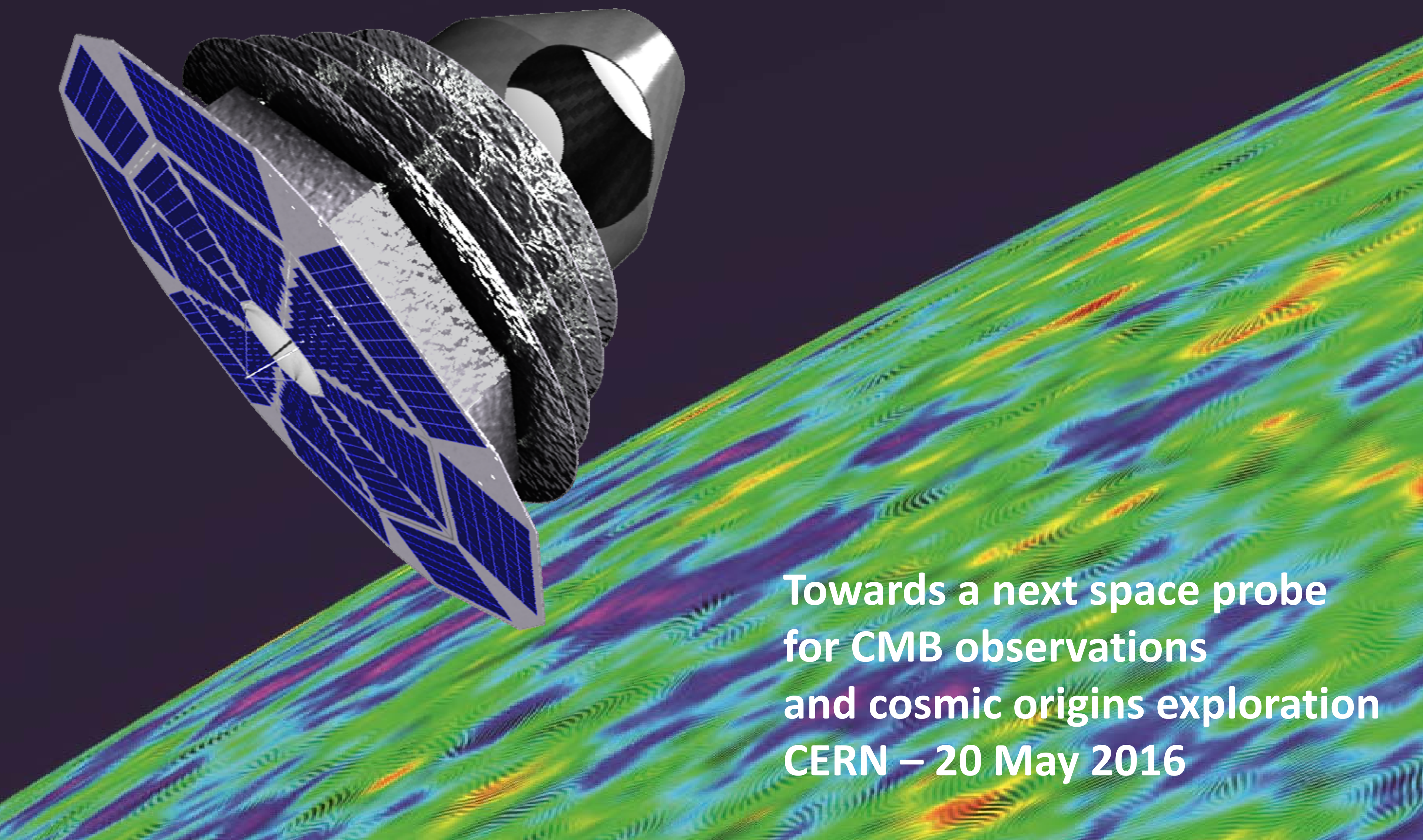
Report from the « Focal Plane / Telescope » parallel session

S. Hanany – University of Minnesota - USA

P. de Bernardis – Sapienza University of Rome and INFN - Italy



Towards a next space probe for CMB observations and cosmic origins exploration

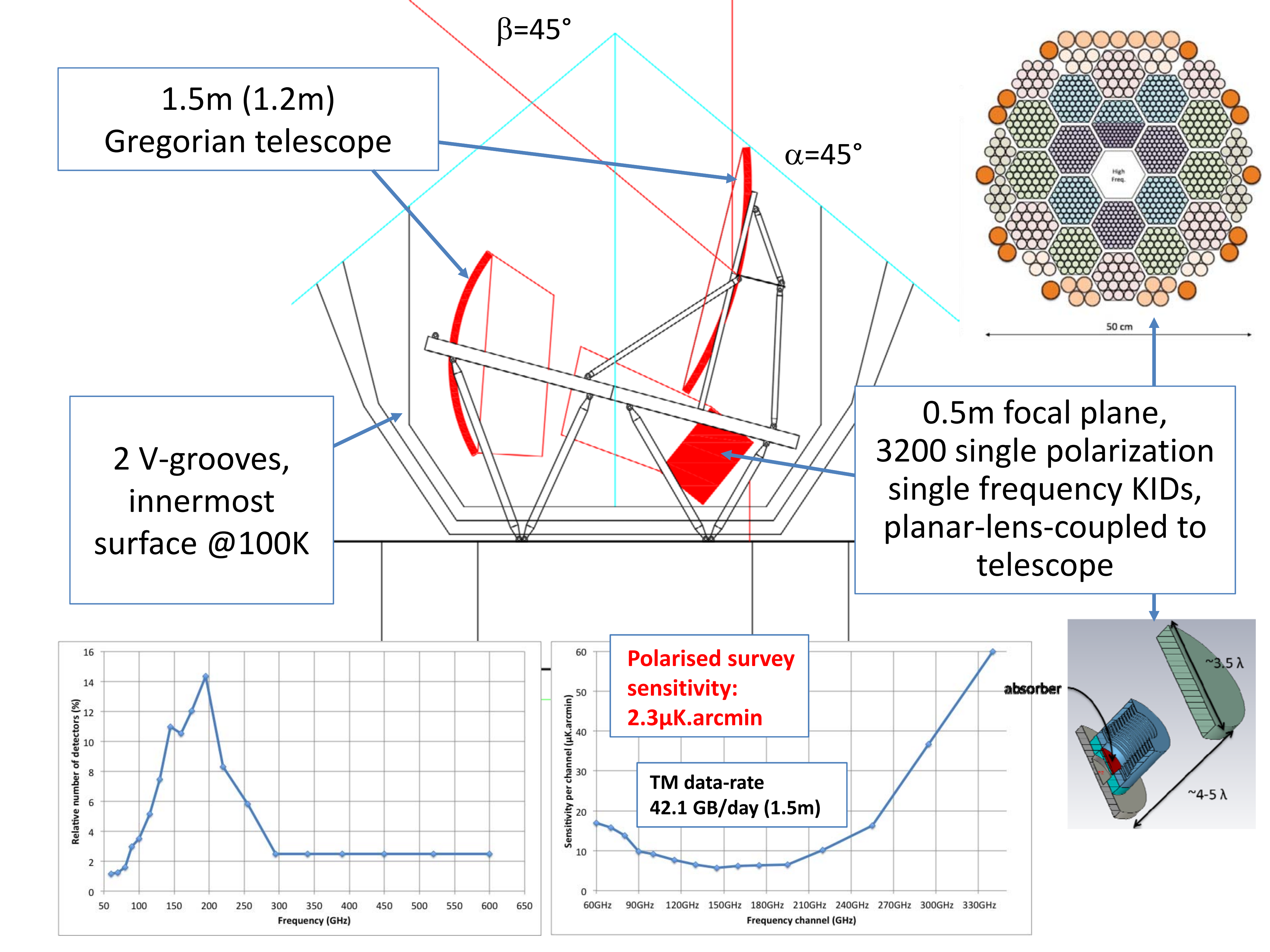
CERN – 20 May 2016

Session target: define a baseline instrument configuration compatible with our tight budget requirements.

Session items:

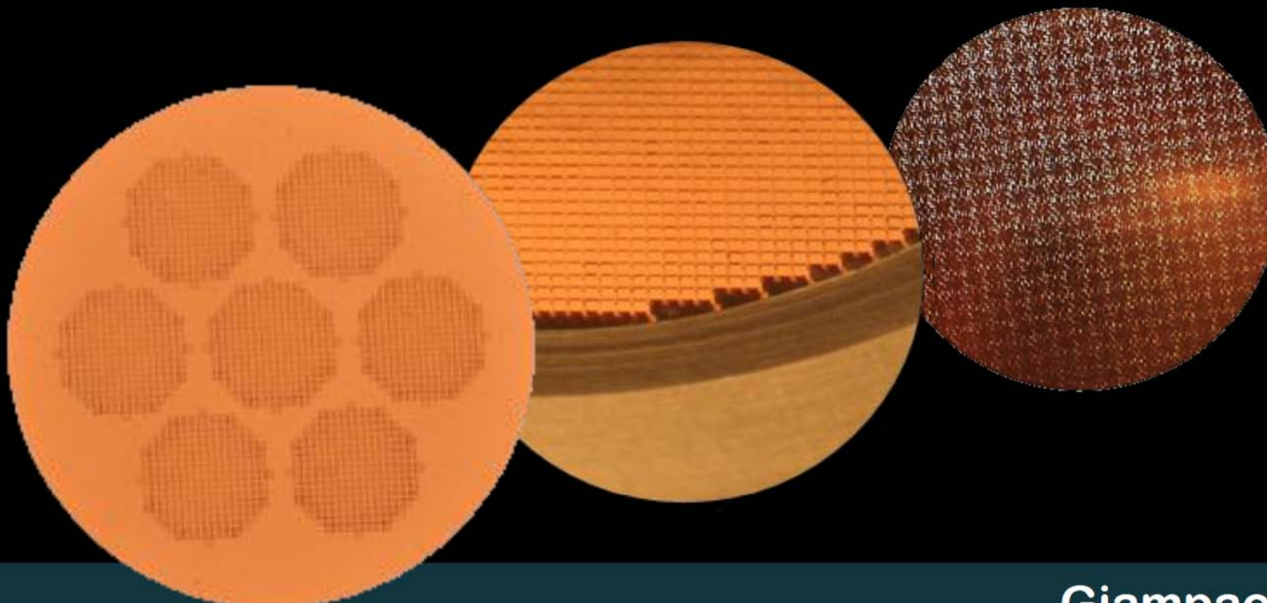
- Instrument baseline
- Telescope
- Detectors
- Open issues

