

Miller Fellow Focus: Heather Knutson



For centuries, astronomers had expected that planetary systems around other stars should echo our own, with small, rocky planets orbiting close to the star and more massive gas giant planets farther out. It therefore came as a surprise when the first planets discovered around nearby stars turned out to be massive gas giants similar to Jupiter orbiting extremely close to their parent stars. Fifteen years later, these “hot Jupiters” have turned out to be merely the tip of the iceberg; we currently know of more than 400 extrasolar planets with a diverse array of properties that continue to defy our expectations of what should be out there.

For most of these planets, we know little more than their masses and orbital periods. This leaves many unanswered questions, including: Is it a gas giant, or a rocky planet? What is its temperature? Does it have an atmosphere, and if so, what is its composition? What

is the weather like? Second-year Miller Fellow Heather Knutson is an astronomer who uses studies of eclipsing systems, where the planet periodically passes in front of its host star, to answer these and other questions about the properties of our closest exoplanetary neighbors. Although much of her present-day work focuses on hot Jupiters, which are more easily observed due to their large sizes and high temperatures, her ultimate goal is to carry out similar studies on smaller and more earth-like worlds.

What do observations of eclipsing systems tell us about hot Jupiter atmospheres?

By measuring the amount of light blocked by the planet when it passes in front of its star we can determine the planet’s radius and, when combined with an estimate of the mass from measurements of the star’s Doppler shift, its mean density. The wavelength-dependence of this transit depth can be used to search for absorption from the planet’s atmosphere, and, by extension, to determine its atmospheric composition. Observations of hot Jupiters, which typically have temperatures between 1000-2000 K, using this technique indicate that their atmospheres contain water, methane, carbon monoxide, and possibly carbon

dioxide in addition to hydrogen and helium.

By measuring the depth of the secondary eclipse, when the planet passes behind the star, we can determine the spectrum of the infrared light emitted by these planets and from that learn something about the properties of their dayside atmospheres. As a graduate student at Harvard University, Heather discovered the first evidence for the presence of molecular emission lines caused by a temperature inversion high in the atmospheres of some close-in hot Jupiters. We still do not know why some of these planets appear to have strong temperature inversions, while others with similar properties do not.

Upon her arrival at Berkeley,

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Heather started a project to estimate the activity levels and corresponding UV fluxes of exoplanet host stars. One of the first results to come out of this project was the surprising realization that planets with temperature inversions tended to orbit magnetically quiet stars, while planets without inversions orbited more active stars. This correlation was the first hint that the high UV fluxes experienced by planets orbiting active stars might be destroying the molecule responsible for the formation of the observed temperature inversions. Although the nature of this molecule is currently unknown, future observations of the wavelength-dependent absorption during transit might eventually detect its unique signature.

As a result of their short orbital periods hot Jupiters are expected to be tidally locked, meaning that the same side of the planet always faces the star. One open question is whether or not heat absorbed on the daysides of these planets is efficiently transported around to their night sides. In the future this question will become increasingly important, as the first detailed atmosphere studies of earth-like planets will likely focus on close-in, tidally locked planets orbiting cool stars. By monitoring changes in the brightness of the planet as it rotates around its parent star it is possible to determine the amplitude of the day-night temperature gradient in its atmosphere. In 2007 Heather measured an infrared phase curve for a close-in hot Jupiter using the *Spitzer Space Telescope*, which

