LSPE

the Large-Scale Polarization Explorer

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for the LSPE collaboration

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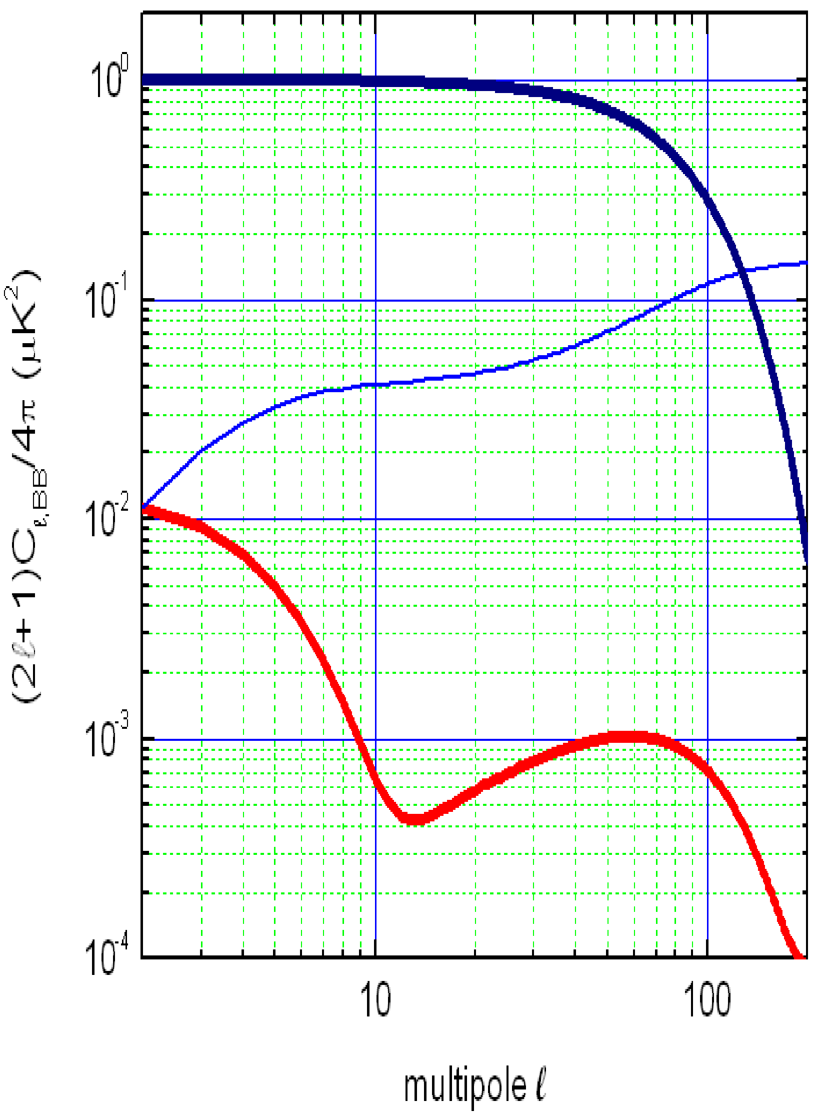
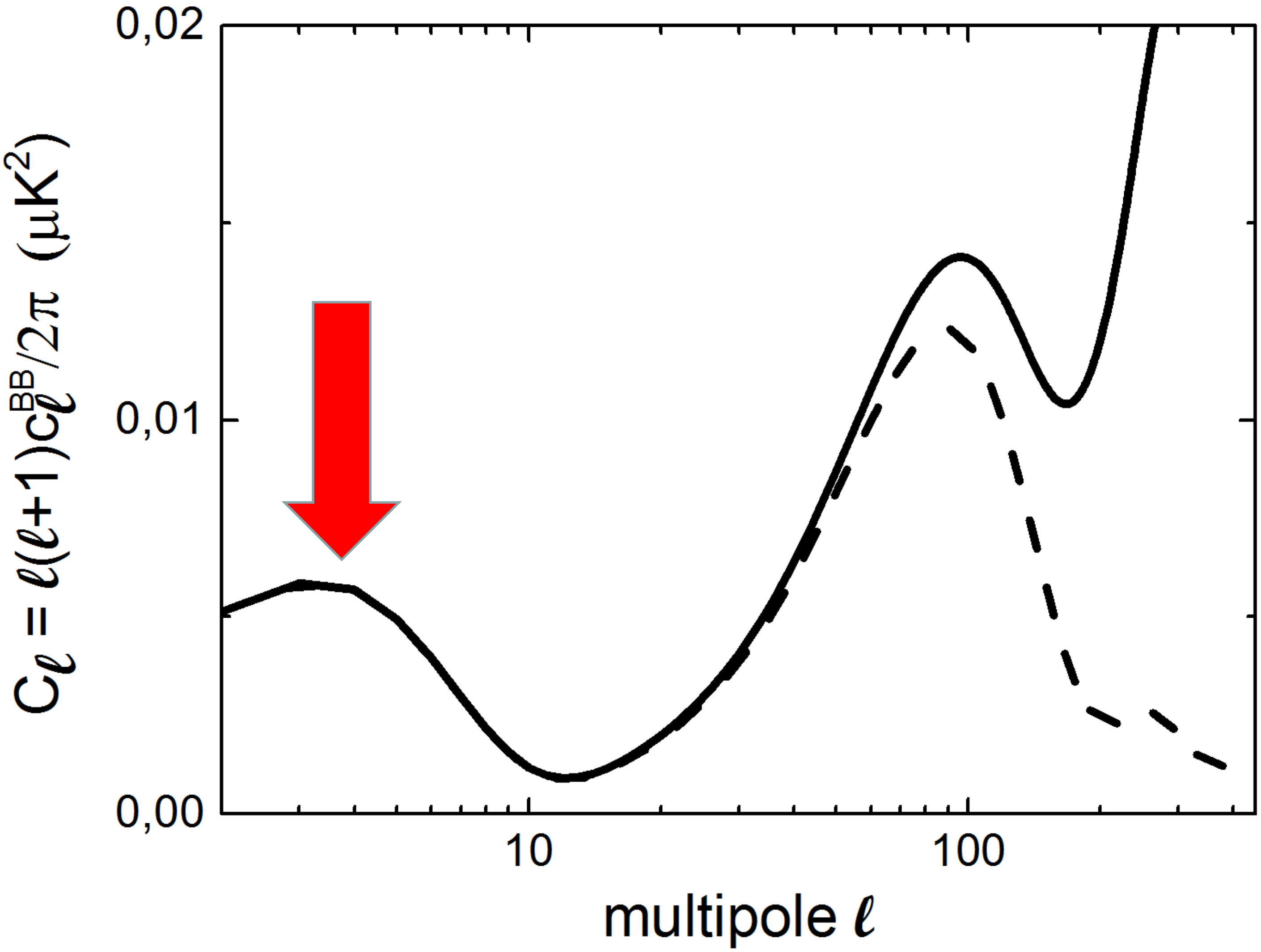
Mario	Zannoni	Dip. Fisica Università di Milano Bicocca

Scientific Target : B-modes

- Red line : contribution from each multipole to the total mean square fluctuation of the tensor component of CMB polarization (B-modes, r = 1).
- Thin blue line : the cumulative of the B-modes, i.e. the variance measured by an experiment sensitive from multipole 2 to a given multipole ℓ.
- The top blue thick line : the beam function B^2_ℓ for an experiment with a 1.5° FWHM Gaussian beam.
- Despite of the coarse angular resolution such an experiment collects most of the polarization signal from B-modes.



main target : reionization peak



A difficult but important target, to complement measurements of the ℓ=80 peak !

the reionization peak is difficult

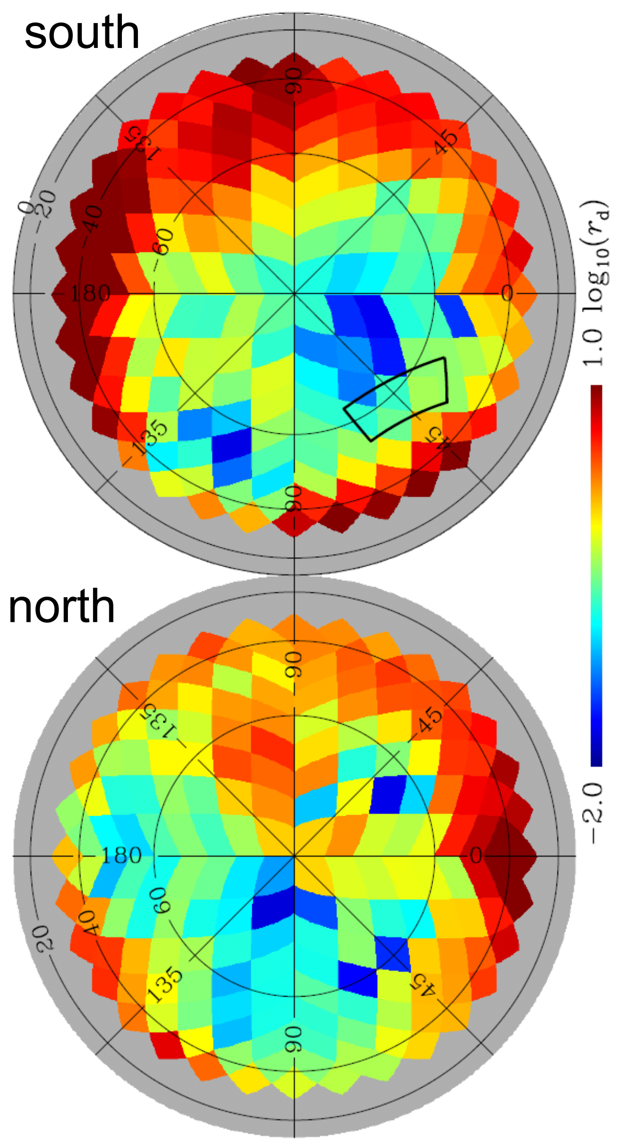
- Large angular scales: wide sky coverage required.
- Foreground contamination is high. From *Planck intermediate results XXX: The angular power spectrum of polarized dust emission at intermediate and high Galactic latitude*
  - Dust B-modes in the best 30% of sky at 350 GHz:

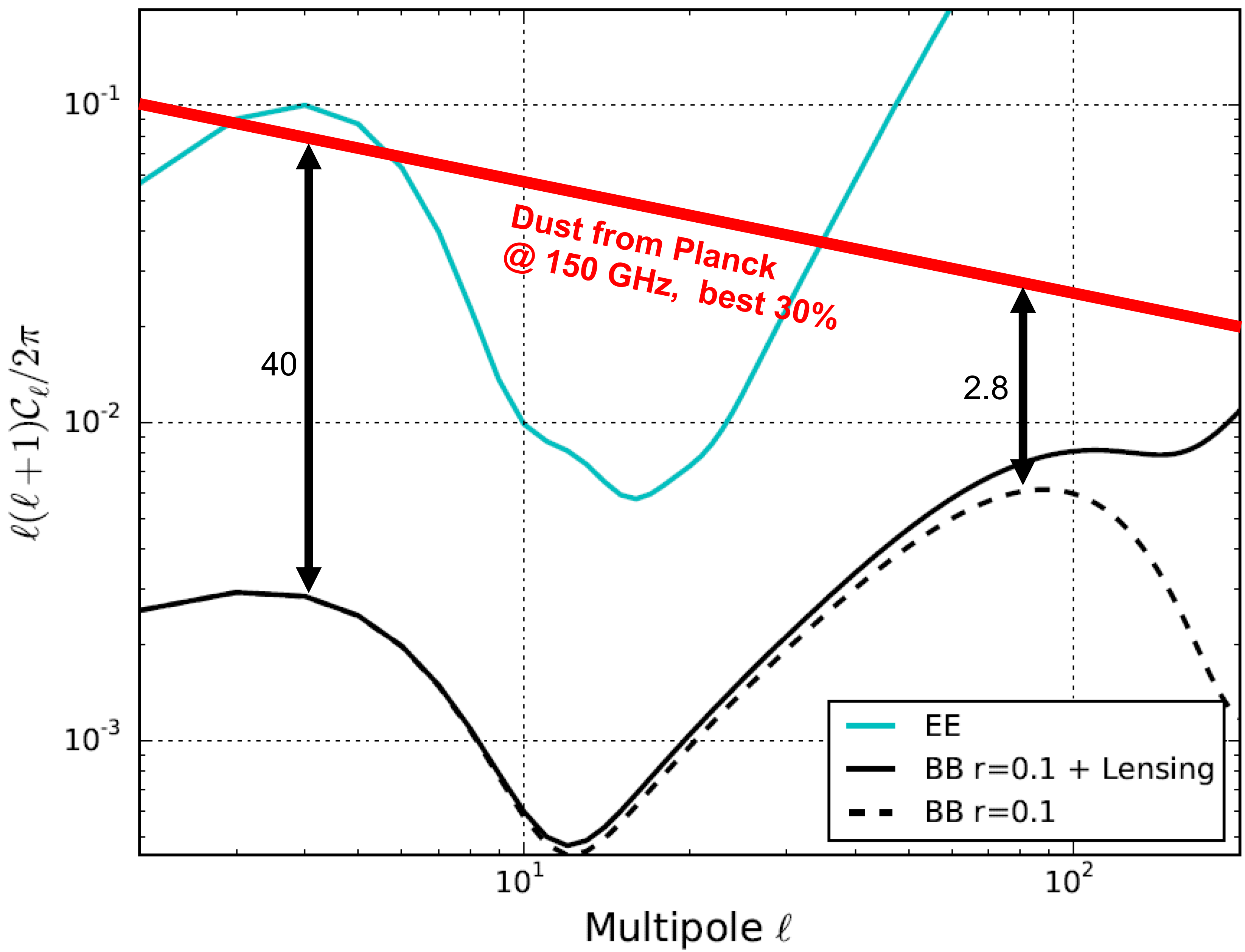
    $$D_\ell = \ell(\ell+1)C_\ell/2\pi$$

    $$D_\ell = 14\mu K^2(\ell/80)^{-0.42}$$

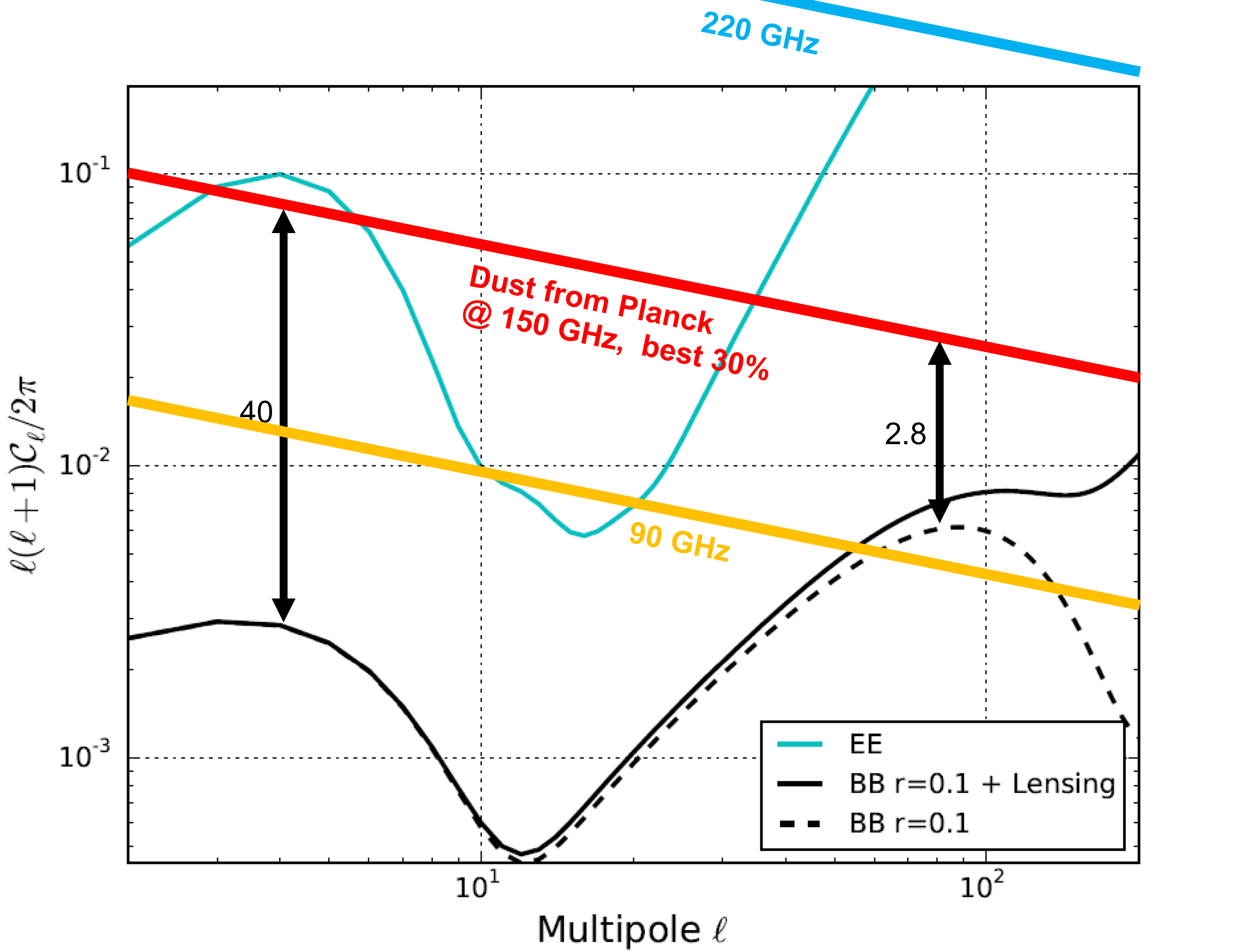
  - Extrapolating to 150 GHz (factor 0.04^2)

