G-band radars: status and opportunities for future space missions

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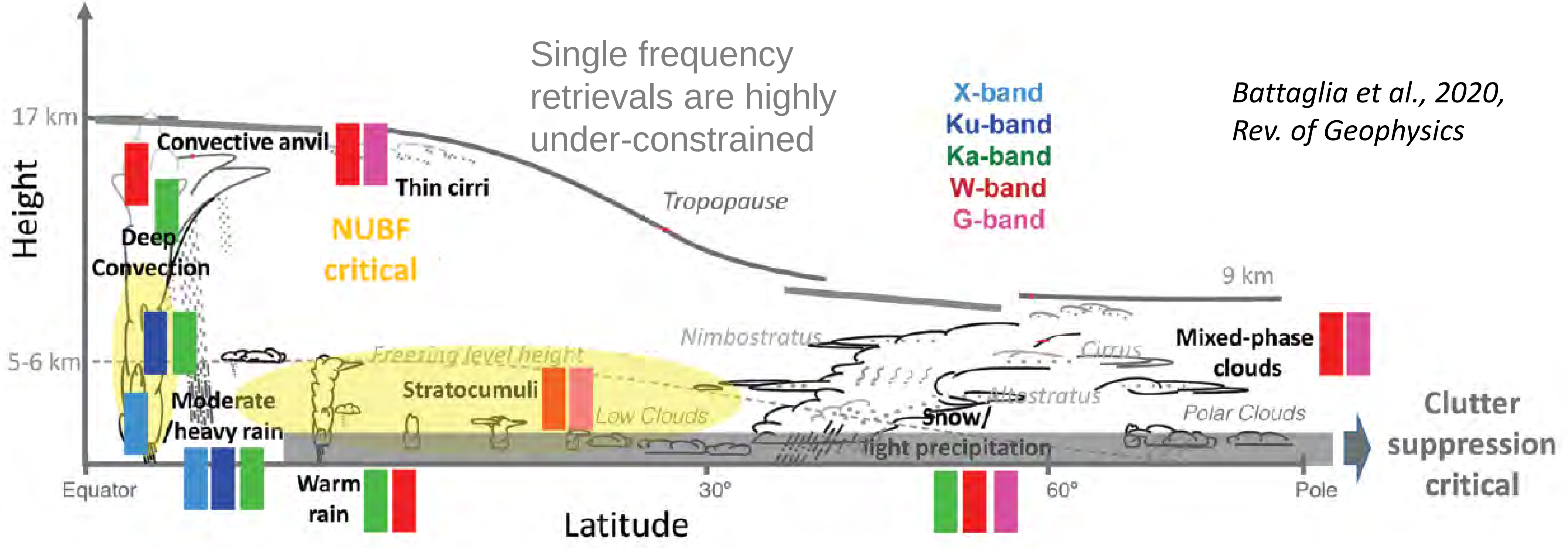
Outline

1. Science background
2. G-band: window and differential absorption radars
3. First-light measurements from recently built G-band systems
4. Potential for space missions

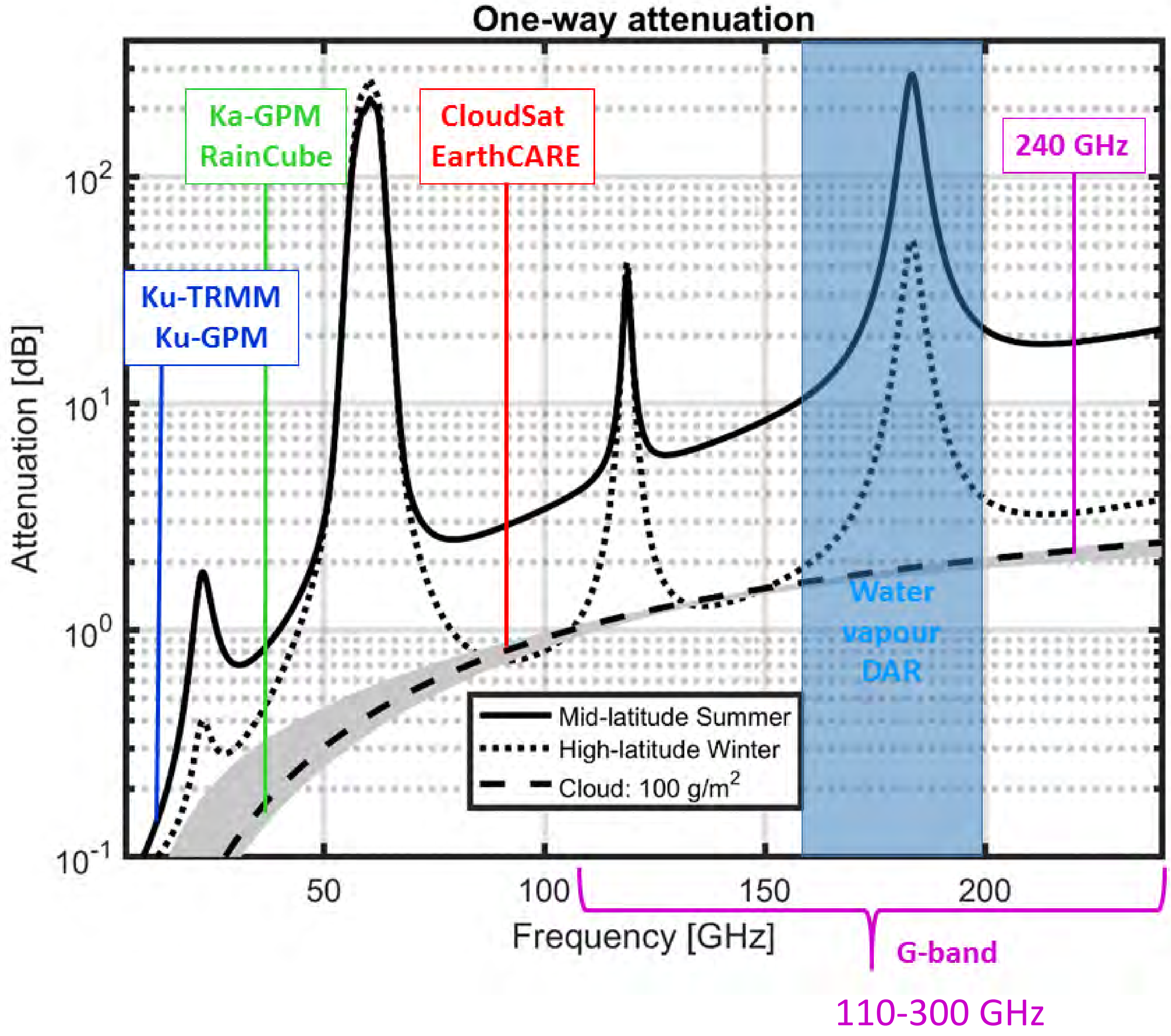
Science case for cloud&precipitation observations

