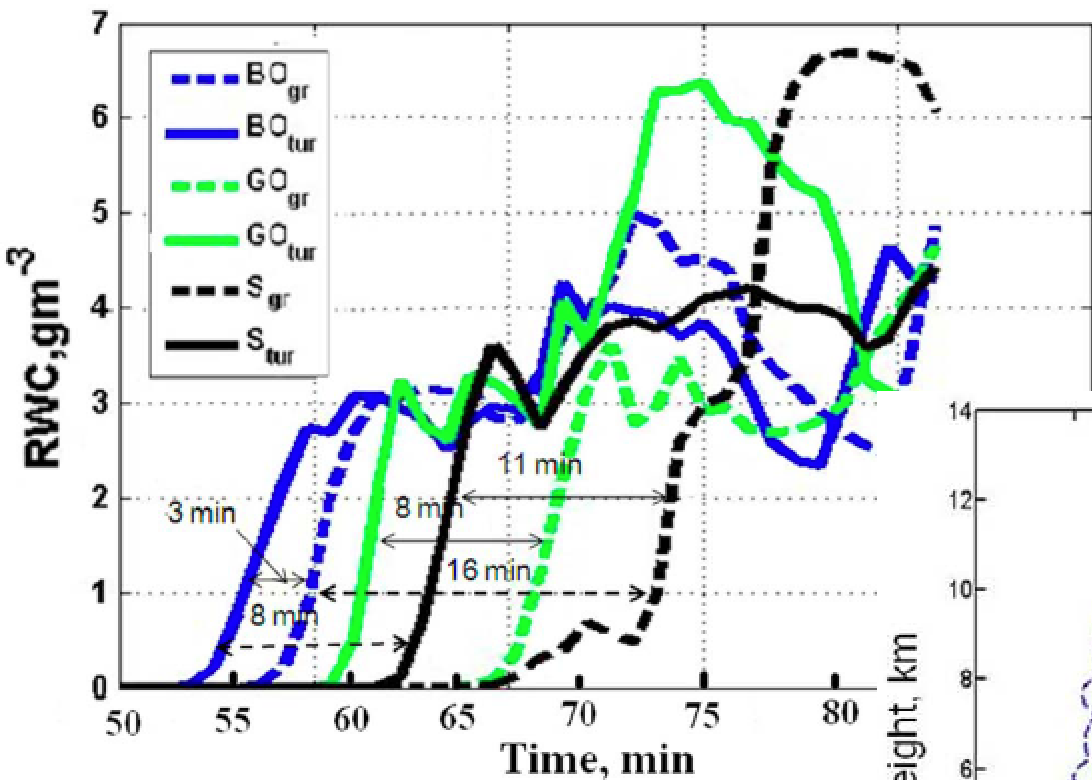
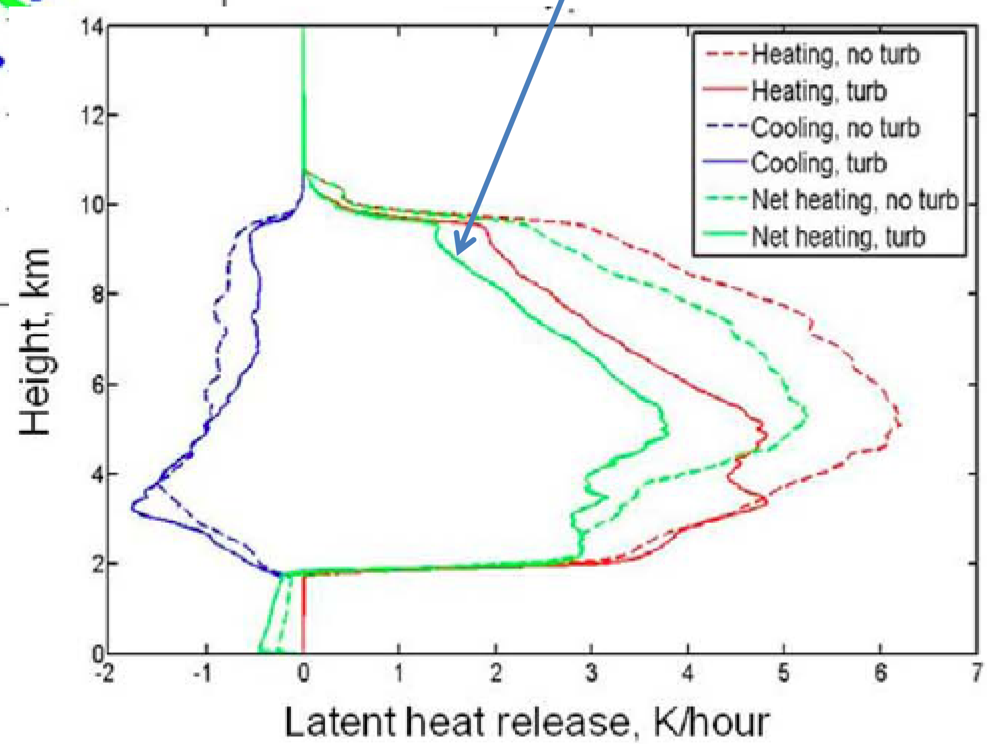
Turbulence enhancements are of the same order as aerosol effects
… and therefore have similar implications for formation of ice

