

Evidence for a Solar System Origin of 3I/ATLAS and Related Small Bodies within World-Universe Cosmology

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Abstract

The object formally designated C/2025 N1 (ATLAS) has been widely discussed as a candidate third interstellar object (“3I/ATLAS”) due to its strongly hyperbolic trajectory. In standard celestial mechanics, an interstellar origin is inferred when the original barycentric eccentricity significantly exceeds unity prior to planetary perturbations. This interpretation, however, implicitly assumes that cometary dynamics are governed solely by gravitational forces and conventional outgassing. In this work, we propose an alternative hypothesis: C/2025 N1 (ATLAS) is not interstellar but a Small Solar System Body (SB) originating from the Oort Cloud, consistent with the framework of World-Universe Cosmology (WUC). We argue that its large excess velocity can be explained by a non-gravitational internal acceleration mechanism involving partial conversion of the rotational energy of the nucleus into the translational kinetic energy of the SB. Within WUC, the Universe is structured as a hierarchy of interaction regimes—Macro-world (gravity), Large-world (extremely-weak interaction), Small-world (super-weak interaction), and Micro-world (weak interaction). Previous studies associate Ball Lightning [1] with SB1 and interpret the Tunguska superbolide [2] as an SB2 analogue. Extending this hierarchy, we identify C/2025 N1 (ATLAS) as an SB3 object. This model naturally accounts for its extreme hyperbolic excess velocity without invoking an interstellar origin and leads to specific, testable predictions regarding kinematics, activity, and radiation signatures. We compare these predictions with observations of ‘Oumuamua, C/2019 Q4 (Borisov), and a growing population of low-albedo asteroids and “dark comets” exhibiting dust-poor outgassing.

Keywords

World-Universe Cosmology, Small Solar System Bodies, Non-Gravitational Acceleration, Multiworld, C/2025 N1 (ATLAS), Internal Energy Conversion

1. Introduction

The Interplanetary Medium comprises the matter and energy filling the Solar System (SS), extending outward to the Heliopause—the boundary where the solar wind is balanced by the surrounding Interstellar Medium (ISM). Measurements by the Voyager spacecraft place this boundary at approximately 120 AU, although its shape is asymmetric, compressed in the direction of solar motion and extended in the polar regions.

Beyond the Heliopause lies ISM. However, the physical and dynamical extent of SS is not necessarily limited to this boundary. The Oort Cloud, a hypothesized reservoir of icy bodies, likely extends from $\sim 10^3$ AU to $\sim 10^5$ AU and remains gravitationally bound to the Sun. It is commonly divided into an inner disk-like component and a distant, nearly spherical outer component. Although often described as lying in interstellar space, the Oort Cloud is generally understood to consist of material formed within the early Solar System and later scattered outward by interactions with the giant planets.

Comets are traditionally classified into short-period (ecliptic) comets with orbits within ~ 10 AU and long-period comets (LPCs) with highly elongated orbits extending to thousands of AU. LPCs appear nearly isotropic in their arrival directions and are widely attributed to the Oort Cloud.

The discovery of objects on strongly hyperbolic trajectories—such as ‘Oumuamua and C/2019 Q4 (Borisov)—has led to the prevailing interpretation that such bodies originate in the ISM. The designation of C/2025 N1 (ATLAS) as a potential third interstellar object (“3I/ATLAS”) follows this paradigm.

However, this interpretation rests on a key assumption that hyperbolic motion necessarily implies an extrasolar origin. In this paper, we challenge this assumption. In WUC, the effective radius of SS is estimated to be $\sim 96,000$ AU, comparable to the outer extent of the Oort Cloud. From this perspective, the Oort Cloud remains an intrinsic component of SS rather than a transitional boundary to interstellar space.

We therefore explore an alternative hypothesis: C/2025 N1 (ATLAS) is SB3 whose hyperbolic excess velocity arises from the proposed internal, non-gravitational energy conversion mechanism, removing the need to invoke an interstellar origin.

2. Long-Period Comets

Astronomical observations since the mid-19th century have revealed numerous weakly hyperbolic comets, many of which are interpreted as Oort Cloud objects subsequently perturbed onto escape trajectories. In several well-studied cases, comets initially bound to SS transitioned to unbound orbits following close encounters with giant planets. Notable examples include C/1980 E1 (Bowell) and C/2024 L5 (ATLAS), both of which acquired hyperbolic trajectories through planetary scattering.

Long-period comets (LPCs) are conventionally defined as bodies with orbital periods exceeding 200 years. A subset—very long-period comets—have orbital periods of millions of years and are believed to originate in the outer Oort Cloud. For example, C/1999 F1 (Catalina) has an orbital period of several million years.

LPCs exhibit several well-established properties:

- Orbital periods: hundreds of years to millions of years
- Dynamical origin: perturbations by passing stars, molecular clouds, and galactic tides
- Isotropic distribution: reflecting the spherical structure of the outer Oort Cloud
- Primitive composition: high volatile content, leading to strong activity near the Sun

Recent surveys have expanded the known population of Oort Cloud comets to several thousand objects, a number expected to grow substantially with the Legacy Survey of Space and Time (LSST). Among these, C/2014 UN271 (Bernardinelli-Bernstein) is the largest known Oort Cloud comet and exhibits activity at unusually large heliocentric distances (see [Table 1](#)).

A key observational result is that hyperbolic trajectories are not uncommon among LPCs. In most cases, their weak hyperbolicity can be explained by:

- planetary perturbations (e.g., scattering by Jupiter or Saturn)
- non-gravitational forces driven by asymmetric outgassing

However, these mechanisms typically produce only weakly hyperbolic orbits, with eccentricities slightly exceeding unity ($e \gtrsim 1$). Even in extreme cases such as C/1980 E1 (Bowell), the observed excess velocity remains modest and can be quantitatively explained within standard dynamical frameworks.

In contrast, C/2025 N1 (ATLAS) exhibits an extraordinarily large eccentricity ($e \approx 6.14$), far beyond the range achievable through known gravitational or outgassing processes. This places it in a fundamentally different dynamical regime.

We therefore argue that the distinction between typical hyperbolic comets and C/2025 N1 (ATLAS) is qualitative rather than merely quantitative. Its extreme trajectory strongly suggests the presence of a powerful Non-Gravitational Acceleration (NGA) mechanism. Within the present framework, this behavior is naturally interpreted as the result of internal energy conversion.

3. Hyperbolic Asteroids

Asteroids are conventionally defined as minor planets—solid bodies larger than meteoroids ($\gtrsim 1$ m) that do not exhibit cometary activity. Most reside in the main asteroid belt between Mars and Jupiter and are composed primarily of rock and metal. However, modern observations increasingly reveal a continuum between asteroids and comets rather than a strict dichotomy.

A hyperbolic asteroid is a small body observed on an orbit with eccentricity $e > 1$, implying that it is not gravitationally bound to the Sun. Unlike comets, such objects initially show no detectable coma or outgassing, and their motion appears consistent with purely gravitational dynamics.

Table 1. Long-period comets with extreme aphelia.

