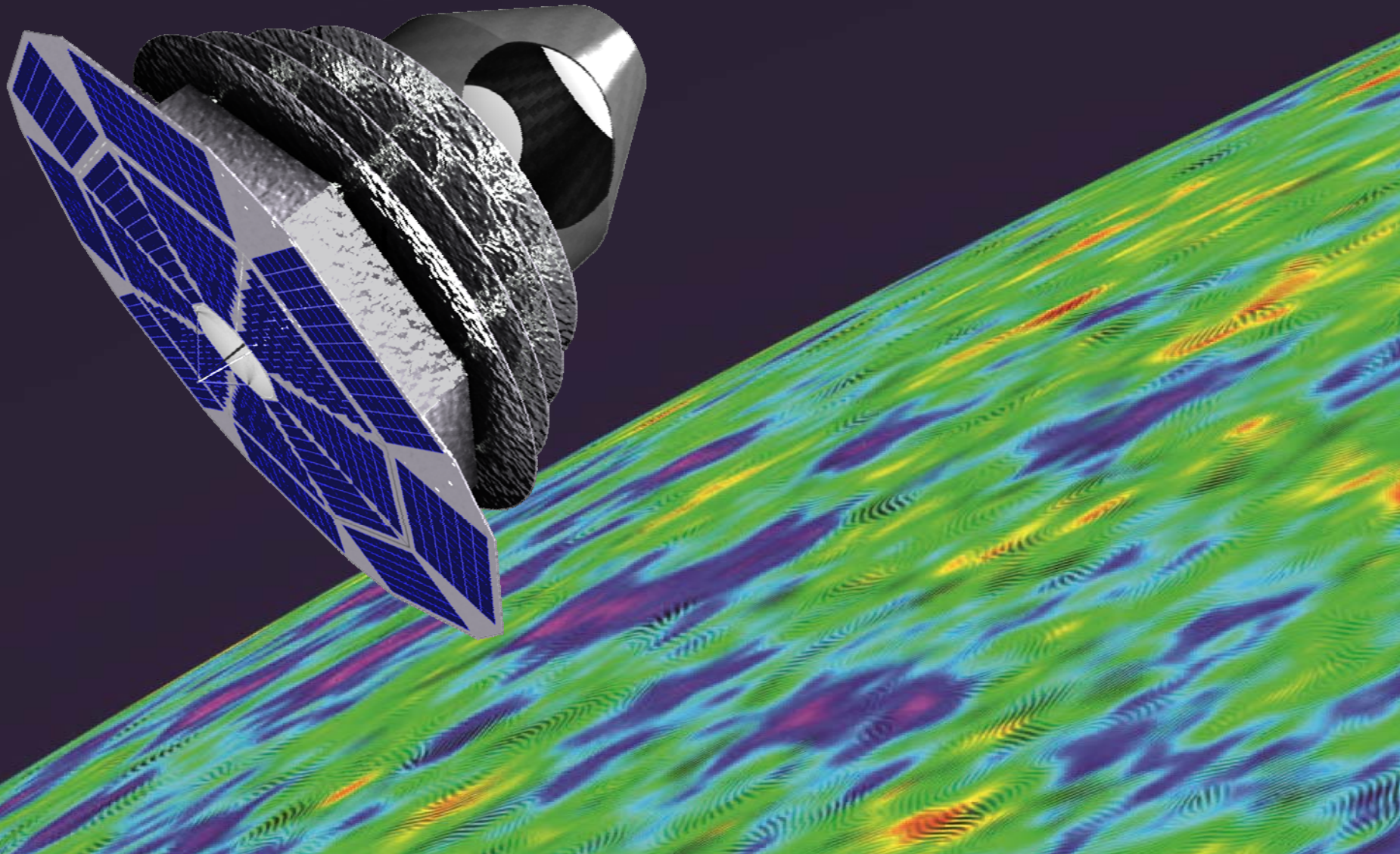


The M5 concept: COrE/LiteCORE design and options

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From CDF study to proposal, and beyond

