Cosmic Microwave Background Ballooning

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Towards the European Coordination of the CMB programme

Villa Finaly – Firenze 20/sep/2018

Stratospheric Balloons :

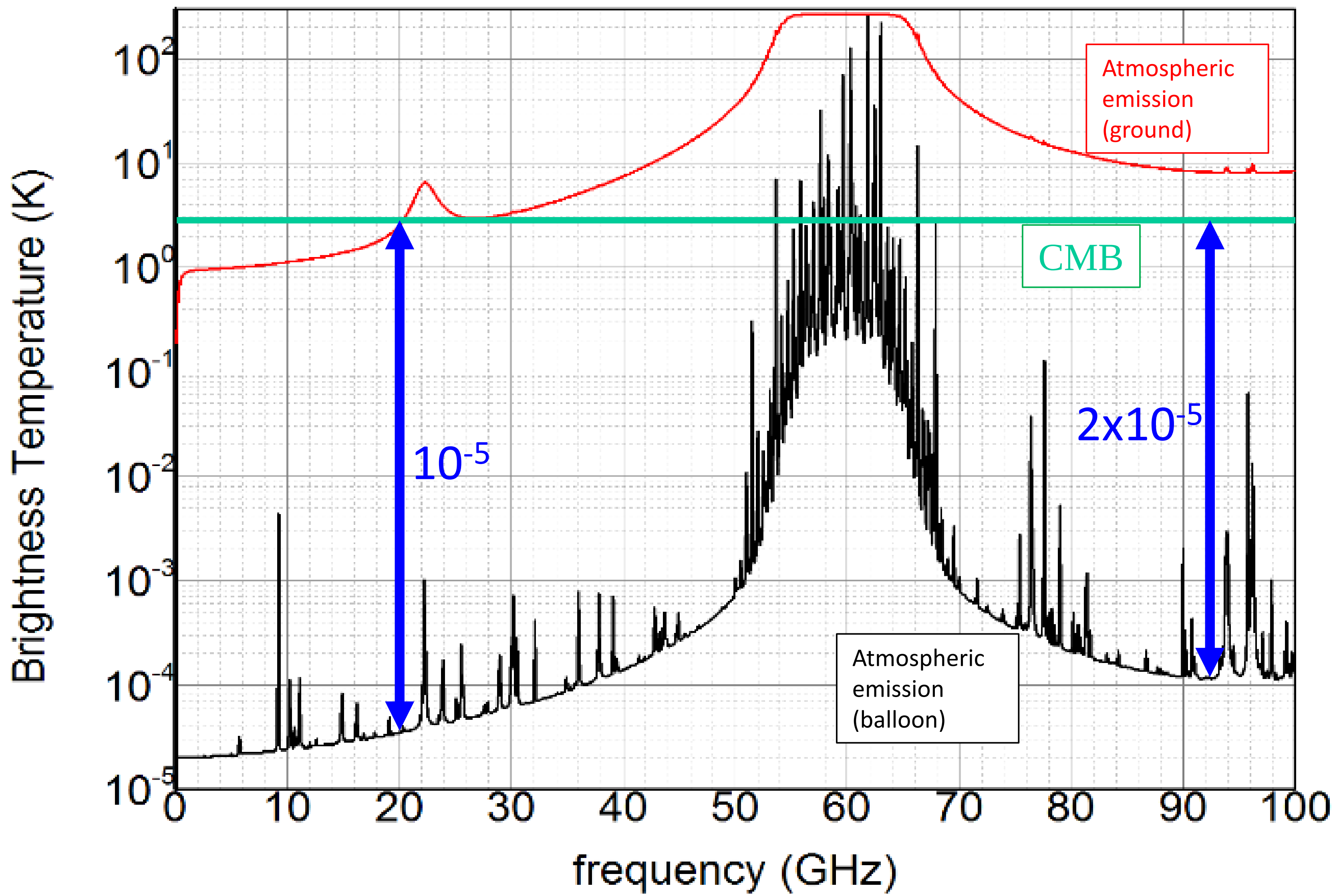
- **Near-space carriers able to:**
  - **Reach 40 km (3 mbar)**
  - **Stay there for up to 40 days**
  - **Lift heavy (2 tons) large payloads (larger than what we can reasonably fly on satellites)**
  - **Cost roughly 1/100 of a satellite mission**
  - **Allow for recovery and refly of the payload**
- **Important for the CMB community:**
  - **To carry out sensitive CMB measurements**
    - **On the high frequency side,**
    - **with high angular resolution,**
    - **at the largest angular scales …**
    - **.. and even absolute measurements**
  - **To qualify instrumentation and experimental methods in preparation of satellite missions**
  - **To educate young experimentalists !**

CMB-related science from balloons

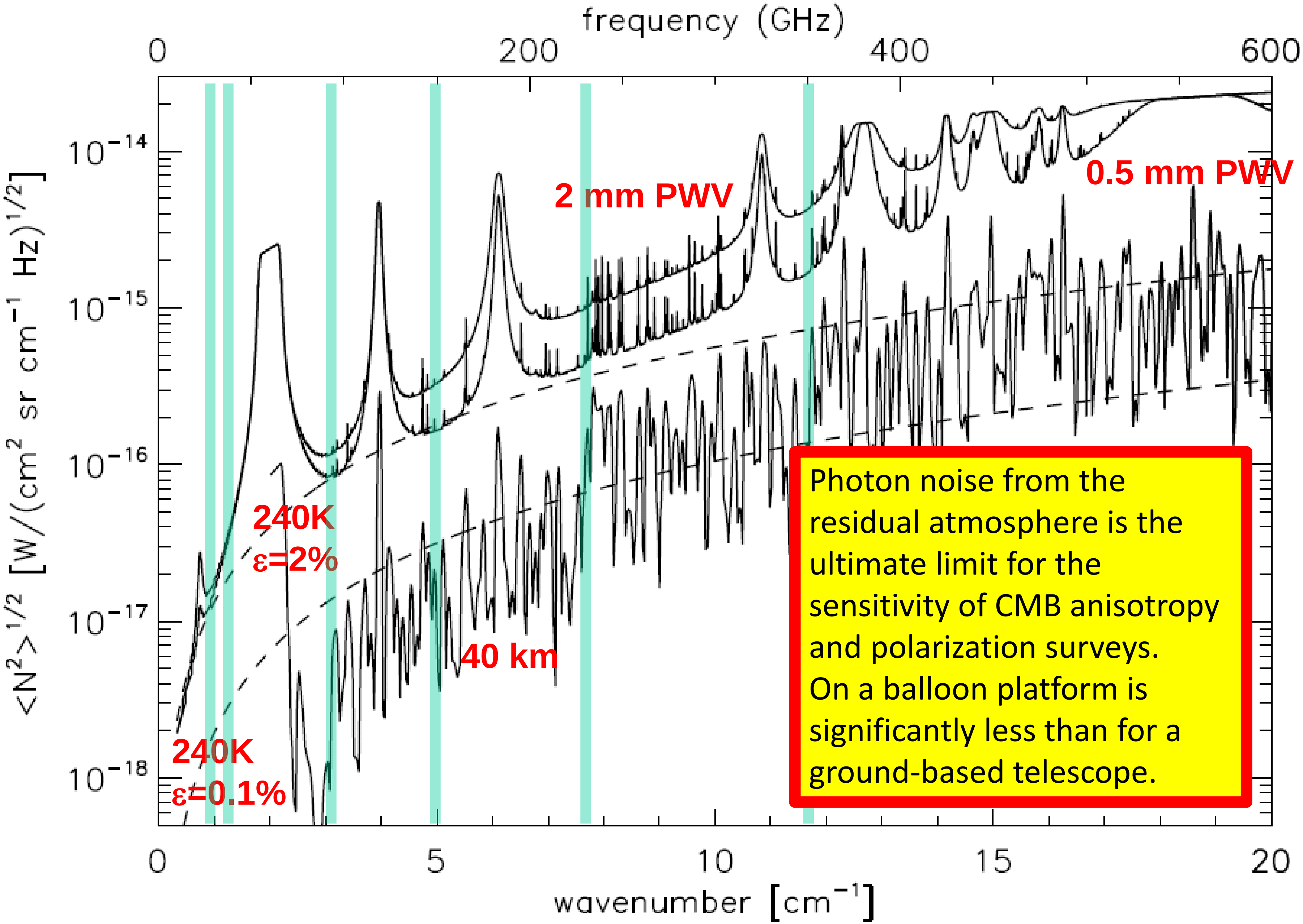
(with large advantage wrt ground-based experiments)

- Dust 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)

Advantage of CMB measurements from balloons:
a) Absolute brightness (low frequency side)



b) Sensitivity: Photon noise from the local environment



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

Advantage of CMB measurements from balloons: **b) 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.

Long Duration Ballooning

Flight Options

- Antarctic Long Duration Balloon (LDB) : 10 – 30 days / 3 tons
- Arctic (Svalbard & Kiruna) Long Duration Balloon (LDB) : 10 – 30 days / 3 tons
- Wanaka Super Pressure Balloon (SPB) : 30 – 100 days / 1 ton
- Polar Night LDB (Svalbard) : ~ 10-20 days (limited by power supply) / 2 tons
- Conventional Flight (Ft. Sumner, Palestine, Timmins) : 1-2 days / 3 tons

Flight Parameters

- 33-37 km altitude
- 1 km altitude stability (200 m for SPB)
- Annual flight windows
  - December/January (Antarctic LDB, Polar night LDB),
  - April (SPB, Wanaka),
  - June (Palestine, Arctic LDB),
  - September (Ft. Sumner)

Antarctic summer LDB: consolidated technology

Longest open balloon flight ever: CREAM payload, flight I

Flown by CSBF in Antarctica

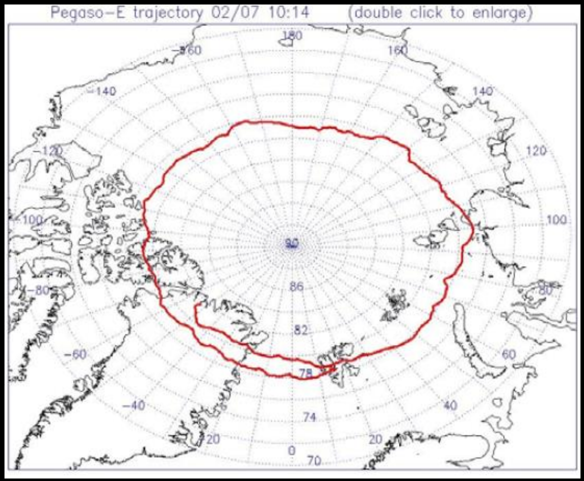
Launch Dec. 16, 2004. Termination January 27, 2005

Duration 41 days and 22 hours

CREAM payload, flight V : 37 days and 10 hours (2009-2010)

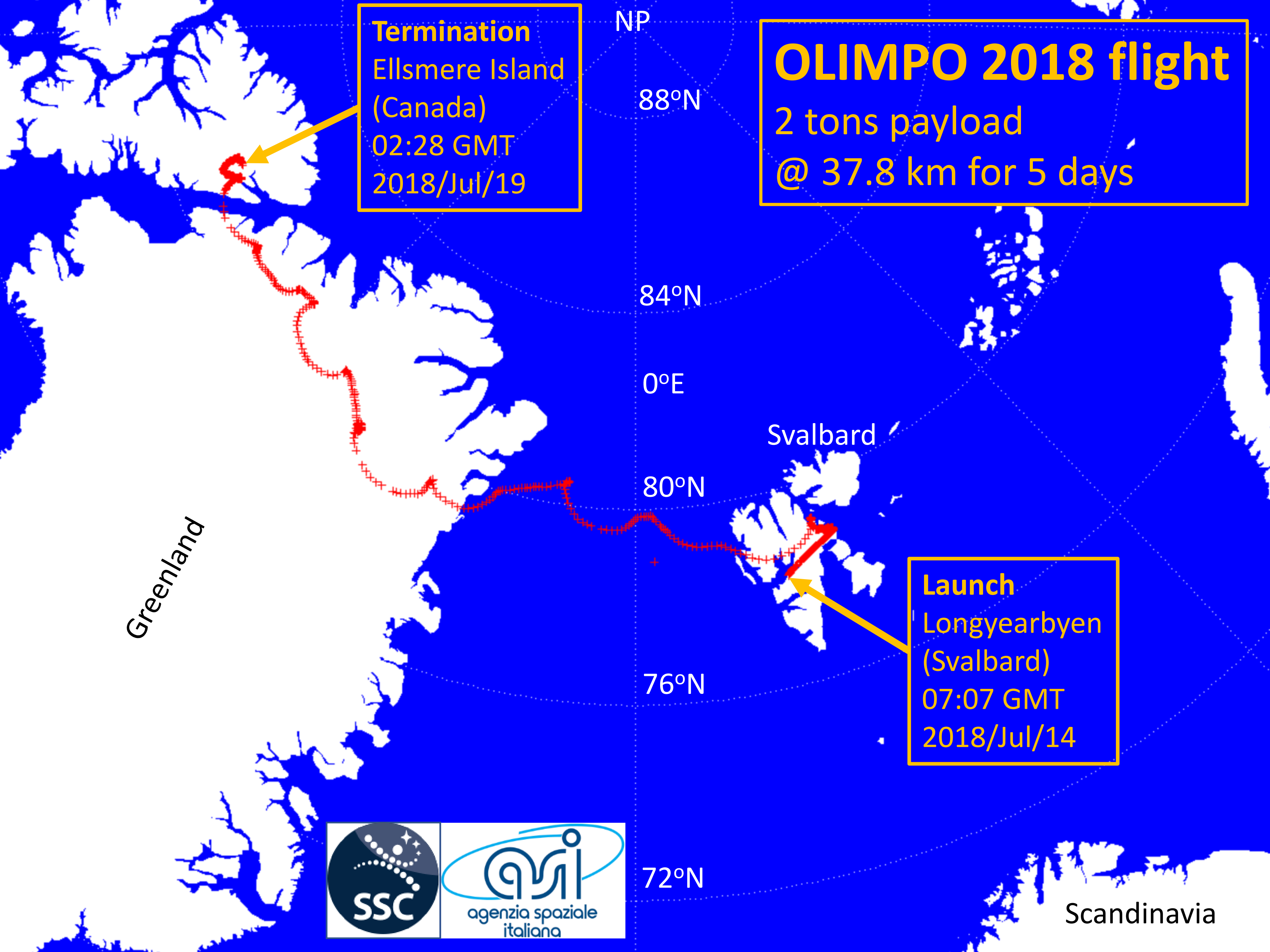
Arctic summer LDB flights

- 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).



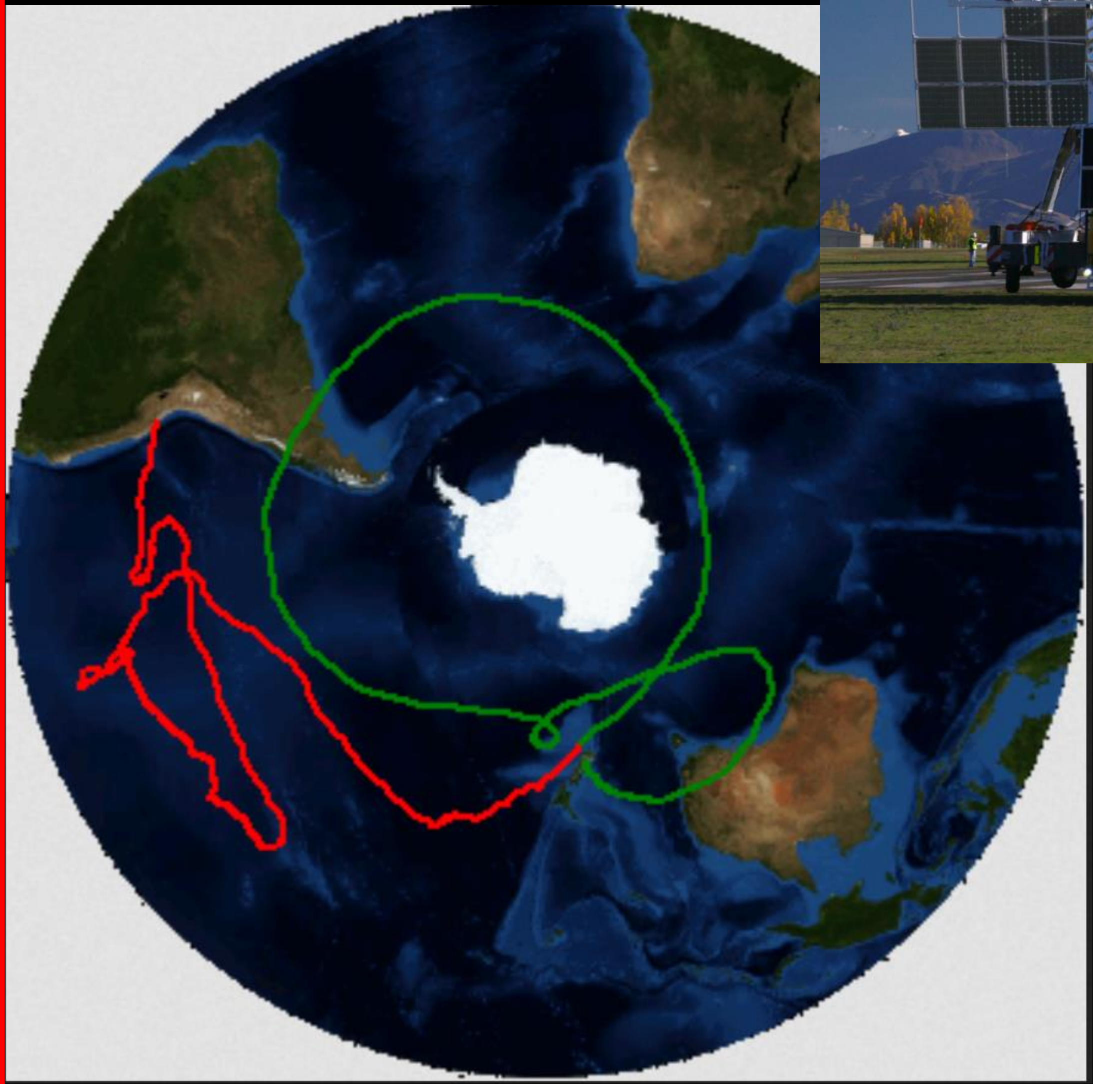
Top: Ground path of a flight performed in June 2007. **Bottom left:** Launch of a heavy-lift balloon from the Longyearbyen airport (Svalbard Islands, latitude 78°N).

- Recent first flight of OLIMPO in the Arctic



OLIMPO 2018 flight
2 tons payload
@ 37.8 km for 5 days
Termination
Ellsmere Island
(Canada)
02:28 GMT
2018/Jul/19
Launch
Longyearbyen
(Svalbard)
07:07 GMT
2018/Jul/14
NP
88ºN
84ºN
0ºE
80ºN
76ºN
72ºN
Svalbard
Greenland
Scandinavia
SSC
agenzia spaziale
italiana

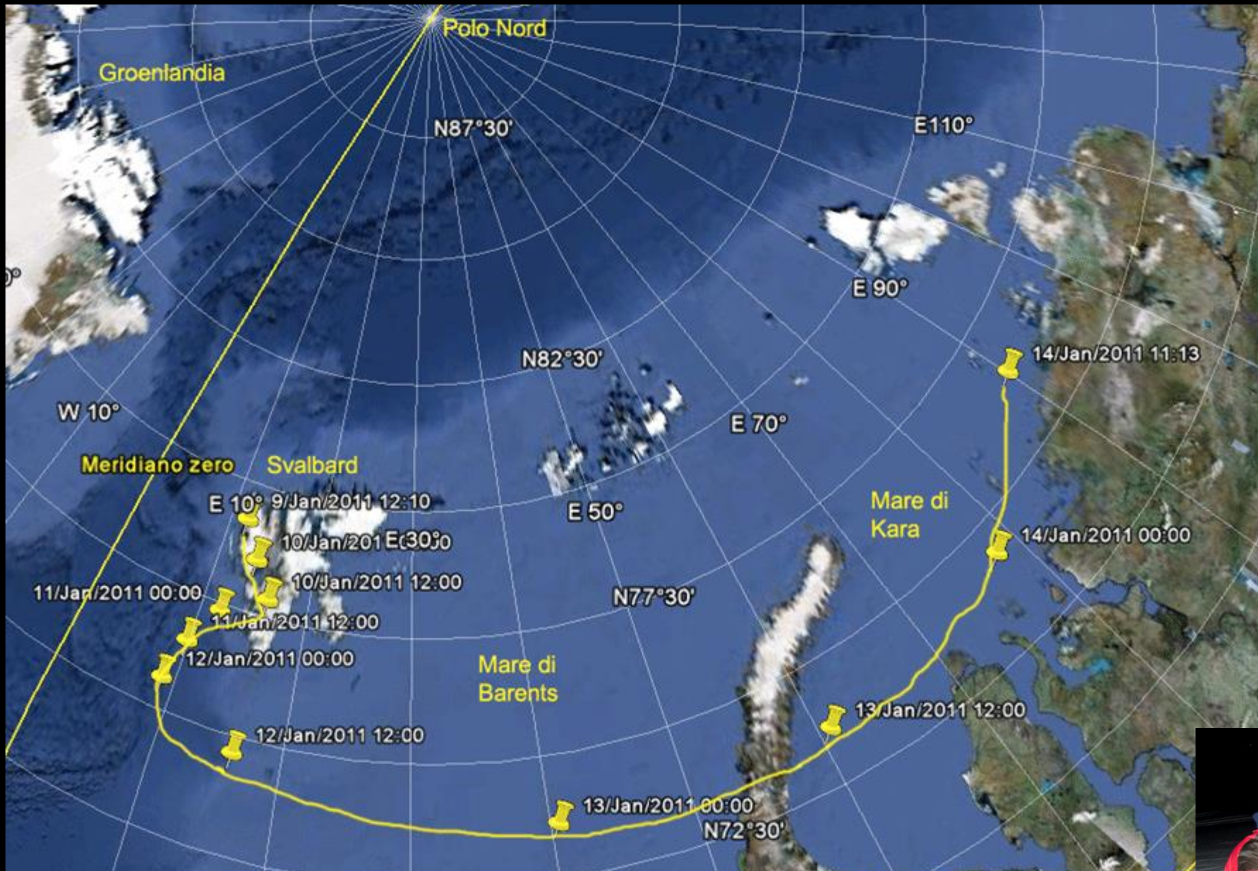
ULDB flights



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 Night Flights



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PROGRAMMA NAZIONALE DI RICERCHE IN ANTARTIDE
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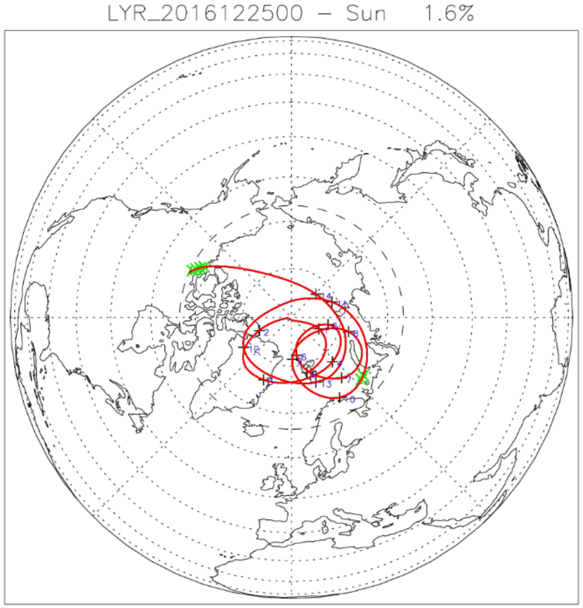
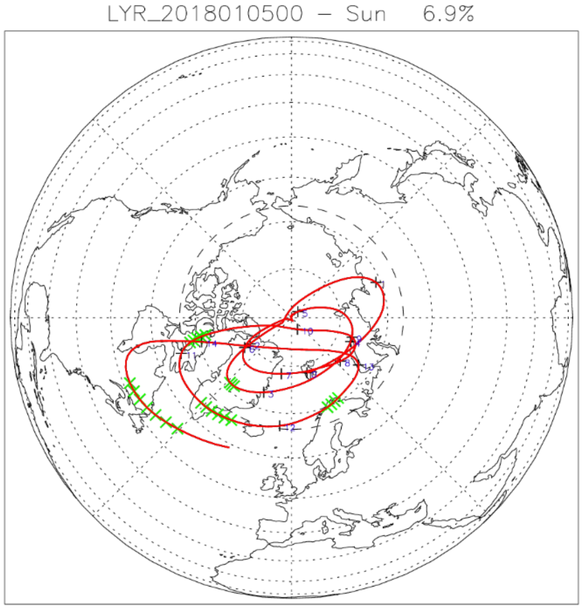
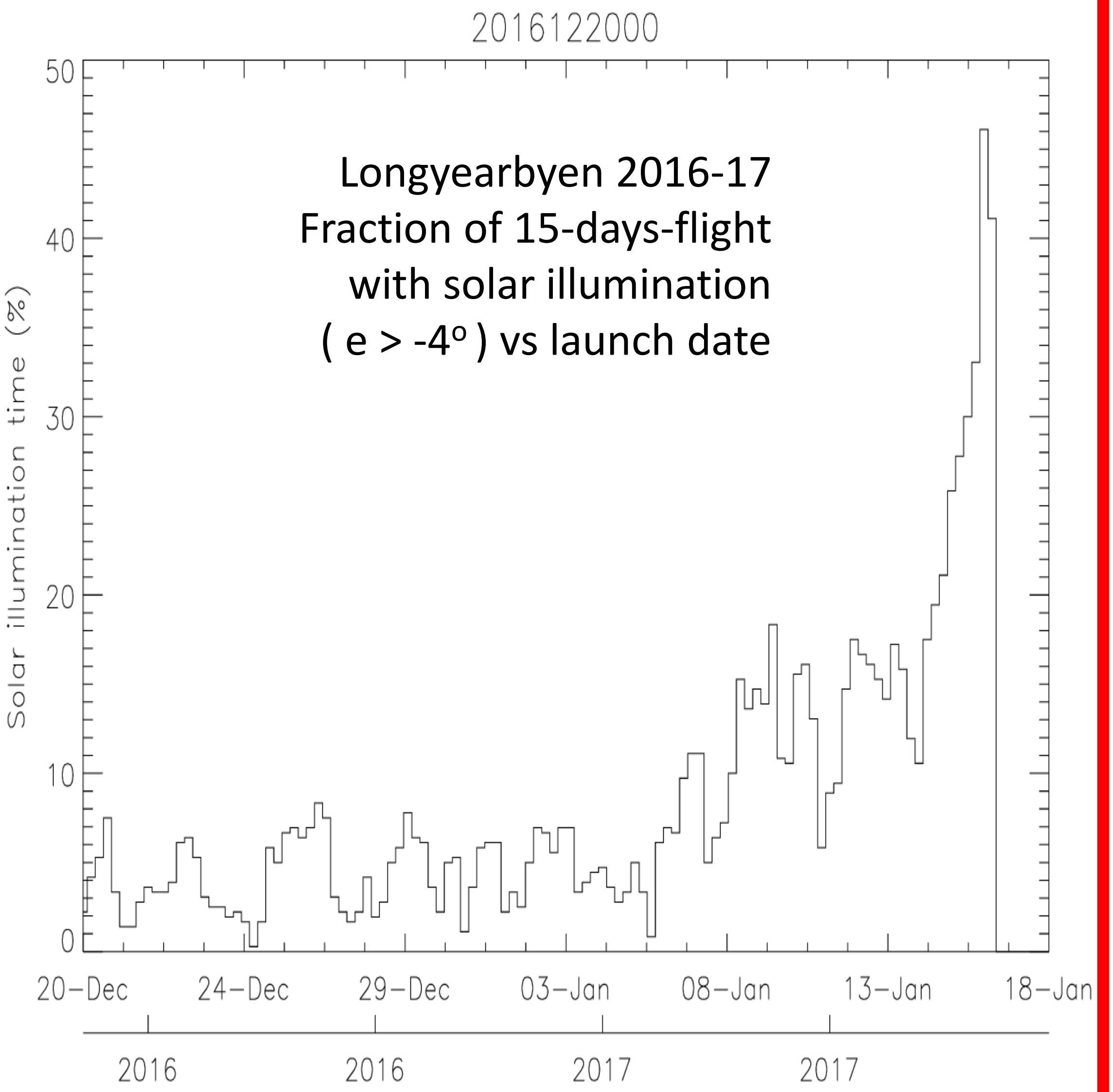
Polar Night Flights

