Analyzing Enceladus' Plume Constituents: First Steps to Experimentally Simulating Hypervelocity Impacts

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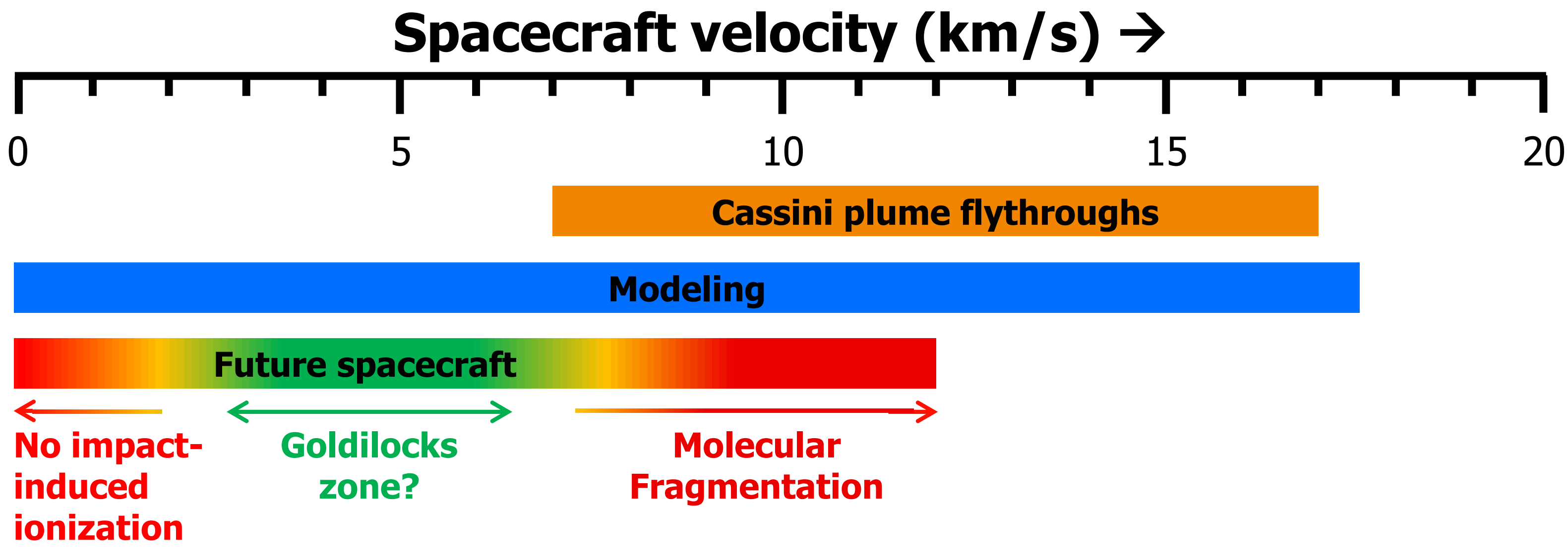
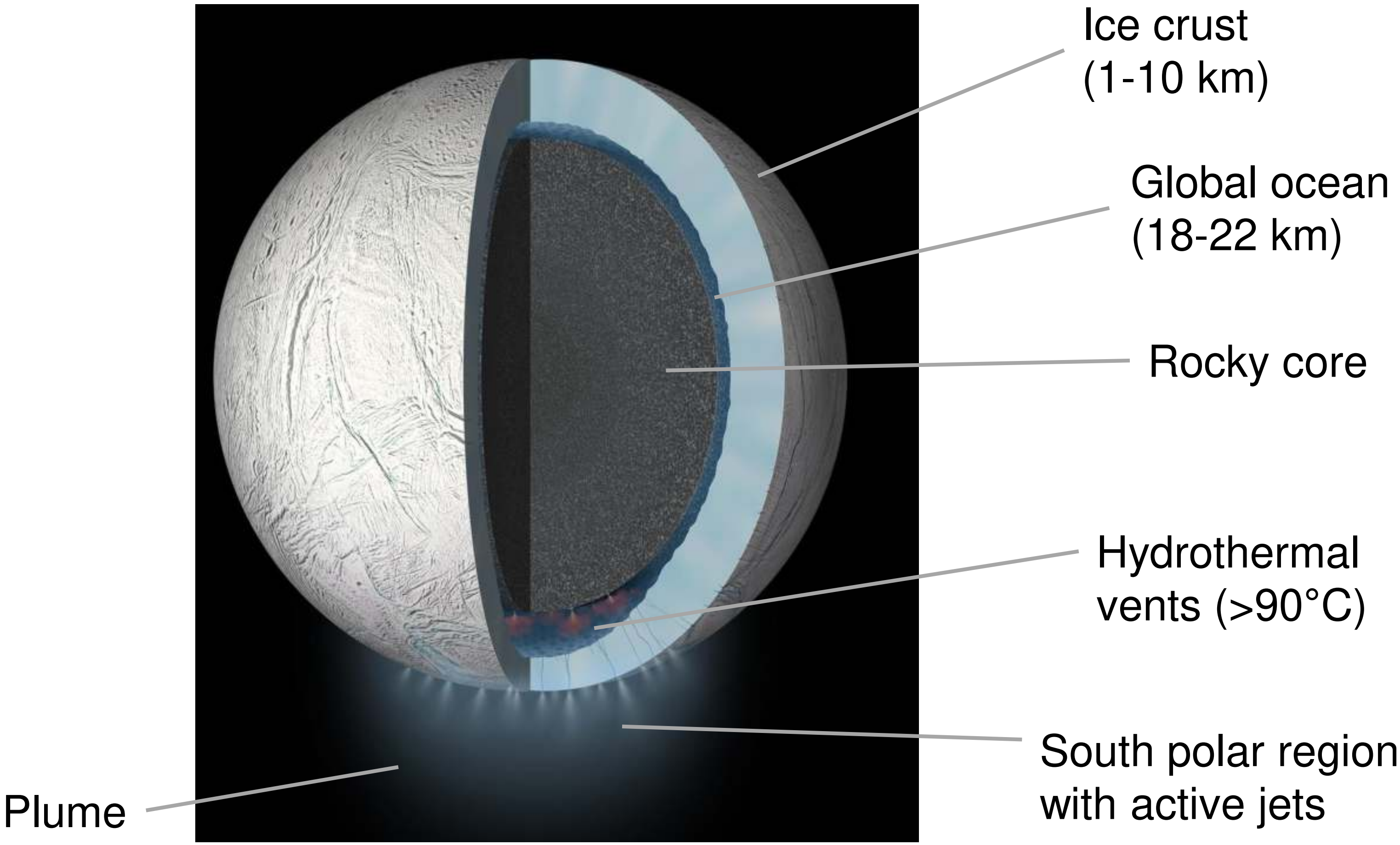
Image: NASA/JPL

Hypervelocity sampling

- Cassini sampled the plume of Enceladus at hypervelocity (>1 km/s)
- Hypervelocity sampling presents challenges
  - Need to balance volatilization, ionization, and fragmentation



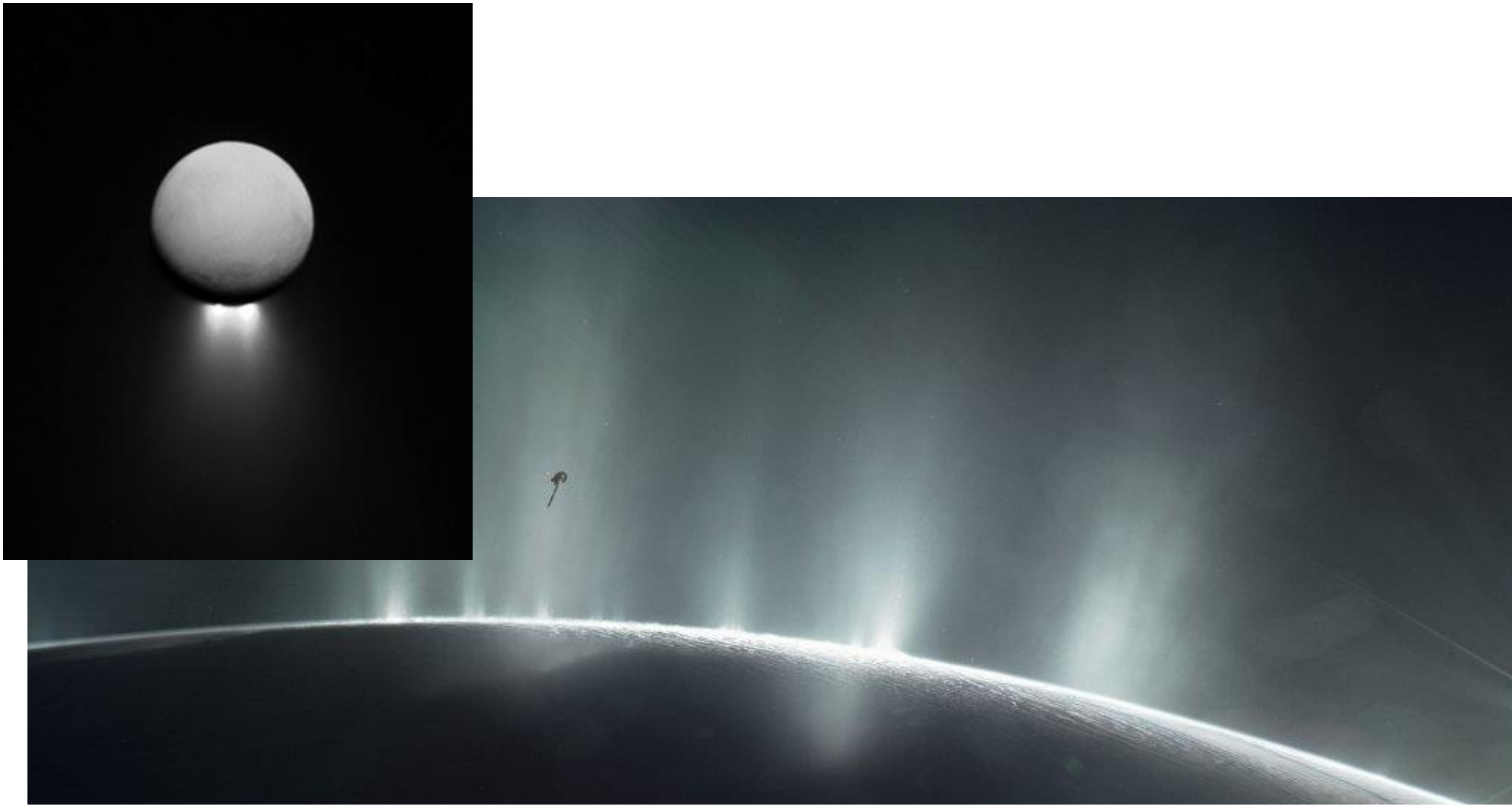
Why Enceladus?



