Spin Evolution and Cometary Interpretation of the Interstellar Minor Object 1I/2017 'Oumuamua

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Abstract

Observations of the first interstellar minor object 1I/2017 'Oumuamua did not reveal direct signs of outgassing that would have been natural if it had a volatile-rich composition. However, a recent measurement by Micheli et al. of a substantial non-gravitational acceleration affecting the orbit of this object has been interpreted as resulting from its cometary activity, which must be rather vigorous. Here we critically reassess this interpretation by exploring the implications of measured non-gravitational acceleration for 'Oumuamua's rotational state. We show that outgassing torques should drive the rapid evolution of 'Oumuamua's spin (on a timescale of a few days), assuming torque asymmetry that is typical for solar system comets. However, given the highly elongated shape of the object, its torque asymmetry is likely higher, implying an even faster evolution. This would have resulted in rapid rotational fission of 'Oumuamua during its journey through the solar system, and is clearly incompatible with the relative stability of its rotational state inferred from photometric variability. Based on these arguments, as well as the lack of direct signs of outgassing, we conclude that the classification of 'Oumuamua as a comet (invoked to explain its claimed anomalous acceleration) is questionable.

Key words: minor planets, asteroids: general – minor planets, asteroids: individual ('Oumuamua) – planetary systems

1. Introduction

The discovery of 1I/2017 'Oumuamua (Meech et al. 2017)—the first macroscopic interstellar object passing through the solar system—by the Pan-STARRS survey (Chambers et al. 2016) gave rise to a number of questions and theories of its origin (Hansen & Zuckerman 2017; Trilling et al. 2017; Ćuk 2018; Jackson et al. 2018; Rafikov 2018a; Raymond et al. 2018). The physical characteristics of 'Oumuamua, namely its composition—refractory or volatile-rich—play a central role in this debate.

'Oumuamua was found to not exhibit the standard, obvious signs of cometary activity (Jewitt et al. 2017b; Knight et al. 2017; Meech et al. 2017; Ye et al. 2017; Fitzsimmons et al. 2018): outgassing, the formation of coma and dust tails, cometary emission lines, etc. Its colors suggest that 'Oumuamua might be a volatile-rich object that suffered long exposure to cosmic rays. Nevertheless, until recently it was mainly the formation arguments (rooted in the idea that it is easier to eject material from the outer, cold regions of the planetary systems) that motivated the possibility of volatile-rich composition for 'Oumuamua (Laughlin & Batygin 2017).

Recently, this hypothesis has received additional (albeit indirect) support. Micheli et al. (2018) used long-term astrometric measurements of 'Oumuamua's orbit to claim the detection of a substantial non-gravitational acceleration affecting its motion. This acceleration is predominantly radial, and has been modeled reasonably accurately by Micheli et al. (2018) as a function of distance r from the Sun (in the range 1 au $< r <$ 3 au) as

$$a_{ng}(r) = A_1 g(r), \quad g(r) = r_1^{-2},$$
$$A_1 \approx 5 \times 10^{-4} \text{ cm s}^{-2} = 2.5 \times 10^{-7} \text{ au day}^{-2}, \quad (1)$$

where $r_1 = r/1$ au.

Anomalous accelerations (unaccounted for by the Solar gravity) are known to affect orbits of many solar system comets (Królikowska 2004; Szutowicz et al. 2008). They are naturally ascribed to the reactive force due to mass loss (outgassing) powered by Solar heating. For this reason, the discovery of the anomalous acceleration of 'Oumuamua led Micheli et al. (2018) to conclude that it must be a volatile-rich object capable of exhibiting cometary activity. At the same time, no other more direct manifestations of the cometary activity of 'Oumuamua were found by either Micheli et al. (2018) or others. To reconcile these mutually exclusive lines of evidence, Micheli et al. (2018) had to suggest a rather exotic scenario, in which mass loss occurs mainly in the form of gas (with almost no ejection of small dust particles) with a composition that is very different from that of the solar system comets.

