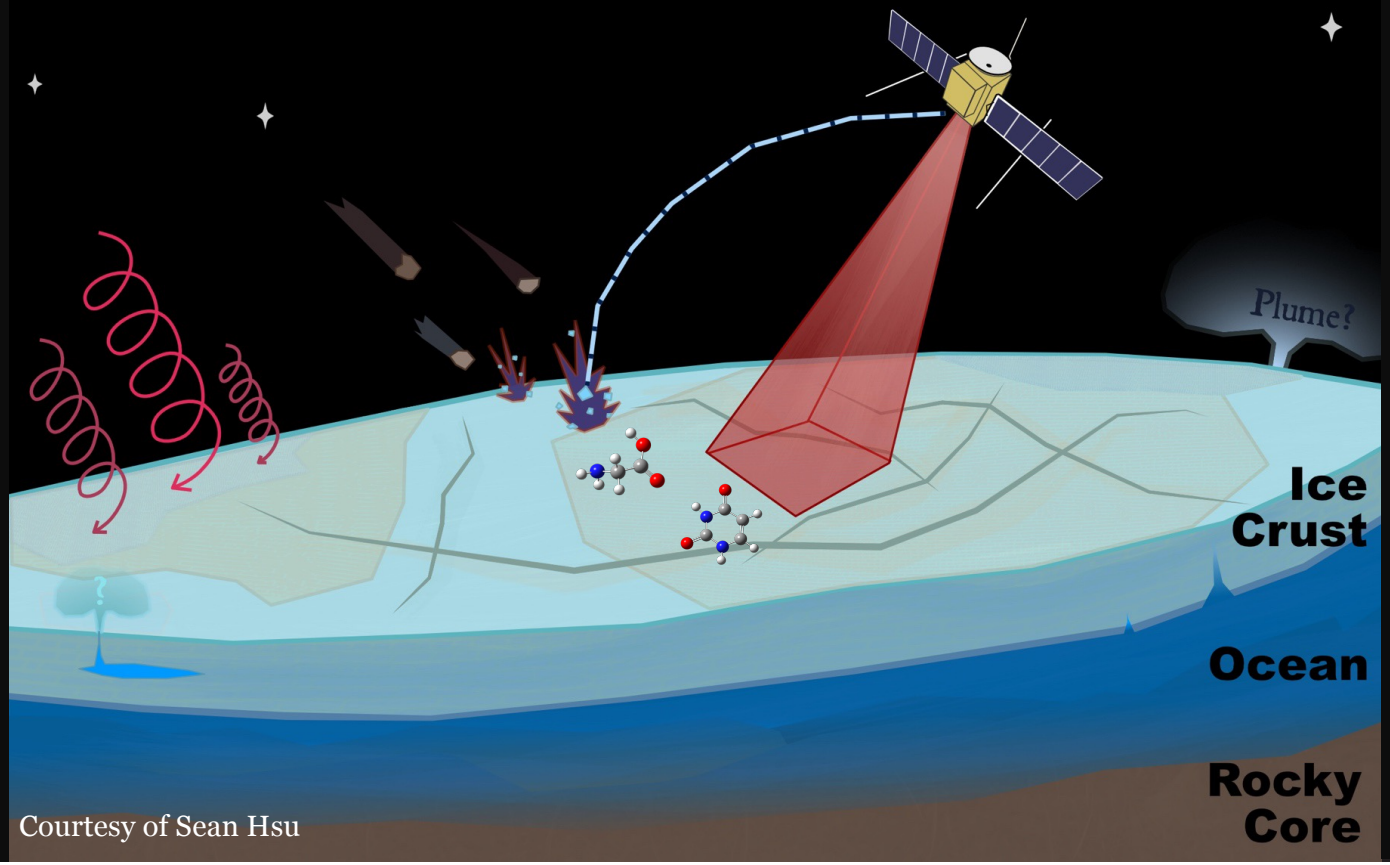
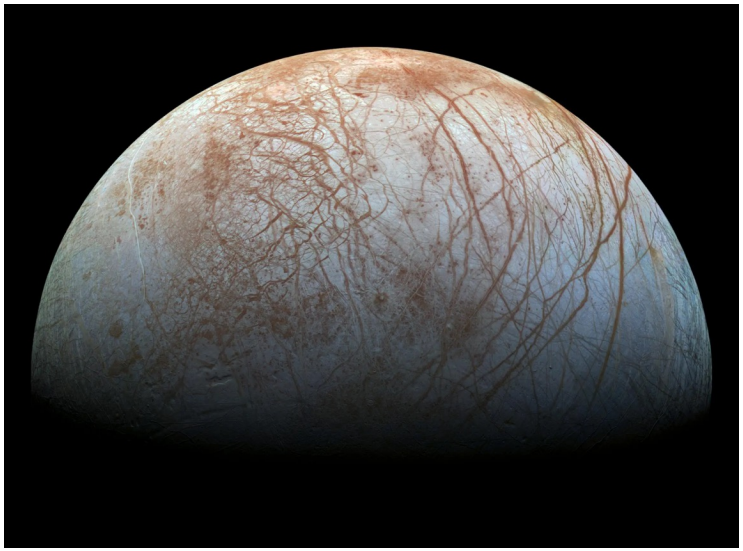
Physical/chemical alterations and detectability of molecular species on Europa's surface using laboratory IR spectroscopy, mass spectrometry, and modeling



