Biological Ice-Nucleating Macromolecules (INMs)

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Climate Change Conference

Valencia, 24.10.2016

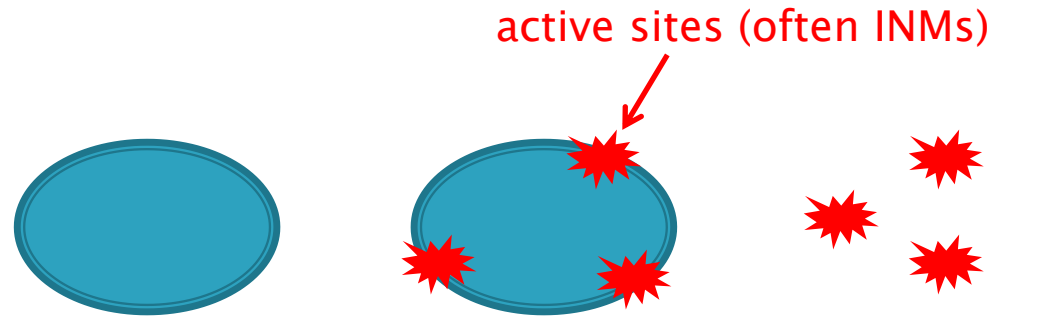
Background

- Water freezes at 0°C / 32°F / 273.15 K
- Wrong!
- Thermodynamics: freezing is favorable
- Kinetics: cluster formation is hindered
- Supercooling down to 230 K is possible (esp. in atmosphere)
- Ice nuclei (IN) are catalysts that structure the water; are very exclusive group
- Freezing at higher temperatures (up to 273 K)

Background

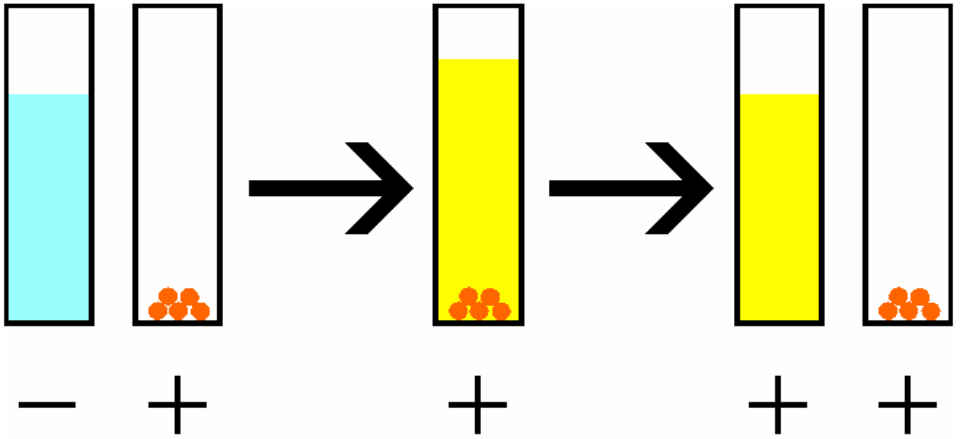
- Why bother?
- In the atmosphere: IN play a huge role
- Cloud glaciation is critical for precipitation (weather) and albedo (global heat budget)
- IPCC: cloud-aerosol interaction = least understood term in climate models

