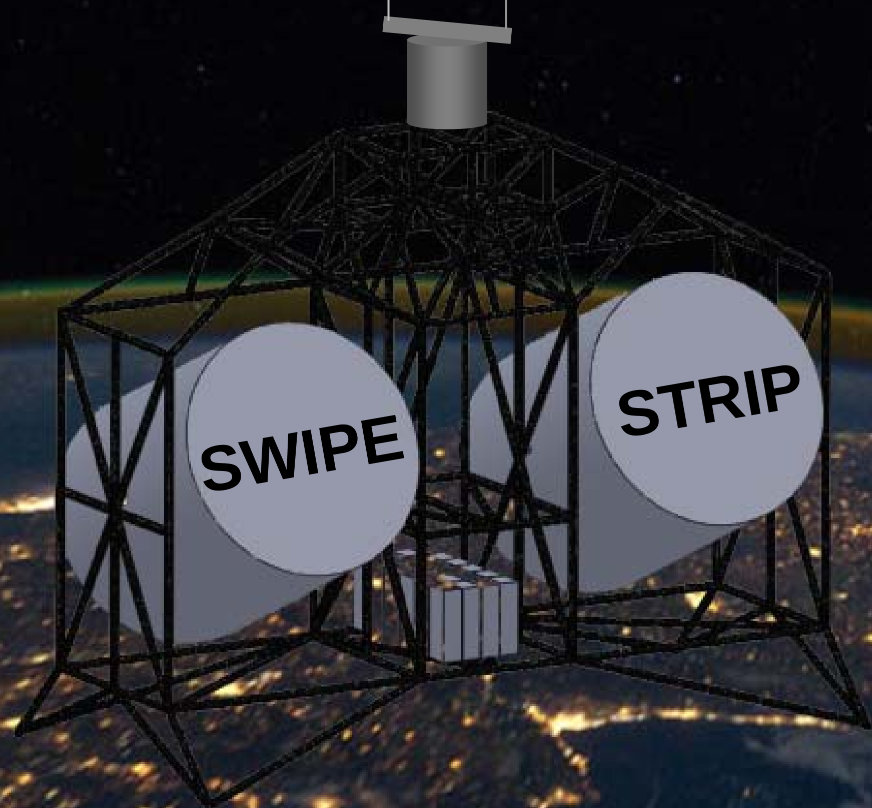
*Astrophysics from the Radio to the Submm*
**Bologna, 14/02/2012**




# The Large Scale Polarization Explorer

**P. de Bernardis, for the LSPE collaboration**

# The LSPE collaboration

Giorgio Amico, Elia Battistelli, Alessandro Baù, Paolo de Bernardis, Marco Bersanelli, Andrea Boscaleri, Francesco Cavaliere, Alessandro Coppolecchia, Angelo Cruciani, Francesco Cuttaia, Antonio D' Addabbo, Giuseppe D'Alessandro, Simone De Gregori, Francesco Del Torto, Marco De Petris, Lorenzo Fiorineschi, Cristian Franceschet, Enrico Franceschi, Massimo Gervasi, David Goldie, Anna Gregorio, Vic Haynes, Luca Lamagna, Bruno Maffei, Davide Maino, Silvia Masi, Aniello Mennella, Ng Ming Wah, Gianluca Morgante, Federico Nati, Luca Pagano, Andrea Passerini, Oscar Peverini, Francesco Piacentini, Lucio Piccirillo, Giampaolo Pisano, Sara Ricciardi, Paolo Rissone, Giovanni Romeo, Maria Salatino, Maura Sandri, Alessandro Schillaci, Luca Stringhetti, Andrea Tartari, Riccardo Tascone, Luca Terenzi, Maurizio Tomasi, Fabrizio Villa, Giuseppe Virone, Stafford Withington, Andrea Zacchei, Mario Zannoni

**S**hort
**W**avelength
**I**nstrument for the
**P**olarization
**E**xplorer
(bolometers, 80-250 GHz)
PI de Bernardis

**STR**atospheric
**I**talian
**P**olarimeter
(radiometers, 40-90 GHz)
PI Bersanelli

P. de Bernardis Bologna 14 feb 2012

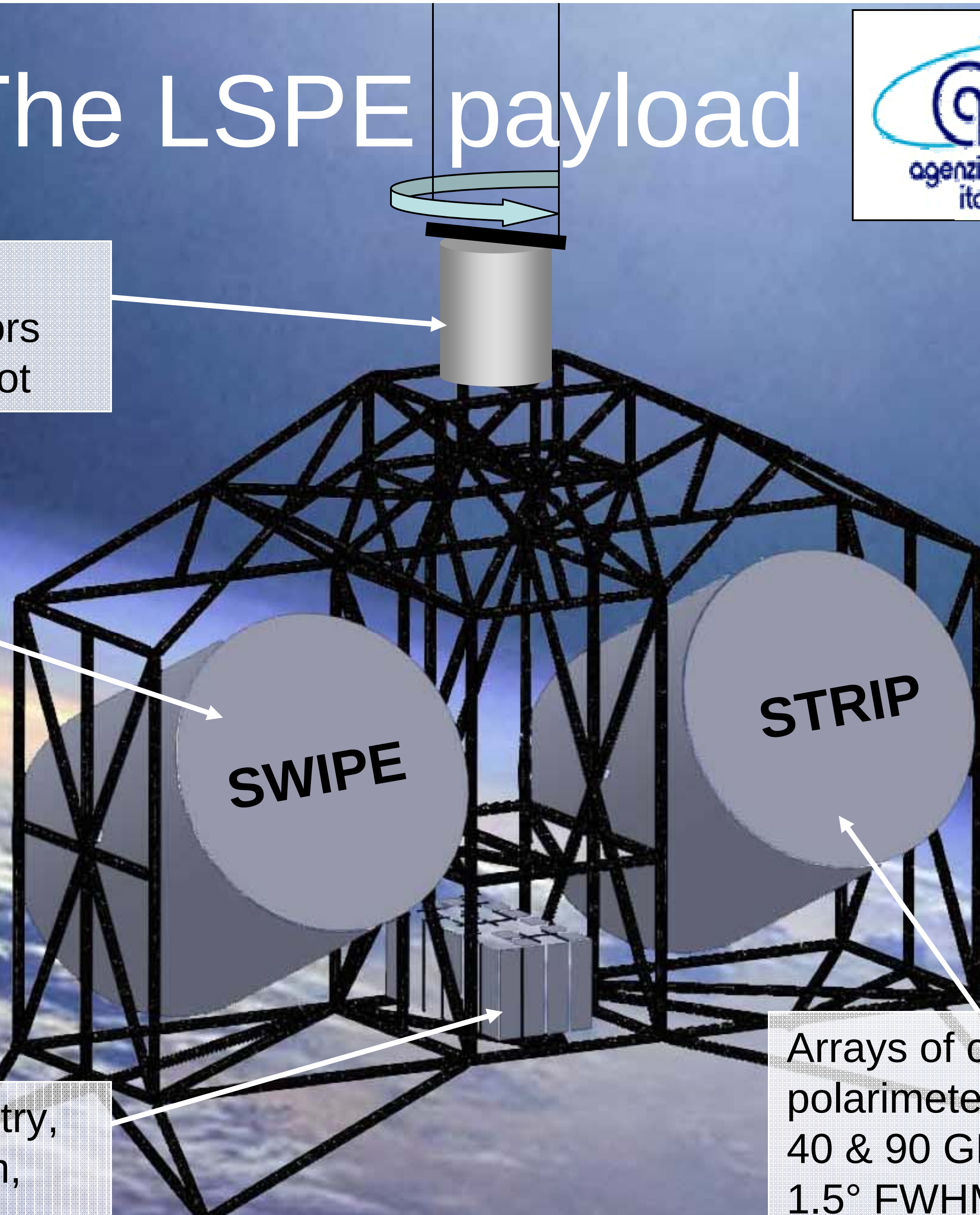
# LSPE in a nutshell

- The Large-Scale Polarization Explorer is
  - a spinning stratospheric balloon payload
  - flying long-duration, in the polar night
  - aiming at CMB polarization at large angular scales
  - using polarization modulators to achieve high stability
- Frequency coverage: 40 – 250 GHz (5 channels)
- Angular resolution: 1.5 – 2.3 deg FWHM
- Sky coverage: 20-25% of the sky per flight
- Combined sensitivity: 10 $\mu K$ *arcmin* per flight

# The LSPE payload

A spinning gondola, rotated by torque motors around an azimuth pivot

Stokes polarimeter with cold stepping HWP and arrays of large-throughput bolometers at 90, 145, 220 GHz; FWHM 2.4° to 1.4°




Arrays of coherent polarimeters at 40 & 90 GHz. 1.5° FWHM

Batteries (1GJ), telemetry, Attitude Control System, data storage

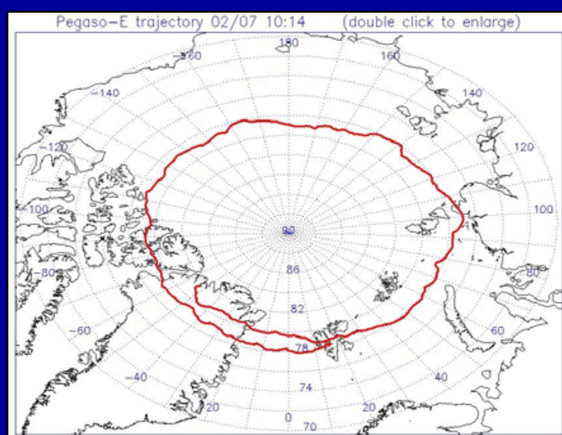
LSPE
Large Scale Polarization Explorer

agenzia spaziale italiana

# Mission profile

- The instrument will be flown at 38 km of altitude by a 800000$m^3$ balloon, at the end of 2014.
- Stratospheric balloons can be flown during the polar night despite of the low temperature of the air (see e.g. Archeops)
- The currently selected launch site is in the Svalbard islands (78° N), and the expected flight path will be a circle at approximately constant latitude.
- With recovery in Greenland, the flight can be 2-3 weeks long. This has been tested already in the summer.
- The site is easily reacheable (international airport) and large payloads have already been launched from there.

