OLIMPO:
a backlight picture of the Universe

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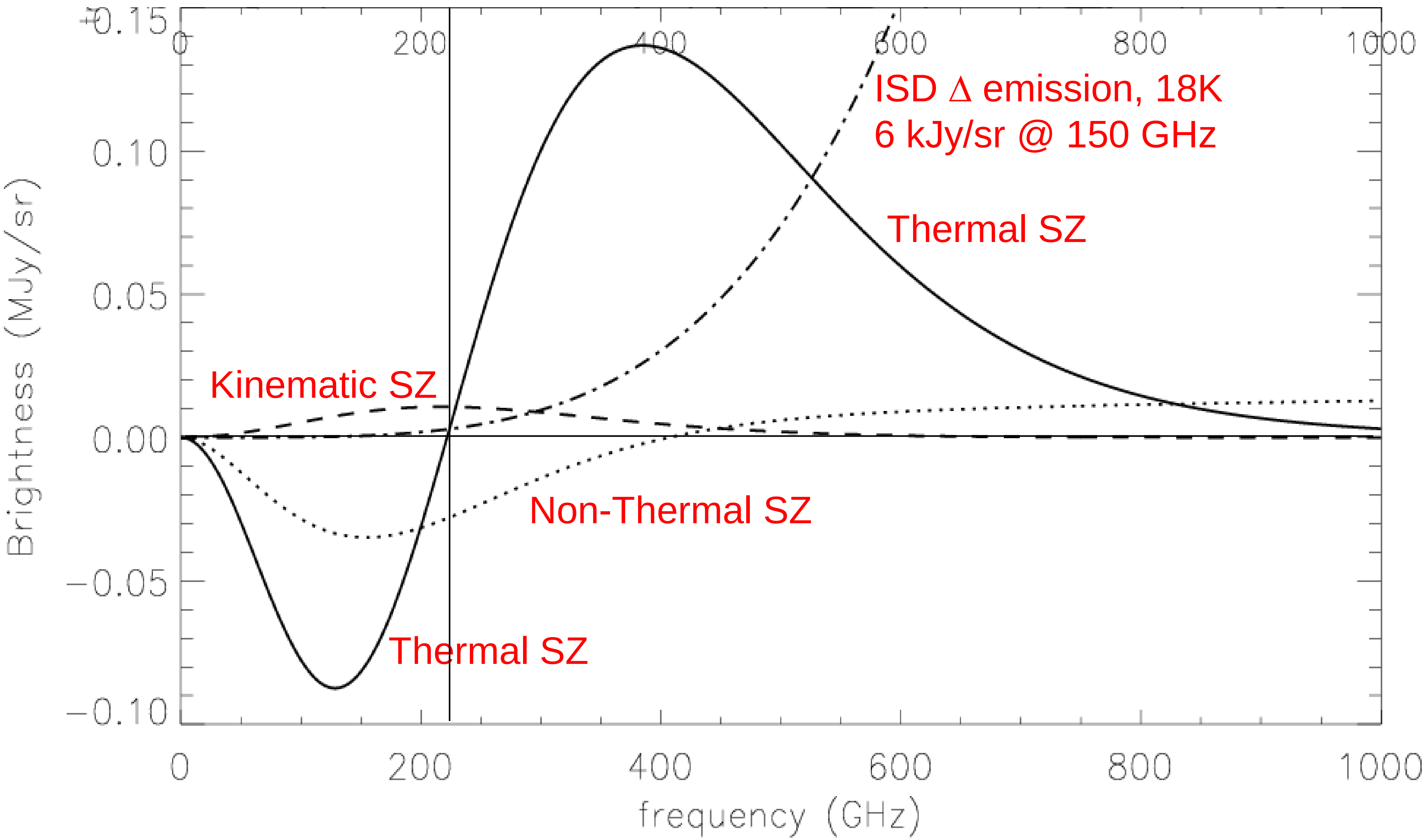
Firenze, August 31st, 2015

A different way to use the CMB

- Compared to the sensitivity of current surveys, the CMB is a ***bright*** background light.
- Most of the matter in the Universe is transparent for CMB photons.
- Important interaction only with molecules (resonant scattering & absorption) and ionized gas (Thomson scattering & Inverse Compton scattering)
  - Molecules form very late and mainly in galaxies, so occupy a very small solid angle. Their interaction with the CMB is masked by dominant galactic emission.
  - Ionized gas, instead, is present at all scales, including the largest structures: clusters, superclusters, filaments: i.e. LSS. Missing baryons !
- So we expect to be able to map the ionized matter in the universe observing the fine-scale anisotropy of the CMB induced by the ionized gas.



- The SZE can be used in a variety of ways, both as a probe of the physics of the intracluster medium, and as a way to probe the universe by means of distant galaxy clusters.

Sunyaev-Zeldovich Effect

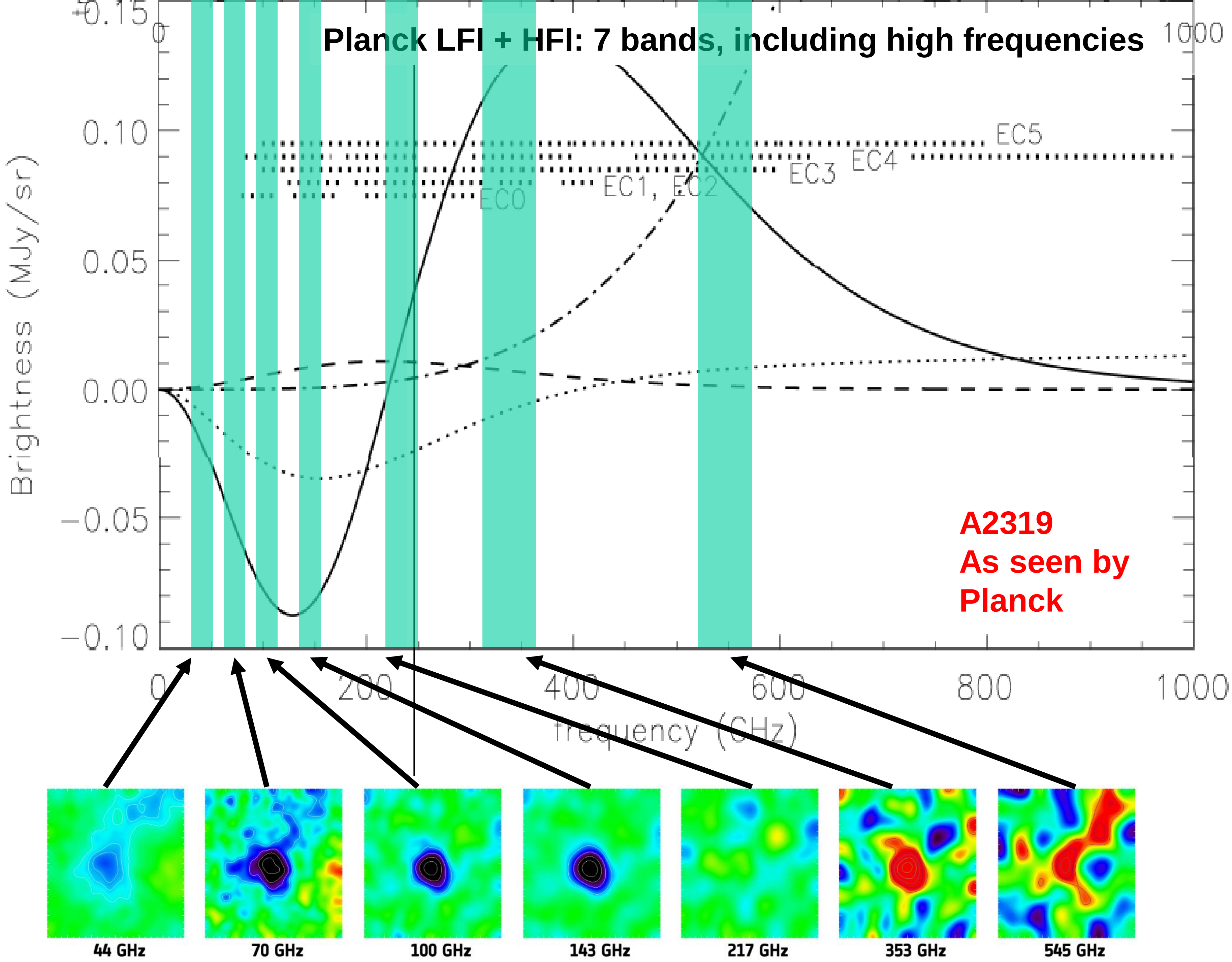
Things you can do with the SZ

- In clusters: combining SZ brightness measurements and X-ray brightness measurements, estimate H_o
- In clusters: measure the density of the gas all the way out, to the periphery (not bright in X rays)
- In clusters: peculiar velocity (kinematic SZ) and bulk flows
- In clusters: Relativistic corrections: Temperature of gas
- In clusters: Non thermal electron populations
- Tracer of the WHIM (in general)
- Probe CMB temperature evolution with z
- Surveys: clusters counts and sz correlation functions as cosmological tools

Planck is a great S-Z machine

14 / May / 2009

Planck LFI + HFI: 7 bands, including high frequencies



A2319
As seen by
Planck

components separation:

the power of Planck !

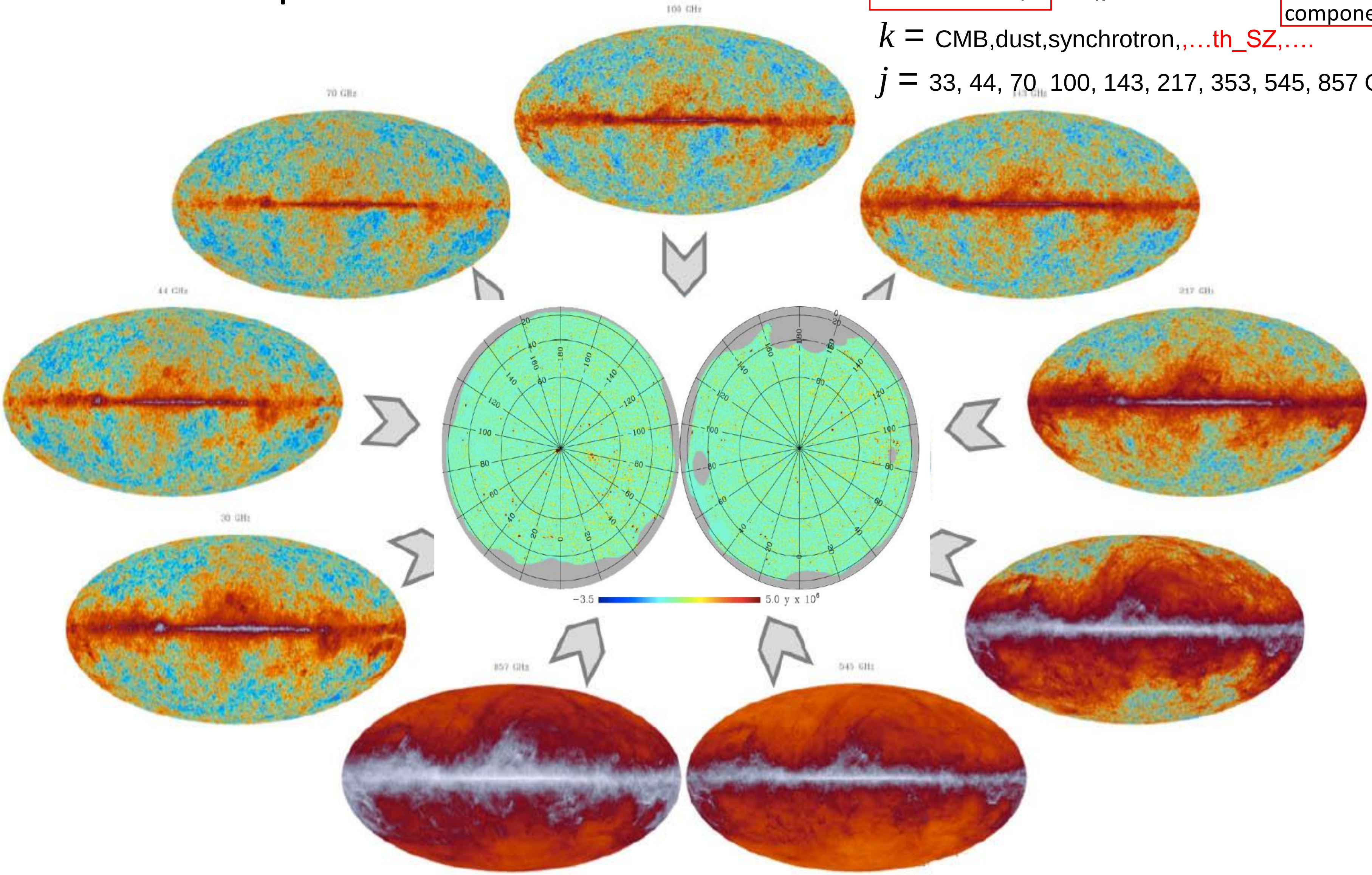
$$\boxed{\Delta T(\nu_j,\ell,b)} = \sum_k a_k(\nu_j,\ell,b)\boxed{C_k(\ell,b)}$$

Measured maps

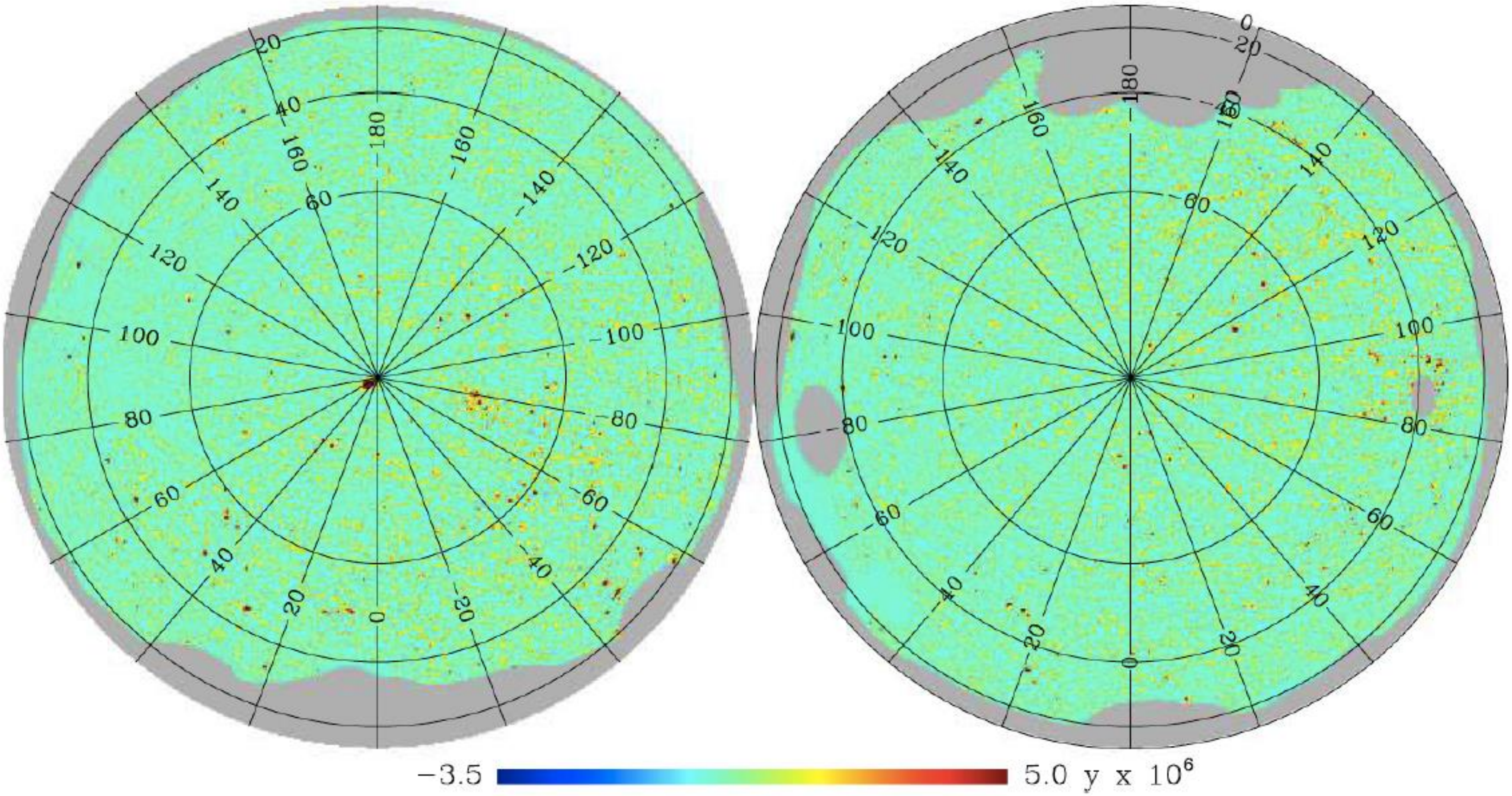
physical components

$k =$ CMB,dust,synchrotron,,…th_SZ,….

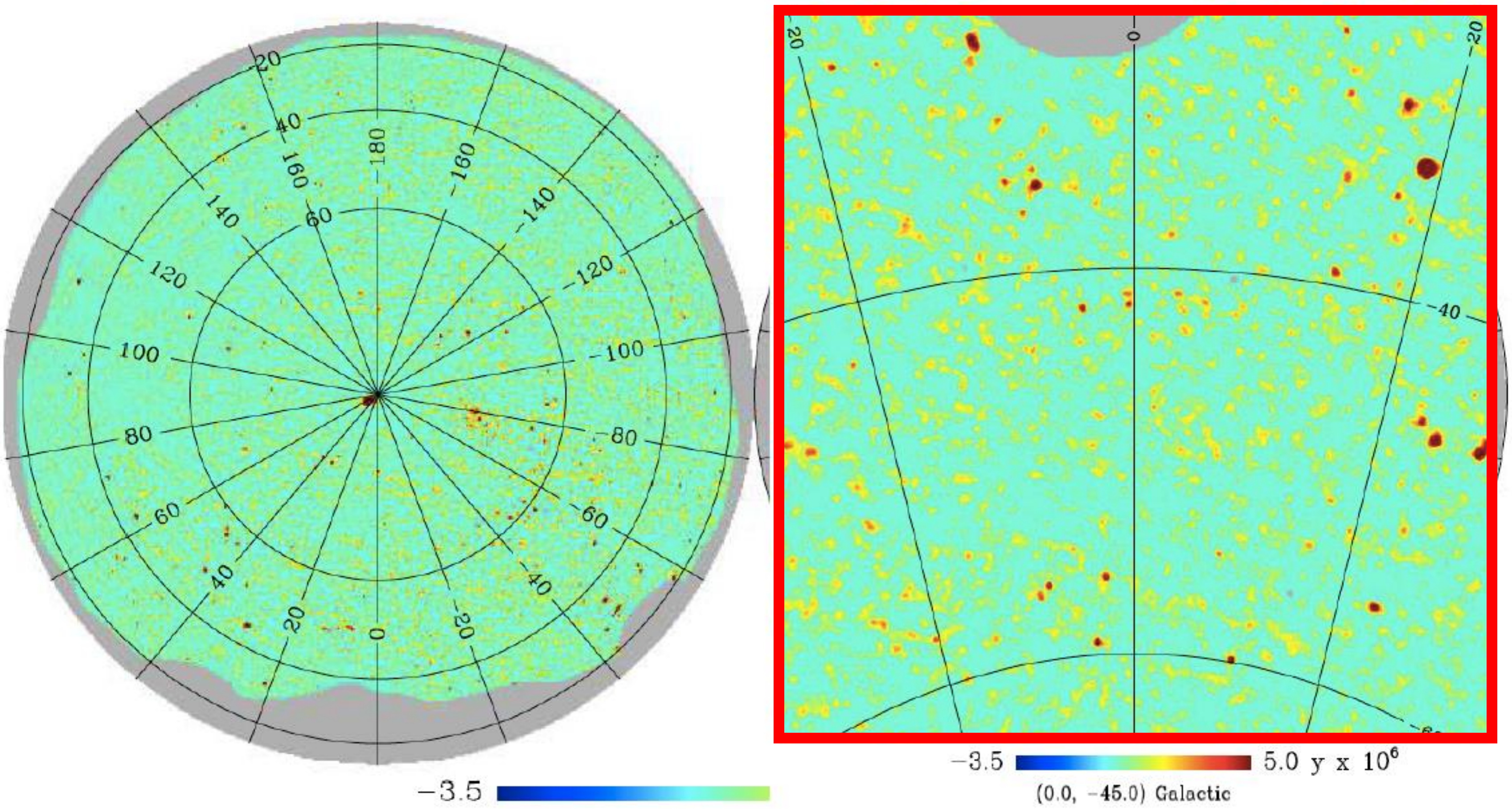
$j =$ 33, 44, 70, 100, 143, 217, 353, 545, 857 GHz



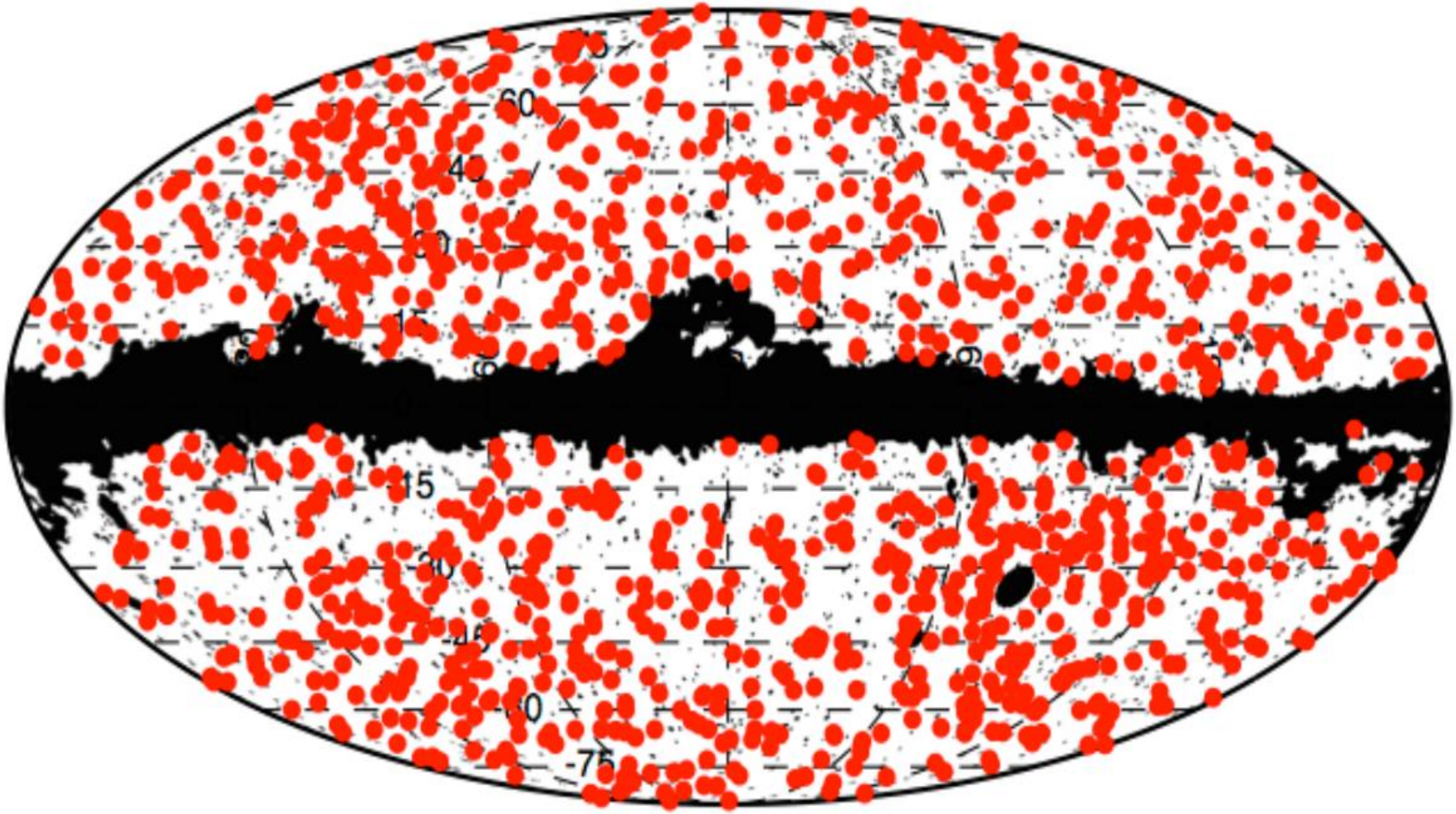
Full-sky map of diffuse SZe (hot baryons)