Comet	Inbound Aphelion (AU) Orbital Period (Myr)	Outbound Aphelion (AU) Orbital Period
C/1973 E1 (Kohoutek)	98,000 (~11 Myr)	3700 (80,000 yr)
C/1999 F1 (Catalina)	54,000 (~4 Myr)	66,000 (~6 Myr)
C/2000 W1 (Utsunomiya-Jones)	70,000 (Myrs) $e = 0.9999996$	1670 (~24,000 yr)
C/2006 P1 (McNaught)	67,000 (~6 Myr)	4100 (~92,600 yr)
C/2010 X1 (Elenin)	97,000 (Myrs)	
C/2010 U3 (Boattini)	34,000 (~2.2 Myr)	9900 (~350,000 yr)
C/2011 L4 (PanSTARRS)	68,000 (Myrs)	4500 (~107,000 yr)
C/2013 A1 (Siding Spring)	52,000 (Several Myr)	13,000 (~500,000 yr)
C/2014 UN ₂₇₁ (Bernardinelli-Bernstein)	42,000 (~3 Myr) $e = 0.99947$	59,000 (~5.1 Myr) $e = 0.99967$
C/2017 K2 (PanSTARRS)	51,200 (~4.1 Myr)	1750 (~25,800 yr)
C/2017 T2 (PanSTARRS)	74,000 (~7 Myr)	3000 (~55,000 yr)
C/2019 E3 (ATLAS)	65,200 (~5.9 Myr)	34,000
C/1980 E1 (Bowell)	75,000 (~7.1 Myr) $e = 1.066$	Oort-cloud comet ejected by Jupiter, Hyperbolic, $e > 1.057$
C/2013 US ₁₀ (Catalina)	38,000 (Several Myr)	Hyperbolic trajectory
C/2024 L5 (ATLAS)	Original barycentric $e \approx 0.999$	Oort-cloud comet ejected by Saturn, Hyperbolic, $e > 1.037$
C/2023 A3 (Tsuchinshan-ATLAS)	$\approx 380,000$ (83 Myr) Original barycentric $e \approx 0.999$	Weakly hyperbolic, Future barycentric $e \approx 1.001 - 1.003$
C/2025 N1 (ATLAS)	Original barycentric $e > 1.01$	Ejected by the Sun, strongly hyperbolic trajectory, $e = 6.14$

In practice, many objects initially classified as hyperbolic asteroids are later re-classified as comets once faint activity is detected. Examples include C/2018 C2 (Lemmon) and C/2018 F4 (PAN-STARRS), both of which exhibited delayed or weak cometary signatures. This highlights the observational challenge of distinguishing inactive comets from asteroids based on early data.

The most notable confirmed hyperbolic asteroid is ‘Oumuamua, which displayed no classical coma yet exhibited significant NGA, likely driven by non-standard outgassing (e.g., H₂ or other low-visibility volatiles).

A key observational trend is that most hyperbolic small bodies are only weakly unbound, with eccentricities slightly above unity. Their trajectories can generally be explained by:

- gravitational perturbations
- radiation pressure
- weak, often undetected outgassing

Thus, even among objects classified as asteroidal, strongly hyperbolic trajec-

ries are rare and typically require additional physical explanation.

4. Small Solar System Bodies

Small Solar System Body is an object in the SS that is neither a planet nor a dwarf planet, nor a natural satellite. The term was first defined in 2006 by the International Astronomical Union as follows: “*All other objects, except satellites, orbiting the Sun shall be referred to collectively as ‘Small Solar System Bodies’*”.

4.1. Dark Comets

The discovery of ‘Oumuamua revealed a new dynamical class of SBs: objects that exhibit NGA without visible cometary activity. Unlike classical comets, ‘Oumuamua showed no detectable coma or dust tail, yet its trajectory deviated measurably from a purely gravitational orbit.

In cometary physics, dust particles are micron- to sub-millimeter-sized solid grains released from the nucleus during volatile sublimation. These grains scatter sunlight and are responsible for the visible coma and dust tail observed in active comets. In contrast, gas species (e.g., H_2O , CO , H_2) are dynamically dominant and can produce NGA through anisotropic outgassing. The absence of a detectable dust component, as observed in ‘Oumuamua, therefore implies either extremely low dust production or preferential release of gas without entrained solids, consistent with the emerging class of “Dark Comets.”

Non-Gravitational Acceleration without a Tail

The motion of ‘Oumuamua was tracked with high precision using facilities including the Hubble Space Telescope. These observations established that:

- **Direction:** The excess acceleration was consistently radially outward from the Sun.
- **Magnitude:** By early 2018, the object was displaced by $\sim 40,000$ km from its predicted gravitational trajectory.

This behavior implies the presence of a continuous, low-level thrust, analogous to cometary outgassing, but without visible ejecta.

Physical Interpretations

Several mechanisms have been proposed to explain this “invisible” acceleration:

Mechanism	Physical Basis
Hydrogen outgassing	Release of trapped H_2 from irradiated ice
Nitrogen ice sublimation	Evaporation of N_2 from Pluto-like fragments
Radiation pressure	Momentum transfer from sunlight
“Dark comet” activity	Dust-poor water vapor outgassing

The emerging consensus favors hydrogen outgassing, consistent with an icy body whose surface layers were chemically altered by long-term cosmic-ray expo-

sure in interstellar space.

Dark Comets in the Solar System

Since the discovery of ‘Oumuamua, astronomers have identified a population of “dark comets”—SBs that exhibit measurable NGA but lack visible comae or dust tails. A notable example is 1998 KY₂₆. It is a nearly spherical asteroid, approximately 11 meters in diameter, and is a fast rotator, having a rotational period of only 5.35 minutes. It was first observed on 2 June 1998. In 2023, 1998 KY₂₆ was identified as a possible dark comet.

Dark comets are asteroids that exhibit comet-like acceleration, but visually appear as asteroids, with no coma or tail. Astronomers who study them believe the acceleration is caused by outgassing on the sunlit side. These SBs suggest that:

- Low-level volatile release can occur without dust entrainment
- Outgassing may be spectrally or photometrically undetectable
- Non-gravitational forces may be more common than previously recognized

Thus, ‘Oumuamua may represent an extreme case within a broader, previously unrecognized population.

Contrast with Classical Cometary Behavior

The comet C/2019 Q4 (Borisov) provides a key comparison. Unlike ‘Oumuamua, Borisov displayed classical cometary activity, including a prominent coma and dust tail driven by sublimation of volatiles such as H₂O and CO. Its NGA is well explained by the rocket effect, in which anisotropic outgassing produces a recoil force on the nucleus. Observations further indicate a high abundance of carbon monoxide, allowing activity to persist at large heliocentric distances.

4.2. Low-Albedo Asteroids

The albedo in visible light ranges from about 0.9 to 0.95 for fresh snow to about 0.04 for charcoal, one of the darkest substances. A key physical property linking these SBs is their extremely low albedo. Typical values for dark bodies are 0.02 - 0.08, significantly lower than those of the Moon (~0.12) or Earth (~0.30). So, these asteroids are darker than charcoal!

Main types of dark asteroids:

- C-type (carbonaceous): Most common (~75% of known asteroids). Rich in carbon and hydrated minerals. Very primitive (early SS material). Examples: 253 Mathilde, albedo ~0.044.
- D-type: Even darker and more organic-rich. Found in outer SS regions. Examples: 624 Hektor, albedo 0.025; 911 Agamemnon, albedo 0.037.
- P-type: low-reflectivity mixtures of carbon, silicates, and organics.

Their darkness is attributed to carbon-rich composition, complex organic residues, and long-term radiation processing.

Connection to Interstellar Objects

- 1I/‘Oumuamua (albedo 0.04 - 0.08).
- 2I/Borisov (albedo 0.03 - 0.04).
- 3I/ATLAS (albedo 0.02 - 0.06).

These objects are almost certainly very dark, but their exact albedo remains unconstrained. Such a low albedo implies either primitive composition (a carbon-rich, organic-coated surface) or surface processing (cosmic rays, UV, gamma radiation) over long timescales.

Observational Bias

Low-albedo bodies are difficult to detect due to their weak reflectivity and are often identified through infrared observations or deep sky surveys such as Pan-STARRS. This introduces a strong observational bias, implying that many such SBs likely remain undetected.

Synthesis

The combined evidence supports a unified interpretation in which:

- Dark comets represent a transitional population between asteroids and comets
- Low albedo reflects primitive composition and/or radiation processing
- NGA arises from dust-poor or dust-free outgassing

Within this framework, SBs such as ‘Oumuamua, C/2019 Q4 (Borisov), and C/2025 N1 (ATLAS) can be understood as members of a continuous population shaped by common physical processes.

4.3. ‘Oumuamua

There is no detailed, high-resolution photograph of ‘Oumuamua. Because the ‘Oumuamua was so small and moving so fast, it appeared only as a single, faint point of light, even to our most powerful telescopes. The iconic “cigar-shaped” or “pancake-shaped” images seen in the media are artist’s impressions based on mathematical models of how the object’s brightness changed as it tumbled.

