■ An artist's concept of the James Webb Space Telescope, its 6.4-metre wide segmented mirror protected from the Sun by a giant shield on the telescope's underside. Image: NASA.

Seeking life on super-earths

The James Webb Space Telescope, slated for launch in 2018, is a far more powerful telescope than Hubble but, **Michael Chorost** asks, will it be able to detect life on exoplanets?

Forget goldilocks worlds around Sun-like stars. Astronomers who will be operating the James Webb Space Telescope (JWST) reckon that its best shot for finding life will be on super-earths orbiting small, cool stars.

It's all about ratios, says Mark Clampin, the telescope's Project Scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland. Clampin explains that a large planet blocks more light than a small one and the smaller and dimmer the star, the more its light will change when a planet crosses in front of it. Life on a big planet orbiting a small star will be easier to 'see' than the reverse.

The word 'see' has to be used carefully. Even for a telescope the size of the JWST, direct imaging of exoplanetary geography is out of the question. Its resolution just isn't good enough. JWST won't see continents with verdant forests of green. It won't resolve clouds or expansive oceans. It certainly won't see the night-time spangles of alien cities.

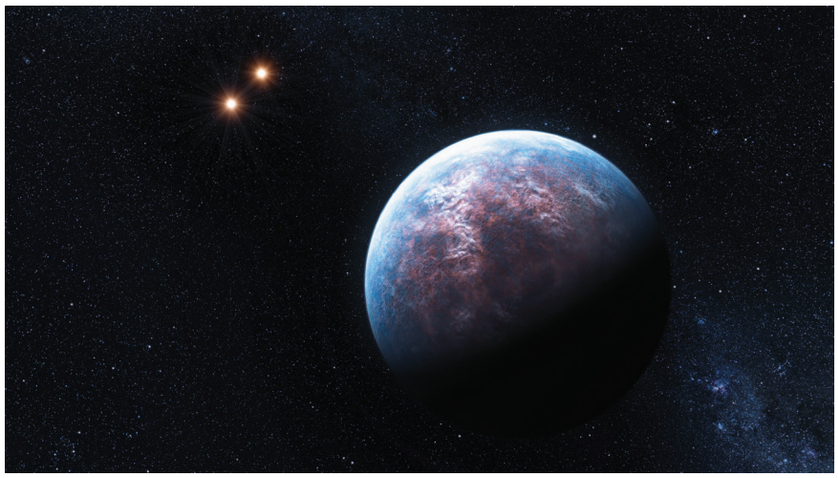
Instead the detection of life will depend on spectroscopy where a prism is used to split up a star's light into its component wavelengths. Elements and molecules in the star will absorb photons of specific wavelengths, leaving telltale patterns of dark lines that can be used to infer their presence.

JWST will use spectroscopy to survey planets for atmospheric gases such as water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), and ozone (O_3). Clampin is bullish on JWST's chances: "JWST is an ideal observatory for doing transit spectroscopy because it's got this massive 25 meter-square collecting area, which is way more than we've ever had before."

In transit spectroscopy, astronomers wait for a planet to cross in front of its Sun. That allows them to compare the star's light with and without the planet's atmosphere. The tiny elemental difference they see belongs to the atmosphere. Since stars are so much brighter and bigger than planets, the difference will be very small even in the best of circumstances. To have confidence in the results, many transits will have to be observed.

