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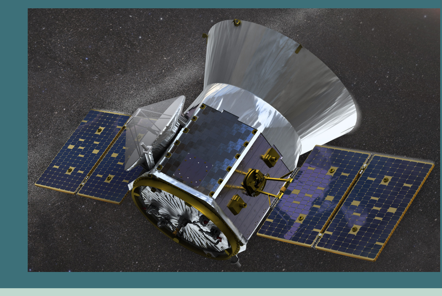
Magnetically-driven hotspot reversals in ultra-hot Jupiter atmospheres

TESS Science Conference II



Background

- Hot Jupiter (HJ) atmospheres generally have eastward (prograde) hotspot offsets [1]
- Eastward hotspots are explained by hydrodynamic simulations & theory of synchronously-rotating HJs [2]
- Five observations of westward/oscillating-east-west hotspots/brightspots: HAT-P-7b (Kepler) [3]; CoRoT-2b (Spitzer) [4]; Kepler-76b (Kepler) [5]; WASP-12b (Spitzer); WASP-33b [7] (TESS)
- 3D magnetohydrodynamic (MHD) simulations show that HJs with strong magnetic fields may experience equatorial wind variations, hence *westward hotspots* [8]
- Other explanations: cloud asymmetry [3] and non-synchronous rotation [9]. To date, not well-explained in ultra-hot Jupiters [10]

Atmospheric magnetic field geometry

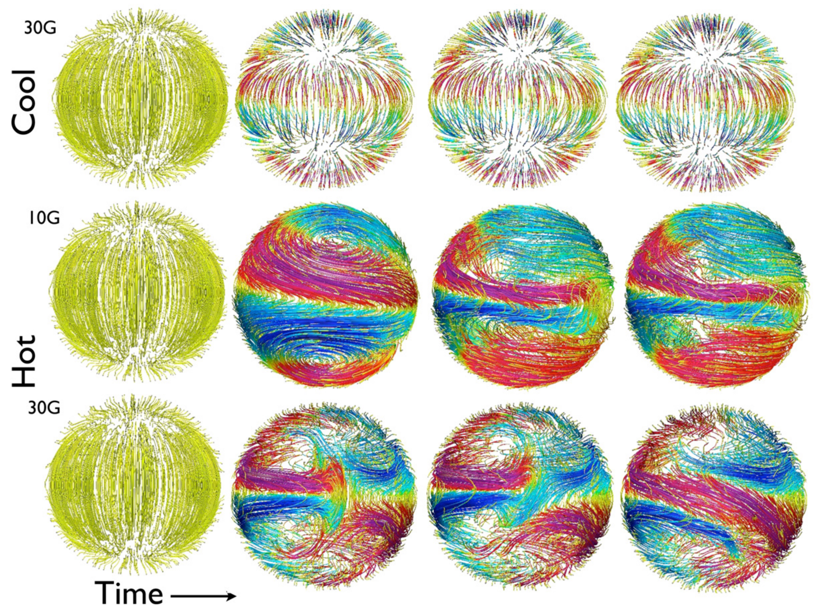


Figure 1: Taken from [8]. Evolution of magnetic field profiles in three-dimensional MHD simulations. Colours represent toroidal field magnitude (red/magenta positive; blue/green negative; yellow moderate)

Shallow-water MHD (SWMHD) model

- **Aim**: understand mechanics of reversals with reduced model

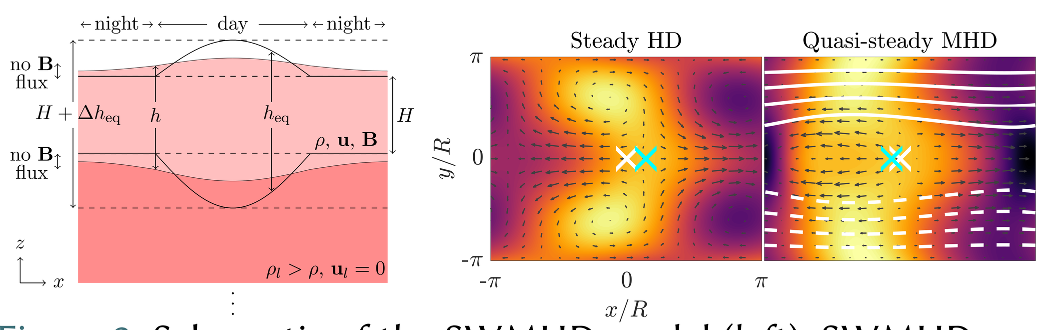


Figure 2: Schematic of the SWMHD model (left); SWMHD solutions (right), with substellar points (white) & hotspots (cyan) marked, and velocity vectors & white magnetic field lines overlaid (solid positive; dashed negative)

