Part 1: Characterizing the Particles that Make Clouds: Findings, Uncertainties and Next Steps

Part 2: Vision

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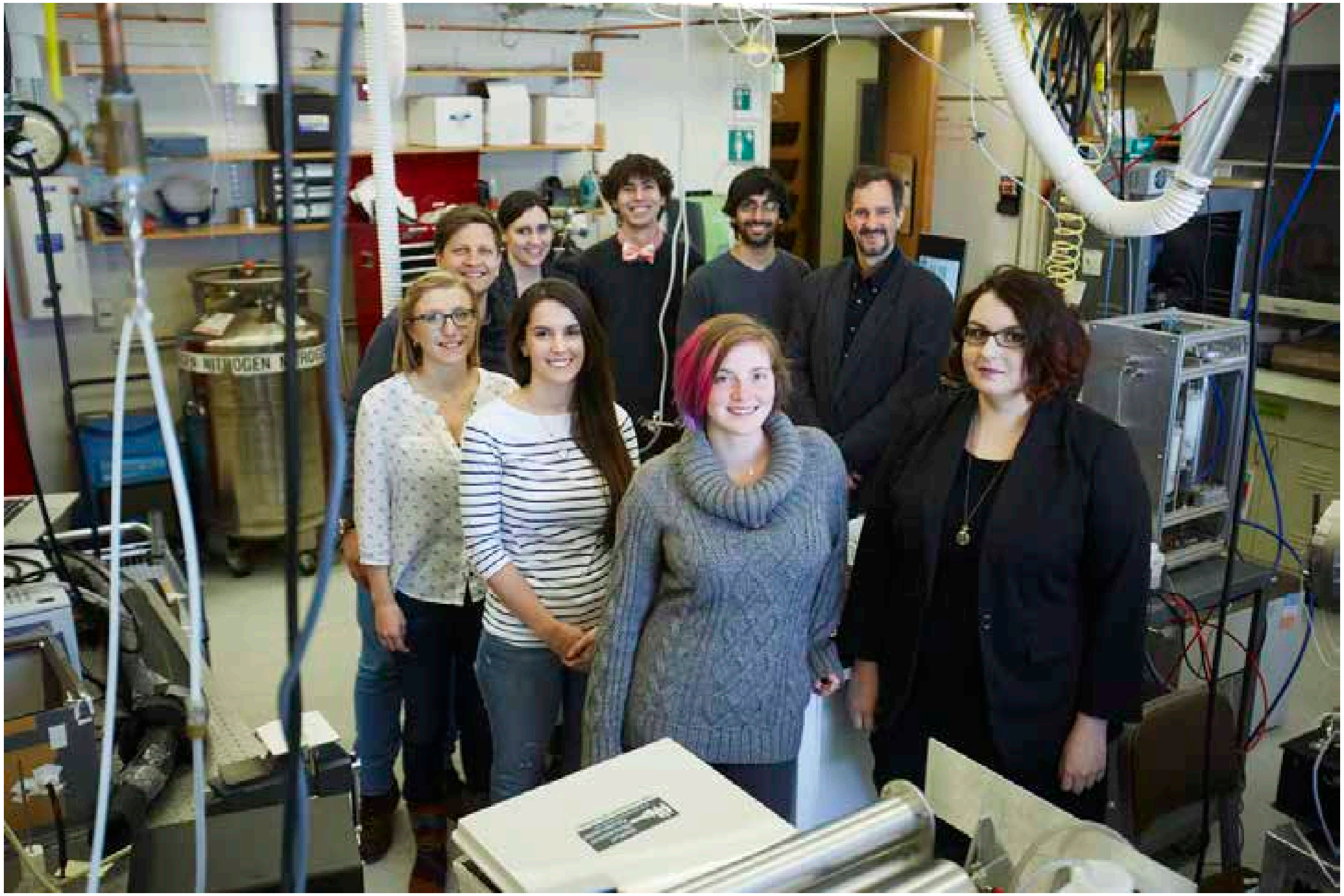
Thanks To:

Civil and Environmental Engineering



Alexandria, Michael, Carolin, Muge, Sarvesh, Maria, Martin, Libby, Costa, Lily, Megan, Sara, Annora and Daisy

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Victor P. Starr, Simons and William Martin Foundations