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 and microphysics needed



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***.

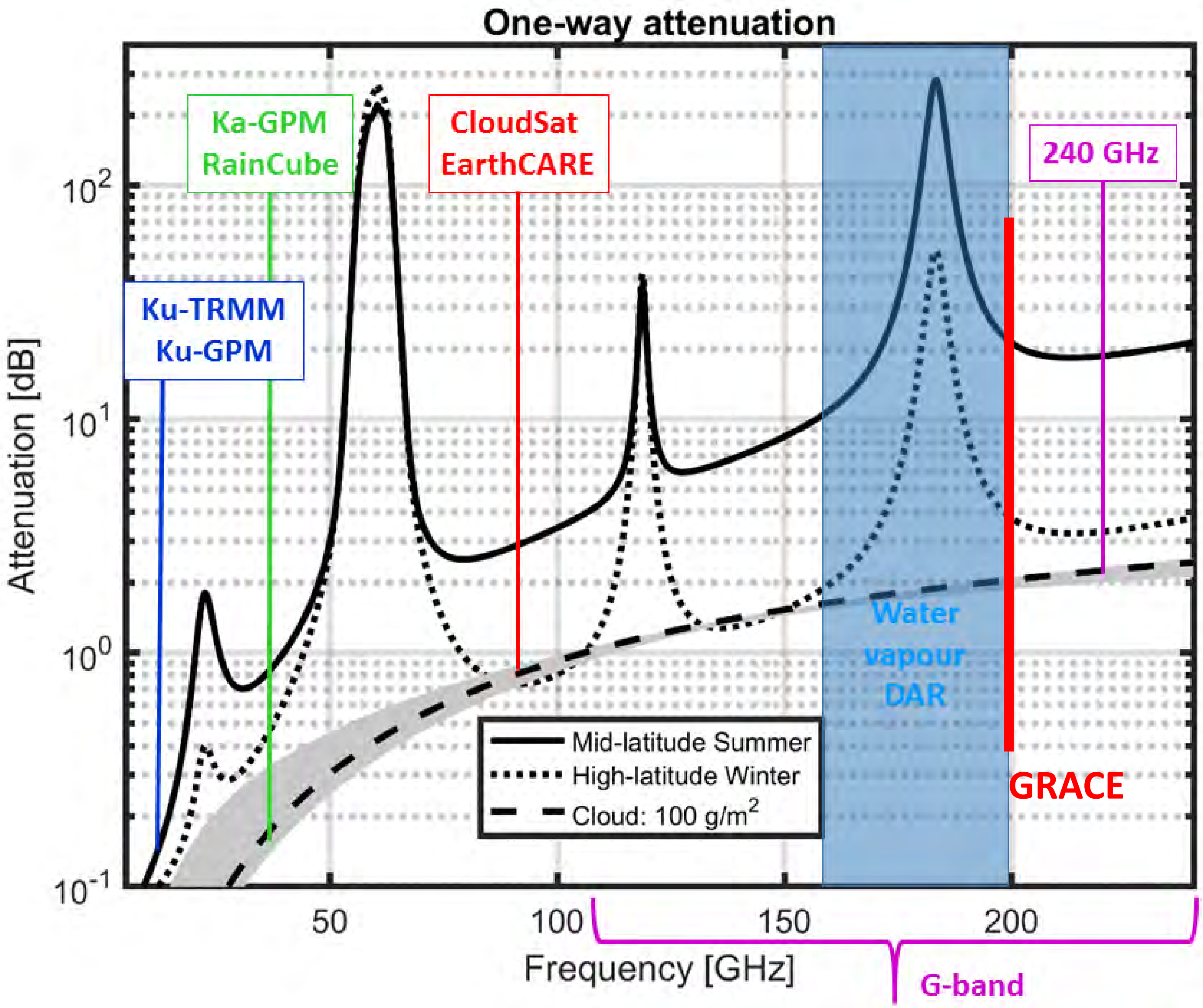
G-band in the cloud&precipitation radar arena



- Cloud radars at 140–215 GHz more than 30 years ago! (*Nemarich et al., 1988; Mead et al., 1989; Wallace, 1988)*
- Notional studies *(Lhermitte 1989, Hogan and Illingworth 1999, Battaglia et al., 2014).*

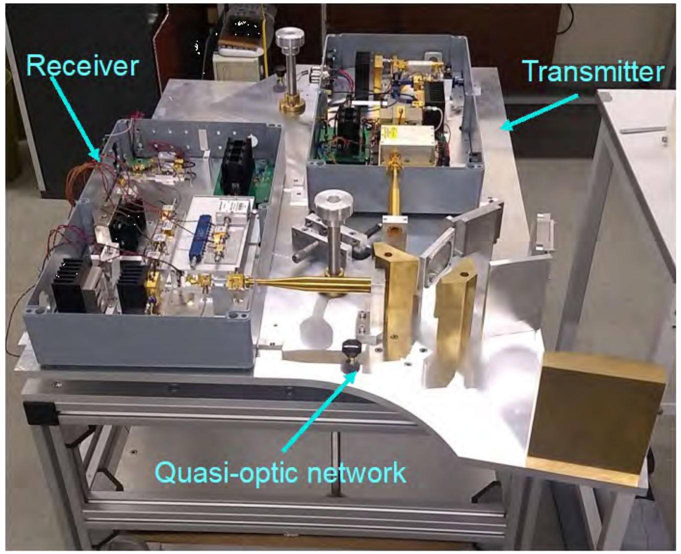
Game changer: mm- and sub-mm solid state power devices and low noise amplifiers have recently enabled higher frequency radar capable of achieving sensitivities good enough for cloud studies.

