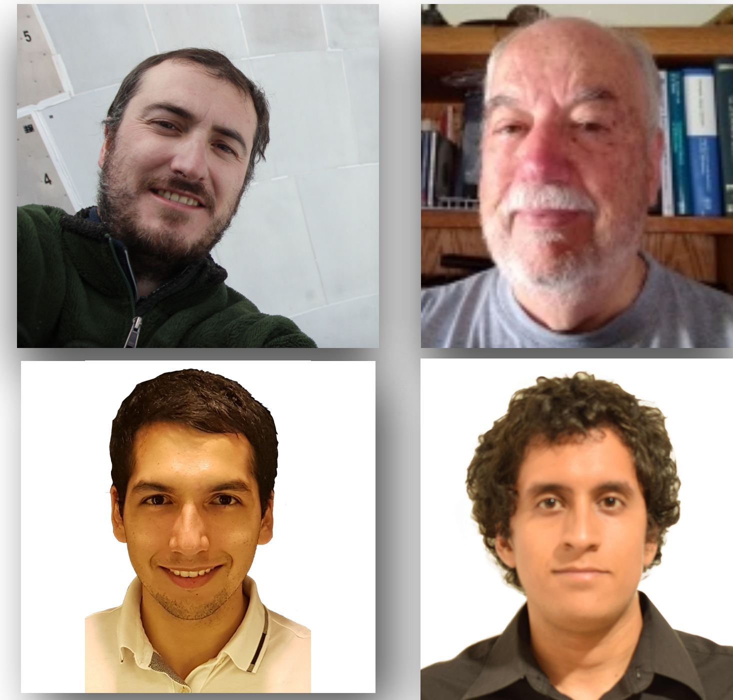


Drone-based polarization calibration source for mm-wave telescopes

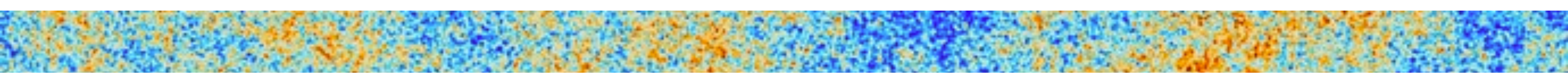
For measurements of the Cosmic Microwave Background

Rolando Dünner, Juan Fluxá, Sergio Best, Felipe Carrero

Instituto de Astrofísica and Centro de Astro-Ingeniería, Facultad de Física,

Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, 7820436, Macul, Santiago, Chile,

rdunner@astro.puc.cl

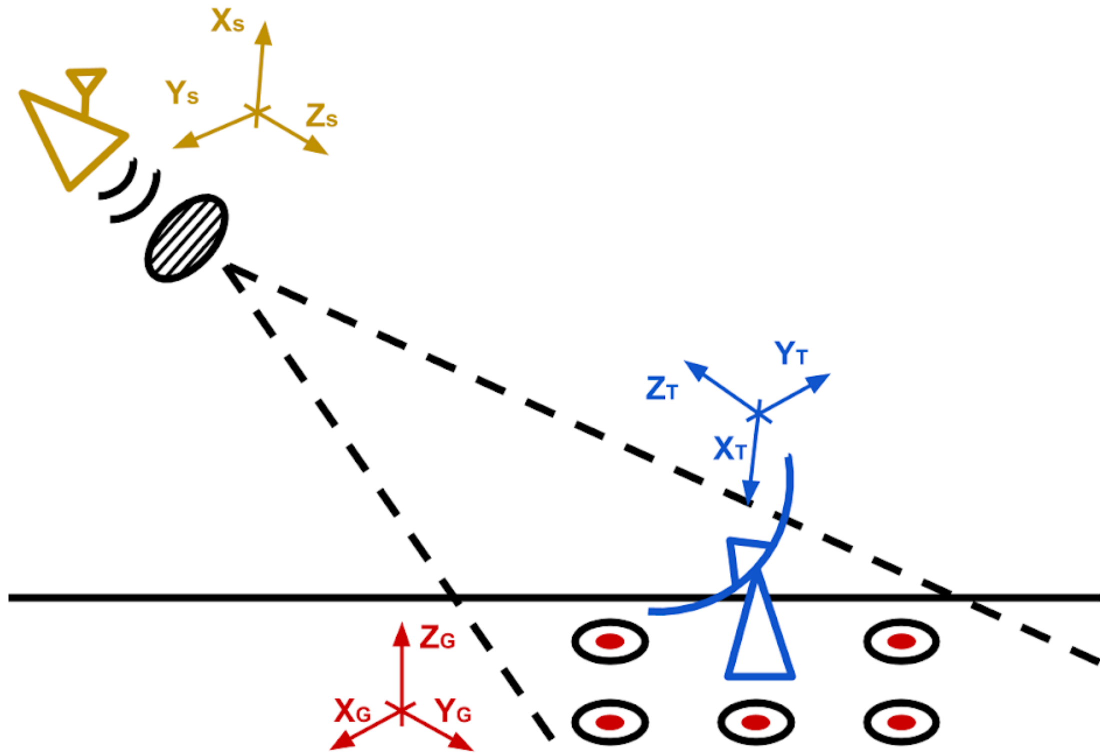


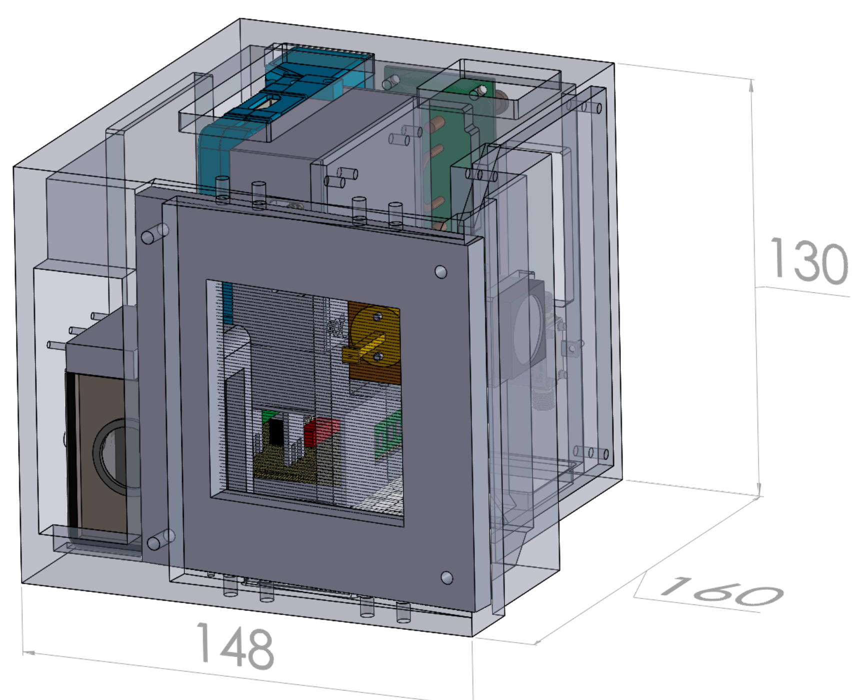
CMB systematics and calibration focus workshop

December 2020

Summary slide

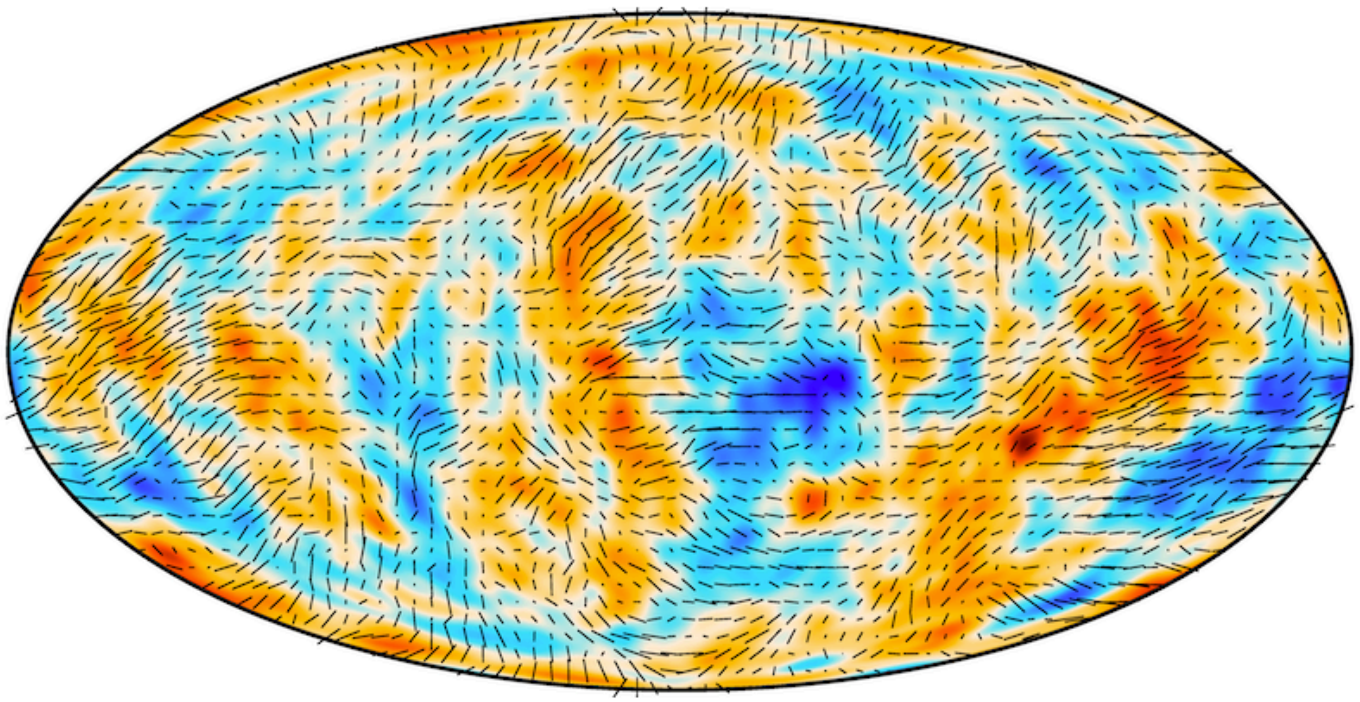
- We propose a drone-based mm-wave calibration source for ground based CMB experiments, such as CLASS and Simons Observatory.
- Our main goal is to determine the absolute polarization angle of the telescopes to better than 0.2 degrees.
- The main challenge is to determine the position and angle of the drone in time while flying with high accuracy, georeferenced to the ground coordinate system.
- Our approach is to use photogrammetry to measure this position in time and relate it to the source polarization angle.
- The same source will help characterized beam shape, sidelobes, passbands and the polarization frequency dependence of the detectors.



