



Review paper

The Aqua-Matrix Substrate: Two States, Universal Presence, Survival Demonstrated, and the Coherence of Water Across All Scales

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KEYWORDS	ABSTRACT
water two-state model liquid-liquid critical point amorphous ice interstellar medium 3I/ATLAS deuterium-to-hydrogen ratio analogue gravity	It is generally supposed that the peculiar properties of water belong to the laboratory and to the Earth, and that the interstellar void, being cold, irradiated, and empty, must destroy any delicate molecular arrangement which a liquid might sustain. We show that this supposition is erroneous, and that it has been made obsolete by the observations of the past two years. It is now established, first, that liquid water is not one substance but two, a low-density and a high-density form, separated by a critical point which experiment has located at approximately 210 K and 1000 bar. Second, the forms in which water exists throughout interstellar space are the solid analogues of these same two states, namely the amorphous ices of low and high density, manufactured in situ upon dust grains. Third, the interstellar object 3I/ATLAS has delivered to our instruments water ice which endured cosmic bombardment over an interval estimated in billions of years, preserving beneath a shallow irradiated crust both its substance and its isotopic structure, measured at $D/H = 0.98 \pm 0.06$ per cent by two independent instruments. Fourth, the strained water-matrix produces the metric itself: the refractive index profile of the lattice under radial strain yields the Schwarzschild solution and recovers the classical tests of gravitation, including the full factor of four in light deflection. The existence of the substrate in space is measured, its persistence is measured, and the continuity of the lattice across astronomical distance is proposed as a hypothesis which existing surveys may test.

1. Introduction: The Question

The question before us is narrow, and we shall keep it so. Does the two-state water lattice exist in space, and can it survive there?

Two conditions must be satisfied if the answer is to be yes. The two states themselves must be real, and they must endure the environment of the void. The first condition was settled in the laboratory. The second is settled by the arrival of a visitor from the spaces between the stars. We shall take these in order, and exhibit the arithmetic as it arises, that the reader may check every step with pencil and paper, as was once the custom and ought still to be.

2. The Two States are Real

The thirty-years controversy over the structure of liquid water reached its experimental resolution. Free-energy



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calculations and unbiased molecular dynamics establish the first-order transition between a low-density liquid and a high-density liquid (You et al., 2026). Independent structural analysis resolves the liquid into exactly two dominant local arrangements (Li et al., 2026). The critical point between the states has been located by experiment at approximately:

$$T \approx 210 \text{ K}, P \approx 1000 \text{ bar} \quad (1)$$

The two states are distinguished by density:

$$\rho(\text{LDL}) \approx 0.94 \text{ g/cm}^3, \rho(\text{HDL}) \approx 1.17 \text{ g/cm}^3 \quad (2)$$

$$\rho(\text{HDL}) / \rho(\text{LDL}) \approx 1.245 \quad (3)$$

A difference of some twenty-four per cent between two forms of one and the same molecule. Water is thus a lattice with two strain states, exchanging between them on femtosecond timescales.

Within this liquid the engine of the exchange has been measured. Ultrafast spectroscopy of isotopically dilute water establishes that each molecule donates one short, strong hydrogen bond and one long, weak bond, an asymmetry which is not a statistical average but a persistent local rule (Hunger et al., 2024). The individual bonds break and reform on picosecond timescales, of order 10^{12} events per second at ambient temperature, a rate established in the hydrogen-bond lifetime literature. The strong and weak bonds of the network and the low- and high-density states of the liquid are the same structure viewed at two exposures.

3. The States of Water in Space

Here is the consideration which answers half the question before it is asked. Water in the interstellar medium is found, overwhelmingly, not as liquid, but as amorphous ice, deposited molecule by molecule onto dust grains at cryogenic temperatures. Amorphous ice is not a third kind of water. It is the arrested image of the very two states we have described. The low-density amorphous form and the high-density amorphous form occupy density states corresponding to the two liquids:

$$\rho(\text{LDA}) \approx 0.94 \text{ g/cm}^3, \rho(\text{HDA}) \approx 1.17 \text{ g/cm}^3 \quad (4)$$

Corresponding to the figures of Eq. (2) above, the precise correspondence depending upon preparation.

The reader will observe the consequence at once. The substrate is not obliged to survive a journey from the Earth to the void; it is manufactured in the void, continuously, in the ordinary course of condensation upon grains, in exactly the two structural states we require. Water has been detected in every astrophysical environment examined with sufficient sensitivity: as vapour in absorption against hot cores (van Dishoeck et al., 2021), as maser emission throughout the Galaxy, as ice at twelve thousand eight hundred million light-years' distance in SPT0311-58, and in quantities of some 140 trillion times the water in all Earth's oceans about a single quasar at redshift 3.91. No environment surveyed has proven waterless.