- The CDF study described by Jacques was an excellent exercise to confirm with ESA the technical feasibility of our mission, with focal plane and telescope similar to our M4 proposal, as shown.
- Now we have to *optimize*, evaluating upgrades and downgrades, to maximize the performance/cost ratio.
- Our target is to propose a mission *simple* enough to be not attackable (neither technically (TRL), nor budget-wise) while still representing a *major scientific breakthrough*.
- This is a *hard challenge*. We urge to propose an implementation well within the 550M€ cost cap of ESA, plus a *credible* share for the payload from the European agencies.
- Meanwhile, we will discuss upgrades and downgrades in the companion papers, which will be the base for discussion during phase-A, when real commitments from NASA and/or JAXA might become available.

directions

Apparently, a wide parameters space:

- Mission: carrier, orbit, duration
- Telescope: size, temperature
- Detectors: technology, coupling, number, λ coverage
- Polarization: modulation method
- Sky: coverage, scan speed



Directions

Constrained optimization. Examples:

- **L2** large orbit only real option, due to Earth & Moon contamination, and radiation belts for LEO and elliptical orbits. L2 used by WMAP and Planck, and required for Litebird and Pixie as well.
- European space carriers: Soyuz probably discontinued by 2025-30 / Vega not enough / Availability of other carriers only if NASA/JAXA commit to support this mission before selection. Only real carrier for proposal is **Ariane6**, to be rediscussed in phase-A. Dual launch would save big money. However, adds important constraints in the schedule, and a partner mission is not easy to find.
- Only high TRL **European detectors** are to be considered for proposal (same reason as above, to be rediscussed in phase-A)
- **No moving parts** in the instrument for polarization modulation (nor for other purposes). A Litebird-like mechanism would add a large cost, a issues in the technical screening (single point failure, TRL, feasibility).
- **Full sky** coverage can be achieved only in space, and a lot of the legacy value of a space-based survey comes from this. It allows for full understanding of foregrounds. We need it.

Directions

Narrower parameters space:

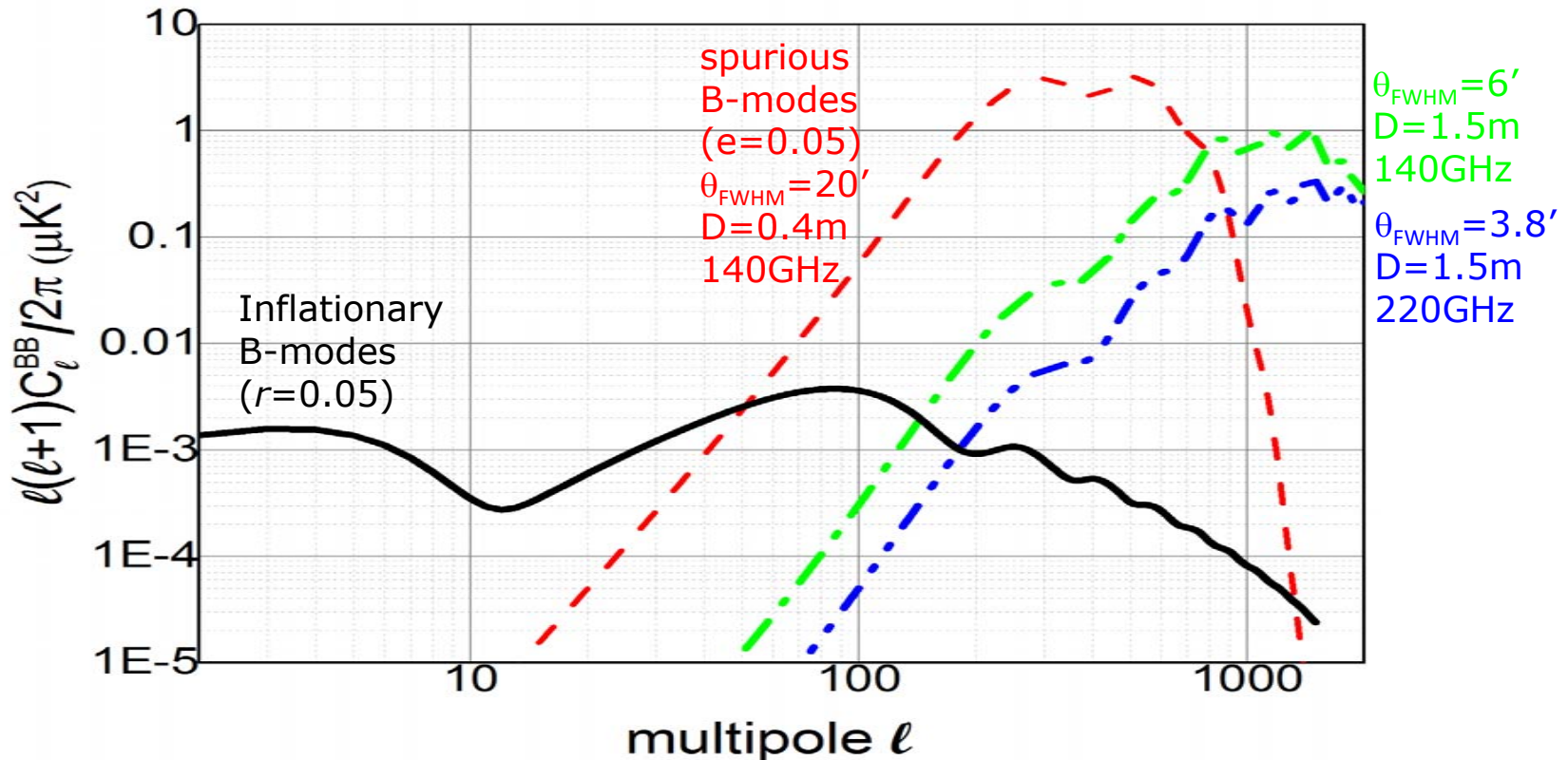
- Mission: ~~carrier~~, ~~orbit~~, duration
Ariane-6 L2 large halo
- Telescope: size, temperature
- **European** Detectors: technology, coupling, number, λ coverage
- Polarization: ~~modulation method~~
By satellite spin/precession
- Sky: ~~coverage~~, scan speed
Full sky

Telescope

- The *size* of the telescope:
 - Heavily impacts the science output :
 - for polarization: internal delensing, acceptable level of beam ellipticity →
 - for galactic science / magnetic field: resolution is essential (cfr. Boulanger)
 - for SZ science: resolution is essential (# of clusters ! cfr. Delabrouille)
 - Larger telescopes can accommodate wider focal planes
 - Affects the cost of the mission in several ways:
 - Fabrication cost of mirrors
 - Mass and volume of telescope propagate into strength/mass of support structure, volume of the payload and size of the shields, i.e. needed size of the rocket bay.
 - Volume of the telescope controls the volume of the test facility
 - No simple cost scaling law.
 - For a credible study we need to investigate a few cases: 1.2, 1.5, 1.8m aperture. For each case, investigate:
 - Science output and quality, with simulations in all areas listed above
 - Cost, with an implementation optimized for that telescope size
 - A painful (but interesting!) process. Alternative ideas welcome.

