Comparative Planetology of Magnetic Effects in Ultrahot Jupiters

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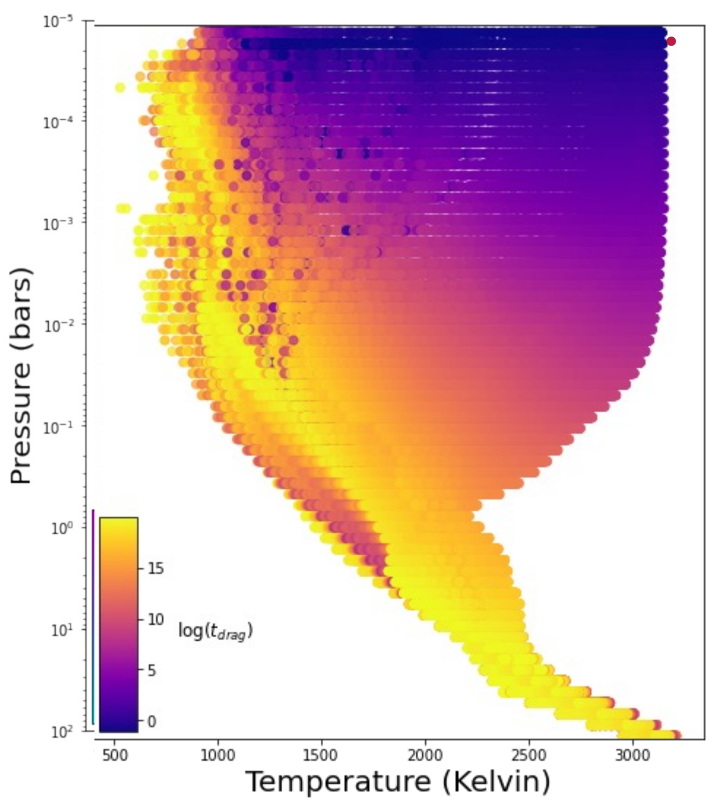
1. Magnetic Effects in (Ultra)Hot Jupiters

- Ultrahot Jupiters (UHJs) have strongly irradiated daysides resulting in **thermal ionization** of atmospheric species [1]. These ions will experience **a Lorentz force** as they move across magnetic field lines via strong planetary winds
- Modeling the effects of magnetism in 3D models is difficult; non-ideal MHD equations are computationally expensive and uniform drag treatments don't allow for variation across temperature regimes
- We use an **active magnetic drag prescription,** [2,3]which uses a drag timescale, applied as a Rayleigh drag, to vary as a function of local density (ρ), resistivity (η), latitude (ϕ), field strength (*B),* and temperature:

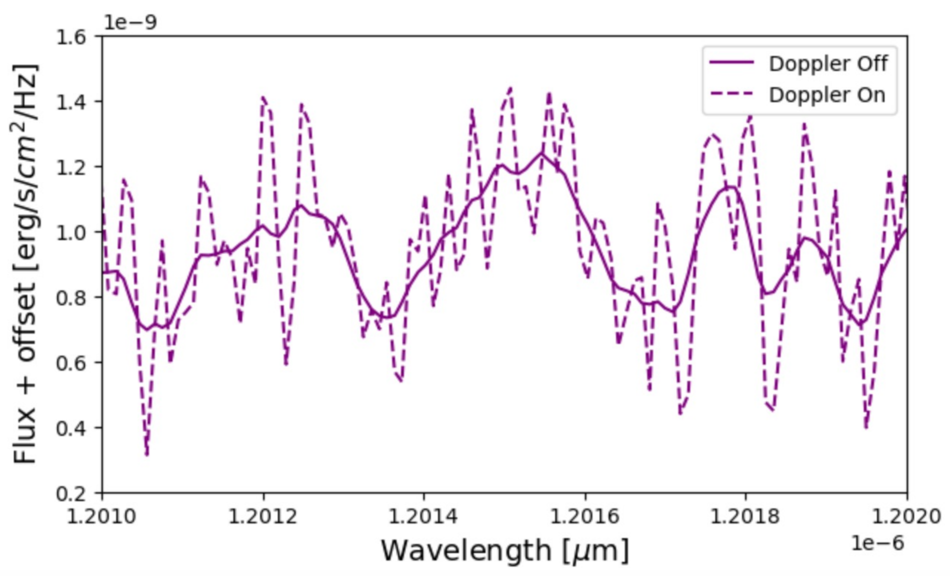
$$\tau_{mag}(B,\rho,T,\phi) = \frac{4\pi\rho\eta(\rho,T)}{B^2|sin(\phi)|}$$



Temperature-pressure profiles (*left*) from our 3 Gauss model of WASP-76b color-coded by the log of the active drive timescale in seconds. With this prescription, a single pressure level can have timescales that vary by over 10 orders of magnitude from day to night! The strongest drag, corresponding to the shortest timescales, occur in the dayside upper atmosphere, where magnetic effects are expected to be the strongest.