09:00	[76] Target sensitivity focal plane tradeoffs and requirements	PIAT, Michel DE BERNARDIS, Paolo
09:20	[77] Telescope: baseline design	TRAPPE, Neil A. HANANY, Shaul
09:40	[78] Discussion on telescope baseline	
09:55	[79] KIDs detectors + developments in France	CALVO, Martino
10:15	[80] KIDs developments in Italy	DE BERNARDIS, Paolo
10:25	[81] CEB developments	KUZMIN, Leonid
10:35	[82] Large■area TES developments in Italy	GATTI, Flavio
10:45	[83] Detectors coupling	PISANO, Giampaolo
11:55	[85] Readout technology in the US	ULLOM, Joel
12:10	[86] Readout technology in France	PRELE, Damien CALVO, Martino
12:20	[87] Discussion on sensors/readout technology end of session	



β=45°
α=45°
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
High Freq.
50 cm
absorber
~3.5 λ
~4-5 λ
Relative number of detectors (%)
Frequency (GHz)
Sensitivity per channel (μK.arcmin)
Frequency channel (GHz)
60GHz 90GHz 120GHz 150GHz 180GHz 210GHz 240GHz 270GHz 300GHz 330GHz
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

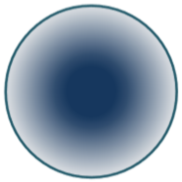
Maynooth, Manchester, Cardiff, Rome, Paris APC & Chalmers

ESA project: *"Next Generation Sub-Millimetre Wave Focal Plane Array Coupling Concepts"*

CMB workshop, CERN, May 17-20, 2016

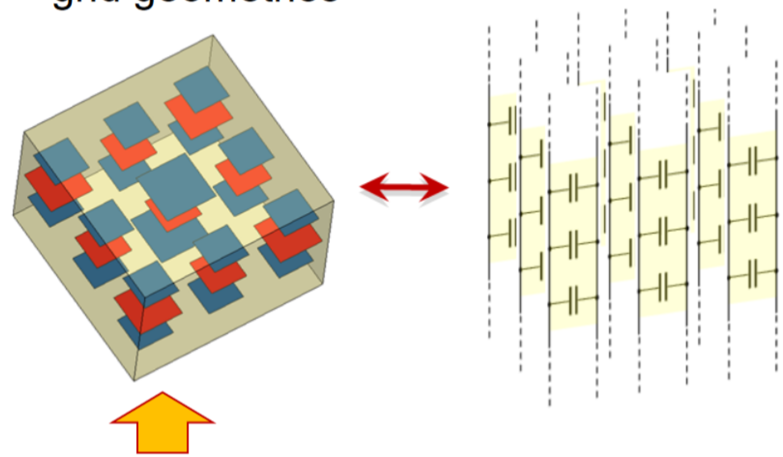
Flat Mesh Lens: Inhomogeneous Phase Delays

G. Pisano et al.
Applied Optics **52**,n.11, (2013)

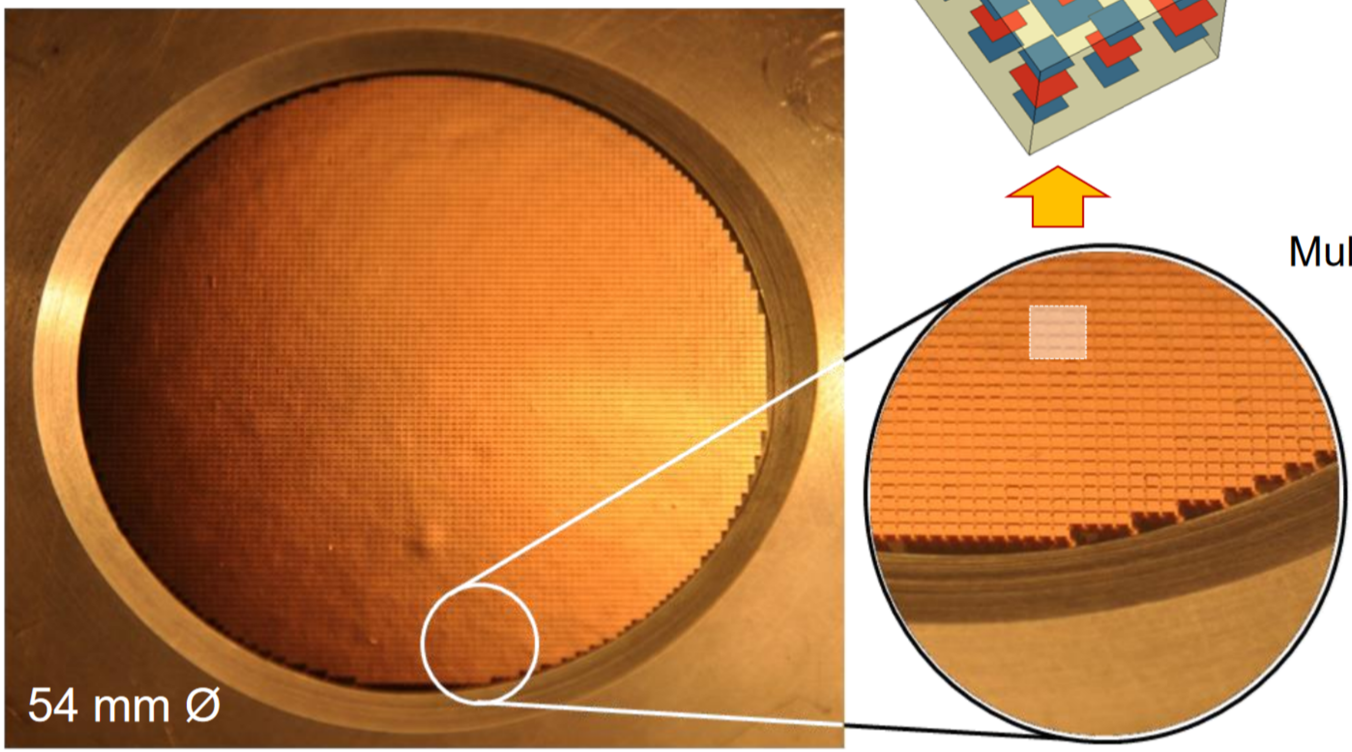


Inhomogeneous grids

Locally variable grid geometries



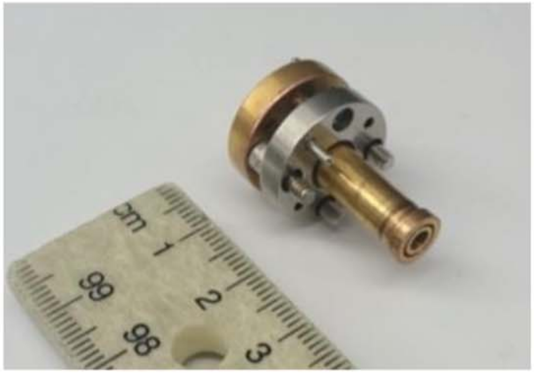
Multiple transmission lines

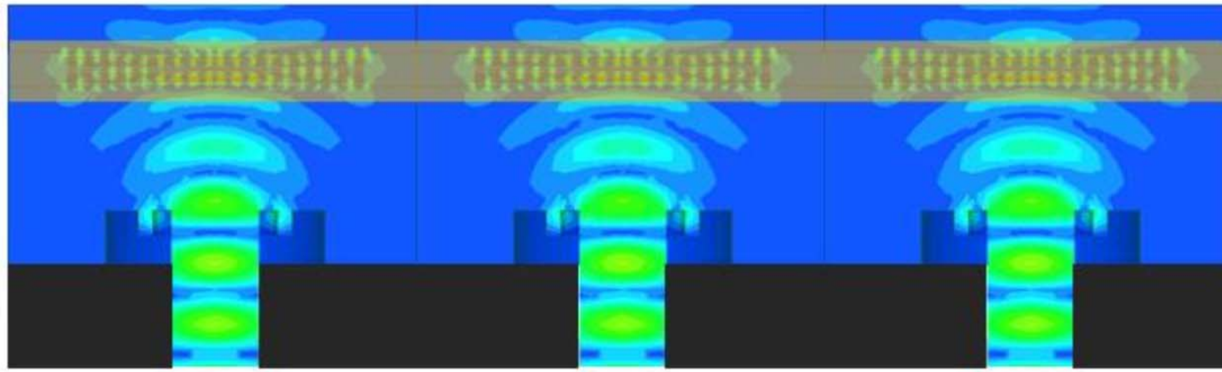


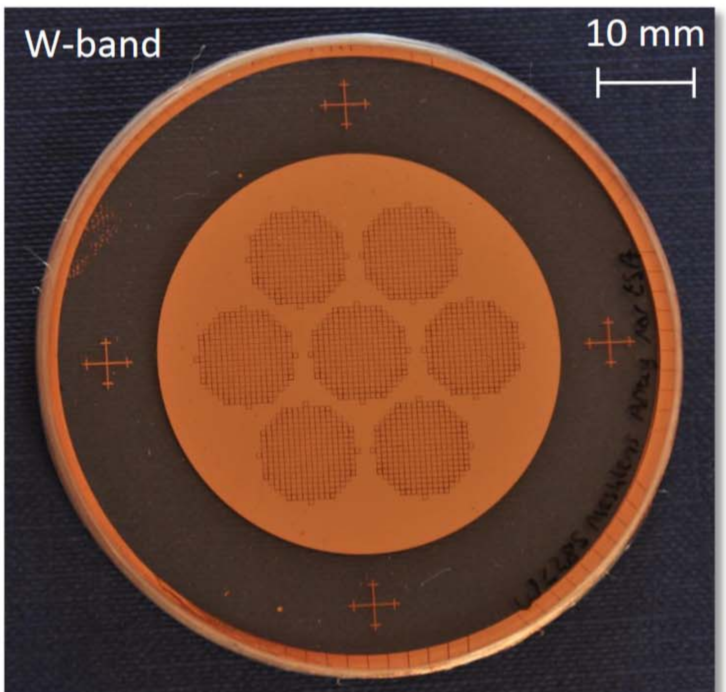
W-Band f/3 lens prototype (1.4mm thick)

