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Status and plans of the CLOUD experiment

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For the CLOUD Collaboration

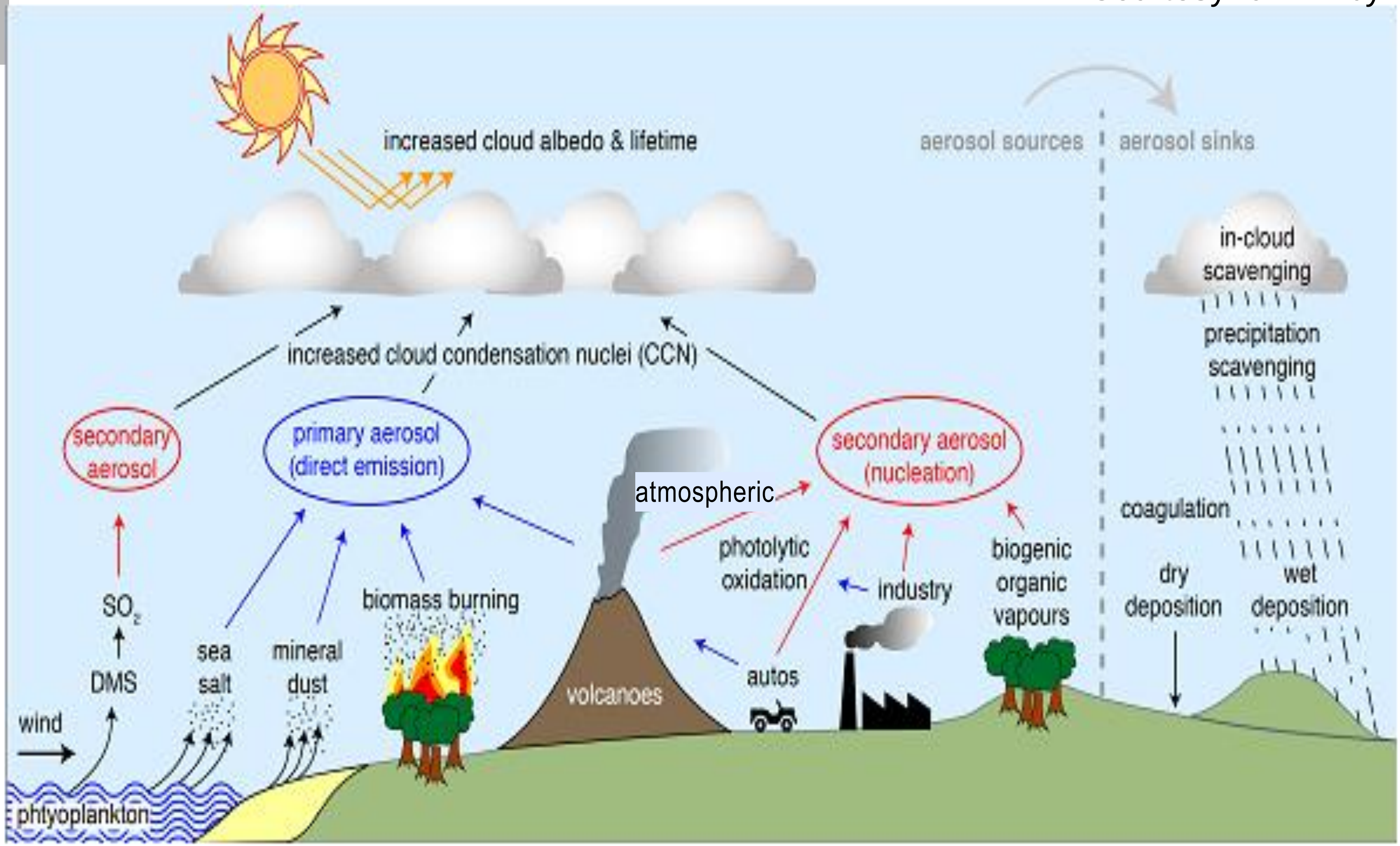
SPSC
Cern, 7 June 2018

Atmospheric aerosol particles:
Solid or liquid particles suspended in the atmosphere

Primary: direct emission into the atmosphere

Secondary: Formation in the atmosphere after oxidation of gaseous precursors

Courtesy: J. Kirkby



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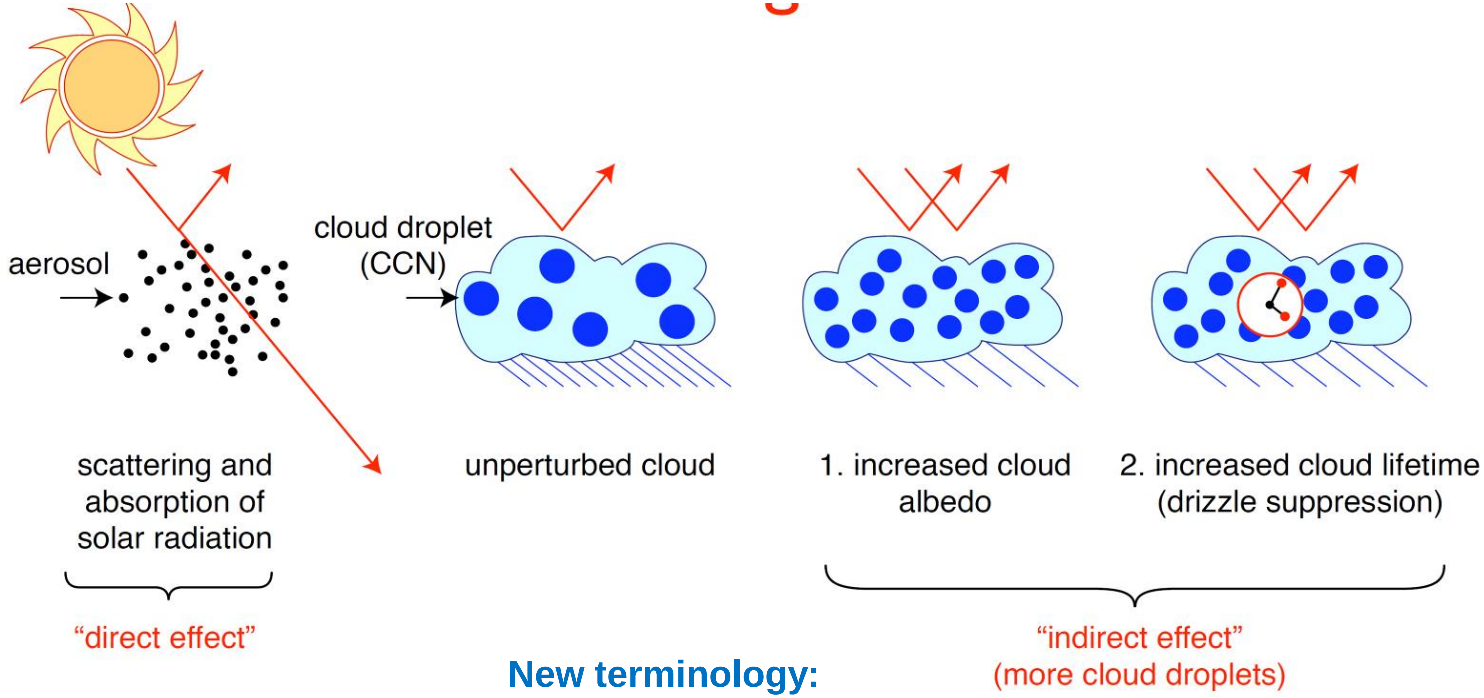
The radiative forcing of aerosols

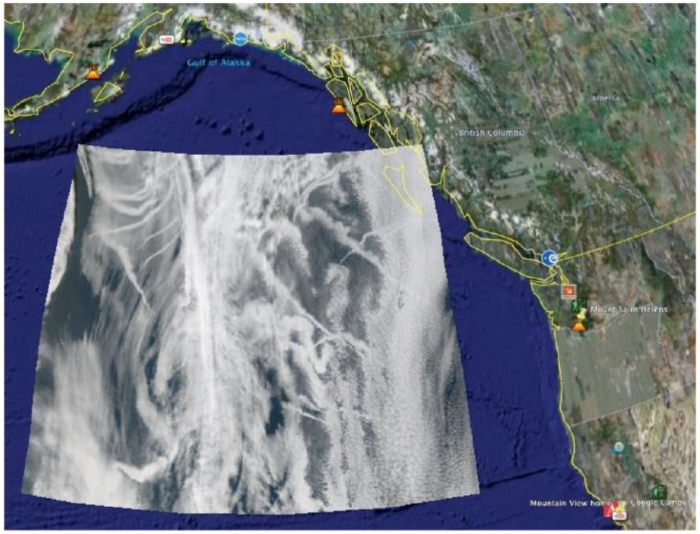
LABOR FÜR ATMOSPHÄREN-CHEMIE



New terminology:

