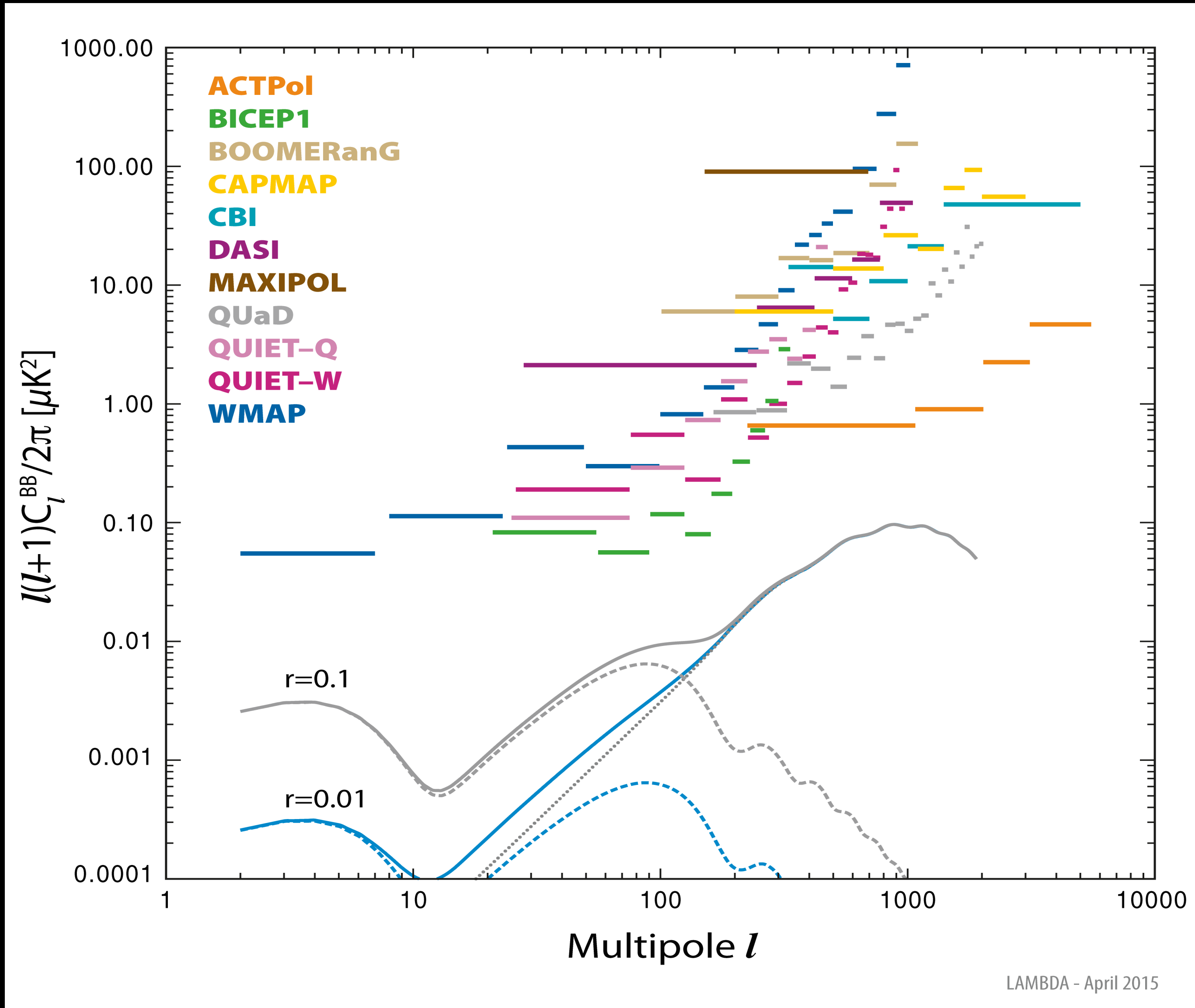
LSPE: the Large-Scale Polarization Explorer

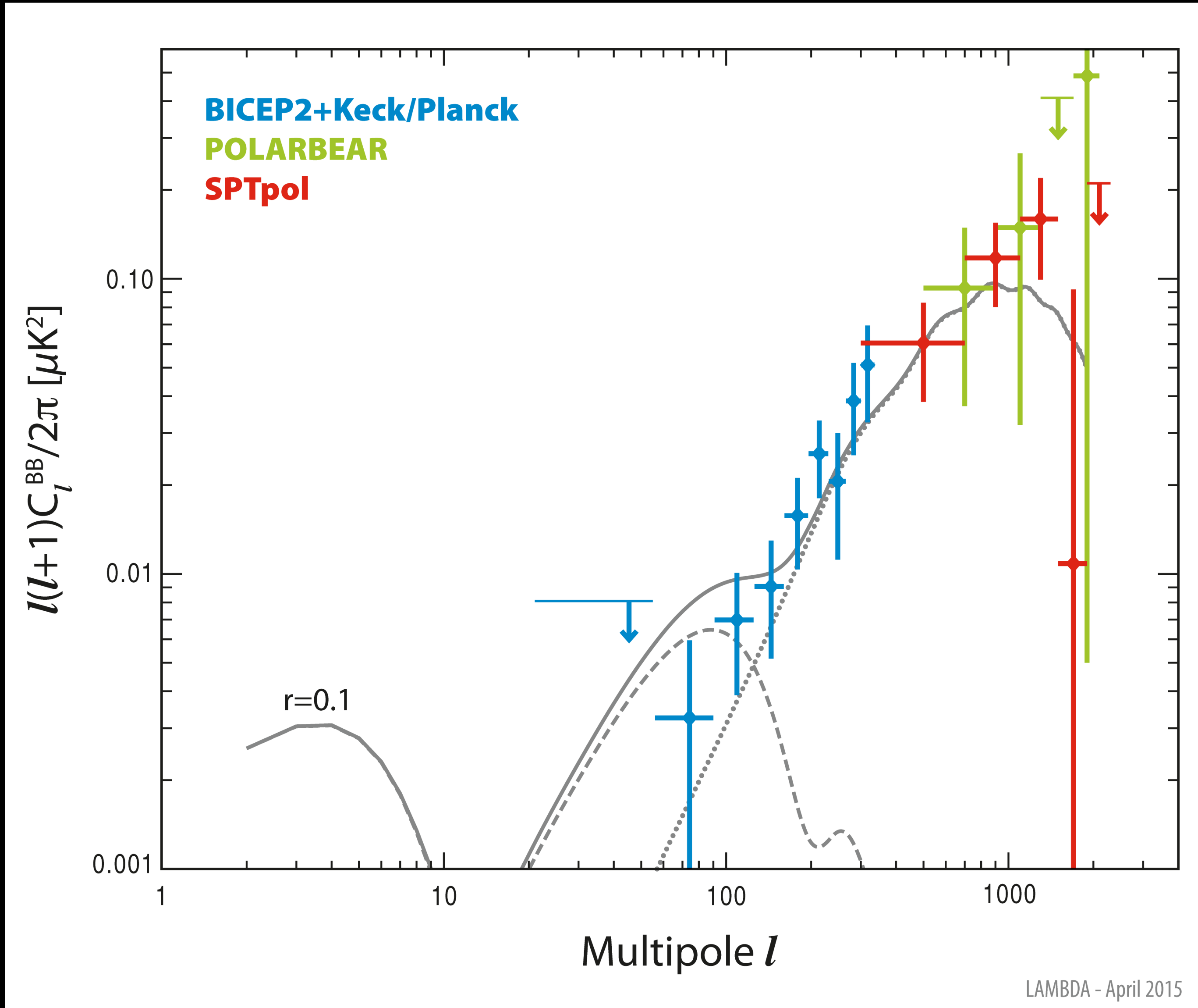
E.S. Battistelli
"Sapienza" University of Rome
for the LSPE collaboration

http://planck.roma1.infn.it/lspe

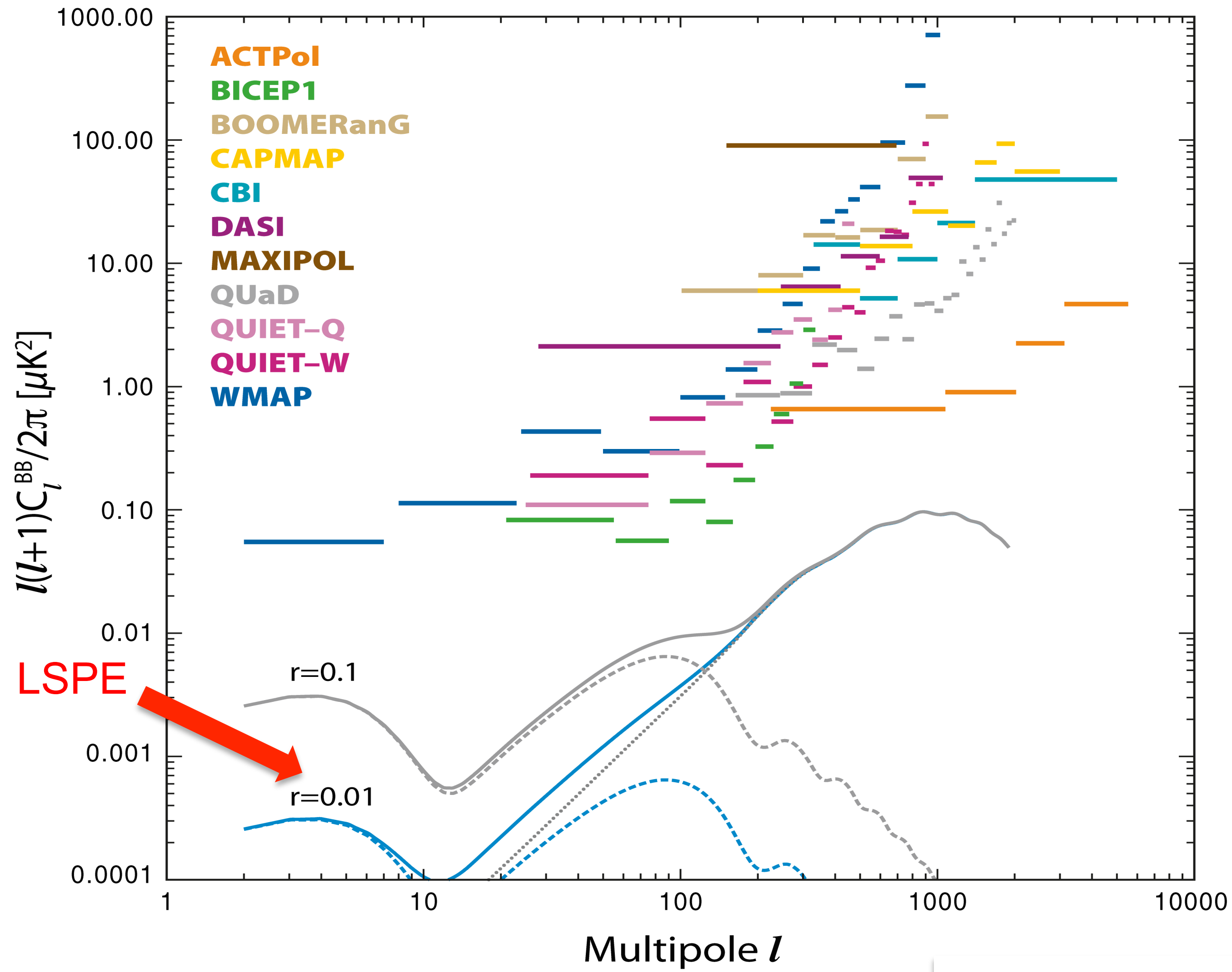
B-modes power spectrum



B-modes power spectrum



B-modes power spectrum



de-lensing required; τ is set by E-modes; degeneracies with n_T require the reionization peak

