EPSC Abstracts,
Vol. 4, EPSC2009-480, 2009
European Planetary Science Congress,

A study of gas-jet interactions; implications for Rosetta

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Abstract

Observations by spacecraft imaging systems of scattered light in the innermost comae of comets indicate an inhomogeneous dust emission from the surface [1-5]. Combined with the observed inhomogeneities in surface appearance, the local topography [6], and the low thermal inertia [7], this suggests that non-uniform outgassing from the nucleus is a ubiquitous property of cometary nuclei.

Several studies of gas-jet interactions resulting from non-uniform outgassing from a cometary nucleus have been published in the past. Most notably, [8] [9], and [10] have simulated relatively high production rates from discrete sources in simple geometries by solving the Navier-Stokes equations. Most sophisticated models taking into account the detailed shape of a cometary nucleus have also been produced by [11] but here with gas emission proportional to the cosine of the solar zenith angle. [12] extended this by showing that solutions using the Navier-Stokes equations could be reproduced using the Direct Simulation Monte Carlo (DSMC) [13] for systems with appropriate initial conditions.

One of the reasons for selecting DSMC is the wide range of cases that can be studied and particularly those where the production rates (and consequently the gas densities at the surface) are low. These types of cases are of considerable interest for the Rosetta mission which will begin monitoring comet Churyumov-Gerasimenko from around 4 AU when production rates of water per unit area are expected to be negligible and CO_2 and/or CO production rates are unlikely to exceed 10^{18} molecule m^{-2} s^{-1}.

A 2-D DSMC code has been used to conduct a study of the phenomena arising from the gas-jet interactions in the vicinity of a cometary nucleus. Of the many possibilities, two types of interaction have been studied in detail. Firstly, a comparison of the coma properties resulting from a single uniform source has been made with a multiple source of similar production rate to establish whether it is possible through measurement to distinguish between these two cases. Secondly, the observations from Deep Impact [5] indicate that different sources may be dominated by different gas species. (In the case of comet 9P/Tempel 1 both H_2O and CO_2 dominated outflows were observed.)

Two Sources

The initial mean free path is a practical length scale for two source expansion problems. The interaction between the sources can be separated into three types (see Figure 1). Where the distance between the two sources is much smaller than the mean free path, the result is a summation of two single source flows. In the transitional type, with separations around the mean free path, the sources do interact, but the gases can mix and become warmer. Finally, where the separation is much larger than the mean free path, the two gases mix only in one small region between the sources. A jet-like structure is formed which separates the two gas flows.

In general, two source flows are slower and warmer than a comparable single source flow. This is a result of the initial flow velocity parallel to the surface and the subsequent collisions. Although the two source flows appear similar to single source flows at large distances, if measurements can be made at several well separated points within the flows, they can be easily distinguished. It should here be noted that transfer of rotational to translational energy is an important factor in these simulations and

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controlled by a rotational collision number which is poorly known.

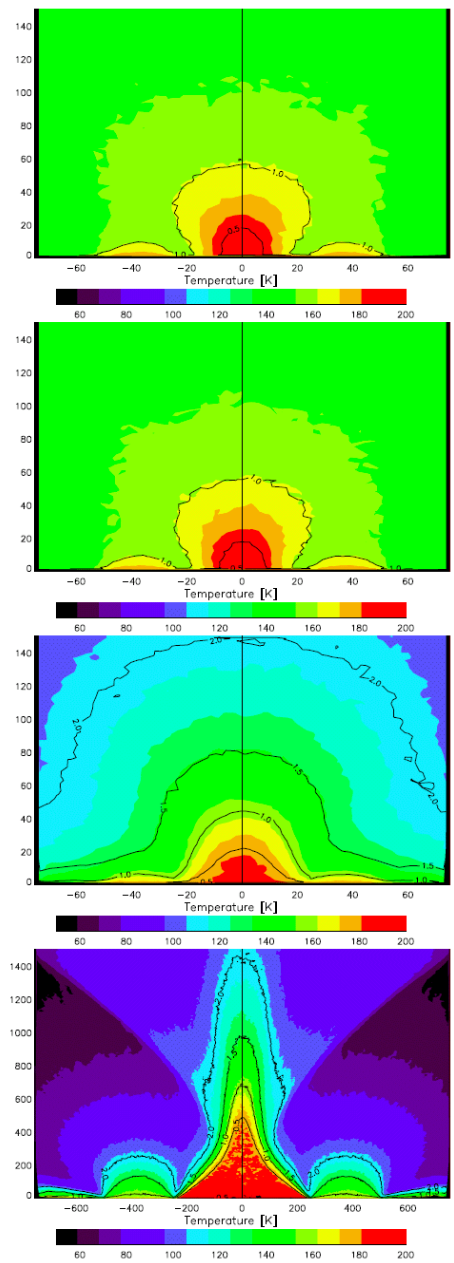

Figure 1 Temperature and Mach number for flows with different distances between the sources. From top to bottom: d = 6 10^{-5} λ, d = 0.06 λ, d = 60 λ, d = 3000 λ. λ is the mean free path at the source.

CO_2 and H_2O Sources

Here we have simulated a CO_2 source near an H_2O source. The symmetry of the final flow is mostly influenced by the energy ratio of the two gases. The region of maximum density of a single gas is typically not over the centre of the source but is shifted to the side, in most cases away from the second source. The region of maximum density of the whole flow is in-between the two individual density maxima, approximately in the middle of the two weighted with the initial number density.

Rosetta and Future Work

The aim of this work is to provide simple test cases which can be used for the initial interpretation of Rosetta observations (by e.g. OSIRIS, ROSINA, and MIRO). Our next goal is to add dust to the simulation.

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