G-band Cloud Radar: Recent results and the route to space

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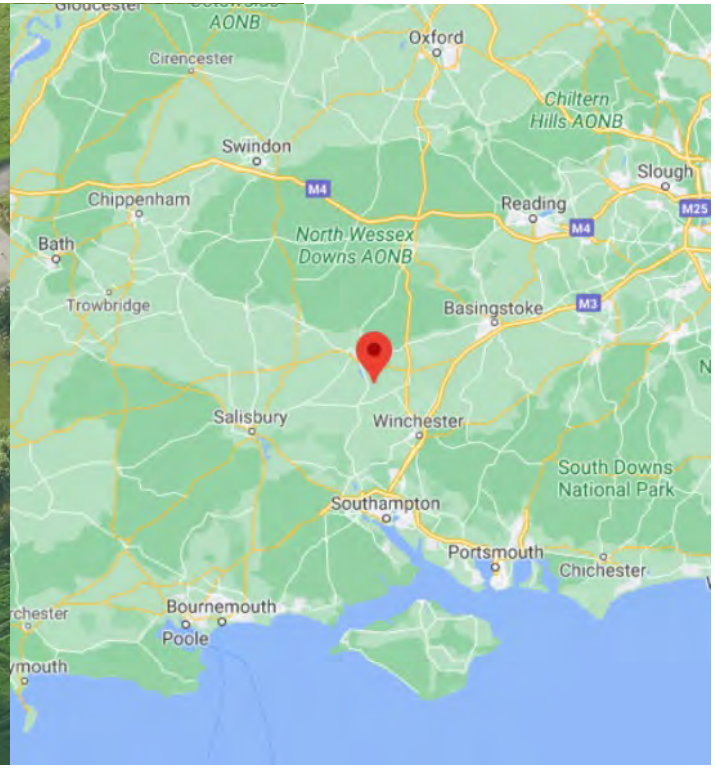
D. A. Robertson: University of St Andrews
C. Westbrook, K. McCusker: University of Reading
P. Kollias: McGill University
L. Richter: Large Space Structures GmbH

CEOI Emerging Technology for Earth Observation Conference
19-20 March 2024

The GRaCE project

- Ground based science and technology demonstrator for a future space radar
- Clouds and ice characterisation are important for precipitation & climate change models
- Monostatic, pulsed, Doppler, zenith looking, solid state radar
- Frequency, 199.5 GHz, set by OFCOM and atmospheric transmission



GRaCE site at Chilbolton Observatory

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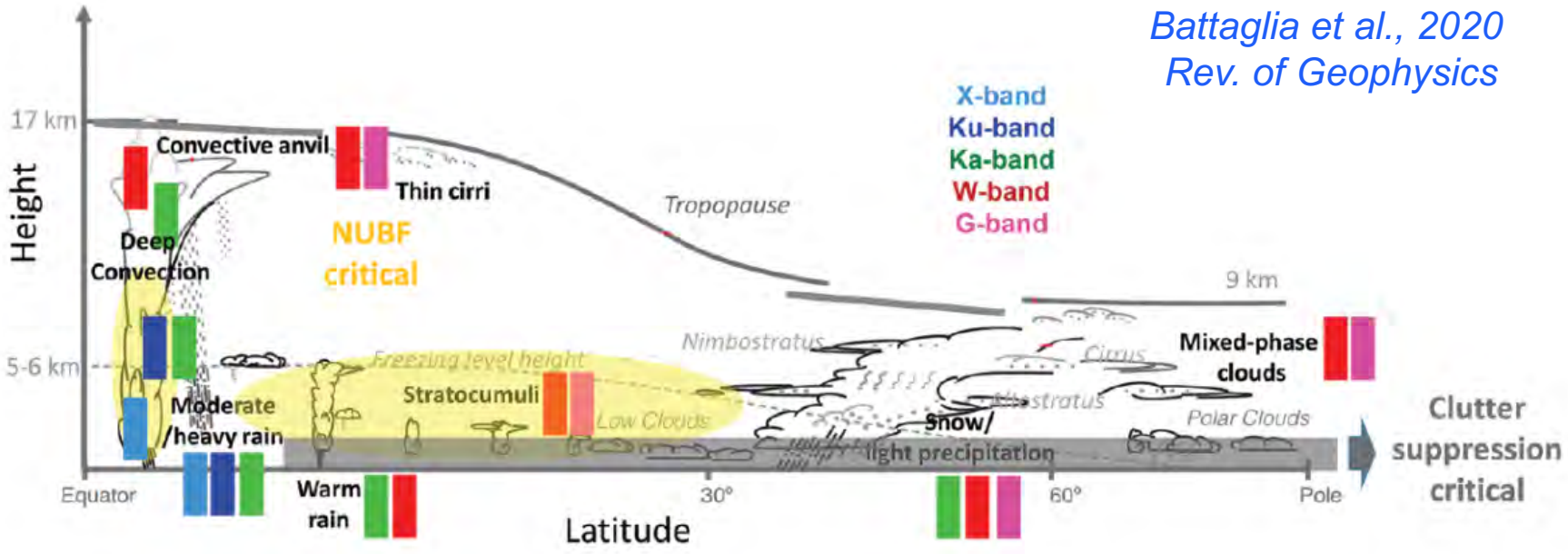
The GRaCE project - Science

Problem: cloud feedback is the major source of ***uncertainty in climate sensitivity*** (from 1.5 up to 4.5^{0}C) ➔ better characterization of cloud & precipitation vertical structure and microphysics is needed

Battaglia et al., 2020
Rev. of Geophysics



Solution: Combining multi-frequency radar observations, from 10 to above 200 GHz, allows characterizing from heavy precipitation particles to small-size ice crystals. Inclusion of GRaCE highly beneficial in three areas: ***boundary layer clouds, cirrus and mid-level ice clouds and precipitating snow***

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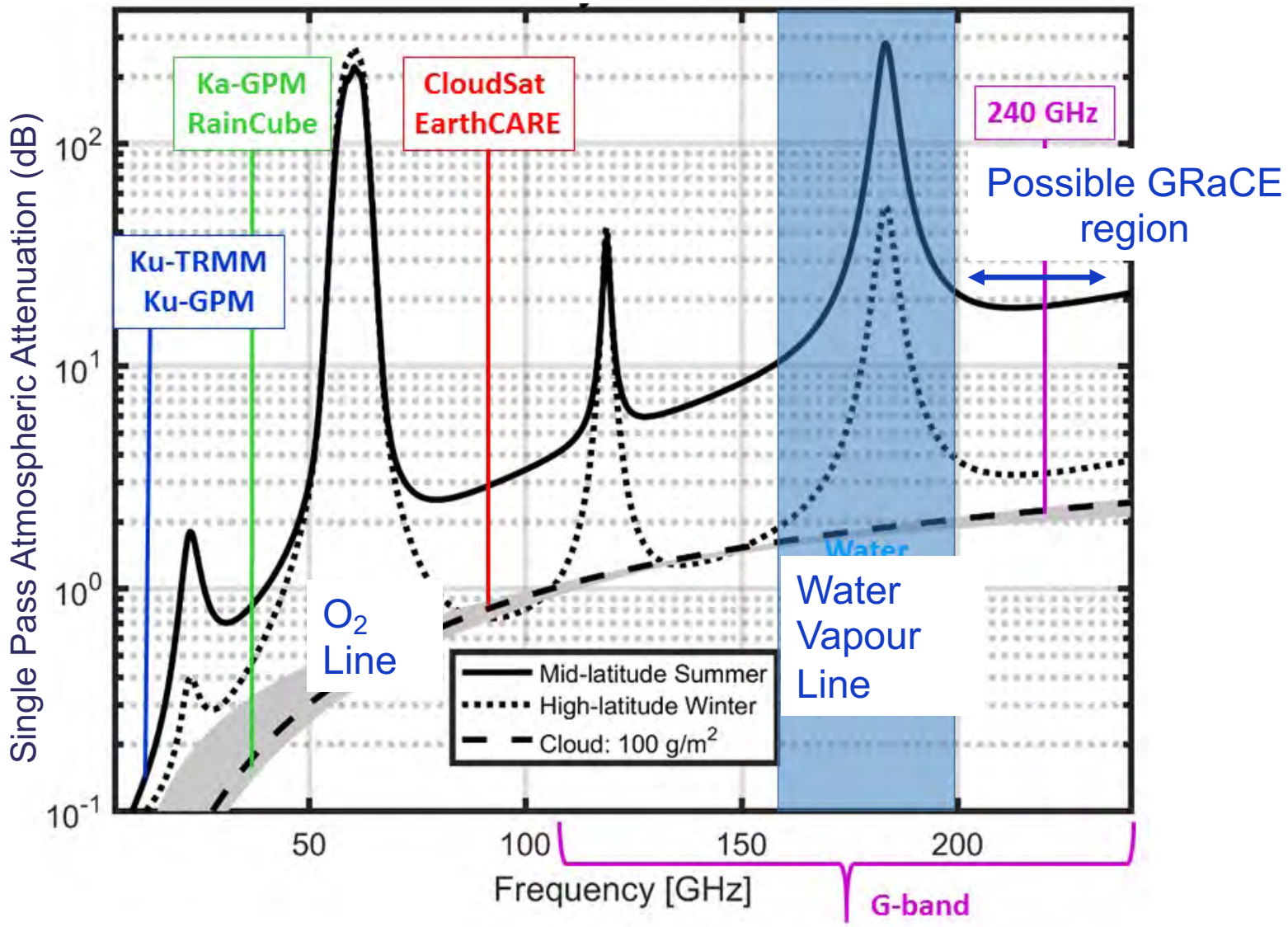
Why 199.5GHz?



