Italian CMB Experiments

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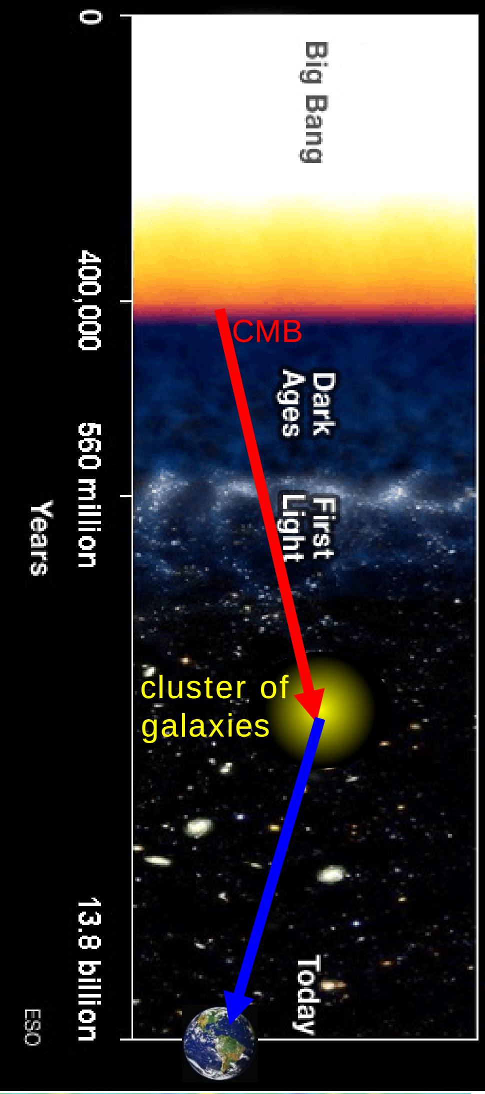
on behalf of the Italian CMB community

Overview

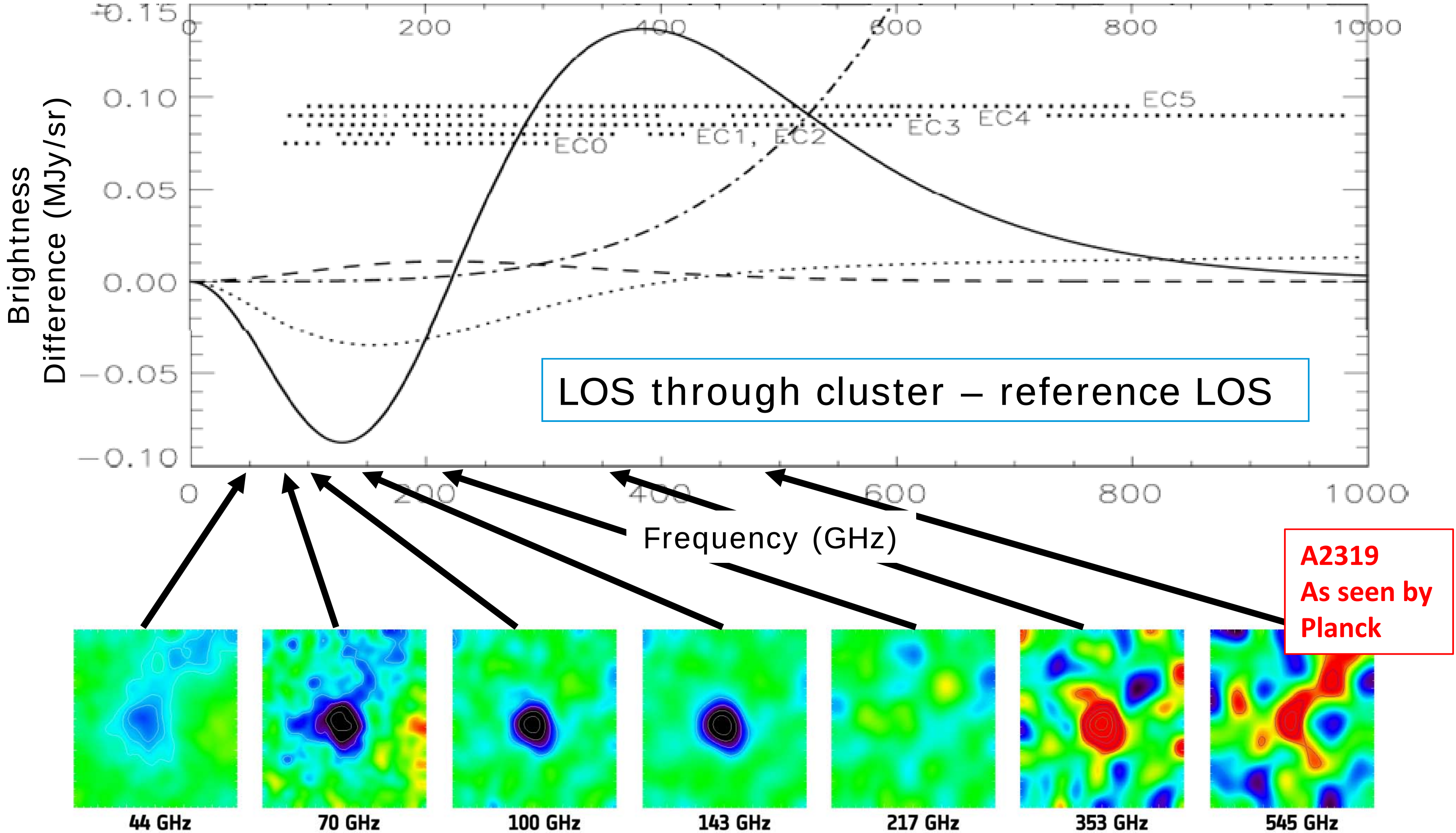
1. Italy is involved *with a leading role* in 3 important CMB-related experiments, aiming at precision measurements of key features of the CMB:
    a. OLIMPO – a balloon-borne instrument to measure the interaction between the CMB and Galaxy Clusters with an innovative spectroscopic instrument. http://planck.roma1.infn.it/olimpo
    b. LSPE – a balloon-borne instrument to measure CMB polarization at large angular scales. http://planck.roma1.infn.it/lspe
    c. QUBIC – a ground-based instrument to measure CMB polarization with bolometric interferometry. http://qubic.in2p3.fr/QUBIC/Home.html
2. Here we review mainly the first two instruments, with focus on:
    a. Scientific potential
    b. Original characteristics
    c. Position in the international effort
    d. Strategic role in the space-based effort for the CMB

OLIMPO & Sunyaev-Zeldovich Effect

- The hot gas filling the volume of clusters of galaxies scatters CMB photons.
- It is an **inverse Compton** scattering, where CMB photons acquire energy from charged scatterers.
- The spectrum of the CMB is perturbed with a a very distinct spectral signature, allowing efficient separation from other signals from the same direction
- The amplitude of the signal is of the order of $\Delta T/T = 10^{-4}$; it is proportional to the **density** of the ionized gas, and **does not depend on the distance** of the cluster.
- The **OLIMPO** balloon-borne mission is aimed at accurate **spectroscopic** measurements of the SZ.

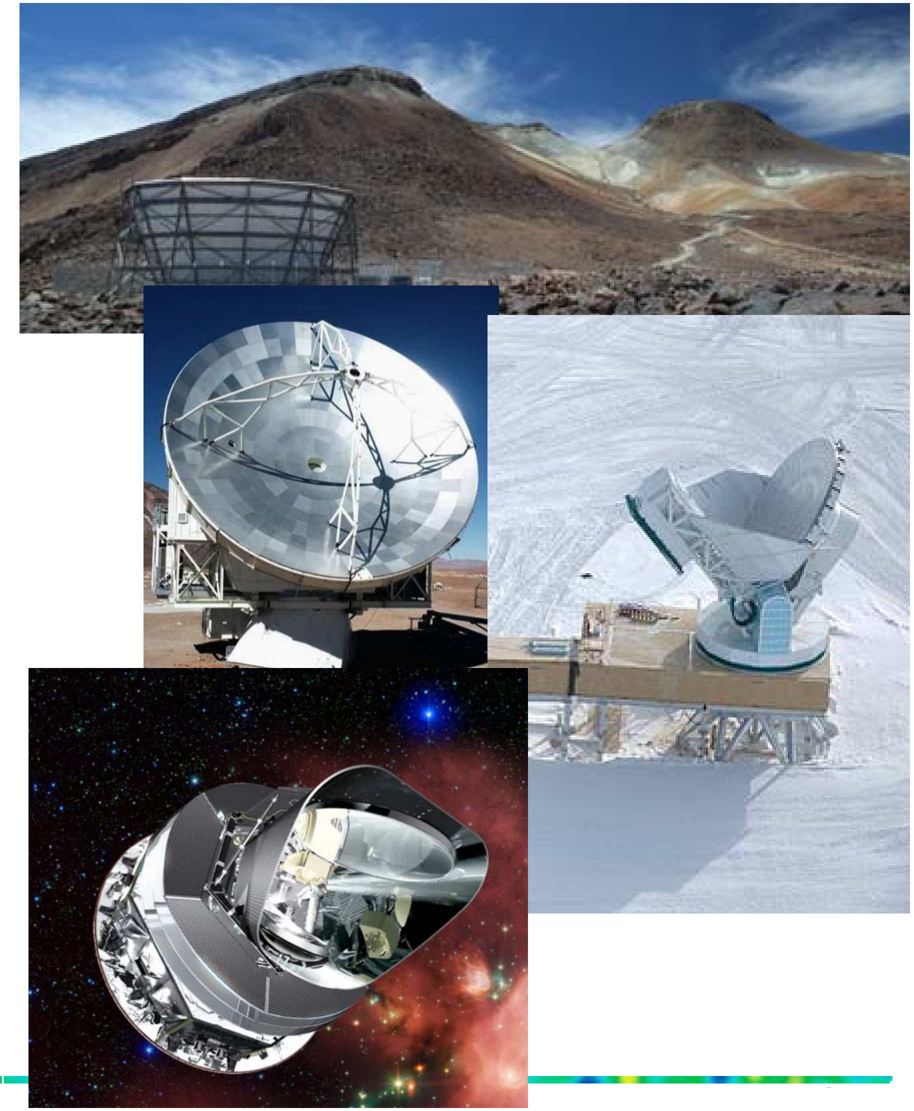


Sunyaev-Zeldovich Effect



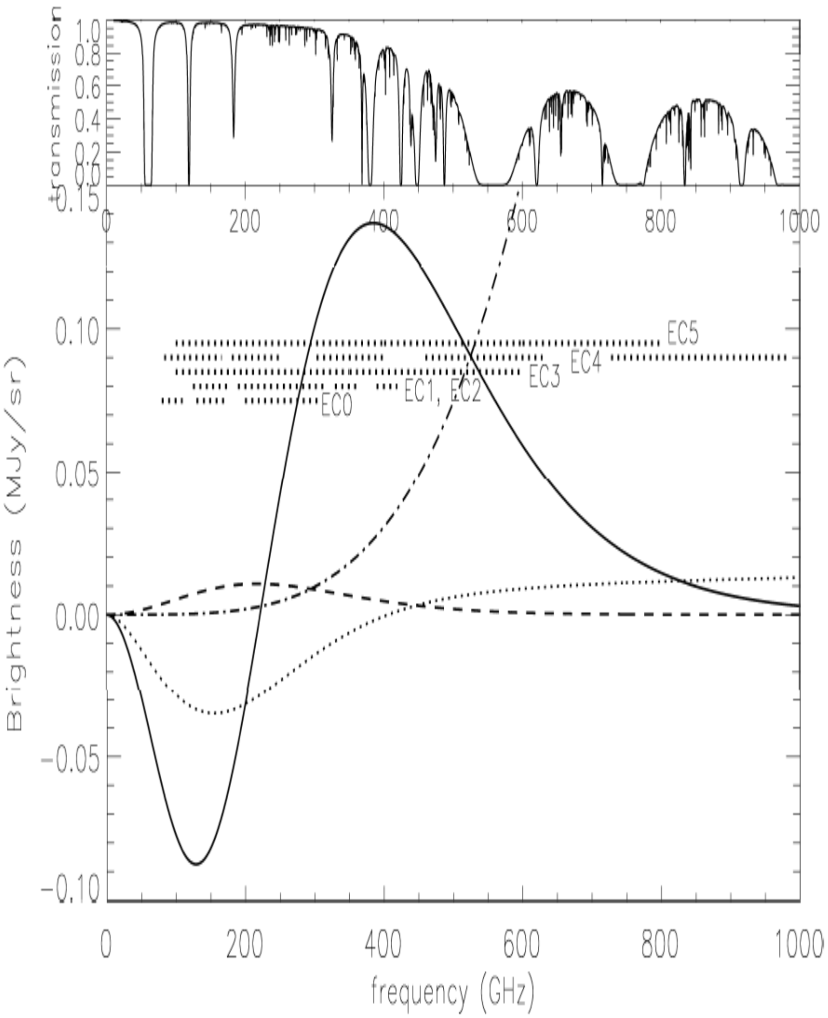
The Sunyaev-Zeldovich effect: measurements

