Including birefringence into time evolution of CMB: current and future constraints

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Based on:
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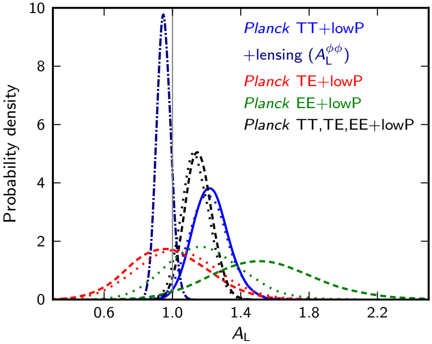
Outline

CMB lensing after Planck

Planck 2015 measured the lensing amplitude A_L

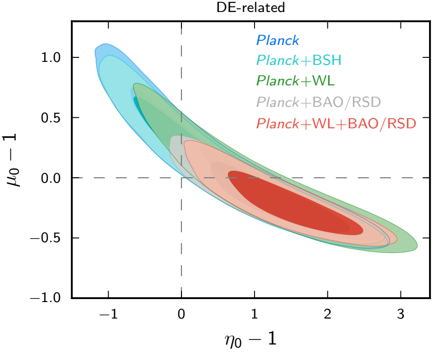
$$C_\ell^{\phi\phi} = A_L \tilde{C}_\ell^{\phi\phi}$$



Planck 2015 results. XIII. Cosmological parameters

Implications of a non standard lensing

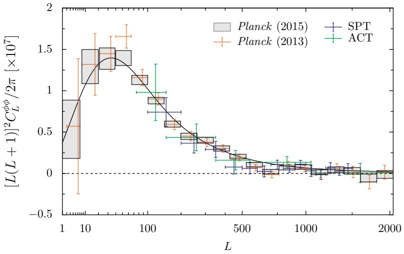
A non standard A_L may have huge implications for cosmology.
It may hint for a deviation from General Relativity



Planck 2015 results. XIV. Dark energy and modified gravity

Lensing extraction

Planck obtained also the reconstruction of CMB lensing from quadratic estimators



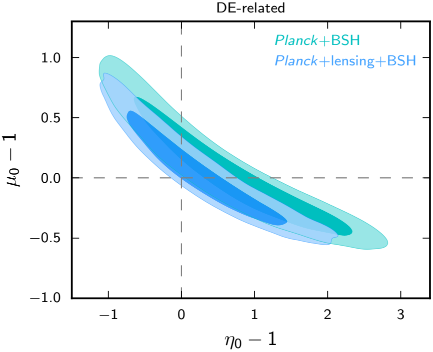
Planck 2015 results. XV. Gravitational lensing

This technique gives a CMB lensing spectrum $1-\sigma$ away from ΛCDM

$$A_L = 0.95 \pm 0.04$$

Lensing extraction

This result show how deviations from standard lensing drive the hint for modifications of gravity.



Planck 2015 results. XIV. Dark energy and modified gravity

The two techniques seem to push in different directions.
Is there a way to reconcile the 2 results on A_L?

Cosmic Birefringence

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Theoretical models departing from the standard ΛCDM cosmology may drive this rotation.

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- Dark Energy motivated quintessence fields coupled to photons.

  Carroll (1998)
- Axions, possible Dark Matter candidate

  Finelli, Galaverni (2009)
- Quantum Gravity theories

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- Miscalibration of polarimeters
  Pagano et al. (2009)