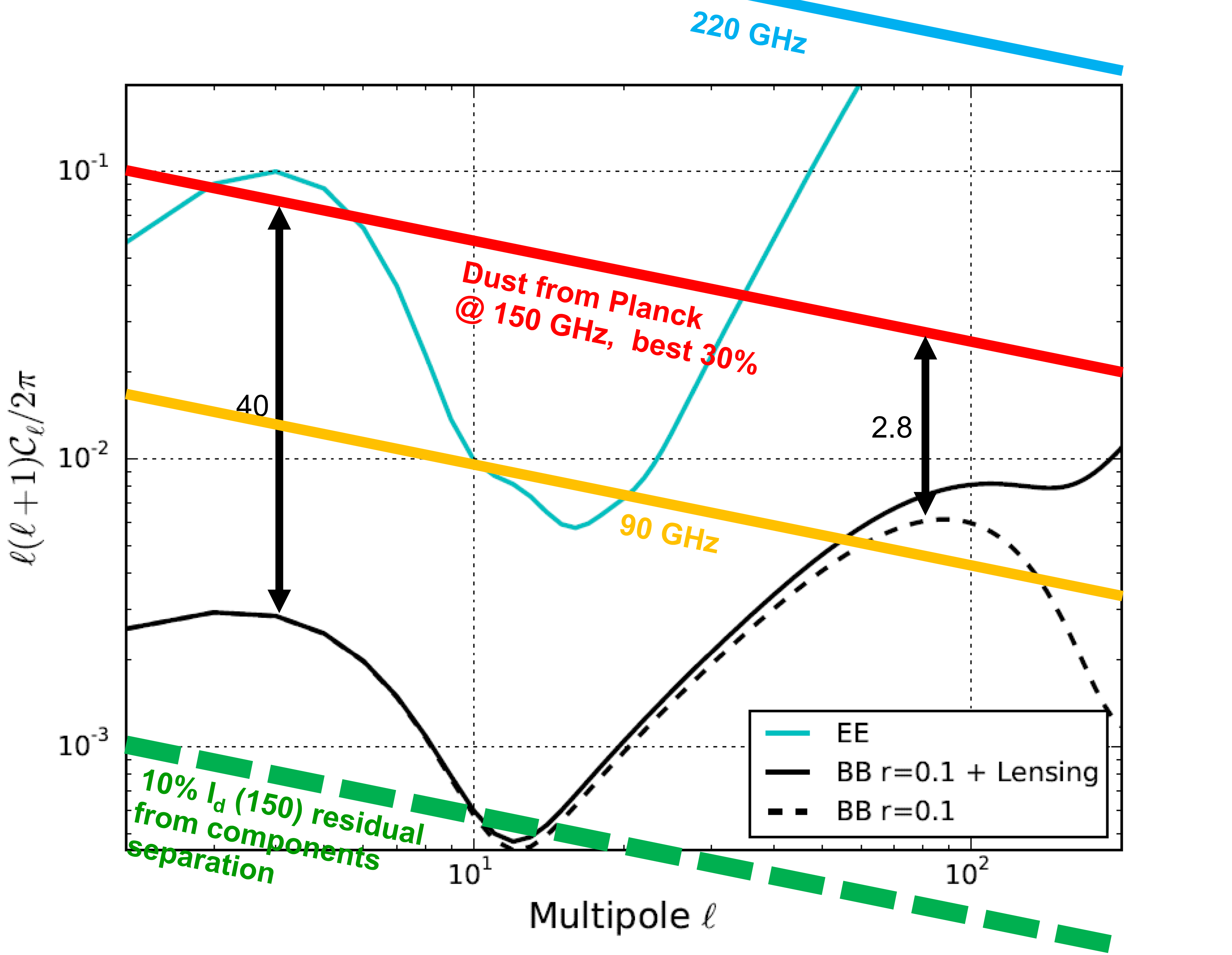
    $$D_\ell = 2.2 \cdot 10^{-2}\mu K^2(\ell/80)^{-0.42}$$





Dust from Planck
@ 150 GHz, best 30%
40
2.8
EE
BB r=0.1 + Lensing
BB r=0.1
$\ell(\ell+1)C_\ell/2\pi$
Multipole ℓ
10^{-1}
10^{-2}
10^{-3}
10^{1}
10^{2}


220 GHz
Dust from Planck
@ 150 GHz, best 30%
40
2.8
90 GHz
EE
BB r=0.1 + Lensing
BB r=0.1
10^{-1}
10^{-2}
10^{-3}
10^{1}
10^{2}
$\ell(\ell+1)\mathcal{C}_\ell/2\pi$
Multipole ℓ



220 GHz
Dust from Planck
@ 150 GHz, best 30%
40
2.8
90 GHz
10% I_d (150) residual
from components
separation
EE
BB r=0.1 + Lensing
BB r=0.1
10^-1
10^-2
10^-3
10^1
10^2
Multipole ℓ
ℓ(ℓ+1)C_ℓ/2π

Experiment Strategy

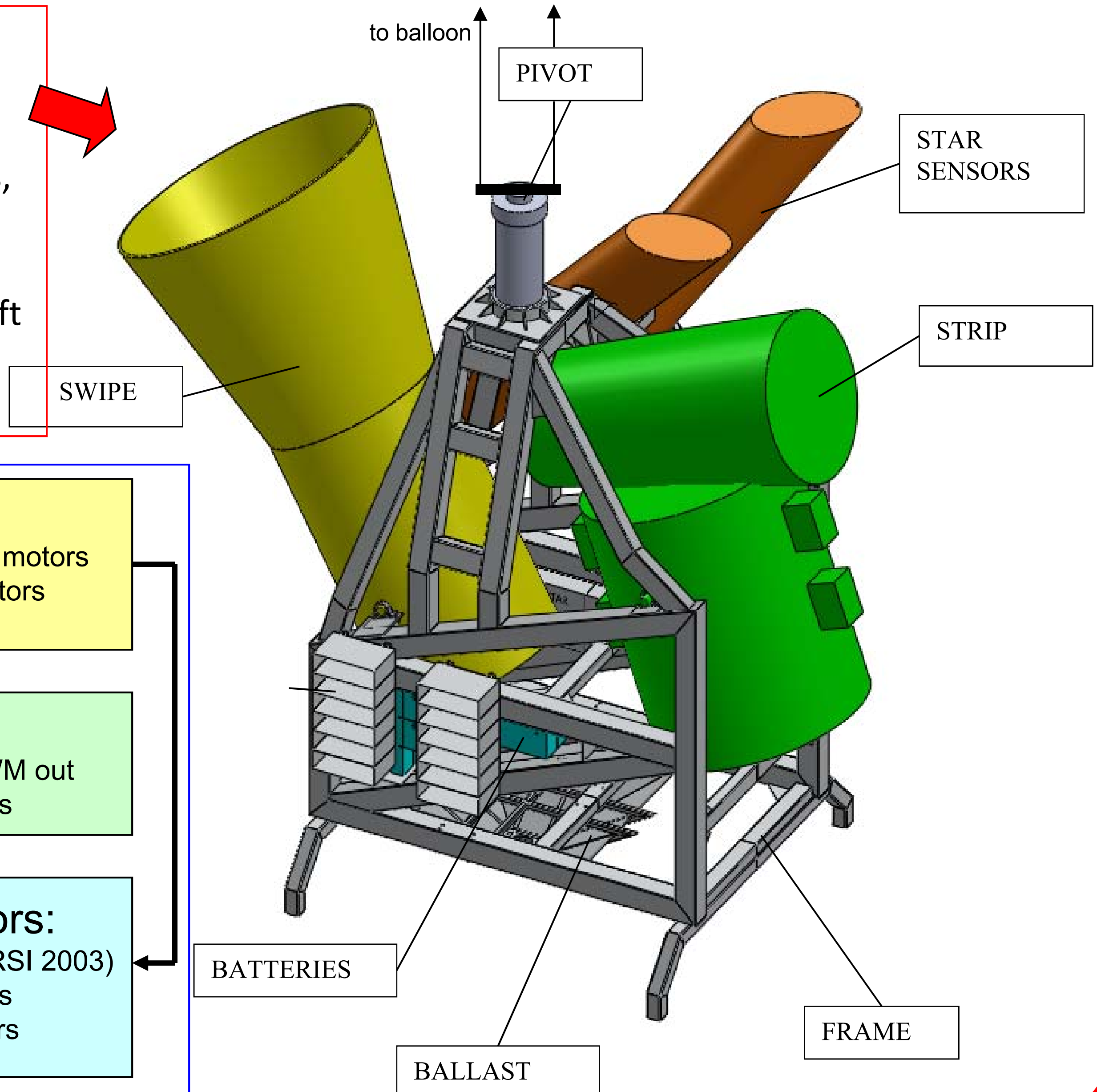
- Large sky coverage and wide frequency coverage call for a space mission. See e.g. COrE+ (just submitted !).
- On a shorter time-scale, experimentation is required to qualify specific instrumentation (optical systems, polarization modulators, detectors …) and methods (sky scan, mapping procedures, polarized foregrounds separation …) and possibly to get detections !
- A *balloon-borne instrument* can
  - avoid atmosperic noise and loading
  - exploit a wide frequency coverage
  - access a large fraction of the sky *during night-time*
  - offer a stable environment *during night-time*
  - reject ground spillover using very large ground-shields

LSPE in a nutshell

- The Large-Scale Polarization Explorer is :
  - an instrument to measure the polarization of the Cosmic Microwave Background at large angular scales
  - using *a spinning stratospheric balloon payload* to avoid atmospheric noise
  - flying *long-duration, in the polar night*
  - using a *polarization modulator* to achieve high stability
- Frequency coverage: 40 – 250 GHz (5 channels, 2 instruments: STRIP & SWIPE)
- Angular resolution: 1.3^o FWHM
- Sky coverage: 20-25% of the sky per flight
- Combined sensitivity: 10 μK arcmin per flight
- Current collaboration: Sapienza, UNIMI, UNIMIB, IASFBO-INAF, IFAC-CNR, Uni.Cardiff, Uni.Manchester. INFN-GE, INFN-PI, INFN-RM1, INFN-RM2
- See astro-ph/1208.0298, 1208.0281, 1208.0164 and forthcoming updates

LSPE gondola : frame + pivot + STRIP + SWIPE

Preliminary sketch of the LSPE experiment, without thermal protections.
The total mass is around 2.5 tons, the overall dimensions are 5.8m(w) x 3.2m(d) x 4.6m (h).
A 800000 m^3 balloon is used to lift the instrument at 37 km of altitude.



ACS block diagram

Actuators:
Azimuth pivot with torque motors
Linear elevation actuators

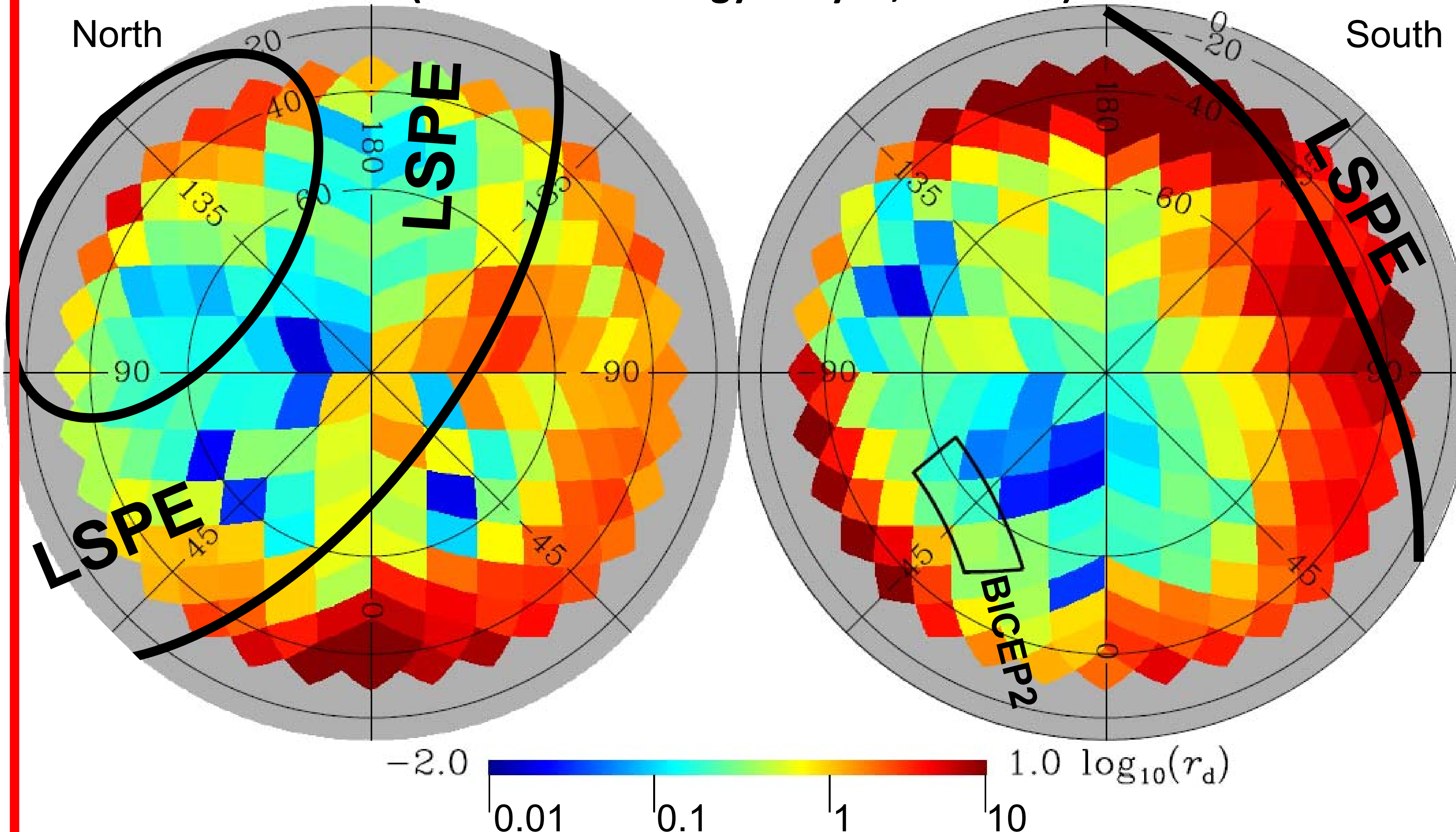
Processor:
PC104 with ADC in / PWM out
H-bridges for motors

