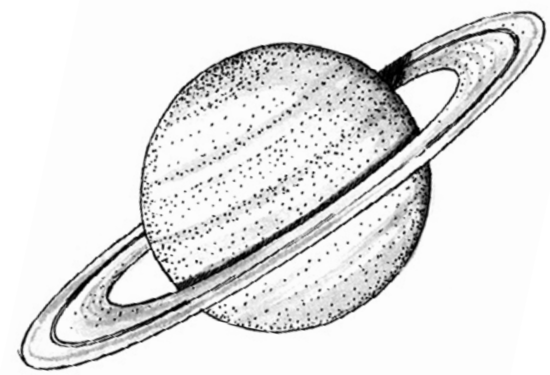
Research Reading: Chemical Fingerprints

Where did we come from? Are we alone in the galaxy? These questions have captured people's imaginations for centuries. Scientists worldwide are continually seeking new ways to find answers to these questions.

But how do scientists look for life on planets too far away to study by spacecraft?

One way is to explore the light given off by faraway planets. Light can reveal clues about a planet's properties. However, a planet's visible light is dim and easily lost in the glare of its parent star. But scientists are working on technologies that will allow them to detect such planets. NASA's Terrestrial Planet Finder (TPF) missions, being planned for launch in the next 10 to 15 years, will include two spacecraft designed to examine the light being emitted from planets. One spacecraft will have an instrument that will block a star's light so that the orbiting planets will be visible. The second spacecraft will work by observing the infrared radiation from the planet. This has two advantages: The first is that there is less glare from the star at infrared wavelengths. The second is that most molecules that would be likely indicators of life emit or absorb radiation in the infrared portion of the electromagnetic spectrum. A similar project is being designed for launch in 2014 by the European Space Agency.

Scientists hope to use spectral analysis to decode the chemicals found in a planet's atmosphere. Spectral analysis is a method that has long been applied to deciphering the chemical composition of stars. If sunlight is passed through a prism, a "spectrum" of the light—a rainbow of colors—is produced. The spectrum from starlight reveals dark regions at certain wavelengths that are associated with chemical elements and compounds present in a star. Each element and compound produces a unique pattern of spectral features that scientists can use to identify a star's composition.



The same technique can be used to identify gases present in a planet's atmosphere. The surface of a planet emits energy in the infrared portion of the electromagnetic spectrum (infrared light cannot be seen with human eyes). The gases in a planet's atmosphere absorb some of these wavelengths. Just which wavelengths get absorbed (and end up missing from the spectrum) depends on which atoms and molecules are present in the planet's atmosphere.

Because every element and all compounds produce unique patterns, scientists can identify what chemicals exist in a planet's atmosphere by looking at the patterns that are produced.

The TPF will be looking for evidence of simple chemicals—oxygen, ozone, carbon dioxide, methane, and water vapor. These chemicals could be produced by life on the surface of a planet, and (in certain quantities) can be absorbed by the atmosphere and detected by spectral analysis. Earth's present atmosphere contains molecules of nitrogen (N_2), oxygen (O_2), and trace gases that include argon (Ar), methane (CH_4) and carbon dioxide (CO_2). Water vapor (H_2O) occurs in varying amounts. In addition, Earth is shielded from ultraviolet radiation by a layer of ozone (O_3), which only forms from oxygen atoms.

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Analyzing an early Earth-like planet that has not yet developed an oxygen-rich atmosphere is more difficult because scientists do not know much about what early life on Earth was like, or what gases were released by early life forms. However, scientists know that certain types of bacteria are very ancient. These bacteria obtain energy by converting carbon dioxide and molecular hydrogen (H_2) to methane and water. Both carbon dioxide and molecular hydrogen are thought to have been relatively abundant early in Earth's history. Early life probably evolved to take advantage of this. Therefore, methane would probably be an important indicator of life on an early Earth-like planet, just as it is today. (Oxygen was likely a toxic gas to early life.) Nitrous oxide, another byproduct of life, could also serve as an indicator of possible life on another planet.