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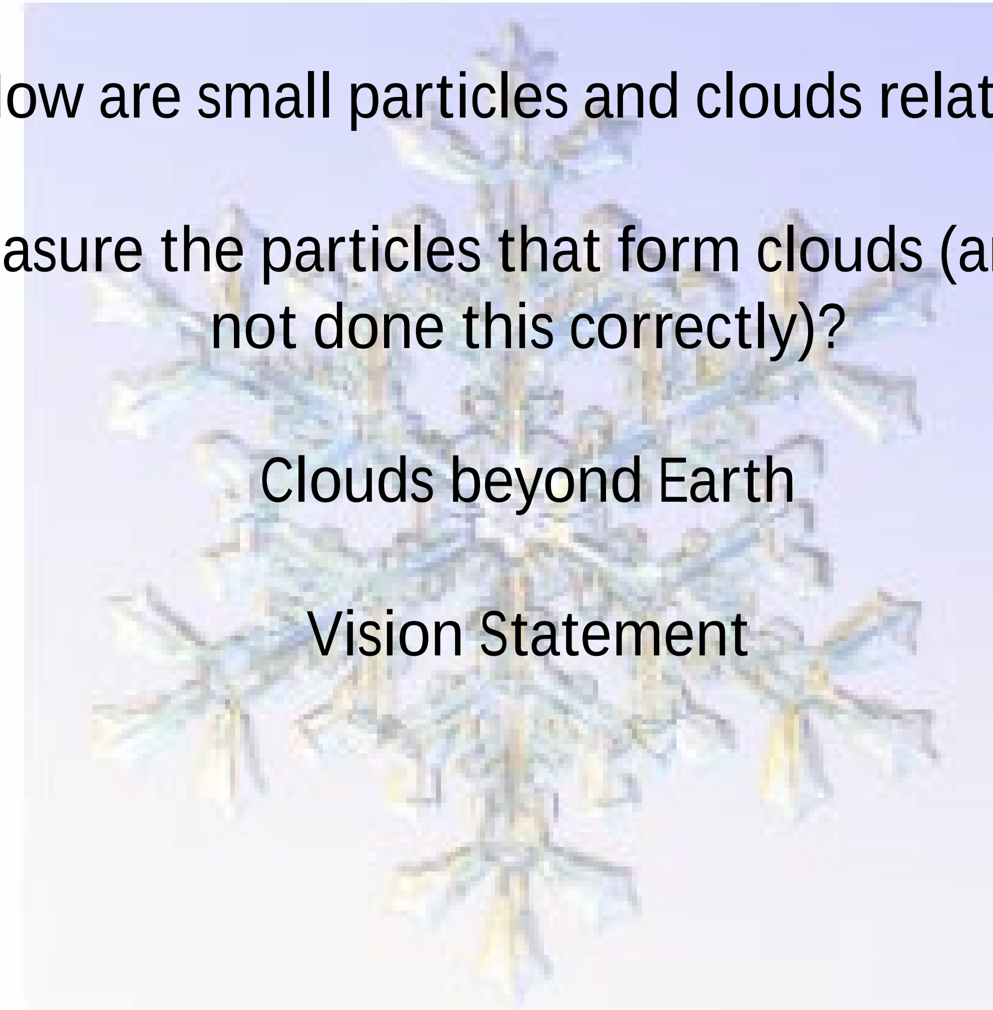
What I hope to provide :



How are small particles and clouds related?

How do we measure the particles that form clouds (and when have we not done this correctly)?

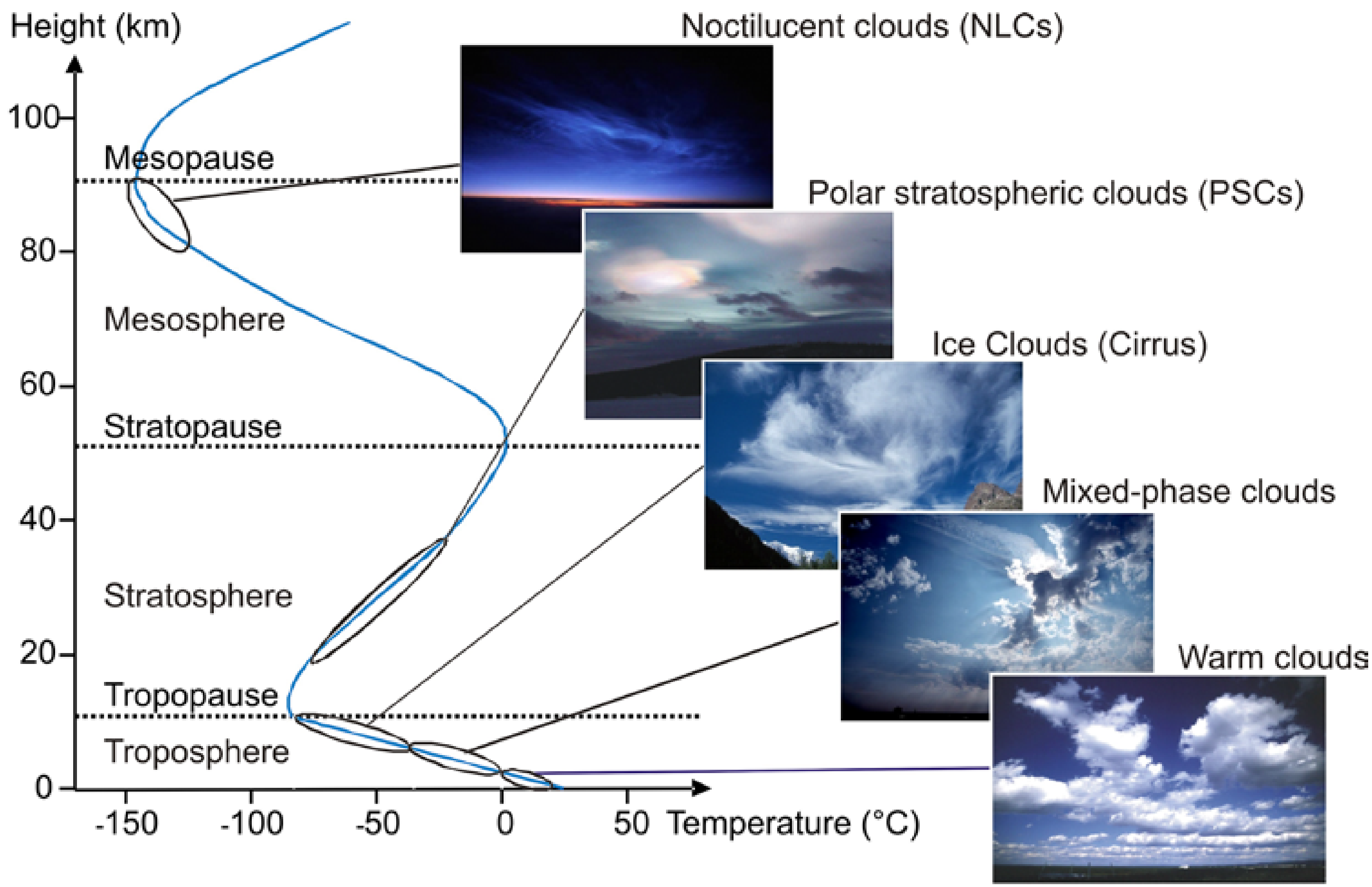
Clouds beyond Earth

Vision Statement

Kenneth Libbrecht, CalTech

Introduction: How Clouds Form
(and why you should care)

