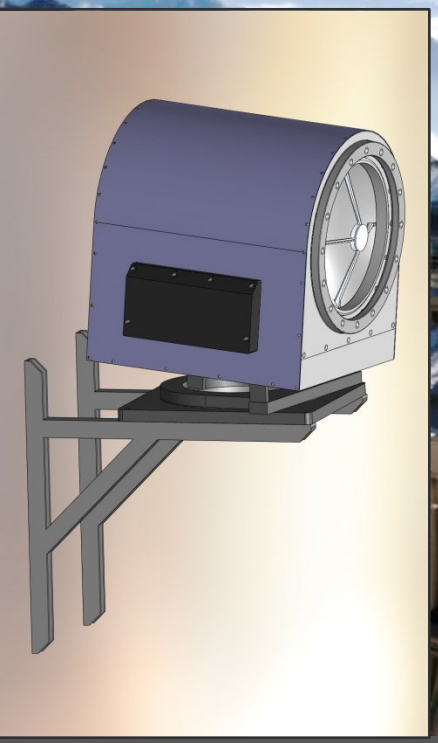
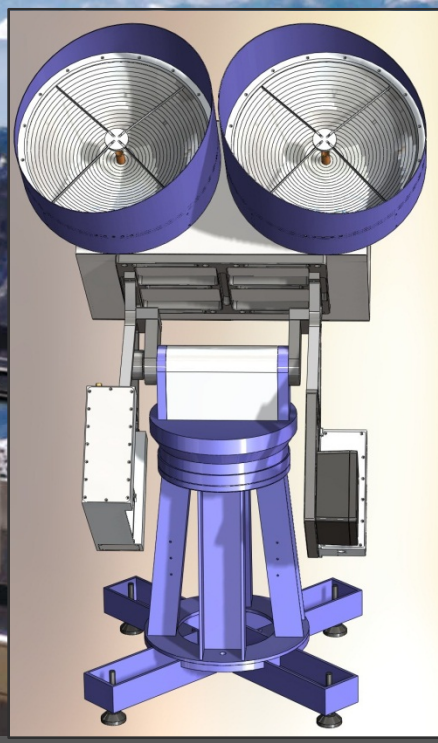
Microwave Remote Sensing of the Boundary Layer





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1: RPG Radiometer Physics GmbH, Meckenheim, Germany

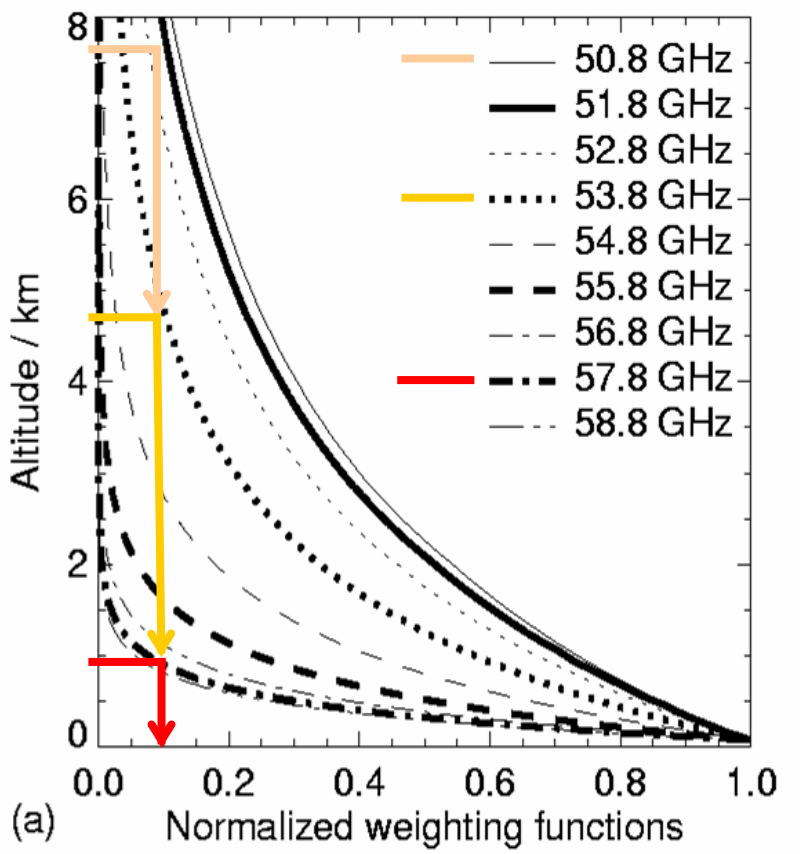
2: Wageningen University, Wageningen, The Netherlands

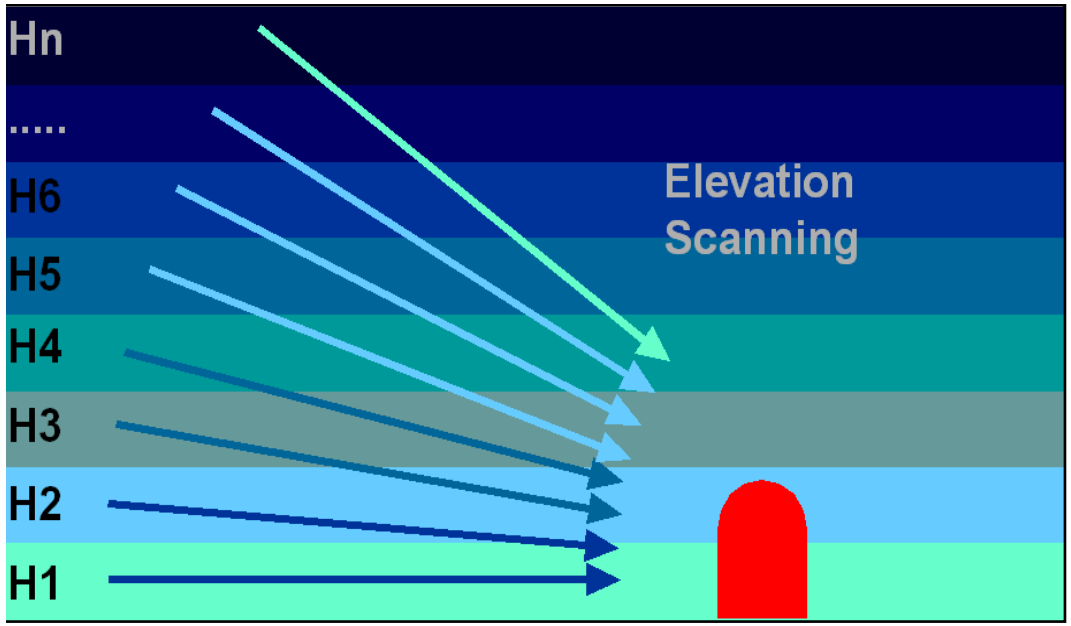
Outline

- **Passive** microwave radiometer for Boundary Layer (BL) T-profiling:
  - The concept of elevation scans with saturated channels
  - The expected signal
  - Requirements on instrument design / receiver improvement
- **Active** / Scintillometry:
  - Concept of direct measurement of latent heat flux (evapotranspiration) *(when combined with optical scintillometer)*
  - Design of Transmit/Receive system at 160.8 GHz
  - Prototype assembly
- **Active** / FMCW cloud radar at 94 GHz
  - Concept, design drivers
  - Preliminary Instrument specifications
- **Summary / Conclusions**

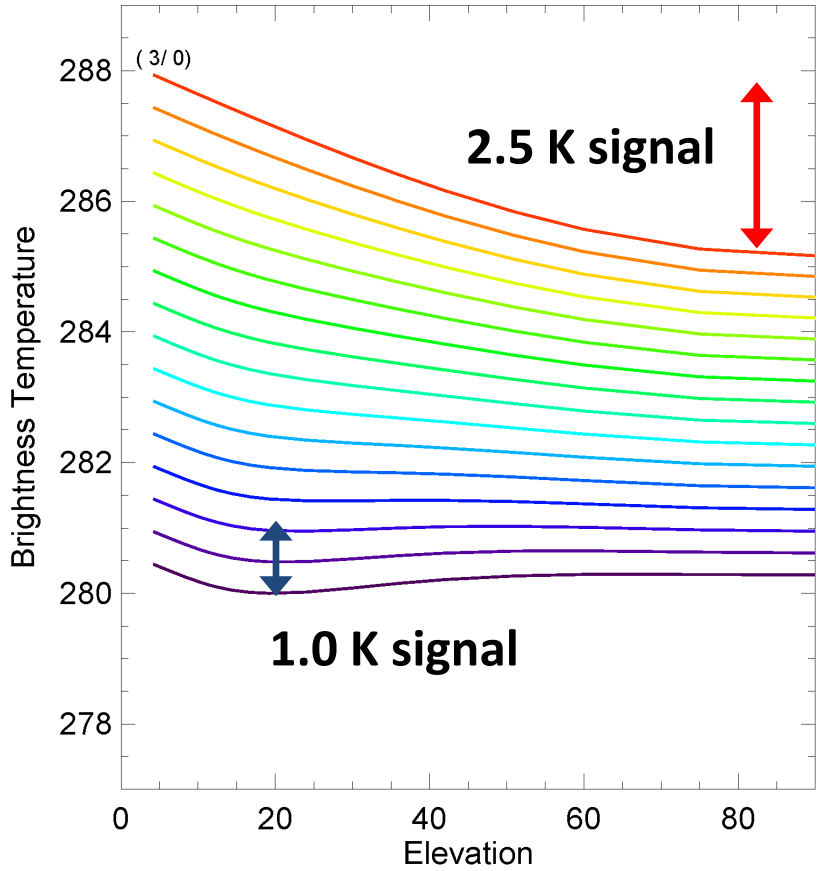
µ-wave BL-Temperature Profiling: The Concept