In this Letter we explore the implications of the claimed substantial non-gravitational acceleration of 'Oumuamua for its rotational state. The observed spin state of 'Oumuamua is far from trivial (see Section 2); however, the most recent observations find its rotational period to remain close to 8 hr over a month-long interval (Bannister et al. 2017; Belton et al. 2018; Bolin et al. 2018; Drahus et al. 2018; Fraser et al. 2018). In this Letter we find that, given the magnitude of the claimed non-gravitational acceleration of 'Oumuamua, this stability of its spin period is highly unusual (Section 3.1). This observation represents yet another argument putting into question the interpretation of 'Oumuamua as a comet. Our calculations make extensive use of the recent results (Rafikov 2018b) on the connection between the outgassing-driven spin evolution and non-gravitational acceleration of solar system comets (Section 3).

2. Rotational State of 'Oumuamua

Here we provide a brief overview of existing results on the spin state of 'Oumuamua. Initial measurements of its photometric variability by different groups did not find a well-defined spin period P for this object, suggesting values in the interval 6.8–8.7 hr (Bannister et al. 2017; Bolin et al. 2018; Drahus et al. 2018; Fraser et al. 2018). This ambiguity is caused by the tumbling motion of 'Oumuamua—its non-principal axis rotation, which complicates the interpretation of its photometric variability. More recently, Belton et al. (2018) analyzed different photometric data sets spanning about a month in duration (from 2017 October 25 to 2017 November 23) and found a set of prominent frequencies in these time series. The dominant period of (8.67 ± 0.34) hr was associated by Belton et al. (2018) with the precession of the 'Oumuamua's long axis. Other periodicities, representing nutation and rotation around the long axis, depend on the interpretation of the dominant mode of the 'Oumuamua's rotation (long or short axis modes).

In this Letter we adopt the conventional interpretation of 'Oumuamua as being in the short axis mode of rotation (Jewitt et al. 2017b; Meech et al. 2017; Bolin et al. 2018). In this case, the high amplitude of its photometric variability is explained by 'Oumuamua's unusual, highly elongated shape. We describe it as a highly prolate ellipsoid with semi-axes (for albedo $p = 0.1$) $a \times b \times c = 230\,\mathrm{m} \times 35\,\mathrm{m} \times 35\,\mathrm{m}$ (Jewitt et al. 2017b). For simplicity, we ignore the complications related to the excited spin state of 'Oumuamua and approximate it as rotation around its short axis with period $P = 8.67$ hr. The moment of inertia relative to this axis should be close to $I = (1/5)M(a^2 + b^2)$, where M is the object mass.

3. Spin Evolution due to Cometary Activity

Our goal is to understand the impact of comet-like outgassing, invoked by Micheli et al. (2018) to explain the non-gravitational acceleration $\boldsymbol{a}_{\mathrm{ng}}$ of 'Oumuamua, on its spin state. Torques due to outgassing can lead to changes of the direction (Whipple & Sekanina 1979) and magnitude (Keller et al. 2015) of the spin. The latter has been measured for a number of solar system comets as the variation of their spin period (Mueller & Ferrin 1996; Belton et al. 2011; Knight et al. 2012; Mottola et al. 2014; Bodewits et al. 2018). Both $\boldsymbol{a}_{\mathrm{ng}}$ and spin evolution are driven by the same underlying mechanism (outgassing), so it is natural to expect that the two outcomes are related in some way.

Rafikov (2018b) has explored this connection by hypothesizing that the projection of the torque on the instantaneous spin axis of the comet T_Ω is related to the magnitude of the non-gravitational force F_{ng} via an "effective lever arm" ζD as

$$T_\Omega = \zeta D F_{\mathrm{ng}}, \tag{2}$$

where D is the characteristic dimension of the object (e.g., radius for roughly spherical objects), and ζ is the dimensionless "lever-arm" coefficient. This simple but intuitive prescription transforms the equation $I\dot{\Omega} = T_\Omega$ for the evolution of spin frequency Ω (I being the moment of inertia with respect to spin axis) into (Rafikov 2018b)

$$\dot{\Omega} = \zeta \frac{DM}{I} a_{\mathrm{ng}}, \tag{3}$$

where $a_{\mathrm{ng}} = \boldsymbol{a}_{\mathrm{ng}}$ is the magnitude of the non-gravitational acceleration, $\boldsymbol{a}_{\mathrm{ng}} = \boldsymbol{F}_{\mathrm{ng}}/M$.