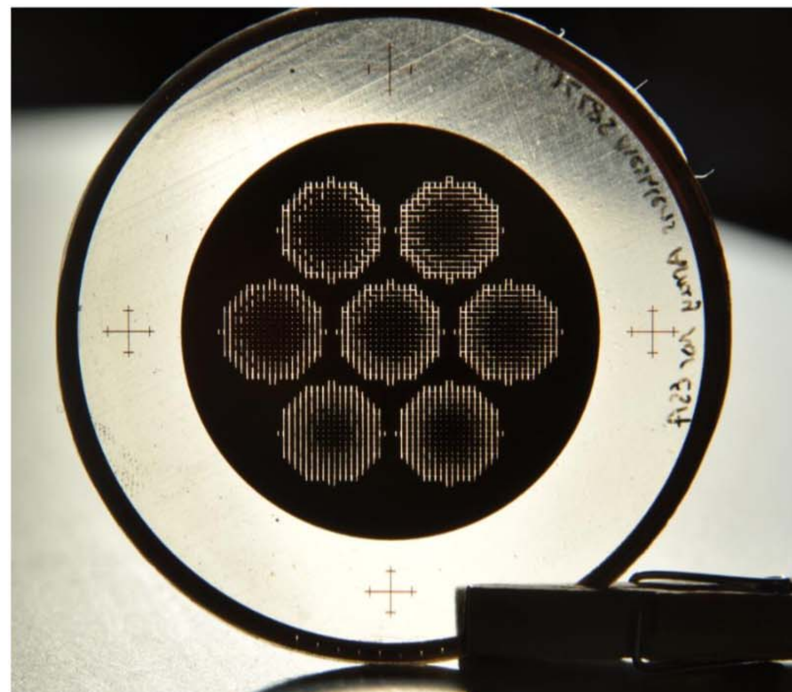
- Very thin and robust
- Very light and low loss
- No Anti Reflection Coatings required

Mesh Lens Array: Coupling to a Waveguide Probe Antenna







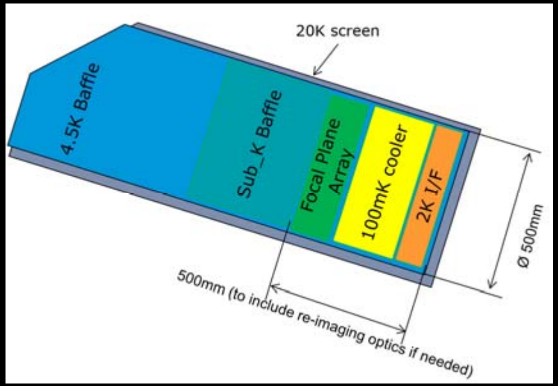


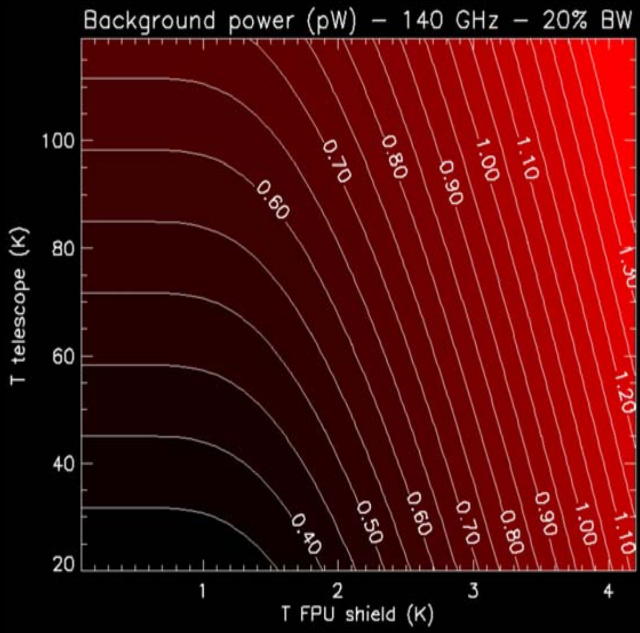
As for all instruments, there are issues:

- 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

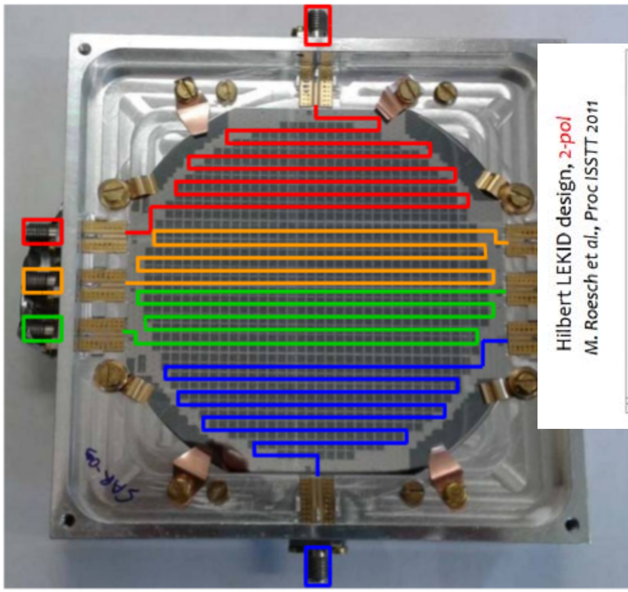
- Detector sensitivity depends on the radiative background on the detectors. Two sources: the telescope/sky and the surrounding environment.
- For this reason we need a cryostat around the focal plane, with an innermost shield black (*to absorb straylight*) and cold (*to limit the background*) and an 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 rise 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.

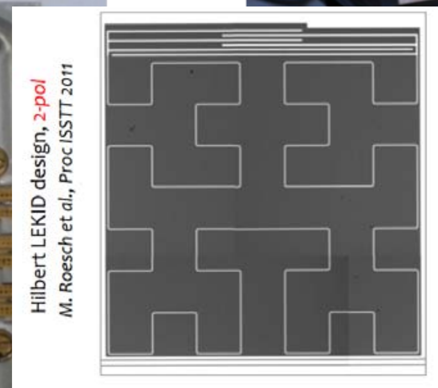


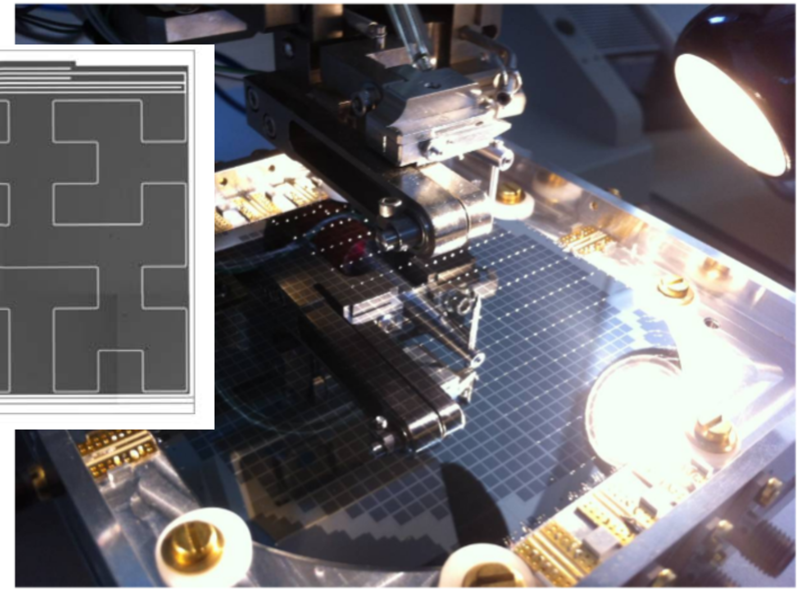


NIKA2 : the arrays

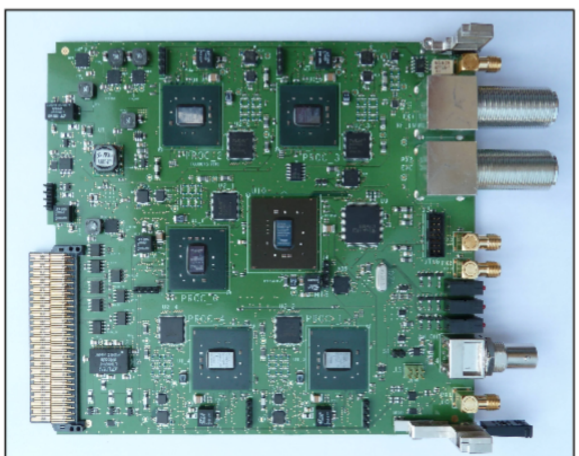
1000 pixels 2mm array







O. Bourrion et al., 2012 JINST 7 P07014



- 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_i on ground!)

The B-SIDE project

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

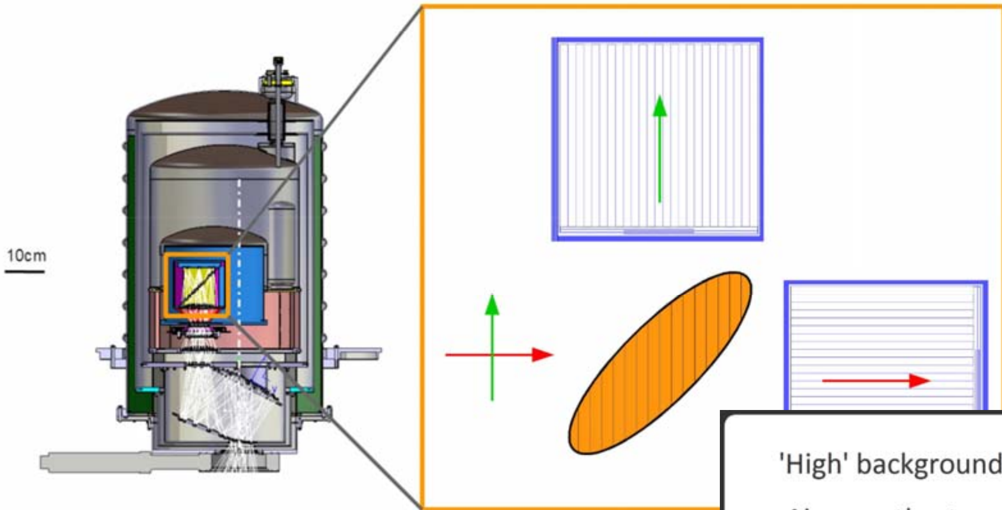
- Funding: on the way! (hopefully..)
- Launch planned for 2018/2019

