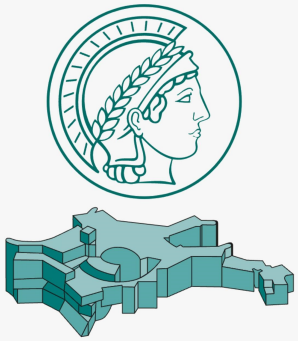

Impact of HWP systematics on the measurement of cosmic birefringence from CMB polarization

Marta Monelli

Max Planck Institut für Astrophysik
Garching (Germany)

September 9th, 2022

searching for B-modes from inflation

Expectation: inflation-sourced perturbations leave traces on the CMB polarization.

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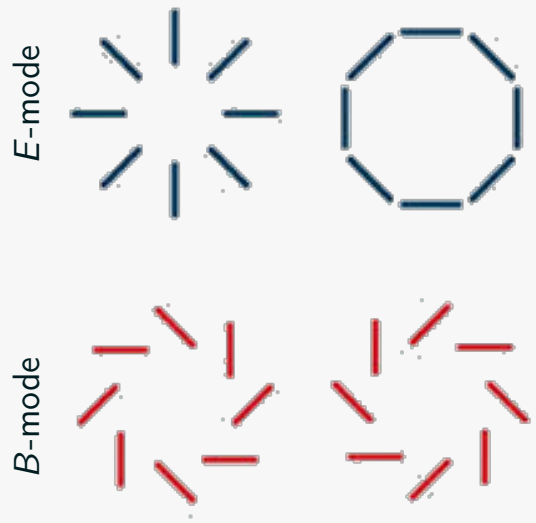

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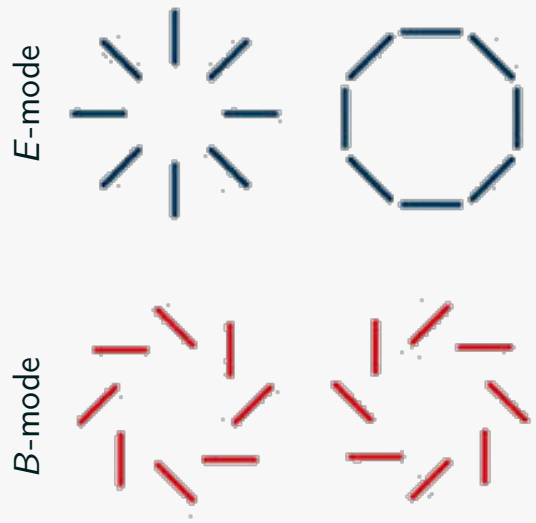

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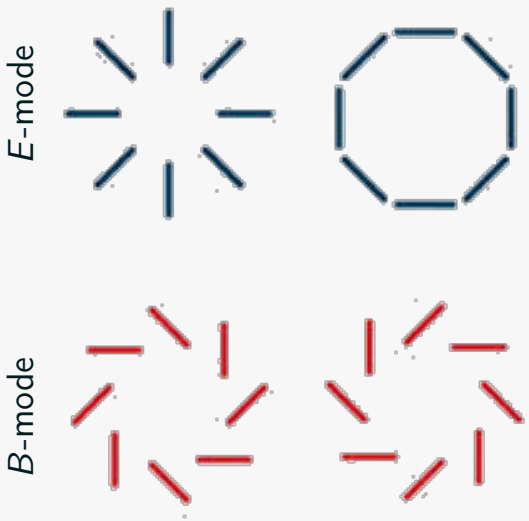

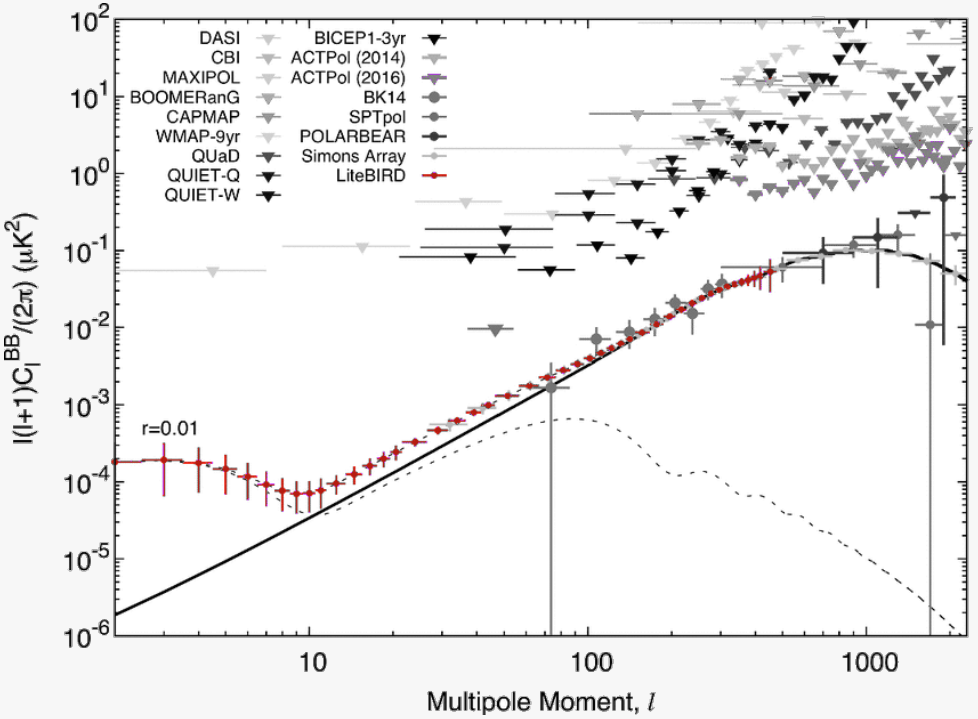

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image credit: Hazumi et al (2019)

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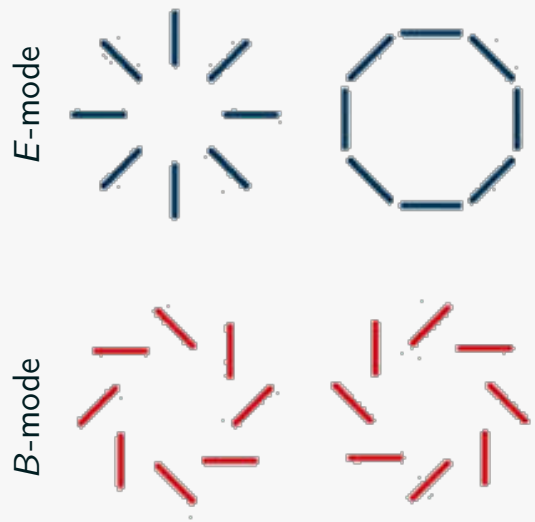

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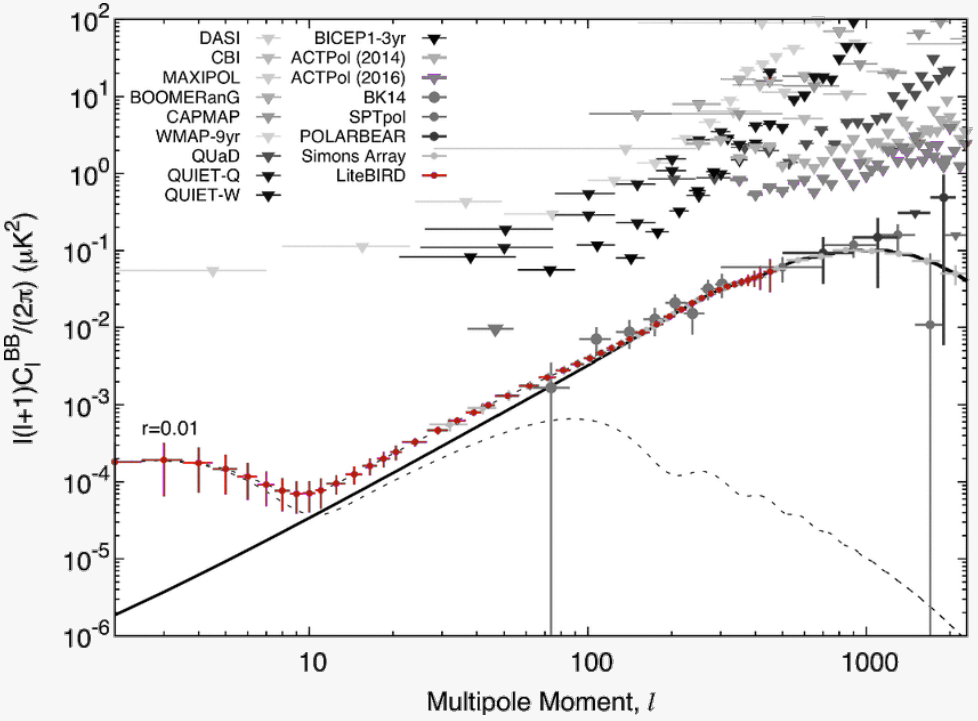

Unprecedented sensitivity requirements!

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a side effect: measuring cosmic birefringence

CMB might also carry information
about parity-violating new physics:
cosmic birefringence.