PEGASO circumpolar flight (2007) launched from Longyearbyen

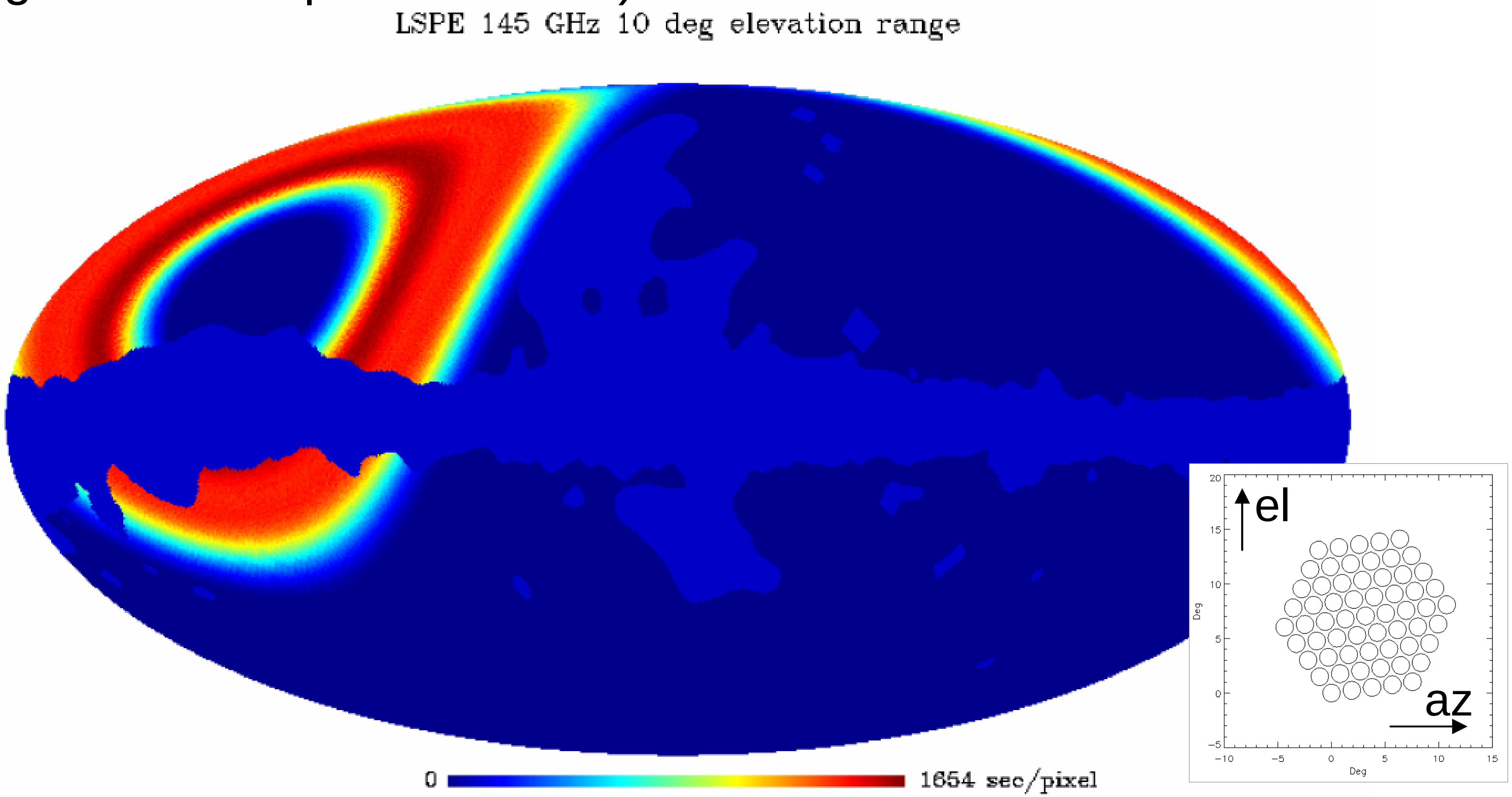



- The same thing can be done, with logistic complications, in Antarctica

Launch of the SORA experiment from the Longyearbyen airport (2009)

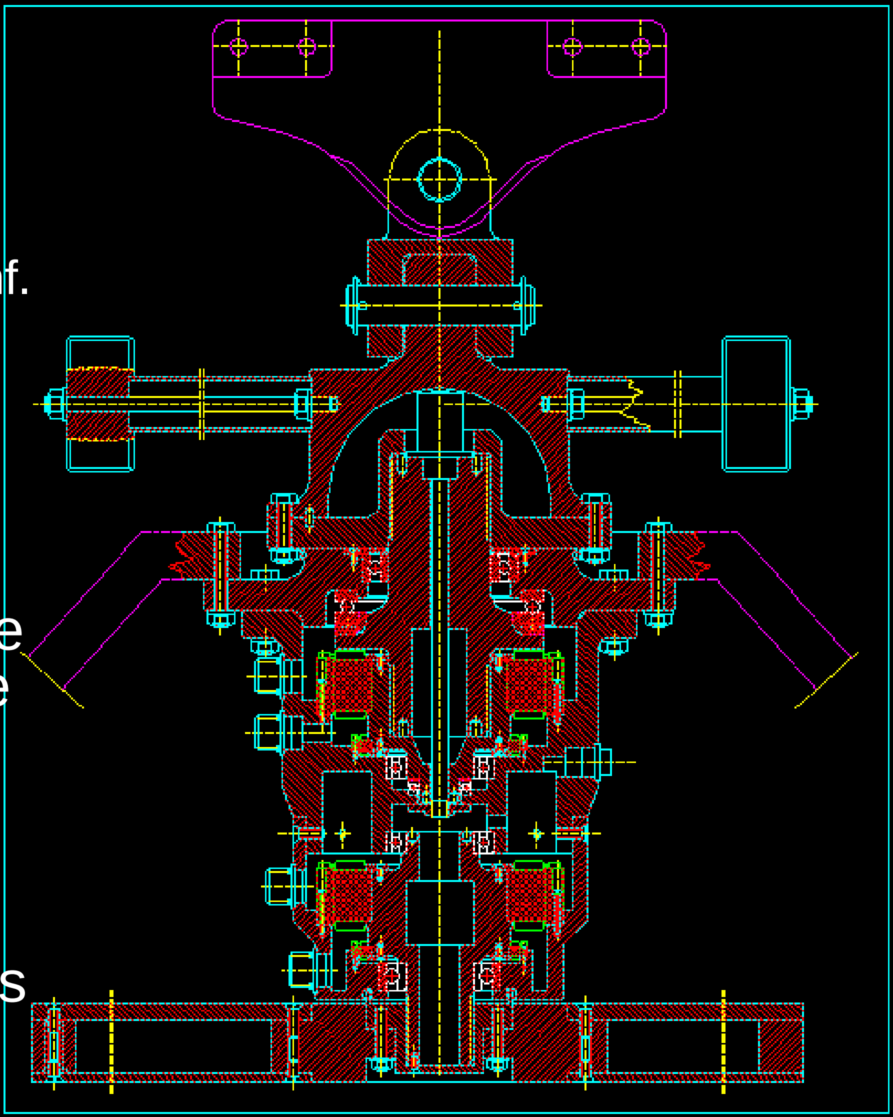
# Sky Coverage

- The payload will just spin in azimuth during the flight.
- The telescopes of the two instruments will scan the sky at constant elevation. Performing a few elevation steps during the 2-3 weeks of the flight, more than 20% of the sky can be covered outside the galactic mask, with good cross-linking and significant integration time per pixel. (cfr. Farhang et al. astro-ph/1108.2043)



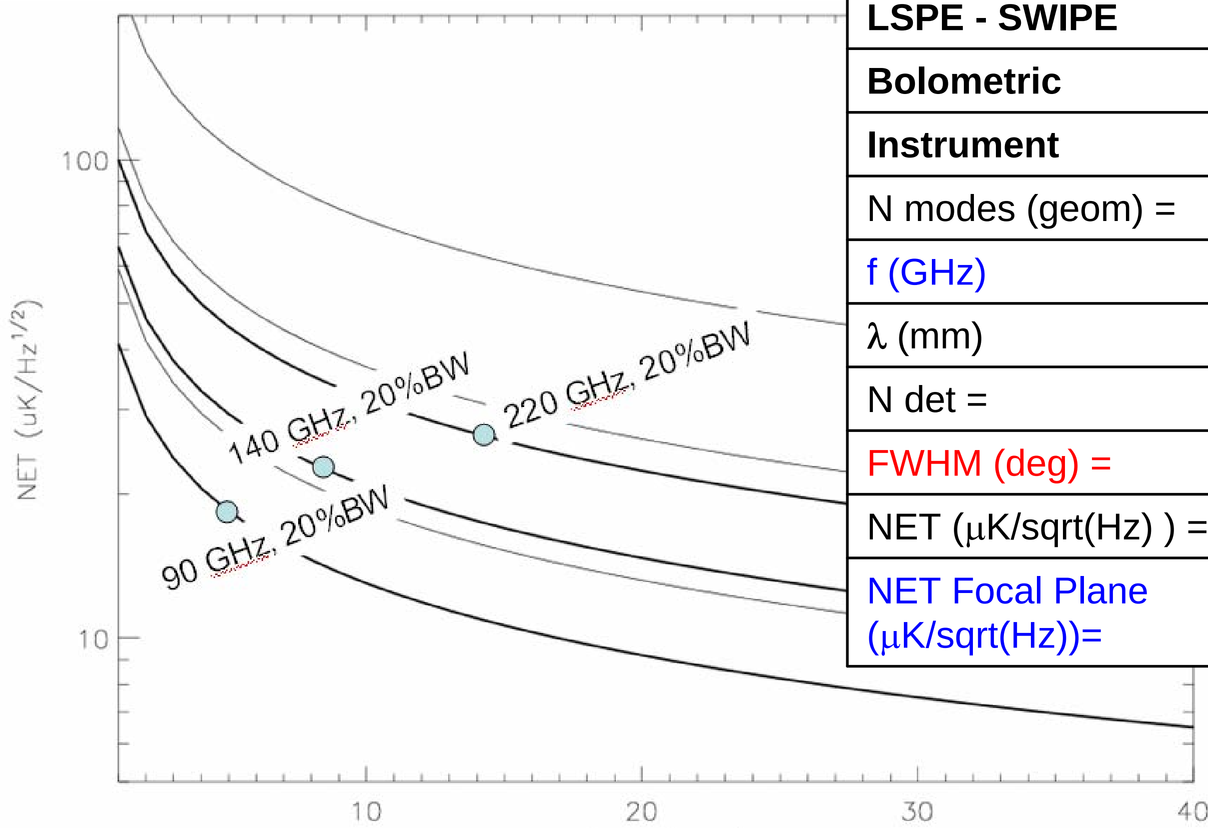
# LSPE – ACS

- The payload spins at 2-3 rpm
- We use an azimuth pivot with torque motors similar to the ones used in BOOMERanG and Archeops (Pascale + Boscaleri AIP Conf. Proc. **616**, 56, 2001)
- The rotation speed is sensed by a set of 3 laser-gyors, driving the ACS control loop.
- The power required to spin the payload (about 100W) is due to the friction in the thrust bearings of the azimuth pivot and is provided by Lithium batteries.
- Absolute attitude is reconstructed by means of a fast star sensor similar to the one used in Archeops (Nati et al., Review of Scientific Instruments, **74**, 4169, 2003)



