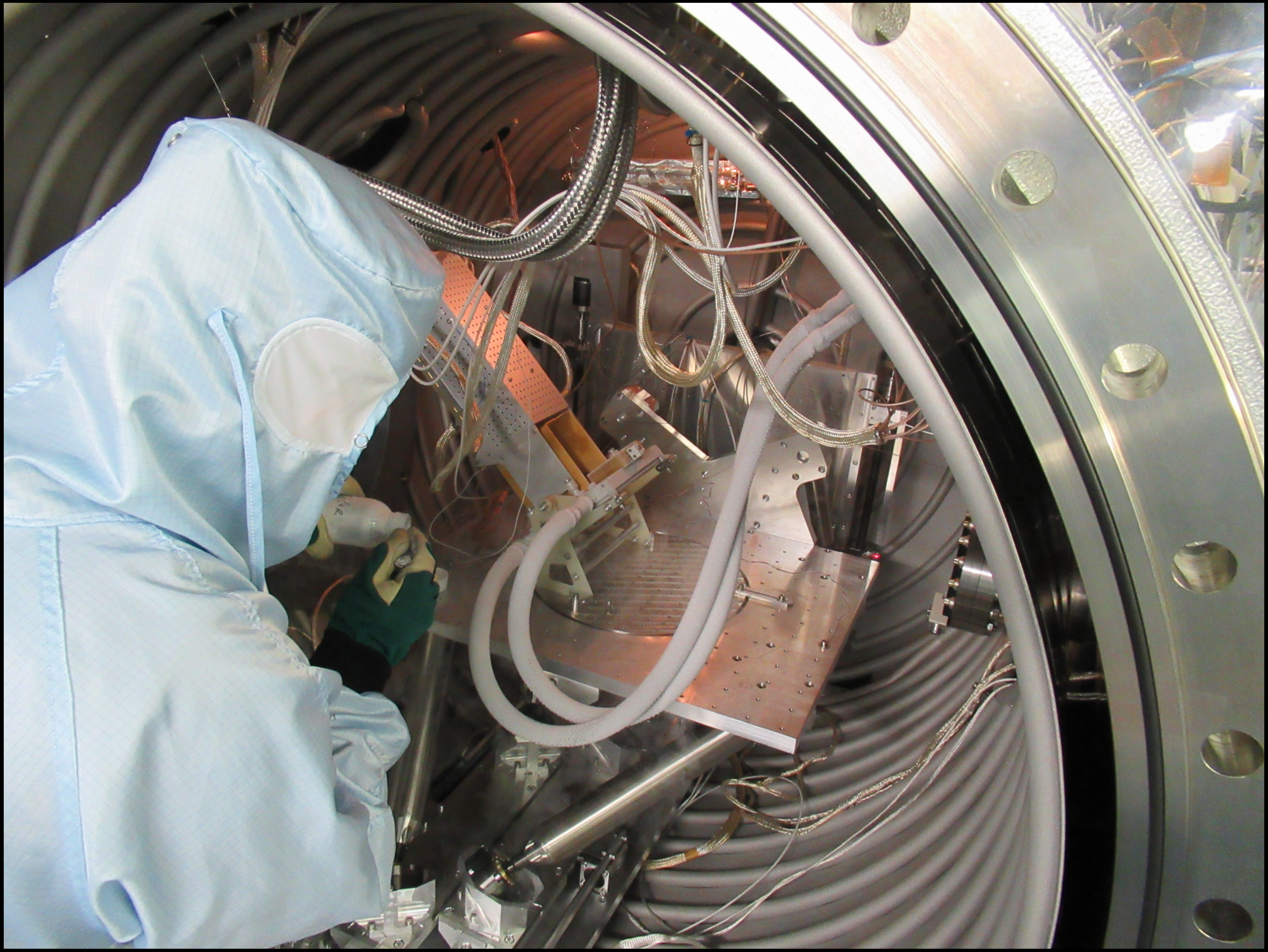
Interaction of plasma with the surface of icy moons: insights from laboratory experiments

Oral presentation, block 6

Authors’ contact: andre.galli@space.unibe.ch



André Galli, *Romain Cerubini, Martin Rubin, Antoine Pommerol, Audrey Vorburger, Peter Wurz, Niels F.W. Ligterink Apurva Oza, Nicolas Thomas*

University of Bern, Space Research and Planetary Sciences & Center for Space and Habitability, Switzerland