Small quantities of methane and nitrous oxide might be difficult to detect with the first TPF instruments. Eventually, however, scientists hope that later instruments will be better equipped to make such measurements. This would be the best way to determine if the potential for life exists on planets around other stars.

Although certain chemicals may give clues to whether a planet is habitable, they don't reveal the characteristics that life might take on or how complex it could be. In addition, the chemical signatures scientists are searching for are based on the understanding of what life needs to survive on Earth. While the chemistry throughout the universe is the same, no one knows all the ways it could form life. Astrobiologists are considering what forms life may take while astronomers continue to identify extrasolar planets that may be candidates for life.

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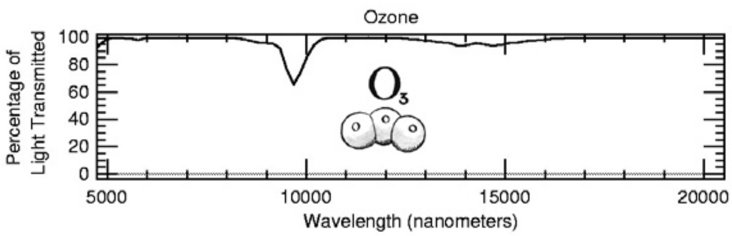
The Search

The TPF will search directly or indirectly for the following chemicals.



Oxygen (O_2) and Ozone (O_3)

Oxygen is important to life on Earth. It is mainly produced as a byproduct of photosynthesis by green plants and certain other organisms.

Without life, oxygen would be rare on rocky planets. A small amount of oxygen can be created when ultraviolet radiation splits water vapor into hydrogen (H_2) and oxygen (O). The hydrogen is very light and can escape into space while the oxygen is left behind. But the oxygen would combine with rocks and minerals on the planet's surface in an "oxidizing" reaction to produce various compounds, such as rust. Gases released by volcanoes can also react with oxygen and remove it from the atmosphere. Geological processes usually work against the accumulation of oxygen.

Therefore, a planet with an oxygen-rich atmosphere is unusual without photosynthetic life to constantly replenish the supply. As Carl Sagan noted in a 1997 *Scientific American* article, "the great concentration of oxygen (20 percent) in Earth's dense atmosphere is very hard to explain by [any means other than life.]" The same would likely be true of planets orbiting other stars.

However, scientists do know of non-biological processes that can result in an oxygen-rich atmosphere. For example, ultraviolet light from the sun can break apart carbon dioxide molecules to form carbon monoxide (CO) and oxygen. Or, as stated previously, ultraviolet sunlight (or starlight) can break apart water molecules into hydrogen and oxygen.

So, the presence of oxygen alone—while exciting and significant—can't be taken as an unambiguous indicator of life. Furthermore, oxygen doesn't produce spectral lines that can be easily observed in the infrared part of the spectrum. However, another form of oxygen, ozone, made of three atoms of oxygen, does produce spectral features in the infrared.

The ozone layer, which is located in Earth's stratosphere, is important to life because it protects Earth from the Sun's harmful ultraviolet radiation. Ultraviolet radiation can cause skin cancer and cataracts in animals and can stunt the growth of many plants.

The presence of ozone in a planet's atmosphere is a reliable indication that normal oxygen is also present. Without oxygen, ozone could not exist. Ozone is not expected to be present in significant amounts unless oxygen is also present.

The detection of ozone along with other gases, such as nitrous oxide (N_2O) or methane, could be taken as convincing evidence that a planet is not only habitable—but that it is inhabited.

If we do not see oxygen or ozone features in a planet's spectrum, does that mean that life is not present? Earth's atmosphere has contained a significant amount of oxygen for only about the past 2 billion years. The earliest fossils suggest life existed 3.5 billion years ago. Indirect evidence for life on Earth may go back even further in time. This suggests that life was present on Earth for more than one and a half billion years before any sign of oxygen or ozone appeared in its atmosphere.