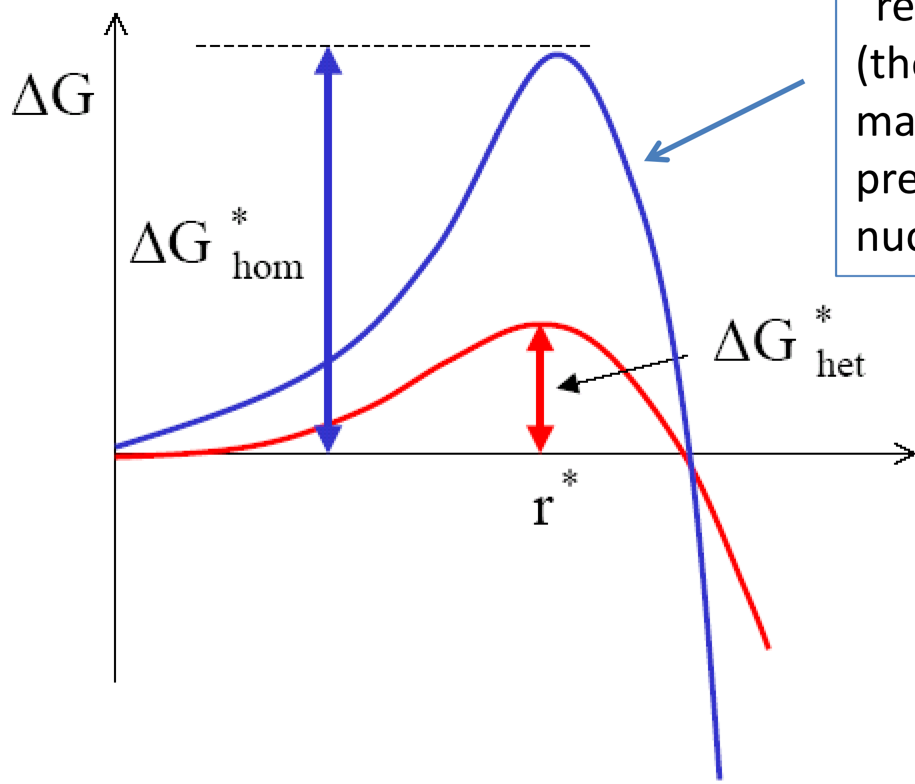


turbulence → efficient coalescence → less ice → weaker heating



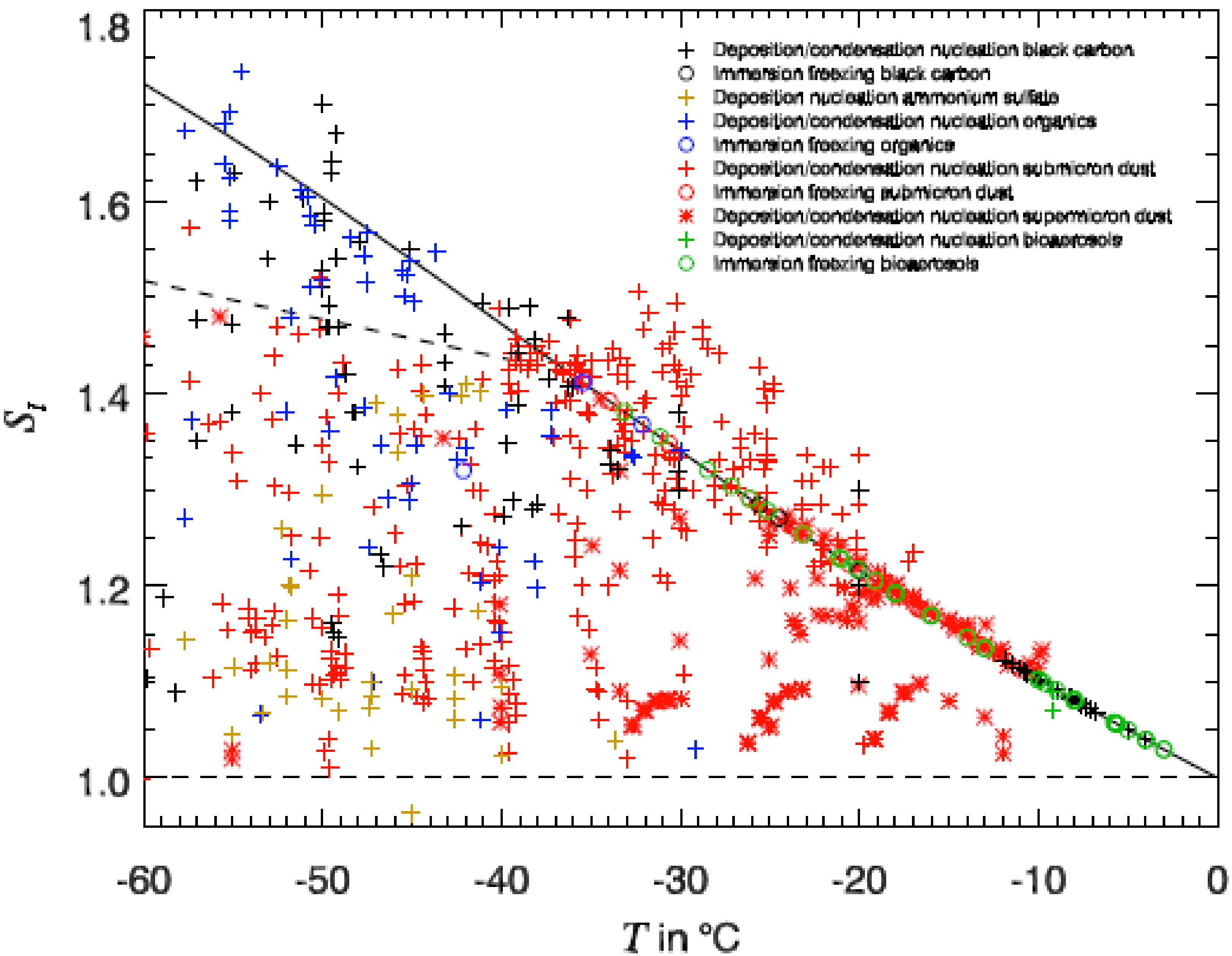
Benmoshe et al. 2012 JGR

Classical nucleation theory applied to a heterogeneous system
… f accounts for interactions with the substrate



