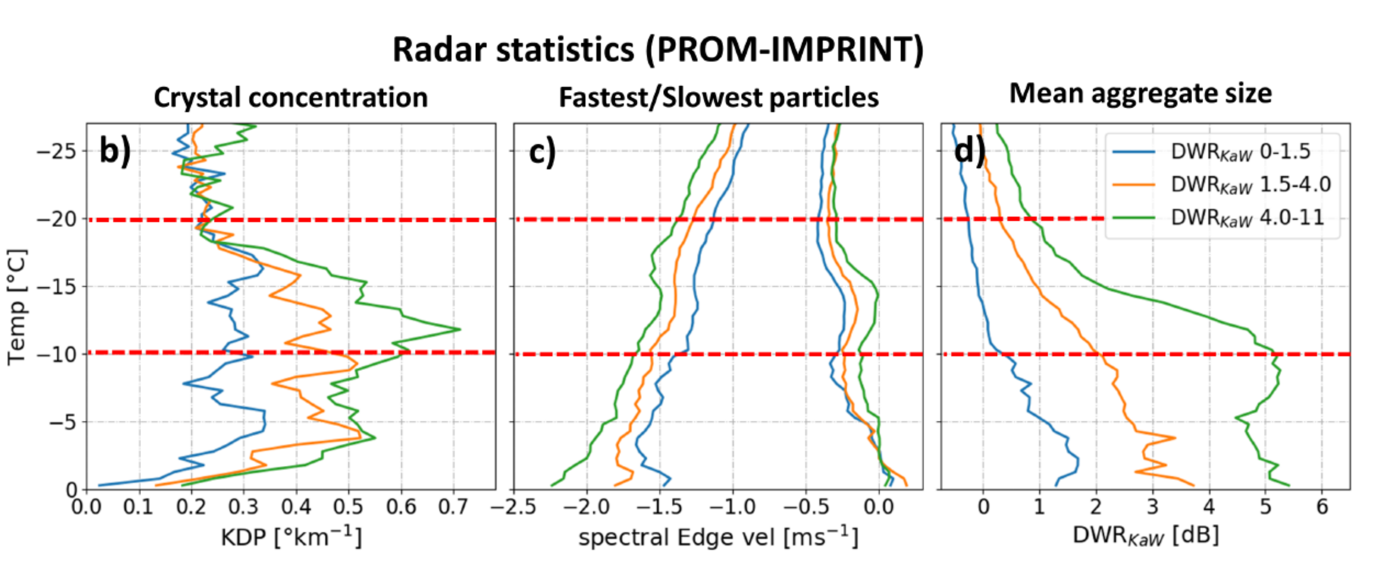
Exploring the role of **FRAG**mentation of ice particles by combining super-part**I**cle modelling, **L**aboratory studies and polarim**E**tric radar observations laboratory studies - FRAGILE

PIs:	Stefan Kneifel, Ludwig Maximilian University, Munich
	Axel Seifert, Deutscher Wetterdienst, Offenbach
	Miklós Szakáll, Johannes Gutenberg University, Mainz
Post-doc:	Alexander Theis, Max Planck Institute for Chemistry, Mainz
	Leonie von Terzi, Ludwig Maximilian University, Munich
PhD-students:	Sudha Yadev, Johannes Gutenberg University, Mainz
	N.N., Deutscher Wetterdienst, Offenbach

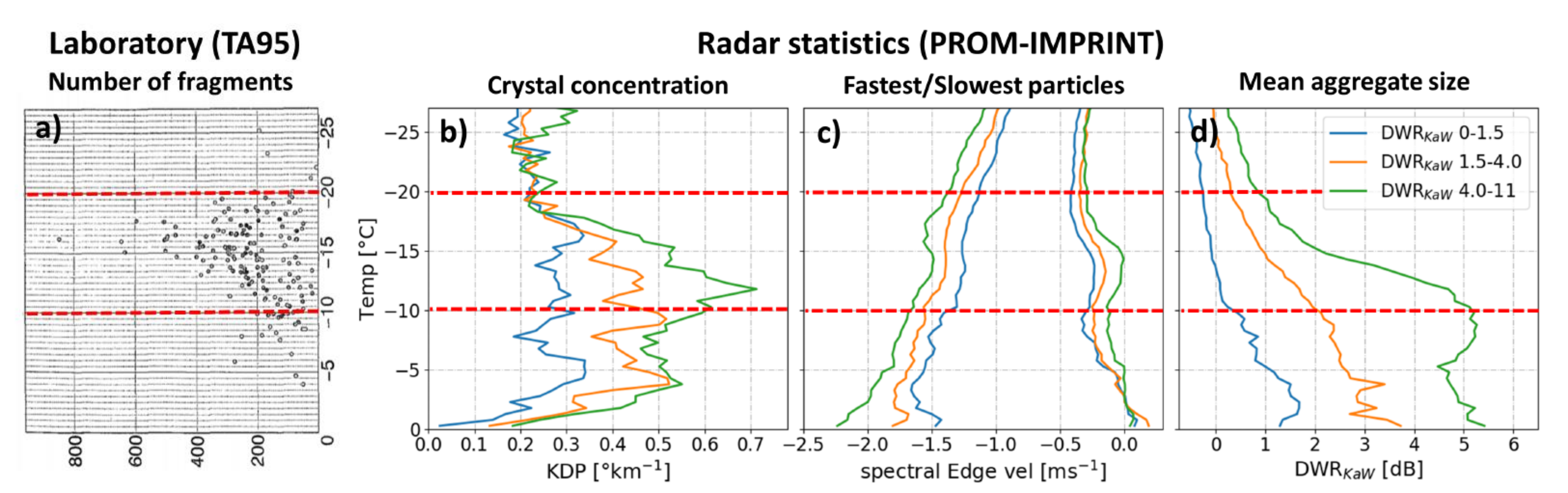
Motivation



Dendritic growth zone

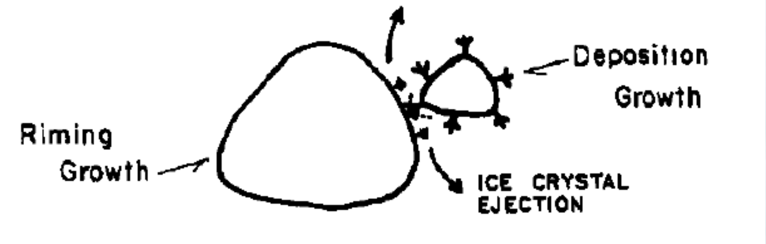
von Terzi et al., ACP, 2022

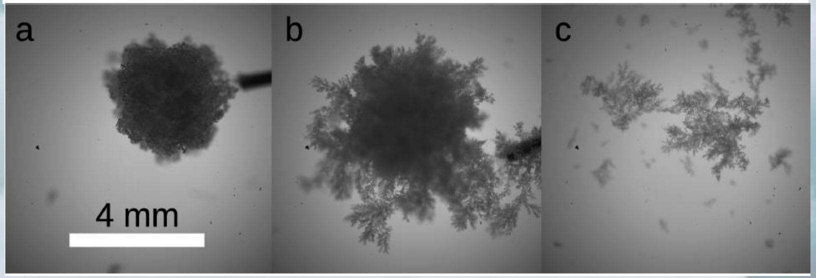
Motivation



Dendritic growth zone

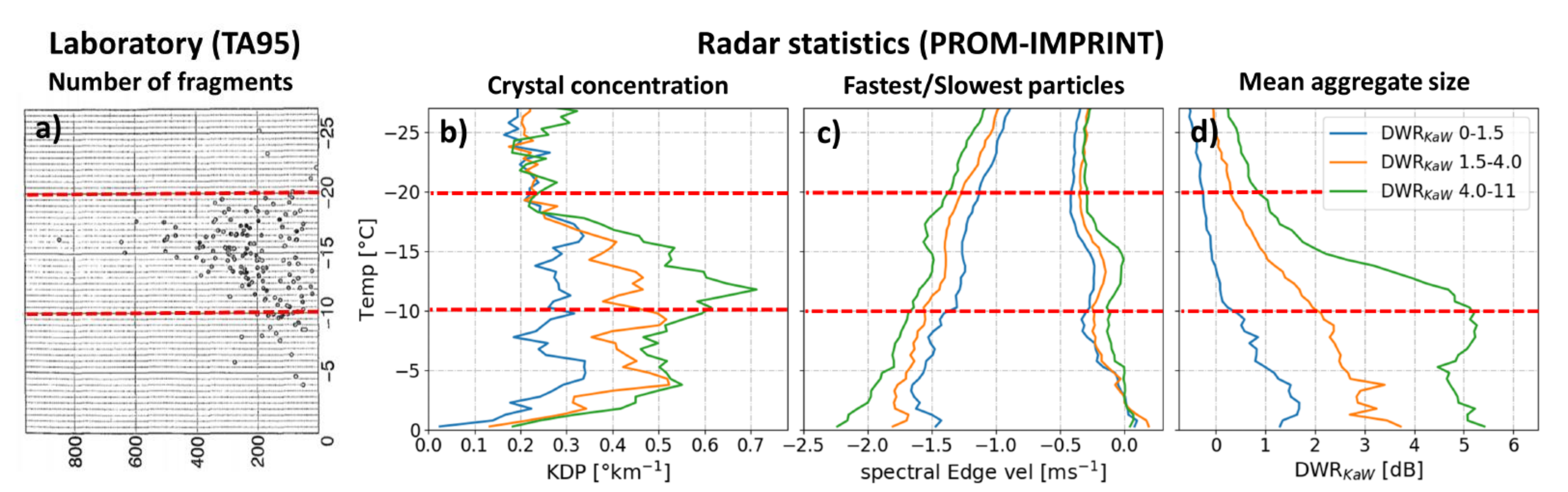
Ice fragmentation?





