# User requirements to level S

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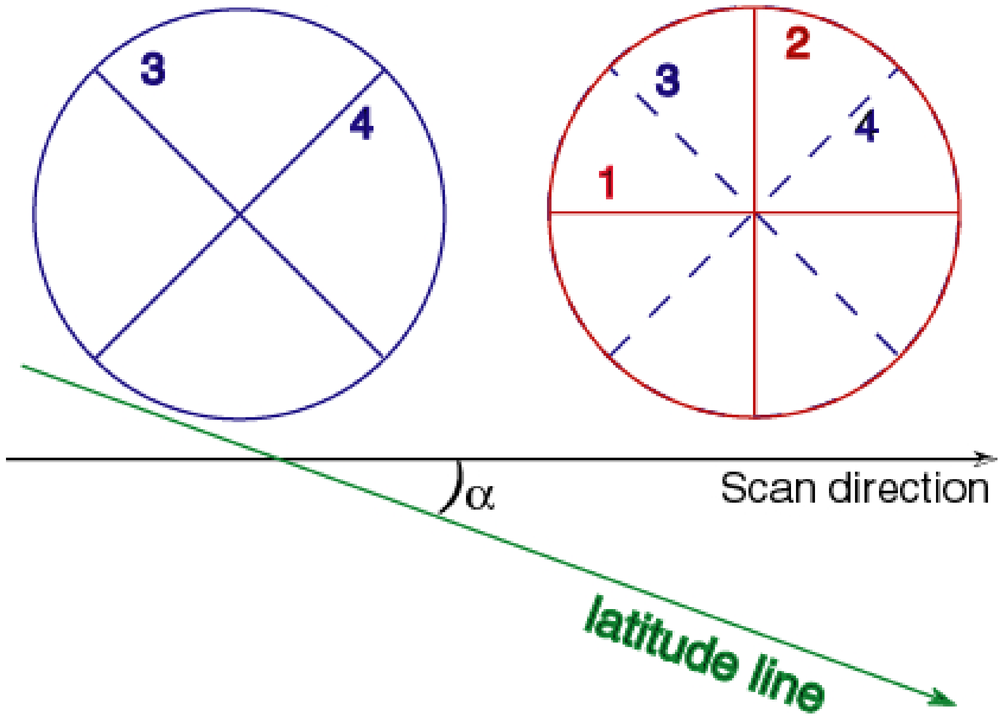
- We begin preparing the treatment of polarization specific systematic effects
- No code delivery is planned for the breadboard model
- Still we want to define now what are the needs in terms of simulated data to prepare the algorithms for data treatment

- This in done in close contact with the Systematic Effects Working Group
- Inside L2 we have to coordinate our work with the people in charge of systematic effects on temperature

# How is polarisation measured?

- By combining the data from two adjacent PSB's




Ideally

$Q_{\text{focal}} = m_1 - m_2, \quad U_{\text{focal}} = m_3 - m_4$

$Q_{sky} = Q_{\text{focal}} \cos 2\alpha + U_{\text{focal}} \sin 2\alpha$

# In reality

$$\begin{pmatrix} m_1 \\ m_2 \end{pmatrix} \leftarrow \boxed{\text{PSB}} \leftarrow \begin{pmatrix} I \\ Q \\ U \end{pmatrix}_{\text{PSB}} \leftarrow \boxed{\text{Telescope} + \text{Horn}} \leftarrow \begin{pmatrix} I(\vec{n}) \\ Q(\vec{n}) \\ U(\vec{n}) \end{pmatrix}_{\text{Far}}$$

$$m_1 = \frac{g_1}{2}\left((1+\varepsilon)I_{\text{PSB}} + (1-\varepsilon)Q_{\text{PSB}}\right)$$

$$m_2 = \frac{g_2}{2}\left((1+\varepsilon)I_{\text{PSB}} - (1-\varepsilon)Q_{\text{PSB}}\right)$$

$\varepsilon$ : cross-polarization leakage rate

$g_{1/2}$ $(1+\varepsilon)$: gain factors, need to be cross-calibrated

$(I, Q, U)_{\text{Far}}$ are the sky Stokes parameters in the spacecraft frame of reference

$$Q_{\text{Far}}(\vec{n}) = Q_{\text{Sky}}(\vec{n}) \cos 2\alpha - U_{\text{Sky}}(\vec{n}) \sin 2\alpha$$

$$U_{\text{Far}}(\vec{n}) = Q_{\text{Sky}}(\vec{n}) \sin 2\alpha - U_{\text{Sky}}(\vec{n}) \cos 2\alpha$$