Cloud Types

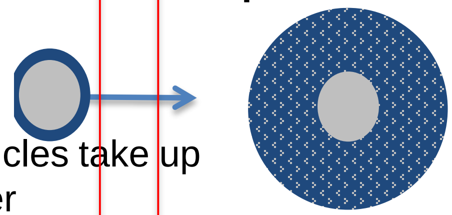


Height (km)
100
80
60
40
20
0
Mesopause
Mesosphere
Stratopause
Stratosphere
Tropopause
Troposphere
-150
-100
-50
0
50
Temperature (°C)
Noctilucent clouds (NLCs)
Polar stratospheric clouds (PSCs)
Ice Clouds (Cirrus)
Mixed-phase clouds
Warm clouds

Need to understand these...

...to understand this.

Droplet Activation



(Grey = Soluble or Insoluble)

Nucleation Mode

Higher Temperature, Lower Humidity → **Lower Temperature, Higher Humidity**

Cziczo and Froyd, 2014

Why Are Clouds Important? : Climate

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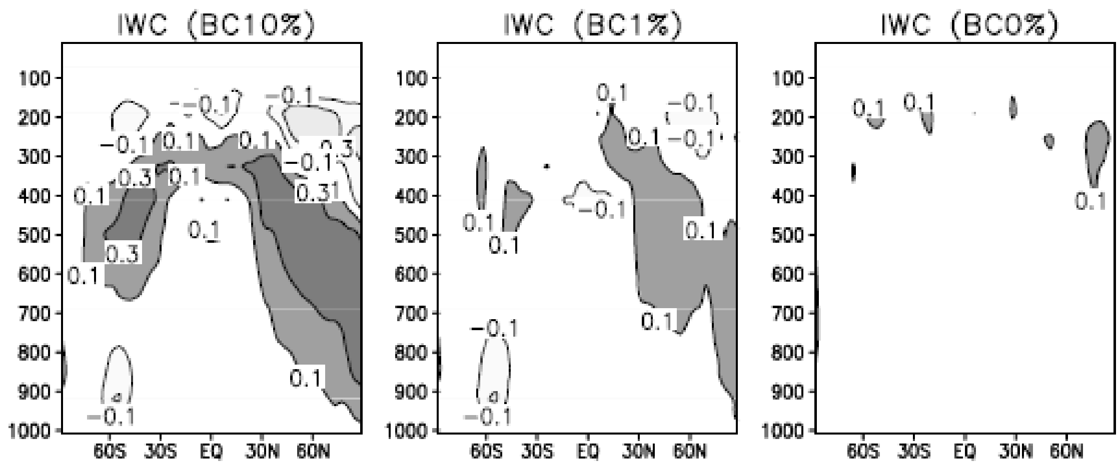

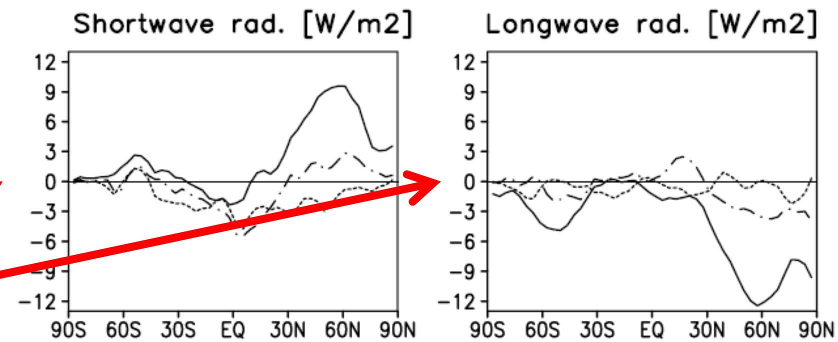

Same as the ENTIRE Direct Aerosol Effect!

Lohmann, 2002

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Why Are Clouds Important? : Precipitation

