In–flight performance of the LEKIDs of the OLIMPO experiment

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for the OLIMPO detector team

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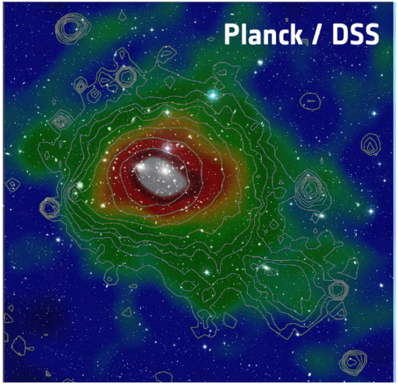
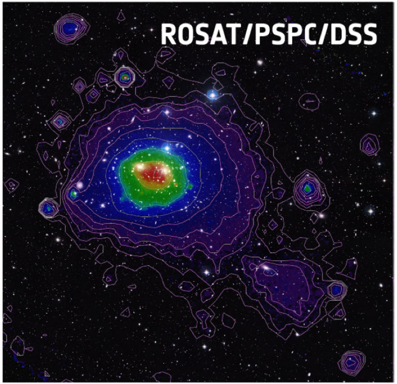
Galaxy Clusters

- Galaxy Clusters are the largest gravitationally bound structures in the Universe, which can be observed across the entire electromagnetic spectrum.
- The strength of observing them at mm wavelengths lies in the possibility to study the low density parts, their periphery, and the filaments of ionized matter connecting clusters.



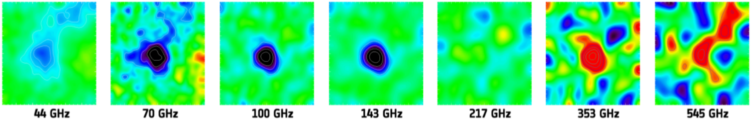


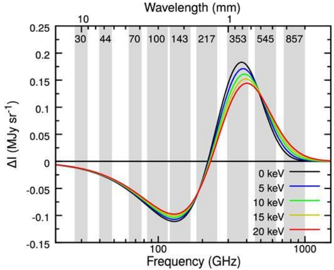
The Coma cluster. Image credits:
LFI & HFI Consortia (Planck image);
MPI (ROSAT image);
DSS2 (visible image)

Sunyaev–Zel'dovich effect

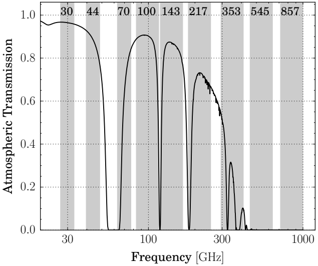
- The way to study galaxy clusters at mm wavelengths is through the Sunyaev–Zel'dovich (SZ) effect of the CMB photons.
- CMB photons crossing the hot gas of clusters of galaxies, acquire energy from charged scatterers (via inverse Compton), and their spectrum is perturbed with a very distinct spectral signature.

A2319 seen by Planck





J. Erler et al. 2018, MNRAS



The am atmospheric model

- A spectral measurement of CMB anisotropy can vastly improve the accuracy, allowing efficient, unbiased separation of the CMB and SZ components from all other components in the same LOS (at least 8 independent points);
- It can be done only from space or the stratosphere due to atmospheric opacity and noise.

OLIMPO (Osservatorio nel Lontano Infrarosso Montato su Pallone Orientabile)

- The OLIMPO experiment is a first attempt at spectroscopic measurements of CMB anisotropy.
- OLIMPO uses the CMB as a backlight to study the largest structures in the Universe.
- OLIMPO is a large balloon-borne observatory
  - with a 2.6 m aperture telescope;
  - with 4 horn-coupled LEKID arrays, centered at 150, 250, 350 and 460 GHz, matching the negative, zero, and positive regions of the SZ spectrum,
  - cooled to 0.3 K by a ^{3}He refrigerator in a wet LN_2+L^4He cryostat;
  - with a plug–in room–temperature differential Fourier transform spectrometer (DFTS);
  - with a custom attitude control system (ACS), which allow to point the telescope in the direction of the selected galaxy clusters with arcmin accuracy.
- For more details see http://olimpo.roma1.infn.it

