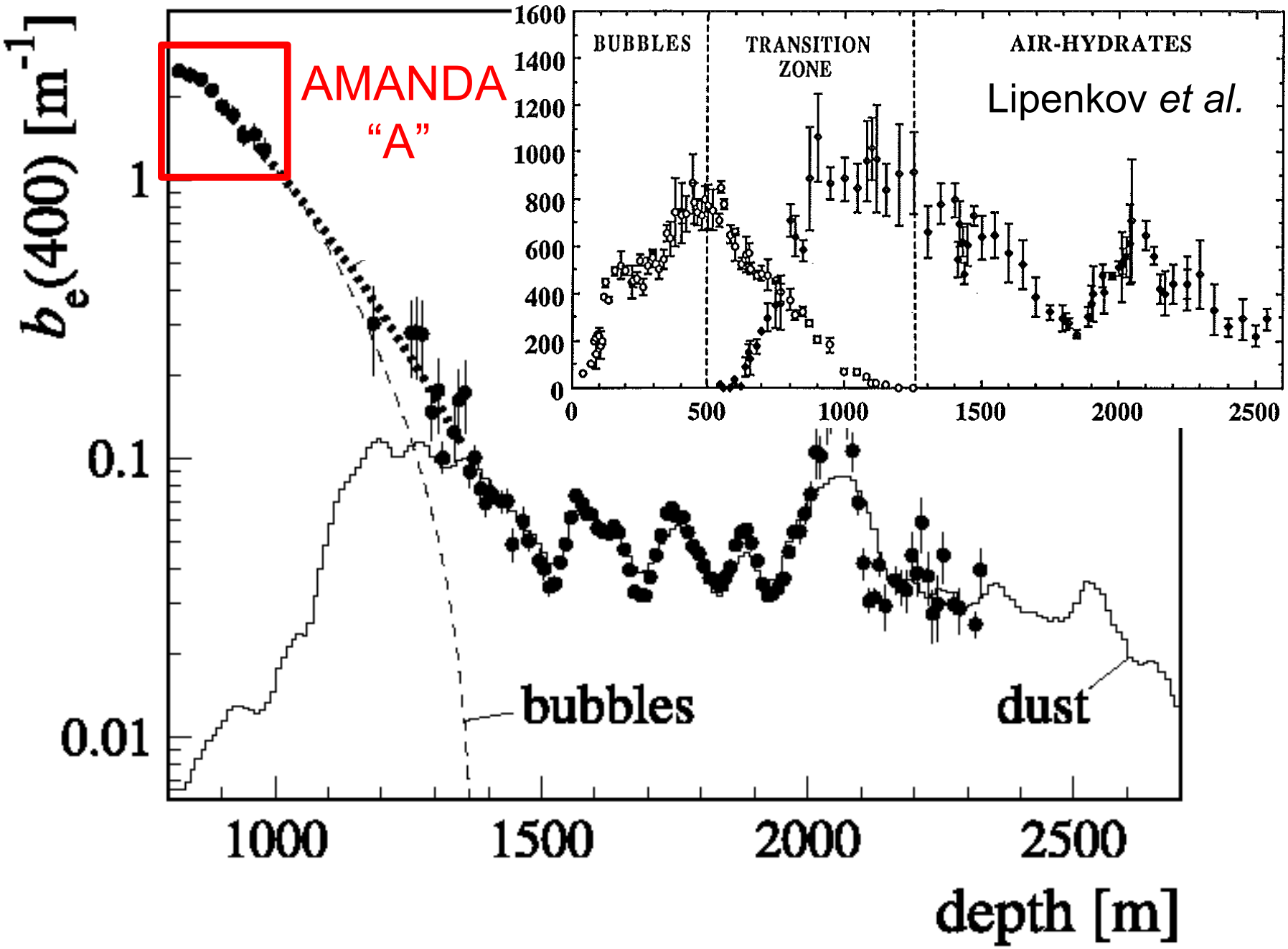
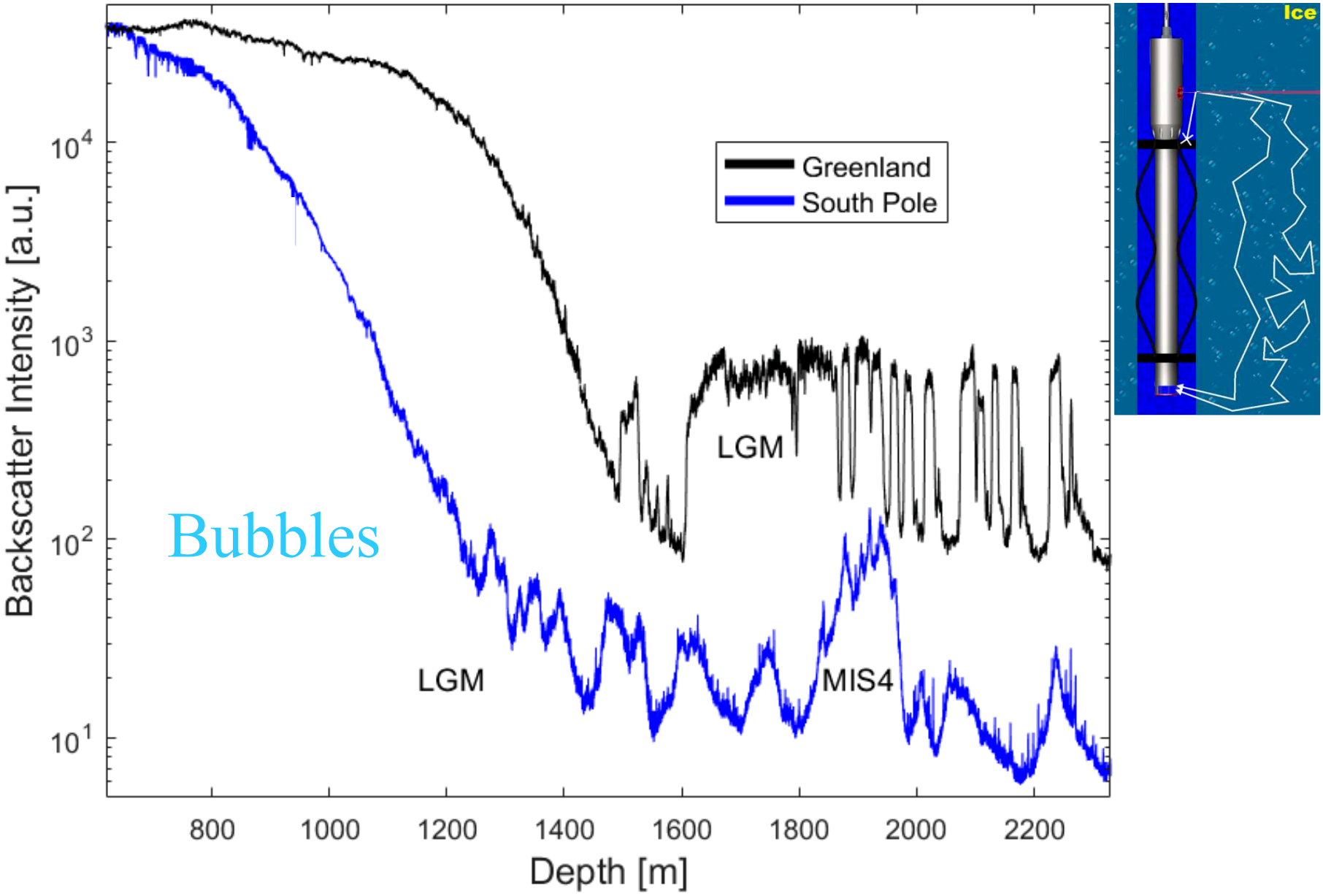
What have we learned about ice since AMANDA?

