Discrimination of cloud and rain liquid water path by groundbased polarized microwave radiometry

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RPG

Overview

1. Introduction
2. Motivation:
   - Rain contamination of microwave liquid water path (LWP) measurements
   - Sensitivity problem
3. Radiative transfer modeling
4. Sensitivity of TB and PD to a raining atmosphere
5. Proposed retrieval technique
6. Validation results
7. Future instrumentation

Rain contamination of LWP measurements

- Thick clouds: „in-cloud“ rain, drizzle, no surface rain
- Definition: r < 0.5 mm „**cloud**“
  r > 0.5 mm „**rain**“
- Mixture of rain/cloud a-priori unknown

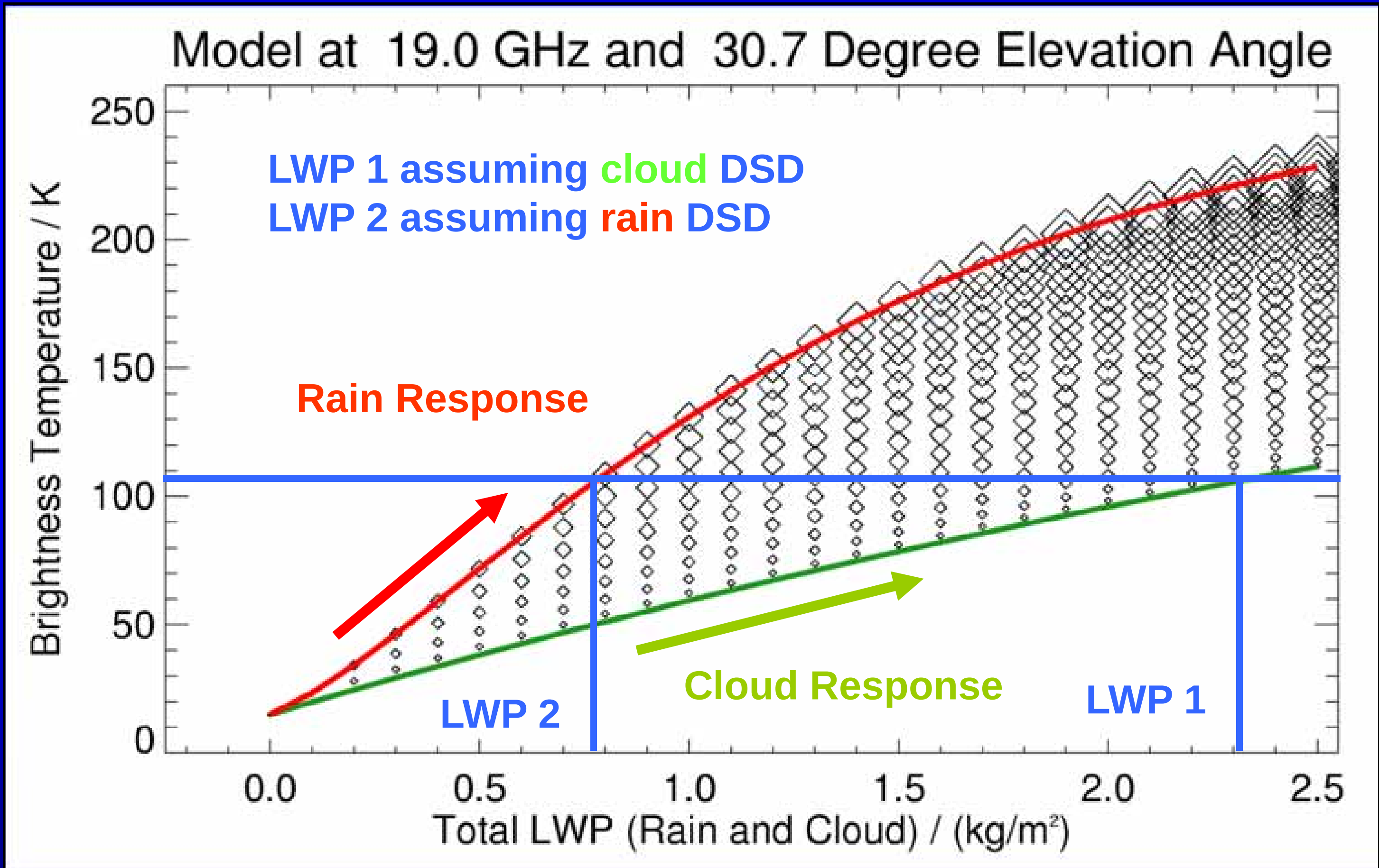
- Passive Microwave observations:
  – ambiguous sensitivity in brightness temperature (TB)
  + polarization difference (PD) caused by rain only
  (definition: PD = TB_v – TB_h)

- Dual-polarized microwave radiometers required for decomposition of rain and cloud fraction

- Radiative transfer model used to calculate the combined TB / PD response of cloud / rain mixtures

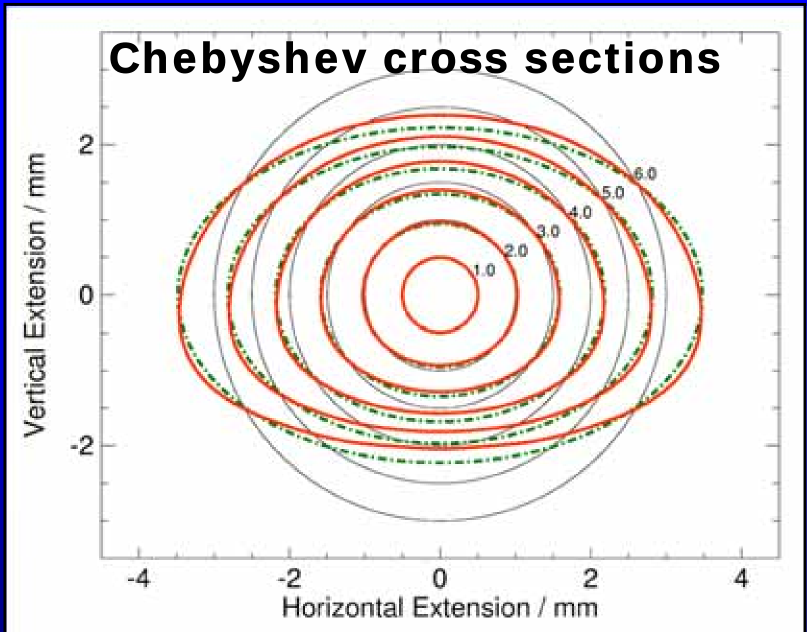
Sensitivity to Drop Size Distribution

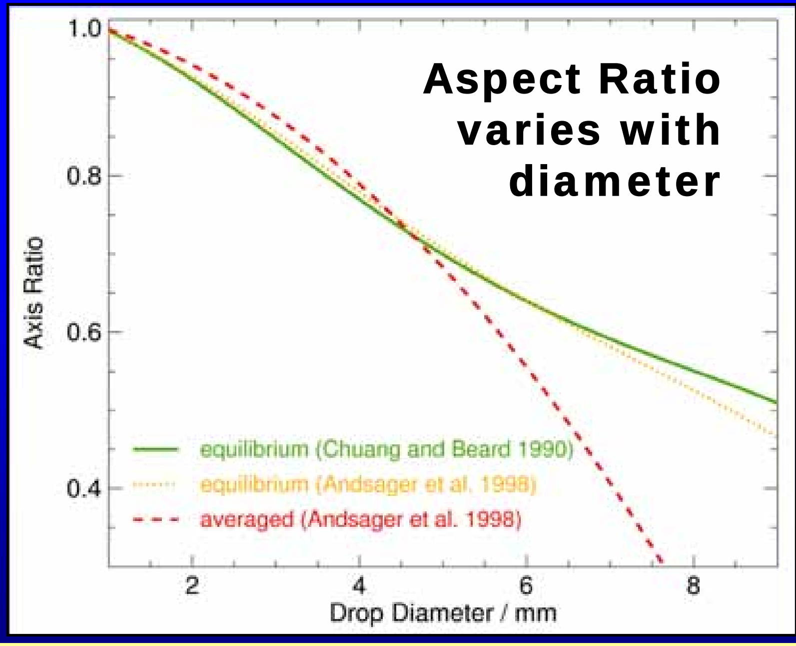
– Sensitivity of TB/LWP dependence different for rain and cloud
– Mixture of rain and cloud unknown
– Ambiguous LWP estimation in the (unknown) presence of rain