G-band: window radars



Window frequencies➔ Ice and light rain microphysics

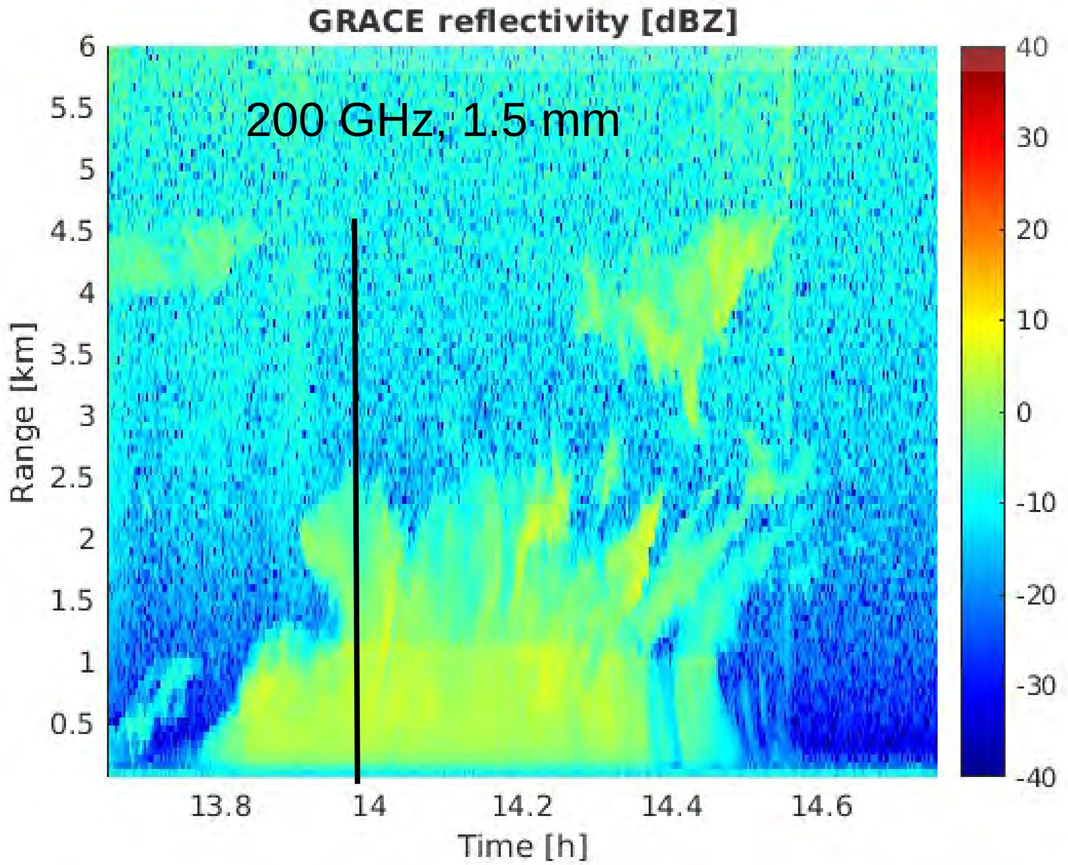
The UK-CEOI G-band Radar for Cloud Experiment (GRACE) (partners involved: RAL Space, STFC Rutherford Appleton Laboratory with Thomas Keating Ltd., University of Leicester & University of St Andrews) has developed a prototype ground-based, zenith looking 200 GHz Doppler cloud radar.

