Balloon-borne experiments for Cosmic Microwave Background studies

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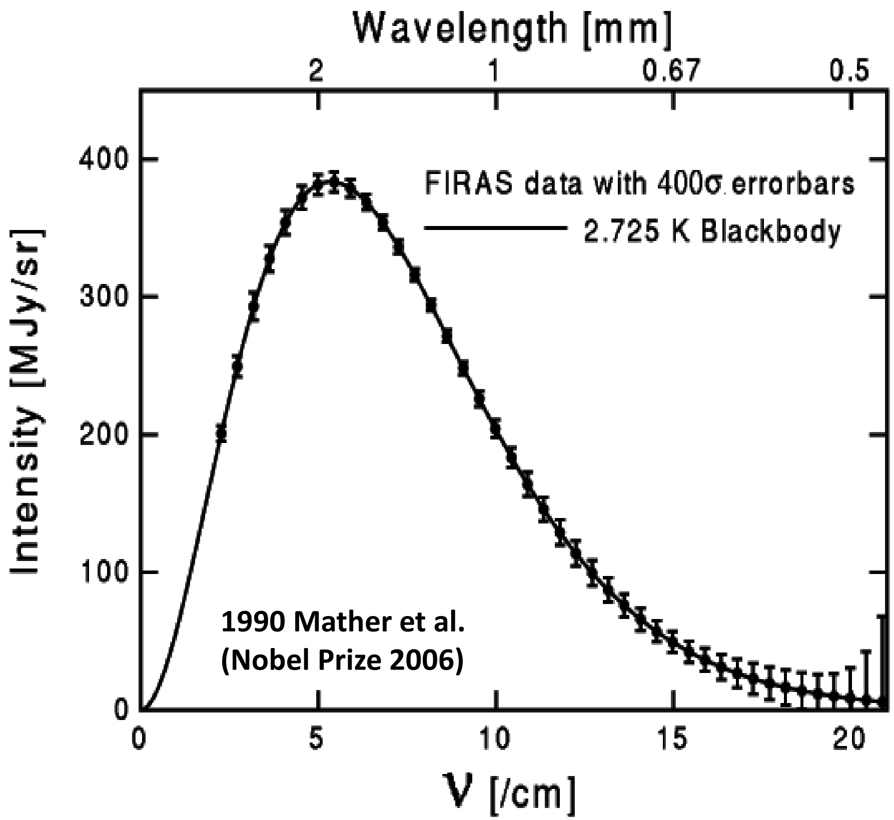
RICAP 18

7th Roma International Conference on AstroParticle Physics

INFN Istituto Nazionale di Fisica Nucleare · Università degli Studi di Roma Tor Vergata · Sapienza Università di Roma · Dipartimento di Matematica e Fisica

The Cosmic Microwave Background

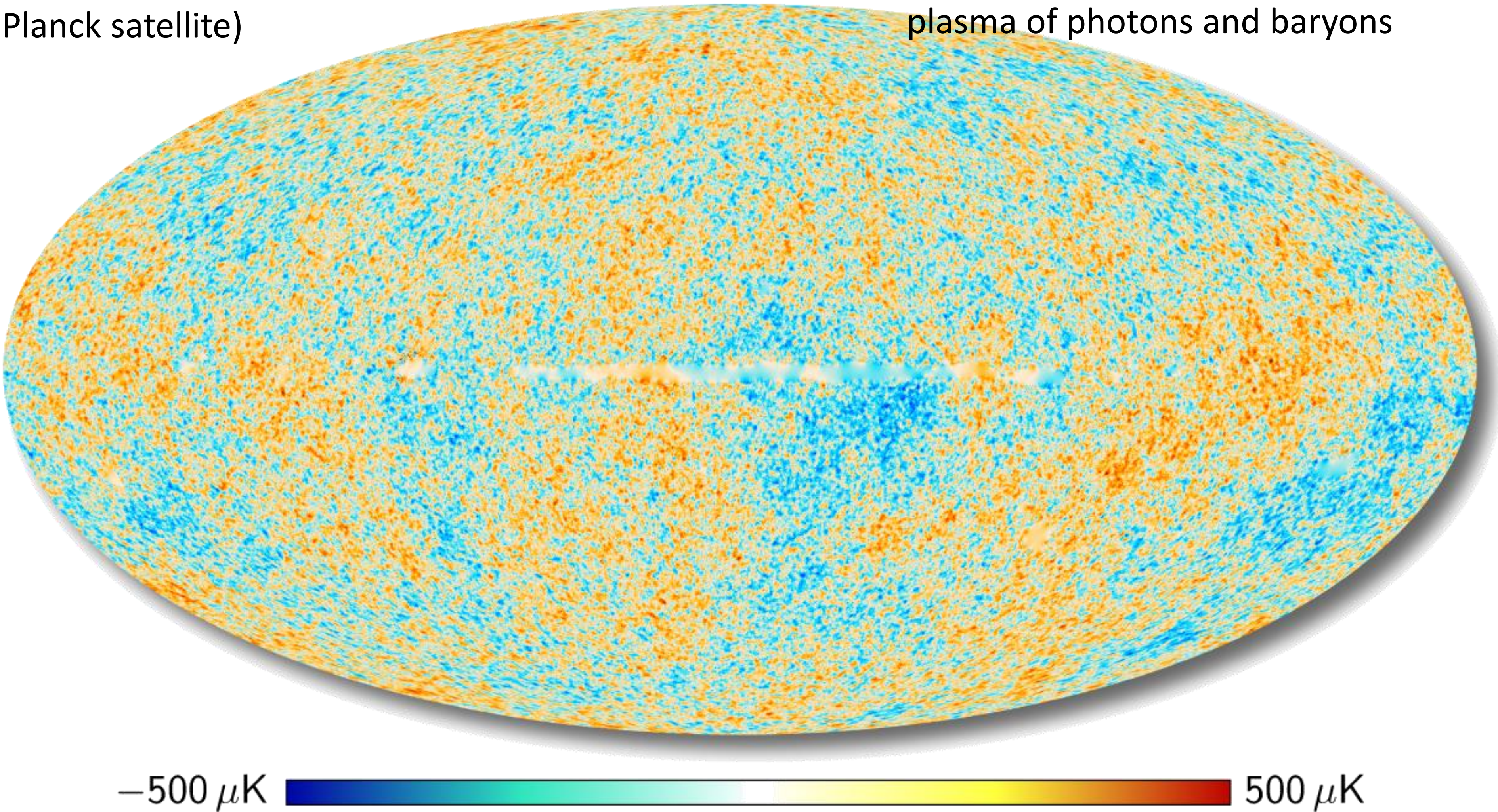
- The CMB is a faint background of thermal photons, filling the entire Universe.
- These photons where generated a few μs after the big bang, when matter and antimatter annihilated.
- They were thermalized by repeated Thomson scatterings in the primeval fireball, when the universe was ionized (first 380000 yrs)
- When the universe became neutral they formed a dazzling 3000K blackbody.
- Afterwards CMB photons did not interact with matter anymore, but were diluted and redshifted,due to the expansion of the universe, becoming today a 2.725K blackbody.



- Having travelled for most of the history of the Universe, CMB photons carry information on all phases of its evolution, with 3 main observables: **spectrum, anisotropy, polarization**.

Map of **CMB anisotropy** (from the Planck satellite)

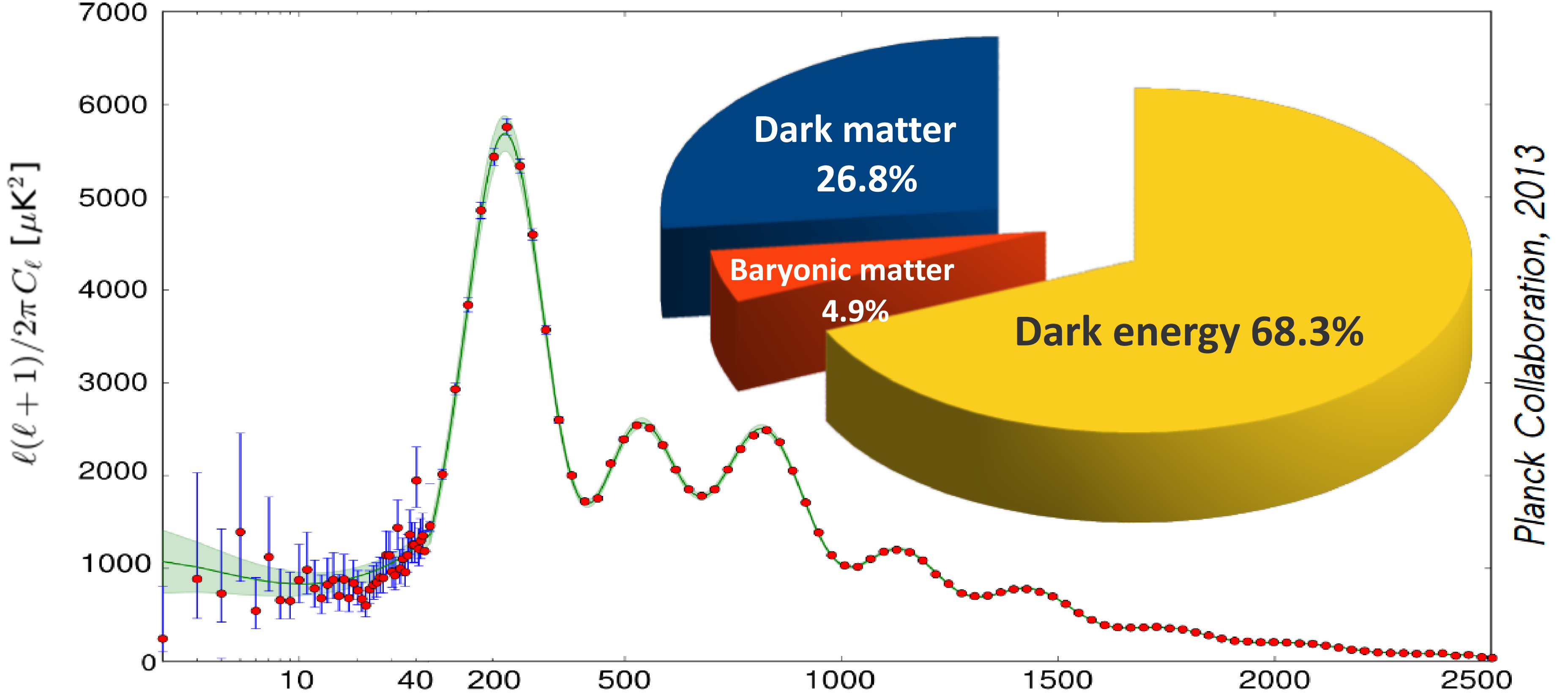
Anisotropy of the order of 100 ppm, due to oscillations of the primeval plasma of photons and baryons



$$\Delta T(\theta, \phi) = \sum_{\ell=1}^{\infty} \sum_{m=-\ell}^{\ell} a_{\ell,m} Y_{\ell,m}(\theta, \phi)$$

$< a_{lm}^2 >=$ Power spectrum

The power spectrum of **CMB anisotropy** is perfectly well fit by an Inflationary, Λ-CDM universe

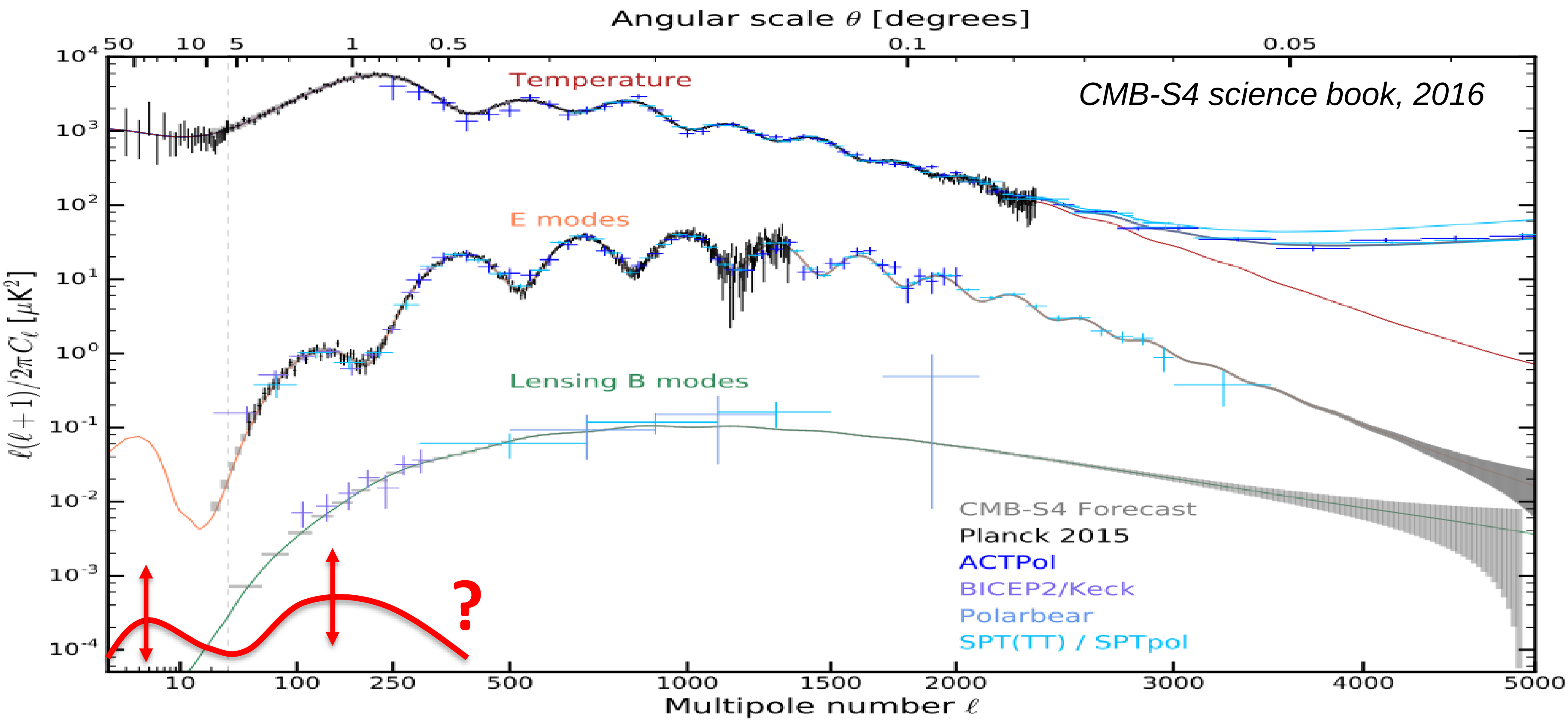


$$C_\ell = \left\langle a_{\ell,m} a^*_{\ell,m} \right\rangle$$

$$\Delta T(\theta, \phi) = \sum_{\ell=1}^{\infty} \sum_{m=-\ell}^{\ell} a_{\ell,m} Y_{\ell,m}(\theta, \phi)$$

Polarization of the CMB

- The CMB is slightly polarized, due to anisotropic Thomson scattering at recombination.
- The component due to density fluctuations (E-modes) has been measured and is consistent with expectations.
- The component due to tensor fluctuations (the gravitational waves generated by the hypothetical inflation phase in the very early universe), called inflationary B-modes, is still to be measured.



Polarization of the CMB

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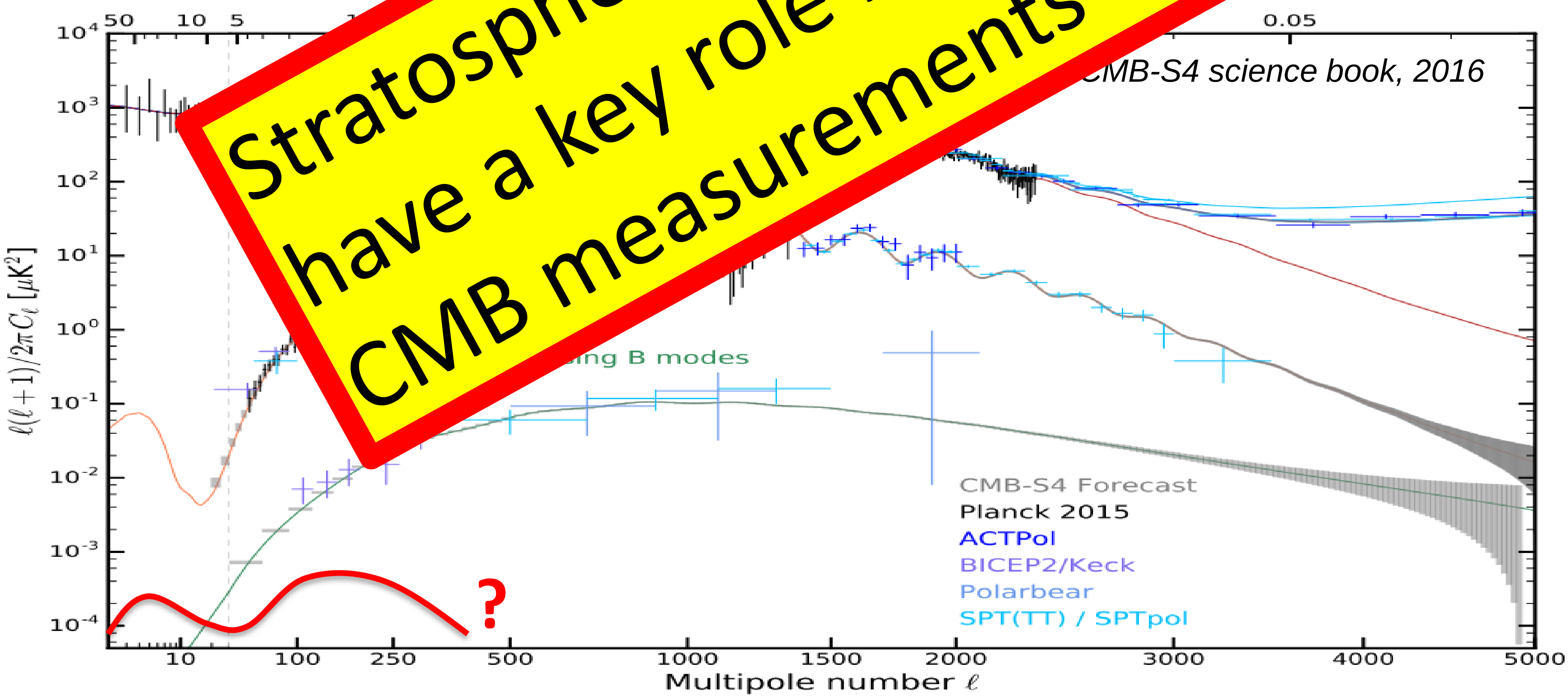
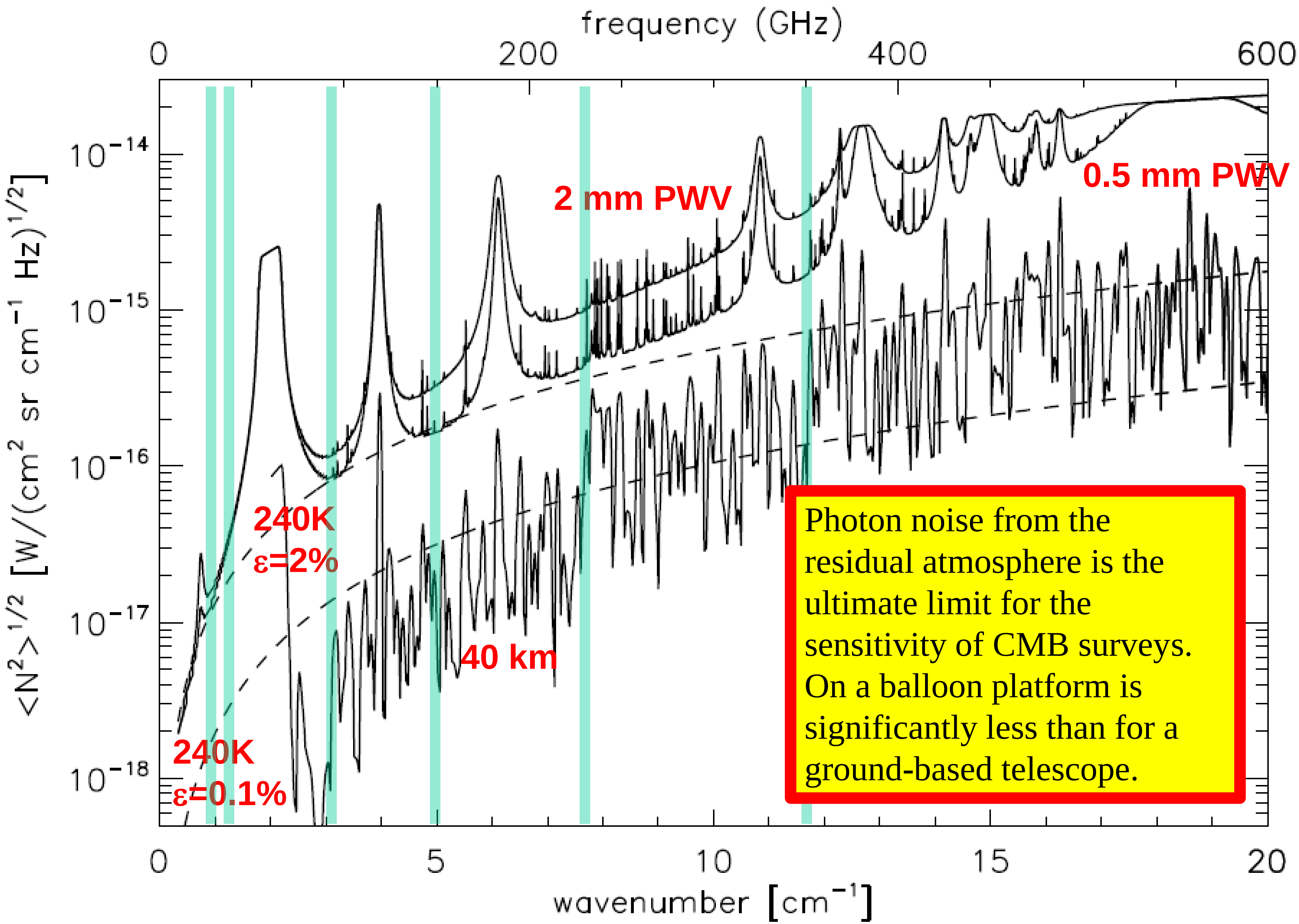
Stratospheric balloons have a key role in all CMB measurements



Stratospheric Balloons :

- Near-space carriers able to:
  - Reach 40 km (3 mbar)
  - Stay there for up to 40 days
  - Lift heavy (2 tons) large payloads (larger than what we can reasonably fly on satellites)
  - Cost roughly 1/100 of a satellite mission
  - Allow for recovery and refly of the payloa
- Important for the CMB community:
  - **To carry out sensitive observations at high frequency, high resolution, and at the largest angular scales**
  - **High f = the only way to monitor polarized interstellar dust. Cannot be done from the ground.**
  - To qualify instrumentation in preparation satellites
  - To educate young experimentalists !

Photon noise from the local environment

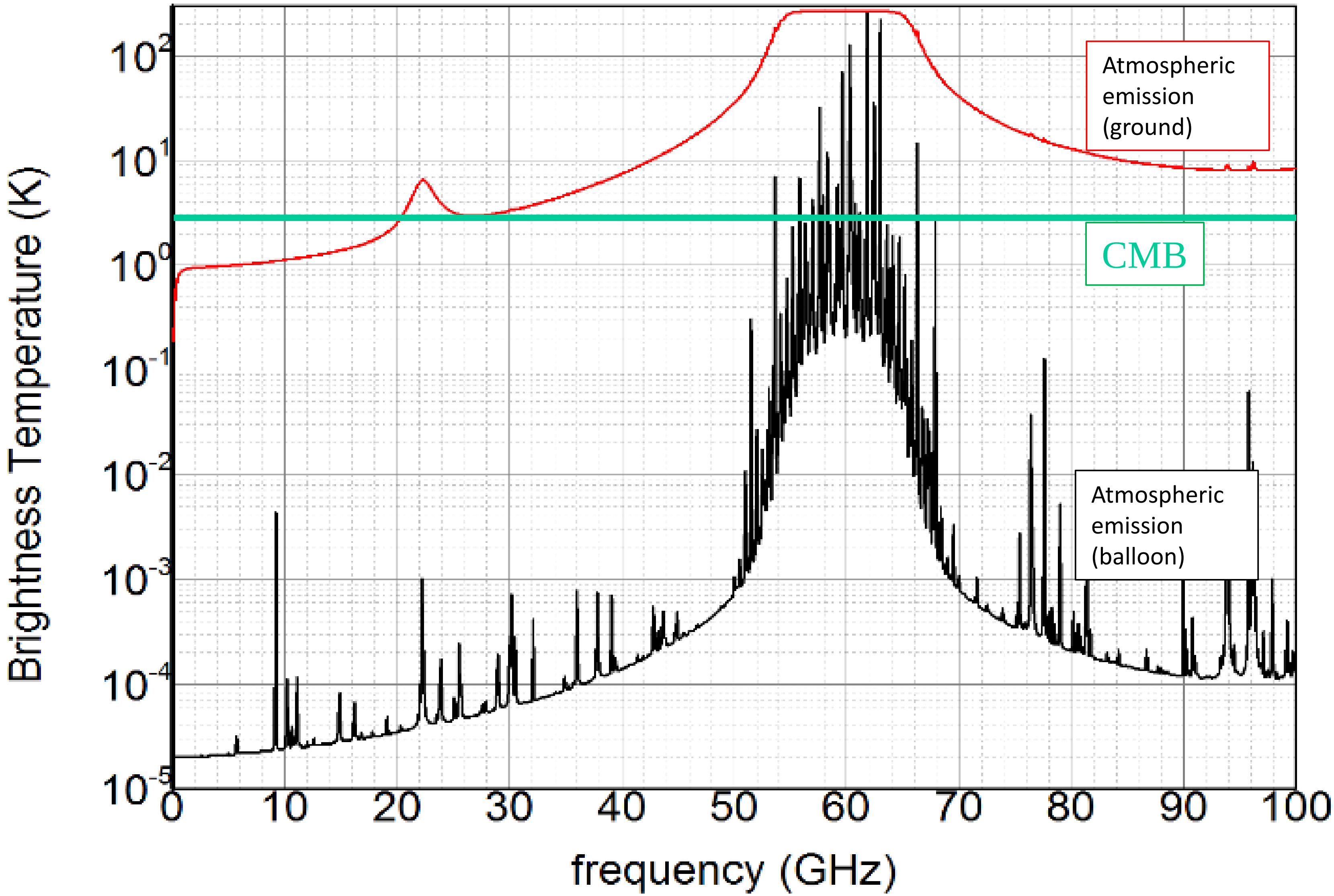


Photon noise from the residual atmosphere is the ultimate limit for the sensitivity of CMB surveys. On a balloon platform is significantly less than for a ground-based telescope.

