Stony Brook University
School of Marine and Atmospheric Sciences

INSTITUTE FOR TERRESTRIAL AND PLANETARY ATMOSPHERES

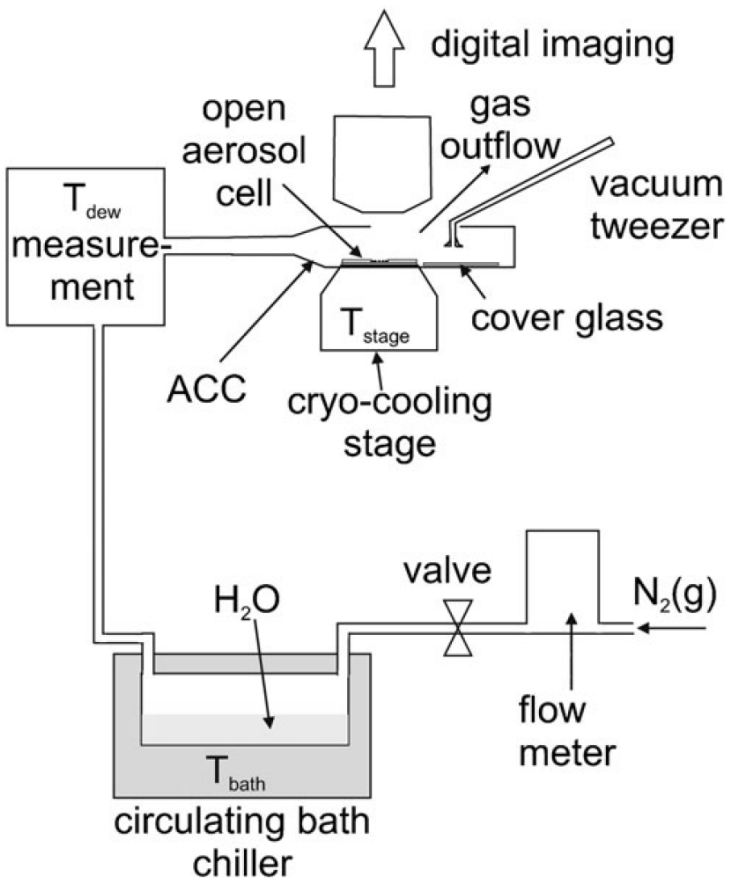
Physical Parameterizations for Immersion and Deposition Ice Nucleation Based on Laboratory Studies

Daniel A. Knopf
Institute for Terrestrial and Planetary Atmospheres
School of Marine and Atmospheric Sciences
Stony Brook University

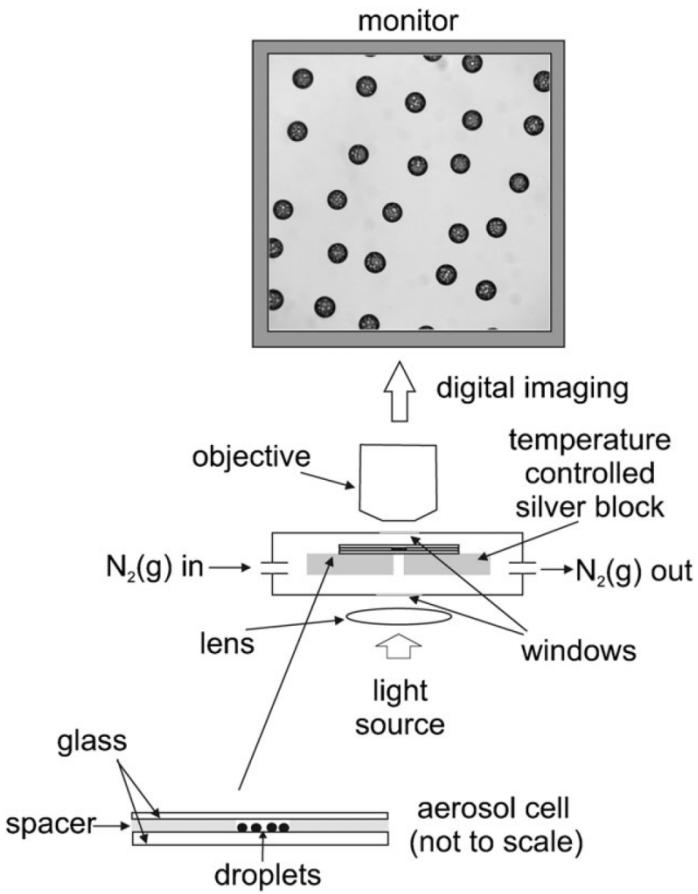
Funding

Experimental Setup for Immersion Mode Freezing - Condition Droplet a_w

Droplet Conditioning
Exposure to Relative Humidity



Ice Nucleation Experiment

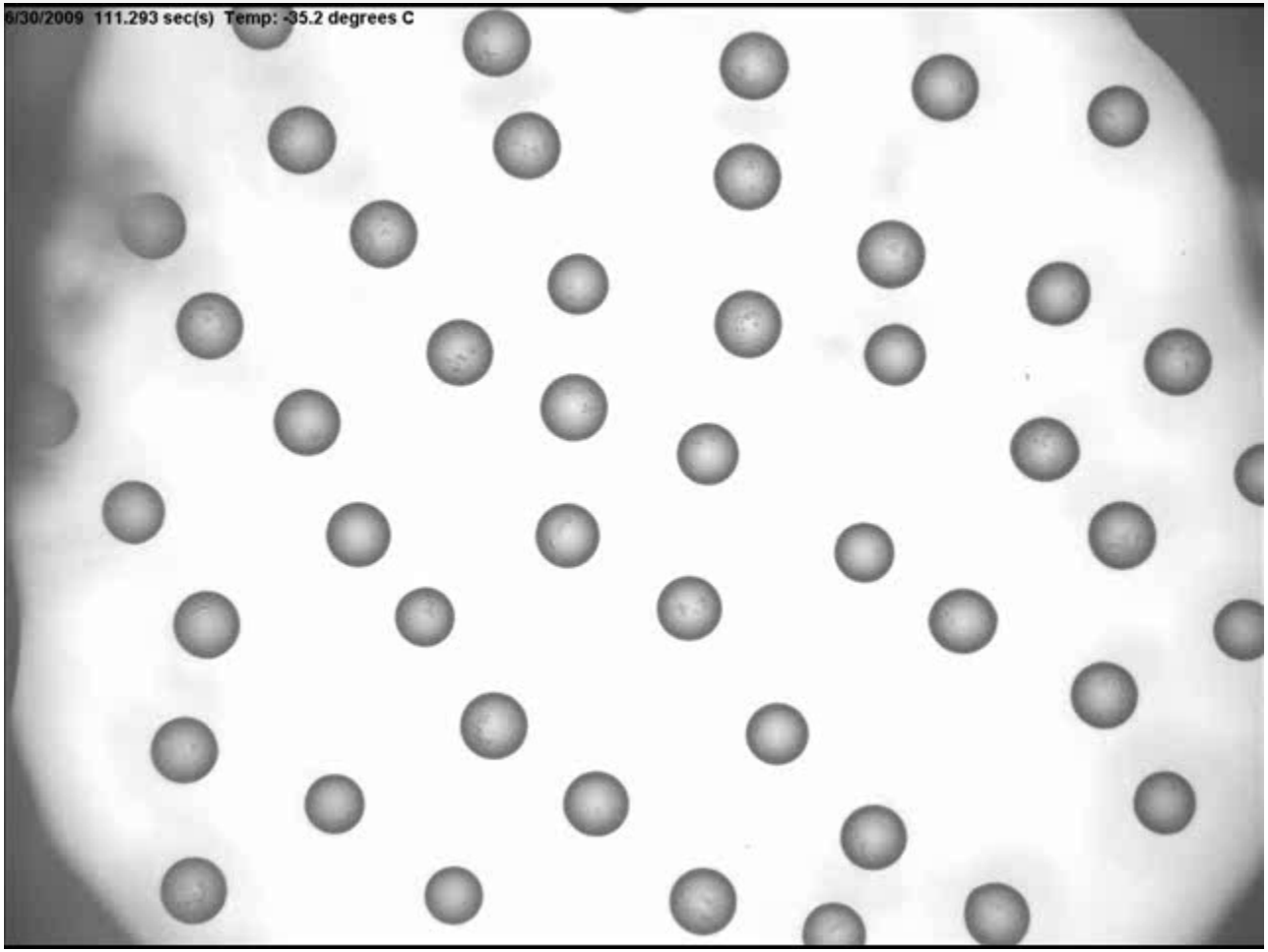


fix a_w = RH, i.e. composition

Knopf and Lopez, PCCP (2009)

