

STEPS TOWARD AN INNOVATIVE ELECTROSPRAY-BASED PARTICLE SOURCE FOR DUST ACCELERATORS. ^{1,2}R. T. Daly, ¹J. D. Kerby, and ¹D. E. Austin, ¹Department of Chemistry and Biochemistry, Brigham Young University, C310 BNSN, Provo, UT 84602, austin@chem.byu.edu, ²Department of Geological Sciences, Brigham Young University, S389 ESC, Provo, UT, 84602, terikdaly@byu.edu.

Introduction: Cosmic dust contains clues to solar system history, bodies, and processes [1]. For example, the Stardust particles revealed much about the mineralogy and organic content of comets [2,3], and data from Cassini's Cosmic Dust Analyzer (CDA) are leading to a better understanding of Enceladus' plume [4].

Instruments like the CDA, called "*in situ* dust analyzers", have also flown on Stardust, Galileo, Ulysses, Giotto, and Vega-1/Vega-2 [5,6]. Each is slightly different [1], but many make use of the impact ionization of dust particles colliding with the instrument at hypervelocity speeds. The impact-generated ions are extracted by ion optics and analyzed via time-of-flight mass spectrometry (TOF-MS) [6].

Data from *in situ* dust analyzers are highly informative; however, correctly interpreting spectra from these instruments requires terrestrial calibration [6,7]. Both pulsed lasers [8] and dust accelerators [9,10] have been used for calibration experiments, but the latter better replicates hypervelocity microparticle impact [11]. Dust accelerators [7,12–15] electrostatically accelerate charged microparticles to tens of km/s. For calibration experiments, the accelerated particles impact a replica or flight spare of the dust analyzer, and the impact ionized species are extracted and analyzed [11].

Dust accelerators can only accelerate charged particles, and current dust accelerator particle sources can only charge electrically conductive projectiles [6,7]. However, many materials of interest, such as silicates and ices, are not conductive and cannot be used as projectiles in dust accelerators unless coated by a conductive material (e.g., certain metals and polymers) [6,7].

While the range of viable projectile materials has increased through the assiduous use of conductive coatings [e.g., 6,7], a particle source that removes the conductive projectile restriction would dramatically expand the range of possible projectile compositions. A dust source that charges ices would be a significant breakthrough because ices have not been successfully coated with conductive materials and are highly relevant to comet studies. In addition, the use of nonconductive projectiles could lead to better dust analyzer calibrations if pre-impact surface ionization [11] of the conductive coatings is significant.

Electrospray—A Widely Applicable Charging Method: We have previously reported [16–19] that electrospray, a method often used to charge large biomolecules [20], successfully charges uncoated quartz microparticles, along with methanol-water ices and

quartz-ice aggregates. We have now expanded our technique to include microparticles of olivine, olivine-ice aggregates, ordinary chondrite particles (Allan Hills A79045), and chondrite-ice aggregates [21].

Successful electrospray charging of these materials suggests that (1) electrospray should charge most, if not all, minerals because quartz and olivine represent the two types of surface charging behavior, (2) electrospray should charge a variety of rocky materials, such as stony meteorites, and (3) electrospray can charge ices of variable composition. Each particle type could be charged without the need for a conductive coating.

The Electrospray Process. Electrospray charges particles suspended in a solvent and introduces them into vacuum. A suspension containing the particles to be charged is slowly pumped through a hollow needle at a high DC voltage (e.g., 3000 V). The needle is ~1 cm away from a grounded orifice into vacuum. Due to the field between needle and orifice, as the suspension exits the needle it breaks into a plume of tiny, charged, solvent-encased particles. As the particles travel into and through vacuum, solvent evaporates from the particle. When the Coulombic forces on the solvent-encased particle exceed surface tension, the droplet breaks apart. The cycle of evaporation and Coulombic explosion continues until all that remains is a single, charged microparticle [20]. If desolvation remains unfinished, the result is a charged particle-ice aggregate.

How much charge is "charged"? The maximum charge an electrosprayed particle can carry is given by the Rayleigh limit q_{RY}

$$q_{RY} = 8\pi\sqrt{\epsilon_0\gamma r^3}$$

where ϵ_0 is the permittivity of vacuum, γ is solvent surface tension, and r is the droplet radius [20]. For a 1 μm particle in water, q_{RY} is 133,787 elementary charges. The Rayleigh limit q_{RY} increases with solvent surface tension. Thus, choosing a solvent with a higher surface tension allows a particle to accumulate greater charge; however, electrospray becomes more difficult as surface tension increases [20].

Acceleration of Electrospray-Charged Particles: Electrostatic acceleration of a charged particle is a function of its mass to charge ratio. The velocity of a particle of density ρ , charged to the Rayleigh limit, and accelerated through a potential difference V is

$$v = \sqrt{\frac{12V\sqrt{\epsilon_0\gamma r^3}}{\rho r^3}}$$

Figure 1 shows the speed of accelerated electro-spray-charged particles, as a function of size, for 100 kV and 3 MV potentials.

Coupling an Electro-spray Source to a Dust Accelerator: An electro-spray particle source differs from existing dust sources, and coupling an electro-spray source to a dust accelerator may be challenging. The source must be housed in the high voltage ball of the Van de Graaff generator, which is in vacuum. Although electro-spray is usually done at atmospheric pressure, it should be possible to electro-spray directly in vacuum. Differential pumping through a large potential difference would probably be more challenging.

