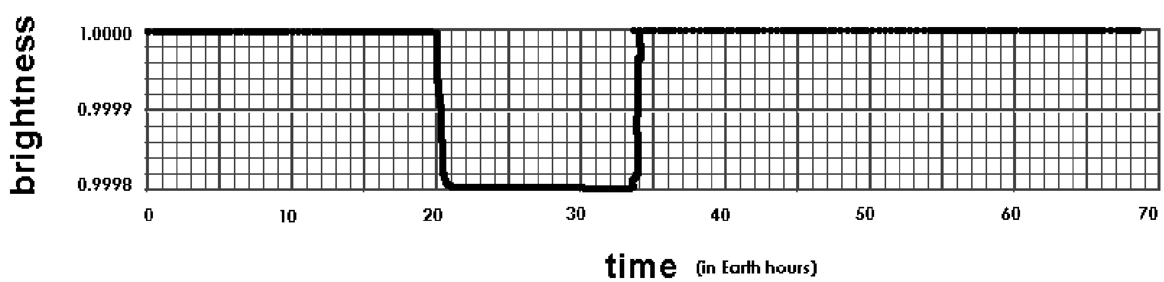
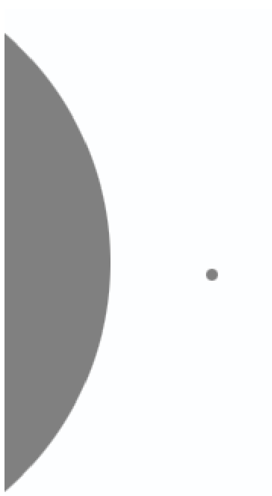
Mystery Planet Challenge
Teacher's Notes

Mystery Planet A: A "water planet"?

Graph 1. This shows the brightness of visible light from the star at different times. It is a transit curve, similar to the one that students will have taken. What can this curve tell us?



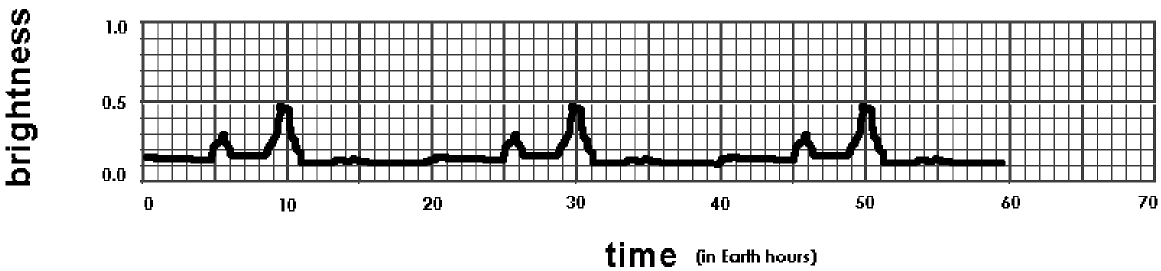


Size of planet: This planet blocks out 0.0002 of the star's light when it transits. For comparison, the Earth would block out 0.0001 of a sun-like star's light (since the Earth is 0.01 times the diameter of a sun-like star and we have to square this to compare the area of their disks.) So the mystery planet is a little bigger than Earth. You would presumably weigh more on this planet, but we don't yet know what it is made of, so we don't know its mass or gravity.

Length of year: We see only one transit, so we don't know from this graph how long it takes for the planet to orbit once around the star. However, there is another clue...

Distance from planet: Although we don't know the period of the orbit, there is another clue that lets us estimate how far the planet is from its star. We know the time it takes to transit across the face of the star. From the graph, the transit takes about 13 hours. This is just the same as it would take the Earth to transit our Sun, if seen from a great distance. (How do we know? We know how fast the Earth moves, and we know how wide the Sun is. So we know how long it should take the Earth to "move across the face of the Sun," namely 13 hours.) We conclude that the mystery planet is the same distance from its star as Earth, i.e., in the habitable zone of its star. This is a subtle argument that students need not grapple with. We'll just assume that the mystery planets are all the same distance from their sun-like star as the Earth is from the Sun. In practice, astronomers would need to observe at least two or three transits to determine the period of the orbit, and to ensure that the orbit is close to circular.