‘Oumuamua was discovered about 40 days after it passed closest to the Sun. Major telescopes like Hubble could not be pointed at it until ‘Oumuamua was already hundreds of millions of kilometers away and fading.

Because ‘Oumuamua moved faster than gravity alone could explain, scientists have proposed several theories for this NGA. Since no visible comet tail was detected, the cause remains a subject of intense debate. There were proposed different mechanisms for NGA:

- 1) Hydrogen Outgassing (Leading Natural Theory)
- 2) Nitrogen Iceberg
- 3) Solar Radiation Pressure.

This theory suggests the acceleration was caused simply by the physical “push” of sunlight (photons) hitting the object’s surface. The Requirement: For light alone to push ‘Oumuamua this much, the object would have to be extremely thin—less than a millimeter thick—acting like a massive sail.

Implication: This led to the controversial suggestion that ‘Oumuamua could be of artificial origin, such as a piece of advanced space debris or a probe. This suggestion was proposed based on eccentricity $e = 1.2$ of its outbound trajectory after full NGA during inbound trajectory. The first quantified value of ‘Oumuamua NGA was obtained by Micheli *et al.* [3]:

$$a_{\text{NG}} \approx (4.9 \pm 0.2) \times 10^{-6} \text{ m} \cdot \text{s}^{-2}$$

that exceeds the NGA values for the classical comets by more than fifty times (see Section 4.6), despite the absence of a detectable dust coma, demonstrating that significant recoil forces can arise from dust-poor or dust-free outgassing.

4.4. C/2019 Q4 (Borisov)

Unlike ‘Oumuamua, where the acceleration was a mystery due to a lack of visible activity, C/2019 Q4 (Borisov) behaved like a “textbook” comet. Its NGA was clearly linked to the visible outgassing of gas and dust as it approached the Sun.

As Borisov got closer to the Sun, its ices (specifically water and carbon monoxide) sublimated directly into gas. This gas, along with dust particles, was ejected from the nucleus in “jets”. These jets created a recoil force that pushed the comet slightly off its purely gravitational path.

Observations showed that Borisov was exceptionally rich in carbon monoxide (CO), which sublimates at much lower temperatures than water ice. This allowed it to remain active and continue accelerating even at great distances from the Sun.

Borisov was so “normal” that it helped astronomers understand what a typical interstellar comet looks like. Its acceleration allowed researchers to estimate its mass and density more accurately than they could for ‘Oumuamua. The mechanism of its NGA $a_{\text{NG}} \sim 10^{-6} \text{ m} \cdot \text{s}^{-2}$ (this value is much larger than the values for outgassing mechanism, see Section 4.6) remains open.

4.5. C/2025 N1 (ATLAS)

Recent high-precision orbit determinations of C/2025 N1 (ATLAS) provide strong evidence for significant NGA well above the levels typically observed in long-period comets. Eubanks *et al.* incorporated six additional observations obtained from two interplanetary spacecraft into the orbital solution. These measurements, acquired from vantage points and epochs inaccessible to ground-based observatories, reduced the formal uncertainties in the derived NGA parameters by approximately 20% - 40% compared to solutions based solely on ground-based data collected between May and December 2025 [4].

Using this expanded dataset, they determined an NGA vector (scaled to 1 AU) of:

$$(89.3 \pm 4.6) \times 10^{-9} \text{ au} \cdot \text{day}^{-2}$$

which corresponds to:

$$(1.79 \pm 0.09) \times 10^{-6} \text{ m} \cdot \text{s}^{-2}$$

Independent analyses by several authors yield comparable or even larger values, as summarized in **Table 2**.

According to *Jet Propulsion Laboratory: Small-Body Database Lookup*, the latest values of NGA for so named “interstellar comets” are presented in **Table 3**.

Table 2. Reported non-gravitational accelerations of C/2025 N1 (ATLAS).

##	Authors	NGA ($\text{m}\cdot\text{s}^{-2}$)	Reference
1	Eubanks, <i>et al.</i>	$(1.79 \pm 0.09) \times 10^{-6}$	[4]
2	Neukart	$(3.0 \pm 0.8) \times 10^{-5}$	[5]
3	Scarmato	$\sim 0.5 \times 10^{-6}$	[6]
4	Ahuja and Ganesh	$\sim 10^{-6}$	[7]
5	Spada, Królikowska, and Dones	$(1.13 \pm 0.036) \times 10^{-6}$	[8]

Table 3. Latest non-gravitational accelerations of “interstellar objects”.

##	Small Objects	NGA ($\text{m}\cdot\text{s}^{-2}$)	Reference
1	1I/‘Oumuamua	$(5.6 \pm 0.72) \times 10^{-6}$	[9]
2	2I/Borisov	$(0.98 \pm 0.08) \times 10^{-6}$	[10]
3	3I/ATLAS	$(1.06 \pm 0.024) \times 10^{-6}$	[11]

A key result emerging from these studies is that the characteristic magnitude of NGA satisfies:

$$a_{\text{NG}} \gtrsim 10^{-6} \text{ m}\cdot\text{s}^{-2}$$

This value is one to four orders of magnitude larger than the typical range observed in comets (Section 4.6).

Implications

Such an unusually large acceleration cannot be readily explained by standard mechanisms:

- Outgassing: would require unrealistically high mass-loss rates or extreme anisotropy
- Radiation pressure: insufficient for an object of typical cometary size and mass
- Thermal effects (Yarkovsky/YORP): too weak by several orders of magnitude

Therefore, **C/2025 N1** (ATLAS) occupies a distinct dynamical regime, in which the conventional framework of cometary physics appears insufficient.

This discrepancy strongly suggests the presence of an additional or alternative acceleration mechanism. Within the present framework, such behavior is naturally interpreted as the result of an internal energy conversion, in which the rotational energy of a nucleus is partially transformed into translational kinetic energy of SB3.

4.6. Sources of Non-Gravitational Accelerations

NGAs are measurable deviations from purely gravitational motion, arising from internal or surface processes, as well as interactions with radiation and plasma. Although typically small in magnitude, NGAs play a crucial role in the orbital evo-

lution of small bodies, particularly those on near-parabolic trajectories.

Principal Sources of NGA

1) Outgassing (dominant for comets). Asymmetric sublimation of volatile ices produces reactive forces that alter the trajectory.

- Typical magnitude near 1 AU:

$$a_{\text{NG}} \sim 10^{-10} \text{ to } 10^{-7} \text{ m} \cdot \text{s}^{-2}$$

- Effects:
 - shifts in perihelion timing (hours to days)
 - changes in eccentricity at the 10^{-7} - 10^{-6} level
 - modification of inferred original orbits

2) Yarkovsky effect (thermal recoil). Anisotropic thermal emission from a rotating body produces a small thrust.

- Typical magnitude:

$$a_{\text{Yark}} \sim 10^{-13} \text{ to } 10^{-10} \text{ m} \cdot \text{s}^{-2}$$

- Important for:
 - long-term orbital drift
 - near-Earth asteroid trajectory prediction

3) YORP effect (rotational dynamics). Radiation and thermal emission exert torques that modify spin rate and axis orientation.

- Consequences:
 - spin-up or spin-down
 - changes in obliquity
 - possible structural disruption or fission
 - indirect influence on orbital evolution via altered outgassing geometry

4) Radiation pressure. Momentum transfer from solar photons affects small or low-mass objects.

- Particularly relevant for:
 - very small bodies
 - low-density or high area-to-mass ratio objects

Summary

NGA in SS bodies arise primarily from outgassing, radiation pressure, and thermal effects. Their typical magnitudes (10^{-10} - 10^{-7} m s^{-2}) are small but dynamically significant, especially for long-period comets near the parabolic limit, where even minute perturbations can produce large changes in inferred orbital parameters.

However, these known mechanisms are insufficient to explain strongly hyperbolic trajectories such as that reported for C/2025 N1 (ATLAS). This discrepancy motivates the exploration of alternative acceleration mechanisms.