Courtesy of Sean Hsu

Europa's surface and composition

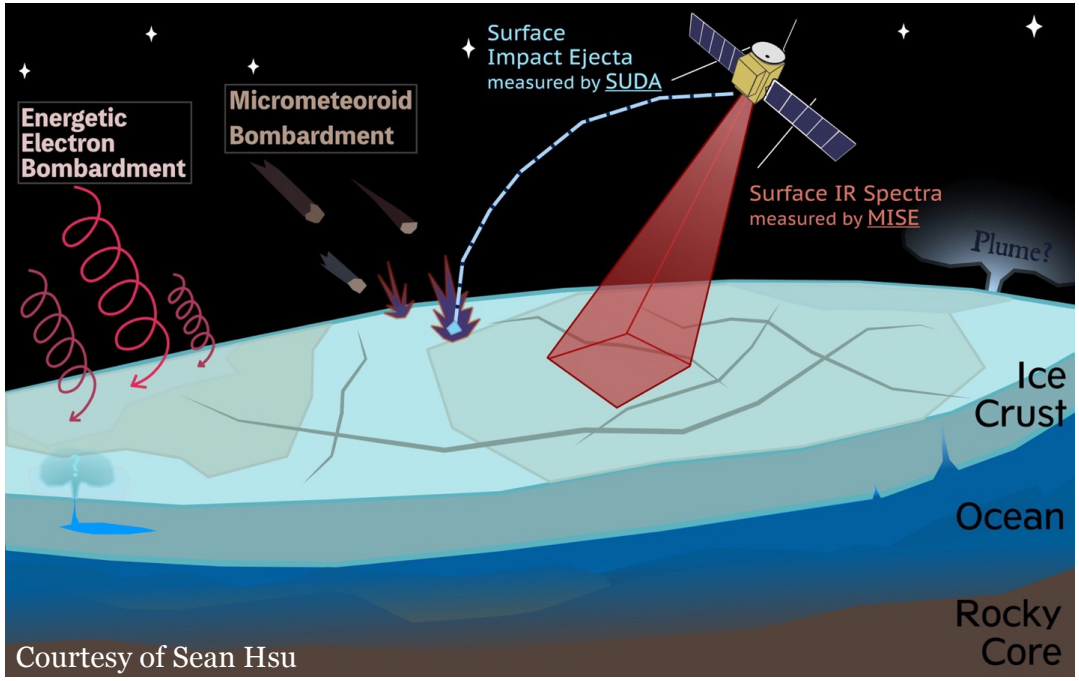
- Observations through remote sensing have indicated the presence of several species
- Mostly water ice in amorphous and crystalline form
- Morphology is indicative of the thermal and processing history of the ice crust (seen by MISE)
- Oxides have been detected (CO_2 SO_2, O_2 and H_2O_2)



- Evidence for NaCl, hydrated sulfates and possibly amide ($-NH_2$) and NH_3

Processing of Europa's surface

- Processing by micrometeoroids
  - Impact speed of 20 km/s
  - Mass flux of $4x10^{-15}$ kg/m^2s
  - Ejecting ice particles from surface
  - Physical/chemical processing
- Processing by radiation
  - Thermal plasma and energetic particles
  - Top ice layer most affected by electrons
  - Electrons drive chemistry