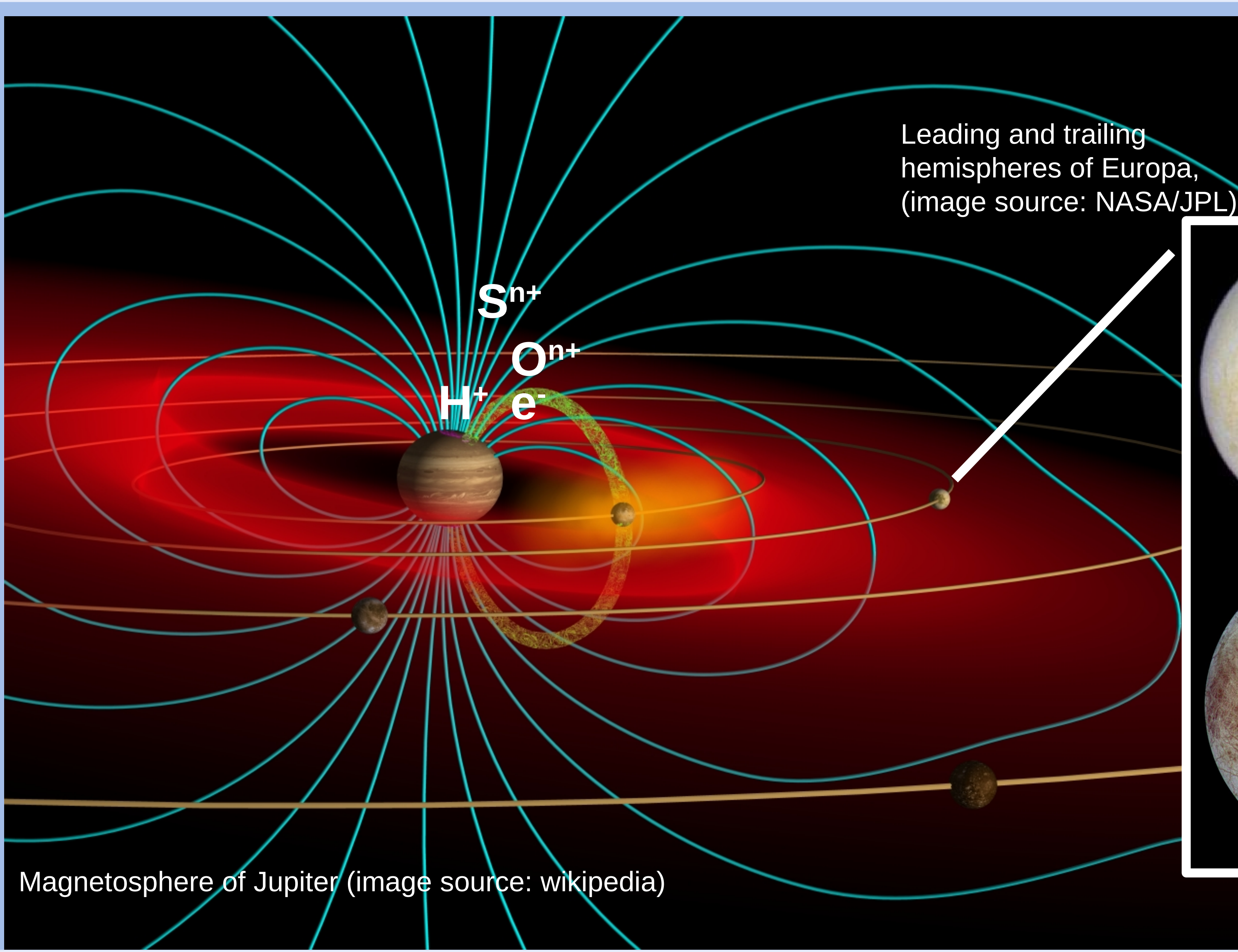
UNIVERSITÄT BERN

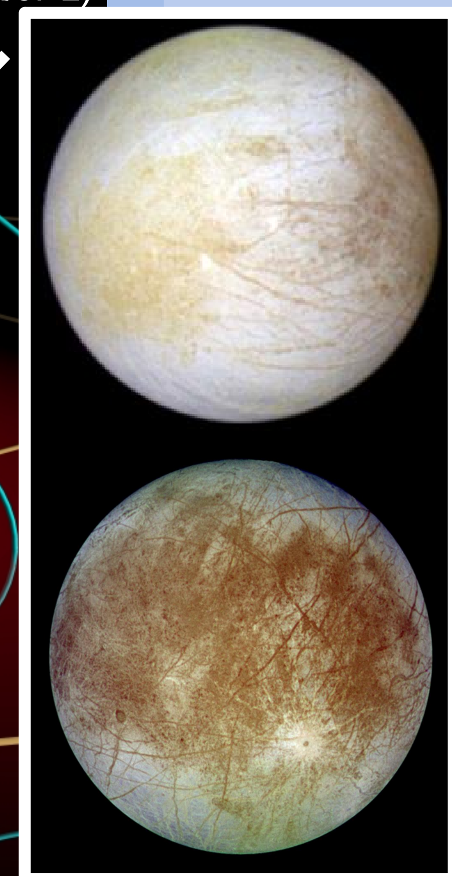
Abstract

UNIVERSITÄT BERN

- **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 electron irradiation of porous water ice samples in laboratory as preparation for ESA's Jupiter's Icy Moons Explorer.**
- Previous studies have shown that most electron-induced H_2O radiolysis products leave the ice as H_2 and O_2 and that O_2 can be trapped under some favourable conditions in ice samples (see references on last slide).
- Questions for our new experiments:
  What is the timescale for formation and release of electron-induced radiolysis products in water ice? 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)? How abundant are rare radiolysis species such as H_2O_2 or H_3O?

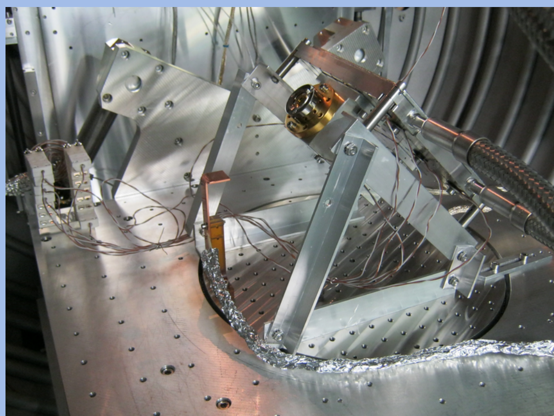
Irradiation of icy surfaces in real life





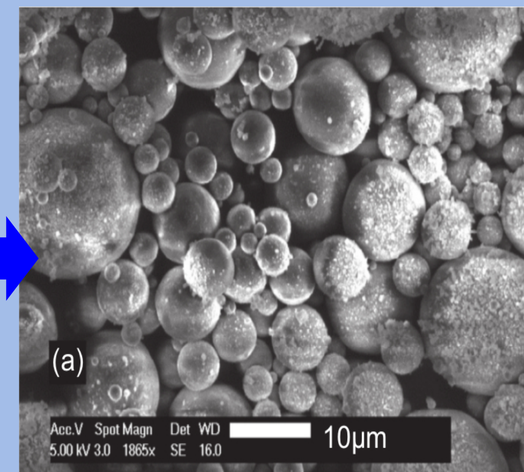
In laboratory: 4 different types of water ice samples, consisting of de-ionized water

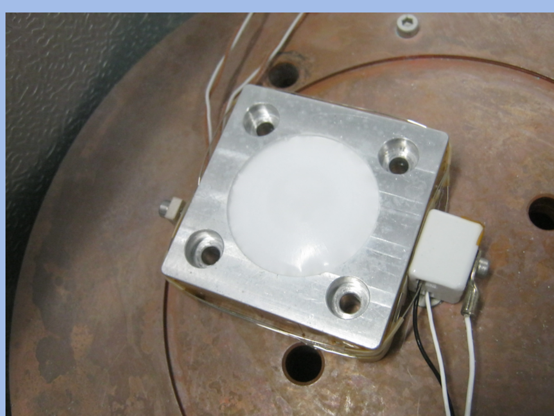
UNIVERSITÄT BERN



Amorphous ice film on microbalance (~1.0 g/cm^3)

