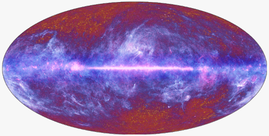
A beamconv-based TOD simulation for a LiteBIRD-like experiment

Marta Monelli

Max Planck Institut für Astrophysik
Garching (Germany)

September 5th, 2022

why do we simulate TOD



CMB sky maps

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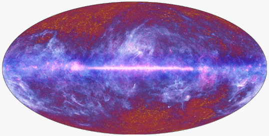

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time ordered data (TOD)

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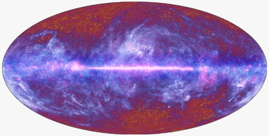

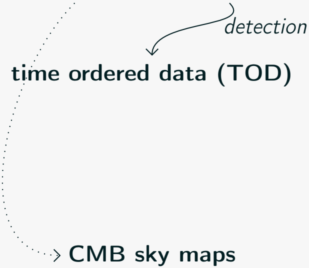

TOD: collection of the signal detected by *each of the (4508) detectors* during *the whole (3-year) mission*.

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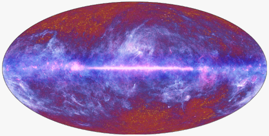

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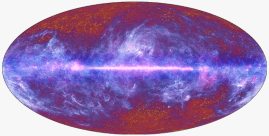

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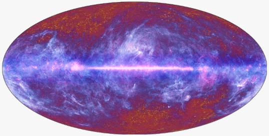

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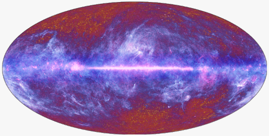

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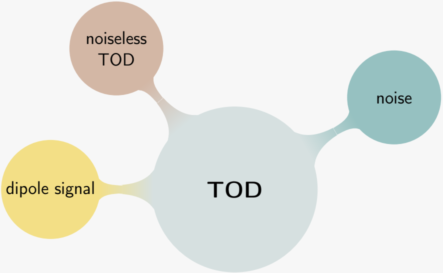
Simulating TOD is crucial in the planning of any CMB experiment: helps studying potential systematic effects.

sketch of the pipeline



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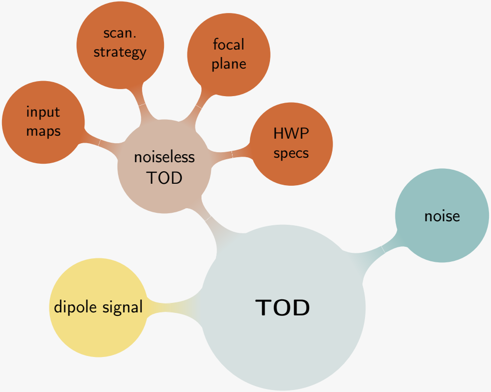

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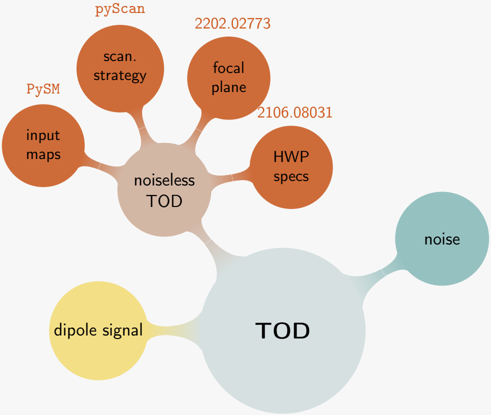

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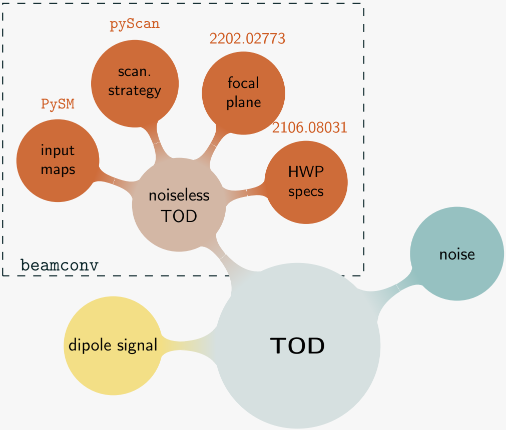
beamconv: convolution code simulating TOD for CMB experiments with realistic polarized **beams**, scanning strategies and **HWP**.



github.com/AdriJD/beamconv, A. Duivenvoorden et al "2012.10437"

