A 350GHz array of LEKIDs for balloon-borne CMB observations

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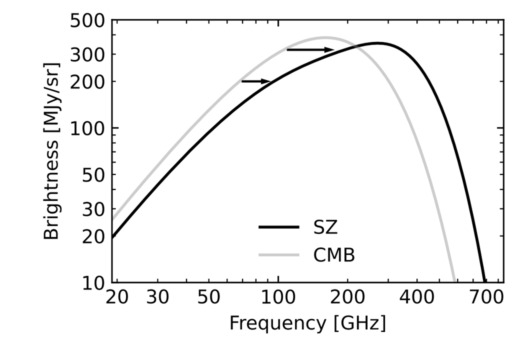
We present the design, optimization and laboratory characterization of an array of Lumped Element Kinetic Inductance Detectors sensitive in a frequency band centered at 350 GHz. The array consists of 313 feed-horn coupled pixels with resonant frequencies spread over 250 MHz. We present measured yield, quality factor, responsivity, quasiparticle lifetime, noise equivalent power and optical efficiency. The array is a prototype for one of the four frequency bands of OLIMPO, a balloon-borne instrument with a 2.6 m primary mirror proposed for an Antarctic flight to measure the Sunyaev-Zel'dovich effect in clusters of galaxies and their connecting filaments. Similar arrays could also be used with instruments studying the polarization of the cosmic microwave background radiation.

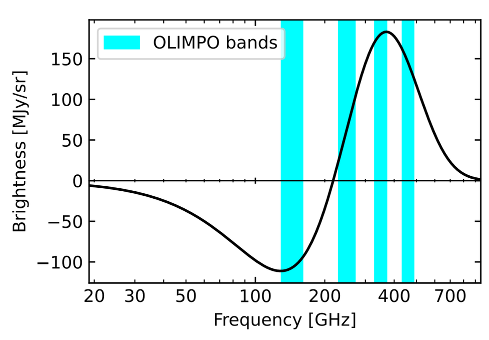
OLIMPO in a nutshell

OLIMPO is a balloon-borne telescope able to map clusters of galaxies with high sensitivity at 145, 250, 350 and 460 GHz. It was flown in 2018 from Svalbard Islands [1,2] and it is now proposed for a second flight from Antarctica.

Science case

OLIMPO will **probe the dynamics of large-scale structure** by directly measuring the kinetic energy of the intracluster medium (ICM) and will **unveil the properties of the warm/hot intergalactic medium (WHIM) baryons** by mapping the temperature, density and velocity profiles of galaxy clusters and cosmic filaments [3]. The ICM and WHIM are probed by OLIMPO in combination with the eROSITA and XMM-Newton X-ray satellites.





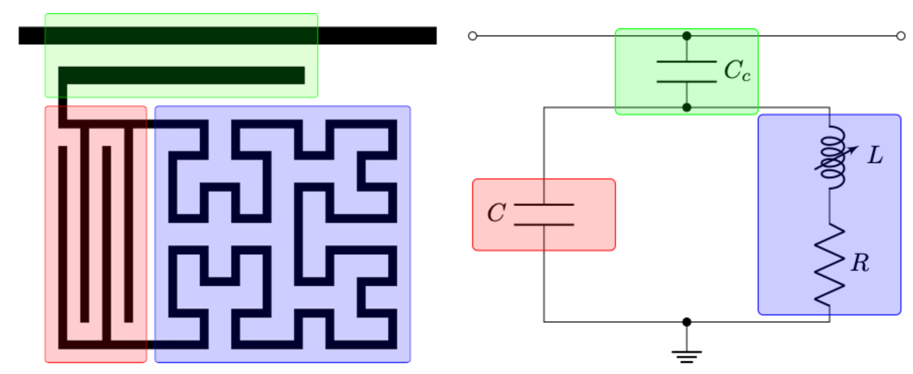
Instrument overview

OLIMPO is an $f/3$ Ritchey-Chretien telescope with a 2.6 m primary mirror and a field of view of 24′. It features **more than a thousand feedhorn-coupled KIDs** over four arrays, one for each spectral band, cooled below 300 mK by a wet cryostat with a He^3 refrigerator [4].