Graph 2. This shows the brightness of the planet (in the visible part of the light spectrum) at different times. We'll assume that 1.0 is the maximum light it could reflect, and 0 is completely black.

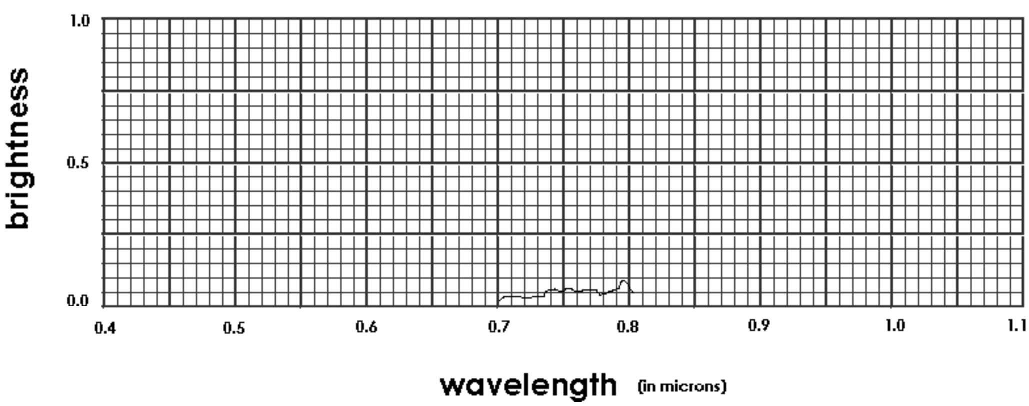


Interpretation 1: The planet appears very dark, except when two brighter features rotate into view. Water is very dark when seen from space, so this may well be a water planet, perhaps with two islands peering up out of the water.

Interpretation 2: It could also be a gigantic lump of coal or some mysterious dark rock—but an ocean is actually darker than coal when seen from space! Note about the peaks: At any given time, we are only measuring the *total* brightness of the planet; there could be a few small, bright areas (e.g. ice) that give the same average brightness as one large, medium-bright area (e.g. a continent). So there is a lot of leeway here for what students may come up with.

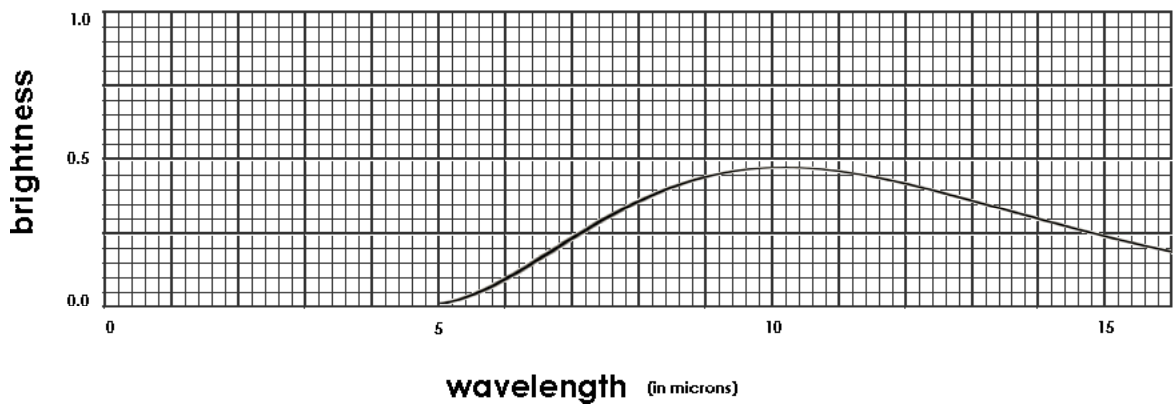
Day Length: The graph pattern repeats every 20 hours. Interpretation: The planet rotates once every 20 hours, bringing the same features into view. A day on this planet would be only 20 Earth hours long.

