

Predicting 3I/ATLAS: Non-Gravitational Acceleration as Geometric Necessity

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Abstract

We make a specific, falsifiable prediction: interstellar object **3I/ATLAS** will exhibit non-gravitational acceleration of approximately 10^{-5} m s^{-2} near its **October 29, 2025** perihelion, with no correlation to outgassing and without spin-up. The acceleration is not anomalous but geometrically necessary—a consequence of torsional stress generation when a compact body traverses solar density gradients. The framework is based on **Projective Reality** identified with **real projective 3-space** (\mathbb{RP}^3) and the invariance of the **Volumetric Cross-Ratio** (VCR). VCR preservation restricts how volumes deform; in non-uniform extent fields, it compels internal circulation (torsion) that produces a small, continuous reactive thrust. This mechanism coherently explains: 'Oumuamua's smooth acceleration with no detectable jets; the angular-locked configurations of **C/2023 A3 (Tsuchinshan-ATLAS)** that contradict conventional dust dynamics; and the persistent transverse components in **1P/Halley**. Early reports for **3I/ATLAS**—interstellar origin, active coma, sunward features, and unusual nickel-bearing emissions—are consistent with internal circulation signatures rather than conventional jet physics. The prediction is parameter-free within the geometric framework and will be decisively confirmed or falsified by post-perihelion orbit solutions.

Keywords: 3I/ATLAS, interstellar objects, non-gravitational forces, projective geometry, torsional stress, density gradients, 'Oumuamua, C/2023 A3, 1P/Halley

1 Introduction

1.1 3I/ATLAS and the Challenge to Cometary Models

3I/ATLAS is the third confirmed interstellar visitor, discovered July 1, 2025 by the ATLAS survey, on a hyperbolic trajectory through the Solar System. It reaches perihelion in late October 2025. Public releases and reporting since discovery identify its interstellar nature and approaching perihelion, with active monitoring campaigns underway.

As the object brightened, observers reported a pronounced **sunward feature** (“anti-tail”/sunward jet in common parlance) and subsequent development of a conventional anti-solar tail. Analyses and commentary have emphasized the unusual geometry of the sunward structure and evolving morphology as heliocentric distance decreased.

Spectroscopy and news releases have also discussed **nickel-bearing** emission signatures (with ongoing debate about interpretation and carriers). These reports are noteworthy regardless of final compositional attribution because they indicate atypical chemistry for a newly observed interstellar comet.

This paper addresses dynamics: we predict a **smooth, continuous, non-gravitational acceleration** near perihelion that is **not** temporally correlated with discrete outgassing events and does **not** induce spin-up.

1.2 The Precedent: 1I/'Oumuamua

'Oumuamua exhibited a statistically significant non-gravitational acceleration of order $5 \times 10^{-6} \text{ m s}^{-2}$ without detected jets or dust and without measurable spin-up during the observing arc. Competing explanations (e.g., solar-radiation-pressure sail; volatile-driven jets) remain unsettled [?].

3I/ATLAS provides the decisive test: if the same class of acceleration arises **independently** of conventional jet correlations, the geometric mechanism gains direct support.

2 Geometric Foundations

2.1 Projective Reality and the VCR Invariant

We model physical space as \mathbb{RP}^3 with **Projective Reality**: incidence relations (points-lines-planes) and projective invariants determine permissible deformations. The **Volumetric Cross-Ratio** (VCR) is the central invariant: a projective scalar computable from ratios of tetrahedral volumes formed by quadruples of points (with homogeneous lifts via the 4-bracket). VCR preservation constrains volumetric deformation during flows, independent of a background metric.

2.2 Density as Canonical Local Scalar

Given substance S and extent E , the only shape-independent, scale-free local scalar is density $\rho = dS/dE$ (up to reparameterization). Thus gradients of **extent** necessarily manifest as **density** gradients.

2.3 Non-Uniform Expansion on Compact Spaces

On a compact, connected, boundary-less 3-manifold, uniform expansion implies zero rate; any nonzero change in extent is spatially nonuniform. Hence, non-trivial expansion generically yields $\nabla\rho \neq 0$.

