

Modeling the Enceladus, Europa and Io Plumes; a contrast. D. B. Goldstein¹, A. Mahieux¹, W. Hoey, P. Ackley, W. McDoniel, [S. Yeoh](#)¹, J. Berg¹, L. Trafton¹ and P. Varghese¹, ¹The University of Texas at Austin, Austin TX 78712.

Introduction: Active plumes have been observed on four extraterrestrial bodies: Io, Enceladus, Triton and probably Europa. Triton plumes occur below a substantial (very collisional) atmosphere but have not been well observed. Ionian plumes are of hot volcanic origin and originate below a tenuous though still collisional atmosphere. The Enceladus and the probable Europa plumes are of a cold or cryovolcanic origin. We have completed a number of studies of the gas dynamics associated with the Io, Enceladus and Europa plumes which have minimal interaction with a background atmosphere and we will compare and contrast the different physical environments and the resulting physics of the plumes.

The dominant physical boundary conditions that determine the nature of the plumes rising over (nearly) airless bodies include: the chemical composition of the plume, the specific kinetic and thermal energy of the constituents at the surface, the shapes of the source regions (the “vents”), the surface gravity, the gas and particulate densities at the surface, and time variability (if any) of the vent output. External inputs such as solar UV and plasma influx can also affect the plume but the external energy inputs in these volcanic plumes are small in comparison to the thermal input from within the bodies (unlike cometary plumes).

Details matter. However, although the precise geometry and conditions just below and at the surface determine the features of the resulting plume (e.g., if an Ionian plume of SO₂ gas and droplets and refractory grains arises from a bubbling partly crusted-over magma surface or a spraying lava fire fountain), we can often abstract those conditions to a small height above the surface where we imagine a “virtual vent” to exist. At that virtual vent, the gas/particulate properties of density, concentration, temperature, velocity, etc. may be assumed uniform even though the virtual vent retains the outline shape of the actual vent we wish to model. Alternatively, for an Enceladus situation, we may choose to begin the simulation well below the surface, deep in a twisted crevasse at a bubbling water surface and track the resulting vapor, droplets and ice grains as they pass up through the assumed conduit geometry, interact with the sidewalls and exhaust into space.

The problem of simulating the plume above the surface has several important complications. In all cases the Mach number becomes high. The Mach number is the ratio of the local gas mixture speed to its local

speed of sound. When the Mach number exceeds ~0.3, flow is compressible (density variations with velocity are significant). In all cases we discuss, the plume flow is into near vacuum (it is an under expanded jet flow) so the density ultimately becomes low and the molecular mean free path (MFP, the mean distance between two successive collisions), becomes large. In this case the local Knudsen number (a local length scale divided by the local MFP) becomes large and a suitable simulation method is the direct simulation Monte Carlo (DSMC) approach. We have developed this approach for the planetary plume problem and can handle all of the complexity described above (gas/particulate mixtures, rarefaction, gravity, plasma and E/M fields in a rotating two-body system, three dimensionality, flow unsteadiness, and condensation) as well as a coupling of the gas dynamics and the radiative transport to model UV photodissociation, radiative heat exchange and synthetic image synthesis.

There are some key differences between the Io, Enceladus and Europa plumes. Although the Io plumes are hot, they do not have enough energy to escape Io’s gravity and they fall back on themselves forming large mushroom shaped canopies topped by a shock wave. In contrast, the Europa cold water vapor plume likely is of cryo-origin and although much less massive, can reach similarly high altitudes before shocking and falling back to the surface. Enceladus has a plume which is similar to the Europa case near the surface. But because of its very low surface gravity, most of the vapor and much of the smaller particulate matter easily escape the small body (Comets and Enceladus thus share some plume features.)

The plumes on all three bodies are unsteady on different time scales for different reasons. The Ionian plumes are unsteady as a result of the source lava dynamics. The Enceladus plume shows orbital tidal variation as well as seasonal variation; there is only weak evidence of minute-scale variation. The probable Europa plume appears to only be occasionally observed – so is unsteady in that sense - but the cause of the variation remains uncertain.

While of interest in themselves, these planet-scale plumes also provide information about their sources and thus the interior of the body. Our presentation will briefly highlight how simulation of the different plumes and comparisons with extant observations can be used to better understand the (cryo)volcanism which produces these jets into space.