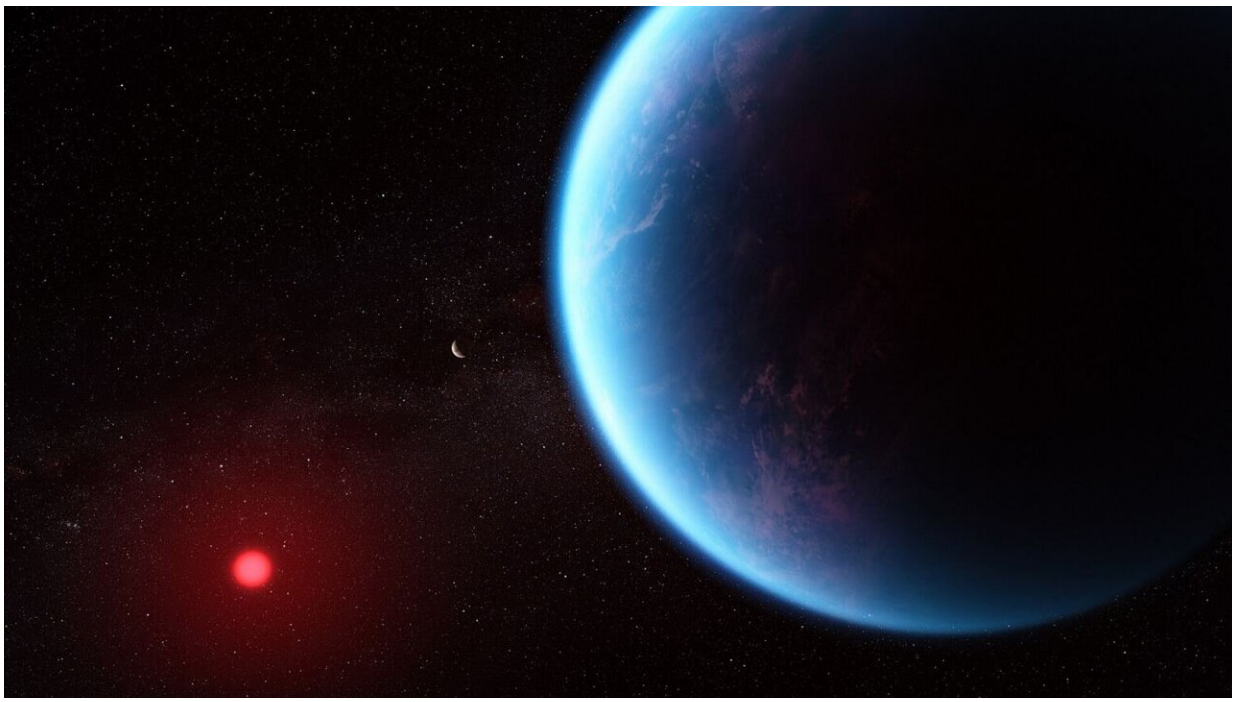
Is K2-18b covered in oceans of water or oceans of lava?

January 17 2024, by Evan Gough



This illustration shows what exoplanet K2-18 b could look like based on science data. NASA's James Webb Space Telescope examined the exoplanet and revealed the presence of carbon-bearing molecules. The abundance of methane and carbon dioxide, and shortage of ammonia, support the hypothesis that there may be a water ocean underneath a hydrogen-rich atmosphere in K2-18 b. Credit: NASA, ESA, CSA, Joseph Olmsted (STScI)Science: Nikku Madhusudhan (IoA)

In the search for potentially life-supporting exoplanets, liquid water is the key indicator. Life on Earth requires liquid water, and scientists strongly believe the same is true elsewhere. But from a great distance, it's difficult to tell what worlds have oceans of water. Some of them can have lava oceans instead, and getting the two confused is a barrier to understanding exoplanets, water, and habitability more clearly.

This brings us to K2-18b, a mini-Neptune orbiting a red dwarf (M dwarf) star about 134 light-years away. The Kepler Space Telescope found it in 2015. NASA's Exoplanet Catalog describes it as a potentially rocky world almost nine times more massive than Earth. It takes about 30 days to complete one orbit and is about 0.1429 AU from its star.