Aerosol-Radiation Interaction **Aerosol-Cloud Interaction**

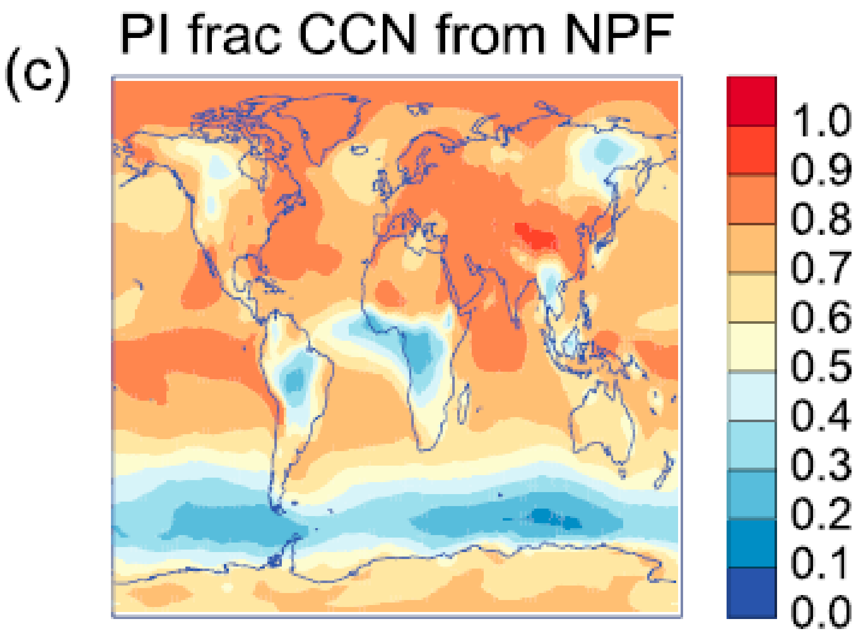
- Aerosols are tiny liquid or solid particles suspended in the atmosphere
- Above 50nm size they provide Cloud Condensation Nuclei (CCN)



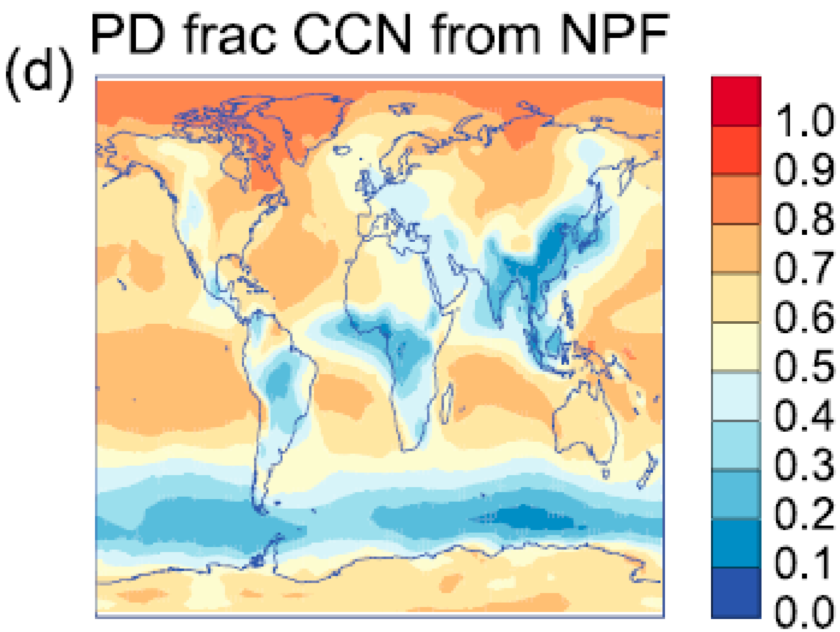
ship tracks forming stratocumulus deck in North Pacific

Courtesy: Jasper Kirkby, CERN

More than 50% of the cloud condensation nuclei (CCN) are formed in the atmosphere via new particle formation (NPF), rather than being directly emitted



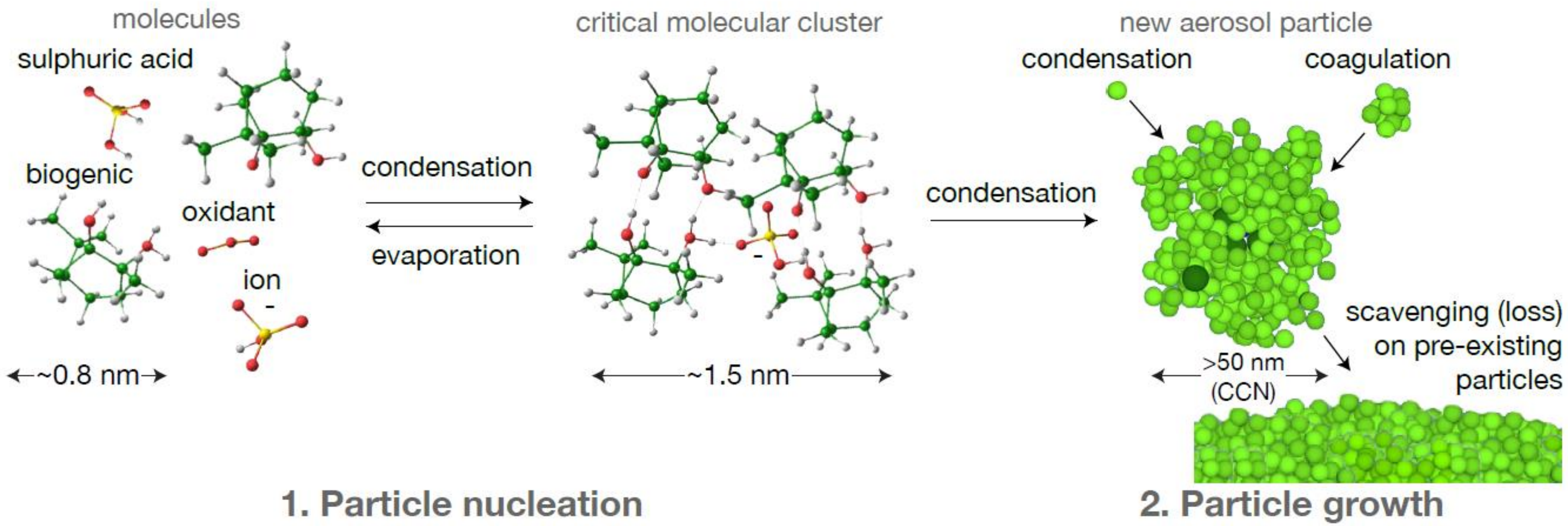
PI: Preindustrial



PD: Present Day

Gordon et al., JGR 2017

New particle formation (NPF) and growth to cloud condensation nuclei (CCN)

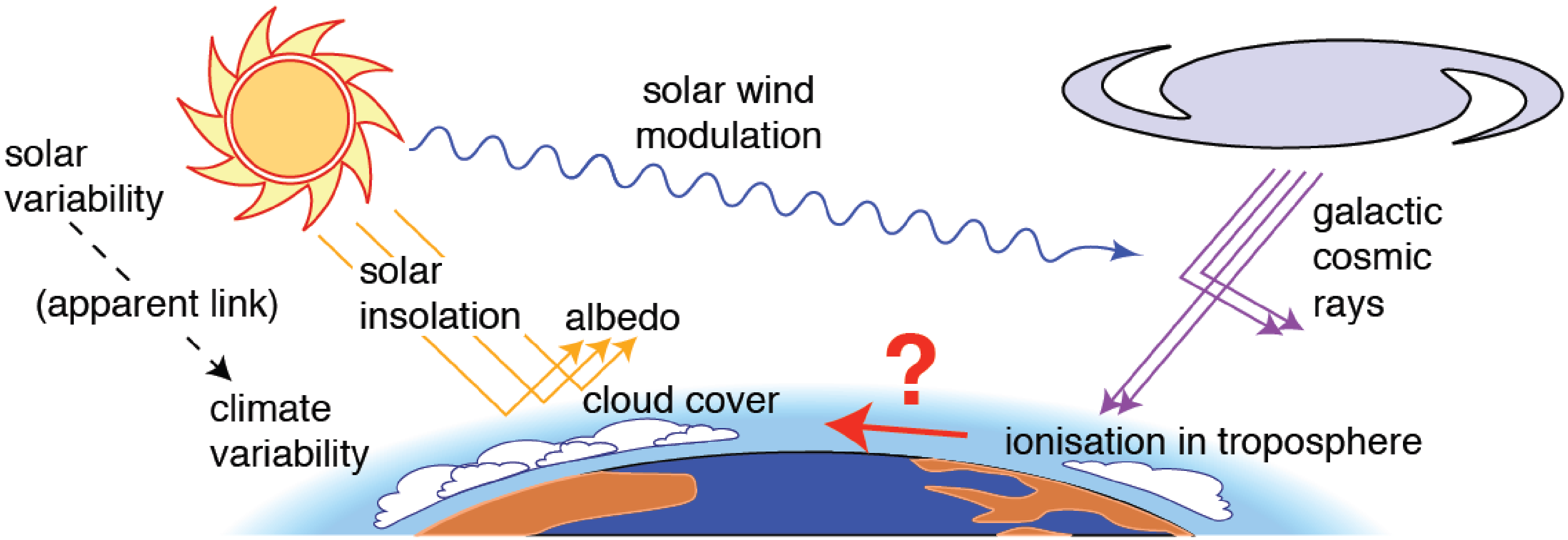


Questions:

How do the molecules from different sources as well as ions influence the formation rate of new particles (in our case: particles with a size of 1.7 nm)? And how do they influence the growth rate of newly formed particles?