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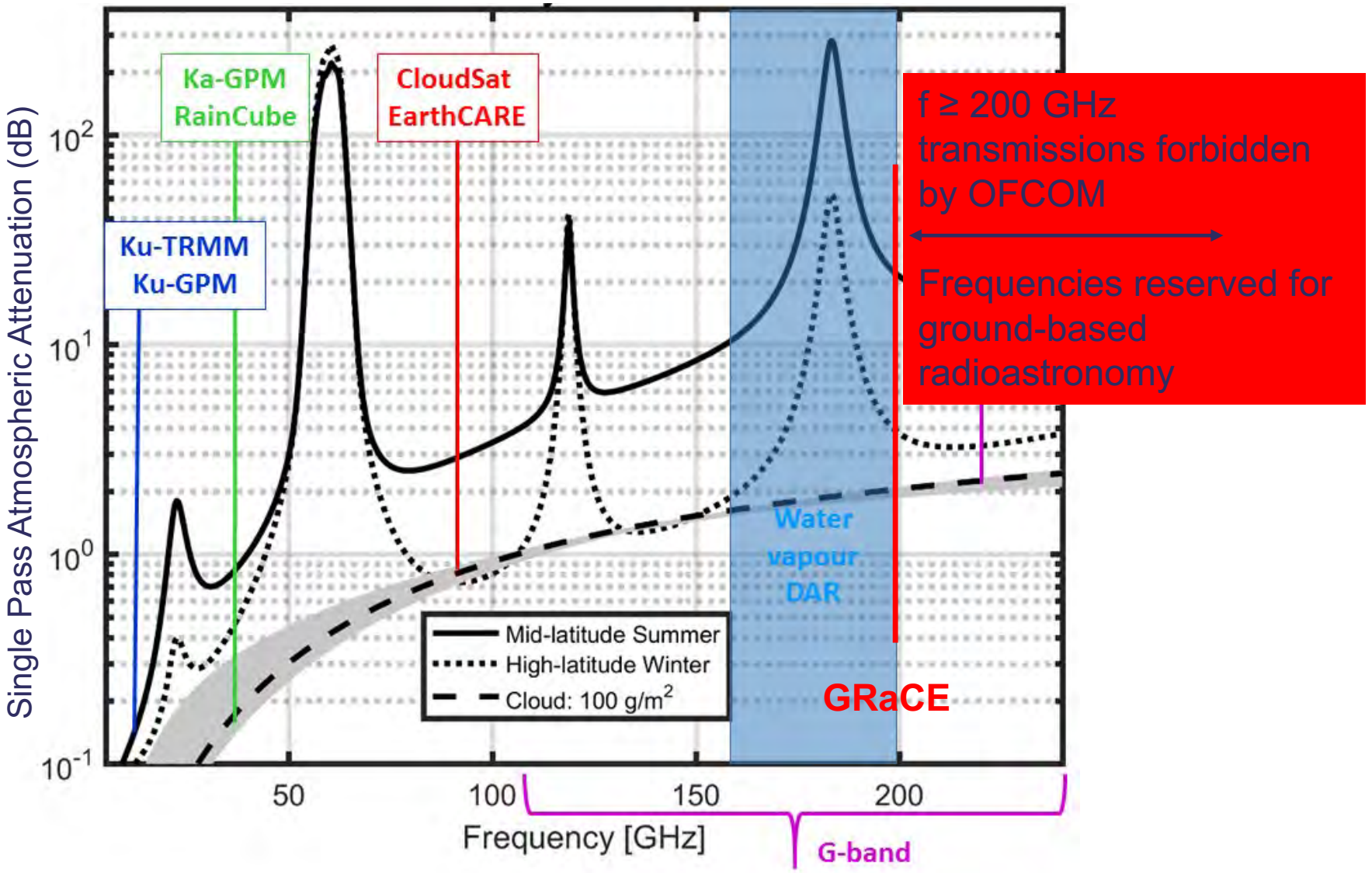
Why 199.5GHz?