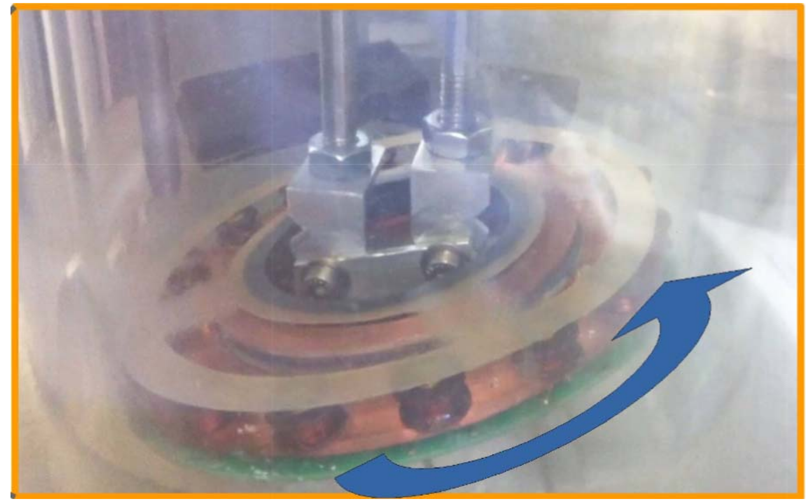
	Specifications	Goals
Primary mirror diameter (m)	0.8	
Instantaneous field-of-view (deg)	2	3
Angular resolution (arc-min)	7	5
Number of bands	1	2
Flight Duration (days)	1	3
Operating frequencies (GHz)	450-630	400-600 & 500-700
Number of pixels	980	1800
NEP ($W/Hz^{0.5}$)	$5 \cdot 10^{-16}$	$2 \cdot 10^{-16}$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

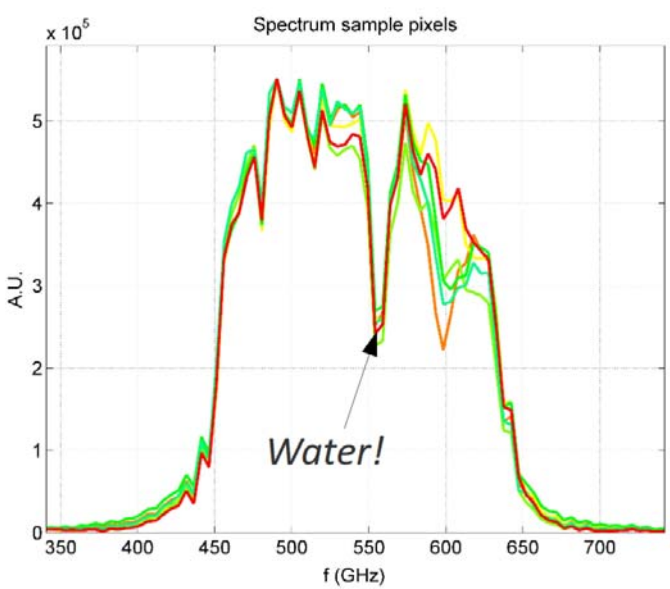
- Work has already begun!

The B-SIDE project

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



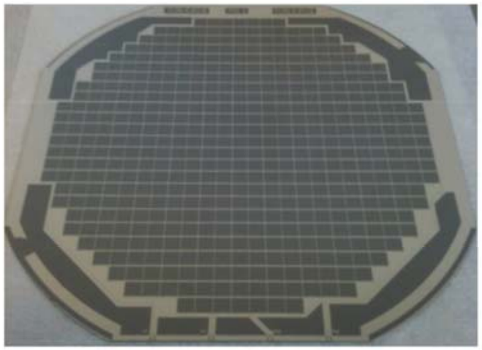


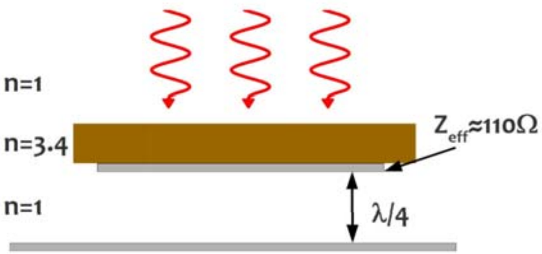


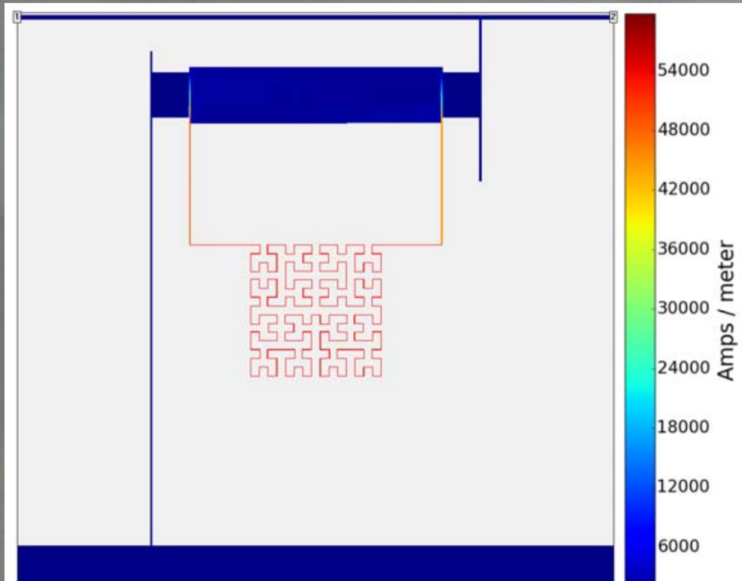
'High' background application (~50 to 100 pW/pixel)

Aim mostly at rapid sky coverage

- *Frequency range: 450 to 700GHZ*





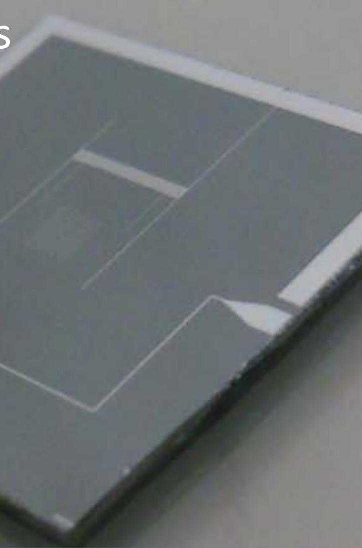


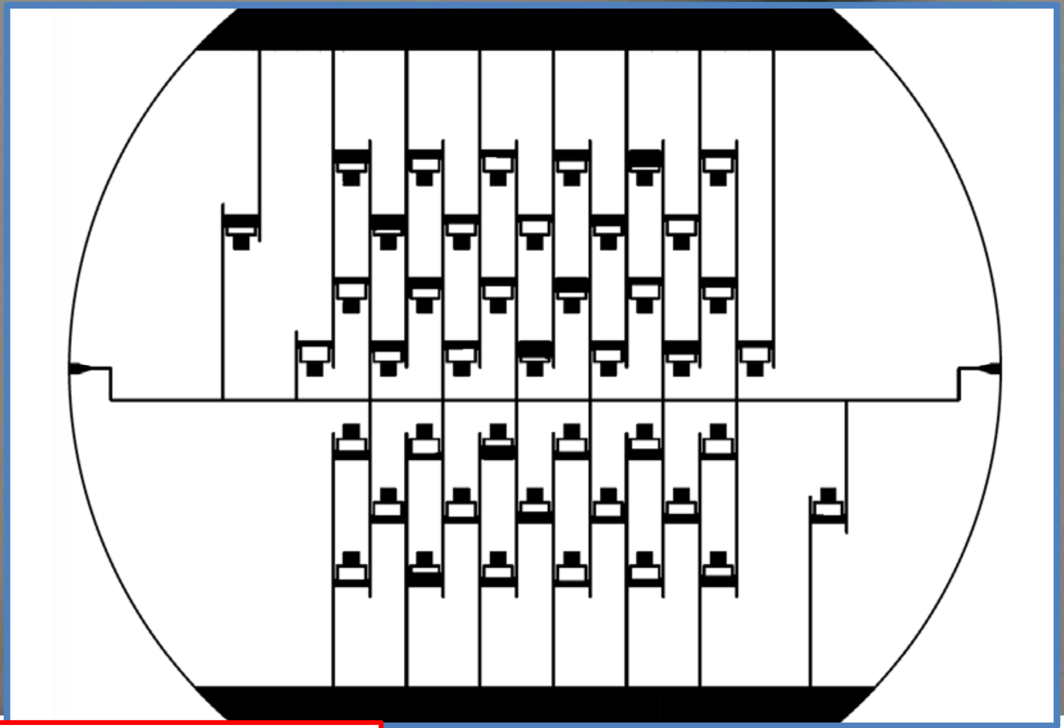
140, 220, 340, 480 GHz Al LEKID arrays

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

agenzia spaziale italiana

INFN

SAPIENZA UNIVERSITÀ DI ROMA

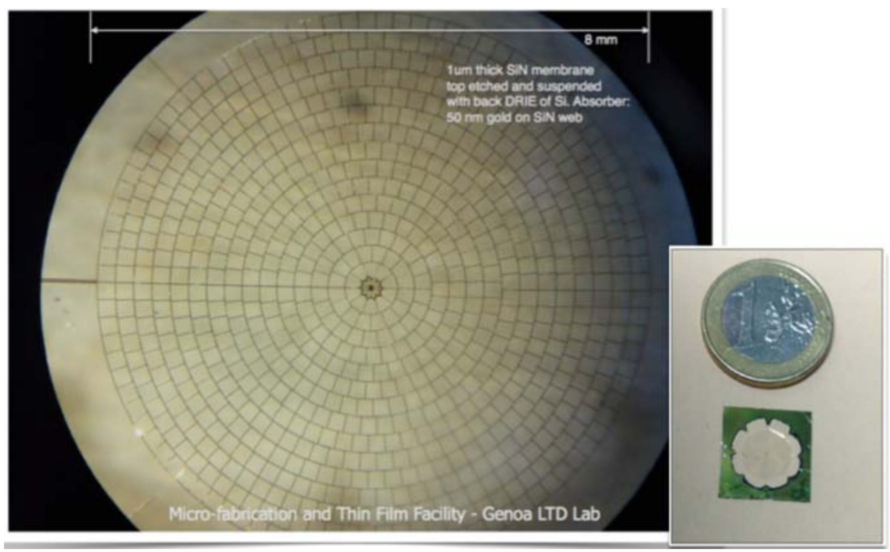
CNR IFN Istituto di Fotonica e Nanotecnologie