➔ Both is important for the formation of CCN

A possible mechanism for a link between galactic cosmic rays and clouds



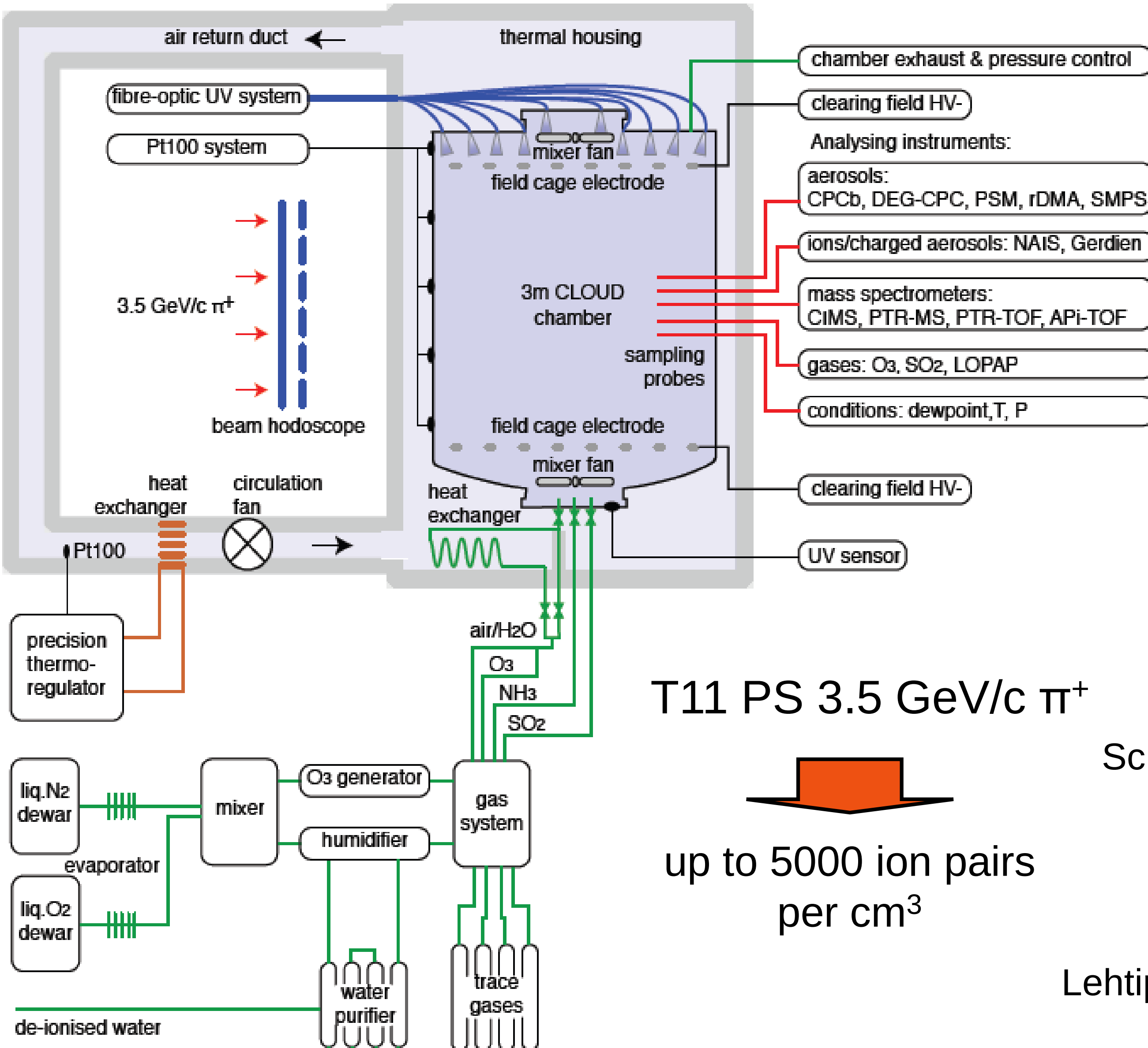
Solar variability → **GCR** → **Ion concentration** → **Nucleation** → **Growth** → **CCN** → **Cloud cover** → **Climate variability**

Solar variability ↕ **Climate variability**

LOSU	
Green arrow	**High**
Orange arrow	**Medium**
Red arrow	**Low**

LOSU: Level of Scientific Understanding

CLOUD was designed to answer these questions



T11 PS 3.5 GeV/c π^+

up to 5000 ion pairs per cm^3

Kirkby et al., Nature 2011
Almeida et al., Nature 2013
Schobesberger et al., PNAS 2013
Kürten et al., PNAS, 2014
Riccobono et al., Science 2014
Kirkby et al., Nature 2016
Tröstl et al., Nature 2016
Lehtipalo et al., Nature Comm. 2016
Gordon et al., PNAS 2016
Dunne et al., Science 2016

The big discovery in 2016: Highly oxygenated organic molecules (HOMs) are able to trigger new particle formation on their own, without the help of sulfuric acid ➔ Implications for the preindustrial time

