# The combination of oxygen and methane could reveal the presence of life on another world

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The Pleistocene of Northern Spain showing woolly mammoths, cave lions eating reindeer, tarpans, and woolly rhinoceros. Credit: Wikipedia Commons/Mauricio Antón

In searching for life in the universe, a field known as astrobiology, scientists rely on Earth as a template for biological and evolutionary processes. This includes searching for Earth analogs, rocky planets that orbit within their parent star's habitable zone (HZ) and have atmospheres composed of nitrogen, oxygen, and carbon dioxide. However, Earth's atmosphere has evolved considerably over time from a toxic plume of nitrogen, carbon dioxide, and traces of volcanic gas. Over time, the emergence of photosynthetic organisms caused a transition, leading to the atmosphere we see today.

The last 500 million years, known as the Phanerozoic Eon, have been particularly significant for the evolution of Earth's atmosphere and terrestrial species. This period saw a significant rise in oxygen content and the emergence of animals, dinosaurs, and embryophyta (land plants). Unfortunately, the resulting transmission spectra are missing in our search for signs of life in exoplanet atmospheres. To address this gap, a team of Cornell researchers created a simulation of the atmosphere during the Phanerozoic Eon, which could have significant implications in the search for life on extrasolar planets.

The research was led by Rebecca Payne and Lisa Kaltenegger, a research associate and assistant professor with the Carl Sagan Institute at Cornell University (respectively). The paper that describes their findings, "Oxygen Bounty for Earth-like exoplanets: Spectra of Earth through the Phanerozoic," was recently published in the *Monthly Notices of the Royal Astronomical Society: Letters*. They have made the full model and high-resolution spectra available online, which provide a tool to plan, optimize, and interpret observations with ground- and space-based telescopes.

The study of exoplanets is currently experiencing a transition. With 5,528 exoplanets confirmed to date, and another 9,899 candidates awaiting confirmation, the process has been moving from discovery to characterization. This transition has benefitted from next-generation ground and space-based telescopes capable of obtaining spectra directly from exoplanet atmospheres. This is a process where light is analyzed using spectrometers to identify absorption features that correspond to different chemical compounds, thus revealing vital data about the composition of an exoplanet's atmosphere.

This can be done using the direct imaging method, where astronomers examine light reflected from a planet's atmosphere (or surface). Another method involves obtaining transmission spectra, where astronomers analyze light passing through an exoplanet's atmosphere as it passes in front of its star relative to the observer (transits). Thanks to observatories like the James Webb Space Telescope (JWST), astronomers can finally obtain transmission spectra from smaller rocky planets that orbit closer to their suns—where potentially habitable, Earth-like planets are believed to reside. As Prof. Kaltenegger told Universe Today via email:

"To date, we know of about 35 rocky exoplanets circling in the habitable zones of their stars. While at the edge of technical capability for NASA's James Webb Space Telescope, analyzing the atmosphere of some of these exoplanets is now a possibility. But scientists need to know what to look for. Our models identify planets like a Phanerozoic Earth as really promising targets to find life in the cosmos, of course, that life by no means would have to be dinosaurs."

Despite the plethora of exoplanets that have been discovered and characterized, there is a shortage of Earth analogs whose atmospheres are in various phases of evolution. This is particularly true of the Phanerozoic Eon, the current and the latest of the four geologic eons preceded by the Proterozoic, Archaen, and Hadeon Eons. This period was particularly important for the evolution of terrestrial lifeforms because of the many crucial developments that took place throughout. This includes the Cambrian Explosion, characterized by the appearance of most modern animal species in the fossil record.

It also included the Devonian, where countless aquatic species adapted to dry land; the Triassic and Jurassic, which began and ended with major extinction events (the Permian–Triassic and the Triassic–Jurassic extinction event extinction events, respectively); the Cretaceous-Paleogene extinction event, the extinction of the dinosaurs; and the Neogene, where mammals and birds continued to evolve into modern forms, and the first modern humans appeared in the geological record. To predict what the atmosphere of this Eon would look like, said Kaltenegger, they created a model that combined established models with new atmospheric simulations:

"Our models simulated the transmission spectra generated by a planet with an atmosphere crossing our line of sight to its star, a transit. The planet's atmosphere absorbs some of the colors of the starlight but lets others filter through, creating a 'light fingerprint' that scientists use to determine the atmosphere's composition and whether there are signs of life in that atmosphere. Using estimates from two established climate models (called GEOCARB and COPSE), Rebecca Payne simulated Earth's atmospheric composition and resulting transmission spectra over five 100-million-year increments of the Phanerozoic, the epoch when the biosphere diversified and forests became widespread, changing the mix of oxygen and other gases in the air."

Key to their simulations was the oxygen content of the atmosphere, which rose from about 10% at the beginning of the Phanerozoic (the Cambrian period) to 35% by the end (the Neogene). The resulting higher oxygen levels, they state, were arguably a prerequisite for the evolution of complex life—including the dinosaurs, mammals, and hominids (eventually leading to modern humans). Regardless, the "light fingerprint" their simulation produced would stand out even more than that of modern-day Earth because of the higher oxygen content.

"Analyzing the most recent 540 million years of Earth's evolution, the Phanerozoic Eon, we found that chemical signatures of life in the atmosphere of an Earth-like exoplanet are more pronounced than for modern Earth," said Kaltenegger. "During the Phanerozoic—that includes the time of the dinosaurs (245-66 Mio years ago), two key biosignature pairs—oxygen and methane, and ozone and methane—appeared stronger about 300 million years ago, when oxygen levels were significantly higher."

This research is bolstered by another recent study led by a team from Dartmouth College (on which Kaltenegger was a co-author). In their paper, which was accepted for publication in the *Monthly Notices of the Royal Astronomical Society* and is available on the *arXiv* preprint server ("An Information Theory Approach to Identifying Signs of Life on Transiting Planets"), the team described how they simulated a range of transmission spectra to create an algorithm for identifying potential biosignatures on Earth-analogs. They tested this algorithm on three epochs of atmospheric evolution for Earth-like planets orbiting a range of host stars.

The resulting diagnostic tool, they said, can be applied to future observations to constrain planetary habitability. This research and the model created by Payne and Kaltenegger could have drastic implications for astrobiology by providing a template for finding planets in various stages of habitability.

As Kaltenegger summarized, "So for identifying potentially habitable worlds, there was a time when this fingerprint of life was even more pronounced than now—and it was during the reign of the dinosaurs. Thus, even though finding life in the cosmos is incredibly hard, it just might have gotten a little bit easier than we thought. Jurrasic worlds—with their large, complex life—might just give us the chance to find it a tiny bit easier. And who knows, maybe we get lucky, and there are other dinosaurs waiting to be found."

**More information:** R C Payne et al, Oxygen Bounty for Earth-like

exoplanets: Spectra of Earth through the Phanerozoic, *Monthly Notices of the Royal Astronomical Society: Letters* (2023). DOI: 10.1093/mnrasl/slad147

Sara Vannah et al, An Information Theory Approach to Identifying Signs of Life on Transiting Planets, *arXiv* (2023). DOI: 10.48550/arxiv.2310.09472

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