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image credit: Yuto Minami;

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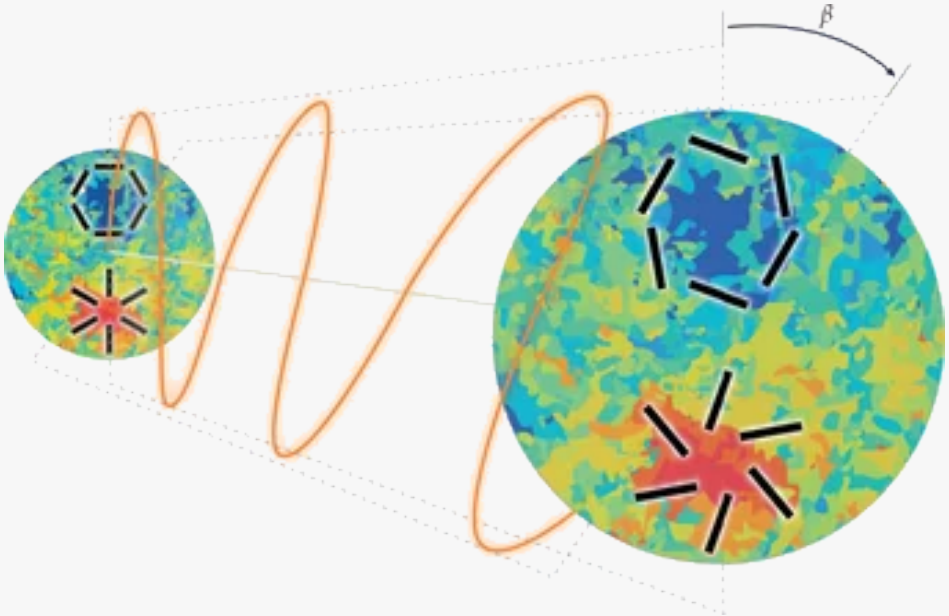

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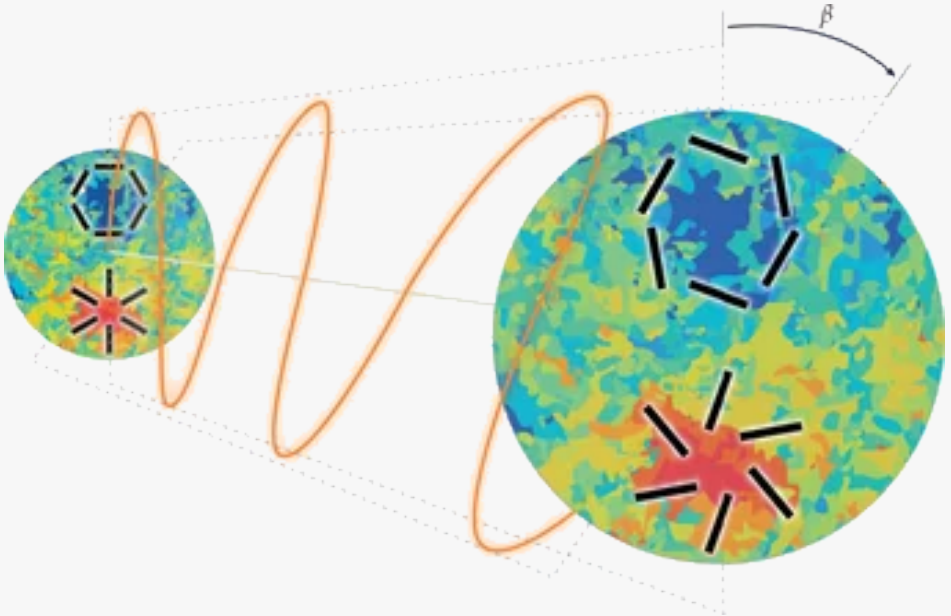

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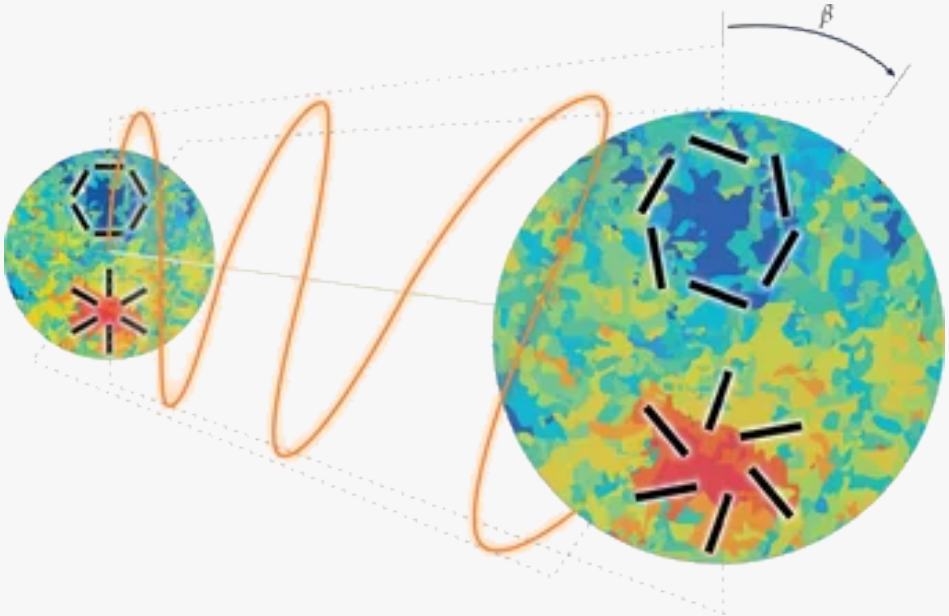

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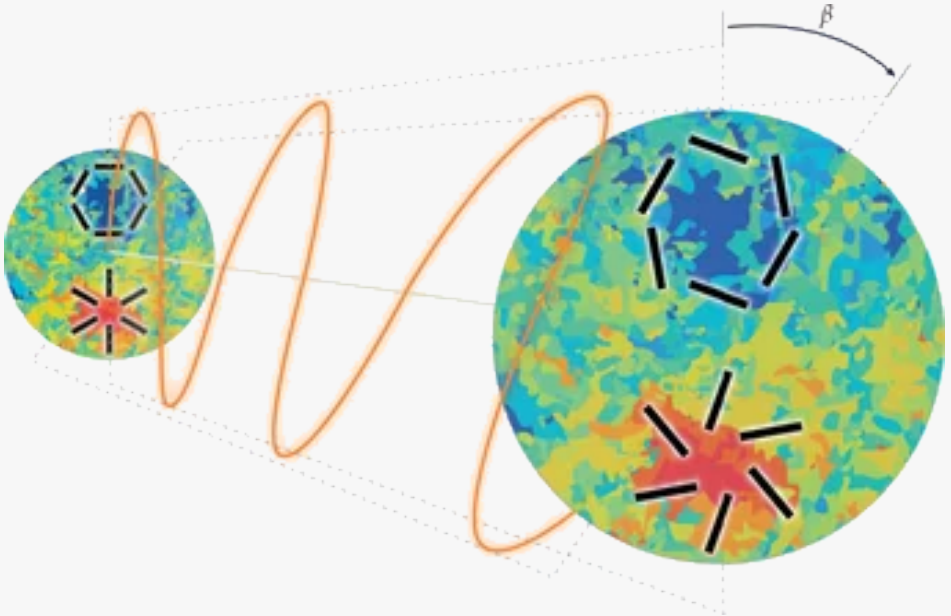

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From *Planck* data:

$\beta = 0.35 \pm 0.14°$ at 68% C.L.

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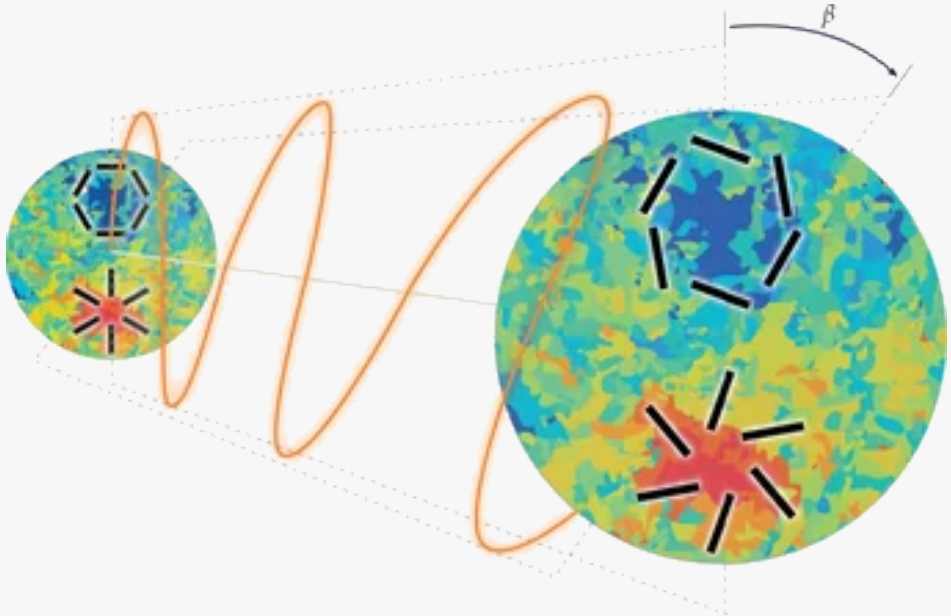

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Constraint expected to **improve**.

