# Atmospheric Science at CERN – the CLOUD Experiment

Eva Sommer

27 November 2024

universität wien
Faculty of Physics

Cosmic rays → NPF → CCN → clouds → global climate

**CLOUD**

**C**osmics **L**eaving **OU**tdoor **D**roplets

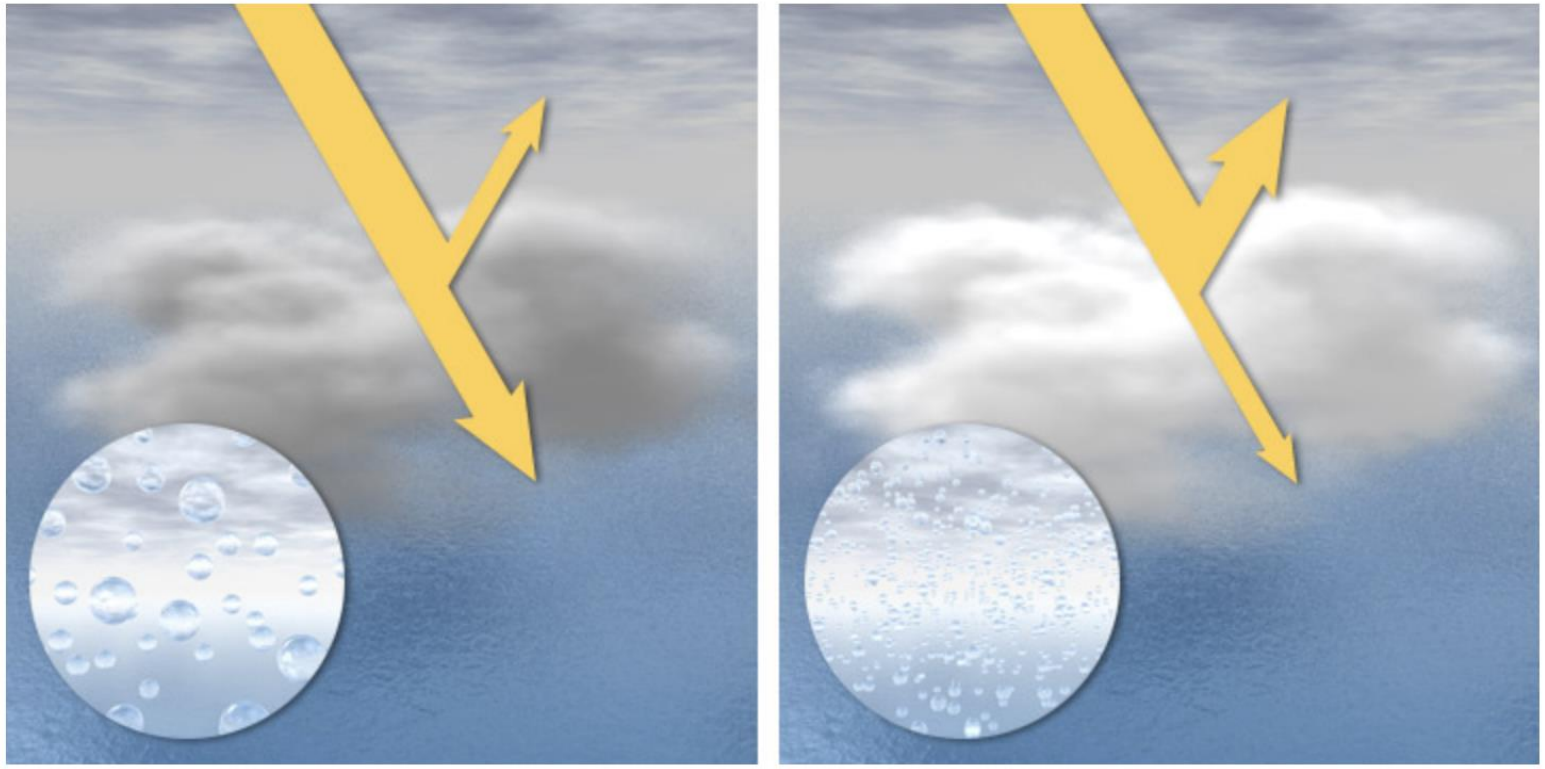
# Cosmic Rays → NPF → CCN → clouds → Global Climate

**C**loud **C**ondensation **N**uclei

Every cloud droplet needs a seed particle (aerosol particle)!

The amount of CCN within a cloud can change its properties!

→ more CCN – brighter cloud



https://earthobservatory.nasa.gov/features/Aerosols/page4.php

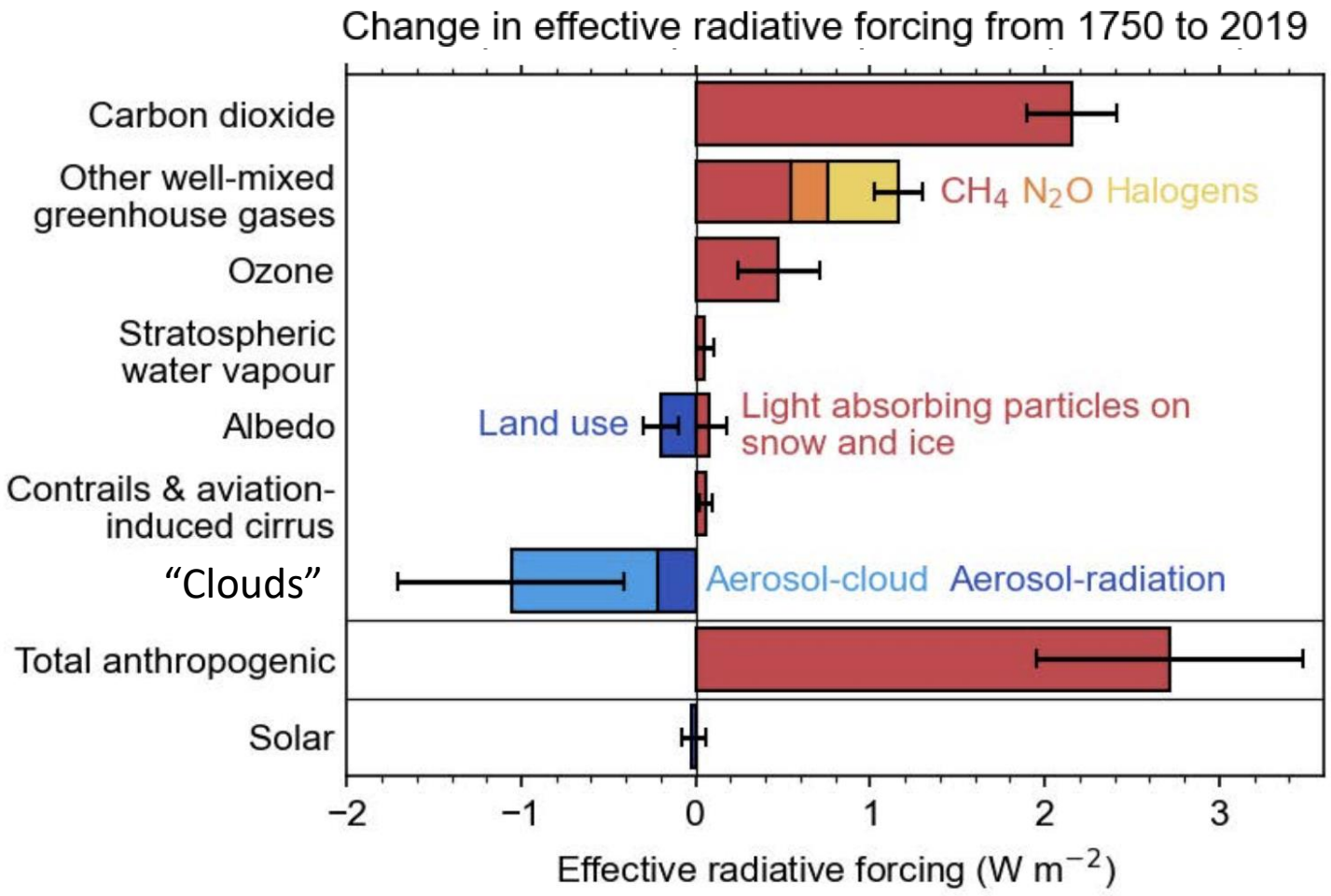
# Cosmic Rays → NPF → CCN → clouds → Global Climate

How to measure human contribution to climate change?

Global radiation balance

**Effective radiative forcing**

How much has men-made change of each of these climate agents contributed to global warming or cooling.

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# Cosmic Rays → NPF → CCN → clouds → Global Climate

**C**loud **C**ondensation **N**uclei

Cloud Condensation Nuclei
→ **aerosol particles**

<u>Aerosol:</u>

- stable suspension system of solid or liquid particles in a carrier gas (air)
- can have various sources (primary/secondary) (natural/anthropogenic)
- **<u>primary aerosol</u>** →

# Cosmic Rays → NPF → CCN → clouds → Global Climate

**N**ew **P**article **F**ormation  **C**loud **C**ondensation **N**uclei

New Particle Formation (nucleation) depends on multiple factors:

- Chemical composition and precursor gas concentration
- Temperature
- Ionisation

**Ion induced nucleation:**

- Cosmic rays create ions in atmosphere
- Presence of ions tends to stabilise aerosol clusters