Full-sky map of diffuse SZe (hot baryons)

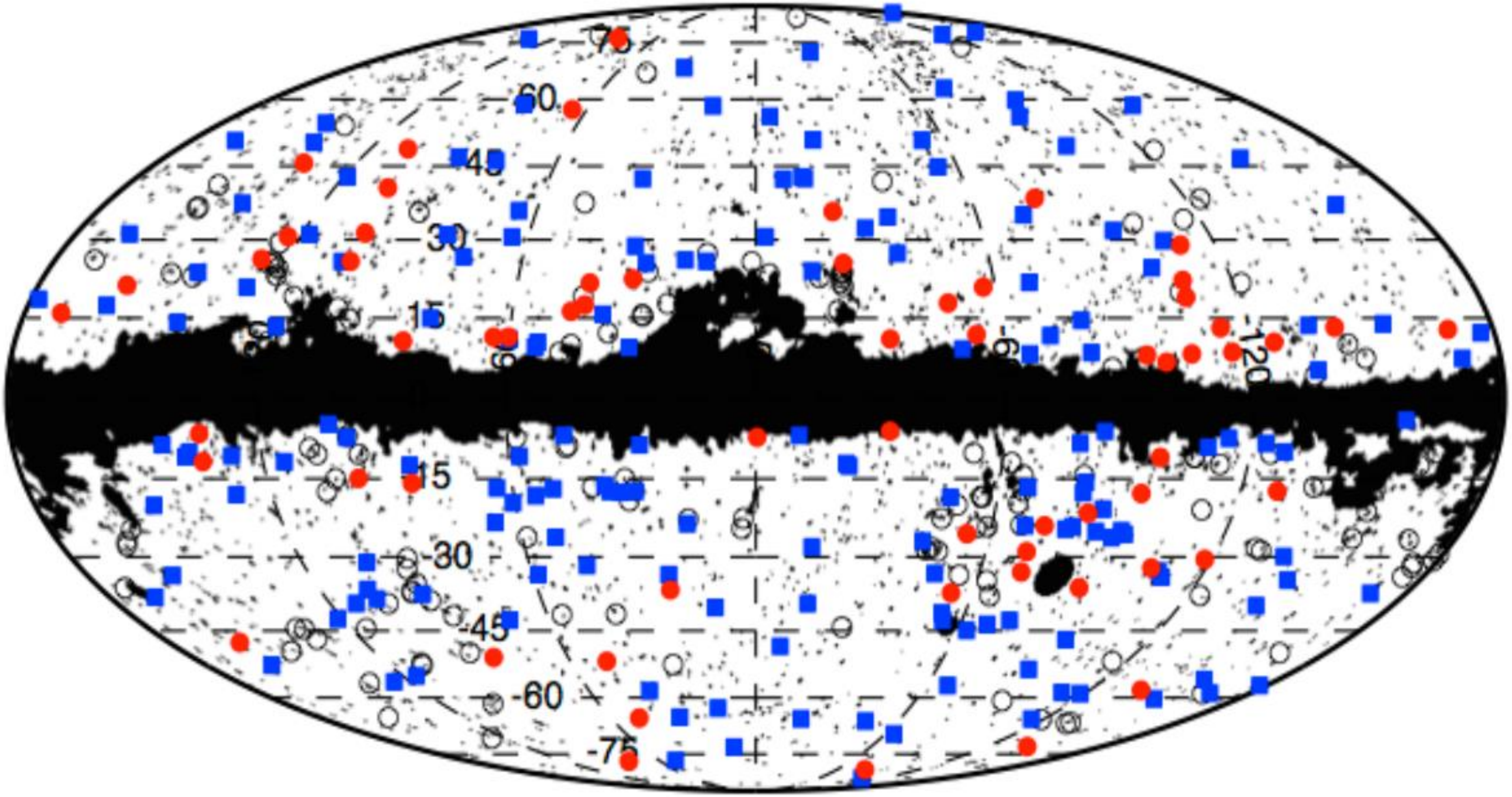


1227 SZ clusters

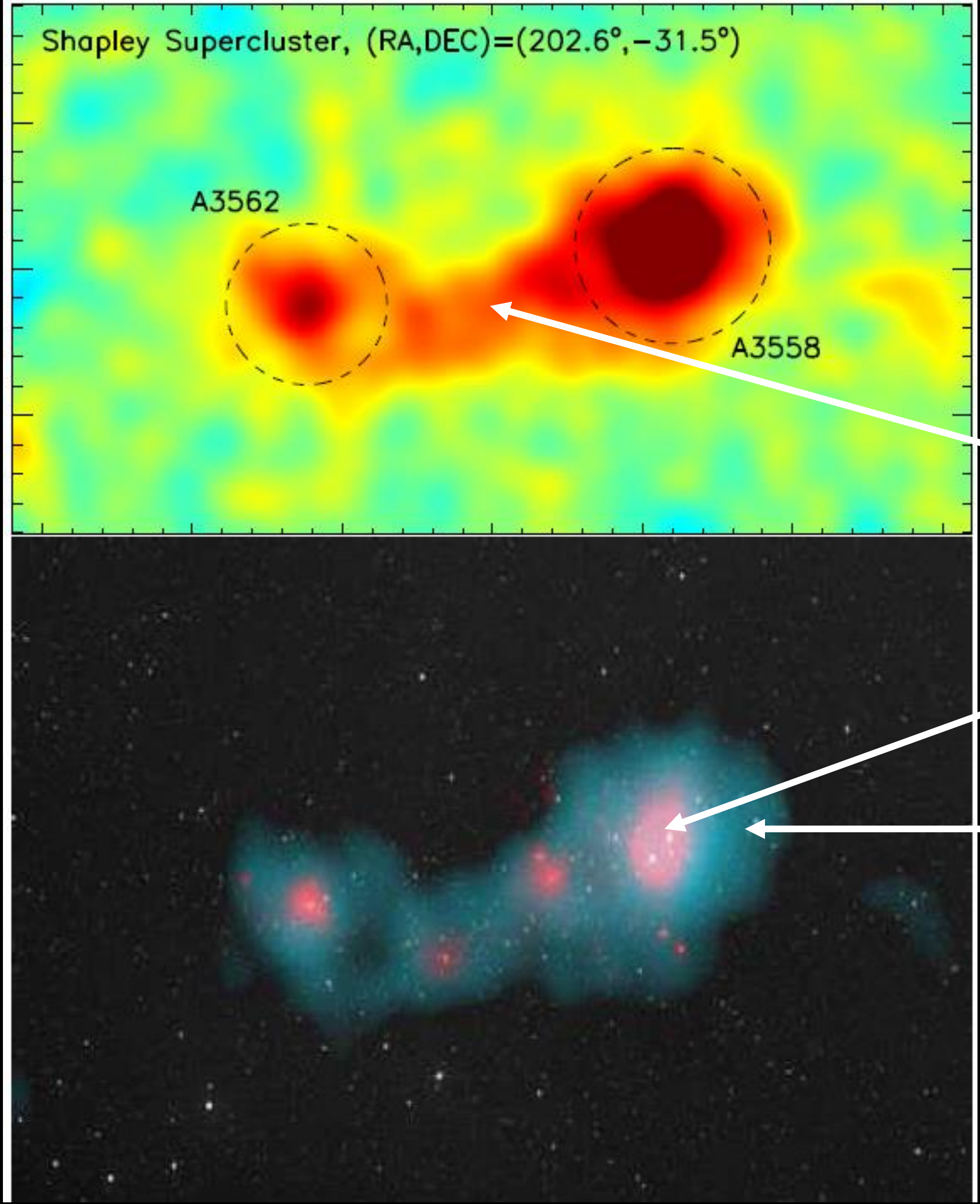


Planck 2013 results. XXIX. Planck catalogue of Sunyaev-Zeldovich sources : arXiv:1303.5089
See also addendum: arxiv:1502.00543

337 brand-new clusters



Filaments of ionized matter !



filament

X rays

SZ

- Planck measurements, together with SPT, ACT and similar results, represent real milestones in SZ cosmology.

However …

- However,important limitations are still present for both ground-based and space-borne photometric measurements.

- Photometric observations of the SZ can be significantly biased, when there are less spectral channels than free parameters.
- Components, LOS through a rich cluster:

ThSZ $$\frac{\Delta I_{\mathrm{t}}}{I_{\mathrm{CMB}}} = y\frac{x^4 \mathrm{e}^x}{(\mathrm{e}^x - 1)^2}[x\coth(x/2) - 4], \quad \boxed{y} = \int_{\mathrm{LOS}} \frac{kT_{\mathrm{e}}}{m_{\mathrm{e}}c^2} n_{\mathrm{e}}\sigma_T \mathrm{d}\ell,$$

NThSZ $$\boxed{p_{min}}, \boxed{Amp}$$

KSZ $$\frac{\Delta I_{\mathrm{v}}}{I_{\mathrm{CMB}}} \sim -\boxed{\tau_{\mathrm{t}}}\boxed{\frac{v_{\mathrm{LOS}}}{c}}\frac{x\mathrm{e}^x}{(\mathrm{e}^x - 1)}$$

CMB $$\frac{\Delta I_{\mathrm{CMBi}}}{I_{\mathrm{CMB}}} = \frac{x\mathrm{e}^x}{(\mathrm{e}^x - 1)}\boxed{\frac{\Delta T}{T}}$$

ISD $$\boxed{T_d}, \boxed{\tau_d} \;....(\beta)$$

At least, 8 independent parameters.
Even Planck does not have enough channels (!)
Moreover the beam of Planck at high frequency is larger than the beam of SPT & ACT at 150 GHz.

The final solution: **spectroscopic** measurements of the SZ

- Requirements:
  - Wide spectral coverage
    (in principle 100 to 1000 GHz)
  - Modest spectral resolution ($\lambda/\Delta\lambda$ = 20 to 100)
  - Differential input, high rejection of common mode signal (CMB is common mode and is 2750000 μK, cluster signal is differential and can be as low as 10 μK).
  - Imaging instrument, resolution ad high frequency comparable to SPT 150 GHz (1 arcmin).
  - Wide field of view to image the whole cluster and have a clean reference area to compare

A&A 538, A86 (2012)
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Astronomy & Astrophysics

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

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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-

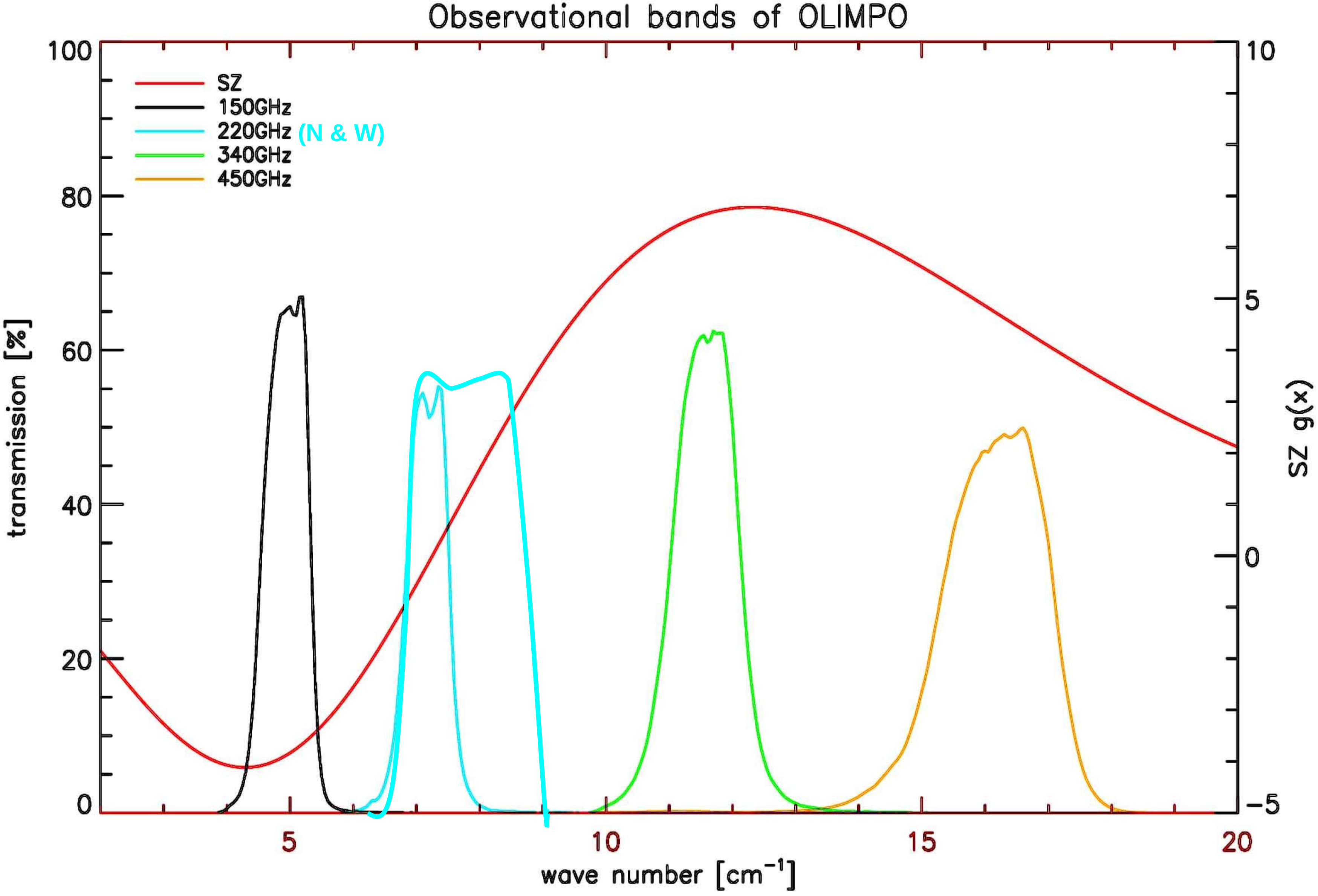
OLIMPO

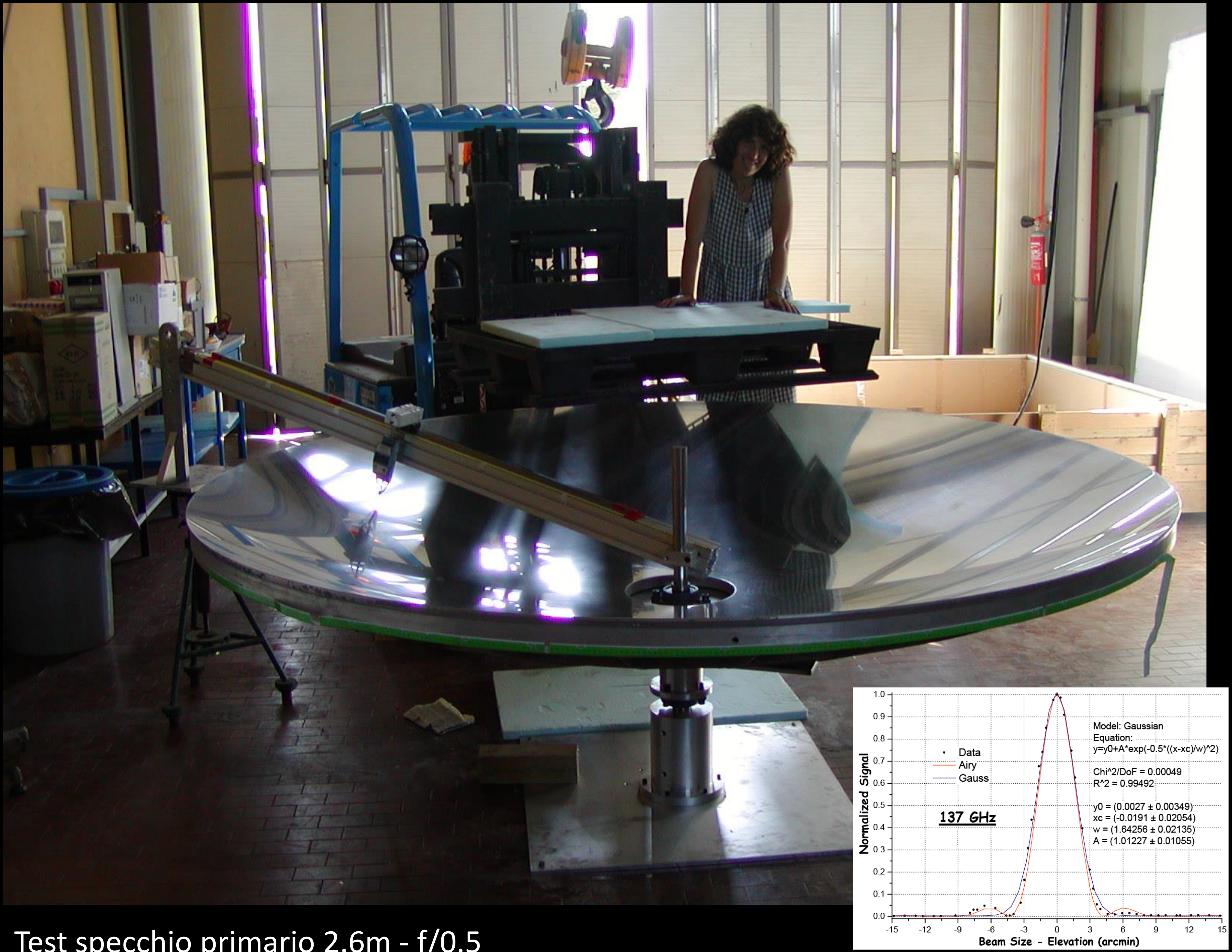
- The OLIMPO experiment is a first attempt at spectroscopic measurements of CMB anisotropy.
- A large balloon-borne telescope with a 4-bands photometric array and a plug-in room temperature spectrometer
- see http://planck.roma1.infn.it/olimpo for a collaborators list and full details on the mission

OLIMPO

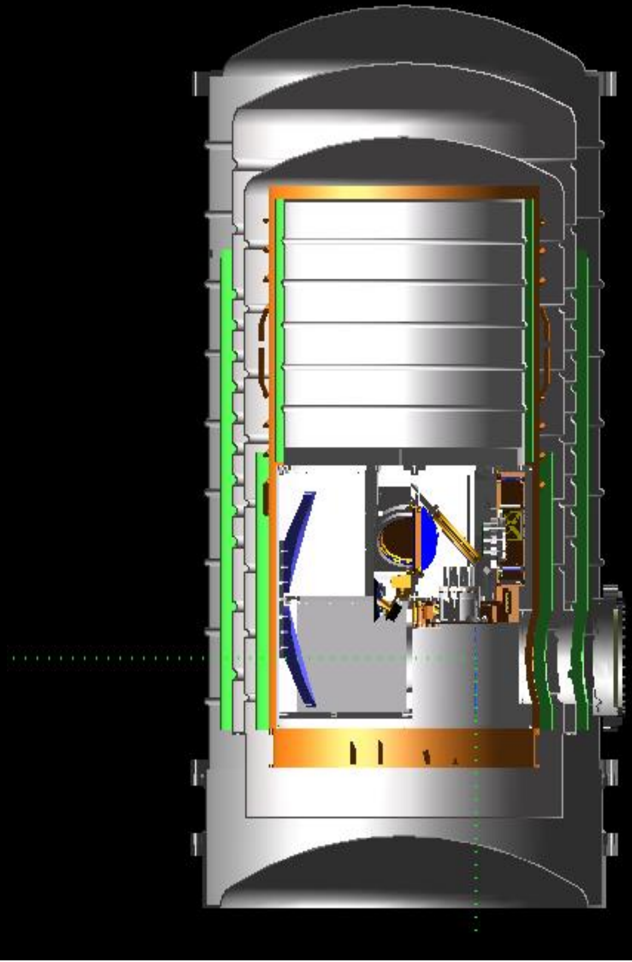
- Long Duration Balloon experiment for mm and sub-mm astronomy
- Operate from the stratosphere
- Launch from Svalbard
- Cassegrain, 2.6 m primary with scanning capability
- Multi-frequency array of bolometers

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)
−5
0
5
10
5
10
15
20
wave number [cm^{-1}]

