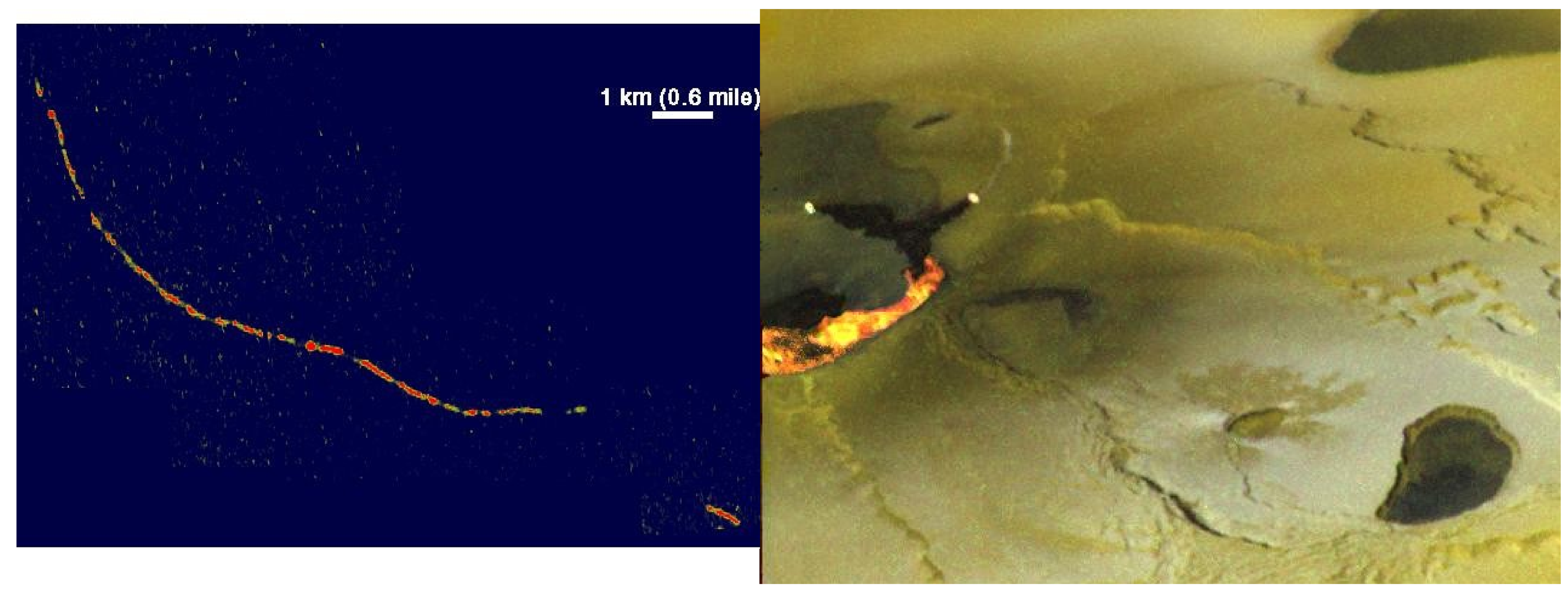
DSMC Modeling of an Irregular Vent Geometry for Ionian Plumes

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: Io's plumes arise in several ways, some from lava impinging on pre-existing ice and some directly from hot rock. Many of their sources have asymmetric and/or complex geometries, but the observed plumes that evolve from such sources are generally symmetric, and their deposition rings are fairly regular.

Method: One type of complex asymmetric source – a c-shape or half annulus – is simulated here with the DSMC method [1]. The half annulus has an outer radius of 8km and a thickness of 1km. Molecules emerge from a reservoir at a number density of $5{\times}10^{16}$, an upwards velocity of 200 m/s, and a temperature of 180K.



(a) (b)

Figure 1ab – Galileo close-up images of Ionian volcanos: (a) the edge of Pele's caldera with only high temperature (>873K) regions visible and (b) Tvashtar erupting. Both sources exhibit obvious curvature. Source: Cassini Imaging Central Laboratory for Operations (ciclops.org)

