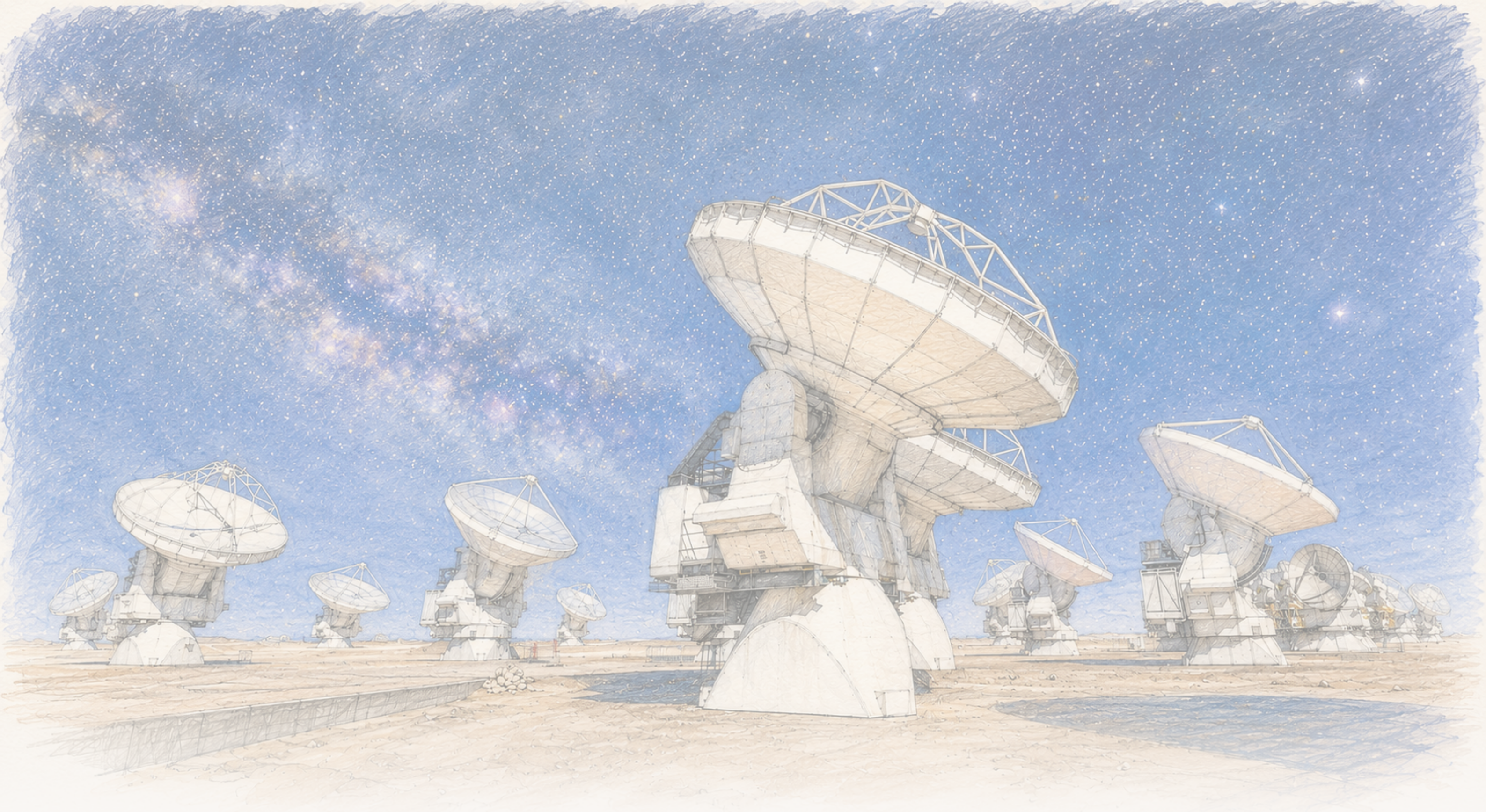

The Clean Paper

WHAT THE PAPER SAYS · WHAT IT DOESN'T · WHY IT MATTERS

Interstellar comet 3I/ATLAS carries water that formed colder than our own comets' — a first chemical reading of another planetary system

Using ALMA, astronomers constrained the ratio of "heavy" to ordinary hydrogen in the water of 3I/ATLAS — the third known interstellar object — and found it strongly deuterium-enriched: at least about 40 times Earth's oceans and 30 times a typical Solar System comet. That points to water that formed under colder conditions than our own comets'. The result is a lower limit, derived indirectly (the water itself was never directly detected), and it says nothing about life or technology — only about chemistry and cold.

