Trajectory of 'Oumuamua and wandering Sun, alien asteroids and comets detected by SOHO

Kuan Peng 彭宽 *titang78@gmail.com*

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Abstract: The apparent non-gravitational acceleration that the extra-solar-system ‘Oumuamua exhibits is puzzling. We find that when the position and velocity of the Sun are correctly set in computing the predicted orbit, ‘Oumuamua’s trajectory can be explained with gravity and we have reproduced the unexpected gap by computation. We also propose to search for new extra-solar-system asteroids and comets with SOHO to check our method with their trajectories.

1. ‘Oumuamua’s acceleration

‘Oumuamua, formally designated 1I/2017 U1, is an interstellar object passing through the Solar System which was first detected by Robert Weryk using the Pan-STARRS telescope on 19 October 2017 [1][2]. It seems to exhibit non-gravitational acceleration, making it go further than expected [3].

In the article « Our Solar System's First Known Interstellar Object Gets Unexpected Speed Boost »[1], it was reported that “'Oumuamua had been boosted by 25,000 miles (40,000 kilometers) compared to where it would have been if only gravitational forces were affecting its motion”, see Figure 1 and Figure 2 which are screenshots of the animation in this article and show the predicted orbit and the unexpected gap of 40 000 kilometers between the last observation of ‘Oumuamua and the predicted spot.

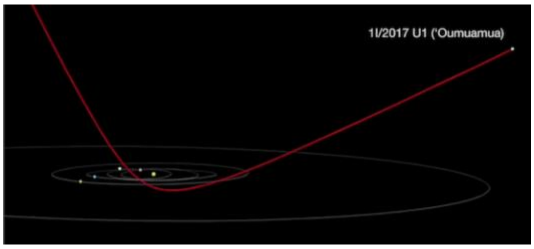

Figure 1

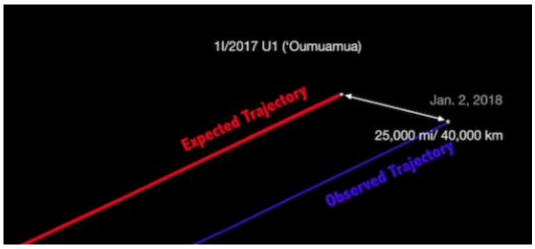

Figure 2

The team led by Marco Micheli has reported that “the observed orbital arc cannot be fit in its entirety by a trajectory governed solely by gravitational forces due to the Sun, the eight planets, the Moon, Pluto, the 16 biggest bodies in the asteroid main belt, and relativistic effects”[3]. In their analysis they have ruled out the following effects:

1. Solar radiation pressure
2. Drag- or friction-like forces
3. Interaction with solar wind for a highly magnetized object
4. Geometric effects originating from ‘Oumuamua potentially being composed of several spatially separated bodies or having a pronounced offset between its photocenter and center of mass.

Although “the Canada-France-Hawaii Telescope (CFHT) and, in the following days, the ESO Very Large Telescope (VLT) and the Gemini South Telescope, both8-meter-class facilities, found no sign of coma despite optimal seeing conditions”, the authors still “find outgassing to be the most physically plausible explanation” [3].

However, because of the lack of coma we think that the boost of 'Oumuamua can still be attributed to some overlooked effects. For example, what if the Sun is moving in the frame of the barycenter of the solar system? What if, due to the motion, the Sun is not at the predicted position? We know that the Sun is not exactly at the barycenter of the solar system and moves relative to it, as shown by Figure 3 in which the Sun is the central point and the barycenter wanders around it. But in reality the solar system is an isolated system the center of which is its barycenter. The frame of the barycenter is an inertial frame in which the barycenter is fixed and the Sun wanders around it.

During the 80 days of observation, the Sun travels about 80 000 km. When 'Oumuamua was observed the Sun was at around one million kilometers away from the barycenter. An error of 80 000 km in one million km is possible

[1] Jet Propulsion Laboratory, June 27, 2018, “Our Solar System’s First Known Interstellar Object Gets Unexpected Speed Boost”, https://www.jpl.nasa.gov/news/our-solar-systems-first-known-interstellar-object-gets-unexpected-speed-boost

in the computation, but enough to create the 40 000 km of unexpected gap. In these cases, the real trajectory of 'Oumuamua will not fit the predicted one.

Pursuing this direction we propose this hypothesis: “The unexpected gap could be the consequence of erroneous position and velocity of the Sun with which the predicted orbit was computed”. For checking this hypothesis we will compute the trajectory of ‘Oumuamua by adjusting the position and velocity of the Sun such as to reproduce approximately the gap of 40 000 km.