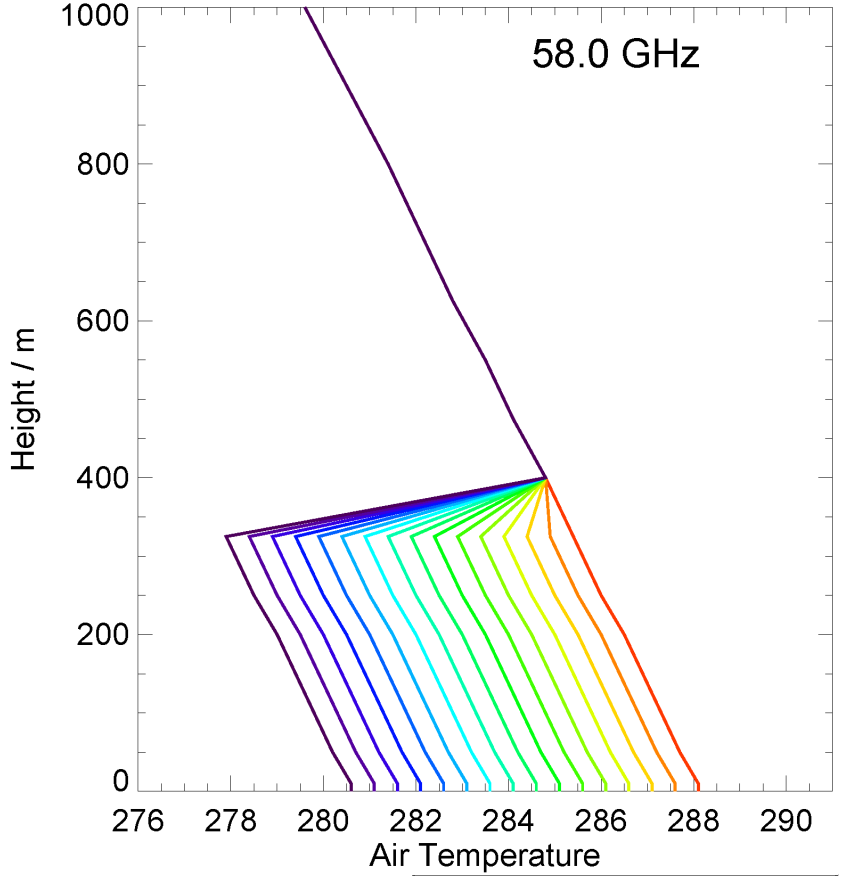
- Absorption length decreases for frequencies at line center (60 GHz)
- Limited (approx. 600 m) emission depth @ 58 GHz
- Weighting functions shifted towards surface by elevation scans

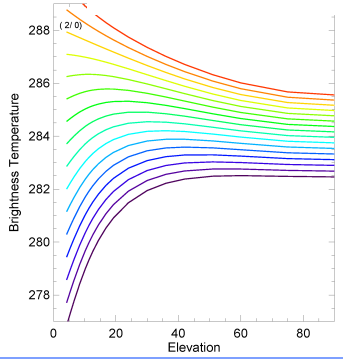


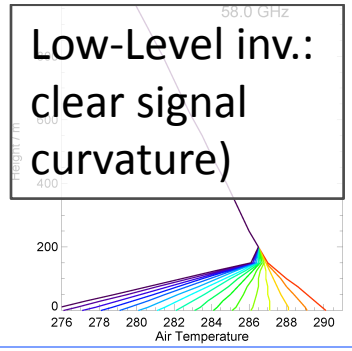


Simulated TB Signature of BL-T-profiles

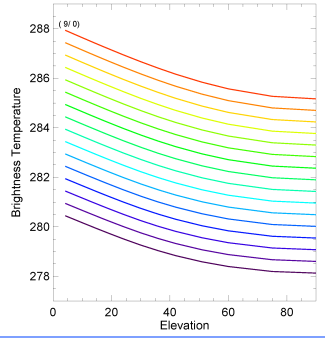


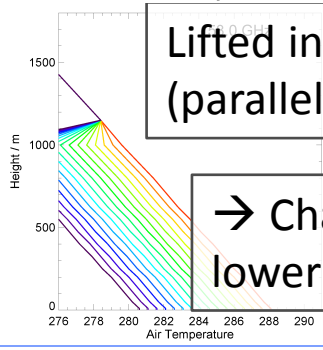






Low-Level inv.: clear signal curvature)



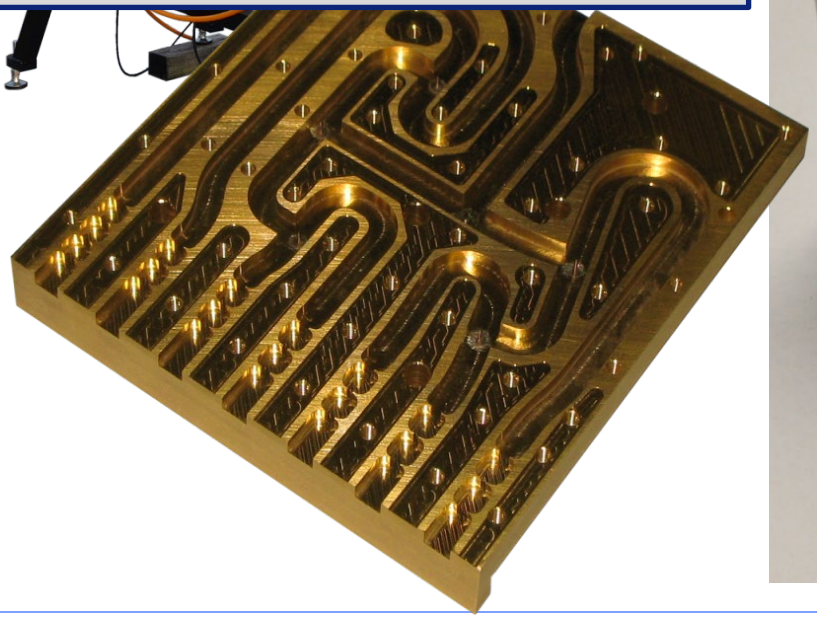


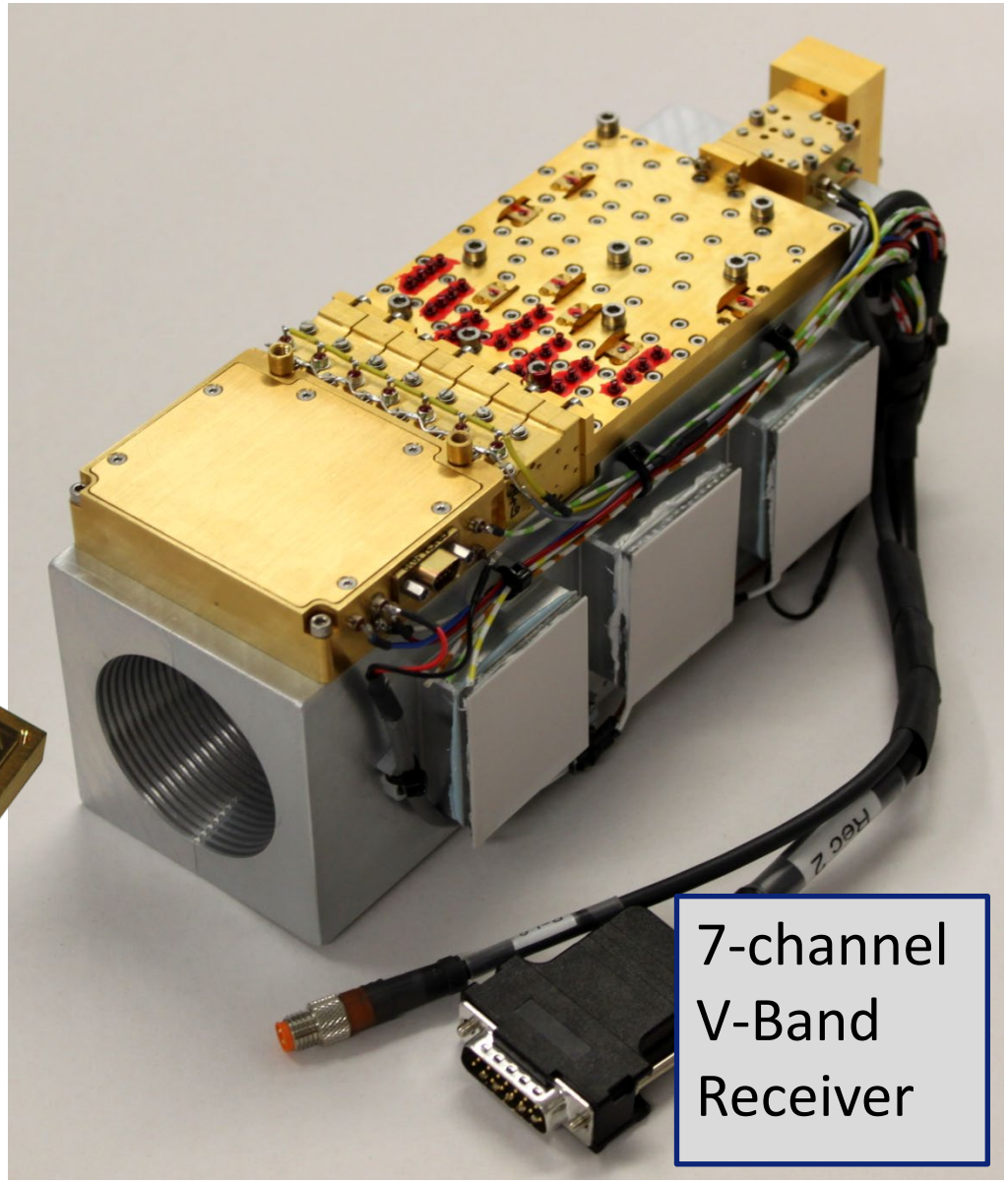
Lifted inv. difficult (parallel lines)

