LABORATORY SIMULATIONS OF ENCELADUS PLUME FOR FLY-BY MASS SPECTROMETERY VALIDATION

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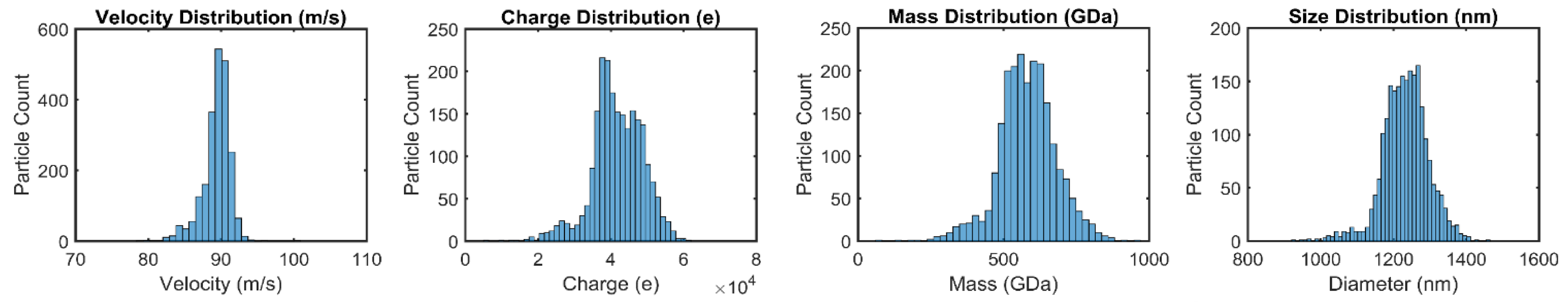
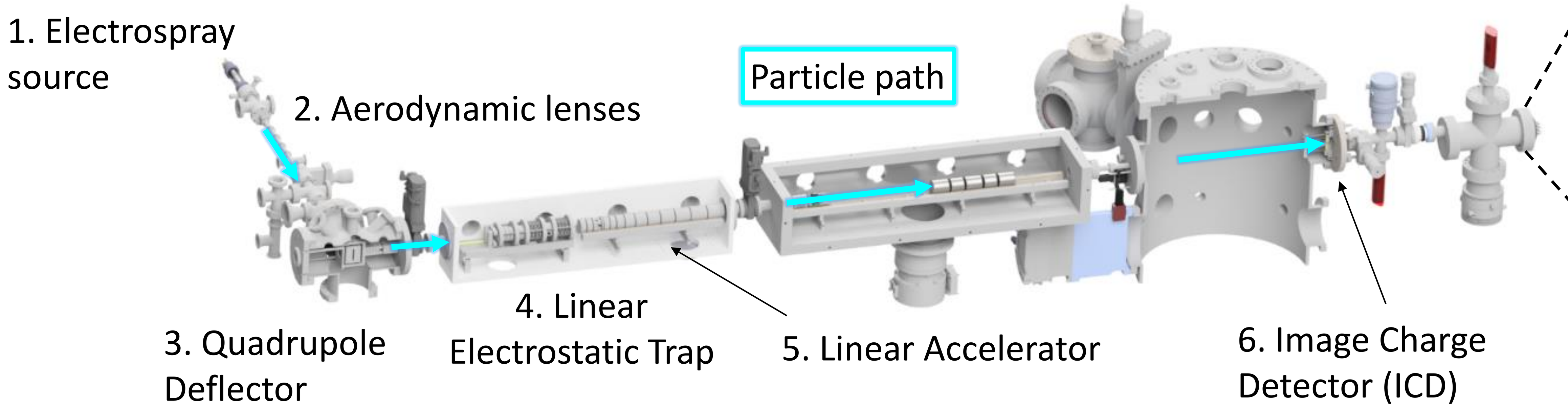
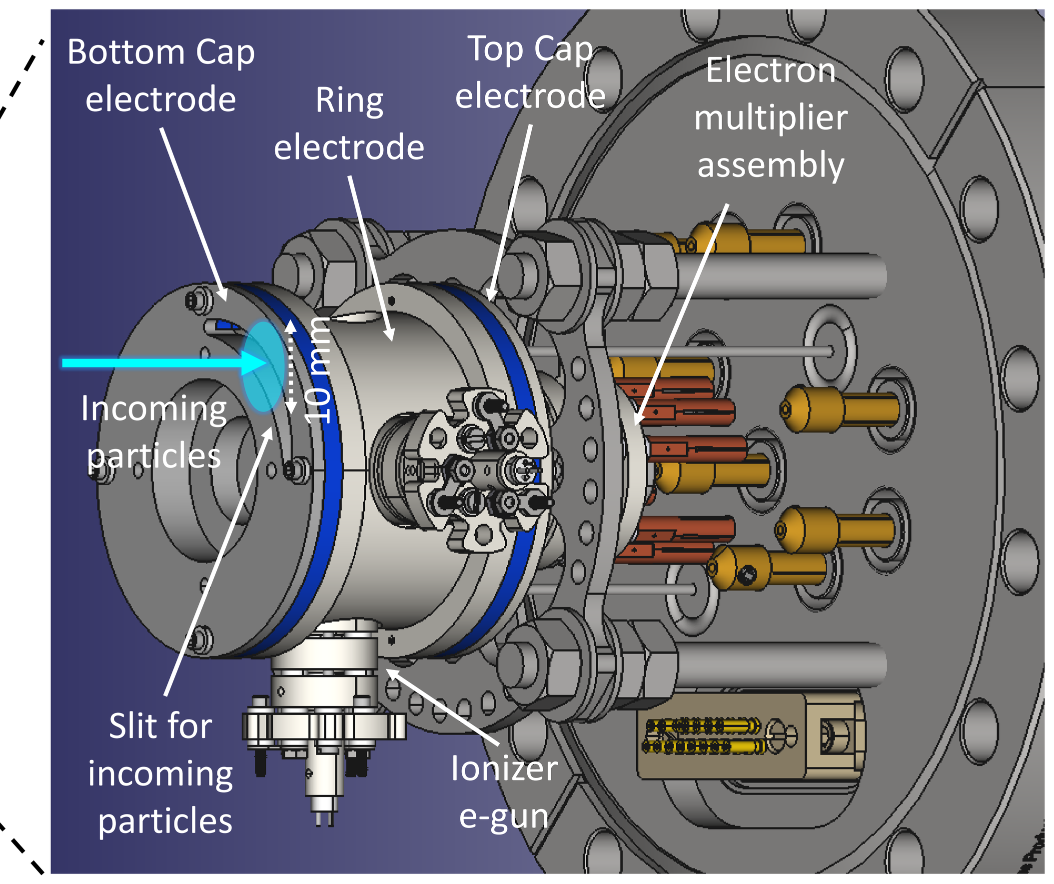
Motivation. Enceladus is currently one of the most promising places to search for extraterrestrial life. Its plumes carry material high above the surface, and is a perfect target for a fly-by mission, equipped with cutting edge in-situ sampling instrumentation. However, the high velocity of the spacecraft relative to the sampled material may introduce additional factors impacting the measurements, such as fragmentation of molecules or induced chemical reactions. For space applications, it is essential to validate the approach and instrument performance with lab measurements under relevant conditions. This work is aimed to develop and validate a testing method to accelerate microscopic ice grains to relevant velocities and inject them into a mass spectrometer for analysis.