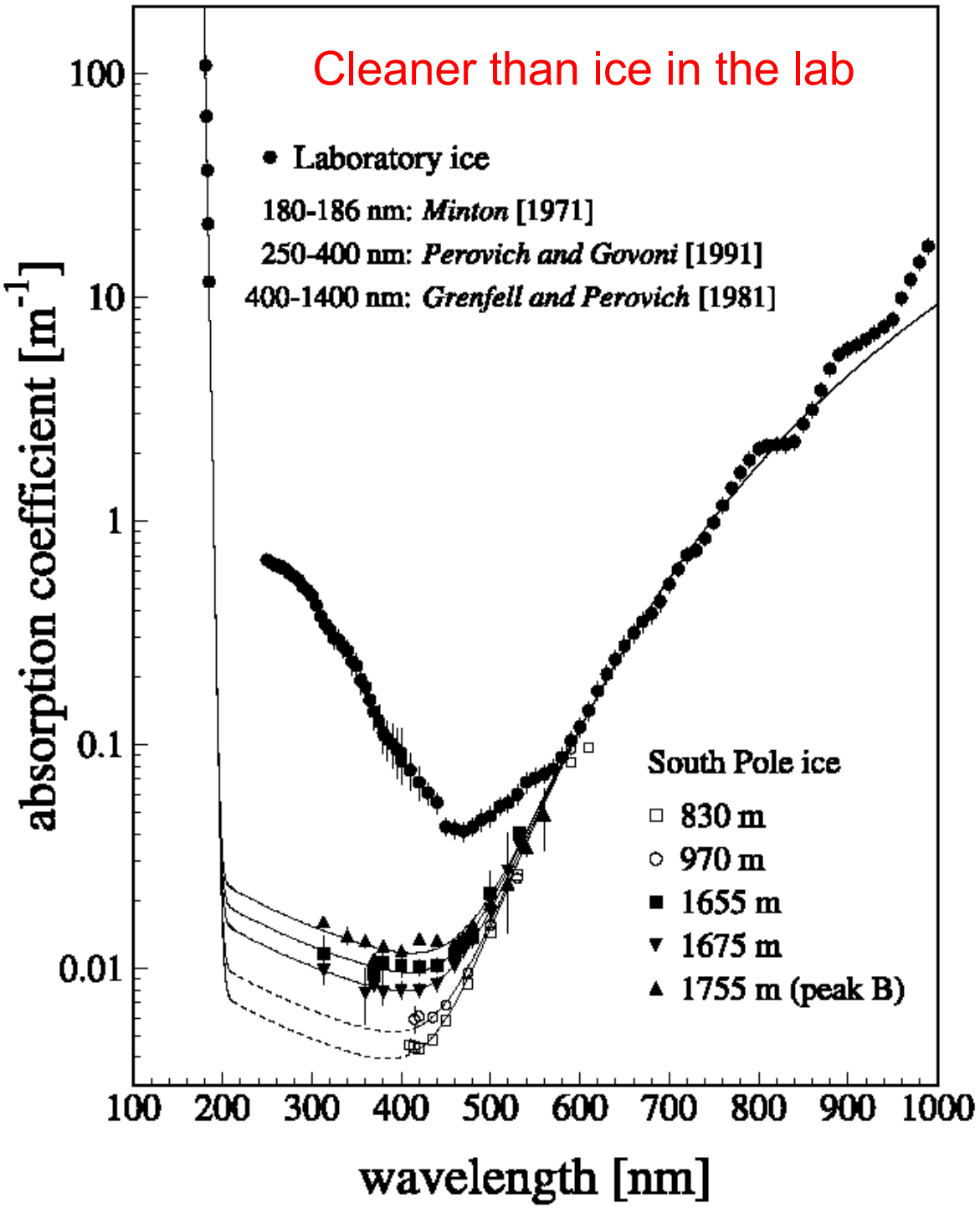
Ryan Bay
UC Berkeley

AMANDA first light

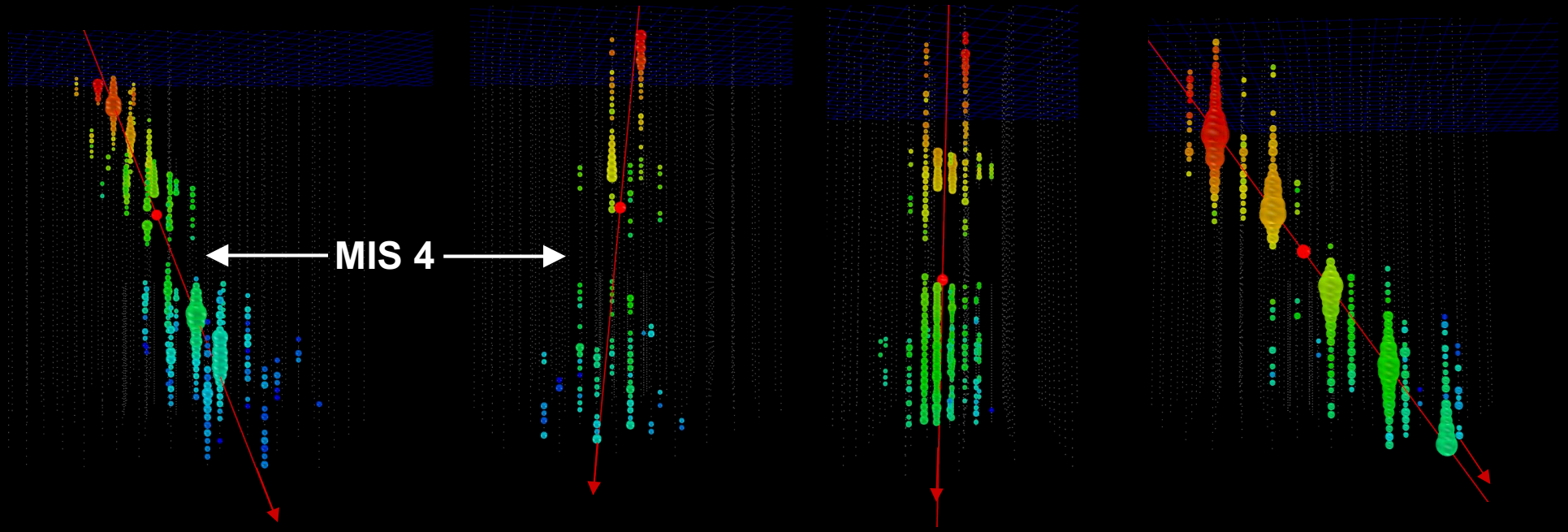


Rapid analysis with dust logging

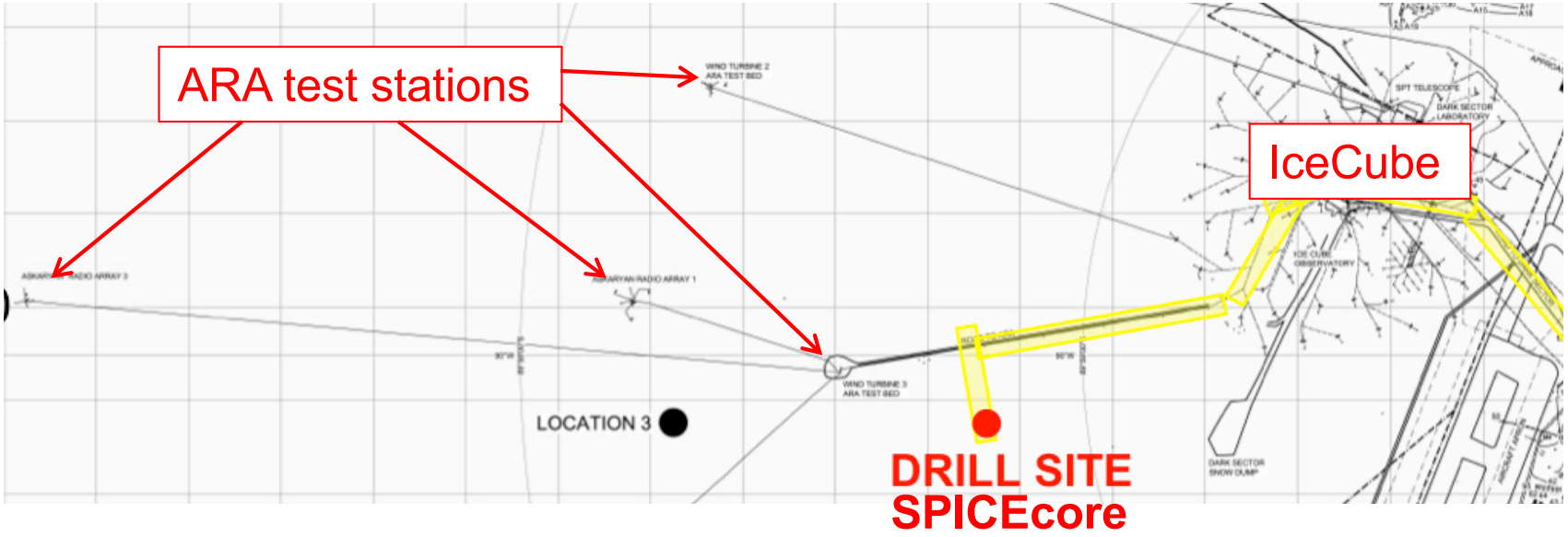



Cleaner than ice in the lab
Laboratory ice
180-186 nm: Minton [1971]
250-400 nm: Perovich and Govoni [1991]
400-1400 nm: Grenfell and Perovich [1981]
South Pole ice
830 m
970 m
1655 m
1675 m
1755 m (peak B)
absorption coefficient [m-1]
wavelength [nm]
100
10
1
0.1
0.01
100
200
300
400
500
600
700
800
900
1000

IceCube events and “The Dust Layer”



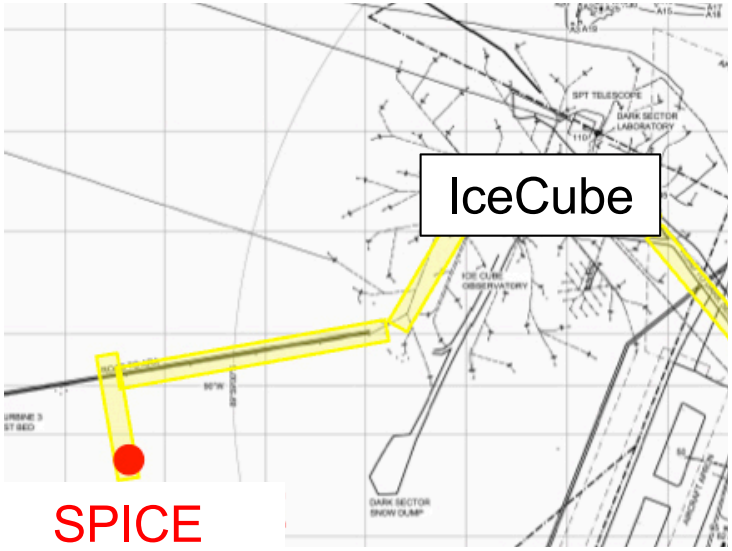
Finally, a deep ice core on AstroTurf

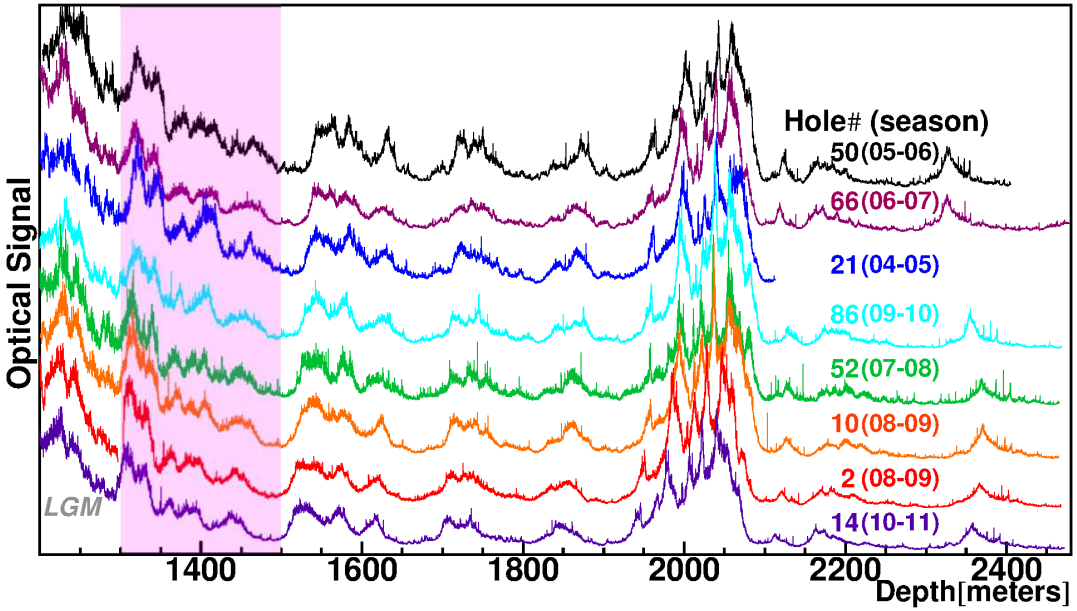


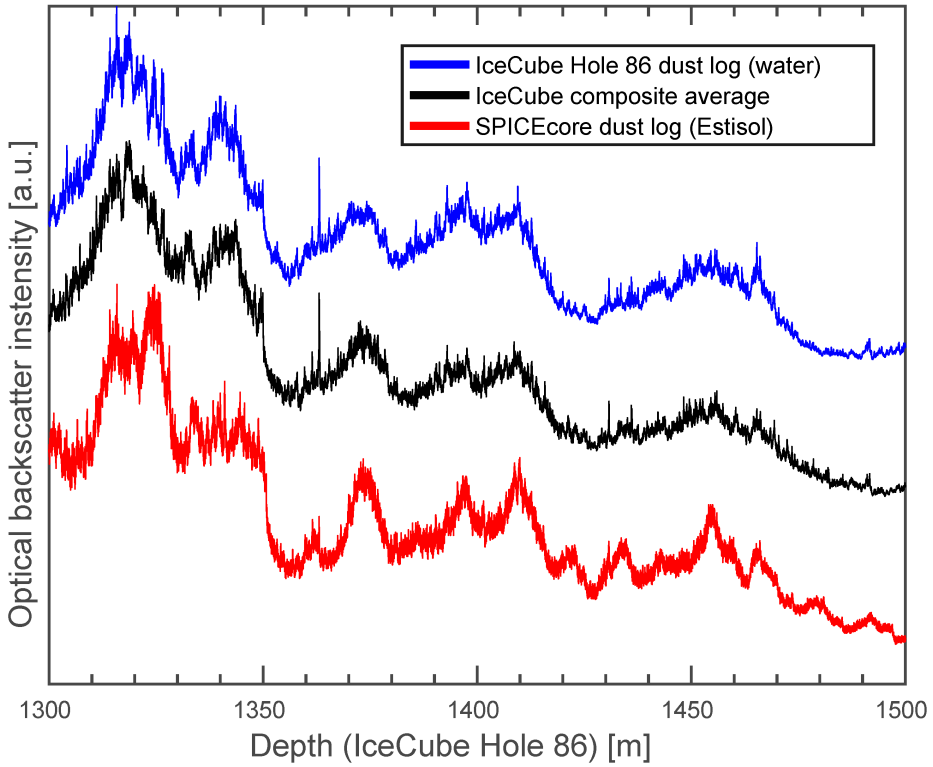
SPICEcore-astroparticle synergies

- Samples(!) for ice properties
- Calibration beacons in borehole
- Anisotropy / Birefringence
- Layering and bedrock mapping
- UV attenuation
- Radioglaciology, cross-borehole tomography
- Complex permittivity vs. depth/temperature