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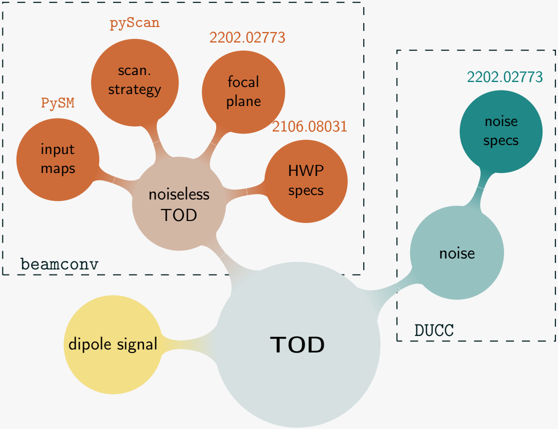
DUCC: collection of basic programming tools for numerical computation: `fft`, `sht`, `healpix`, `totalconvolve`...



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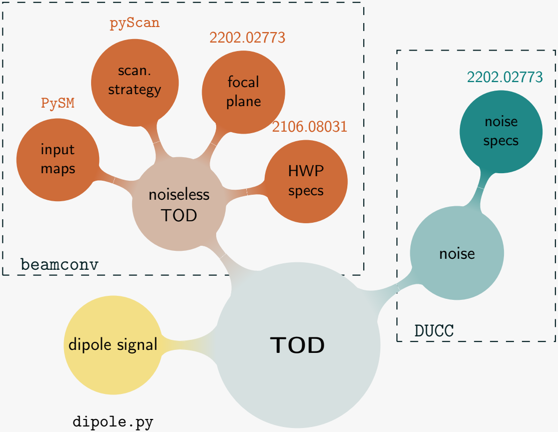

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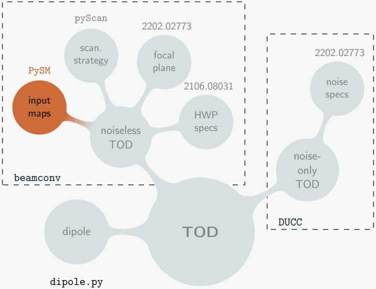
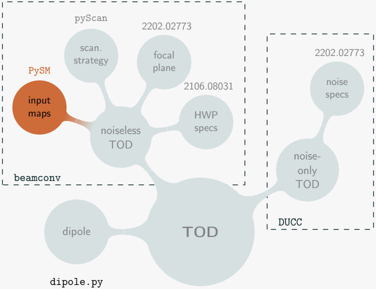
Noiseless component

input maps



Depending on the specific interest, one can use CMB-only input maps or include foreground emission.

input maps



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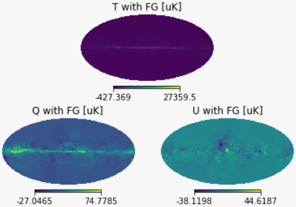
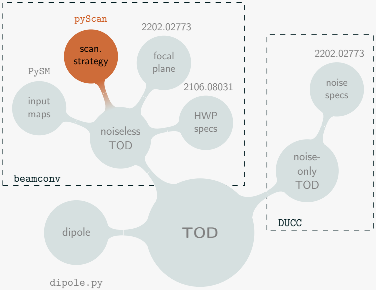
Based on the Planck Sky Model, `PySM` can simulate both (FG: thermal dust, synchrotron, free-free and AME).



scanning strategy



The pipeline can read pointings in input, or calculate them in a few cases.

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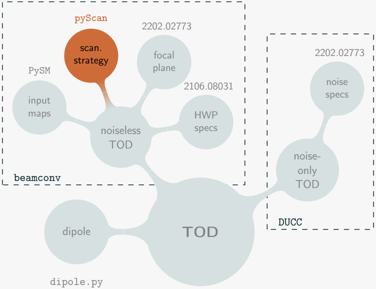

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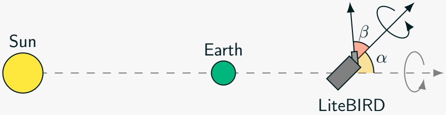

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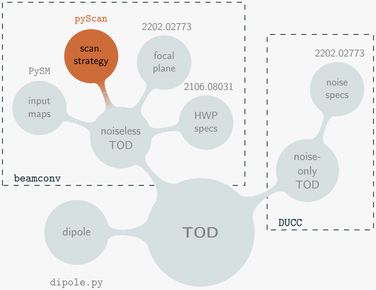