"reasonable" theory (thermodynamic and material parameters predict observed, intensive nucleation rates)

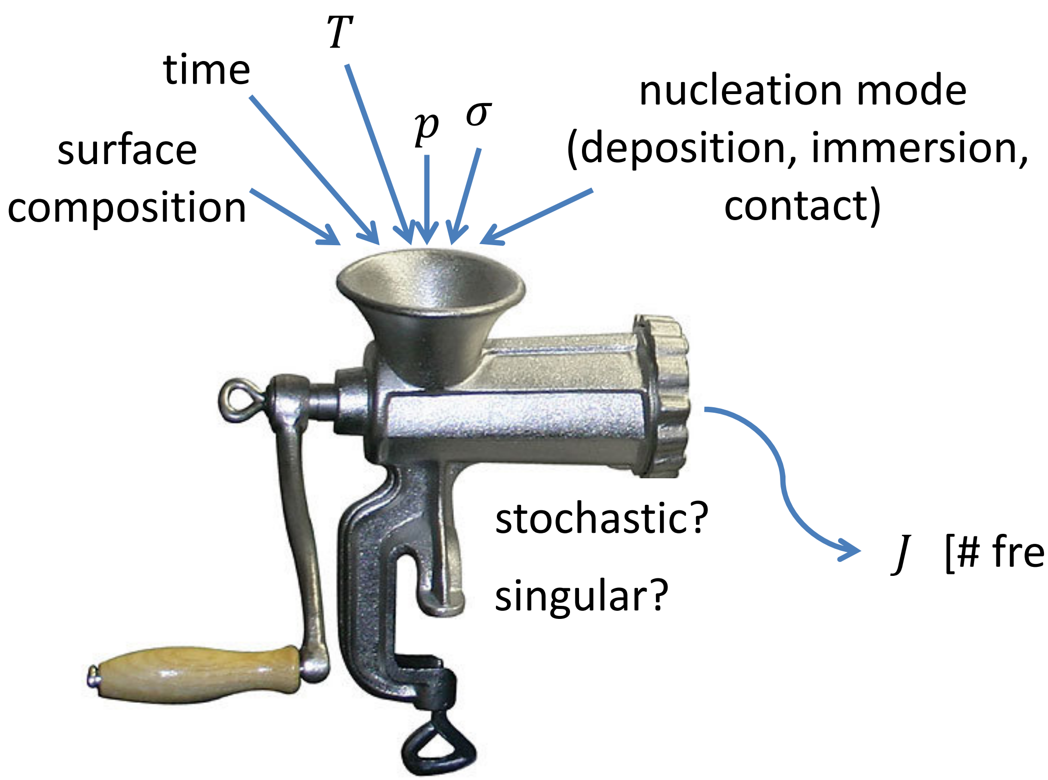
$$J(T) = n_w \frac{k_B T}{h} A \exp\left(-\frac{\Delta g}{k_B T}\right) \exp\left(-\frac{16\pi\sigma^3 T_0^2 f}{3k_B T (n_i l_f)^2 \Delta T^2}\right)$$



