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‘Oumuamua’s Geometry Could be More Extreme than Previously Inferred

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‘Oumuamua, the first known interstellar object detected in the Solar System, was discovered by the Pan-STARRS telescope (Meech et al. 2017; Micheli et al. 2018). Photometry of ‘Oumuamua was conducted over Oct. 25-30 and Nov. 21-23, 2017 (Meech et al. 2017; Belton et al. 2018).

Conventionally, the axis ratio of ‘Oumuamua has been quoted to be between 6:1 and 10:1 for a constant albedo, due to the differences between the brightest and dimmest phases of the object in the Oct. 25-30, 2017 observations (Trilling et al. 2018; Meech et al. 2017).

However, this conclusion neglects the reported 1 magnitude brightening between the averaged Oct. observations and the averaged Nov. observations, which included corrections for helio- and geocentric distances and solar phase angle, assuming isotropic uniform albedo and the canonical phase function slope value for cometary and D-class objects of -0.04 magnitude per degree (Belton et al. 2018). Here we study the implications of the reported 1 magnitude brightening of ‘Oumuamua. We note that, since the full light curve was not sampled in the Nov. observations, the minima may be missing, which would signify an actual brightening of less than 1 magnitude.

The solar phase angle only changed by 7° between Oct. 25 and Nov. 23, so an imperfect correction of the phase effect as an explanation for the reported brightening would necessitate extreme variations in surface geometry. Here, we focus on the implications of the changing viewing geometry, since no corrections were made for viewing geometry in Belton et al. (2018).

The viewing geometry of ‘Oumuamua relative to the Earth between Oct. 25 and Nov. 23, 2017, is shown in Table 1. Since the viewing angle changes rapidly between Oct. 25 and Oct. 30, we compare the viewing angle at the midpoint, Oct. 27, to the viewing angle at Nov. 22, resulting a change in viewing angle of only 11°.

‘Oumuamua’s excited spin could be a long axis mode state, in which case low rotational energy corresponds to a ‘cigar-like’ geometry and high rotational energy implies a ‘pancake-like’ geometry (Belton et al. 2018).

The fact that the viewing angle did not change drastically implies that the brightest phase of ‘Oumuamua became ~ 2.5 times brighter between Oct. 27 and Nov. 22, 2017.

We first explore the implications of a 1 magnitude brightening on a ‘pancake-like’ geometry, assuming isotropic uniform albedo. We compute θ, the viewing angle of ‘Oumuamua on Oct. 27, 2017, where $\theta = 90°$ describes a ‘face-on’ orientation and $\theta = 0°$ describes an ‘edge-on’ orientation relative to the line-of-sight. We attribute all of the observed brightening to the change in orientation of the ‘face,’ obtaining a upper bound on θ, and therefore a lower bound on the axis ratio. Since we are considering an object with a two-dimensional maximum ‘face,’ each axis needs to grow by $\sqrt{2.5}$ in order to explain a brightening of ~ 2.5 times,

$$\frac{\sin(\theta + 11°)}{\sin(\theta)} = \sqrt{2.5} \ . \tag{1}$$

We find that $\theta = 18°$. The bounds for the actual aspect ratio, modulo the assumptions, is computed from the apparent aspect ratio (between 6:1 and 10:1) as follows: $\frac{6}{\sin(\theta)}$ is the lower bound, and $\frac{10}{\sin(\theta)}$ is the upper bound. We find that the ratio between ‘Oumuamua’s brightest and dimmest phases is between 20:1 and 30:1. Such a ratio would be consistent with a thin sheet (Bialy & Loeb 2018).

We explore next the implications for a ‘cigar-like’ geometry, similarly computing θ,

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$$\frac{\sin(\theta + 11^\circ)}{\sin(\theta)} = 2.5 \quad . \tag{2}$$

We find that $\theta = 7^\circ$, and subsequently compute that the ratio between 'Oumuamua's brightest and dimmest phases is between 50:1 and 80:1.