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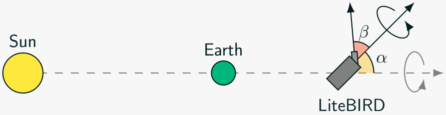
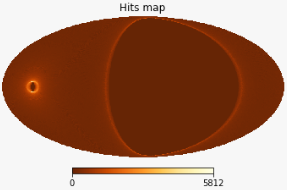
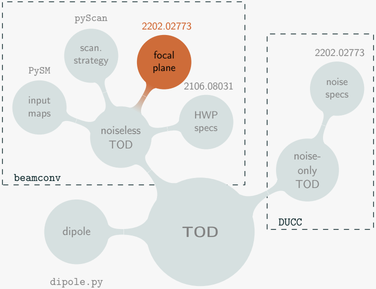




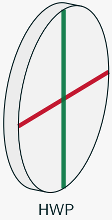
focal plane specifics



For LiteBIRD, relevant info in the Instrument Model Database (IMO):

```
{'name': 'M02_030_QA_140T',
 'wafer': 'M02',
 'pixel': 30,
 'pixtype': 'MP1',
 [...]
 'pol': 'T',
 'orient': 'Q',
 'quat': [1, 0, 0, 0]}
```

the half-wave plate (HWP)



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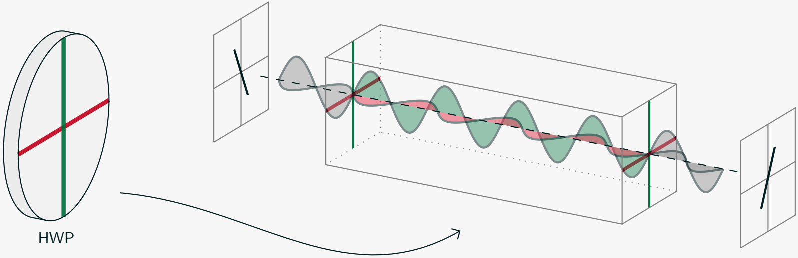

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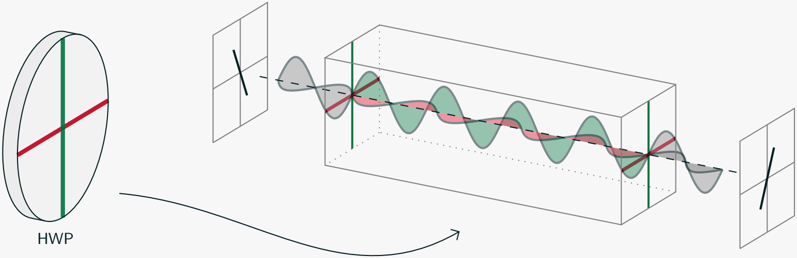
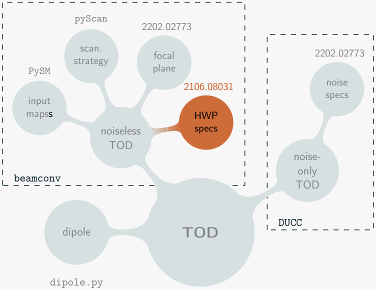


A **rotating** HWP as first optical element: reduces both $1/f$ noise and pair-differencing systematics.

HWP specifics

Describing radiation as $S = (I, Q, U, V)$ and HWP effects by $\mathcal{M}_{\mathrm{HWP}}$: $S' = \mathcal{M}_{\mathrm{HWP}} S$.

$$\mathcal{M}_{\mathrm{ideal}} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$



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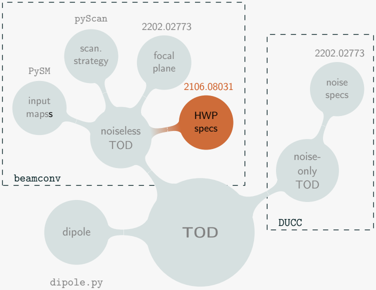

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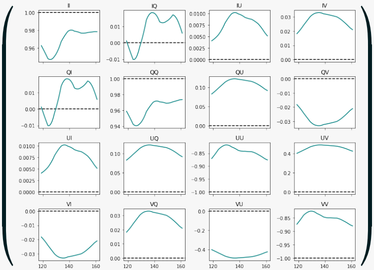
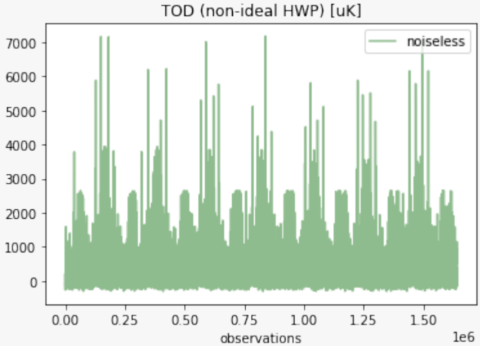