Multi-borehole laser particulate stratigraphy

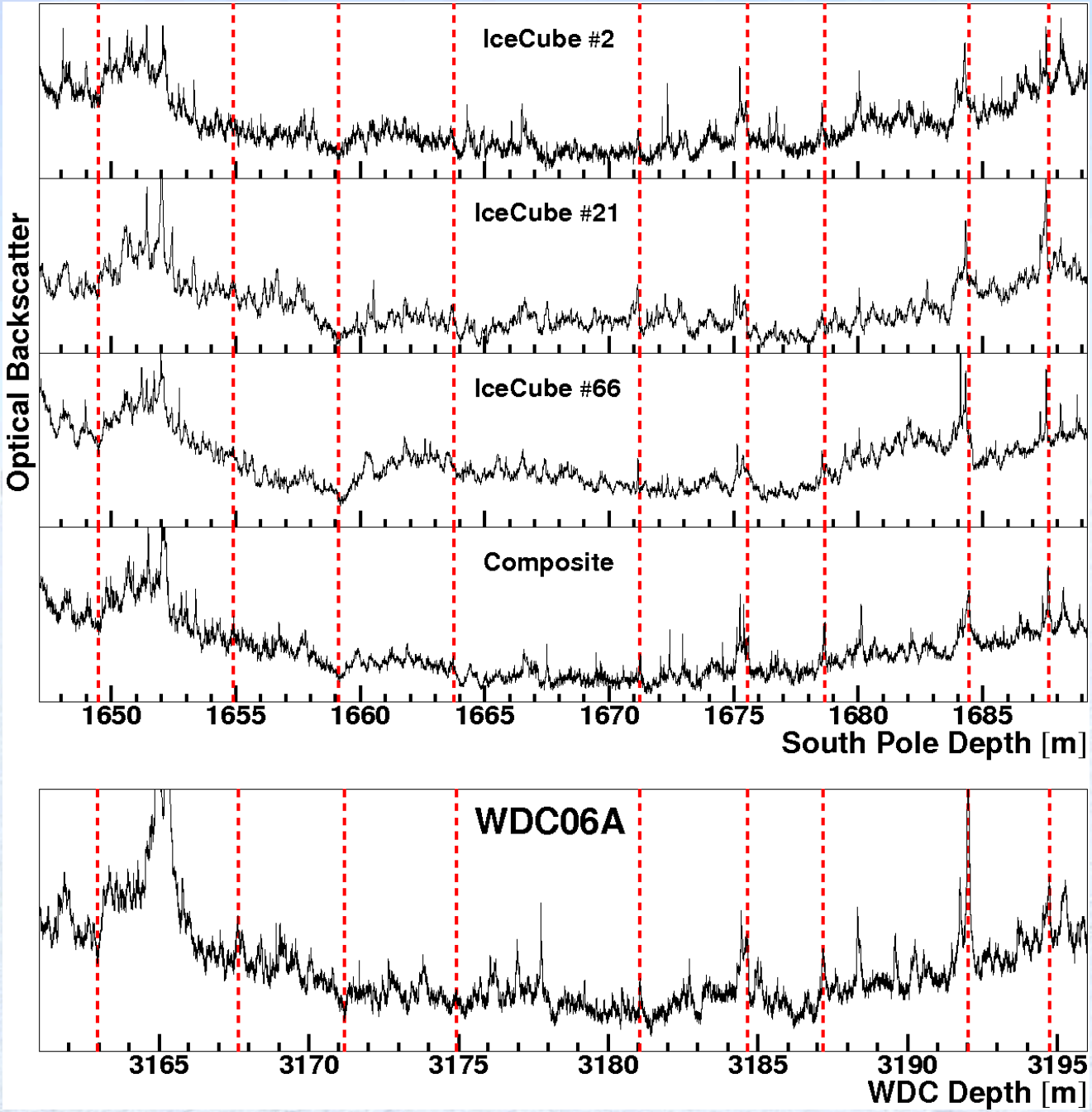






- Eight holes (hot water) dustlogged 2004-11
- SPICE (Estisol cored) logged December