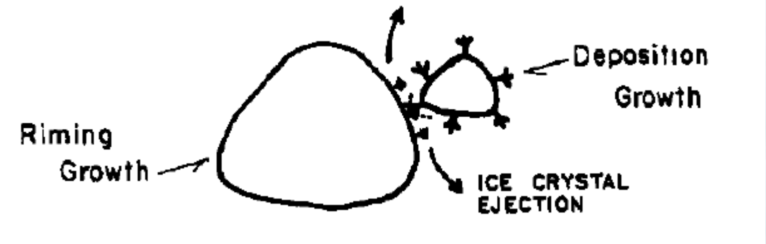
von Terzi et al., ACP, 2022

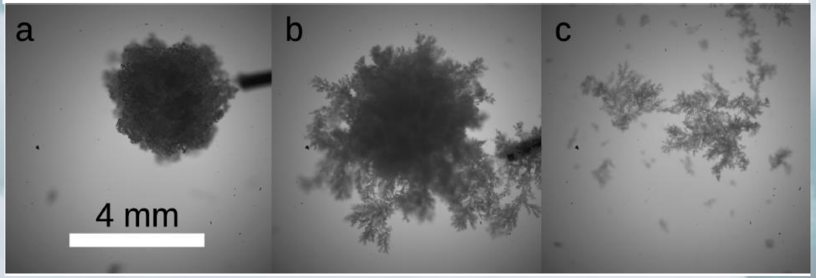
Motivation



Dendritic growth zone

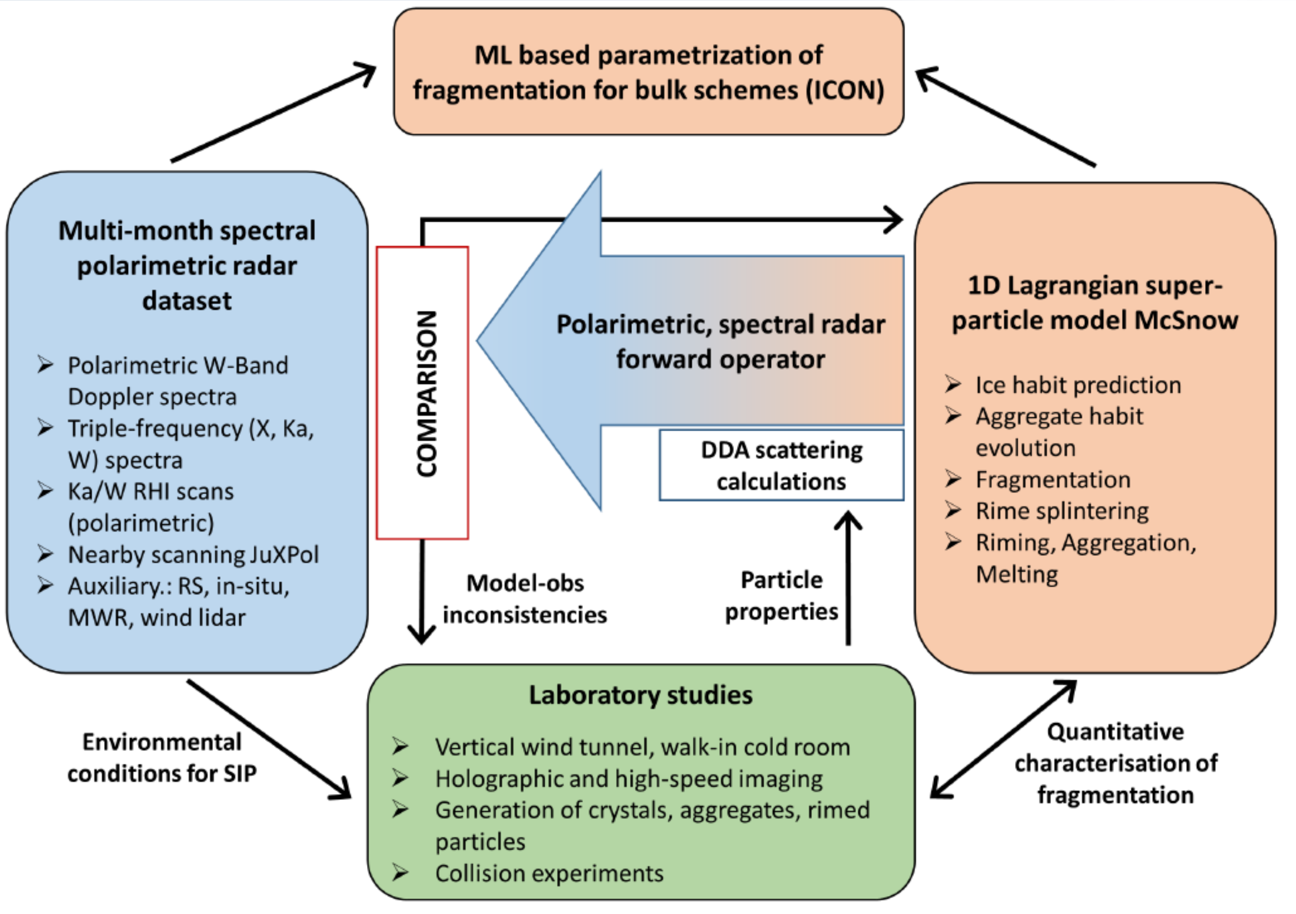
Ice fragmentation?



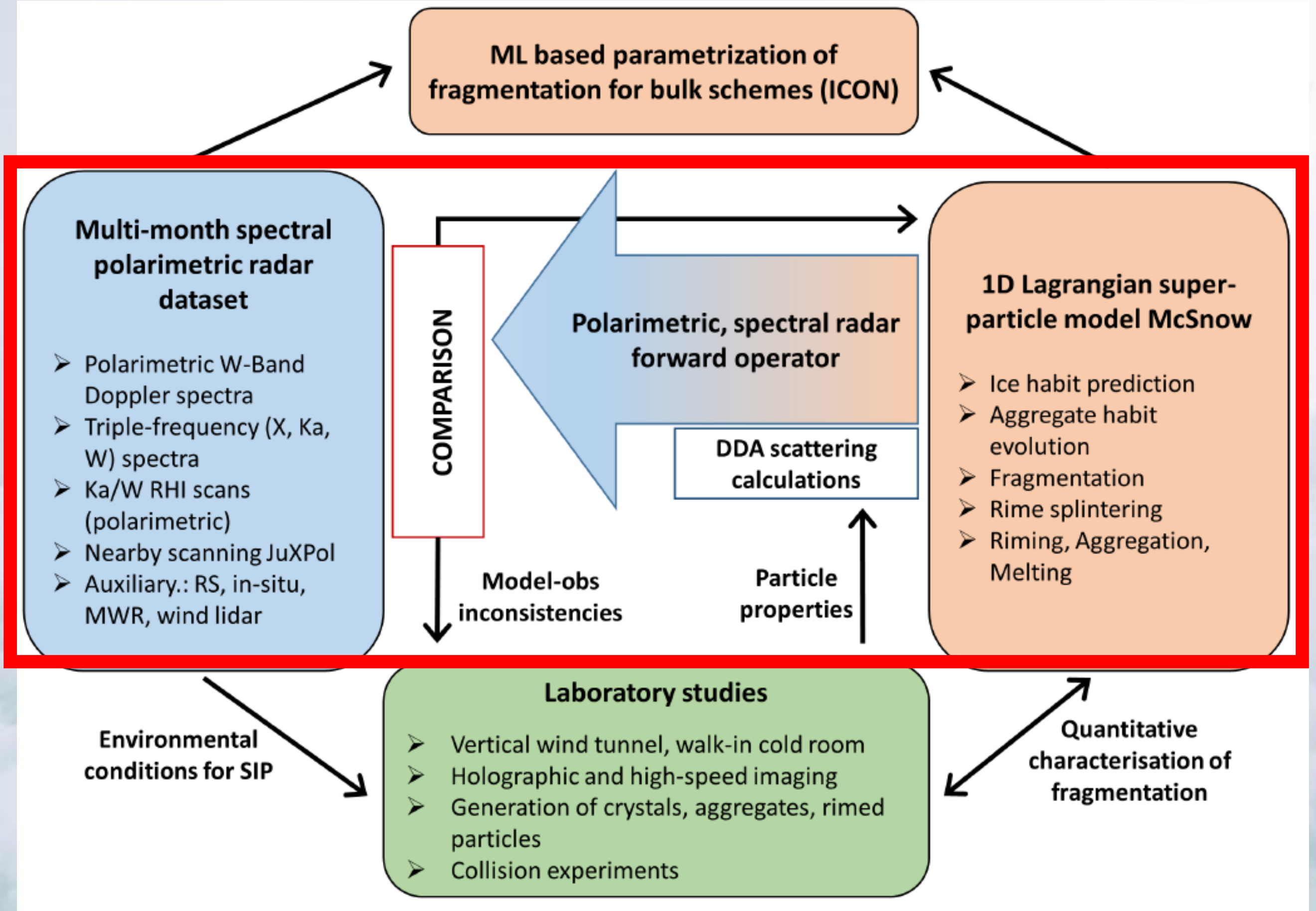


The main goal of FRAGILE is to significantly improve our current understanding of ice fragmentation

