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K2-18b

K2-18b, also known as **EPIC 201912552 b**, is an exoplanet orbiting the red dwarf K2-18, located 124 light-years (38 pc) away from Earth. The planet is a sub-Neptune about 2.6 times the radius of Earth, with a 33-day orbit within the star's habitable zone. This means it receives about a similar amount of starlight as the Earth receives from the Sun. Initially discovered with the Kepler space telescope, it was later observed by the James Webb Space Telescope (JWST) in order to study the planet's atmosphere.

In 2019 the presence of water vapour in K2-18b's atmosphere was reported, drawing attention to this system. In 2023, the JWST detected carbon dioxide and methane in the atmosphere of exoplanet K2-18b. JWST's data has been variously interpreted as indicating a water ocean or a magma ocean planet with a hydrogen-rich atmosphere, and a gas-rich mini-Neptune. K2-18b has been studied as a potential habitable world that, temperature aside, more closely resembles a gas planet like Uranus or Neptune than Earth.

K2-18b

Artist's impression of K2-18b *(right)* orbiting red dwarf K2-18 *(left)*. The exoplanet K2-18c is shown between them.

Discovery	
Discovery site	Kepler space telescope
Discovery date	2015
Detection method	Transit
Orbital characteristics[1]	
Semi-major axis	$0.159\,10^{+0.000\,46}_{-0.000\,47}$ au
	21,380,000 km
Eccentricity	$0.09^{+0.12}_{-0.09}$[2]
Orbital period (sidereal)	32.940 045 ± 0.000 100 d
Star	K2-18
Physical characteristics	
Mean radius	2.610 ± 0.087 $R_\oplus$
Mass	8.63 ± 1.35 $M_\oplus$
Mean density	$2.67^{+0.52}_{-0.47}$ g/cm^3
Surface gravity	$12.43^{+2.17}_{-2.07}$ m/s^2
Temperature	265 ± 5 K (−8 ± 5 °C)

Host star

K2-18 is an M dwarf of the spectral class M3V[3] in the constellation Leo,[4] 38.025 ± 0.079 parsecs (124.02 ± 0.26 ly) away from the Sun.[1] The star is colder and smaller than the Sun, having a temperature of 3,457 K (3,184 °C; 5,763 °F) and a radius 45% of the Sun's,[5] and is not visible to the naked eye.[6] The star is 2.4 ± 0.6 billion years old[7] and displays moderate stellar activity, but whether it has star spots,[8] which would tend to create false signals[a] when a planet crosses them,[10] is unclear.[10][8] K2-18 has an additional planet inside of K2-18b's orbit, K2-18c,[11] which may interact with K2-18b through tides.[b][13]

It is estimated that up to 80% of all M dwarf stars have planets in their habitable zones,[5] including the stars LHS 1140, Proxima Centauri and TRAPPIST-1. The small mass, size and low temperatures of these stars and frequent orbits of the planets make it easier to characterize the planets. On the other hand, the low luminosity of the stars can make spectroscopic analysis of planets difficult,[14][5] and the stars are frequently active with flares and inhomogeneous stellar surfaces (faculae and starspots), which can produce erroneous spectral signals when investigating a planet.[9]

Physical properties

K2-18b has a radius of 2.610 ± 0.087 $R_\oplus$, a mass of 8.63 ± 1.35 M_E, and orbits its star in 33 days.[5] From Earth, it can be seen passing in front of the star.[15] The planet is most likely tidally locked to the star, although considering its orbital eccentricity, a spin-orbit resonance like Mercury is also possible.[16]

The density of K2-18b is about $2.67^{+0.52}_{-0.47}$ g/cm^3 – intermediate between Earth and Neptune – implying that the planet has a hydrogen-rich envelope.[c][14] The planet may either be rocky with a thick envelope or have a Neptune-like composition.[d][18] A pure water planet with a thin atmosphere is less likely.[19] Planets with radii of about 1.5–2 $R_\oplus$ are unexpectedly rare relative to their expected occurrence rate, a phenomenon known as the *radius valley*. Presumably, planets with intermediary radii cannot hold their atmospheres against the tendency of their own energy output and the stellar radiation to drive atmospheric escape.[20] Planets with even smaller radii are known as Super-Earths and those with larger radii as Sub-Neptunes.[21]