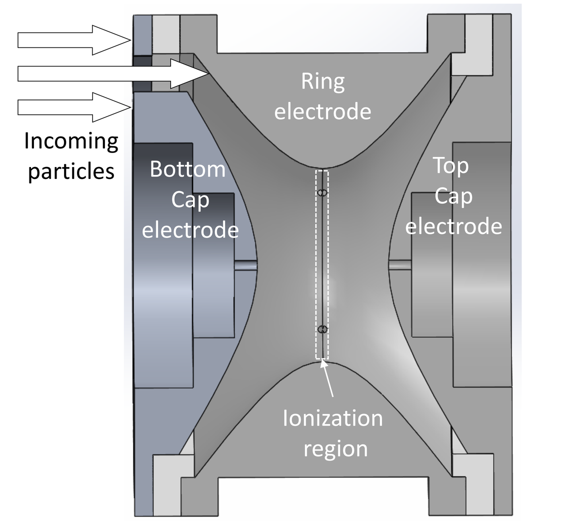




Ice grain source/accelerator – Aerosol Impact Spectrometer



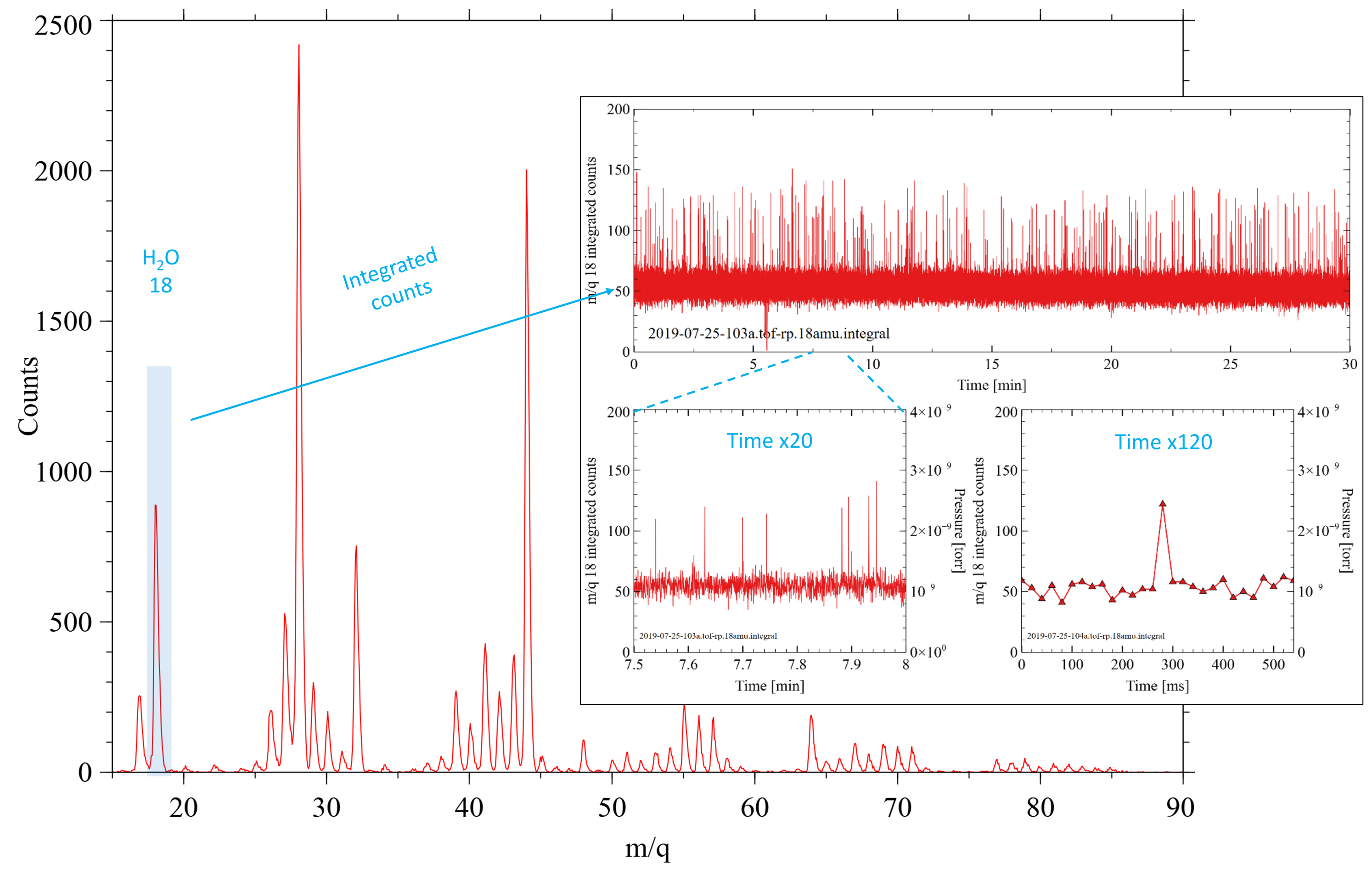
The QITMS mounted on 6" CF flange at the end of the beam line. Incoming particle beam with a diameter of 10 mm (blue oval) is aligned at the banana shaped slit in the Bottom Cap electrode.



Cross section of the QITMS. Some of the incoming grains pass into the inner volume of the trap through the opening in the Bottom Cap electrode.

