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AEROSPACE MICRO-LESSON

Easily digestible Aerospace Principles revealed for K-12 Students and Educators. These lessons will be sent on a bi-weekly basis and allow grade-level focused learning. - AIAA STEM K-12 Committee.

EXOPLANETS

After several false alarms, astronomers finally in 1992 confirmed the existence of a planet around something besides the Sun. Since then, the number of detected "exoplanets," as they are called, has increased into the thousands. This lesson explores the discovery of exoplanets and describes some of them.

Next Generation Science Standards (NGSS):

- Discipline: Earth and Space Sciences
- Crosscutting Concept: Patterns
- Science & Engineering Practice: Developing and Using Models

GRADES K-2

1-ESS1-1. Use observations of the sun, moon, and stars to describe patterns that can be predicted.

What exactly is a planet? It took scientists a long time, but in 2006 they put forward a formal definition—although they are still arguing over that definition. "They said a planet must do three things. The first thing might seem obvious: it has to orbit around the Sun. Second, it must be big enough to have enough gravity to force it into a more-or-less spherical shape. And third, it must be big enough that its gravity has cleared away any other objects of a similar size near its orbit around the Sun." Because of that definition, Pluto was removed from the list of planets and labeled a dwarf planet instead. The others are a mix of small rocky planets and large gaseous giants. Of all the planets, Earth is the only one in our solar system that supports life.

Earth is close enough to the sun to keep most of its water from freezing and far enough away to keep the water from being turned into steam. Liquid water is necessary for life as we know it, so this planetary placement is very important. Remember the story of Goldilocks and her search for porridge, a chair, and a bed that were not too hot or too cold, too big or too small, but "just right"? Scientists say that planets which are within the distance from their star that would allow liquid water to exist are within the "Goldilocks zone."

But what about objects orbiting other stars that seem to follow these rules? We call them exoplanets, or extrasolar planets (because they are outside our Solar System). Scientists use various methods to search for these faraway planets. Some have been discovered by noticing

GRADES K-2 (CONTINUED)

that a star has a wobble because of a large planet in orbit around it (just as you would wobble if you spun around while holding something heavy out arm's length), while others have been found because of their shadow showing up against the light of their star as they pass in front of it. It is believed that these exoplanets also have either a small rocky form or a large gaseous composition, although there may be other types of exoplanet as well. Those who are searching for these faraway planets are also looking to see if any of them are lucky enough to be within the "Goldilocks zone" of their own star, and therefore might also support life.

The European Space Agency's web site has a page with information for children about exoplanets. NASA's Space Plane site also has a page with information about exoplanets for young astronomers and another page with specific details about the search for them. Idaho Public Television also has an excellent page for children about exoplanets.

GRADES 3-5

5-ESS1-1. Support an argument that differences in the apparent brightness of the sun compared to other stars is due to their relative distances from the Earth.

With literally thousands of exoplanets now being known—or at least strongly hinted at—astronomers have started to sort them into various types. (There is more than one way of classifying exoplanets, though. Astronomers have not yet settled on a single system.) Not surprisingly, they have used the planets in the Solar System as starting points for their sorting. The first exoplanet to be discovered, in 1992, was a "pulsar planet" with the very prosaic name of "HD 114762 b." A "pulsar planet" does not orbit a real star like the Sun; it orbits something called a "pulsar" which is what some stars turn into when they die. This surprised astronomers because they thought that the process of a star "dying"—running out of hydrogen to fuse into helium (stars aren't really alive the way people are)—should make such a disturbance in its neighborhood that it would destroy any neighboring planets.

Three years after discovering the first confirmed exoplanet, astronomers announced that they had found a planet orbiting an actual star. This one is called "51 Pegasi b" because it orbits the star "51 Pegasi." This planet also surprised astronomers: they calculated that it is about as large as our planet Jupiter but that it is so close to its star that it goes around it in only four days, in contrast to Jupiter's 12-year orbit around the Sun. Astronomers call this kind of exoplanet a "hot Jupiter" because it is about the same size and mass as Jupiter but so close to its star that it is very hot.

GRADES 3-5 (CONTINUED)

A year after the discovery of 51 Pegasi b, a team of astronomers announced the discovery of a Jupiter-sized exoplanet which they called "47 Ursae Majoris b" orbiting its star once every three of Earth's years. This was the first discovery of an exoplanet orbiting a star at a distance comparable to the Solar System's planetary distances. For once, astronomers were not surprised at it; here was an exoplanet that is similar to a Solar System planet.

The ways of sorting exoplanets into different types depend on their sizes, what they orbit, and what they are made of. Naturally with these different schemes, a single exoplanet can fall into more than one group, although at this point very few (if any) have. An exoplanet can be Jupiter-sized, Neptune-sized, or Earth-sized (not exactly those sizes, but in the range). It can orbit a pulsar, a star, or nothing at all. It can be made mostly of gas, of ice, of rock, of liquid water, or of something else entirely. And it can be so close to its star that it orbits in a few days, or farther out so that it orbits in some months, or even farther out so that it takes many of our years to finish an orbit.

One burning question that people have about exoplanets is whether any of them have life on them. At this point, nobody really knows. Most exoplanets have not been seen directly but have been detected by their effects on other things, giving us no way at all to determine whether or not they can support life. And even if an exoplanet can support life, that is no guarantee that it does. Right now we have only a single example—the Earth—of a planet that supports life. We do not know whether this sort of thing is common, unusual, or unique.

