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Centre for EO Instrumentation

GRaCE: G-band Radar for Cloud Evaluation

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RAL Space

University of St Andrews

TK INSTRUMENTS

UNIVERSITY OF LEICESTER

CEOI Showcase, June 23rd 2021

The GRaCE project

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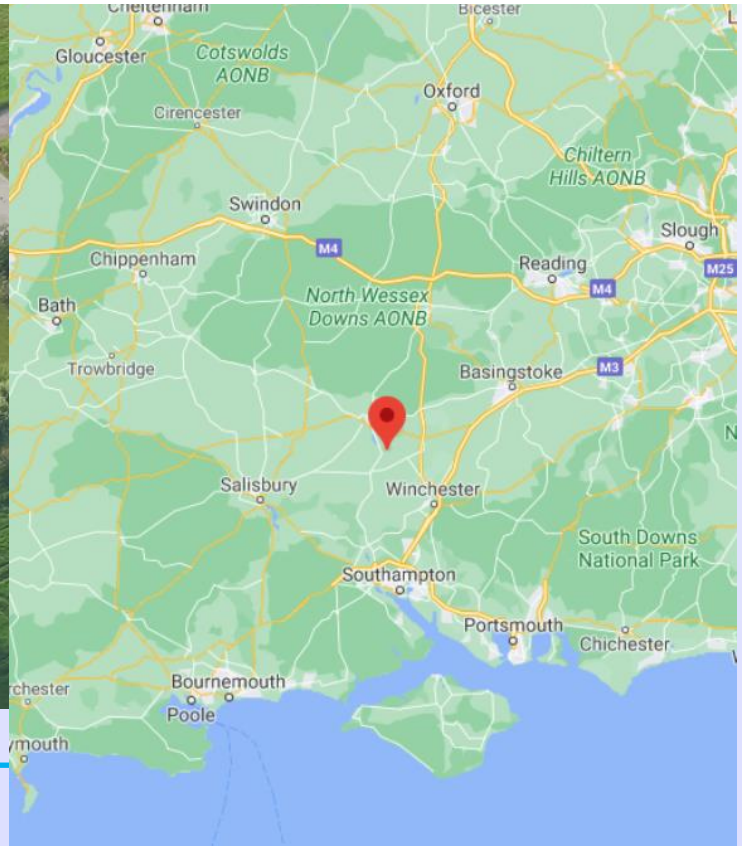
- Ground based science and technology demonstrator for a future space radar (export opportunity)
- Clouds and ice characterisation are important for precipitation & climate change models
- Monostatic, pulsed, Doppler, zenith looking, solid state radar
- Frequency, 199.5 GHz, set by OFCOM and atmospheric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