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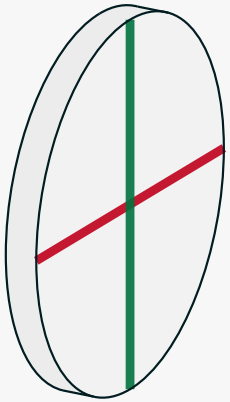
the HWP: reducing systematics



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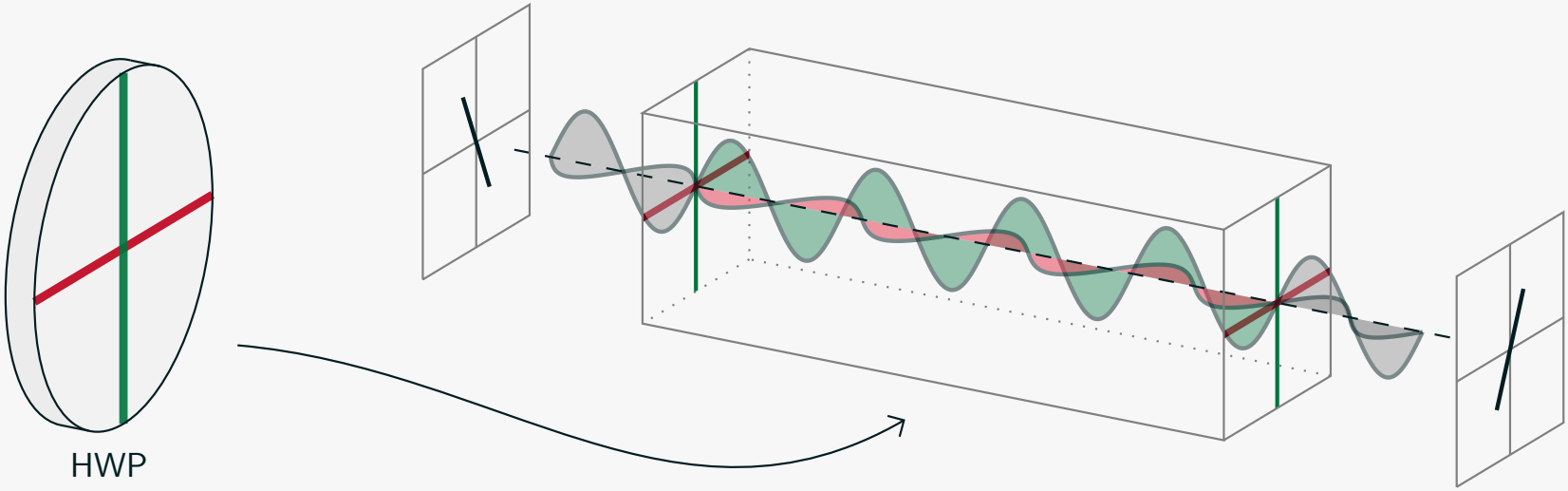

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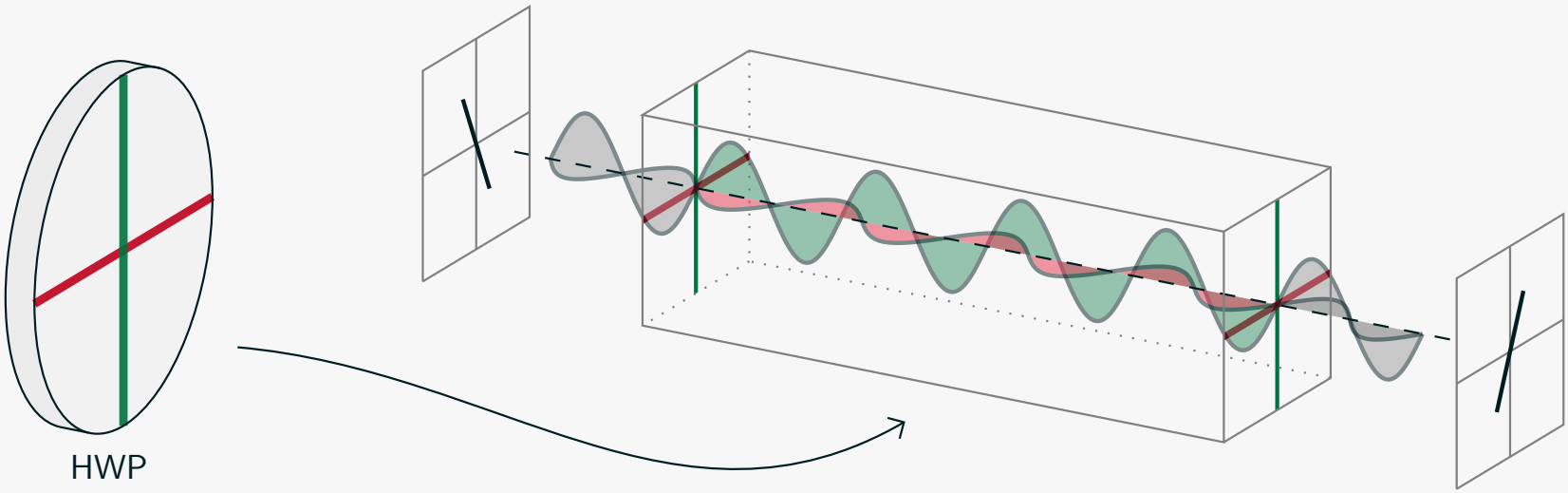

A **rotating** HWP as first optical element:

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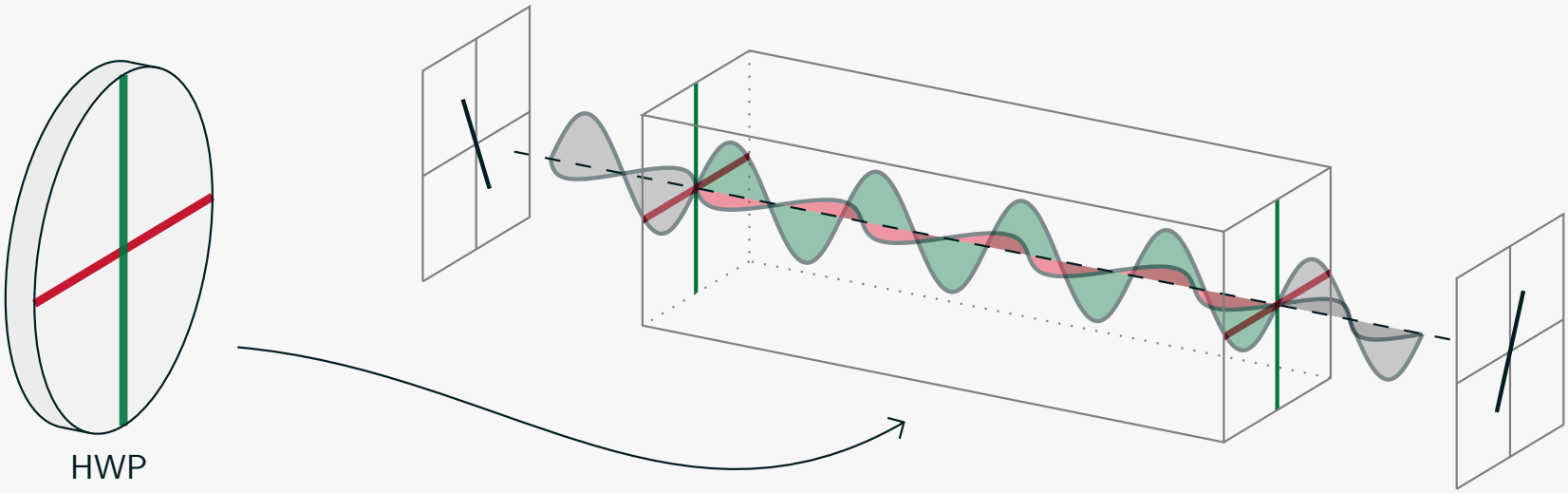

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- modulates the signal to $4f_{\mathrm{HWP}}$, allowing to "escape" $1/f$ noise;

