UNIVERSITY OF HELSINKI

INAR
Institute for Atmospheric and Earth System Research

cloud

MARIE CURIE ACTIONS

CLOUD experiment at CERN

Prof. Katrianne Lehtipalo

HIP SAB meeting August 2026

CLOUD

Cosmics Leaving Outdoors Droplets

Main goals is to find out:

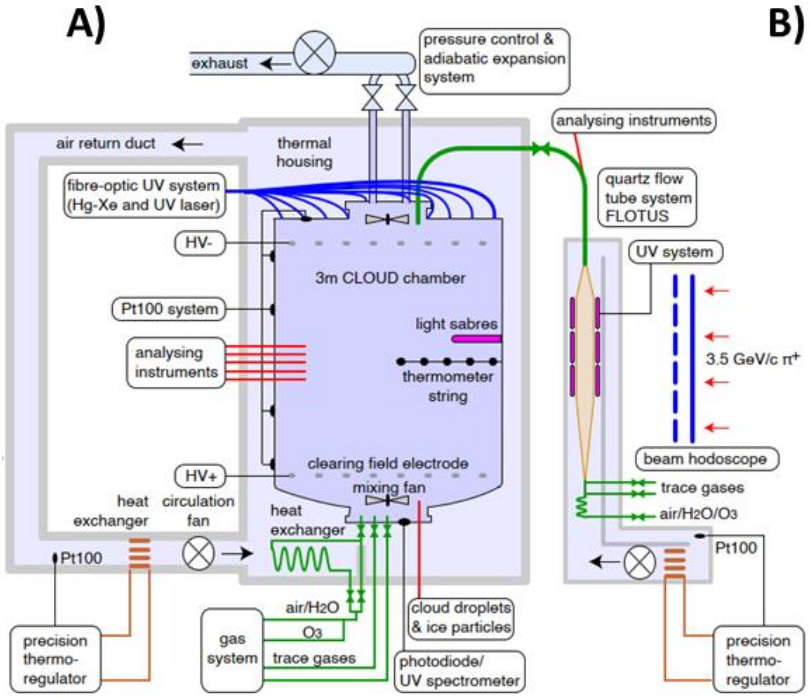
- the influence of cosmic rays on clouds and climate
- aerosol particle formation and growth processes in different atmospheric environments, ice nucleation and aqueous phase processes in cloud droplets

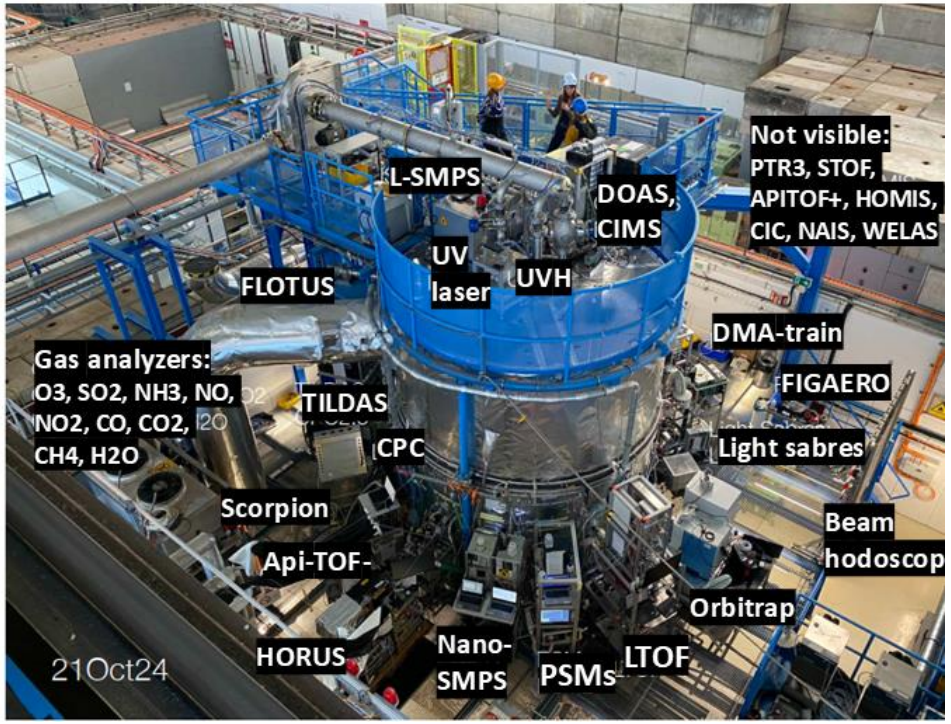
- Collaboration of 21 institutes in 12 countries
- 4 Horizon-2020 MSCA Doctoral Traning Networks
  - CLOUD-ITN (2008-2012)
  - CLOUD-TRAIN (2012-2016)
  - CLOUD-MOTION (2017-2021)
  - CLOUD-DOC (2022-2026)

connected also to several Finnish Academy, MSCA-IF and ERC projects

Main updates 2024-2026

- Experiments are proceeding as planned
  - CLOUD17 (fall 2024, 10w)
  - CLOUD18 (fall 2025, 10w)
  - CLOUD19 (planned for Oct-Noc 2026)