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Paper: *Water D/H in 3I/ATLAS as a Probe of Formation Conditions in Another Planetary System*, L. E. Salazar Manzano, T. Paneque-Carreño et al., Nature Astronomy (2026) · DOI: 10.1038/s41550-026-02850-5

The DV-59 antenna in the foreground, with multiple ALMA antennas observing the moonlit night sky. Credit: Alex Pérez / ALMA Observatory.

A comet from another star, and the fingerprint in its water

Every so often something falls through the Solar System that was never ours. Not a stray rock from the asteroid belt, not a comet swinging back from the Oort cloud on its long leash, but an object on an open, hyperbolic path — one that came in from interstellar space, will loop once around the Sun, and leave forever. We have now seen three. The first, ʻOumuamua in 2017, was gone almost before anyone agreed on what it had been. The second, 2I/Borisov in 2019, was unmistakably a comet. The third, discovered in July 2025, is 3I/ATLAS — and it arrived wrapped in a coma active enough to do real chemistry on.

Here is the part worth holding onto before the noise sets in. An interstellar comet is, quite literally, a chip of another planetary system: ice and dust that condensed around some other star, was most likely flung out by a gravitational kick long ago, drifted across the Galaxy, and happened to pass close enough to our Sun for its ices to start boiling off exactly where our telescopes could watch. That is the genuinely remarkable fact, and it is astonishing enough that it does not need help.

It tends to get help anyway. Interstellar objects attract a particular kind of breathless coverage — the dimmed lights, the *but what if someone built it* — and 3I/ATLAS got its share. The honest answer to that question is the boring one, and the boring one is more interesting: it is a comet. The real question was never whether somebody made it. It was the quieter one — if you could read the chemistry of something assembled around another star, what would it tell you about that star's family? And how would you even read it?

The reading instrument, this time, is water. Water is two hydrogens and an oxygen, but a small fraction of its hydrogen is *deuterium* — a heavier twin, an ordinary hydrogen atom carrying one extra neutron. The ratio of heavy hydrogen to ordinary hydrogen in water, written D/H, is not random. It is set, by chemistry, largely by how cold it was where the water first formed: the colder and quieter the cradle, the more deuterium gets locked in. And because a comet is essentially a deep-freezer — one that can hold its ices in cold storage for billions of years — the D/H ratio of its water can preserve a fingerprint of the conditions under which that water formed.

We know our own system's fingerprints reasonably well: Earth's oceans and the various families of Solar System comets cluster in a fairly narrow band. What nobody had ever pinned down was that same fingerprint for water that formed around *another* star. That is what this paper set out to read in 3I/ATLAS.

What the authors did

They pointed ALMA — the large array of radio dishes in the Chilean desert — at 3I/ATLAS on 4 November 2025, six days after the comet rounded the Sun. They tuned it to catch the faint millimetre-wavelength glow of three molecules in the coma: ordinary water (H_2O), *heavy* water (HDO, where one hydrogen is a deuterium), and methanol (CH_3OH).

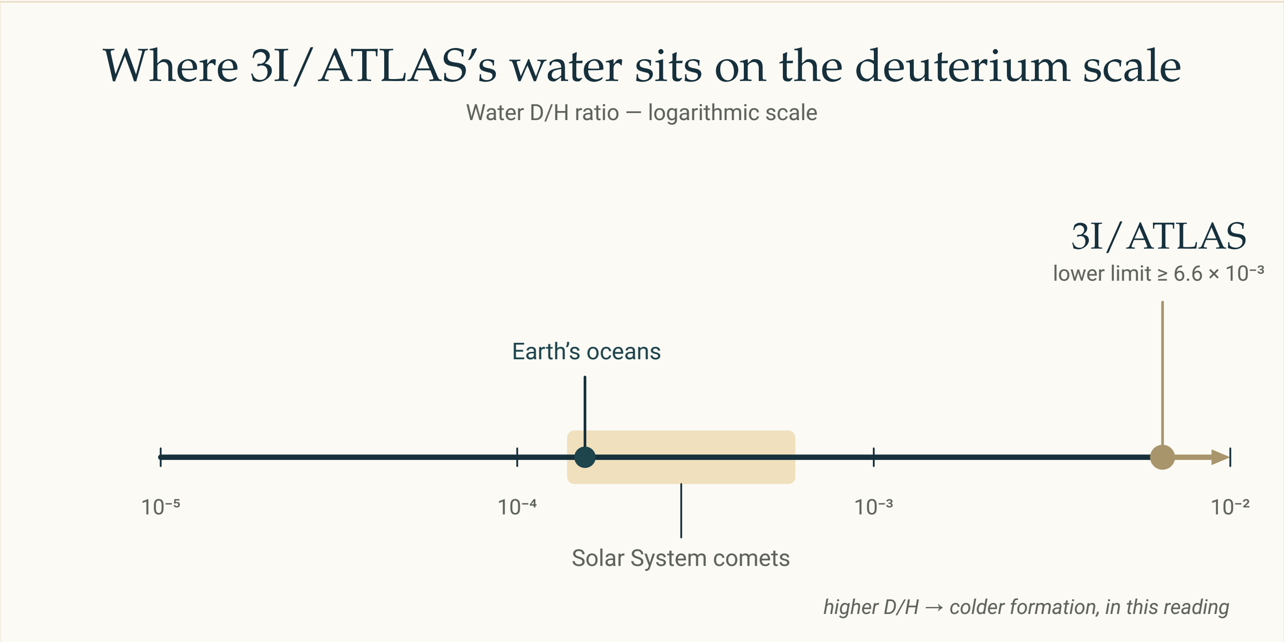
The D/H ratio they were after is, in effect, the ratio of heavy water to ordinary water. So they needed both. They then fed the spectra through a radiative-transfer model of an expanding cometary atmosphere (a code called SUBLIME) and fit it with the same kind of statistical machinery used to retrieve the make-up of exoplanet atmospheres, to pull out the temperature, the outflow, and how much of each molecule the comet was producing.