Output: time ordered data

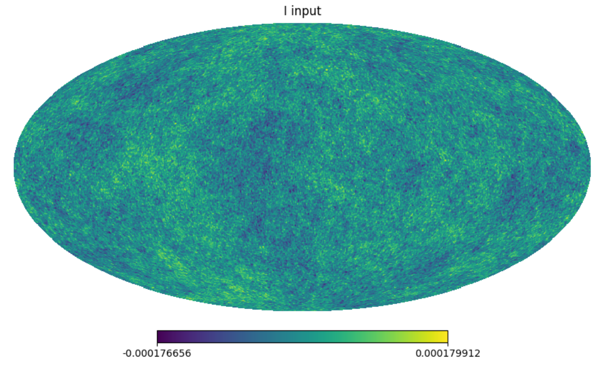


This is a day of observation for a single detector.

The signal is dominated by the foreground emission.

The "periodicity" corresponds to a precession period.

Output: binned maps



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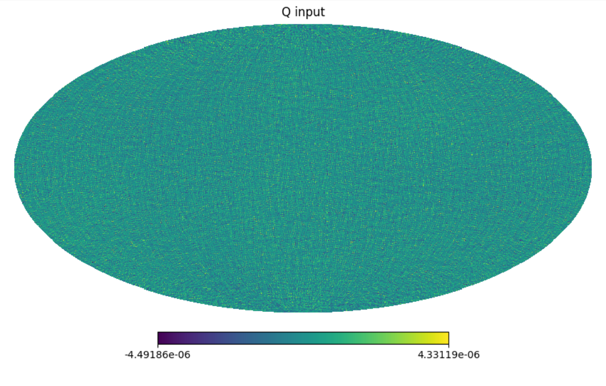

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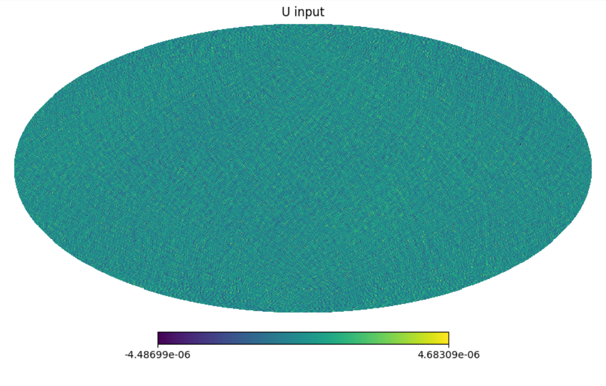
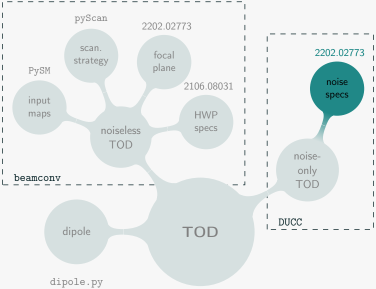


Noise and dipole

noise specifics



The IMO contains also the parameters that enter in the noise power spectrum:

$$P(f) = NET^2 \left[\frac{f^2 + {f_{\text{knee}}}^2}{f^2 + {f_{\text{min}}}^2} \right]^{\alpha}.$$

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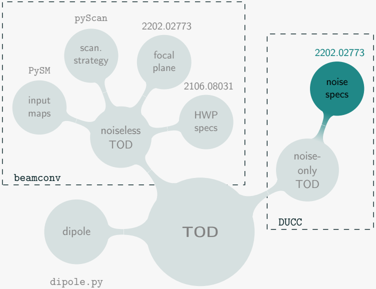

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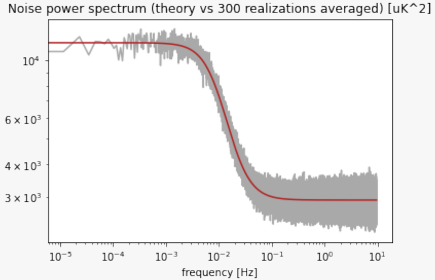
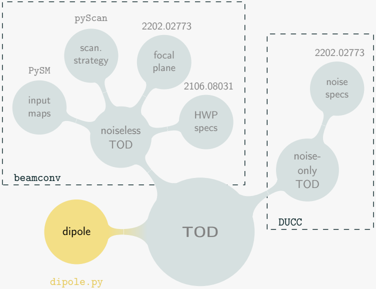


injection of the CMB dipole



The dipole signal is calculated by following the procedure employed in `litebird_sim`'s dipole module.