Beam ellipticity

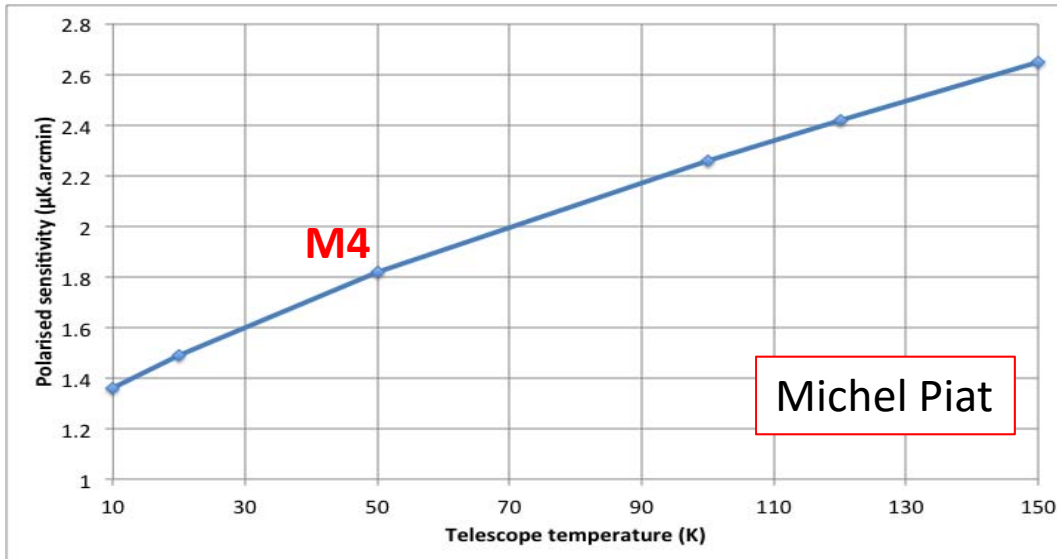
- The ellipticity of the beam converts unpolarized CMB anisotropy into spurious polarization. The effect at large scales is mitigated for small beams:



- For small apertures, a Half-Wave Plate is a must (e.g. LITEBIRD, $D = 40$ cm)

Telescope

- The *thermodynamic temperature* of the telescope:
 - Affects an important part of the power background / noise budget of the detectors, i.e. the *survey sensitivity*, for a given focal plane and mission duration.




$T_{\text{tel}}=100\text{K}$: noise increased by a factor 1.25 wrt M4; can be recovered:

- with a survey duration 1.56 times longer
- with 1.56 times denser population of focal plane
- with 25% reduction of mirror emissivity

- Can affect the *heat load on the cryogenic system*. Increasing the temperature of the telescope and of its surroundings might reduce the power margins of the cryogenic system.
- Affects the choice of the *cryo/vacuum test facility* for the end-to-end test of the payload. Facilities with LHe shrouds (as the Liege one, used for Planck) are extremely expensive. Facilities using only LN (77K) are cheaper to operate and more widely available.
- 100K cryo option (1 V-groove shield removed) was studied and validated in the CDF.