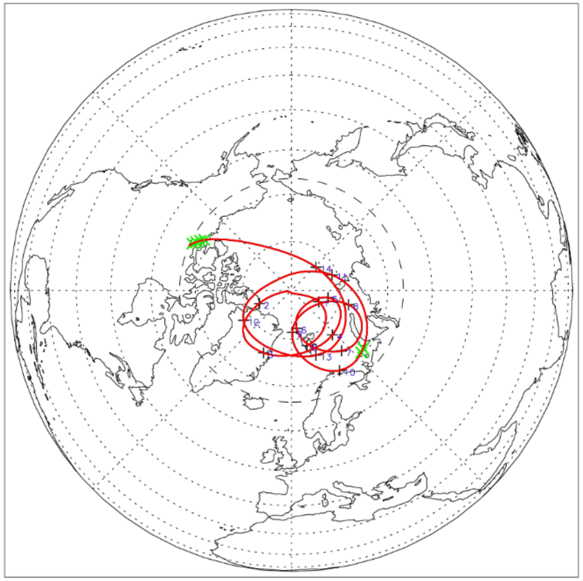


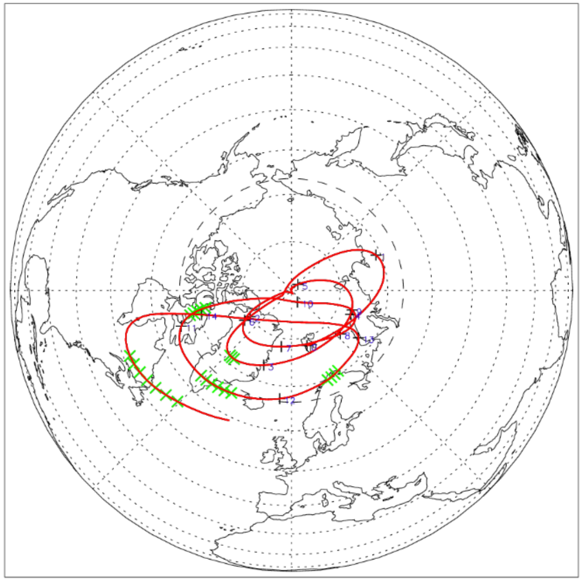


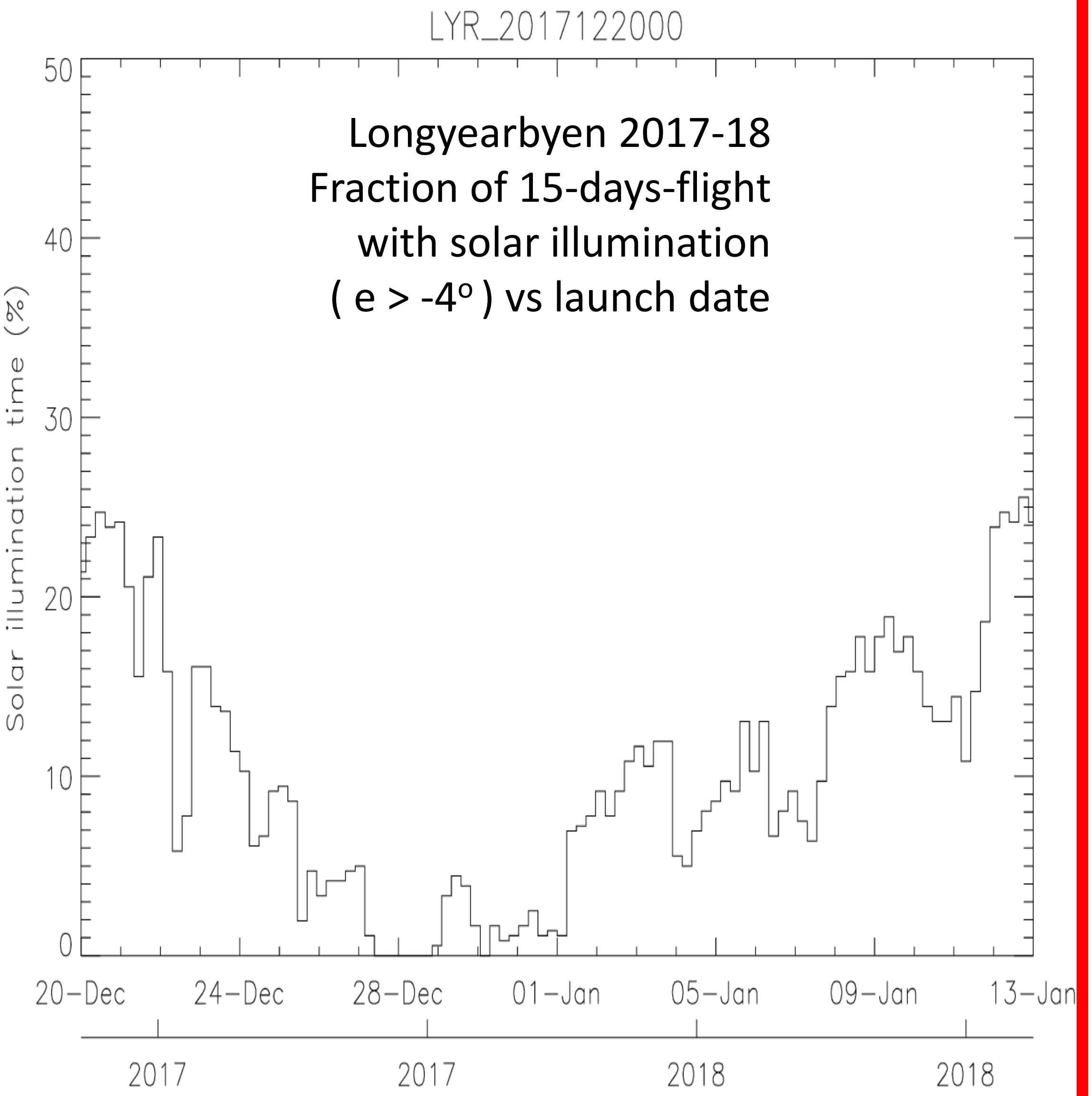


Simulation: F. Piacentini

Polar Night Flights







Simulation: F. Piacentini

Stratospheric Balloons:

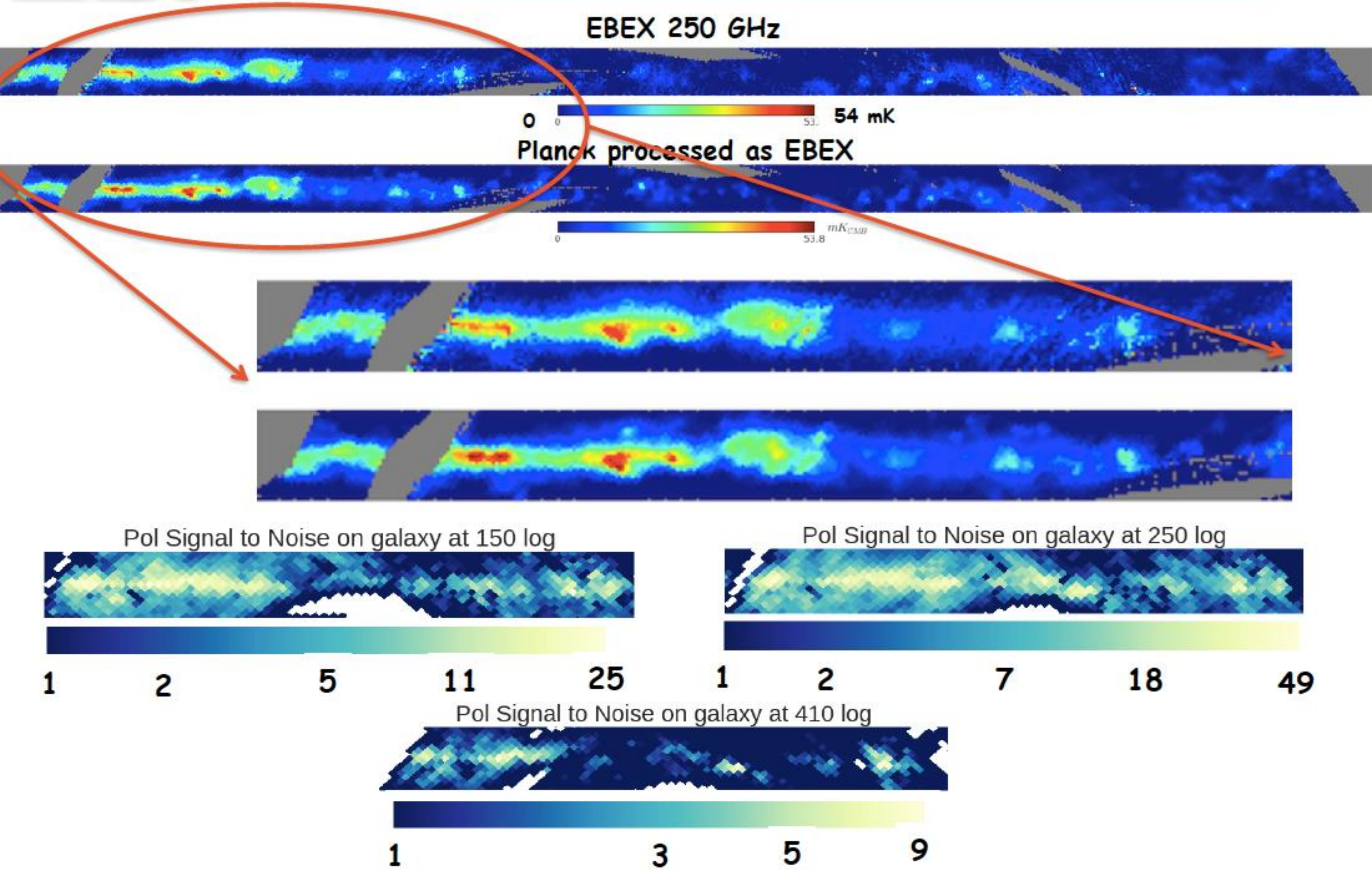
Disadvantages:

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

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, 2017)	<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
BLAST-TNG (LDB 2018) OLIMPO (2020?)	< 0.01 0.01	1200, 860, 600 140-220-340-450	1 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
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
0
53.8
mK_{CMB}
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

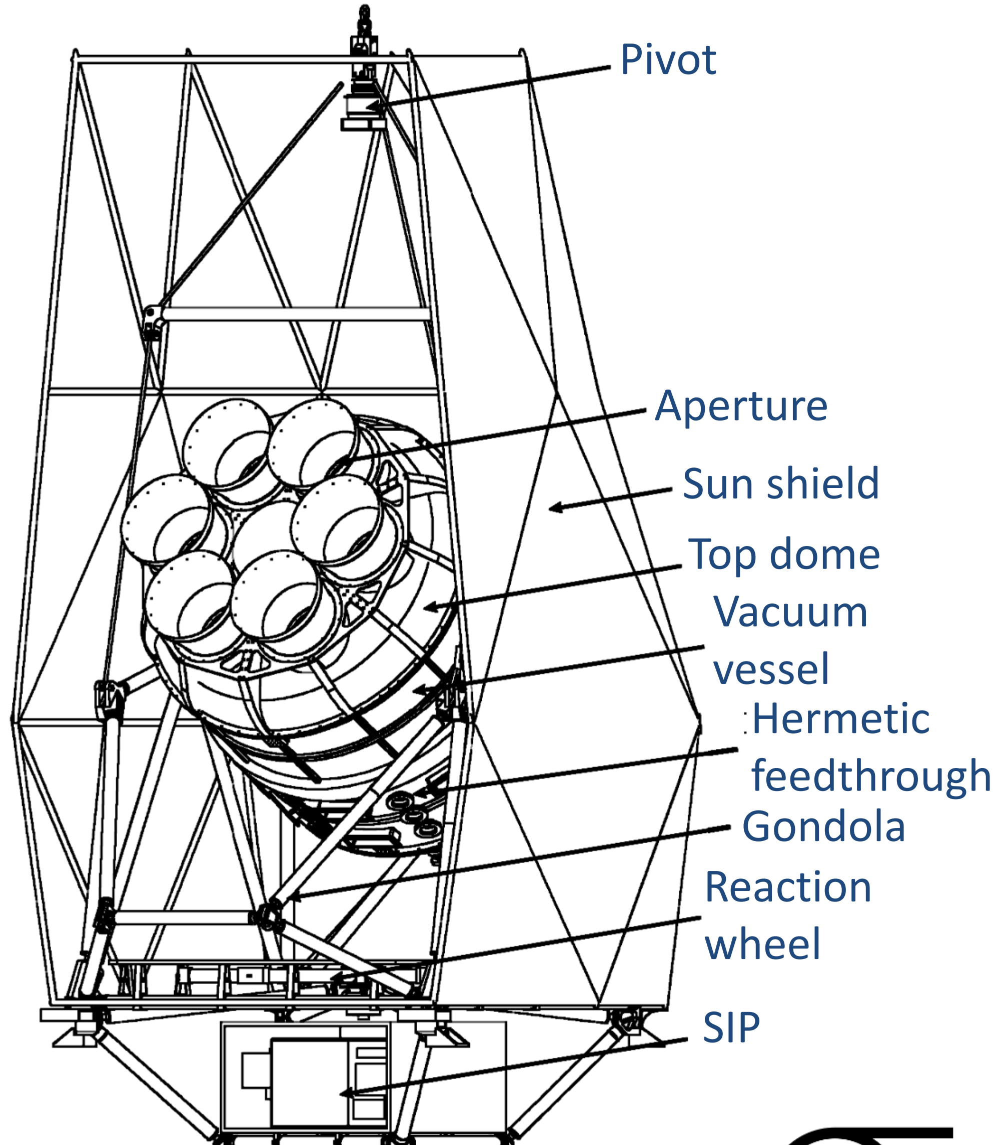
Spider 2015: Overview

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	$10 < \ell < 300$
Observation time	16 days at 36 km
Limits on r†	0.03

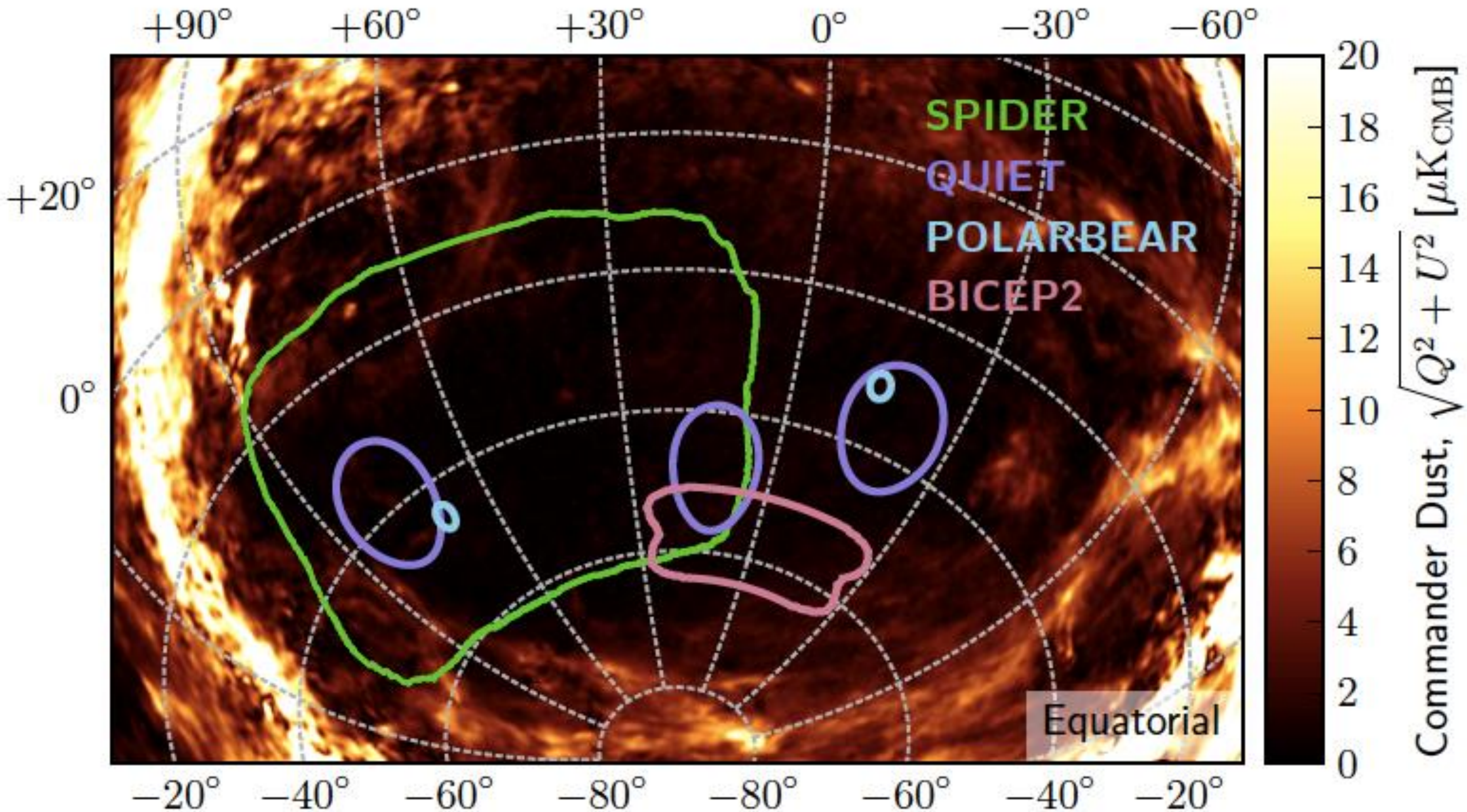
† Ignoring all foregrounds, at 99% confidence

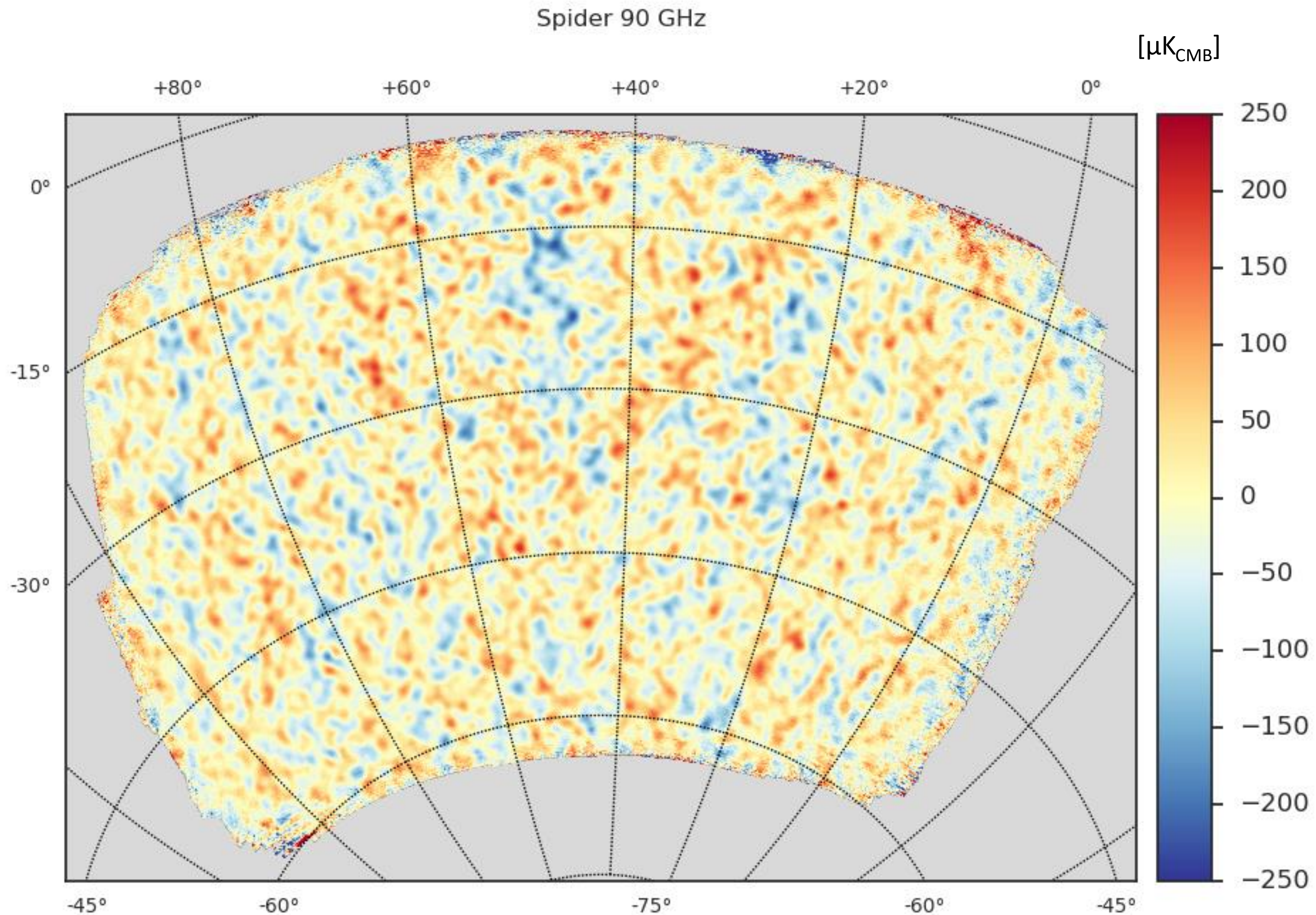
	Frequency [GHz]	
	94	150
Telescopes	3	3
Bandwidth [GHz]	22	36
Optical efficiency	30-45%	30-50%
Angular resolution* [arcmin]	42	28
Number of detectors†	652 (816)	1030 (1488)
Optical background‡ [pW]	≤ 0.25	≤ 0.35
Instrument NET† [μK·rts]	6.5	5.1