# Beams

$$I_{\text{PSB}} = \int a_I^I(\vec{n}) I_{\text{Far}} + a_Q^I(\vec{n}) Q_{\text{Far}} + a_U^I(\vec{n}) U_{\text{Far}} \, d\vec{n}$$

$$Q_{\text{PSB}} = \int a_I^Q(\vec{n}) I_{\text{Far}} + a_Q^Q(\vec{n}) Q_{\text{Far}} + a_U^Q(\vec{n}) U_{\text{Far}} \, d\vec{n}$$

2 sets of polarized beam patterns are needed

$a^I_{I,Q,U}$ and $a^Q_{I,Q,U}$

# Cross polarisation leakage

1) A known rate $\varepsilon = I \; / \; I_{//}$ of cross polarisation leakage only increases the statistical error by a factor $1/(1-\varepsilon)^{1/2}$

2) Uncertainties on the rate of cross polarisation leakage or polarimeter directions introduce systematic errors :

| 4 polarimeters | T(μK) 2.73E+06 | Q=U(μK) 1 |
|---|---|---|
| Error on leakage rate | Relative RMS error on polarisation | Average Error on polarisation direction |
| 0.01 | 1.4% | 0.2 deg |
| 0.05 | 7% | 2 deg |
| 0.1 | 15% | 4.5 deg |
| 0.2 | 35% | 8 deg |

We need inputs with cross-polarisation leakage to try and evaluate it from the data

# Polarimeter orientations in the sky

Uncertainties on the angle α and the relative orientation of the two polarisation sensitive directions of the PSBs, with typical impact:

| 4 polarimeters | T(μK) 2.73E+06 | Q=U (μK) 1 |
|---|---|---|
| Error on polarimeter directions | Relative RMS error on polarisation | Average Error on polarisation direction |
| 0.1 deg | 0.2% | 0.1 deg |
| 0.5 deg | 1% | 0.5 deg |
| 1 deg | 2% | 0.9 deg |
| 2 deg | 5% | 2 deg |
| 5 deg | 12% | 5 deg |
| 10 deg | 24% | 10 deg |

These uncertainties can arise from

- Implementation defects of the focal plane
- Optical polarisation rotation in the telescope

Timelines with imperfect orientations needed

# cross-calibration

- The gains $g_1$, $g_2$ of the two bolometers in one PSB may be different from each other and from the gains $g_3$, $g_4$ of the second PSB.
- A ratio $g_1/g_2 \sim 1+\eta$ induces spurious polarization fluctuations correlated to temperature fluctuations

$$\Delta Q, \Delta U \sim \eta\, \Delta T$$

- This ratio will in general vary.
Variations of order $\Delta\eta$ induces polarisation fluctuations

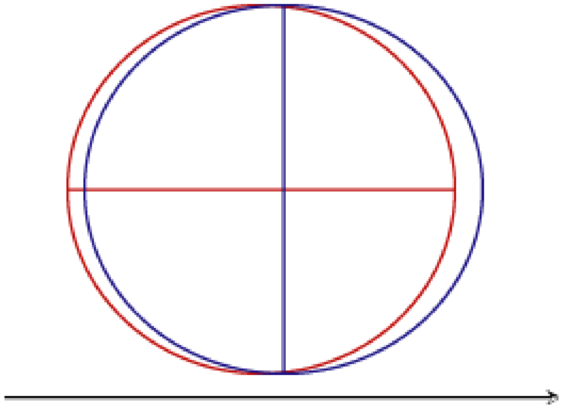
$$\Delta Q, \Delta U \sim \Delta\eta\, T$$

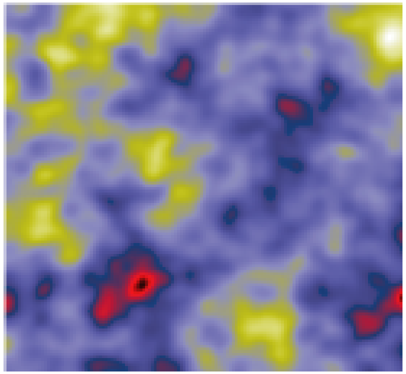
- Timelines with varying gains are needed

# Pointing mismatch

Within a PSB, there can be a pointing mismatch e.g. from different time constants