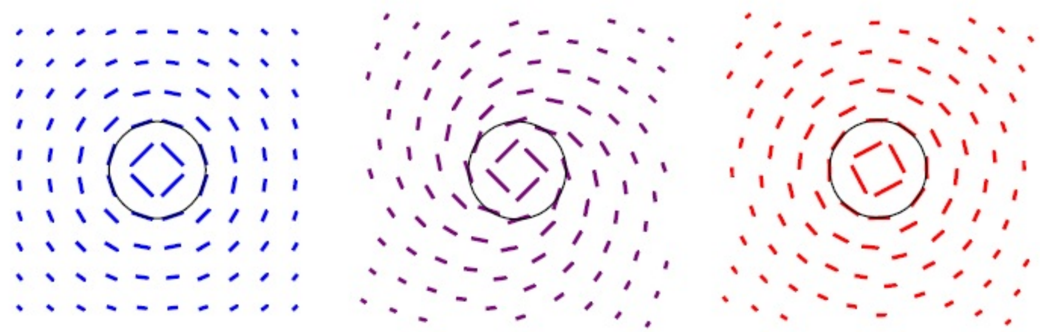


Motivation

Absolute polarization angle calibration



Sky map of CMB polarization measured by the Planck satellite (2018).

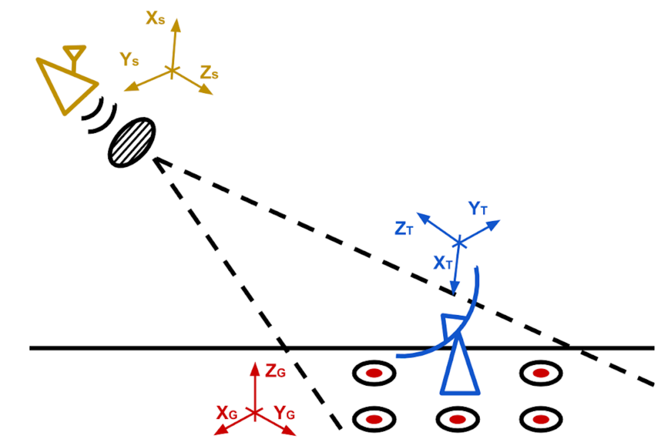


Polarization maps illustrating the rotation of photon polarization.
Credit: Liang Dai. ©2014 American Physical Society

- Standard models predict null TB and EB power spectra.
- These correlations may provide hints for non-standard physics or may be due to instrumental systematics.
- To detect new physics we need to calibrate the absolute polarization angle of CMB telescopes to better than 0.2 degrees.
- The lack of well suited natural calibrators justifies the development of artificial alternatives.
- Our proposal is to develop a UAV-based calibration source.

Photogrammetric position reconstruction

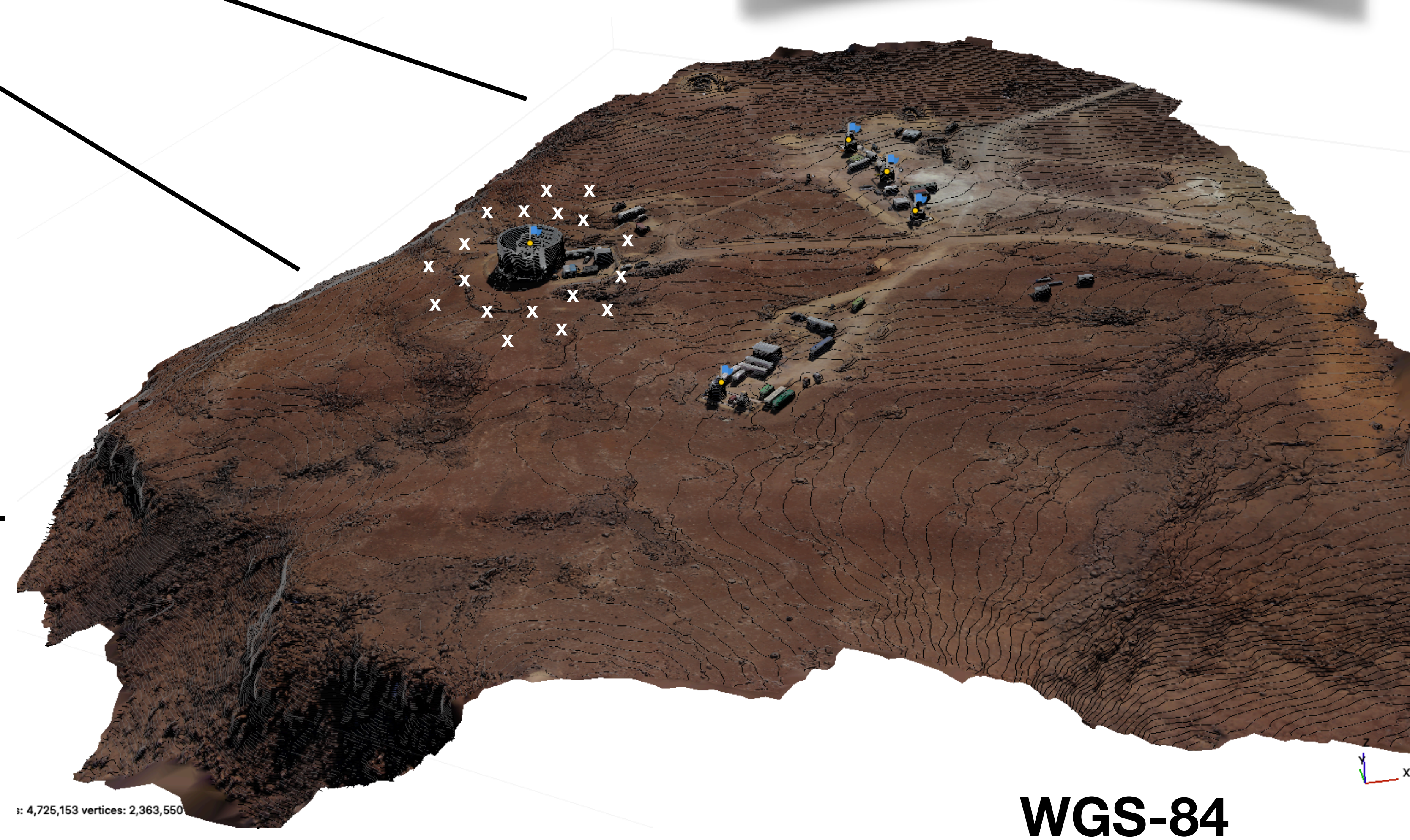
High precision in-time metrology



Determine camera coordinates and angles: (x,y,z,θ,ϕ,ψ)

Build a reference coordinate system

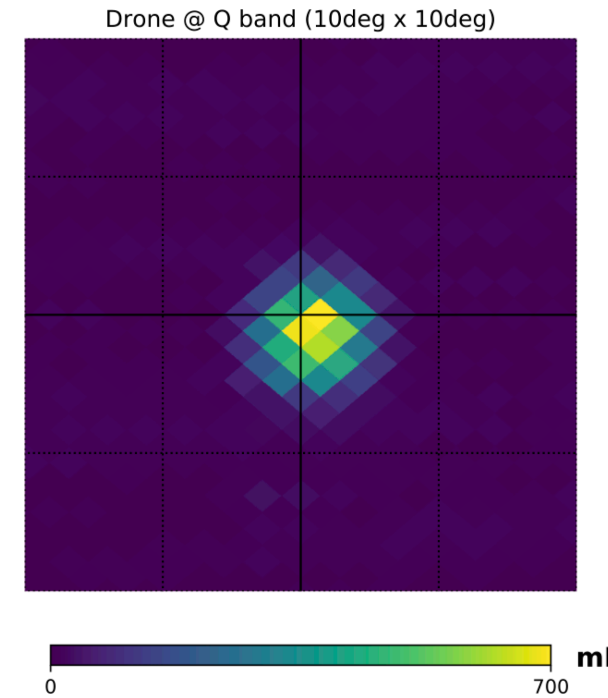
- We plan to use photogrammetry to measure the time varying position of the source with high accuracy.
- The camera position and angle can be precisely reconstructed from fiducial marks on the ground.
- The polarization angle of the source will be referenced to the angle of the camera.
- The source and camera will be held on a rigid frame, and their relative angles will be calibrated in the laboratory.



