No. 75 • Spring 2009 www.astrosociety.org/uitc

Probing Extrasolar Planets with the Spitzer Space Telescope

by Michelle Thaller (Spitzer Space Center)

When the Spitzer Space Telescope was launched in August of 2003, astronomers around the world were looking forward to all the new discoveries they knew would be coming down the pike; spectacular images of star-forming clouds, detections of distant galaxies and the like. What almost no one expected, however, was that Spitzer would revolutionize the study of exoplanets, or planets that orbit other stars. In fact, Spitzer was the first telescope to capture light coming directly from exoplanets. Before that time, the presence of exoplanets had been deduced by the gravitational tug they exerted on their stars; the orbiting planets caused a "wobble" in their parent stars that allowed astronomers to measure the orbital period and mass of these planets which still remained invisible. Spitzer observed two of these planetary systems in 2005 and, for the first time ever, observed light coming not from a star, but from planets in another solar system.

To begin with, Spitzer had a huge advantage for detecting light from exoplanets. Spitzer is an infrared space telescope, seeing the universe entirely in what we commonly think of as "heat" radiation. Infrared light is a lower-energy light than what our eyes see, and anything with warmth can be detected by Spitzer's heat-sensitive detectors. Exoplanets are terribly difficult to see in visible light, as planets don't give off visible light of their own; they only reflect light from their stars. In terms of brightness levels, that would mean a relatively tiny planet would be billions of times fainter than its parent star. In infrared, while the central star is still millions of time brighter than a planet (stars put off plenty of heat too), the planet is at least giving off an active signal of its own (see Figure 1).

By looking very carefully at the infrared light from the whole system, you can begin to determine which light is moving with the planet, and which is associated with the star. All of the planets that Spitzer has observed so far are very hot and very massive. These so-called "hot Jupiters" are the easiest kind of planets to detect, as they give out lots of infrared radiation and orbit their stars very quickly. With the first two planets that Spitzer detected, there was an added benefit that the planets orbited behind their stars, from our solar system's point of view. That meant that the stars blocked out the infrared light from the planets during part of their orbits, allowing Spitzer to measure the drop in infrared light from the total system (see Figure 2, next page).

Not only was Spitzer able to isolate light from these planets,

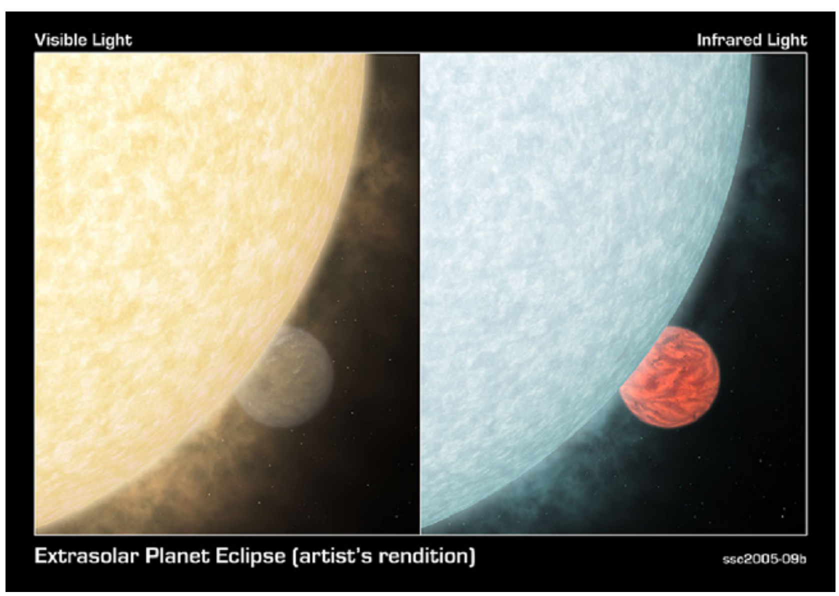

Figure 1: Planets are much easier to see in infrared light, where at least they give off their own light instead of being totally swamped by their parent star.

but by using its infrared spectrograph, Spitzer was also able to sample the chemistry of these distant planets and get a good estimate of their temperatures. Using this technique, Spitzer has found evidence of all kinds of interesting molecules in the atmospheres of exoplanets, including silicates and water vapor!

Alien Sunset

In one planetary system called Epsilon Andromedae, Spitzer found distinct temperature variations that correlated to the period of the planet's orbit. The surprising thing was that, in this case, the planet did not transit behind that star, but was visible to Spitzer at all times. What was causing the variation in temperature? It turned out that this change in heat was the result of the planet showing its different faces to Spitzer as it traveled around the star. When the planet's sunlit side was in Earth's view, Spitzer detected more heat from the system; when its dark side was facing us, it picked up less heat. Amazingly, Spitzer was observing the change in temperature brought on by sunrise and sunset on a planet over 40 light-years away! Now, to be fair, the temperature change is a lot more extreme than we experience on Earth. Epsilon Andromedae's planet is about the size of Jupiter and located well within where the orbit of Mercury would be in our solar system, meaning that the "day" side of the planet is about 2500 degrees Fahrenheit hotter than the "night" side! That's like jumping into a volcano when the Sun comes up.

