Metal-poor stars are more life-friendly, suggests study

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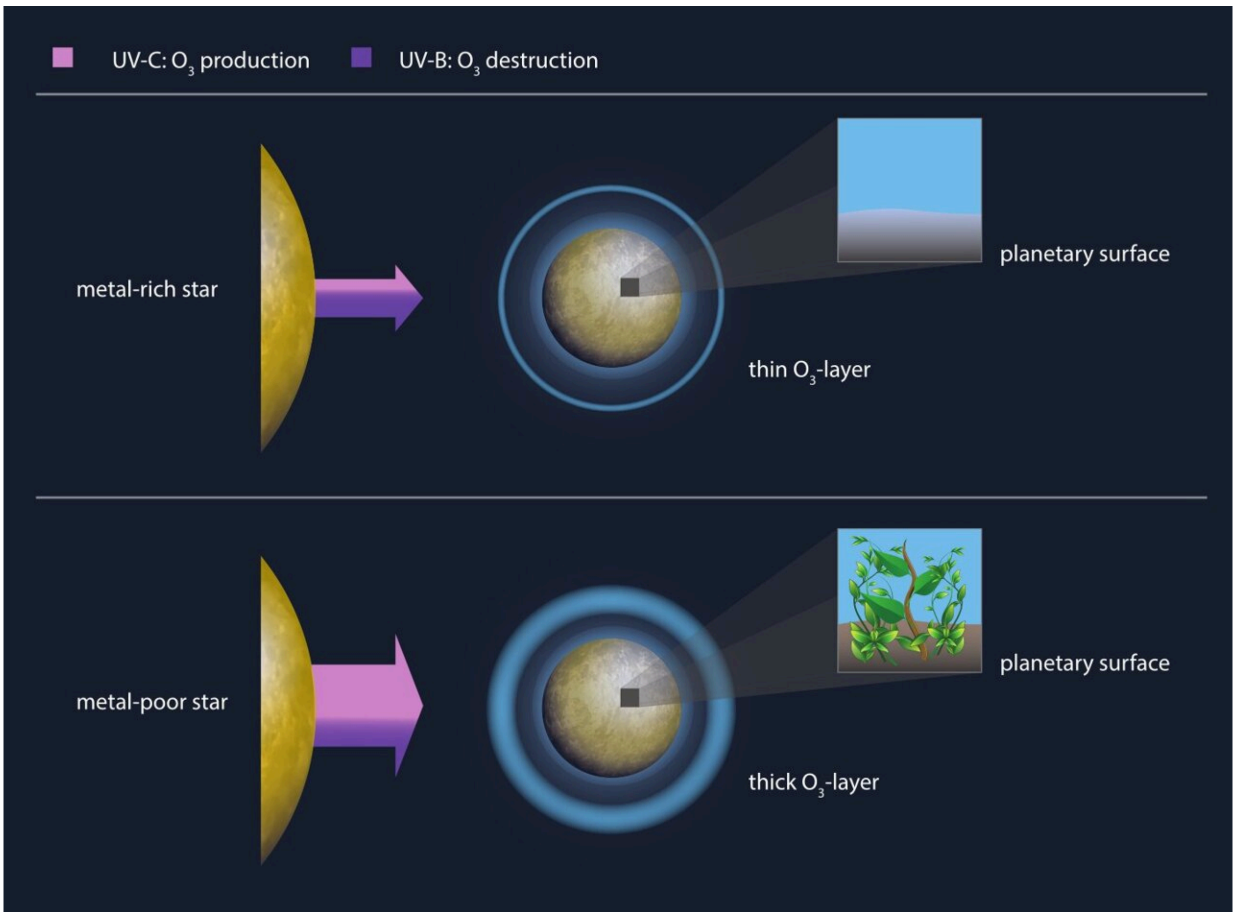

While metal-poor stars emit more UV radiation overall than metal-rich ones, for metal-poor stars the ratio of ozone-generating UV-C radiation to ozone-destroying UV-B radiation allows for the formation of a thicker protective ozone-layer around the orbiting planets. Therefore, the planets belonging to metal-poor stars provide more favorable conditions for the emergence of complex life. Credit: MPS/hormesdesign.de

Stars that contain comparatively large amounts of heavy elements provide less favorable conditions for the emergence of complex life than metal-poor stars, as scientists from the Max Planck Institutes for Solar System Research and for Chemistry as well as from the University of Göttingen have now found.

The team showed how the metallicity of a star is connected to the ability of its planets to surround themselves with a protective ozone layer. Crucial to this is the intensity of the ultraviolet light that the star emits into space, in different wavelength ranges. The study provides scientists searching the sky with space telescopes for habitable star systems with important clues as to where this endeavor could be particularly promising.

It also suggests a startling conclusion: as the universe ages, it becomes increasingly unfriendly to the emergence of complex life on new planets.

In the search for habitable or even inhabited planets orbiting distant stars, researchers have in the past years increasingly focused on the gas envelopes of these worlds. Do observational data show evidence of an atmosphere? Does it perhaps even contain gases such as oxygen or methane, which on Earth are produced almost exclusively as metabolic products of lifeforms?

In the next years, such observations will be pushed to new limits: Nasa's James Webb Telescope will make it possible to not only characterize the atmospheres of large gas giants like Super-Neptunes, but also to analyze for the first time the much fainter spectrographic signals from rocky planet atmospheres.

