Workshop LiteBIRD-Italia 2023 @ INFN-LNF

## Beam systematics

C. Franceschet, D. Maino \& M. Bersanelli

## MHFT beam systematic effects - context

- Beam systematics and LiteBIRD
- Control of beams is a critical aspect for the mission
- Very stringent requirements on beam knowledge
- Both main beam and sidelobes
- Very large number of detectors
- Beam characterization involves several steps
- Beam computation (e.g. GRASP)
- H/W measurements
- Straylight simulations through the mission
- Impact on science (mainly on $r$ )
- Different expertises are required
- Clarify languages and definitions
- Requirements are «difficult to specify» (especially for far sidelobes)
- Coordination / joint work is crucial


## MHFT beam systematic effects - summary

- Optical model (C. Franceschet)
- MFT realistic model implementation with GRASP
- MFT focal plane configuration IMo v 1.3
- Main beam \& sidelobes simulation
- Assessment of the impact of beam systematics on observations (D. Maino)
- From sidelobes to instrument requirements (from L3 to L4 reqs)
- Different convolution approaches
- Preliminary results


## The MHFT optical model

- MFT optical model
- PH-PE-2lens-MFT-300x22-frozen-april2019 by Pete Hargrave (Apr. 2019)
- Aperture stop $\varnothing=300 \mathrm{~mm}$ (aperture in screen model)
- HDPE lenses ( $n=1.52$ )
- No tube, filters and HWP
- No FPU \& internal baffles
- FPU \& beam former
- FPU configuration IMO v $1.3^{(*)}$
- 49 MFT pixels implemented
- Lenslet pattern by Greg Jaehnig (Apr. 2022)
- V-grooves
- Model based on SHI drawings
- Perfectly reflective panels
- Only three panels of the first layer included
- No other payload/satellite structures (e.g. telescopes envelope, etc.)


## Sinuous antenna + lenslet response

- Sinuous antenna coupled to Si-lenslet
- HFSS model "SinuousAntenna LBMF_A_HFSS_20210420 p17_dL10mm_v1_ant4um" by G. Jaehnig
- Converted into GRASP ".cut" format
- Verification after spherical waves expansion by GRASP (constant phi cuts)



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- Verification after spherical waves expansion by GRASP (uv-grids)



## MFT focal plane configuration

- FPU configuration reported in IMo version 1.3
- $7 \times 7$ pixels sampled on the focal plane (white circles)
- 001_00X_000_YYY
- 001_00X_004_YYY
- 001_00X_026_YYY
- 001_00X_030_YYY (center pixel of the wafer)
- 001_00X_034_YYY
- 001_00X_056_YYY
- 001_00X_060_YYY
- $\mathrm{X}=$ wafer number, $\mathrm{YYY}=$ frequency
- Di-chroic and tri-chroic channels
- W0 : 119-166GHz
- W1 : 119-166GHz
- W2 : 100-140-195GHz
- W3 : 100-140-195 GHz
- W4 : 100-140-195GHz
- W5 : 119-166 GHz
- W6 : $119-166$ GHz



## MFT beams with Physical Optics (PO)

- GRASP ${ }^{\circledR}$ PO simulations of MFT on-axis pixel @140 GHz
- Gaussian pattern vs Sinuous antenna plus lenslet
- Phi $=0$ and phi $=90$ planes at LOS direction
- Beam former $\rightarrow$ aperture stop $\rightarrow$ baffle aperture




Sinuous antenna \& lenslet




## MFT beams with Physical Optics (PO)

- Co-polar and cross-polar MFT beams at 100, 119, 140, 166 and 195 GHz



## MFT side-lobes with Physical Optics (PO)

- GRASP ${ }^{\circledR}$ PO simulations of MFT on-axis pixel @140 GHz
- 3 front panels of $1^{\text {st }} V$-groove
- $\operatorname{Phi}=0$ and $\mathrm{phi}=90$ planes at LOS direction
- Beam former $\rightarrow$ aperture stop $\rightarrow$ baffle aperture $\rightarrow$ VG1




