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SHORT COMMUNICATION

Life in the Exoplanet K2-18b?

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ABSTRACT

The possible presence of dimethyl sulfide (DMS) in the atmosphere of the exoplanet K2-18b—an ocean-bearing Hycean world candidate—has intensified the interest in its potential habitability. This sulfur compound, primarily produced by marine life on Earth, is considered a potential biosignature. We investigate whether the observed atmospheric DMS levels could plausibly originate from biological activity, assuming Earth-like metabolic pathways. Through energy budget modeling, this study estimates the DMS production capacity of a hypothetical biosphere on K2-18b and finding that, even under optimistic assumptions, biogenic DMS levels would fall several orders of magnitude short of those inferred from James Webb Space Telescope (JWST) observations. Additionally, we examine DMS atmospheric lifetimes under K2-18b's environmental conditions. The results suggest that, while the presence of DMS cannot be conclusively attributed to biological activity, its detection remains inconclusive as a biosignature due to possible non-biological production mechanisms and uncertainties in spectral retrieval procedures. We conclude that current evidence does not support the presence of life on K2-18b and emphasize the need for more refined observational data and atmospheric models.

Keywords: Exoplanets; K2-18b Atmosphere; Dimethyl Sulfide; Atmospheric Biosignatures

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1. Introduction

K2-18b is an exoplanet orbiting an M-type star with an orbital period of approximately 33 days. Based on revised data[1,2], the planet's mass is 8.63 ± 1.35 $M_{\oplus}$, and its radius is 2.61 ± 0.09 $R_{\oplus}$. The orbit of K2-18b potentially places it within the habitable zone (HZ) of its host star, provided that sufficient atmospheric pressure exists to sustain liquid water on its surface[3–5].

The planet's bulk properties suggest a layered internal structure comprising a silicate core, an ice-rich mantle likely containing condensed volatiles such as ammonia, carbon dioxide, and methane, and a primitive atmosphere dominated by hydrogen and helium. An ocean may also expected to exist at the surface. This configuration is consistent with what has been termed a "Hycean" world—a class of planets characterized by a hydrogen-rich atmosphere and a liquid-water ocean ("Hy" for hydrogen and "cean" for ocean). Hycean planets are regarded as promising candidates for hosting life[6].

However, counterarguments exist regarding the Hycean-world hypothesis. A global surface ocean requires atmospheric pressures below approximately 10 bar. In a hydrogen-rich atmosphere, pressures exceeding this threshold could lead to extremely high surface temperatures due to an enhanced greenhouse effect, potentially causing ocean water to evaporate and generating a steam-dominated atmosphere[7]. Conversely, increased atmospheric albedo—arising from vapor clouds or scattering hazes—could mitigate this effect by reducing the amount of stellar radiation absorbed by the planet[8].

K2-18b has been observed using the James Webb Space Telescope (JWST) with the Near Infrared Imager and Slitless Spectrograph (NIRISS) and the Near Infrared Spectrograph (NIRSpec), covering the spectral range of 0.9–5.2 μm[9]. Atmospheric models fitted to these data suggest the presence of methane (CH_4) and carbon dioxide (CO_2), but not ammonia (NH_3) or water vapor (H_2O). According to these models, methane and carbon dioxide are present at approximately 1–2% by volume relative to molecular hydrogen (H_2).

However, photochemical and climate models[10] predict significantly lower abundances of these gases if K2-18b is an abiotic Hycean world. To reconcile the high methane and carbon dioxide levels inferred in previous studies[9], a methane-producing biosphere—similar to that which existed on Earth 3 billion years ago—would be required. Alternatively, K2-18b could be a gas-rich mini-Neptune[10], where CH_4 and CO_2 are generated thermochemically in deep atmospheric layers and subsequently transported upward via mixing processes. However, this scenario would only be consistent with JWST data if the planet's atmospheric metallicity exceeds that of the Sun.