Hoose & Moehler 2012 ACPD

Are we closer to a practical "theory" of ice nucleation?

i.e., given aerosol size and composition, as well as thermodynamic conditions, can we predict the number of IN?



J [# freezing events per unit time]

$$P_f = 1 - \exp(-Jt)$$

Analogy: modified Kohler theories give "reasonable" prediction of CCN.
Note: Even if the theory is not used directly, it provides guidance for development of physically-based parameterizations.

Pragmatic goals:

- Empirical measurements of IN concentration and onset temperature for different conditions (desert dust, biological, arctic haze, etc.)
- Closure experiments – agreement between IN and ice crystal populations
- Laboratory investigation of different nucleation modes (e.g., immersion vs. contact), thermodynamic dependence (e.g. stochastic vs. singular), and representative materials and processes (e.g., chemical processing)
- Cloud and cloud-system modeling to study sensitivity to plausible IN distributions and nucleation mechanisms
- All provides guidance for strategies to connect to global-scales

Examples of some major European ice lab facilities

AIDA (Karlsruhe)

LACIS (Leipzig)

MIC (Manchester)

ZINC (Zurich)

Examples of some US ice nucleation facilities *field

CSU (DeMott)*

Michigan Tech (Cantrell, Shaw)

MIT (Cziczo)*

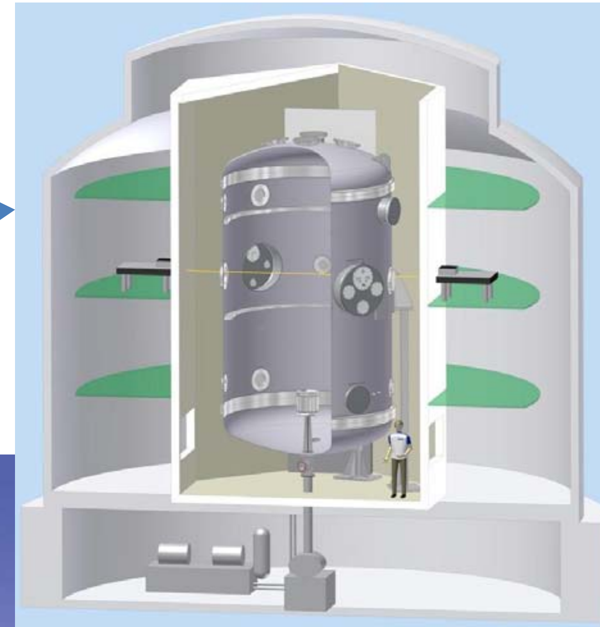
North Carolina (Petters)

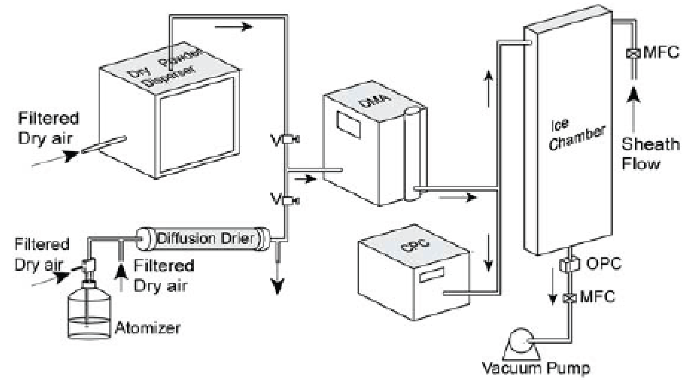
Penn State (Harrington)