Advantage of CMB measurements from balloons: **a) sensitivity**

- In absolute terms, a large array of photon-noise limited detectors on a ultra-long-duration balloon is able to reach cosmic variance limits at all interesting angular scales.
- The comparison to the theoretical sensitivity of ground-based experiments is interesting because defines the frequency range where the balloon advantage is larger.
- In the absence of atmospheric turbulence:
  - one day of integration on a balloon equals:
    - 12 days of operation on the ground at 220 GHz
    - 34 days of operation on the ground at 270 GHz
    - 198 days of operation on the ground at 340 GHz
    - 1390 days of operation on the ground at 480 GHz
  - At these high frequencies, the advantage of a balloon mission is going to improve if atmospheric turbulence is taken into account.

Advantage of CMB measurements from balloons:
b) Absolute brightness



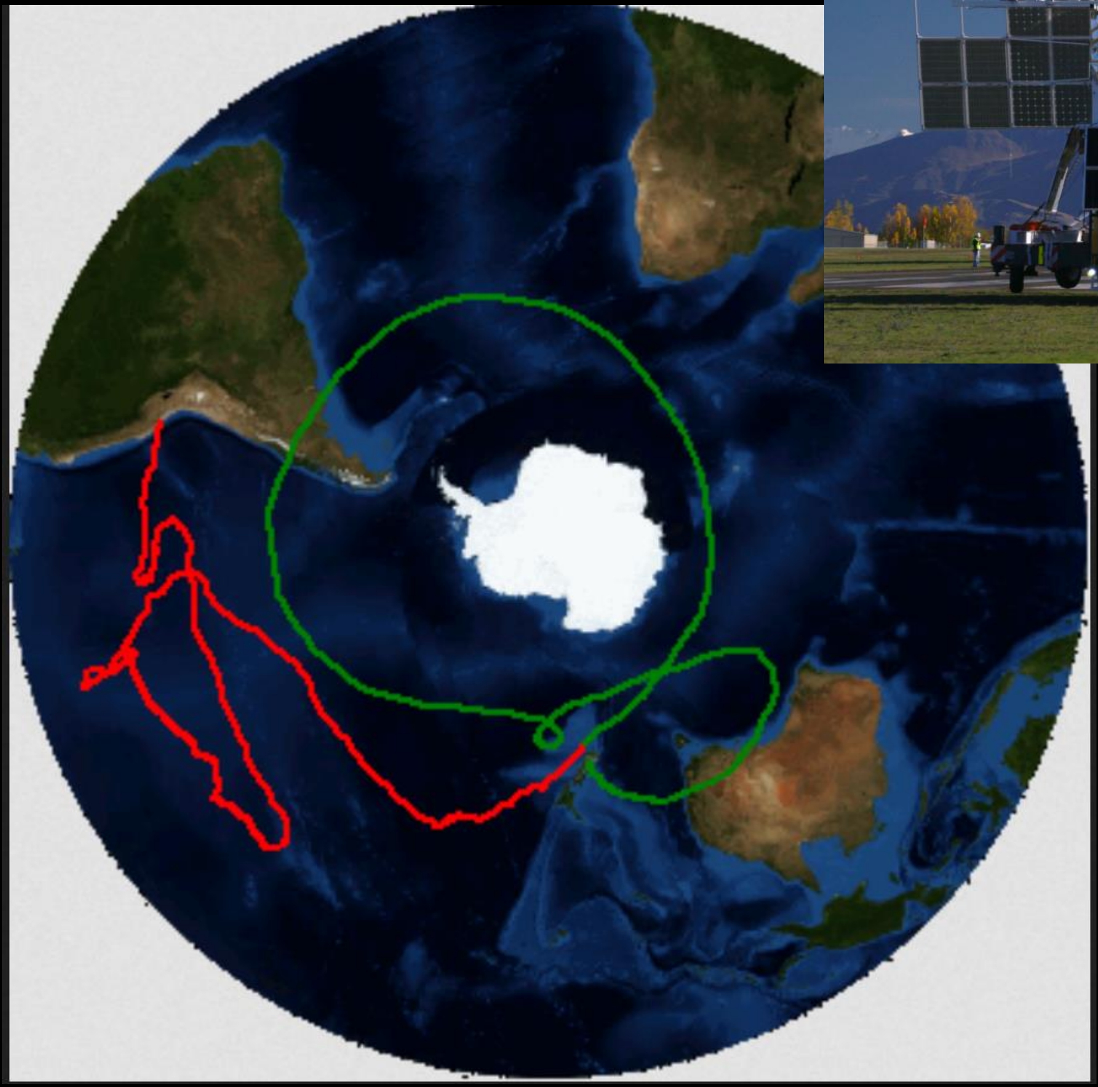
Long Duration Ballooning

Flight Options

- Antarctic Long Duration Balloon (LDB) : 10 – 30 days / 3 tons
- Svalbard & Kiruna Long Duration Balloon (LDB) : 10 – 30 days / 3 tons
- Wanaka Super Pressure Balloon (SPB) : 30 – 100 days / 1 ton
- Polar Night Flights : ~ 10 days
- Conventional Flight (Ft. Sumner, Palestine, Timmins,Kiruna) : 1 day

Flight Parameters

- 33-37 km altitude
- 1 km altitude stability (200 m for SPB)
- Annual flight windows
  - January (LDB, McM,LYR), April (SPB, Wanaka), June (Palestine,LYR,Kiruna), September (Ft. Sumner)

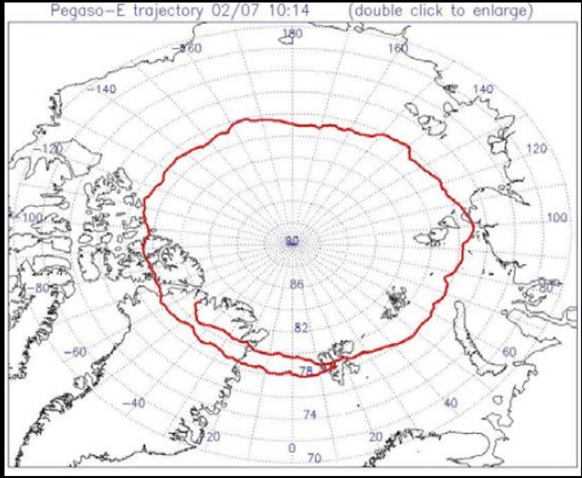


Great progress with super-pressure balloons: COSI payload flown by CSBF in may 2016 for over 46 days at altitudes between 33 km and 21 km, with a with a $0.5Mm^3$ SPB

https://blogs.nasa.gov/superpressureballoon/

Polar flights

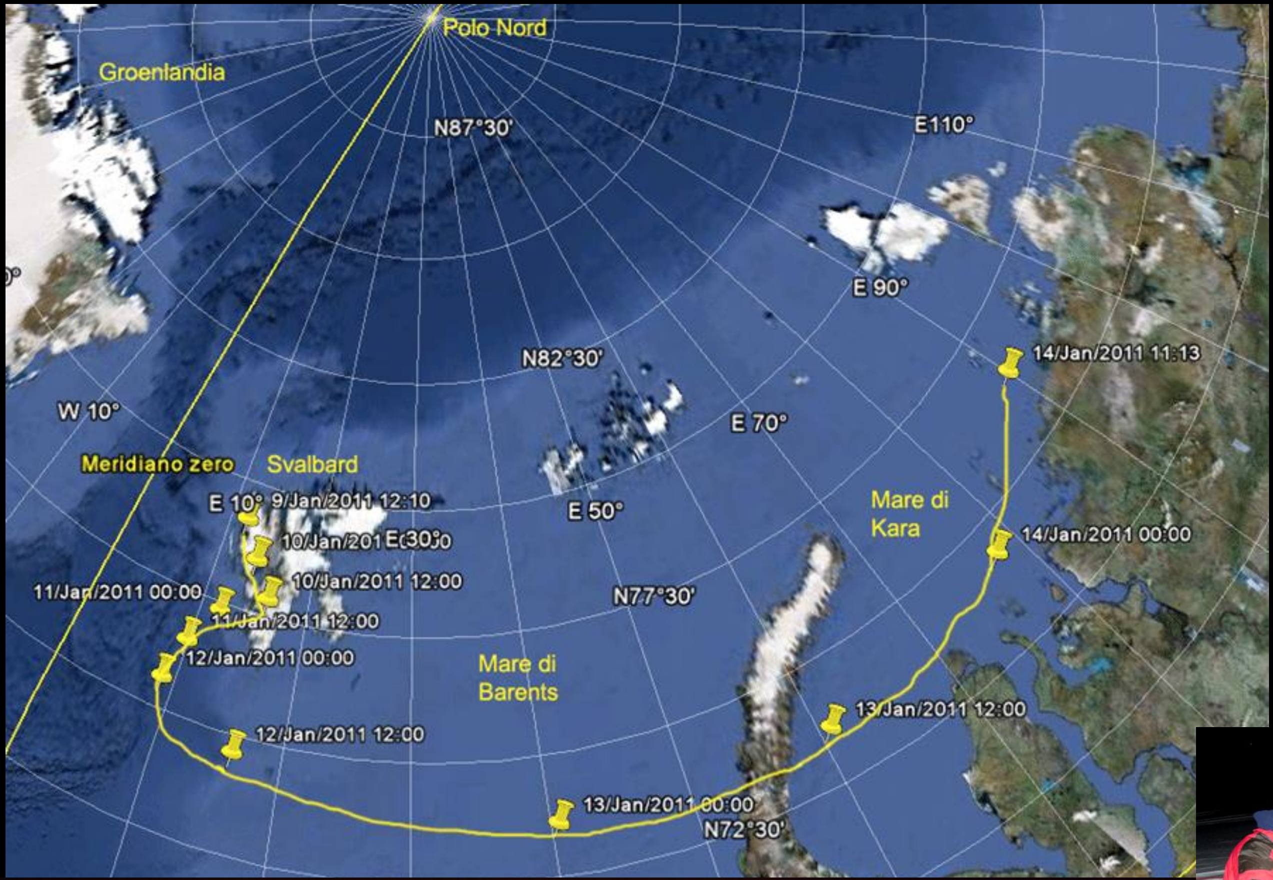
- We have flown long duration stratospheric balloons around the North Pole launching from **Longyearbyen** (Svalbard) both in the summer (heavy lift payloads) and in winter (pathfinders) [see Peterzen, S., Masi, S., et al., Mem. S. A. It., 79, 792-798 (2008), and PdB+SM Proc. of the I.A.U., 8, 208-213 (2013)]
- In this way 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).



Top: Ground path of a flight performed in June 2007. **Bottom right:** Launch of a heavy-lift balloon from the Longyearbyen airport (Svalbard Islands, latitude 78°N).

- OLIMPO has had its first flight in the Arctic (and the second one is supposed to be done from Antarctica (pending recovery and approval)

Polar Night Flights



Stratospheric Balloons:

Disadvantages:

- Stringent limits on mass, power
- Complexity of automation
- Insane integration schedule
- Narrow, and scarce, flight windows
- Risky recovery

CMB-related science from balloons

(with large advantage wrt ground-based experiments)

- Dust-cleaned polarization & Dust-cleaned inflationary and lensing B-modes
- CMB Polarization at very large angular scales
- Spectral measurements of the SZ
- Spectral measurements of CIB anisotropy
- Precision measurements of CMB spectrum (at selected frequencies)

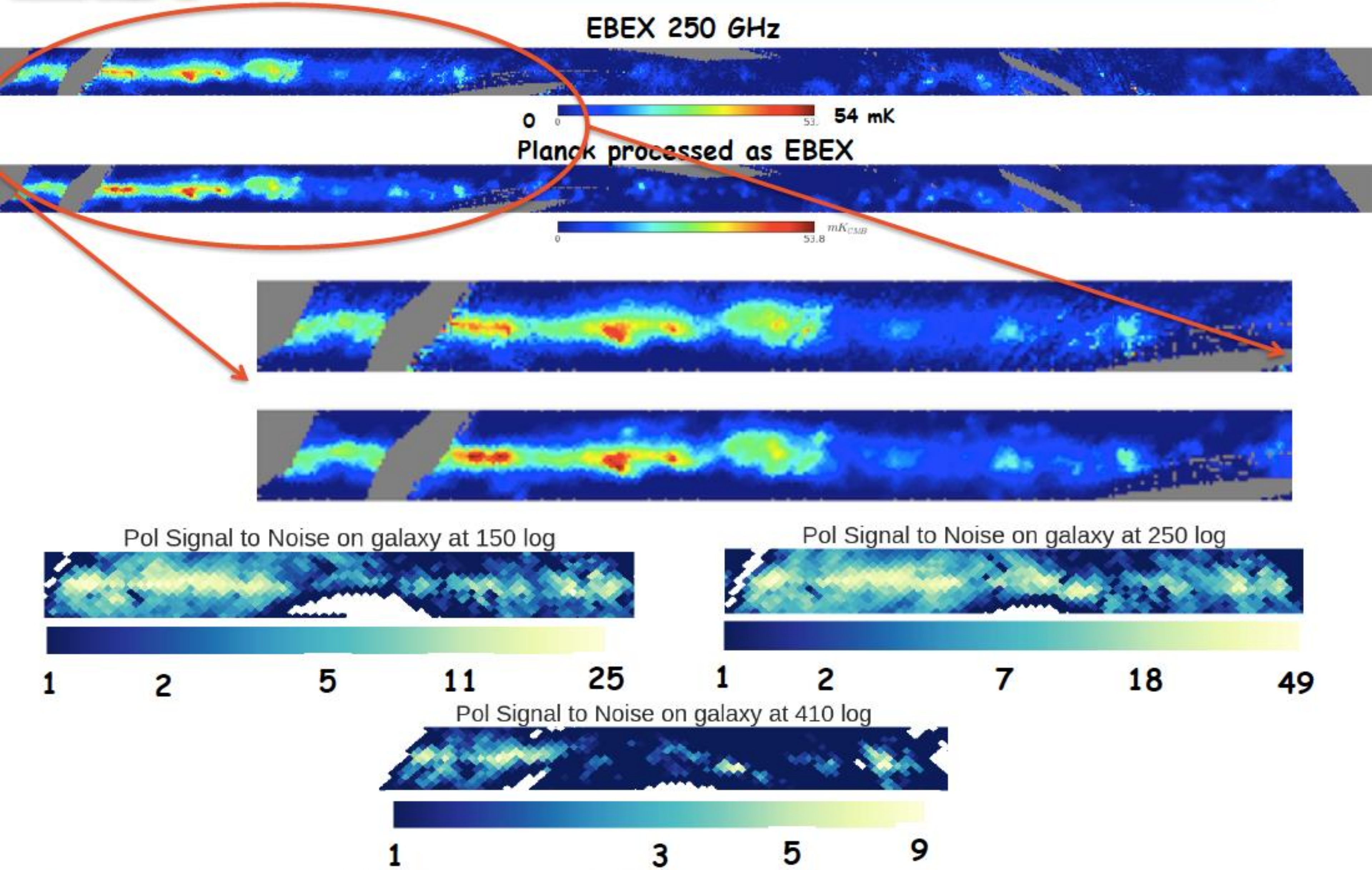
Current / Pending Balloons for CMB-related science

Missions Recently Flown	survey area [sky fraction]	frequencies [GHz]	resolution [arcmin]
EBEX (2012/13)	0.2	150/250/410	8/5/5
Spider (2014/15)	0.1	94/150	42/28
PILOT (2015)	<0.01	1200/545	3
Piper (2017)	0.8	200	36
OLIMPO (N.LDB 2018)	0.01	140-220-340-450	2/4

Missions Planned	survey area [sky fraction]	frequencies [GHz]	resolution [arcmin]
Spider (LDB 2018)	0.1	94-285 (3)	42-15
OLIMPO (S.LDB 2021)	0.01	140-220-340-450	2/4
LSPE (N.LDB 2019)	0.25	44-240 (4)	85-20

Missions in Preparation	survey area [sky fraction]	frequencies [GHz]	resolution [arcmin]
Piper (2018-2020)	0.8	200-600 (4)	36-12
BLAST-TNG	< 0.01	1200, 860, 600	1
EBEX-IDS	0.035	150-360 (7)	8-3
BFORE	0.23	270-600 (3)	4
BSIDE	0.05	600-700	7

2013 Flight


EBEX 250 GHz
0
54 mK
Planck processed as EBEX
53.8
Pol Signal to Noise on galaxy at 150 log
1 2 5 11 25
Pol Signal to Noise on galaxy at 250 log
1 2 7 18 49
Pol Signal to Noise on galaxy at 410 log
1 3 5 9

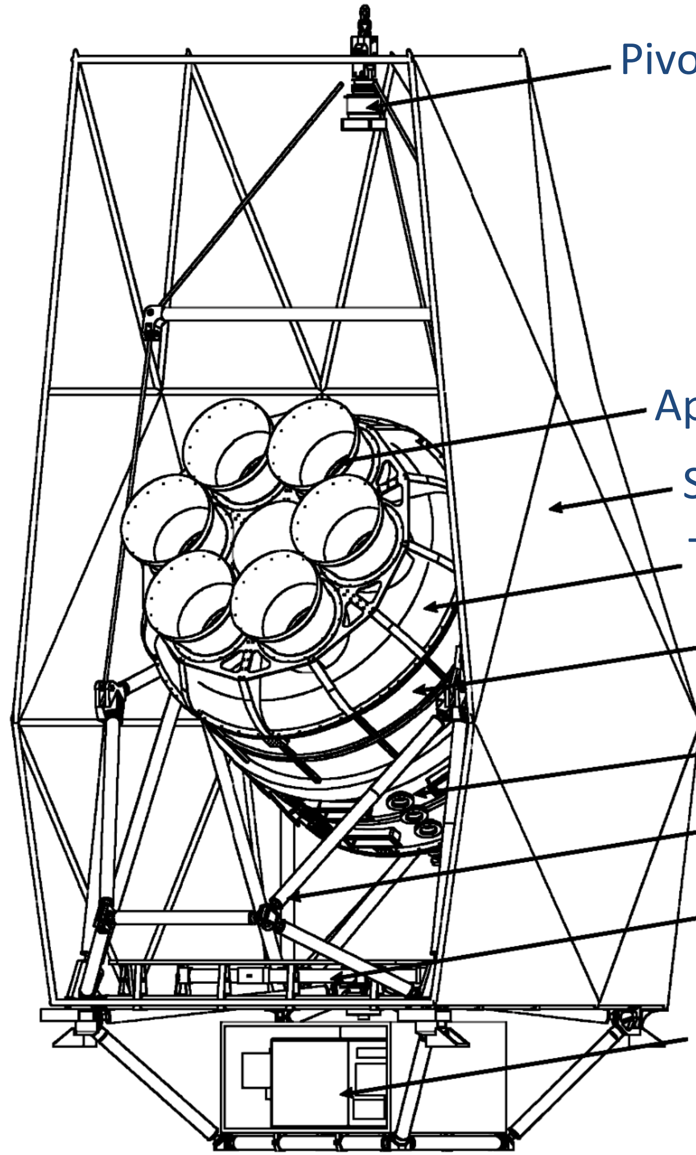
Spider 2015: Overview

Sky coverage	About 10 %
Scan rate (az, sinusoid)	3.6 deg/s at peak
Polarization modulation	Stepped cryogenic HWP
Detector type	Antenna-coupled TES
Multipole range	10 < ℓ < 300
Observation time	16 days at 36 km
Limits on r†	0.03

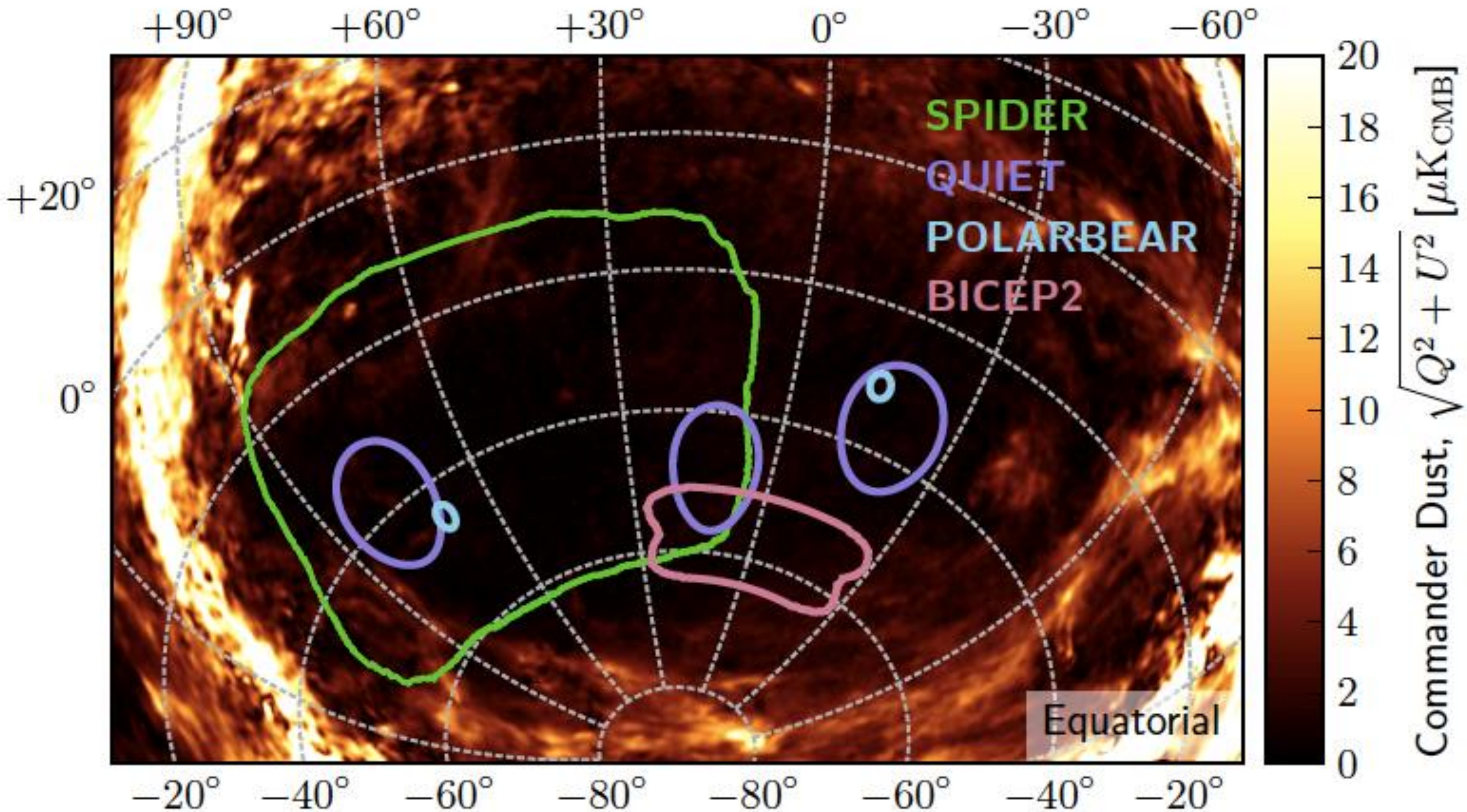
† Ignoring all foregrounds, at 99% confidence

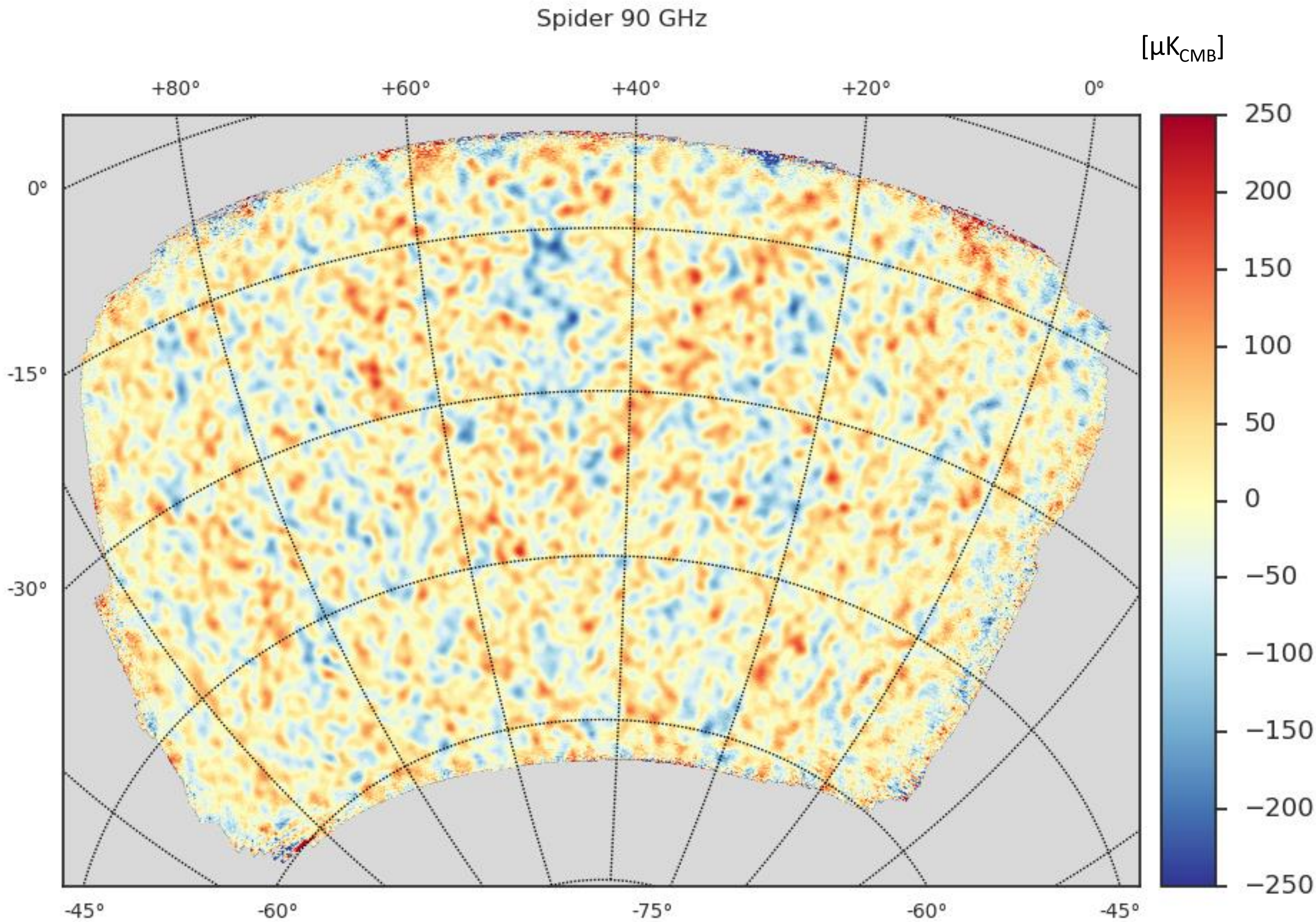
	Frequency [GHz]	
	94	150
Telescopes	3	3
Bandwidth [GHz]	22	36
Optical efficiency	30-45%	30-50%
Angular resolution* [arcmin]	42	28
Number of detectors†	652 (816)	1030 (1488)
Optical background‡ [pW]	≤ 0.25	≤ 0.35
Instrument NET† [μK·rts]	6.5	5.1