Enceladus is one of the prime targets to search for aqueous-based life

Image: NASA/JPL

Plume discovery –Cassini



Images: NASA/JPL-Caltech; NASA/JPL/SSI

An epic photobomb

Image: NASA/JPL/Ted Stryk

T.Stryk (2017) 48th LPSC, Abstract #1603

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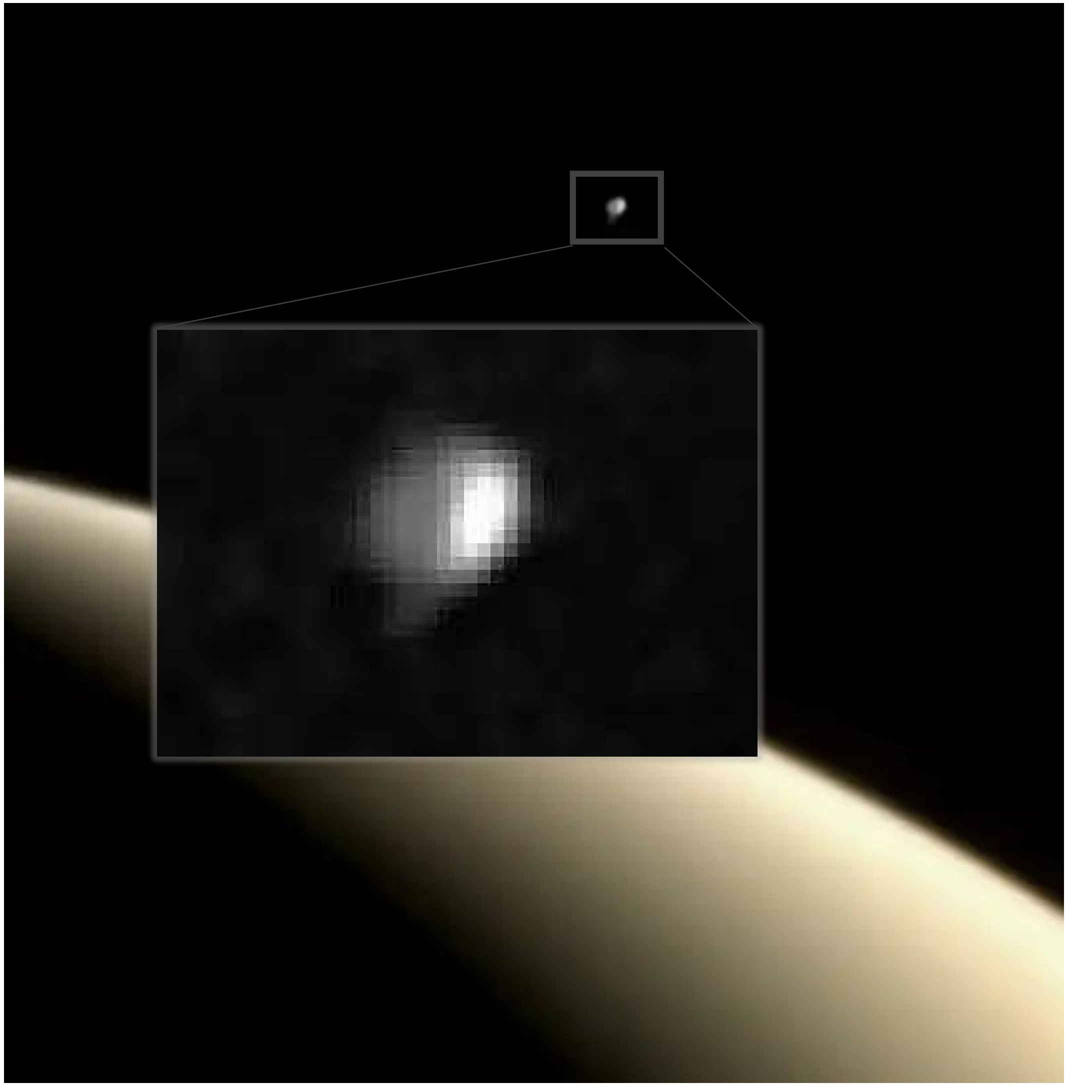
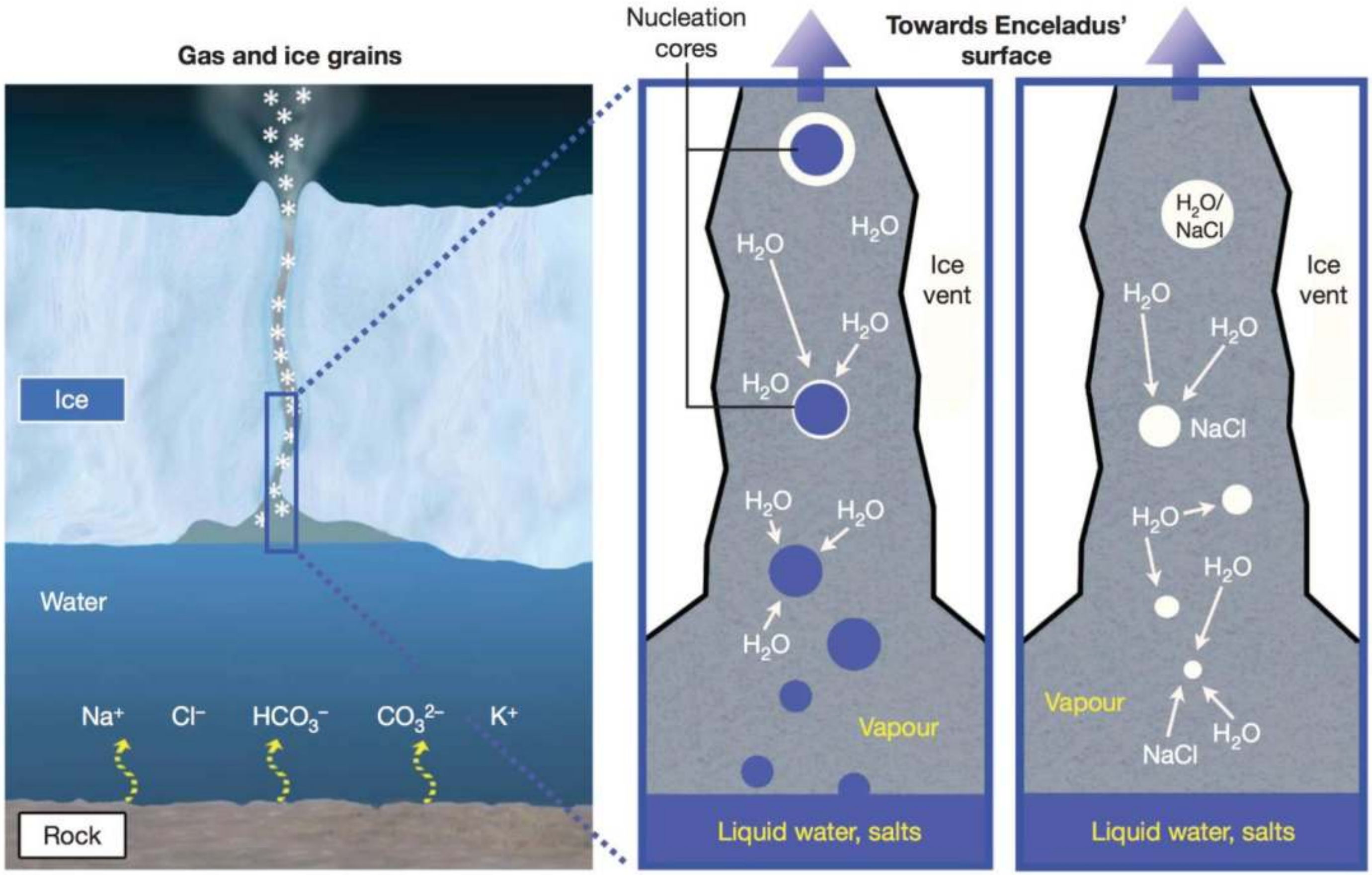