When it was confirmed as a planet, the authors of the paper presenting the results published in *The Astrophysical Journal* wrote that "the planet orbiting K2-18 may be an interesting target for atmospheric studies of transiting exoplanets."

Prophetic words, and when the JWST examined K2-18b's atmosphere in 2023, it found the carbon-bearing molecules methane and carbon dioxide. "Webb's discovery adds to recent studies suggesting that K2-18b could be a Hycean exoplanet, one which has the potential to possess a hydrogen-rich atmosphere and a water ocean-covered surface," a NASA press release said.

Planetary scientists are very interested in Hycean exoplanets. As things stand now, they're purely hypothetical. But if scientists could confirm the existence of one of these ocean-bearing planets, the outlook for life elsewhere in our galaxy would change considerably. (If they're not subject to the runaway greenhouse effect.) If we could reliably find a population of Hycean worlds spread out among the stars, surely that would constitute a powerful signal that life is not confined to Earth.

But there's a lot of uncertainty regarding Hycean worlds. Do they exist? Can they hold onto their oceans, or are they too hot? Could something else explain the JWST's atmospheric findings? Why is there a discrepancy between observation and climate modeling? The authors of a new paper point out that, observationally, K2-18b is the archetypal Hycean world. As such, it's a good place to try to answer some of our scientific questions. The authors say that K2-18b could indeed be an ocean planet, but an ocean of lava rather than water.

The new paper is "Distinguishing oceans of water from magma on mini-Neptune K2-18b." The lead author is Oliver Shorttle, who studies planetary chemistry at the Institute of Astronomy at Cambridge University. The paper is in pre-print and hasn't been peer-reviewed yet but is available on *arXiv*.

"We propose a solution to this discrepancy between observation and climate modeling by investigating the effect of a magma ocean on the atmospheric chemistry of mini-Neptunes," the authors write.

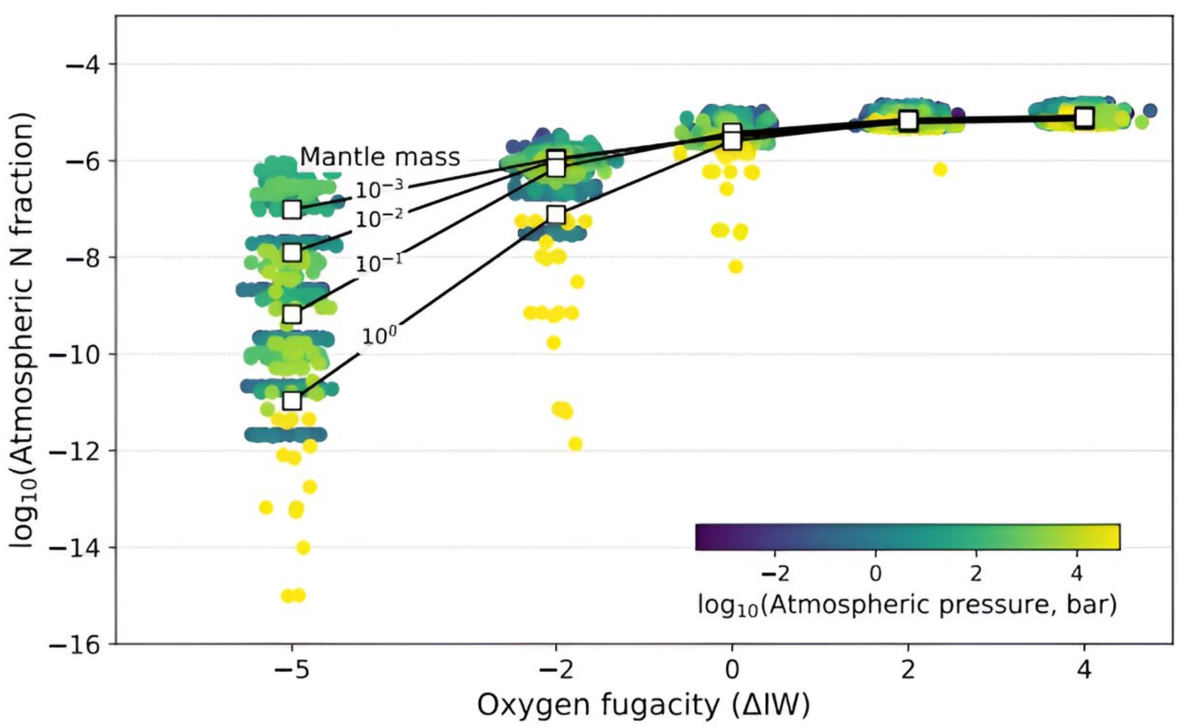
K2-18b is a puzzle. Its density is in between Neptune's and Earth's, meaning its composition is uncertain. Its density covers a range of possible compositions. JWST observations show that it has a carbon-rich atmosphere and an ammonia-poor atmosphere. These observations are both indicators of an ocean world with a thick H/He atmosphere.