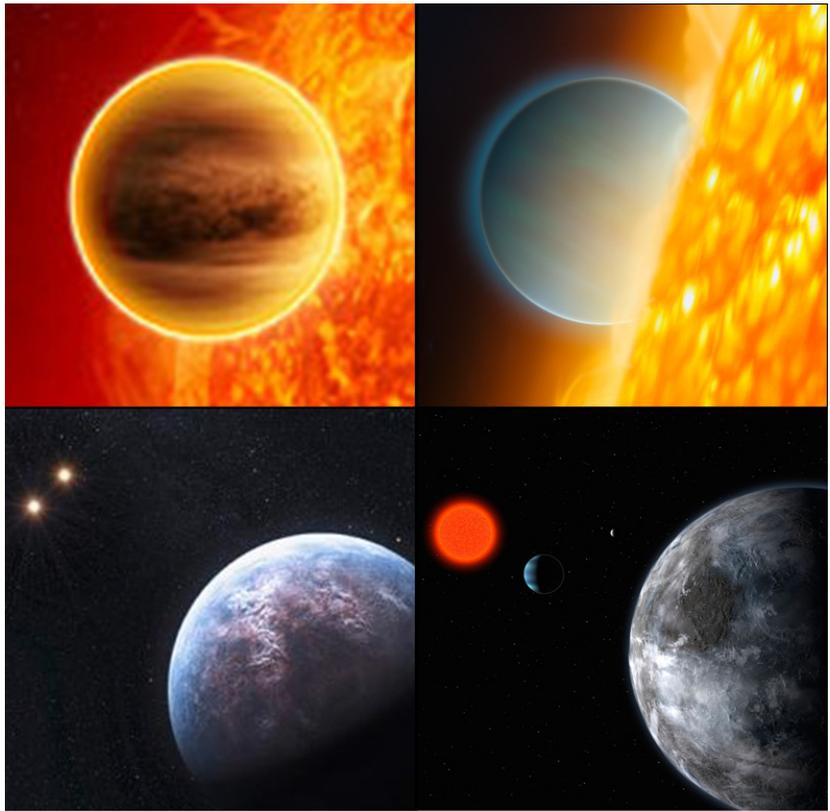


Figure 1: Four different artist's impressions of known extrasolar planets. Some planets are gas giants orbiting very close to their host stars (top left, top right), while others are smaller and may be terrestrial or even earth-like in their properties (lower left, lower right). The best targets for detailed characterization are planets orbiting cool, low-mass stars (lower right).

Image credits (clockwise from top left): HD 189733, ESA/C. Carreau; HD 189733, ESA, NASA, & G. Tinetti; Gl 581, ESO; Gl 667, ESO.

she then inverted to produce the first-ever map of the temperature as a function of longitude for an extrasolar planet. This map indicated that the hottest spot on the planet was not at the substellar point, but instead was shifted approximately 30 degrees to the east, presumably by strong equatorial winds.

Since then Heather has obtained similar observations of other hot Jupiters indicating that most have warm night sides, although there are hints that the most highly irradiated planets (i.e., those with temperatures above 2500 K) may have larger temperature gradients. Heather's

observations also indicate that these planets have fairly stable weather patterns, as repeated observations of the dayside fluxes from two representative planets over a period of several years rule out any significant variability.

How can we use these techniques to study smaller and more earth-like planets?

The studies of hot Jupiters described above rely primarily on observations with the *Hubble* and *Spitzer Space Telescopes*, and often push the limits of both. How then can we hope to study much smaller planets with the same

instruments? The answer is simple in principle: we look for planets around smaller stars. Because the measured eclipse depths in these systems scale as the square of the planet-star radius ratio, it is possible to find small planets orbiting small stars with transit depths equal to those of their more massive hot Jupiter counterparts.

Heather's current favorite planet is a Neptune-sized world known as GJ 436b, which orbits a bright, nearby star with a mass approximately half that of the sun. Temperatures in this planet's atmosphere range between 700-800 K, cool enough that most of the carbon in the atmosphere should be tied up in methane rather than the carbon monoxide found in hotter atmospheres. Heather's observations of this planet's wavelength-dependent transit depth failed to detect any methane absorption, and she speculates that the planet may have a high-altitude haze or cloud layer that increases the opacity of the atmosphere, washing out any molecular absorption features.

This is a pivotal time for studies of exoplanet

atmospheres. Although we currently know of only a handful of low-mass transiting planets, ongoing ground- and space-based surveys (e.g., NASA's Kepler mission) are expected to dramatically expand this sample over the next several years. It is likely that we will soon be able to carry out the first studies of the atmospheres of terrestrial and potentially habitable worlds. We have very little idea as to what we will find, but past experience indicates that whatever it is, it will surprise us.

As a child Heather was fascinated by astronomy, but by the time she started college at Johns Hopkins University she was convinced that no one actually made a living doing it and so she chose to major in physics instead. A summer internship at the Space Telescope Science Institute, home of the famous *Hubble Space Telescope*, soon convinced her otherwise, and she went on to earn her Ph.D. in astronomy working with David Charbonneau at Harvard University. For the past year she has enjoyed the opportunity to work with Geoff Marcy and his dedicated team of planet hunters here at UC Berkeley.

