DSMC Modeling of 3D Vent Geometries for Ionian Plumes. W. J. McDoniel[1], D. Goldstein[1], P. Varghese[1], L. Trafton[2], and B. Stewart[1], [1]Department of Aerospace Engineering, [2]Astronomy Dept, University of Texas at Austin (mcdoniel@mail.utexas.edu)

Introduction: Volcanic plumes potentially provide us with evidence of some of a planet's dominant geologic and atmospheric processes, and can be the primary agent controlling the environment and the evolution of a planetary surface over modest time scales. This is especially true for Io, where the volcanic plumes are an ongoing phenomenon of nearly global scale that resurfaces the moon at rates estimated at more than 0.02 cm/yr and possibly as high as 2 cm/yr. The morphology and composition of these plumes is our prime clue to the subsurface geologic processes and composition, which is critical to understanding Io's formation and evolution.

Excellent progress has been made in modeling Io's plumes realistically by using Direct Simulation Monte Carlo (DSMC) techniques [1]. Until now, simulated plumes have been treated as evolving from disk-like circular vents, but many of Io's volcanoes do not conform to this simple geometry. For the various types of observed plumes, the simulation of plausible vent geometries requires three-dimensional representation that has not yet been included in models.

Background: By remote observation, we can categorize Io's plumes, and certain features of the lava lakes and flows, by temperature (e.g., the Near-Infared Mapping Spectrometer (NIMS) on Galileo; the ISS data from Cassini), composition and geomorphology (e.g., the SSI instrument on Galileo), and spectral characteristics.

As summarized by Geissler and Goldstein [2], the volcanoes have been classified into four types: **"**Promethean", associated with surface lava flows; **"**Pillanian", showing short, hot, explosive eruptions of gas and particles; "Lokian", with sources such as lava flows and lakes confined within patera walls; and "stealth", which are undetectable by instruments but inferred to exist. As with terrestrial volcanoes, the modes can switch over time or be combined in a single location. Each of these types of plumes has distinctive source geometries, and several require more than axisymmetric modeling. Geissler and Goldstein suggest, however, that perhaps only two broad categorizations exist: plumes arising from lava impinging on pre-existing ice (Prometheus-type) and those in which the gas evolves directly from hot rock (Pele-type) [2].

Modeling: *DSMC:* Except for regions extremely close to the physical vents on the surface of the planet, Io's plumes are of density. We simulate rarefied atmospheric flow with the DSMC molecular method. This method is the engineering approach of choice for modeling a wide range of rarefied flows around spacecraft when the mean free path is large. Such flows commonly involve high temperatures, chemical reactions, droplet formation, radiation – many of the same phenomena of interest in Ionian plumes. In DSMC the motions and collisions of a relatively small number ($O(10^7)$) of representative molecules are computed, from which the flow of the entire gas is statistically extrapolated. The multiple time scales involved in the different physical phenomena can be handled with spatially variable time steps and grids and different overlay techniques.

Source Types: With the possible exception of some Pillanian and stealth types, plumes probably do not evolve from disk-like sources. Those that arise from lava impinging on pre-existing ice draw material from the boundary between a lava flow and surface frost, while those which evolve directly from hot rock can come from long fissures in the ground or from multiple individual sources close together.

For our purposes, these different complex geometries have been classified into several simplified types of sources. Of interest here are edge sources, such as the curved boundary between a creeping lava flow and surface frost that we see with Prometheus. These can be modeled as arcs of the area between two concentric circles. In the axisymmetric case, this yields an annulus. Our simulations are for a half annulus, where the plume evolves from an asymmetric 180 degree arc.

This model can be used to study the relation between non-circular and often asymmetric vent shape and the relatively symmetric observed plumes. If the plume source is particularly complex, the details of the near-vent conditions may be dramatically different than those for circular sources, yet such sources lead to plume deposits that appear remarkably symmetric. At Pele, gasdynamic processes somehow turn a curved line source into a fairly symmetric plume that leaves a heart-shaped red ring deposit. Similarly, at Prometheus a presumed crescent-like line source ahead of the advancing lava front produces an axisymmetric far field structure.

Results: The figures on the following page are time-averaged slices of Prometheus-type plumes created with disk and half annulus sources at steady state.