One catch shapes everything that follows: **they did not actually detect the water.** HDO and methanol showed up; H_2O itself stayed below the noise. That is not for lack of ordinary water — there is far more of it than of the heavy kind. Whether a line shows up depends not only on how much of the molecule is present, but on how observable that particular line happens to be, and two things work against the water line here. The first is the atmosphere: the H_2O line they could target (near 183 GHz) sits right where Earth's own water-laden air absorbs most fiercely, so reading a comet's water there from the ground is a little like trying to see a candle through fog — the paper notes that these low-energy water bands suffer strong atmospheric absorption, while the heavy-water (HDO) line near 241 GHz falls in a cleaner window. The second is sensitivity: the water channel was far noisier — about 500 mJy per beam against 21 for HDO — so even an abundant signal could sit beneath it. Between the fog and the noise, the plentiful ordinary water stayed under the threshold, while the much rarer heavy water, caught in a clean, quiet window, showed up clearly. (From space, above the atmosphere, the same water is far easier to see: JWST later detected the comet's water in the infrared, after perihelion

— so ALMA's non-detection is about that one line through Earth's air, not about water being absent.) So the amount of ordinary water had to be inferred *indirectly* — chiefly from how the methanol lines were excited, which depends on how often methanol molecules collide with water. That is a real measurement, but it is a model-dependent one, and the authors are explicit about it.

What they found

- **Heavy water, but no plain water.** HDO and several methanol lines were clearly detected; H_2O was not. Because the D/H ratio rests on an *upper limit* for the ordinary-water production rate — treated that way deliberately, since the water line itself stayed below the noise — the deuterium ratio comes out as a **lower limit**, not a single value.
- **A strong deuterium enrichment.** In their conservative scenario the water D/H ratio is **greater than** 6.6×10^{-3} — more than about **40 times** the value of Earth's oceans, and more than about **30 times** that of a typical Solar System comet. By either of their two estimates, 3I/ATLAS sits at the very high end of every water D/H measurement made so far.
- **It is probably not a fluke of this one night.** The measurement is from a single epoch, but a preliminary look at nearby ALMA data shows no large day-to-day swing, and an independent JWST analysis of 3I/ATLAS, taken more than a month later, points the same way — deuterium-rich water.



Where 3I/ATLAS's water sits on the deuterium scale: far to the deuterium-rich end, beyond Earth's oceans and the whole Solar System comet population (shown here as an approximate range). The arrow marks a *lower limit* — the true value could be higher. A high D/H ratio is a clue to *cold formation conditions*, not a home address.

What this probably means

A high water D/H ratio is the signature of water that froze where it was very cold (below about 30 K) and was not heavily reworked afterwards by heat. So the cleanest reading is that 3I/ATLAS's water formed under *colder, gentler* conditions than the water in our own Solar System's comets — and therefore that its parent planetary system assembled its ices differently from ours.

The authors are careful about the next step, and so should we be. There are two ways to get water this deuterium-rich, and this measurement cannot tell them apart: the water could have *inherited* its enrichment from the cold cloud the system was born in, or it could have been set later, during the comet's formation in a cold outer disk. Either way the conclusion that matters survives — the conditions that shaped 3I/ATLAS were not the conditions that shaped our comets — but the *why* is left open.

What this is, then, is the first time anyone has read the water-formation fingerprint of material from another planetary system, and found it does not match our own.

