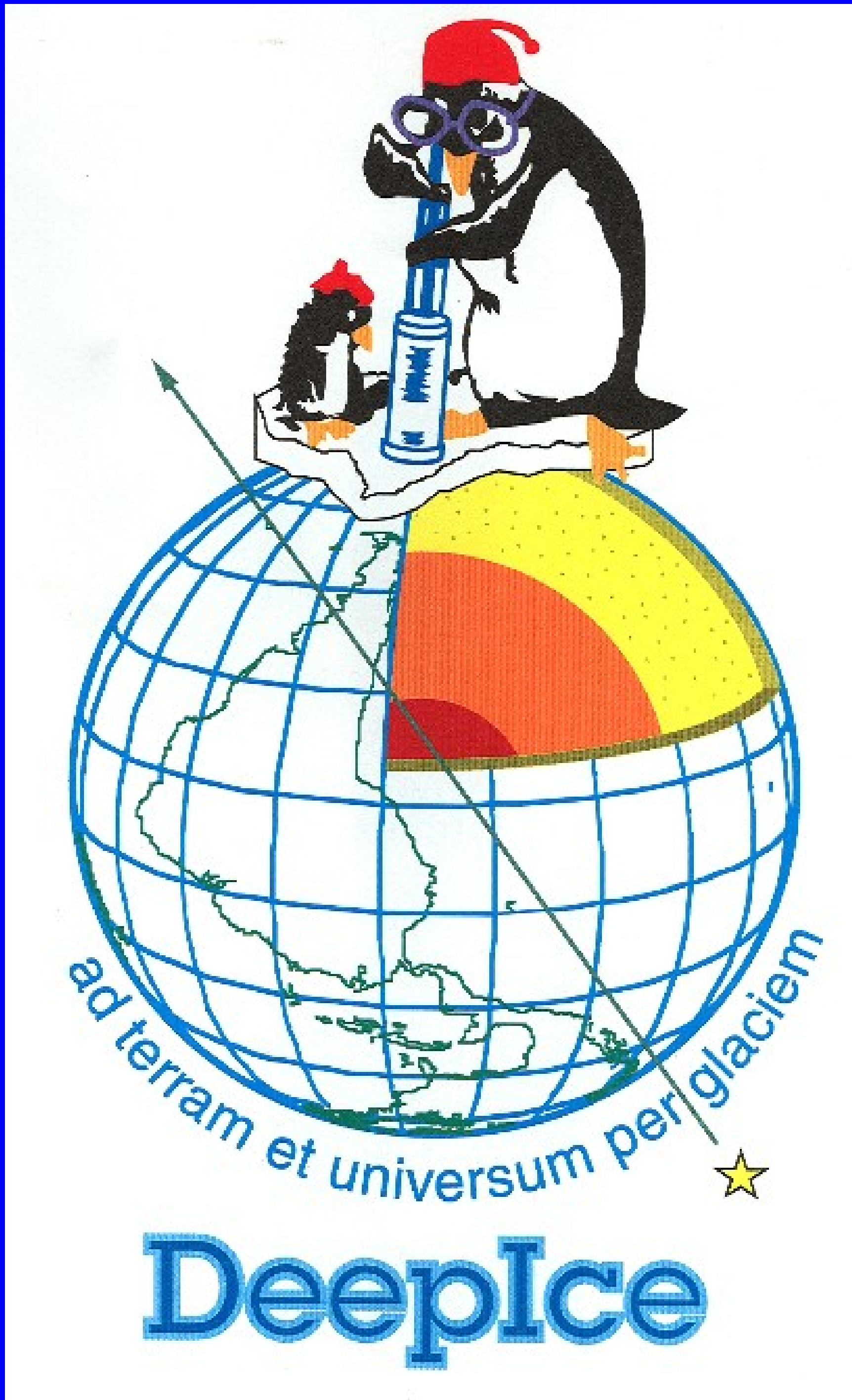


In 1999 I proposed to NSF an interdisciplinay "DeepIce Science and Technology Center", with U. S. and European colleagues.

- UHE ν-astronomy (AMANDA ⟶ IceCube)
- 3-D seismic array
- Climatology
- Glaciology
- Cosmogenic nuclides
- Microbial life in ice
- Subglacial Lake Vostok
- Interdisciplinary theory

It reached the finals but was not funded.

not yet

not yet

^{60}Fe

yes

yes

yes

beginning

indirect evidence in favor

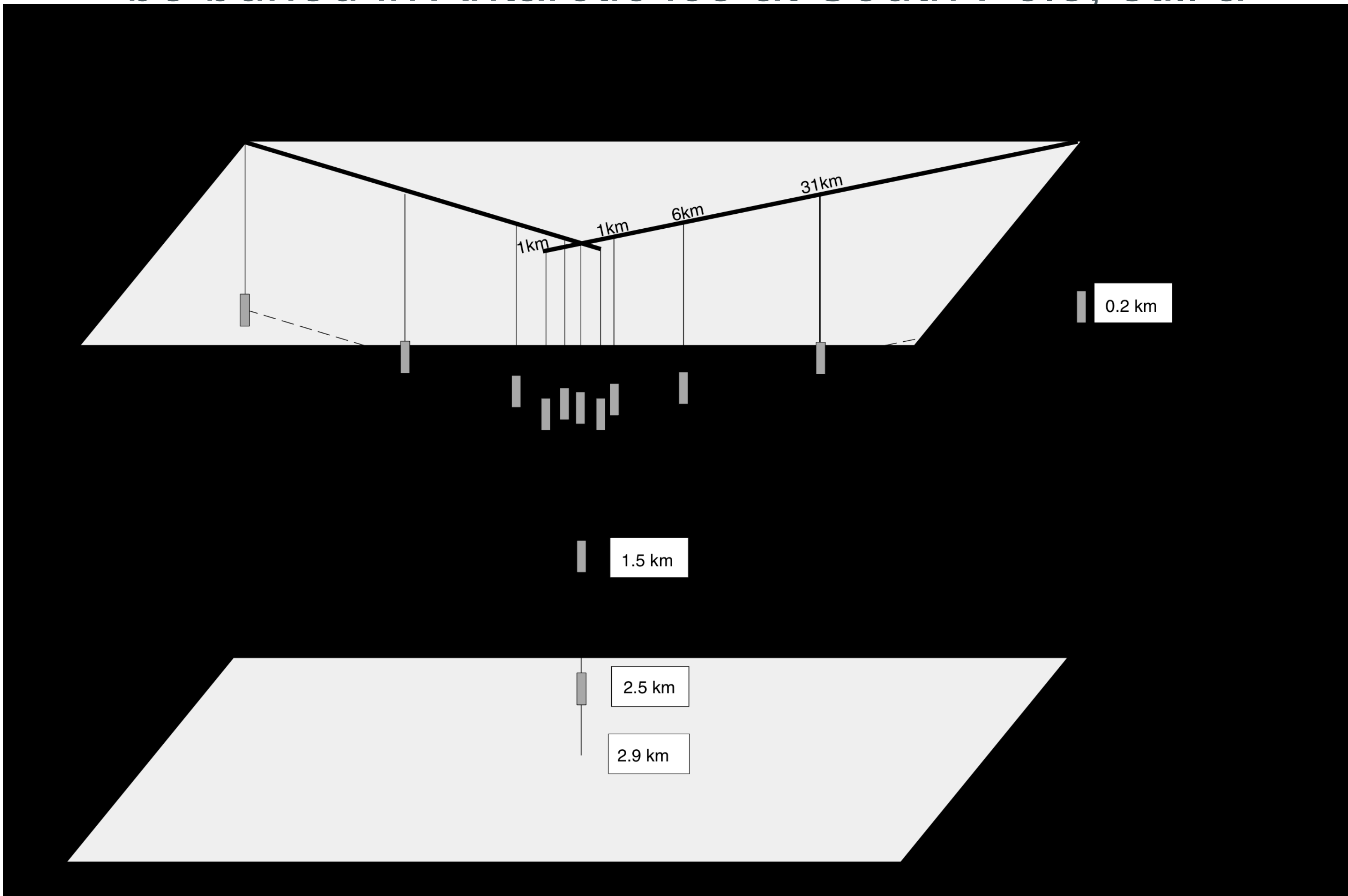
in progress

different in details

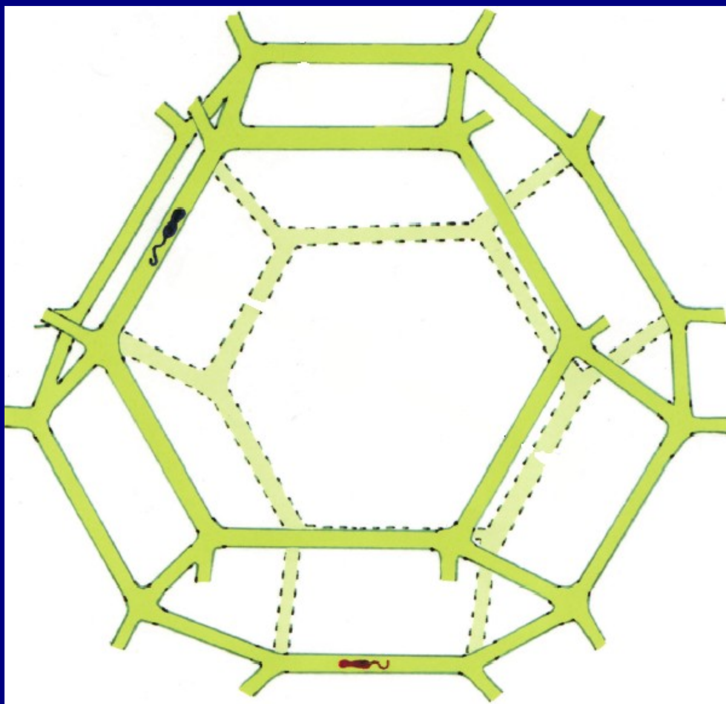
not yet

not yet

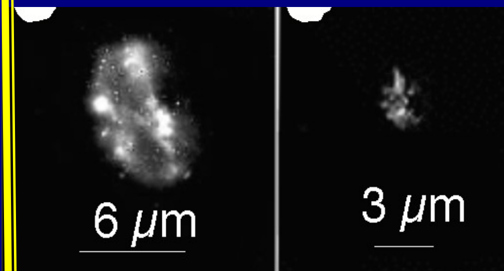
DeepIce proposed a 3D phased seismic array to be buried in Antarctic ice at South Pole; still a

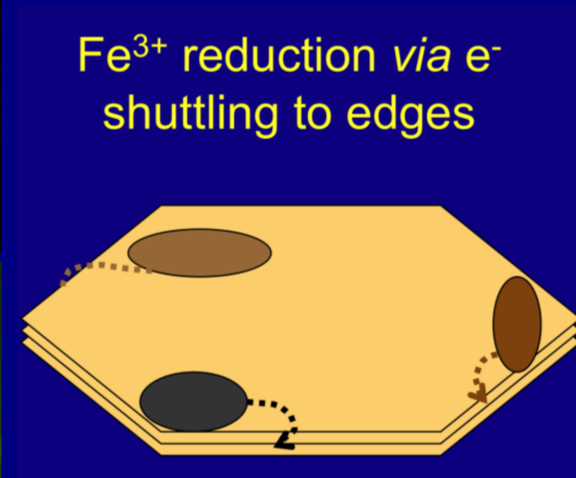


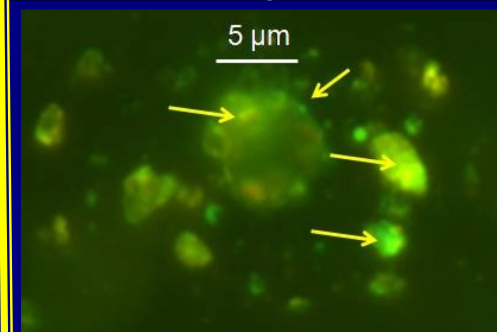
Habitat 1: unfrozen veins provide energy and nutrients; spinoff of DeepIce



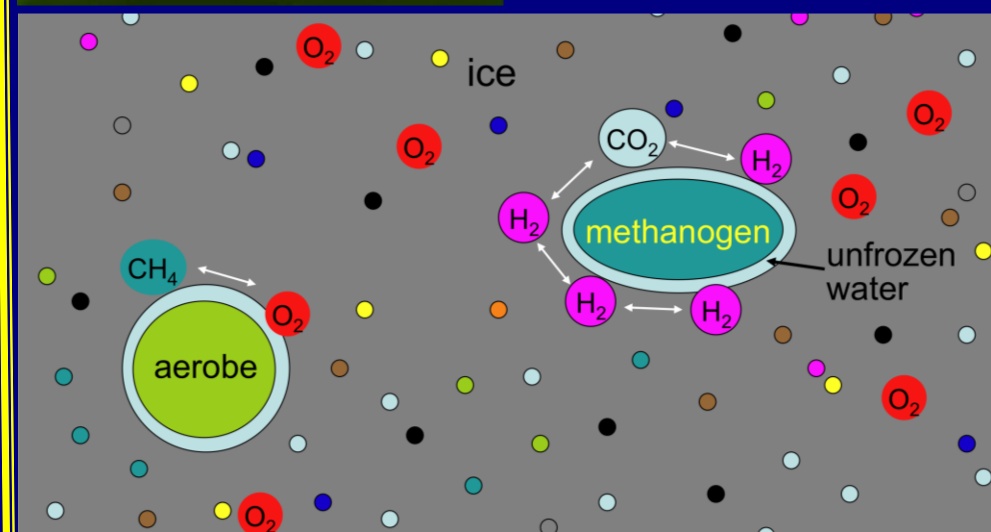
Habitat 2: grain surfaces in ice; e.g., electron shuttling to edges of clay grains for nutrients