GRaCE site at Chilbolton Observatory



Completed 200 GHz Hardware

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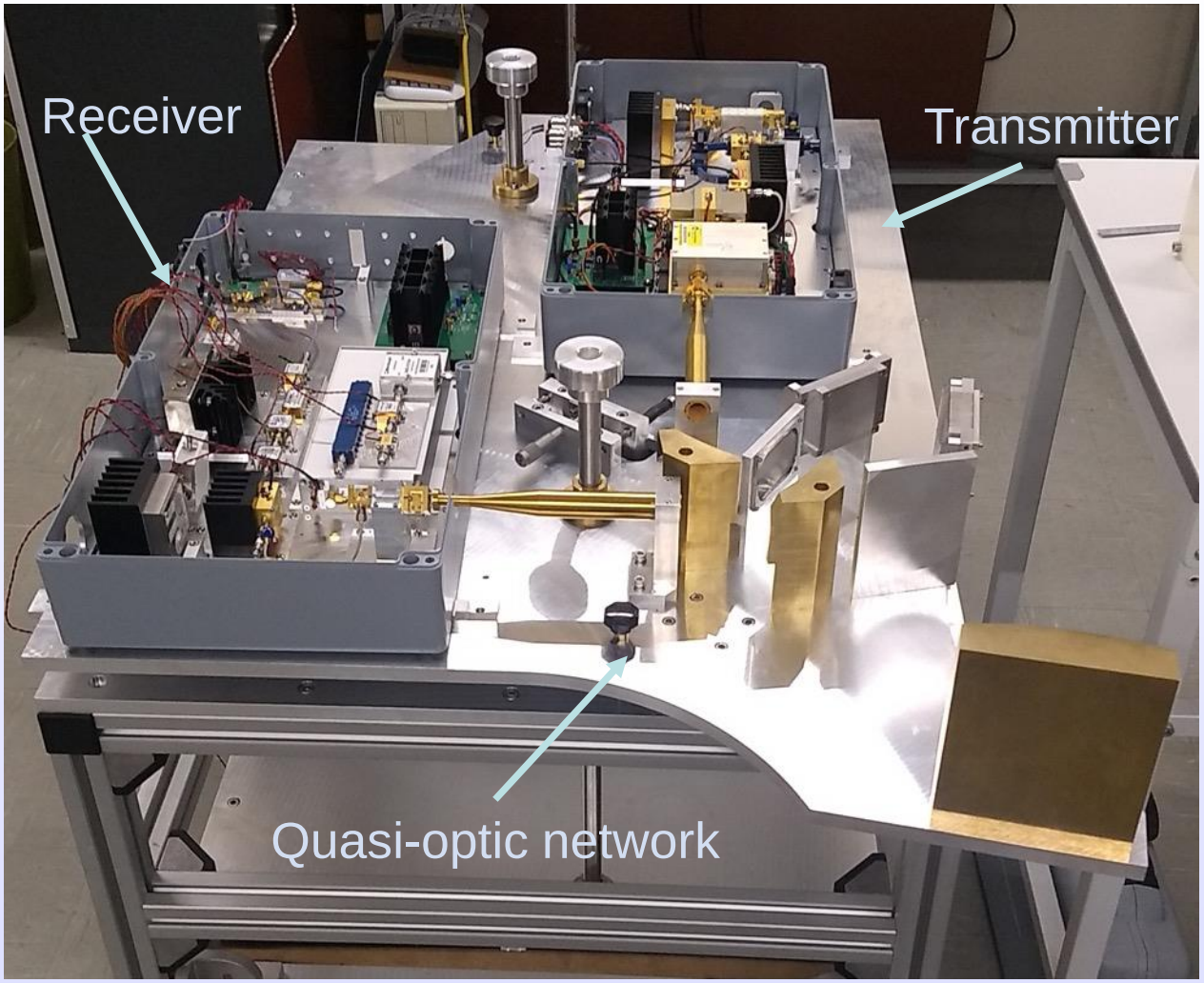
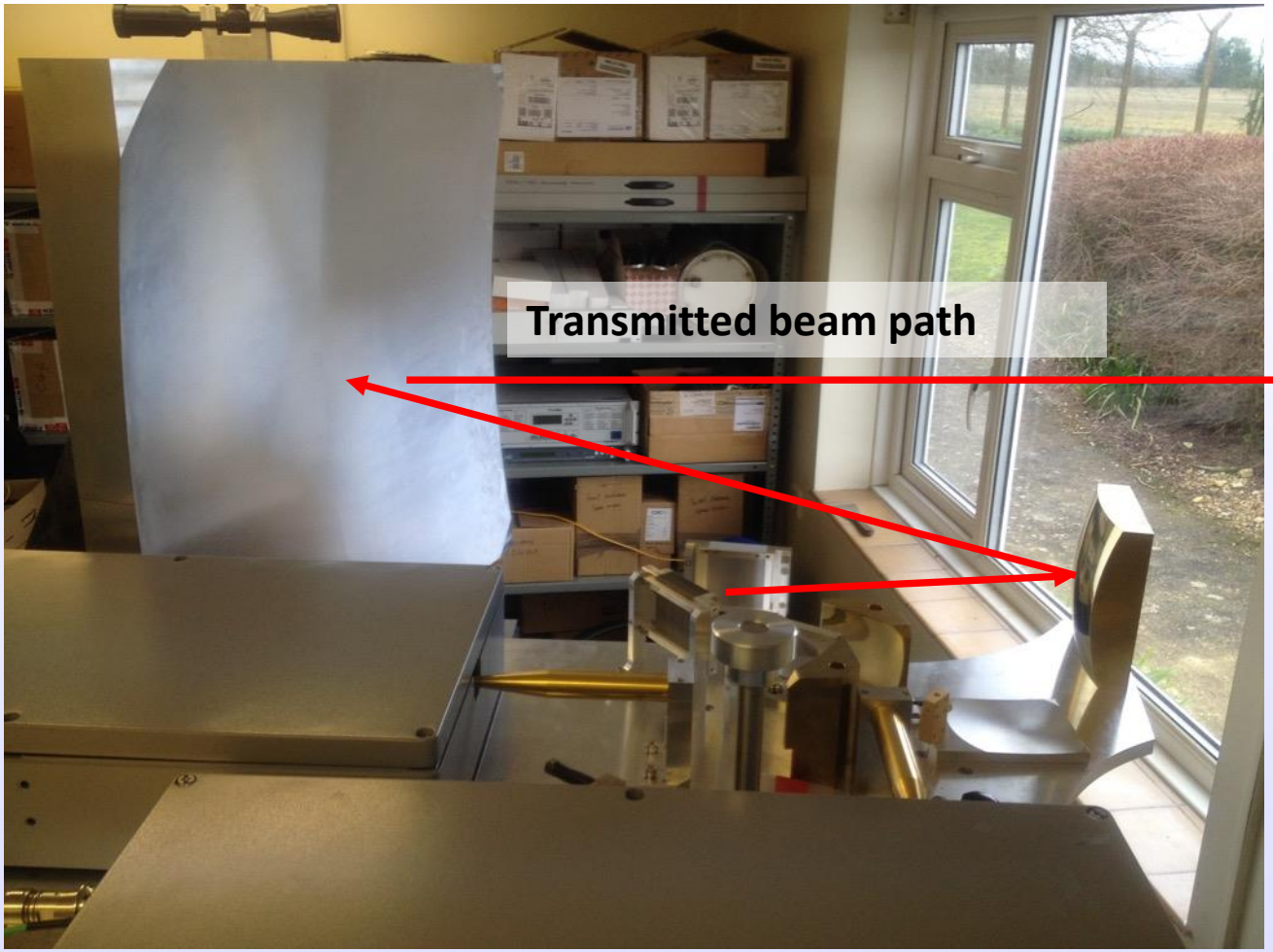


