Ground-based Photometric Detections of Thermal Emission from Hot Jupiters

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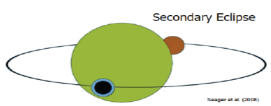
Introduction



The ever-increasing number of exoplanet detections provides an opportunity to study a larger sample of planetary atmospheres, and under different conditions than found in the solar system, such as tidal heating and extreme irradiation. Currently there are two successful methods of detecting light from exoplanets: direct imaging, in which the planet (usually massive, in a long-period orbit around a nearby star) is spatially resolved from the star, but also via secondary eclipse photometry, in which the planet's light is *temporally* distinguished from the starlight as the planet passes behind its host star. By detecting emission at different wavelengths, one can describe the temperature, energy balance, and composition of the planet's atmosphere. A number of detections have been made with the *Spitzer, Hubble, CoRoT*, and *Kepler* space telescopes, but these space-borne observatories are limited in their lifespans and available passbands. Fortunately, this technique has been made possible from the ground, extending the direct study of exoplanet atmospheres to more wavelengths and a larger sample.

Why observe from the ground?
- More telescope time
- Less expensive
- More instruments available
- Fills void between end of *Spitzer* and beginning of *James Webb Space Telescope*


Apache Point Observatory, Sunspot, NM

Disadvantages
- Limited parts of the spectrum available
- Atmospheric interference greatly increases noise

Acknowledgments

Based on observations collected with the Apache Point Observatory 3.5-meter telescope, which is owned and operated by the Astrophysical Research Consortium (ARC).

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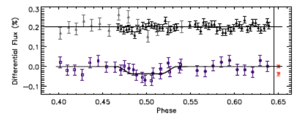
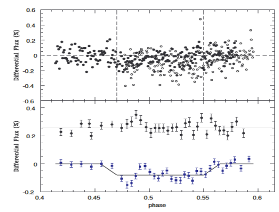
Detections

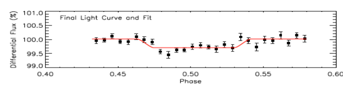


OGLE-TR-56b, z′-band
VLT / FORS2 and Magellan / MagIC-E2V
Eclipse depth 0.0363 ± 0.0091%
Mid-eclipse phase $\phi_{me} = 0.497^{+0.010}_{-0.006}$



WASP-12b, z′-band
ARC 3.5m / SPIcam
Depth 0.082 ± 0.015%
ϕ_{me} = 0.5100 ± 0.0022
Suggests e cos ω = 0.0156 ± 0.0035

This eccentricity is refuted, however, by IRAC (Campo 2010) and ground-based JHK detections (Croll 2010c)



CoRoT-1b, K_S band
ARC 3.5m / NICFPS
Depth 0.336 ± 0.042%
$\phi_{me} = 0.5022^{+0.0023}_{-0.0027}$

Also:
- TrES-3b in K (de Mooij & Snellen 2009), K_S (Croll et al. 2010a)
- CoRoT-1b in NB2090 (Gillon et al. 2009)
- WASP-19b in H (Anderson et al. 2010), NB2090 (Gibson et al. 2010)
- HD189733b in 2.0-2.4 and 3.1-4.1 μm spectra (Swain et al. 2010)
- TrES-2b in K_S (Croll et al. 2010b)
- WASP-12b in J, H, K_S (Croll et al. 2010c)

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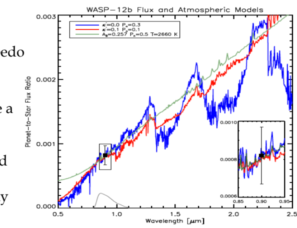
Atmospheric Model Fits

Black body-based models
Planet dayside temperature depends on Bond albedo A_B and energy redistribution factor f [a].

Physical models
Absorption lines will make the planet quite unlike a black body
Radiative transfer, chemical equilibrium
Often require an extra optical absorber to be added

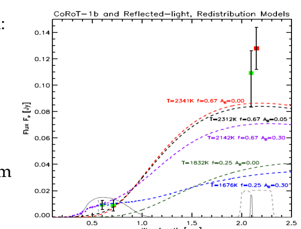
With only one point (e.g. WASP-12b, z′-band), many models fit equally well.



[a] f = ¼ corresponds to equal redistribution of incident energy around the planet; f = 2/3 corresponds to no redistribution from the day side before re-radiation.

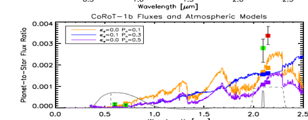
Multi-band color constraints

Combined CoRoT-1b K_S detection with:
NB2090 (Gillon et al 2009)
CoRoT "red" (Snellen et al. 2009)
CoRoT "white" (Alonso et al. 2009)

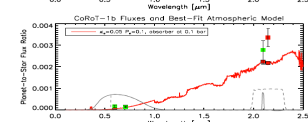


Best-fit black body model suggests:
Very low albedo
Almost zero energy redistribution from day to night side

Physical models:
Extra optical absorber required:
Opacity κ_e = 0.05 cm^2 g^{-1}
Placed at 0.1 bar pressure level, 10 times deeper than in best models for Spitzer detections of other hot Jupiters



No model could sufficiently reproduce the high flux levels in the 2 μm regime (K_S, NB2090).



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