Atmospheric entry of fluffy cometary particles under early Earth's conditions

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INTRODUCTION

At the epoch of the Late Heavy Bombardment (LHB), the delivery of complex organic compounds on Earth, necessary for the apparition of life, was likely favored by the fluffy structure of the interplanetary dust of cometary origin (e.g. Lasue et al. , 2007). We have used Direct Simulation Monte Carlo (DSMC) methods (Bird, 1994) to simulate the entry of compact spherical particles and fractal aggregates of spherical grains (representative of fluffy cometary particles found in the interplanetary dust cloud), with a fractal dimension of 2.31, under early Earth's conditions. We performed 2-D calculations at the onset of particle ablation. Particle size varies from 2 mm to 100 µm. Several entry speed have been tested: 12 km.s^{-1} (prograde orbit), 30 km.s^{-1} and 71.5 km.s^{-1} (retrograde orbit). Results show significant differences between compact and irregular particles in terms of temperature distribution.

Methods

We performed our simulations with the Direct Simulation Monte Carlo (DSMC) method implemented by Bird (1994). This method is based on the random generation of representative atmospheric molecules locations and velocities as initial conditions to simulate the evolution of dilute gas flows.
Considering Earth atmosphere as a dilute gas flow at the altitude where the onset of ablation is taking place, the code takes into account the effect of external forces, collisions and interactions of molecules with the particle surface to calculate their subsequent motion. The onset altitude of particle ablation is defined when the molecular mean free path is of the order of the particle size (Öpik, 1958). The simulations were thus done without integrating the physical and chemical modifications that happen during the ablation of the particles (e.g. fusion, ablation, chemical reaction with atmospheric molecules).

Entry parameters :

- **Entry velocity:** 12, 30 or 71.5 km.s^{-1}.
- **Composition of primitive Earth atmosphere:** 100 % CO_2 (e.g. Zahnle et al. 2011).
- **Particle size:** Spheres with radius of 1, 0.5, 0.25, 0.1, and 0.05 mm; aggregates of 8 or 13 spherical grains (in 2-D) with radius of 0.05 mm each.
- **Atmospheric density**: 7.22×10^{20} mol/m^3 .
- **Altitude**: 60 km (onset of particle ablation).

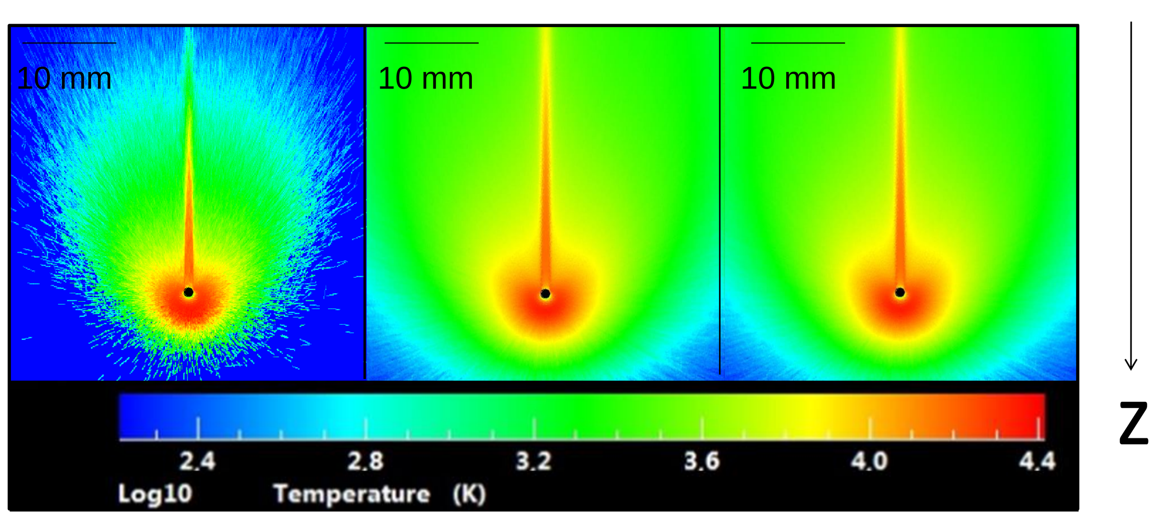

Figure 1: *Simulation evolution until steady state reached.*
Sphere of 1 mm diameter;
Entry velocity : 12 km.s^{-1};
Calculation time (from left to right): 2 h, 26 h, 28 h.