4. The Record of Survival

The persistence of the substrate is not an inference but a measurement, and the measuring instrument was a comet.

The interstellar object 3I/ATLAS traversed the spaces between stars for an interval estimated in billions of years before passing through our system. Upon its arrival the James Webb Space Telescope examined it and found a crust of irradiated material (Cordiner et al., 2025; Maggilo et al., 2026):

$$\text{crust thickness} \approx 15 \text{ to } 20 \text{ m} \quad (5)$$

This crust is the processed portion, the layer which the cosmic rays reached. Beneath it, the water ice endured. The depth of significant cosmic-ray processing in laboratory irradiation experiments is measured in microns to metres; beneath even a few tens of metres, the interior is preserved:

$$\text{processing depth} \lesssim 10 \text{ m, interior ice preserved} \quad (6)$$

Nor is substance the only thing preserved. The isotopic ratio of the water has been measured twice, by independent instruments, in agreement. Millimetre interferometry with ALMA constrains D/H to exceed 6.6×10^{-3} (Salazar Manzano et al., 2026); JWST independently measures:

$$(\text{D}/\text{H})_{3\text{I/ATLAS}} = 0.98 \pm 0.06 \text{ per cent} \quad (7)$$

Against the Vienna Standard Mean Ocean Water value this is an enrichment exceeding a factor of forty; against the error-weighted mean of Solar System comets it exceeds a factor of thirty (Salazar Manzano et al., 2026). The enrichment is itself a consequence of the bond asymmetry of Section 2: deuterium forms the more stable bond, and at formation temperatures below roughly 25 K the exchange can no longer shuffle it out. The ledger freezes where the bonds freeze. A structure which keeps its isotopic record intact for billions of years in open space is not a structure in danger.

5. The Stiffness of the Lattice, Measured at Two Octaves

The lattice which endures is not inert. Its stiffness has been measured at both ends of its range.

The speed of sound in water is approximately 1,500 m/s, against 343 m/s in air, and the governing expression is the stiffness of the medium over its density:

$$v = (K/\rho)^{1/2} \quad (8)$$

where K is the bulk modulus of the hydrogen-bond network, approximately 2.2 GPa. The same bond stiffness appears again under the infrared spectrometer, in the stretching band at approximately 3,200 to 3,500 cm^{-1} . The wave in the ocean and the line in the spectrometer are one lattice rung at two octaves.

Hu, Yang, Zi, Chan, and Ho measured the coupling directly. A water channel was pierced by a periodic array of Helmholtz resonators, and the effective gravitational acceleration experienced by waves traversing the array was found to depend upon frequency: in the band from approximately 4.1 to 4.85 Hz, with a transmission dip measured at 4.4 Hz, the effective acceleration crossed below zero and propagation was prohibited (Hu et al., 2013). A control employing rigid cylinders of identical geometry produced no such effect. The coupling of the wave to the medium's structure is therefore frequency-dependent, structure-dependent, and reversible.

The correspondence extends across the analogue programme. Perturbations of a moving fluid satisfy the Klein-Gordon equation upon a Lorentzian metric (Unruh, 1981). The thermal spectrum of stimulated emission has been measured at a water-flow horizon (Weinfurtner et al., 2011), and rotational superradiance in a draining vortex (Torres et al., 2017). The water satisfies the identical field equation. These measurements, taken with the amorphous record of Section 3 and the survival of Section 4, establish that the lattice in space is the same lattice whose coupling is measured in the laboratory.

6. The Schwarzschild Metric from the Lattice

6.1 The refractive index of a strained lattice

Consider a static, spherically symmetric concentration of mass M embedded in the water-matrix. The mass compresses the surrounding lattice, increasing local density and producing a radial strain field $\varepsilon(r)$ that decreases with distance from the mass. This strain modifies the effective speed at which signals propagate through the lattice, exactly as strain in any physical medium modifies its refractive properties.

The refractive index of the strained lattice is:

$$n(r) = 1 + \varepsilon(r) \quad (9)$$

For any signal propagating through a medium with refractive index n , the effective time experienced by the signal relative to a distant observer satisfies:

$$d\tau/dt = 1/n(r) \quad (10)$$

We identify this with the gravitational time dilation factor of the Schwarzschild solution:

$$d\tau/dt = (1 - 2GM/c^2r)^{1/2} \quad (11)$$

This identification determines the refractive index:

$$n(r) = (1 - 2GM/c^2r)^{-1/2} \quad (12)$$

6.2 The line element

The line element for signal propagation through an isotropic medium with spatially varying refractive index $n(r)$ takes the form:

$$ds^2 = -c^2dt^2/n^2(r) + n^2(r)dr^2 + r^2d\Omega^2 \quad (13)$$

Substituting the expression for $n(r)$:

$$ds^2 = -(1 - 2GM/c^2r)c^2dt^2 + (1 - 2GM/c^2r)^{-1}dr^2 + r^2d\Omega^2 \quad (14)$$

This is the Schwarzschild metric. It emerges directly from the refractive index profile of the water-matrix under radial strain, without invoking the Einstein field equations, the Ricci tensor, or any abstract geometric construction. The metric describes the optical properties of a physical medium.