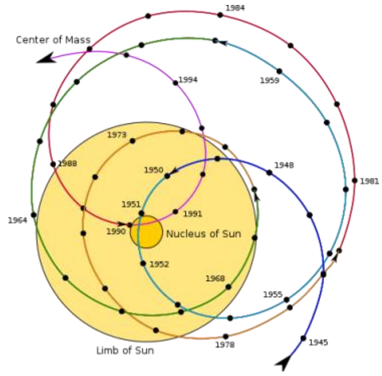

Figure 3 Motion of the barycenter of the Solar System relative to the Sun, 1945–1995,[2]

2. Static and shifting orbits

The basic parameters of the predicted orbit for ‘Oumuamua are published by JPL / NASA in the page 'Oumuamua (A/2017 U1)[3]. The eccentricity ε, the semi-major axis *a*, the orbital elements[4] and the standard gravitational parameter of the Sun GM⊙[5] are given in Table 1. The semi-latus rectum *l* and specific relative angular momentum *h* are computed in (2) and (3). The predicted orbit is a hyperbolic orbit which is expressed by equation (1).

$$r = \frac{l}{1 + \varepsilon \cos\theta} \quad (1) \qquad l = a(1 - \varepsilon^2) \quad (2) \qquad h = \sqrt{l \cdot GM} \quad (3)$$

Eccentricity ε	1.201133796102373
Semi-major axis *a*, in AU	-1.27234500742808
Orbital inclination, in deg	122.7417062847286
Longitude of the ascending node, in deg	24.59690955523242
Argument of perihelion, in deg	241.8105360304898
Standard gravitational parameter of the Sun GM⊙ , in $m^3 s^{-2}$	$1.32712440018 \times 10^{20}$

Table 1

Let us take the frame of the barycenter of the solar system as the reference frame. Suppose that the Sun is at the point **P** which is static in this frame. Then the focus of the predicted orbit is **P** and we call this orbit the **static orbit**. In the case where the Sun is moving, the orbit of 'Oumuamua shifts with the Sun and we call this orbit the **shifting orbit**.

3. Motion of the Sun

For making a guess about the position and velocity of the Sun we compute for the Sun the velocities induced by each planet. Let us take a system of two masses M_1 and M_2 which rotate around the center of mass of the system, see Figure 4. Suppose that the mass M_1 travels the distance L_1, then the mass M_2 will travel the distance L_2 which is computed with equation (4). Then the velocity $\boldsymbol{v}_2$ of M_2 is computed with $\boldsymbol{v}_1$ the velocity of M_1 in (5).

[2] Carl Smith derivative work: Rubik-wuerfel, https://en.wikipedia.org/wiki/Barycenter#/media/File:Solar_system_barycenter.svg

[3] Jet Propulsion Laboratory, Jun 26 2018, 'Oumuamua (A/2017 U1). https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/?sstr=3788040

[4] Orbital elements, Wikipedia, Retrieved 20:37, May 2, 2023, from https://en.wikipedia.org/w/index.php?title=Orbital_elements&oldid=1151462327

[5] Standard gravitational parameter, Wikipedia. Retrieved 20:34, May 2, 2023, from https://en.wikipedia.org/w/index.php?title=Standard_gravitational_parameter&oldid=1152355380

$$M_1L_1 = M_2L_2 \quad (4) \qquad v_2 = v_1\frac{M_1}{M_2} \quad (5) \qquad D_2 = D_1\frac{M_1}{M_2} \quad (6)$$

The velocities of the Sun induced by each planet are given in Table 2. We see that the influence of Jupiter largely dominates those of the other planets. So, just for checking our hypothesis we decide to use the velocity induced by Jupiter as the velocity of the Sun. The distance of the Sun from the center of mass of the system Sun-Jupiter D_2 is computed in (6) and gives an idea about where the Sun could be.

Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
0.0078623	0.0857233	0.0894439	0.0077474	12.46815	2.7673733	0.296905	0.2797201

Table 2 Velocity of the Sun induced by each planet, in m/s

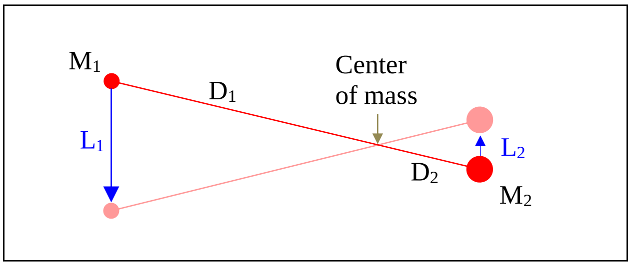

Figure 4 System of two masses M_1 and M_2

'Oumuamua was first discovered on Oct 14th 2017 and last observed on Jan 02nd 2018. The locations of Jupiter on these two dates are given in Table 3 and obtained using the Solar System Calculator by Don Cross[6]. The corresponding D_2 are computed using (6) and given in Table 3. On the first date, the modulus of D_2 equals 777 246 km which means that the Sun was at approximately 777 246 km from the center of the solar system. For comparison, the radius of the Sun is 696 342 km.