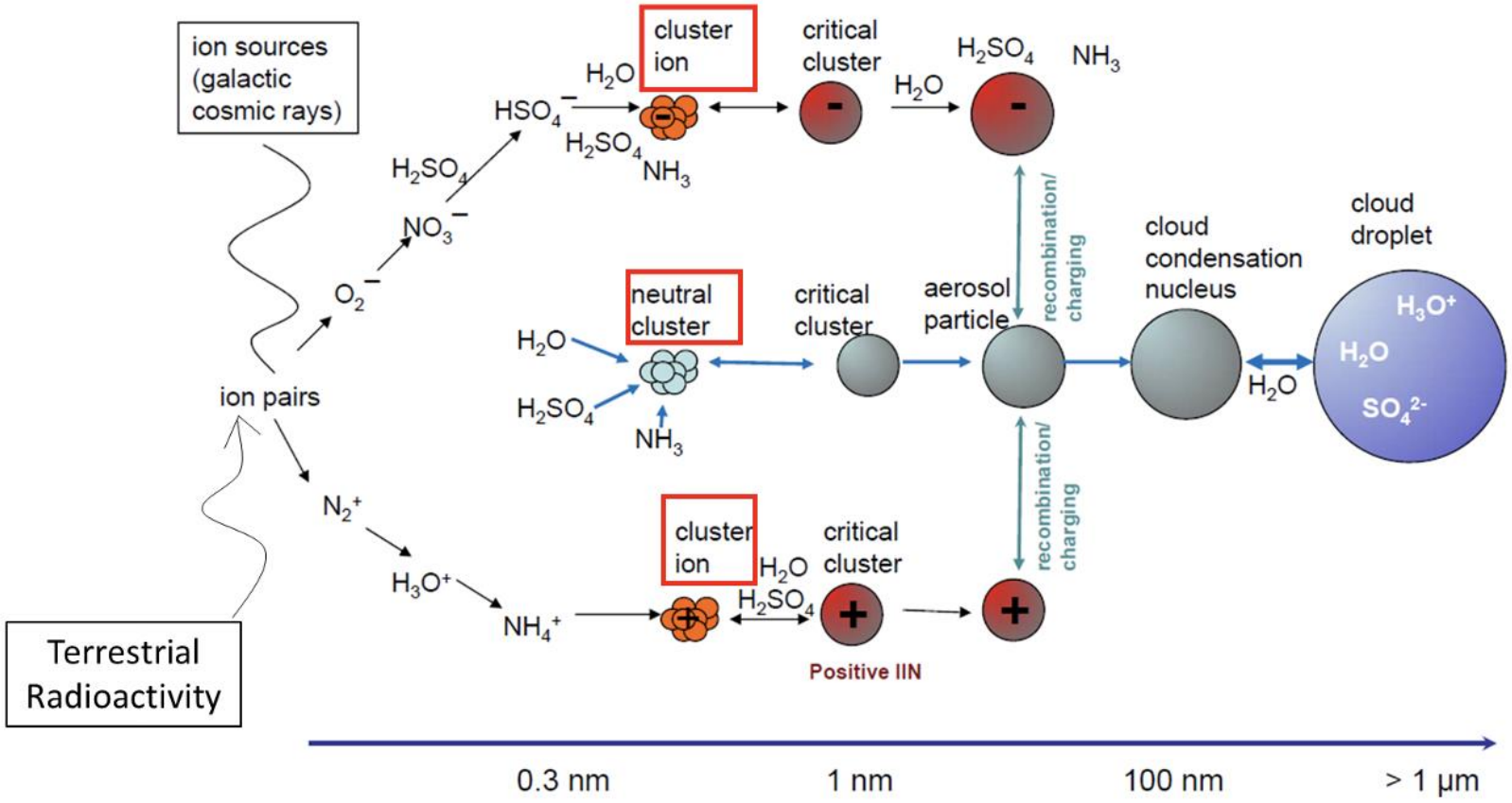



Figure by Joachim Curtius

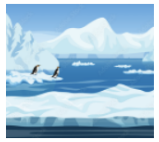
# Cosmic Rays → NPF → CCN → clouds → Global Climate

**N**ew **P**article **F**ormation  **C**loud **C**ondensation **N**uclei

Aerosol particles:

- **secondary aerosol** → New Particle Formation
- volatile precursore vapors are oxidised to “sticky vapours”
- precursors can have natural and anthropogenic origin

$SO_2$



$I_2$

biogenic vapours

**volatile precursor vapours**

oxidation in the atmosphere ($O_3$, OH·)