Organisation of FRAGILE

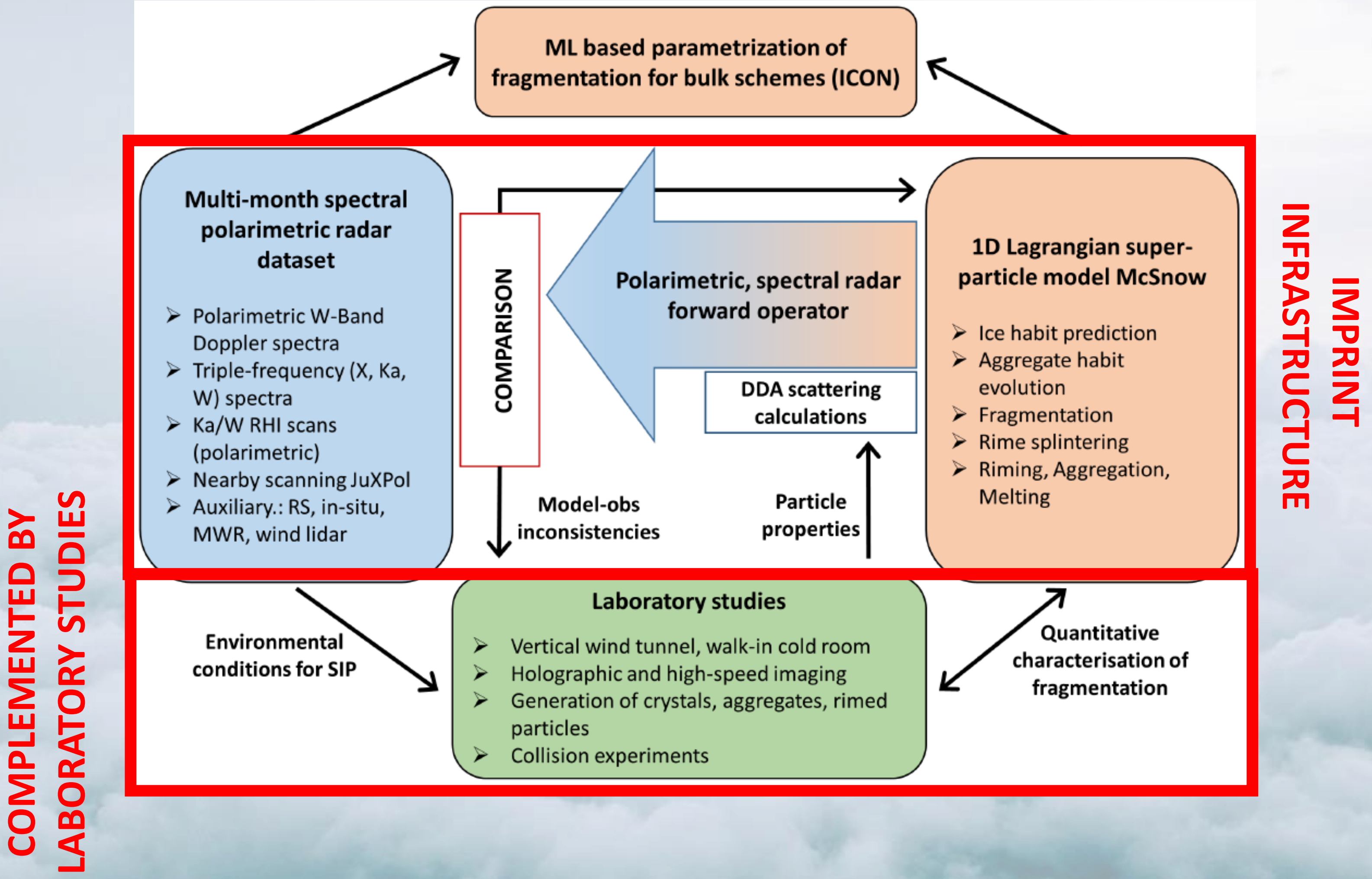


Organisation of FRAGILE

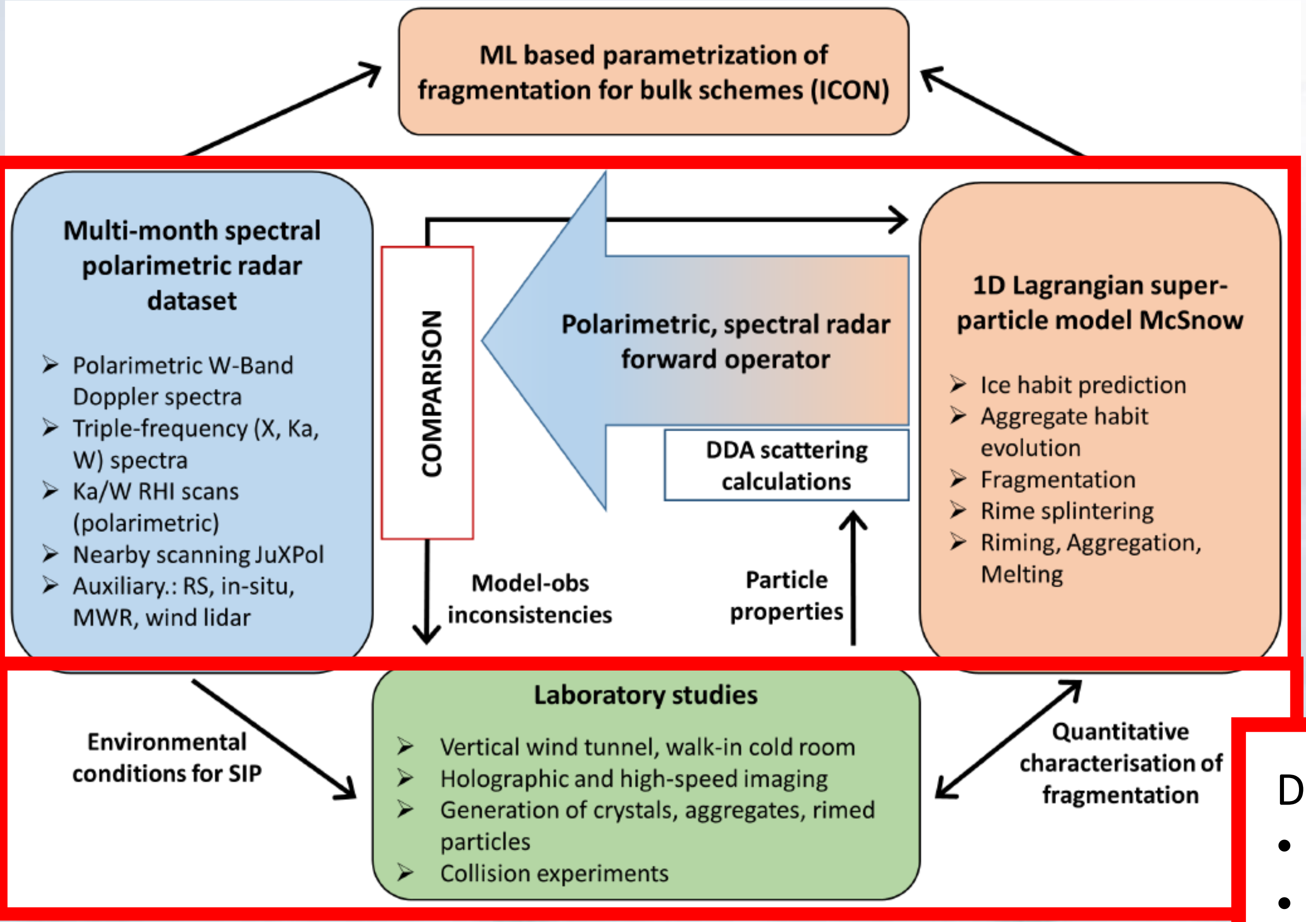


IMPRINT INFRASTRUCTURE

Organisation of FRAGILE



Organisation of FRAGILE



IMPRINT INFRASTRUCTURE

COMPLEMENTED BY LABORATORY STUDIES

DELIVERABLES:

- Number concentration
- Shape
- Terminal fall velocity
- CKE

Experimental background

- **Takahashi (1993) Observation:** large graupel (4mm) + small graupel (<2mm) with stellar crystals
  → high ice crystal concentration
- **Takahashi *et al*. (1995):** graupel-graupel (with dendrites) collision experiments