Ice nuclei: INPs and INMs

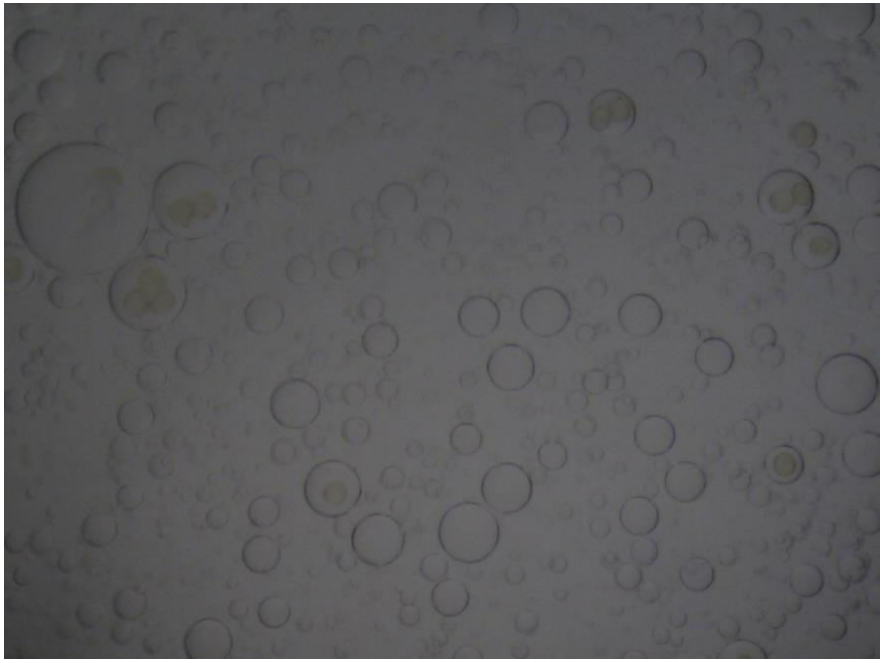


INP–INA = INM–INA

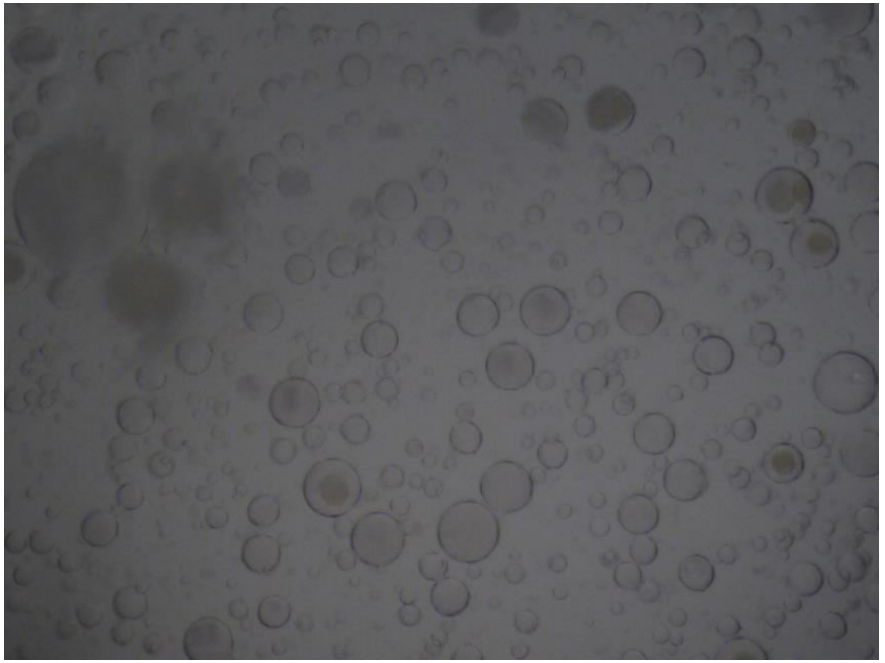
INP = ice-nucleating particle
INM= ice-nucleating macromolecule
INA = ice nucleation activity