Band [GHz]	Number of detectors	FWHM [arcmin]
150	55	3.3
250	151	1.9
350	313	1.3
460	511	1.0

KIDs

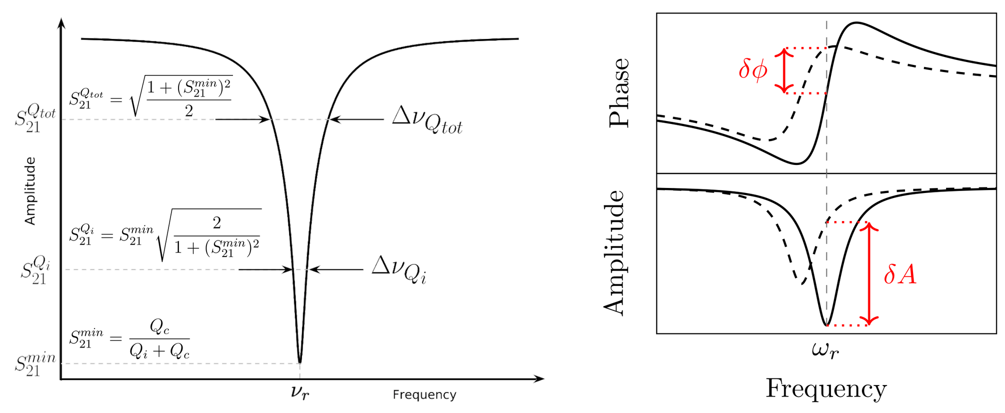
KIDs are high-Q factor superconducting resonators. Their resonant frequency ν_r depends on the kinetic inductance L_k of the superconducting film.



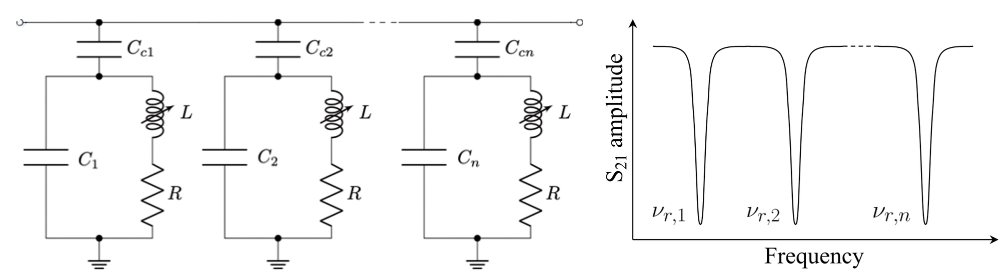
L_k changes if the KID is exposed to pair-breaking radiation leading to a measurable change in their ν_r.

$$S_{21}(\nu) = 1 - \frac{Q_{tot}/Q_c}{1 + 2iQ_{tot}\frac{\nu-\nu_r}{\nu_r}} \quad \text{and} \quad Q_{tot}^{-1} = Q_i^{-1} + Q_c^{-1}$$

Q_i is the **internal** Q-factor and Q_c is the **coupling** Q-factor.

