

Macromolecular Organic Compounds from the Depths of Enceladus

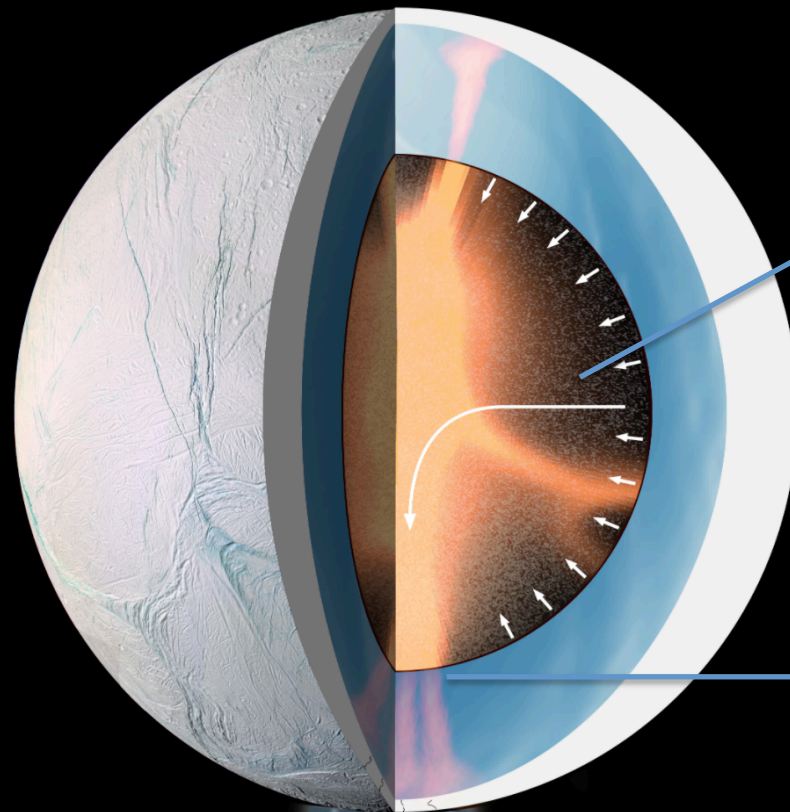
Frank Postberg

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N. Khawaja, B. Abel, G. Choblet, C. Glein, M. Gudipati, B. Henderson, H.-W. Hsu, S. Kempf, F. Klenner, G. Moragas-Klostermeyer, B. Magee, L. Nölle, M. Perry, R. Reviol, J. Schmidt, R. Srama, F. Stolz, G. Tobie, M. Trieloff, H. Waite

OPAG Meeting September 2018, Pasadena

Exploring a deep hydrothermal water world



**Tidal dissipation
powerhouse**

Choblet et al. 2017

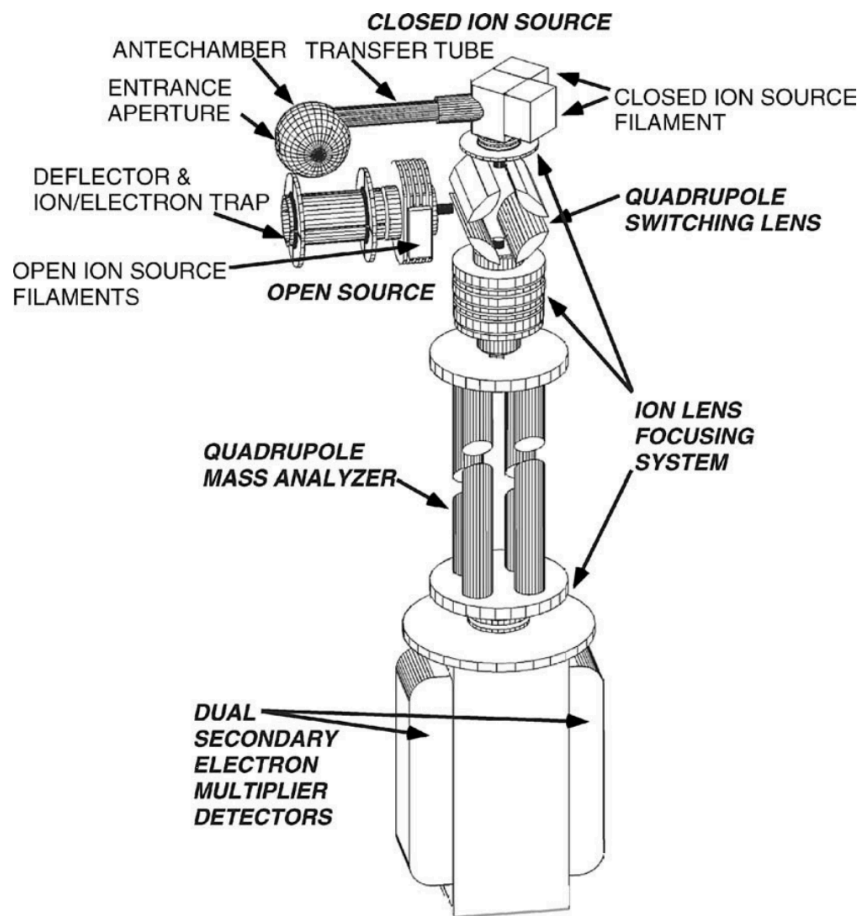
Hydrothermal activity:

Hsu et al. 2015

Waite et al. 2017

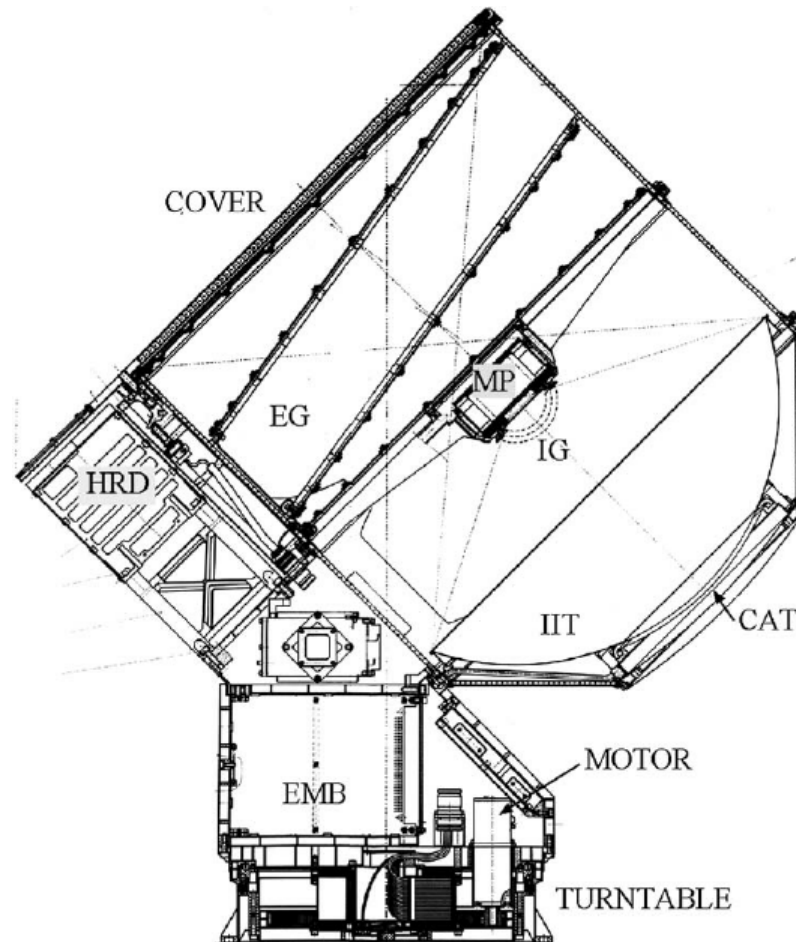
Cassini's Mass Spectrometers

Ion and Neutral Gas Spectrometer (INMS)



