PAST THERMAL AND ORBITAL HISTORIES OF 1999JU3 AND 1999RQ36: TWO POTENTIAL TARGETS OF SAMPLE RETURN SPACE MISSIONS TO A PRIMITIVE ASTEROID.

P. Michel and M. Delbo, University of Nice-Sophia Antipolis, CNRS, Observatoire de la Côte d'Azur (Laboratoire Cassiopée, BP 4229, 06304 Nice Cedex 4, France, michelp@oca.eu).

Introduction: Knowledge of physical and chemical properties of small bodies can provide important clues to the composition of the solar nebula in which planets formed. Most asteroids and comets are assumed to be relatively pristine objects, compared to the larger and differentiated planetary bodies, their satellites and the largest asteroids. This is believed to be even more true regarding low-albedo asteroids, generally related to the taxonomic classes C, D and other flat-spectrum types (e.g. B-types). These arguments motivated to propose sample return missions to a primitive asteroid with the goal of bringing back pristine material for laboratory analysis. The Japanese JAXA mission Hayabusa was the first sample return mission launched to an asteroid [1]. It visited the 500 m-long Near-Earth Asteroid (NEA) Itokawa in fall 2005 and succefully returned some sample in June 2010. However, Itokawa belongs to the S taxonomic class, whose composition is not considered as primitive as that of asteroids belonging to dark taxonomic classes (e.g. C, D, B).

The search for asteroids with a primitive and possibly unaltered composition motivated our investigation of the orbital and temperature evolutions of the main current target candidates for a sample return mission to a primitive asteroid. We first determined whether we can link those objects to a potential source region from which they originate. The knowledge of their potential origin can allow us to relate a sample in the laboratory to the asteroid from which it was taken and in turn to relate this body to its history and a source region, providing us a complete picture as never before. Moreover, estimating the radiative heating due to the Sun that potential sample return mission targets may have suffered during their past histories on their surface and at a few centimeters below, is very important for mission planning. This is because it allows us to determine whether a sample collected on either the surface or the subsurface from each target is likely to have undergone high temperature levels which may have altered its pristine properties. Some of the compounds expected to be found on NEOs of primitive composition break up at moderate temperatures, e.g. 300–670 K. Our study can then help deciding also which of these targets is a better candidate for a sample return mission and interpreting the analysis of the sample. We considered several potential targets [2] but here we focus on the asteroid (162173) 1999JU3, that is the target of the Japanese JAXA mission Hayabusa 2 to be launched in 2014-2015, and the asteroid (101955) 1999RQ36, that is the target of the mission OSIRIS-REx proposed to the program New Frontiers of NASA.

Method: Our method consists in combining a Thermo-Physical Model (TPM), allowing us to calculate the temperatures on the asteroid, and a model of the orbital evolution of the asteroid. The latter provides the changes of the perihelion distance (q), which determines the maximum temperature on the asteroid. Indeed, temperatures on asteroids are function of the heliocentric distance, albedo, obliquity of the spin vector, rotation rate (P), and the surface thermal inertia (Γ). The latter controls the rate of the heat flow in the subsurface. For $\Gamma > 0$ there is a delay between the maximum insolation (at perihelion) and the maximum temperature. However, this delay is negligible within the first 5 cm of the subsurface [3].

We ran the TPM at different values of q between 0.05 and 1.0 AU, assuming a spherical shape with the spin vector perpendicular to the object's orbital plane. Other physical property (rotation period, albedo) are taken from real observations of the two considered objects. The emissivity is set to 0.9 (a value in general adopted for asteroid: see e.g. [4]), and a thermal inertia Γ=600 J m^{-2} s$^{-0.5}$ K^{-1} [5]. Boundary conditions of the model assume a flat surface, and therefore we do not consider roughness effects on the surface temperature.

We calculated the temperature at the subsolar point, and the temperature to which 50% of the surface area of the body is heated as a function of q. We also calculated the temperature to which 50% of the area of the sub-surface at depths of 3 and 5 cm is heated. This procedure allowed us to build a set of functions describing the surface and subsurface temperatures as a function of q (see [2], [3], [6], for a detailed description of the adopted procedure).

During the orbital evolution of a NEA, the value of q can undergo great variations. The past orbital history of 1999JU3 and 1999RQ36 cannot be determined by integrating the equations of motion backward in time. A correct approach is rather to integrate the equations of motion of a statistically significant number of particles from their potential source region(s) in the main belt and to observe which of them reach the current object's orbit. This is the approach used by [6] and [7], based on the orbital model of [8]. Using this model, from the orbital evolutions leading to each object's current orbit, we extracted the probability that each object reached a perihelion distance q below a given threshold (q_s) from 0.05 to 1.0 AU and the cumulative time during which each object's orbit had $q \leq q_s$.

Given the temperatures as function of q, the probability that each asteroid had $q \le q_s$ and the total time spent with $q \le q_s$, we calculated the probability that their surface and subsurface were heated above given temperatures and the total time over which these temperatures were reached at perihelion (see Fig. 1 for 1999RQ36). Note that we evaluated the maximum temperatures only: this is because we need to make sure that the temperatures did not reach the break-up temperature of the organics present on their surface and in their subsurface.