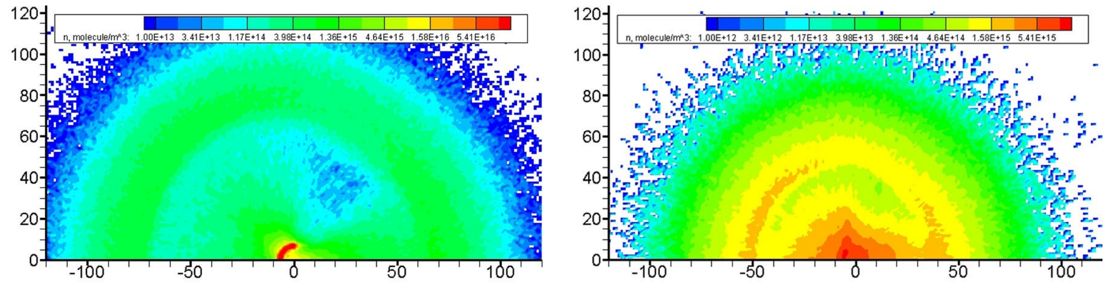

Figure 1: Number density contours at ground level (left) and at 26.4km above the surface (right). The view looks down on the plume from above, and only half of the plume is pictured (it is symmetric about the horizontal axis). The source can clearly be seen in the image on the left.

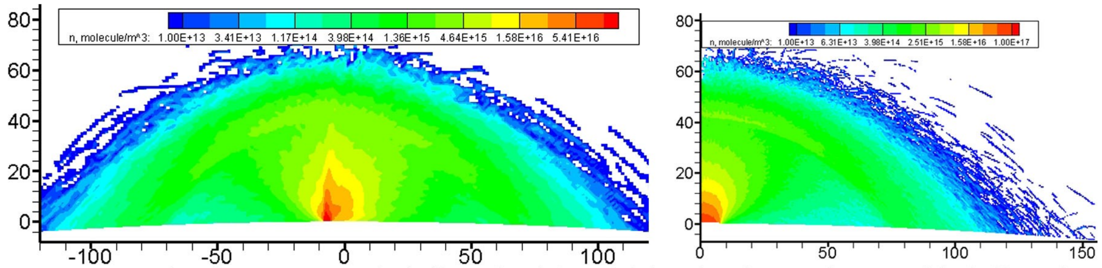

Figure 2: Number density contours for half annulus (left) and disk (right) plumes. The view of the half annulus case is of the plane of symmetry (along the horizontal axis of Figure 1). The disk case is an axisymmetric slice.

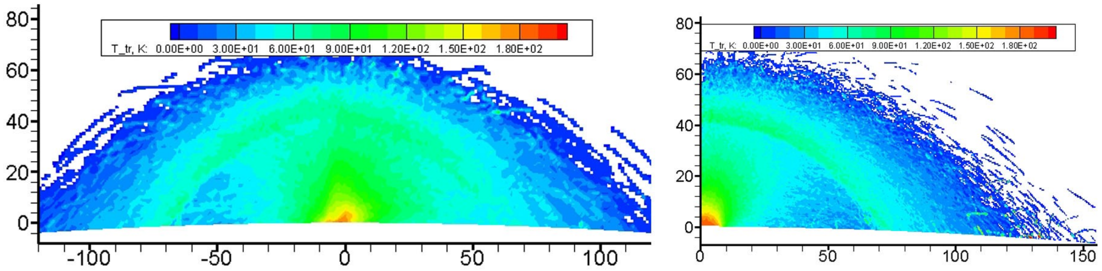

Figure 3: Temperature contours for half annulus (left) and disk (right) plumes. The views are the same as for Figure 2.

Molecules are generated at a source (outer radius 8 km) with an upwards velocity of 200 m/s, a temperature of 180K, and a number density of $5{\cdot}10^{17}$ for the half annulus case and about $5{\cdot}10^{16}$ for the disk case (to equalize the mass flux into the domain). The ground temperature is 90K, so there is essentially no sublimation, and any molecules impacting the surface are assumed to stick.

Figure 1 illustrates the process by which the half annulus plume becomes almost axisymmetric over time. Close in, the obviously asymmetric plume broadly expands out from the annulus to the left while jetting out in a narrow stream from the inside of the annulus to the right. However, as seen in the right hand figure, these differences have started to smear out well below the canopy shock, and the deposition ring at ground level is nearly uniform.

Figures 2 and 3 compare the densities and temperatures seen in half annulus plumes on the left with those seen in disk-source plumes on the right. While both exhibit a canopy shock at the same height, the gas dynamics within the annular plume are very different than those associated with a disk source. The left side of the half annular case appears to evolve upwards in much the same way that the disk case does, but the right side, which jets out of the annulus at high speed (see Figure 1), moves upwards at an angle. Near-vent initial shocks heat the flow, and the canopy shock is relatively weaker, but the density and shape of the canopy turn out to be very similar to the axisymmetric disk case with the same mass flux through the source.

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References: [1] Zhang J. et al. (2003) *Icarus*, *163*, 182-197. [2] Geissler P. E. and Goldstein D. B. (2006), *Io After Galileo*, 163-188.