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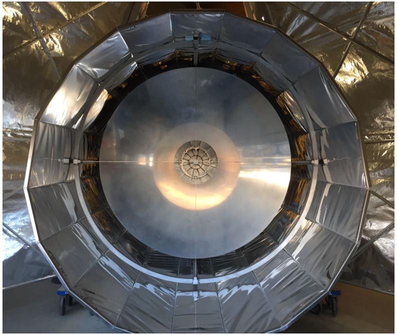

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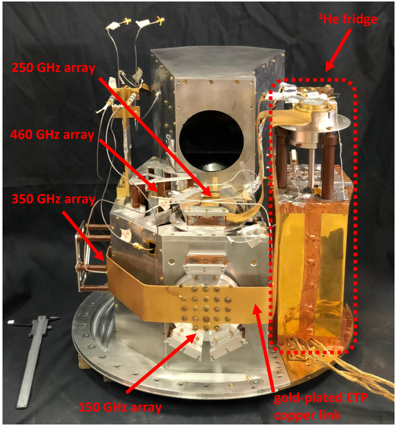

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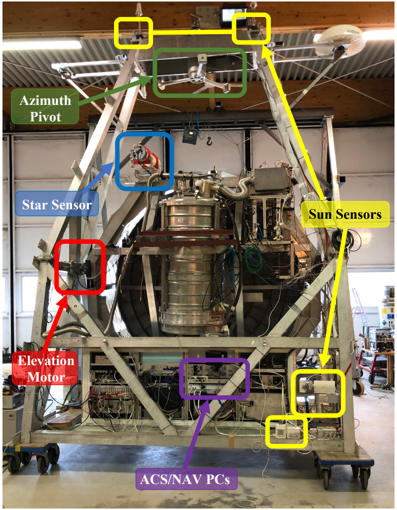
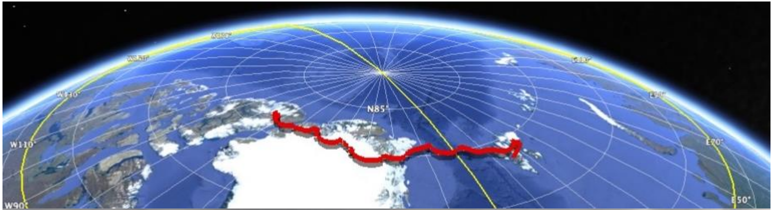


OLIMPO flight

- OLIMPO was launched from the Longyearbyen airport (78 °N), in Svalbard Islands, at 07:07 GMT on July 14th, 2018.
- In–flight analysis: measurements carried out in the first day of the flight, when the fast (500 kbps) bidirectional LOS telemetry was active.



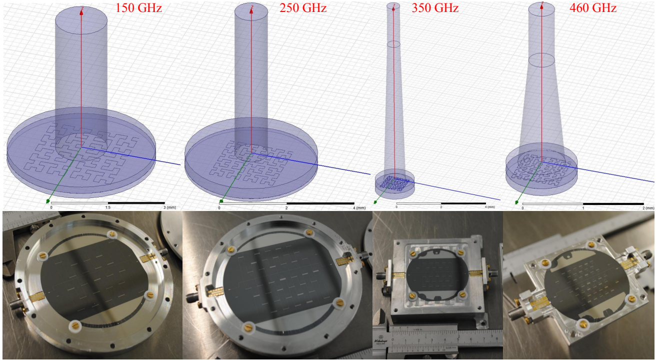
Fast Forward 4×

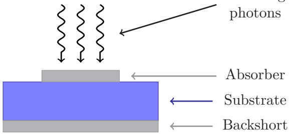
OLIMPO LEKIDs

- Absorber/Inductor: IV order Hilbert in Al 30 nm thick ($T_c = 1.31\,\mathrm{K}$, $R_\square = 1.21\,\Omega/\square$);
- Radiation coupling: front–illuminated via single–mode (flared) circular waveguide;
- Substrate, number of detectors & resonant frequencies:

Channel [GHz]	Si wafer $d['']\times t\,[\mu\mathrm{m}]$	#	ν_r [MHz]

- Electrical coupling: via capacitors to a $50\,\Omega$–matched microstrip feedline and to the ground, and such that $Q_c \sim 15\,000$.
- More details in *A. Paiella et al., JCAP 2019*.





