

# The analysis of ice cores: from first pioneering studies to the modern continuous flow analysis systems

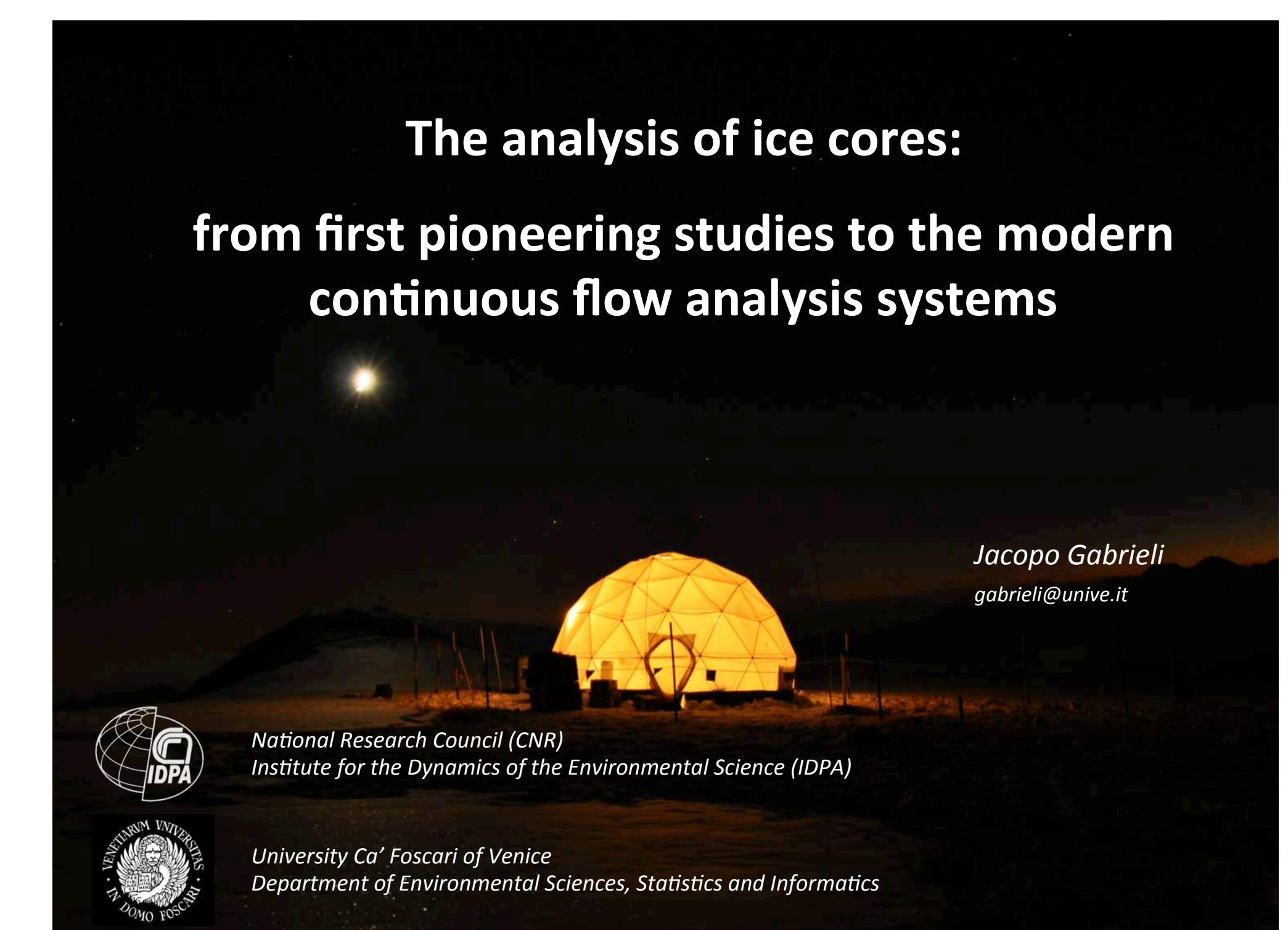


National Research Council (CNR)  
Institute for the Dynamics of the Environmental Science (IDPA)



University Ca' Foscari of Venice  
Department of Environmental Sciences, Statistics and Informatics

Jacopo Gabrieli  
[gabrieli@unive.it](mailto:gabrieli@unive.it)



## news feature

### Frozen time

Researchers have pulled the oldest-yet core of ice from the Antarctic — giving us a 740,000-year record of the planet's climate. Gabriele Walker braves the cold to find out how they did it, and what they hope to learn.

**A**fter two days of grueling work in the freezing cold, French glaciologist Frédéric Chapellez is pulling on a fluffy parka and new boots. He has just finished drilling a bore hole into a vast continental cold store, where whirling fans add a little wind chill to the temperature of -23 °C. Although we have arrived at the site in the middle of summer, with three boxes of wooden pillars stacked up to be used as bearing sites of half-metre-wide yellow-green plastic boxes of frozen samples.

"Now I will take a moment that I never dare to meditate, as we were always close to losing our samples," says Chapellez, from France's Météorology and Geology laboratory, the Laboratoire de Géologie et de Physique de l'Atmosphère (LGP2) in Grenoble, 15 kilometers from Le Puy-en-Velay. "But they have millions of years of wisdom here, so there's no way they will let them."

Chapellez is talking about ice cores, which are cylinders of snow and ice drilled from the surface down to the bedrock. They are the most extraordinary archive — a record of ancient climate written in the layers of ice cores, taken from numerous glaciaries in the Alps, Greenland, the Arctic and Antarctica. Chapellez wants to drill a core, and he looks along this ridge of ice, where curved ridges connect with spiraling facets back up to the top of the drill bit. Although it is the middle of summer, the air is cold enough for him to shiver and he has to put on a heavy coat of clothing to remain comfortable deep in the Antarctic ice sheet that any bubbles have had the breath snatched out of them, and the air is clear as glass. During his many field campaigns, he has never had to sleep outside.

The ice was drilled at Dome C in the East Antarctic ice sheet, a continental-scale dome of snow and ice, some 3,250 meters above sea level (Dome C). It has recently doubled the age record for an ice core — previously set by a core drilled 500 kilometers from Dome C, at the Australian Vostok station, which is 420,000 years old. The new core is 740,000 years old, and contains four ice ages<sup>1</sup>. It was a rewarding success for researchers demonstrating — among other things — that carbon dioxide levels in the atmosphere have matched the



Final step with temperature for hundreds of thousands of years?

#### Cold comfort

But, fortunately, the Vostok core stopped in the middle of a perched layer of ice, some 3,000 meters above sea level, at 230,000–235,000 years ago, and which the IPICA core has now fully entered. Researchers are particularly keen to explore this period because it is the last time the world was relatively similar (in its present form, making it a potential model for our own climate future). With its record of atmospheric gases and the ice core's temperature and mass balance, the core will also reveal the implications of a previous glaciation that started a million years ago.

The ice at Dome C is known for its exceptionally thick snow, dry, white, and brittle cold air, and it is very cold, with temperatures falling to -50 °C at the start of the season to -23 °C in the middle of the Antarctic summer. But it is a surprisingly pleasant place to work, located at the summit of a cluster of ice, where the chilling winds that sweep down

Antarctica's slopes. There are heated huts for sleeping, a team, and unheated hot showers. "It's really comfortable," says chief driller Laurent Augustin, "it's like Cliff's Med".

The team's drill contains a metal tube 2.5 centimeters in diameter, which is lowered

as a mechanical lift for lowering each run, a few tonnes of ice are collected in the tube, and brought back to the surface, where the core is melted and analyzed.

Ice cores of this length have transmission problems. For the first 1,000 metres, air bubbles tend to form in the boundaries between ice sections, making the core so brittle that the researchers have to use a hammer to break it into smaller pieces and chop it.