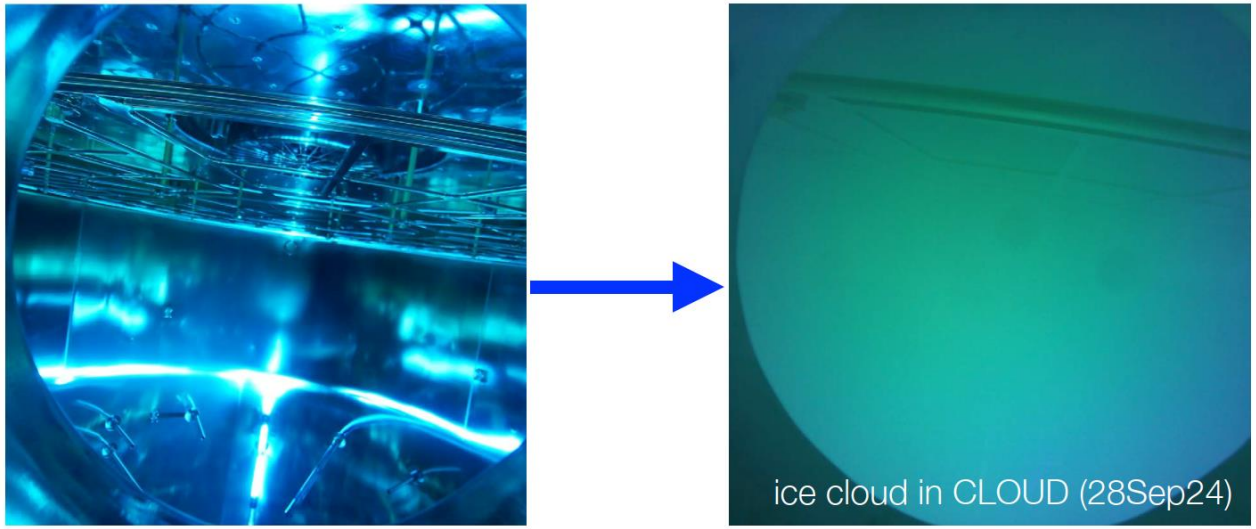


CLOUD19 programme (Oct-Nov 2026)

- RH dependency of pure sulfuric acid-water nucleation, with and without small quantities of organics.
- Isoprene and dimethylsulfide oxidation in clouds with different droplet pH
- Release of ammonia from freezing droplets under shallow and deep convective transport
- Particle formation and multiphase chemistry of nonanal

Future plans of CLOUD

- Complex multi-component chemical systems
- Parameterisations to implement new particle formation and growth mechanisms (incl. effects of charge) from CLOUD into climate models
- Aerosol-cloud processes in supercooled liquid or ice clouds



Generation of continuous liquid- or ice-clouds in the CLOUD chamber by injecting humid air and cloud condensation nuclei from FLOTUS.

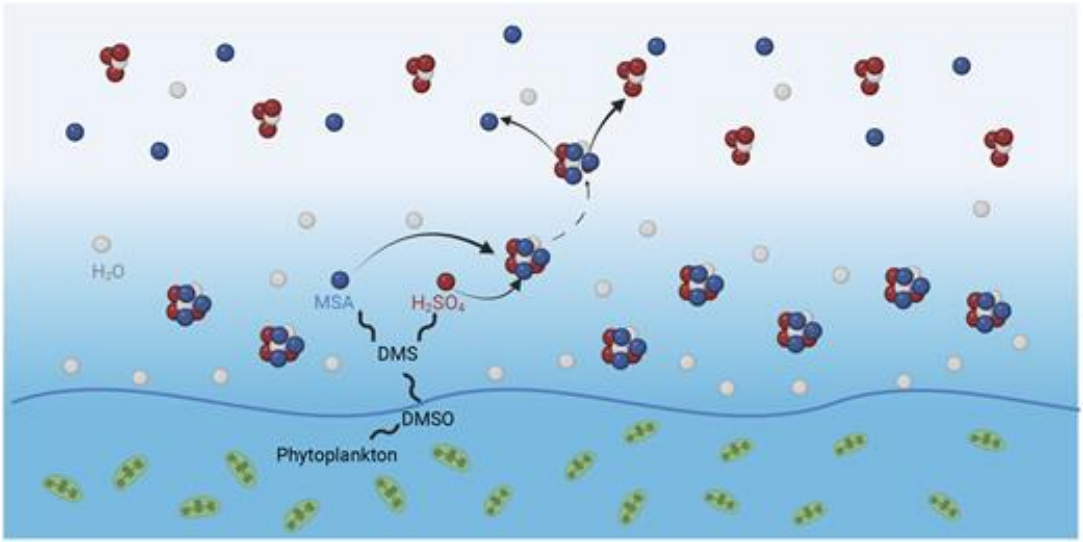
CLOUD publications

- 7 in 2023 (**1 Science***, **1 Nature Comm***, 1 Nature Geo, **1 Science Adv***)
- 5 in 2024 (**1 Nature***)
- 5 on 2025 (1 Nature Geoscience, 1 Nature Communications, 1 PNAS)
- 6 in 2026 so far (**1 Nature***)

**First author from Univ. Helsinki*

In summer 2026 came out a series of 4 papers about methanesulfonic acid (MSA), which is formed when dimethylsulfide (DMS), emitted from marine phytoplankton, is oxidized.