f ≥ 200 GHz transmissions forbidden by OFCOM

Frequencies reserved for ground-based radioastronomy

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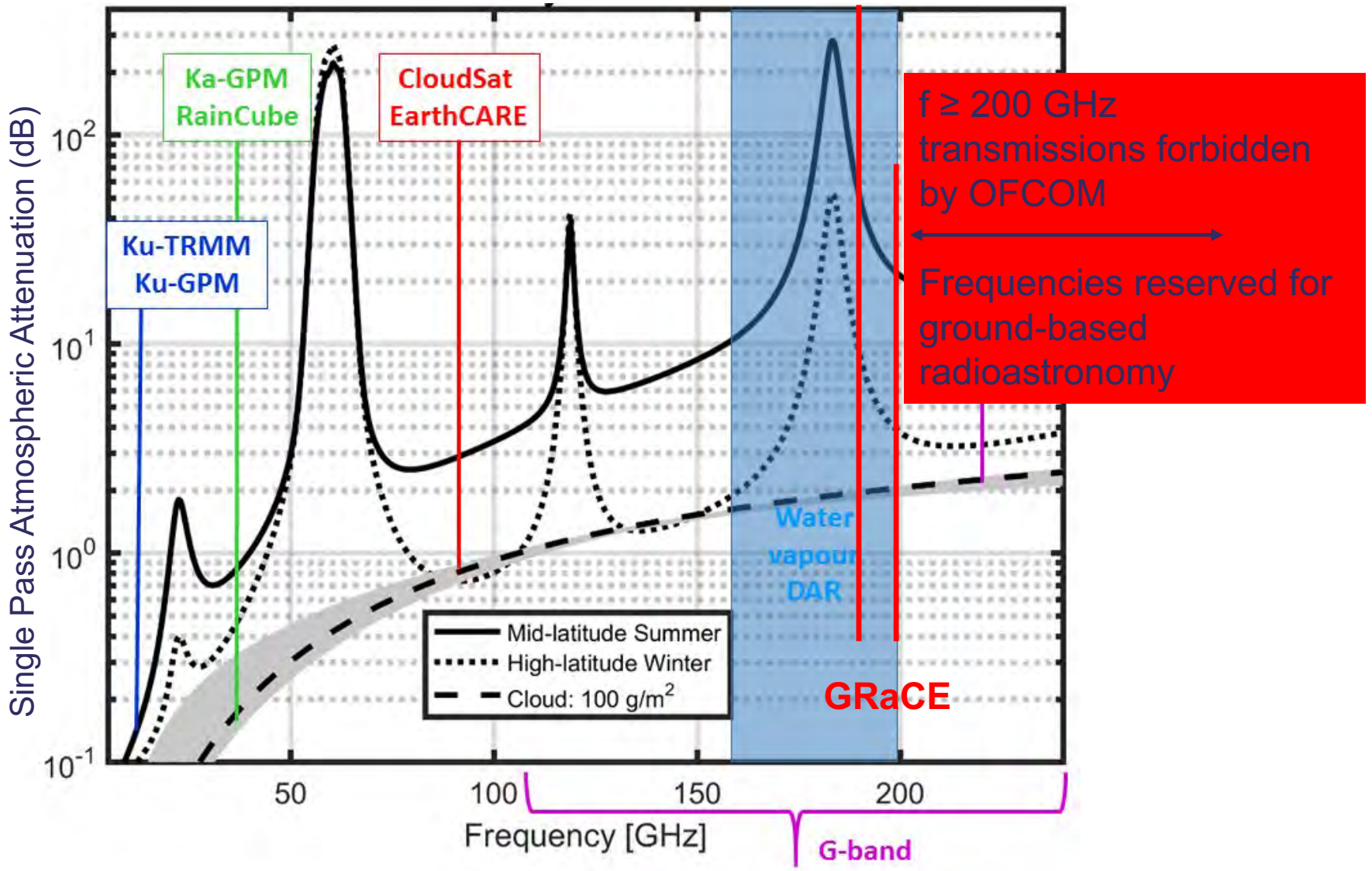
Why 199.5GHz?

Upgraded with second channel
at 192GHz (Dec. 2023)



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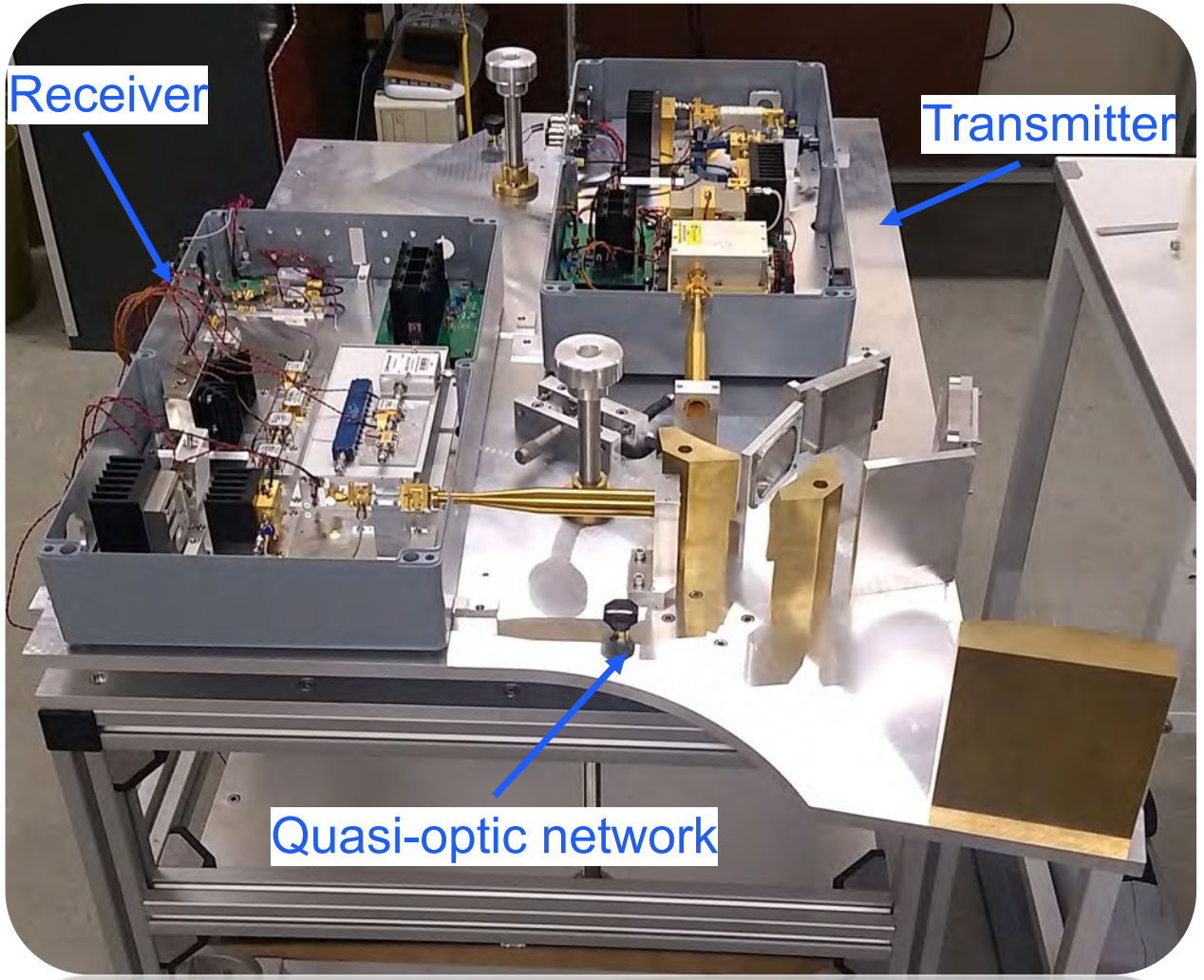
GRaCE hardware



