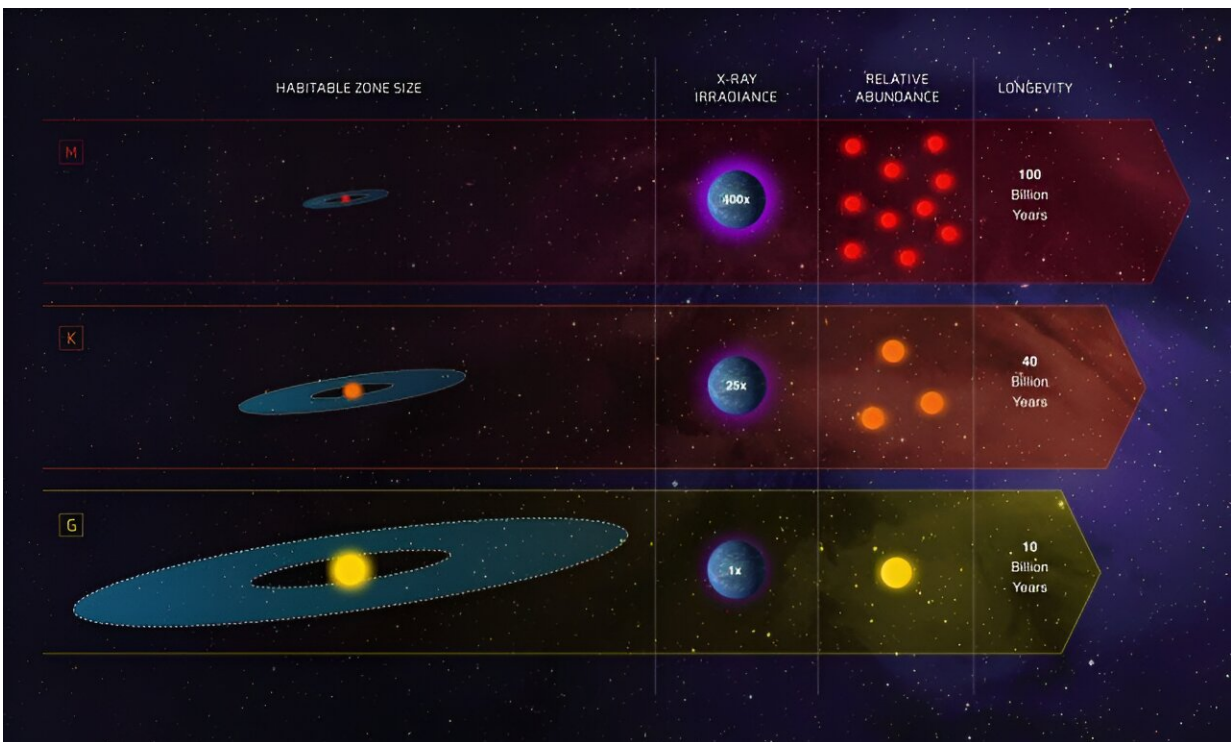


Reconnaissance of potentially habitable worlds with Webb

June 5 2024, by Thaddeus Cesari



This infographic compares the characteristics of three classes of stars in our galaxy: Sunlike stars are classified as G stars; stars less massive and cooler than our Sun are K dwarfs; and even fainter and cooler stars are the reddish M dwarfs. The size of the habitable zone is different for each class of star. In our solar system, the habitable zone begins just beyond the orbit of Venus and almost encompasses Mars. Credit: NASA, ESA and Z. Levy (STScI)

Exoplanets are common in our galaxy, and some even orbit in the so-called habitable zone of their star. NASA's James Webb Space Telescope has been busy observing a few of these small, potentially habitable planets, and astronomers are now hard at work analyzing Webb data. We invite Drs. Knicole Colón and Christopher Stark, two Webb project scientists at NASA's Goddard Space Flight Center, to tell us more about the challenges in studying these other worlds:

"A potentially habitable planet is often defined as a planet similar in size to Earth that orbits in the 'habitable zone' of its star, a location where the planet could have a temperature where liquid water could exist on its surface. We currently know of around 30 planets that may be small, rocky planets like Earth and that orbit in the habitable zone. However, there is no guarantee that a planet that orbits in the [habitable zone](#) actually is habitable (it could support life), let alone inhabited (it currently supports life). At the time of writing, there is only one known habitable and inhabited planet—Earth.