WGS-84

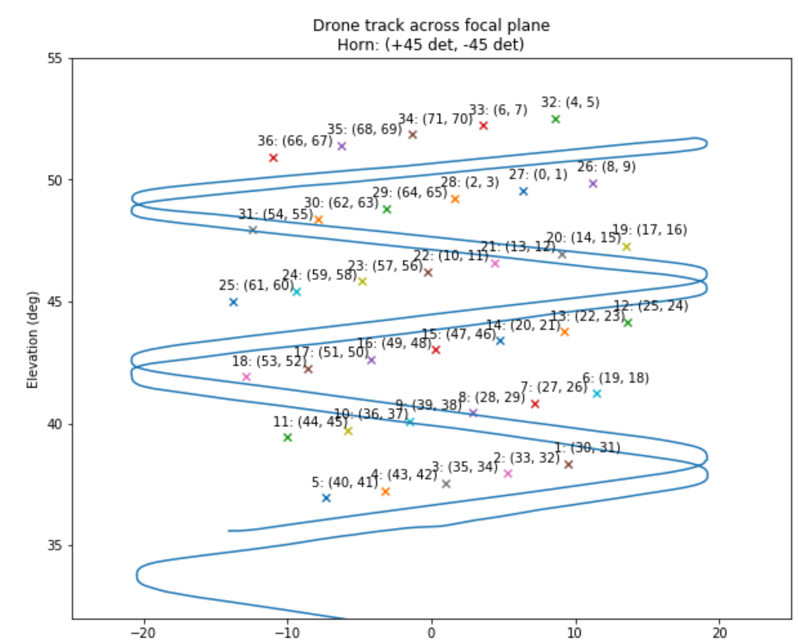
Preliminary Tests

We demonstrated that it is physically possible



Reconstructed temperature map of the drone's body as seen by CLASS Q-band, when flying at 300 m from the telescope.

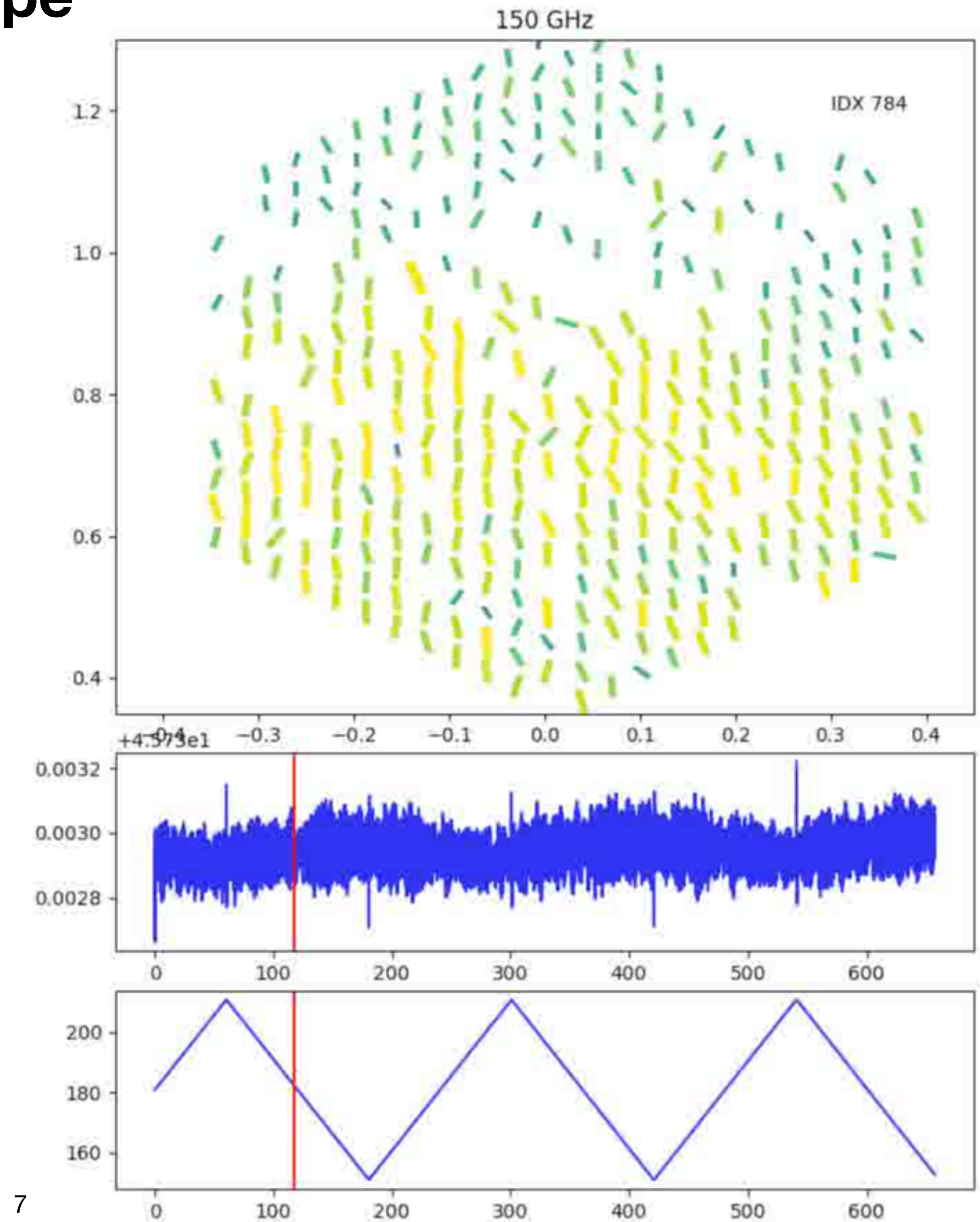
- A DJI Matrice 600 pro with high altitude blades can lift up to a 4 kg payload at the Cerro Toco site, located at 5200 m.
- The software limit for commercial drones sets a maximum flight height of 500 m above the ground.
- The emission of the drone is crudely modeled as a blackbody of temperature 290 K and cross section 24 cm.
- Preliminary flights using a 145 GHz coherent source and a mechanical chopper allowed us to detect polarized signals from the ACT far sidelobes.