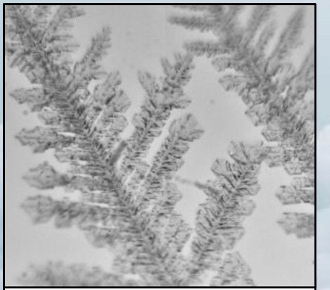
Improve graupel-graupel (with dendrites) collisions experiments

- **Vardiman (1978)** & **Griggs and Choularton (1986):** Single crystal fragmentation experiment
- **Graupel and crystals are expecting to produce numerous ice particles**

Graupel-snowflake collisions experiments

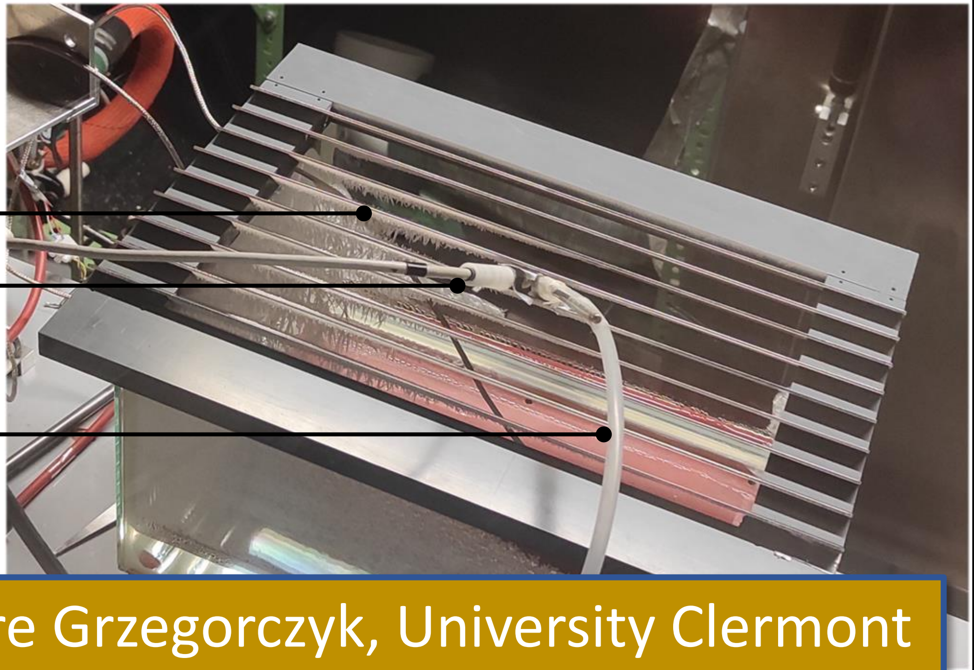
Ice crystals production

Dendrite

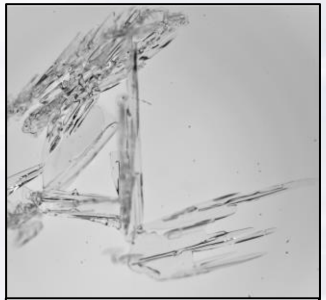


Dendrite with sectors

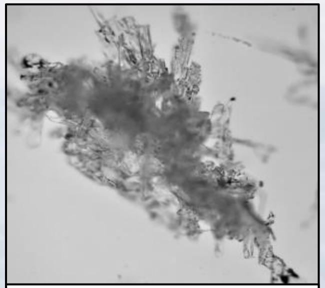
Glass aquarium inside the cold room



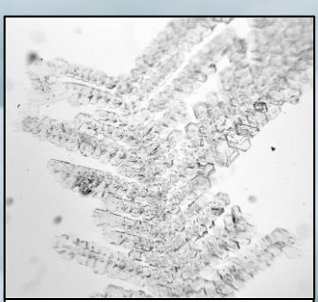
Credits: Pierre Grzegorczyk, University Clermont