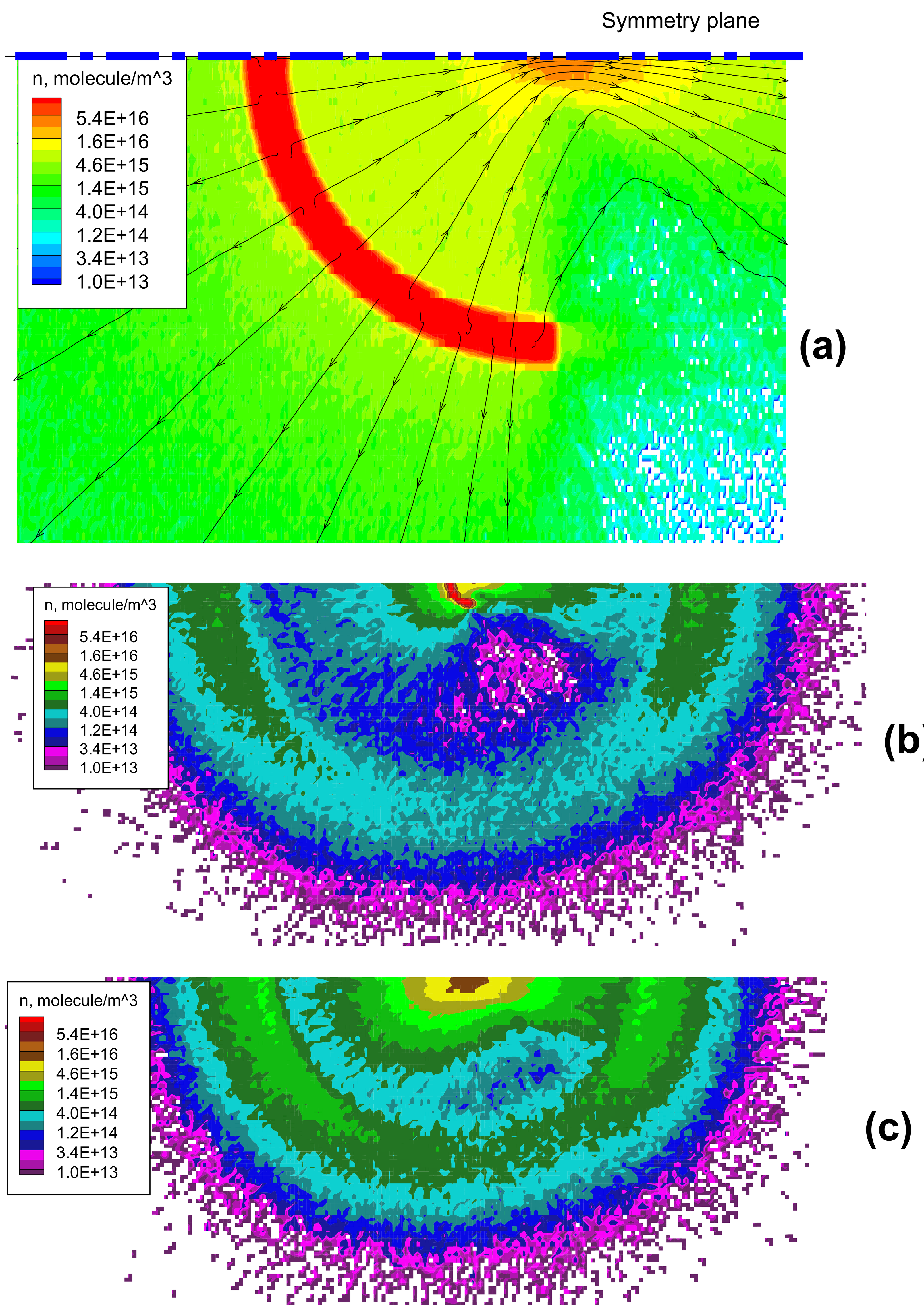


Figure 2abc – Density contours of constant-altitude slices: (a) close-up of the plume source at 500m above ground level with streamlines, (b) whole plume at ground level, and (c) whole plume at 12km above ground level.

The close-up shows a focusing effect on the concave side of the source and a radial expansion on the convex side. The flow at the focal point shocks (M ~ 2.5), and this produces the rightward jet seen in the far-field views. Although this asymmetry starts to smear out towards the canopy shock (this is seen in the high-altitude slice) the deposition ring remains thickest near the symmetry axis, especially on the concave side of the vent. The thinnest portion of the deposition ring occurs 90° off of the symmetry axis and corresponds to the low density regions adjacent to the focusing jet.