**low volatility vapours**

$H_2SO_4$

$HIO_3$

$HOM$

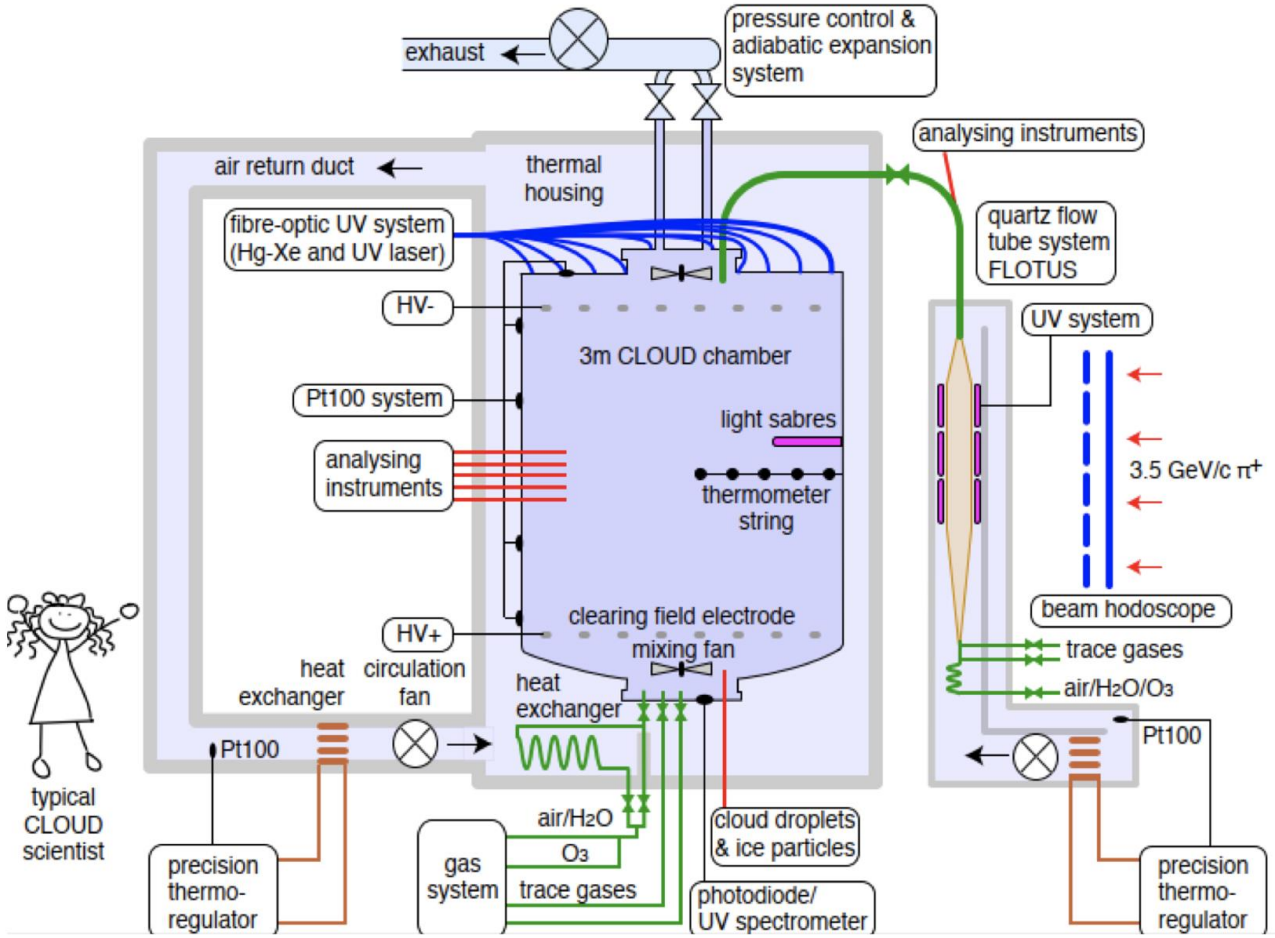
Highly-oxygenated Organic Molecules

nucleation and growth

**aerosol particles**

# The CLOUD experiment at CERN

## **C**osmics **L**eaving **OU**tdoor **D**roplets

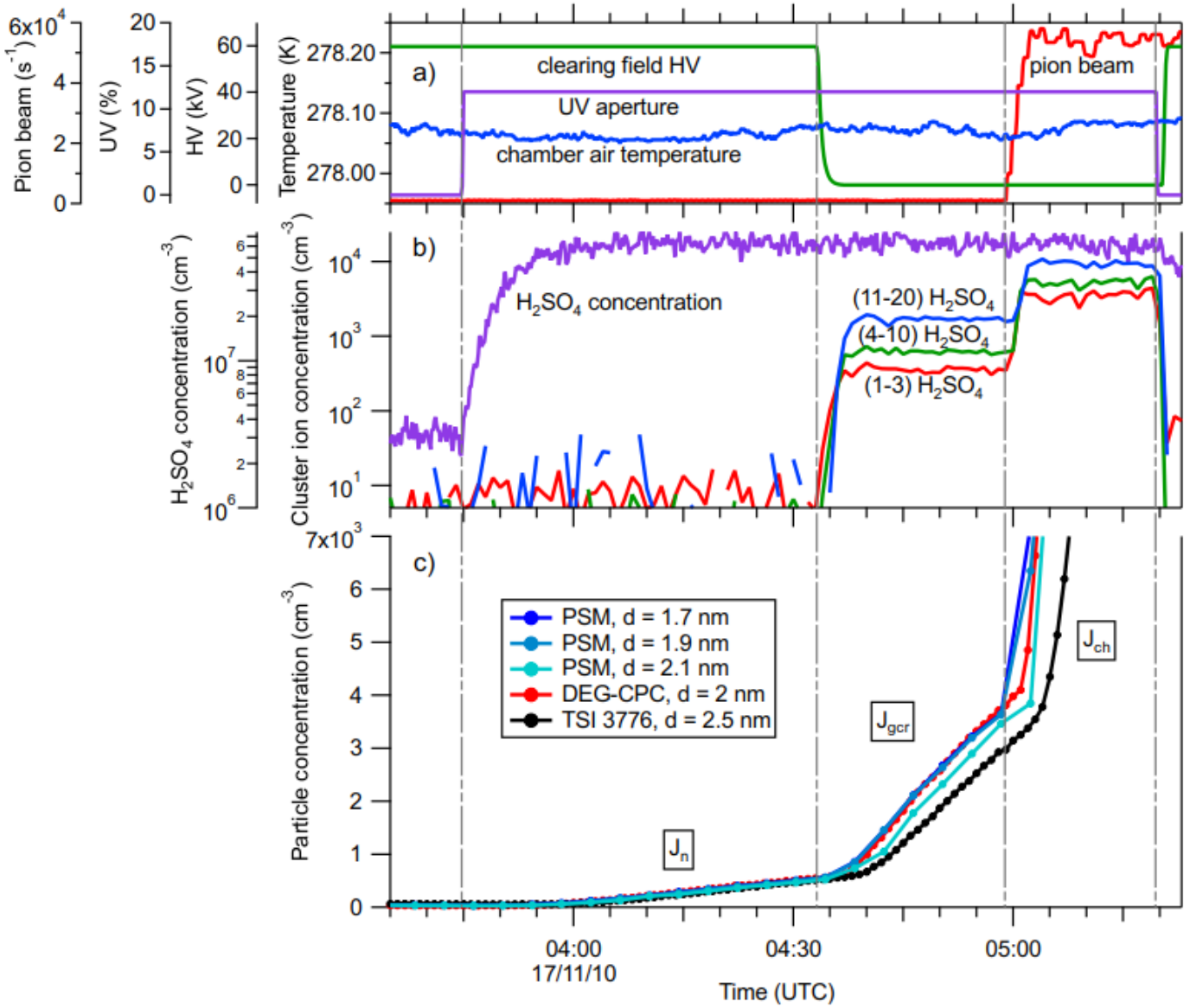



**studying the influence of cosmic rays on aerosol, clouds and climate**

**CLOUD recreates true atmospheric conditions**

- Contaminants < p.p.t.v
- Synthetic air created from liquid $N_2$ and $O_2$
- Stable temperature control from -65°C to +100°C
- Multiple light sources at different wavelengths
- 3.5 GeV/c pion beam simulating cosmic rays
- HV field cage to remove all ions
- Up to 40 state-of-the-art analysing instruments
- Observing new particle formation in real time

# Results of the CLOUD experiment




Monitoring:
- Chamber conditions
- Gas phase chemistry
- Aerosol particles

Important quantity:
**J-rate** → rate at which aerosol particles with a diameter of 1.7 nm appear
$J_N$ [cm$^{-3}$ s$^{-1}$]
$J_{GCR}$ [cm$^{-3}$ s$^{-1}$]
$J_{Beam}$ [cm$^{-3}$ s$^{-1}$]


Kirkby, J., & Collaboration, C. L. O. U. D. (2013, May). Atmospheric nucleation and growth in the CLOUD experiment at CERN. In *AIP Conference Proceedings* (Vol. 1527, No. 1, pp. 278-286). American Institute of Physics.

# The CLOUD experiment at CERN

# The CLOUD collaboration

# The CLOUD experiment at CERN

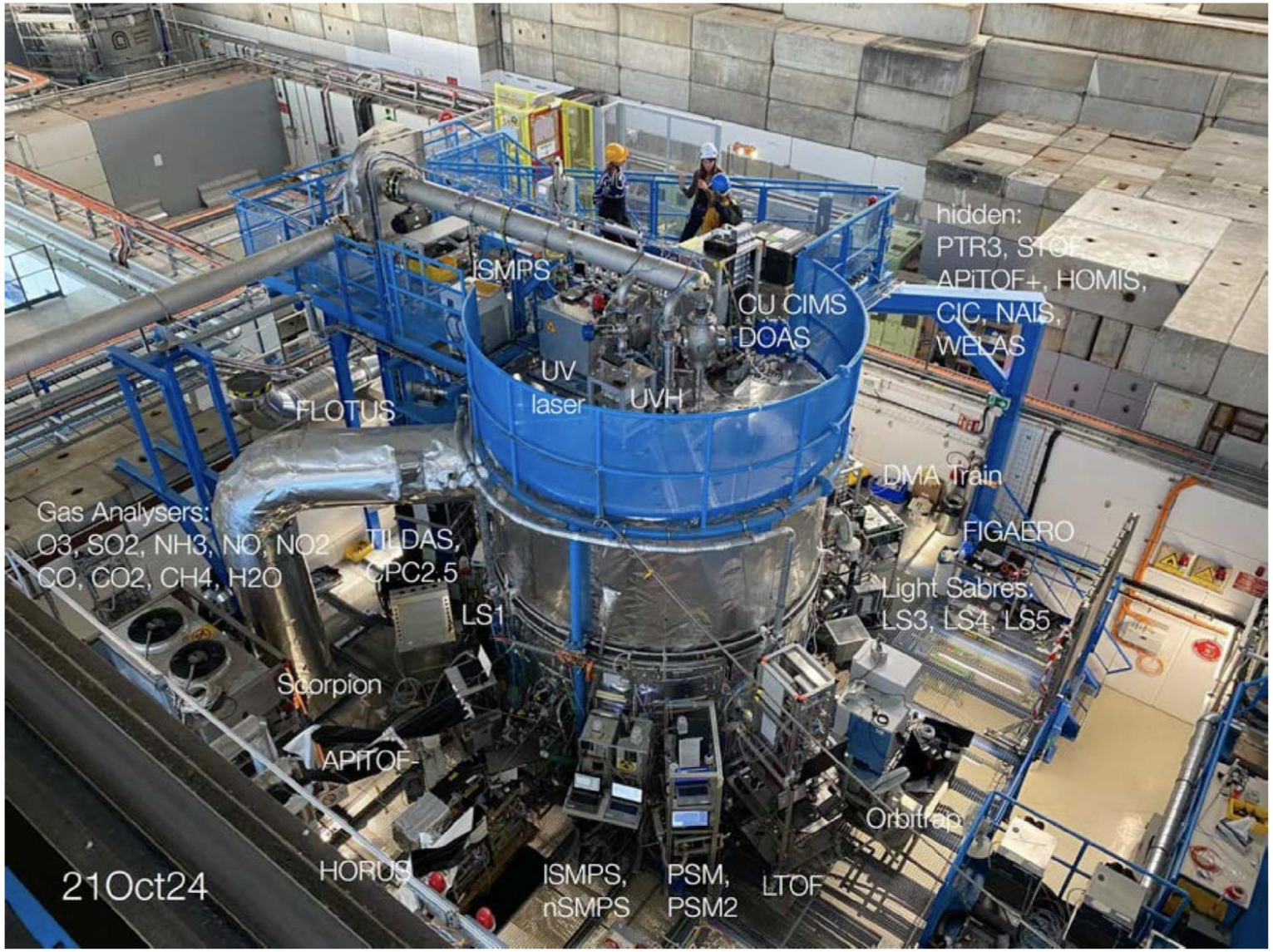


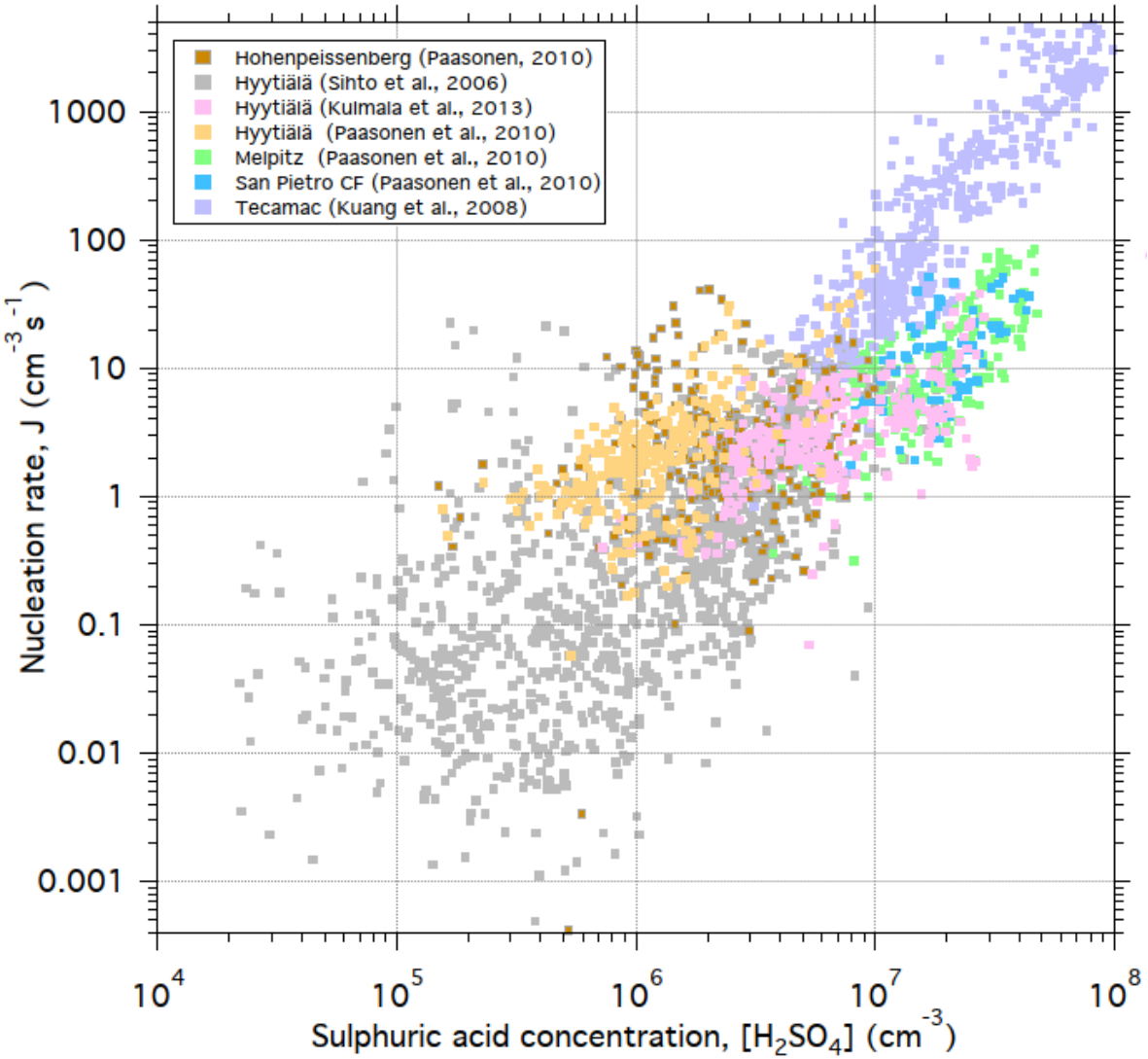

Image: Jasper Kirkby

# What have we learned so far?

**Before CLOUD (2010)**

**H2SO4 alone thought to account for atmospheric nucleation, with organics responsible for particle growth**

- Clear dependency of nucleation rate on H2SO4
- But why are data so scattered, especially at low concentrations