→ Channels with lower saturation

µ-wave BL-Temperature Profiling: The Instrument

HATPRO Direct Detection
Filterbank Profiler
(parallel data aquisition 14 ch.)





7-channel
V-Band
Receiver

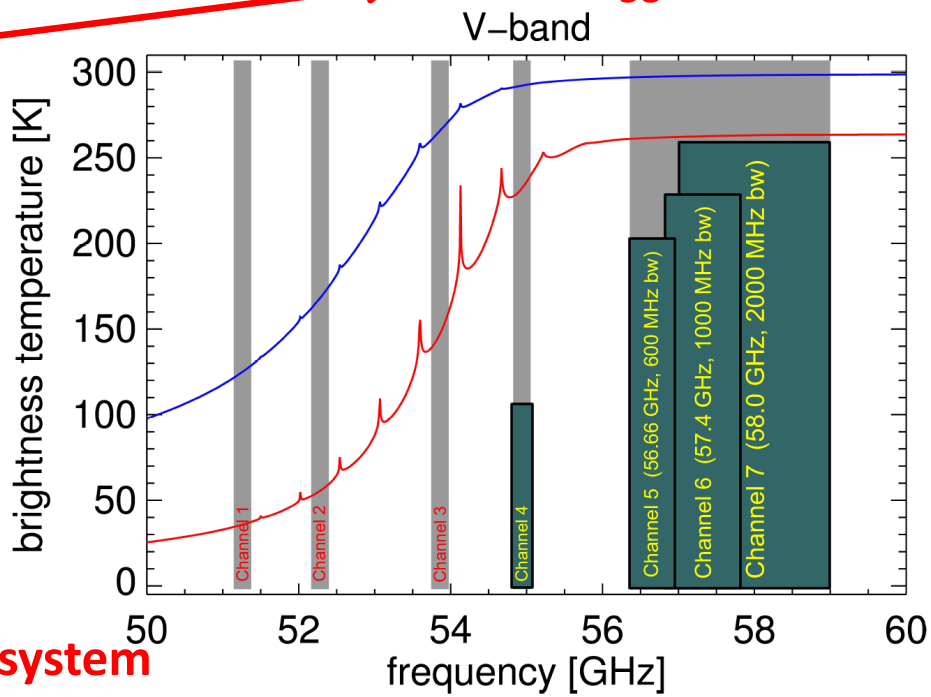
MWR Design Driver: Noise Reductionat 58 GHz

To resolve shape of temperature profile, the radiometer needs

- Increased bandwidth at saturated channels only (2000 MHz vs. 230 MHz, noise reduction 1:3)
- Increased integration time: 15 s

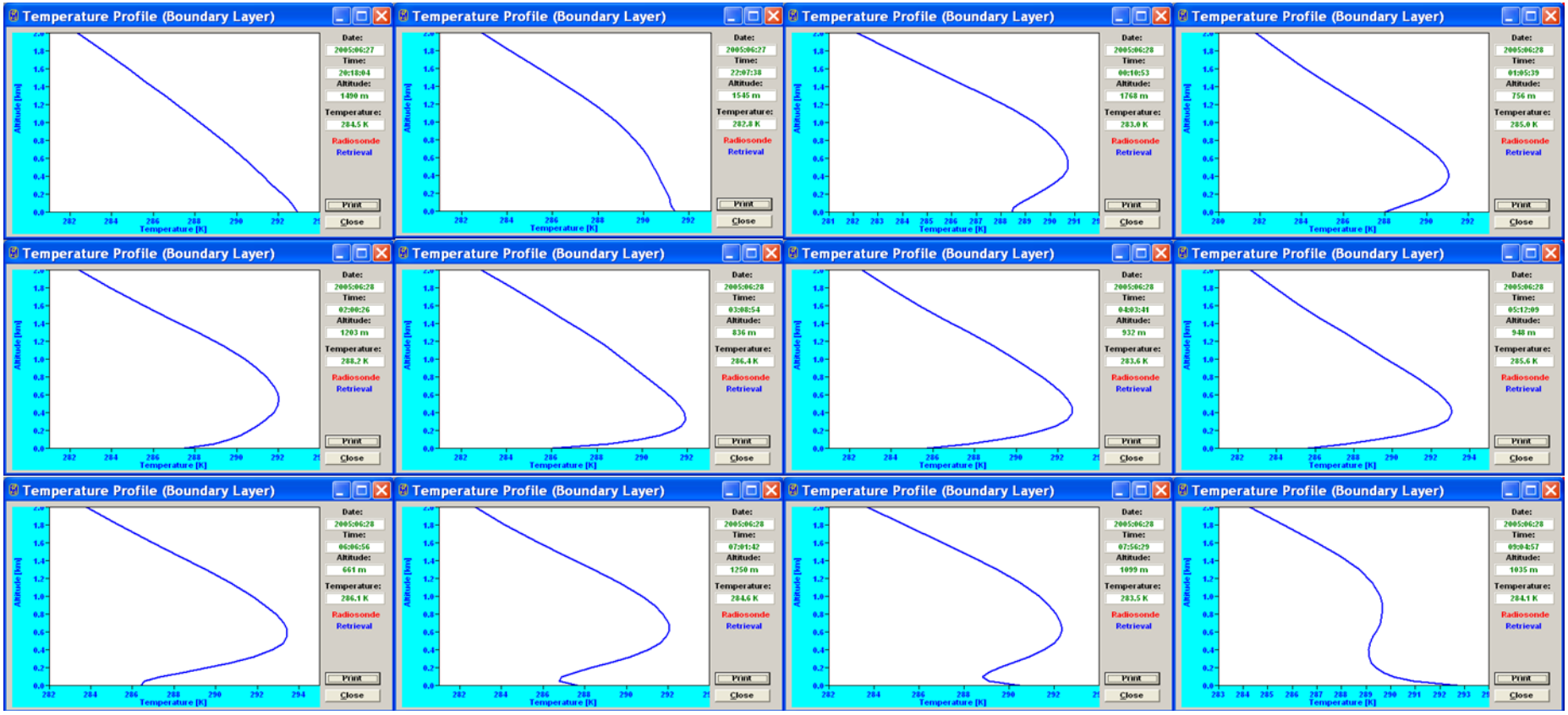
→ **RMS TB_{58} < 0.05 K**

- Multi-channel obs. (in parallel) to avoid saturation (limited range)
- Large optics, small beam **1.8°**
- Recent developments:
  - Space qualified/optimised RF amplifiers from UMS
  - Better noise temperature **300 K full system**
  - Better 1/f performance (MMIC material GaAs vs. InP)
  - Better calibration repeatability (standing wave problem solved)