## MFT side-lobes with Physical Optics (PO)

- GRASP ${ }^{\circledR}$ PO simulations of MFT on-axis pixel @140 GHz
- 3 front panels of $1^{\text {st }} \mathrm{V}$-groove
- $\operatorname{Phi}=0$ and phi $=90$ planes at LOS direction
- Beam former $\rightarrow$ aperture stop $\rightarrow$ baffle aperture $\rightarrow$ VG1

- Some notes on the PO approach
- Not feasible for the whole model
- $1^{\text {st }}$ order interactions only at the VG1 front panels
- Reflections
- Diffraction
- At the top and side edges
- Panels bottom is not illuminated
- $2^{\text {nd }}$ order interaction does not converge
- "Back lobes" difficult (impossible?) to be evaluated


## MFT side-lobes with Physical Optics (PO)

- Co-polar and cross-polar MFT beams at 100, 119, 140, 166 and 195 GHz

| $\begin{gathered} \text { 001_000_000_119 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} 001 \text { _000_000_166 } \\ \text { GHz_co.png } \end{gathered}$ | 001_000_004_119 GHz_co.png | 001_000_004_166 GHz_co.png | $\begin{gathered} 001 \text { _000_026_119 } \\ \text { GHz_co.png } \end{gathered}$ | 001_000_026_166 GHz_co.png | $\begin{gathered} 001 \text { _000_030_119 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} 001 \text { _000_030_166 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} 001 \text { _000_034_119 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} 001 \text { _000_034_166 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} 001 \text { _000_056_119 } \\ \text { GHz_co.png } \end{gathered}$ | 001_000_056_166 GHz_co.png | $\begin{gathered} 001 \text { _000_060_119 } \\ \text { GHz_co.png } \end{gathered}$ | 001_000_060_166 GHz_co.png | $\begin{gathered} \text { 001_001_000_119 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_001_000_166 } \\ \text { GHz_co.png } \end{gathered}$ |
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| 001_002_004_140 GHz_co.png | $\begin{gathered} \text { 001_002_004_195 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_002_026_100 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_002_026_140 } \\ \text { GHz_co.png } \end{gathered}$ | 001_002_026_195 GHz_co.png | $\begin{gathered} \text { 001_002_030_100 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_002_030_140 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_002_030_195 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_002_034_100 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_002_034_140 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_002_034_195 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_002_056_100 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_002_056_140 } \\ \text { GHz_co.png } \end{gathered}$ | 001_002_056_195 GHz_co.png | $\begin{gathered} \text { 001_002_060_100 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{aligned} & \text { O01_002.060_140 } \\ & \text { GHz_co.png } \end{aligned}$ |
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| 001_002_060_195 GHz_co.png | $\begin{gathered} \text { 001_003_000_100 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_003_000_140 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_003_000_195 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_003_004_100 } \\ \text { GHz_co.png } \end{gathered}$ | 001_003_004_140 GHz_co.png | $\begin{gathered} 001 \text { GHz_co3_004_195 } \\ \text { GHy } \end{gathered}$ | $\begin{gathered} 001 \text { GHz_003_o26_100 } \\ \text { Gng } \end{gathered}$ | $\begin{gathered} 001 \text { GHz_003_026_140 } \\ \text { Gng } \end{gathered}$ | $\begin{gathered} \text { 001_003_026_195 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_003_030_100 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_003_030_140 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_003_030_195 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_003_034_100 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} 001 \text { GHz_003_034_140 } \\ \text { Gng } \end{gathered}$ | 001_003_034_195 GHz_co.png |
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|  | : | \% | : |  | \% | \% | 2) | [ 0 | : | : |  | 2- | \% | 92 |  |
| 001_004_030_140 GHz_co.png | 001_004_030_195 GHz_co.png | 001_004_034_100 GHz_co.png | $\begin{gathered} \text { 001_004_034_140 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_004_034_195 } \\ \text { GHz_co.png } \end{gathered}$ | 001_004_056_100 GHz_co.png | $\begin{gathered} 001 \text { GHz_coos_o56_140 } \\ \text { Gng } \end{gathered}$ | $\begin{gathered} \text { 001_004_056_195 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_004_060_100 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} \text { 001_004_060_140 } \\ \text { GHz_co.png } \end{gathered}$ | 001_004_060_195 GHz_co.png | $\begin{gathered} \text { 001_005_000_119 } \\ \text { GHz_co.png } \end{gathered}$ | $\begin{gathered} 001 \text { GHz_005_000_166 } \\ \text { Go.png } \end{gathered}$ | 001_005_004_119 GHz_co.png | $\begin{gathered} 001 \text { GHz_005_004_166 } \\ \text { GHy } \end{gathered}$ | 001_005_026_119 GHz_co.png |
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## Next steps