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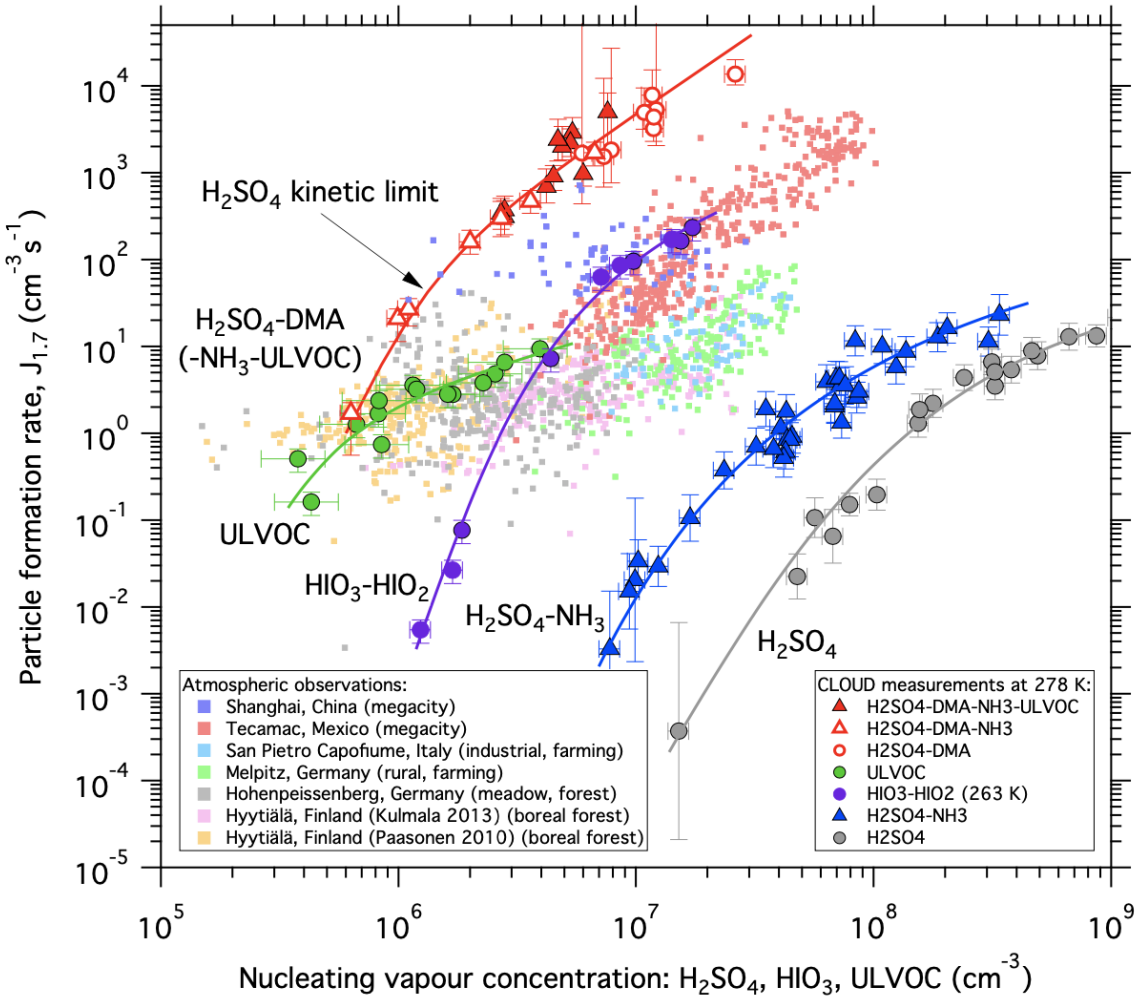
- But why are data so scattered, especially at low concentrations

## CLOUD has shown

- Not a single point is pure binary H2SO4-H2O nucleation!
- The NPF events are mainly H2SO4-NH3-HOM
- Scatter is due to unmonitored variations of NH3, amines, HOMs…



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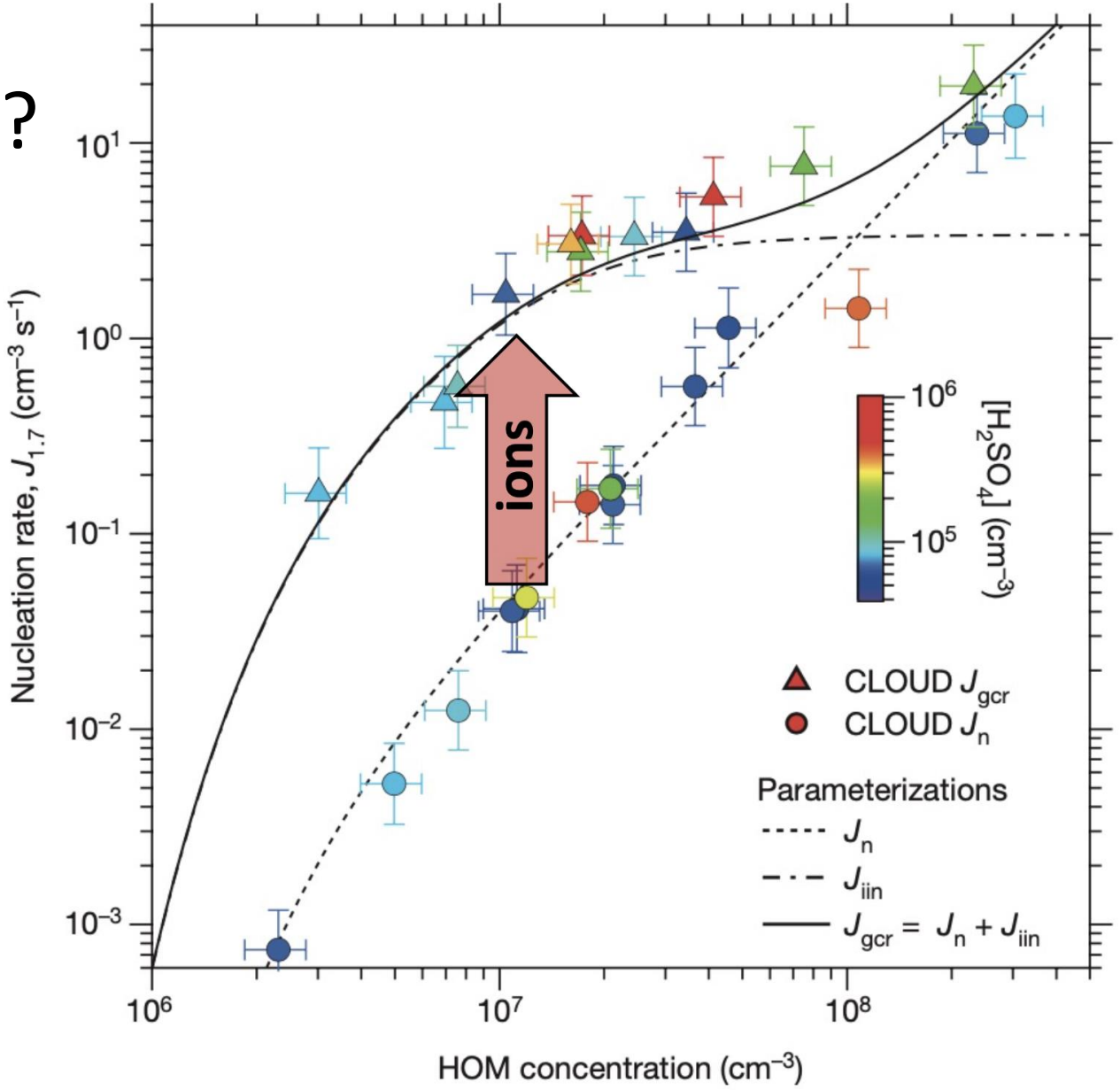
**CLOUD has shown**

- Oxidised organic molecules (HOMs) can form aerosol particles independently of $H_2SO_4$
- Strong ion enhancement effect, but again depending on concentration