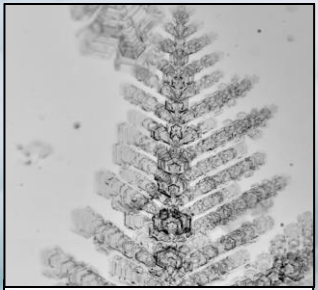
Needles



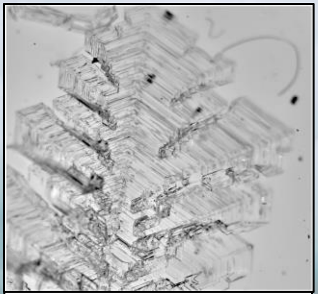
Bundle of sheaths



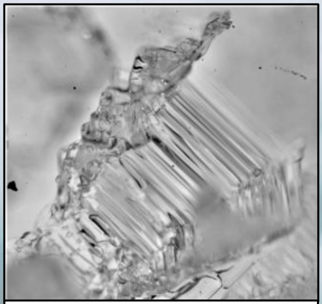
Dendrite with plates



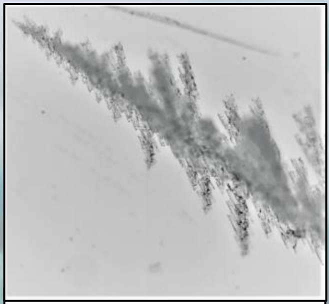
Plates with dendrites



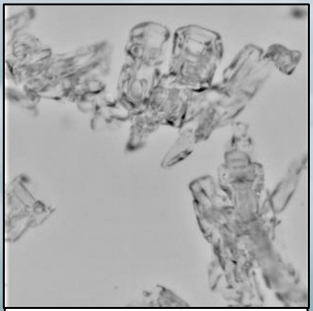
Assemblage of crossed plates



Skeletal plate



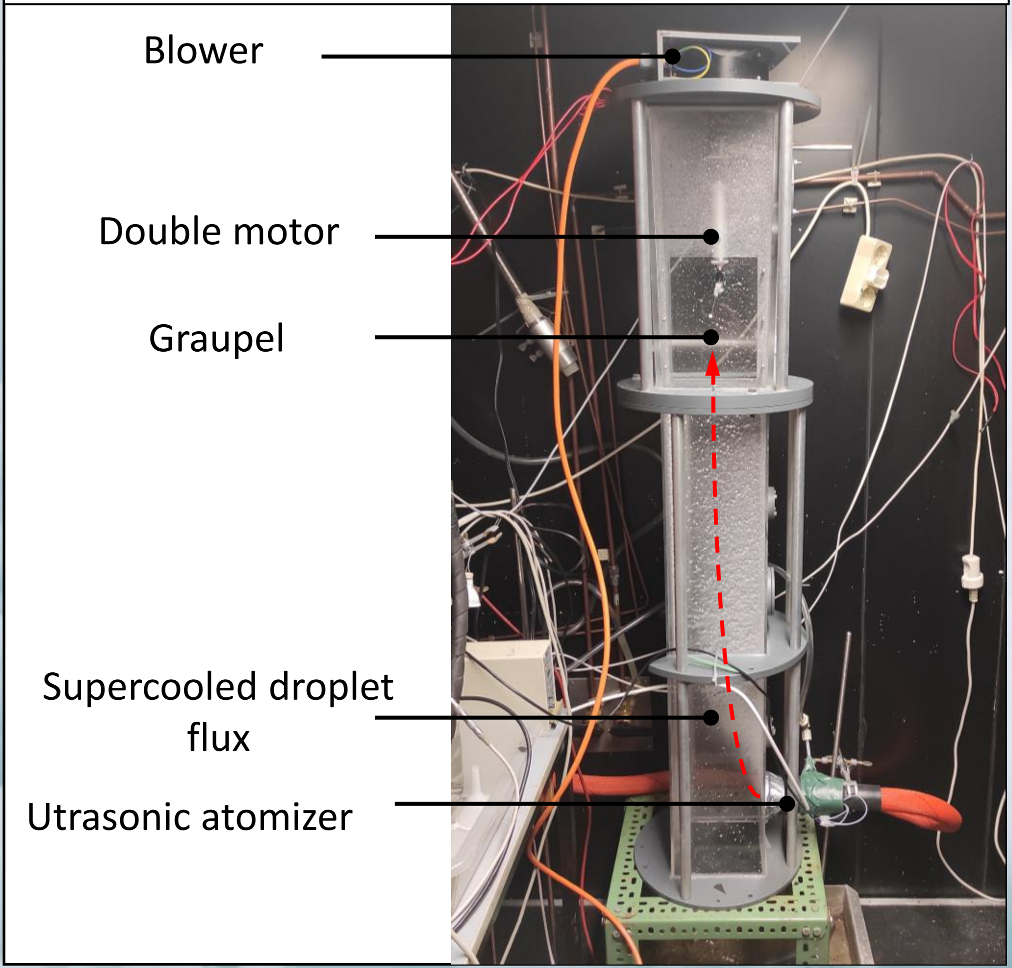
Dendrite with columns



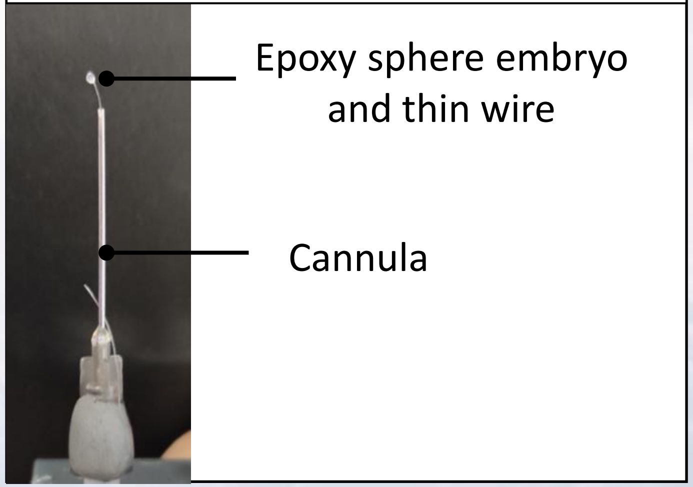
Skeletal column with scrolls

Graupel production

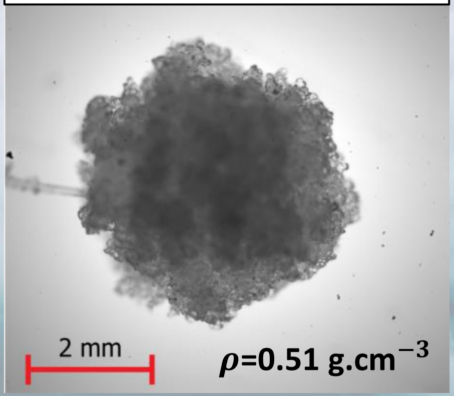
Graupel generator



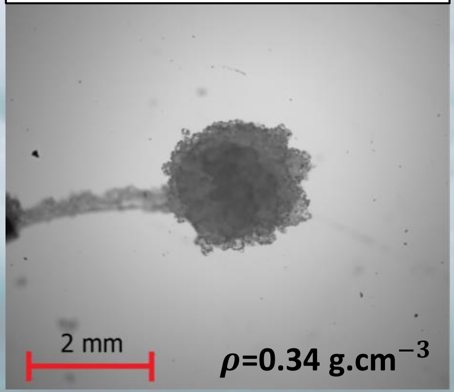
Graupel starter



Large 4 mm graupel



Small 2 mm graupel



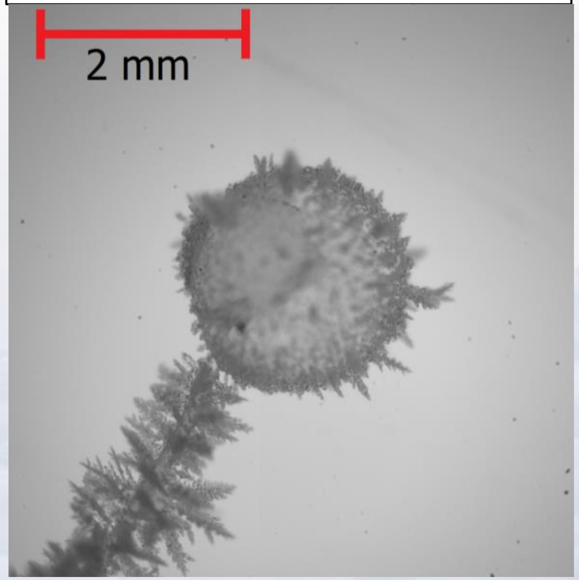
Dendritic growth

Based on **Takahashi (1993)** observation

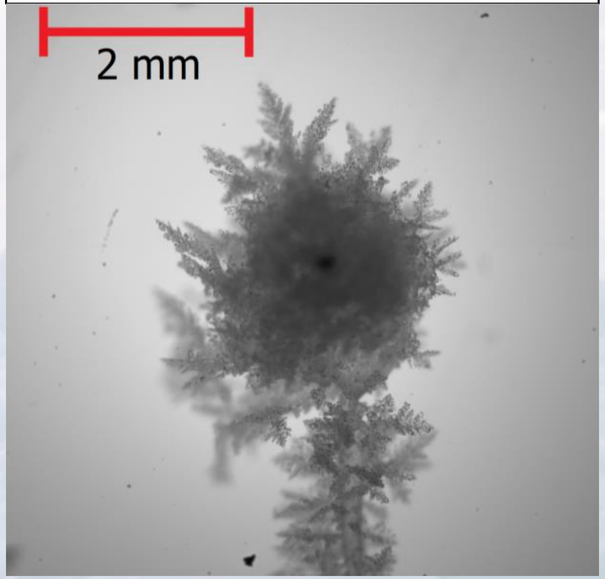
- Aquarium
- Blower
- Rotation motor

Dendritic growth

Ice sphere with dendrites



