Enceladus geyser study using Markov Chain Monte Carlo fits of DSMC simulations

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The two-phase water plumes arising from the Enceladus South pole and extending hundreds of km from the moon are a key signature of what lies below the surface. Multiple Cassini instruments measured the gas-particle plume over the warm Tiger Stripe region during several close flybys. A lot of work has been put into constraining the vent and flow characteristics, such as the vent positions and orientations, the mass flows, speeds and temperatures.

The most likely source for these extensive geysers is a subsurface liquid reservoir of somewhat saline water and other volatiles boiling off through crevasse-like conduits into the vacuum of space. The plumes thus provide a window for understanding Enceladus' subsurface composition and geysering.

We used a DSMC code to simulate the plume, as it exits a vent, under axisymmetric conditions, in a vertical domain extending up to 10 km, where the flows become collisionless. We performed a DSMC parametric study of the flow parameters considering the following eight parameters: vent diameter, outgassed flow density, water vapor/ice mass ratio, gas and ice speed, ice grain diameter, temperature and vent exit angle.

We constructed parametric expressions for the plume characteristics – number density, temperature, velocity components – using simple analytic expressions to depict the constrained surfaces of these parameter values, at the 10 km upper boundary.

We use these parametrizations to propagate the plumes to higher altitudes – up to thousands of km – assuming free-molecular conditions. The density field at higher altitude is determined from the parametrizations described above, and explicit analytical expressions for the various force fields that the plumes are experiencing: Enceladus and Saturn gravity fields, Coriolis and centripetal accelerations due to Enceladus rotation.

This split domain approach enables rapid numerical computations – ~10 minutes – and tabulations of the density and velocity fields in space.

We then performed a formal Monte Carlo sensitivity analysis of twelve vent parameters – the ones cited above plus vent latitude, longitude, azimuth and zenith angles of the venting direction – conditioned on the number density field measured by the INMS instrument, considering the 98-vent geometry reported in Porco et al. (2014). The sensitivity analysis is used to determine which vent parameters should be considered for a subsequent fit of the INMS observation. We present an advanced way to constrain the vent parameters by performing a Markov Chain Monte
Carlo search that returns probability values for the preselected vent parameters, considering a few INMS observations. This approach allows us to constrain many vent parameters (up to a few hundreds), and, uniquely, return probability distribution for each of them.