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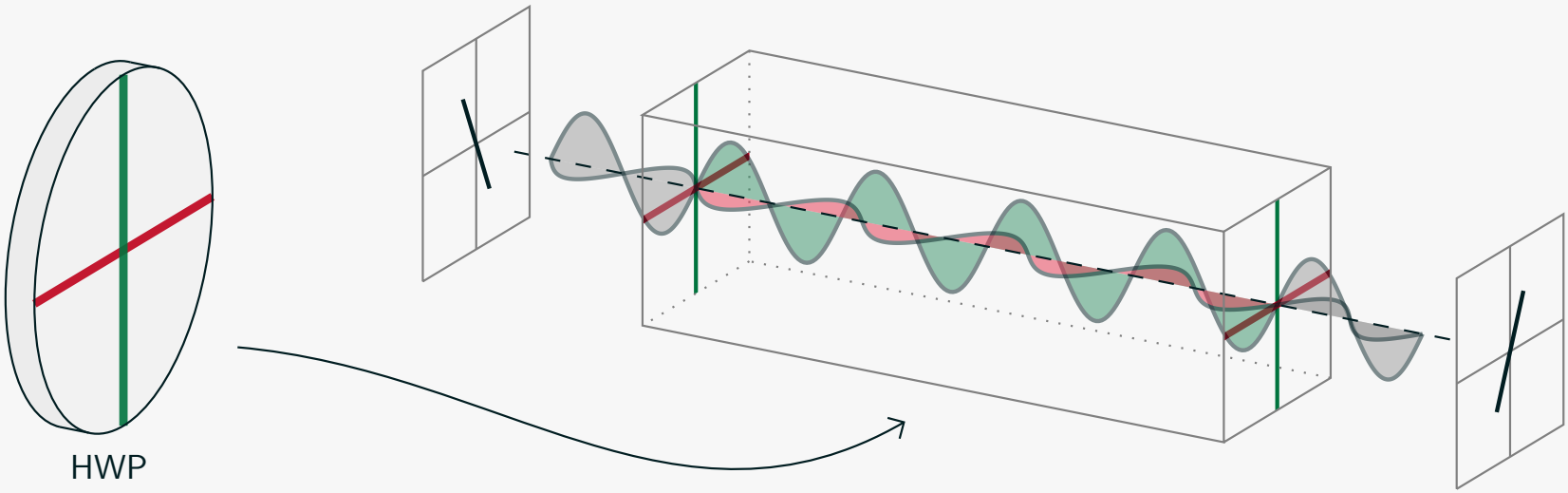

A **rotating** HWP as first optical element:

- modulates the signal to $4f_{\mathrm{HWP}}$, allowing to "escape" $1/f$ noise;
- makes possible for a single detector to measure polarization, reducing pair-differencing systematics.

the HWP: inducing systematics

Mueller calculus: radiation described as $S = (I, Q, U, V)$ and HWP effects parametrized by $\mathcal{M}_{\mathrm{HWP}}$, so that $\mathrm{S}' = \mathcal{M}_{\mathrm{HWP}}\mathrm{S}$.

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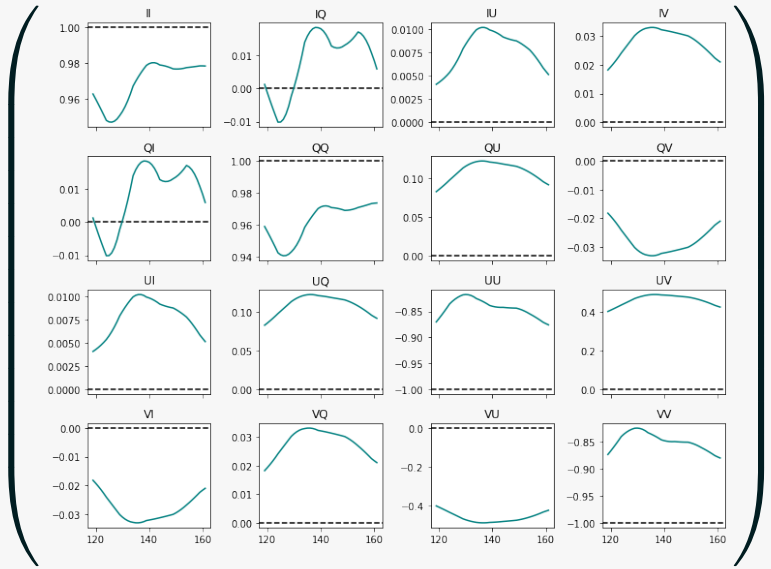

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Giardiello et al. (2022) A&A 658

outline of the talk

- framework of the simulations and their output;
- non-idealities' impact on the C_ℓs (simulated and analytic approx);
- impact on cosmic birefringence.

simulations

simulation imput

- I, Q and U **input maps** ($n_{\mathrm{side}} = 512$) from best-fit 2018 Planck power spectra;

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HWP rpm	39
FWHM	30.8 arcmin
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- Non-ideal **HWP**: Mueller matrix elements from Giardiello et al. (2022) A&A 658.

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ideal and non-ideal TODs, both processed with **ideal** map-maker.

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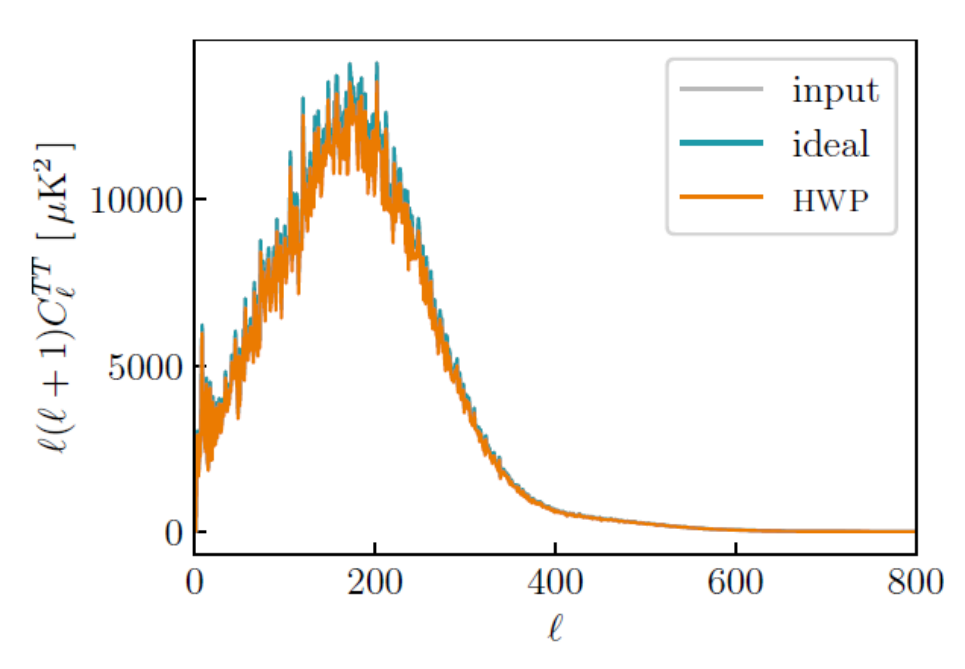

- *TT* slightly affected

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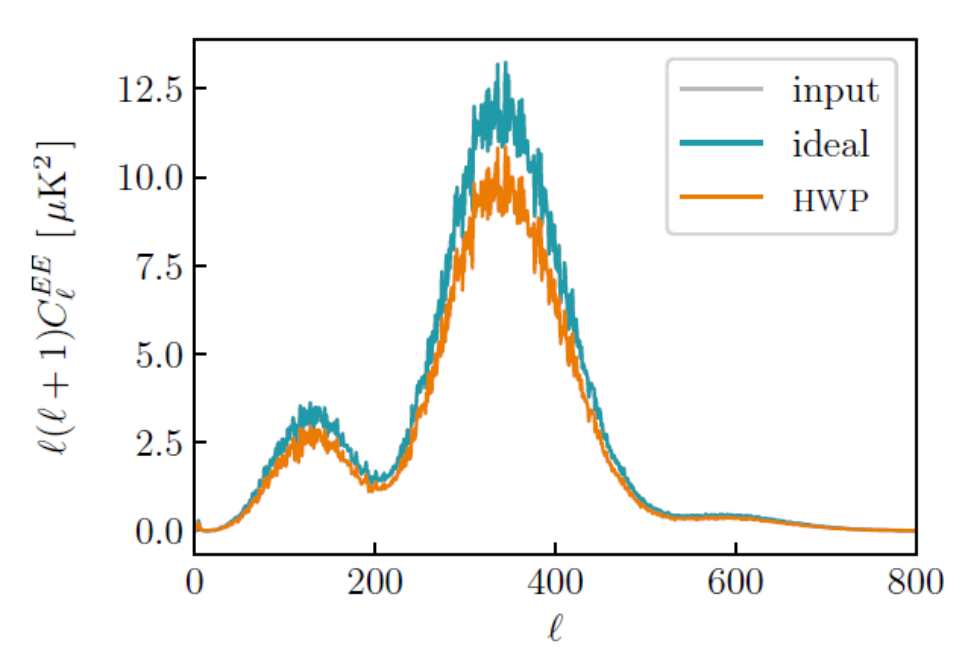