Introduction of the dimensionless lever-arm parameter ζ effectively absorbs our ignorance of many aspects of the cometary outgassing: geometry of mass loss, shape of the object, etc. Some symmetric models of mass loss, for example, those with the reactive force passing through the rotational axis of the object at every point on the surface (Whipple & Sekanina 1979; Sekanina 1984), naturally result in $\zeta = 0$. On the other hand, if the reactive force is constant in magnitude and always normal to the surface, then $\boldsymbol{F}_{\mathrm{ng}}$ is identically zero, while T_Ω does not have to vanish if the comet has irregular shape, meaning $\zeta \to \infty$.

Rafikov (2018b) used Equation (3) to determine the values of ζ for seven comets, which have measurements of both spin rate change per orbit $\Delta\Omega$ and non-gravitational acceleration a_{ng}. He found a strong linear correlation between $\Delta\Omega$ and a_{ng} (the radial dependence of a_{ng} was modeled using the conventional prescription of Marsden et al. 1973). The basic characteristics of the distribution of $\log\zeta$ for this sample (mean and dispersion) are Rafikov (2018b)

$$\langle \log\zeta \rangle = -2.21, \qquad \sigma_{\log\zeta} = 0.54, \tag{4}$$

implying a rather small spread. The values of ζ corresponding to $\langle \log\zeta \rangle$, and $\langle \log\zeta \rangle \pm \sigma_{\log\zeta}$ are quite low: $\zeta = 0.006$, 0.0017, and 0.021, respectively. Note that because $\Delta\Omega$ is an integral characteristic (change of Ω accumulated over the full orbit), the values of ζ determined in this way effectively represent averages of instantaneous ζ defined by Equation (2) over an orbit.

3.1. Spin Evolution of 'Oumuamua

Encouraged by the results of Rafikov (2018b), we now apply this framework for assessing the spin period variability of 'Oumuamua. More specifically, we use the measurement of its non-gravitational acceleration to estimate the spin rate change $\Delta\Omega$ accumulated along its trajectory through the solar system. While this exercise is very similar to what has been done in Rafikov (2018b), there are a couple of important differences.

First, unlike solar system comets, 'Oumuamua moves on a hyperbolic trajectory. To characterize its motion through the solar system we adopt the velocity at infinity $v_\infty = 26\,\mathrm{km\,s}^{-1}$ and periastron distance $r_p = 0.26$ au. Conservation of energy and angular momentum leads to the following expression for the radial velocity v_r at a distance r from the Sun:

$$v_r(r) = v_\infty r^{-1}\sqrt{(r - r_p)[r + r_p(1 + \Theta)]}, \tag{5}$$

where $\Theta = 2GM_\odot/(r_p v_\infty^2) \approx 10.2$. At 1 au the radial velocity of 'Oumuamua is $v_r(1\,\mathrm{au}) = 44\,\mathrm{km\,s}^{-1}$.

Second, the non-gravitational acceleration of comets is usually modeled using the radial profile of a_{ng} suggested by Marsden et al. (1973), which is motivated by the expected rate of sublimation of water ice. At the same time, the fit to the astrometric data attempted by Micheli et al. (2018) used a non-standard expression for the function $g(r)$, which is different from that of Marsden et al. (1973), see Equation (1).

Keeping this in mind, we now go back to Equation (3). It is natural to associate the characteristic dimension D of 'Oumuamua with its long semi-axis a. Substituting the expression (1) into Equation (3) and using moment of inertia

I around its minor axis (see Section 2), one finds

$$\dot{\Omega} = 5\zeta \frac{A_1 a}{a^2 + b^2} r_1^{-2}. \qquad (6)$$

Integrating this equation over $dt = dr/v_r$ from $r = r_p$ to $r = \infty$ using the expression (5) and doubling the result (to account for both the incoming and outgoing parts of the trajectory), one finds the full change of the spin rate of 'Oumuamua during its passage through the solar system to be

$$\Delta\Omega = \zeta \Delta\Omega_1. \qquad (7)$$

Here

$$\Delta\Omega_1 = 10 \frac{(\mathrm{au})^2 A_1 a}{(a^2 + b^2) v_\infty r_p} \int_1^\infty \frac{x^{-1} dx}{\sqrt{(x-1)(x+1+\Theta)}}$$
$$\approx 3.62 \ \mathrm{s}^{-1}. \qquad (8)$$

is the value of the spin rate change if the lever-arm parameter ζ were equal to unity.