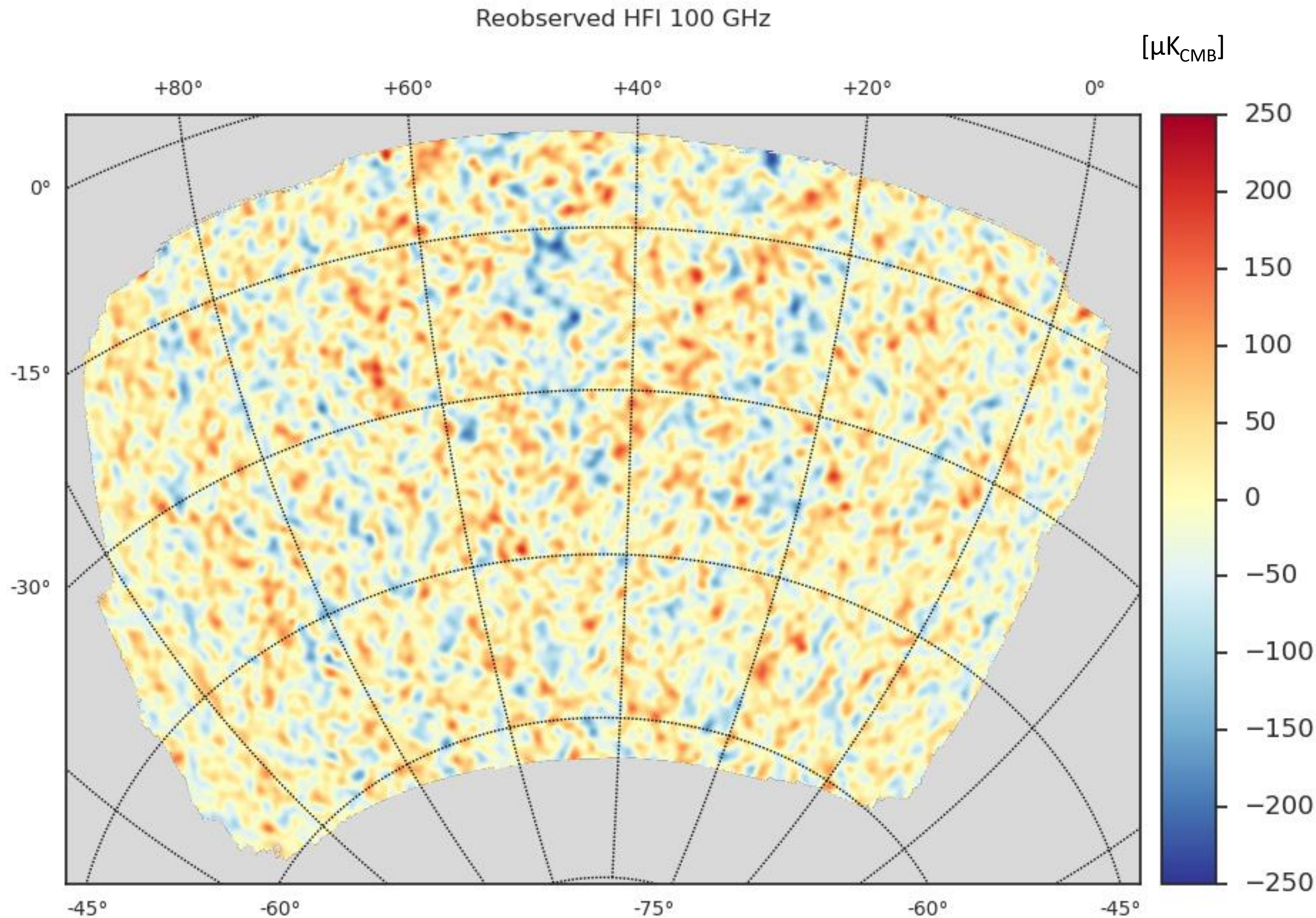
*FWHM. †Only counting those currently used in analysis
‡Including sleeve, window, and baffle

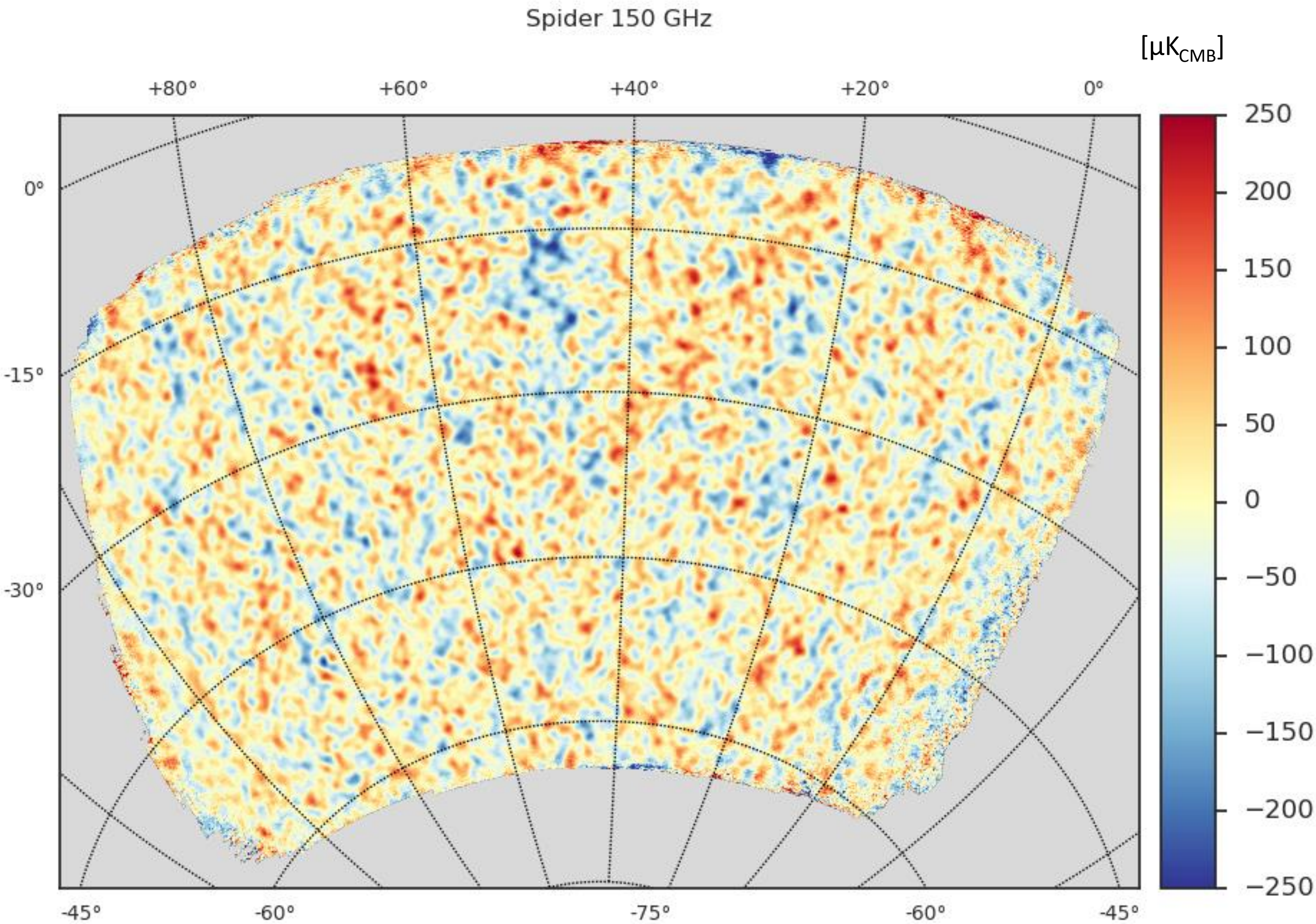


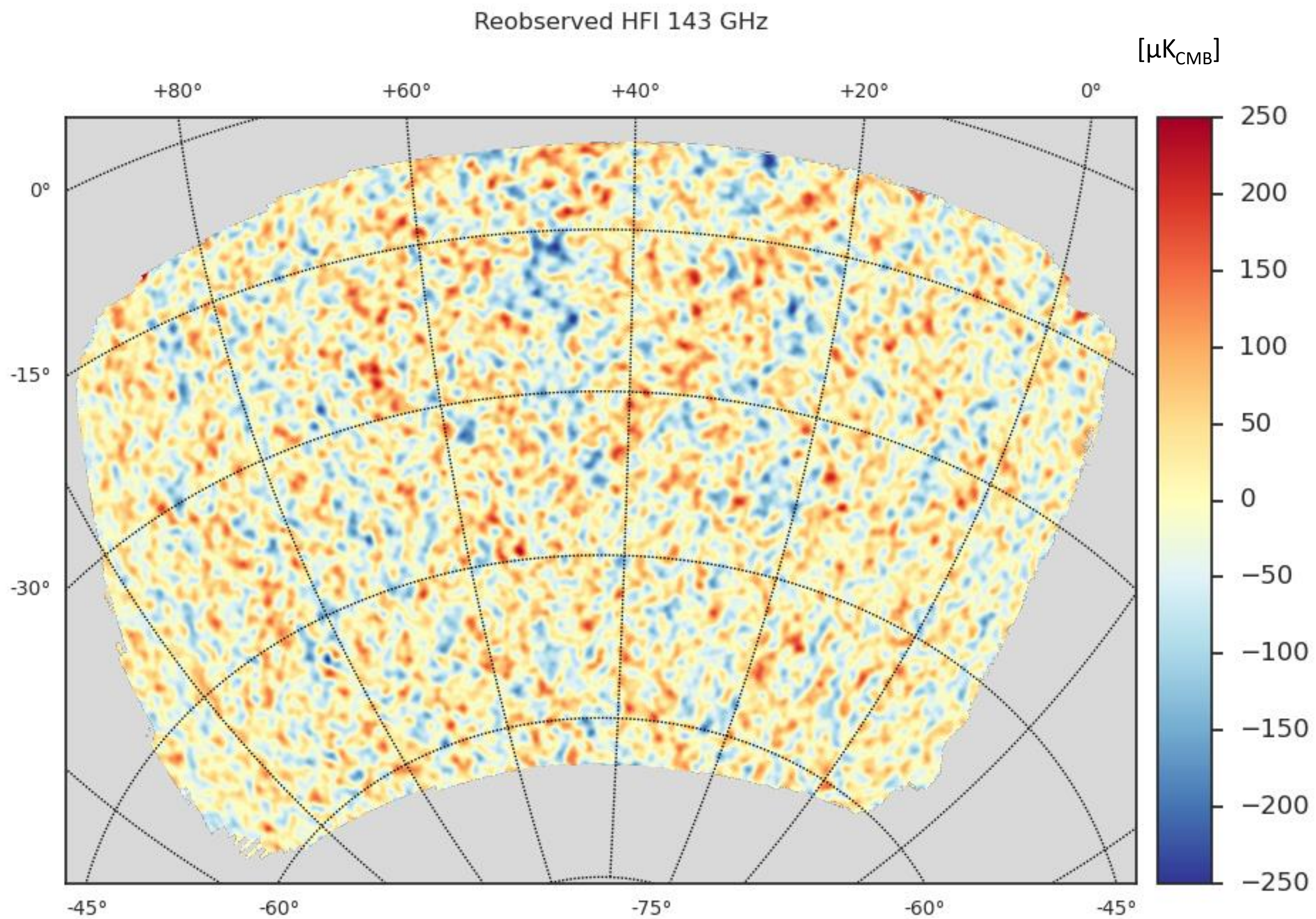
Spider 2015: survey coverage



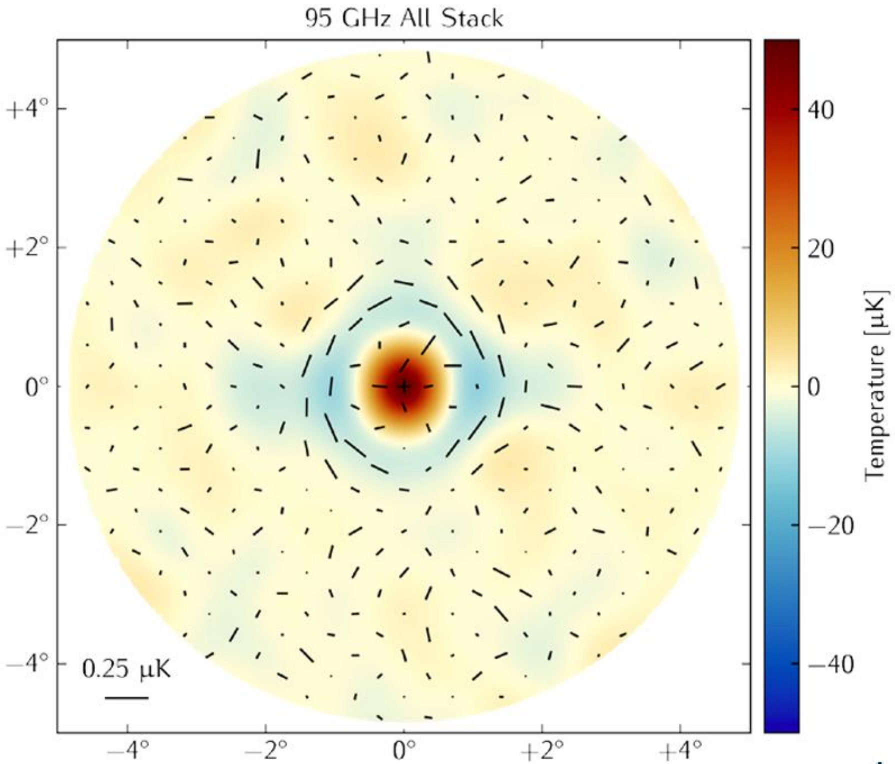

Spider 90 GHz
[μK_CMB]
+80°
+60°
+40°
+20°
0°
0°
-15°
-30°
-45°
-60°
-75°
-60°
-45°
250
200
150
100
50
0
−50
−100
−150
−200
−250

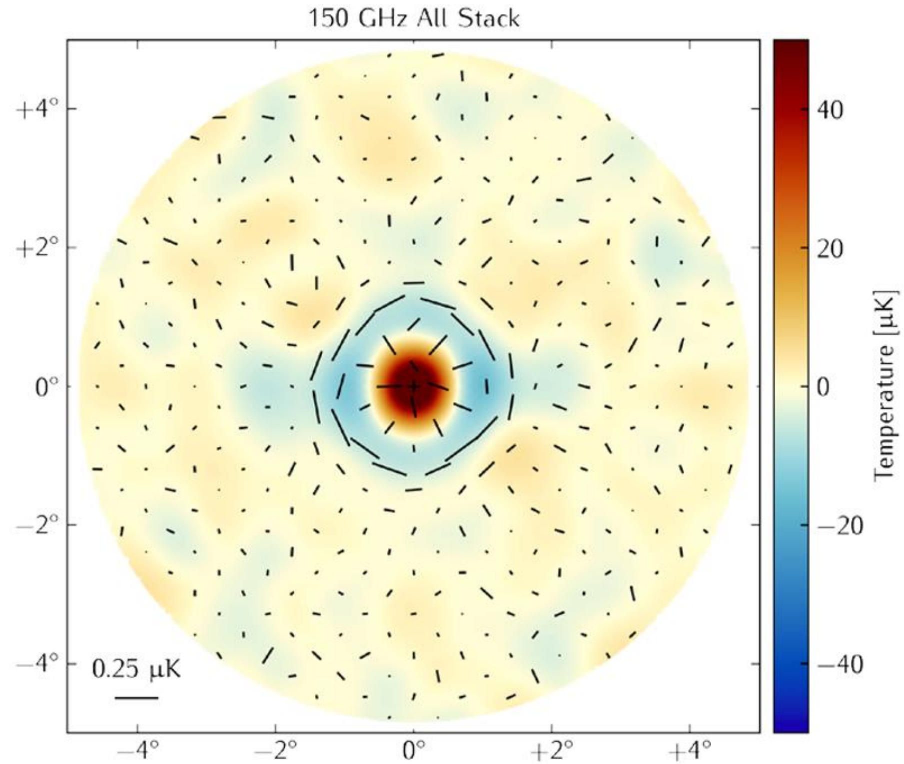

Reobserved HFI 100 GHz
[μK_CMB]
+80°
+60°
+40°
+20°
0°
0°
-15°
-30°
-45°
-60°
-75°
-60°
-45°
250
200
150
100
50
0
−50
−100
−150
−200
−250


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

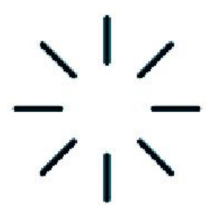

Reobserved HFI 143 GHz
[μK_CMB]
+80°
+60°
+40°
+20°
0°
0°
-15°
-30°
-45°
-60°
-75°
-60°
-45°
250
200
150
100
50
0
−50
−100
−150
−200
−250

Stacking hot spots : SPIDER

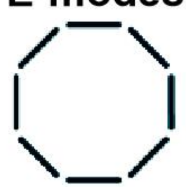




PRELIMINARY



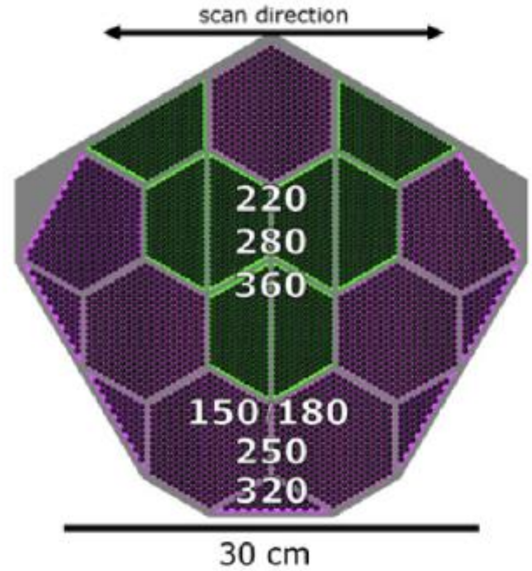
E-modes



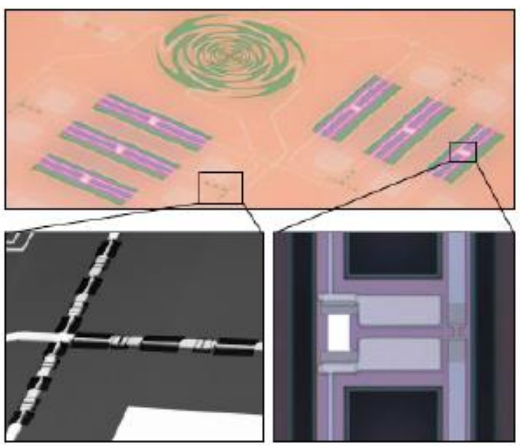
PRELIMINARY

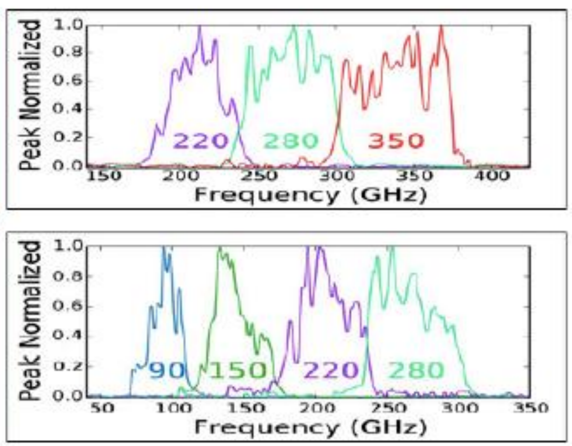
EBEX-IDS

- 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)

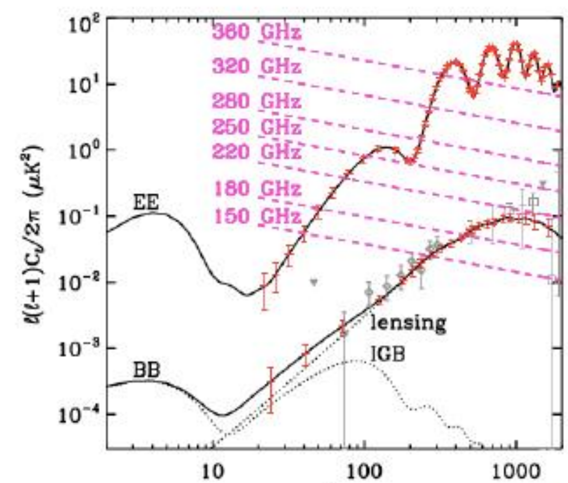


Total of 20562 detectors

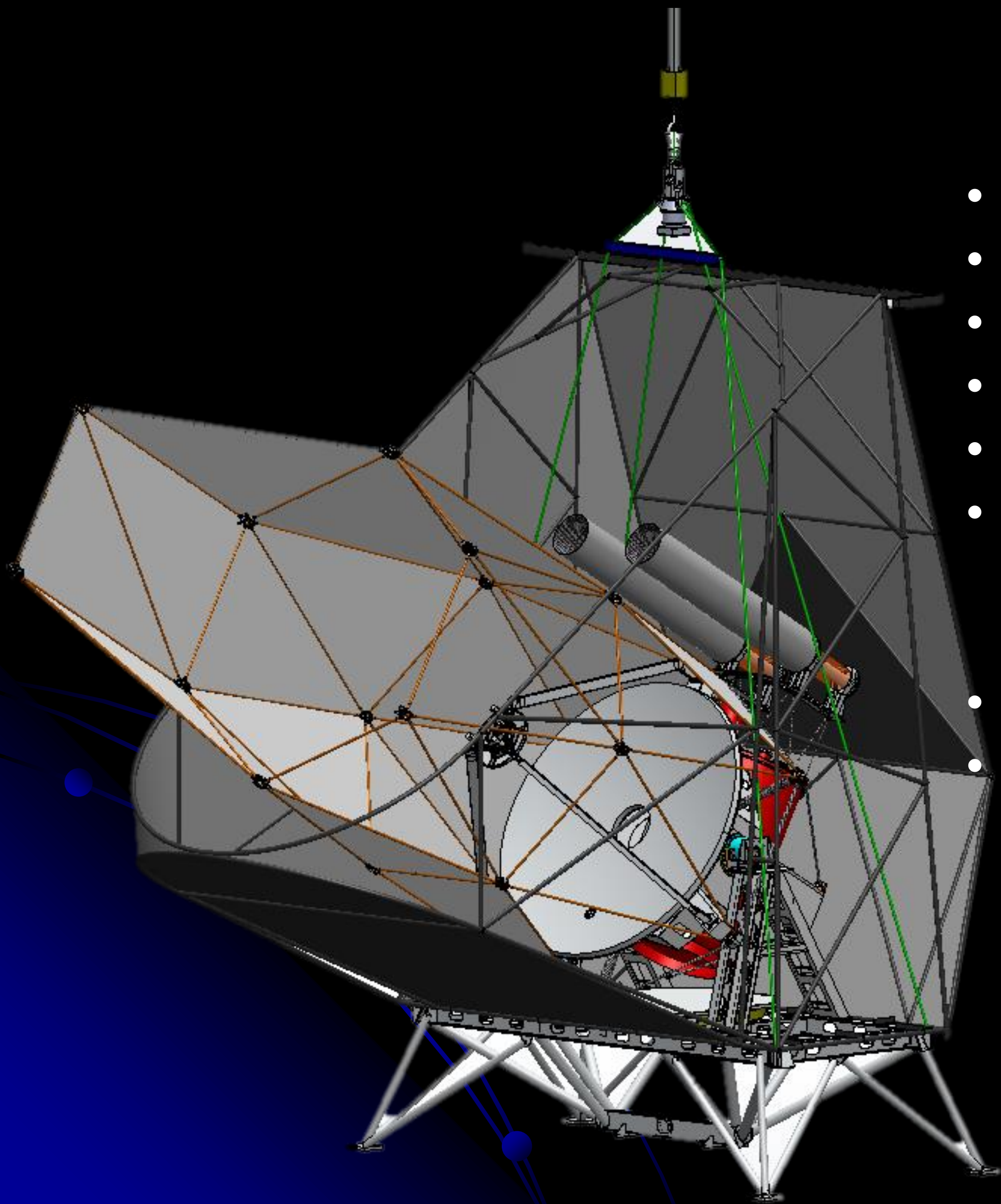




Lee + Westbrook, UCB



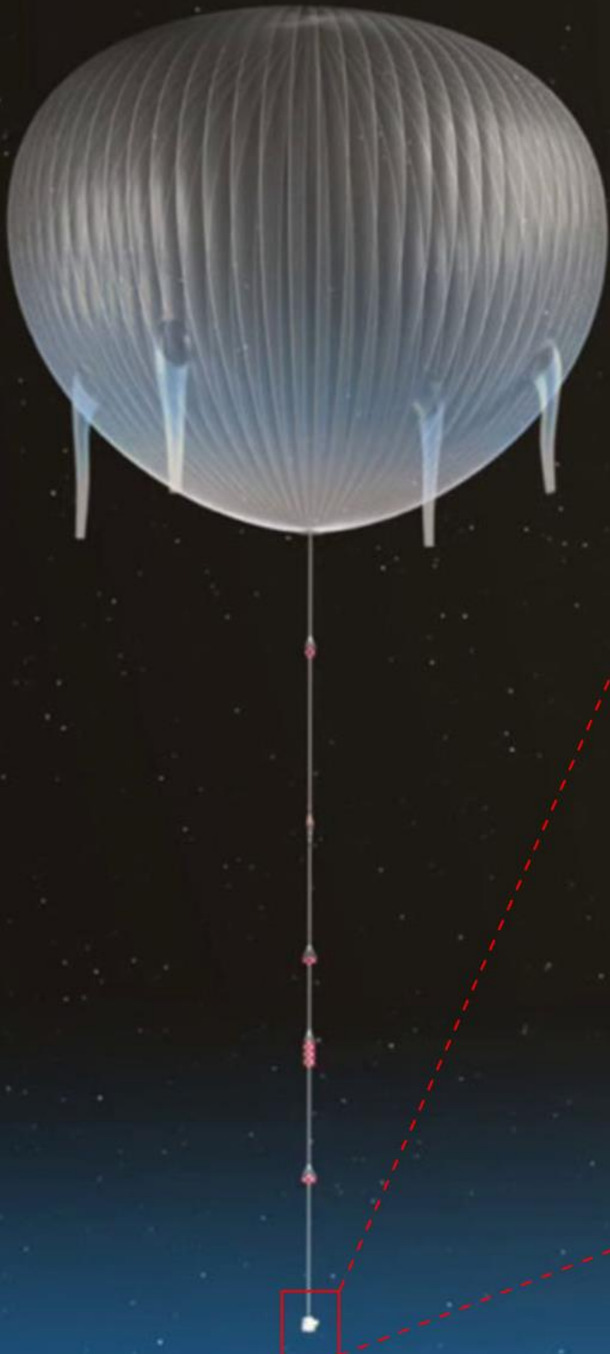
BLAST-TNG

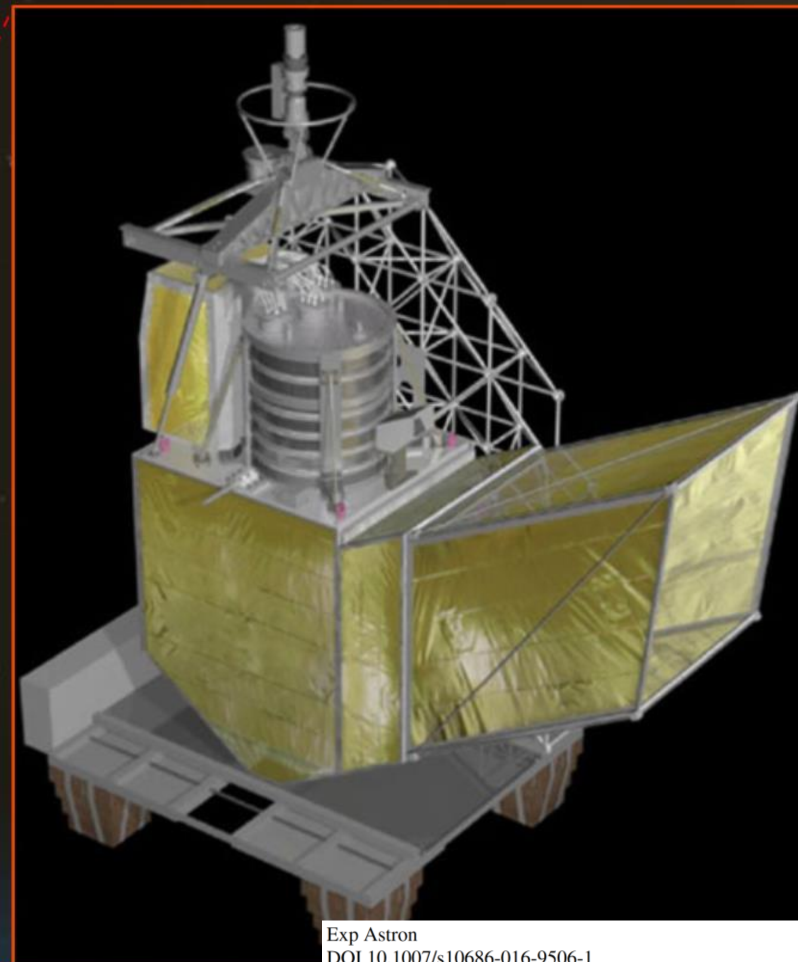


- 2.5 meter Carbon Fiber Mirror
- 2200 Polarized KID detectors
- Three bands: 250, 350, and 500 μm
- 22 arcsec resolution at 250 μm
- 28 day flight!
- 10 times the mapping speed of BLAST-pol