Radiative Transfer Model

- Solves the vector radiative transfer equation (VRTE)
- One-dimensional, plane parallel (coordinates z and Theta)
- Multiple scattering: Successive order of scattering (SOS)
- Single scattering properties: T-Matrix code by Mishchenko
- Rain drops: Chebyshev shapes, Marshall-Palmer DSD
- Mixing of rain and cloud simultaneously in one layer





Vector radiative transfer equation VRTE

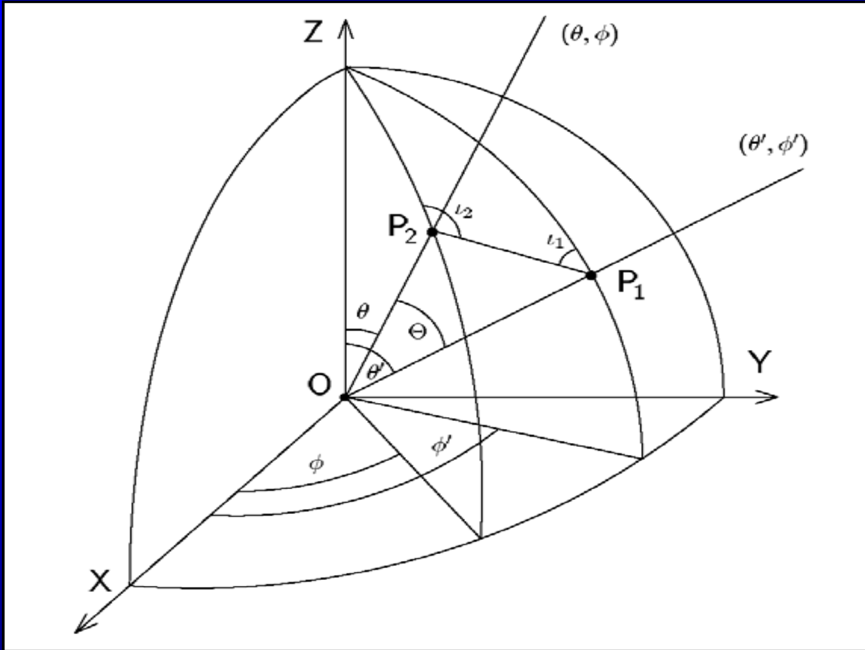
$$\frac{d^3\,\overline{\mathbf{I}}(x,y,z,\theta,\phi)}{\frac{1}{\gamma}dx\;\frac{1}{\delta}dy\;\frac{1}{\mu}dz} = -\;\overline{\overline{\sigma}}_e(x,y,z,\theta,\phi)\,\overline{\mathbf{I}}(x,y,z,\theta,\phi)$$ **extinction matrix**

differential change of Stokes vector

$$+\;\overline{\sigma}_a(x,y,z,\theta,\phi)\,B(T(x,y,z))$$ **absorption vector**

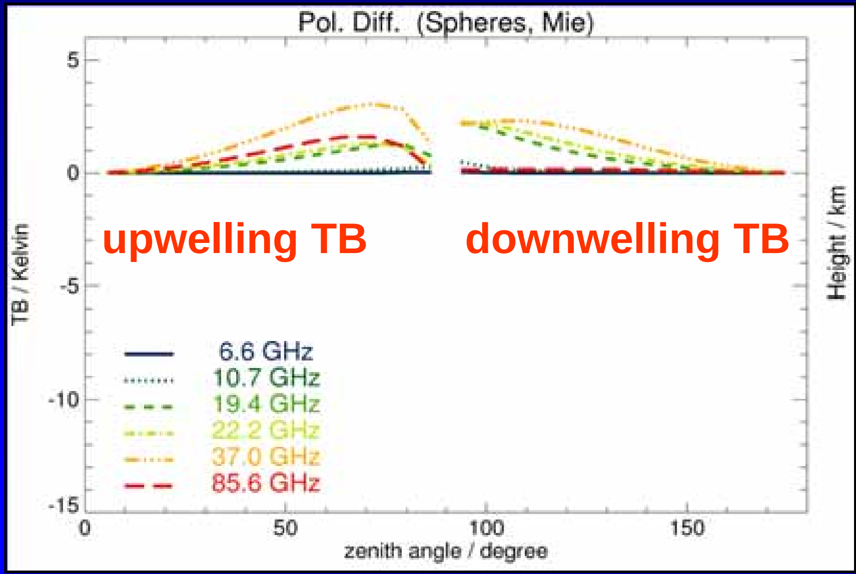
$$+\int_0^{2\pi}\int_0^{\pi}\overline{\overline{\mathbf{P}}}(x,y,z,\theta,\phi,\theta',\phi')\,\overline{\mathbf{I}}(x,y,z,\theta',\phi')\,\sin\theta'd\theta'\,d\phi'$$