Optics



Quasi-Optic Network

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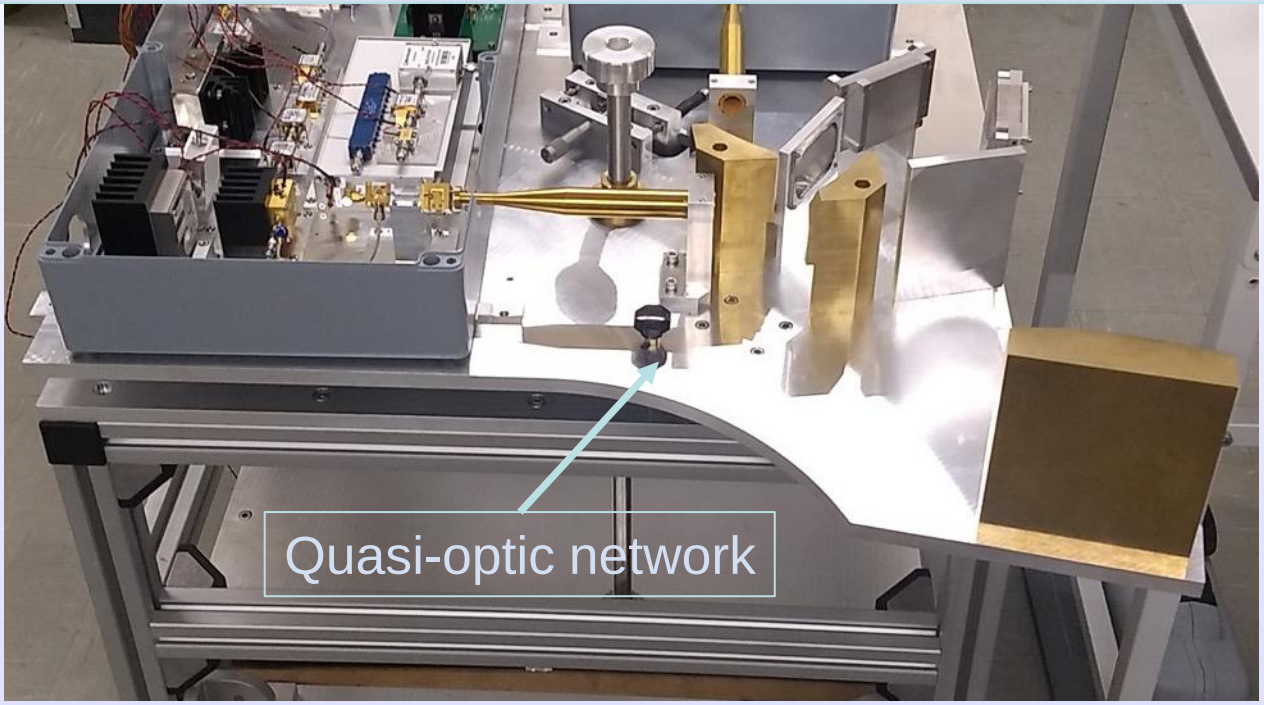
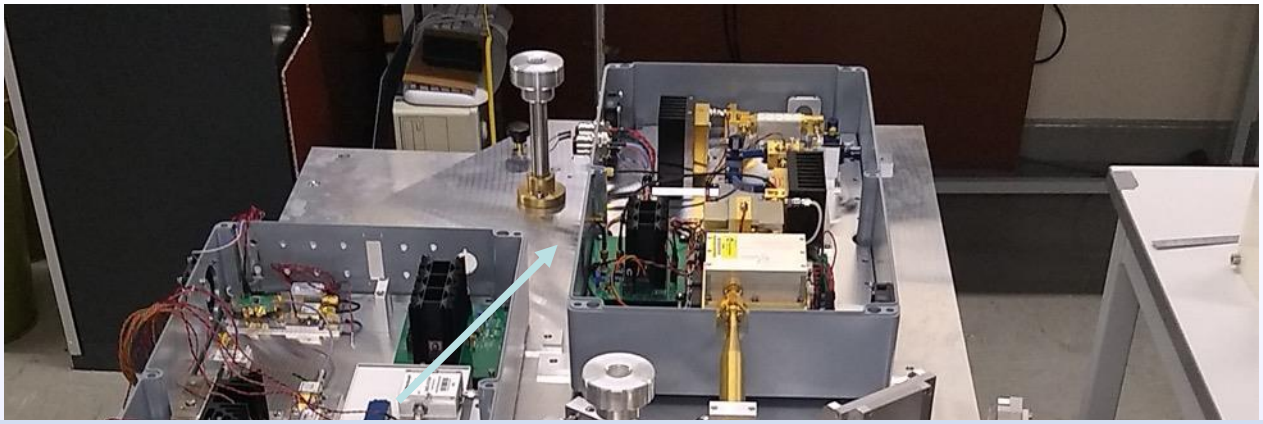
Quasi-optic network allows transmitter and receiver to share common antenna

