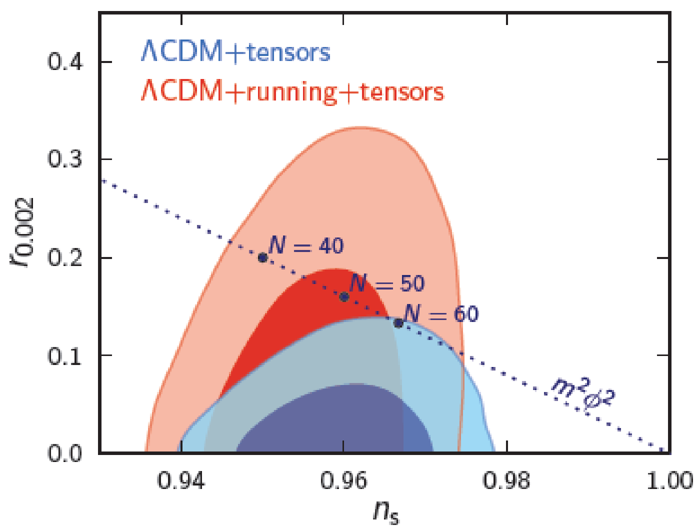
slow roll parameters

$$r = \frac{T}{S} \equiv \frac{\mathcal{P}_h}{\mathcal{P}_\zeta} = 16\epsilon_1 = -8n_{\rm T}$$

$$n_{\rm S} - 1 \equiv \frac{{\rm d}\ln\mathcal{P}_\zeta}{{\rm d}\ln k}, \quad n_{\rm T} \equiv \frac{{\rm d}\ln\mathcal{P}_h}{{\rm d}\ln k}$$

$$n_{\rm S} - 1 = -2\epsilon_1 - \epsilon_2, \quad n_{\rm T} = -2\epsilon_1$$

(n_s , r) plane allows to test inflationary potentials !



from Planck XVI

$$\mathcal{P}_h \simeq \left(\frac{H}{m_{\rm Pl}}\right)^2 \simeq 0.2\left(\frac{\delta T}{T}\right)^2 \simeq 0.2\times 10^{-10}$$

$$H \simeq 1.23\left(\frac{r}{0.2}\right)^{1/2} 10^{14}{\rm GeV}$$

$$\rho^{1/4} \simeq 2.26\left(\frac{r}{0.2}\right)^{1/4} 10^{16}{\rm GeV}$$

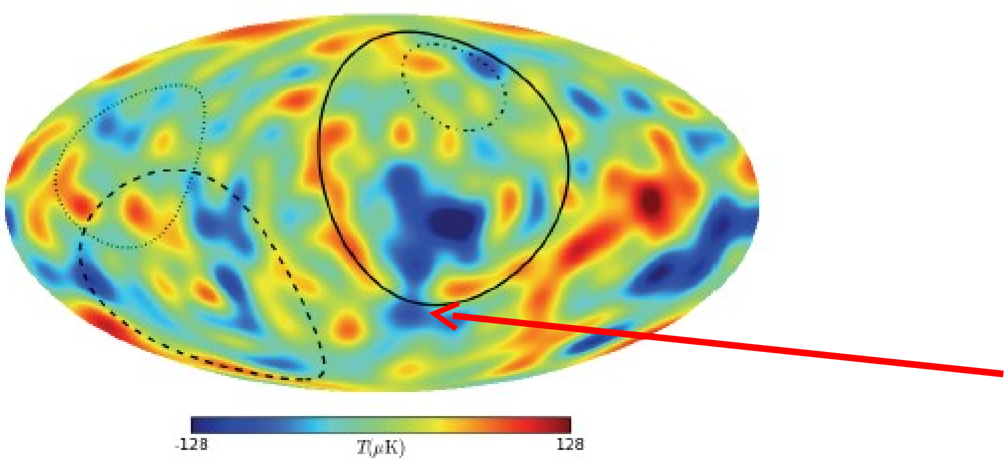
GUT scale

How reliable is BICEP2 result?