TM
TC

Attitude sensors:
Star sensors (Nati et al. RSI 2003)
Laser Gyroscopes
Elevation Encoders

Sky coverage of LSPE

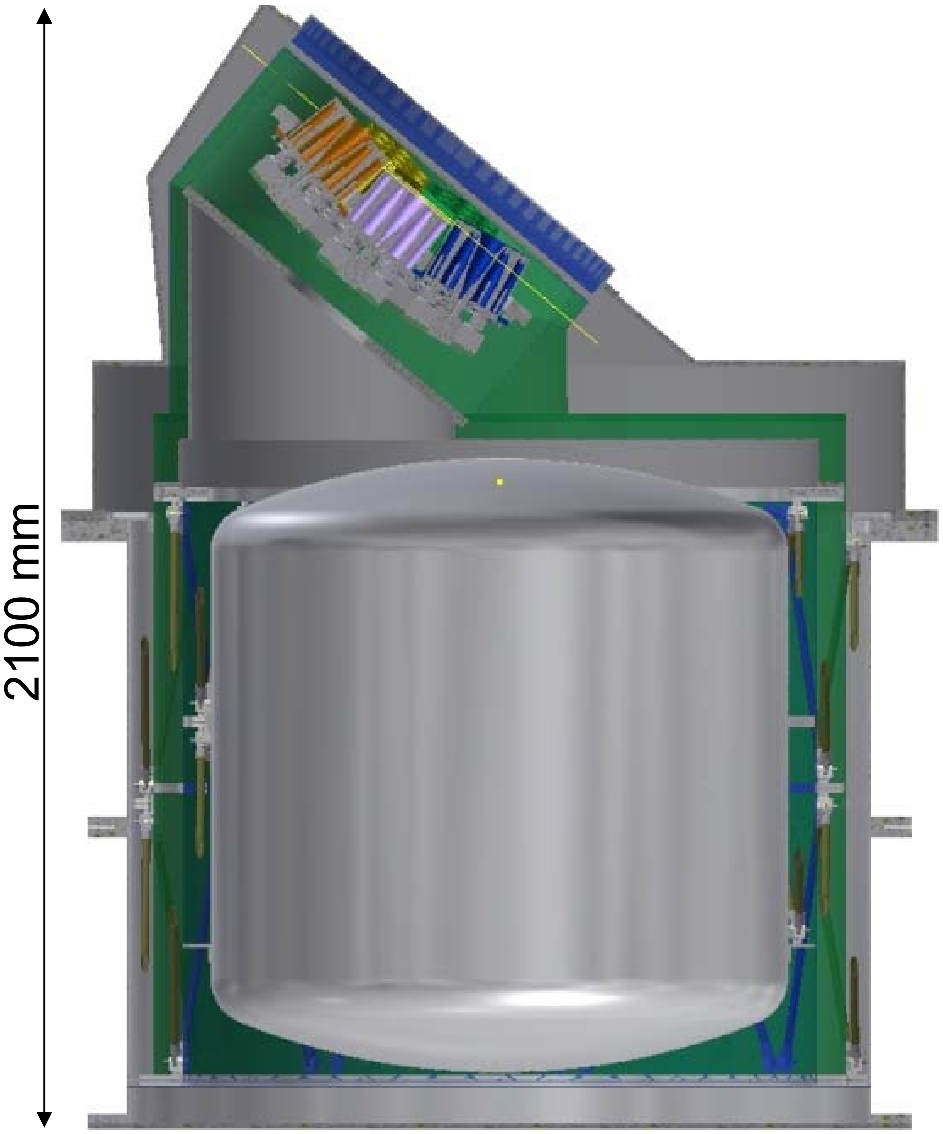
(Launch from Longyearbyen, Svalbard)



B-modes from dust @140 GHz, as estimated from Planck 343 GHz dust polarization - Planck PIP XXX 1409.5738

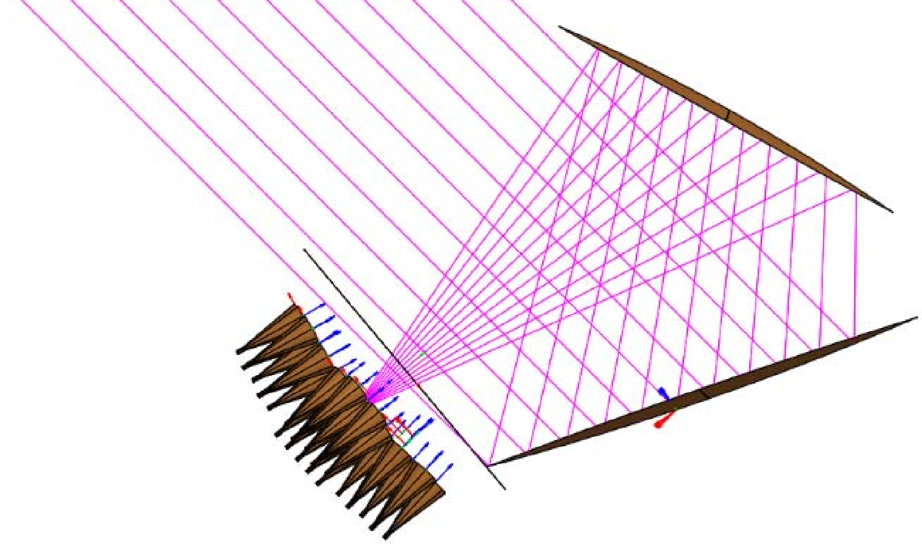
The STRIP Instrument

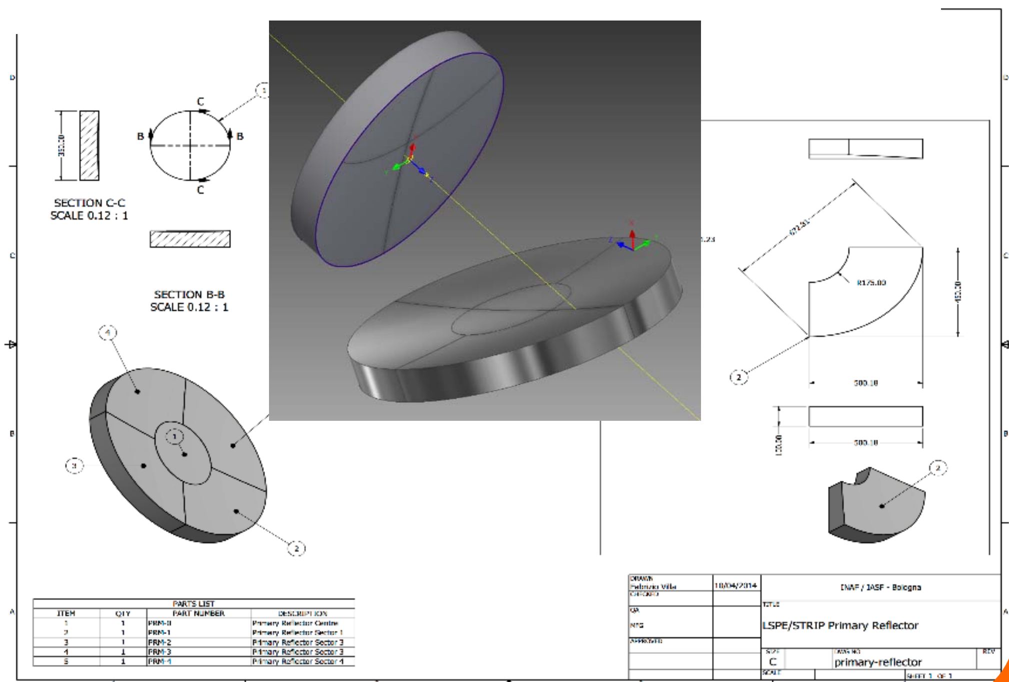
- STRIP is the STRatospheric Italian Polarimeter, aimed at accurate measurements of the low-frequency (44 and 90 GHz) polarized emission, dominated by Galactic synchrotron.
- Its sensitivity at 44 GHz in a single flight is twice better than the final sensitivity of the Planck LFI survey.
- The correlation radiometers are contained in a large cryostat and cooled at 20K by evaporating ^{4}He.



The STRIP Instrument

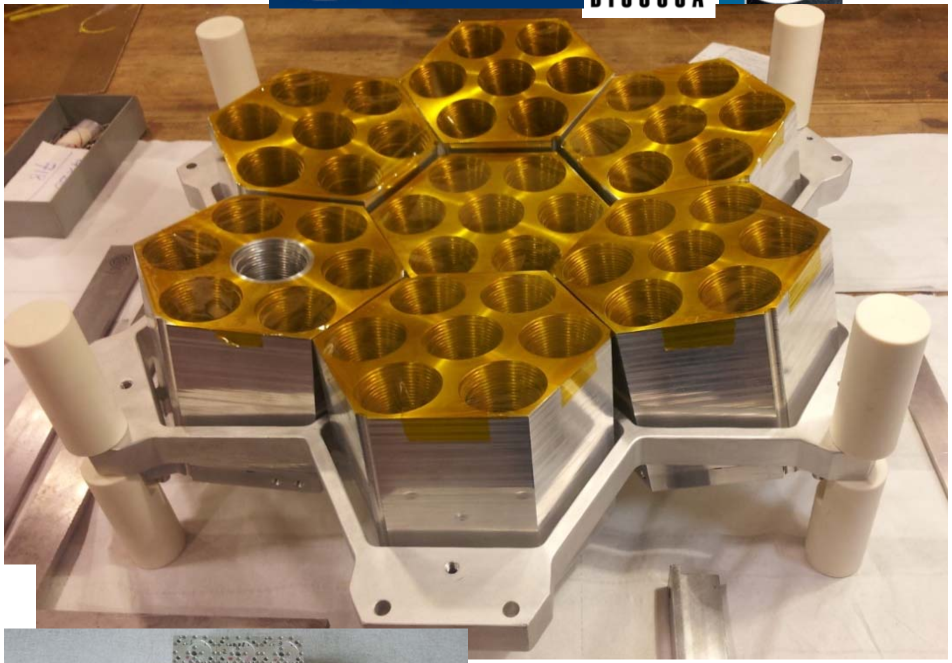
- The beam is defined by a 600 mm aperture side-fed crossed-Dragone telescope, selected for best polarization purity
- Challenging for spillover, stray-light and obscuration
- Modular Primary and secondary mirrors to reduce fabrication costs
- Lightened structure to reduce weight

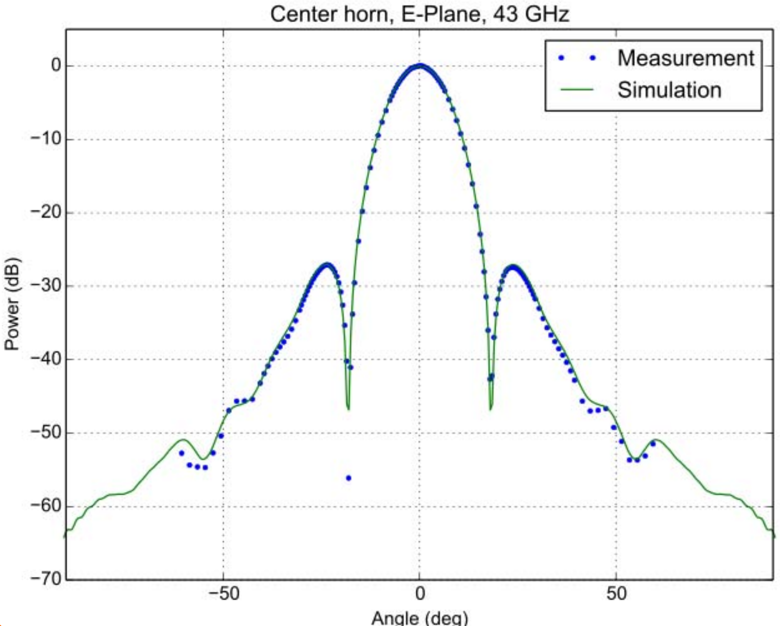


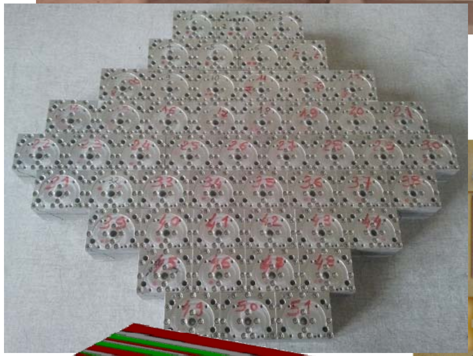


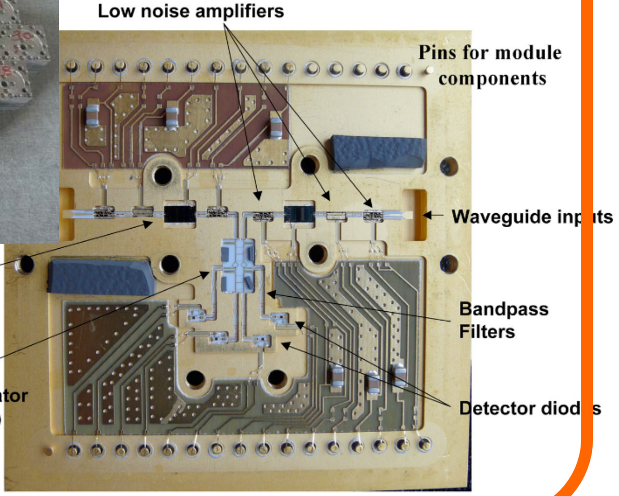
The STRIP Instrument

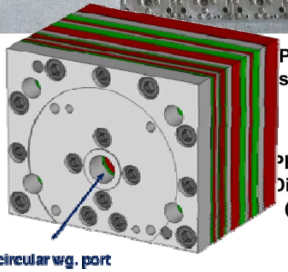
- In the focal plane, an array of 44 GHz platelet feedhorns (already manufactured) feeds high performance OMTs and LNAs derived from the QUIET exp.
- The measured response of the corrugated feedhorns confirms the expected performance down to -55 dB