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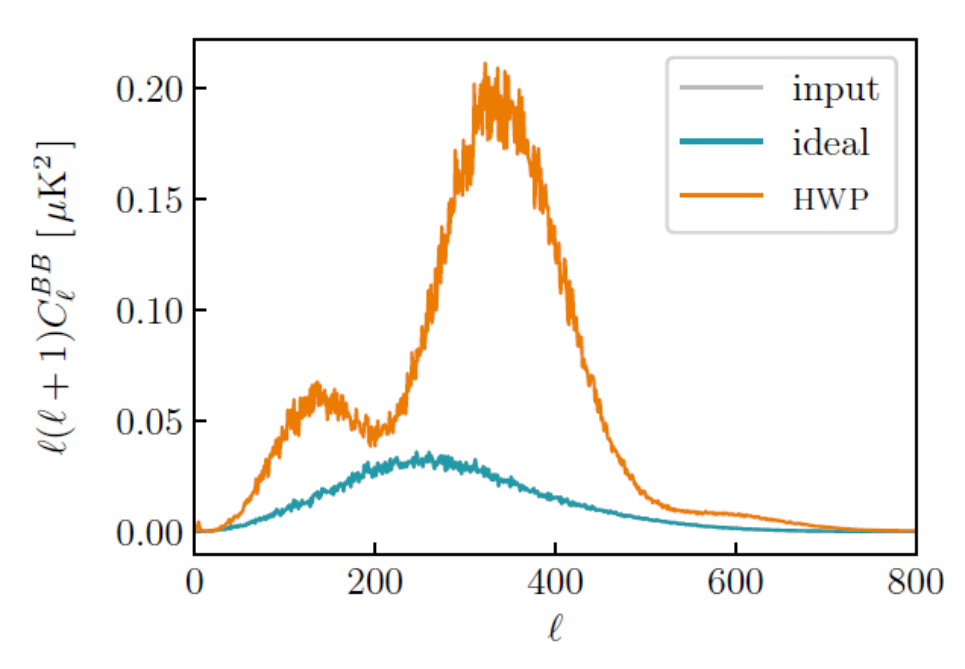

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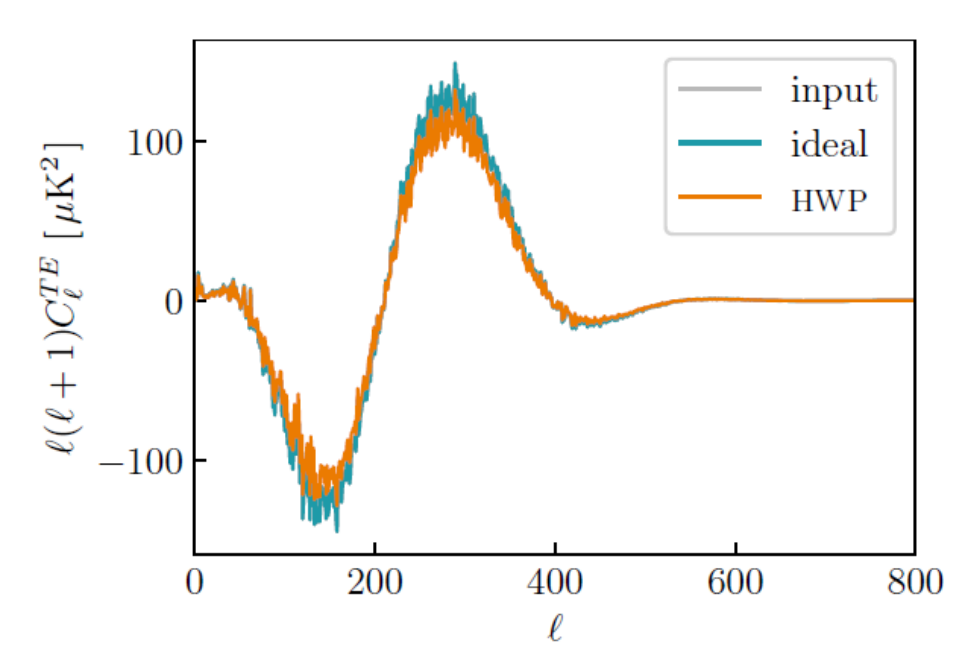

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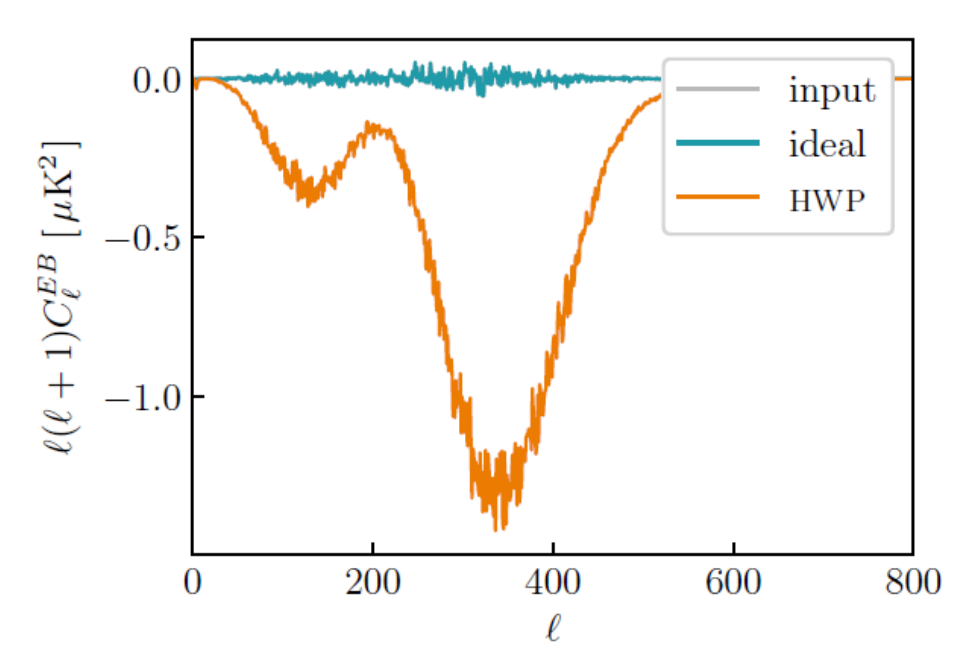

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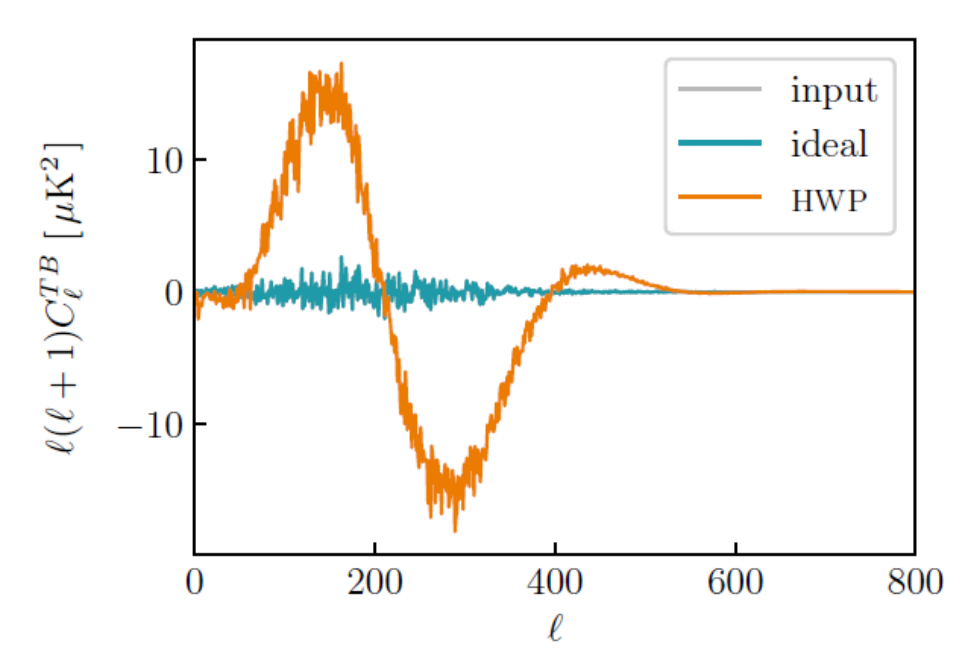

- *TT* slightly affected
- *EE* lost power
- *BB* much larger (*EE* shape)
- *TE* slightly affected
- *EB* non-zero!
- *TB* non-zero!

how can we understand?

the idea

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Detected signal modeled as $d = (1\ 0\ 0) \cdot \mathcal{M}_{\mathsf{det}} \mathcal{R}_{\xi-\phi} \mathcal{M}_{\mathsf{HWP}} \mathcal{R}_{\phi+\psi} \cdot \mathsf{S}$;

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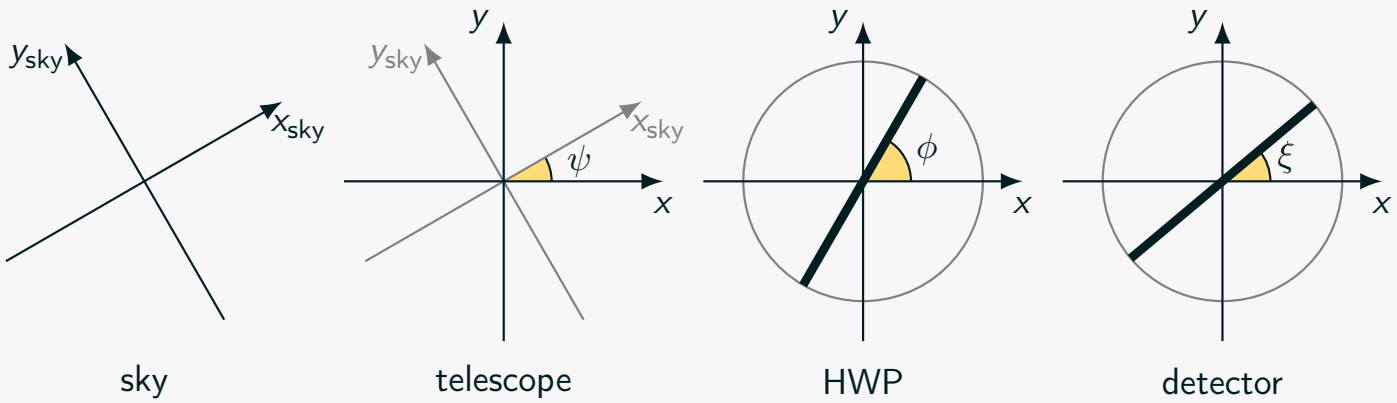