EFFECT OF PHASE DIFFERENCE

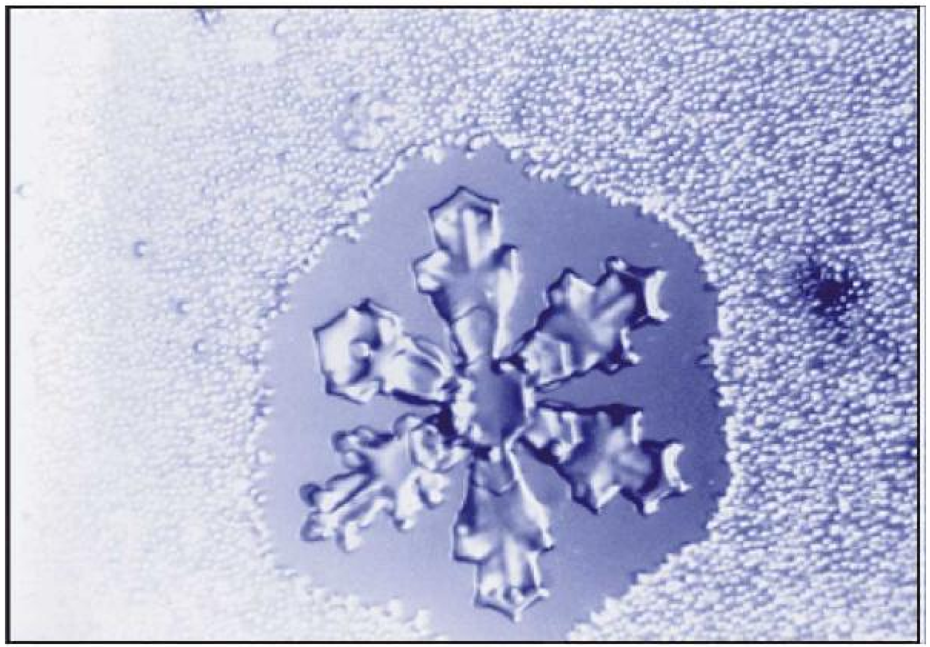

Photo by R. Pitter

http://wdict.net/gallery/bergeron+process/; Pruppacher and Klett, 1997

Why are Cloud Important?: Icing

http://www.weather.gov/source/zhu/ZHU_Training_Page/icing_stuff/icing/icing.htm
ae.illinois.edu

How Do We Study Clouds?

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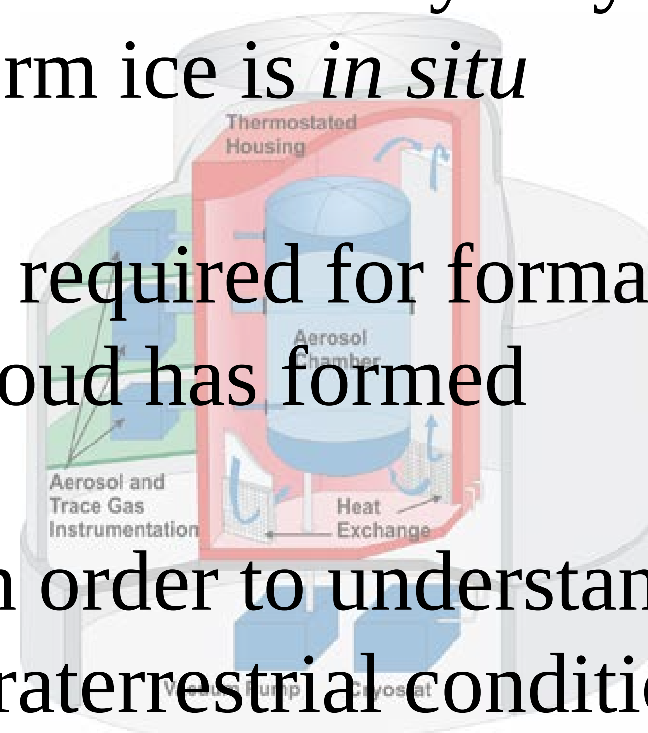
“Finding” or “Making” Clouds

• “Find a Cloud” is more intuitive : the only way to determine what really form ice is *in situ*

•However, the initial conditions required for formation are lost as soon as the cloud has formed

•So we also “Make” clouds in order to understand formation conditions (or for extraterrestrial conditions)



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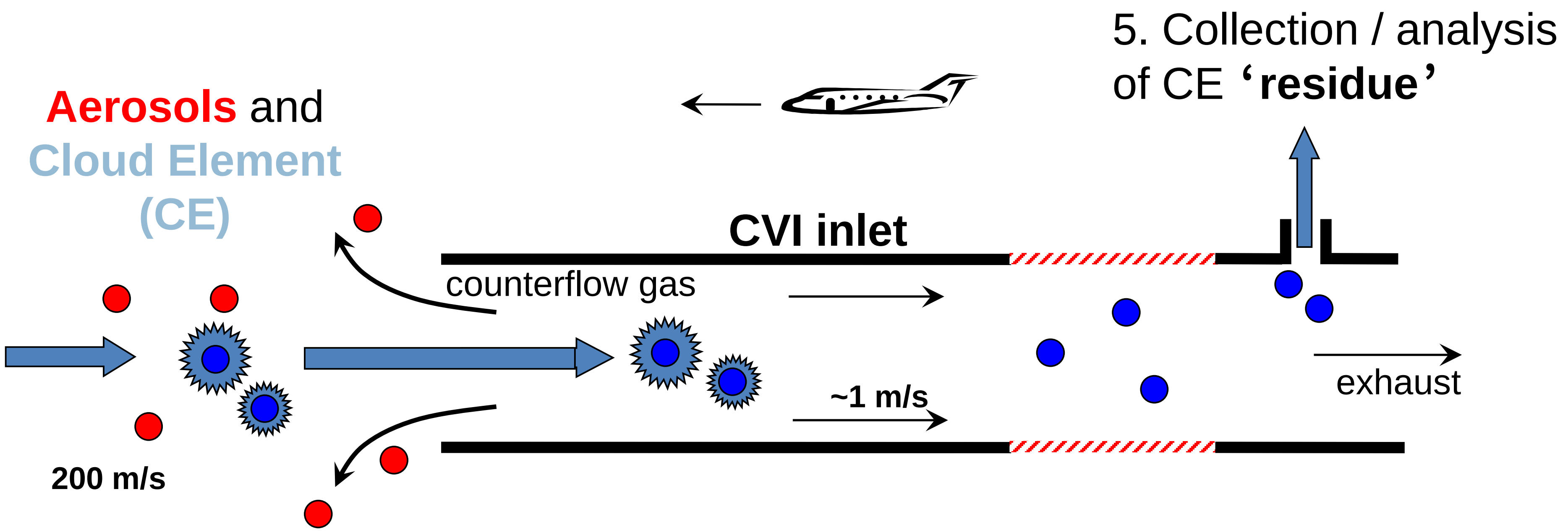
In Cloud Sampling