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250	3×100	$37+2$	[150; 335]
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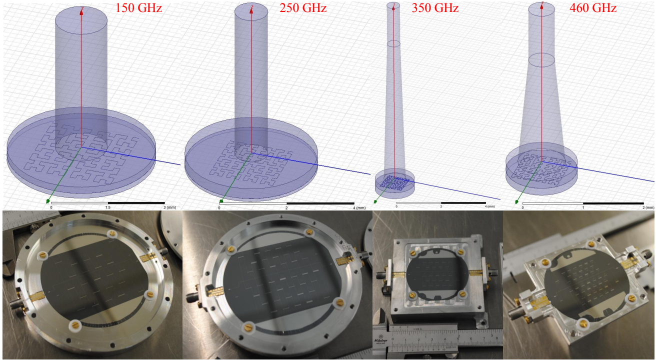

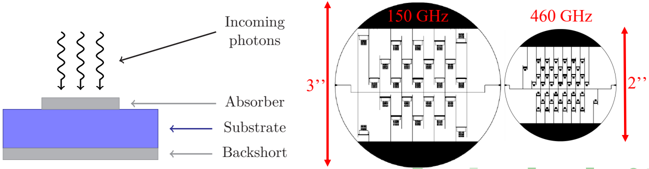

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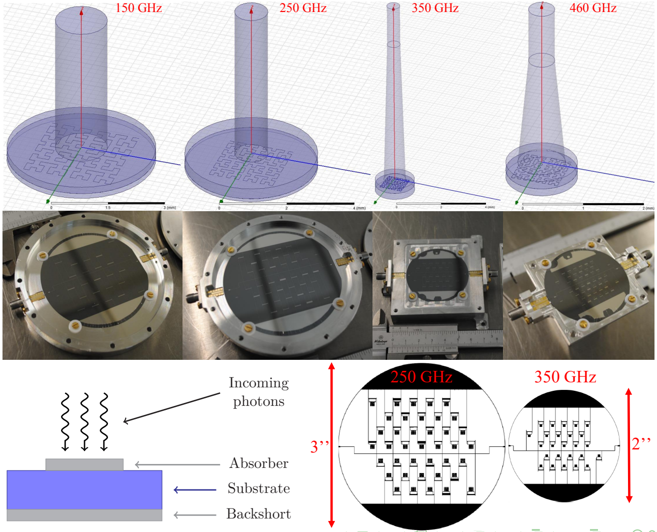

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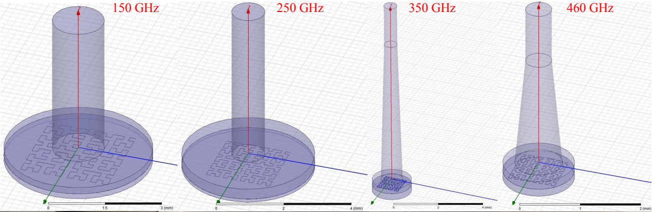
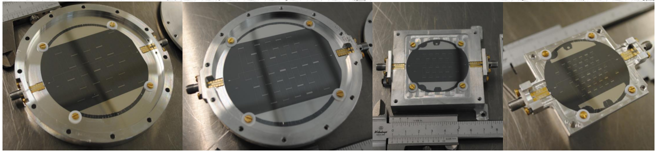
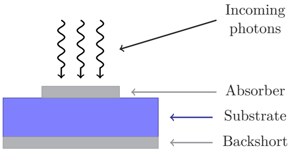
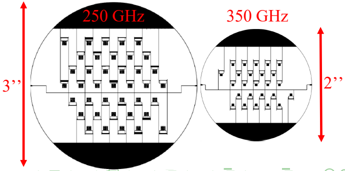
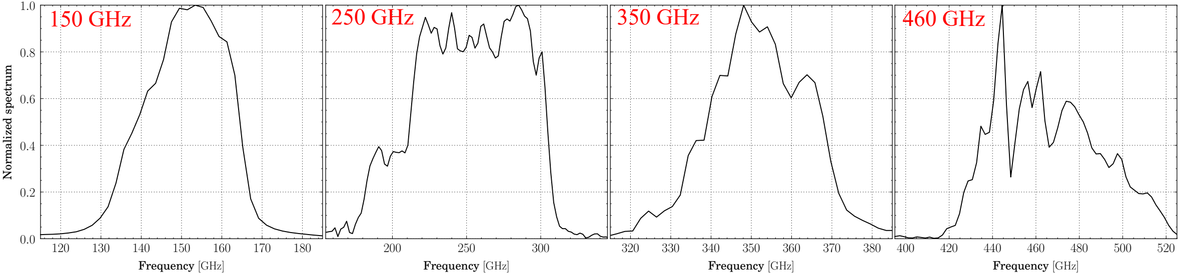