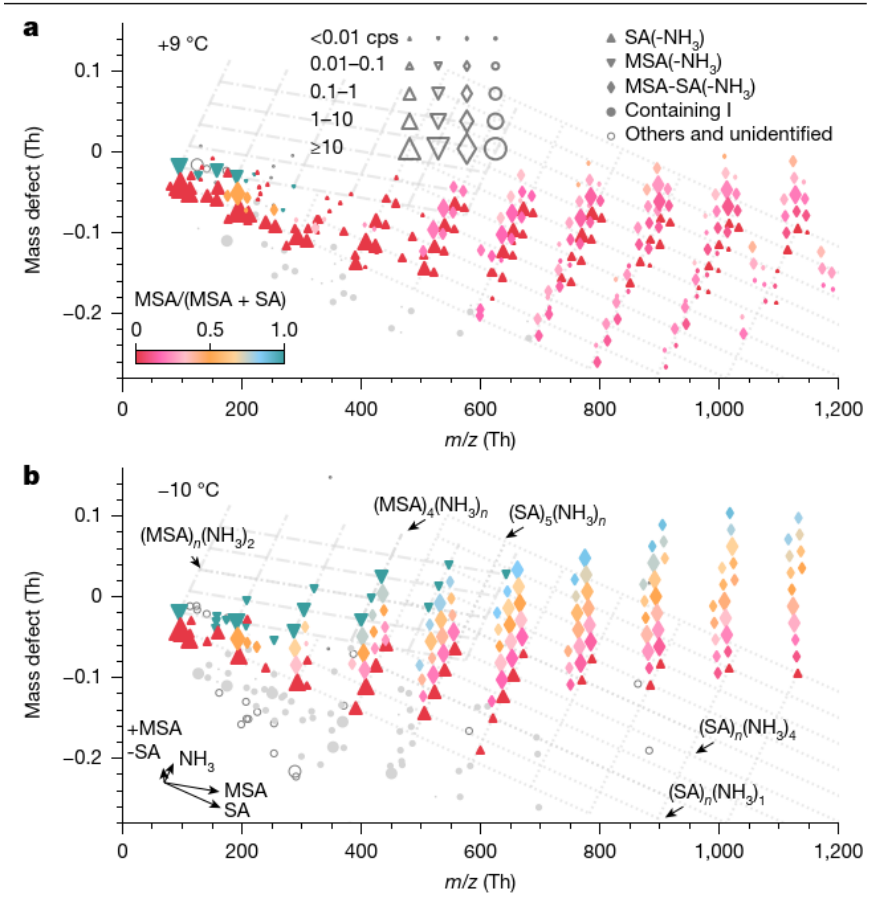
The role of MSA in particle formation and early growth has been unclear.



Role of MSA in particle formation

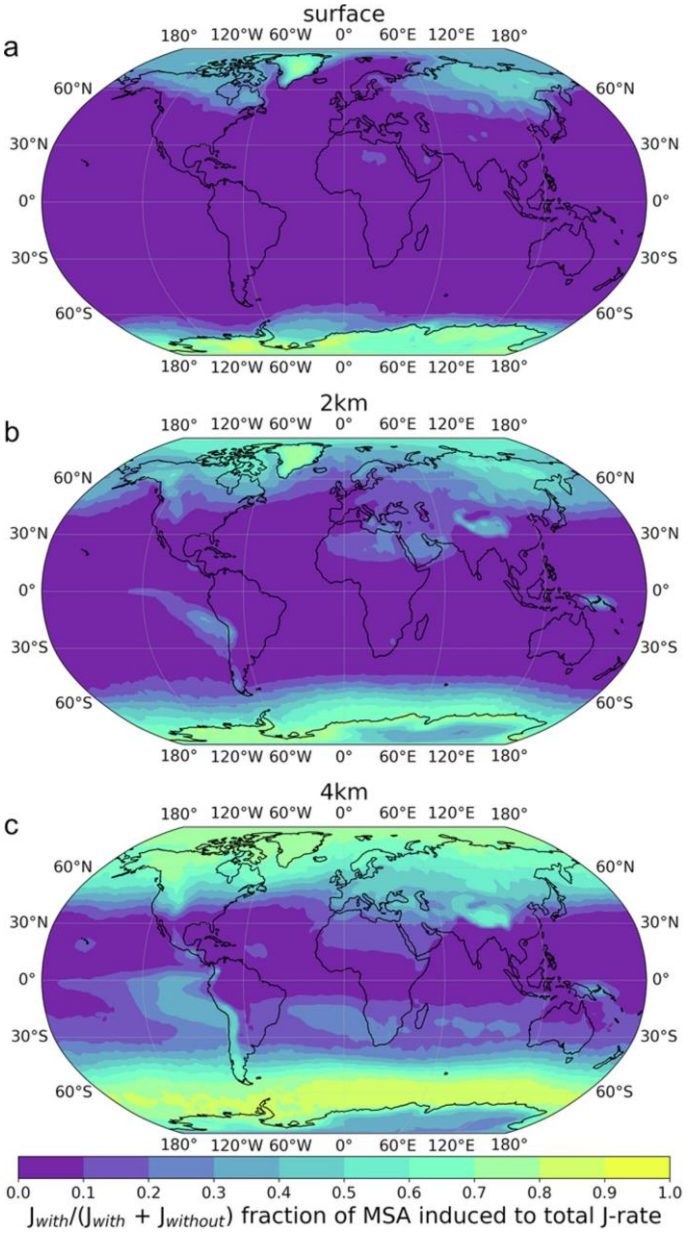
- **”Role of methanesulfonic acid in atmospheric particle nucleation and growth" by Baalbaki and Shen et al. Nature 2026**
- "Impact of humidity on aerosol growth from methanesulfonic acid" by Yu et al. ES:Atmosphere, 2026
- "Rapid new particle formation driven by methanesulfonic acid and amines" by Klebach et al.: ES:Atmosphere, 2026
- "Oxidation mechanisms for volatile methylated sulfur compounds and the major contribution of methanesulfonic acid to Southern Ocean aerosol particles" pre-print by Ruhl et al., 2026