1. counterflow rejects aerosol particles

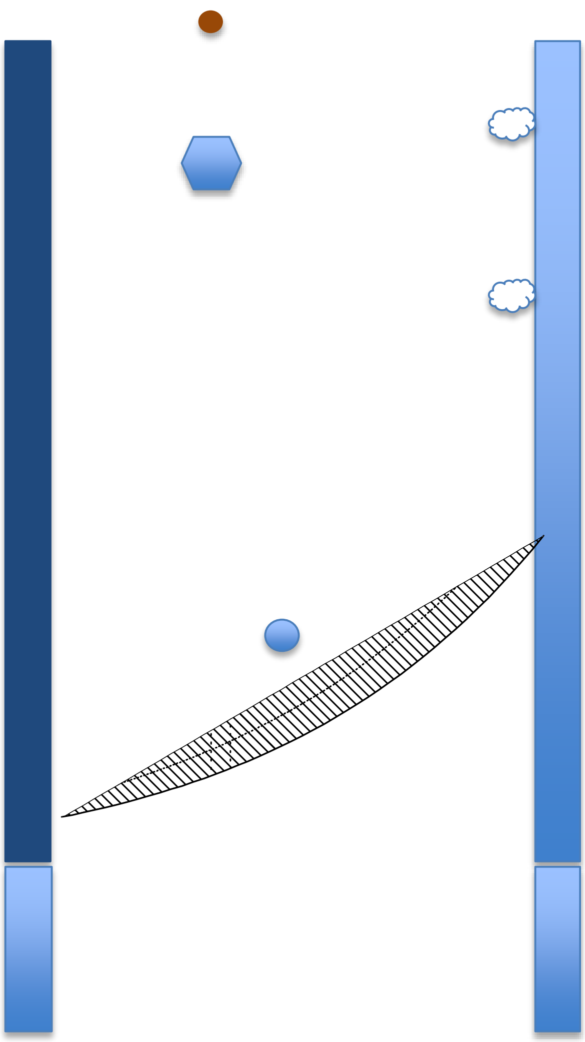
2. sample only CE

3. equilibrate with flow

4. heat to remove water

Seminal work by Ogren, Heintzenberg, Noone, et al. : CN, OPC, SMPS, EM

Making Clouds

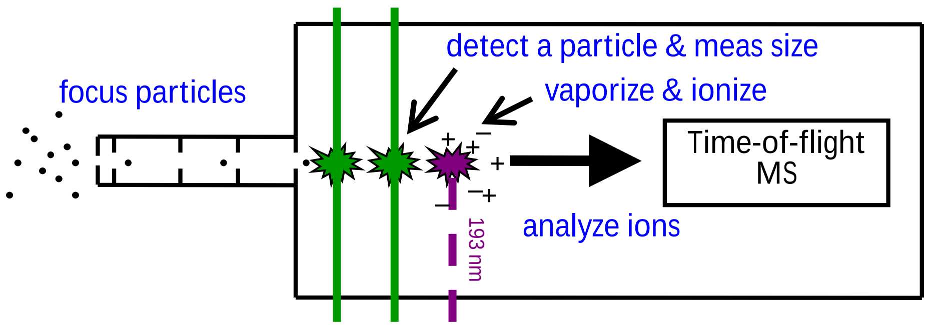


Spectrometer for Ice Nuclei (SPIN)
Commercially available from DMT, Boulder, CO
Based on Zurich Ice Nucleation Chamber (Stetzer & Lohmann)

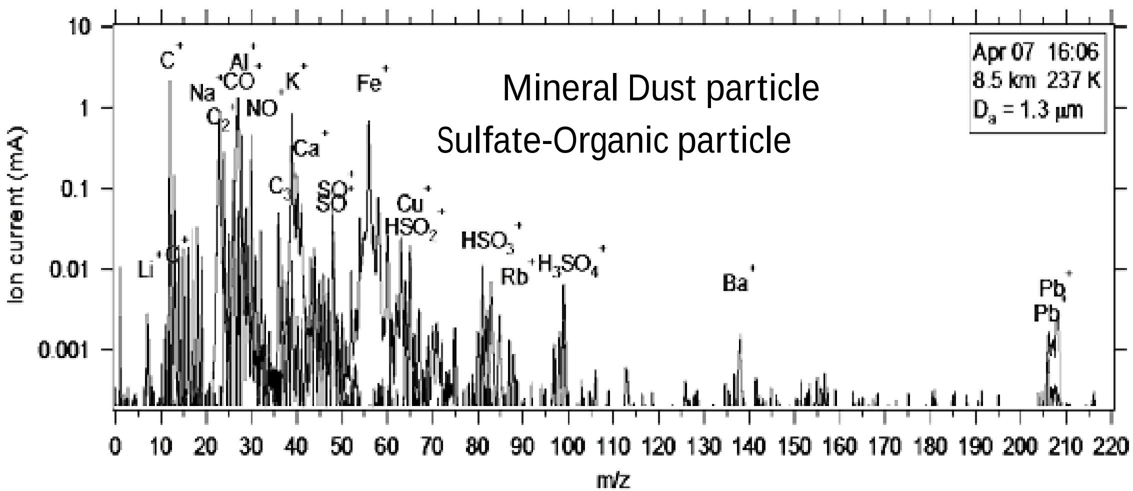
Analysis of Ice Residuals

Single particle size and composition (0.2 – 3 mm)

