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new hot papers - 2010

March 2010

(Commentary added in March 2010 for January 2010 late entry.)

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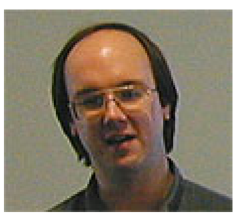
Christian Marois & Bruce Macintosh talk with *ScienceWatch.com* and answer a few questions about this month's New Hot Papers in the field of Space Science. The authors have also sent along an image of their work.



Top: Christian Marois, bottom: Bruce Macintosh.

Article Title: Direct Imaging of Multiple Planets Orbiting the Star HR 8799
Authors: Marois, C;Macintosh, B;Barman, T;Zuckerman, B;Song, IS;Patience, J;Lafreniere, D;Doyon, R
Journal: SCIENCE, Volume: 322, Issue: 5906, Page: 1348-1352, Year: NOV 28 2008
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SW: Why do you think your paper is highly cited?

The discovery of the planetary system orbiting HR 8799 (a nearby star in the constellation Pegasus) (see Fig. 1) is unique in several ways that have contributed to its high citation rate. It is one of the first unambiguous direct detections (actual images) of an exoplanet, and also the first multi-planet system that has ever been imaged.

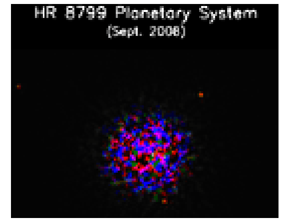
These planets are the first one to be detected at orbital separations—24-68 astronomical units (an astronomical unit is the average distance between the Sun and Earth), similar to the outer part of our own solar system. This system shows other similarities to our own, with a known Kuiper belt and an asteroid belt (detected by their infrared glow).

In other ways the system is very different than our own. These are young planets, still glowing with the heat of their formation. The HR 8799 planets are massive, 7-10 times the mass of that of Jupiter.

Explaining why such massive planets are found at those wide separations is a challenge for current planet formation scenarios. Since the planets are seen directly, they can be studied in detail, and photometry and spectroscopy have shown that they do not resemble atmospheric model predictions, leaving theorists (like Dr. Travis Barman from our discovery team) much work to modify their models to better understand the role of dust clouds and unexpected chemistry.

The fact that three planets are found in orbit around the same star allows for additional analysis that would not be possible if only one planet had been found. Gravitational interactions between the planets can be used to further constrain the planet masses and/or the system stability with time: (Will any planet be ejected from the system? Did they form closer in and then, after planet-planet interactions, move out?, etc.). The HR 8799 system is really the first system from which such a complete analysis is possible. It thus has generated a large amount of follow-up papers.

Figure 1



+View larger image & details...

SW: Does it describe a new discovery, methodology, or synthesis of knowledge?

Our paper describes the discovery, via direct imaging, of the HR 8799 three planets system. Imaging of extrasolar planets—resolving the faint planet from the bright star—has been attempted for many years but with little success. Through advanced image processing and adaptive optics, careful target selection, and good luck, we succeeded with this system, making it a milestone on the path to fully characterizing other solar systems.

SW: Would you summarize the significance of your paper in layman's terms?

Up to now, more than 400 exoplanets have been found orbiting stars. These exoplanets were all found indirectly, generally by the radial velocity method that uses the small color shift generated by the planet's gravitational tug on the parent star. Those results are very exciting since they show the plurality and diversity of planetary systems that exist in our galaxy, but are not visual (people like images) and are limited in the amount of information obtained on the planet's physical characteristics.

A direct detection allows a vast array of analyses that are not possible otherwise, like studying the planet's atmosphere to better understand the ongoing complex chemistry, watching the planet's brightness vary to see evolving cloud features or tracking the planet around the star to characterize its orbit. Since the first indirect discovery of a planet around a star in 1995 (51 Pegasus), many teams have been trying to take an image of an exoplanet, with very limited success.

Our paper presents the imaging discovery of three Jupiter-like planets orbiting the nearby young ~60 million years old star HR 8799 (Fig. 1). This system is the first convincing image of a planetary system (other than our own) and the first planets discovered by any means in orbits similar to the massive planets of our solar system (> 5 astronomical units).

This discovery clearly shows that a population of massive Jupiter-like planets in wide orbits, similar to the massive planets of our Solar system, exists around stars. This is a milestone discovery in the long path of finding a pale blue dot (an Earth-like planet) in the goldilocks zone (separation regime around a star where water could be found in a liquid state on a planet's surface) showing a life-supporting atmosphere around a nearby star.

Our current imaging instruments are not sensitive enough to study the inner part of nearby planetary systems. Maybe we will discover, using larger ground-based telescopes, such as the Thirty-Meter Telescope, to be constructed in Mauna Kea, Hawaii, or more optimal space-based observatories, that such a special planet exists in the inner part of the HR 8799 planetary system.

SW: How did you become involved in this research, and were there any problems along the way?

"The discovery of the planetary system orbiting HR 8799 (a nearby star in the constellation Pegasus) (see Fig. 1) is unique in several ways that have contributed to its high citation rate."

I (Christian Marois) became involved in this field nine years ago when I started my Ph. D. thesis at the University of Montreal. At that time, the exoplanet imaging field was just starting, due to the recent availability of 8-10m diameter telescopes that are equipped with adaptive optics systems—small mirrors that change shape 1,000 times/s to correct for Earth's atmospheric turbulence that is blurring astronomical images. The combination of a large aperture and blur-free images allowed the search for Jupiter-like planets > 20 astronomical units around nearby stars.