Courtesy of Sean Hsu

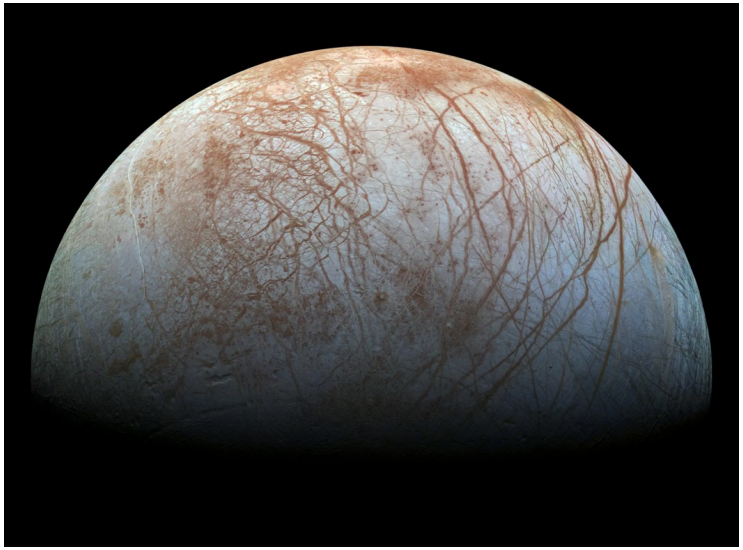
Program science goal

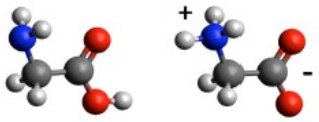
- Europa Clipper's primary goal is to assess the habitability of the moon

- Bio-essential elements (H, C, O, S, P, N) are critical for habitability of the moon and nitrogen is characterized as a prime indicator

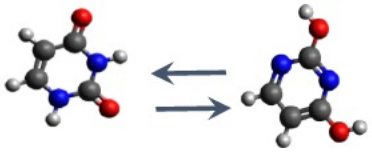
  D. G. Capone + Science, 312 (2006) 708–709

- **The main goal of our study is to supply data that will facilitate the identification of N-bearing molecules with Europa Clipper**

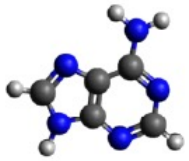




Amino acids



Uracil (amide and imide form)



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Our program

- New ice target system for studying IR spectra and processing of Europa's surface
- Ice accelerator measurements for simulating detection of organics using SUDA
- Modeling the chemistry on Europa's surface

Ice accelerator and dust impact measurements

Jordy Bouwman
CU Boulder
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Morgan Cable
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Co-I

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Co-I

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CU Boulder
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Collaborators:
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Edith Fayolle – NASA JPL
Sascha Kempf – CU Boulder / LASP
Tobin Munsat – CU Boulder
Frank Postberg – Freie Universität Berlin

