Planetary Physics from Transits

Sara Seager
Massachusetts Institute of Technology

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Image credit: NASA/JPL-Caltech/R. Hurt (SSC)
Transiting Planet Science

Primary Eclipse
Measure size of transiting planet, see radiation from star transmitted through the planet’s atmosphere

Secondary Eclipse
See thermal radiation from planet disappear and reappear

Learn about:
- Global structure
- Atmospheres
- Eccentricity & Obliquity

Courtesy T. Brown
Zone where transit can be seen from Geometric Transit Probability

\[ P \sim \left( \frac{R_*/a}{a} \right) \]

\[ P(0.05 \text{ AU}) = 10\% \]
\[ P(1 \text{ AU}) = 0.5\% \]
\[ P(5 \text{ AU}) = 0.1\% \]

All known transiting planets have \( P < \) a few days

Loser

Winner
Physics from Transits

Introduction
Interiors
Atmospheres
Habitable Worlds
Interior Composition

An Earth-like planet with Gl 436 b’s mass

Courtesy G. Laughlin
Exoplanet Mass and Radius

Doppler Method

Transit Method

\[ g_P = \frac{2\pi}{P} K^* \left[ \frac{a}{R^*} \right]^2 \frac{1}{\sin i} \]

Seager and Mallen-Ornelas 2003
Southwick et al. 2007
Sozzetti et al. 2007
We infer an exoplanet’s bulk composition from its $M$ and $R$. 


Zapolsky and Salpeter 1969
See also: Stevenson 1985, Valencia et al. 2006ab, 2007; Fortney et al. 2007; Sotin et al. 2007

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See also: Stevenson 1985, Valencia et al. 2006ab, 2007; Fortney et al. 2007; Sotin et al. 2007
GJ 436b may be a water planet with ~10% H/He, or it may be an iron/silicate planet with ~15% H/He, or something else.

Elisabeth Adams, Seager, Elkins-Tanton, submitted to ApJL
Physics from Transits

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Primary and Secondary Eclipse

HD189733 phase curve from Knutson et al. 2007
Eccentricity from Primary and Secondary Eclipse Times

$GJ436b \, e = 0.16 \pm 0.012$

Deming et al. submitted to ApJL

Figure courtesy G. Laughlin
Transit Planet Atmospheres

- **Transit** \([R_p/R_*]^2 \sim 10^{-2}\)
  - Transit radius -> density
- **Thermal Emission** \(T_p/T_*(R_p/R_*)^2 \sim 10^{-3}\)
  - Emitting atmosphere \(\tau \sim 2/3\)
  - Temperature and \(\nabla T\)
  - Thermal phase curve
- **Transmission Spectra** \(\text{atm}/R_*^2 \sim 10^{-4}\)
  - Upper atmosphere
  - Exosphere (0.05-0.15)
- **Reflection** \(p[R_p/a]^2 \sim 10^{-5}\)
  - Albedo
  - Reflected light phase curve
  - Polarization
  - Scattering atmosphere

Each gives complementary information

Seager et al. 2005
Hot Jupiters orbit at ~ 8 R$_*$ and are heated to $T \geq 1000$ K
The Solar System at 10 Parsec

Planets have two flux peaks

Seager et al. 2003
The Solar System at 10 Parsec

Planets have two flux peaks

Seager et al. 2003
Secondary Eclipse

Charbonneau et al. 2005, Deming et al. 2005
Secondary Eclipse

\[ \text{Flux ratio} = 0.551\% \pm 0.030\% \]

\[ \frac{T_p}{T_*} \left( \frac{R_p}{R_*} \right) \approx 5 \times 10^{-3} \]

\[ T_b = 1117 \pm 42 \text{ K} \]

Deming, Harrington, Seager, Richardson 2006
Seager et al. 2005

Four different hot Jupiters have published Spitzer secondary eclipses. All can be fit with black body spectra!
Transmission Spectra
Transmission Spectra

Diagram:
- $R_p$: Substellar point
- Arrow indicating direction of light from star to $R_p$
Transmission Photometry

Water vapor on HD189733
G. Tinetti et al. 2007
Hot Jupiters are Tidally-Locked
Physics from Transits

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The Race to Find a Habitable Planet

Sun-like star

M3

T (K)

9.5404E+02

7.7711E+02

6.0019E+02

4.2326E+02

2.4633E+02
In the News: Gl 581 c

What we know
• A three-planet system
  • a) \( M = 16 \, M_\oplus \), \( a = 0.041 \, \text{AU} \)
  • b) \( M = 5.03 \, M_\oplus \), \( a = 0.073 \, \text{AU} \)
  • c) \( M = 7.7 \, M_\oplus \), \( a = 0.25 \, \text{AU} \)
• Star has \( T_{\text{eff}} \sim 3400 \text{K} \)

Gl 581 Udry et al. 2007

What we do not know
• Radius
• Surface Temperature

GJ 436b: example
• \( T_b = 712 \, \pm 36 \, \text{K} \)

Deming et al. submitted to ApJL
Planetary Physics from Transits

Primary Transit: Bulk Composition from M and R
- Densities of ~20 hot Jupiter exoplanets
- Density for 1 hot Neptune

Secondary Eclipse
- \( T_b \) of 4+ exoplanets
- Eccentricity

Transit Transmission Photometry
- Sodium and water vapor detections

Transiting Super Earths are Highly Anticipated