- First flight December 2018
- with Shared Risk Observing

PILOT





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

ORIGINAL ARTICLE

PILOT: a balloon-borne experiment to measure the polarized FIR emission of dust grains 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]

LSPE

the Large-Scale Polarization Explorer

MILANO
GENOVA
PISA
FERRARA
ROMA 1
ROMA 2

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Giovanni	Romeo	INGV - Roma
Maria	Salatino	Dip. Fisica Sapienza & INFN Roma1
Maura	Sandri	INAF - IASF Bologna
Alessandro	Schillaci	Dip. Fisica Sapienza & INFN Roma1
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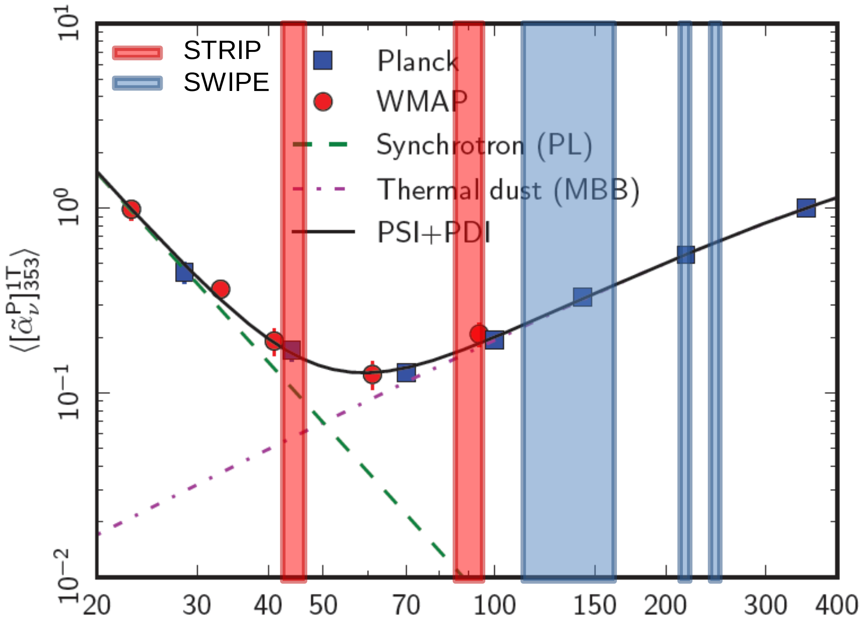
Luca	Terenzi	INAF - IASF Bologna
Maurizio	Tomasi	Dip. Fisica Università di Milano
Elisabetta	Tommasi	Italian Space Agency
Carole	Tucker	University of Cardiff
Fabrizio	Villa	INAF - IASF Bologna
Giuseppe	Virone	IEIIT - CNR - Torino
Nicola	Vittorio	Università di Roma TorVergata & INFN Roma2
Andrea	Zacchei	INAF Osservatorio Trieste
Mario	Zannoni	Dip. Fisica Università di Milano Bicocca
Guido	Zavattini	Università di Ferrara & INFN Ferrara

LSPE in a nutshell

- The Large-Scale Polarization Explorer is an experiment to measure the polarization of the Cosmic Microwave Background at large angular scales
- Frequency coverage: 40 – 250 GHz (5 channels, 2 instruments: STRIP on the ground & SWIPE on a balloon)
- Angular resolution: around 1^o FWHM
- Sky coverage: 20-25% of the sky
- Current collaboration: Sapienza, UNIMI, UNIMIB, IASFBO-INAF, IFAC-CNR, Uni.Cardiff, Uni.Manchester, INFN-GE, INFN-PI, INFN-RM1, INFN-RM2, INFN-FE
- PI: P. de Bernardis (Sapienza), M. Bersanelli (UniMI), F. Gatti (INFN)
- See astro-ph/1208.0298, 1208.0281, 1208.0164 and forthcoming update
- Combined sensitivity: 10 μK arcmin

LSPE : Foreground cleaning strategy



44 GHz
Monitor polarized synchrotron

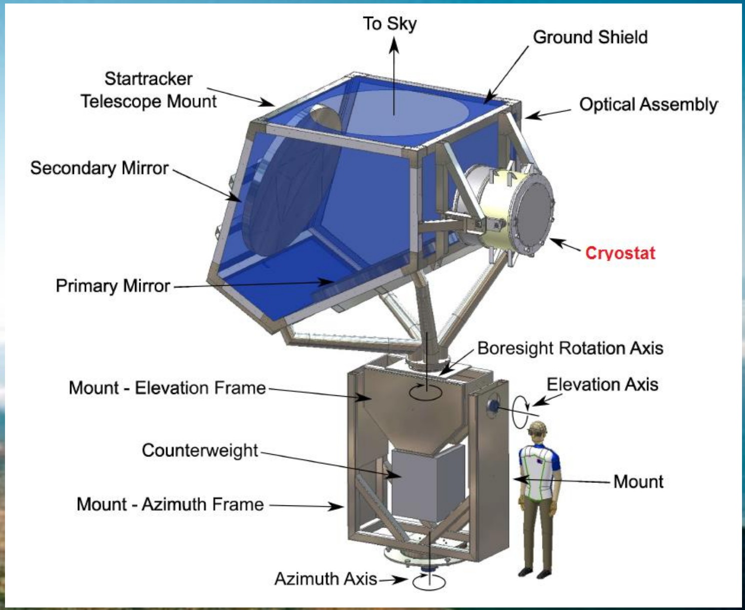
90 GHz
atmospheric monitor

140 GHz
Main CMB channel

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

To date extrapolated from 350 GHz only

LSPE/STRIP

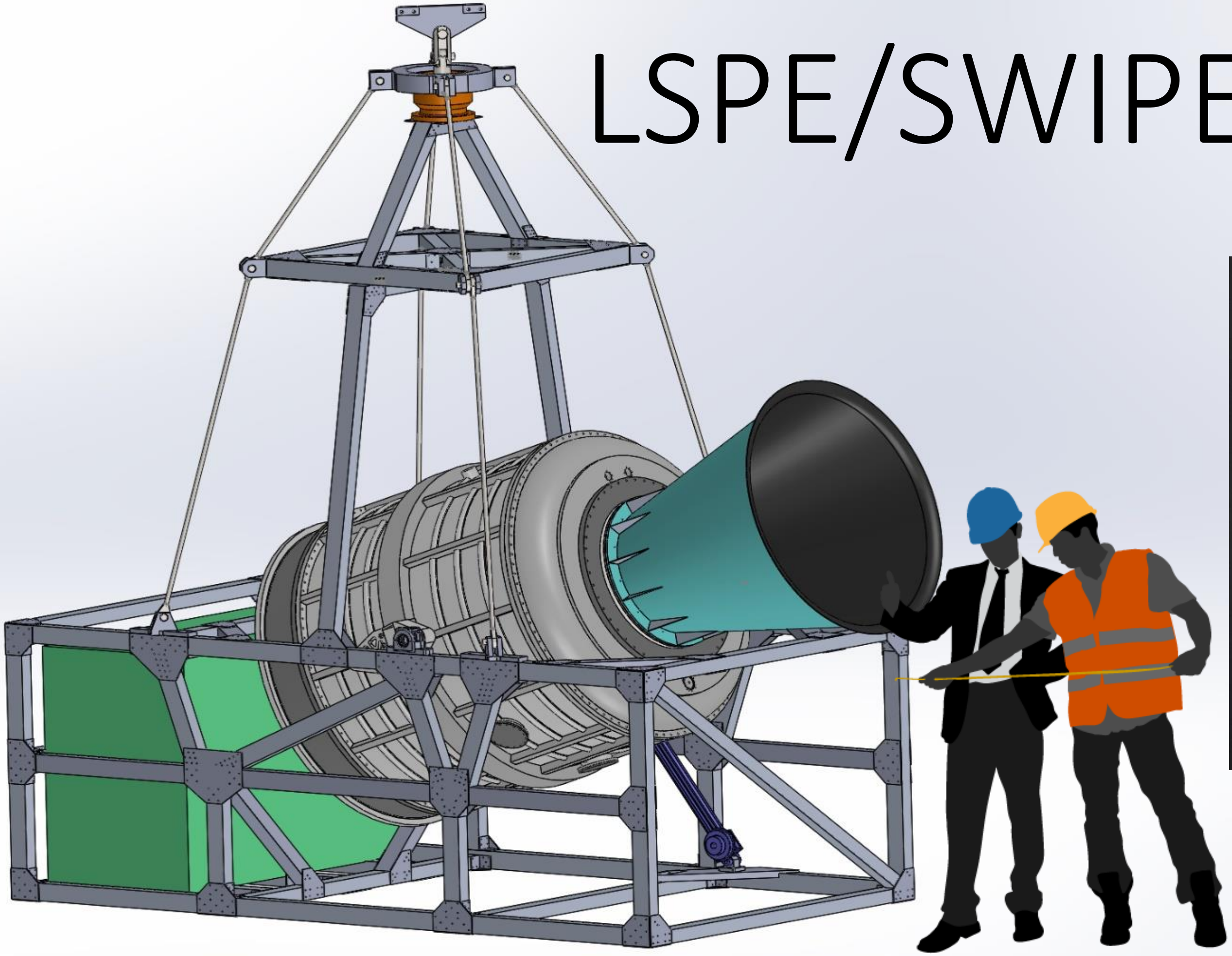


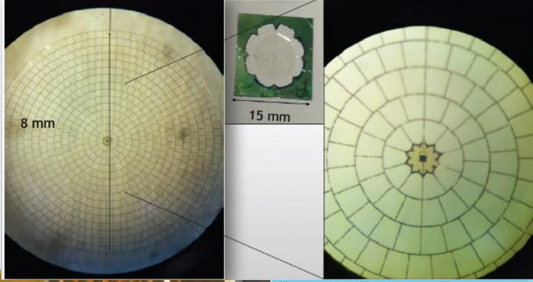
STRIP telescope

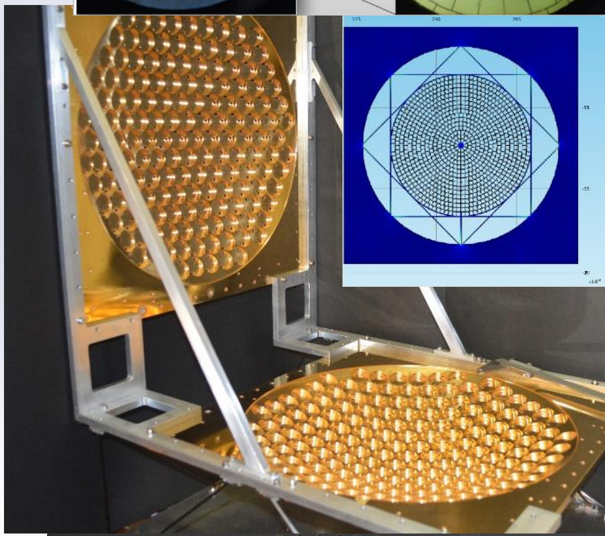
STRIP 44GHz polarimeters arrays

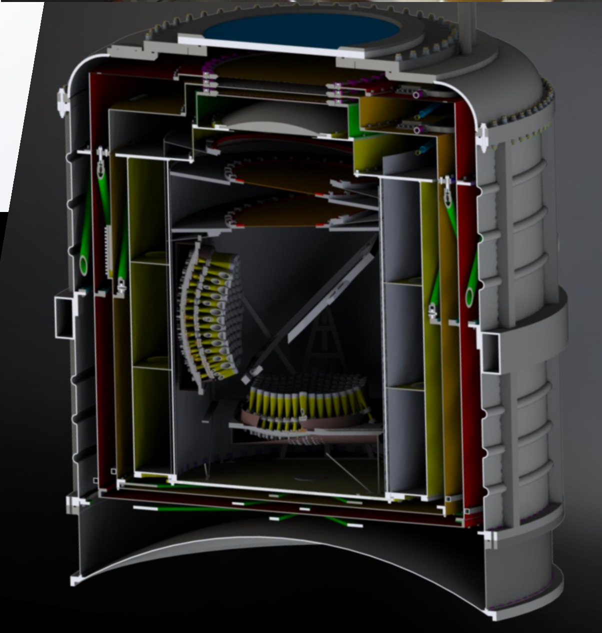
STRIP observing site : Tenerife

LSPE/SWIPE









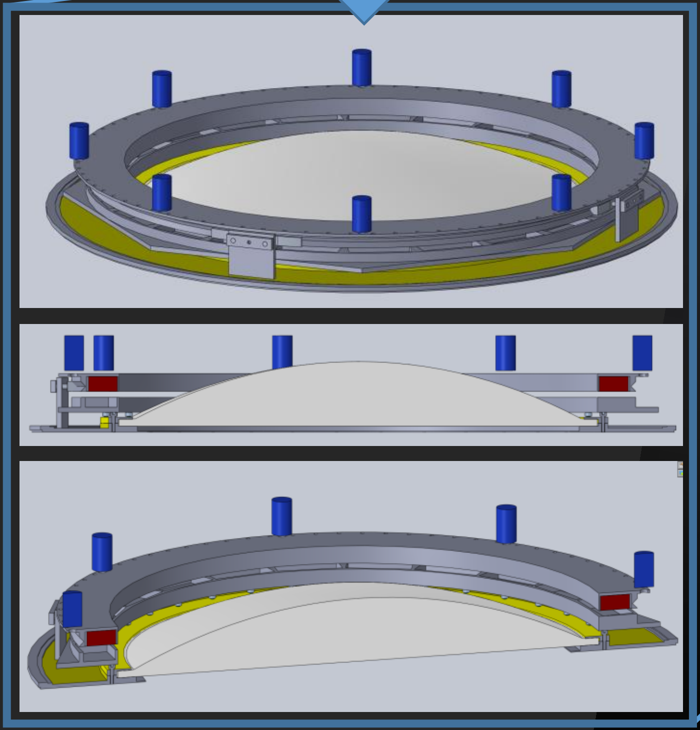
The SWIPE instrument (120-250 GHz) uses:

- *a spinning stratospheric balloon payload* to avoid atmospheric noise, flying *long-duration, in the polar night* to avoid diffracted solar pickup
- a *polarization modulator* to achieve high stability
- Large arrays of multimode bolometers for high sensitivity (8800 radiation modes)