The Hottest Planet

We knew these planets were hot, but just how hot was downright shocking. The planet HD 149026b is located 256 light-years away in the constellation Hercules. It is the smallest and densest known transiting planet, with a size

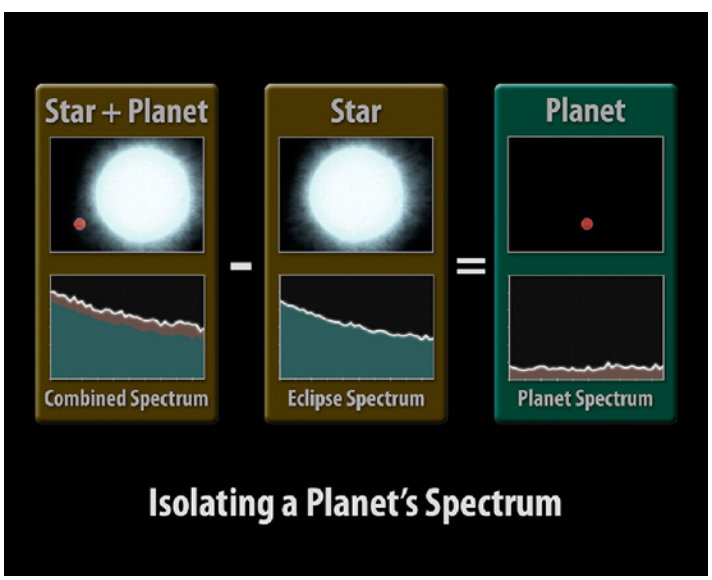

Figure 2: Coaxing a signal from a faint planet is easier when the planet orbits behind its star.

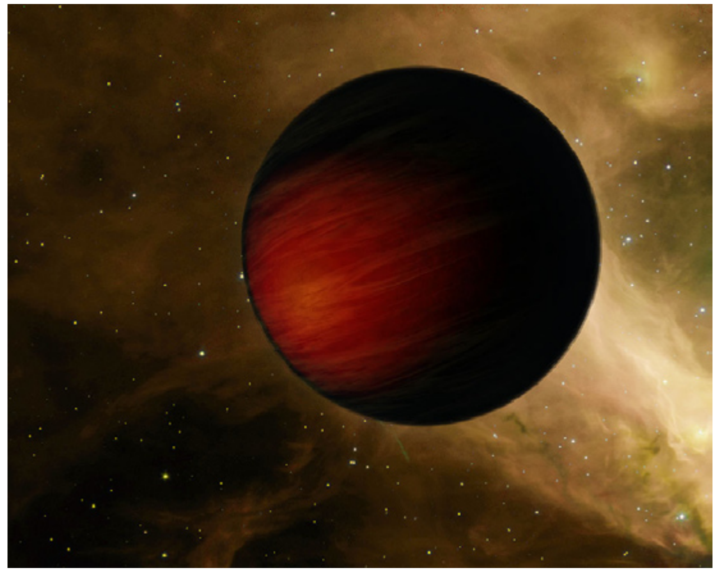

Figure 3: An artist's rendition of the hottest known planet.

similar to Saturn's and a core suspected to be 70 to 90 times the mass of Earth, speeding around its star every 2.9 days. Spitzer's temperature measurements showed the planet to be a scorching 3,700 degrees Fahrenheit, which is even hotter than some of the coolest known stars (see Figure 3).

It amazed astronomers that any planet could reach those temperatures; in order for that to happen, the planet must be absorbing almost all the light and heat it gets from its star. For this reason, the planet must be almost completely black –as black as a lump of coal. There is a hot spot in the atmosphere directly facing the star that actually is hot enough to glow faintly in visible light, which would make the planet resemble a giant back eyeball with a hot, glowing iris.

Weather maps of distant worlds

As Spitzer astronomers gained confidence with their techniques, they realized that they could create real, albeit crude, weather maps of exoplanets. A particularly interesting case was the planet HD 189733b, located 60 light-years away in the constellation Vulpecula. Spitzer measured the infrared light coming from the planet as it circled around its star every 2.2 days, revealing its different faces. These infrared measurements, comprising about a quarter of a million data points, were then assembled into pole-to-pole strips, and, ultimately, used to map the temperature of the entire surface of the cloudy, giant planet.