# SWIPE

- The **S**hort **W**avelength **I**nstrument for the **P**olarization **E**xplorer
- Uses overmoded bolometers, trading angular resolution for sensitivity
- Sensitivity of photon-noise limited bolometers vs # of modes:

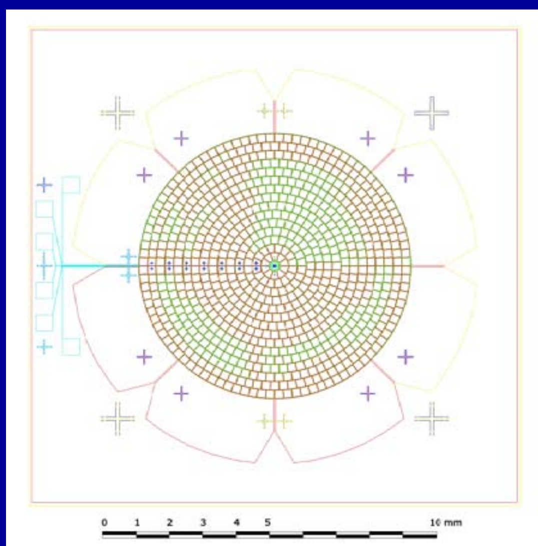


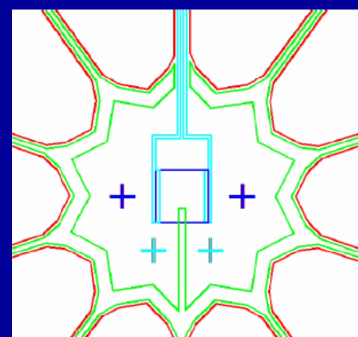

| **LSPE - SWIPE** | eff = | 0.25 | |
|---|---|---|---|
| **Bolometric** | D lens = | 0.4 | m |
| **Instrument** | F = | 0.8 | m |
| N modes (geom) = | 15 | 25 | 40 |
| f (GHz) | 90 | 145 | 220 |
| λ (mm) | 3.3 | 2.1 | 1.4 |
| N det = | 37 | 58 | 83 |
| FWHM (deg) = | 2.4 | 1.9 | 1.6 |
| NET (μK/sqrt(Hz) ) = | 15 | 25 | 30 |
| NET Focal Plane (μK/sqrt(Hz))= | **2.5** | **3.3** | **3.2** |

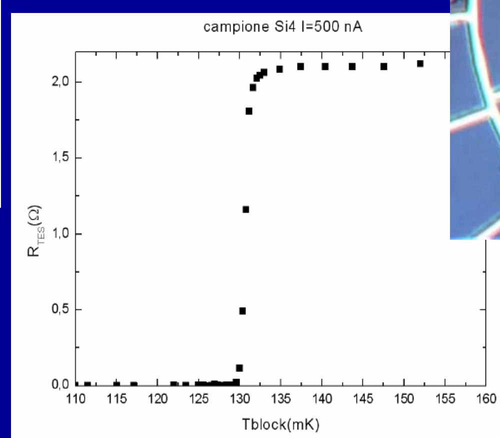
Number of modes actually coupling to the bolometer absorber

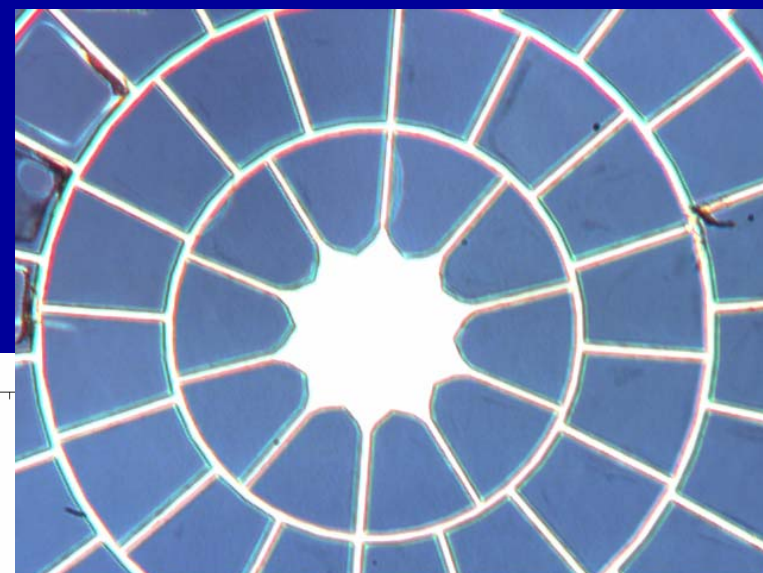
# SWIPE

- Overmoded detectors are obtained coupling large area bolometer absorbers to Winston horns.
- Example of large-throughput spider-web bolometer (being developed in Italy, F. Gatti)



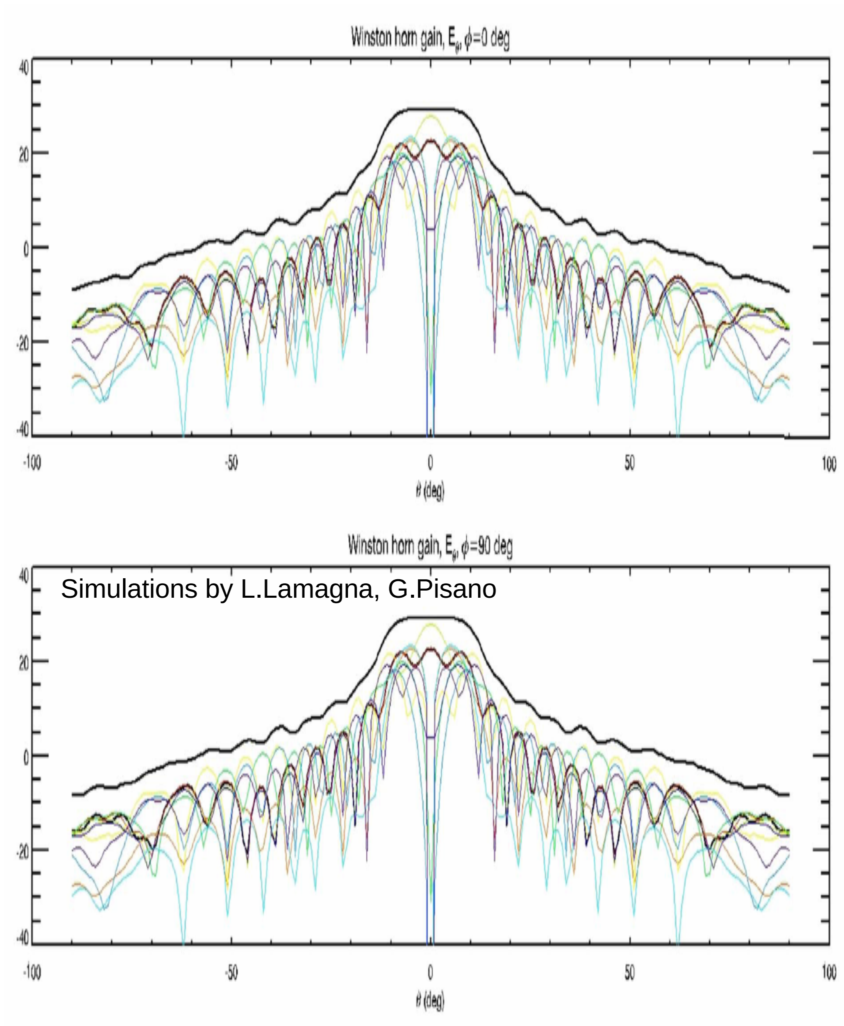


- SWIPE bolometers will be made in Cambridge (Withington)

# SWIPE

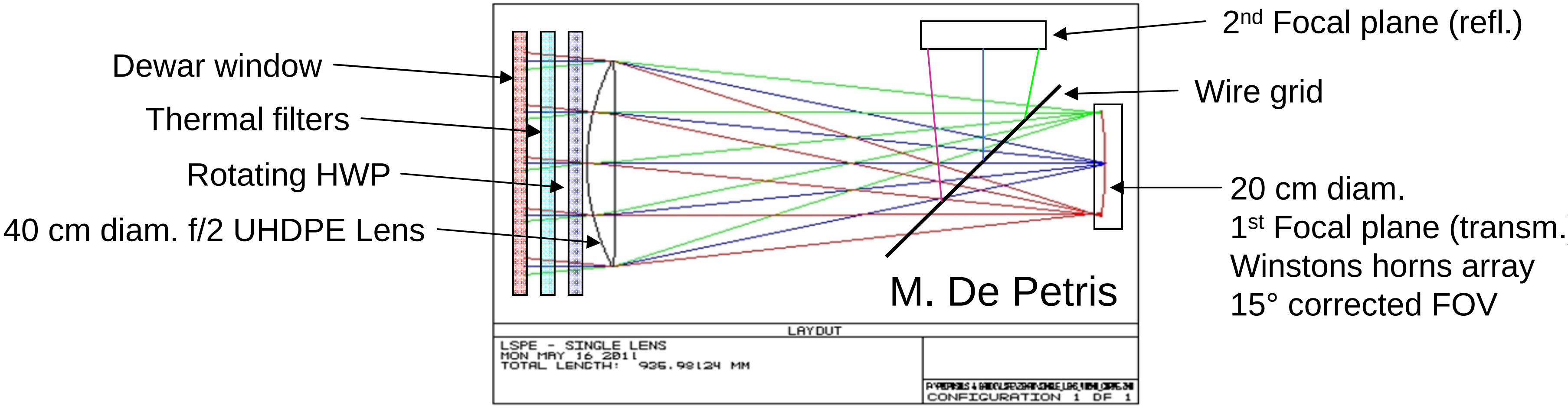
- Overmoded detectors are obtained coupling large area bolometer absorbers to Winston horns.