Immersion Freezing Experiment Involving Phytoplanktonic Material

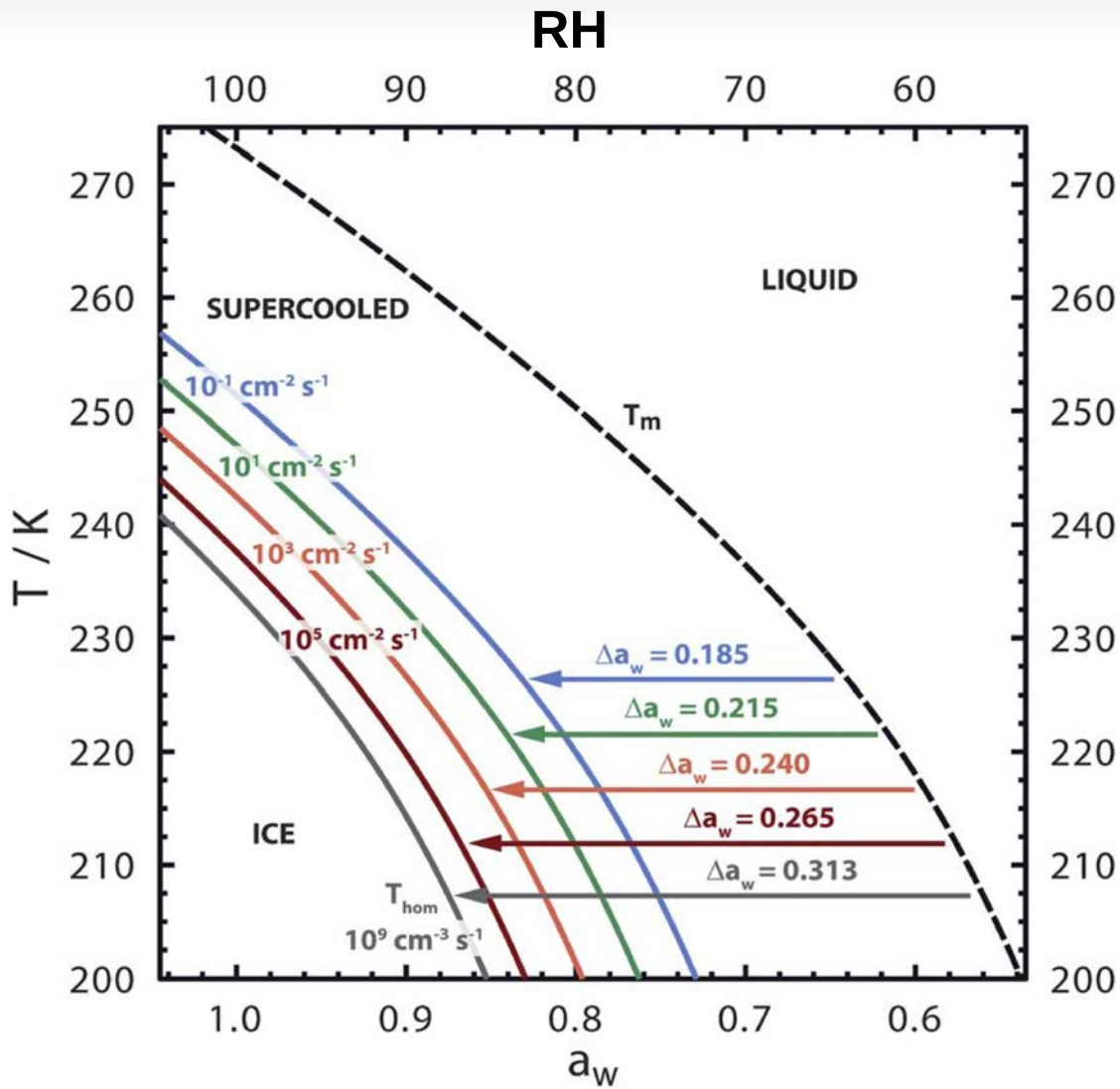
1 mm



Immersion freezing of aqueous NaCl droplets containing whole and fragmented diatoms. Droplet diameter is about 50 µm.

Water Activity Based Immersion Freezing Model

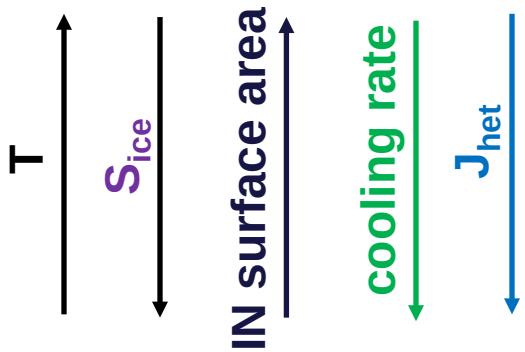
Knopf and Alpert, Farad. Discuss., 2013:

