Tensor to Scalar Ratio : CMB Lensing

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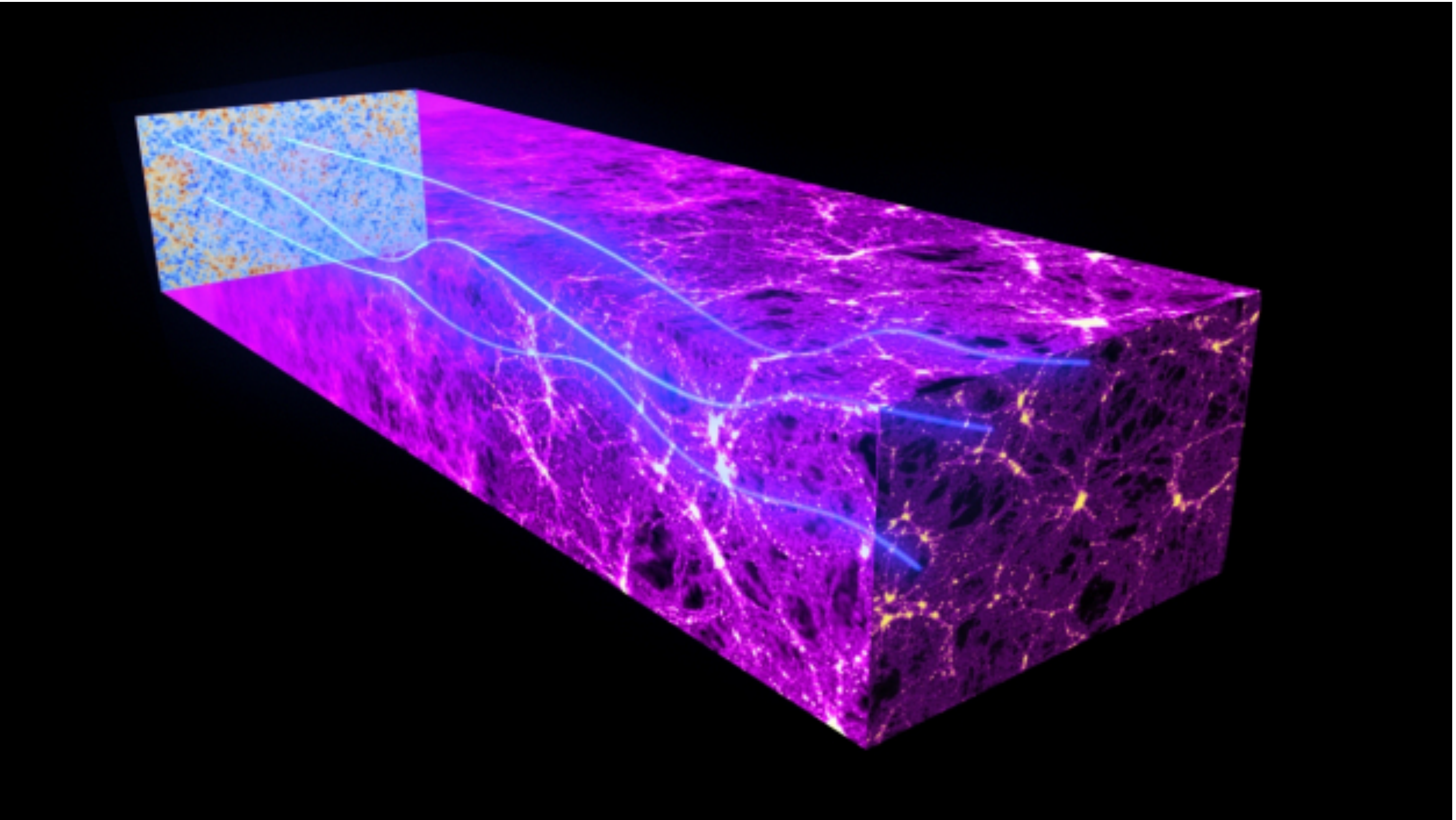
The CMB is lensed by foreground structure