Courtesy of Gerrit Maschwitz, University of Cologne, Germany

Result: Time Series of Temperature Inversion

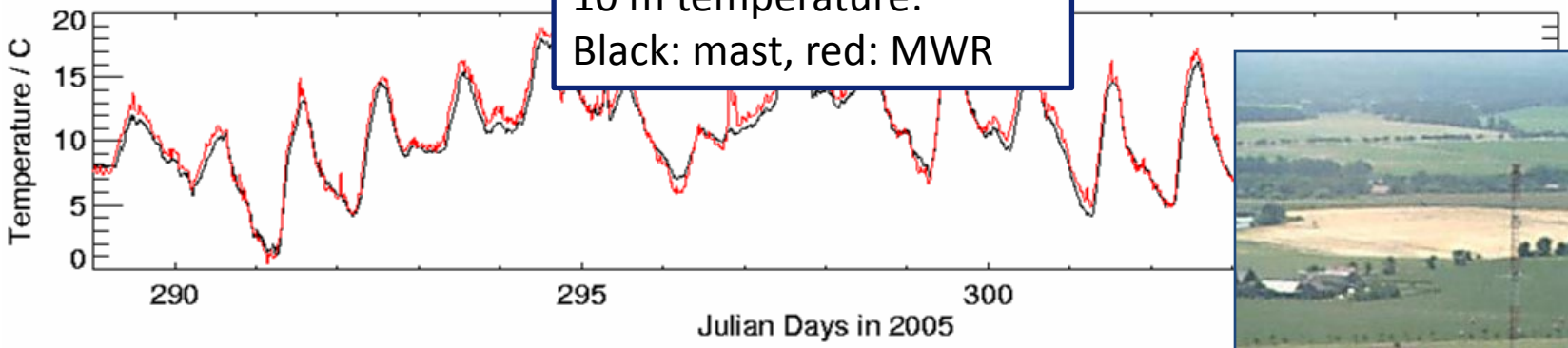


Regression Retrievals: Elevation angles, airmass, and channel usage

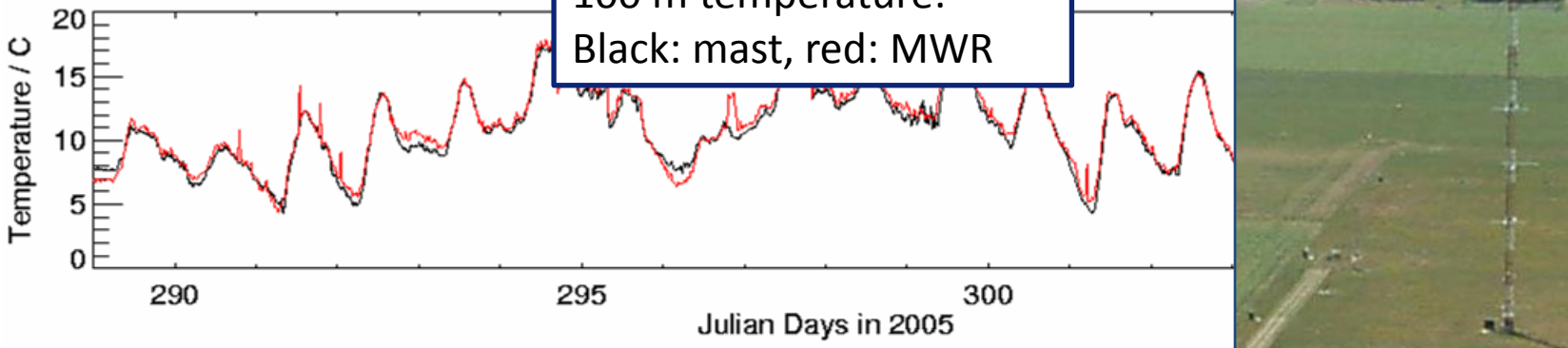
Regr.	90°	30°	19.2°	14.4°	11.4°	8.4°	6.6°	4.8°
Linear	1 – 7	4 – 7	4 – 7	6 + 7	6 + 7	7	7	7
Quad.	1 – 7	–	–	–	–	–	–	–
Airm.	1.00	2.00	3.04	4.02	5.05	6.84	8.70	11.95