But there's another possible explanation: A magma ocean. "We demonstrate that atmospheric NH_3 depletion is a natural consequence of the high solubility of nitrogen species in magma at reducing conditions, precisely the conditions prevailing where a thick hydrogen envelope is in communication with a molten planetary surface," the authors write.

As is so often the case when it comes to atmospheres, the availability of oxygen plays an enormous role. Oxygen is a swinger; it likes to bond with almost anything. Its presence dictates a lot of what happens in an atmosphere.

"How oxidizing a magma is has a profound effect on the solubility of nitrogen," the authors. Nitrogen is necessary for ammonia to form since ammonia is NH_3. So when the JWST found no ammonia in K2-18b's atmosphere, it may not indicate a Hycean world after all. Instead, it may indicate a magma ocean.

The researchers used models and simulations to try to determine what the JWST observations mean for K2-18b.



This figure from the study shows the relationship between oxygen fugacity and how much nitrogen can stay in the atmosphere of a magma ocean planet. "As oxygen fugacity is decreased, nitrogen's increased solubility depletes the atmosphere by orders of magnitude," the authors explain. (Each coloured circle represents a model run for a given set of parameters.). Credit: *arXiv* (2024). DOI: 10.48550/arxiv.2401.05864

The researchers found that some of their modeled results of a magma ocean world agree with what the JWST found. "A set of the resulting atmospheres in the magma ocean scenario are consistent with the full transmission spectrum of K2-18b observed by JWST," they write, adding that "this self-consistent magma ocean model can produce a qualitatively similar transmission spectrum to that observed for K2-18b, and those hypothesized for Hycean planets generally."

If Shorttle and his colleagues are correct, then a dearth of ammonia can no longer be used to indicate the presence of an ocean on a Hycean world. Ammonia's profile in an atmosphere can be attributed to both the magma ocean scenario and the water-world scenario. They're not exclusive.

What's the solution?

"Thus, alternative mutually exclusive chemical tracers of the presence of a water ocean versus a magma ocean should be sought so that future observations can distinguish these potential scenarios," the researchers write.

The authors think they may have found a chemical tracer that can do the job. They say that finding both CO_2 and CO in an exoplanet atmosphere could contra-indicate a magma ocean. "One such possible tracer, and source of potential misfit of the magma ocean scenario with the observed spectrum of K2-18b, is the co-existence of CO_2 and CO," they explain. The problem is that the presence of any CO in K2-18b's atmosphere is uncertain.

The researchers have shown that we can't rely on the detection of carbon and the non-detection of ammonia to indicate a Hycean world because, in some circumstances, a magma ocean can produce the same atmospheric chemical profile. What can be done?

Better data and more research, of course.

"Developing clear disambiguating atmospheric tracers for the presence of liquid water versus magma oceans is key in our quest of finding potentially habitable worlds among the exoplanet population," they conclude.

More information: Oliver Shorttle et al, Distinguishing oceans of water from magma on mini-Neptune K2-18b, *arXiv* (2024). DOI: 10.48550/arxiv.2401.05864

Provided by Universe Today

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