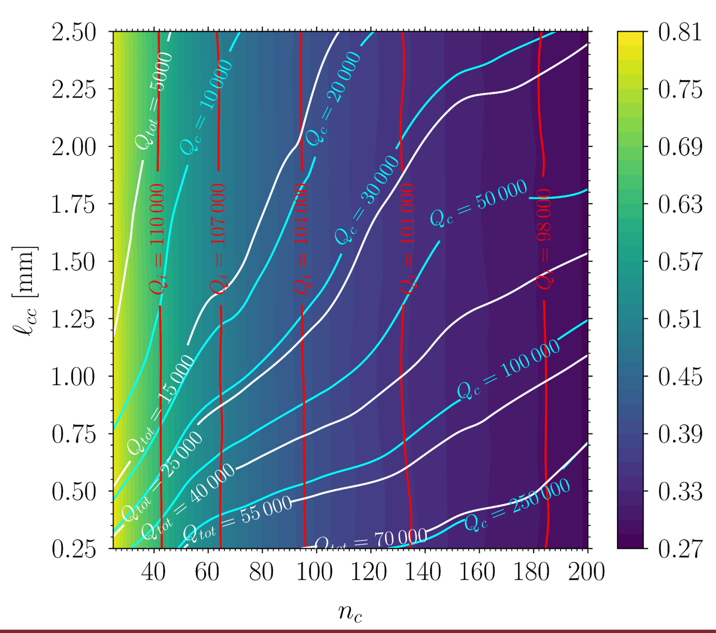


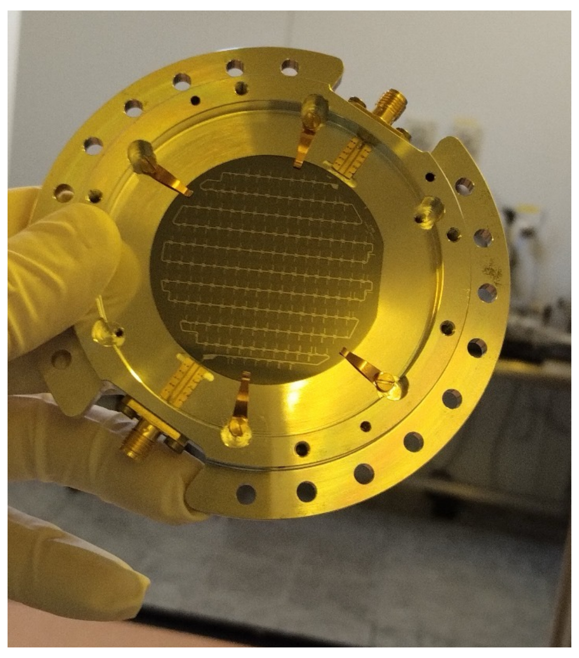
Intrinsic frequency domain multiplexing: feed and readout thousands KIDs with just two coaxial cables, meaning small thermal load for the cryogenic system and high sensitivity.

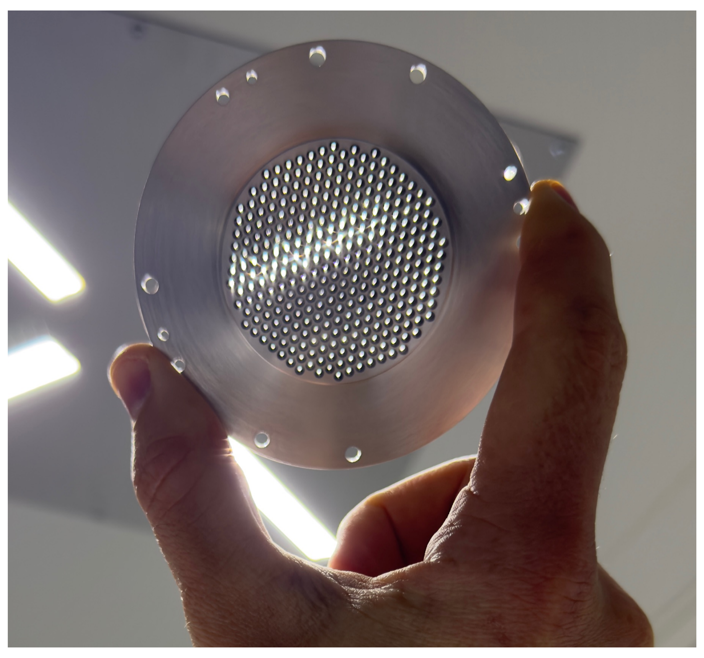


Focal plane design and optimization

The OLIMPO 350 GHz detector array is a 2" silicon wafer with 313 feedhorn-coupled microstrip line KIDs with a single feedline. The feedline and KIDs are made out of 30 nm thick aluminum with a critical temperature of ~ 1.3 K. The KIDs resonante between 350 and 600 MHz and their resonant frequency, along with their Q-factor, have been optimized through electromagnetic simulations (where ℓ_c is the length of the coupling capacitor and n_c is the numeber of fingers of the KID capacitor).