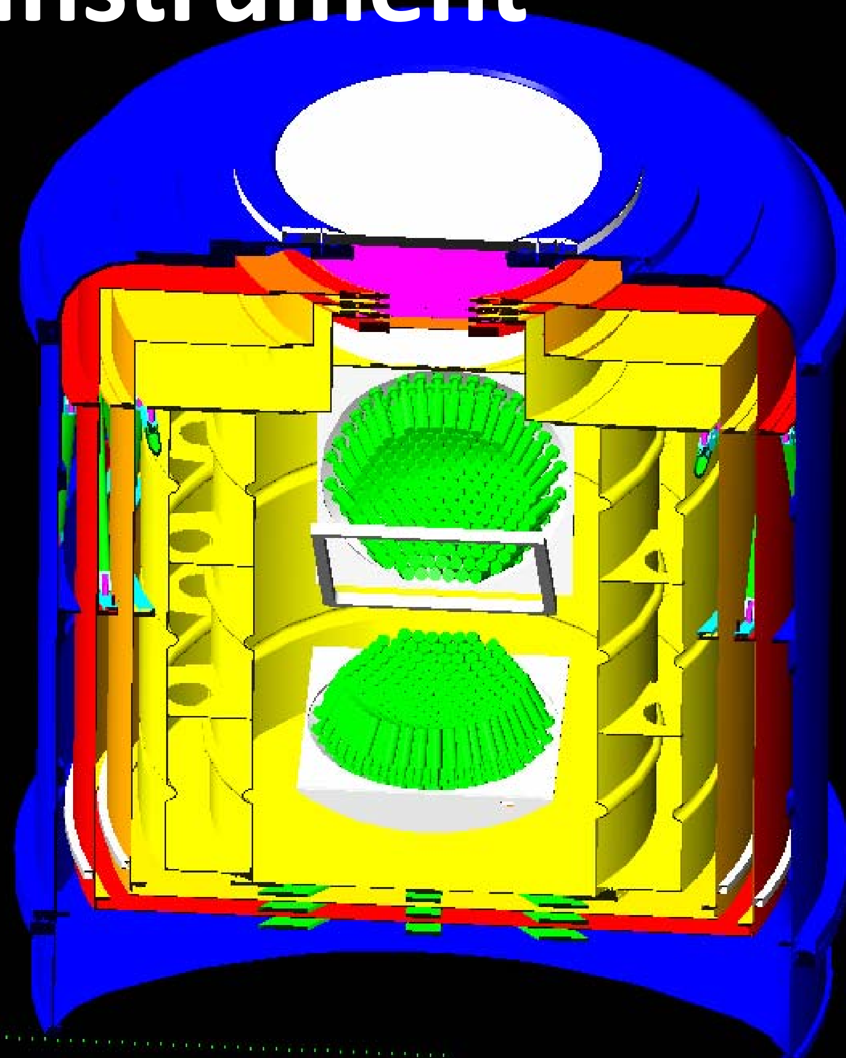




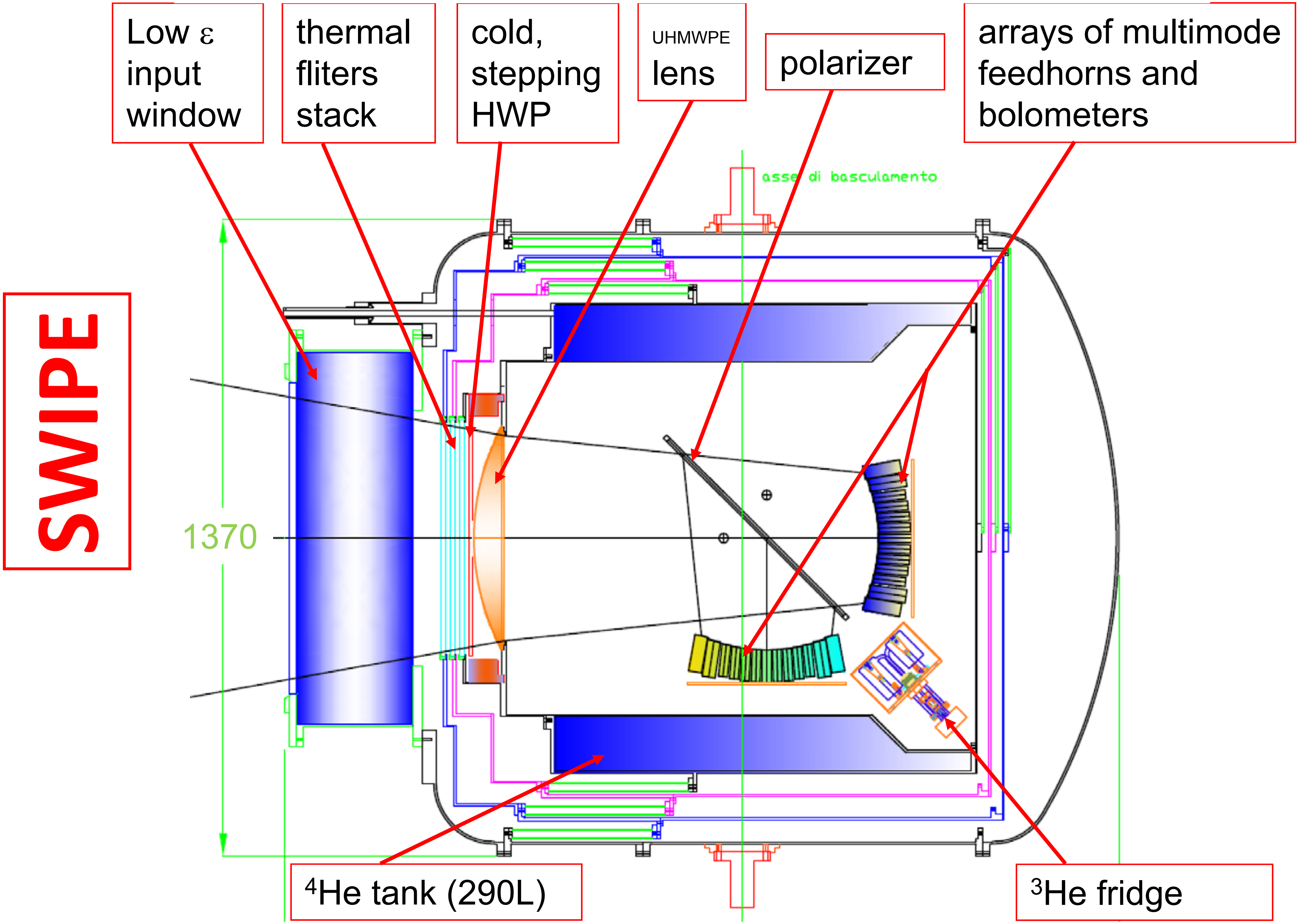


The SWIPE Instrument

- SWIPE is the Short Wavelength Instrument for the Polarization Explorer
- It is a Stokes Polarimeter, based on a simple 50 cm aperture refractive telescope, a cold HWP polarization modulator, a beamsplitting polarizer, and two large focal planes, filled with multimode bolometers at 140, 220, 240 GHz.
- Everything is cooled by a large L^{4}He cryostat and a ^{3}He refrigerator, for operation of the bolometers at 0.3K

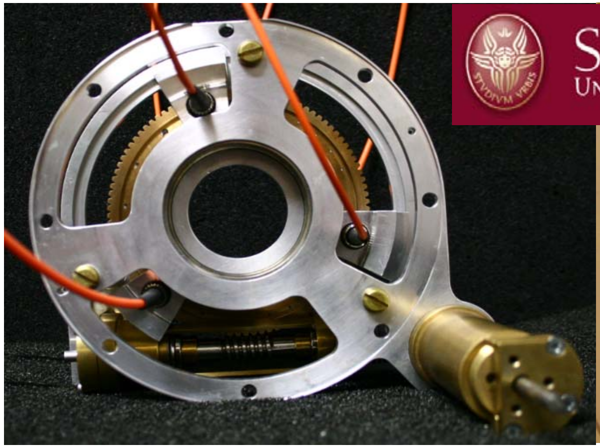


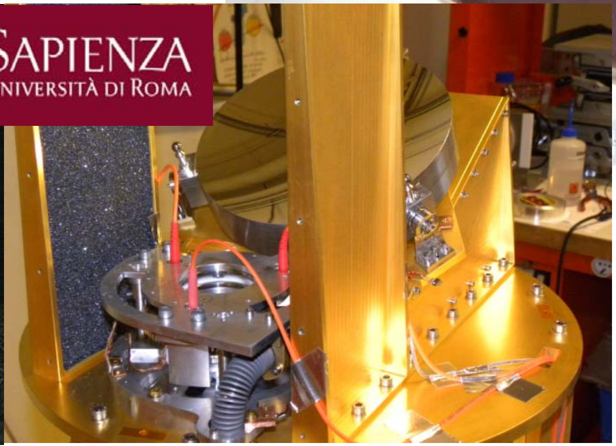
A cryogenic Stokes polarimeter



SWIPE – polarization modulator

- Is a cold (2K), large (50 cm useful dia.), wide band metamaterials HWP, placed immediately behind the window and thermal filters stack.
- HWP characteristics for the ordinary and extraordinary rays are well matched: $(T_o-T_e)/T_o < 0.001$, $X_{pol}<0.01$, over the 100-300 GHz band.
- Its orientation is stepped by 11.25° or 22.5° every few scans.

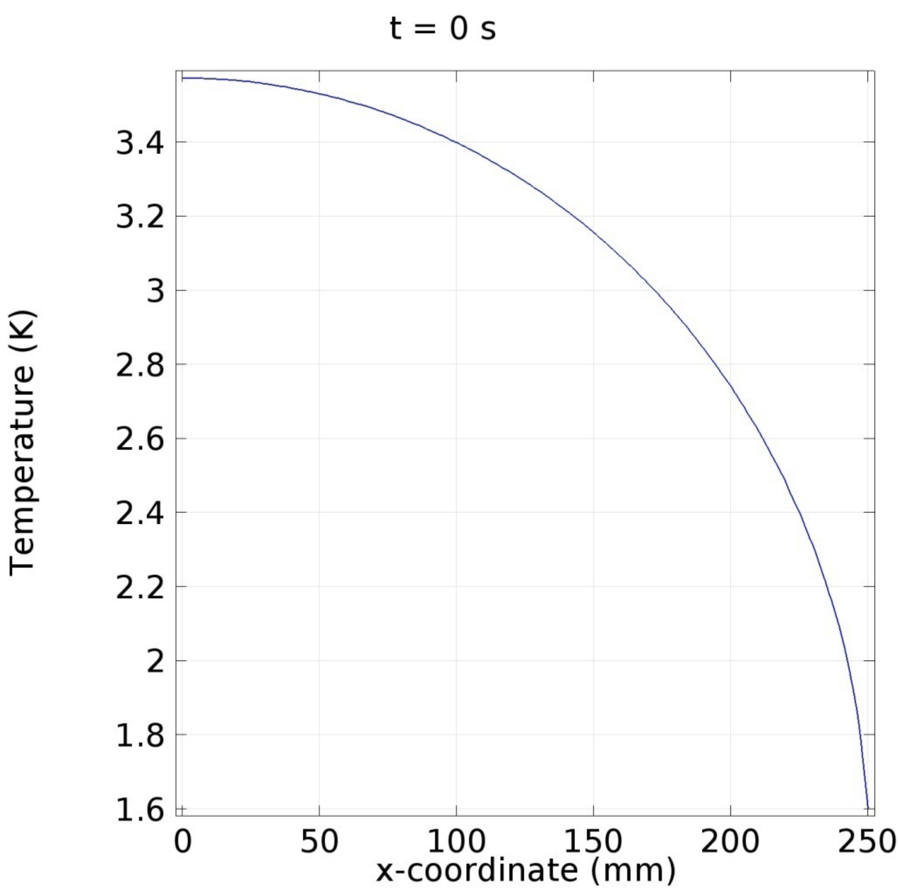


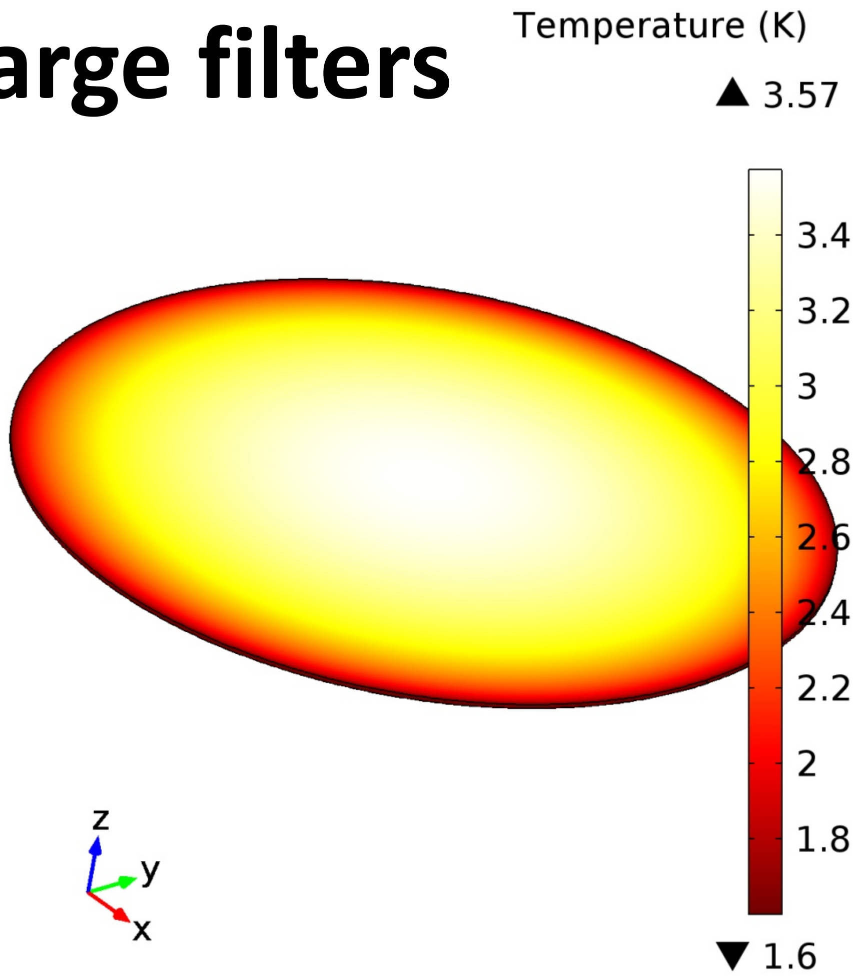


The cryogenic HWP rotator made for the PILOT experiment. The LSPE one will be based on the same design, and scaled up in dimensions (see Salatino et al. A&A 528 A138 2011)

Thermalization of large filters

incoming flux heats the HWP up to 3.57K





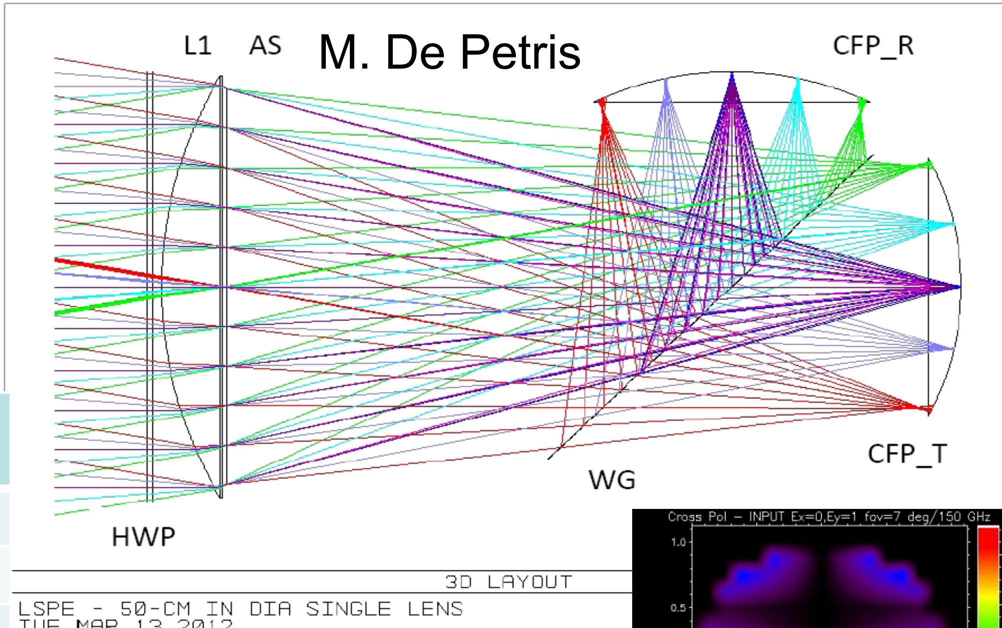
This results in a background on the detectors of 0.5, 0.12, 0.12 pW @ 140, 220, 240 GHz : negligible.