Reversal mechanism

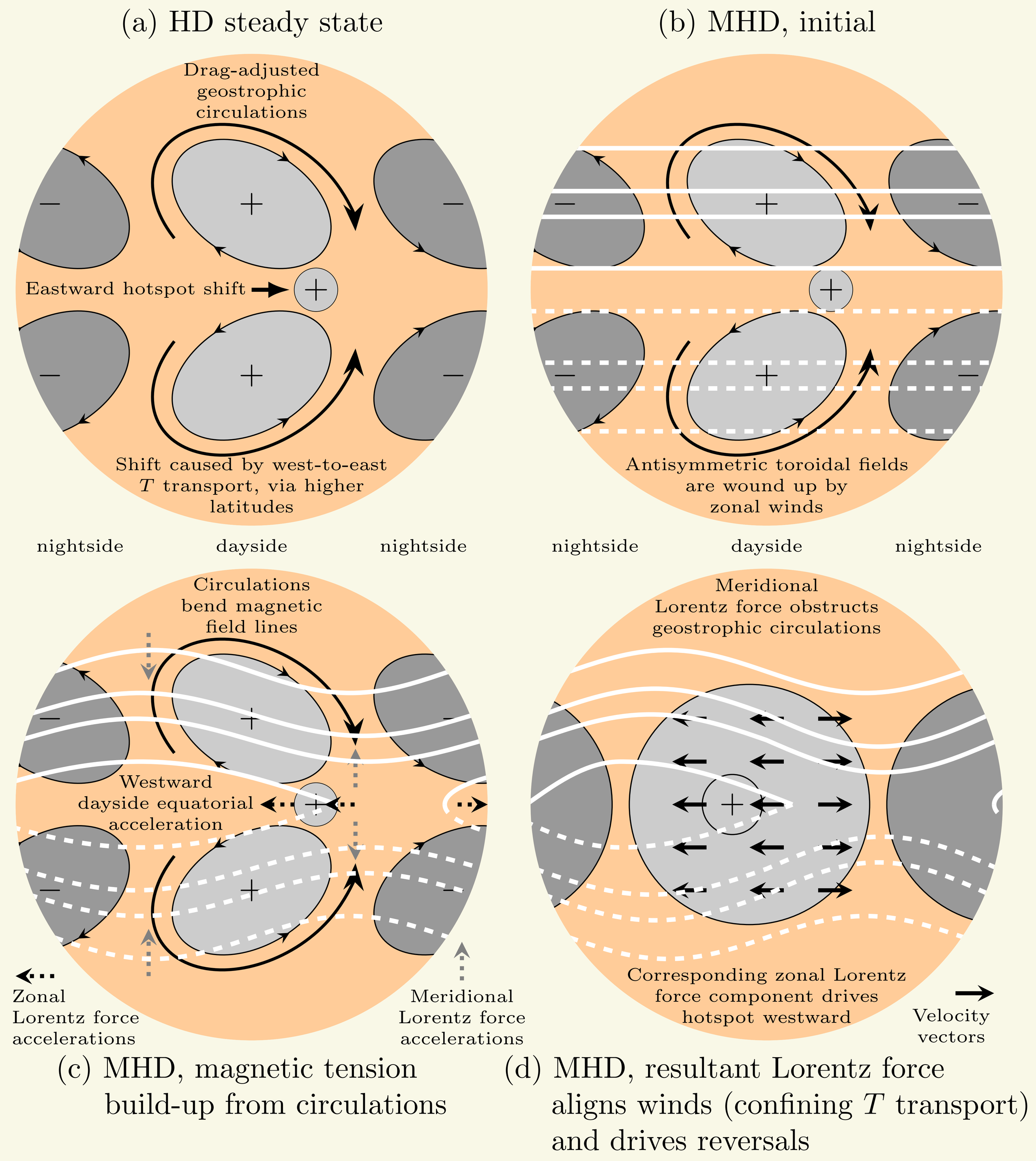


Figure 3: Schematic of magnetic reversal mechanism, with grey temperature contours and white magnetic field lines (solid positive; dashed negative) [12]