- **Corrugated feedhorns: measured single pass insertion loss at 200 GHz is ≈ 0.35 dB**
- **Network insertion loss at 200 GHz is ≈ 1.2 dB**
- **Reflective polarisation rotation gives Tx to Rx isolation > 60 dB**
  - **Prevents a high power transmitter destroying the receiver**

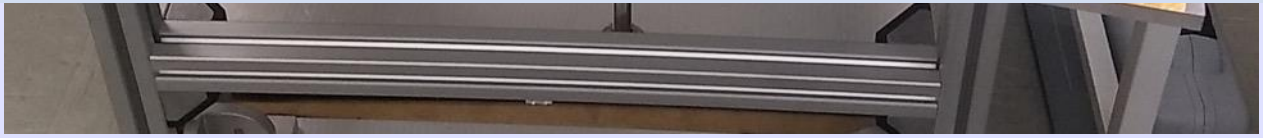


Transmitter

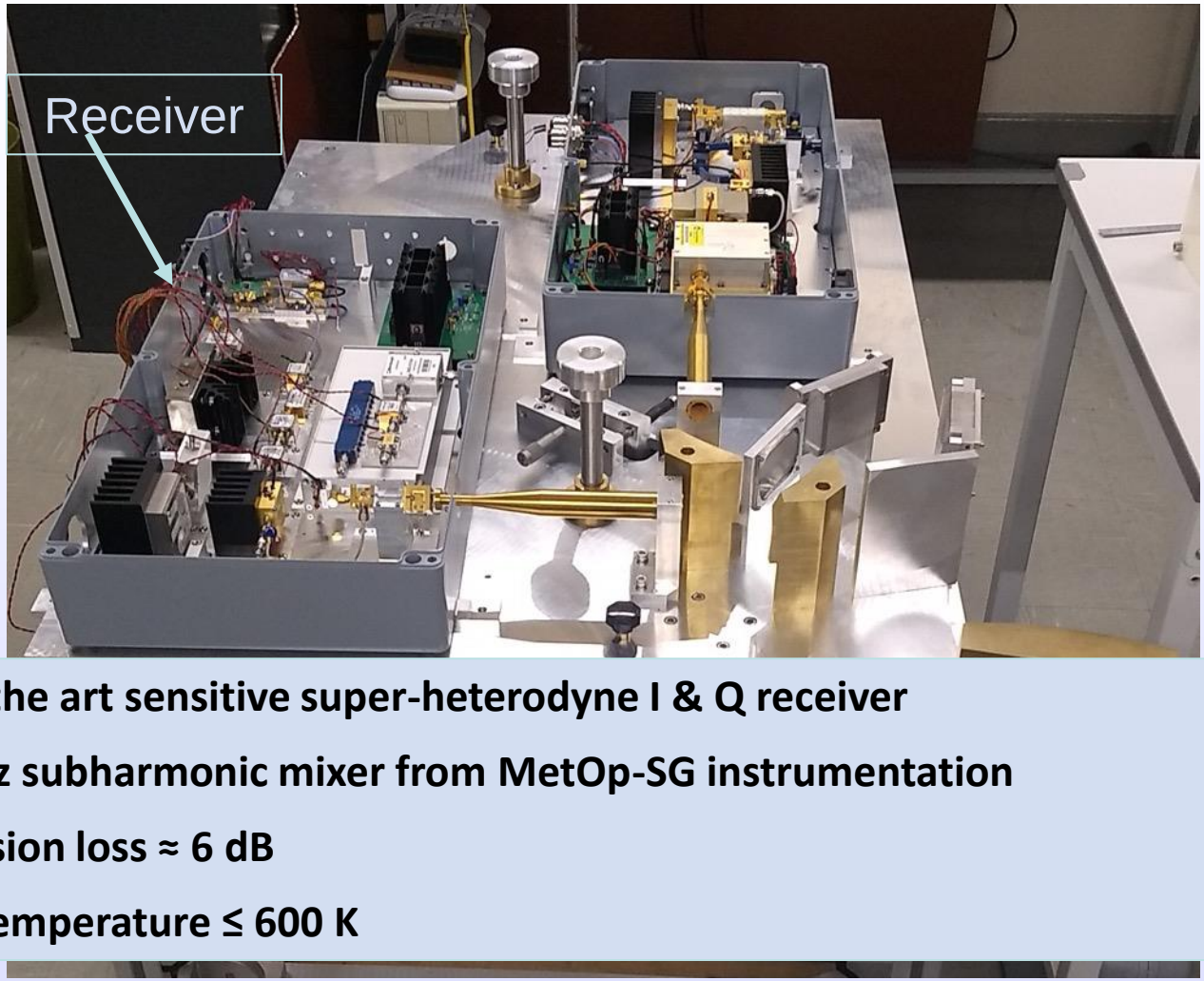


High power solid state transmitter

- **100 GHz QuinStar power amplifier**
- **Teratech frequency doubler**
- **Pulse lengths 10 ns to 300 ns via fast pin switch at 33 GHz**
- **Range resolution 3 m to 100 m**
- **Peak transmitted power 80 mW**



