PROM-FRAGILE:

Exploring the role of **FRAG**mentation of ice particles by combining super-part**I**cle modeling, **L**aboratory studies and polarim**E**tric radar observations

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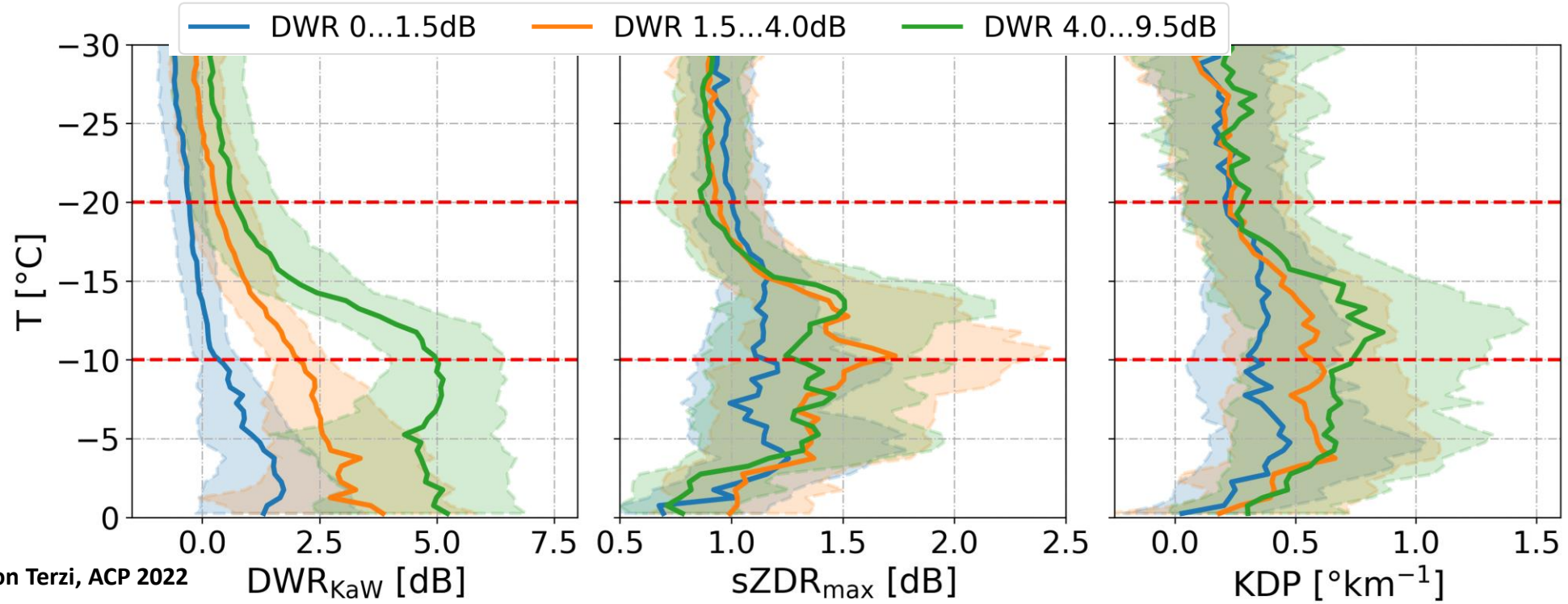
Sudha Yadav, Miklós Szakall (Uni Mainz)

Simone Wald, Axel Seifert (DWD)

Multi-month spectral polarimetric multi-frequency radar dataset



von Terzi, ACP 2022

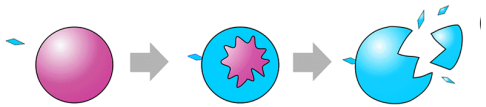
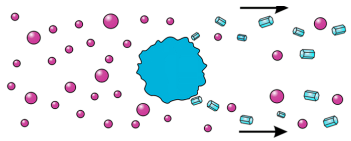
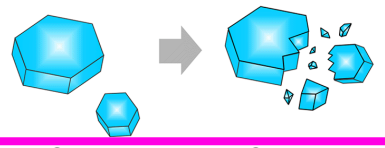
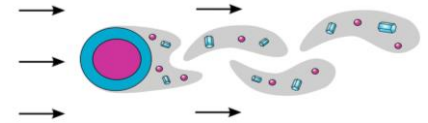
- Increase in ice crystal number concentration alongside enhanced aggregation

→ Source of ice particles needed!

→ Secondary ice processes?

Why Fragmentation?

- Status of SIP research: (as in talk from Korolev at ICCP 2021)

Description	Mechanism	# Lab works	Lab studies quantification	# years	simulations
	**Droplet fragmentation during freezing**	35	Work-in-progess (ongoing)	69	Early stage
	**Splintering during riming (HM process)**	22	Work-in-progess (ongoing)	61	Yes physical mechanism under debate
	**Fragmentation during ice-ice collision**	2	Work-in-progess (deeply hybernated)	49	Early stage
	**Fragmentation during sublimation**	9	Work-in-progress (deeply hibernated)	47	Early stage
	**Activation of INPs in transient supersaturation**	5	Not attempted	49	no

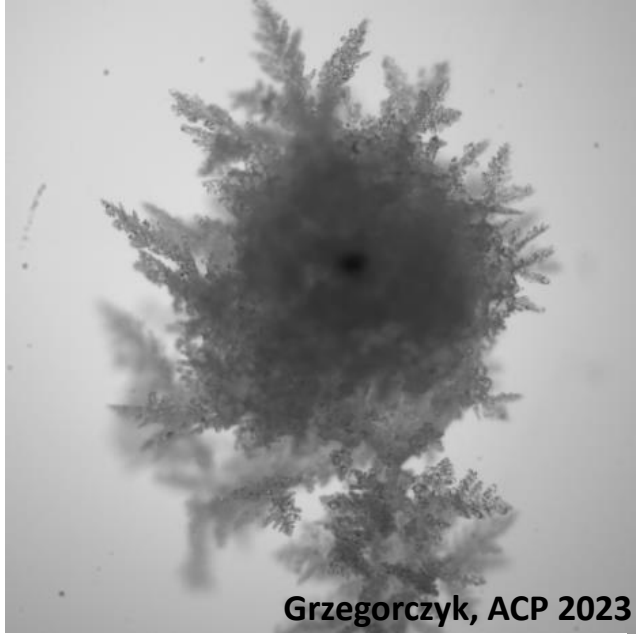
Why Fragmentation?

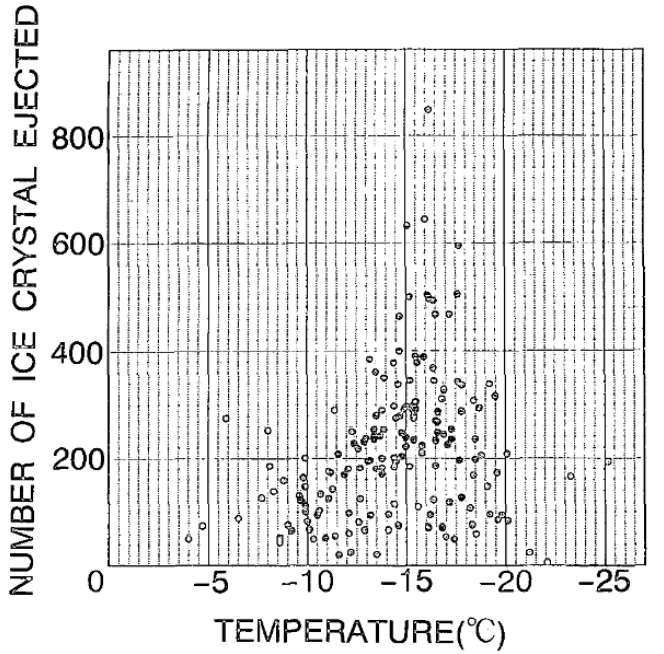
Fragmentation:

- Fragile dendritic arms growing on ice particles and aggregates
- Arms break off during collisions
- Potential to be active over wide parameter range (not like other SIP)

Problem:

- Very little understanding

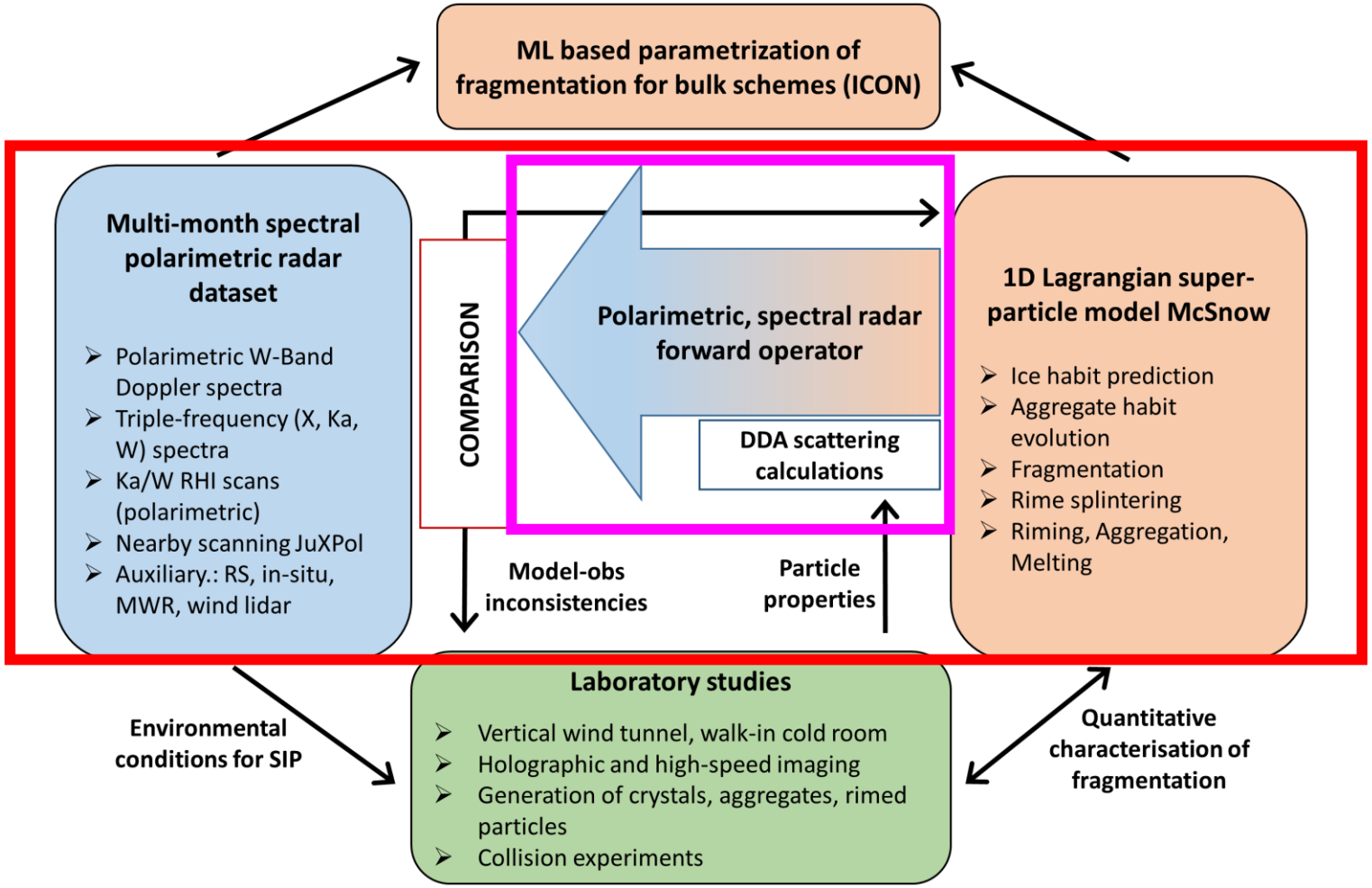

Grzegorczyk, ACP 2023



Takahashi 1995

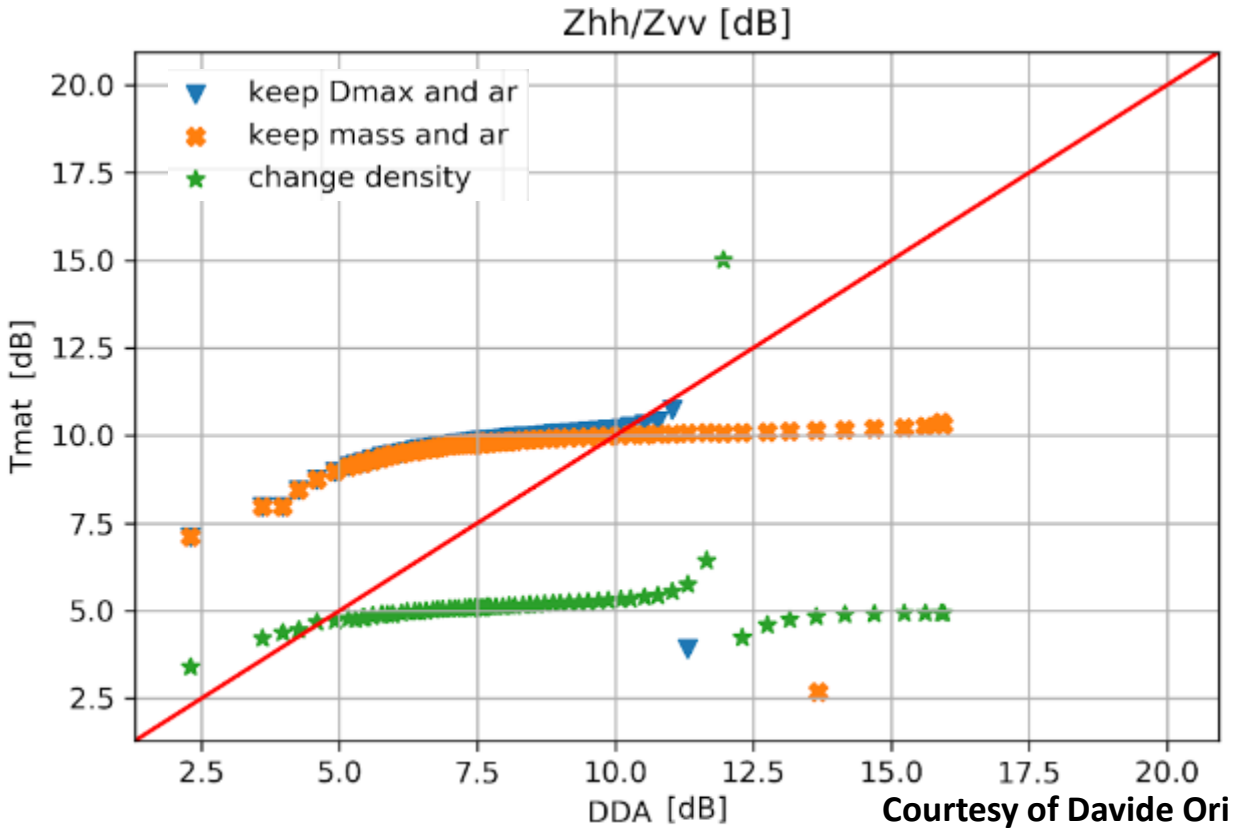
FRAGILE:

Is fragmentation a relevant process which can explain the discrepancies between ice crystal number concentration and ice nucleating particles?

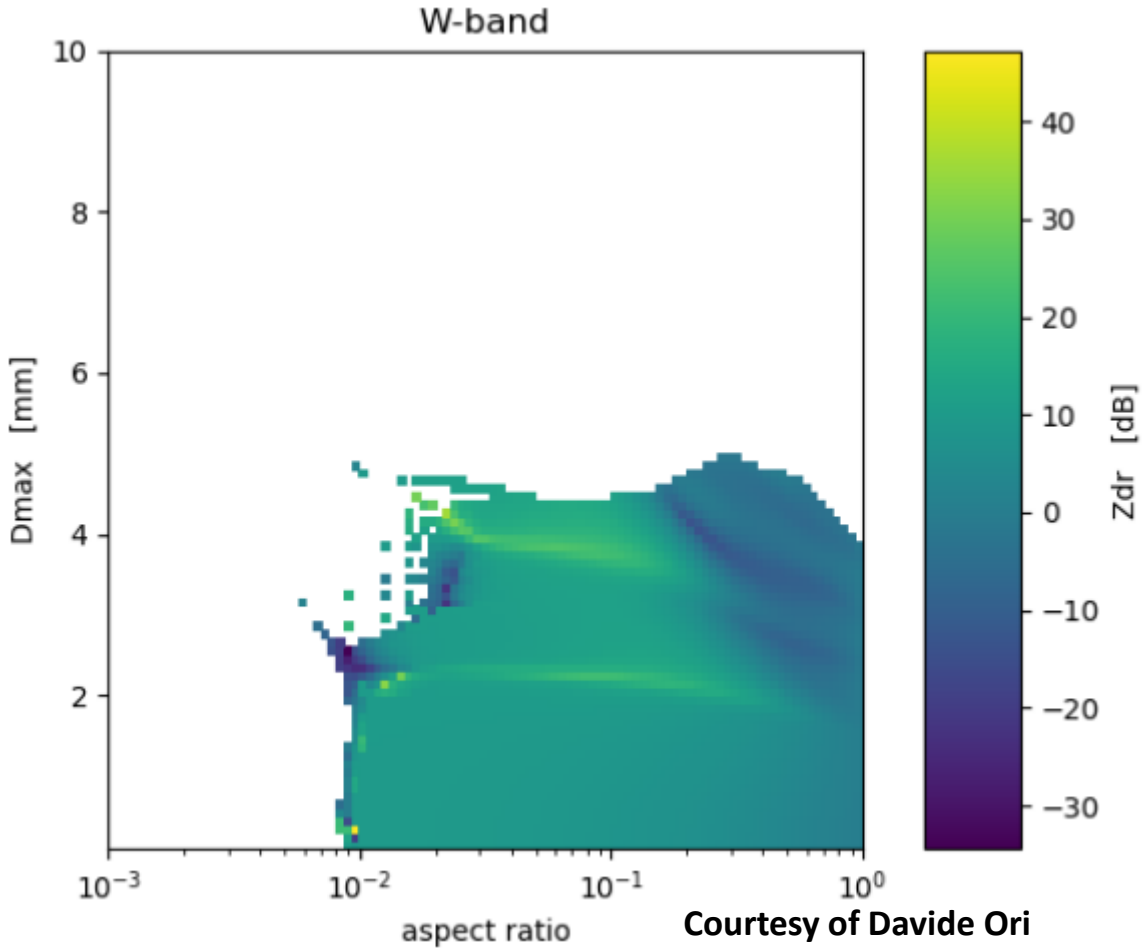


Forward simulations: from T-matrix to DDA

Comparison of DDA and T-matrix calculated for Dendrites at X-band



Tmatrix has a convergence problem!