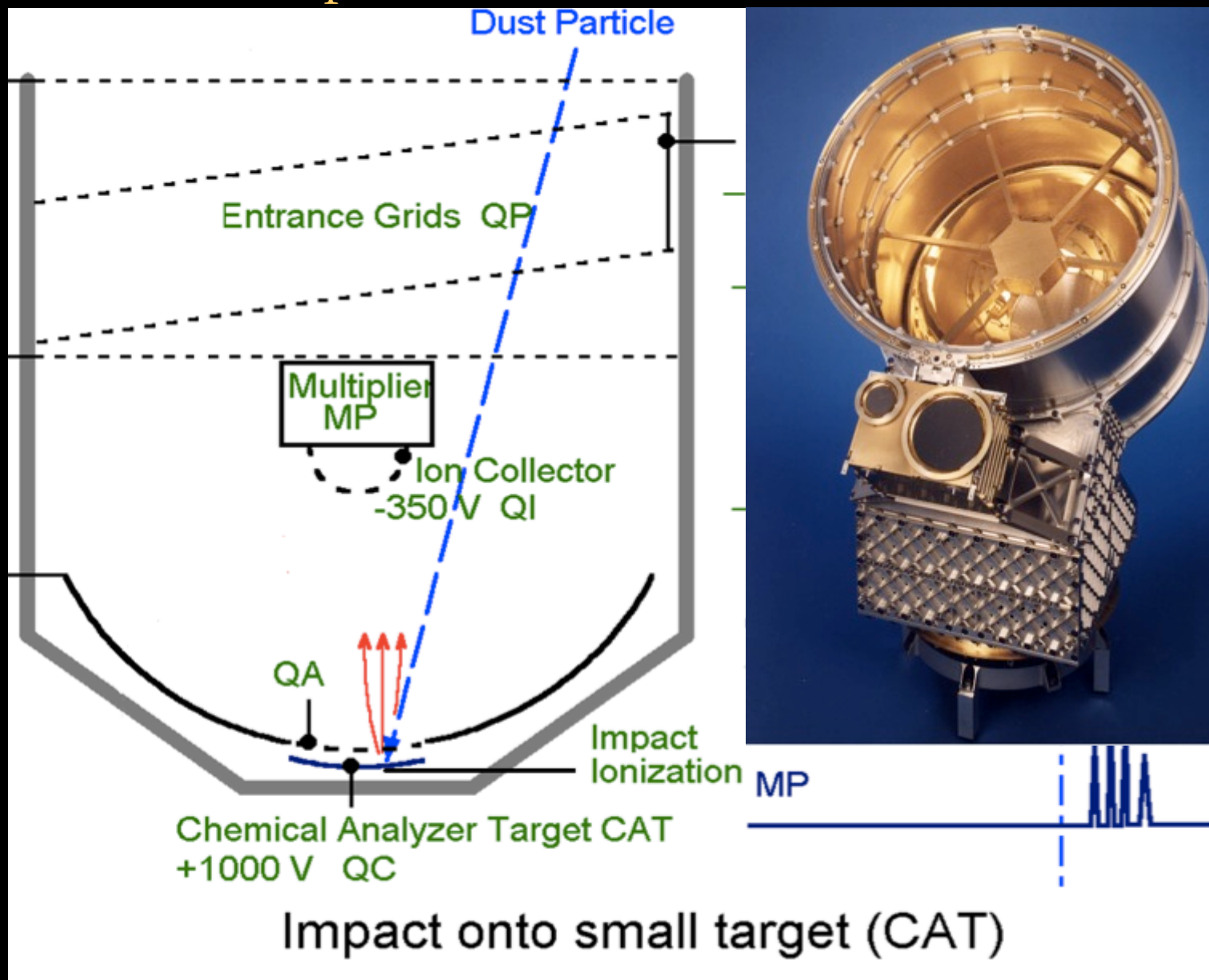
Sampling Gas

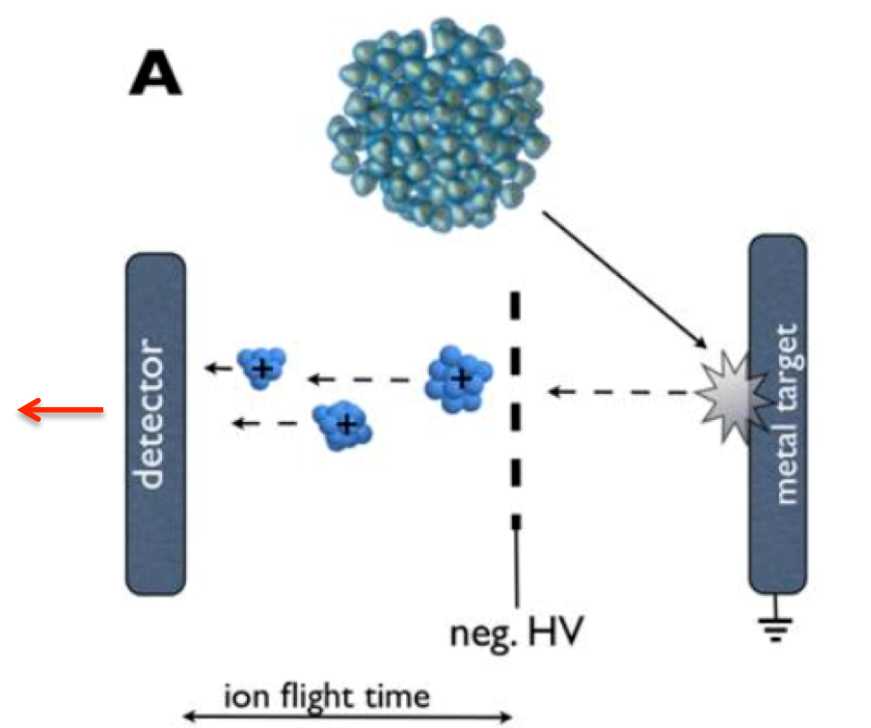
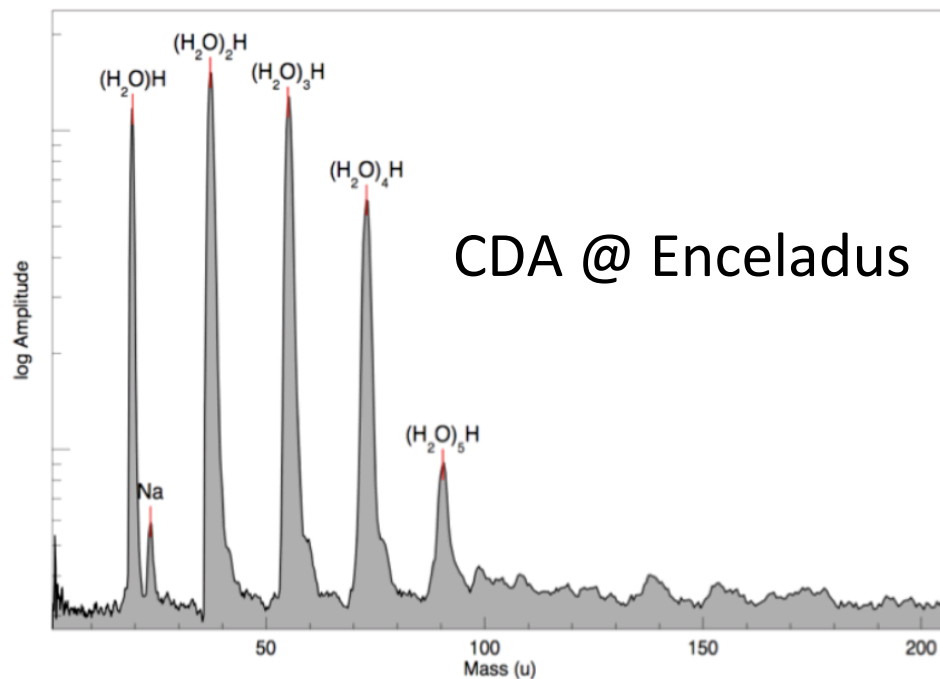
Cosmic Dust Analyzer (CDA)



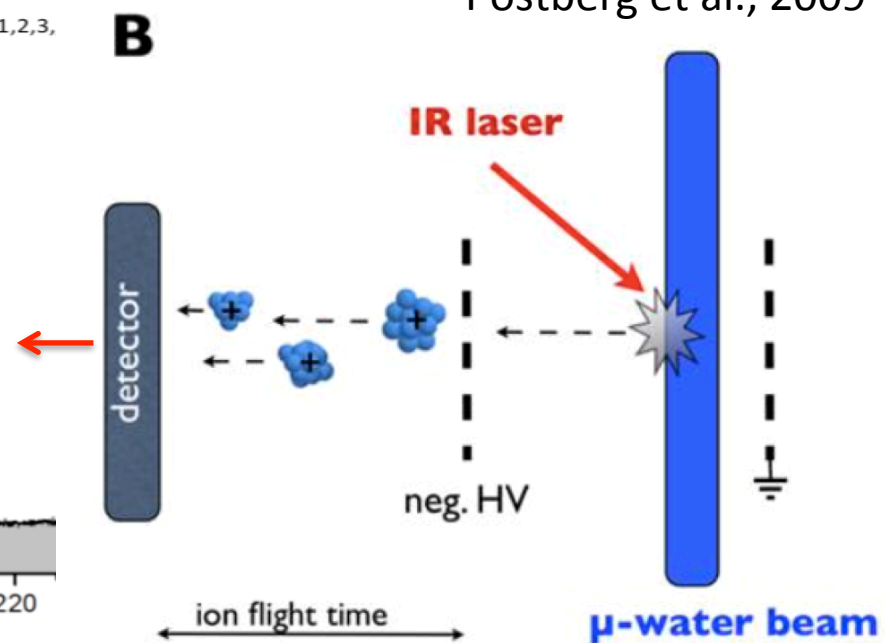
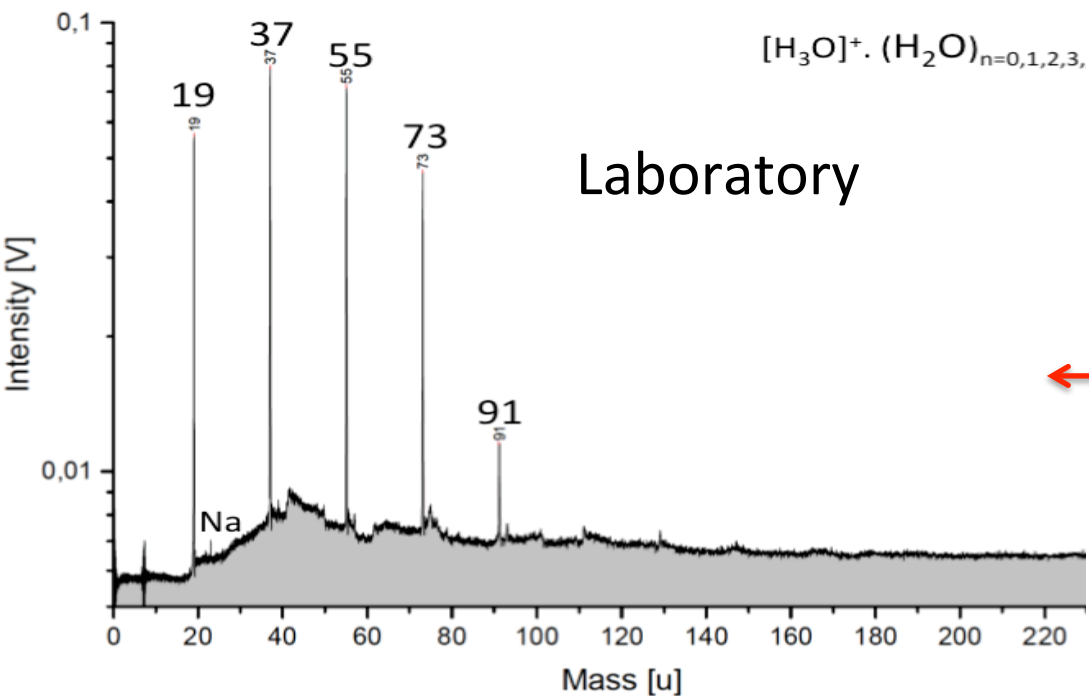
Sampling Ice Grains

Chemical characterisation of icy dust with Cassini's (CDA) Impact Ionization TOF-MS