Laser dust mapping near and far



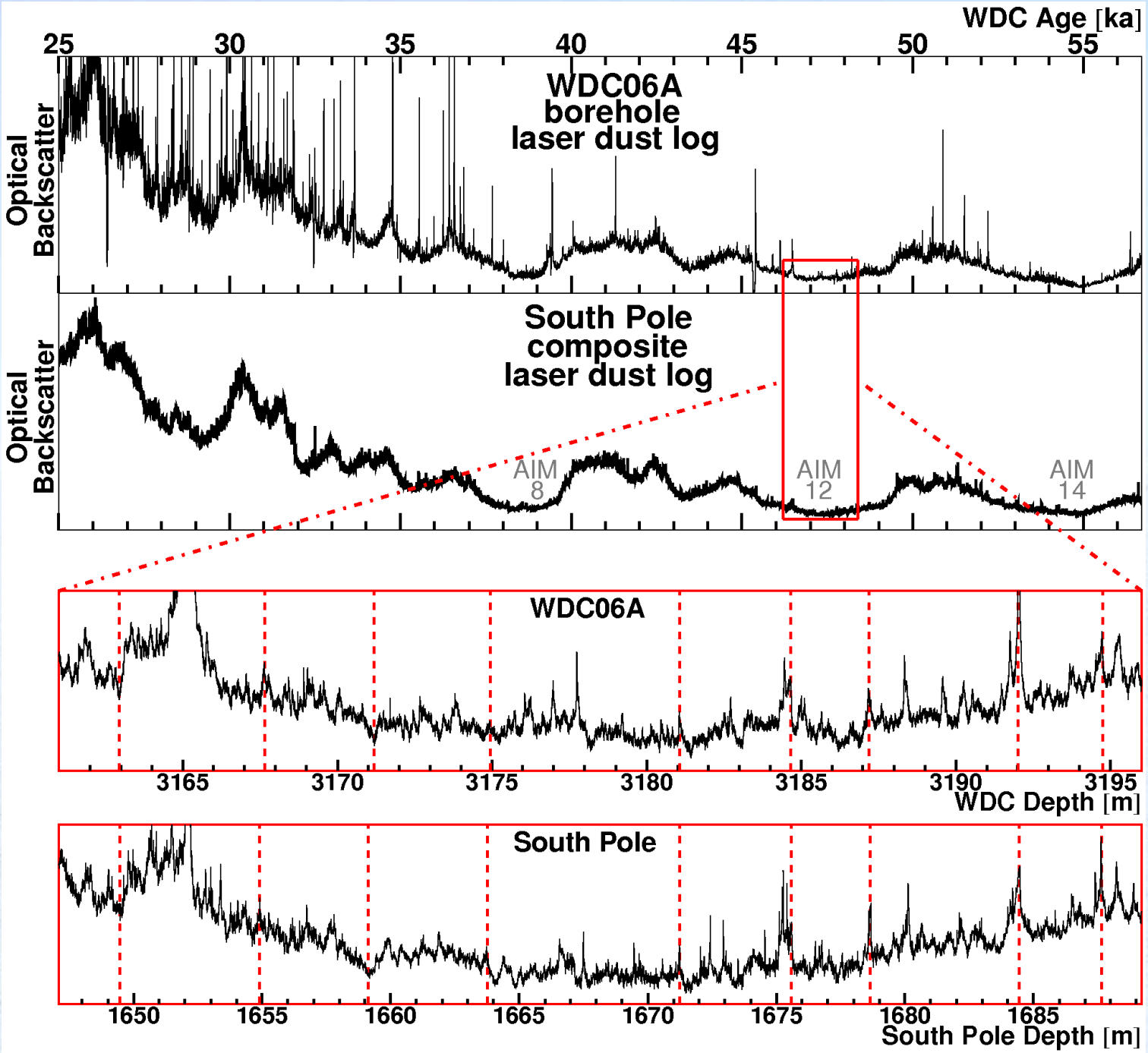
South Pole

10^2 -10^3 m

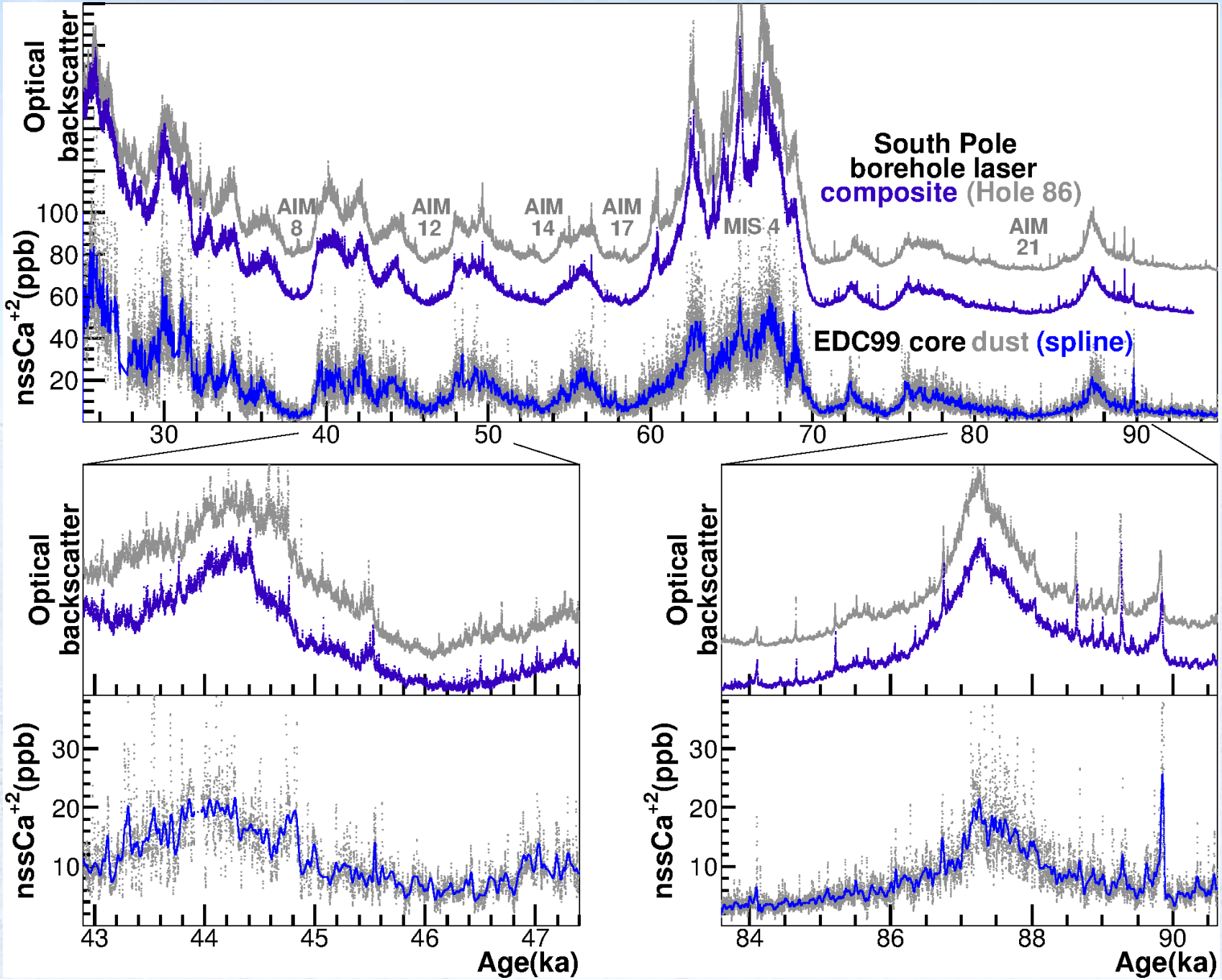
$>10^6$ m

WAIS Divide

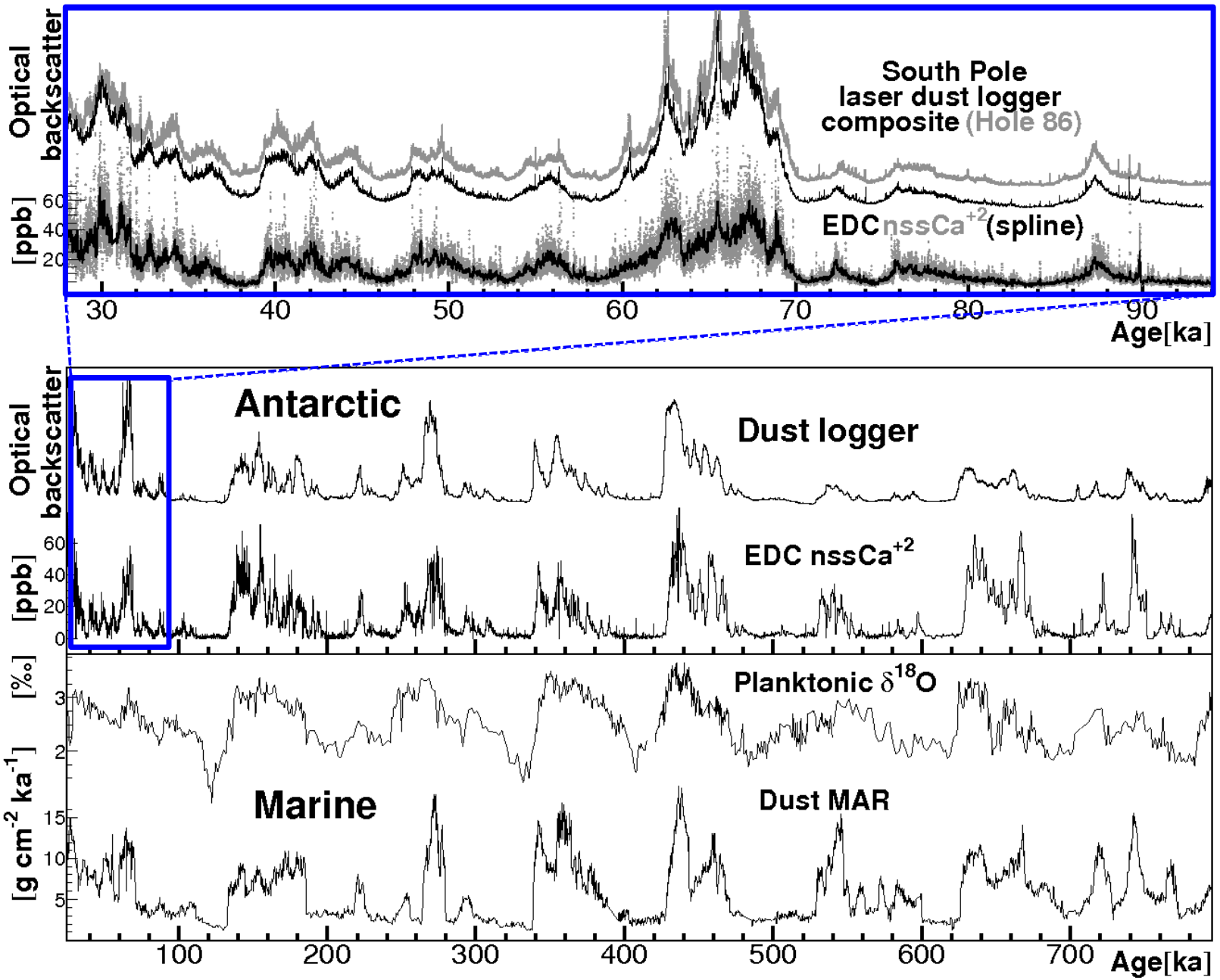
Laser dust mapping far and wide



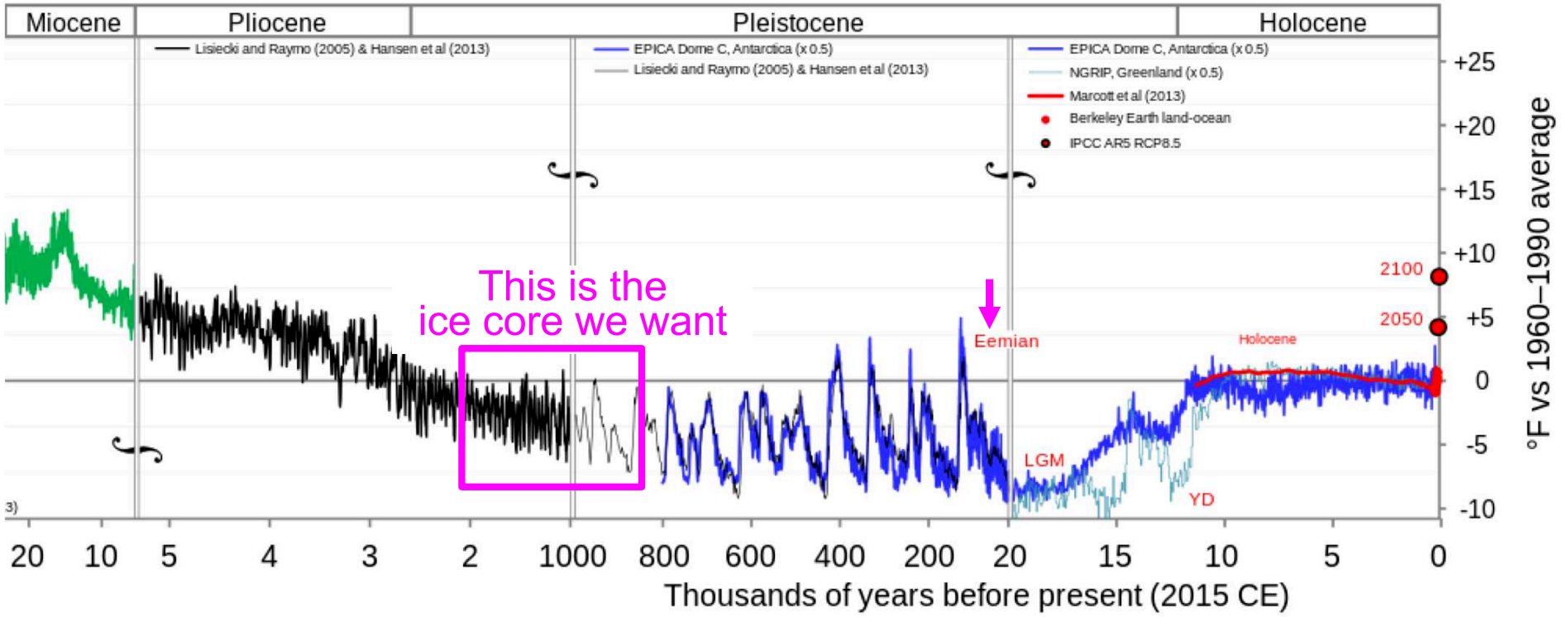
South Pole - Dome C dust synchronization