- The most recent surveys of the SZ, with thousands of clusters, known and new, have been carried out by
  - o Large ground based mm-wave telescopes (**SPT, ACT, Apex**) at 90 GHz and 140 GHz (atmospheric opacity and noise reduce the spectral coverage to a few bands with f < 180 GHz)
  - o **Planck** over 7 bands from 44 to 540 GHz (1.8m telescope)
- These are all photometric measurements (and typically a single band for ground-based experiments)



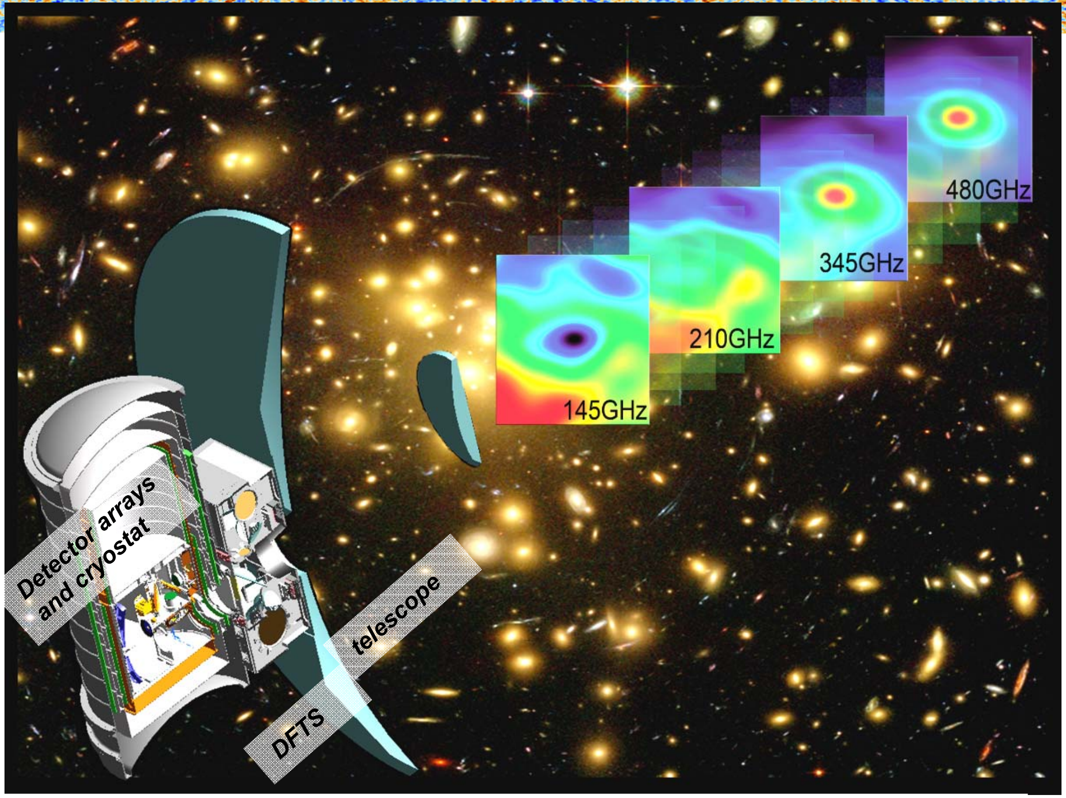
Spectral measurements of CMB anisotropy and SZ

- A **spectral** measurement of CMB anisotropy, which can be done only from space or (partially) from the stratosphere, can:
- Vastly improve the **accuracy**, allowing efficient, unbiased separation of the CMB and SZ components from all other components in the same LOS (see A&A 538 A86 2012).
- Produce **unique science**, (see also talk of Pasquale Mazzotta) like:
  - The study of patchy reionization
  - Unbiased estimates of cluster parameters and SZ clusters catalogues
  - Temperature profiles of clusters, including the periphery
  - Study of low-density ionized regions (e.g. filaments of the LSS)
  - Accurate $T_{CMB}(z)$ measurements



OLIMPO

- The OLIMPO experiment is a first attempt at spectroscopic measurements of CMB anisotropy.
- A large balloon-borne telescope (2.6m) with a 4-bands photometric array and a plug-in room temperature spectrometer
- see http://planck.roma1.infn.it/olimpo for a collaboration list and full details on the mission
- Photon-noise limited detectors
- Spectroscopic resolution: 1.8 GHz within 4 bands centered @ 140, 210, 345, 480 GHz



- At high frequency, OLIMPO has the same angular resolution as the ground-based large telescopes used for SZ surveys @140 GHz.

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OLIMPO: science

- OLIMPO uses the Cosmic Microwave Background (CMB) as a backlight to study the largest structures in the Universe.
- It is optimized to detect the inverse Compton scattering of CMB photons crossing clusters of galaxies (Sunyaev-Zeldovich effect, or SZ).
- Using the SZ, OLIMPO can
  - detect very distant galaxy clusters, which have not been detected yet in other ways
  - Map the temperature and density profile of selected clusters all the way to $3r_{500}$
- Additional science targets of OLIMPO: multifrequency high resolution maps of the CMB provide:
  - the spectral–spatial anistropies of the CMB
  - the sum of neutrino masses

OLIMPO

OLIMPO Payload integrated @ the launch site – Longyearbyen – 5/July/2014

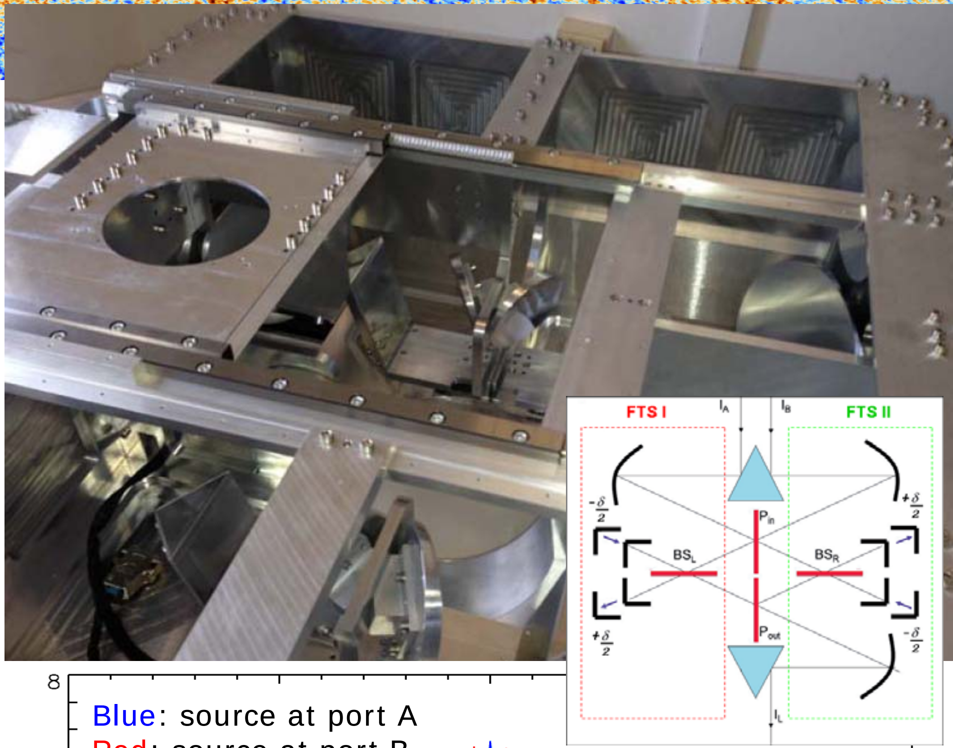
Front side: shiny and smiling !