Graph 3:



Interpretation: We're looking at the brightness of the planet at a given time, at a range of wavelengths between 0.7 and 0.8 microns (= 700 to 800 nanometers = 7000 to 8000 Angstroms). This is the "near-infrared" part of the spectrum; plants would strongly reflect at 0.75 microns and longer wavelengths. There is no obvious "red edge" signal here; therefore, no *detectable* earthlike plants.

Graph 4: This shows the brightness of the mystery planet in the mid-infrared range of the spectrum, between 5 and 15 microns.



Interpretation: This is (infrared) light that is *emitted* by the planet itself. The peak in the curve—the wavelength where the most infrared is emitted—is at about 10.1 microns. This peak is determined by the temperature of the planet:

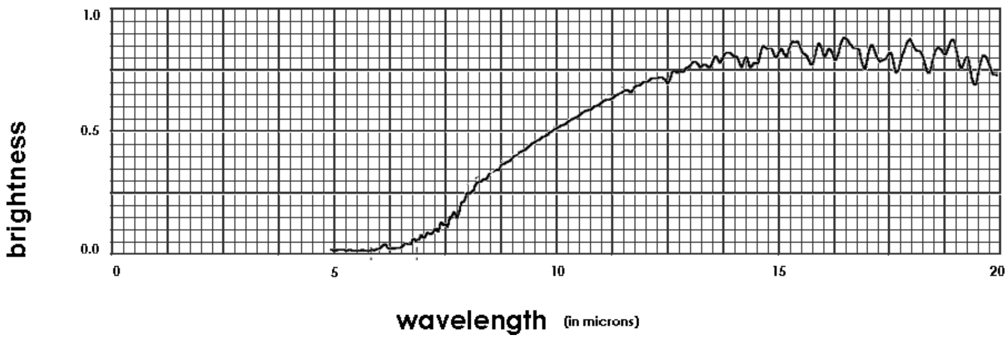
Temperature (in degrees Kelvin) = 2900 / wavelength (in microns)

So temperature = 2900 / 10.1 = 287 degrees K., or 14 degrees Centrigrade. This is about 57 degrees - a bit chilly for swimming, but certainly pleasant enough.

Note 1: To make things more interesting, we have *assumed* that this corresponds to the temperature of the planet's surface. In reality, we would be seeing the top of the planet's atmosphere, which is much colder For example, the Earth looks to be very cold from space, because the top of its atmosphere is way below freezing. In practice, scientists have to use a *model* of how temperature changes with altitude, in order to tell anything about the planet's surface. But they would start with the same kind of curve we are using here.

Note 2: In reality, we would also be seeing absorption by the planet's atmosphere. These would be dips in the light curve (see Graph 5). To make things clearer, we omitted those dips and troughs in this illustration. So this is an *idealized* curve—or if you prefer, a low-resolution graph that doesn't show all the features that the next graph shows.

Graph 5: This shows the brightness of the planet in the mid-infrared part of the spectrum.



Interpretation: Some of the infrared light emitted by the warmth of the planet, is absorbed by substances in the planet's atmosphere. By matching this absorption spectrum with the spectra in the Atmospheres Modeling Lab (or with the standard spectra printed in the Student Guide), we see that the atmosphere of the planet contains water vapor (H_2O), and possibly a small amount of methane (CH_4) as well. The spectrum does not show any absorption for carbon dioxide, or oxygen in the form of ozone (O_3), so these gases would be present in the atmosphere in very small amounts, if at all.

The atmosphere is consistent with our evidence that the planet may be a water world—almost entirely water on its surface—except for the "blips" in Graph 2, indicating small islands of land of some sort. But remember, the planet could be teeming with life in its ocean. Or life could be just starting up on this planet. Whatever life there might be, we don't see its effect yet on the atmosphere of the planet.

