Hypervelocity Sampling Across the Solar System

Retiring Risks for Enceladus, Europa, Titan and Venus

Principal Investigator: Morgan L. Cable (322)

Co-Investigators: J. Rabinovitch (352), A. Hofmann (322), R. Hodyss (322), M. Malaska (322), S. Waller (353), A. Belousov (389), N. Tallarida (389), J. Lambert (389), S. Madzunkov (389), M. Darrach (389)

External Collaborators: A. Jaramillo-Botero (Caltech), R. Continetti (UCSD), T. Minton (MSU), M. Gallis (Sandia), A. Borner (NASA ARC)

Program: Strategic Initiative

Project Objective:

The goal of this initiative is to determine whether current hypervelocity sampling strategies are able to analyze samples from planetary **atmospheres** and **plumes** during fast flyby/flythrough encounters, without introducing significant fractionation or fragmentation errors that would compromise subsequent sample measurements. **Basically, if you sample gas or ice grains at > 1 km/s, can you accurately determine the original composition?** The project is divided into three subtasks focused on retiring hypervelocity sampling risks for a specific environment: Enceladus/Europa plume, Titan atmosphere, and Venus atmosphere. For each, we leverage both experimental (laboratory) and theoretical (modeling) work.

Benefits to NASA and JPL:

Enceladus/Europa. Our results will be fed directly into the next JPL-led mission proposal for Enceladus in New Frontiers 5, as we are providing scientific underpinning to justify the plume flythrough velocity and expected limits of detection for biosignature molecules (amino acids and fatty acids) at that velocity.

Titan. We have identified fragmentation pathways that could lead to misinterpretation of mass spectra collected in the Titan atmosphere at hypervelocity. This will be critical for any future Titan mission sampling the atmosphere at velocities >2 km/s.

Venus. This work is demonstrating that 2D and 3D simulations can quantify gas fractionation expected in a Cupid's Arrow type sampling system at 10.5 km/s. This powerful capability will ensure that any future Venus missions that include a hypervelocity sampling component will be able reliably determine the real atmospheric noble gas isotope ratios based on sampled gases.

Enceladus/Europa FY19 Results:

Experimental

Hypervelocity Ice Grain System (HIGS) at JPL: We have generated ions and clusters at velocities > 3 km/s. Currently working to characterize the larger ice grains produced.

Aerosol Impact Spectrometer (AIS) at UCSD: We have accelerated ice grains at velocities > 1 km/s. Now upgrading the system to reach 5 km/s.

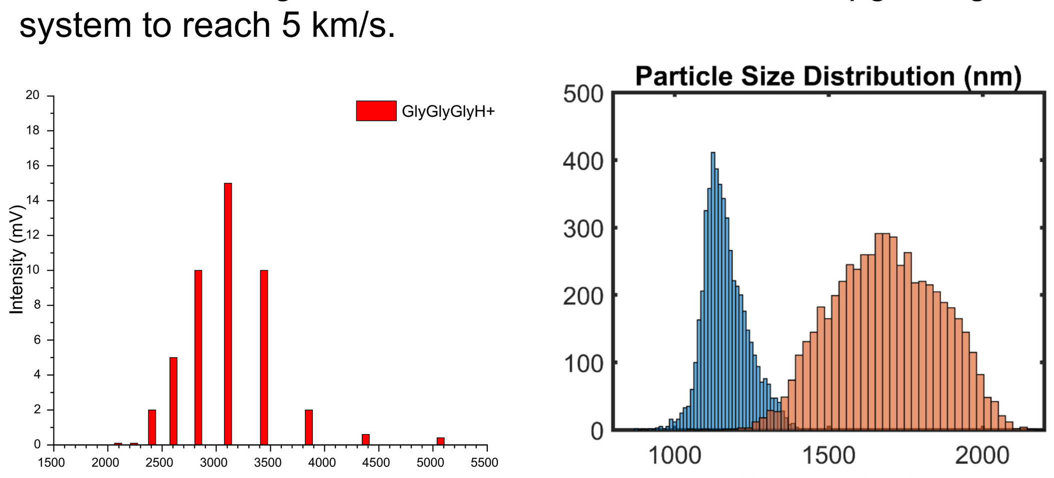


Figure 1. Velocity distribution of a polypeptide (tri-glycine) accelerated with HIGS (left). Ice grain size distributions generated using AIS (right).

Modeling

We used a first-principles quantum mechanics based reactive molecular dynamics (RMD) approach at Caltech to simulate hypervelocity impact of organic molecules. For most, 50% fragmentation occurred at 5 km/s. We are repeating this with the organics embedded in water ice grains.