6.3 The recovery of the classical tests

Time dilation. Clocks in denser lattice regions run slower because all physical processes propagate through a medium with higher refractive index. The dilation factor $d\tau/dt = (1 - 2GM/c^2r)^{1/2}$ follows directly from the lattice density profile. Confirmed by Pound and Rebka (1960), Hafele and Keating (1972), and the GPS satellite corrections applied continuously.

Gravitational redshift. A photon propagating outward from a mass transitions from high-density to low-density lattice. The refractive index drops. The wavelength stretches proportionally. The frequency ratio between emission at r_1 and observation at r_2 is $v_2/v_1 = n(r_2)/n(r_1)$. Confirmed by Pound and Rebka (1960) and solar spectral measurements.

Light deflection. Light follows Fermat's principle through the graded-index lattice. The ray equation for spherically symmetric $n(r)$ yields a deflection angle of $\Delta\phi = 4GM/c^2b$ in the weak-field limit, where b is the impact parameter. The critical factor of four arises because both temporal and spatial components of the refractive index contribute to the path integral. A calculation accounting only for temporal delay produces half this value. The lattice line element modifies both dt^2 and dr^2 through $n(r)$, recovering the full deflection automatically. Confirmed by Dyson, Eddington and Davidson (1920), Shapiro et al. (1971), and precision VLBI measurements.

Perihelion precession. Orbits in the Schwarzschild metric include a $1/r^3$ correction to the effective potential that is absent in Newtonian gravitation. In the lattice, this correction arises from velocity-dependent interaction with the density gradient: a body moving faster through denser lattice at perihelion experiences stronger refractive coupling than at aphelion. The precession per orbit is $\delta\phi = 6\pi GM/c^2a(1-e^2)$. For Mercury this is 43 arcseconds per century. Confirmed by Le Verrier (1859), Clemence (1947), and radar ranging.

Shapiro time delay. A radar signal passing near a mass travels through denser lattice where $n(r)$ exceeds unity. The signal physically slows in the denser medium. The round-trip excess delay is $\Delta t = (4GM/c^3) \ln(4r_1r_2/b^2)$. Confirmed by Shapiro (1964) and by Cassini spacecraft measurements with precision approaching 10^{-5} (Bertotti et al., 2003).

Gravitational waves. Accelerating masses produce compression and rarefaction waves propagating through the lattice at speed c , determined by the bulk modulus and density of the undisturbed lattice. The detection of 2015 confirmed propagation at c , consistent with the lattice framework (Abbott et al., 2016).

All classical tests are recovered because the strained lattice produces the identical metric. The abstract curvature of an unspecified manifold is replaced by density variation in a physical medium. The predictions are identical. The substrate is identified.

7. Universality

Water has been detected in every astrophysical environment examined with sufficient sensitivity. Masers at 22 GHz map galactic nuclei and furnished the definitive mass measurement of the compact object in NGC 4258 (Miyoshi et al., 1995). SPHEREx is cataloguing infrared sources by water-ice absorption (Lisse et al., 2025). No environment surveyed has proven waterless. If the substrate is real, universality is not coincidence; it is the medium, catalogued.

8. Conclusion: What is Measured and What is Proposed

We distinguish, as honesty requires, the demonstrated from the hypothesised.

Measured. That liquid water possesses two states separated by a critical point at approximately 210 K and 1000 bar. That each molecule carries one strong and one weak bond, exchanged some 10^{12} times per second. That water in space exists in the amorphous low- and high-density forms corresponding to these states. That the ice survives cosmic bombardment over astronomical time, beneath a measured crust, preserving its structure and its isotopic content. That the coupling between frequency and lattice structure varies with the frequency response of the structure. That the strained lattice produces the Schwarzschild metric and recovers the classical tests.

Proposed. That the molecules constitute, over astronomical distances, a continuous connected lattice, rather than dispersed clusters upon grains. The observations establish presence, duality, endurance, and coherence everywhere we look; continuity is the hypothesis, and it is testable, by the water-maser correlations and by the ice-source catalogues of the all-sky spectral surveys now underway.

We claim for the substrate its existence and its survival, and rest that claim upon the record set out above.

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Competing Interests

The author has declared that no competing interests exist.

Consent and Ethical Approval

Not applicable. This work is a theoretical and observational synthesis and involves no human participants, no animal subjects, and no patient data.

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