Note A: This absorption spectrum has an "envelope" that looks like the blackbody curve in Graph 6. However, students may notice that the curve peaks at a different place (longer wavelength, therefore colder temperature). To simplify these activities, we have used a single set of absorption spectra corresponding to a single temperature, which happens to be colder than the blackbody curves shown in Graph 4 for the mystery planets. Have students ignore this envelope, and look only at the absorption features themselves. (A later version of this activity will have accurate curves.)

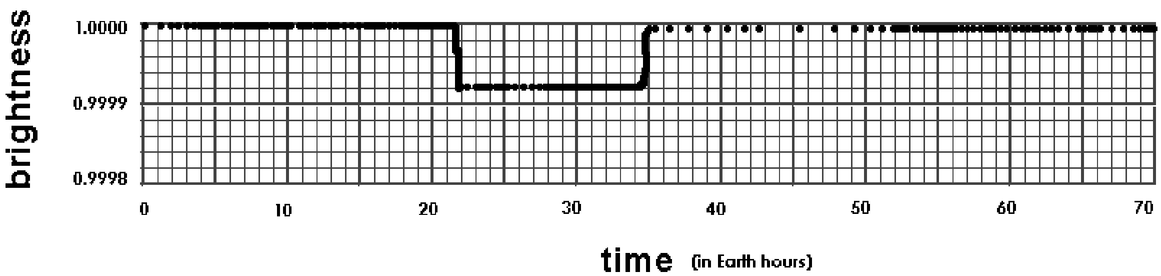
Note B: The scale of the x-axis of this graph has been expanded, compared to Graph 4, in order to show the absorption features more clearly.

Summary:

The evidence is *consistent with* a water world—a planet that is essentially all ocean, with what may be two patches of land. The temperature is a cool 57 degrees Fahrenheit, and the atmosphere has water vapor, consistent with a water world. Life could exist in the oceans here, but we don't see evidence of it in the atmosphere.

Mystery Planet B: A "desert planet"?

Graph 1. This shows the brightness of visible light from the star at different times. It is a transit curve, similar to the one that students will have taken. What can this curve tell us?

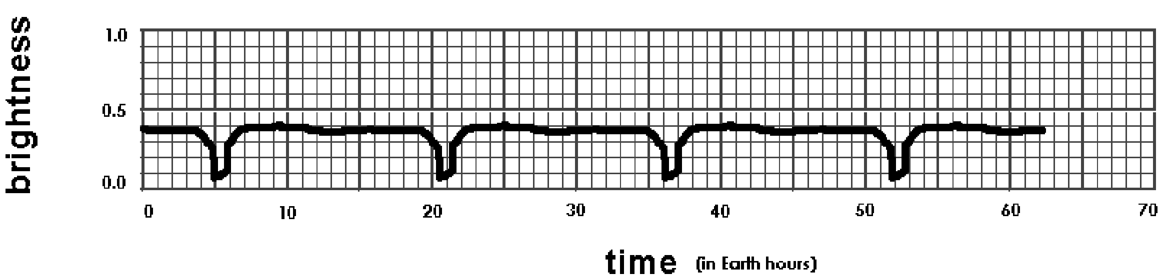


Size of planet: This planet blocks out *less than* 0.0001 of the star's light when it transits. For comparison, the Earth would block out 0.0001 of a sun-like star's light. So mystery planet B is slightly smaller than the Earth. You would presumably weigh less on this planet than you would here on Earth. One consequence is that life forms, if there are any, could grow larger than they do on Earth.

Length of year: We see only one transit, so we don't know from this graph how long it takes for the planet to orbit once around the star.

Distance from planet: As with mystery planet A, the transit takes about 13 hours. Since this is about the same as Earth would take, we conclude that the planet is about the same distance from its star as Earth is from the Sun.

