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DSMC Simulations of the near nucleus coma of Comet 9P/Tempel 1

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Abstract

We have performed DSMC simulations of the near nucleus coma of comet 9P/Tempel 1 and compared the simulated column densities of H_2O vapour to the observations of [5]. The shape model produced by P.C. Thomas and found in the PDS databank was used. Two different activity models were calculated: In the first case, the surface was assumed to be the same everywhere. In the second case, the surface outgasses only in some regions. The regions are distributed and defined in a way that agrees with [8]. A collisionless model shows agreement with observation. The presentation will show first results from a collisional calculation.

1. Introduction

1.1 DSMC

Direct Simulation Monte Carlo (DSMC), invented by Bird [1], is a simulation method based on particle collision kinetics, in which many simulation particles move, collide and are sampled into macroscopic properties wherever and whenever is appropriate. DSMC is widely used in simulation of cometary comae.(e.g. [3]). Because of the nature of the DSMC method, it has the advantage of simulating gas flow with strong thermal non-equilibrium without any convergence problem (unlike other continuum models). The disadvantage is that the computational time increases with increasing density of the gas flow. Fortunately, parallel computing of DSMC can greatly reduce the runtime.

Lukianov and Khanlarov [9] showed that gas flow, sublimating from a sphere, with global Knudsen number (the ratio of the mean free path to the radius of the source) of 10^{-3} or more fails to reach LTE (local thermal equilibrium). In the case of Tempel 1 at the time of the encounter with the Deep Impact spacecraft at 1.5 AU, the production rate was about $5\ 10^{27}$ #/s [9] or (9.4 +/- 0.7) 10^{27} #/s [3]. This results in a Knudsen number of $\sim 10^{-3}$ ($\lambda \sim 1$ m and D ~ 1 km). On the night side, the production rates are lower and therefore the Knudsen number becomes higher.

In the present study, we use a parallel DSMC code (named "PDSC") with an unstructured grid, developed by Wu and his co-workers for more than a decade (e.g. [2], [11], [12]). It runs on 32 processors in parallel in the current study. The shape model derived from Deep Impact observations was ingested. To test the input conditions we decreased the density of the gas so that the flow is collisionless and simulated this as a first step with Bird's 3D DSMC code. Figure 1 shows the density distribution, which is similar to those observed experimentally in Figure 2.

1.2 Homogeneous Structure

The position of the sun was calculated with SPICE for the time of Feaga's observations [5]. The sub-solar point is at a longitude of 12.6°W and a latitude of 13.7°. The total production rate was set to 9.4 10^{27} #/s. The temperature map was calculated by assuming that all solar energy goes into IR flux or into sublimation. The gas flux is everywhere proportional to the Hertz-Knudsen Flux. The sublimation vapour pressure was calculated with the expression from [7].

1.3 Inhomogeneous Structure

In this model, we assume an inhomogeneous distribution of sublimating surfaces. The activity is again proportional to the Hertz-Knudsen flux but this time the proportionality constant is calculated by assuming dust layers of different thicknesses (Long tube formula [8]). We are effectively modifying the gas production distribution over the surface. To constrain this we use the results of [8].

[7] shows that the production rate behavior over the whole orbit of comet 9/P Tempel 1 can be explained by the existence of active regions at latitudes of -12°,

-21° and -30°. An active sector centered at -61° is possible: it does not influence the total production rate greatly. An active area at +61° has a larger impact, but observations in [5] show activity at the north pole. Therefore we place a weak source at this sector, too.

The longitudes of the active sectors are chosen to fit the observations. The sides of the active regions are smoothed in order to avoid artifacts. The total production rate is here 8.8 10^{27} #/s.

The upper surface temperature is calculated by considering only solar irradiation and IR flux. The ice temperature is given by the constraint that all energy conducted through the dust layer goes into sublimation. The heat conductivity is assumed to be constant.

2. Results

The homogeneous structure case shows clearly a high production rate at the sub solar point. This does not fit the observations.

The inhomogeneous structure case has an inactive area (e.g. a thick dust mantle) at this point. Together with the active regions at the poles, the main structure of the observed gas distribution (figure 2) is also visible in the simulation (figure 1). The model of Kossacki et al. appears to give a useful estimate of the activity distribution on the nucleus surface.

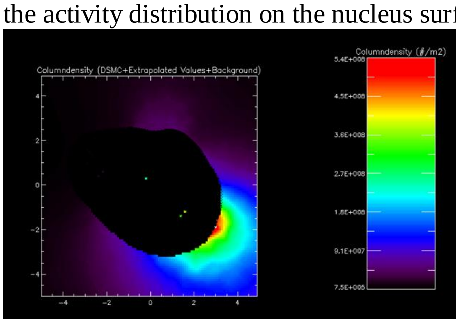

Figure 1: Column densities of H_2O vapor in the "Inhomogeneous Structure" case. Collision less DSMC. [1]

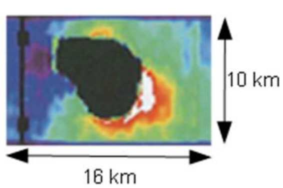

Figure 2: Radiance map of H_2O vapor. Taken from [5]

3. Summary and Conclusions

3D DSMC simulations of the gas flows from a measured comet shape model are presented.

Two hypotheses about the structure of the activity were tested: A homogeneous structure and an inhomogeneous one. The inhomogeneous structure shows the better agreement. The homogeneous structure shows clear derivation from the observed gas coma. Therefore it is unlikely that the comet has a homogeneous structure. The shape of the nucleus itself is not enough to explain the observed coma structures.

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