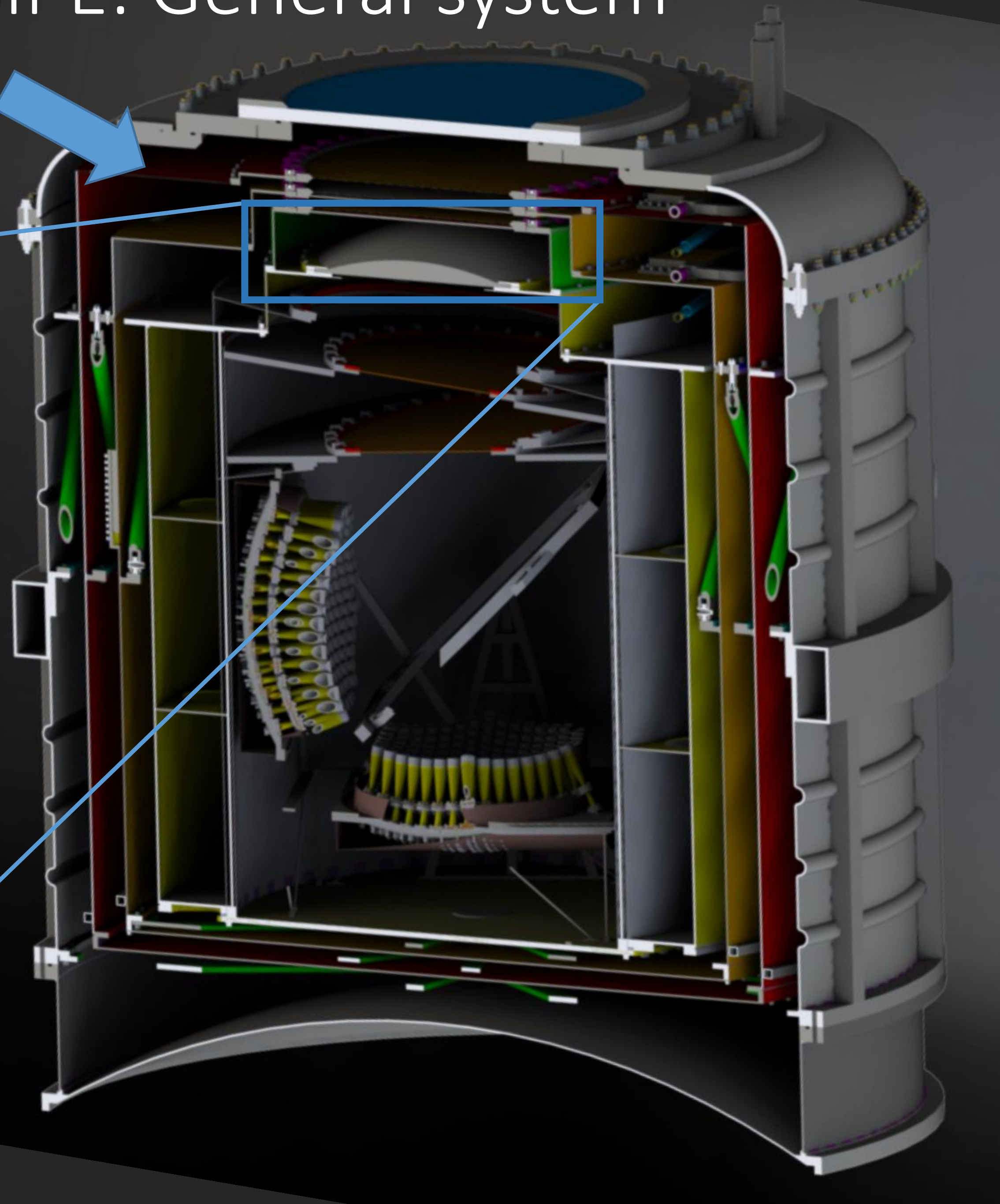
LSPE/SWIPE: General system

LSPE-SWIPE polarimeter and cryostat

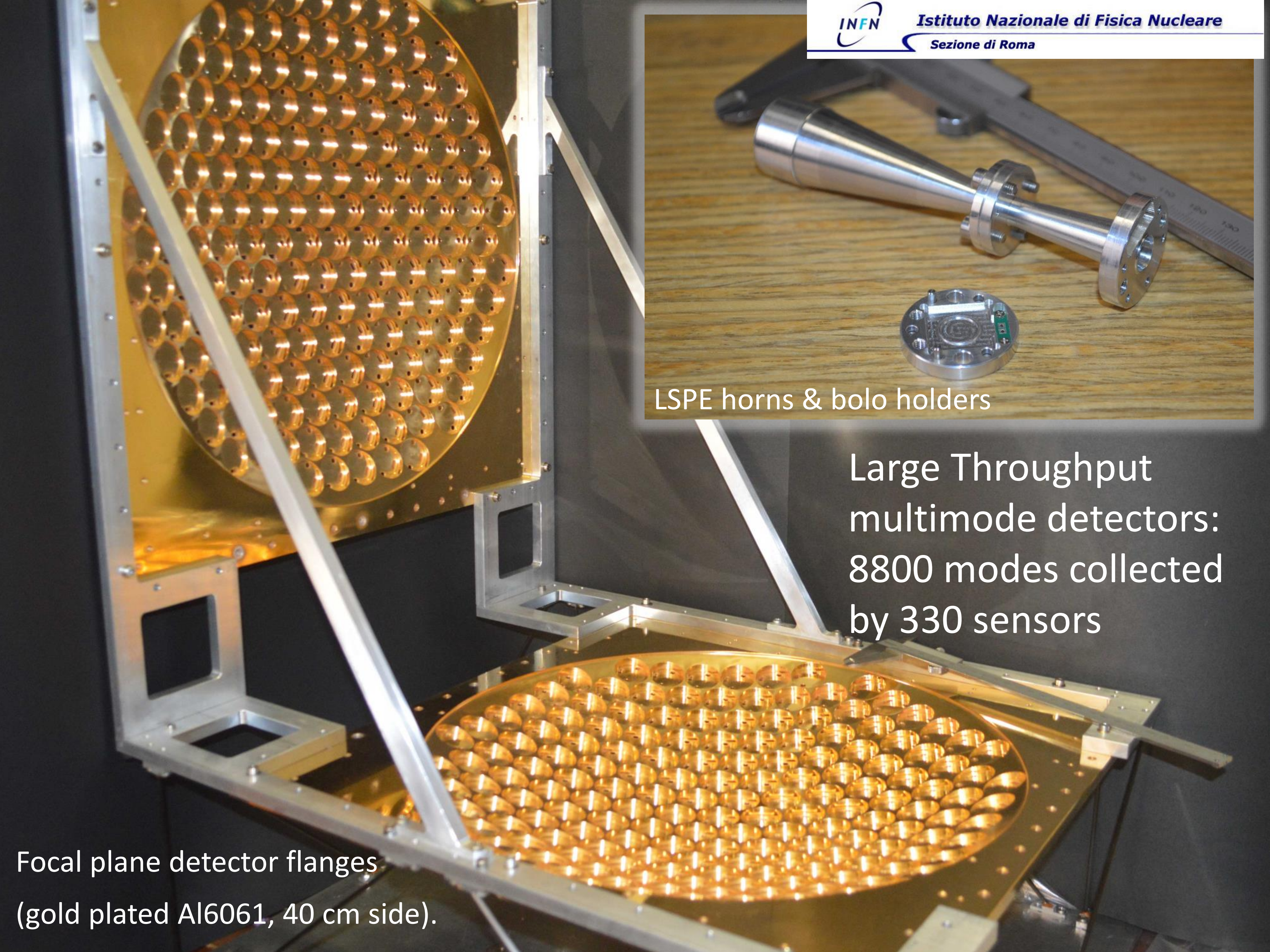
LSPE-SWIPE polarization modulator



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



INFN Istituto Nazionale di Fisica Nucleare
Sezione di Roma



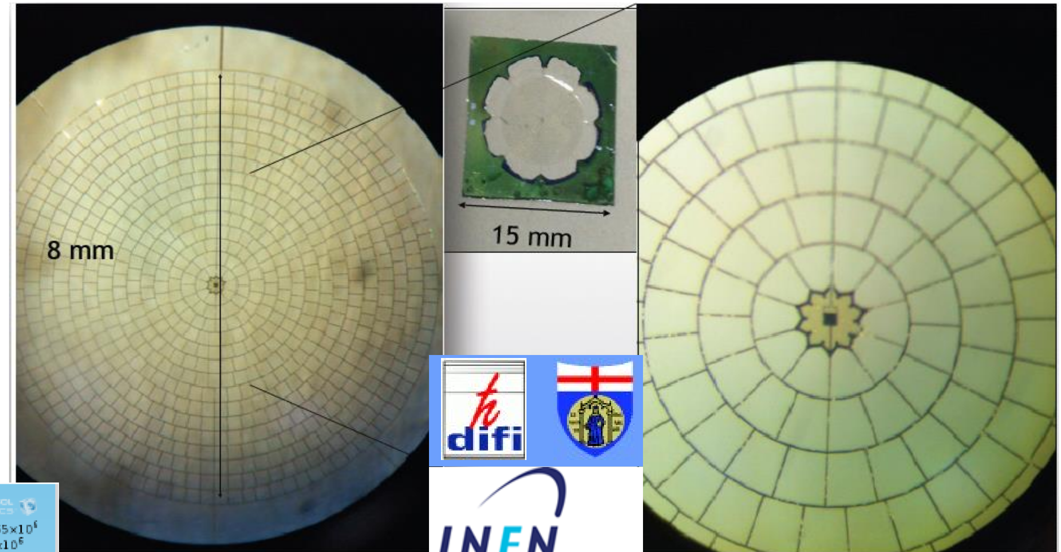
LSPE horns & bolo holders

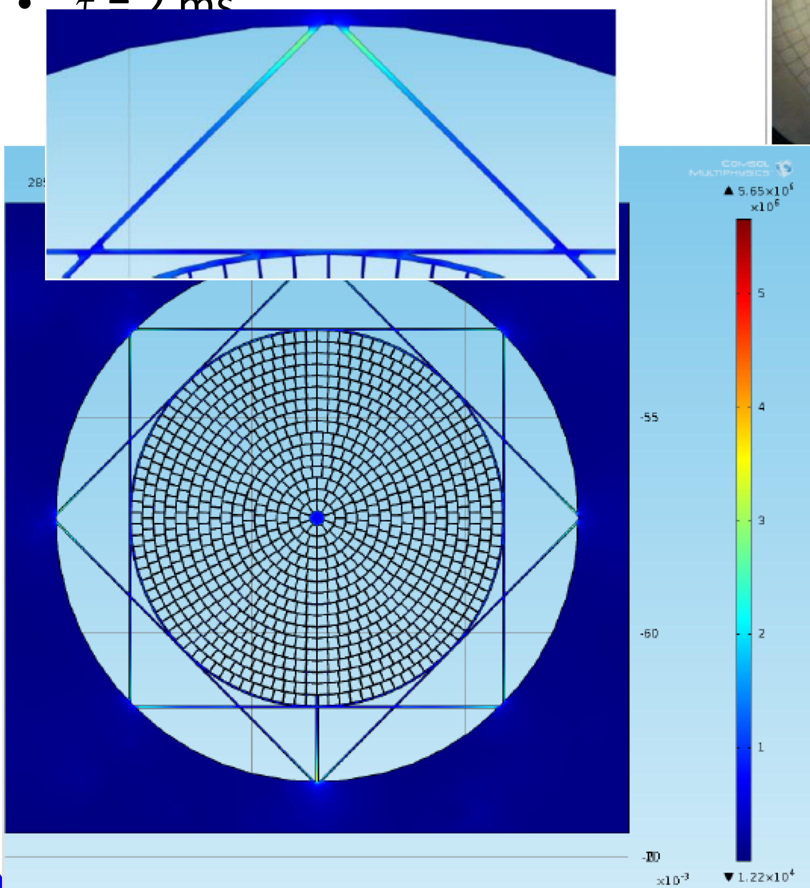
Large Throughput multimode detectors: 8800 modes collected by 330 sensors

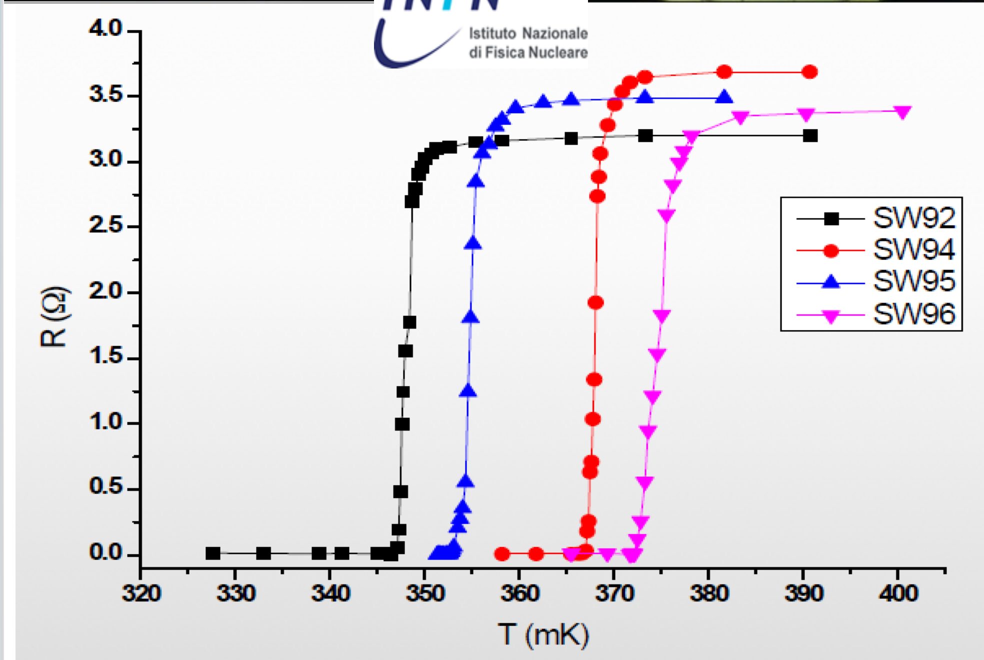
Focal plane detector flanges
(gold plated Al6061, 40 cm side).

SWIPE - multimode absorbers & TES

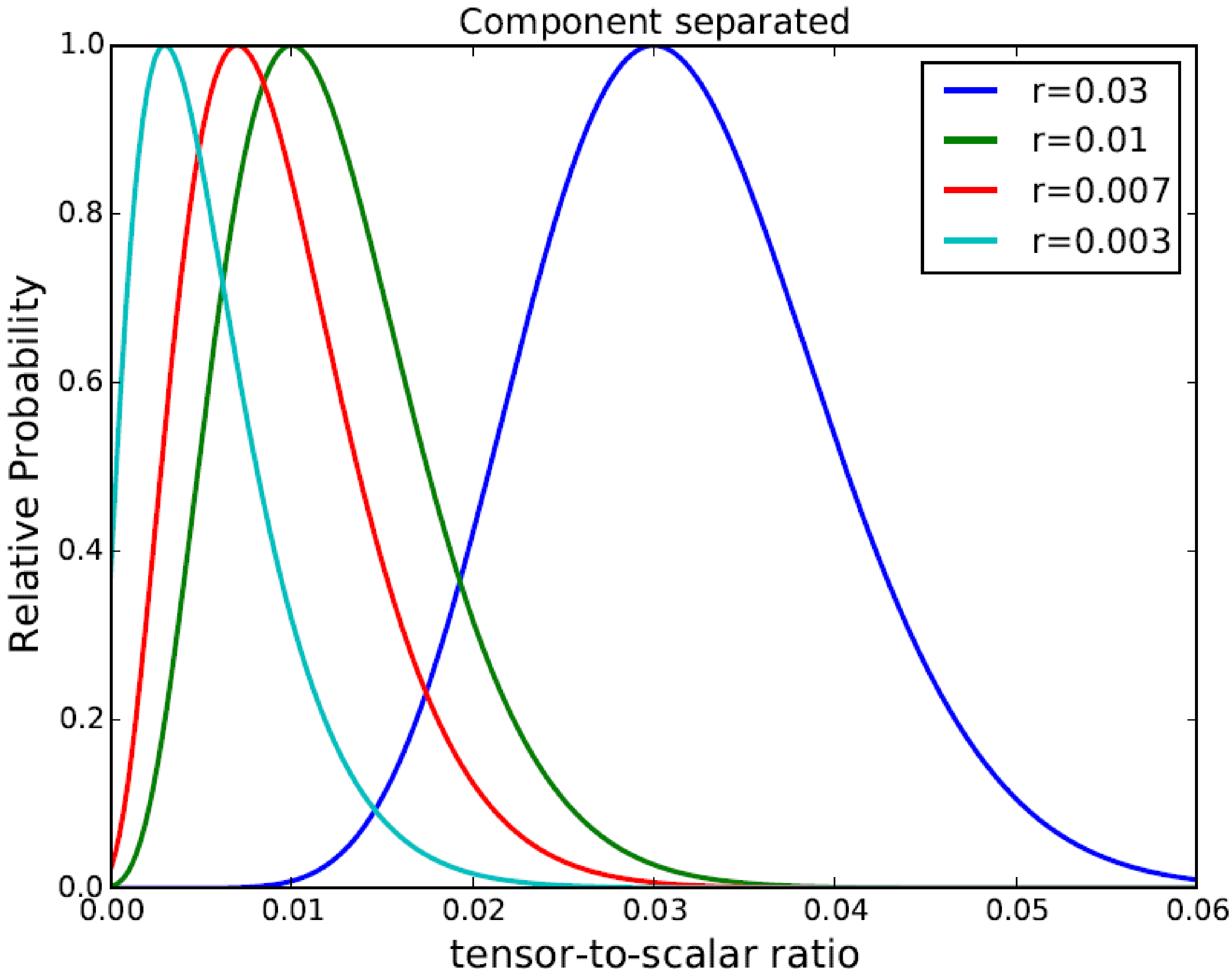
- The absorbers are large Si_3N_4 spider-webs (8 mm diameter, multimode)
- Sensors are Ti-Au TES
- Photon noise limited
- τ = 2 ms







SWIPE Performance Forecast (1^{st} flight)

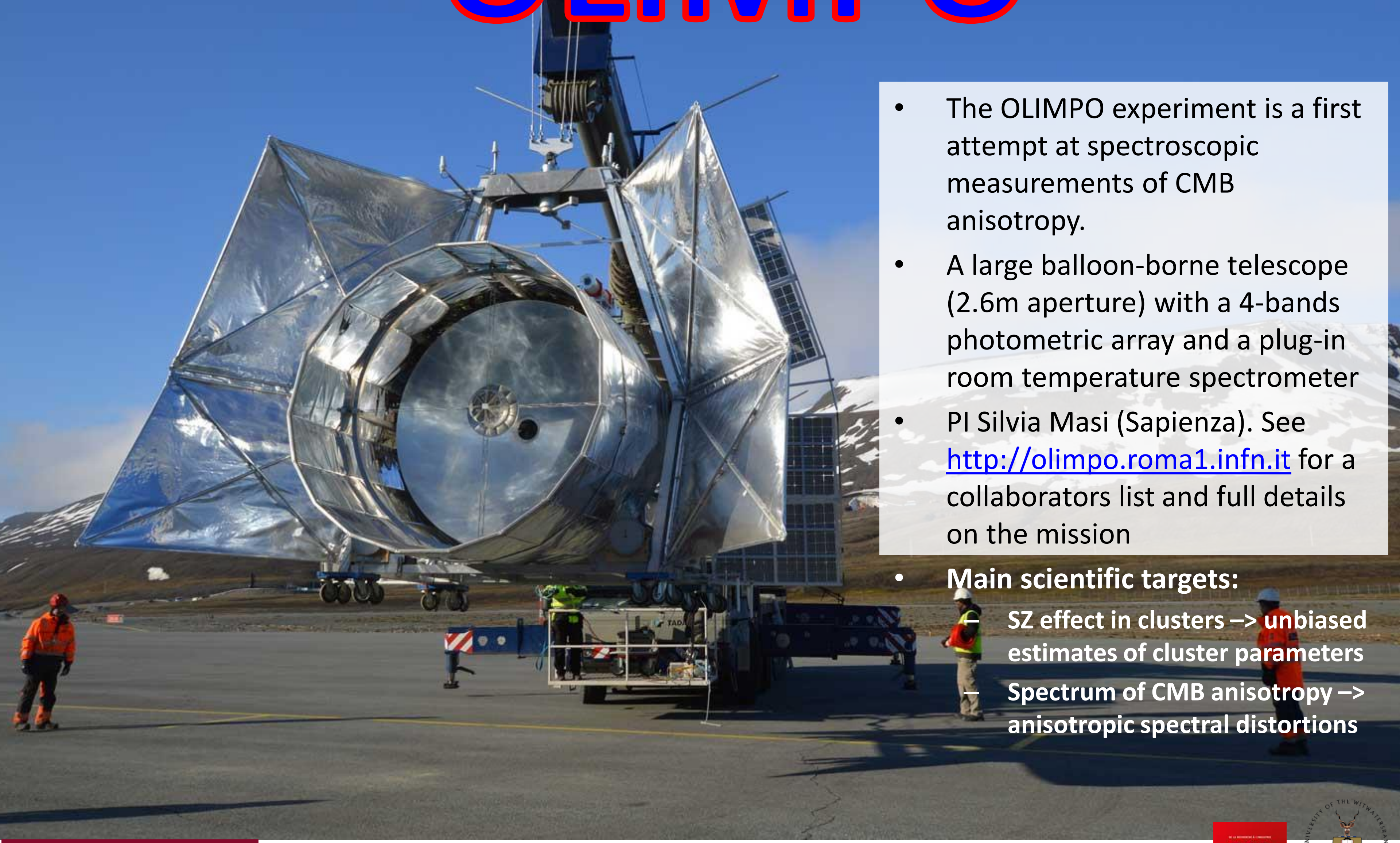


L. Pagano, F. Piacentini

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 2020/21 for SWIPE and start of data taking in 2020 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 (2.6m aperture) with a 4-bands photometric array and a plug-in room temperature spectrometer
- PI Silvia Masi (Sapienza). See http://olimpo.roma1.infn.it 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**

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

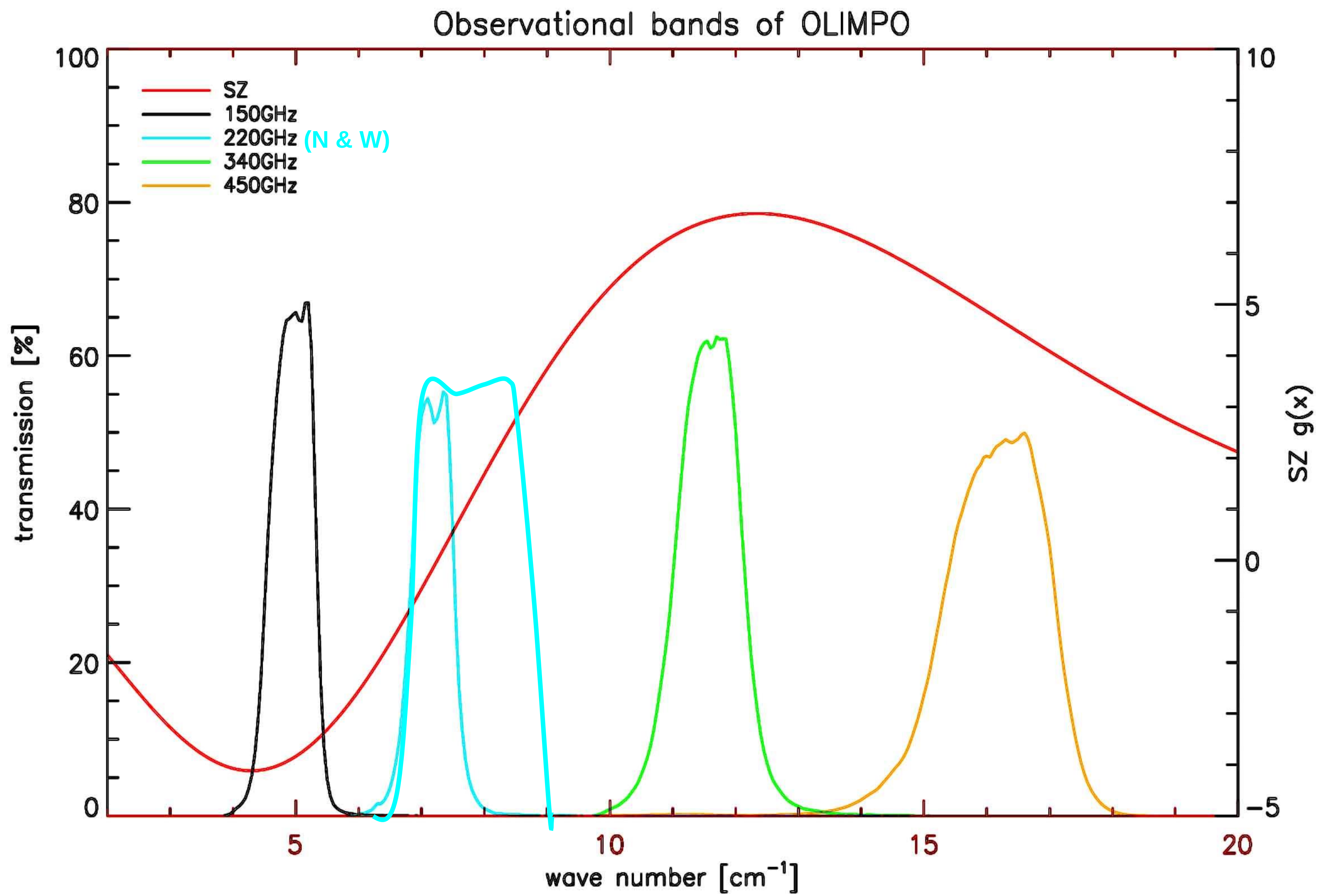
ABSTRACT

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-

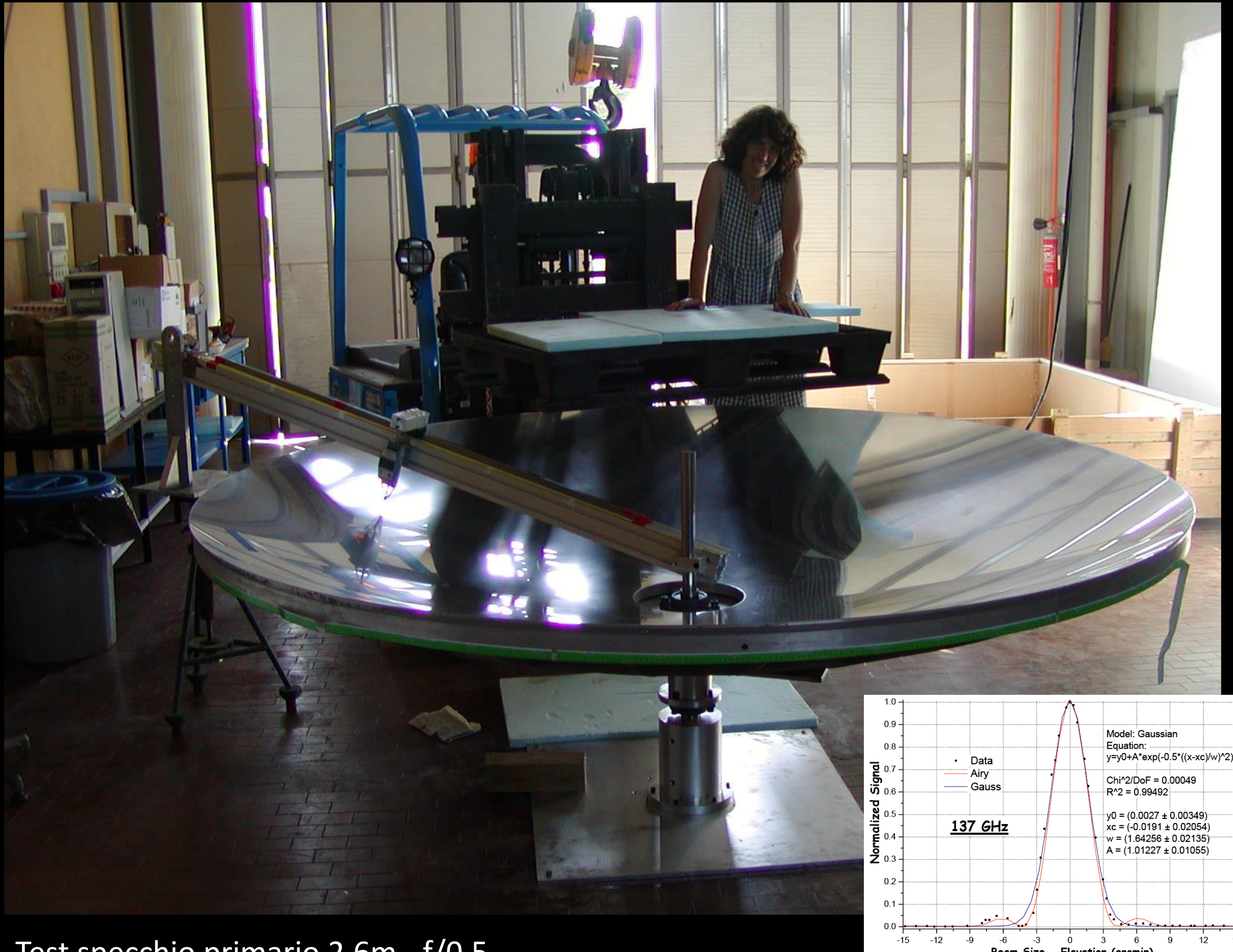
OLIMPO

- 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

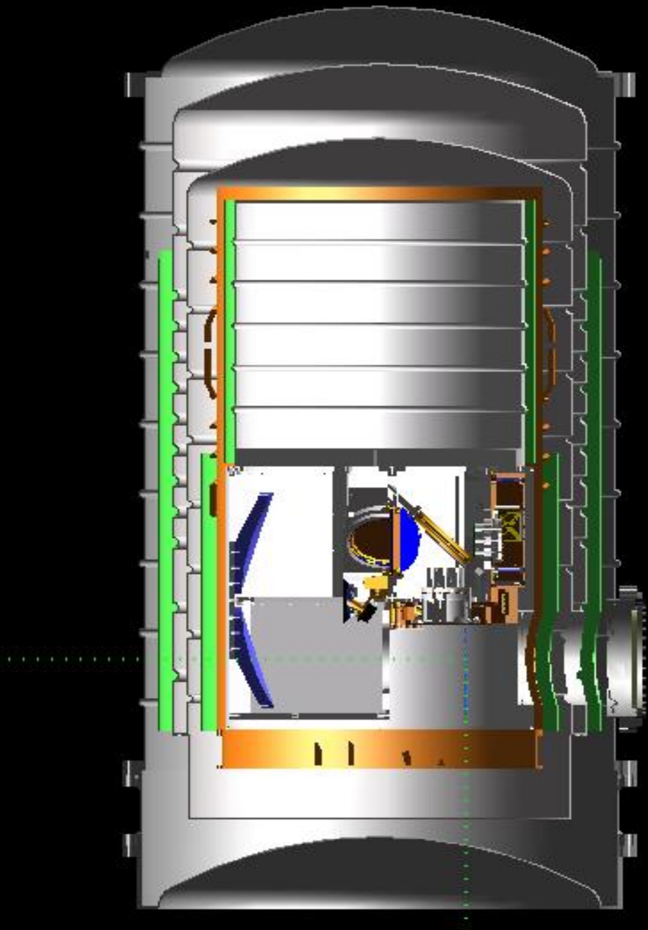
ch	ν_{eff} [GHz]	$\Delta\nu_{FWHM}$ [GHz]	Res. [‘]
I	148.4	21.5	4.2
II	215.4	20.6	2.9
III	347.7	33.1	1.8
IV	482.9	54.2	1.8



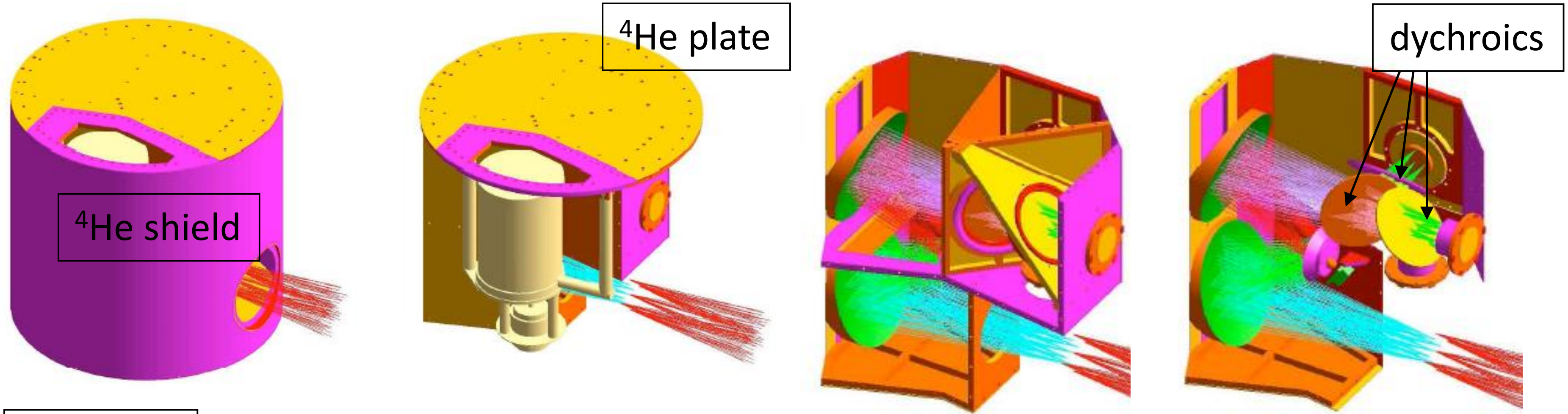
Observational bands of OLIMPO
SZ
150GHz
220GHz (N & W)
340GHz
450GHz
transmission [%]
100
80
60
40
20
0
10
5
0
−5
SZ g(x)
5
10
15
20
wave number [cm^{-1}]