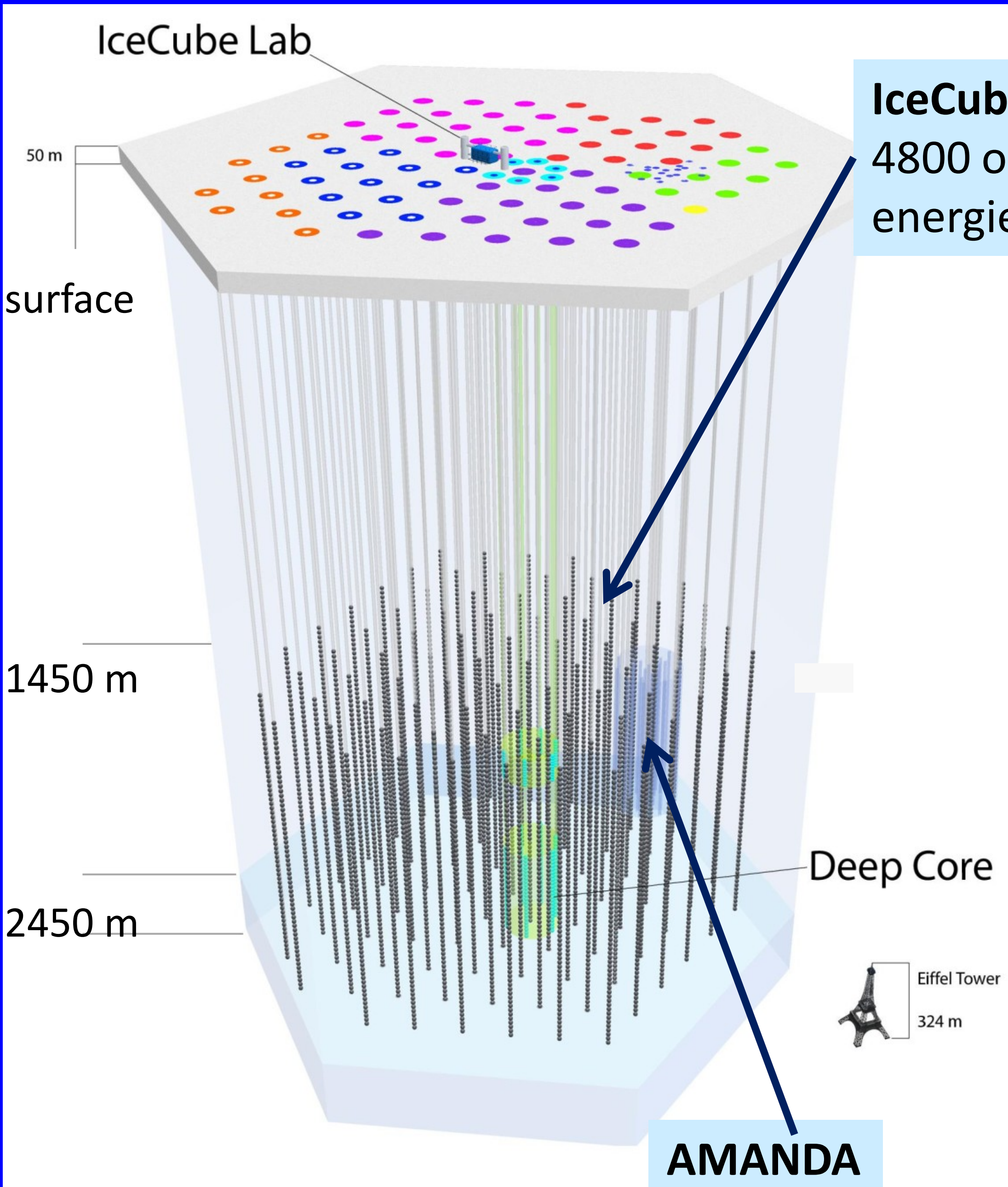


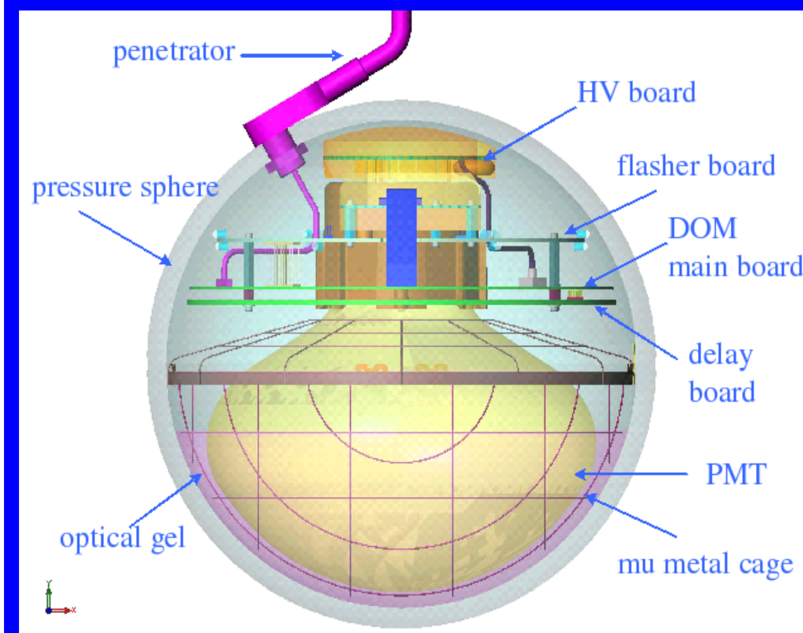
Habitat 3: grain interiors Small molecules diffuse in ice fast enough to undergo redox reactions at cell membranes. Aerobes and strict anaerobes can coexist.

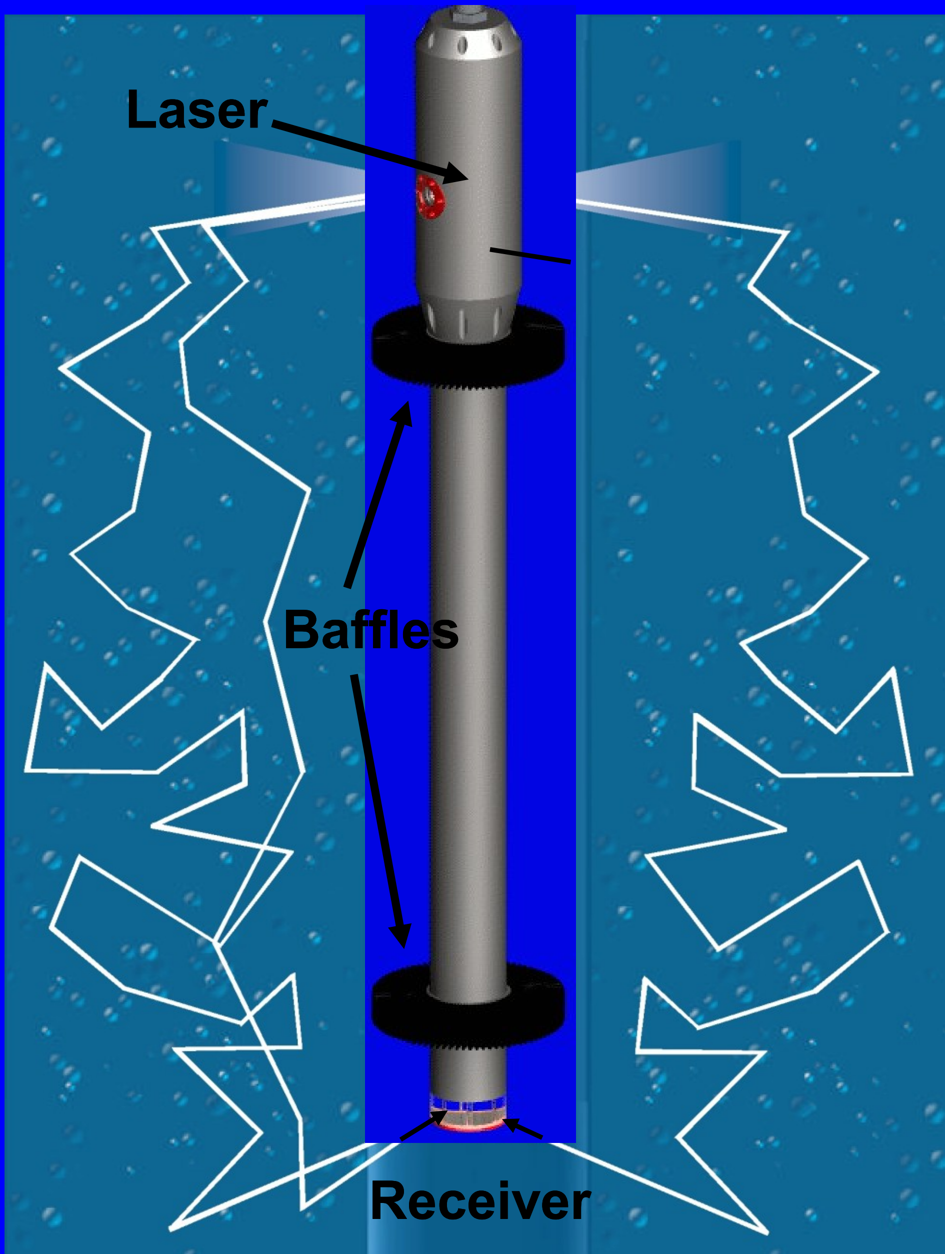


AMANDA -> IceCube (Halzen, Price, Barwick, Spiering, Hulth...)

IceCube (2011) 1 km^3 of ice; 80 strings; 4800 optical sensors + Deep Core (low-energies: 6 strings/360 optical sensors)





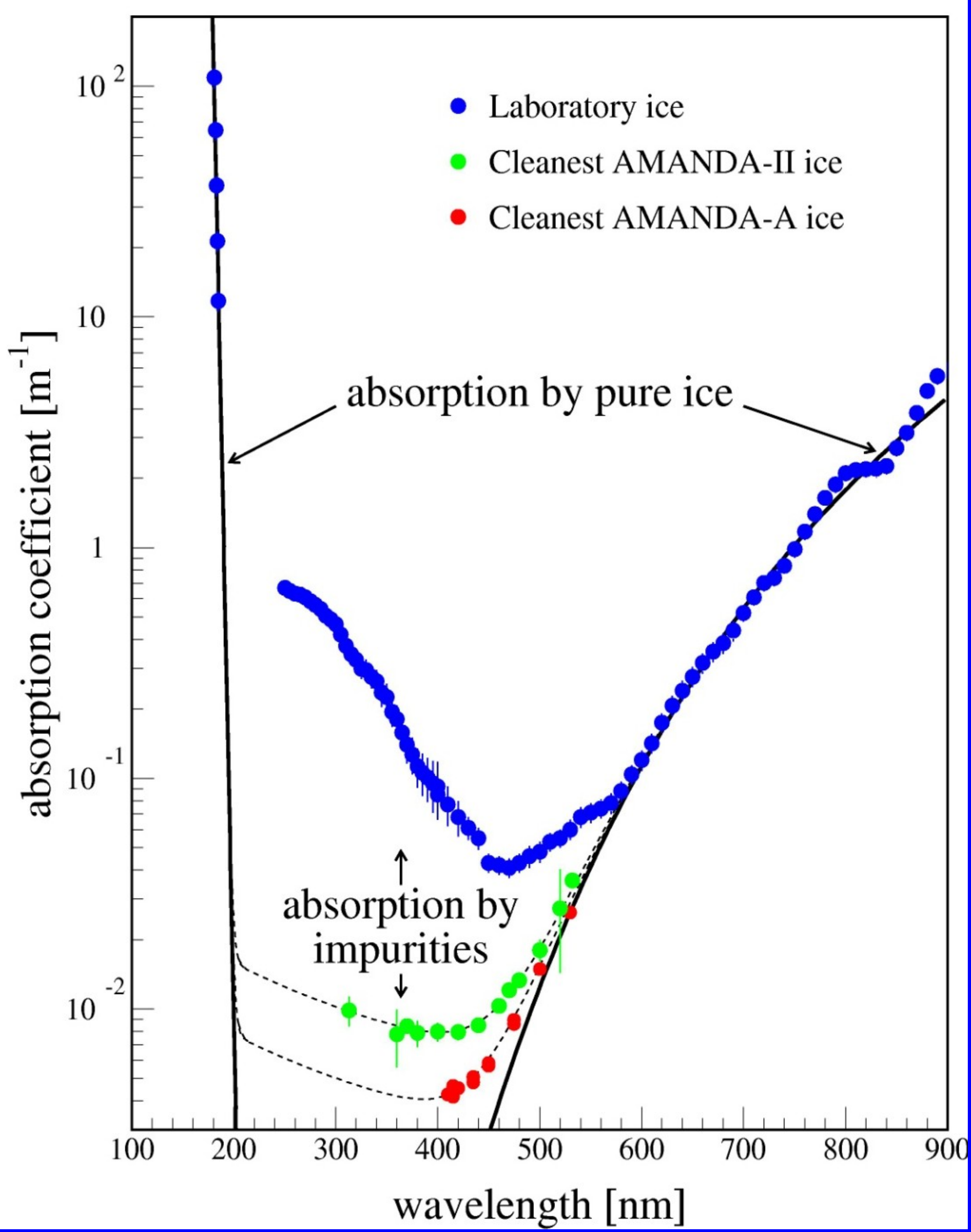


Bay and Price invented the Dust Logger during DeepIce brain-storming sessions. Two years later Ryan did the first of many successful logs of dust and volcanic ash in ice:

2001; 2002	Siple Dome W. Ant.
2002	GISP2 Greenland
2003	NGRIP Greenland
2004	GRIP Greenland
2005-10	South Pole
2010	Dome C East Ant.

