DSMC Modeling of Tvashtar Eruption: Matching Simulation Results of two-phase flow with New Horizons LORRI and MVIC Observations. A. O. Adeloye[1], D. B. Goldstein[1], L. M. Trafton[2], P. L. Varghese[1], A. Mahieux[1,3], [1]Department of Aerospace Engineering and Engineering Mechanics, The University of Texas at Austin, Austin, TX 78712, [2]McDonald Observatory, The University of Texas at Austin. [3]Belgian Institute for Space Aeronomy, Brussels, Belgium. (adeloye@utexas.edu)

Introduction: Io, one of Jupiter's four Galilean moons, is locked in tidal resonance with Jupiter and the other Galilean satellites, primarily Europa. Being the innermost Galilean moon, it experiences significant internal friction and deformation under tidal forces to create magma, making it the most volcanically active body in our solar system. Over a 3-4-day flyby period in 2007, the New Horizons (NH) Long-Range Reconnaissance Imager (LORRI) obtained a unique and dramatic time series of 25 high spatial resolution images of the volcanic eruption of Tvashtar, a Pele-class silicate volcano, which documented a surprising rise in the brightness of its plume over the flyby, superposed on short-term changes. The images captured an uneven increase in the brightness of Tvashtar's erupting plume by over an order of magnitude. The sub-spacecraft Io latitude changed from −8.9 to 2.09 as Io rotated twice during the flyby. At the closest approach, NH was ~2.26 million km from the center of Io. This imaging time series offers an opportunity for gaining insight on the cause of this unexpected behavior through spatial simulation of the volcanic plume in the time domain. We examine the feasibility of doing this by simulating the plume at the time of closest approach of NH to Io.

To pursue this objective, we examine a high-resolution LORRI image taken near closest approach of the spacecraft with the aim of reproducing the size and column density of the Tvashtar eruption plume. We simulate number density profiles of simplified dust grains in the plume using our PLANET Direct Simulation Monte Carlo (DSMC) code. Using a set of vent conditions/parameters appropriate for Pele class volcanoes [1], we extract a central set of parameters from which we construct axisymmetric plume simulations for Tvashtar that reference Io's limb.

Methodology: *DSMC Method.* The DSMC method models gas flows in individual cells stochastically using a representative set of computational particles that imitate the movement and collisions of real gas molecules [2]. Using PLANET, we have previously simulated plumes and atmospheres of Io ([1]; [3]; [4]), south polar two-phase plumes of Enceladus [5], impacts of comets on the Moon and subsequent water deposition [6] and plume impingement of rocket landing and ensuant dust dispersal [7]. PLANET can model dust grains as representative particles fully coupled to the gas, where the gas molecules are influenced by stochastic interactions with dust particles. Over each timestep, interactions between gas and dust particles cause the dust particles to experience a drag force and heat transfer rate determined by the velocity distribution function of gas molecules in the DSMC cell [8]. This is implemented in PLANET using a quasi-analytical expression developed by McDoniel. [9]. In this work, the dust mass loading is assumed below ~5%.

Source and staging through multiple domains. Given a hot magma vent stagnation temperature (1240 K) and area (30 km^2), here we model the mass flux through a virtual vent as ~100,000 kg/s [3]. The gas temperature and velocity were chosen to provide a good match to the observation from the NH LORRI camera. The flow enters the simulation domain at about Mach 1. The flow is also uniformly seeded with spherical dust grains from a chosen size distribution. Previous Tvashtar simulations were 3-D asymmetric with only SO_2 molecules present [3]. In this work, we instead construct 2-D axisymmetric simulations of Tvashtar with both gas molecules and dust particles with the dust particles being fully coupled to the gas motion. The 2-D axisymmetric simulation is run in four stages. Figure 1 below shows the number density profile for 75 nm dust particles in the final stage of the simulation.