This calculation assumes that the $a_{\mathrm{ng}}(r)$ profile given by Equation (1) holds along the full orbit of 'Oumuamua through the solar system. However, this fit was established by Micheli et al. (2018) using astrometric data acquired only between 1 and 3 au. Thus, it makes sense to also evaluate the change of Ω accumulated over just this outgoing portion of the orbit. Proceeding analogous to the calculation of $\Delta\Omega$ (but integrating only between 1 and 3 au), one finds

$$\Delta\Omega^{(1-3)\,\mathrm{au}} = \zeta \Delta\Omega_1^{(1-3)\,\mathrm{au}}, \qquad \Delta\Omega_1^{(1-3)\,\mathrm{au}} = 0.27 \ \mathrm{s}^{-1}. \qquad (9)$$

Let us now assume for simplicity that the value of the 'Oumuamua's dimensionless lever arm ζ is comparable to that found for the solar system comets (this is a very conservative assumption given the object's highly asymmetric shape; see Section 4). Then, adopting $\zeta = 10^{\langle \log \zeta \rangle}$ (see Equation (4)), one finds

$$\Delta\Omega = 0.022 \ \mathrm{s}^{-1}, \qquad \Delta\Omega^{(1-3)\,\mathrm{au}} = 0.0016 \ \mathrm{s}^{-1}. \qquad (10)$$

These values correspond to spinning up an initially non-rotating object to very short periods of ≈ 5 minutes and ≈ 1 hr, respectively.

4. Implications for 'Oumuamua

It is clear that both $\Delta\Omega$ and $\Delta\Omega^{(1-3)\,\mathrm{au}}$ are very large. To better put these values into context, we compare our expectations for the spin evolution of 'Oumuamua with a large sample of solar system comets previously studied by Rafikov (2018b). Figure 1 shows $\Delta\Omega_1$ computed for a sample of 209 solar system comets with measured non-gravitational accelerations. The data on A—amplitude[3] of a_{ng} at 1 au, orbital parameters, and sizes (when available, filled symbols; for objects with no size information we assign a radius of 10 km, open symbols) of comets come from the JPL Small Body Database.[4] Green dots at the very top of the plot represent $\Delta\Omega_1$ and $\Delta\Omega_1^{(1-3)\,\mathrm{au}}$, correspondingly, see Equation (10). This figure is similar to Figure 3 of Rafikov (2018b).

One can see that 'Oumuamua's spin rate change per orbit $\Delta\Omega_1$ (green hexagon) exceeds that of any solar system object. This makes this interstellar object unique in yet another

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[3] Calculation of $\Delta\Omega_1$ for these comets uses the $g(r)$ profile from Marsden et al. (1973).
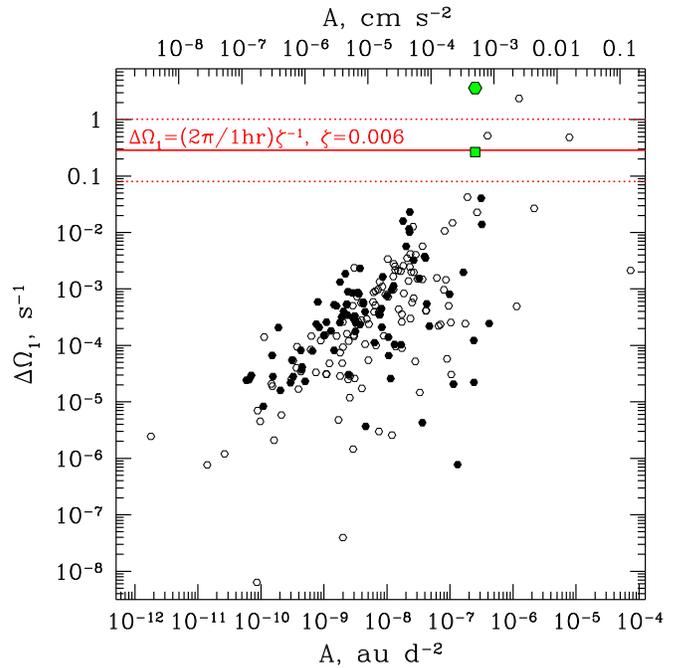[4] https://ssd.jpl.nasa.gov/?comets

