The Effects of Kinematic MHD on Eccentric Hot/Near-Ultrahot Jupiter GCMs

Willow Houck[1], Hayley Beltz[1], Thaddeus Komacek[1]
[1]University of Maryland, College Park

3D GCMs of an Eccentric Hot/Near-Ultrahot Jupiter

Hot and Ultrahot Jupiters are expected to be in tidally locked orbits with their host star, causing there to be a permanent dayside and nightside. However, when a sufficient eccentricity is applied to the system, they will not be tidally locked, resulting in non-synchronous rotation [3]. Previously, studies using 3D atmospheric models have been done on the effects of eccentricity on Hot Jupiter atmospheres. However, these studies were on planets solely in the warm or Hot Jupiter regimes [4].

- We study the case of HJ **TOI-150b.** Its characteristics include [2,5]:
  - e=0.26
  - Maximum full-redistribution temperature of 1711K and minimum full-redistribution temperature of 1310K
  - Radius of 1.38 RJ
  - Orbits a F-type star

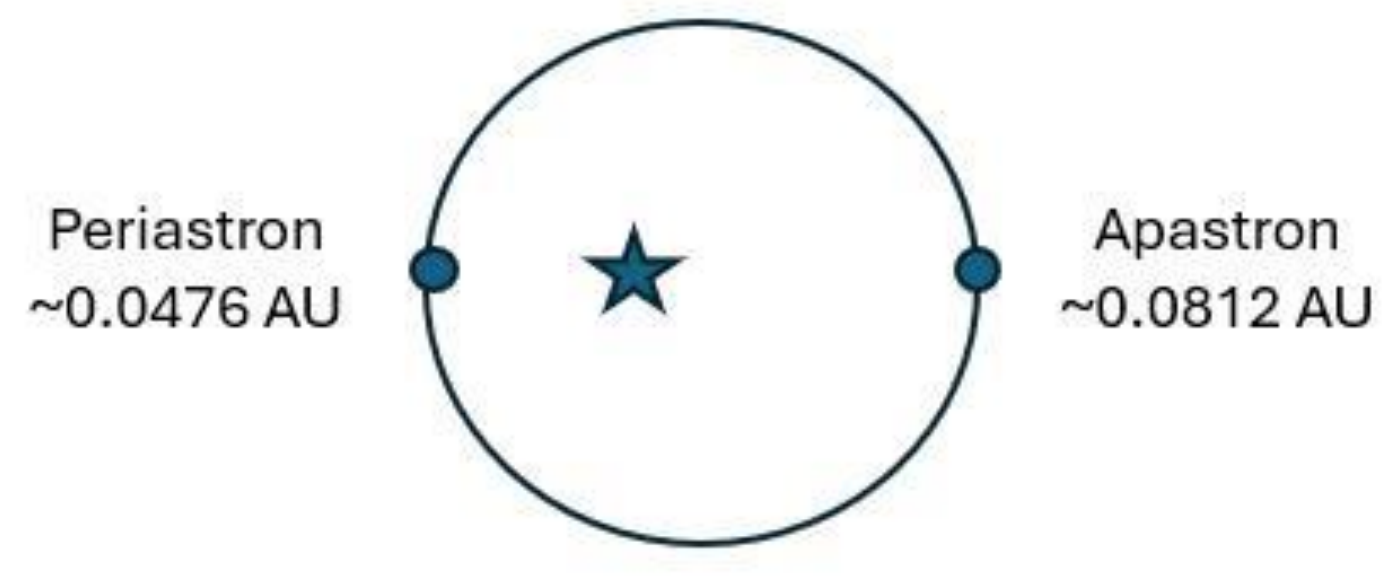

Figure 1: Apastron and periastron and the farthest and closest points the planet is to its host star throughout its orbit. For TOI-150b, the apastron is located approximately 0.0812 AU away from the host star, and the periastron is located approximately 0.0476 AU away from the host star.

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

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We chose to model this planet with our 3D atmospheric model that utilizes a local drag timescale. To **locally** calculate the magnetic drag timescale, we utilized *(left, bottom)* [6].

We ran 4 different magnetic models with varying field strengths of 0, 3, 10, and 30 Gauss applied to analyze the range of effects present and compared them to a baseline circular model. For the circular model, we assumed **synchronous rotation** (P = 5.86 days) while the eccentric models' rotation rate were **pseudo-synchronous** (P = 4.14 days), following [3-4].