We now explore the possibility that the 'Oumuamua phase function slope value is larger than the canonical value of -0.04 magnitude per degree. Specifically, if the value for 'Oumuamua was larger by a factor of 2, namely -0.08 magnitude per degree, there would be only a $\sim$ 0.4 magnitude brightening between the October and November observations, corresponding to the brightest phase of 'Oumuamua appearing $\sim$ 1.4 times brighter. Following the same method as outlined in the previous paragraphs, we find that if 'Oumuamua has a 'pancake-like' geometry, the ratio between its brightest and dimmest phases would be between 9:1 and 15:1. Under the same assumptions, if 'Oumuamua has a 'cigar-like' geometry, the ratio between its brightest and dimmest phases would be between 15:1 and 25:1. Unless the phase slope value is three times the canonical value, namely -0.12 mag per degree, which would thereby explain the $\sim$ 1 magnitude brightening yet constitute another unusual property of 'Oumuamua, the geometry of 'Oumuamua must be more extreme than previously thought.

These results imply a much more extreme geometry than inferred from the reported brightness variations of between 6:1 and 10:1 across its light curve from the 2017 Oct. 25-30 observations suggest. For an isotropic uniform albedo, and assuming canonical phase function slope value for cometary and D-class objects of -0.04 magnitude per degree, we find that 'Oumuamua could have an axis ratio of at least 20:1 for a 'pancake-like' geometry or an axis ratio of at least 50:1 for a 'cigar-like' geometry. These results would imply that 'Oumuamua is either a thin sheet or an extremely elongated 'cigar.' These are lower limits since there is no guarantee that the object was viewed edge-on at its faintest phase.

An unlikely explanation would be that 'Oumuamua's area changed due to disintegration. A collection of independent fragments that are bound only by gravity have a maximum spin period given by a fraction of $\sqrt{\mathrm{G}\rho}$, where G is Newton's constant and ρ is the mean density. For the low density required by Micheli et al. (2018) to account for radiation pressure, the maximum spin period is at least an order of magnitude larger than 8 hours. While a complete light curve of 'Oumuamua's $\sim$ 8 hour period was not achieved in the 2017 Nov. 21-23 observations, two distinct brightness variations on the order of 2 magnitudes occur, suggesting that the spin period is far too fast for 'Oumuamua to have disintegrated. Moreover, the spin period was constant throughout the Oct. 21-25 interval as expected for a solid object.

It is possible that, if 'Oumuamua disintegrated by spin or heat, a fragment escaped by extracting a fraction of energy from the primary's spin, allowing the spin period to remain relatively unchanged (Pravec et al. 2018).

An alternative explanation could be attributing the brightness change to albedo variation. This would require sharp albedo variations for a minor change in viewing angle of $\sim 11^\circ$, which is possible depending on the structure and composition of the surface, but unprecedented for known asteroids or comets.

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Table 1. Observing geometry of ‘Oumuamua from Oct. 25 to Nov. 23, 2017, showing geocentric ecliptic longitude, geocentric ecliptic latitude, and the total change in viewing angle relative to Oct. 25, $\Delta\theta$.

Date (UT, 0:00)	Geo. Ec. Long. (deg.)	Geo. Ec. Lat. (deg.)	$\Delta\theta$ (deg.)
2017-Oct-25	5.23	2.91	0
2017-Oct-26	3.58	3.8	1.88
2017-Oct-27	2.17	4.56	3.48
2017-Oct-28	0.97	5.21	4.85
2017-Oct-29	359.93	5.78	6.03
2017-Oct-30	359.02	6.27	7.06
2017-Oct-31	358.23	6.7	7.96
2017-Nov-01	357.54	7.09	8.75
2017-Nov-02	356.94	7.43	9.45
2017-Nov-03	356.4	7.73	10.06
2017-Nov-04	355.93	8	10.61
2017-Nov-05	355.51	8.25	11.09
2017-Nov-06	355.14	8.47	11.52
2017-Nov-07	354.82	8.67	11.9
2017-Nov-08	354.53	8.86	12.24
2017-Nov-09	354.28	9.02	12.55
2017-Nov-10	354.05	9.18	12.82
2017-Nov-11	353.86	9.32	13.05
2017-Nov-12	353.69	9.45	13.27
2017-Nov-13	353.54	9.56	13.45
2017-Nov-14	353.41	9.67	13.62
2017-Nov-15	353.31	9.78	13.76
2017-Nov-16	353.22	9.87	13.89
2017-Nov-17	353.14	9.96	13.99
2017-Nov-18	353.08	10.04	14.09
2017-Nov-19	353.04	10.11	14.16
2017-Nov-20	353.01	10.18	14.23
2017-Nov-21	352.99	10.25	14.28
2017-Nov-22	352.98	10.31	14.31
2017-Nov-23	352.98	10.37	14.34

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