Three-Dimensional Atmospheric Circulation of the Highly Eccentric Extrasolar Planet HD80606b

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Introduction

HD80606b is a 'hot Jupiter' (M_p=4.12 M_J, R_p=1.043 R_J) on an extremely eccentric orbit (e=0.93366, a=0.458 AU). During its ∼111 day orbit, HD80606b experiences huge shifts in the amount of incident flux it receives from its host star, especially near periapse passage. These huge variations in stellar insolation are likely to cause not only dramatic changes in the thermal structure of the planet, but also in global wind patterns. Because HD80606b is known to transit its host star as seen from earth and possess a secondary eclipse that is closely aligned with the periapse of its orbit, it is an ideal target for observations to probe the atmospheric composition, temperature, and dynamics of this planet. Here we present a few results from our study of the atmospheric circulation of HD80606b utilizing our coupled three-dimensional dynamics and radiative transfer model (see [1] for the full details of the SPARC model).

Model Setup

In the simulations presented here we have assumed an atmospheric composition of 1× solar values and have excluded TiO and VO from the opacity tables since it is likely that these species are 'cold trapped' deep in the atmosphere. The nominal rotation rate of the planet was calculated assuming the pseudo-synchronous rotation relationship presented in [2] to be 39.87214 hours. These simulations utilize the cubed-sphere grid [3] with a horizontal resolution of C32 (∼64×128 in latitude and longitude) and a vertical pressure range from 200 bar to 20μbar broken down into 47 layers with even log spacing.

Global Winds

Because HD80606b is subject to large variations in the amount of flux it receives from its host star it is likely to show distinct changes in global wind patterns as a function of orbital phase. Figure 1 shows the zonal-mean zonal winds for HD80606b near the apoapse and periapse of its orbit. The term zonal wind refers to the component of the wind vector that is in the east-west direction while the zonal mean is an average over all longitude for a given latitude. For most of its orbit HD80606b maintains a steady westward jet at the equator with two high latitude eastward jets (top panel). However, during periapse passage the jet structure of planet changes significantly with strong westward winds developing in the upper atmosphere and a strengthening of the eastward jets at higher pressures (bottom panel).

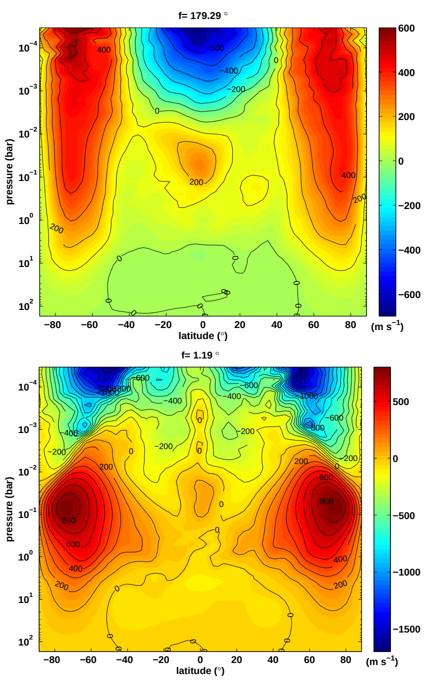

Figure 1: *Zonal-mean zonal winds for HD80606b near apoapse (top) and periapse (bottom). Apoapse and periapse occur at true anomalies (f) of 180° and 0° respectively. The colorbar shows the strength of the zonally averaged winds in m s^{-1}. Contours are spaced by 100 m s^{-1}. Positive wind speeds are eastward, while negative wind speeds are westward. Note the significant change in the jet structure as a function of orbital position.*

The rapid heating that HD80606b experiences as it passes through periapse results not only in changes in the planet's jet structure, but also produces a 'shock-like' feature on the night side of the planet. Figure 2 presents temperature as a function of latitude and longitude at the 1 bar level of our simulation at approximately 16 hours after periapse passage. The strong temperature peak on the night side of the planet remains approximately stationary with respect to the substellar longitude and persists for ∼36 hours after periapse passage.

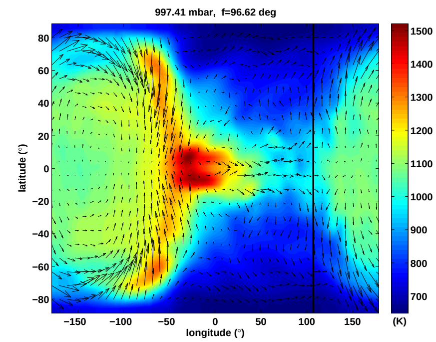

Figure 2: *Temperature (colorscale) and horizontal winds (arrows) at the 1 bar level of our HD80606b model. The length of the arrows represent the strength of horizontal winds with a maximum wind speed of ∼1800 m s^{-1}. The longitude of the substellar point is indicated by the solid vertical line. This is a snap shot taken at f=96°, about 16 hours after periapse passage. Notice the 'shock-like' feature around -50° longitude, which corresponds to the night side of the planet.*

Global Phase Variations

Since our simulations are performed in three-dimensions it is possible for us to investigate changes in the global thermal structure and wind speeds of HD80606b as a function of depth in the atmosphere. Figure 3 presents average temperatures and RMS horizontal velocities as a function of pressure and time relative to the periapse of HD80606b's orbit. At all pressure levels peak temperatures and wind speeds are reached within a few hours after periapse passage. However, both temperatures and wind speeds remain elevated with respect to their pre-periapse values for several days to weeks depending on the pressure level.