Images: NASA/JPL/Ted Stryk

T.Stryk (2017) 48th LPSC, Abstract #1603

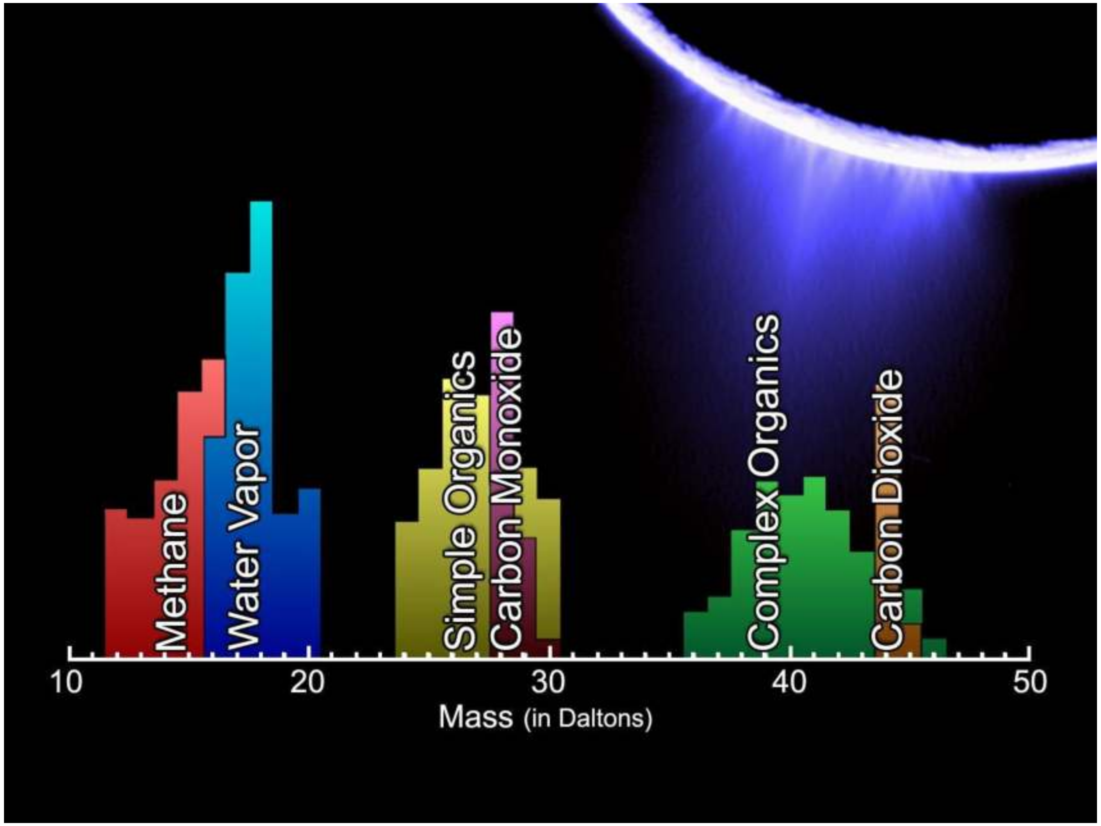
Cryovolcanic plume



The plume expresses the subsurface ocean into space.

Postberg et al. (2009) Nature, 459, 1098-1101.

Plume composition –Vapor



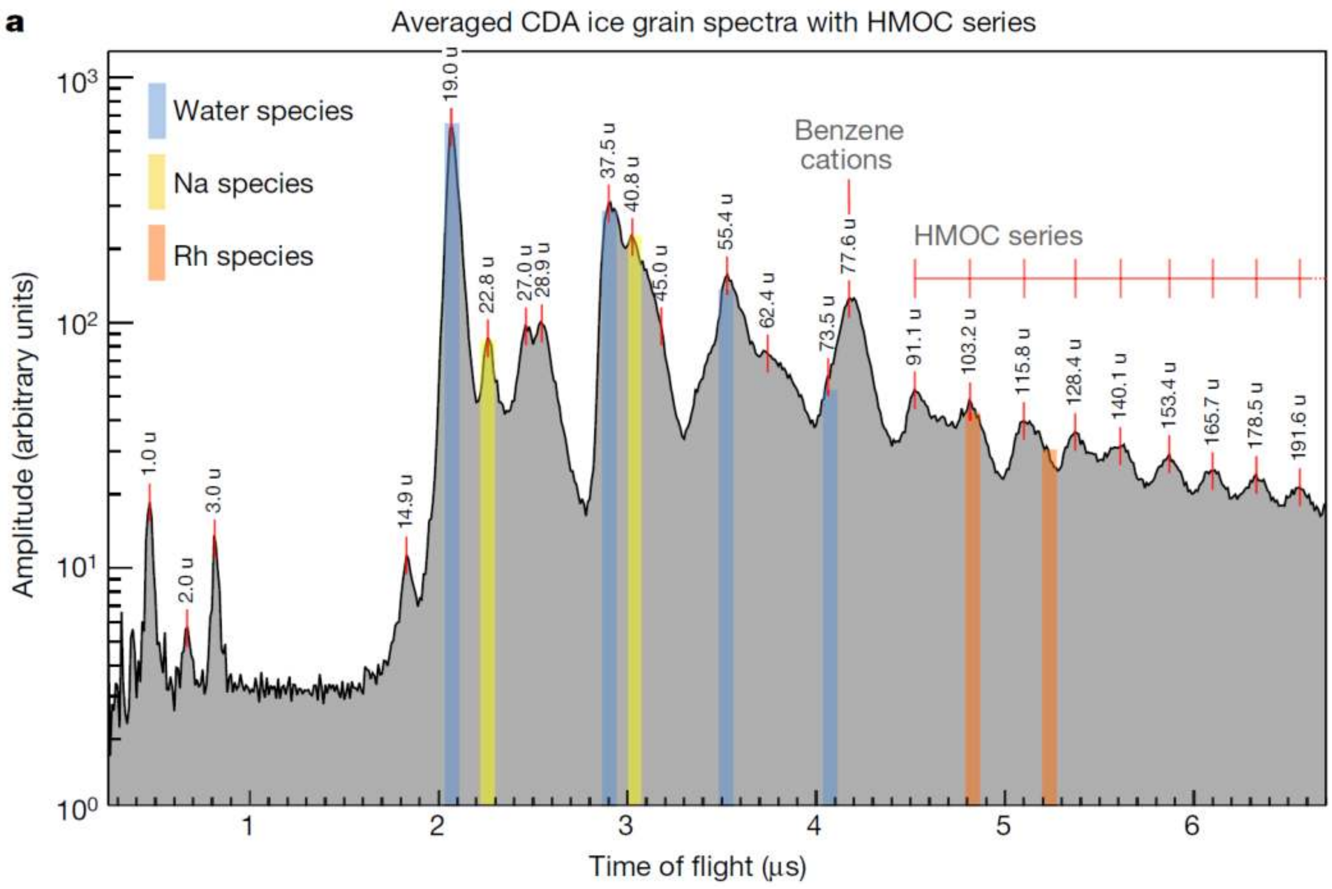
Gas component

- H_2O, CO_2, CH_4, NH_3, and H_2
- Heavier hydrocarbons
- Simple and complex organics

Constituent	**Mixing ratio (%)**
H_2O	96 to 99
CO_2	0.3 to 0.8
CH_4	0.1 to 0.3
NH_3	0.4 to 1.3
H_2	0.4 to 1.4

Waite et al. (2009) Nature 460, 487-490.
Waite et al. (2017) Science 356, 155-159.

Plume composition –Solid



Grain component

- Water-ice
- Salts (mostly NaCl)
- <u>High mass organic cations (HMOC)</u>

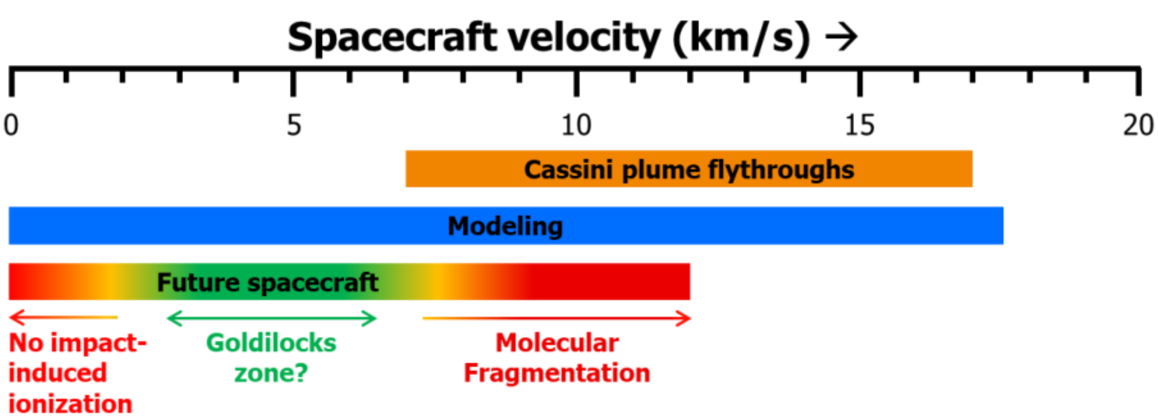
Average grain size:
0.6 µm

Postberg et al. (2009) Nature, 459, 1098-1101.
Postberg et al. (2018) Nature, 558, 564-568.