Where is it in the spectrum? Oxygen does not show up in the infrared part of the spectrum. But ozone produces spectral features at infrared wavelengths. One feature is located at about 9,500–9,700 nanometers.

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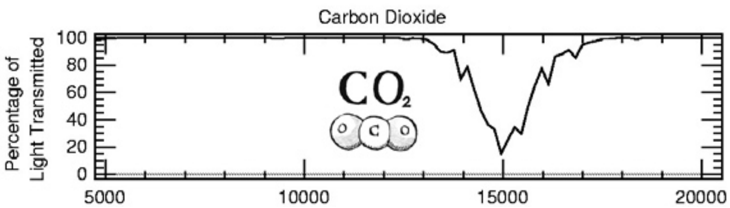
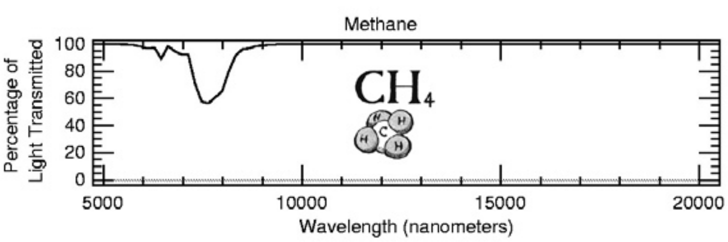


Carbon Dioxide (CO_2)

Carbon dioxide is a gas that increases a planet's temperature by a process called the greenhouse effect. Carbon dioxide is also used (along with water) by plants to produce sugars used for energy. Oxygen is released into the air as a result. This process is called photosynthesis. Animals consume plants and oxygen and release carbon dioxide and water through respiration. If scientists found carbon dioxide, it would mean that the planet might be able to support plant life, but it is not a strong indicator of life by itself, since planets can have carbon dioxide atmospheres without life. Venus and Mars are examples of this.

Where is it in the spectrum? Carbon dioxide produces spectral features at various infrared wavelengths. A prominent feature is located at about 15,000 nanometers.

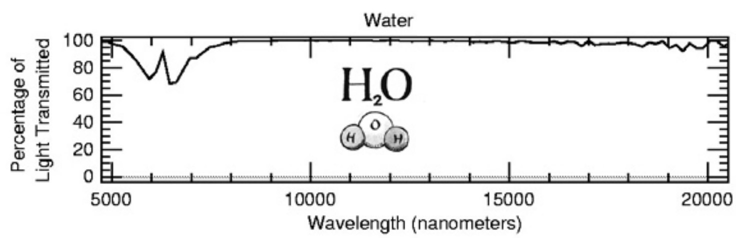


Methane (CH_4)

Scientists suspect that for roughly the first billion years of its history, life on Earth had not yet evolved oxygen-producing organisms. Instead, the micro-organisms that dominated the planet tapped the energy in gases that leaked out of Earth's interior and some microbes created methane as a by-product. (Methane and nitrous oxide, another gas that can be associated with life, are not abundant in present-day Earth's atmosphere.)

On a planet with a similar geology to Earth, methane levels greater than about 100 parts per million would suggest a significant probability of the presence of life. But methane would be a more ambiguous discovery than oxygen, because planets of a different geological make-up might produce abundant methane without life. However, a spectrum that shows signs of both methane and oxygen would provide a very strong indication of life.

Where is it in the spectrum? Methane produces spectral features at infrared wavelengths. One of these is located at about 7,600 nanometers.



Water Vapor (H_2O)

Water vapor is one of the greenhouse gases that absorbs infrared radiation emitted from Earth's surface and helps warm the planet. Water vapor is also the source of all clouds, rain, and snow. It is an important influence on weather and climate.

If a scientist found water vapor in the atmosphere of another planet, it would be a good sign that there might be liquid water on its surface. Water is the most important ingredient for life on Earth, so another planet with water on it would be a promising place to look for life.

Where is it in the spectrum? Water vapor produces spectral features at many infrared wavelengths. One feature is located at about 6,000 nanometers.

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