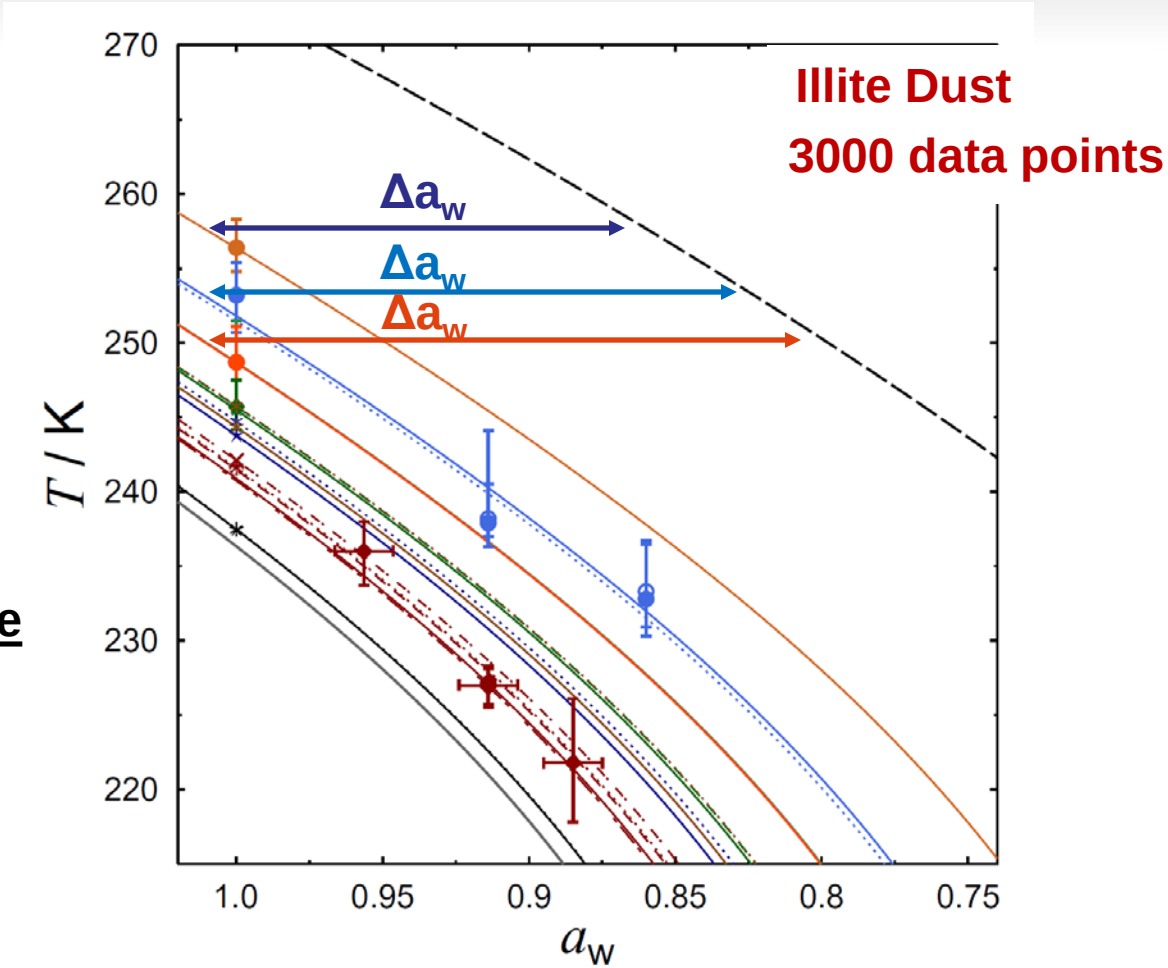


Do immersion freezing and homogeneous ice nucleation behave similarly, in terms of solution water activity, temperature, and kinetics?

Water Activity Based Immersion Freezing Model

Thermodynamic and kinetics:



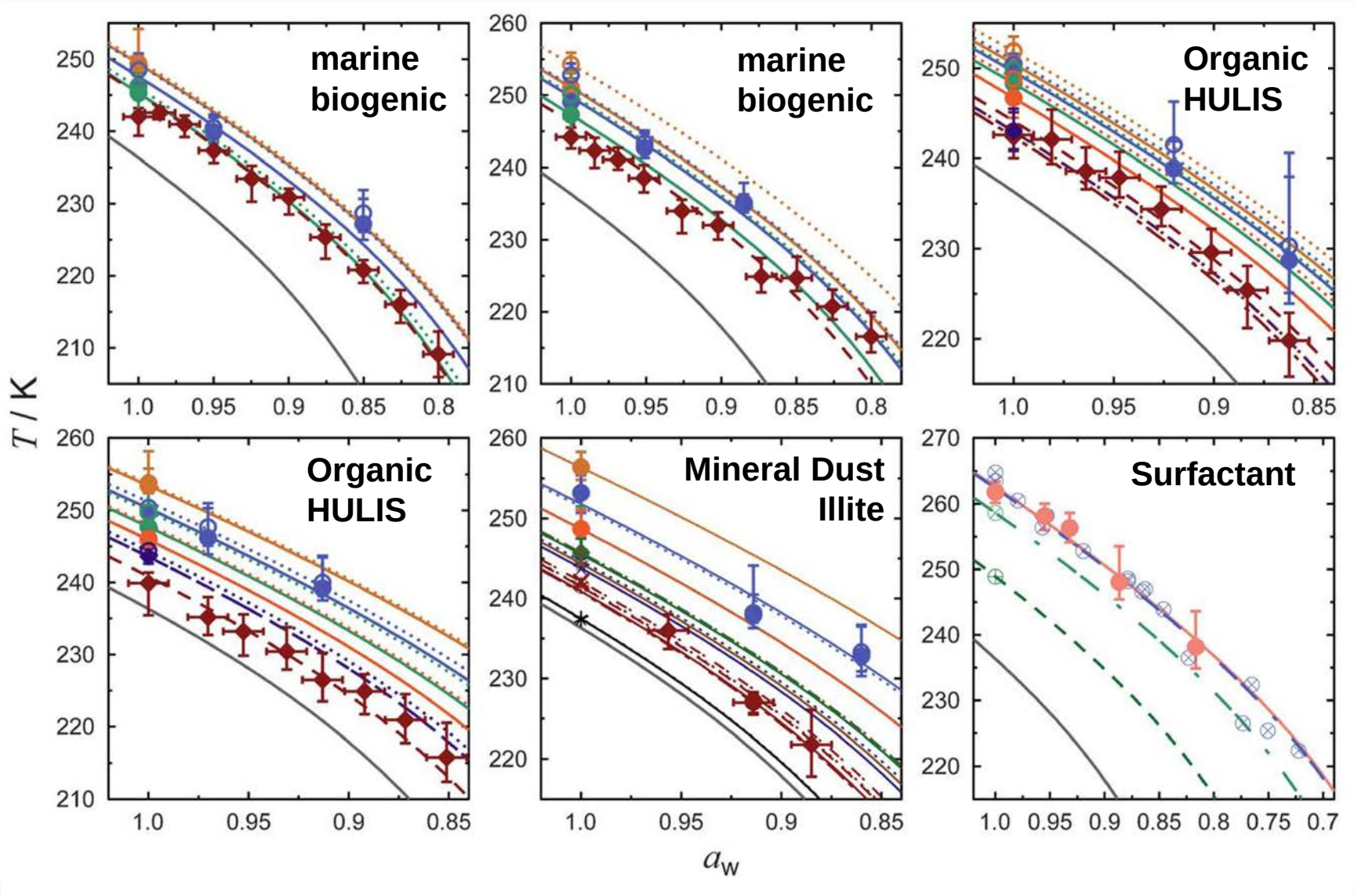


Experiments <u>in accordance with</u> classical nucleation theory.

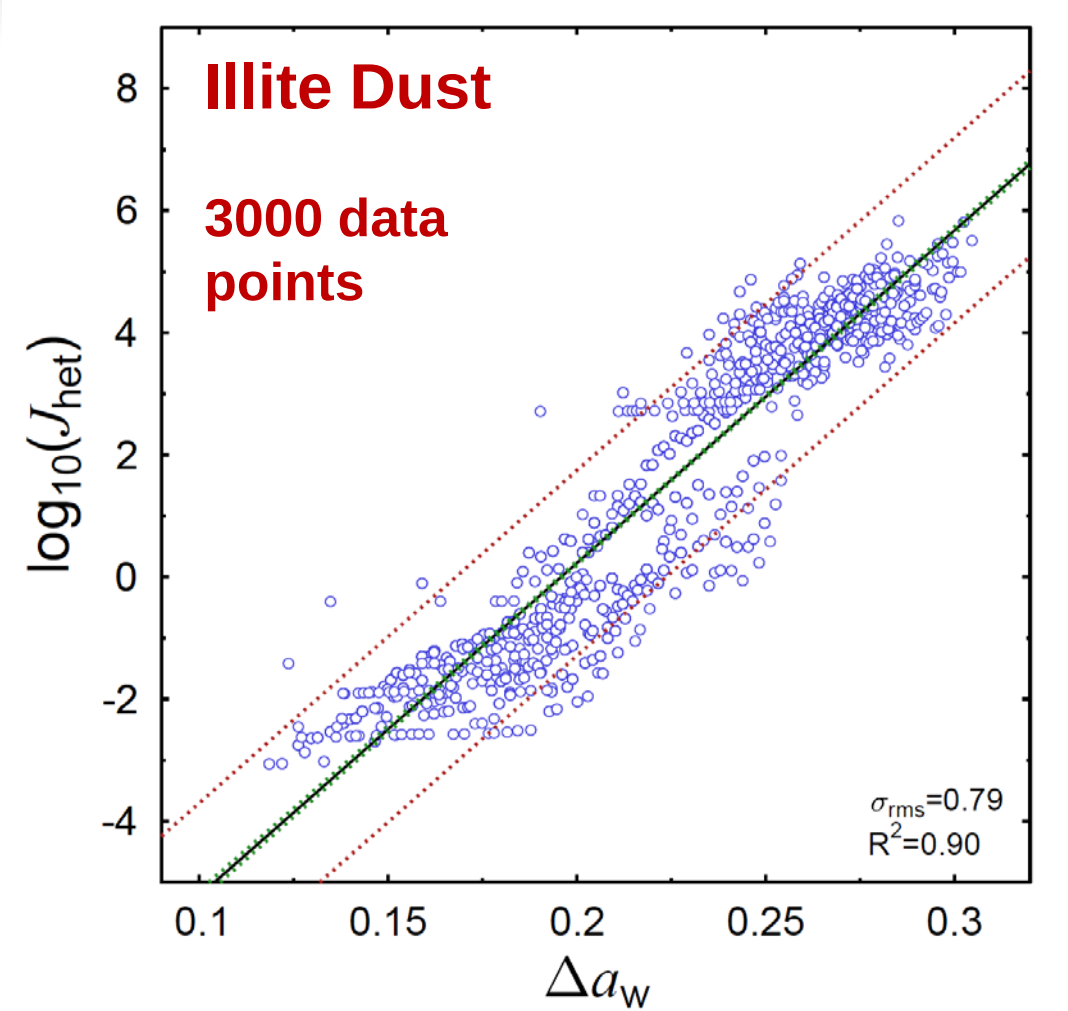
This model predicts immersion freezing T and RH for a variety of IN in various aqueous solutions accounting for changes in IN surface areas by 9 orders of magnitude and ice nucleation activation times by over 2 orders of magnitude.