LSPE in a nutshell

- The Large-Scale Polarization Explorer is :
  - an instrument to measure the polarization of the CMB at large angular scales
  - using a spinning stratospheric balloon payload
  - flying long-duration (> 10 days), in the polar night
- Frequency coverage: 40 – 250 GHz (2 instruments: STRIP & SWIPE)
- Angular resolution: 1.4° FWHM
- Sky coverage: 20-25% of the sky per flight
- Use a polarization modulator or OMT to achieve high stability
- Combined sensitivity: 10 μK/arcmin per flight
- See arXiv:1208.0298, 1208.0281, 1208.0164
- Current collaboration: Italian Universities, INAF, INFN + UK

LSPE collaboration:

PI: Paolo de Bernardis:

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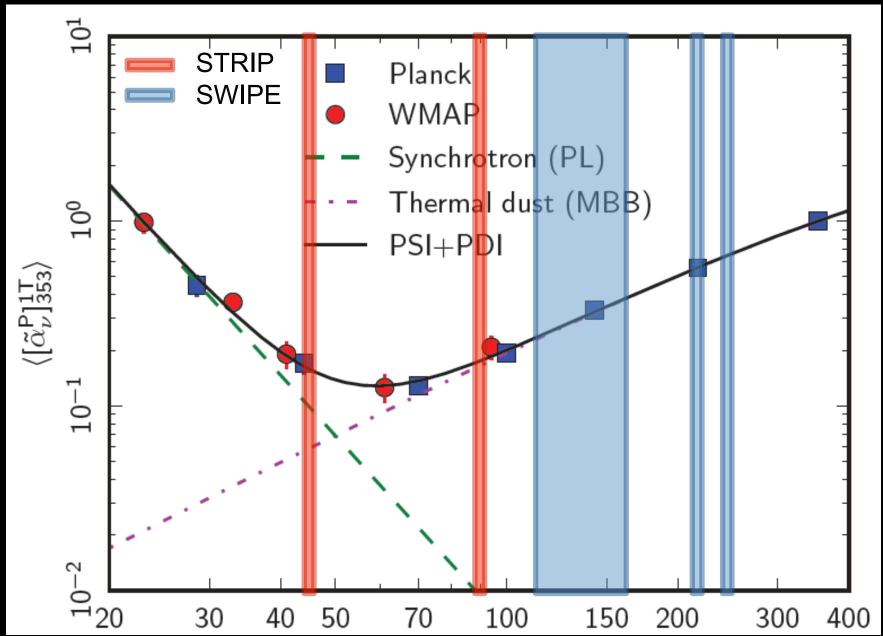
Andrea	Zacchei	INAF Osservatorio Trieste
Mario	Zannoni	Dip. Fisica Università di Milano Bicocca

http://planck.roma1.infn.it/lspe

The strategy

- Large sky coverage and wide frequency coverage (→ call for a space mission).
- A balloon-borne instrument can:
  - avoid (most of) atmospheric noise and loading
  - exploit a wide frequency coverage
  - offer a stable and cold environment during night-time
  - reject ground spillover using very large ground-shields
  - Night time flight → no sun→ access a large fraction of the sky through a 3 rpm spinning payload



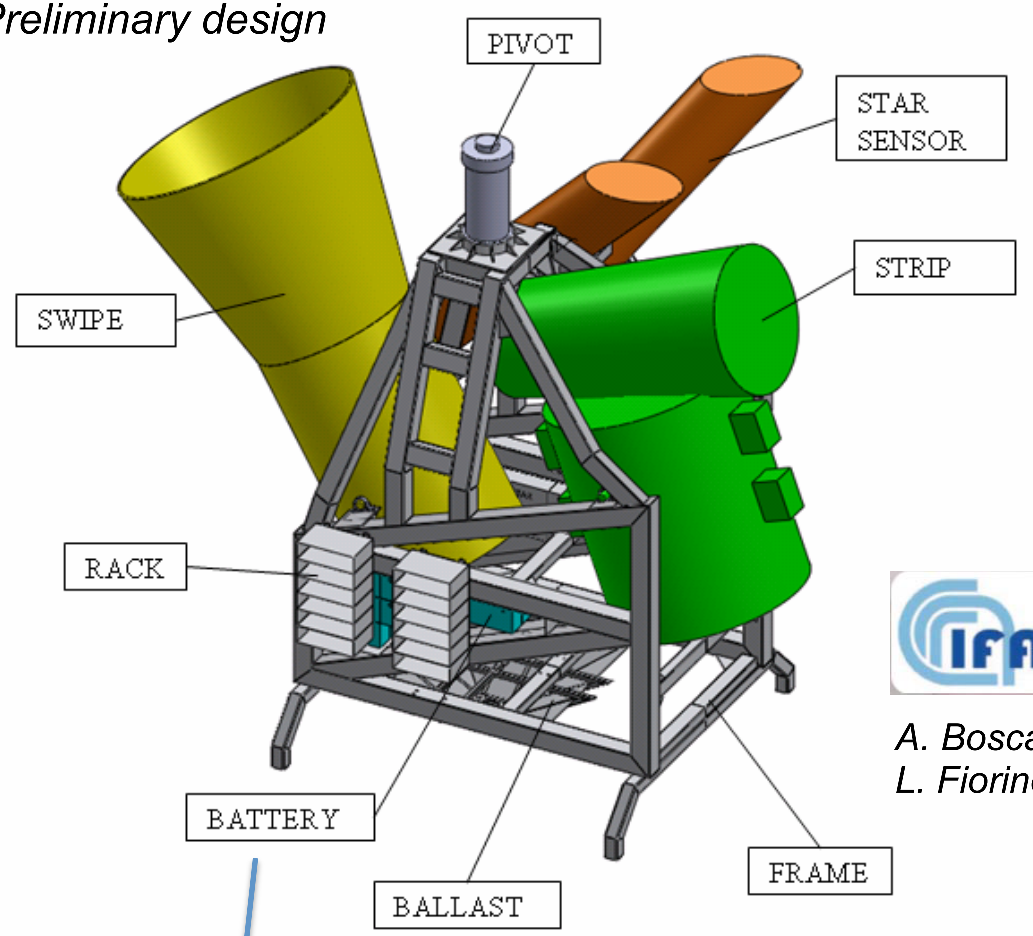
Dust B signal extrapolated at 150GHz from 350GHz (best 30%). Planck int. XXII, XXX. Acknowledgments L.Lamagna

- Once detectors are photon noise limited you can only increase the number of pixels…or the number of photons (see eg. PIXIE or MUSE)!
- Experimentation required to qualify specific instrumentation (optical systems, polarization modulators, detectors …) and methods (sky scan, mapping procedures, polarized foregrounds separation …) and possibly to get detections !

LSPE: gondola+pivot+STRIP+SWIPE

- Total mass ~2.5 tons
- Dimensions:
  5.8m x 3.2m x 4.6m (h)
- 800000 m^3 balloon
- ACS: feedback system heritage of Boomerang and OLIMPO (star sensor, laser gyroscopes, elevation encoders, azimuth pivot torque motors…)
- STRIP: radiometers
- SWIPE: bolometers
- No Solar panels → batteries