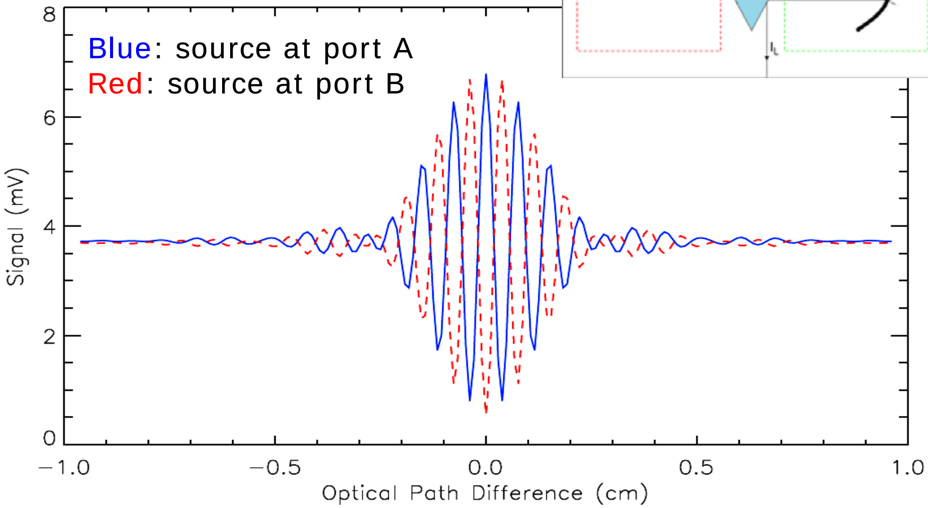
OLIMPO

Rear side: complex HW and heavy work

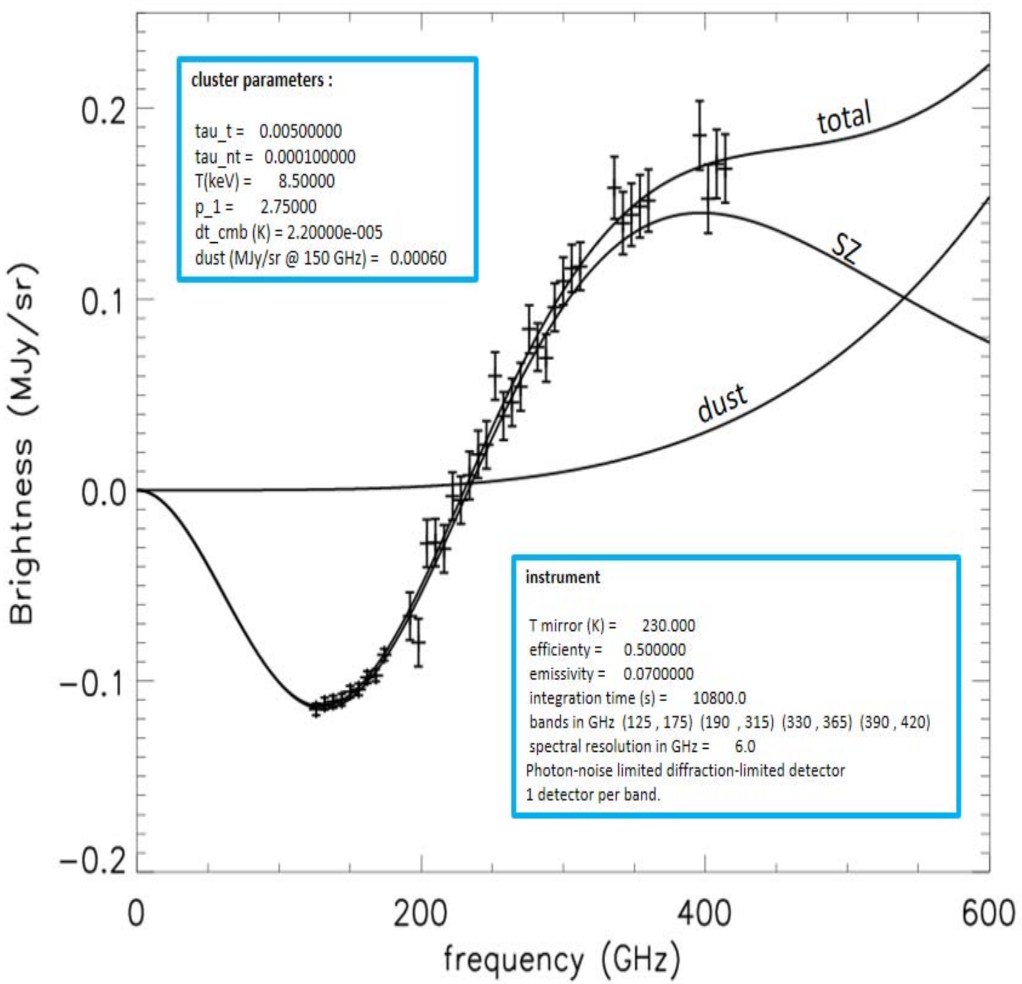
OLIMPO: DFTS

- OLIMPO uses an imaging Differential Fourier Transform Spectrometer (**DFTS**, see Schillaci et al. A&A **565**, A125 (2014))
- The instrument is able to measure the **difference in brightness** between the two input ports, which are placed in different locations in the focal plane of the telescope.
- This instrument has an excellent rejection of the common mode signal, allowing to measure the spectrum of small signals (like the SZ) embedded in an overwhelming background (from the CMB, the residual atmosphere, and the instrument, see D'Alessandro et al. App.Opt. **54**, 9269-9276 (2015))





OLIMPO: Expected performance



- In a FTS the spectral resolution can be changed (changing the path of the moving mirror). Mind the noise, however: it is proportional to the inverse of the spectral bin-width. In the case of OLIMPO, with a spectrometer at 250K, photon noise is important.
- 1.8 GHz resolution: About 110 independent spectral bins, within optimized bands.
- 6 GHz resolution: About 34 independent spectral bins, within the same bands.

Products: For a single flight:
high accuracy multi(34)frequency maps of selected sky regions (2°x2° tiles, 2’ FWHM resolution) centered on ~50 clusters and ~50 blank-sky regions.

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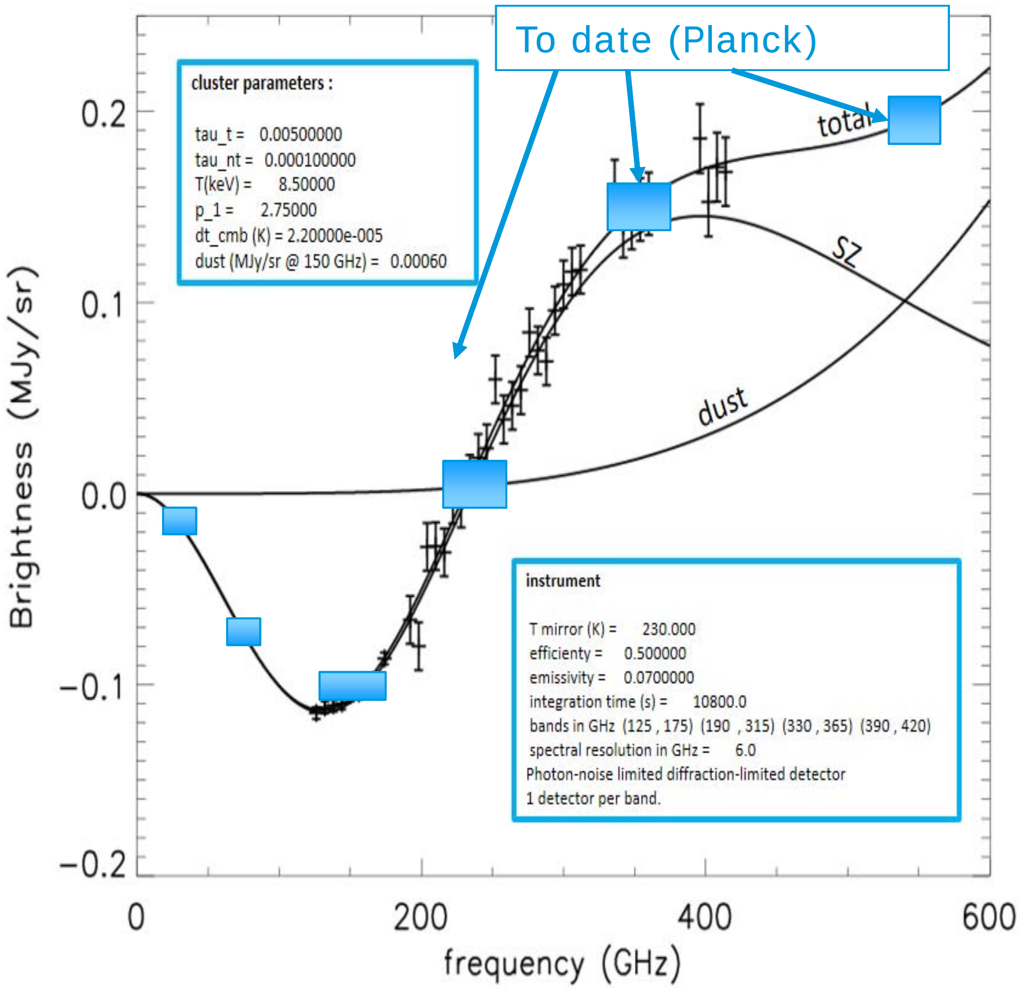

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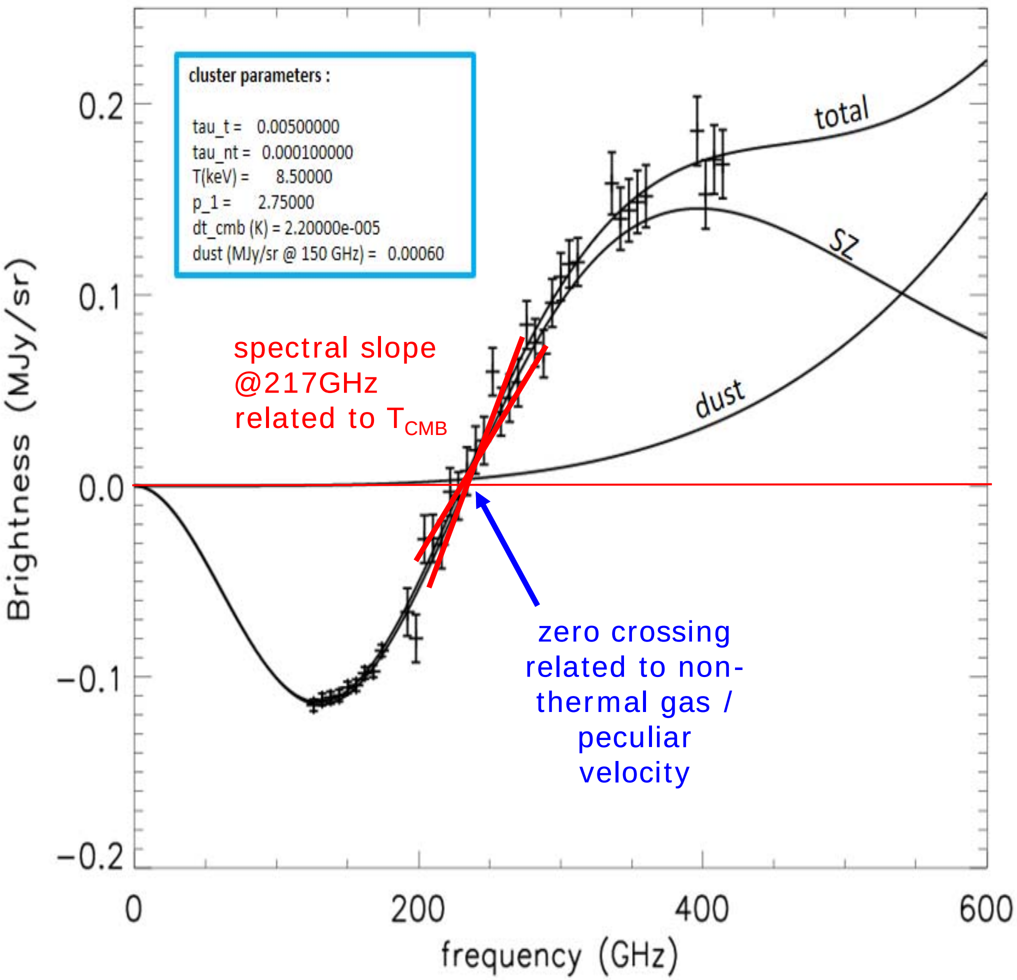

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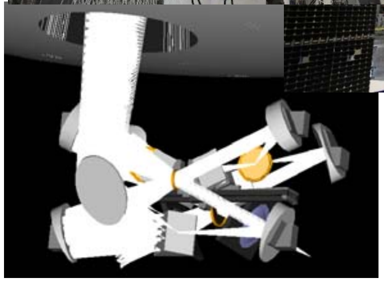
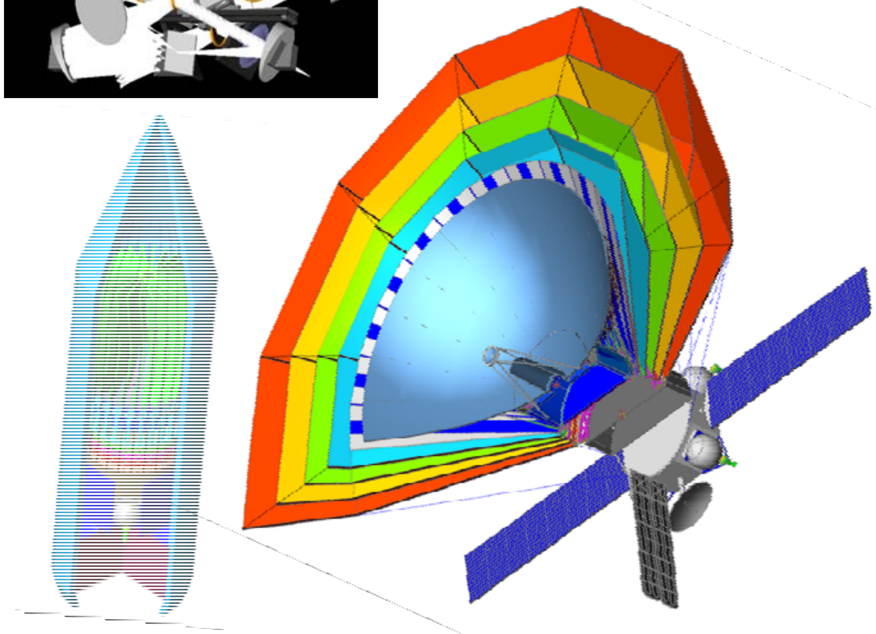
OLIMPO as a precursor of forthcoming space-missions