	Position of Jupiter in AU			Position of the Sun in km		
Coordinates	x	y	z	x	y	z
Oct 14th 2017 00:00:00	-4.5955105	-2.9118369	0.1150135	656398	415911	-16427
Jan 02nd 2018 00:00:00	-4.2531053	-3.3760883	0.1092752	607491	482223	-15608

Table 3

Let L_1 be the distance traveled by Jupiter between these two dates. L_1 represents 6.65° of the Jupiter's circular orbit and thus is almost a straight line. In the same way, L_2 the distance traveled by the Sun will be seen as a straight line. L_2 equals 82 400 km which is approximately twice the 40 000 km of the unexpected gap. The observation lasted 80 days, or 6 912 000 seconds. L_2 divided by 6 912 000 seconds gives the velocity of the Sun due to Jupiter which equals 11.92 m/s.

4. Trajectory of 'Oumuamua

a) The coordinate system of the Sun

For our purpose we suppose that the Sun moves at constant speed. In this case, the frame of the Sun is an inertial frame in which the orbit of 'Oumuamua is Newtonian and is a hyperbola with the Sun at its focus. Let $\mathbf{X}_s$ be the position of the Sun in the reference frame which varies with time. Let t_1 be the time at the first observation and $\mathbf{D}_s$ the position of the Sun at this time. The Sun moves at the velocity $\boldsymbol{v}_s$ and at time t the Sun arrives at the point $\mathbf{X}_s$ expressed by equation (7). $\mathbf{X}_s$, $\boldsymbol{v}_s$ and $\mathbf{D}_s$ are vectors. Notice that the point **P** is not $\mathbf{X}_s$ because **P** is static and $\mathbf{X}_s$ mobile.

$$\boldsymbol{X}_s = \boldsymbol{D}_s + \boldsymbol{v}_s(t - t_1) \quad (7)$$

If we have a vector in the coordinate system of the Sun and want to use it in that of the reference frame, its coordinates must be converted. Let $\boldsymbol{r}_b$ be a vector pointing from the **P** to a point, then $\boldsymbol{r}_b$ defines this point in the reference frame. Let $\boldsymbol{r}_m$ be a vector pointing from the Sun to the same point, then $\boldsymbol{r}_m$ defines this point with respect to the Sun. $\boldsymbol{r}_m$ is converted from $\boldsymbol{r}_b$ using equation (8). Let this point move at the velocity $\boldsymbol{v}_b$ in the reference frame,

[6] Solar System Calculator - by Don Cross, http://cosinekitty.com/solar_system.html

then the velocity of this point in the coordinate system of the Sun is the $\boldsymbol{v}_m$ in equation (9) which is converted from $\boldsymbol{v}_b$.

$$\boldsymbol{r}_m = \boldsymbol{r}_b - \boldsymbol{X}_s \quad (8) \qquad \boldsymbol{v}_m = \boldsymbol{v}_b - \boldsymbol{v}_s \quad (9)$$

b) Crossing point

The shifting orbit is determined by the position and velocity of ‘Oumuamua at a given point. The first observation is done at the same point for both orbits, so the shifting orbit crosses the static orbit at this point and we call it the crossing point. For our purpose this point is the given point for determining the shifting orbit.

Let us label the crossing point in the reference frame with $\boldsymbol{r}_b$ and write it in (10) where r_b is the radial coordinate, $\mathbf{e}_{rb}$ the unit radial vector of this point. The velocity at this point is labeled as $\boldsymbol{v}_b$ and is computed by taking the time derivative of $\boldsymbol{r}_b$ in (11), The radial and tangential components of the velocity are labeled as v_r and v_θ and are expressed in (12) and (13)[7].

$$\boldsymbol{r}_b = r_b \boldsymbol{e}_{rb} \quad (10)$$

$$\begin{aligned}\boldsymbol{v} &= \frac{dr\boldsymbol{e}_r}{dt} = \frac{dr}{dt}\boldsymbol{e}_r + r\frac{d\boldsymbol{e}_r}{dt} \\ &= \frac{d}{dt}\left(\frac{l}{1+\varepsilon\cos\theta}\right)\boldsymbol{e}_r + r\frac{d\theta}{dt}\frac{d\boldsymbol{e}_r}{d\theta} \\ &= \frac{\varepsilon h}{l}\sin\theta\,\boldsymbol{e}_r + \frac{h}{r}\boldsymbol{e}_\theta\end{aligned} \quad (11)$$

$$\boldsymbol{v} = v_r\boldsymbol{e}_r + v_\theta\boldsymbol{e}_\theta \quad (12) \qquad v_r = \frac{\varepsilon h}{l}\sin\theta\,, v_\theta = \frac{h}{r} \quad (13)$$

v_r and v_θ are in the plane of the static orbit. For deriving the shifting orbit, v_r and v_θ must be converted into the coordinate system of the reference frame. Let $\boldsymbol{M}$ be the matrix that does this conversion. In equation (14) $\boldsymbol{M}(\boldsymbol{r}_b)$ is this matrix at the point $\boldsymbol{r}_b$. v_r and v_θ are converted into v_x, v_y and v_z the Cartesian components of the velocity which is labeled as $\boldsymbol{v}_b$ and is expressed as the vector (v_x, v_y, v_z) in (15).