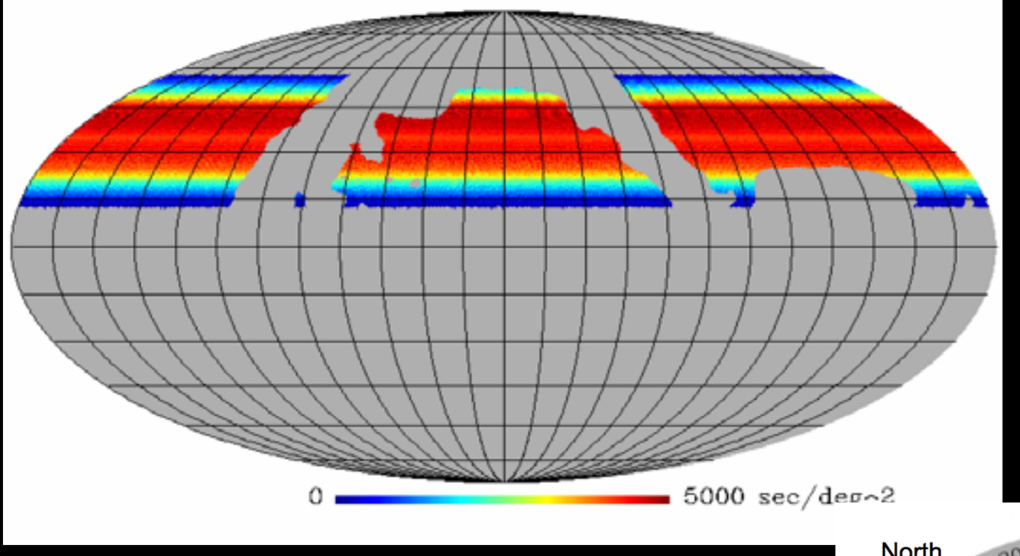
Preliminary design



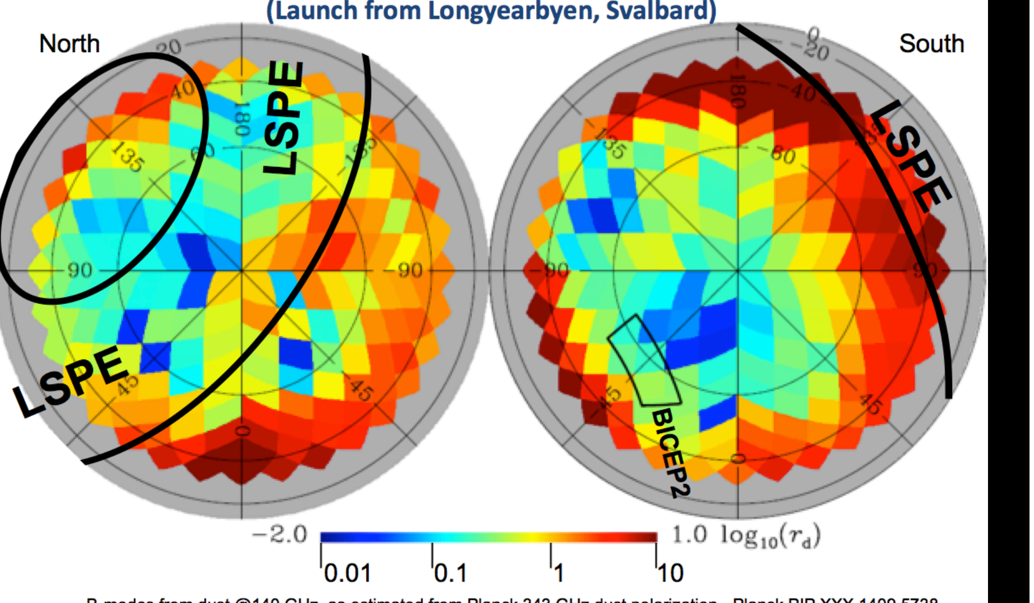
A. Boscaleri
L. Fiorineschi

> 500Kg Lithium cell G62.1 batteries kept warm by RO and control electronics (~200W out of 900W total)

LSPE sky coverage



- Sky coverage set by the launch location
- Winter launch from Longyearbyen (+78°N), Svalbard: 25% of the sky

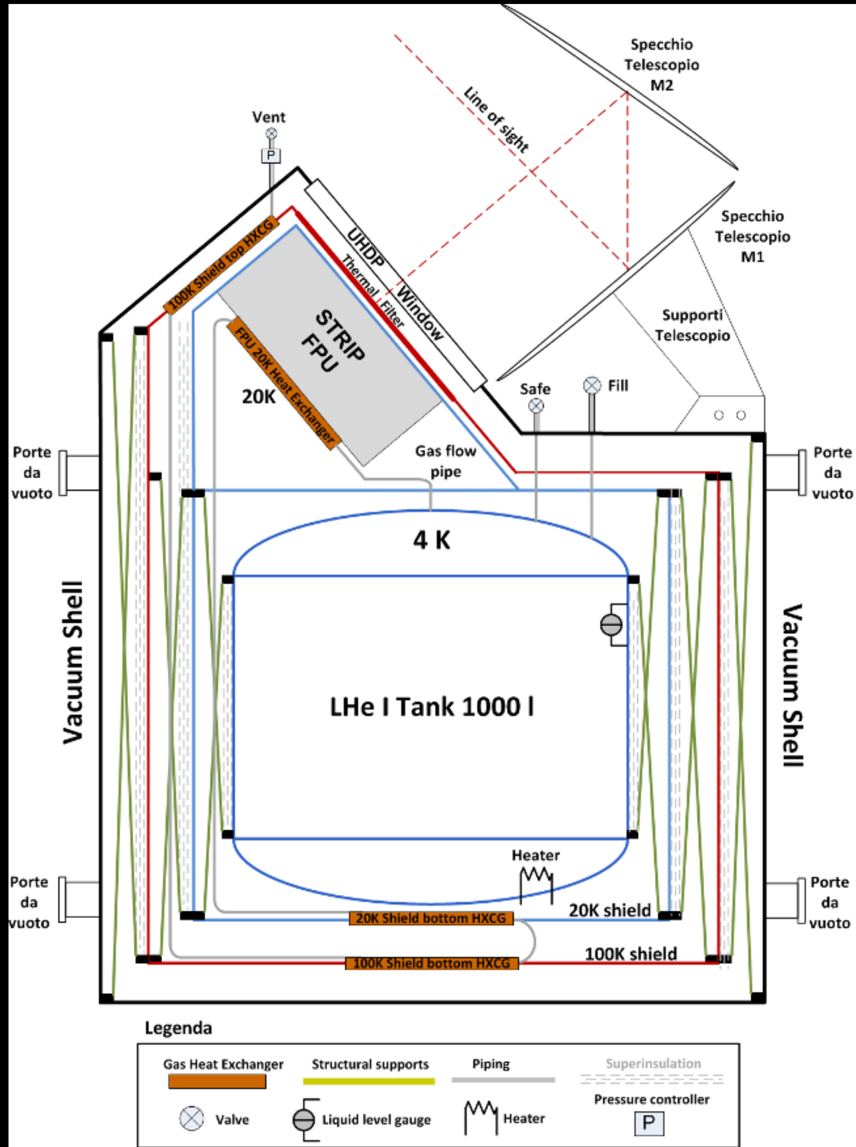


B-modes from dust @140 GHz, as estimated from Planck 343 GHz dust polarization - Planck PIP XXX 1409.5738

STRIP: STRatospheric Italian Polarimeter

PI: M. Bersanelli

- STRIP: accurate measurements of the low-frequency (44 and 90 GHz) polarized emission, dominated by Galactic synchrotron
- 20K correlation polarimeters with activelly controlled system using with 1000l LHe boil off (3W)
- The beam is defined by a 600mm aperture side-fed crossed-Dragone telescope, selected for best polarization purity (trading off f# and focal plane size size)
- 49 horns x 44 GHz
- 7 horns x 90 GHz



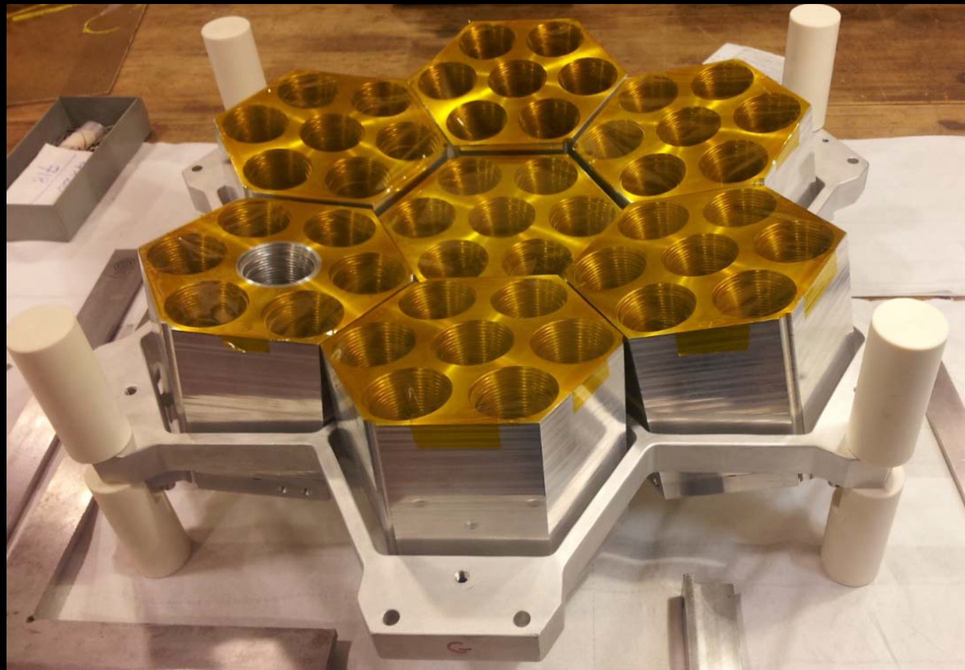
STRIP: STRatospheric Italian Polarimeter

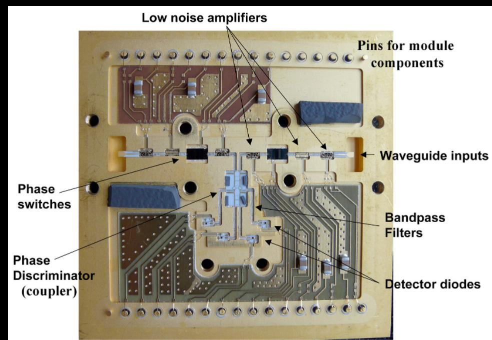
LSPE
Large Scale Polarization Explorer

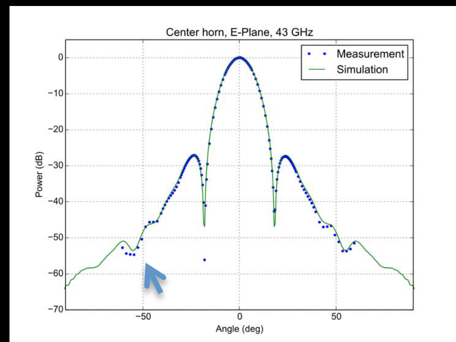
- 49 x 44 GHz and 7 x 90 GHz corrugated horns made by aluminium alloy platelets
- Grooved polarizer and OMT
- QUITE-like polarimeters working in double polarization
- Custom ASIC+ADC+FPGA RO and control electronics

Table 1. STRIP performance requirements

	43 GHz	90 GHz
Angular resolution (°)	1.5	0.7
Observed sky fraction (%)	18	
Flight duration (days)	14	
Noise temperature (including telescope and window – K)	27	49
Contribution from telescope and window to noise temperature (K)	7	8
Number of polarimeters	49	7
Q/U 1-second sensitivity ($\mu K_{CMB}\, s^{1/2}$)	239	338







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Bersanelli et al. 2012 arXiv:1208.0164