4.7. Origin of Comets and Asteroids

Comets and asteroids are widely understood as remnants of the early SS, formed approximately 4.6 billion years ago from the protoplanetary disk surrounding the young Sun. Their formation reflects the thermal gradient within this disk:

- Inner SS (high temperature): Formation of rocky and metallic bodies → asteroids.
- Outer SS (low temperature): Condensation of volatile ices mixed with dust → comets.

Asteroids primarily formed in the region now occupied by the asteroid belt, where gravitational perturbations from Jupiter inhibited accretion into a full-sized planet. Comets formed beyond the “snow line,” where volatile compounds such as water, CO₂, methane, and ammonia could condense.

Subsequent gravitational interactions with the giant planets redistributed these bodies:

- Kuiper Belt: reservoir of short-period comets
- Oort Cloud: source of long-period comets

This standard model implies a common origin in the protoplanetary disk, with present-day differences arising from thermal history and dynamical evolution. At the same time, growing observational evidence supports a continuum between asteroids and comets, blurring traditional classification boundaries.

Key question. What is the ultimate origin of the material—dust, metals, ices, and complex molecules—that formed these primordial bodies? This question remains open and is central to alternative cosmological frameworks such as WUC.

5. Multiworld Framework [1]

The concept of multiple coexisting physical regimes has been previously hinted at in the literature. As noted by Oreshko, Pyotr Kapitsa suggested that *ball lightning may represent a “window” into another world* [12]. Motivated by this idea, we developed a hierarchical Multiworld framework consisting of Macro-world, Large-world, Small-world, and Micro-world.

In contrast to the standard cosmological paradigm invoking dark matter, WUC assumes that the World is composed of:

- Ordinary Matter (protons, electrons, photons, neutrinos)
- Universe-Created Matter (UCM), consisting of Universe-Created Particles (UCPs)

These components interact through a hierarchy of interactions with different strengths and characteristic scales.

5.1. Macro-World (Gravitational Regime)

Gravity is described by a scale-dependent gravitational parameter:

$$G = G_0 \times Q^{-1}$$

where: $G_0 = \frac{a^2 c^4}{8\pi h c}$ is an extrapolated value of G at $Q = 1$, h is the Planck constant, c is a gravitodynamic constant, a is a basic length unit:

$$a = 1.7705641 \times 10^{-14} \text{ m}$$

Q in the present Epoch equals $Q = 0.759972 \times 10^{40}$. The corresponding char-

acteristic scale (radius of the World R) is:

$$R = a \times Q = 1.34558 \times 10^{26} \text{ m}$$

The total mass and average critical density of the Macro-world are:

$$M_{\text{MW}} = 6\pi^2 m_0 \times Q^2 = 4.27 \times 10^{53} \text{ kg}$$

$$\rho_{\text{MW}} = 3\rho_0 \times Q^{-1} = 8.88 \times 10^{-27} \text{ kg} \cdot \text{m}^{-3}$$

where m_0 is a basic mass unit: $m_0 = h/ac$ and ρ_0 is a basic density unit:

$$\rho_0 = h/ca^4.$$

5.2. Hierarchy of Interactions

WUC introduces three additional interactions beyond gravity: Weak, Super-Weak, and Extremely-Weak, characterized by the following parameters respectively:

$$G_{\text{W}} = G_{\text{O}} \times Q^{-1/4}$$

$$G_{\text{SW}} = G_{\text{O}} \times Q^{-1/2}$$

$$G_{\text{EW}} = G_{\text{O}} \times Q^{-3/4}$$

Each interaction defines the integrity and scale of the corresponding world (**Table 4**).

Table 4. Parameters of the Multiworld.

Type of World	Type of Interaction	Rel. Interaction Parameter, G/G_0	Rel. Range of Interact, R_{max}/a	Rel. Mass, $M_{\text{max}}/4\pi m_0$	Rel. Density, $\rho/3\rho_0$
Macro-World	Gravity	Q^{-1}	Q	$1.5\pi \times Q^2$	Q^{-1}
Large-World	Extremely-Weak	$Q^{-3/4}$	$Q^{3/4}$	$Q^{3/2}$	$Q^{-3/4}$
Small-World	Super-Weak	$Q^{-1/2}$	$Q^{1/2}$	Q	$Q^{-1/2}$
Micro-World	Weak	$Q^{-1/4}$	$Q^{1/4}$	$Q^{1/2}$	$Q^{-1/4}$

5.3. Large-World (Extremely-Weak Interaction)

The Large-world is governed by the extremely-weak interaction, approximately 10 orders of magnitude stronger than gravity. Its characteristic range is:

$$R_{\text{EW}} = a \times Q^{3/4} = 1.44 \times 10^{16} \text{ m} \approx 1.52 \text{ ly} \approx 96335 \text{ AU}$$

This scale defines the boundary of Extra-Solar Systems (ESS), interpreted as spherical structures separating Solar-type systems from the Interstellar Medium.

The maximum total mass of such a system is:

$$M_{\text{ESS}} = 4\pi m_0 \times Q^{3/2} = 1.04 \times 10^{33} \text{ kg} \approx 523 M_{\odot}$$

with a corresponding maximum stellar mass:

$$M_{\text{Star}} = 1/3 M_{\text{ESS}} \approx 174 M_{\odot}$$

The average density:

$$\rho_{\text{EW}} = 3\rho_0 \times Q^{-3/4} = 8.29 \times 10^{-17} \text{ kg} \cdot \text{m}^{-3}$$

exceeds the critical density by ten orders of magnitude.

5.4. Small-World (Super-Weak Interaction)

The Small-world is governed by the super-weak interaction, approximately 20 orders of magnitude stronger than gravity. Its characteristic range is:

$$R_{\text{SW}} = a \times Q^{1/2} = 1.54 \times 10^6 \text{ m}$$

The maximum mass and density are:

$$M_{\text{SW}} = 4\pi m_0 \times Q = 1.19 \times 10^{13} \text{ kg}$$

$$\rho_{\text{SW}} = 3\rho_0 \times Q^{-1/2} = 7.74 \times 10^{-7} \text{ kg} \cdot \text{m}^{-3}$$

Within this framework:

- Ball Lightning → Small Body SB1 [1]
- Tunguska Superbolide → Small Body SB2 [2]
- C/2025 N1 (ATLAS) → Small Body SB3

Thus, C/2025 N1 (ATLAS) is interpreted as a higher-order Small Body SB3, whose anomalous dynamics arise from internal processes associated with UCM Nucleus.

Notably, the concept of superweak interactions was also explored by Wolfenstein [13], providing partial conceptual precedent.

5.5. Micro-World (Weak Interaction)

The Micro-world is governed by an interaction approximately 30 orders of magnitude stronger than gravity, with range:

$$R_{\text{W}} = a \times Q^{1/4} = 1.65 \times 10^{-4} \text{ m}$$

This scale is many orders of magnitude larger than the conventional weak nuclear force range, implying a fundamentally different interaction regime.

The maximum mass is:

$$M_{\text{W}} = 4\pi m_0 \times Q^{1/2} = 1.37 \times 10^{-7} \text{ kg} \approx 6.28 M_{\text{Pl}},$$

and the density:

$$\rho_{\text{W}} = 3\rho_0 \times Q^{-1/4} = 7.23 \times 10^3 \text{ kg} \cdot \text{m}^{-3}$$

Micro-world objects, with masses about the Planck mass M_{Pl} (including dust particles), are proposed as fundamental building blocks of all macroscopic structures.

5.6. Cosmic Bubbles

All four regimes—Macro, Large, Small, and Micro—are interpreted as Cosmic Bubbles with boundaries characterized by a universal surface energy density:

$$\sigma_0 = hc/a^3$$

The total energy E_{CB} of a Cosmic Bubble of radius R_{CB} is [14]:

$$E_{\text{CB}} = 4\pi\sigma_0 R_{\text{CB}}^2$$

This relation provides a unifying description of structure formation across all scales, linking geometry, energy, and interaction strength.