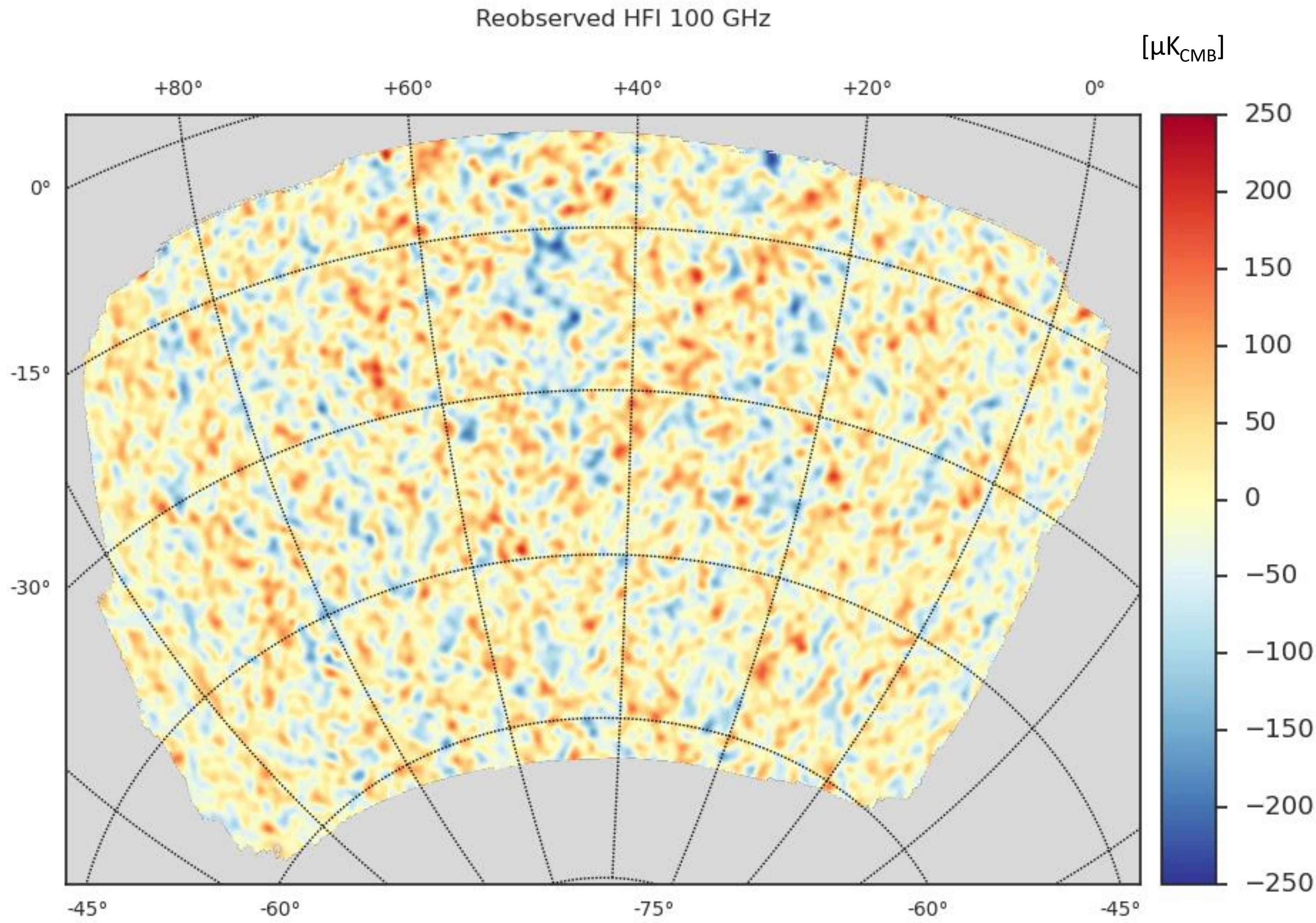
*FWHM. †Only counting those currently used in analysis
‡Including sleeve, window, and baffle

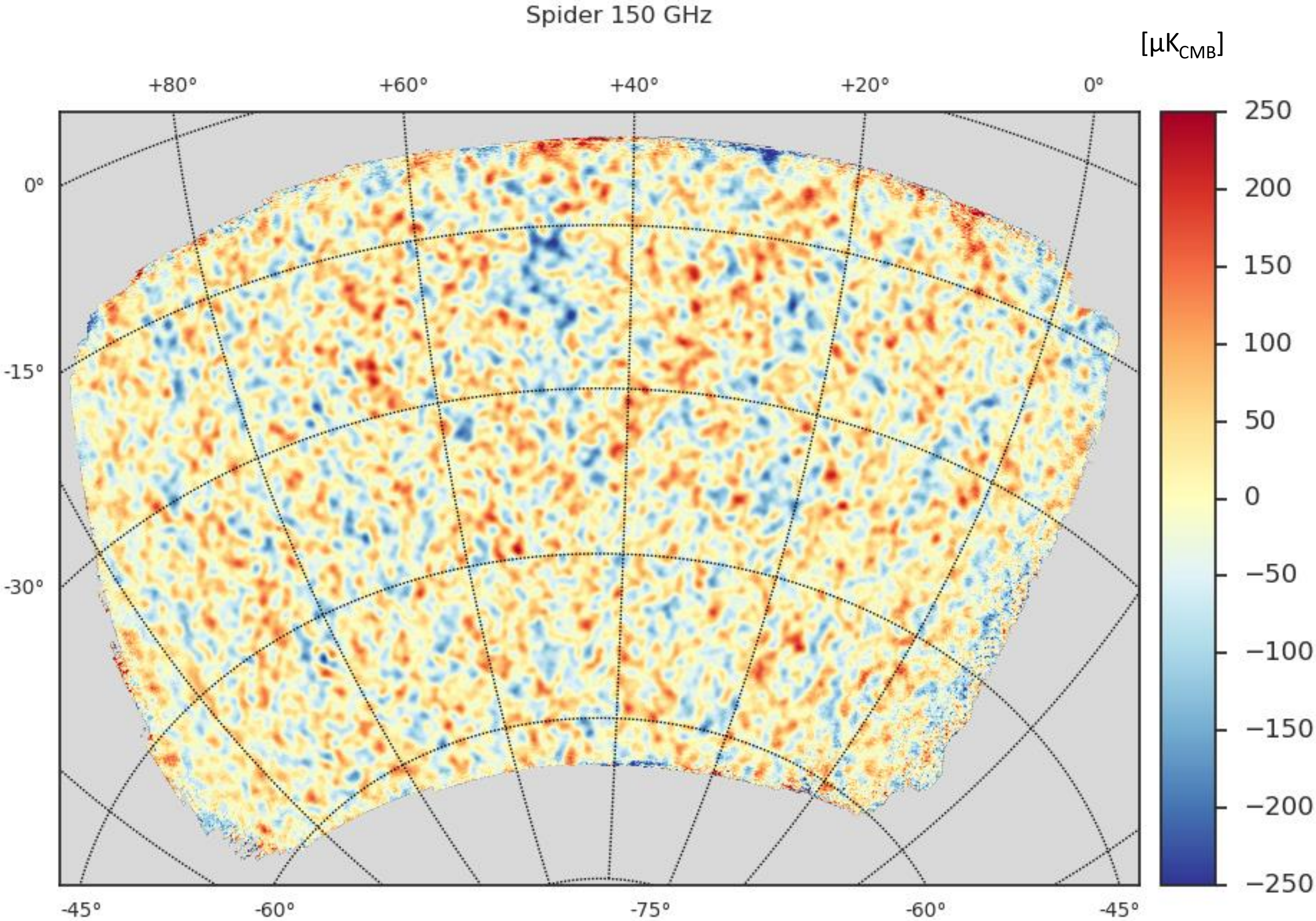


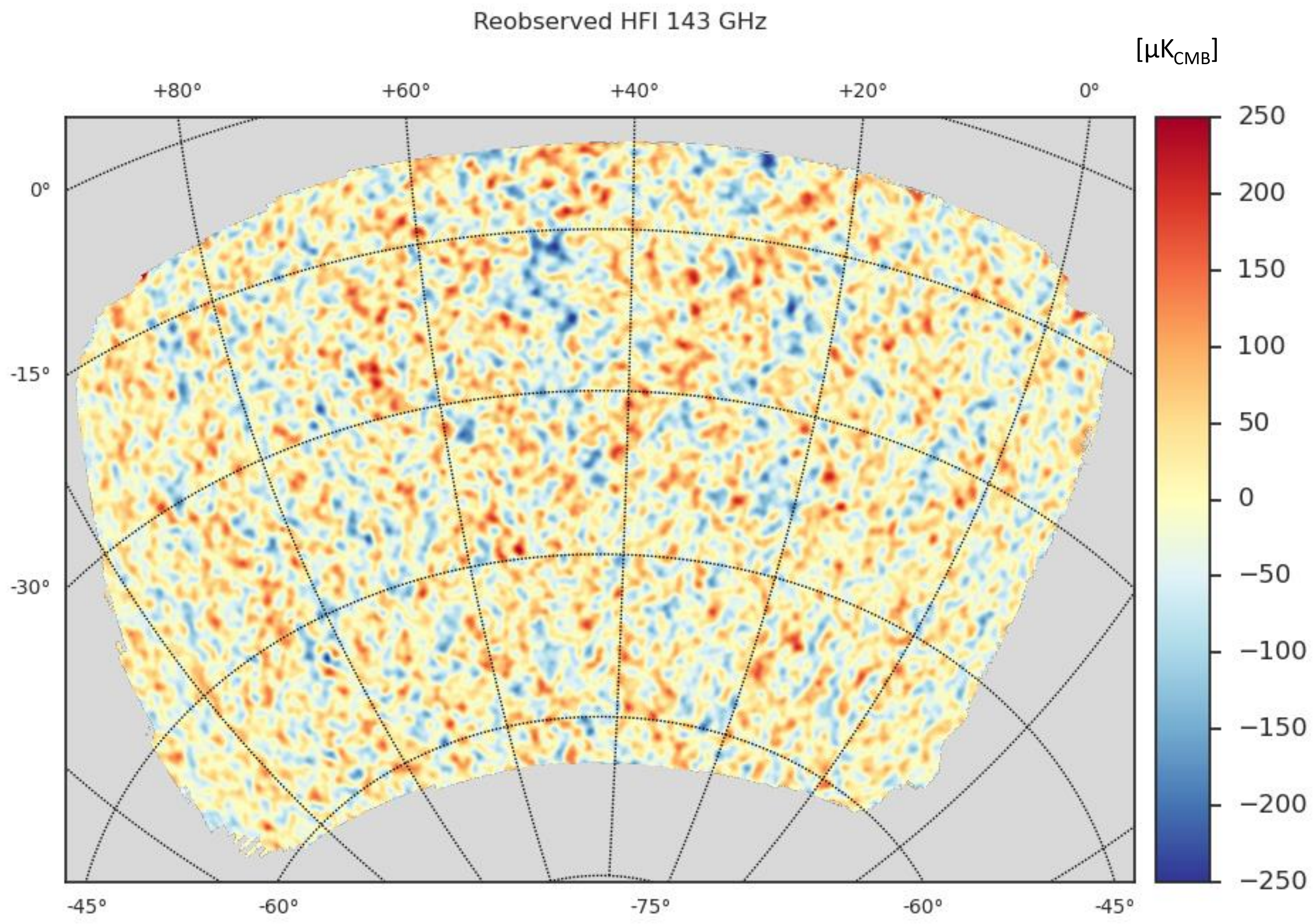
Spider 2015: survey coverage



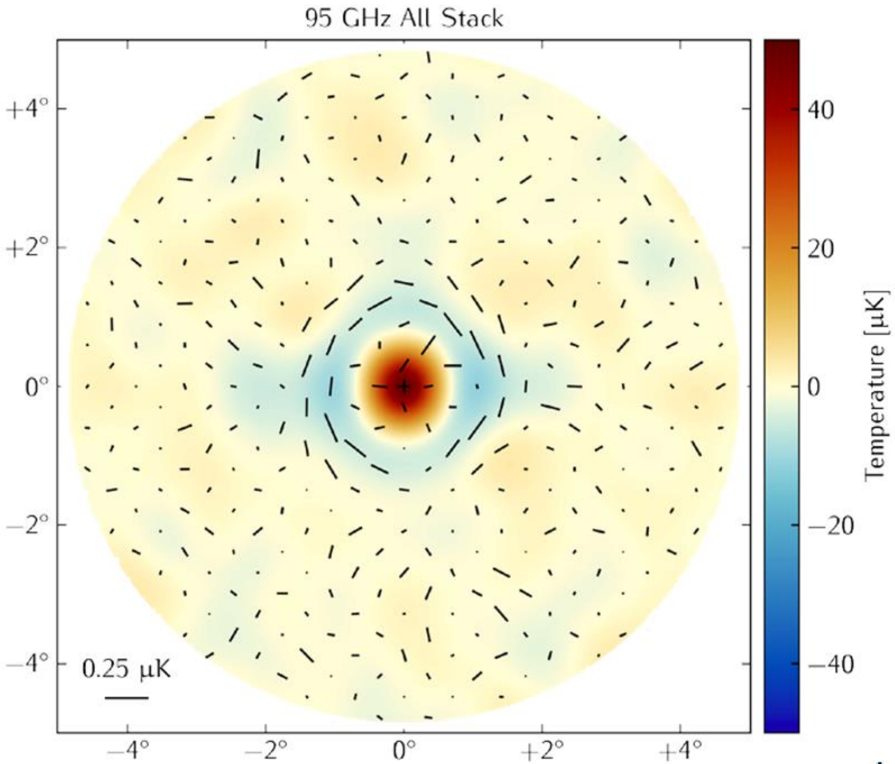

Spider 90 GHz
[μK$_{CMB}$]
+80°
+60°
+40°
+20°
0°
0°
-15°
-30°
-45°
-60°
-75°
-60°
-45°
250
200
150
100
50
0
−50
−100
−150
−200
−250

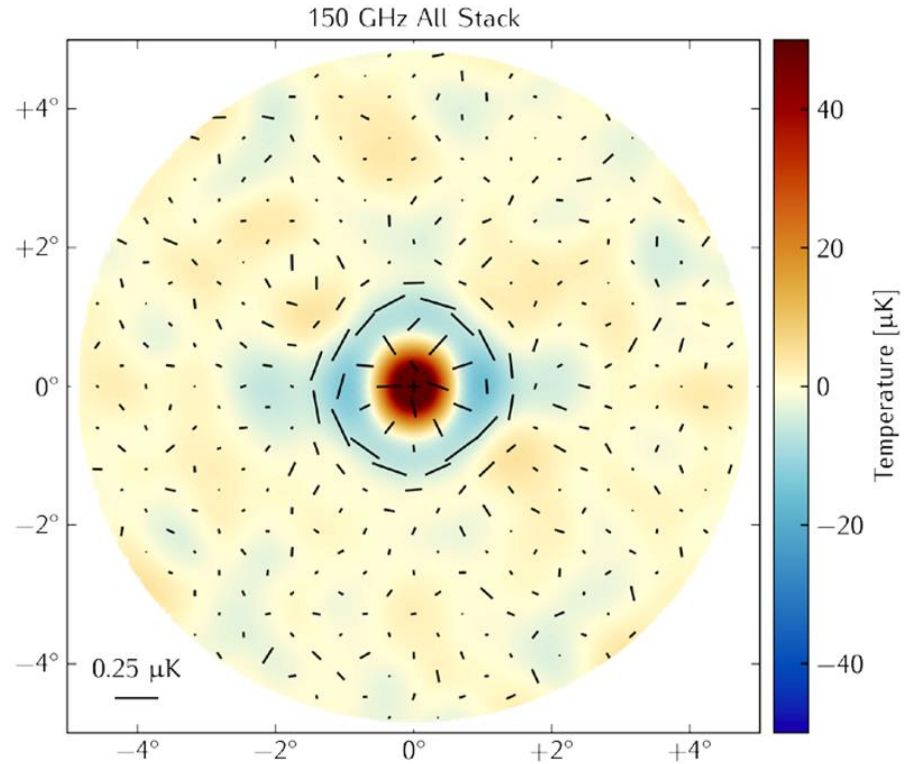

Reobserved HFI 100 GHz
[μK_CMB]
+80°
+60°
+40°
+20°
0°
0°
-15°
-30°
-45°
-60°
-75°
-60°
-45°
250
200
150
100
50
0
−50
−100
−150
−200
−250


Spider 150 GHz
[μK_CMB]
+80°
+60°
+40°
+20°
0°
0°
-15°
-30°
-45°
-60°
-75°
-60°
-45°
250
200
150
100
50
0
−50
−100
−150
−200
−250

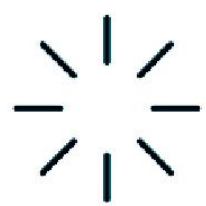

Reobserved HFI 143 GHz
[μK$_{CMB}$]
+80°
+60°
+40°
+20°
0°
0°
-15°
-30°
-45°
-60°
-75°
-60°
-45°
250
200
150
100
50
0
−50
−100
−150
−200
−250

Stacking hot spots : SPIDER

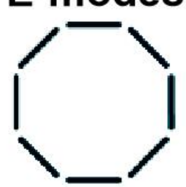




PRELIMINARY



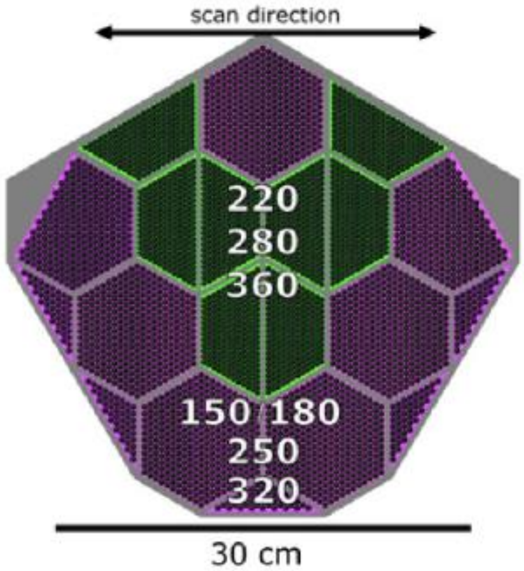
E-modes



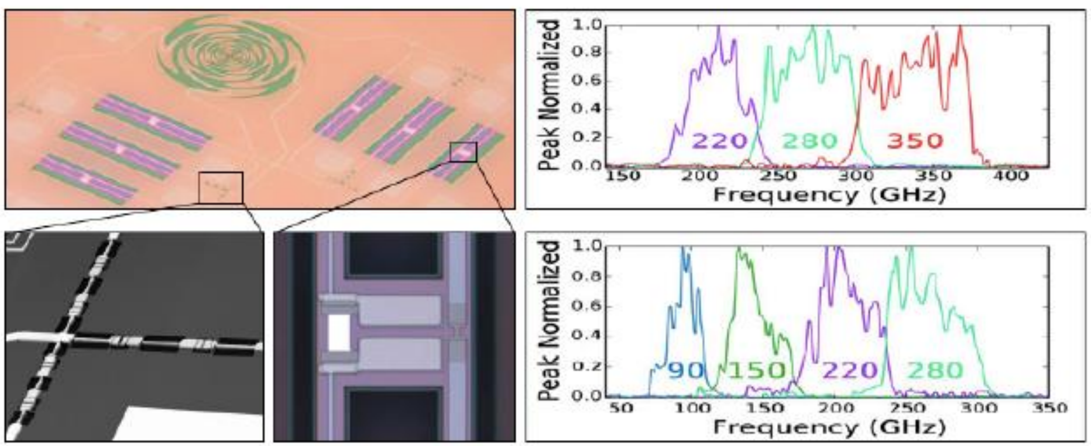
PRELIMINARY

EBEX-IDS

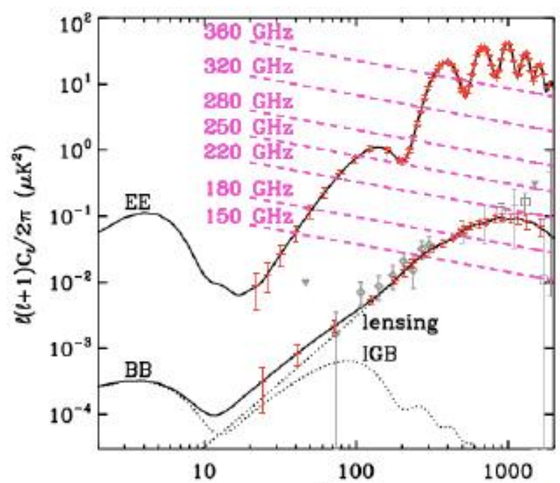
- 7 bands: 150, 180, 220, 250, 280, 320, 360 GHz
- 1500 sq. deg. Co-observe with BICEP/Keck + Simmons Array
- Sinuous Antenna Trichroic Pixels (PB2, SPTPol, LiteBIRD)



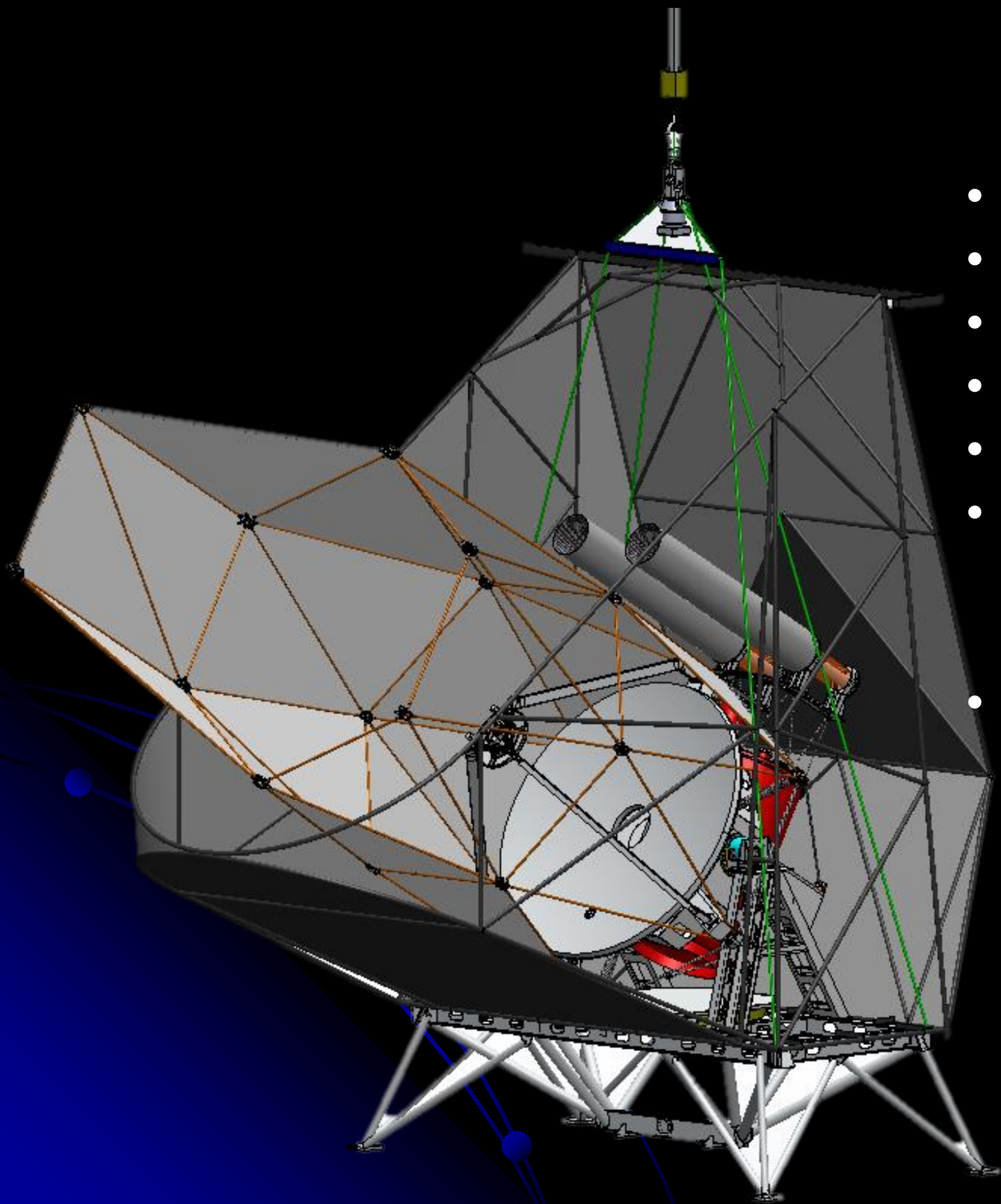
Total of 20562 detectors



Lee + Westbrook, UCB



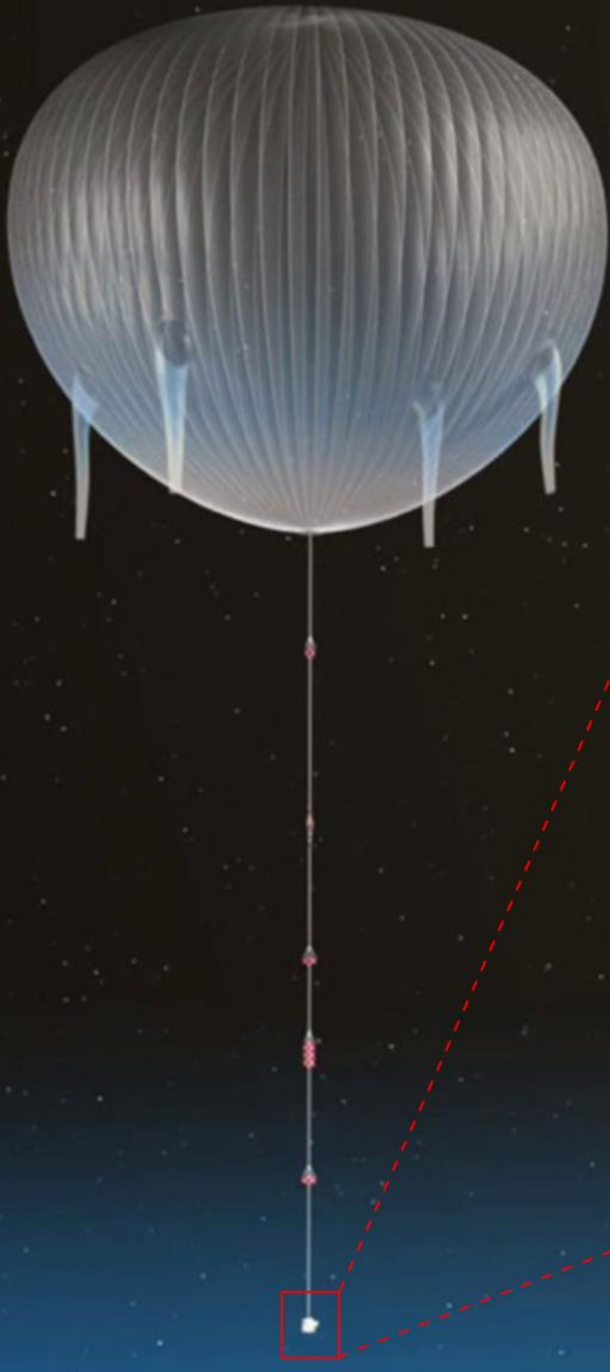
BLAST-TNG

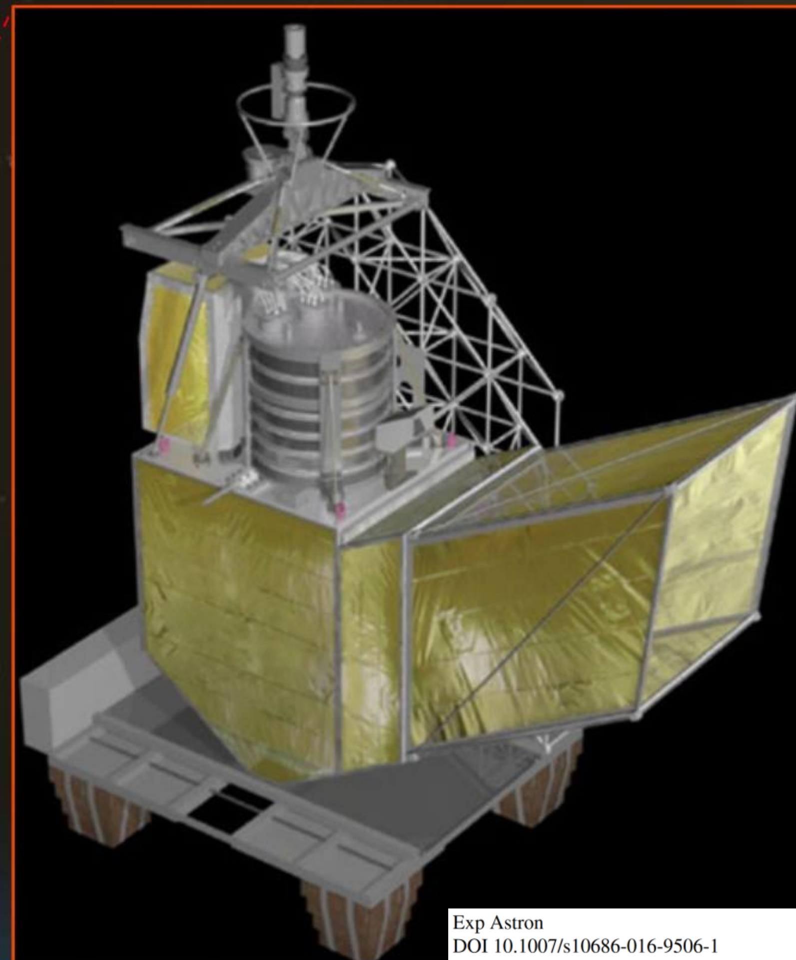


- 2.5 meter Carbon Fiber Mirror
- 2200 Polarized KID detectors
- Three bands: 250, 350, and 500 μm
- 22 arcsec resolution at 250 μm
- 28 day flight!
- 10 times the mapping speed of BLAST-pol