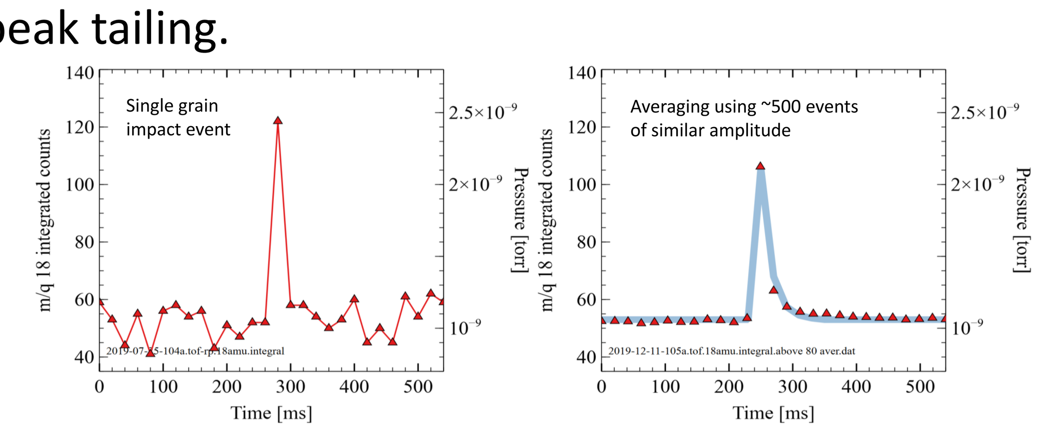
Ice grains are created and accelerated in the apparatus in the following steps: (1) electrospray ionization, (2) aerodynamic lenses that collimate the particle beam and reduce the pressure from an atmosphere to high vacuum, (3) energy selection using a quadrupole deflector, (4) optional trapping and characterization of individual particles in a linear Nanoparticle Electrostatic Trap (NET), (5) acceleration of the particles, using known particle characteristics, (6) Image Charge Detector (ICD) registers particles, that reach the end of the beamline and are traveling towards the QITMS. Distributions of particles measured in the NET are centered at mass ~600 GDa, charge of ~4x10^4 e, velocity around 90 m/s, and resulting diameter of 1.3 microns calculated for ice.

QITMS is a miniature mass spectrometer developed at the Jet Propulsion Laboratory (JPL) for space applications. It's a Paul Trap type instrument with electron impact ionization. When ice grains reach the inner volume of the QITMS a sample of the resulting water molecules will be ionized, trapped and analyzed.