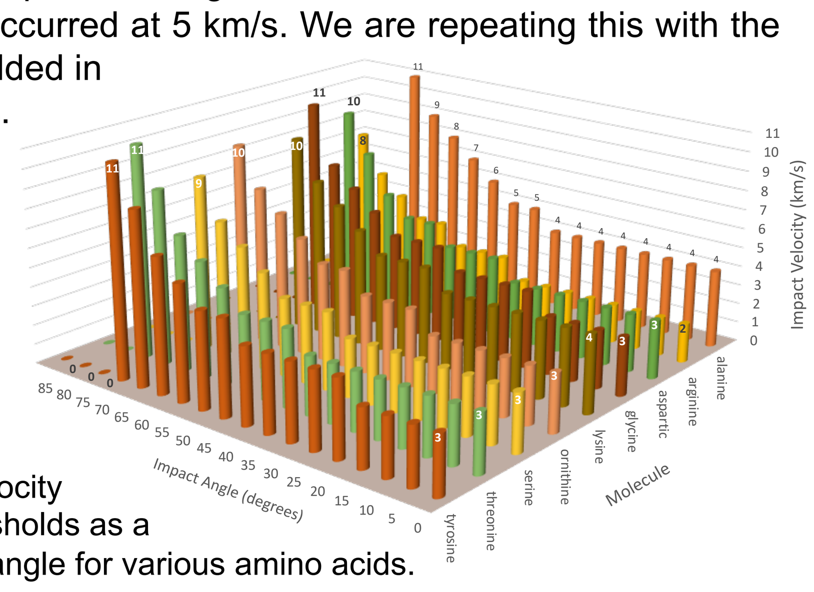


Figure 2. Hypervelocity fragmentation thresholds as a function of impact angle for various amino acids.

Titan FY19 Results:

Experimental

We accelerated naphthalene, 2-octanone, and 1,3-dicyano-benzene (isobaric species at 128 u) in a molecular beam up to 2.9 km/s and impacted them against a surface. Greater fragmentation was observed when scattering more normal to the surface, indicating higher vibrational excitation.

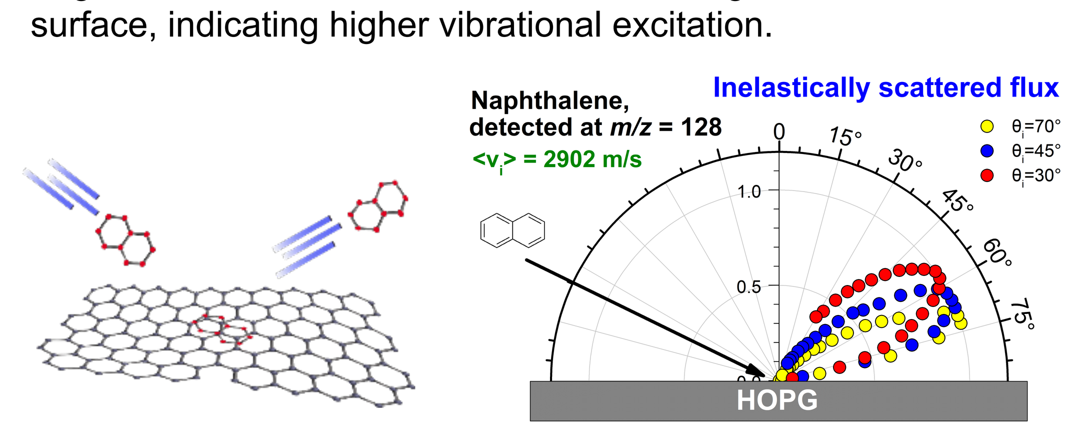


Figure 3. Angular distributions of inelastically scattered naphthalene, with an incident velocity of 2902 m/s, from a layered graphene surface, for different angles of incidence (θ_i) with respect to the surface normal.

Modeling

RMD simulations at Caltech of the same isobaric molecules produced mass spectra consistent with experimental results. Fragmentation thresholds and pathways were also predicted as a function of velocity, impact angle and landing orientation.