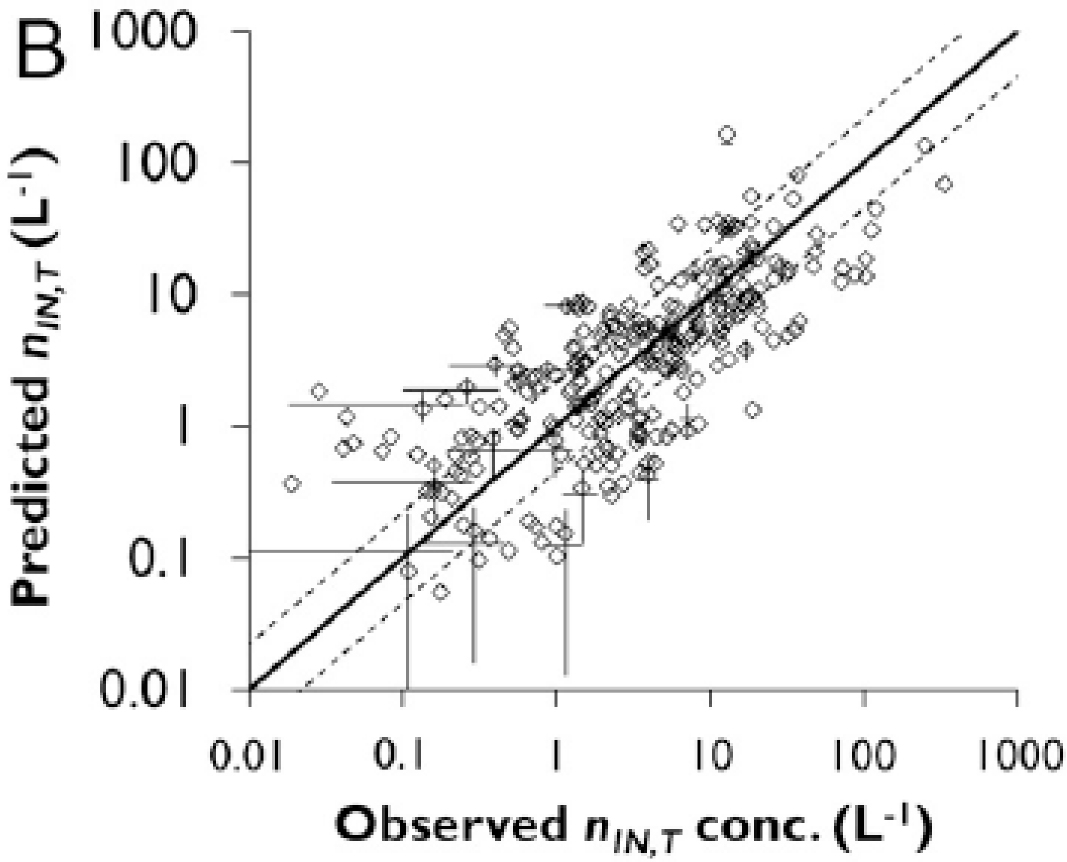
PNNL (GK et al.)

Stony Brook (Knopf)

