Introduction: The composition of the jets erupting from Enceladus’ south pole is water vapor and salty ice grains with traces of organic compounds [1]. The mass fraction of icy grains to vapor \( f_m \) in the jets is currently largely unconstrained varying from < 0.1 to 0.7 [3, 4, 5, 6, 7, 8]. This large variation mostly stems from the lack of simultaneous measurements of abundances of icy grains and vapor which is needed to account for the temporal and spatial variations in both dust and gas outputs.

The mass fraction \( f_m \) might help to differentiate between the direct sources of the jets being liquid water reservoir or sublimation of ice: if the water vapor in the jets stems from evaporation from ice, it can not have high icy grains mass fraction [7].

A unique opportunity to investigate the gaseous and solid components of Enceladus jets comes from joint occultation observation conducted by the Cassini spacecraft’s Visual and Infrared Mapping Spectrometer (VIMS) and Ultraviolet Imaging Spectrograph (UVIS) on 18 May 2010. Both instruments followed the Sun being occulted by the Enceladus jets. The absorption of the signal provides information about the composition and physical properties of the jets. It can be converted to column density along the line of sight (LoS) of the instruments focusing on icy grains for VIMS and water vapor for UVIS.

Observations: UVIS is best suited to derive water vapor abundances, while VIMS is sensitive to icy grains. During the solar occultation, UVIS detected spatially resolved collimated vapor jets inside the plume [5]. They correspond to the peaks in column density along UVIS line of sight (Fig. 1, blue dashed curve). VIMS temporal and hence spatial resolution is lower (green line on Fig. 1). But the fact that the observations were taken simultaneously gives us the possibility to examine the relation between vapor and icy grains.

Model: We have used a 3D direct simulation Monte Carlo (DSMC) model for Enceladus’ jets to model both vapor and ice components of the water jets [9]. For this project, we consider vapor and icy components independent, i.e. they do not interact after exiting the vent. It is generally accepted assumption considering the low densities of vapor and icy grains [1]. The Monte Carlo model tracks test particles from their source at the surface into space. Each test particle represents an ensemble of physical particles (either water vapor molecules or icy grains). The required number of the test particles for each model run is determined by the model resolution, physical number densities in the considered jet, and mean particle velocity. The model accounts for the gravity of Enceladus and Saturn. The particles are given starting velocity distribution with thermal component isotropic in upward hemisphere and satisfying a Boltzmann distribution plus a component perpendicular to the surface. The initial positions of test particles are chosen at one of the 100 single jets sources identified in [2].

The same core of the model is used for both the vapor and icy grains model. The minimal modification includes adjustment of particle properties (mass, mean velocity) and removal of consideration of collisions for icy grains, i.e. reducing the model to a simple ballistic case. This is a reasonable assumption for the case of low icy grains densities in the jets.

During each simulation run, the model is required to reach a steady-state. Each model run results in a set of coordinates and velocities of a given set of test particles. These are converted to the test particle number densities and then integrated along LoS for each time step of the occultation observation. The geometry of the observation is calculated using SPICE [10].

The overarching result of the simulation run is a test particle number density along LoS for each time point during the occultation observation for each of the jets separately. To fit the model to the data, we integrate all jets that are crossed by the LoS at each point.

Figure 1: Comparison of normalized water vapor column density derived from the UVIS solar occultation observation (blue dashed line), VIMS icy grains column density (green line) and the integrated model of 100 jets of equal strength (red line).
Figure 2: Comparison of the locations of jets that compose best fits to UVIS solar occultation profile (yellow circles panel) and VIMS occultation profile (magenta stars) on the surface of Enceladus. Relative strengths of the jets are shown with the relative sizes of the markers. The LoS ground track for this observation is marked by the green line and the locations of 6 most prominent peaks in column density detected by UVIS are marked along it from a to f.

of time during the observation. Fig. 1 shows such an integration for the icy grains model assuming that all the 100 jets are of the same strength, i.e. without fitting it to the data (red line). Even without varying the relative strength of the jets, the model correctly predicts the position of the maximum of column density detected by VIMS (green curve). Comparing this model outcome to the UVIS profile (blue dashed line) reveals that at ingress (et = 125 – 150) vapor jets were much stronger and more pronounced than icy grains jets. At this time, LoS was crossing over the Alexandria and Cairo tiger stripe. Another difference is seen at egress, pointing to lower mass fraction icy grains ($f_m$) in jets emitting from Damascus.

**Fitting procedure:** The relative strength of the jets must be determined to fit the observed UVIS and to a degree VIMS curves. The geometry of the occultation observation is such that the LoS at each point of time crosses multiple jets from different tiger stripes. This leads to some jets being linear combination of the others. Thus, the first step in the fitting procedure is to reduce the original set of 100 jets to a linearly independent set. By the nature of this procedure multiple combinations of the jets can constitute the resulting linearly independent solution set. The number of linearly independent jets is a function of observational geometry, model resolution, and single jet geometry that mostly results from particles velocities.

Considering the linearly independent set, we perform constrained linear least squares fitting to write the UVIS/VIMS measurements as a combination of these jets with varying strengths.

**Results:** Fig. 2 shows locations of the set of water vapor jets constituting the best fit to the UVIS solar occultation profile from Fig. 1 (yellow circles). The linearly independent set of jets in this case has 72 jets from the original 100. The remaining 28 jets could be written as a linear combination of these 72 jets. The fitting procedure eliminated additional 31 jet with negligible contributions leaving a solution of 41 jets.

Magenta stars on Fig. 2 show one of the best fit configurations for icy grains jets and VIMS profile. Naturally, compared to UVIS, fewer jets are required to fit VIMS profile due to lack of small scale features in it. The shown solution has 15 jets. The linearly independent set however for this case included almost all the original jets: 97 out of 100. This is because of low velocities of the grains and resulting wide opening angles. Both of the shown solutions are not unique in the sense that equally good fit can be achieved with the linear combination of the linearly dependent jets.

**Conclusions:** The modelled distribution of jets needed to reproduce the VIMS and UVIS results are different, indicating different mass fraction icy grains ($f_m$) across the active south polar region. This means that the bulk plume mass fraction icy grains ($f_m$) estimates do not provide a representative measure of this parameter. The variable composition also suggests variable influence of the subsurface processes in plume generation at different source fissures.