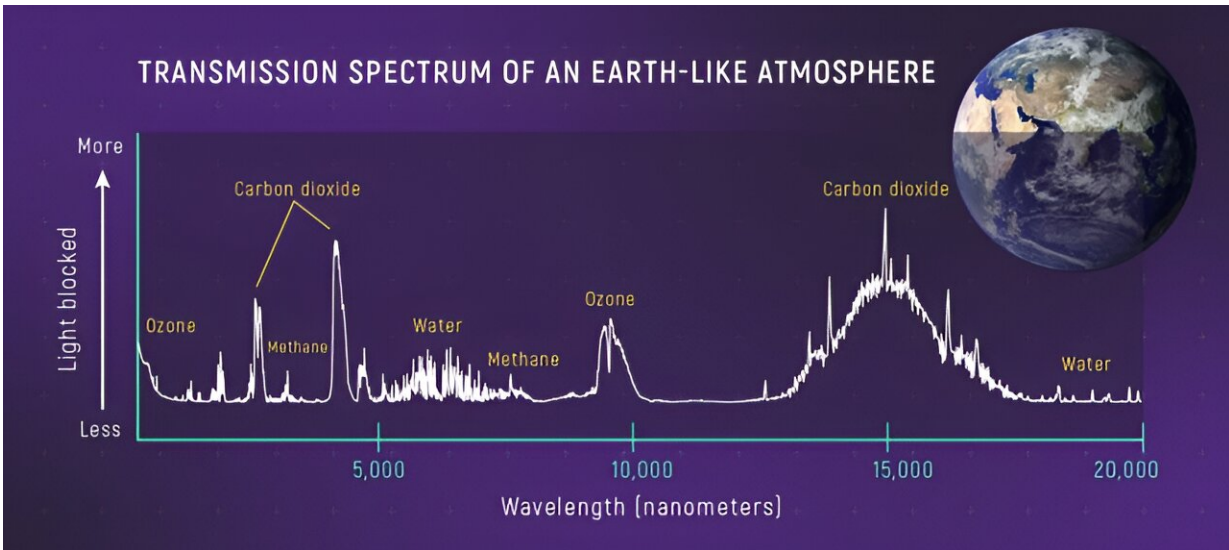
"The potentially habitable worlds Webb is observing are all transiting exoplanets, meaning their orbits are nearly edge-on so that they pass in front of their host stars. Webb takes advantage of this orientation to perform transmission spectroscopy when the planet passes in front of its star. This orientation allows us to examine the starlight filtered through the atmospheres of planets to learn about their chemical compositions.

"However, the amount of starlight blocked by the thin atmosphere of a small rocky planet is tiny, typically much smaller than 0.02%. Simply detecting an atmosphere around these small worlds is very challenging. Identifying the presence of water vapor, which may bolster the possibility of habitability, is even harder. Searching for biosignatures (biologically produced gases) is extraordinarily difficult, but also an exciting endeavor.

"There are currently only a handful of small, potentially habitable worlds that are considered accessible to atmospheric characterization with Webb, which includes the planets LHS 1140 b and TRAPPIST-1 e.

"Some recent theoretical work exploring the detectability of gaseous molecules in the atmosphere of the super-Earth-size planet LHS 1140 b highlights several challenges in searching for biosignatures. The work notes approximately 10–50 transits of the planet around its host star, equivalent to 40–200 hours of observing time with Webb, would be needed to attempt a detection of potential biosignatures, such as ammonia, phosphine, chloromethane, and nitrous oxide, in the best-case scenario of a clear, cloud-free atmosphere.