Results and Discussion

Velocity (km.s^{-1}):

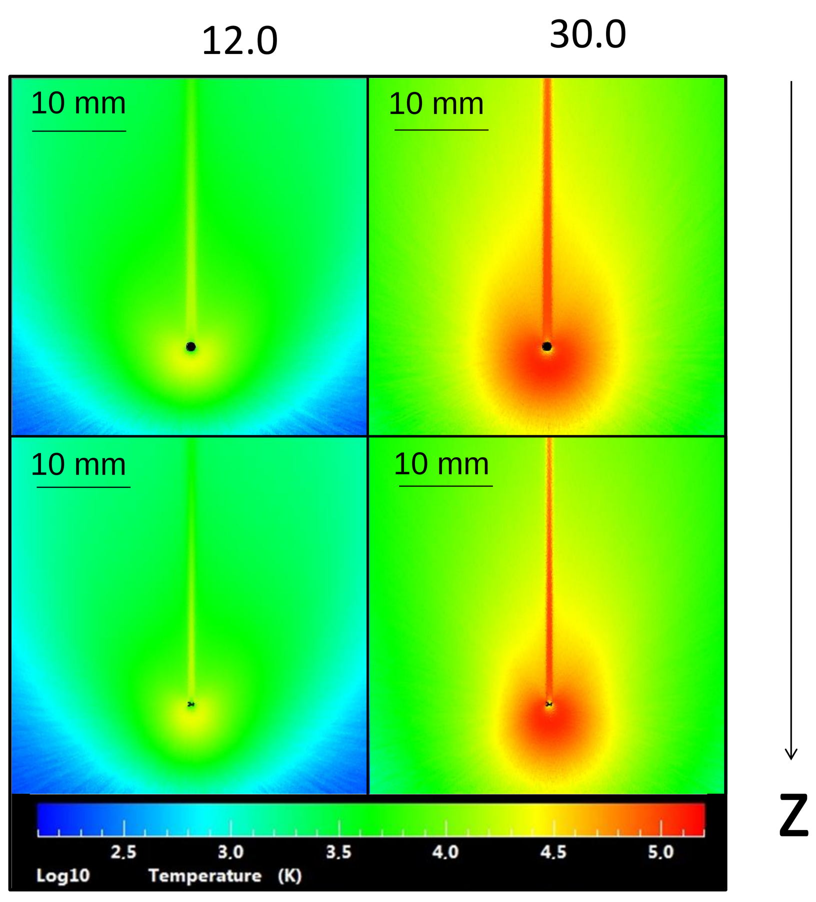

Figure 2: *Comparison between atmospheric entry of a 1 mm diameter sphere and a fractal aggregate of 13 grains of 0.05 mm each (large field of view).*

- As expected, the temperature increases drastically with increasing velocity.
- For a given velocity, for a rather large field of view, the thermal environments are about similar for a sphere and an aggregate, whose gyro-radius is similar than of the sphere. It is not necessary the case in the immediate vicinity of the particle (see figure 3).

Velocity (km.s^{-1}):

