EPSC Abstracts
Vol. 6, EPSC-DPS2011-573-1, 2011
EPSC-DPS Joint Meeting 2011

Atmospheric Circulation of hot Jupiters on highly eccentric orbits

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Abstract

We present results from our systematic study of generic hot Jupiters on highly eccentric orbits ($e = 0.0 - 0.75$) using the SPARC/MITgcm, a model that couples a state-of-the-art general circulation model, the MITgcm, with a plane-parallel, two-stream, multi-band radiative transfer model developed by Marley & McKay (1999). In our simulations, we vary the eccentricity of the planet over a wide range to assess the role of time-variable heating on the atmospheric circulation, considering both synchronous and pseudo-synchronous rotation. In particular, we compare pseudo-synchronously rotating eccentric planets to those on circular orbits with equal average stellar flux. Keeping average stellar flux constant serves to disentangle the heating effects due to varying orbital position from those caused by circulation of the atmosphere. In each of these cases, we analyze the planets temperature structure, jet streams and waves, and diagnose dynamical mechanisms for their formation. We expand on previous work by focusing on observational implications. For each of these simulations, we will present synthetic full-orbit light curves to determine the extent to which the meteorological properties can be inferred from from lightcurves and spectra; these observations are greatly affected by the geometry of the system as seen from Earth, as well as the position of the planets hot spot as it orbits its parent star. This work is a vital step to understanding what current and upcoming lightcurve data can say about the physical nature of planets on eccentric orbits.

1. Introduction

To date, approximately 500 extrasolar planets have been detected by various ground and space-based methods. Over half of these are on non-circular orbits, with eccentricities as high as 0.97. Such scenarios lead to highly time-variable heating, which has large implications for the planet's overall temperature structure and atmospheric circulation.

A number of these highly eccentric exoplanets transit their host stars (e.g. HD80606b, GJ436b, HAT-P-2b), allowing us to probe their atmospheres from transit to secondary eclipse as has been done for those on circular orbits (e.g. HD189733b, [1]; HD209458b, [2]). However, extracting planetary information from the data can be challenging, as the convolution of spatial effects (hot spots rotating into and out view), and temporal effects (planet getting colder/warmer at apoapse/periapse passage) can complicate its interpretation. Hence, a comprehensive study that establishes the dynamical regime, temperature structure, and observational implications of this unique class of planets is crucial.

Therefore, we use the SPARC/MITgcm to conduct a systematic study of highly eccentric hot Jupiters (see below). Here we a description of our model, as well as anticipated results.

2. Model description and anticipated results

We use the Substellar Planetary Atmospheric and Radiation Circulation (SPARC) Model, which couples the MITgcm [3] with a plane-parallel, two-stream radiative transfer model developed by [4] (see [5] for a full description of the model). The MITgcm solves the primitive equations, a simplified set of the Navier-Stokes equations assuming hydrostatic balance. The MITgcm utilizes a cubed-sphere grid geometry that eliminates the polar singularities that arise from a traditional latitude-longitude geometry. This also allows for a longer dynamical timestep. The radiative transfer code by [4] assumes a plane-parallel atmosphere, solving for upward and downward fluxes through each pressure level. Opacities are binned using the correlated-k method ([6]).

For our simulations, we assume the mass, radius and gravity of a "generic" hot Jupiter – HD189733b, although we could have easily chosen HD 2095458b or any other hot Jupiter. We assume an atmospheric composition of 1$\times$ solar with no stratospheric absorber (e.g. no TiO, VO). Each simulation has a horizontal resolution of C32 (64x128 in latitude and longitude) and a vertical pressure range of $\sim$200 bar to $\sim$20 μbar split into 76 levels with even log spacing.

Figure 1 shows our simulations as a function of eccentricity and semimajor axis, plotted against a portion of the current exoplanet population. Each row from left to right has constant average stellar flux, thus eliminating ambiguity about variable heating affects due to eccentricity. Planets on circular orbits are assumed to synchronously rotate their host star ($T_{rot} = T_{orb}$). For all eccentric cases, the rotation rate was calculated using the pseudo-synchronous formulation in [7].

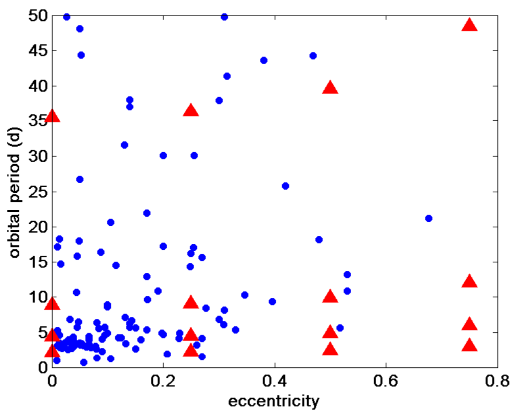

Figure 1: Grid simulations plotted as a function of eccentricity and semimajor axis. Red triangles denote our simulations, while blue circles denote detected exoplanets.

Using these inputs and assumptions, we will conduct our study aiming to answer the following questions:

- How does the wind/temperature structure of each planet's atmosphere vary with average stellar flux and eccentricity?
- How do atmospheric features such as jet streams and waves vary with orbital phase? What mechanisms drive their formation?
- How might these characteristics affect the planet lightcurves and spectra? What, if any, meteorological and physical properties can be obtained from these observations?

References

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