Comparison with Mast data: 15 day time series

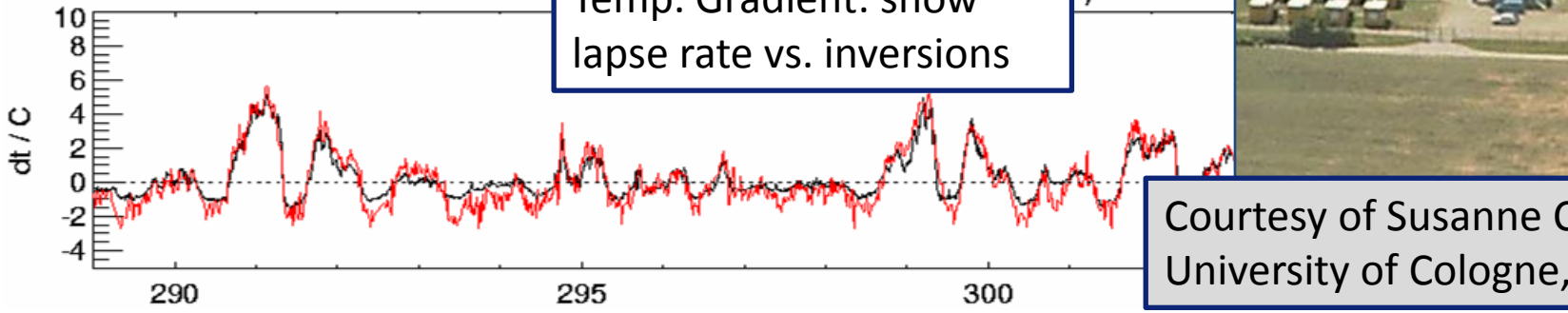
10 m temperature:
Black: mast, red: MWR

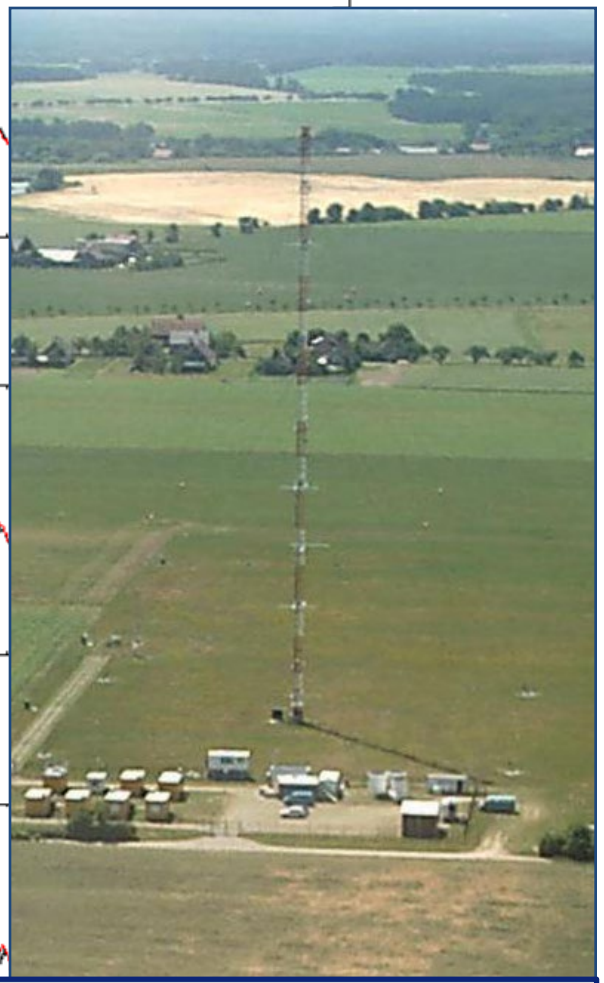


100 m temperature:
Black: mast, red: MWR



Temp. Gradient: show lapse rate vs. inversions





Courtesy of Susanne Crewell, University of Cologne, Germany

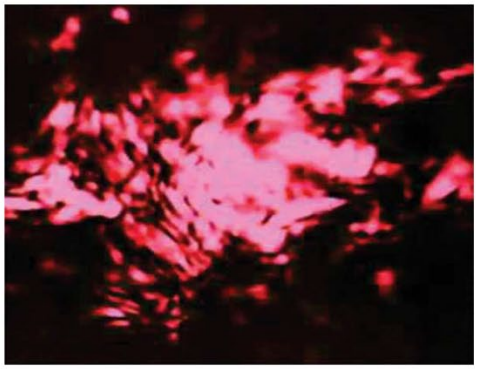
RPG-MMWS-160

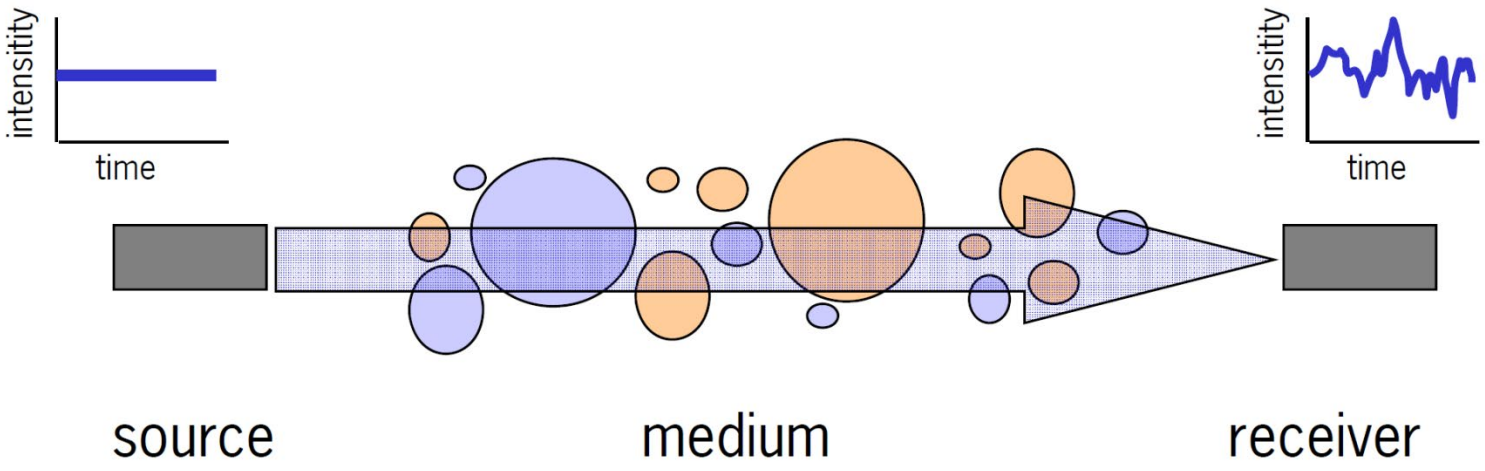
A Millimeter-wave Scintillometer for Latent Heat Flux Measurements

- Co-operation of Wageningen University (WU) and RPG
- Wageningen: Concept, user requirements, test, evaluation
- RPG: Technical design and realisation
- Prototype: Jointly funded by STW, The Netherlands, and RPG
- First instrument to be tested in September/October 2012

Scintillometry : The Concept

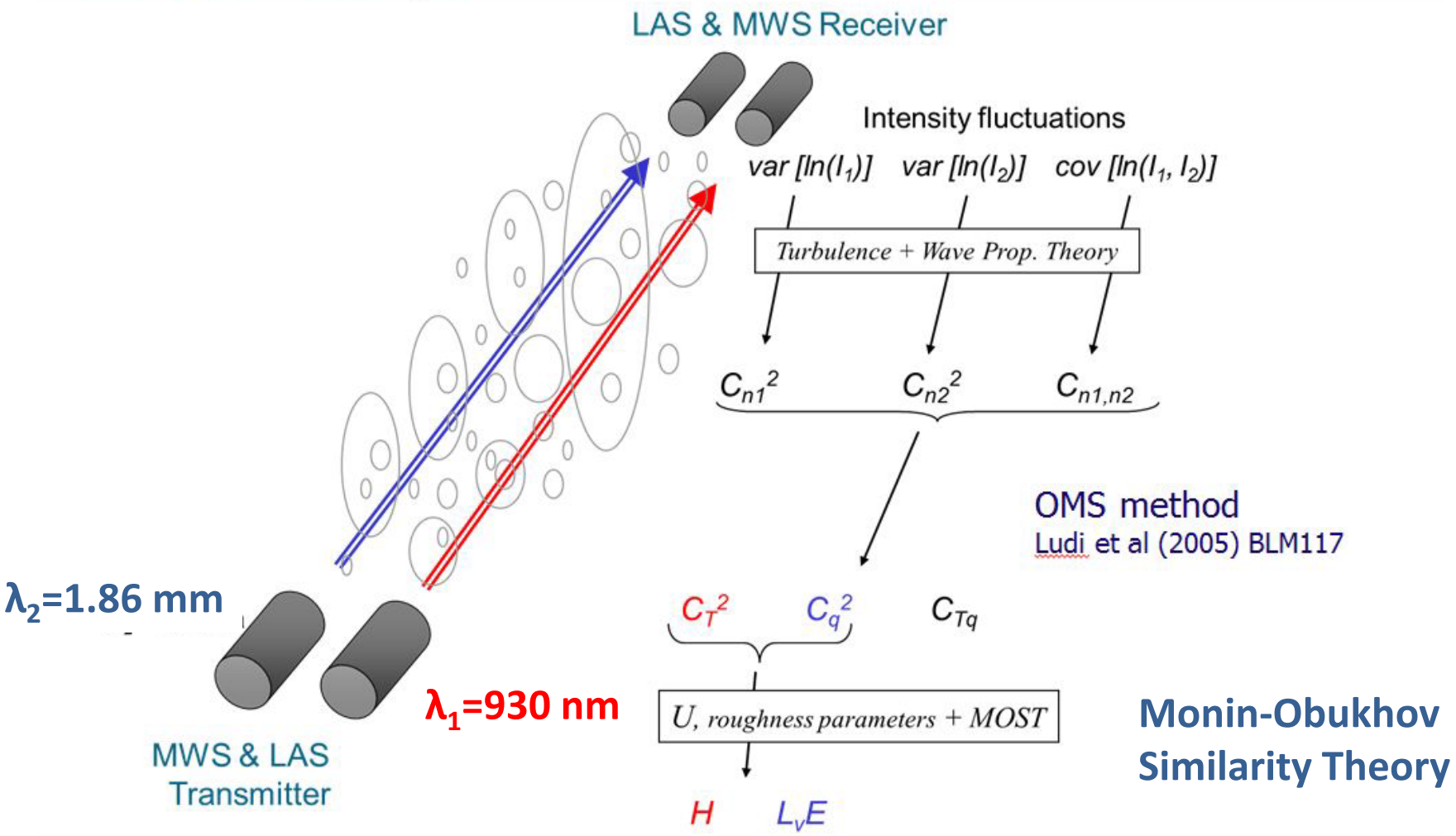
Scintillation – Diffraction Process





Scintillometry: The Concept / Theory

OMS System Description

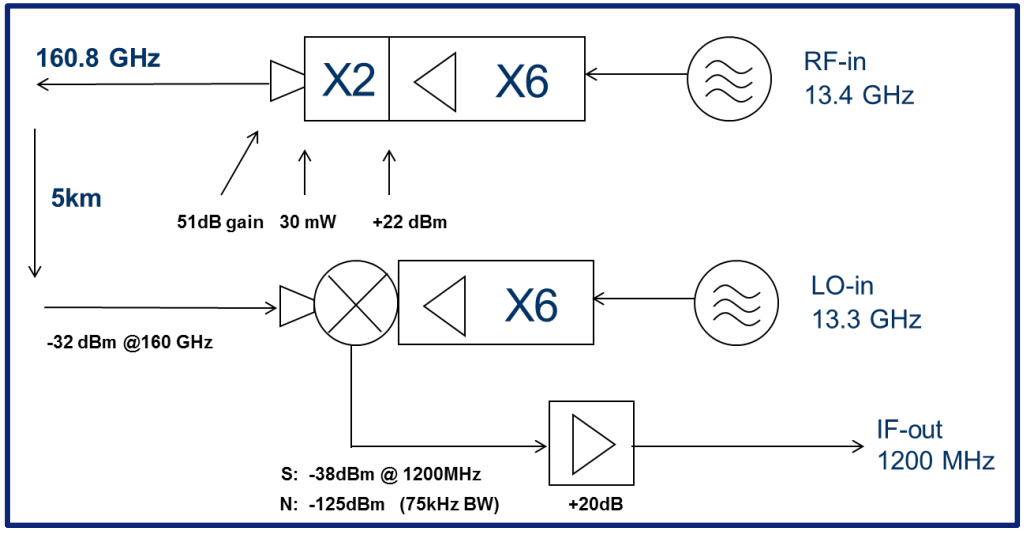


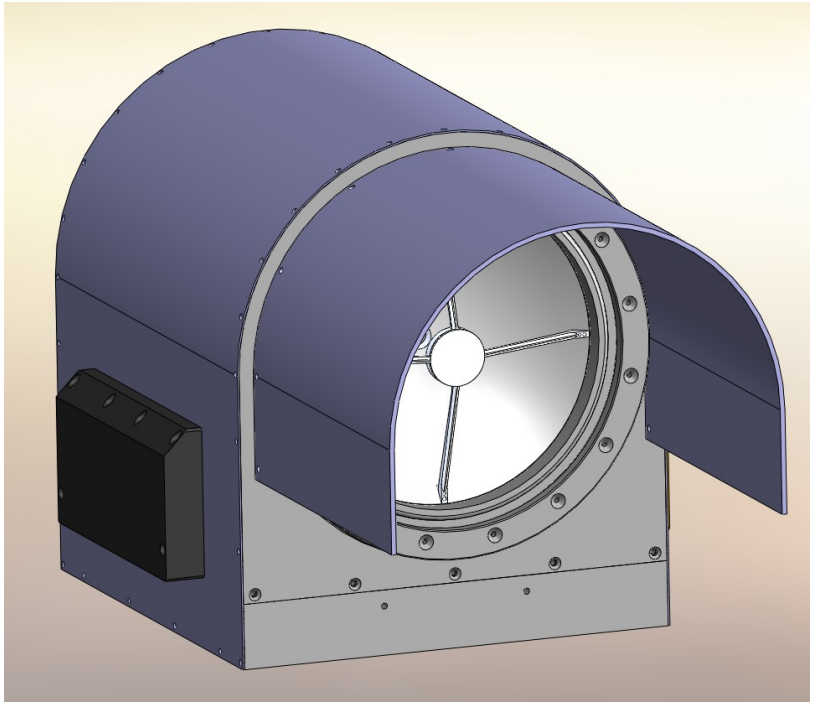
WAGENINGEN UR
METEOROLOGY AND AIR QUALITY