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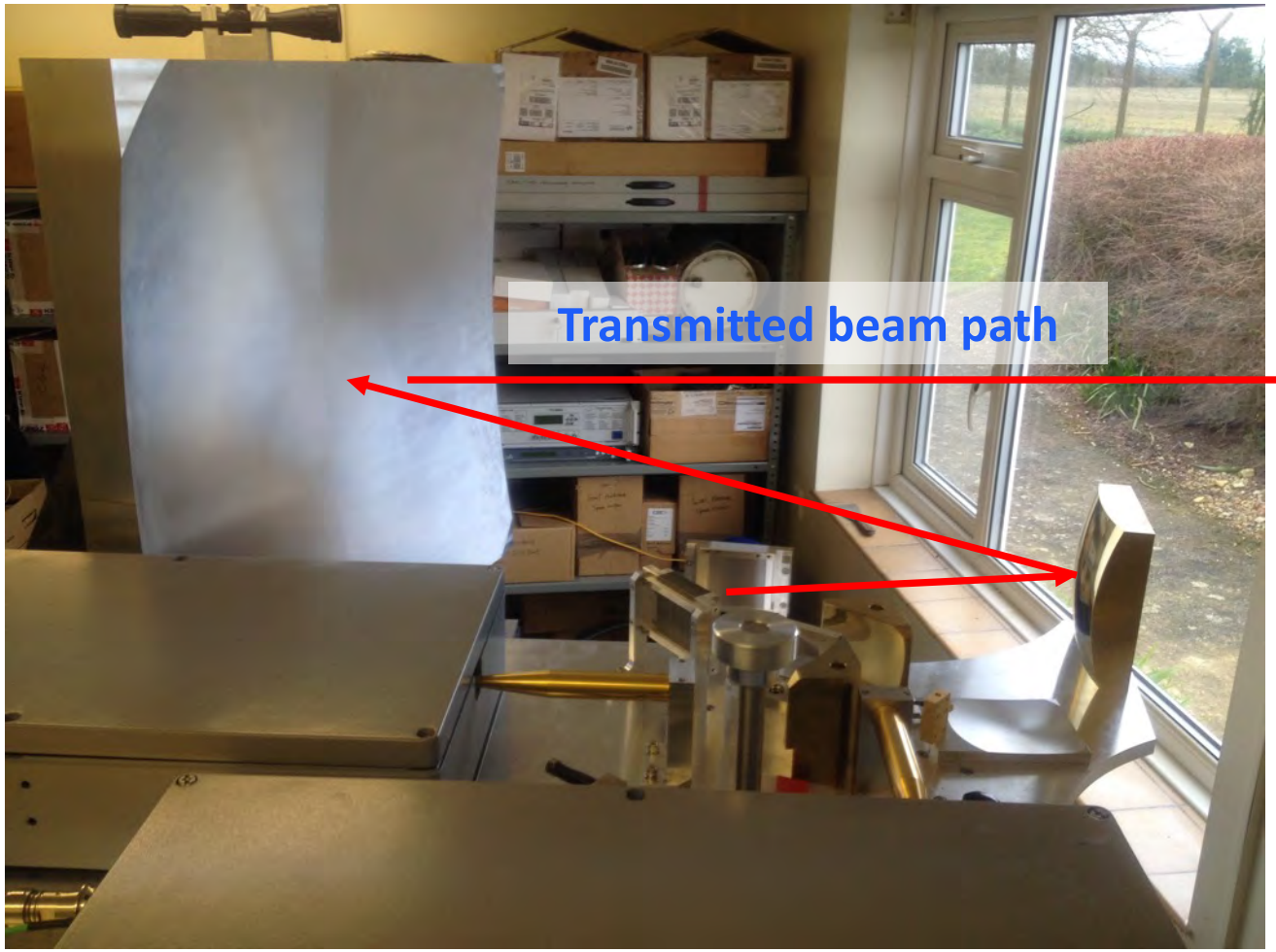
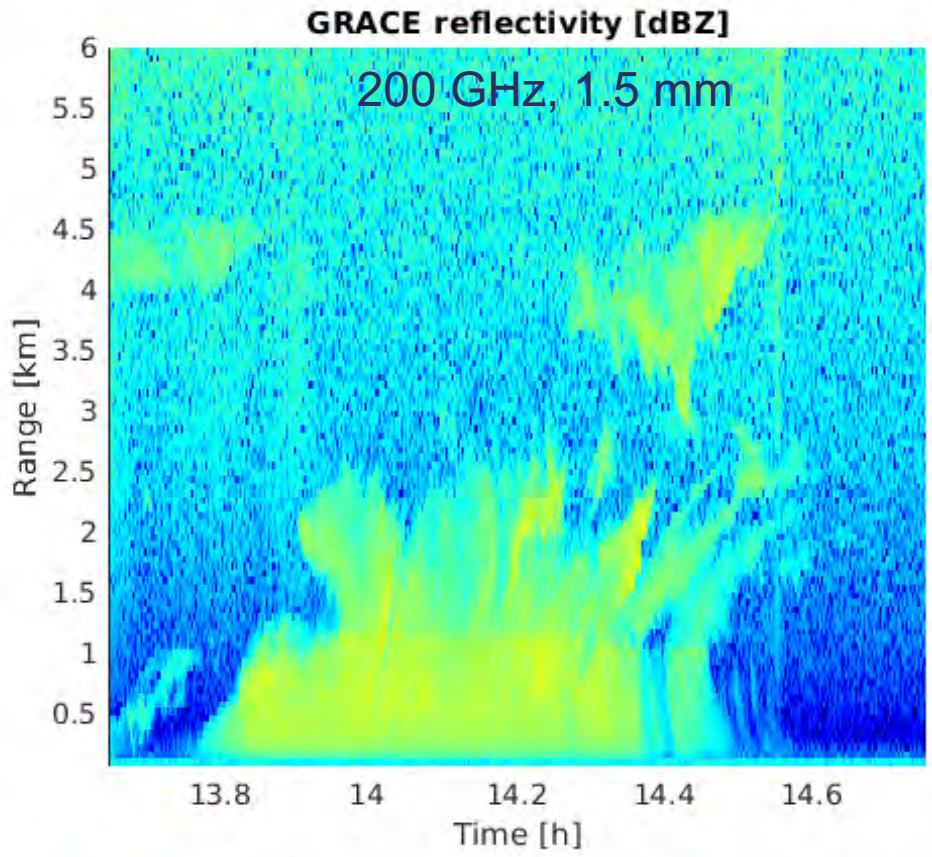
GRaCE at Chilbolton

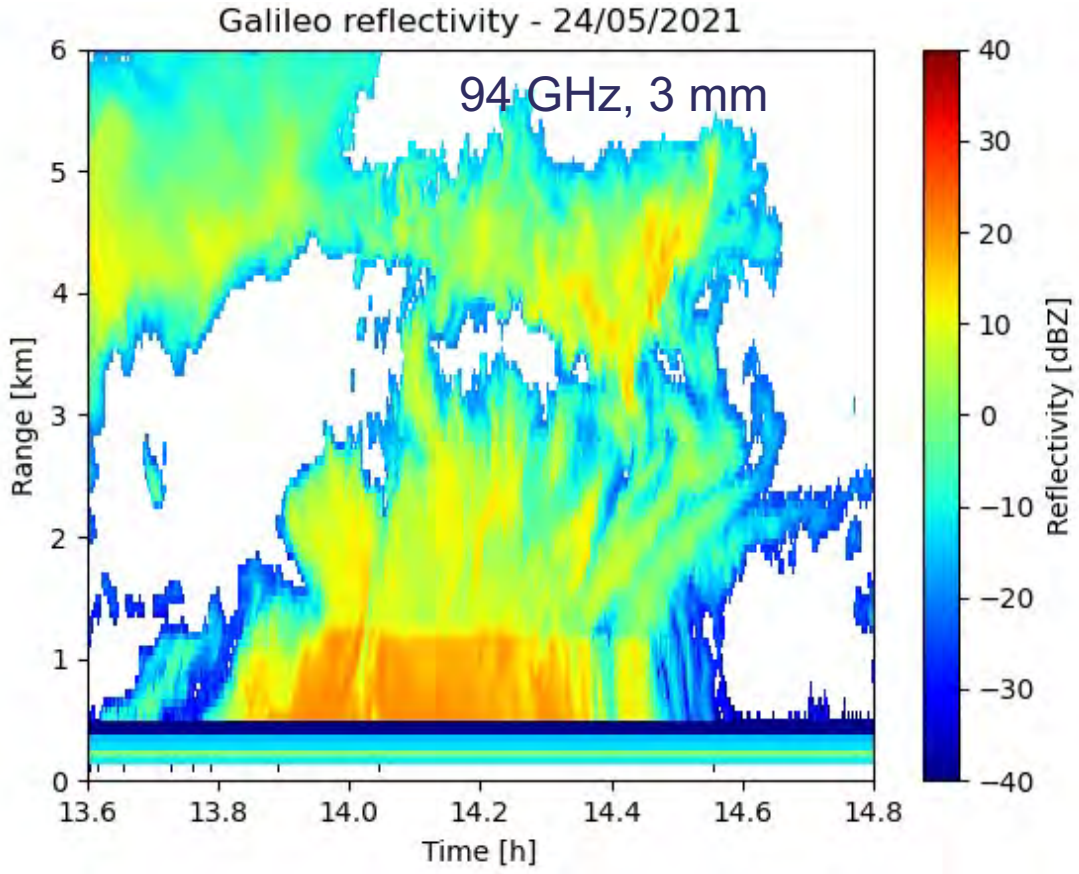


First light of GRaCE

Comparison with co-located 94 GHz kW pulsed Galileo radar

Courier et al., 2021, GRL





- Rain event on May 24th 2021, freezing level at around 1 km (UK "summer" atmosphere conditions)
- Observations to ≈ 5 km altitude
- Reduced dead zone close to the ground
- GRACE reduced reflectivity arises from attenuation and non-Rayleigh effects