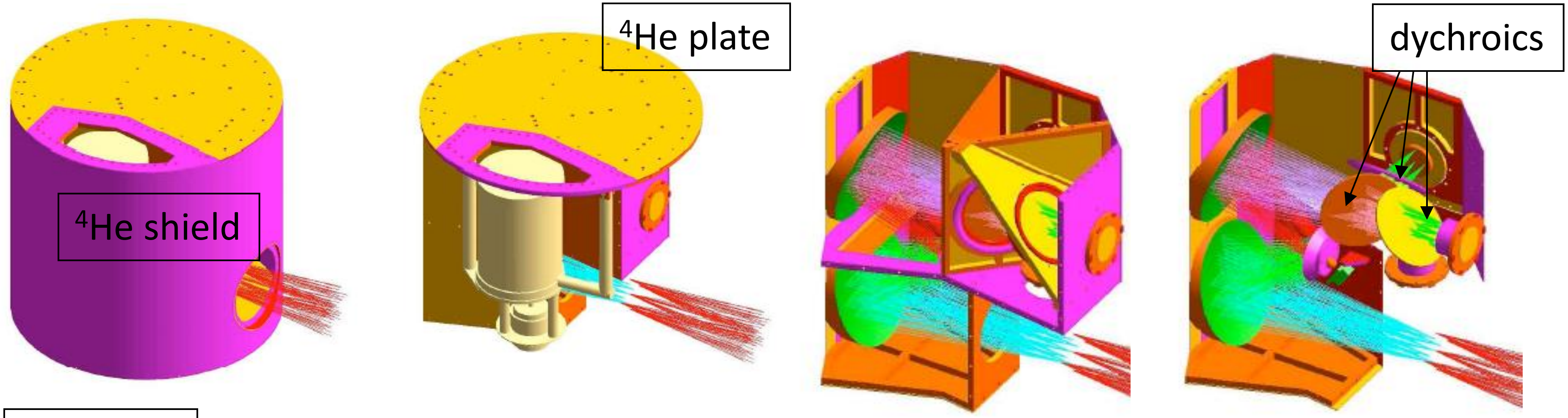


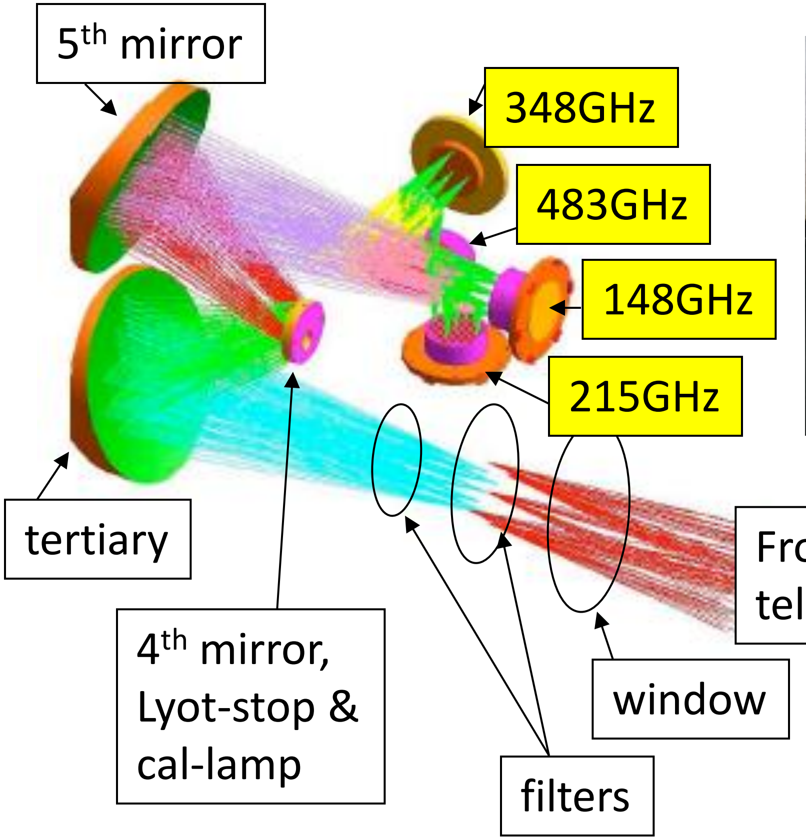
Test specchio primario 2.6m - f/0.5



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

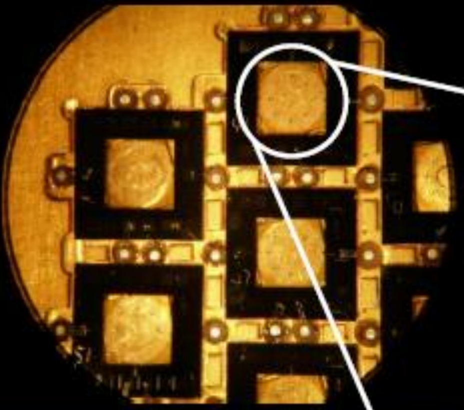
OLIMPO: Cold Optics and Arrays

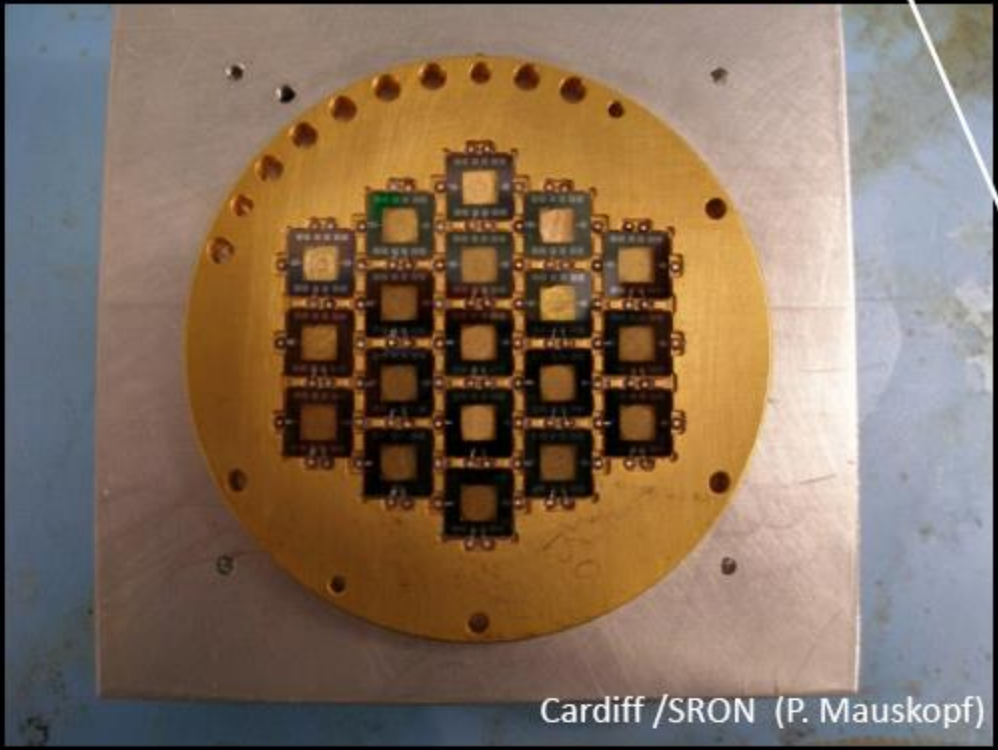




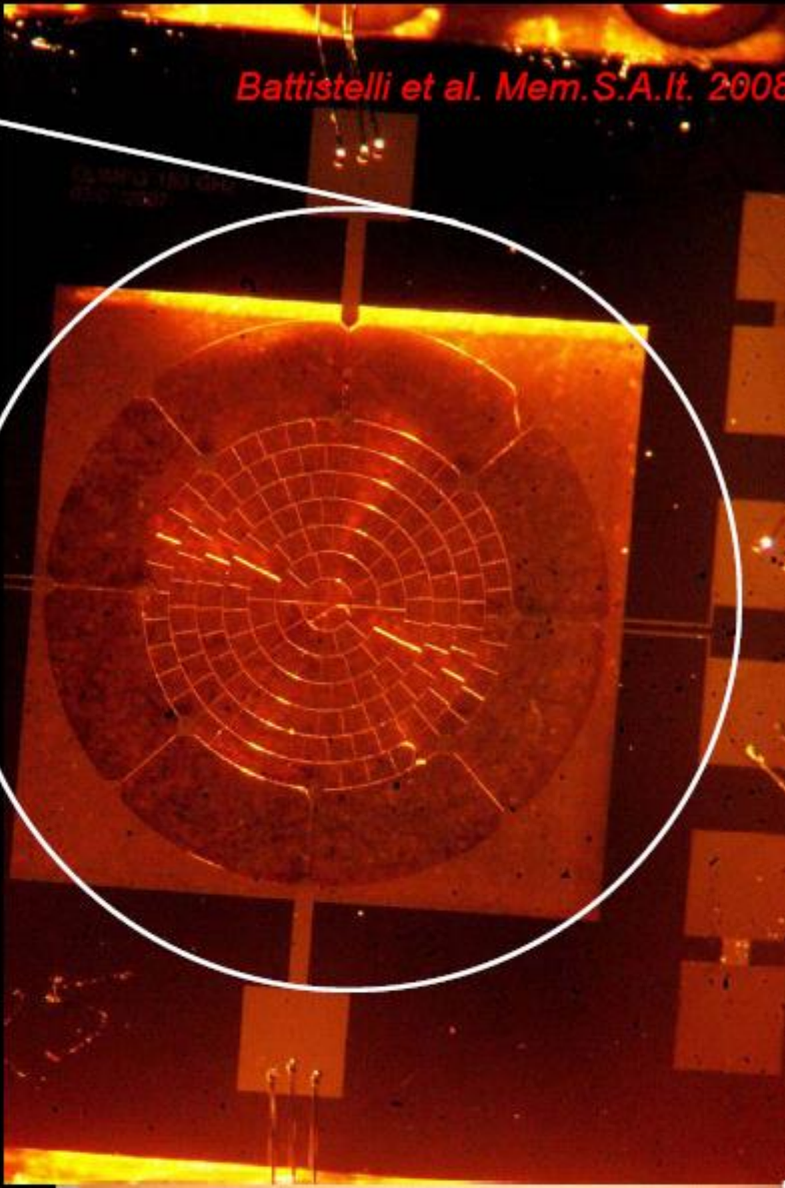
OLIMPO: Low-frequency arrays (140 GHz & 220 GHz)

- Wafer: Si_3N_4
- Thermistor: Ti (60nm) + Au (10/20nm)
- Absorber/heater: spiderweb Ti (10nm) + Au (5nm), filling factor 5%



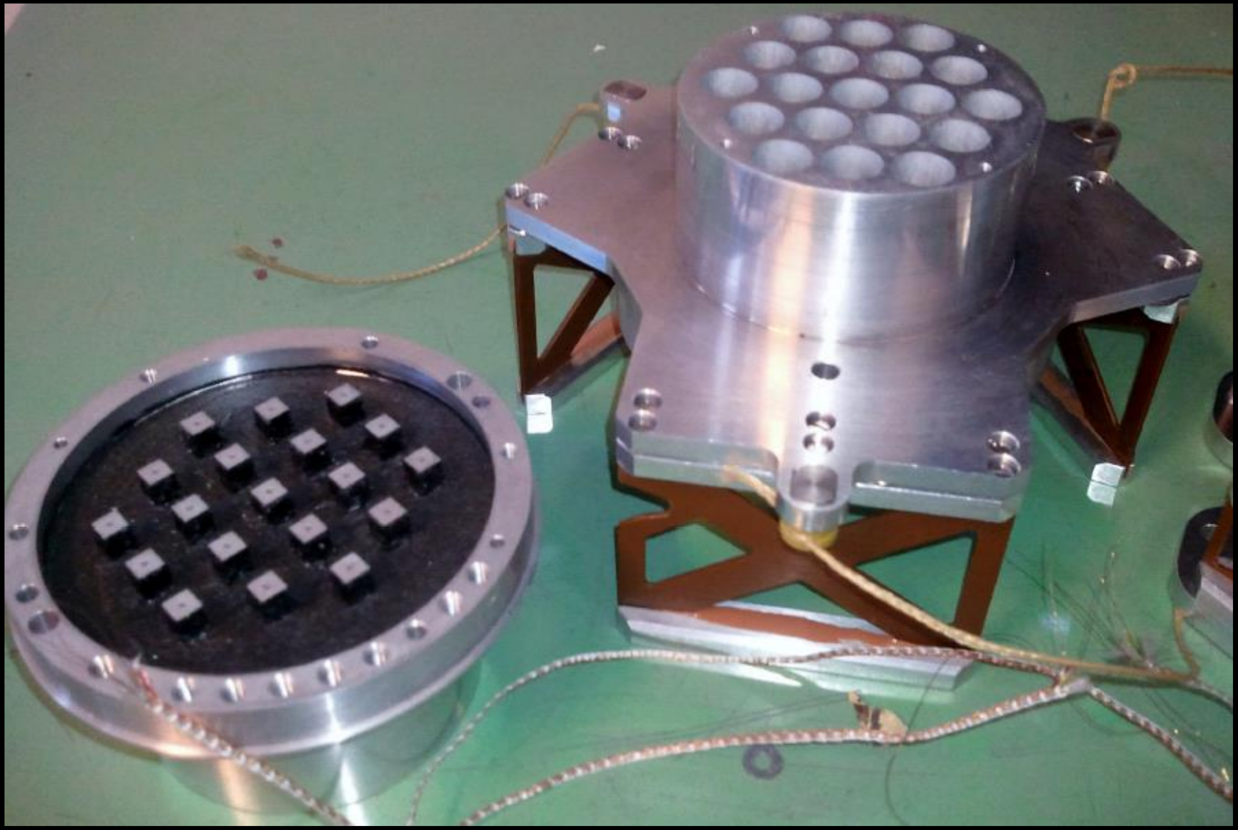


Cardiff /SRON (P. Mauskopf)

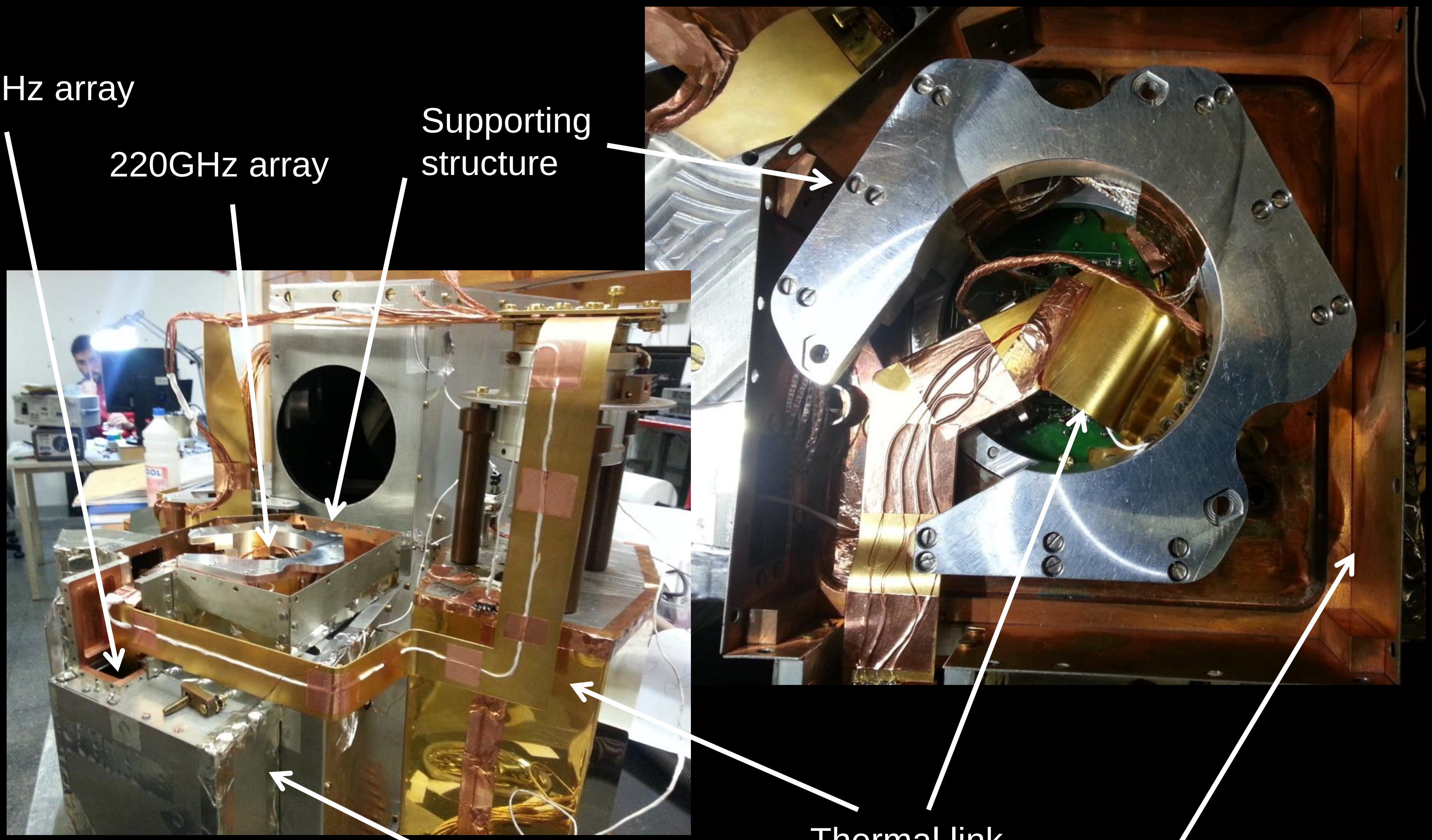


Battistelli et al. Mem.S.A.It. 2008

OLIMPO: Low-frequency arrays (140 GHz & 220 GHz)



TES in OLIMPO



150GHz array

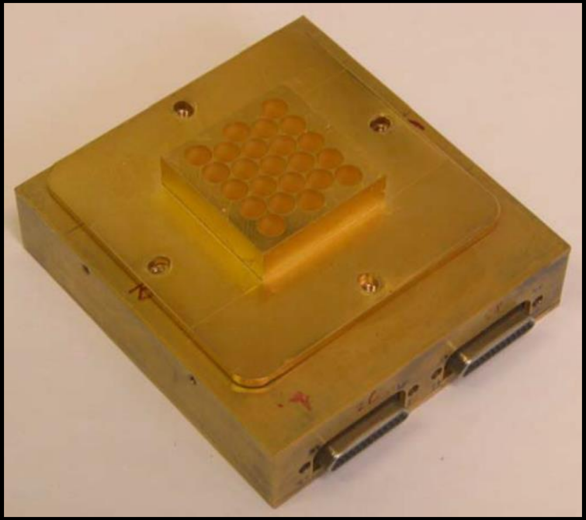
220GHz array

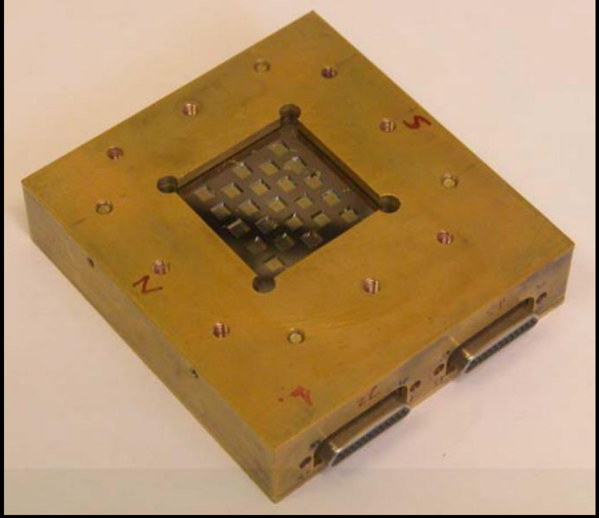
Supporting structure

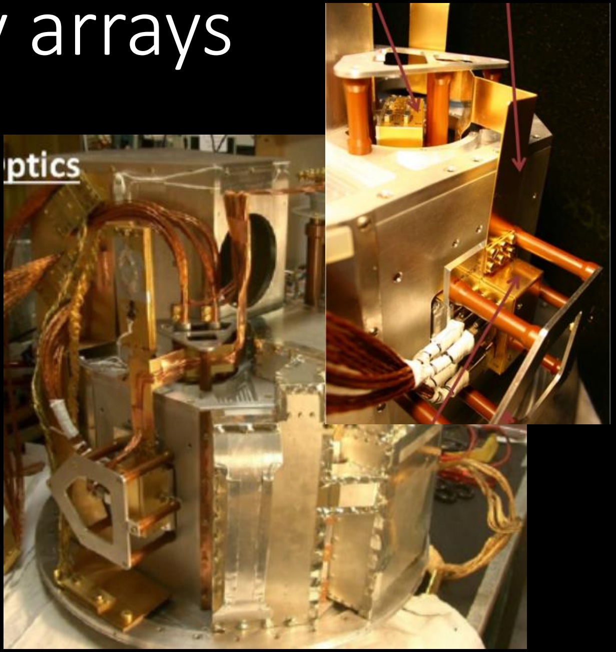
Thermal link

Superconducting tinned copper magnetic shield

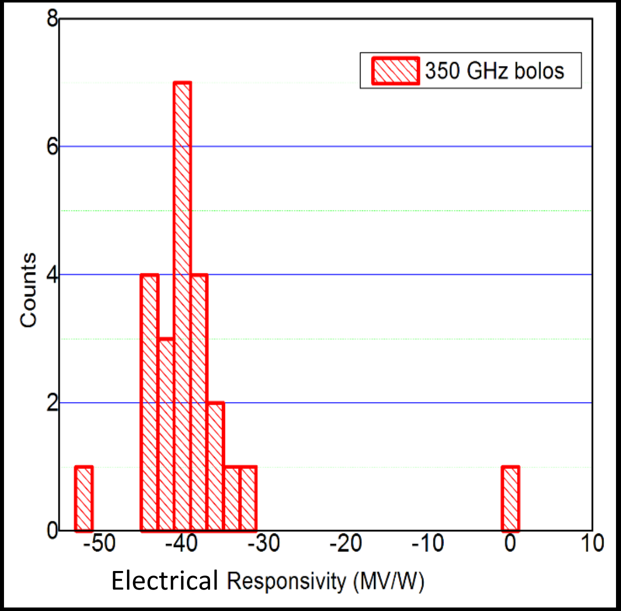
OLIMPO: High-frequency arrays



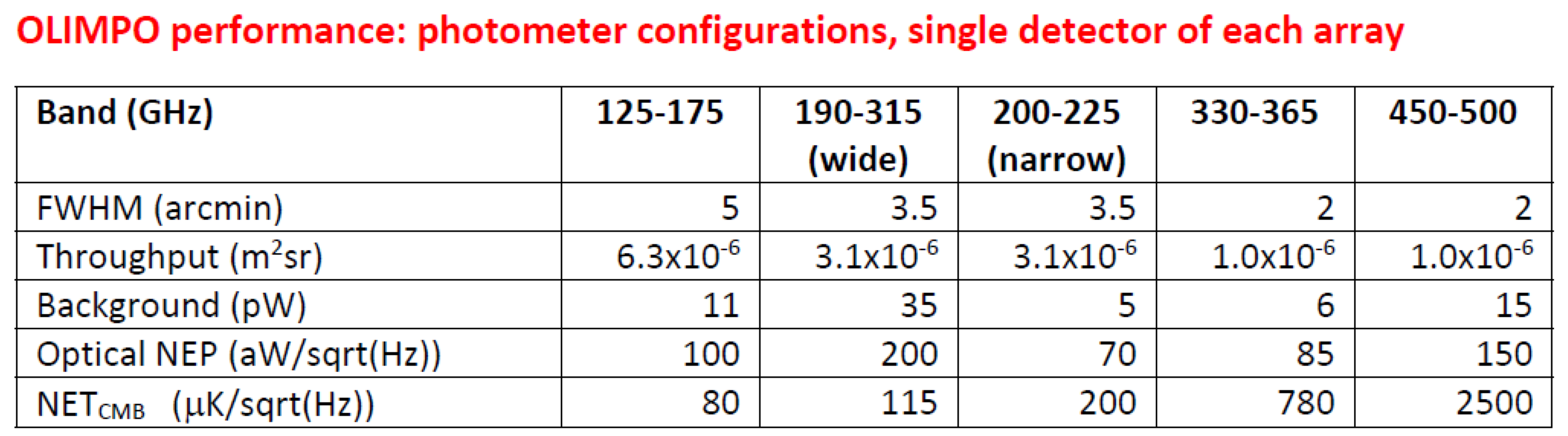




- Made in Grenoble (Neel institute, P. Camus)
- Si_3N_4 membranes with absorbing Bi layer
- NbSi thermistors (S. Marnieros)
- Bandpass filters matching the 350 GHz and 480 GHz bands (Cardiff)
- JFET readout (a la Planck, made in Sapienza)
- Room temperature biasing/demodulating electronics made in CEA Saclay (D. Yvon)
- Measured optical NEP around a few x 10^{-15} W/$Hz^{1/2}$ with OLIMPO fridge @0.3K and flight background.



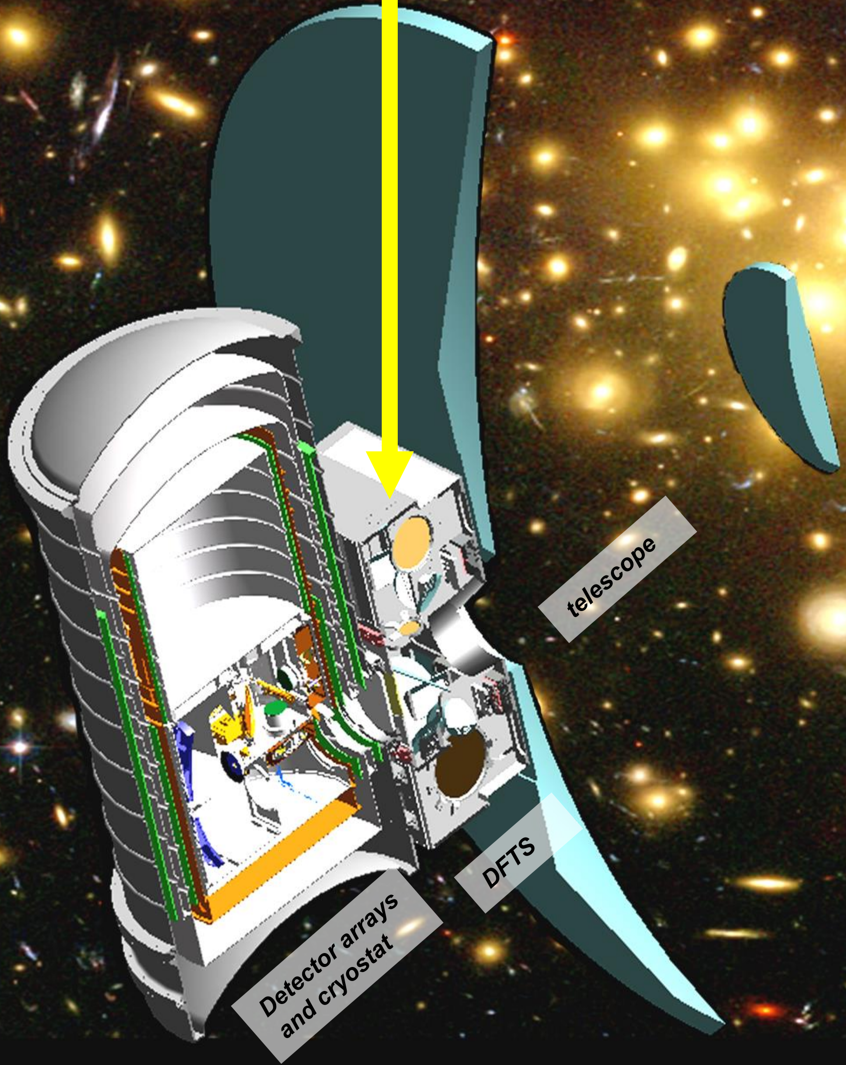
Expected performance for OLIMPO (photon noise limited)

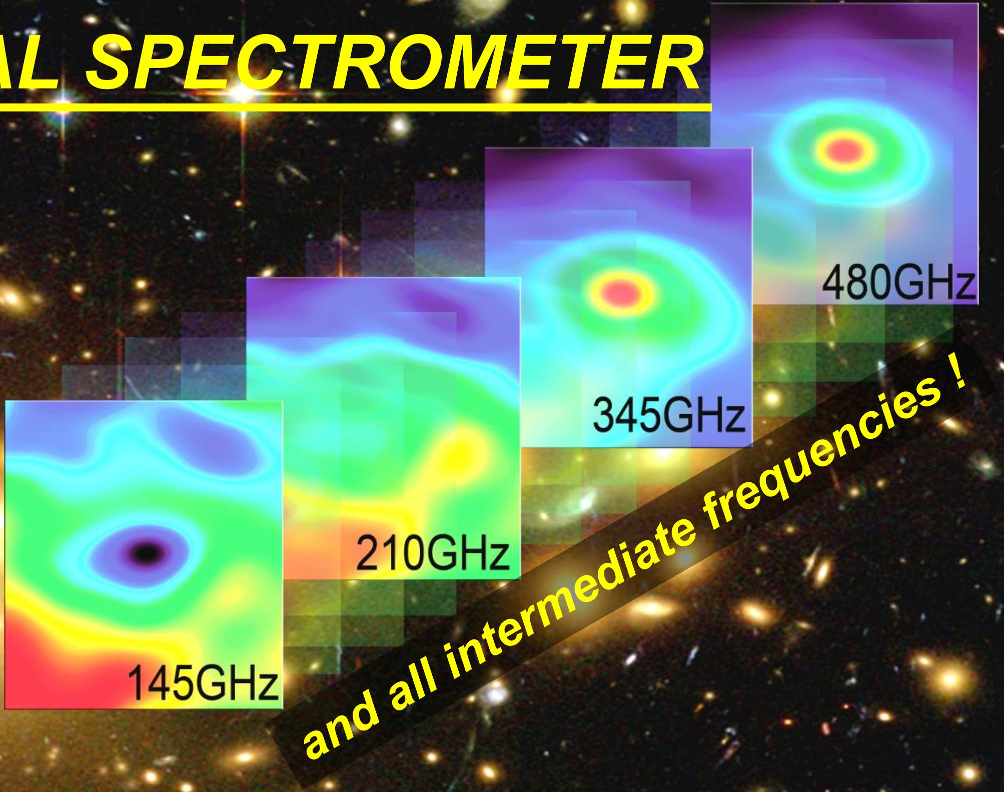


OLIMPO performance: photometer configurations, single detector of each array

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

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.