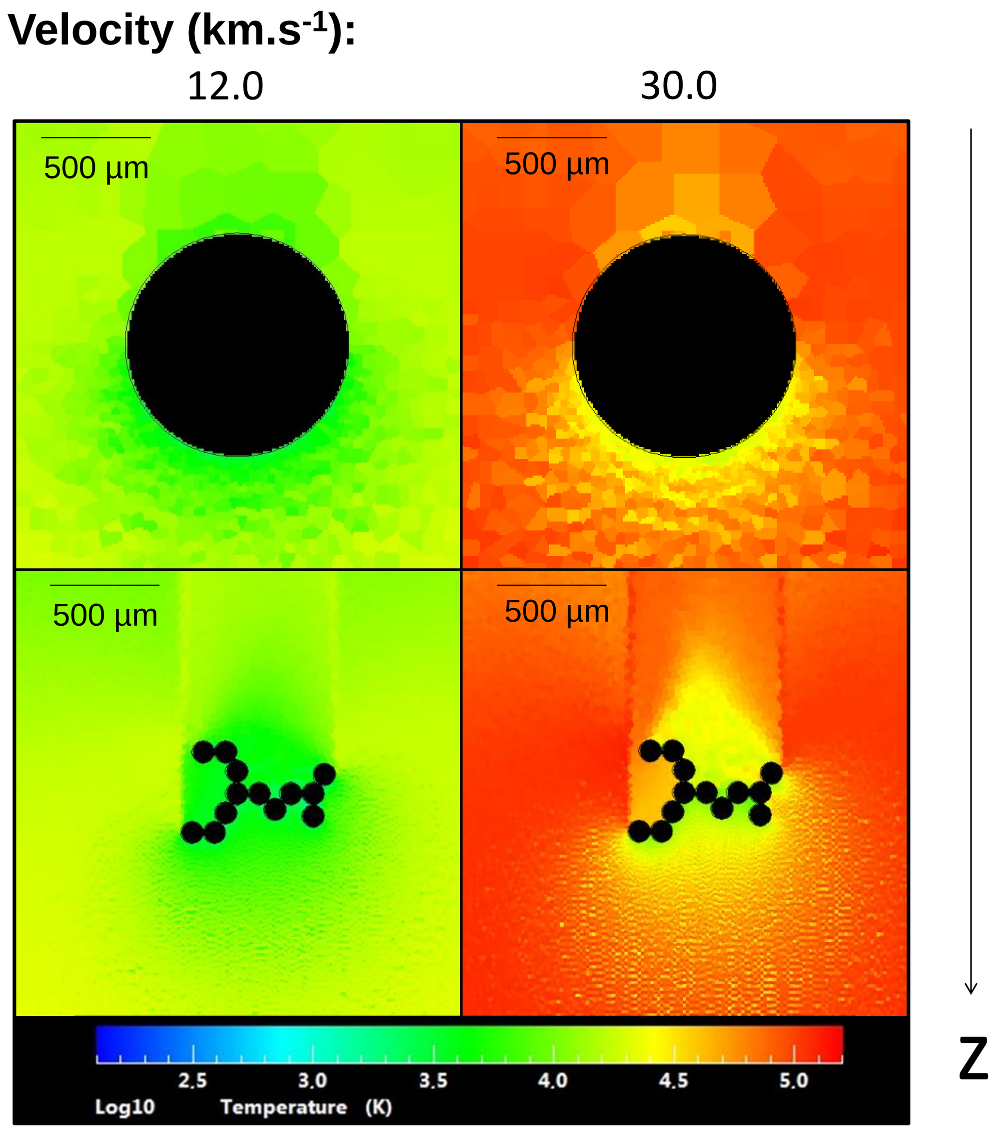

Figure 3: Comparison between atmospheric entry of a 1 mm diameter sphere and a fractal aggregate of 13 grains of 0.05 mm each (zoom on the particle)

Velocity (km.s^{-1}): 12.0 (for all).