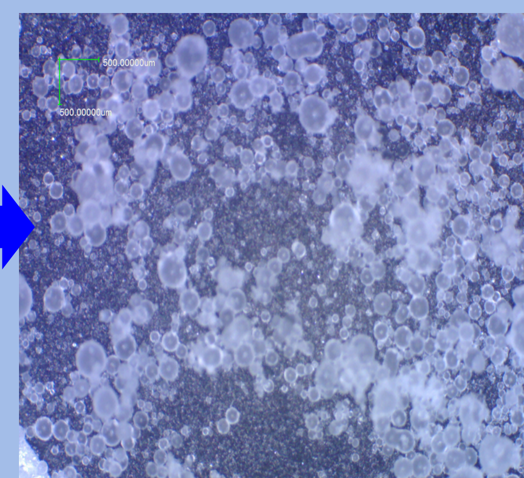
Regolith ice, (5 µm grains, 0.23 g/cm^3)



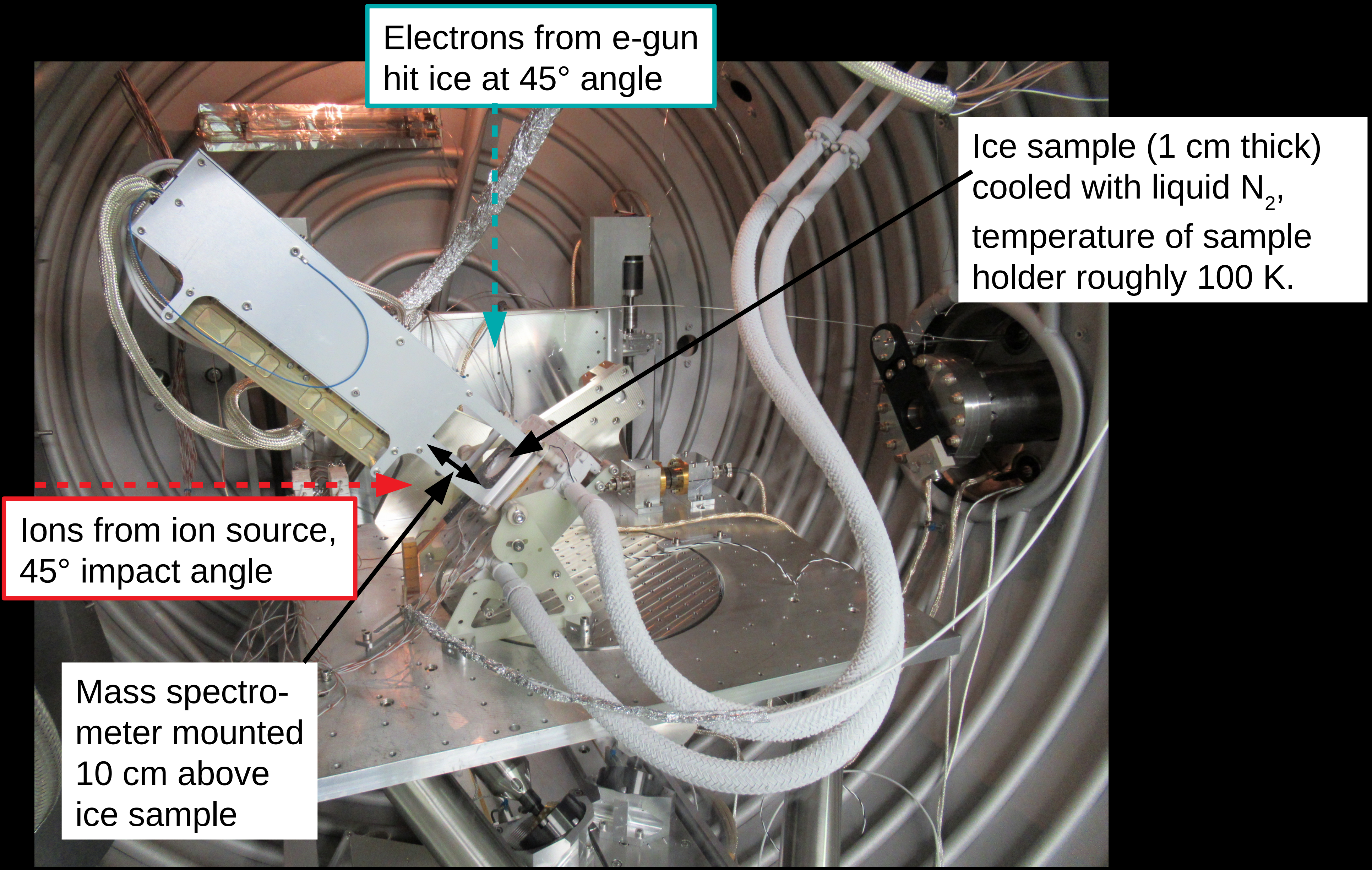


Slab of ice (~1.0 g/cm^3)