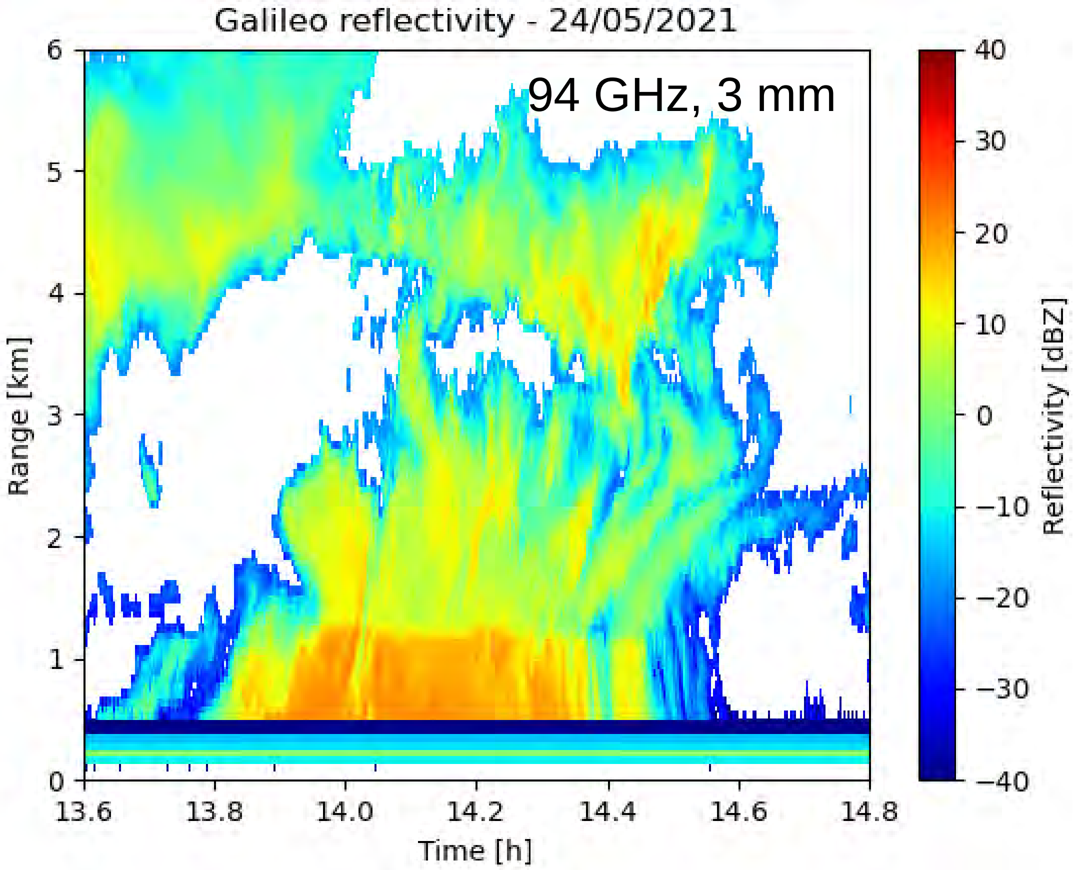


Currently deployed at Chilbolton observatory

First light of GRACE system in Chilbolton

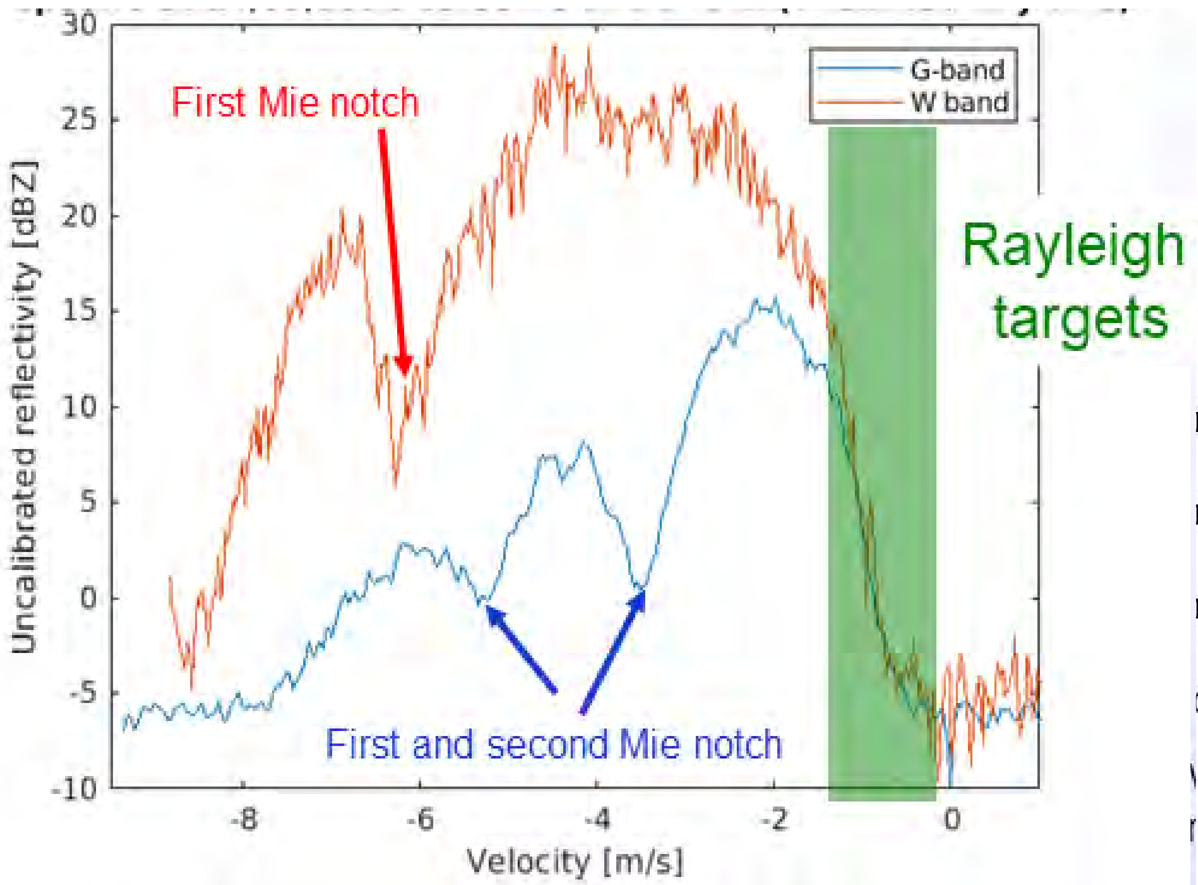
Courier et al., 2021, GRL

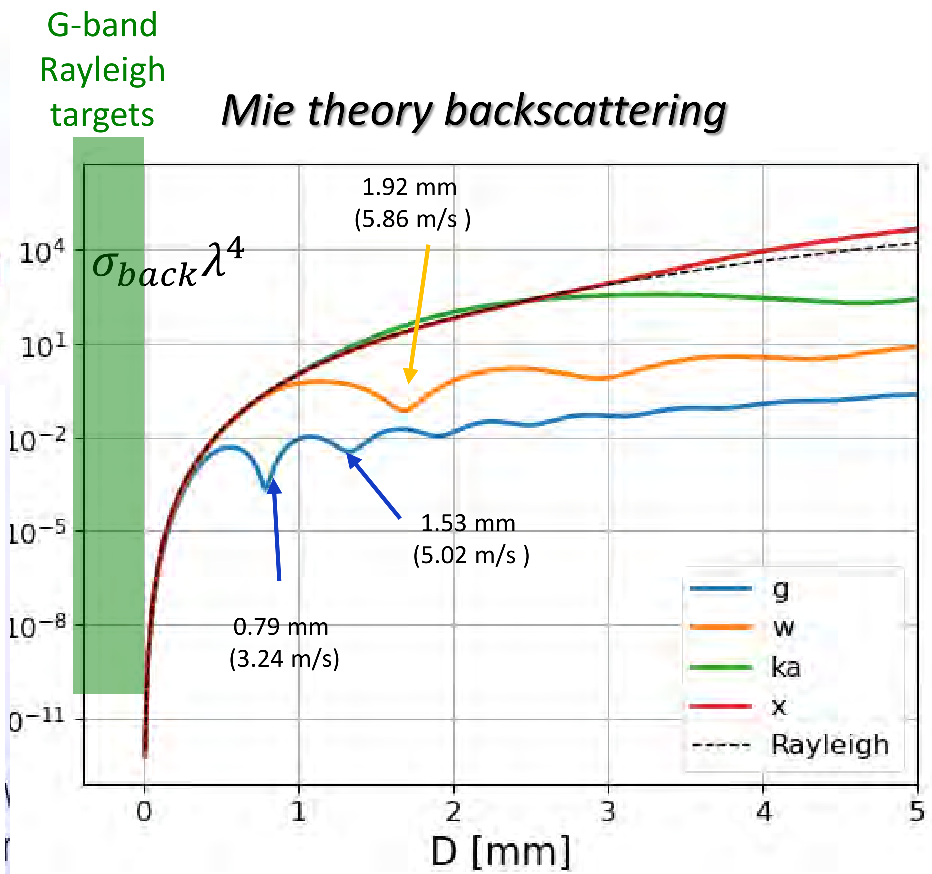




- **Rain event on May 24th, freezing level at around 1 km (UK "summer" atmosphere conditions).**