INMs: discovery



Birch pollen 259.0 K

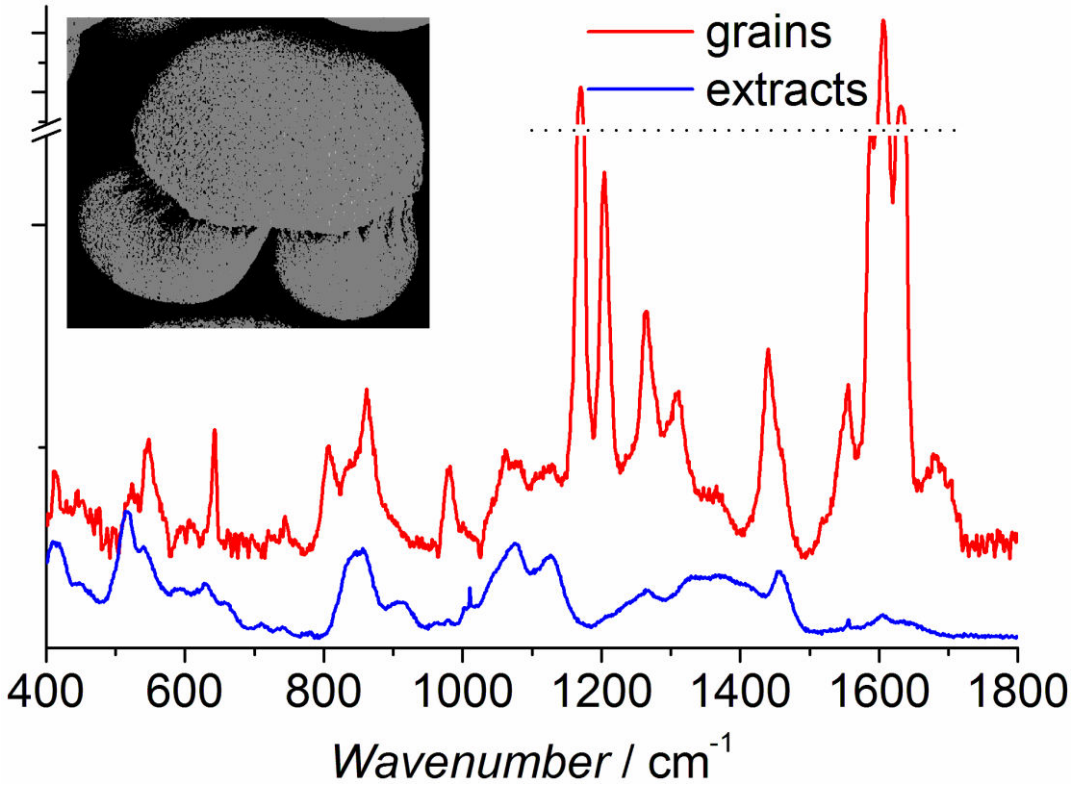


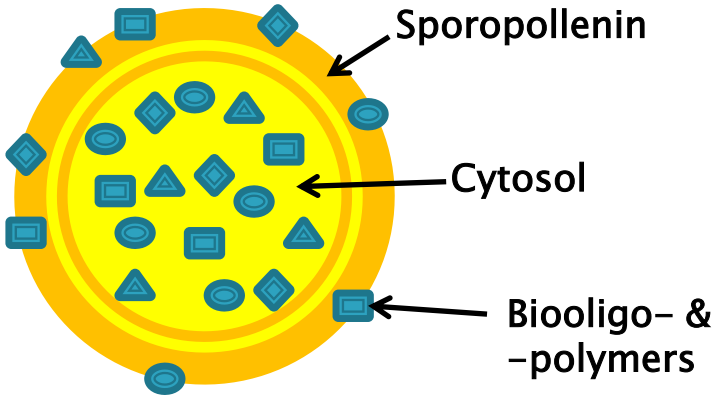
Birch pollen 255.6 K

T_{hom} = 237 K

Pummer et al.: Atmos. Chem. Phys., 12, 2541–2550, 2012.

INMs: discovery





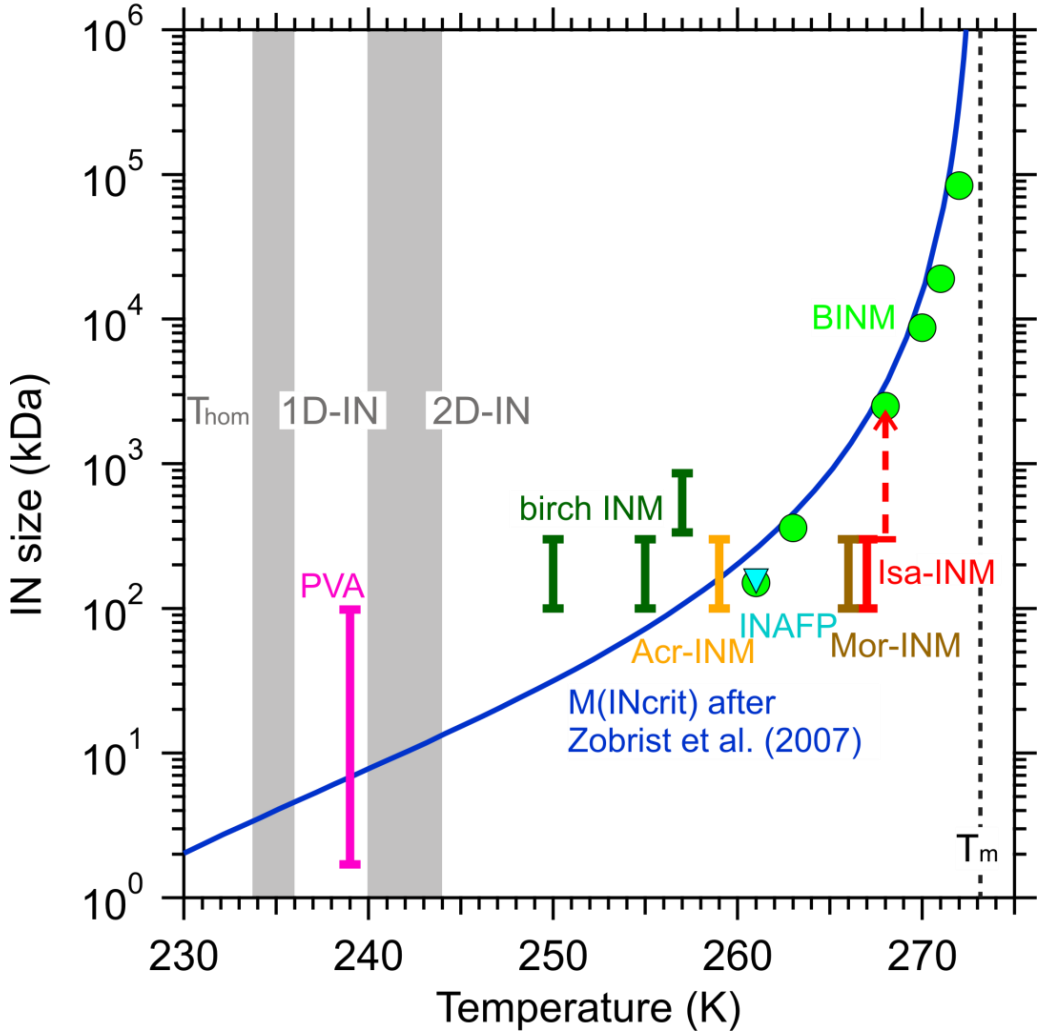
- But Nobody Believed Me!