$$[v_x \quad v_y \quad v_z] = [v_r \quad v_\theta]\,\boldsymbol{M}(\boldsymbol{r}_b) \quad (14) \qquad \boldsymbol{v}_b = \left(v_x, v_y, v_z\right) \quad (15)$$

Let us label the crossing point in the coordinate system of the Sun as $\boldsymbol{r}_m$. The velocity with respect to the moving Sun is labeled as $\boldsymbol{v}_m$. So, the position and velocity of ‘Oumuamua with respect to the Sun are $\boldsymbol{r}_m$ and $\boldsymbol{v}_m$ and are converted from $\boldsymbol{r}_b$ and $\boldsymbol{v}_b$ using (8) and (9). $\boldsymbol{r}_m$ and $\boldsymbol{v}_m$ are expressed in the coordinate system of the reference frame.

c) Deriving the shifting orbit

For converting $\boldsymbol{v}_m$ into the coordinate system of the Sun, we first compute its radial component v_{rm} by dotting $\boldsymbol{v}_b$ with $\mathbf{e}_{rm}$ the unit radial vector at this point which is computed with $\boldsymbol{r}_m$ in (16). The scalar v_{rm} is obtained in (17). The vector tangential component $\boldsymbol{v}_{\theta m}$ is computed using (18). The unit tangential vector at this point is $\mathbf{e}_{\theta m}$ and is computed in (19).

$$\boldsymbol{e}_{rm} = \frac{\boldsymbol{r}_m}{|\boldsymbol{r}_m|} \quad (16) \qquad v_{rm} = \boldsymbol{v}_m \cdot \boldsymbol{e}_{rm} \quad (17) \qquad \boldsymbol{v}_{\theta w} = \boldsymbol{v}_m - v_{rm}\boldsymbol{e}_{rm} \quad (18) \qquad \boldsymbol{e}_{\theta m} = \frac{\boldsymbol{v}_{\theta m}}{|\boldsymbol{v}_{\theta m}|} \quad (19)$$

The specific relative angular momentum h of the shifting orbit is computed in (20) using Kepler's second law. The semi-latus rectum l is computed in (21), the eccentricity ε is computed in (22), see equations (27), (28), (29), (30), (31) and (32). With these l, h and ε the shifting orbit is completely defined with respect to the Sun. The unit radial and tangential vectors $\mathbf{e}_{rm}$ and $\mathbf{e}_{\theta m}$ define the plane of the shifting orbit in the reference frame.

$$h = rv_\theta = |\boldsymbol{r}_m||\boldsymbol{v}_{\theta m}| \quad (20) \qquad l = \frac{h^2}{GM_\odot} \quad (21) \qquad \varepsilon = \sqrt{\left(\frac{v_r}{rv_\theta}l\right)^2 + \left(\frac{l}{r} - 1\right)^2} \quad (22)$$

[7] Orbit. Wikipedia, Retrieved 20:35, May 2, 2023, from https://en.wikipedia.org/w/index.php?title=Orbit&oldid=1142780050

'Oumuamua was first observed 35 days after perihelion. Using equation (23) [4] we have found that the angular coordinate at this date is approximately 114° on the static orbit. So, we decide that 114° is the angular coordinate of the first observation.

$$t_a - t_0 = \int_0^a \frac{l^2}{h} \frac{d\theta}{(1 + \varepsilon \cos \theta)^2} \quad (23)$$

We compute the radial coordinate r, the radial and tangential components of the velocity v_r and v_θ of the point 114° which gives $\boldsymbol{r}_b$ and $\boldsymbol{v}_b$. We convert them into the reference frame. Using (8) and (9) $\boldsymbol{r}_b$ and $\boldsymbol{v}_b$ are converted into $\boldsymbol{r}_m$ and $\boldsymbol{v}_m$ with which we compute the parameters l, h and ε of the shifting orbit, see (20), (21) and (22). Then the shifting orbit is completely defined.

d) The last observation

'Oumuamua was last observed 115 days after the perihelion (80+35 days). Using equation (23) [4] we have found that on this date the angular coordinate on the static orbit is approximately 132.05°. We decide that 132.05° is the angular coordinate of the last observation on this orbit.

Why do we need to decide the angular coordinates of the first and the last observations? In fact, the same point of observation has different angular coordinate on each orbit, but the time of observation are the same. So, for computing exactly the time lasted between the two observations we have to decide exactly the angular coordinates of the first and last observations and compute exactly the time lasted between the points 114° and 132.05° on the static orbit.

Let t_{b1} and t_{b2} be the times for the points 114° and 132.05° on the static orbit. The lasted time Δt_b equals t_{b2}- t_{b1}. t_{b1} , t_{b2} and Δt_b are shown in the columns 1, 2 and 3 of Table 4.

t_{b1}	t_{b2}	$\Delta t_b = t_{b2} - t_{b1}$	t_{m1}	$t_{m2} = t_{m1} + \Delta t_b$
3019901	9934706	6914805	3020739	9935544

Table 4 Time after the perihelion in second

Let t_{m1} and t_{m2} be the times at the first and last observations on the shifting orbit. The point 114° is the crossing point and is known for both orbits, so t_{m1} is computed from the angular coordinate of the crossing point on the shifting orbit. We add the lasted time Δt_b to t_{m1} to get the time of the last observation on the shifting orbit. Notice that t_{m1} does not equal t_{b1}. t_{m2} equals $t_{m1}+\Delta t_b$. t_{m1} and t_{m2} are given in the column 4 and 5 of Table 4.