SWIPE: Short Wavelengths Instrument for the Polarization Explorer

PI: P. de Bernardis

Large Scale Polarization Explorer

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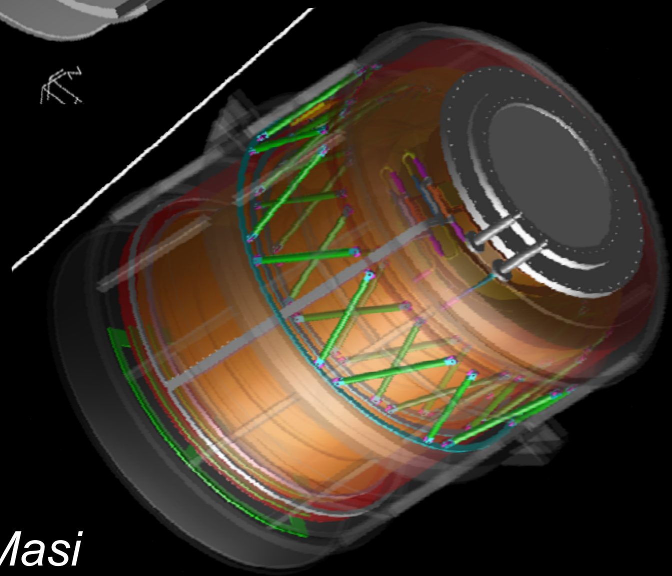
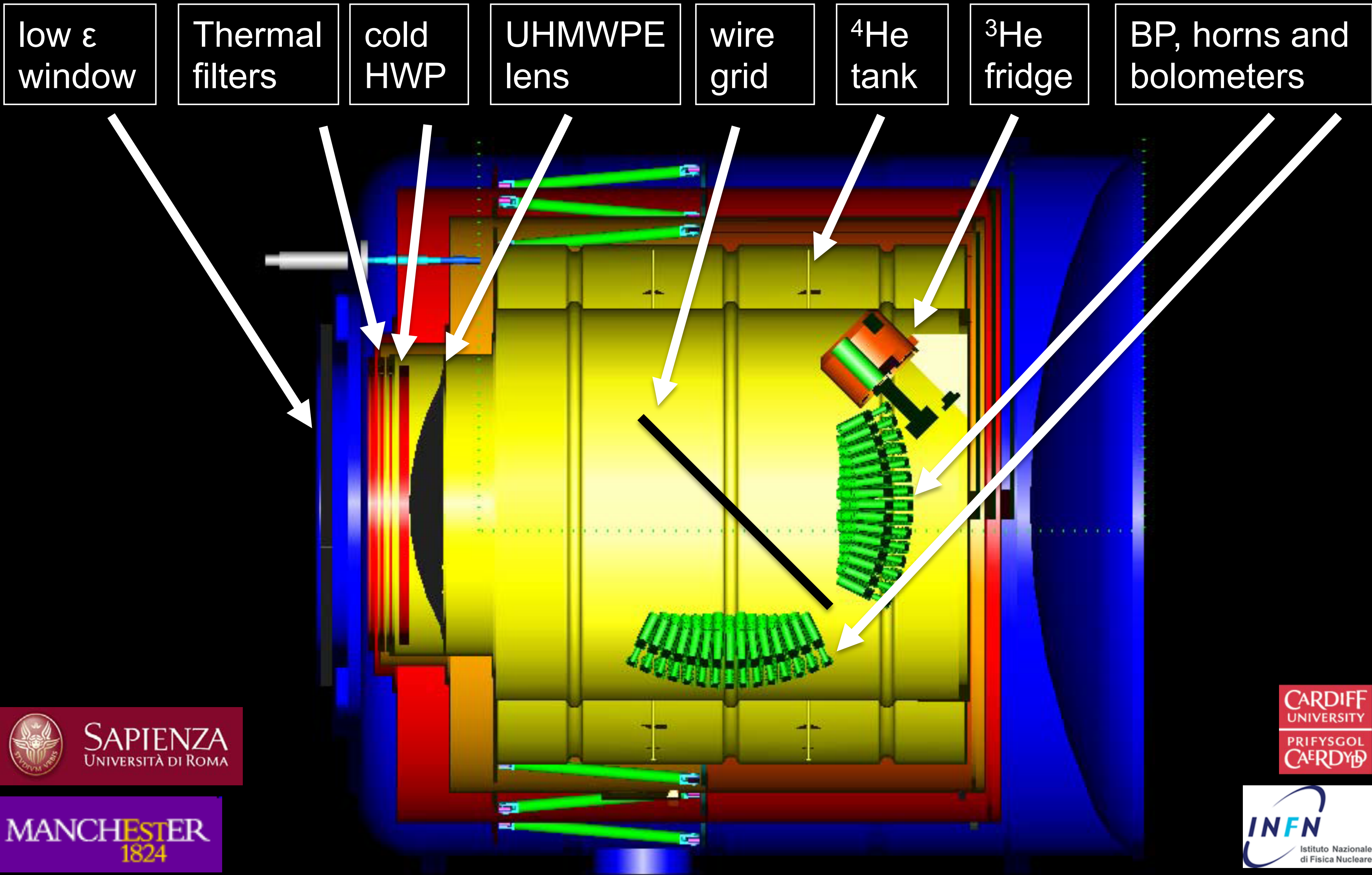
- 50 cm aperture refractive telescope
- Cold HWP polarization modulator + a beamsplitting polarizer
- Two (not extremely-)large focal planes, filled with multimoded bolometers at 140, 220, 240 GHz: more photons but reduced angular resolution
- Cryostat:
  - 460kg
  - 290lt L^{4}He cryostat
  - 19…23 days hold time
  - Under fabrication
  - ^{3}He refrigerator, for operation of the bolometers at 0.3K



S. Masi
A. Schillaci

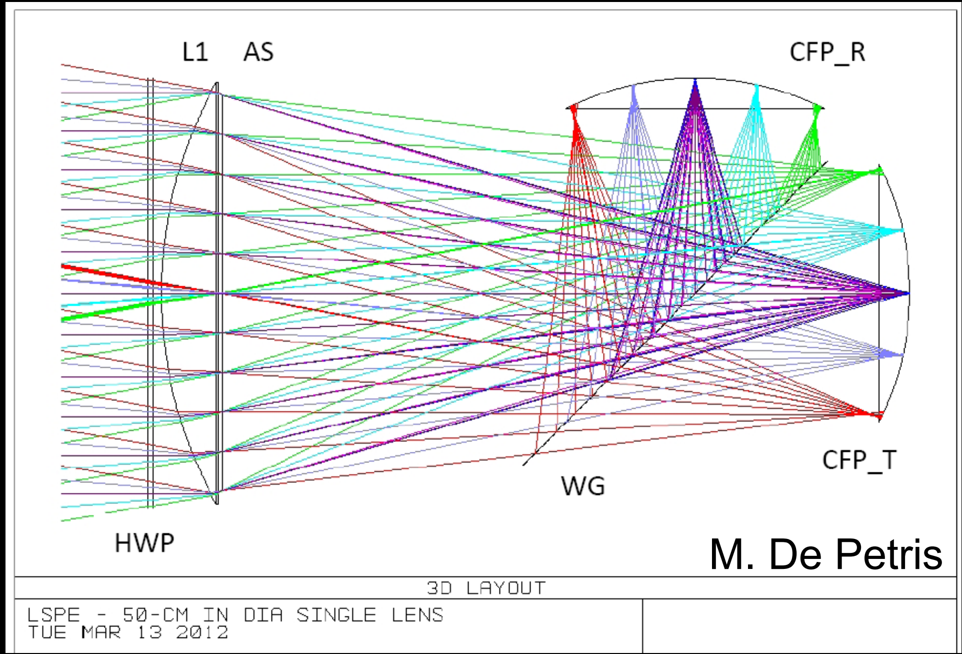
SWIPE: general layout

PI: P. de Bernardis

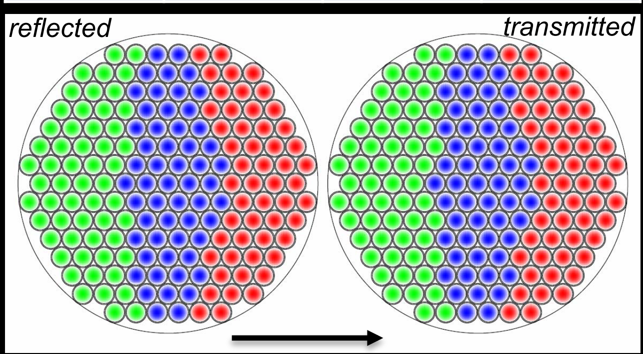


SWIPE: optics

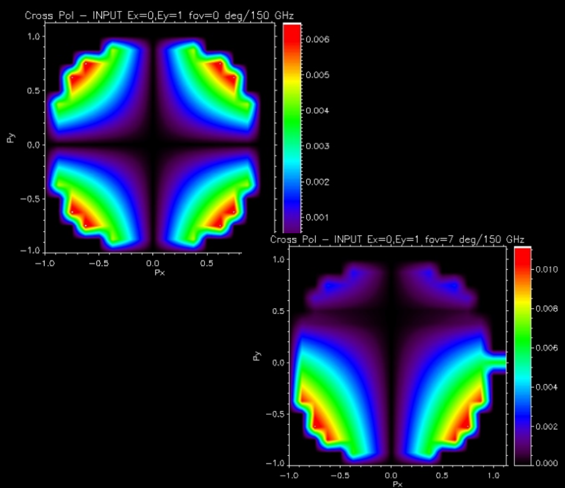
- Single lens UHMWPE @2K, AR coating, D=480, f=800: simple and polarization pure. With a 440mm cold stop
- Two curved focal planes populated with multimode bolometric detectors, resulting in 1.4° FWHM beams
- Horizontal scan: multifrequency measurements of the same sky patch

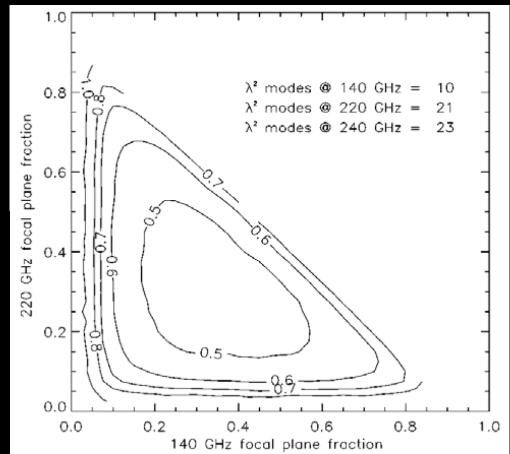


Band (GHz)	Width (%)	Total # detector	# λ^2 modes
140 GHz 🔴	30	110	12
220 GHz 🔵	5	110	30
240 GHz 🟢	5	110	34