1. It is hard to compare quickly Planck limit r<0.13 with BICEP2 r =0.2
Planck bound is T based (indirect, derived within a particular model)

2. Thorough discussion of dust polarization uncertainty
M.J. Mortonson, U. Seljak arXiv: 1405.5857
L.Flauger, J.C. Hill, D.Spergel arXiv:1405.7351v1

3. Galactic Loop I and CMBR H.Liu, P.Mertsch, S. Sarkar arXiv:1404.1899



BICEP field

arXiv:1405.7351v1

Toward an Understanding of Foreground Emission in the BICEP2 Region

Raphael Flauger,[1,2] J. Colin Hill,[3] and David N. Spergel[3]

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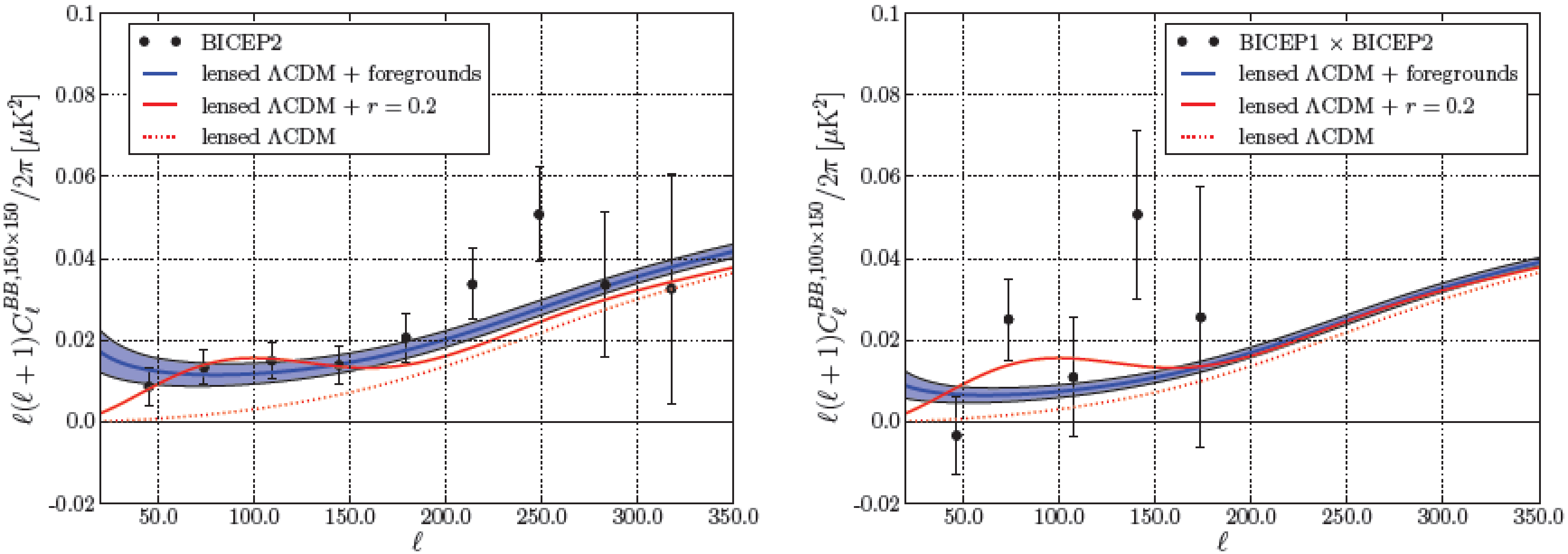
[3]Dept. of Astrophysical Sciences, Peyton Hall, Princeton University, Princeton, NJ 08544, USA



Both BICEP2 and BICEP1xBICEP2 data compatible with primordial GW as well as with foregrounds only

Arguments:

•Synchrotron emission evaluated from WMAP (K 23GHz, Ka 33 GHz) bands extrapolated to BICEP2 150 GHz (synchrotron index is uncertain) can account to 10% of the signal – not enough to explain it