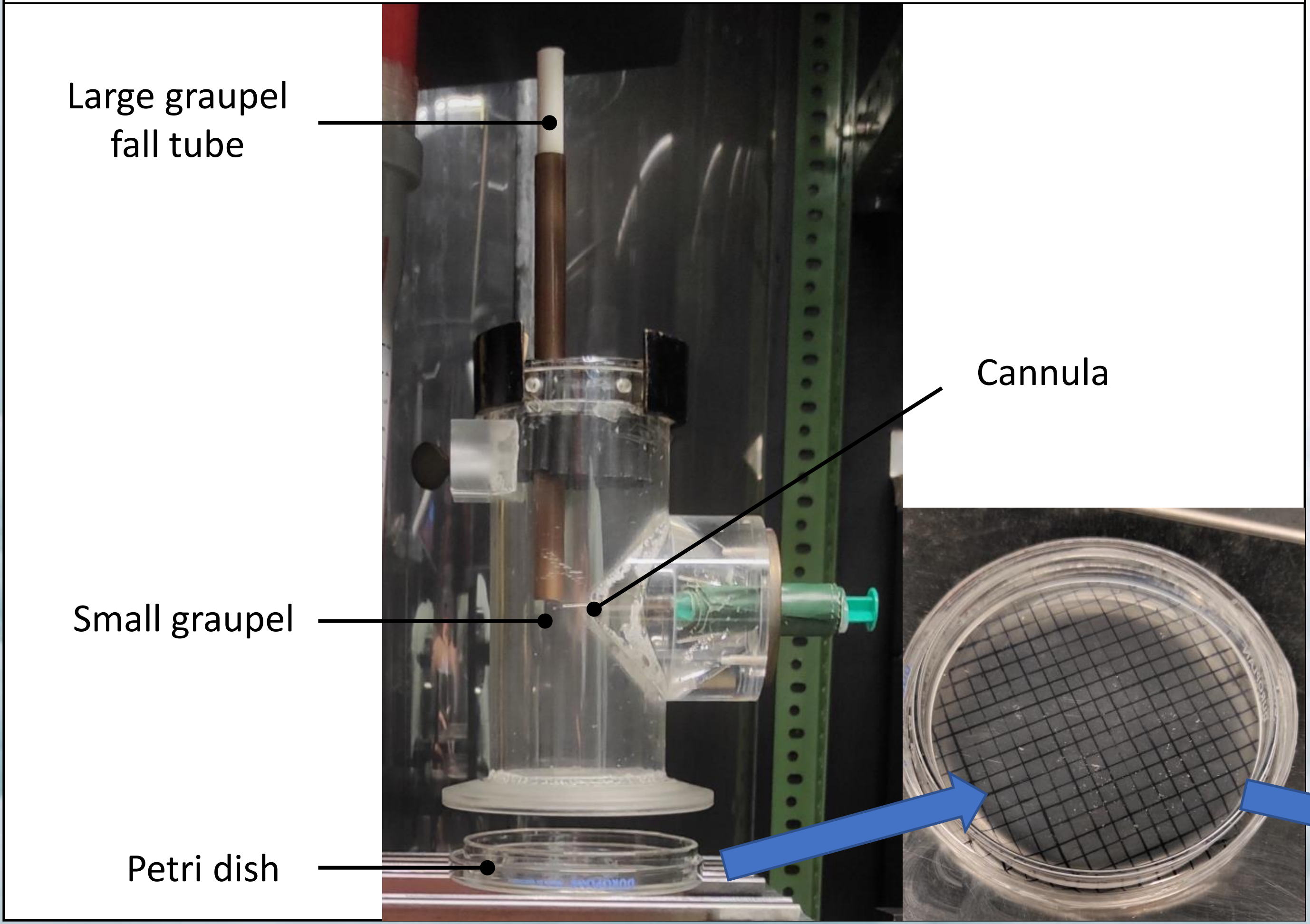
Graupel with dendrites



- Dependency on ice structure
- Takahashi *et al*. (1995) used ice sphere

Graupel-graupel collision

Collision setup



High speed camera video

- Microscope pictures
- Data analysis

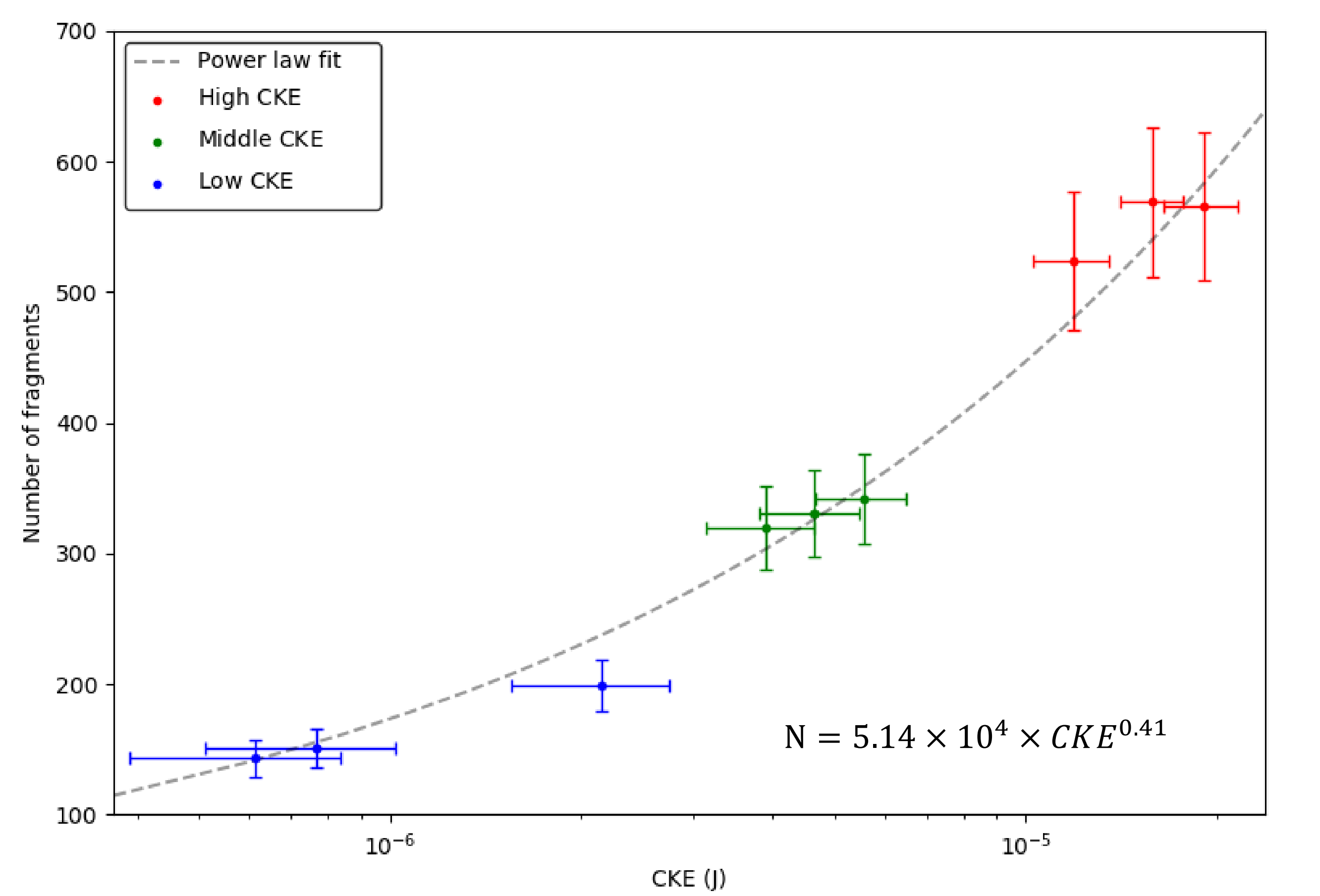
Graupel-graupel collision results

Collision kinetic energy (CKE)

$$k_0 = \frac{1}{2}\frac{m_1 m_2}{m_1 + m_2}(v_1 - v_2)^2$$

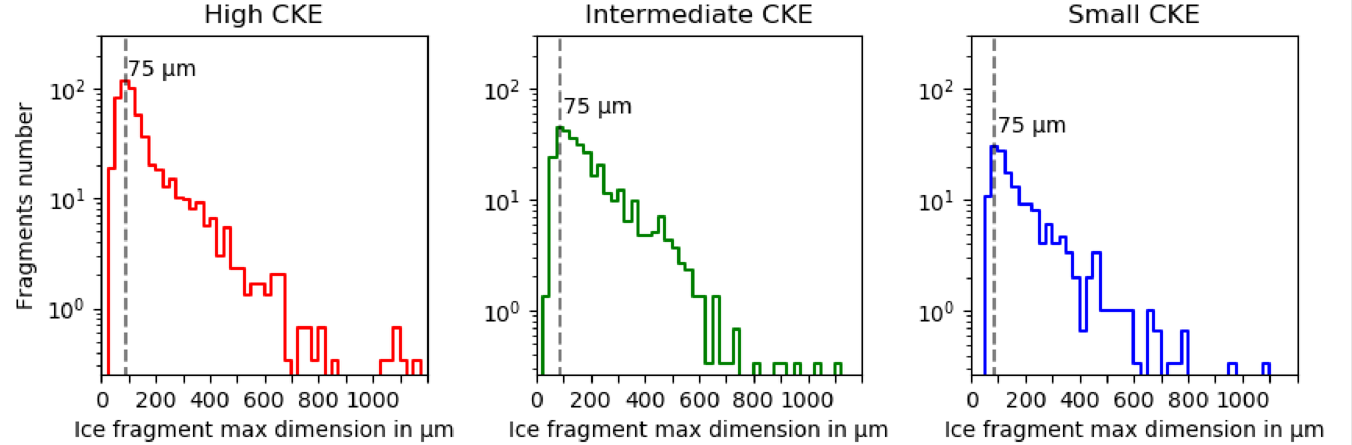
From the collision theoritical formulation of Phillips et al. (2017)

Number of fragments produced by graupel-graupel collision



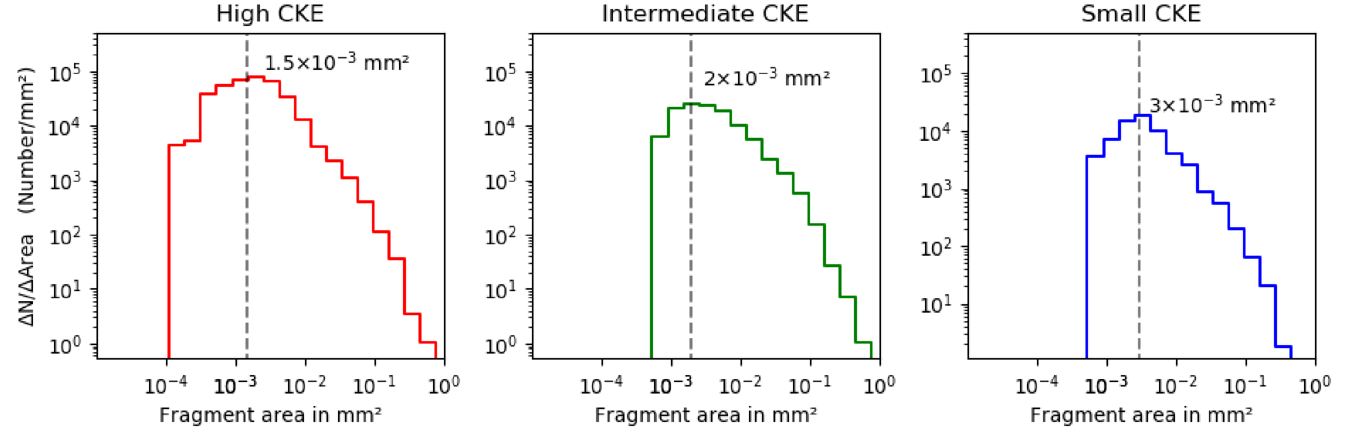
Fragments shape and size

Mean distributions of fragments **maximum size**



- Same distribution shape
- Maximum at 75 µm
- **Similar to Takahashi (1993) observation of 60/100 µm crystals**

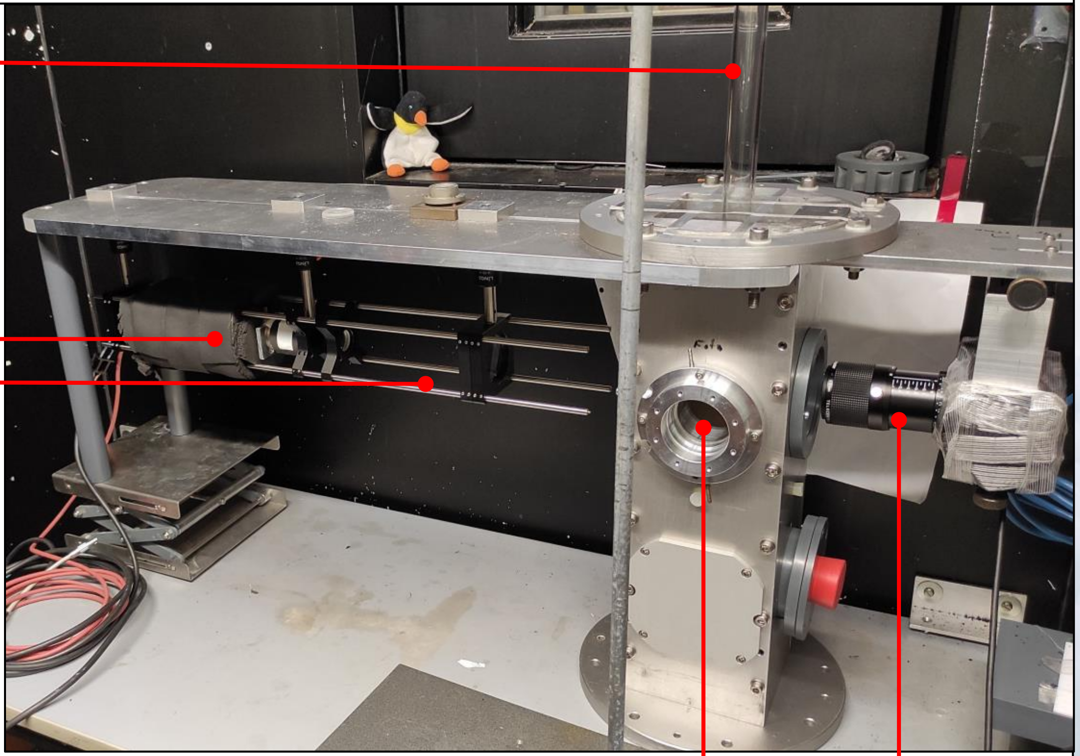
Mean distributions of fragments **area**