Recent observations by the James Webb Space Telescope (JWST) in the 6–12 μm range have suggested the possible presence of dimethyl sulfide (CH_3–S–CH_3) in the atmosphere of K2-18b[11]. The significance of this finding lies in the fact that, on Earth, dimethyl sulfide (DMS), a sulfur-containing compound, is primarily produced by marine phytoplankton, specifically unicellular algae. As such, its detection could be indicative of potential biological activity on K2-18b.

However, the possibility of abiotic production cannot be ruled out. DMS has been detected in comet 67P/Churyumov-Gerasimenko[12] and in the interstellar molecular cloud G+0.693–0.027, located toward the Galactic center[13]. Notably, the DMS-to-dimethyl ether (CH_3–O–CH_3) abundance ratio measured in comet 67P (1.3×10^{-3}) is comparable to that estimated for G+0.693–0.027 (1.7×10^{-3}), suggesting similar chemical pathways in both environments.

Although the chemistry of DMS beyond Earth remains poorly understood, these findings provide compelling evidence for efficient abiotic synthesis in the interstellar medium. This, in turn, raises important questions about the reliability of DMS as a definitive atmospheric biosignature.

The potential detection of DMS in the atmosphere of K2-18b is based primarily on comparisons between observational data and atmospheric models. However, these models incorporate only a limited set of chemical species[14]. Notably, their analysis demonstrated that the inclusion of propyne (C_3H_4) can produce spectral fits that are comparable to, or even better than, those obtained with DMS. Further analyses[15] reprocessing the JWST data, and using two independent retrieval frameworks, support this conclusion. These new results indicate that the evidence for DMS is not statistically robust, as other molecules containing methyl functional groups can yield fits of equivalent quality to the observed spectrum.

In light of the considerations outlined above, it is not possible to definitively assert the detection of a positive biosignature in the atmosphere of the exoplanet K2-18b. Several factors contribute to this uncertainty. First, dimethyl sulfide (DMS) can be produced through abiotic processes, as evidenced by its detection in comets and the interstellar medium. Second, current spectral models do not account for all potential molecules that could explain the infrared features observed in the planet's spectrum. Third, recent reanalyses of JWST data have not found compelling evidence for the presence of DMS, as other compounds can yield spectral fits of comparable or greater statistical significance.

Despite the ongoing controversy, the possibility of DMS detection in the atmosphere of K2-18b cannot be entirely dismissed. In this context, the potential for microbial life on K2-18b has been investigated, as well as its dependence on the planet's physical environment [6]. Building on this, the present study examines the energetic requirements for biotic DMS production on K2-18b, assuming general metabolic pathways analogous to those found on Earth. Under these assumptions, the resulting DMS abundance in the planet's atmosphere is estimated to be several orders of magnitude lower than the values recently reported based on JWST observations [11]. These findings support the conclusion that there is currently no robust evidence for the presence of a biosignature on K2-18b. This paper is organized as follows: in Section 2, the DMS production pathway on Earth is revisited and an estimate of the molecule lifetime in the atmosphere is performed. Based on simple models, the energy required to maintain the observed DMS production rate in oceans is estimated. Section 3 applies terrestrial DMS chemistry to K2-18b in order to estimate the expected production rate and atmospheric concentration. Section 4 presents the main conclusions.

2. DMS Production on Earth

On Earth, dimethyl sulfide (DMS) is produced as a metabolic byproduct and is not directly driven by sunlight or external chemical inputs. Its formation is indirectly linked to photosynthesis through the biosynthesis of dimethylsulfoniopropionate (DMSP), a compound synthesized by certain marine algae—particularly dinoflagellates and haptophytes—as an osmolyte and cryoprotectant. DMSP production requires energy in the form of ATP and reducing equivalents like NADPH (nicotinamide adenine dinucleotide phosphate), both derived from photosynthetic processes. Carbon is fixed from CO_2, while sulfur is assimilated from sulfate (SO_4^{2-}), drawing indirectly on solar energy via the Calvin cycle and sulfur metabolism.