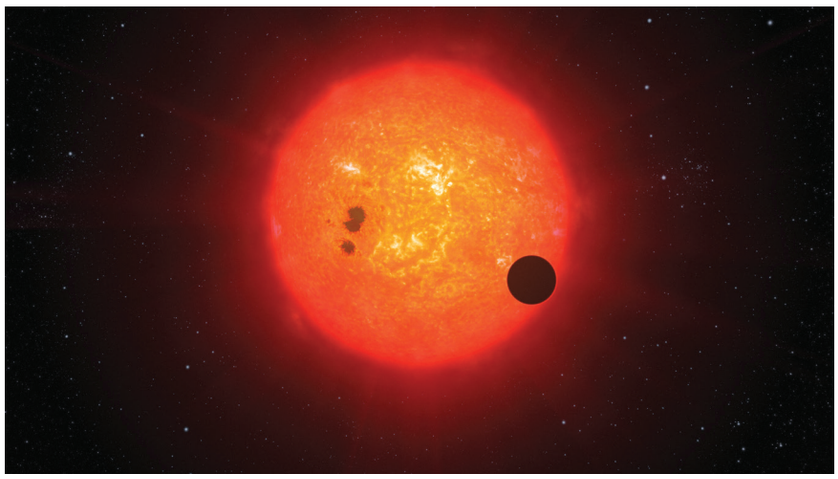
Red dwarfs

The advantage of small, cool stars is that their habitable zone is very close to them. A rocky planet inside the zone will have an orbit just a few days long, thus transiting very frequently. It'll take much less time to accumulate the needed data than for, say, Earth, which to alien telescopes would transit only once every 365 days. For example, the astronomers Sara Seager, Drake Deming and J A Valenti estimated that for an ocean planet orbiting a class M star every 29 days, it would take ten transits (totaling 28 hours of observing time) to get an acceptable signal-to-noise ratio for firm detection of water and carbon dioxide. With a transit every 29 days, one could accumulate ten transits in less than a year.



▲ **A potentially habitable planet GJ 667Cc orbits a red dwarf that is in orbit around two other stars, forming a triple star system. Image: ESO/L Calçada.**

▼ **The ratio of the sizes of small red dwarf stars and their planets, combined with the short orbits of planets in a red dwarf's Goldilocks zone, means potentially habitable worlds are easier to find transiting red dwarfs than stars like the Sun. Image: ESO/L Calçada.**



That's why astronomers are excited about examining super-earths orbiting class M stars, which are at the tail end of the traditional O-B-A-F-G-K-M stellar classification. Class M stars are mostly red dwarfs with less than half the mass of the Sun and luminosities between a tenth and one ten-thousandth of it. They are correspondingly cooler, with a surface temperature of less than 4,000 kelvin (3,726 degrees Celsius) compared to our Sun's surface temperature of 5,778 kelvin (5,504 degrees Celsius).

A number of potentially habitable exoplanets have already been discovered orbiting M-type stars. One of them is GJ 667Cc, 23.6 light-years away, with a year only 28 days long. Its host star is part of a triple system, orbiting around a double star, which is undoubtedly going to slow down the work of any local analogues of Copernicus and Kepler. GJ 667Cc's mass is 4.91 times Earth's and its radius is 1.86 times larger. That works out to a surface gravity of 1.42 times stronger than Earth's. A 120-pound (54 kilogram) woman would weigh 170 pounds (77 kilograms) on GJ 667Cc.

Apart from being disconcertingly heavy, our 170-pound woman might be reasonably comfortable on GJ 667Cc where the mean surface temperature is estimated to be 300 kelvin (27 degrees Celsius). This estimate is based on a number of assumptions, including the presence of a similar atmosphere-to-planet ratio as ours, a greenhouse effect caused by a one percent carbon dioxide concentration and an albedo (how much sunlight is reflected back into space) of 0.3. Obviously, these are just guesses at this stage.

Disequilibrium gases

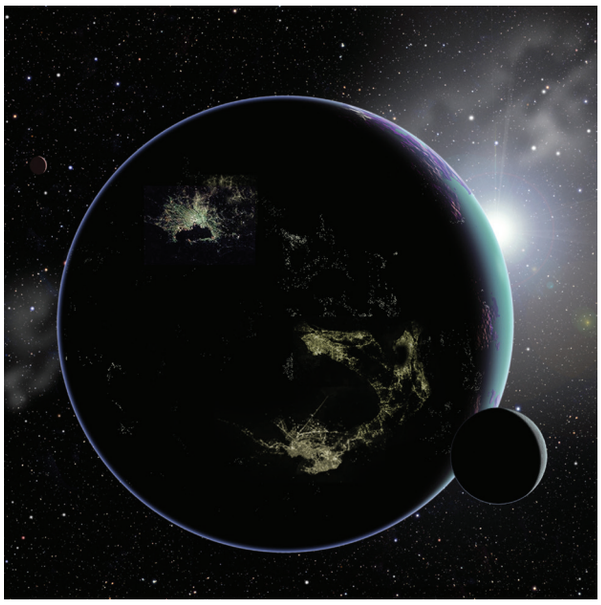
Detecting water, carbon dioxide, methane or ozone on a super-earth would automatically flag it as a potential candidate for life. But, as Goddard astrophysicist and exoplanet specialist Aki Roberge explains, astronomers won't so much be looking for individual gases as they will be for 'disequilibrium atmospheres', in which there are combinations of gases that couldn't exist unless some active process was replenishing one or more of them. That active process would have to be one that couldn't be explained in terms of pure chemistry. "In some ways you can you think of it as forcing the atmosphere to an unnatural state," Roberge says. Then she rethinks her choice of words: "Actually, I hate to use the word unnatural." An active, forcing process would be life – a quintessentially natural thing.