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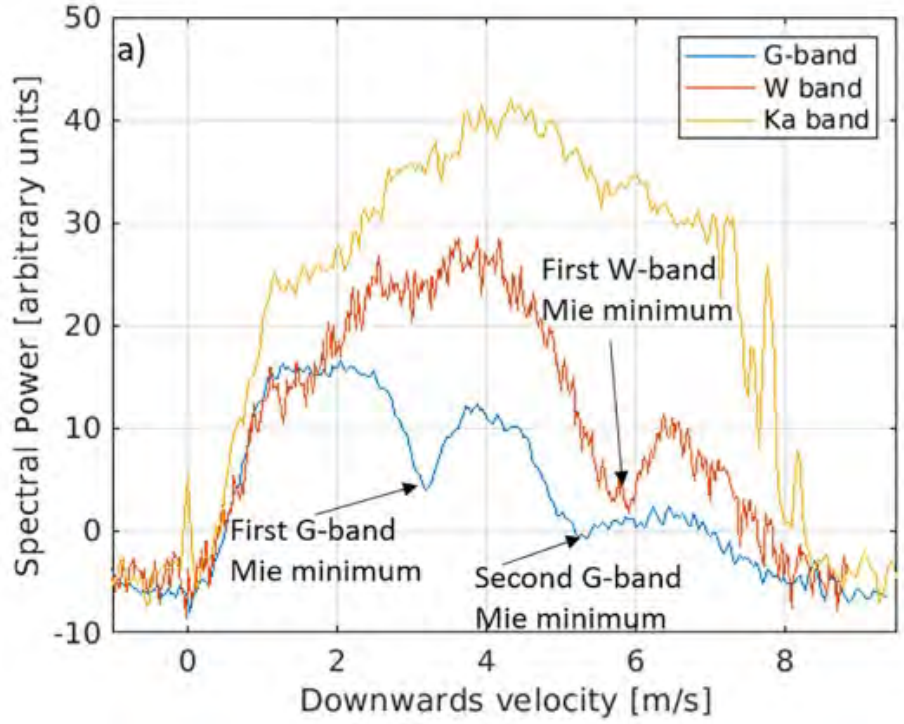
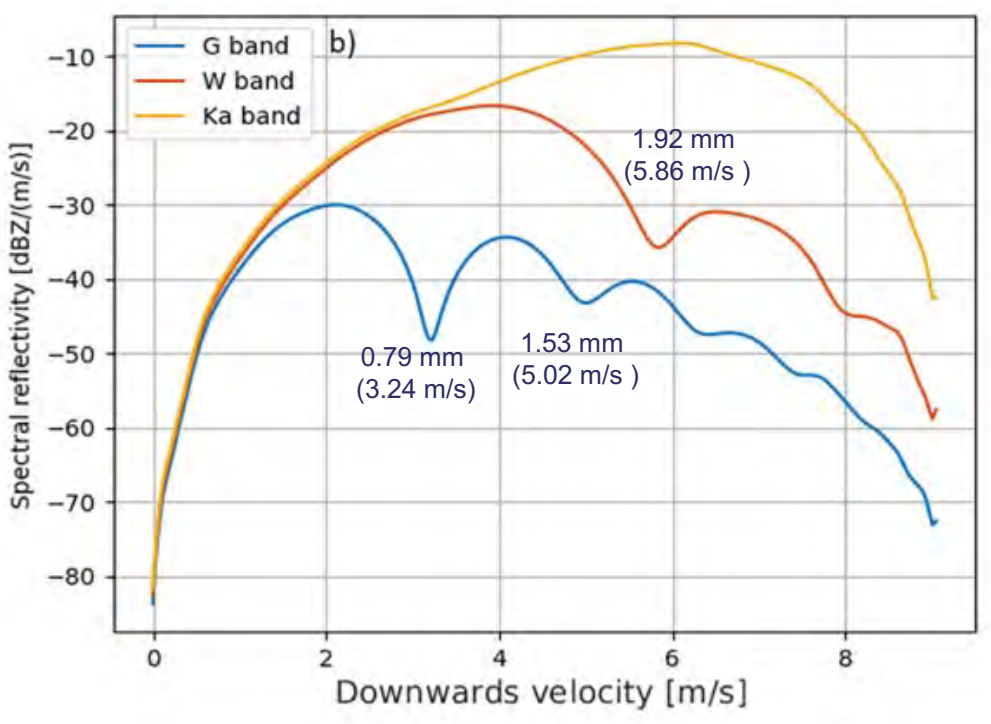
First ever 200GHz Doppler results





- **Distinguish fall velocities of ice and rain**
- **Doppler spectra in rain present peaks and valleys ➔ raindrops are non Rayleigh targets at 200 GHz ➔ specific sizes produce constructive or destructive interference of the backscattering cross sections ➔ "Mie notches"**

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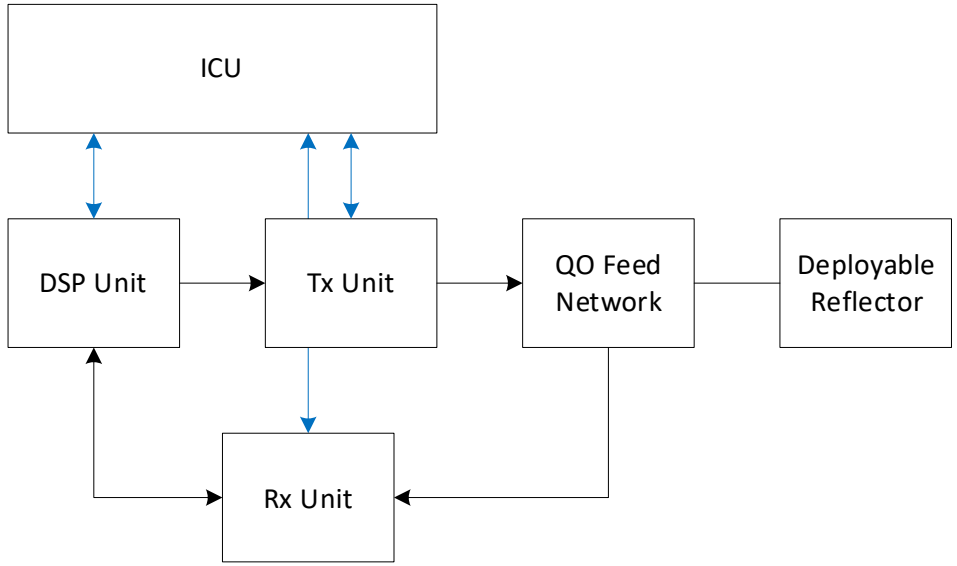
Courier et al., 2022, GRL

G-Band Spaceborne Radar – ESA Study

- To develop baseline mission concepts for two class of mission
  - SCOUT: compatible with micro satellite approach, 30MEuro budget
  - Earth Explorer: high reliability, high resource platform, ~350MEuro budget
- To identify low TRL technology so development programmes can be planned
- RAL led with support from:
  - Scientists from Politecnico di Torino and McGill University, Canada
  - Thomas Keating Ltd (quasi-optics)
  - Large Space Structures GmbH (large deployable antennas)

SCOUT Mission

Parameter	Value
Frequency	G-band, 238 GHz
Polarisation	Single, circular
Transmitter	Solid-state, 0.1-0.2W
Antenna size	1.5m deployable reflector antenna
Pointing	Nadir only
Instrument Modes	Mode 1: Tropics, max. sensitivity @ 5km altitude Mode 2: Polar, max sensitivity at Earth's surface
Noise Mode	Included – measurement of Earth's brightness temperature
Redundancy	None
Orbit	400-500 km
Launcher	Vega-C or Ariane 6