6. Orbital Parameters of Solar System Bodies

In celestial mechanics, there is no sharply defined maximum cometary aphelion, as long-period orbits are highly sensitive to perturbations and observational uncertainties. Nevertheless, empirical evidence suggests a practical upper limit of order

$$R_{\text{max}} \sim 10^5 \text{ AU} \approx 1.6 \text{ ly},$$

as illustrated by the comets listed in **Table 1**.

6.1. Solar System Hill Sphere (Galactic Context)

The Hill sphere defines the region within which the gravitational influence of a system dominates over external tidal forces. For SS embedded in the Milky Way, the Hill radius R_H can be approximated as

$$R_H = R_{\text{GC}} \left(\frac{M_{\text{SS}}}{3M_{\text{MW}}} \right)^{1/3}$$

where:

- $R_{\text{GC}} \approx 26.7 \text{ kly}$ is the Galactocentric distance of the Sun
- $M_{\text{SS}} \approx 2 \times 10^{30} \text{ kg}$ is the SS mass
- $M_{\text{MW}} \approx 1.15 \times 10^{12} M_{\odot}$ is the enclosed Galactic mass

This yields

$$R_H \approx 1.67 \times 10^{16} \text{ m} \approx 1.11 \times 10^5 \text{ AU} \approx 1.76 \text{ ly}$$

The characteristic Large-world scale is

$$R_{\text{EW}} = 1.44 \times 10^{16} \text{ m} \approx 0.963 \times 10^5 \text{ AU} \approx 1.52 \text{ ly}$$

The close agreement between R_H and R_{EW} suggests that:

- the outer boundary of the Oort Cloud lies near $\sim 10^5 \text{ AU}$
- stable cometary aphelia significantly beyond this scale are dynamically disfavored

The corresponding maximum orbital period is

$$T = \sqrt{\frac{\pi^2 R_{\text{EW}}^3}{2GM_{\odot}}} \approx 15 \text{ Myr}$$

consistent with longest reliably determined periods of long-period comets (**Table 1**).

The extremely large aphelion ($\sim 380,000$ AU) and orbital period (~ 83 Myr) sometimes reported for C/2023 A3 (Tsuchinshan-ATLAS) are likely influenced by:

- observational uncertainties
- non-gravitational perturbations

For comparison, the distance to Proxima Centauri (≈ 4.24 ly) highlights that such orbital solutions approach interstellar scales.

In standard astrophysics, the SS boundary is often associated with the Helio-pause (~ 120 AU). In contrast, within the present framework the effective boundary is set by the Large-world scale ($\sim 10^5$ AU), consistent with the observed cutoff in comet aphelia.

No Solar System comet has a securely determined original barycentric aphelion exceeding $\sim 10^5$ AU; larger formal values arise naturally from uncertainties in near-parabolic orbit solutions.

6.2. Motion with Non-Gravitational Acceleration

To examine the dynamical impact of sustained NGA, consider radial motion under solar gravity plus a constant outward acceleration a_{NG} :

$$\frac{d^2 r}{dt^2} = -\frac{GM_{\odot}}{r^2} + a_{\text{NG}},$$

with initial condition

$$\left. \frac{dr}{dt} \right|_{r=r_0} = v_0 = 0.$$

Integration yields

$$v^2 = 2 \left[GM_{\odot} \left(\frac{1}{r} - \frac{1}{r_0} \right) + a_{\text{NG}} (r_0 - r) \right].$$

For $r \ll r_0$, this simplifies to

$$v^2 \approx 2 \left(\frac{GM_{\odot}}{r} + a_{\text{NG}} r_0 \right).$$

Taking the perihelion distance

$$r_p = 1.35645 \text{ AU} \approx 2.03 \times 10^{11} \text{ m},$$

the gravitational contribution alone yields

$$v_{\text{grav}} \approx 3.62 \times 10^4 \text{ m} \cdot \text{s}^{-1}$$

The observed maximum velocity is

$$v_{\text{max}} \approx 6.83 \times 10^4 \text{ m} \cdot \text{s}^{-1}$$

Thus, the excess component satisfies

$$v_{\text{NG}}^2 = v_{\text{max}}^2 - v_{\text{grav}}^2 \approx 3.36 \times 10^9 \text{ m}^2 \cdot \text{s}^{-2}$$

Assuming the NGA acts over a characteristic distance comparable to the Large-world scale,

$$r_0 \approx R_{EW} = 1.44 \times 10^{16} \text{ m}$$

we obtain

$$a_{NG} \approx \frac{v_{NG}^2}{2r_0} \approx 1.17 \times 10^{-7} \text{ m} \cdot \text{s}^{-2}$$

This represents a lower bound, corresponding to acceleration acting over the maximum distance r_0 . Even in this limiting case, the required acceleration lies at the upper end of—or exceeds—the typical range for cometary non-gravitational effects ($10^{-10} - 10^{-7} \text{ m} \cdot \text{s}^{-2}$).

However, directly inferred values for C/2025 N1 (ATLAS) (Section 4.5) are of order

$$a_{NG} \sim 10^{-6} \text{ m} \cdot \text{s}^{-2}$$

significantly exceeding expectations from standard outgassing models. We emphasize that the derived NGA is independent of the assumed initial velocity v_0 . Consequently, an “interstellar body,” regardless of the value of v_0 , cannot account for the directly inferred magnitude of a_{NG} .

This analysis shows that:

- sustained NGA can significantly modify cometary velocities
- the magnitude required for C/2025 N1 (ATLAS) exceeds that attainable by conventional mechanisms
- a fundamentally different physical process must therefore be considered

Within the present framework, this is naturally interpreted as internal energy conversion, whereby rotational energy of the nucleus is transformed into translational kinetic energy of SB3.

Moreover, weaker analogues of this process may contribute to the dynamics of other long-period comets, suggesting a broader role for NGA than traditionally assumed.

6.3. Gravitationally Rounded Objects in the Solar System

Within the present framework, all gravitationally rounded bodies—from planets to galaxy clusters—are proposed to contain cores composed of Universe-Created Matter (UCM). These cores consist of UCPs undergoing continuous self-annihilation, forming Self-Annihilating Reactors (SARs) that function as persistent internal energy sources.

A representative lower bound for gravitationally rounded in SS is Saturn’s moon Mimas, with:

- Mean radius: $198.2 \text{ km} \pm 0.4 \text{ km}$
- Mass: $3.75 \times 10^{19} \text{ kg}$
- Mean density: $\sim 1.15 \times 10^3 \text{ kg} \cdot \text{m}^{-3}$
- Surface temperature: $\sim 64 \text{ K}$

The observed temperature exceeds that expected from solar heating alone. Within the present framework, this discrepancy is attributed to internal energy generation within the UCM core. Even at relatively low densities ($\sim 10^3 \text{ kg}\cdot\text{m}^{-3}$), self-annihilation processes may remain effective.

Extending this concept, SARs are proposed to operate in all planetary bodies, including Earth, providing energy for:

- volcanism
- seismic activity
- long-term geological evolution

6.4. Tunguska Superbolide

The Tunguska event is commonly interpreted as the atmospheric disruption of a $\sim 50 - 60 \text{ m}$ body, releasing $\sim 3 - 30 \text{ Mt}$ TNT equivalent at an altitude of $\sim 5 - 10 \text{ km}$ without forming an impact crater. Such events belong to the class of airbursts (fireballs or bolides), with the most energetic classified as superbolides.

Meteoroids enter Earth's atmosphere at velocities $\geq 11 \text{ km/s}$, compressing the air ahead of them and generating extreme temperatures through adiabatic heating (ram pressure). This process leads to ablation, fragmentation, or explosive disruption.

WUC Interpretation

The Tunguska object (SB2) is interpreted as follows:

- It possessed a low-density UCM core ($< 10^3 \text{ kg}\cdot\text{m}^{-3}$).
- Under normal conditions, self-annihilation was inefficient, allowing stability in space.
- Atmospheric entry increased core density via ram pressure.
- A critical threshold triggered rapid self-annihilation, producing explosive energy release.