Credit:
ESA, Planck

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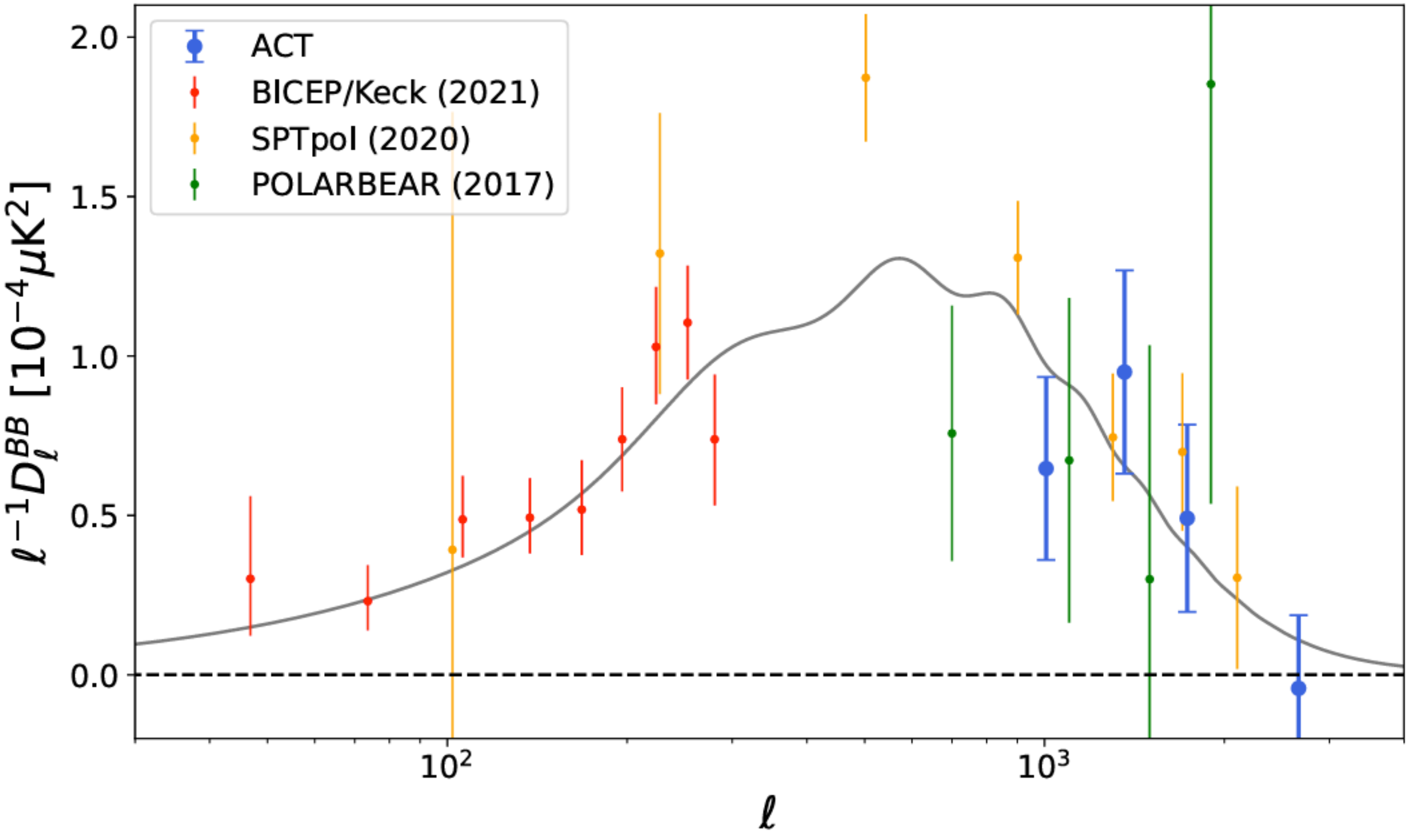
Measured B-polarization spectrum



