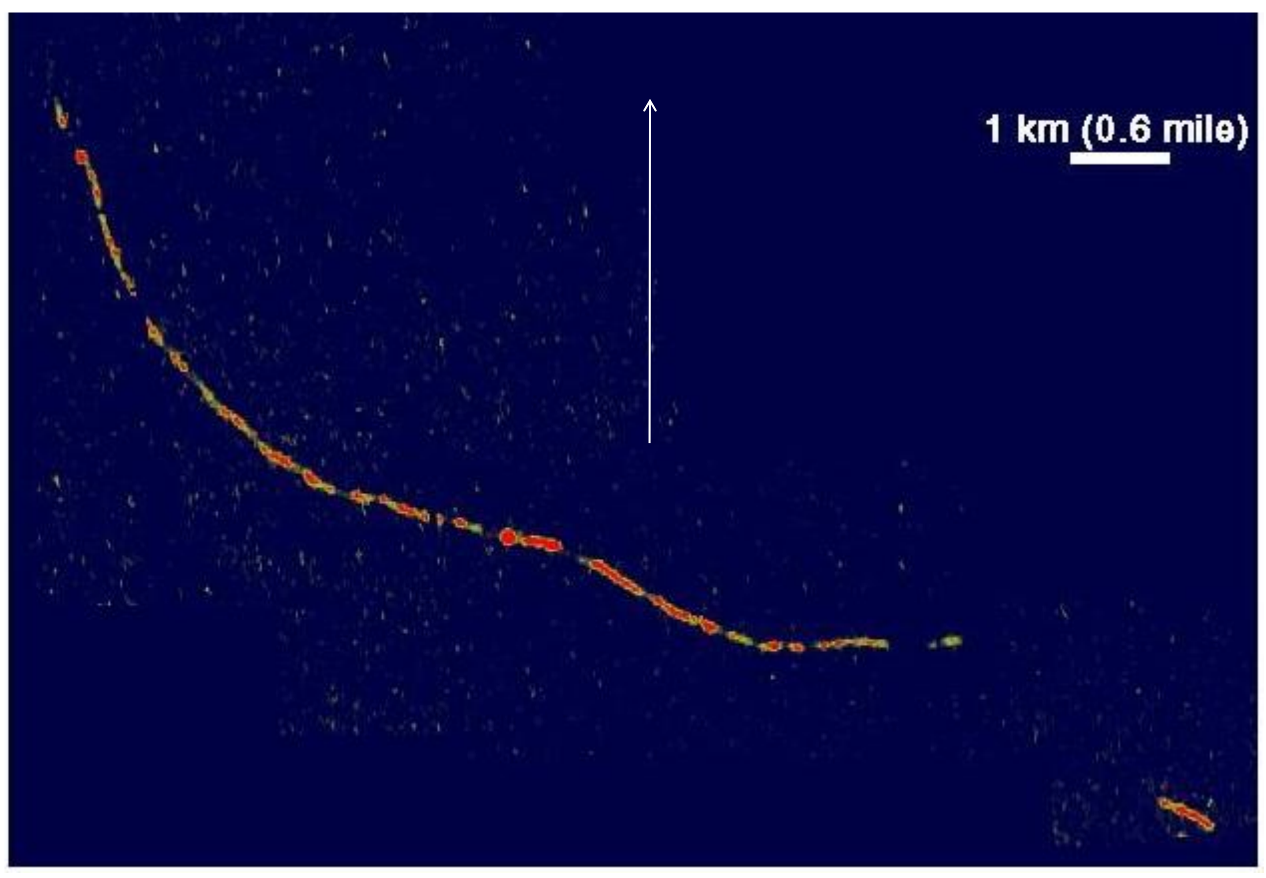
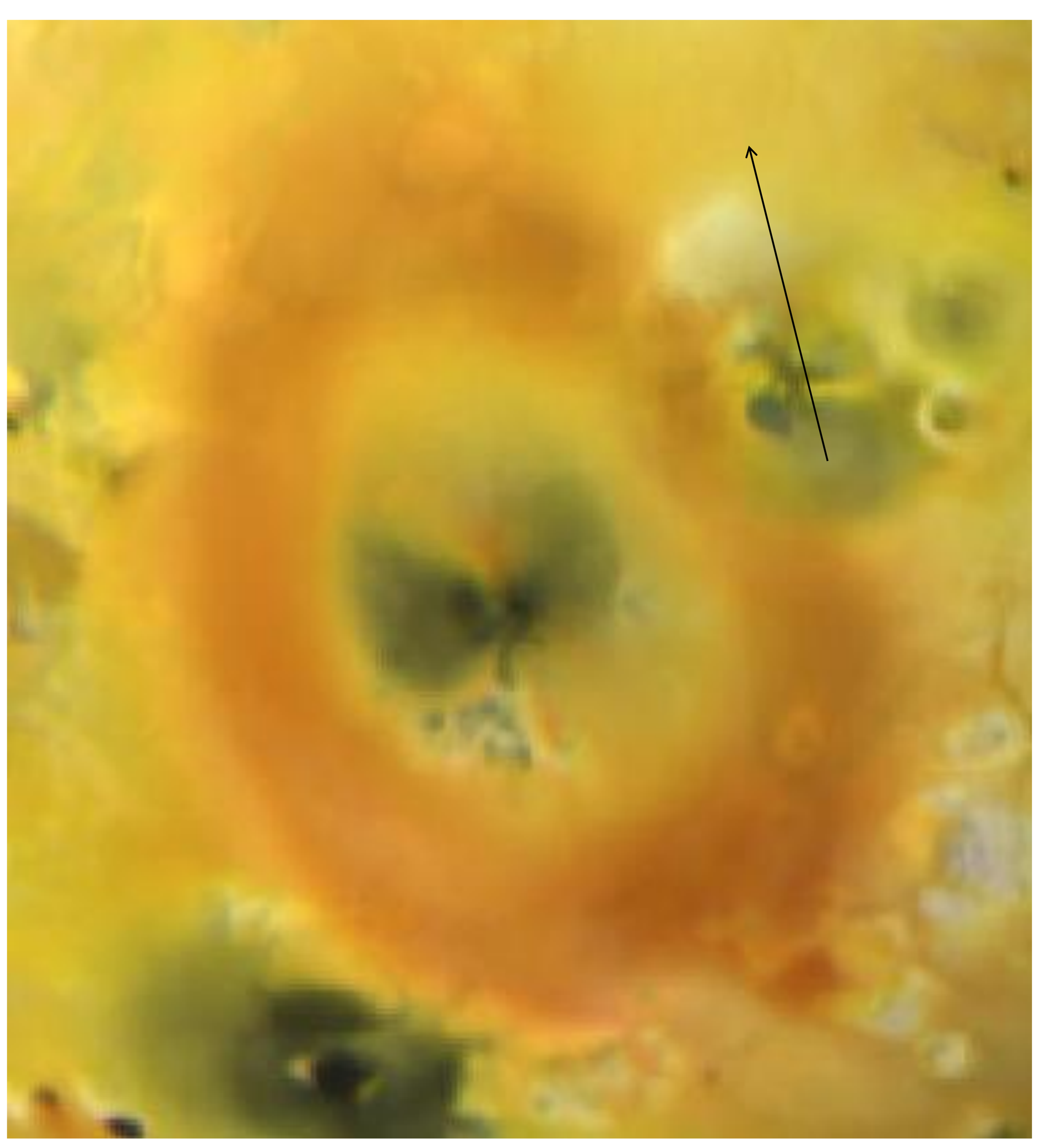
DSMC Modeling of the Pele Plume on Io