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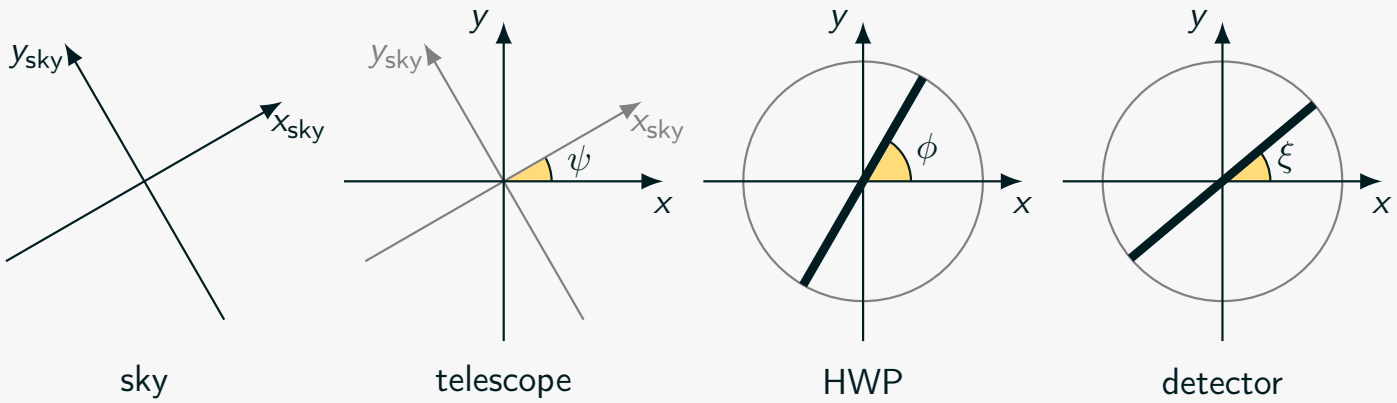

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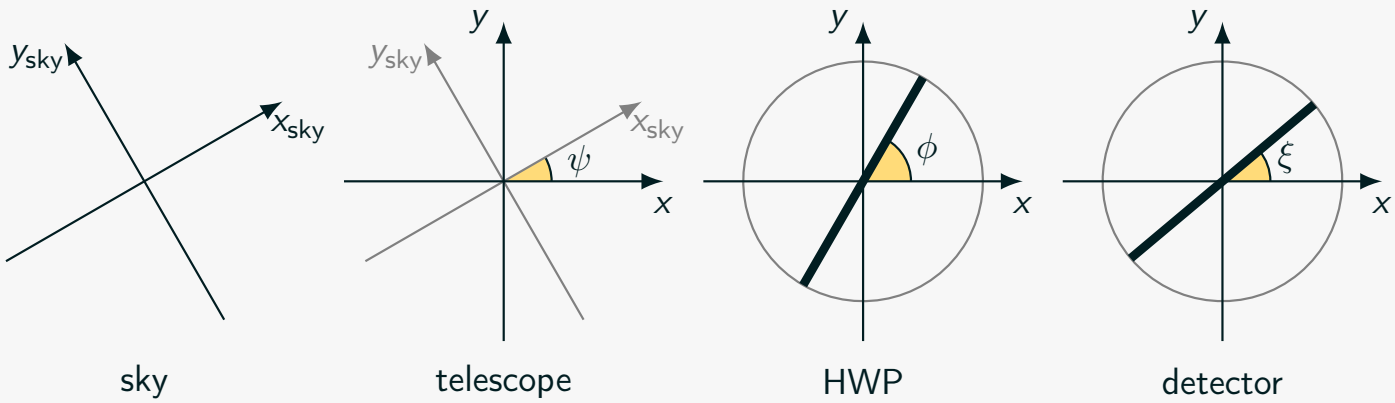

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$$\widehat{\mathrm{S}} \simeq \begin{pmatrix} m_{ii}\, I_{\rm in} \\ [(m_{qq} - m_{uu}) Q_{\rm in} + (m_{qu} + m_{uq}) U_{\rm in}]/2 \\ [-(m_{qu} + m_{uq}) Q_{\rm in} + (m_{qq} - m_{uu}) U_{\rm in}]/2 \end{pmatrix} .$$

equations for the $\widehat{C}_\ell$s (new result!)

Expanding $\widehat{S}$ in spherical harmonics:

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$$\widehat{C}_\ell^{TT} \simeq m_{ii}^2 C_{\ell,\mathrm{in}}^{TT},$$

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$$\widehat{C}_\ell^{TE} \simeq \frac{m_{ii}(m_{qq}-m_{uu})}{2} C_{\ell,\mathrm{in}}^{TE} + \frac{m_{ii}(m_{qu}+m_{uq})}{2} C_{\ell,\mathrm{in}}^{TB},$$

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equations for the $\widehat{C}_\ell$s (new result!)

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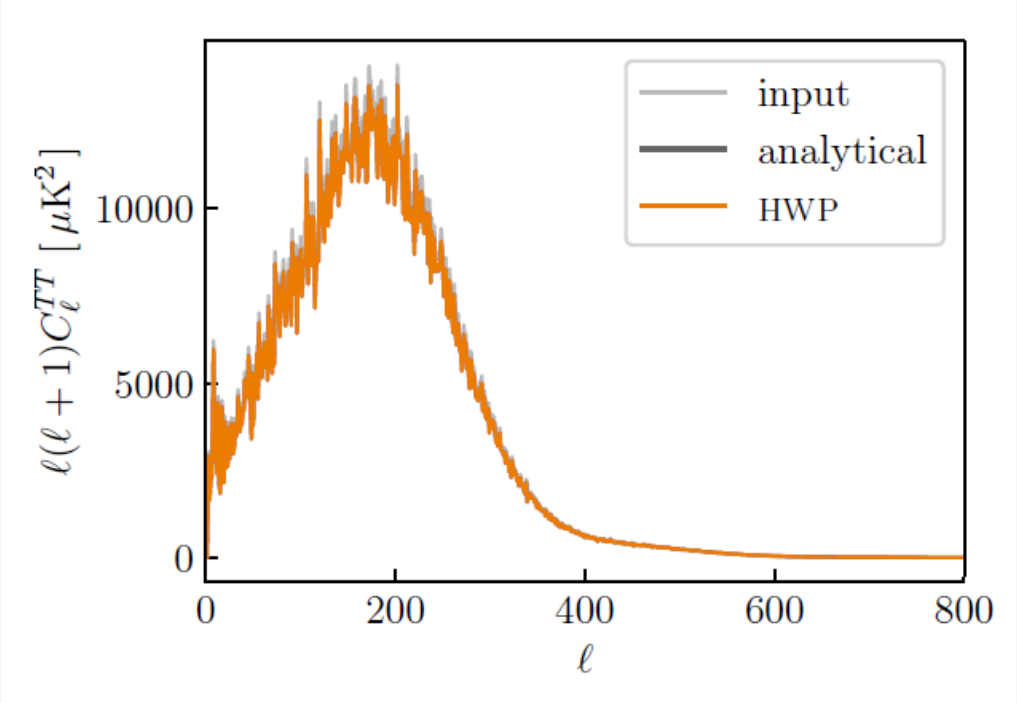
...Let's see if this makes sense!

analytical vs non-ideal output spectra

the analytical and the output spectra almost perfectly overlap!

