One Down, Six To Go

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A team of astronomers from Caltech and the Johns Hopkins University have taken pictures and spectra of what they believe is a brown dwarf—one of a class of objects intermediate in mass between the smallest stars and the "gas giant" planets such as Jupiter. Astronomers have long theorized that brown dwarfs must exist, and in recent years several candidates have been nominated by various observers, but until now the proof has always been indirect and never 100 percent convincing. The team includes Professor of Astronomy Shrinivas Kulkarni, Senior Research Fellow in Astronomy Tadashi Nakajima, Member of the Professional Staff Keith Matthews, and grad student Ben Oppenheimer, of Caltech, and Sam Durrance and David Golimowski of Johns Hopkins.

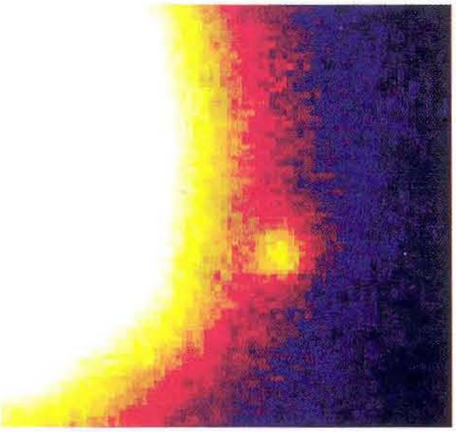
The brown dwarf, known as GL 229B, lies in the constellation Lepus, near Orion, and orbits a small, dim star called GL 229 that's 17 light-years—about 100 trillion miles—away from us. This is the first detection of so faint and cool an object outside the solar system.

Brown dwarfs are made of the same gaseous material as stars, but are much less massive. Current theories put the upper limit to the mass of brown dwarfs at about one-twelfth the mass of the sun. Above this limit, the energy released by the contracting gas generates enough heat to ignite and sustain nuclear fusion, and a star shines forth. Below this limit, the gas never gets hot enough to "burn." Young brown dwarfs can shine quite brightly for a little while, due to frictional heat from gravitational contraction, but this source of energy isn't nearly as long-lasting or as powerful as fusion. So brown dwarfs fade rapidly until they glow only from their meager internal heat, and are much cooler, dimmer, and harder to see than stars.

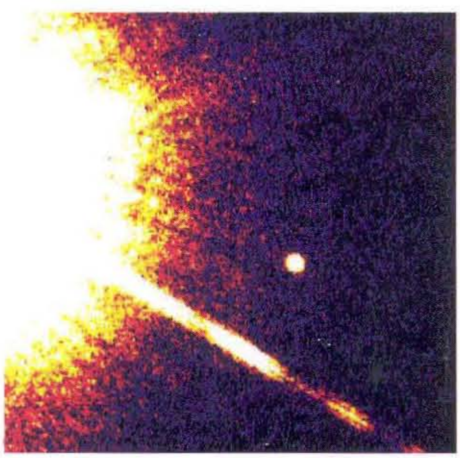
Astronomers want to find brown dwarfs for two reasons. First, they want to determine the smallest-mass object that can form in a starlike manner by condensation of interstellar gas clouds, and whether enough of these hard-to-detect objects exist to solve a difficult cosmological puzzle. Our galaxy is spinning so fast that it would fly apart if the gravity from its known contents were all that was holding it together. Could brown dwarfs account for some of the missing "dark matter?" Second, astronomers want to study the atmospheres of brown dwarfs and learn how they are related to the atmospheres of planets. Such understanding is important to the search for other planetary systems.

Because of their importance both to cosmology and to finding other planets, astronomers have searched diligently for brown dwarfs, especially young ones that are still hot, relatively bright, and more easily seen. Young brown dwarfs are most likely to appear in star clusters, the "nurseries" where stars form.

But the Caltech/Johns Hopkins team took a different approach. Instead of scouring relatively distant stellar nurseries for young brown dwarfs, they looked for older, cooler ones as companions to stars within our local neighborhood—within 45 light-years, or about 265



Above: The brown dwarf (dot in center) was first observed on October 27, 1994, using Johns Hopkins University's Adaptive Optics Coronagraph and the 60-inch telescope at Palomar. (Photo by Nakajima and Golimowski.) Below: This follow-up image was made on November 17, 1995, with the Hubble Space Telescope's Wide-Field and Planetary Camera 2. (Photo by Kulkarni and Durrance.) In both cases, the main star is out of the field of view to the left, but residual glare extends out nearly to the brown dwarf.



trillion miles, of the sun. These stars are middle-aged, on average about five billion years old.

There are two advantages to searching for nearer, older brown dwarfs. First, scientists know the distances to nearby stars pretty accurately, so a brown dwarf candidate's intrinsic luminosity can be deduced. The lowest luminosity of any normal, hydrogen-fusing star is one ten-thousandth that of the sun, so if the candidate's calculated luminosity is less than this limit, the object can't be a star. But brown dwarfs can have much lower luminosities.