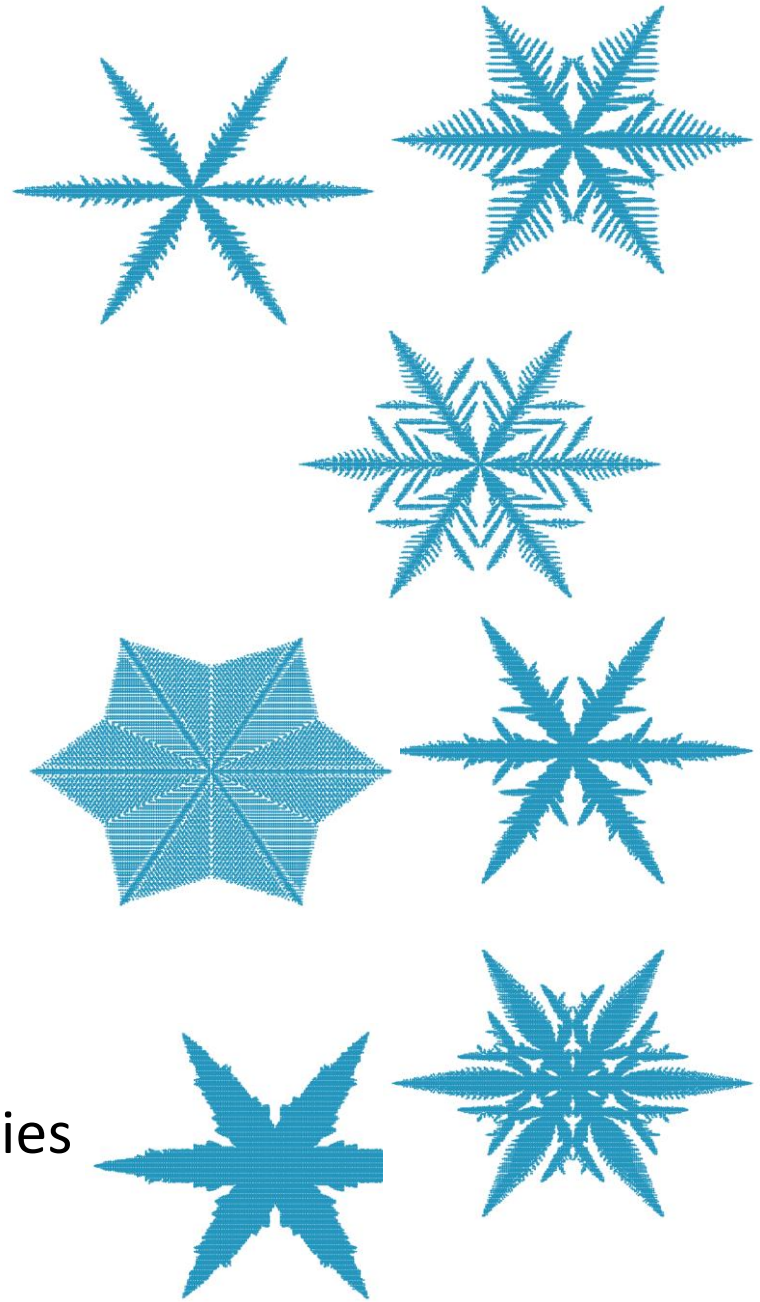


Strong dependence on definition of the circumscribing spheroid

Forward simulations: from T-matrix to DDA

Problems:

- For DDA we need specific 3D shape
  → we need realistic particles
- McSnow has habit prediction
  → wide range of masses, sizes, densities and aspect ratios!

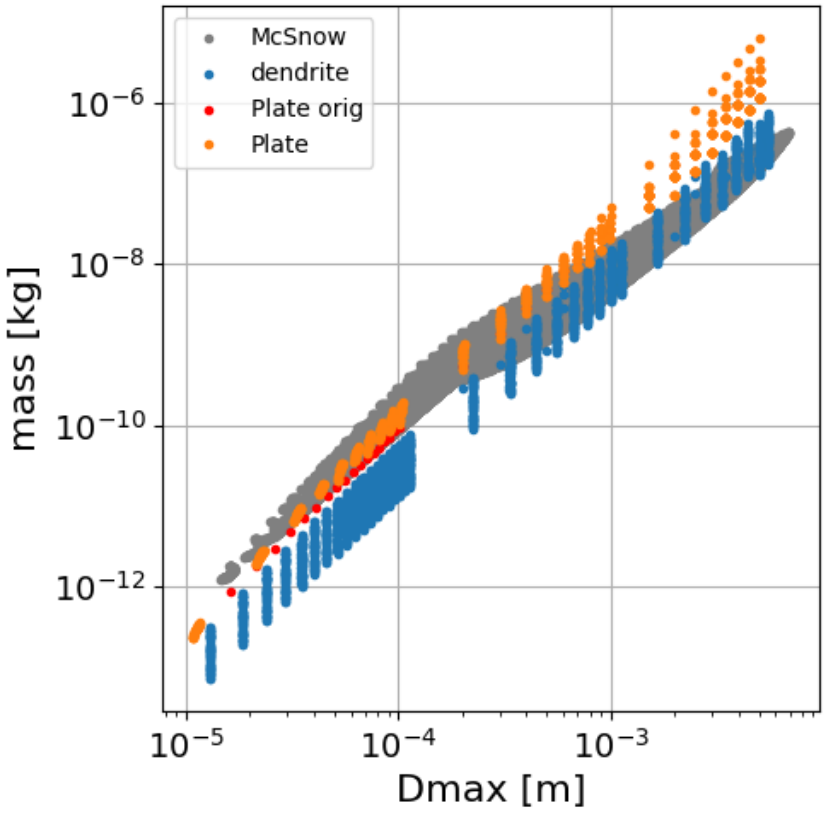


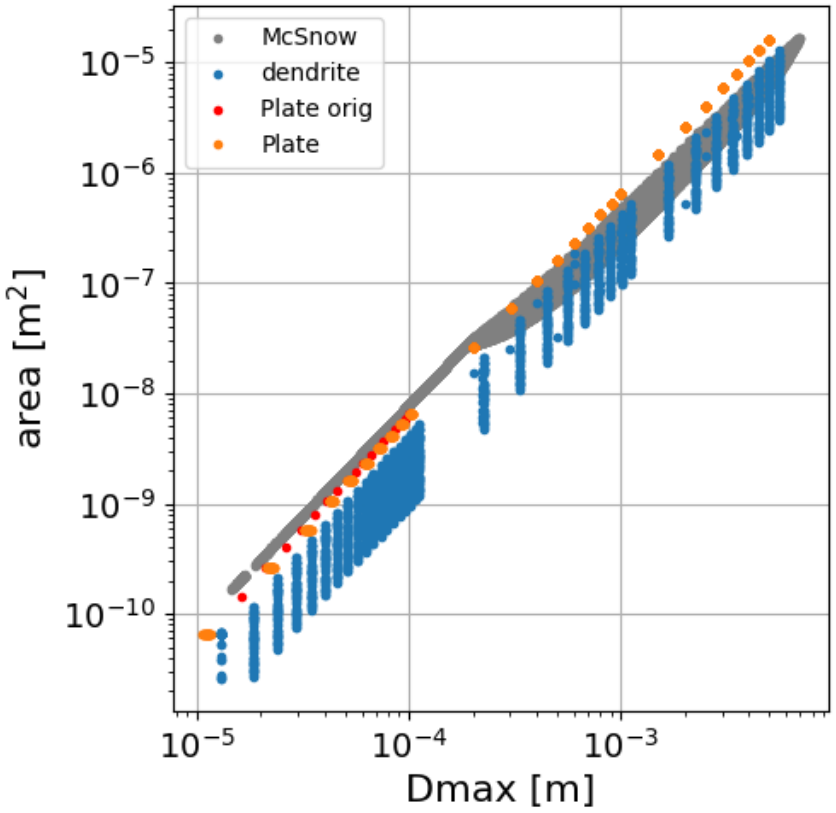
Solution:

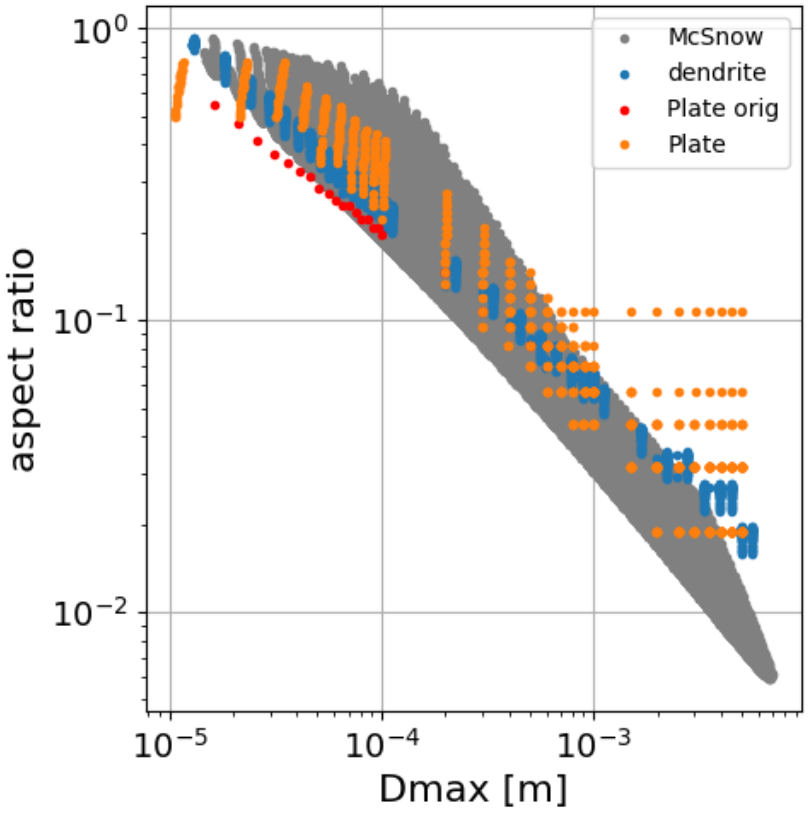
- generating dendrites with the Reiter algorithm
- plates with varying aspect ratios
- Needles and columns with varying aspect ratios and densities

Forward simulations: towards a DDA LUT

McSnow ensemble simulations for DGL





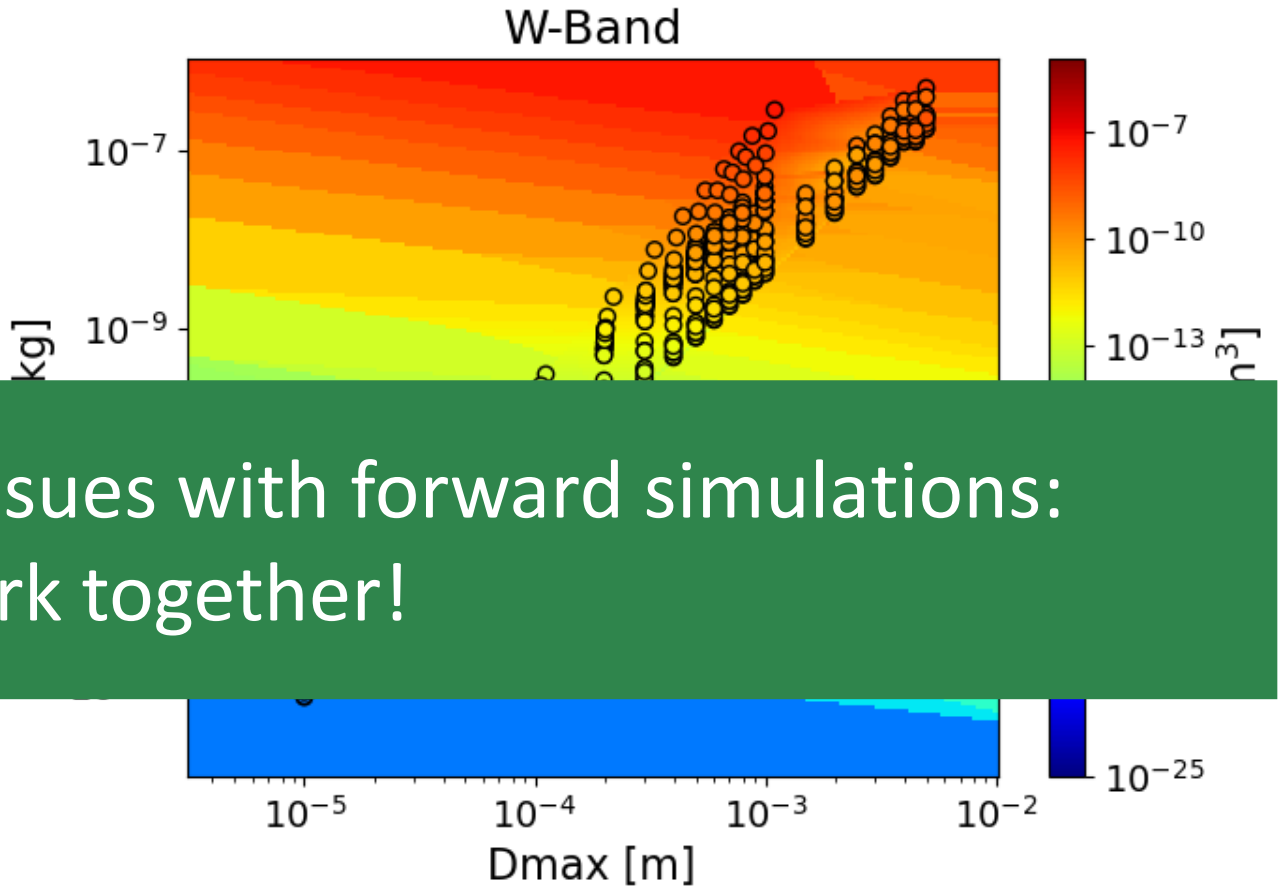


→ LUTs containing DDA calculations of ~1000 crystals (plates, dendrites, columns)
→ and 50 unrimed aggregates (+200 rimed aggregates ongoing)

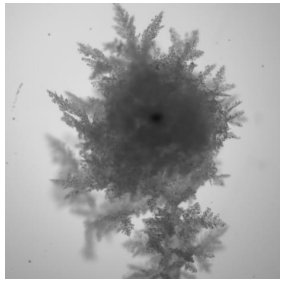
Forward simulations: from T-matrix to DDA

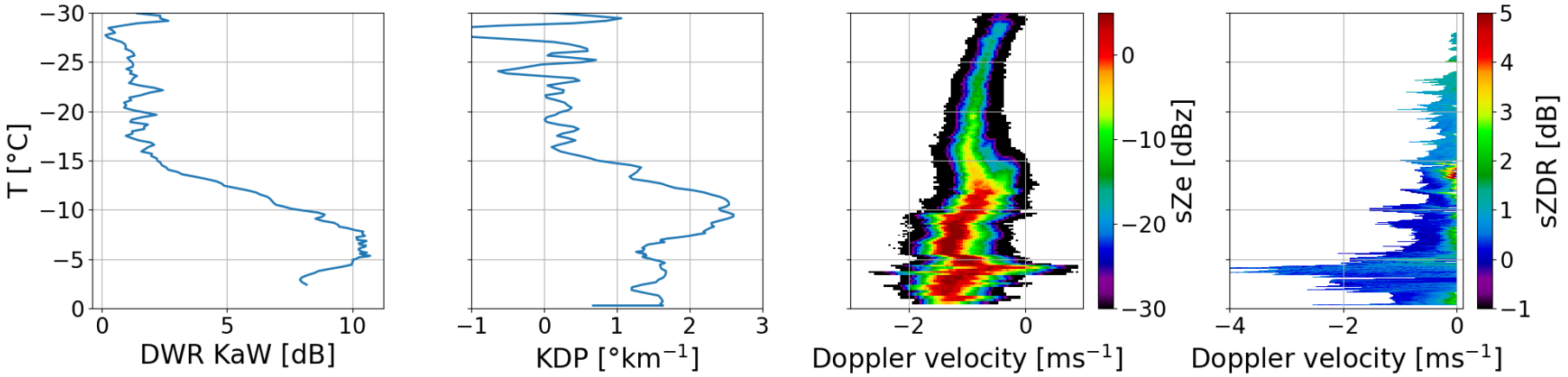
LUT:

- Entries of the Mueller and amplitude matrices
- 5 dimensions:
  - Radar elevation (0-90 with 5° res.)
- Linear Interpolation, nearest neighbour extrapolation



Everyone here probably has issues with forward simulations:
→ let's work together!