Figure 1. Change of the spin rate due to non-gravitational forces accumulated over a single orbit $\Delta\Omega_1$ (assuming the lever-arm parameter $\zeta = 1$), computed for a sample of 209 solar system comets with available data on the amplitude of the non-gravitational acceleration. This parameter measures object's potential for rapid spin evolution; A is the normalization of a_{ng} at 1 au, assuming $a_{\mathrm{ng}}(r)$ profile from Marsden et al. (1973). Filled hexagons represent objects with measured sizes; empty ones have no size information available and we set radius $R = 10$ km for them. The green hexagon and square represent 'Oumuamua (we set $A = A_1$ for it) and correspond to $\Delta\Omega_1$ and $\Delta\Omega_1^{(1-3)\,\mathrm{au}}$. The horizontal solid curve describes a rotation rate change of 2π hr^{-1} (i.e., spin-up to 1 hr period from a non-rotating state) for $\zeta = 0.006$ (corresponding to the mean of $\log \zeta$); dashed lines illustrate 1σ deviation in $\log \zeta$ (see Equation (4)). See the text for more details.

category. Its value of $A = A_1$, non-gravitational acceleration at 1 au, is also among the highest in our sample (Micheli et al. 2018). Even considering the change of Ω between 1 and 3 au (i.e., $\Delta\Omega_1^{(1-3)\,\mathrm{au}}$; green square), 'Oumuamua still ends up squarely among a handful of objects that are most susceptible to spin variations. Only three comets (discussed in detail in Rafikov 2018b) have $\Delta\Omega_1$ larger than $\Delta\Omega_1^{(1-3)\,\mathrm{au}}$.

To put these comparisons into absolute terms, we assume for now that 'Oumuamua's outgassing asymmetry is not too different from that of the solar system comets and set $\zeta = 0.006$, corresponding to the mean of $\log \zeta$ found in Rafikov (2018b, see Equation (4)). This allows us to relate $\Delta\Omega_1$ in Figure 1 to the actual spin rate variation $\Delta\Omega = \zeta \Delta\Omega_1$.

An important value of $\Delta\Omega$ is the one that would result in the rotational fission of an object. Using the results of Davidsson (2001) we find that, in the absence of internal strength (i.e., if the object is held by gravity alone), rotational breakup of 'Oumuamua would happen at a longer critical period $P_{\mathrm{crit}} \approx 9.8$ hr (for bulk density of 1 g cm^{-3}) than for a spherical object with the same density and mass, for which $P_{\mathrm{crit}} \approx 3.3$ hr (see also Meech et al. 2017 and McNeill et al. 2018). This is a consequence of the highly elongated shape of 'Oumuamua. However, if we account for the non-zero tensile strength of the object according to the prescription of Davidsson (2001), we find $P_{\mathrm{crit}} < 1$ hr.

Unfortunately, neither density nor tensile strength are known for 'Oumuamua. For this reason we opted to assume, rather

conservatively, that breakup happens at spin period of $P_{crit} = 1$ hr (although the critical period is likely longer). An object starting out as slowly spinning would need to acquire $\Delta\Omega = 2\pi P_{crit}^{-1} = 2\pi$ hr^{-1} to get to P_{crit}. The corresponding value of Ω_1, assuming $\zeta = 0.006$, is shown as a horizontal solid line in Figure 1. Dotted lines correspond to values of ζ deviating from $10^{\langle\log\zeta\rangle}$ by $\sigma_{\log\zeta}$ (see Equation (4)).

One can see that 'Oumuamua's $\Delta\Omega_1$ exceeds the limit of rotational fission (even when the low value of $\zeta = 0.0017$ is adopted). Even spin-up between only 1 and 3 au would still get the rotation period down to P_{crit} (the green square falls on top of the horizontal solid line). Thus, outgassing-driven spin evolution of 'Oumuamua is expected to result in its rotational fission at some point along its orbit, as has been observed for some solar system objects (Jewitt et al. 2016, 2017a).