"Given that Webb cannot view the LHS 1140 system year-round because of the system's location on the sky, it would take multiple years if not close to a decade to collect 50 transit observations of LHS 1140 b. Searching for biosignatures may require even more than 50 transit observations if the planet atmosphere is cloudy. Most small exoplanets are known to have clouds or hazes that dampen or obscure the signal being searched for. The atmospheric signals of these biosignature gases also tend to overlap with other expected atmospheric signals (e.g. due to gaseous methane or carbon dioxide), so distinguishing between the various signals is another challenge.



A simulated transmission spectrum of an Earth-like atmosphere shows wavelengths of sunlight that molecules like ozone (O_3), water (H_2O), carbon dioxide (CO_2), and methane (CH_4) absorb. (Notice that on this graph, the y-axis shows amount of light blocked by the Earth-like planet's atmosphere rather than brightness of sunlight that travels through the atmosphere: Brightness decreases from bottom to top.) Model transmission spectrum from Lisa Kaltenegger and Zifan Lin 2021 ApJL 909. Credit: NASA, ESA, Leah Hustak (STScI)

"A potential avenue in the search for biosignatures is in the study of Hycean planets, which are a theoretical class of super-Earth-size planets with a relatively thin hydrogen-rich atmosphere and a substantial liquid water ocean. The super-Earth K2-18 b is a candidate for a potentially habitable Hycean planet based on current data from Webb and other observatories.

"Recently published work used NIRSpec and NIRISS to detect methane and carbon dioxide in the atmosphere of K2-18 b, but not water. This means the suggestion that K2-18 b is a Hycean world with a liquid water ocean remains based on theoretical models, with no direct observational

evidence yet. The authors of the work also hinted at the possible presence of the potential biosignature dimethyl sulfide in the atmosphere of K2-18 b, but the potential dimethyl sulfide signal is too weak for a conclusive detection in the current data.

"The concept and study of the class of Hycean planets is very new, such that alternative interpretations to the [liquid water](#) ocean scenario (and therefore to the potential for a habitable environment) are still being explored. Upcoming Webb observations with the NIRSpec and MIRI instruments should shed further light on the nature of the potential Hycean planet K2-18 b and on the possible presence of dimethyl sulfide in its atmosphere.

"One other confounding factor that makes Webb's study of small, potentially habitable worlds challenging is that the host stars can exhibit signs of water vapor, too. This was explored in recent Webb observations of the rocky exoplanet known as GJ 486 b. We therefore have the added challenge of determining whether water vapor detected by Webb is actually from a planet's [atmosphere](#) and not from its star.

"The detection of biosignatures in the atmospheres of small, potentially habitable transiting planets that orbit cool stars is an extremely challenging endeavor, typically requiring ideal conditions (e.g., cloud-free atmospheres) or assuming early Earth environments (i.e., different than modern Earth as we know it), the detection of signals significantly smaller than 200 parts per million, a well-behaved star without significant water vapor in star spots, and a significant amount of telescope time to reach sufficient signal-to-noise.

"It is also important to keep in mind that detection of a single biosignature by any means does not constitute discovery of life. Discovery of life on an exoplanet will likely require a large set of unambiguously detected biosignatures, data from multiple missions and

observatories, and extensive atmospheric modeling efforts, a process likely taking years.

"The power of Webb is that it has the sensitivity to detect and begin to characterize the atmospheres of a handful of the most promising potentially [habitable planets](#) orbiting cool stars. Webb particularly has the ability to detect a range of molecules important for life, like water vapor, methane, and [carbon dioxide](#). Our goal is to learn as much as we can about worlds that may be potentially habitable, even if we cannot definitively identify habitable signatures with Webb.

"Webb observations, combined with exoplanet studies by NASA's upcoming Nancy Grace Roman Space Telescope, will ultimately lay the foundation for the future Habitable Worlds Observatory, which will be NASA's first mission purpose-built to directly image and search for chemical traces caused by life on Earth-like planets around sun-like stars."

Provided by NASA

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