The planet may have taken a few million years to form.[22][23] Tidal heating is unlikely.[11] Internal heating may increase temperatures at large depths, but is unlikely to significantly affect the surface temperature.[23] If an ocean exists, it is probably underlaid by a high-pressure ice layer on top of a rocky core,[24] which might destabilize the planet's climate by preventing material flows between the core and the ocean.[25]

Possible ocean

At temperatures exceeding the critical point, liquids and gases stop being different phases and there is no longer a separation between an ocean and the atmosphere.[26] It is unclear whether observations imply that a separate liquid ocean exists on K2-18b,[2] and detecting such an ocean is difficult from the outside;[27] its existence cannot be inferred or ruled out solely from the mass and radius of a planet.[28]

The existence of a liquid water ocean is uncertain.[29] Before the James Webb Space Telescope observations, a supercritical state of the water was believed to be more likely.[30] JWST observations were initially considered to be more consistent with a fluid-gas interface and thus a liquid ocean[31] - trace gases such as hydrocarbons and ammonia can be lost from an atmosphere to an ocean if it exists; their presence may thus imply the absence of an ocean-atmosphere separation.[32] However, a subsequent work finds that a magma ocean is also capable of dissolving ammonia and explaining the observation results,[33] while another paper suggests that a gas-rich mini-Neptune model is capable of replicating the observed amount of methane and carbon dioxide, while a liquid water ocean model requires the presence of a biosphere in order to produce sufficient amount of methane.[34]

Atmosphere and climate

Observations with the Hubble Space Telescope have found that K2-18b has an atmosphere consisting of hydrogen.[35] The presence of water vapour is likely[36] but with uncertainty,[37] as James Webb Space Telescope observations indicating concentrations of less than 0.1%;[38] this may be due to the JWST seeing a dry stratosphere.[31] Ammonia concentrations appear to be unmeasurably low.[e][35] JWST observations indicate that methane and carbon dioxide make up about 1% of the atmosphere.[41] Other carbon oxides were not reported;[42] only an upper limit to their concentrations (a few percent) has been established.[43] The atmosphere makes up at most 6.2% of the planet's mass,[18] and its composition probably resembles that of Uranus and Neptune.[44]

There is little evidence of hazes in the atmosphere,[45] while evidence for water clouds, the only kind of clouds likely to form at K2-18b,[46] is conflicting.[47] If they exist, the clouds are most likely icy but liquid water is possible.[48] Apart from water, ammonium chloride, sodium sulfide, potassium chloride and zinc sulfide could form clouds in the atmosphere of K2-18b, depending on the planet's properties.[49] Most computer models expect that a temperature inversion will form at high elevation, yielding a stratosphere.[50]

Evolution

High-energy radiation from the star, such as hard[f] UV radiation and X-rays, is expected to heat the upper atmosphere and fill it with hydrogen formed through the photodissociation of water, thus forming an extended hydrogen-rich exosphere[53] that can escape from the planet.[7] The X-ray and UV fluxes that K2-18b receives from K2-18 are considerably higher than the equivalent fluxes from the Sun;[7] the hard UV radiation flux provides enough energy to drive this exosphere to escape at a rate of about 350^{+400}_{-290} tons per second, too slow to remove the planet's atmosphere during its lifespan.[54] Observations of decreases of Lyman alpha radiation emissions during transits of the planet may show the presence of such an exosphere; this discovery requires confirmation.[55]

Alternative scenarios

Detecting atmospheres around planets is difficult, and several reported findings are controversial.[56] Barclay *et al.* 2021 suggested that the water vapour signal may be due to stellar activity, rather than water in K2-18b's atmosphere.[3] Bézard *et al.* 2020 proposed that methane may be a more significant component, making up about 3–10% while water may constitute about 5–11% of the atmosphere,[47] and Bézard, Charnay and Blain 2022 proposed that the evidence of water is actually due to methane,[57] although such a scenario is less probable.[58]