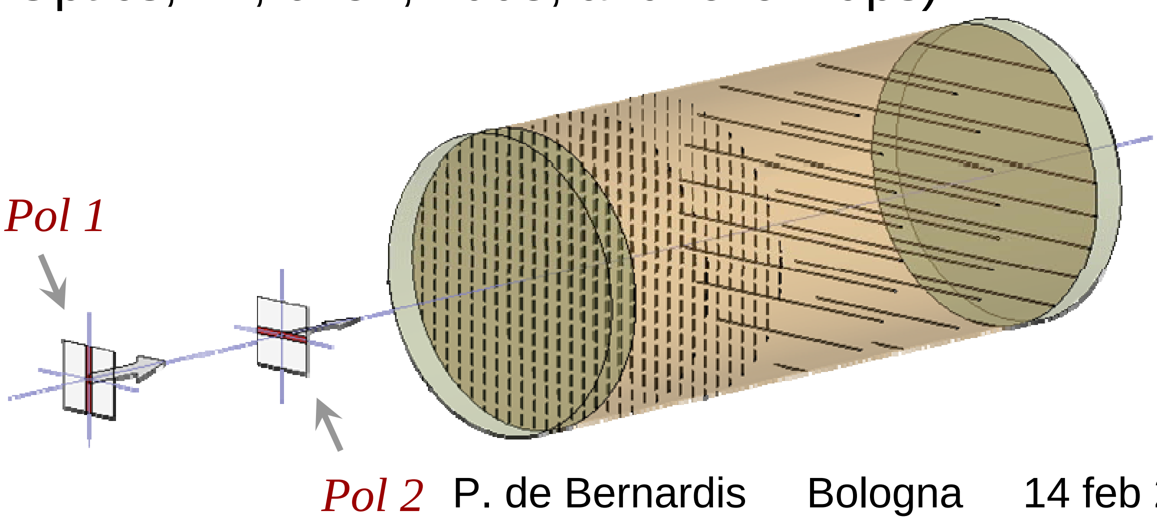

Simulations confirm that about half of the modes collected by the Winston horn actually couple to the bolometer absorber
(in single-polarization detectors).

# SWIPE

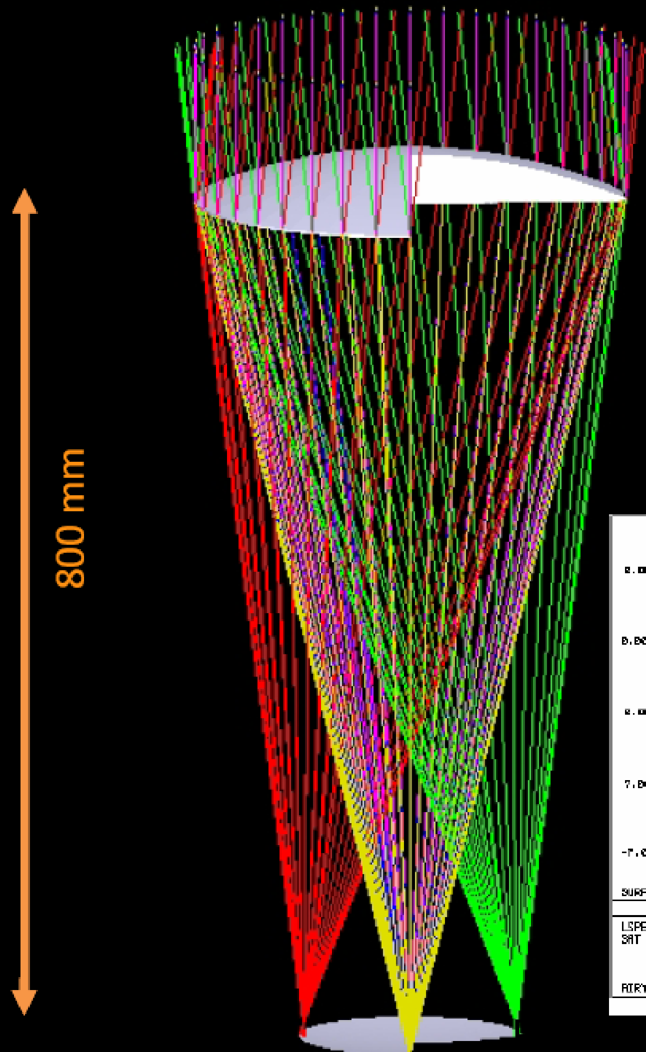
- Polarimetry is implemented with a classical Stokes configuration.




- The first optical element is a large diameter (50 cm TBC) HWP, obtained by means of diectric-embedded metal meshes (G. Pisano et al. Applied Optics, **47**, 6251, 2008, and follow-ups)

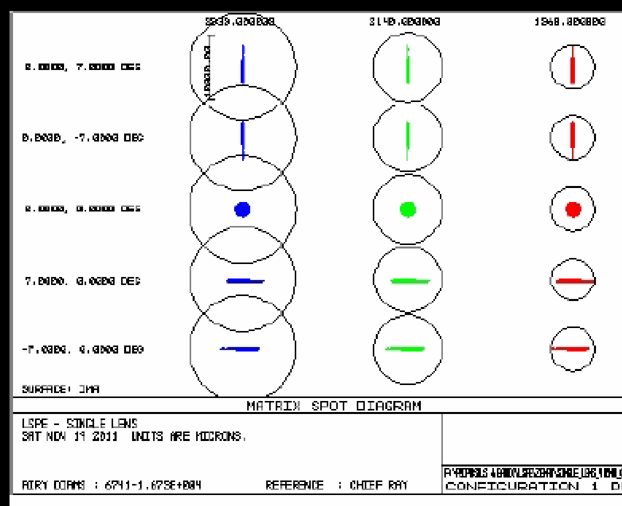


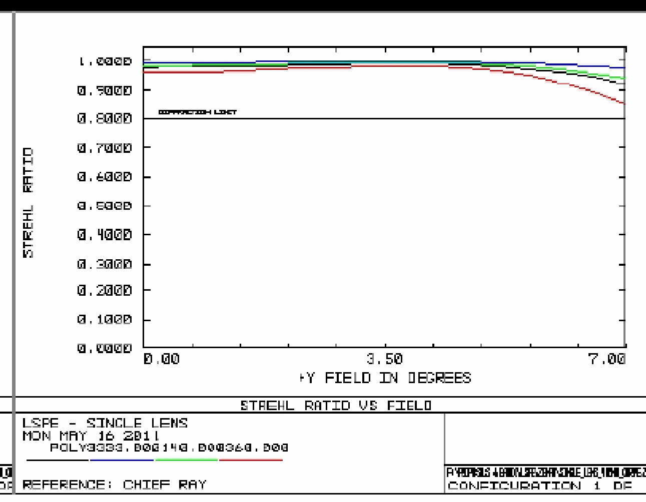

# SWIPE




## LSPE-SAF: OPTICS REQUIREMENTS

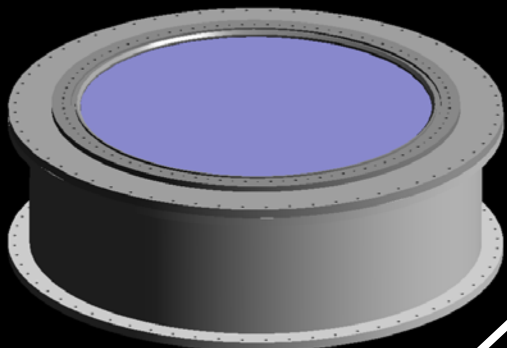
| | | | | |
|---|---|---|---|---|
| Entrance Pupil Diameter | (mm) | 400 | | |
| Effective Focal Length | (mm) | 800 | | |
| f-number | | 2 | | |
| Focal Plane Diameter | (mm) | 200 | | |
| Image Object Space | (deg) | 14,3 | | |
| Focal plane scale | ('/mm) | 4,3 | | |
| Focal Plane Surface | | curved | | |
| Optics Symmetry | | cilindrical | | |
| Spectral Range | (GHz) | 90 | 140 | 220 |
| waves | (mm) | 3,33 | 2,14 | 1,36 |
| Angular Resolution | (arcmin) | 28,6 | 18,4 | 11,7 |
| number of modes | | 20 | 20 | 20 |
| throughput (N lambda^2) | (cm^2 sr) | 2,22 | 0,92 | 0,37 |
| FWHM | (deg) | 1,68 | 1,08 | 0,69 |
| Strehl Ratio | | > 95% | | |
| Strehl Ratio variation along fov | | < 1% | | |
| Beam ellipticity | | 1% | | |
| Cross Polarization | | 1% | | |
| Instrumental Polarization | | <1% | | |



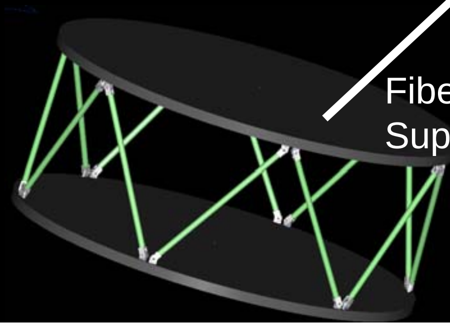



# SWIPE

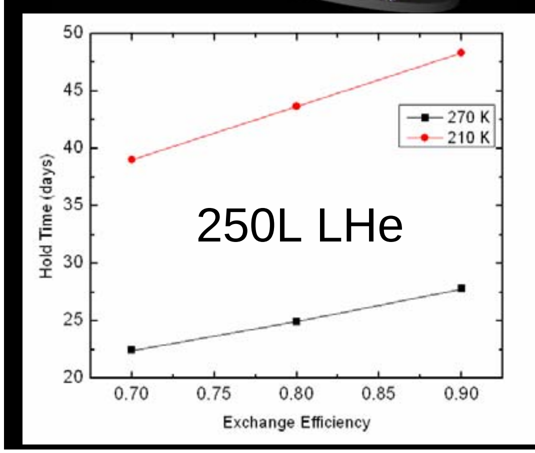
Custom cryostat (S. Masi)