Postberg et al., 2009

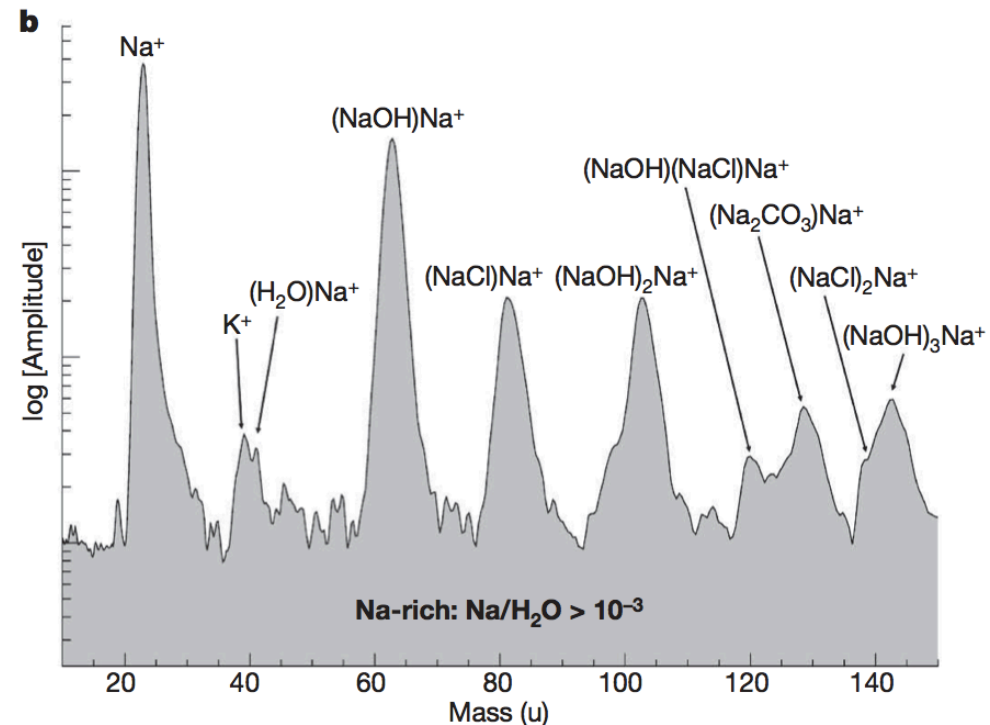
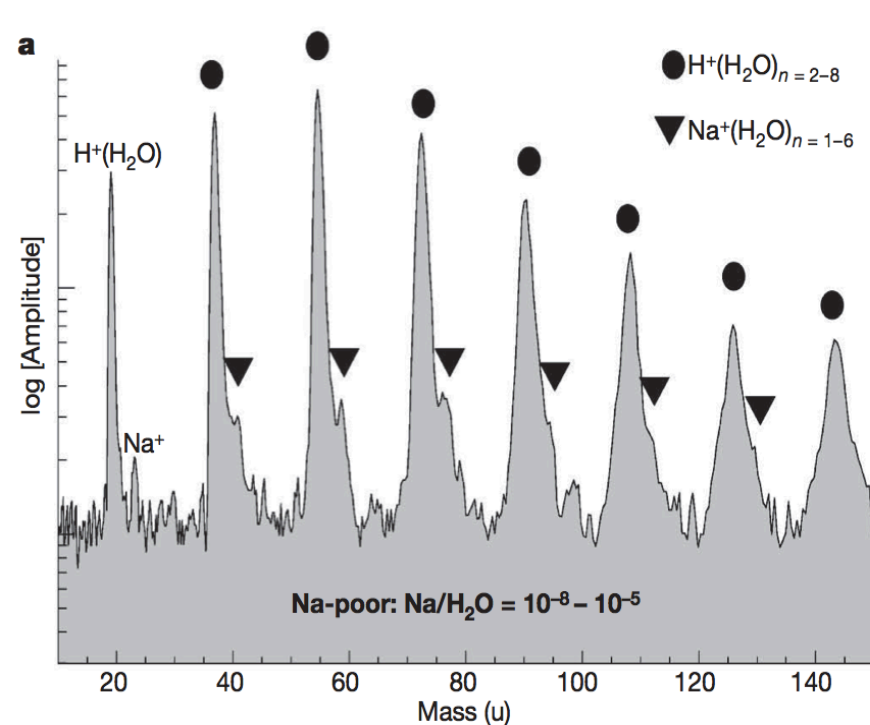


Three ice grain populations – Three spectrum types

Hillier et al. 2007; Postberg et al. 2008, 2009, 2011

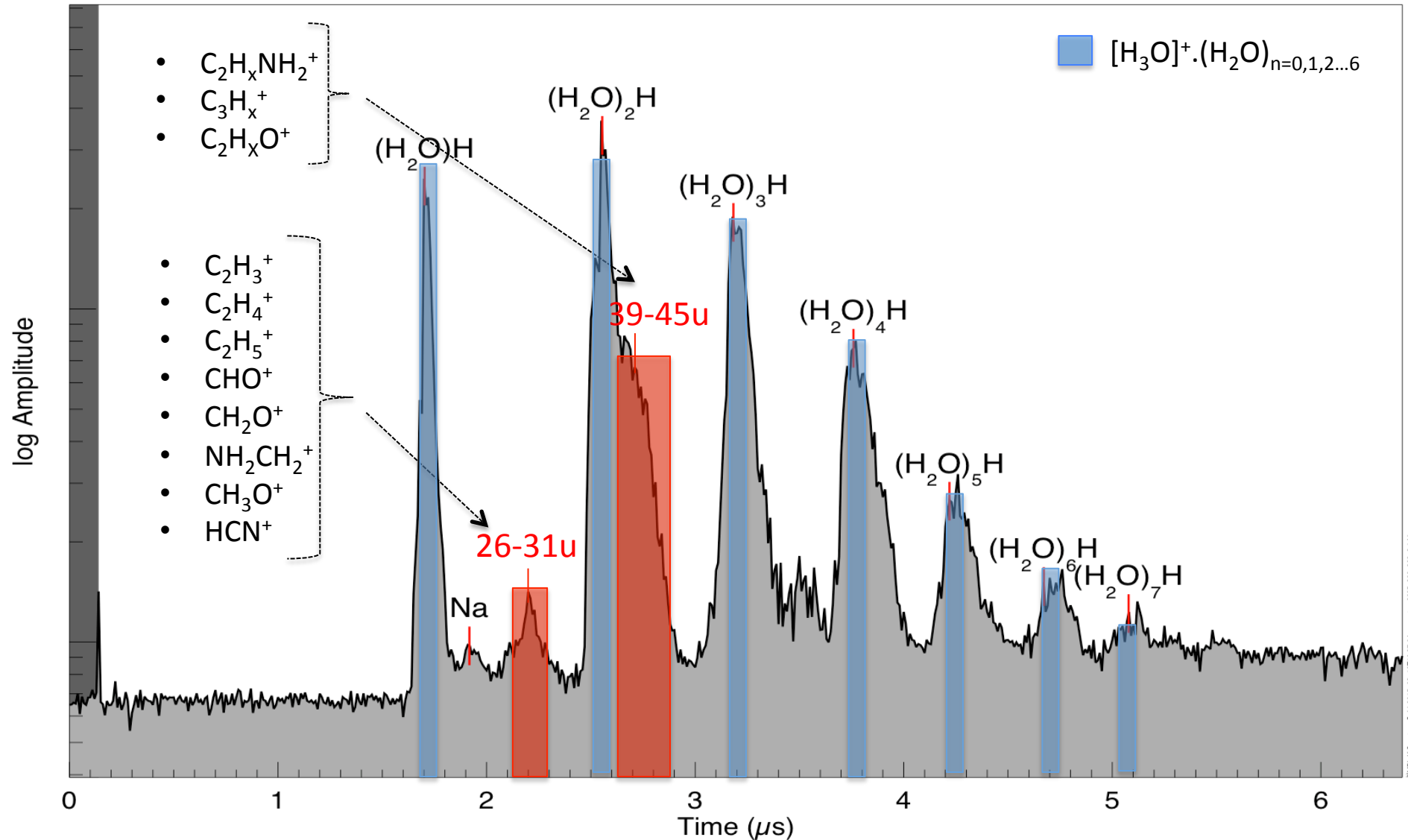
Type 1: pure water ($\approx 65\%$)

Type 3, salty water ($\approx 10\%$)



Type 2: Organic bearing ice ($\approx 25\%$)

