Using the cryogenic impact ionization target at the University of Colorado dust accelerator, ices with complex organics or specified isotopic ratios can be created. These ices are then bombarded with hypervelocity dust and the ejecta plume is sampled with time-of-flight (TOF) mass spectrometry. Such analysis can be used to determine what types of chemistry can be measured by impact ionization TOF instruments on flyby spacecraft. Amino acids are of particular importance for habitability assessments, and it is therefore necessary to understand if and how such organic molecules fragment during impact ionization, if there is some critical flyby velocity beyond which fragmentation increases dramatically, and if and how the presence of water ice reduces fragmentation rates.

Experiment 1

The water is pump out, freeze-drying the ice and leaving a surface of pure amino acid.

Experiment 2

Water ice is vapor deposited onto a freeze-dried surface to create an amino acid under a 60 nm ice layer.

Water clusters (blue dotted lines)

Experiment 1: Bare Histidine

Experiment 2: Histidine under 60 nm Water Ice

Using water clusters (as indicated by blue dotted lines), the high velocity datasets show increases beyond 7 km/s. At higher velocities, the increased kinetic energy of the impacting iron dust particle creates more fragmentation, and the breakup products begin to dominate over the parent molecule.

High velocity summed spectra for Experiment 2 (where the amino acid was shielded by 60 nm of water ice) is shown in blue. Here, fragmentation is dramatically reduced compared to the high velocity Experiment 1 data. This can be most easily seen by comparing the strength of the mass 110 breakup product and the parent molecule for the two high velocity summed spectra.

Quantitatively, this can be observed by plotting the ratio of the ion yield from all breakup products to the ion yield of the parent molecule as a function of impactor velocity, shown below. Dotted lines show linear fits to the lowest three velocity bins, from 3-6 km/s. Solid lines show linear fits to the higher velocity bins.

Results and Discussion

Summed spectra from Experiment 1 (bare histidine) are shown in purple for low velocity (3-4 km/s) and high velocity (14-15 km/s) data in the center column. At low velocity the parent histidine molecule dominates the spectrum, but fragmentation products can be seen, most notably at masses 81-83 and at mass 110. At higher velocities, the increased kinetic energy of the impacting iron dust particle creates more fragmentation, and the breakup products begin to dominate over the parent molecule.

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Note that below 6 km/s, the fragmentation rates are largely flat, but they rise dramatically beyond 7 km/s. It can also be seen that the presence of the water ice layer significantly reduces the fragmentation rates at higher velocity.

The convergence of the fitted lines for the low and high velocity regimes can be used as an estimate for the critical breakup velocity. In Experiment 1, this occurs at 6.1 km/s. In Experiment 2, an outlier data point at 7-8 km/s complicates this, but the critical velocity is between 7.1 and 8.5 km/s (depending on whether one accepts or rejects that data point). The major results can thus be summarized:

- Amino acids can be detected by impact ionization TOF
- Fragmentation increases dramatically beyond 6 km/s for bare histidine and 7 km/s for histidine under 60 nm of water ice
- Water ice significantly reduces fragmentation rates at higher velocities