Dust logging for oldest ice

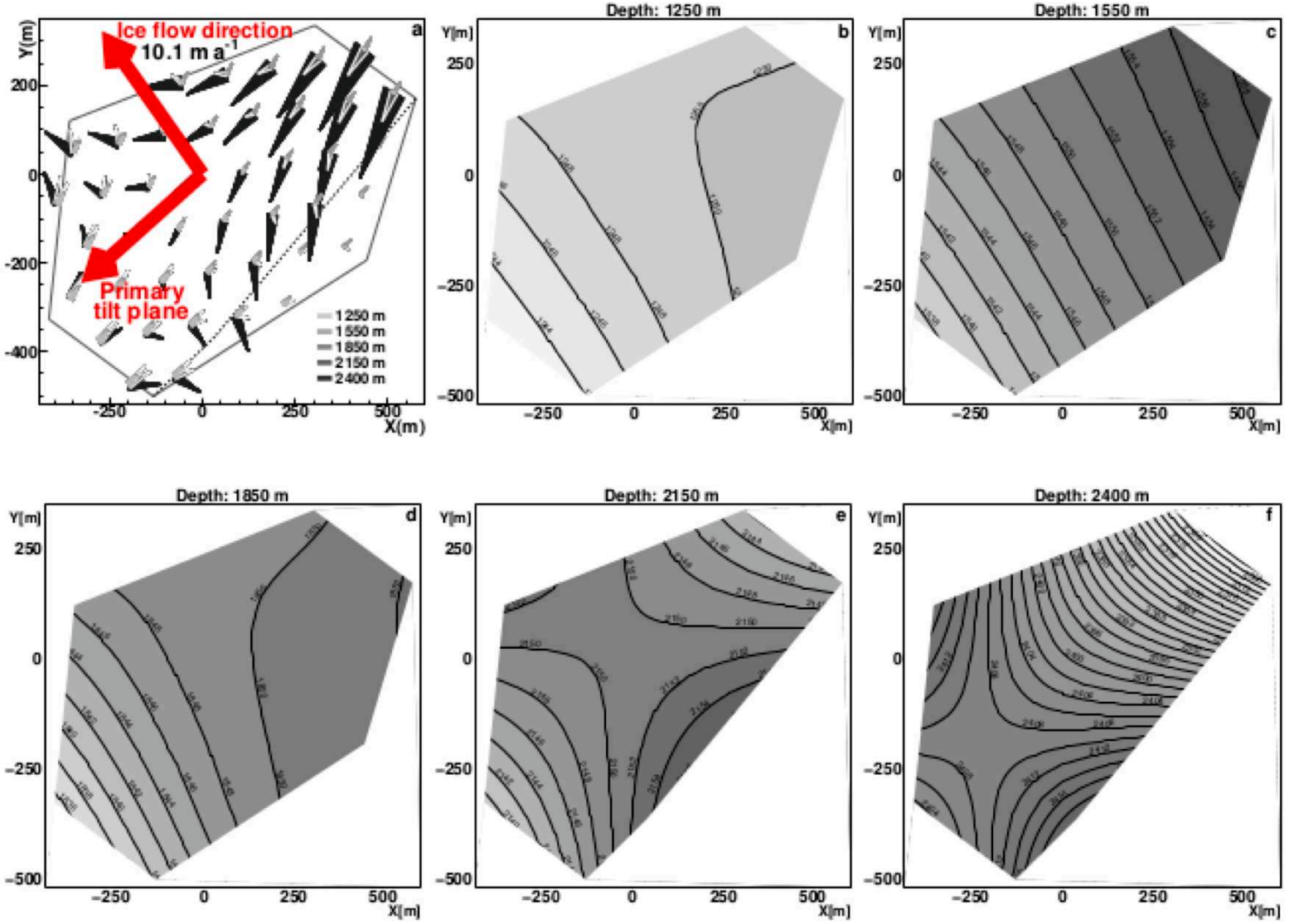


Temperature of Planet Earth

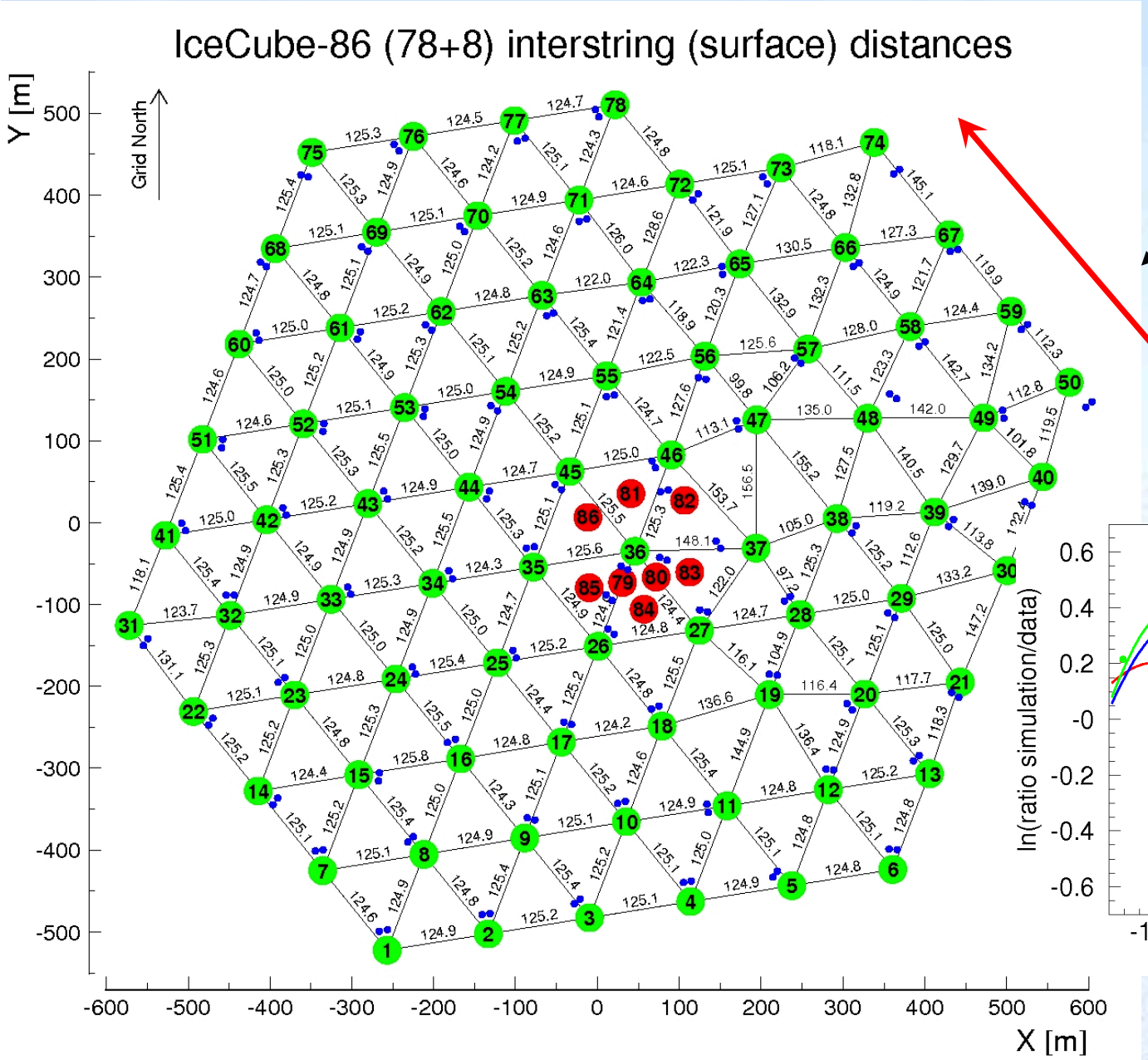


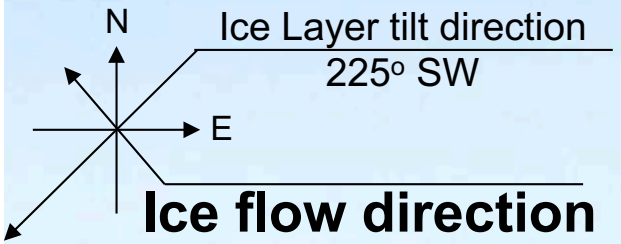
South Pole layer tilting

Up to 10% grade (100 m per lateral kilometer across IceCube)



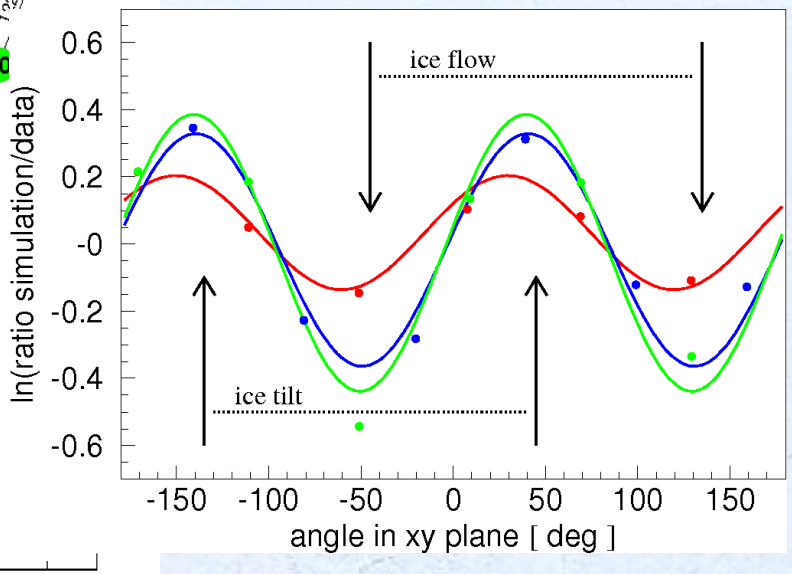
Anisotropy in South Pole ice



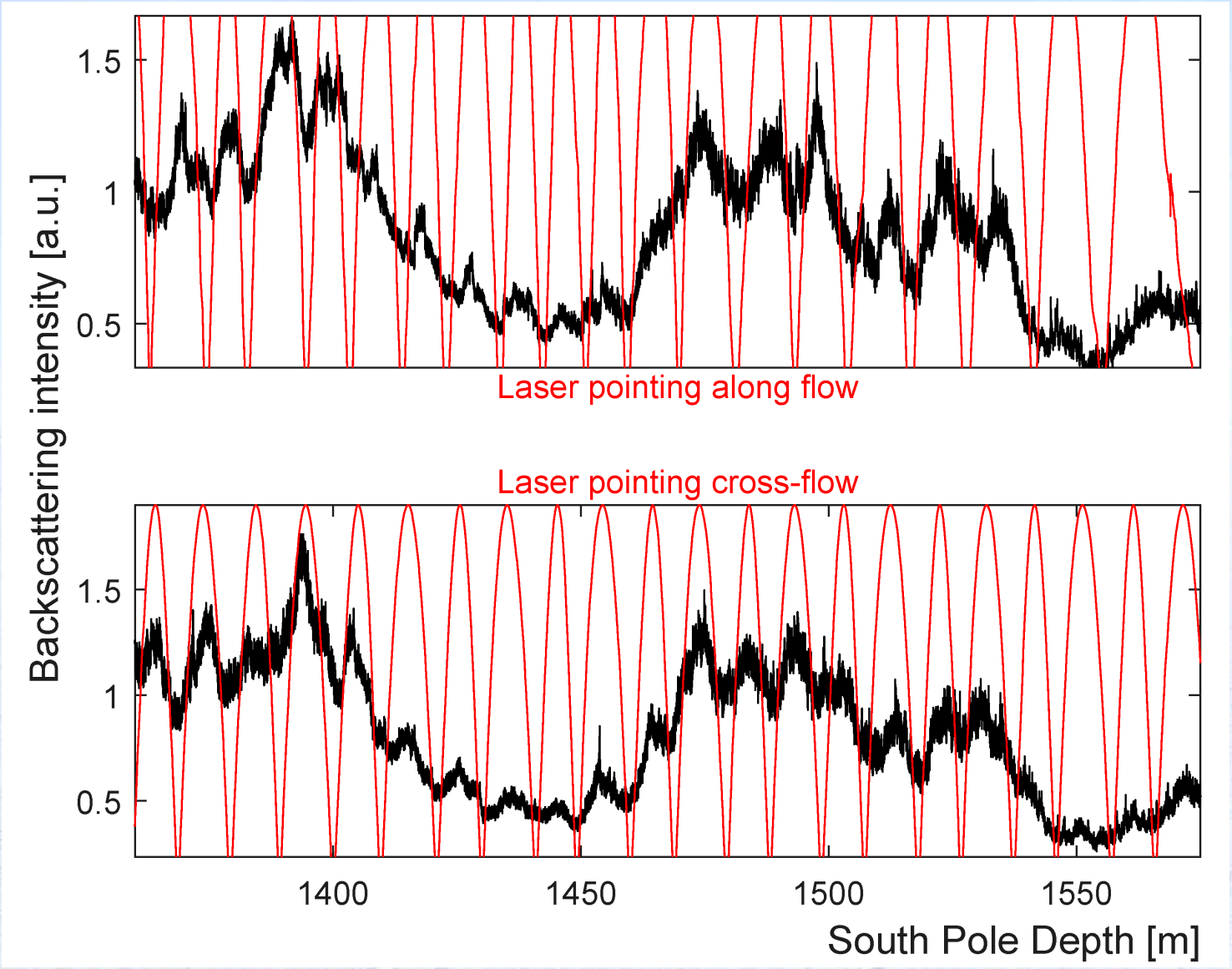


Ice flow direction
41° NW

9% less scattering
41° NW

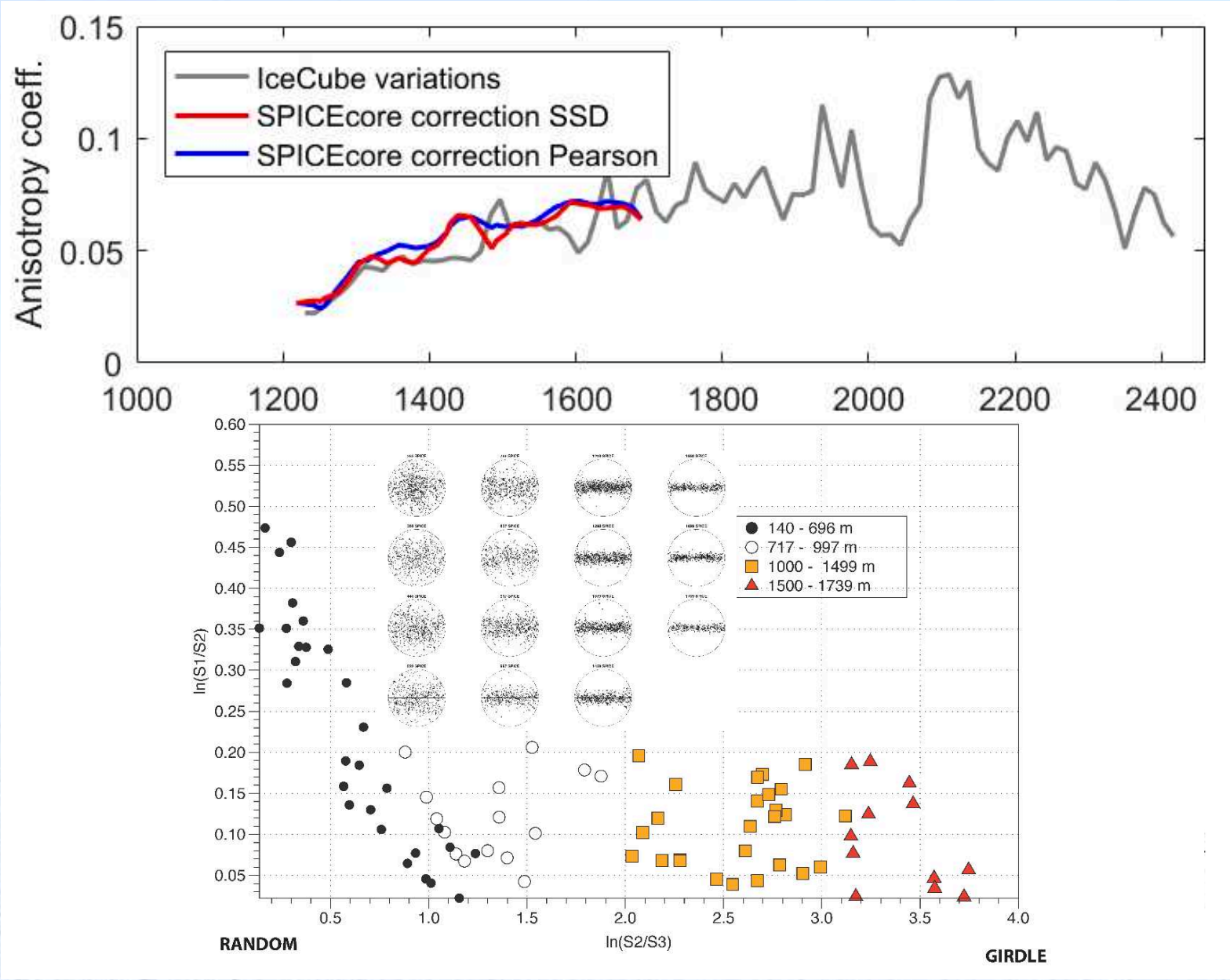


Anisotropy in SPICE dust log
(preliminary)