$D_\ell = C_\ell \ell(\ell+1)/2\pi$

From: ACT, Louis et al. 2503.14452

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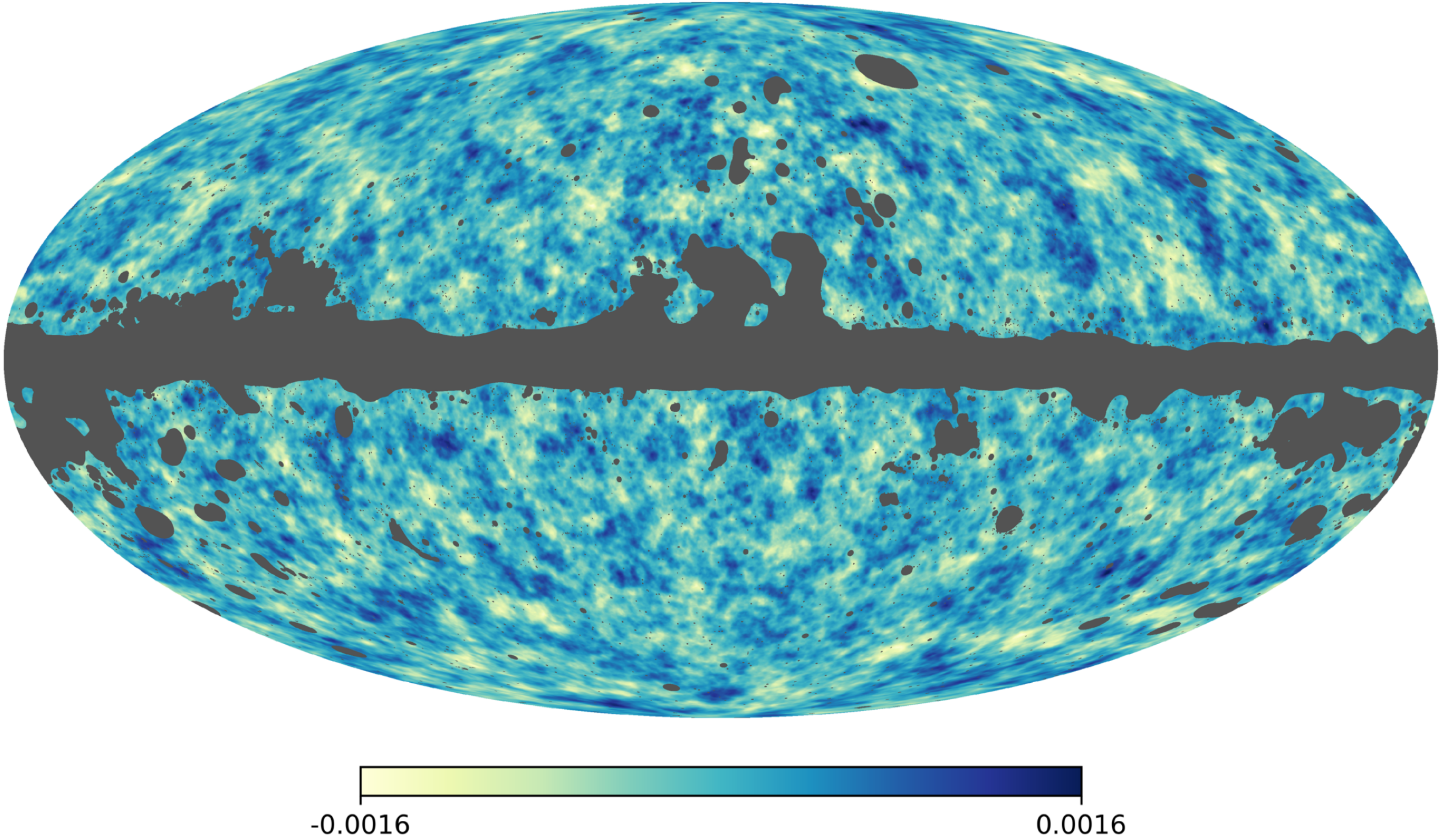
Map of the lensing potential