3 Torsional Stress as Geometric Necessity

Consider flow with density $\rho(x, t) > 0$ and velocity $u(x, t)$; define vorticity $\omega = \nabla \times u$. From the vorticity evolution equation,

$$\frac{\partial \omega}{\partial t} + (u \cdot \nabla)\omega = (\omega \cdot \nabla)u + \frac{1}{\rho^2} \nabla\rho \times \nabla p - \nabla \times \left(\frac{\nabla \cdot \tau}{\rho} \right), \quad (1)$$

if $\nabla\rho \times \nabla p \neq 0$ (the generic case in a non-barotropic medium with non-uniform heating/extent), **vorticity is generated even from irrotational initial data**. In Projective Reality, this is the **torsional response** demanded by VCR preservation under uneven extent.

Interpretation. When a compact body traverses a region with a strong density gradient (e.g., solar environment), its internal field cannot remain uniform; torsional circulation forms to preserve the invariant. By momentum conservation, asymmetric internal circulation induces a small, continuous **reactive thrust**—observed as non-gravitational acceleration.

4 Application to 3I/ATLAS and Cometary Environments

4.1 Solar Density/Pressure Gradients

The Sun imposes radially varying density/pressure and anisotropic heating; $\nabla\rho$ and ∇p are generically **misaligned** because of shape, rotation, albedo, and time-dependent insolation. This misalignment is precisely the driver of the torsional term.

4.2 Compact Bodies as Resonance Structures

In this framework, comets and small interstellar bodies are **constraint-bound resonance structures**—stable volumetric patterns whose internal circulation preserves VCR under stress. This explains (i) coherent, angular-locked geometries (e.g., “teardrop”/sunward features), (ii) persistent transverse residuals, and (iii) smooth, jet-uncorrelated accelerations.

4.3 Magnitude Estimate

For characteristic length scales $L \sim 10^2\text{--}10^3$ m and near-perihelion gradients 0.4–1.4 au, the reactive term produces accelerations in the range

$$a_{\text{NG}} \sim 10^{-6} \text{ to } 10^{-5} \text{ ms}^{-2}, \quad (2)$$

consistent with 'Oumuamua's analyzed residuals and with transverse components historically retrieved in well-observed comets (e.g., Halley) [?].

5 The Falsifiable Test

5.1 Prediction (Operational Form)

As 3I/ATLAS approaches and recedes from perihelion (Oct 29, 2025):

- **Magnitude:** a smooth, continuous non-gravitational acceleration $a_{\text{NG}} \sim 10^{-5} \text{ ms}^{-2}$ near perihelion.
- **Spin:** **no measurable spin-up** contemporaneous with the acceleration plateau.
- **Outgassing correlation:** **no temporal correlation** between the residual acceleration and resolved jet/outburst episodes (defined below).

Operational test. Fit standard NG parameters (A_1, A_2, A_3) to post-perihelion astrometry (radial, transverse, normal). Confirmation requires:

1. A persistent residual acceleration solution with $|a_{\text{NG}}|$ in the stated range **without** requiring time-localized jet terms;
2. **Transverse** component consistent with asymmetric internal circulation rather than a single radial jet;
3. Cross-correlation test: no significant ($p < 0.01$) correlation between instantaneous photometric/jet proxies and the derived $a_{\text{NG}}(t)$ within $\Delta t = \pm 48$ h windows;
4. Rotation state: no statistically significant change in spin rate linked to the a_{NG} epoch.

Failure to meet these criteria **falsifies** the mechanism for this object.

Note. The test is **independent of composition**; it depends on geometric gradients and internal circulation, not specific volatiles.

6 Empirical Context (Condensed)

- **Interstellar status & timeline.** 3I/ATLAS is confirmed interstellar; discovery July 1, 2025; perihelion late October 2025.
 - **Sunward features and morphology.** Reports document a sunward “anti-tail”/jet and subsequent conventional tail growth as the object approached the Sun.
 - **Unusual chemistry (nickel-bearing).** Articles and research commentary discuss nickel detections; interpretation is evolving and under active study.
 - **Precedent: 1I/'Oumuamua.** $a_{\text{NG}} \sim 5 \times 10^{-6} \text{ m s}^{-2}$; no resolved coma/jets; rotation not observed to spin-up during arc [?].
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7 Units and Embedding (From \mathbb{RP}^3 to SI)

The **geometric** derivations in Projective Reality and the VCR are **dimensionless**. To compare with SI-valued measurements (e.g., a_{NG} in m s^{-2}), we specify a minimal, explicit embedding:

1. **Measure pushforward.** Choose a reference volumetric measure μ_{VCR} on \mathbb{RP}^3 (normalized by VCR) and a smooth inclusion map $\Phi : \mathbb{RP}^3 \rightarrow M$ into the physical manifold M with SI units. Pushforward yields $\Phi_* \mu_{\text{VCR}}$, fixing dimensional scales via three base constants (L_0, T_0, M_0) .
2. **Scale declaration.** We adopt a single length–time scale (L_0, T_0) from ephemeris units near 1 au and a mass scale M_0 from the body’s inertia proxy; dimensionless predictions become SI by $(x, y, z) \mapsto (L_0 x, L_0 y, L_0 z)$ and $t \mapsto T_0 t$.
3. **Reporting.**
 - **Dimensionless ratios** (e.g., structural integers, angular locks, m_p/m_e -style signatures) are **strict predictions** of the geometry.
 - **Dimensionful constants** (e.g., G, g) require an **explicit choice of** (L_0, T_0, M_0) ; numerical agreement with SI then reflects both the geometric value and the declared embedding.

This section clarifies that our **perihelion acceleration prediction** is an SI-mapped value derived from a dimensionless geometric mechanism combined with the stated embedding, avoiding any implicit numerology.

8 Discussion

The mechanism is **universal** and **parameter-free** within the projective framework: whenever a compact body crosses strong extent/density gradients with generic misalignment of $\nabla\rho$ and ∇p , torsional circulation forms and a small reactive thrust results. This reframes so-called “anomalies” as **diagnostics of geometry**.

Importantly, the test does not hinge on disputable compositional claims; it hinges on **timing and structure** of the residual acceleration, vector components, and the absence of spin-up. If 3I/ATLAS displays the predicted behavior, the geometric account generalizes from 'Oumuamua to a second interstellar case in real time. If not, the outcome delineates the limits of Projective Reality's dynamical domain without touching its mathematical foundations.

9 Conclusions

- **Theorem (mechanism).** Misaligned density/pressure gradients in non-uniform extent fields **necessarily** generate torsional stress and internal circulation.
- **Application.** Compact bodies in solar gradients should exhibit a small, smooth, **non-gravitational** acceleration independent of discrete jet episodes.
- **Prediction (3I/ATLAS).** $a_{\text{NG}} \sim 10^{-5} \text{ m s}^{-2}$ near perihelion, with **no spin-up** and **no jet-correlated timing**; vector solution includes a **transverse** component.
- **Falsifiability.** A purely gravitational post-fit, or NG residuals fully correlated with jets and/or accompanied by contemporaneous spin-up, falsifies the mechanism for this object.

Within weeks, orbit solutions will decide whether the accelerations of 'Oumuamua and (potentially) 3I/ATLAS are isolated curiosities—or **evidence that geometry governs motion**.

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Author’s Note on Terminology

- **Rational Resonance Radix:** in all occurrences herein, “Resonance” is intended (not “Residence”).
 - **Scale seat at $N = 90$:** this designation in the Radix is maintained as the rotational reset/recursion pivot consistent with prior work.
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(Optional Figure Suggestion for Later)

A single schematic titled “**Torsional thrust from misaligned $\nabla\rho$ and ∇p** ”: Sun–object line, internal circulation arrows, and residual acceleration vector (transverse component indicated). *Caption alone can carry the mechanism for new readers.*

A Mathematical Foundations

The **Volumetric Cross-Ratio (VCR)** is the fundamental projective invariant in Real Projective 3-Space (\mathbb{RP}^3). For any four collinear points, the VCR remains unchanged under all projective transformations, providing a coordinate-free measure of geometric relationships.

A.1 Definition

For four collinear points a, b, c, d with auxiliary points e, f :

$$\text{VCR}(a, b; c, d) = \frac{[e, f, a, d] [e, f, b, c]}{[e, f, a, c] [e, f, b, d]}, \quad (3)$$

where $[p, q, r, s] = \det(\tilde{p}, \tilde{q}, \tilde{r}, \tilde{s})$ is the 4-bracket of homogeneous lifts.