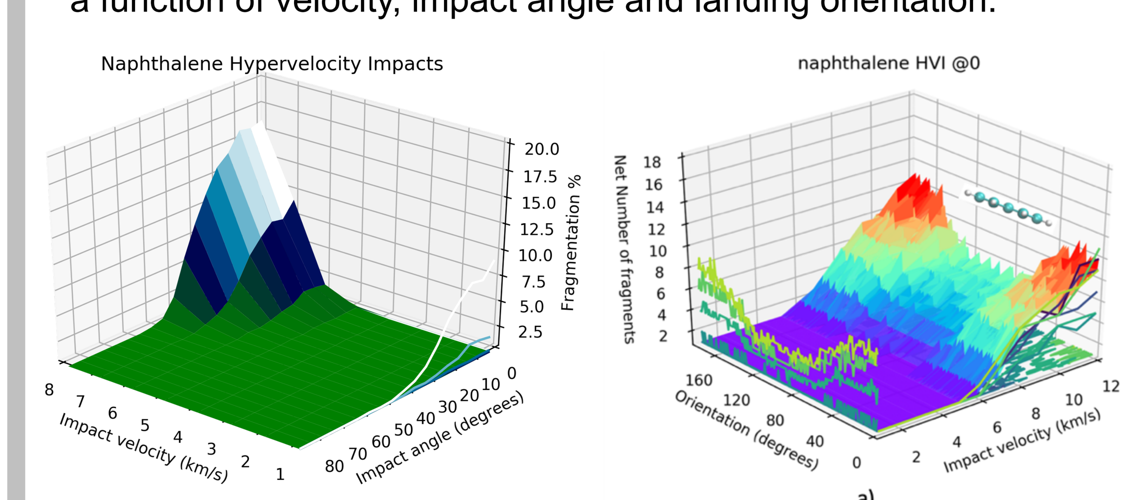


Figure 4. Hypervelocity impact heat maps for naphthalene as a function of impact angle (left) and molecule landing orientation (right).

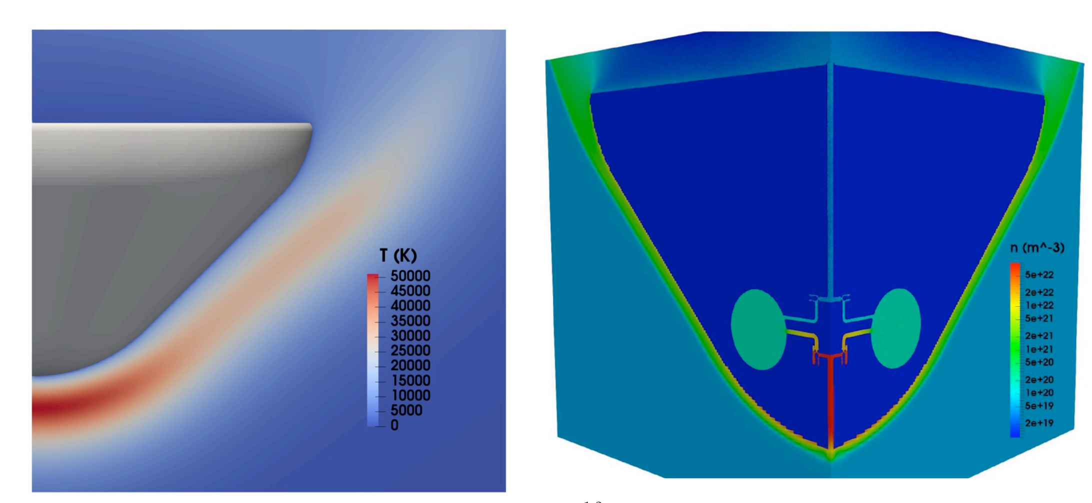
Venus FY19 Results:

Experimental

ArcJet experiments are planned in the third year of this effort.

Modeling

Computational fluid dynamics (CFD) simulations were performed using the SPARTA computational framework at Sandia. These efforts are focused specifically on the Cupid's Arrow concept (which would sample the Venus atmosphere at 10.5 km/s), and include either a 2D or 3D representation of that mission's sample inlet and gas storage tank. Preliminary results show that while there is no significant isotopic fraction for Xe or Ar isotopes, the total ratio of Ar to Xe does change from the Venus atmosphere to the gas captured in the sampling tanks. Currently we are working to quantify the expected error of the simulations to ensure that the Cupid's Arrow Science Objectives can still be achieved.