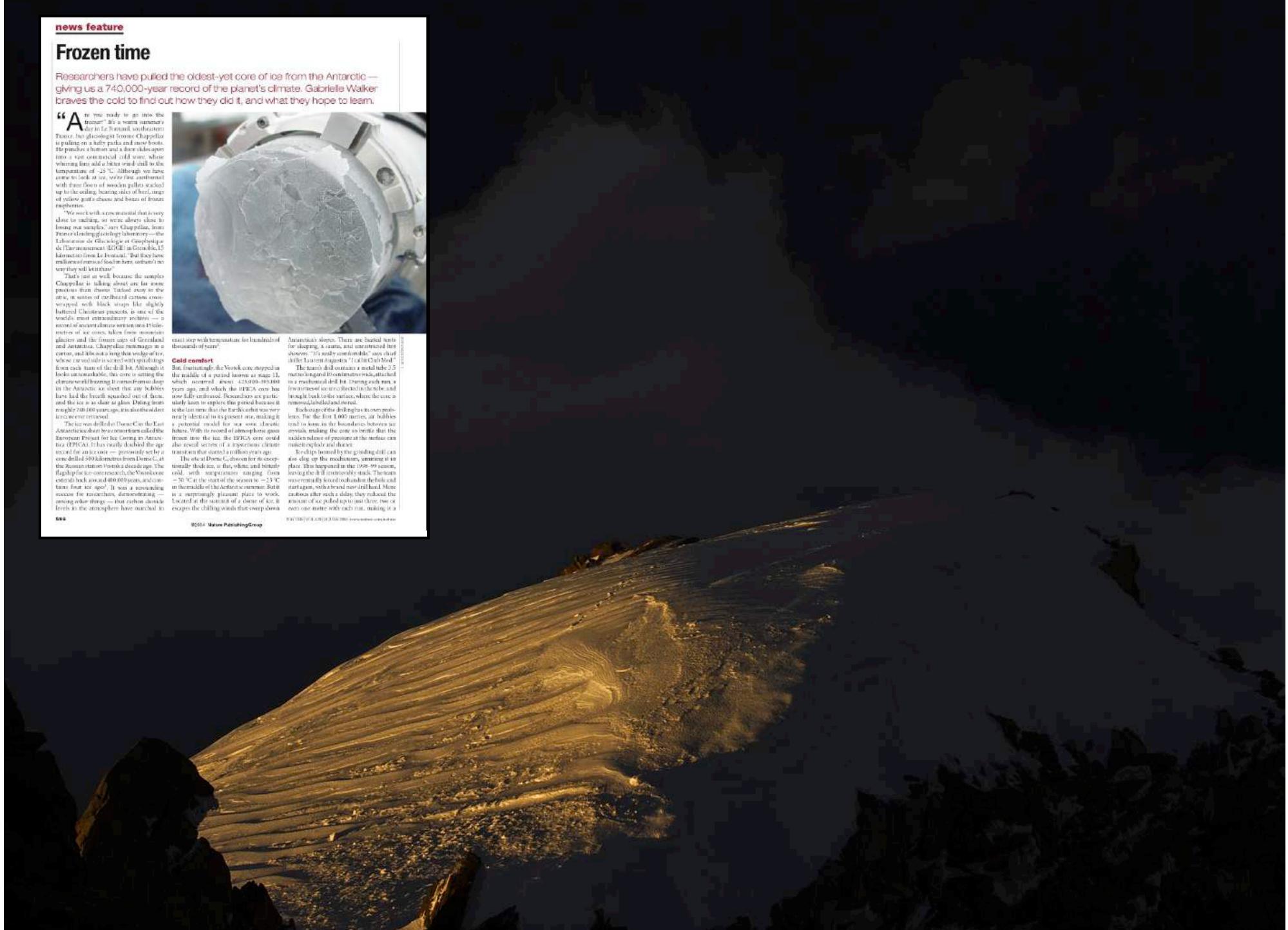
Tendrils formed by the ground effect can also stop up the mechanism, jamming it in place. This happened in the 1998–99 season, so the team had to make a special device to systematically knock out tendril-like blocks and start again, with a brand-new drill head. More cautious after such a slide, they reduce the amount of ice pulled up to just three, two or even one metre with each run, making it a

long day's work.

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## Ice... not only frozen water

1. Major ions ( $\text{Ca}^{2+}$ ,  $\text{K}^+$ ,  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ , ...)
2. Stable O and H isotopes
3. Trace elements
  - Geochemical tracers (REEs, Pb, Sr isotopes)
  - Anthropogenic (Pb, Cd, Cr, U, As, PGEs, ...)
  - Cosmogenic ( $^{10}\text{Be}$ ,  $^{36}\text{Cl}$ )
  - Radioactive tracers ( $^{137}\text{Cs}$ ,  $^3\text{H}$ , Pu, ...)
4. Dust particles
5. Organic compounds
  - Combustion markers (OC, PAHs levoglucosan, ...)
  - Industrial (PCBs, PBDEs, PCDEs, PFCs, ...)
  - Agriculture (pesticides, HCB, ...)
6. Dissolved greenhouse gasses ( $\text{CO}_2$ ,  $\text{CH}_4$ , ...)
7. ...





Low concentrations



$$1.0 \text{ ng/kg (ppt)} = 1 / 1,000,000,000,000 = 10^{-12}$$





## External contamination



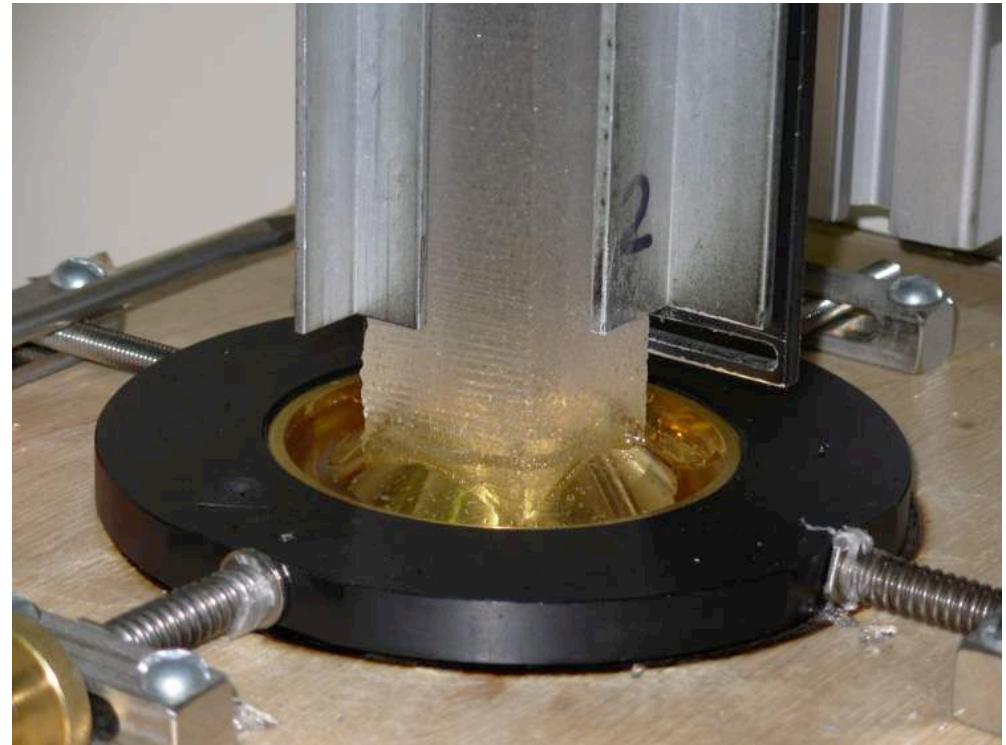
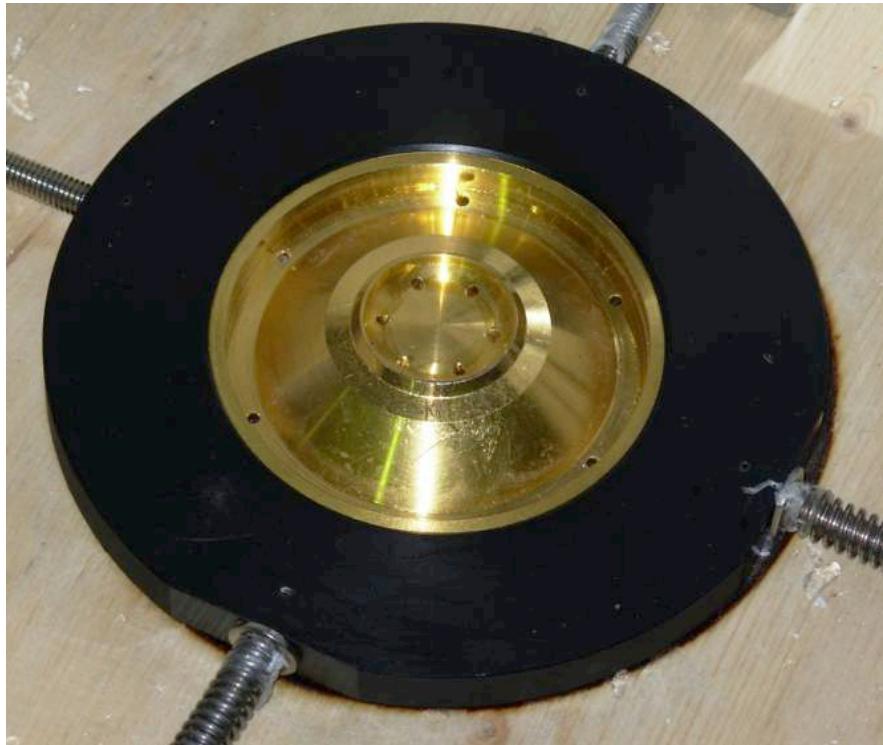