Pummer et al.: J. Raman Spectrosc., 44, 1654-1658, 2013.

INMs: the size issue

for proteins:
10^1 kDa > 1.4 nm
10^2 kDa > 3.1 nm
10^3 kDa > 6.6 nm
10^4 kDa > 14.2 nm

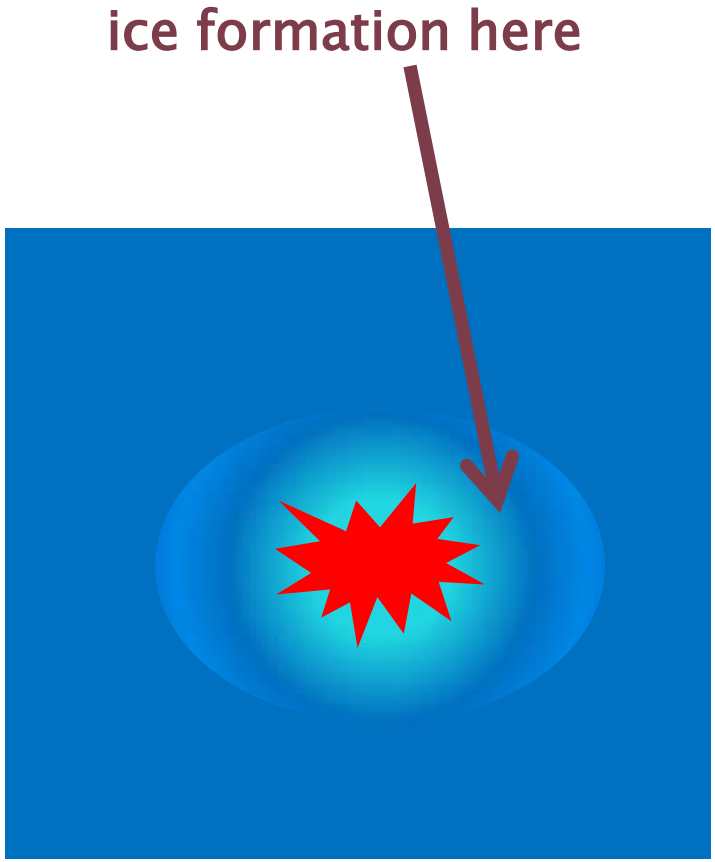
Erickson (2009)