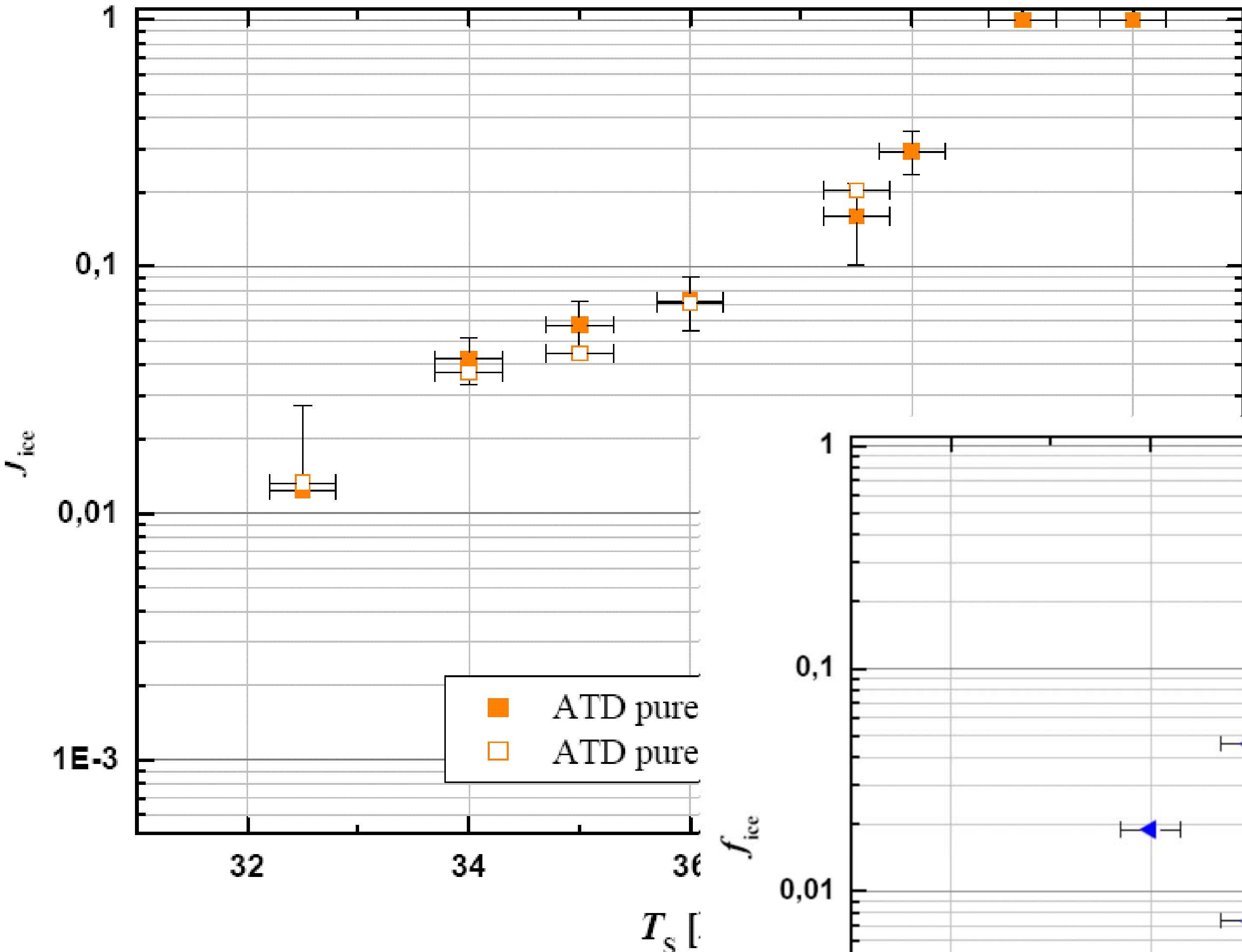
Texas A&M (Brooks)*

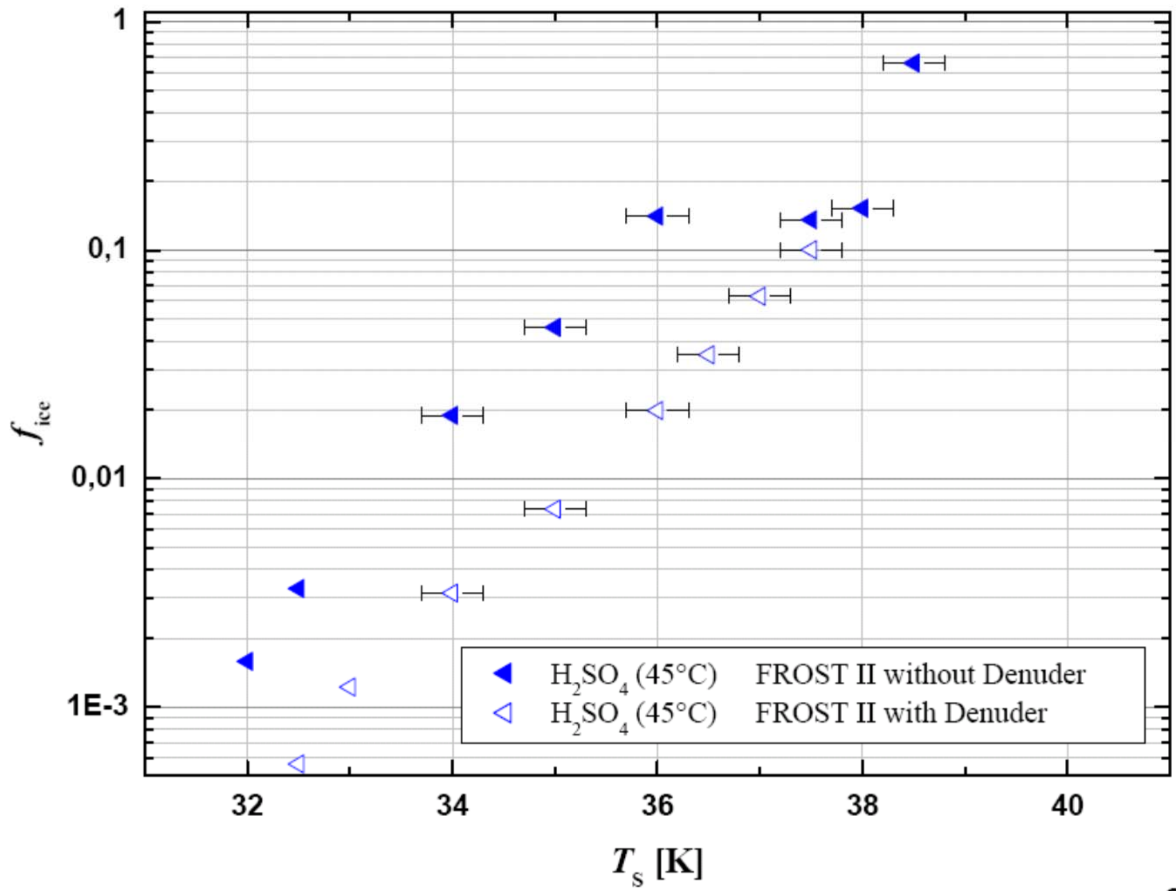






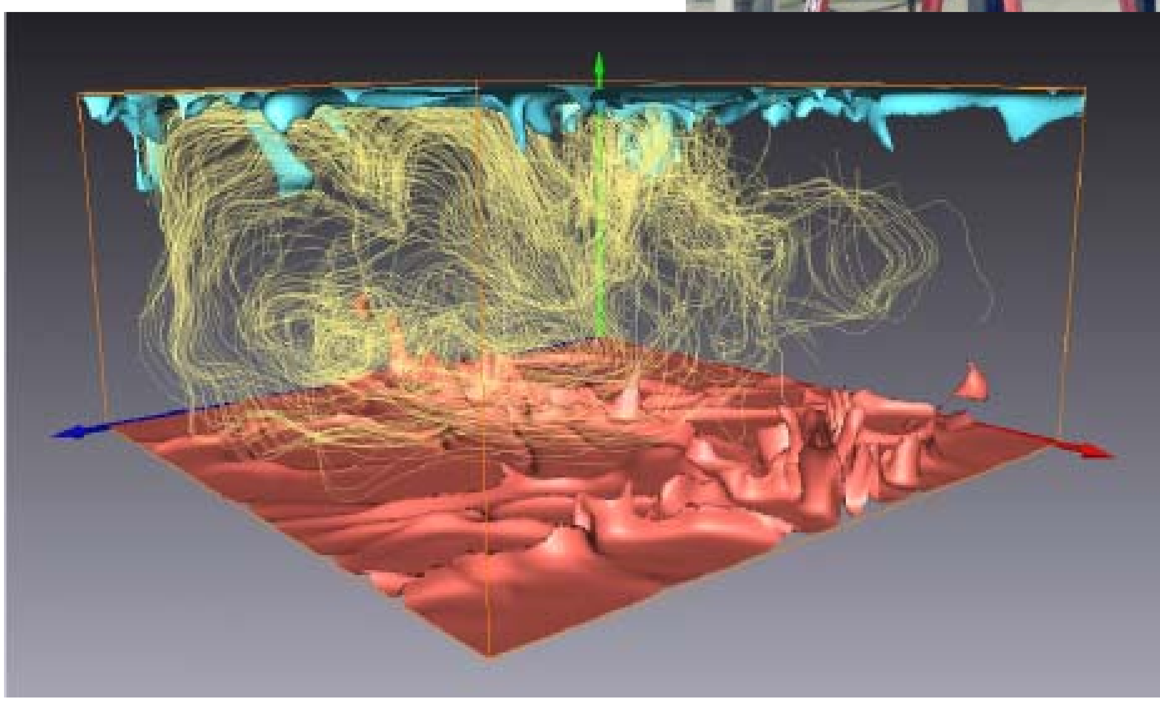
