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No. 19 - Winter 1991-92

The Search for Planets Around Other Stars

by Andrew Fraknoi, Astronomical Society of the Pacific

The question of whether there are planets outside our Solar System has intrigued scientists, science fiction writers and poets for years. But how can we know if any really exist? We devote this issue of *The Universe in the Classroom* to the search for planets around other stars.

What is the difference between a planet and a star?

Stars are huge luminous balls of gas powered by nuclear reactions at their centers. The enormously high temperatures and pressures in the core of a star force atoms of hydrogen to fuse together and become helium atoms, releasing tremendous amounts of energy in the process. Planets are much smaller with core temperatures and pressures too low for nuclear fusion to occur. Thus they emit no light of their own. When you see Venus or Jupiter in the night sky, you're really seeing sunlight reflected by those planets back to you.

Some planets, like Earth and Mars are solid rocky bodies, but others, like Jupiter and Saturn are mostly gas and liquid. Jupiter, the largest planet in our solar system, is roughly 300 times more massive than the Earth, but only one-thousandth the mass of the Sun. However, had Jupiter been 75 times more massive, it would just have been large enough for the pressures and temperatures at its core to ignite nuclear fusion, and the Earth would have had two Suns in our skies.

Why do we think there might be planets around other stars?

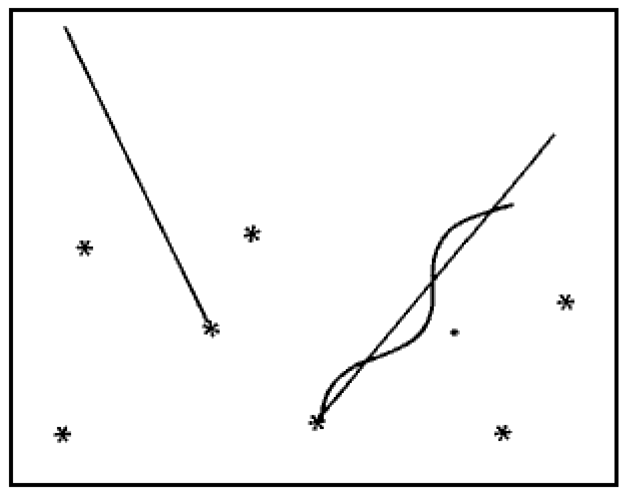
We think our own Solar System formed as a natural by-product of the formation of the Sun. About five billion years ago, a huge, amorphous cloud of gas and dust, thousands of times larger than the present Solar System, began to contract. The exact reason why the contraction began is not clear; one idea is that a nearby exploding star gave it a push. But once started, the cloud collapsed under its own gravity, with most of the gas and dust falling to the center to form the Sun. The remaining material fell into a broad, flattened disk. Throughout the disk, dust grains orbiting the proto-Sun collided with one another, occasionally sticking together. Small clumps joined together to make ever larger ones, eventually forming the planets. This process of accumulating material is called *accretion*. According to this scenario, planets are a natural by-product of the formation of the Sun. Thus astronomers think many stars like the Sun should have planets.

Why is it so hard to see planets around other stars?

Because planets are small, appear to lie close to their parent star, and shine only by reflected starlight, the faint glimmer of a planet is lost in the brilliant glare from its parent star. Imagine suspending a grain of rice an inch or two from a lighted 100 Watt light bulb. Someone standing at the end of a long dark hall would see only the light bulb, not the grain of rice. It's the same with planets and stars. Consider the case of Jupiter and the Sun. Jupiter is only a tenth the size and has one hundredth the surface area of the Sun. As seen from the nearest star, Alpha Centauri, mighty Jupiter would appear extremely faint, a *billionth* as bright as the Sun. Jupiter would also appear extremely close to the Sun, a mere four arc seconds away (an arc second is a unit of angular measurement equal to the apparent size of a U.S. quarter from a distance of five kilometers or three miles). An Alpha Centauran, with equipment similar to our best instruments on our largest telescopes, would simply not be able to see Jupiter in the glare of the Sun. Since most stars are much farther away than Alpha Centauri, there is little chance of seeing or photographing individual planets around other stars.

If we can't see them, how can we find out if there *are* planets around other stars?

Although we cannot see the planet itself, we can see the effect of the gravitational tug the planet exerts on its parent star. As the planet revolves around the star, it pulls the star first one way, then the other. The more massive the planet, the more noticeable its effect on the star will be. As the star moves through space, the planet's tugs show up as tiny deviations from a straight-line path. That's because the star and the planet actually move around the *center of mass* of the star-planet system, the point where one would balance a seesaw holding the star on one end and the planet on the other. For example, the Sun is a thousand times more massive than Jupiter, so the center of mass of the Sun-Jupiter system lies very close to the Sun. Nevertheless, an extraterrestrial observer measuring the Sun's motion through space would detect a slight wobble in the Sun's path, a wobble with a period of twelve years, the same time it takes Jupiter to orbit once around the center of mass. Smaller planets like the Earth also cause perturbations on the Sun's orbit, but they are so tiny they couldn't be detected across interstellar distances. Analysis of the wobbles can give information about the planet's mass, orbit, period and distance from the star.