Second, an aged brown dwarf's spectral features may help unmask it. A star's minimum surface temperature is about 1800 K, while old brown dwarfs can have much lower temperatures. Thus their cool atmospheres are similar to those of the gas-giant planets in our solar system. (In fact, prominent absorption features are seen in Jupiter's spectrum that do not appear in the spectrum of any star.) And Takashi Tsuji of the University of Tokyo has found that below 1000 K, carbon prefers to attach to hydrogen and form methane, instead of reacting with oxygen to form the carbon monoxide seen in cool stars. So the presence of methane absorption lines in a candidate's spectrum are a sure sign of less-than-stellar temperatures.

The astronomers first made an image of each of the stars in their survey with a "coronagraph," a camera with the ability to see faint objects in the glare of an adjacent bright star. The coronagraph blocks light from the star so that dimmer nearby objects become visible. This coronagraph, used at optical wavelengths, was made by the Johns Hopkins team and has been used extensively at the 60-inch telescope at Caltech's Palomar Observatory. A similar device built by Matthews to detect infrared wavelengths has been commissioned recently at the 200-inch Hale Telescope at Palomar.

The astronomers looked at each star twice, at an interval of one year. All stars move relatively quickly, so unrelated objects that were lined up by chance in the first look will have drifted apart by the second. But true companion stars will remain together. The astronomers identified brown dwarf candidates on the 60-inch telescope and examined them more closely with the Hale Telescope.

This method paid off with GL 229. Its putative companion, christened GL 229B, moved in tandem with it, and the two appear to be in orbit around each other. Using the known distance to GL 229, the astronomers calculated GL 229B's luminosity to be only seven millionths that of the sun, almost 10 times less than the faintest known star. And absorption lines betraying the presence of water were found in the spectrum of GL 229B, showing that its surface temperature is less than 1,000 K—800 K lower than the coolest known star. Methane absorption lines were also found, confirming the object's substellar temperature.

This discovery is an important first step in the search for planetary systems beyond the solar system. GL 229B's strange colors—extremely red in the optical wavelengths and blue in the near-infrared—and the presence of methane suggest new strategies to search for brown dwarfs and massive Jupiter-like planets. The spectra of faint objects could be screened for these unusual characteristics, allowing astronomers to concentrate on the most likely brown dwarf candidates.

GL 229B is about four billion miles from its main star, a bit farther than Pluto is from the sun. Although its mass is some 20 times that of Jupiter, it is so dense that its diameter is about the same—80,000 miles. It's unclear whether GL 229B formed like a star, by direct condensation of interstellar gas, or like a planet, by condensation of material within a protoplanetary disk that formed around the star. However, the proximity of the parent star to the companion suggests that it formed in a planetary disk rather than directly from the interstellar medium. The astronomers are continuing to observe GL 229B, and have obtained images and spectra of it using the Hale Telescope, the 10-meter Keck Telescope, and the Hubble Space Telescope.

The results appeared in the November 30 issue of *Nature* and the December 1 issue of *Science*. □

Below: The arrow on this Hubble Space Telescope image marks where the probe hit, at approximate Jovian latitude 6.5° north and longitude 4.4° west. This photo dates from October 5, however, and the cloud patterns may have changed significantly in the interim.
Right: Talk about your visual aids! In the JPL pressroom on Arrival Day, TV reporters did their standup routine under a life-sized replica of the spacecraft.

Galileo Hits the Spot

Well, no, it didn't—not the Great Red Spot, anyhow. But on December 7, after a six-year voyage filled with dramas too numerous to mention, the Galileo spacecraft buzzed Jupiter's pizza-faced volcanic moon Io at an altitude of some 890 kilometers, skimmed the giant planet's cloud tops by a distance of three Jupiter radii, and fired the main engine to plop itself into permanent orbit around its new home. Meanwhile, an atmospheric probe dropped from the spacecraft back in July did hit a spot, or very nearly, plunging into the planet's roiling skies close to the outskirts of a "hot spot" visible in infrared light.

The probe, which is managed by NASA Ames, entered the top of Jupiter's atmosphere—defined as 450 kilometers above the altitude where Jupiter's atmospheric pressure equals that on Earth's surface—at an angle to the horizon of roughly 8.3°. This was the center of a very narrow safe zone—a degree and a half shallower, and the probe would have skipped off the atmosphere like a pebble across a pond; a degree and a half steeper, and the probe would have taken too great a jolt for its instruments to withstand. Not that they're wimpy, mind you—they rode out a deceleration shock some 215 times the force of gravity here on Earth.

Then, heat shields jettisoned and parachute deployed, the probe's instruments took the measure of Jupiter's atmosphere—its pressure, temperature, and chemical makeup—and sent 57 minutes' worth of data to the orbiter.

Due to the famous antenna problem, however, the data could not be relayed to Earth in real time, but were stored on tape for later playback. A compressed version of the data was also stored in Galileo's computer, in case the tape recorder decided to do something exciting again. This meant that plans to take extreme close-ups of the moon with the worst case of acne in the solar system had to be scrapped. This is unfortunate, because Galileo won't come close to Io again—the radiation environment there is just too hot for the spacecraft.

The first 40 minutes of probe data were relayed to Earth on December 10–13, but the full playback won't start until January, 1996, once Jupiter clears the sun. (Jupiter hits superior conjunction—meaning that it's diametrically opposite us, behind the sun—on December 19. And as the sun gets in the way, radio communication with Galileo goes from normal to lousy to nonexistent.) Stay tuned... □—*DS*