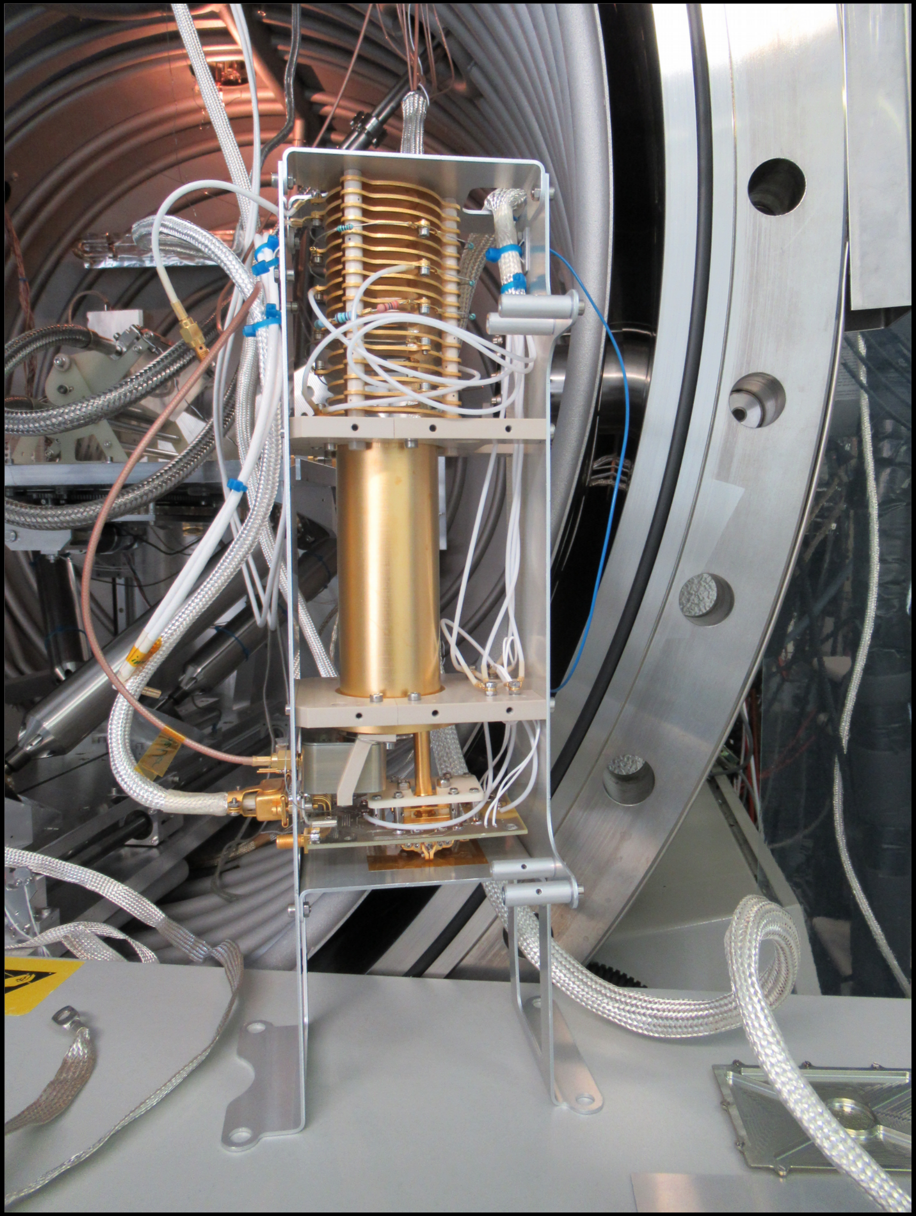
Regolith ice, (50 µm, 0.5 g/cm^3)



Laboratory setup for ice irradiation experiments



Laboratory setup: Analysis tools



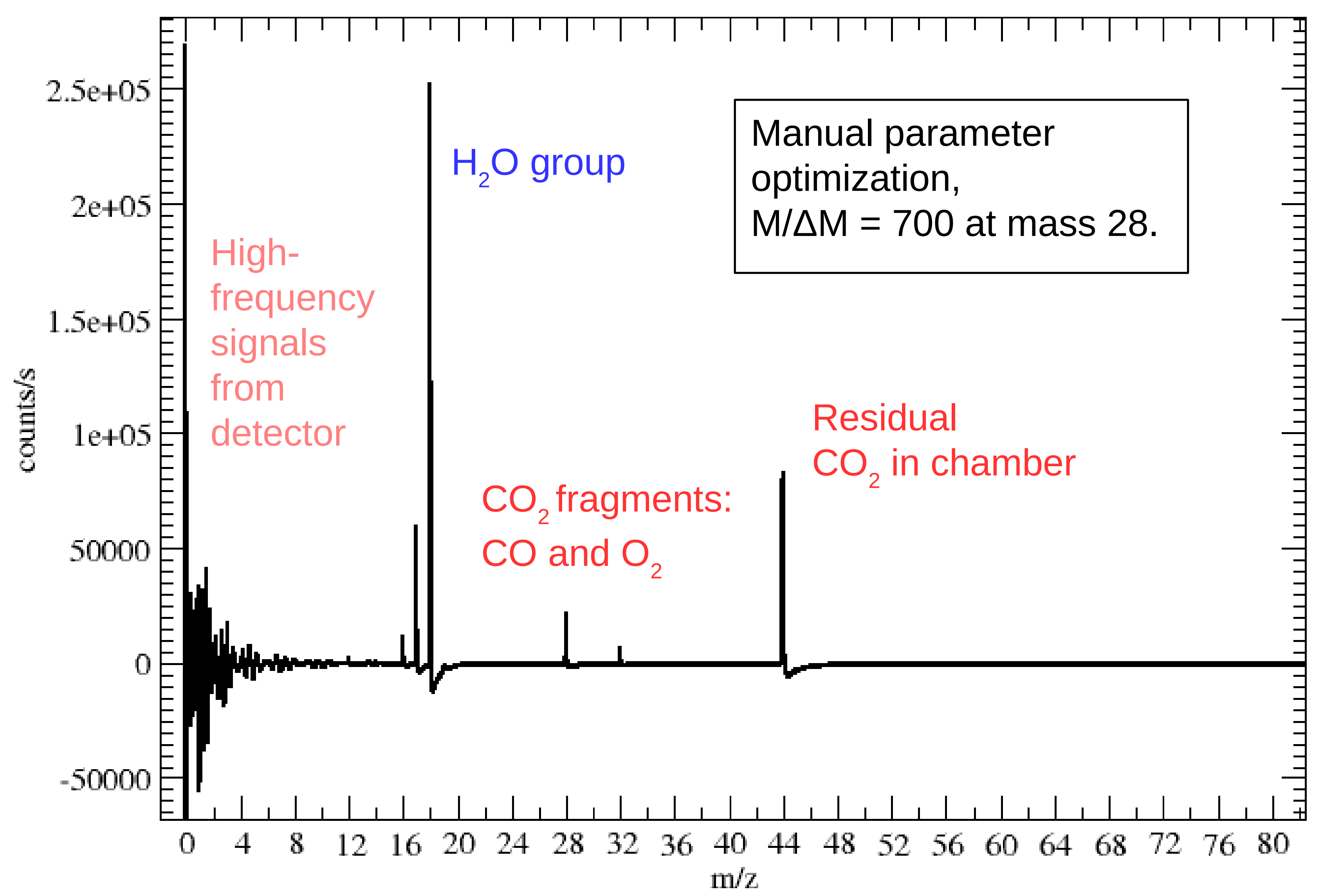
We have built a new time-of-flight mass spectrometer for ice experiments in house: faster, more sensitive, and higher mass resolution than old QMS.