Baalbaki, Shen et al. Nature 2026



Role of MSA in particle formation

- At +9C (and below) MSA participates efficiently in early growth, even at low NH3
  - RH seems to be important in controlling the growth (Yu et al. 2026 ES:A)
- At -10C (and below) MSA nucleates with NH3, at rates comparable to SA-NH3
  - Also with amines (Klebach et al. 2026 ES:A)
- Modelling study indicate that the mechanism is important in polar areas, especially at higher altitudes



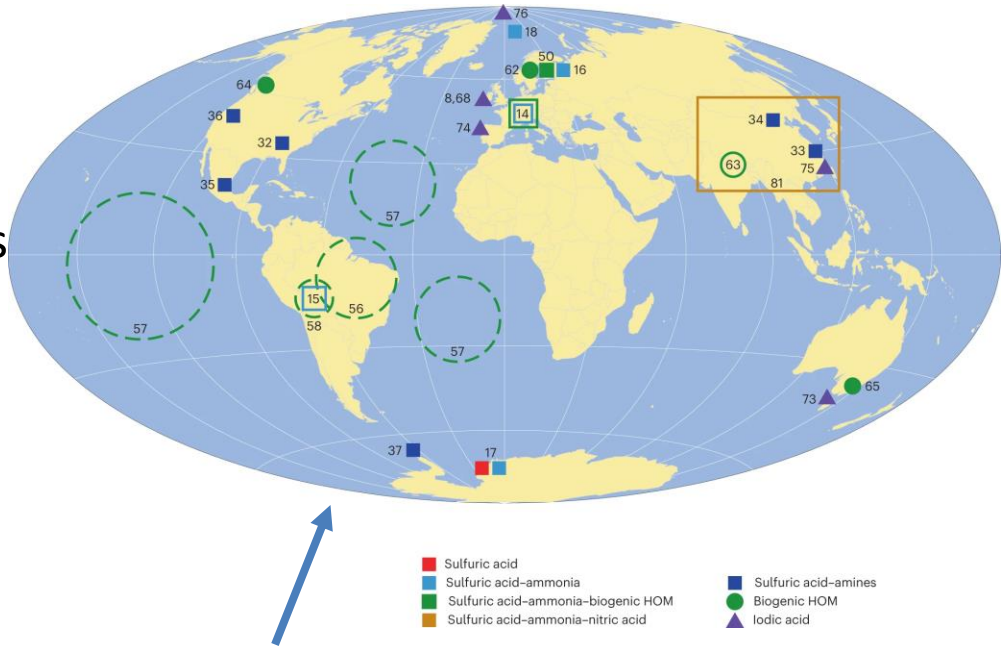
CLOUD Marie Curie Doctoral network

- CLOUD-DOC
  - 1 Sep 22- 31 Aug 26
  - 12 PhD students at different CLOUD institutes
  - 5 private sector partners

New proposal will be coordinated in Helsinki (submitted first time 2025, resubmitted 2026)

Summary

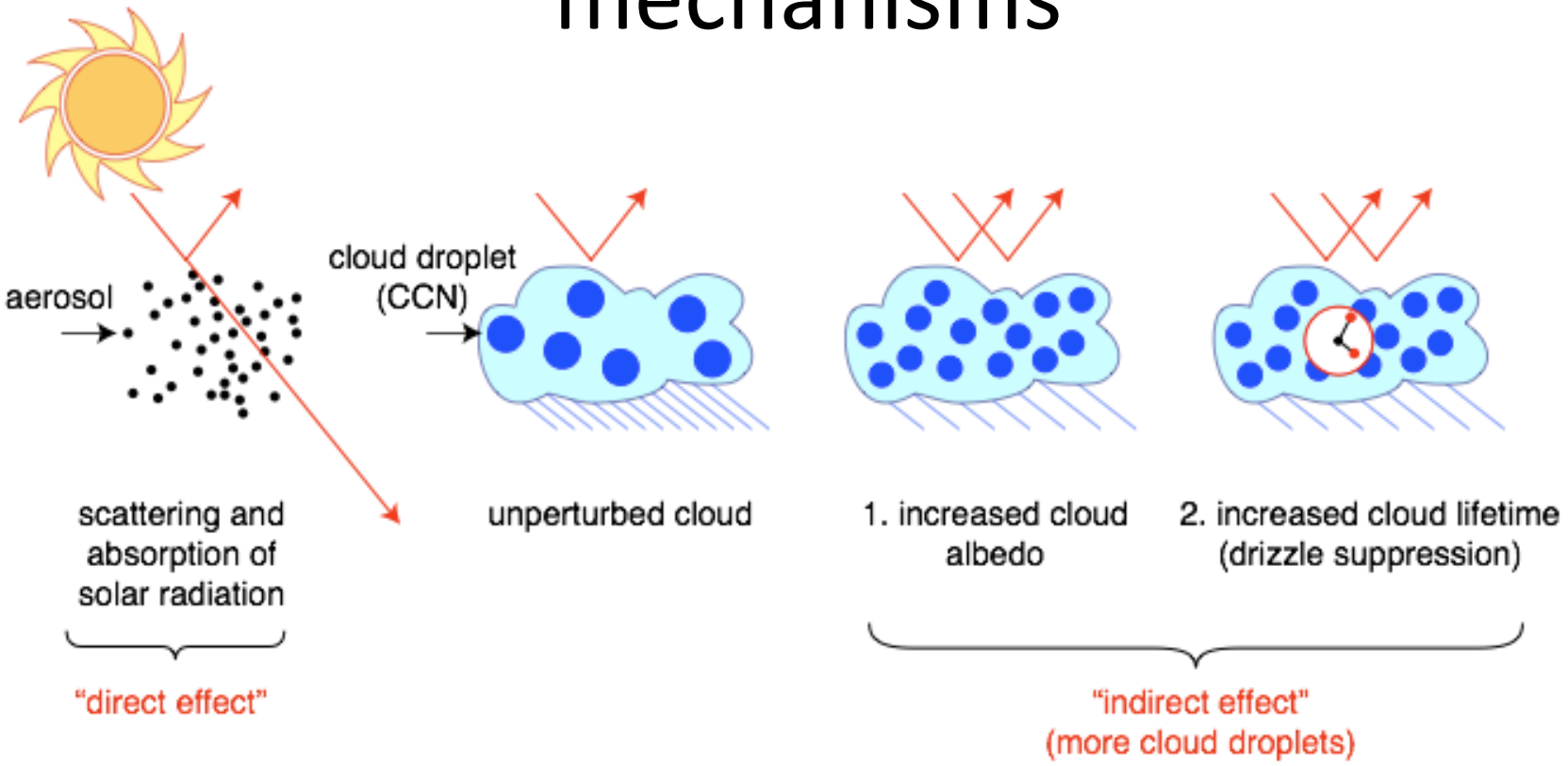
- CLOUD is providing a mechanistic understanding of aerosol particle formation and growth starting from molecular level up to cloud droplets
- It has transformed the view of which chemical compounds are relevant for atmospheric new particle formation
- The information is crucial for improving global atmospheric chemistry and climate models