Planck, 2018

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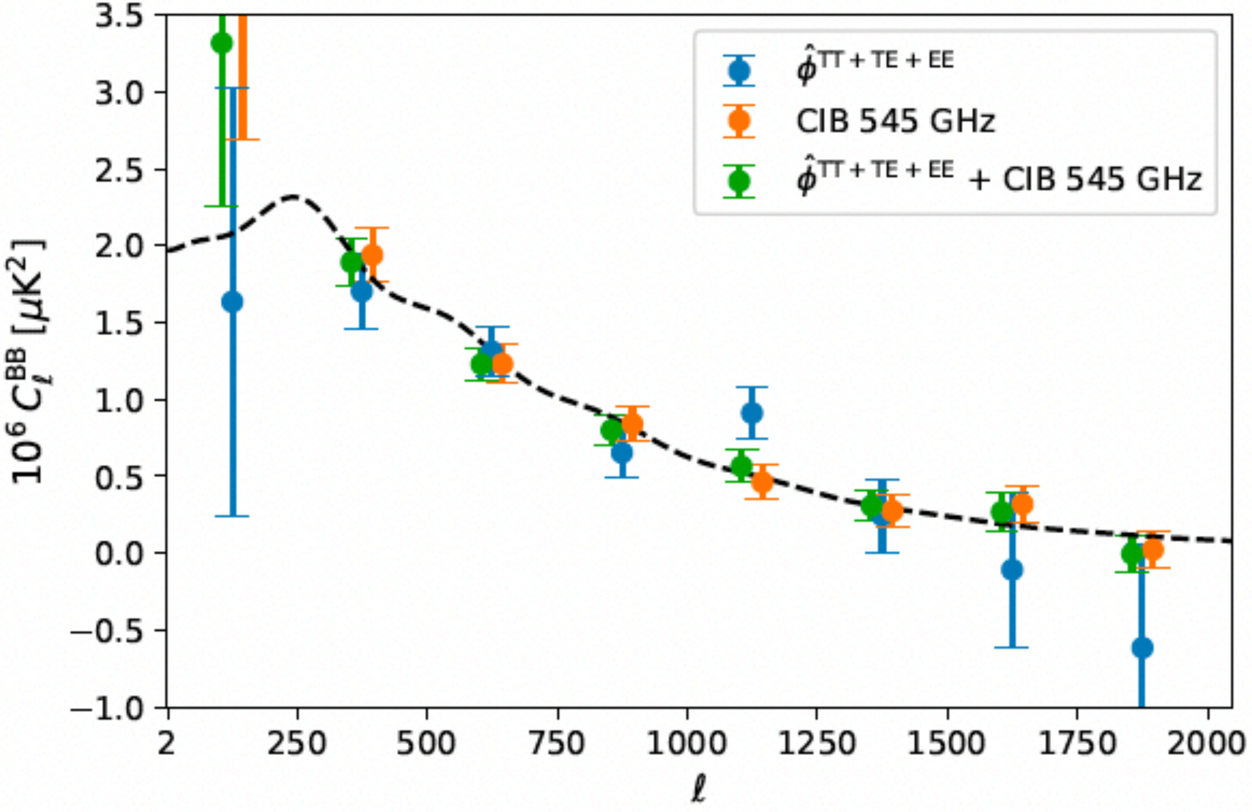
B-mode from lensing



Planck, 2018

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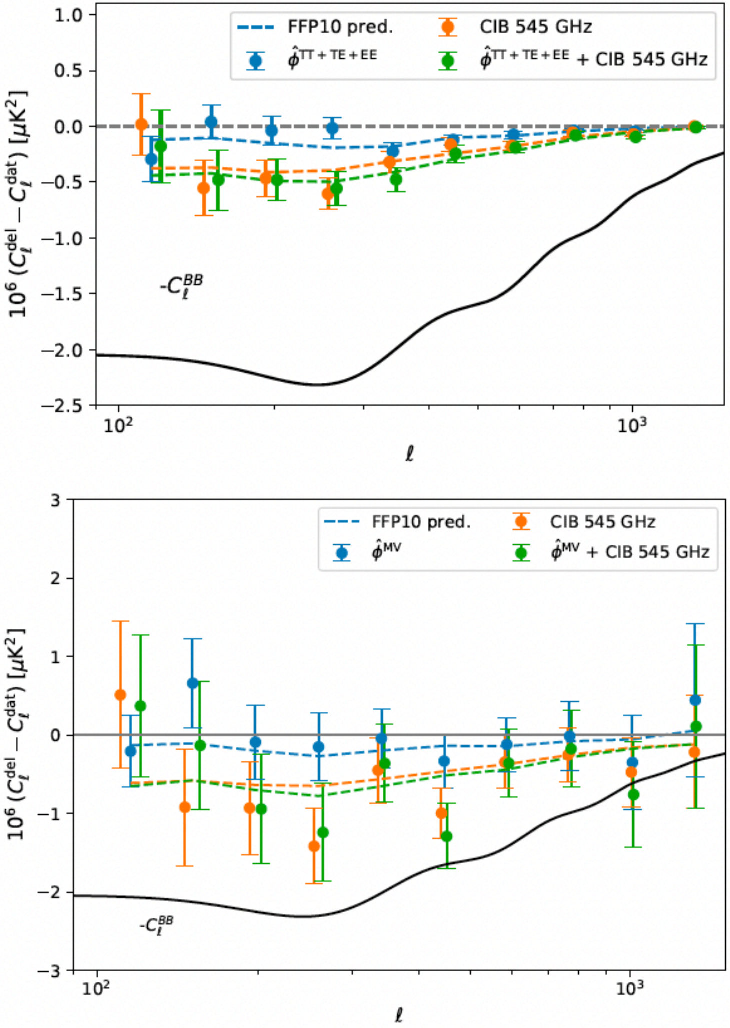