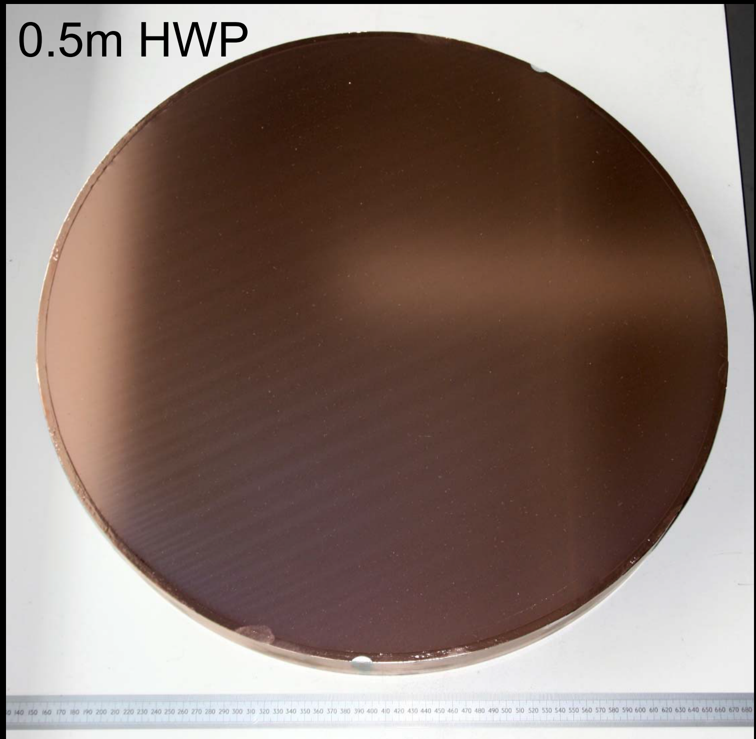


scan direction





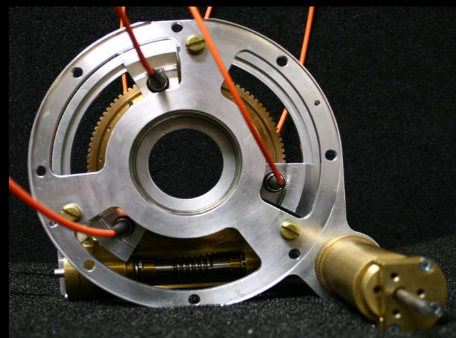
SWIPE: filters and HWP



Photolitographic polarizer

Mesh filters: one per horn

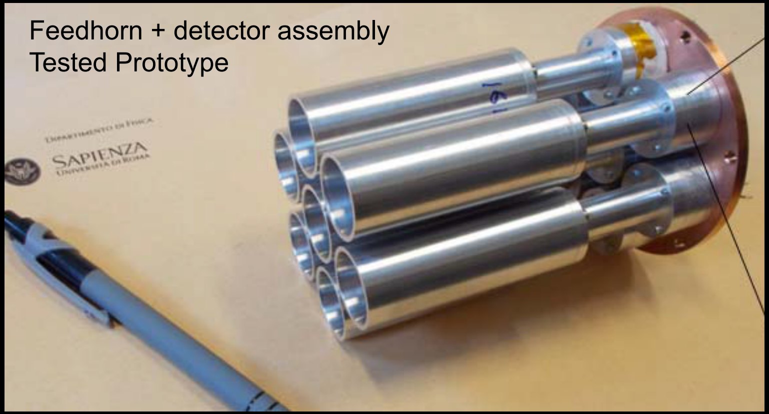
- 2K, 50 cm “thin” wide band metamaterials HWP
- $(T_o-T_e)/T_o < 0.001$, $X_{pol}<0.01$, over the 100-300GHz band
- Orientation stepped by 11.25° or 22.5° every few scans

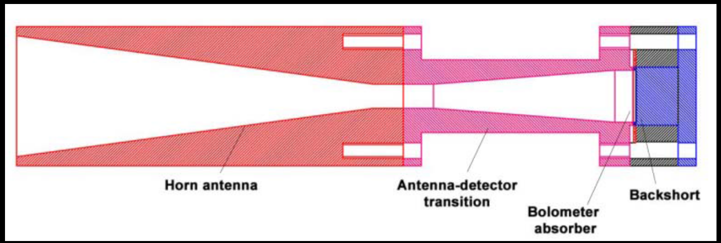


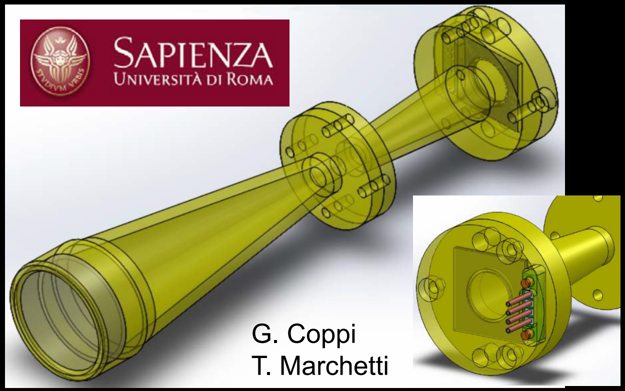
Salatino et al. A&A 2011

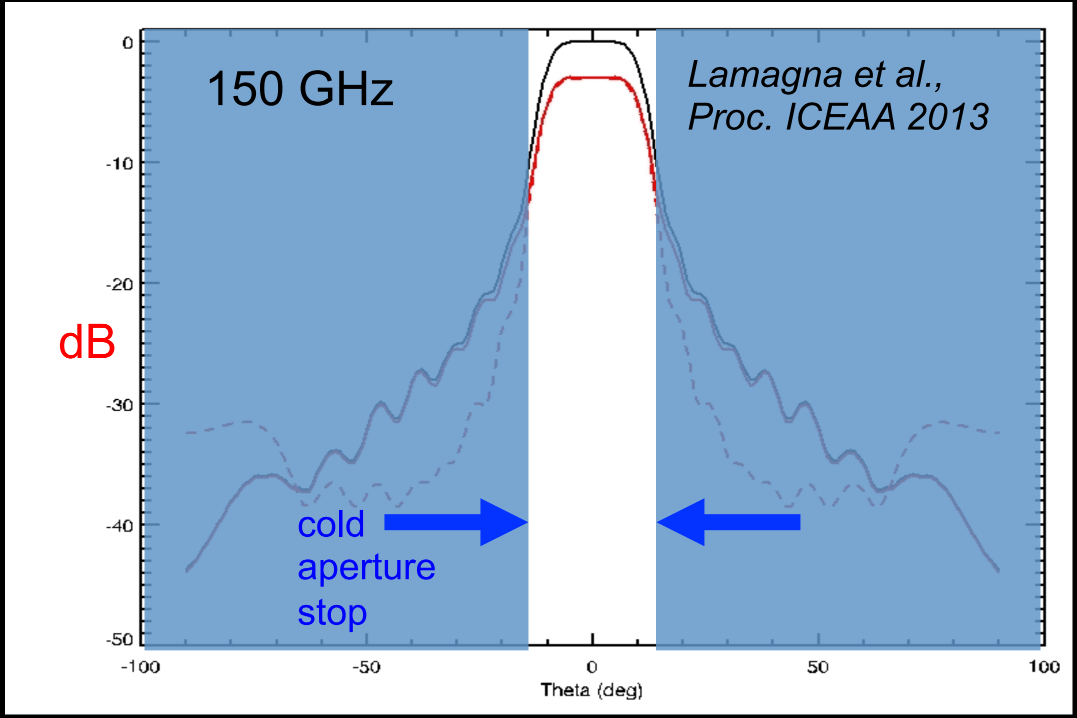
SWIPE: multimoded feedhorns

- 12, 30, 34 λ^2 modes @ 140, 220, 240 GHz = few-moded?
- 20 mm aperture, 2mm WG, 10mm long (to clean evanescent modes) modelled also with HFSS
- High-efficiency, easy-to-machine coupling structure
- Resonant cavity optimization
- Post processing pipeline to account polarization and non-idealities: top-hat beams, cleaned by cold stop