DeMott et al. 2010 PNAS

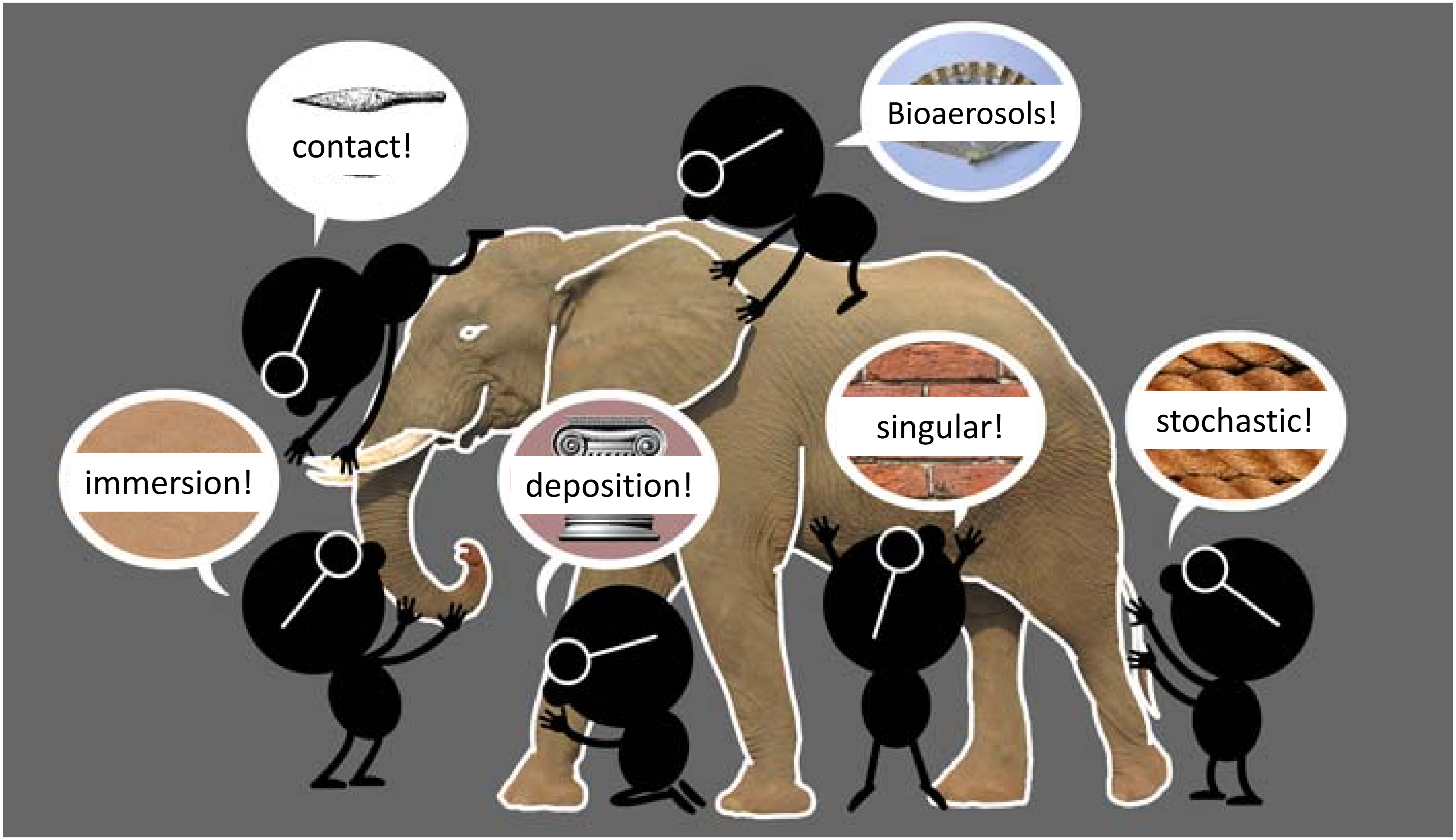




Niedermeier et al. 2011 ACP

π-chamber
($V = 3.14$ m^3
$-40 \leq T \leq 20$ °C
$100 \leq p \leq 1000$ hPa
turbulence)





Original image courtesy of simoncamilleri.com

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