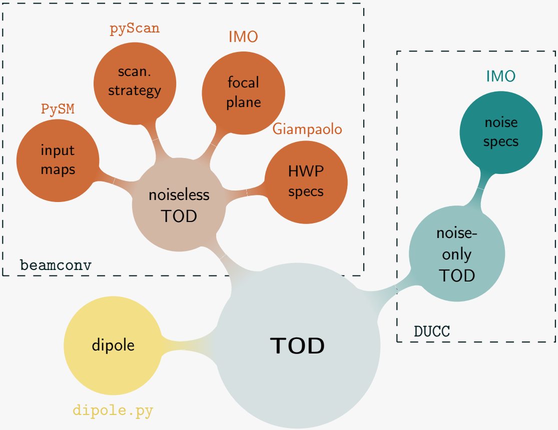
A beamconv-based LiteBIRD simulation

Marta Monelli
Max Planck Institut für Astrophysik
Garching (Germany)

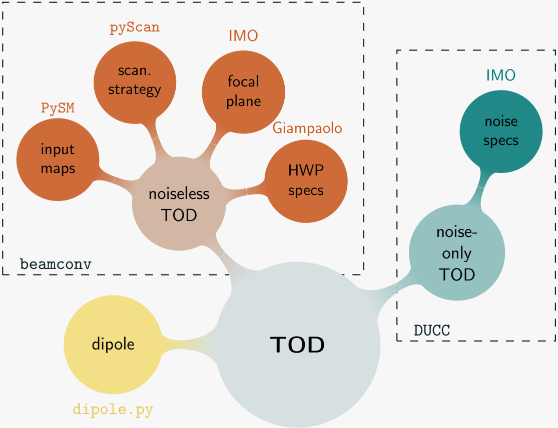
December 1st, 2021

A sketch of the pipeline



A sketch of the pipeline

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

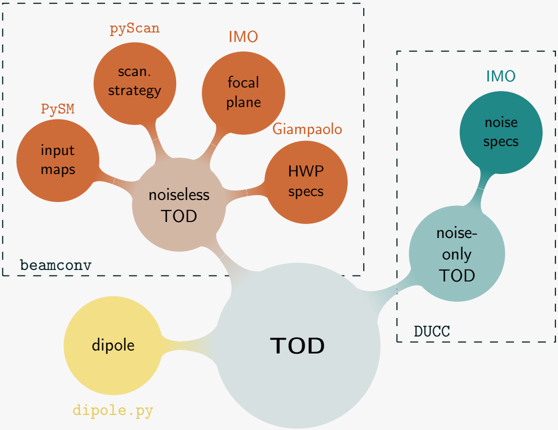


github.com/AdriJD/beamconv, A. Duivenvoorden et al "2012.10437",

A sketch of the pipeline

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

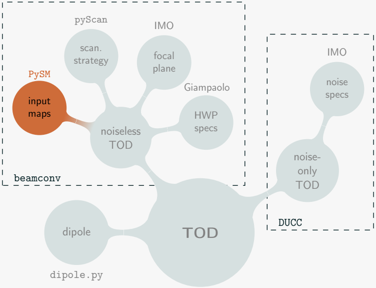
`DUCC`: collection of basic programming tools for numerical computation: `fft`, `sht`, `healpix`, `totalconvolve`...



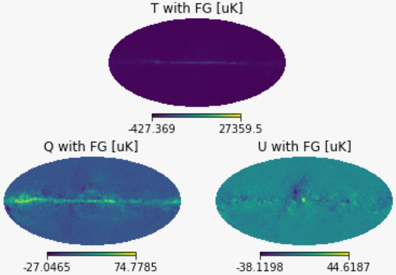
github.com/AdriJD/beamconv, A. Duivenvoorden et al "2012.10437", gitlab.mpcdf.mpg.de/mtr/ducc.

Input

Input maps

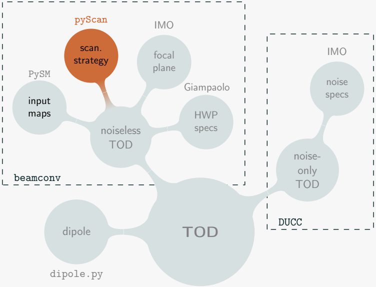


The input maps are obtained by making use of `PySM`, including both CMB signal and foreground emission (thermal dust, synchrotron, AME and free-free).



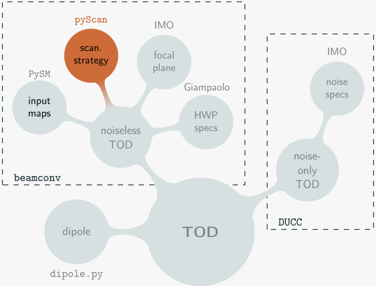
Single frequency FG maps (140 GHz).