Modeling effort

Rob Garrod
UVA
Co-I

Sydney Willis
UVA
GRA

Our program

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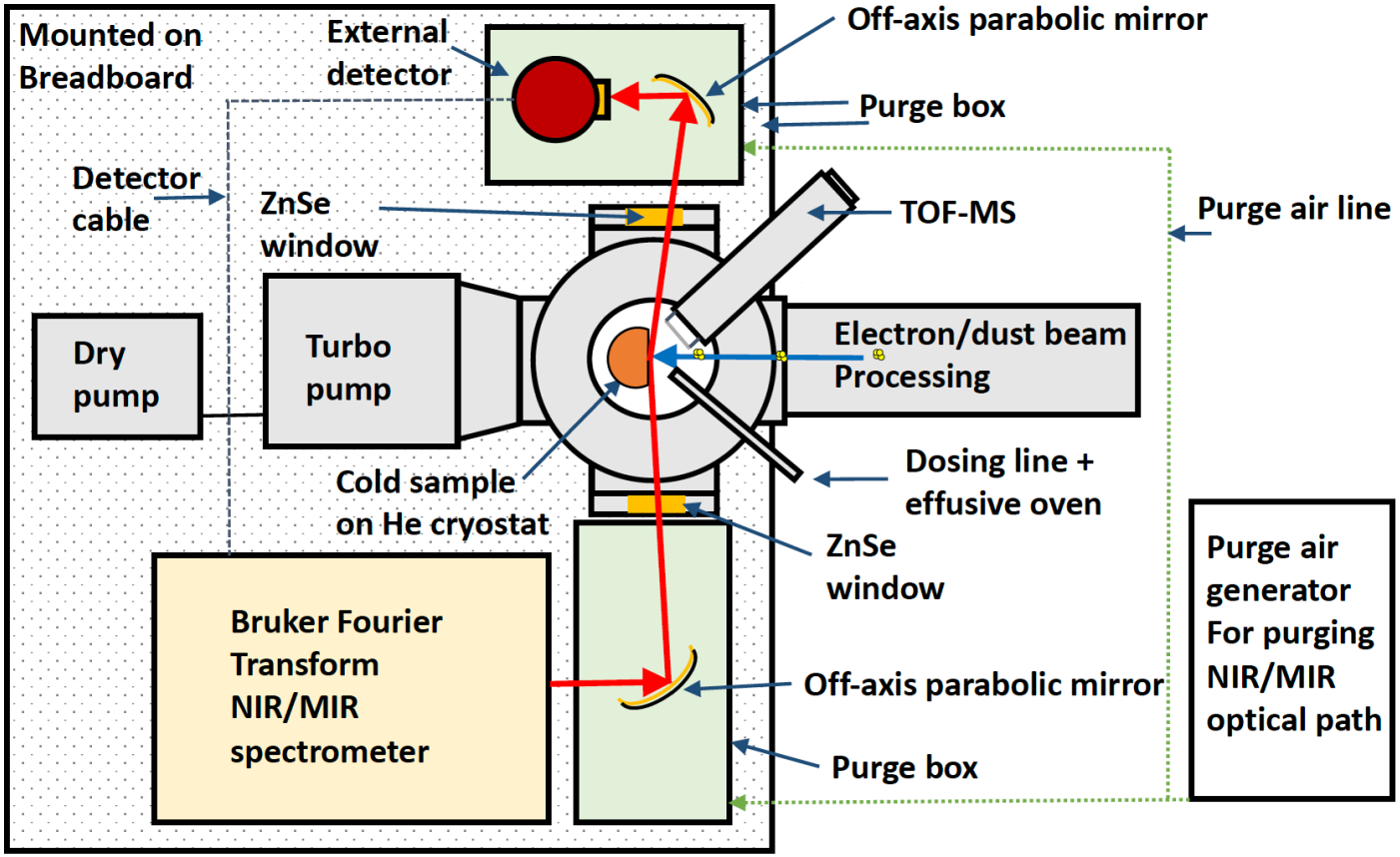
New ice target system for processing ices



Experimental details

- High vacuum chamber (pressure better than 10^{-8} mbar) with possibility for UHV operation ($\sim 10^{-10}$ mbar)
- Cryostat allows cooling of sample between 10-300 K
- IR spectrometer (Bruker Invenio R) covers 400 – 12500 cm^{-1} (25 – 0.8 μm)
- Organic effusion cell with shutter for accurate deposition of organic molecules
- Electron flood gun (5 kV 1 mA) and/or dust accelerator for processing of ices

Growing and characterizing ices

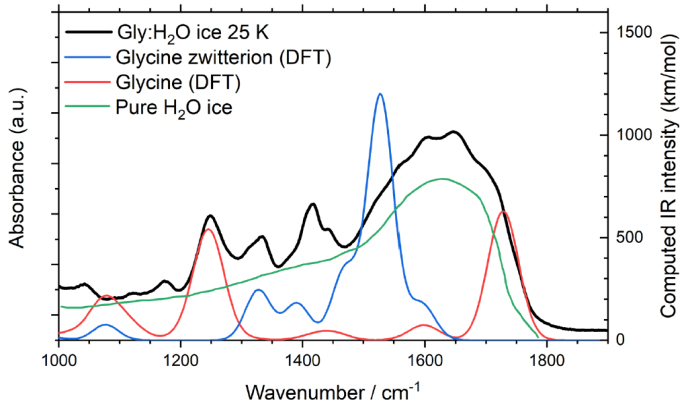
- Grow water ice containing organic species under laboratory-controlled conditions