Receiver



State of the art sensitive super-heterodyne I & Q receiver

- **200 GHz subharmonic mixer from MetOp-SG instrumentation**
- **Conversion loss ≈ 6 dB**
- **Noise temperature ≤ 600 K**

Installation

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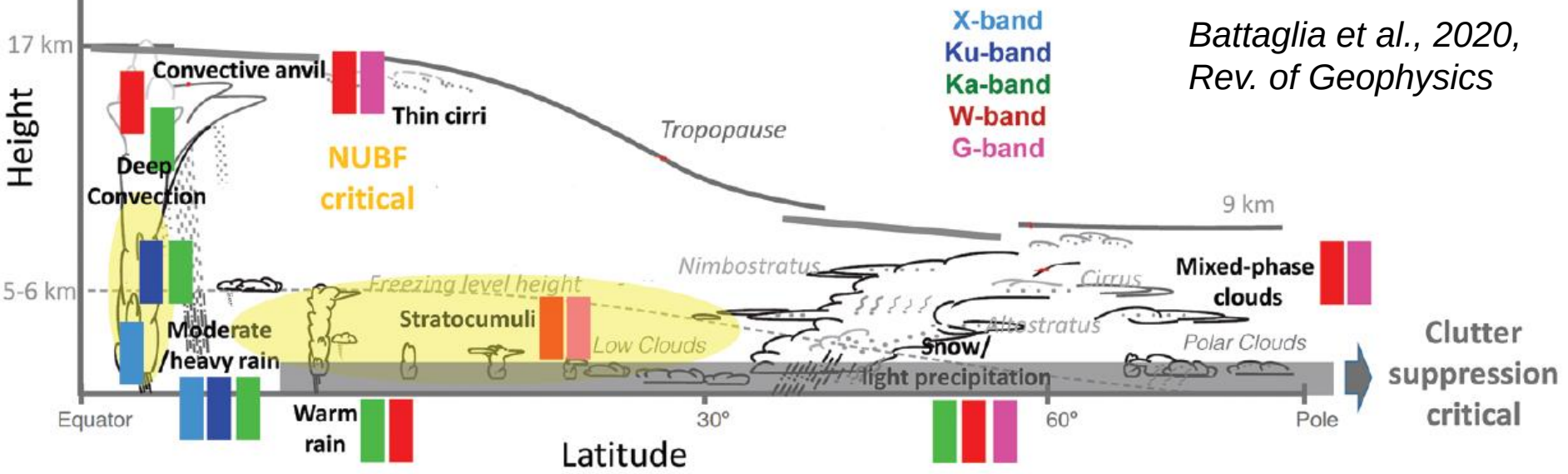
This window pane is removed during operation

Science Case

Problem: limited understanding of cloud feedbacks 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 needed