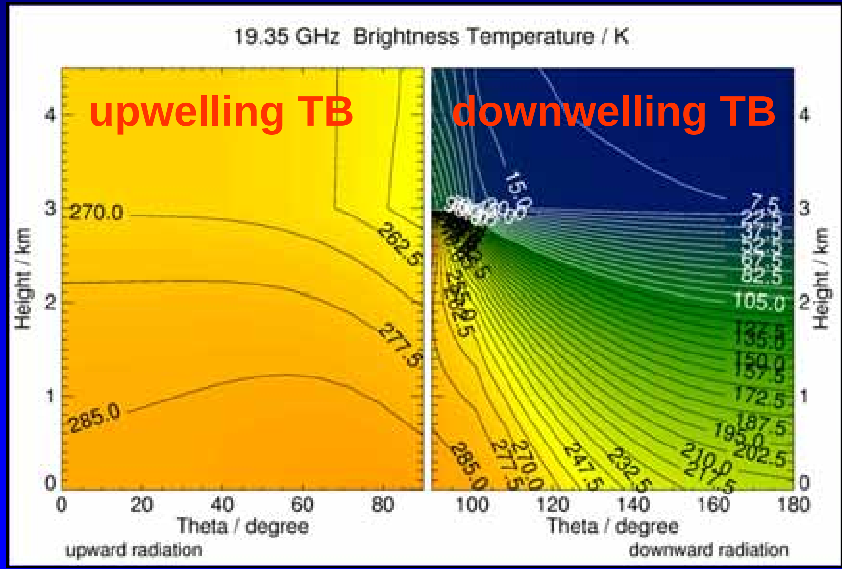
scattering phase matrix

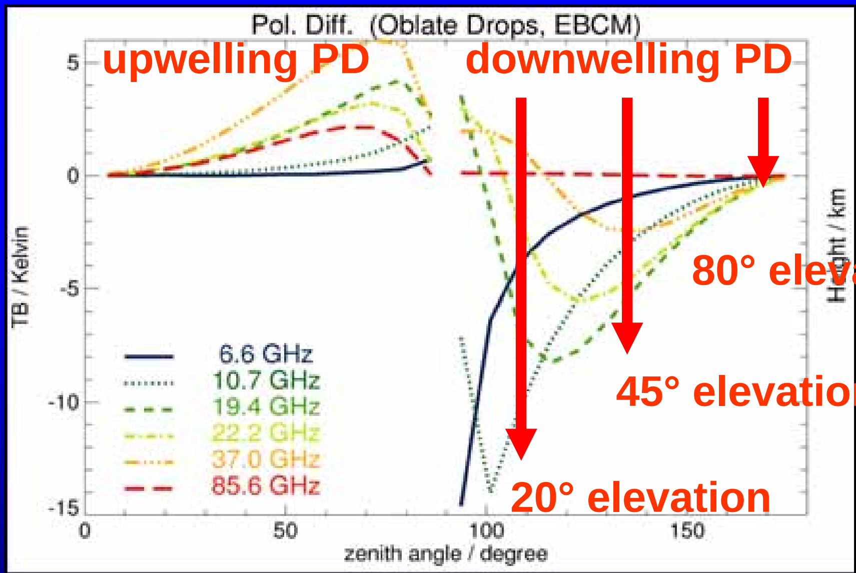


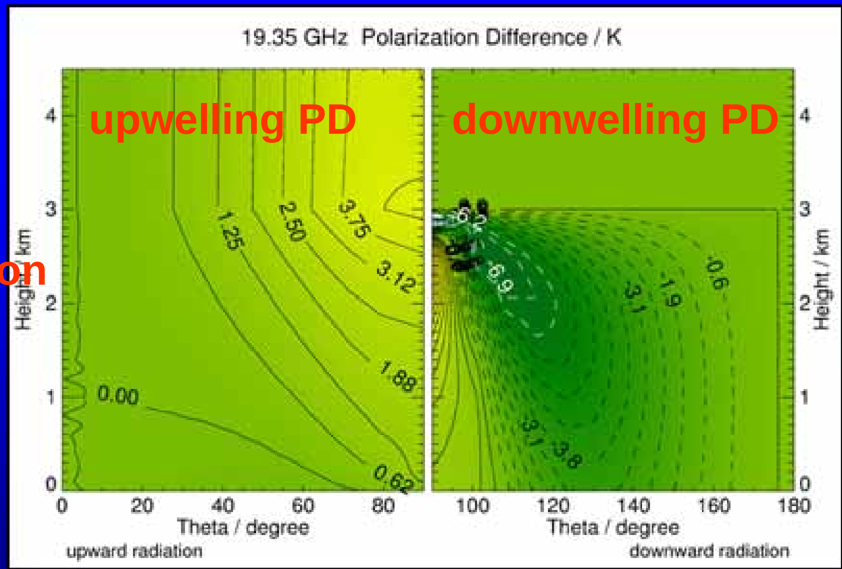
angles and planes of polarization

Radiative transfer results



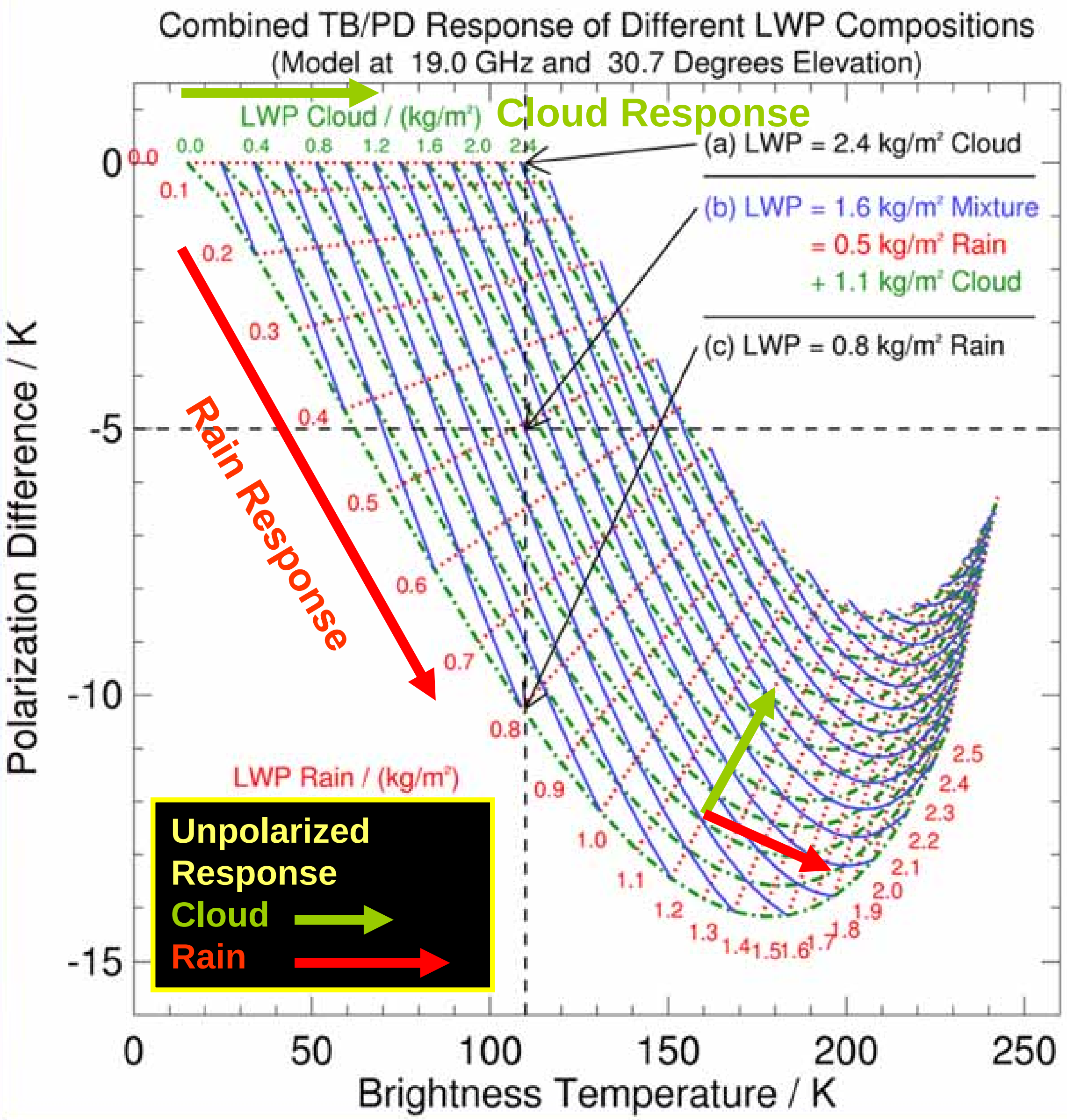






Proposed Retrieval Method

Czekala et al, Geophys. Res. Lett. 28 (2), 267–270, 2001.