Another useful way to characterize the spin variability of 'Oumuamua is via its instantaneous rotational evolution timescale $\tau_\Omega = |\Omega/\dot\Omega|$. Using Equation (6) we can write τ_Ω as

$$\tau_\Omega = \frac{2\pi}{5\zeta}\frac{a^2 + b^2}{PaA_1}r_1^2 \approx 4\ \frac{0.006}{\zeta}r_1^2\ \text{day}, \qquad (11)$$

where $P = 2\pi/\Omega = 8.67$ hr is the adopted rotation period of 'Oumuamua.

Alternatively, by looking in some detail at the actual physics of outgassing, Jewitt (1997) suggested the following expression for the spin evolution timescale:

$$\tau_\Omega \approx \frac{I\Omega}{k_T D\dot M v_{th}}, \qquad (12)$$

where $\dot M$ is the mass loss rate due to outgassing, and v_{th} is the speed of escaping gas (as before I and D are the moment of inertia and characteristic size). The dimensionless asymmetry parameter k_T is closely related to our lever-arm parameter ζ; $k_T = 1$ and 0 for purely tangential and central mass loss, respectively.

Jewitt (1997) advocated using $k_T = 0.05$. Adopting this value, as well as $v_{th} = 0.5$ km s^{-1} and $\dot M = 10^4$ g s^{-1}, used by Micheli et al. (2018) to explain the high value of a_{ng} for 'Oumuamua, we find $\tau_\Omega \approx 14$ hr. This is almost an order of magnitude lower than the estimate (11). This discrepancy suggests that $k_T = 0.05$, adopted by Jewitt et al. (2017b), is a significant overestimate of the asymmetry of outgassing, something that has been noted already by Rafikov (2018b). A different estimate $0.005 < k_T < 0.04$ obtained by Belton et al. (2011) based on observations of 9P/Tempel 1 leads to better quantitative agreement between the estimates (11) and (12).

Regardless of the method used to derive τ_Ω, its short value again implies that the spin period of 'Oumuamua should be changing very rapidly. Based on (11), for $\zeta = 0.006$ one expects a change of P of more than an hour to occur in less than a day! Within several weeks torques due to outgassing should have spun 'Oumuamua up to breakup. However, obviously this has not happened.

Moreover, despite the complications related to the tumbling motion of 'Oumuamua, the most recent analysis (Belton et al. 2018) of its photometric variability using observations extended over a period of about a month reports $P = 8.67$ hr, close to many previous determinations (Bannister et al. 2017; Bolin et al. 2018; Drahus et al. 2018; Fraser et al. 2018). If we interpret the formal uncertainty of this measurement (±0.34 hr) as resulting from outgassing-driven spin variability, then this

would imply $\tau_\Omega \gtrsim 2$ year, much longer than suggested by our estimate (11).

A naive way to resolve this discrepancy is to suppose that $\zeta = 0.006$, adopted in our calculations (Rafikov 2018b), is an overestimate of 'Oumuamua's lever-arm parameter. However, according to Equation (11), to get τ_Ω up to 2 year would require $\zeta \approx 3 \times 10^{-5}$, an extremely small value. The physical size of the corresponding lever arm would then be $\zeta D \approx 0.7$ cm for the object's size $D = a = 230$ m. Such a degree of symmetry, resulting in an almost complete cancelation of the torques while leaving a substantial linear acceleration a_{ng}, is highly improbable. In fact, based on the lack of solar system comets with very high values of $\Delta\Omega_1 \gtrsim 1$ s^{-1} (see Figure 1) Rafikov (2018b) has argued for the existence of a lower limit on ζ of about 10^{-3}, still much higher than the value quoted above.

Moreover, given the extreme elongation of 'Oumuamua compared to the vast majority of the solar system objects, one should, in fact, expect its ζ to be substantially higher than $10^{\langle\log\zeta\rangle} = 0.006$ typical for the solar system comets. This would reduce τ_Ω given by Equation (11), further increasing tension with the observed lack of spin evolution for this object.