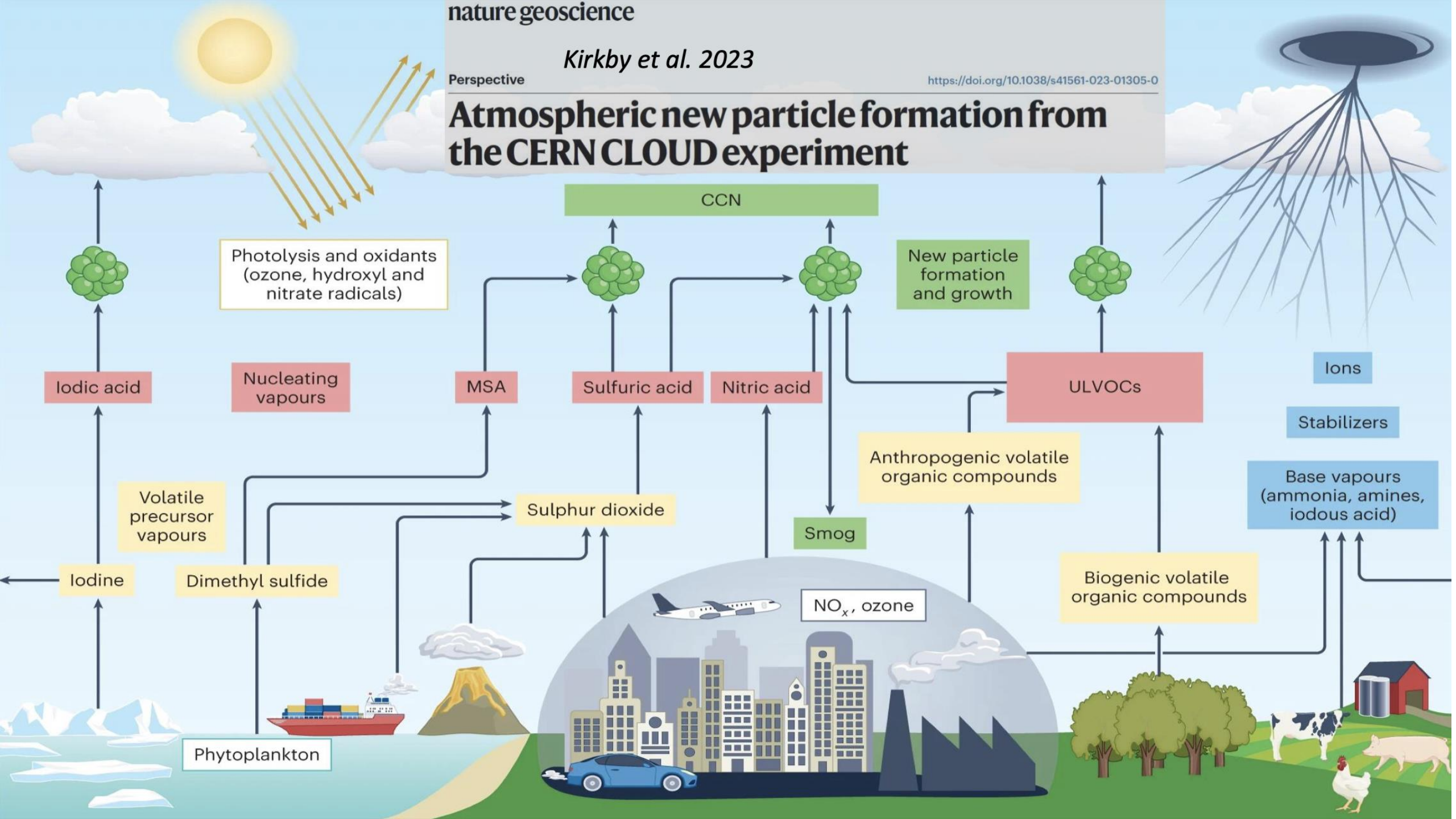

Kirkby, Jasper, et al. "Ion-induced nucleation of pure biogenic particles." *Nature* 533.7604 (2016): 521-526.

nature geoscience

*Kirkby et al. 2023*

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

# Atmospheric new particle formation from the CERN CLOUD experiment



University of Colorado Boulder

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universität innsbruck

CERN

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University of Eastern Finland

Stockholms Universitet

Stockholm University

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U Lisboa
Universidade de Lisboa

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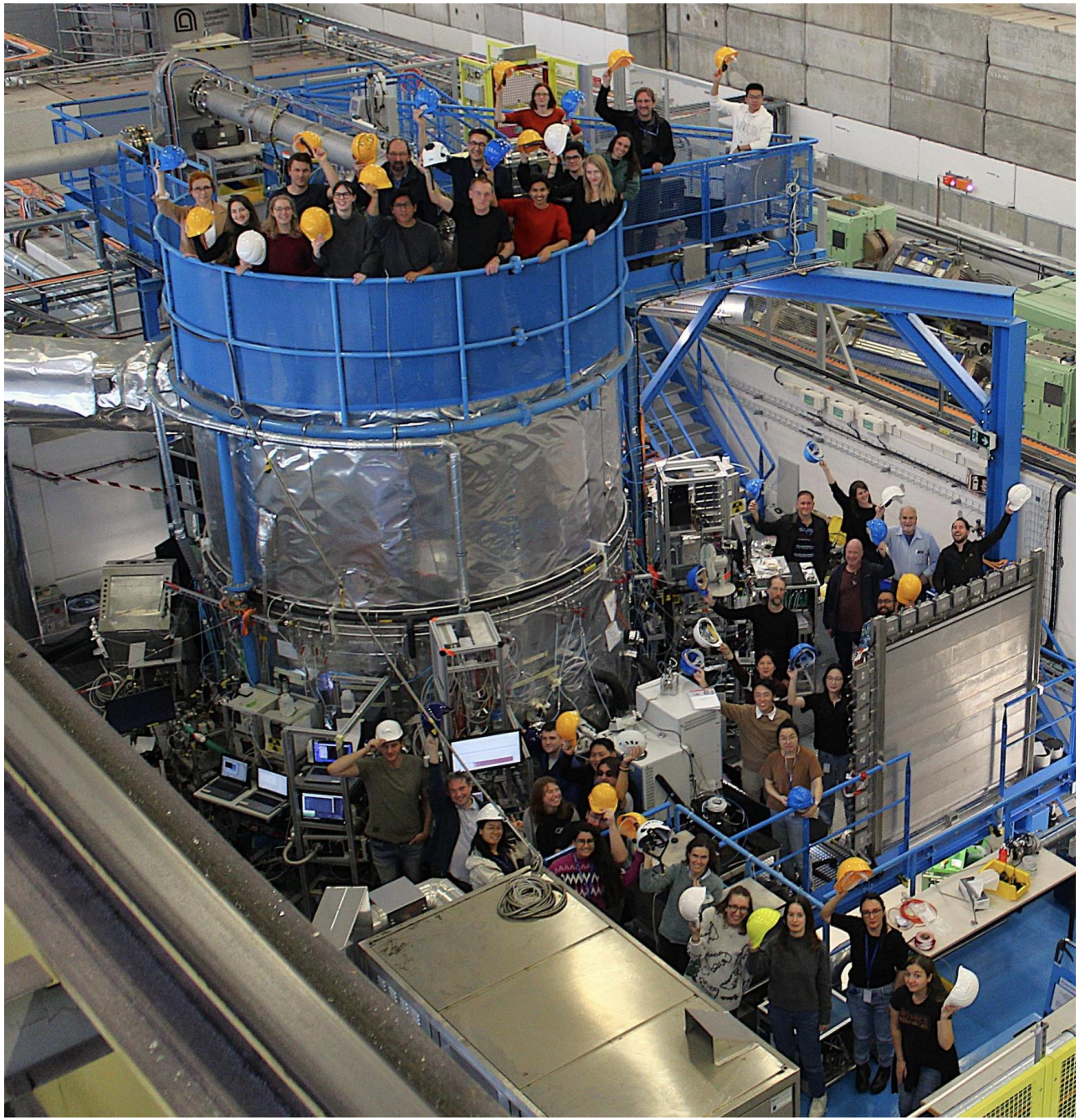
Helsingin yliopisto
Helsingfors universitet
University of Helsinki

KIT
Karlsruher Institut für Technologie

Max Planck Institute for Chemistry

Universidade da Beira Interior



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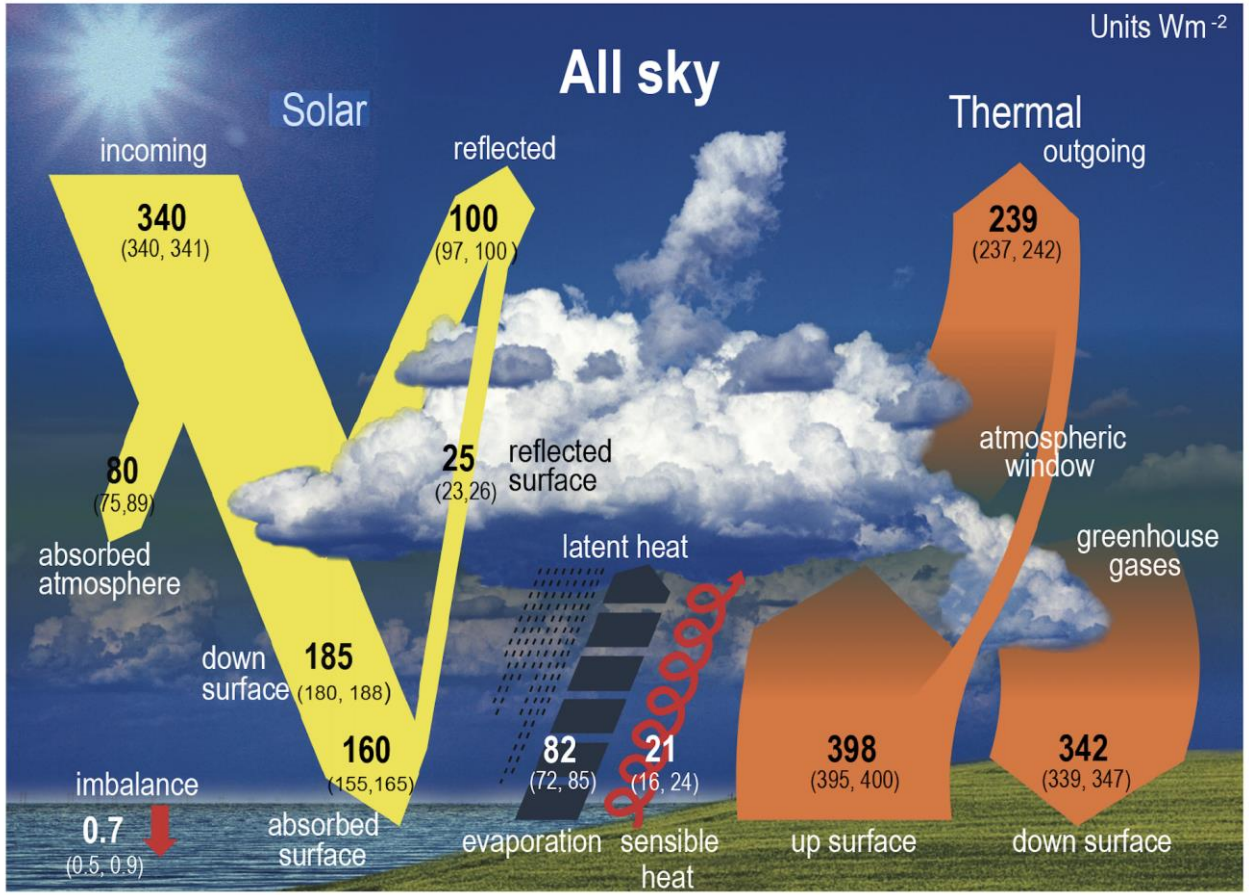
How to measure human contribution to climate change?