- **GRACE reduced reflectivity results from attenuation and non-Rayleigh effects.**
- **Sensitivity of GRACE not as good as VIPR (system is undergoing upgrade)**

First-ever Doppler spectra at G-band



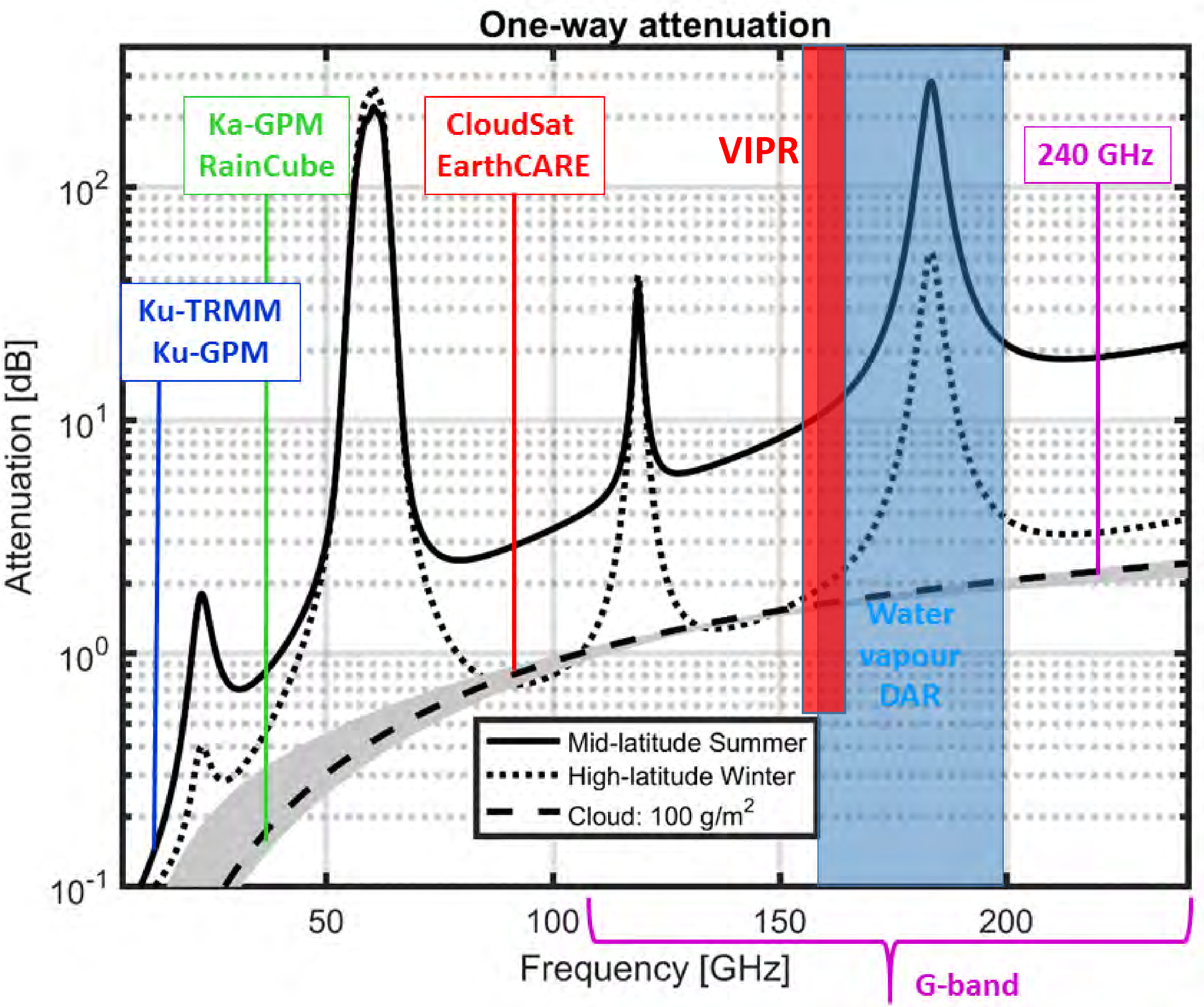


Clear transition from ice to rain in fall speeds

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"