The enzymatic cleavage of DMSP into DMS is catalyzed by lyase enzymes and does not consume ATP. This reaction is often triggered by environmental stressors such as oxidative stress or grazing by zooplankton, possibly serving defensive or osmoregulatory functions. Thus, while the biosynthesis of DMSP is light-dependent, the release of DMS itself is not directly powered by light. This distinction is crucial when assessing the plausibility of DMS as a biosignature on exoplanets like K2-18b, where the environmental conditions and ecological interactions necessary for DMS release may differ markedly from those on Earth. Given this context, the mere detection of DMS—if confirmed—should not be interpreted as definitive evidence of life. High atmospheric DMS concentrations would imply not only the existence of DMSP-producing organisms but also environmental or ecological conditions conducive to their enzymatic cleavage. Without additional constraints on the planet's biosphere or stress-inducing factors, the interpretation of DMS as a reliable biosignature remains uncertain.

The global marine sulfur production on Earth is variable, with early estimates ranging from Q_S = 13–37 teragrams (Tg) of sulfur per year [16]. More recent assessments suggest a value closer to 27 Tg S/yr [17], which can be converted to an estimated dimethyl sulfide (DMS) production rate of approximately $Q_{DMS} \approx 52$ Tg/yr.

Satellite-based measurements of chlorophyll-a (Chl-a) are a fundamental tool for estimating oceanic phytoplankton biomass. When combined with in situ observations at various depths—gathered by autonomous profiling robots—these data allow for an estimation of total phytoplankton biomass at approximately 314 Tg of carbon [18].

Phytoplankton species vary widely in size and cellular composition [19], but typical values include a carbon content of about 10% of wet mass and a cellular mass of approximately 10^{-10} g (i.e., 100 pg wet mass). Using these assumptions, the global DMS productivity per unit of biomass is estimated as:

$$\mathrm{P} = 17 \text{ mg DMS/g biomass/yr} \tag{1}$$

while the productivity per individual cell is

$$\mathrm{P_c} = 1.7 \text{ pg DMS/cell/yr} \tag{2}$$

These productivity values provide a quantitative benchmark for assessing the potential scale of DMS production on exoplanets such as K2-18b, assuming the presence of Earth-like microbial biospheres and metabolic pathways.

2.1. DMS Lifetime in the Earth's Atmosphere

In Earth's atmosphere, *DMS* is primarily removed through reactions with atmospheric radicals, most notably hydroxyl radicals (OH) during the daytime and nitrate radicals (NO_3) at night. Another relevant destruction pathway is photolysis, as DMS can absorb ultraviolet photons with wavelengths shorter than 250 nm, initiating dissociation reactions:

$$DMS + hv \rightarrow photoproducts \tag{3}$$

To estimate the average atmospheric lifetime of *DMS*, a simple global box model is used, based on the steady-state balance between production and loss. Under these conditions, the lifetime τ of *DMS* molecules is:

$$\tau = \left(\frac{\mu_{DMS}}{\mu_{at}}\right)\left(\frac{M_{at}}{Q_{DMS}}\right)c \tag{4}$$

where $\mu_{DMS} = 62$ and $\mu_{at} = 28.97$ are respectively the molecular weight of DMS and air molecules, $M_{at} = 5.14 \times 10^{21}$ g is the mass of the atmosphere, $Q_{DMS} = 52$ Tg DMS/yr is the total DMS production rate by oceans and c is the atmospheric concentration of DMS. Observed DMS concentrations vary seasonally and spatially, especially during phytoplankton blooms, ranging from 10 to 100 pptv (parts per trillion by volume) [20–22]. Notice that (uncertain) retrieval values estimated from atmospheric models for K2-18b are several orders of magnitude higher, that is varying from 130 ppbv (parts per billion by volume) [9] up to 295 ppmv (parts per million by volume) [11]. For the present calculation, a representative average value of c = 50 pptv is adopted. Substituting these values into Equation (4) yields an average atmospheric lifetime of 3.9 days. It should be mentioned that this estimate is based on a zero-dimensional, globally averaged model that does not account for atmospheric layering or transport processes, which can locally affect DMS lifetime.