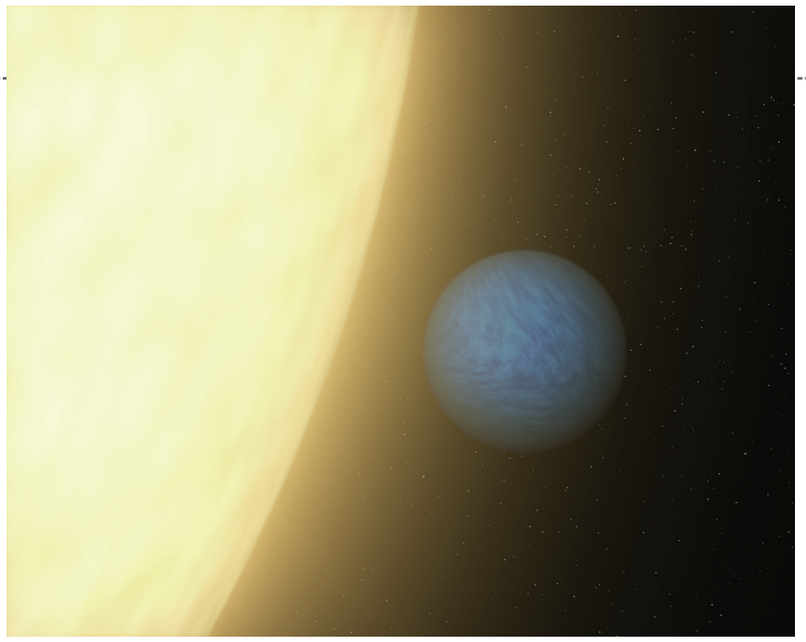
Oxygen offers the simplest example of what Roberge is talking about. An atmosphere with significant amounts of molecular oxygen is by definition a disequilibrium atmosphere. Free molecular oxygen quickly disappears unless something is replenishing it. Goddard's Michelle Thaller explains that oxygen is so eager to combine with other molecules that it's hard to keep it in an atmosphere. "Oxygen wants to combine with things to make stable molecules. It combines with rocks. It combines with soil and minerals and iron. Volcanoes consume it in the process of combustion. So if there's a lot of oxygen in an atmosphere, that would be very interesting." That's because the main thing we know of that produces lots of free oxygen is photosynthesis.

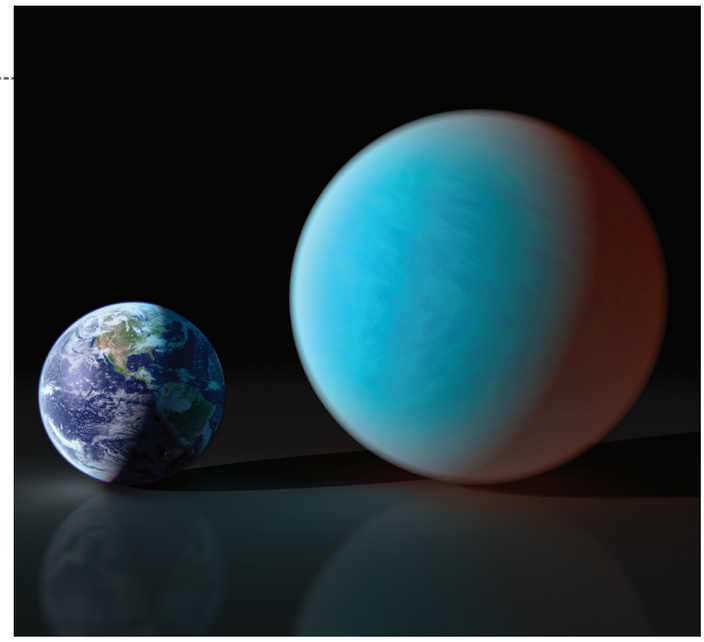
This doesn't mean that any detection of oxygen is automatically a sign of life. Avi Mandell, an exoplanet scientist at Goddard, warns that "Even oxygen and ozone, which seem like obvious smoking guns, have been shown to form abiotically under certain atmospheric conditions." The lesson, Mandell says, is that every potential biomarker has to be evaluated in the context of the planet, using data on size, temperature, composition, and other things. Context is always needed to assess whether a given gas is really a biomarker of life.