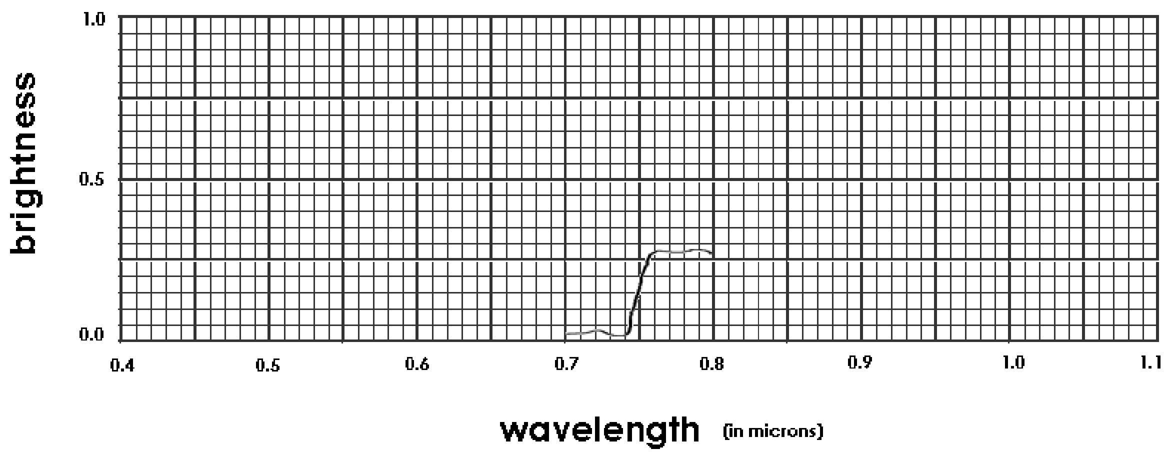
Graph 2. This graph shows the brightness of the visible light from the *planet*, at different times.



Interpretation 1: The planet has medium brightness—roughly the brightness of desert sand. There is some much darker feature hat rotates periodically into view. This is so dark that it could be a large inland sea or lake.

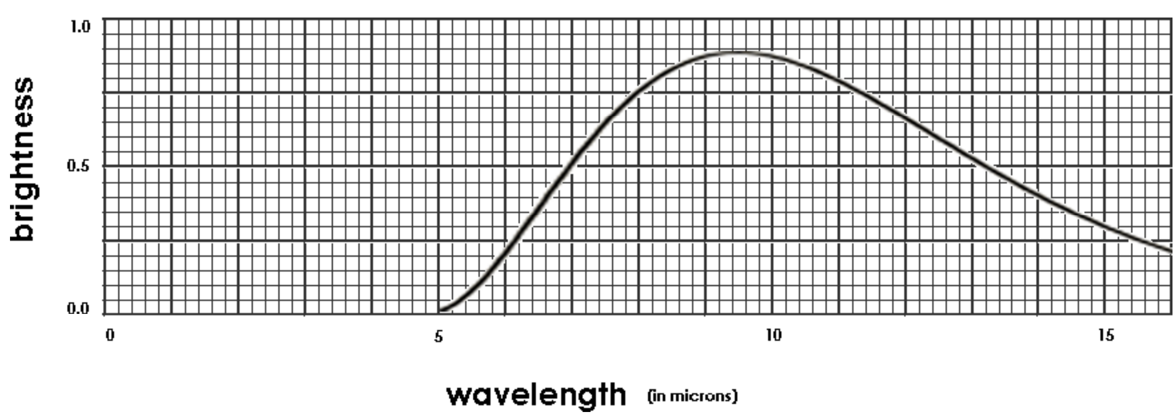
Interpretation 2: If something very bright (like ice) and very dark (like water), were present in equal parts over most of the planet, then they would average to produce the mostly medium brightness shown on the graph. This could be a water world, e.g., with 50% icebergs, and some strange dark feature that could be a patch of water that never froze. But the other evidence (e.g. temperature) may help rule this out. Other surfaces for this planet are possible too.

Graph 3: This shows the brightness of the planet in the near-infrared range between 0.7 and 0.8 microns.