Scintillometer Design

Key features of the MWSC:

- Frequency: 160.8 GHz (λ=1.86 mm) for small beam and sufficient co-spectrum with optical LAS
- 300 mm Cassegrain optics (51 dB gain)
- 40 mW transmitted power
- Detection bandwidth: 10 kHz
- Sensitivity of 90 dB

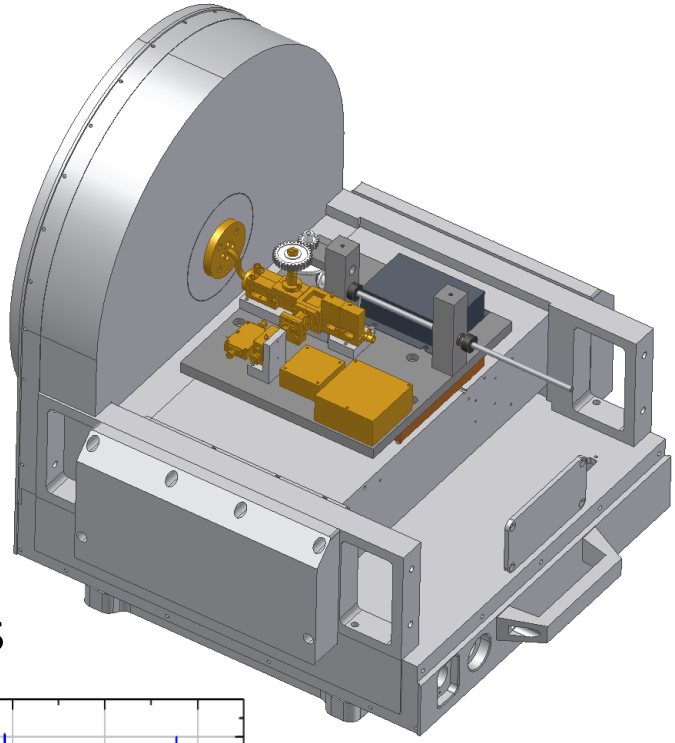


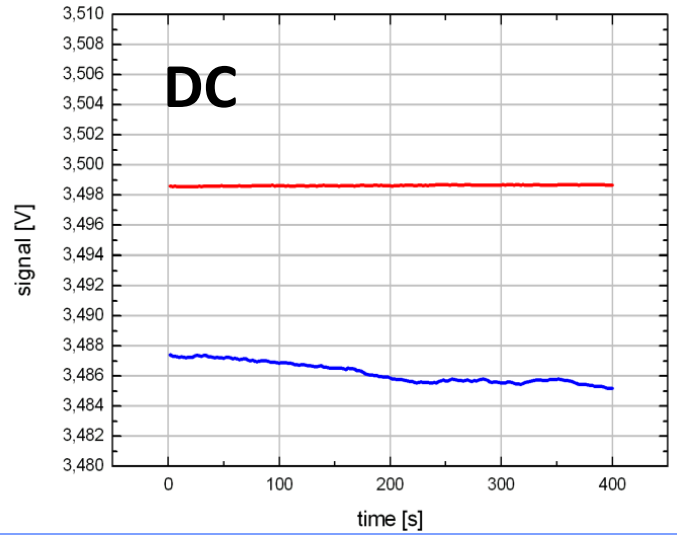


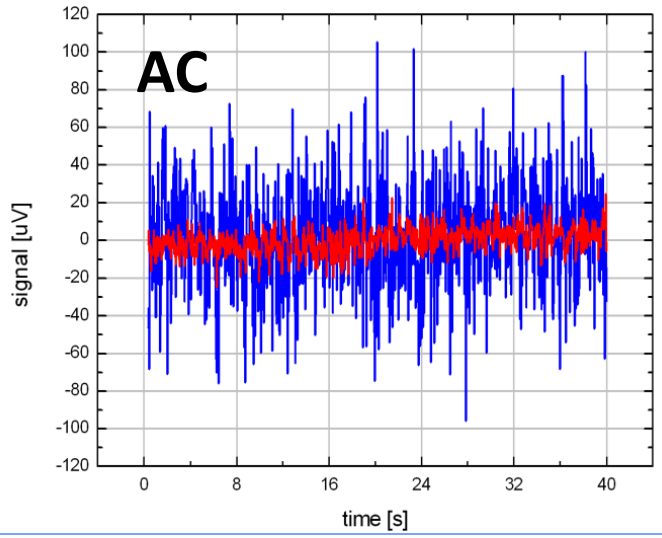
Scintillometer Technology

MWSC Technology Heritage:

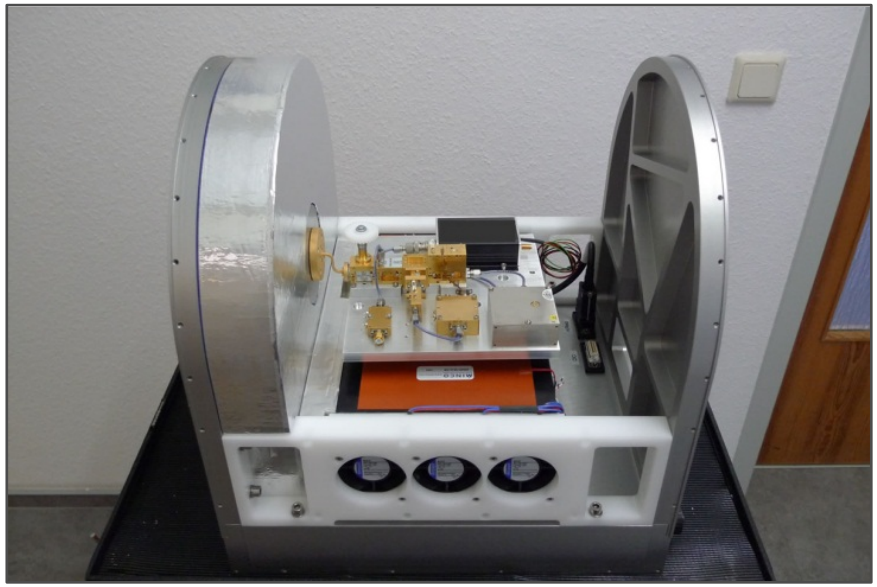
- Housing, power supply, T-control: Heritage from µ-wave radiometer
- 160 GHz source originally designed as 166 GHz source for MetOp-SG 664 LO
- Receiver: Modified 150 GHz Space FE
- Source stability (with AGC): 1.8 e-6
- Ultra-stable frequency at Tx and Rx units