Scanning strategy

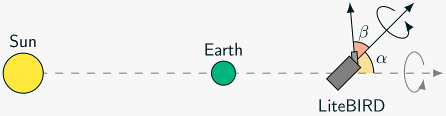


In order to simulate LiteBIRD's scanning strategy, some functionalities of `pyScan` have been implemented in `beamconv`.

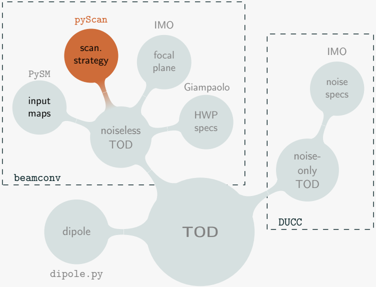
Scanning strategy



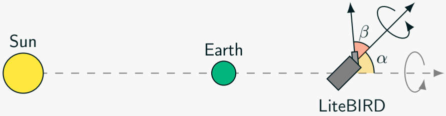
In order to simulate LiteBIRD's scanning strategy, some functionalities of `pyScan` have been implemented in `beamconv`.

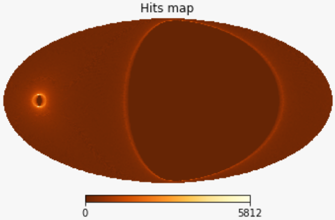


Scanning strategy

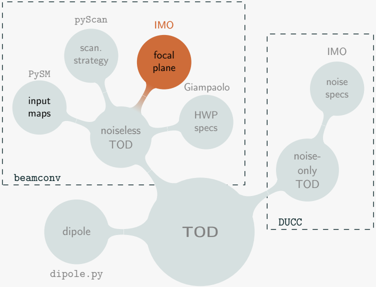


In order to simulate LiteBIRD's scanning strategy, some functionalities of `pyScan` have been implemented in `beamconv`.





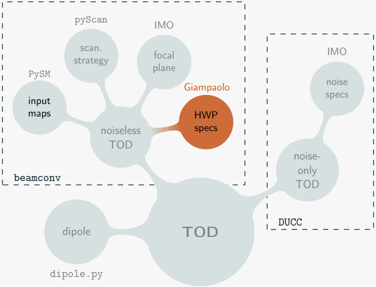
Focal plane specifics



The Instrument Model Database (IMO) contains all the relevant information:

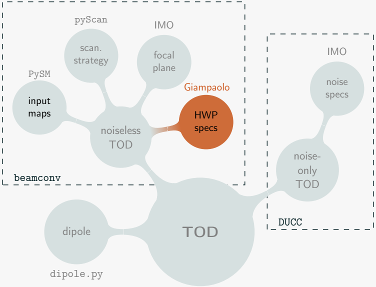
```
{
 'name': 'M02_030_QA_140T',
 'wafer': 'M02',
 'pixel': 30,
 'pixtype': 'MP1',
 [...]
 'pol': 'T',
 'orient': 'Q',
 'quat': [1, 0, 0, 0]
}
```

HWP specifics

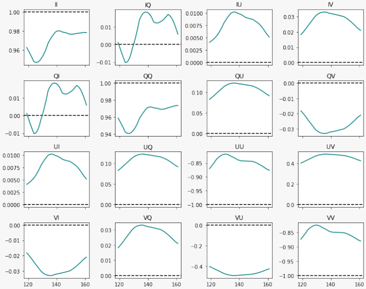


$$\mathcal{M}_{\text{ideal}} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}.$$

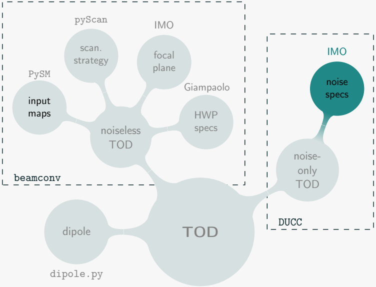
HWP specifics



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



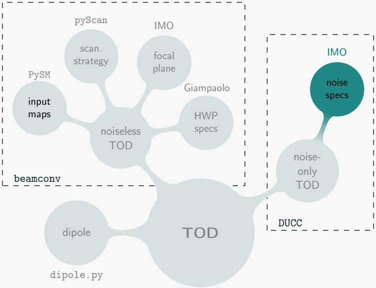
Noise specifics



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

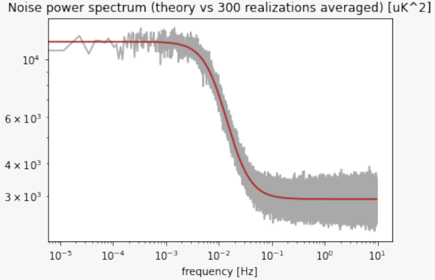
$$P(f) = NET^2 \left[\frac{f^2 + f_{\text{knee}}{}^2}{f^2 + f_{\text{min}}{}^2} \right]^{\alpha}.$$