→ Commissioned in 2019.

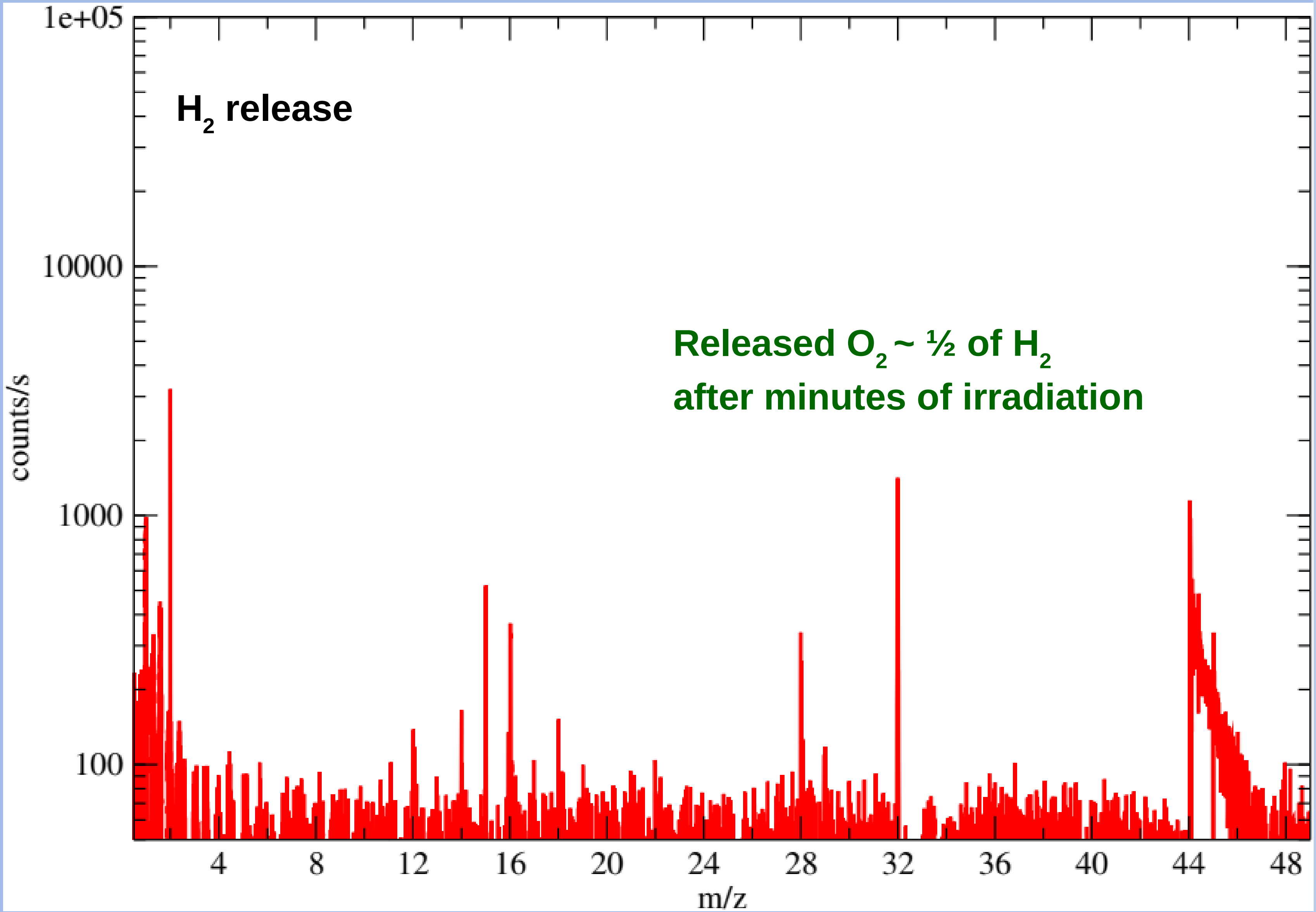
→ First measurements with ice sample in November 2019 (see next page).

For some experiments we also monitored the ice sample with a hyperspectral camera, covering 400 nm – 2500 nm.