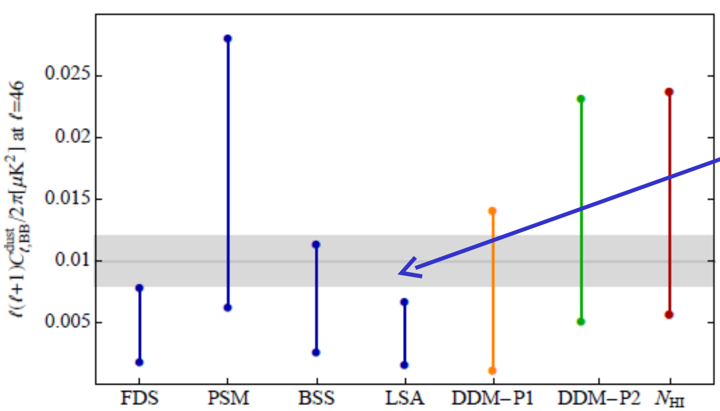
•Dust polarization: BICEP region is clear in dust emission and gas column density it doesn't guarantee negligible polarization ! (WMAP3 → 30% polarization in large scale synchrotron; Planck → BICEP region overlaps regions of 30%,40%,50% pol. intensity)

•Polarized dust emission is uncertain and could be large enough to account for the excess of power seen by BICEP

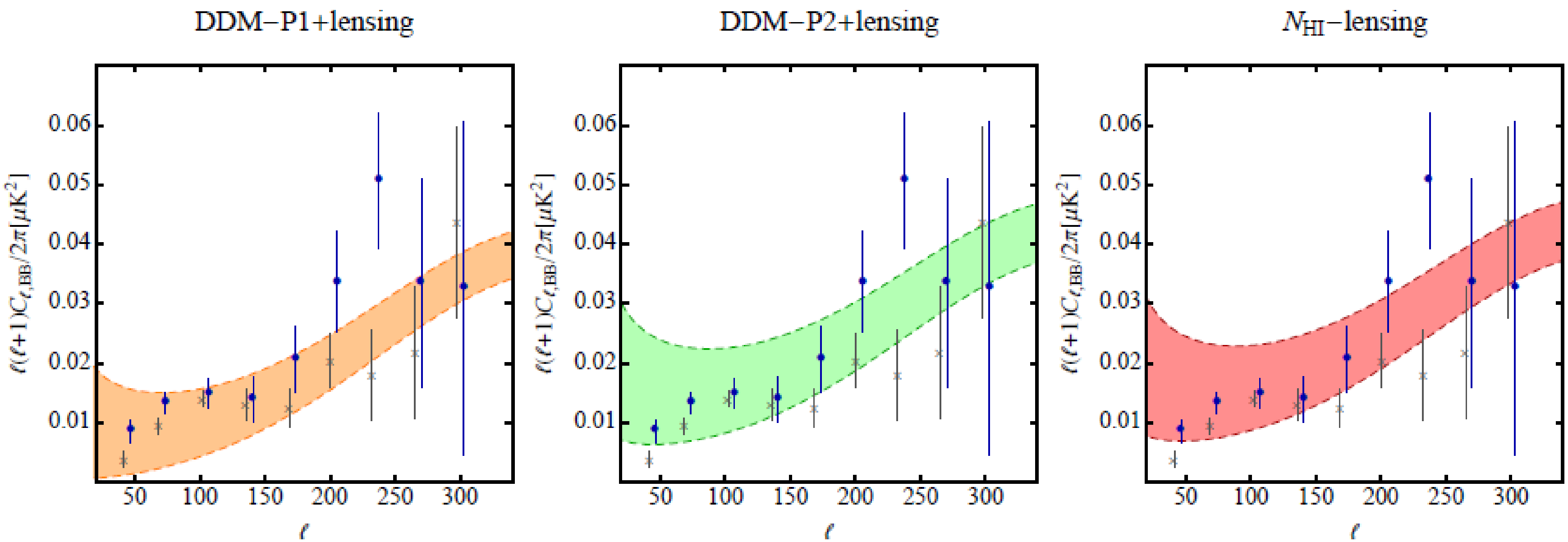
$$\ell(\ell+1)\hat{C}_\ell^{BB}/2\pi = 0.010 \pm 0.003\,\mu\mathrm{K}^2 \text{ at } \bar{\ell} = 46$$

Best fit amplitude of polarized dust emission in BICEP region

DDM1 and DDM2 depend on dust polarization fraction p



Region that led to conclusions from previous figure



There's a long way …

But we're standing at gates of a new era !

What next?