## External contamination





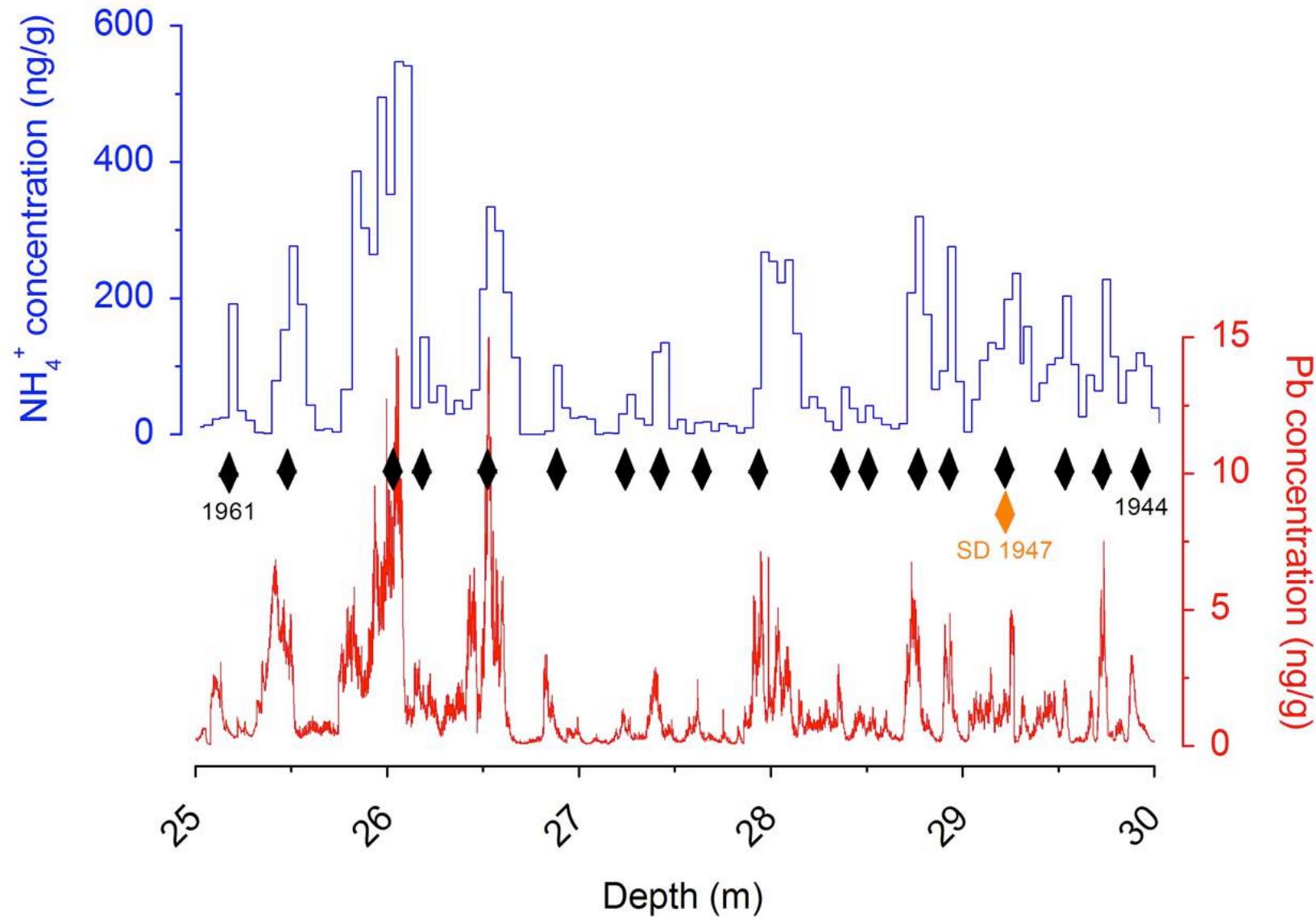
## From chisseling to continuous melting systems