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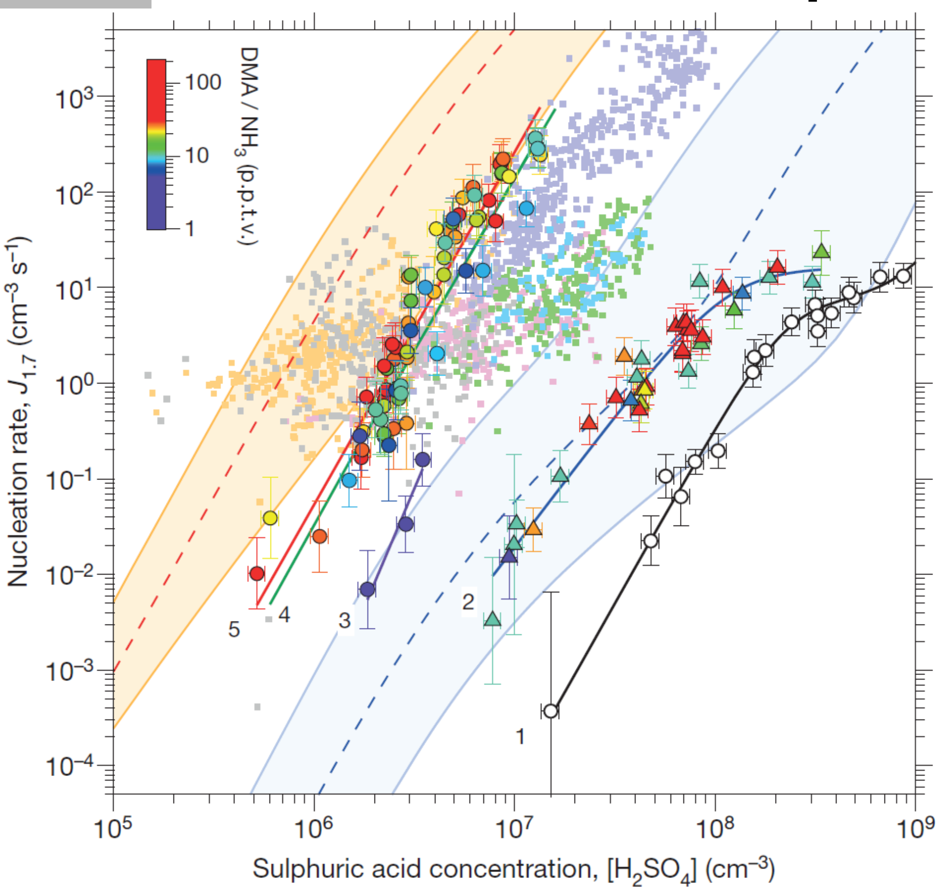
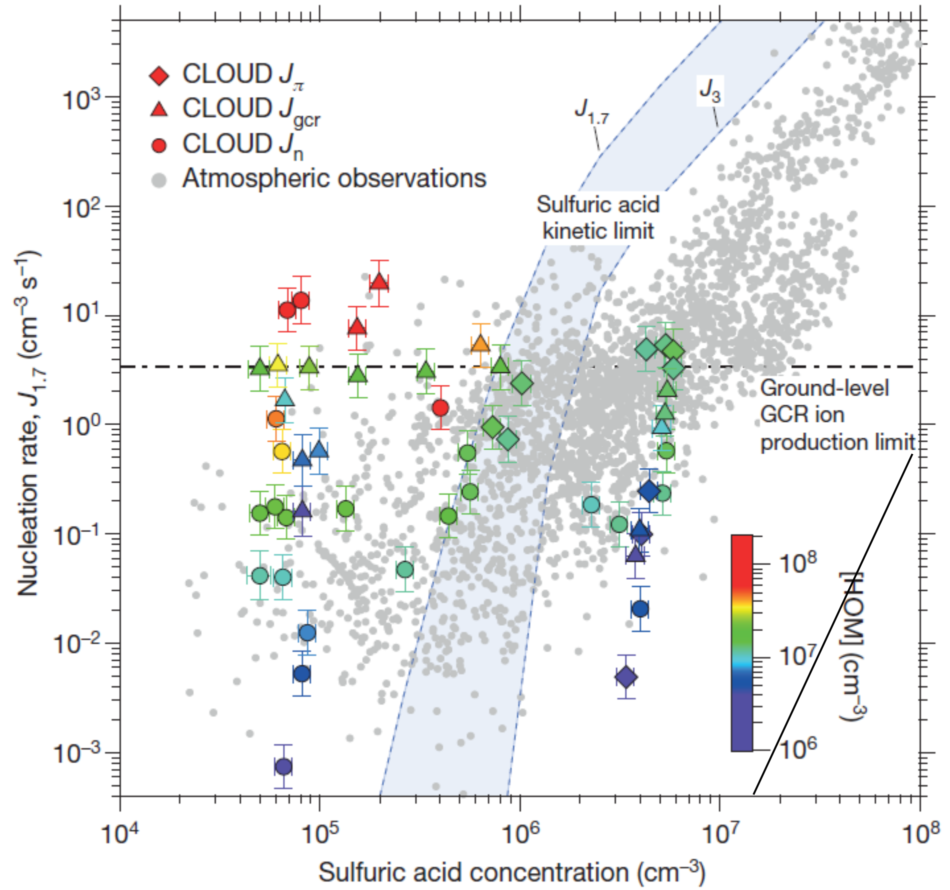




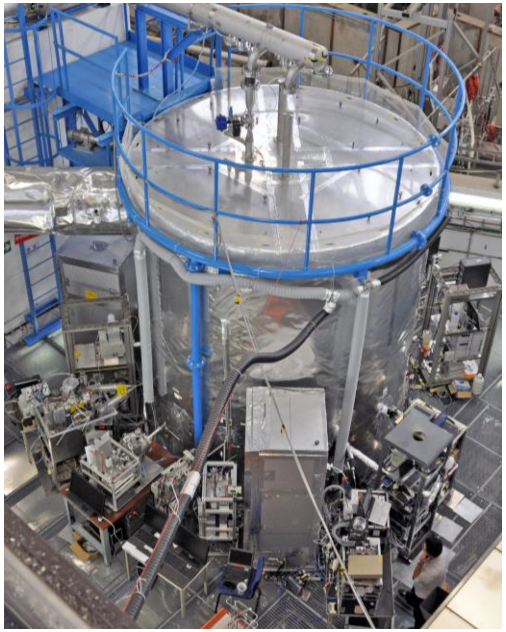
Sulfuric acid with either NH_3 or dimethylamine (DMA)
Almeida et al., Nature 2013

With HOMs
Kirkby et al., Nature 2016

Feedback loops between laboratory and field experiments as reality check: Is there agreement concerning NPF rate, growth rate, and cluster molecular composition?

Urban environments

Marine environment

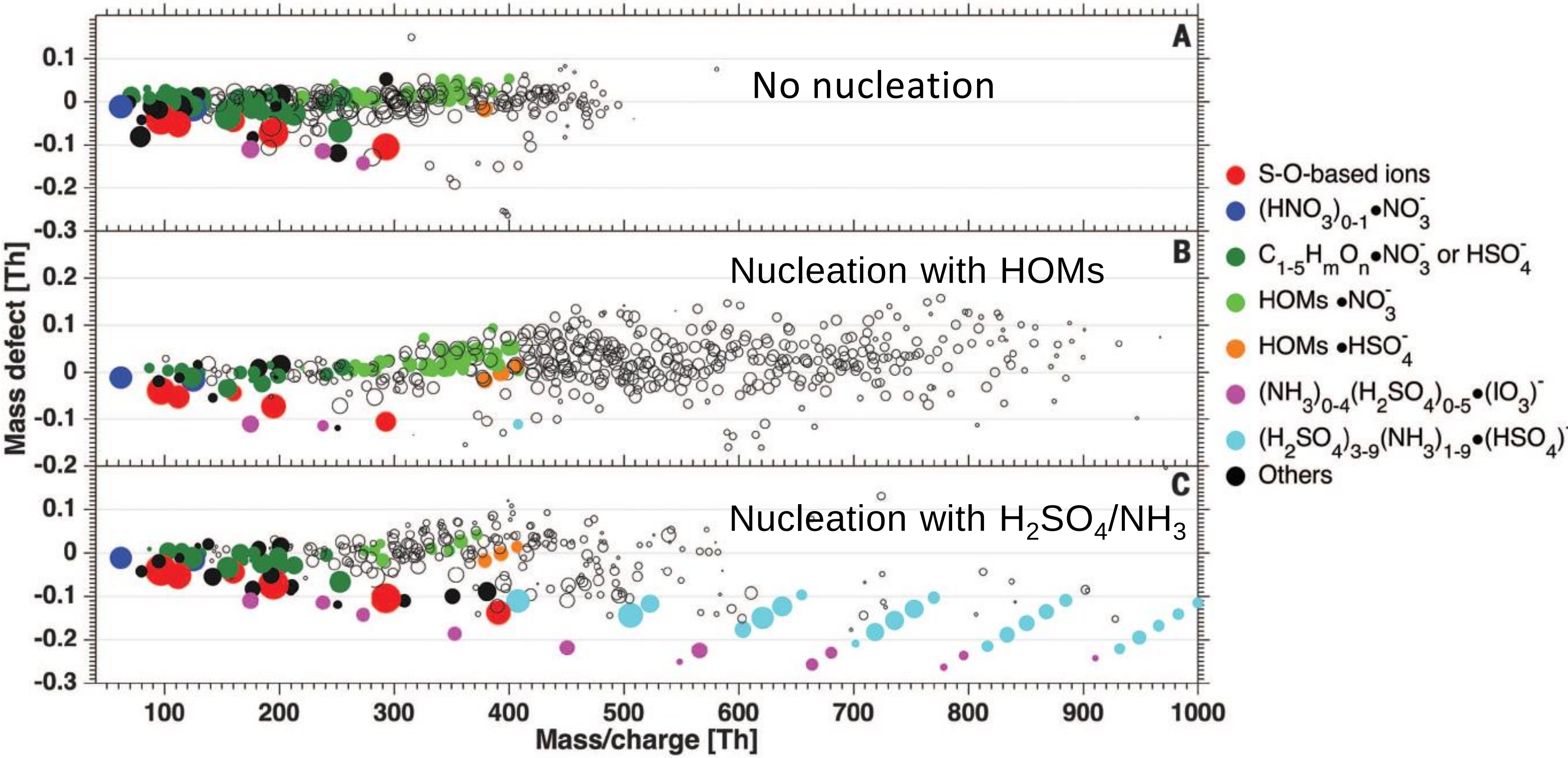


Boreal forest

Lower free troposphere

Upper free troposphere

Reality check in the lower free troposphere: Yes, also at the Jungraujoch (3580 m asl) importance of highly oxygenated organic molecules (HOMs) and in other cases sulfuric acid confirmed



Every dot is a species with a different molecular weight and chemical composition