- First flight December 2018 (TBC) with Shared Risk Observing

PILOT





Exp Astron
DOI 10.1007/s10686-016-9506-1

ORIGINAL ARTICLE

PILOT: a balloon-borne experiment to
the polarized FIR emission of dust grai
in the interstellar medium

Table 1 Key characteristics and performance of the *PILOT* instrument in its nominal configuration. The last lines gives the expected 3σ performance in the two extreme observing modes corresponding to deep ($5^{\square}$/hour) and large ($150^{\square}$/hour) surveys respectively, where the $^{\square}$ symbol stands for square degree. Our estimated polarization sensitivity assumes a dust polarization fraction of 10 %

Primary mirror diameter [mm]	730	
Equivalent focal length [mm]	1800	
Numerical aperture	$F/2.5$	
Detector temperature [mK]	300	
Mapping speed [$^{\square}$/h]	[5-150]	
FOV [°]	1.0×0.8	
	SW Band	LW Band
λ_0 [μm]	240	550
ν_0 [GHz]	1250	545
$\Delta\nu/\nu$	0.27	0.31
Tr(dust)	0.025	0.136
beam FWHM [′]	1.9	3.29
Number of Detectors	1024	1024
background [pW/pix]	5.7	4.0
NEP_{Det} [$W/\sqrt{Hz}$]	$2.0\,10^{-16}$	$2.0\,10^{-16}$
NEP_{Phot} [$W/\sqrt{Hz}$]	$9.8\,10^{-17}$	$6.0\,10^{-17}$
NEP_{Tot} [$W/\sqrt{Hz}$]	$2.2\,10^{-16}$	$2.1\,10^{-16}$
Sensitivity (3σ in 3.5′)		
Intensity [MJy/sr]	[0.98-6.28]	[0.33-2.13]
Av [mag]	[0.05-0.30]	[0.12-0.75]
Av polar [mag]	[0.47-2.99]	[1.17-7.48]

Large Scale Polarization Explorer

agenzia spaziale italiana

INFN Istituto Nazionale di Fisica Nucleare

LSPE

the Large-Scale Polarization Explorer

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Mario	Zannoni	Dip. Fisica Università di Milano Bicocca
Guido	Zavattini	Università di Ferrara & INFN Ferrara

SAPIENZA UNIVERSITÀ DI ROMA

UNIVERSITÀ DEGLI STUDI DI MILANO

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IASF Bologna

IEIIT

IFAC

MANCHESTER 1824

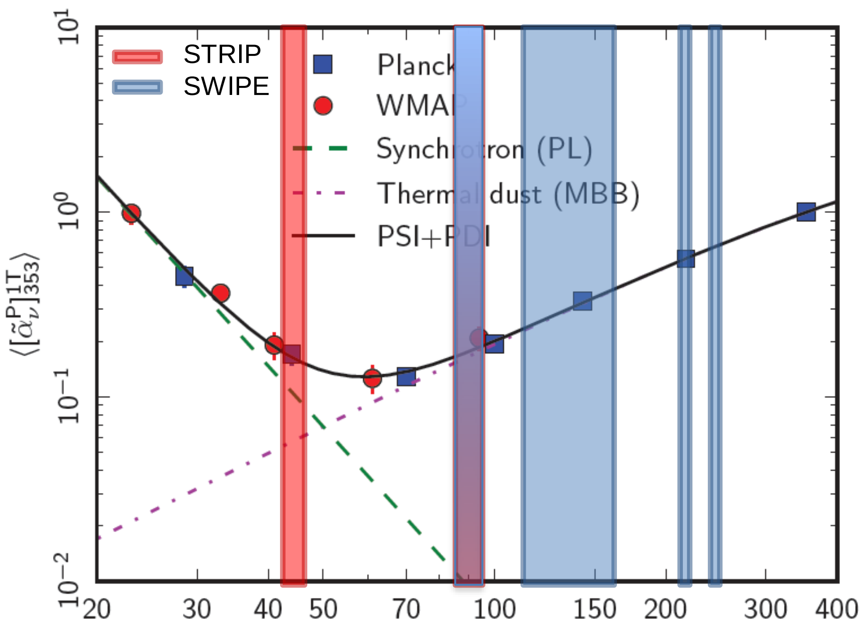
CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

INFN Istituto Nazionale di Fisica Nucleare

MI
GE
PI
FE
RM1
RM2

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
  - The SWIPE instrument uses *a spinning stratospheric balloon payload* to avoid atmospheric noise, flying *long-duration, in the polar night*
  - uses 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 / year
- 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 : Foreground cleaning strategy

44 GHz
Monitor polarized synchrotron

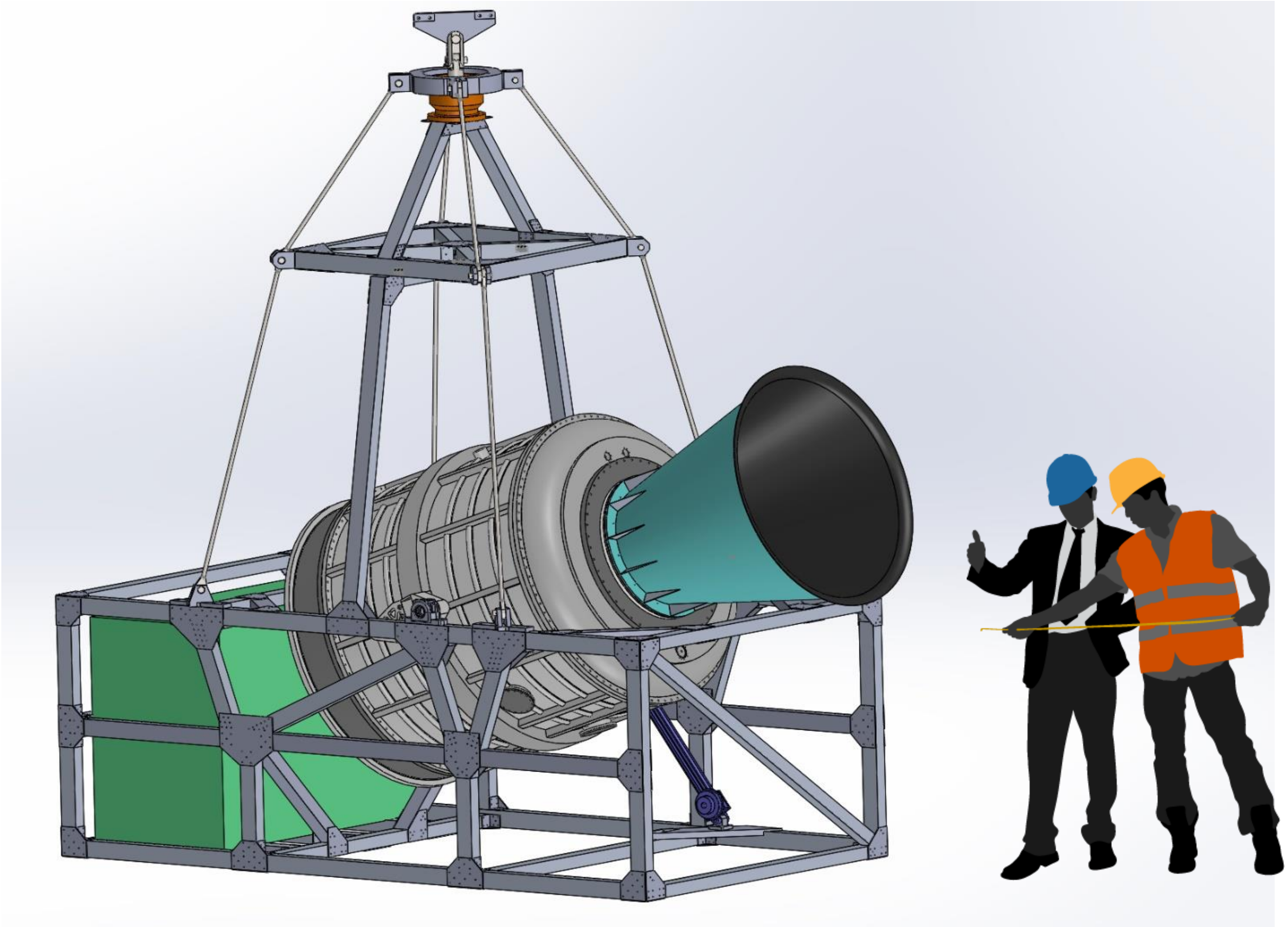
90 + 140 GHz
Main CMB channels

220 + 240 GHz
Monitor level **and slope and rotation** of polarized dust emission

To date extrapolated from 350 GHz only

STRIP polarimeter in Tenerife

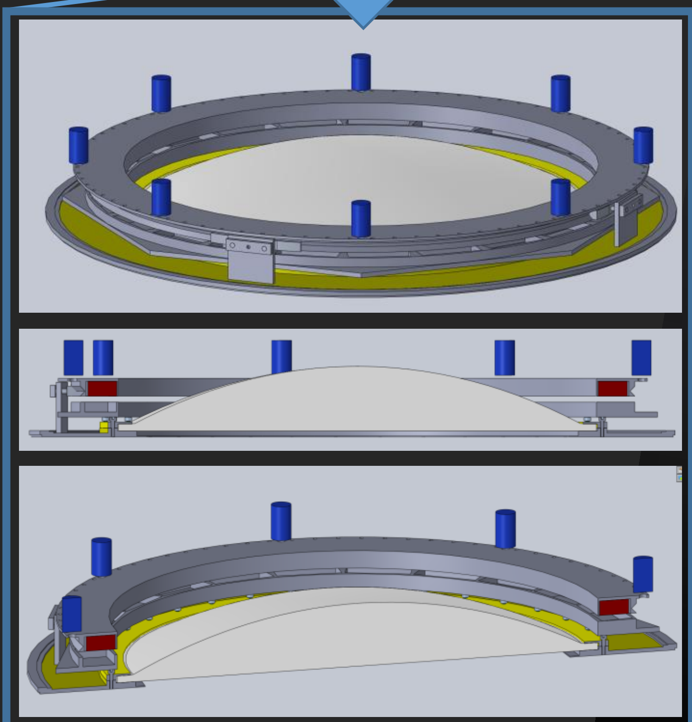
LSPE/SWIPE

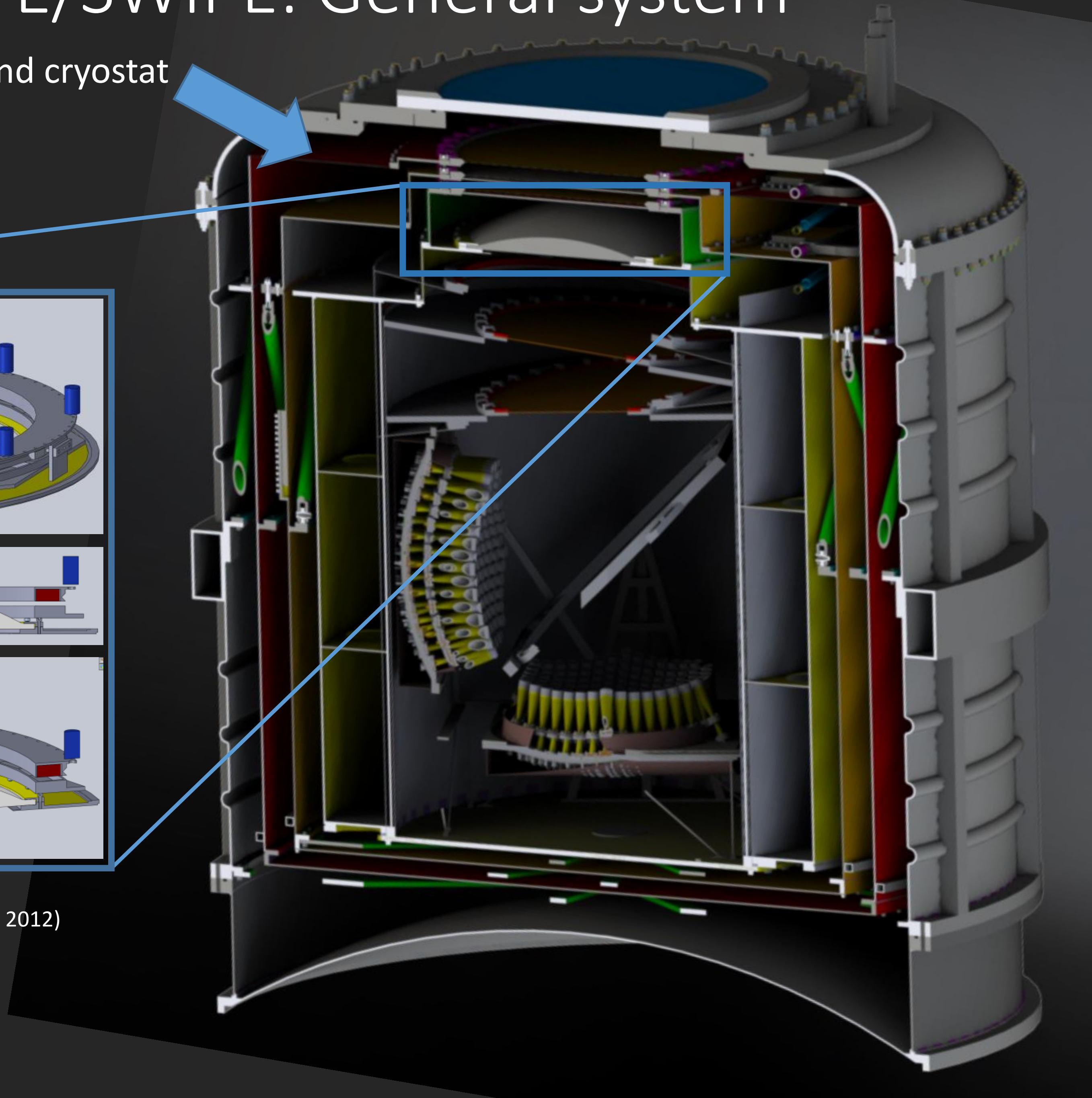


LSPE/SWIPE: General system

LSPE-SWIPE polarimeter and cryostat

LSPE-SWIPE polarization modulator





Study of a fast (1-2 rps) levitating modulator
Current baseline: stepper (See Salatino et al. 2012)

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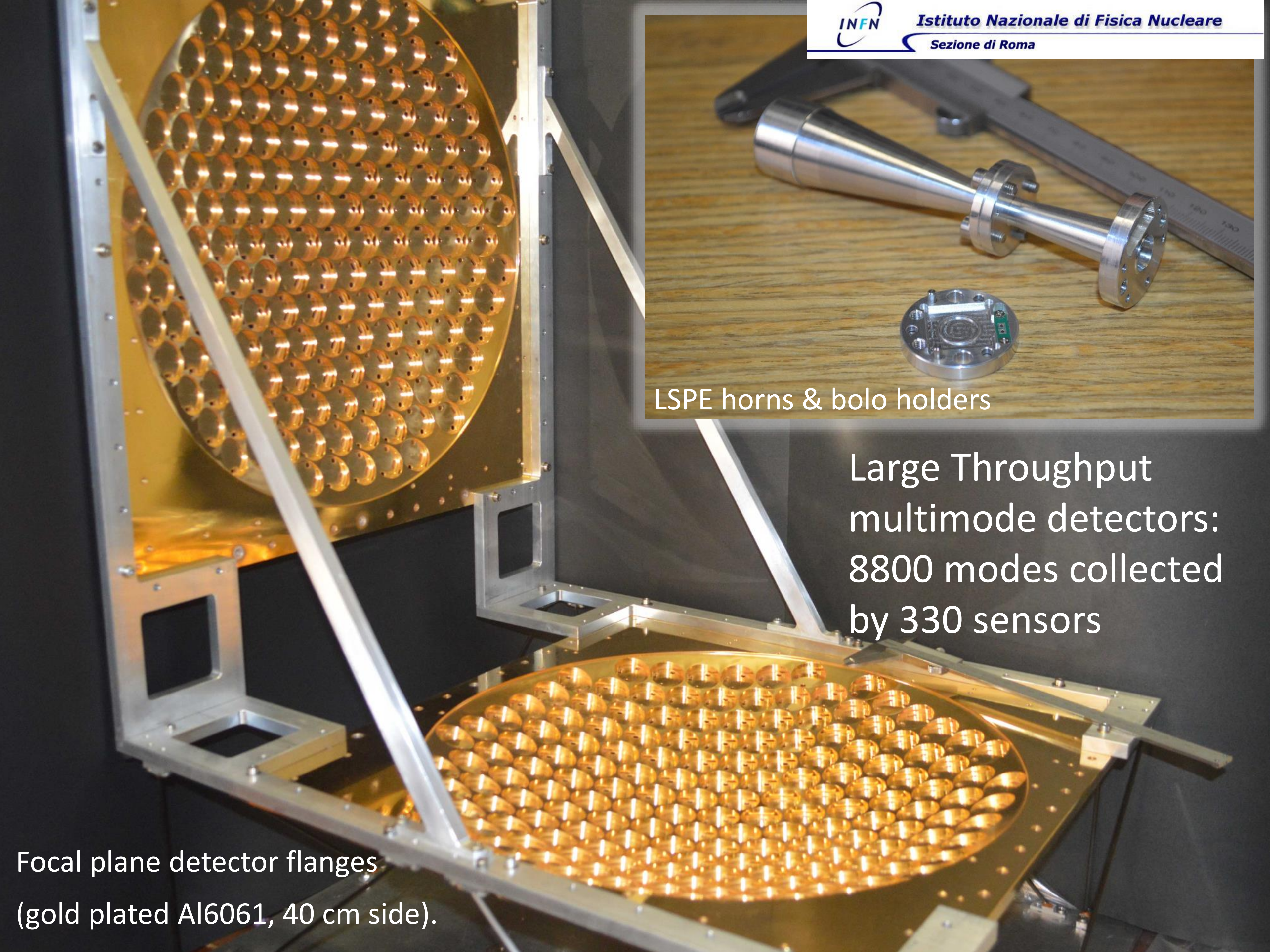

Large Throughput multimode detectors: 8800 modes collected by 330 sensors

Focal plane detector flanges (gold plated Al6061, 40 cm side).

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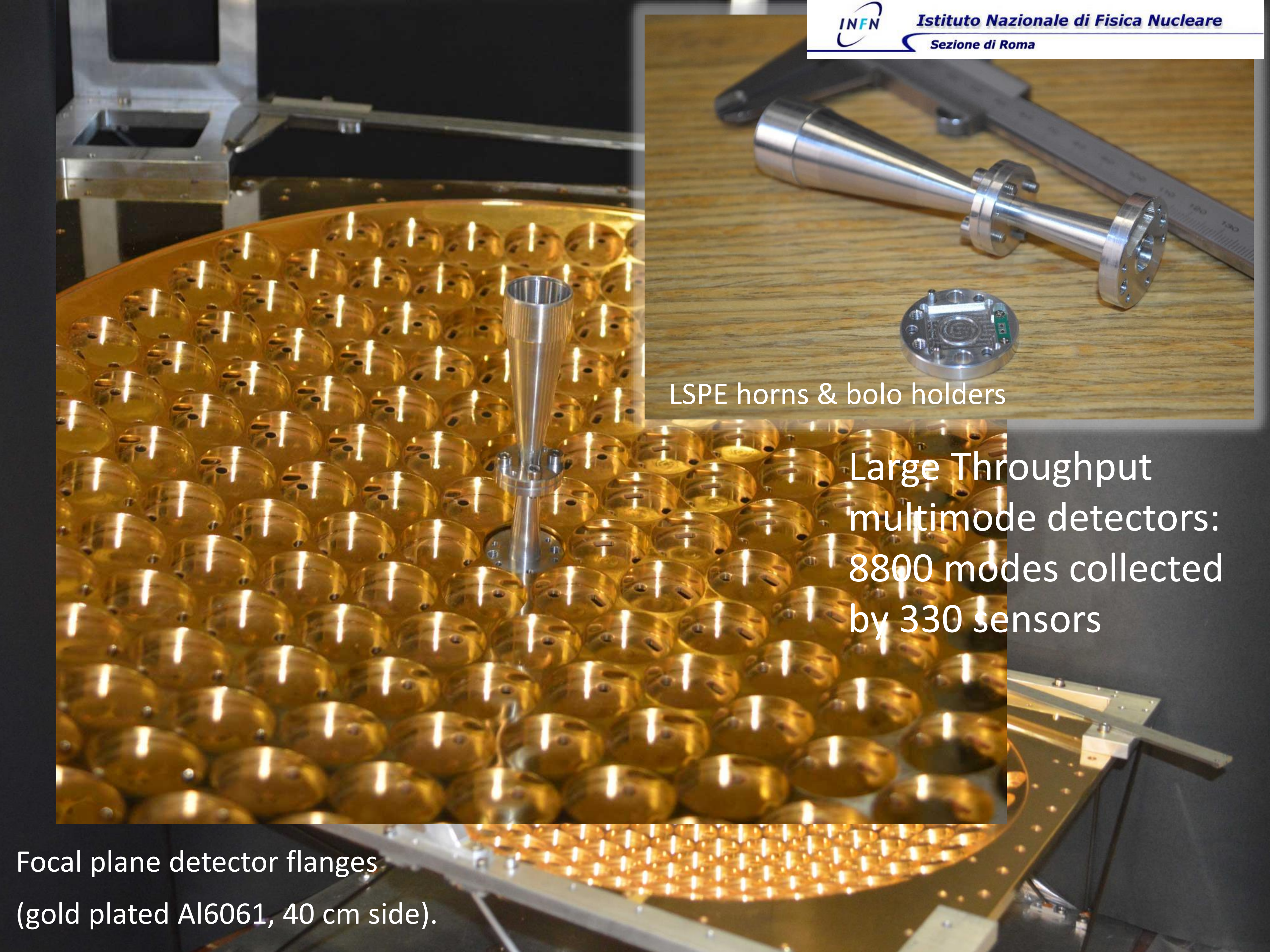
Sezione di Roma