Ryan Bay getting his dust logger ready to deploy in IceCube at South Pole

Optical properties of ice



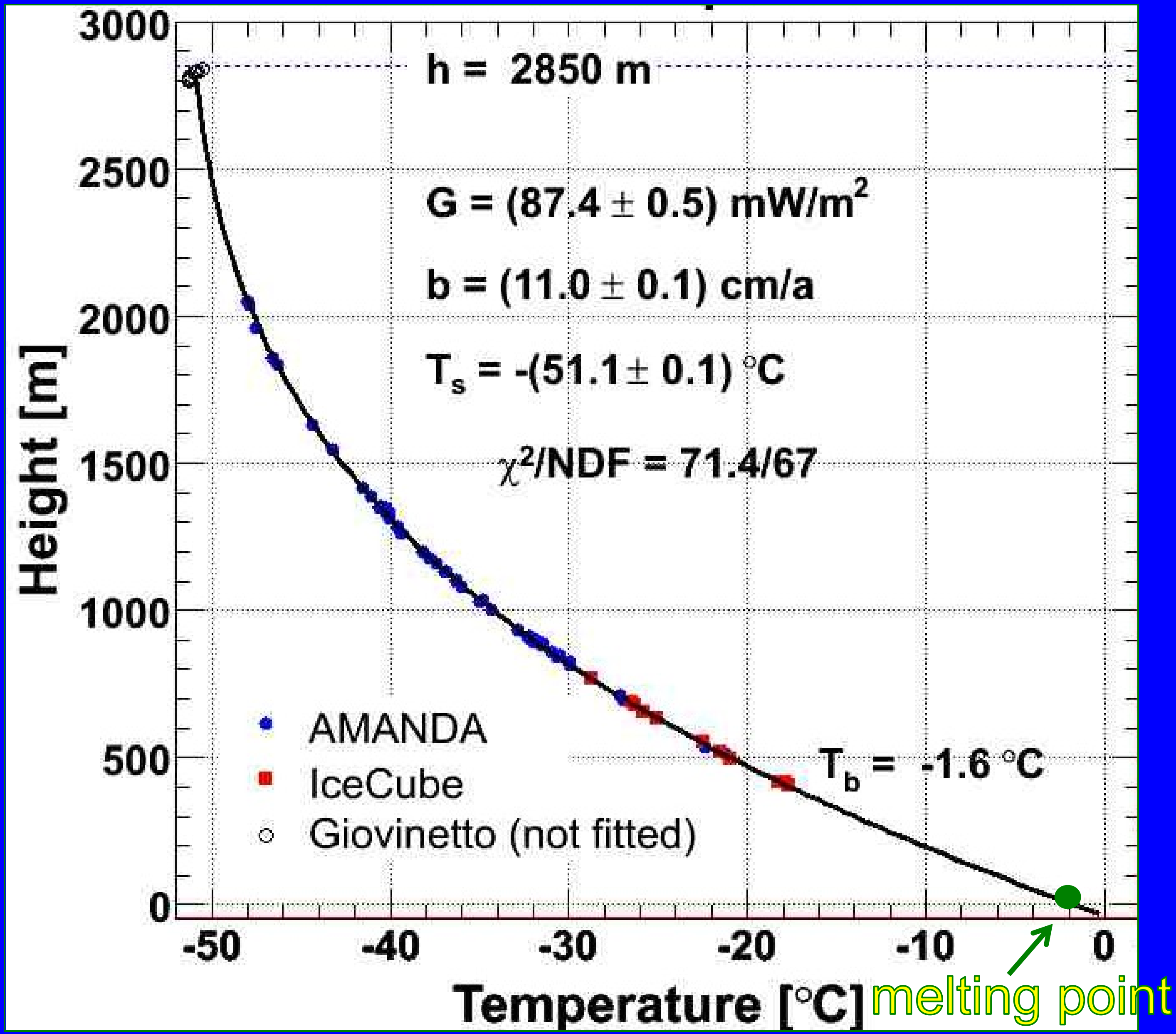
In 1991, with muons, we showed that Antarctic ice is most transparent natural solid known.

Average optical ice parameters:

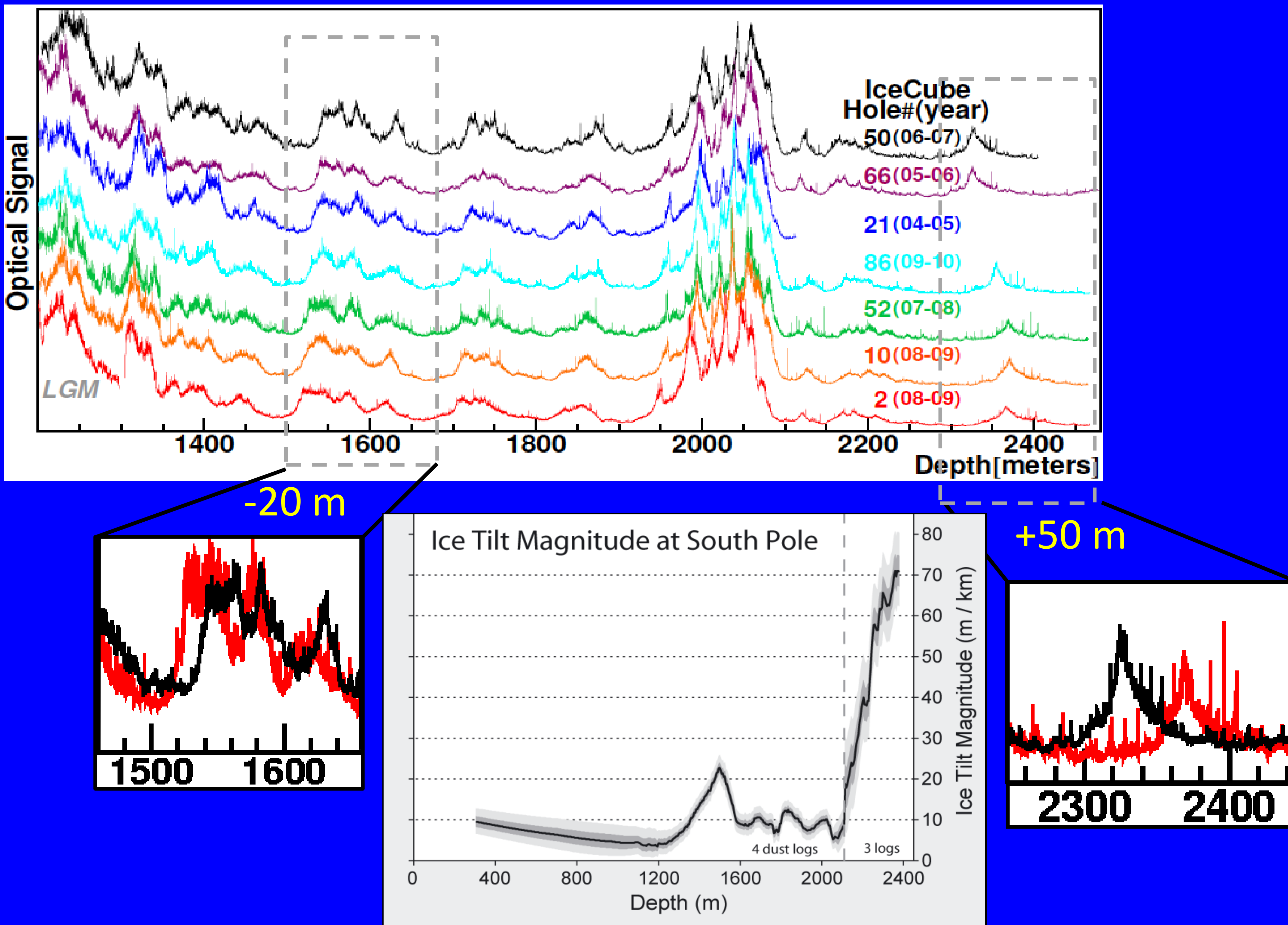
λ_{abs} ~ 110 m @ 400 nm
λ_{scat} ~ 20 m @ 400 nm

Ice scatters more but is absorbed less than ocean.

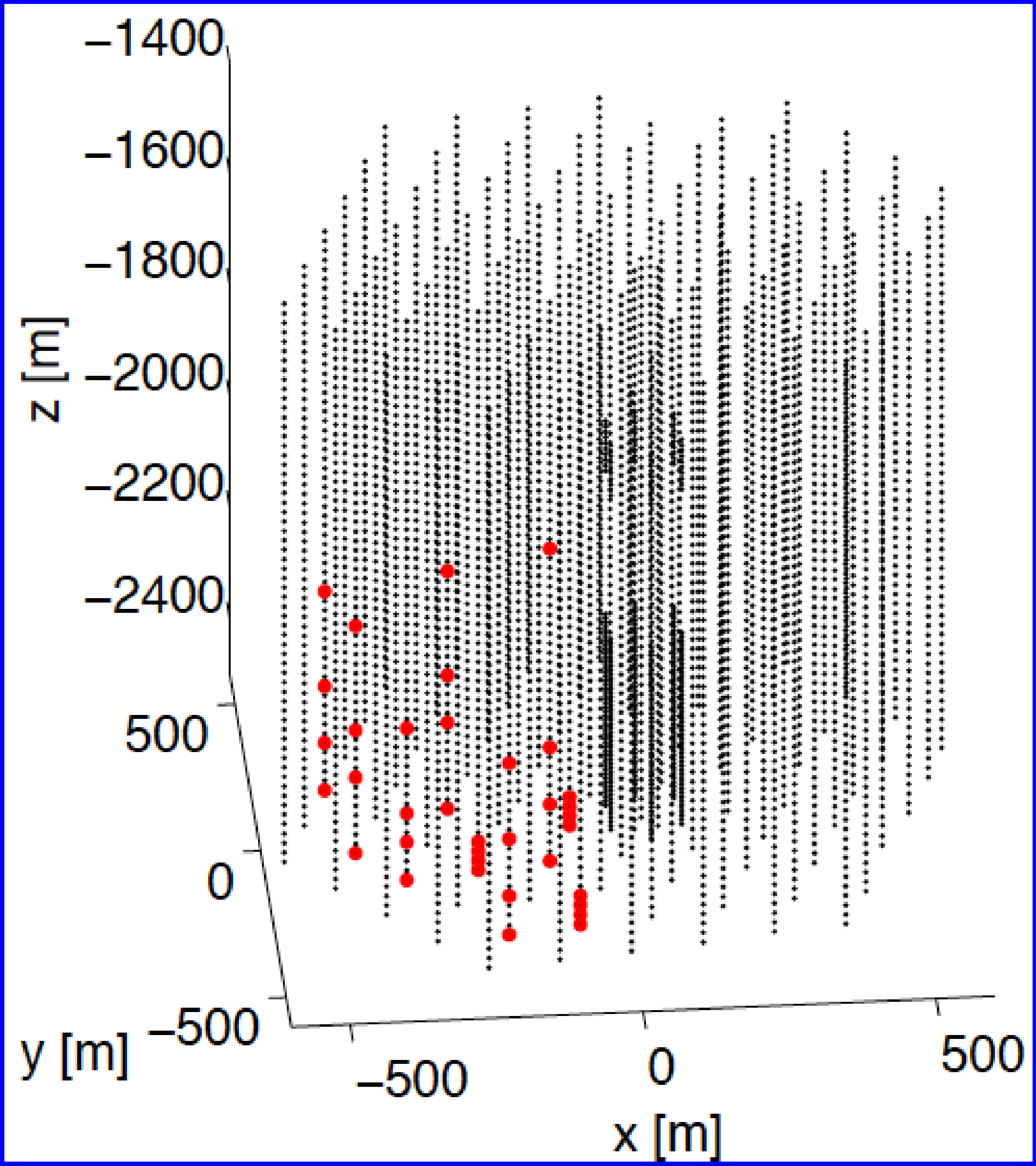
South Pole ice temperature *vs* depth. With embedded thermistors we found that base is likely liquid, like a subglacial lake at ~8 km.