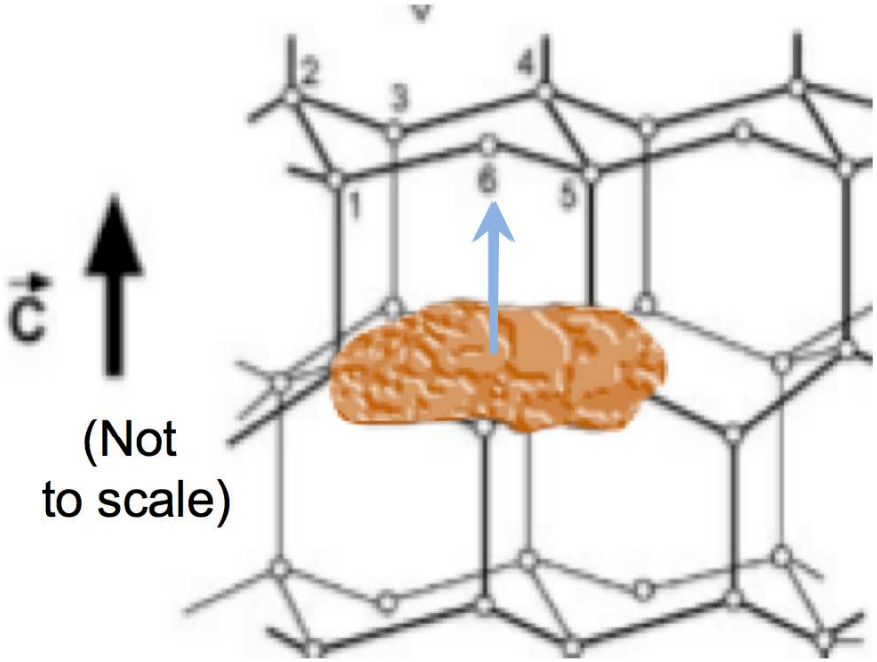


Fluxgate compass

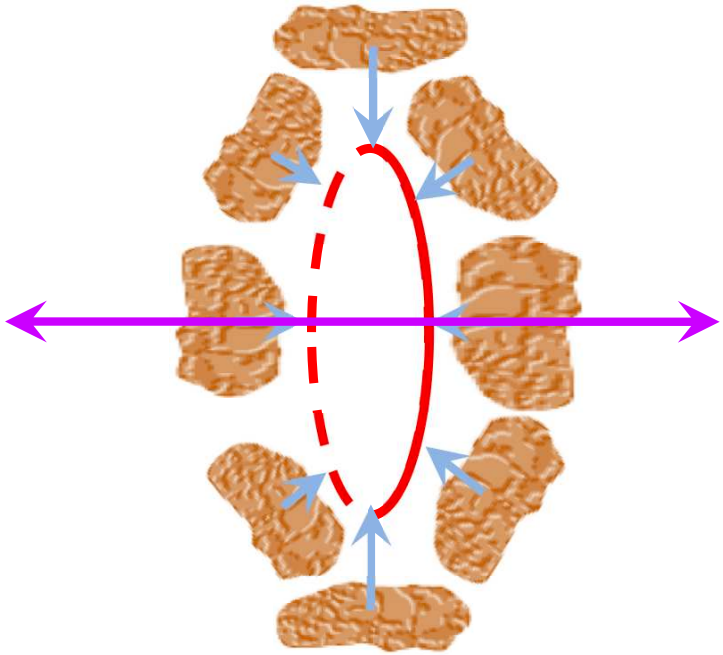
SP anisotropy in SPICE and IceCube dust logs
(preliminary)



Explanation #1:
Preferred orientation, fabric & scattering

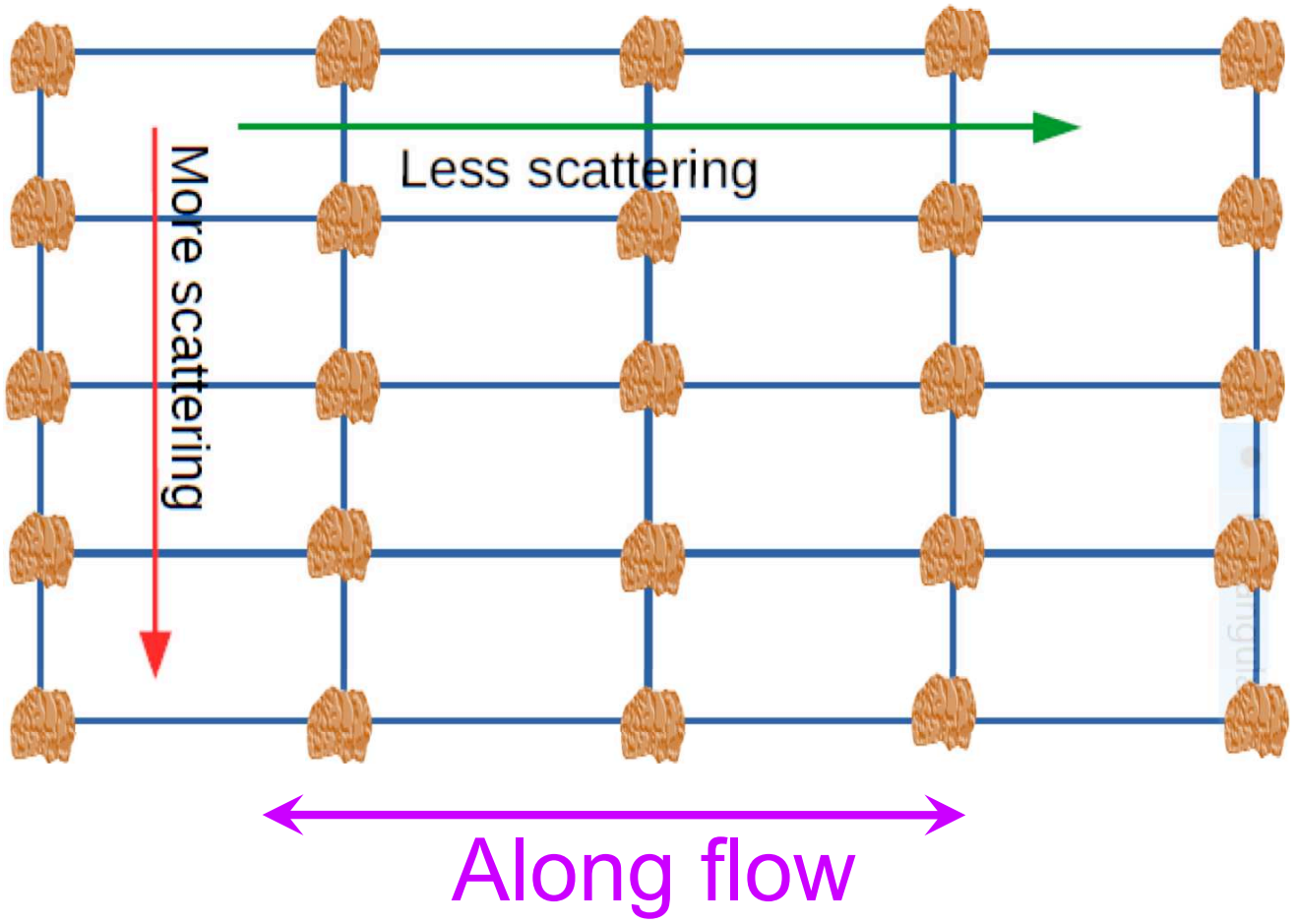


Vertical girdle

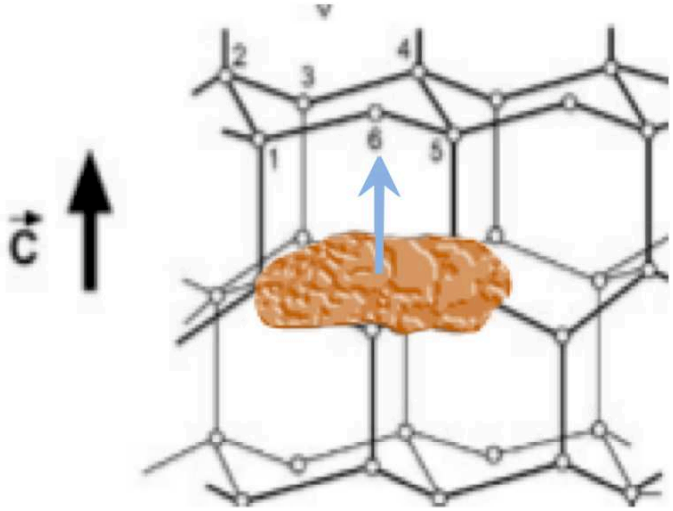


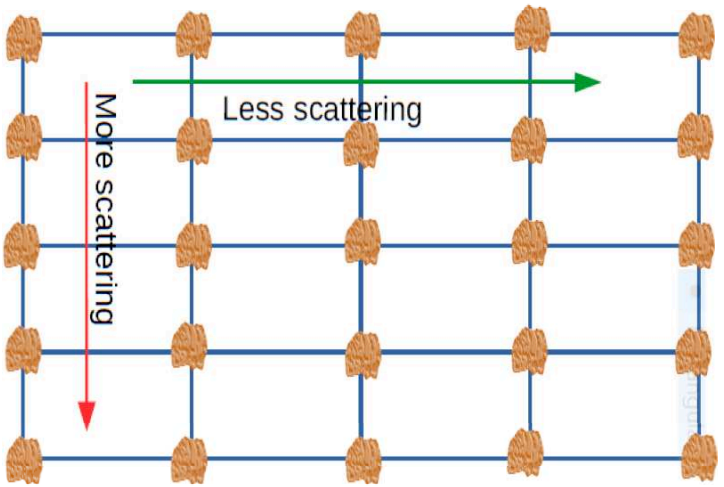
Less scattering
along flow

Explanation #2:
Preferred dilution (inhomogenous density)