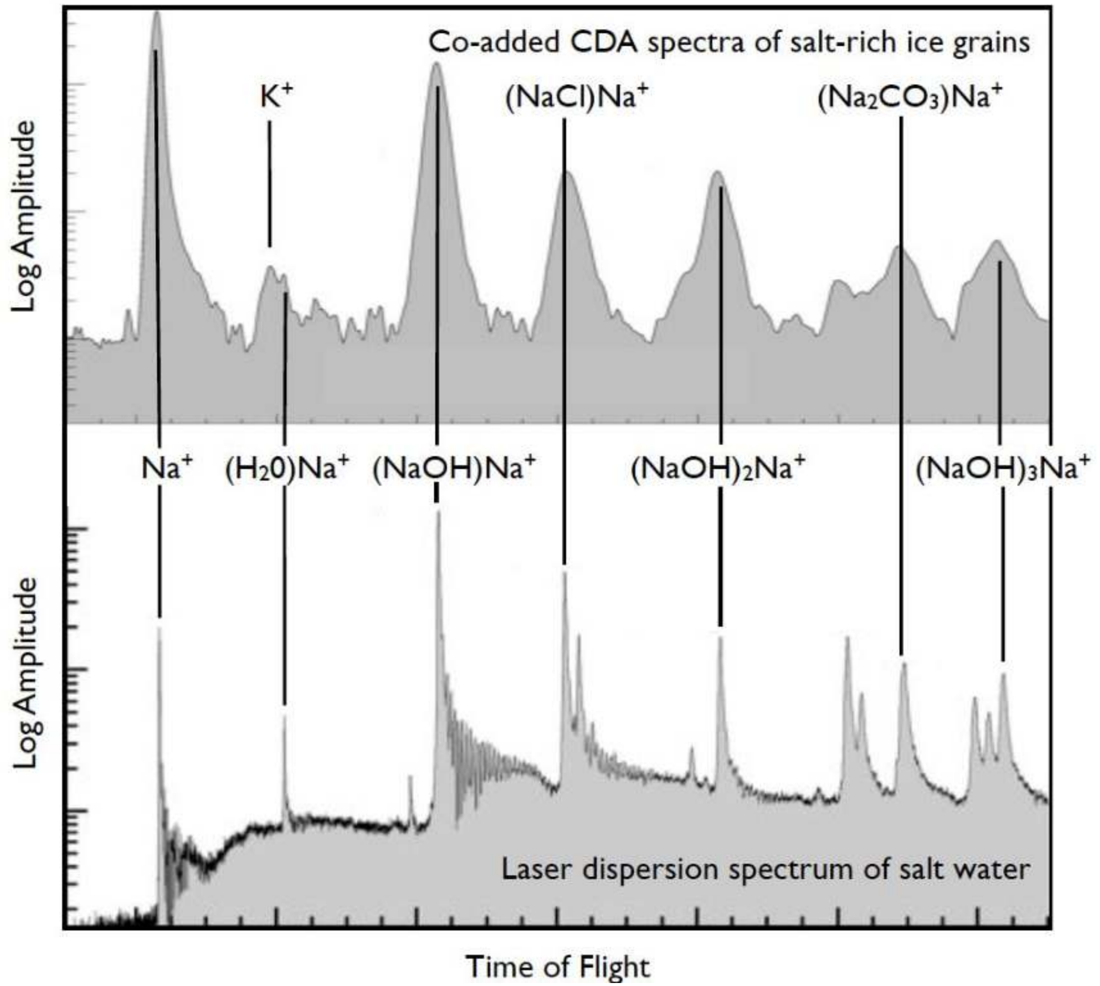
The trouble with plumes…

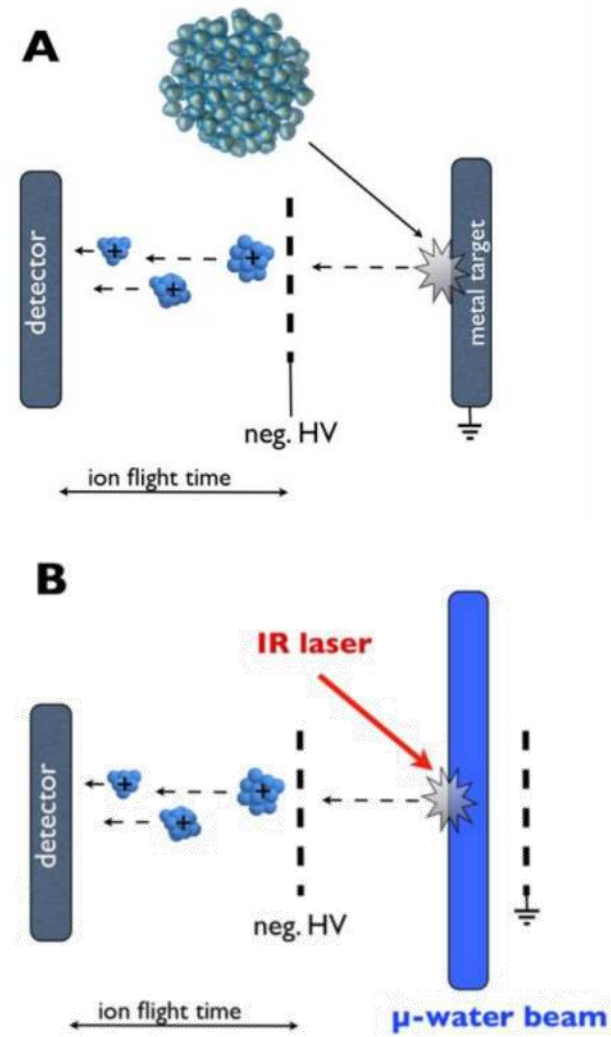
- Hypervelocity sampling (>1 km/s)
- At what velocity will molecules volatilize or fragment?
- Test with laboratory measurements
    - Accelerate *intact* molecules/ice grains
    - Impact those species and analyze with mass spectrometry


Image: wikipedia.org/wiki/Hypervelocity



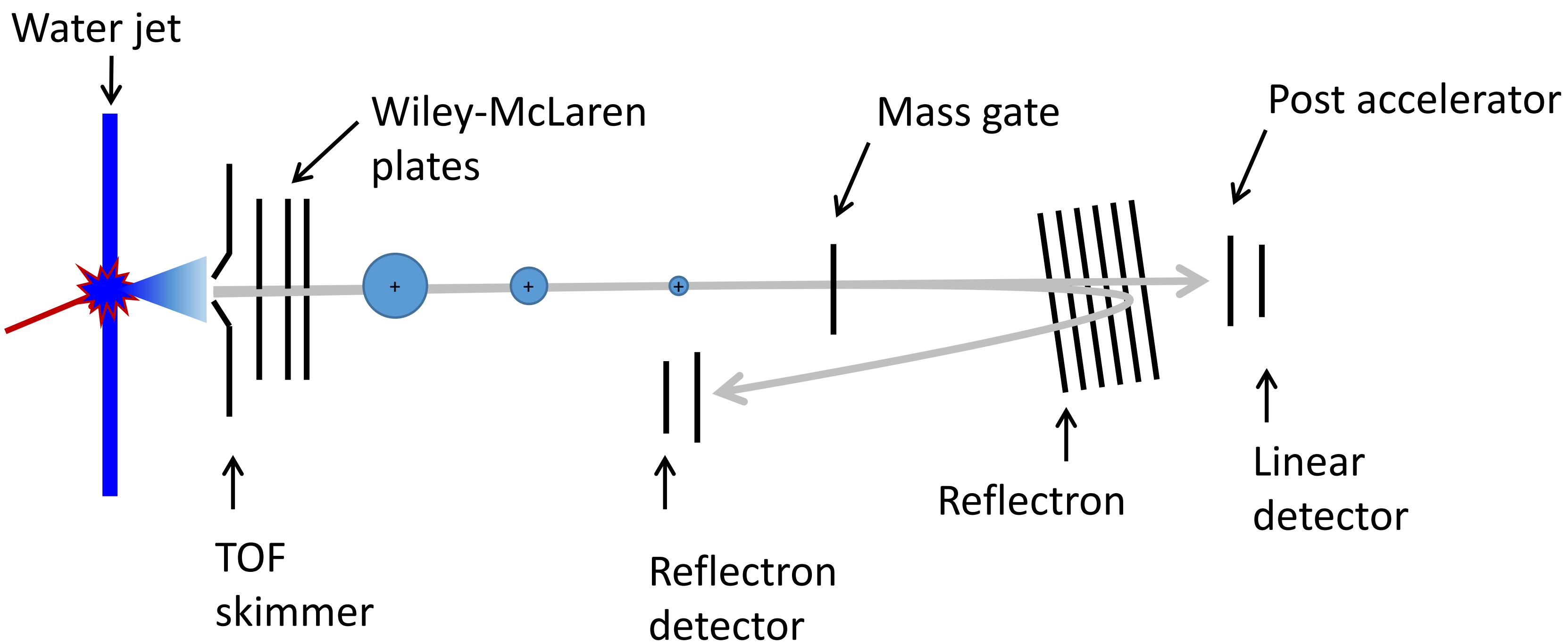
Reproducing CDA's Data





Postberg et al. (2009) Nature, 459, 1098-1101.
Beinsen, (2008)

Hypervelocity Ice Grain System



- Generates ice grains, hydrated clusters, and bare ions that travel at hypervelocity
    - Laser-induced ion desorption (LID) source
    - Time-of-flight (TOF) mass spectrometry