**Global radiation balance**

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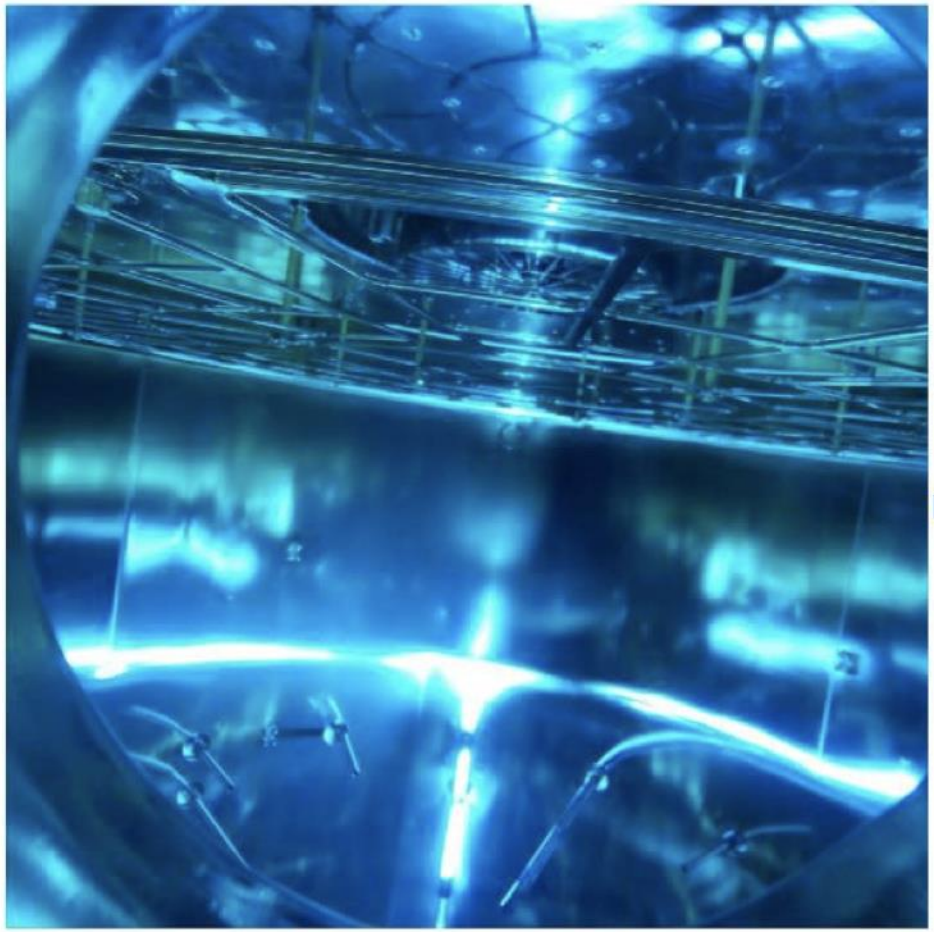
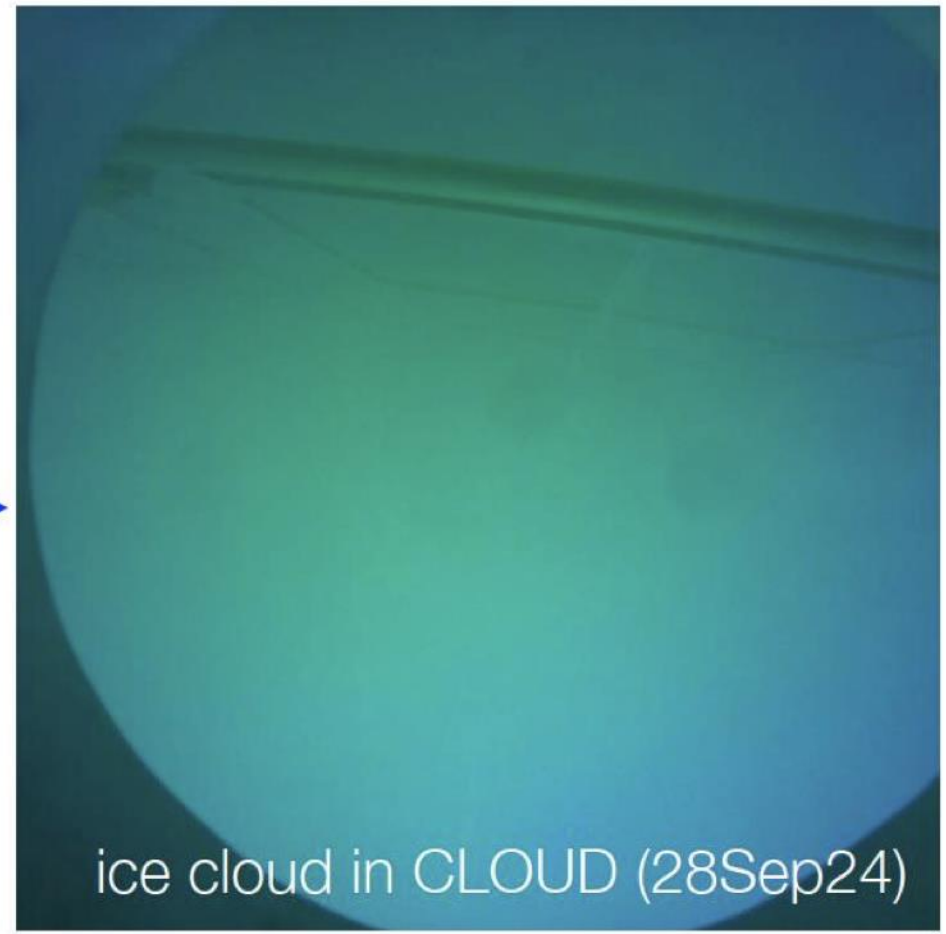
# Using FLOTUS to create ice clouds in the CLOUD chamber





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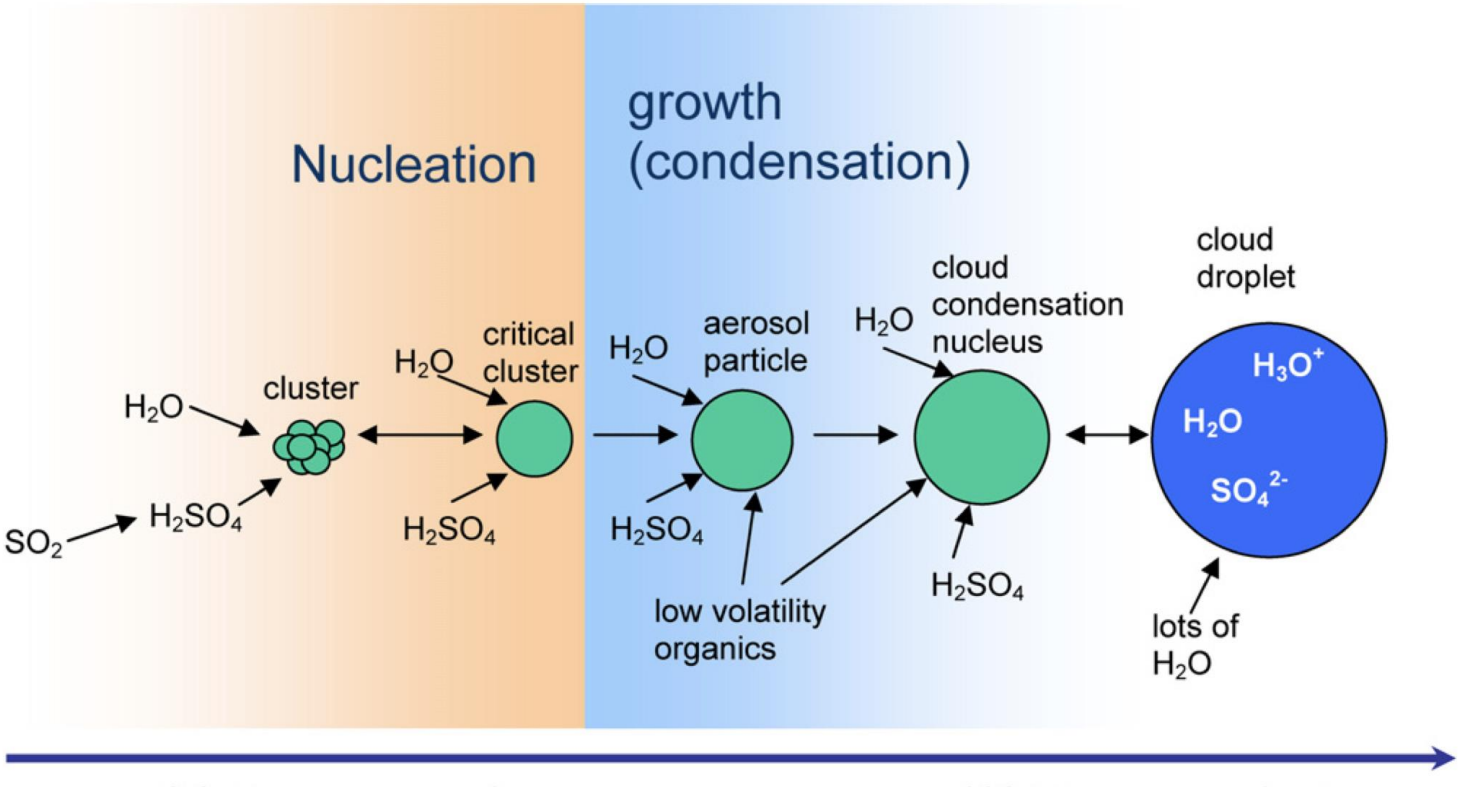
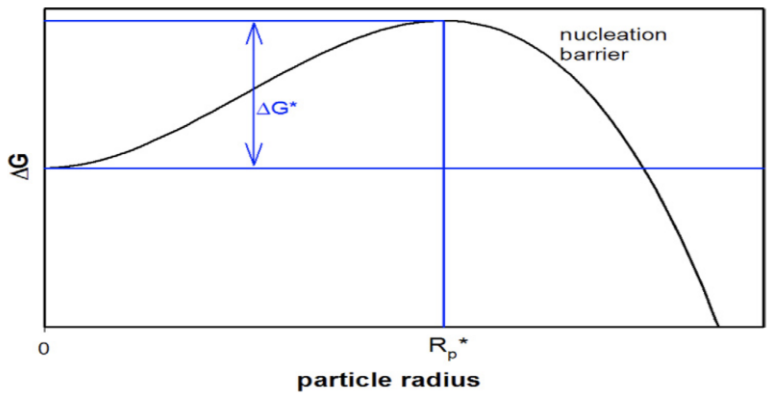
Aerosol particles:

- **secondary aerosol** → New Particle Formation
- Low volatility vapours can form aerosol particles directly from the gas phase
- globally, more than half of all CCN are secondary aerosol particles
- critical cluster radius ~ 1.7 nm




Curtius, J. (2006). Nucleation of atmospheric aerosol particles. *Comptes Rendus Physique*, *7*(9-10), 1027-1045.