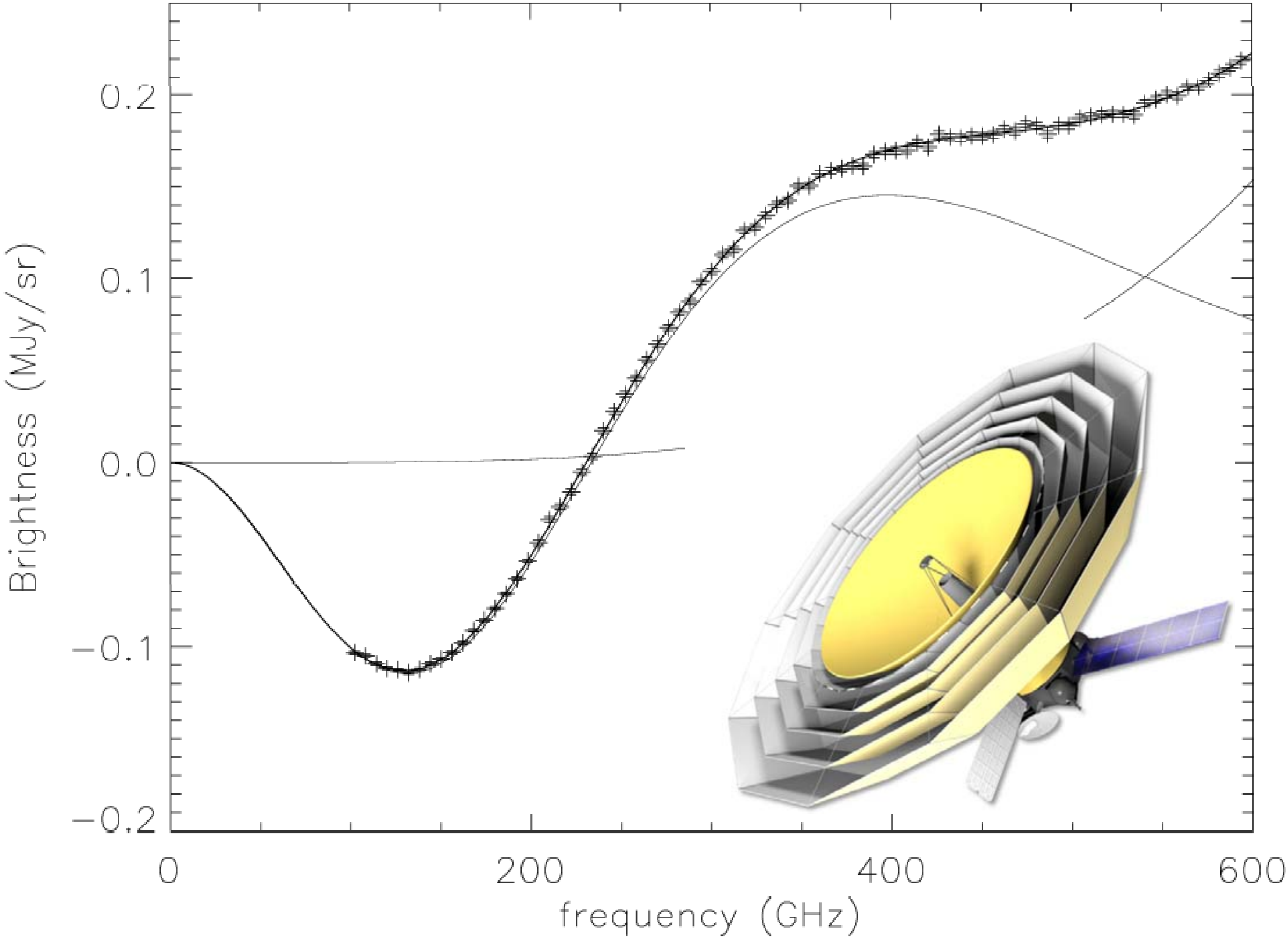




- OLIMPO is extending BLAST observations at low frequencies
- Is a demonstrator of new detectors, to be used in forthcoming missions (COrE++ etc.)
- Will demonstrate the power of polar ballooning in the northern hemisphere for CMB missions
- The DFTS Methodology has been used in space (COBE-FIRAS, missions for remote sensing), and will be used again (PIXIE, PRISM, Millimetron)
- >20% of fhe focal plane of **Millimetron** (a ROSCOSMOS mission) is available for a cryogenic version of the OLIMPO DFTS (ASI phase-A study).

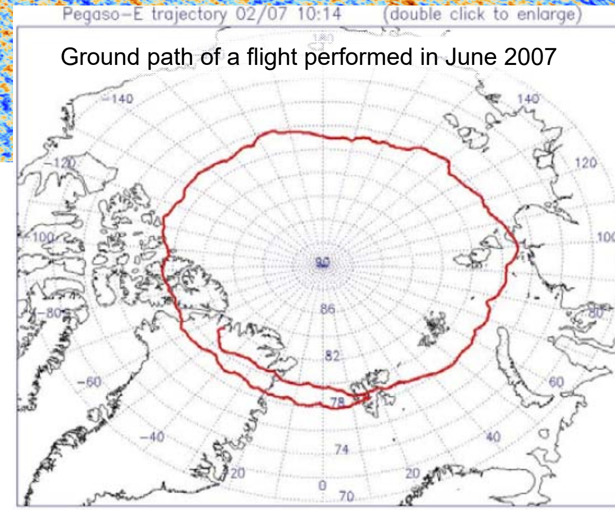
Millimetron DFTS

3 hours of observations of a rich cluster with a DFTS on **millimetron**
Using a photon-noise limited detector in the cold environment of L2, with a 10m telescope cooled to <10K. (see A&A 538 A86 2012)



Long-duration flights in the Arctic

- The Longyearbyen (Svalbard) launch site offers circumpolar flights, in both summer and winter (see Mem. S. A. It., 79, 792-798 (2008), ESA SP-700 (2011), Proc. of the I.A.U., 8, 208-213 (2013)).
- CMB experiments can access most of the northern sky in a single flight,
  - within a cold and very stable environment
  - Accumulating more than 10 days of integration at float (>38 km altitude).
- ASI is organizing the forthcoming OLIMPO flight campaign.
- The OLIMPO payload is ready to be flown since July 2014. Only modification needed: the on-board software has to be modified to cope with the limited coverage of the new TM system.
- Alternative flight opportunity: LDB from Antarctica, with CSBF (no TM problems …)

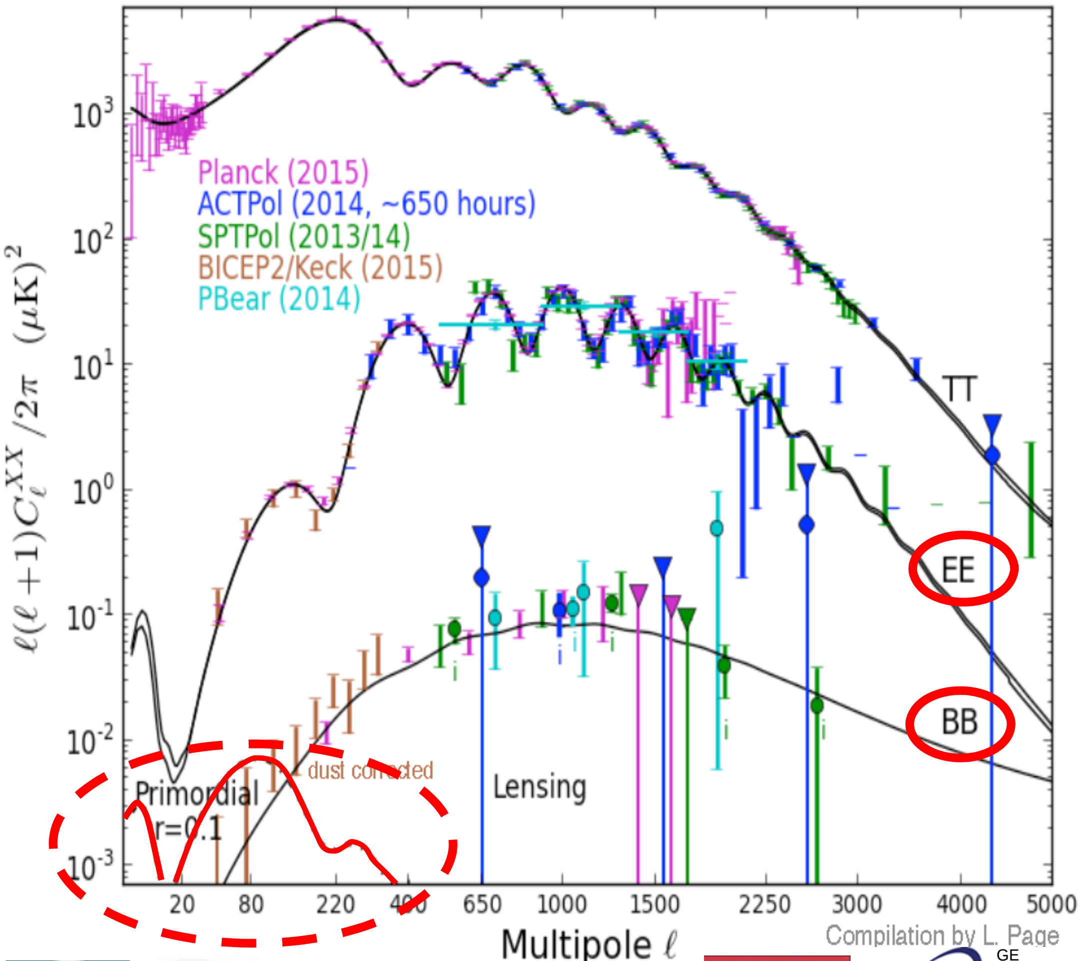


Ground path of a flight performed in June 2007


Launch of a heavy-lift balloon from the Longyearbyen airport (Svalbard 78°N).

The Large-Scale Polarization Explorer LSPE

- LSPE is a CMB polarization mission.
- The inflation signature of B-modes is at large angular scales, and requires large sky and frequency coverage.
- Space mission in the future.
- 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 !



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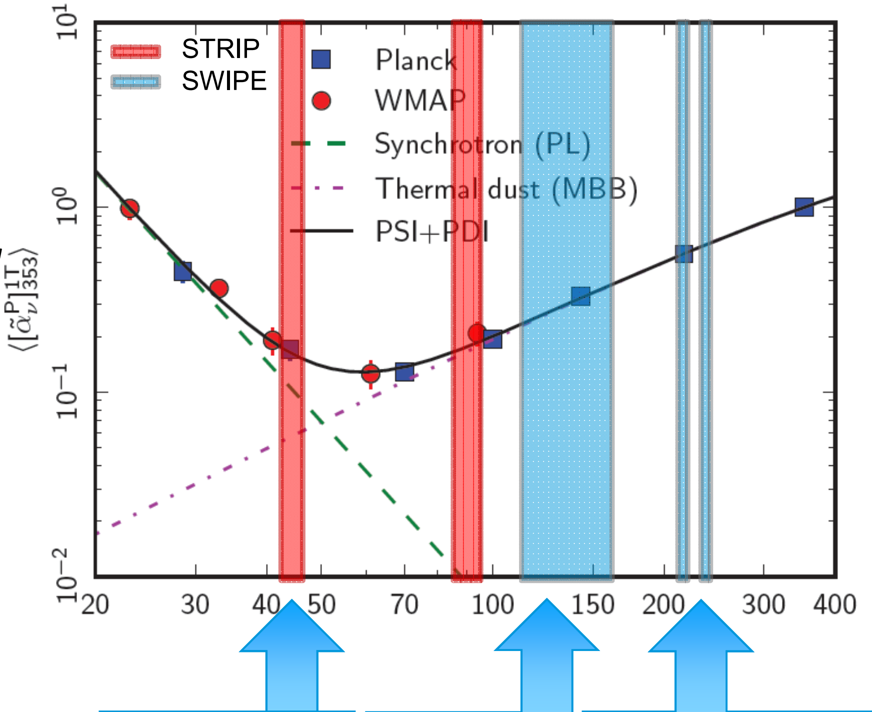
The Large-Scale Polarization Explorer LSPE

- A *balloon-borne instrument* can
  - avoid atmospheric 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** will fly in the polar night, exploiting the infrastructure and launch capability in Longyearbyen.
- The balloon environment will allow a wide frequency coverage, for efficient and accurate cleaning of polarized foregrounds.