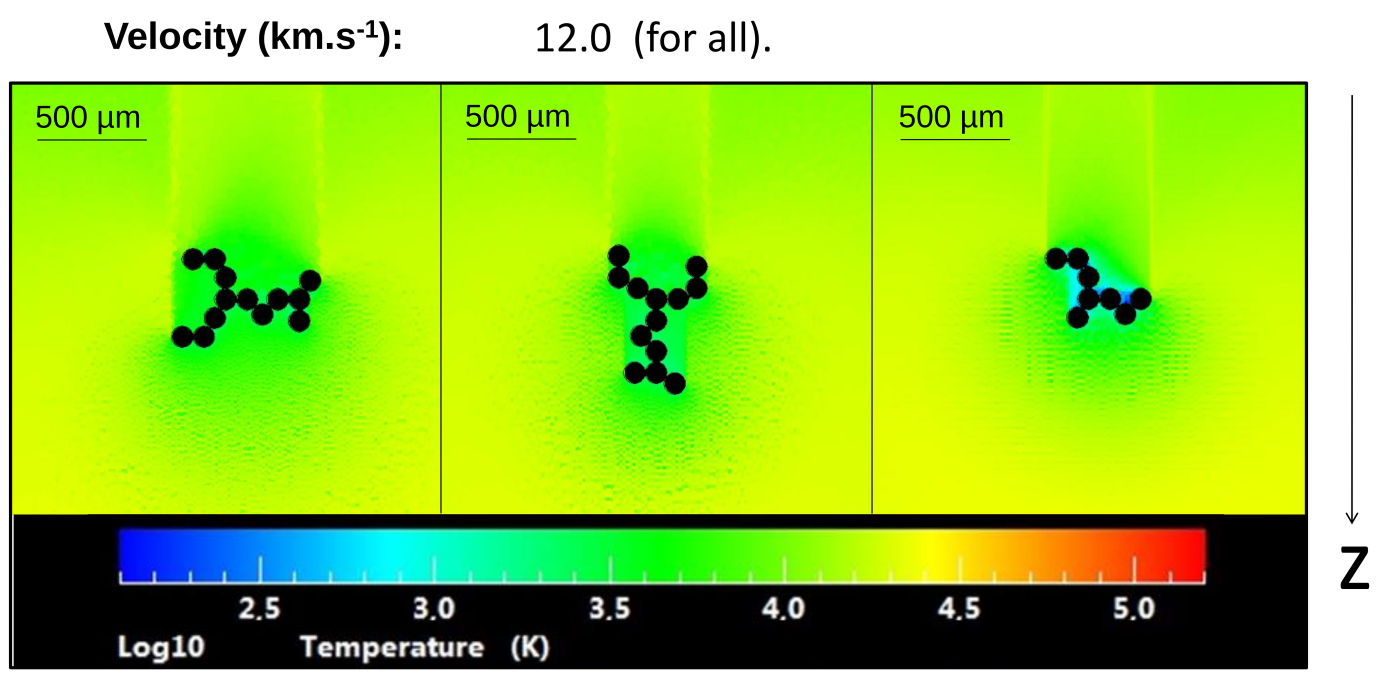

Figure 4: *Comparison between the atmospheric entry (at 12 km/s) of two fractal aggregates of 13 grains, with orientations at 90° from one another, and a fractal aggregate of 8 grains.*

- It may be noticed that gas temperature close to the particle surface is systematically smaller for an aggregate than for a sphere. For an entry velocity of 12 km.s^{-1}, gas temperature close to the surface particle is about 6 000 K for a sphere and about 3 000 K for an aggregate of 13 grains (see figure 3).
- With a different orientation of the particle, temperature close to the surface appears to be similar (see figure 4).
- Typically, for an aggregate of 8 grains, temperature close to the particle surface varies between about 200 and 1000 K (see figure 4). At theses temperatures some organic materials, expected to be present in cometary dust, can survive : for HCN polymers degradation occurs for a temperature higher than 450 K (Fray et al. 2004) ; for amorphous carbon and carbon nitrile, it occurs between 600 and 800 K (Zhang et al. 2002).
- Both aggregates presented here have the same fractal dimension but not the same number of grains. Aggregate of 8 grains is more compact. This shape particularity seems to be more efficient to protect organic material.

CONCLUSION and PERSPECTIVES

Structure of the particles and entry velocity are key parameters to the temperature in the immediate vicinity of the particles. Lower temperatures, which may avoid the destruction of fragile organic compounds, are more easy to obtain with fluffy aggregates than with spheres.

Taking into account the huge amount of dust particles, originating in comets and rich in organic compounds, that have been reaching the early Earth atmosphere, the delivery on Earth's surface of a significant fraction of this organic material is likely to have been favored by the structure of cometary dust (see Levasseur-Regourd et al. 2011).

Simulations for different sizes and fractal dimensions of dust aggregates, leading to even lower temperatures during atmospheric entry, are still to be done.

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