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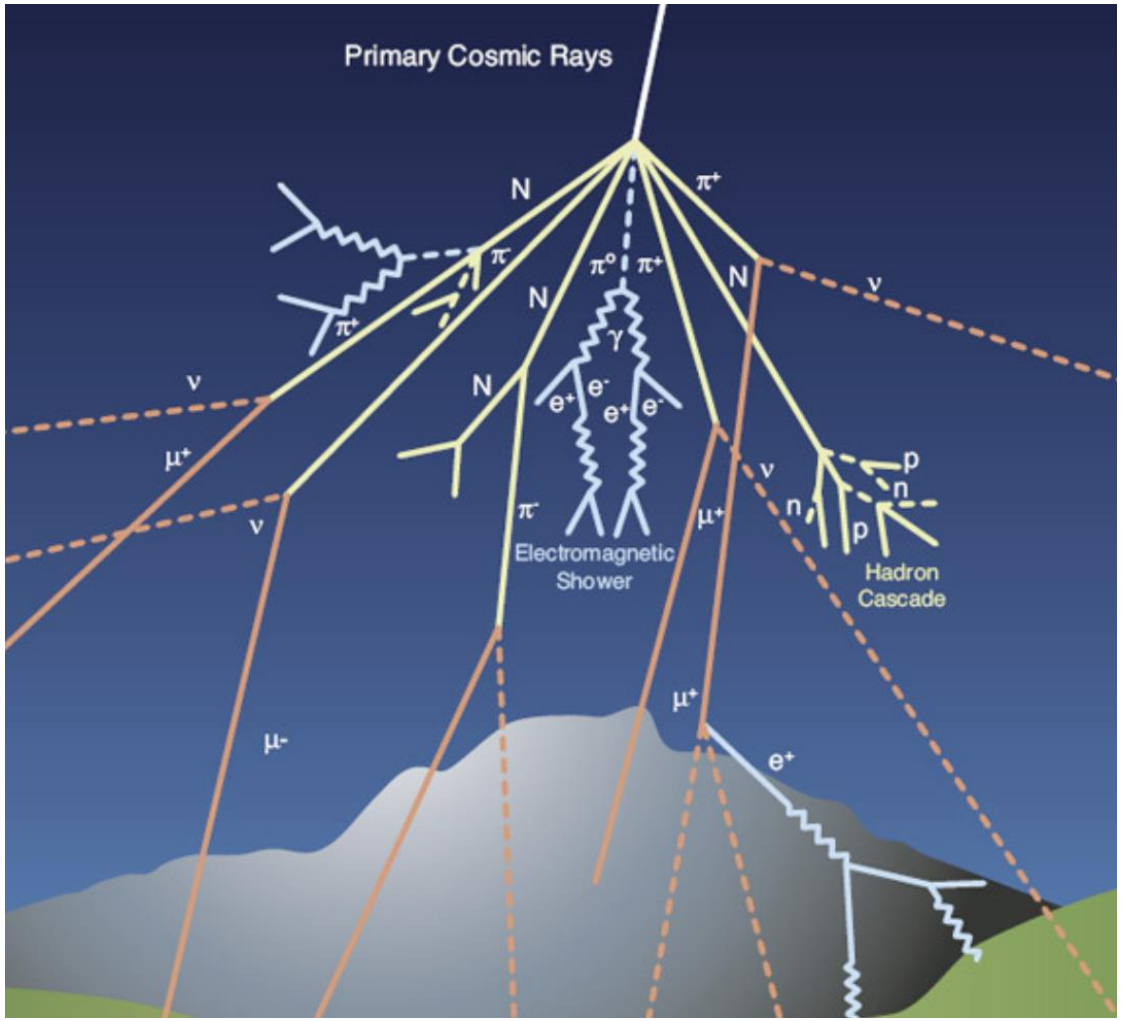
New Particle Formation (nucleation) depends on multiple factors:

- Gas phase composition
- Precursor gas concentration
- Temperature
- Ionisation → **Cosmic rays**



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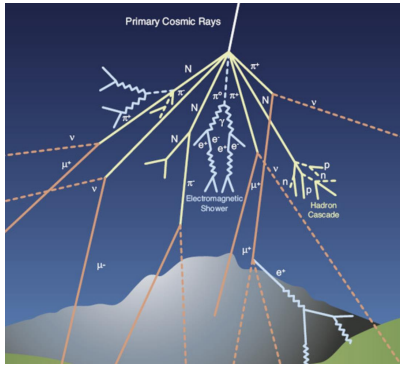


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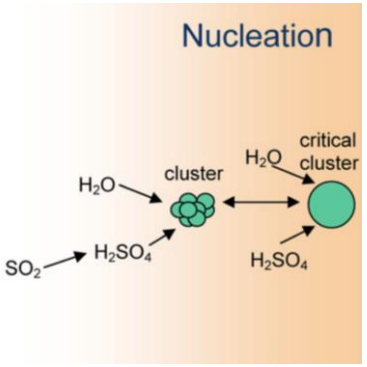


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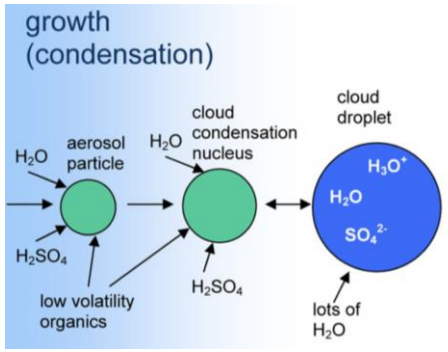


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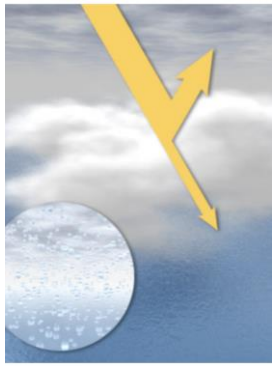

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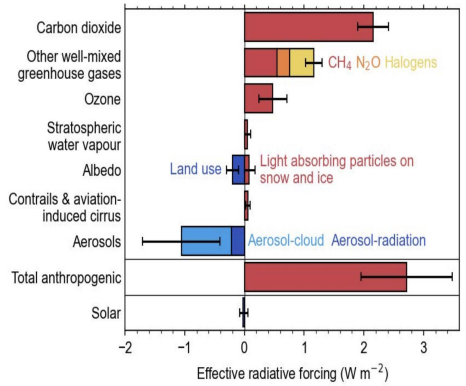



## CERN CLOUD Experiment

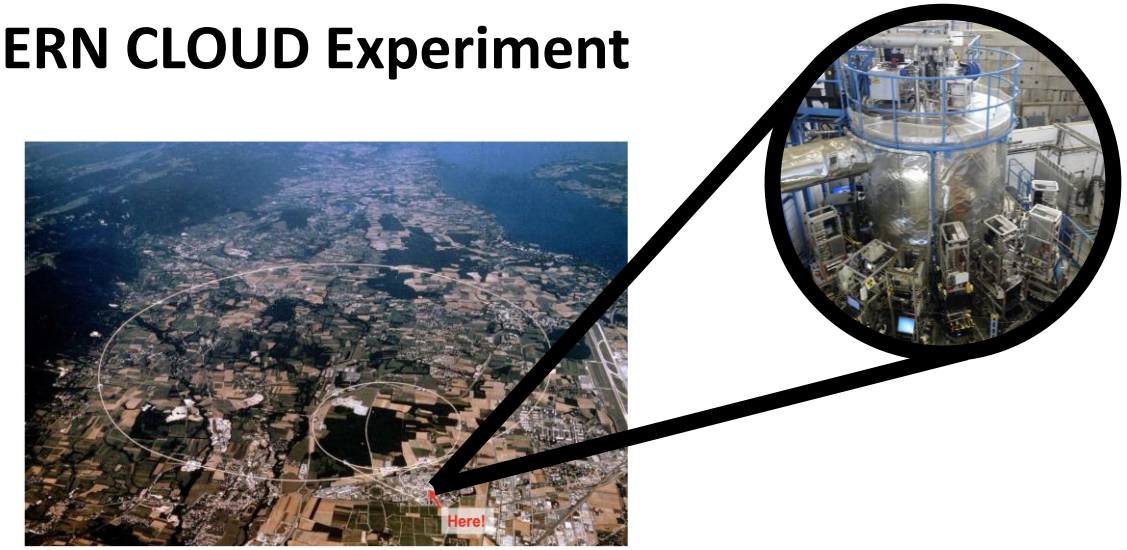
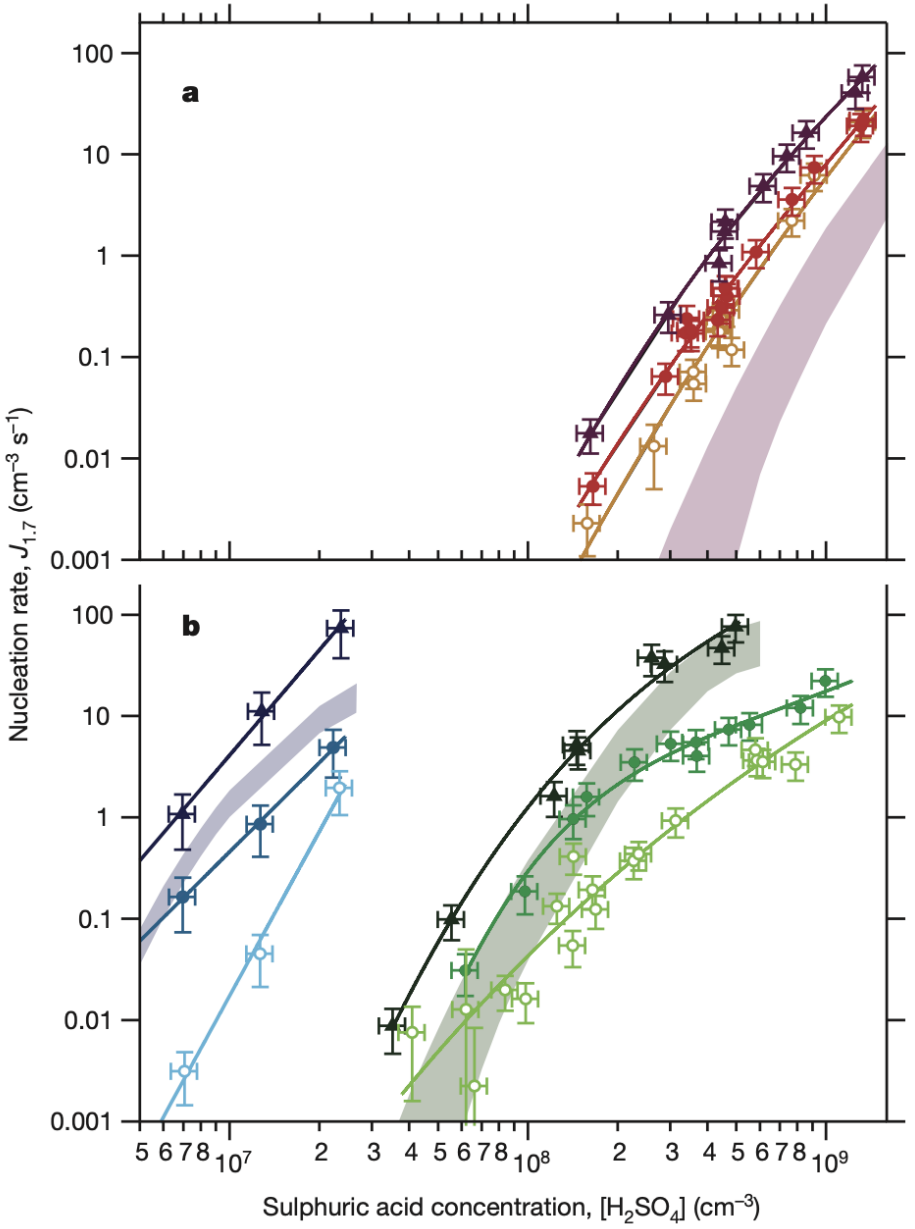