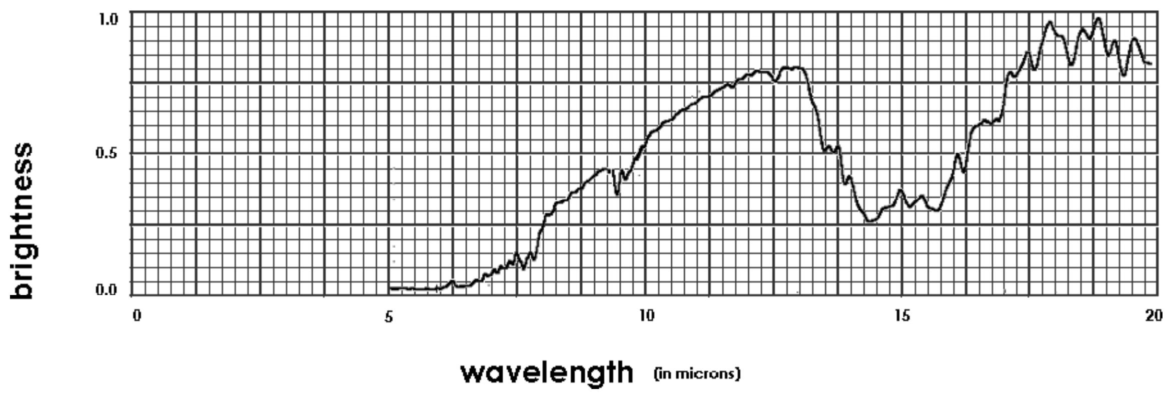
Interpretation: The sudden rise in reflectance at 0.75 microns (750 nm) is the so-called "red edge" feature that is characteristic of virtually all plants on Earth. As we saw with the telescope activity, plants are pretty dark in the visible part of the spectrum, but appear very bright in the near-infrared. We conclude that there may well be vegetation of some sort on this planet.

Graph 4:



In the mid-infrared, the planet appears to emit most strongly at about 9.4 microns. (Students may read the peak slightly differently; that's fine!) This corresponds to a temperature of about 2900 / 9.4 degrees Kelvin, or about 309 degrees Kelvin = 36 degrees Centigrade. This corresponds to almost 97 degrees Fahrenheit. No picnic here!

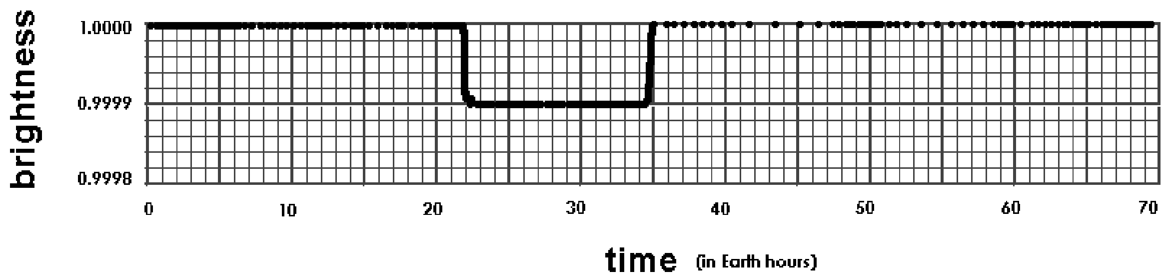
Graph 5:



Interpretation: In addition to water vapor and methane, this atmosphere also contains carbon dioxide (the dip around 15 microns) and a small amount of ozone (the feature around 8 microns).

Mystery Planet C. An earthlike planet?