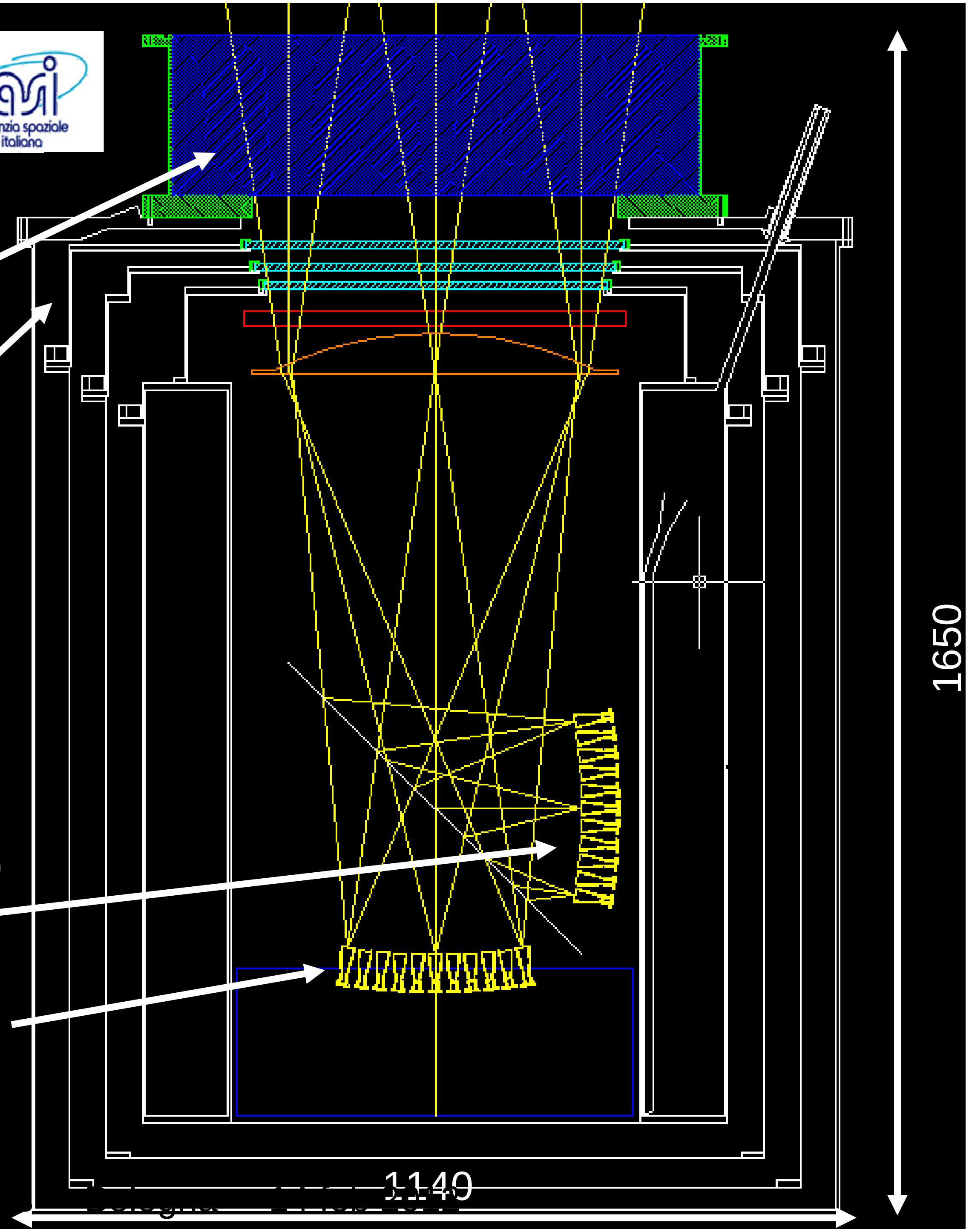


Plastazote window



Fiberglass struts
Support system



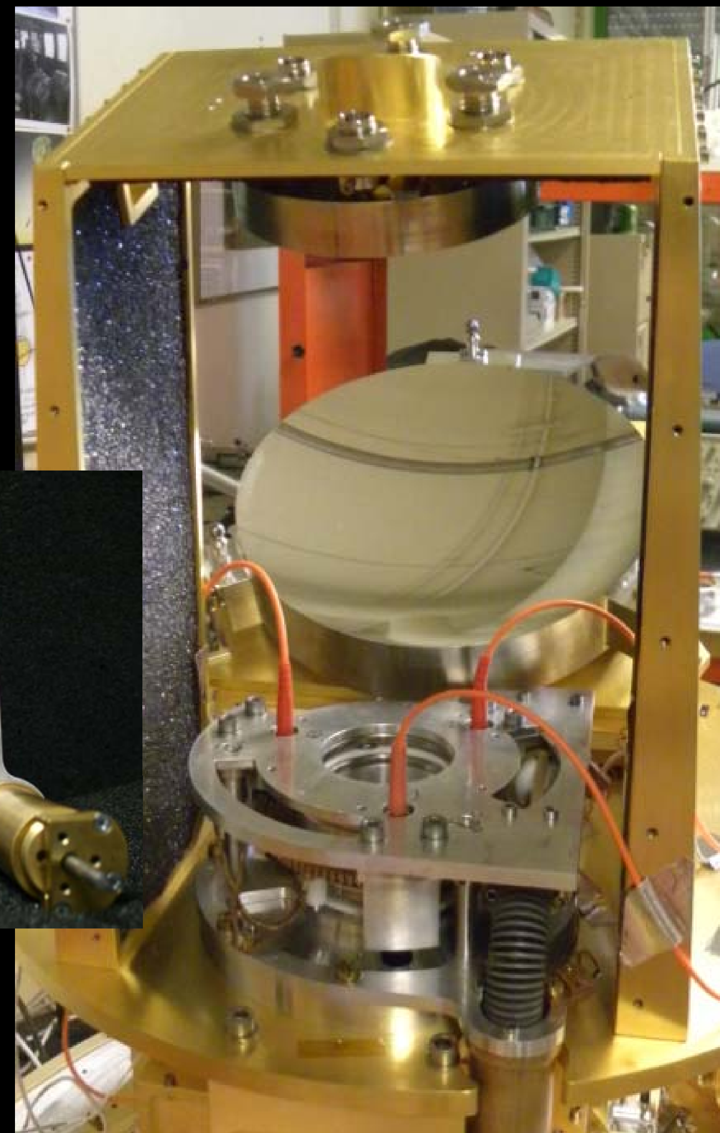



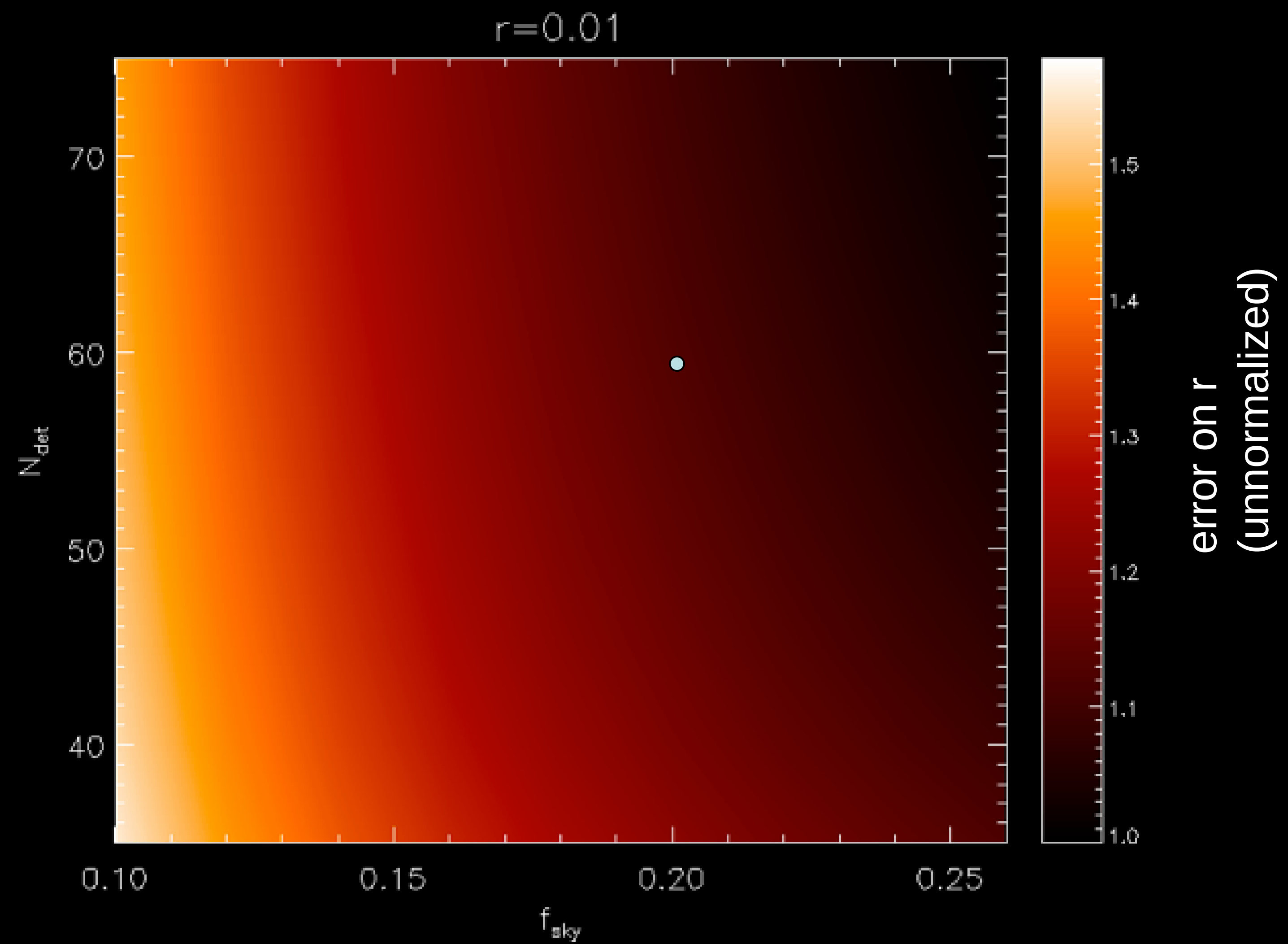

Arrays 90
& 220

Array 140

# SWIPE

- The HWP will be rotated in steps using a low-friction cryogenic mechanism based on thrust bearings, similar to the one we have developed for PILOT (Salatino et al. A&A 528, A138, 2011).
- 11.25° step, 1 step/min, < 10mW
- Precision position readout with optical fibers & pinholes





r=0.01
70
60
50
40
$N_{det}$
0.10
0.15
0.20
0.25
$f_{sky}$
1.5
1.4
1.3
1.2
1.1
1.0
error on r
(unnormalized)

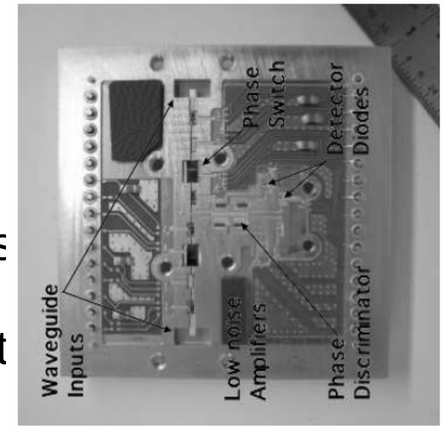
# SWIPE

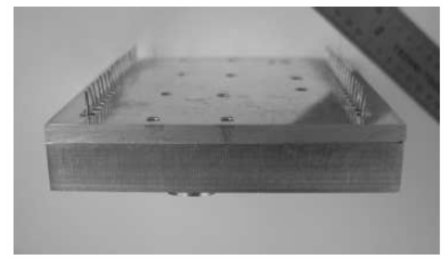
- Simulations show that a step/integrate approach with 11.25° per step, 1 step/min and a gondola spinning at 3 rpm is already very effective in removing 1/f and drifts.
- Assuming drifts are negligible, the white-noise sensitivity of SWIPE is compared to the HFI in the table below:

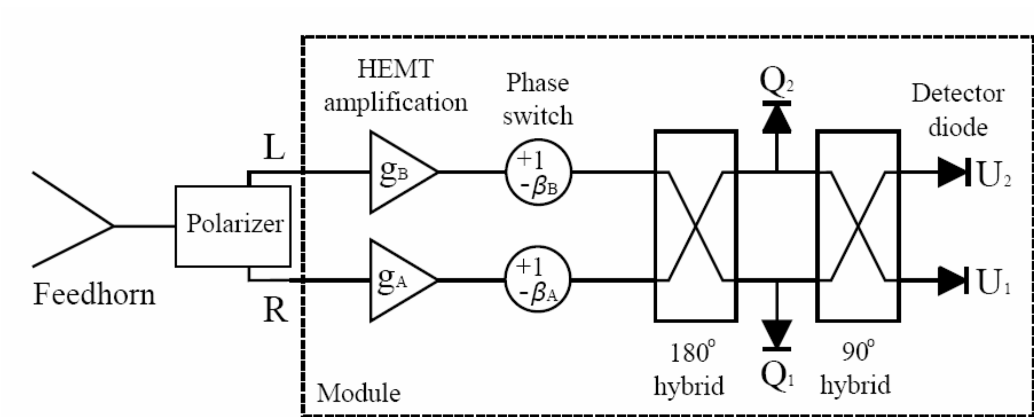
| | PLANCK – HFI (full sky) | | | | | | LSPE – SWIPE (20%) | | |
|---|---|---|---|---|---|---|---|---|---|
| Frequency (GHz) | 100 | 143 | 217 | 353 | 545 | 857 | 90 | 145 | 220 |
| FWHM Resolution (arcmin) | 9 | 7 | 6 | 5 | 5 | 5 | 144 | 114 | 96 |
| Sky coverage (%) | 100 | 100 | 100 | 100 | 100 | 100 | 20 | 20 | 20 |
| Obs Time (months) | 30 | 30 | 30 | 30 | 30 | 30 | 0.467 | 0.467 | 0.467 |
| Bandwidth (%) | 33 | 33 | 33 | 33 | 33 | 33 | 25 | 25 | 25 |
| N_det (polarized) | 8 | 8 | 8 | 8 | 0 | 0 | 37 | 58 | 83 |
| Channel NET (uK s^1/2) | 25 | 31 | 45 | 140 | // | // | 2.47 | 3.25 | 3.21 |
| Integration/beam (s) | 33 | 20 | 15 | 10 | - | - | 660 | 415 | 225 |
| **Delta Q(U) (uK) on LSPE beams** | **0.27** | **0.42** | **0.84** | **2.6** | **-** | **-** | **0.10** | **0.16** | **0.21** |
| | | | | | | | | | |
| | **Improvement factor with respect to Planck-HFI (2° pixels)** | | | | | | **2.8** | **2.7** | **3.9** |

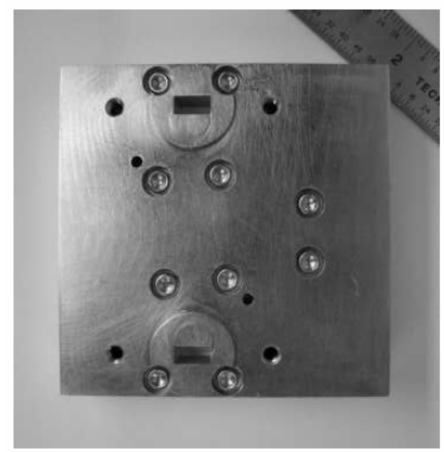
# STRIP

- The **STR**atospheric **I**talian **P**olarimeter uses coherent polarimeters working at 40 and 90 GHz, with a target sensitivity twice better than Planck LFI
- The main target is the polarized foreground (synchrotron), studied by means of 49 polarimeters in Q band. This is mandatory for an effective component separation, to remove foreground contamination from the cosmological channels (90 & 140 GHz from SWIPE).
- The 9 polarimeters in W band performs the same measurements as the bolometric W-band channel, using a completely independent technique. This provides the opportunity for a direct comparison, very efficient in detecting systematic effects.
- The required angular resolution (1.5°) is obtained by means of a 1.5m diameter telescope, focusing on an array of corrugated feedhorns, followed by high efficiency pseudo-correlation polarimeters (similar to the QUIET ones, see K. A. Cleary, Proc. SPIE 7741, 77412H, 2010).