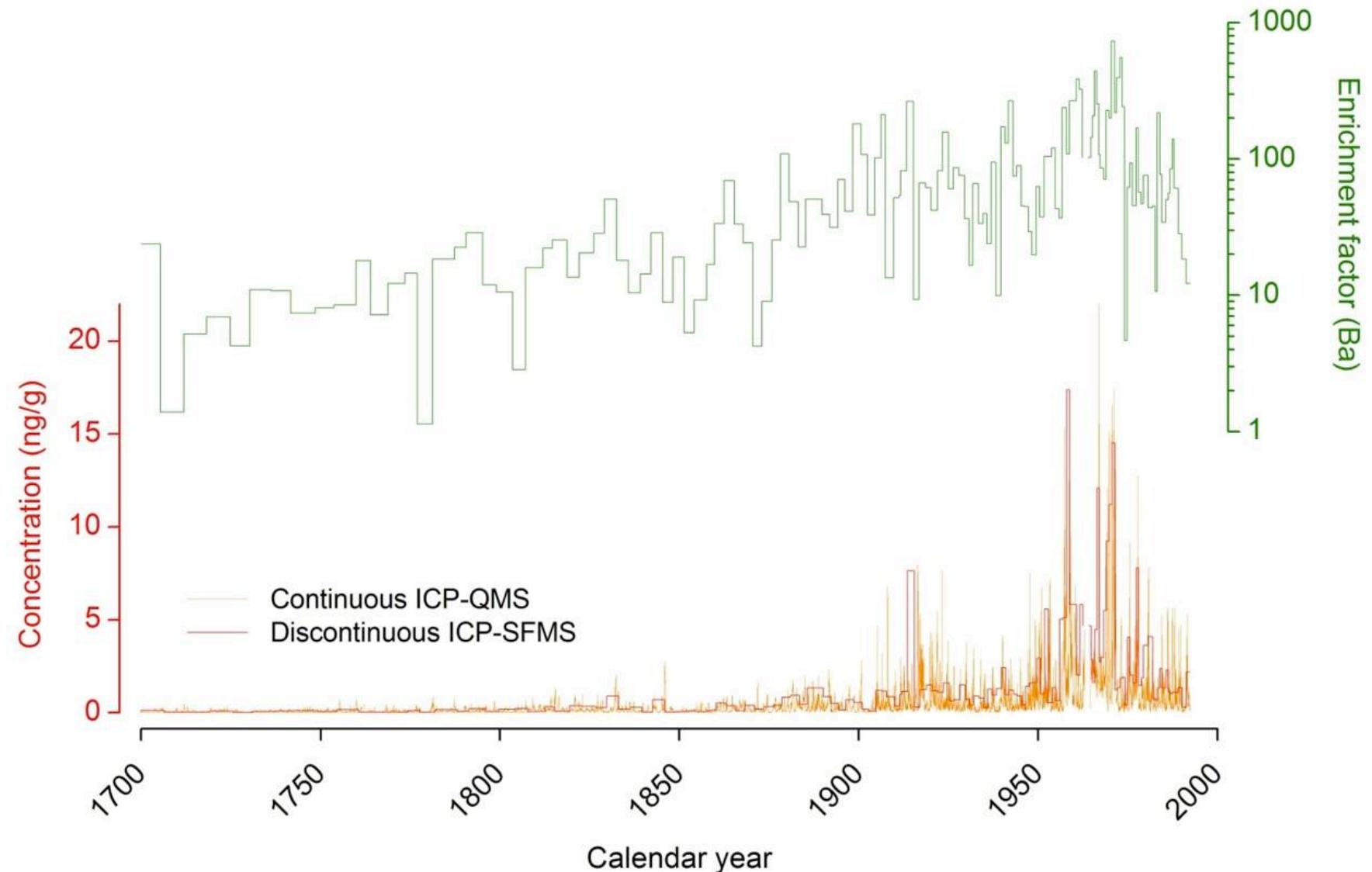


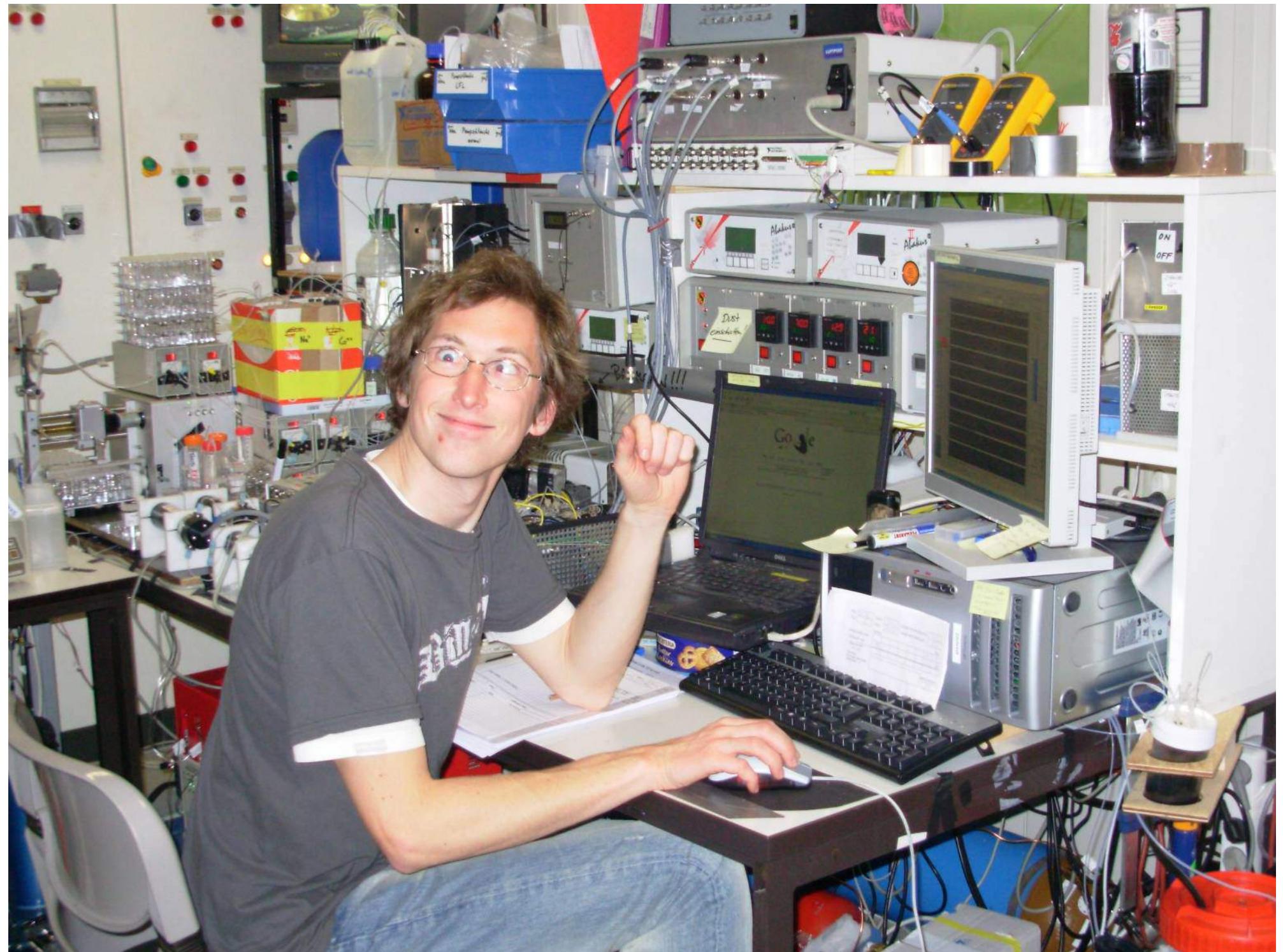
## Colle Gnifetti – seasonal signals





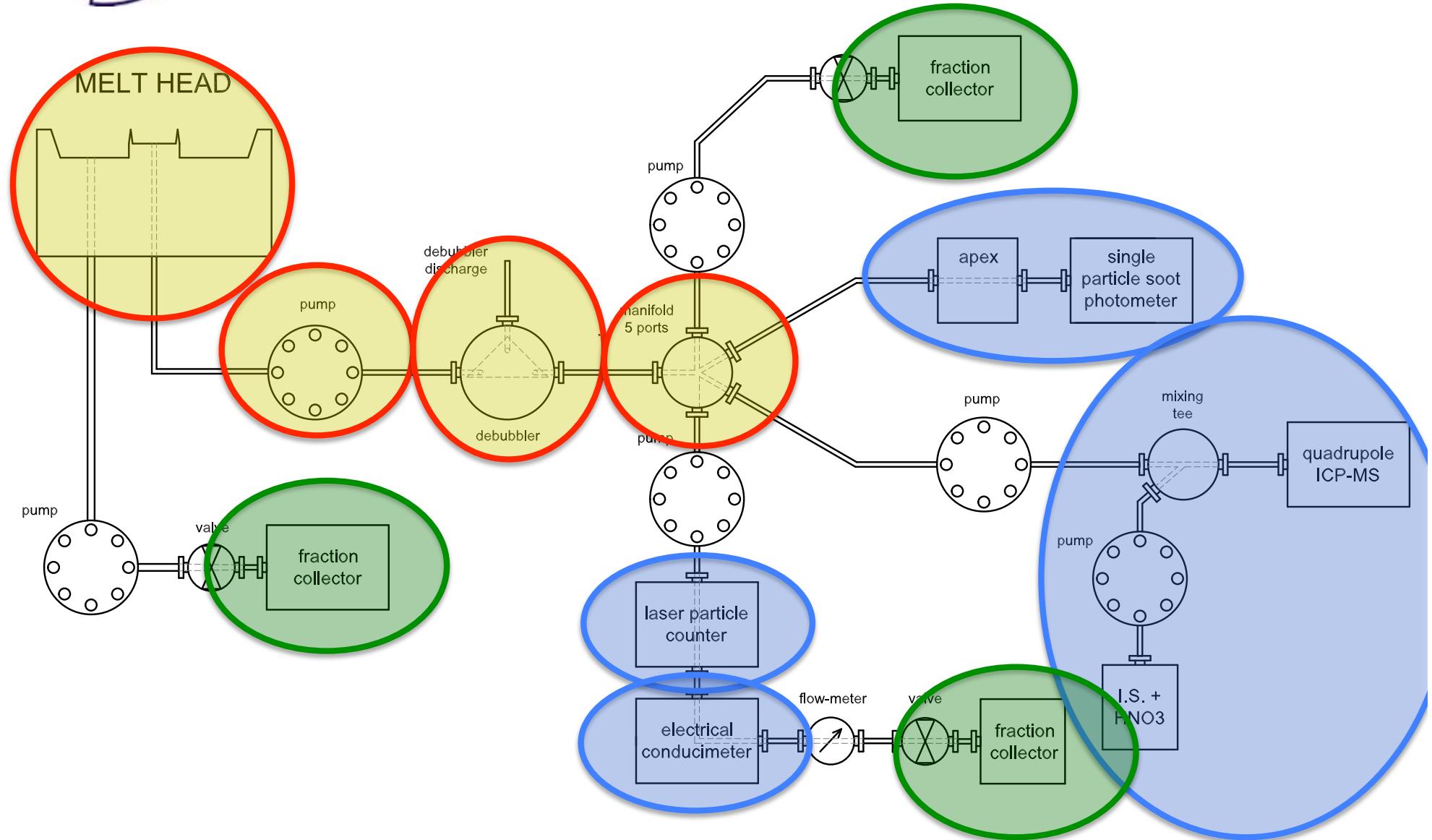
## Colle Gnifetti – Pb deposition over the last 300 yrs