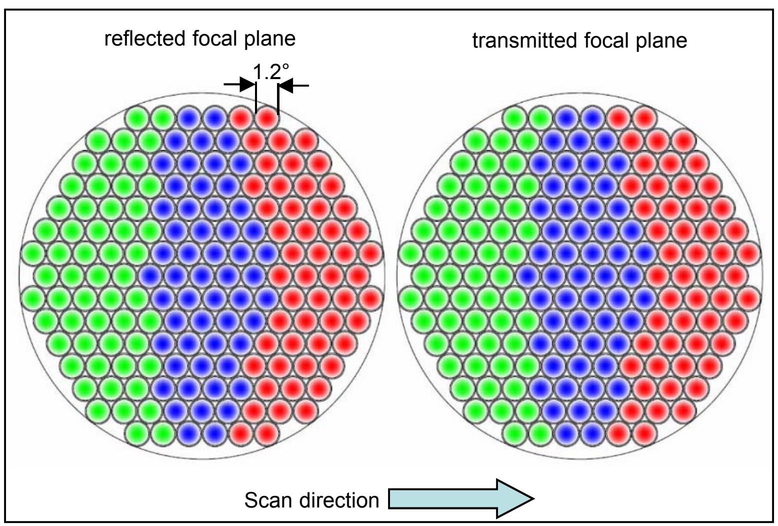
M.Salatino

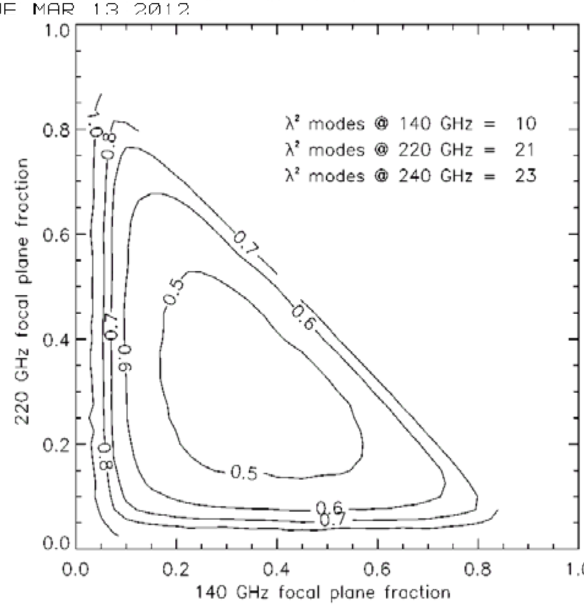
SWIPE – optical system

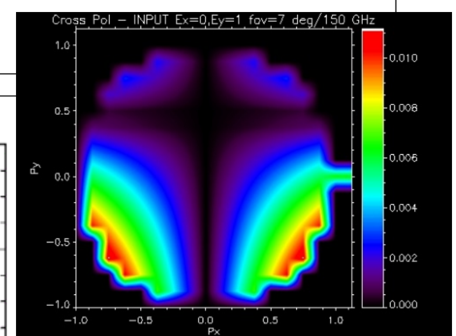
- Single lens UHMWPE @4K, AR coating, D=480, f=800
- Two curved focal planes populated with multimode bolometric detectors, resulting in 1.2°FWHM beams

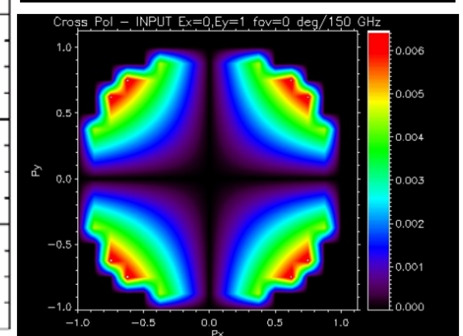
Band (GHz)	Width (%)	Total # detectors	# λ^2 modes
140 GHz	30	110	10
220 GHz	5	110	21
240 GHz	5	110	23







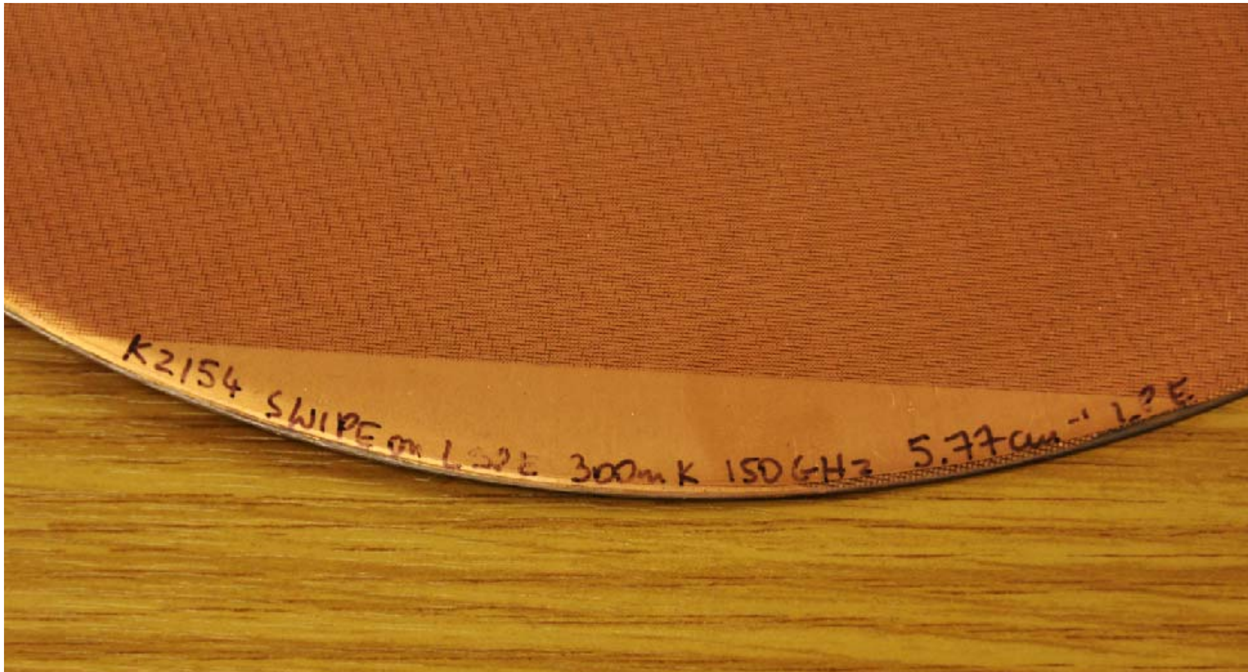


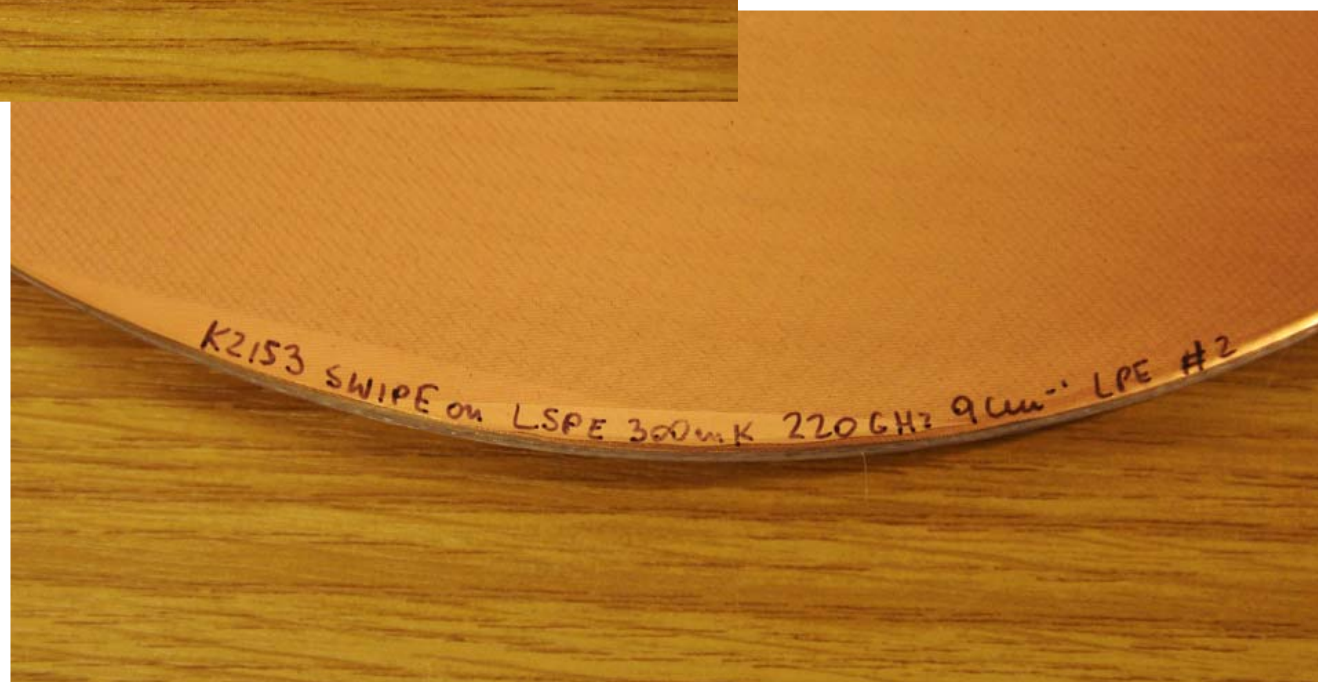


LSPE - Photolithographic polariser - Period: 20μm , Diameter: 42 cm

LSPE - Mesh Filters - Focal plane band defining Low Pass Edges

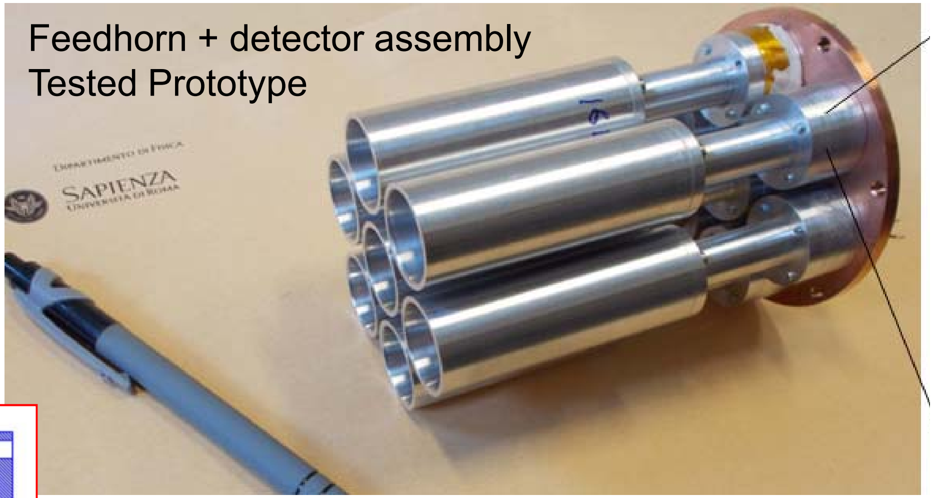
LSPE - Mesh Filters - Focal plane band defining Low Pass Edges

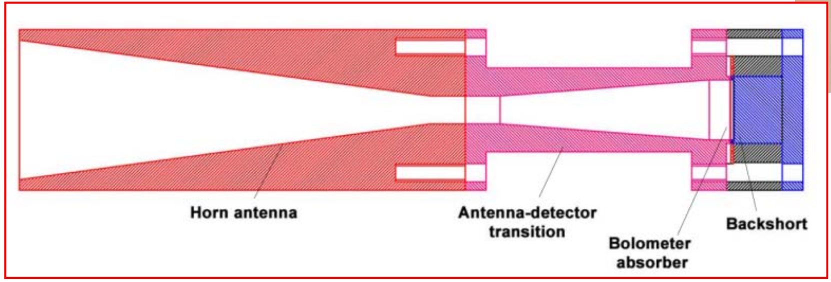


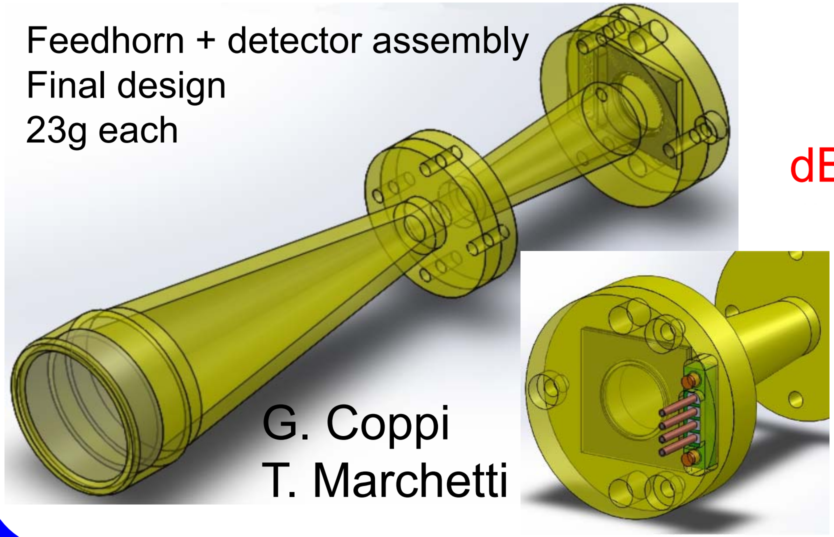


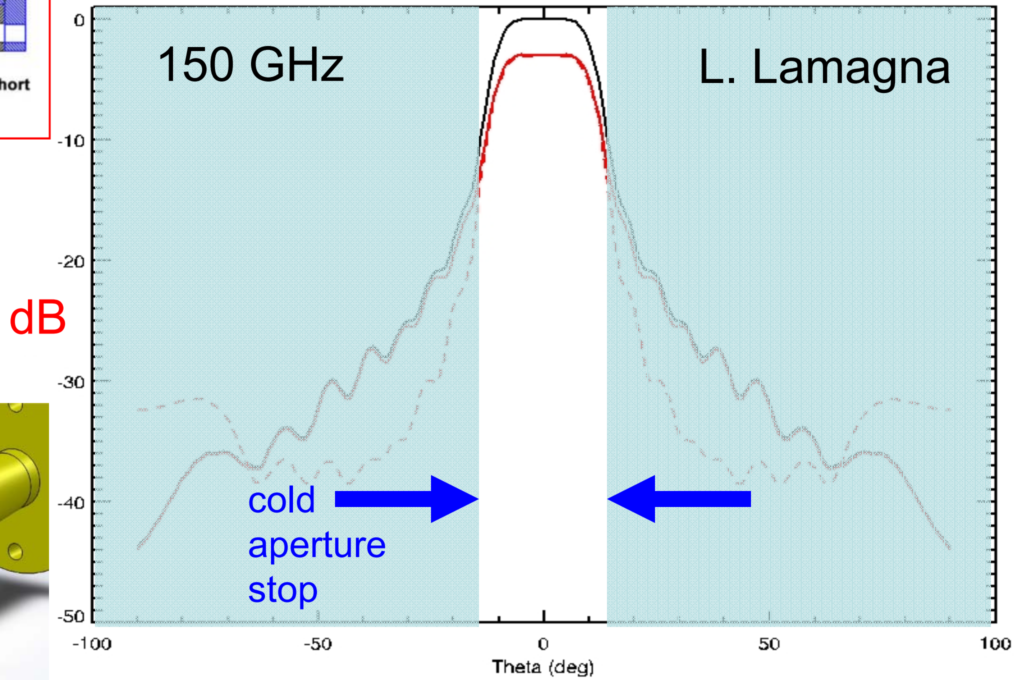
SWIPE – multimode feedhorns

- 20 mm aperture
- High efficiency coupling structure, easy to machine
- Nice top-hat beams
- 10, 21, 23 λ^2 modes @ 140, 220, 240 GHz