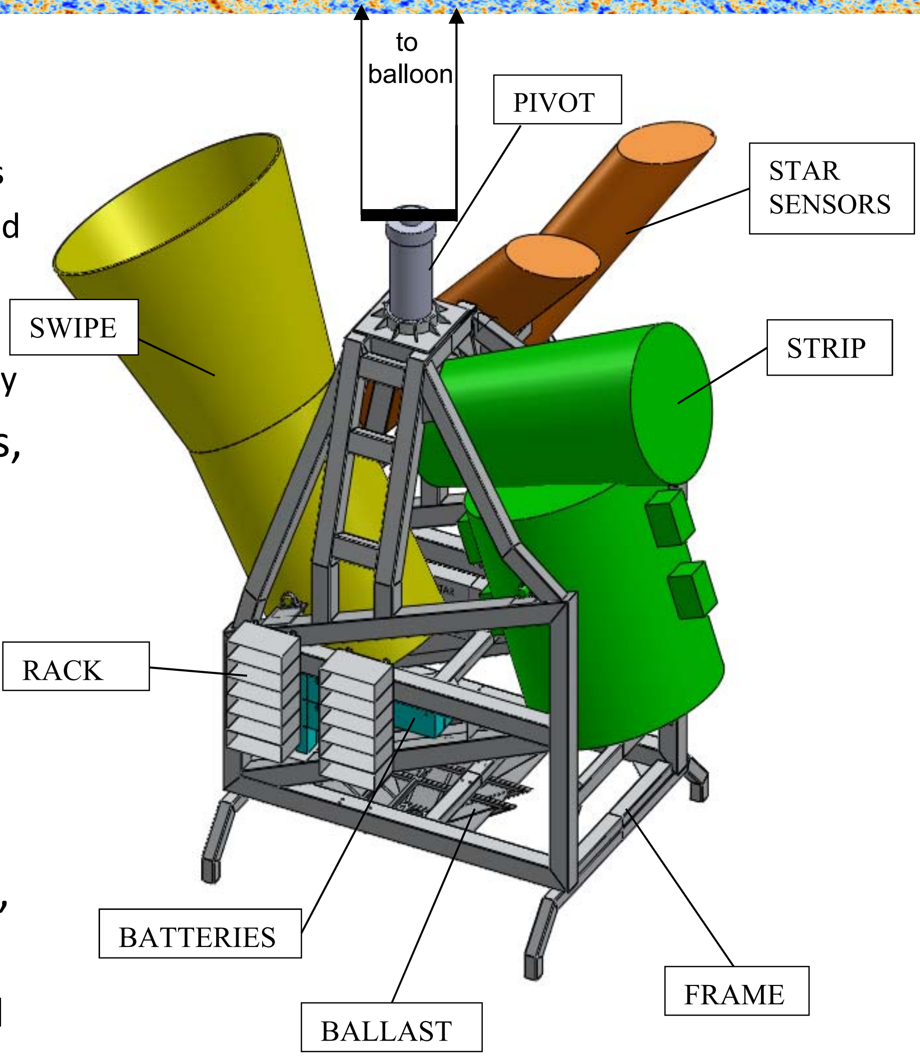
44 GHz monitor of polarized synchrotron

90 + 140 GHz main CMB channels

220 + 240 GHz Monitor level **and slope and rotation** of polarized dust emission
To date extrapolated from 350 GHz only

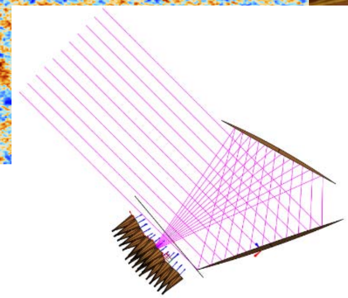
The Large-Scale Polarization Explorer LSPE

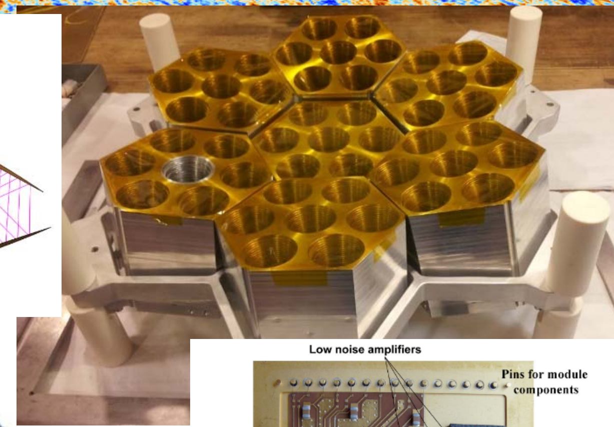
- The Large-Scale Polarization Explorer is :
  - an instrument to measure the polarization of the Cosmic Microwave Background at large angular scales
  - using *a spinning stratospheric balloon payload* to avoid atmospheric noise
  - flying *long-duration, in the polar night*
  - using a *polarization modulator* to achieve high stability
- Frequency coverage: 40 – 250 GHz (5 channels, 2 instruments: STRIP & SWIPE)
- Angular resolution: 1.3° 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, INFN-FE
- See astro-ph/1208.0298, 1208.0281, 1208.0164 and forthcoming updates

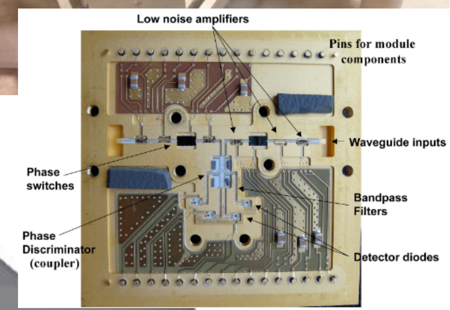


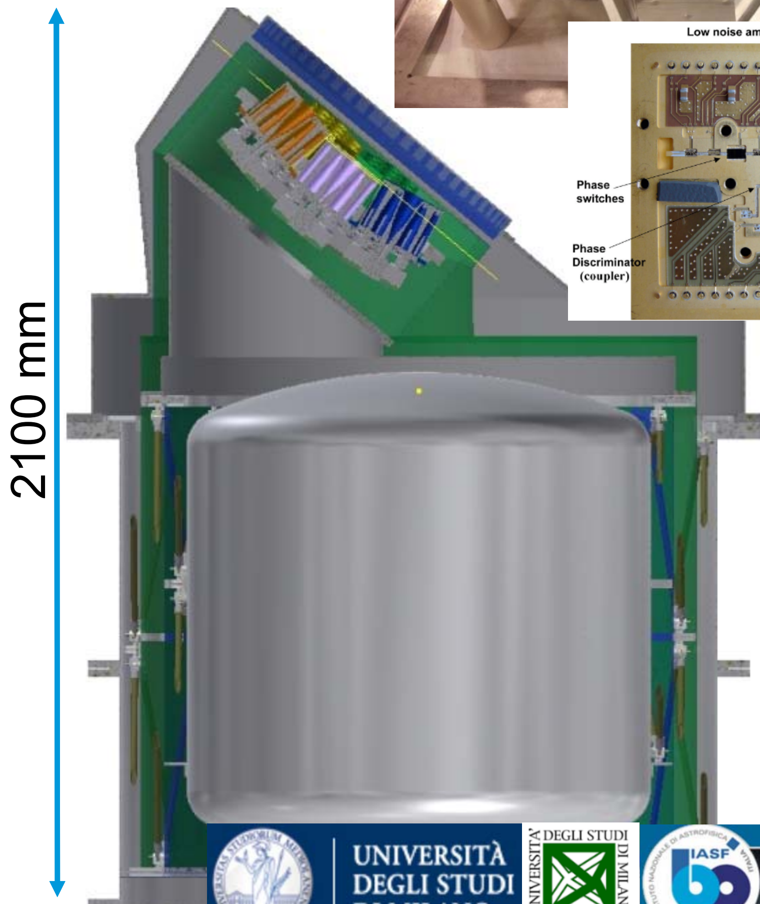
LSPE - STRIP

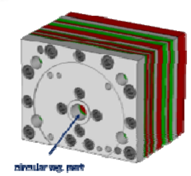
- STRIP is the STRatospheric Italian Polarimeter, aimed at accurate measurements of the low-frequency (44 and 90 GHz) polarized emission, dominated by Galactic synchrotron.
- Its sensitivity at 44 GHz in a single flight is twice better than the final sensitivity of the Planck LFI survey.
- The correlation radiometers are contained in a large cryostat and cooled at 20K by evaporating ^{4}He.
- ASI is considering operating STRIP from the ground to save payload weight. Pending this decision, cryostat fabrication is on hold.





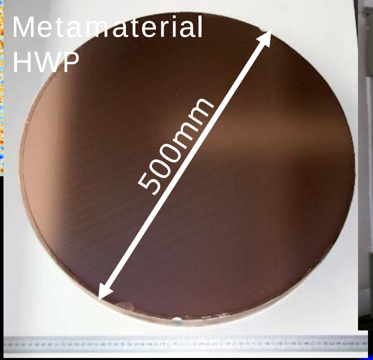


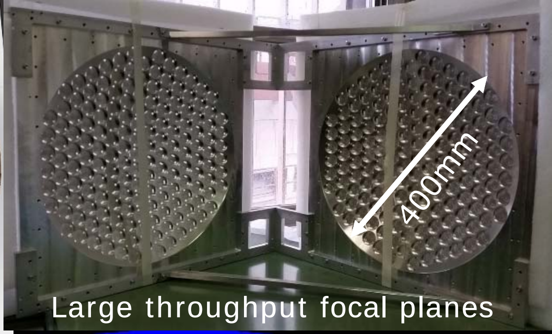


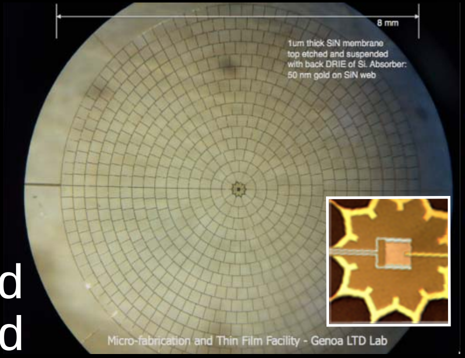


LSPE - SWIPE

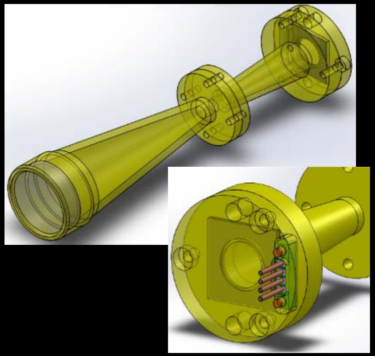
- SWIPE is the Short Wavelength Instrument for the Polarization Explorer
- It is a Stokes Polarimeter, based on a simple 50 cm aperture refractive telescope, a cold HWP polarization modulator, a beamsplitting polarizer, and two large focal planes, filled with 330 *multimode* bolometers at 140, 220, 240 GHz (for a total of about 8500 λ^2-modes).
- Everything is cooled by a large L^4He cryostat and a ^3He refrigerator, for operation of the bolometers at 0.3K