Then we solve numerically (23) for t_{m2} and obtain the angular coordinate of the last observation which is labeled as θ_{m2}. We compute the radial coordinate r_{m2} from θ_{m2} using (1). r_{m2} and θ_{m2} define the vector $\boldsymbol{r}_{m2}$ shown in (24) where $\mathbf{e}_{rm2}$ is the unit radial vector at the last observation on the shifting orbit.

$$\boldsymbol{r}_{m2} = r_{m2} \cdot \boldsymbol{e}_{rm2} \quad (24)$$

By reversing equation (8), we get (25) in which $\boldsymbol{r}_{m2}$ is converted into $\boldsymbol{r}_{c2}$ which is in the reference frame. By reversing equation (9), we convert $\boldsymbol{v}_{m2}$ into $\boldsymbol{v}_{c2}$ in the same coordinate system and express $\boldsymbol{v}_{c2}$ in (26).

$$\boldsymbol{r}_{c2} = \boldsymbol{r}_{m2} + \boldsymbol{X}_s \quad (25) \qquad \boldsymbol{v}_{c2} = \boldsymbol{v}_{m2} + \boldsymbol{v}_s \quad (26)$$

Because $\boldsymbol{X}_s$ depends on time the shifting orbit shifts with time and 'Oumuamua travels on a trajectory that is a combination of the shifting orbit and the motion of the Sun. We call this trajectory the combined trajectory.

e) The unexpected gap

The two orbits separate after the crossing point and create the unexpected gap. The point of last observation is $\boldsymbol{r}_{b2}$ on the static orbit and $\boldsymbol{r}_{c2}$ on the shifting orbit, both $\boldsymbol{r}_{b2}$ and $\boldsymbol{r}_{c2}$ are in the reference frame. The gap corresponding to the unexpected gap equals $\boldsymbol{r}_{c2}$ - $\boldsymbol{r}_{b2}$ which is labeled as **Gap**. By keeping the velocity of the Sun $\boldsymbol{v}_s$ constant and adjusting the position of the Sun $\mathbf{D}_s$, see (7), we have found 40 860 km for **Gap**, which almost equals the 40 000 km of the unexpected gap. In fact, by adjusting $\mathbf{D}_s$ we can give any value to **Gap**. The vector components of $\boldsymbol{r}_{b2}$, $\boldsymbol{r}_{c2}$ and **Gap** are given in Table 5. Their magnitudes are given in the fifth column.

Coordinate in km	x	y	z	Magnitude
$\boldsymbol{r}_{b2}$	403745715	123403336	86850341	431024324
$\boldsymbol{r}_{c2}$	403775228	123431275	86846107	431059115
Gap = $\boldsymbol{r}_{c2}$ - $\boldsymbol{r}_{b2}$	29 513	27 939	-4 234	40 860

Table 5

We have drawn the computed vector **Gap** as the blue arrow in Figure 5. This vector points slightly downward to the right, which is similar to the gap shown in « Our Solar System's First Known Interstellar Object Gets Unexpected Speed Boost », see Figure 2.

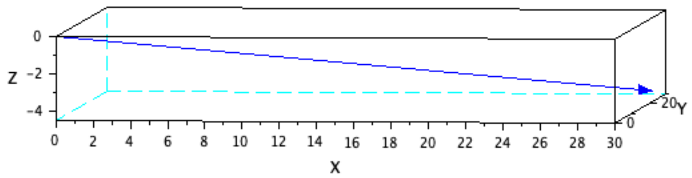

Figure 5 Computed **Gap** vector

For obtaining the 40 860 km for **Gap,** the velocity of the Sun $\boldsymbol{v}_s$ and the position of the Sun $\mathbf{D}_s$ were set to the values shown in Table 6. Notice that the magnitude of $\mathbf{D}_s$ is only 81 610 km, which equals 12% of the 696 342 km of the radius of the Sun. The magnitude of $\boldsymbol{v}_s$ is 11.92132 m/s which is similar to the speed of a man's sprint. So, the unexpected gap can be the result of very small error on the position and velocity of the Sun.

Coordinate	x	y	z	Magnitude
$\boldsymbol{v}_s$ in m/s	-7.075722	9.593645	0.118581	11.92132
$\mathbf{D}_s$ in km	-76841	10942	-25219	81 610

Table 6 Velocity and position of the Sun

What is the part created by $\mathbf{D}_s$ and that created by $\boldsymbol{v}_s$ in the 40 000 km of the gap? We have computed the gap for $\boldsymbol{v}_s = 0$ and $\mathbf{D}_s$ given in Table 6, we got 37 000 km. Then for $\mathbf{D}_s = 0$ and $\boldsymbol{v}_s$ given in Table 6 we got 8 000 km. So, the unexpected gap is in most part created by $\mathbf{D}_s$ rather than $\boldsymbol{v}_s$.