- Currently measuring LID product velocities

Hypervelocity Ice Grain System

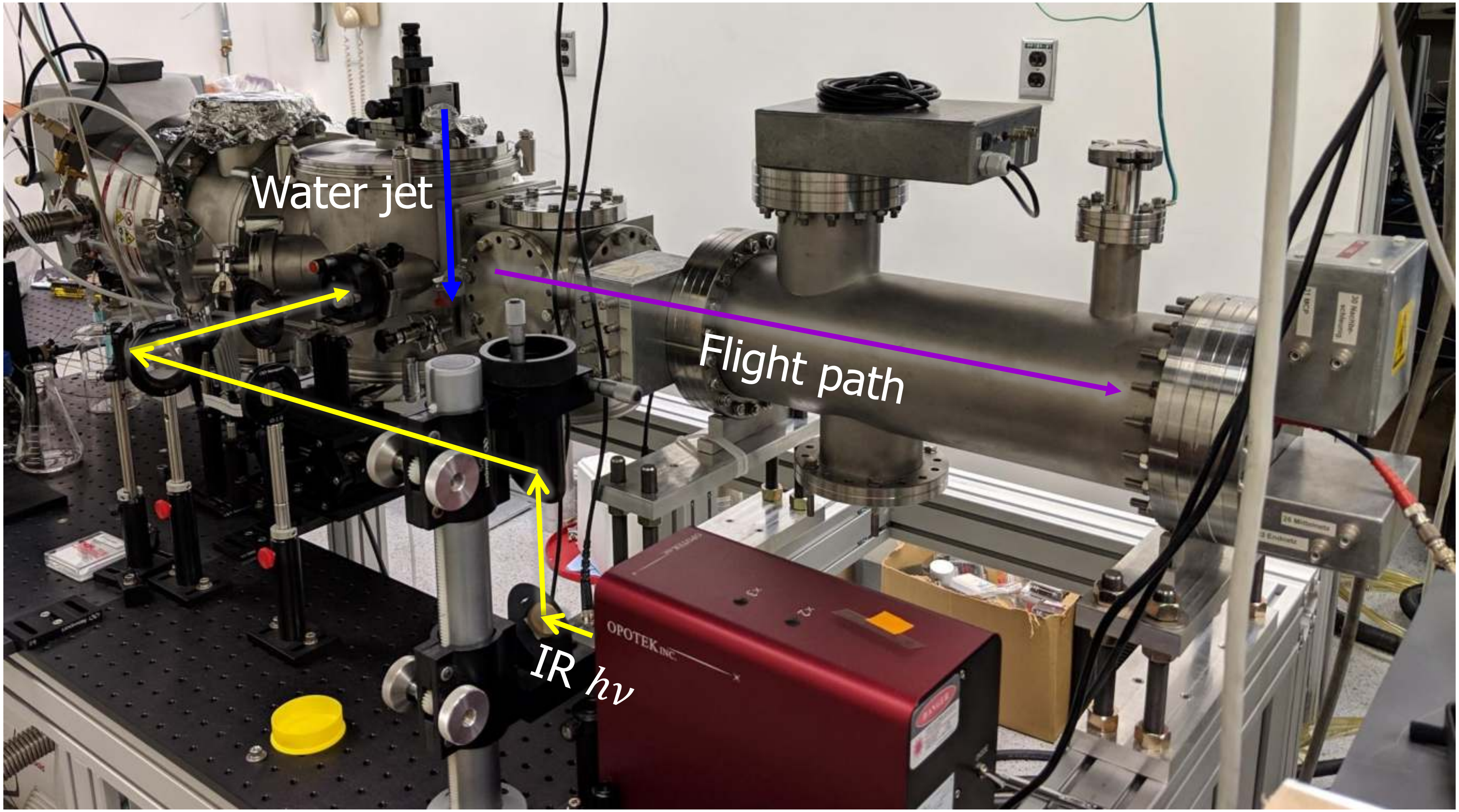
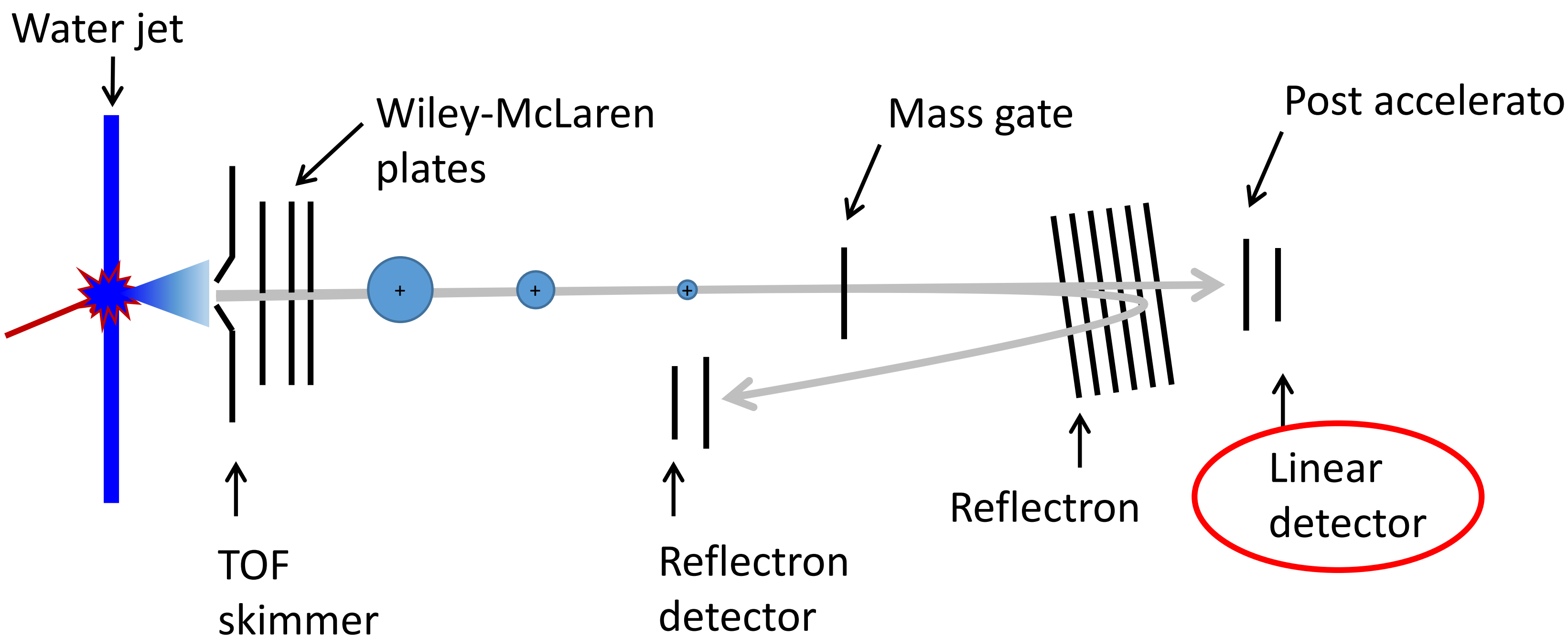