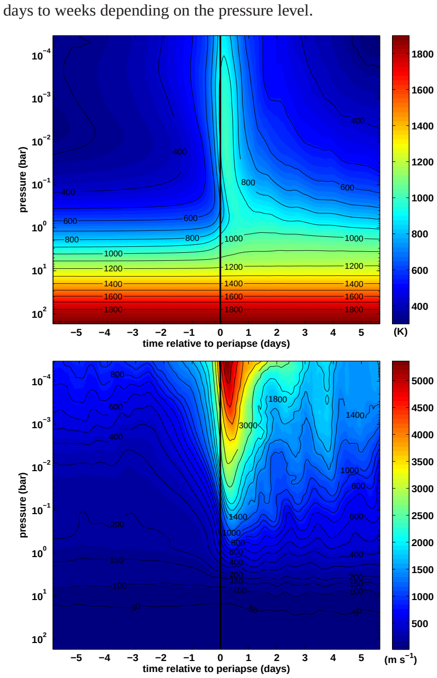

Figure 3: *Average temperature (top) and RMS horizontal velocity (bottom) as a function of time relative to periapse passage. The temperatures and RMS velocities represent averages over latitude and longitude as a function of pressure. Periapse passage is represented by the solid vertical line. On average, peak global atmospheric temperatures and winds are reached ∼5 hours and ∼9 hours after periapse passage respectively.*

Light Curves and Rotation Rate

Our model is uniquely equipped to produce theoretical light curves and spectra for HD80606b that account for both spatial thermal variations and dynamics within the atmosphere. This capability allows us to make observational predictions based on a variety of assumptions about the planet's composition, internal heating, and rotation rate. Figure 4 presents theoretical light curves at each of the *Spitzer* bandpasses for HD80606b assuming rotation rates equal to, less than, and greater than the nominal pseudo-synchronous rotation rate. It is possible for pseudo-synchronous theory to not correctly predict the rotation rate of the planet. The amplitude and shape of the light curves near periapse passage is a strong function of the assumed rotation rate. Extended observations of HD80606b for a day or more after secondary eclipse could possibly be used to determine the rotation rate of this planet.

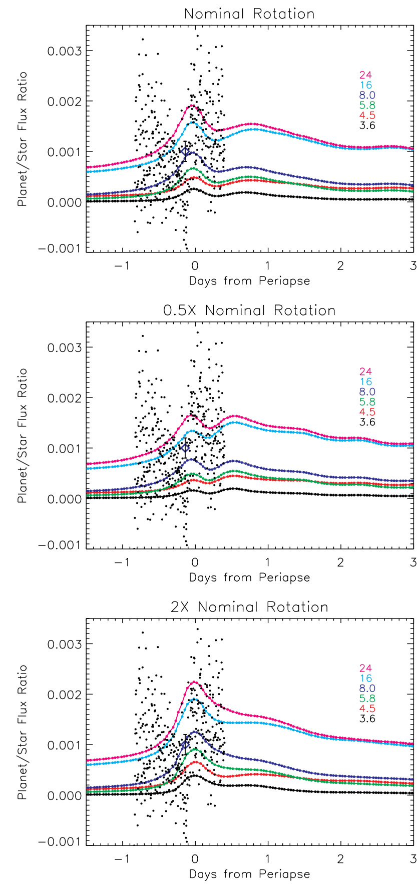

Figure 4: *Planet/Star flux ratio as a function of time from periapse passage in each of the Spitzer bandpasses assuming 1× (top), 0.5× (middle), and 2× (bottom) the nominal pseudo-synchronous rotation rate. Black points represent the 8μm data from [4]. The blue diamond represents the secondary eclipse measurement with error bars from [4]. Varying the rotation rate of the planet has a clear affect on the predicted shape of the light curves around periapse passage.*

Future Work

Our current modeling effort for HD80606b has focused on understanding the basic dynamical changes that occur within the atmosphere as a result of extreme changes in stellar insolation. Future simulations will focus on variations in the composition of the atmosphere and the incorporation of tidal heating effects. Since HD80606b is a prime target of the Warm *Spitzer* mission it is hoped that our models may help to explain these observations in addition to gaining a basic understanding of the dynamical mechanisms at play in this extreme atmospheric regime.

References

[1] Showman et al. (2009), *ApJ*, 699, 564
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[4] Laughlin et al. (2009), *Nature*, 457, 562