Electron irradiation of water ice samples in the laboratory - Implications for icy moons and comets

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Live Chat on Wednesday, May 6, 14:00 – 15:45

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Radiolysis of water ice on airless bodies: State of knowledge and open questions

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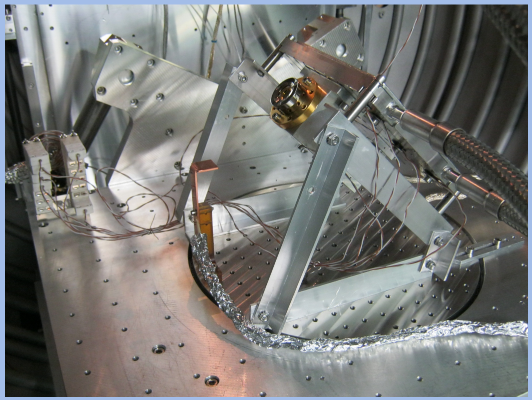
- **Irradiation by energetic ions, electrons, and UV photons induces sputtering and chemical processes (radiolysis) in the surfaces of icy moons and comets. We currently study electrons irradiating pure water ice samples in laboratory.**
- Previous studies have shown that O_2 can be trapped under some favourable conditions in ice samples and that most electron-induced H_2O radiolysis products leave the ice as H_2 and O_2: *Orlando&Sieger 2003*, *Teolis et al. 2009* , *Hand&Carlson 2011* , *Teolis et al. 2017* , *Shi et al. 2009* and *2011* , *Petrik et al. 2006* , *Henderson&Gudipati 2015* , *Abdulgalil et al. 2017* , *Laufer et al. 2018*, *Galli et al. 2018.*
- Questions to investigate: What is the timescale for creation and release of electron-induced radiolysis products in various water ice targets? Can build-up of O_2 be reproduced in laboratory ice samples, as suggested by observations of the surfaces of Jupiter's icy moons (*Spencer&Calvin 2002*) and comet 67P-Churyumov-Gerasimenko (*Bieler et al. 2015*)? What is the abundance of rare radiolysis species such as H_2O_2 or H_3O?

The laboratory facility at the University of Bern

MEFISTO vacuum chamber:
cool ice samples with liquid N_2
(T = 90-120 K),

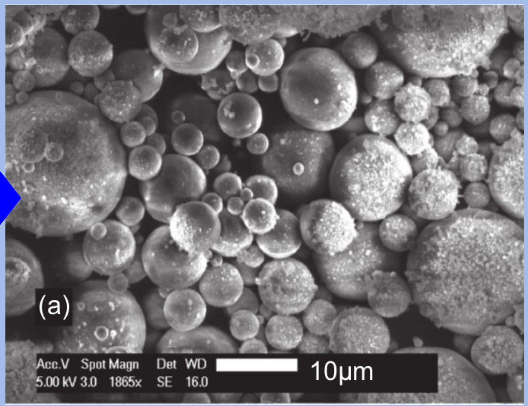
vacuum pressure ~10^{-8} mbar,
particle sources:
electrons (0.1-10 keV)
and various ion species
from electron-cyclotron-
resonance-ion-source
(0-100 keV),
UV source available,
duration: several days

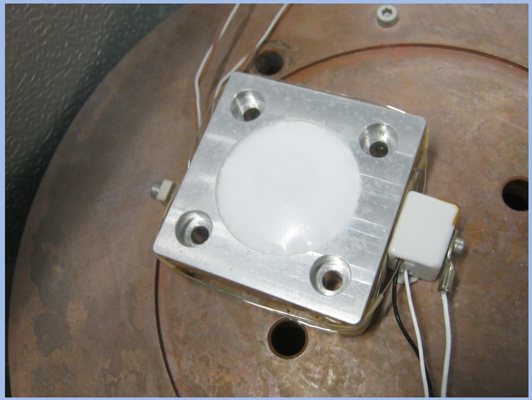
Our approach: a multitude of ice samples