The star moving in a straight line has no planets; the one which "wobbles" around a straight path is being influenced by an unseen planet's orbital motion. (Diagram courtesy David C. Black, NASA Ames Research Center)

If we make extremely detailed measurements of a star's position, accurate to one-thousandth of an arc second, we might be able to see wobbles in its motion due to a large unseen companion. Current techniques in *astrometry*, the branch of astronomy that deals with measuring positions of stars, are becoming capable of detecting Jupiter-sized planets around nearby stars.

Have any planets been detected from stellar wobbles?

Several stars do indeed seem to follow slightly wavy paths through space. Some astronomers have reported that a few stars have companions with masses similar to that of Jupiter (perhaps the most famous is *Barnard's Star*), but other astronomers have been unable to confirm these claims. Astrometric observations are extremely difficult to make since the sought-after wiggles are very small, about one-thousandth the size of a star's image on an astronomical photograph. One problem is that the errors inherent in making the observations and measurements are about the same size as the planetary-induced wiggles astronomers are seeking, making it very difficult to be sure if a measured wobble is real. So far there have been no uncontested detections of planets from stellar wobbles.

The Case of Barnard's Star

Barnard's Star is a faint, red star about two-tenths as massive as the Sun. It is six light years away (fourth closest star to the Sun), and has the largest proper motion (angular motion across the sky) of any known star. In 1963, Peter van de Kamp, then director of Swarthmore College's Sproul Observatory, announced that, based on an analysis of its motion, Barnard's Star had an unseen companion. Van de Kamp estimated that the companion was 50 percent heavier than Jupiter, much too small to be a star. Six years later, van de Kamp revised his analysis and declared that Barnard's Star actually had *two* planetary companions, one 0.7 times the mass of Jupiter, the other half Jupiter's mass. It seemed that the first real planetary system had been found around another star.

But other astronomers, using different telescopes, didn't see any evidence of van de Kamp's perturbations when they studied the motion of Barnard's Star. Critics questioned his procedures and charged that he had not properly corrected for small changes in his telescope over time, especially when its lenses were cleaned and reinstalled. So far, no one has been able to duplicate his results. Van de Kamp still believes in his perturbations and his two-planet interpretation. But most astronomers today doubt they are real.

Are there other ways to detect planets?

A planet's gravitational tug on a star can also be seen in measurements of the star's *radial velocity*, its motion toward or away from us along the line of sight from Earth to the star. As the star orbits the system's center of mass, it alternately moves toward, then away from us. Features in the star's rainbow-like spectrum are *Doppler shifted* slightly toward the blue end of the spectrum when the star is approaching and toward the red end when it is receding. It's the same principle that causes the sound waves in a police car's siren to change pitch as it approaches you, and then recedes from you. Because a star is much more massive than a planet, the size of the Doppler shift is extremely small, requiring very sophisticated instruments to measure it.

Bruce Campbell of the Dominion Astrophysical Observatory in Victoria, British Columbia has studied a number of nearby stars, looking for subtle shifts in radial velocity. About half show velocity variations indicative of possible planet-sized companions from one to ten times Jupiter's mass. But variations in the star itself, pulsations, for example, could also cause small radial velocity changes like those observed. If these pulsations are periodic, they could easily be mistaken for planetary companions. There are ways to tell planets from pulsations, but they require years of painstaking observations and analysis, which have not yet been completed. Nevertheless, these observations remain some of the more promising candidates for extrasolar planetary systems.

Can we see the large disks of gas and dust around other stars out of which planets form?

In 1983, the ***I****nfra-****R****ed* ***A****stronomical* ***S****atellite* (*IRAS*) surveyed the sky, measuring the heat given off by astronomical objects. Among its many discoveries was that several nearby stars, including the bright stars *Vega* and *Fomalhaut*, are surrounded by shells or disks of orbiting solid particles. Most of the disks stretch several hundred AU from their parent stars (one Astronomical Unit, or AU, is the distance from the Sun to the Earth, about 150 million kilometers or 93 million miles). In the case of Vega (the brightest star in the constellation Lyra) the disk extends out 7.4 billion miles from the star, or about twice the distance from the Sun to Pluto, our farthest planet. Astronomers think that the disks are remnants of the formation of the star, and possibly an early stage in the formation of a planetary system.