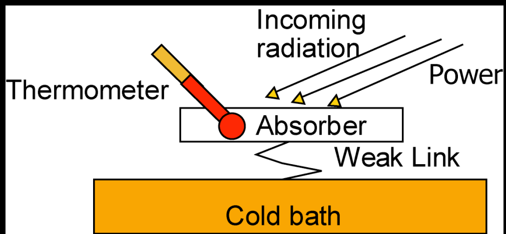


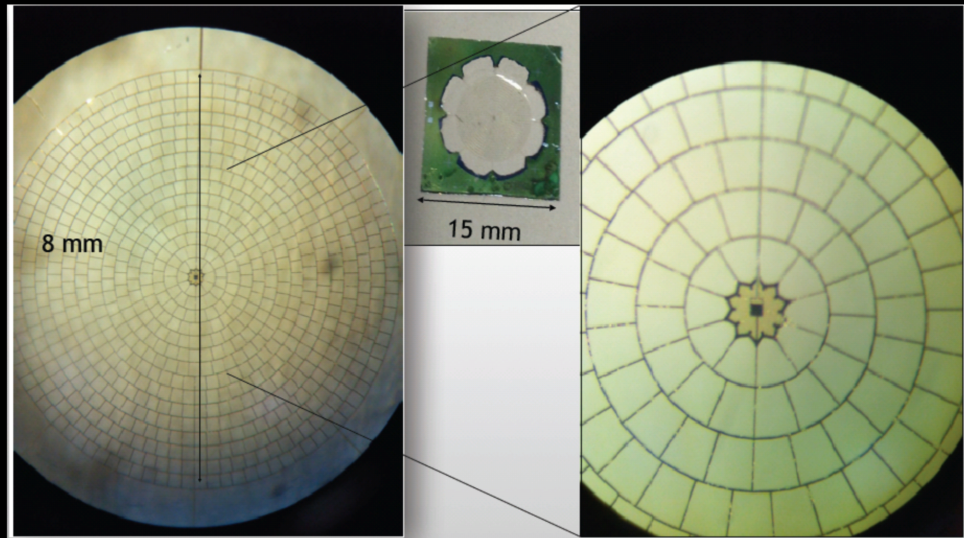


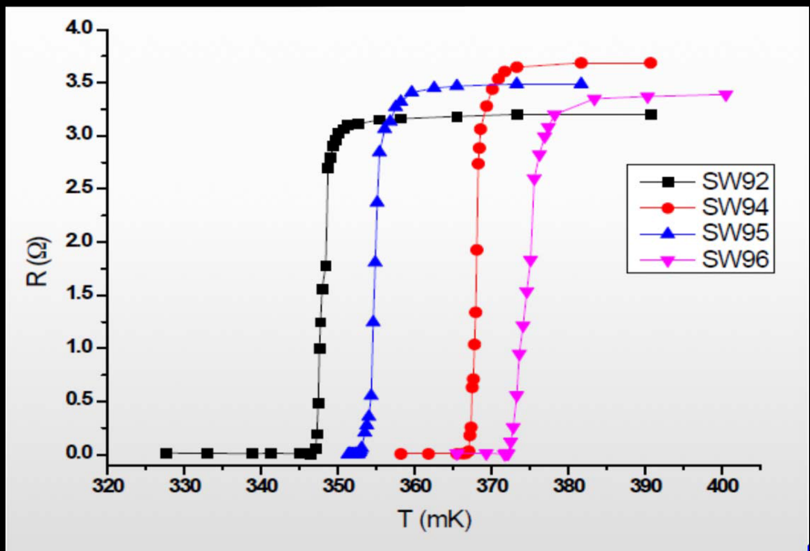


SWIPE: multimoded bolometers

- The absorbers are large Si_3N_4 spider-webs (8 mm diameter), 1μm thick, 250μm mesh size
- Photon noise limited
- Low thermal conductivity thermal link







- Sensors are Mo-Au bilayer TES
- FDM read-out
- Voltage biased negative ETF
  - $P_J=V^2_{bias}/R$
  - Keeps @ T_c
  - Increases linearity
  - Makes it faster
  - Reduces Johnson noise
- But…saturate @ P_{sat}

INFN PI: F. Gatti @

+

+

SWIPE: multimoded TES

- The scanning strategy (+ the beam) and the FDM read-out sets the requirements for the TIME CONSTANT. This should include the ETF loop gain:

$$0.1\text{ms} < \tau < 15\text{ ms} \rightarrow \tau = C/[G(1+L)] \rightarrow G > 50\text{ pW/K}$$

- Photon noise estimations set limits on the THERMAL (phonon) NOISE → G, T_c

$$\begin{cases} NEP_{th}^{140GHz} < 4.0\ 10^{-17}\ W/\sqrt{Hz} \\ NEP_{th}^{220GHz} < 3.2\ 10^{-17}\ W/\sqrt{Hz} \\ NEP_{th}^{240GHz} < 5.5\ 10^{-17}\ W/\sqrt{Hz} \end{cases}$$

$$NEP_{th} \sim \sqrt{4k_b T_c^2 G F}$$

- Optical load estimation sets limits on the SATURATION POWER:

$$P_{sat} > 2.5\ P_{opt} \rightarrow \begin{cases} P_{sat}^{140GHz} > 28pW \\ P_{sat}^{220GHz} > 15pW \\ P_{sat}^{240GHz} > 50pW \end{cases}$$

$$P_{sat}(T_c) = K(T_c^n - T_{bath}^n)$$

SWIPE: multimoded TES

From the NEP formula:

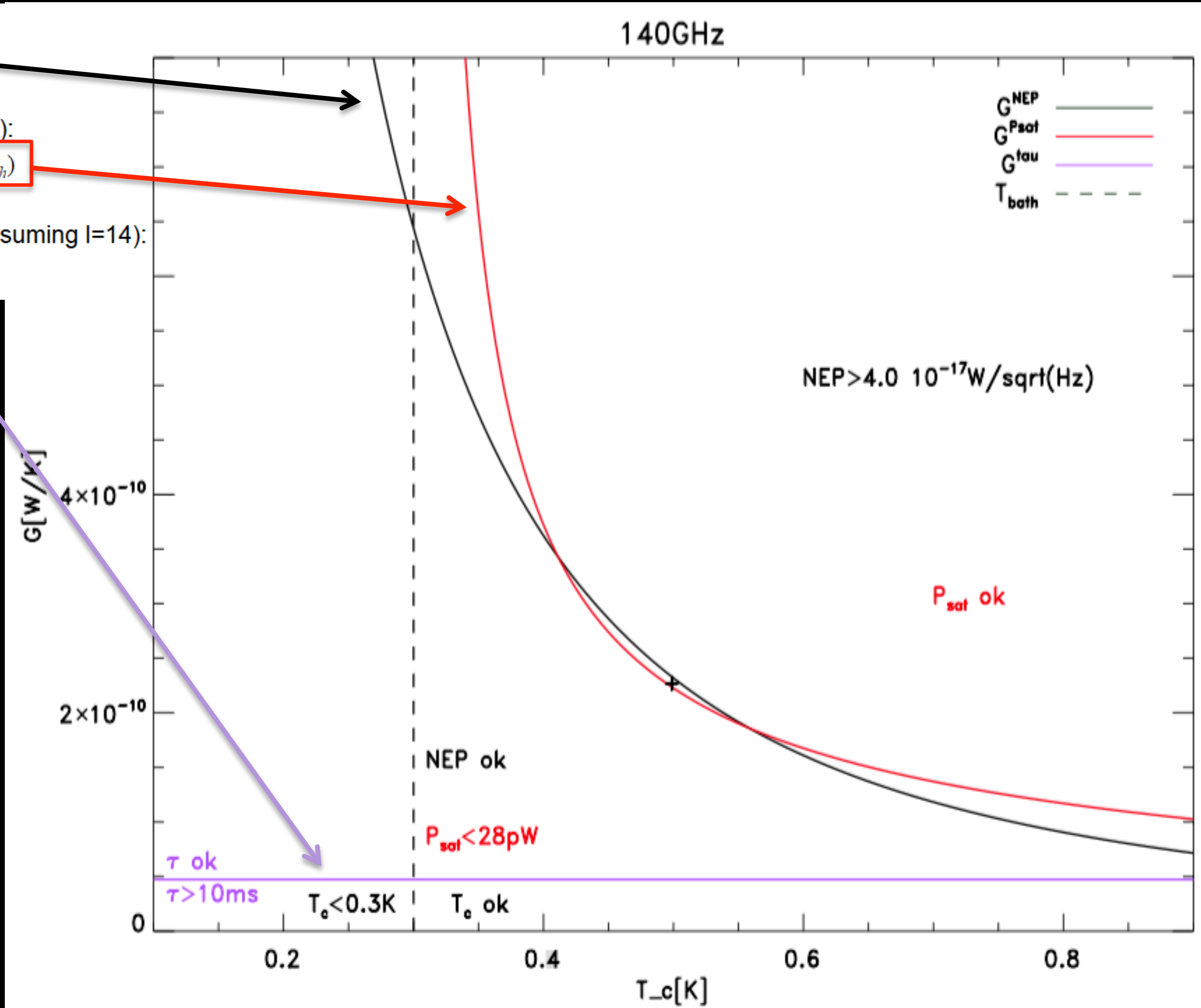
1) $G^{NEP} = NEP^2/(4F k_b T_c^2)$

From the P_{sat} formula (solving for K):

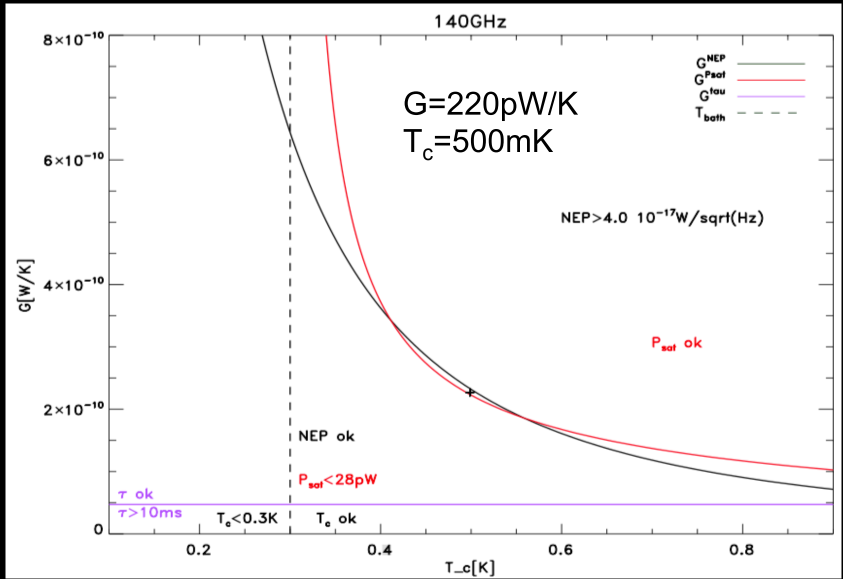
2) $G^{P_{sat}} = 3.2\, P_{sat} T_c^{2.2}/(T_c^{3.2} - T_{bath}^{3.2})$

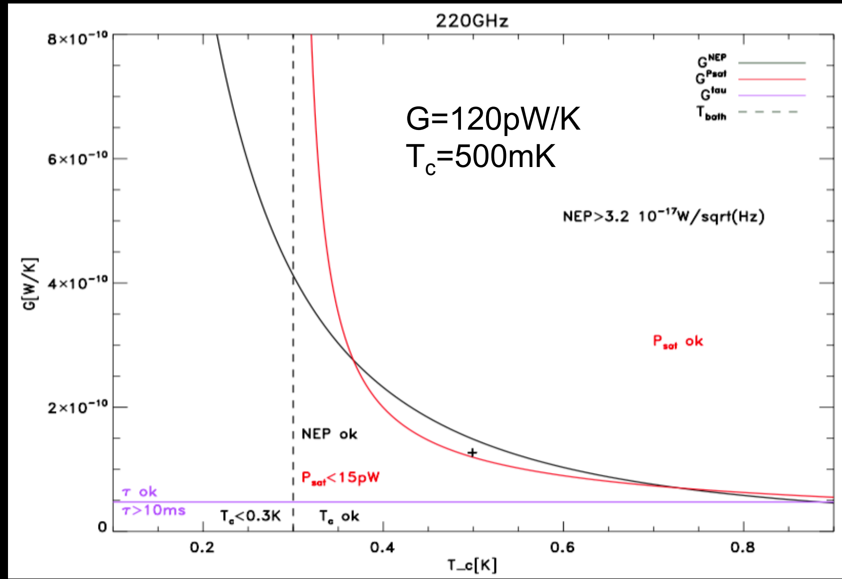
From the time constant formula (assuming l=14):

