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1I/‘Oumuamua - probably too small to ever be an active comet

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Abstract

The nature of the first interstellar object observed in the Solar System, 1I/‘Oumuamua, was speculated about since its discovery. Though no cometary activity was observed, it was suggested that 1I/‘Oumuamua might be in fact a dormant comet with a thin, devolatilized surface layer. We evaluated this scenario with a simple model of rotational acceleration and stability of cometary nuclei. It turns out that under reasonable physical assumptions cometary origin of 1I/‘Oumuamua can be ruled out.

1. Introduction

On 19 October 2017 the first interstellar object, 1I/‘Oumuamua, was discovered. Immediately after the discovery the object was extensively observed, however, it was discovered already after the closest approach to the Earth and Sun and thus faded quickly. At first, ‘Oumuamua was though to be a comet based on general expectations concerning interstellar bodies, but deep images soon revealed that it did not show any cometary activity [1, 2]. Consequently, it was reclassified as an asteroid. According to models, many more comets than asteroids were ejected from the Solar System shortly after its formation, thus the lack of activity of ‘Oumuamua was surprising. Despite having obviously no cometary activity, reddish color of its surface led to suggestions that ‘Oumuamua might be a dormant comet [3, 4].

2. Model

The loss of mass in a process of sublimation exerts torques on cometary nuclei. The torques changes the rotation rate of cometary nuclei, finally leading to rotational disruption. To test the hypothesis of cometary origin of ‘Oumuamua we employed a model of rotational acceleration and stability of a prolate spheroid as a function of the thickness of the speculated volatile surface lost by sublimation. The model consists of two components. First, for the assumed shape of cometary nuclei, the maximum allowable rotation rate to remain intact is given by:

$$\omega_{\mathrm{c}} = \sqrt{\frac{4}{3}\pi G \rho S + \frac{4T}{\rho R^2}\left(1-\phi^2\right)^{\frac{2}{3}}}, \tag{1}$$

where $G = 6.67384 \times 10^{-11}$ m^3 kg^{-1} s^{-2} is the gravitational constant, T is tensile strength and $\phi = \sqrt{1 - 1/f^2}$ is a function of the long-to-short axis ratio f and S is a shape factor given by:

$$S = \frac{3}{2}\frac{(1-\phi^2)[\ln\left(\frac{1+\phi}{1-\phi}\right) - 2\phi]}{\phi^3} \tag{2}$$

For a spherical body, S approaches unity. Moreover, for a given gas sublimation velocity v and effective moment arm [5] κ measuring acceleration efficiency, a change of rotation rate depends solely on initial and final volume-equivalent radius of nucleus R_1 and R_2 respectively:

$$\omega_2 - \omega_1 = \frac{15}{2} v \kappa \left(\frac{1}{R_2} - \frac{1}{R_1}\right) \tag{3}$$

Thus, the ultimate fate of such a body depends on its shape, density, tensile strength and the effective thickness of the sublimated layer.

3. Results

We assume that maximum allowable rotation rate change is the sum of a rotation rate of ‘Oumuamua $\omega_2 = 2.31 \times 10^{-4}$ s^{-1} corresponding to its measured rotational period of 7.56 hr [2] and maximum allowable rotation rate calculated with equation 1. That represents the most optimistic scenario at which the sublimating body rotated with maximum allowable rotation rate at the beginning of its active phase, decelerated its rotation and started to rotate the opposite direction before the activity deceased. We consider typical asteroid density in the range of 1 - 3 g cm^{-3}, gas expansion velocity $v \sim 250$ m s^{-1} [6] and tensile strength ranging from 0 to 50 Pa, consistent with observations of

Solar System comets [7]. We also assume the final volume-equivalent radius of ‘Oumuamua $R_2 = 75$ m as estimated in [2] and axis ratio between 5 - the smallest value possible for ‘Oumuamua [2] and 10 for less optimistic case. We note that for typical $\kappa \sim 0.04$, derived for comet 9P/Tempel [8] and consistent with model [5], sublimation of layer < 1 meter thick is enough to break the comet nucleus apart even if it has non-negligible tensile strength. Some comets exhibits atypically low acceleration efficiency, e.g. for 103P/Hartley the measurements show $\kappa \sim 0.0004$ [9]. Such an object would sublimate $\sim$ 10 meters before breaking apart. The results are presented in Figure 1.

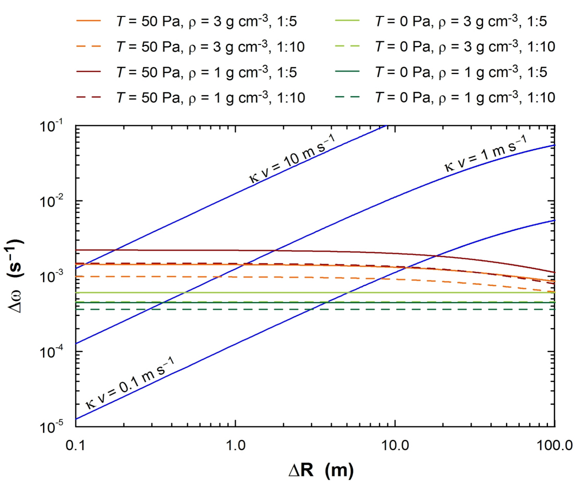

Figure 1: Rotational stability of sublimating minor body under different assumptions on tensile strength, density, axis ratio and acceleration efficiency. Blue solid lines represent change in angular rotation frequency, while orange, brown and green lines represent the critical frequency change for various scenarios.

As previous investigations showed, a typical periodic comet may loose $\sim$ 1 meter [10] of its equivalent surface layer during one perihelion passage, yet we observe periodic comets for dozens of passages (e.g. 1P/Halley or 2P/Encke) and there is no single example of an active comet known to have devolatilized and become dormant. This indicates that in order to build an insulating mantle on cometary nucleus, sublimating surface layer of thickness of a few dozens of meters is not enough. On the other hand, such a loss of matter is much more than needed to rotationally disrupt the object of size and shape of ‘Oumuamua, thus we conclude that 1I/‘Oumuamua has most probably never been an active comet.

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