Ice film on microbalance

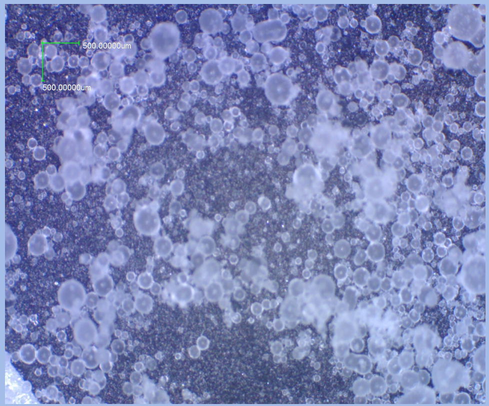
Regolith ice,
(5 µm grains, 0.3 g/cm^3)





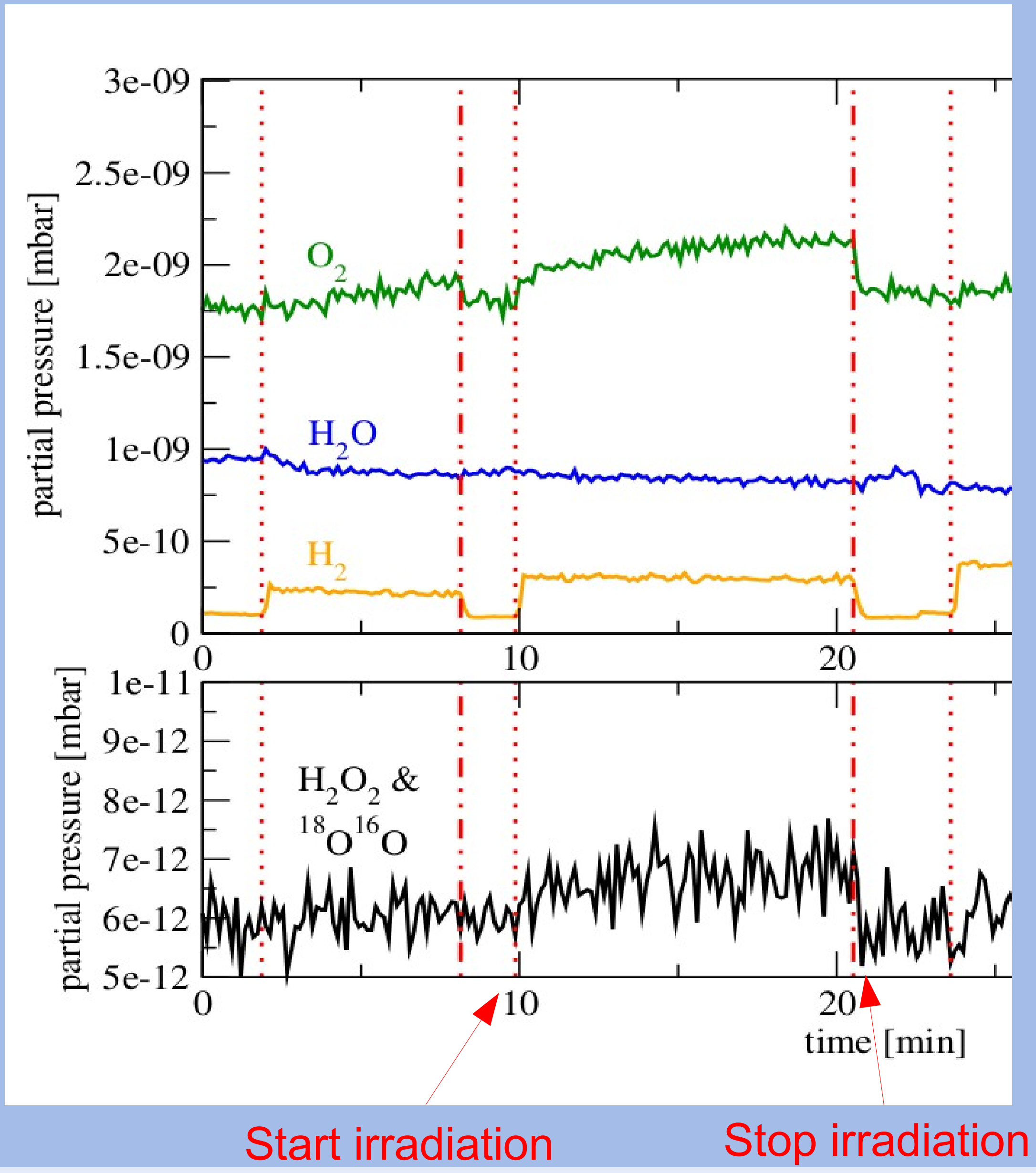
Slab of ice (~0.9 g/cm^3)