- Improve the MFT realistic model
- Include the forebaffle with "trumpet-shaped" aperture edge
- Include tube, baffles, etc.
- Include small and large structures
- Repeat MFT optics simulations with MoM and GTD
!!! Simulation time strongly limits this activity !!!
- Implementation of HFT model \& optical simulations
- Far sidelobes simulations for a subset of pixels (in progress)
!!! Simulation time strongly limits this activity !!!


Simulation time vs frequency (HFT w/o V-grooves)


## From beam profiles to instrument requirements

## Motivation

- find a simple and direct way to derive beam requirements:
- closer to actual beam measurement procedure
- directly related to actual beam properties specified by, e.g., power dB level
- avoid complications due to full data processing: clearly isolate the actual impact of beam shape only


## Proposed approach

- Assume that we recover the input CMB B spectrum but for cosmic variance (CV)
- No component separations, no instrumental noise
- Use sidelobe convolved galactic signal as residual contamination
- Compare CMB B spectrum + galactic signal w.r.t. CV (we cannot beat cosmic variance!)
- visual inspection of contaminating signal
- construct likelihood for $r$ to evaluate its impact in terms of $\Delta r$
- Useful to evaluate the goodness of polarised beam approximation in convolution with/without HWP
- III:used in PTEP (the same I beam used also for $\mathbf{Q}$ and $\mathbf{U}$ components)
- IPP: combine $Q$ and $U$ beam to create a "polarised" beam ( $\left.P^{2}=Q^{2}+U^{2}\right)$
- TEB: from beam alm: use alm ${ }^{T}$ for total intensity and create $a l m^{P}$ as linear combination of $a l m^{E}$ and alm ${ }^{B}$ for convolution of the polarised signal
- NO-HWP: use Planck totalconvolver with beam as produced by GRASP (this is the actual beam shape)


## Preliminary results (PTEP) @ MFT 100/140/195







- No III/TEB convolution @195
- III and IPP very similar: both 5 and 10 degs cuts are larger than CV
- TEB and No-HWP very similar with only 5deg cuts showing smaller excess over CV


## Preliminary results: rlikelihood



Impliment a simple $r$ likelihood (no noise, CV and residual galactic sidelobes signal as contaminant)

- III and IPP cannot go lower than 5 $10-5$ very similar: both 5 and 10 degs cuts are larger than CV
- TEB: near sidelobes are more important than far sidelobes
- No-HWP (actual beam shape):
- $\quad 140$ \& 195: beam knowledge down to 5 degs is enough to reach rerror budget and.
- ... this is true @100 with knowledge between 5 and 10 degs


## Next steps

- Use latests beams from Cristian: on-going already produce beam alm
- Consider 3 cases:
- central beams in the central Wafer (for trichroic 100/140/195)
- use larger off-axis beams
- use all beams combined
- Cut the beam not in angle but according to its own power level (should be closer to actual beam measurements)
- We are in touch with Clement and provide him with our No-HWP beam convolver maps to derive his own beam requirements and compare with our simple approach. This should be the basis for moving from L3 to L4 requirements.