The observations reveal that temperatures on this balmy world are fairly even, ranging from 1,200 Fahrenheit on the dark side to 930 degrees 1,700 Fahrenheit on the sunlit side. HD 189733b, and all other hot Jupiters, are believed to be tidally locked like our Moon, so one side of the planet always faces the star. Since the planet's overall temperature variation is mild, scientists believe winds must be spreading the heat from its permanently sunlit side around to its dark side. Such winds might rage across the surface at up to 6,000 miles per hour. For comparison, the jet streams on Earth travel at about 200 miles per hour. Also, HD 189733b has a warm spot 30 degrees east of "high noon," or the point directly below the star (see Figure 4).

In other words, if the high-noon point were in Seattle, the warm spot would be in Chicago. Assuming the planet is tidally locked to its parent star, this implies that the fierce winds are blowing eastward.

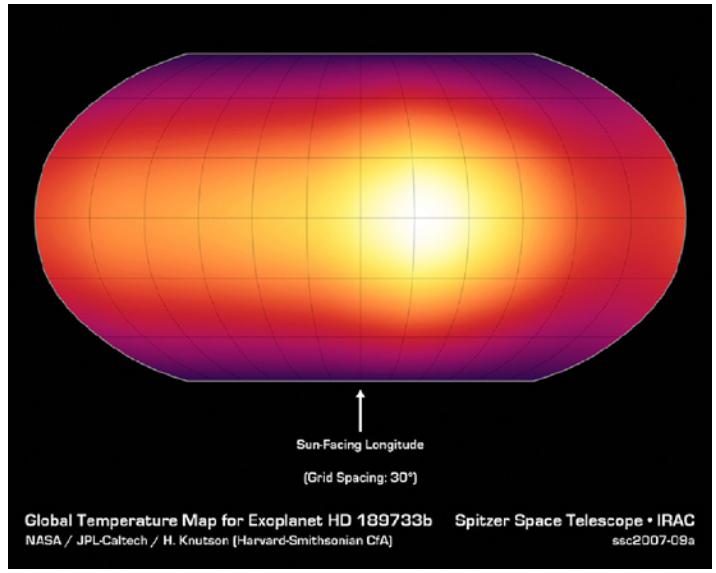

Figure 4: The first weather map of a distant world, and the detection of the fastest winds ever measured.

New "World" Records

Beginning with Spitzer, exoplanets are no longer just mysterious invisible masses around other stars but real places with exotic environments that test our imagination. In just a few years of observations, we have discovered the hottest temperatures and the fastest winds every recorded. But there is no reason to assume these records will last. And as with every new discovery, a whole slew of new questions have to be asked. Why do some hot Jupiters have huge day to night temperature variations while others have strong winds? How did planets like these form in the first place? How do these extreme weather conditions effect how these planets evolve? NASA's next planet-finding missions, from Kepler to the Terrestrial Planet Finder, will begin to find answers, as well as show us just how special a place like Earth may be.

Classroom Activities

1. View Podcasts about exoplanets:

coolcosmos.ipac.caltech.edu/videos/irrelevant/files/IRAstroSpaceship2.m4v

www.spitzer.caltech.edu/features/hiddenuniverse/files/016-showcase_xplanets.m4v

www.spitzer.caltech.edu/features/hiddenuniverse/files/010-m51gizmo.m4v

2. Detect Infrared Radiation the same way William Herschel did in 1801:

coolcosmos.ipac.caltech.edu/cosmic_classroom/classroom_activities/herschel_experiment.html

3. See what the world looks like through an infrared camera:

coolcosmos.ipac.caltech.edu/videos/more_than_your/index.html

4. See what animals looks like in the infrared (lesson plans included)

coolcosmos.ipac.caltech.edu/image_galleries/ir_zoo/index.html

5. Use an animated infrared camera

spaceplace.nasa.gov/en/kids/sirtf1/sirtf_action.shtml

6. Build a model of the Spitzer Space Telescope

coolcosmos.ipac.caltech.edu/resources/buildit/index.html

Resources

The Spitzer Space Telescope
www.spitzer.caltech.edu

CoolCosmos Infrared Education
coolcosmos.ipac.caltech.edu

Planetquest: Exoplanet Exploration
planetquest.jpl.nasa.gov

NASA's Jet Propulsion Laboratory
jpl.nasa.gov

NASA's SpacePlace
spaceplace.nasa.gov

References

Charbonneau et al., Detection of Thermal Emission from an Extrasolar Planet, Astrophys.J. 626 (2005) 523-529

Hansen et al., The Phase-Dependent Infrared Brightness of the Extrasolar Planet Upsilon Adromedae b, Science Magazine 27 October 2006 314: 623-626

Harrington et al., the Hottest Planet, Nature, Volume 447, Issue 7145, pp. 691-693 (2007)

Knutson et al., A map of the day-night contrast of the extrasolar planet HD 189733b, Nature Volume 447, Issue 7141, pp. 183-186 (2007)