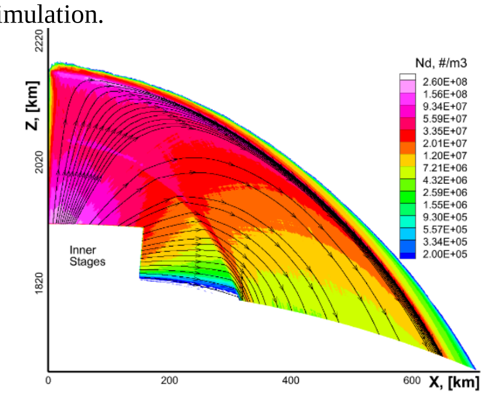

Figure 1: Number density profile of spherical dust grains uniformly seeded into the simulation. The spherical dust grains reach a maximum altitude of ~370 km. (Inner stages are not shown).

In figure 1, the black lines are streamlines describing the motion of the dust grains in the flow (though we understand that these do not accurately represent the motion of these particles in real time). There are two distinct shock-like structures in the flow due to the interaction of the falling dust grains with the rising gas molecules. This interaction causes the dust grains to slide off to the right, forming the inner and outer canopies.

Computation of Column Density. In the following example, we navigate the observing geometry for each LORRI image using the SPICE ephemeris files in the Planetary Data System (PDS) to determine Io's apparent rotational phase, the distance and location of Tvashtar's vent, the apparent tilt of the plume relative to the Line of Sight (LOS), and Io's limb for reference in fitting the plume. The brightness of the plume for a given scattering geometry is directly proportional to the particulate column abundance along the LOS through the plume because of the plume's optical thinness at 5% dust loading.

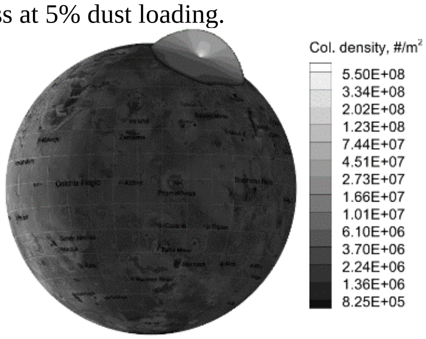

Figure 2: Column density of dust grains in an axisymmetric DSMC plume simulation as observed from NH at closest approach to Io (~2.26 million km) and $-4°$ *sub-spacecraft Io latitude.*

A circular vent is assumed here yielding an axisymmetric flow and the DSMC two-phase flow is simulated in a 1° wedge. To generate the column density of the grains, the results in the 1° wedge are revolved around 360°. The DSMC simulation is run at the north pole of Io. We perform a coordinate transformation, using approximate coordinates of Tvashtar's vent, to place the simulated plume at the known longitude and latitude on Io $(62°N, 123°W)$. Afterwards, integration of number densities along lines of sight originating from the satellite position is used to generate the column density profile. Figure 3 shows an overlay of the column density image with the LORRI image. In this image, the Tvashtar's glowing vent is visible from NH.

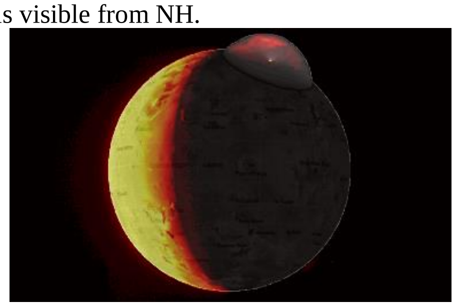

Figure 3: An overlay of DSMC simulation with LORRI image of Io and the Tvashtar plume (LORRI image with orange hue). The image was captured on March 1, 2007, during closest approach.

Conclusion: The preliminary result reported here for a single epoch indicates that our approach should work in simulating Tvashtar's volcanic activity throughout the flyby. Thus, we can examine whether the observed radical brightening of Tvashtar's eruption during the flyby is a result of the scattering phase angle variation of the dust grains or a result of significant increase in volcanic activity.

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