  Bouwman + A&A, 25 A93, 2011

- Monitor the ice growth using mid-IR spectroscopy and using known IR band strength

Example of a mid-IR spectrum of a glycine containing water ice taken from Ioppolo et al. Nat. Astro, **5**, 197–205 (2021)

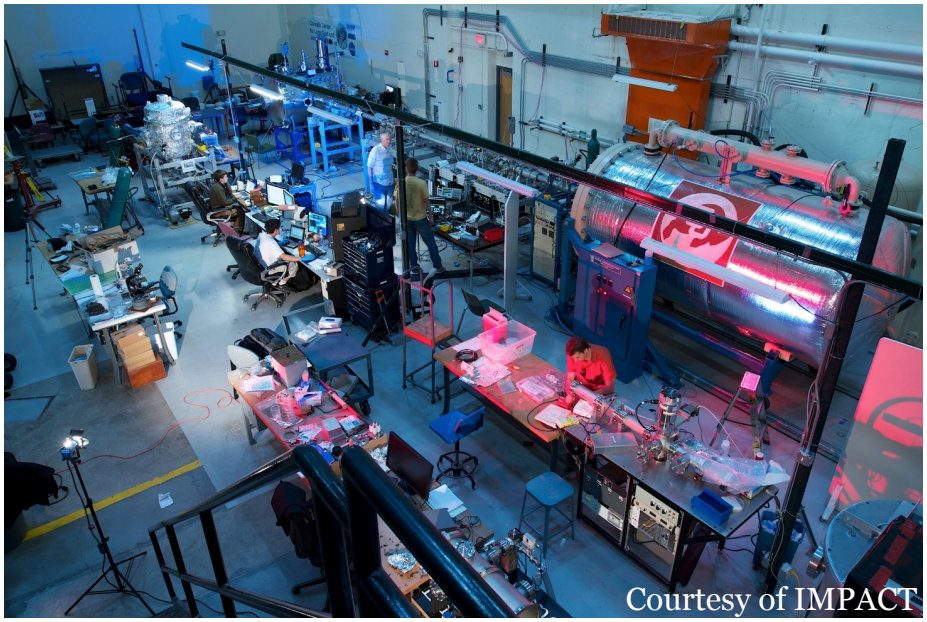
Added are DFT calculated normal modes of glycine in its normal and zwitterionic form



- Expose the ice to energetic sources; hypervelocity dust particles and/or electrons

Hypervelocity dust particles

- Dust accelerator at the Institute for Modeling Plasma Atmospheres and Cosmic Dust (IMPACT) at CU Boulder
- A 3 MV pelletron accelerates micron-sized particles to velocities up to 100 km/s
- Olivine particles to simulate interstellar/ interplanetary dust hitting Europa's surface