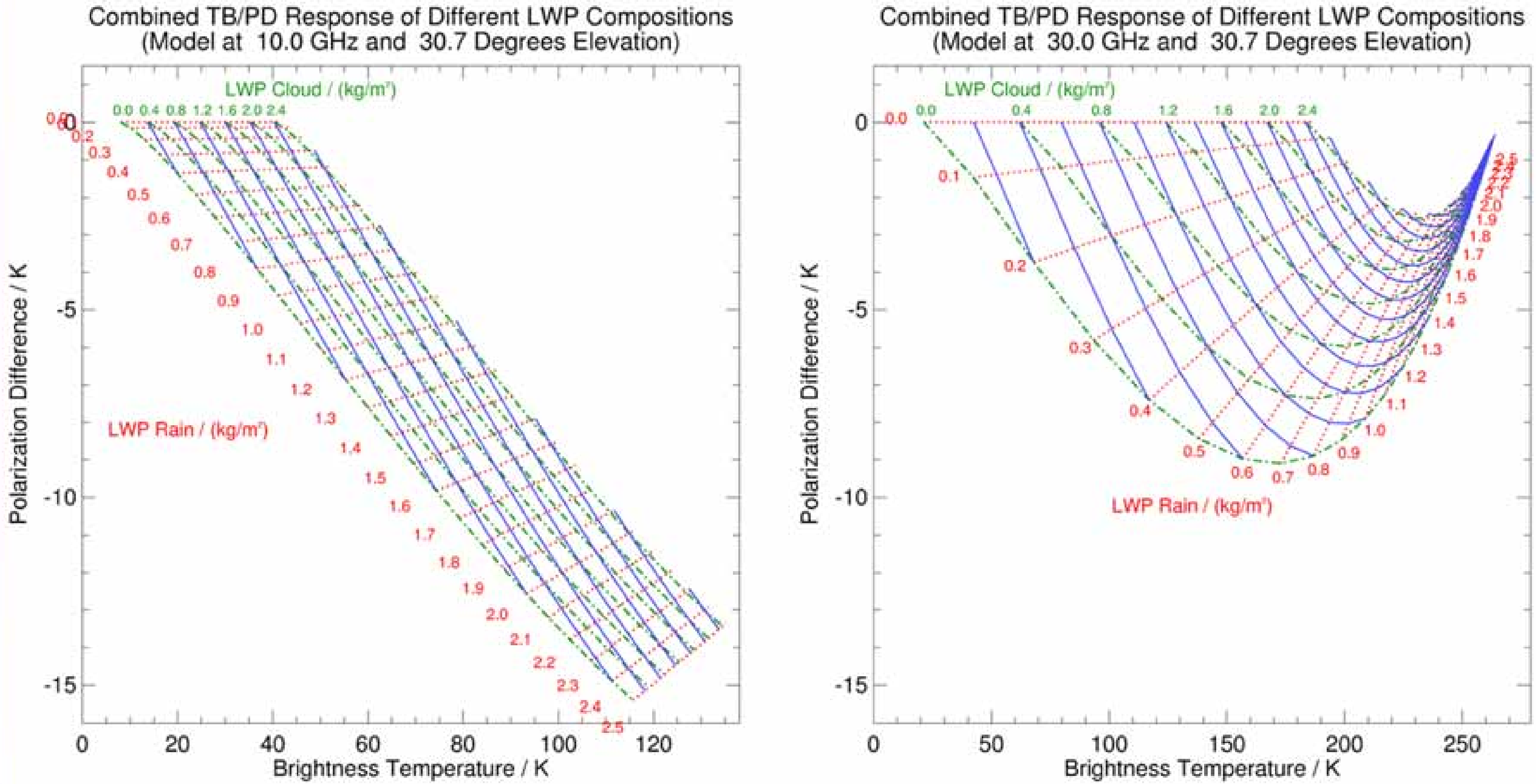


- Along red lines: rain LWP constant, increasing cloud LWP (left to right)
- Along green lines: cloud LWP constant, increasing rain LWP (top to bottom)
- Along blue lines: total LWP constant

- Simultaneous measurement of brightness temperature and polarization difference
- Independent retrieval of cloud and rain fractions possible
- Accuracy of polarization measurement crucial
- Re-calibration with clear sky conditions

Sensitivity to Frequency (10 and 30 GHz instead of 19 GHz)

- Less saturation at smaller frequencies, but smaller sensitivity to rain
- Higher sensitivity to rain with increasing frequency
- Multi frequency measurements allow for complete coverage of LWP range



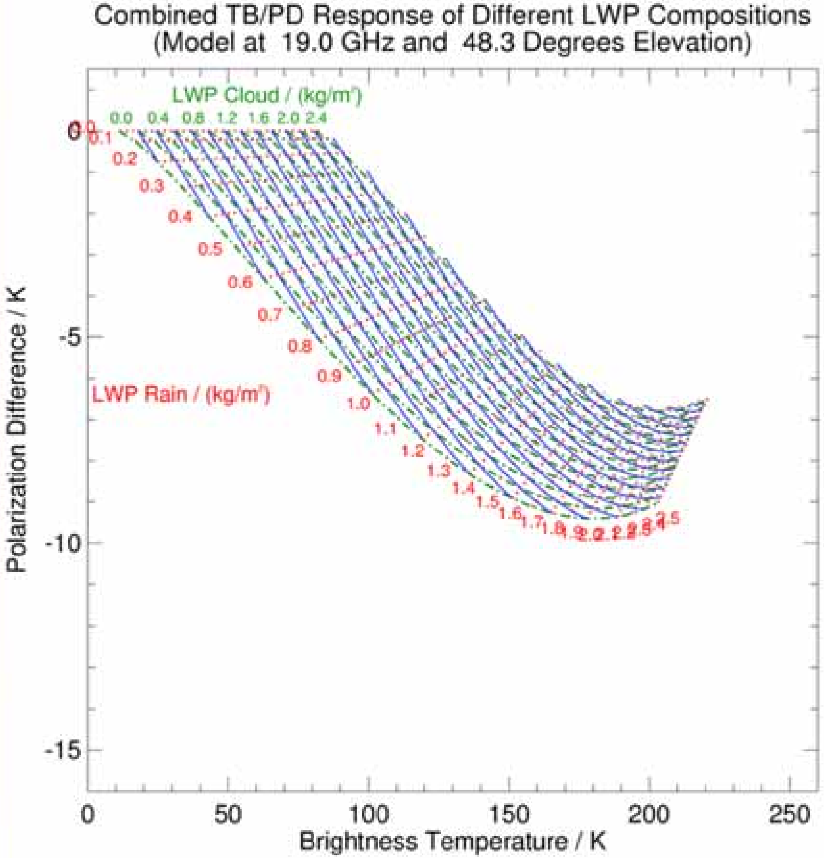
10 GHz: no saturation, good for heavy precip

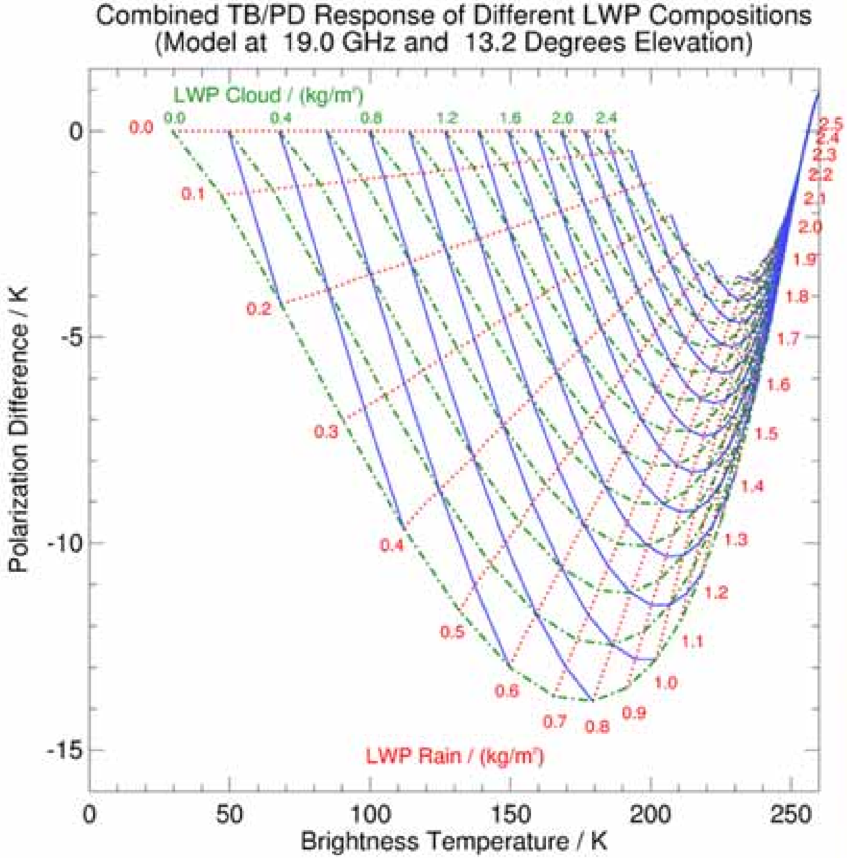
30 GHz, better for light rain

Sensitivity to Elevation Angle

(48 and 13 degrees instead of 30 degrees)

- Change in total optical thickness with path length
- Sensitivity changes with elevation angle
- Field-of-view problem towards low elevation angles