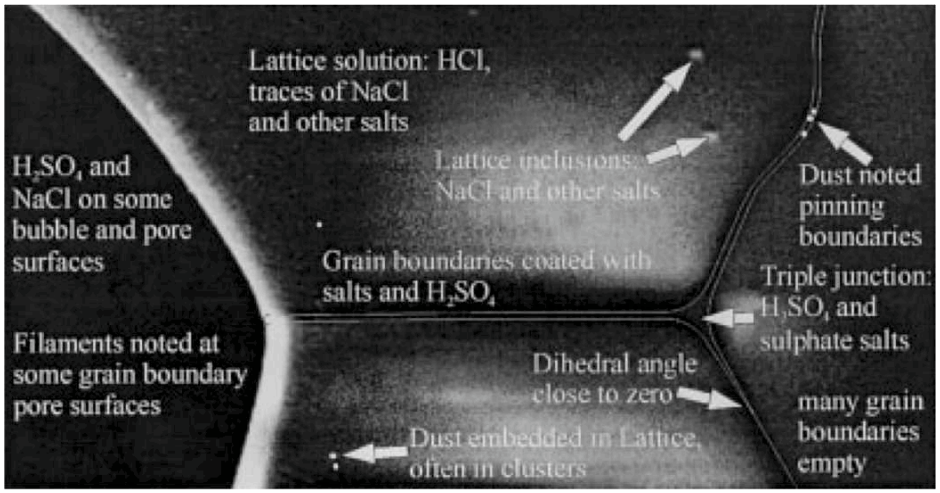


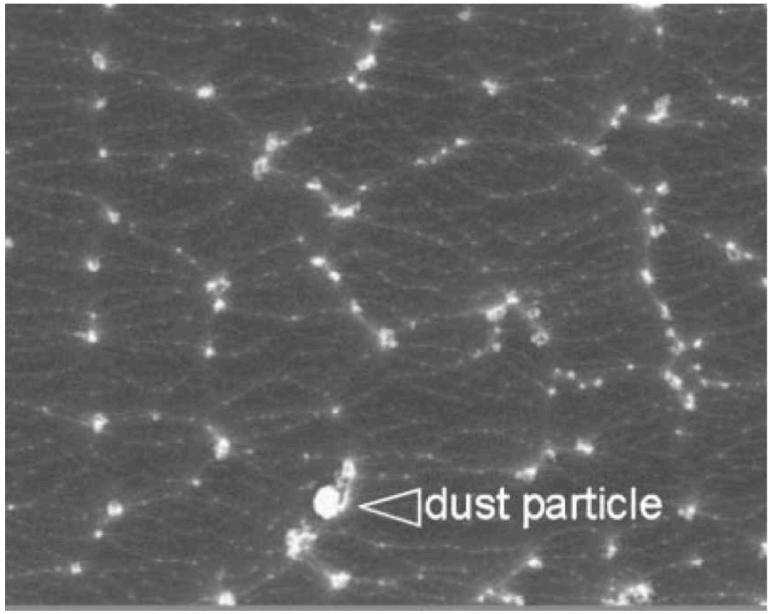
Preferred scattering



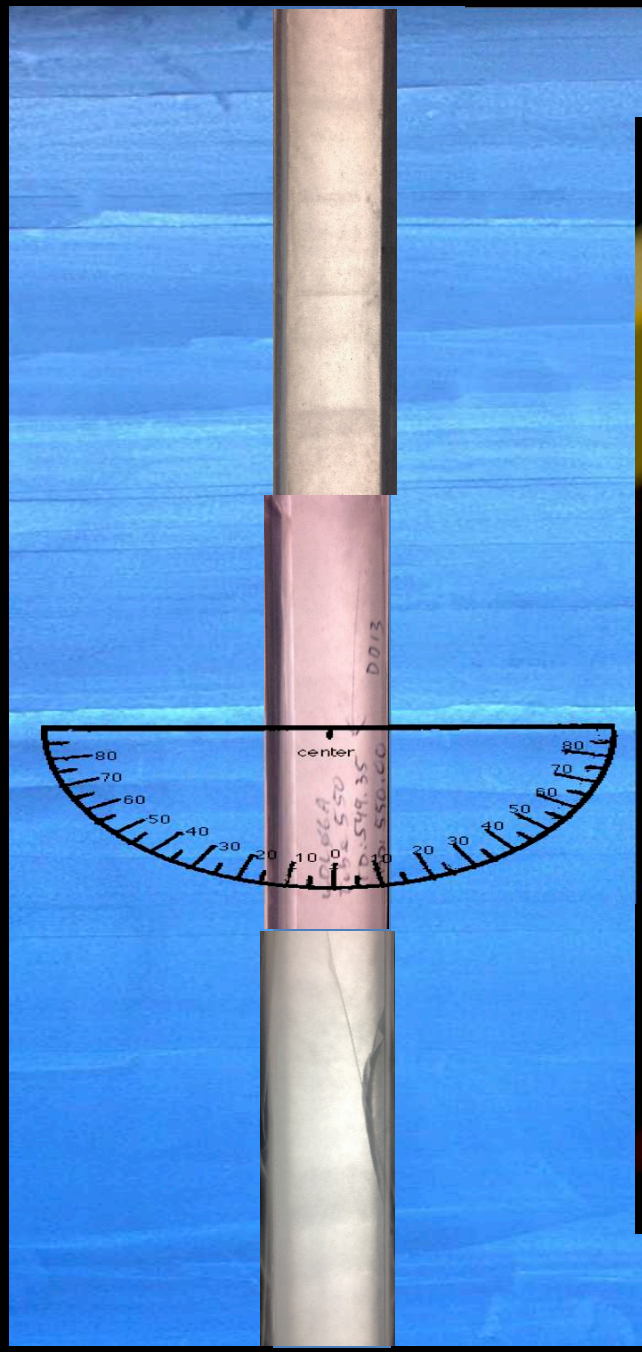


SEM (Barnes, Wolff *et al*. 2003)





Oriented ice coring?



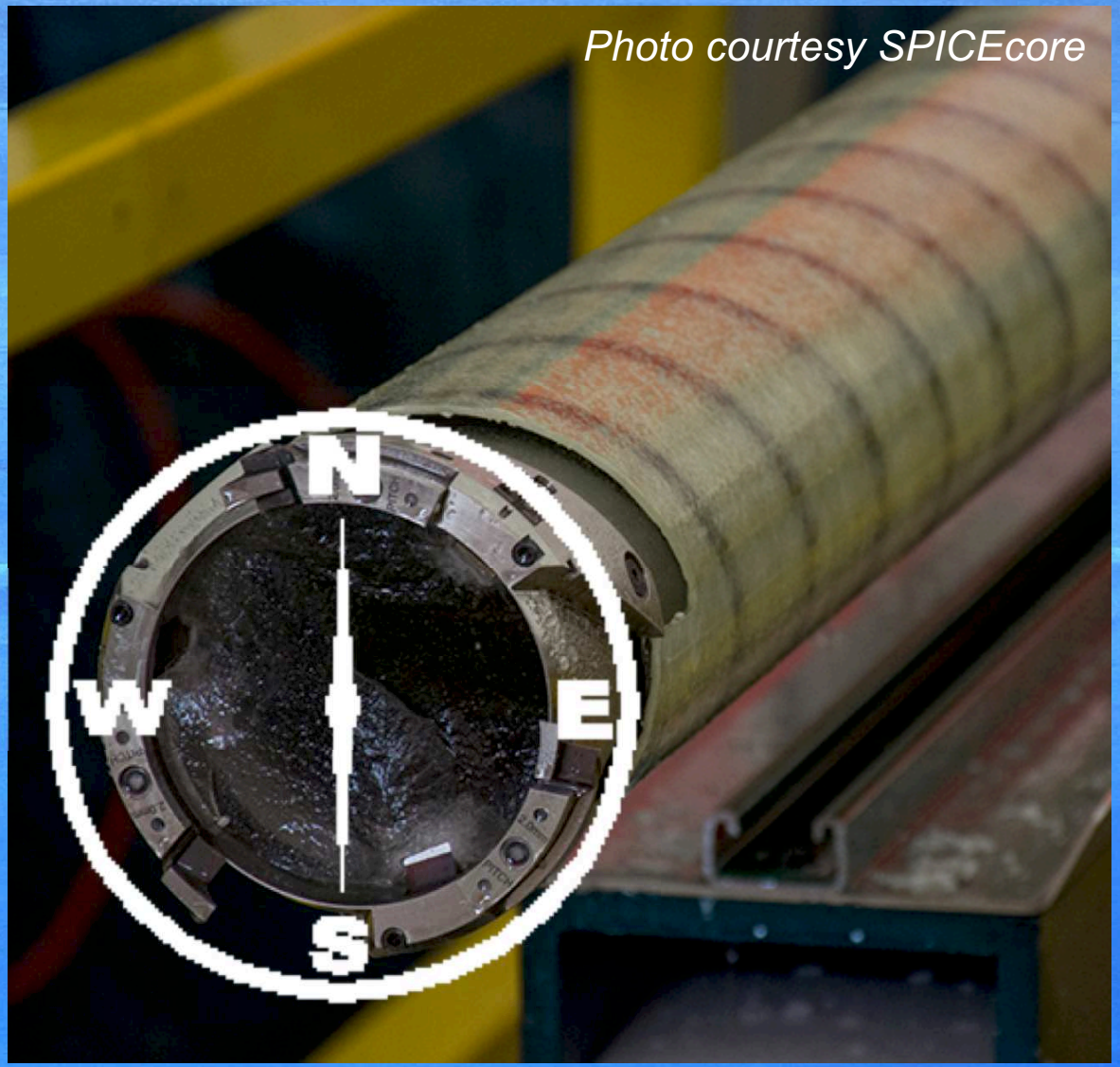
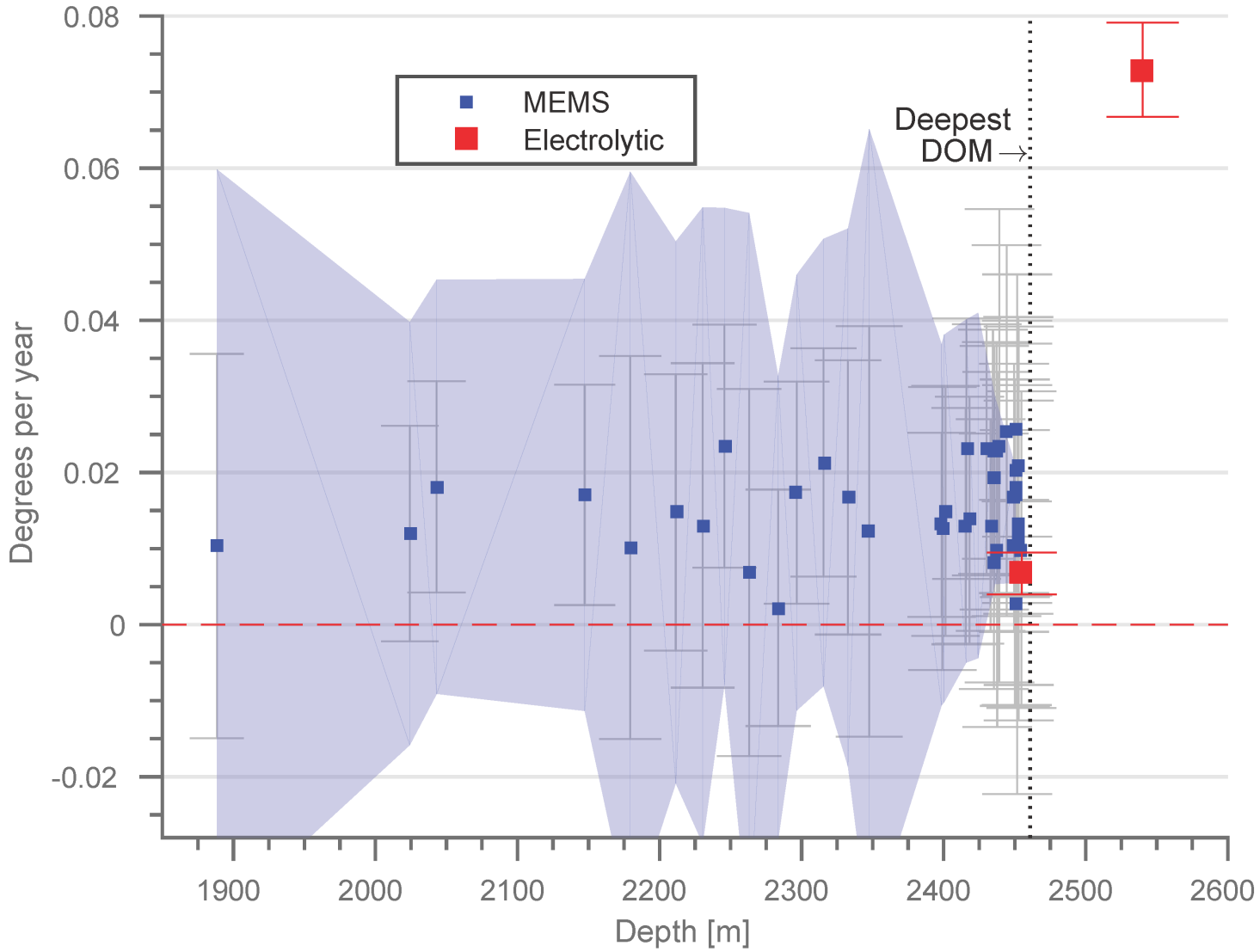


Photo courtesy SPICEcore

IceCube shear measurement

- 3D tracking of deep flow for evaluating complex full-stress models
- Compression-dominated → shear-dominated transition depends on temperature, grain size, impurities, fabric



Spotted: recent IceCube papers…

"Reconstruction...is challenging due to the complex optical properties of the natural medium.“

"...systematic uncertainties in the ice model"