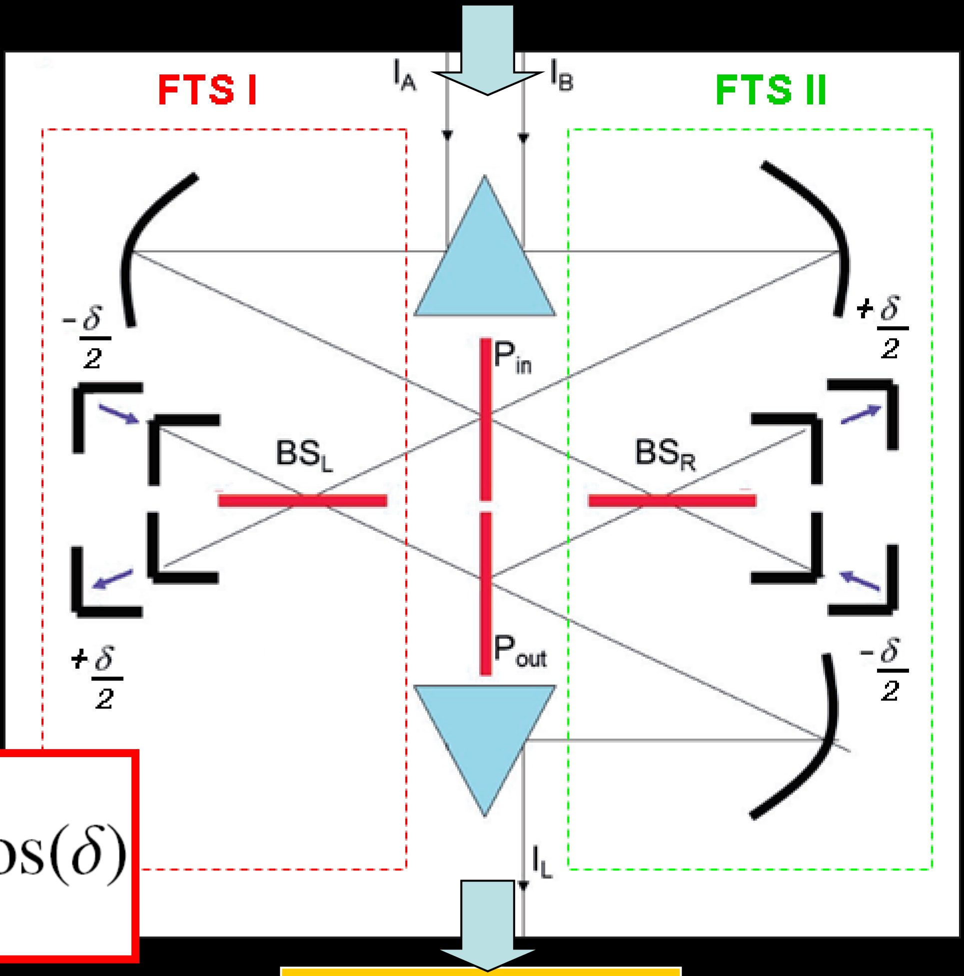
See Schillaci et al. A&A 565, A125, 2014 for a detailed description of the instrument. The output brightness is

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

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

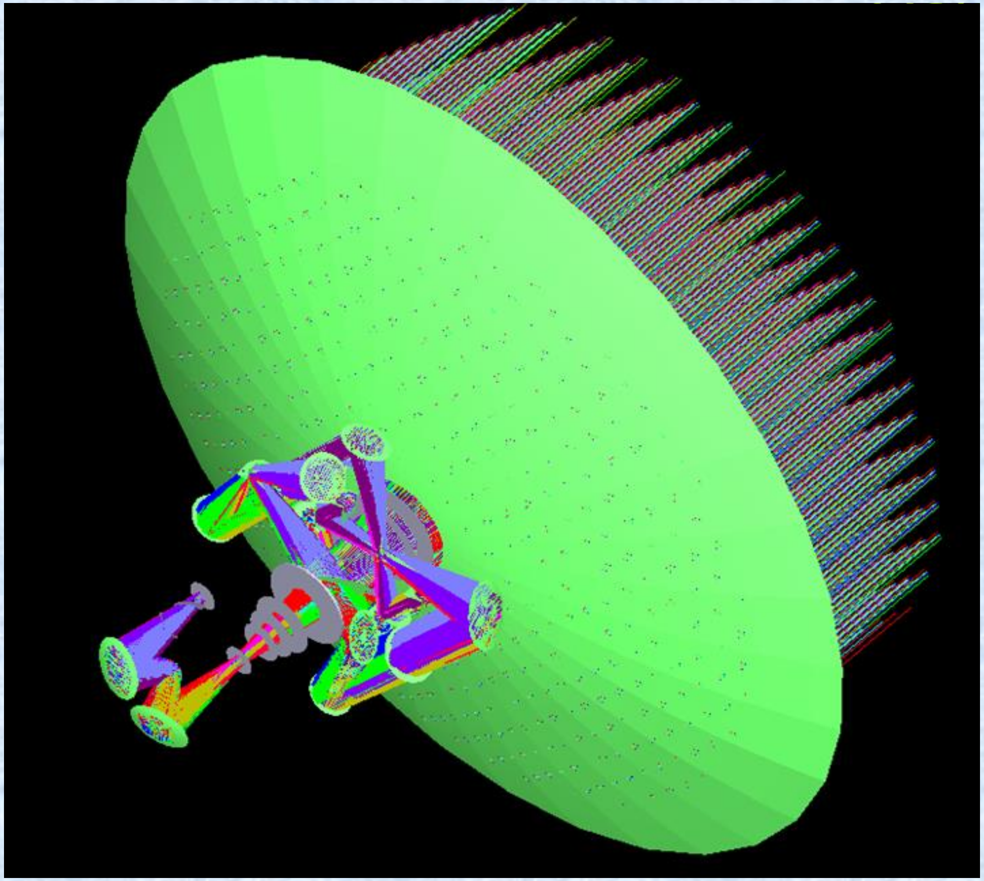
Only the *difference* between the two input brightnesses is modulated by the variable optical path difference.

Olimpo Telescope

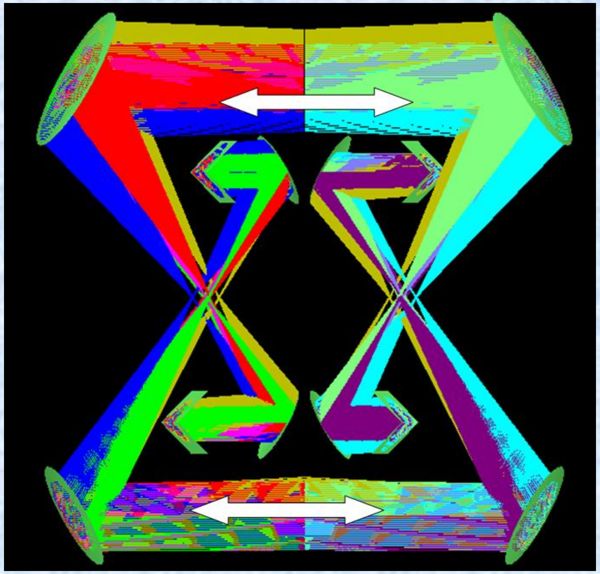


Olimpo Cryostat

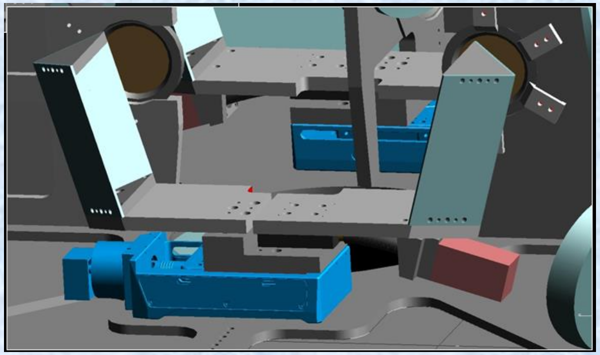
The OLIMPO Martin-Puplett Differential Fourier Transform Spectrometer



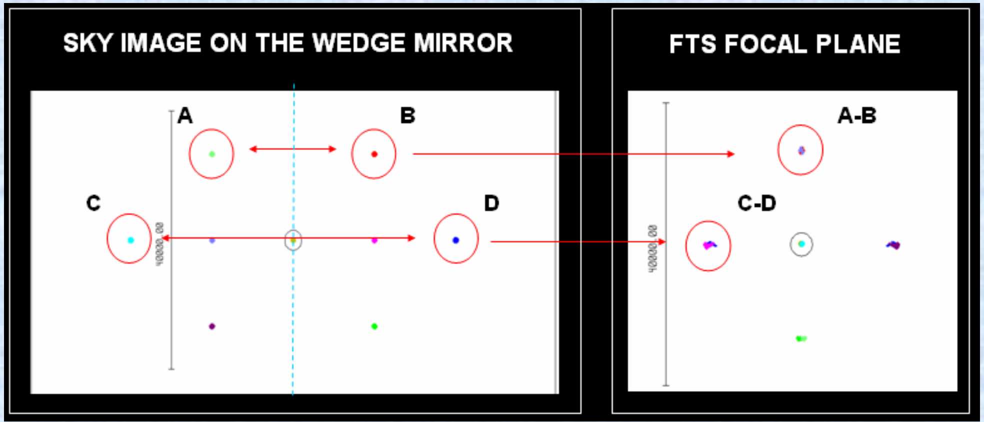
Global design of the optical system



Optical layout of the doublel Martin-Puplett FTS

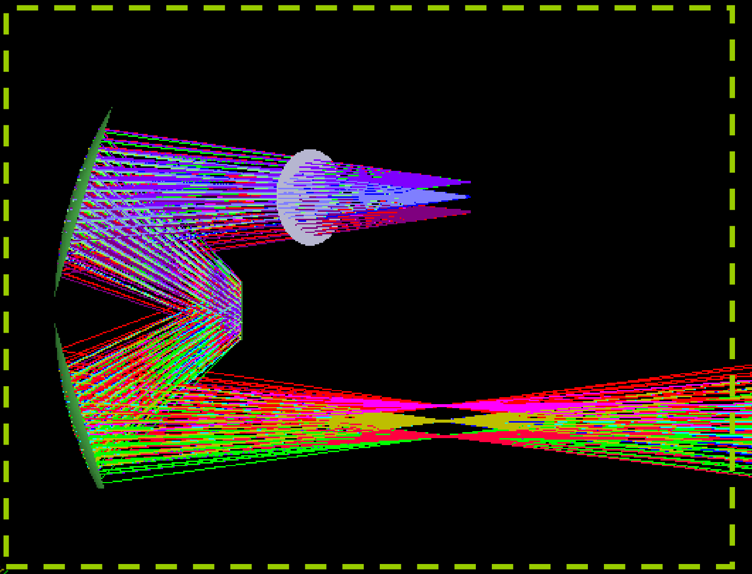


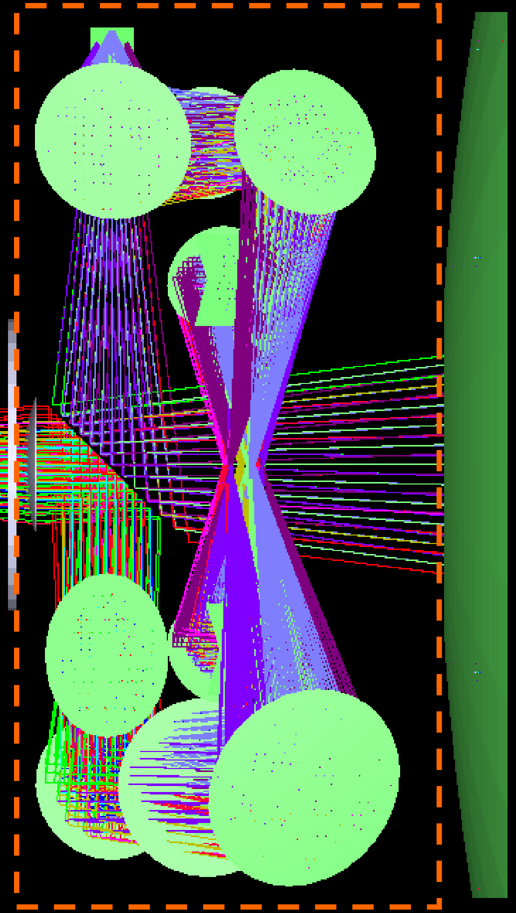
Mechanical arrangement of the translation stages

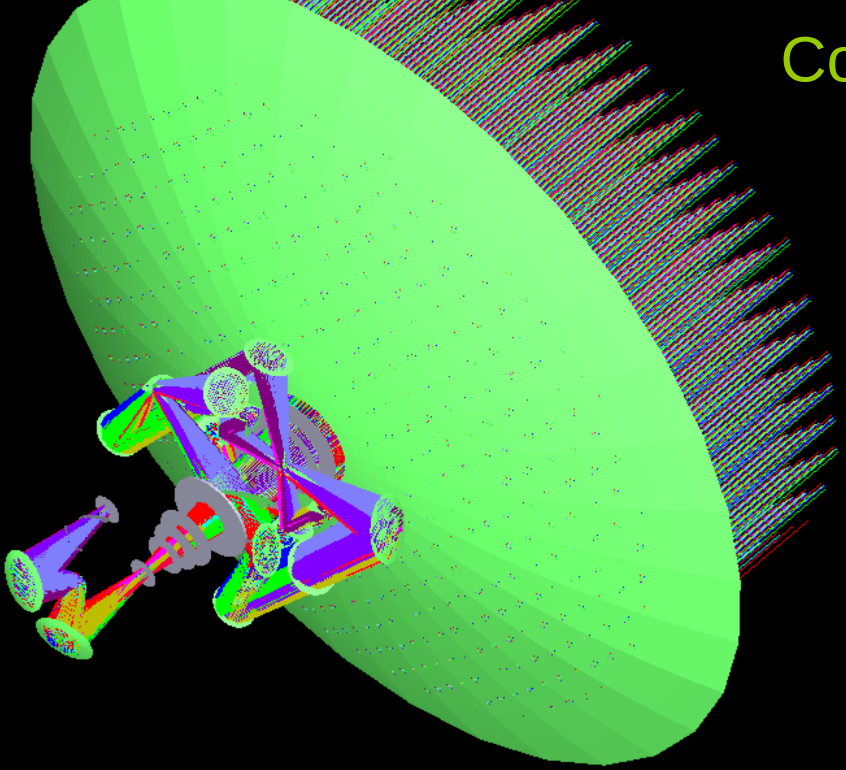


Differential field of view

Optical optimization has been performed using ZEMAX™ software optimizing the optical quality in the full FOV of OLIMPO.







The instrument was designed to fit the available room in between the primary mirror and the cryostat, a 75x75x30 cm3 box.(A.Schillaci)

bands

- In a FTS radiation from the whole covered range hits the detector at all times
- This is an advantage in terms of signal, but increases significantly the background.
- In the case of OLIMPO, the spectrometer is a room-temperature plug-in maintaining the same 4-bands and photometer arrays: spectroscopy is achieved within each band.
- The bandwidths cannot be too wide, otherwise the detectors saturate.

TES and P_{sat}

$\langle T_C \rangle = (495 \pm 10)$ mK

$\langle G \rangle = (1.56 \pm 0.19)\ 10^{-10}$ W/K

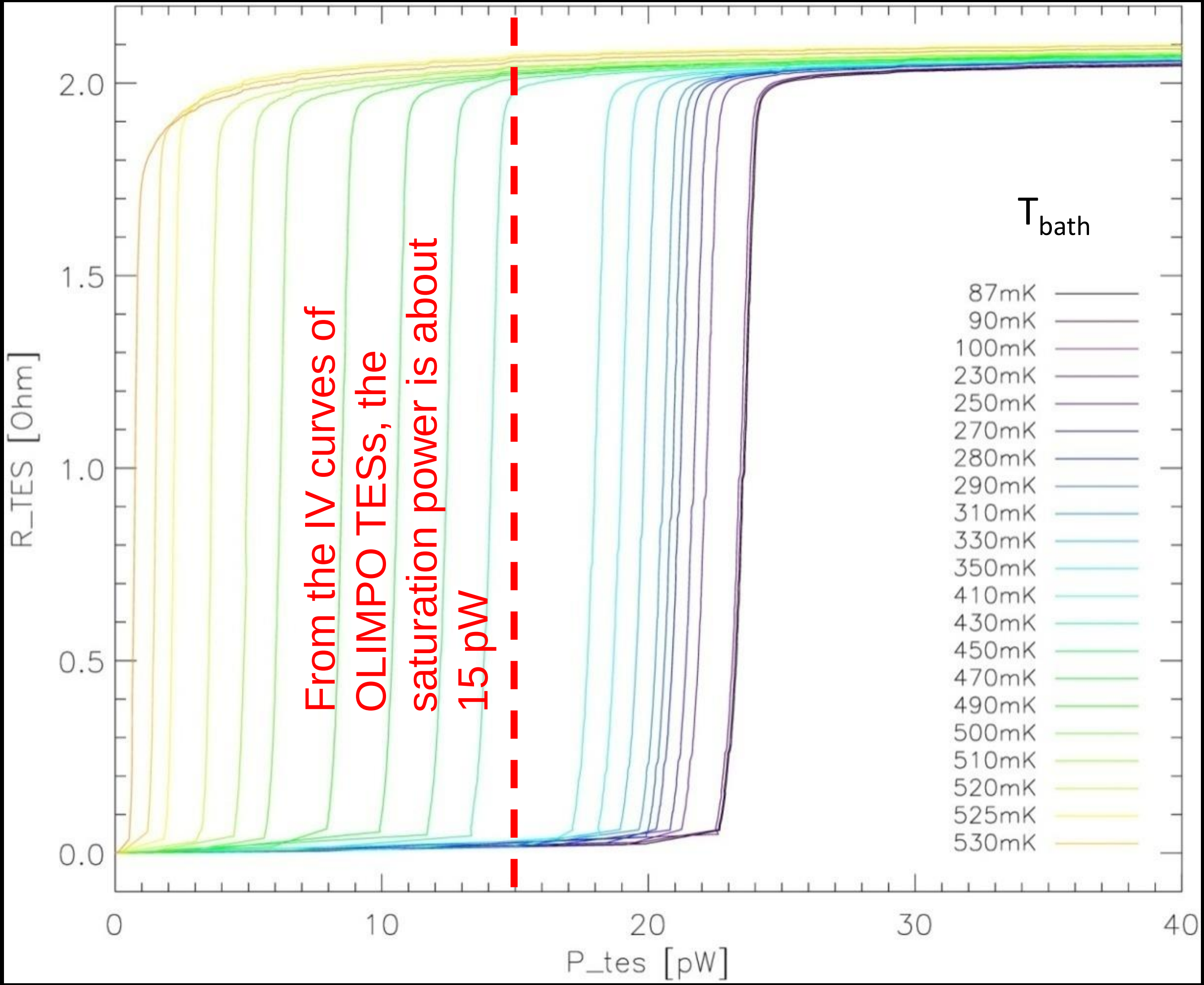
$\langle NEP \rangle = (3.7 \pm 0.2)\ 10^{-17}$ W/ √Hz

$\langle R_N \rangle = (2.15 \pm 0.22)$ Ohm

$\langle P_{SAT} \rangle = (15.5 \pm 1.4)$ pW…
…@ 290-310 mK

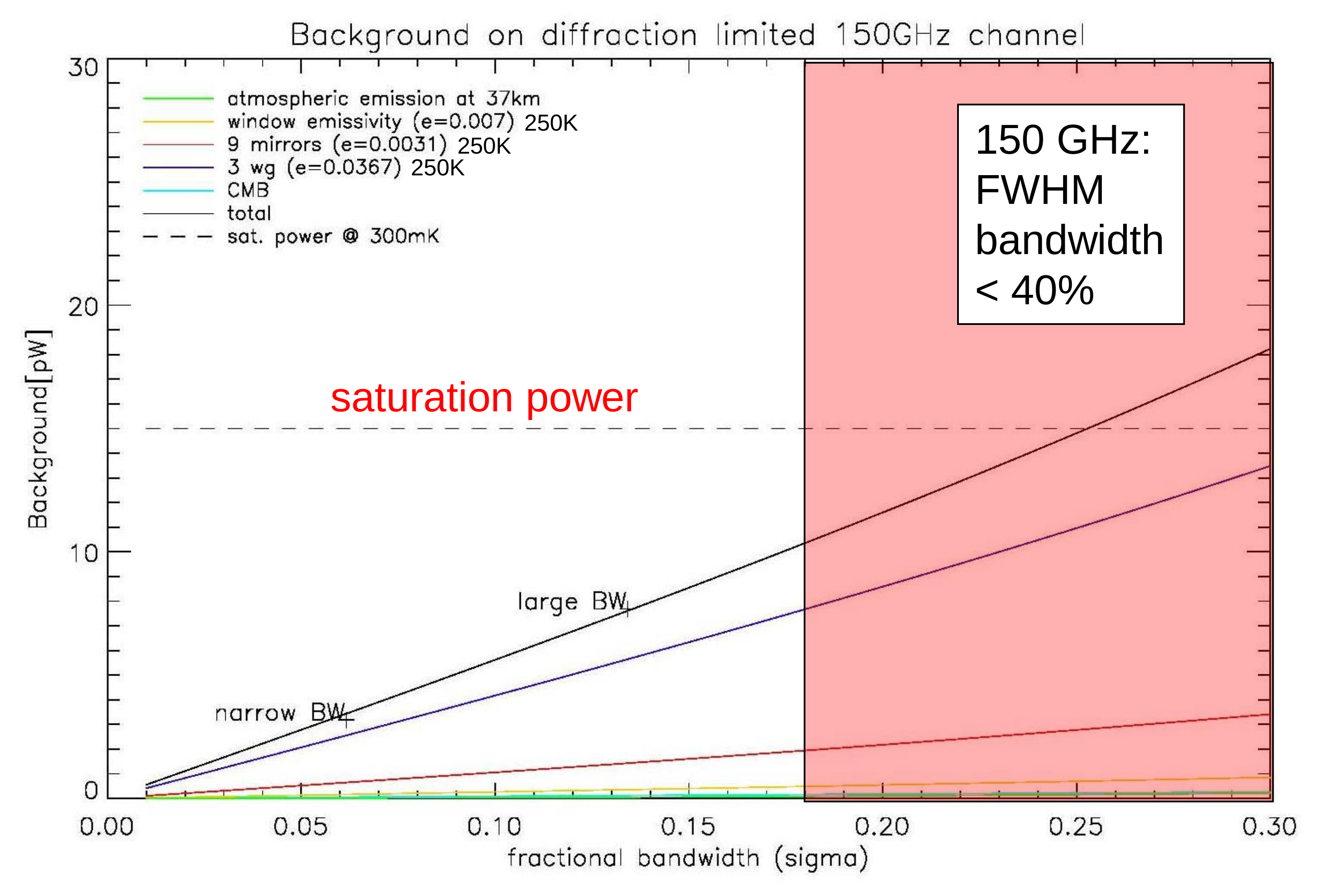
- Background MUST be strictly lower than P_{sat}!!!