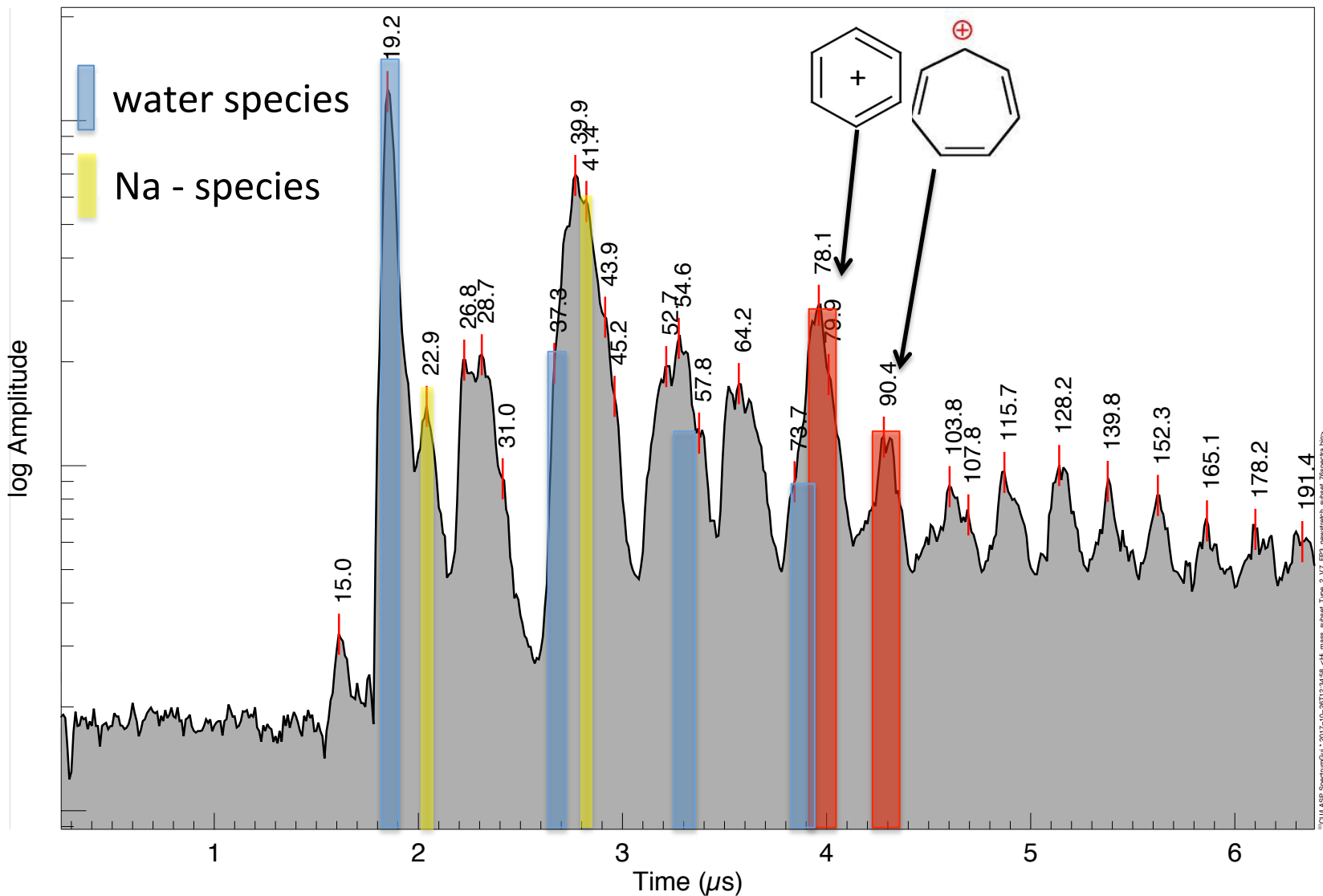
Organics in Type 2 spectra



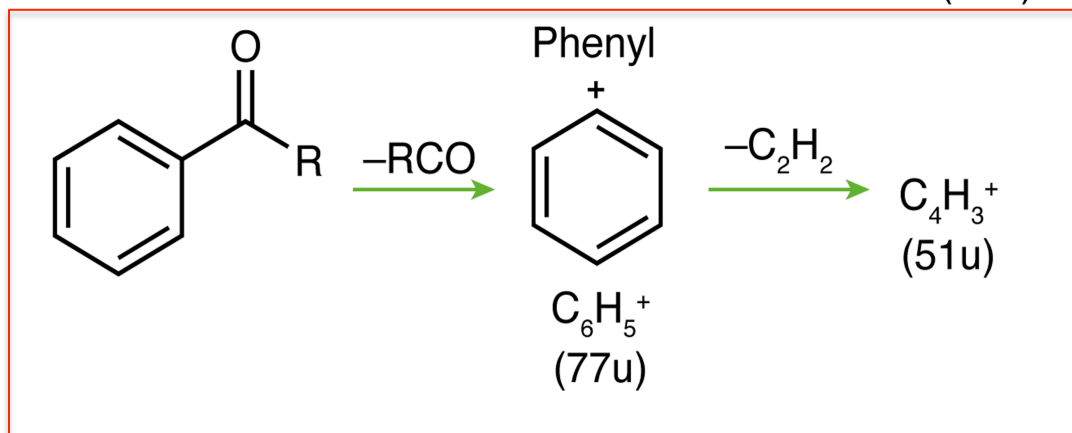
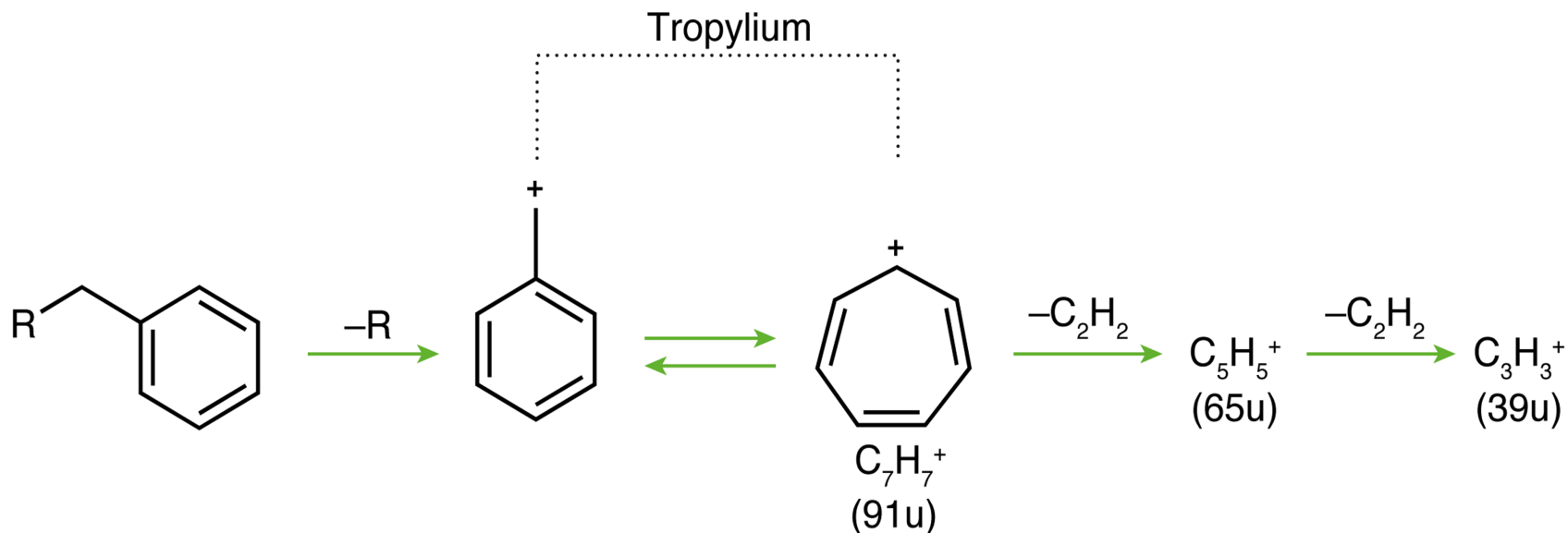
This talk → complex organic material → subgroup ($\approx 4\%$) of Type 2

Fragment ions from complex organic material ($\approx 1\%$ of E ring ice grains)

2005-358/15:57:10 (1514132787)