In conclusion the "unexpected speed boost" of 'Oumuamua can be well explained with the gravitational force of a wandering Sun only.

f) How is the trajectory combined?

The trajectory of 'Oumuamua combines the effect of $\mathbf{D}_s$ and the effect of $\boldsymbol{v}_s$. So, the position of 'Oumuamua equals its position on the hyperbolic shifting orbit plus the distance traveled by the Sun plus $\mathbf{D}_s$. This combination results in a trajectory that could not necessarily be a hyperbola in the reference frame.

For showing how this combination works, we have made the Figure 6 in which the blue curve is the static orbit, the red dashed curves are the shifting orbit and the green curve the combined trajectory. The red dashed curves move from right to left.

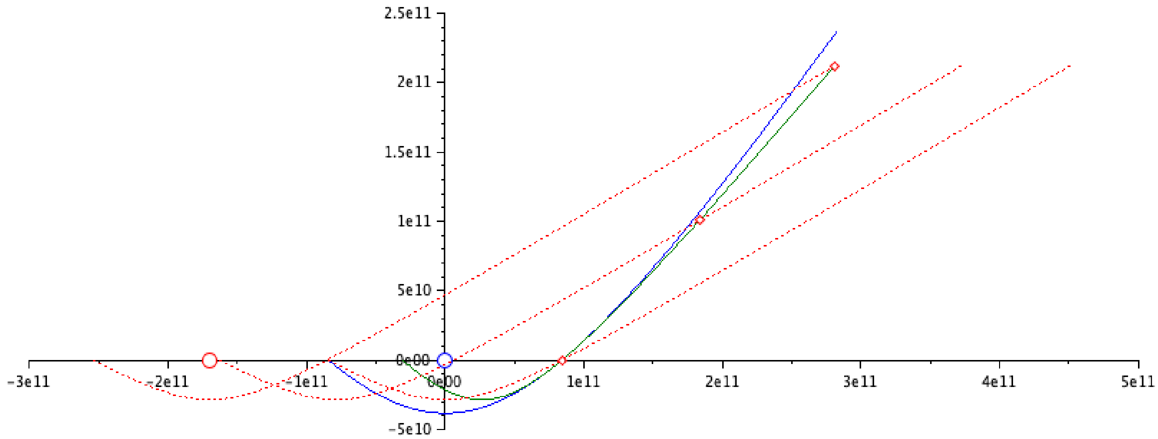

Figure 6 Static orbit (blue), combined trajectory (green) and shifting orbit (red)

The three red diamonds at the intersections of the green curve and the red dashed curves correspond to ‘Oumuamua. So, ‘Oumuamua, by following the red dashed curves, which in turn moves to the left, draws the green curve in the reference frame and creates the unexpected gap.

The blue circle is the Sun at the point **P**, the red circle is the Sun at the focus of the left most red hyperbola.

For showing clearly the gap we had to make the blue and green curves sufficiently apart. $v_s = -11.92132$ m/s is too small for this purpose and we had to put $v_s = -29\,782$ m/s which is the orbital velocity of the Earth around the Sun. This way, we look at the combined trajectory as if we look ‘Oumuamua from the Earth. We also had to put the crossing point on the horizontal axis for the same reason.

Because the combined trajectory (the green curve) is not necessarily a hyperbola in the reference frame and due to the motion of the shifting orbit, it does not have a “focus”. Its unusual shape makes people think that there is a non-gravitational acceleration that pushes ‘Oumuamua. But this unusual shape is due to gravity and the combined trajectory could explain why “the observed orbital arc cannot be fit in its entirety by a trajectory governed solely by gravitational forces due to the Sun, the eight planets, the Moon, Pluto, the 16 biggest bodies in the asteroid main belt, and relativistic effects” [3] and may make non-gravitational acceleration unnecessary.

5. Search for high speed asteroids near the Sun

Beside of computing the trajectory of ‘Oumuamua, a better way to check our hypothesis is by experiment, that is, by observing new high speed asteroids and comets and compare their trajectories with prediction. However, recorded asteroids and comets coming from the outside of the solar system are scarce. But I think that in reality such objects are not so rare, only that far from the Sun they are too faint to be detected. When they are near the Sun they become very bright and can be detected by Sun gazing satellites such as SOHO (Solar and Heliospheric Observatory).

Many such alien asteroids and comets are already recorded by SOHO and are dormant in great number in the archives of SOHO. Thanks to NASA Goddard’s YouTube Movie “Decades of Sun from ESA & NASA’s SOHO” [8], which is a video made with all the photos taken by LASCO/C3 between 1998/01/06 and 2020/10/23, I have found several high speed asteroids and comets in it.