Results: We find that 1999RQ36 has a 10% probability of having spent some time with $q \le 0.3$ AU (corresponding to a temperature of 710 K at the subsolar point). The probability becomes greater than 50% for $q \le 0.6$ AU (480 K at the subsolar point), and than 80% for $q \le 0.8$AU (400 K at the subsolar point). Note that at present q =0.8965 AU (371 K at the subsolar point). Figure 1 shows the probability that 1999RQ36 was heated on the surface and in its shallow subsurface above a certain temperature. There is a 20% probability that the surface temperature of 1999RQ36 was ever above 600 K. The probability that 1999JU3 had 50% of its surface heated above 520 K, the temperature of thermal decomposition of organic matter in macromolecules, is of about 40%.

For temperatures below 600 K, the probability rises rapidly. For 1999RQ36, there is 50% and 80% probability that the temperature was 500 K and 450 K, respectively. The probability is ~1 that the surface was heated above 400 K. Figure 2 also shows that the temperatures in the subsurface - at a depth of a few centimeters - are significantly lower than at the surface. For 1999JU3, the probability that 50% of its subsurface at 3 cm depth was heated above 420 K is about 50%. The probability that half of its subsurface was heated above 520 K is about 10%. At 5 cm depth, the material is then strongly protected from the Sun radiative heating.

Our TPM shows that the temperature difference between the surface and the subsurface is a quasi-linear function of the surface temperature. The temperature drop at 5-cm depth is about 50, 70, 90, 100 and 130 K for surface temperatures of, respectively, 400, 450, 500, 550 and 600 K. We can also to estimate the duration with a temperature above a certain threshold at perihelion (see Fig. 1 for 1999RQ36).

Conclusion: Our study suggests that the material of 1999JU3 and 1999RQ36 at depths of 3-5 cm, which is not considered difficult to reach with some of the current designs of sampling devices, has experienced temperatures about 100 K below those at the surface. This is sufficient to protect some organics from thermal break-up.

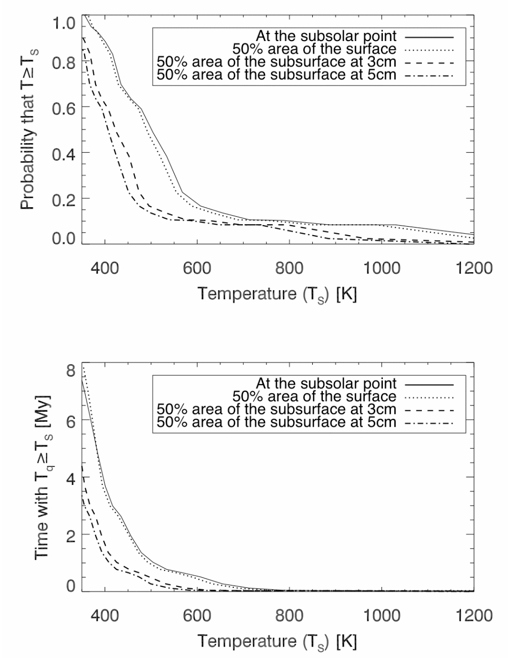

Figure 1: Top: probability that 1999RQ36 was heated to a temperature (T) greater than a given temperature threshold (T_S) in the past. Bottom: the time (in 10^6 yrs) over which $T_q \ge T_S$, where T_q is the temperature at perihelion. Solid line: maximum surface temperature at the equator. Dotted line: probability that 50% of the surface area was heated above a given temperature. Dashed line: same for the sub-surface area at a depth of 3 cm. Dashed-dotted line: same for the subsurface at a depth of 5 cm.

It is also unlikely that water was lost from the dehydroxylation of phyllosilicates at the surface of the asteroids, and even less likely at the subsurface, which is a positive information for sample return missions. Finally, we recall that our estimates are based on the assumption that the same material is constantly located at the same depth, i.e. there is no material turnover. Future studies should address the material motion on the surface and subsurface due, e.g., to seismic vibrations (see [9], and references therein) and its consequences on maximal temperatures.

References: [1] Fujiwara A. et al. (2006) *Science, 312*, 1330-1334. [2] Michel P. and Delbo M. (2010) *Icarus, 209*, 520-534. [3] Delbo M. and Michel P. (2011) *ApJL*, in press. [4] Mustard J. F. and Hays J. E. (1997) *Icarus, 125*, 145-163. [5] Emery J. P. et al. (2010) *LPS XLI*, Abstract #1533. [6] Marchi S. et al. (2009) *MNRAS, 400*, 147–153. [7] Michel P. and Yoshikawa M. (2006) *A&A, 449*, 817-820. [8] Bottke W. F. et al. (2002) *Icarus, 156*, 399-433. [9] Binzel R. P. et al. (2010) *Nature, 463*, 331-334.

Acknowledgments: We thank the French Programme National de Planétologie and the BQR program of the Observatoire de la Côte d'Azur (OCA) for financial support. Computations were performed on the ”Mesocentre SIGAMM” machine, hosted by OCA.