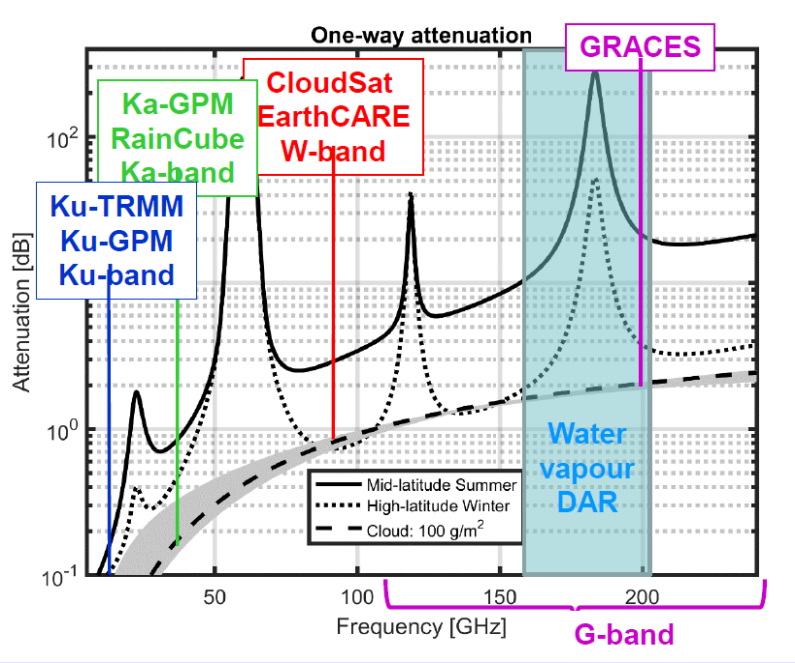


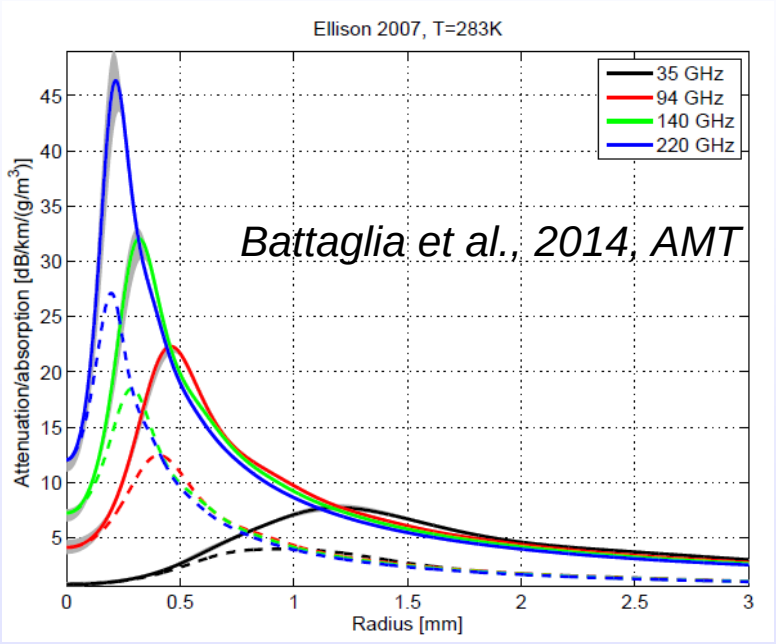
Battaglia et al., 2020, Rev. of Geophysics

Solution: combination of multi-frequency (Doppler) radars with frequencies ranging from 10 to above 200 GHz allows characterizing from heavy precipitation particles to small-size ice crystals. Inclusion of G-band (1.5 mm) highly beneficial in three areas: ***boundary layer clouds, cirrus and mid-level ice clouds and precipitating snow***.

Science Case

Main drawback: clouds and atmospheric gases produce strong attenuation at G-band
➔ use recommended in cold season/high altitude or in air/space-borne deployments.





Currently the only other radar system above 100 GHz worldwide is VIPR (Vapor In-cloud Profiling Radar), a differential absorption radar operating in the 183 GHz absorption band, developed at JPL *(Cooper et al, JTech 2020).* Attenuation can be used as a source of information.

Cloud detection: comparison with collocated 94 GHz Galileo radar

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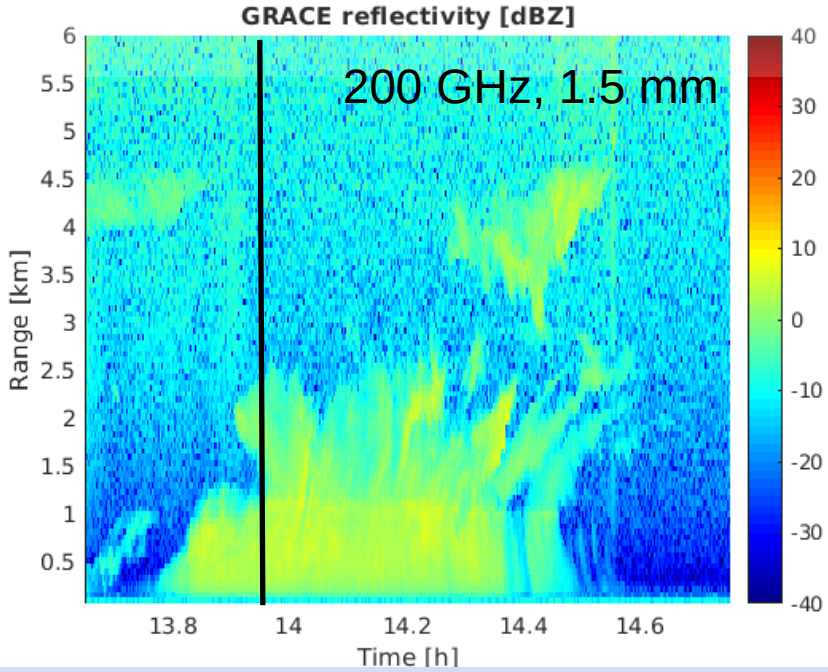