- We need to account for the additional mirrors and wire grids in the FTS



From the IV curves of OLIMPO TESs, the saturation power is about 15 pW

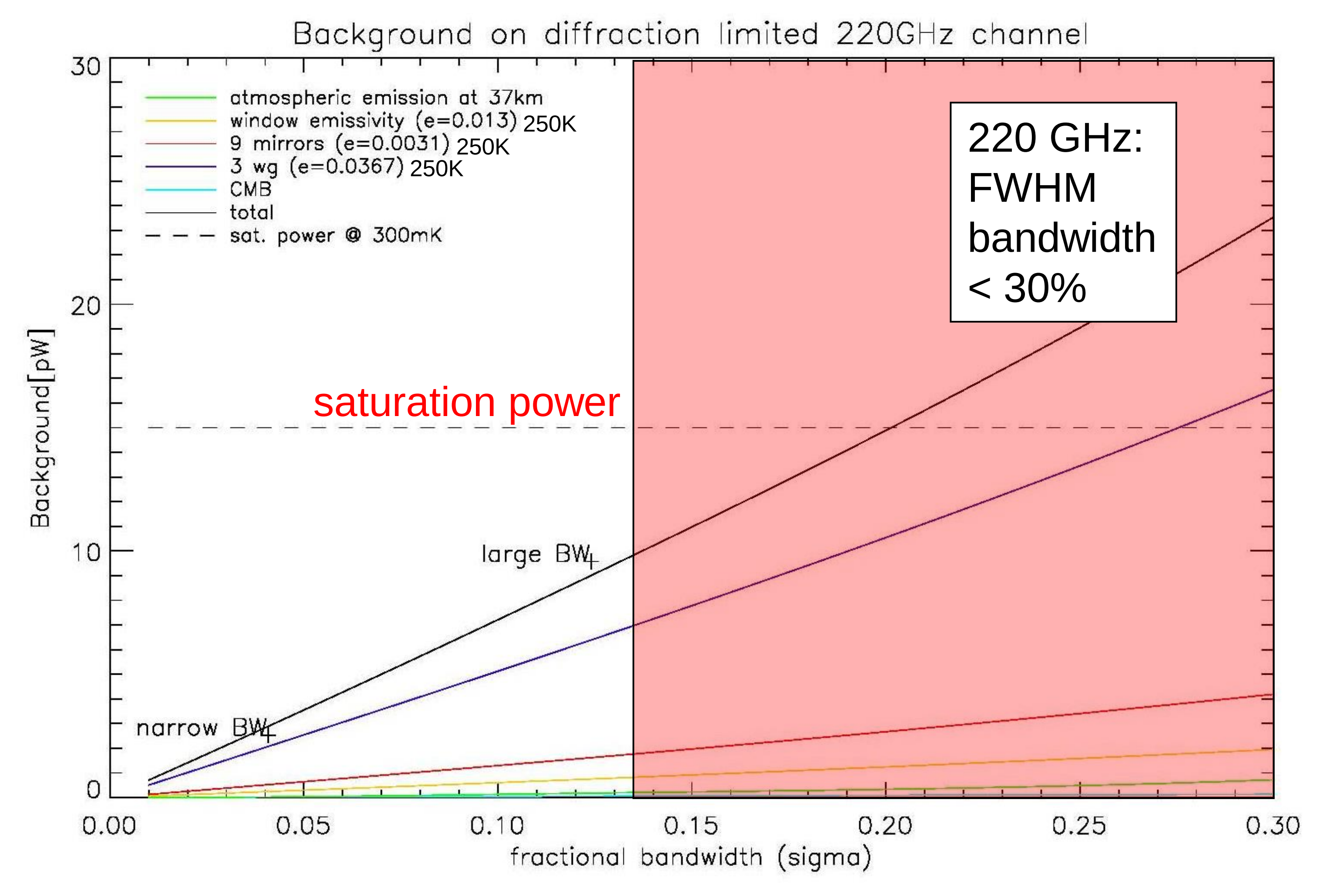
Background on the 150GHz TES



150 GHz:
FWHM
bandwidth
< 40%

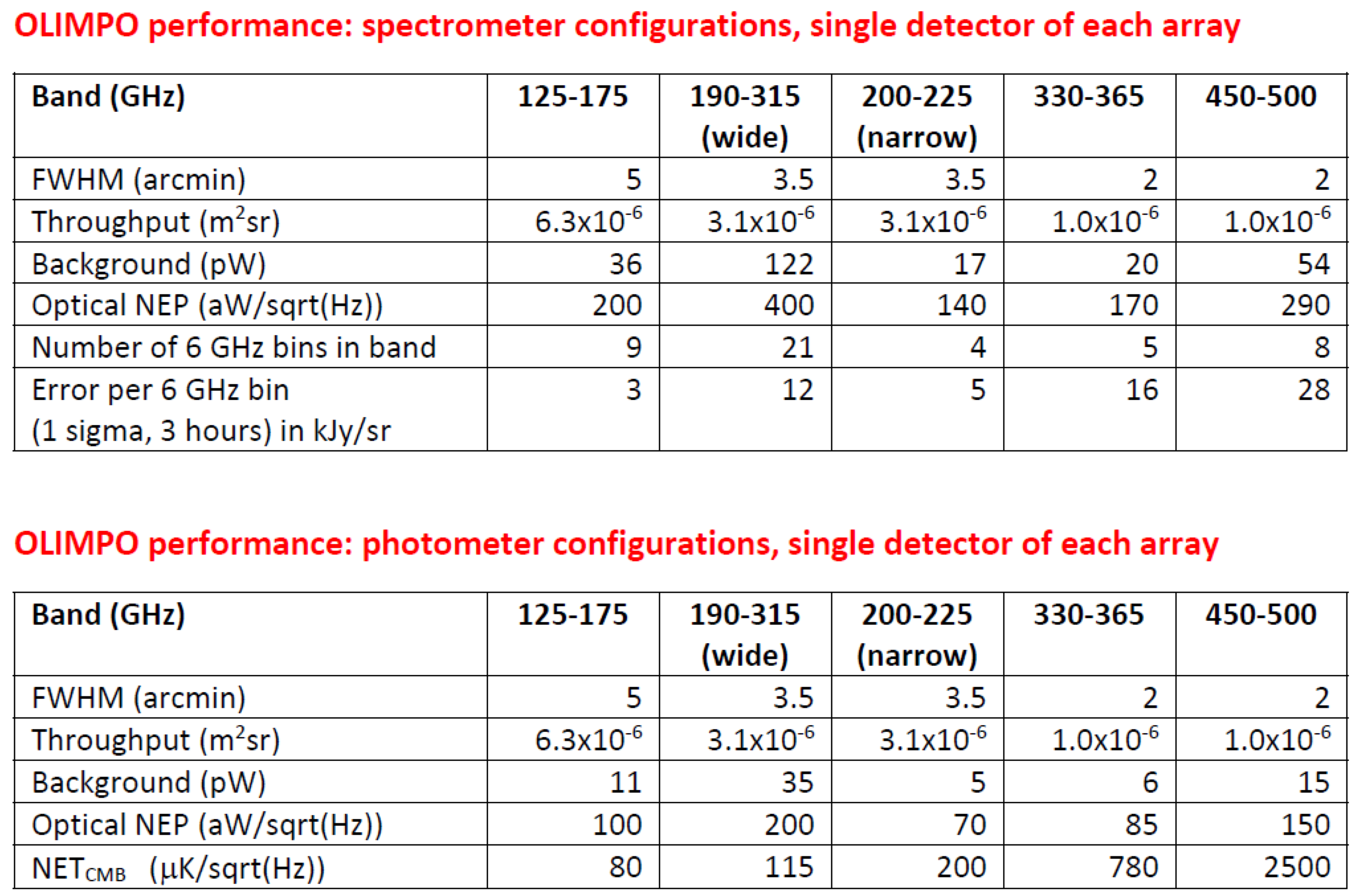
E. Battistelli

Background on the 220GHz TES



E. Battistelli

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)	6.3x10^{-6}	3.1x10^{-6}	3.1x10^{-6}	1.0x10^{-6}	1.0x10^{-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**
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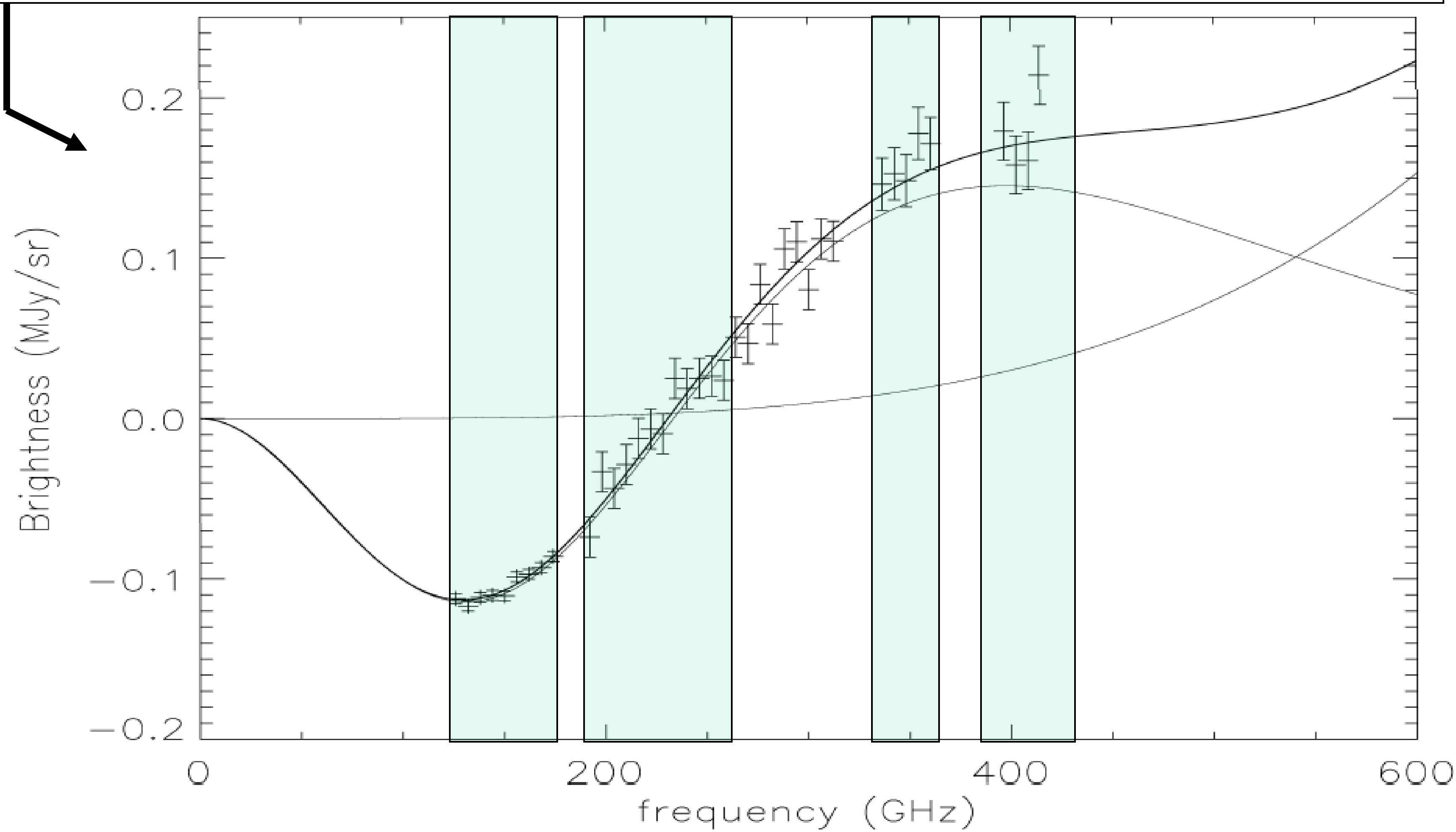
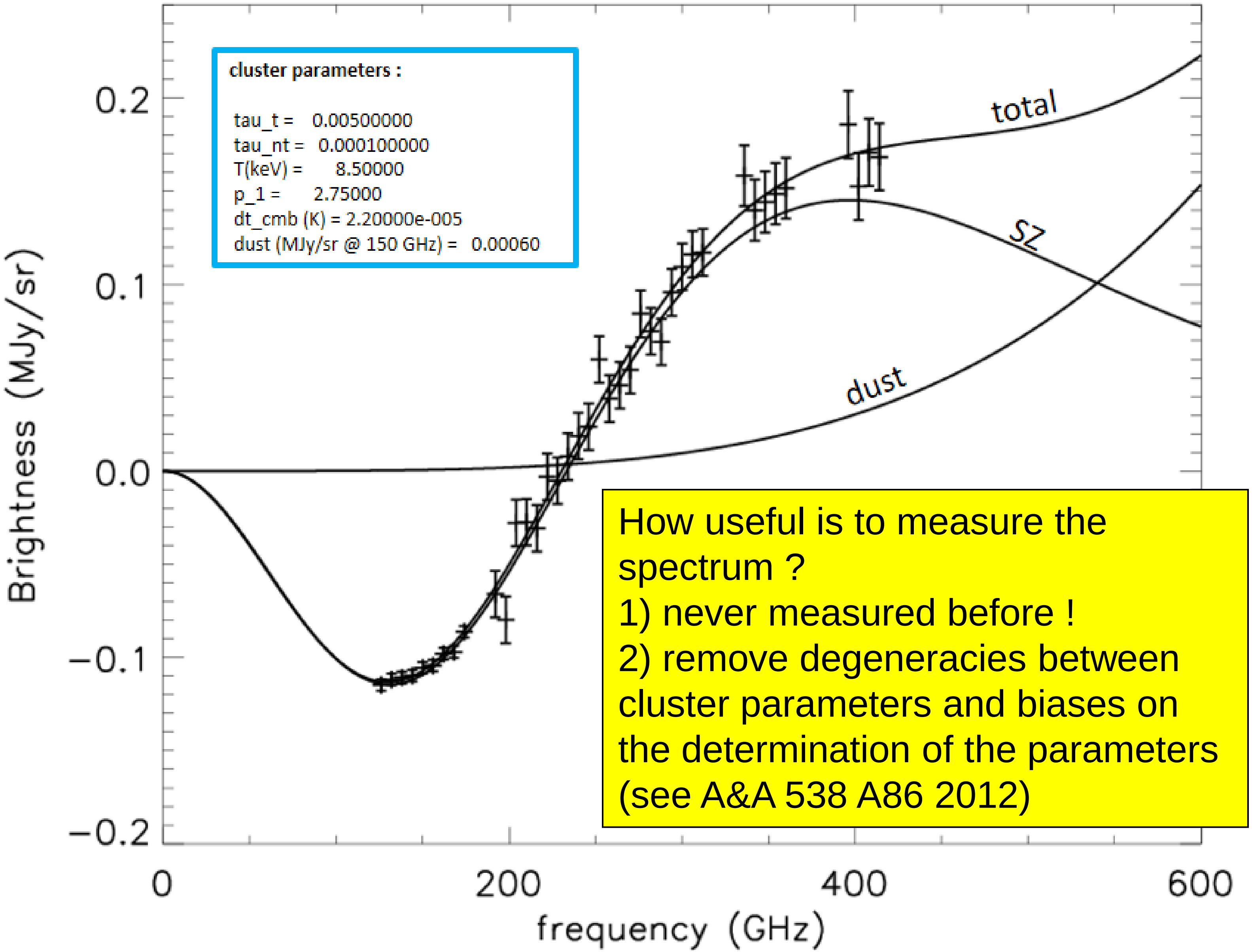
Background (pW)	11	35	5	6	15
Optical NEP (aW/sqrt(Hz))	100	200	70	85	150
$\mathrm{NET}_{\mathrm{CMB}}$ (μK/sqrt(Hz))	80	115	200	780	2500

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.





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)

Parameters Determination

- In the presence of peculiar velocities, non-thermal populations (from AGNs in the cluster), and foreground dust, there are simply too many free parameters to be determined with the observation of a few frequency bands.
- We have carried out detailed simulations of OLIMPO observations in the spectroscopic configuration with an extended 200-300 GHz band.
- The spectroscopic configuration has superior performance in converging to the correct estimate of thermal optical depth and dust parameters, while the photometric configuration, *in the absence of priors*, tends to converge to biased estimates of the parameters.
- See de Bernardis et al. A&A 538 A86 (2012) for details

Input parameters

τ_{th} =50x10^{-4}

T = 10 keV

τ_{non-th}=1x10^{-4}

ΔT_{CMB}=22μK

$\Delta I_{dust150}$=6 kJy/sr

OLIMPO

FTS

3h integ.

one

detector

- No priors

τ_{th} =(63$\pm$27)10^{-4}

T = (9.0$\pm$4.1) keV

τ_{non-th}=(14$\pm$9)10^{-5}

ΔT_{CMB}=(24$\pm$43)μK

$\Delta I_{dust150}$=(5.7$\pm$1.6)kJy/sr

- Prior T=(10$\pm$3) keV

τ_{th} =(49$\pm$6)10^{-4}

T = (9.6$\pm$0.5)keV

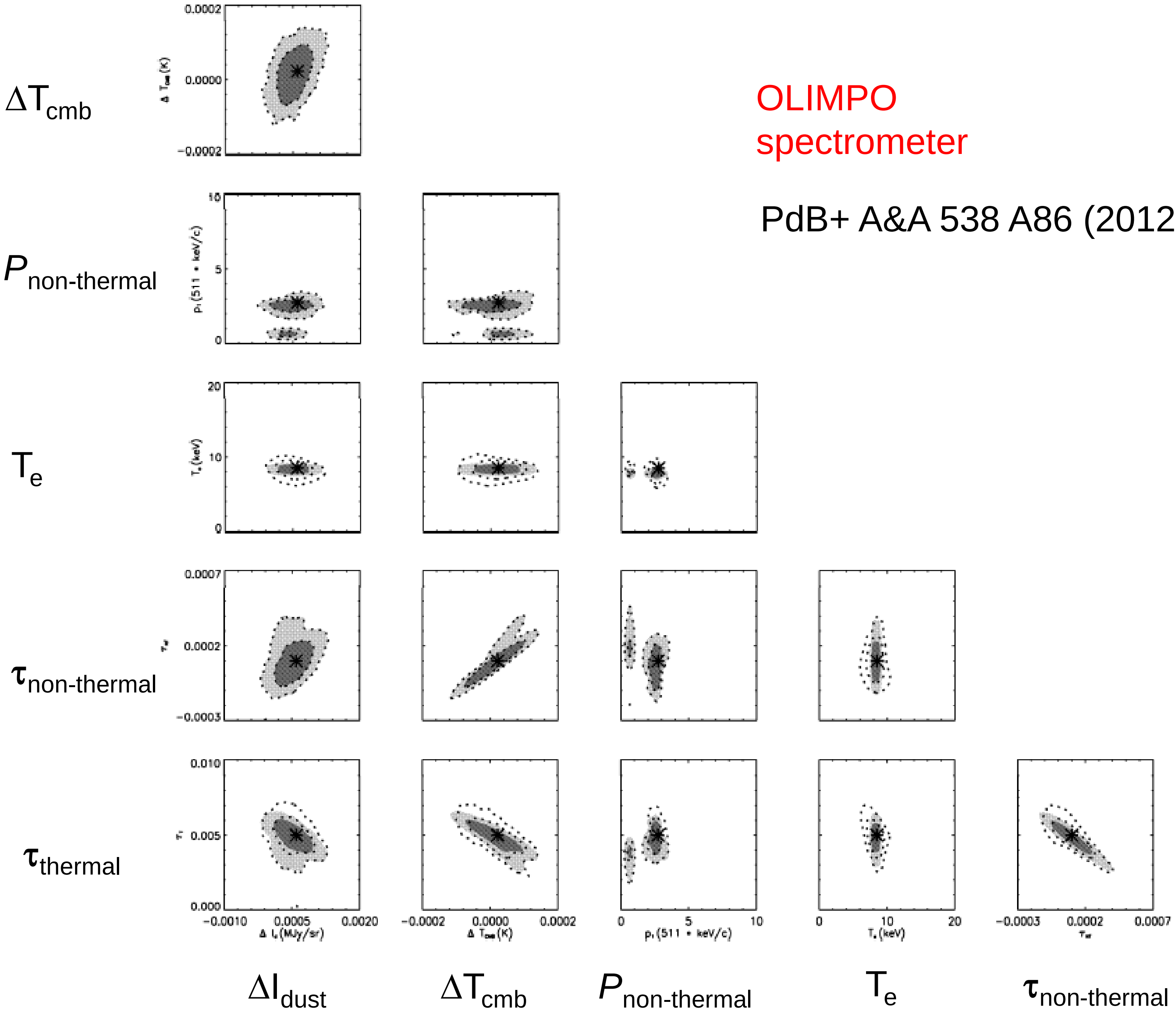
τ_{non-th}=(11$\pm$9)10^{-5}

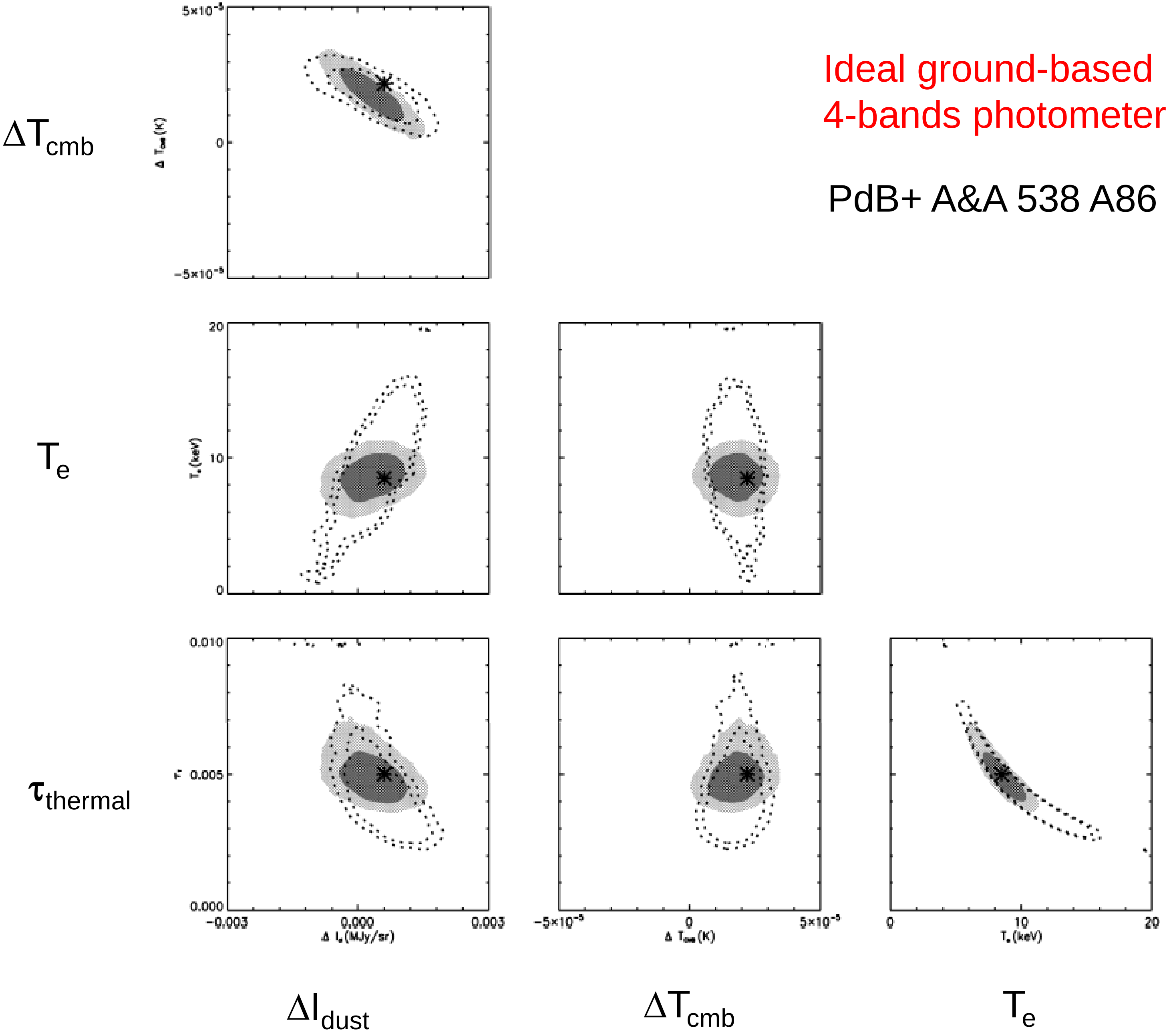
ΔT_{CMB}=(22$\pm$43)μK

$\Delta I_{dust150}$=(5.8$\pm$0.9)kJy/sr

OLIMPO
spectrometer

PdB+ A&A 538 A86 (2012)