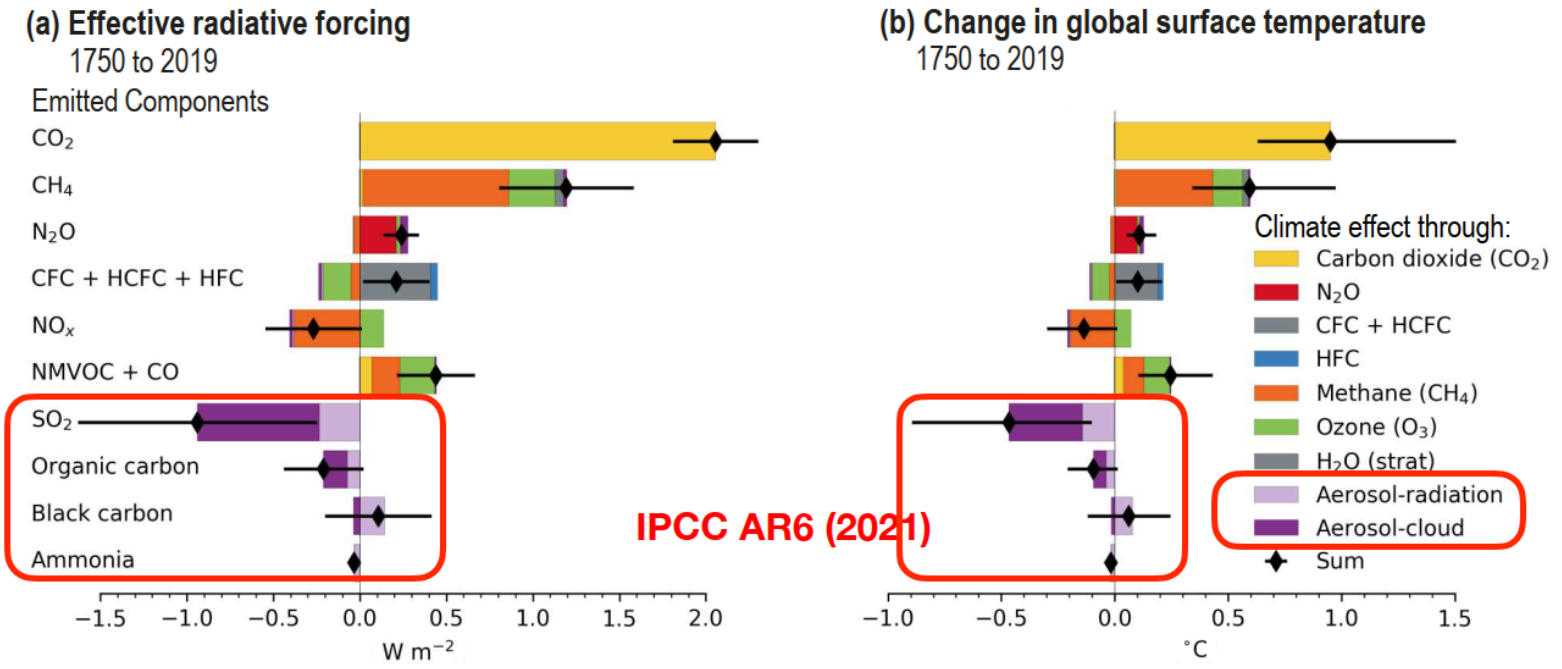
Geographical locations where mechanisms found at CLOUD has been measured in real atmosphere

Background slides on CLOUD

Atmospheric aerosol particles affect climate through direct and indirect mechanisms