B-mode subtraction (de-lensing)

Planck's de-lensing efficiency for B-modes is rather poor (of order 20% at large scales.

Present ground based experiments do significantly better.

Planck, 2018

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Present limits on the scalar tensor ratio r

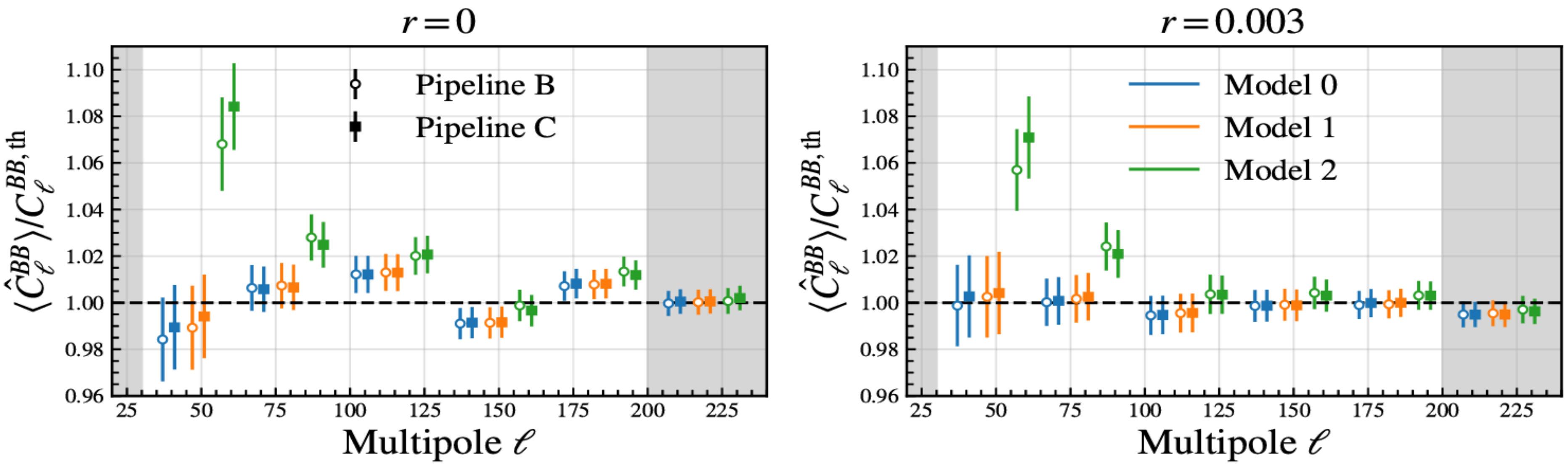
Present observational limits on r (<0.032 to 0.038) are still dominated by the measurements of the temperature power spectrum C_ℓ^{TT} .

In the future we want to limit r much more precisely with the measurement of B-polarization.

However, in the future constraints from B-modes, de-lensing will be crucial. The observational limits we can achieve for r will depend on our capability to ‘de-lens’ CMB maps.

We have to go beyond GMV (‘Generalized Minimum Variance’) or QE (quadratic estimator) methods which are based on the assumption that lensing is a small contribution, which is not true for the B-polarization spectra for S4 experiments where the noise is beyond the lensing signal..