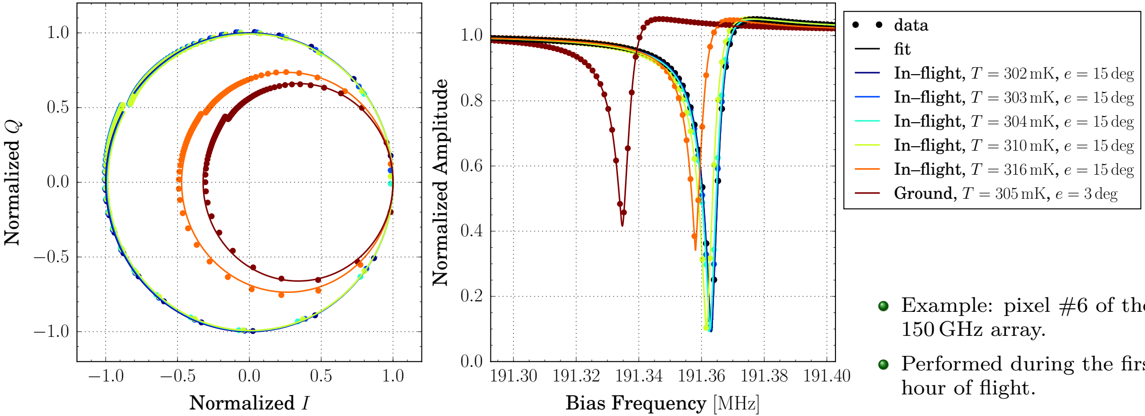


Ground Performance (*A. Paiella et al., JCAP 2019*)



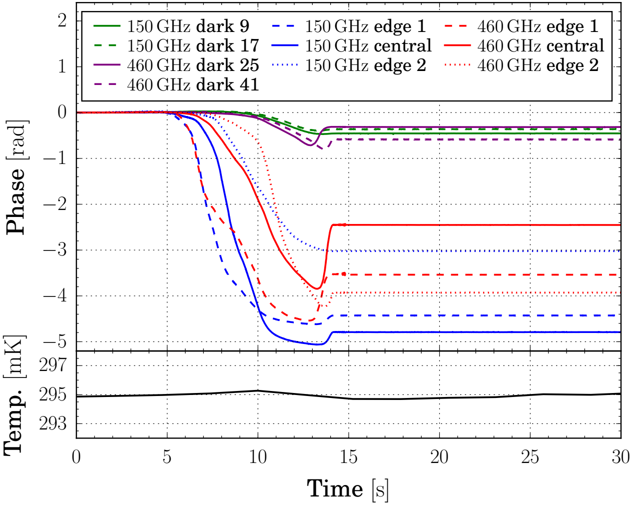
Channel [GHz]	Active Pixels	FWHM [GHz]	$\mathcal{R}_{el}$ [rad/pW]	$\mathcal{R}_{op}$ [rad/pW]	$\varepsilon = \mathcal{R}_{op}/\mathcal{R}_{el}$ %	NEP $\left[\mathrm{aW}/\sqrt{\mathrm{Hz}}\right]$	$\mathrm{NET_{RJ}}$ $\left[\mu\mathrm{K}\sqrt{\mathrm{s}}\right]$
150	16 + 4 (87%)	25	1.4 ± 0.1	0.24 ± 0.04	$> 18 \pm 3$	178 ± 27	182 ± 27
250	32 + 2 (87%)	90	1.8 ± 0.4	0.16 ± 0.01	$> 9 \pm 2$	879 ± 132	250 ± 38
350	21 + 2 (92%)	30	2.8 ± 0.1	0.29 ± 0.03	$> 10 \pm 1$	289 ± 43	247 ± 37
460	41 + 2 (100%)	60	4.2 ± 0.2	0.16 ± 0.04	$> 4 \pm 1$	771 ± 116	329 ± 49

Tuning (*S. Masi et al., JCAP 2019*)



- Example: pixel #6 of the 150 GHz array.
- Performed during the first hour of flight.