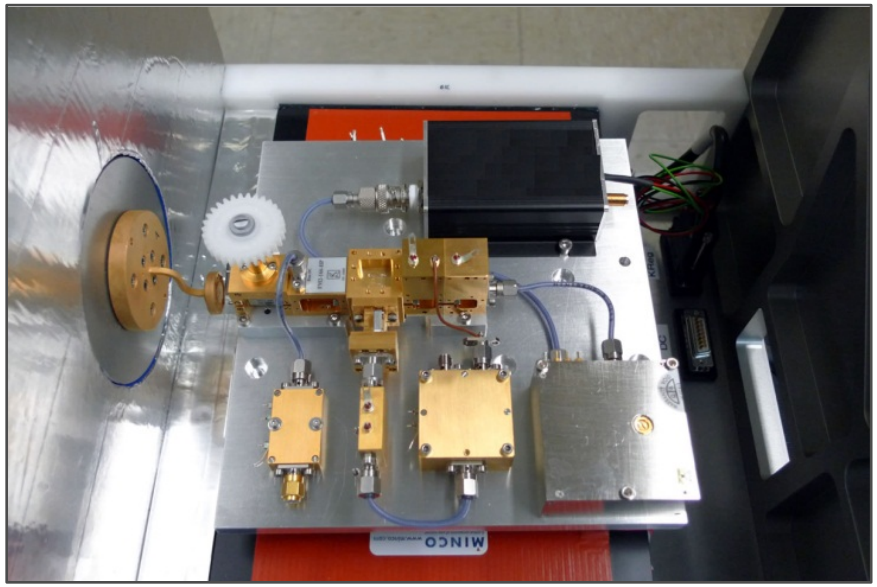


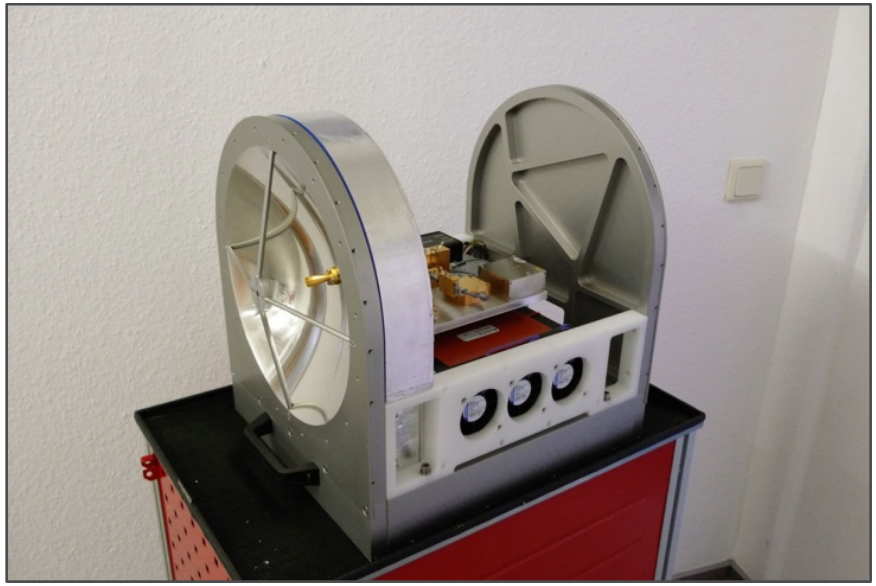




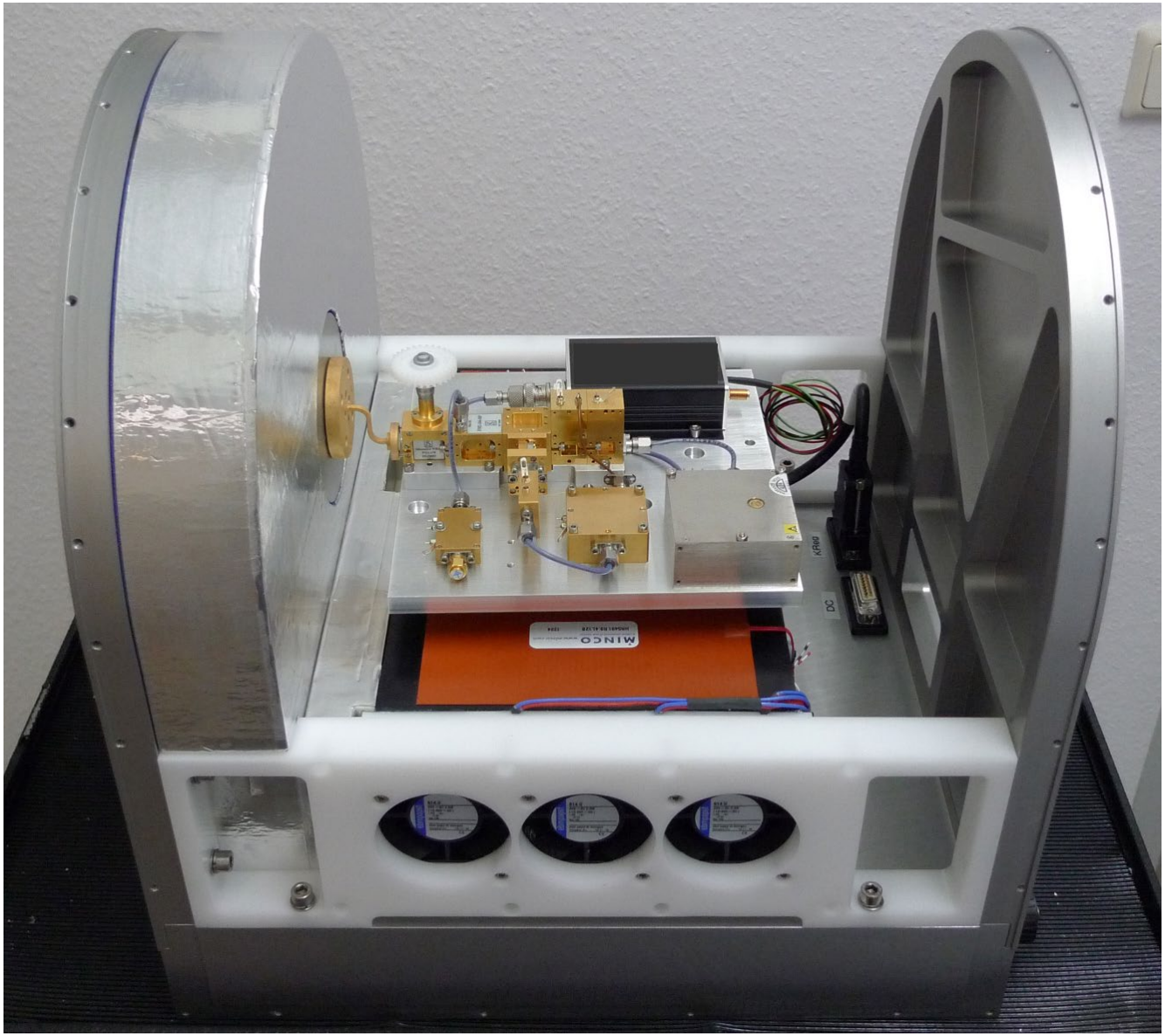
MWSC Integration: End of August 2012







MWSC Integration: End of August 2012



RPG-FMCW-94

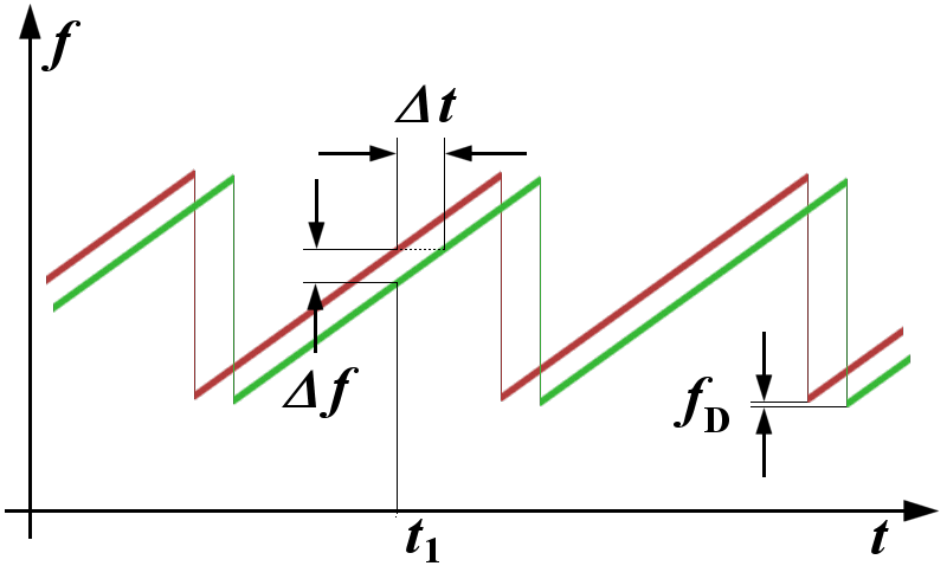
RPG-FMCW-94-DP

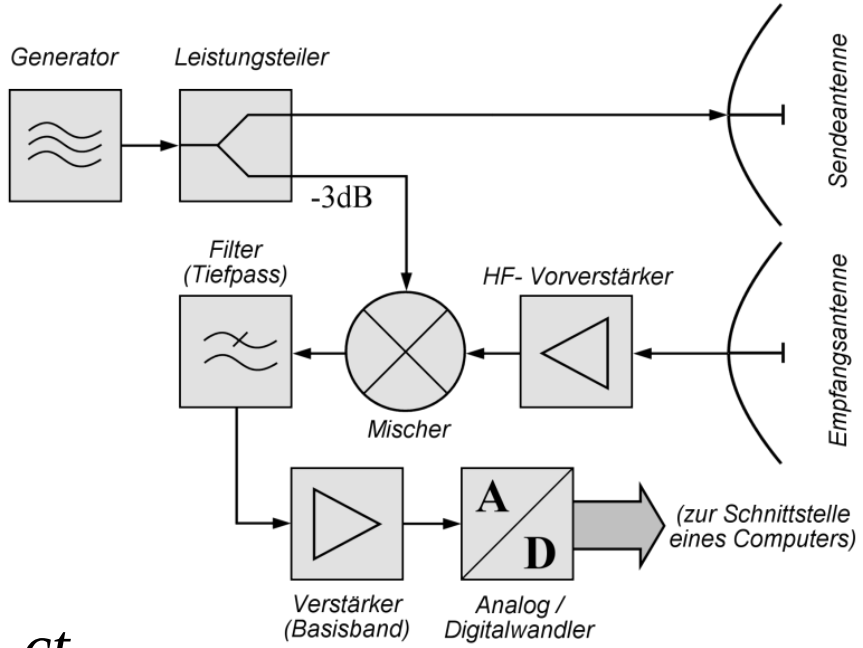
A Cloud Radar by RPG

- Frequency Modulated, Continuous Wave, 94 GHz
- Low mode for fog, high mode up to 12 km
- Re-using RPG technology from Tx/Rx systems and network analysis
- Re-using instrument infrastructure (housing, steering, control, data processing) from microwave radiometers
- Supported by Fraunhofer Institute for RF Technology and Radar (FhG-FHR, Wachtberg, Germany, formerly FGAN)