Effect on CMB spectra

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\begin{aligned}
C_\ell^{EE} &= \tilde{C}_\ell^{EE}\cos^2(2\alpha_0) + \tilde{C}_\ell^{BB}\sin^2(2\alpha_0) - \tilde{C}_\ell^{EB}\sin(4\alpha_0) \\
C_\ell^{BB} &= \tilde{C}_\ell^{EE}\sin^2(2\alpha_0) + \tilde{C}_\ell^{BB}\cos^2(2\alpha_0) + \tilde{C}_\ell^{EB}\sin(4\alpha_0) \\
C_\ell^{EB} &= \frac{1}{2}\left(\tilde{C}_\ell^{EE} - \tilde{C}_\ell^{BB}\right)\sin(4\alpha_0) + \tilde{C}_\ell^{EB}\left(\cos^2(2\alpha_0) - \sin^2(2\alpha_0)\right) \\
C_\ell^{TE} &= \tilde{C}_\ell^{TE}\cos(2\alpha_0) - \tilde{C}_\ell^{TB}\sin(2\alpha_0) \\
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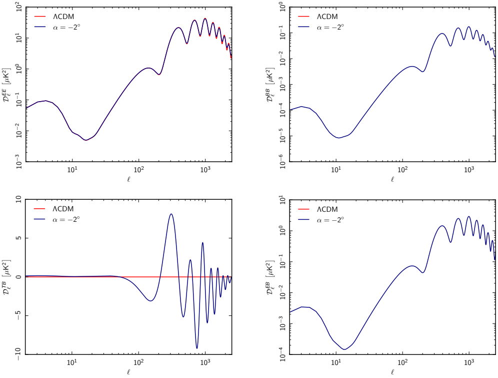
C_\ell^{TB} &= \tilde{C}_\ell^{TE}\sin(2\alpha_0) + \tilde{C}_\ell^{TB}\cos(2\alpha_0)
\end{aligned}
$$

Just a simple example: equations do not include CMB lensing and a constant rotation is assumed.

Full equations can be found in *Gubitosi, Martinelli, Pagano (2014)*

Effect on CMB spectra

Cosmic birefringence leads to non vanishing primordial BB, TB and EB spectra.
These are not produced in the standard model (BB is produced by lensing and tensor perturbations)



Lensing and birefringence

Birefringence produces a leakage from E to B modes, thus can partially mimic the effect of gravitational lensing on CMB spectra.

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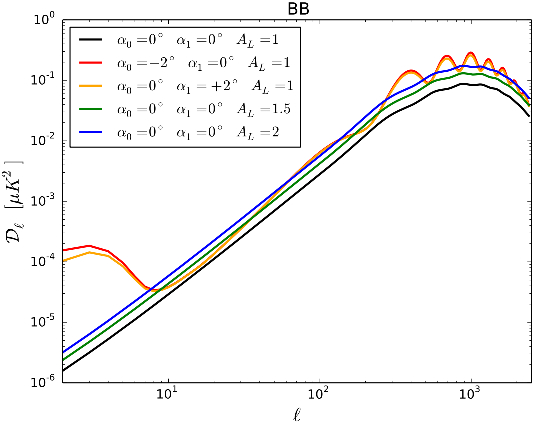
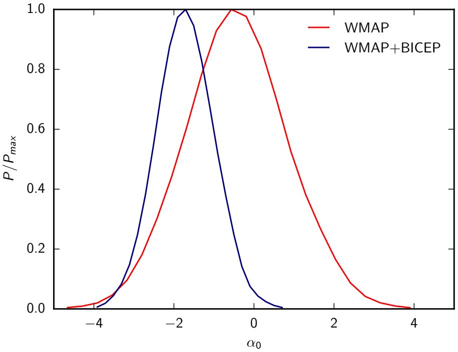


WMAP+BICEP

We used a cosmology including both CMB lensing and cosmic birefringence to fit WMAP and BICEP data.

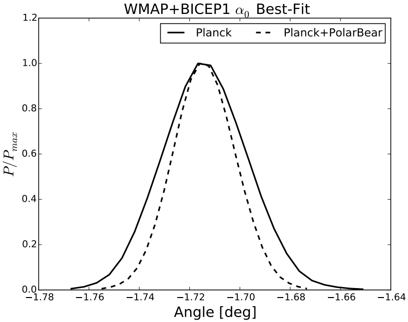


While still compatible with a vanishing rotation angle, the combination of the two experiments hints for $\alpha \neq 0$.