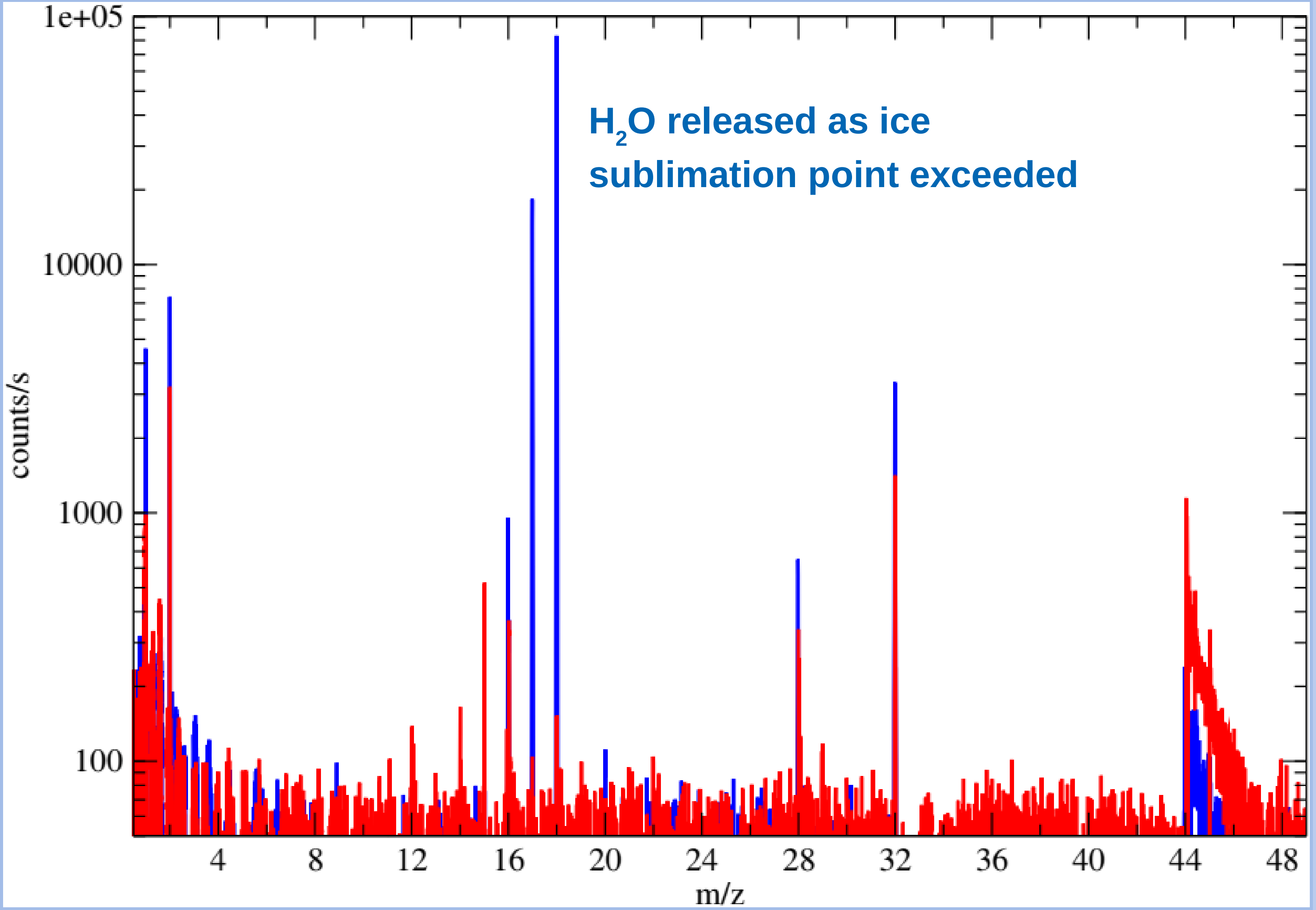
First residual gas spectrum with new TOF mass spectrometer, coarse-grained pure water ice



Results with new TOF mass spectrometer:
Net increase of species upon 1 keV electron irradiation of water ice sample (fine-grained ice at 96 K)



Results with new TOF mass spectrometer:
Net increase of species upon intense 5 keV electron irradiation



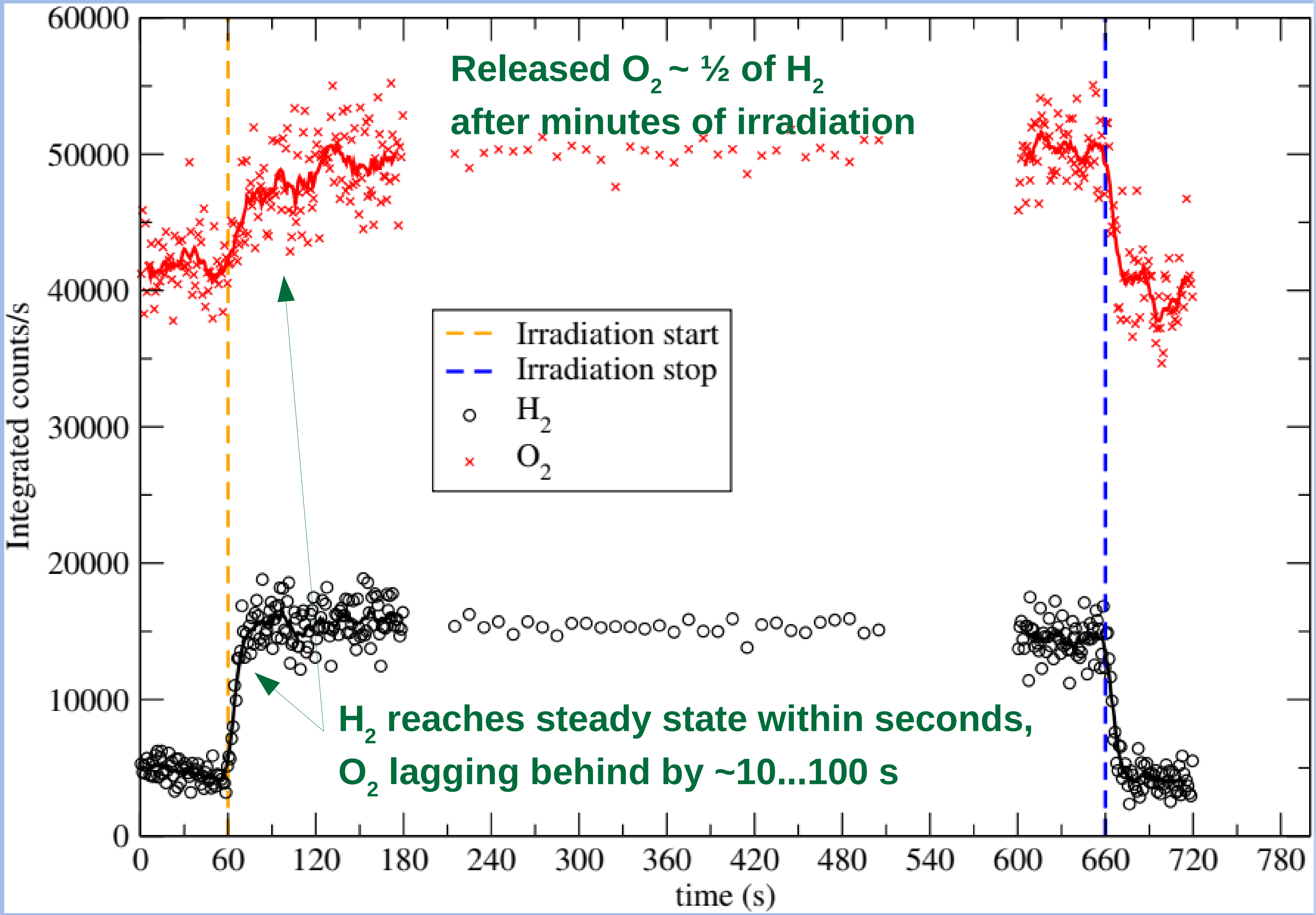
Results with new TOF mass spectrometer:
Average irradiation-induced signal in gas phase once saturation (~10^{16} el./cm^2) is reached