Polarized sidelobe signal

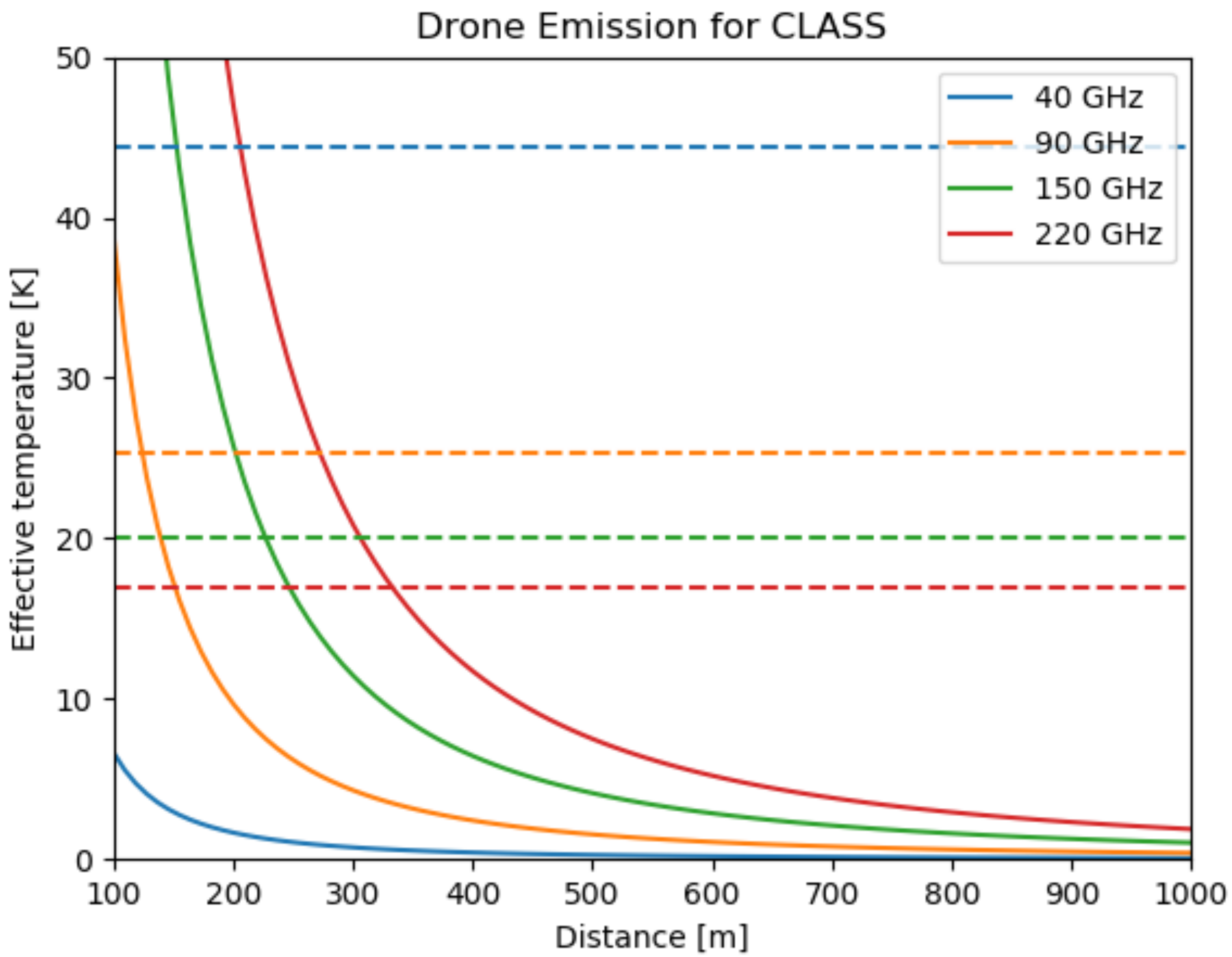
Atacama Cosmology Telescope

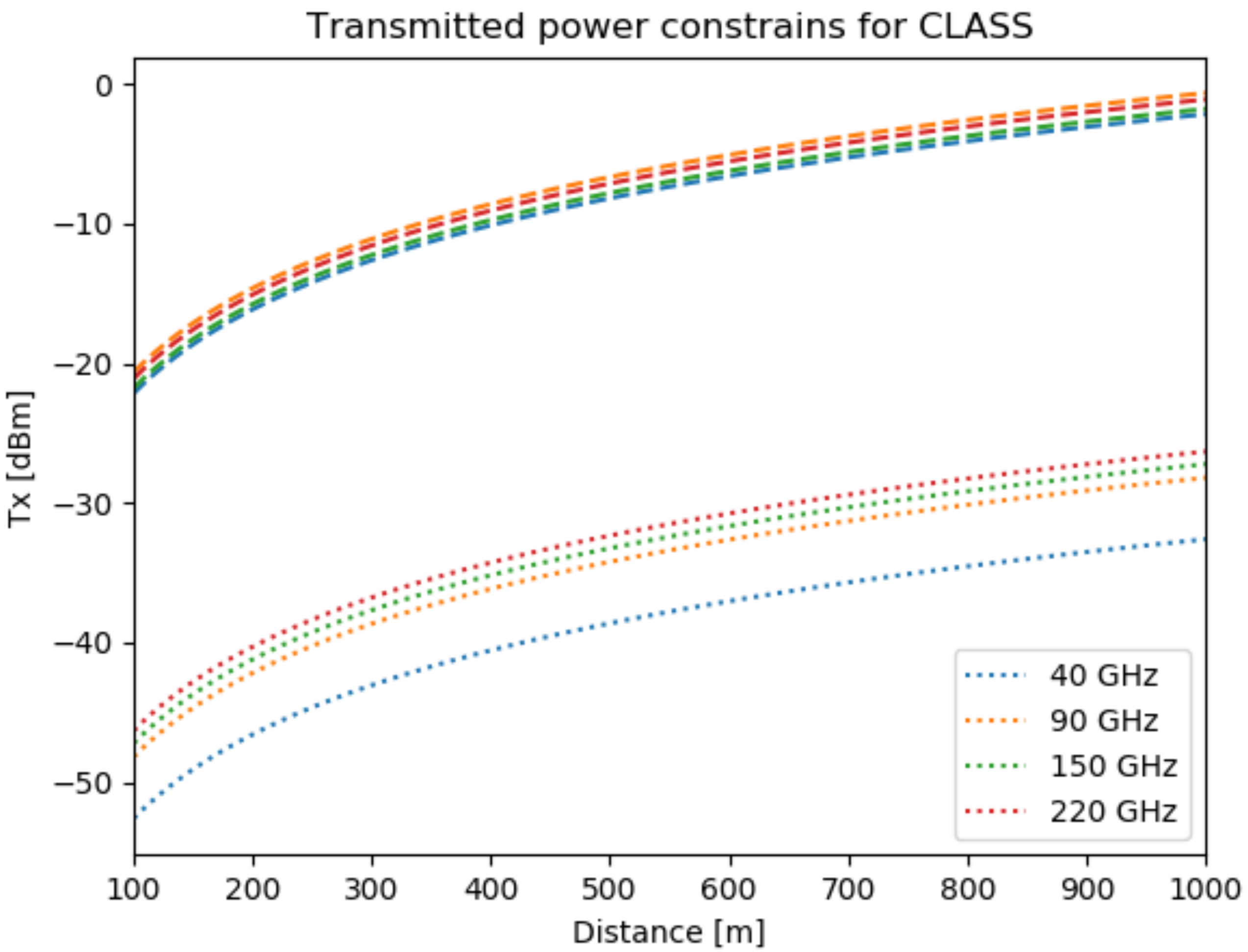
- Sidelobe signal in AR6, at 150 GHz.
- Scanning with drone 10 deg below the boresight
- Can see a coherent polarization across the array
- The signal strength is not very homogeneous across the array, being stronger on the lower half.



Thermal loading and power constrains

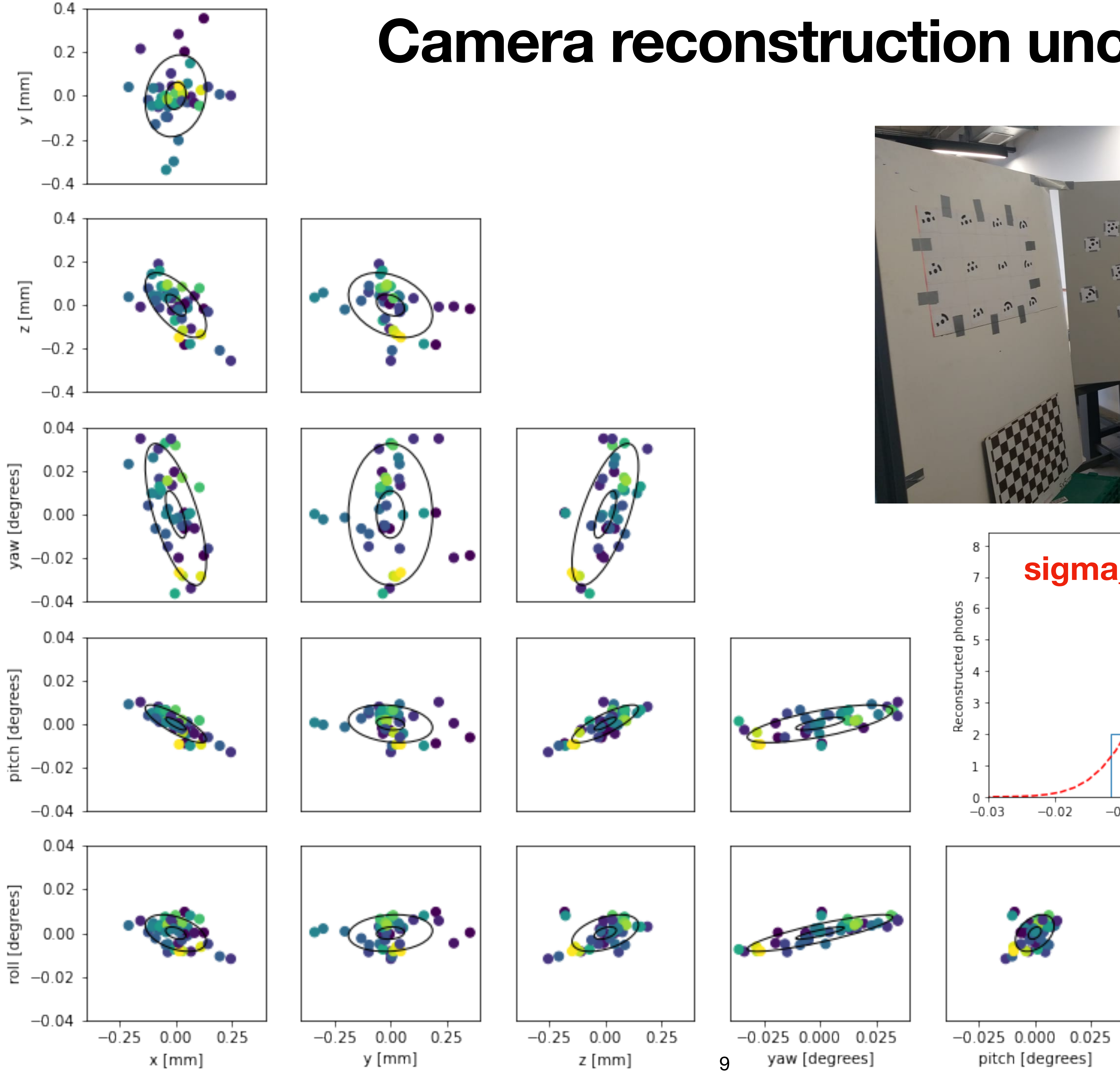
Using CLASS as reference

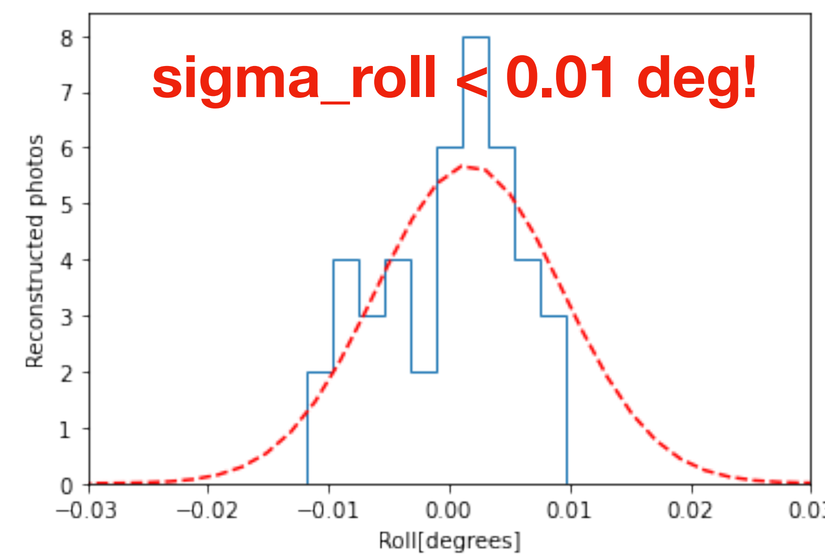




- The diluted temperature of the drone sets a limit to the minimum distance, which is more stringent at higher frequency bands. We will consider 500 meters to be our nominal distance.
- For direct beam measurements, we estimate that a forward transmitted power of -25 dBm will suffice all distances and frequency bands.