Bianchi et al., Science 2016

➔ **2 papers in Nature and 1 in Science, coordinated by Nature and Science appeared simultaneously on 26 May 2016:**

CLOUD experiment:

- Kirkby et al., Nature 2016

- Tröstl et al., Nature 2016

Field experiment at the Jungfraujoch:

- Bianchi et al., Science 2016 (including cover)

CLOUD results are highly cited

Ion-induced nucleation of pure biogenic particles

By: Kirkby, Jasper; Duplissy, Jonathan; Sengupta, Kamalika; et al.
NATURE Volume: 533 Issue: 7604 Pages: 521-+ Published: MAY 26 2016

S·F·X | Free Full Text from Publisher | View Abstract

Times Cited: 104
(from Web of Science Core Collection)

Hot Paper
Highly Cited Paper

Usage Count

The role of low-volatility organic compounds in initial particle growth in the atmosphere

By: Troestl, Jasmin; Chuang, Wayne K.; Gordon, Hamish; et al.
NATURE Volume: 533 Issue: 7604 Pages: 527-+ Published: MAY 26 2016

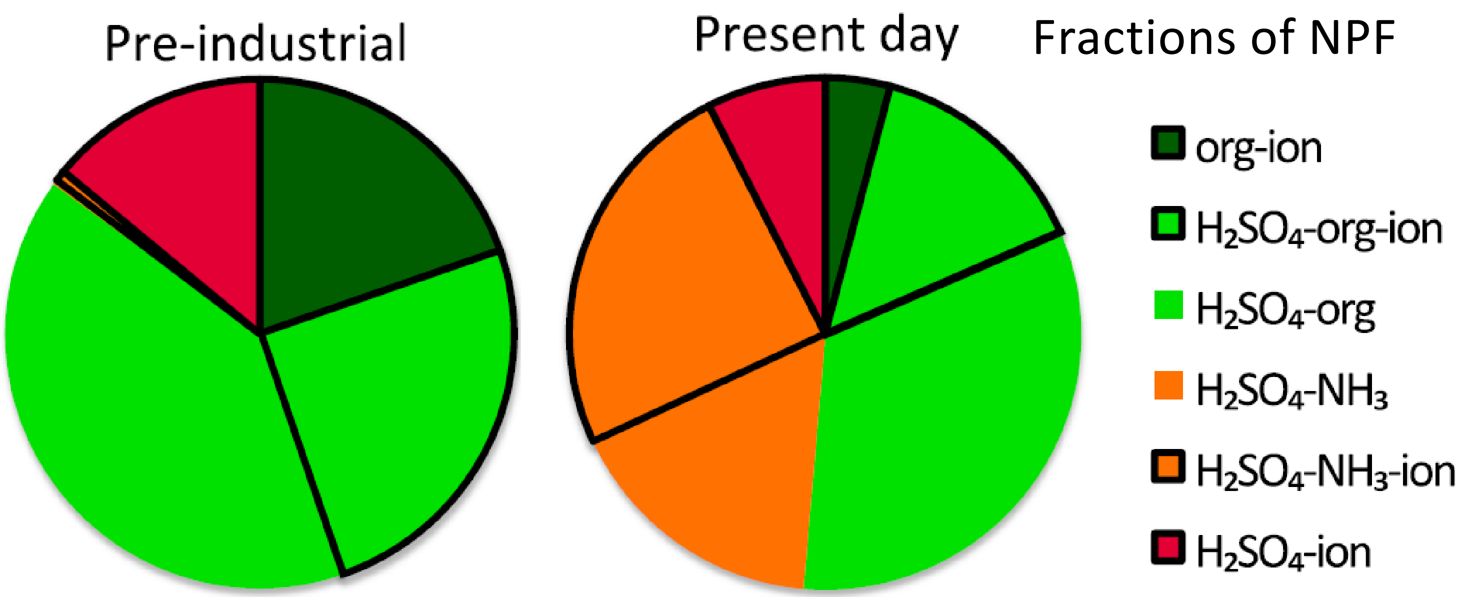
S·F·X | Free Full Text from Publisher | View Abstract

Times Cited: 102
(from Web of Science Core Collection)

Hot Paper
Highly Cited Paper

Hot Papers: ranked in the top 0.1% highly cited papers in geoscience for their age

The ultimate answers come from model calculations: Fractions of NPF and in preindustrial and present-day atmospheres



NPF below 5.8 km altitude

50% in present day atmosphere and 59% in pre-industrial atmosphere involve ions

CCN (0.2% SS) from ion-induced NPF:

27% in present-day atmosphere and 40% in preindustrial atmosphere

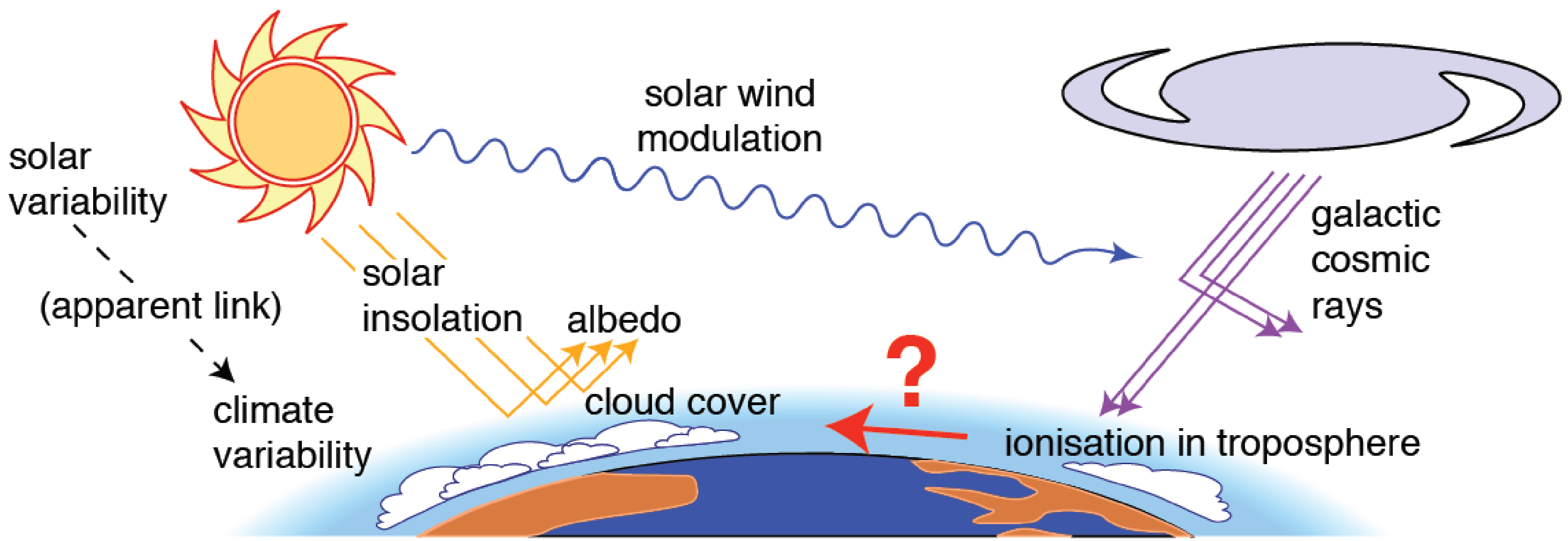
Solar cycle variations of ion concentration:

max. 1% variation of CCN (0.2% SS)