UNIVERSITÄT BERN

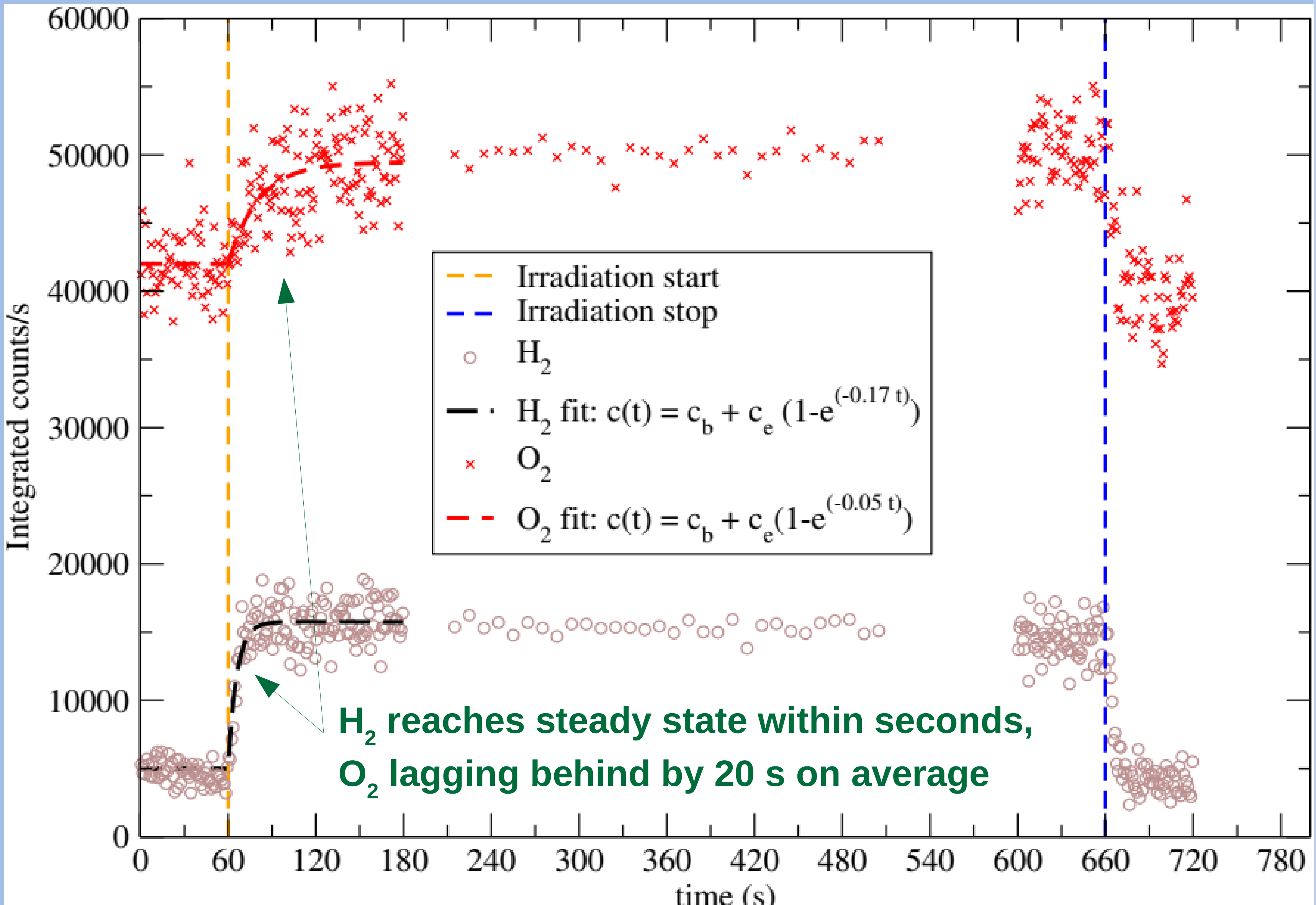
Species	Rel. abundance in % w.r.t. H_2
H_2	**100**
O_2	**52 ± 10**
CH_3	13 ± 6
H	< 10
O	< 10
CH_2	< 3
H_2O	< 1
H_2O_2	< 0.5
O_3	< 0.5

This is valid for all cases, where sublimation threshold is NOT exceeded

Results with new TOF mass spectrometer: Temporal evolution and saturation effects



Results with new TOF mass spectrometer: Temporal evolution and saturation effects