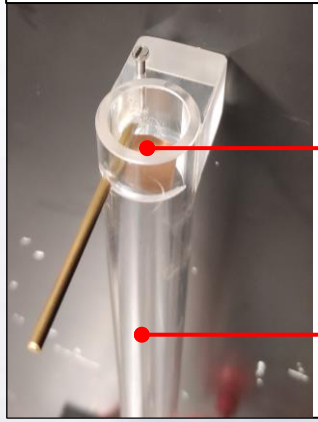
- **Distribution peak** depends on CKE
- **Minimum area** depends on CKE
- Same distribution shape

Graupel-snowflake setup

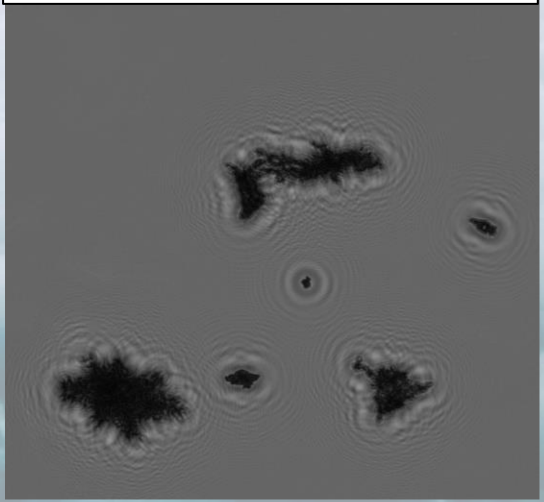
Holographic instrument



Launch system

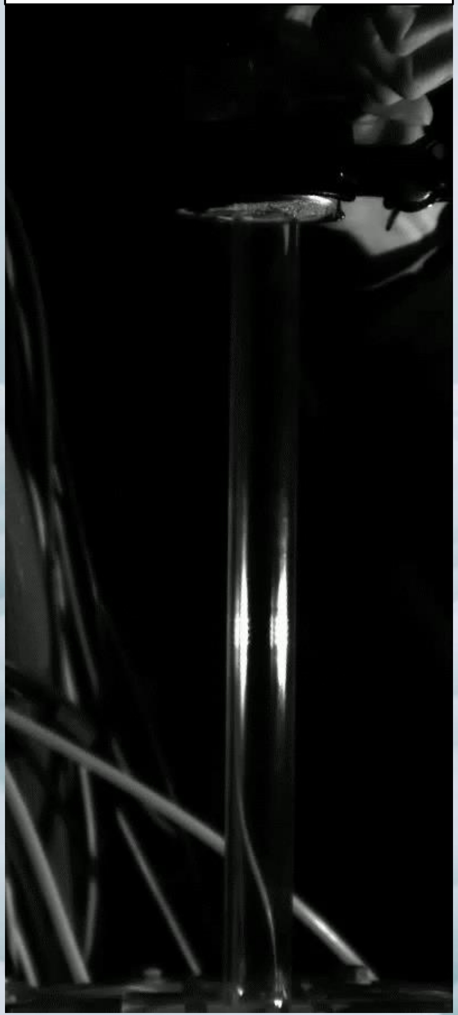


Crystals holographic picture

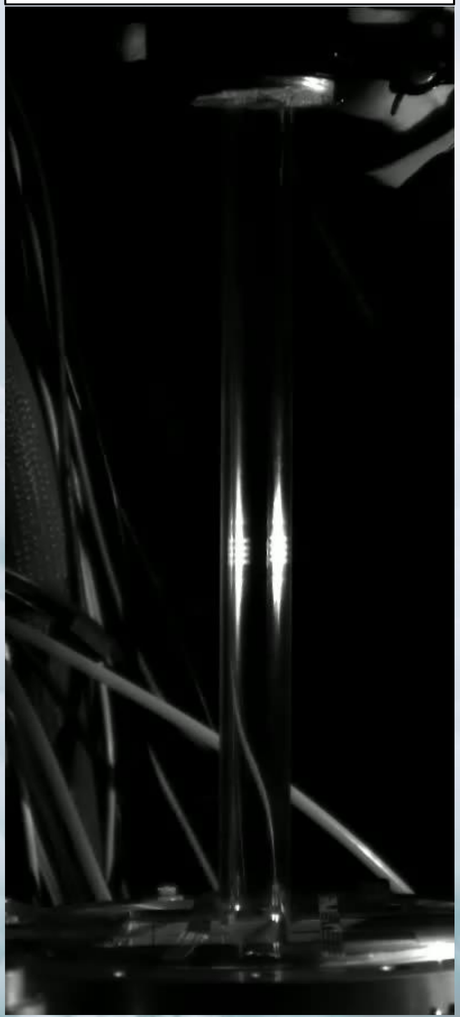


Graupel-snowflake collision

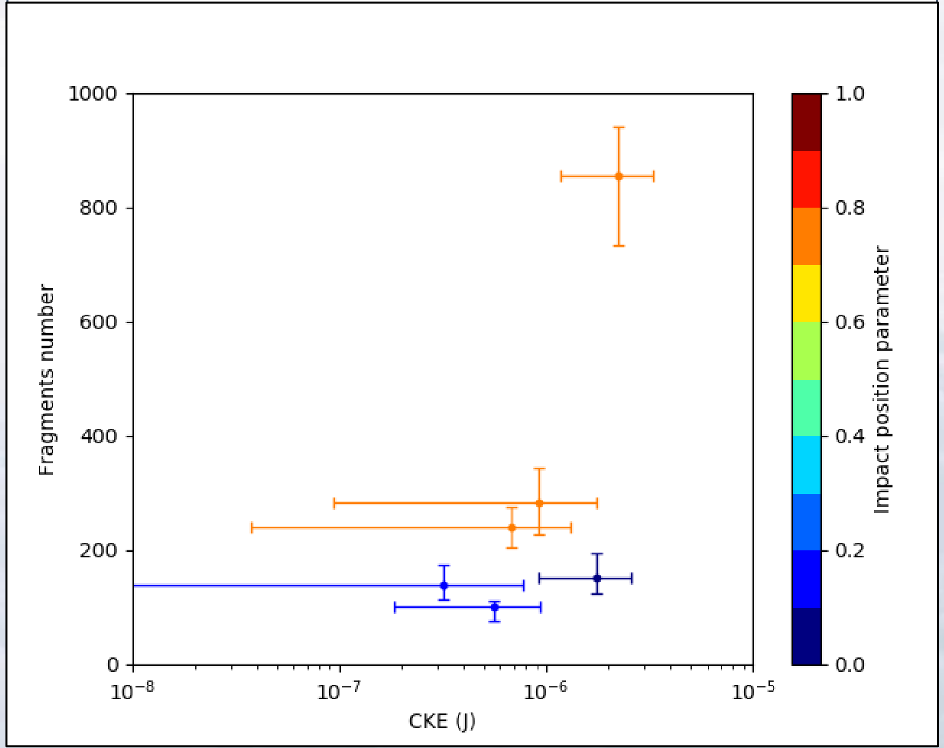
Side collision



Central collision

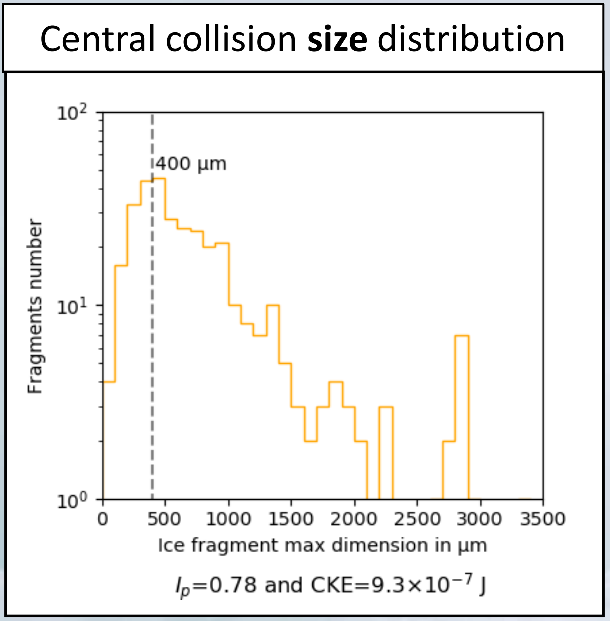


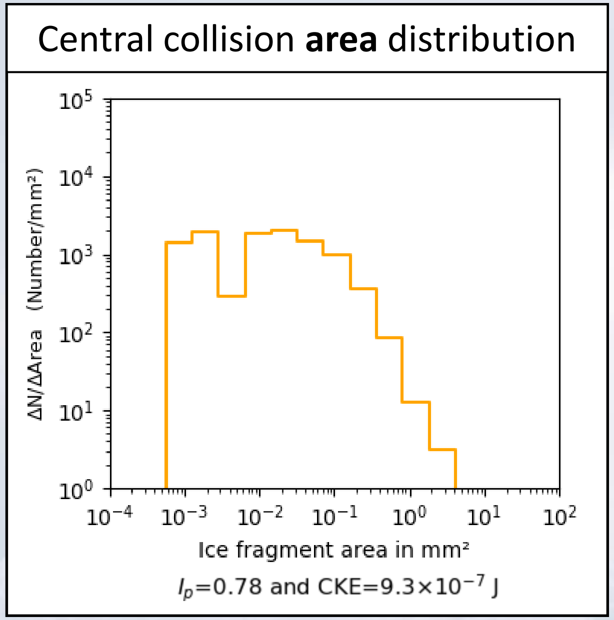
Number of fragments produced by **graupel-snowflake** collision