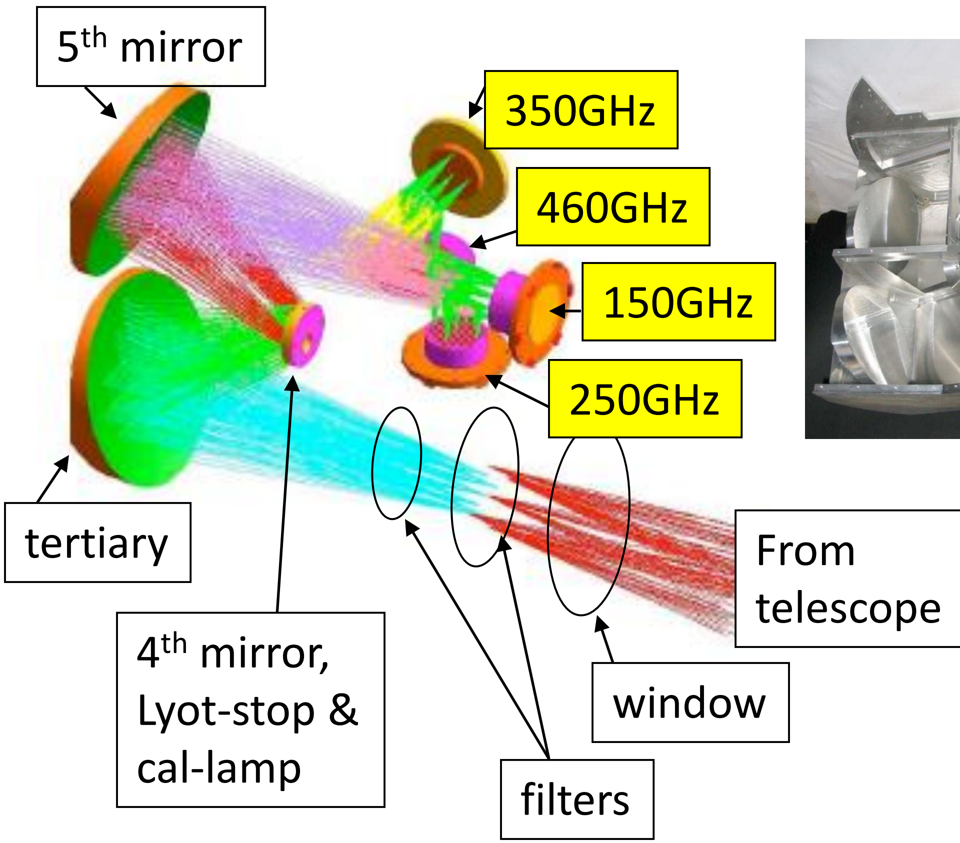


Test specchio primario 2.6m - f/0.5



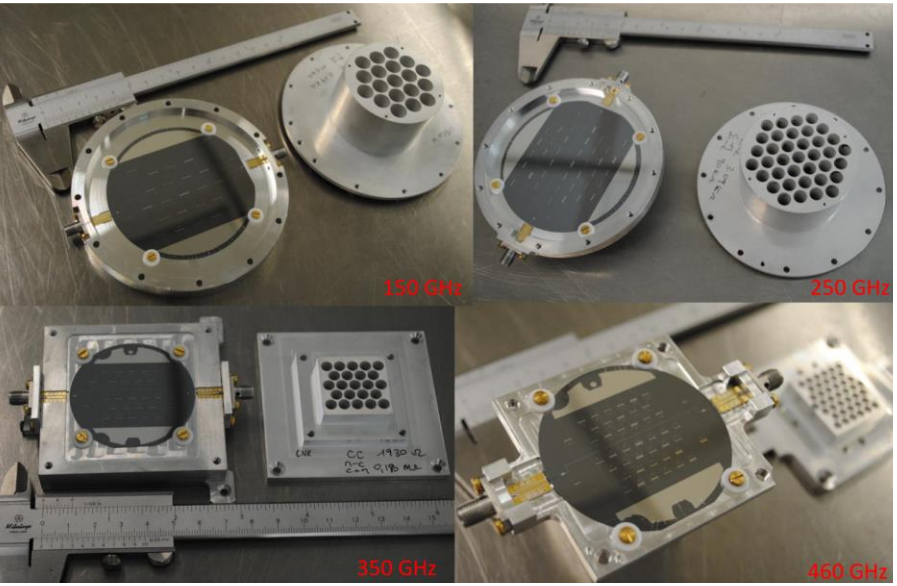
0.3K cryostat (made in Sapienza)
65L superfluid ^{4}He
70L liquid N
40LSTP ^{3}He refrigerator
50L experimental volume
Hold time – 15 days @ 0.3K





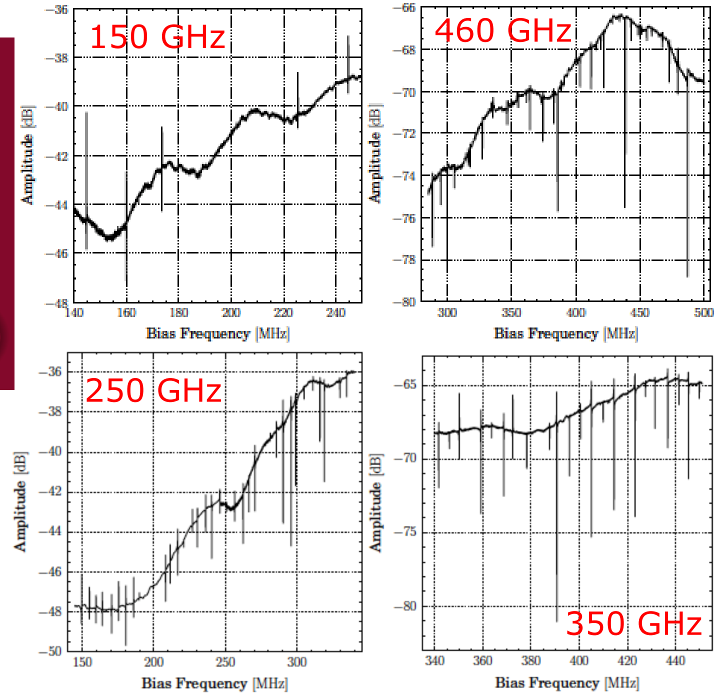
OLIMPO: Cold Optics and Arrays

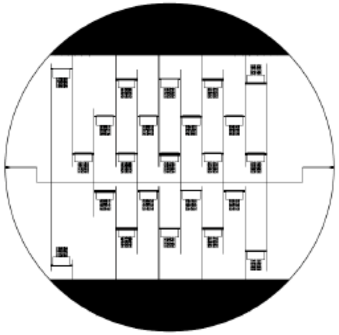
OLIMPO - Kinetic Inductance Detectors

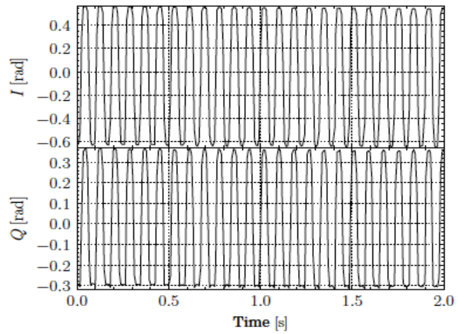


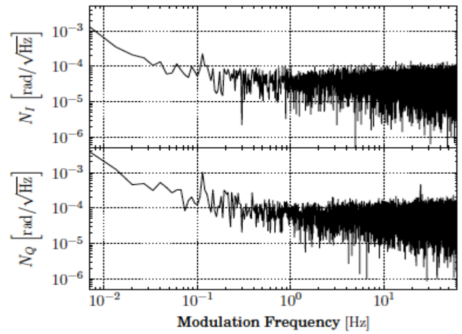
CNR IFN Istituto di Fotonica e Nanotecnologie

SAPIENZA UNIVERSITÀ DI ROMA







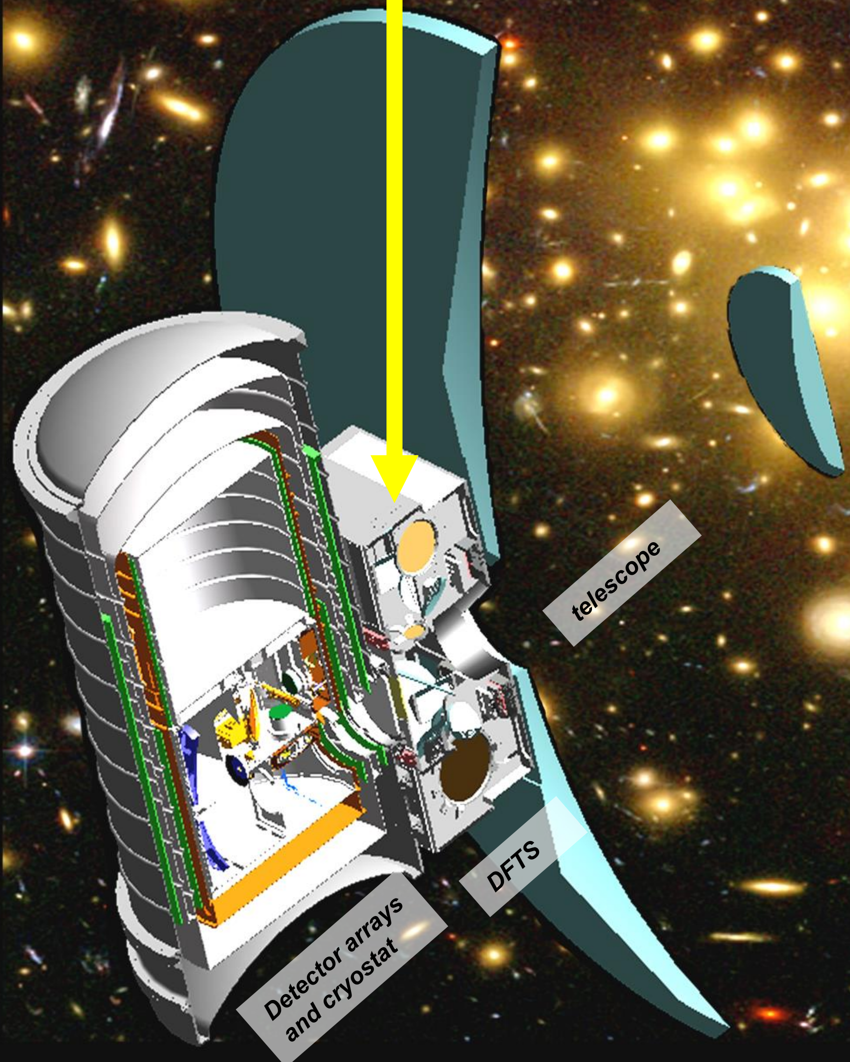


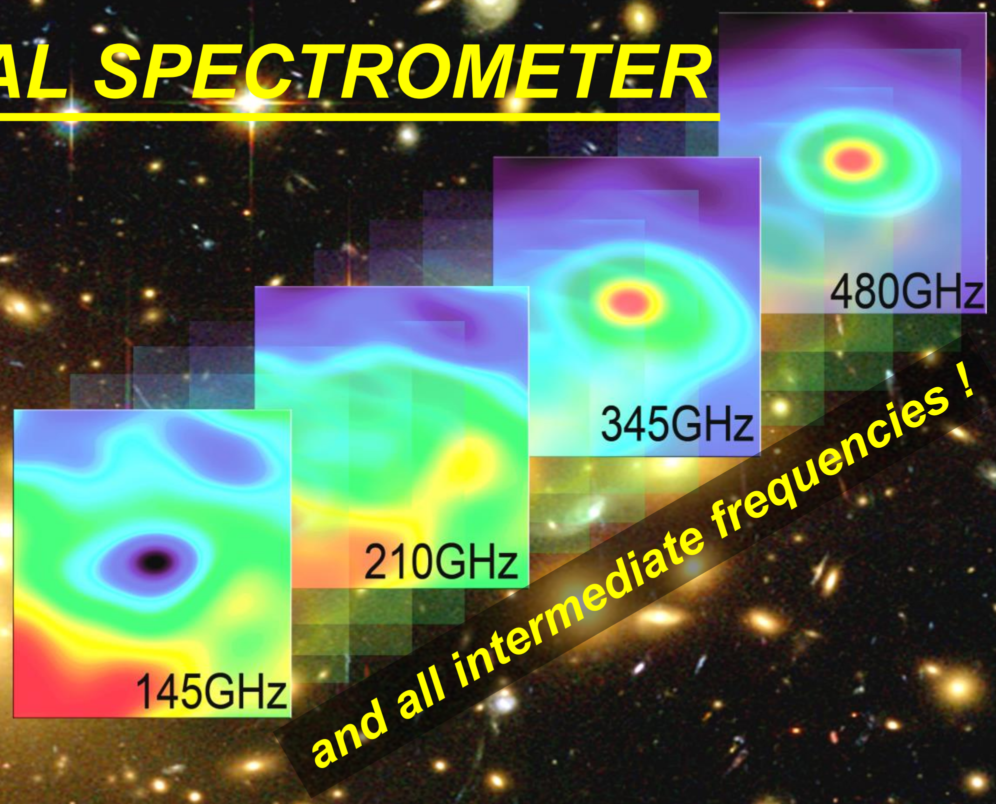
Channel	NET_{RJ} $[mK/\sqrt{Hz}]$
150 GHz	0.180
250 GHz	0.145
350 GHz	0.288
460 GHz	0.433

typical NET including radiative load from warm spectrometer

agenzia spaziale italiana

OLIMPO’s DIFFERENTIAL SPECTROMETER

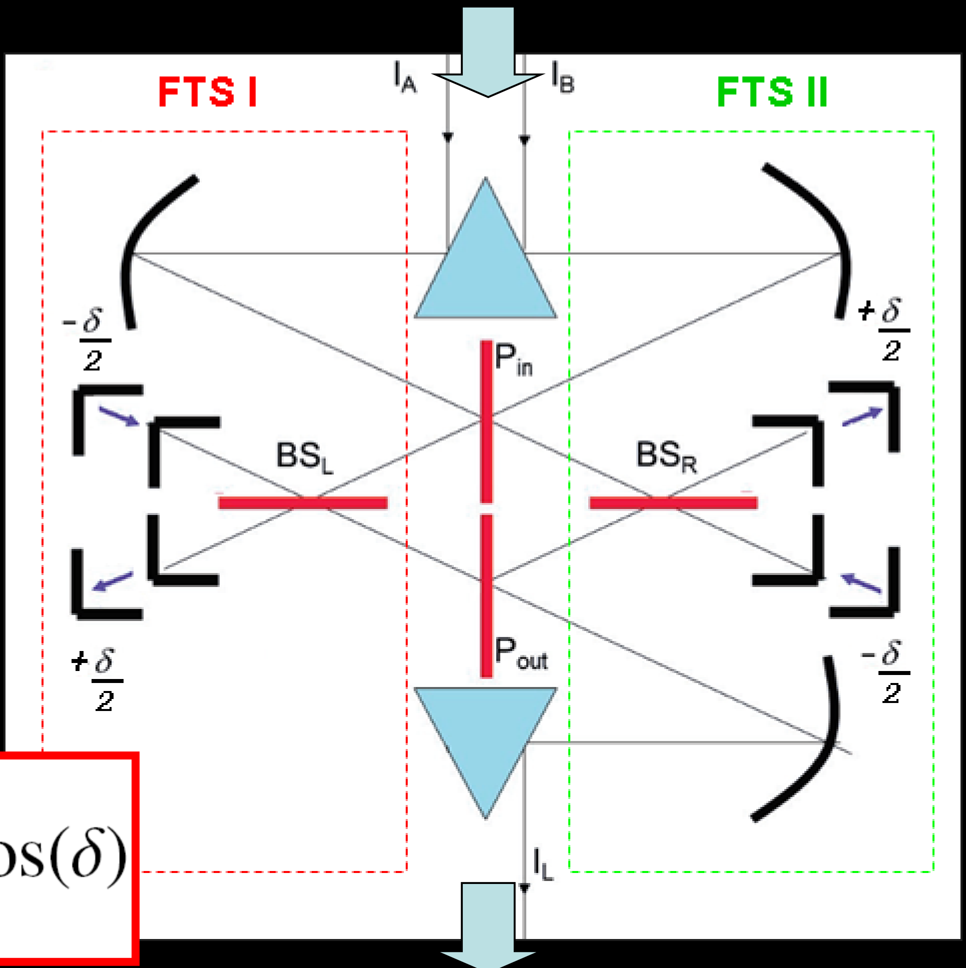




A Differential Fourier Transform Spectrometer (DFTS).
Similar to COBE-FIRAS but…
.. rather than measuring the brightness difference between the sky and an internal blackbody, it measures the **brightness difference between two directions in the sky**

- **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

Alessandro Schillaci[1], Giuseppe D'Alessandro[1], Paolo de Bernardis[1], Silvia Masi[1], Camila Paiva Novaes[2], Massimo Gervasi[3], and Mario Zannoni[3]

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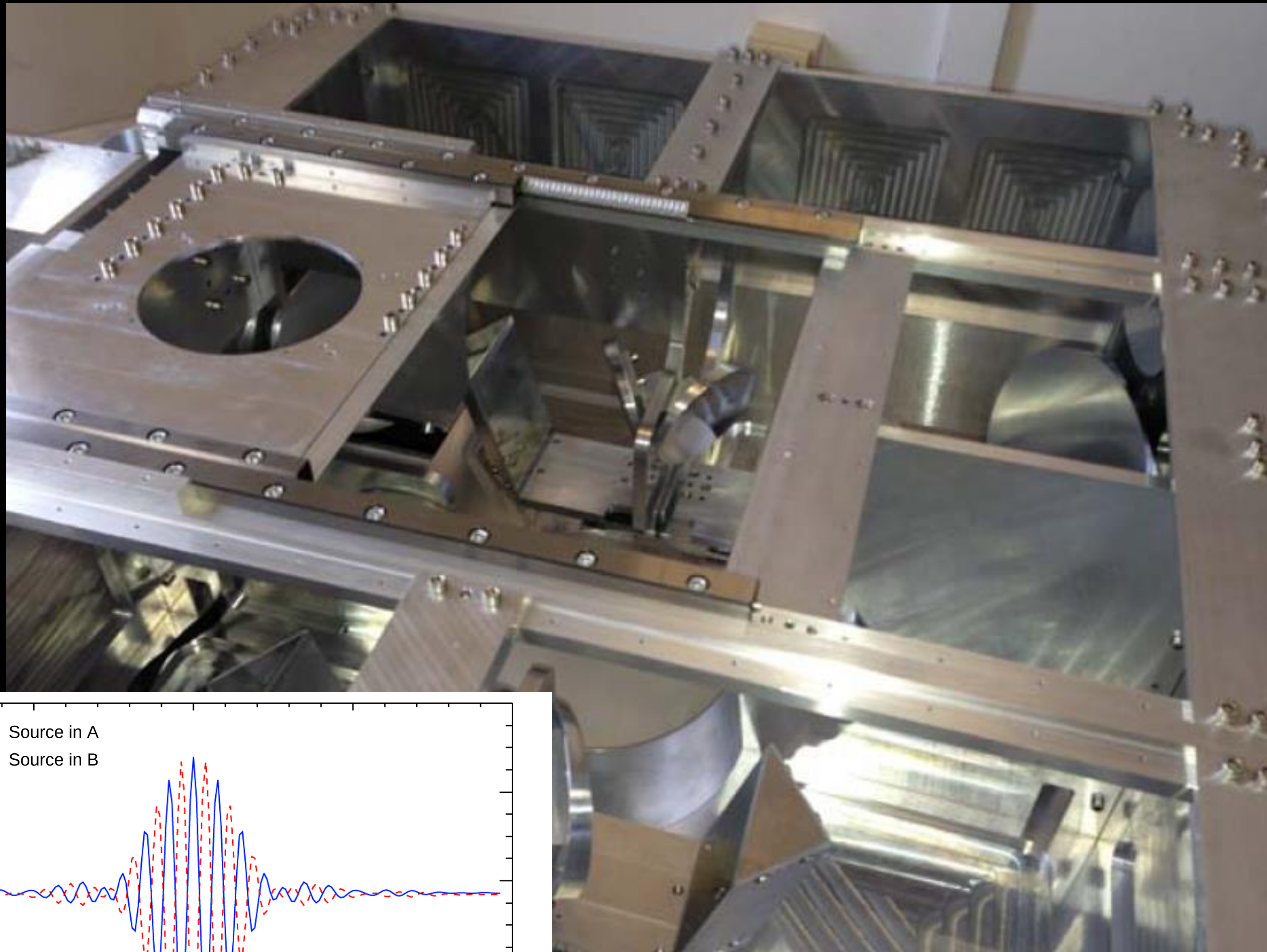
Received 13 February 2014 / Accepted 11 April 2014

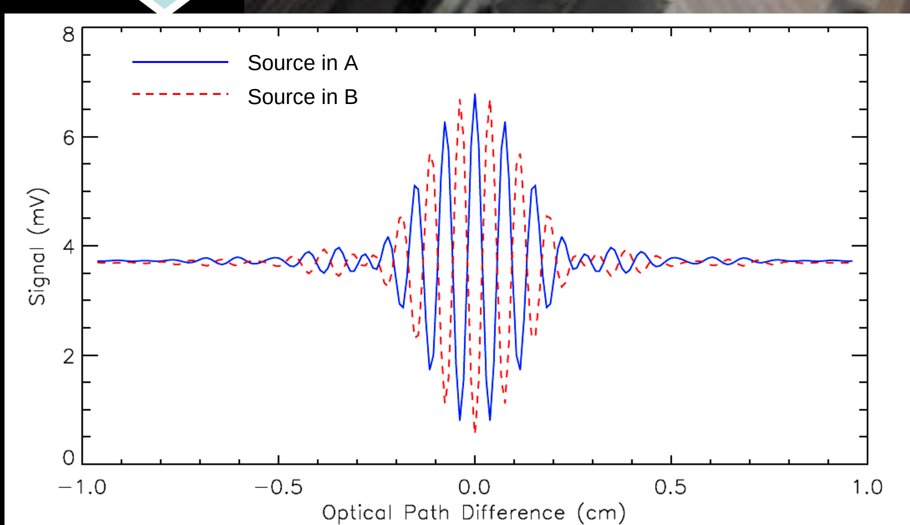
ABSTRACT

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 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

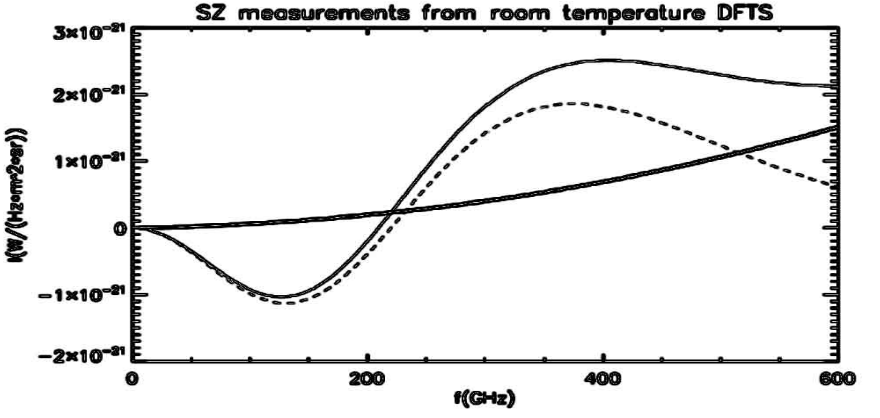
The real thing….
and measured interferograms

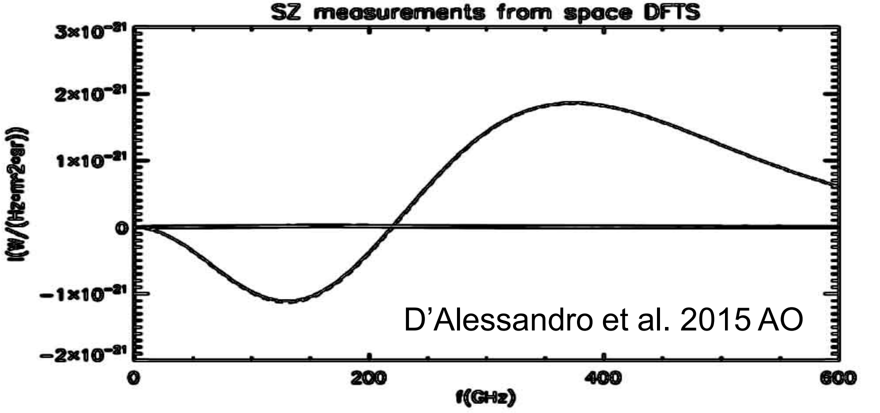


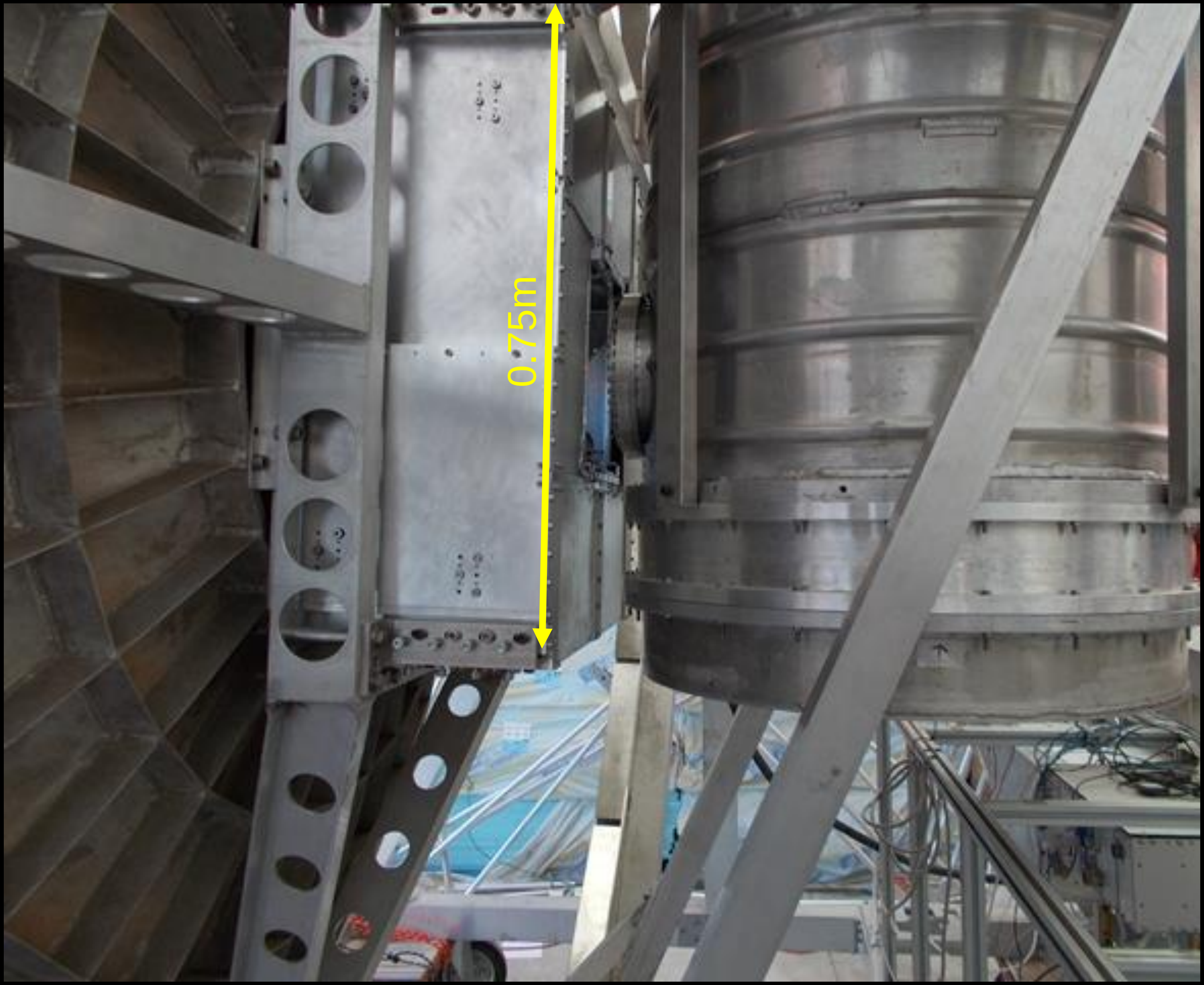


CMRR

- 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.