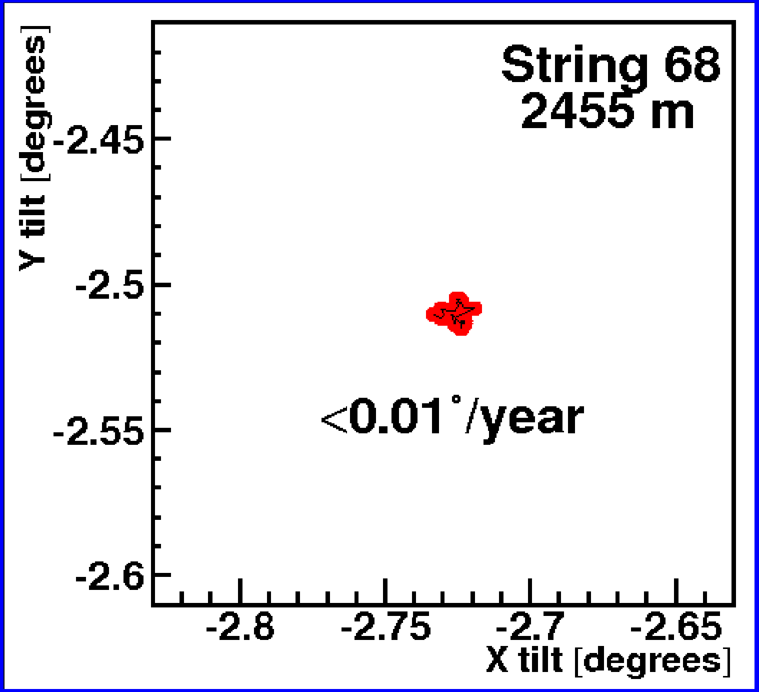


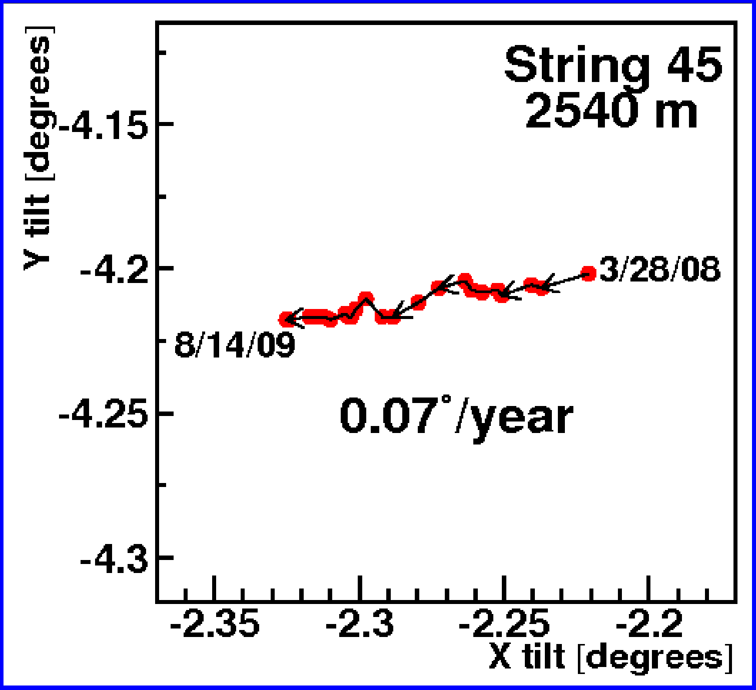
Ryan Bay’s 7 dust logs in IceCube map the tilt surfaces.



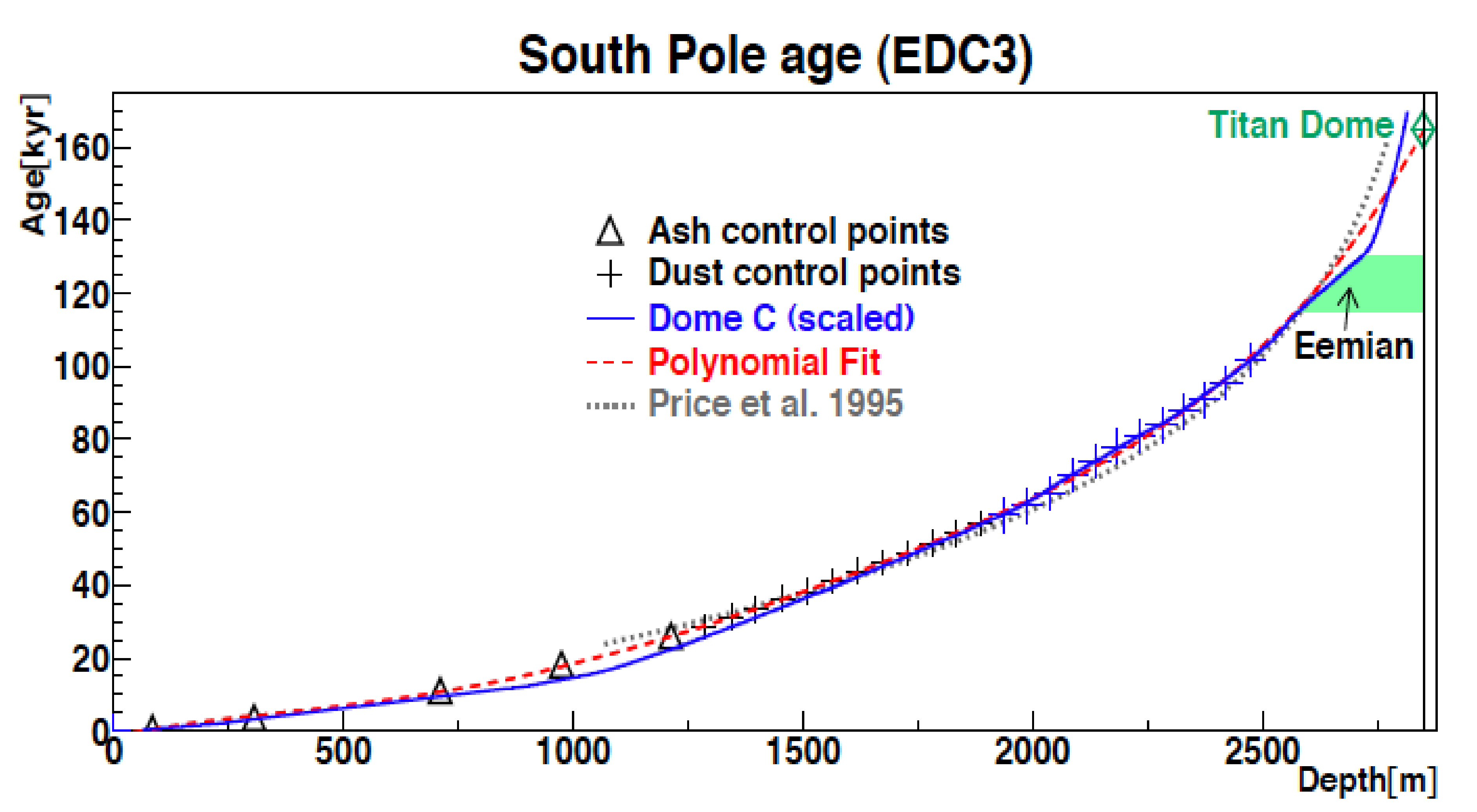
Bay's microinclinometers detect abrupt onset of shear at ~2500 m.



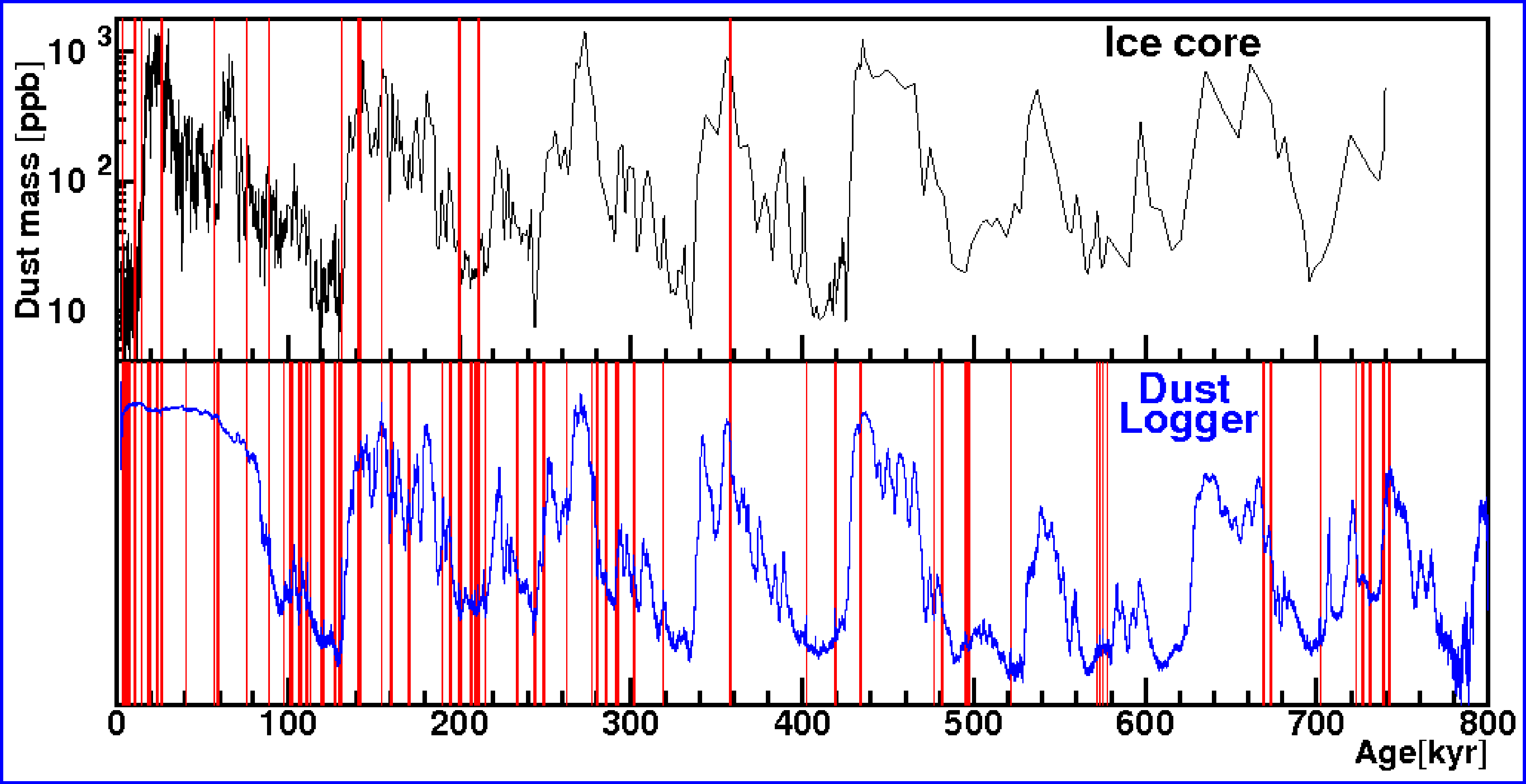




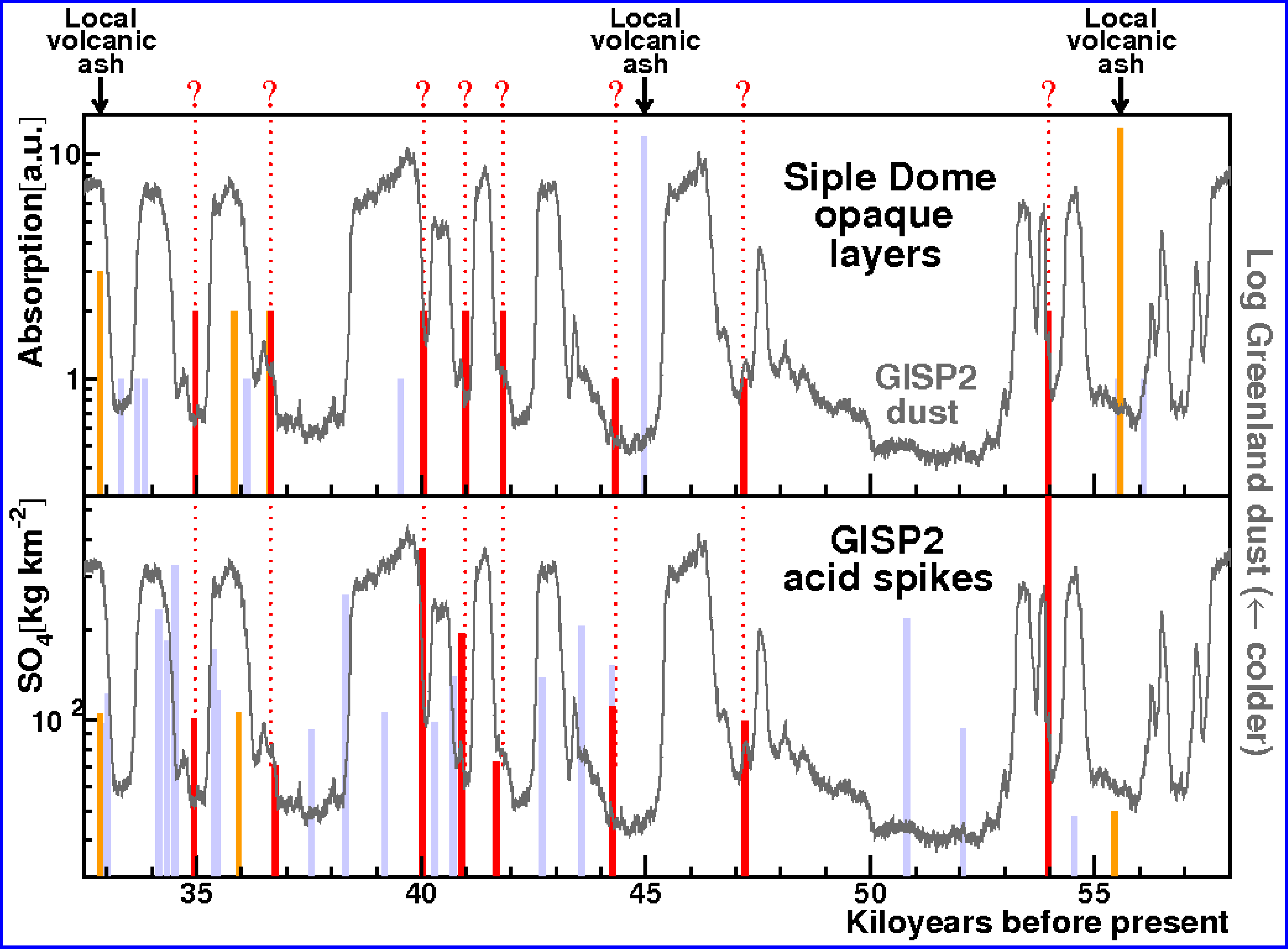
Bay, Rohde, and Price: South Pole age vs. depth
=> a deep core could recover Eemian ice.