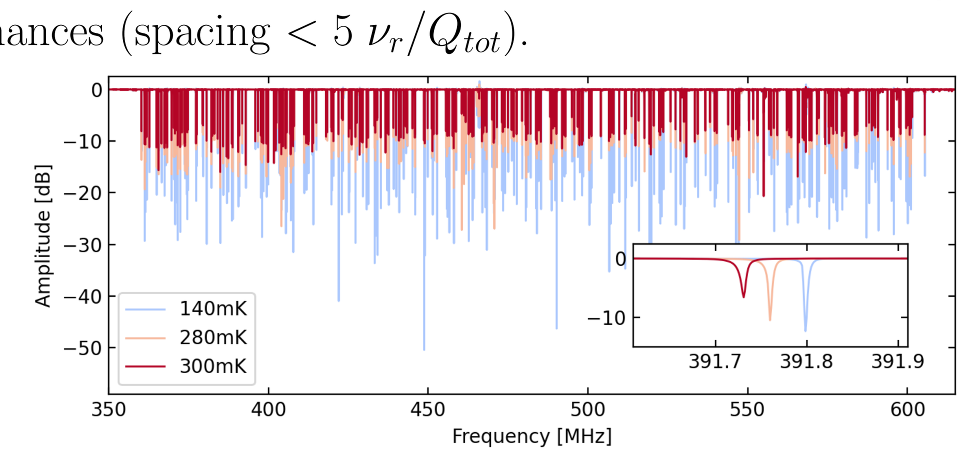




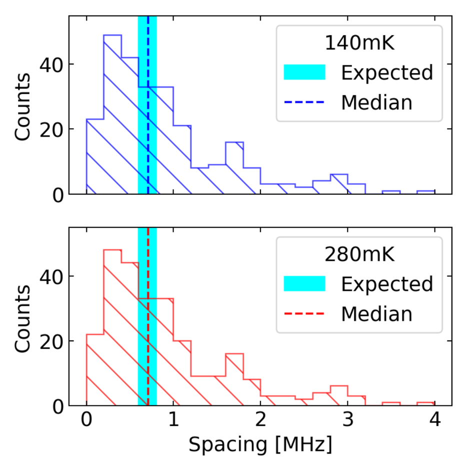


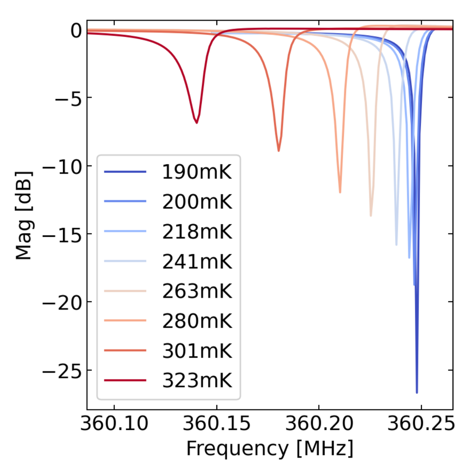
Detector Performance

Yield: 92% at 140 mK in 250 MHz of readout bandwidth lowered to 85% at 280 mK due to a 7% of overlapping resonances (spacing $< 5\,\nu_r/Q_{tot}$).