Models

Climate models have been used to simulate the climate that K2-18b might have, and an intercomparison of their results for K2-18b is part of the CAMEMBERT project to simulate the climates of sub-Neptune planets.[59] Among the climate modelling efforts made on K2-18b are:

- Charnay *et al.* 2021, assuming that the planet is tidally locked, found an atmosphere with weak temperature gradients and a wind system with descending air on the night side and ascending air on the day side. In the upper atmosphere, radiation absorption by methane produced an inversion layer.[60] Clouds could only form if the atmosphere had a high metallicity; their properties strongly depended on the size of cloud particles and the composition and circulation of the atmosphere. They formed mainly at the substellar point and the terminator. If there was rainfall, it could not reach the surface; instead it evaporated to form virga.[61] Simulations with a spin-orbit resonance did not substantially alter the cloud distribution.[62] They also simulated the appearance of the atmosphere during stellar transits.[63]
- Innes and Pierrehumbert 2022 conducted simulations assuming different rotation rates and concluded that except for high rotation rates, there is not a substantial temperature gradient between poles and equator.[64] They found the existence of jet streams above the equator and at high latitudes, with weaker equatorial jets at the surface.[65]
- Hu 2021 conducted simulations of the planet's chemistry.[46] They concluded that the photochemistry should not be able to completely remove ammonia from the outer atmosphere[66] and that carbon oxides and cyanide would form in the middle atmosphere, where they could be detectable.[67] The model predicts that a sulfur haze layer could form, extending through and above the water clouds. Such a haze layer would make investigations of the planet's atmosphere much more difficult.[68]
- Tsai *et al.* 2024 ran chemical and physical models.[69] They found a prograde jet stream in the troposphere and a retrograde one above 0.0001 bar altitude, with thermally-driven circulation in-between the two.[70] They found that for dimethyl sulfide to be detectable, its production needs to exceed Earth's by a factor of 20,[71] a rate not impossible for a plausible ecosystem.[72] Several hydrocarbons can mask the dimethyl sulfide signal.[73]

Habitability

Incoming stellar radiation amounts to 1368^{+114}_{-107} W/m^2, similar to the average insolation Earth receives.[5] K2-18b is located within or just slightly inside the habitable zone of its star,[74] – it may be close to[75] but fall short of the runaway greenhouse threshold[76] – and its equilibrium temperature is about 250 K (−23 °C; −10 °F) to 300 K (27 °C; 80 °F).[14] Whether the planet is actually habitable depends on the nature of the envelope[30] and the albedo of clouds;[69] the deeper layers of the atmosphere may be too hot,[40] while the water-containing layers might[25] or might not have temperatures and pressures suitable for the development of life.[77]

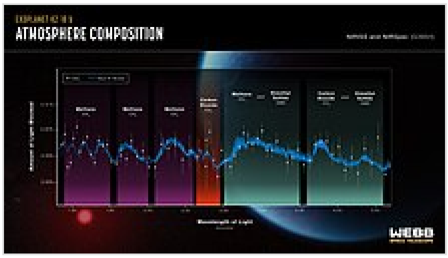
Microorganisms from Earth can survive in hydrogen-rich atmospheres, illustrating that hydrogen is no impediment to life. However, a number of biosignature gases used to identify the presence of life are not reliable indicators when found in a hydrogen-rich atmosphere, thus different markers would be needed to identify biological activity at K2-18b.[78] According to Madhusudhan et al., several of these markers could be detected by the James Webb Space Telescope after a reasonable number of observations.[79]

Discovery and research history

The planet was discovered in 2015 by the Kepler space telescope,[80][81][82] and its existence was later confirmed with the Spitzer Space Telescope and through Doppler velocity techniques.[53] Analyses of the transits ruled out that they were caused by unseen companion stars,[82] by multiple planets or systematic errors of the observations.[83] Early estimates of the star's radius had substantial errors, which led to incorrect planet radius estimates and the density of the planet being overestimated.[84] The discovery of the spectroscopic signature of water vapour on K2-18b in 2019 was the first discovery of water vapour on an exoplanet that is not a Hot Jupiter[7] and drew a lot of discussion.[27]