Image: Waller

Hypervelocity Ice Grain System



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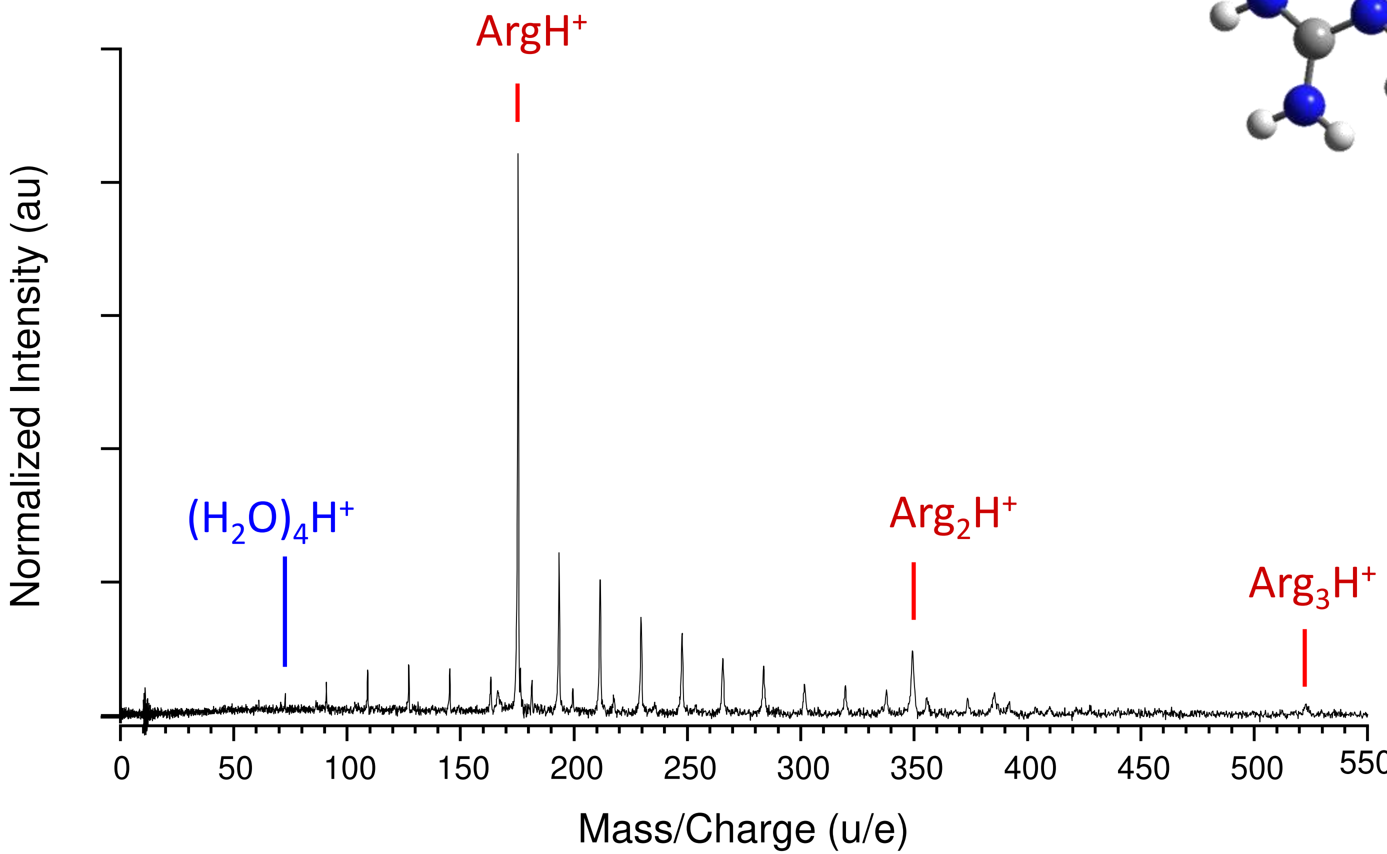
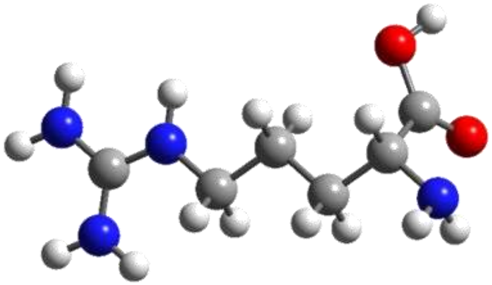
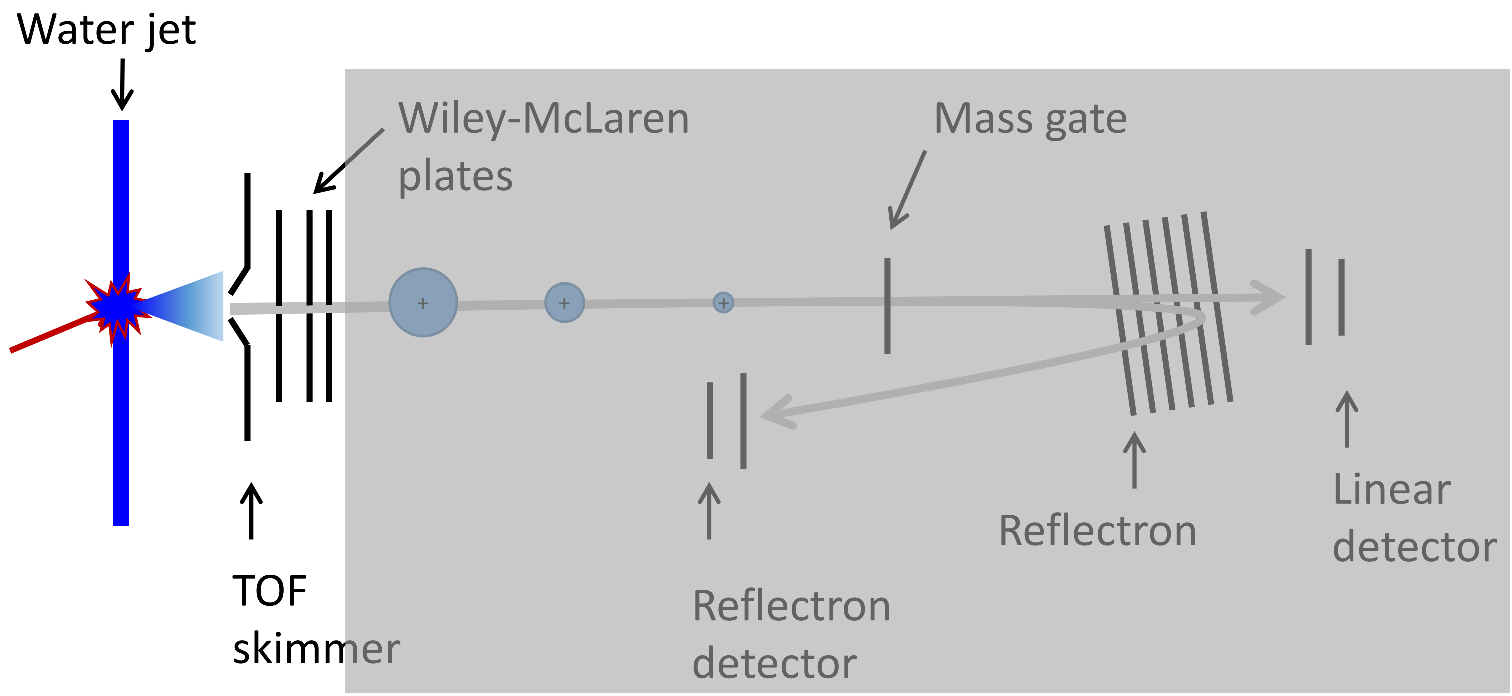
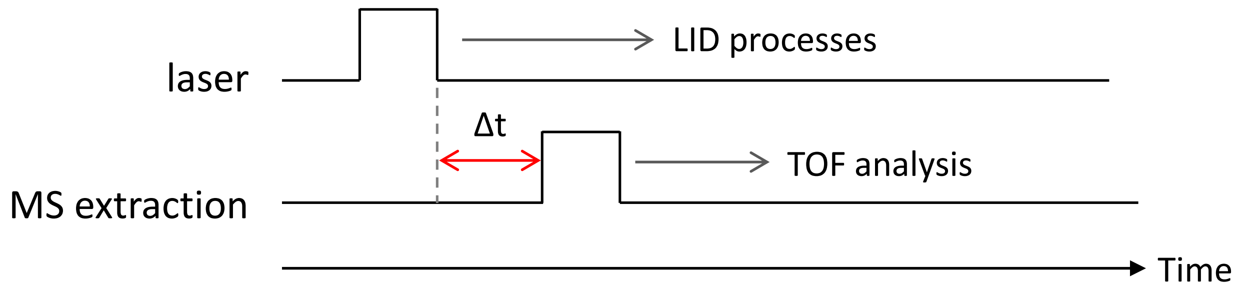
10mM Arginine



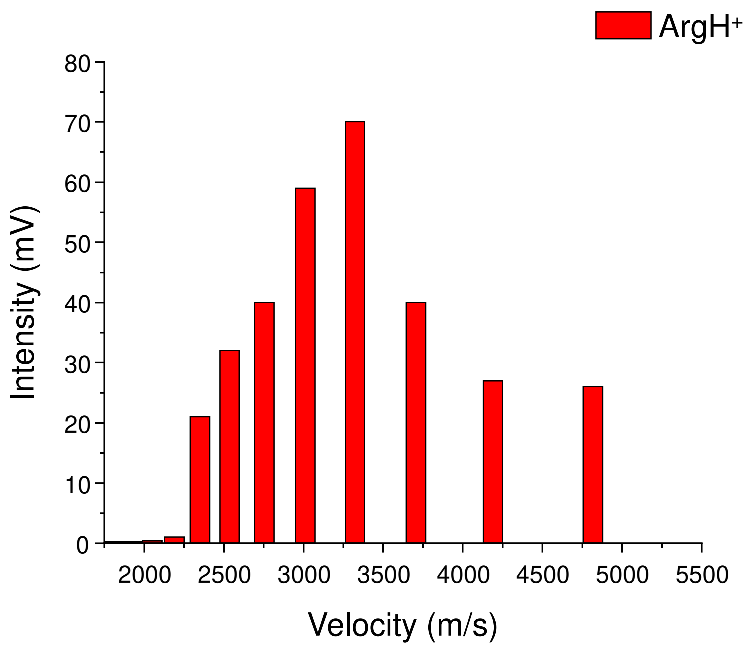


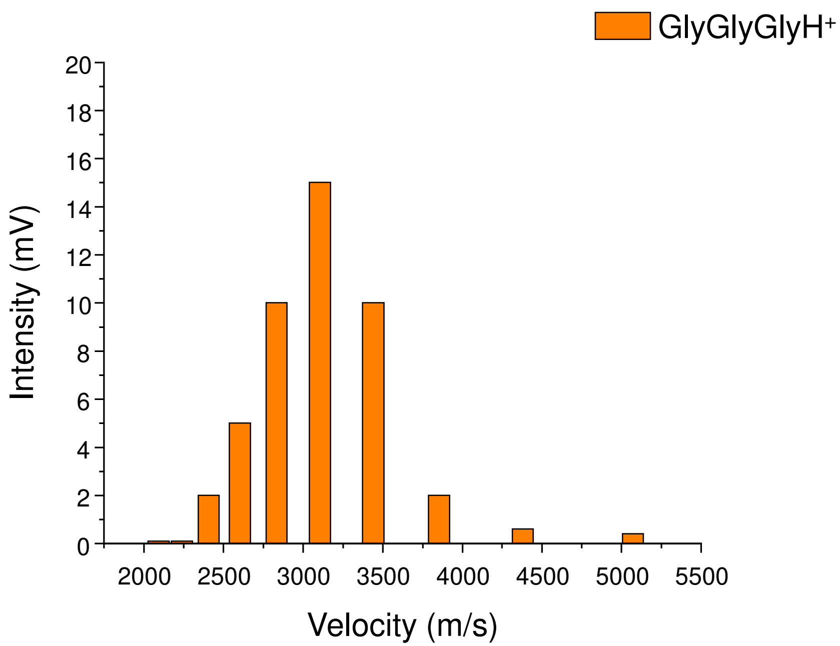
Ion velocities





Ion velocities –Small organics





- These are LID velocity distributions collected by monitoring a specific ion in the mass spectrum while varying the delay between the laser and the MS analysis trigger