What this does *not* prove

- It says **nothing** about life, technology, or intent. There is no "it" that was built; "interstellar" describes a trajectory, not an origin story. This is a measurement of water chemistry.
- It is **not** a precise D/H value. It is a *lower limit*, and the water it refers to was never directly detected — its abundance was inferred from the excitation of a different molecule, methanol, under the assumption that water is the main thing methanol is bumping into.
- It does **not** reveal where 3I/ATLAS was born. The parent star cannot be reliably identified, and a high D/H ratio is a clue to *conditions*, not a home address.
- It does **not** settle *why* the water is deuterium-rich. "Inherited from a cold birth-cloud" and "set during disk formation" both fit the data; the paper does not choose between them.
- It is **one** object, measured at **one** epoch. The corroboration is encouraging, not a long baseline.

How strong is the evidence?

Two things should be weighed separately: the direction of the result, and the exact number.

- **The direction is robust.** That 3I/ATLAS's water is markedly deuterium-rich is a conservative lower limit, sits well above the entire Solar System comet population, and is supported by an independent JWST analysis. This part is not fragile.
- **The number rests on a modelling chain.** Because H_2O was not detected, the water abundance — and hence the D/H ratio — leans on inferring water indirectly from methanol excitation. That assumes water is the dominant collision partner in the coma (plausible near perihelion, but a contribution from CO_2 can't be ruled out) and uses approximate, admittedly poorly-constrained

collision rates. The authors flag all of this and deliberately quote the result as a limit rather than a measurement.
- **The interpretation is well-motivated but not unique.** Cold formation is the natural explanation for high D/H; whether that cold was inherited or imposed later is unresolved, and the parent system is unidentifiable.

In short: that the water formed cold is on solid ground; precisely *how* cold, and precisely *why*, is honestly held open.

Why it matters

For decades, the question of where Earth's water came from — and what sets the deuterium fingerprint of water across forming planetary systems — has been answered entirely with measurements made inside our own Solar System. This is the first time that chart has been extended to material that demonstrably formed around another star.

The answer it gives is not "everywhere is like home." It is the opposite: another system can lay down its ices under conditions cold enough to leave a fingerprint our comets never carried. That is a small, concrete piece of evidence for something quietly large — that the chemistry and history of the solids that build planets can differ from one star to the next. And it came not from a spacecraft sent across light-years, but from catching a stray fragment of another system as it fell past, and reading its water before it was gone.

Clean summary

3I/ATLAS is the third known interstellar object and the second active interstellar comet — a piece of another planetary system passing once through ours. Using ALMA near the comet's closest approach to the Sun, astronomers detected heavy water (HDO) and methanol in its coma but not ordinary water, and from this inferred the water deuterium-to-hydrogen ratio. They find it strongly enriched in deuterium — a lower limit above 6.6×10^{-3}, roughly 40 times Earth's oceans and 30 times a typical Solar System comet — which points to water that formed under colder, less-processed conditions than the Solar System's comets. The figure is a lower limit obtained indirectly through a model, not a direct measurement, and it cannot say whether the enrichment was inherited from a cold birth-cloud or set later in a cold disk, nor where the comet came from. It is, even so, the first reading of this particular chemical fingerprint for water from another star — and the fingerprint does not match ours.

No-BS check

What the paper shows: From ALMA observations of interstellar comet 3I/ATLAS near perihelion, a lower limit on its water D/H ratio of $>6.6 \times 10^{-3}$ (conservative scenario) — about 40$\times$ Earth's oceans and 30$\times$ a typical Solar System comet — implying water that formed under notably colder, less thermally processed conditions than Solar System comets. An independent JWST analysis agrees on the direction.

What is plausible but not proven: That the enrichment was inherited directly from a cold prestellar cloud, versus being set during the comet's formation in a cold protoplanetary disk. Both scenarios fit; the data do not distinguish them.

What it does not show: Anything about life, technology, or artificial origin; a precise D/H value (it is a lower limit); the identity or location of the parent star; the specific mechanism behind the high D/H; or that this single-epoch result is immune to coma variability.

Main limitations: H_2O was not directly detected, so the water abundance — and thus the D/H ratio — is inferred indirectly from methanol excitation, assuming water is the dominant collider and using approximate collision rates the authors call poorly constrained; the result is a single-epoch, model-dependent limit; the parent system is unidentifiable.

How much confidence should a general reader have? High that 3I/ATLAS's water is genuinely deuterium-rich and formed colder than our comets', and that this says nothing whatsoever about aliens. Moderate on the exact degree of enrichment, which is a model-dependent lower limit. Low on the specific cause and birthplace, which remain open. Appropriate stance: quiet wonder at a chemical postcard from another star system — not a mystery, and not a spaceship.

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