Background and Temperature variations (*S. Masi et al., JCAP 2019*)



- $6\,\mathrm{s} < t < 10\,\mathrm{s}$ insertion of the (room–T) DFTS
  - through a moving relay mirror, which introduces the DFTS optical system in the optical path between the telescope and the cryostat.
  - All the optically active pixels react to the radiative background change, which gradually illuminates the entire array.
  - The dark pixels do not respond.
- $t \sim 9\,\mathrm{s}$ all the dark pixels react and their response is coherent and smaller: thermal.
  - We estimated the temperature variation of the arrays: 7 mK for the 150 and 250 GHz arrays, 10 mK for the 350 GHz array and 14 mK for the 460 GHz array.
- $t > 14\,\mathrm{s}$ all detectors outputs remain stable after the insertion of the relay mirror is completed.

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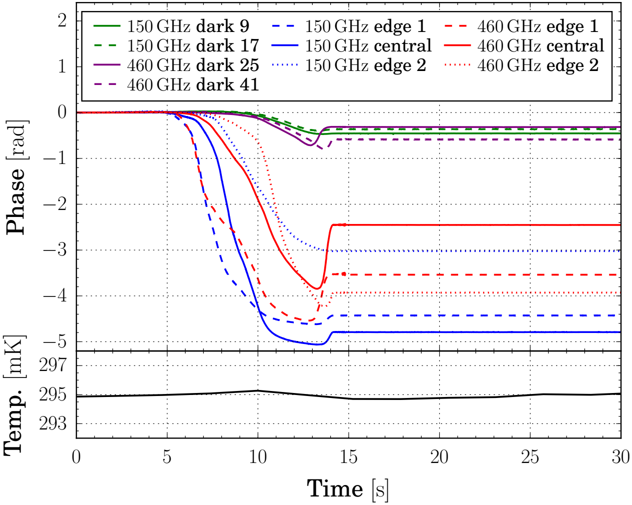

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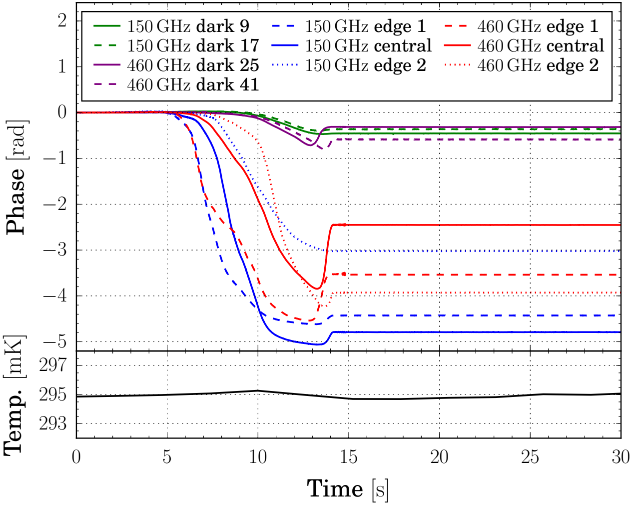

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  - We estimated the temperature variation of the arrays: 7 mK for the 150 and 250 GHz arrays, 10 mK for the 350 GHz array and 14 mK for the 460 GHz array.
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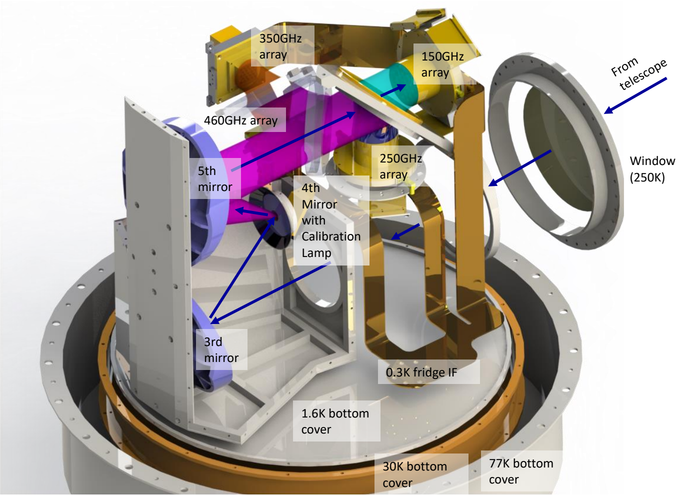
Calibration Lamp