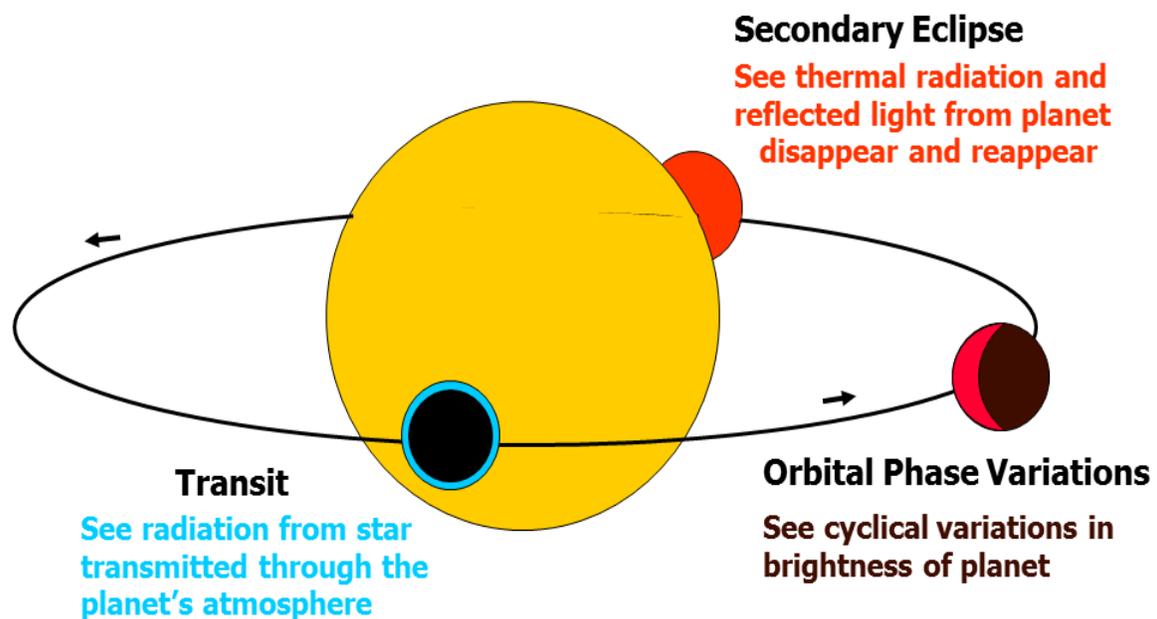


Figure 2: Schematic diagram of an eclipsing extrasolar planet indicating different kinds of observations. Measurements of the wavelength-dependent transit depth tell us about the composition of the planet's atmosphere at the day-night terminator. Secondary eclipse observations can be used to characterize the planet's dayside emission spectrum, which tells us about the composition and temperature vs. height in this part of the atmosphere. Observations of the planet's emission at different orbital phases allow us to map the temperature of the atmosphere as a function of longitude, and to characterize the corresponding atmospheric circulation.

Credit: Heather Knutson

Miller Professorship Awards

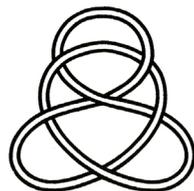
The Miller Institute is proud to announce the awards for Miller Research Professorship terms during Academic Year 2011-2012. These outstanding scientists are released from teaching and administrative duties during their Miller appointments, allowing them to pursue their research, full-time, following promising leads as they develop.

Christopher Chang
Chemistry

N. Louise Glass
Plant & Microbial Biology

Geoff Marcy
Astronomy

Joel Moore
Physics



Xiang Zhang
Mechanical Engineering

Visiting Miller Professorship Awards

The Advisory Board of the Miller Institute is pleased to announce the recipients of the Visiting Miller Professorship Awards for 2011-12. The purpose of the Visiting Professorship is to bring promising or eminent scientists to the Berkeley campus on a short-term basis for collaborative research interactions. The recipients of the 2011-12 awards were selected from an outstanding pool of nominees. Visits to Berkeley will range from 30 days to a full academic semester. The terms of the Miller bequest requires visitors to be devoted to full time research and collaboration. Though they have no regular teaching duties, Visiting Miller Professors may speak at seminars and present guest lectures.