Nonetheless, abundant molecular oxygen would be, as Thaller says, "very interesting." However, there's a wrinkle that has to be taken into account. JWST is actually not going to be able to detect molecular oxygen because it doesn't have strong absorption peaks in the infrared range at which JWST will operate. But oxygen's variant form, ozone (O_3), does have strong infrared peaks. JWST will be able to see it.

▼ **The JWST won't be able to photograph continents or city lights on habitable planets, but it will be able to detect the gaseous signatures of life in a planet's atmosphere. Image: David A Aguilar (CfA).**







▲ **Top left: By comparing the light of a planet and star together, with the light of just the star when the planet is off-transit, it's possible to isolate the planet's light. Image: NASA/JPL–Caltech/MIT.**

Ozone is effectively a proxy for molecular oxygen. It's formed when ultraviolet light or lightning hits oxygen molecules, thus it can't exist unless oxygen does. In short, if you find ozone, you've found oxygen.

Alternatives to oxygen

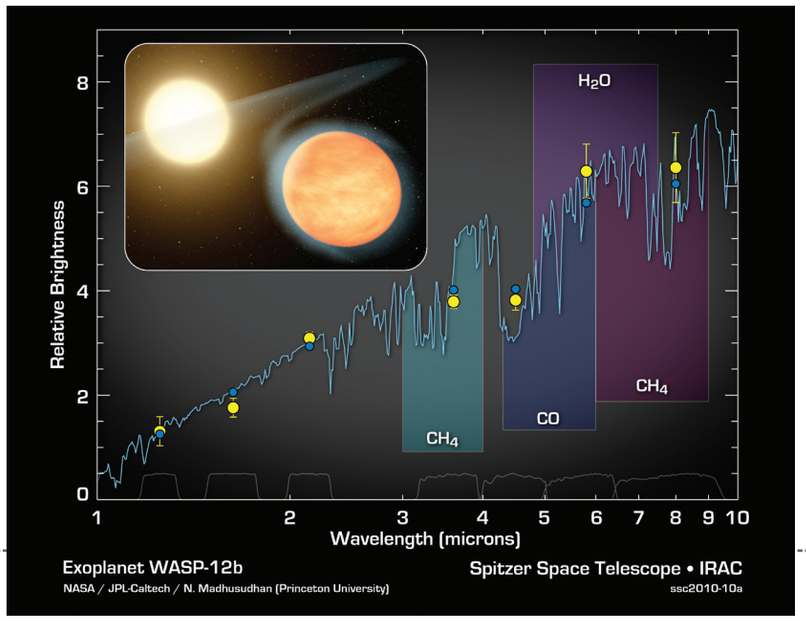
A life-bearing planet doesn't necessarily have to be rich in oxygen. For billions of years, Earth was inhabited by anaerobic life to which oxygen would have been a poison. Two billion years ago, a visitor to Earth would have seen almost no oxygen and continents devoid of multicellular life. Life would have existed mostly in the seas as teeming bacteria. Free oxygen appeared in Earth's atmosphere about 1.7 billion years ago and reached its present abundance of about 21 percent only about 350 to 400 million years ago. (Since then, it has fluctuated between 15 and 35 percent.) Robert Hazen, an exobiologist at the Carnegie Institute's Geophysical Lab in Washington DC, comments that "Most of us think of an 'Earth-like' planet as one with a rich green terrestrial biosphere, not totally barren continents. In that sense, Earth has only looked like what it does today since about 400 million years ago – or eight percent of its history."

So how might JWST find life on a planet that, like ancient Earth, is life-bearing but devoid of oxygen? Again, the key is to find a gas, or combination of gases, that exists in disequilibrium. A good example is an atmosphere that has both carbon dioxide and methane. Avi Mandell explains that the oxygen atom in carbon dioxide will rip hydrogen atoms away from methane, destroying it in a process called oxidisation. Therefore, if an atmosphere has carbon dioxide but also large quantities of methane, something has to be replenishing the methane.