European detectors

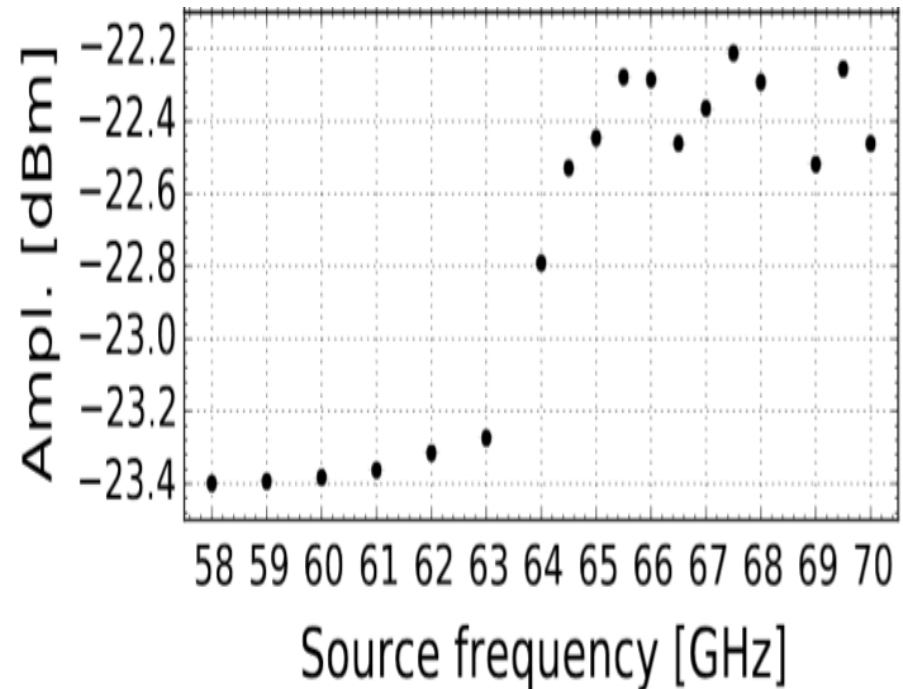
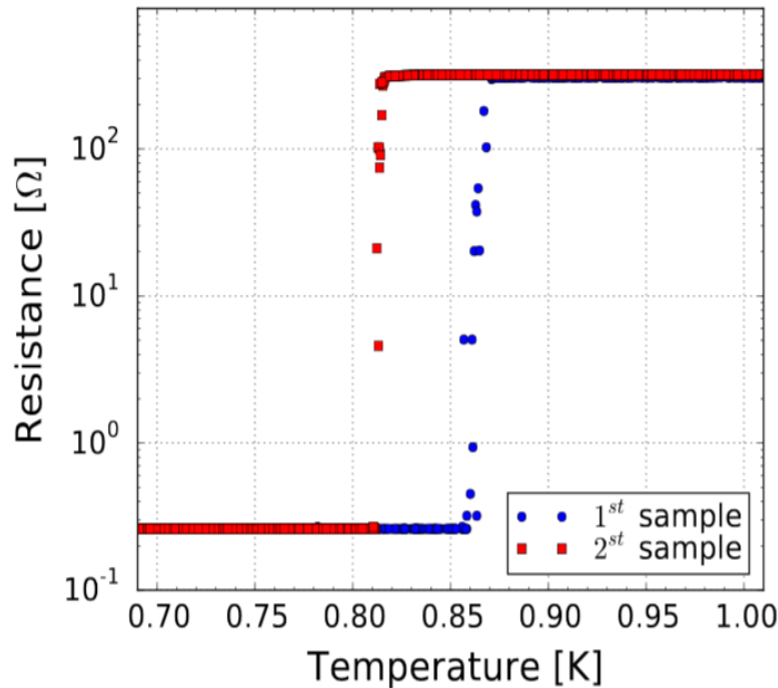
- Highest TRL to date, in Europe: single frequency, single polarization Al LEKIDs.
- Successfully operated at the telescope (NIKA, NIKA2)
- Built in France, Italy, Spain.
- Operation down to 65 GHz demonstrated (with bilayer)
- Hear Martino Calvo later. 
- After selection, dual polarization, multichroic pixels will be considered,
 - if a TRL as high as for the baseline has been demonstrated
 - If partners producing these detectors can commit through their space agency.
- This will boost the sensitivity of the survey and the overall performance.

focal plane: European detectors for CMB: KIDs

Low-f operation of KIDs demonstrated:

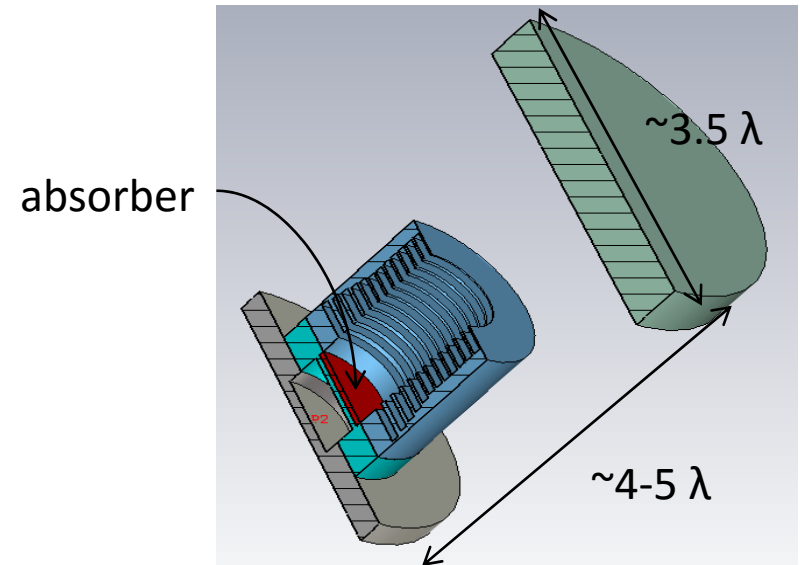
- Catalano et al. A&A 580, A15 (2015)
- Paiella et al. Astro-ph/1601.01466