Laboratory

Observations

Hypothesis

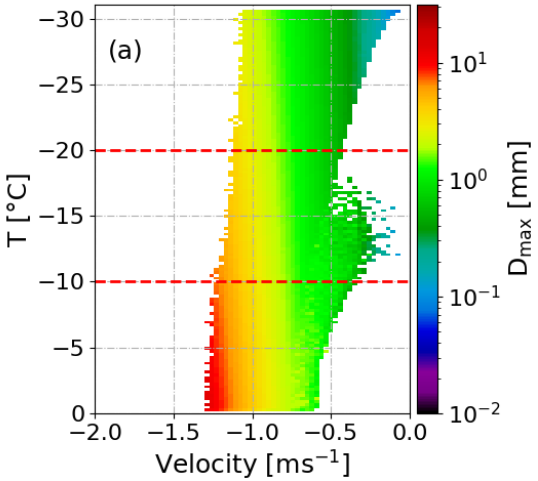
Parametrisation

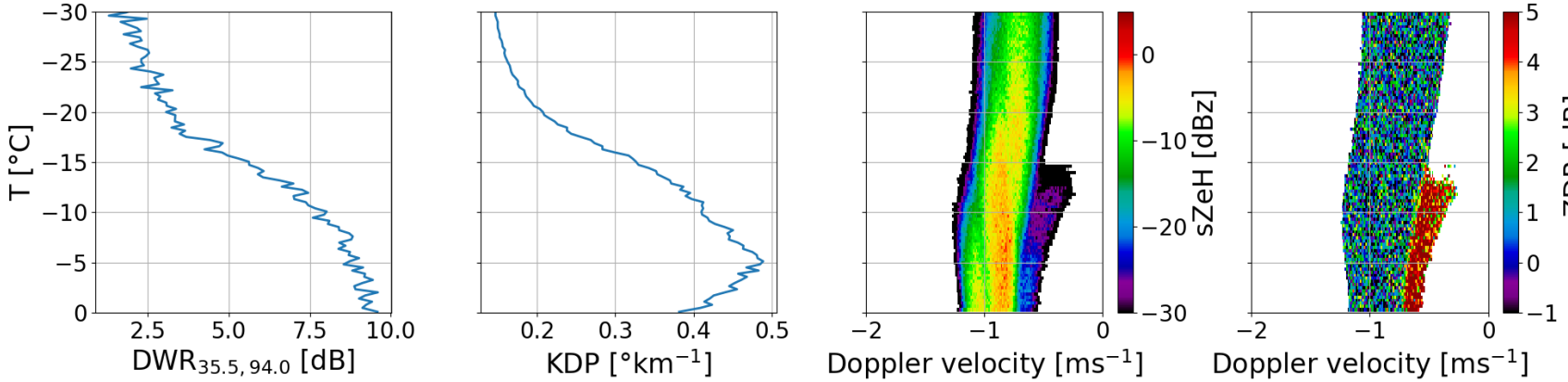
Re-evaluation

Comparison

McSnow simulation

Forward simulation



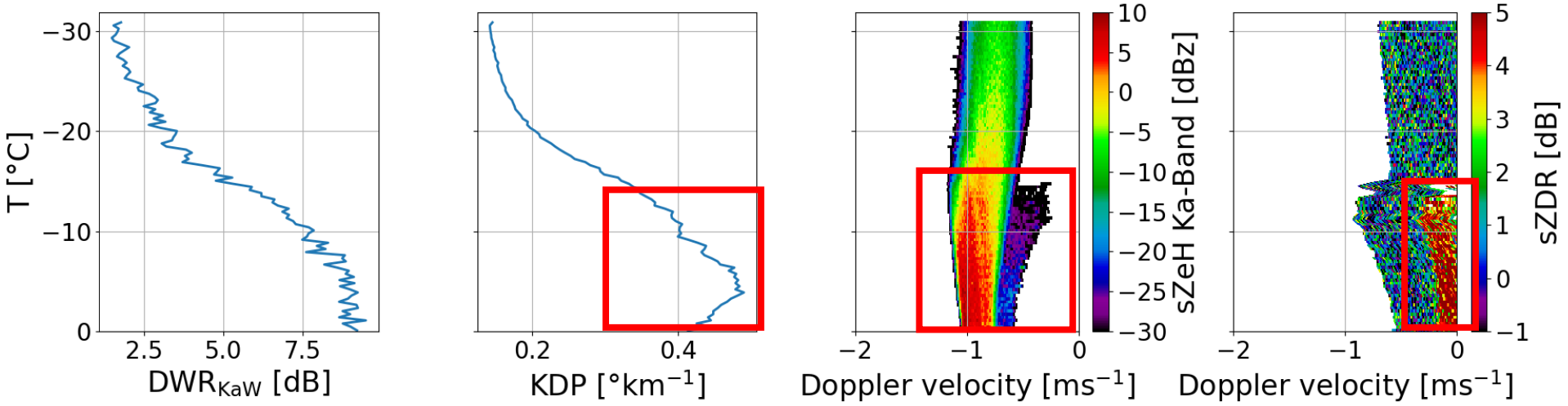


Do ice-ice collisions in the DGL cause fragmentation?

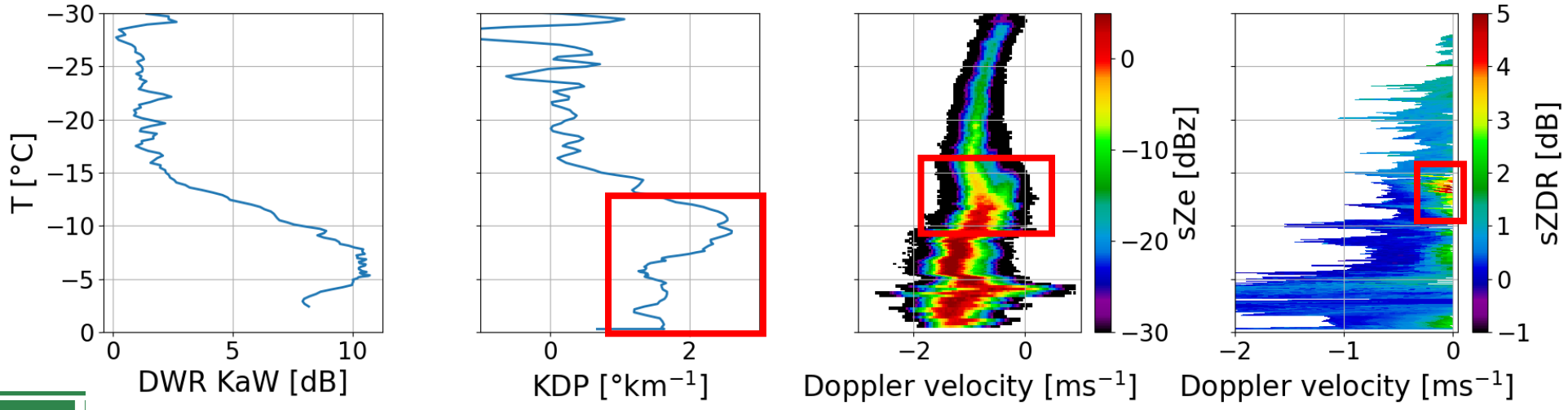
- First simulation experiments
- Physically based scheme from Philipps
  → several parameters currently not well constrained by lab studies
- Simplified fragmentation scheme
  - based on initial fragmentation experiments (Grzegorczyk, ACP 2023)
  - fragmentation is limited to the DGL
  - Ad-hoc parametrisation

Do ice-ice collisions in the DGL cause fragmentation?

Simulation



Observation



sZDR:

- reasonable range
- 2. Mode too persisent

sZe:

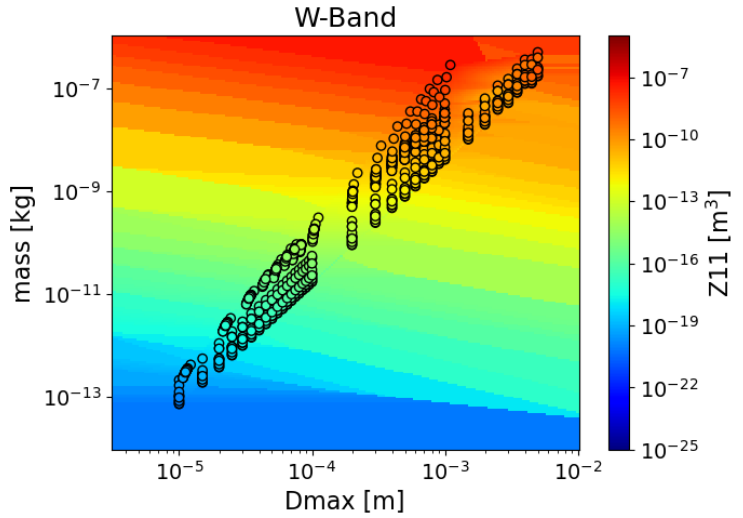
- 2. Mode too small
- Modes do not merge

KDP:

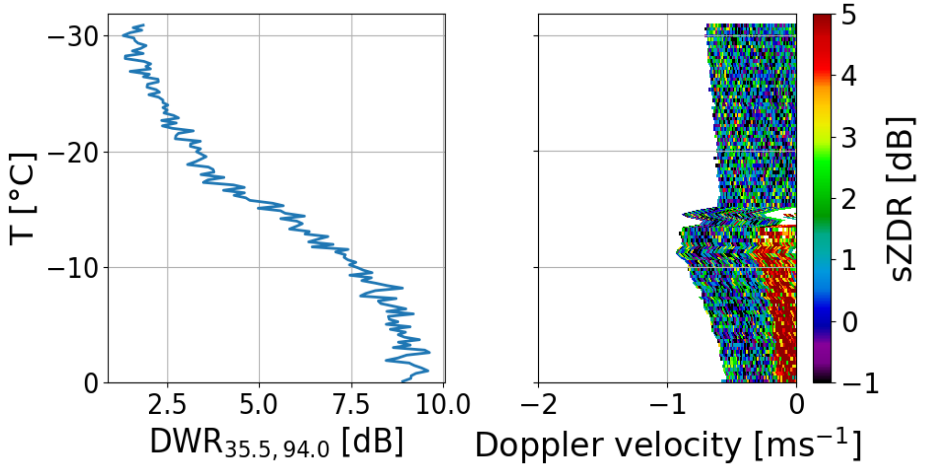
- too small
  → not enough fragments?