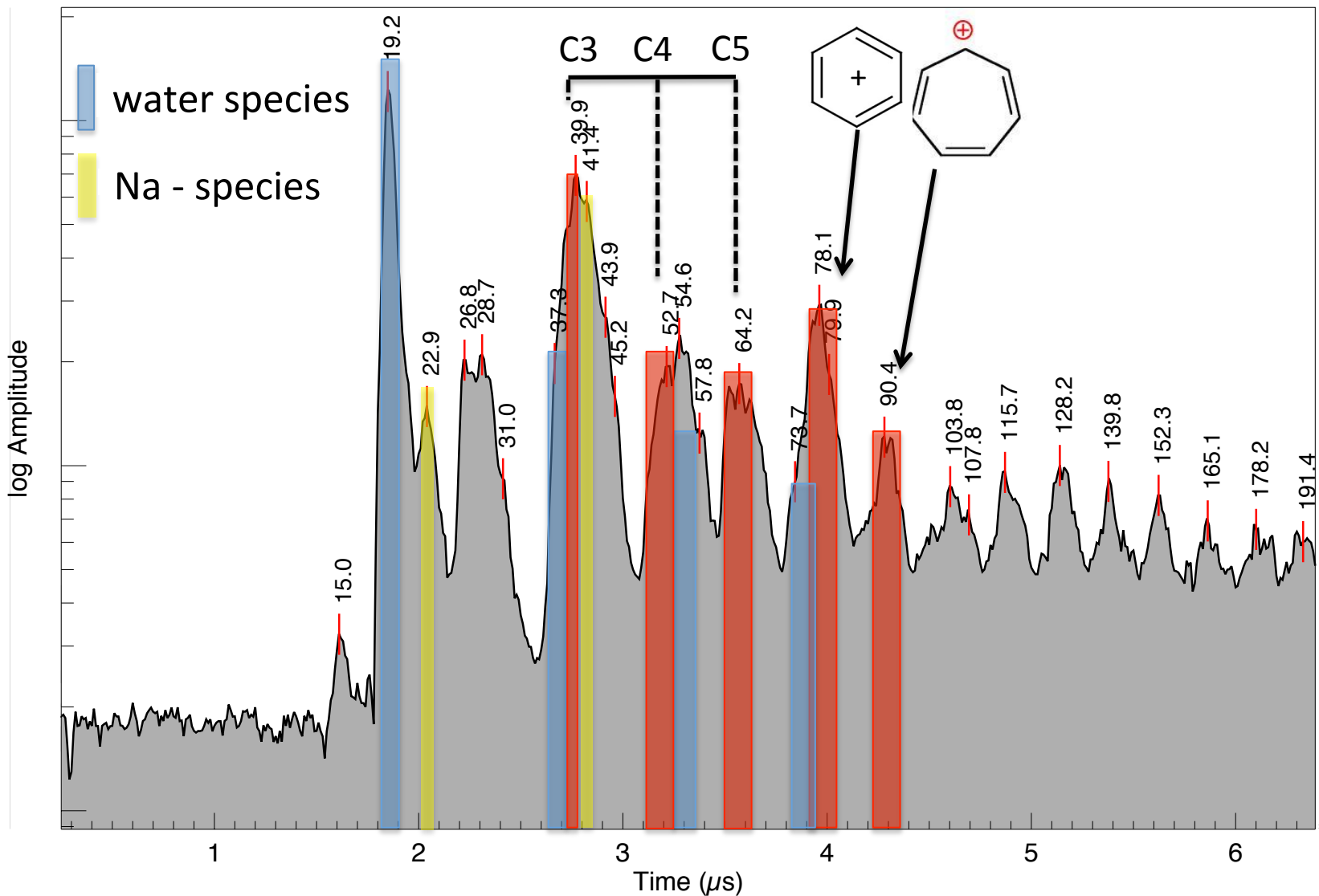


Formation and fragmentation of aromatic cations



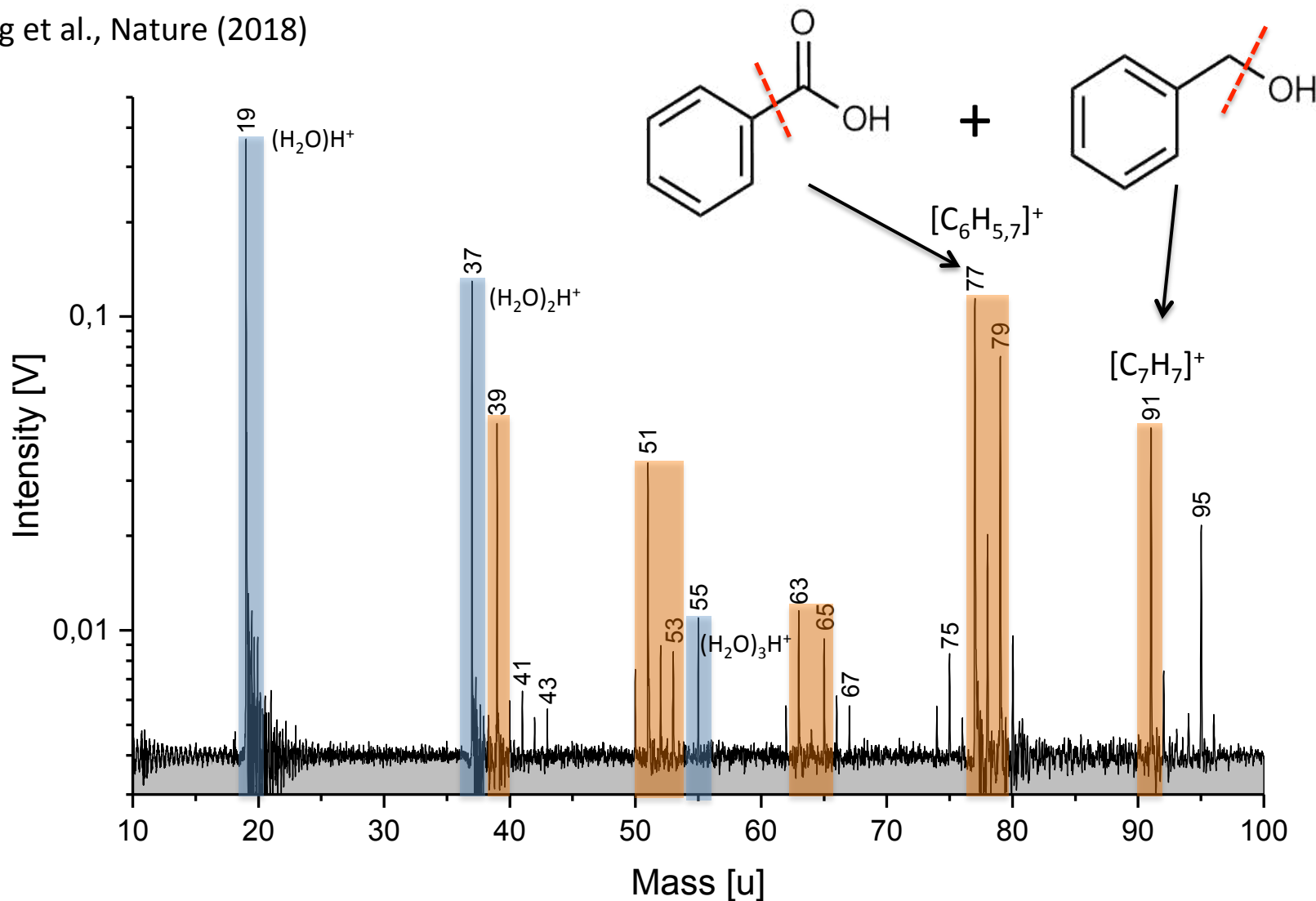
Fragment ions from complex organic material ($\approx 1\%$ of E ring ice grains)

2005-358/15:57:10 (1514132787)



Aromatic fingerprint reproduced with laboratory setup

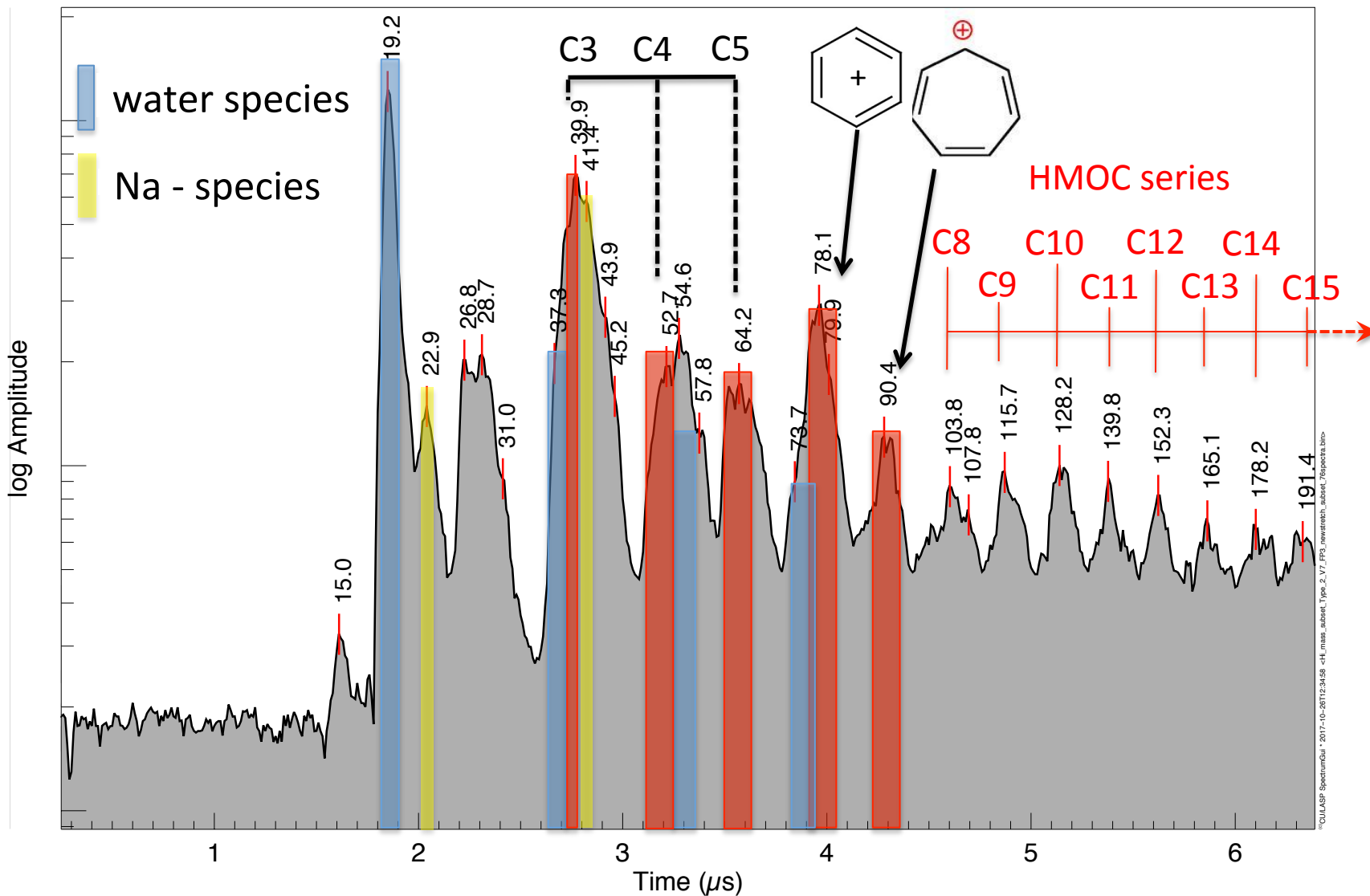
Postberg et al., Nature (2018)