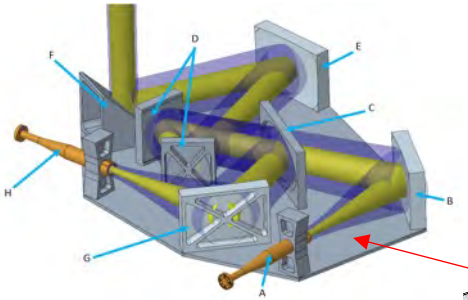


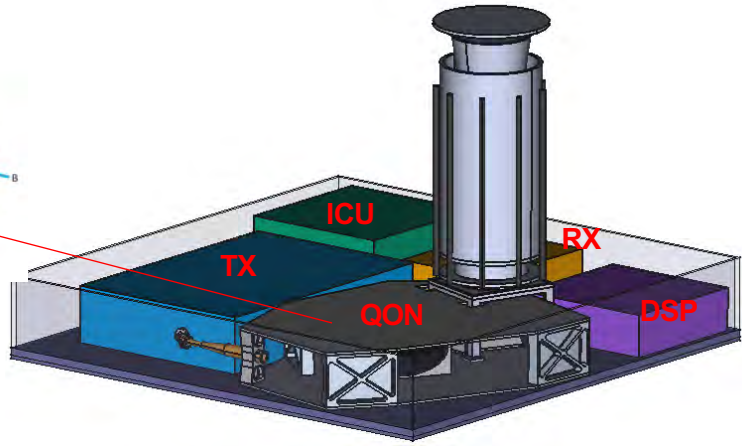
SCOUT G-Band Instrument Block Diagram

- Limited to solid-state transmitter technology
- Need to maximise antenna size to improve radar sensitivity
- Nadir viewing only – no swath requirement

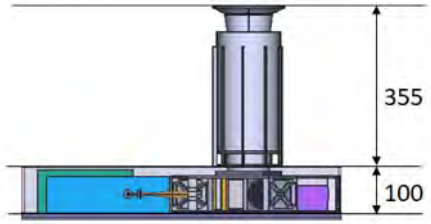
SCOUT Mission

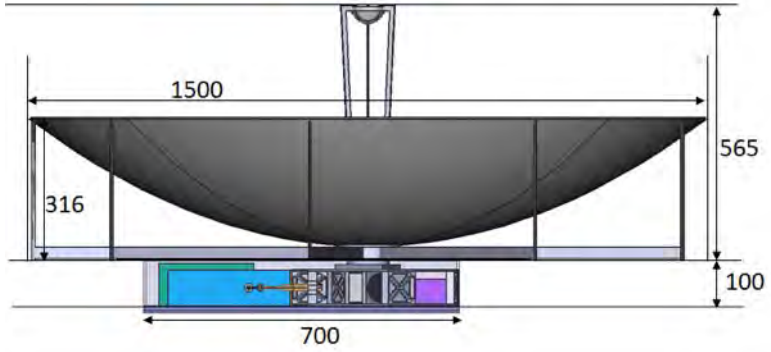
- Payload mass: 50kg
- Payload Power: 100W
- SSTL300 Platform



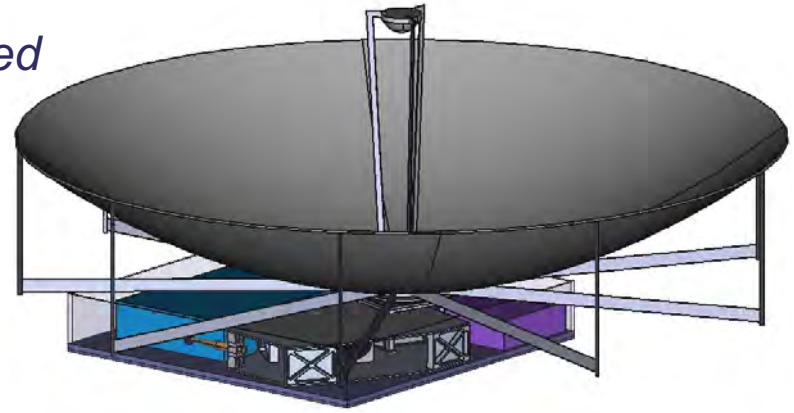


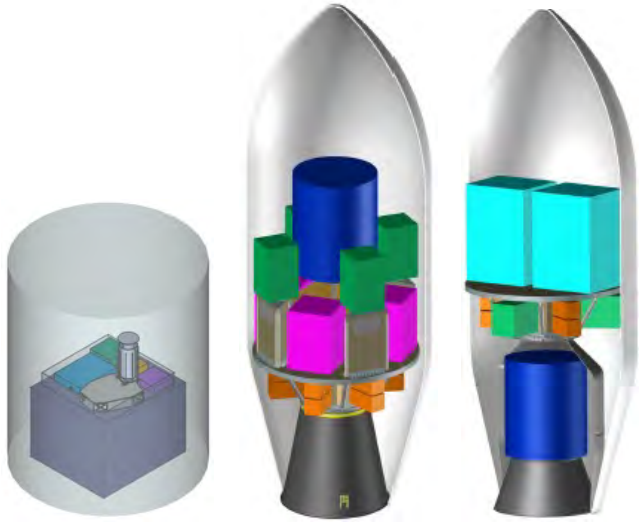
Stowed



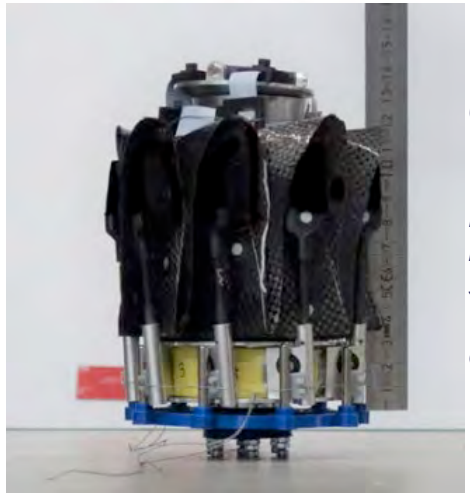


Deployed



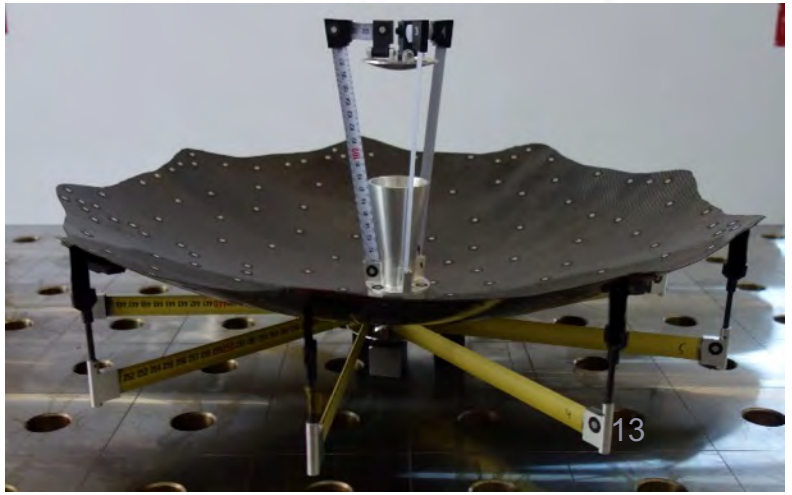


Vega-C accommodation (Blue Cylinder)



Centre-fed REVOLVE "origami-folded" reflector, 0.5m, Ka-band (credit: LSS GmbH).