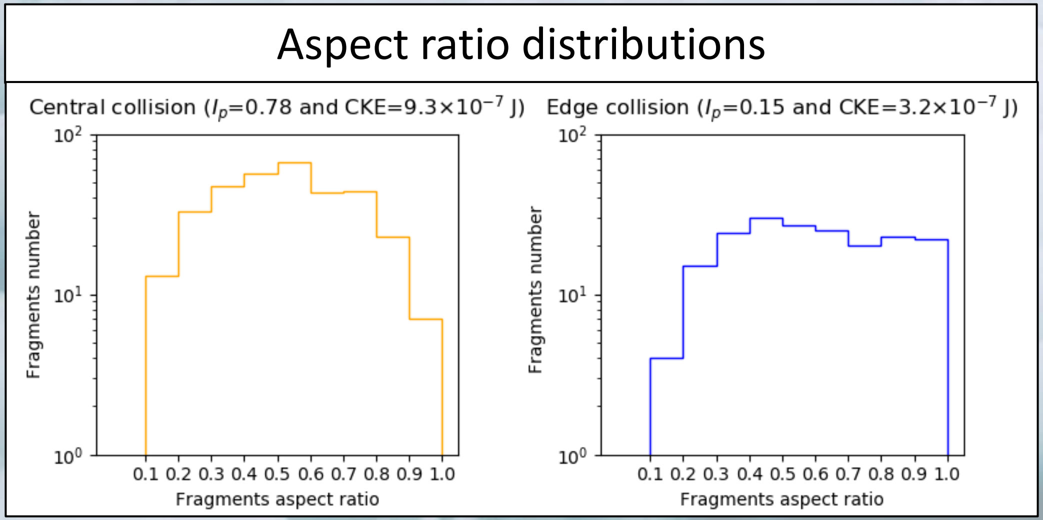
- Number of fragments depends on
  - **CKE**
  - **Impact position**

Fragments size, area and shape



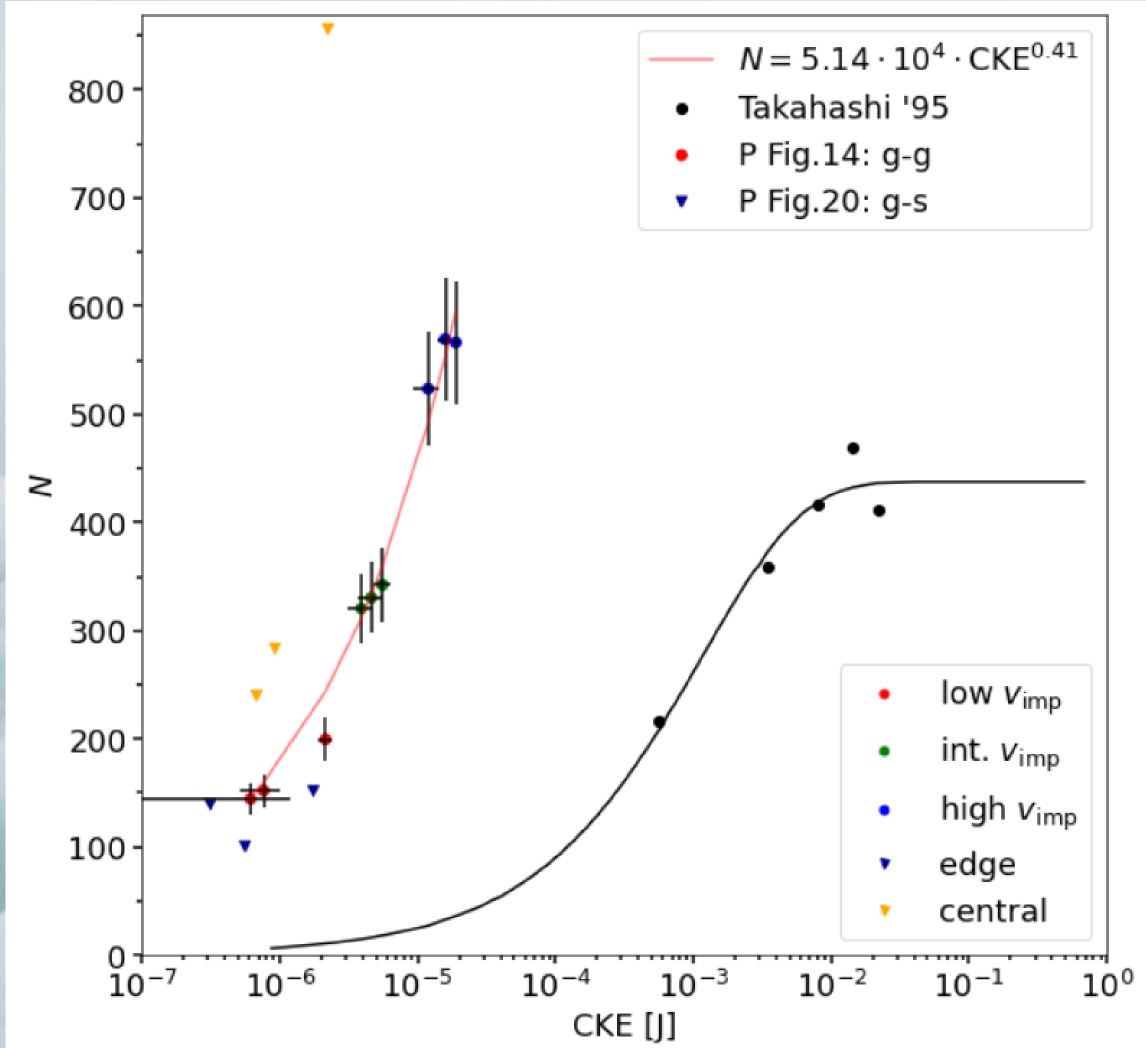


- Similar to graupel-graupel distribution
- Distribution peak at **400µm**
- Size distribution consistent with **Vardiman (1978)**



- Aspect ratio depends on the impact position
- Central collision: symmetrical and maximum of aspect ratio at 0.5
- Edge collision: almost constant aspect ratio

Comparison with Takahashi's results



Possible explanations for the differences:

- Our results are valid for T ~ -14 °C
- Graupel asperities were grown with ventilation which might lead to more fragility and maybe a higher number of asperities
- Dendritic growth on a solid ice sphere considerably different from a graupel

Conclusions, Outlook

- Experiments can produce close to realistic ice collisions to get the data to improve the model and backscatter calculations
- Setups need to be improved, especially the dendritic growth setup and the snowflake collision setup
- Extension of the experiments to a broader temperature and humidity range
- Investigation of the influence of the degree of snowflake riming and graupel shape on fragmentation
- Better characterization of the snowflake characteristics, including their densities
- Determination of the density of the particles incuding their asperities
- Extension of the experiments to the wind tunnel

References

- Hobbs, P. V., Politovich, M. K., & Radke, L. F. (1980). The structures of summer convective clouds in eastern montana. i: Natural clouds. Journal of Applied Meteorology
- Vardiman, L. (1978). The generation of secondary ice particles in clouds by crystal–crystal collision. Journal of the Atmospheric Sciences
- Griggs, D. J., & Choularton, T. W. (1986). A laboratory study of secondary ice particle production by the fragmentation of rime and vapour-grown ice crystals. Quarterly Journal of the Royal Meteorological Society,
- Takahashi, T. (1993). High ice crystal production in winter cumuli over the Japan Sea. Geophysical Research Letters
- Takahashi, T., Nagao, Y., & Kushiyama, Y. (1995). Possible high ice particle production during graupel–graupel collisions. Journal of the Atmospheric Sciences
- Phillips, V. T. J., Yano, J.-I., & Khain, A. (2017). Ice Multiplication by Breakup in Ice–Ice Collisions. Part I: Theoretical Formulation. Journal of the Atmospheric Sciences,