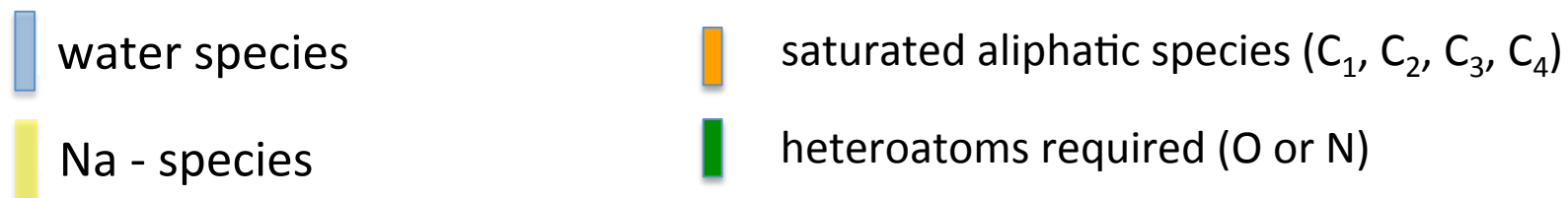


0.3 wt.% Benzoic acid and 0.015 wt.% Benzyl alcohol

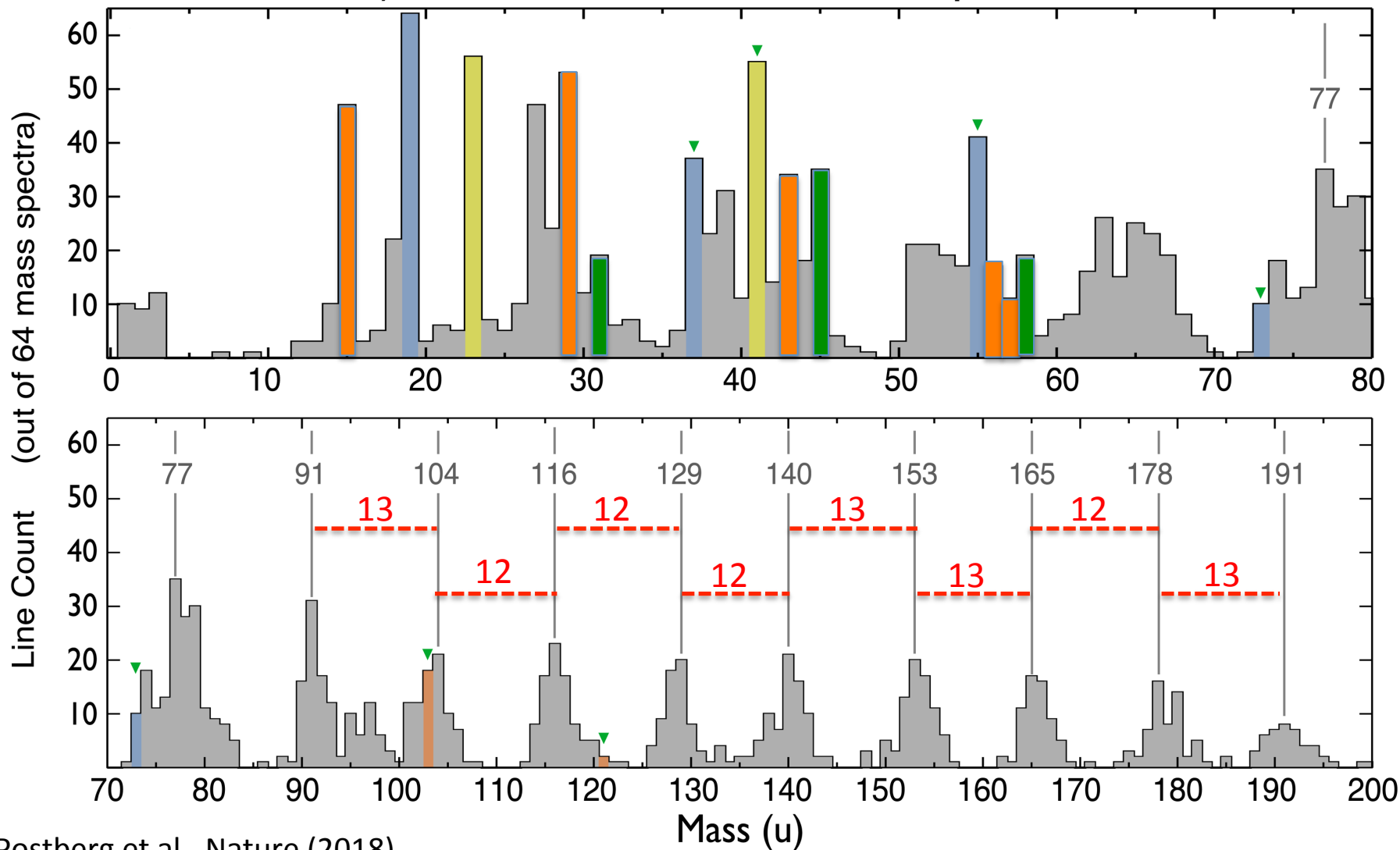
Fragment ions from complex organic material ($\approx 1\%$ of E ring ice grains)

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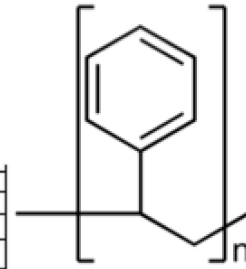
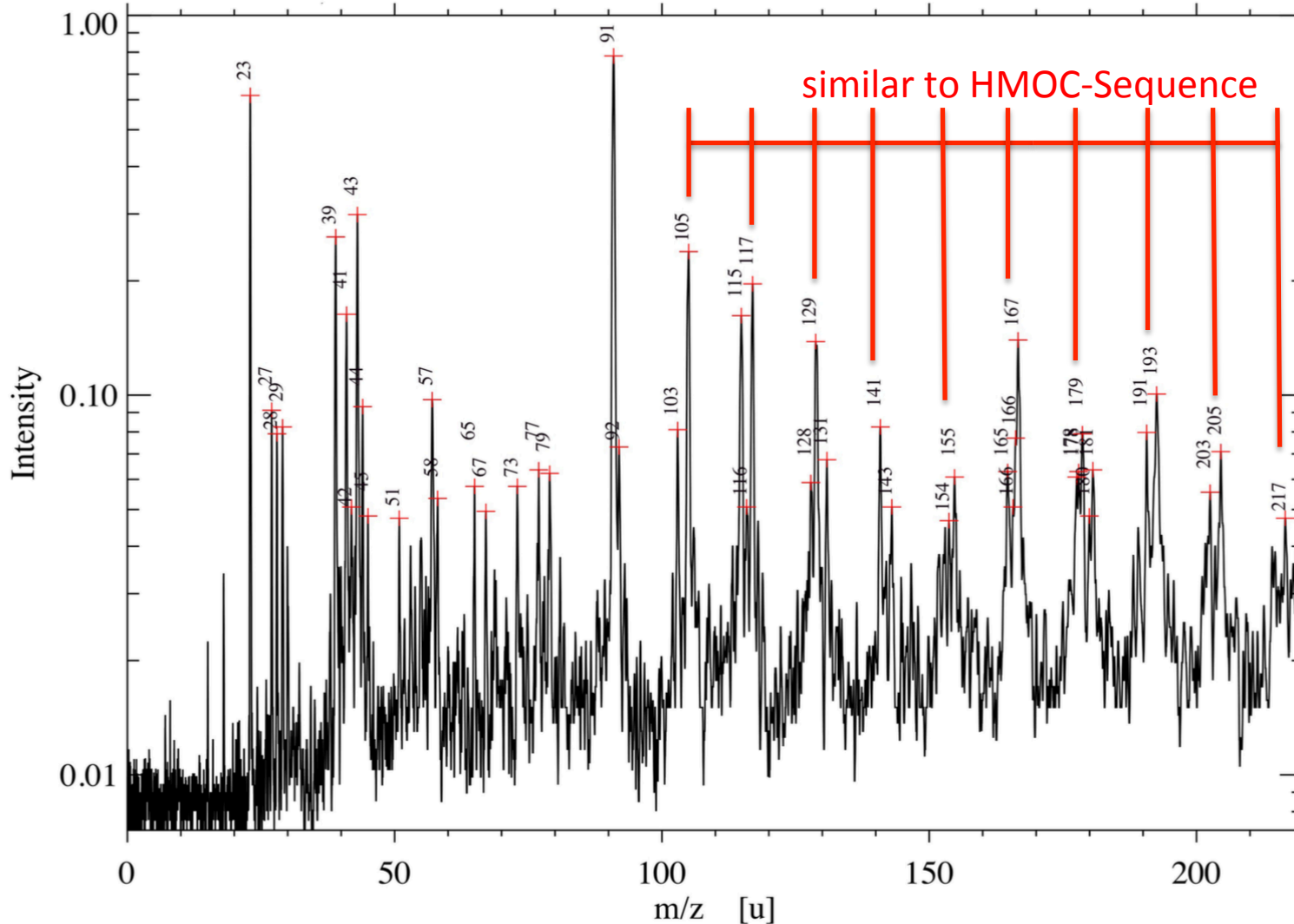


b) Line Statistics of HMOc Spectra



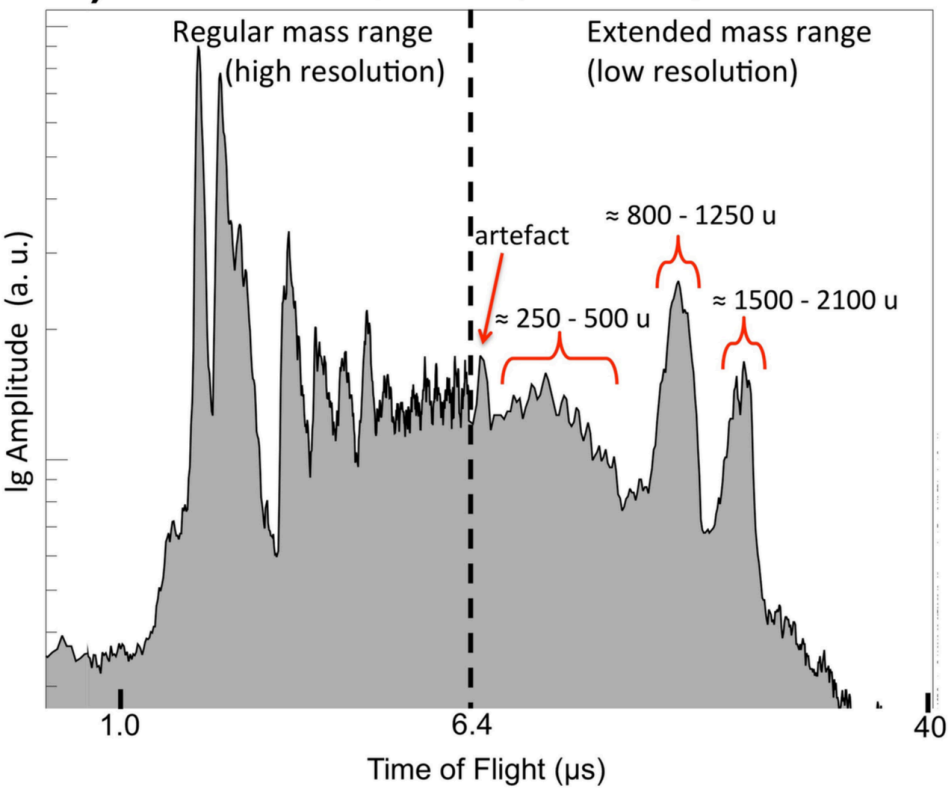
Impact ionization lab spectrum of Polystyrene (C / H = 1)

Srama et al., 2009

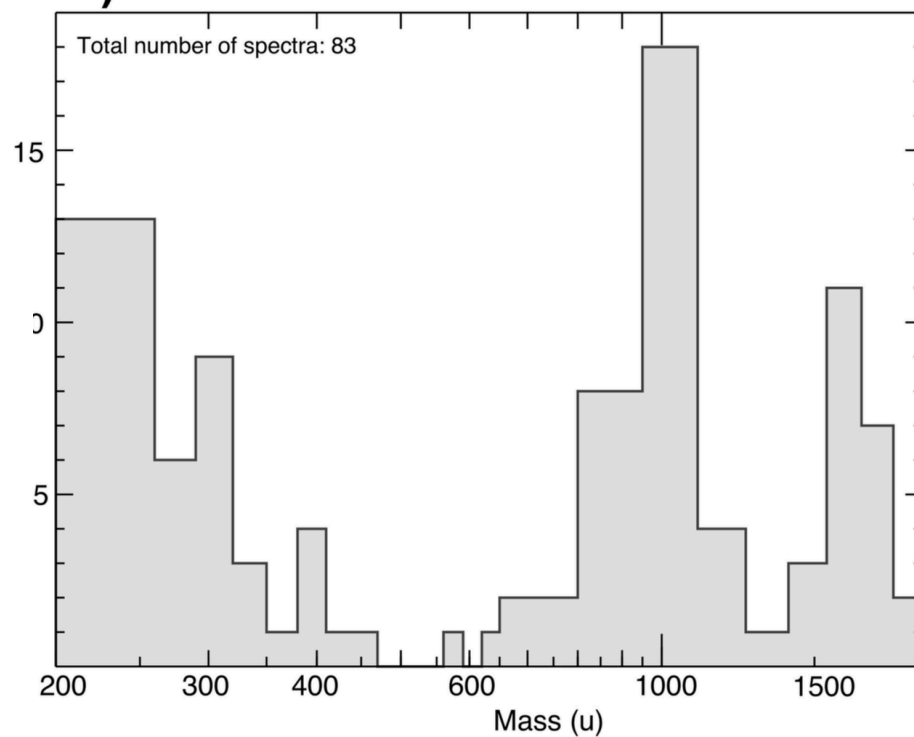


a)