Water Activity Based Immersion Freezing Model

Knopf and Alpert, Farad. Discuss., 2013:

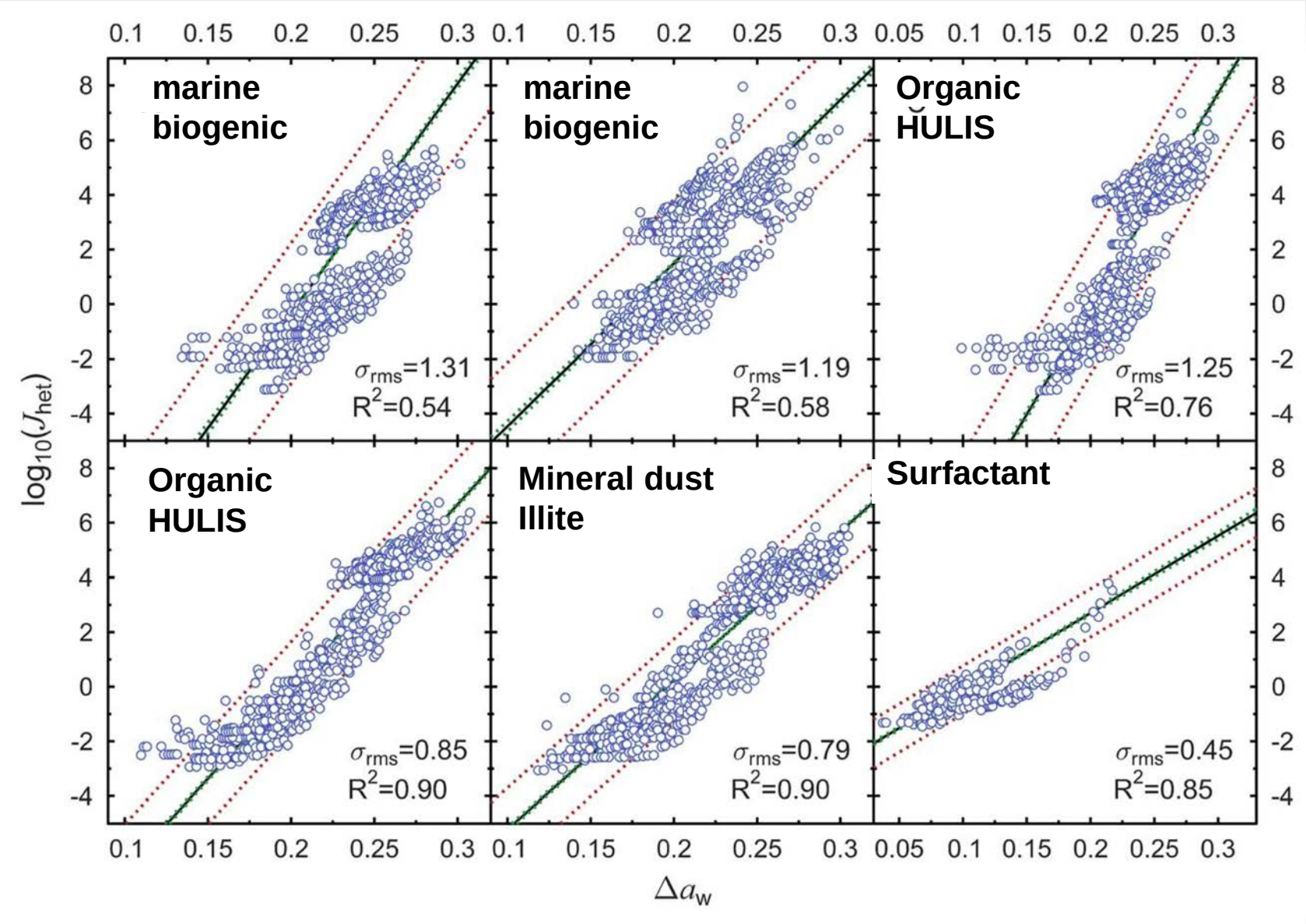


Water Activity Based Immersion Freezing Model



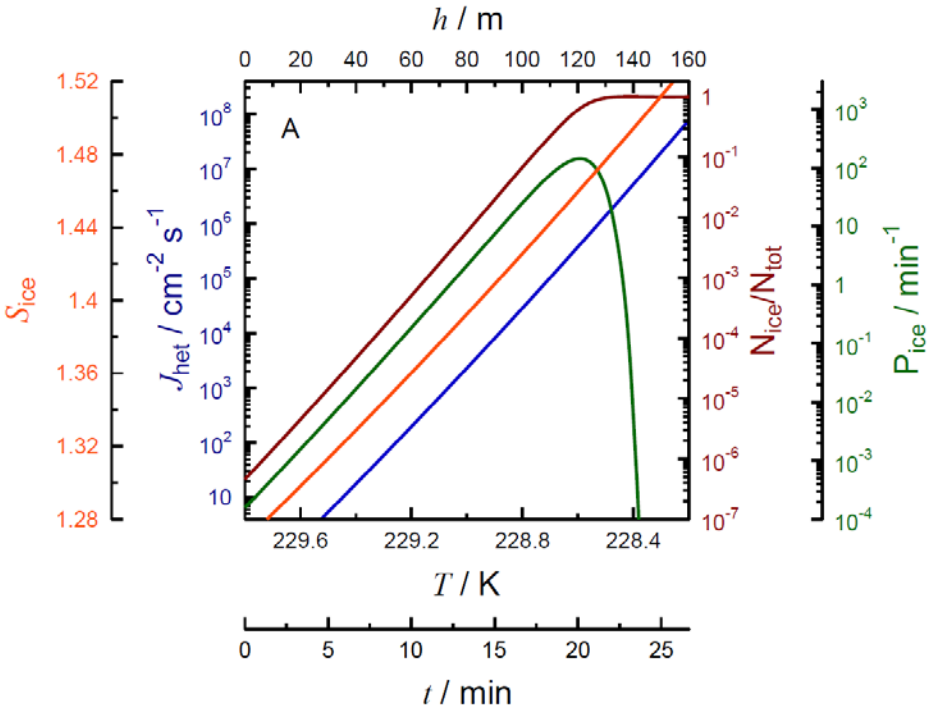
$\log(J_{het})$ as a function of Δa_w. Uncertainty of linear parameterization is < ±2 orders of magnitude, although J_{het} spans > 10 orders of magnitude.