Limits on the scalar tensor ratio r to be reached with CMB S4 for 3 different foreground models



Bianchini et al., 2502.04300

$r < 10^{-3}$ at 95% confidence

$r=0.003$ at 5σ

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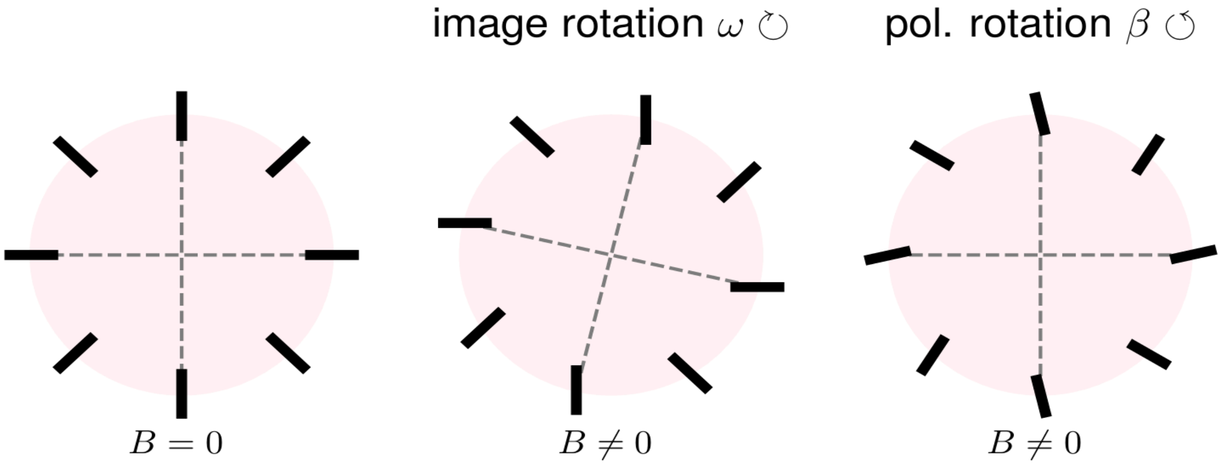
Lensing rotation

At 2nd order lensing may also induce rotation of the polarization.

$$\alpha_i^{(2)}(\hat{n}, z_*) = -2\int_0^{r_*} dr \frac{r_* - r}{r_* r} \nabla_j \nabla_i \Phi(r\hat{n}, t_0 - r)\alpha_j^{(1)}(\hat{n}, z(r))$$
$$= 4\int_0^{r_*} dr \frac{r_* - r}{r_* r} \nabla^j \nabla^i \Phi(r\hat{n}, t_0 - r)\int_0^{r} dr' \frac{r - r'}{r r'} \nabla_j \Phi(r'\hat{n}, t_0 - r') \,.$$



Carron, Di Dio, RD
2501.04158

Measuring lensing rotation is a test of GR frame dragging on cosmological scales

	$100 \cdot f_{\rm sky}$	$\beta = -\omega[\kappa, g]$	$\beta = -\omega[\kappa, I]$	$\beta = -\omega[g, I]$	$\beta = -\omega[\kappa, g, I]$
LiteBird	60	0.9	0.2	1.4	1.6
SO-baseline (P-only)	40	2.6	0.4	4.1	4.6
SO-baseline (GMV)	40	4.3	0.6	4.9	6.0
SO-goal (P-only))	40	4.7	0.7	6.0	7.0
SO-goal (GMV)	40	6.3	0.9	6.6	8.3
SPT-3G-7y	3.6	6.4	0.8	5.0	7.1
PICO	60	36.6	5.7	25.0	39.4
S4-wide	40	32.0	4.1	22.7	34.7
S4-deep	3.6	37.3	5.1	20.4	38.3

S/N values for different experiments
From: Carron, Di Dio, RD 2501.04158

Resumé

A good modeling of CMB lensing is crucial for the detection and for best limits on the tensor to scalar ratio r.

With CMB S4 experiments we can hope to reach $r \sim 10^{-3}$.

This will constrain interesting contenders of inflation like the R^2 model of Starobinsky, Higgs inflation or, more generally, α- attractors (some of these are already in tension with the newest value of $n_s \cong 0.974$).

However, as $r \propto (E/M_{Pl})^4$ we cannot expect to see inflationary GWs generated from quantum fluctuations in (std.) inflationary models at energy scales $E \ll 10^{15}$GeV (corresponding to about $r=10^{-5}$).

But lensing is also an interesting signal in the CMB by itself and 2nd order lensing may provide a test of frame dragging on cosmological scales.