48 degrees, closer to nadir

13 degrees, closer to horizontal

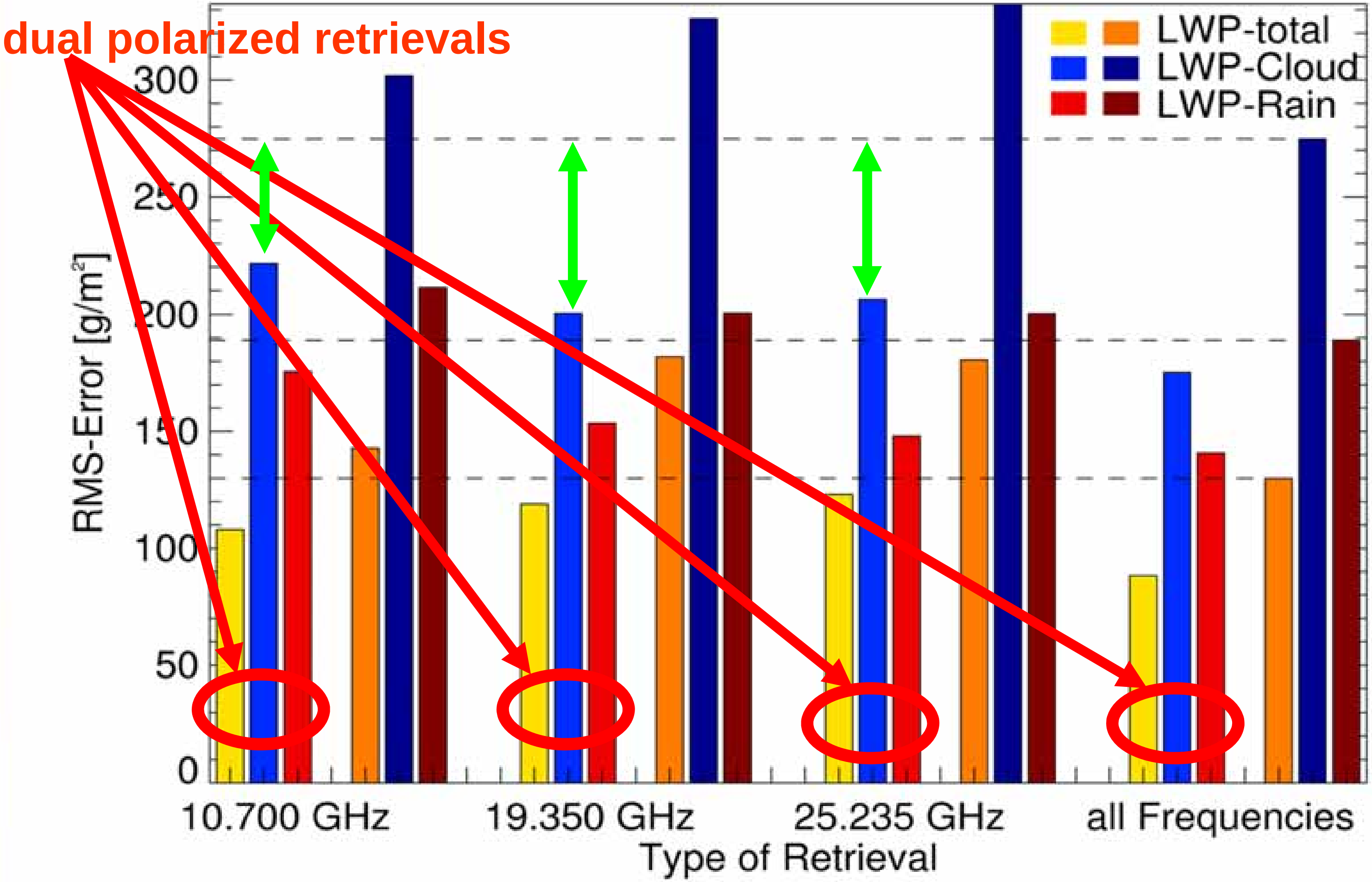
Simulated Effects on LWP Retrieval

(from: Thiele et al. 2001)

- Regression with and without the polarization difference as input
- Three different single frequencies, one combined retrieval

⟹ One polarized channel is better than 3 unpolarized channels!

Realistic drop size distributions from detailed microphysical cloud model



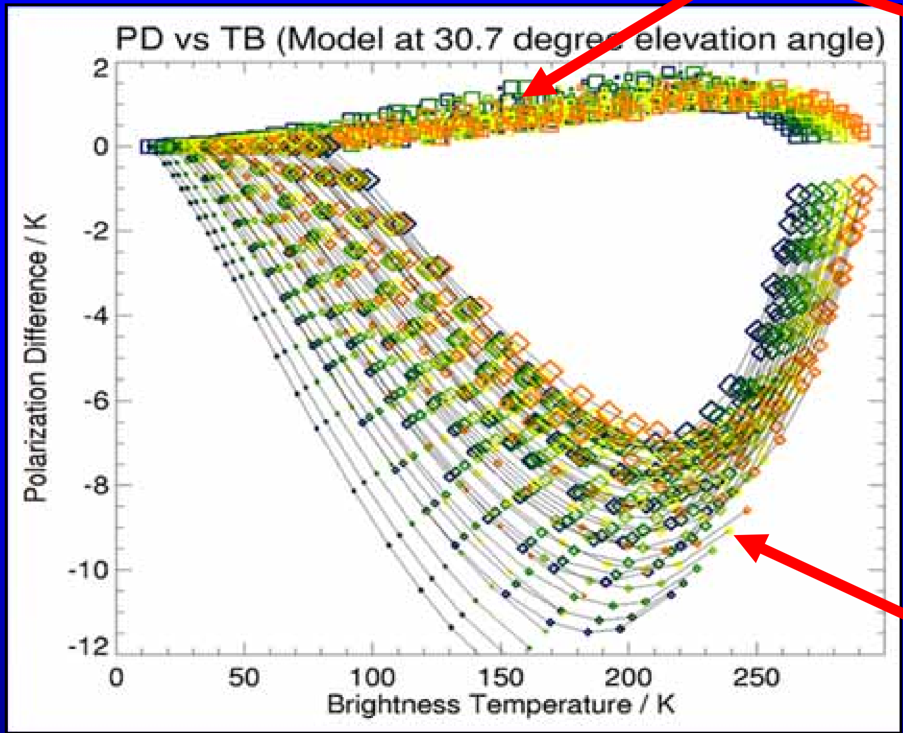
Validation: Model versus Measurements

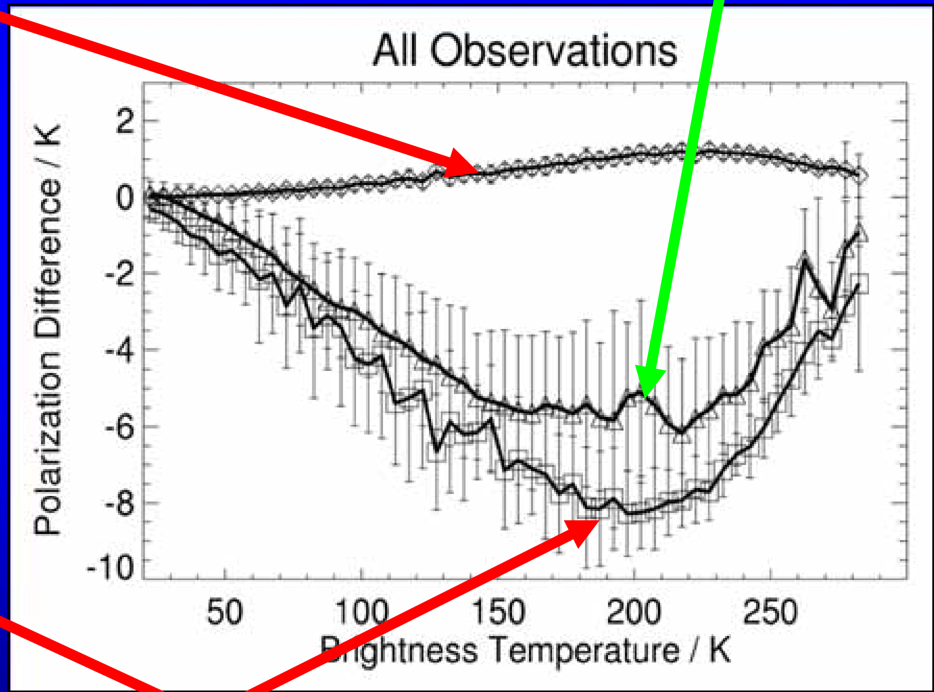
Model calculation with varying
- rain rate
- rain layer height
- air temperature