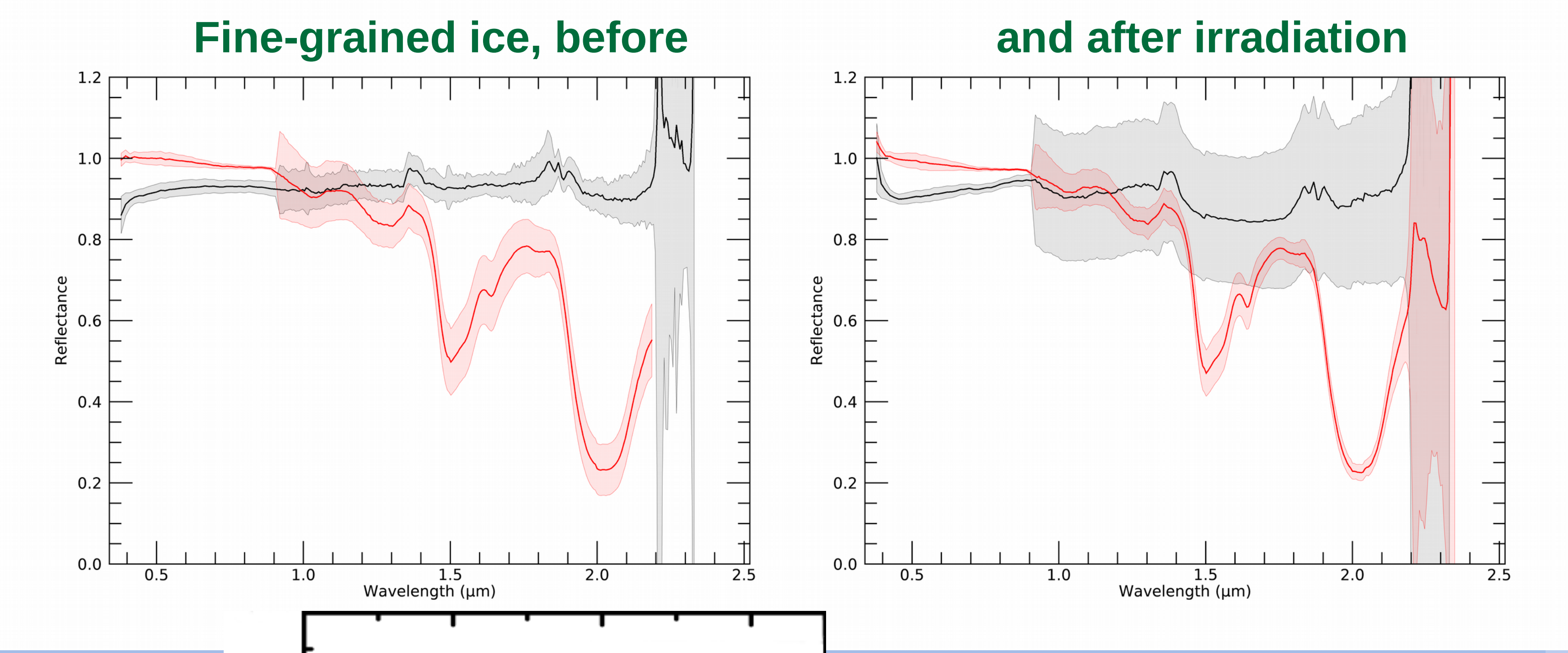
Results with new TOF mass spectrometer: The O2/H2O ratio retained in the ice

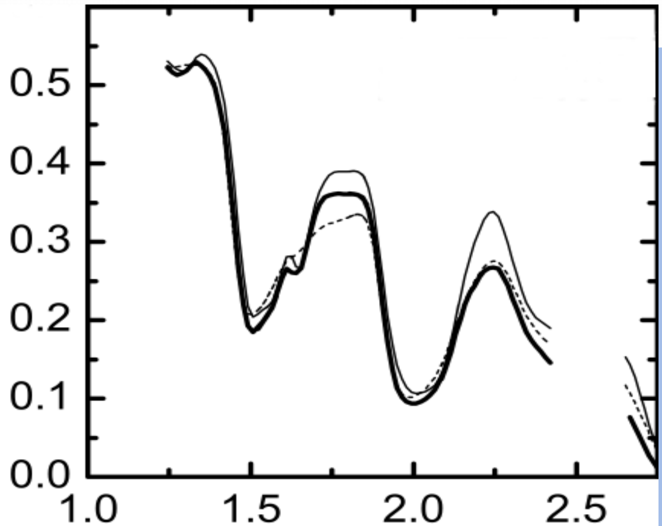
- We have evidence that O_2 formed from radiolysis is retained in irradiated ice to a certain threshold.
- Assuming d=46 nm for 1 keV electrons from theory, calculate the O_2/H_2O ratio in the irradiated layer from excess of released H_2 to O_2 within the first 20 seconds (for O_2, $\lambda = 0.03 \pm 0.02\ s^{-1}$):

$$r(\mathrm{O2/H2O}) = \frac{Y_{\mathrm{O2}}\, j}{e^{-}\lambda} \times \frac{m_{\mathrm{mol}}}{A d \rho N_{\mathrm{A}}} \approx 0.015$$

- Range of uncertainty 0.9%…4.5% because of λ.
- This is comparable to the Ganymede surface (r = 0.1...1%, Calvin et al. 1996) and to gas abundances of comet 67P/C-G (r = 3.8±0.85%, Bieler et al. 2015)
- Revisit the sputtering yield Y_{O2} needed for this estimate (Meier and Loeffler 2020, Galli et al. 2018,Teolis et al. 2017)

Spectral reflectance of fine-grained ice: Realistic for icy moons, but irradiation effects not notable





NIMS/Galileo reflectance spectrum of Europa's ice-rich hemisphere [Hansen & McCord, 2004]

Preliminary results

- New TOF mass spectrometer commissioned. We can analyse 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. But:
- H_2 cannot be retained in ice, O_2 release shows clear saturation effect; derived O_2/H_2O ratio retained in irradiated ice ~ few % (comparable to surfaces of Ganymede, Europa, and Callisto)
- Minor radiolysis species: Upper limits for H_3O and H_2O_2 are < 0.5% (compared to the H_2 released from the ice sample)
- Analysis to be finished

Acknowledgements

- This work has been performed with the support of the Swiss National Science Foundation. We also would like to thank J. Gonseth and A. Etter for their relentless support of the scientific work at the MEFISTO facility.

References

- Abdulgalil 2017, https://doi.org/10.1021/acsearthspacechem.7b00028
- Bieler et al. 2015, https://doi.org/10.1038/nature15707
- Galli et al. 2018, https://doi.org/10.1016/j.pss.2017.11.016
- Hand & Carlson 2011, https://doi.org/10.1016/j.icarus.2011.06.031
- Henderson&Gudipati 2015, https://doi.org/10.1088/0004-637x/800/1/66
- Laufer et al. 2018, https://doi.org/10.1093/mnras/stx3359
- Meier and Loeffler 2020, https://doi.org/10.1016/j.susc.2019.121509
- Orlando & Sieger 2003, https://doi.org/10.1016/S0039-6028(02)02602-X
- Petrik et al. 2006, https://doi.org/10.1063/1.2345367
- Shi et al. 2009, https://doi.org/10.1103/PhysRevB.79.235422
- Shi et al. 2011, https://doi.org/10.1088/2041-8205/738/1/l3
- Spencer & Calvin 2002, https://doi.org/10.1086/344307
- Teolis et al. 2009, https://doi.org/10.1063/1.3091998
- Teolis et al. 2017, https://doi.org/10.1002/2017JE005285