Image: Maximilien Brice

# What have we learned so far?

**CLOUD has shown**

- The presence of ions greatly enhances aerosol particle formation from $H_2SO_4$
- The magnitude of this effect strongly depends on temperature and $H_2SO_4$ concentration




Kirkby, J., Curtius, J., Almeida, J., Dunne, E., Duplissy, J., Ehrhart, S., ... & Kulmala, M. (2011). Role of sulphuric acid, ammonia and galactic cosmic rays in atmospheric aerosol nucleation. *Nature*, *476*(7361), 429-433.

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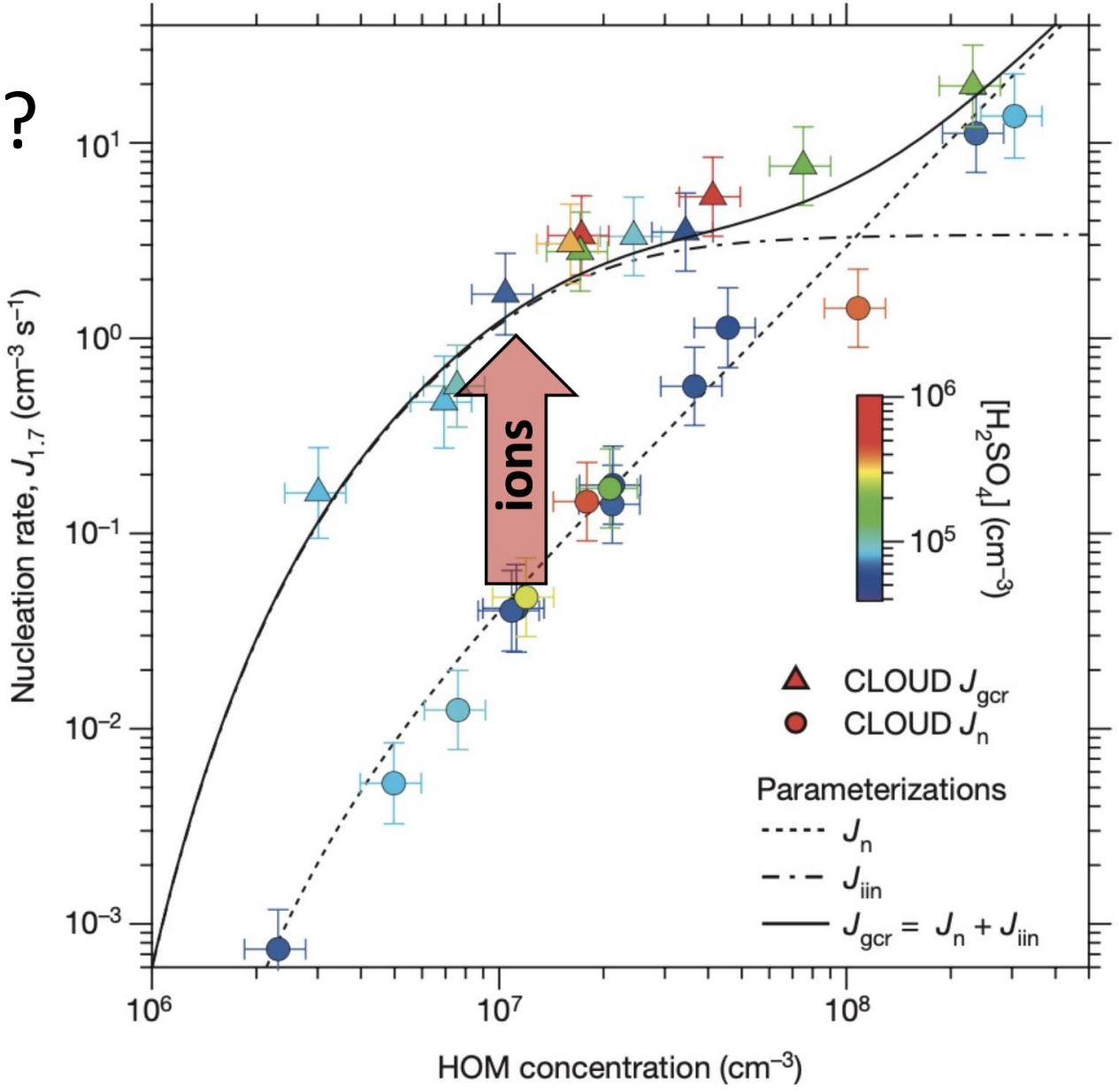


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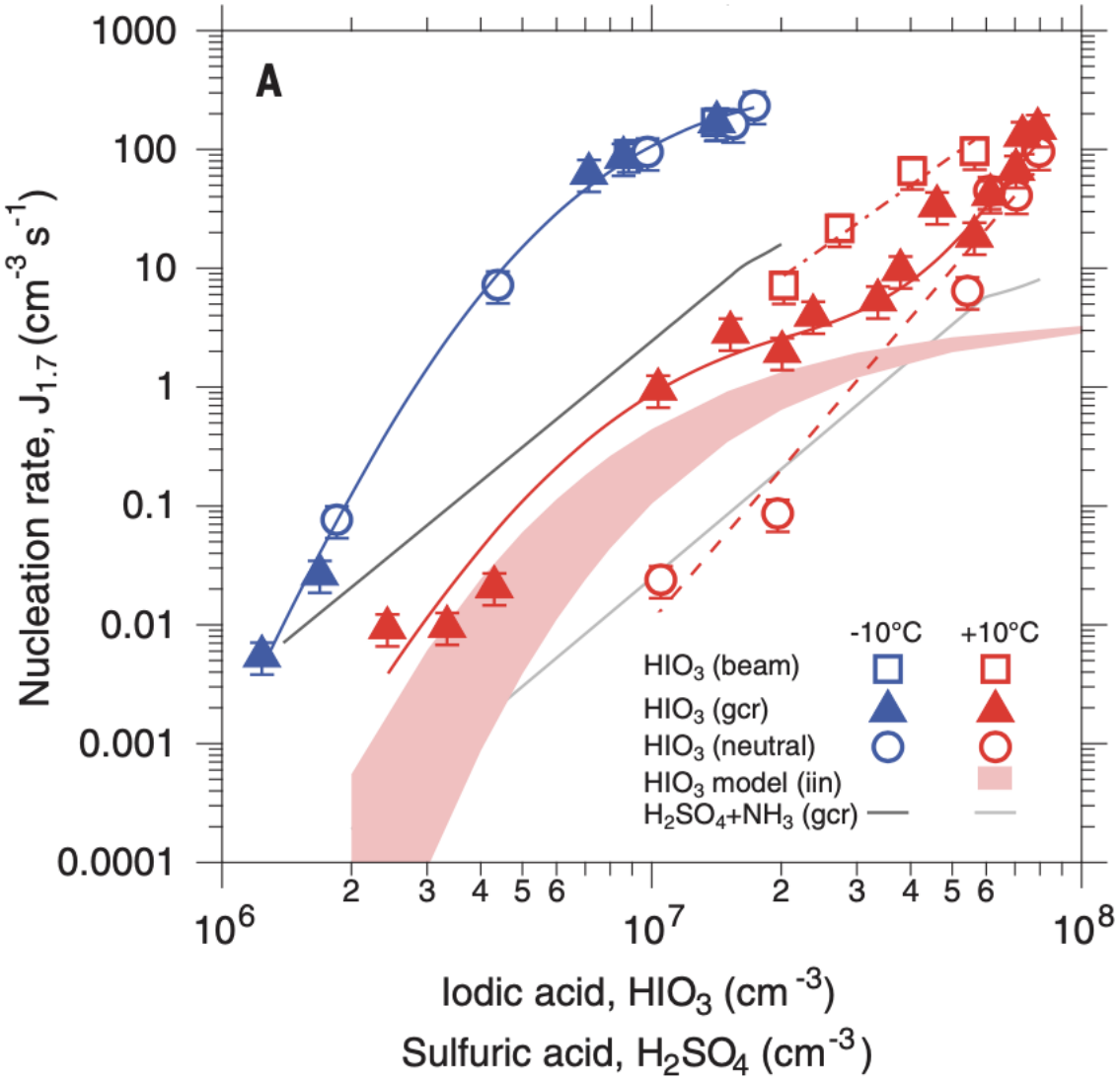
**CLOUD has shown**

- Iodic acid can form aerosol particles even without $H_2SO_4$
- Ion enhancement effect strongly temperature dependant

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