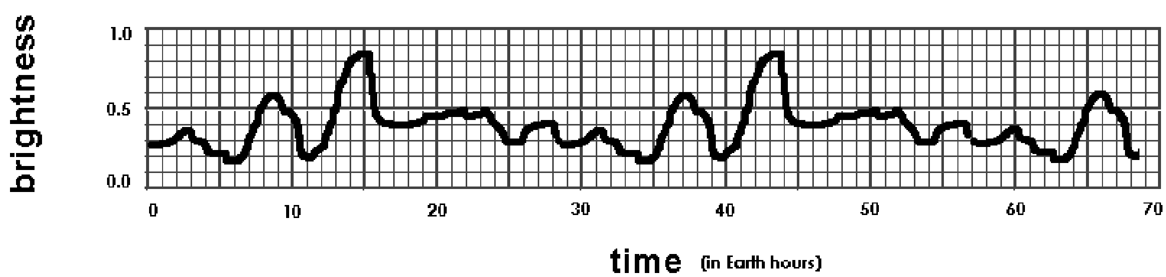
Graph 1. This graph shows the brightness of the visible light from the *star*, at different times.



Interpretation: As the planet passes in front of the star, it blocks out about 0.0001 of the star's light. So the planet is about 0.01 times the diameter of its star—the same size as Earth. As mentioned before, we can't tell how long one orbit takes, because there is only a single transit, but we assume that the planet is the same distance from its star as Earth is from the Sun.

Graph 2.

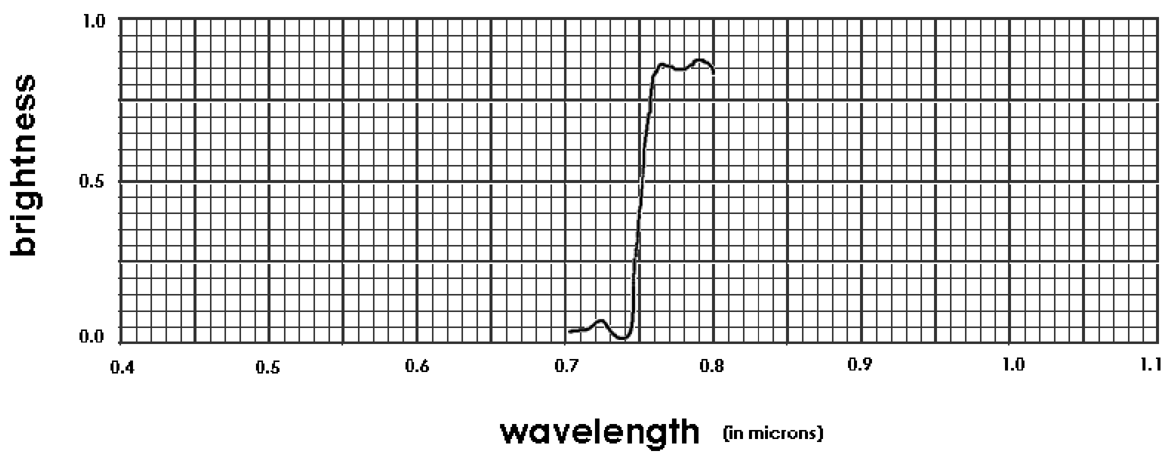
This graph shows the brightness of the visible light from the *planet*, at different times.



Interpretation: The surface of this planet seems to have a complicated mix of dark, medium, and bright features. This is consistent with features such as water, land, and snow or ice co-existing. The pattern repeats every 29 hours, so we conclude that a day on this planet is 29 Earth-hours long.

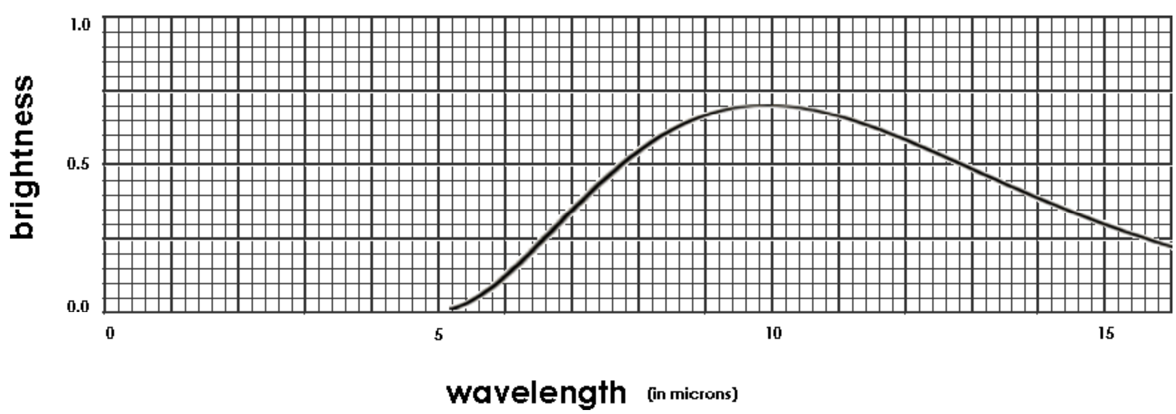
These graphs show the brightness of the *planet*, at different wavelengths of light.