2. Doppler Shifts as a Function of Phase with High Resolution Spectroscopy

With High Resolution Spectroscopy (HRS), we are able to probe atmospheric dynamics to an unprecedented level of precision[4]. Doppler effects from winds and rotation will broaden and shift the lines (*below*).



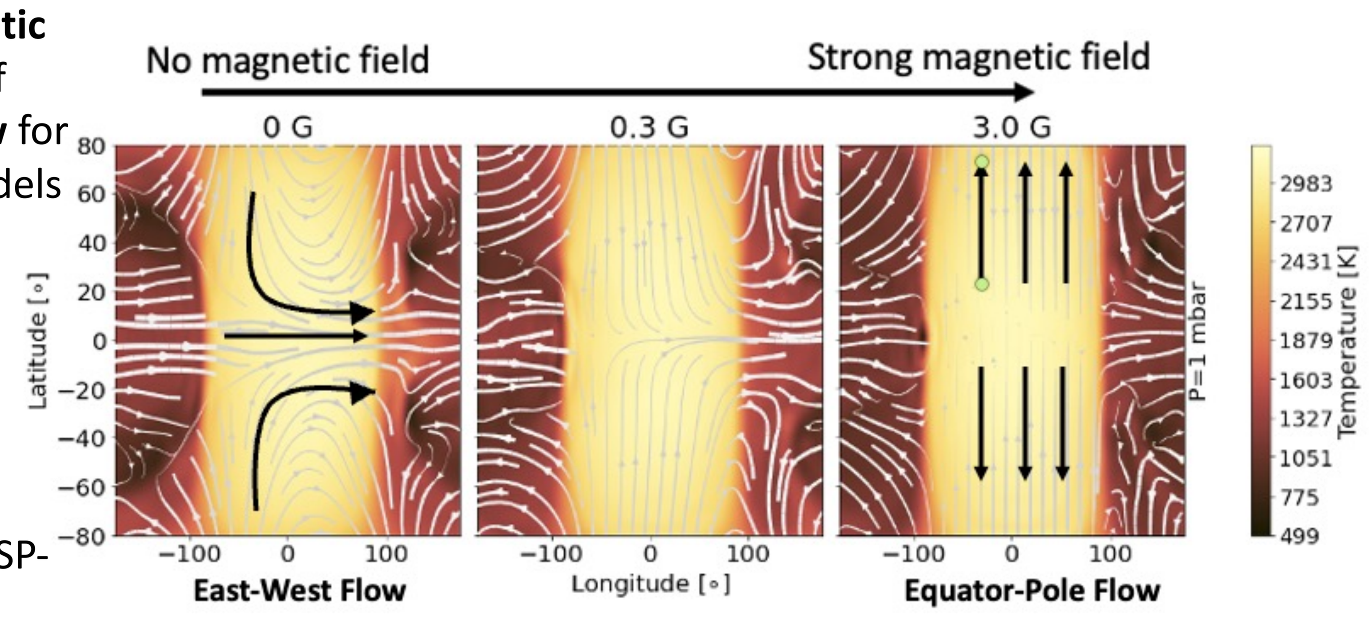
With cross-correlation, we are able to detect the velocity shift that is a best match to the Doppler On spectra, telling us **the velocity shift of the spectra at that phase!**

3. Magnetic Circulation Regime for UHJs

In Beltz et al 2022a[5], we identified the emergence of a **magnetic circulation regime** present in the dayside upper atmospheres of UHJs. This circulation pattern consists **of dayside poleward flow** for a non-tilted, dipolar magnetic field while our non-magnetic models show dayside east to west flow. **We searched for Doppler shift patterns in this circulation regime** for three different UHJs:

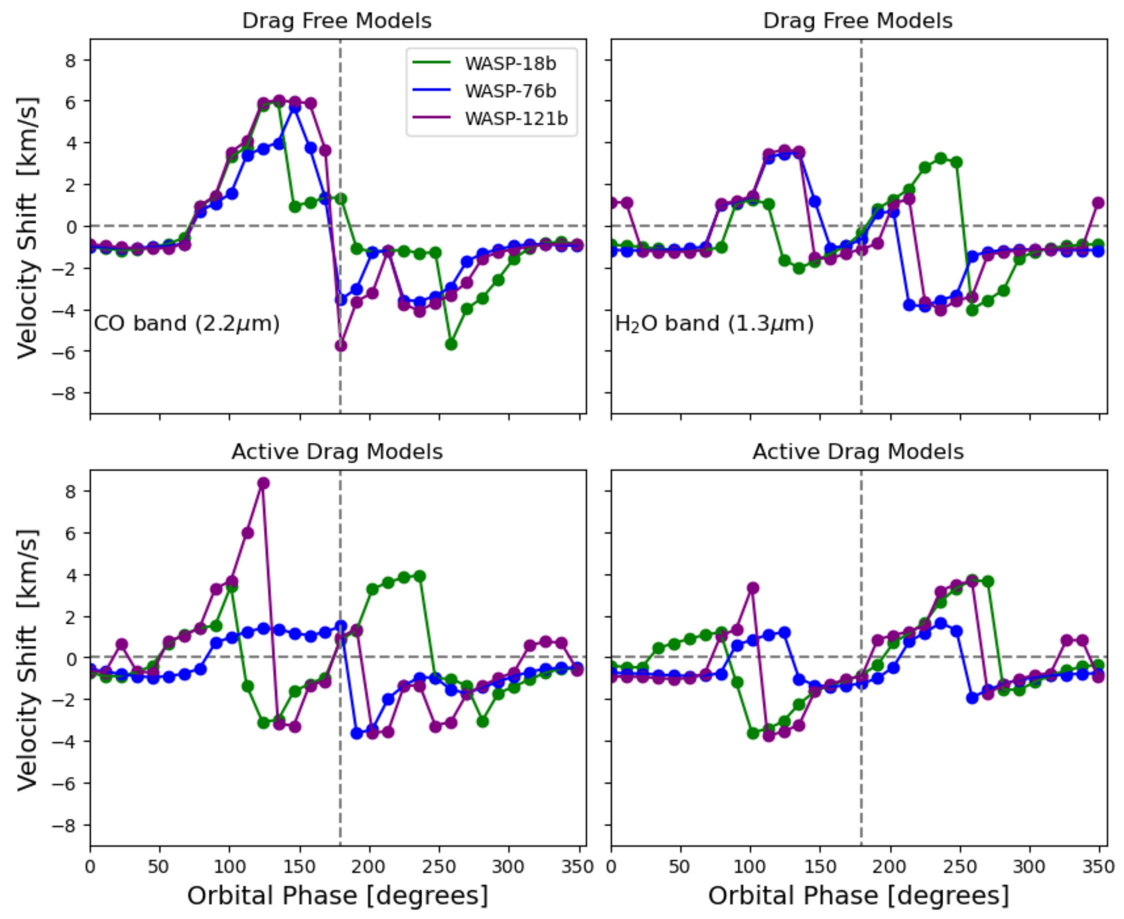
Planet	Radius	Gravity	Orbital Period	Substellar Irradiation	Equilibrium Temperature
WASP-76b	1.31×10^8 m	6.83 m s^{-2}	1.81 days	5.14×10^6 W m^{-2}	2183 K
WASP-121b	1.33×10^8 m	8.45 m s^{-2}	1.27 days	7.01×10^6 W m^{-2}	2358 K
WASP-18b	0.89×10^8 m	166.28 m s^{-2}	0.94 days	8.02×10^6 W m^{-2}	2469 K

We chose field strengths of 3G, 3G, and 20G for WASP-76b, WASP-121b, and WASP-18b respectively, based on published phase curves.



4. Initial Results: Magnetic Effects in High Resolution Spectra

Trends in Emission:



By comparing the net Doppler shifts of the high-resolution emission spectra in a CO and a water band between our drag free and active drag models (*above)* **we can identify trends in our active model near secondary eclipse.**

-For CO, our active drag models are more likely to be blueshifted prior to secondary eclipse

-For water, our active drag models are more likely to be redshifted after secondary eclipse

These trends are due to a combination of the 3D structure of winds, temperatures, and wavelength choice.