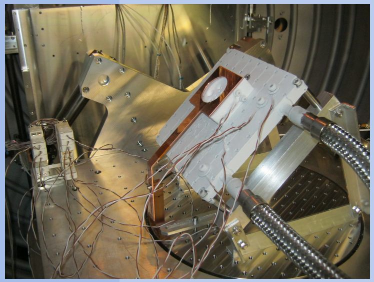
Regolith ice,
(50 µm, 0.6 g/cm^3)



> Salts, silicates and other chemical impurities can easily be added. This presentation restricted to pure water ice samples.

Results from Galli et al. 2018:
Electrons radiolyse $H_2O \rightarrow H_2 + ½O_2$ (mostly)





Timeseries of ejected H_2O (blue), O_2 (green), H_2 (orange), and H_2O_2 & $^{18}O^{16}O$ (black, lower panel) for a sequence of electron irradiation on the same spot of fine-grained water ice.

These data were measured with an old quadrupole mass spectrometer (QMS).

What do those laboratory observations mean for icy objects in the solar system?

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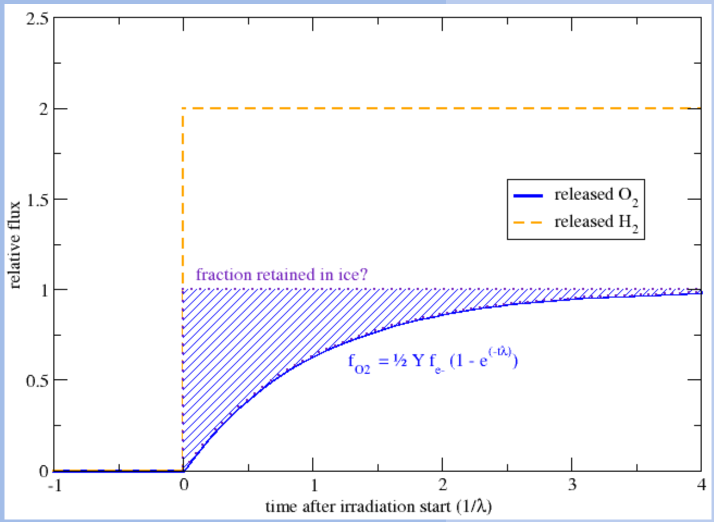
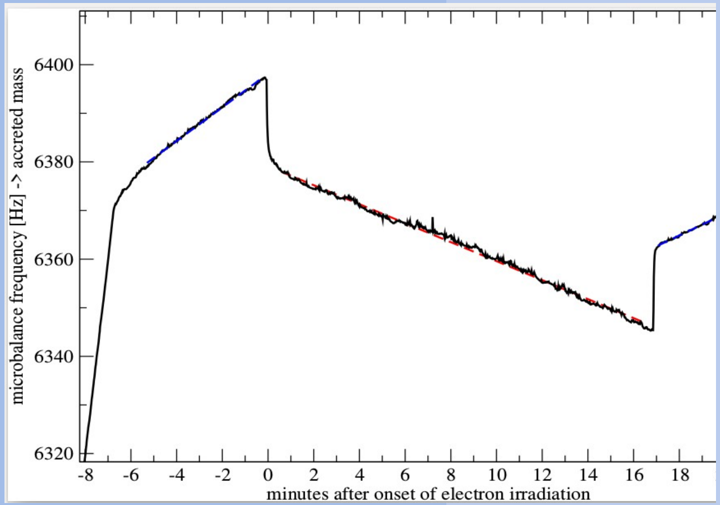
- **H_2 leaves irradiated ice immediately, O_2 lags behind until steady-state loss rate is reached. Is the surplus of O_2 retained inside the ice permanently?**
- With old QMS only one experiment with pristine thick ice was achieved: O_2/H_2O = 1.5%...7% for 1 keV electron beam on fine-grained water ice.
- This would be similar to the O_2/H_2O inferred from surface reflectance spectra for Ganymede, Europa, and Callisto and from mass spectrometer data for comet 67P/C-G. But...
- Such an O_2 retention was not observed in 2019 for ice films on microbalances (10-100 nm of amorphous, dense ice irradiated with electrons between 0.1 and 1 keV). See to the right:
- **Next step: examine porous ice samples again with new mass spectrometer!**