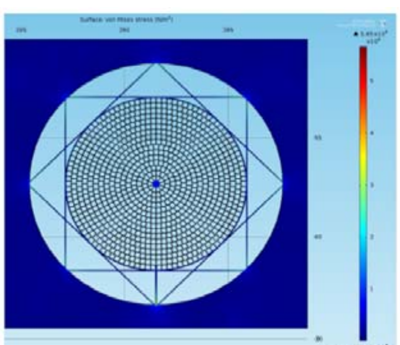
Issues with KIDs

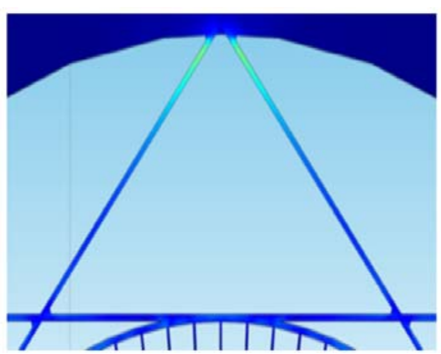
- Long wavelengths ? (high TRL at f>110 GHz, Al LEKID). Mitigation: a credible development plan for f < 110GHz european LEKIDs
- Low-f noise ? Action: laboratory measurements of noise at 10-100 mHz. Mitigation: frequency modulation / self calibration
- Readout ? Well developed in Europe and USA.
  - Space-qualification ? Development plan.
  - Power ? Study ASICs based readout to substitute FPGAs

Alternative European detectors

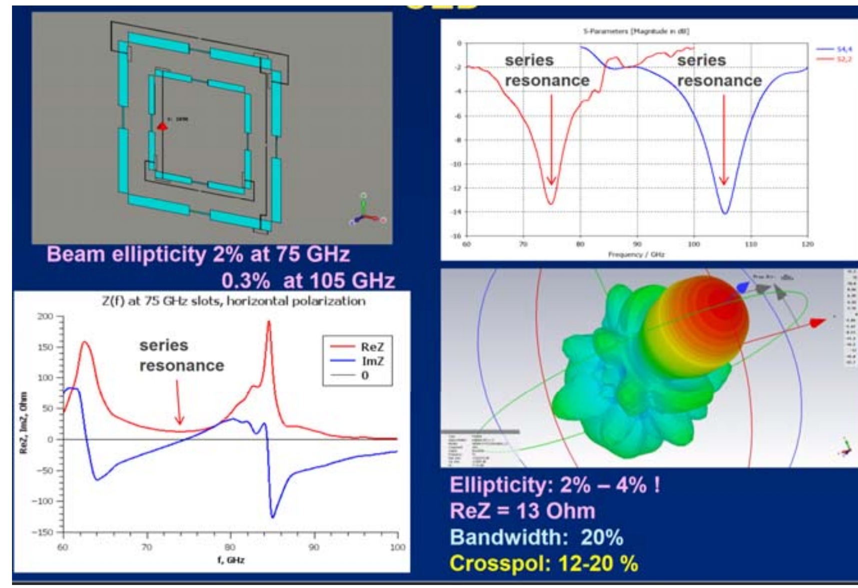
Large-area TES spiderweb (multimode, LSPE) developed in Genoa (see talk by F. Gatti), working single-mode down to 30 GHz

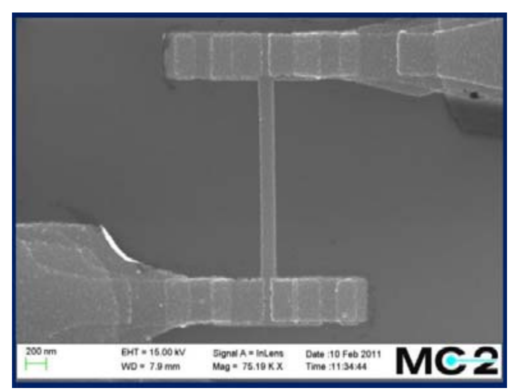






CEB detectors (see talk by L. Kuzmin) with high sensitivity, frequency selective, high cosmic rays immunity