Criteria for hotspot reversals

- Hotspots reverse when $V_A \geq V_{A,crit}$, where V_A is the Alfvén speed, and

$$\frac{V_{A,crit}}{c_g} \approx \max\left[\frac{\beta/c_g}{1/R^2+3\beta/c_g}, \alpha\left(\frac{\Delta h_{eq}}{H}\right)\left(\frac{\tau_{rad}}{\tau_{wave}}\right)^{-1}\left(\frac{2\Omega\tau_{wave}^2}{\tau_{rad}}+1\right)^{-1}\right] \quad (1)$$

- The toroidal field strength (B_ϕ) is related V_A by $B_\phi = \sqrt{\mu_0\rho}V_A$
- The deep-seated magnetic field strength (B_{dip}) is related to B_ϕ by $B_\phi \sim R_m B_{dip}$ [8, 11], where

$$R_m = \frac{U_\phi H}{\eta}, \quad \eta = 230\times10^{-4}\frac{\sqrt{T}}{\chi_e(T,\rho)}\,\mathrm{m^2\,s^{-1}}$$

- χ_e and, therefore, R_m are *highly* T dependent
- $R_m \gtrsim 1$ for $T_{eq} \gtrsim 1500$ K
- At $P = 10$ mbar, $100\,G \lesssim B_{\phi,crit} \lesssim 450\,G$

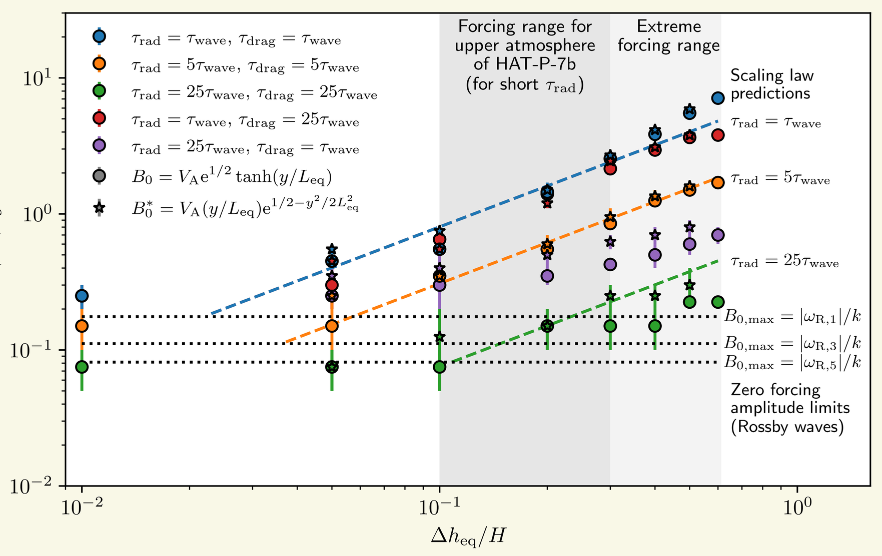


Figure 4: Equation (1) vs. simulations. [12]