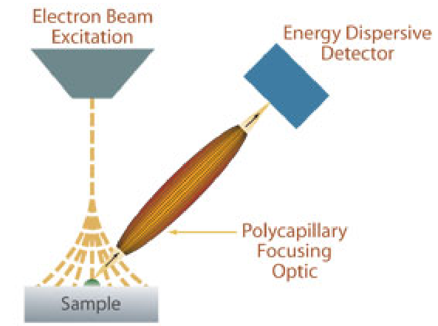
Online - PALMS



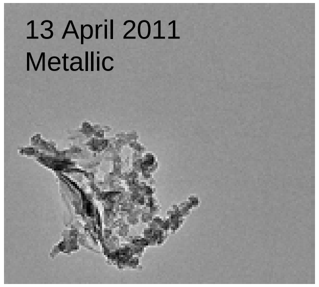
Size and composition



Offline – SEM + EDS



Size, morphology, and composition



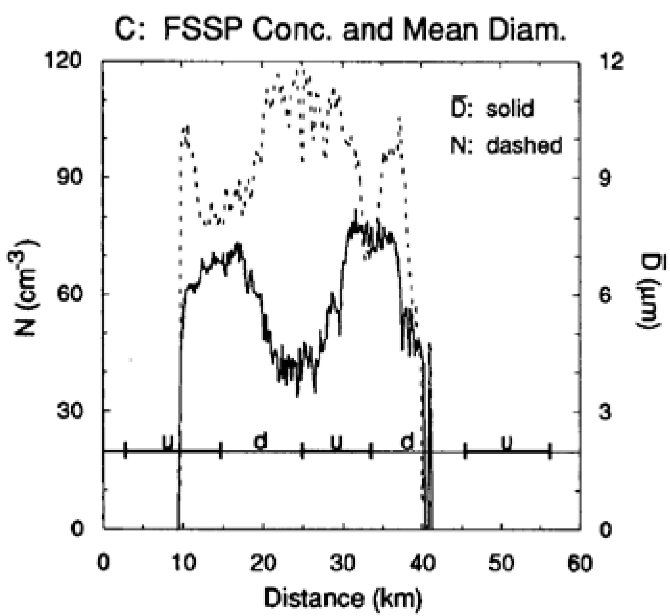
Too Easy...

Homogeneous Ice Nucleation and Supercooled Liquid Water in Orographic Wave Clouds

ANDREW J. HEYMSFIELD AND LARRY M. MILOSHEVICH

National Center for Atmospheric Research, Boulder, Colorado*

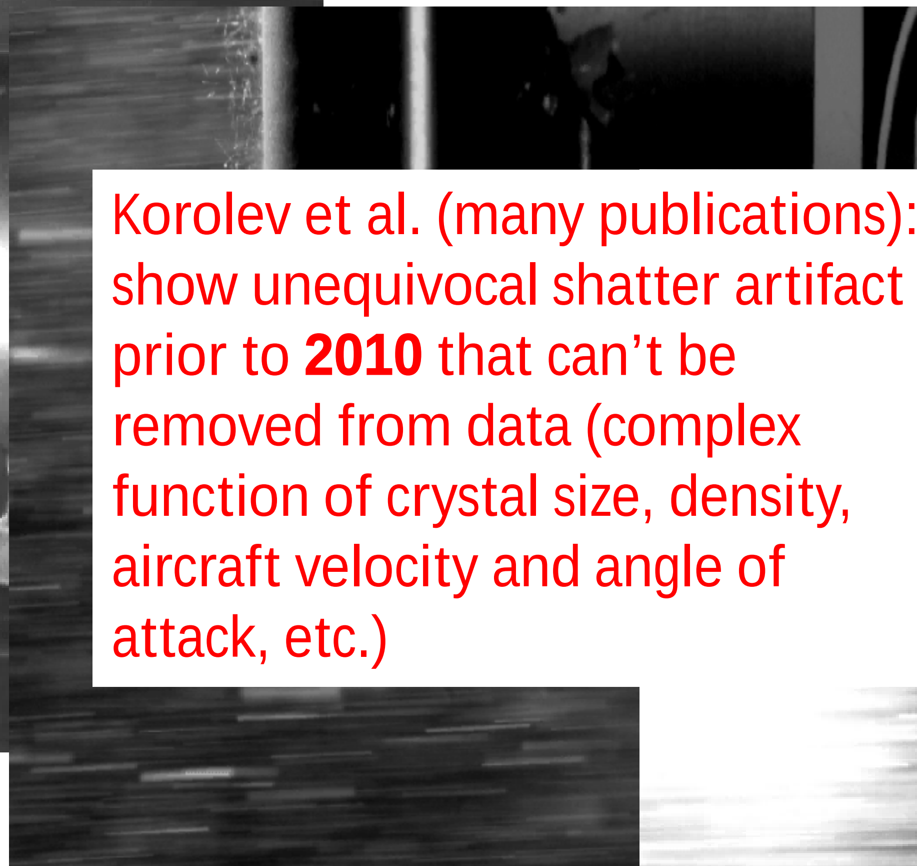
(Manuscript received 4 June 1992, in final form 12 October 1992)