Graph 3:



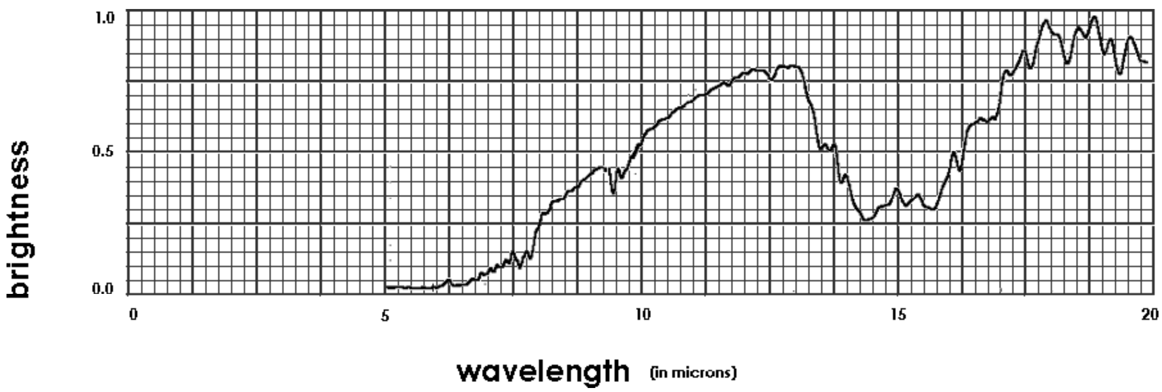
Interpretation: This graph shows a very strong “red edge” feature characteristic of plants: The surface reflects very strongly in the near-infrared, starting at a wavelength of 0.75 microns. This is evidence for an abundance of plant life on the surface of the planet, and indication that the biochemistry of life on this planet may be similar to that of Earth—at least for the vegetation.

Graph 4:



Interpretation: This shows the light emitted by the planet in the mid-infrared range. It is the “blackbody” curve that all objects emit, and that is characteristic of their temperature. The curve peaks at a wavelength of about 10 microns. This corresponds to a temperature of about (2900 / 10) = 290 degrees Kelvin, or about 17 degrees Centigrade = 63 degrees Fahrenheit. Not a bad average temperature for a planet.

Graph 5:



Interpretation: Infrared light emitted by the planet, due to its warmth, is partly absorbed by substances in the atmosphere. This curve shows absorption features for water vapor, carbon dioxide, methane, and ozone (a proxy for oxygen). This is consistent with an Earthlike atmosphere.

Note that neither nitrogen gas nor oxygen gas (O_2)—the major part of Earth's atmosphere— absorb light at these wavelengths. So we don't have direct evidence for these molecules. But ozone (O_3) is produced by the action of light on oxygen, so there is good indirect evidence for oxygen.

Scientists consider the presence of methane and oxygen, together, as a strong indicator of life. That's because methane would react with oxygen (as it does in your gas stove!) and quickly disappear, were it not continually being replenished. Both living things, produce gasses, - methane by bacteria and oxygen by plants.

Summary: This planet is about the same size as Earth, appears to have water, land, a temperate climate, and a friendly atmosphere. All in all, a good vacation spot—if only we could get there!