Al-Ti
 $f > 65$ GHz



European detectors

- Detector coupling:
 - Horns based (M4):
 - very nice beam and crosspol, high TRL
 - Heavy 0.1K focal plane
 - Planar lens coupling (hear Giampaolo Pisano tomorrow)
 - Arguably same TRL as quasi-optical filters
 - Substantially reduced mass of the 0.1K focal plane
 - To be optimized
 - Allows for a higher density of detectors in focal plane area



European detectors

- The cost of detectors and readout is on the national agencies, which are not as rich as some time ago.
- KIDs fabrication relatively cheap.
- For M4 (baseline) we assumed 2000 single-f single polarization detectors.
- The cost of the national contributions can be reduced by reducing the number of detectors:
 - Smaller focal plane area, easier FP shielding and filtering
 - Smaller 1K black shield around focal plane
 - Increased margin for cryogenic system (reduced # of cables)
 - Reduced power for readout electronics
- Study required to investigate is with 1000 well distributed detectors the mission is still compelling.

Sky scan

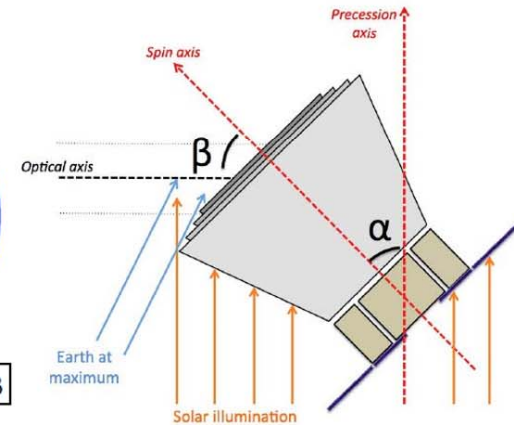
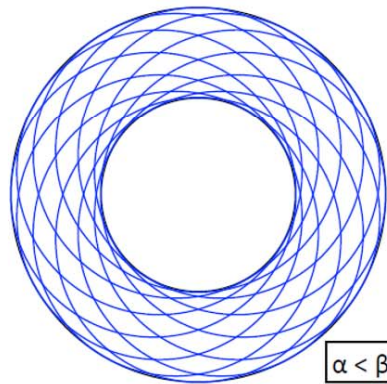
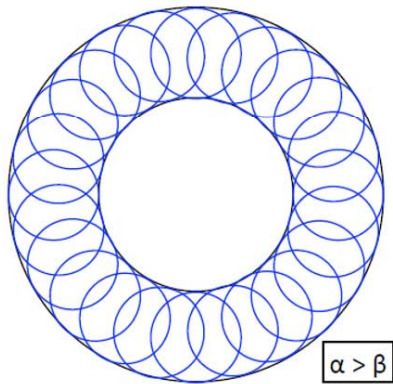
- Spin + precession required for polarization modulation
- Sky scan speed affects:
 - The requirement on time constant of detectors (not a real issue for KID)
 - The TM data rate (linearly) and on-board mass memory
 - The requirements on ACS actuators (for 1rpm: large flywheel required, US technology)
 - The requirements on the ACS (for 1 rpm: re-development of fast star sensors, similar to the Planck ones, required)
 - Reducing it down to 0.5 rpm would reduce the cost of the ACS.
 - Requirement on $1/f$ noise of detectors to be studied, running simulations to prove the efficiency of destriping methods in our case.

Sky scan

- Precession and beam off-axis angles to be optimized ($\alpha + \beta = 90^\circ - 95^\circ$).