Conclusions

- Scattering database:
  - Initial LUTs with DDA calculations of 1000 ice particles
  - **Let's discuss possible collaborations!**

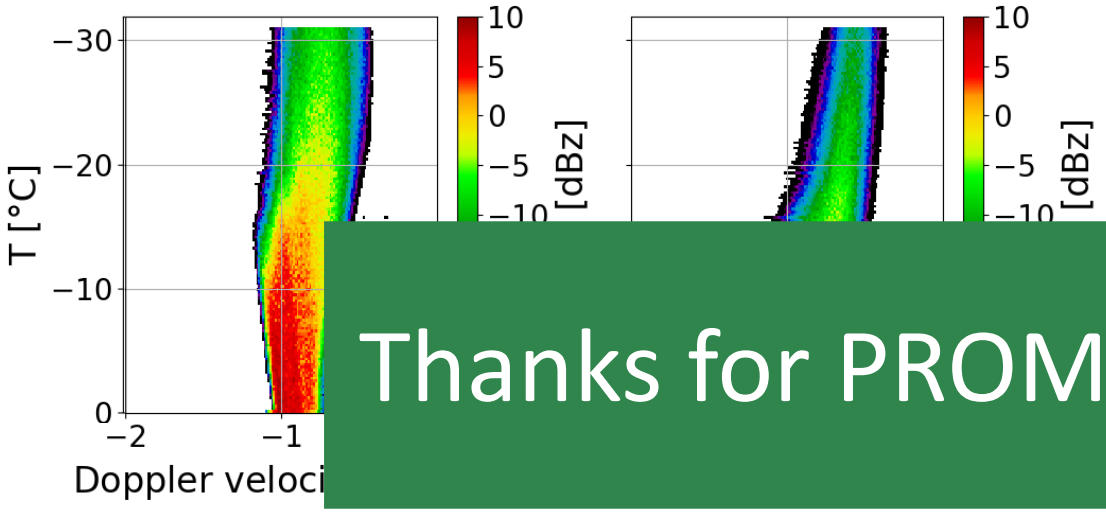


- Simulation experiments of fragmentation produce a second mode with reasonable ZDR, but KDP underestimated
- Additional McSnow simulations with
  - Primary nucleation
  - Varying aggregate PSD



Outlook: PSD retrieval

- For McSnow simulations (and evaluation), PSD information is crucial

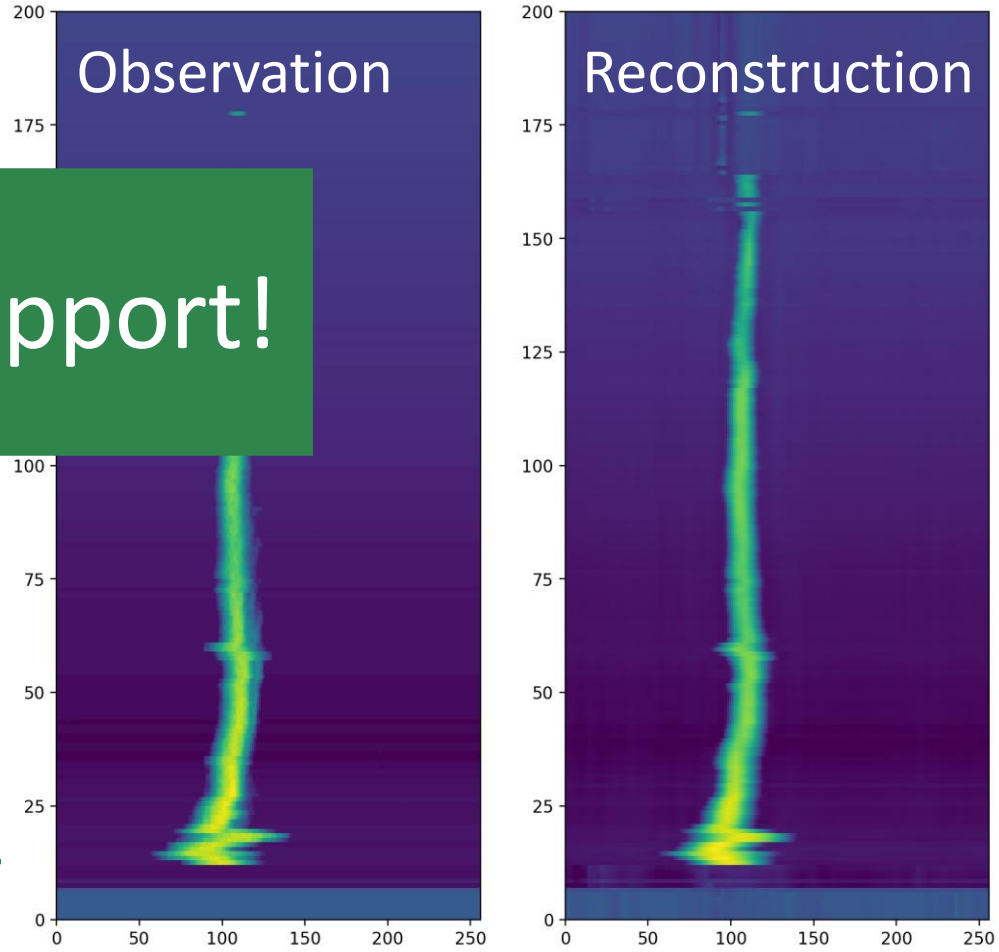


Thanks for PROM travel support!

- Observations indicate: aggregation might be correlated to width of PSD above DGL

Collarobation with Anne-Claire Billault-Roux (EPFL):

- ML PSD retrieval based on triple-freq. Doppler spectra



Conclusions

- Scattering database:
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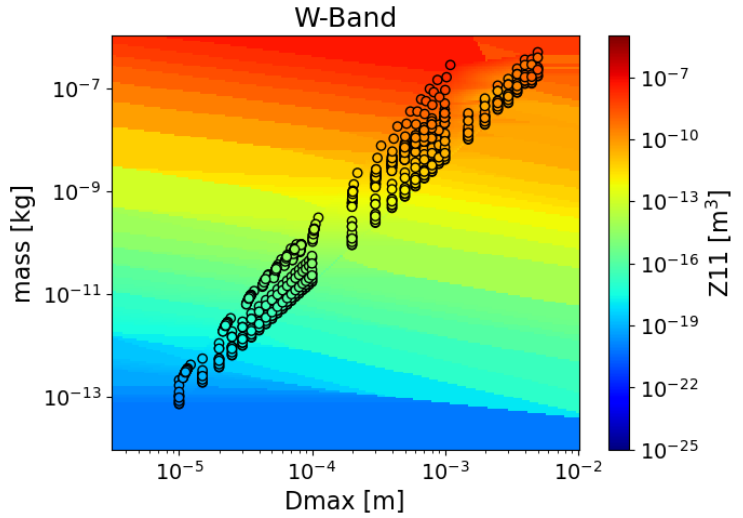
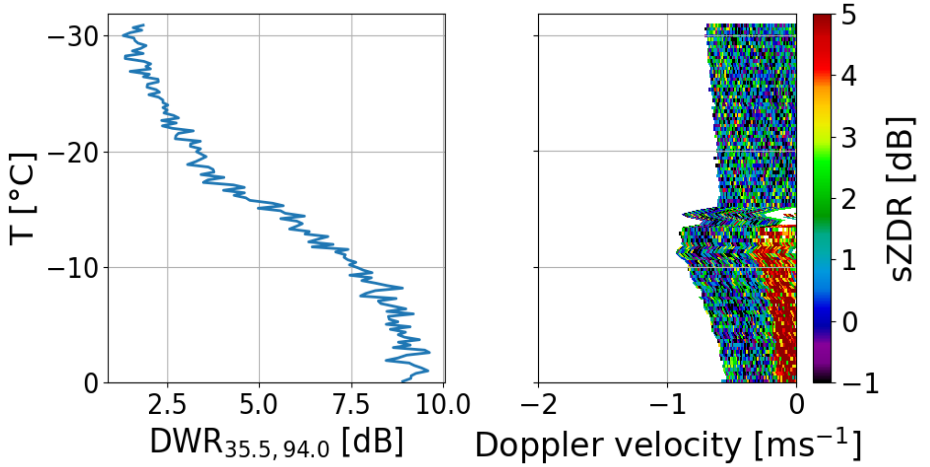
  - **Let's discuss possible collaborations!**



- Fragmentation does produce a second mode with reasonable ZDR, but KDP underestimated



→More lab work on fragmentation is needed! (Sudhas talk)

Anhang

Outlook McSnow simulations

- Fragmentation produces 2. Mode with reasonable sZDR
  - KDP is too small – can we produce more fragments?
  - Which conditions are most favourable for fragmentation?
- Are there other explanations for 2. Mode?
  - Local enhancement of relative humidity
    → INP get activated and new ice crystals are formed

- Both hypothesis are currently investigated in more detailed with a statistical approach!

