SF2A 2008
C. Charbonnel, F. Combes and R. Samadi (eds)

COLLISION-INDUCED THERMODYNAMIC EVOLUTION OF PLANETESIMALS IN THE PRIMORDIAL EDGEWORTH-KUIPER BELT

Marboeuf, U.[1], Petit, J.-M.[1] and Mousis, O.[1]

Abstract. Kuiper Belt Objects and cometary nuclei are considered to be among the most primitive bodies of the outer Solar system. However, their composition may not reflect that of the primordial planetesimals from which they formed since these latter might have experienced some physico-chemical differentiation, due to the heating of impacts. Here, we examine the implications of collisional effects on the physical and chemical differentiation of the planetesimals located in the primitive Edgeworth-Kuiper Belt by using a cometary nucleus model that ensures conservation of mass and energy during and after the impact. We then discuss the influence of the composition (dust fraction and CO/H_2O ratio) and of the adopted values for heat capacity and conductivity within the matrix. We observe that deep modifications of the physical composition in the planetesimals are only possible in the case of a poorly dusty planetesimal without CO inside the body. In all other cases, variations of the parameters show that collisions induce modifications on the initial physical and chemical composition only in the subsurface layers.

1 Introduction

Kuiper Belt Objects (hereafter KBOs) and cometary nuclei are considered to be among the most primordial objects of the outer solar system. However, 90% of the mass of the Kuiper belt was lost through collisions and ejections by dynamical interactions with Neptune (Stern and Colwell 1997; Leinhardt et al. 2008). Due to the heating generated by collisions during this period, and since they might have experienced some physico-chemical differentiation, the composition of these bodies might not reflect that of the primordial planetesimals. Here, we investigate the post-impact thermochemical evolution of a cometary nucleus located in the outer solar system.

2 Insertion of the collision energy in planetesimals

The nucleus model employed in this work is the 1D model described by Marboeuf et al. (2008). This model takes a sphere (initially homogenous) composed of a porous predefined mixture of water ice and dust with different ices in specified proportions. The collision between the projectile and target is characterized in terms of the fraction f^c of kinetic energy delivered in the form of heat to the target by the impactor itself. We neglect the destruction or erosion which can be caused to the target by the impactor. Original accretion and radioactive heating are also neglected in our calculations. Immediately after collision, impact heat is transfered to the nucleus and its propagation within the cometary nucleus is described following the approach of Orosei et al. (2001) and Mousis et al. (2005). We also assume that the impact strength for a porous icy target impacted by a porous icy projectile is $Q_D^* \leq 5.10^4$ $(J\,.m^{-3})$ (Ryan et al. 1999). This value implies that the largest impactor size cannot exceed $\sim$ 3–5% of the target's one.

3 Choice of the parameters

At the beginning of the computation, the objects share a similar composition. The main physical parameters and initial composition defining our model of planetesimal are standard for comet nuclei. According to Kouchi et al. (1994) and Chick and Cassen (1996), planetesimals of the Kuiper Belt are expected to be formed from

[1] Laboratoire UTINAM, UMR-CNRS 6213, Observatoire de Besancon, 41 bis avenue de l'observatoire, 25010 Besancon France

amorphous ice and the initial temperature is assumed equal to 30 K. The orbital elements (semi-axis $a = 35$ AU, excenticity $e = 0$) are those of a generic member of the primitive Kuiper Belt. The size of the target is assumed to be 10 km and the size of the impactor is set to 300 m (see Sect. 2). Since the composition (dust/ice mass ratio and CO/H_2O mol ratio) and values of the heat capacity and conductivity remain poorly known within planetesimals, we considered a range of plausible values for each of these parameters in order to investigate their influence on the result of collisions. To this end, we adopt $3.T$ and 1200 $J.Kg^{-1}.K^{-1}$ for the heat capacity of the dust's grains (T being the local temperature of the matrix), 10^{-4} and 10 $W.m^{-1}.K^{-1}$ for the heat conductivity of the dust's grains, 0.1, 1 and 10 for the dust/ice mass ratio, and 0 and 10% for the CO/H_2O mol ratio.

4 Results

We have first investigated the influence of different values of the dust's heat capacity on the post-impact evolution of the target. A low dust's heat capacity ($C_d = 3.T J.Kg^{-1}.K^{-1}$) induces the crystallisation of the target's ice on a depth of order 1–2 times the size of the impactor, after one collision, whereas a higher value ($C_d = 1200 J.Kg^{-1}.K^{-1}$) inhibits the crystallisation. In this case, several consecutive impacts are needed in order to start the crystallisation process. In the same time, the value of the heat conductivity of dust's grains, it poorly influences the amplitude of crystallisation in the target. Poor (great) conductivities for dust's grains ($K_d = 10^{-4} W.m^{-1}.K^{-1} / K_d = 10 W.m^{-1}.K^{-1}$) increases (decreases) the depth of crystallisation in the planetesimal. In addition, the choice of the heat capacity, and then of the dust/ice mass ratio, strongly influences the evolution of crystallisation in the target. A small dust/ice mass ratio ($\frac{M_d}{M_i} = 0.1$) in the planetesimals results in the crystallisation of the nucleus for any values of the dust's heat capacity and conductivity, and immediately after the first collision. Inversely, at greater dust/ice mass ratio ($\frac{M_d}{M_i} = 10$), several successive collisions are needed to start the crystallisation within the target's matrix. Moreover the presence of CO in the pores of the planetesimals weakens the alteration of their structure and composition after collisions because it partially absorbs the energy coming from the impacts and crystallisation when it escapes from the nucleus, due to sublimation.

5 Conclusions

We have studied the post-impact thermochemical evolution of a cometary nuclei located in the outer solar system. The composition and the structure of a cometary nucleus can be affected by the choice of its thermodynamic parameter. We observe that deep modifications of the ice's structure in the planetesimals are only possible in the case of a poorly dusty planetesimal ($\frac{M_d}{M_i} = 0.1$) without CO inside the body. In all other cases, variances of the parameters show that the collisions induce modifications on the initial physical and chemical composition only in the subsurface layers.

References

Chick, K. M. and Cassen, P. 1997. Astrophysical Journal 477, 398

Kouchi, A., Yamamoto, T., et al. 1994. Astronomy and Astrophysics 290, 1009-1018

Leinhardt, Z. M., Stewart, S. T., et al. 2008. The Solar System Beyond Neptune 195-211

Marboeuf, U., Petit, J.-M. et al. 2008. Astronomy and Astrophysics, submitted

Mousis, O., Marboeuf, U., et al. 2005. Monthly Notices of the Royal Astronomical Society 362, L40-L44

Orosei, R., Coradini, A., et al. 2001. Advances in Space Research 28, 1563-1569

Ryan, E. V., Davis, D. R., et a. 1999. Icarus 142, 56-62

Stern, S. A. and Colwell, J. E. 1997. Astrophysical Journal 490, 879