Camera reconstruction uncertainties

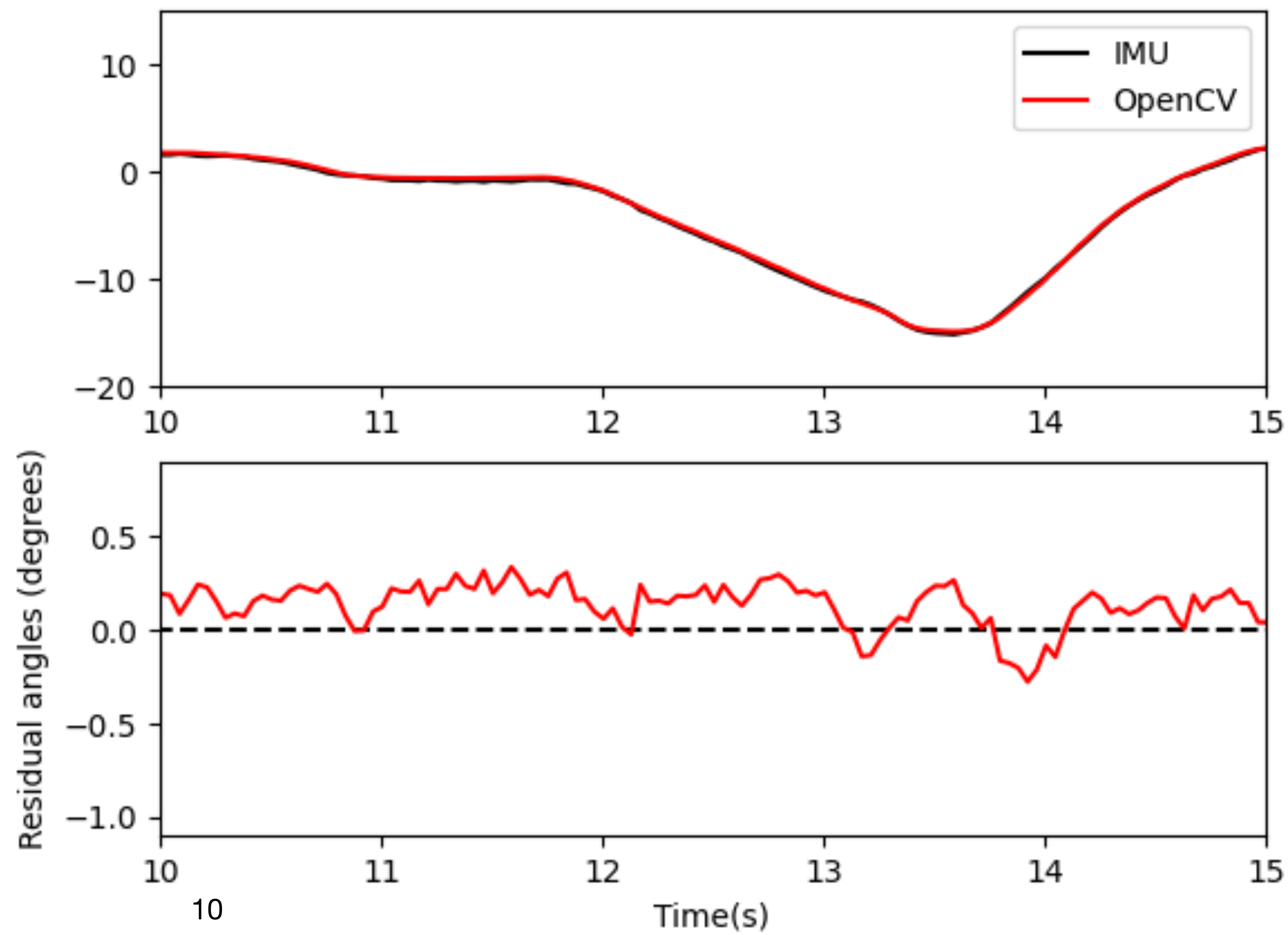




Photogrammetry from the air

Compared to differential RTK GPS

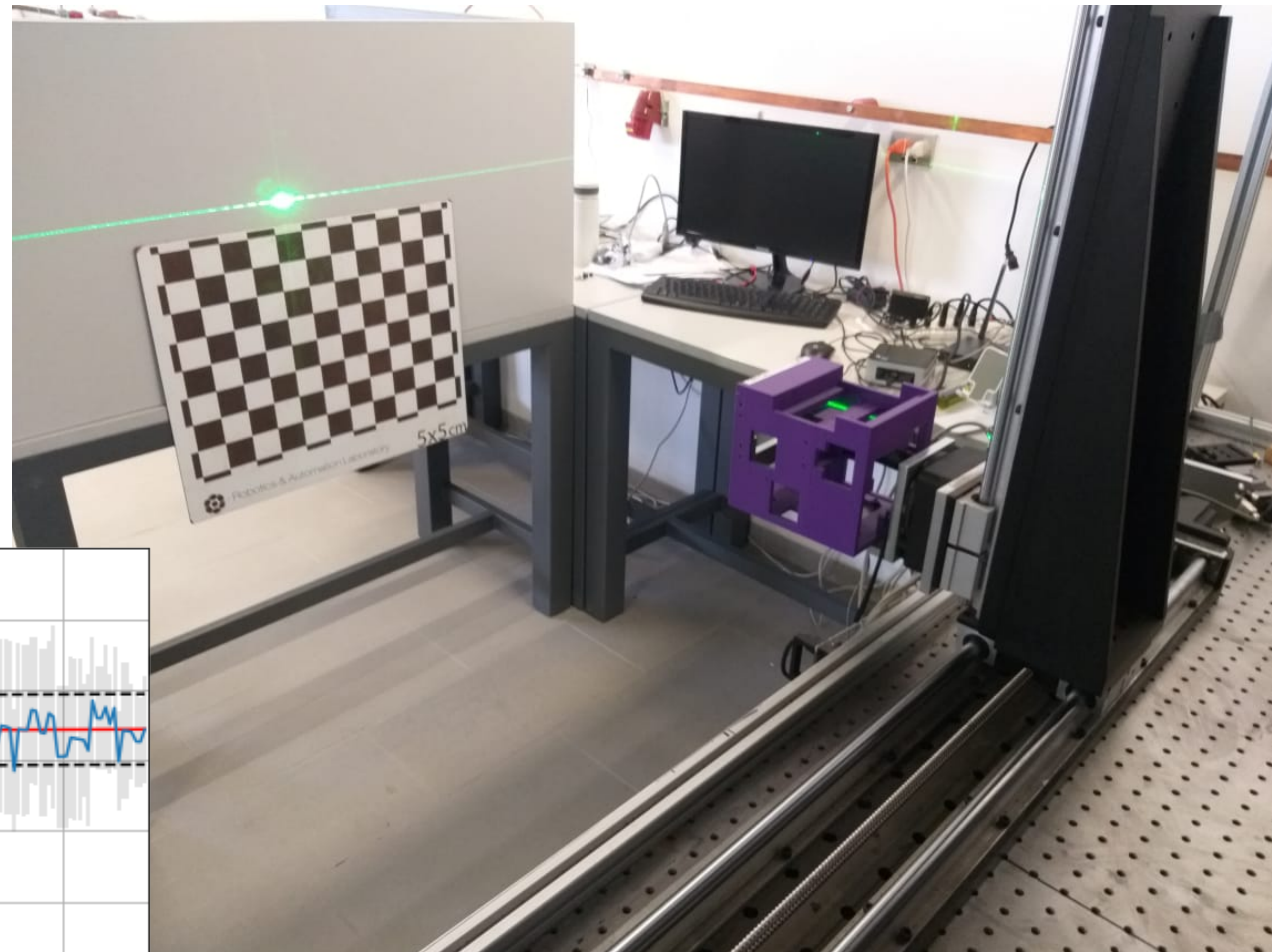
- Performed more realistic tests with the camera directly attached to the drone's body.
- The camera pointed down to coded targets on the ground.
- The photogrammetry reconstruction was made out of 4K video recording.
- There is a clear agreement between the RTK GPS positions and the photogrammetrical reconstruction.
- The reported errors in roll angle are probably dominated by GPS uncertainties.