W. J. McDoniel, D. B. Goldstein, L. M. Trafton, and P. L. Varghese, Computational Fluid Physics Lab, The University of Texas at Austin, TX 78712. mcdoniel@mail.utexas.edu

Introduction: One of Io's most spectacular plumes, Pele reaches heights in excess of 300km and its deposition ring lies more than 500km from its source. Galileo imaging reveals a narrow, curved high-temperature line (perhaps a fissure) only ~20km long. Taking this line as the source of the plume, we use DSMC [1] to model the gas dynamics and show how focusing caused by the curvature in the near-field gives rise to the egg-shaped ring in the far-field.



(a)



(b)

Fig 1ab – (a) Galileo close-up of the edge of Pele's caldera with only high-temperature (>873K) regions visible, and (b) Galileo image of Pele's egg-shaped deposition ring, with "butterfly wings" of red and black visible inside. Arrows point north.

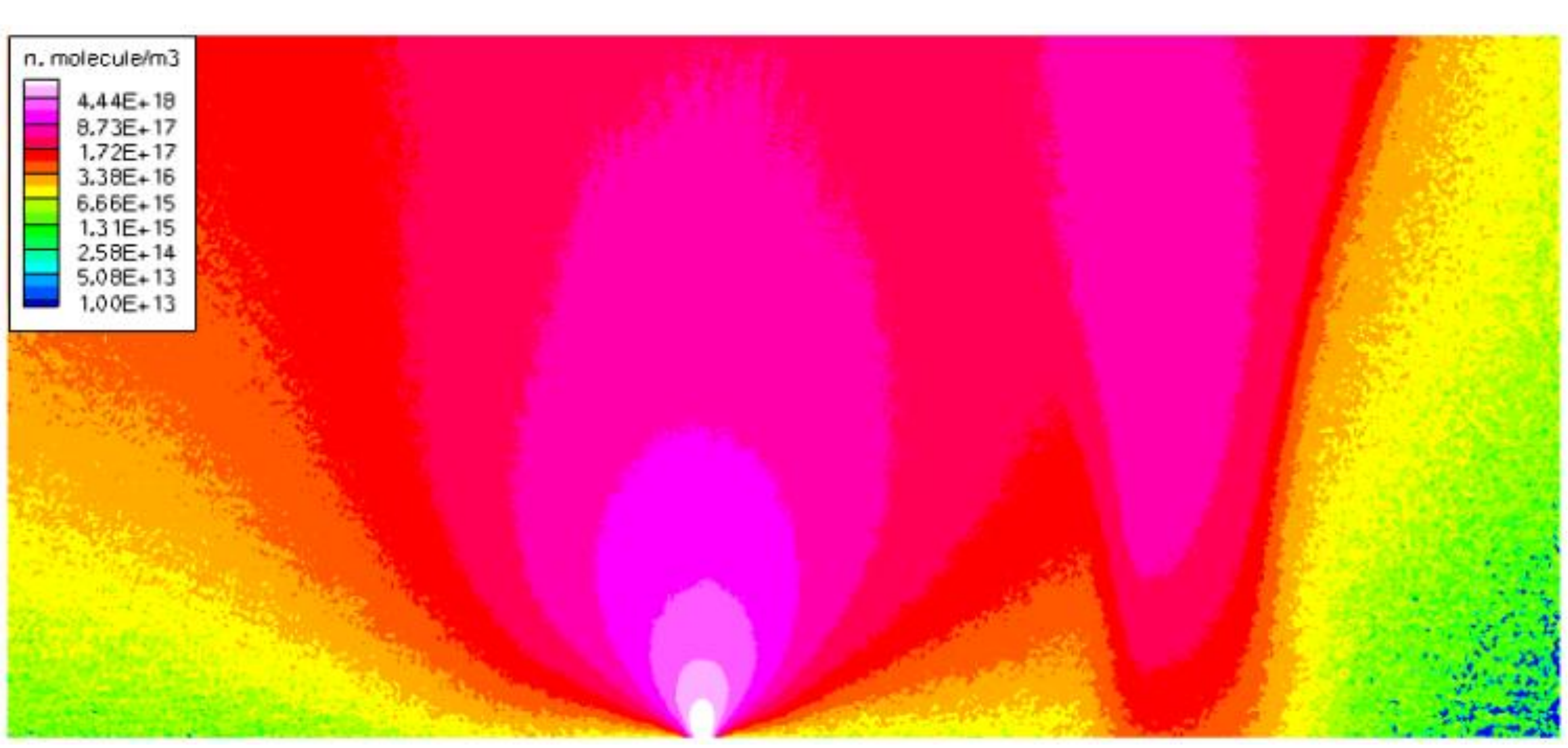
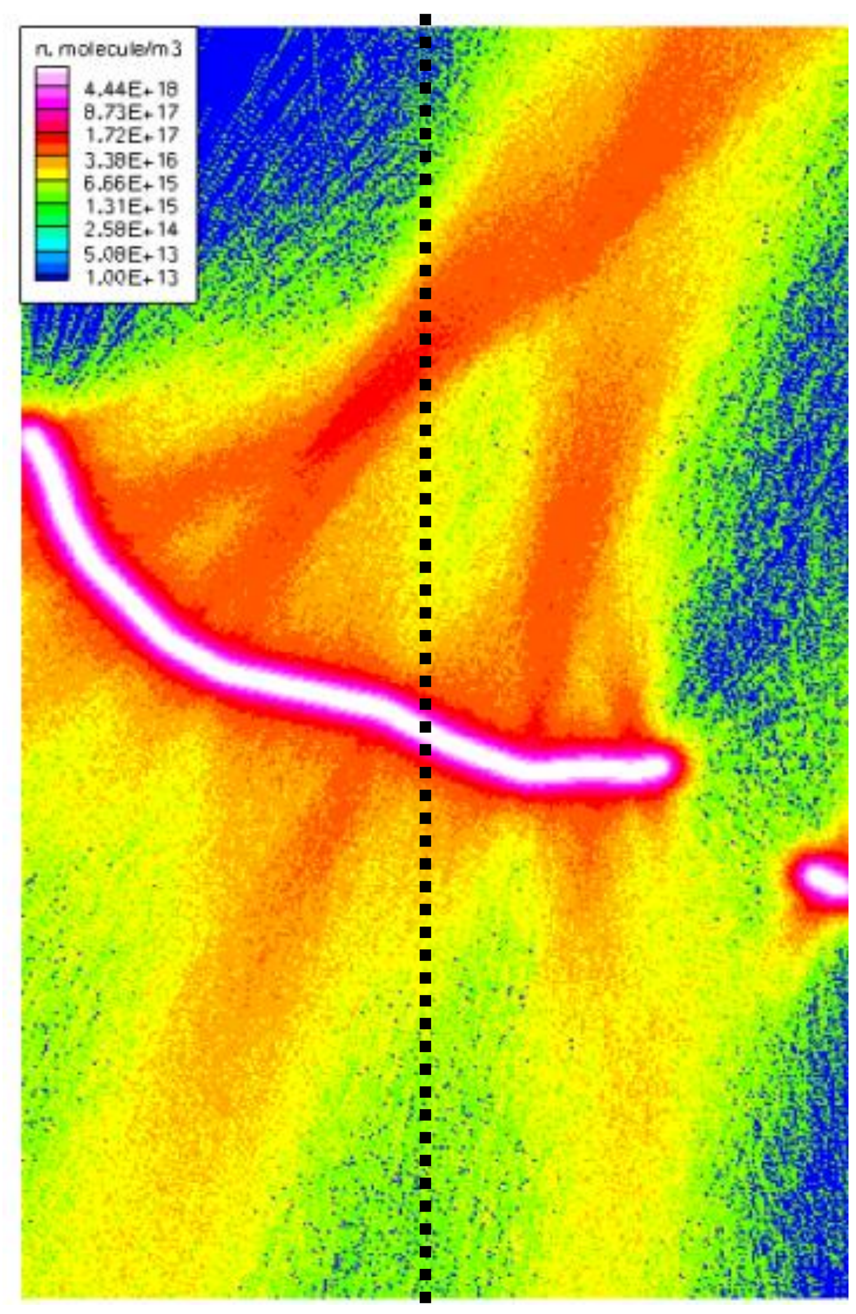
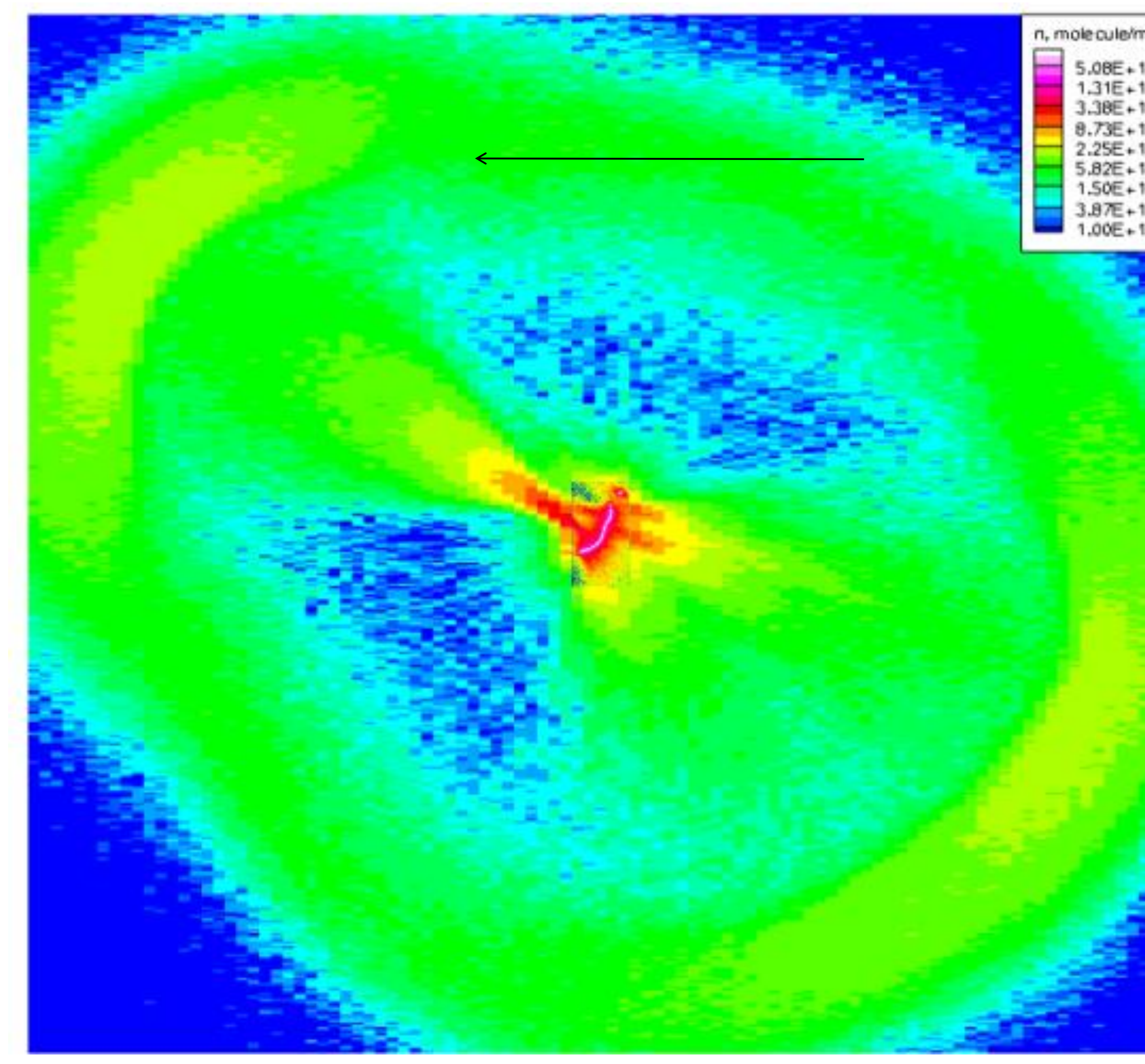