(the black line is behind the orange one)



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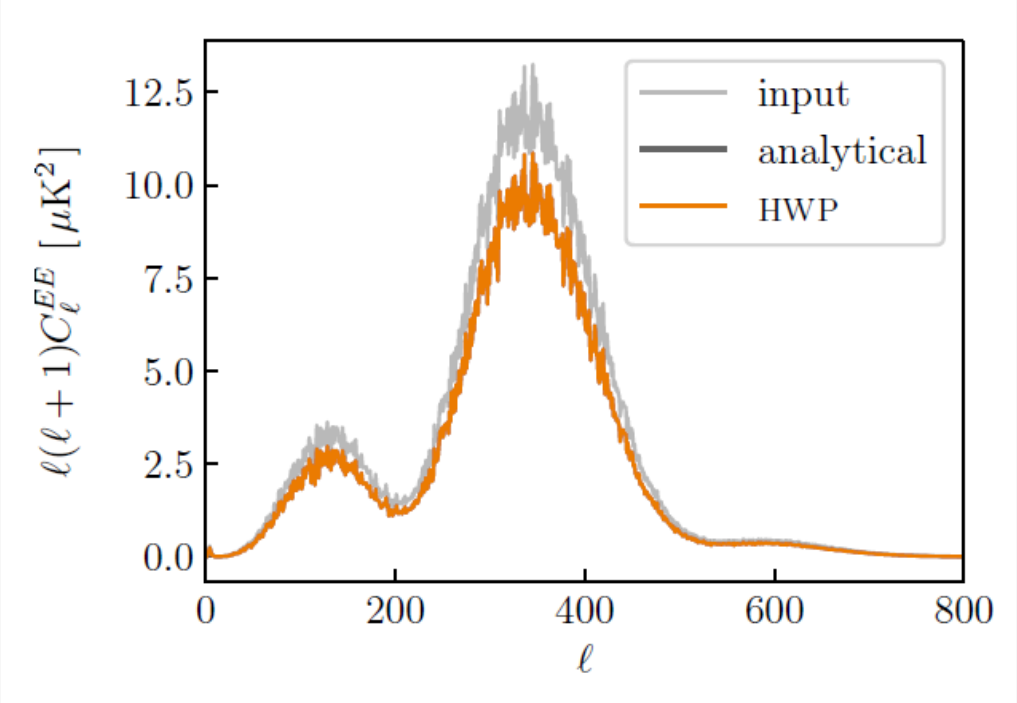

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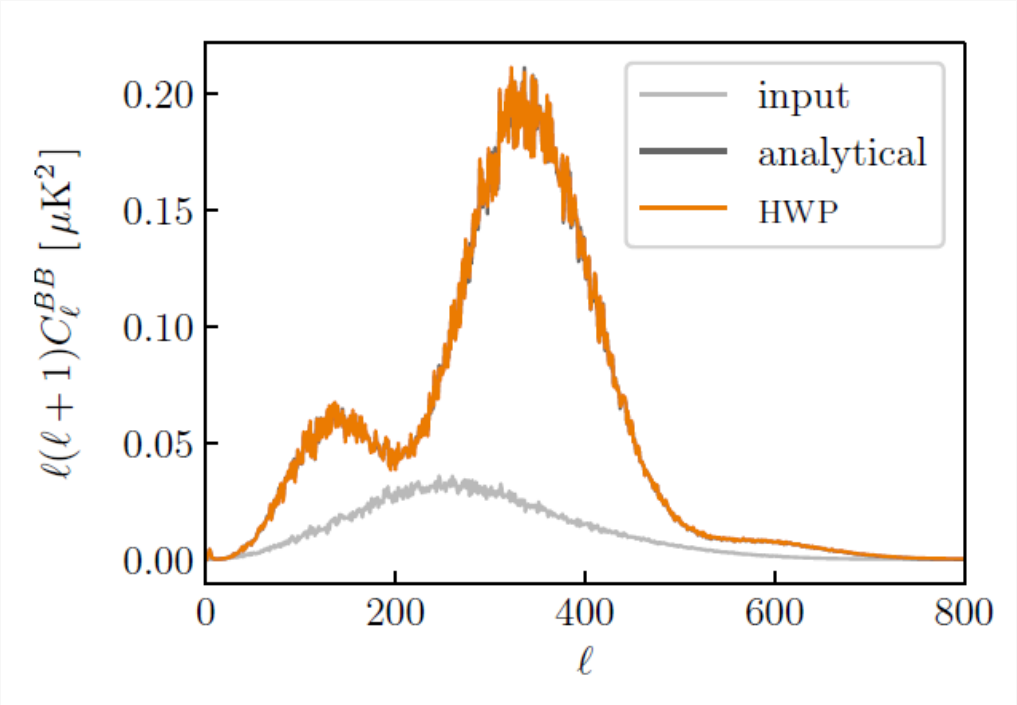

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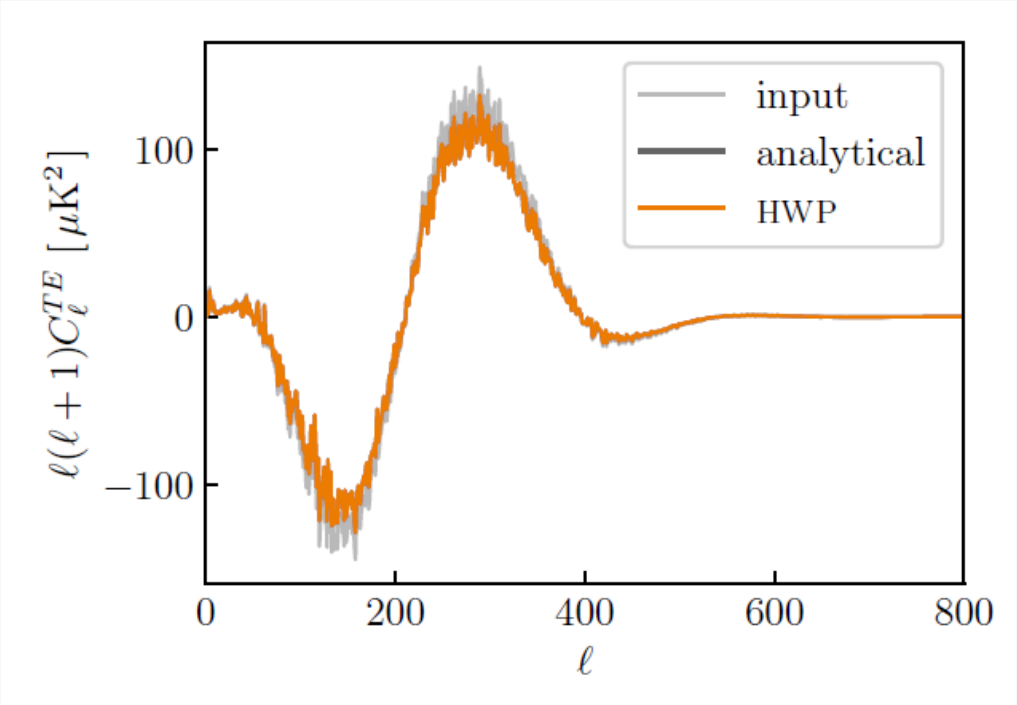

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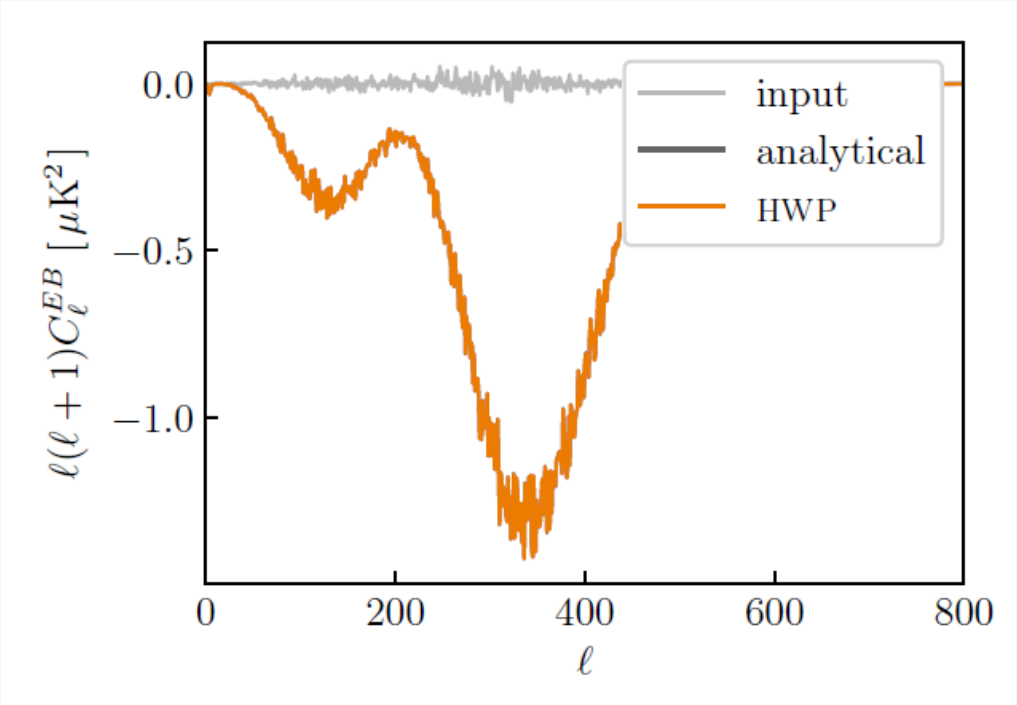