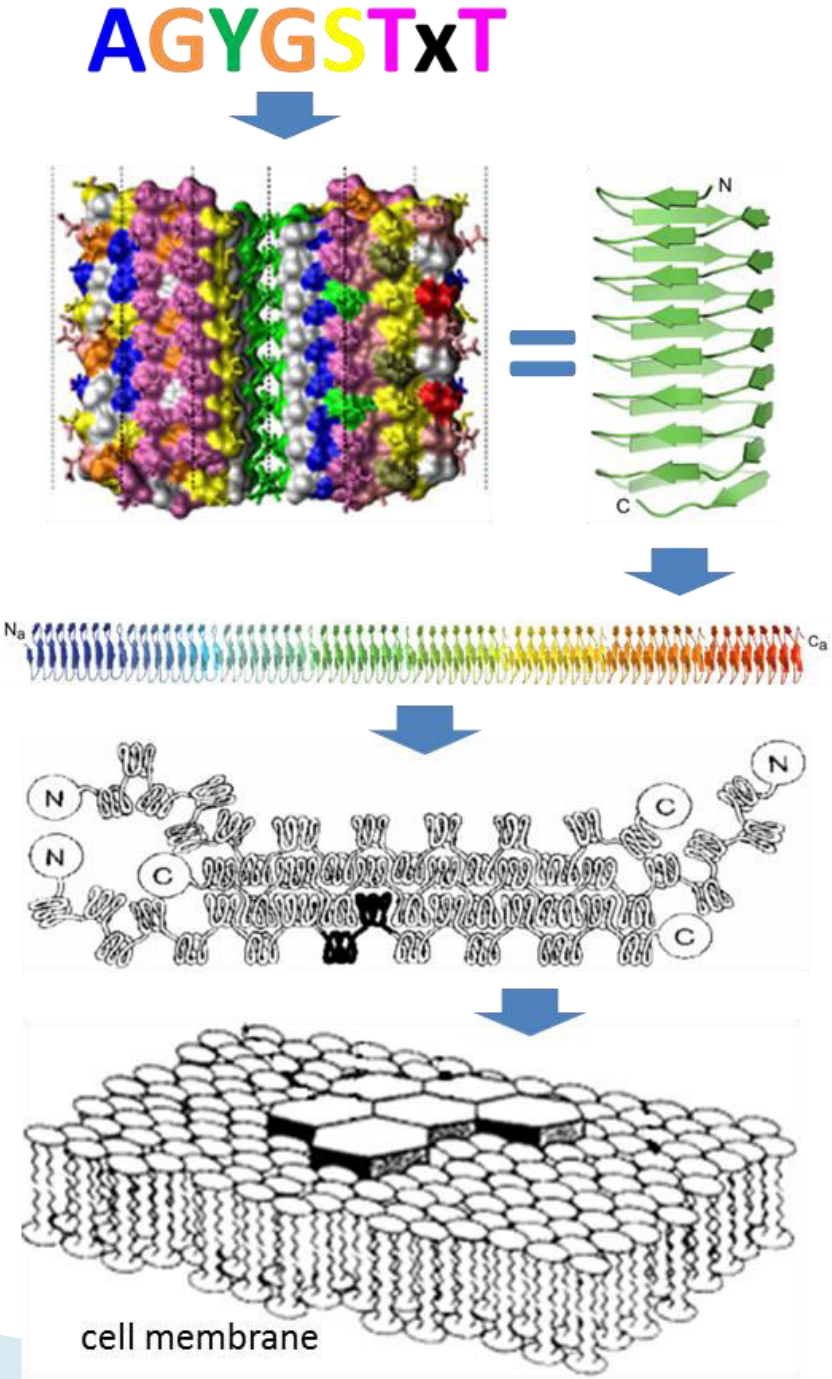
Pummer et al.: Atmos. Chem. Phys., 15, 4077–4091, 2015.

INMs: the solubility issue

- „IN have to be insoluble“
- INMs are in solution, but large enough to be ice templates
- INMs carry hydration shells → site of embryo formation



bactINMs



References:

- Pandey et al. (2016)
- Garnham et al. (2011)
- Kajava and Lindow (1993)
- Warren and Wolber (1991)