Measurement data:
- Dual pol. 19 GHz radiometer
- 18 months of data, 10s res.
- groundbased
- 30° elevation

model with spheres

measurement data



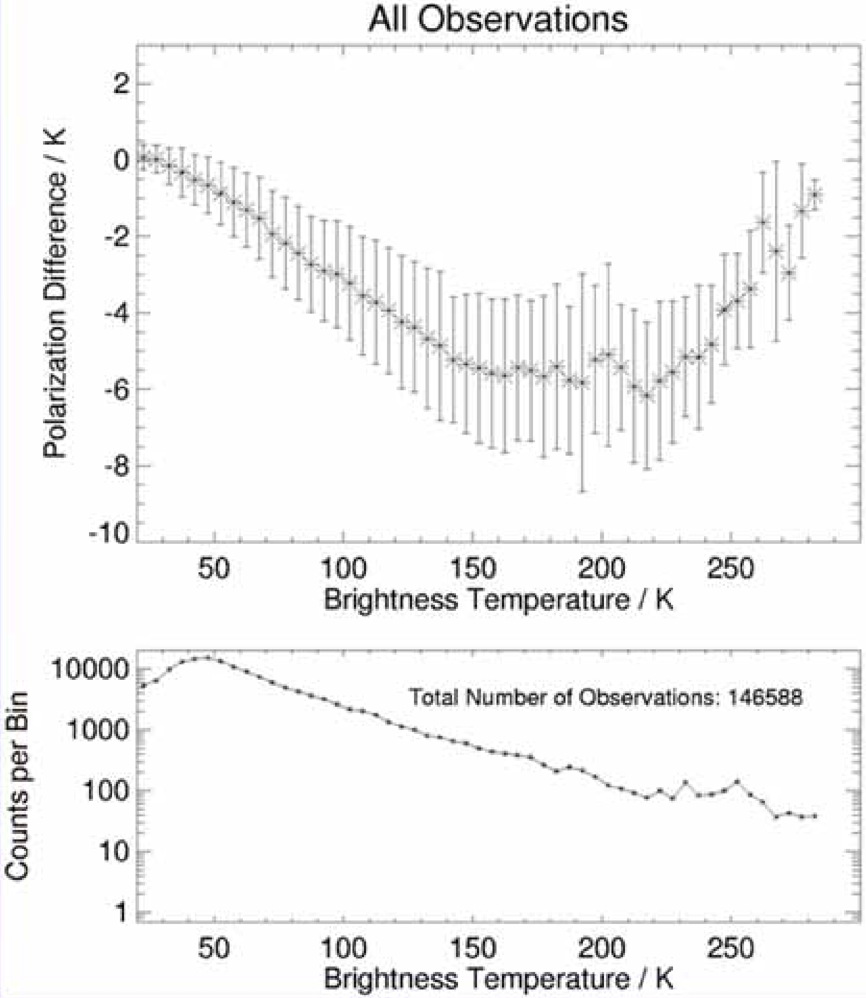


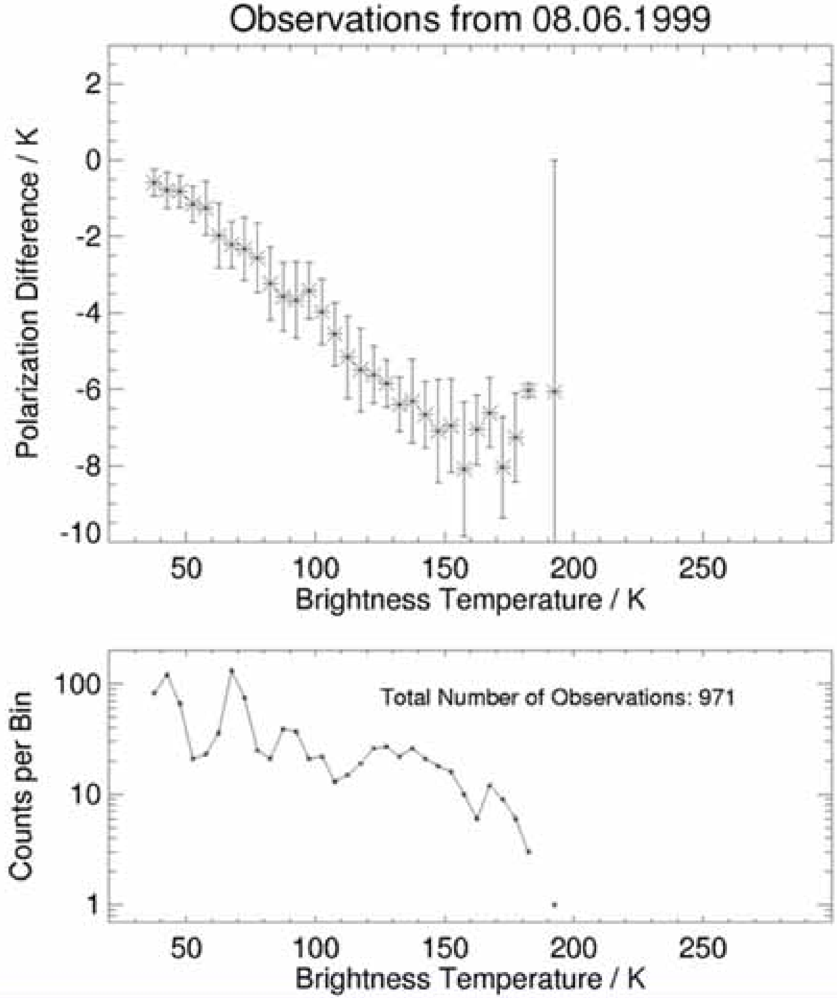
model with non-spherical rain drops

More Measurements

Czekala et al, Journal of Applied Meteorology 40 (11), 1918–1932, 2001.