Vacuum electro-spray has been successful with very viscous liquids, like ionic liquids [22] and glycerol [23]. While such viscous liquids would impart more charge to electro-sprayed particles, they are very hard to remove from the particles. This is problematic for producing bare mineral particles. One research group recently reported successful vacuum electro-spray of methanol-water mixtures through a heated capillary, with an infrared laser to aid desolvation [24]. This may be one solution to the challenge of vacuum electro-spray.

Other challenges associated with coupling an electro-spray source to a dust accelerator include electric discharge and bubbles in the suspension to be electro-sprayed. Electrical discharge could be minimized by careful counter electrode design and using a halogenated solvent [20]. Bubbles in the suspension could be mitigated by using a narrower needle [25] or sonicating [23] or degassing the suspension *in vacuo* prior to experiments [26]. Sonication or degassing is favored because a narrower needle increases the risk of needle clogs.

Conclusion: Electro-spray charges microparticles of minerals, ices, mineral-ice mixtures, stony meteorites, and stony meteorite-ice mixtures. The charge imparted by electro-spray is sufficient for the particles to be accelerated to hypervelocity speeds comparable to those attained by particles charged with existing dust sources. Coupling an electro-spray source to a dust accelerator will be challenging, but the challenges are surmountable.

The power of an electro-spray source is that it charges particles regardless of their electrical conductivity. As a result, experiments could be done with projectiles that are exceptional

analogues for planetary materials. Such experiments would be of interest to those working to calibrate *in situ* dust analyzers, those trying to understand the Stardust particles, and those interested in the physics and chemistry of impact ionization and vapor plumes.

References: [1] Grün E. et al., eds. (2001) *Interplanetary Dust*. [2] Zolensky M. E. et al. (2006) *Science*, 314, 1735–1739. [3] Sandford S. A. et al. (2006) *Science*, 314, 1720–1724. [4] Postberg F. et al. (2011) *Nature*, 474, 620–622. [5] Austin D.E. (2003) PhD dissertation, California Institute of Technology. [6] Hillier J. K. et al. (2009) *Planet. Space Sci.*, 57, 2081–2086. [7] Mocker. A. et al. (2011) *Rev. Sci. Instr.*, 82, 095111. [8] Ahrens T. J. et al. (2003) *JGR*, 108, E2, 5007. [9] Göller J. R. et al. (1987) *Astro. Astrophys.*, 187, 693–698. [10] Goldsworthy B. J. et al. (2002) *Adv. Space Res.*, 29, 1139–1144. [11] Austin D. E. et al. (2003) *JGR*, 108, E5, 5038. [12] Burchell M. J. et al. (1999) *Meas. Sci. Tech.*, 10, 41–50. [13] Shibata, H. et al. (2001) *Rad. Phys. Chem.*, 60, 277–282. [14] Shu A. J. et al. (2010) *AGU Fall Meeting*, Abstract # P33C-1581. [15] Manning, H. K. L. and Gregoire, J. M. (2006) *Int. J. Impact Eng.*, 33, 402–409. [16] Daly R. T. et al. *Met. Planet. Sci.*, in review. [17] Daly T. et al. (2010) *LPS XXXXI*, Abstract # 2270. [18] Daly T. et al. (2010) *AGU Fall Meeting*, Abstract # V31C-2338. [19] Daly T. et al. (2011) *LPS XXXXII*, Abstract # 2078. [20] Cole R. B, ed. (1997) *Electrospray ionization mass spectrometry: Fundamentals, instrumentation, and applications*. [21] Kerby J. D. et al. *Earth, Planet. Space*, submitted. [22] Fujiwara, Y. et al. (2011) *Chem. Phys. Lett.*, 501, 335–339. [23] Ku, B. K. and Kim, S. S. (2003) *J. Electrostat.*, 57, 109–128. [24] Ninomiya, S. et al. (2011) *59th ASMS Conf.*, Abstract # 1061. [25] Page, J. S. et al. (2008) *Anal. Chem.*, 80, 1800–1805. [26] Krpoun, R. and Shea, H. R. (2009) *J. Microchem. Microeng.*, 19, 045019.

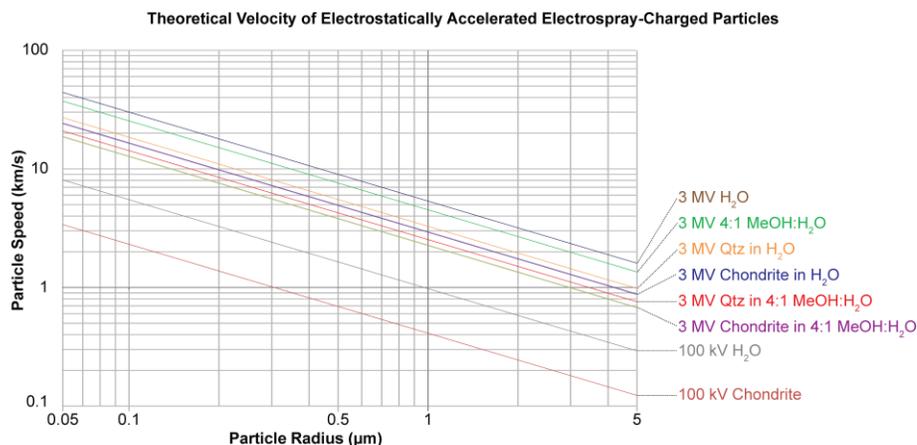


Figure 1. This plot shows the final velocity of electrostatically accelerated electro-spray-charged particles. With 100 kV, sub-micron particles may reach speeds over 1 km/s. With a 3 MV accelerator, particles could reach ~50 km/s. Changing the solvent should lead to greater velocities.