2006-337/00:41:01 (1543799608)



CDA extended
low resolution spectra

b)

Summary—I

Chemical properties of detected complex organic material

- ◆ HMOC (High Mass Organic Cations, $C_8 - C_{16}$) are **unsaturated fragments** from parent molecules with a ratio $C/H \approx 1 - 2$.
- ◆ Indication of parent molecules **with atomic masses $\gg 200u$** , some signals $> 1000u$.
- ◆ Abundant sub-structures of **isolated benzene rings**.
- ◆ Most rings are attached to **non-carbon functional groups** or to **dehydrogenated C atoms**.
- ◆ Low mass **saturated aliphatic species C_1 to C_4** .
- ◆ **O-bearing species** are indicated in both CDA & INMS spectra.
- ◆ **N-bearing species** are in good agreement with some features but not a unique interpretation.

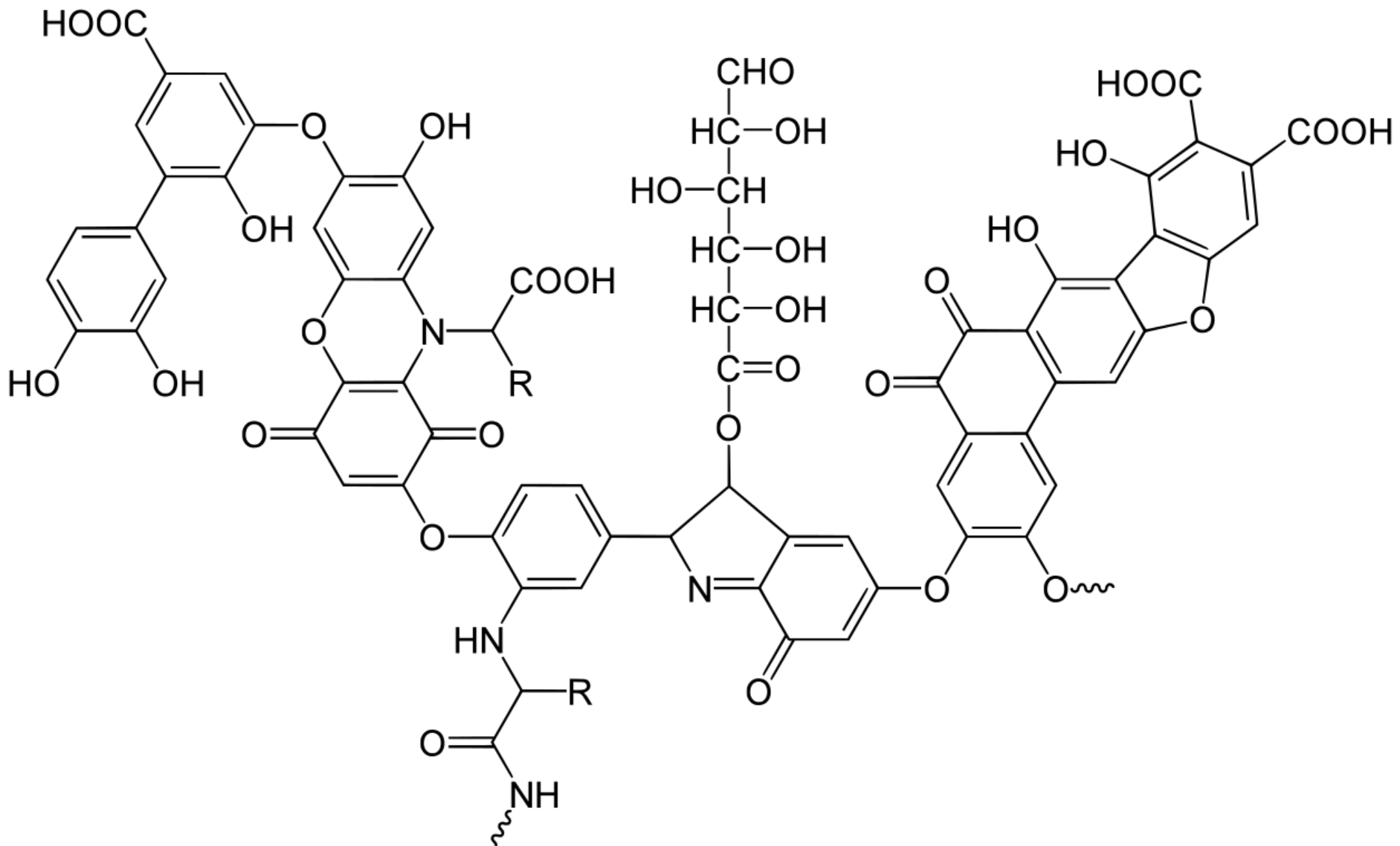
Summary—I

Chemical properties of detected complex organic material

One plausible interpretation

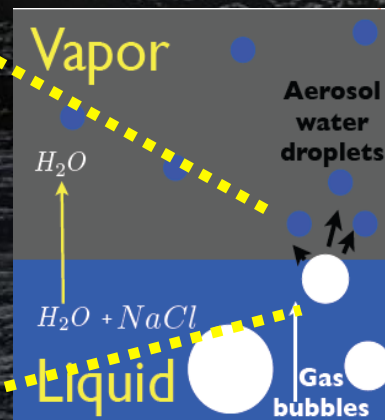
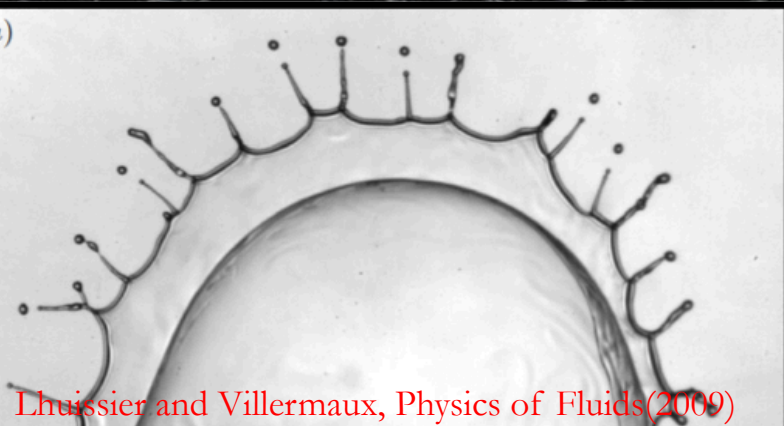
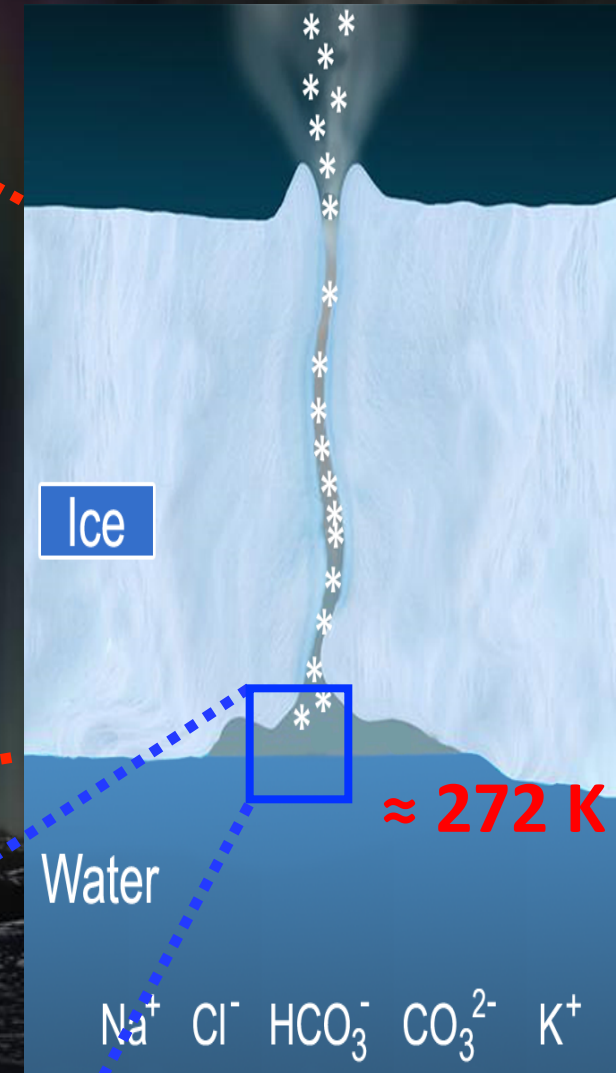
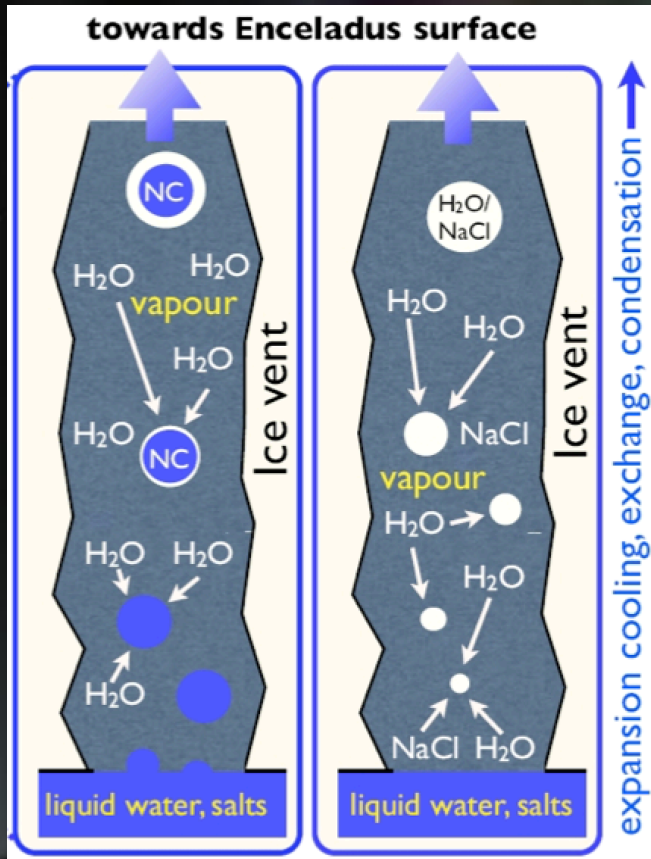
Cross-linked macromolecular or polymeric material ...