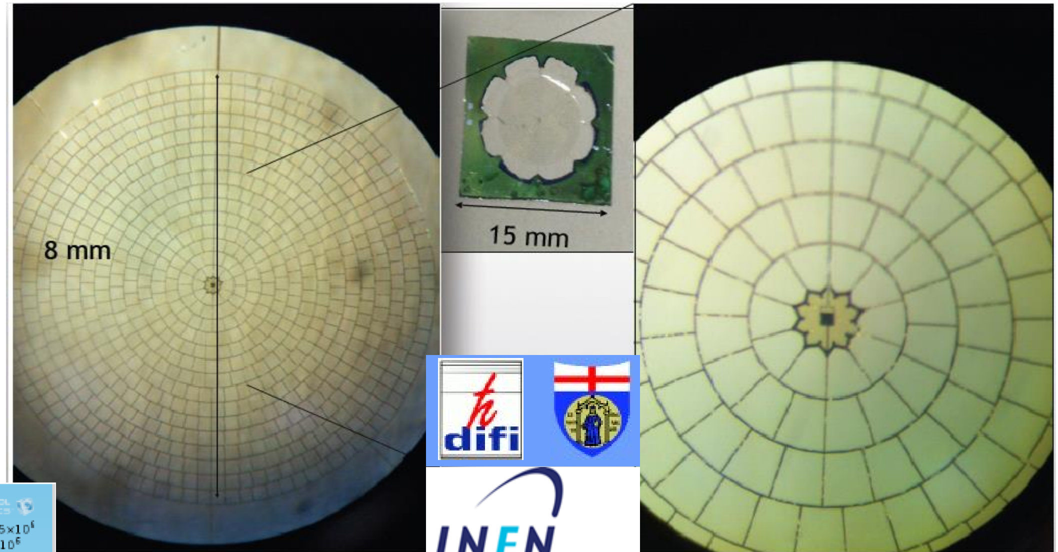
LSPE horns & bolo holders

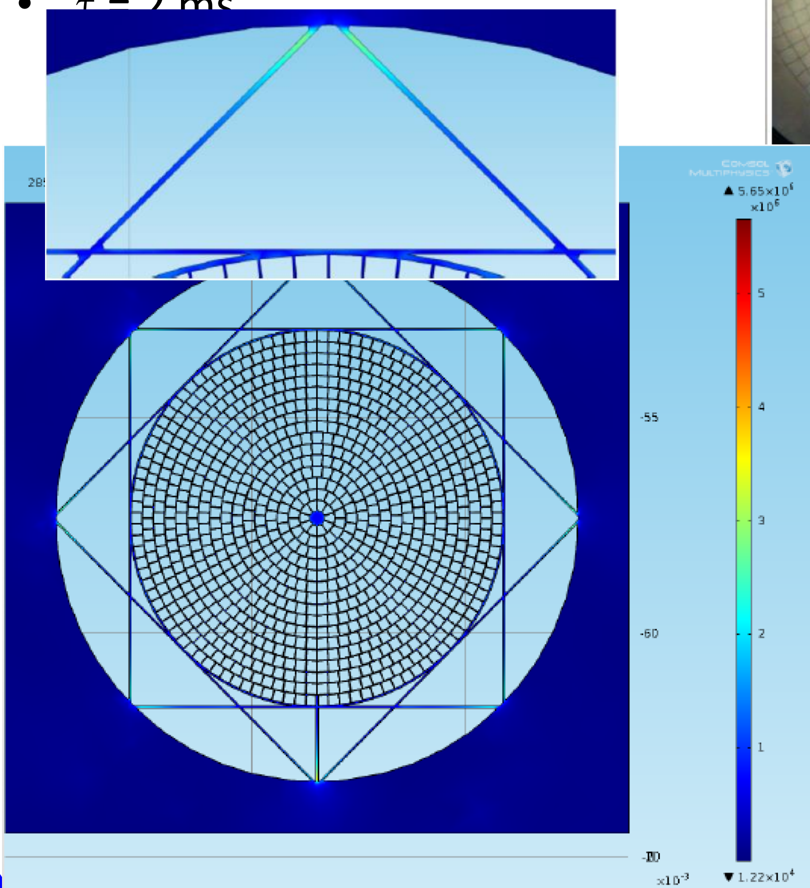
Large Throughput multimode detectors: 8800 modes collected by 330 sensors

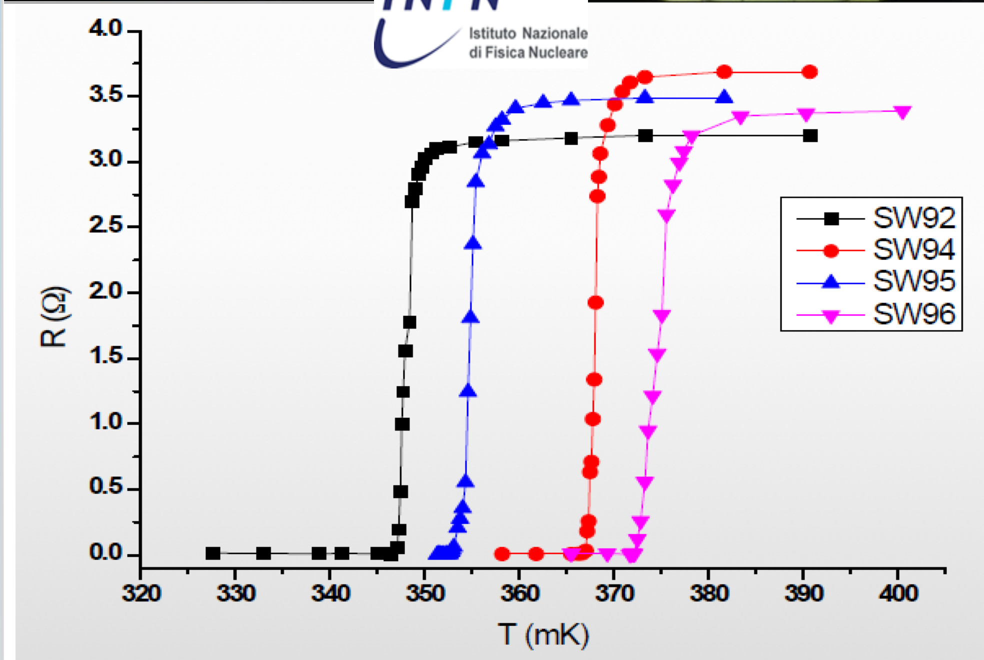
Focal plane detector flanges (gold plated Al6061, 40 cm side).

SWIPE - multimode absorbers & TES

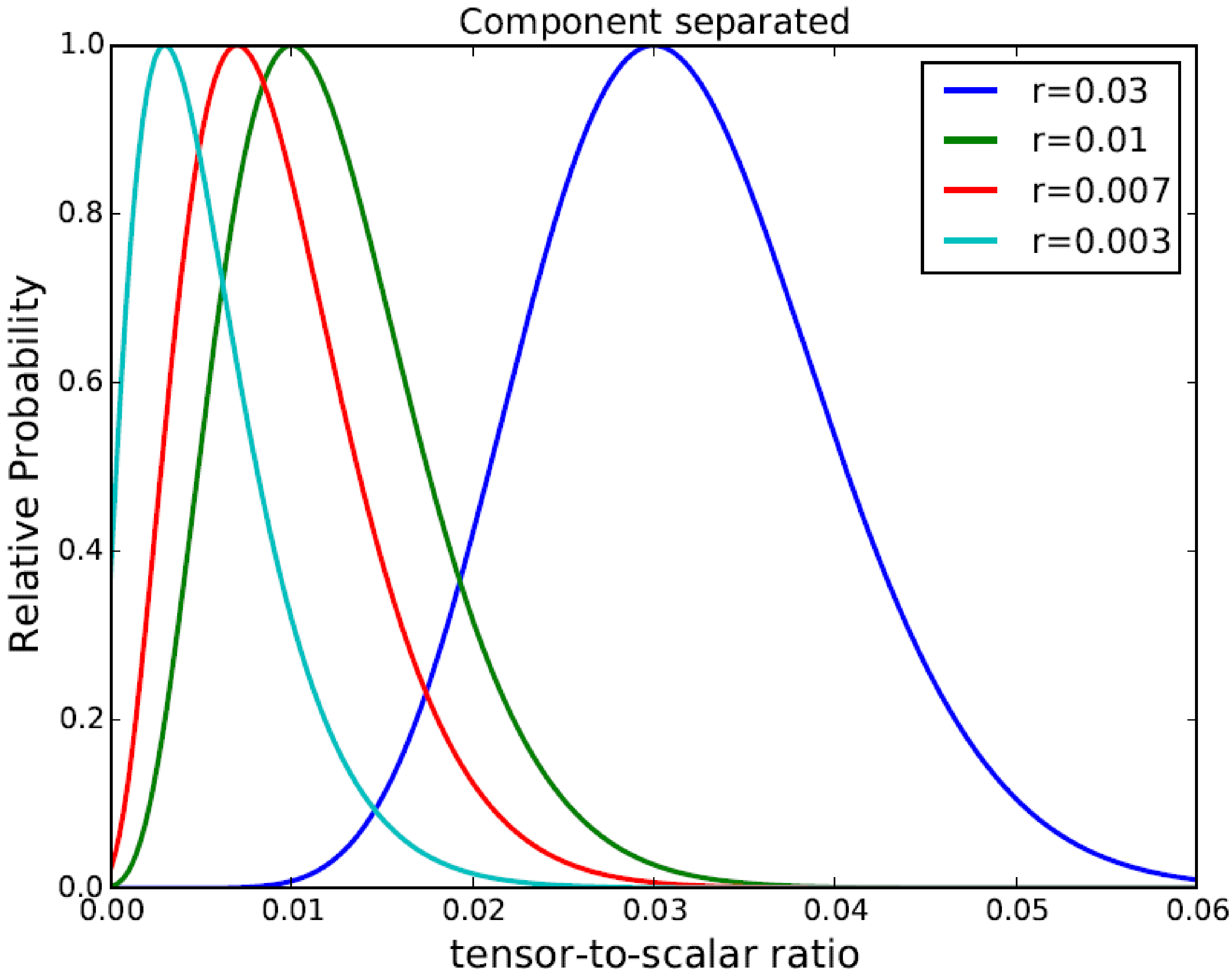
- The absorbers are large Si_3N_4 spider-webs (8 mm diameter, multimode)
- Sensors are Ti-Au TES
- Photon noise limited
- τ = 2 ms







SWIPE Performance Forecast (1^{st} flight)



L. Pagano, F. Piacentini

Current Status

- LSPE is fully funded by ASI and INFN
- STRIP will operate from the ground (Tenerife) covering the same sky as SWIPE
- STRIP and SWIPE in due course of development, consistent with a 1st launch opportunity from Svalbard (78°N) in Winter 2019/20 for SWIPE and start of data taking in 2019 for STRIP.
- Baseline science expected from (one flight + 1 year) is competitive with current gen B-mode experiments – and contributions to polarized foreground science will provide a great complement the CMB science.

OLIMPO

- The OLIMPO experiment is a first attempt at spectroscopic measurements of CMB anisotropy.
- A large balloon-borne telescope with a 4-bands photometric array and a plug-in room temperature spectrometer
- see http://planck.roma1.infn.it/olimpo for a collaborators list and full details on the mission
- **Main scientific targets:**
  - **SZ effect in clusters –> unbiased estimates of cluster parameters**
  - **Spectrum of CMB anisotropy –> anisotropic spectral distortions**

Latest γ interaction: clusters of galaxies

- Inverse Compton Effect for CMB photons against charged particles in the hot gas of clusters (same as y-type distortion)
- Cluster optical depth: $\tau = n\sigma \mathbf{l}$

  $\mathbf{l}$ = a few Mpc = 10^{25} cm

  $n < 10^{-3}$ cm^{-3}

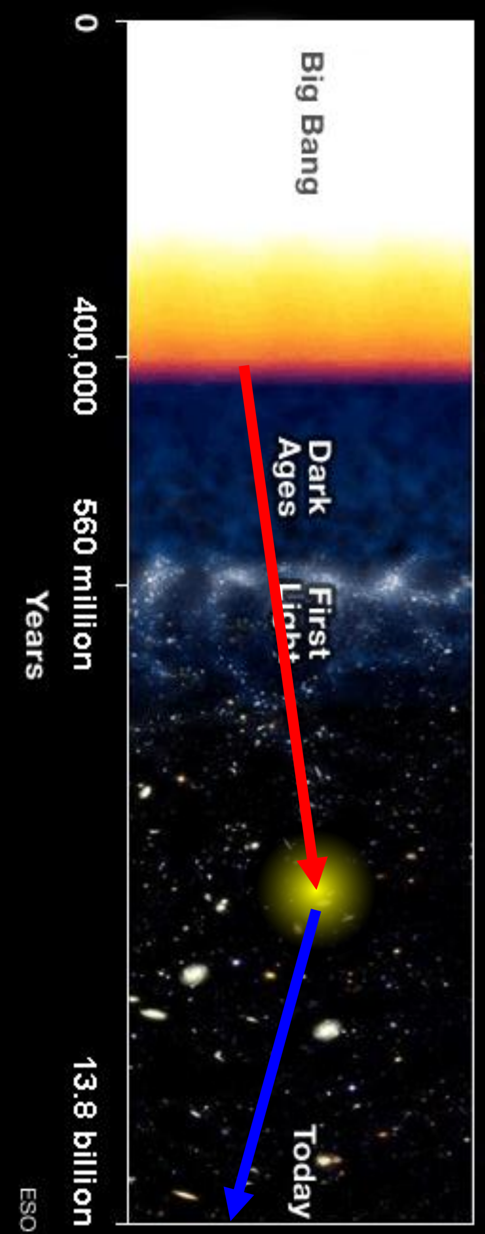
  $\sigma = 6.65\text{x}10^{-25}$ cm^2

- So $\tau = n\sigma \mathbf{l} < 0.01$: there is a 1% likelihood that a CMB photon crossing the cluster is scattered by an electron
- $E_{electron} \gg E_{photon}$, so the electron transfers energy to the photon. To first order, the energy gain of the photon is

$$\frac{\Delta \nu}{\nu} = \frac{kT_e}{m_e c^2} \approx \frac{5keV}{500keV} = 0.01$$

- The resulting CMB temperature anisotropy is

$$\frac{\Delta T}{T} \approx \tau \frac{\Delta \nu}{\nu} \approx 0.01 \times 0.01 = 10^{-4}$$



Sunyaev R., Zeldovich Y.B., 1972, Comm. Astrophys. Space Phys., 4, 173
Birkinshaw M., 1999, Physics Reports, 310, 97-195

A&A 538, A86 (2012)
DOI: 10.1051/0004-6361/201118062

Astronomy & Astrophysics

Low-resolution spectroscopy of the Sunyaev-Zel'dovich effect and estimates of cluster parameters

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Received 9 September 2011 / Accepted 8 November 2011

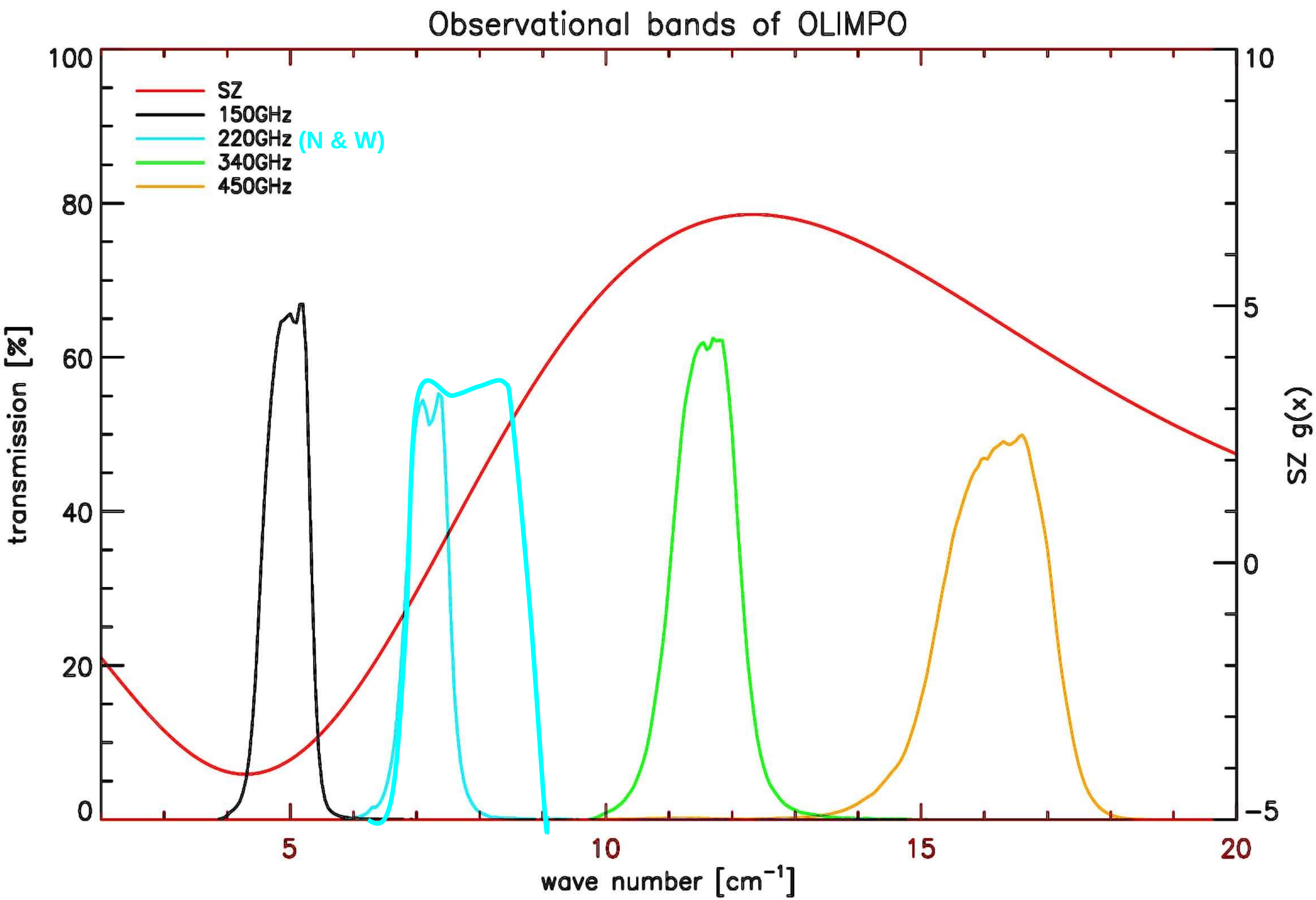
ABSTRACT

Context. The Sunyaev-Zel'dovich (SZ) effect is a powerful tool for studying clusters of galaxies and cosmology. Large mm-wave telescopes are now routinely detecting and mapping the SZ effect in a number of clusters, measure their comptonisation parameter and use them as probes of the large-scale structure and evolution of the universe.
Aims. We show that estimates of the physical parameters of clusters (optical depth, plasma temperature, peculiar velocity, non-thermal components etc.) obtained from ground-based multi-band SZ photometry can be significantly biased, owing to the reduced frequency coverage, to the degeneracy between the parameters and to the presence of a number of independent components larger than the number of frequencies measured. We demonstrate that low-resolution spectroscopic measurements of the SZ effect that also cover frequencies >270 GHz are effective in removing the degeneracy.
Methods. We used accurate simulations of observations with lines-of-sight through clusters of galaxies with different experimental configurations (4-band photometers, 6-band photometer, multi-range differential spectrometer, full coverage spectrometers) and dif-

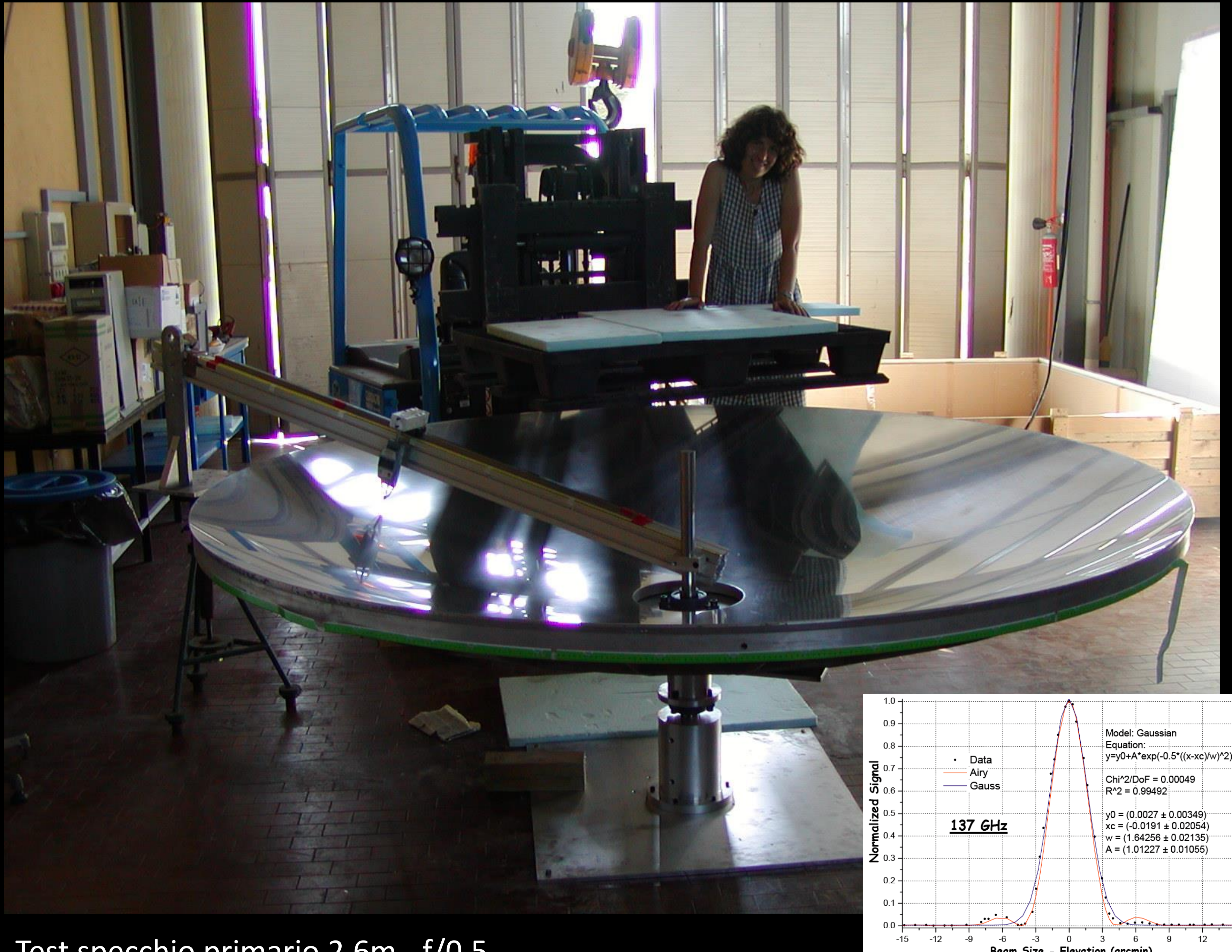
OLIMPO

- Long Duration Balloon experiment for mm & sub-mm astronomy
- Operates from the stratosphere - launch from Svalbard
- Cassegrain telescope, 2.6m aperture
- Multifrequency arrays of bolometers
- Low resolution spectrometer

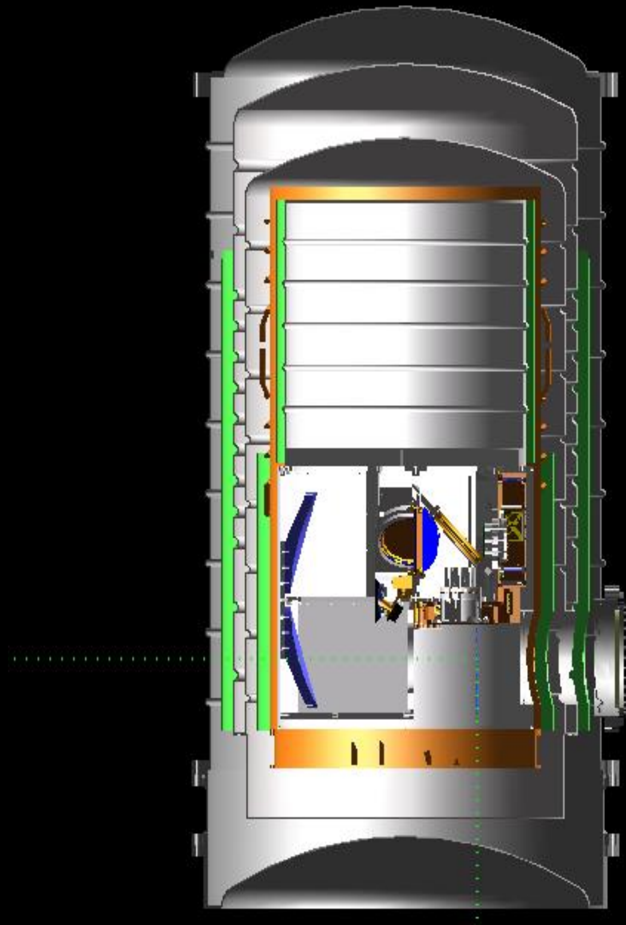
ch	ν_{eff} [GHz]	$\Delta\nu_{FWHM}$ [GHz]	Res. [‘]
I	148.4	21.5	4.2
II	215.4	20.6	2.9
III	347.7	33.1	1.8
IV	482.9	54.2	1.8



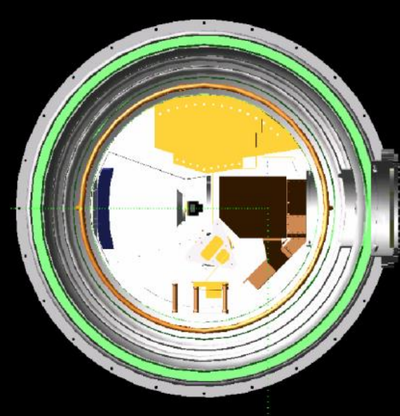
Observational bands of OLIMPO
SZ
150GHz
220GHz (N & W)
340GHz
450GHz
transmission [%]
0
20
40
60
80
100
SZ g(x)
10
5
0
−5
5
10
15
20
wave number [cm⁻¹]

