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IS THE ANTI-TAIL OF 3I/ATLAS COMPOSED OF MACROSCOPIC NON-VOLATILE OBJECTS?

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ABSTRACT

I suggest that the teardrop shape of the coma in post-perihelion images of 3I/ATLAS is a result of a large number of macroscopic non-volatile objects that separated from it as a result of its non-gravitational acceleration away from the Sun.

1. INTRODUCTION

During the month of November 2025, post-perihelion images of the interstellar object 3I/ATLAS(Seligman et al. 2025) showed a tear-drop shape of its coma with an anti-tail extension of about an arcminute towards the Sun (Jewitt & luu 2025).

During the same period, the JPL Horizons tracking of 3I/ATLAS reported[1] a non-gravitational acceleration. Its radial component - normalized at a heliocentric distance of 1 au to $A_1 = 7.2(\pm 2.1) \times 10^{-8}$ au d^{-2}, amounts to a small fraction $\Delta = 2.4 \times 10^{-4}$ of the gravitational acceleration from the Sun.

JPL Horizons scales the non-gravitational acceleration inversely with the square of the heliocentric distance (assuming CO_2 sublimation interior to 5 au), exactly as the Sun's gravitational acceleration. This means that the ratio between the two accelerations remains constant along the orbit of 3I/ATLAS.

2. DYNAMICS

The dominant component of the non-gravitational acceleration is in the radial direction away from the Sun. A simple way to incorporate it into the dynamics is to consider 3I/ATLAS as accelerating in response to a slightly reduced mass of the Sun, by a fraction of Δ.

If 3I/ATLAS is surrounded by a swarm of macroscopic non-volatile objects that do not share its non-gravitational acceleration, then these objects will tend to be closer to the Sun relative to 3I/ATLAS, because 3I/ATLAS is pushed away from the Sun relative to the objects through its non-gravitational acceleration. As long as these objects are much larger than micron-scale dust particles, the solar radiation pressure and solar wind will have a negligible effect on their dynamics.

Energy per unit mass is a conserved constant of motion in trajectories shaped by the Sun's gravity. However, the trajectory of 3I/ATLAS has a slightly smaller gravitational binding energy because of the reduction in the effective mass of the Sun by the non-gravitational acceleration.

If the objects started at the same velocity and position as 3I/ATLAS, then they would have a surplus in gravitational binding energy by a fraction of Δ relative to 3I/ATLAS. However, they would have the same binding energy and track 3I/ATLAS if they move at the same velocity and are displaced from its heliocentric distance by a fraction Δ.

At the current separation of 3I/ATLAS from the Sun of 2.7×10^8 km as of December 1, 2025, the displacement would imply that the objects are closer to the Sun than 3I/ATLAS by about 6.5×10^4 km if they overlapped (e.g. as a result of being broken off) at perihelion. This displacement corresponds to an angular separation of $\sim 0.8'$ in the sky at the current distance of 3I/ATLAS from Earth, ~ 1.9 au. This angular

[1] https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/?sstr=3I%2FATLAS&view=VOP

separation is comparable to the sunward elongation of the teardrop glow around 3I/ATLAS in recent images (Jewitt & luu 2025).

As long as the objects are made of refractory elements with no volatiles and do not experience non-gravitational acceleration from mass loss as a result of the solar illumination, they should maintain an anti-tail geometry - pointing always towards the Sun relative to 3I/ATLAS and converging to its location at perihelion.

3. IMPLICATIONS

A large swarm of objects could have a much larger surface area than that of 3I/ATLAS, even if the total mass in them is a small fraction of the mass of 3I/ATLAS. For example, 10^{12} similar objects carrying a total fraction of merely 10^{-3} of the mass of 3I/ATLAS would amount to a total surface area that is 10^2 times larger than that of 3I/ATLAS (since surface area scales as radius squared whereas mass scales as radius cubed). This swarm would create the appearance of a coma that reflects 99% of the sunlight in the glow around 3I/ATLAS. This is consistent with the fraction of light in the coma within the image of 3I/ATLAS taken by the Hubble Space Telescope on July 21, 2025 (Jewitt et al. 2025).

As long as the non-gravitational acceleration of 3I/ATLAS scales inversely with the square of heliocentric distance, the spatial extent of the objects would be of order Δ times the heliocentric distance of 3I/ATLAS, always pointing towards the Sun. This model predicts that the teardrop shape towards the Sun will maintain its angular shape in the coming months.

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