EPSC Abstracts
Vol. 6, EPSC-DPS2011-603-1, 2011
EPSC-DPS Joint Meeting 2011

Doppler signatures of the atmospheric circulation on hot Jupiters

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Abstract

To date, the exotic meteorology of hot Jupiters has primarily been characterized with thermal measurements of secondary eclipse depths and phase curves, providing only indirect clues to the wind regime. Recently, however, Snellen et al. (2010) presented high-resolution groundbased spectra of HD 209458b obtained during transit. From analysis of the data, they reported an overall 2±1 km/sec blueshift in 56 spectral lines of carbon monoxide, which they interpreted as a signature of atmospheric winds flowing from dayside to nightside toward Earth along the planet's terminator. Although the detection is tentative, these observations pave the way for an entirely new approach to characterizing hot Jupiter meteorology.

Motivated by these observations, we describe the types of Doppler signatures generated by the atmospheric circulation and show how Doppler measurements can place powerful constraints on the meteorology. We show that, depending on parameters, the atmospheric circulation—and Doppler signature—of hot Jupiters split into two regimes. In one regime, at moderate stellar insolation, the day-night thermal forcing generates fast east-west jet streams from the interaction of standing planetary-scale waves with the mean flow. In this regime, air along the terminator (as seen during transit) flows strongly toward Earth in some regions and away from Earth in others, leading to a bimodal Doppler signature exhibiting distinct, superposed blue- and redshifted velocity peaks. In the other regime, which occurs at intense stellar insolation, the thermal forcing is so strong that it damps these planetary-scale waves, inhibiting their ability to generate jet streams. As a result, this second regime exhibits a circulation dominated primarily by high-altitude, day-to-night airflow along both terminators rather than longitudinally symmetric jets. This implies that air flows toward Earth along most of the terminator, leading to a predominantly blueshifted Doppler signature during transit. We present state-of-the-art three-dimensional circulation models including non-grey radiative transfer to quantify this regime shift and the resulting Doppler signatures; these models suggest that HD 189733b lies in the first regime while HD 209458b lies in the second regime. Moreover, we show how the amplitude of the Doppler shifts and the inferred velocities place strong constraints on the strength of frictional drag—due to Lorentz-force braking or other processes—in the upper atmospheres of hot Jupiters.

References

[1] Snellen, I.A.G., de Kok, R.J., de Mooij, E.J.W., and Albrecht, S.: The orbital motion, absolute mass and high-altitude winds of explanet HD 209458b. Nature, Vol. 465, 1049-1051, 2010.