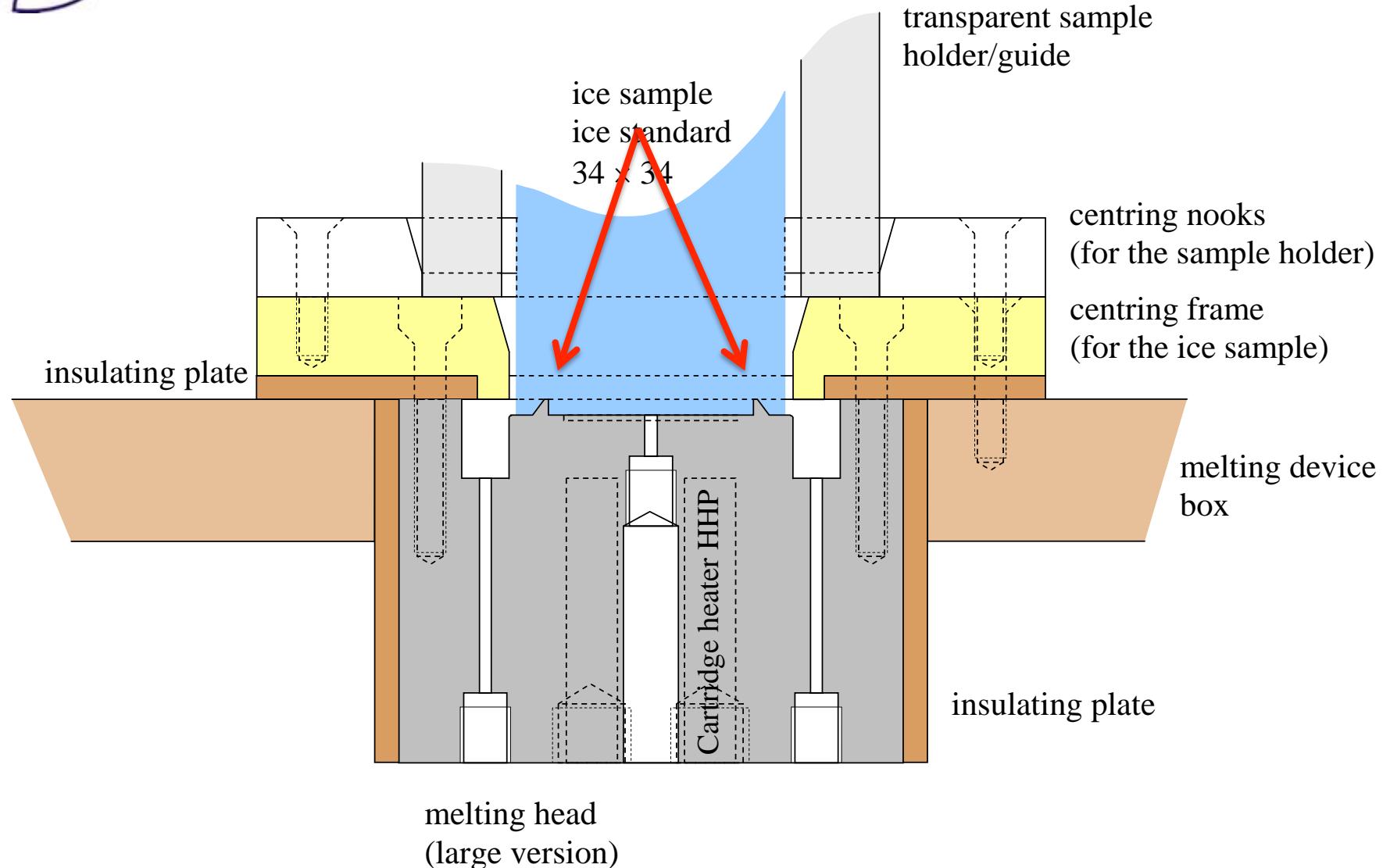


# The new “venetian” melting system



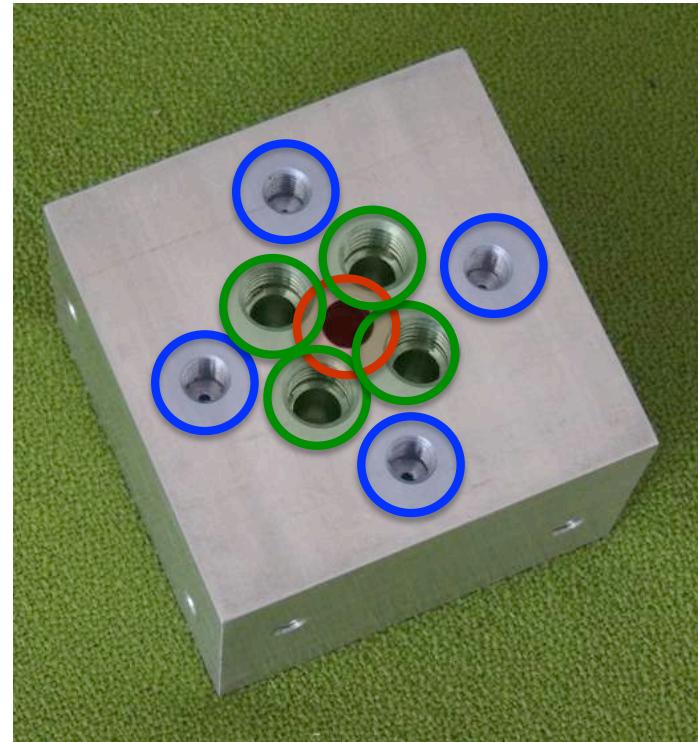
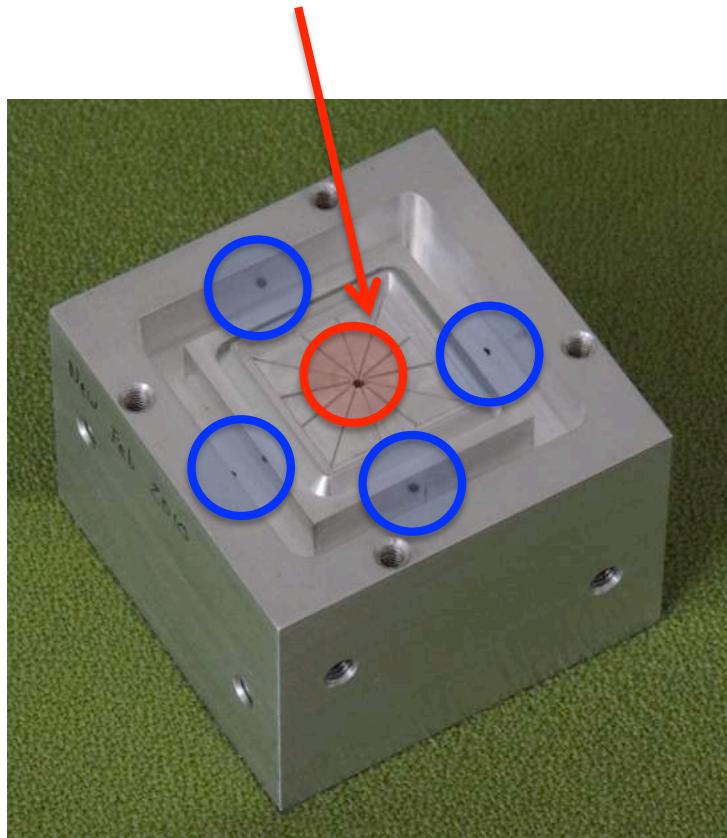