"IF JWST CAN FIND LIFE – ANY KIND OF LIFE – ITS PLACE IN HISTORY WILL BE ASSURED"

Suppose JWST discovers a planet with an atmosphere that's mostly nitrogen, carbon dioxide and water vapour, but also has significant amounts of methane. Earth's anaerobic atmosphere looked a lot like this. After due consideration of what we can learn about the planet's age, size, composition, temperature, and so forth, we might become fairly sure we've discovered a life-bearing planet that looks the way Earth did millions or billions of years ago.

▼ **An example of an exoplanet spectra detected through transit spectroscopy. In this case, the planet WASP-12b is a hot jupiter that orbits close to its Sun-like star and displays absorption lines of carbon monoxide (CO) and methane but not much water vapour. In this case the methane is not produced by life as the planet is a gas giant that is too hot. Rather, the planet is the most carbon-rich world discovered thus far. Image: NASA/JPL–Caltech/N Madhusudhan (Princeton University).**



The chilled out planet-finder

JWST has a number of design features that make it an especially good instrument for detecting water vapour, carbon dioxide, methane and ozone. The main one is that it observes in infrared wavelengths and its 18 hexagonal mirrors are made of beryllium coated with gold, which optimises reflectance of infrared light. To eliminate thermal interference from its own components the telescope will operate at cryogenic temperatures, down to –220 degrees Celsius. To keep it that cold, a giant, five-layered sunshade – nearly the dimensions of a Boeing 737 – will shield it from the Sun. Furthermore, it'll be positioned 1.5 million kilometres (930,000 miles) from

◀ **Super-earths (as on the right in this image) are bigger but not necessarily better than our planet. With masses up to about ten times the mass of Earth, super-earths have higher surface gravity but their sheer mass may render plate tectonics, which drive the carbon cycle that helps regulates climate, inactive. Nevertheless, these planets are the best choice for study by the JWST. Image: NASA/JPL–Caltech/R Hurt (SSC).**

Earth, nearly four times further than the Moon. That will minimise heat interference from Earth itself.

The advantage of infrared is that the spectral lines for methane, water vapour, ozone and carbon dioxide are very visible in that range. JWST is optimised for seeing light at wavelengths between 0.6 microns and 29 microns (by contrast, visible light is between 0.3 and one micron). Methane absorbs light at three and seven microns; water vapour absorbs at six microns; ozone at nine microns; and carbon dioxide at 15 microns. "Luckily, methane, water, ozone, and carbon dioxide all have whopping big features in the mid-infrared," Thaller says.

Thus the case seems pretty good that JWST will be able to find evidence of life on exoplanets if the circumstances line up right. It has to observe large rocky planets rapidly orbiting small, cool, relatively nearby stars and the planets must have an orbital inclination such that their transits are visible from Earth.