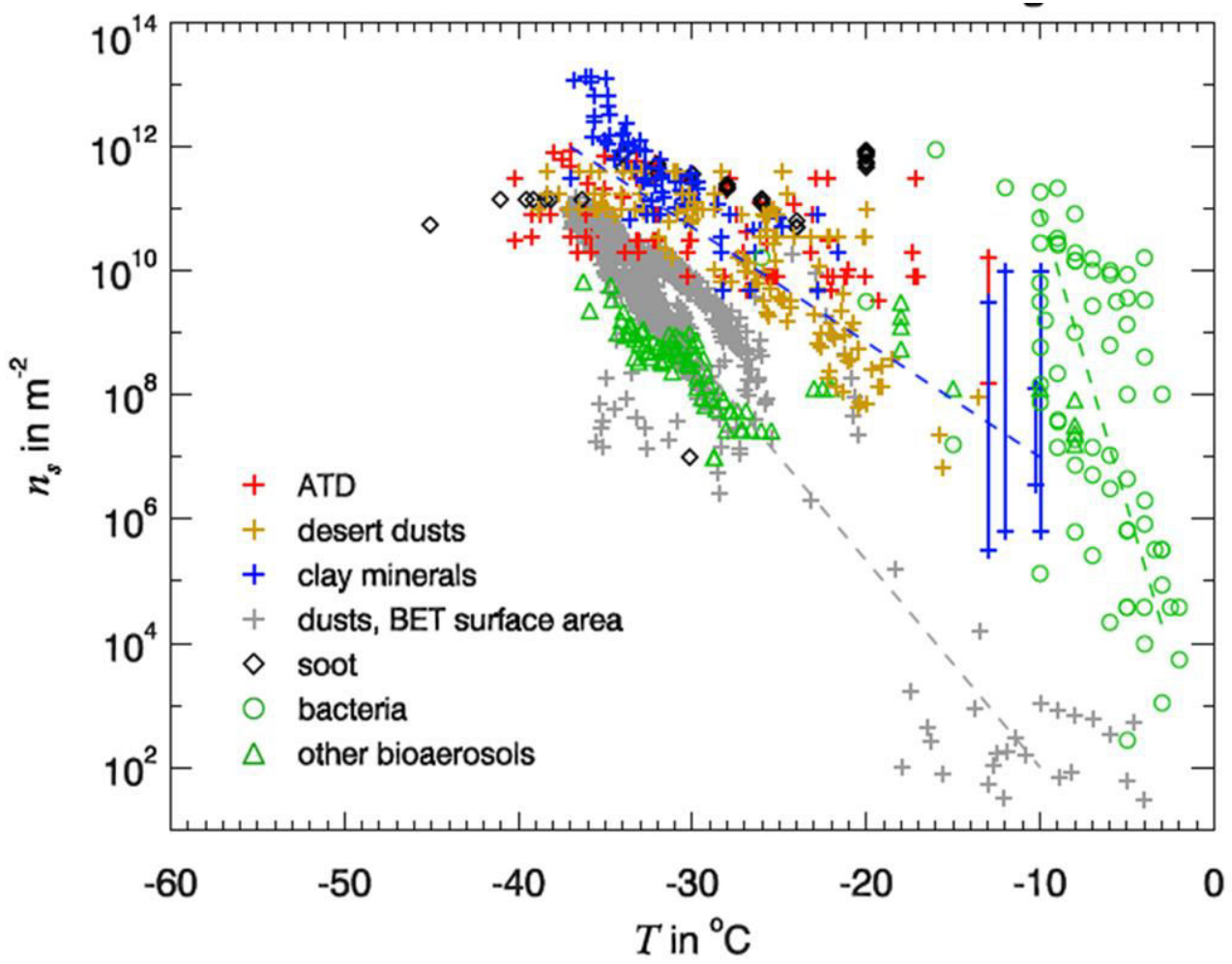
Type	Organism	INM?	Protein?	Sacch.?	References
Bact.	*Pseudomonas syringae*	+	+	+	Govindarajan and Lindow (1988)
	Pantoea agglomerans (*Erwinia herbicola*)	+	+	+	Govindarajan and Lindow (1988)
Fungi	*Rhizoplaca chrysoleuca*	+	+	–	Kieft and Ruscetti (1990)
	Fusarium avenaceum	+	+	–	Pouleur et al. (1992), Hasegawa et al. (1994)
	Sarocladium (*Acremonium*) *implicatum*	+	+	–?	Pummer et al. (2015)
	Isaria farinosa	+	+	–?	Pummer et al. (2015)
	Mortierella alpina	+	+	–?	Fröhlich-Nowoisky et al. (2015)
	Puccinia (rust) spp.	+	??	+	Morris et al. (2013a)
Animals	*Tipula trivittata*	+	+	+?	Duman et al. (1985, 1991), Neven et al. (1989)
	Dendroides canadensis	+	+	–?	Olsen and Duman (1997)
	Vespula maculata	+	+	–	Duman et al. (1984)
	Eurosta solidaginis (phosphate spherules)	–	–	–	Mugnano et al. (1996)
	Rana sylvatica	??	??	??	Storey and Storey (1985)
	Mytilus edulis	??	??	??	Lundheim (1997)
Plants	*Secale cereale* leaves	+	+	+	Brush et al. (1994)
	Prunus spp. wood	??	–	??	Gross et al. (1988)
	Betula pendula pollen	+	–	+	Pummer et al. (2012)
	Lobelia telekii fluid	+	–	+?	Krog et al. (1979)
	Opuntia ficus-indica fluid	+	–	+	Goldstein and Nobel (1991)
	cellulose	+	–	+	Hiranuma et al. (2015)
	lignin	+	–	–	Gao et al. (1999)
	some algae	+?	??	??	Schnell (1975), Wilson et al. (2015)

Effects of Experiments

Species	birch pollen	Snomax™	*Mortierella*	*Isaria*	*Saro-cladium*
T_{INA}	255 K	271 K	267 K	269 K	264 K
heat	460 K	310 / 415 K	<371 K	>335 K	>335 K
0.1 µm	none	–	none	none	none
300 kDa	none	–	none	minor	none
100 kDa	major	major	major	major	major
CN_3H_6Cl	none	major	major	major	major
H_3BO_3	minor	–	none	none	none
proteases	none	major	major	major	major
lipases	none	minor	none	none	minor
saccharases	none	minor	none	none	none

Pummer et al., 2012, 2015; Fröhlich-Nowoisky et al., 2015

Atmospheric Relevance



Hoose and Möhler: Atmos. Chem. Phys., 12, 9817–9854, 2012.