## Melting head geometry





## Melting head geometry





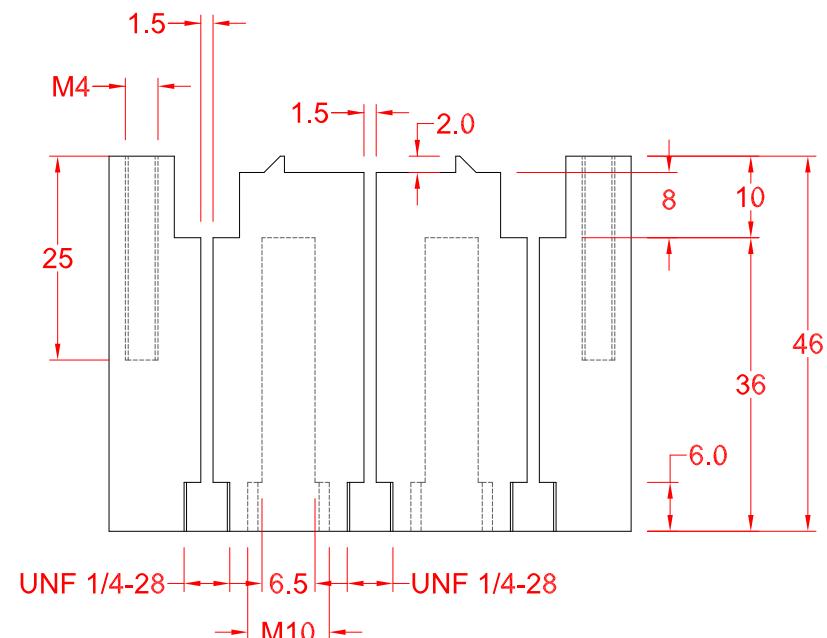
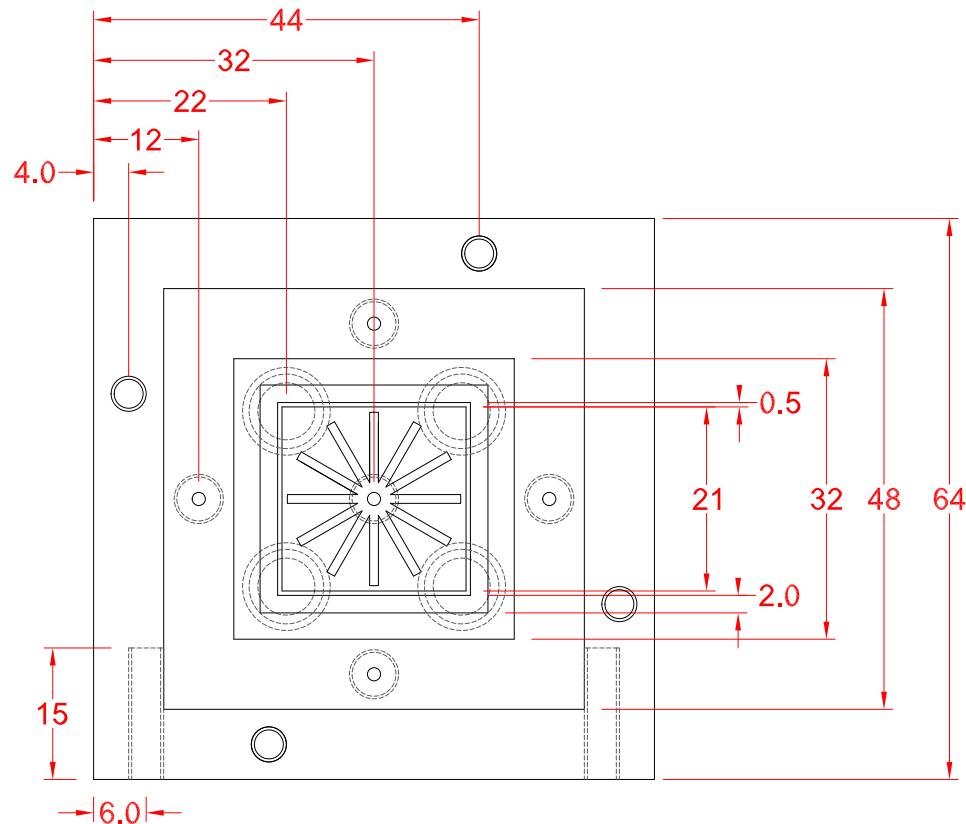
## The melt head: which metal?

| Metal           | Thermal Cond.<br>(W/mK) | Machinability | Chemical<br>stability | Price  |
|-----------------|-------------------------|---------------|-----------------------|--------|
| Cu              | 390                     | 😊             | 😢                     | €€ (*) |
| Al              | 237                     | 😊             | 😊                     | € (*)  |
| Ni              | 91                      | 😢             | 😊                     | €€€    |
| Stainless-steel | 16 - 52                 | 😢             | 😊                     | €€     |
| Ti              | 22                      | 😢             | 😊                     | €€€    |

(\*) Cu and Al meltheads require electrolytic deposition and anodizing, respectively

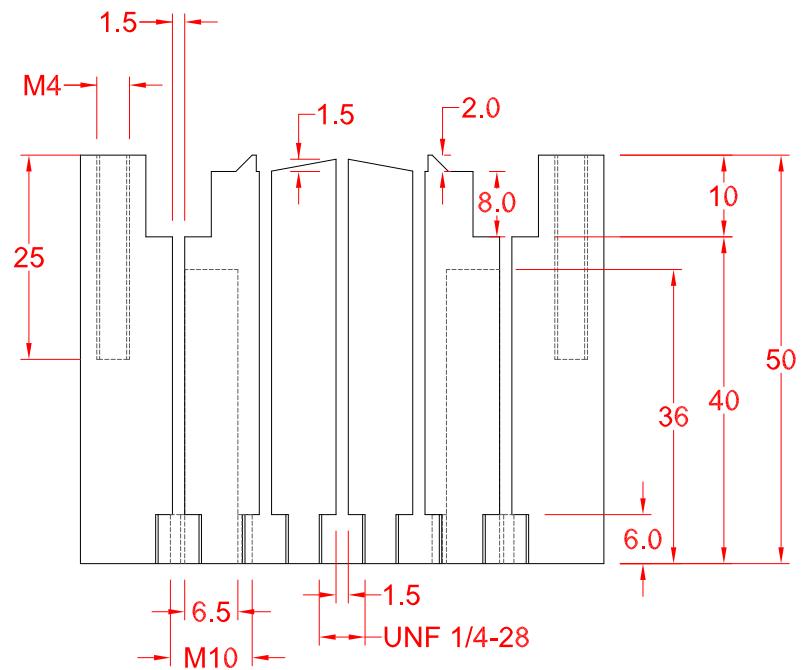
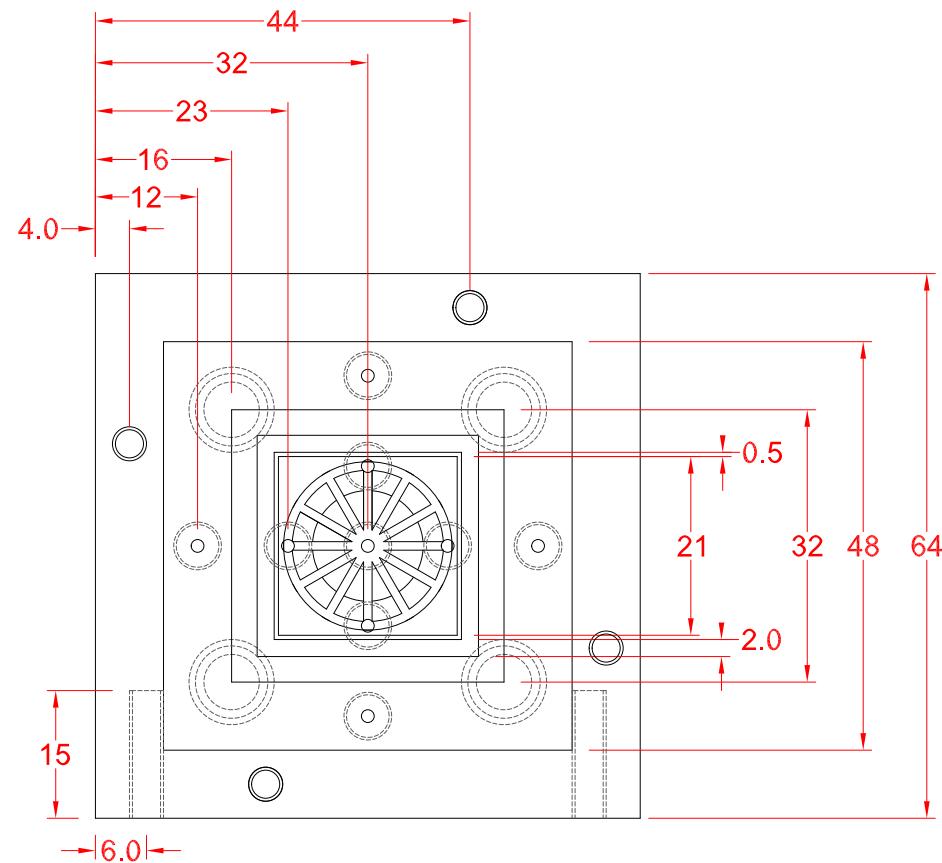