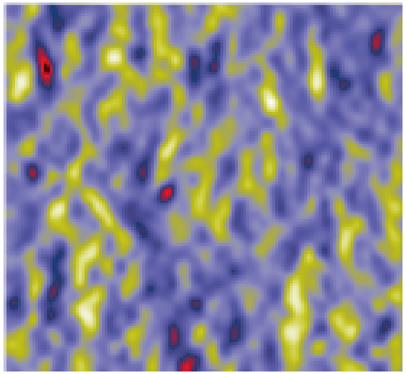
$\Delta\tau \sim 1ms \;\; -> \;\; \Delta\varphi \;\; 0.5'$



$\Delta T, \Delta Q = 0$

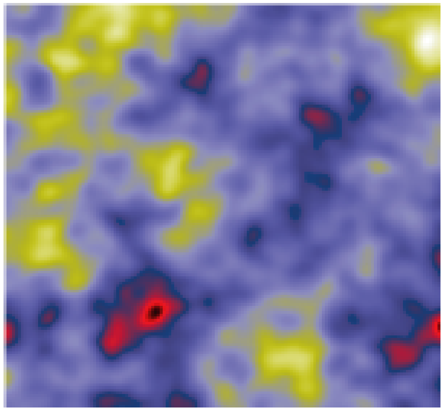
shift
0.5’
Beam
7.5’



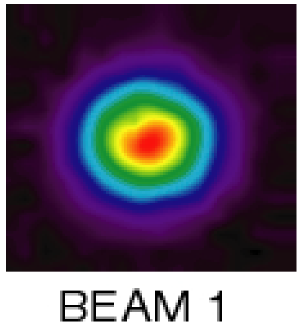
$\Delta Q \sim 0.03\, \Delta T$

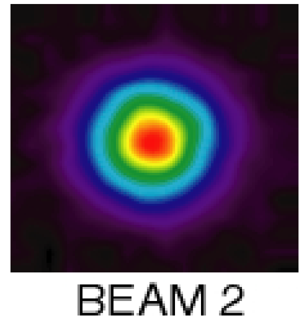
Timelines with mismatched pointing needed

# Beam mismatch

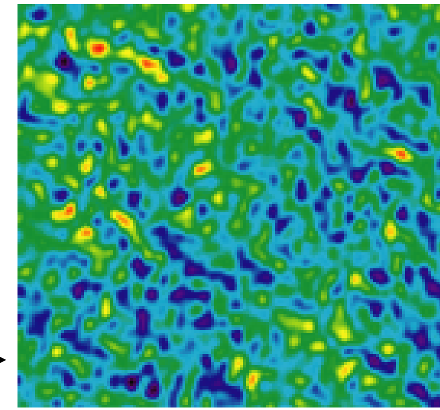


$\Delta T$, $\Delta Q = 0$




Relative difference on the beams : 2.5 % of the max, on 1/3 beam size scales

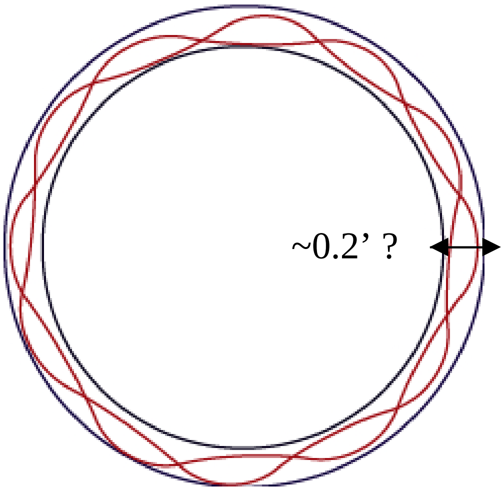


$\Delta Q \sim 0.01\ \Delta T$

## Timelines with mismatched beams needed

# Imperfect rings

Due to wobbling and nutation, the pointing will oscillate around the theoretical scanning circle.




At the moment, timelines are generated by sampling in time preexisting rings

Need for timelines including wobbling and nutation to generate real rings.

Notes added after discussion during the meeting:
1) 0.2’ is the pointing accuracy, the amplitude of the expected nutation is larger, of order 2’ (A. Jaffe).
2) the nutation period is much larger than suggested by the drawing. The nutation damps within a few circles after depointing (J.P. Bernard)

# Conclusions

- We need (by order of increasing difficulty)
  - a Full set of 4 timelines for 2 PSBs (urgent)
  - with small noise level differences
  - with cross polarization leakage
  - with imperfect polarimeter orientations
  - with varying gains
  - with realistically different time response (from both bolometers and readout)
  - 2 sets of polarized beam patterns per PSB are needed $a^{I}_{I,Q,U}$ and $a^{Q}_{I,Q,U}$ (ideally the full Mueller matrix)
  - Timelines including wobbling and nutation