Spitzer’s Exoplanets: From Hot Jupiters to Earths
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Statement about the Astronomy & Astrophysics 2010 – 2020 Decadal Survey
The Question:

What is the Exoplanet Legacy of the Spitzer Space Telescope?

Legacy: Something received from an ancestor or from the past
Transits Permit Direct Estimates of Masses and Radii

HD 149026 b
Saturn
Jupiter

HD 209458 b

molecular hydrogen and helium
liquid metallic hydrogen
heavy element core

Figures courtesy G. Laughlin
Transits Allows Studies of the Atmospheres That Are Not Possible for Non-Transiting Planets

Transit
See radiation from star transmitted through the planet’s atmosphere

Secondary Eclipse
See thermal radiation and reflected light from planet disappear and reappear

Such studies have proved so penetrating because mass and radius are known.
Transits Allows Studies of the Atmospheres That Are Not Possible for Non-Transiting Planets

Charbonneau, Brown, Collier-Cameron, Deming, Richardson, Wiedemann, and others struggled towards ground-based detection.

Slide courtesy D. Deming
Transits Allows Studies of the Atmospheres That Are Not Possible for Non-Transiting Planets
Important Guideline for Atmospheric Studies:

You need to know of the existence of a planet prior to characterizing its atmosphere.
Exoplanet Masses and Sizes (Entire Universe)

- HD 209458b
- Jupiter
- Saturn
- Uranus
- Neptune

SIRTF Launch Imminent

- 2002
Exoplanet Masses and Sizes

2006: Extent of Known Systems

2006

Cryogen $\frac{1}{2}$ Depleted

radius of planet ($R_{\text{Jup}}$)

mass of planet ($M_{\text{Jup}}$)

Uranus
Neptune
Saturn
Jupiter
Exoplanet Masses and Sizes

Summer 2009

2006: Extent of Known Systems
Spitzer Photometry of an Exoplanet Passing *Behind* Its Star

Charbonneau, Knutson et al. 2008
These Observations Permit Us to Study the Temperature and Chemistry of Exoplanet Atmospheres

Charbonneau, Knutson et al. (2008)
The Infrared Spectrum of the Dayside of a Hot Jupiter

Modest day/night temperature difference indicates efficient heat redistribution.

Hottest point on planet lies east of “high noon”, indicating winds.
Transits Allows Studies of the Atmospheres That Are Not Possible for Non-Transiting Planets

**Detection of:**
- Molecules
- Clouds
- Temperature Inv.
- Day/Night Contrast

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**Secondary Eclipse**
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A Brief History of Progress in Comparative Exoplanetology


Transit Detection

Atmospheric Characterization

Ground Based

Space Based
How did Spitzer inform our quest to study the atmosphere of a habitable exoplanet?
Space-based Searches for Transiting Rocky Exoplanets

- Will monitor 60,000 stars for 150 days
- Can detect Super-Earths

- Will monitor 150,000 stars for 3.5 years
- Will determine rate-of-occurrence of true Earth analogs
Kepler Mission
Successful Launch
March 6th, 2009
Kepler Mission Photometry of the Known Exoplanet HAT-P-7

Borucki et al. Science (2009)
Confirmation and Characterization of Kepler Mission Exoplanets: The Era of Rock and Ice Exoplanets

Warm Spitzer Exploration Science Program
(PI David Charbonneau)
Rejection of Astrophysical False Positives

- If a Kepler candidate results from blend of eclipsing binary, transit will be color dependent.

- Spitzer/IRAC photometry can detect transits as small as 0.03% (perhaps smaller)

- Crucial for physically-associated triples for which Kepler will not detect shift of photocentroid

Spitzer has ALREADY done this for the first transiting Super-Earth, Corot-7b (DDT Program; F. Fressin et al.)
Warm Spitzer Exploration Science Program
800 hours

**Goal 1:**
Directly detect photons from previously inaccessible classes of exoplanets, namely cool Jupiters, hot Neptunes and superhot SuperEarths.
- Dayside temperature
- Presence or absence of temperature inversion
- Determine if eccentricity is near zero

*Study 20 planets at each of 3.6 & 4.5 µm (one 10 hour eclipse per band) for a total of 400 hours*

**Goal 2:**
Transit photometry of candidate terrestrial planets to reject blends of eclipsing binaries.
- Confirm planetary nature of candidate by color-invariance of transit depth.

*Study 40 candidates at 4.5 µm (one 10 hour transit) for a total of 400 hours*
The Path Ahead for Kepler-Detected Rock + Ice Habitable Worlds

Transit Detection → Atmospheric Characterization

Space Based
The Small Star Opportunity

**Habitable Zones**
The habitable zone (gray)—the region where water stays liquid—lies much closer to tiny M stars (below left) than it does to brighter, more massive stars like the sun (right). Earth’s orbit lies beyond the sun’s habitable zone, but atmospheric gases warm the planet.
The Small Star Opportunity

Consider a $7-M_{\text{Earth}} \ 2-R_{\text{Earth}}$ habitable zone planet:

- Transits are deeper
  - Sun: 0.03%
  - M5V: 0.5%
- Transits are more frequent
  - Sun: 365 days
  - M5V: 15 days
- Transits are more likely
  - Sun: 0.5%
  - M5V: 1.6%
- Greater Doppler Wobble
  - Sun: 1.3 m/s
  - M5V: 10 m/s
The MEarth Project

*with* P. Nutzman, J. Irwin, C. Burke, Z. Berta, and E. Falco
Transit Studies of the Atmospheres Are Facilitated by the Small Size of the Star

Secondary Eclipse
See thermal radiation and reflected light from planet disappear and reappear

Transit
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Habitable-Zone Planets Orbiting Low-Mass Stars are Ideal Targets for Atmospheric Studies to Search for **BIOMARKERS**

James Webb Space Telescope is scheduled for launch in 2014.
Planning for JWST Studies of Habitable Super-Earths

See Deming et al. (2009) for details
The Question:

What is the Exoplanet Legacy of the Spitzer Space Telescope?

Legacy: Something received from an ancestor or from the past
Spitzer’s Exoplanet Work:


Transit Detection → Atmospheric Characterization

Spitzer’s Exoplanet Legacy:

2009+: Rock + Ice Habitable Worlds

Transit Detection → Atmospheric Characterization
Spitzer’s Exoplanet Legacy:
An entirely novel, fast-tack approach to the study of inhabited worlds beyond the Solar system.