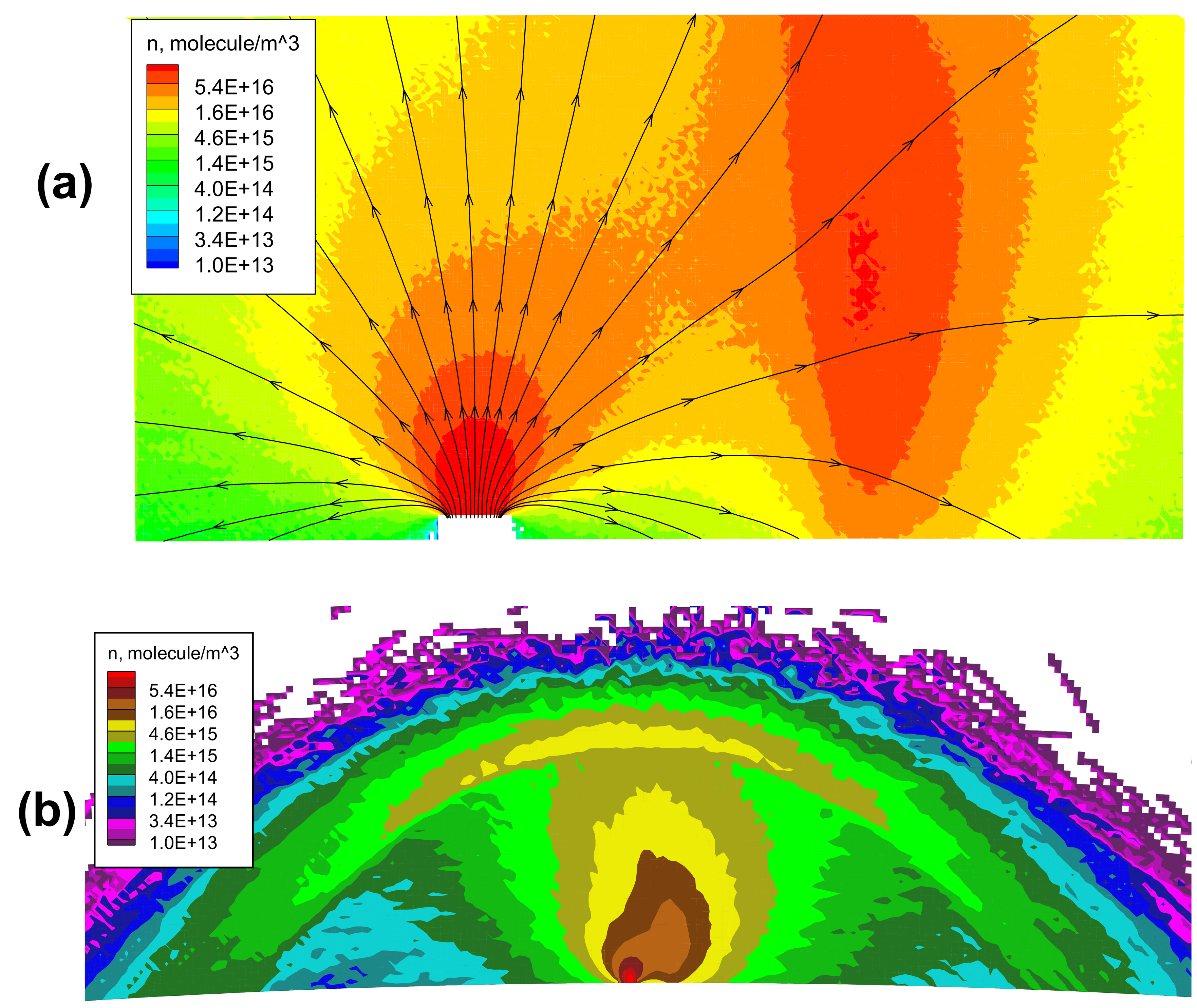


Figure 3ab - Density contours of the symmetry plane through the center of the plume: (a) close-up of the source with streamlines and (b) whole plume.

The close-up shows that the focusing region seen earlier is actually significantly taller than the dense region immediately above the plume source, and the gas along the columnar focus achieves pressures and temperatures comparable to those at the source. The far-field image illustrates that, from a distance, this focusing region could easily be mistaken for the actual source of the plume.

Conclusions: The canopy looks very similar to that produced by a symmetric disk source 16km in diameter at the same mass flow rate [2]. Complex interactions near the vent focus the flow and produce a jet in the concave direction, thinning the deposition ring away from the symmetry plane. The focused flow ascends at an angle, and there are more molecules closer to the ground on the right side of the plume. However, the plume on the convex side of the vent looks very similar to a disk source – the two sides do not seem to have much interaction with each other, and the complex interactions seen are almost entirely restricted to the concave side of the vent.

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.
[2] Zhang J. et al. (2003) *Icarus*, 163, 182-197.