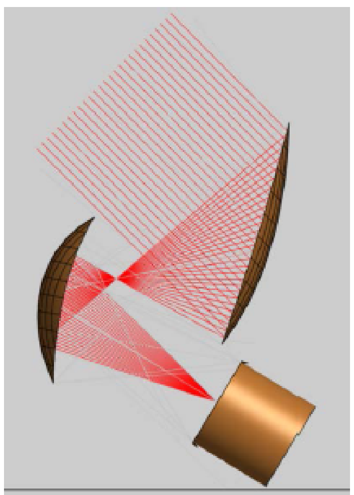


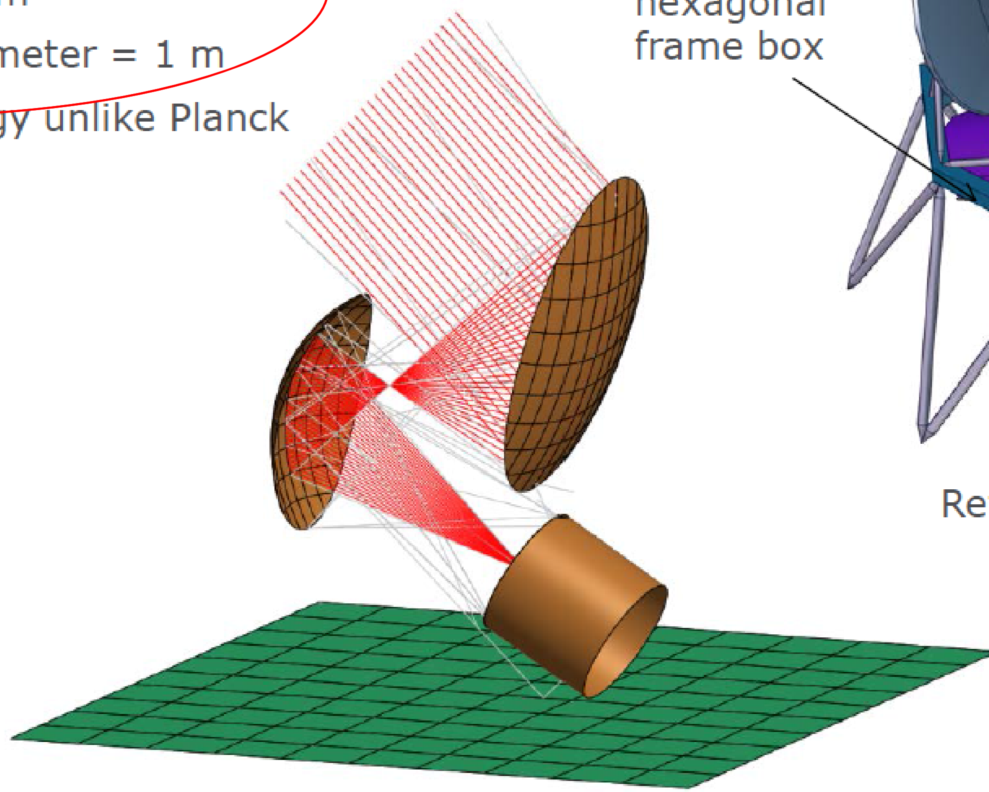


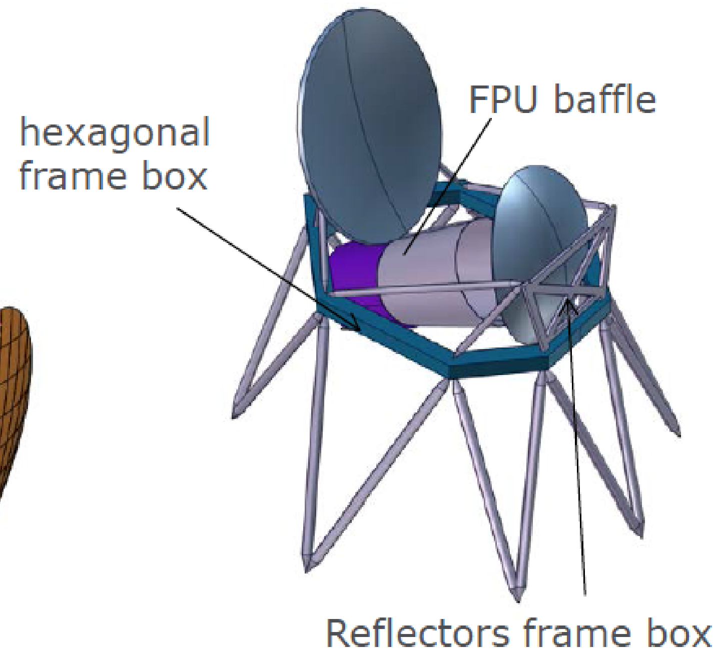
Telescope baseline

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







Focal plane layout

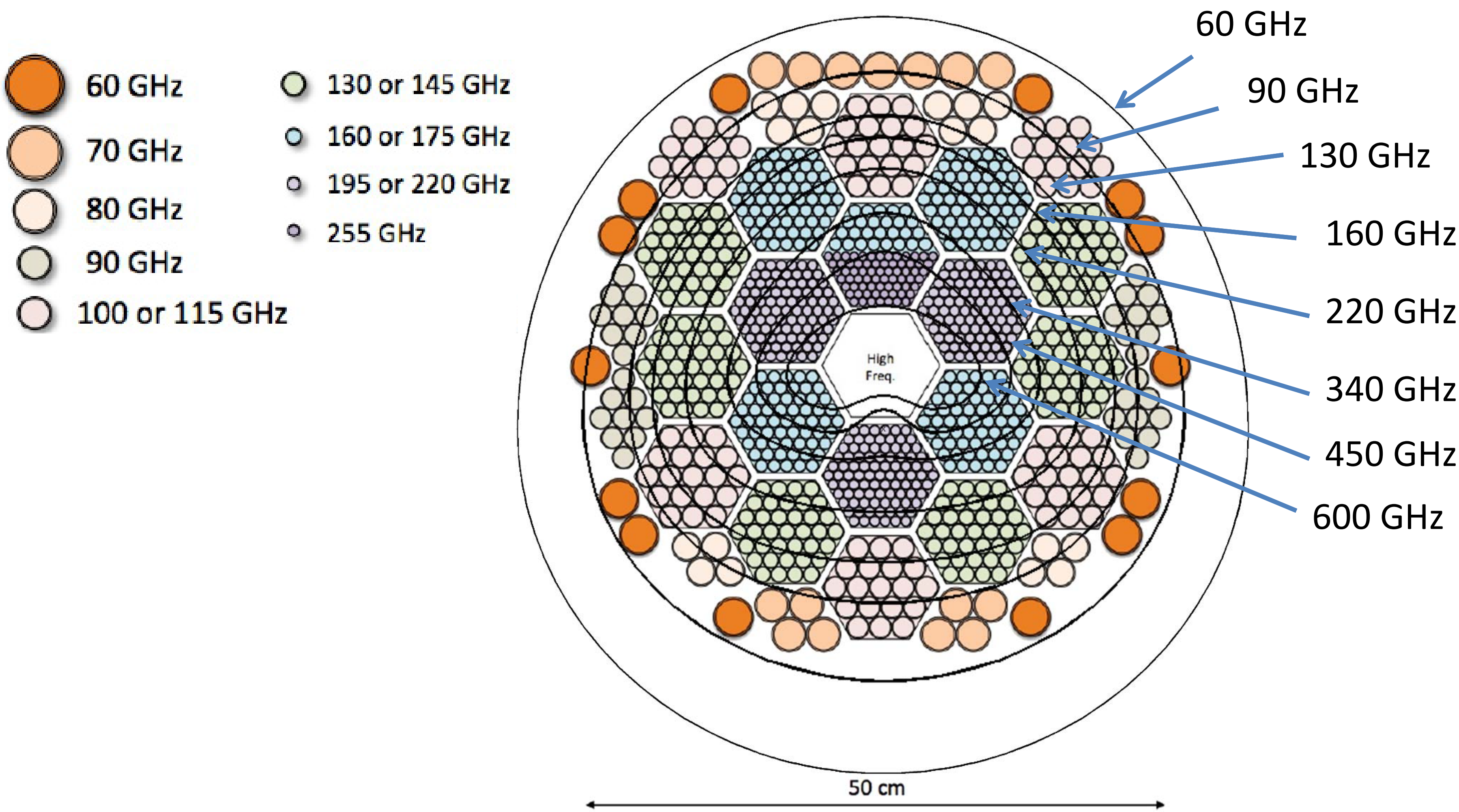
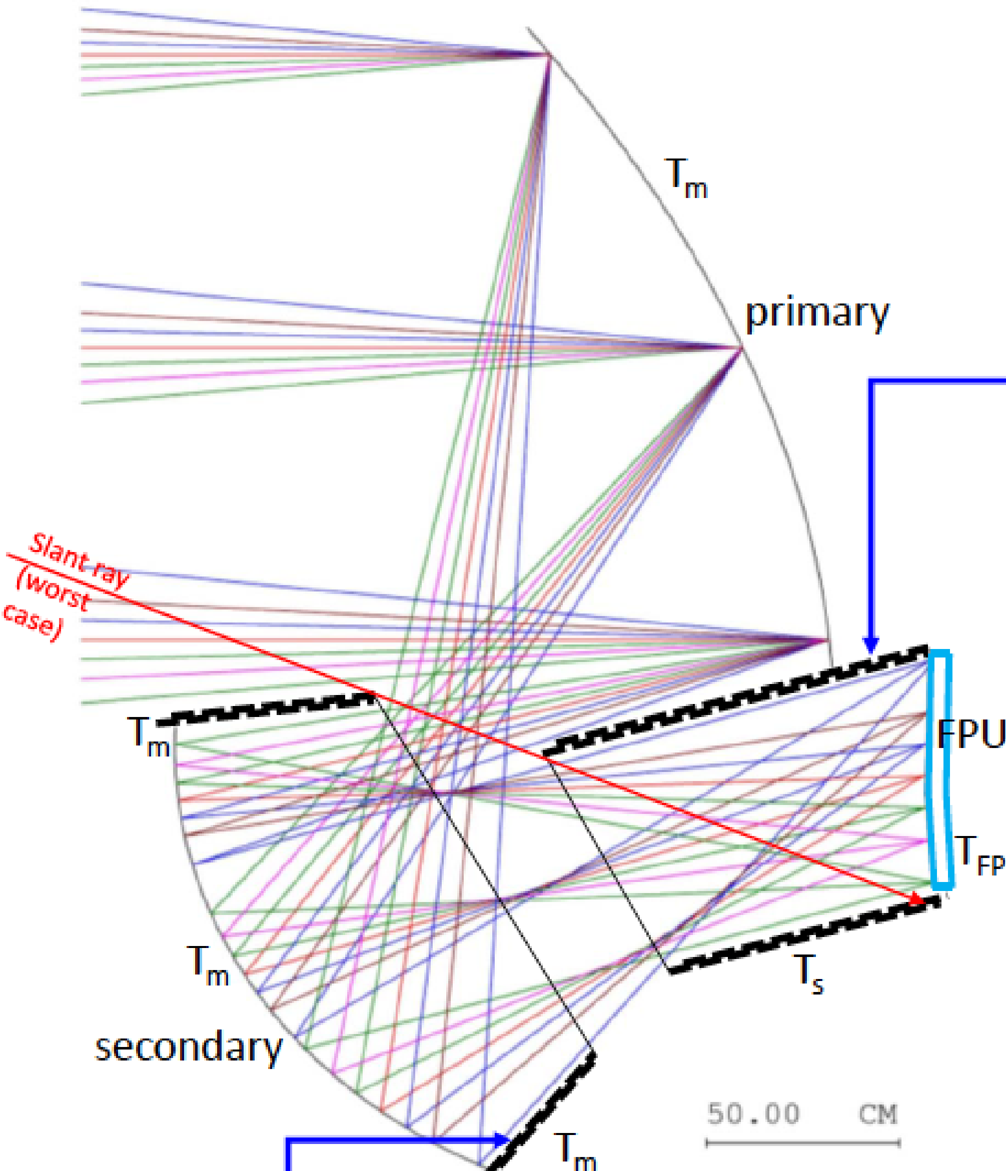


Figure 3: Sketch of the focal plane of COrE+ Light. Contours are Strehl= 0.8 for 60, 90, 130, 160, 220, 340, 450, and 600 GHz.

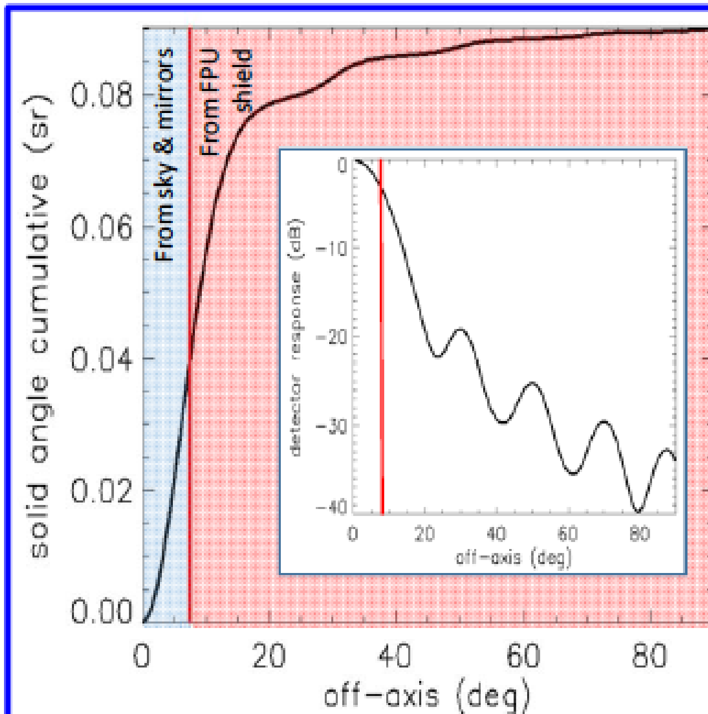
Gregorian telescope – simpler to baffle



Secondary baffle : Probably shiny, to reduce BKG.

Cold & black FPU baffle :

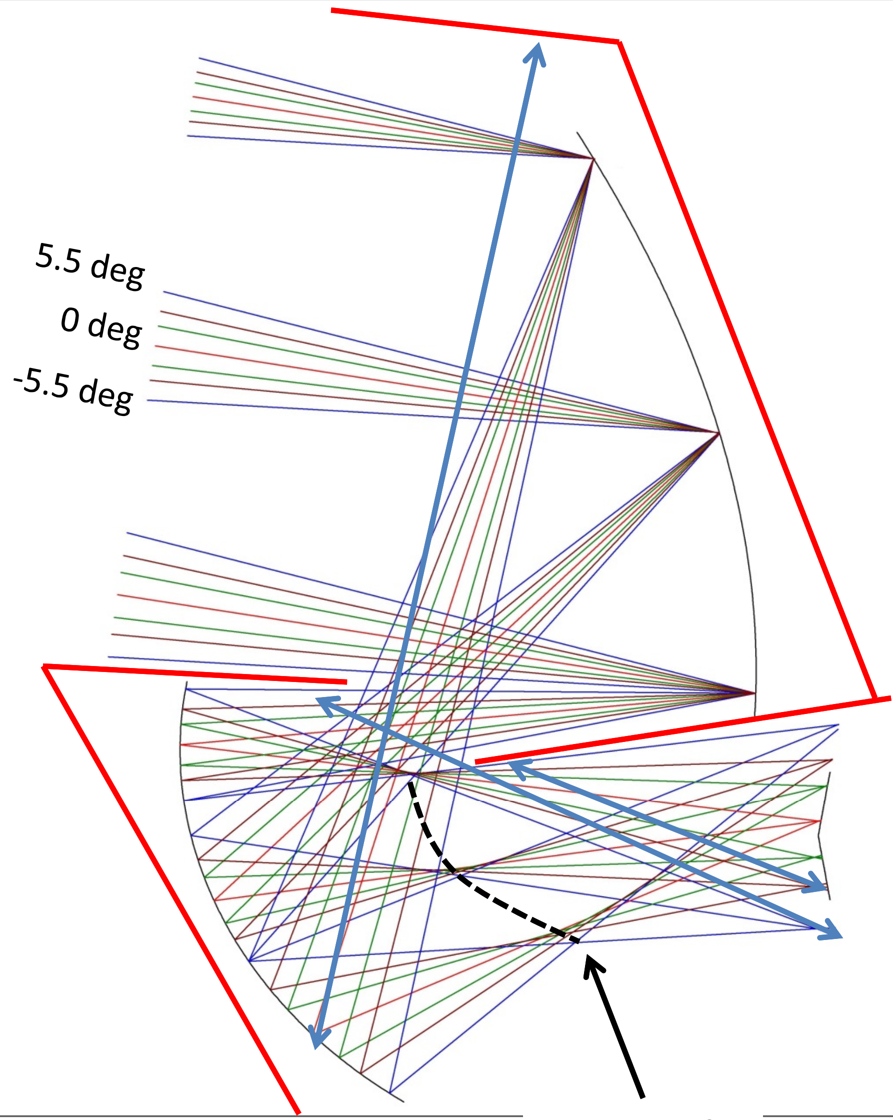
- Reduces straylight (combined with secondary baffle)
- Reduces the radiative background on the detectors:
  - No need for horns
  - T mirrors does'nt need to be extremely low