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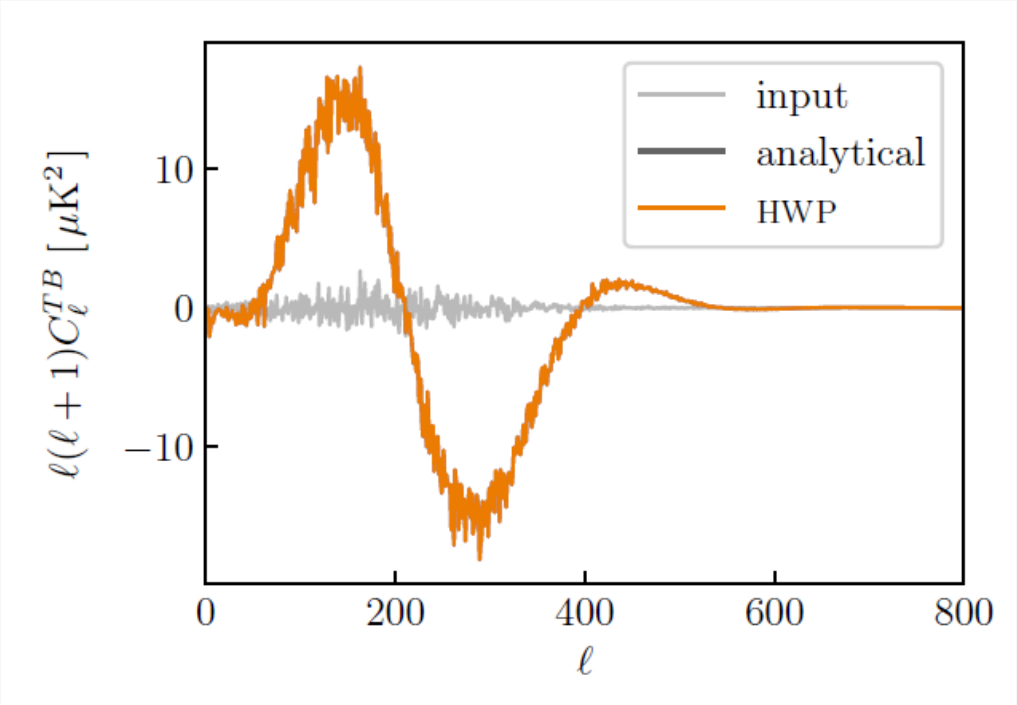

impact on cosmic birefringence

HWP-induced miscalibration

Analytic $\widehat{C}_\ell$s satisfy the relations:

$$\begin{cases} \widehat{C}_\ell^{EB} \simeq \tan(4\widehat{\theta})/2 \left[\widehat{C}_\ell^{EE} - \widehat{C}_\ell^{BB} \right] \\ \widehat{C}_\ell^{TB} \simeq \tan(2\widehat{\theta}) \widehat{C}_\ell^{TE} \end{cases}$$

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Degeneracy with cosmic birefringence and polarization angle miscalibration!

In first approximation, HWP induces an additional miscalibration.

θ_{EB}, θ_{TB} and $\widehat{\theta}$

analytical expectation: $\widehat{\theta} \sim -3.8°$.

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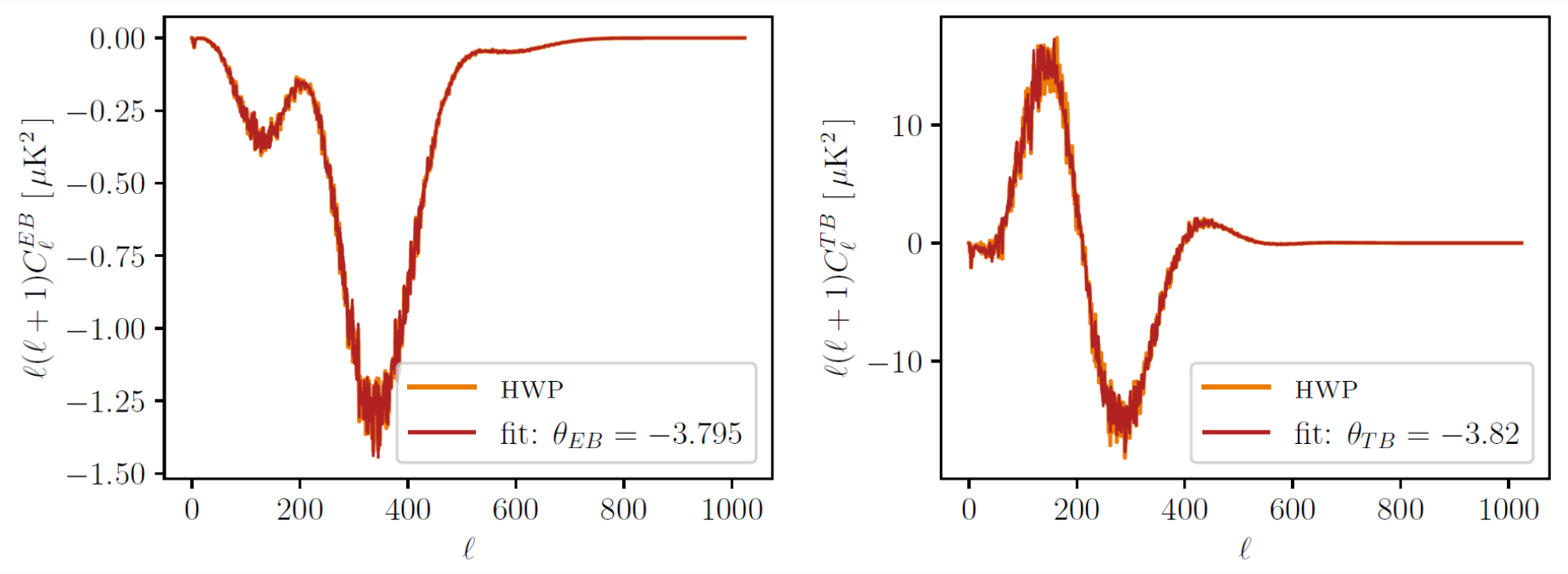

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No: this effect is understood and can be calibrated.

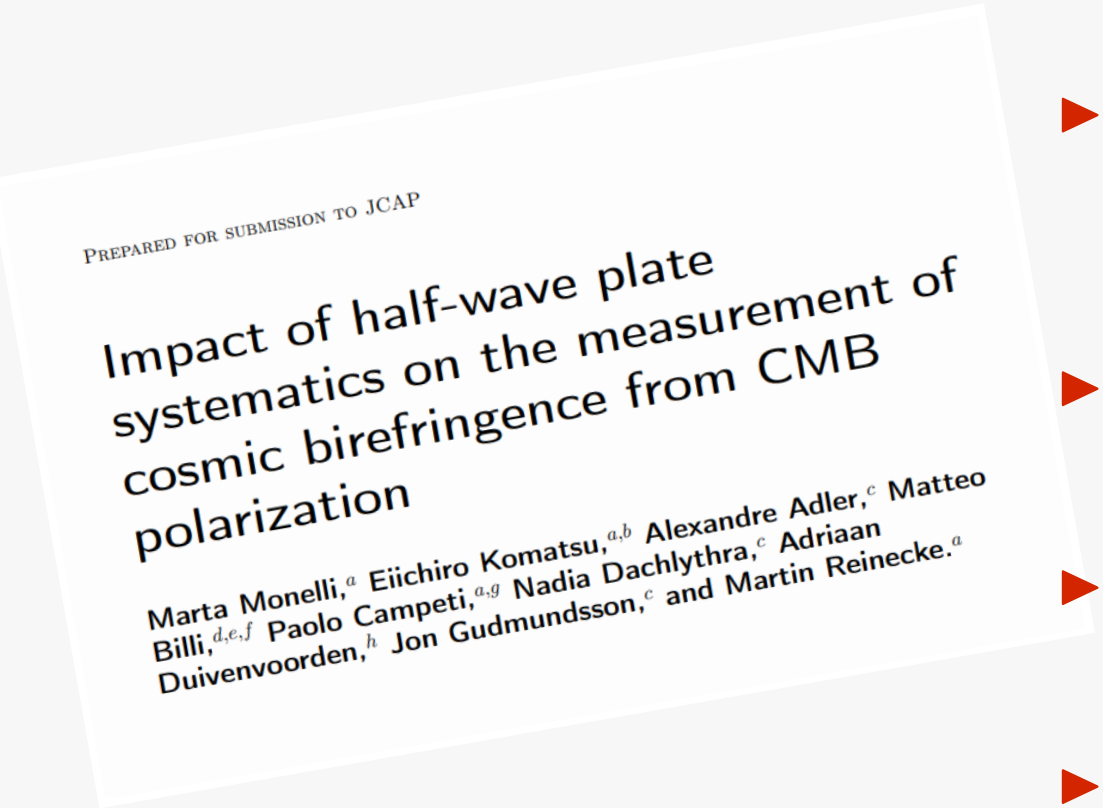
However, it shows how important it is to carefully calibrate $\mathcal{M}_{\mathrm{HWP}}$.

conclusions and outlook

Prepared for submission to JCAP

Impact of half-wave plate systematics on the measurement of cosmic birefringence from CMB polarization

Marta Monelli,[a] Eiichiro Komatsu,[a,b] Alexandre Adler,[c] Matteo Billi,[d,e,f] Paolo Campeti,[a,g] Nadia Dachlythra,[c] Adriaan Duivenvoorden,[h] Jon Gudmundsson,[c] and Martin Reinecke.[a]



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- determine requirements on non-idealities so that systematics on β below 0.1°;
- study impact of non-idealities on EB angle calibration;
- study impact of non-idealities on Q/U maps of Tau A;
- include frequency dependence.