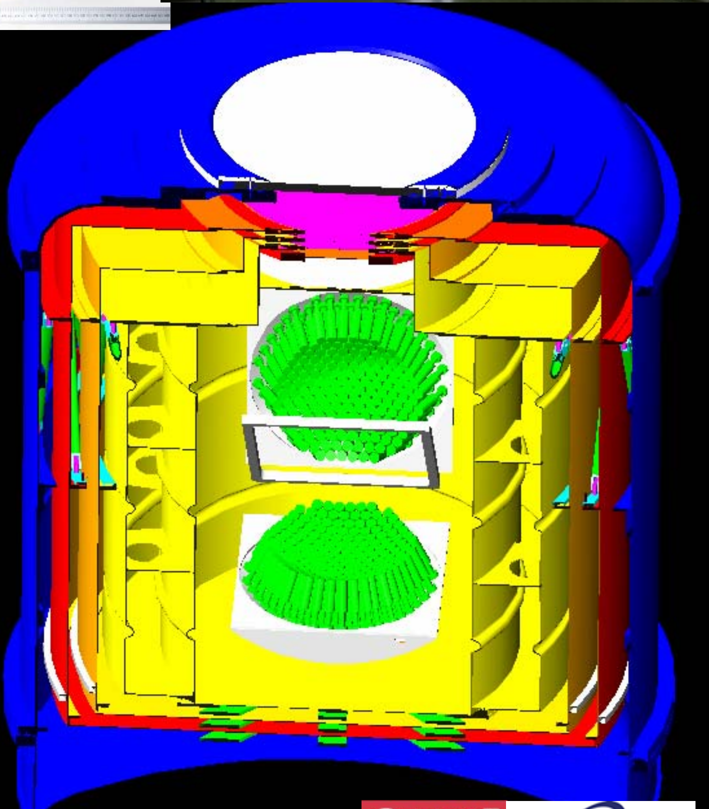






Multimode TES bolometers





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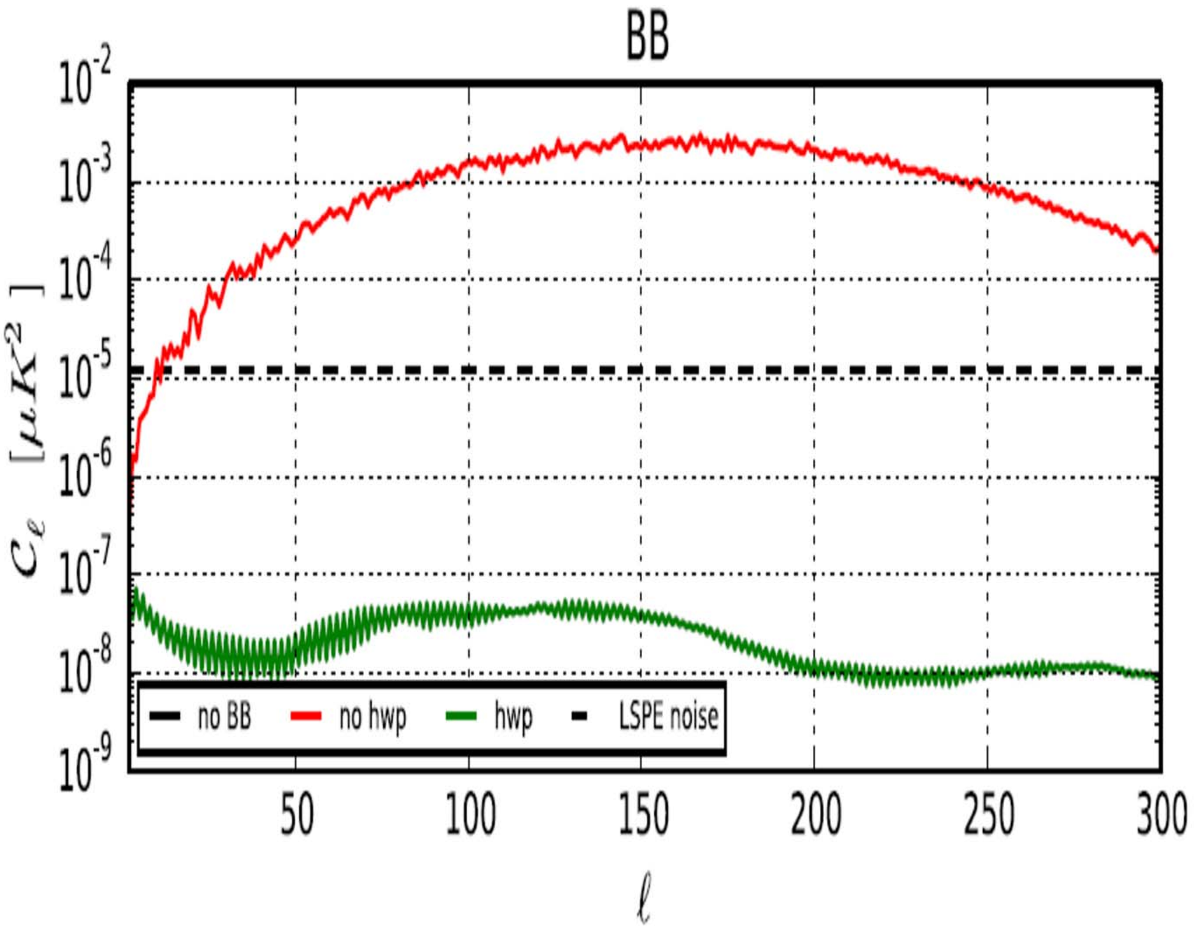
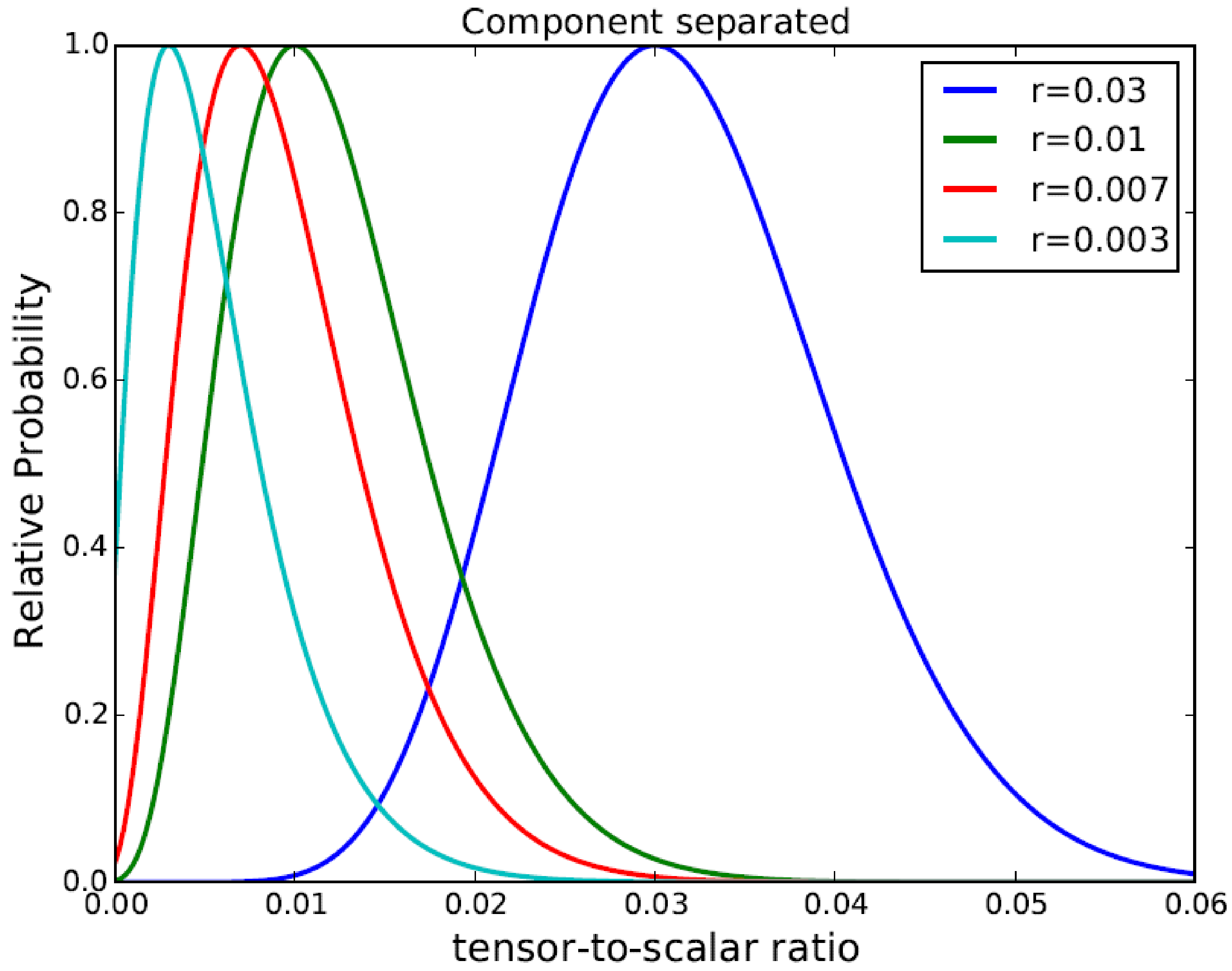
RM2

LSPE - SWIPE

- 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 0.01



L. Pagano, F. Piacentini


Component separated
Relative Probability
tensor-to-scalar ratio
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.01
0.02
0.03
0.04
0.05
0.06
r=0.03
r=0.01
r=0.007
r=0.003

LSPE - SWIPE

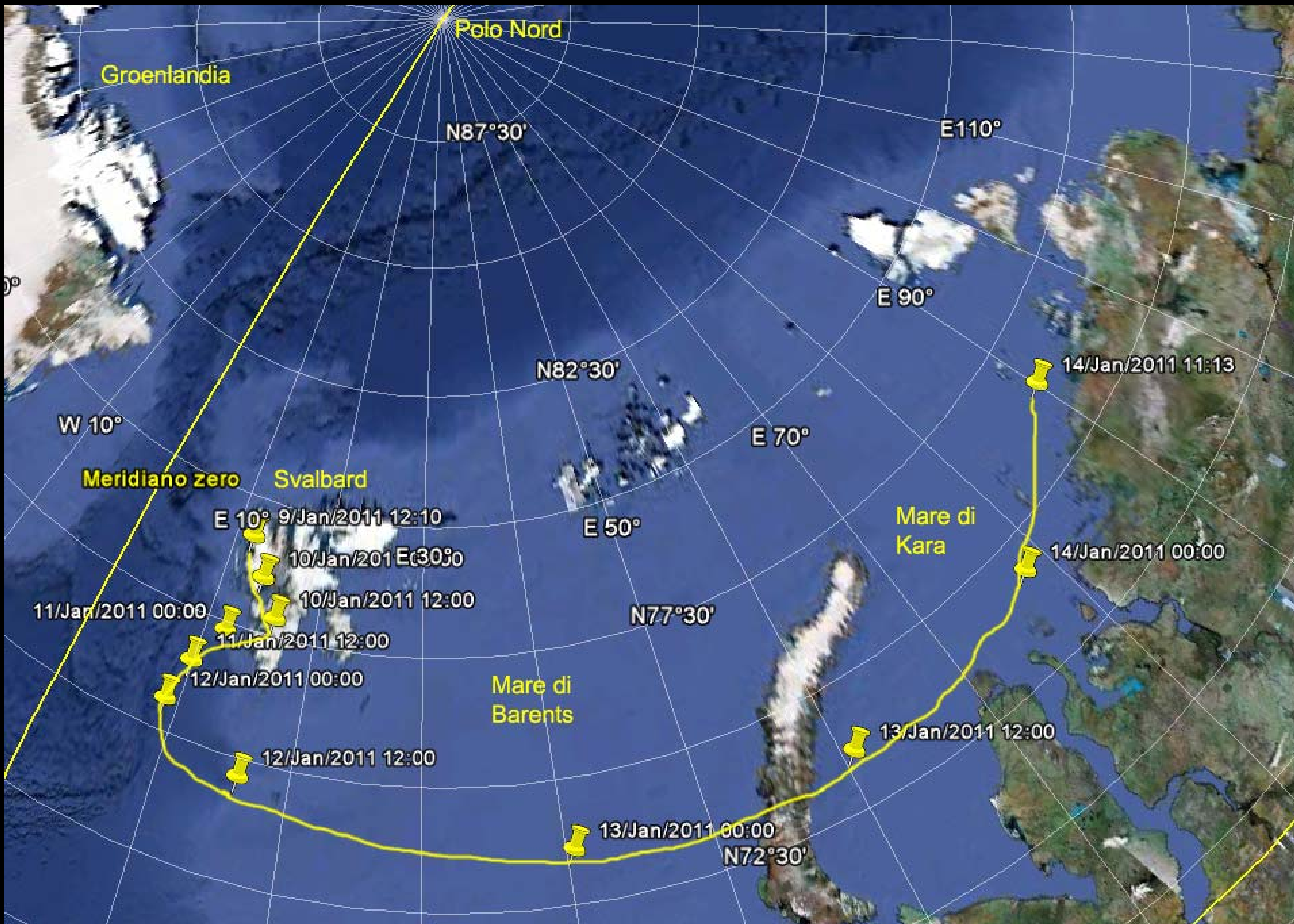
- Not just B-modes, also Cosmic Polarization Rotation
- The orientation of polarization appears to be the most stable property of photons.
- Changes in the polarization angle of photons traveling over cosmological distances are foreseen, for example, if fundamental physical principles, such as the Einstein Equivalence Principle, are violated, or if there is a Faraday rotation.
- A very difficult measurement. Usually based on non-zero <TB> &<EB>
- Current limits on CPR are of the order of $\sigma_\alpha < 1^\circ$
- Expected calibration precision for LSPE $<0.1^\circ$ (polarimeter axis set by 50 cm diameter polarizer)
- Expected performance including instrument noise, from detailed simulations: $\sigma_\alpha = 0.15^\circ$ (20% of the sky, r, τ, α free, A_s from Planck)