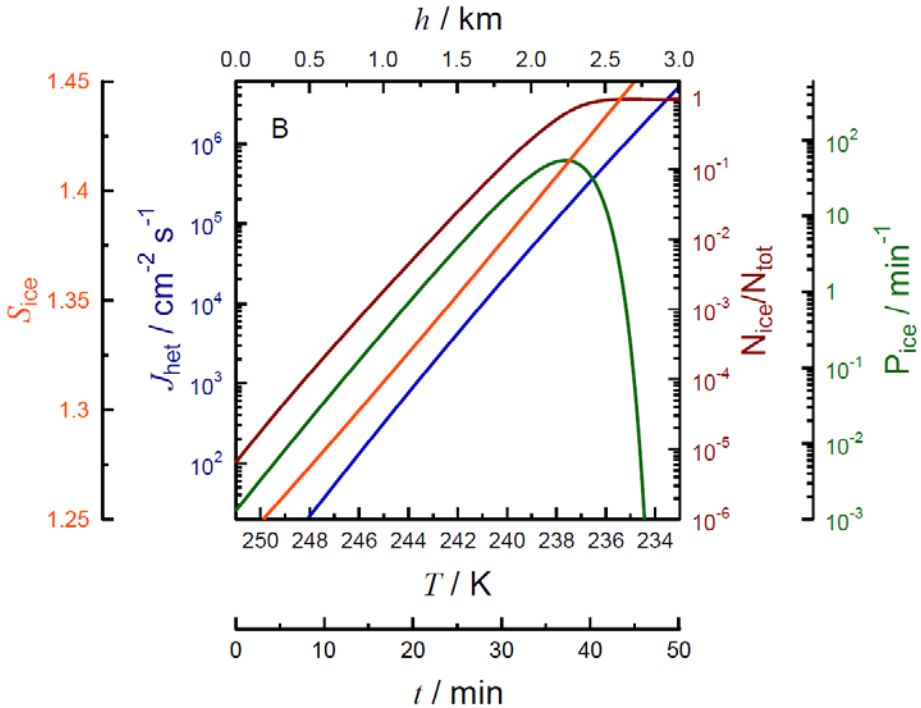
Water Activity Based Immersion Freezing Model