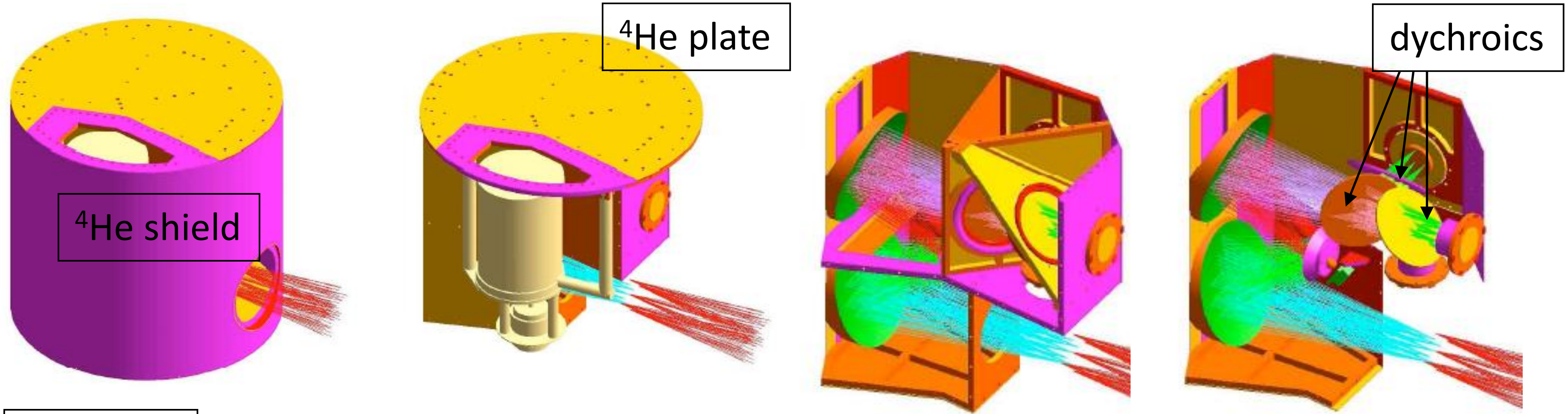


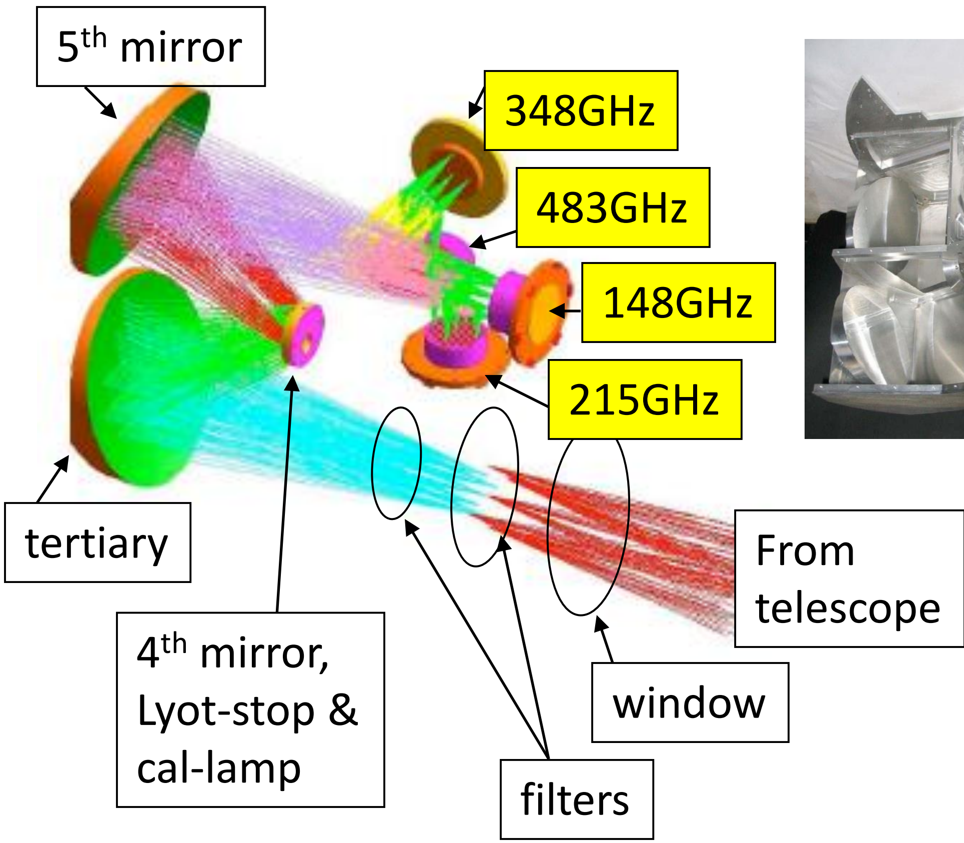
Test specchio primario 2.6m - f/0.5



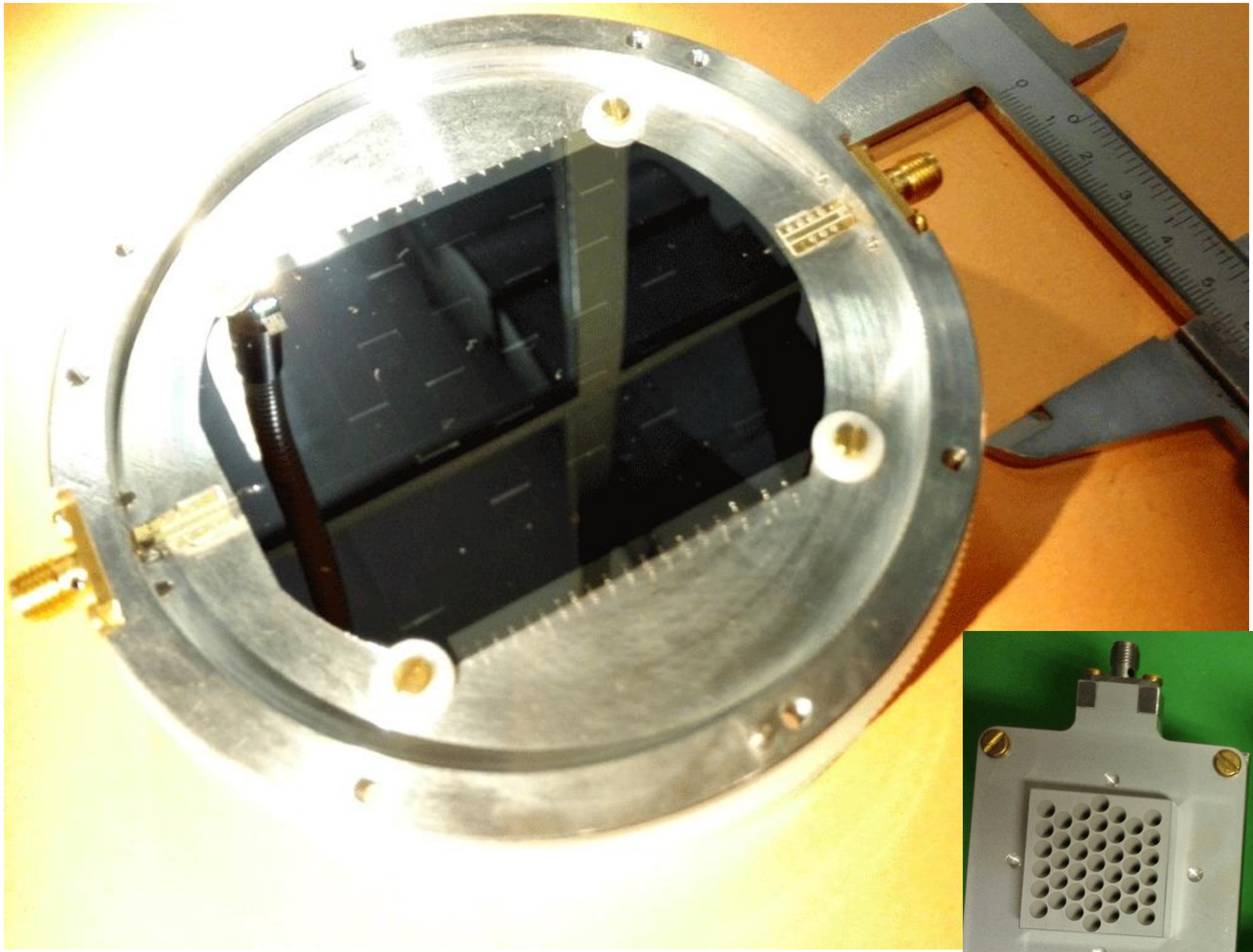
- 0.3K cryostat (made in Sapienza)
- 65L superfluid ^{4}He
- 70L liquid N
- 40LSTP ^{3}He refrigerator
- 50L experimental volume
- Hold time – 15 days @ 0.3K







OLIMPO: Cold Optics and Arrays

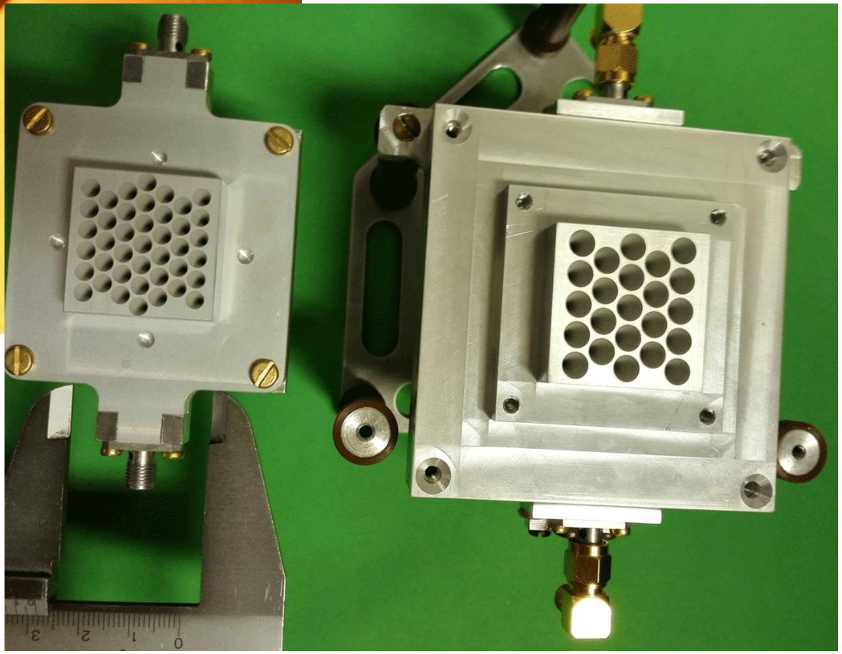


OLIMPO
Kinetic Inductance
Detectors

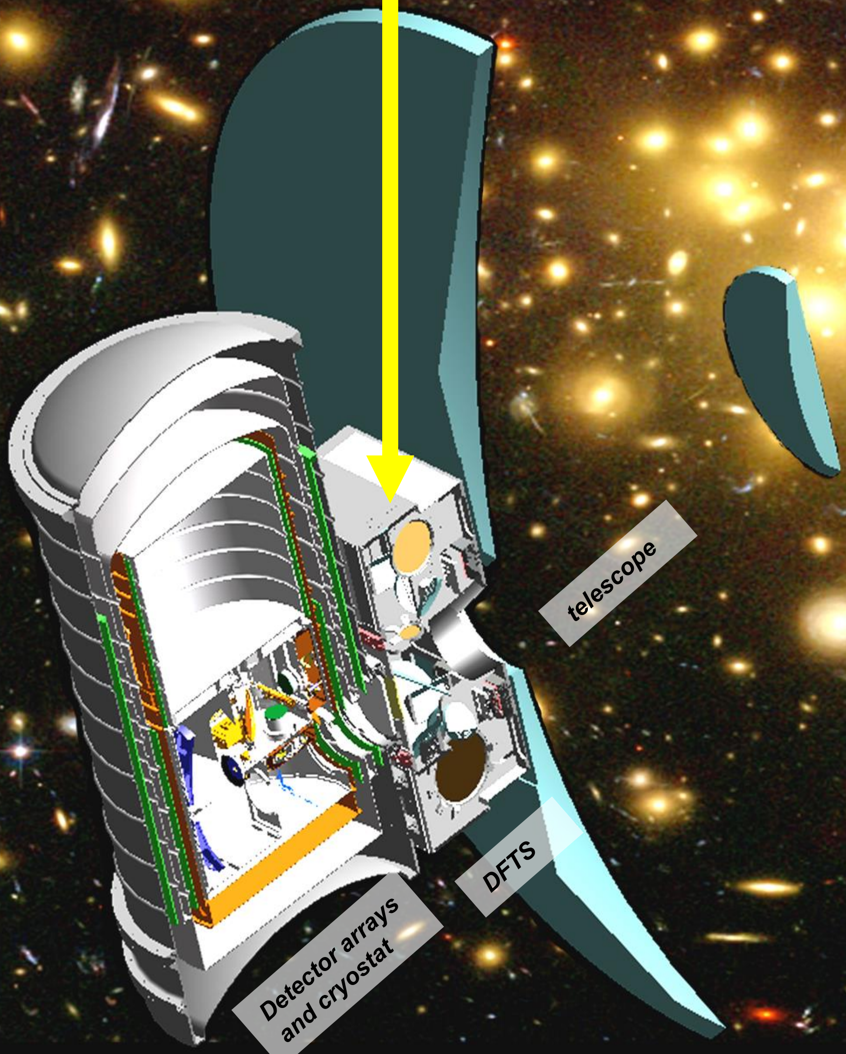
AL LEKIDs @
140, 200, 340, 480 GHz

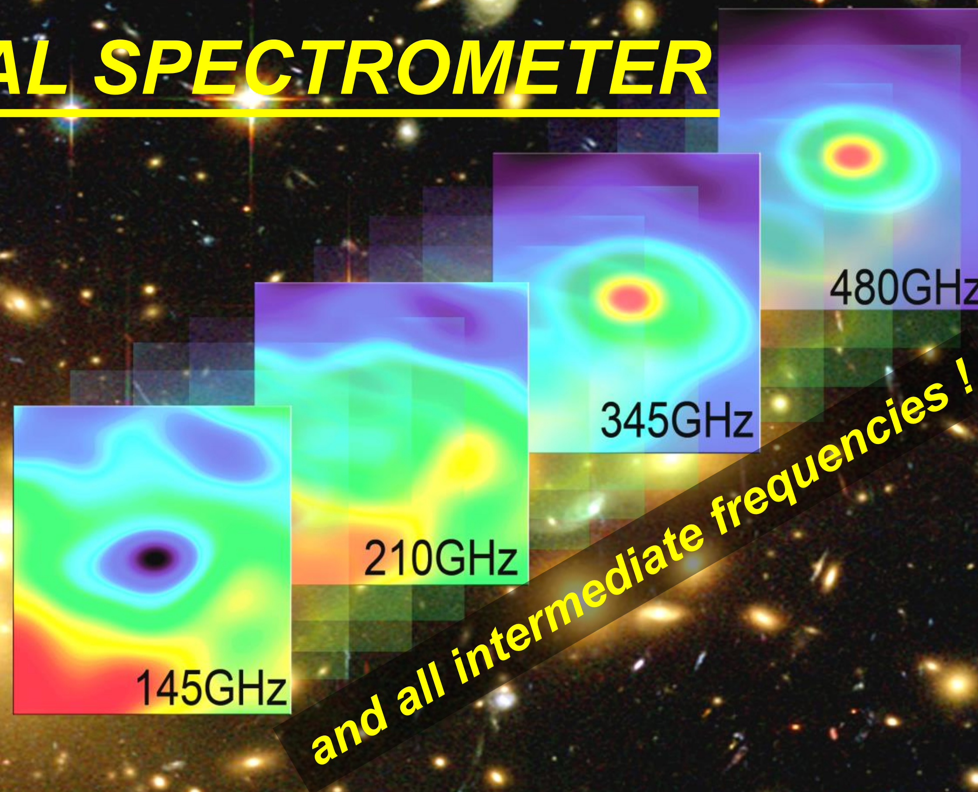
100-600 MHz res.

CNR-IFN + Sapienza



OLIMPO's DIFFERENTIAL SPECTROMETER

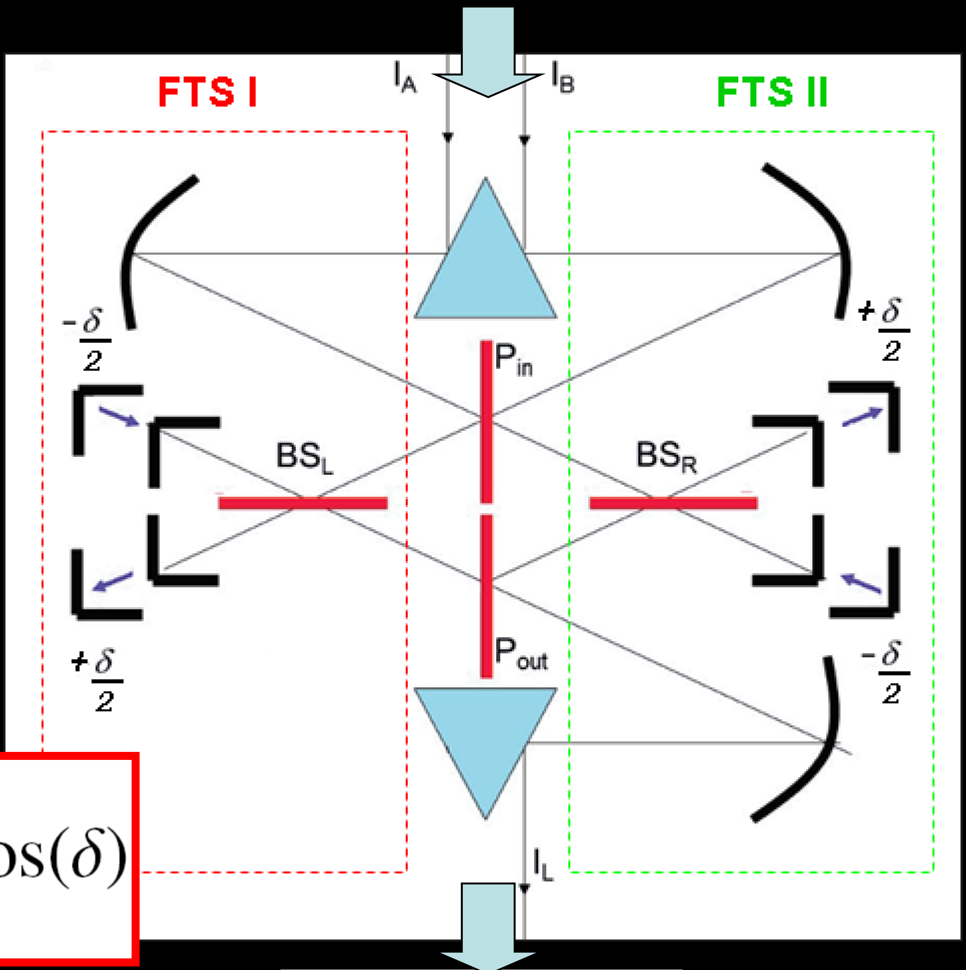




A Differential Fourier Transform Spectrometer (DFTS).
Similar to COBE-FIRAS but…
.. rather than measuring the brightness difference between the sky and an internal blackbody, it measures the **brightness difference between two directions in the sky**

- **The instrument is based on a double Martin Puplett Interferometer configuration to avoid the loss of half of the signal.**
- **A wedge mirror splits the sky image in two halves I_a and I_b, used as input signals for both inputs of the two FTS's.**
- **In the FTSs the beam to be analyzed is split in two halves, and a variable optical path difference is introduced.**

Olimpo Telescope



Olimpo Cryostat

See Schillaci et al. A&A 565, A125, 2014 for a detailed description of the instrument. The output brightness is

$$I_L = \frac{1}{2}(I_a + I_b) + \frac{1}{2}(I_a - I_b)\cos(\delta)$$

δ = variable phase shift, introduced by the variable optical path difference.

Only the *difference* between the two input brightnesses is modulated by the variable optical path difference.

A&A 565, A125 (2014)
DOI: 10.1051/0004-6361/201423631

Astronomy & Astrophysics

Efficient differential Fourier-transform spectrometer for precision Sunyaev-Zel'dovich effect measurements

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Received 13 February 2014 / Accepted 11 April 2014

ABSTRACT

Context. Precision measurements of the Sunyaev-Zel'dovich effect in clusters of galaxies require excellent rejection of common-mode signals and wide frequency coverage.

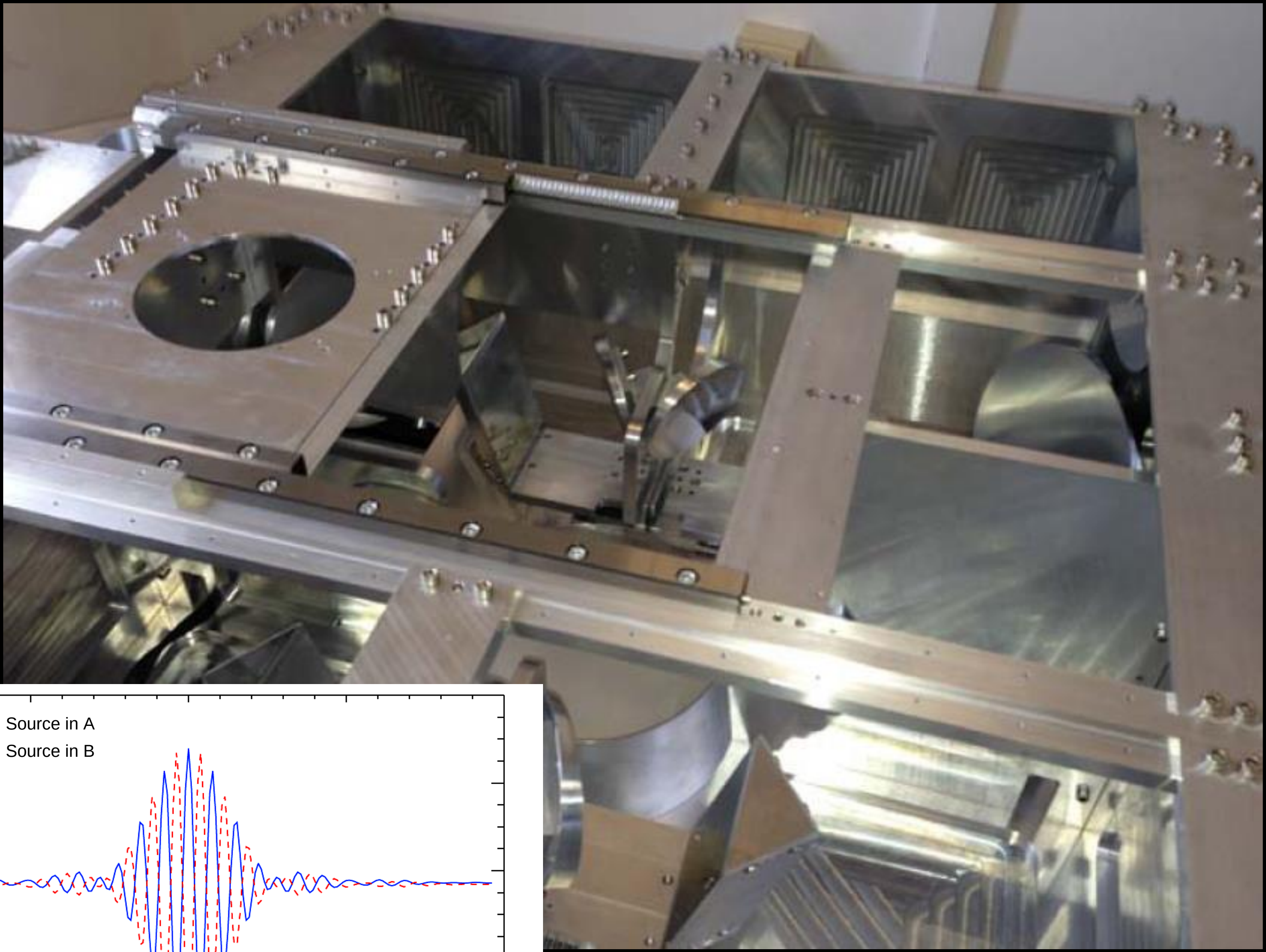
Aims. We describe an imaging, efficient, differential Fourier transform spectrometer (FTS), optimized for measurements of faint brightness gradients at millimeter wavelengths.

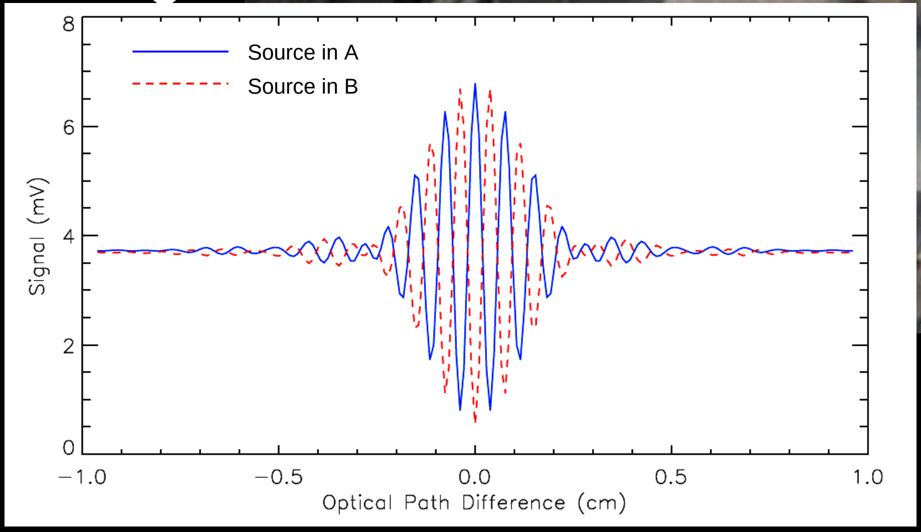
Methods. Our instrument is based on a Martin-Puplett interferometer (MPI) configuration. We combined two MPIs working synchronously to use the whole input power. In our implementation the observed sky field is divided into two halves along the meridian, and each half-field corresponds to one of the two input ports of the MPI. In this way, each detector in the FTS focal planes measures the difference in brightness between two sky pixels, symmetrically located with respect to the meridian. Exploiting the high common-mode rejection of the MPI, we can measure low sky brightness gradients over a high isotropic background.

Results. The instrument works in the range $\sim$1–20 cm^{-1} (30–600 GHz), has a maximum spectral resolution $1/(2\,\mathrm{OPD}) = 0.063$ cm^{-1} (1.9 GHz), and an unvignetted throughput of 2.3 cm^{2}sr. It occupies a volume of $0.7 \times 0.7 \times 0.33$ m^3 and has a weight of 70 kg. This design can be implemented as a cryogenic unit to be used in space, as well as a room-temperature unit working at the focus of suborbital and ground-based mm-wave telescopes. The first in-flight test of the instrument is with the OLIMPO experiment on a stratospheric balloon; a larger implementation is being prepared for the Sardinia radio telescope.