Availability: Mid of 2013

FMCW Radar Concept (in brief)





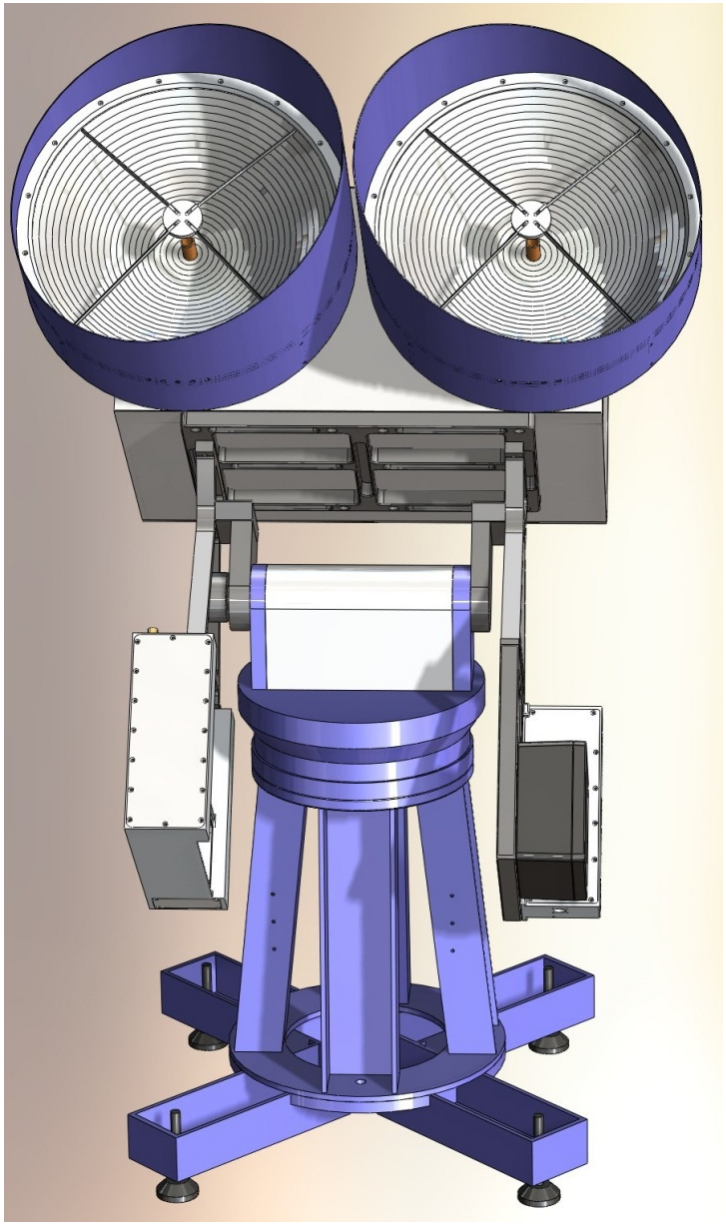
Distance to Object: $$D = \frac{c\Delta t}{2} = \Delta f \frac{ct_1}{2B}, \qquad B = Chirp - Bandwidth$$

Altitude Resolution: $$\delta D = \frac{c}{B}$$

Velocity: $$v = \frac{cf_D}{f}$$

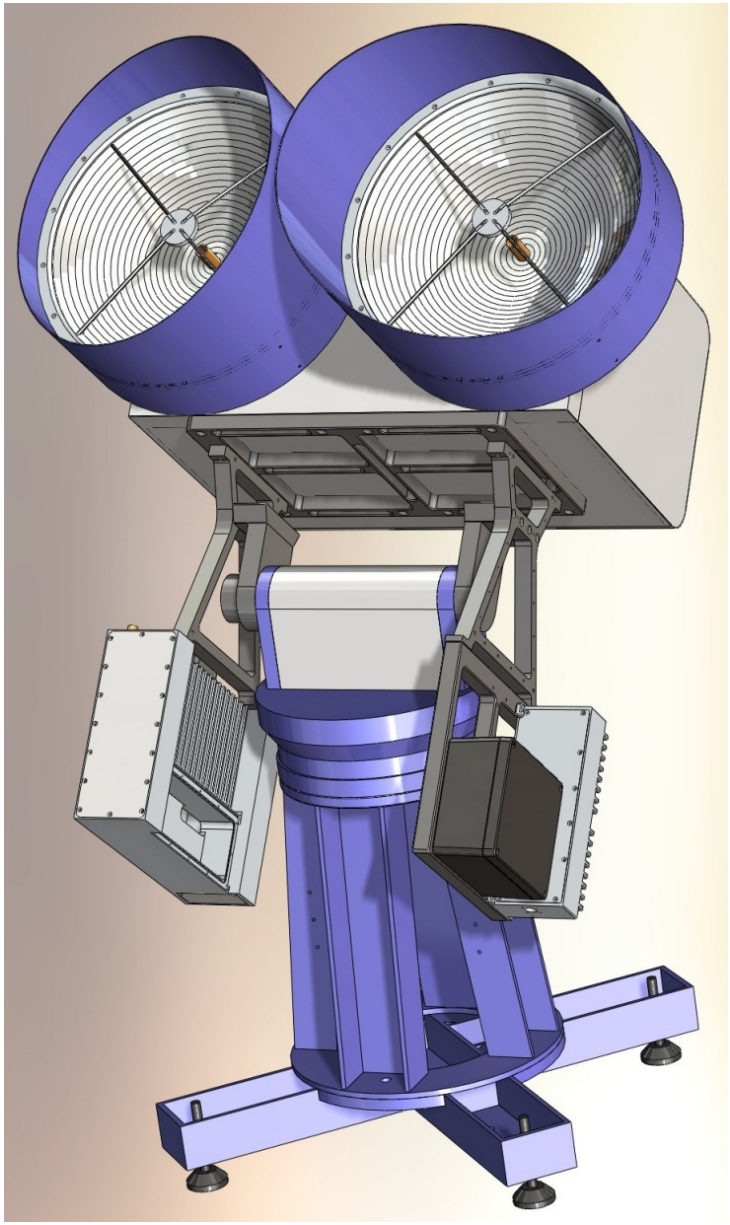
Radar Reflectivity: $$P_R = P_T \frac{G^2 \sigma \lambda^2}{(4\pi)^3 R^4}, \quad or \quad R = \sqrt[4]{\frac{G^2 \sigma \lambda^2 P_T}{(4\pi)^3 P_R}}$$

RPG-FMCW-94 Specifications (I)



Operating Frequency:	94 GHz +/-150 MHz
IF Range:	0.5 MHz to 1.3 MHz
Continuous Power:	500 mW (Solid State)
T/R Type:	Bi-static
Antenna Diameter:	500 mm
Gain:	52 dB
Chirp Rate:	100 / sec
Chirp Variations:	7
Passive LWP Channel:	89 Ghz (optional)
Dynamic Range:	-100 dBz to +20 dBz

RPG-FMCW-94 Specifications (II)



Ranging:	10 m to 12 km
Sampling Rate:	1 / 4 seconds
Vertical Resolution:	1 m (r: 10m - 600 m)
	2 m (r: 0.6 – 1.0 km)
	4 m (r: 1.0 – 2.5 km)
	8 m (r: 2.5 – 5.0 km)
	16 m (r: 5.0 – 12.0 km)
Doppler Resolution:	+/- 15 cm/sec
Polarisation:	v / h (optional)

Availability: Mid of 2013

Possible extensions by

- Additional frequencies
- Passive microwave channels
- Polarisation options

Summary / Conclusions

- Microwave Radiometers
  - High-resolution boundary layer tenperature profiling possible with suitable/optimized receiver architecture
  - Optimization / synergy with space projects (60 GHz LNA, calibration concepts)
- Scintillation
  - Transfer of known concept (optical LAS for sensoble heat flux) to microwave / millimeter wave region @160 GHz
- FMCW cloud radar
  - Transfer of existing Tx/Rx technology from Lab to field
- Rapid Prototyping and reduced time to market only possible due to broad field of applications at RPG.

Thank you!

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