Courtesy of IMPACT

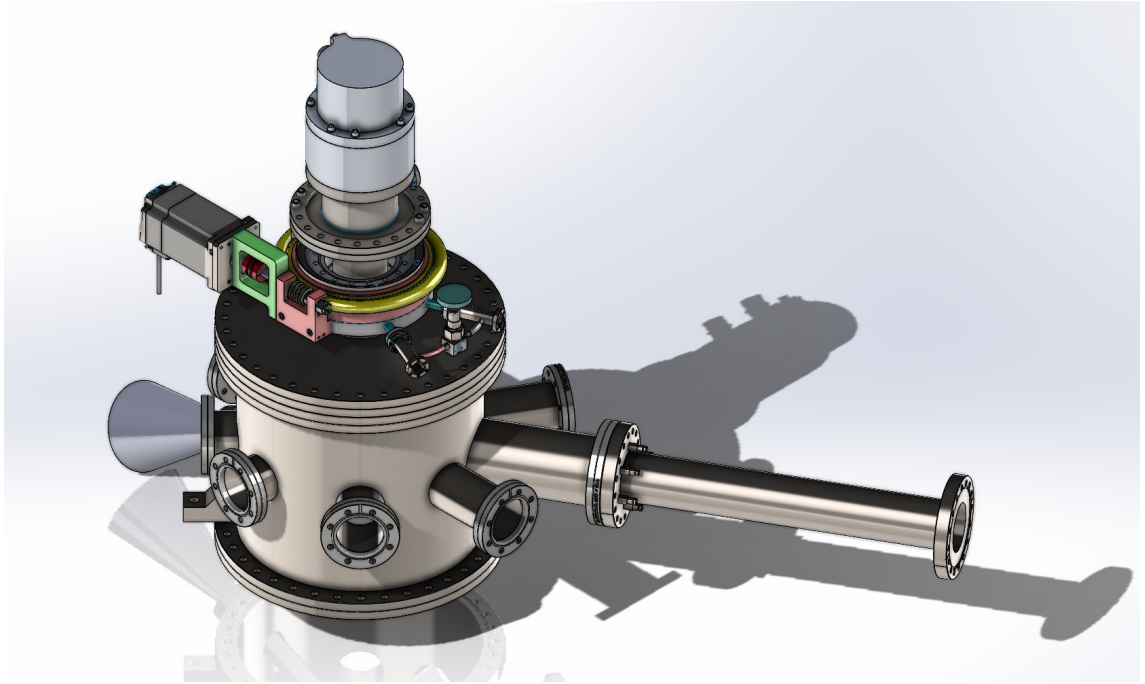
- Ice target system is connected to the dust accelerator exposing the ice to velocity-selected dust particles

Specific goals

- Monitor the survivability of complex organic hydrocarbons on the surface of Europa
- Characterize chemical reactions in the ice and identify reaction products using a combination of IR spectroscopy and time-of-flight mass spectrometry
- Quantify rate constants that serve as input for chemical models
- Characterize the near-IR reflection spectra of nitrogen-bearing complex organic molecules

Project status

- Design for the ice target vacuum chamber is ready
- Frame is currently being designed.
- Major parts and equipment ready to be ordered
- Assembly of system planned for summer of 2024



Our program

- New ice target system for studying IR spectra and processing of Europa's surface

- **Ice accelerator measurements for simulating detection of organics using SUDA**

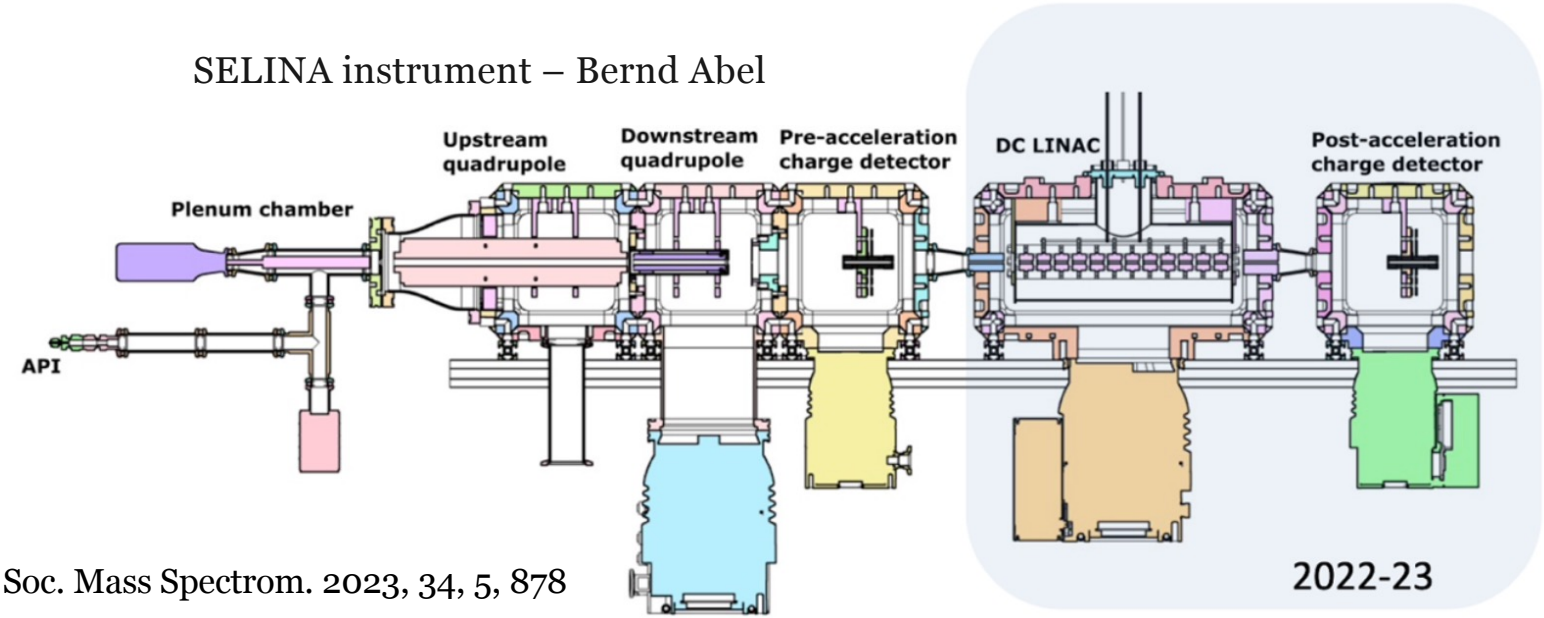
- Modeling the chemistry on Europa's surface