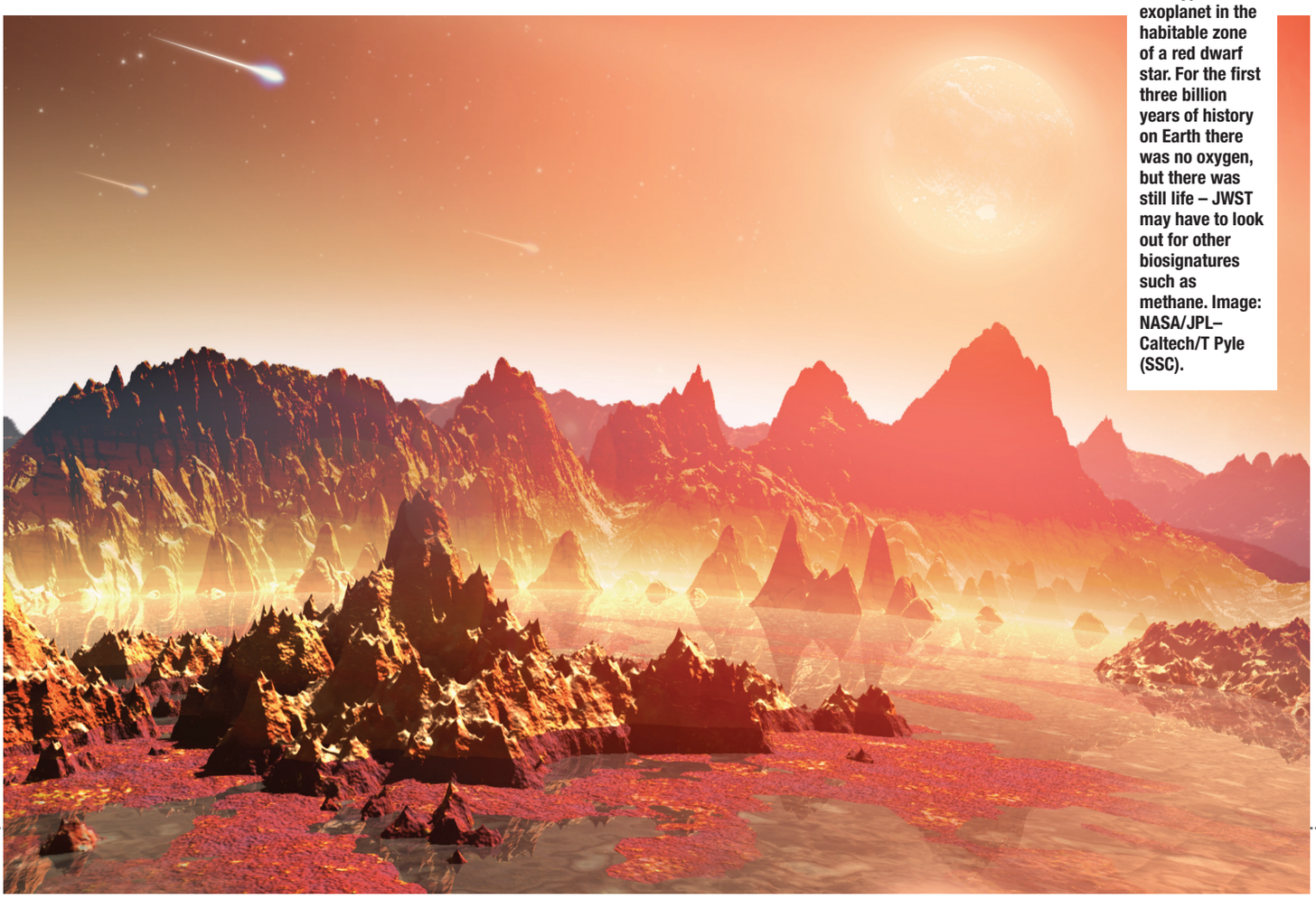
How likely is this, statistically? Apparently, the answer is 'very'. In March 2012, the European Southern Observatory (ESO) estimated the Galaxy's number of rocky planets in the habitable zones of faint red stars, using data from the High Accuracy Radial Velocity Planet Searcher (HARPS) on ESO's 3.6-metre telescope (see *Focus*, pages 60–70). The answer: tens of billions. HARPS surveyed 102 nearby red dwarf stars over the course of six years and found nine super-earths among them. Extrapolating from that, the team thinks there are about one hundred super-earth planets less than about 30 light years away from us. Xavier Bonfils, the team's leader, said in a press release, "Our new observations with HARPS mean that about 40 percent of all red dwarf stars have a super-earth orbiting in the habitable zone where liquid water can exist on the surface of the planet."

So JWST should have many exoplanetary candidates to study upon its commission in 2018. GJ 667Cc, for one. What JWST almost certainly won't be able to find is a true Earth twin – an Earth-sized life-bearing planet orbiting a G-type star like the Sun about once a year. Says Aki Roberge, "Pretty much all the simulations that I've seen say that is really hard for JWST imaging. Maybe impossible."

That would be a job for an even more advanced telescope. NASA has proposed one, the Terrestrial Planet Finder (TPF), but its funding was cancelled in 2007. Roberge thinks that of the two telescopes, JWST was comparatively easier to build. "JWST is hard, but we basically knew what we wanted and how to do it. With TPF there's some big technological problems that have not yet been solved."

At this point, just finding life – any kind of life – is more important than finding an exact Earth analogue. For now, a super-earth orbiting a small red dwarf in a month will do. If its life proves to be bacterial, even anaerobic, that will do too. If JWST can find that, its place in history will be assured.

Michael Chorost is a science writer based in Washington DC and author of two books, including World Wide Mind. *Visit his website at www.michaelchorost.com.*



▼ **The surface of a hypothetical exoplanet in the habitable zone of a red dwarf star. For the first three billion years of history on Earth there was no oxygen, but there was still life – JWST may have to look out for other biosignatures such as methane. Image: NASA/JPL–Caltech/T Pyle (SSC).**