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Dynamical theory driven west on CoRoT-2b

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A peak in the infrared phase curve occurring after eclipse suggests a westward shift in the dayside hotspot of hot giant exoplanet CoRoT-2b, calling into question our understanding of atmospheric dynamics on hot gas giants.

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Gas giant exoplanets in close orbits around their parent stars experience extreme irradiation. Previous theoretical studies[1,2] indicate that the hottest region of the planet is usually shifted eastward (in the direction of rotation) from the point on the planet directly beneath the star – the substellar point. Writing in *Nature Astronomy*, Lisa Dang and collaborators[3] describe observations of hot Jupiter CoRoT-2b, obtained using NASA's infrared Spitzer space telescope, that suggest this planet bucks the trend with a westward shift in the position of the hotspot.

Due to their close orbits, hot Jupiters are expected to be tidally locked and in synchronous rotation. Spitzer measurements of planetary flux as a function of orbital phase have provided longitudinal temperature maps for several of these. The majority of these phase curves show a peak in brightness that occurs prior to secondary eclipse[4–10], interpreted as a shift in the hottest region of the atmosphere eastward from the substellar point (Figure 1). A large day-night temperature gradient is typical for a hot Jupiter, and drives a broad equatorial eastward-flowing jet which shifts the hottest region to eastern longitudes.

Dynamical models of hot giant exoplanets predicted this eastward shift[1] and to date all Spitzer phase curve observations have been consistent with this, or with no shift at all. Dang et al.[3] present the first counter example. Their target, CoRoT-2b, is not a typical hot Jupiter: it orbits a particularly active host star; its radius is extremely inflated; and it has a remarkably featureless emission spectrum. A westward hotspot shift can now be added to this list of unusual attributes, and this is probably not a coincidence.

The authors of the study present three possible explanations for a westward hotspot (Figure 1). If expectations of hot Jupiter tidal locking are flawed, the planet may be rotating more slowly than (or in the opposite direction to) its orbit, resulting in westward rather than eastward winds as a resut of this sub-synchronous rotation. Westward winds could also result from magnetic effects in the atmosphere even if the planet is tidally locked[11]. A third possibility is that CoRoT-2b's eastern hemisphere is cloudy and the western hemisphere relatively clear, which would mute the thermal signal from the eastern hemisphere and potentially decrease stellar heating in the eastern hemisphere relative to the western.