For example, the asteroid that was recorded from 2004/02/26 to 2004/02/28. I have computed its visual velocity which is the velocity of the dot on the image and got 160 km/s, see Figure 7. The comet recorded from 2015/02/18 to 2015/02/21 is measured at 182 km/s, see Figure 8. For comparison, the speed of ‘Oumuamua at perihelion is 87.71 km/s. I used the diameter of the view field of LASCO/C3 which equals 30 radii of the Sun[9] and the time printed on the images to compute its visual velocity. As the actual trajectories make an angle with the plane of the image, their real velocities are forcefully bigger. I have made clips of the asteroid and of the comet[10]:

The view field of LASCO/C3 is 41 800 000 km across[9]. The radius of this field equals 0.14 AU, in comparison ‘Oumuamua’s perihelion is 0.255916 AU from the Sun. We find that the velocity of alien asteroids and comets in this field should be at least 113 km/s. LASCO/C3 takes 1 frame every 2 hours, alien asteroids and comets would cross the field in 103 hours or 4.3 days, we would see them in 51 frames. So, the above asteroids and comets are really from the outside of the solar system. For those who are interested in seeing the asteroids and comets that I have found I have put in the appendices the links that point to the frames of the Movie “Decades of Sun from ESA & NASA’s SOHO”[8] where they appear.

The alien asteroids and comets in the archives of SOHO are interesting. We can count their number, mapping their direction and measure their record breaking speed and size. On the other hand, we can monitor in real time the appearance of new alien asteroids and comets, work out their orbits for observing them later.

[8] NASA's Goddard Space Flight Center, Dec 2, 2020, “Decades of Sun from ESA & NASA’s SOHO” https://www.youtube.com/watch?v=o-DHwNFDgOU

[9] LASCO/C3, https://en.wikipedia.org/wiki/Large_Angle_and_Spectrometric_Coronagraph

[10] Super-fast alien asteroid (160 km/s), taken by SOHO in 2004, https://youtu.be/GTGuEKndNIc, Super fast comet 180 km/s, https://youtu.be/t-x2NdTmm_E

In searching asteroids in the Movie "Decades of Sun from ESA & NASA's SOHO" [8], the background stars and the streaks left by space particles are very dizzying which makes the researcher miss interesting asteroids and comets. So, I suggest that the background stars and streaks be removed for this research.

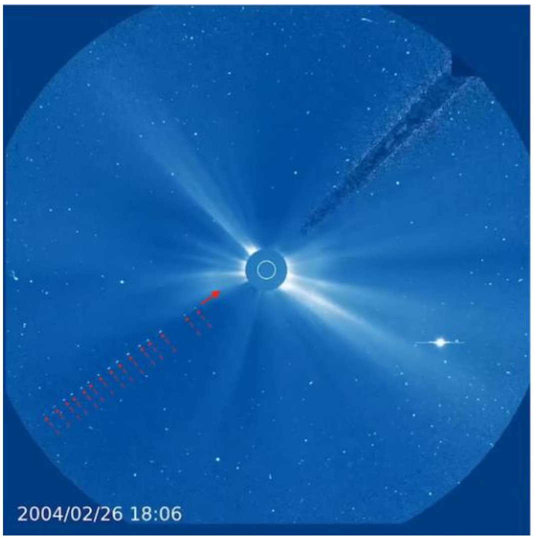

Figure 7 High speed asteroids, 160 km/s

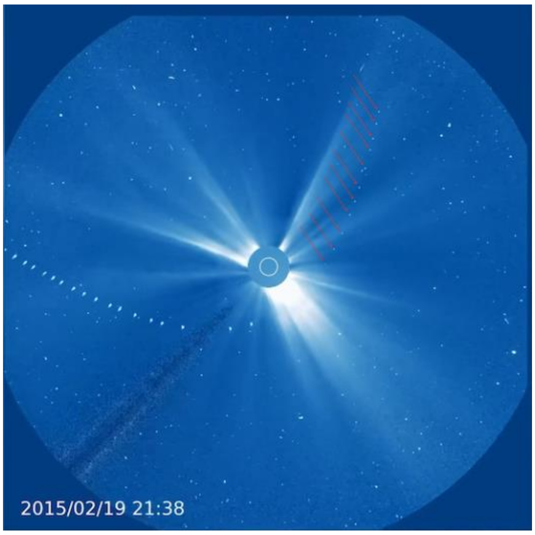

Figure 8 High speed comet 182 km/s

6. Discussion

The analysis above shows that the unexpected gap can be well explained by the gravity of the Sun provided that the position and velocity of the Sun be correctly set in computing the predicted orbit. What matters is that the position and velocity of 'Oumuamua be given with respect to the Sun's actual position and velocity. If the predicted orbit of 'Oumuamua were computed with respect to the point **P** while the Sun is not there, the predicted orbit would be wrong.

We have shown that because the combined trajectory is not a hyperbola and has not fixed focus, the non-gravitational acceleration may be unnecessary to explain that "the observed orbital arc cannot be fit in its entirety by a trajectory governed solely by gravitational forces due to the Sun, the eight planets, the Moon, Pluto, the 16 biggest bodies in the asteroid main belt, and relativistic effects" [3]. This is corroborated by the lack of coma.