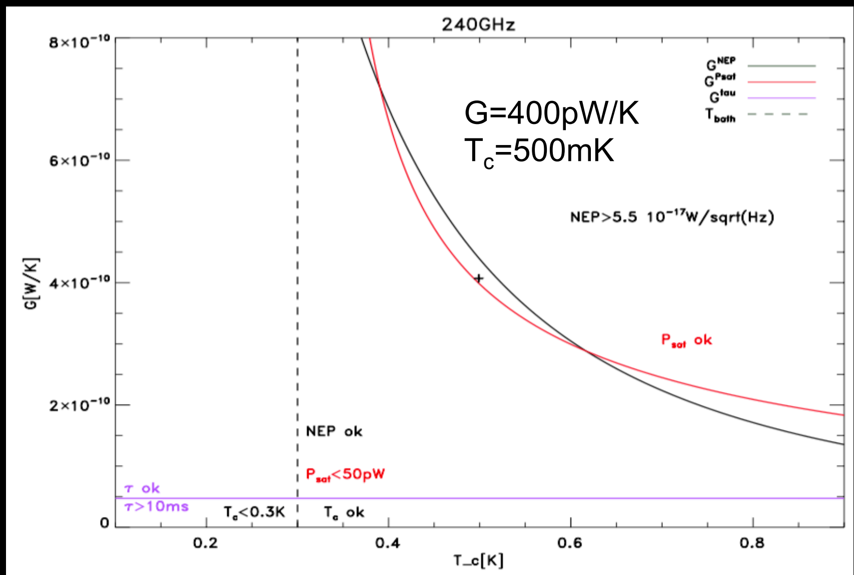
3) $G^{\tau} = C/[\tau(1+l)]$



SWIPE: multimoded TES

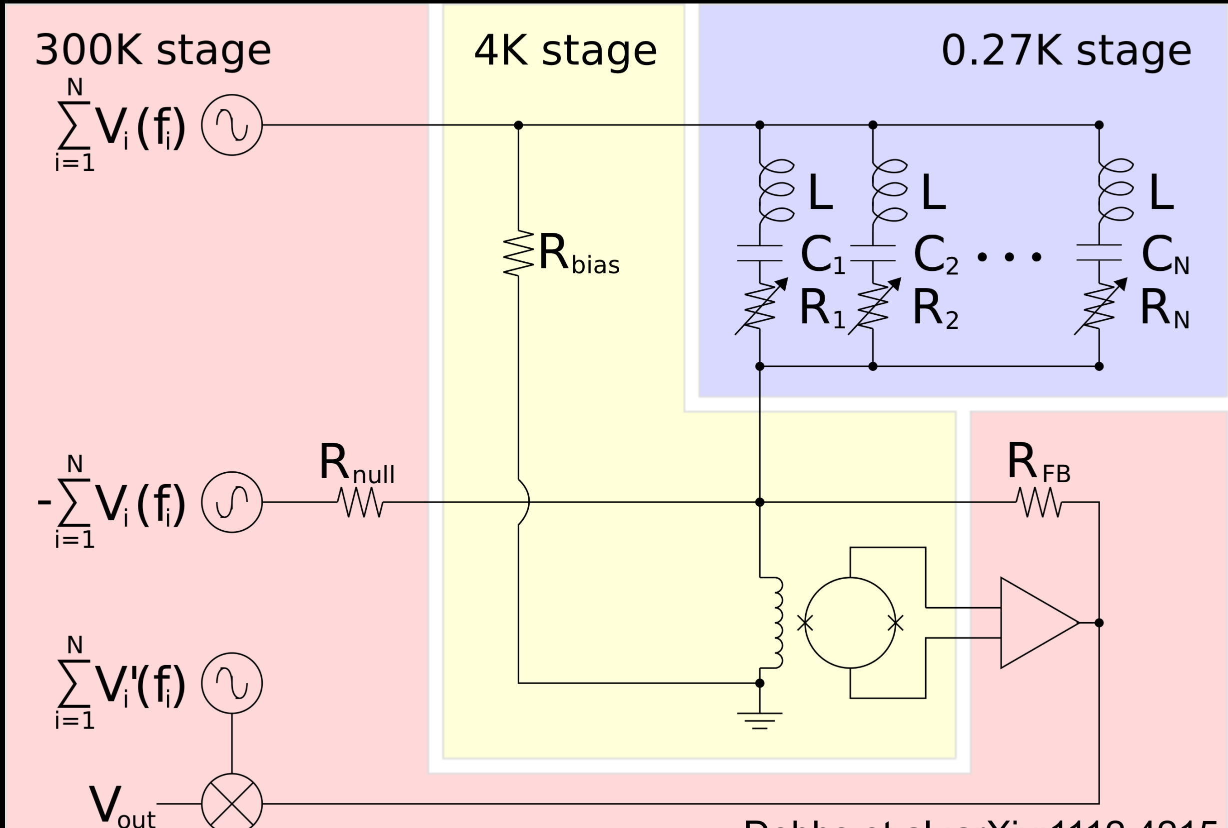






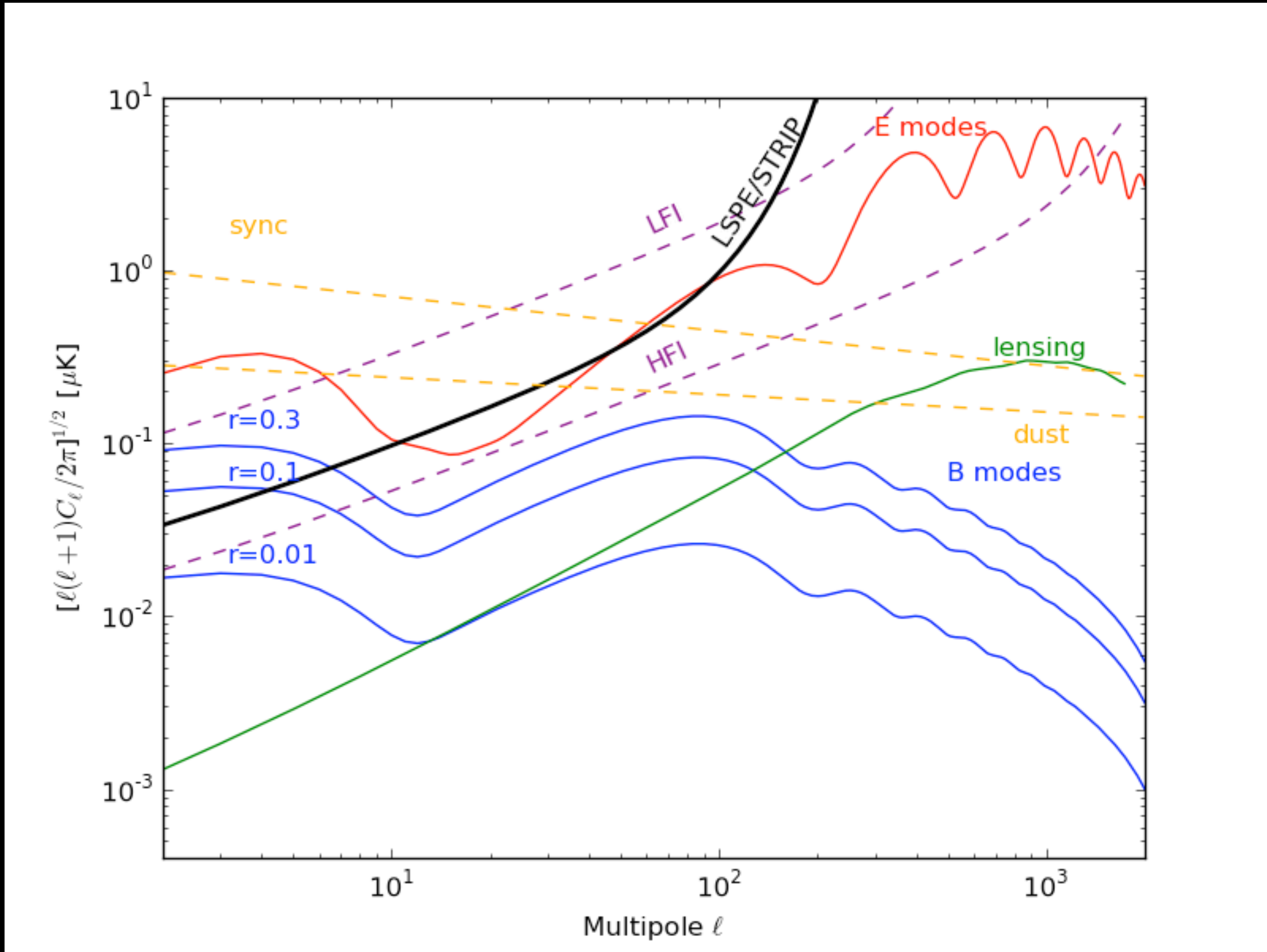
SWIPE: RO electronics

- TES are placed each in series with an inductor L and capacitor C creating a unique frequency resonance (set by C_n)
- $R_{bolo}C_nL$ are in parallel and each has its sine bias sent
- 1 SSA @ 4K with high enough transipedance not to be limited by warm read-out and cables
- Randomizing the relative phases of each carrier frequency increases the BW
- SQUIDs need to be Flux Lock Loopped and nulled
- 2 MHz bandwidth, n=16
- SPT/EBEX/Polarbear/ APEX like



Dobbs et al.:arXiv:1112.4215

LSPE-STRIP: performance forecast



Preliminary optmistic sensitvity based on uniform sky coverage and no systematics