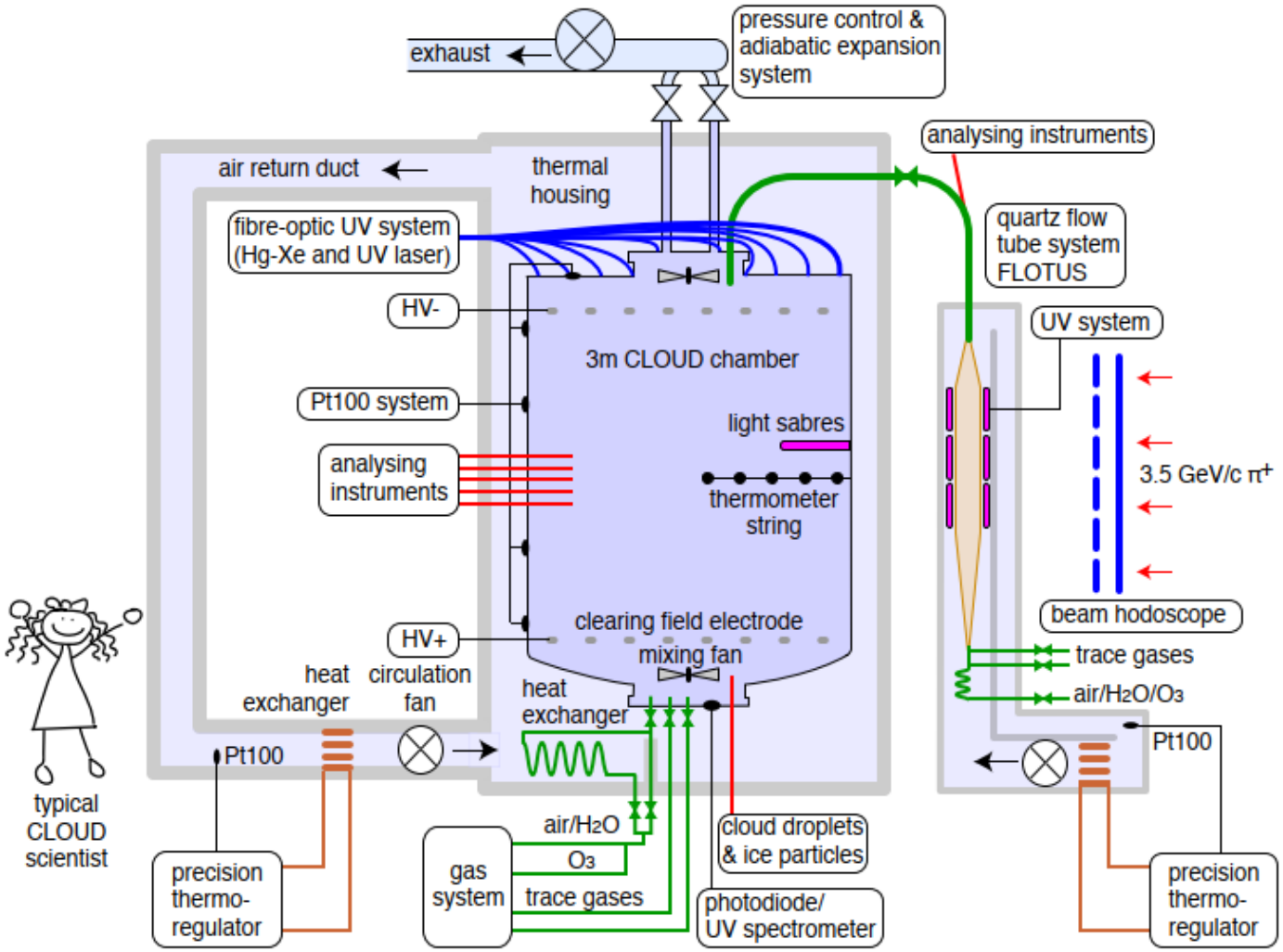
However, aerosols are still the biggest uncertainty in climate models



→ We need climate models that include the underlying atmospheric chemical and physical mechanisms
to predict: a) pre-industrial aerosol and clouds (Earth's climate sensitivity) & b) Earth's future climate.

CLOUD chamber

- Key features::
  - Ultra-low contaminants
  - Atmospheric concentrations
  - Precise and steady control of all conditions over long periods:
    - vapours
    - T, UV
    - ionisation (n, gcr, π)
  - Comprehensive analysis instruments
  - FLOTUS (FLOw TUbe System)