## Melting head geometry



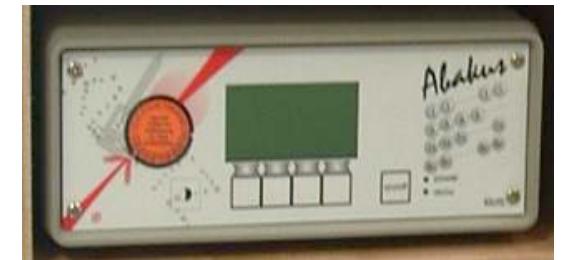


## Melting head geometry



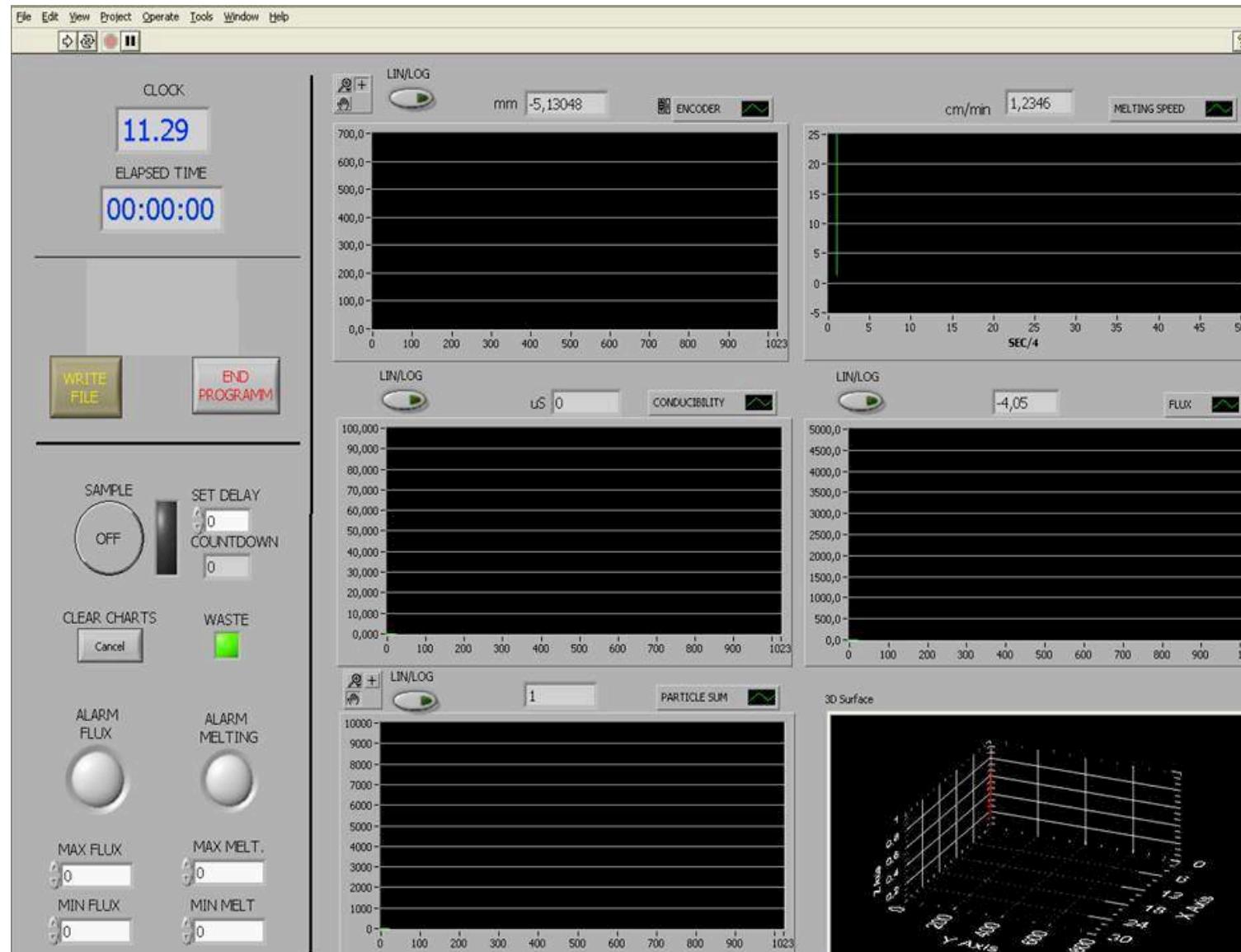


# Continuous flow analysis





# NI acquisition software





## Continuous measurements – current configuration

- Melting head temperature 25°C
- Melting rate  $3.2 \pm 0.16$  cm/min (n=27)

### CONTINUOUS MEASUREMENTS

- Electrical Conductibility
- Dust (ABAKUS, 32 channels)
- Up to 28 trace elements (Agilent ICP-QMS)
- Black carbon by SP2

### ANCILLARY PARAMETERS

- Melting rate (drawwire sensor)
- Flux (Abakus-Conductibility channel)



Instrumental resolution  $0.8 \div 1.1$  mm (theoretical...)  
Final CFA resolution  $\sim 5 \div 8$  mm



## Discrete sampling

### DISCRETE SAMPLING



- Two flows from inner channel
- 1° flow (dedicate tube), flux = 5.26 mL/min
- 2° flow (abakus-conductibility), flux = 2.84 mL/min
- External layer, flux > 9.6 mL/min

|                        |        |                   |          |
|------------------------|--------|-------------------|----------|
| Heavy metals, REE, ... | volume | 2.5 ÷ 4.0 mL      | 5 cm     |
| Major ions             | volume | ~ 5 mL (1.0 mL ?) | 5 cm     |
| Levoglucosan           | volume | < 1.0 mL          | 30 cm    |
| Stable isotopes        | volume | ~ 2 mL            | 3÷5 cm   |
| Dust                   | volume | ~ 10 mL           | 8÷10 cm  |
| Pollen                 | volume | ~ 25 ÷ 50 mL      | 15÷20 cm |

A large, dark, billowing cloud of smoke or dust rises from a steep, rocky mountain slope. The slope itself is light-colored with dark, horizontal streaks, suggesting sedimentary rock layers. The rising plume is thick and turbulent, with darker edges and lighter center, indicating it's a massive, fast-moving event.