Pre-development required to reach 1.5m diameter and surface finish for operation at G-band. QON included in pre-development to demonstrate Tx/Rx isolation.



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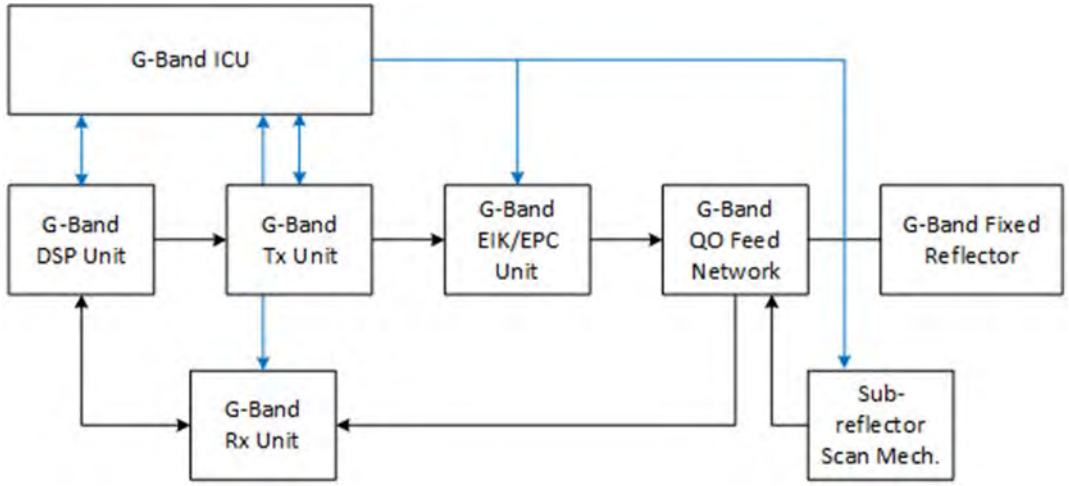
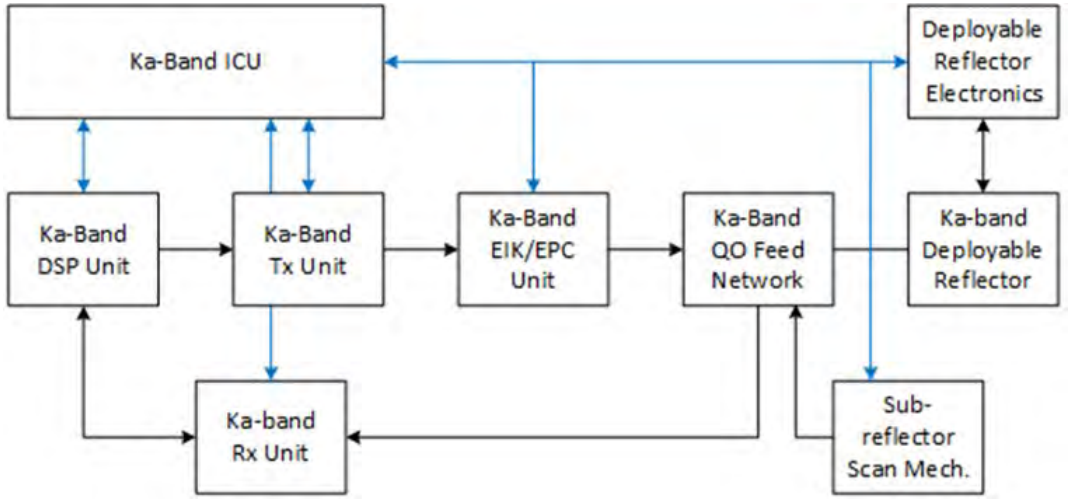
EE Mission

Parameter	Value
Frequency	G-band, 238 GHz; Ka-band, 35.75 GHz (2 separate radars)
Polarisation	Single, circular
Transmitter	EIK: G-band 0.1kW, Ka-band 2kW. 5% duty cycle.
Antenna size	G-band: 2m solid; Ka-band: 7m (deployable)
Pointing	Nadir + swath (swath between 1.25-10 km)
Instrument Modes	High sensitivity (fine cloud structure) High vertical resolution (precipitation)
Noise Mode	Included – measurement of Earth's brightness temperature
Redundancy	Tx unit output driver amplifier, EIKA and PSU, DSP unit, ICI, Rx unit
Orbit	400-500 km
Launcher	Vega-C

- Ka-band companion radar (differential measurements)
- Nadir + swath: mechanically scanned sub-reflector on both radars. Swath requirement adds significant complexity/cost for limited increase in coverage. Swath requirement requires further assessment.
- EIK Tx on both radars



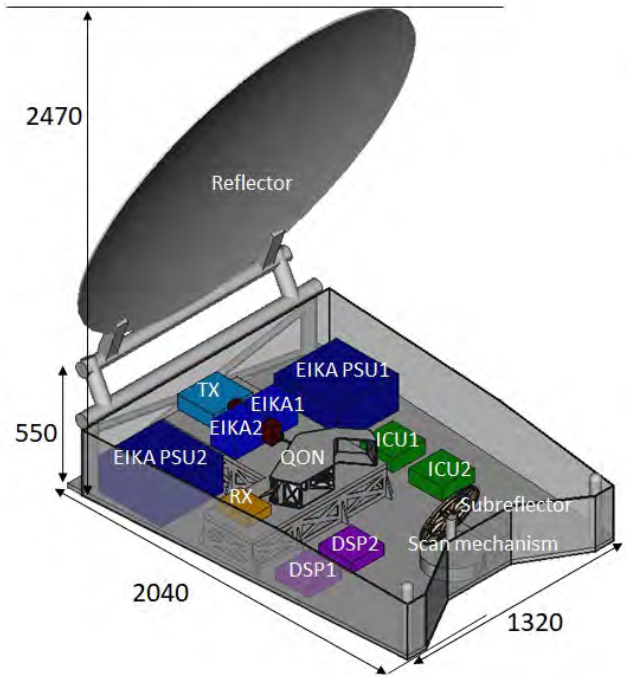
EE G-Band Instrument Block Diagram

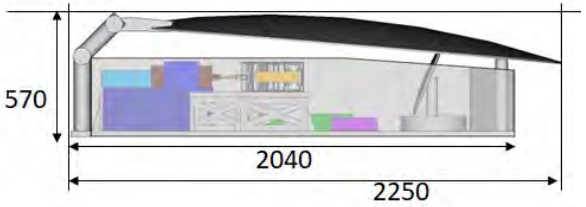


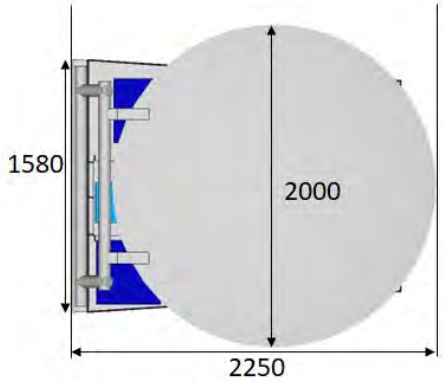
EE Ka-Band Instrument Block Diagram

EE Mission

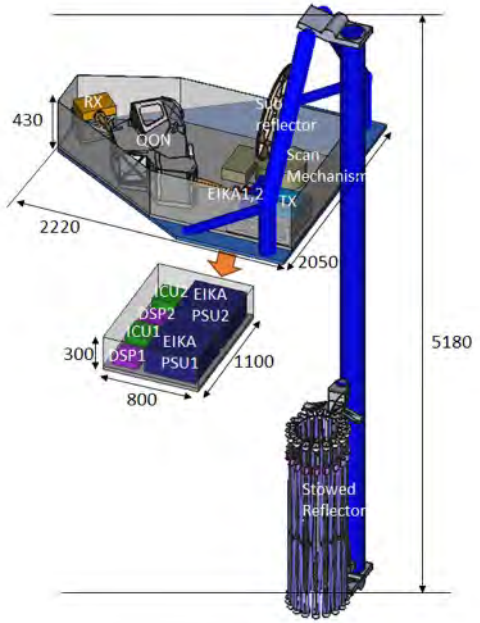
- G-Band Payload mass: 240kg
- G-Band Payload Power: 270W