Steven Balbus
École Normale Supérieure
Astronomy
Host: Eliot Quataert

Cin Ty Lee
Rice University
Earth & Planetary Science
Host: Barbara Romanowicz

James Bullock
UC Irvine
Astronomy
Host: Chung-Pei Ma

Allan MacDonald
University of Texas at Austin
Physics
Host: Ashvin Vishwanath

Pierre Colmez
Institut de Mathématiques de Jussieu
Mathematics
Host: Kenneth Ribet

David Manolopoulos
Oxford University
Chemistry
Host: William Miller

Robert Griffiths
University of Oxford
Statistics
Host: Steven Evans

Lisa Randall
Harvard University
Physics
Host: Lawrence J. Hall

Stephen Harris
General Motors R&D Center
Chemistry
Host: C. Bradley Moore

Mario Szegedy
Rutgers University
EECS
Host: Umesh Vazirani

2011 Miller Senior Fellowship Announced



The Miller Institute is pleased to name Professor Raymond Jeanloz the 2011 Miller Senior Fellow for a five-year term beginning July 1, 2011. Professor Jeanloz is known for his basic research on the physics and chemistry of materials at high pressures and temperatures and his studies of the structure and evolution of planetary interiors. His work helped obtain the first experimental constraints on the temperature at the center of the Earth, and showed that a single perovskite-structured mineral (stable only at pressures above 20 GPa) makes up the bulk of Earth's mantle. He has also shown that the crystalline oxides of the deep mantle react chemically with the liquid iron alloy of the outer core, thus making the core-mantle boundary one of the most dynamic regions of the Earth.

Professor Jeanloz has made remarkable contributions to science on the national and local levels. He has received many notable awards including the James Macelwane Medal from the American Geophysical Union, a MacArthur Fellowship, The Hans Bethe Award from the Federation of American Scientists and the Leo Szilard Award of the American Physical Society. He is a Fellow of the American Academy of Arts and Sciences and a member of the National Academy of Sciences. A

prominent figure in nuclear weapons policy, Jeanloz has served as chair of the National Academy's Committee on International Security and Arms Control. He is a member of, and serves as an advisor to, numerous committees and panels, including serving as a Senior Advisor to the Under-Secretary of Energy and helped lead the National Nuclear Security Administration's Advisory Committee under Admiral Henry G. Chiles.

Locally, he has advised the President of the University of California and the Directors of the Los Alamos, Lawrence Livermore and Lawrence Berkeley National Labs. He was a former Executive Director of the Miller Institute and founded the Institute's well-regarded Annual Interdisciplinary Symposium, which he has chaired for the past 15 years.

As the fourth Miller Senior Fellow named, Jeanloz will join Randy Schekman, Professor of Molecular and Cell Biology, Gabor Somorjai, Professor of Chemistry, and Saul Perlmutter, Professor of Physics as part of our community of world-renown scientists. The Miller Senior Fellow Program was established in 2008, taking its place alongside the Institute's other programs: the Miller Fellowships, the Miller Research Professorships and the Miller Visiting Professorships. The purpose of the Senior Fellow Program is to support excellence in basic science at UC Berkeley by providing distinguished faculty on campus with significant discretionary research funds, and by involving them in the activities and intellectual fellowship of the Miller Institute. The Miller Senior Fellow Program enhances the Institute's mission by fostering interactions between distinguished senior scientists in different disciplines and our postdoctoral fellows.

Next Steps

The Miller Institute congratulates **Julius Lucks** on his position as Assistant Professor of Chemical and Biomolecular Engineering at Cornell University.



Awards and Honors

December 16, 2010: **Joe Dufek** (Miller Fellow 2006 - 2008) was awarded the 2010 Hisashi Kuno Award.

November 17, 2010: **Bill Dietrich** (Miller Professor 1998 - 1999) was awarded the Arthur Holmes Union Medal and Honorary Membership of the EGU.

November 17, 2010: **Michael Manga** (Miller Fellow 1994 - 1996, Miller Professor 2008 - 2009, Executive Director 2010 - 2011) was awarded the Robert Wilhelm Bunsen Medal of the European Geosciences Union.

November 5, 2010: **Josh Shaevitz** (Miller Fellow 2004 - 2007) was awarded a Presidential Early Career Award for Scientists and Engineers, the US government's highest honor given to early-career scientists.

October 26, 2010: **Dan Rabosky** (Miller Fellow 2009 - 2012) was awarded the Young Investigator Award from the American Society of Naturalists.