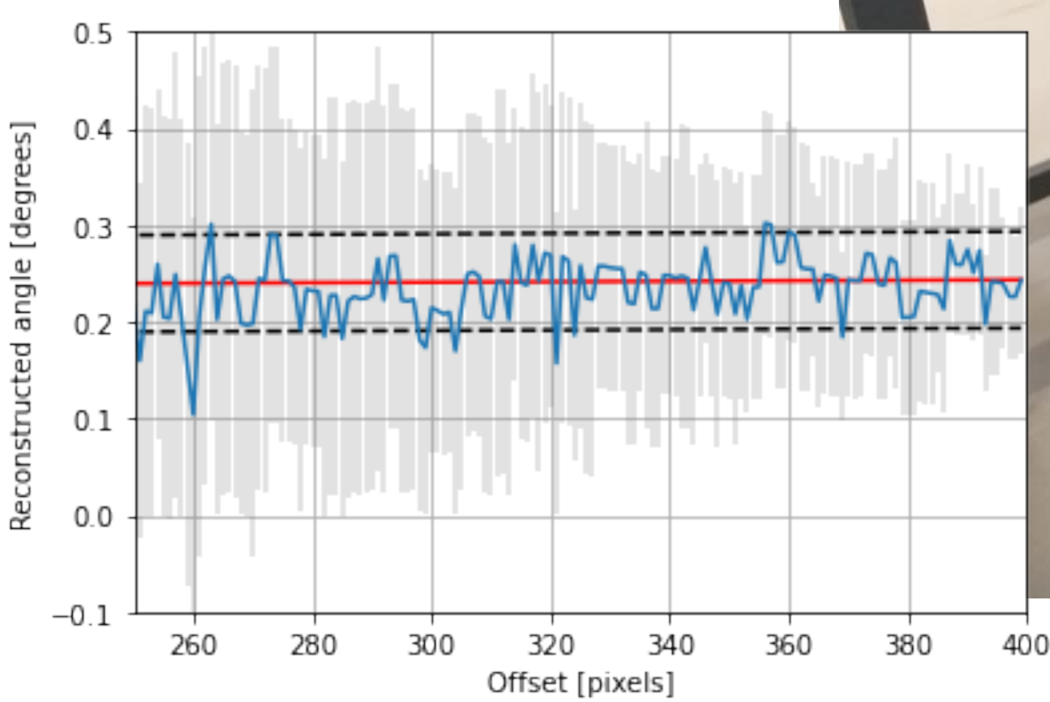


Camera - Wire Grid Alignment

Using laser diffraction pattern

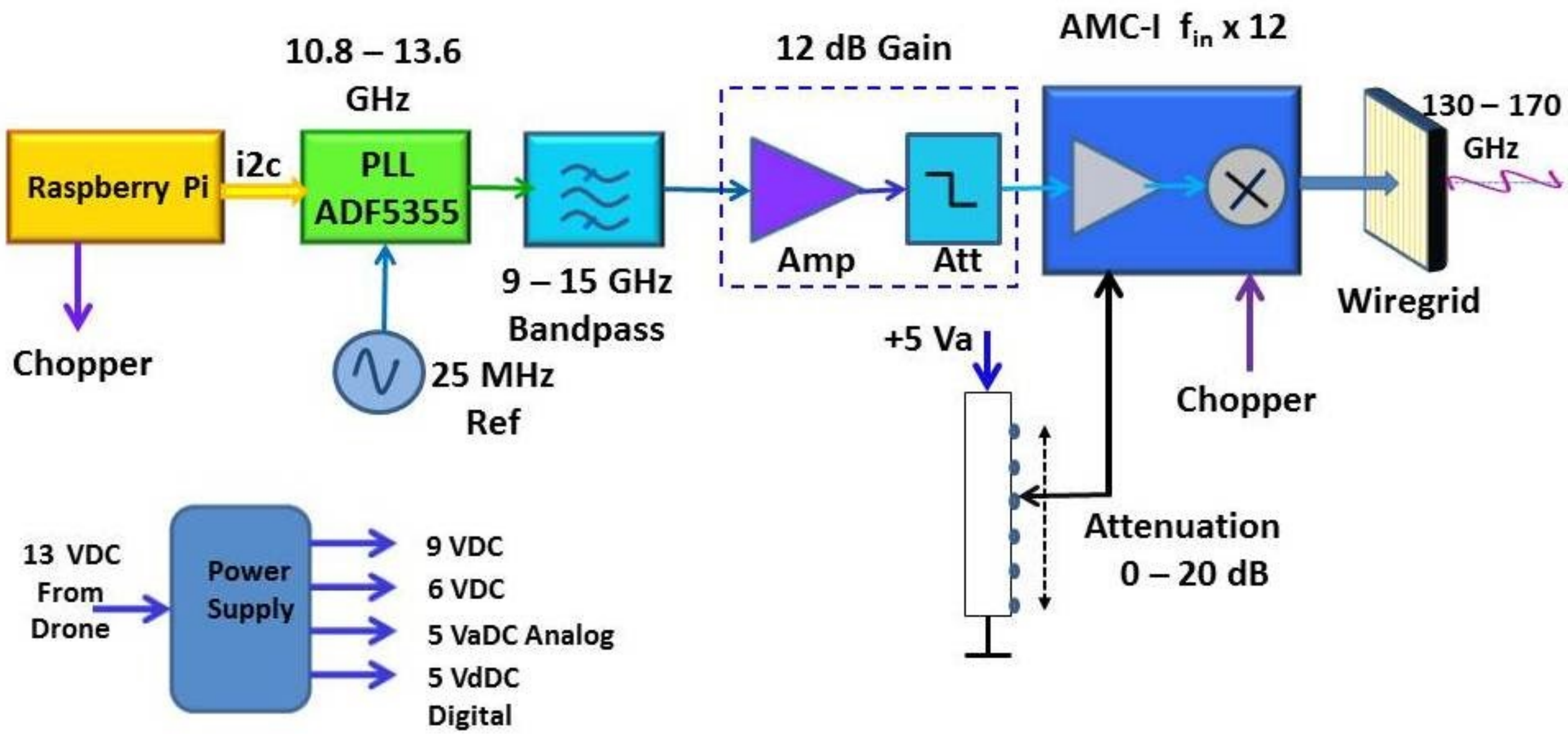
- The camera and the polarizing grid must be carefully aligned in the laboratory previos to the experiment on the field.