Water Activity Based Immersion Freezing Model - Modeling Approach

<u>Case:</u> Mineral dust Illite



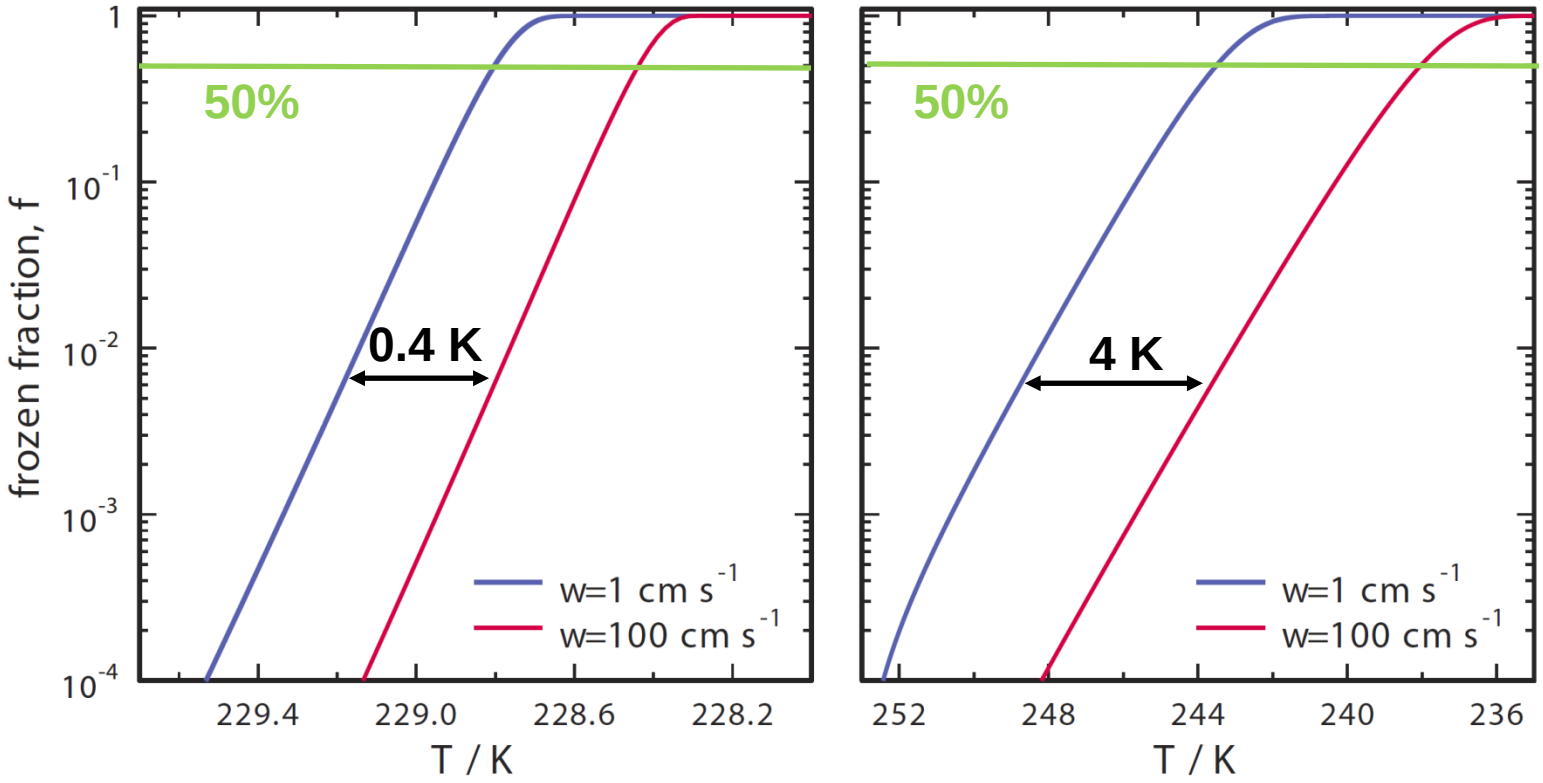


cirrus cloud | **mixed-phase cloud**

Updraft: 10 cm s^{-1} | 1 m s^{-1}

total IN: 500 L^{-1}

Water Activity Based Immersion Freezing Model - Cooling Rate Dependence

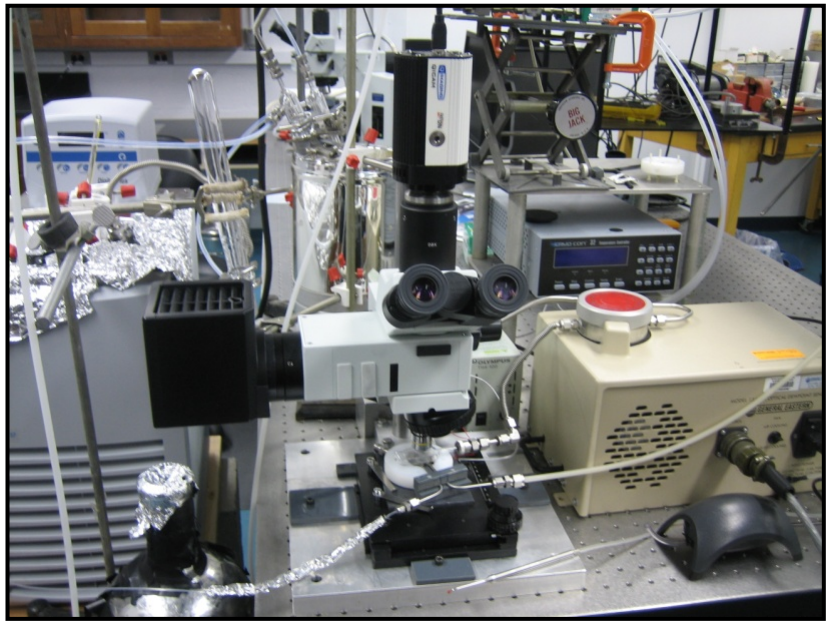


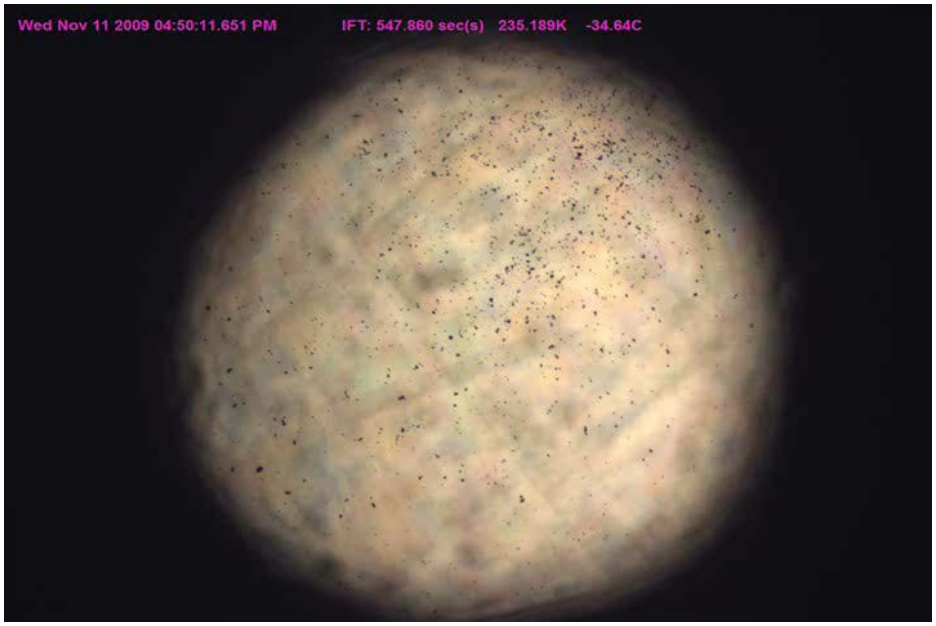
cirrus cloud **mixed-phase cloud**

total IN: 500 L^{-1}

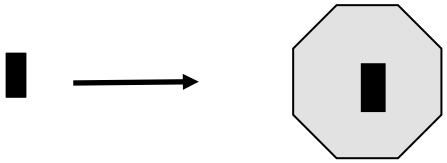
Time dependence of nucleation process can be crucial for cloud development.

Deposition Ice Nucleation Experiments





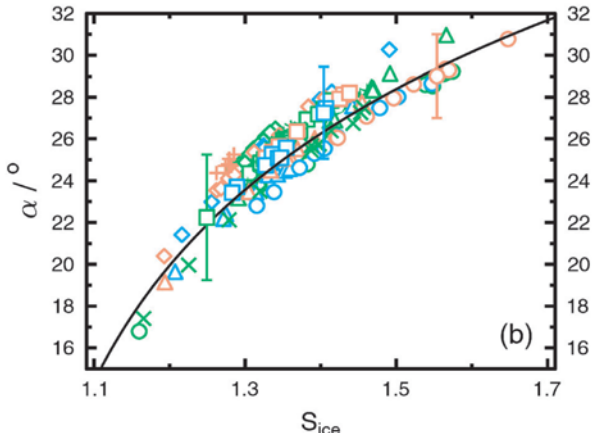
1 mm

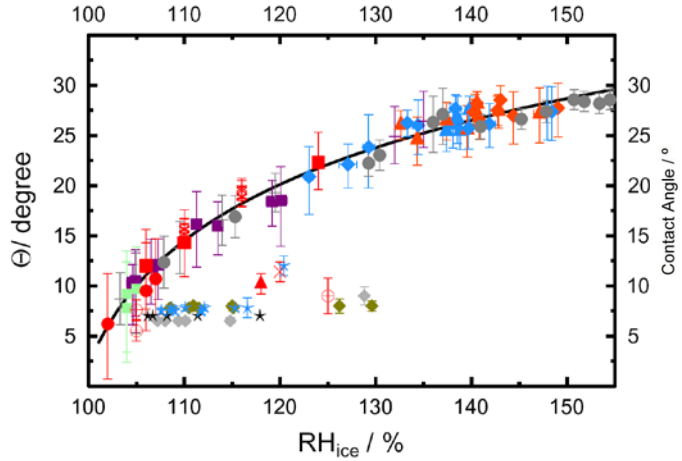


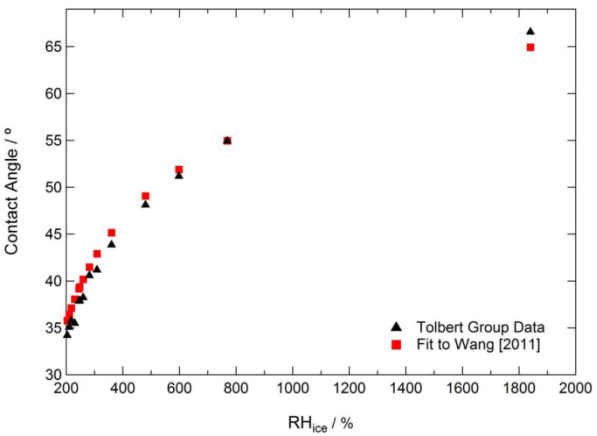
deposition
ice nucleation

Deposition Ice Nucleation Parameterization

Comprises: various mineral dust types, humic acids, marine biogenic material, field-collected particles (M.C., L.A.) **Wang and Knopf, JGR, 2011**