Conclusions

- Observations show an increase in number concentration in DGL alongside second mode and enhanced sZDR
- Simulations indicate that second mode might be more likely related to fragmentation than new INP activation

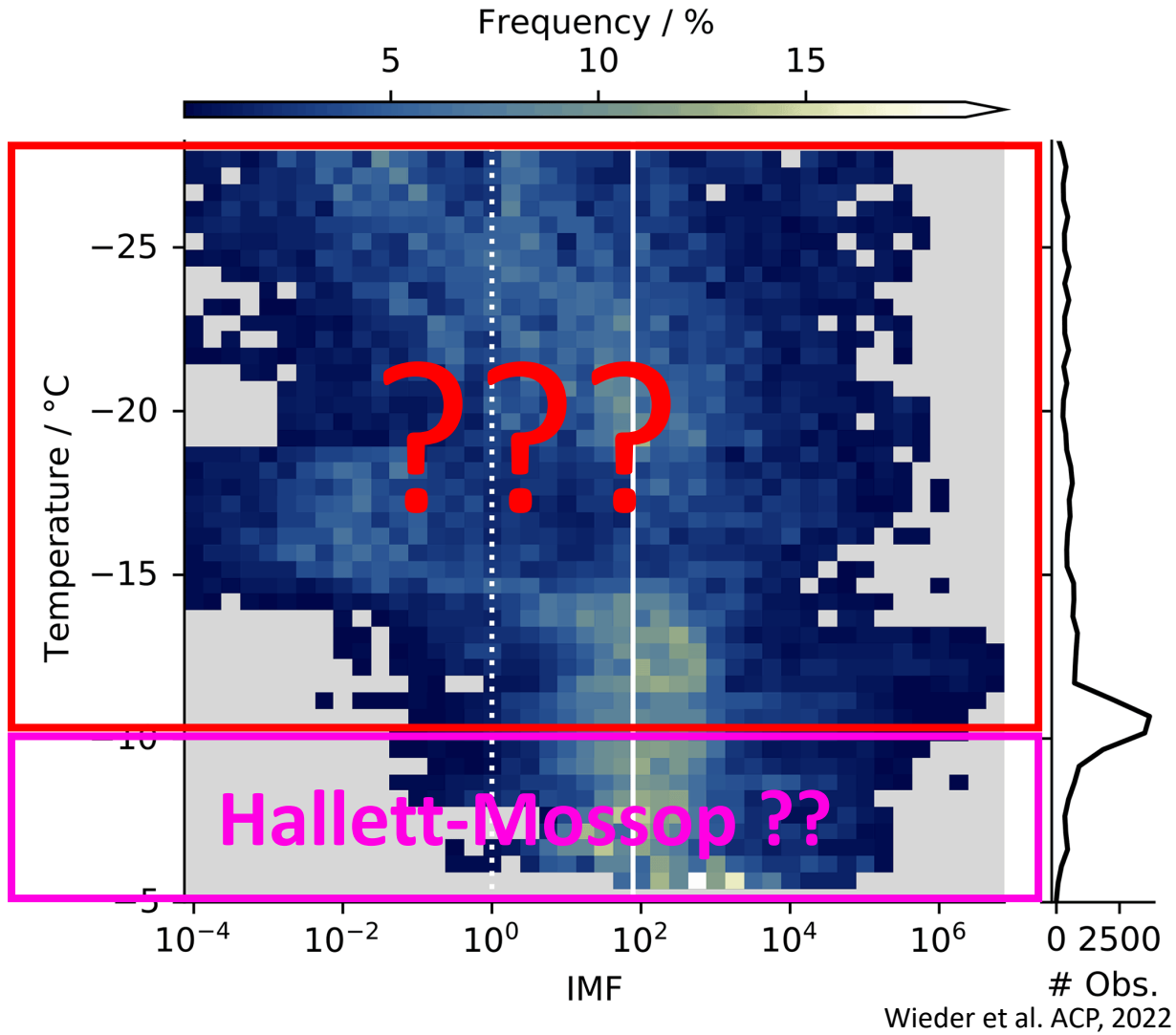
… of course more simulations are needed to investigate in a more objective way…

… more information on fragmentation is needed to constrain fragmentation scheme in McSnow …

Why Fragmentation?

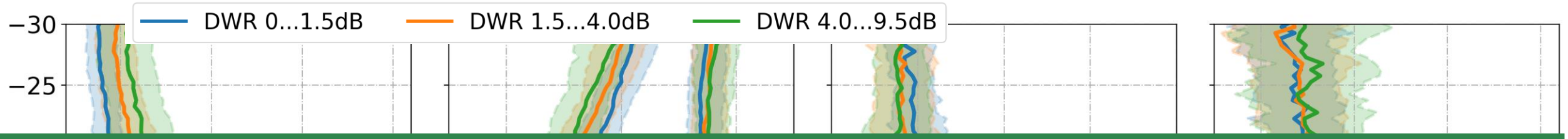
- factor 10 to 100 more ice particles (IP) observed than ice nucleating particles (INP) measured
- E.g. ice multiplication factor $\mathrm{IMF} = \frac{N(IP)}{N(INP)}$

→ Secondary ice production (SIP)



Wieder et al. ACP, 2022

Multi-month spectral polarimetric multi-frequency radar dataset



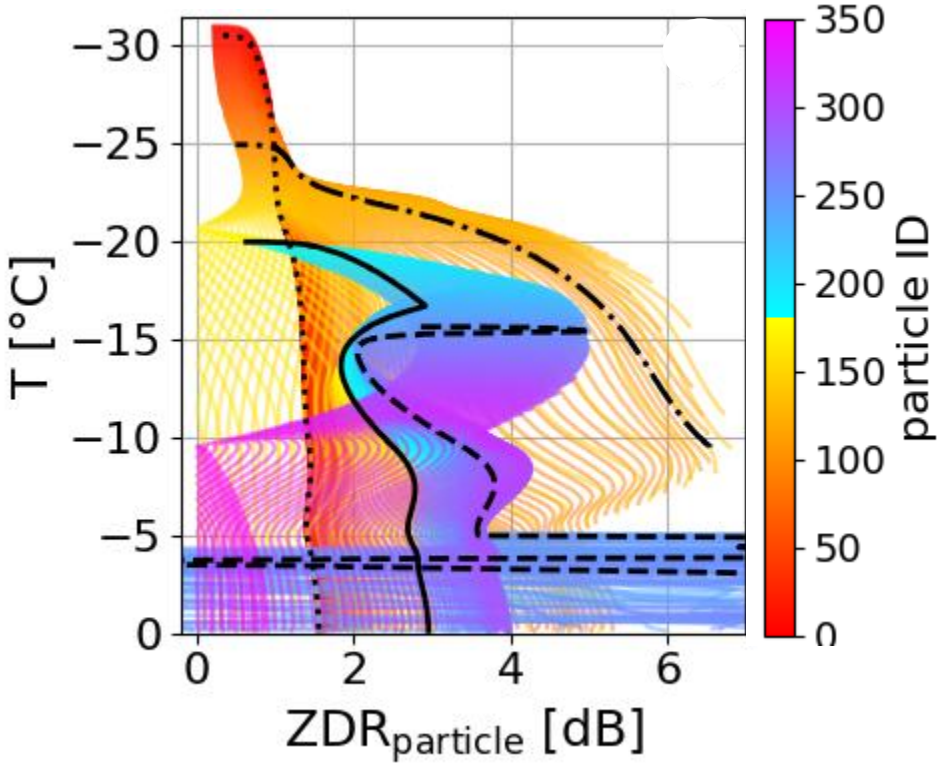
Radars only observe the **effect** of microphysical processes, **not the processes themselves**!!