The estimated maximum energy

$$E_{\text{SB2}} \approx 1.26 \times 10^{17} \text{ J}$$

implies a core volume

$$V_{\text{core}} \approx 0.4 \text{ m}^3$$

corresponding to a characteristic diameter

$$D_{\text{core}} \sim 1 \text{ m}.$$

Thus, SB2 bodies are interpreted as metastable UCM structures capable of rapid energy release under external perturbations.

7. Solar System Small Bodies

7.1. Origin of Solar System Small Bodies

In the present framework, Ecliptic Small Bodies (SBs) were produced by the Sun as the result of Volcanic Rotational Fission (VRF) of the Sun's UCM Core 4.57

Byr ago [1].

Nearly isotropic SBs were produced by Giant Planets with different directions of their rotational axes (which are, in fact, “Failed stars”) as the result of VRF of their UCM cores 4.57 Byr ago.

UCM cores of satellite objects can be any size from micrometers to thousands of km. Satellites are rocky or icy bodies as the result of the self-annihilation of UCPs inside of their cores with a density $\gtrsim 10^3 \text{ kg}\cdot\text{m}^{-3}$.

All chemical elements, compositions, and radiative outputs are generated in situ through UCP self-annihilation within UCM cores of asteroids and comets. The formation of all objects in SS has a good explanation.

In case when the density of UCM cores of satellites is $<10^3 \text{ kg}\cdot\text{m}^{-3}$, the self-annihilation process is not efficient. Then, there is a possibility of stable UCM Bolides (SB2), which are the analog of Ball Lightnings (SB1) with much larger internal energy.

7.2. Characteristics of Small Solar System Bodies

SBs are governed by the super-weak interaction. Its characteristic interaction range is:

$$R_{\text{SW}} = a \times Q^{1/2} \approx 1.54 \times 10^3 \text{ km} ,$$

The theoretical maximum Small-world mass is:

$$M_{\text{SW}} = 1.19 \times 10^{13} \text{ kg}$$

SBs consist of Nuclei and Inner Comae. Nuclei are Rotating Balls made of UCM with density in the range from $3.44 \text{ kg}\cdot\text{m}^{-3}$ up to $\sim 10^3 \text{ kg}\cdot\text{m}^{-3}$, at different rotation speeds up to the maximum speed at the nucleus equator equals the escape velocity.

The range of the weak interaction for particles UCF1 (1.3 TeV) is:

$$R_{\text{UCF1}}^{\text{W}} = 0.88 \times 10^{-8} \text{ m}$$

and a calculated minimum particle concentration is:

$$n_{\text{UCF1}} = 1.47 \times 10^{24} \text{ m}^{-3} .$$

Considering the rest energy of UCF1:

$$E_{\text{UCF1}} = 1.315 \text{ TeV} = 2.11 \times 10^{-7} \text{ J} ,$$

we can calculate the minimum energy density of the UCM core:

$$\rho_{\text{UCF1}} = 3.1 \times 10^{17} \text{ J/m}^3$$

that is equivalent to the mass density of $3.44 \text{ kg}\cdot\text{m}^{-3}$ that is not enough for efficient self-annihilation.

Inner Comae have different diameters D_{IC} in the range of $\sim 10^3 \text{ km}$ up to the maximum diameter:

$$D_{\text{IC}} = 2R_{\text{SW}} \approx 3.1 \times 10^3 \text{ km}$$

Micro-World Connection: Dust and Coma Formation

The weak-interaction scale:

$$R_W \approx 1.65 \times 10^{-4} \text{ m} \approx 165 \text{ } \mu\text{m}$$

matches the observed diameters of large dust grains D_{DG} in the inner comae [15] up to the maximum diameter D_{max} :

$$D_{\text{max}} = 2R_W \approx 330 \text{ } \mu\text{m}$$

This suggests that:

- Micro-world objects (UCM fragments) are continuously generated due to the Rotational Fission of Nuclei made of UCM.
- These fragments evolve into dust grains and volatiles via UCP self-annihilation.
- The Inner comae are thus a direct manifestation of internal UCM processes.

Micro-Volcanism (MiV) Mechanism

The activity of SBs is driven by recurrent MiVs, governed by the following cycle:

1) Energy Release Phase

- o The UCM core ejects material.
- o A small fraction of mass is lost.
- o A significant fraction of rotational angular momentum is dissipated.

2) Accumulation Phase

- o The core continuously absorbs UCPs from the four-dimensional Nucleus of the World created by the Eternal Universe.
- o Mass increases as $M \propto \tau$ (cosmological time).
- o Angular momentum increases faster $L \propto \tau^{3/2}$.

3) Instability Threshold

- o When the rotational velocity of the core approaches the escape velocity, a new MiV event is triggered.

4) Continuous Outflow

- o Dust grains and volatiles are continuously replenished.

Energy Conversion Mechanism

A key feature of the model is the conversion of rotational energy into translational kinetic energy:

- MiVs generate internal torques.
- These torques reduce the rotational energy of nuclei while increasing their translational kinetic energy.
- The process is analogous to a rotating body converting spin into linear motion under frictional interaction.

This mechanism naturally explains:

- The large NGA.
- The enhanced perihelion velocity.
- The stability of NGA over time.

Importantly, the Nucleus is assumed to rotate at a near-critical equatorial velocity, approximately equal to its escape velocity, maintaining a quasi-steady energy conversion regime.

Synthesis

Within the present framework:

- C/2025 N1 (ATLAS) is interpreted as a Small Body (SB3).
- Its coma, dust production, and dynamics arise from internal UCM processes.
- Its anomalous trajectory is explained by continuous internal energy conversion, rather than external forces alone.

This interpretation provides a unified explanation linking:

- Cometary activity
- NGA
- Hyperbolic motion

7.3. Nucleus of Small Body

Estimates of the Nucleus properties of C/2025 N1 (ATLAS) are highly model-dependent. Reported values include [16]:

- Density: $\rho \approx 200 - 600 \text{ kg} \cdot \text{m}^{-3}$
- Mass: $M \approx 4.4 \times 10^{10} \text{ kg}$
- Diameter: $D \approx 0.520 - 0.748 \text{ km}$

However, within the present framework, the only directly measured parameters are:

- Rotation period: $T = (16.16 \pm 0.01) \text{ h}$
- Diameter (Hubble): $D_H = 0.32 - 5.6 \text{ km}$

Rotation-Constrained Density ρ

Assuming that the equatorial velocity equals the escape velocity $v = v_{esc}$, that is a condition for the production of dust grains due to the Rotational Fission of the nucleus made of Universe-Created Matter (UCM):

$$v^2 = \frac{2GM}{R} = \frac{8\pi G\rho}{3} R^2$$

we obtain:

$$\omega = \frac{v}{R} = \sqrt{\frac{8\pi G\rho}{3}} = \frac{2\pi}{T}$$

This yields a density depending only on the rotation period:

$$\rho = \frac{3\pi}{2GT^2}$$

For $T = 16.16 \text{ h}$:

$$\rho \approx 20.9 \text{ kg} \cdot \text{m}^{-3}$$

Implications

- $\rho \gg 3.44 \text{ kg} \cdot \text{m}^{-3}$ (minimum UCM core density)
- $\rho \ll 10^3 \text{ kg} \cdot \text{m}^{-3}$ (efficient SAR threshold)

Thus, the nucleus is long-term stable, with low-rate self-annihilation.

Size and Mass Constraints

Maximum possible radius (using Small-world mass limit

$M_{sw} = 1.19 \times 10^{13} \text{ kg}$):

$$R_{\max} \approx 5.15 \text{ km} \quad D_{\max} \approx 10.3 \text{ km}$$

For the reported mass $4.4 \times 10^{10} \text{ kg}$:

$$R \approx 0.80 \text{ km} \quad D \approx 1.6 \text{ km}$$

Using the observational upper bound $R_H \leq 2.8 \text{ km}$, the corresponding mass is:

$$M_H \lesssim 1.92 \times 10^{12} \text{ kg}$$

These values define a physically consistent parameter space for the Nucleus.