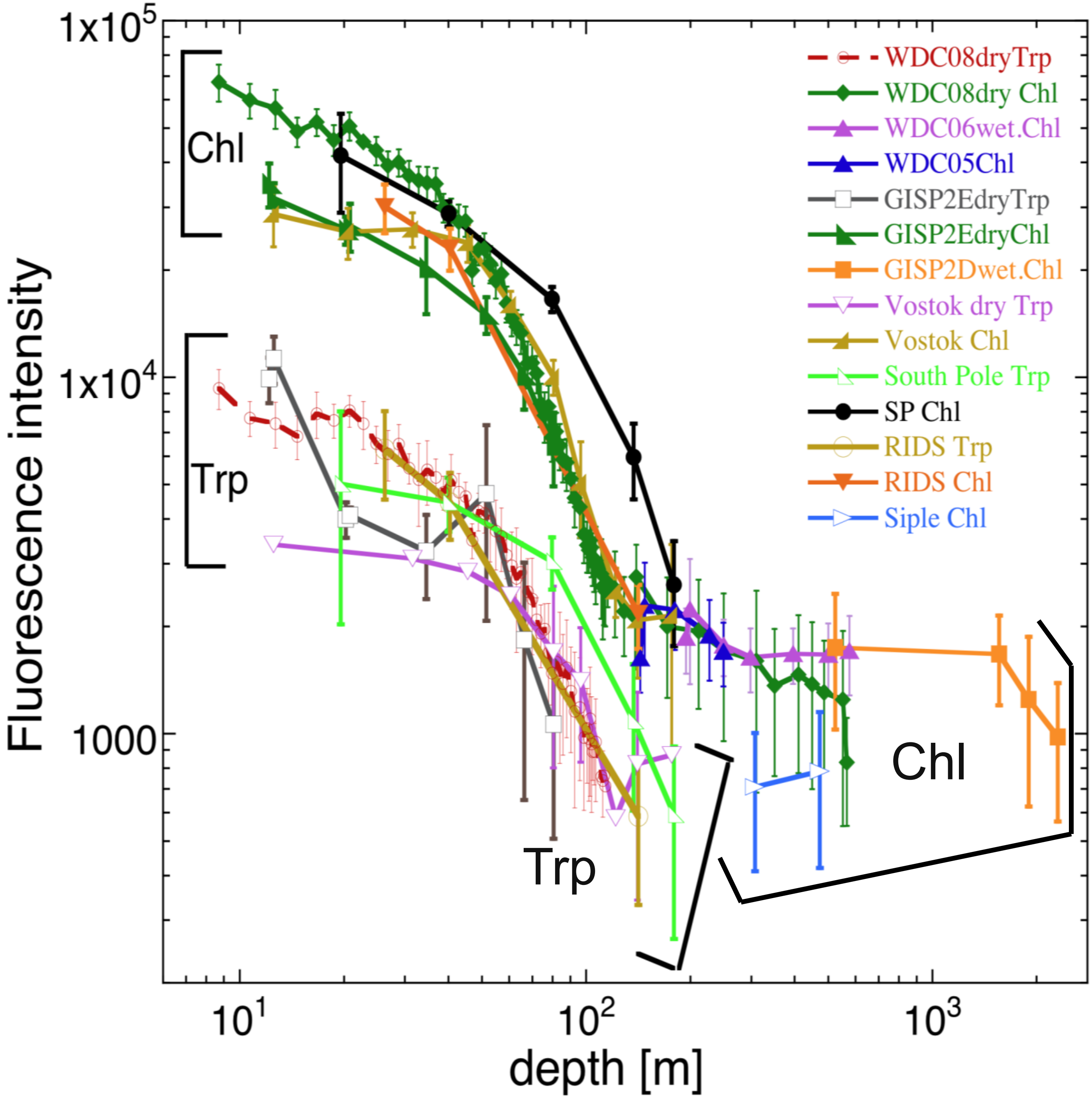
Order-of-magnitude more Dome C ash candidates found with dust logger than in analysis of Dome C ice core.



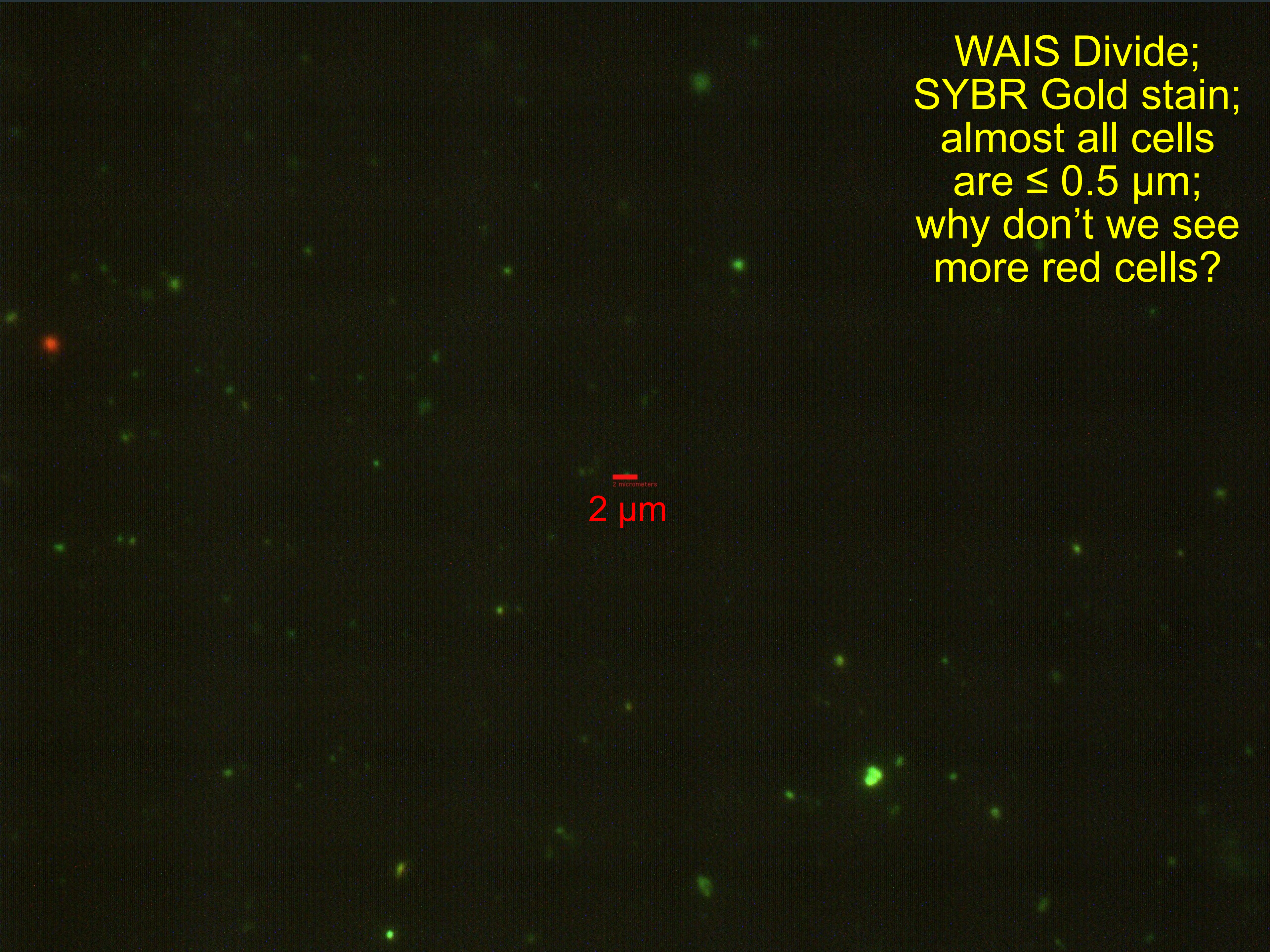
Bay discovered a causal relationship between strong volcanism and abrupt climate change.



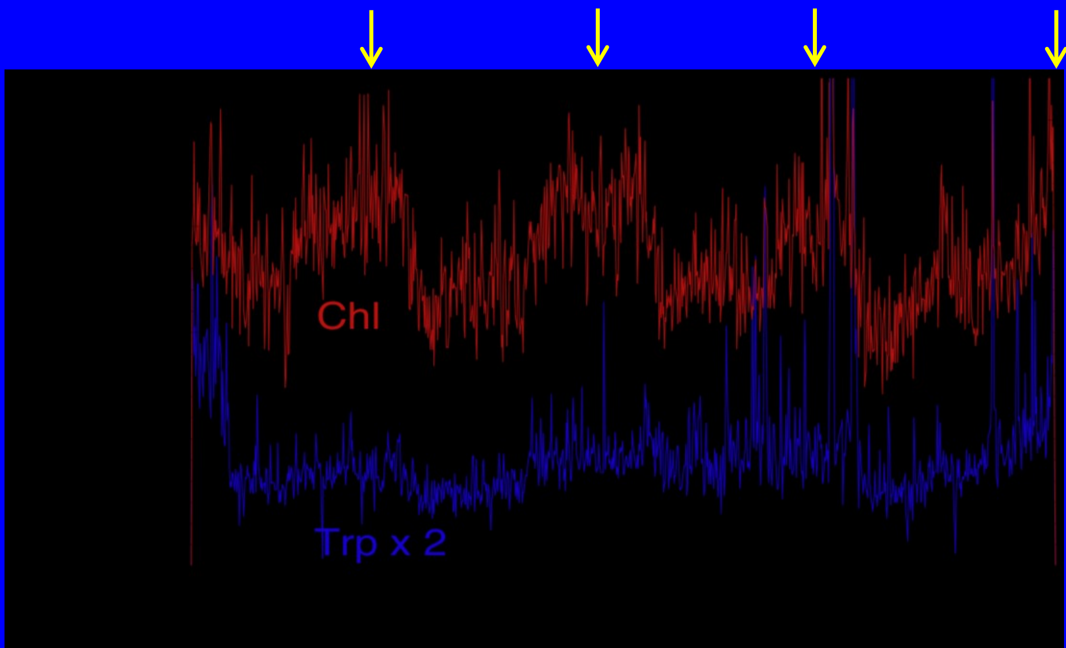
Berkeley Fluorescence Spectrometer (BSF) maps autofluorescence of tryptophan (Trp) and chlorophyll (Chl) with 1400 spectra/m in 2 min. Ice protects cells from photobleaching.