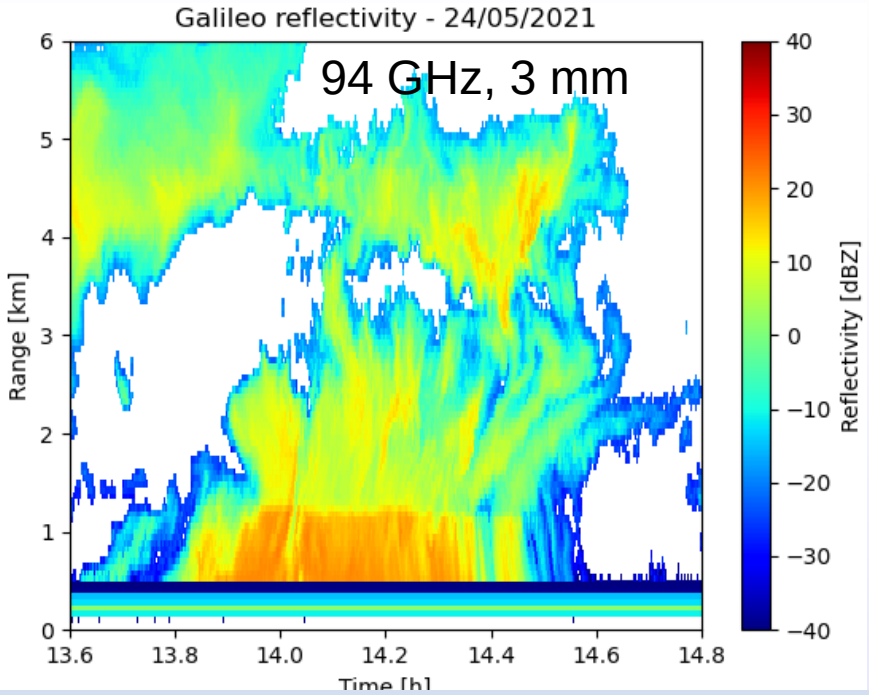

- **Rain event on May 24th, freezing level at around 1 km (UK "summer" atmosphere conditions).**
- **For 2 second averaging, 60 m range resolution, sensitivity limit ≈ 0 dBz at 4 km range (less than expected, on-going work to improve that).**
- **GRACE reduced reflectivity results from attenuation and non-Rayleigh effects (which will provide the additional information for microphysical characterization).**
- **Less ground clutter compared with 94 GHz system: much better short range performance.**

First-ever Doppler spectra at G-band

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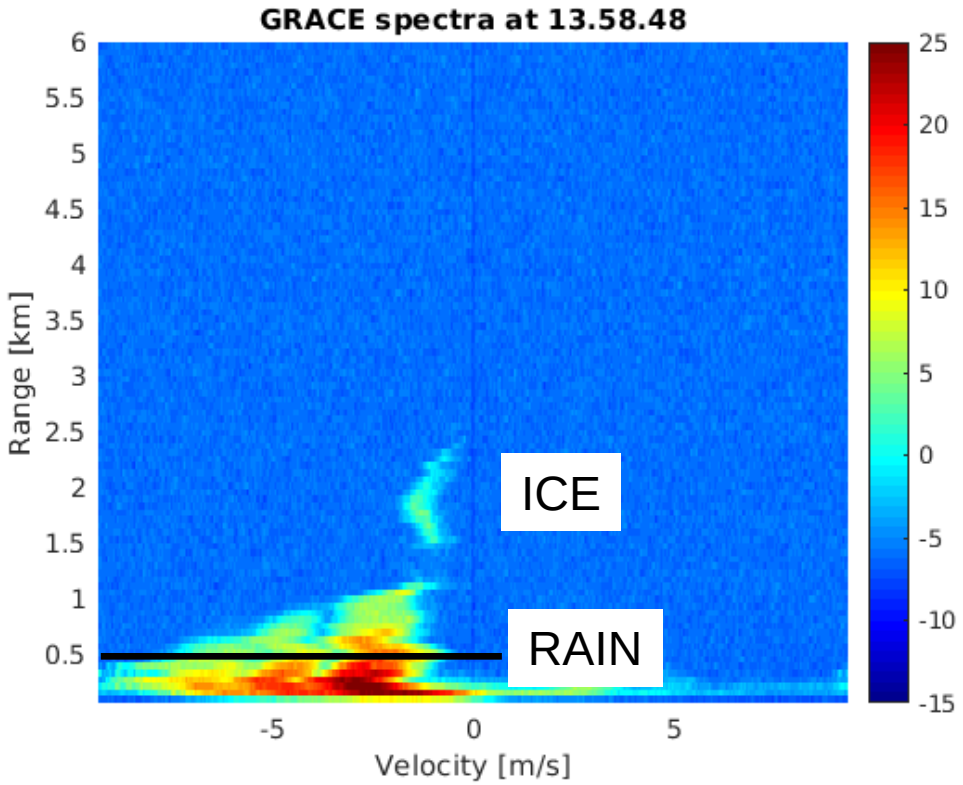
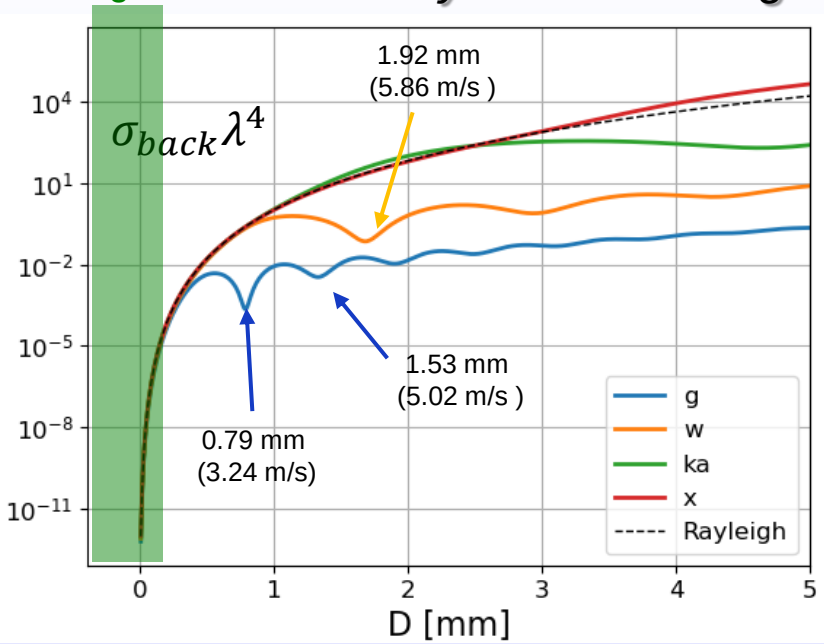