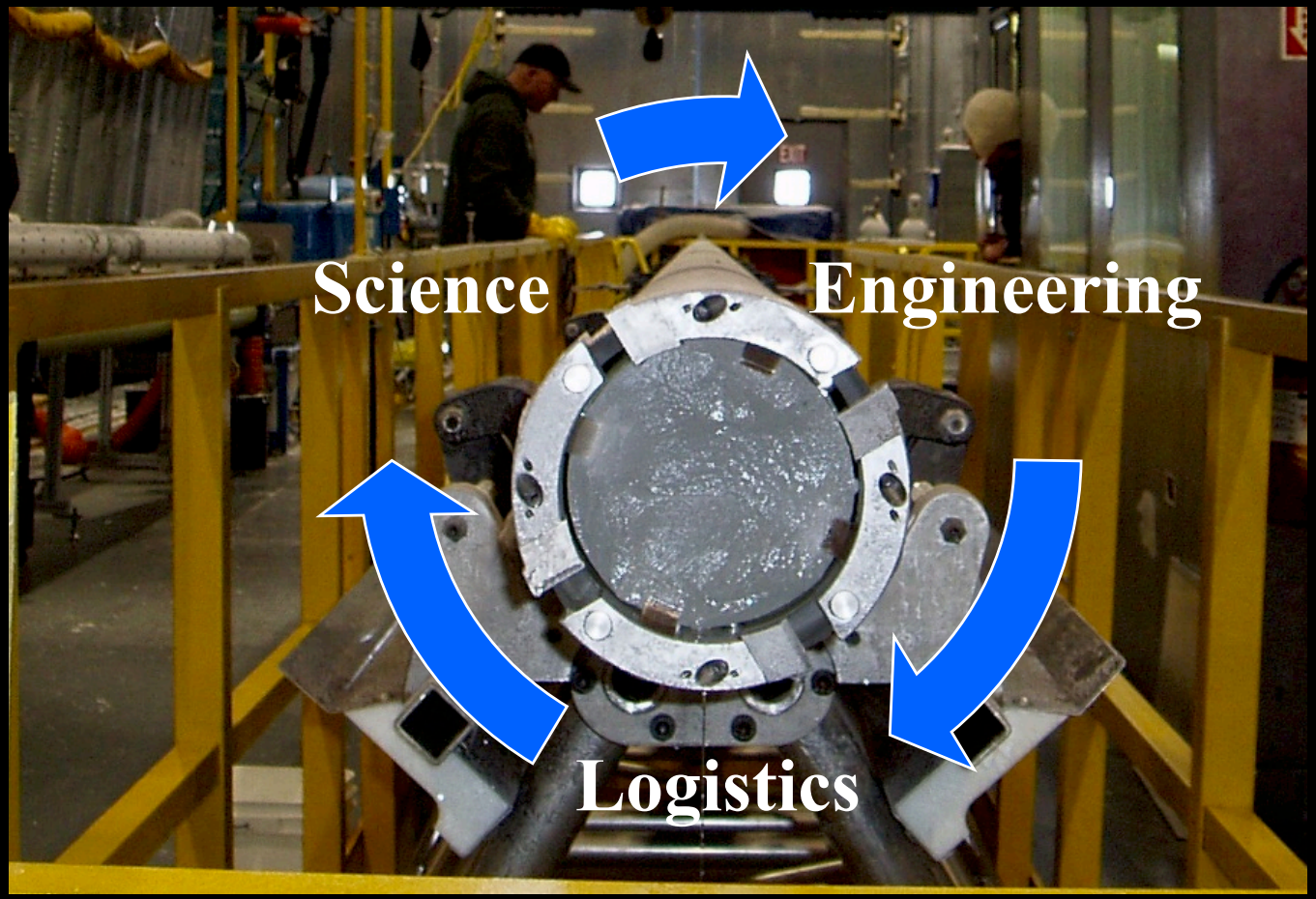
"...uncertainties in the description of the ice...“

“…systematic uncertainties...associated with the scattering and absorption of photons in the glacial ice at the South Pole."

"...a bin-by-bin effect of the ice..."

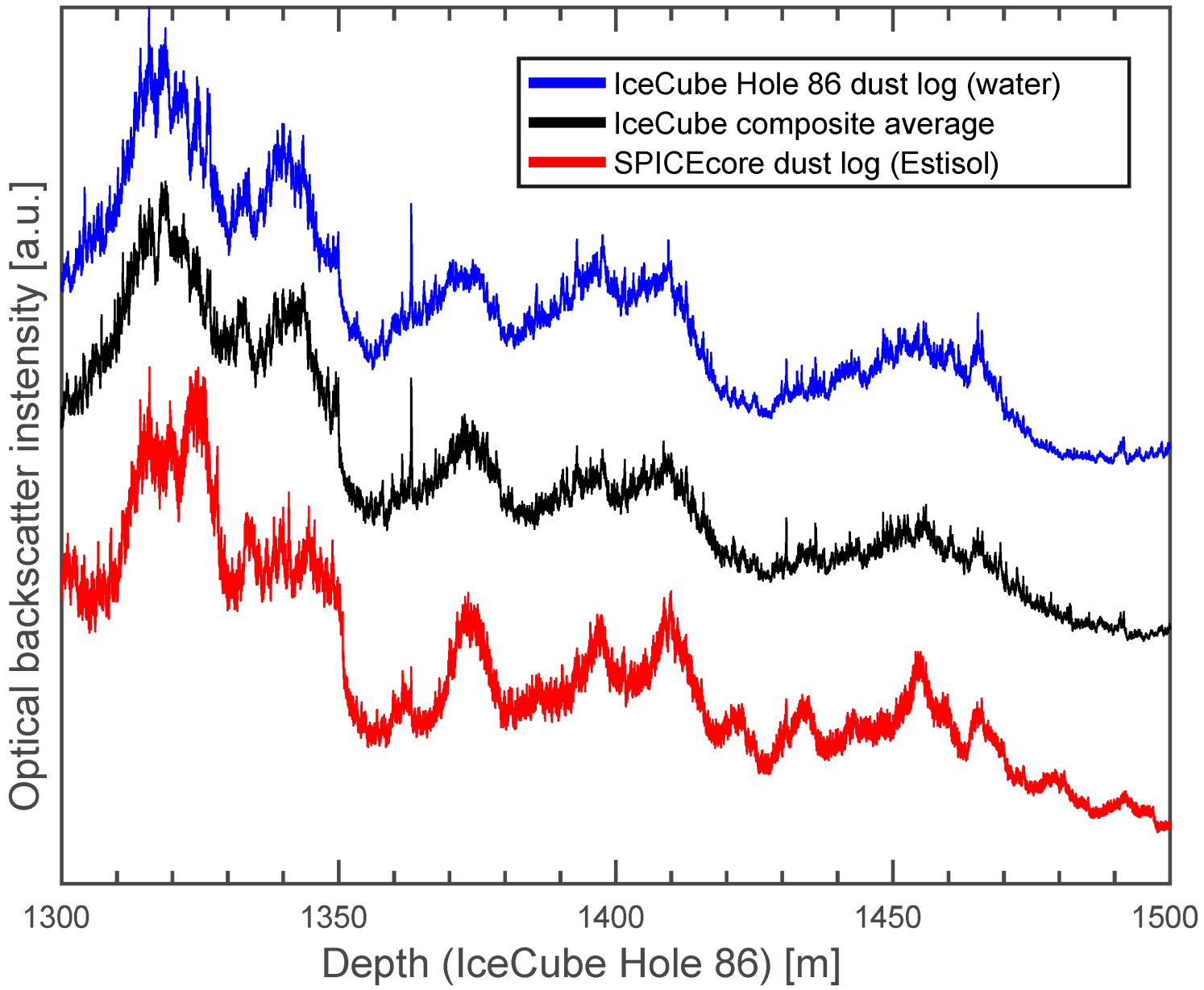
"The effect of the refrozen ice column..."

Holistic experimental science



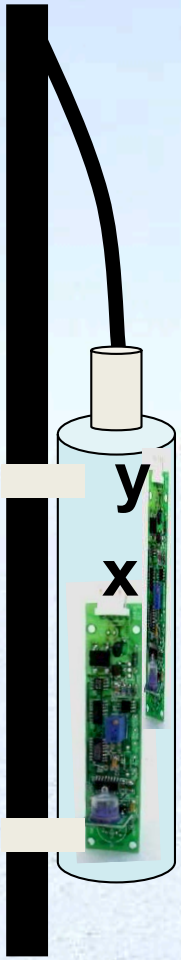
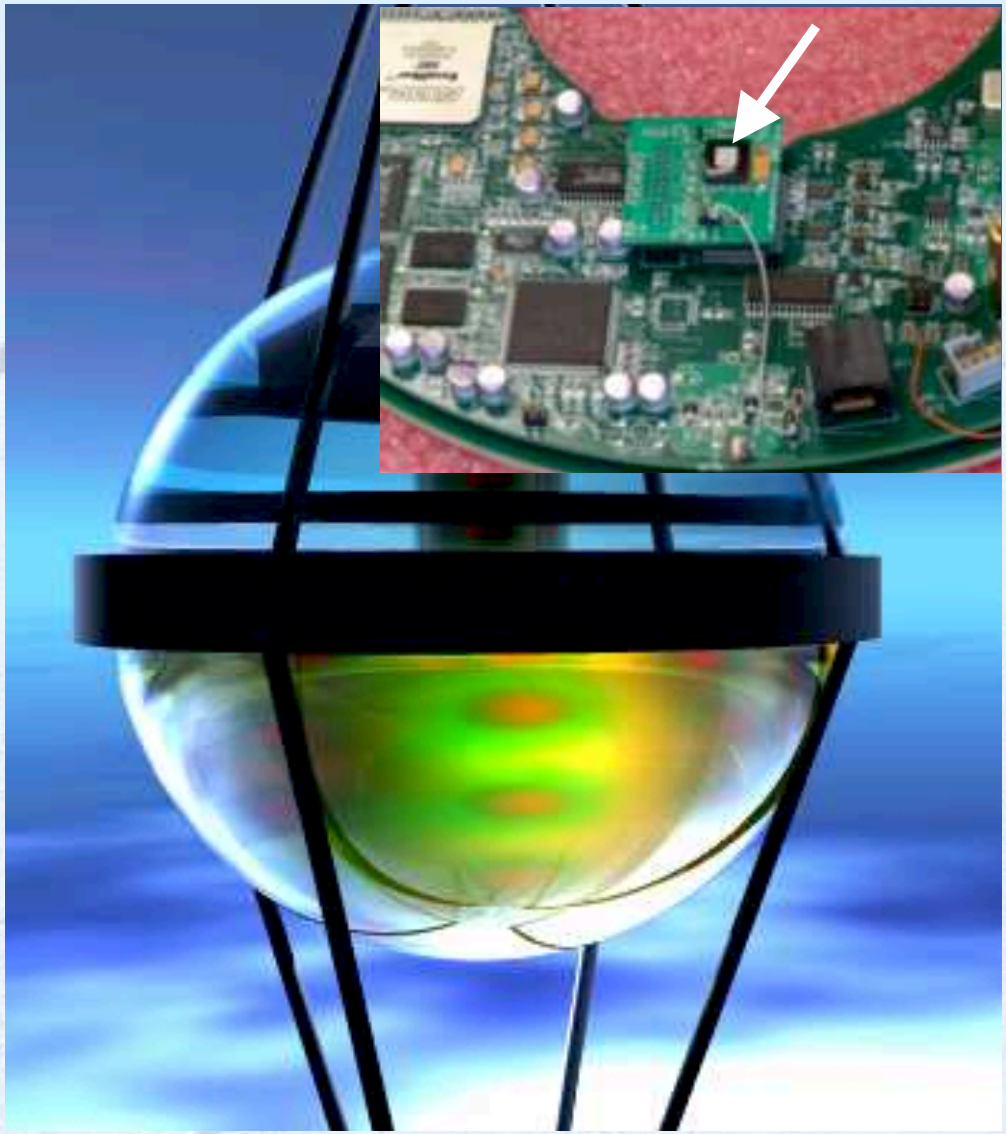
Logistics Engineering:
Ensuring the "thing" is where it's needed, when it's needed, and operating the way it's needed all at an acceptable cost.

Laser logging in Estisol *vs.* water



IceCube inclinometers

Electrolytic ×3



DOM-embedded MEMS ×48