IMPACT-IONIZATION MASS SPECTROMETRY OF COSMIC DUST

Thesis by

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A primary segment of my thesis research was conducted on the van de Graaff dust accelerator at Concordia College, Moorhead, Minnesota. While many other microparticle accelerators from the 1960’s have long since been disassembled, the faculty at Concordia have carefully maintained this instrument in working condition. It is the only functional dust accelerator in the Western Hemisphere, and my research would have been much more complicated had it been necessary to go overseas for fast dust. I am grateful to Carl Bailey and Heidi Manning, both of the Concordia Physics faculty, for hosting my research visit, running the accelerator, and helping solve every problem that arose. I also thank Jim Farnsworth, an undergraduate physics student, who spent many days and evenings recording particle velocities in my lab notebook.

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while I was having fun in the lab shooting lasers or small projectiles at things and calling it “work.”

Abstract

In situ characterization of cosmic dust grains typically involves impact-ionization time-of-flight mass spectrometry. Considering the performance and limitations of previous instruments, I designed and tested a novel, compact time-of-flight mass spectrometer for cosmic dust analysis. The instrument, Dustbuster, incorporates a large target area with a reflectron, simultaneously optimizing mass resolution, particle detection, and ion collection. Dust particles hit the 65-cm^2 target plate and are partially ionized by the impact. The resulting ions, with broad energy and angular distributions, are accelerated through the modified reflectron, focusing ions spatially and temporally to produce high-resolution spectra.

Initial performance tests of the Dustbuster used laser desorption ionization of embedded metal and mineral samples to simulate particle impacts. Mass resolution (mass/peakwidth) in these experiments ranged from 60 to 180, permitting resolution of isotopes. Subsequent experiments included hypervelocity microparticle impacts. Charged iron and copper microparticles, accelerated to 2-20 km/s in a 2 MV van de Graaff accelerator, impacted the Dustbuster. Mass resolution in these experiments ranged from 150 to 300 for iron and copper. Hydrogen, carbon, and oxygen ions appeared in many spectra. Field-induced emission of electrons immediately before impact is a possible cause of ion formation from species with high ionization potentials. The implications of this ionization effect are discussed in relation to interpretation of mass spectra from other *in situ* dust analyzers.

Another time-of-flight instrument, originally designed as an energy analyzer, shows promise as a high-resolution mass spectrometer for high-flux cosmic dust environments.

Ice is an important component of particulates ejected from comets and other icy bodies in the solar system. Due to limited experimental data on ice particle impacts, I built an ice particle source based on a vibrating orifice aerosol generator connected directly to vacuum. Ice particles produced in this manner can be electrostatically accelerated for impact ionization studies.

Hypervelocity impact vaporization may have played a key role in the mass extinction that occurred at the Cretaceous-Tertiary (K-T) boundary. In order to study the speciation of gases that may have been produced in such an asteroid impact, I designed a specialized orthogonal extraction mass spectrometer for future laboratory impact experiments.

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Appendix A

Abbreviations and Acronyms

AU	Astronomical unit
CDA	Cosmic Dust Analyzer
CIDA	Cometary and Interstellar Dust Analyzer
GORID	Geostationary ORbit Impact Detector
IR	infrared
MCP	microchannel plate ion detector
m/z	mass to charge ratio
PIA	Particulate Impact Analyzer
PUMA	Russian acronym for 'dust impact mass analyzer'
SIMS	secondary ion mass spectrometry
UV	ultraviolet
VOAG	vibrating orifice aerosol generator