1. Confirm BICEP2 result & determine the amplitude of the GW signal

* detection of reionization bump by Planck
* other ground based experiments
* future missions like CoRE+

2. Measure r and n_s more accurately

* models make predictions concerning (n_s, r)
* future galaxy surveys can reduce error of n_s by factor of 5
* future polarization missions (e.g. COrE+) can reduce errors on r to the % level

3. Measure the running of the n_t and test the prediction $n_t = - r/8$

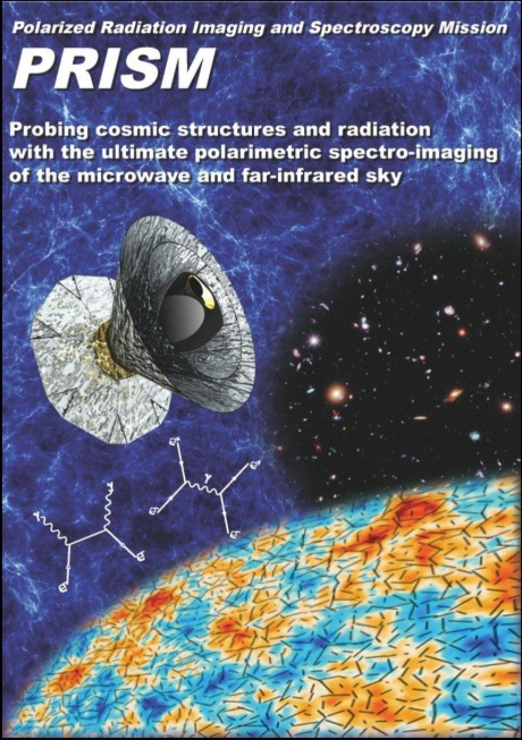
Develop further theory behind the inflation – inflation has severe conceptual problems …

Inflationary schism after Planck2013

arXiv: 1402.6980

Anna Ijjas,[1,2] Paul J. Steinhardt,[3] and Abraham Loeb[4]

	Inflaton Potential +	Initial Conditions +	Measure ⟹	Predictions
Classic inflationary paradigm	**Simple –** Single, continuous stage of inflation governed by potentials with the fewest degrees of freedom, fewest parameters, least tuning.	**Insensitive –** Inflation transforms typical initial conditions emerging from the big bang into a flat, smooth universe with certain generic properties.	**Common-sense –** It is more likely to live in an inflated region because inflation exponentially increases volume $\Rightarrow$ measure = volume	**Generic –** Based on simplest potentials: - red tilt: $n_S \sim .94 - .97$, - large $r \sim .1 - .3$*, - negligible f_{NL}, - flatness & homogeneity
Conceptual problems known prior to WMAP, ACT & Planck2013	**Not so simple –** Even simplest potentials require fine-tuning of parameters to obtain the right amplitude of density fluctuations.	**Sensitive –** The initial conditions required to begin inflation are entropically disfavored/exponentially unlikely. There generically exist more homogeneous and flat solutions without inflation than with.	**Catastrophic failure –** Inflation produces a multiverse in which most of the volume today is inflating and, among non-inflating volumes (bubbles), Inflation predicts our universe to be exponentially unlikely.	**Predictability problem –** No generic predictions; "anything can happen and will happen an infinite number of times." The probability by volume of our observable universe is less than $10^{-10^{55}}$.
Observational problems after WMAP, ACT & Planck2013 [1]***	**Unlikeliness problem –** *Simplest* inflaton potentials disfavored by data; favored (plateau) potentials require more parameters, more tuning, and produce less inflation.	**New initial conditions problem –** Favored plateau potentials require an initially homogeneous patch that is a billion times** larger than required for the simplest inflaton potentials.	**New measure problem –** All favored models predict a multiverse yet data fits predictions assuming no multiverse.	**Predictability problem unresolved –** Potentials favored by data do not avoid the multiverse or the predictability problems above. Hence, no generic predictions.



COrE / PRISM workshop for a M4 ESA mission
Laboratoire Astroparticule et Cosmologie
Paris, 10-11.02.2014

Cosmology with PRISM – Polish commitment

Marek Biesiada
Institute of Physics,
University of Silesia,
Katowice, Poland

On behalf of Polish supporters of PRISM Project

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Jakub Mielczarek
…
22 in total

This could be the opening of the gates …

NEW CMB Polarization Mission