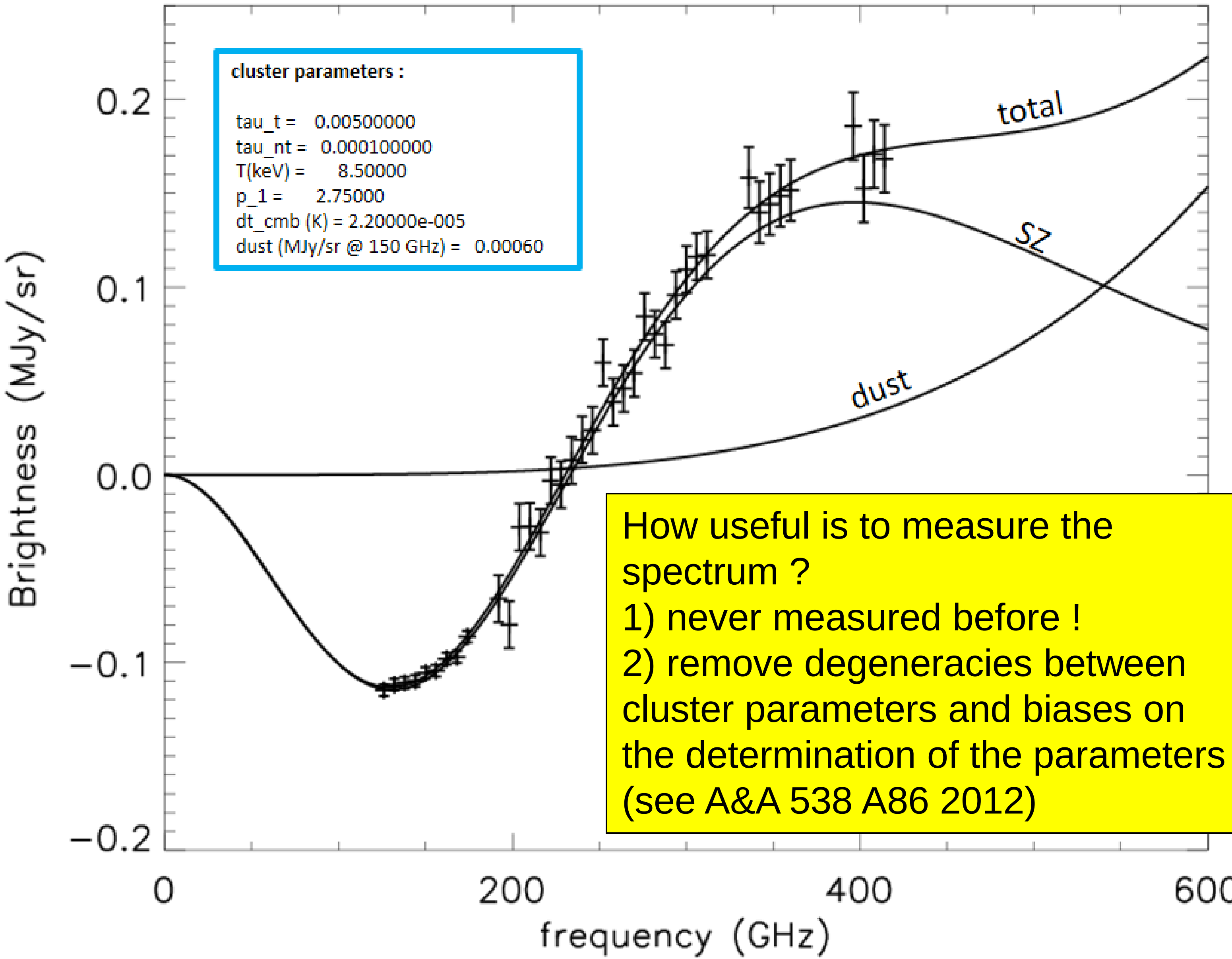






Telescope / primary mirror DFTS cryostat / detectors arrays

Main components of OLIMPO integrated on the payload

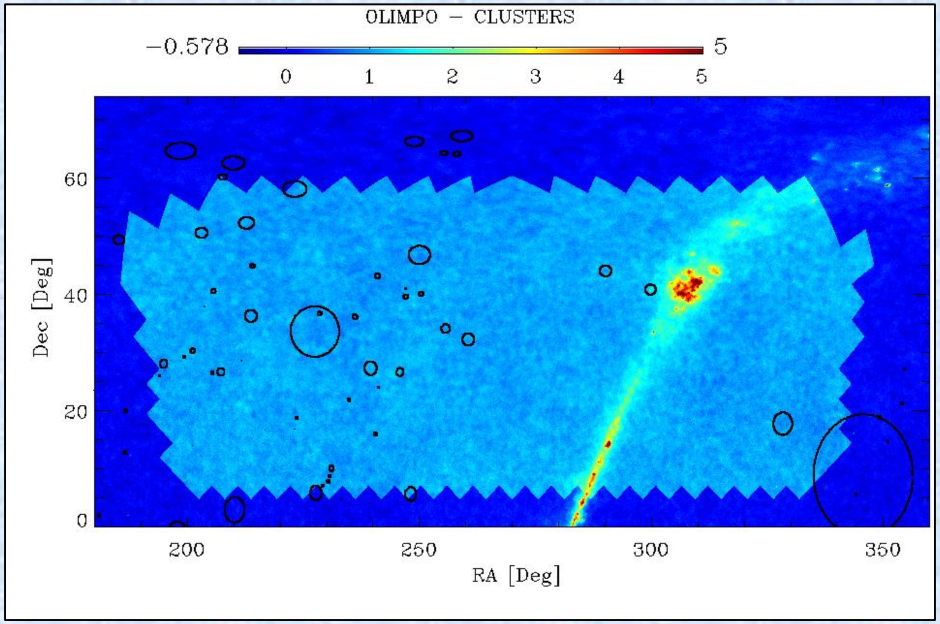


How useful is to measure the spectrum ?

1) never measured before !

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

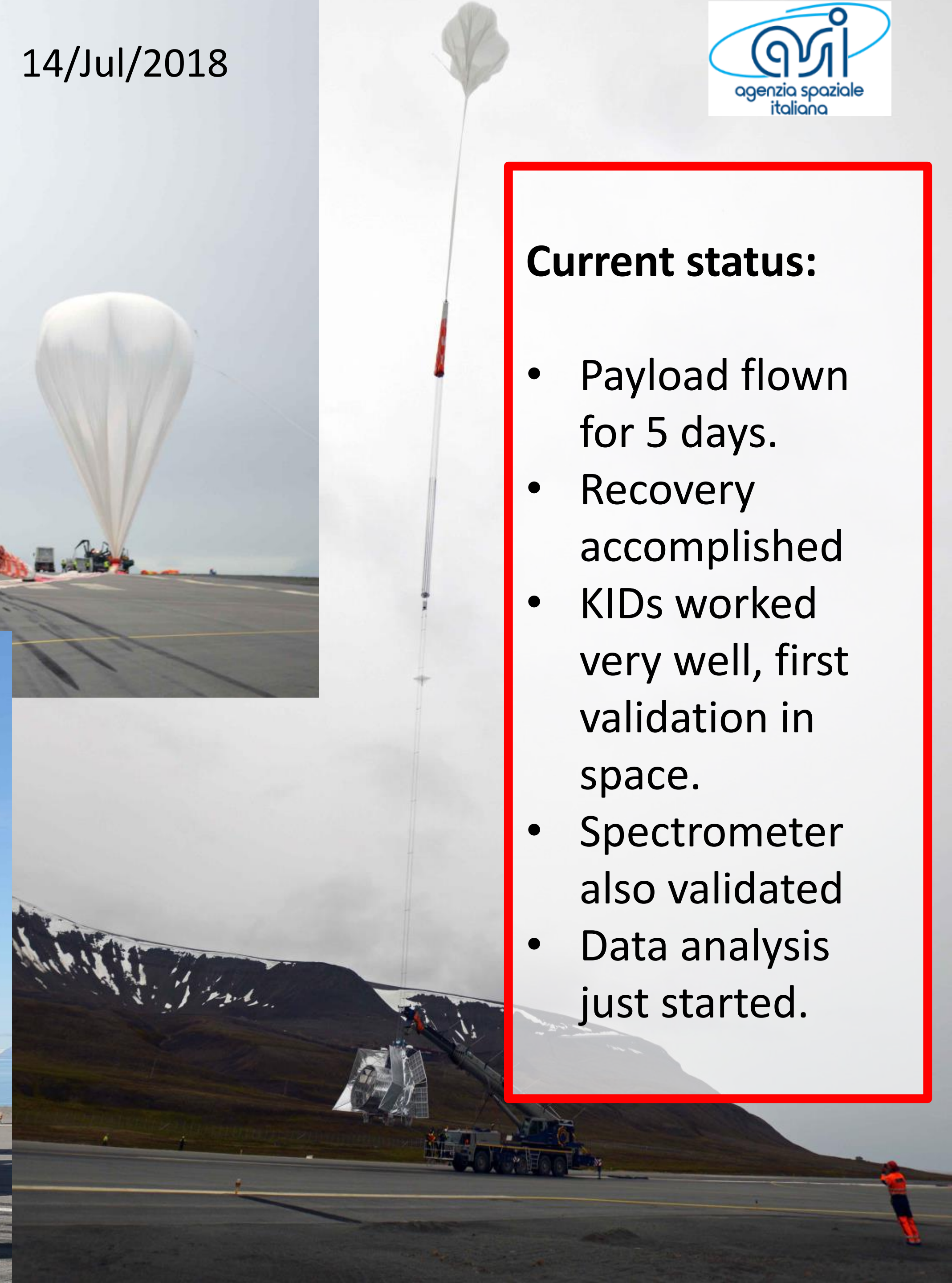
Observation Program



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

- 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.

14/Jul/2018



Current status:

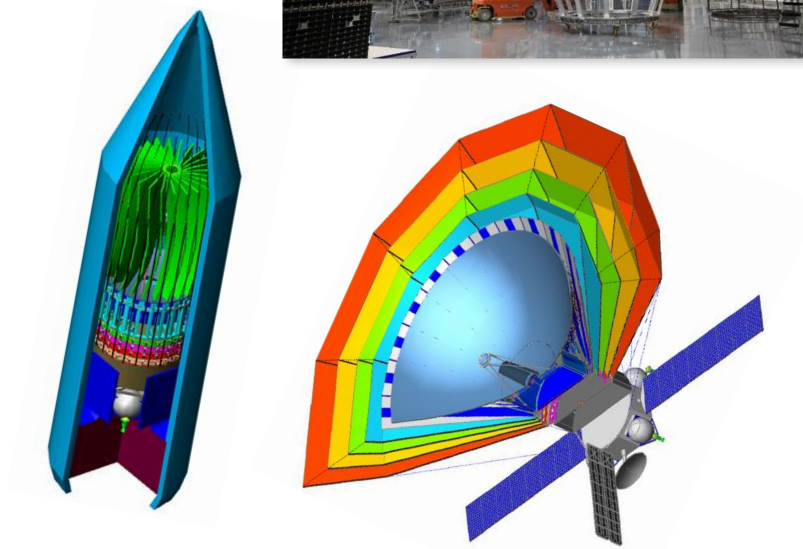
- Payload flown for 5 days.
- Recovery accomplished
- KIDs worked very well, first validation in space.
- Spectrometer also validated
- Data analysis just started.

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

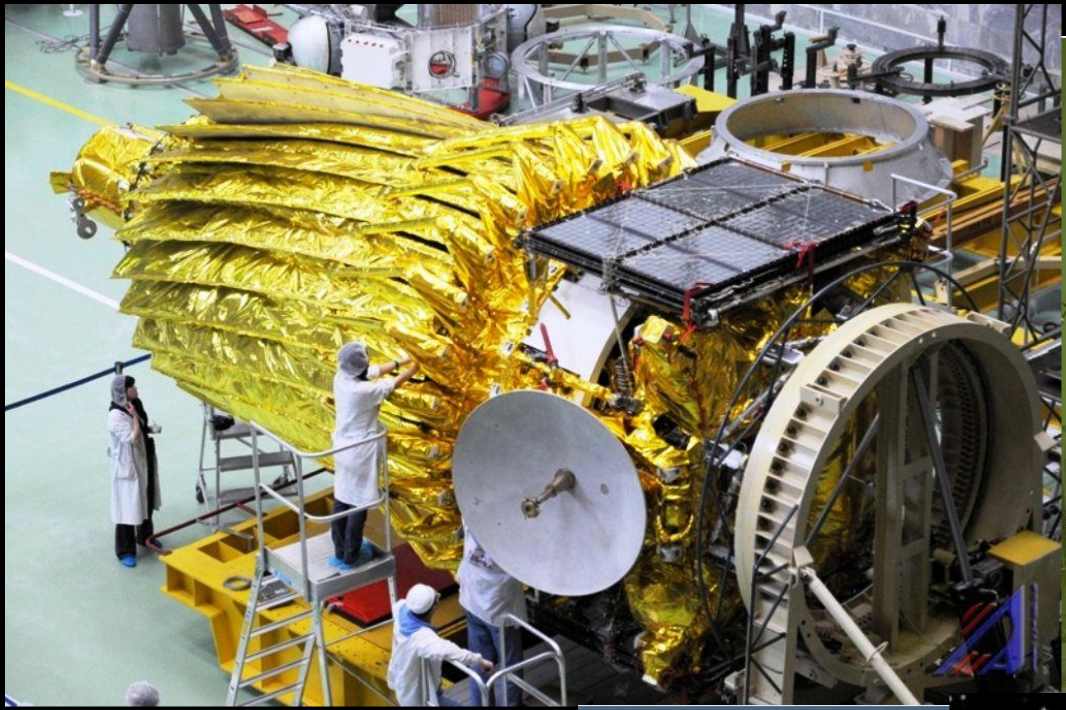
- So, once again, stratospheric balloons are effectively used as pathfinders for satellite experiments.

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).



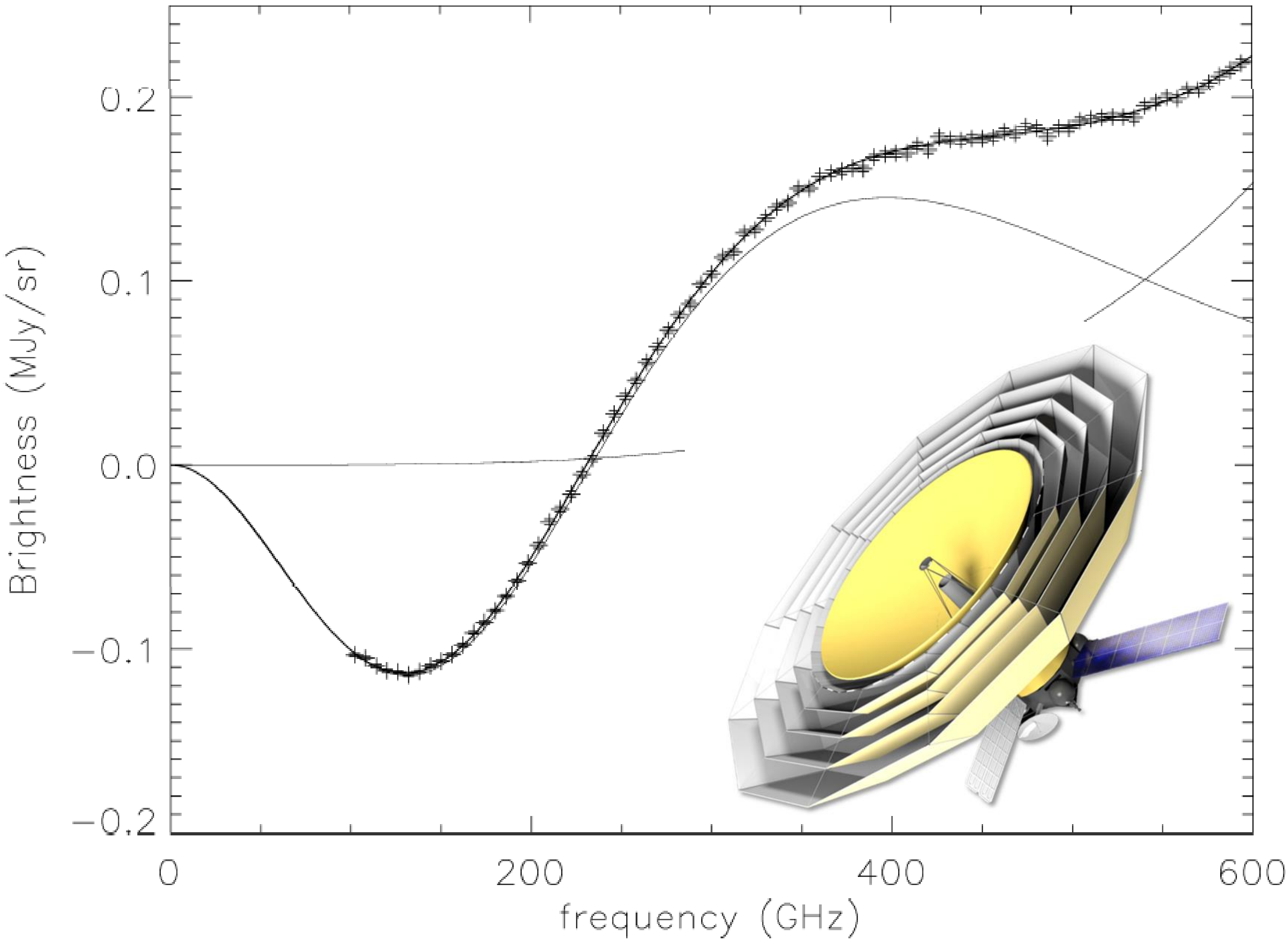
- Antenna diameter: 10 m
- Range of wavelengths: 0.01 – 20 mm
- Bolometric sensitivity (λ0.3mm, 1h integration): 5×10^{-9} Jy
- Interferometry sensitivity (λ0.5mm, 300s integration, 16 GHz bw) : 10^{-4} Jy
- Interferometer beam: 10^{-9} arcsec



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)



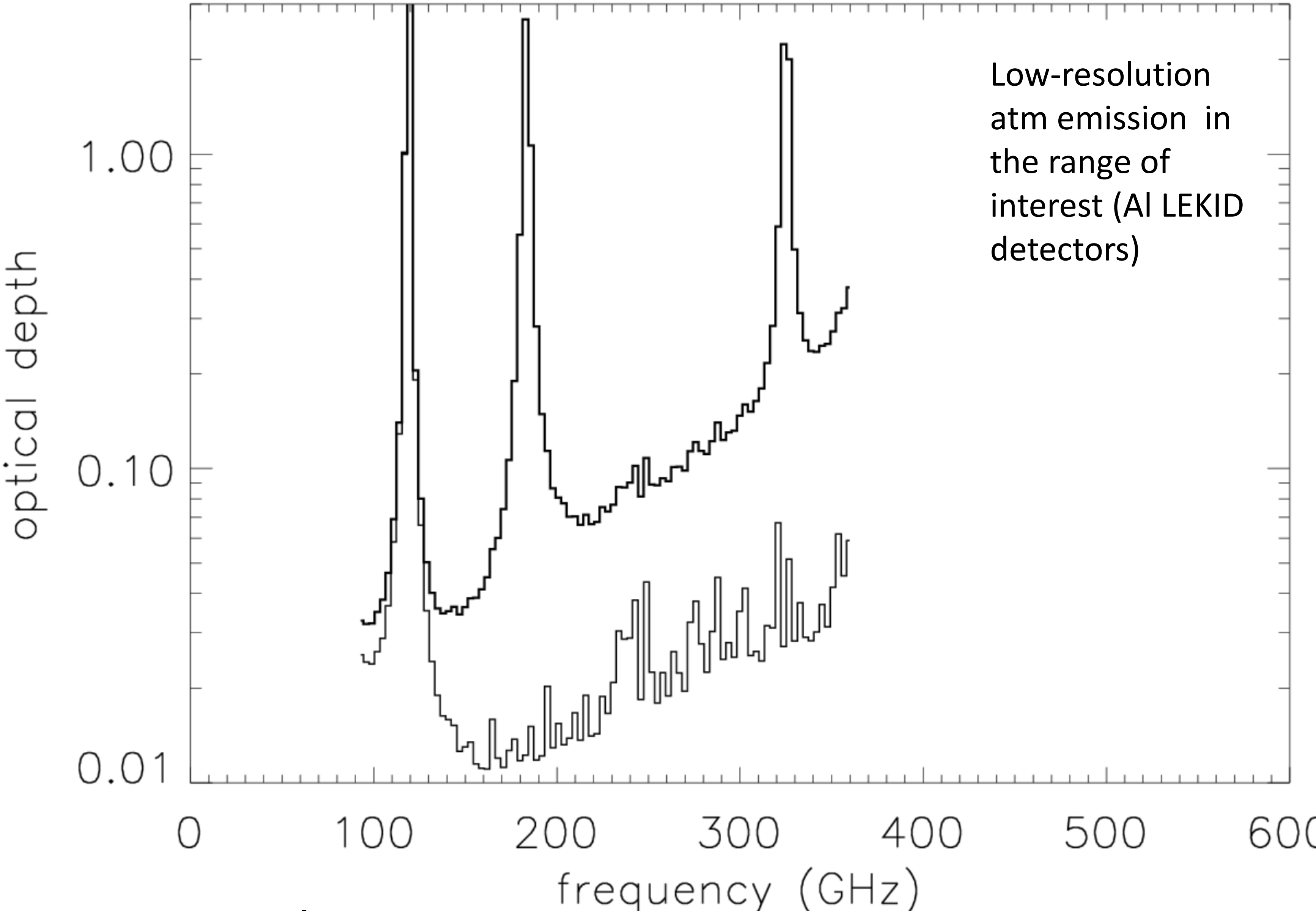
Absolute measurements (spectral distortions)

COSMO

The **COS**mic **M**onopole **O**bserver :

- An attempt to measure **spectral distortions of the absolute brightness** of the CMB from the ground (Dome-C, Antarctica)
- Uses a differential Fourier Transform Spectrometer comparing sky emission to the emission of an internal blackbody.
- Copes with atmospheric emission
  - Selecting the best site in the world for observations
  - Using fast detectors and fast modulation
- Funded by Programma Nazionale di Ricerche in Antartide

Why Dome-C : optical depth of the atmosphere (credits : AM code)



Low-resolution atm emission in the range of interest (Al LEKID detectors)

+ <T>=200K in the winter

COSMO : coping with the atmosphere

- We have to measure and subtract atmospheric emission, and we have to do it very quick.
- Recipe to mitigate the problem:

1. Work from a high altitude, cold and dry site (Dome-C, Antarctica) to minimize the problem
2. Measure the specific spectral brightness of atmospheric emission while measuring the brightness of the sky, modulating the optical depth
3. Use fast, sensitive detectors (KIDs, heritage from OLIMPO developments), and fast modulators (a spinning wedge mirror, rotating at 2500 rpm in front of the instrument).