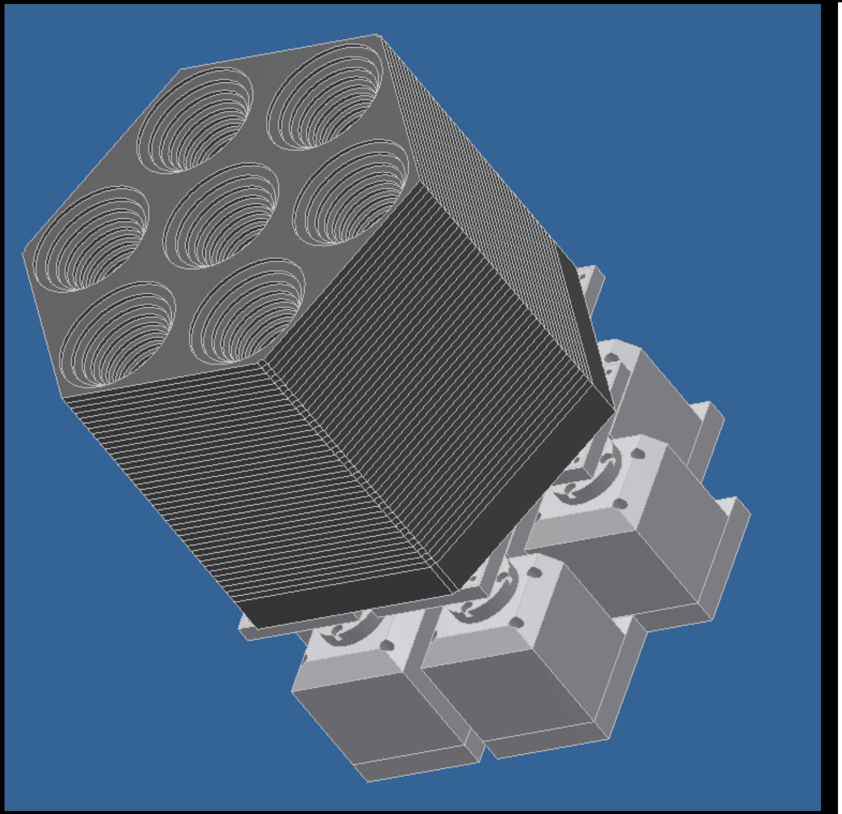


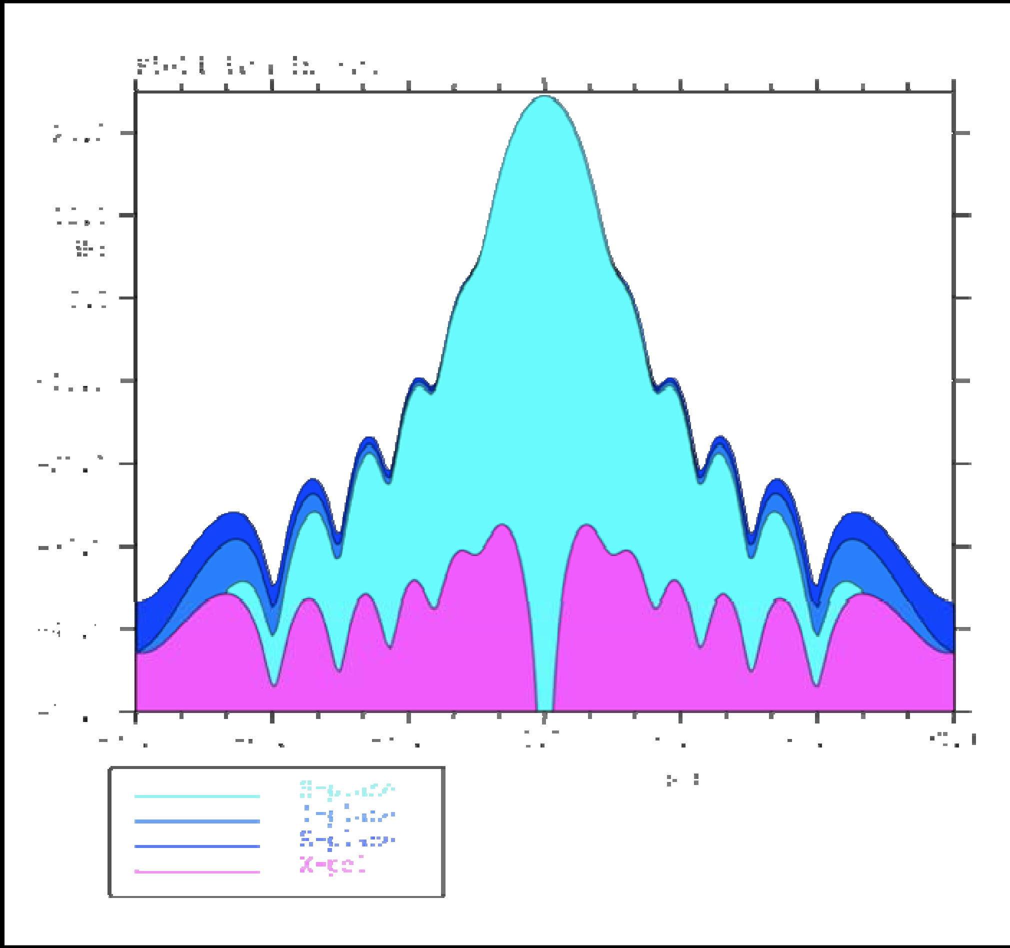





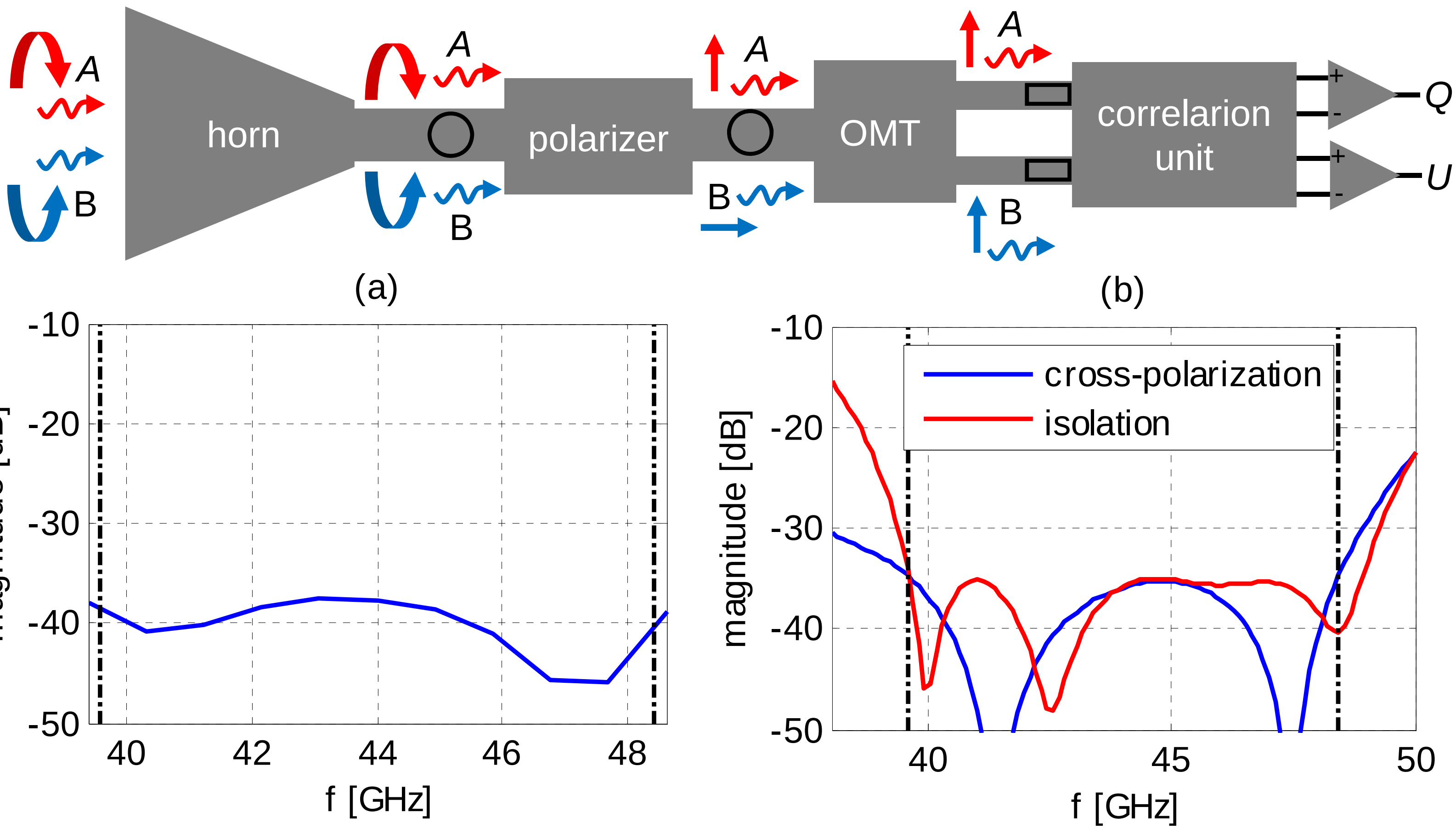
# STRIP





The corrugated feedhorns arrays are produced using the platelets technology (see e.g. Del Torto et al. JNST 6, 6009, 2011).

# STRIP

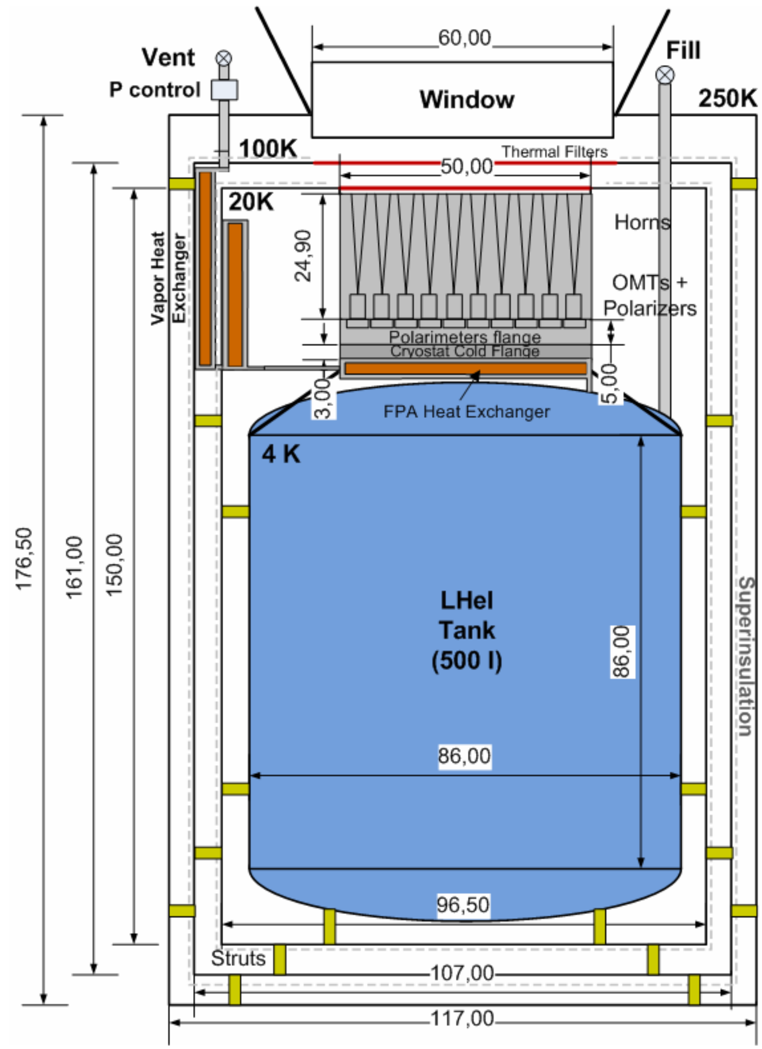



- High efficiency, wide band, polarizers and OMTs have been custom designed for this application at IEIIT

# STRIP

- The polarimeters are cooled at the optimal operation temperature by cold He gas, evaporating from a large (500L) He cryostat (G. Morgante)

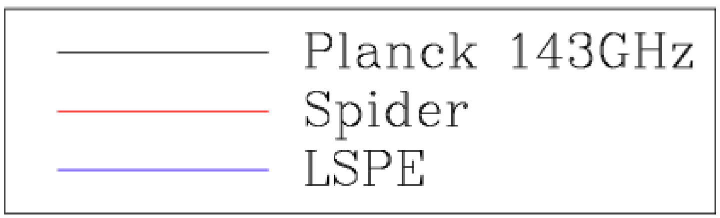
| Stage | 4K | 20K | 100K | Comments |
|---|---|---|---|---|
| Radiative (mW) | 6,38 | 259,06 | 6156,87 | *MLI 30 layers, 15 layers/cm* |
| Conductive (mW) | 2,05 | 493,89 | 3052,94 | *Piping in SS, Struts in G10, Wires in PhBronze (all harness in Flexi Cu with 20-30 cm thermal breaks)* |
| Active (mW) | 832,00 | 1845,00 | 0,00 | *On 4K stage heater dissipation is added on top of the parasitics load to maintain massflow, on the 20K stage the polarimeters dissipation plus active temperature control (0,2W average)* |
| Total (mW) | 840,42 | 2597,95 | 9209,80 | *no margin* |
| with margin | 1092,55 | 3377,34 | 11972,74 | *30% margin has been considered here* |

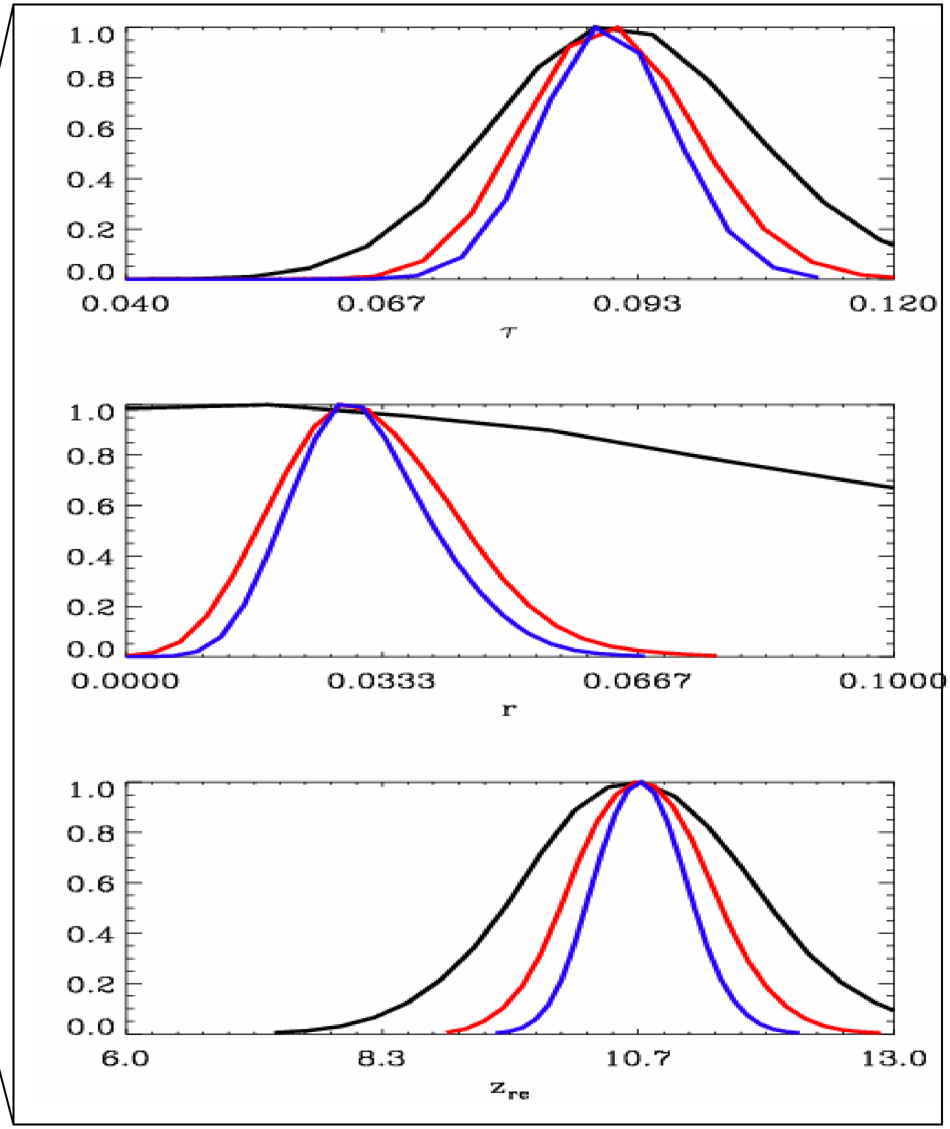


# LSPE

Our target is *r* = 0.03, 3σ.