Rotational Energy

For $R_H = 2.8 \text{ km}$:

$$v = \omega R_H \approx 0.30 \text{ m} \cdot \text{s}^{-1}$$

$$E_{\text{rot}} = \frac{1}{5} M v^2 \approx 3.5 \times 10^{10} \text{ J}$$

This rotational energy of the nucleus acts as a reservoir for conversion into translational kinetic energy of C/2025 N1 (ATLAS), contributing to the observed NGA.

8. WUC Explanation of C/2025 N1 (ATLAS) Observations

8.1. Key Observations of C/2025 N1 (ATLAS)

C/2025 N1 (ATLAS) appears distinctly diffuse in telescope images, indicating that its nucleus is surrounded by a coma—a cloud of gas and dust produced by out-gassing. Coma maps of H_2O , CO_2 , and CH_4 (Figure 1) reveal structured emission

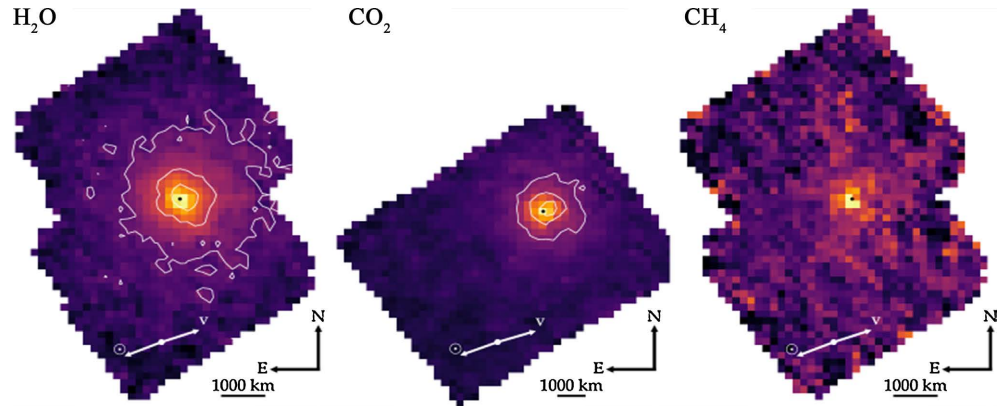


Figure 1. Coma maps of H_2O , CO_2 , and CH_4 , computed as the integrated emission flux across the corresponding fluorescence bands for Observations 6, 15, and 13, respectively. The sunward and target velocity directions are denoted by the white arrows. The target centroids, computed as the photocenter in the median-stacked images, are marked with the black points. For H_2O and CO_2 , the white contours correspond to emission levels of 75%, 50%, and 25% relative to the maximum value and illustrate the slight anti-sunward extension of the respective comae. The precise spatial distribution of CH_4 in the near-nucleus region is poorly constrained due to the low signal-to-noise ratio of the data. Adapted from [17].

with a modest anti-sunward extension. The inner coma has a characteristic scale of several thousand kilometers that is in good agreement with the observed data [17].

Space-based imaging further confirms typical cometary morphology. Observations from ESA's *JUICE* mission show a bright coma, extended tail, and fine structures including jets, filaments, and streams [18] (**Figure 2**). Although often described as an interstellar visitor, its observed behavior is consistent with that of an active comet.

Ultraviolet observations obtained by NASA's *Europa Clipper* spacecraft (**Figure 3**) reveal a compact UV-bright region near the nucleus, although its precise size remains unconstrained due to instrumental limitations [19].

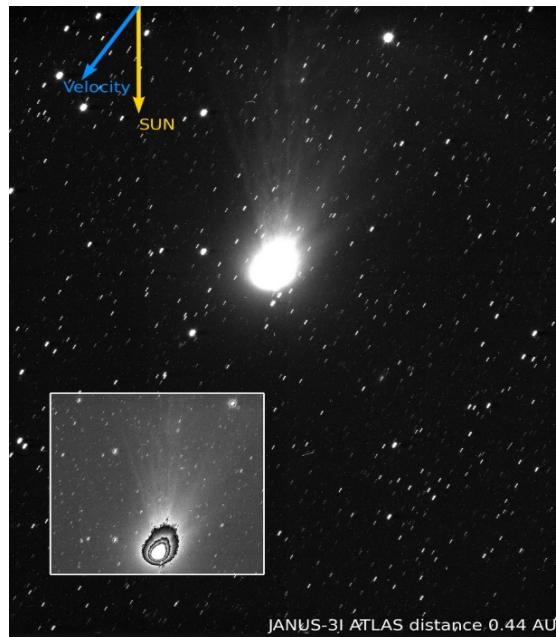


Figure 2. The arrows in the top left indicate the direction in which the comet was moving (blue) and the relative direction of the Sun (yellow). Adapted from [18].

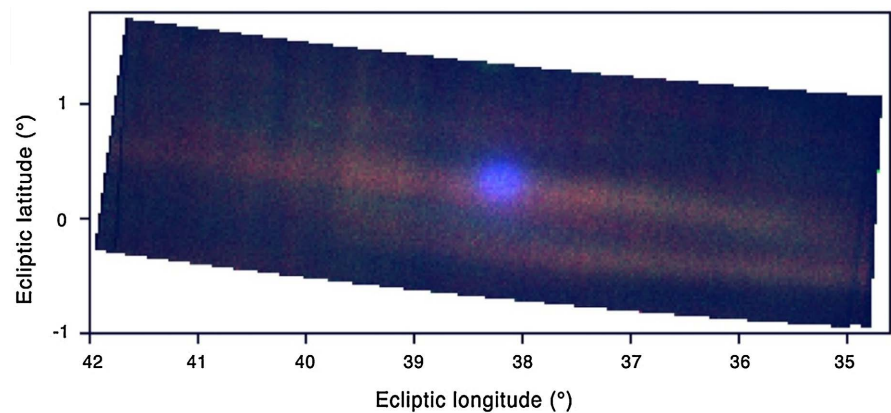


Figure 3. Interstellar comet 3I/ATLAS is seen in this composite image captured on Nov. 6, 2025, by the Europa Ultraviolet Spectrograph instrument on NASA's Europa Clipper spacecraft, from a distance of around 103 million miles (164 million kilometers). Adapted from [19].

X-ray observations by *XMM-Newton* and *XRISM* [20]–[22] (**Figure 4**) detect:

- extended emission in the 0.3 - 1.0 keV range
- spatial scales up to $\sim 4 \times 10^5$ km
- spectral features associated with C, N, and O

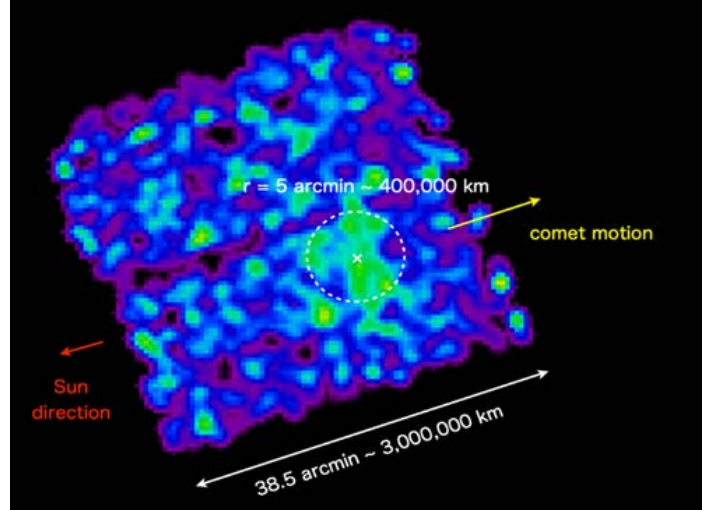


Figure 4. An image of comet 3I/ATLAS from the X-Ray Imaging and Spectroscopy Mission (XRISM). Image credit: JAXA.

These emissions are conventionally interpreted as solar wind charge exchange with neutral coma gas. Notably, X-ray diagnostics are particularly sensitive to hydrogen and nitrogen species that are difficult to detect at optical and infrared wavelengths.