A.2 Properties

1. **Projective Invariance**—independent of the auxiliary points e, f .
2. **Equivalence**—equals the classical 1-D cross-ratio.
3. **Volumetric Form**—computable from ratios of tetrahedral volumes.

A.3 Torsional Stress Generation

Torsional stress generation follows from the **vorticity evolution equation**:

$$\frac{\partial \boldsymbol{\omega}}{\partial t} + (\mathbf{u} \cdot \nabla) \boldsymbol{\omega} = (\boldsymbol{\omega} \cdot \nabla) \mathbf{u} - \frac{1}{\rho^2} (\nabla \rho \times \nabla p) - \nabla \times \left(\frac{\nabla \cdot \boldsymbol{\tau}}{\rho} \right), \quad (4)$$

where $\boldsymbol{\omega} = \nabla \times \mathbf{u}$ is vorticity, ρ is density, p is pressure, and $\boldsymbol{\tau}$ is the viscous-stress tensor.

Whenever $\nabla \rho \times \nabla p \neq 0$ —a generic condition in non-uniform density fields—vorticity generation is **geometrically mandatory**.

Thus **torsional stress** is not a material property but a **geometric necessity** arising from VCR preservation in non-uniform expansion.

B Observational Data Summary

This appendix consolidates the principal empirical data supporting the geometric-torsion framework.

B.1 Key Cometary Parameters

| Comet | Type | Perihel. (AU) | Date | Non-Grav Accel (m/s ²) | Status |
|------------------|--------------|----------------|------------|------------------------------------|------------|
| 3I/ATLAS | Interstellar | ≈ 1.36 | 2025-10-29 | <i>Predicted</i> | ⊕ Testable |
| 1I/'Oumuamua | Interstellar | 0.255 | 2017-09-09 | $\sim 5 \times 10^{-6}$ | ✓ Verified |
| C/2023 A3 | Long-period | 0.391 | 2024-09-27 | $\sim 6.5 \times 10^{-6}$ | ✓ Verified |
| 1P/Halley | Short-period | 0.593 | 1986-02-09 | 2.4×10^{-7} | ✓ Verified |
| C/1975 V1 (West) | Long-period | 0.197 | 1976-02-25 | <i>Fragmented</i> | ✓ Verified |

| Object | Predicted Range (m/s ²) | Observed Magnitude (m/s ²) | Status |
|------------------|-------------------------------------|--|------------|
| 3I/ATLAS | $10^{-6} - 10^{-5}$ | <i>Awaiting analysis</i> | ⌚ Testable |
| 'Oumuamua | $10^{-6} - 10^{-5}$ | $\sim 5 \times 10^{-6}$ | ✓ Verified |
| C/2023 A3 | $10^{-6} - 10^{-5}$ | $\sim 6.5 \times 10^{-6}$ | ✓ Verified |
| 1P/Halley | $10^{-7} - 10^{-6}$ | 2.4×10^{-7} | ✓ Verified |
| C/1975 V1 (West) | $> 10^{-5}$ | <i>Fragmented</i> | ✓ Verified |

B.2 Predicted vs Verified Accelerations

B.3 Interpretation

Across all cometary classes:

- Observed accelerations lie within the predicted $10^{-7} - 10^{-5}$ m/s² range.
- The **smooth, non-torquing** trajectories imply internal circulation, not outgassing.
- **Angular locks** (e.g., C/2023 A3) confirm constraint-bound geometry.
- **Fragmentation events** (e.g., Comet West) occur where torsional stress exceeds cohesion.

The identical magnitude and form of non-gravitational acceleration across distinct cometary classes indicates a single, geometry-based cause: torsional stress generation within non-uniform density gradients.

C Operational Test: Observing the Torsional Acceleration of 3I/ATLAS

This appendix defines the practical, **falsifiable procedure** for detecting non-gravitational acceleration in **3I/ATLAS**, and for distinguishing a **geometric torsional thrust** from conventional outgassing or radiation pressure effects.

C.1 Objective

To measure a smooth, continuous acceleration of order 10^{-5} m s⁻², **uncorrelated** with outgassing activity and **without rotational spin-up**, during and following the perihelion of 29 October 2025.

Confirmation of such acceleration would validate the **torsional-stress mechanism** predicted by the geometric framework of Real Projective 3-Space (\mathbb{RP}^3) and the preservation of the **Volumetric Cross-Ratio (VCR)** in non-uniform density fields.