One of the main issues that remained to be overcome was noise generated by optical defects on the telescope mirrors and instrument optics. To subtract this noise, I have invented a new observation strategy called "Angular Differential Imaging," during my Ph.D. thesis, which has allowed two orders of magnitude gain in sensitivity. After finishing my PhD I was hired as a postdoctoral researcher at the Lawrence Livermore National Laboratory, and I worked with collaborators to improve this algorithm. The remaining problems were that of selecting optimal targets and getting access to a large amount of 8-10m telescope time to perform a survey.

Our team had to observe nearly 200 nearby young stars in a period of five years at the Gemini North and the Keck 2 in Mauna Kea, Hawaii, the Gemini South in Cerro Pachon, Chile, and the Yepun Very Large telescope at the Paranal Observatory on Cerro Paranal in the Atacama desert in northern Chile, before making the HR 8799 discovery. I am now still pursuing the survey as an astronomer at the National Research Council of Canada, Herzberg Institute of Astrophysics, with my team of international collaborators.

SW: Where do you see your research leading in the future?

The next several years will see a dramatic shift in the rate of detected planets by the use of direct imaging. I am involved in a new instrument, called the "Gemini Planet Imager" (PI Dr. Bruce Macintosh, also a member of the HR 8799 discovery team), that is optimized to search for Jovian planets orbiting > 5 astronomical units around nearby young stars. This instrument will further enhance our current sensitivity by another 2 order-of-magnitude, allowing the detection of less massive planets which are located much closer to their star.

We are also part of the design team for an exoplanet imaging instrument for the upcoming Thirty-Meter Telescope that will offer some unique possibilities to study giant planet formation in nearby very young star clusters as well as possibly image a few super-Earth (rocky planets having several times the mass and radius of Earth).

SW: Do you foresee any social or political implications for your research?

The search for planets around other stars has far-reaching implications. It has helped humanity realize our place in the Universe. It is also a way to complete the Copernican revolution: the Sun, the Earth, and our solar system are not the center of the Universe, but they are also not unique and other planets like ours do exist in our Galaxy.

Finding a candidate Earthlike planet around a nearby star would trigger a vast endeavor to study its atmosphere and a search for life signatures. Our images are a long way from the level of sensitivity needed to see an Earthlike planet, but the HR 8799 system discovery is a crucial step along that road. In the distant future, perhaps humanity will be colonizing the planets, or even one of their moons, which we are in the process of discovering today.

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Figure 1:

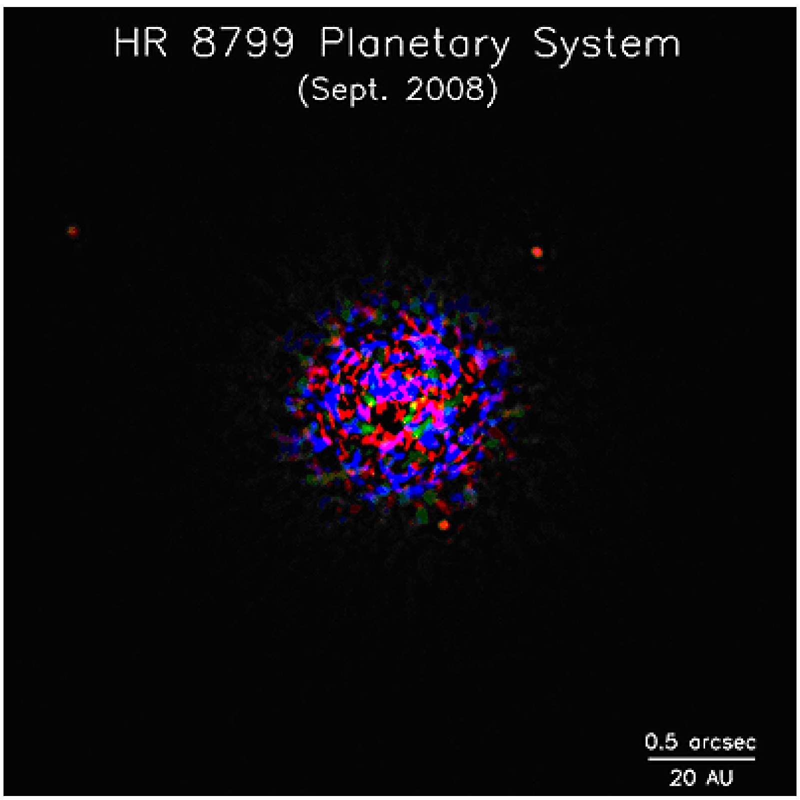

Figure 1 description:

The HR 8799 planetary system. Three Jupiter-like planets (red spots at 1h, 5h and 10h) have been directly imaged using the Keck and Gemini North telescopes (the stellar primary is located at the center of the noisy area – this noise is residual light from the star after image processing). The system is located 130 light years away in the constellation of Pegasus. The planets are between 7 and 10 Jupiter mass and orbit the star between 24 and 68 astronomical units. A multi-epoch astrometry analysis suggests that all three orbits are nearly circular and viewed mostly pole-on. The three planets orbit the star in 100-400 years.

KEYWORDS: DUSTY DEBRIS DISKS; A-TYPE STARS; CIRCUMSTELLAR DISKS; DETERMINISTIC MODEL; GIANT PLANETS; MASS STARS; DWARF; LUMINOSITY; PHOTOMETRY; SYSTEMS.

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