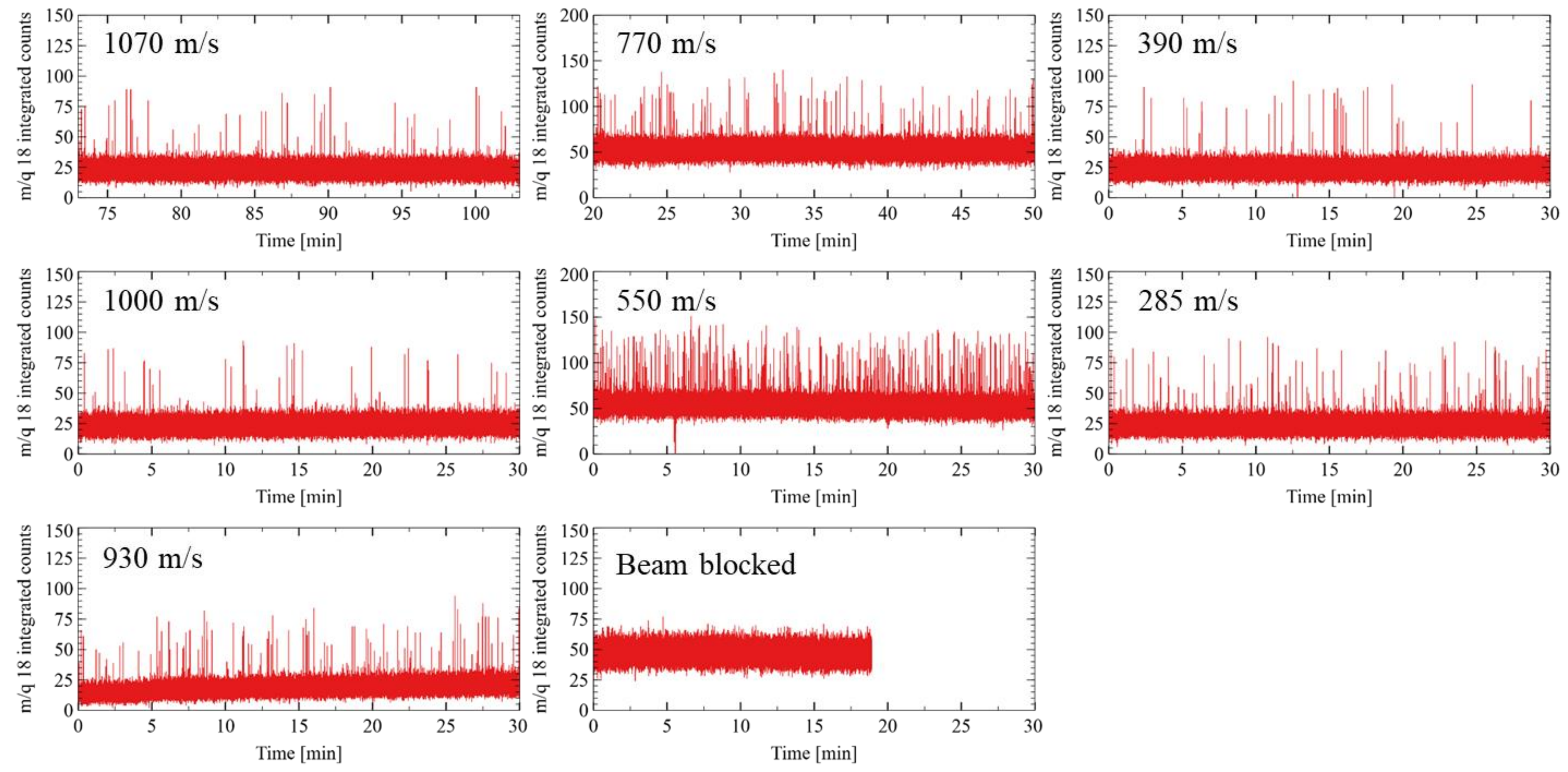


Background mass spectrum (10 second integration). Inset: m/q 18 peak area is integrated and plotted versus time with 20 ms resolution. Ice grain impacts are contributing to water partial pressure and seen as spikes on m/q 18 integrated counts.

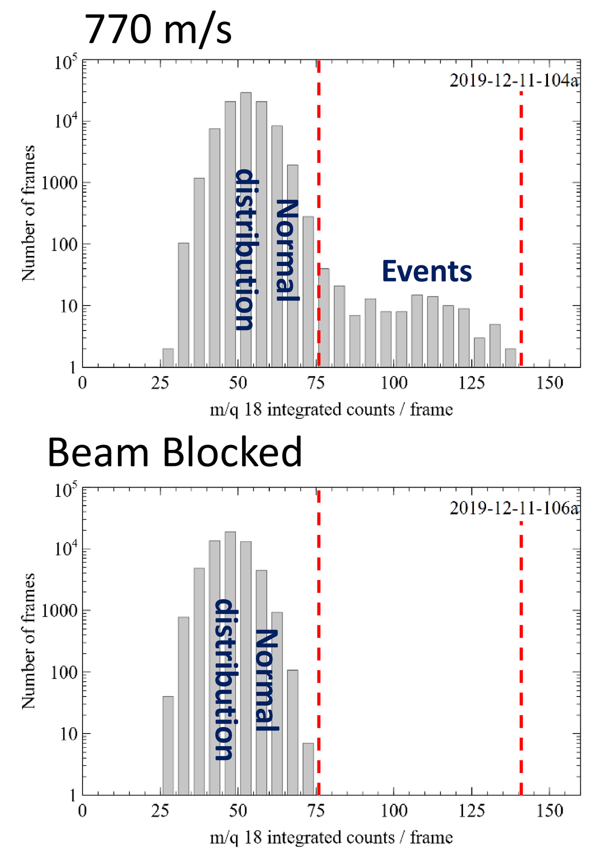
Mass spectra are collected with the QITMS 50 times per second, providing a 20 ms resolution in time. A background mass spectrum shows dominant species at m/q: 18 (water), 28 (CO and N_2), 32 (O_2), 44 (CO_2). Brief frequent spikes in the integrated counts for m/q 18 peak appear due to ice grain impacts. When calibrated to pressure, the value of the mass 18 spikes is approximately 1x10^{-9} Torr, while the water background is 1.1x10^{-9} Torr. When ~500 of the events are averaged, statistical noise is reduced, revealing peak tailing.