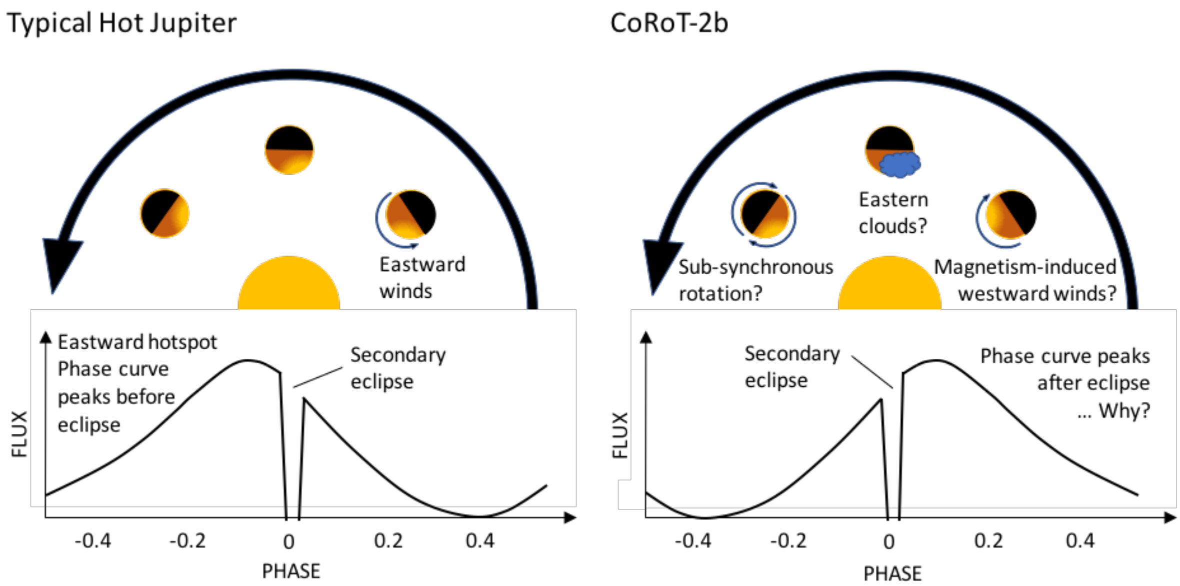

Figure 1. Phase curve of a typical hot giant exoplanet. The left panel shows a typical hot Jupiter phase curve with the peak occurring prior to secondary eclipse. This is explained by eastward (synchronous) rotation of the planet and super-rotating winds shifting the hottest region to the east. The right panel shows a similar phase curve but with the peak occurring after secondary eclipse, similar to that observed for CoRoT-2b. Scenarios that could explain this include sub-synchronous rotation, magnetically induced westward winds, or clouds in the eastern hemisphere.

Dang et al. suggest that the westward hotspot may be linked to the other unusual attributes of CoRoT-2b. The highly active parent star makes it likely that the planet experiences high levels of X-ray and extreme ultraviolet radiation. The resultant photo-ionization in the atmosphere could induce a magnetic field, coupled to the magnetic dynamo of the planet itself, which may provide an underlying mechanism for westward winds. Strong internal magnetic fields are likely to be correlated with inflated planetary radii[12], so CoRoT-2b's inflated radius provides supporting evidence for this scenario.

The featureless secondary eclipse spectrum lends weight to the eastern cloud hypothesis. In eclipse, the planet/star flux contrast can be measured as a function of wavelength; atmospheric absorbers leave their fingerprints on the spectrum, and the temperature-pressure profile can be inferred from the variation in contrast between wavelengths of high and low atmospheric opacity. Hot Jupiters are expected to show absorption due to H_2O at near-infrared wavelengths, so the absence of molecular features in the spectrum of CoRoT-2b implies that the atmospheric temperature is the same at all pressures probed across the observed wavelength range, with a possible explanation being the presence of an opaque, grey cloud.

A cloud that is thicker over the eastern hemisphere of the planet compared with the western hemisphere could produce the observed westward hotspot shift. However, an eastern cloud is contrary to predictions by dynamical models, which suggest that clouds condense out on the cool nightside of the planet, are advected onto the dayside by eastward winds, and gradually evaporate, resulting in a cloudy western hemisphere and a clear eastern hemisphere[2]. Condensational clouds coupled with westward winds — either magnetically induced or due to sub-synchronous rotation — could be the answer, or photochemically-produced aerosols produced in the substellar region that would then be advected eastwards.

Further observation at shorter wavelengths may be used to test the cloud hypothesis. Phase curves obtained using the Kepler Space Telescope for Kepler-7b have shown apparent westward shifts in the brightest part of the planet[13]. The Kepler bandpass is sensitive to both reflected starlight and thermal emission from the planet, and western clouds with a high albedo can explain the observed shifts. A visible wavelength phase curve of CoRoT-2b – perhaps obtained with the future NASA TESS or ESA CHEOPS satellites – could therefore potentially place constraints on the eastern cloud hypothesis. Even more intriguingly, HAT-P-7b shows varying westward and eastward shifts in the Kepler phase curves, suggesting subtle time-variable interaction between reflection and emission components[14]. With only a single full orbit observed here for CoRoT-2b, similar variability cannot be ruled out and is an exciting possibility.

All of the explanations put forward by Dang et al.[1] are plausible, but in different ways call into question our current understanding of exoplanet science. Mechanisms for sub-synchronous rotation and magnetically induced westward winds are unknown, and so far are not predicted by models. Similarly, atmosphere models predict a cloudier western hemisphere, which does not explain the observations. CoRoT-2b presents an ideal opportunity to improve our understanding in all of these areas through further observation and modelling.

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