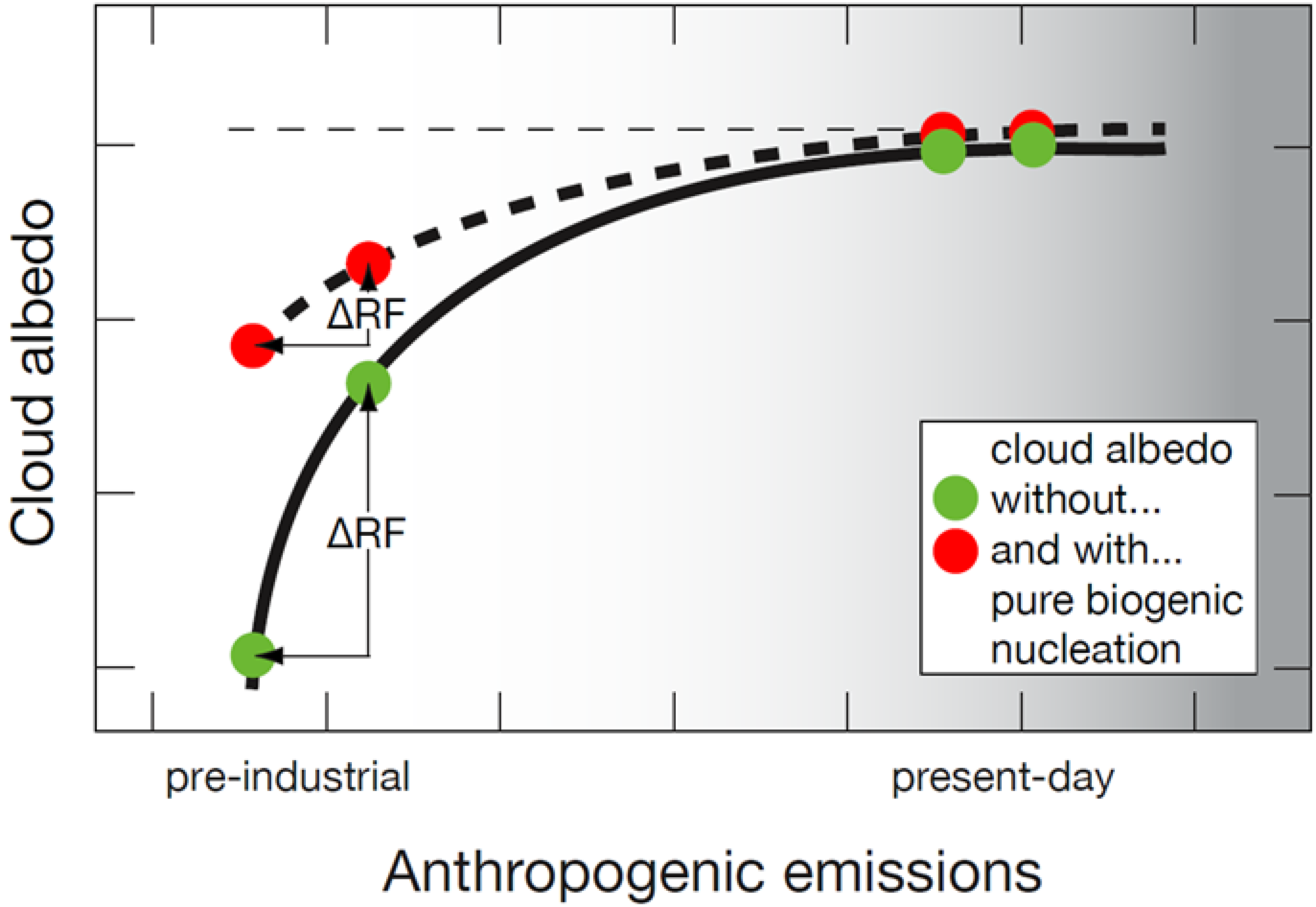
Gordon et al., JGR 2017

CLOUD has answered a first important question

The fluctuations of the 11-year cycle have a negligible impact on climate via the ion – new particle – CCN mechanism



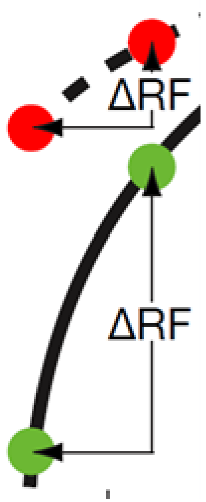
Important questions remain: How about the pre-industrial period?



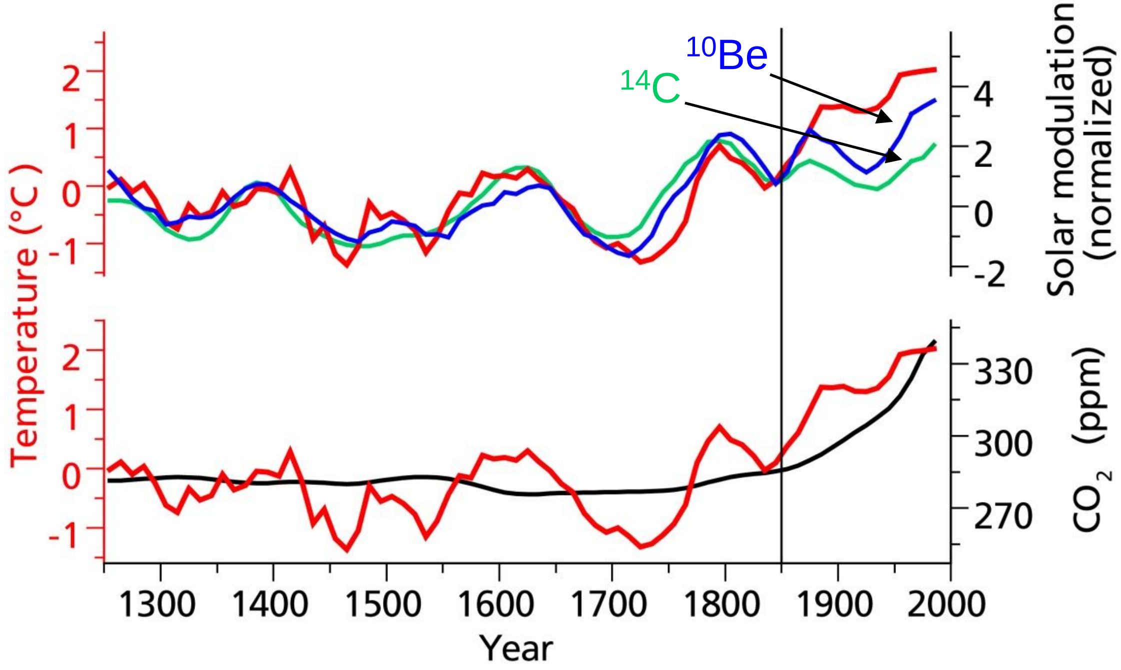
The pre-industrial aerosol is one of the biggest uncertinties in the calculation of climate forcing.
Important uncertainties in our parametrization remain

Courtesy: K. Carslaw, Leeds

Not answered yet: Is there an effect of GCR on climate in the preindustrial time?



Eichler et al. GRL 36 (2009)



Temperature proxy: ice core oxygen isotope

➔ Important uncertainties remain
Also: CLOUD has evolved answering fundamental research questions of high relevance
➔ Further evolution of CLOUD required

- Constant improvement of facility
  ➔ New light sources (next slide)

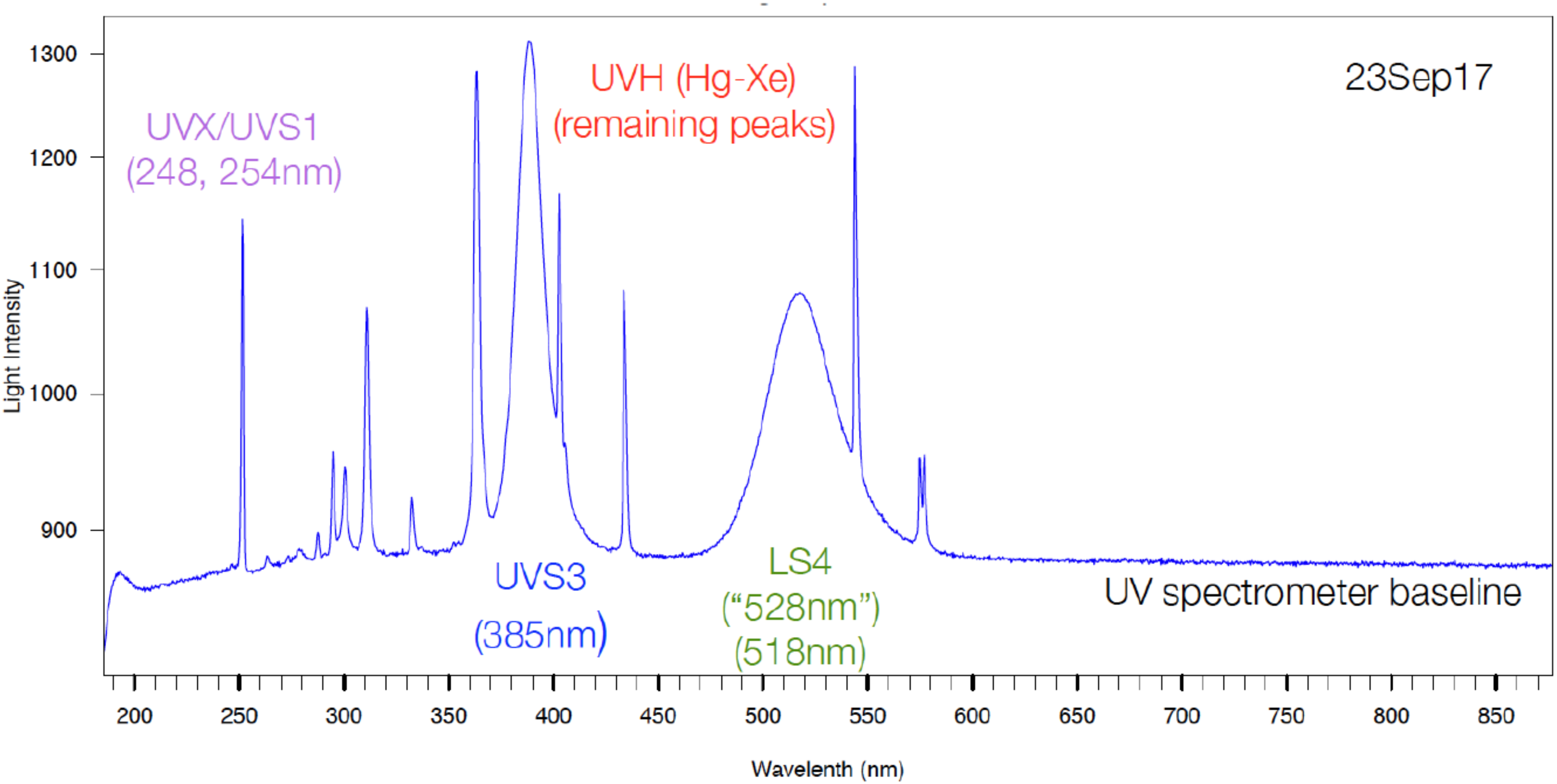
- Constant improvement / addition of instrumentation:
  ➔ New mass spectrometers (in CLOUD12, 2017: around 45 analysing instruments, including 12 mass spectrometers)