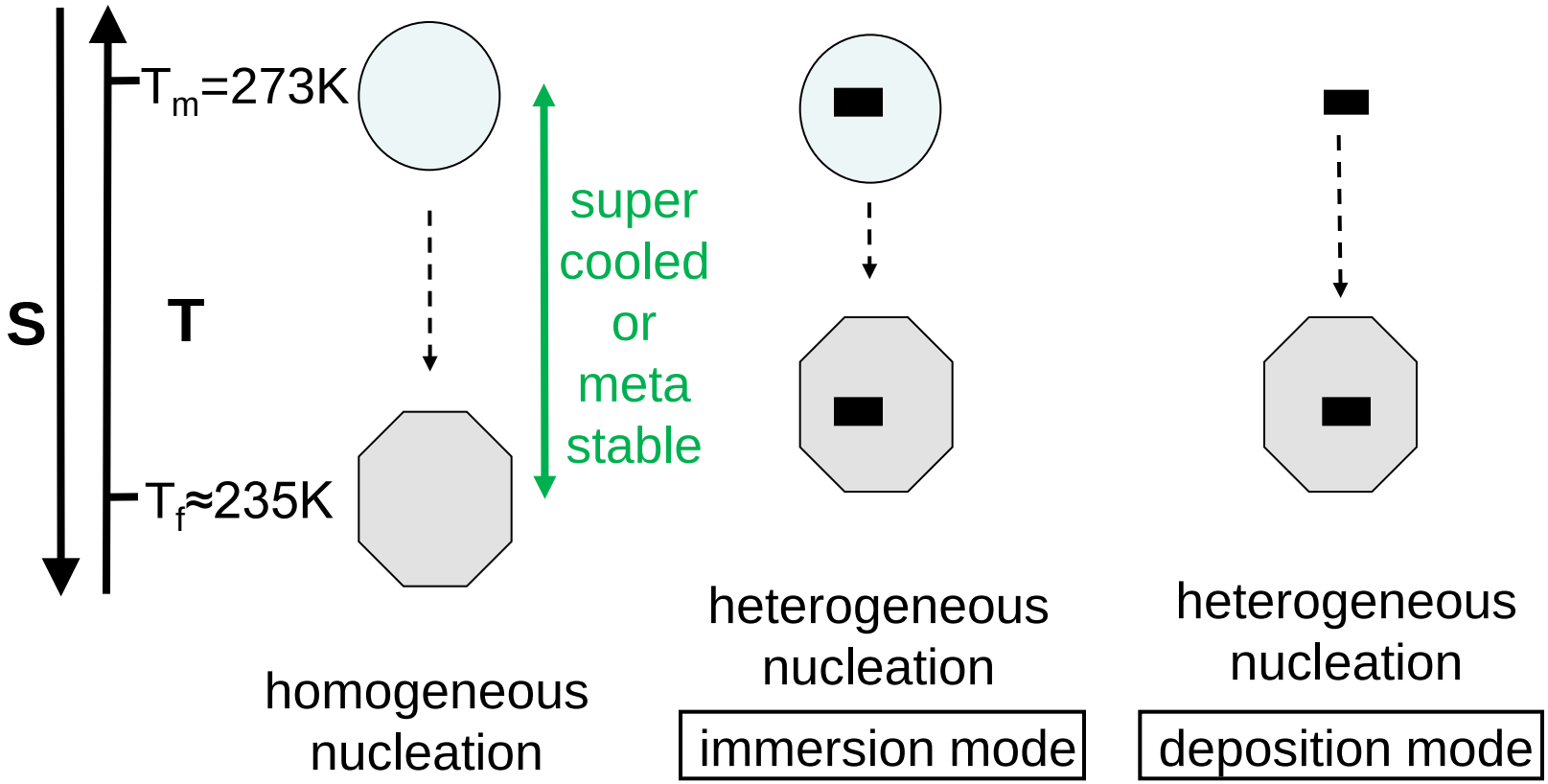
contact angle as a function of RH_{ice}

$$J_{het} = A \cdot exp(\frac{-\Delta F_{g,het}}{kT}) \qquad \Delta F_{g,het} = \frac{16\pi M_w^2 \sigma_{i/v}^3}{3[RT\rho lnS_{ice}]^2} \cdot f(m,x)$$

Method: 1. Get T and RH from model -> RH_{ice}
2. Read off contact angle
3. Use T, RH_{ice}, and contact angle to derive J_{het}
4. RH_{ice} allows determination of frozen fraction, ice crystal numbers etc.

Ice Nucleation Mechanisms

Ice formation can proceed via homogeneous nucleation or heterogeneous nucleation:

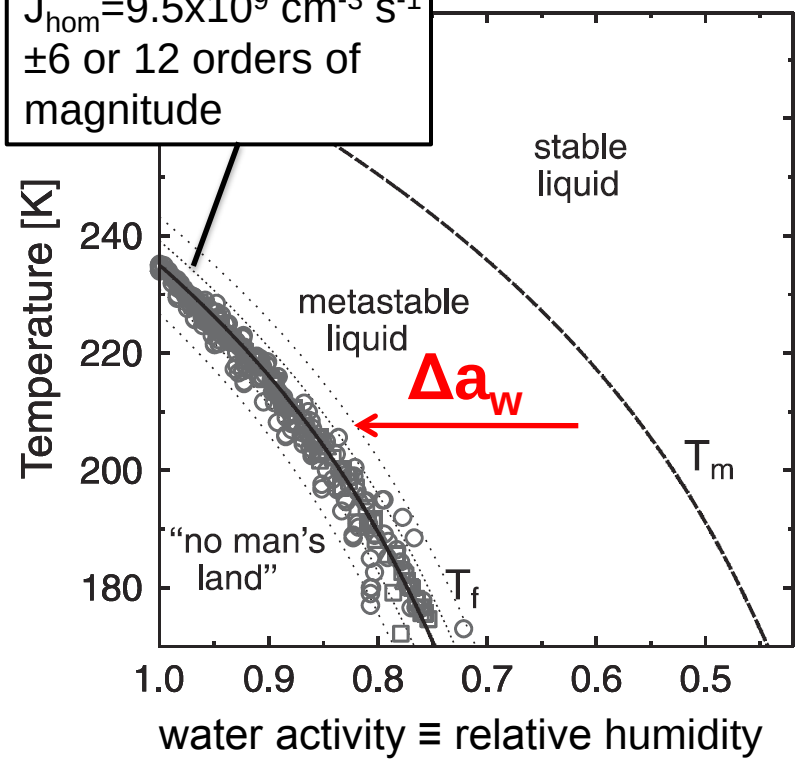


$[J_{hom}]=cm^{-3}\ s^{-1}$ $[J_{het}]=cm^{-2}\ s^{-1}$ $[J_{het}]=cm^{-2}\ s^{-1}$

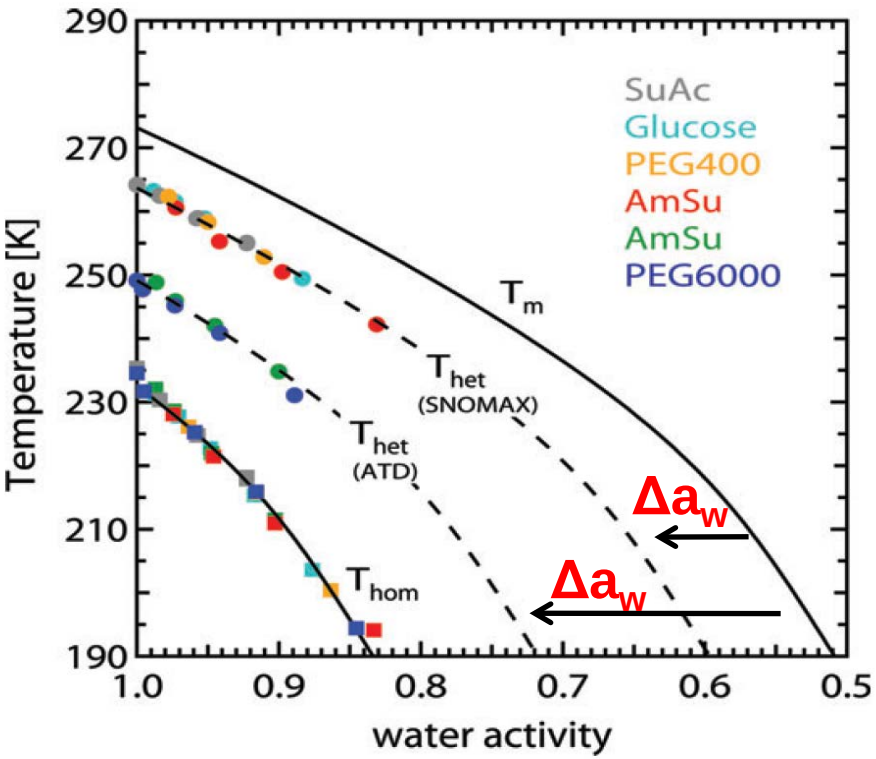
Theoretical Description of Heterogeneous Ice Nucleation

Water Activity Based Nucleation Approach

Line corresponds to:
J_{hom}=9.5x10^9 cm^{-3} s^{-1}
±6 or 12 orders of magnitude