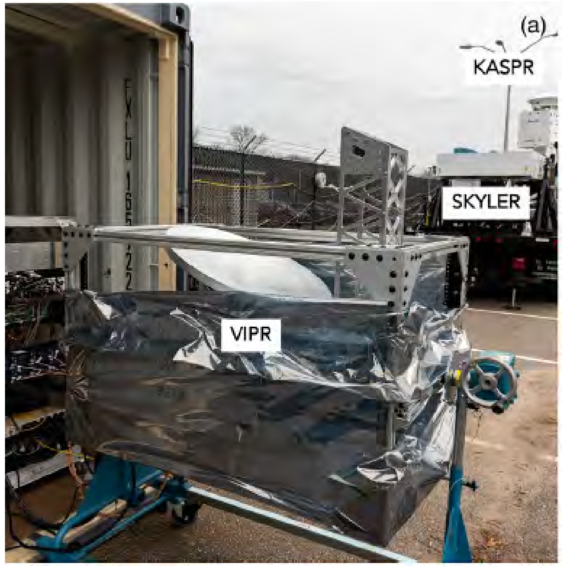
The decrease in backscattered power with respect to lower frequency can be used to size particles

G-band: differential absorption radars



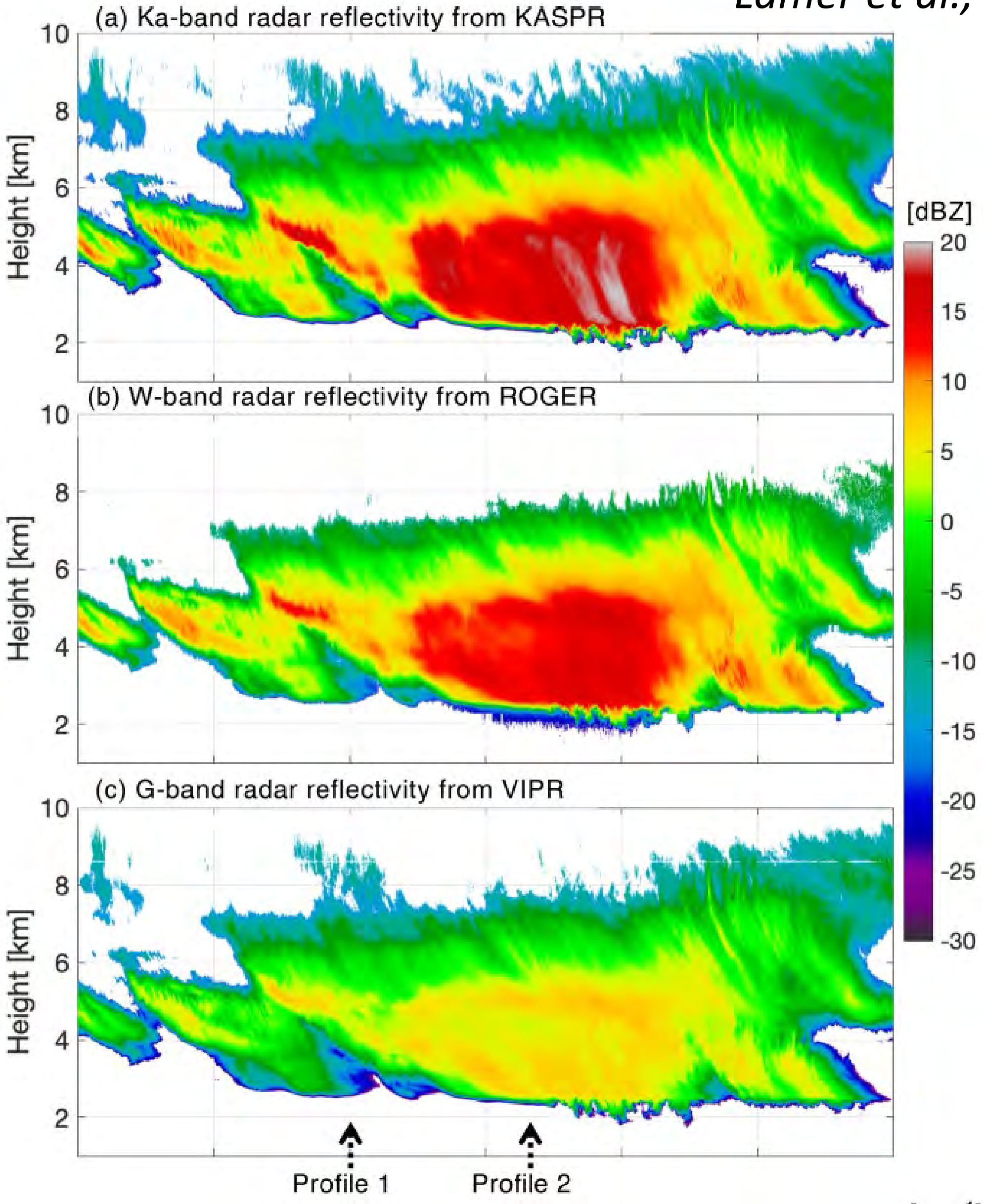
Absorption band freq ➔ water vapour profiling in the 183 band

The JPL Vapor In-cloud Profiling Radar (VIPR) demonstrated the possibility of operating a radar system in differential absorption mode with tones within the 183 GHz water vapour absorption band (*Cooper et al., 2018, Roy et al., 2018*).