Critical dipole magnetic field strengths

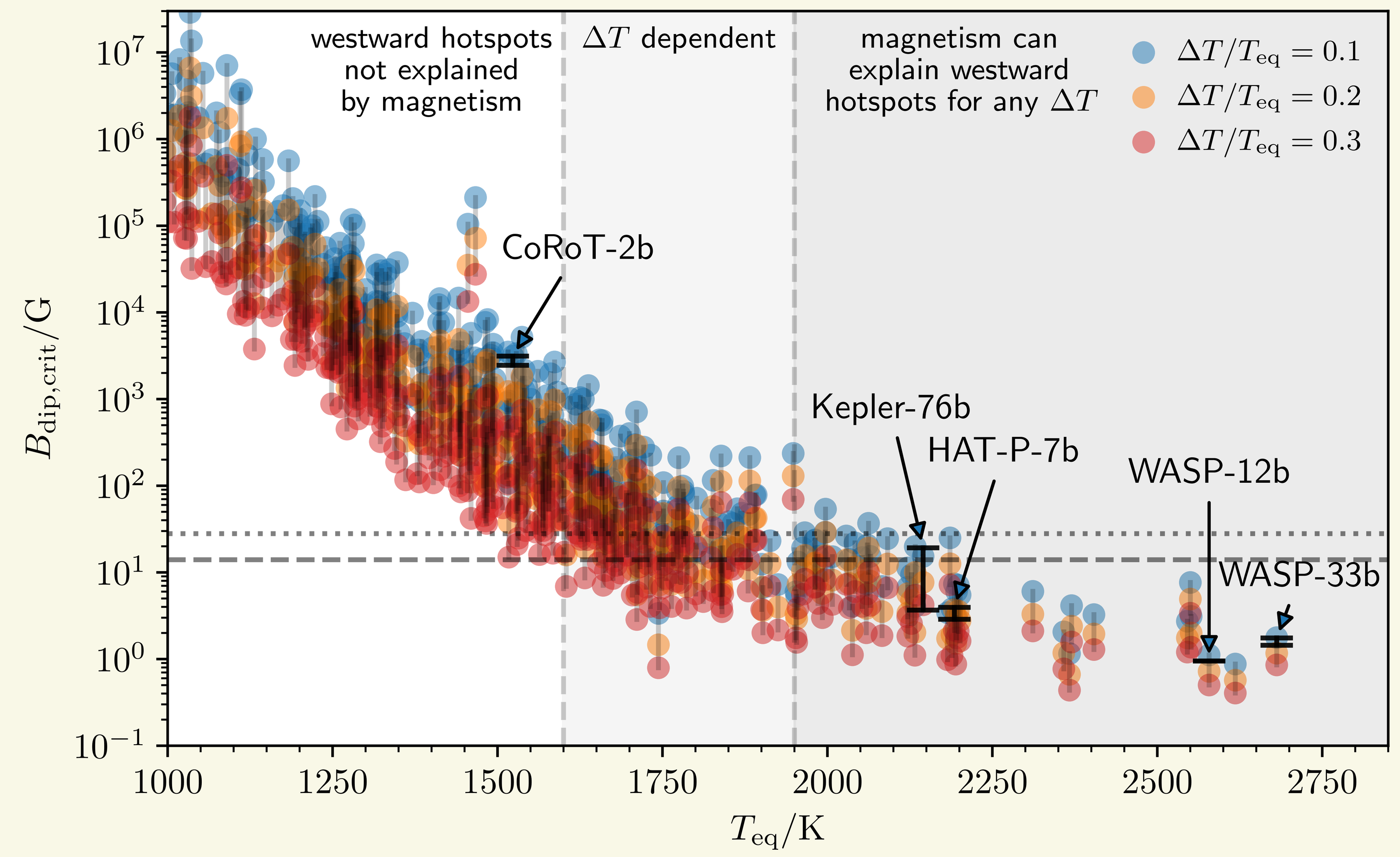


Figure 5: T_{eq} vs. $B_{dip,crit}$ (at $P = 10$ mbar), for HJs in the exoplanet.eu dataset. Reference lines at 14 G (dashed; Jupiter's polar surface magnetic field strength) and 28 G (dotted; twice this) are included. Calculated for $T_{day} = T_{eq} + \Delta T$, with $\Delta T/T_{eq} = 0.1, 0.2, 0.3$ (blue, orange, red) or with $\Delta T/T_{eq}$ based on phase curve measurements (annotated error bars). [13]

Guiding future TESS research

- Can indicate HJs likely to exhibit magnetic signatures
- Guiding future work, with *B. Jackson & E. Adams*, investigating the following HJs of interest (*see Brian Jackson's poster*):

Candidate	T_{eq}/K	$B_{dip,c,0.1}$	$B_{dip,c,0.2}$
Qatar-10b^{TESS}	1955	13G	7G
WASP-3b^{TESS}	1997	29G	16G
Kepler-7b^{Kepler}	1632	50G	19G
KELT-18b^{TESS}	2083	7G	4G
WASP-48b^{TESS}	2059	7G	4G

Table 1: A Reversal criteria, $B_{dip,c,0.1}$ (taking $\Delta T/T_{eq} = 0.1$) and $B_{dip,c,0.2}$ (taking $\Delta T/T_{eq} = 0.2$), at $P = 10$ mbar tabulated with T_{eq}.

- 65 HJs of interest are highlighted in [13]
- Future observations can inform on typical HJ B_{dip} values
- Note: HAT-P-7b & Kepler-76b's observed brightspot oscillations ~10-100 days [3, 5]

References

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