Planck Forecast

The best fit obtained by WMAP+BICEP is used to simulate datasets with Planck and PolarBear sensitivity

We obtained a strong constraint for a non vanishing birefringence angle



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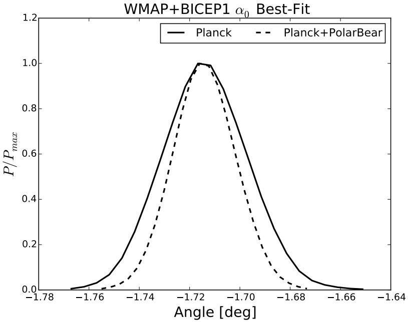
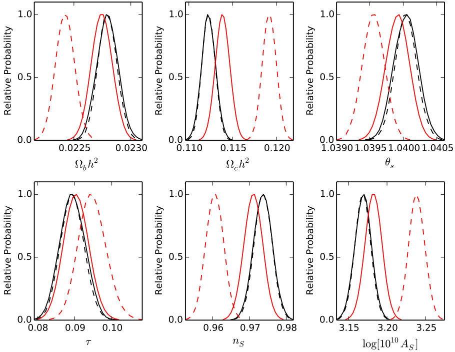


WARNING: this is not a result from Planck data!

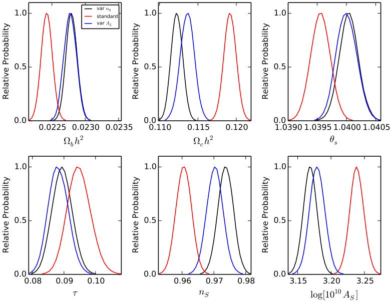
Neglecting birefringence

The birefringence cosmology we consider deviates significantly from a standard cosmological model.
A standard analysis of a cosmological model containing this effect leads to a bias on the recovered best fit parameters.



Neglecting birefringence $(+A_L)$

If we fit the same mock dataset including A_L the bias on parameters is significantly reduced



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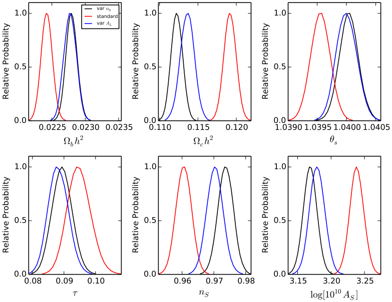

The price to pay is the detection of a non standard lensing amplitude

$$A_L = 1.29 \pm 0.03$$

The real Planck

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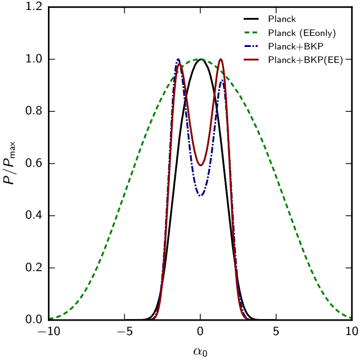

see also *Gruppuso et al. arXiv:1509.04157*

The real Planck

Including birefringence into time evolution of CMB: current and future constraints

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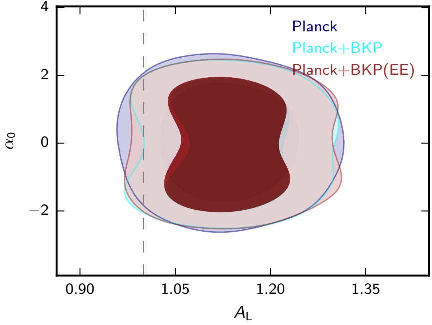
With Planck data there is also no hint for a $\alpha_0 - A_L$ degeneracy



It's likely that stronger constraints are necessary.

TB and EB spectra are needed!