Observation from 18 months	Observations of single rain event





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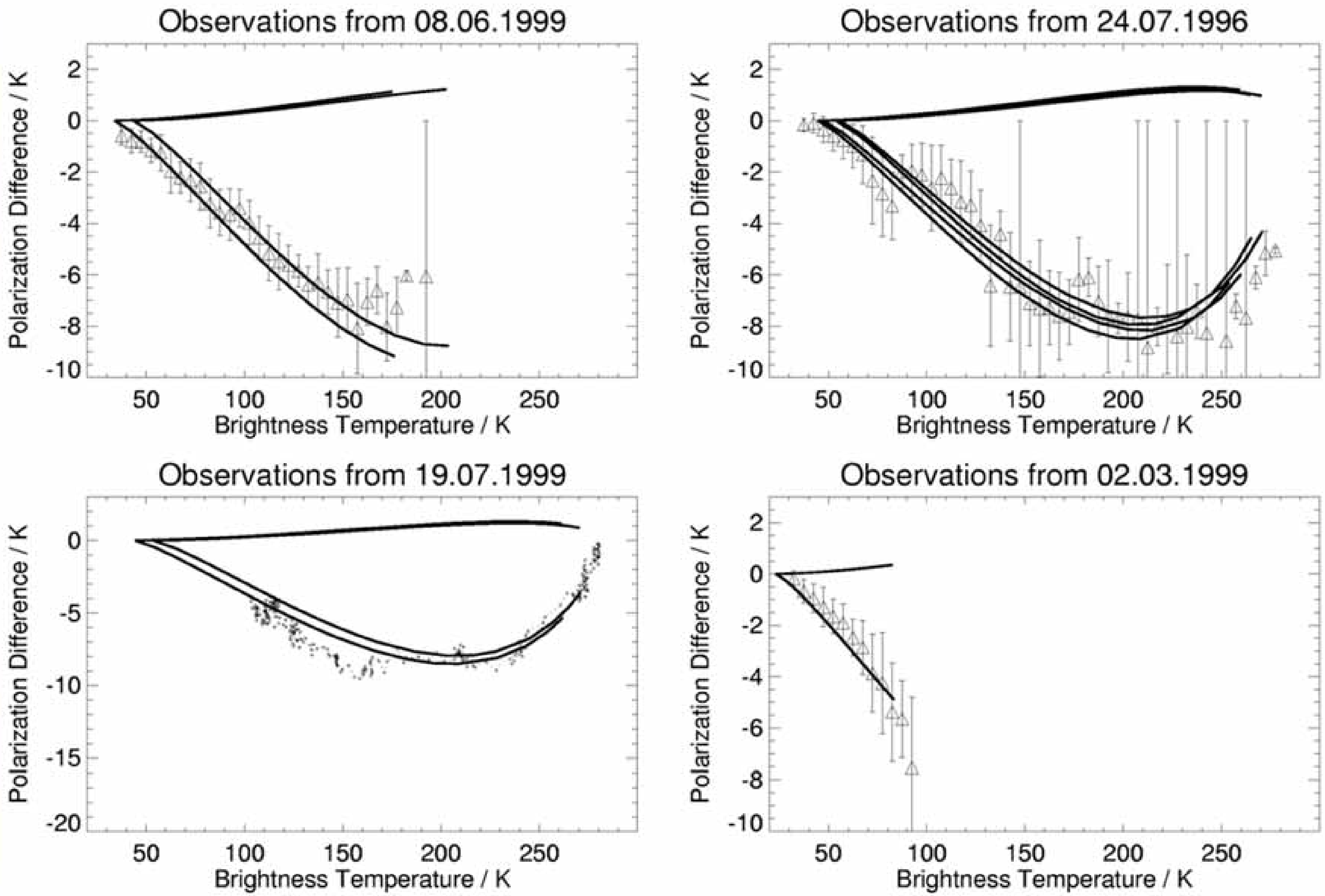
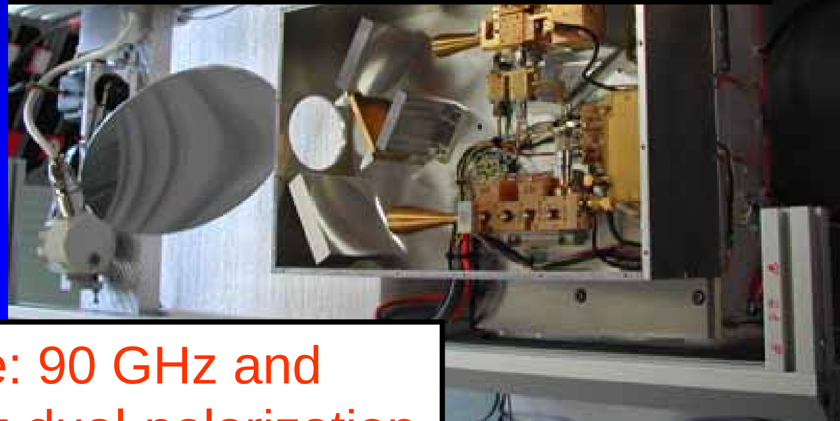
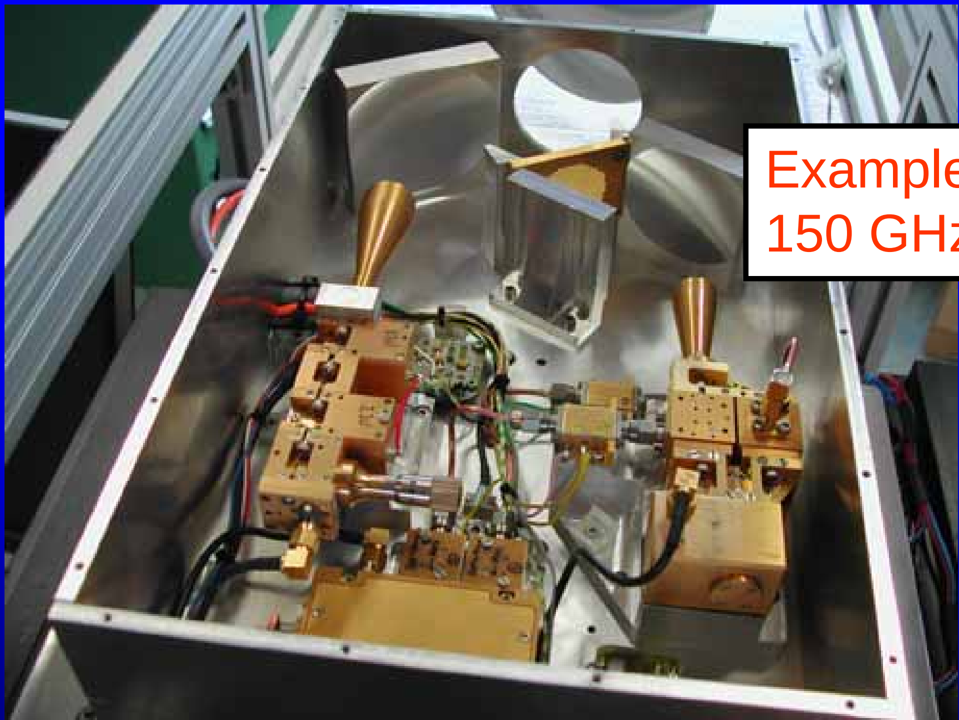


Dual polarized radiometers

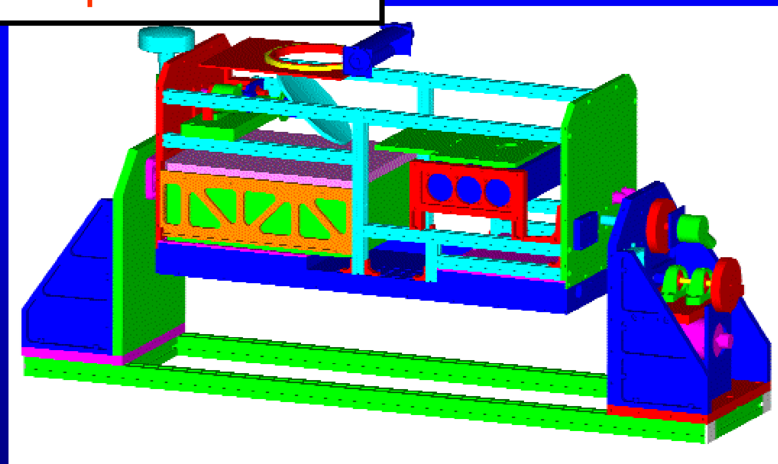
- Precipitation: 19 GHz, additional channels at 10 GHz and 30 to 40 GHz
- Ice clouds: 90 and 150 GHz
- Vertical and horizontal polarization with high accuracy (< 1.0 K)

University of Bonn: pending proposal for 6 channel system (Alessandro Battaglia)