- 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

Image of Primary

50.00 CM

COrE gregorian 1.5meter f/2

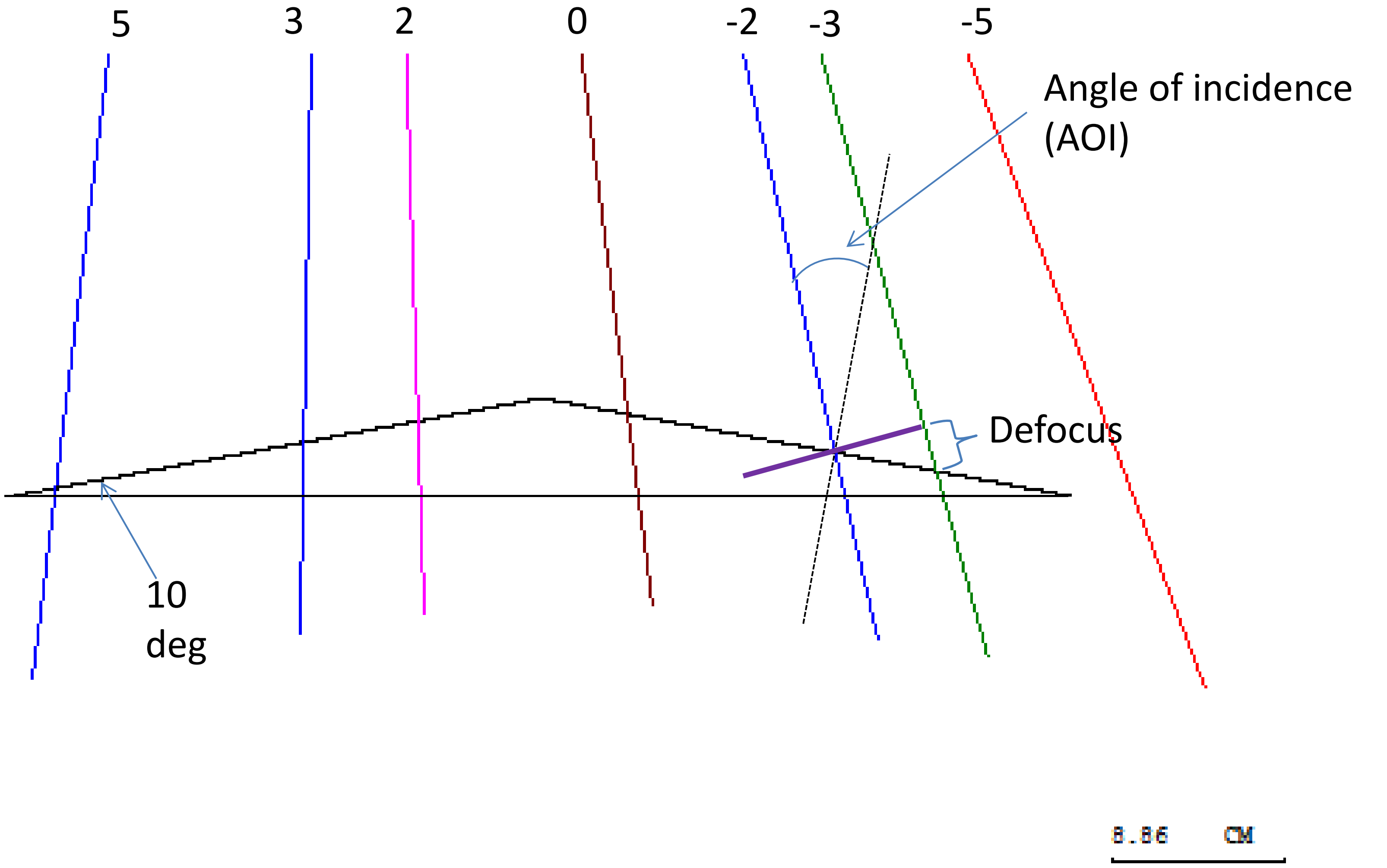
03-May-16

Cold Stop Enforced (for most of the rays)

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

Conic, Non-telecentric, Focal Surface: What if we tilt the arrays?

Chief rays for 7 field angles.

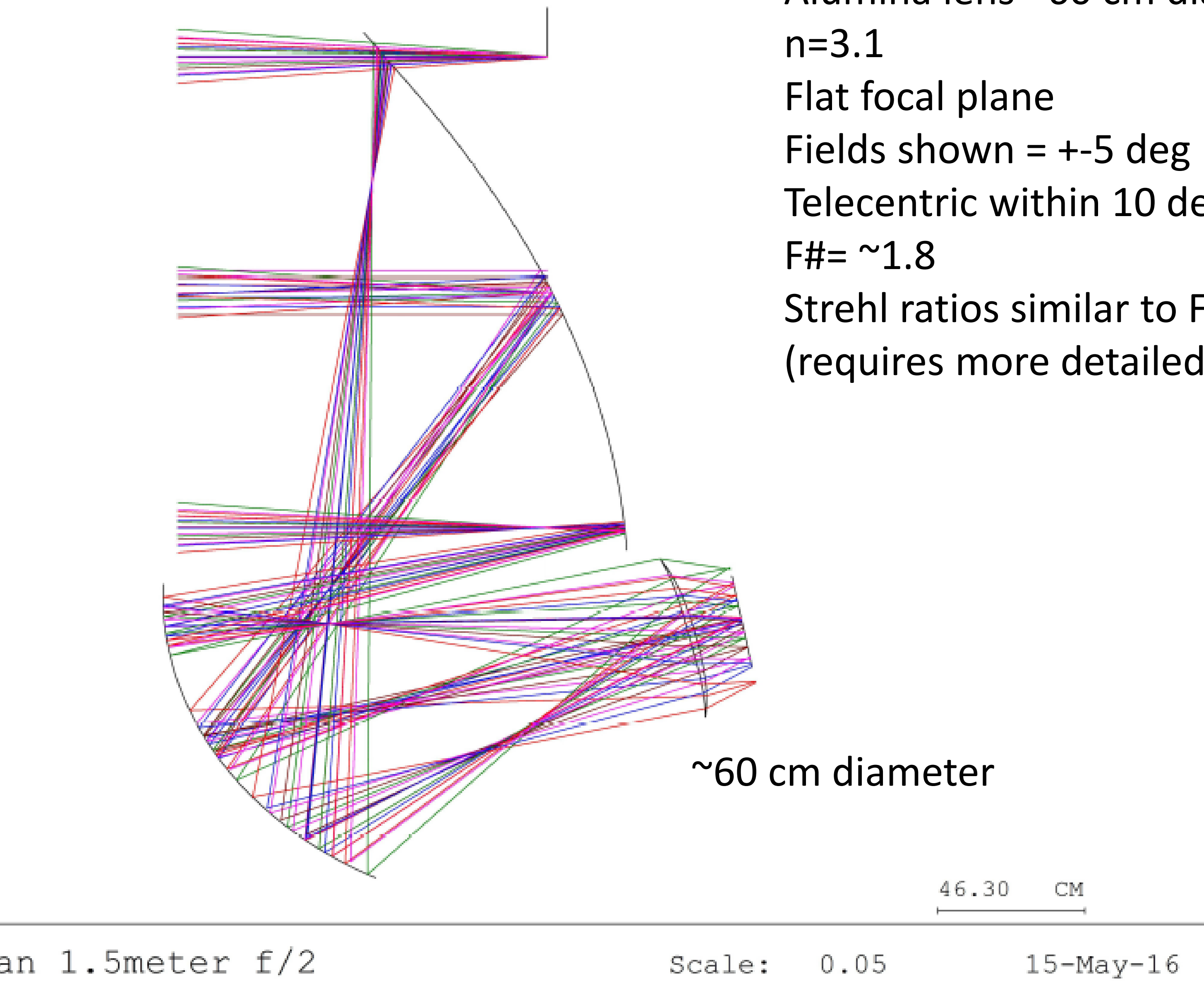


Results

Field (degrees)	Freq. (GHz)	AOI (deg)	Defocus (cm)		Strehl at focus	Strehl				average delta strehl/cm
			4''	3''		4'' outer	4'' inner	3'' outer	3'' inner	
-5	60	30.9	3.150	2.347	0.89	0.81	0.72	0.85	0.78	0.03
-3	150	25.9	2.419	1.803	0.93	0.57	0.60	0.70	0.740	0.13
-2	300	23.3	2.031	1.514	0.90	0.22	0.40	0.35	0.62	0.28
0	600	17.9	1.214	0.904	0.90	0.28	0.23	0.45	0.38	0.53
2	300	8.6	0.216	0.161	0.71	0.70	0.71	0.70	0.71	0.025
3	150	11.5	0.231	0.172	0.81	0.80	0.81	0.81	0.81	0.01
5	60	17.39	1.136	0.846	0.86	0.88	0.83	0.87	0.84	0.02