G-band Rayleigh targets

Mie theory backscattering



Clear transition from ice to rain in fall speeds

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"

W and G-band Doppler spectra

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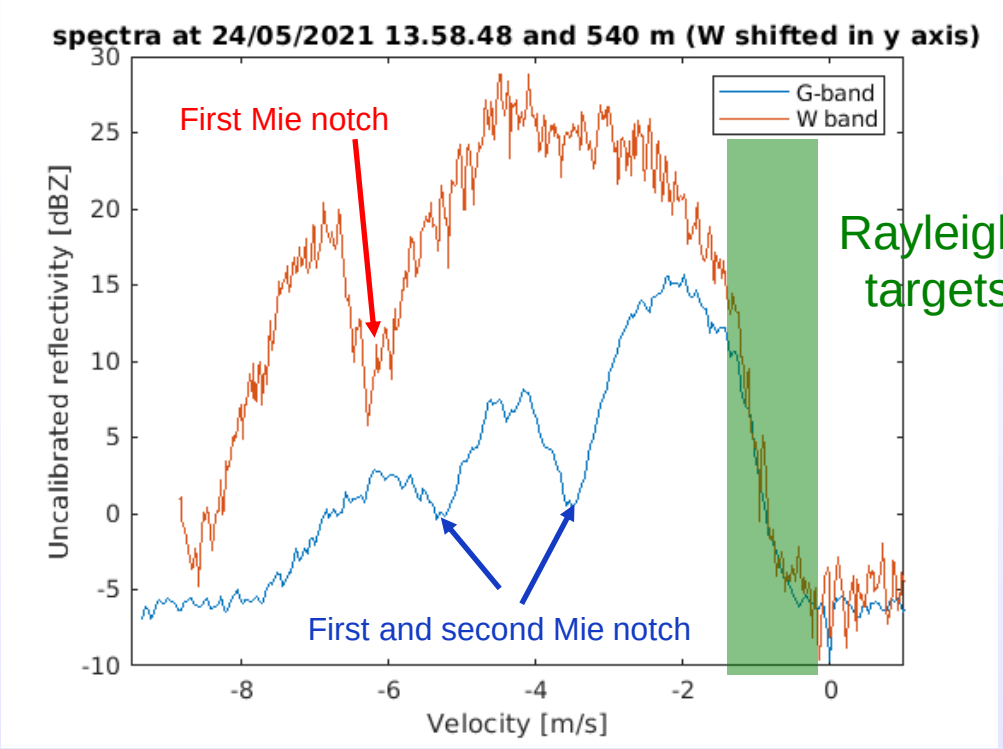

GRaCE Doppler spectra shows the first Mie notch at ~3.5m/ s, with a second Mie notch at ~5.3 m/s both consistent with 0.27 m/s downdraft. Benefits:

1) Unprecedented possibility of retrieving vertical winds for light rain (several situation when no Mie notch at W-band is detected)

2) Retrieval of drop size distribution for light rain

Conclusions

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- 200 GHz GRaCE radar hardware completed and the instrument has been deployed at Chilbolton Observatory.
- First 200 GHz atmospheric returns have been obtained, and comparison with a co-located kW pulsed radar allows sensitivity estimation of 0 dBz at 4 km altitude.
- First-ever 200 GHz Doppler spectra extracted from processing of IQ data

Acknowledgements / The Future

GRaCE is grant funded by the UK Space Agency through the UK Centre for Earth Observation Instrumentation

- Work on a follow-on GRACES NERC grant, with Universities of Reading and Leicester, has commenced
- Strong export possibilities/contract under negotiation (TK) for spacecraft demonstrator in Shanghai, China
- ESA is now funding a study for deploying a G-band radar in space (UoL)