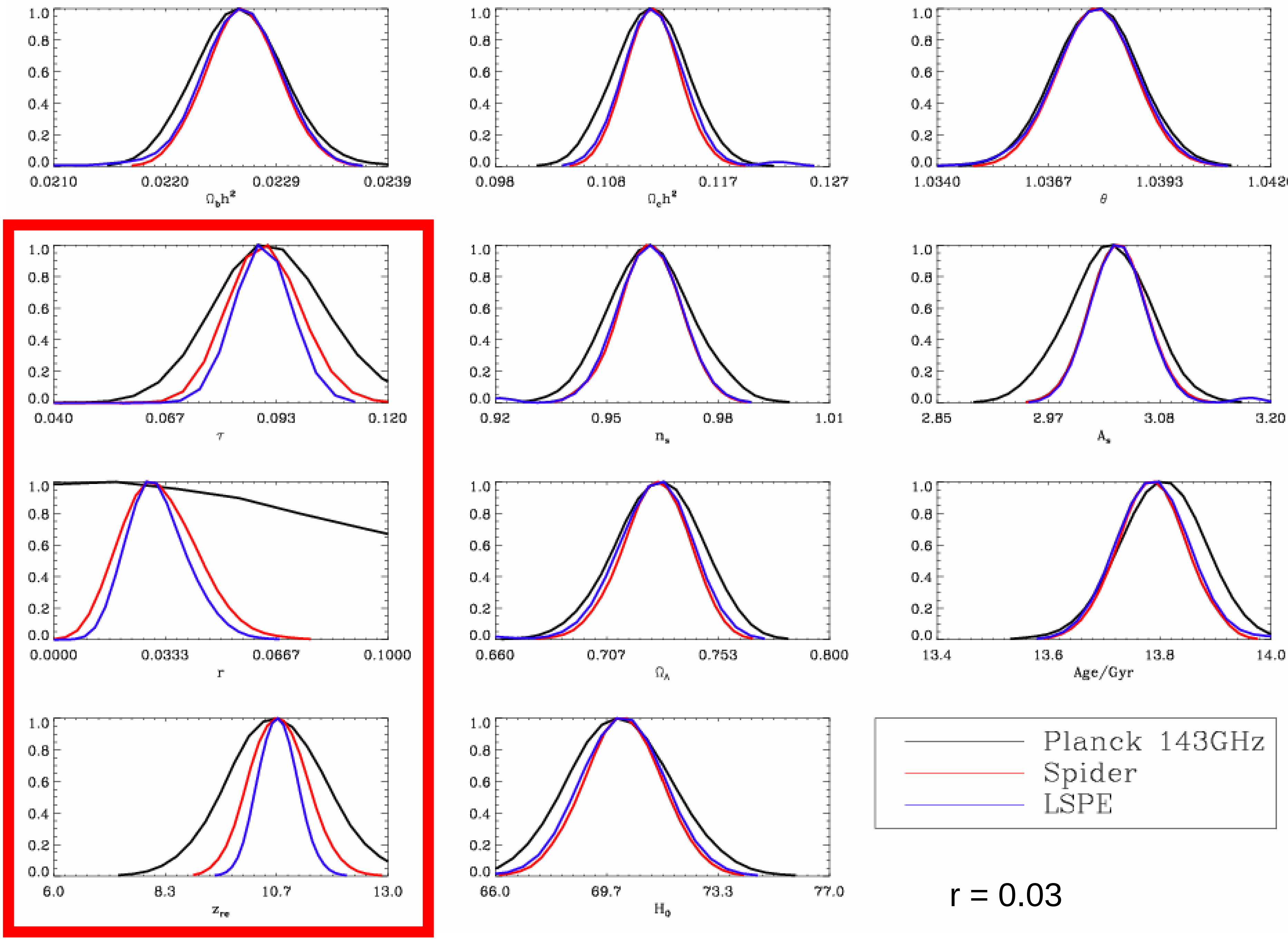
Expected performance of LSPE in constraining cosmological parameters, compared to Planck and SPIDER
(simulation by L. Pagano)



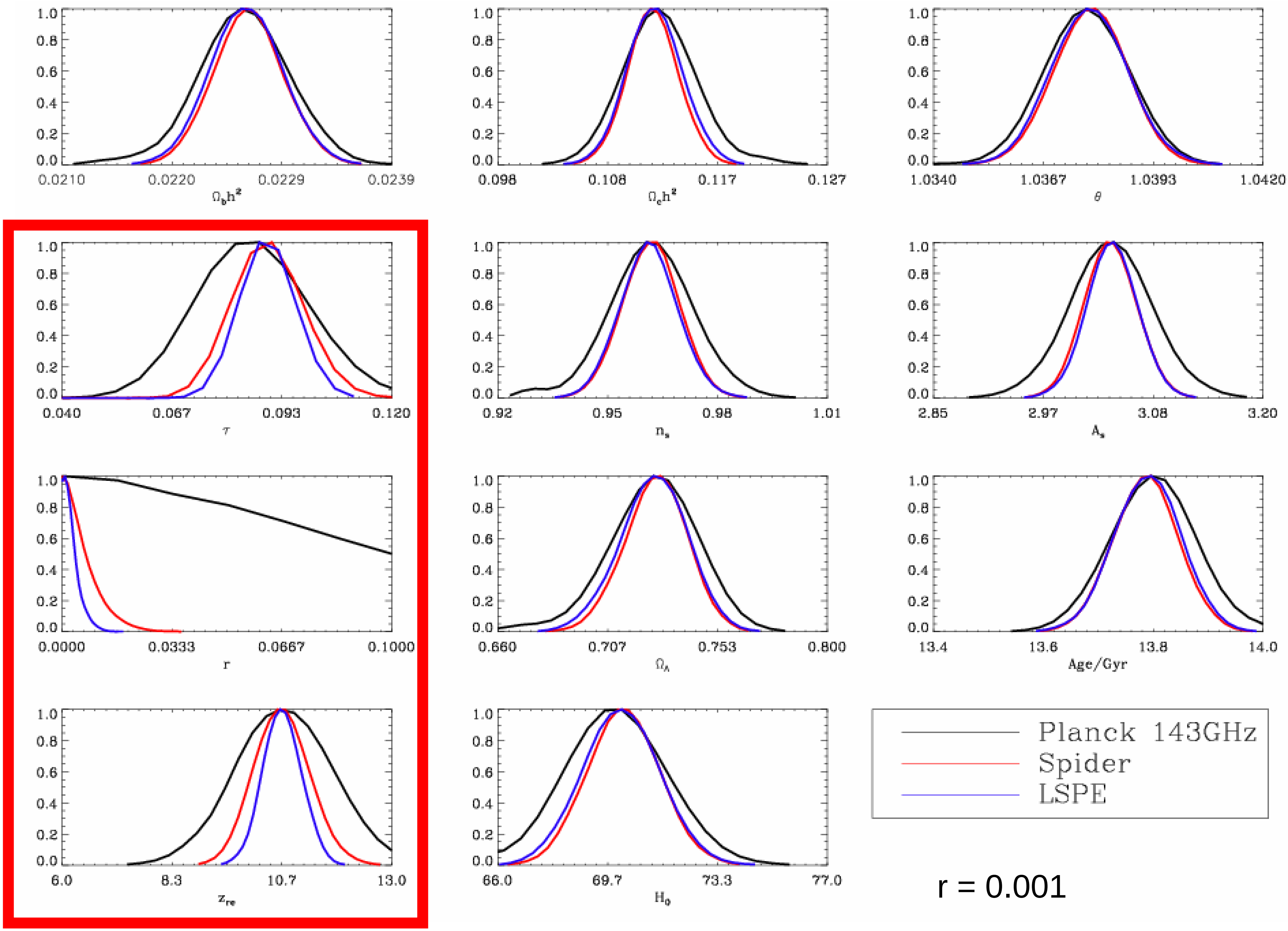

On the paper, a very competitive instrument

Certainly independent and using different methodology



0.0210 0.0220 0.0229 0.0239
$\Omega_b h^2$
0.098 0.108 0.117 0.127
$\Omega_c h^2$
1.0340 1.0367 1.0393 1.0420
$\theta$
0.040 0.067 0.093 0.120
$\tau$
0.92 0.95 0.98 1.01
$n_s$
2.85 2.97 3.08 3.20
$A_s$
0.0000 0.0333 0.0667 0.1000
r
0.660 0.707 0.753 0.800
$\Omega_\Lambda$
13.4 13.6 13.8 14.0
Age/Gyr
6.0 8.3 10.7 13.0
$z_{re}$
66.0 69.7 73.3 77.0
$H_0$
Planck 143GHz
Spider
LSPE


r = 0.03



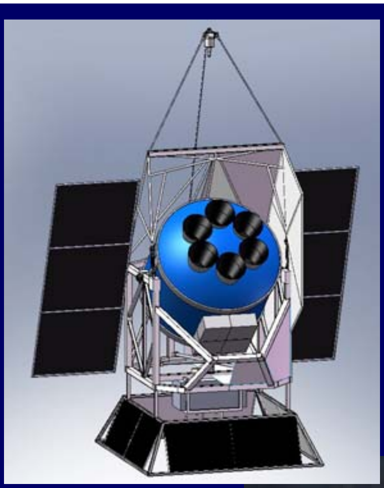
Planck 143GHz
Spider
LSPE
r = 0.001

# LSPE schedule

Still a long way to go …

| event | date |
|---|---|
| KO | Apr. 29, 2011 |
| PDR | Dec 20, 2011 |
| CDR | Apr. 30, 2012 |
| IHDR | Oct. 29, 2012 |
| TRR | Aug. 29, 2013 |
| FAR | Jan. 29, 2014 |
| Flight | End of 2014 |

# Balloons for CMB Polarization



- Balloon experiments can access high frequencies, necessary for foreground monitoring
- Balloons experiments can use the latest technology (e.g. polarization modulators, large detector arrays, multimoded systems)
- EBEX: Small angular scales
  Oxeley et al. Proc.SPIEInt.Soc.Opt.Eng. 5543: 320, (2004) astro-ph/astro-ph/0501111
- SPIDER: Intermediate scales
  Crill et al. Proceedings of SPIE Volume 7010 (2008), astro-ph/0807.1548
- LSPE: Large scales
- The signal we are looking for is so small and systematic effects are so important that *only a set of consisting detections obtainied by completely independent experiments will be convincing*.

more on balloons: see the poster by Masi et al. upstairs
and A&A, **583**, A86 (2012)

OLIMPO