Ion velocities –better LID

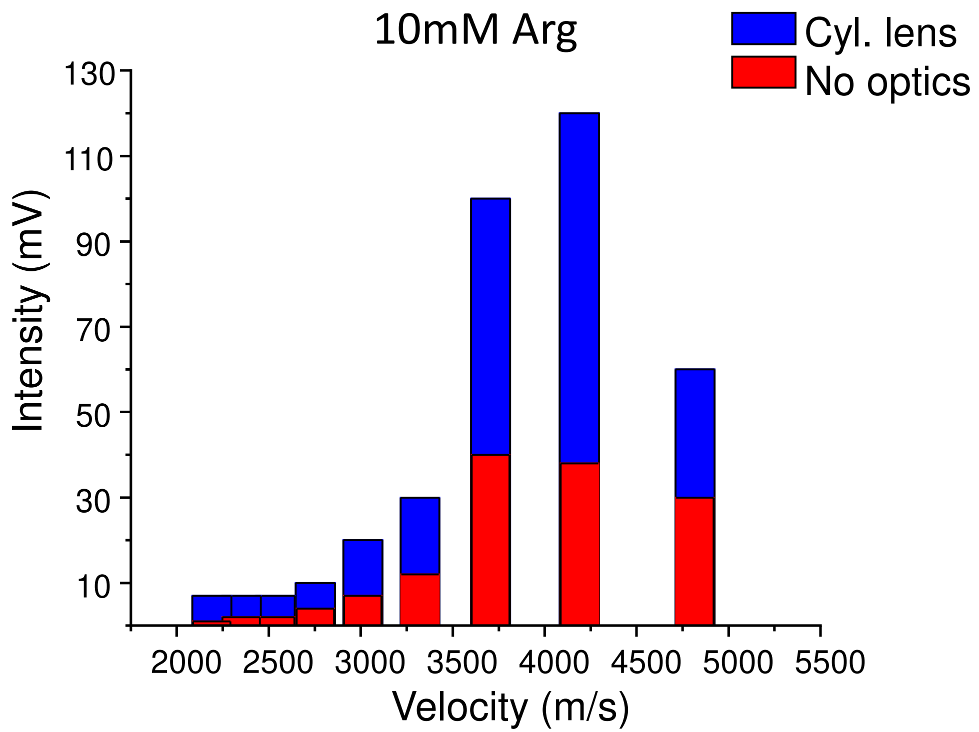


Image: Waller

- Changing the laser shape yields *more* ions, not faster/slower ions

Ion velocities –better LID

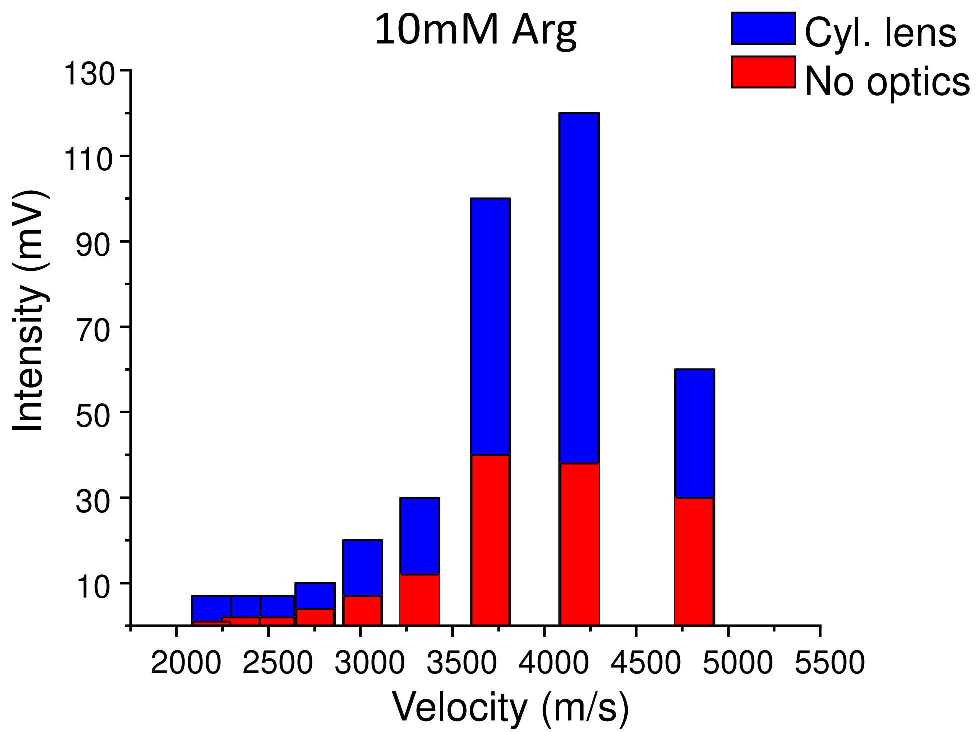


Image: Waller

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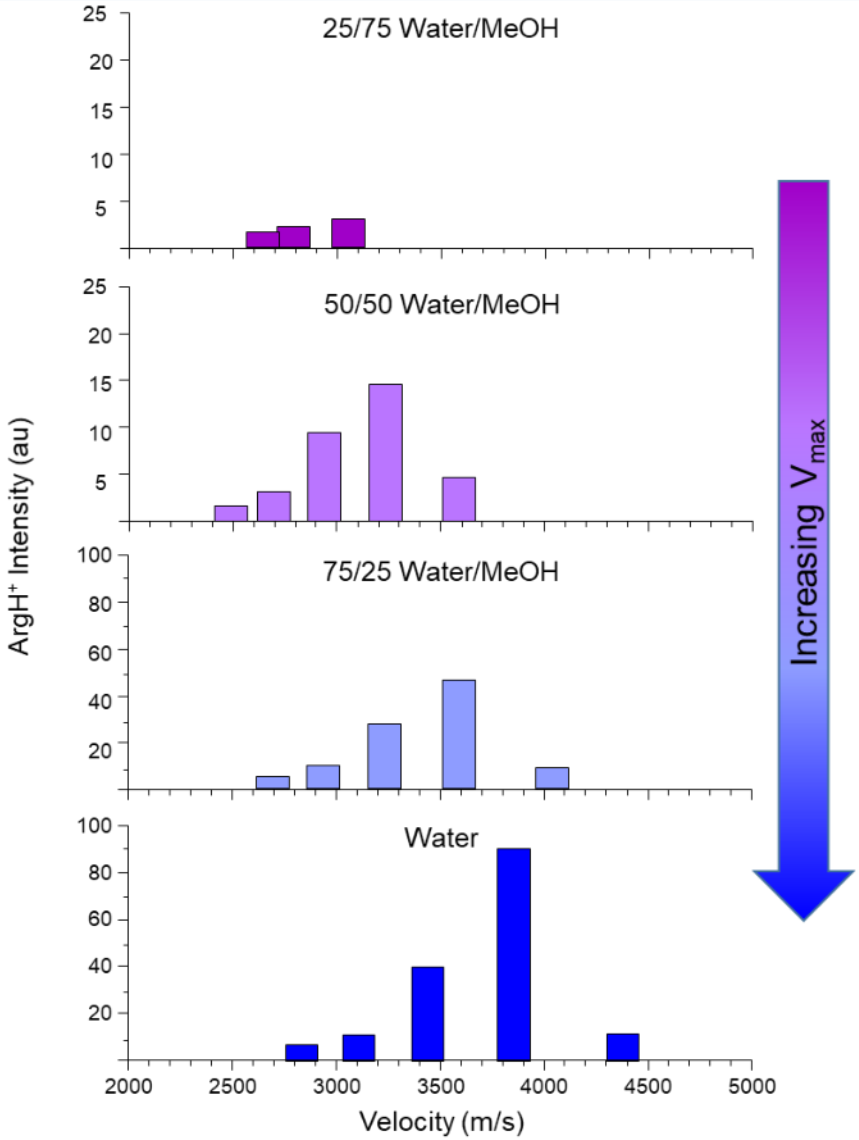
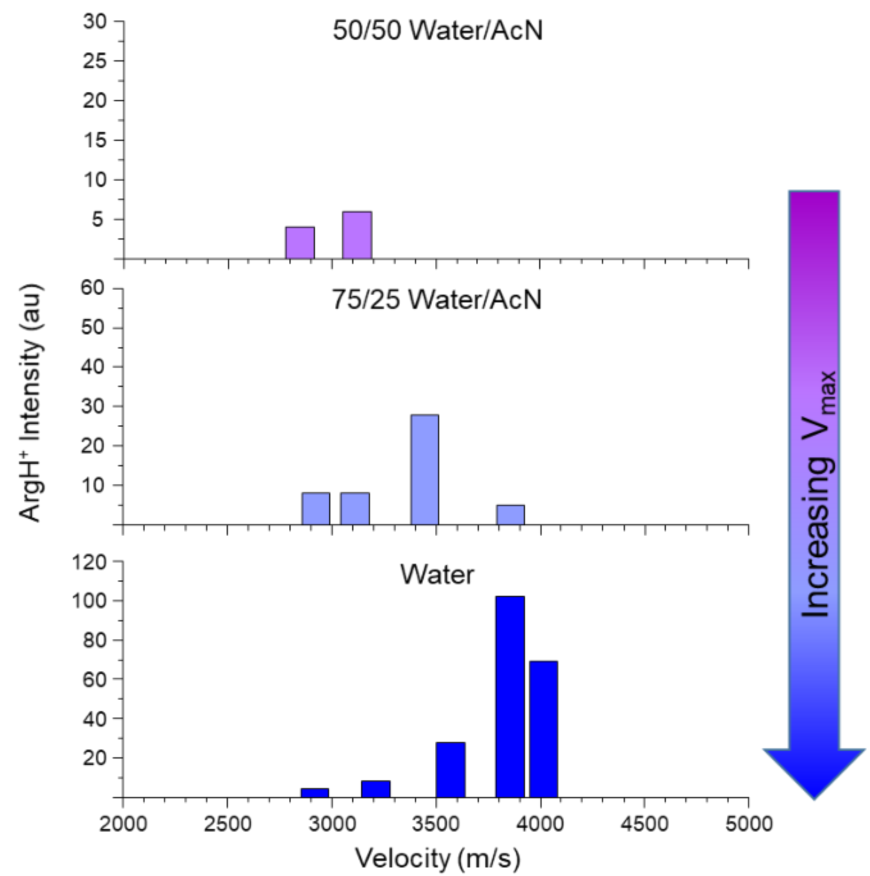
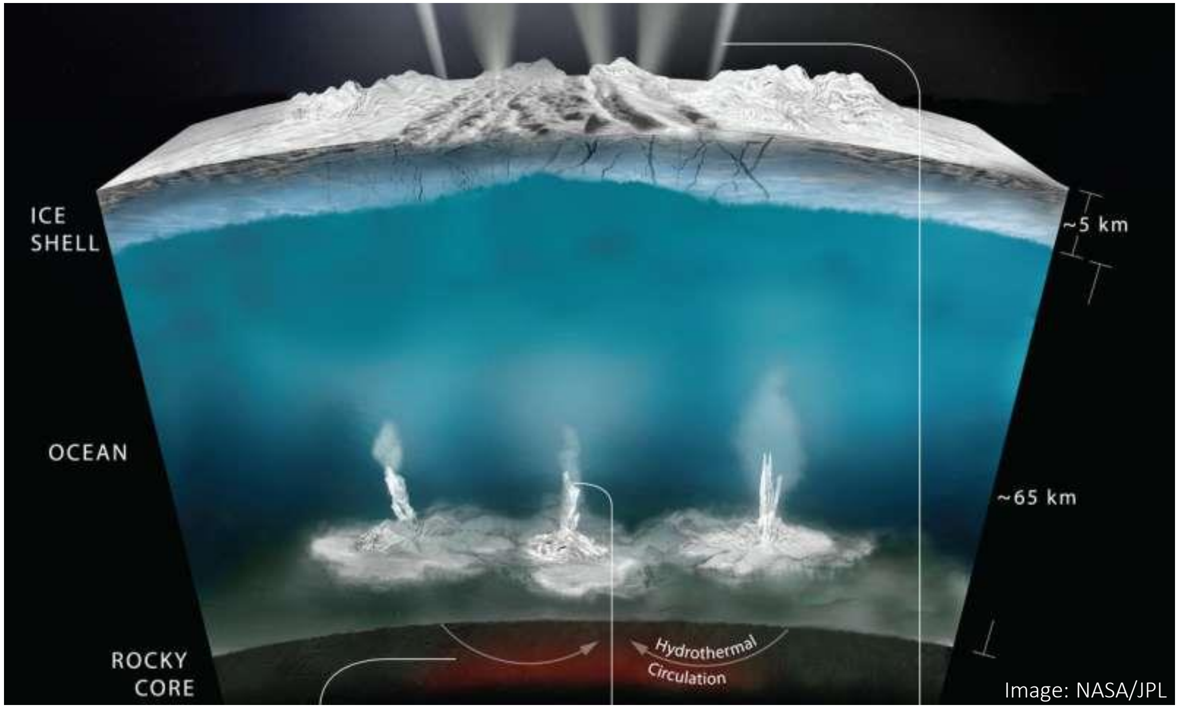
Controlling ion velocities