2.2. Energetics of DMS Formation

In this section, we estimate the energy required to produce one mole of DMS. As noted earlier, DMS is not directly synthesized using light or external chemical energy; rather, it is a metabolic byproduct indirectly powered by photosynthesis. Specifically, phytoplankton synthesize DMSP, which is subsequently cleaved to form DMS.

The biosynthetic pathway can be divided into two main steps: (1) Synthesis of DMSP – This step requires energy in the form of ATP and reducing equivalents (mainly NADPH), both of which are produced via photosynthesis. The process involves carbon fixation from CO_2 and sulfur assimilation from environmental sulfate (SO_4^{2-}) through biochemical pathways such as the Calvin cycle. This energy-intensive step is indirectly powered by sunlight; (2) Cleavage of DMSP into DMS—This reaction is catalyzed by DMSP lyase enzymes and does not require ATP input. It typically occurs in response to cellular stress (e.g., oxidative stress or grazing) and may serve physiological functions such as osmotic regulation or chemical defense.

Based on metabolic energy requirements, it is estimated that approximately 45 moles of ATP are needed to synthesize one mole of DMSP. Assuming a 1:1 conversion from DMSP to DMS, which represents an idealized, maximally efficient scenario, the energy cost to produce one mole of DMS is equivalent to the energy needed for generating 45 mol of ATP.

Given that the formation of one mole of ATP requires roughly 35 kJ [23], the energy required to produce one mole of DMS is:

$$E_{DMS} \approx 45 \times 35 \text{ kJ} = 1575 \text{ kJ/mol} \quad (5)$$

At the observed DMS production rate (see Section 2), this translates into a total energy rate $R_{DMS} = Q_{DMS} \times E_{DMS}$ of approximately 4.2×10^{10} W to sustain the observed DMS production. If solar radiation is considered the ultimate energy source for this process, then DMS production would require only a tiny fraction f of the incident stellar energy, estimated as

$$f = \frac{R_{DMS}}{E_{\odot}} = 4\left(\frac{a}{R_{\oplus}}\right)^2 \frac{R_{DMS}}{L_{\odot}} \quad (6)$$

where a is the Earth-Sun distance, $R_{\oplus}$ is the Earth's radius and $L_{\odot}$ is the solar luminosity. Numerically, one obtains $f = 2 \times 10^{-7}$.

3. DMS Production in K2-18b

If life has emerged in the ocean of K2-18b and produces DMS, it would likely rely on energy-harvesting mechanisms similar to photosynthesis, although chemosynthesis based on redox gradients—such as those exploited by certain Earth microbes—cannot be entirely ruled out. Regardless of the energy source, the surrounding environment must provide accessible sources of both carbon and reduced sulfur.

The detection of methane (CH_4) and carbon dioxide (CO_2) in the planet's atmosphere, as suggested by JWST observations [9], indicates a plausible reservoir of carbon. Both gases are soluble in water and could serve as key carbon sources for microbial life. Sulfur, on the other hand, is likely present as hydrogen sulfide (H_2S), a common product of reducing, anoxic environments. Upon dissolution in water, H_2S forms bisulfide (HS^-) and sulfide (S^{2-}) ions, forms that are readily assimilated by microbial sulfur metabolism.

The lifetime of DMS in the atmosphere of K2-18b is expected to be significantly longer than on Earth, primarily due to the presumed scarcity of hydroxyl (OH) radicals, which are the major DMS-destroying agents in Earth's atmosphere. However, in a hydrogen-rich and photochemically active environment, methane photolysis can generate reactive radicals such as CH_3^* and H•, which may still contribute to DMS degradation. Although these reactions proceed more slowly than OH-mediated reactions, they are nonetheless viable under reducing conditions. In addition, DMS can be photodissociated by stellar UV radiation at wavelengths shorter than 250 nm, as described by Equation (3).

It is important to note that M-dwarf stars, like K2-18, have a distinct UV emission spectrum compared to the Sun, largely shaped by chromospheric activity. The likely active nature of K2-18 means that stellar flares and high-energy particle emissions could sporadically enhance the production of reactive species, thereby increasing DMS breakdown rates. However, due to the overall lower steady-state UV flux and reduced radical abundance in the planet's hydrogen-rich atmosphere, these destruction processes are expected to be relatively inefficient.