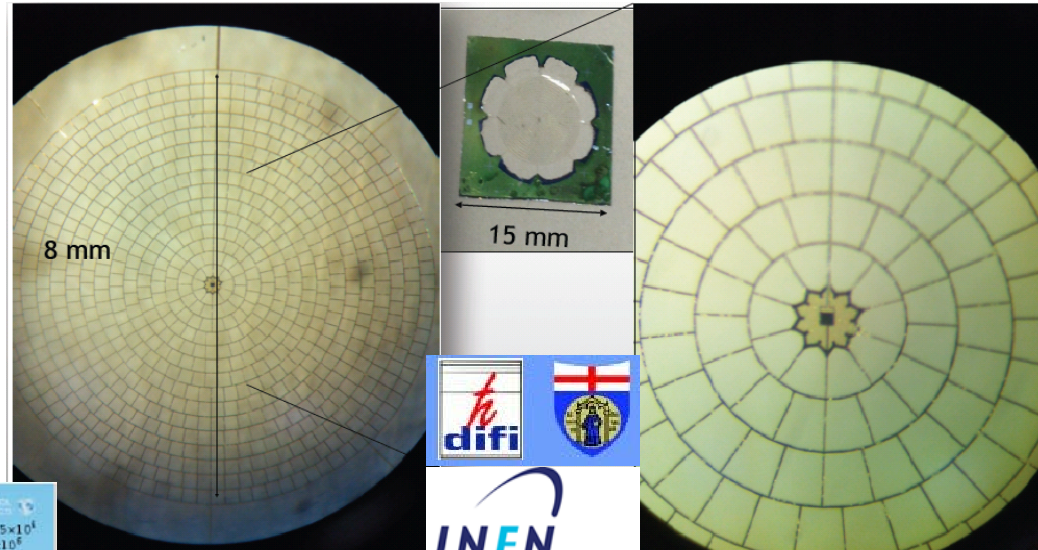


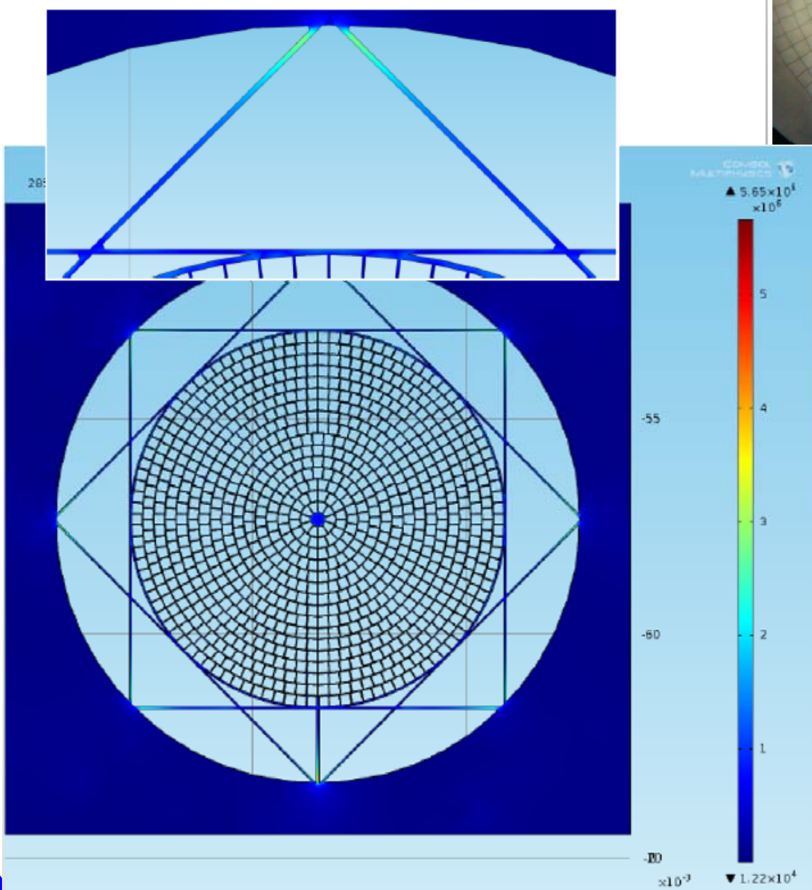


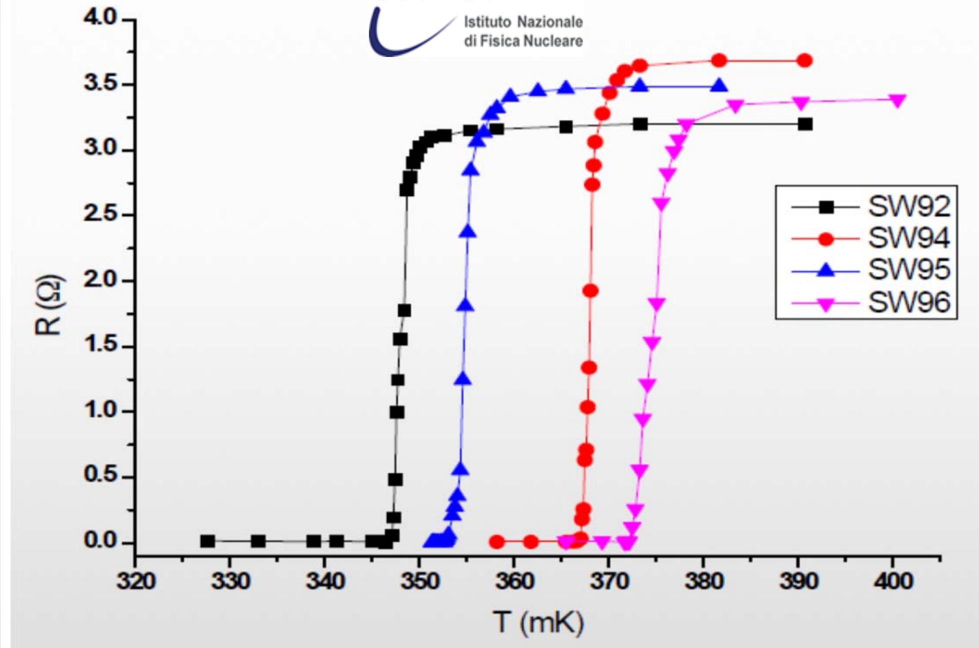


SWIPE - multimode absorbers & TES

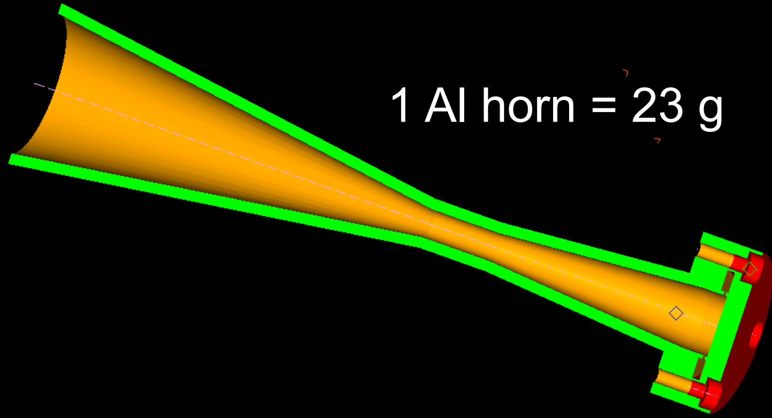
- The absorbers are large Si_3N_4 spider-webs (8 mm diameter, multimode)
- Sensors are Ti-Au TES
- Photon noise limited
- τ = 2 ms



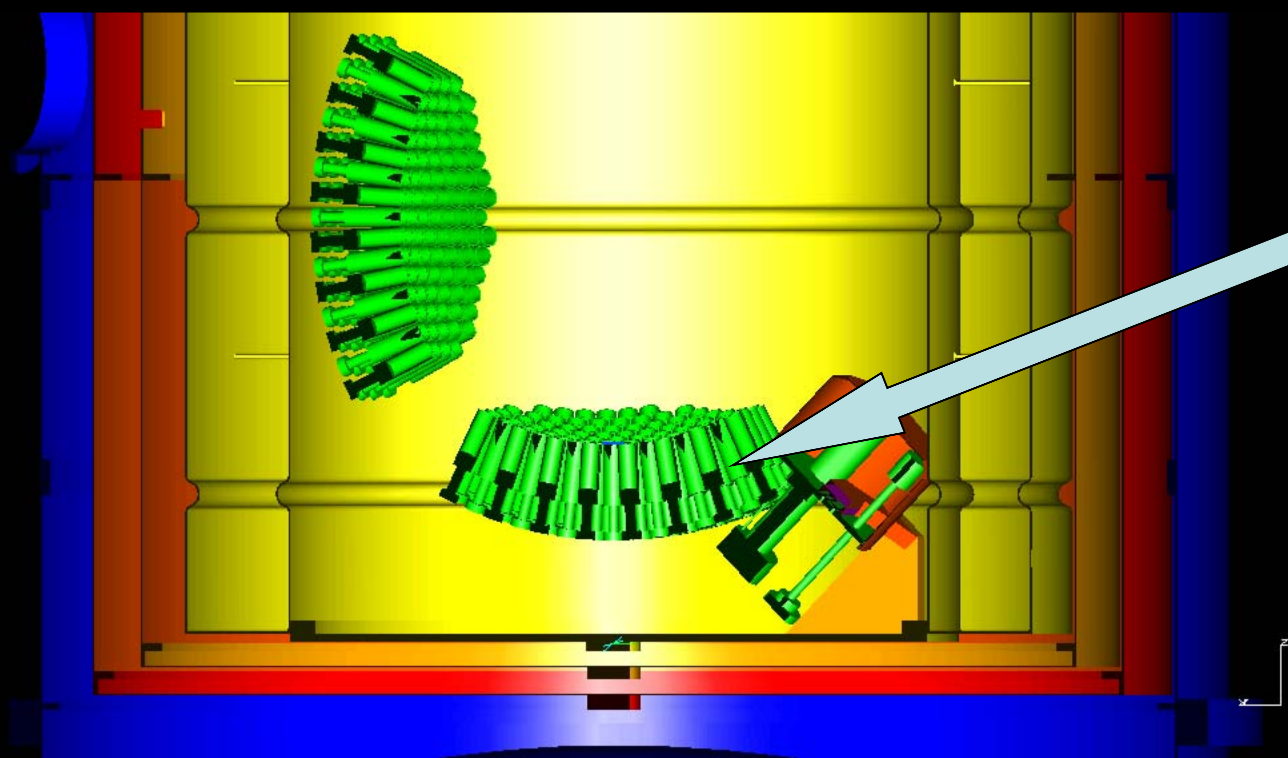




Cryogenic design of LSPE-SWIPE focal planes



1 Al horn = 23 g

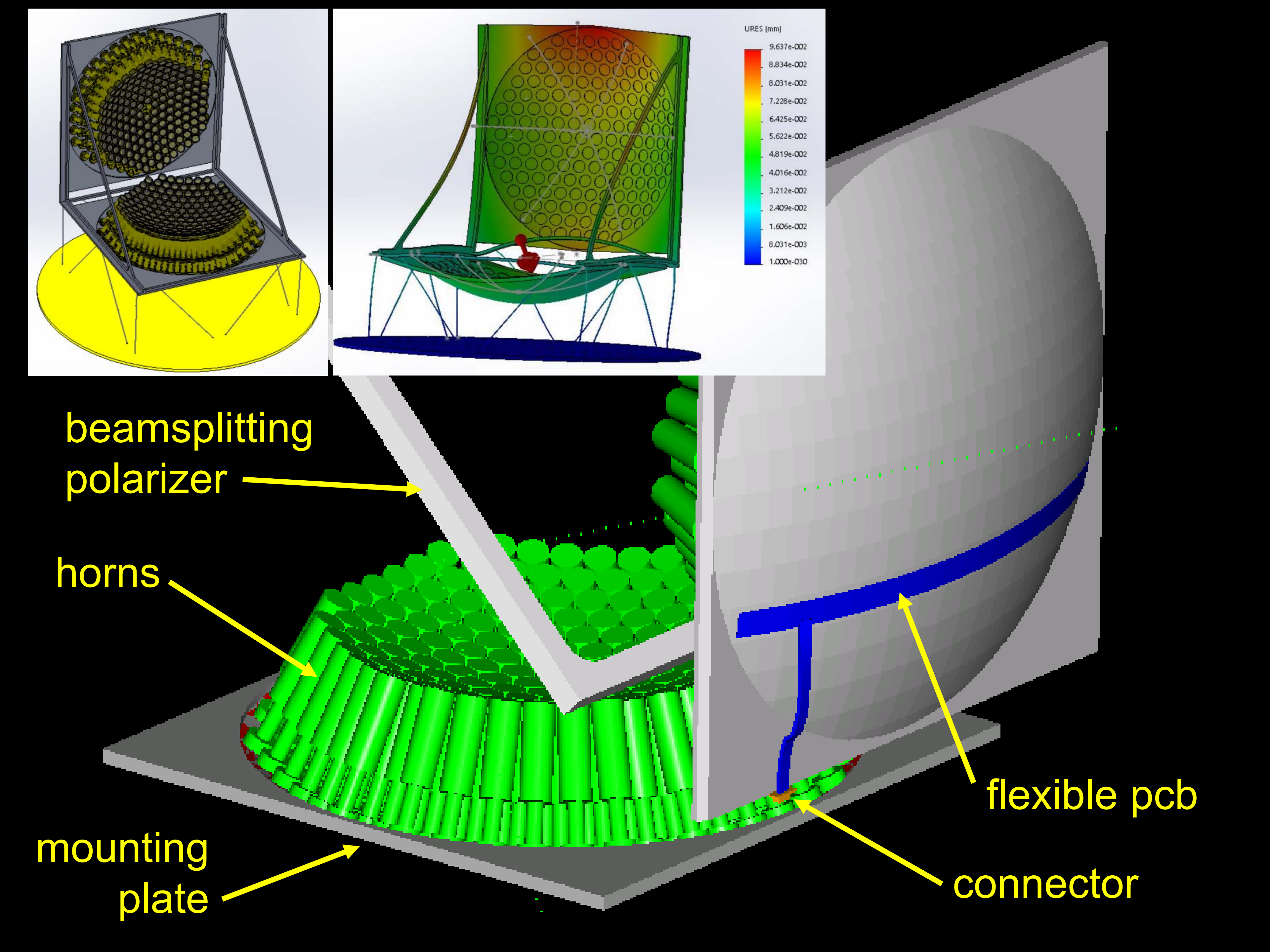


165 Al horns = 3.6 kg

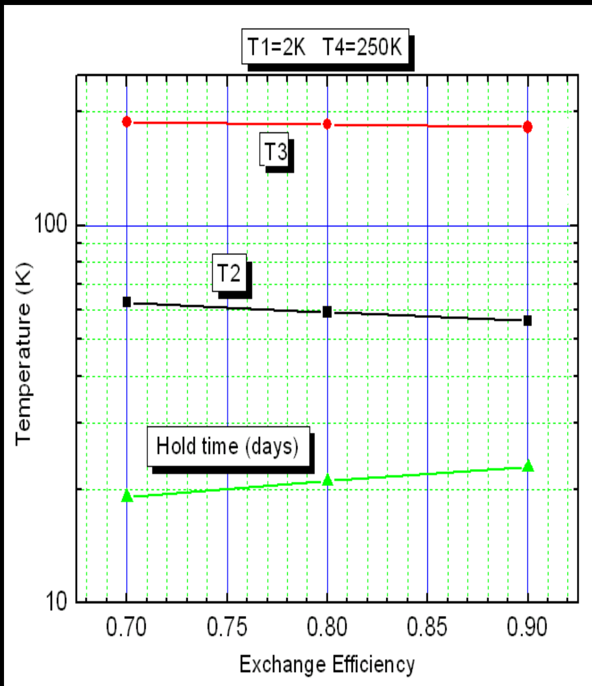
Al mounting plate = 1.6 kg

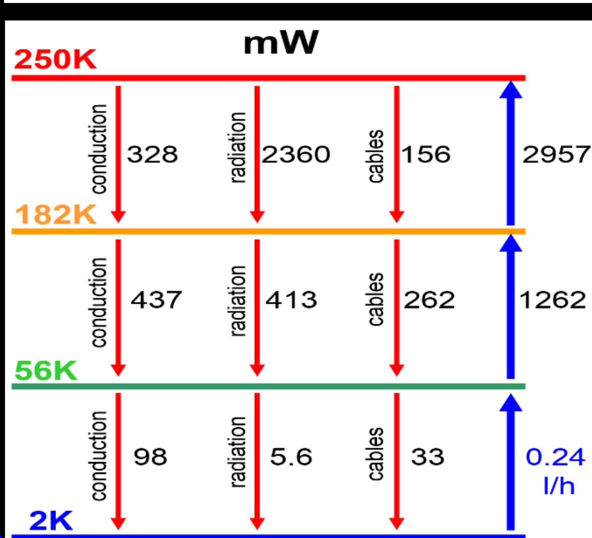
Screws, filters, connectors, cables = 1 kg

Total suspended mass = 6.3 kg For 1 focal plane


URES (mm)
9.637e-002
8.834e-002
8.031e-002
7.228e-002
6.425e-002
5.622e-002
4.819e-002
4.016e-002
3.212e-002
2.409e-002
1.606e-002
8.031e-003
1.000e-030
beamsplitting polarizer
horns
mounting plate
flexible pcb
connector