Radio-Frequency Design

Lightweight, tunable, modulated and electronically controlled

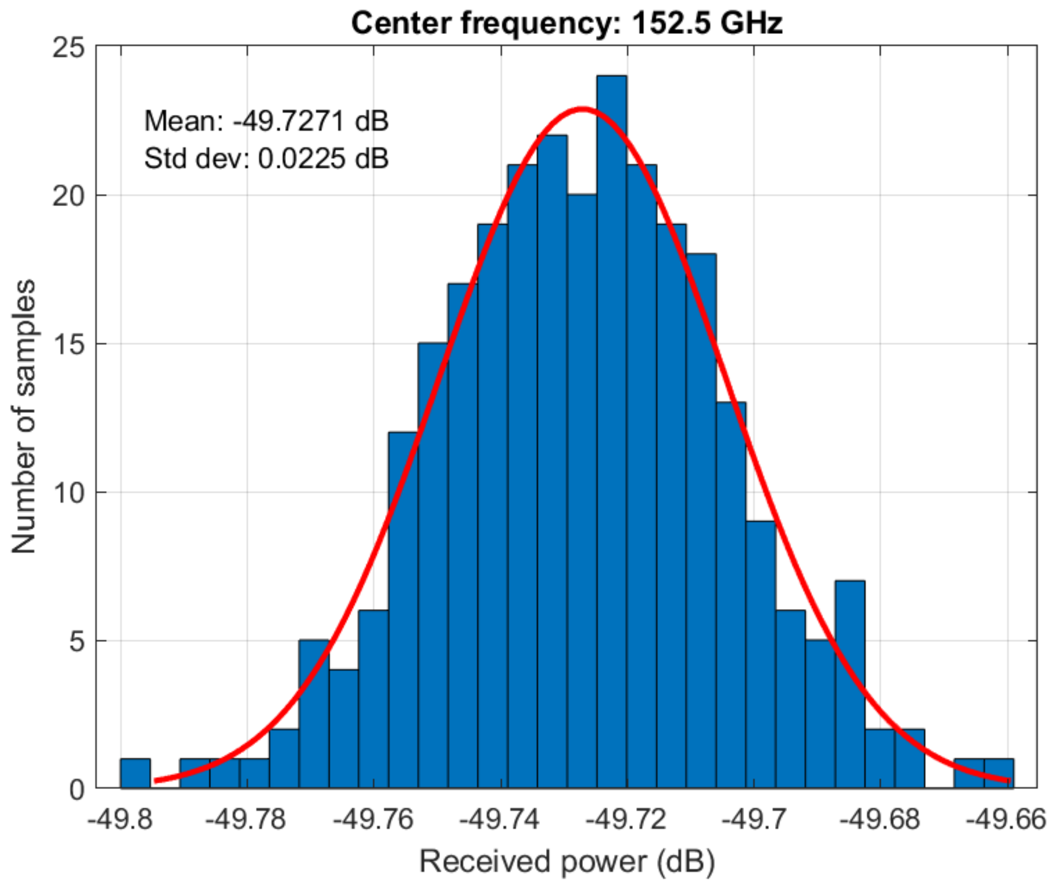


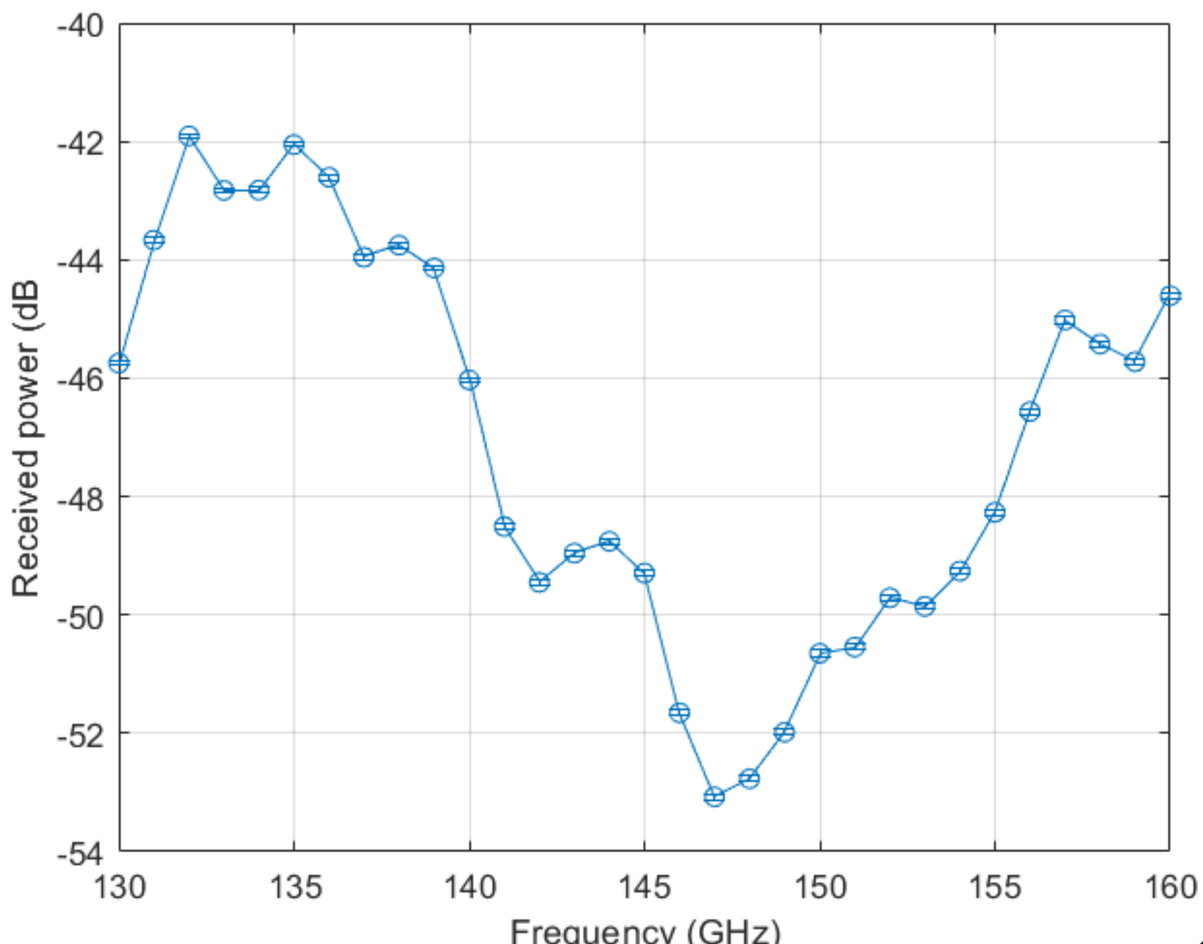
- Generates a single tone, tunable between 130 and 163 GHz.
- The attenuation can be adjusted as needed to keep the telescope detectors in their linear regime.
- The signal is electronically chopped at the multiplier stage.
- An open waveguide is used to feed the signal into the air, minimizing the directivity of the source.
- A wire grid polarizer determines the output polarization angle and ensures a 99.9% degree of polarization.

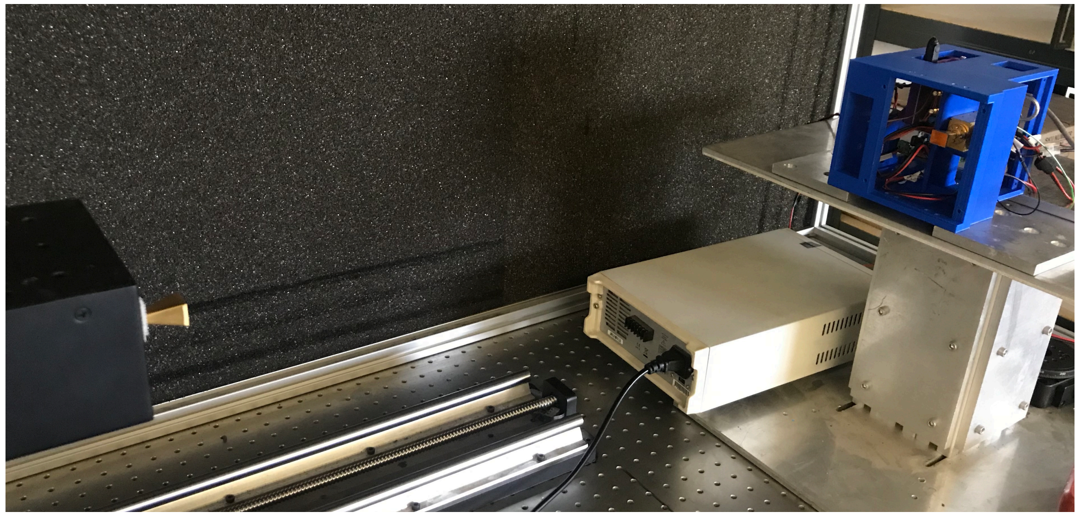
Frequency coverage and power stability

Source Characterization at 150 GHz

- Measured with a calibrated Keysight spectrum analyzer + VDI extender.
- Characterized the full 130-160 GHz frequency range.
- Measured the power stability sampling over an hour, showing better than 0.5% variations.
- Currently working on measuring the temperature/ power dependence.