The solvent does impact the LID velocity distribution!



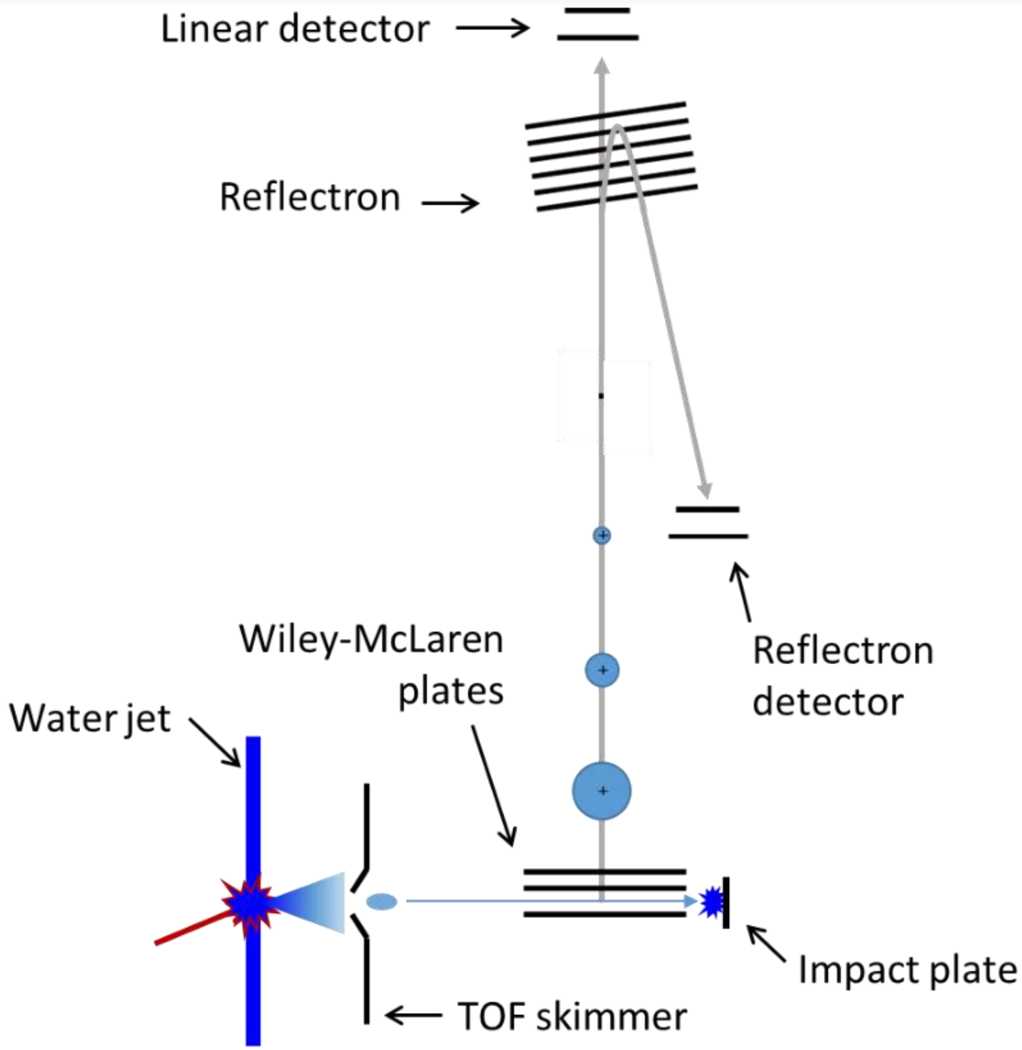
Upcoming experiments



- Enceladus brines
  - NaCl, KCl
- Enceladus pH's (8.5-11)
  - $NaHCO_3$, Na_2CO_3
- Cation & Anion distributions
- In-source charge detector

Glein et al. (2015) *Geochim. Et Cosmo. Acta*, 162, 202-219.
Postberg et al. (2009) Nature, 459, 1098-1101.
Glein et al. (2018) "The Geochemistry of Enceladus: Composition and Controls" in *Enceladus and the Icy Moons of Saturn*, Eds. P.M. Schenck, et al., pp. 39-56.

Upcoming modifications



These mods will allow us to investigate post-impact MS distributions

Conclusions

Image: NASA/JPL

- Generate lab-based analogs to hypervelocity ice grains
- Study MS distributions after hypervelocity impacts
- Determine Goldilocks zone thresholds
- Ease mass spectral analysis of Enceladus' plume

Acknowledgements

Hypervelocity Sampling Team:

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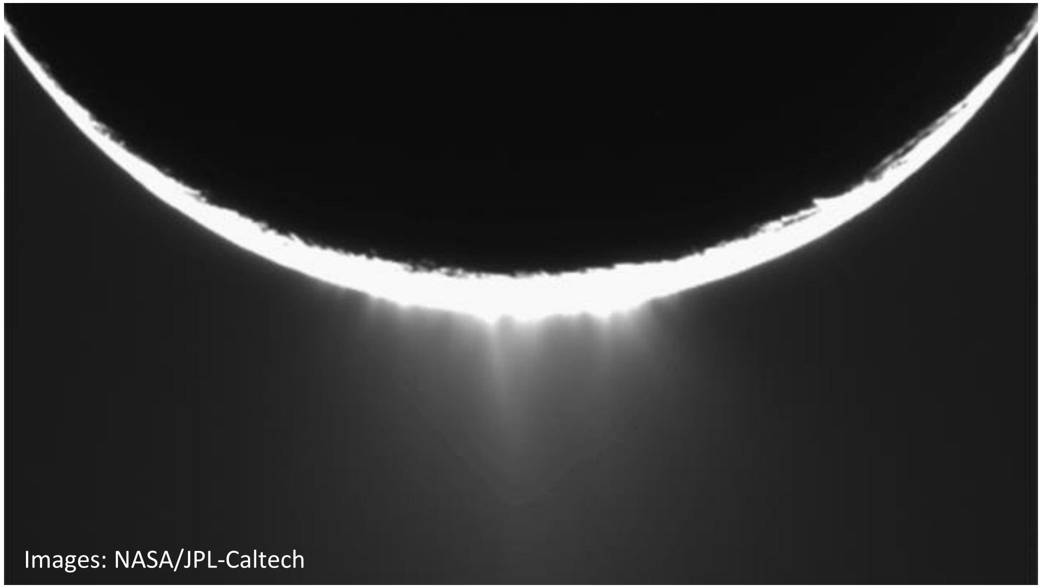
Morgan Miller
Steve Fuerstenau


Images: NASA/JPL-Caltech

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