SWIPE - cryostat

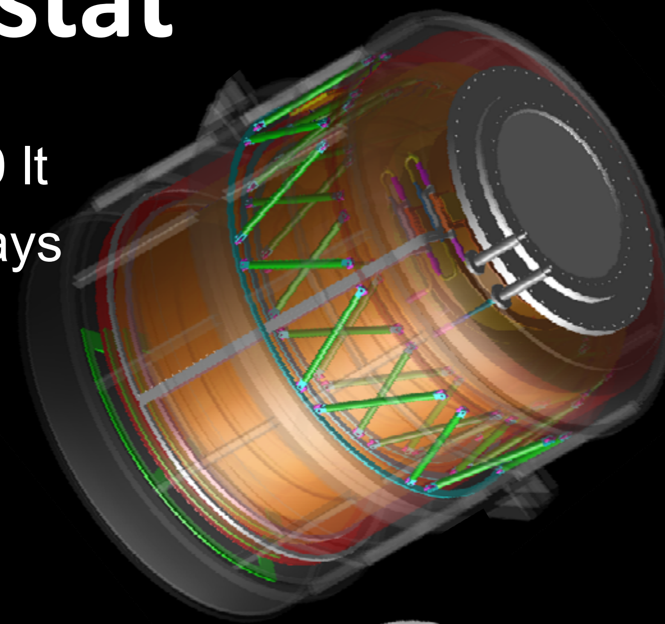


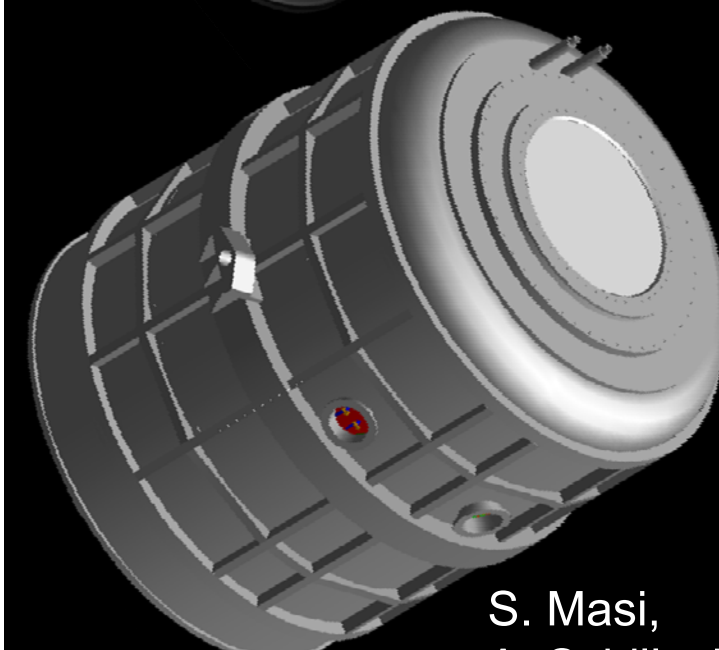


mass = 460 kg

He volume = 0.9 x 290 lt

Hold time = 19 .. 23 days

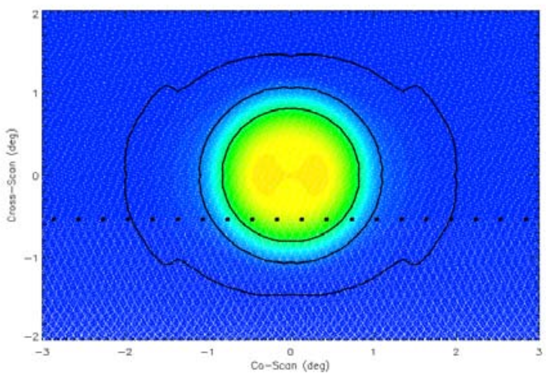




S. Masi,
A. Schillaci

Observations and Calibration Plan

- Scanning strategy: payload spin in azimuth, at 3 rpm (18°/s)
- Coverage of the same sky area by the two instruments
- Elevation changes once a day, at the same time for both instruments
- Specific calibration observations of
  - Jupiter (to map the main beam, see figure below, samples = white dots)



  - the Crab nebula and the Moon Limb (to calibrate the main axis of the polarimeters)
  - the Moon can be used to map sidelobes

LSPE coverage for different sets of elevation changes. The first column reports the boresight elevation range in degrees for the two instruments. Second column, the full coverage. Third column, the coverage after masking the galaxy with the WMAP polarization mask.

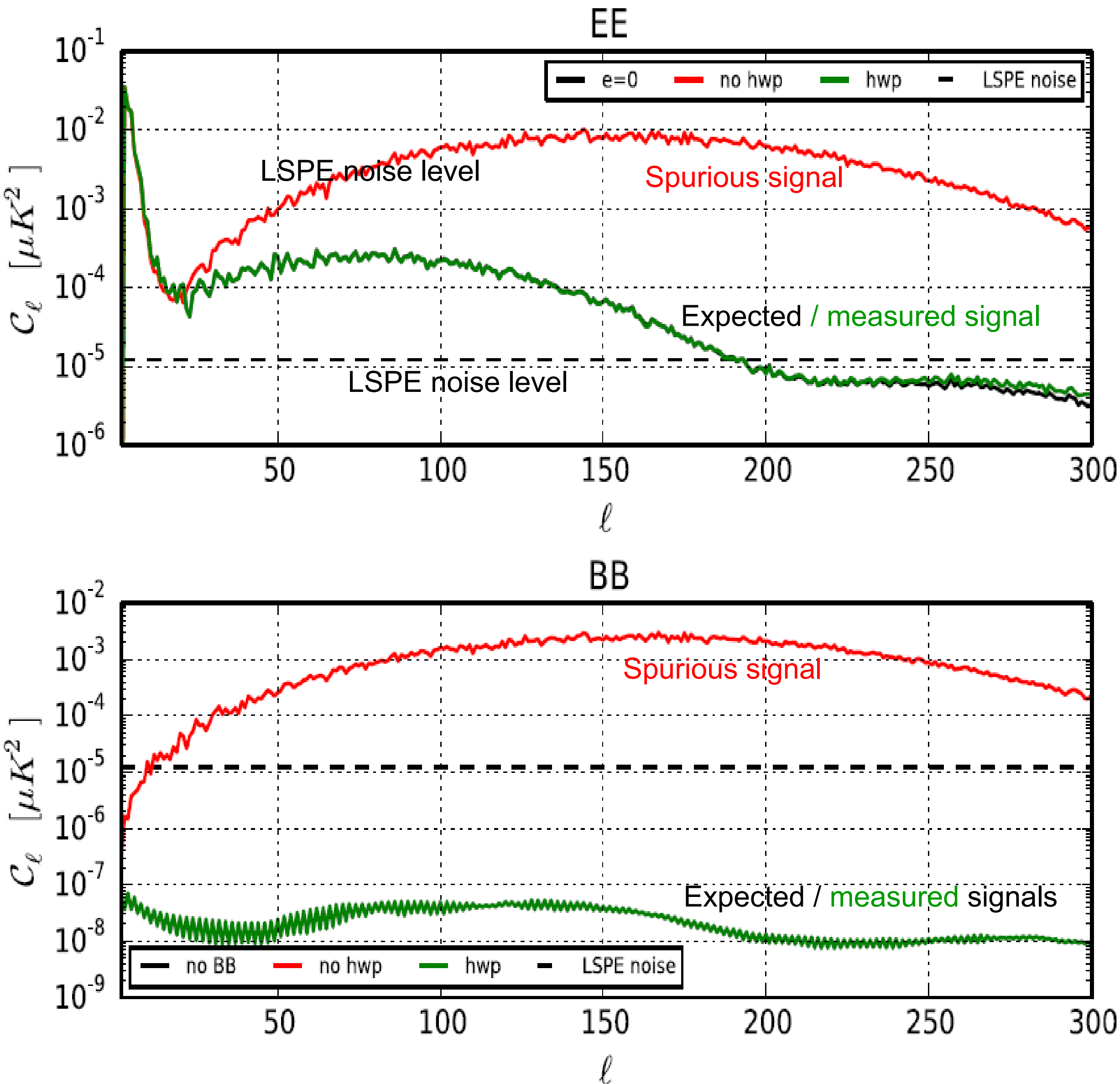
Elevation	Coverage	Unmasked
SWIPE [30-40]	31%	23%
SWIPE [40-50]	27%	20%
SWIPE 35	24%	19%
SWIPE 45	22%	18%
SWIPE [30-50]	35%	26%
STRIP 45	27%	20%
STRIP 30	33%	24%

		STRIP			SWIPE	
Source	Culmination (deg)	S/N per sample at 44 GHz	S/N per sample at 90 GHz		S/N per sample at 145 GHz	S/N per sample at 245 GHz
Moon	30	37500	200000		700000	2000000
Crab	34	20	18		23	28
~~Mars~~	0	0.30	1.6		5.6	18
Jupiter	27	15	80		275	850
~~Saturn~~	-6	1.4	7		24	70
~~Uranus~~	16	0.05	0.24		0.8	2.5

Sources culmination angle, and expected S/N per sample. Sampling rate is set at 60 Hz. We assume full Moon, as it is when it is observable by LSPE. The Crab flux is based on the free-free spectrum reported in Macías-Pérez, et al. Ap. J., 711, 417 (2010)

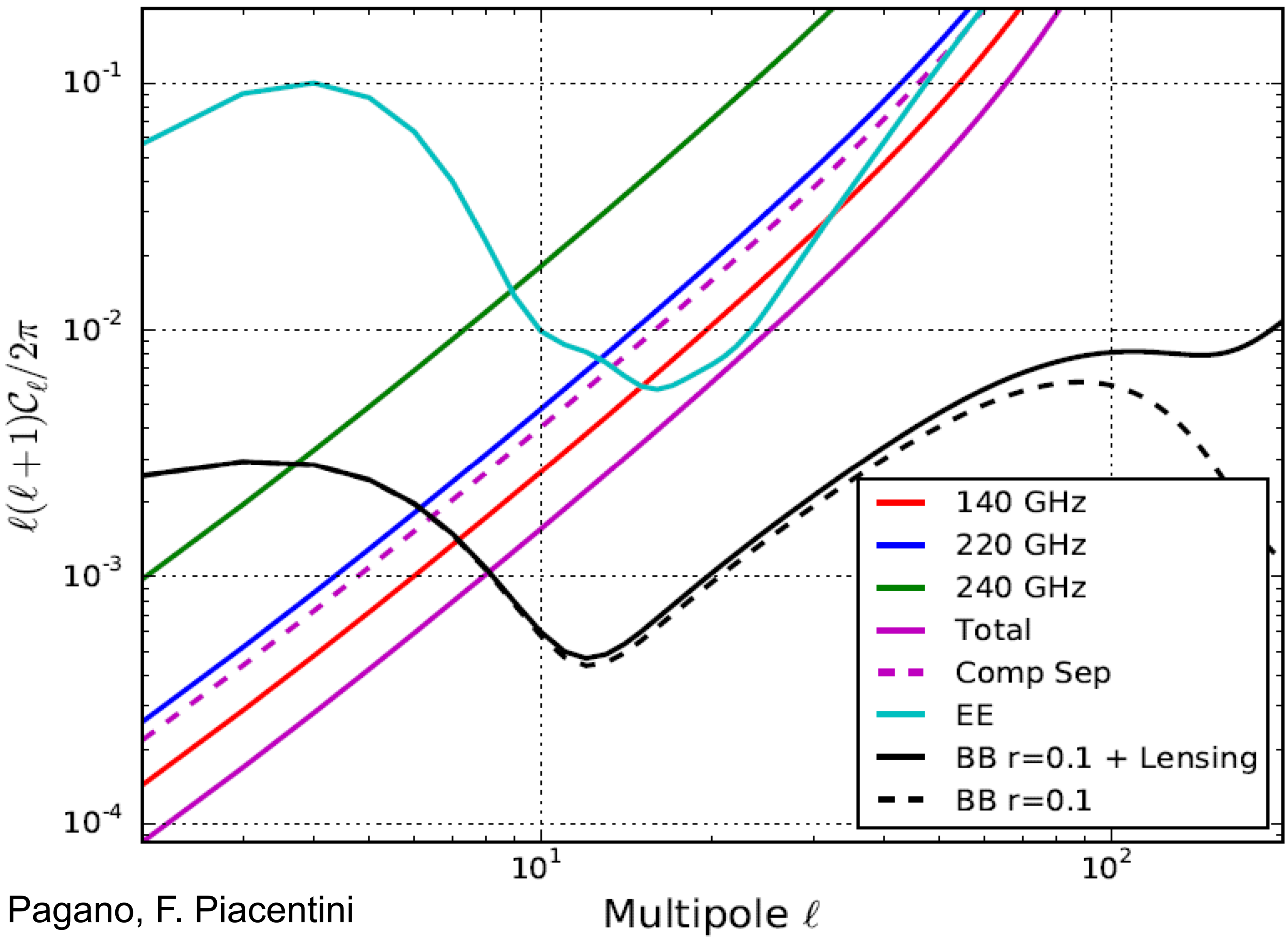
Performance Forecast

- The presence of the HWP allows to fully exploit the sensitivity of LSPE-SWIPE.
- Realistic simulations to assess systematic effects (mainly beam asymmetries) which become irrelevant if the HWP is used.
- The final sensitivity target for *r* is around 0.02



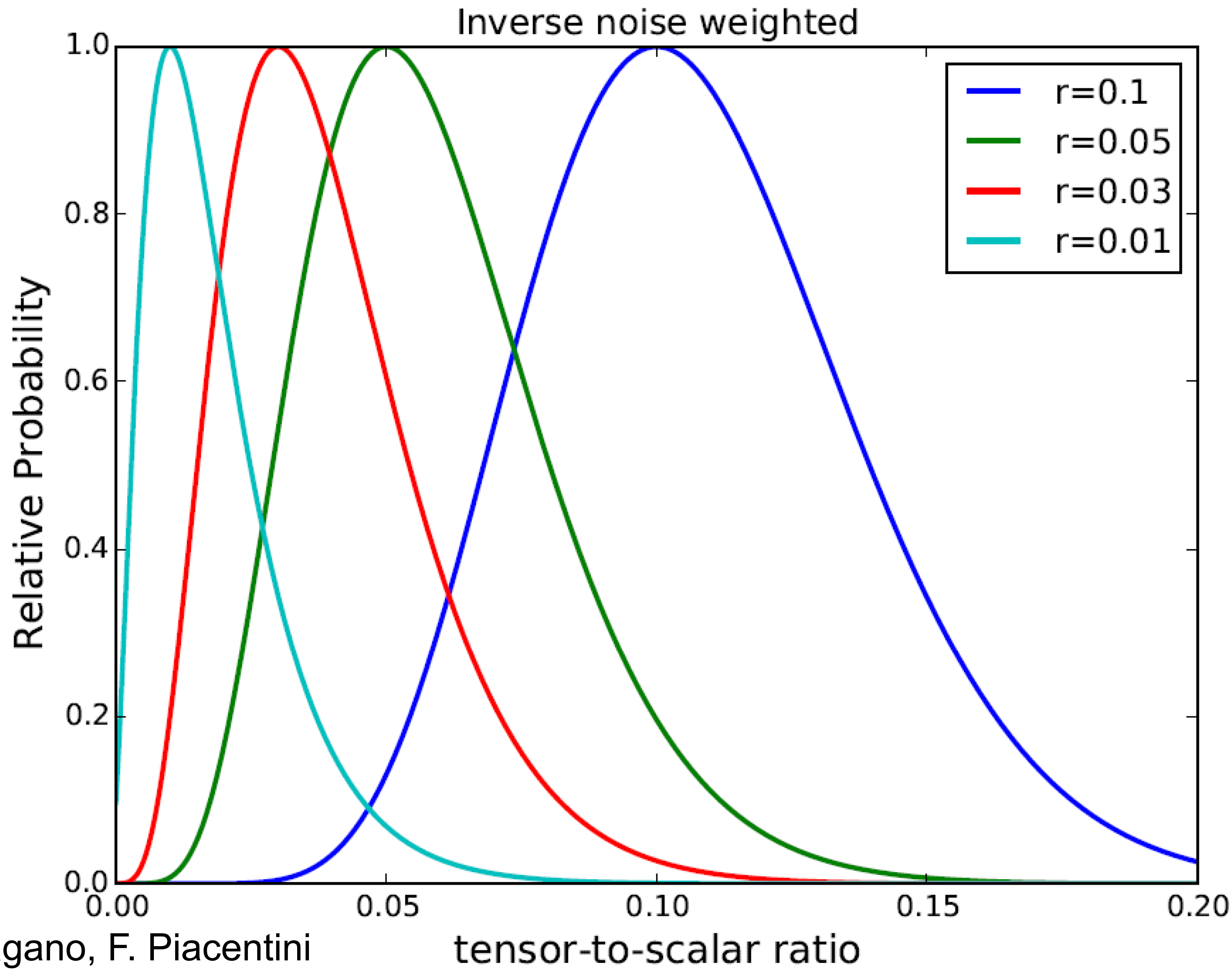
L. Pagano, F. Piacentini

SWIPE Performance Forecast (1st flight)