Fig 3 – Number density contours of the near-field through the middle of the plume, along a plane extending from the ground-level image (see dashes in Fig 2a). Focusing can be seen to give rise to larger regions of high density than those found directly over the vent.

Method: The line source shown in red in Fig 1a is modeled as a series of 61 circular disc sources with 90m radii. Molecules are created in "wells" under each of these circles and are allowed to drift out every timestep. Inside the wells, the molecules are created at a number density of 5×10^{18} and a temperature of 650K, with an upwards velocity of 900 m/s. The near-field is simulated on a uniform grid with cells 40m to a side, using 64 processors with several million molecules apiece. The far-field accepts the near-field flow as input and is run on 2 processors with several million molecules each, on a uniform grid of 200m cells.





(a) (b)

Fig 2ab –Simulated number density contours: (a) at 100m in altitude and in the 13km ×20km near-vent area and (b) at ground level in the far-field. Note that the far-field simulation is of a colder plume at 180K and 200 m/s.

The near-field image displayed in Fig 2a shows the focusing effects of the vent curvature, with converging jets to the top of the image, a diverging fan of gas to the bottom, and little flow along the major vent axis. The far-field image shows the ring of falling gas resulting from these near-field jets. The converging jets to the top form a narrower point than the diverging fan to the bottom, and the focusing pushes the top and bottom of the ring out further than the sides, giving rise to the egg-shape seen in the Galileo image. The "butterfly wings" in the Galileo image are also visible as regions of higher and lower density inside of the ring.

Conclusions and Future Work: Simulations based on this assumed vent geometry are in good agreement with observations of Pele's ring, indicating (1) that vent geometry has a significant effect on easily-observable phenomena in the far-field such as ring shape and the existence of "butterfly wings", and (2) that the assumed vent is similar to the actual vent. It may be that observed variations in Pele's ring over time are caused by unsteadiness or a different shape at the vent, perhaps as the lava lake breaks through in new places and old hot spots crust over.

This work was funded by NASA-PATM grant NNX08AE72G. Large simulations were done on parallel supercomputers at the Texas Advanced Computing Center.

[1] Bird, G.A. 1994. *Molecular Gas Dynamics and the Direct Simulation of Gas Flows*. Oxford University Press, London.