Noise specifics

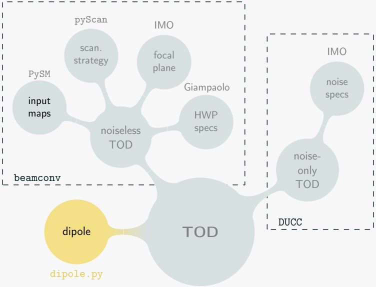


The IMO contains also the parameters that enter in the noise power spectrum:

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



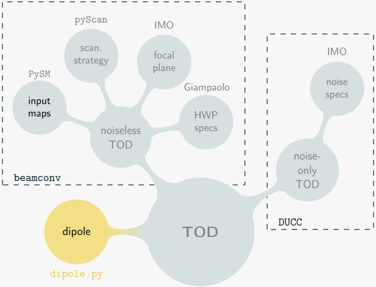
Injection of the CMB dipole

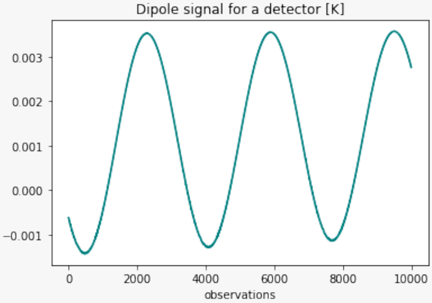


The dipole signal is calculated by following the procedure employed in `litebird_sim`'s dipole module.

Injection of the CMB dipole

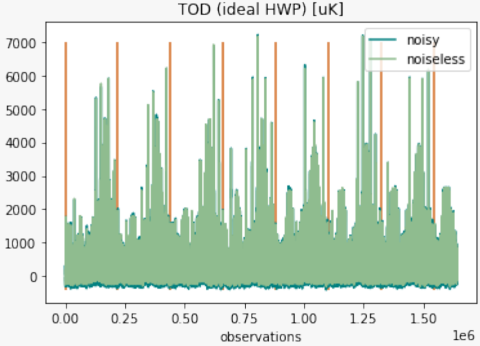
The dipole signal is calculated by following the procedure employed in `litebird_sim`'s dipole module.





Output

Time ordered data

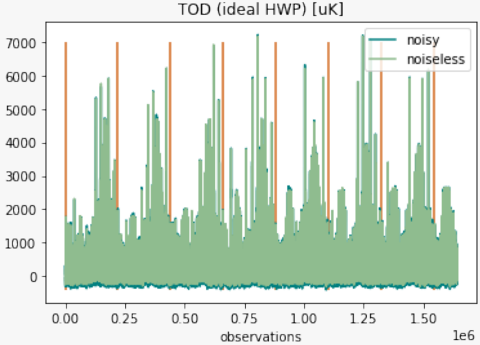


This is a day of observation for a single detector.

The signal is dominated by the foreground emission.

The "periodicity" corresponds to a precession period.

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.

Let’s give a closer look:
demo on GitHub.

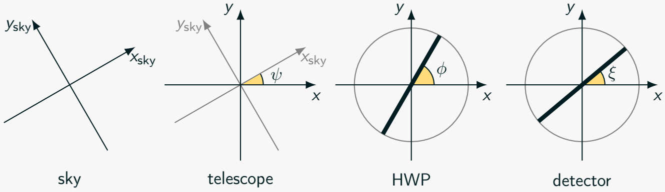
A countercheck (expectation)

Data model with ideal HWP:

$$d = \frac{1}{2} m_{ii} I + \frac{1}{2}[m_{qq} \mathrm{c}_1 \mathrm{c}_2 + m_{uu} \mathrm{s}_1 \mathrm{s}_2] Q + \frac{1}{2}[m_{qq} \mathrm{s}_1 \mathrm{c}_2 - m_{uu} \mathrm{c}_1 \mathrm{s}_2] U \,.$$

Difference between d with and without HWP:

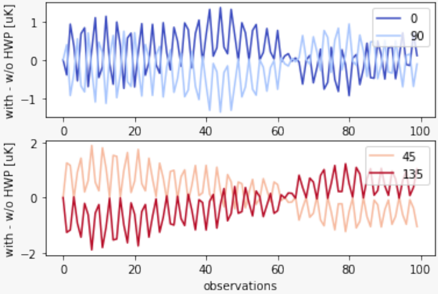
$$\Delta d = \sin 2(\psi - \xi) \left[-\sin 2(\phi + \psi) Q + \cos 2(\phi + \psi) U \right] ,$$



A countercheck (result)

$$\Delta d = \sin 2(\psi - \xi)\left[-\sin 2(\phi + \psi)Q + \cos 2(\phi + \psi)U\right] ,$$

This quantity has opposite sign for detectors sensitive to orthogonal direction of the polarization angle ($\xi \to \xi \pm \pi/2$). This effect is visible in the simulation:



Moving forward

Still to be implemented

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

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

Still to be implemented

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

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

Still to be implemented

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

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

Still to be implemented

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

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

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.

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.

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.

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.

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.