LSPE-SWIPE: performance forecast

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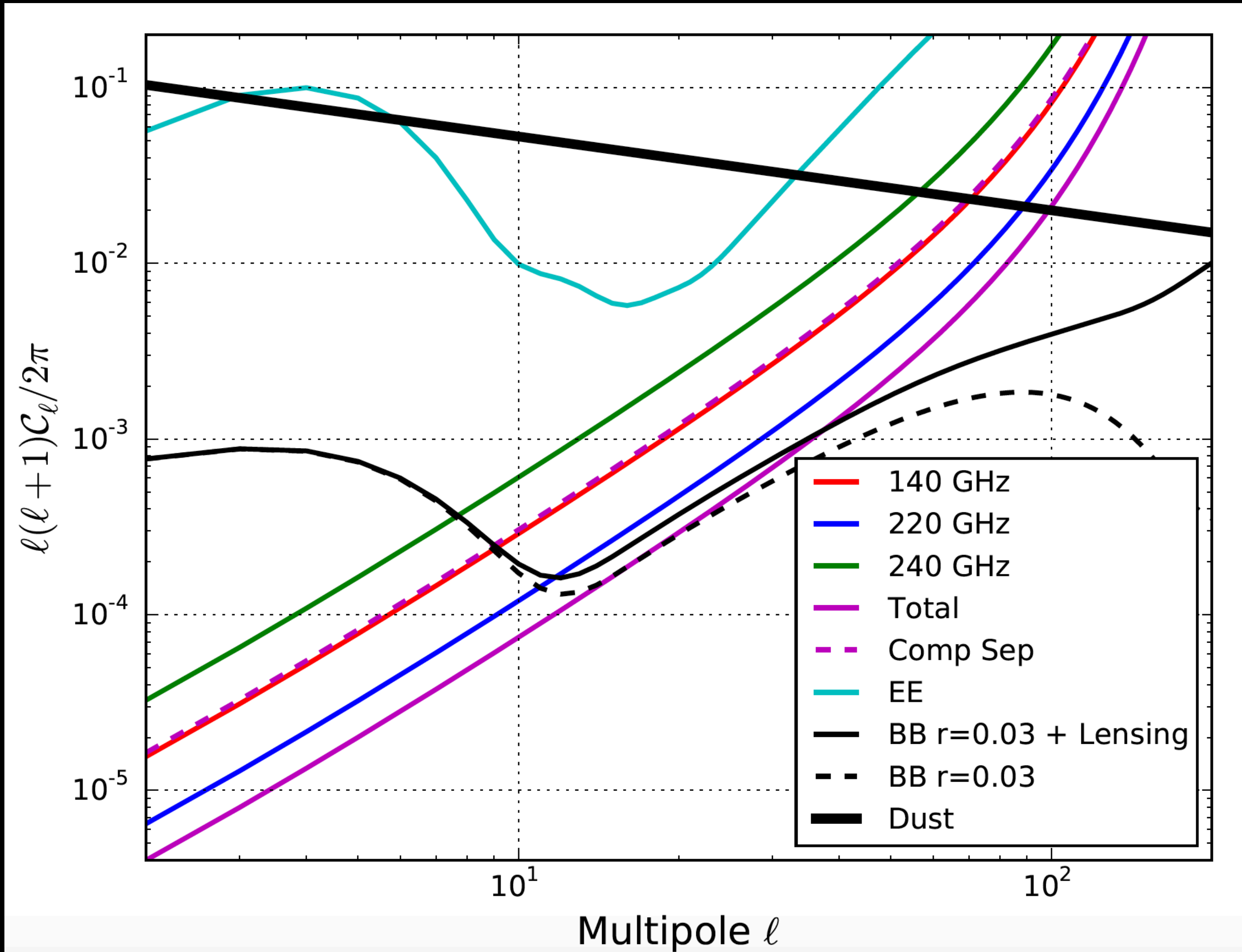
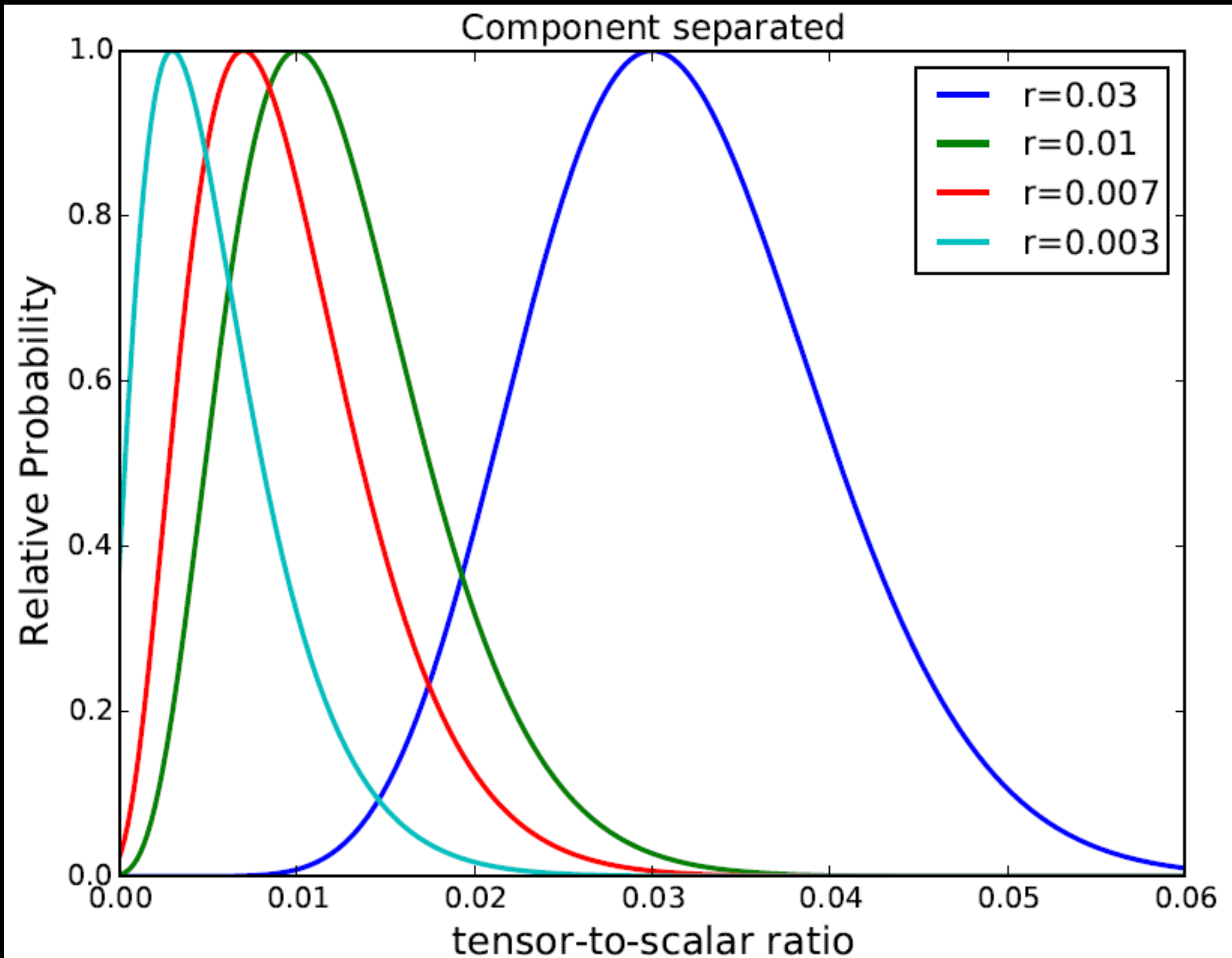
L. Pagano
F. Piacentini



SWIPE performance forecast (f_sky and cosmic variance not included), 1st flight

LSPE-SWIPE: performance forecast



L. Pagano
F. Piacentini

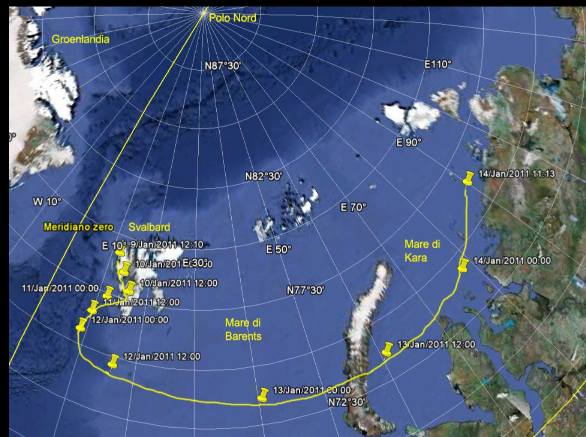
SWIPE performance forecast (f_sky and cosmic variance included), 1st flight

Flights from Svalbard

- Polar night flight from Longyerbyen, Svalbard
- Launch managed by ASI: our schedule compatible for a launch on december 2016

WINTER
- 1° winter LDB launched on Jan 2011
- From CNR Dirigibile Italia base
- Payload prepared by La Sapienza

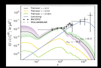
SUMMER
- PEGASO: 100000m^3, June 2006
- SORA: 800000m^3 July 2009



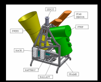
SORA 800000m^3 balloon

5 days at 32 Km, Eastward path

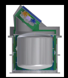
Resume and current status



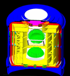
- Low-l B-modes detection is clearly important especially in the de-lensing era…



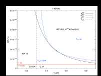
- LSPE wants to address this target with a night LDB flight
- LSPE is fully funded by the ASI (detector development co-funded by INFN)



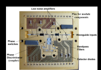
- STRIP: low frequency instrument (40 and 90GHz) to monitor synchrotron

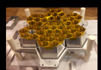


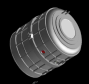
- SWIPE: high Frequency Instrument (150, 220 and 240GHz) with multimoded TES



- Careful optimization of multimoded horns, of TES properties, of cryogenics…

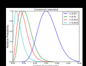






- STRIP and SWIPE in due course of development:
  - HEMT in our hands
  - platelets fabricated
  - SWIPE cryostat being manufactured
  - SWIPE horns prototype being tested
  - TES prototype being tested
  - …

- Consistent with a 1st launch opportunity from Svalbard (78°N) in December 2016



- Forecast suggest we can go down to r=0.01

- ASI will manage the night flight but some work has already been done

Thank you!

E.S. Battistelli
"Sapienza" University of Rome
for the LSPE collaboration

http://planck.roma1.infn.it/lspe