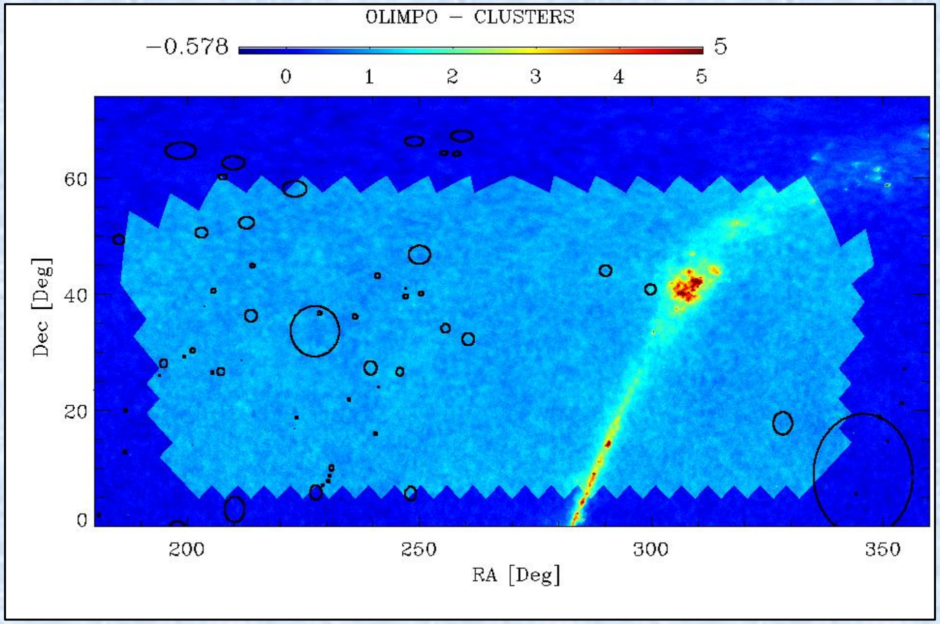




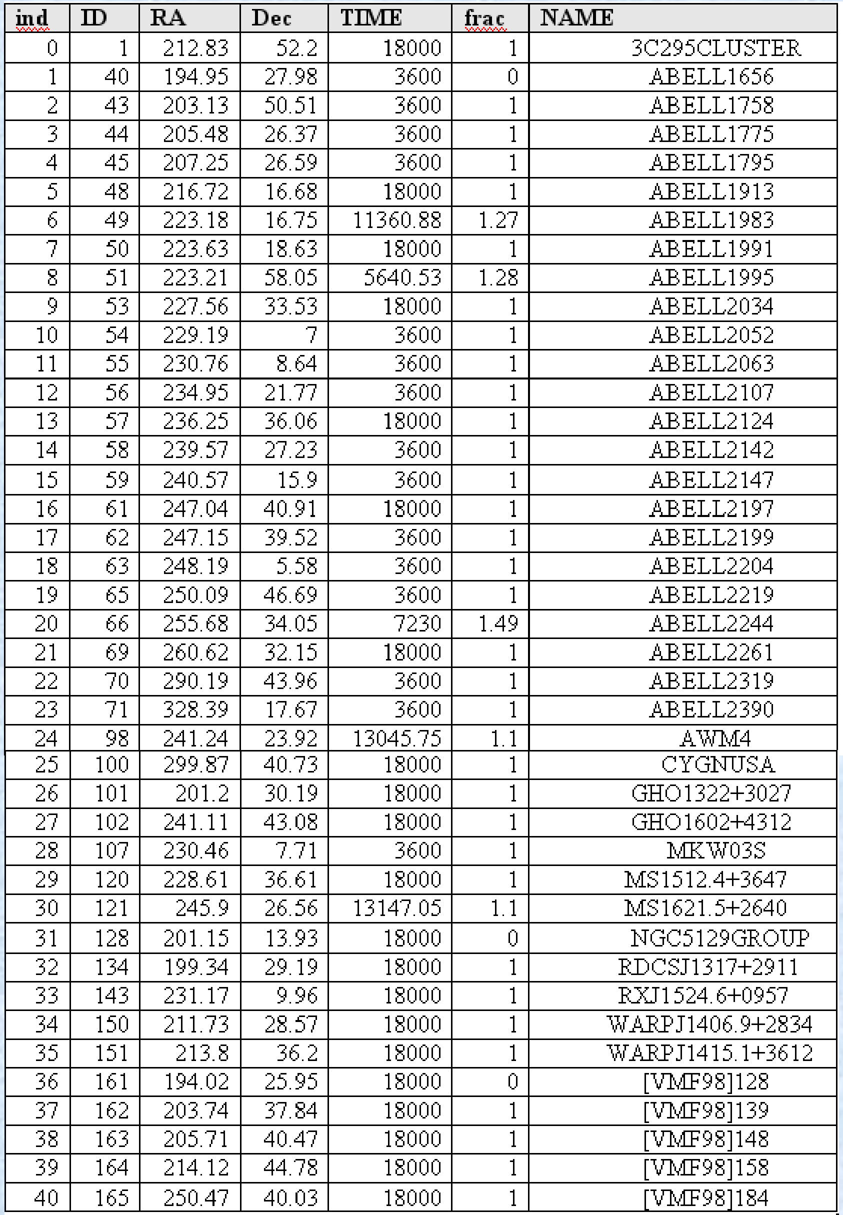
Ideal ground-based
4-bands photometer

PdB+ 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

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Astronomy & Astrophysics

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

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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.

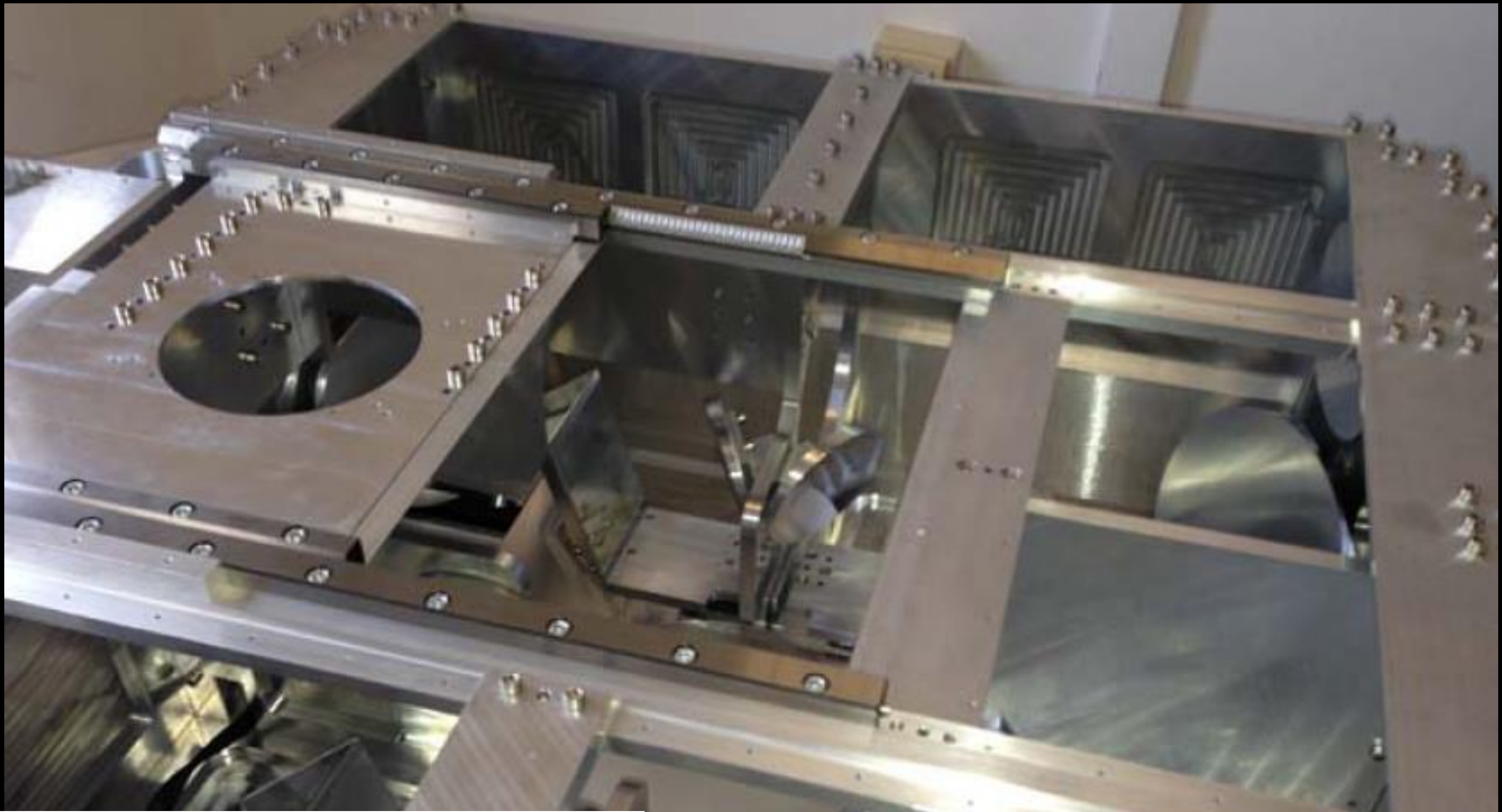
Methods. Our instrument is based on a Martin-Puplett interferometer (MPI) configuration. We combined two MPIs working synchronously to use the whole input power. In our implementation the observed sky field is divided into two halves along the meridian, and each half-field corresponds to one of the two 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.

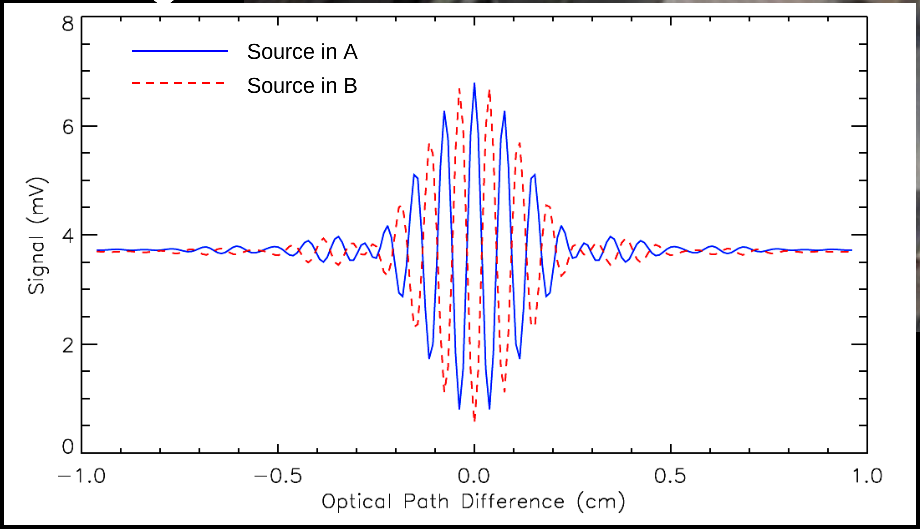
Results. The instrument works in the range $\sim$1–20 cm^{-1} (30–600 GHz), has a maximum spectral resolution $1/(2\,\mathrm{OPD}) = 0.063$ cm^{-1} (1.9 GHz), and an unvignetted throughput of 2.3 cm^{2}sr. It occupies a volume of $0.7 \times 0.7 \times 0.33$ m^3 and has a weight of 70 kg. This design 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….

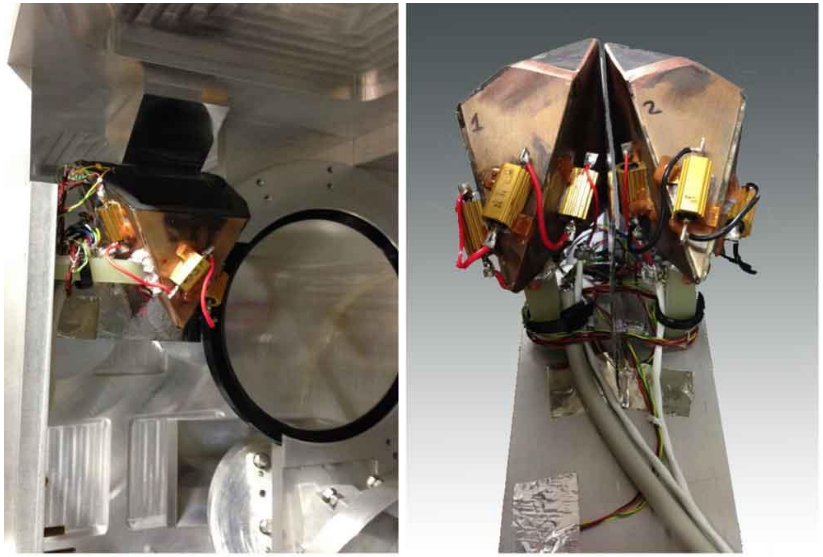
and measured interferograms

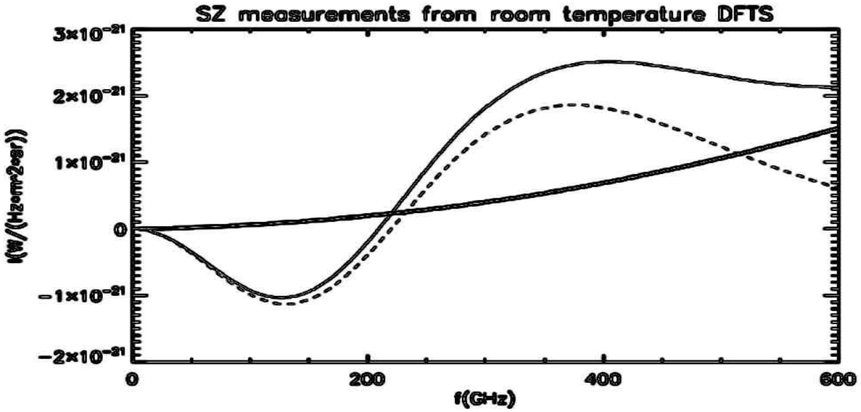


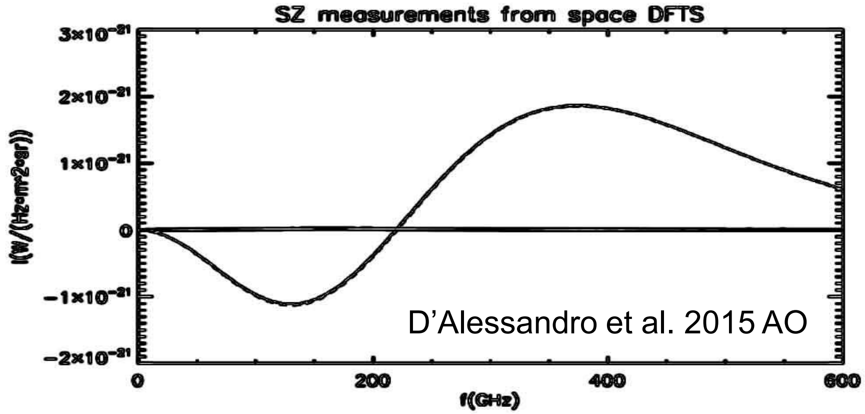


CMRR

- 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.





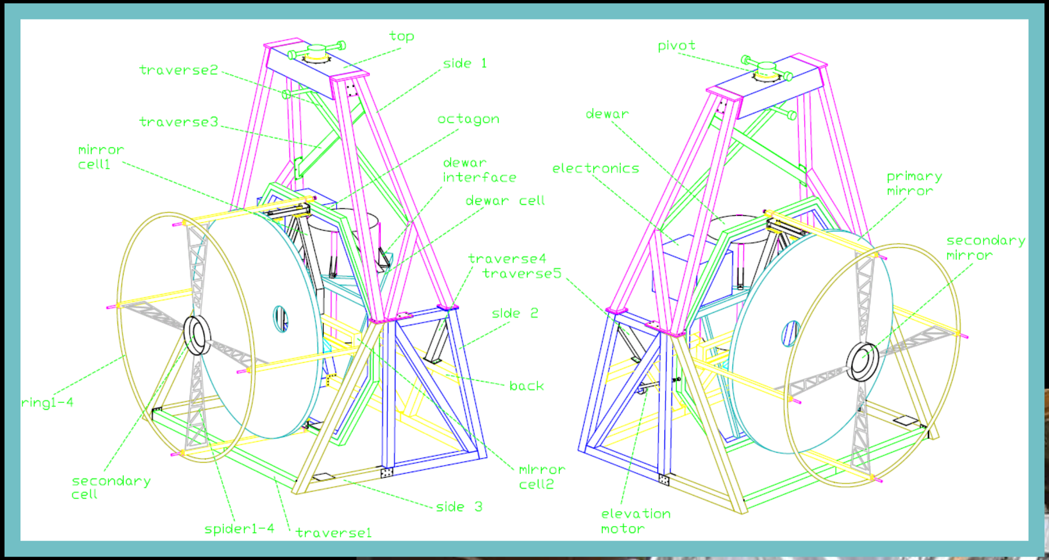


D'Alessandro et al. 2015 AO

Telescope / primary mirror DFTS cryostat / detectors arrays

Main components of OLIMPO integrated on the payload

OLIMPO calibration night (Rome, 25/4/2014) $T_{atm}(350GHz)=0.001$!!

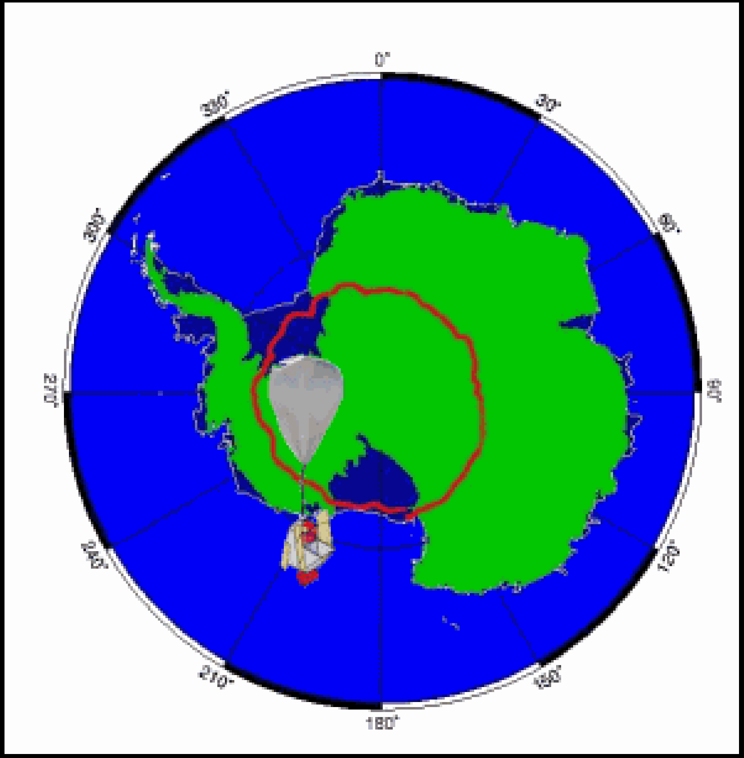


The Payload

The OLIMPO payload prepared for a long-duration stratospheric flight, at the airport of Longyearbyen (Svalbard) on July 3rd, 2014.

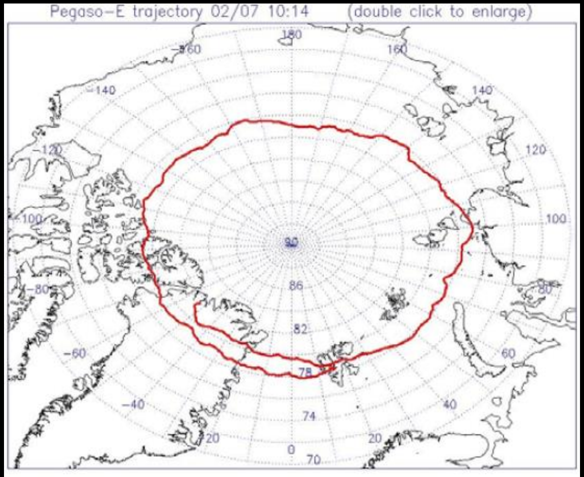
Polar flights

- NASA-CSBF has flown balloons around the south pole for many years, including the very successful BOOMERanG experiments (1998, 2003).



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).

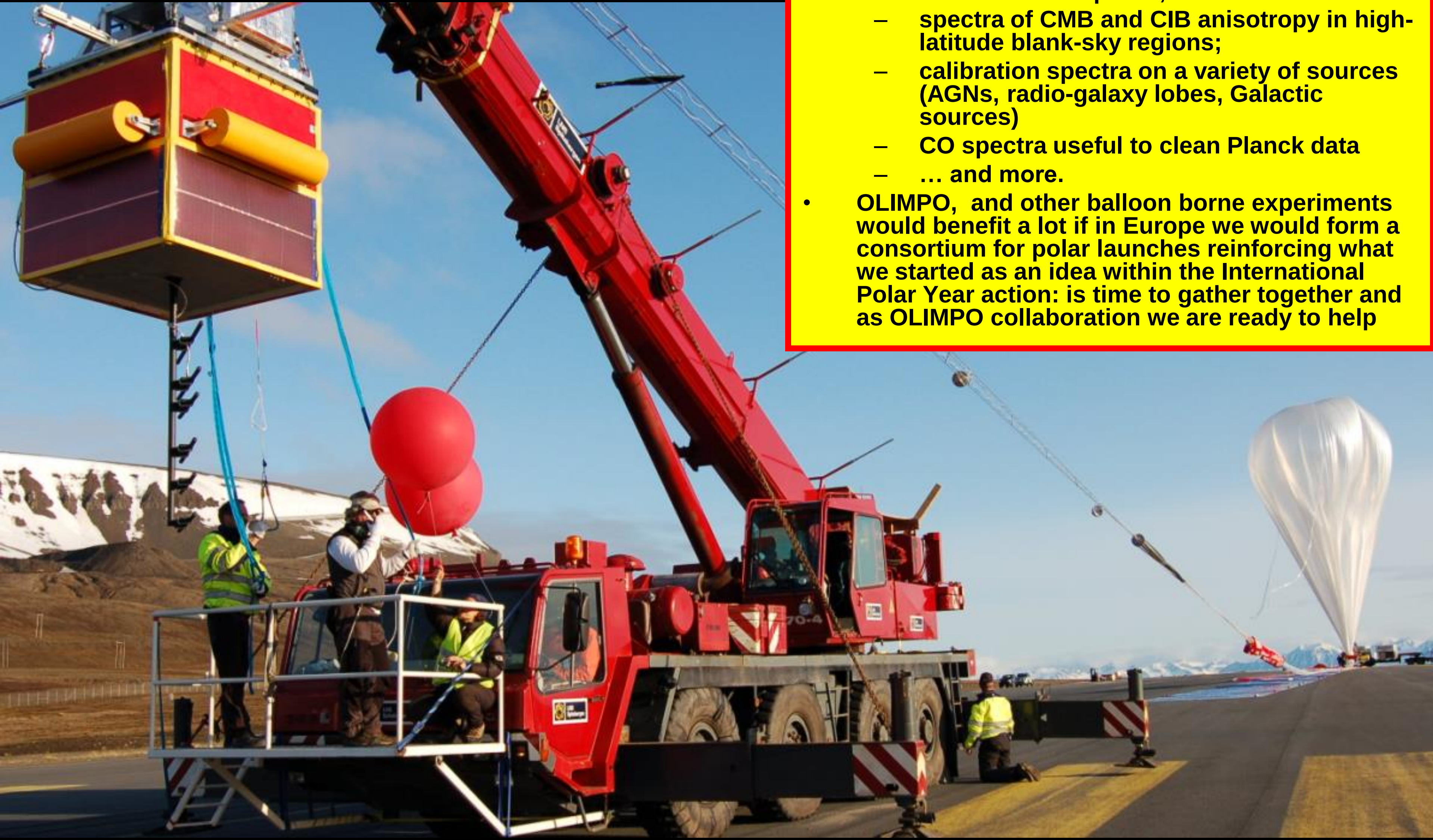


Top: Ground path of a flight performed in June 2007. **Bottom left:** Launch of a heavy-lift balloon from the Longyearbyen airport (Svalbard Islands, latitude 78ºN).