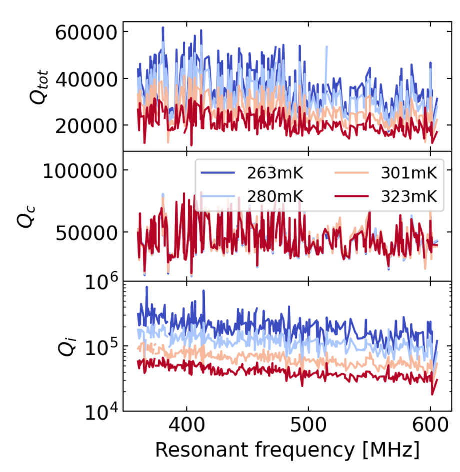
Median frequency spacing of 0.7 MHz in line with the expected value by design.

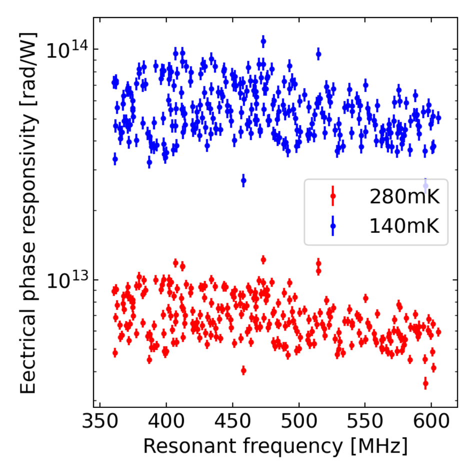




By fitting the S_{21} scattering parameter, we measured the Q-factors at different temperatures and the electrical responsivity, given by

$$\mathcal{R}_{\phi,elec} = -\frac{4Q_{tot}\tau_{qp}}{\Delta}\frac{\delta x}{\delta N_{qp}} \quad \text{where} \quad \delta x = \frac{\nu - \nu_r}{\nu_r}$$

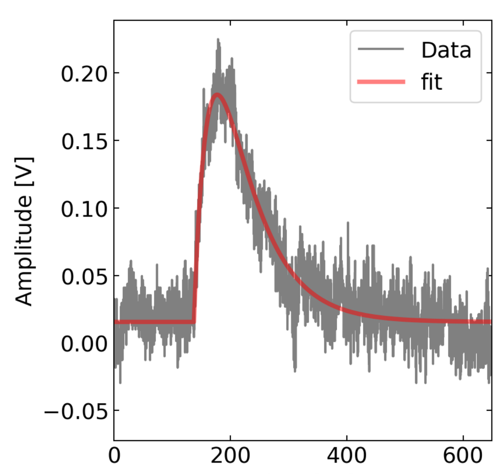


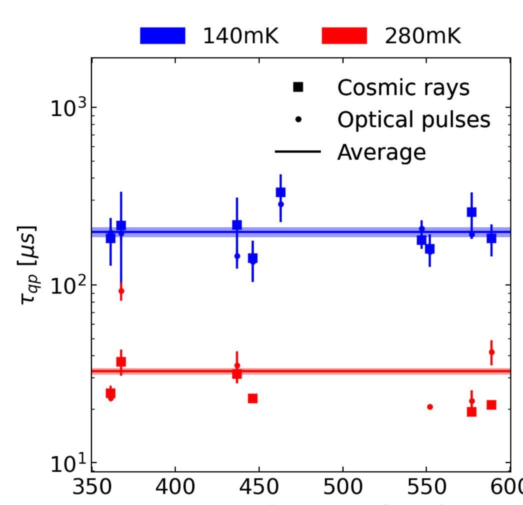


Cosmic rays and microsecond-long light pulses produce glitches in the KIDs time streams which are modeled by a finite impulse response (fir) function:

$$fir(t) = A(e^{-t/\tau_{qp}} - e^{-t/\tau_r})$$

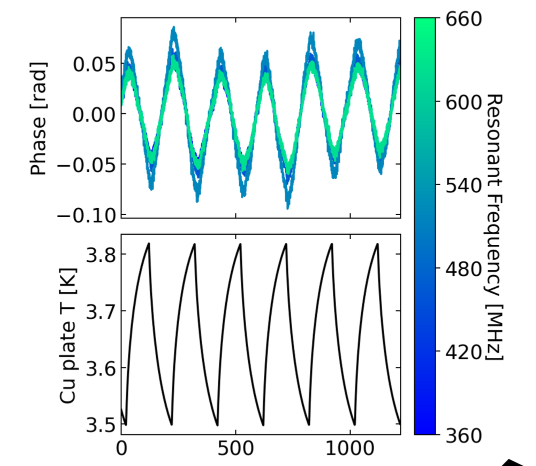
where τ_{qp} is the quasiparticle recombination time.

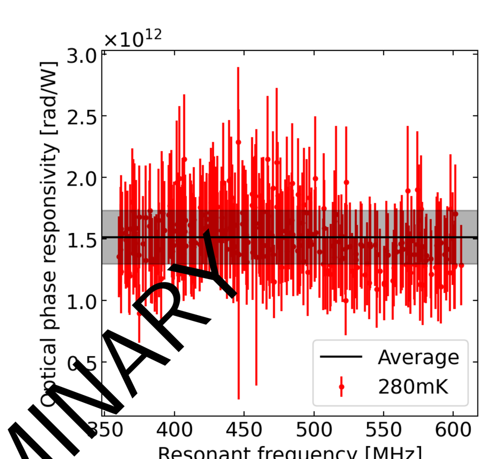


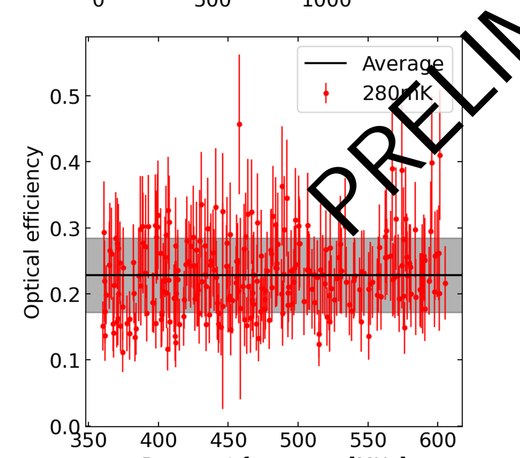


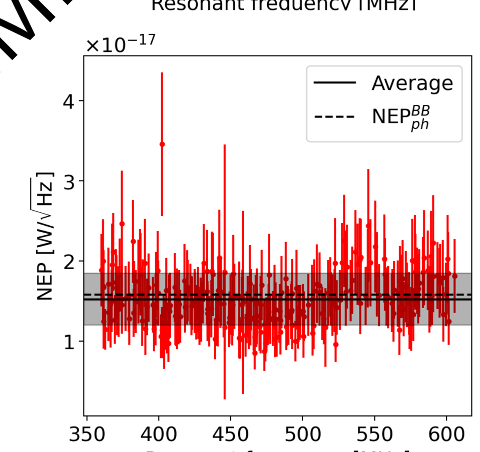
We found (198 ± 12) µs and (32.6 ± 1.4) µs as array-average values at 140 and 280 mK respectively.

Optical performance has been measured at 280 mK by using a 4 K blackbody [5]. The blackbody has been modulated at 5 mHz between 3.55 and 3.77 K, providing an optical signal of $\sim 6 \times 10^{-2}$ pW over a background of ~ 0.6 pW.









We estimated an array-average of $(1.51 \pm 0.22) \times 10^{12}$ rad/W for the optical responsivity and $23 \pm 6\%$ of optical efficiency. Estimated optical NEP, $(1.52 \pm 0.32) \times 10^{-17}\,\mathrm{W}/\sqrt{\mathrm{Hz}}$ on average, is consistent with the blackbody photon noise, $\mathrm{NEP}_{ph}^{BB} \sim 1.6 \times 10^{-17}\,\mathrm{W}/\sqrt{\mathrm{Hz}}$.

References

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