Ice accelerator measurements

- Generate ice particles of a premixed solution

- Electrospray ionization, mass selection and linear acceleration

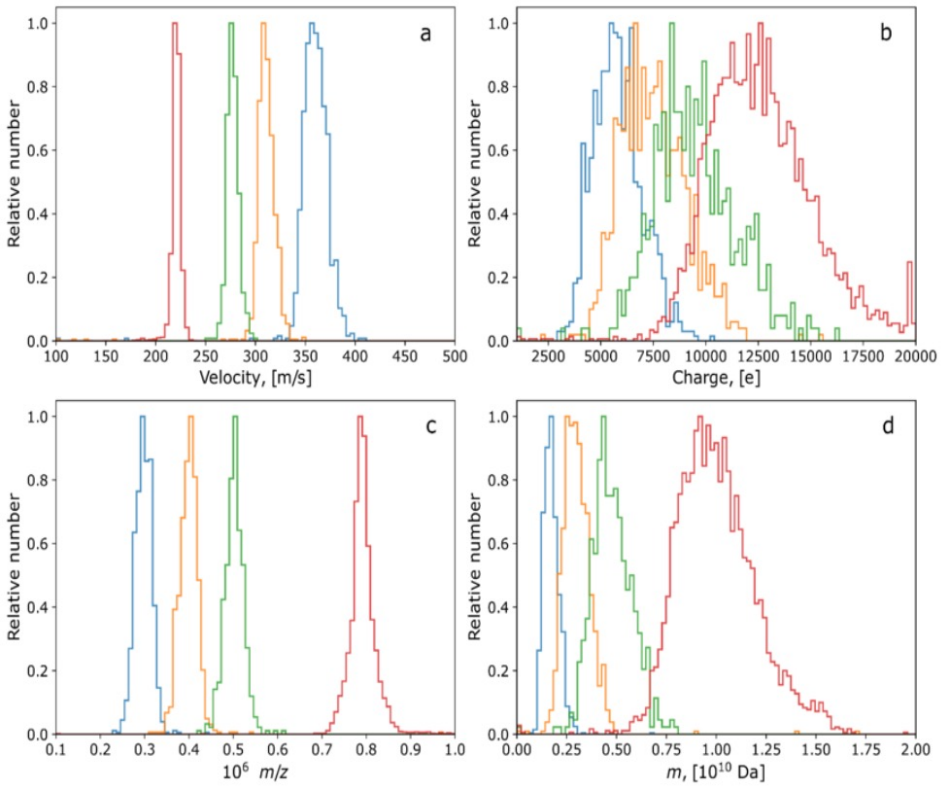
SELINA instrument – Bernd Abel



Spesyvyi + J. Am. Soc. Mass Spectrom. 2023, 34, 5, 878

Ice particle size and velocity

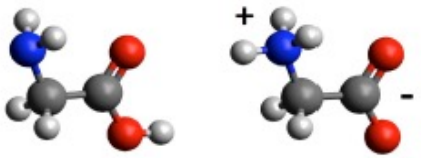
- Particles of 0.2 – 0.6 micron in size
- Velocities from 1 – 6 km/s
- About 1 ice particle per second
- Detection of particles performed using Time-of-flight mass spectrometer