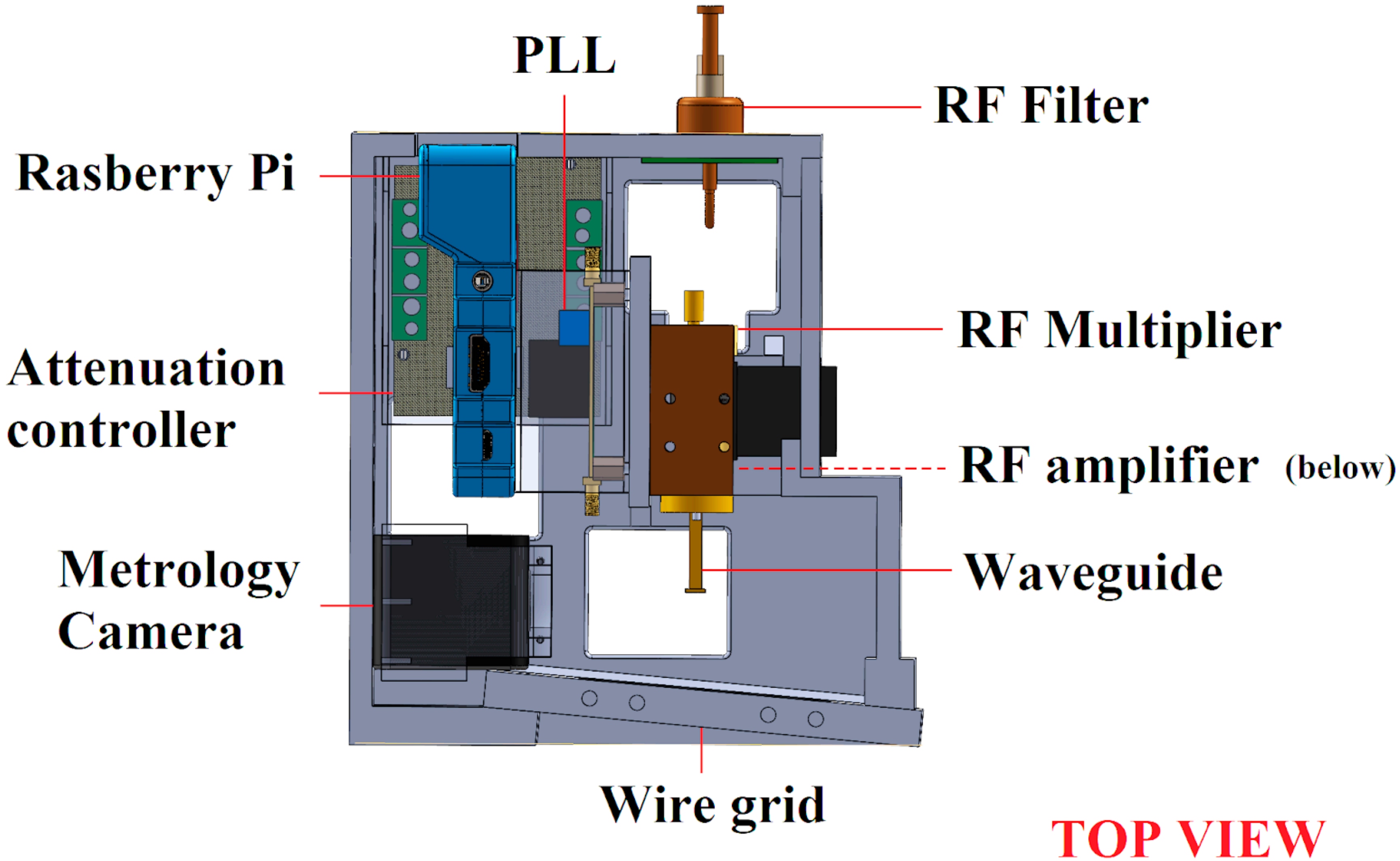






Mechanical Design

Lightweight and rigid

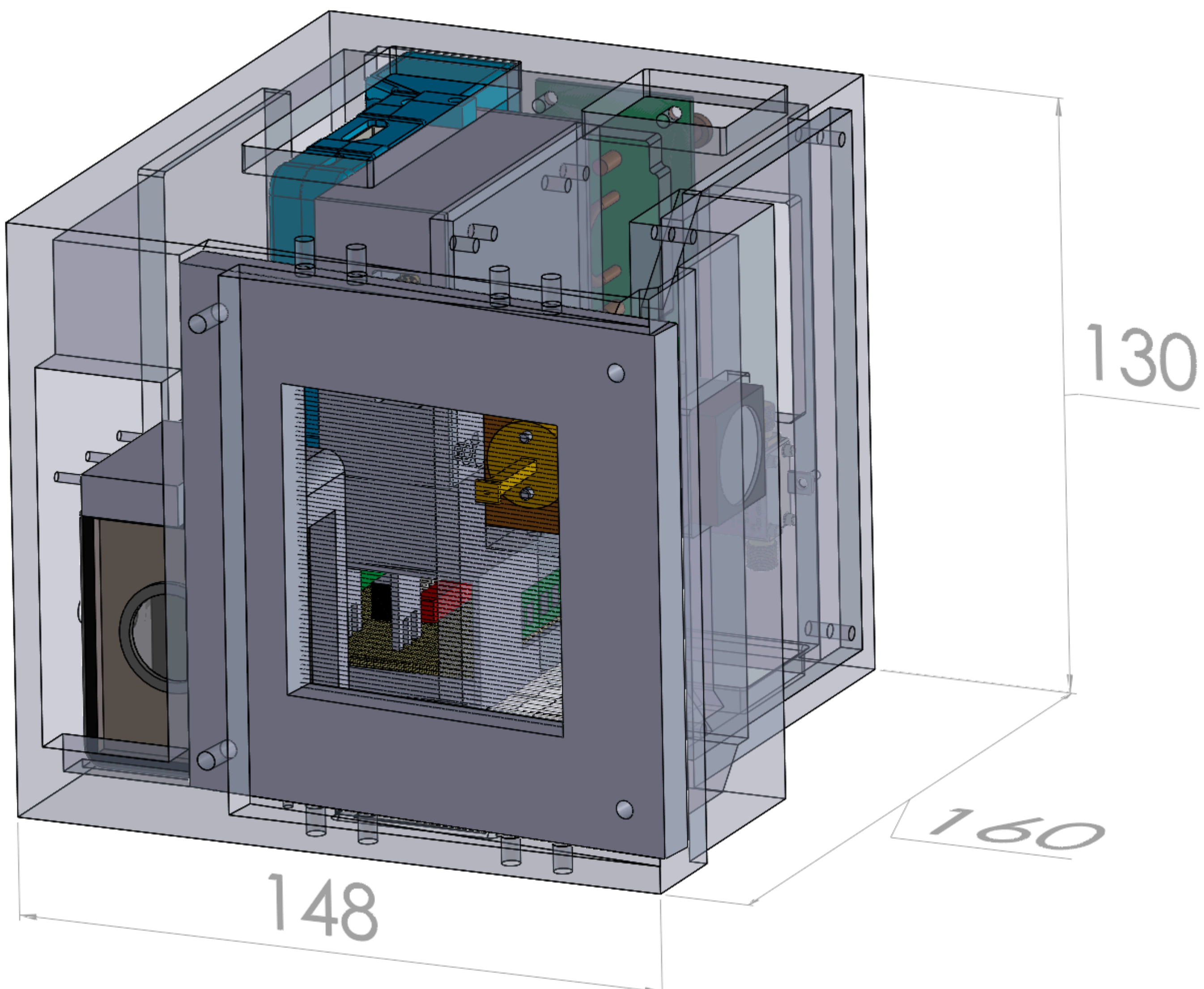


- The source frame is key to maintain the mechanical alignment between the polarizing grid and the metrology camera, which will set the reference coordinate frame.
- The size restrictions are imposed by the Ronin MX gimbal used to hold and point the source.
- The first prototypes have been 3D printed using PLA plastic, but it is possible to use a carbon fiber composite in case that extra rigidity is shown to be necessary.

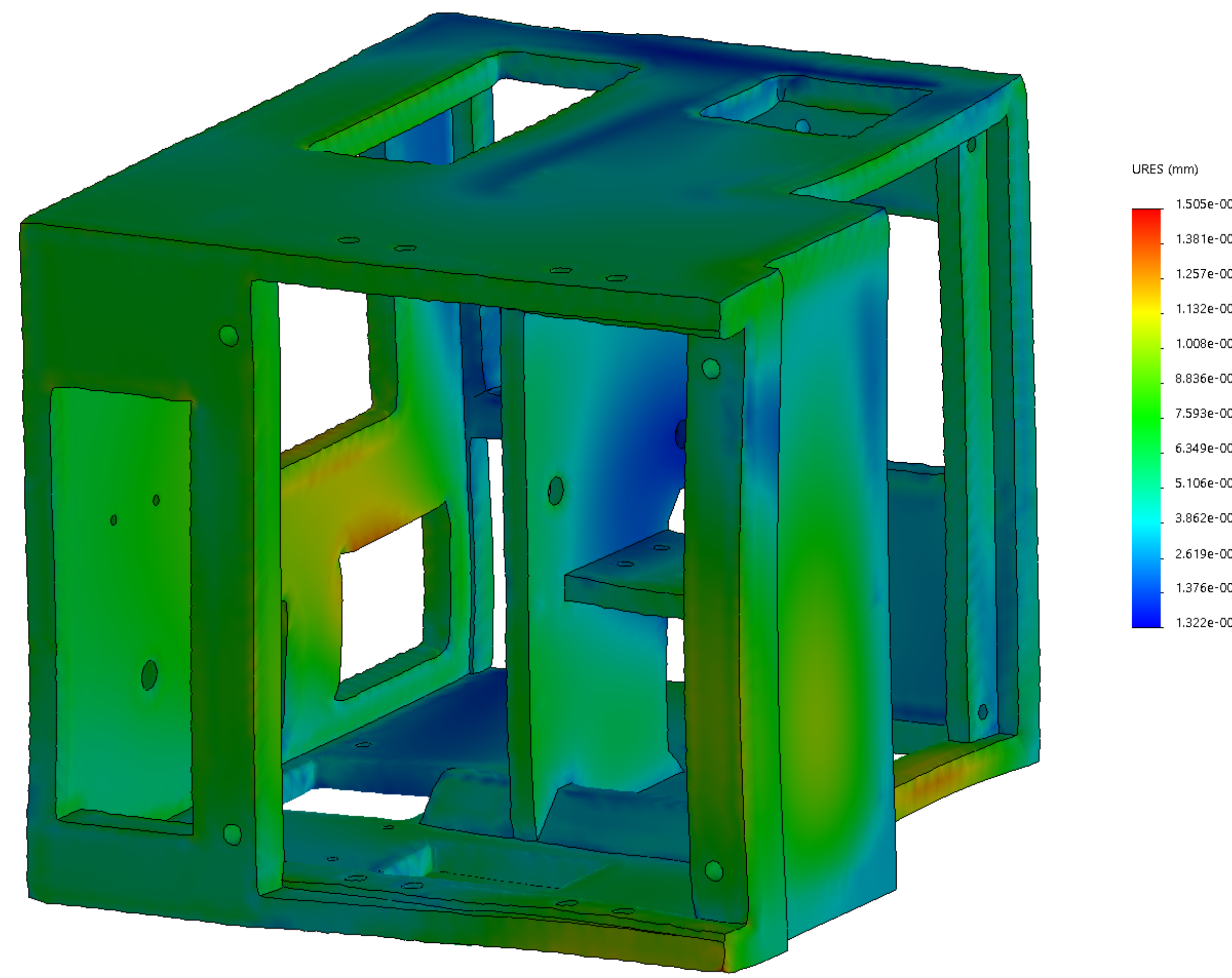
Mechanical Design

3D mechanical and thermal modeling

Isometric view



Thermal deformations



- Modeling done considering 3D printing with PLA, resulting in thermal deformations of less than 15 microns when a 35 K temperature change is applied, producing negligible changes in polarization angle.

Conclusions

- We have shown a novel UAV-based design for a polarization calibration source for CMB experiments.
- The system heavily relies on a metrology system based on differential GPS and photogrammetry to provide an absolute reference system in-time during the flight.
- Preliminary metrology tests show that it will be possible to achieve the accuracy of 0.1 degrees in polarization angle needed.
- This calibration source will serve all CMB experiments installed in Chile, including ACT, Polarbear, CLASS, Simons Observatory and CCAT-prime.
- This new technique will open a new field for the optical characterization of radio telescopes.
- We foresee on this as a route for the development of satellite calibrators in the future.
- The current plan is to fly again in March!