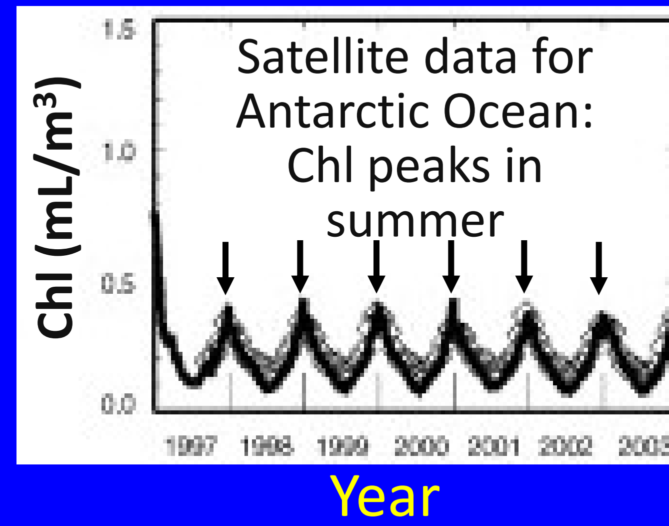


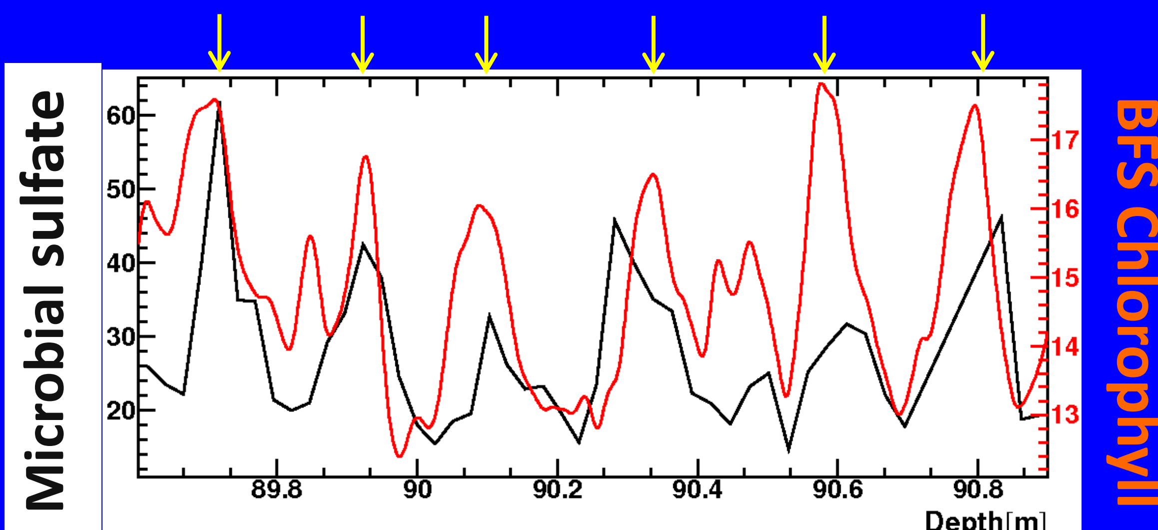
BFS measures Chl and Trp without melting ice or damaging cells. Each point is averaged over 1400 spectra in ~1 m of ice core. Chl fluorescence suggests phototrophs?


WAIS Divide;
SYBR Gold stain;
almost all cells
are ≤ 0.5 μm;
why don't we see
more red cells?
2 μm

Chl fluorescence in ice has an annual modulation; peaks occur in Antarctic summer, correlated with microbial sulfate (DMSO, MSA, SO_4^-)

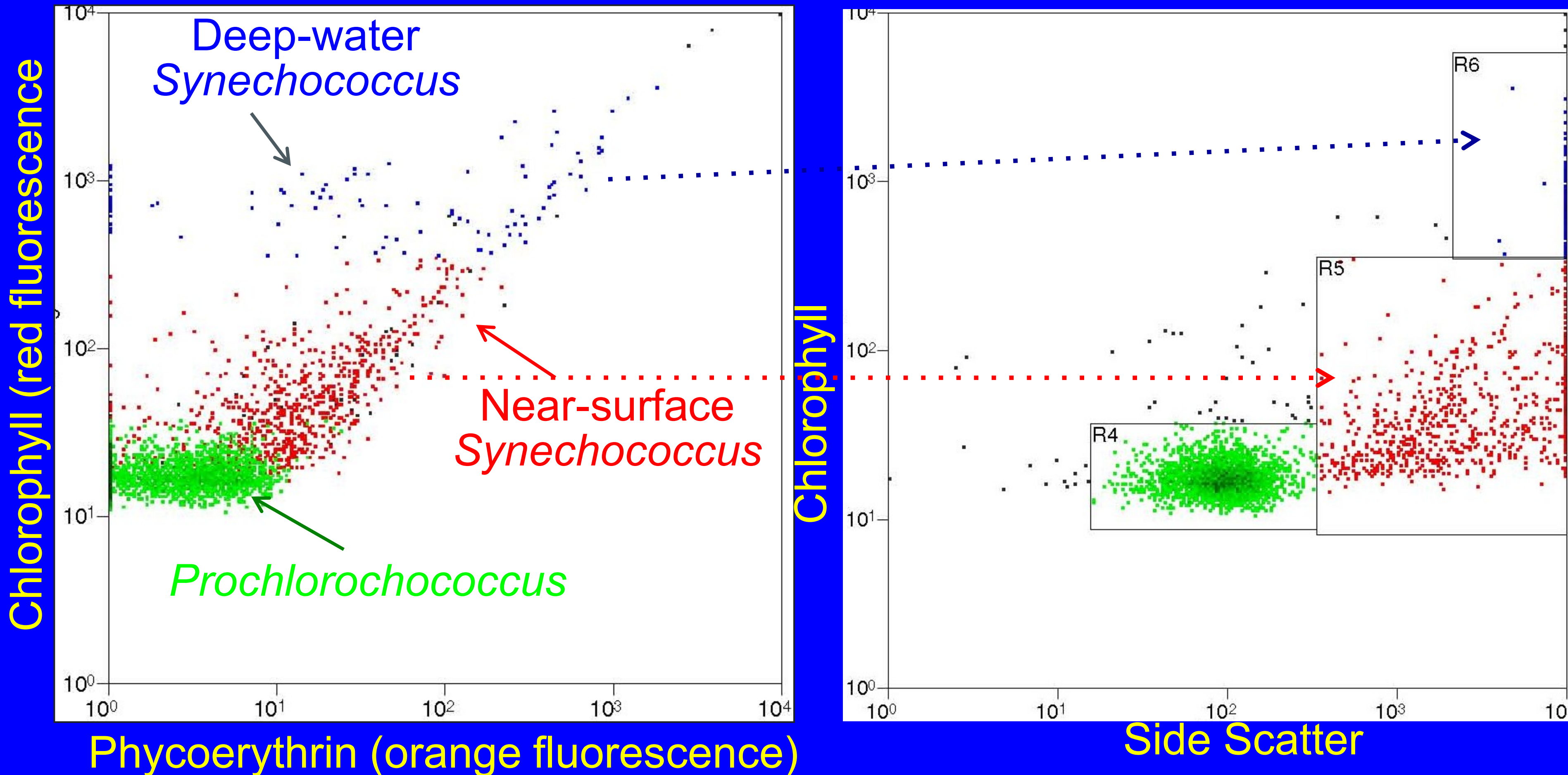




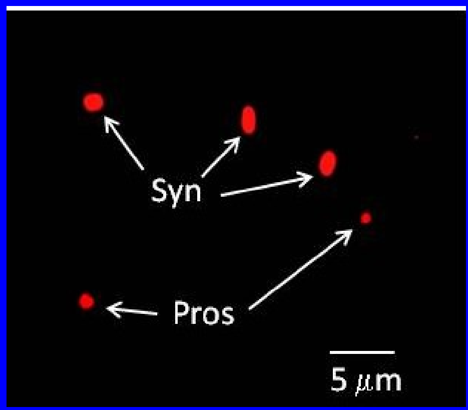


Microbial sulfate (Cole-Dai) and Chl were measured in same core. Synchronism with satellite record of Chl shows that the Chl-bearing phototrophs originated in the Antarctic ocean.

Flow cytometry: Siple Dome, West Antarctica, 80 m depth



Using ice to do marine oceanography: Tiny cells *of Prochlorococcus* and *Synechococcus* in the ocean account for ~half the oxygen we breathe.

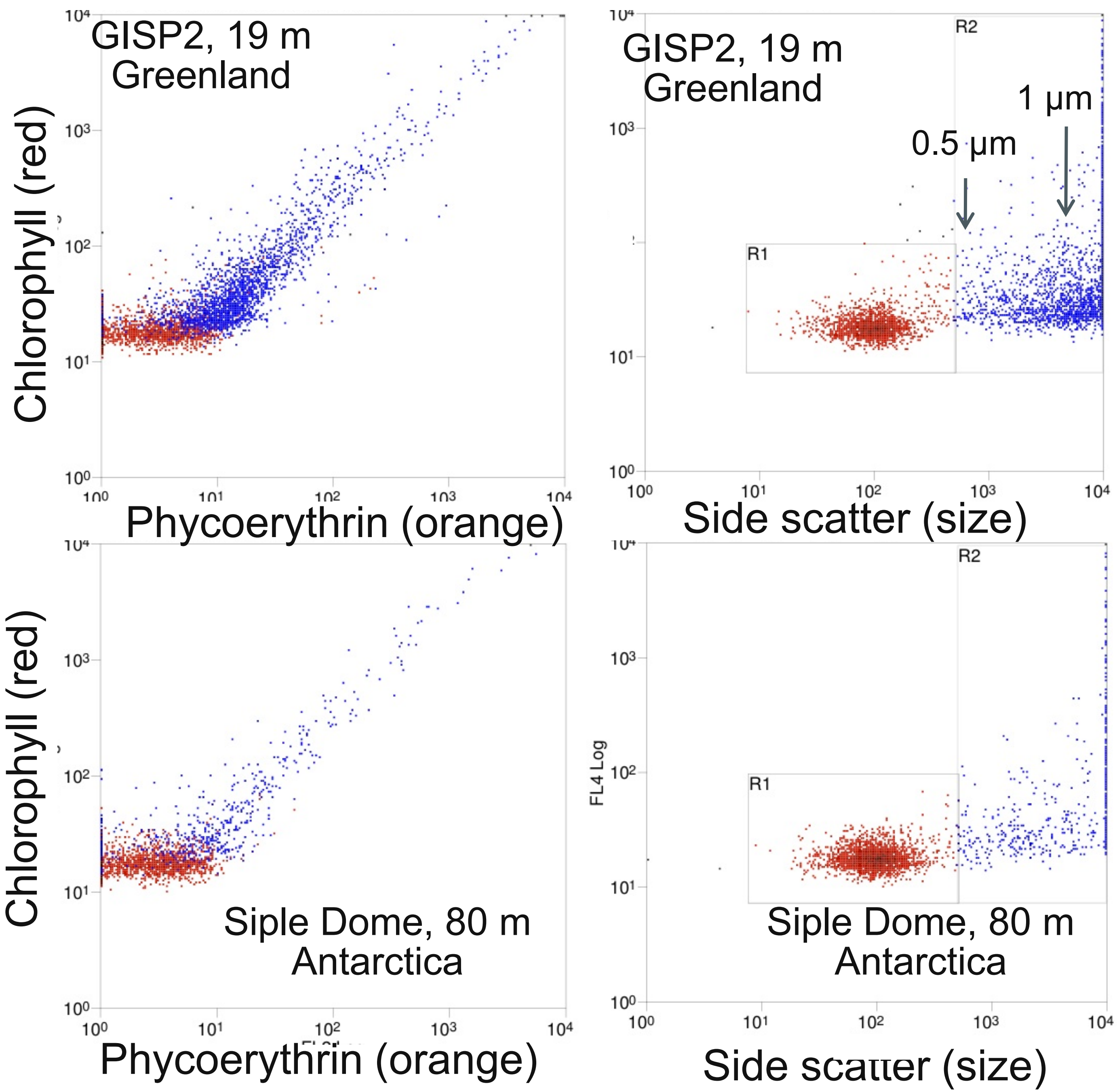


Prochlorococcus and *Synechococcus* are also present in Greenland ice.

Red points, *Prochlorococcus*, cell diam.≈0.4μm

Distribution of cells is similar in both polar icecaps

Blue points, *Synechococcus*, cell diam.≈ 1μm



- We have found that the habitats of *Prochlorococcus and Synechococcus* have expanded from $\pm$ 45° latitude to Arctic and Antarctic Oceans and they are windborne from ocean to ice.

- Their sizes and concentrations in ice are so small that it is a challenge to confirm their presence by genomic analysis.

- We propose to study molecular evolution using cells in ice at low temperature as a proxy for their mutations in the ocean.