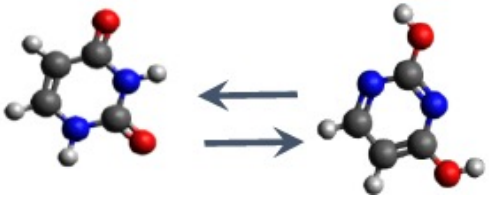
Spesyvyi + J. Am. Soc. Mass Spectrom. 2023, 34, 5, 878

Specific Goals

- Study the same organic species as for the ice processing measurements:



Glycine and zwitterionic form



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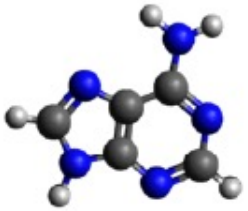

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- Investigate how these hydrocarbons show up in dust impact TOF data at Europa relevant velocities (4.5 – 6 km/s)

- Investigate the effect of pH (NH_3OH, NaOH, HCl, H_3PO_4) and salt concentration (NaCl, $MgSO_4$) on the appearance and detectability of the organics

Our Program

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- Ice accelerator measurements for simulating detection of organics using SUDA

- **Modeling the chemistry on Europa's surface**

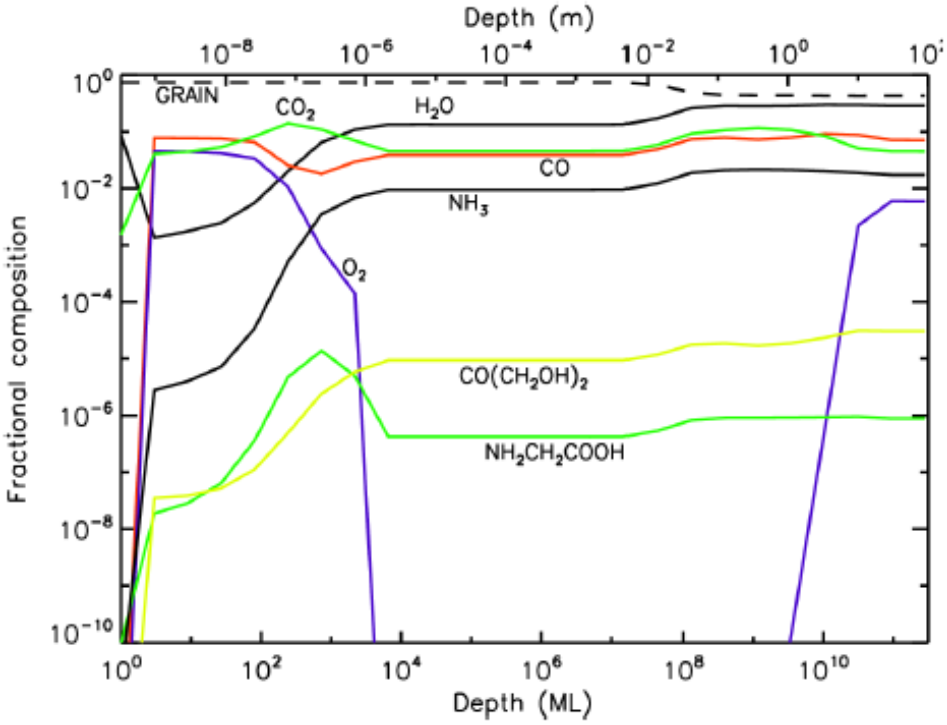
Modeling chemistry in Europa's ice crust

- Convert an interstellar/cometary chemistry model to simulate solid-state chemistry on Europa

  Jin & Garrod Astrophys. J. Sup. Series 2020, **249**, 26

- Model contains photon-driven radical chemistry, radiolysis driven ion chemistry

- Experimentally determined rates will be included



Outlook & Acknowledgement

- We will soon hold a kick-off meeting with the team members
- Ordering of parts for constructing ice target has commenced; construction of the system in summer 2024
- First set of ice accelerator measurements planned for May 2024
- Next presentation we will share our first results!
- A big thank you to NASA for funding our PSIE program