Key words. cosmic background radiation – instrumentation: spectrographs – techniques: spectroscopic – galaxies: clusters: general

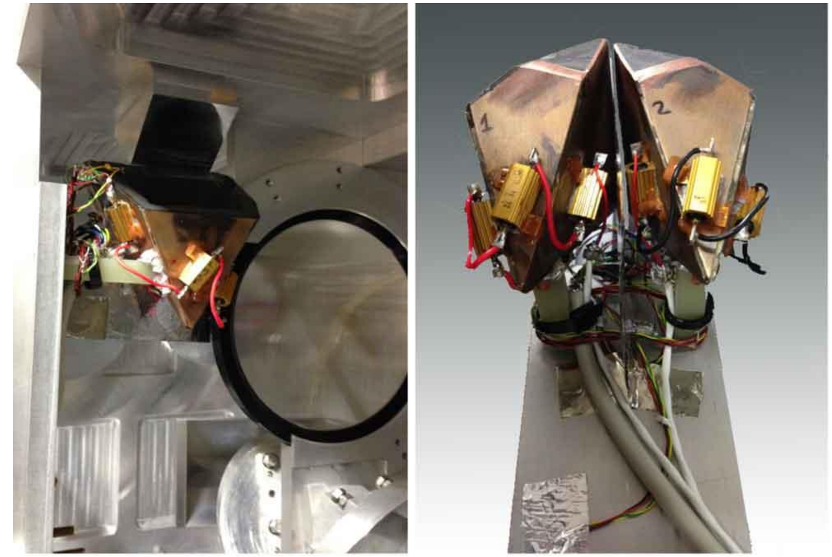
The real thing….
and measured interferograms

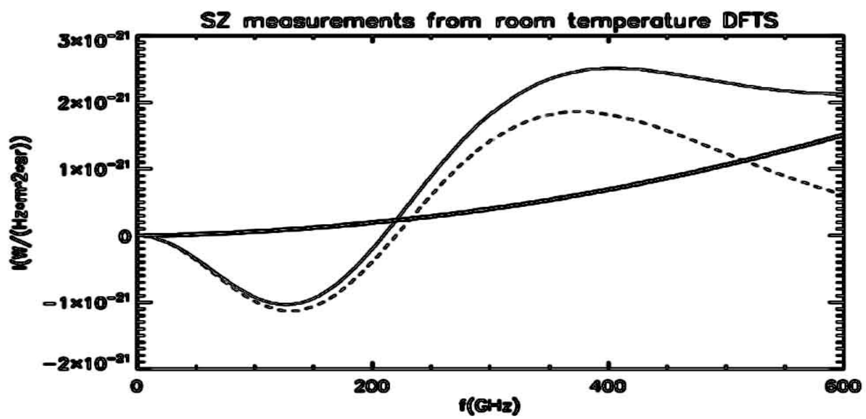


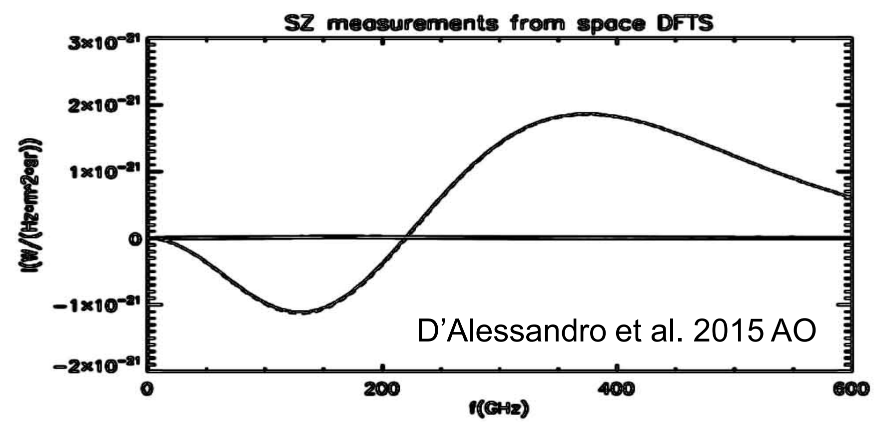


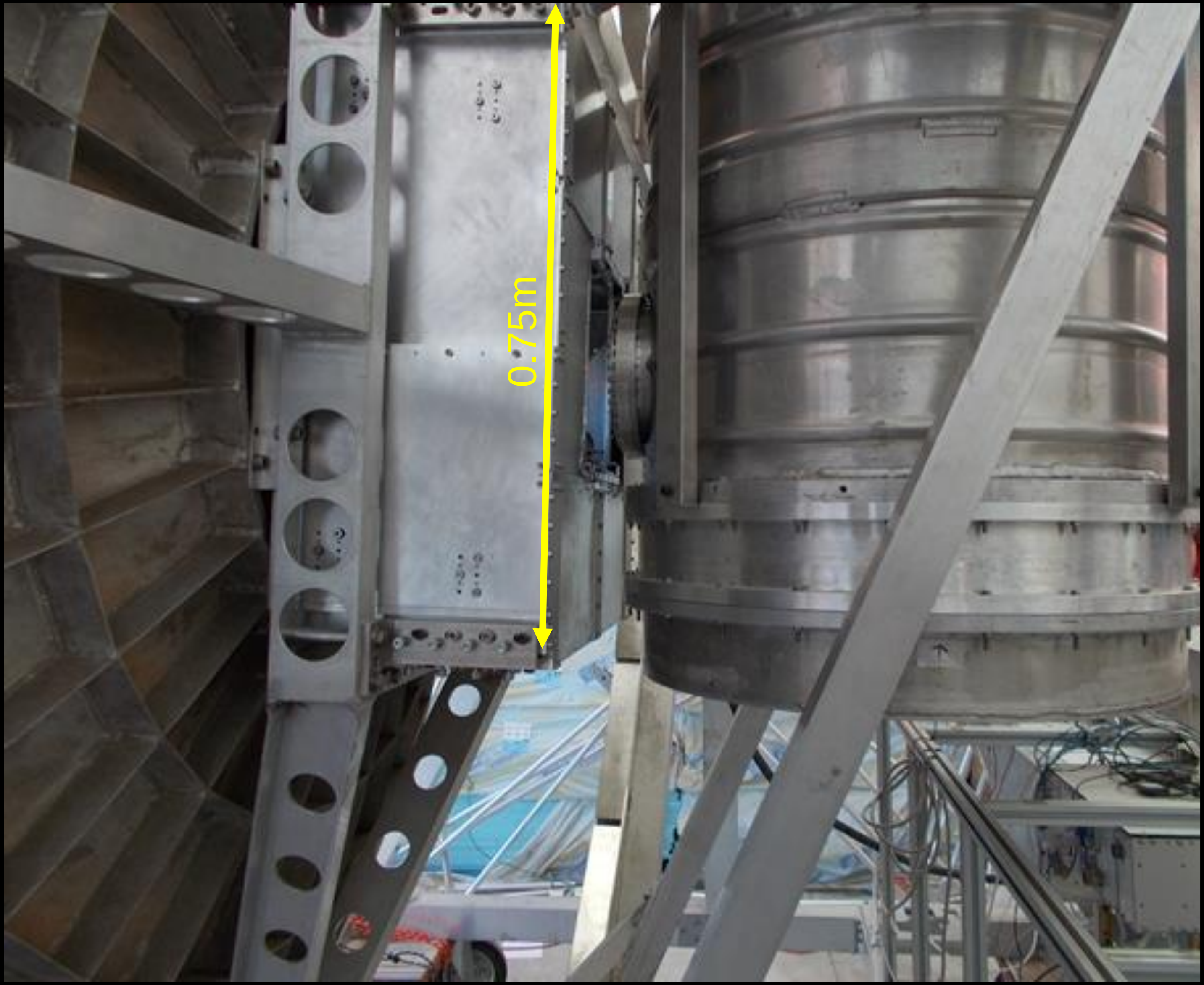
CMRR

- The differential signal (SZ) is much smaller than the common mode, which is CMB + instrument emissivity (a few %) + residual atmosphere.
- We have measured the common-mode rejection ratio of the FTS using custom temperature-controlled blackbody sources at the two entrance ports of the FTS.
- It turns out that the CMRR of our DFTS is <-55dB
- This means that the offset is less than the SZ signal in OLIMPO, and will be much less than the SZ signal in a cryogenic/space implementation.



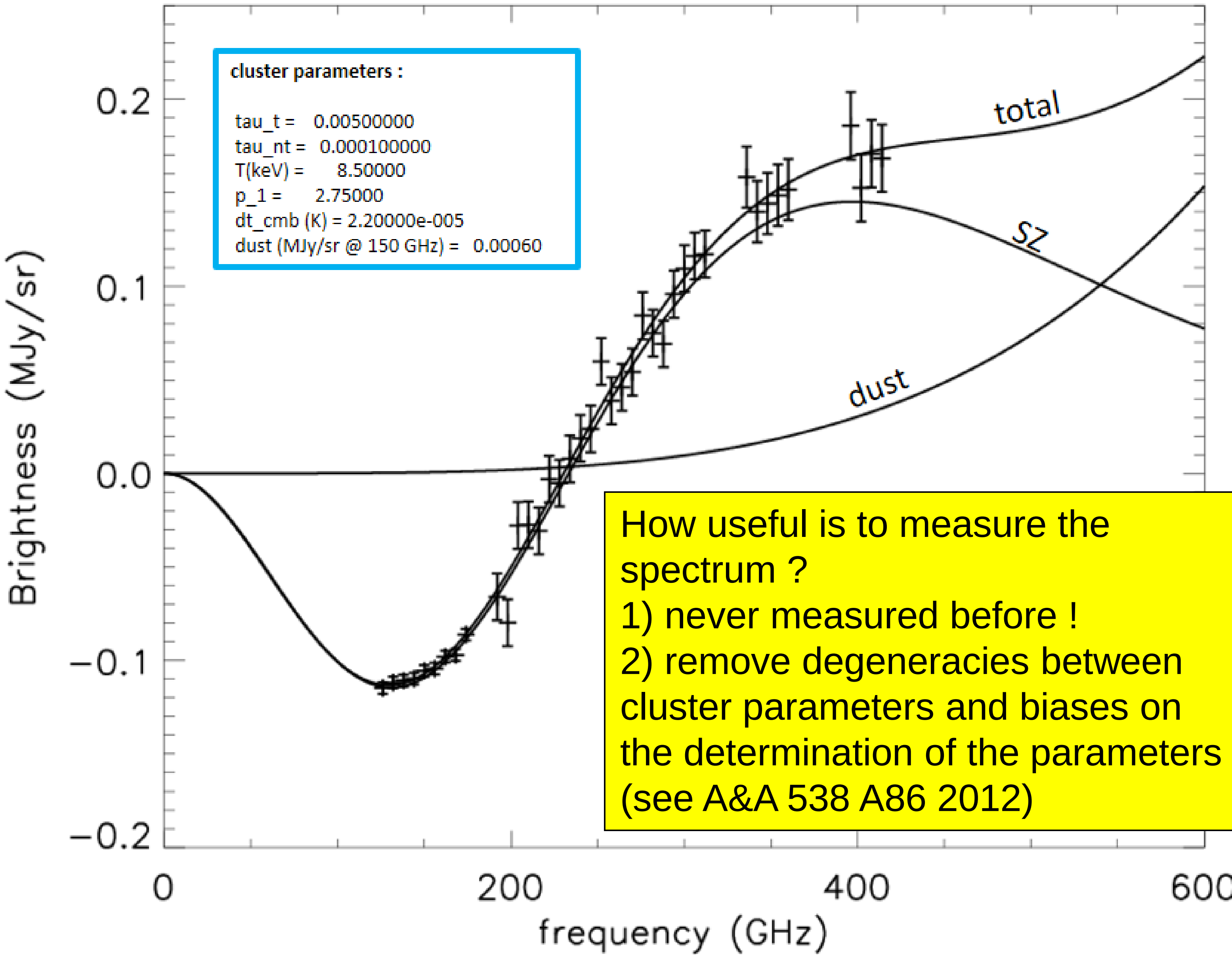






Telescope / primary mirror DFTS cryostat / detectors arrays

Main components of OLIMPO integrated on the payload

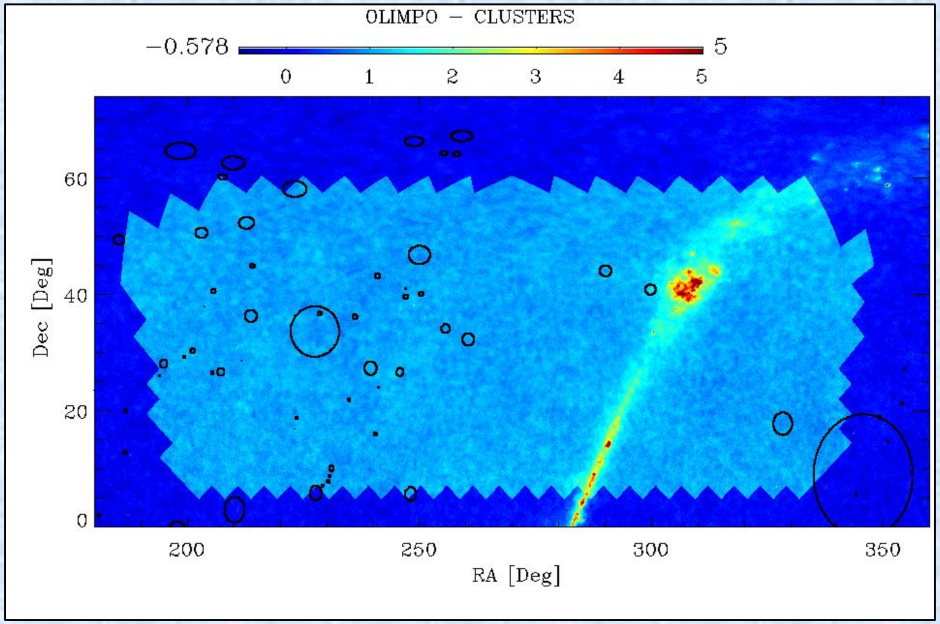


How useful is to measure the spectrum ?

1) never measured before !

2) remove degeneracies between cluster parameters and biases on the determination of the parameters (see A&A 538 A86 2012)

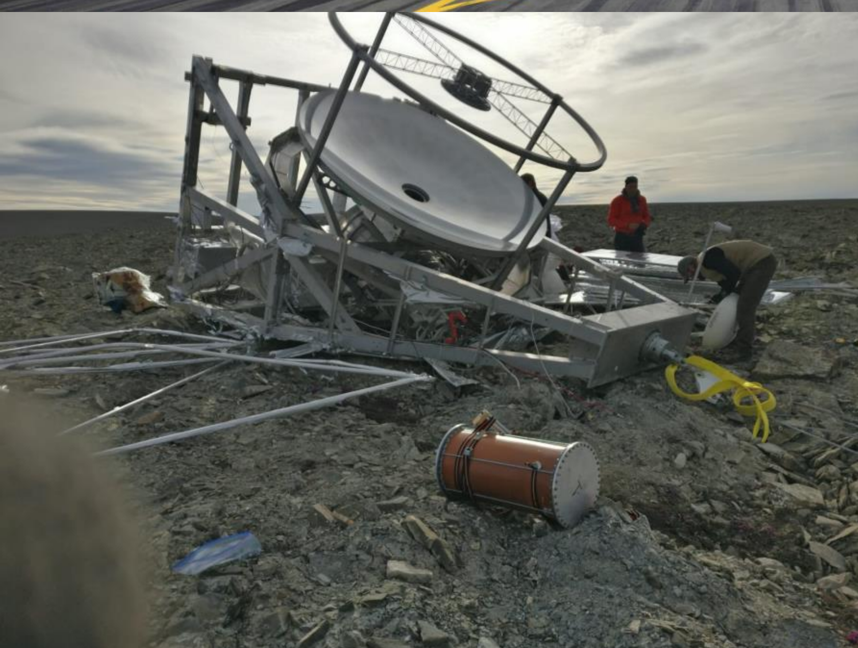
Observation Program



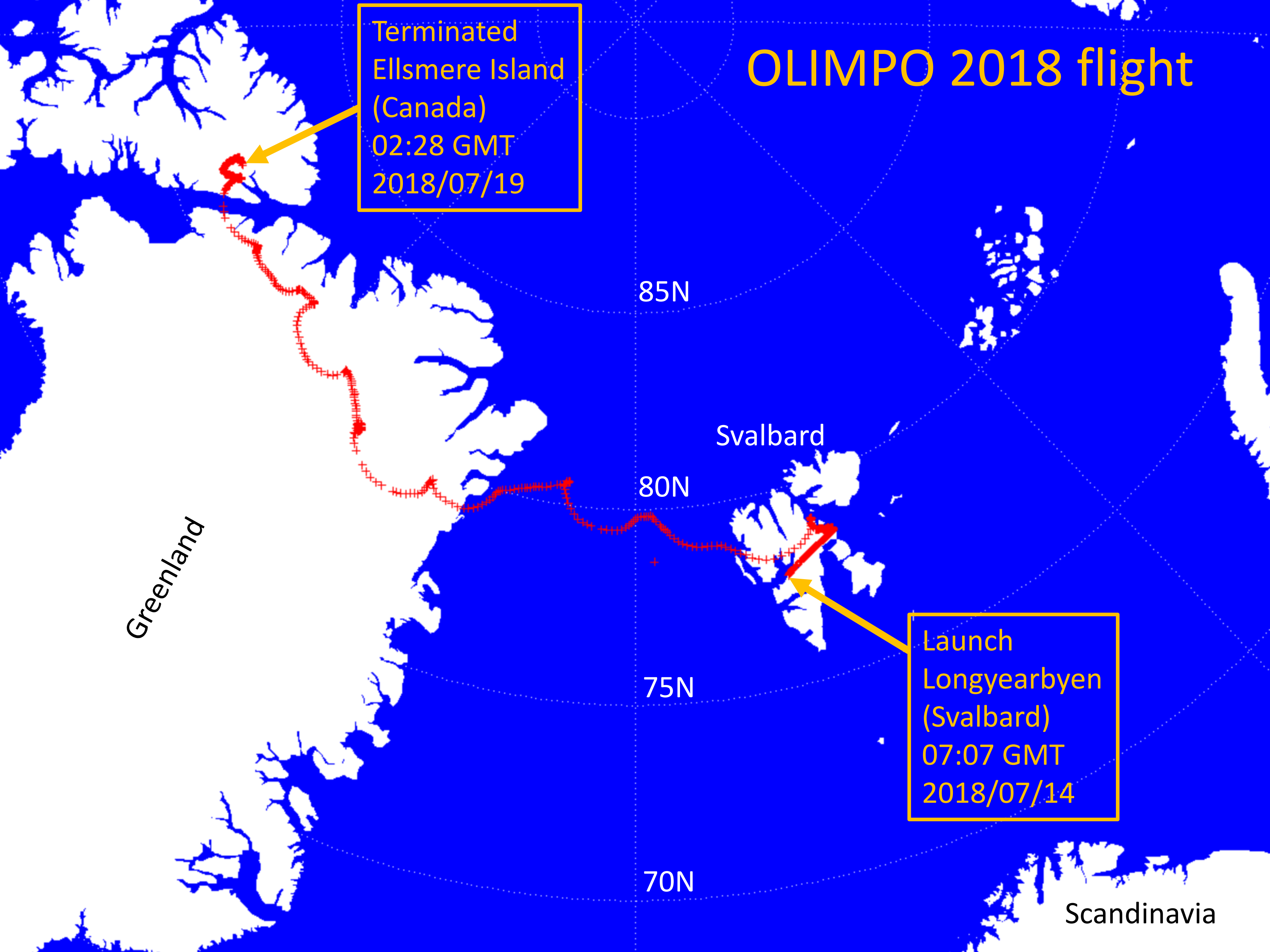
- In a circumpolar summer long duration flight (>200h) we plan to observe 40 selected clusters and to perform a blind deep integration on a clean sky region
- We have optimized the observation plan distributing the integration time among the different targets according to their brightness and diurnal elevation.

ind	ID	RA	Dec	TIME	frac	NAME
0	1	212.83	52.2	18000	1	3C295CLUSTER
1	40	194.95	27.98	3600	0	ABELL1656
2	43	203.13	50.51	3600	1	ABELL1758
3	44	205.48	26.37	3600	1	ABELL1775
4	45	207.25	26.59	3600	1	ABELL1795
5	48	216.72	16.68	18000	1	ABELL1913
6	49	223.18	16.75	11360.88	1.27	ABELL1983
7	50	223.63	18.63	18000	1	ABELL1991
8	51	223.21	58.05	5640.53	1.28	ABELL1995
9	53	227.56	33.53	18000	1	ABELL2034
10	54	229.19	7	3600	1	ABELL2052
11	55	230.76	8.64	3600	1	ABELL2063
12	56	234.95	21.77	3600	1	ABELL2107
13	57	236.25	36.06	18000	1	ABELL2124
14	58	239.57	27.23	3600	1	ABELL2142
15	59	240.57	15.9	3600	1	ABELL2147
16	61	247.04	40.91	18000	1	ABELL2197
17	62	247.15	39.52	3600	1	ABELL2199
18	63	248.19	5.58	3600	1	ABELL2204
19	65	250.09	46.69	3600	1	ABELL2219
20	66	255.68	34.05	7230	1.49	ABELL2244
21	69	260.62	32.15	18000	1	ABELL2261
22	70	290.19	43.96	3600	1	ABELL2319
23	71	328.39	17.67	3600	1	ABELL2390
24	98	241.24	23.92	13045.75	1.1	AWM4
25	100	299.87	40.73	18000	1	CYGNUSA
26	101	201.2	30.19	18000	1	GHO1322+3027
27	102	241.11	43.08	18000	1	GHO1602+4312
28	107	230.46	7.71	3600	1	MKW03S
29	120	228.61	36.61	18000	1	MS1512.4+3647
30	121	245.9	26.56	13147.05	1.1	MS1621.5+2640
31	128	201.15	13.93	18000	0	NGC5129GROUP
32	134	199.34	29.19	18000	1	RDCSJ1317+2911
33	143	231.17	9.96	18000	1	RXJ1524.6+0957
34	150	211.73	28.57	18000	1	WARPJ1406.9+2834
35	151	213.8	36.2	18000	1	WARPJ1415.1+3612
36	161	194.02	25.95	18000	0	[VMF98]128
37	162	203.74	37.84	18000	1	[VMF98]139
38	163	205.71	40.47	18000	1	[VMF98]148
39	164	214.12	44.78	18000	1	[VMF98]158
40	165	250.47	40.03	18000	1	[VMF98]184

- OLIMPO launched ! 07:09 GMT, 14/Jul/2018, Longyearbyen (Svalbard)
- 5 days flight
- Great performance of Kinetic Inductance Detector Arrays, Telescope and Spectrometer.
- First Validation of KIDs in space conditions




agenzia spaziale
italiana

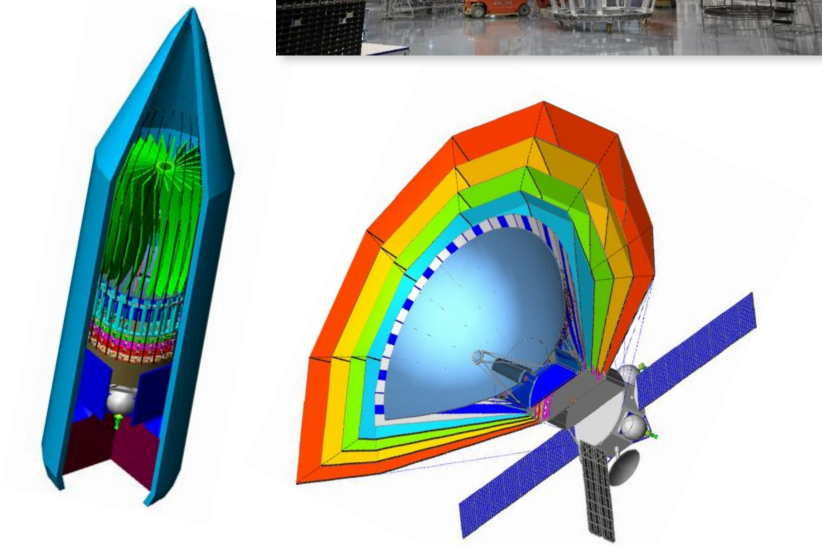

OLIMPO 2018 flight
Terminated
Ellsmere Island
(Canada)
02:28 GMT
2018/07/19
Launch
Longyearbyen
(Svalbard)
07:07 GMT
2018/07/14
85N
80N
75N
70N
Svalbard
Greenland
Scandinavia

- The OLIMPO spectrometer is the prototype for a similar Differential Fourier Transform Spectrometer to be flown on the Millimetron space mission ….

- So, once again, stratospheric balloons are effectively used as pathfinders for satellite experiments.

OLIMPO as a precursor of forthcoming space-missions

- OLIMPO is a demonstrator of new detectors, to be used in forthcoming missions (PRISM 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).