L. Pagano, F. Piacentini

SWIPE Performance Forecast (1st flight)



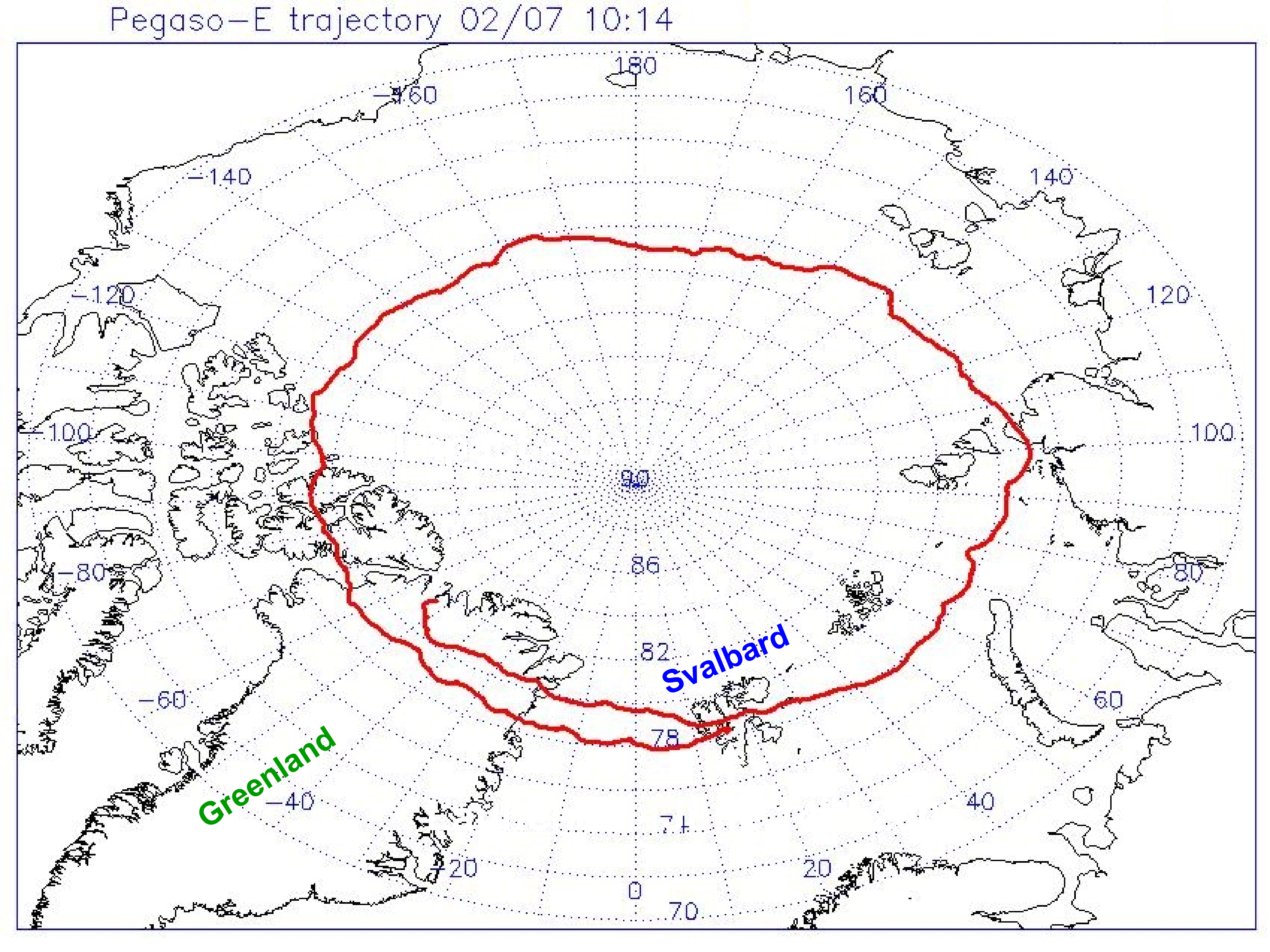
L. Pagano, F. Piacentini

Mission

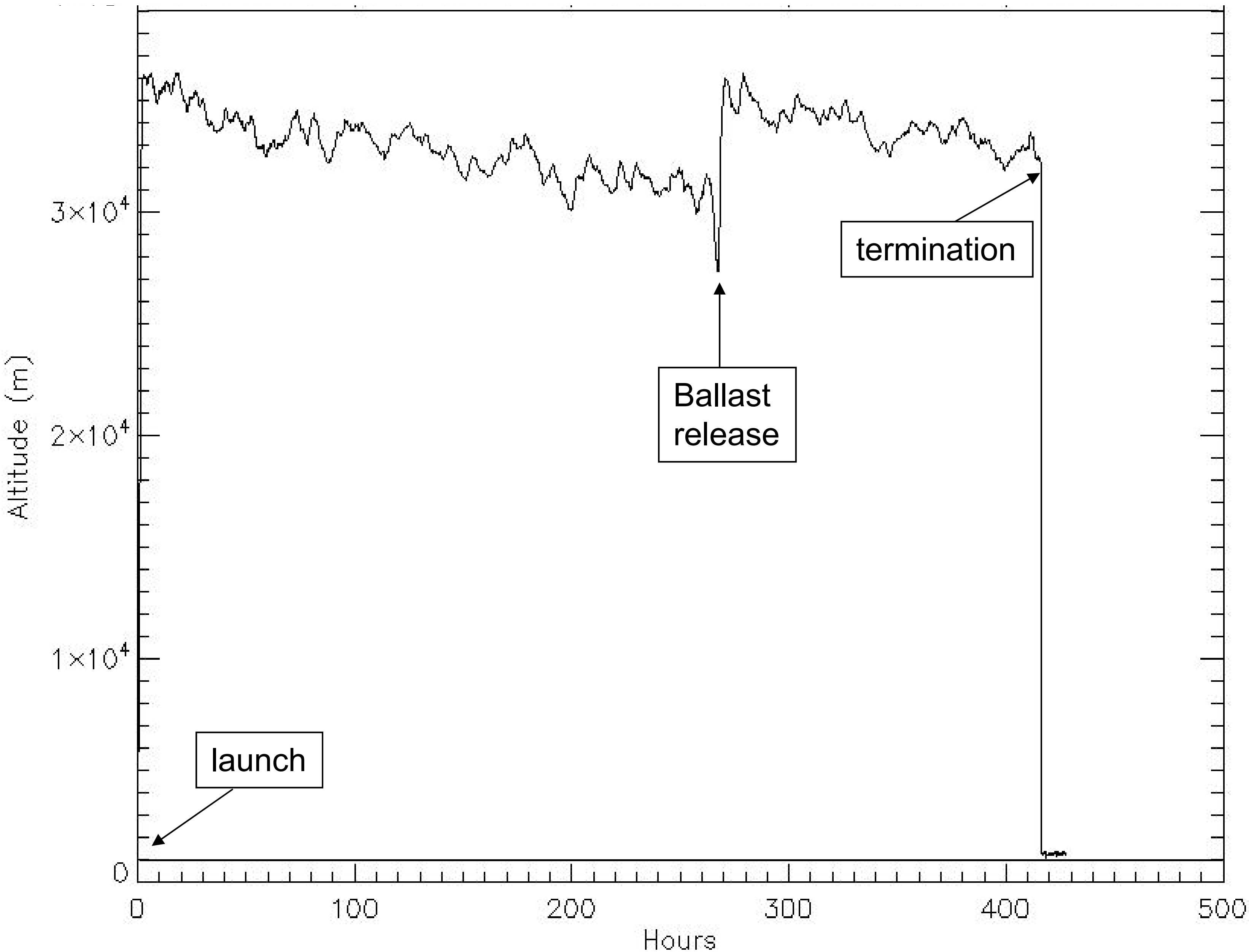
- The experiment is flown as a stratospheric balloon payload during the polar night, in a long duration flight launched from Longyearbyen (Svalbard). In this way it can access most of the northern sky in a single flight,
  - without contamination from the sun in the sidelobes
  - within a very stable (cold!) environment
  - Accumulating more than 14 days of integration at float (38 km altitude).
- Flight scheduled by ASI for end of 2016

Bottom: Ground path of a small pathfinder test flight performed in January 2011, in the middle of the polar night. The eastward trajectory is evident.. **Top:** Launch of a heavy-lift balloon from the Longyearbyen airport (Svalbard Islands, latitude 78°N).

See Peterzen, S., Masi, S., et al., "Long Duration Balloon flights development ", Mem. S. A. It., 79, 792-798 (2008) for further information on balloon flights from the Svalbard.


Pegaso-E trajectory 02/07 10:14
180
-160
160
-140
140
-120
120
-100
100
90
86
82
78
-80
80
-60
60
-40
40
-20
20
0
70
Svalbard
Greenland

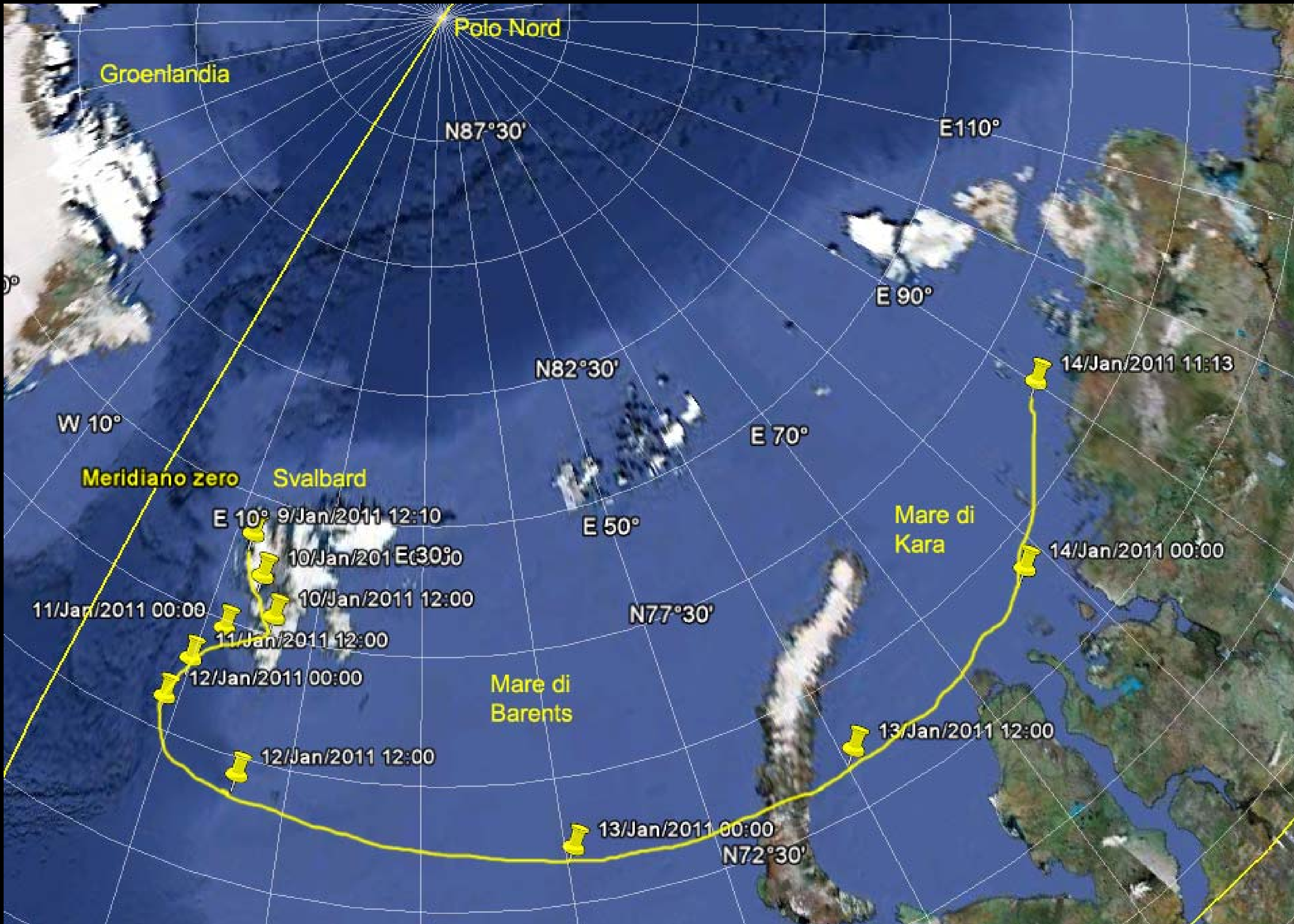
sample flight profile



Night Time Long Duration Stratospheric Balloon Flights

1° LDB launched on Jan. 9°, 2011
From CNR Dirigibile Italia base
With support from ISTAR, AWIPEV
Ny Alesund, Svalbard Islands

5 days at 32 Km, Eastward path
Payload prepared by La Sapienza


Polo Nord
Groenlandia
N87°30'
E110°
E 90°
N82°30'
14/Jan/2011 11:13
W 10°
E 70°
Meridiano zero
Svalbard
E 10°
9/Jan/2011 12:10
E 50°
Mare di
Kara
10/Jan/201
E 30°
14/Jan/2011 00:00
10/Jan/2011 12:00
11/Jan/2011 00:00
N77°30'
11/Jan/2011 12:00
12/Jan/2011 00:00
Mare di
Barents
13/Jan/2011 12:00
12/Jan/2011 12:00
13/Jan/2011 00:00
N72°30'

References

- The LSPE collaboration: *“The Large-Scale Polarization Explorer (LSPE)” Proc. SPIE* 8446, Ground-based and Airborne Instrumentation for Astronomy IV, 84467A (2012); doi: 10.1117/12.926095; astro-ph/1208.0281
- P. de Bernardis, et al. *“SWIPE: a bolometric polarimeter for the Large-Scale Polarization Explorer” Proc. SPIE* 8452, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VI, 84523F (October 5, 2012); doi: 10.1117/12.926569; astro-ph/1208.0282 (2012).
- M. Bersanelli, et al. *“A coherent polarimeter array for the Large Scale Polarization Explorer balloon experiment” Proc. SPIE* 8452, Proc. SPIE 8446, Ground-based and Airborne Instrumentation for Astronomy IV, 84467C (24 September 2012); doi: 10.1117/12.925688 ; astro-ph/1208.0164 (2012).
- P. de Bernardis, S. Masi, for the OLIMPO and LSPE teams, “*Precision CMB measurements with long-duration stratospheric balloons: activities in the Arctic*”, In Astrophysics from Antarctica - IAU Symposium **288**, Proceedings of the Internatonal Astronomical Union, 8, 208-213 (2013) M. G. Burton, X. Cui & N. F. H. Tothill, eds., Cambridge. doi: 10.1017/S1743921312016894
- Peterzen, S., Masi, S., et al., *“Long Duration Balloon flights development ”,* Mem. S. A. It., 79, 792-798 (2008)
- F. Nati, A. Benoit, P. de Bernardis, A. Iacoangeli, S. Masi, D. Yvon, *A fast and reliable star sensor for spinning balloon payloads*, Review of Scientific Instruments, **74**, 4169-4175, (2003)