Based on these considerations, the average atmospheric lifetime of DMS on K2-18b is likely to exceed that on Earth by at least an order of magnitude - potentially greater than 40 days, enhancing the molecule's detectability.

Using the previous approximate approach, the energy (rate) available from star at the ocean surface used for DMS production can be derived from Equation (6), that is

$$R_{DMS^*} = \frac{f}{4}\left(\frac{R_p}{a_p}\right)^2 L_* \quad (7)$$

where now parameters refer to the K2-18 system, listed in **Table 1**, according to data given in reference [2]. The first three columns give respectively the luminosity, the radius and the mass in solar units, the fourth column gives the effective temperature and the last column gives the metallicity (in dex) with respect to the solar value taken from the Hypatia catalog. Using these data and the observed orbital period, the distance of the planet to star is $a_p = 23.85 \times 10^6$ km.

Table 1. Stellar parameters of K2-18.

$L_*/L_\odot$	$R_*/R_\odot$	$M_*/M_\odot$	$T_{\rm eff}$ (K)	[Fe/H]
0.02512	0.4445	0.4951	3457	−0.02

We further assume that the fraction f of the stellar radiation used in the process is the same as that estimated for Earth. This is certainly not true because terrestrial algae absorb radiation selectively, mainly in the UV around 430–440 nm and secondarily in a peak around 660 nm [24,25]. This behavior reflects probably an adaptation of the chlorophylls to optimize the absorption of the solar radiation. The analogous forms of life that would present in K2-18b probably have also evolved in order to optimize the absorption of radiation from the M-star, which emits more infrared radiation than the Sun. Since we are interested mainly in order of magnitude estimates, we adopt the same value of f derived above. In this case, one obtains from Equation (7), $R_{DMS^*} = 2.43 \times 10^{11}$ W. Notice that this value is about a factor of six higher than the terrestrial rate estimated previously, despite the lower luminosity of the M-star. This is explained by the much smaller distance between the planet and the star. From this result, the production rate of DMS in the atmosphere of K2-18b can be estimated as

$$Q_{DMS^*} = R_{DMS^*}/E_{DMS} = 1.54 \times 10^5 mol\ DMS/s \quad (8)$$

where we have used Equation (5) to derive the numerical value.

The expected concentration of the DMS molecule can be computed now from Equation (4). The mass of the K2-18b atmosphere was estimated from an isothermal model, that is

$$M_{at} = 4\pi R_p^2 \frac{P_a}{g_p} = 2.8 \times 10^{19} \left(\frac{P_a}{1bar}\right) kg \quad (9)$$

Notice that in this approach, the final result depends only on the surface atmospheric pressure (P_a). Combining Equations (4), (8) and (9), one obtains

$$c = 6.6 \times 10^{13} \left(\frac{\tau}{1day}\right)\left(\frac{1bar}{P_a}\right) \quad (10)$$

Figure 1 illustrates the expected atmospheric concentration of dimethyl sulfide (DMS) on K2-18b as a function of the molecule's atmospheric lifetime, across a range of surface pressures. It is important to note that atmospheric pressure is related not only to the total atmospheric mass but also to the climate conditions necessary to sustain a surface ocean, as previously discussed. In addition, the atmospheric mass can influence the planet's rotational dynamics. Thermal tides in dense atmospheres influence spin-orbit coupling [26], and according to these models, K2-18b is likely to be in synchronous rotation if the surface pressure lies between 1 and 10 bar, while lower pressures may lead to asynchronous rotation.