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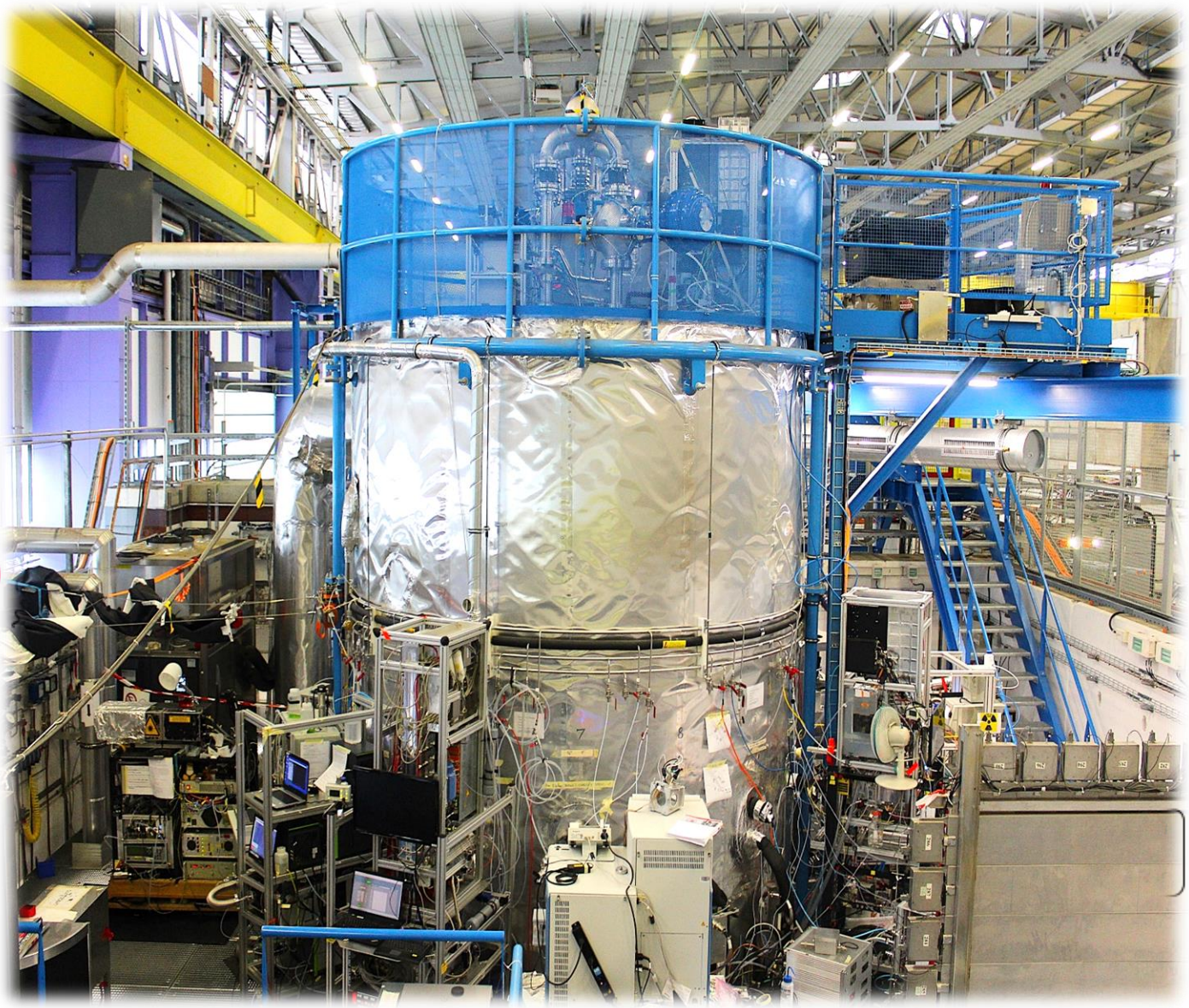
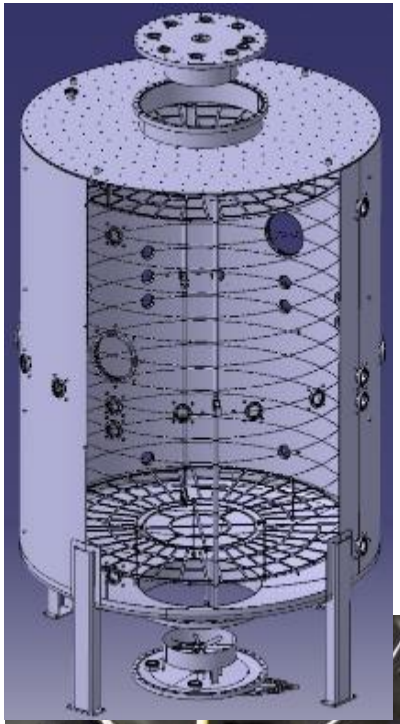