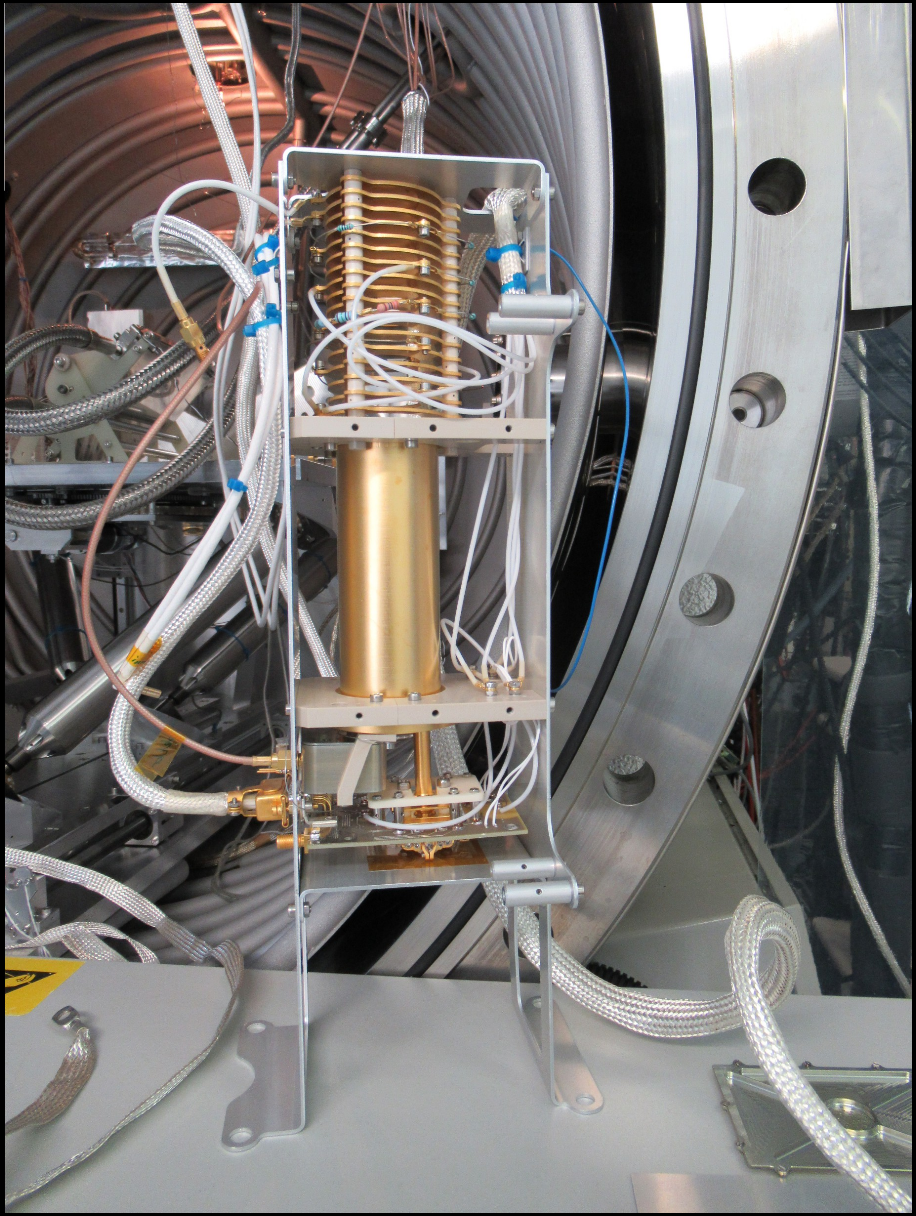
Ideal case for thick, porous ice



Experiment with dense ice film



Building a new TOF mass spectrometer

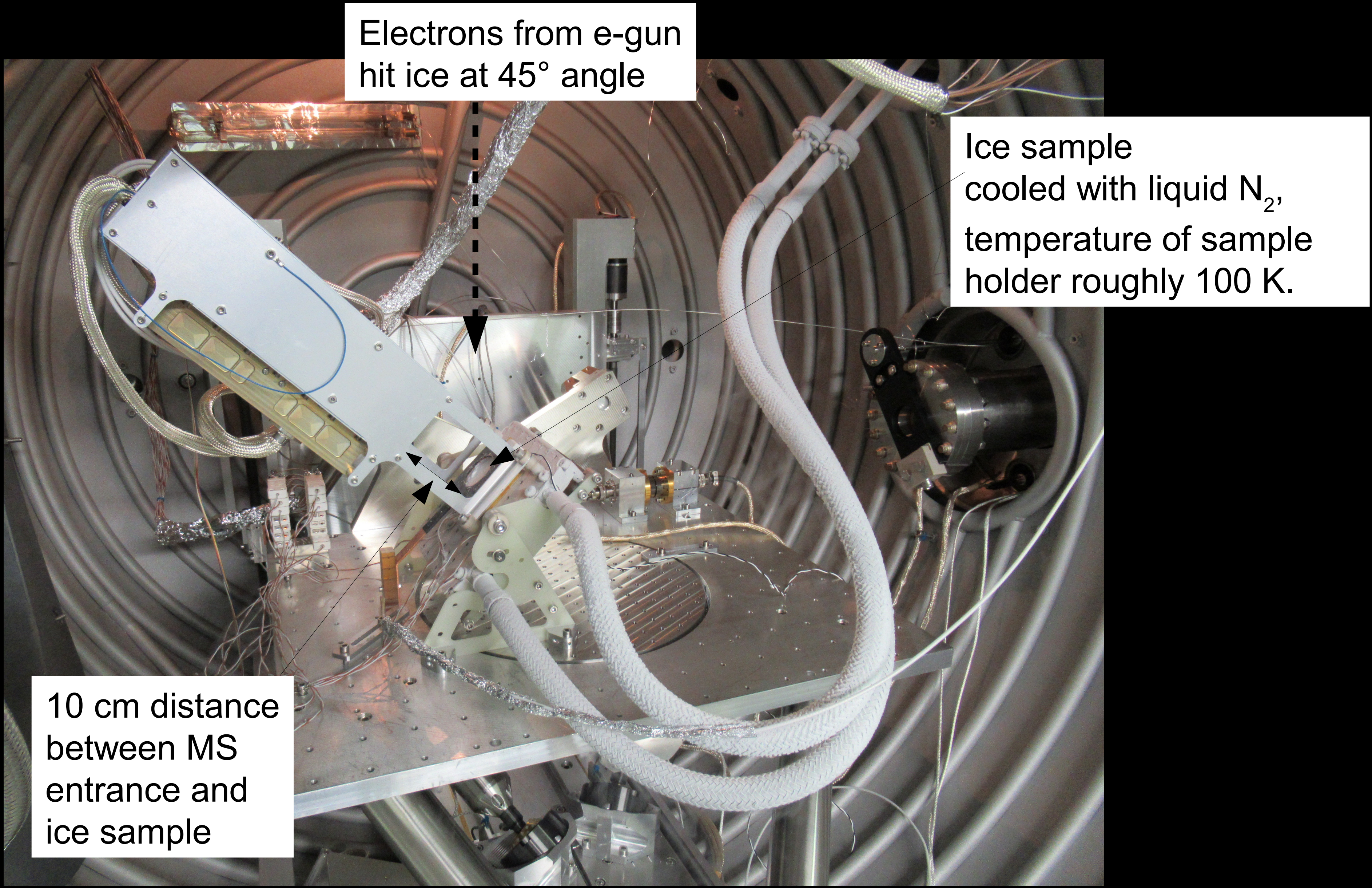


We have built a new time-of-flight mass spectrometer for ice experiments in house: faster, more sensitive, and higher mass resolution than old QMS.

→ Commissioned in 2019.

→ First measurements with ice sample in November 2019 (see next page).