COSMO sky/atmosphere scan strategy

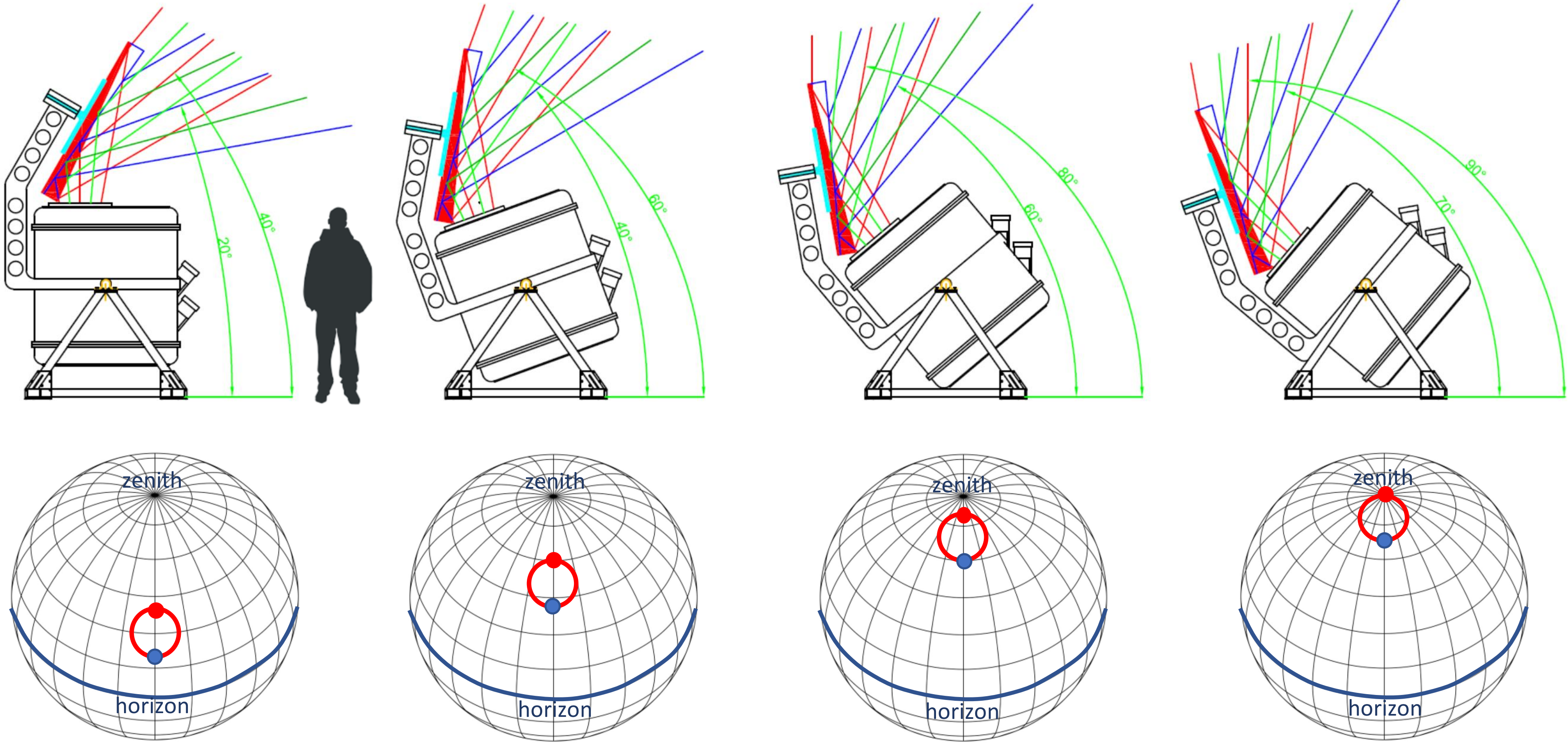
Oversized (1.6m diameter), spinning flat mirror, 10° wedge (red/blue)
To scan circles (D=5°-20°) in the sky modulating atmospheric emission.
Center elevation ranges between 30° and 80° depending on cryostat tilt.

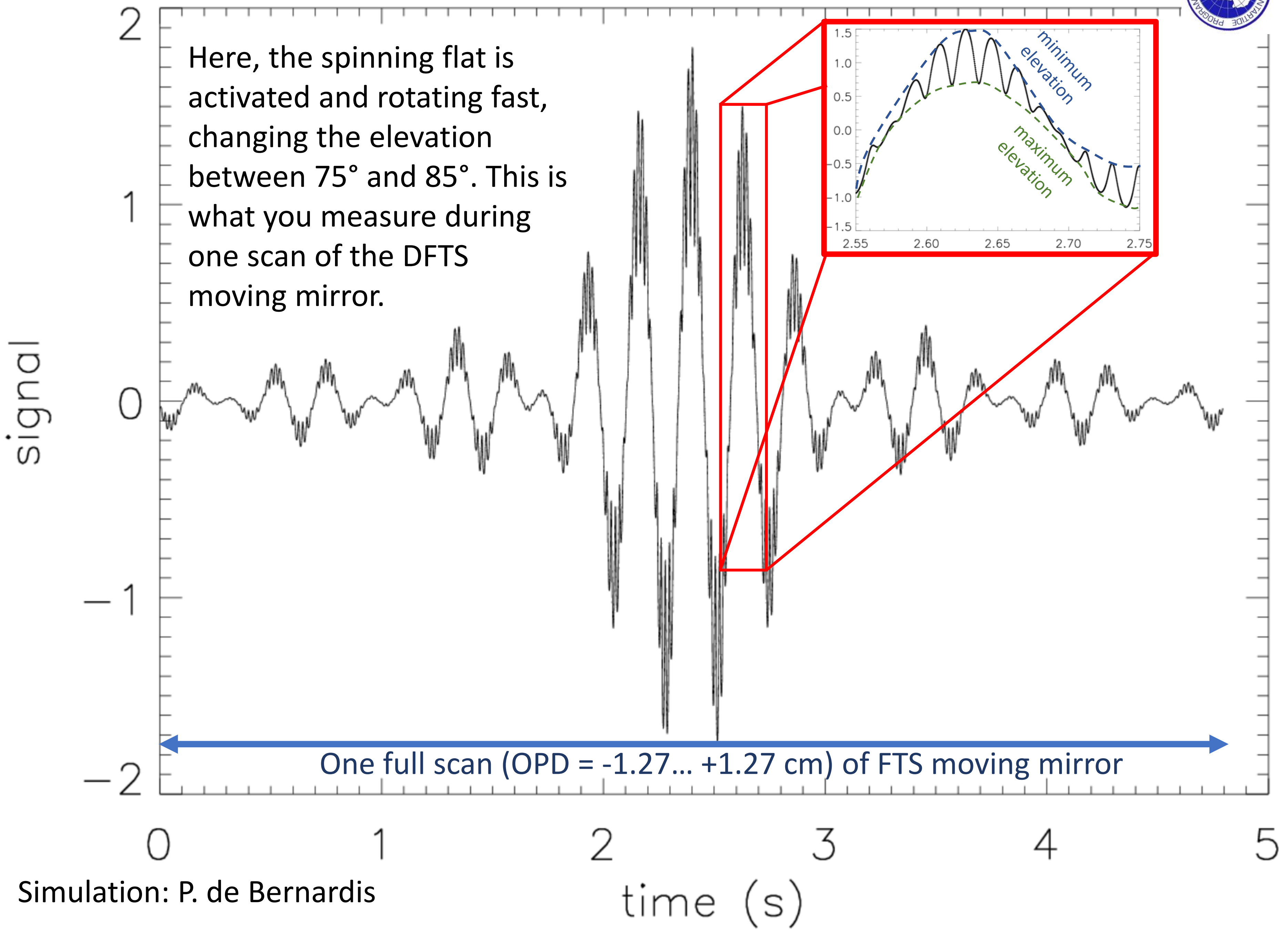
Cryostat tilt = 0°
PT tilt = 40°
Min. elev. = 20°
Max. elev. = 40°

Cryostat tilt = 20°
PT tilt = 20°
Min. elev. = 40°
Max. elev. = 60°

Cryostat tilt = 40°
PT tilt = 0°
Min. elev. = 60°
Max. elev. = 80°

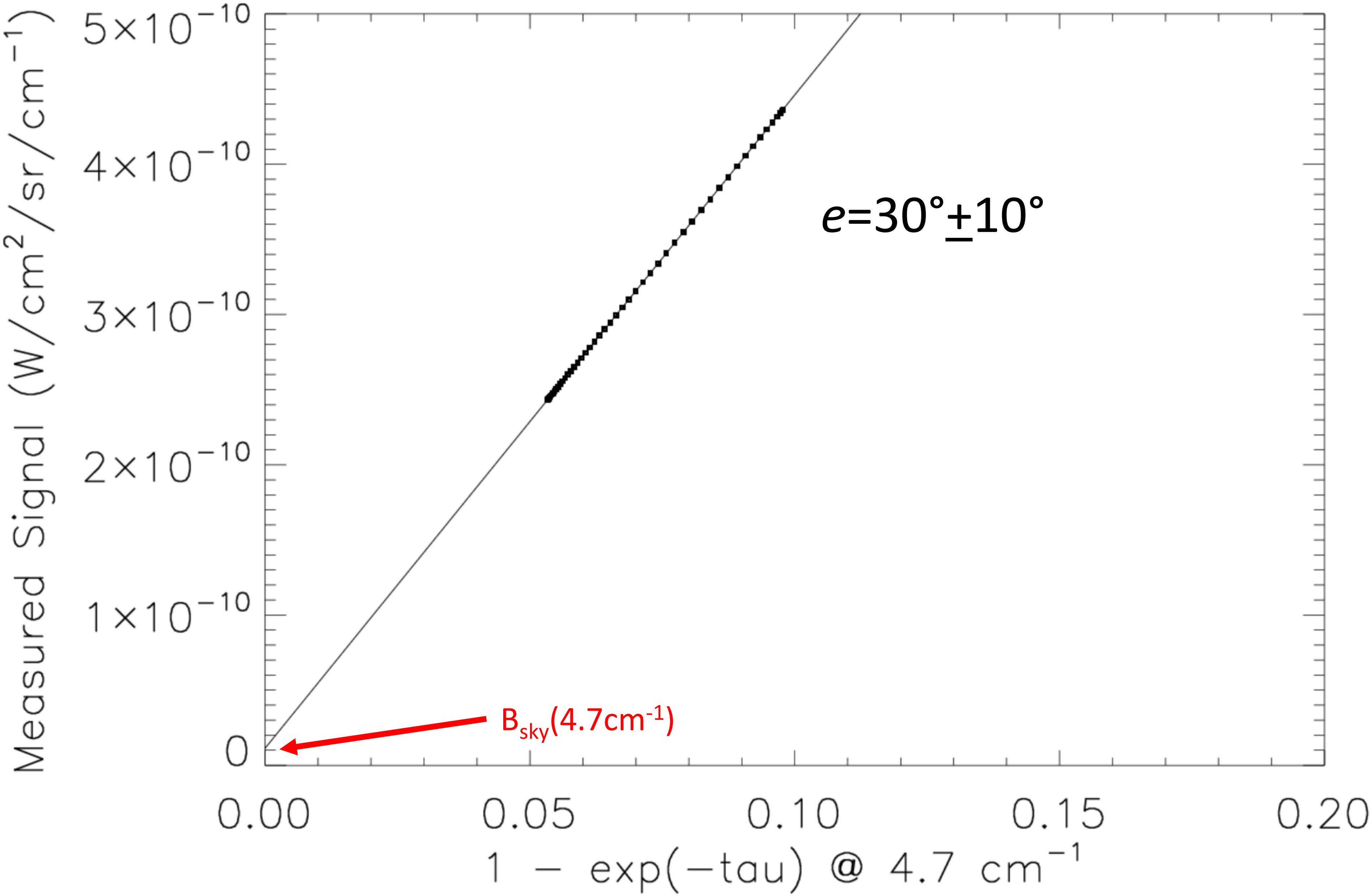
Cryostat tilt = 50°
PT tilt = -10°
Min. elev. = 70°
Max. elev. = 90°





Simulation: P. de Bernardis

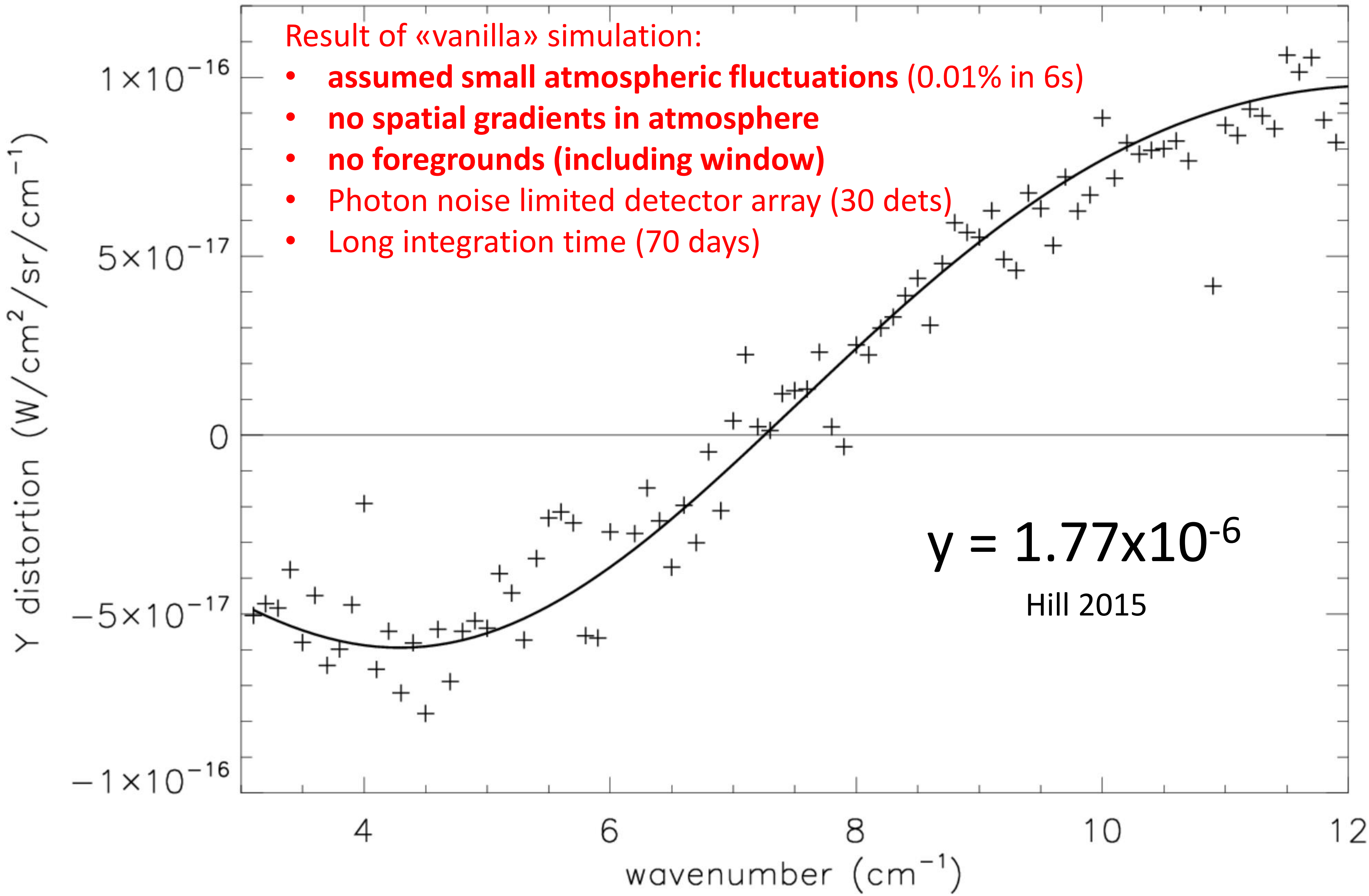
COSMO sky / atmosphere scan simulation



COSMO sky / atmosphere scan simulations

Result of «vanilla» simulation:

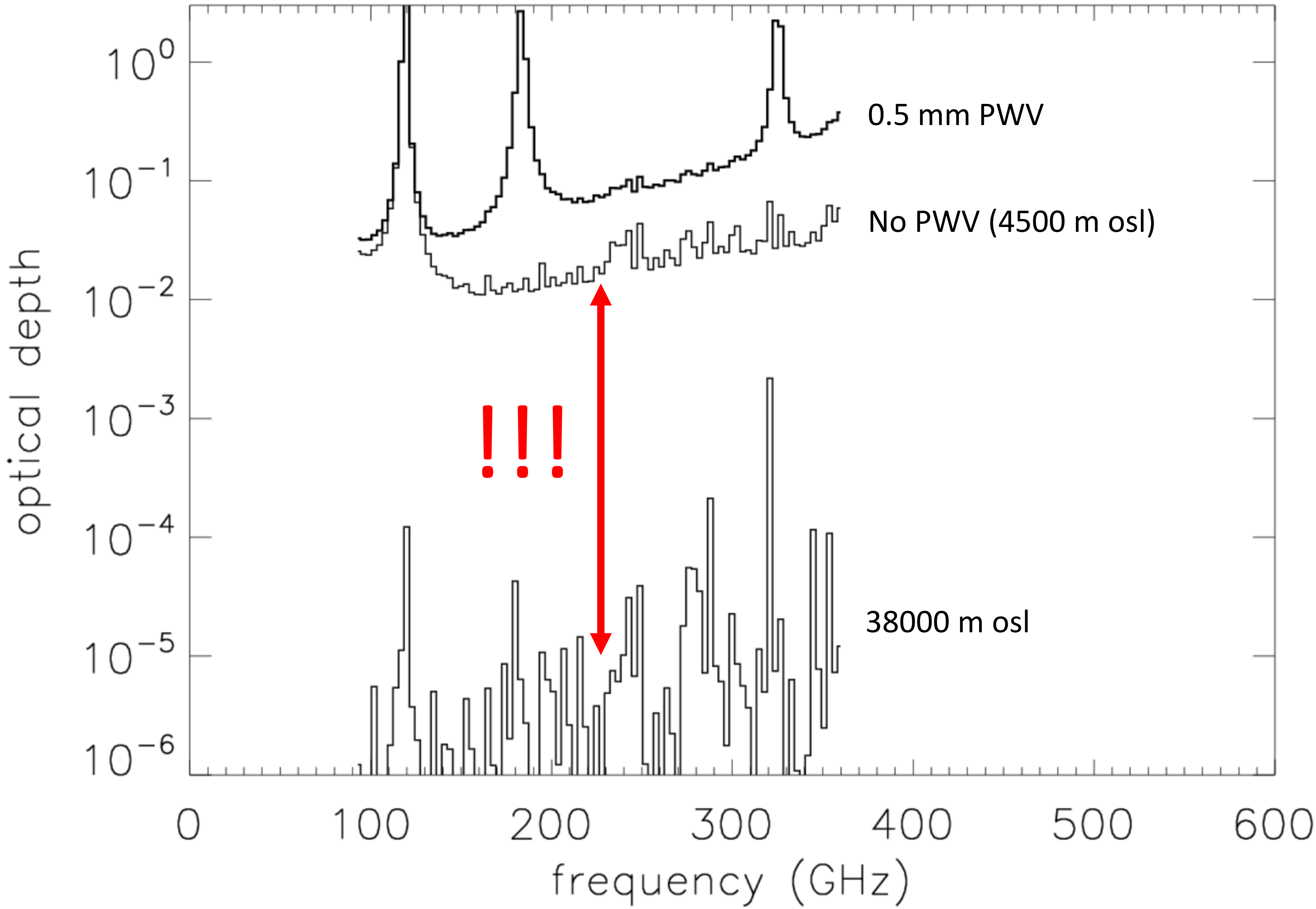
- **assumed small atmospheric fluctuations** (0.01% in 6s)
- **no spatial gradients in atmosphere**
- **no foregrounds (including window)**
- Photon noise limited detector array (30 dets)
- Long integration time (70 days)



COSMO implementation

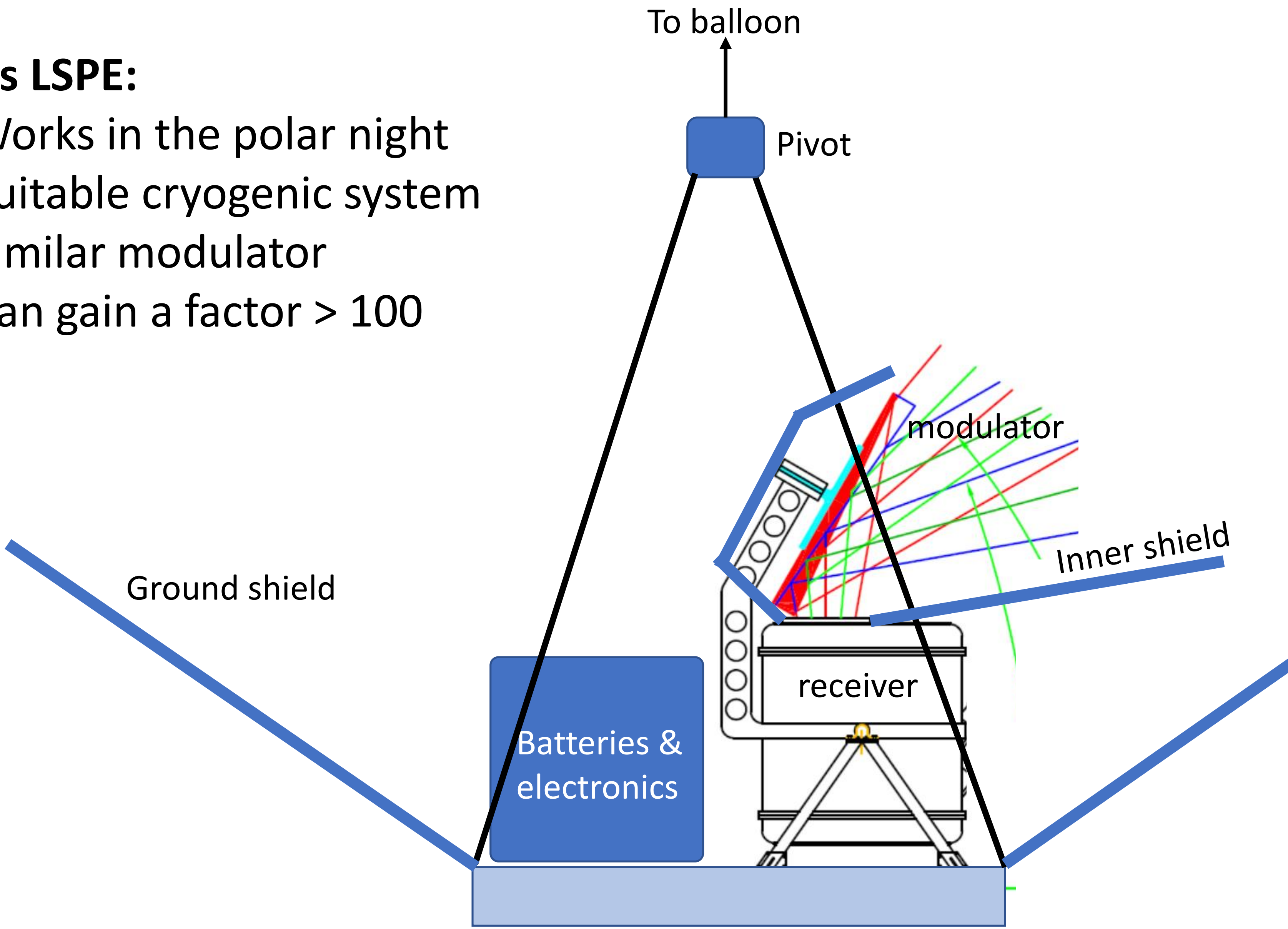
- As of today, still moving from *concept* into *instrument design*
- However:
  - PNRA proposal funded to provide cryogenic system, optics, and logistic support for the Concordia base (PI Silvia Masi, partner institutions UniMI (Mennella), UniMIB (Zannoni))
  - PNRA proposal funded to support development of KID detector arrays and coupling optics (PI Elia Battistelli, partner institutions CNR-IFN (Castellano), UniMI, UniMIB)
  - PRIN proposal being finalized to support development of optical design and construction of the cryogenic interferometer (PI P. de Bernardis, partners CNR-IFN (Cibella), UniMI, UniMIB)
  - Additional partner Cardiff University
- International interest expressed from other international institutions … the experiment is gaining momentum.
- Further step: COSMO on a stratospheric balloon

COSMO's successor: a balloon-borne (ULDB) instrument ?



COSMO's successor: a balloon-borne instrument ?

- **As LSPE:**
- Works in the polar night
- Suitable cryogenic system
- Similar modulator
- Can gain a factor > 100



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.