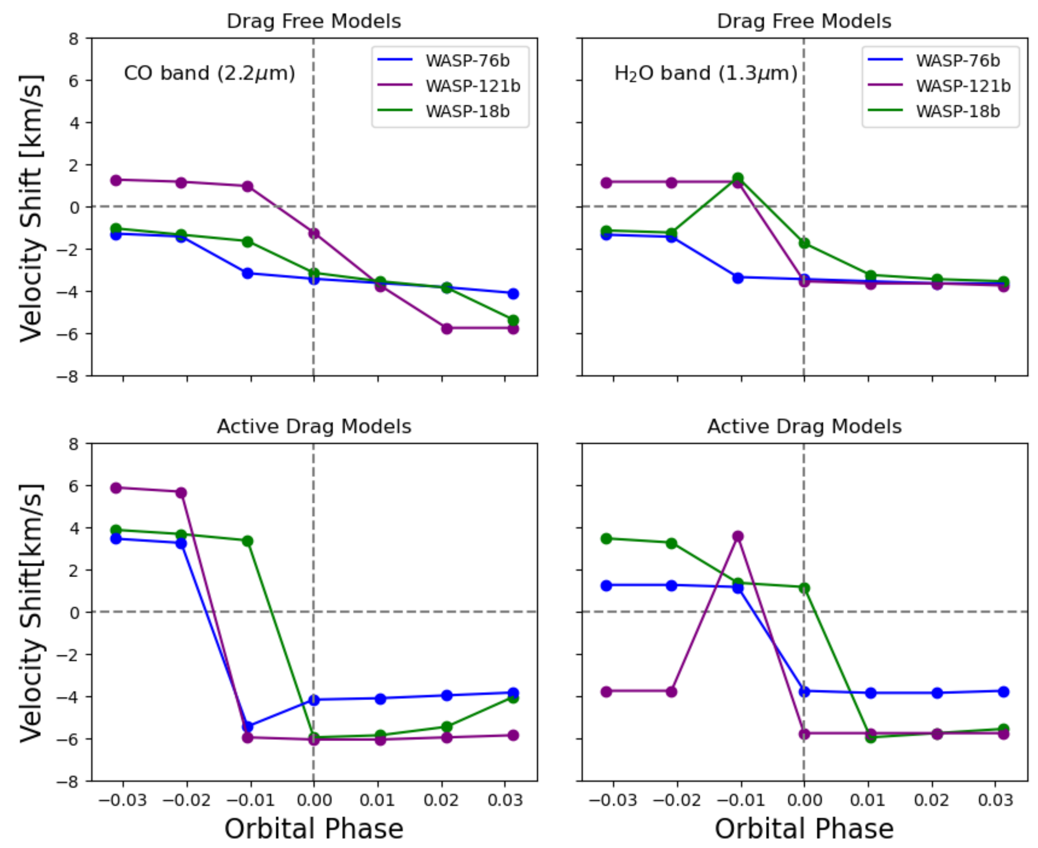
Trends in Transmission:

We also calculated the net Doppler shifts for seven phases during transit for each model (*below).* For transmission spectra, we note that **the shape of our Doppler shift as a function of phase depends on the choice of drag prescription**:

-Our drag free models tend to have a shallow slope and slowly become more blueshifted as transit progresses

-Our active drag models show a steep slope followed by a flattening of the net Doppler shift

-This is more strongly seen in the CO band, but strong hints of this trend are still present in the water band



5. Preliminary Conclusions and Future Steps

We have explored the effects of our active drag prescription for three different UHJs. Our initial conclusions are:

-all three UHJs modeled showed the emergence of the magnetic circulation regime

-In high-resolution emission spectra, **we have identified trends in net Doppler shifts near secondary eclipse that could indicate the presence of this magnetic circulation regime** for two different species: CO and H_2O

-In high-resolution transmission spectra, we found **that models with magnetic drag show a distinct shape in their Doppler shift as a function of orbital phase curves that differs from the drag-free models,** particularly for the CO band.

Future work will explore the impact of non-solar metallicity, tilted dipoles, H_2 dissociation on our active drag models.

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References

1. Parmentier et al 2018
2. Perna et al 2010
3. Rauscher & Menou, 2013
4. Birkby & Brogi 2021
5. Beltz et al 2022a