First multi-frequency G-band radar observations of ice clouds

Lamer et al., AMT, 2021



Ka-band

W-band

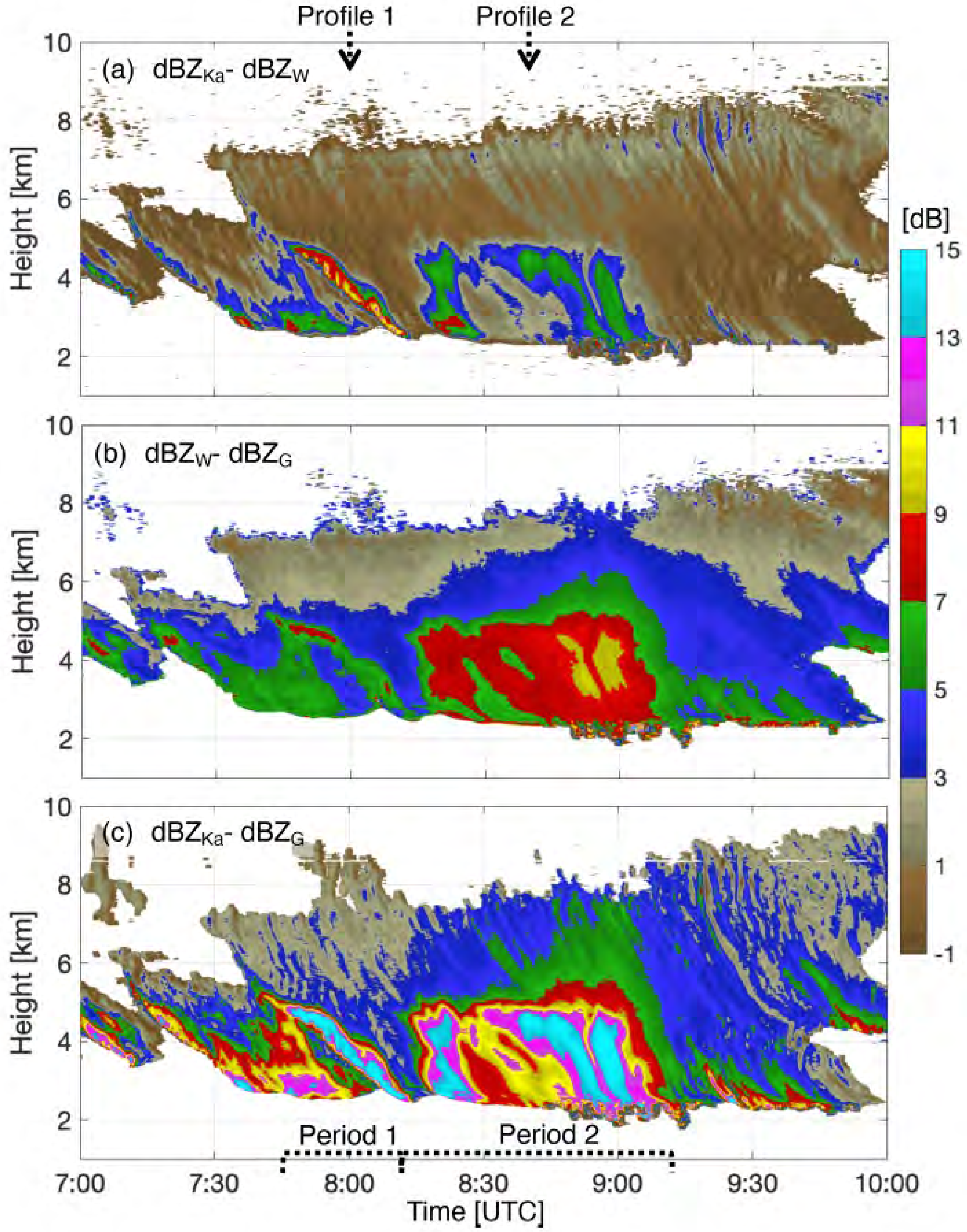
VIPR G-band (167 GHz)

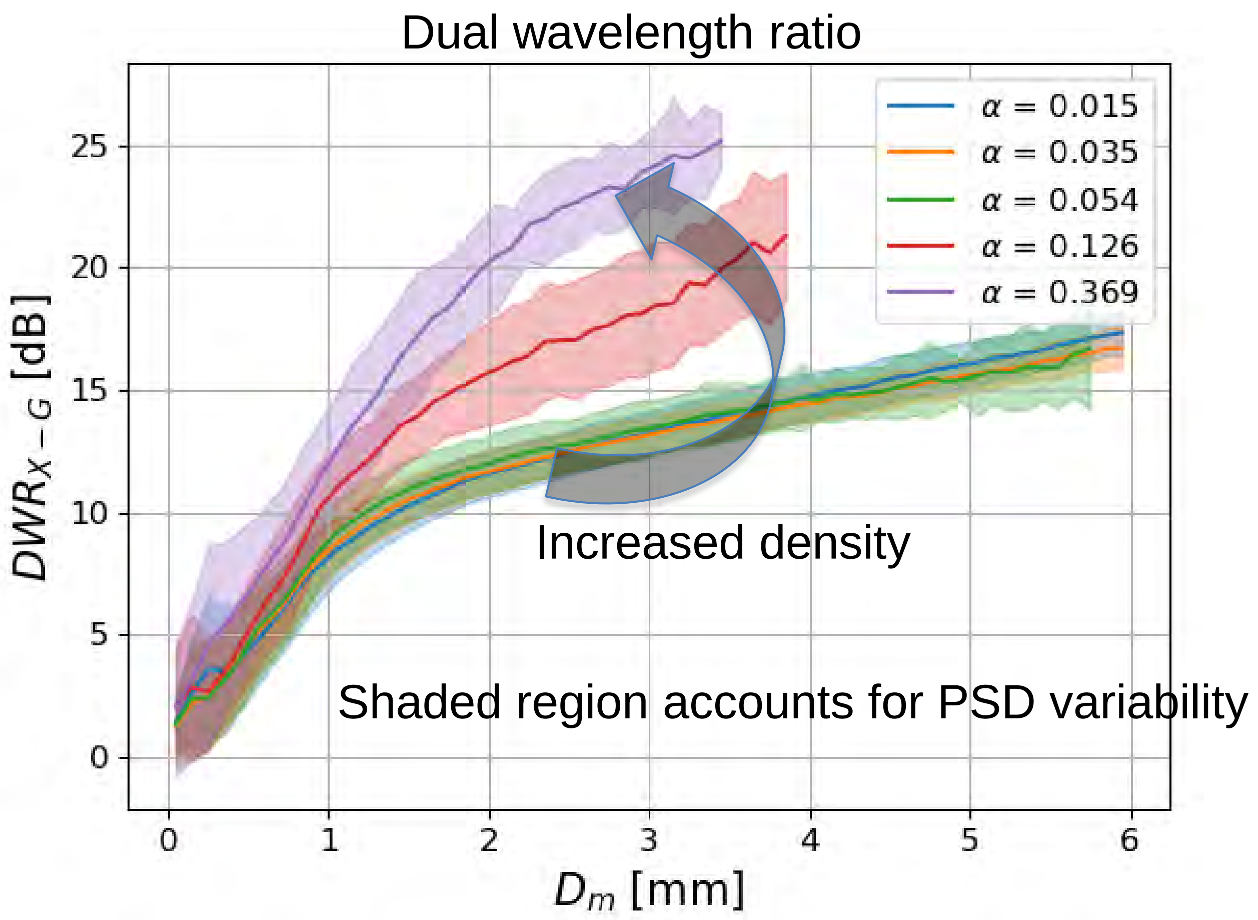
Two days of data collected during February 2020 at the StonyBrook Radar facility