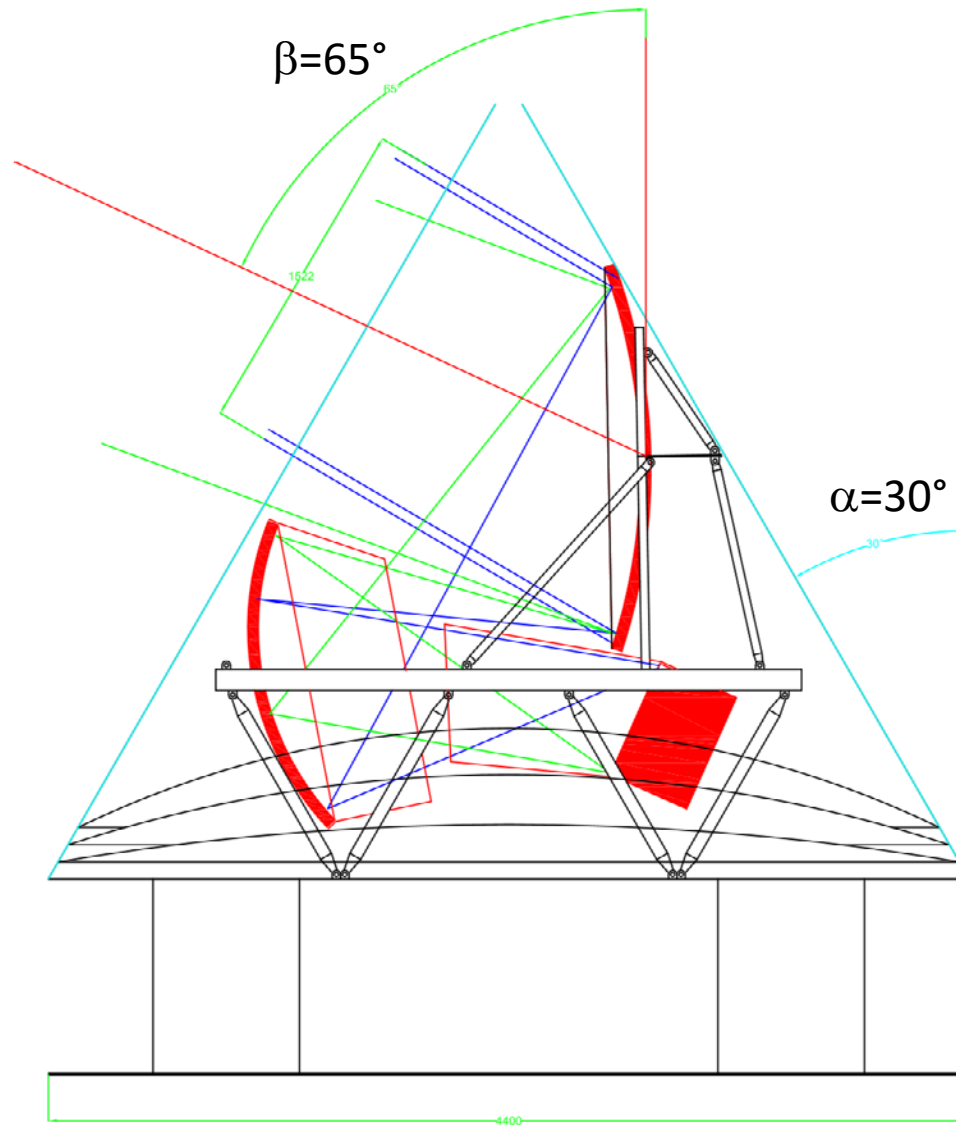
Starting point for CDF:

- $\alpha = 50^\circ$ $\beta = 45^\circ$, spin rate (1 rpm) \rightarrow 2 rpm, precision: 4 days