October 19, 2010: **Randy Schekman** (Miller Senior Fellow 2008 - 2013) was awarded the Massry Prize.

October 15, 2010: **Feng Wang** (Miller Fellow 2005 - 2008) was awarded a Packard Fellowship for his work on graphene.

September 20, 2010: Mathematics prizes were awarded to the following members:

--**Alexandre Chorin** (Visiting Miller Professor 1971 - 1972, 1982 - 1983) - Lagrange Prize

--**James Sethian** (Miller Professor Spring 2011) - Pioneer Prize

August 24, 2010: **Cédric Villani** (Visiting Miller Professor Spring 2004) was awarded the Fields Medal, one of the highest awards in the field of mathematics.

Birth Announcements

The Miller Institute congratulates:

Darius Plummer and **Tessa Burch-Smith** (Miller Fellow 2007 - 2010) on the birth of Cassandra Averi Plummer on September 24, 2010.

Jeff Townsend (Miller Fellow 2002 - 2005) and **Alison Galvani** (Miller Fellow 2002 - 2005) on the birth of Emily Ella Galvani-Townsend on November, 14 2010.

Obituaries

Daniel Rudolph (Miller Fellow 1976 - 1978), a world leader in the mathematical area of ergodic theory, passed away on February 4, 2010. He was 60 years old.

Roger C. Green (Visiting Miller Professor Fall 1994), an influential archaeologist in the field of Pacific Ocean prehistory and linguistics, passed away on October 4, 2009. He was 77 years old.

Gifts to the Miller Institute

The Miller Institute gratefully acknowledges the following contributors to the Miller Institute programs during 2010. These generous donations help support both the Miller Fellowship program and the general programs of the Institute. Donations can be made by linking to the Miller Institute site at Give to CAL: <https://givetocal.berkeley.edu/browse/?u=77>

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Joshua Shaevitz
Felix Solomon
Jesse Thaler
George & Madeleine Trilling
Dan Virgil Voiculescu

Publications

The following Miller Institute members have recently published works resulting from research during their Miller Institute terms. For more information about these publications, please visit the Miller Institute's website at: millerinstitute.berkeley.edu/publications.htm.

Prashant Jain

Miller Fellow 2008 - 2011

Julius Lucks

Miller Fellow 2007 - 2010

Nicholas Mathevon

Visiting Miller Professor Fall 2008

Isamu Matsuyama

Miller Fellow 2008 - 2011

Maryam Modjaz

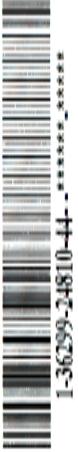
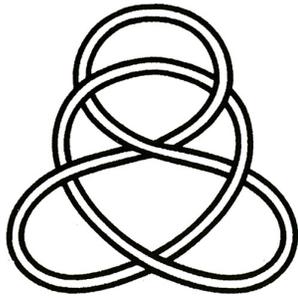
Miller Fellow 2007 - 2010

Daniel Rabosky

Miller Fellow 2009 - 2012

Barbara Romanowicz

Miller Professor Spring 2010



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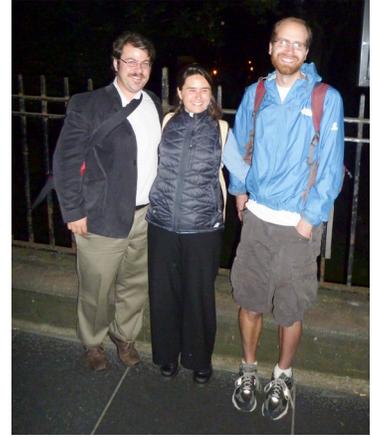
Miller Snapshots



2010 Miller Senior Fellow Saul Perlmutter & Executive Director Michael Manga at the Fall Dinner



Miller Professors Richard Harland and Kathleen Collins with Executive Committee member Craig Evans at the Fall Reception



Jason Stajich (Miller Fellow 2006 - 2009), Anne Pringle (Miller Fellow 2001 - 2004), and Marcus Roper (Miller Fellow 2008 - 2011) at the International Mycological Conference in Edinburgh, Scotland

The Miller Institute is “dedicated to the encouragement of creative thought and the conduct of research and investigation in the field of pure science and investigation in the field of applied science in so far as such research and investigation are deemed by the Advisory Board to offer a promising approach to fundamental problems.”