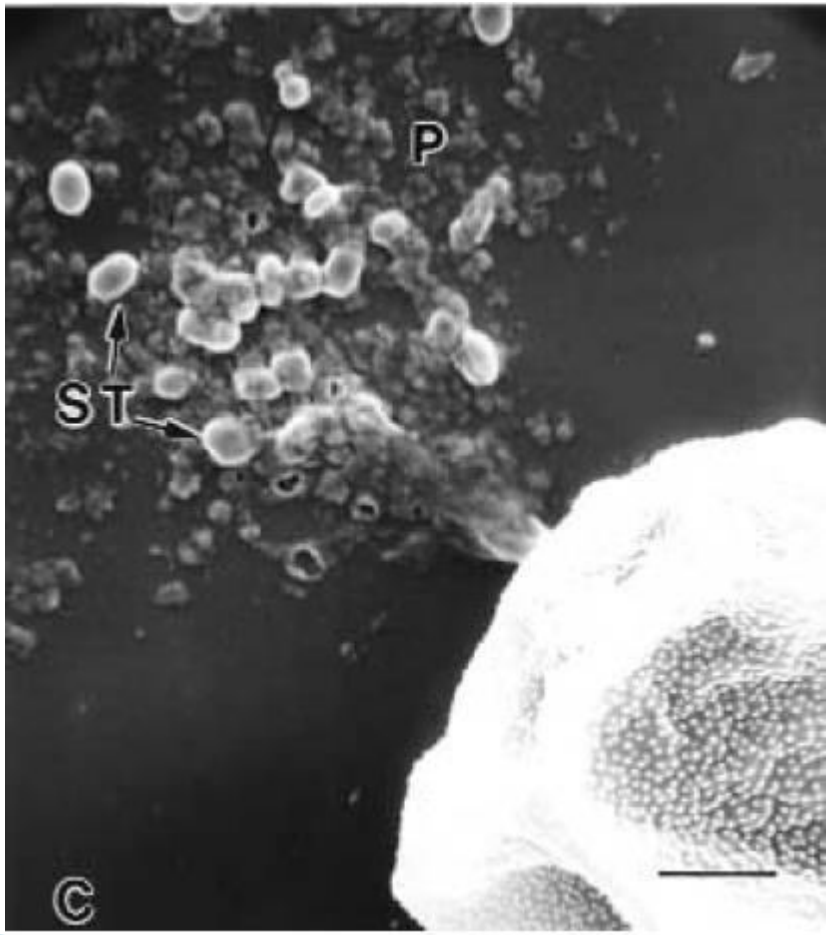
Atmospheric Relevance

- BioINMs are – mostly – easily extracted from carrier cells with water (Pummer et al., 2015)
- In nature: water = clouds, precipitation, lakes, rivers, oceans, soil humidity
- Distribution in soil, water, air
- Precipitation increases atmos. IN conc. (Huffman et al., 2015)
- Feedback cycle: IN <=> precipitation (Morris et al., 2014)

Huffman et al.: Atmos. Chem. Phys., 13, 6151–6164, 2013.
Morris et al.: Global Change Biol., 20, 341–351, 2014.