Building and testing new TOF mass spectrometer



First spectrum with new TOF mass spectrometer, coarse-grained water ice beneath TOF entrance

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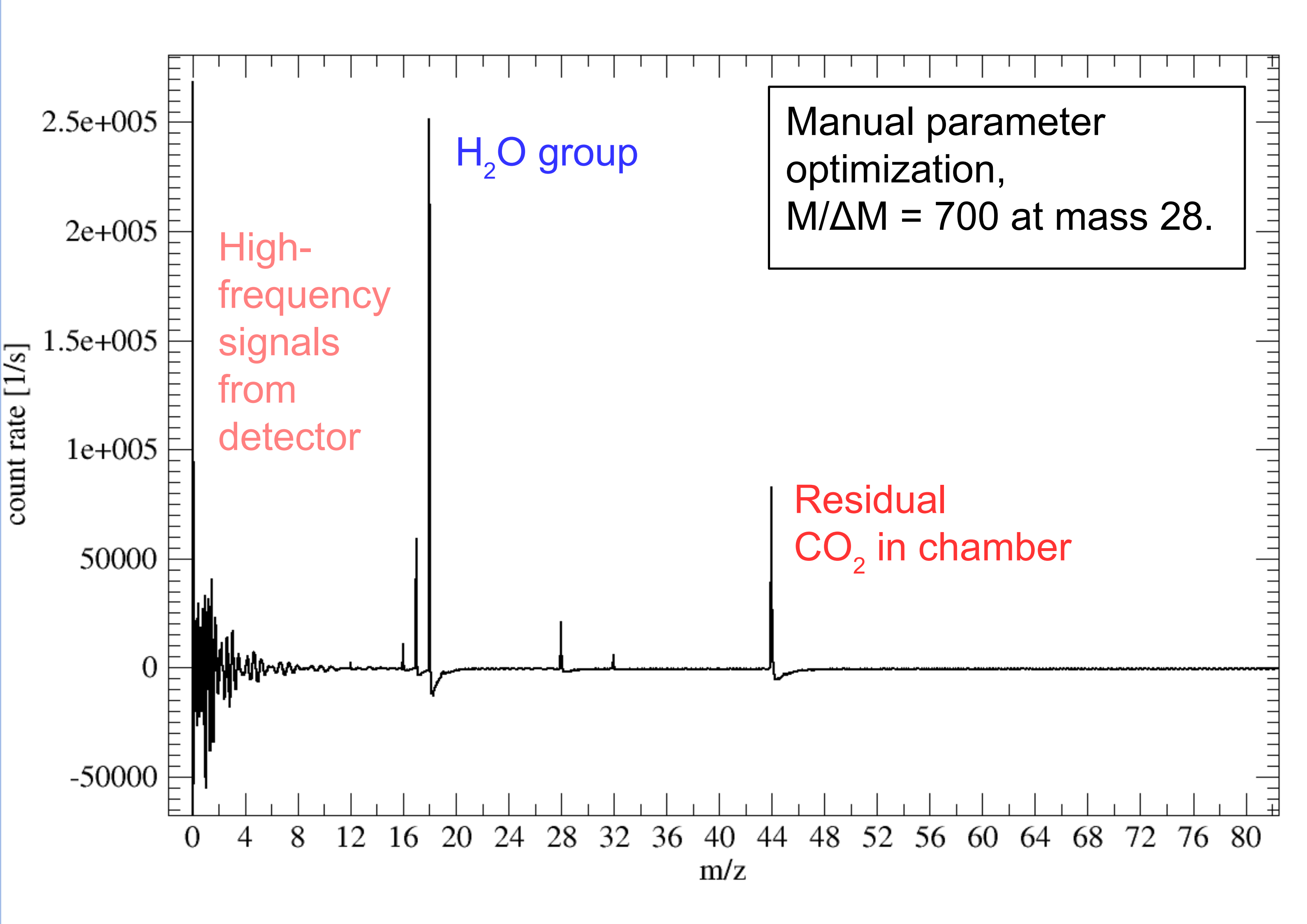

First time series of released H_2 and O_2 observed with new TOF mass spectrometer