We have also discovered that even the smallest error on the position and velocity of the Sun is enough to create an unexpected gap. Indeed, the distance used to reproduce the unexpected gap is only 12% of the radius of the Sun. How could such error occur? In fact, the Sun was about 1 million km from the barycenter when 'Oumuamua was observed, the $\mathbf{D}_s$ = 81 610 km is 8% of this distance. Usually, the position of the Sun is computed using NASA's Horizons System and taken as correct. But an error of 8% of this distance is enough to create the 40 000 km of unexpected gap. So, when we compute for objects like 'Oumuamua, we have to pinpoint where the objects is, but also where the Sun is. The point of our research is to find error in the predicted orbit rather than on 'Oumuamua itself.

On the other hand, our hypothesis must be checked again and again before being validated. Indeed, other value was given to this gap, for example, in the article « THIS INTERSTELLAR ASTEROID IS ACCELERATING » [5], 100 000 km has been given to the gap rather than 40 000 km. Obviously, there are several different predicted trajectories for 'Oumuamua with different results. The correct theoretical trajectory for 'Oumuamua must give **Gap** = 0 and our method can help for finding it.

We have proposed to check our hypothesis using the SOHO satellite in real time to find new alien asteroids and comets, work out their orbits for observing them later. It will be interesting to search for alien asteroids and comets in the archives of SOHO, which I have done partly.

7. Appendices

a) Computation for eccentricity

Using v_r and v_θ in (13), we obtain (27), (28), (29) and (30). (31) is derived from (1). (30) and (31) give (32) the expression of eccentricity squared.

$$v_r = \frac{\varepsilon h}{l} \sin\theta \quad (27) \qquad v_\theta = \frac{h}{r} \quad (28) \qquad \frac{v_r}{v_\theta} = \frac{r\varepsilon}{l} \sin\theta \quad (29) \qquad \varepsilon \sin\theta = \frac{v_r}{v_\theta} \frac{l}{r} \quad (30) \qquad \varepsilon \cos\theta = \frac{l}{r} - 1 \quad (31)$$

$$(\varepsilon \sin\theta)^2 + (\varepsilon \cos\theta)^2 = \varepsilon^2 = \left(\frac{v_r}{v_\theta} \frac{l}{r}\right)^2 + \left(\frac{l}{r} - 1\right)^2 \quad (32)$$

b) Asteroids and comets near the Sun

Here are all the asteroids and comets that I have found in the Movie "Decades of Sun from ESA & NASA's SOHO" 0. The velocities are visual velocities on the image plane. The numbers in the form 9h – 3h indicate the direction of motion of the objects on the image, for example 9h – 3h means the object travels from 9 to 3 on a dial. The links point to the frames around which the objects are visible in the Movie.

1. Passing asteroids

1999/11/14	72 km/s	9h-Sun	https://youtu.be/o-DHwNFDgOU?t=146
2000/09/14	44 km/s	Sun-8h	https://youtu.be/o-DHwNFDgOU?t=258
2004/02/29	160 km/s	8h-Sun	https://youtu.be/o-DHwNFDgOU?t=734
2008/07/04	78 km/s	5h-Sun	https://youtu.be/o-DHwNFDgOU?t=1316

2. Passing Comets

2002/01/07	115 km/s	7h-2h	https://youtu.be/o-DHwNFDgOU?t=438
2002/04/15	70 km/s	7h-0h	https://youtu.be/o-DHwNFDgOU?t=477
2004/12/23	82 km/s	4h-11h	https://youtu.be/o-DHwNFDgOU?t=836
2011/12/15	120 km/s	6h-5h	https://youtu.be/o-DHwNFDgOU?t=1773
2012/07/13	92 km/s	4h-0h	https://youtu.be/o-DHwNFDgOU?t=1842
2013/11/29	141 km/s	4h-1h	https://youtu.be/o-DHwNFDgOU?t=2011
2015/02/21	182 km/s	1h-9h	https://youtu.be/o-DHwNFDgOU?t=2165
2017/03/12	82 km/s	9h-4h	https://youtu.be/o-DHwNFDgOU?t=2416
2017/10/28	104 km/s	5h-1h	https://youtu.be/o-DHwNFDgOU?t=2492
2020/06/17	51 km/s	6h-3h	https://youtu.be/o-DHwNFDgOU?t=2811

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P.S.: This article is Rejected by an Astrophysical Journal. The editor's argument is :
"One way of describing Oumuamua's odd motion is to note that the numerous objects we monitor within the solar system do not show such anomalies. Therefore the solution cannot be that the Sun is moving in some unexpected way".

The decision of editor cannot be challenged. So, I put my argument here. In fact, no object was as speedy as Oumuamua and none was observed with telescopes as many and precise as for Oumuamua. So, it is not sure that the other objects move precisely as described by our theory, except that they are not revealed by observation. It is important to include precise position and speed of the Sun in their predicted orbit because they can hit the Earth in the future.