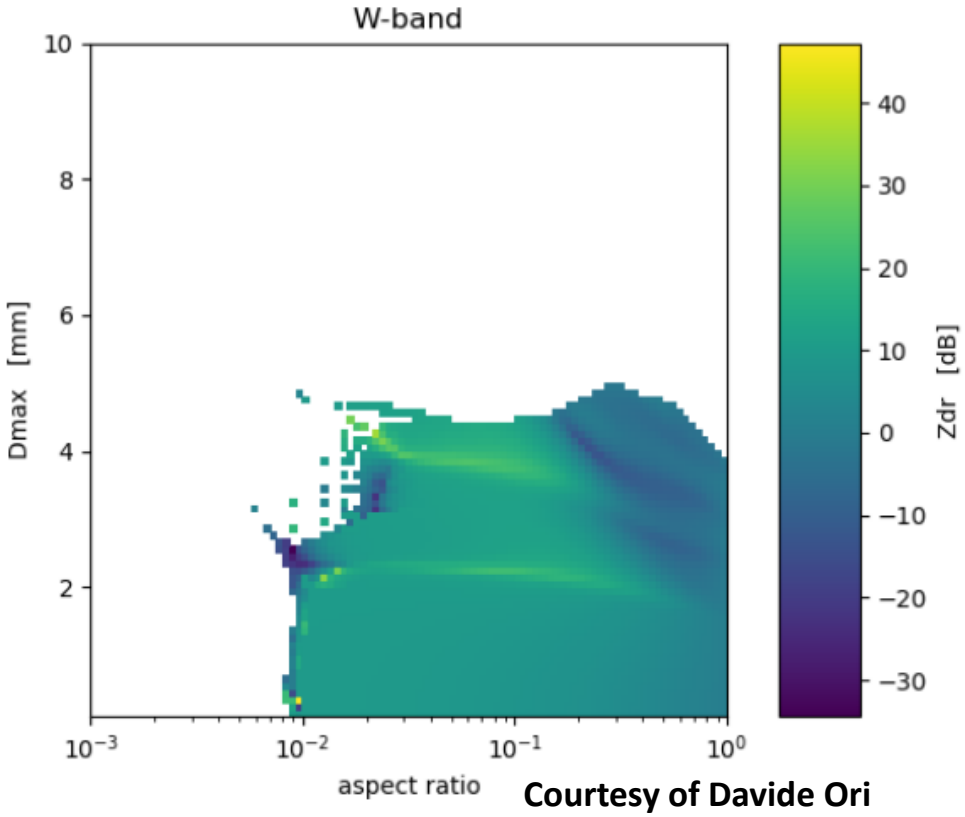
→ Model where current knowledge of microphysical processes is implemented and hytpothesis can be tested

- Do ice – ice collisions in the DGL cause fragmentation?
- Ice nucleating particles (INP) get activated and produce new primary ice

Forward simulations: from T-matrix to DDA

- Tmatrix has a convergence problem!

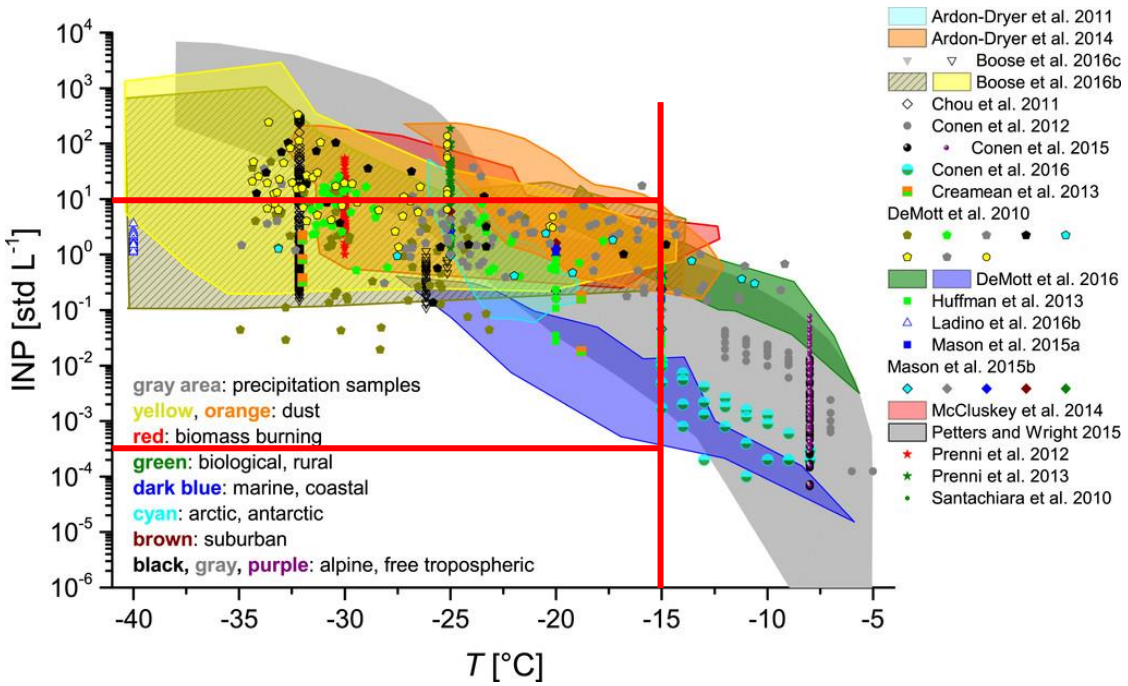




Courtesy of Davide Ori

Are new INP activated in DGL?

- Mode of aggregates from above
- Second nucleation layer in DGL
- Nucleation rate was adapted to have 2-3 L^{-1} ice crystals in the second mode
- McSnow mit habit prediction (Welss, JAMES 2023)
- Atmosphere setup:
  - Temp: const. Lapse rate
  - Rhi: 105% (median of radiosonde observations)



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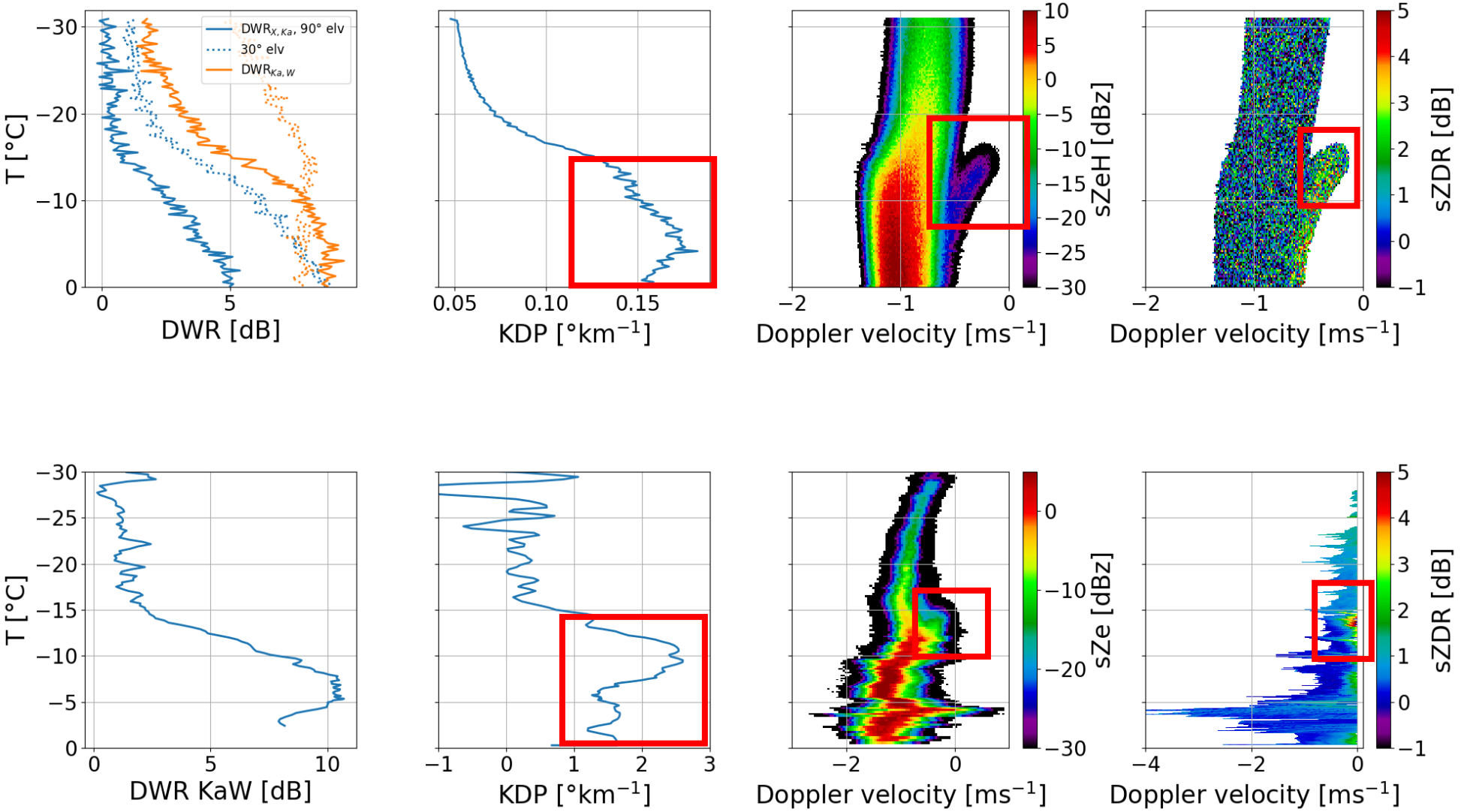

Simulation

- KDP too small → not enough particles?
- ~~sZE too small~~ → aspect ratios
- Particles not ~~too large~~ asymmetric or size too small enough?

Observation