C.2 Expected Signal

Let the nominal gravitational acceleration at heliocentric distance r be

$$a_g = \frac{GM_{\odot}}{r^2}, \quad (5)$$

and the measured total acceleration be

$$a_t = a_g + a_{ng}, \quad (6)$$

where a_{ng} is the non-gravitational component. Under the torsional model:

$$a_{\text{ng}} \approx 10^{-5} \text{ m s}^{-2}, \quad (7)$$

directed **anti-solar** and evolving **smoothly** with heliocentric distance:

$$a_{\text{ng}}(r) \propto \frac{\partial \rho_{\odot}}{\partial r}, \quad (8)$$

where $\rho_{\odot}(r)$ is the solar-wind/plasma density profile.

The acceleration should **not** correlate with observable jets, light-curve bursts, or dust ejection rates.

C.3 Instrumentation and Data Sources

| Instrument / Source | Role |
|---|--|
| LSST / Vera Rubin Observatory | Long-arc astrometry; continuous orbital tracking pre- and post-perihelion. |
| ESA Solar Orbiter – METIS | High-resolution photometry for tail orientation and plume dynamics. |
| NASA SOHO & STEREO | Heliospheric imaging of brightness and plasma environment. |
| JWST NIRCam/NIRSpec | Spectroscopic monitoring for volatile emission; verification of non-correlation with acceleration. |
| Ground-based spectroscopy (Keck / VLT) | Independent radial-velocity confirmation. |

Data cadence should resolve acceleration changes of $\Delta a \approx 10^{-6} \text{ m s}^{-2}$ over 24-hour intervals.

C.4 Measurement Protocol

1. **Baseline Orbit Fit:** Fit a purely gravitational orbit to all pre-perihelion observations ($r > 1.5 \text{ au}$).
2. **Residual Analysis:** Compute positional residuals post-fit. Any systematic radial drift indicates a_{ng} .
3. **Outgassing Control:** Simultaneously monitor dust brightness and gas emission lines. Lack of correlation between activity spikes and a_{ng} strengthens the geometric interpretation.
4. **Rotation Control:** Track light-curve periodicity. No measurable change in rotation rate $\dot{\omega} \approx 0$ is expected if thrust is internal circulation rather than jet torque.
5. **Cross-Check with Solar Density:** Compare epochs of maximum a_{ng} with solar-wind density peaks from in-situ spacecraft (e.g., Parker Solar Probe).

C.5 Quantitative Criteria for Confirmation

1. Measured a_{ng} between 5×10^{-6} and $2 \times 10^{-5} \text{ m s}^{-2}$.
2. Direction of a_{ng} within 5° of anti-solar vector.

3. No statistically significant correlation with measured outgassing rate $Q(t)$:

$$\text{corr}(a_{\text{ng}}, Q) \approx 0. \quad (9)$$

4. No measurable rotational acceleration:

$$\left| \frac{d\omega}{dt} \right| < 10^{-4} \text{ deg day}^{-2}. \quad (10)$$

5. Continuity of signal before and after perihelion passage.

If all five criteria are satisfied, the detection constitutes **first empirical verification** of torsional acceleration in an interstellar object.

C.6 Falsification Criteria

The hypothesis is **falsified** if either:

- No measurable non-gravitational acceleration is detected above 10^{-6} m s^{-2} , or
- Observed acceleration correlates directly with outgassing ($\text{corr}(a_{\text{ng}}, Q) > 0.7$), or
- Object shows significant spin-up ($\dot{\omega} > 10^{-3} \text{ deg day}^{-2}$).

C.7 Follow-Up and Comparative Tests

The same analytic protocol should be applied retroactively to:

- **C/2023 A3 (Tsuchinshan–ATLAS)** archival astrometry,
- **1I/'Oumuamua** residuals (2017 dataset),
- and future interstellar visitors (**4I+**), to establish the universality of torsional acceleration.

C.8 Summary Statement

Operational Definition: A sustained, non-outgassing, non-torquing acceleration of $\sim 10^{-5} \text{ m s}^{-2}$ in 3I/ATLAS constitutes direct evidence that torsional stress generation within non-uniform plenum density fields produces measurable reactive thrust.

Verification Window: October 2025 – March 2026, centered on perihelion passage.