8.2. Cosmic-Ray Processing Signatures

Spectroscopic observations using *JWST/NIRSpec* and *SPHEREx* reveal an unusually high CO_2 enrichment:

$$\text{CO}_2/\text{H}_2\text{O} = 7.6 \pm 0.3,$$

significantly exceeding typical SS comet values [23]. Elevated CO abundance

$$\text{CO}/\text{H}_2\text{O} = 1.65 \pm 0.09$$

and pronounced red spectral slopes further characterize the object [24].

In standard interpretations, this composition is attributed to galactic cosmic ray processing of surface layers. Laboratory studies show that irradiation can convert CO into CO_2 and produce organic-rich crusts. The observed outgassing is therefore thought to sample only a shallow processed layer (~ 15 - 20 m), rather than pristine interior material.

This interpretation implies that long-residence interstellar objects primarily expose radiation-processed material rather than original formation signatures.

8.3. Coma Composition and Dust Properties

The coma of C/2025 N1 (ATLAS) exhibits:

- strong and evolving outgassing (e.g., [25]-[28])
- dominance of relatively large ($\sim 100 \mu\text{m}$) dust grains [29]
- chemically complex molecular composition

Detected species include (e.g., [30]-[38]):

- Optical: CN, Ni
- Radio: CH_3OH , HCN
- Infrared: H_2O , CO_2 , CO, CH_4

Post-perihelion evolution shows:

- increasing CO production
- emergence of organic emission bands ($3.2 - 3.4 \mu\text{m}$)
- asymmetry in H_2O production rates

A key observational result is the elevated $\text{CO}_2/\text{H}_2\text{O}$ ratio, significantly above typical cometary values.

Key question: What is the origin of the complex chemistry and large dust grains? Within conventional models, these properties are attributed to primordial composition modified by irradiation. Within the present framework, they arise from ongoing internal processes associated with the nucleus.

8.4. Sun-Facing Plume and Rotational Modulation

During mid-2025, the coma exhibited a pronounced sunward-directed plume, distinct from the classical anti-solar tail [23]-[25] [31] [39] [40]. This feature:

- originates from localized activity on the illuminated hemisphere
- is consistent with anisotropic emission of large dust particles
- resembles behavior observed in C/2014 UN271 (Bernardinelli-Bernstein) [41]

Subsequent observations revealed [42] [43]:

- a persistent sunward plume linked to a localized active region
- a faint high-latitude jet in the inner coma
- periodic modulation of jet orientation

The inferred rotation period is:

$$P_{\text{rot}} = (15.48 \pm 0.70) \text{h}$$

consistent with photometric estimates of rotation period: $T = (16.16 \pm 0.01) \text{h}$ [27]. This represents one of the clearest detections of rotationally modulated jet activity in a cometary coma.

8.5. WUC Interpretation of Observations

Within the present framework, the same observational dataset admits a fundamentally different interpretation:

1) Internal Chemical Production

Molecular species are generated by ongoing processes associated with UCPs, rather than being solely primordial. The observed composition reflects active internal chemistry.

2) Coma as a Self-Annihilating Reactor (SAR) Output

The coma is continuously replenished by internally generated gas and dust:

- no requirement for preserved “pristine” material
- sustained activity independent of heliocentric distance

3) X-Ray Emission Mechanism

X-ray emission may include contributions from:

- gamma radiation produced by UCP self-annihilation
- subsequent interaction with coma gases

4) Isotopic and Chemical Anomalies

Observed compositional anomalies are interpreted as signatures of ongoing particle processes rather than evidence of ancient interstellar origin.

Synthesis

The principal observational features of C/2025 N1 (ATLAS):

- strong NGA
- unusual chemical composition
- dominance of large dust grains
- persistent activity at large heliocentric distances

are commonly interpreted as evidence for an interstellar origin and prolonged cosmic-ray processing.

Within the present framework, these same features are instead understood as intrinsic properties of SB3 characterized by:

- an active UCM nucleus
- continuous matter and energy production
- internal conversion of rotational energy into translational motion

This interpretation provides a unified explanation of both the dynamical and physical properties of the object without invoking an interstellar origin.

9. WUC Explanation of 3I/ATLAS Observations

The full set of observations of C/2025 N1 (ATLAS) and related small bodies can be interpreted coherently within the present framework. In this approach, the dominant factor governing their behavior is not external forcing but internal physical processes within the nuclei and comae.

9.1. Non-Gravitational Acceleration

NGA arises from internal energy conversion and is characterized by:

- quasi-constant magnitude
- weak dependence on heliocentric distance
- persistence even at large distances where sublimation is negligible

9.2. Spin Evolution of the Nucleus

The rotational state of the nucleus is expected to evolve through:

- systematic angular momentum loss due to internal processes
- discrete, step-like changes associated with micro-volcano (MiV) events
- long-term evolution toward a critical rotation state

9.3. Coma Composition and Evolution

The coma is internally generated and its composition exhibits:

- non-solar abundance ratios
- temporal variability not strictly correlated with heliocentric distance
- emergence of previously undetected molecular species

9.4. Dust Grain Properties

Dust production is linked to Micro-world processes, leading to:

- characteristic grain sizes about $10^2 \mu\text{m}$
- continuous replenishment independent of solar heating

9.5. Sun-Facing Plume

The sunward-directed plume is interpreted as a consequence of ram-pressure-driven activation. As the Small Body moves through the Interplanetary Medium, compression of the upstream gas leads to adiabatic heating. This increases the effective density within the nucleus, enhancing the efficiency of the self-annihilating reactor (SAR). As a result:

- internal energy release intensifies
- dust production increases preferentially in the sunward direction
- a persistent sun-facing plume is generated

9.6. Activity at Large Heliocentric Distances

Sustained activity is expected at all heliocentric distances, including regions where solar-driven sublimation is negligible. Gas and dust production are therefore intrinsic rather than externally driven.

9.7. X-Ray and High-Energy Signatures

X-ray emission is interpreted as arising from:

- interaction of internally generated gamma radiation with coma gases
- rather than solely from solar wind charge exchange

9.8. Trajectory Evolution

The trajectory is expected to show:

- systematic deviations from purely gravitational plus outgassing models
- persistent excess velocity not reproducible by standard non-gravitational laws

9.9. Broader Population Prediction Final Statement

WUC predicts that a subset of long-period comets will exhibit:

- anomalously high NGA
- unusual chemical compositions
- similar dynamical signatures indicative of internal energy processes

9.10. Dark Comets and Low-Albedo Asteroids

“Dark comets” and objects such as ‘Oumuamua are interpreted as small bodies that:

- exhibit measurable NGA
- lack visible comae or dust tails

Their dynamics are explained by the same internal mechanism—conversion of rotational energy of the nucleus into translational kinetic energy.

Extremely low albedo values (0.02 - 0.08) are attributed to:

- low concentrations of ordinary matter in the surrounding coma
- dominance of non-luminous Universe-Created Matter

Final Statement

Within the present framework, internal energy mechanisms are fundamental in governing the dynamical behavior of C/2025 N1 (ATLAS). These processes are not secondary corrections but primary drivers that determine the object’s origin, evolution, and observable properties. More broadly, they offer a new perspective on Small-Body physics and the processes underlying SS formation.

10. Conclusions

World-Universe Cosmology provides a self-consistent framework capable of describing key cosmological parameters and their interrelations while offering quantitative predictions. In several cases, WUC yields values that align closely with observational data, strengthening its internal coherence.

The model does not claim to explain all cosmological phenomena, nor to constitute a complete and final theory. Substantial further development is required. However, in its current form, WUC offers a viable foundation for a new classical cosmological framework, echoing ideas originally proposed by Dirac in 1937.

The Solar System has effectively become an experimental laboratory for astrophysics, providing high-quality observational constraints. Recent advances in observational astronomy open the possibility of testing new physical models at unprecedented levels of precision.

We are entering a new era in astronomy, cosmology, and astrophysics. Continued progress will depend on the willingness to explore alternative frameworks and to confront them with observational data.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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