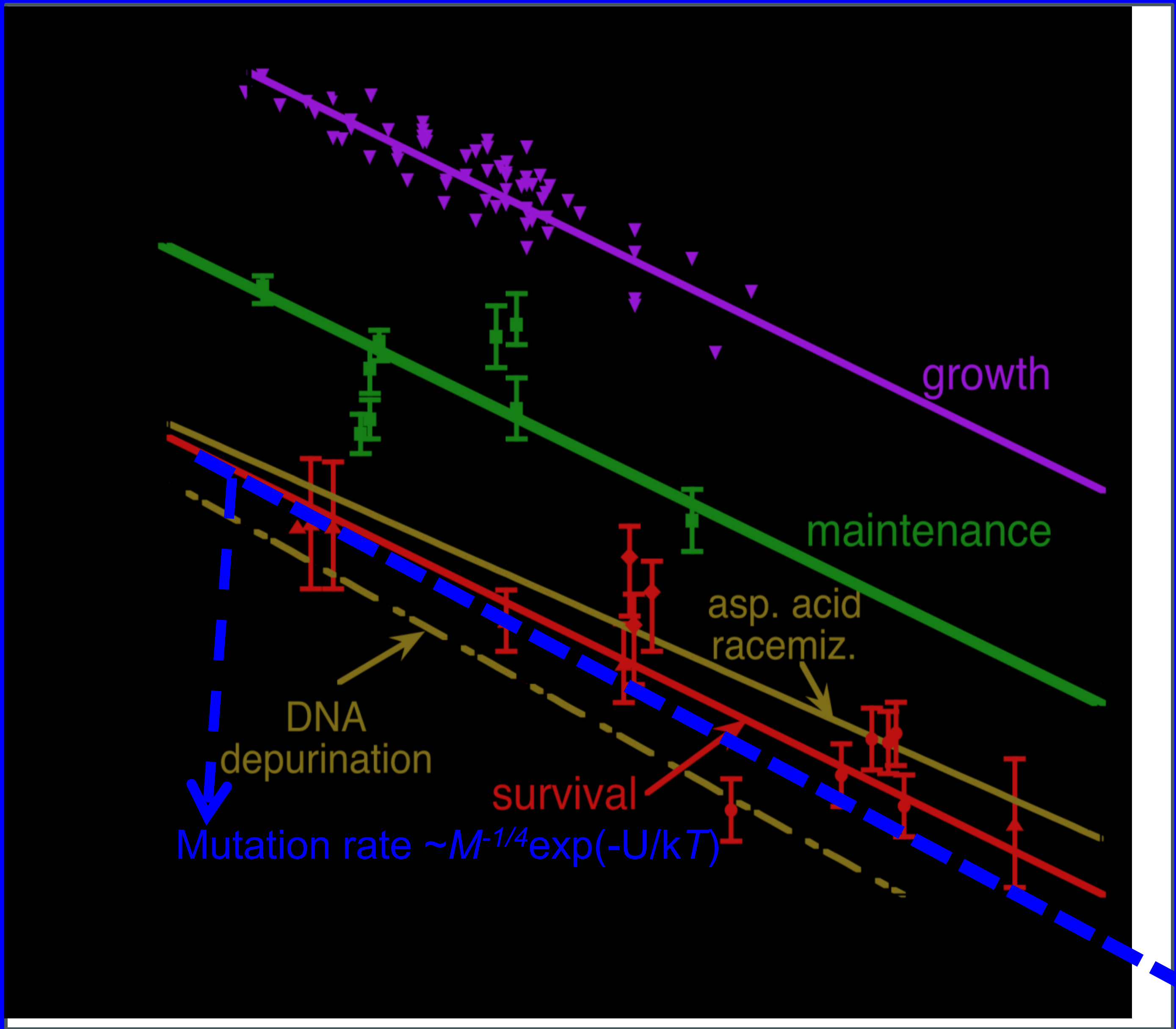
- Look for changes in genomes of *Prochlorococcus* and *Synechococcus* with time over $>10^4$ yrs or $>2 \times 10^6$ generations.

- To correct for mutations of cells in the ice, we will compare genomic changes at -51° C (South Pole) and -25° C (Siple Dome). Mutation rate depends on body size and k*T*:

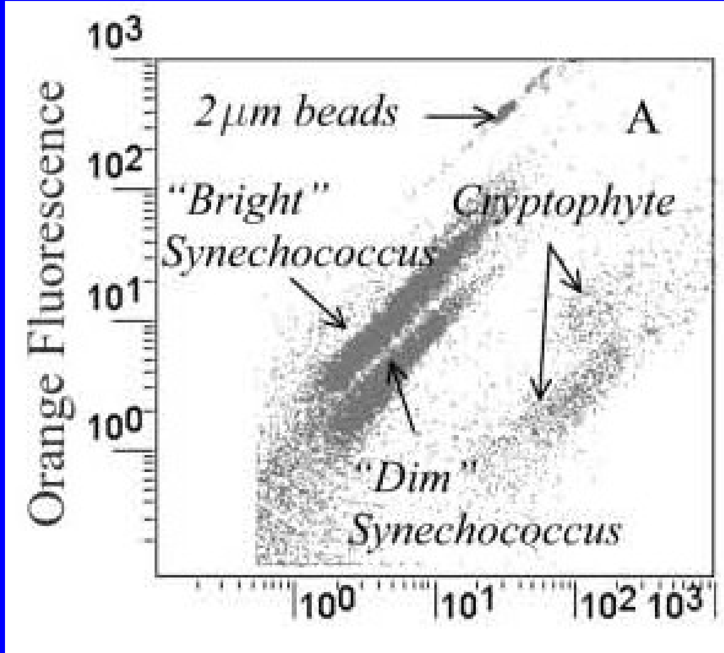
$$\alpha \sim e^{-E/kT}$$

where *E* is same activation energy as for metabolism.

Metabolic rates, repair rates of damage to DNA and amino acids, and mutation rates have ~ same T-dependence. They decrease a factor ~300 from -30° C to -51° C.



Thanks for your attention



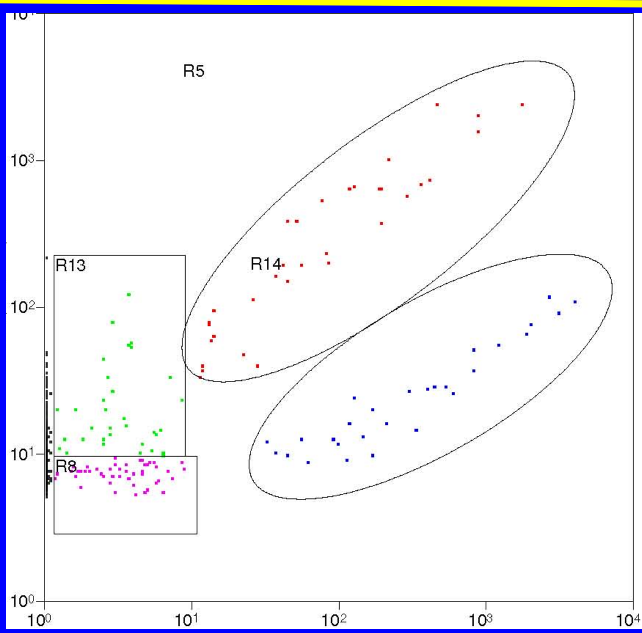
Red Fluorescence

2 strains of *Synechococcus* in water around Singapore harbor

We discovered both *Prochlorococcus* and *Synechococcus* cells in polar ice..

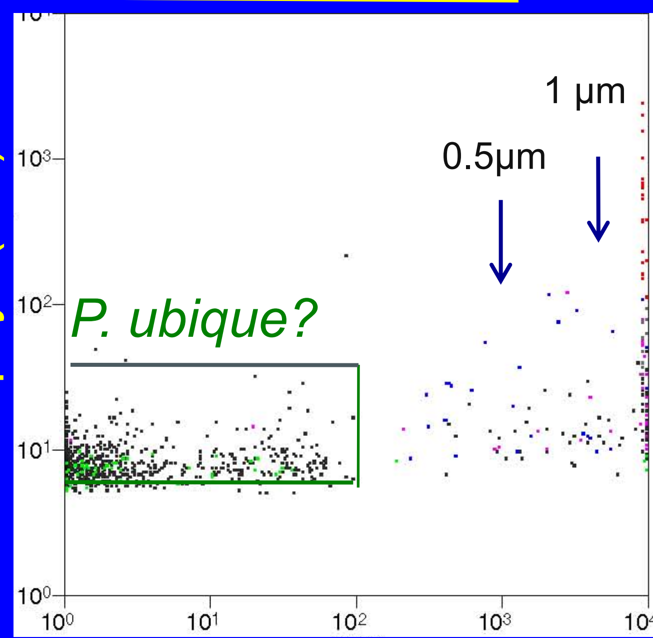
Points with small side-scatter may be due to *Pelagibacter ubique* (<0.5 µm).

Chlorophyll (red)



Phycoerythrin (orange)

Chlorophyll (red)

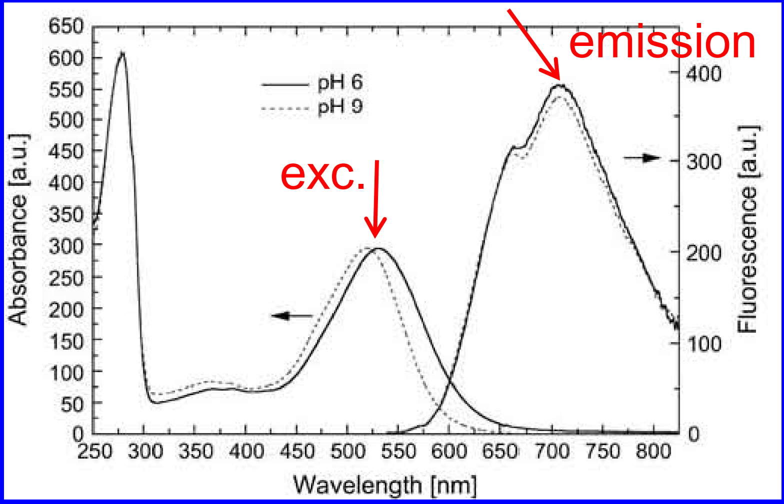


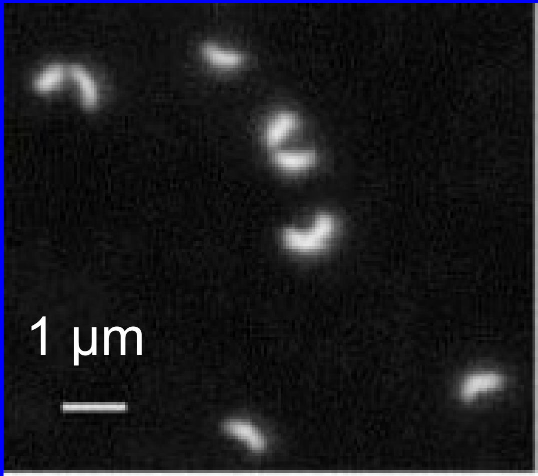
Side scatter

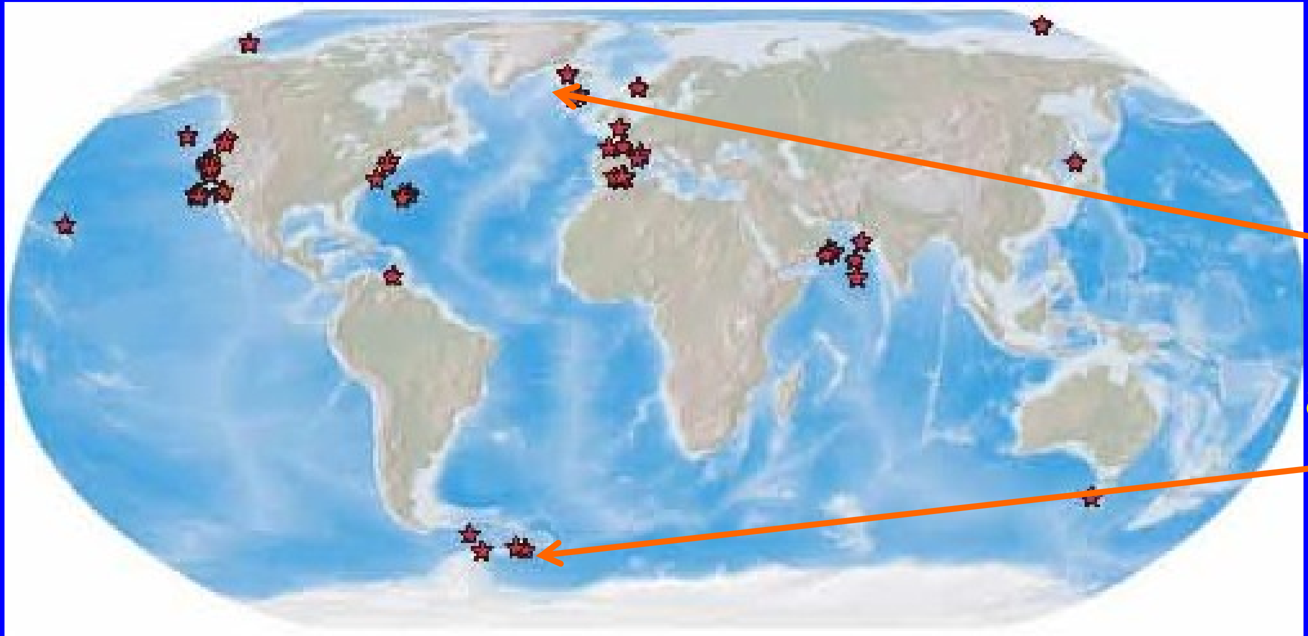
- R13 = *Prochlorococcus;*
- R5 = high-Chl *Synechococcus*
- R14 = low-Chl *Synechococcus*
- R8 = noise

Pelagibacter ubique

- The tiniest and most abundant bacteria in the oceans;
- ~2.4 x 10^{28} cells; 1 out of 3 in surface waters is *P. ubique*;
- Total mass of *P. ubique* outweighs the combined weight of all the fish in the ocean.
- Their proteorhodopsin fluorescence peaks at ~700 nm, similar to that of Chl.
- We are searching for them with flow cytometry.