Atmospheric Relevance

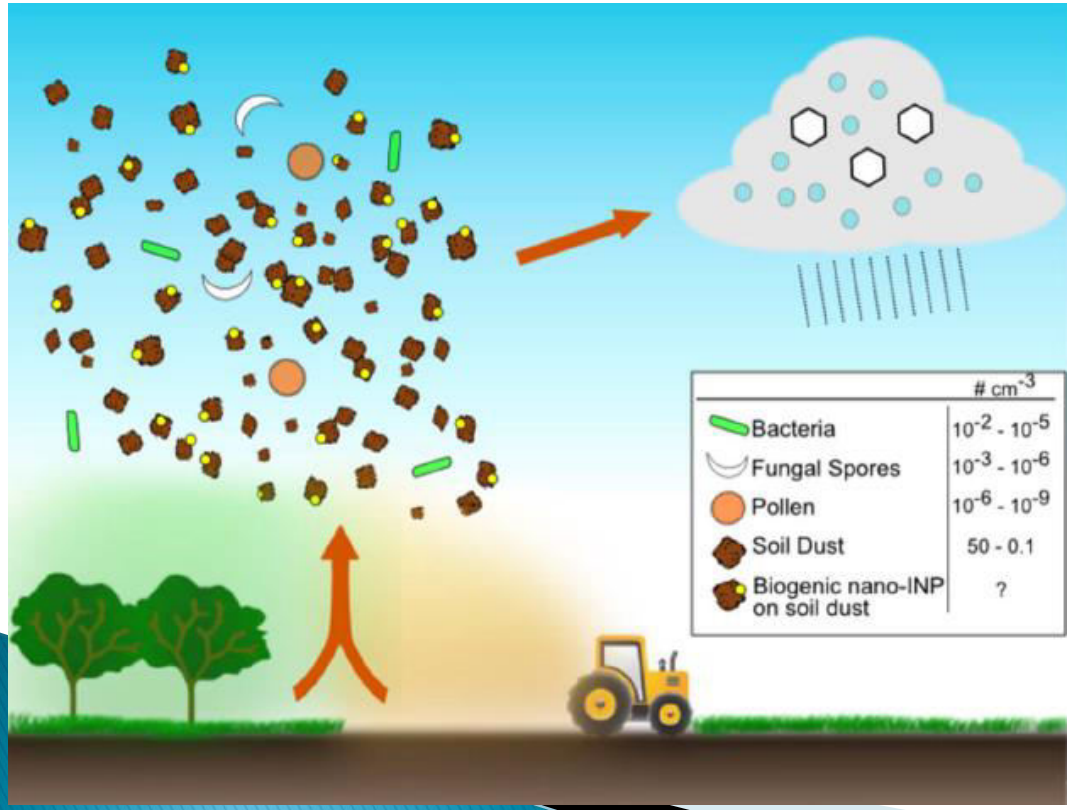
- Bursting processes

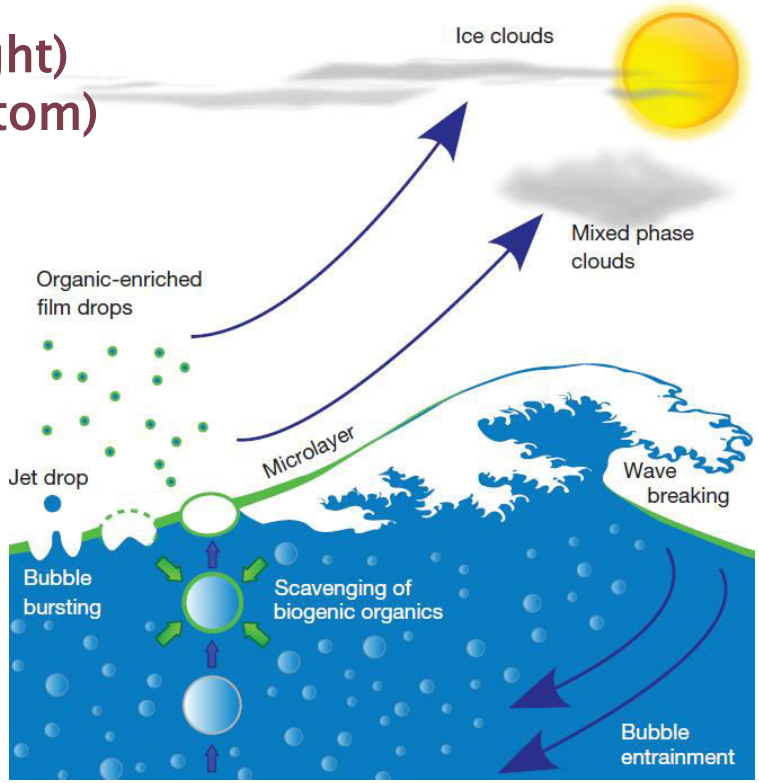


Grote et al.: J. Allerg. Clin. Immunol., 105, 1140-1145, 2000.

Atmospheric Relevance

Wilson et al.: Nature, 525, 234–238; 2015. (right)
O'Sullivan et al.: Sci. Rep., 5, 8082; 2015. (bottom)





Acknowledgement

- Max Planck Society, Vienna University of Technology …for funding
- WG Koop (Bielefeld), WG Stratmann (Leipzig)
- Family & Friends
- **Thank you for your attention!**
- **Questions?**

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