Report from the « Focal Plane / Telescope » parallel session

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Towards a next space probe for CMB observations and cosmic origins exploration
CERN – 20 May 2016
Session target: define a baseline instrument configuration compatible with our tight budget requirements.

**Session items:**
- Instrument baseline
- Telescope
- Detectors
- Open issues
1.5m (1.2m) Gregorian telescope

2 V-grooves, innermost surface @100K

0.5m focal plane, 3200 single polarization single frequency KIDs, planar-lens-coupled to telescope

Polarised survey sensitivity: 2.3µK.arcmin

TM data-rate 42.1 GB/day (1.5m)
Detector coupling with mesh-lenses

Giampaolo Pisano
on behalf of
Maynooth, Manchester, Cardiff, Rome, Paris APC & Chalmers
ESA project: “Next Generation Sub-Millimetre Wave Focal Plane Array Coupling Concepts”

CMB workshop, CERN, May 17-20, 2016
Flat Mesh Lens: Inhomogeneous Phase Delays

Inhomogeneous grids

Locally variable grid geometries

Multiple transmission lines

54 mm Ø

W-Band f/3 lens prototype (1.4mm thick)

- Very thin and robust
- Very light and low loss
- No Anti Reflection Coatings required

G. Pisano et al.
Mesh Lens Array: Coupling to a Waveguide Probe Antenna
As for all instruments, there are issues:

• Background on the detectors – from the 100K (or 60K) environment. Mitigation:
  – Cold cryostat around focal plane
  – Low emissivity of 100K (60K) environment
• Heat load on the 0.1K and 1K cryostat stages. Mitigation:
  – Low emissivity of the 100K (60K) environment
  – Connect black shield around focal plane to 4K and improve sidelobe rejection (larger flat lenses)
• Need for accurate analysis (view factors, emissivity of V-grooves, emissivity of telescope shields, edge taper of flat lenses / detector).
• Coordinated effort of a group including optics/cryo/system experts.
Issues with this configuration

- Detector sensitivity depends on the radiative background on the detectors. Two sources: the telescope/sky and the surrounding environment.
- For this reason we need a cryostat around the focal plane, with an innermost shield black (*to absorb straylight*) and cold (*to limit the background*) and an appropriate stack of low-pass filters.
- For a 100K temperature of the telescope, the innermost shield must be at 1K, otherwise its background dominates over the background from the telescope and the sky.
- However, a black shield with these dimensions absorbs radiation from the telescope environment at 100K. To avoid unacceptable load on the cryogenic system (0.2mW heat lift @ 1K), the environment must be low emissivity (only reflecting/diffusing shields, shiny inner surface of the innermost V-groove).
- An alternative is to raise the temperature of the innermost shield from 1K to 4K, where the heat lift of the cryogenic system is 30mW. But this requires also to improve the edge taper of the planar-lens coupling to the detectors, otherwise the 4K background dominates over the background from the sky and the telescope. The flat lenses should be larger diameter, and the number of detectors will be reduced (as well as the survey sensitivity).
- A combination of the two mitigations might still work.
- To be investigated in detail, better specifying the view factors, the telescope environment, the optical coupling.
NIKA2: the arrays

- 2mm: 600÷1000 pixels → 4 feedlines
- 1.25mm: 1200÷2000 pixels → 8 feedlines

Single 4" wafer fabrication

NIKELv1 boards: MUX factor 400 over 500MHz band

Current MUX factor: **250** (for safety + Q_q on ground!)
The B-SIDE project

B-SIDE: a balloon-borne experiments for the study of polarized foregrounds

- Funding: on the way! (hopefully..)
- Launch planned for 2018/2019

<table>
<thead>
<tr>
<th></th>
<th>Specifications</th>
<th>Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary mirror diameter (m)</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Instantaneous field-of-view (deg)</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Angular resolution (arc-min)</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Number of bands</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Flight Duration (days)</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Operating frequencies (GHz)</td>
<td>450-630</td>
<td>400-600 &amp; 500-700</td>
</tr>
<tr>
<td>Number of pixels</td>
<td>980</td>
<td>1800</td>
</tr>
<tr>
<td>NEP (W/Hz^0.5)</td>
<td>$5 \cdot 10^{-16}$</td>
<td>$2 \cdot 10^{-16}$</td>
</tr>
<tr>
<td>Background per pixel</td>
<td>50-100 pW</td>
<td></td>
</tr>
</tbody>
</table>

- Work has already begun!

Martino Calvo

COre+ workshop, CERN, 19/05/2016
The B-SIDE project

B-SIDE: a balloon-borne experiments for the study of polarized foregrounds

'Significant background application (≈50 to 100 pW/pixel)
Aim mostly at rapid sky coverage

- Frequency range: 450 to 700 GHz

Water!