- with oxygen- and nitrogen-bearing functional groups...
- where mostly isolated aromatic rings...
- are connected by short aliphatic chains.



Humic Acid (source: Wikipedia)

Bubble bursting & Formation of ice grains



Postberg et al., Nature (2009, 2011)

Lhuissier and Villermaux, Physics of Fluids (2009)

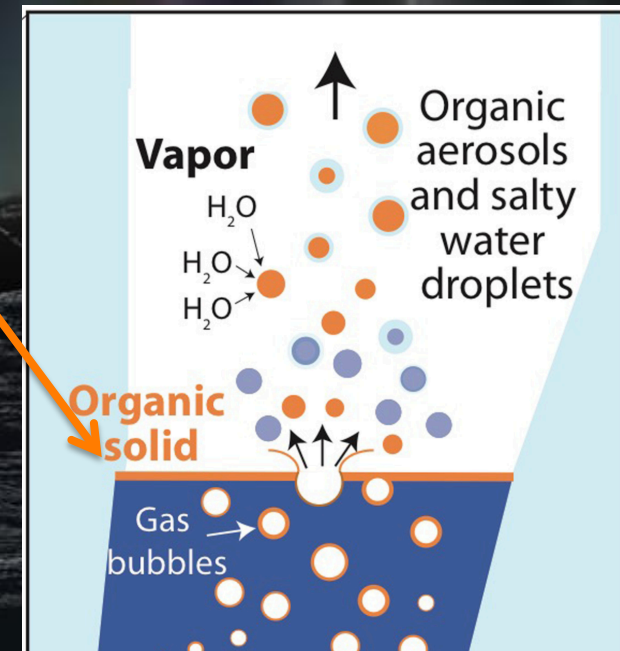
Hypothesis I

➤ Diagnostic observations

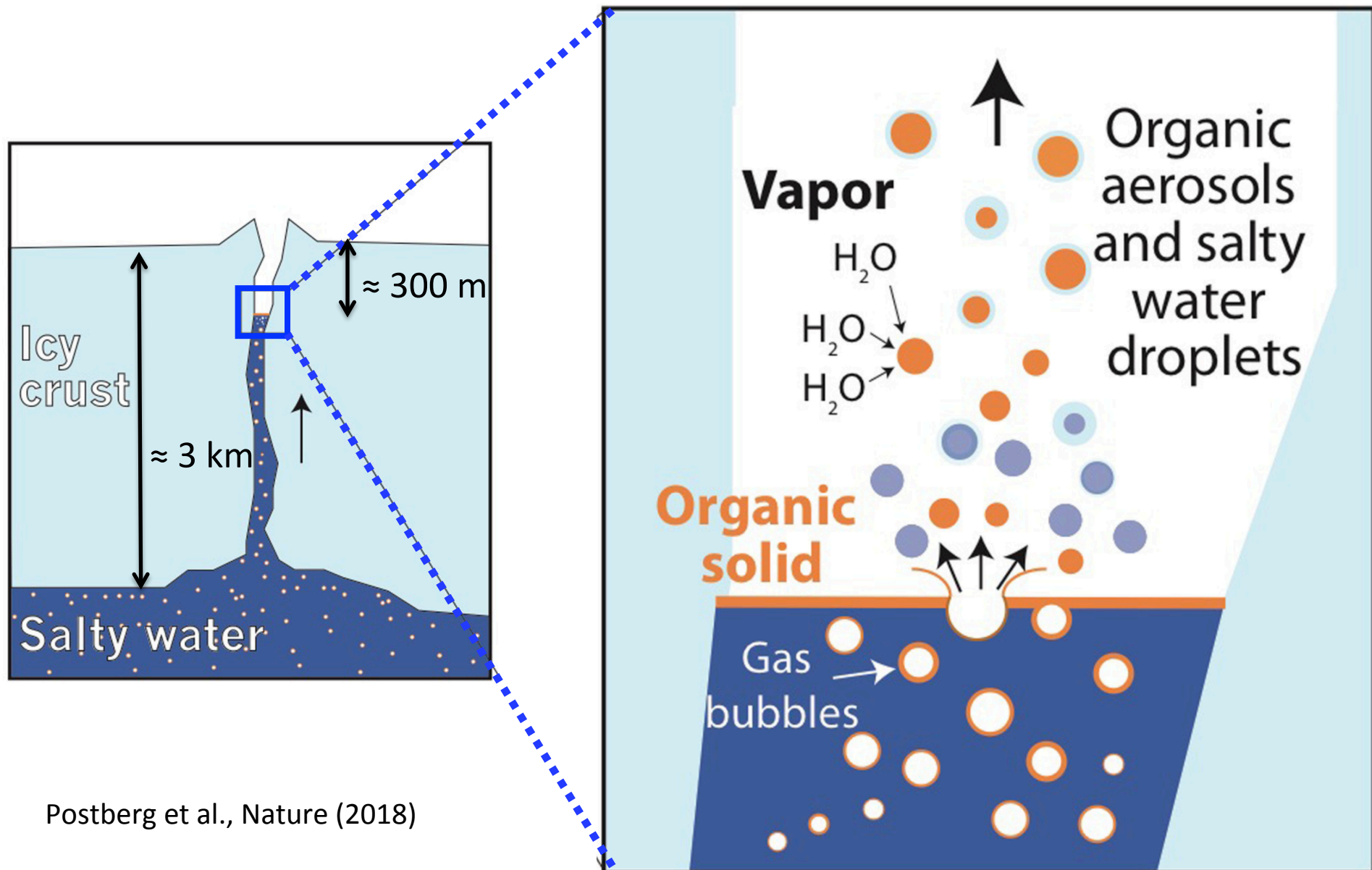
- HMOC are in salt poor grains → organics **not dissolved** in water
- High molecular mass → **not in the gas phase** at 272 K.
- **High concentration** of organics in ice grains (> 1%)

➔ Organic material forms a thin layer at the oceanic water table.

- Bubble bursting releases pure organic aerosols (in addition to salty ocean spray)
- Vapour flow (driven by pressure gradient) carries grains upward through ice vents
- Organic aerosols are then ice coated by freezing of salt poor vapours



Ocean water is partially filling crustal cracks



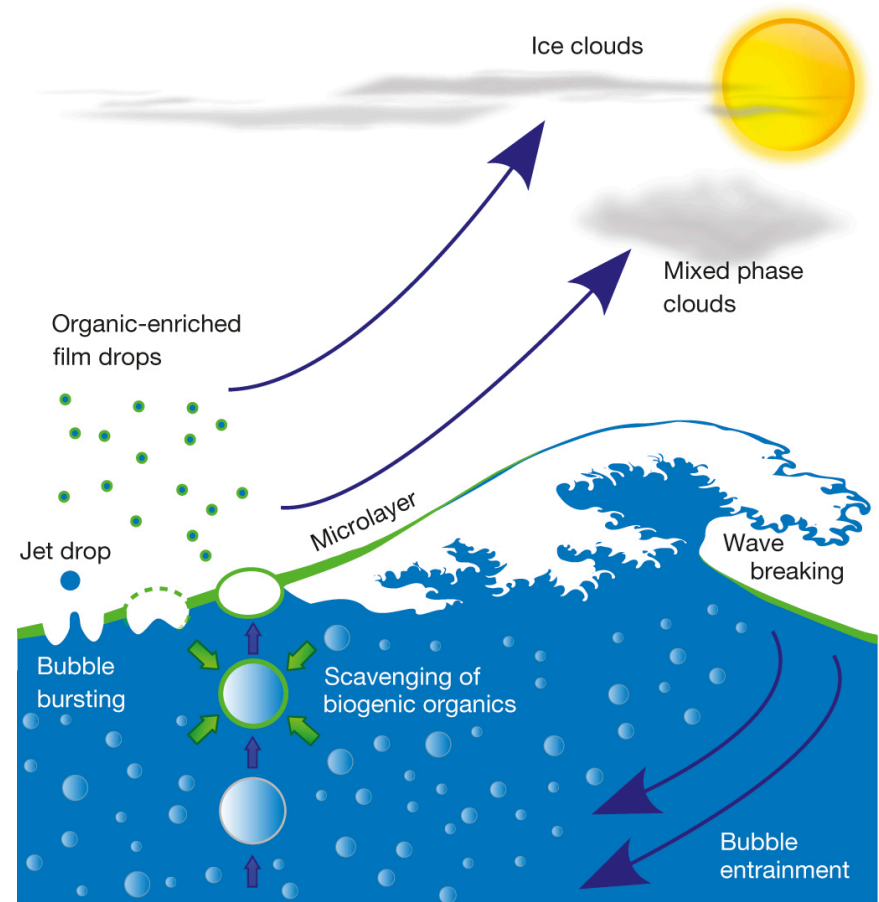
Cloud nucleation after bubble bursting in Earth's ocean

Sea-spray aerosol particles enriched in organic material are generated when bubbles burst at the air–sea interface.

“Here we show that organic material in the sea surface microlayer nucleates ice under conditions relevant for mixed-phase cloud and high-altitude ice cloud formation. The ice-nucleating material is probably biogenic and less than approximately $0.2\ \mu\text{m}$ in size.”

Simultaneous creation of

- Pure salt water grains
- Pure organic ($r < 200\ \text{nm}$)
- Mixed phase grains



Hypothesis II

- The HMOC material probably emerges from the hydrothermal active Enceladus core
- Transported upwards by
 - a) large scale thermal convection
 - b) ascending bubbles
- HMOC material might only be the tip of an “organic iceberg” on Enceladus