LSPE as a precursor of forthcoming space missions

- Large scales are obviously important for inflation-related B-modes. No measurements from the ground are expected before the next space mission at the scales of the reionization peak.
- Data from a balloon mission like LSPE are needed to test and qualify new, specific analysis methods and foregrounds removal in the relevant frequencies and multipoles ranges
- LSPE will also qualify
  - large diameter cryogenic HWP (and cryogenic rotator) and filters
  - Italian TES detectors & readout, to be proposed for forthcoming space missions
  - Methods for operation in extreme environment
  - Ballooning in the polar winter darkness: a unique opportunity for astronomy

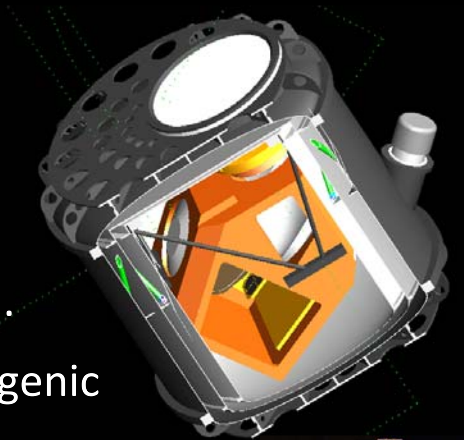
Night Time Long Duration Stratospheric Balloon Flights

- 1st LDB launched on Jan. 9th, 2011 From the Dirigibile Italia (CNR) base, in Ny Alesund, Svalbard Islands
- With support from ISTAR, AWIPEV
- 5 days at 32 Km, Eastward path
- Payload prepared by La Sapienza

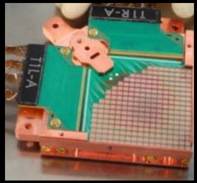

Polo Nord
Groenlandia
N87°30'
E110°
E 90°
N82°30'
W 10°
E 70°
Meridiano zero
Svalbard
E 10°
9/Jan/2011 12:10
E 50°
Mare di
Kara
10/Jan/201
E 30°
14/Jan/2011 11:13
14/Jan/2011 00:00
10/Jan/2011 12:00
11/Jan/2011 00:00
N77°30'
11/Jan/2011 12:00
12/Jan/2011 00:00
Mare di
Barents
13/Jan/2011 12:00
12/Jan/2011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

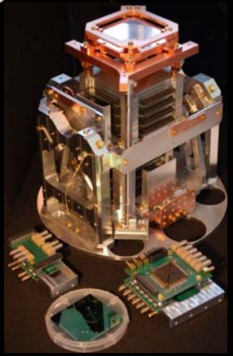
QUBIC (http://qubic.in2p3.fr)

An international, ground-based, CMB polarization experiment, aimed at B-modes at intermediate angular scales, with several original features.

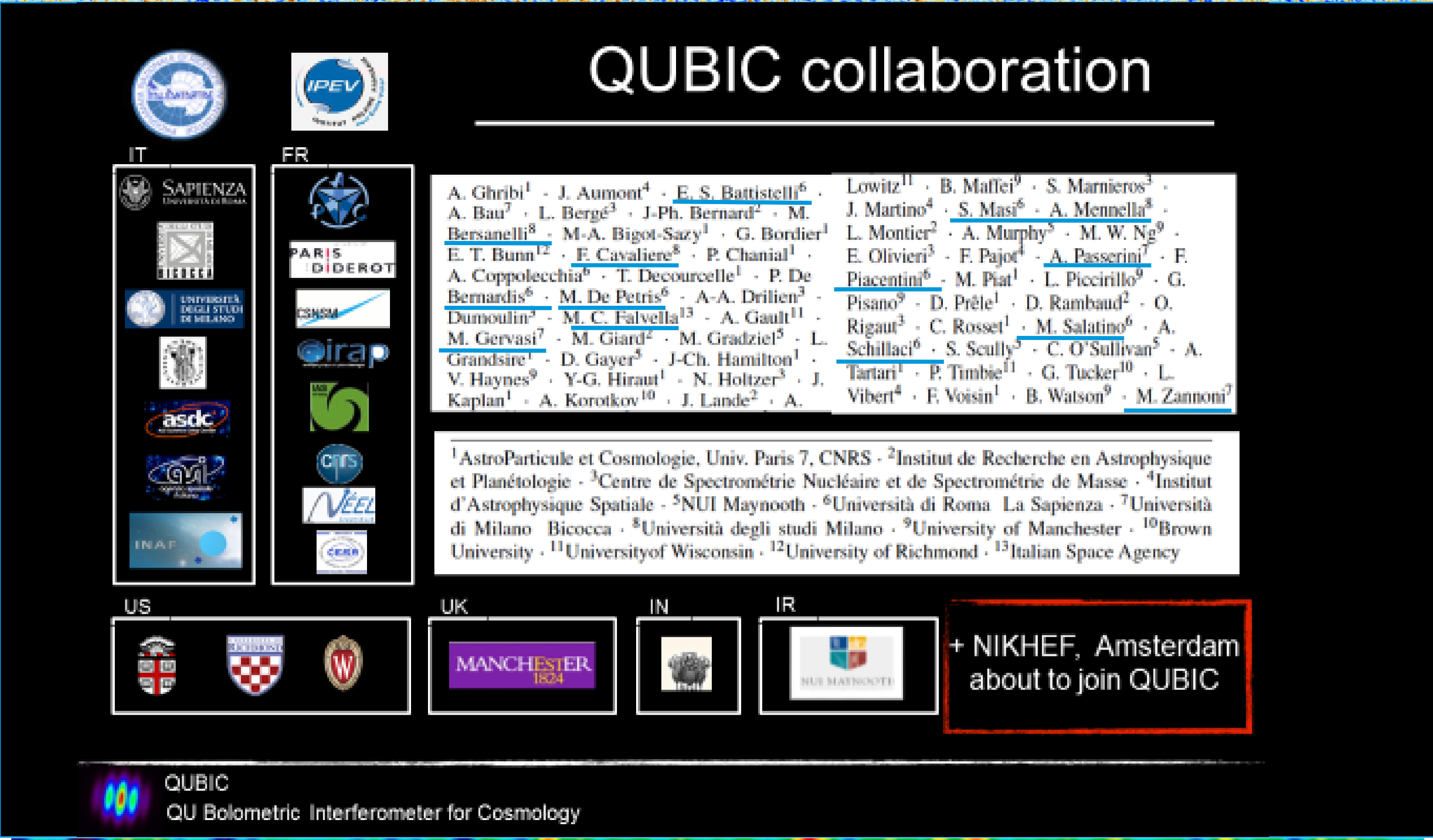


- It is a **bolometric interferometer**, combining the sensitivity of bolometers and the precise beam synthesis of interferometers,
- A **self-calibration** procedure is possible.
- The baseline site is the French-Italian Antarctic base of **Concordia**, probably the best site in the world for ground-based CMB research.
- Italian contributions: Dome C site testing, rotating HWP, main cryogenic system, corrugated feedhorns arrays , mirrors.
- **Sinergies** between LSPE and QUBIC:
    - Technology: large aperture cryostat, rotating HWP
    - Science: complementary multipoles and frequency coverage
- Poses very interesting data analysis challenges. Aiming at r=0.01 in 3 yr.



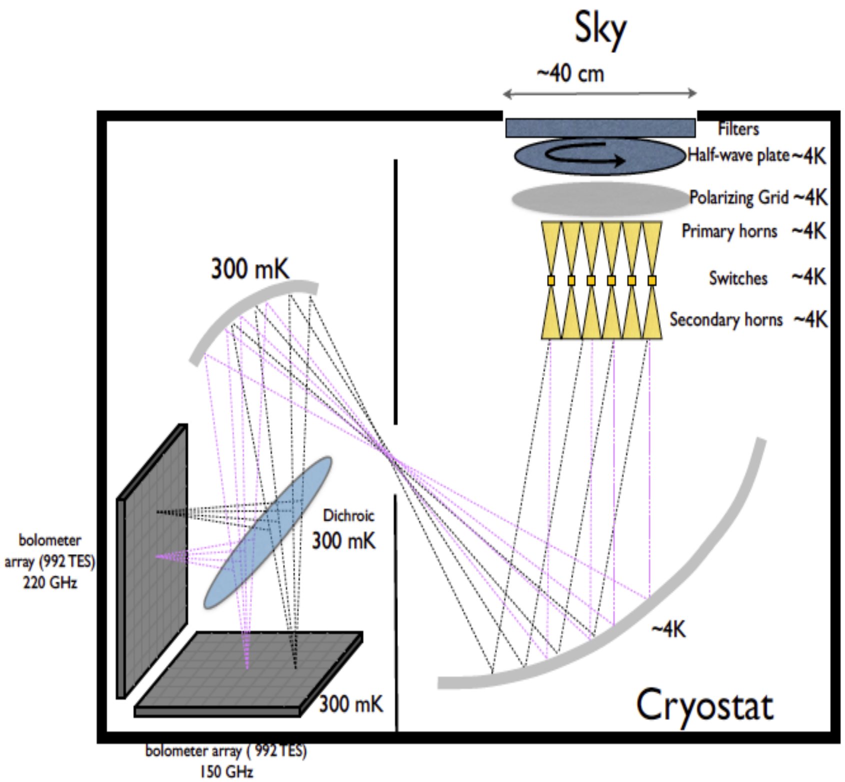


Detectors almost ready, cryostat under construction, lot of work done also in the past for site testing!!!