K2-18b has been used as a test case for exoplanet studies.[46] The properties of K2-18b have led to the definition of a "hycean planet", a type of planet that has both abundant liquid water and a hydrogen envelope. Planets with such compositions were previously thought to be too hot to be habitable; findings at K2-18b instead suggest that they might be cold enough to harbour liquid water oceans conducive to life. The strong greenhouse effect of the hydrogen envelope might allow them to remain habitable even at low instellation rates.[85] K2-18b is probably the best known "hycean" planet.[86] Other, non-hycean compositions are possible, both habitable and uninhabitable.[87][69]

There is some evidence of dimethyl sulfide (DMS) and methyl chloride being present in the atmosphere. The presence of DMS is a potential biosignature, as the bulk of the DMS in Earth's atmosphere is emitted from phytoplankton in marine environments,[88] although further observation to confirm the presence of DMS and rule out a geological or chemical origin for the compound is required.[89][90] Some scientists have voiced concerns about the statistical significance of the DMS signal at K2-18b, and how its putative detection might be understood in an environment different than Earth.[91] In 2024, Wogan *et al.* suggested that the high methane concentrations might either imply the presence of methanogenic life[92] or upwards mixing of gases from the deep interior, if the planet is too hot for life.[93]



K2-18b James Webb Space Telescope spectra from 2023. Credit: NASA, CSA, ESA, J. Olmstead, N. Madhusudhan

A podcast on the Planetary Society's website in January 2024 featured NASA astrophysicist Knicole Colón describing some of the scientific results from the observations of K2-18b by JWST. Data from JWST's MIRI instrument was expected to be gathered in January 2024 about which Colón said: "MIRI will be able to see additional features, absorption features from these molecules, and validate again, the presence of what we've seen and even the abundance." Colón also talks about the lack of evidence of water in the atmosphere: "The fact that the JWST data basically didn't find strong evidence of water in the atmosphere, that could indicate a couple things".[94]

See also

- Extraterrestrial liquid water – Liquid water naturally occurring outside Earth
- Habitability of natural satellites#In the Solar System – Measure of the potential of natural satellites to have environments hospitable to life
- Habitability of red dwarf systems – Possible factors for life around red dwarf stars
- List of potentially habitable exoplanets
- Planetary habitability – Known extent to which a planet is suitable for life

Notes

a. Observations of transiting planets rely on comparing the appearance of the planet with the appearance of the star's surface that is not covered with the planet, so variations in the star's appearance can be confused with the effects of the planet.[9]

b. Tidal interactions are mutual interactions, mediated by gravity, between astronomical bodies that are in motion with respect of each other.[12]

c. An envelope is an atmosphere that originated together with the planet itself from a protoplanetary disk. In gas giants, atmospheres make up the bulk of the planet's mass.[17]

d. A Neptune-like composition implies that apart from water and rock the planet contains substantial amounts of hydrogen and helium.[18]

e. The lack of ammonia and methane in Neptune-like exoplanet atmospheres is known as the "missing methane problem", and is an unresolved mystery as of 2021.[39] The unusually low ammonia and methane concentrations could be due to life, photochemical processes[30] or the freezing-out of methane.[40]

f. Hard UV radiation means UV radiation with short wavelengths;[51] shorter wavelengths imply a higher frequency and higher energy per photon.[52]

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External links

- K2-18 b Confirmed Planet Overview Page (http://exoplanetarchive.ipac.caltech.edu/cgi-bin/DisplayOverview/nph-DisplayOverview?objname=K2-18+b&type=CONFIRMED_PLANET), NASA Exoplanet Archive
- NASA says distant planet could hold life after they spot signs of rare water ocean - MSN News (https://www.msn.com/en-us/news/technology/nasa-says-distant-planet-could-hold-life-after-they-spot-signs-of-rare-water-ocean/ar-AA1gOuta?rc=1&ocid=winp1taskbar&cvid=b0a89305eba942b8ab2a3ed18ff223b0&ei=14)