Belton et al. (2018) raised the possibility that 'Oumuamua may be a highly oblate spheroid in a long-axis mode of rotation. This would not change our spin-up timescale estimate (11) and other conclusions appreciably as the moment of inertia for this rotational state is essentially the same as for a cigar-shaped object spinning around its short axis. One could also argue that 'Oumuamua's tumbling motion represented by precession around the long axis (if it is cigar-shaped) with a period of ≈54.5 hr (Belton et al. 2018) would result in a periodic torque flip, slowing down (or at least complicating) the object's evolution toward rotational breakup. However, the period of such precession is comparable to τ_Ω given by the Equation (11), so that variations of 'Oumuamua's spin period should have been observable even during a single precessional cycle. Also, the period of precession around the long axis would be changing rapidly as well (given the low moment of inertia around this axis), likely resulting in a very chaotic evolution of the spin, which is not supported by observations (Belton et al. 2018).

Our conclusions are also relatively robust with respect to the uncertainties in the determination of various parameters of 'Oumuamua. For example, they are insensitive to its bulk density, which is essentially unknown. Also, the dimensions of the object scale with its (unknown) albedo p as $\propto p^{-1/2}$. Thus, a change of an adopted value of p by a factor of 4 would result in variation of our estimates (8) and (11) by only a factor of 2. This would have little effect on our conclusions.

The calculations presented in this Letter make it obvious that the large magnitude of the observed anomalous acceleration of 'Oumuamua is difficult to explain via its cometary activity, i.e., by intense outgassing from its surface. Our arguments against cometary activity as the driver of the anomalous acceleration of 'Oumuamua are quite fundamental and are based on the conservation of angular momentum[5] for this object. The high intensity of outgassing implied by the measurement of a_{ng} by Micheli et al. (2018) is also in drastic contrast with the lack of clear signs of mass loss from 'Oumuamua, despite multiple targeted observations aimed at addressing this issue (Jewitt et al. 2017b; Knight et al. 2017; Meech et al. 2017; Ye et al. 2017). As

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[5] Similar arguments are independently advanced by Guzik & Drahus in their abstract (301.05) for the upcoming DPS meeting.

a result, we believe that the classification of 'Oumuamua as an interstellar asteroid (rather than a comet) is more robust and justified by observations at the moment. The puzzle of its anomalous acceleration would need to be resolved without invoking powerful outgassing from its surface (we do not suggest an alternative mechanism in this Letter).

This conclusion would have significant implications for understanding the origin of this unique object. Indeed, refractory asteroids are far more difficult to detect than the volatile-rich, cometary objects (Engelhardt et al. 2017). The asteroidal nature of 'Oumuamua would imply that refractory asteroids dominate the Galactic population of free-roaming 0.1–1 km objects, in agreement with some theories for the origin of 'Oumuamua (Ćuk 2018; Rafikov 2018a).

5. Summary

In this Letter we have explored the implications of a recent measurement of non-gravitational acceleration a_{ng} of the interstellar minor object 'Oumuamua (Micheli et al. 2018) for its rotational state. Our main conclusions are as follows.

1. Torques caused by outgassing (the same process that gives rise to the claimed a_{ng}) should drive rapid spin evolution of 'Oumuamua on a characteristic timescale of several days. This conclusion assumes that reactive torques and a_{ng} are related via the dimensionless lever-arm parameter typical for the solar system comets, $\zeta = 0.006$ (Rafikov 2018b).
2. Such a fast spin evolution is incompatible with the observed stability of the object's spin rate on month-long timescales. Matching observations would require extreme degree of symmetry of outgassing (leading to torque cancellation), $\zeta \lesssim 3 \times 10^{-5}$, which is implausible.
3. Moreover, given the amplitude of its claimed non-gravitational acceleration, 'Oumuamua should have been spun up to the limit of rotational fission and fragmented during its travel through the solar system.
4. The fact that this did not happen, as well as the observed spin stability of 'Oumuamua, both strongly argue against its cometary activity (i.e., powerful outgassing from its surface), which was invoked to explain its claimed a_{ng} in the first place (Micheli et al. 2018).

Based on these arguments, as well as the lack of direct indicators of outgassing, we conclude that the classification of 'Oumuamua as a volatile-rich comet is dubious and raises more questions than it provides explanations. We encourage further analyses of the astrometric data to better characterize its anomalous acceleration (Micheli et al. 2018). Settling the issue of whether this unique object has asteroidal or cometary composition is crucial for understanding its origin (Rafikov 2018a).

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