Astronomers have also found disks of material around a class of very young stars called *T Tauri stars* (named after the prototype star in the constellation of Taurus). Disks of material seem to be a common attribute of young stars. But they are not planetary systems. There is no way to tell for sure if there are planets present in addition to the disks, if the disks will some day form planets, or if the disks are all that will ever be there. But they do indicate that solid matter can form in a disk-like configuration very similar to the one out of which astronomers think our Solar System condensed.

What about recent reports of planets around pulsars?

Pulsars are compact, ultra-dense, rapidly spinning stars with strong magnetic fields, believed to be born in the fiery debris of a *supernova* explosion, the enormously powerful death throes of a giant star. As the pulsar spins on its axis several times a second, a powerful pulse of energy sweeps by the Earth, rather like the rotating beacon of an interstellar lighthouse. These pulses are normally very regular, but last July, British astronomer Andrew Lyne and colleagues found that the radio pulses from one pulsar had a puzzling variation. At first the signals arrived a hundredth of a second earlier than average. Three months later they were a hundredth of a second late. After another three months it was early again, and so on. Lyne thought the radio pulse variations were Doppler shifts as the pulsar, tugged by an unseen companion about ten times the mass of the Earth, orbited a center of mass.

Several months later, Alexander Wolszczan, of the Arecibo Radio Observatory in Puerto Rico, and Dale Frail, of the National Radio Astronomy Observatory, reported semi-regular variations in radio pulses from a different pulsar. They concluded that this pulsar has two companions, each about 3 times the mass of the Earth. They also reported a possible third planet about the same size as Earth.

But in January 1992, Lyne reported that his team had not properly removed the effects of the Earth's motion around the Sun from their analysis, and, when the calculations were redone correctly, the pulse variations disappeared. There was no planet. The variations Wolszczan and Frail noticed are too complex to be caused by the Earth's motion, but most astronomers are waiting for more information before deciding if Wolszczan and Frail have indeed detected planets around a pulsar.

Summary

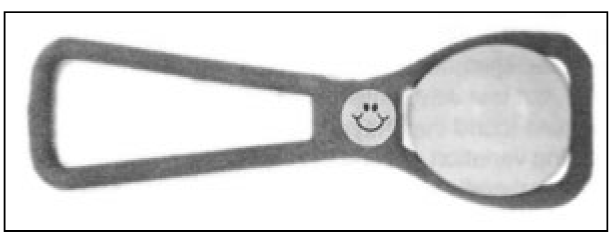
The search for planets outside our Solar System is a difficult one, hampered by the extremely large distances between stars and the inherent faintness of the objects we seek. So far, there is no proof that any star other than the Sun has planets circling it. There are several tantalizing hints and possible detections, but none is without controversy. As Percival Lowell, a 19th century astronomer who saw seasonal variations in the surface markings of Mars and convinced himself he was seeing evidence of a dying civilization (later proven to be wrong), once said: "When dealing with the most far-reaching scientific questions, it can be hard to separate one's science from one's imagination." Still, in the next few years, better instruments and more sophisticated techniques may yet tell us whether planets exist around other stars.

Activity: Center of Mass Demonstration

by Thomas Hockey, University of Northern Iowa

Materials

- Elongated rubber pet toy
- Two rubber or plastic balls (of similar size but unequal mass)
- Bright sticker (phosphorescent sticker is optional)
- Phosphorescent ball (or a ball painted with phosphorescent paint)



Instructions

Attach the two rubber balls to the pet toy. The "double loop" design of the toy holds the balls in place without fasteners. When tossed, the model turns end over end; the two balls revolve around a point on the toy, the center of mass. Ask students to estimate where the center of mass is located. They can then determine experimentally where this center is by placing the model on a finger - the center of mass occurs where the model balances. Students may be surprised that this point is not situated half way between the balls but at a point closer to the more-massive ball. Mark the center of mass with a bright sticker. Now throw the model again. The balls will revolve around an axis beneath the sticker. If one of the balls is exchanged with a more or less massive one, the sticker will no longer remain "steady" in flight but will itself revolve around the new center of mass.

To illustrate the astrometric wobble of a star with a planetary companion, remove the two balls from the toy. Turn off the classroom lights. Toss the phosphorescent ball by itself and ask the students to observe the relatively simple curve of its path (analogous to a star with no planets). Then place the phosphorescent ball in the small loop of the toy (leaving the other loop empty, symbolizing a planet with much less mass than its star) without the students knowing it. Toss the model once again in darkness, and note the more complicated path of the glowing ball. Ask the students to hypothesize why the apparent motion of the ball differed between the two tosses. Then show them the model with the lights on, and discuss the empty loop's role as an unseen planetary companion. Finally you can toss the model again, this time with phosphorescent paint or a phosphorescent sticker applied to the center of mass.