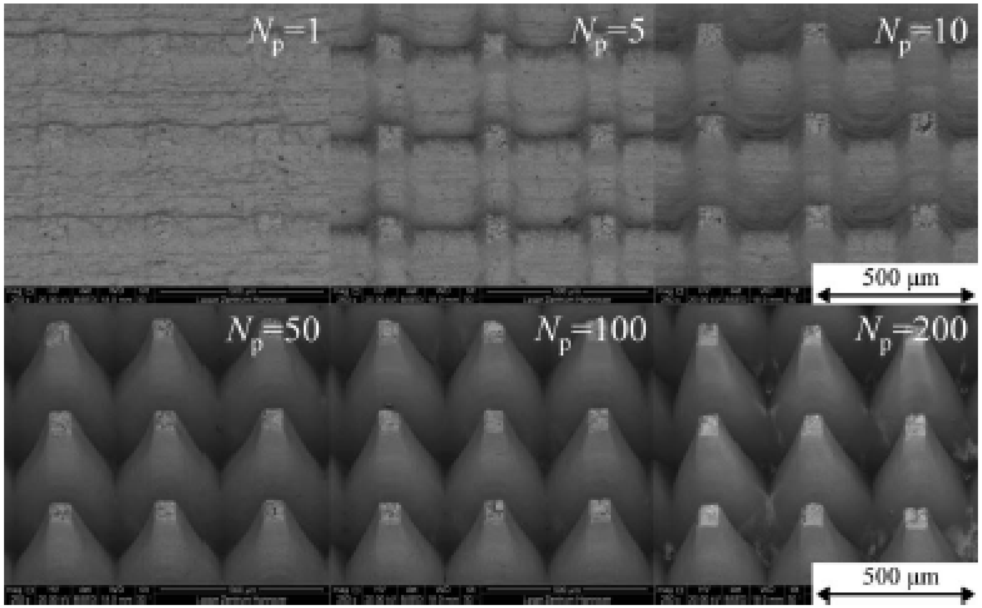
Need to steer the beams

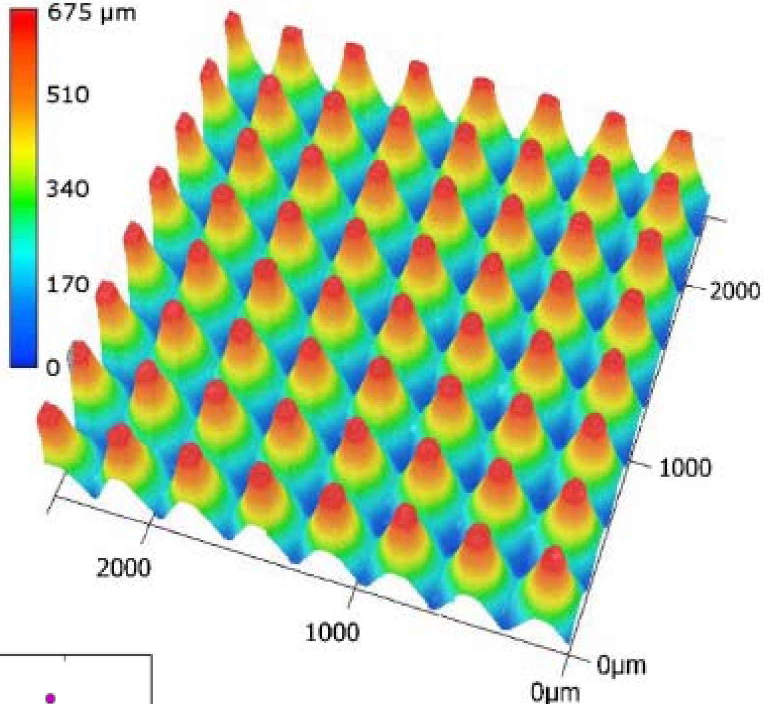
Or – Use a Lens?

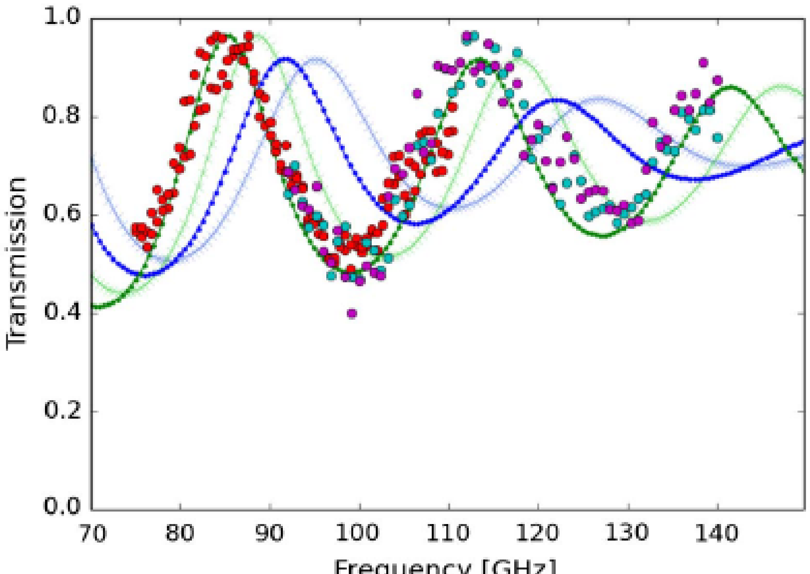


Alumina lens ~60 cm diameter
n=3.1
Flat focal plane
Fields shown = +-5 deg
Telecentric within 10 deg
F#= ~1.8
Strehl ratios similar to F#=2
(requires more detailed study)

Broadband ARC – Laser Ablation





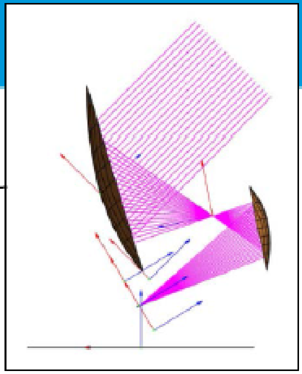


Matsumura et al. 2016

Telescope configuration trade-off

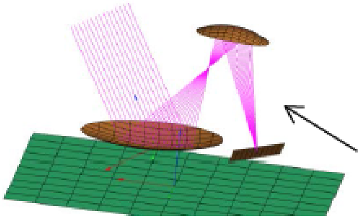
Four configurations considered:

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

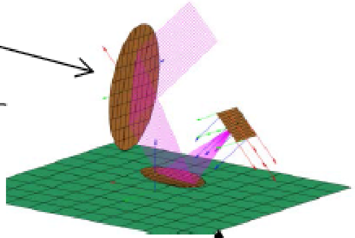


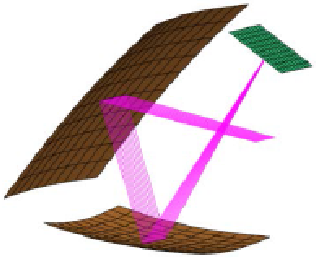
Selected option:

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

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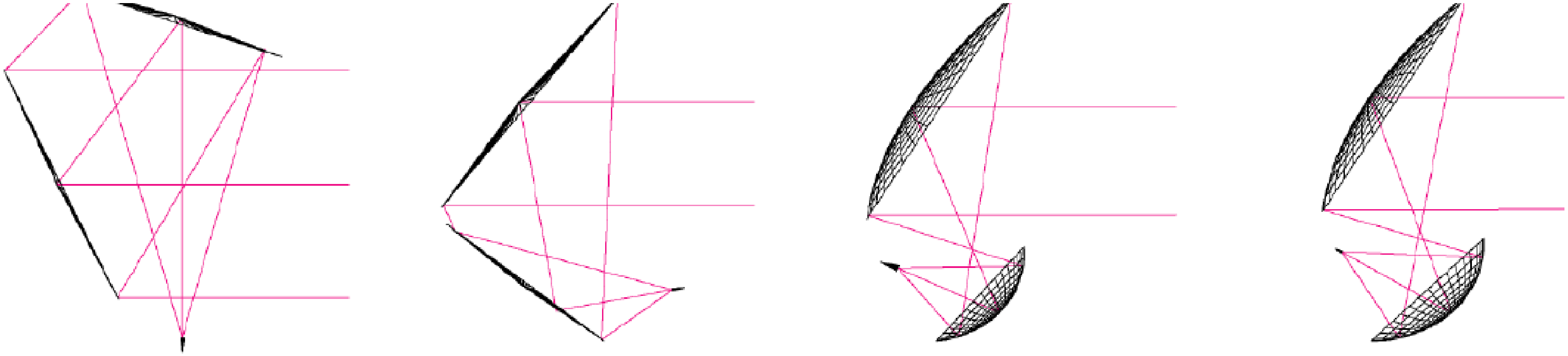
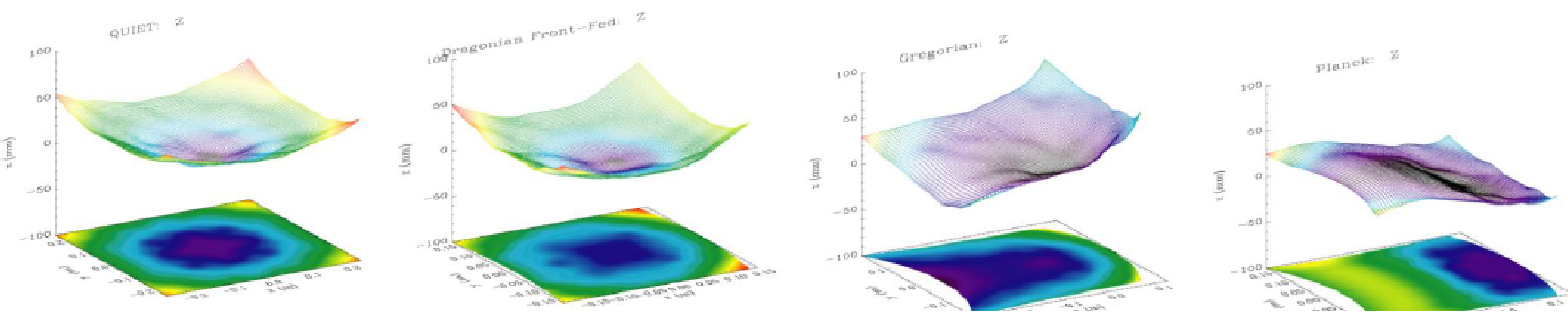


(a) (b) (c) (d)

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?