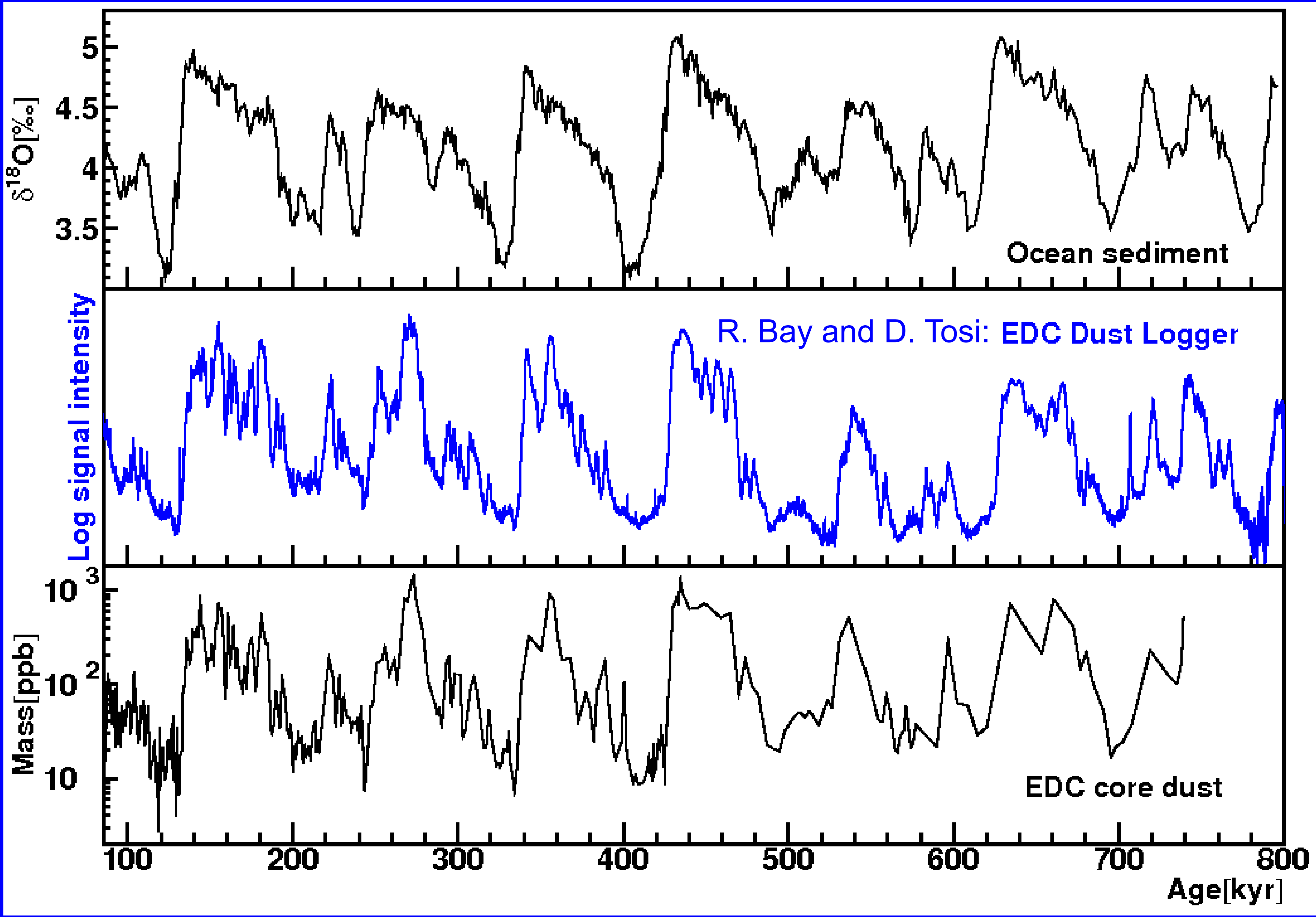




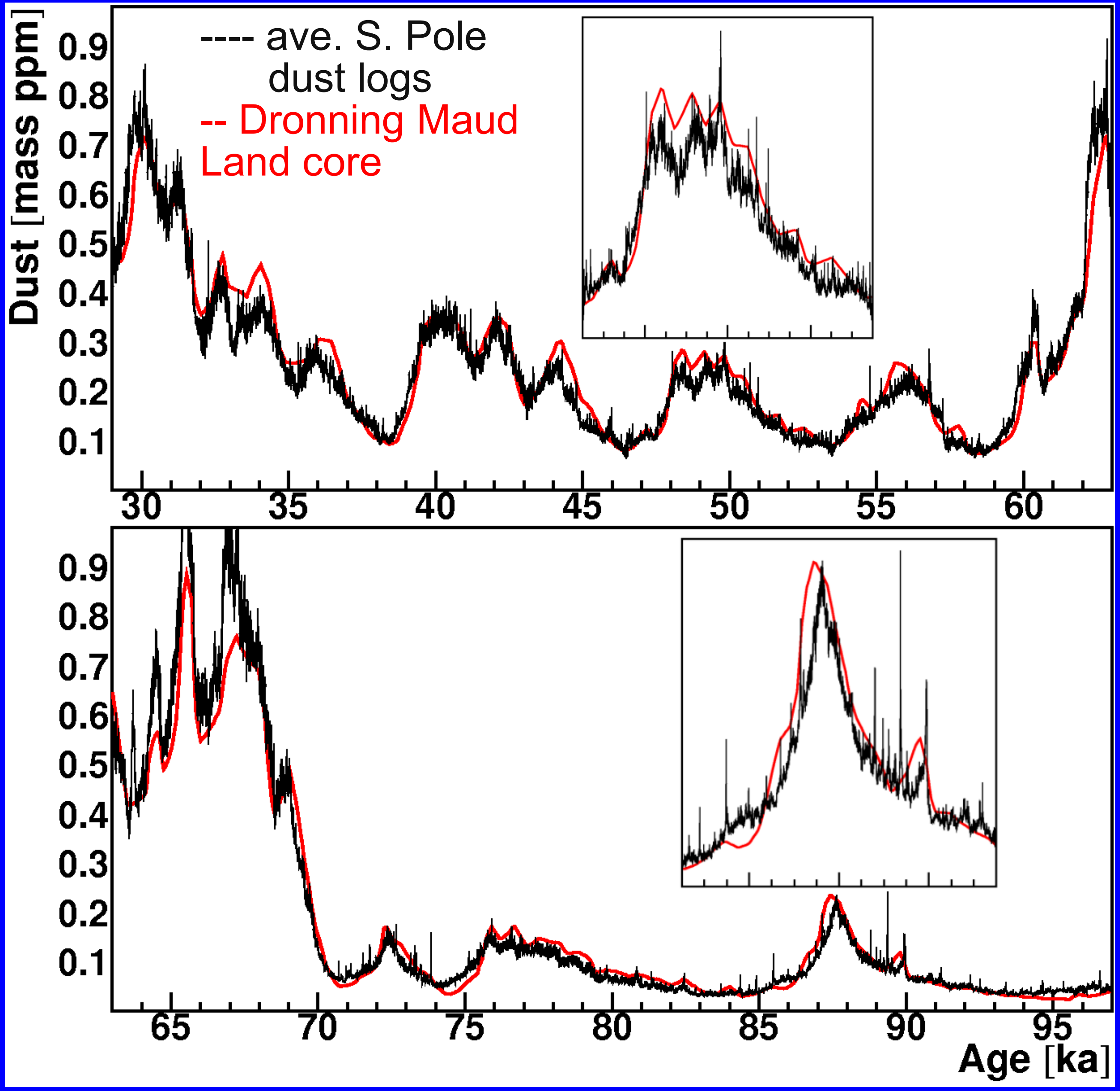


Found in both Arctic and Antarctic Ocean

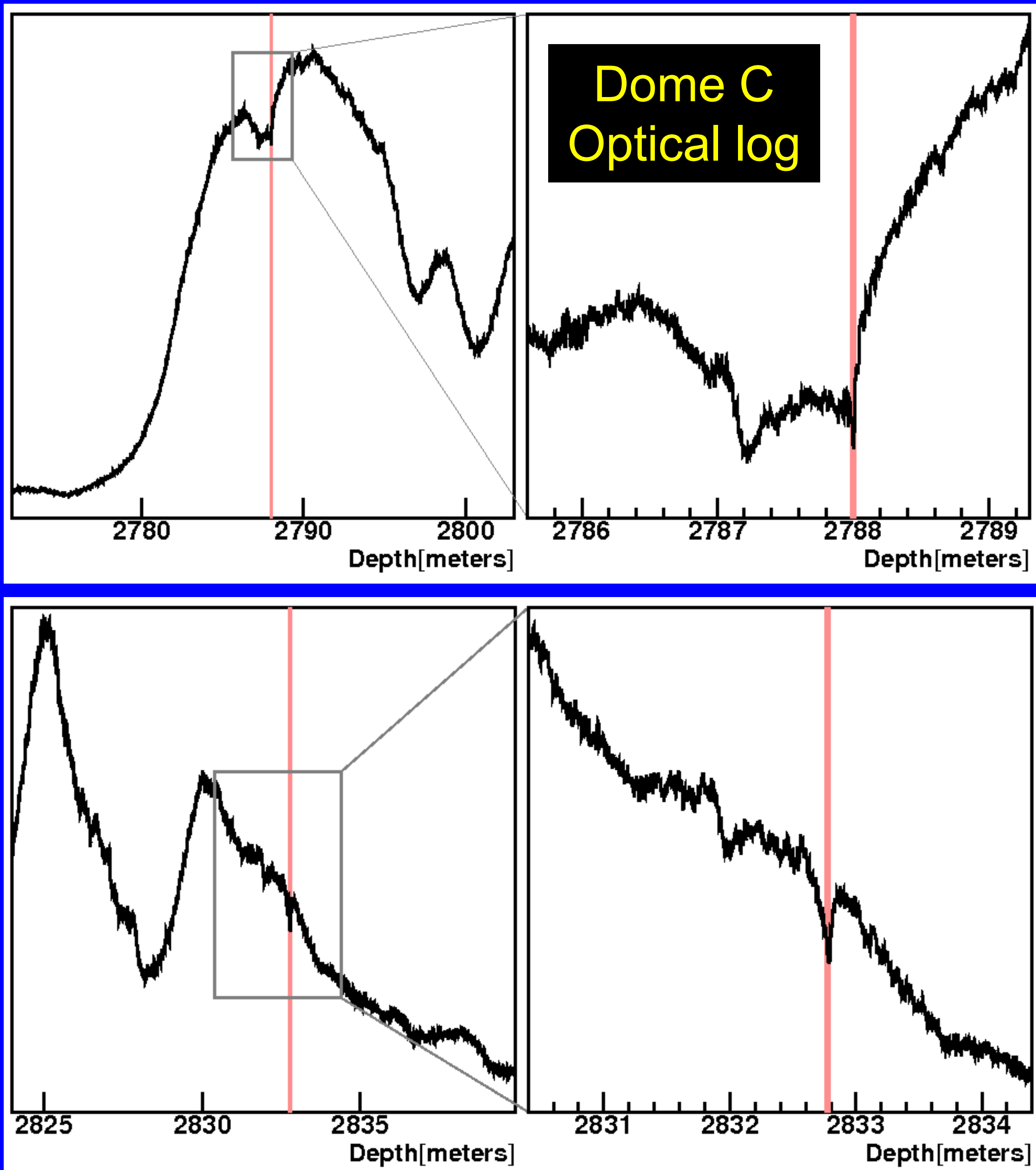
Dust Log of Dome C

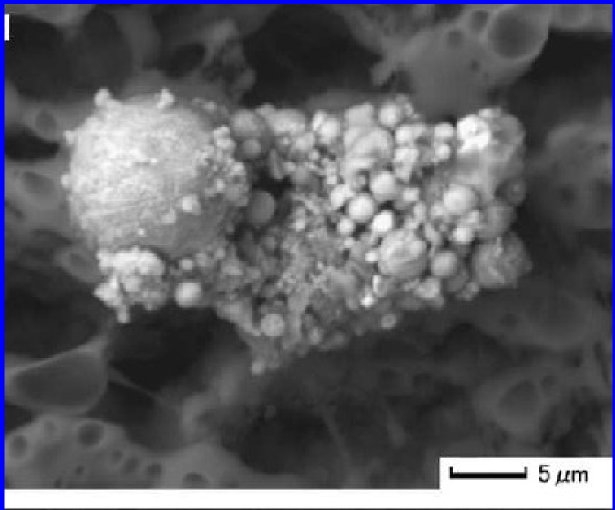


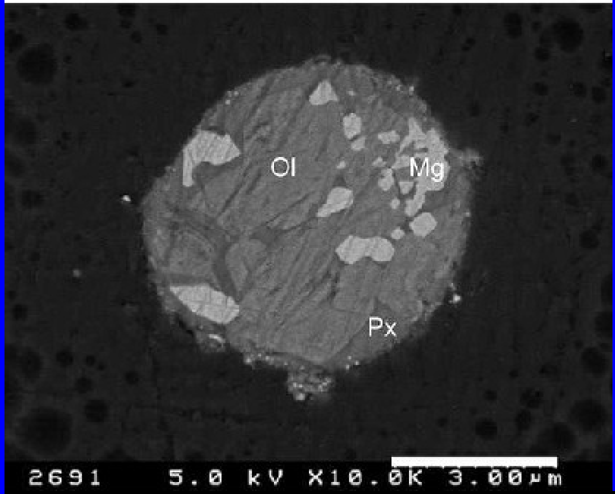
Composite High Definition Dust Record



E. Antarctic extraterrestrial impact layers ~434 and 481 ka







Particulates from
Dome Fuji core
(K. Misawa *et al*. 2010)