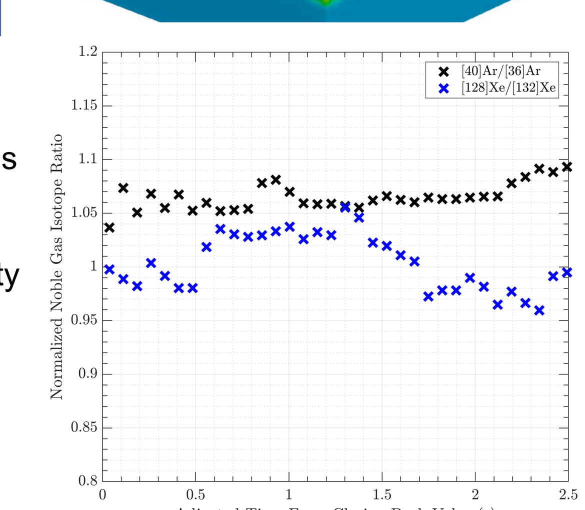


Figure 5. Translational temperature contours for a 2D-axisymmetric simulation of Cupid's Arrow (top left). Preliminary 3D simulation results (top right), with colors showing the number density (number/m³) of molecules in the Venus atmosphere as they flow around the spacecraft and enter the atmospheric sampling inlet. Preliminary gas ratio predictions for argon and xenon (lower right).

Papers:

Waller S. E., Belousov A., Kidd R. D., Nikolic D., Madzunkov, S. M., Wiley, J. S., Darrach, M. R. (2019) Chemical ionization mass spectrometry: Applications for the in situ measurement of nonvolatile organics at ocean worlds. *Astrobiology*, 19 (10), 1-15.

Conference Proceedings:

- Rabinovitch, J., Sotin, C., Borner, A., Gallis, M. A., et al. (2018) Feasibility of Hypervelocity Sampling of Noble Gases in the Upper Atmosphere of Venus. 16th VEXAG Meeting, 6-8 Nov 2018, Laurel, MD. LPI Contribution No. 2137, ID 8022.
- Sotin C., Borner A. P., Gallis M. A., Rabinovitch J., Avice G., Darrach M., Madzunkov S., et al. (2018) Sampling Venus' atmosphere to measure noble gases and their isotope ratios, AGU Fall Meeting, 10-14 Dec 2018, Washington, D. C.
- Baker J., Sotin C., Rabinovitch J. (2019) Cupid's Arrow: Mission Concept and Overview, 13th IAA Low-Cost Planetary Missions Conference, 3-5 Jun 2019, Toulouse, France.
- Rabinovitch J., Borner A., Gallis M. A., Sotin, C. (2019) Hypervelocity Noble Gas Sampling in the Upper Atmosphere of Venus. AIAA Aviation 2019 Forum, 17-21 Jun 2019, Dallas, TX.
- Jaramillo-Botero A., Cable M., Hofmann A., Malaska M., Hodyss R. (2019) Hypervelocity impact-induced fragmentation for different amino/fatty acids of interest in Enceladus' plume. AbSciCon, 24-28 Jun 2019, Seattle, WA.
- Waller S., Belousov A., Wiley J. S., Tallarida N. R., Madzunkov S. M., Darrach M. R., Lambert J. L., et al. (2019) Towards Measuring Enceladus' Plume Constituents at Hypervelocity. AbSciCon, 24-28 Jun 2019, Seattle, WA.
- Xu C., Treadway C., Minton, T. K. (2019) Scattering Dynamics of Naphthalene on Highly Oriented Pyrolytic Graphite. Dynamics of Molecular Collisions XXVII, 7-12 July 2019, Big Sky, MT.
- Rabinovitch J., Borner A., Gallis M. A., Sotin C., Baker J. (2019) Cupid's Arrow: Hypervelocity Noble Gas Sampling in the Upper Atmosphere of Venus, International Planetary Probe Workshop 2019, 8-12 Jul 2019, Oxford, UK.
- Sotin C., Borner A., Gallis M., Rabinovitch J., et al. (2019) Modelling the performance of Cupid's Arrow, a small satellite that would measure noble gases in Venus atmosphere, EPSC-DPS Joint Meeting, 15-20 Sept 2019, Geneva, Switzerland.
- Borner A., Gallis M. A., Rabinovitch J., Sotin C. (2019) DSMC Simulations of Hypervelocity Sampling in Venus' Upper Atmosphere, DSMC 2019 Conference, 22-25 Sept 2019, Santa Fe, NM.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Abbreviations: AIS, Aerosol Impact Spectrometer; CFD, computational fluid dynamics; HIGS, Hypervelocity Ice Grain System; HOPG, highly ordered pyrolytic graphite; RMD, reactive molecular dynamics; VEXAG, Venus Exploration Analysis Group.

PI/Task Mgr. Contact Information:

Email: Morgan.L.Cable@jpl.nasa.gov
Phone: (818) 354-2126

www.nasa.gov

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