GRADES 6-8

MS-ESS1-2. Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.

A writer once said, "Space is big. You just won't believe how vastly, hugely, mind-bogglingly big it is. I mean, you may think it's a long way down the road to the chemist's, but that's just peanuts to space." Ancient peoples, not having any way to know better, considered the Earth to be the only place with solid ground and looked at the planets as wandering lights in the night sky. (In fact, the word "planet" comes from the Greek word "planets," meaning "wanderer.") Two thousand years ago, Greek astronomers established that the Earth has the shape of a sphere and that its size—which they had measured some centuries earlier—was negligible relative to the distances to the heavens. (Another web page which discusses the measurement of the Earth's diameter is here.)

GRADES 6-8 (CONTINUED)

Sixteen hundred years later, with the invention of the telescope, astronomers were able to see more details on the planets. Seeing Venus show phases much as the Moon does gave them a three-dimensional perspective, showing Venus' position relative to the Sun as well as to the Earth. Seeing satellites orbiting Jupiter gave them an idea that the Earth was not unique in having a moon while Saturn's ring—first misidentified as adjacent bodies and then as arms or handles—showed that the planets could be quite different from the Earth. As decades turned into centuries, scientists became comfortable with the idea that the Earth was just one of several planets—and a host of smaller bodies such as asteroids and comets—orbiting the Sun.

As astronomy advanced further, scientists also realized that the stars in the sky are similar to the Sun but their great distance makes them appear as points of light. With this realization, the question naturally came up: do the stars have planets just as the Sun does? Astronomers quickly realized that between the vast differences in brightness between a star and its planets and the limitations of their telescopes, seeing a planet orbiting another star would be well-nigh impossible.

But one does not need to see something in order to be able to conclude that it is there. There are at least four ways to detect a planet circling a distant star without seeing it directly. Two of them, detecting the "wobble" of the star's radial velocity and seeing a drop in brightness as the planet passes in front of the star, are probably intuitive enough for middle-school students to understand. (Detecting radial velocity from the Doppler shift can be demonstrated by listening to a siren of a fire truck or ambulance as it approaches and recedes. There is also a rather nifty classroom demonstration here.) Using these and other indirect methods, astronomers have found almost 4,000 planets circling stars other than our own.

GRADES 9-12

HS-ESS1-3. Communicate scientific ideas about the way stars, over their life cycle, produce elements.

The existence of exoplanets raises several philosophical questions. Leaving aside the obvious ones about whether life exists elsewhere in the Universe—let alone intelligent life—let us consider a more basic one. Are exoplanets real?

GRADES 9-12 (CONTINUED)

This question has much history. Science, when properly understood, involves observing the physical universe, forming hypotheses to fit the observations into categories, and then making more observations as guided by the hypotheses. One philosopher of science observed that "theories are like scalpels, to be used while they are sharp and discarded when they become dull." History is littered with old theories, things that scientists used to believe were real but which turned out not to be. Phlogiston, caloric, Planet Vulcan, and the luminiferous ether, are all things or substances that scientists widely accepted but which we now "know" do not exist. The debate over whether atoms and molecules really existed raged well into the twentieth century; Albert Einstein's explanation of Brownian motion was the first direct evidence that they actually existed rather than being a convenient mathematical construction.

With this in mind, what is the evidence that exoplanets are Real with a capital R? NASA lists five different ways to sense an exoplanet: sensing a regular variation in a star's radial velocity component, watching a star dim in a very specific way, actually taking a photograph of the planet next to the star, watching the brightness of a background star increase in another very specific way as the exoplanet passes in front of it, and watching the star wobble from side to side in a regular fashion. Only one of these ways involves actually detecting an exoplanet—and this method accounts for only about one percent of the exoplanets that NASA claims have been discovered. The other 99 percent of exoplanets have not been discovered, per se; their existence has been inferred as the most logical explanation of an observation of something else.

The knowledge of the average person with respect to the existence of exoplanets is even more tenuous. Except for a very few astronomers and analysts of astronomical data, nobody has directly seen any of the evidence for exoplanets. We have only seen data interpreted and published by those with direct access to it and repeated by others. In essence, the average person's "knowledge" of exoplanets depends entirely on faith in what scientists are telling him. This is not a reason to deny that exoplanets exist; it is simply a reminder of how things are. This article describes the discoveries, retractions, and confirmations of various putative exoplanet discoveries.

There are two useful criteria for deciding whether a scientific object is real or whether it simply a mathematical convenience. The first is that there is a general consensus among scientists about it. This is not foolproof—just over a century ago, there was strong scientific consensus that the luminiferous ether was real—but it is a pretty good guide. The

GRADES 9-12 (CONTINUED)

second is that when scientists start measuring the properties (and not just speculating on what those properties must be) of the object or substance in question, one can be pretty sure that it is a real thing. Scientists have started measuring the masses, diameters, and orbital periods of exoplanets; at this point we can conclude that they—or at least many of them—are real. NASA has a list of exoplanets and their properties as best as they know them at the moment.

Sixty Years Ago in the Space Race:

January 2, 1959: The Soviet Luna 1 spacecraft was launched toward the Moon but missed and went into orbit around the Sun, becoming the first artificial object to do so.

January 12, 1959: The American space agency NASA signed a contract with McDonnell Corporation to build the Mercury space capsules.