**Once upon a time...**

**...the Ortles drilling**



## Ortles – Vedretta Alta



### Vedretta Alta

Surface (2006): 105 ha  
Maximum elevation: 3905 m  
Minimum elevation: 3018 m  
Average elevation: 3535 m  
Exposure: NW  
Average slope: 29°

### Climatology

Precipitation (valley floor, 1900 m): **750 mm y<sup>-1</sup>**  
Annual air temperature (3850 m): **-9°C**



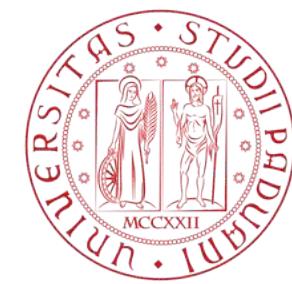
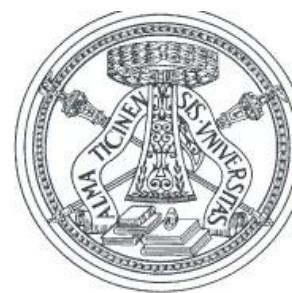


## The Ortles work group



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UNIVERSITÄT  
BERN



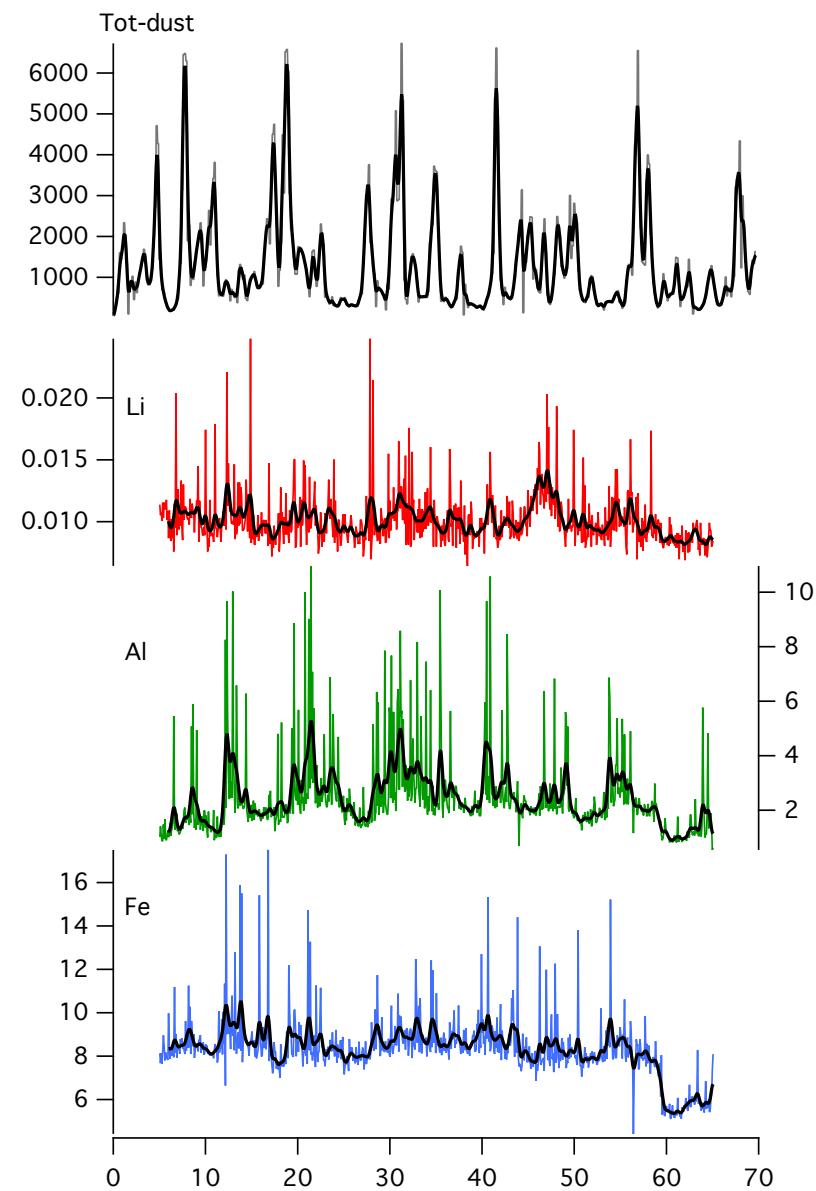
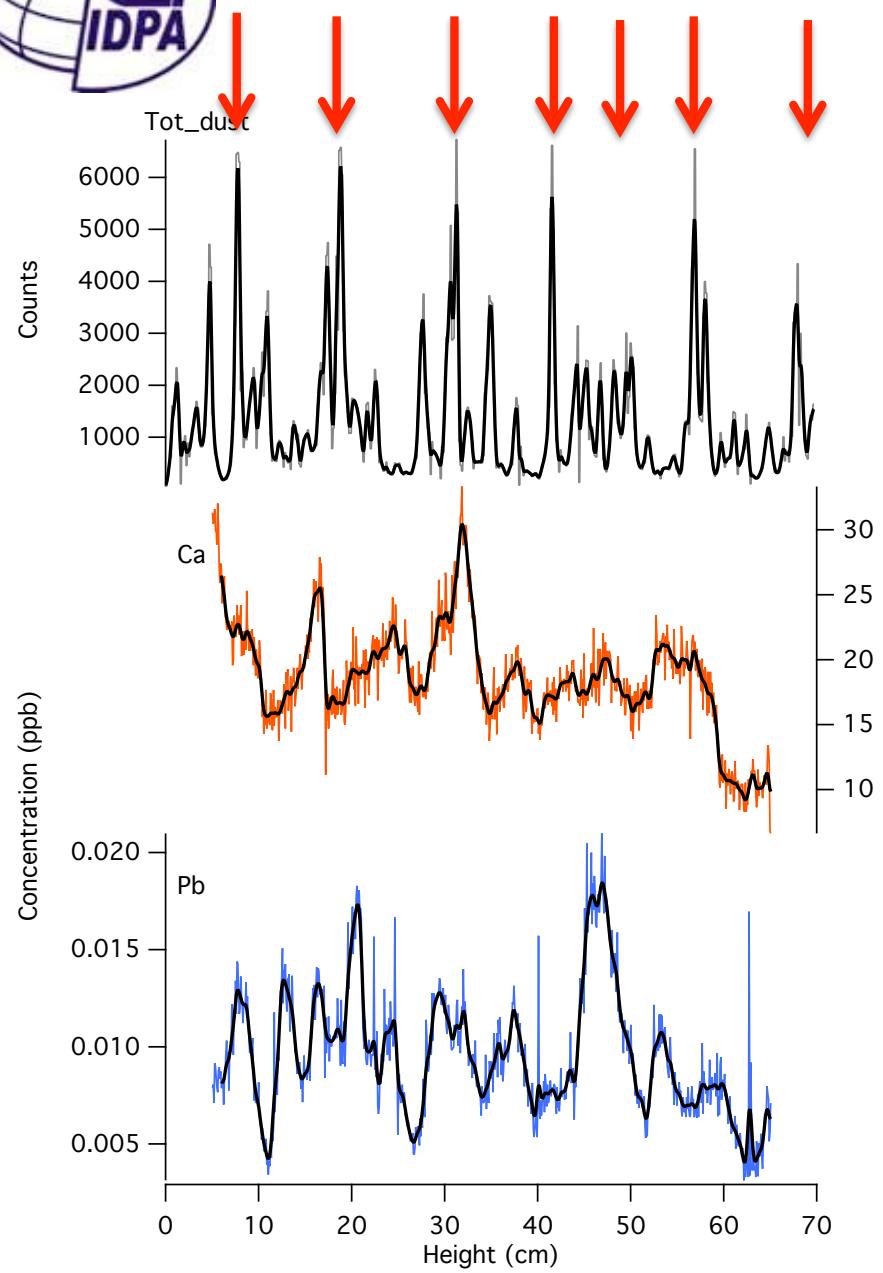
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A wide-angle photograph of a coastal landscape at dusk or dawn. In the foreground, dark, choppy water reflects the warm light of the setting or rising sun. A range of mountains is visible in the middle ground, their peaks partially obscured by thick, billowing clouds. The sky above is filled with various layers of clouds, some illuminated from behind by the low sun, giving them a golden or orange glow. The overall atmosphere is serene and majestic.

Some preliminary results...



## First test – Ortles core #1, bag 85 (64.2 – 64.9 m)





- Fixing a few bugs identified from preliminary tests
  - SP2 connection and testing
  - Analysis of Ortles core #1 (106 bags, 75.1m)
  - Replicate of a few Ortles bags for reproducibility tests
  - Data processing and management
- 
- Installation of a second CFA system at Ohio State Univ.
  - Intercomparison tests between CNR, LGGE, OSU

# Thanks for your attention !

*Jacopo Gabrieli*  
*gabrieli@unive.it*



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