Single ice grain impact event (left), ~500 averaged events with similar amplitude averaged to reveal tailing peak (right).



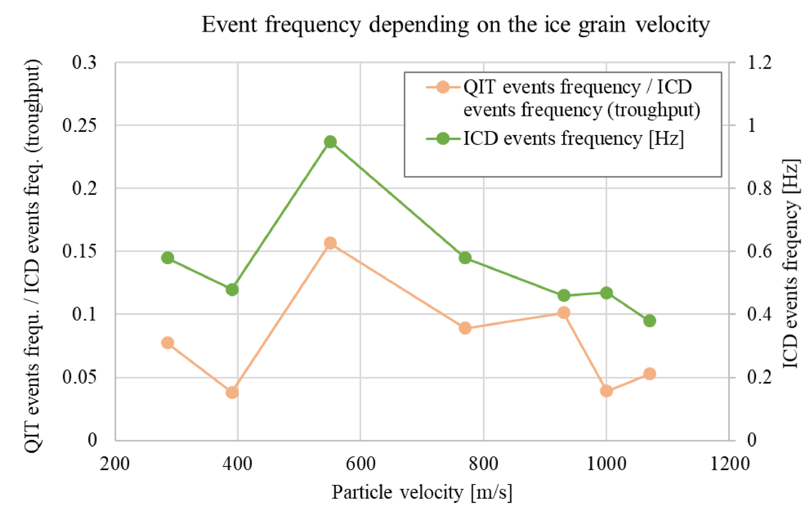
Integrated m/q 18 counts versus time with 20 ms resolution for different incoming ice grain velocities.

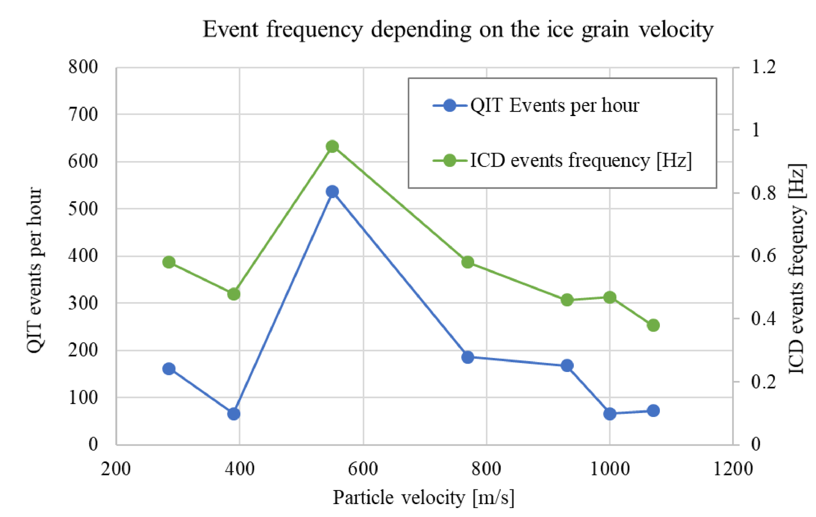


Statistics on integrated m/q 18 counts.

Runs were completed for various acceleration energies, resulting in ice grain velocities 285 – 1070 m/s. Statistical analysis shows a distinctive normal distribution representing background water level signal for a case with the ice grain beam blocked electrostatically (other conditions unchanged). The histograms for different ice grain runs in addition show hit events distribution.

The frequency of events is compared for different particle velocities. Image Charge Detector (ICD) shows the rate of particles reaching the end of the accelerator beam line and varies from about 0.5 to 1.0 Hz (●). QITMS spikes in m/q 18 integrated counts show from 70 to 540 ice grain hits into the mass spectrometer per hour (●). At 550 m/s, both the QITMS and ICD show increased event rate. Throughput (●) between ICD and QITMS varies from 0.04 to 0.015 and is also increased at 550 m/s. This increase is likely due to favorable focusing along the beamline for a given ice particle energy.





Event frequency registered on the ICD and from QITMS data depending on incoming ice grain velocity.

Summary: microscopic ice grains were produced and accelerated in vacuum to velocities up to 1000 m/s and impacted into the sampling port of the mass spectrometer, where final analysis took place. Path forward includes LINAC upgrade to allow velocities up to 5 km/s, mass spectrometer coupling optimization to increase the amount of sample captured and introducing organic dopants into the ice grains.

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.