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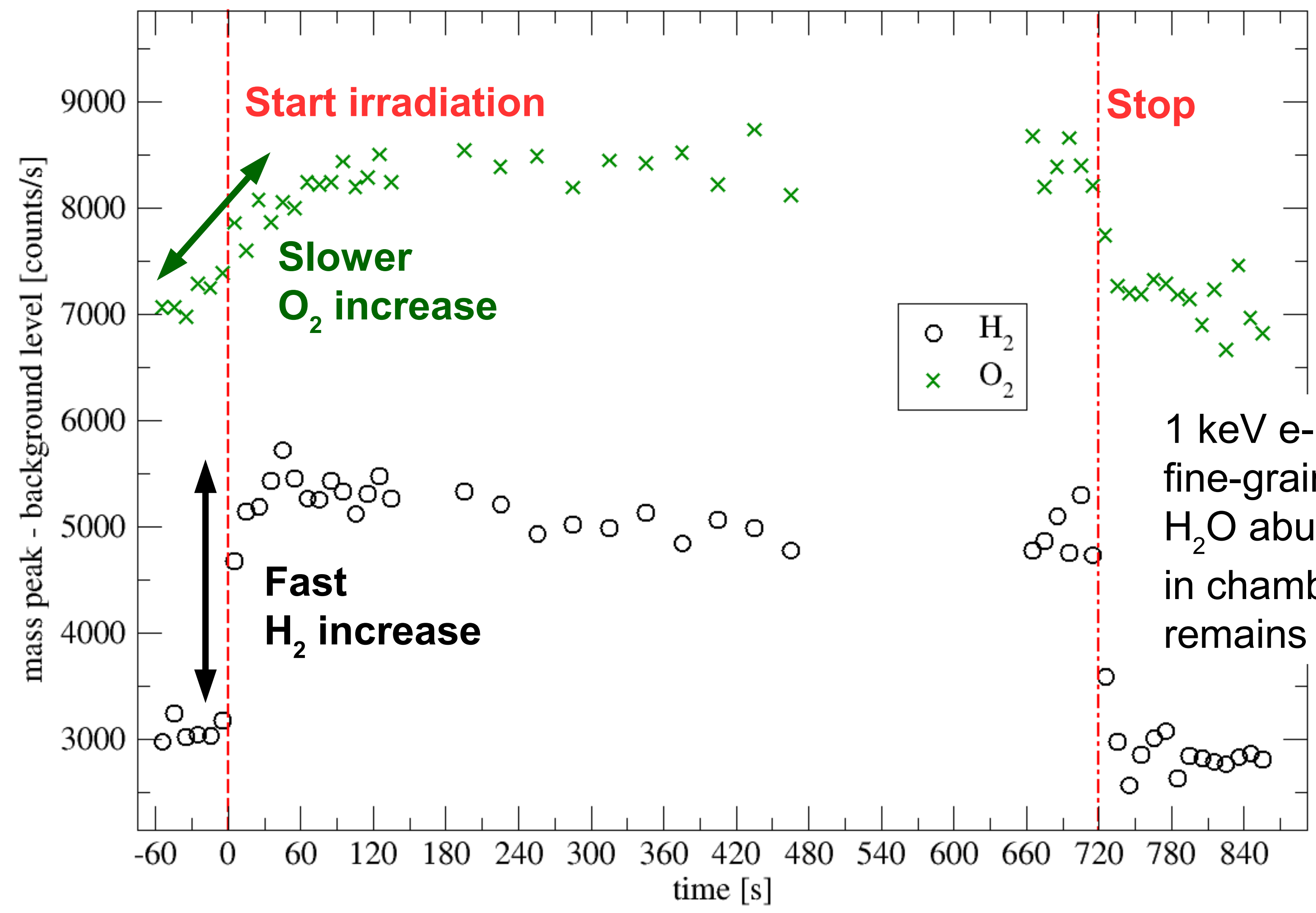

1 keV e- irradiating fine-grained water ice; H_2O abundance in chamber remains constant

Preliminary conclusions

- New TOF mass spectrometer commissioned. We can analyze released species from irradiated ice films and deep porous ice samples.
- $H_2O \rightarrow H_2 + ½\ O_2$ upon e^- irradiation to first order correct for any water ice target: Released $H_2/O_2 = 1.8 \pm 0.3$ after steady state is reached.
- No minor radiolysis species detected so far.
- Results about production and release timescales and the O_2/H_2O build up ratio in porous ice pending as we wait to return to the laboratory after the COVID19-pandemic.