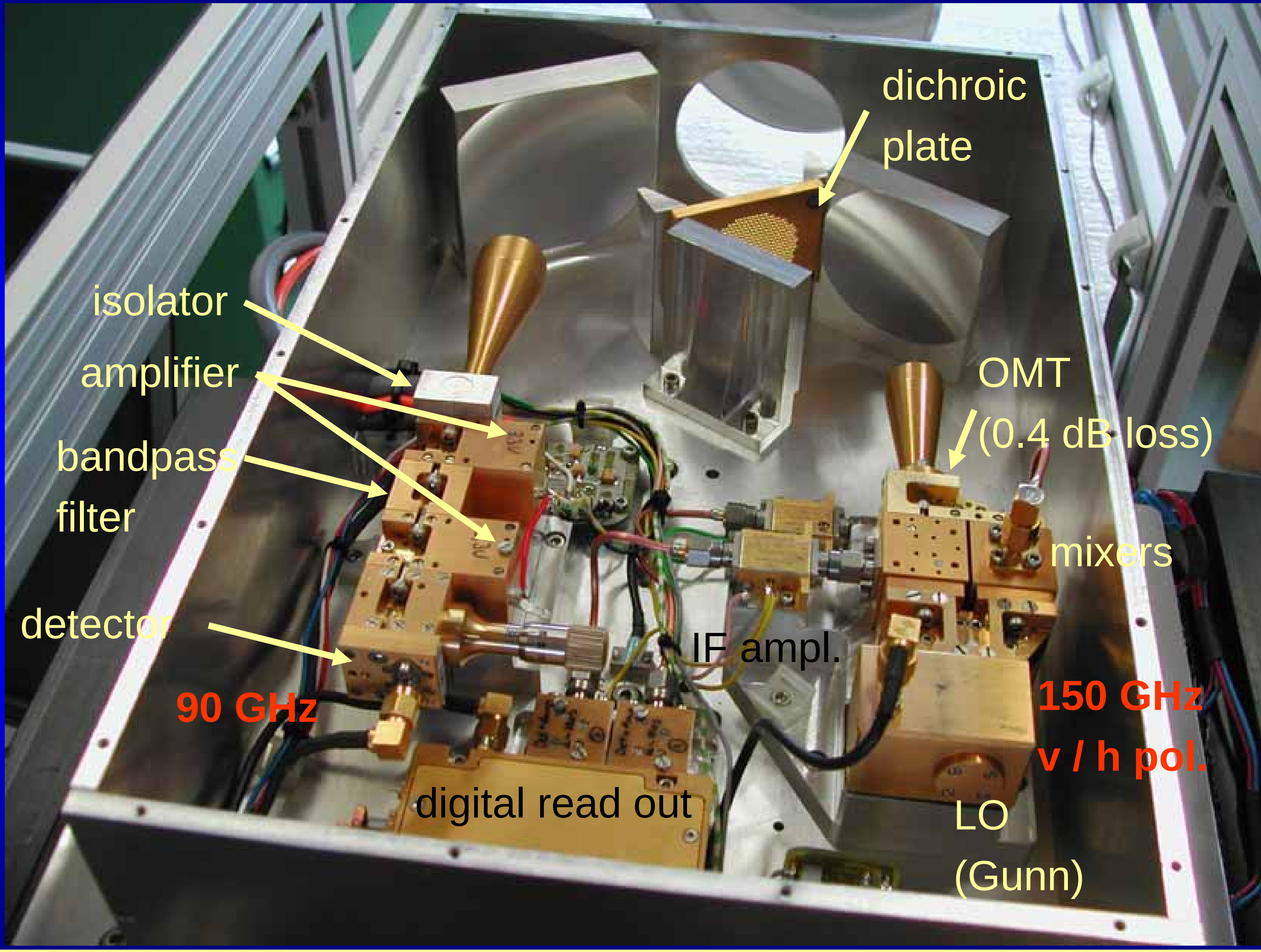




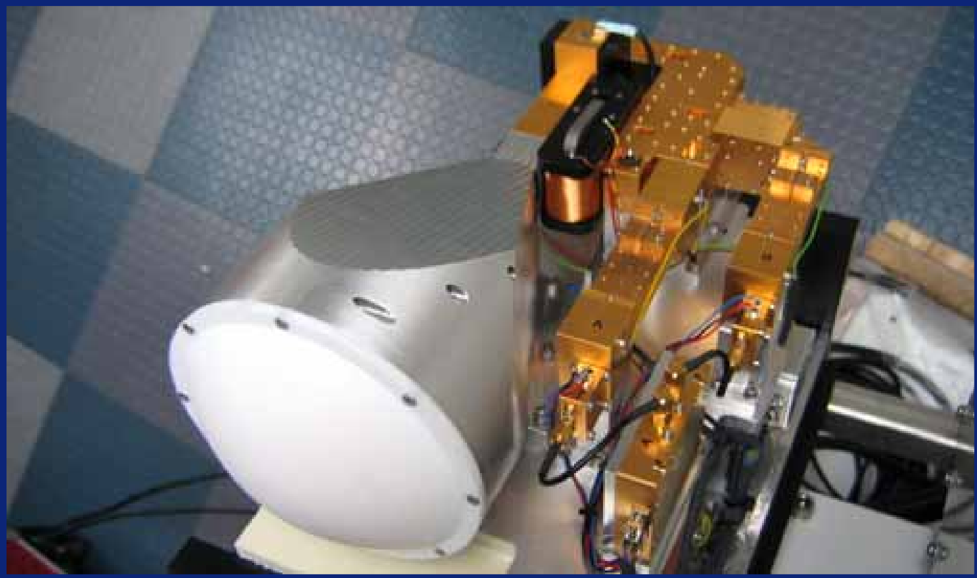
Example: 90 GHz and 150 GHz dual-polarization



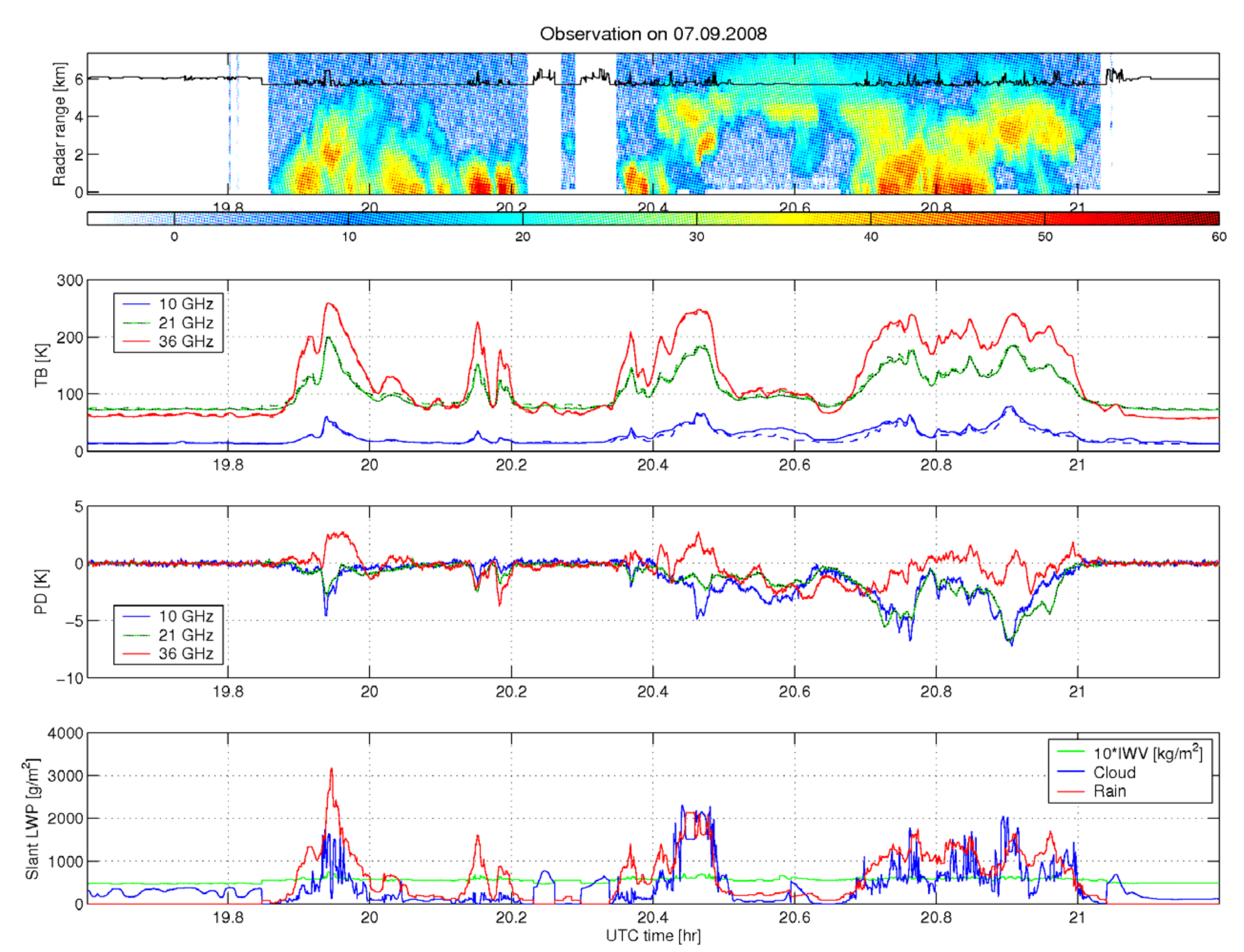
90 / 150 GHz radiometer



Dual polarized radiometers



ADMIRARI
(10.65, 21.0, 36.5 GHz)
Dual-Polarisation


Observation on 07.09.2008
Radar range [km]
TB [K]
10 GHz
21 GHz
36 GHz
PD [K]
10 GHz
21 GHz
36 GHz
Slant LWP [g/m^2]
10*IWV [kg/m^2]
Cloud
Rain
UTC time [hr]

Conclusions

- **Polarization** signal from oriented nonspherical rain drops gives **additional information** for the remote sensing of LWP
- Use of polarization leads to **higher accuracy** of LWP in thick clouds
- Cloud and rain LWP can be derived independently
- **Rain detection** possible (even with no surface rain rate)
- Some information about drop size distribution may be derived
- Cloud process studies: Observe drop size distributions evolving from cloud droplets towards falling rain drops

For further information on polarized instruments and algorithms:

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http://www.radiometer-physics.de