- OLIMPO will have its first flight in the Arctic (2016?) and the second one from Antarctica (2018 if recovered well)

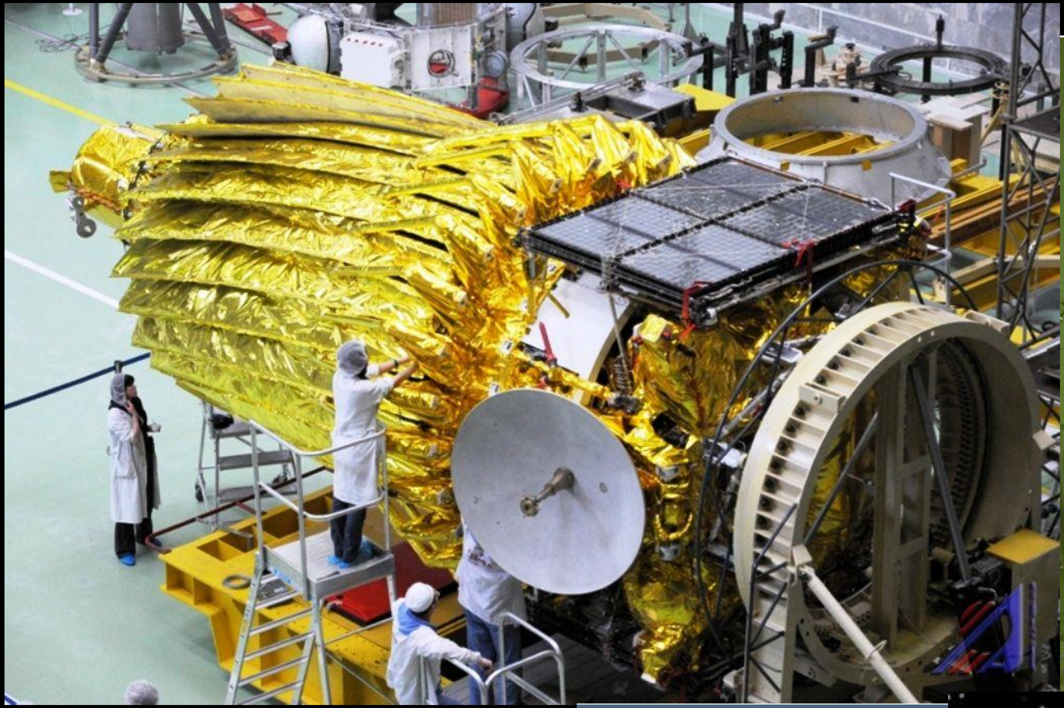
Stay tuned …

- OLIMPO will be the first space-based validation of the DFTS approach.
- The observation program includes
  - spectra of the SZE in tens of clusters in the northern hemisphere;
  - spectra of CMB and CIB anisotropy in high-latitude blank-sky regions;
  - calibration spectra on a variety of sources (AGNs, radio-galaxy lobes, Galactic sources)
  - CO spectra useful to clean Planck data
  - … and more.
- OLIMPO, and other balloon borne experiments would benefit a lot if in Europe we would form a consortium for polar launches reinforcing what we started as an idea within the International Polar Year action: is time to gather together and as OLIMPO collaboration we are ready to help



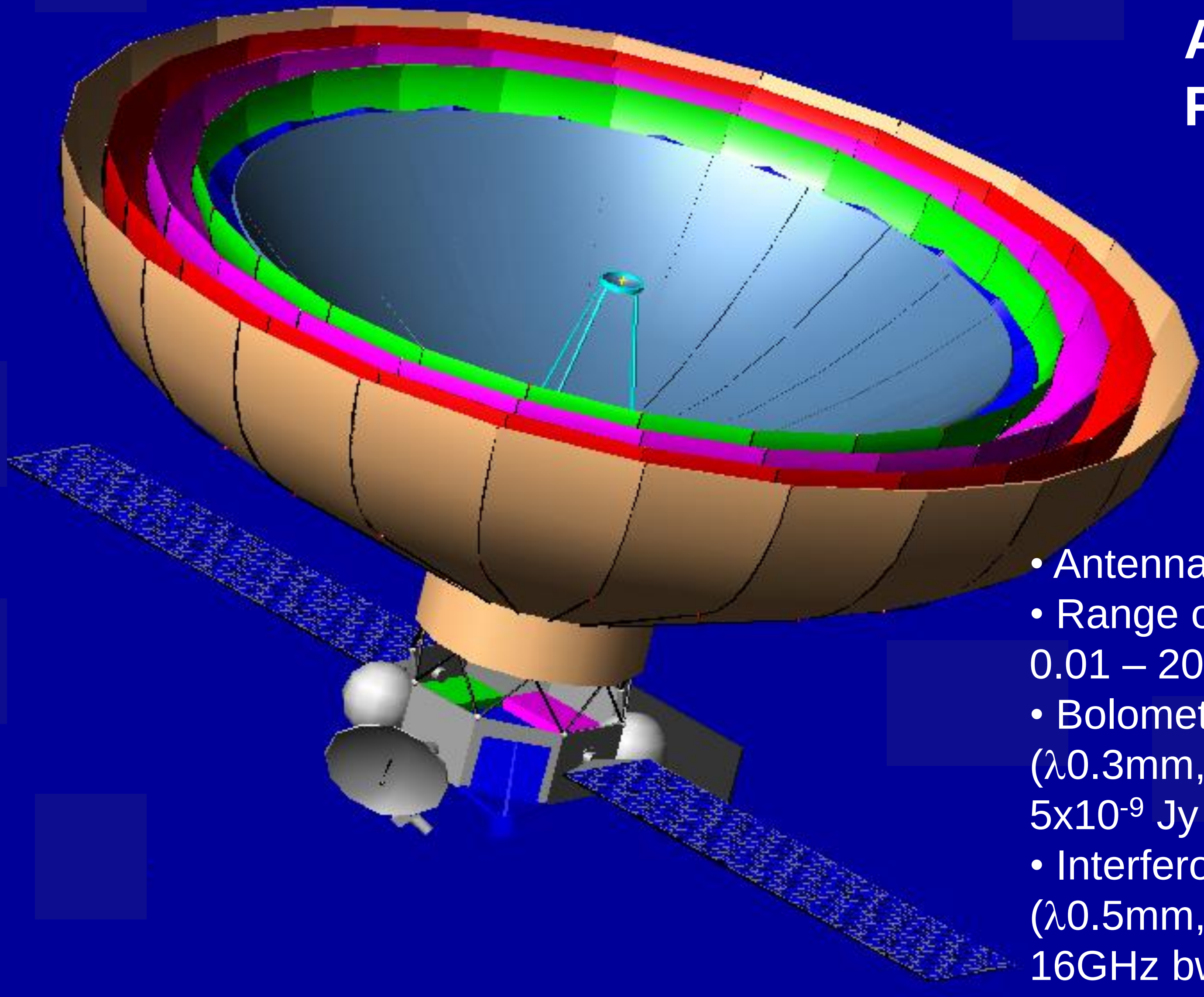
- The OLIMPO spectrometer is the prototype for a similar Differential Fourier Transform Spectrometer to be flown on the Millimetron space mission ….

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

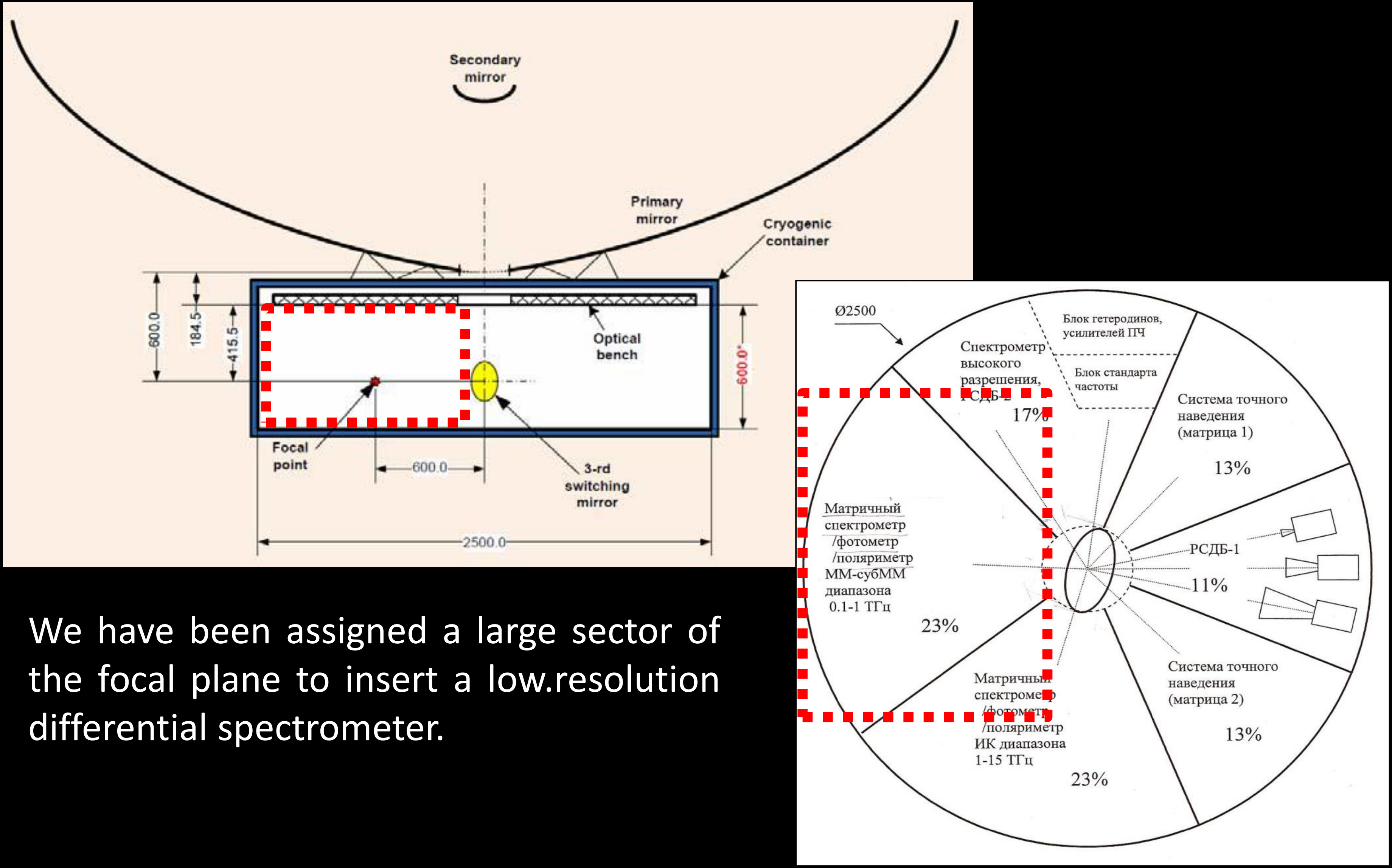


РадиоАстрон

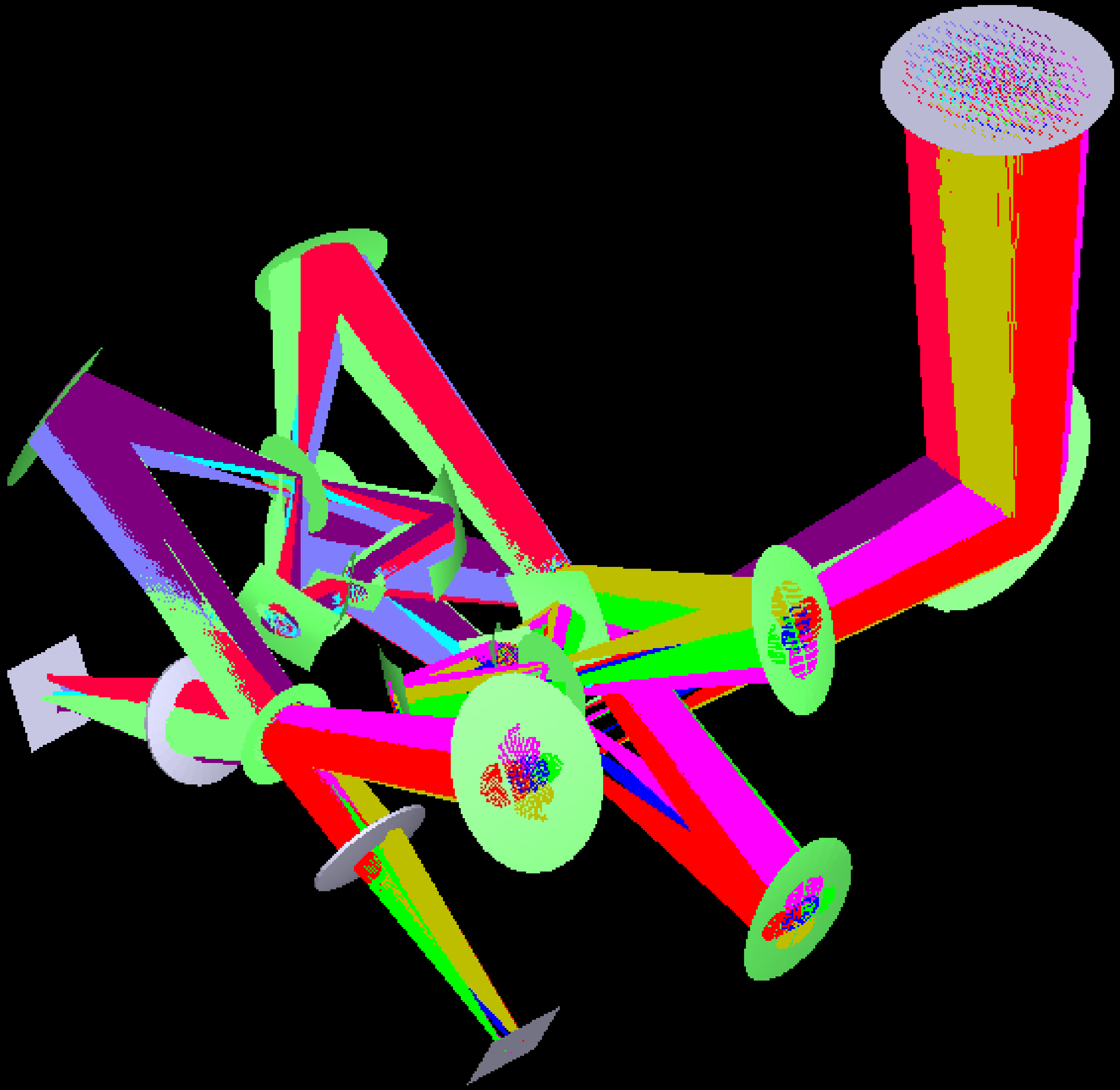
Millimetron
ASC Moscow
ROSCOSMOS



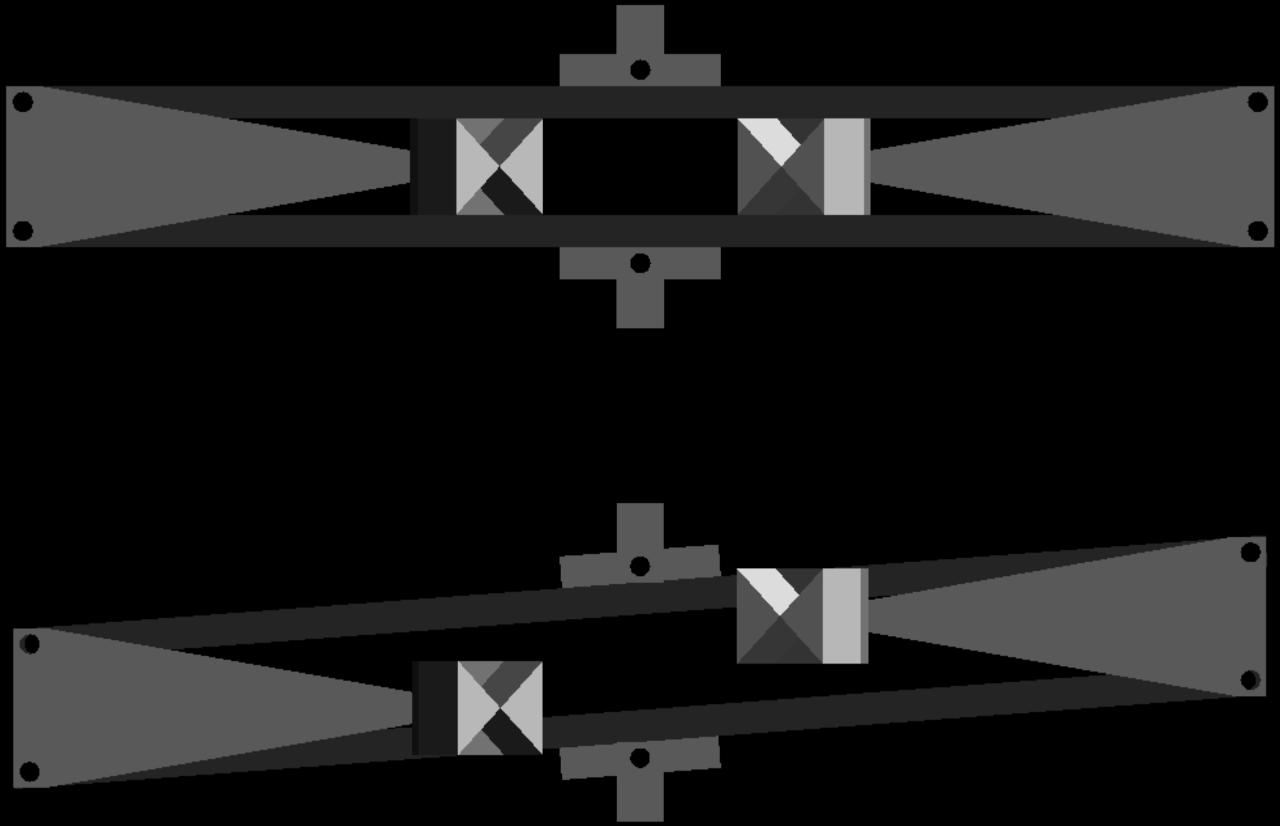
- Antenna diameter: 10 m
- Range of wavelengths: 0.01 – 20 mm
- Bolometric sensitivity (λ0.3mm, 1h integration): 5x10^{-9} Jy
- Interferometry sensitivity (λ0.5mm, 300s integration, 16GHz bw) : 10^{-4} Jy
- Interferometer beam: 10^{-9} arcsec

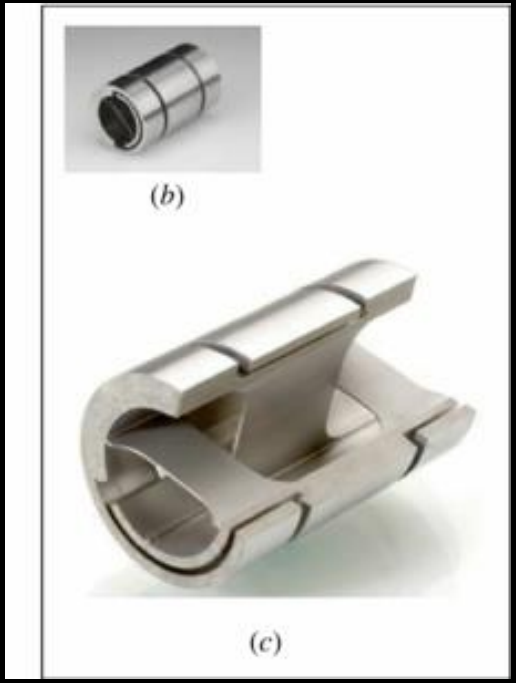


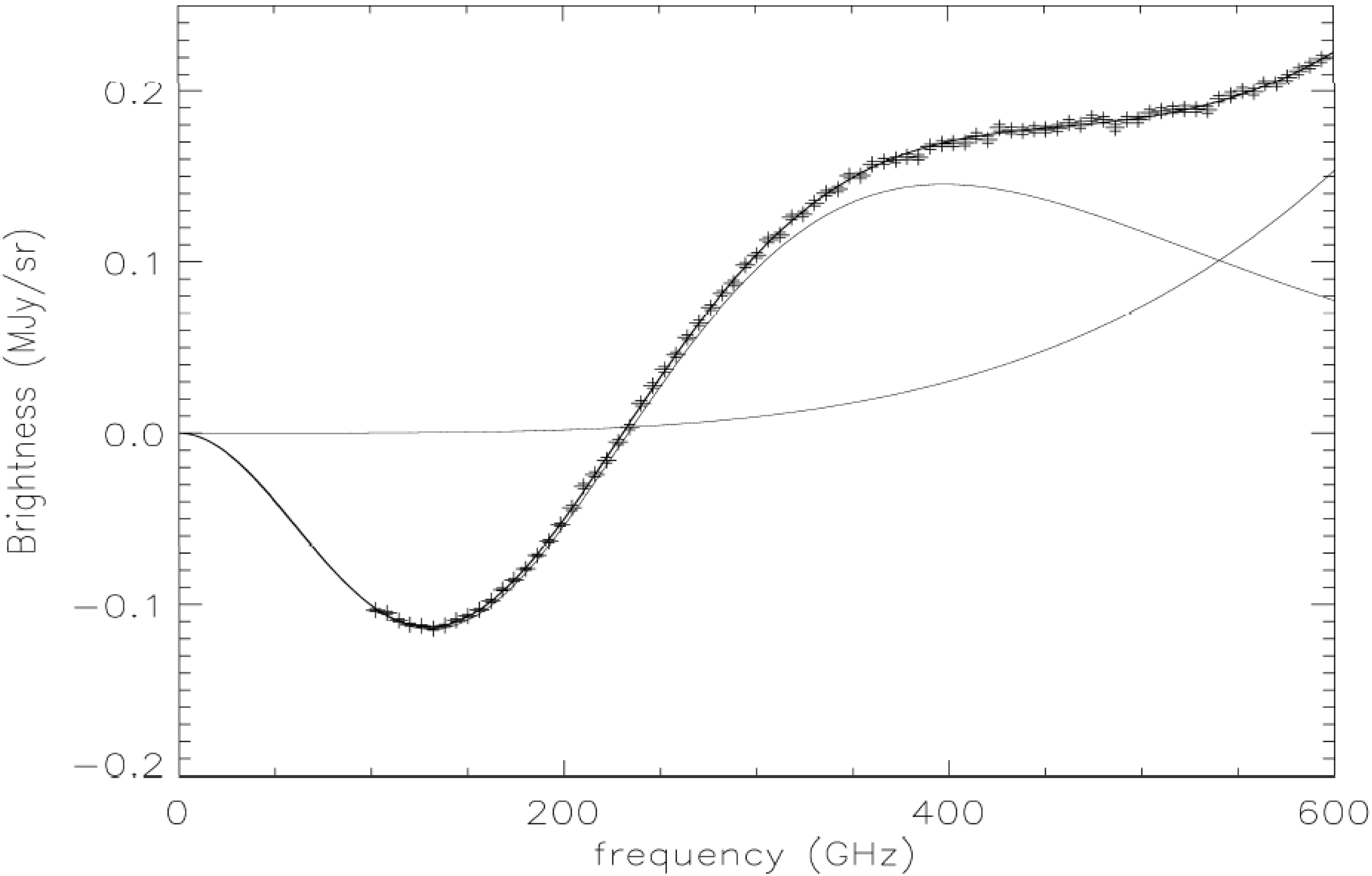
We have been assigned a large sector of the focal plane to insert a low.resolution differential spectrometer.



Oscillating pantograph (negligible dissipation) for cryogenic delay lines.