The CLOUD chamber allows studying the effect of ionization on aerosol formation

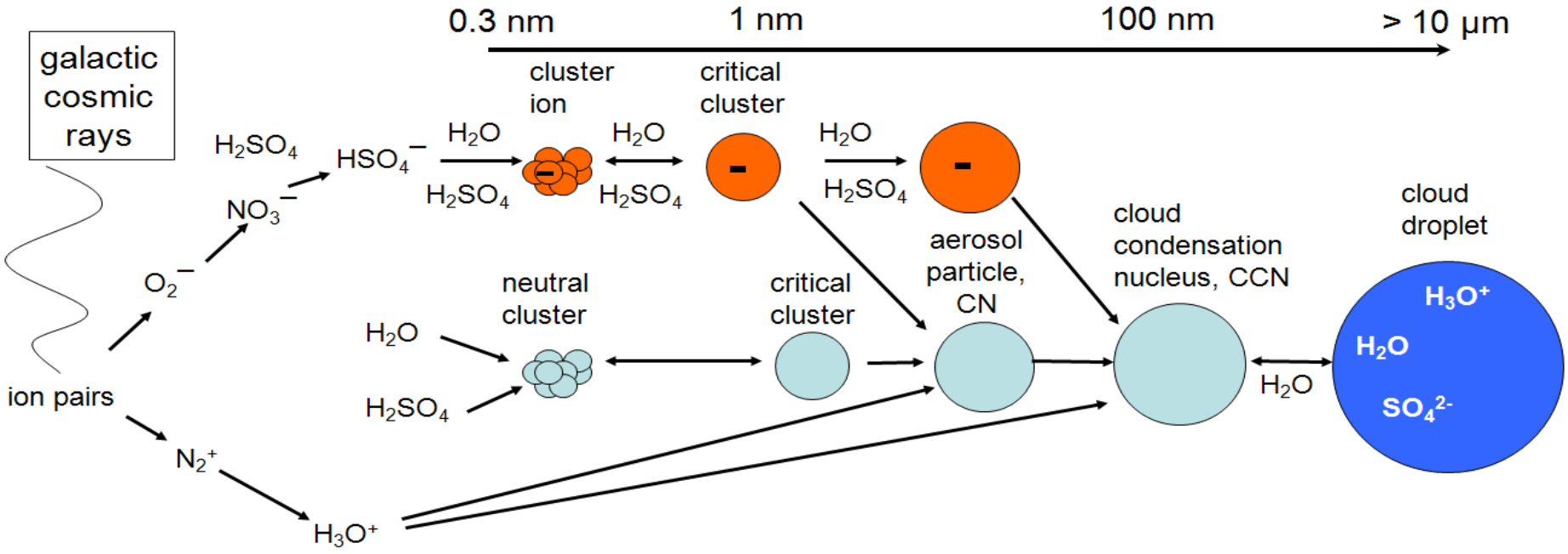


High-voltage clearing field

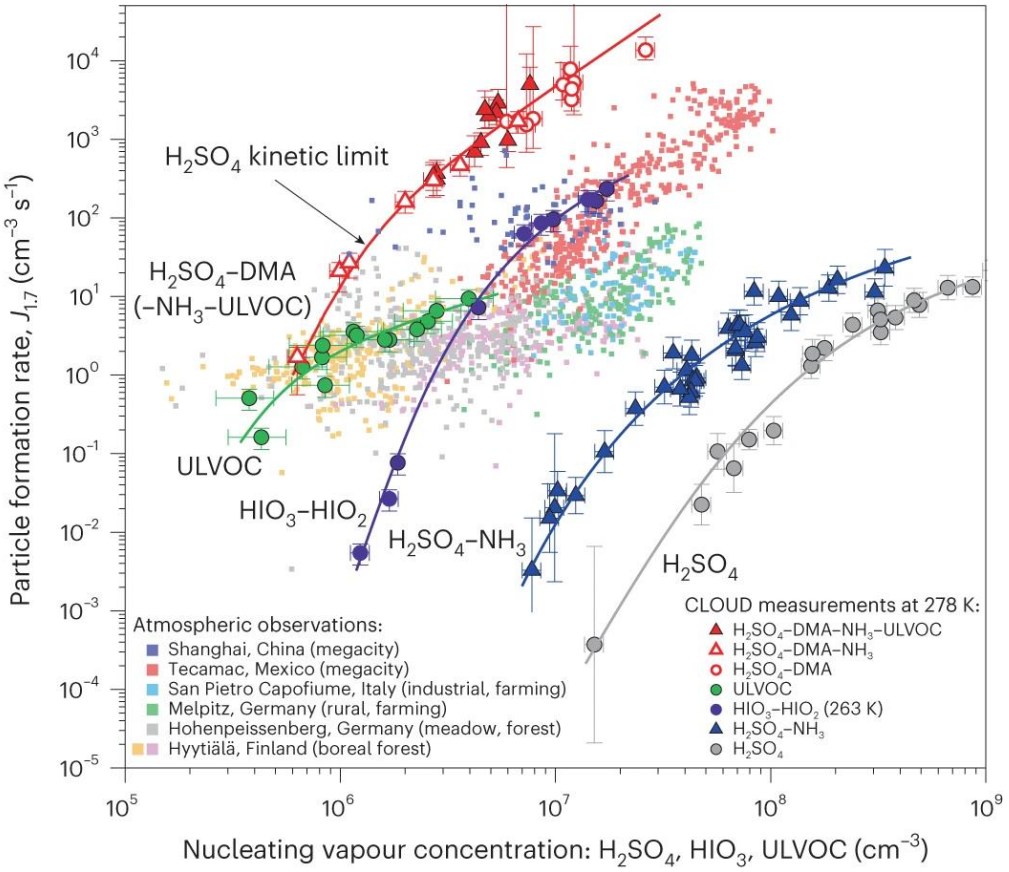
- Ions are created in the chamber naturally due to galactic cosmic rays (GCR) (~500/cm^3)
- Additional ionization from proton syncrotron beam (<3000/cm^3)
- High-voltage clearing field can be used to remove all the ions (~0/cm^3)

- →neutral, gcr and beam runs to simulate ionization rate at different altitudes of the atmosphere

Comprehensive set of instrumentation to measure ultra-low vapor concentrations and particles from 1 nm to >10 µm



CLOUD has provided quantification of the particle production from different precursor vapors



Key questions for each system of precursor vapours and ambient conditions (T, relative humidity...):

- *What is the aerosol particle formation rate vs vapour concentrations?*
- *What is the influence of ions from galactic cosmic rays between 0 and 10 km altitude?*
- *How fast do the particles grow from molecular (~1 nm) to CCN sizes (~50 nm)?*
- *Which chemical compounds are involved in a) particle formation and b) growth?*
- *What are the chemical pathways transforming volatile precursor vapours into ultra-low-volatility nucleating vapours?*

nature geoscience

Perspective

https://doi.org/10.1038/s41561-023-01305-0

Atmospheric new particle formation from the CERN CLOUD experiment

Kirby et al. 2023: Review of 15 years of CLOUD - Synthesis of the current understanding of atmospheric new particle formation

https://doi.org/10.1038/s41561-023-01305-0