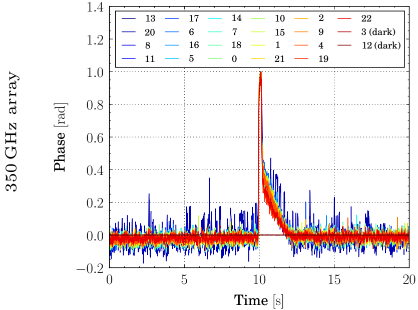


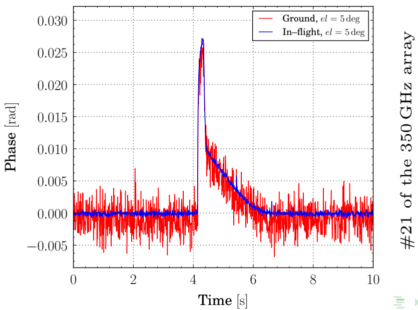
- The calibration lamp is composed of
  - a resistor heating, from 1.6 K to 25 K,
  - an absorbing surface (emissivity 28%),
  - in an integrating cavity coupled to a Winston cone (efficiency 50%).
- It is placed at the center of the Lyot stop of the OLIMPO Offner reimaging system and has an aperture which fills the 5% of the Lyot stop area.
- Its emission illuminates with an approximately parallel beam all the detectors, with a maximum variation of a factor 2 of the illumination level across each focal plane surface.
- As a result, its 25 K blackbody emission is diluted by a factor of the order of ∼150 to ∼300 depending on the position of the pixels in the focal plane.

Calibration Lamp (*S. Masi et al., JCAP 2019*)

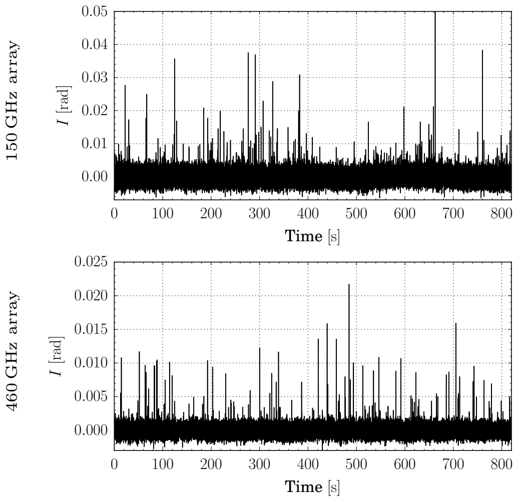
- We used the calibration lamp to estimate the in–flight performance.
- We normalized the ground and in–flight calibration lamp signals to the same value, transferring all the information in the noise.
- We obtained in–flight performance very close to be photon–noise limited for all the arrays.

Channel [GHz]	N_g/N_f	photon–noise $\mathrm{NET_{RJ}}$ $\left[\mu\mathrm{K}\sqrt{\mathrm{s}}\right]$	$\mathrm{NET_{RJ}}$ $\left[\mu\mathrm{K}\sqrt{\mathrm{s}}\right]$
150	2	70	91 ± 18
250	8	30	31 ± 6
350	3.5	80	71 ± 14
460	4.5	90	73 ± 15





Cosmic Ray data contamination (*S. Masi et al., JCAP 2019*)



- 820 s–long timestream, 100 000 samples (stable telescope boresight);
- 150 GHz array: $\tau \sim 17$ ms, presence of thermal effects.
- 460 GHz array (representative for the 250 and 350 GHz arrays): $\tau < 8$ ms and amplitudes consistent with the expected ones.
- Count fit: Gaussian noise+dN/dS