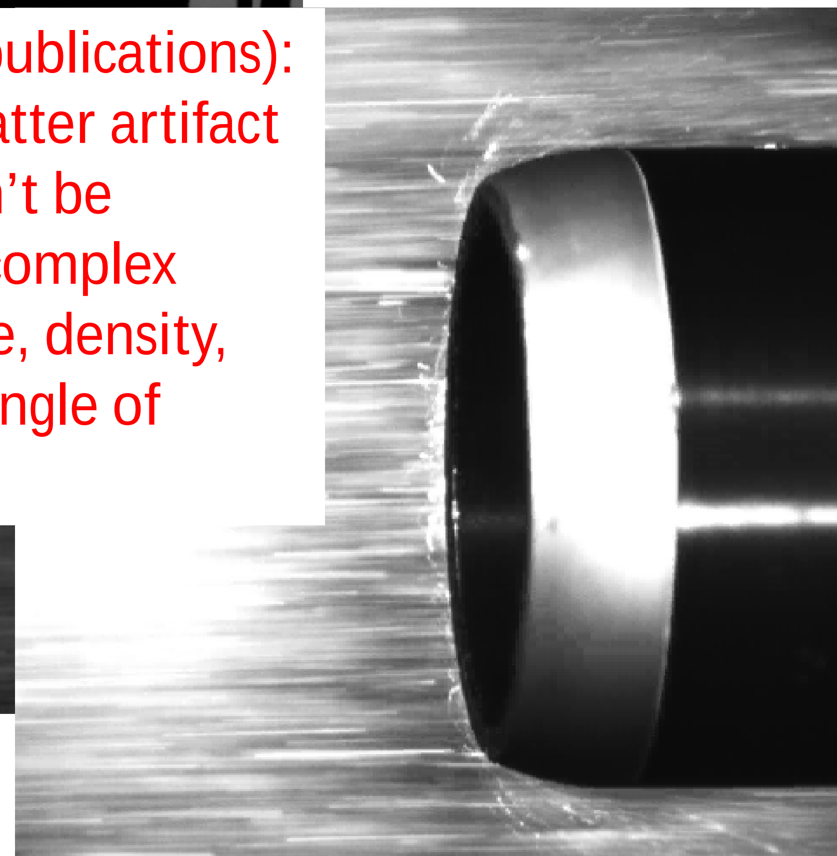


"It is concluded that homogeneous ice nucleation is responsible for the ice production in these clouds at temperatures below about −33°C."

By ~2001 it was becoming clear N_{ice} often > $N_{aerosol}$ and D_{ice} <remote sensing…

Artifacts





Korolev et al. (many publications): show unequivocal shatter artifact prior to **2010** that can't be removed from data (complex function of crystal size, density, aircraft velocity and angle of attack, etc.)

Alexei Korolev
Cloud Physics and Severe Weather Section
Environment Canada

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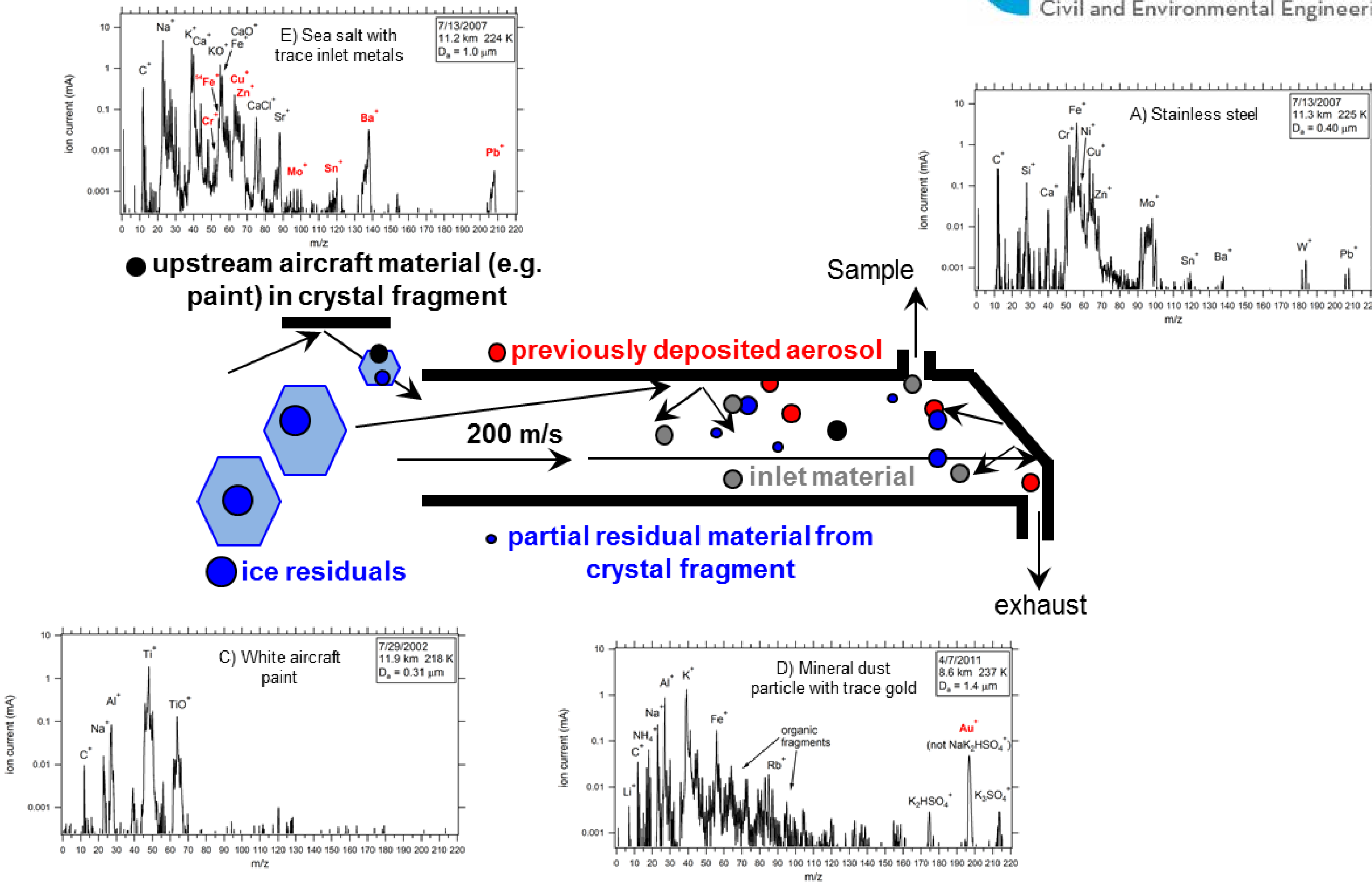
CVI Sampling Artifacts