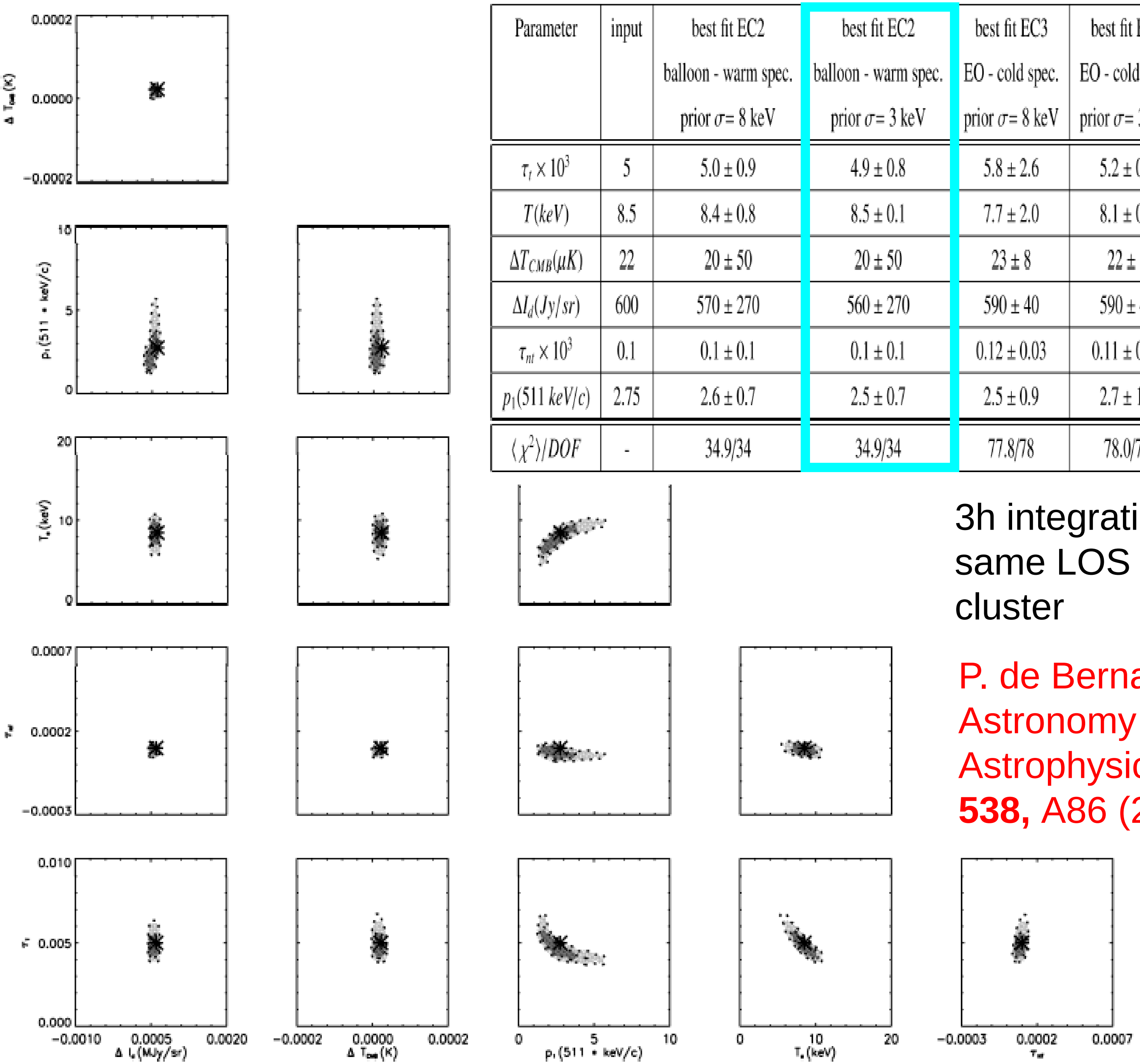






3 hours of observations of a rich cluster with a DFTS on Millimetron

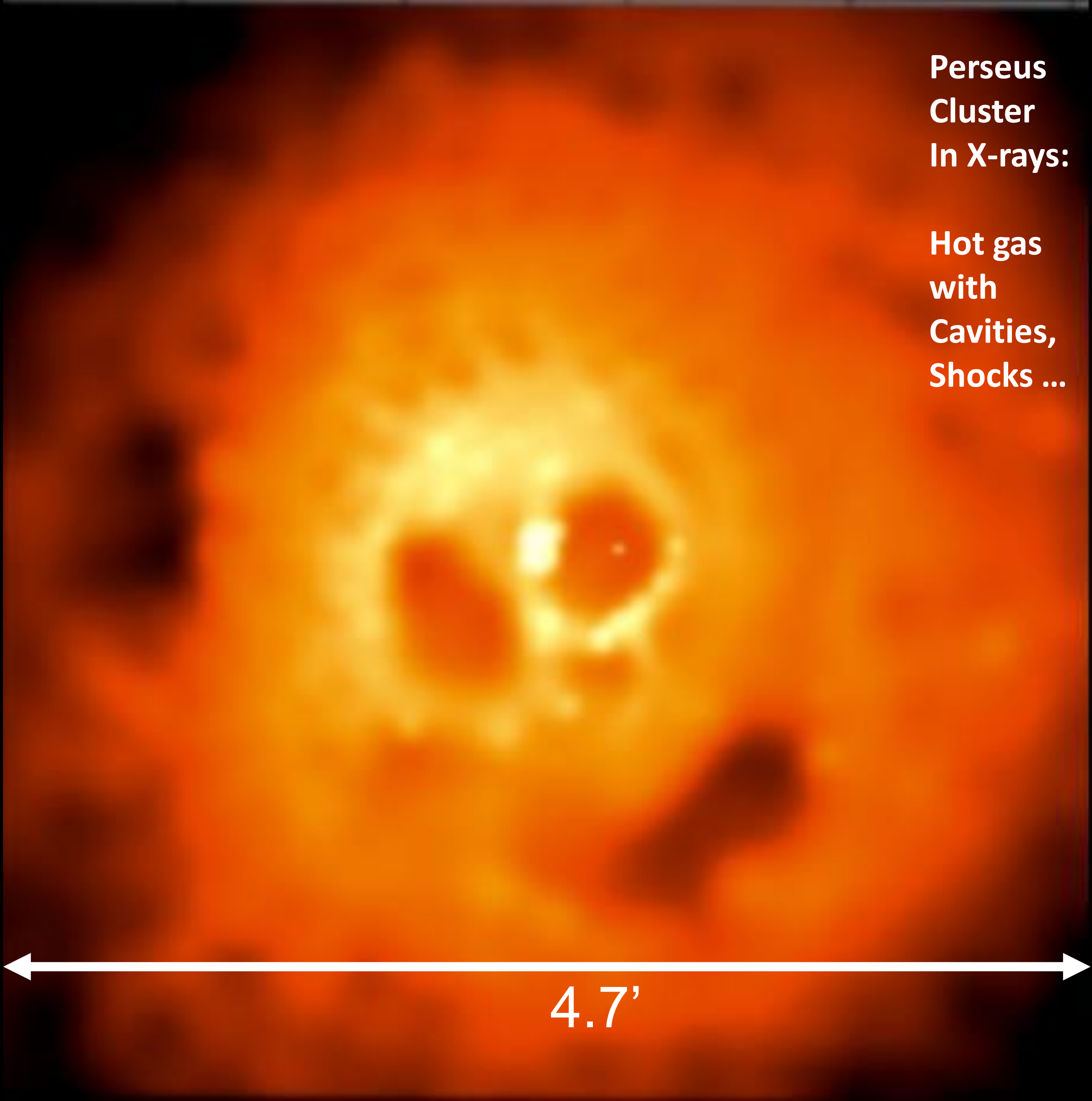
Absolutely outstanding. USING A PHOTON NOISE LIMITED BOLOMETER IN THE COLD ENVIRONMENT OF L2 WITH A 4K TELESCOPE



Parameter	input	best fit EC2 balloon - warm spec. prior σ= 8 keV	best fit EC2 balloon - warm spec. prior σ= 3 keV	best fit EC3 EO - cold spec. prior σ= 8 keV	best fit EC3 EO - cold spec. prior σ= 3 keV	best fit EC5 L2 - cold spec. prior σ= 8 keV	best fit EC5 L2 - cold spec. prior σ= 3 keV
$\tau_t \times 10^3$	5	5.0 ± 0.9	4.9 ± 0.8	5.8 ± 2.6	5.2 ± 0.6	5.1 ± 0.6	5.1 ± 0.5
$T(keV)$	8.5	8.4 ± 0.8	8.5 ± 0.1	7.7 ± 2.0	8.1 ± 0.8	8.5 ± 1.2	8.5 ± 1.0
$\Delta T_{CMB}(\mu K)$	22	20 ± 50	20 ± 50	23 ± 8	22 ± 8	22 ± 4	22 ± 4
$\Delta I_d(Jy/sr)$	600	570 ± 270	560 ± 270	590 ± 40	590 ± 40	600 ± 4	600 ± 4
$\tau_{nt} \times 10^3$	0.1	0.1 ± 0.1	0.1 ± 0.1	0.12 ± 0.03	0.11 ± 0.02	0.10 ± 0.01	0.10 ± 0.01
$p_1(511\ keV/c)$	2.75	2.6 ± 0.7	2.5 ± 0.7	2.5 ± 0.9	2.7 ± 1.1	3.0 ± 1.0	2.9 ± 0.9
$\langle \chi^2 \rangle / DOF$	-	34.9/34	34.9/34	77.8/78	78.0/78	110.0/110	110.1/110

3h integration on the same LOS through a rich cluster

P. de Bernardis, et al., Astronomy and Astrophysics, **538,** A86 (2012)



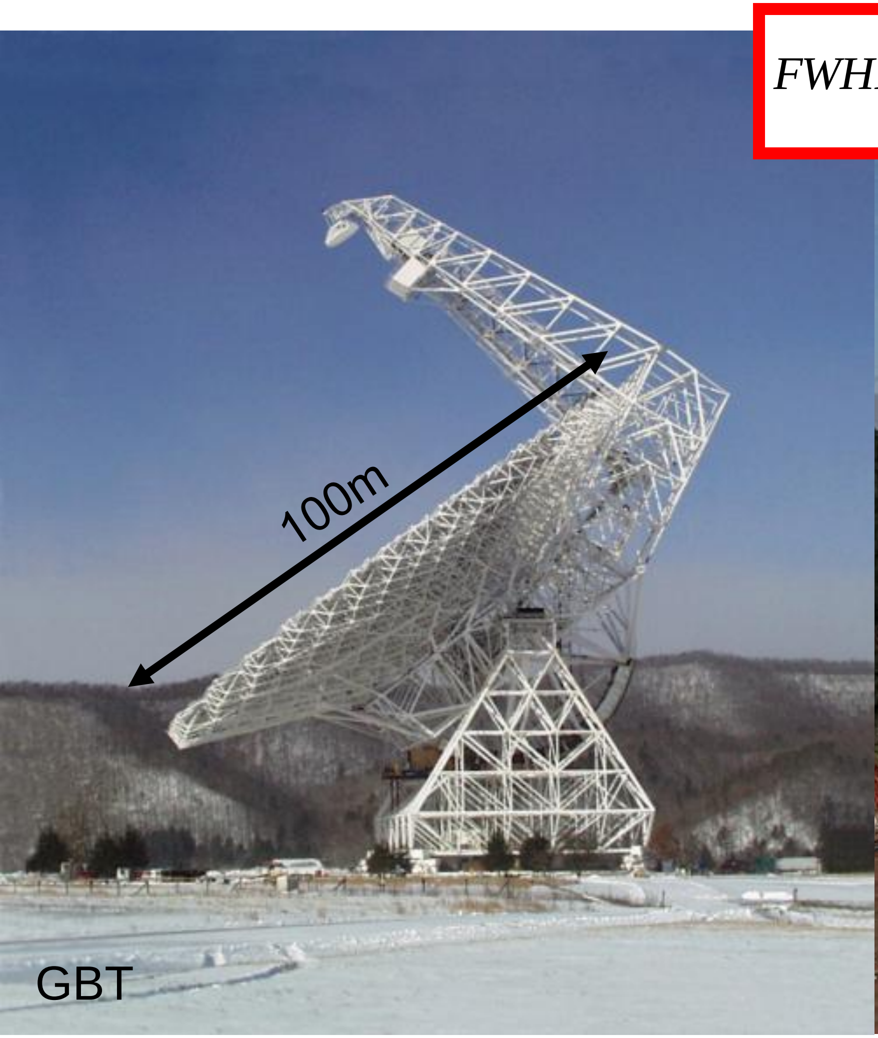
Perseus
Cluster
In X-rays:

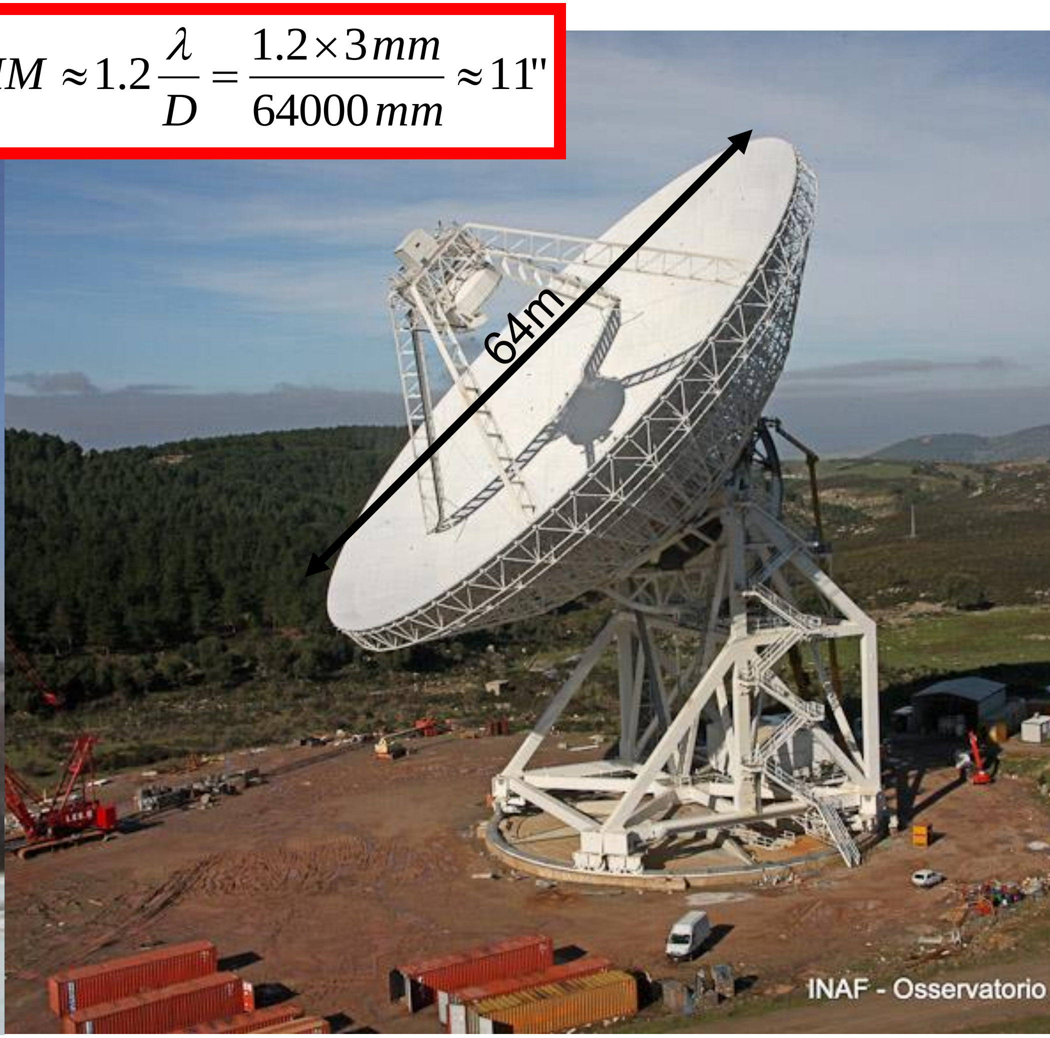
Hot gas
with
Cavities,
Shocks ...

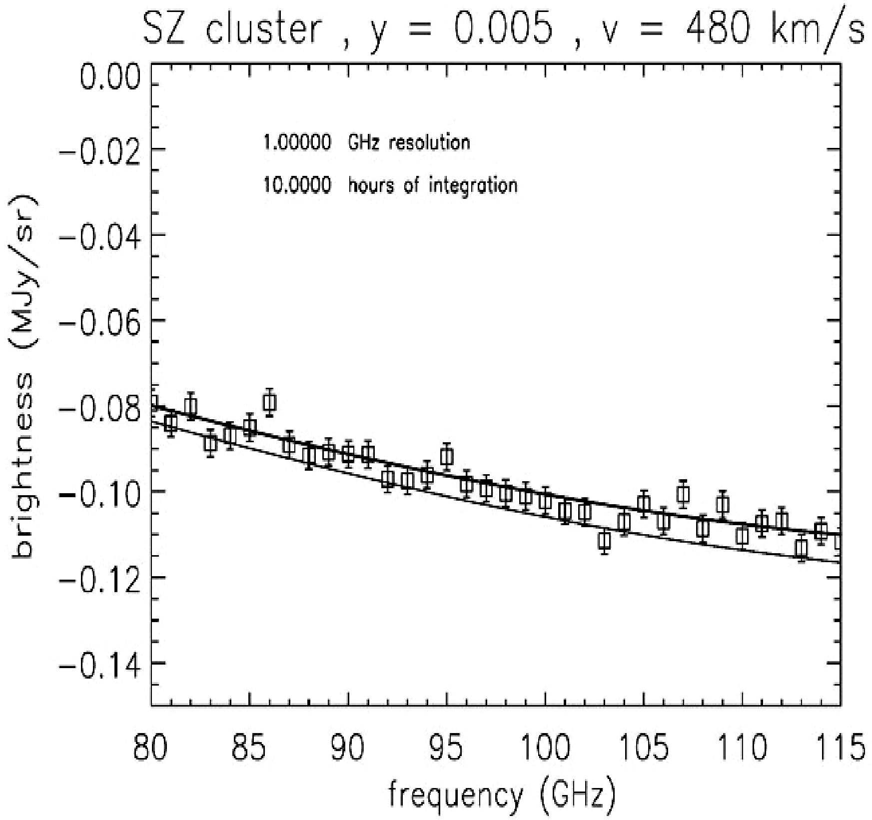
XXXL telescopes & SZ

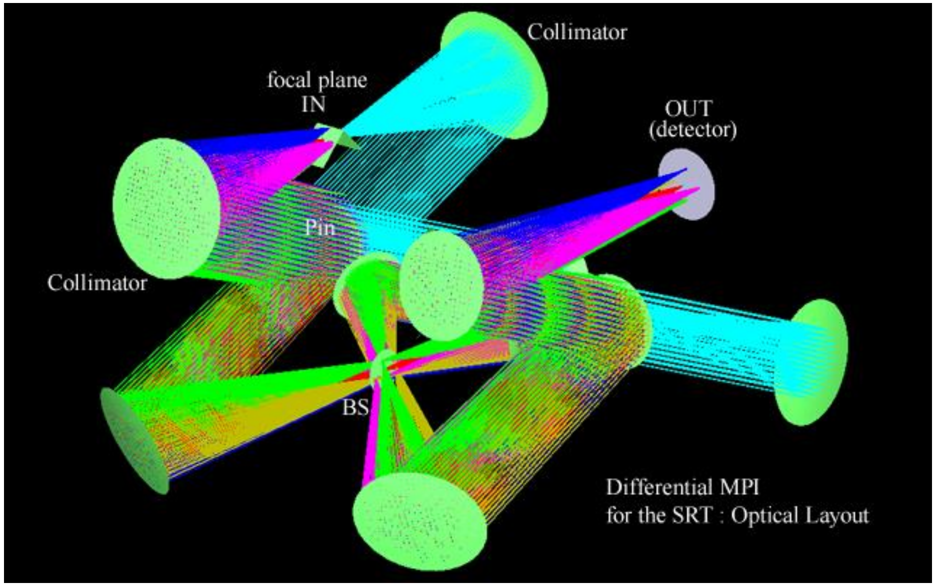
- Very useful to study the internal structure of clusters (shocks, cavities, cooling flows …)
- The 100 m Green Bank Telescope (USA) has a W-band array (Mustang)
- We have the 64m Sardinia Radio Telescope, and we are considering to install a DFTS for the W-band at the focus.

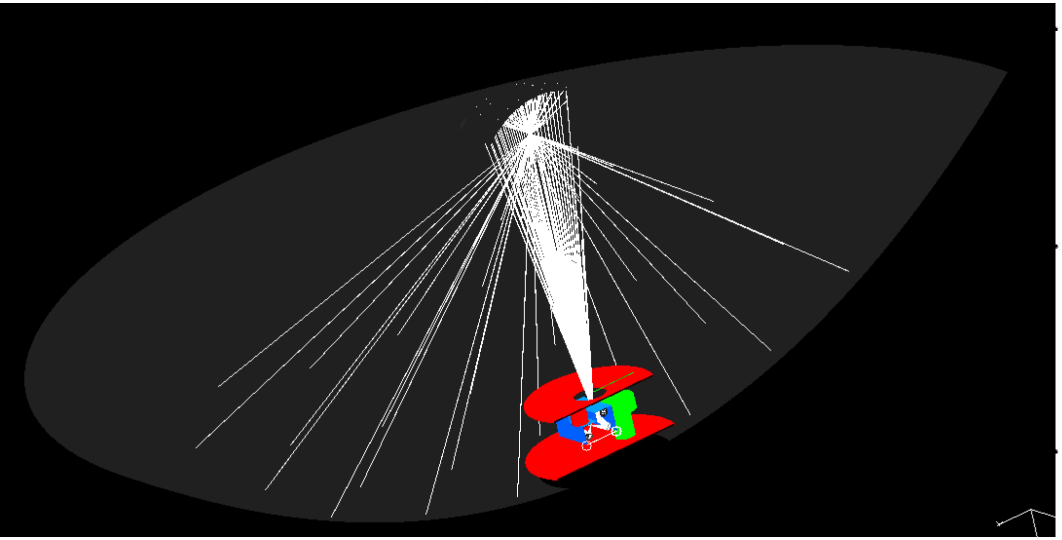
$$FWHM \approx 1.2\frac{\lambda}{D} = \frac{1.2\times 3\,mm}{64000\,mm} \approx 11''$$

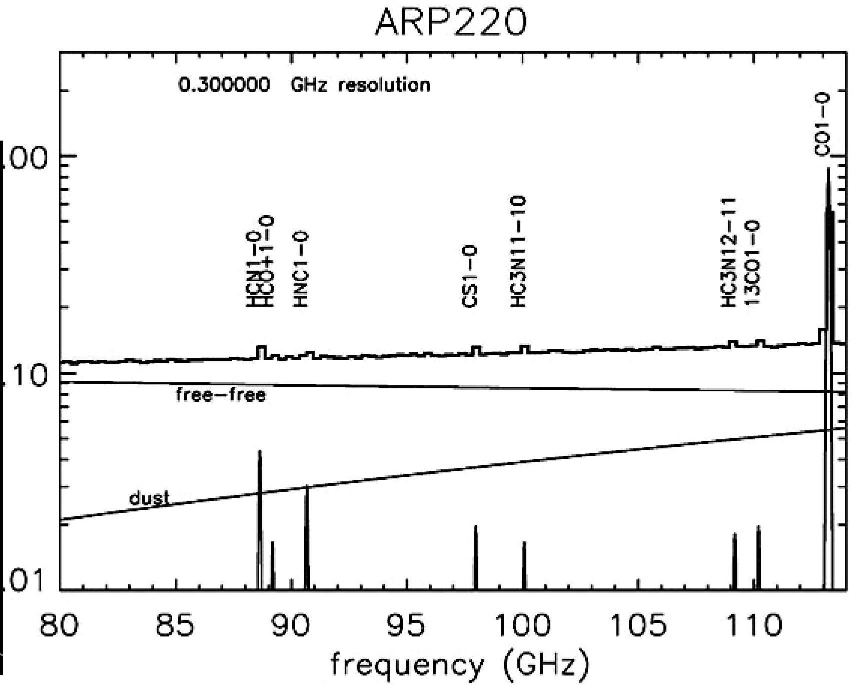





SZ cluster , y = 0.005 , v = 480 km/s
1.00000 GHz resolution
10.0000 hours of integration
brightness (MJy/sr)
0.00
−0.02
−0.04
−0.06
−0.08
−0.10
−0.12
−0.14
80
85
90
95
100
105
110
115
frequency (GHz)


Collimator
focal plane
IN
OUT
(detector)
Pin
Collimator
BS
Differential MPI
for the SRT : Optical Layout




ARP220
0.300000 GHz resolution
.00
.10
.01
HCN1−0
HCO+1−0
HNC1−0
CS1−0
HC3N11−10
HC3N12−11
13CO1−0
CO1−0
free−free
dust
80
85
90
95
100
105
110
frequency (GHz)

Conclusions

- Measurements of the SZ are effective and unique to study:
  - Directly ionized matter in the Universe
  - Indirectly: H_o, Ω_Λ ….
- OLIMPO will be the first instrument to host a DFTS.
  - ASI is working to provide us with a first flight in June 2016
  - We expect to map spectrally 40 clusters in a single long duration flight
  - The sensitivity will be enough to separate reliably the parameters of the cluster (y, τ_t, τ_{NT}, T, v_{pec}) and the foregrounds.
  - Will validate the method in view of Millimetron / SRT
- A DFTS on Millimetron would produce an incredibly rich dataset.
- A DFTS on SRT (W-band) would allow to investigate cluster substructures & lots of additional science (e.g. CO in galaxies in the redshift desert etc …)
- Balloon campaigns from Svalbard: a unique opportunity for a strong European program supporting a range of scientific applications.