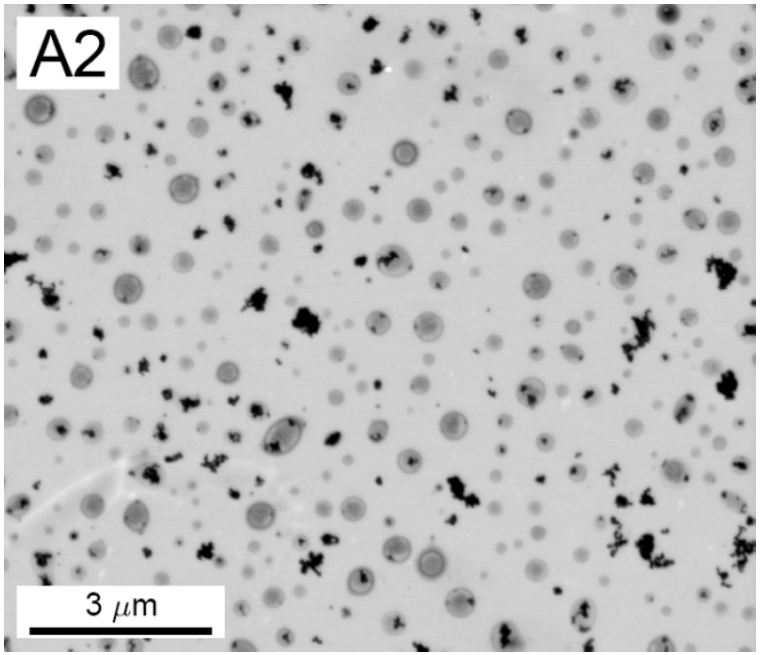
$= p_{H2O}(C,T)/p^0_{H2O}(T)$

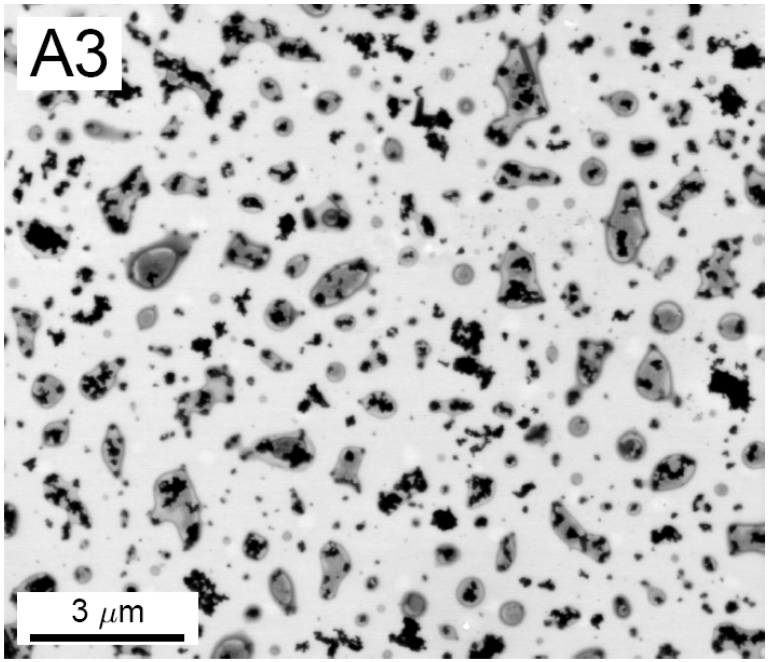


Koop et al., Nature, 2000, PCCP, 2009

Heterogeneous Nucleation of Ice on Organic Containing Particles Collected within Los Angeles Area

B. Wang, A. Laskin (PNNL), R. C. Moffet (LBNL), and M. K. Gilles (LBNL)



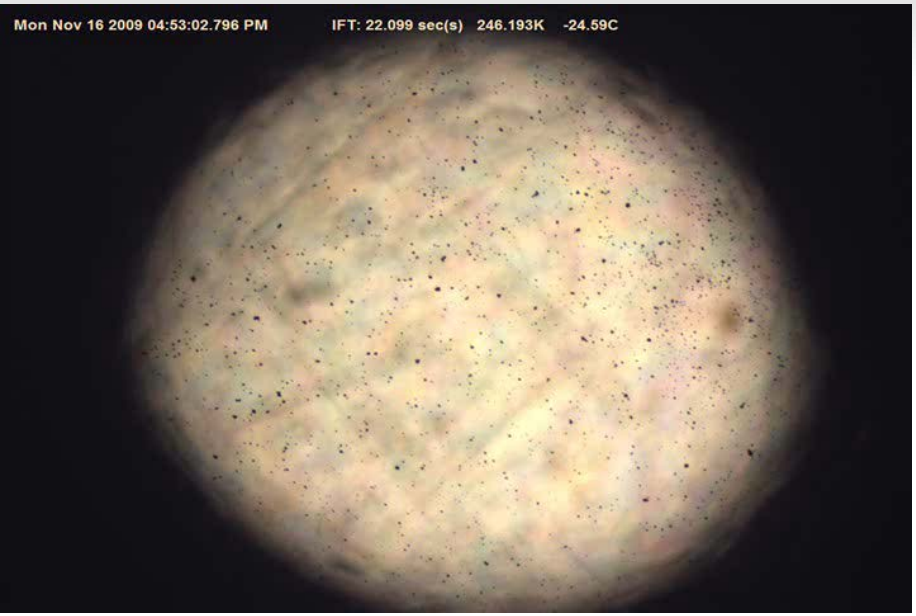


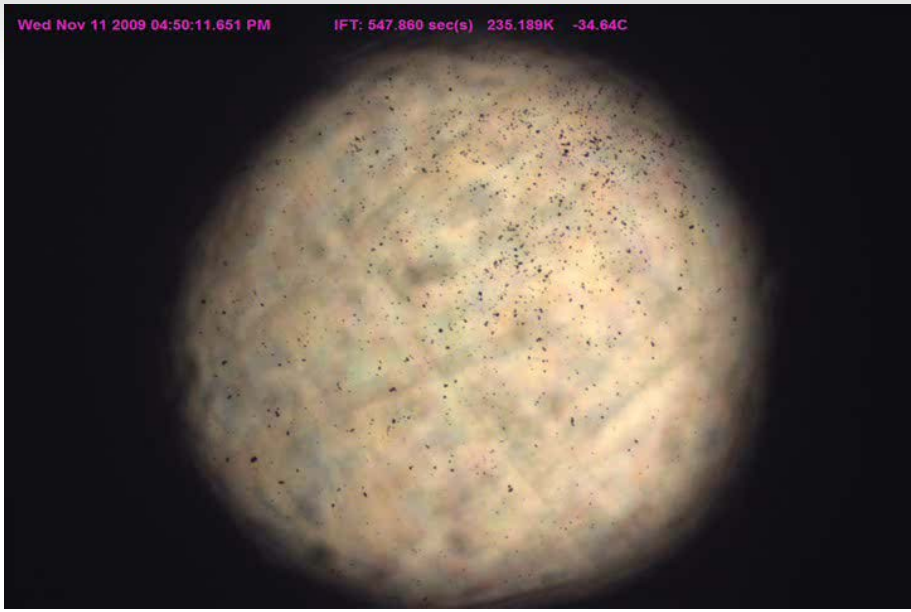
05/19/10, 6 am

05/19/10, 12 pm

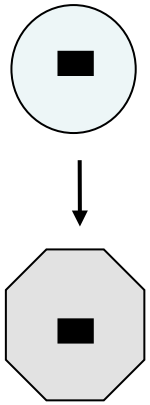
Wang et al., JGR, 2012

Setup to Control Temperature and Water Partial Pressure

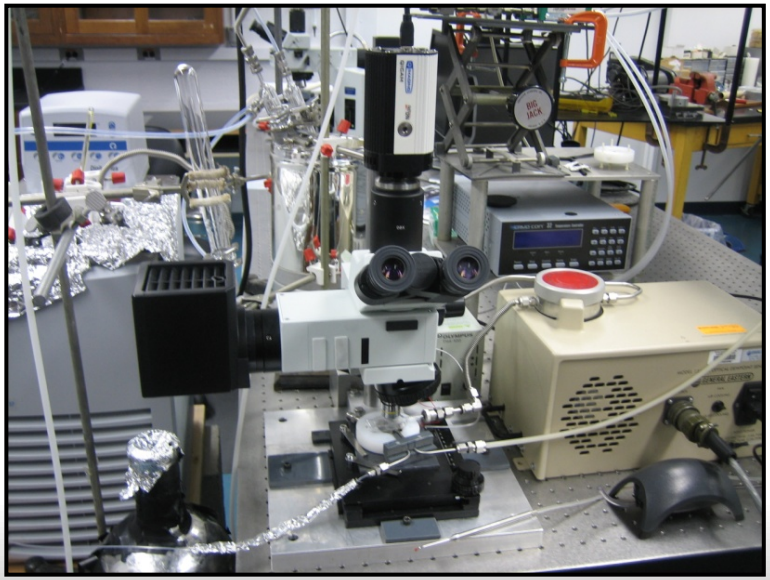


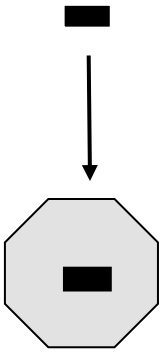


1 mm



immersion
freezing





deposition
ice nucleation