Summary

- results from CMB spectra and lensing extraction seem to push in different directions
- Cosmic birefringence has an effect on CMB spectra similar to gravitational lensing
- Neglecting birefringence in the analysis of CMB data may lead to a false detection of $A_L > 1$
- Preliminary: TB and EB spectra are crucial to constrain birefringence.
- Upcoming polarization data (ACTpol, PolarBear...) will greatly improve results on this mechanism
- Can we distinguish cosmological birefringence from miscalibration?

Calibration issues

Cosmic birefringence could also be mimicked by a simple mismatch in the calibration of the axis orientation of polarimeters

Pagano et al. (2009)

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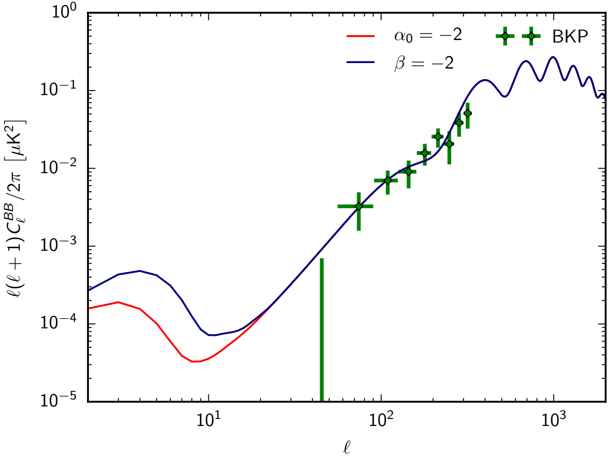
As this effect is related to the experimental setup it mixes spectra **after** their time evolution.
Miscalibrition brings to a constant, sudden rotation of evolved spectra.

$$\begin{aligned} Q &= \tilde{Q}\cos 2\beta + \tilde{U}\sin 2\beta \\ U &= \tilde{U}\cos 2\beta - \tilde{Q}\sin 2\beta \end{aligned}$$

This rotation acts on spectra **after** CMB lensing!

Calibration issues

Extremely sensitive BB measurements at low multipoles would be needed to distinguish this from a cosmological effect



An example: Planck scale modifications to electrodynamics

In the context of quantum gravity, electrodynamics can be modified at Planck scales

Gubitosi et al. (2009)

$$\mathcal{L} = \frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{\xi}{2E_P}\epsilon^{jkl}F_{0j}\partial_0 F_{kl}$$

Right and left-circularly polarized components of an electromagnetic wave satisfy different dispersion relations

$$\omega_{\pm} \approx p\left(1 \pm \frac{\xi}{E_P}p\right)$$

Assuming linear polarization, a wave propagating for a time η will experience a rotation of its polaration plane by an angle

$$\theta(\eta) = (\omega_{-} - \omega_{+}) = 2\frac{\xi}{E_P}p^2\eta$$

Accounting for CMB lensing

Warning: gravitational lensing affects photons during their evolution.
If birefringence is present, B modes and TB and EB cross correlation would have already been generated.
To compute the C_ℓ we can obtain the real space correlation functions

$$\xi_X(\gamma) \equiv < T(\hat{n}_1)P(\hat{n}_2) > = \sum_\ell \frac{2\ell+1}{4\pi}(C_\ell^{TE} - iC_\ell^{TB}) \text{ [lensing terms]}$$

$$\xi_+(\gamma) \equiv < P^*(\hat{n}_1)P(\hat{n}_2) > = \sum_\ell \frac{2\ell+1}{4\pi}(C_\ell^{EE} + C_\ell^{BB}) \text{ [lensing terms]}$$

$$\xi_-(\gamma) \equiv < P(\hat{n}_1)P(\hat{n}_2) > = \sum_\ell \frac{2\ell+1}{4\pi}(C_\ell^{EE} - C_\ell^{BB} - 2iC_\ell^{EB}) \text{ [lensing terms]}$$

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