- Constant replenishment of the young scientists
  ➔ CLOUD has been awarded an unprecedented third Marie Curie Innovative Training Network grant, (CLOUD-MOTION, 15 PhD students, start 1 Sept 2017)

Extension of light sources

1. Fibre optic Hg-Xe system (250-570 nm): O_3 photolysis to OH radical, and broad spectrum photolysis
2. Fibre optic UV excimer laser (248 nm, adjustable): O_3 photolysis to OH radical
3. 50W UV sabre 1 (254 nm, not adjustable): diiodomethane photolysis to I radical
4. 400W UV sabre 3 (385 nm): NO_2 photolysis to NO, and HONO photolysis to OH radical
5. 150W light sabre 4 (528 nm): I_2 photolysis to I radical

CLOUD12 light spectrum from the 5 sources in operation

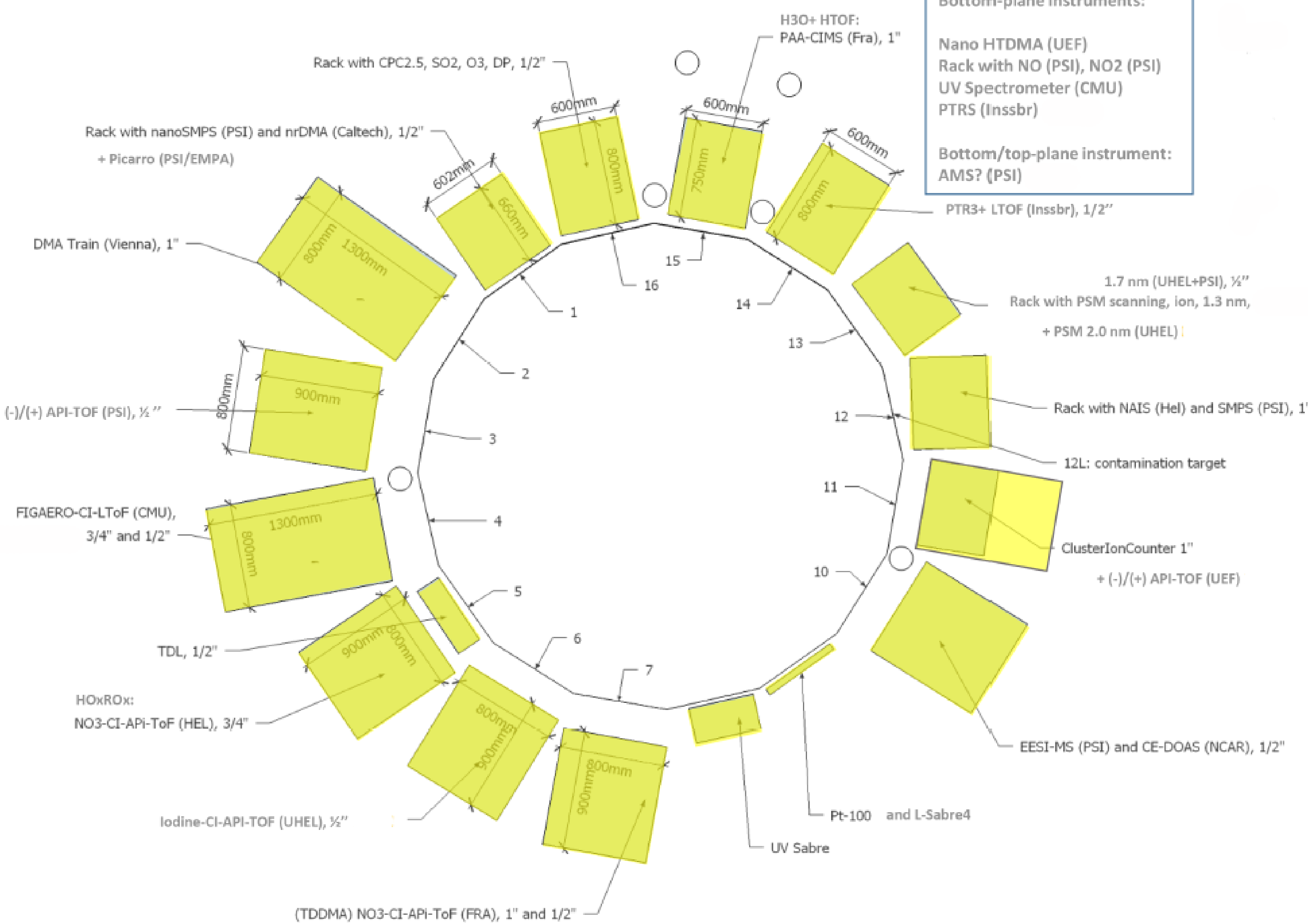


Layout of the analysing instruments around the chamber during CLOUD12

Bottom-plane instruments:

Nano HTDMA (UEF)
Rack with NO (PSI), NO2 (PSI)
UV Spectrometer (CMU)
PTRS (Inssbr)

Bottom/top-plane instrument:
AMS? (PSI)



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CLOUD12 scientific programme (18 September – 27 November 2017)

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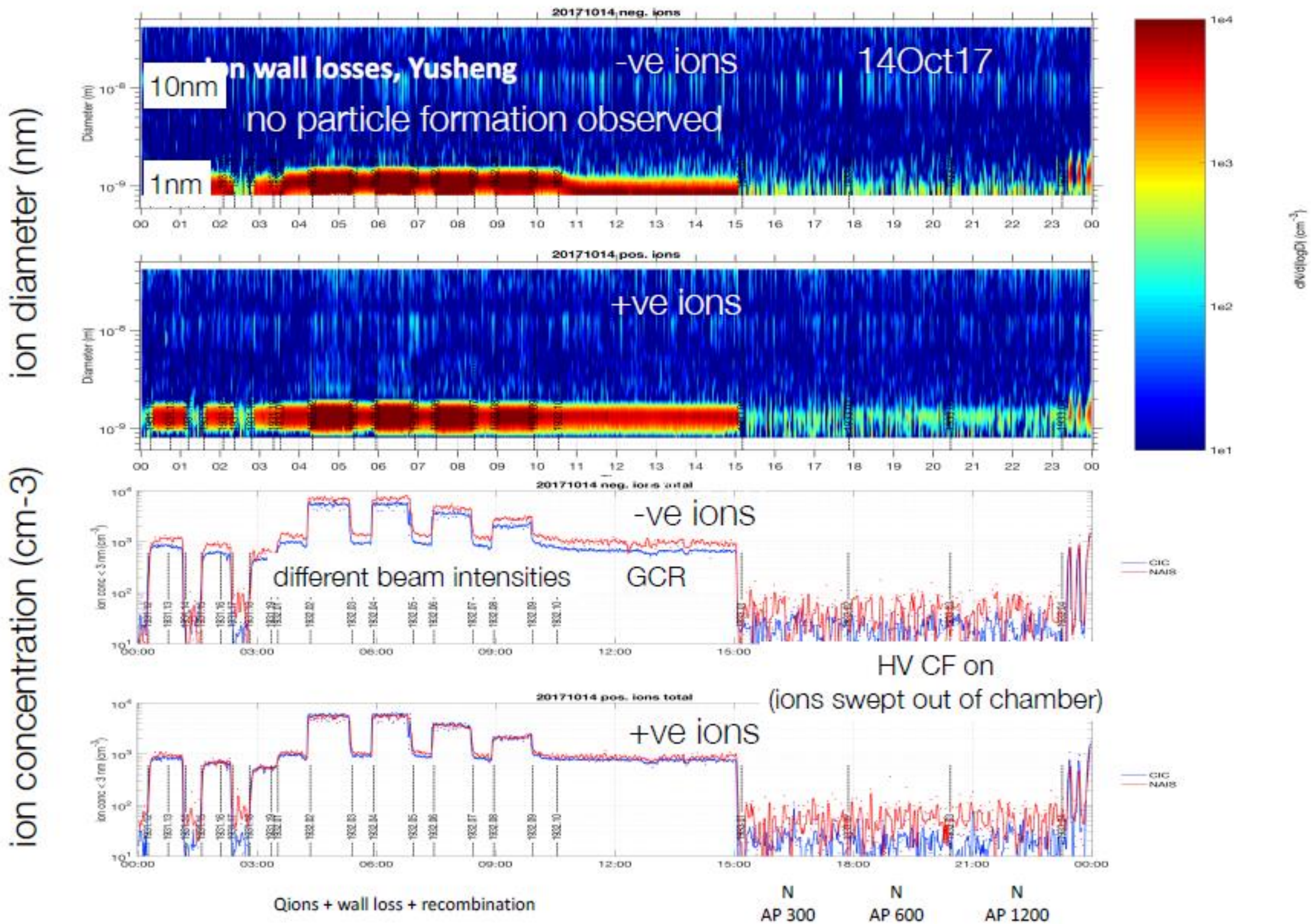
- Marine nucleation and growth involving iodine compounds (2 wk) (new in CLOUD, observed in coastal regions with exposed seaweed