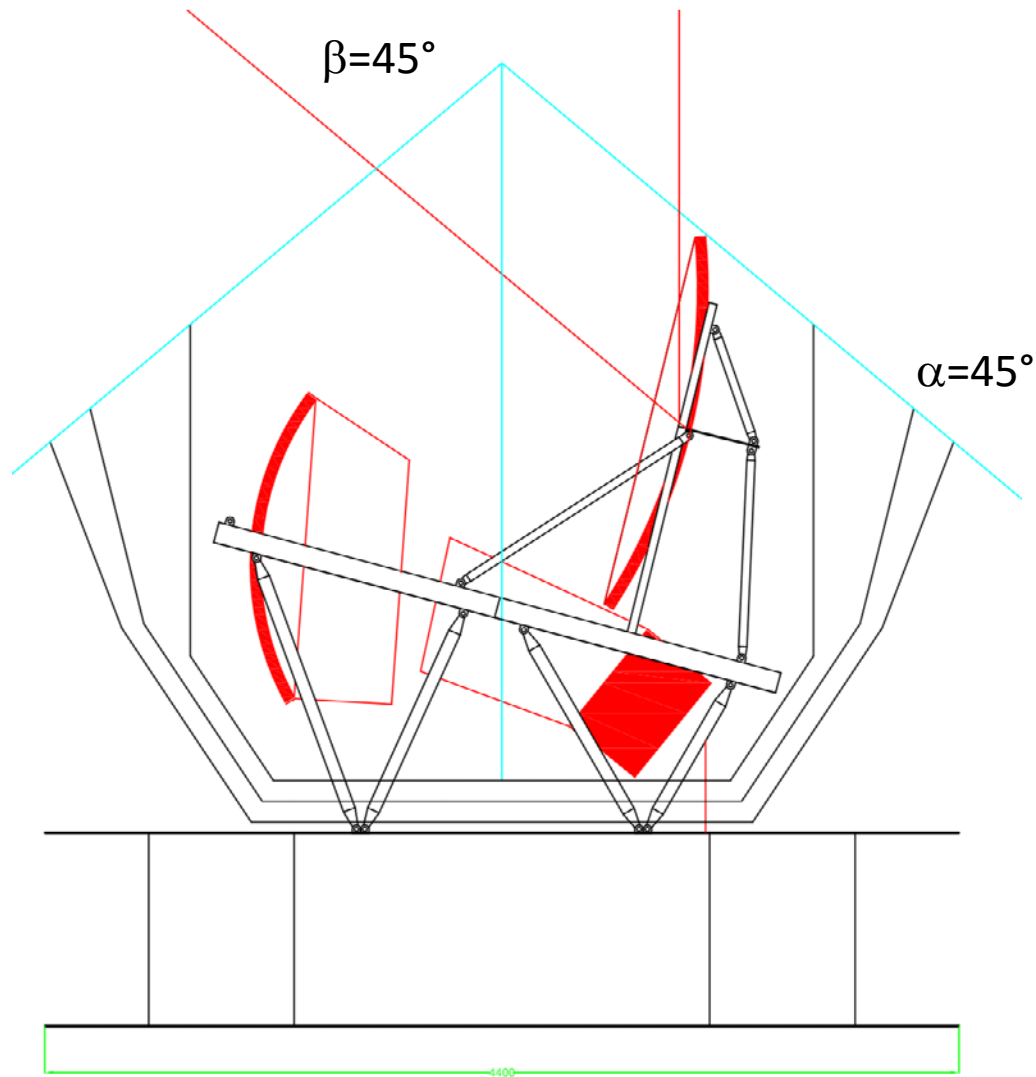


- Have a large impact on the size of the telescope shields / V-grooves.
- Extreme option: reduce α .
 - This will reduce the size of the shields wrt CDF
 - Will reduce the size of the solar panels (more favorable average solar illumination angle) – might be to the extent that we do not need deployable solar panels anymore

1.5m telescope @ 50K



1.5m telescope @ 100K



Summary

- Directions to be explored for improving the global robustness of proposal (against ESA selection process):
 - Baseline 100K for the telescope/payload
 - Maintain the 1.5 and 1.2 m options (and study both thoroughly)
 - Consider and study a 0.5 dps spin rate
 - Consider a significant reduction of the number of detectors
- All to be discussed now and tomorrow in the instrument parallel session.