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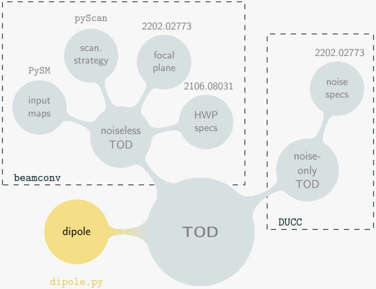

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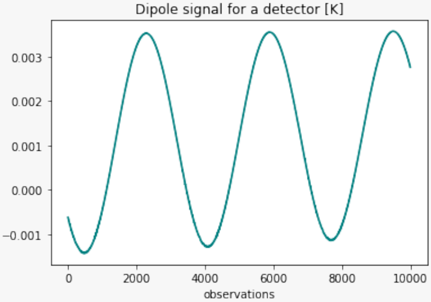

Moving forward

to-do list

Besides smaller adjustments, there are a few major changes that are will be implemented in the near future:

- ☐ adapt the pipeline for production purposes.
- ☐ use more realistic beam shapes;
- ☐ include frequency-dependence of HWP non-idealities;

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the code now runs on a cluster (160 dets on a single node, easily extendable to more dets)

wish list

Once those changes will be implemented, the pipeline could be used to

- study how the HWP non-idealities affect the measurement of the cosmic birefringence angle β;
- determine requirements on non-idealities so that the systematics on β are well below $0.1°$;
- study the impact of non-idealities on the EB angle calibration;
- study the impact of HWP non-idealities on Q/U maps of Tau A.

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HWP and cosmic birefringence


Prepared for submission to JCAP

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

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[b]Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU, WPI), UTIAS, The University of Tokyo, Chiba, 277-8583, Japan
[c]The Oskar Klein Centre for Cosmoparticle Physics, Department of Physics, Stockholm University, SE-106 91 Stockholm, Sweden
[d]Instituto de Física de Cantabria (IFCA), CSIC-UC, Avenida de Los Castros s/n, 39005 Santander, Spain
[e]Dipartimento di Fisica e Astronomia, Alma Mater Studiorum Università di Bologna, Via Gobetti 93/2, I-40129 Bologna, Italy
[f]Istituto Nazionale di Astrofisica - Osservatorio di Astrofisica e Scienza dello Spazio di Bologna, via Gobetti 101, I-40129 Bologna, Italy
[g]Excellence Cluster ORIGINS, Boltzmannstr. 2, 85748 Garching, Germany
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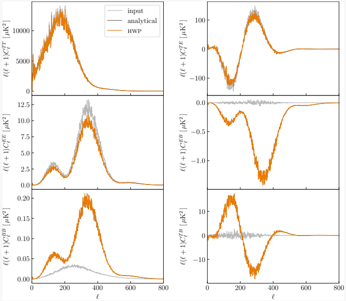
Abstract. Non-idealities in the half-wave plate (HWP) potentially represent a relevant source of systematics for CMB experiments that employ it as polarization modulator. In this paper we study the impact that neglecting the HWP non-idealities in the map-making step has on the observed angular power spectra. We find that the effect is partially degenerate with a non-zero cosmic birefringence angle and/or an instrumental miscalibration of the polarization angles, and could therefore be misinterpreted as a signature of cosmic birefringence. For the particular choice of HWP we employ, such HWP-induced miscalibration amounts to an angle $\theta \sim -4°$. We obtain this value by running full-sky beam convolution time-ordered data (TOD) simulations and processing the output noiseless TOD through a naive bin averaging map-maker. We derive a set of approximate analytic formulae which accurately model the observed spectra and predict a value of the HWP-induced miscalibration angle that is compatible with simulation results.



$$C_{\ell,\mathrm{obs}}^{EB} = \frac{\tan(4\theta)}{2}\left[C_{\ell,\mathrm{obs}}^{EE} - C_{\ell,\mathrm{obs}}^{BB}\right],$$

$$C_{\ell,\mathrm{obs}}^{TB} = \tan(2\theta)\, C_{\ell,\mathrm{obs}}^{TE},$$

wish list (again)

- ☑ study how the HWP non-idealities affect the measurement of the cosmic birefringence angle β;
- ☐ determine requirements on non-idealities so that the systematics on β are well below $0.1°$;
- ☐ study the impact of non-idealities on the EB angle calibration;
- ☐ study the impact of HWP non-idealities on Q/U maps of Tau A.