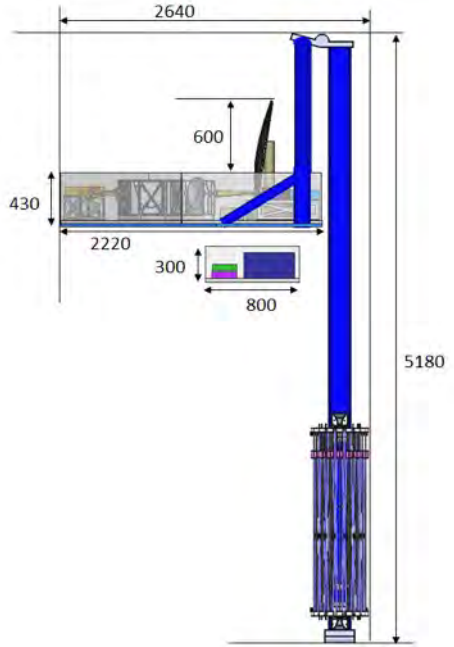


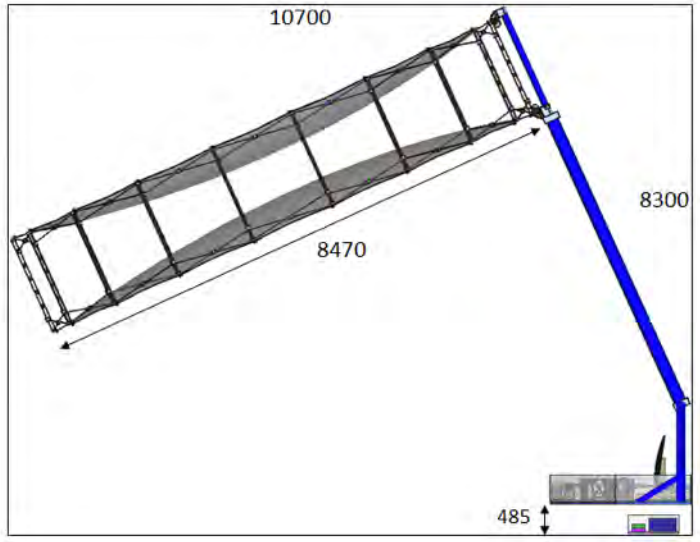


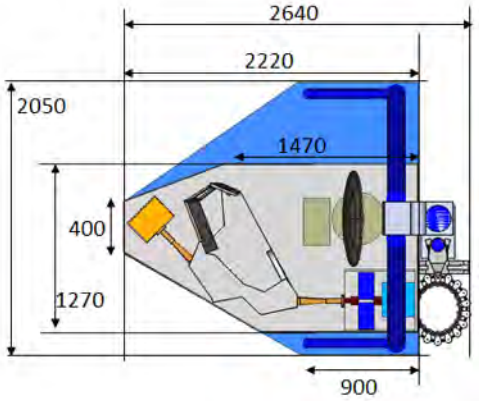


- Ka-Band Payload mass: 475kg
- Ka-Band Payload Power: 615W









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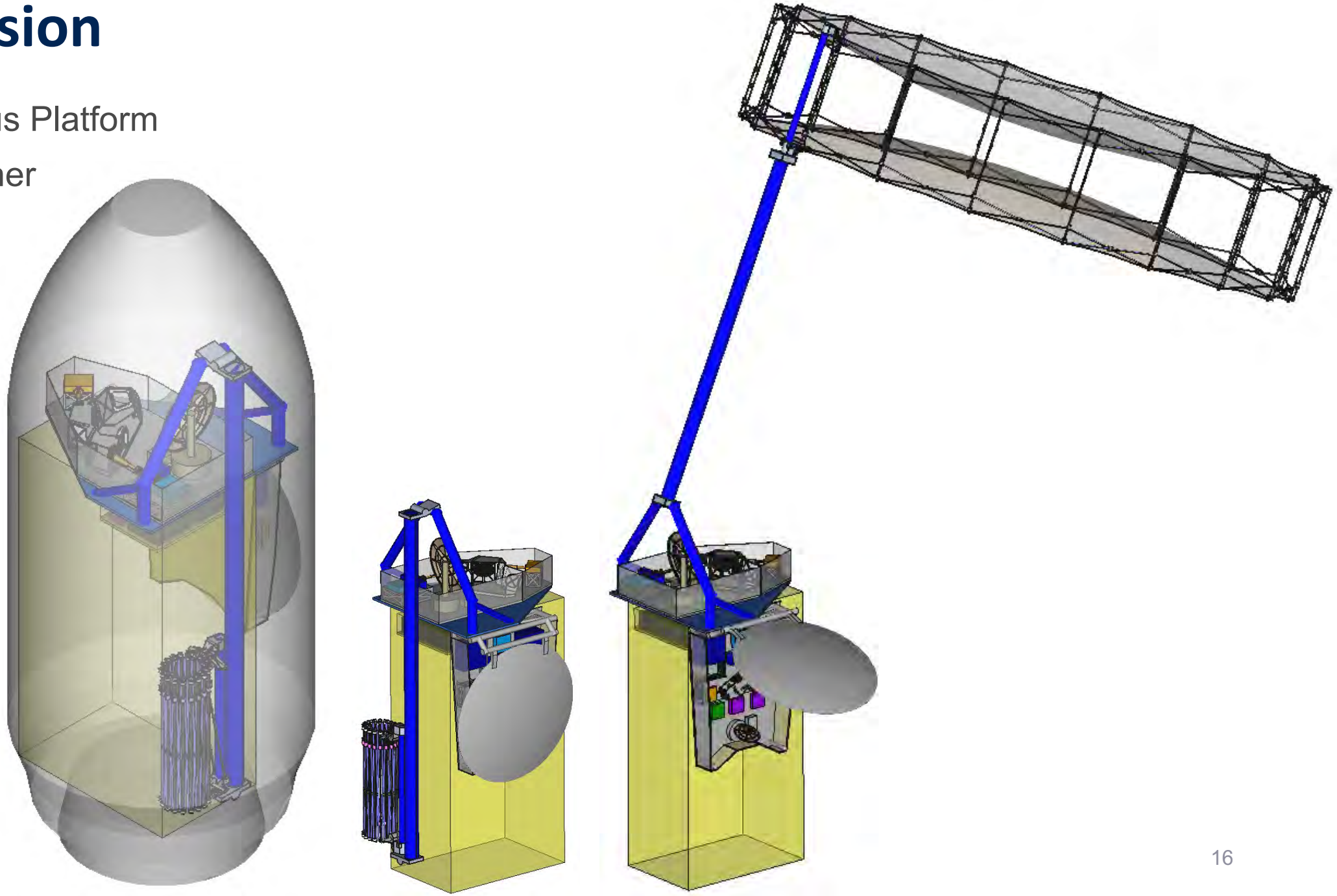
EE Mission

- Airbus Astrobus Platform
- Vega-C launcher



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Conclusion

- G-band radar performance has been demonstrated via GRaCE.
- GRaCE observations and data analysis continue to support a better understanding of the potential of the data.
- ESA study will complete in March. Next steps:
  - G-band radar airborne demonstrator ITT expected from ESA soon.
  - Lobbying for proposed technology pre-developments to be included in ESA's Technology Development Programme
  - SCOUT type mission is a more realistic near-term goal

Acknowledgements

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