- Growth rates of pure sulphuric acid particles at small sizes (3 d) (test new instrumentation, compare to theory)

  Multi-component aerosol particle nucleation and growth (4 wk) (Extension of the H_2SO_4-NH_3-HOM-H_2O parameter space, extension of temperature range to upper free troposphere, for a refined parameterization (HOM = Highly Oxygenated Molecules)

- Anthropogenic aerosol particle nucleation and growth (2 wk) (frequently observed in urban environments, typical aromatic compounds w'/w'out sulphuric acid, ammonia, dimethylamine, and high concentrations of NOx, ozone, and hydroxyl radicals (OH)

Variation of ion concentrations in the CLOUD chamber during CLOUD12



Beam requests 2018

CLOUD13T beam request, 11 June – 6 July 2018

1. Ion production and loss rates
2. Ion non-uniformities in the CLOUD chamber

CLOUD13 beam request, 17 September – 26 November 2018

1. Marine nucleation and growth involving iodine compounds and dimethylsulphide (3 wk): DMS from phytoplankton to be studied for the first time
2. Multi-component aerosol particle nucleation and growth (3 wk): Completion of experiments for parameterization up to 12 km, inclusion of nitric acid (produced with new generator)
3. Anthropogenic aerosol particle nucleation and growth (3 wk): Extension of CLOUD12, addition of new compound (cresol), understanding of nucleation in Chinese megacities; adding one more aromatic compound, w'/w'out sulphuric acid, ammonia, dimethylamine, varying NOx, ozone, OH, surface area of pre-existing aerosols

CLOUD requests

- **Permanent CLOUD open office/meeting room**
  CLOUD needs a dedicated 50 m^2 open office space and meeting room. This is needed for its daily run coordination meetings and for use by CLOUD experimenters at CERN (25–30 scientists during runs at the PS)
  From 2015 to 2017, a temporary meeting room in bat. 510 was provided by EP, but this will become unavailable.
  The room needs to be close to the T11 experimental zone

- **CLOUD operation during LS2 East Area Renovation, 2019–2020**
  CLOUD requests to run with cosmic rays (without beam) during the fall 2019 and fall 2020 periods
  Urgency to continue with CLOUD data collection in view of the important impact of CLOUD on the understanding of aerosols on climate change. Also we have just hired 15 PhD students in the new H2020 Marie Curie Initial Training Network (CLOUD-MOTION) who will rely on CLOUD data collected during the 2018–2020 period

Summary

- CLOUD is the ‘gold standard’ for new particle formation experiments worldwide
- CLOUD has made a paradigm change on how aerosols are represented in global climate models
- Unprecedented combination of wide variety of models (theoretical, empirical, mechanistic, global) with laboratory data, complemented by permanent reality check in the field
- An ambitious research programme ahead: marine environments, more complex multi-component systems, polluted urban environments

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Acknowledgments

We would like to thank
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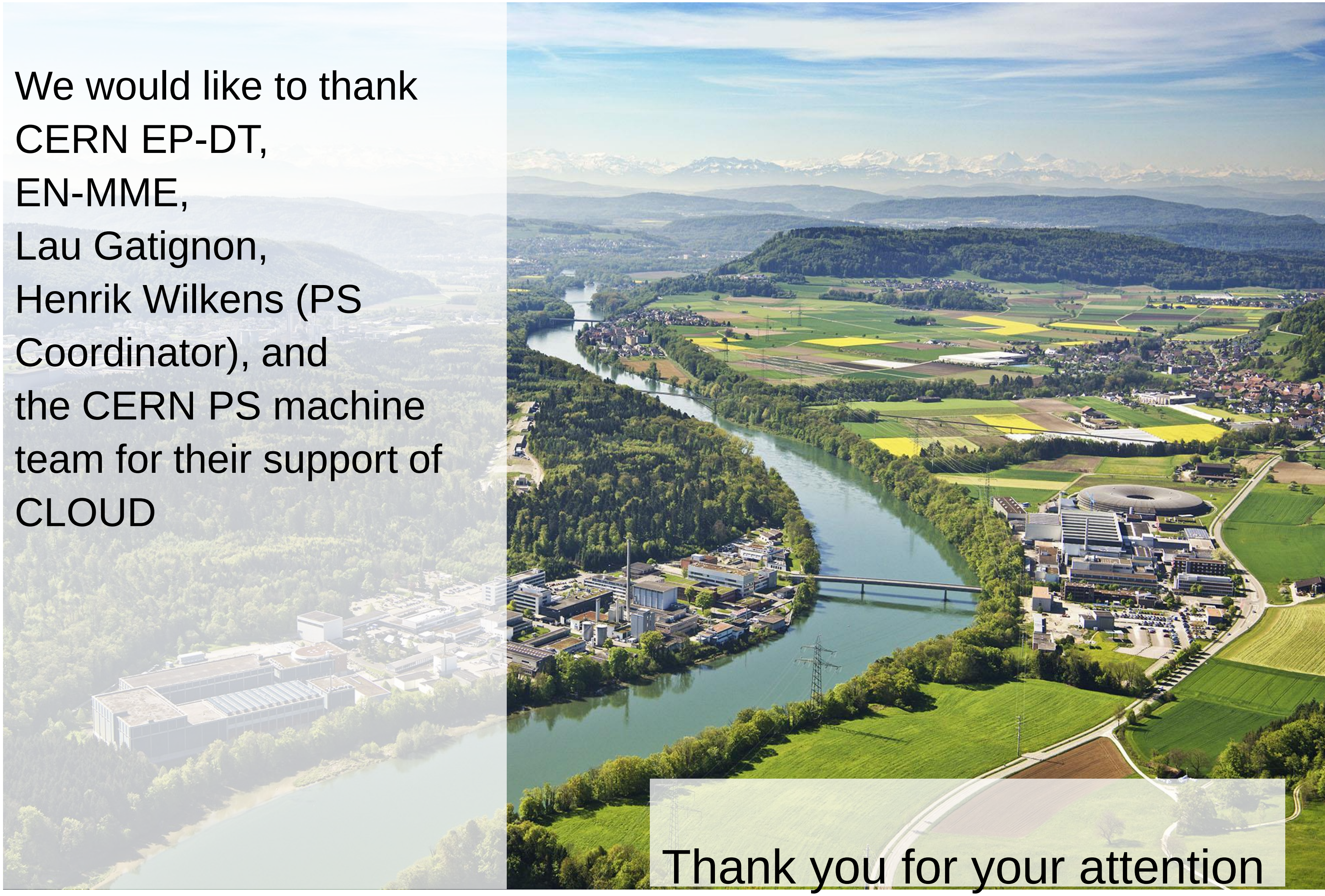

Thank you for your attention