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- Range of wavelengths: 0.01 – 20 mm
- Bolometric sensitivity (λ0.3mm, 1h integration): 5×10^{-9} Jy
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- Interferometer beam: 10^{-9} arcsec

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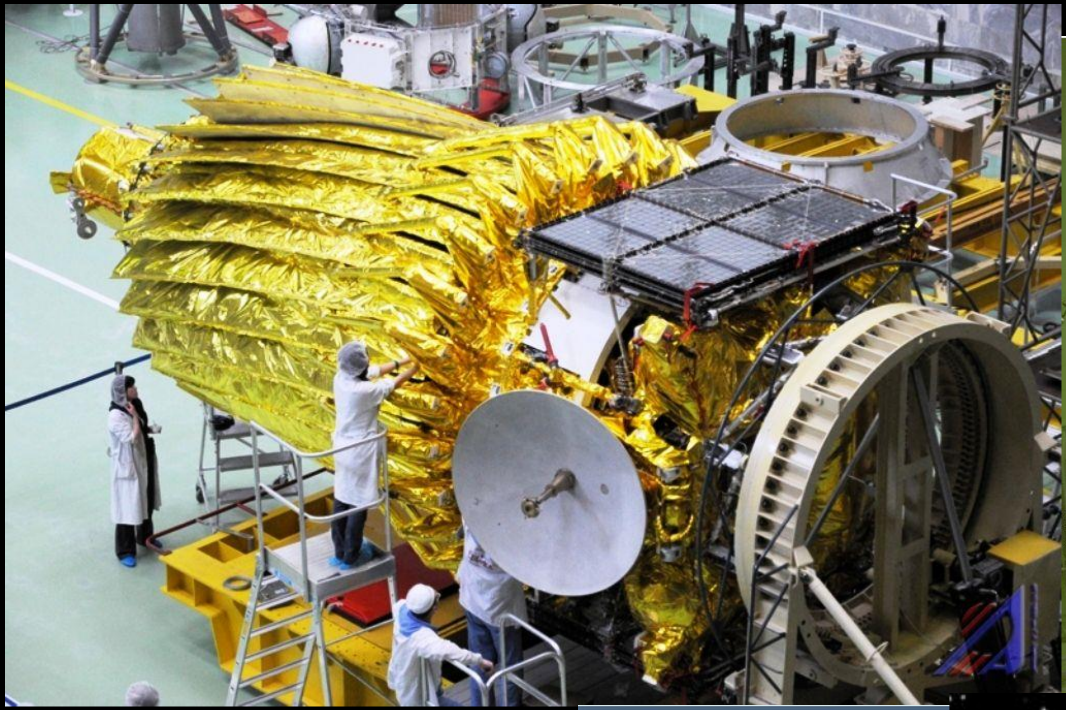
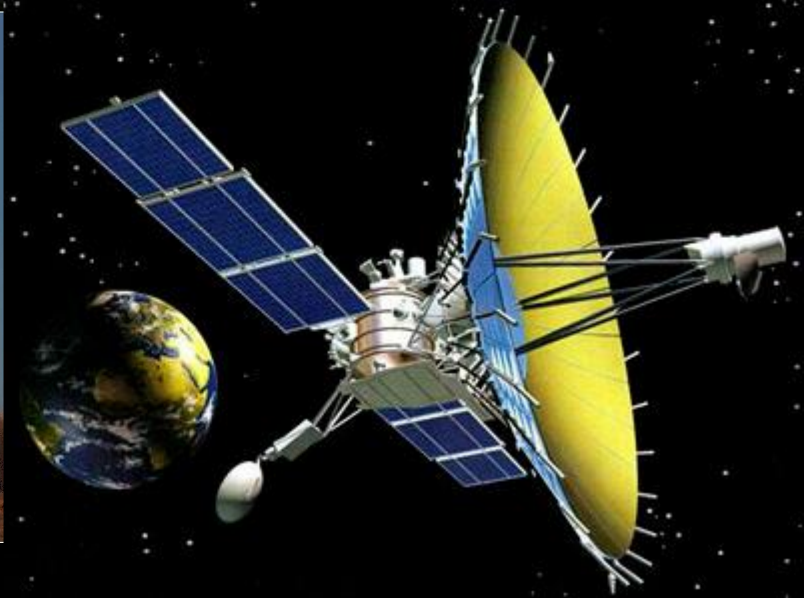
SAPIENZA UNIVERSITÀ DI ROMA

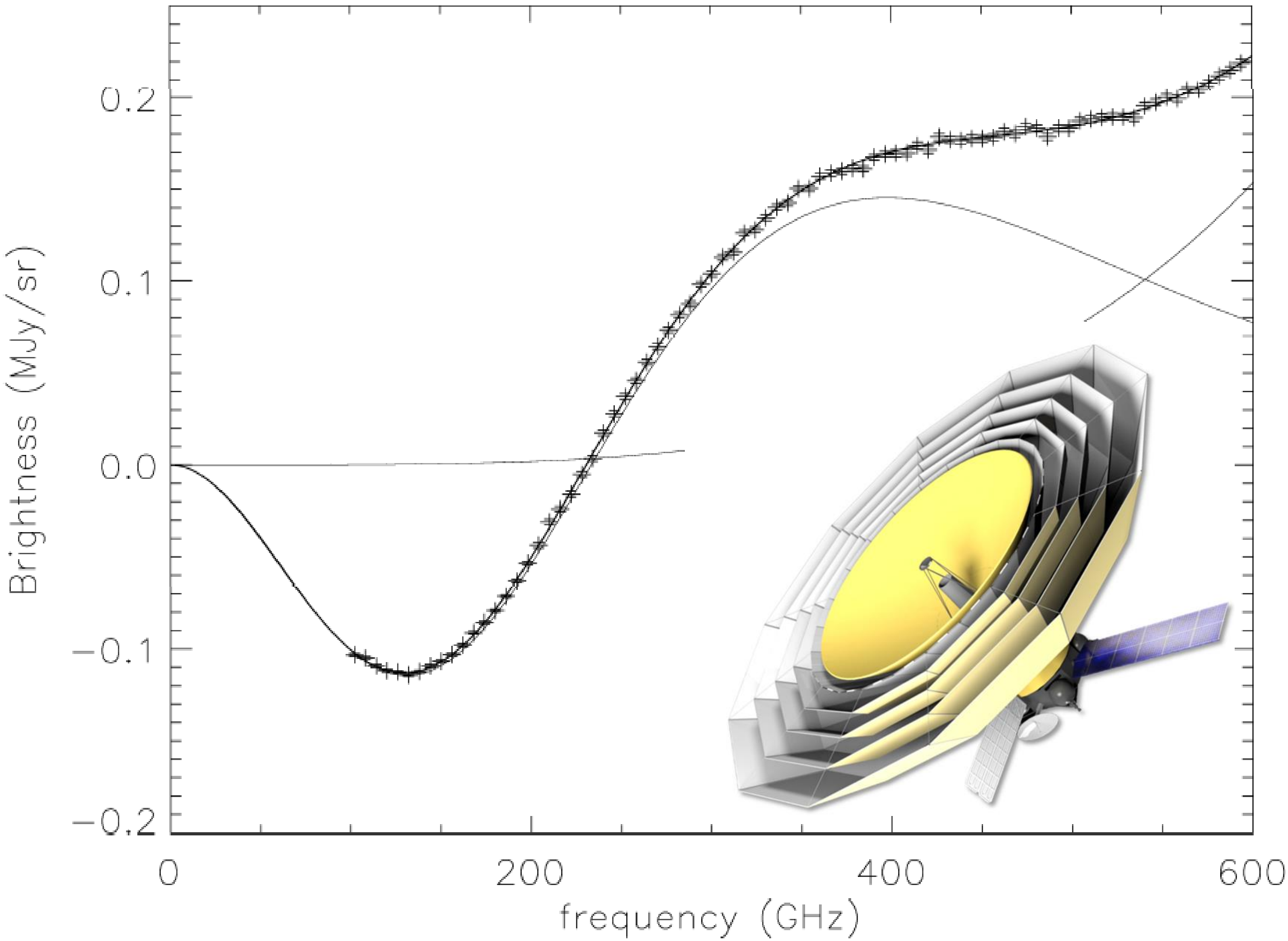


РадиоАстрон



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)



Conclusions

- Balloons offer a great deal of opportunities for CMB research.
- They will add reliability to ground based B-modes measurements (waiting for a final space mission, for which they should be used to qualify instruments / detectors / methods)
- Original/new satellite-based science can and should be first implemented using balloon-borne experiments.

LSPE/SWIPE:
large polarizer and HWP

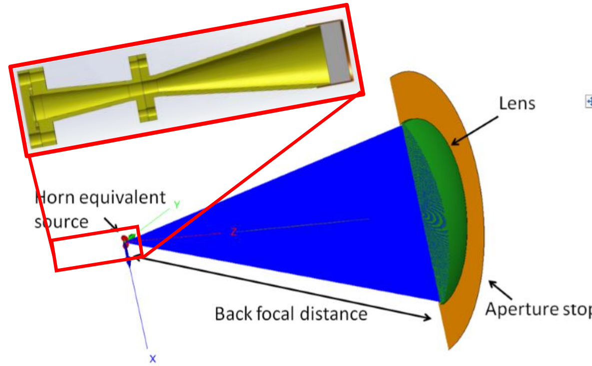
- Made in Cardiff (G.Pisano P. Ade, C. Tuker)
- Production phase started for polarizer and HWP, thermal filters.

50 cm diameter polarizer – defining principal angle – accurate measurement of angles.

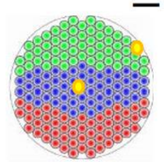
CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

LSPE/SWIPE: multimode optical system

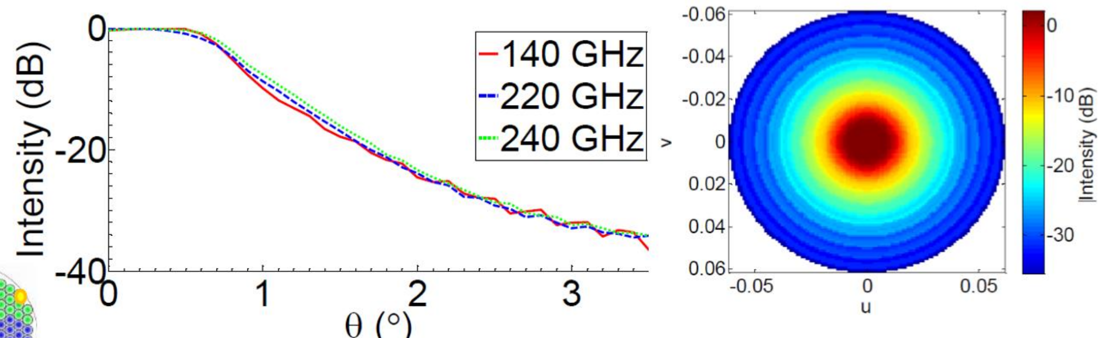
- Whole system multi.mode EM simulation described in: Legg, Lamagna, Coppi, de Bernardis, Giuliani, Gualtieri, Marchetti, Masi, Pisano, Maffei, *Development of the multi-mode horn-lens configuration for the LSPE-SWIPE B-mode experiment* Proc. SPIE 9914, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VIII, 991414 doi:10.1117/12.2232400

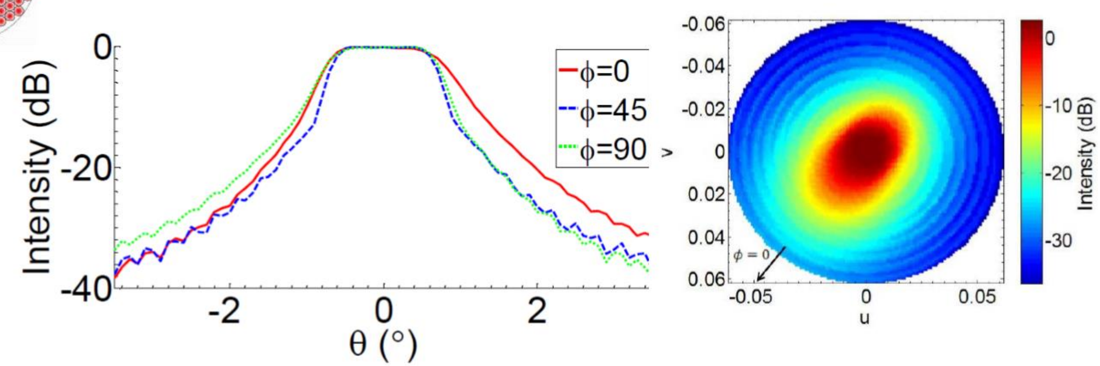


Diameter (mm)	428
Centre thickness (mm)	60
Focal length (mm)	805
Refractive index	1.57
Conic constant	-0.54
Cold stop diameter (mm)	420



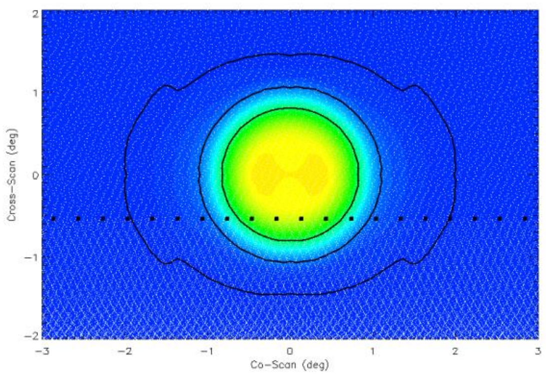
Coupling analysis – small angle beams
L. Lamagna, S. Legg





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.

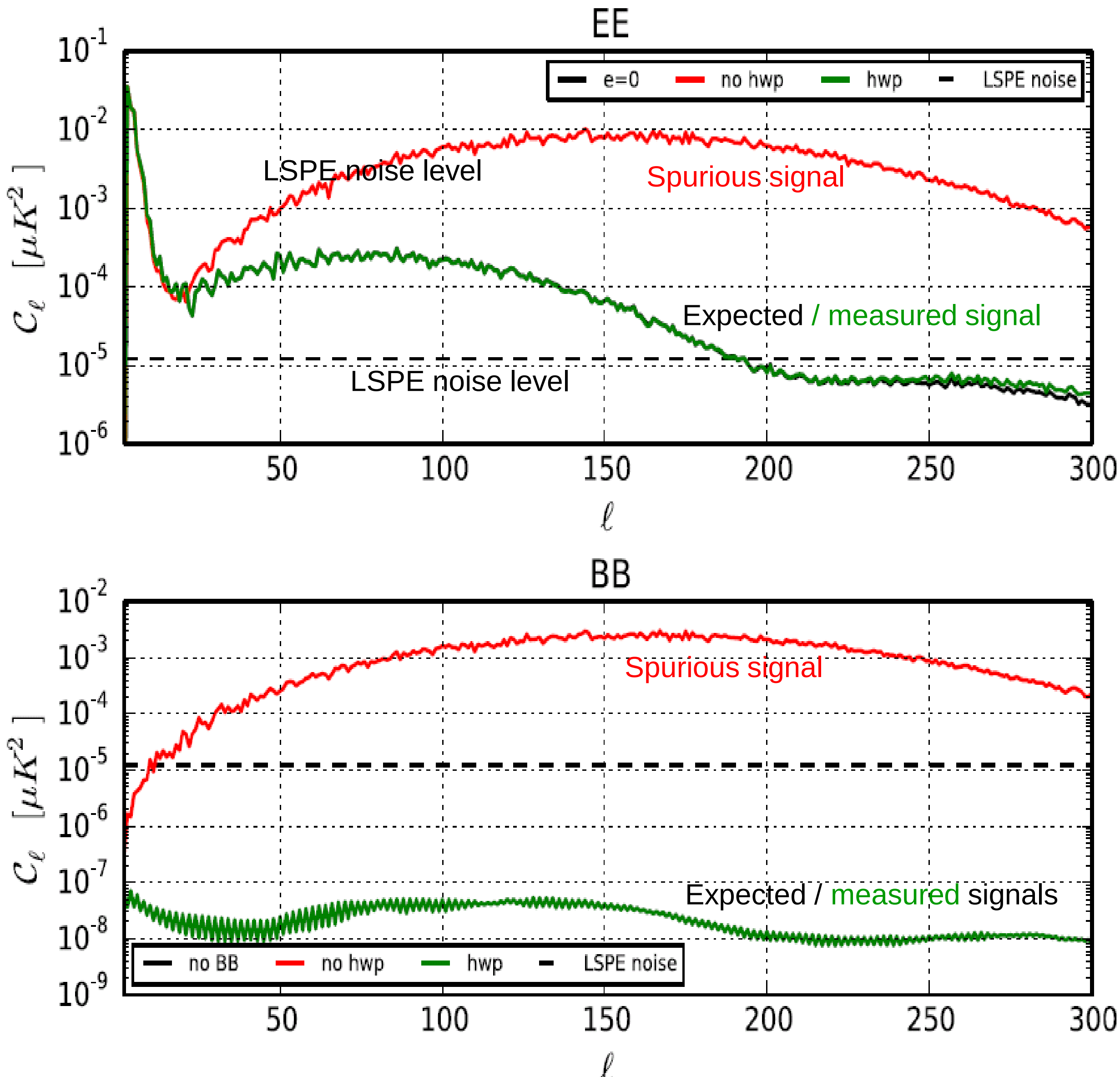
Elevation	Coverage	Unmasked
SWIPE [30-40]	31%	23%
SWIPE [40-50]	27%	20%
SWIPE 35	24%	19%
SWIPE 45	22%	18%
SWIPE [30-50]	35%	26%
STRIP 45	27%	20%
STRIP 30	33%	24%

		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)

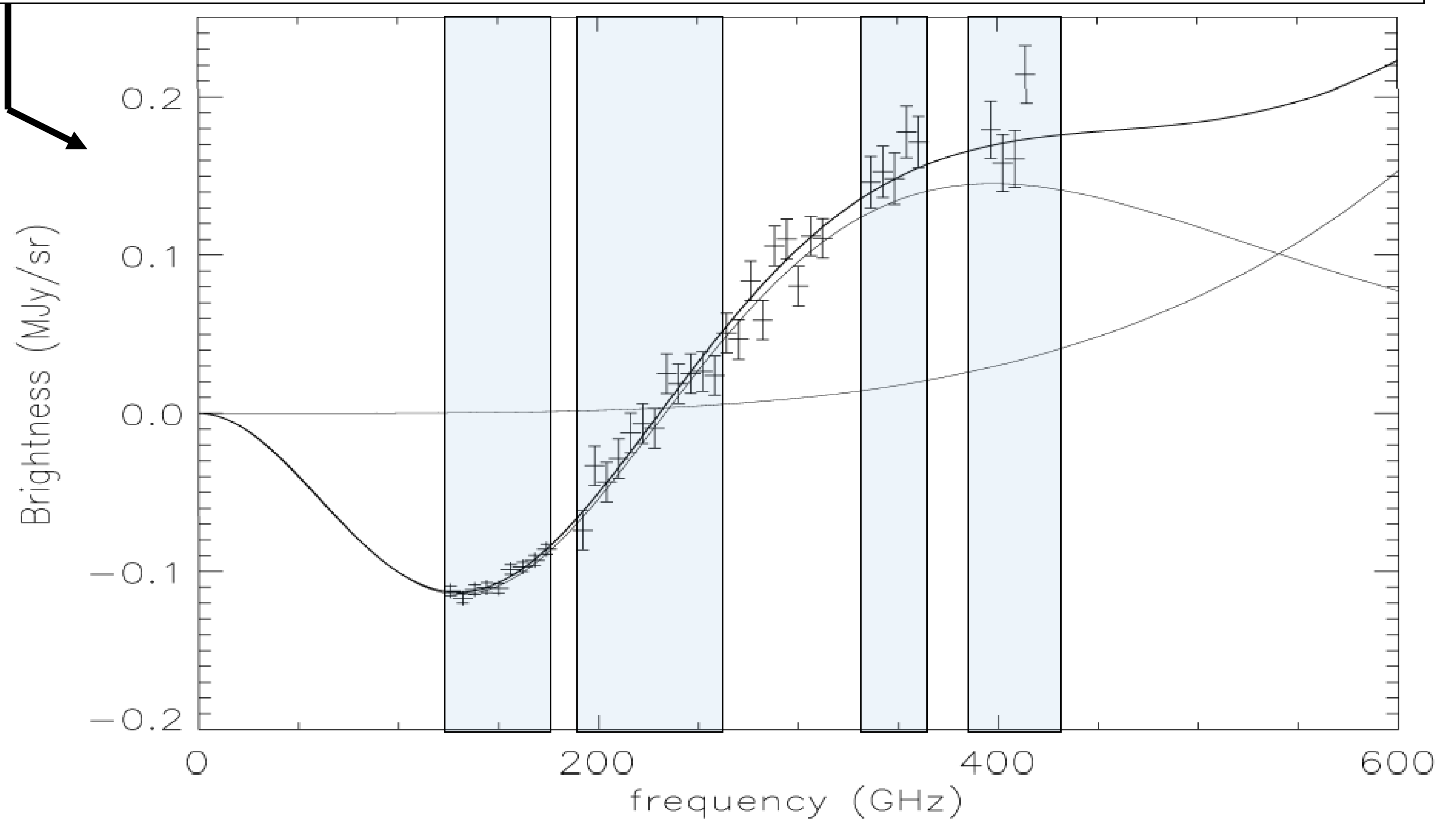
Performance Forecast

- 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 < 0.01



L. Pagano, F. Piacentini

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.



Expected performance for OLIMPO (photon noise limited)

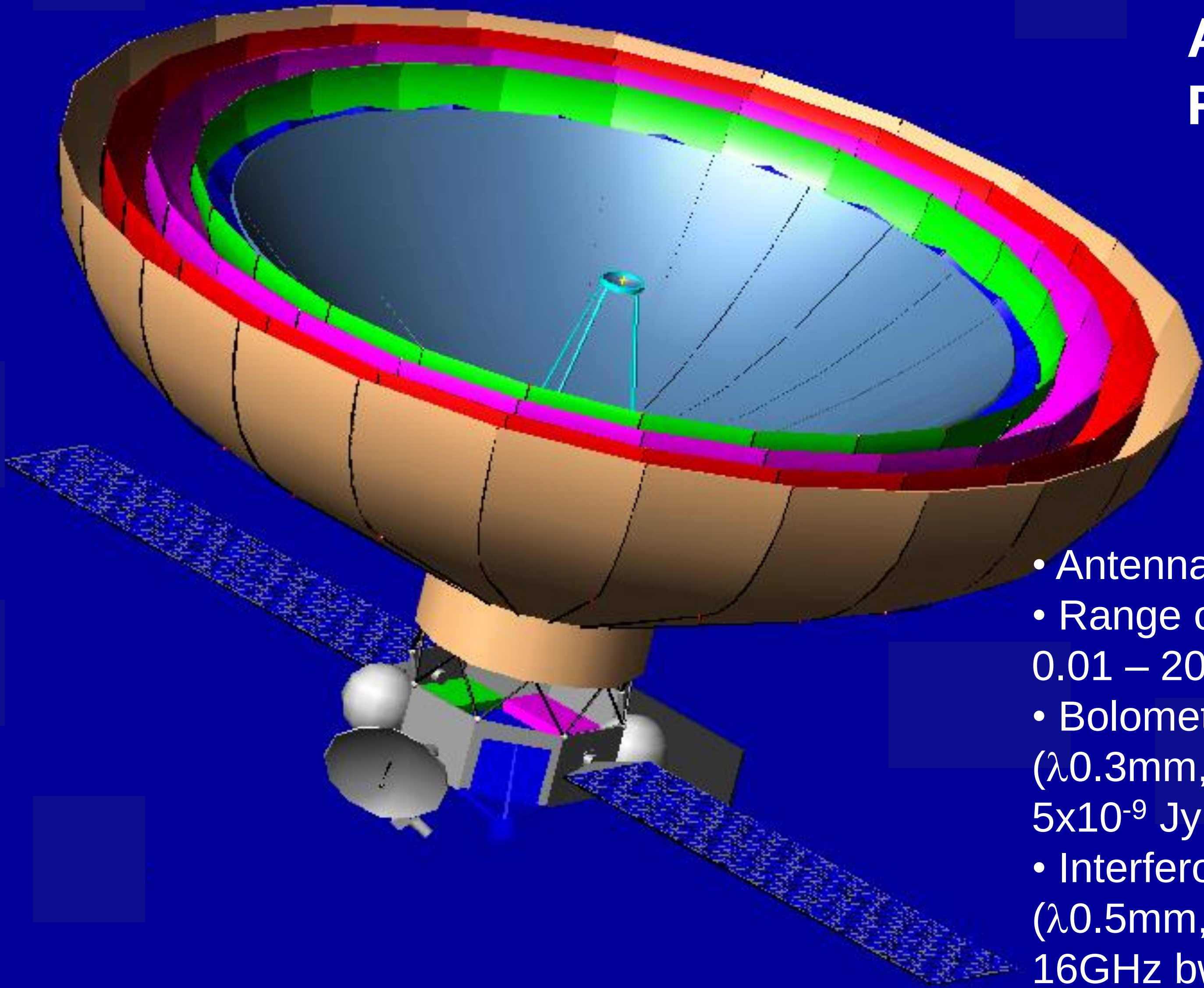
OLIMPO performance: spectrometer configurations, single detector of each array

Band (GHz)	**125-175**	**190-315 (wide)**	**200-225 (narrow)**	**330-365**	**450-500**
FWHM (arcmin)	5	3.5	3.5	2	2
Throughput (m^2sr)	6.3×10^{-6}	3.1×10^{-6}	3.1×10^{-6}	1.0×10^{-6}	1.0×10^{-6}
Background (pW)	36	122	17	20	54
Optical NEP (aW/sqrt(Hz))	200	400	140	170	290
Number of 6 GHz bins in band	9	21	4	5	8
Error per 6 GHz bin (1 sigma, 3 hours) in kJy/sr	3	12	5	16	28

OLIMPO performance: photometer configurations, single detector of each array

Band (GHz)	**125-175**	**190-315 (wide)**	**200-225 (narrow)**	**330-365**	**450-500**
FWHM (arcmin)	5	3.5	3.5	2	2
Throughput (m^2sr)	6.3×10^{-6}	3.1×10^{-6}	3.1×10^{-6}	1.0×10^{-6}	1.0×10^{-6}
Background (pW)	11	35	5	6	15
Optical NEP (aW/sqrt(Hz))	100	200	70	85	150
NET_{CMB} (μK/sqrt(Hz))	80	115	200	780	2500

Millimetron
ASC Moscow
ROSCOSMOS



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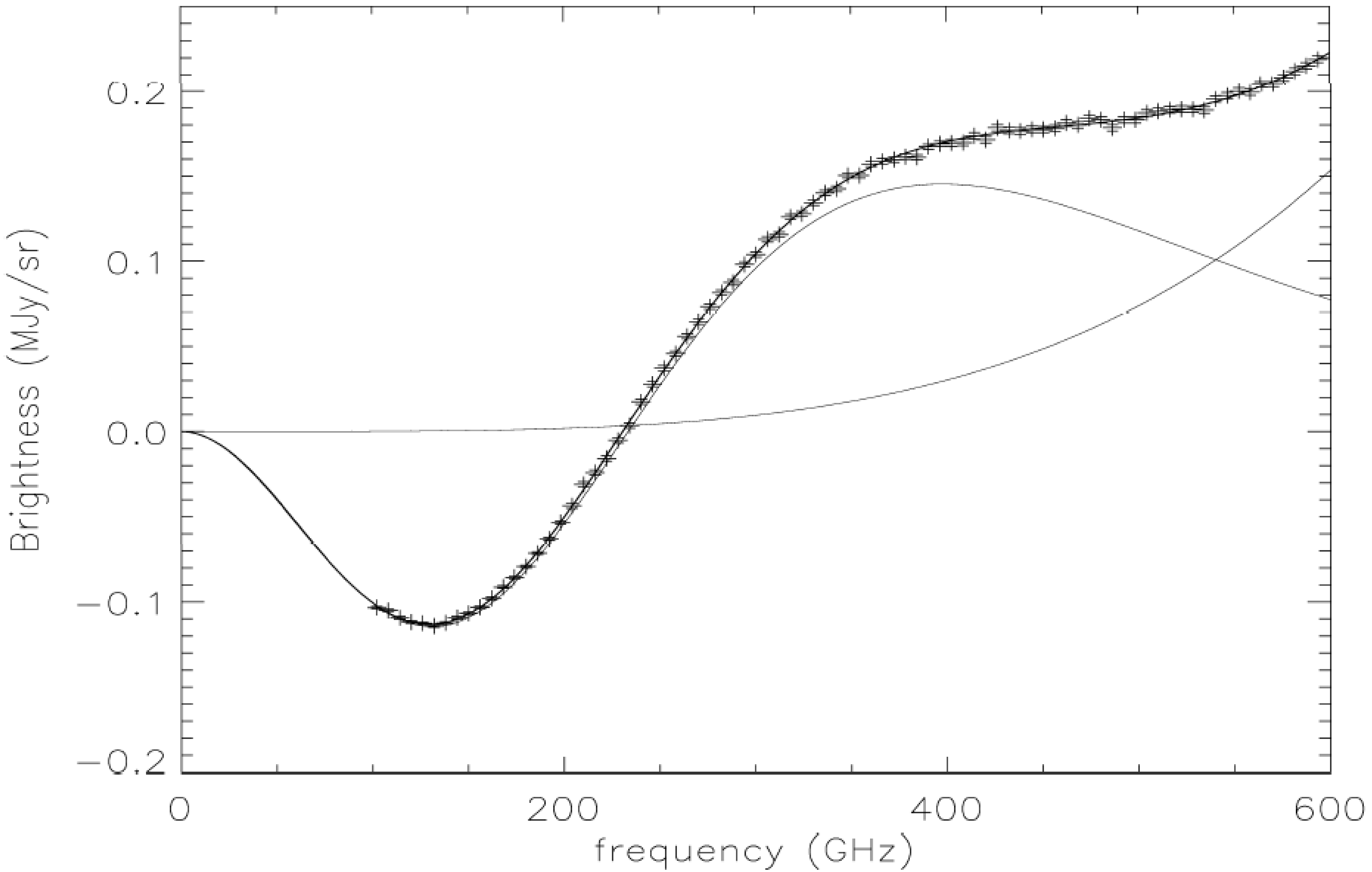

2 hours of observations of a rich cluster with a DFTS on Millimetron

USING A PHOTON NOISE LIMITED BOLOMETER IN THE COLD ENVIRONMENT OF L2 WITH A 4K TELESCOPE