EPSC Abstracts
Vol. 12, EPSC2018-409, 2018
European Planetary Science Congress 2018

The Lagrangian SPH approach applied to the cometary gas-dust emission.

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Abstract

The evolution of the dust and its interaction with gas systems constitute an important physical feature characterizing the minor bodies of the Solar System. In this work, we aim to discuss some suitable numerical Smoothed Particle Hydrodynamics (SPH) techniques to model the interaction and time-evolution of gas and dust systems. We focus our attention on the peculiar problem of jets expelled by the cometary surfaces, in the framework of the recent ESA Rosetta fly-by mission which provided a deep analysis of the properties of the comet 67P/Churyumov-Gerasimenko, during its approach to the internal Solar System.

1 Introduction

Among the minor bodies, comets constitute the most important trace of the origin of the Solar System, since their nucleus contains matter built in the first phases of the protoplanetary disk condensation and remained nowadays unpreserved. Nevertheless, cometary nuclei, especially the ones belonging to short period comets, can undergo important changes during their approach to the Sun. Cometary activity constitutes a series of important processes involving the expulsion of sublimating gas which drags out dust grains. It is a very important mechanism which can give us important information about the internal structure of the nucleus and, at the same time, can explain the matter observed in the coma. We have a few examples of direct observations of gas emission. Fig.1(a), shows a trace of matter expulsion from 1P/Halley through the radiation emitted by H_2O photo-dissociation and dust grains ([1]). As we can see from the picture, collimated structures (jets) of water gas are emitted from the surface.

Generally, a direct observation of the surface activity is not possible, since the very large coma and the dust tails are together the primary and, often, the only source of radiation we can detect. They obstruct a detailed observation of the expulsion of matter out of the cometary surface. For such reason, we need a realistic model to connect the rate of gas and dust expelled to the one observed.

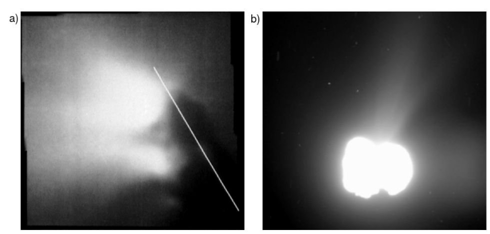

Figure 1: Panel (a): nucleus activity of 1P/Halley comet, observed with the ESA's Giotto spacecraft. Panel (b): nucleus activity of comet 67P/C.G., from OSIRIS camera of probe Rosetta.

2 Modellization of Cometary Activity

2.1 Basic model

A simple model for a cometary jet consists in assuming a comet to be spherical and considering a circular hot active region from which the ice, trapped in the porous rock, sublimates and flows away by dragging a little number of dust grains (typical size ranges from 10^{-7} to 10^{-3} m). The main interaction between dust and gas is given by the drag force i.e. the net momentum impressed by the gas to the surface of the dust grains. According to a simple model in which the grains are spherical, it has been found the following expression for the acceleration impressed to a single dust particle:

$$\vec{a}_d = \frac{\vec{F}_d}{m_d} = \frac{3}{8}\frac{C_D \rho_g |\Delta\vec{v}|}{a\rho_d}\Delta\vec{v}\,. \qquad (1)$$

It depends mainly on the ratio $\frac{\rho_g}{\rho_d}$ between the local gas density and the bulk grain density, on the grain size a, and on the relative velocity of the two components $\Delta\vec{v}$. C_D represents the so called *drag coefficient* (see [6]).

A systematic ejection activity could deplete the surface while forming a crater. The following sublimation of gas from the base of the craters can drive the gas to a preferential direction and, as a result, the jet turns out to be collimated.

2.2 SPH numerical simulations for gas and dust

SPH constitutes a suitable and well-known approach to integrate the fundamental hydrodynamical equations that describe the time evolution of a fluid. The SPH is able to schematize a system by means of a distribution of free points (pseudo-particles) which give a discrete and macroscopic representation of the fluid. The fundamental quantities, like density or pressure gradient, are then evaluated through suitable interpolations over a finite discrete domain. For an exhaustive explanation see, for example, [5].

In a simple framework in which the dust is made of equal-sized grains, it can be coupled to the gas and treated as a second component by using the same basic SPH formalism (see [4]). The dust component is thus represented, like the gas, by a set of interpolating particles. Moreover, if the dust grains constitutes a full non-collisional system, its pressure can be set to zero and thus no equation of state needs to be used. The evolution of the new component is thus described by only its equation of motion, in which the acceleration field is given by a drag term strictly connected with the drag acceleration (equation [1]), and an additional term which depends on the macroscopic local *volume-density* of the dust.

Differently from a Eulerian approach with fixed grids, the Lagrangian SPH methods allow easily to reproduce the shape and density distribution of a system: the higher the density, the more the concentration of points, without introducing any artificial grid. Moreover, during the time evolution, the particles follow the actual motion of the fluid and participates to the local and global density variation. Boundary conditions, like walls, or the flux of gas from a surface with a prefixed velocity, can be included with suitable techniques which adopt static particles (see [3, 2]). All these features turn out to be well appropriate to investigate the surface activity of a comet, in particular for 67P/CG, which is characterized by an irregular surface and for which the geometry of dusty-gas jets can be very complex if compared with the simple spherical models usually adopted for the cometary shape. Fig.1(b) illustrates a shot of the comet during its approach to the internal Solar System (at a distance of 550 km from the Sun) which shows indeed a very irregular shape.

3. Aims and Conclusions

Some examples of applications of the SPH algorithms on gas plus dust multi-fluid are presented. In particular, we aim at focusing our attention on collimated jet emissions from a crater, in which the dynamical evolution of matter is strictly dependent on the environment conditions (shape of the crater, surface temperature) and on the physical properties of dust grains (bulk density and size).

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