Cziczo & Froyd, Atmos Res2014

Re-evaluate that early work…

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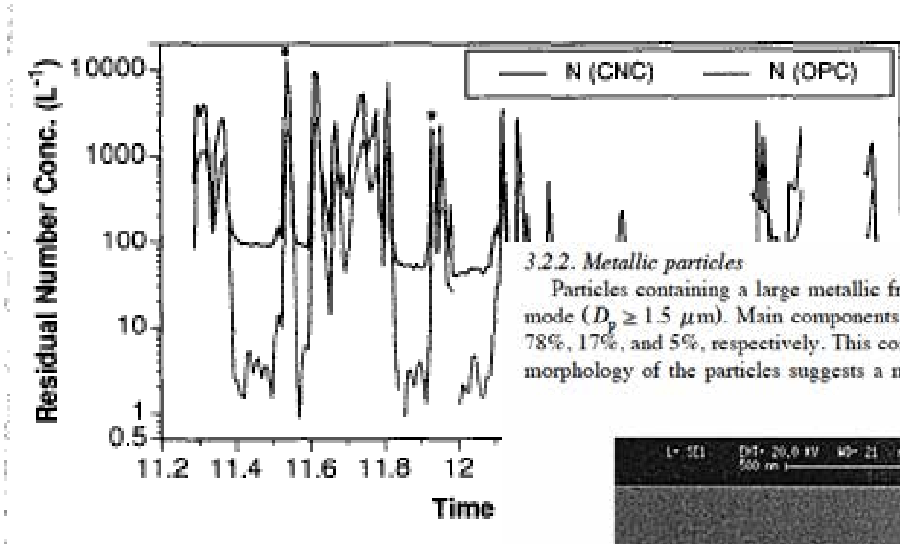

3.2.2. Metallic particles

Particles containing a large metallic fraction are observed only in the coarse particle mode ($D_p \geq 1.5$ μm). Main components are Fe, Cr and Ni with relative abundance of 78%, 17%, and 5%, respectively. This composition is consistent with stainless steel. The morphology of the particles suggests a mechanical generation, e.g., within jet engines.

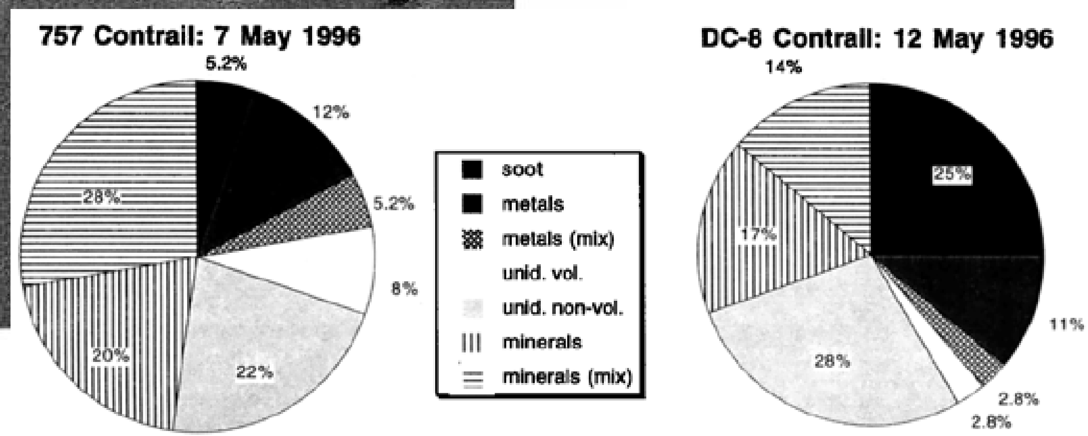

Figure 2. Pie chart showing percentages of various residual particle types observed in the 757 and DC-8 contrails. Soot was identified by its morphology, metals were Fe/Cr or Ti, and minerals were predominately Ca, but also Na, Al, K, and/or Fe. "Mix" means sulfur was also present in substantial abundance. Non-volatiles could be silicates or soot, while at least some volatiles contained carbon.

Noone, Heintzenberg, Petzold 1992 - ; Twohy et al. 1998 -

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