With the help of numerical simulations, the current study, which was published in *Nature Communications* today, now turns to the ozone content of exoplanet atmospheres. As on Earth, this compound of three oxygen atoms can protect the planet's surface (and life forms residing on it) from cell-damaging ultraviolet (UV) radiation.

A protective layer of ozone is thus an important prerequisite for the emergence of complex life. "We wanted to understand what properties a star must have in order for its planets to form a protective ozone layer," Anna Shapiro, scientist at the Max Planck Institute for Solar System Research and first author of the current study, explains the basic idea.

As often in science, this idea was triggered by an earlier finding. Three years ago, researchers led by the Max Planck Institute for Solar System Research had compared the sun's brightness variations with those of hundreds of sun-like stars. The result: the intensity of the visible light from many of these stars fluctuates much more strongly than in the case of the sun. "We saw huge peaks in intensity," says Alexander Shapiro, who was involved in both the analyses from three years ago and the current study.

"It is therefore quite possible, that the sun, too, is capable of such spikes in intensity. In that case, also the intensity of the ultraviolet light would increase dramatically," he adds. "So naturally we wondered, what this would mean for life on Earth and what the situation is like in other star systems," says Sami Solanki, director at the Max Planck Institute for Solar System Research and co-author of both studies.

Dual role of UV radiation

At the surface of about half of all stars around which exoplanets have been shown to orbit, temperatures range from about 5,000 to about 6,000 degrees Celsius. In their calculations, the researchers therefore turned to this subgroup. With a surface temperature of approximately

5500 degrees Celsius, the sun is also one of them. "In the Earth's atmospheric chemistry, ultraviolet radiation from the sun plays a dual role," explains Anna Shapiro, whose past research interest focused on the influence of solar radiation on Earth's atmosphere.

In reactions with individual oxygen atoms and oxygen molecules, ozone can both be created and destroyed. While long-wave UV-B radiation destroys ozone, short-wave UV-C radiation helps create protective ozone in the middle atmosphere. "It was therefore reasonable to assume that ultraviolet light may have a similarly complex influence on exoplanet atmospheres as well," the astronomer adds. The precise wavelengths are crucial.

The researchers therefore calculated exactly which wavelengths make up the ultraviolet light emitted by the stars. For the first time, they also considered the influence of metallicity. This property describes the ratio of hydrogen to heavier elements (simplistically and somewhat misleadingly called "metals" by astrophysicists) in the building material of the star. In the case of the sun, there are more than 31000 hydrogen atoms for every iron atom. The study also considered stars with lower and higher iron content.

Simulated interactions of UV radiation with gases

In a second step, the team investigated how the calculated UV radiation would affect the atmospheres of planets orbiting at a life-friendly distance around these stars. Life-friendly distances are those that allow moderate temperatures—neither too hot nor too cold for liquid water—at the planet's surface. For such worlds, the team simulated on the computer exactly which processes the parent star's characteristic UV light sets in motion in the planet's atmosphere.

To compute the composition of planetary atmospheres the researchers used a chemistry-climate model that simulates the processes that control oxygen, ozone, and many other gases, and their interactions with ultraviolet light from stars, at very high spectral resolution. This model allowed the investigation of a wide variety of conditions on exoplanets and comparison with the history of the Earth's atmosphere in the last half billion years.

During this period the high atmospheric oxygen content and the ozone layer were established that allowed the evolution of life on land on our planet. "It is feasible that the history of the Earth and its atmosphere holds clues about the evolution of life that may also apply to exoplanets," says Jos Lelieveld, Managing Director of the Max Planck Institute for Chemistry, who was involved in the study.

Promising candidates

The results of the simulations were surprising for the scientists. Overall, metal-poor stars emit more UV radiation than their metal-rich counterparts. But the ratio of ozone-generating UV-C radiation to ozone-destroying UV-B radiation also depends critically on metallicity: in metal-poor stars, UV-C radiation predominates, allowing a dense ozone layer to form. For metal-rich stars, with their predominant UV-B radiation, this protective envelope is much more sparse.

"Contrary to expectations, metal-poor stars should thus provide more favorable conditions for the emergence of life," Anna Shapiro concludes.This finding could be helpful for future space missions such as Esa's Plato mission, which will comb through a vast array of stars for signs of habitable exoplanets. With 26 telescopes on board, the eponymous probe will be launched into space in 2026 and will focus its attention primarily on Earth-like planets orbiting sun-like stars at life-friendly distances.

The mission's data center is currently being set up at the Max Planck Institute for Solar System Research. "Our current study gives us valuable clues as to which stars Plato should pay special attention to," says Laurent Gizon, Managing Director at the Institute and co-author of the current study.

Paradoxical conclusion

Moreover, the study yields an almost paradoxical conclusion: as the universe ages, it is likely to become increasingly hostile to life. Metals and other heavy elements are formed inside stars at the end of their several-billion-year lifetimes and—depending on the mass of the star—are released into space as stellar wind or in a supernova explosion: the building material for the next generation of stars.

"Each newly forming star therefore has more metal-rich building material available than its predecessors. Stars in the universe are becoming more metal-rich with each generation," says Anna Shapiro. According to the new study, the probability that star systems will produce life thus also decreases as the universe ages. However, the search for life is not hopeless. After all, many host stars of exoplanets have a similar age as the sun. And this star is indeed known to harbor complex and interesting lifeforms on at least one of its planets.

More information: Anna V. Shapiro, Metal-rich stars are less suitable for the evolution of life on their planets, *Nature Communications* (2023). DOI: 10.1038/s41467-023-37195-4.
www.nature.com/articles/s41467-023-37195-4

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