The nice old pre-Covid19 times …

G-band radars can be made sensitive enough to probe clouds and light precipitation in spite of the strong water vapour attenuation occurring at this frequency (VIPR has sensitivity similar to KASPR).

First multi-frequency G-band radar observations of ice clouds





Larger DWRs ➔ G band observations have potential for quantitative retrievals of smaller size crystals compared to those achievable by using longer wavelengths.

ESA on-going space-borne G-band studies

A G-band system could be flown in space in constellation/formation with other cloud radars (e.g. those to be deployed in the NASA-JAXA EarthCARE or the polar component of the NASA A-CCP mission) and/or with passive microwave high frequency systems (AWS, ICI).

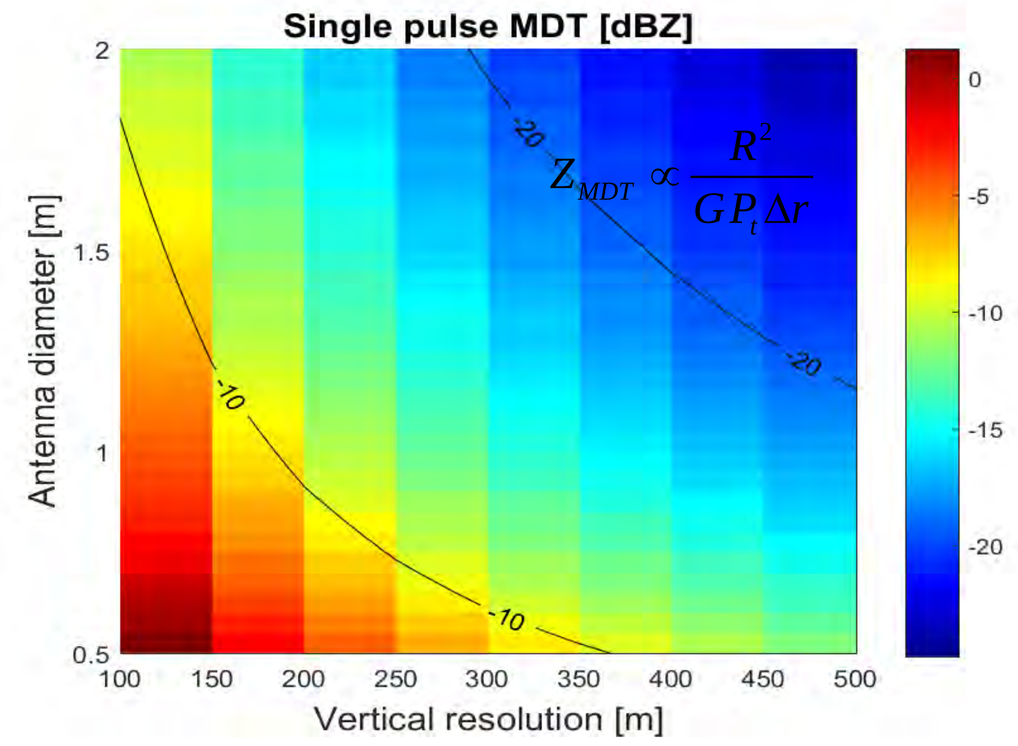
Three research avenues are currently explored

1) **Quantify the benefit of a W/Ka-G band Doppler radar in terms of ice/snow retrievals**. This underpins the idea that a dual-frequency radar instrument could act as calibrator for snowfall passive microwave radiometers (synthetic retrieval studies + field campaign data).

2) **Assess the potential of the synergy between a DAR G-band radar and high-frequency water vapour sounders** (calibration for the AWS constellation of water vapour profiling systems for the integrated water vapor in clear sky & cloudy conditions).

3) Investigate the **performances and technology feasibility of a DAR systems** that operate at even higher frequencies within the **sub-millimeter absorption lines** at **325 and 380 GHz**

Space-borne G-band specs and minimum detection threshold



Parameter	Space Radar
Transmit frequency	160 – 260 GHz
Transmit power	100 W
Transmitter Technology	EIK
Transmit polarisation / Receive polarisation	Circular
Main antenna diameter	≥2 m
Beam divergence	≈ 0.05°
Antenna Gain	70 dBi
Antenna sidelobe level	<-50 dB
Range resolution	500 m
Pulse length / coding	3.3 μs
Maximum instrument range	500 km
Receiver Noise Figure	6 dB
Receiver Technology	N/A
Single shot Sensitivity	-22 dBZ

Thus better sensitivity than CloudSat (EarthCARE) which have a single pulse MDT of –16.5 dBZ (-21.5 dBZ)

Conclusions and future outlook

- Progress in G-band technology is driving sensitivities to levels appropriate for cloud studies ➔ **G-band cloud radars** are now a **reality**.

- First ground-based demonstrators now acquiring measurements, with airborne demonstrators under constructions.

- Funded on-going ESA studies for a space-borne system considering different options:

  1. to be flown in constellation with lower frequency radars (already planned by NASA/JAXA/ESA) to better characterize ice microphysics and high latitude precipitation processes (Explorer opportunities);

  2. to be flown in constellation with passive microwave radiometers (like those of the Arctic Weather Satellite constellation) for profiling relative humidity (Copernicus operational applications)