Martino Calvo
140, 220, 340, 480 GHz Al LEKID arrays
Resonances in the fewx100MHz range
Optimized for balloon with 240K telescope (photon noise limited)
Collaboration with ASU (Mauskopf)

KIDs development in Italy – to be tested in forthcoming OLIMPO flight
Issues with KIDs

- Long wavelengths? (high TRL at f > 110 GHz, Al LEKID). Mitigation: a credible development plan for f < 110GHz european LEKIDs

- Low-f noise? Action: laboratory measurements of noise at 10-100 mHz. Mitigation: frequency modulation / self calibration

- Readout? Well developed in Europe and USA.
  - Space-qualification? Development plan.
  - Power? Study ASICs based readout to substitute FPGAs
Alternative European detectors

Large-area TES spiderweb (multimode, LSPE) developed in Genoa (see talk by F. Gatti), working single-mode down to 30 GHz

CEB detectors (see talk by L. Kuzmin) with high sensitivity, frequency selective, high cosmic rays immunity
Gregorian configuration:
- Aperture = 1.2 m - F/D ∼ 2.
- Primary Mirror 1.5X1.2 m
- Secondary reflector diameter = 1 m
- Monolithic SiC technology unlike Planck
Figure 3: Sketch of the focal plane of COrE+ Light. Contours are Strehl= 0.8 for 60, 90, 130, 160, 220, 340, 450, and 600 GHz.
Gregorian telescope – simpler to baffle

Cold & black FPU baffle:
- Reduces straylight (combined with secondary baffle)
- Reduces the radiative background on the detectors:
  - No need for horns
  - T mirrors doesn’t need to be extremely low

Secondary baffle: Probably shiny, to reduce BKG.
- 0.04 sr from sky (140 GHz)
- 0.05 sr from cold FPU baffle
1.5 m Aperture Gregorian, Optimized Dragone, with Aspherics

- Baffles are necessary
- Note compactness of system
- Need GRASP including baffles

The primary mirror is the aperture stop

Fields at:
- -5.5 deg
- -3.5 deg
- -2.0 deg
- 0 deg
- 2.0 deg
- 3.5 deg
- 5.5 deg

COR E gregorian 1.5 meter f/2

Image of Primary

03-May-16
Cold Stop Enforced (for most of the rays)

Vignetting: Some rays are limited by the stop, some by the primary.

Fields at:
-5.5 deg
-3.0 deg
0 deg
3.0 deg
5.5 deg
Conic, Non-telecentric, Focal Surface: What if we tilt the arrays?

Chief rays for 7 field angles.

Angle of incidence (AOI)

Defocus

10 deg

5 3 2 0 -2 -3 -5
## Results

<table>
<thead>
<tr>
<th>Field (degrees)</th>
<th>Freq. (GHz)</th>
<th>AOI (deg)</th>
<th>Defocus (cm)</th>
<th>Strehl at focus</th>
<th>4'' outer</th>
<th>4'' inner</th>
<th>3'' outer</th>
<th>3'' inner</th>
<th>average delta strehl/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5</td>
<td>60</td>
<td>30.9</td>
<td>3.150</td>
<td>2.347</td>
<td>0.89</td>
<td>0.81</td>
<td>0.72</td>
<td>0.85</td>
<td>0.78</td>
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<tr>
<td>-3</td>
<td>150</td>
<td>25.9</td>
<td>2.419</td>
<td>1.803</td>
<td>0.93</td>
<td>0.57</td>
<td>0.60</td>
<td>0.70</td>
<td>0.740</td>
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<tr>
<td>-2</td>
<td>300</td>
<td>23.3</td>
<td>2.031</td>
<td>1.514</td>
<td>0.90</td>
<td>0.22</td>
<td>0.40</td>
<td>0.35</td>
<td>0.62</td>
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<tr>
<td>0</td>
<td>600</td>
<td>17.9</td>
<td>1.214</td>
<td>0.904</td>
<td>0.90</td>
<td>0.28</td>
<td>0.23</td>
<td>0.45</td>
<td>0.38</td>
</tr>
<tr>
<td>2</td>
<td>300</td>
<td>8.6</td>
<td>0.216</td>
<td>0.161</td>
<td>0.71</td>
<td>0.70</td>
<td>0.71</td>
<td>0.70</td>
<td>0.71</td>
</tr>
<tr>
<td>3</td>
<td>150</td>
<td>11.5</td>
<td>0.231</td>
<td>0.172</td>
<td>0.81</td>
<td>0.80</td>
<td>0.81</td>
<td>0.81</td>
<td>0.81</td>
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<tr>
<td>5</td>
<td>60</td>
<td>17.39</td>
<td>1.136</td>
<td>0.846</td>
<td>0.86</td>
<td>0.88</td>
<td>0.83</td>
<td>0.87</td>
<td>0.84</td>
</tr>
</tbody>
</table>

Need to steer the beams
Or – Use a Lens?

Alumina lens ~60 cm diameter
n=3.1
Flat focal plane
Fields shown = +−5 deg
Telecentric within 10 deg
F# = ~1.8
Strehl ratios similar to F#=2
(requires more detailed study)

~60 cm diameter

Plan 1.5 meter f/2
Scale: 0.05
15-May-16
Broadband ARC – Laser Ablation

Matsumura et al. 2016
Four configurations considered:

- **Gregorian option 1**
- **Gregorian option 2**
- **Open Dragone**
- **Cross-Dragone with F~2**

Selected option:
Fits in V-Grooves and can easily be mounted.

- Does not fit in V-Grooves
- Focal plane too high.
  - Complex Thermo-Mechanical accommodation
  - Large secondary mirror
Figure 3. Optical configurations: Dragonian Side-Fed (a), Dragonian Front-Fed (b), Classic (c) and Aplanatic (d) Gregorian.
Optics Summary

• So far: 1.5 m; Should we look at 1.2 m?

• Low T baffles/stop
  – Baffles: OK
  – Stop: questionable
  – Do more detailed GRASP for polarization and far sidelobes

• Focal Plane:
  – Steer the beam
  – Use lens?