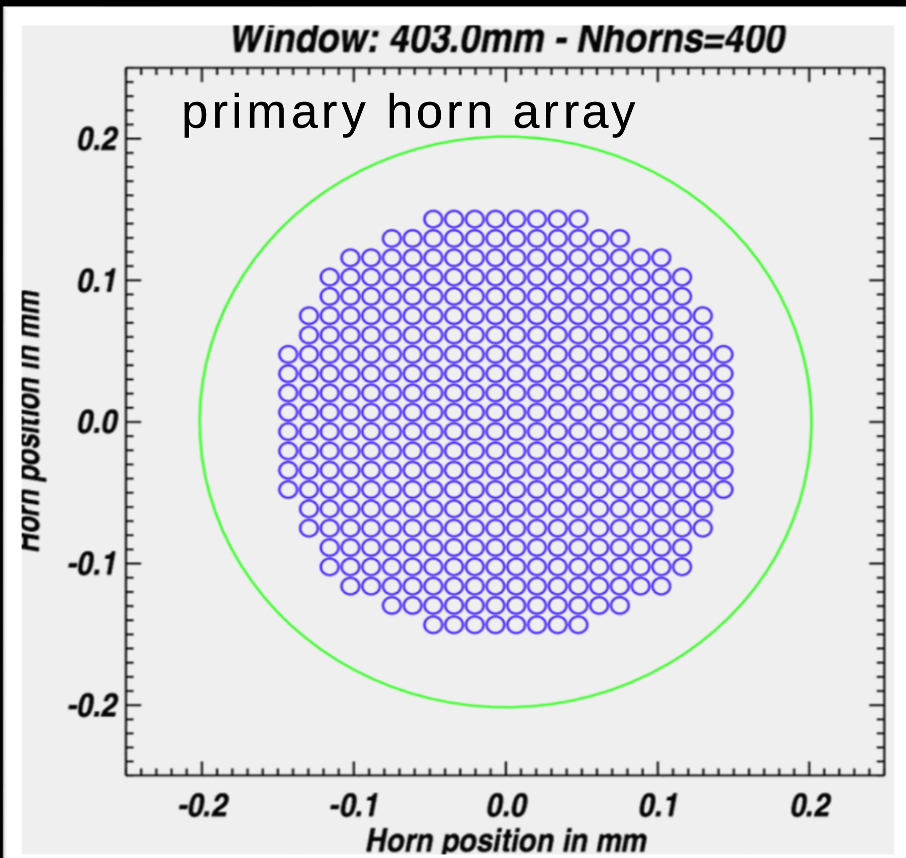
Dual Band QUBIC (150/220 GHz in the first module)

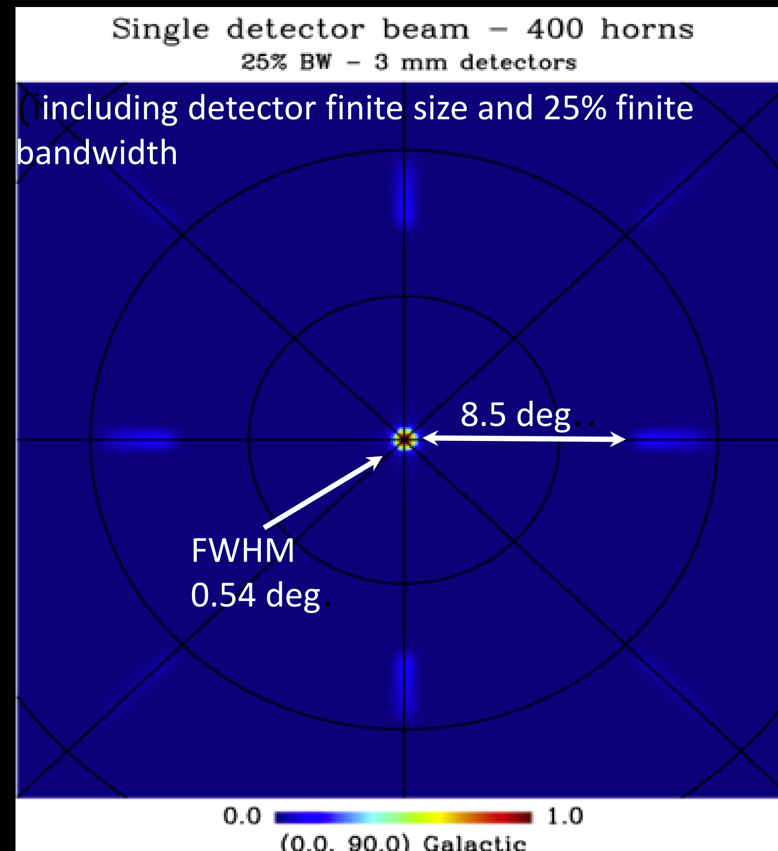
- The instrument looks at the sky through a diffractive aperture (a set of back-to-back horns on a square grid).
- The beam combiner has the B2B horns in the focus and illuminates the detector arrays.
- The B2B are single mode at 140 GHz and few-modes at 220 GHz.
- Each pixel of the array receives the sum of the signals from all the horns, each with a different phase shift depending on the location of the source.
- The instrument is a Fizeau (intensity) interferometer, with a well defined synthetic beam.



QUBIC (http://qubic.in2p3.fr)

B.I. = Synthesized imager

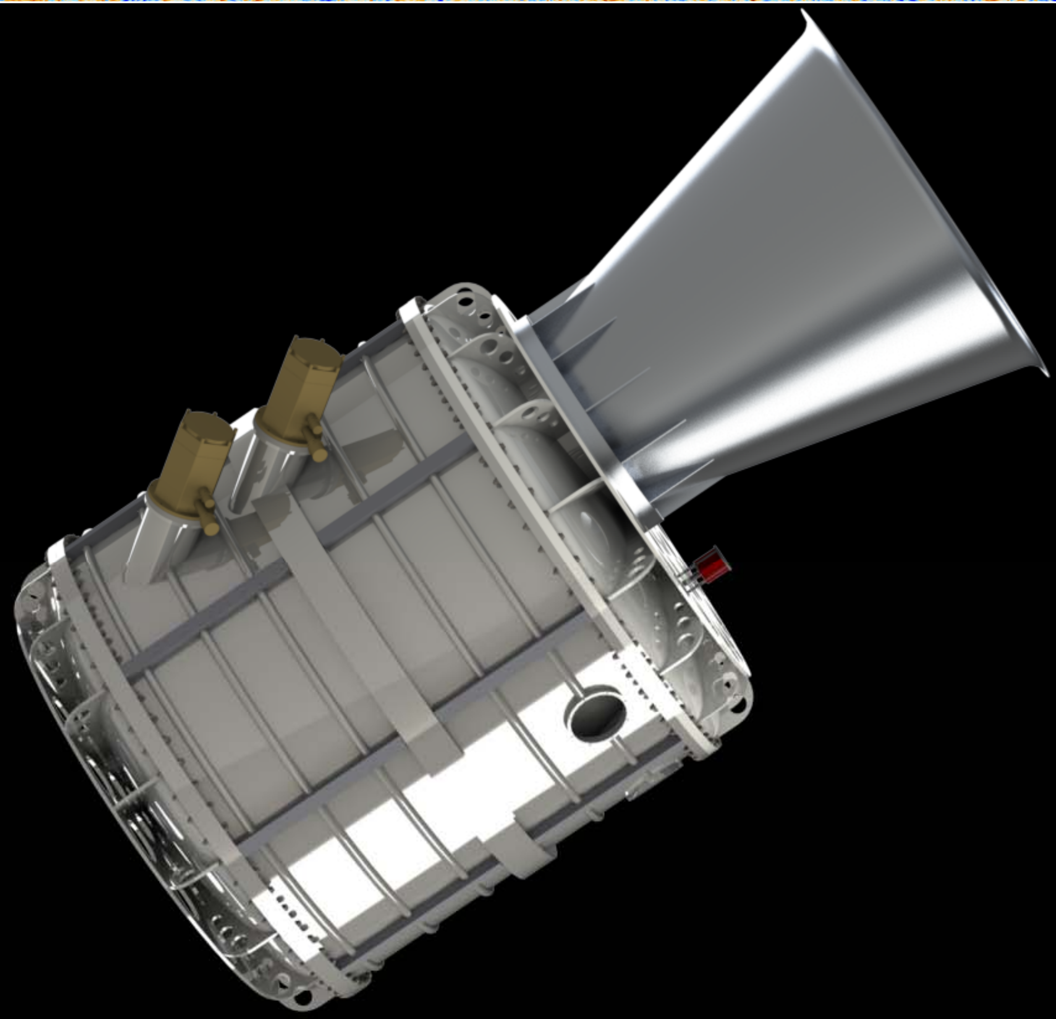




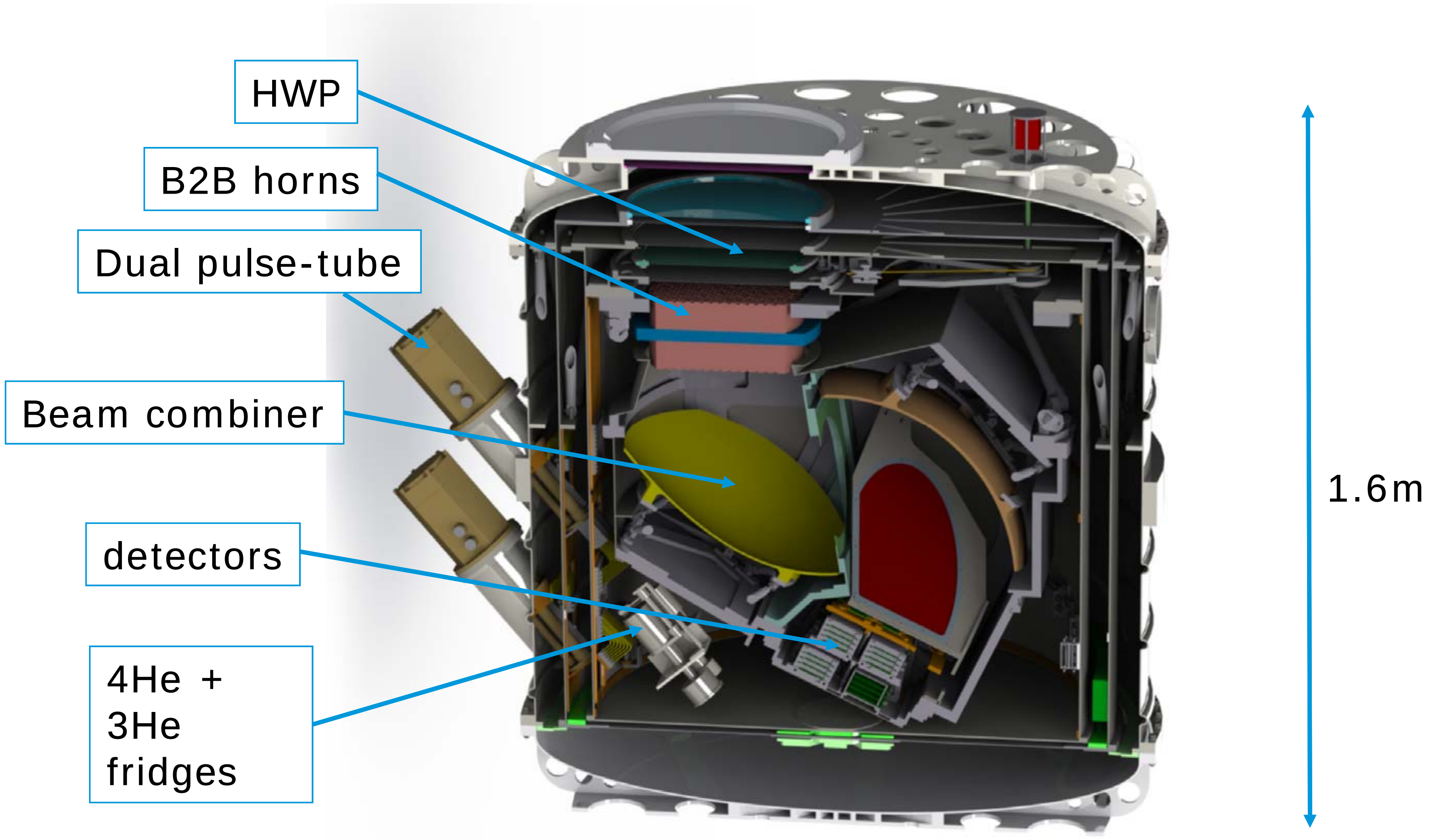
20*20 horns, 14° FWHM D=1.2cm

Synthesized beam used to scan the sky as for an imager

General view of the instrument (external)



General view of the instrument (section)



Conclusion

- Italy is leading two important CMB experiments on stratospheric balloons, OLIMPO and LSPE
- ASI plays a pivotal role for both.
- Their finalization is top priority for this community, to
  - Obtain high quality data for the Italian CMB community
  - Maintain the Italian position in the field in the short term after Planck
  - Qualify experimental methods and devices needed for forthcoming space missions
  - Demonstrate, with scientific results, scientific ballooning in polar regions, a strategic asset for Italy and Europe.
- Italy has an important role in an original Stage-3 ground-based experiment, QUBIC, a demonstrator of the new technique of bolometric interferometry, currently funded by PNRA.