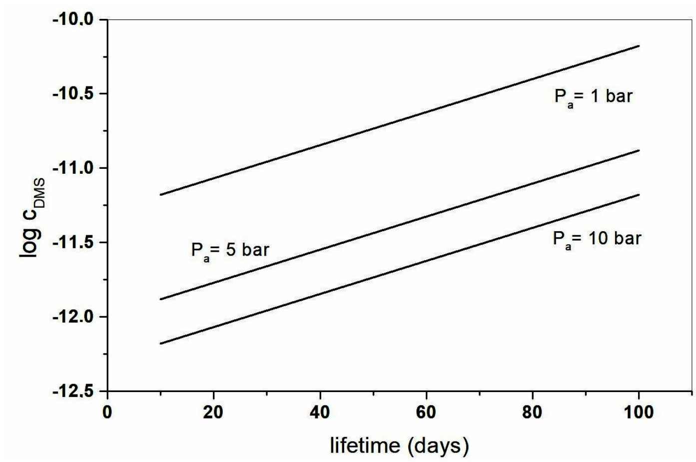

Figure 1. Estimated DMS concentration in the atmosphere of K2-18b as a function of the molecule lifetime, and for several values of the surface pressure.

A straightforward analysis of **Figure 1** reveals that the expected atmospheric concentrations of DMS—assuming biogenic production pathways—are several orders of magnitude lower than the values inferred from JWST infrared spectroscopic data reported in reference [9]. Even under highly favorable assumptions, such as increasing the efficiency of stellar energy conversion into biochemical output by two to three orders of magnitude, the predicted DMS levels remain inconsistent with those retrieved from spectral model fits. These findings imply that, if DMS is indeed present in the atmosphere of K2-18b at concentrations on the order of $c \sim 10^{-4}$, this may point to a non-biological (abiotic) origin of the molecule.

4. Conclusions

In this study, we investigated the potential biological origin of dimethyl sulfide (DMS) in the atmosphere of the exoplanet K2-18b by modeling its production based on known terrestrial biochemical pathways. Assuming Earth-like microbial processes, we estimated that the energy required to synthesize one mole of DMS is approximately 1575 kJ. Using the observed global oceanic DMS production rate as a benchmark, and supposing that ATP generation is powered by stellar radiation, we estimated that only a small fraction—about 2×10^{-7}—of the incident stellar energy would be required to sustain such biosynthesis under Earth-like terms.

In a second step, we applied a simplified atmospheric model to K2-18b, assuming hypothetical photosynthetic organisms capable of utilizing the energy spectrum of its M-dwarf host star. While the exact adaptation of such pigments remains speculative, we adopted an efficiency comparable to that of terrestrial photosynthesis as a baseline. Our calculations indicate that, under plausible surface pressures (1–10 bar) and assuming DMS atmospheric lifetimes between 10 and 100 days, the resulting DMS concentration would be on the order of 10^{-11} by volume—about seven orders of magnitude lower than the concentration suggested in reference [9], based on JWST spectroscopic retrievals.

Photochemical models for Hycean planets with tidally locked rotation and surface pressures around 1 bar suggest that DMS destruction lifetimes are similar on both the day and night sides, owing to efficient global atmospheric circulation [27]. At higher altitudes, corresponding to pressures of approximately 10^{-4} bar, representative of the upper troposphere, the average DMS lifetime has been estimated to be as long as 15.8 years. This is significantly longer than the several-week timescale adopted in our own calculations. Under these conditions, the peak DMS mixing ratio reaches 5×10^{-9}, which is comparable to the present global average estimates given by Equation (10). However, it is important to note that these models assume atmospheric metallicities two orders of magnitude greater than solar. According to those authors, detectable levels of biogenic sulfur gases in Hycean atmospheres would only be expected if the global biosulfur flux exceeds Earth's present value by at least a factor of 20.

Even allowing for optimistic assumptions about biological efficiency—up to two or three orders of magnitude greater than Earth's—the predicted DMS levels remain incompatible with the reported values. This significant discrepancy implies that, if high atmospheric DMS concentrations are confirmed by future independent observations, an abiotic origin must be considered more likely.

Given these findings, and the current uncertainties surrounding spectral retrievals and molecular species identification, we conclude that there is, at present, no robust evidence supporting the presence of a biosignature in the atmosphere of K2-18b. Future observations with higher signal-to-noise ratios, improved retrieval models, and tighter constraints on atmospheric chemistry will be essential for resolving this question.

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The author declares no conflict of interest.

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