$$\frac{dN}{dS} = 2\pi A_o \frac{dN}{dA d\Omega} \frac{(kx)^2}{S^3}$$

Channel [GHz]	Fraction of contaminated data
150	$< 2.7\%$
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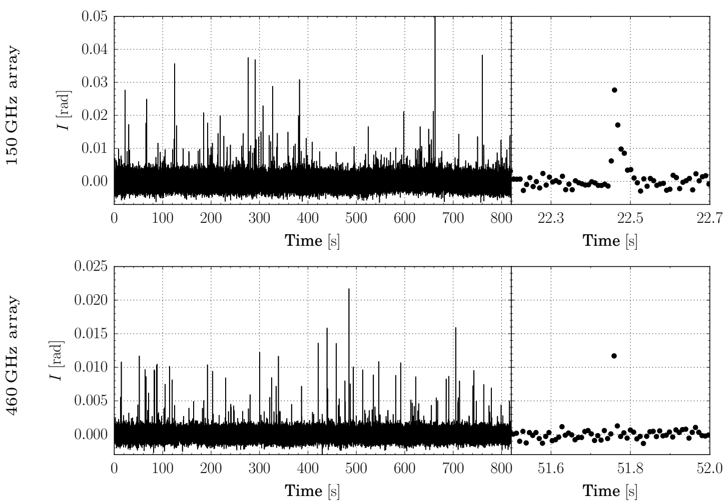

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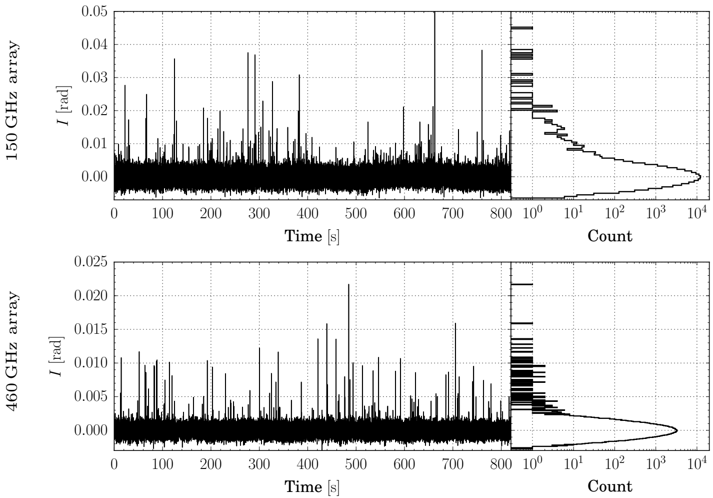

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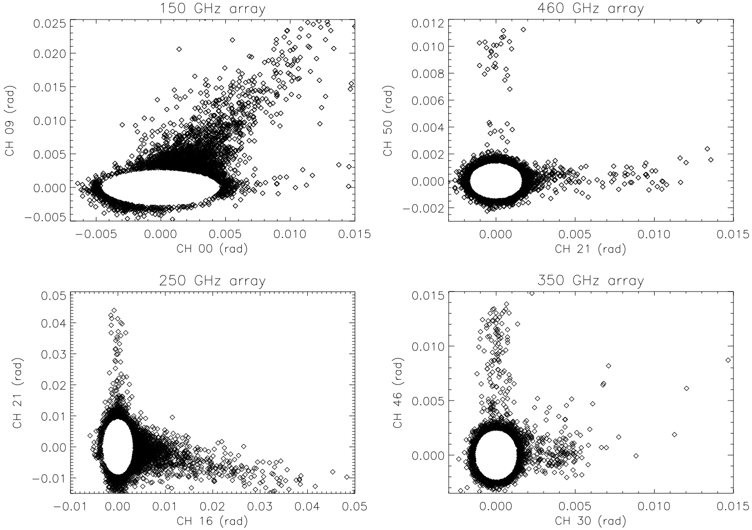

- Dark pixel vs. centre pixel scatter plots;
- data with $r > \sqrt{\sigma_x^2 + \sigma_y^2}$, where σ_x and σ_y are the standard deviations of the despiked signals.
- 150 GHz array: correlation of the spikes, even if the considered pixels are separated by a physical distance of 35 mm.
- 250, 350 and 460 GHz arrays: the L–shaped clouds demonstrate that CR events producing spikes in one of the two pixels do not produce spikes in the other one.
- Our strategies to thermalize the arrays and damp the propagation of phonons was much less effective for the 150 GHz array.

Conclusions

- OLIMPO operated 4 arrays of horn–coupled Al LEKIDs in the stratosphere, which is a representative near–space environment:
  - OLIMPO LEKID arrays showed in–flight performance very close to be photon–noise–limited under the low radiative background of the stratosphere.
  - The cosmic ray background experienced by OLIMPO is representative of the primary cosmic ray background in low–Earth orbit.
- We are analyzing the scientific data.
- OLIMPO was recovered and all the subsystems were checked: the gondola, the cryostat plumbing and the ACS are damaged.
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