Effects of Magnetism in Thermal Structure

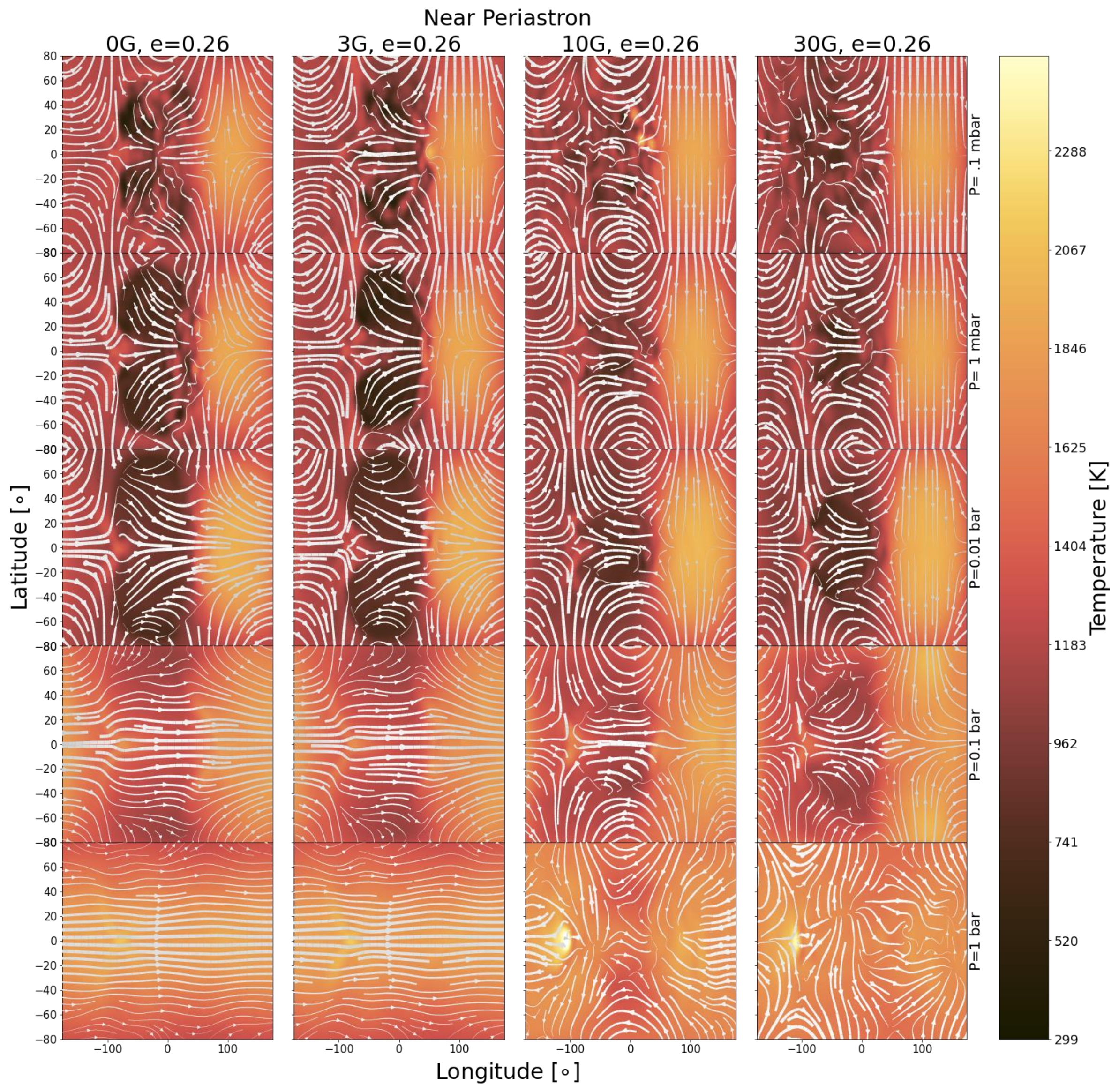

Figure 3: We displayed the wind and thermal structure of TOI-150b at varying levels of atmospheric depth. We compared each of our 4 eccentric models to see how the magnetic field influences these structures at differing strengths.

In order to see the magnitude of the impact that magnetic drag has on the wind and thermal structure, Figure 3 above shows temperature and wind maps. We compared the magnetic and non-magnetic eccentric cases (where e=0.26) near periastron. As the magnetic field strength **increases**, the strength of the **zonal winds decreases**. This effect is mainly seen on the dayside of the planet, which leaves a magnetic circulation regime [1]. Primarily **meridional winds** are present in the dayside **upper atmosphere**.

At high magnetic field values of 10 and 30 Gauss, the magnetism impacts the **deeper atmosphere** at pressures of 0.1 and 1 bar, which does not occur at lower field strengths. There is a **large** difference in wind structures between the 3 and 10 Gauss cases. However, there is only a slight change between the 10 and 30 Gauss cases. This indicates that the magnetic drag effects **plateau** at higher field strengths.

Effects of Eccentricity and Magnetism in Wind Structure

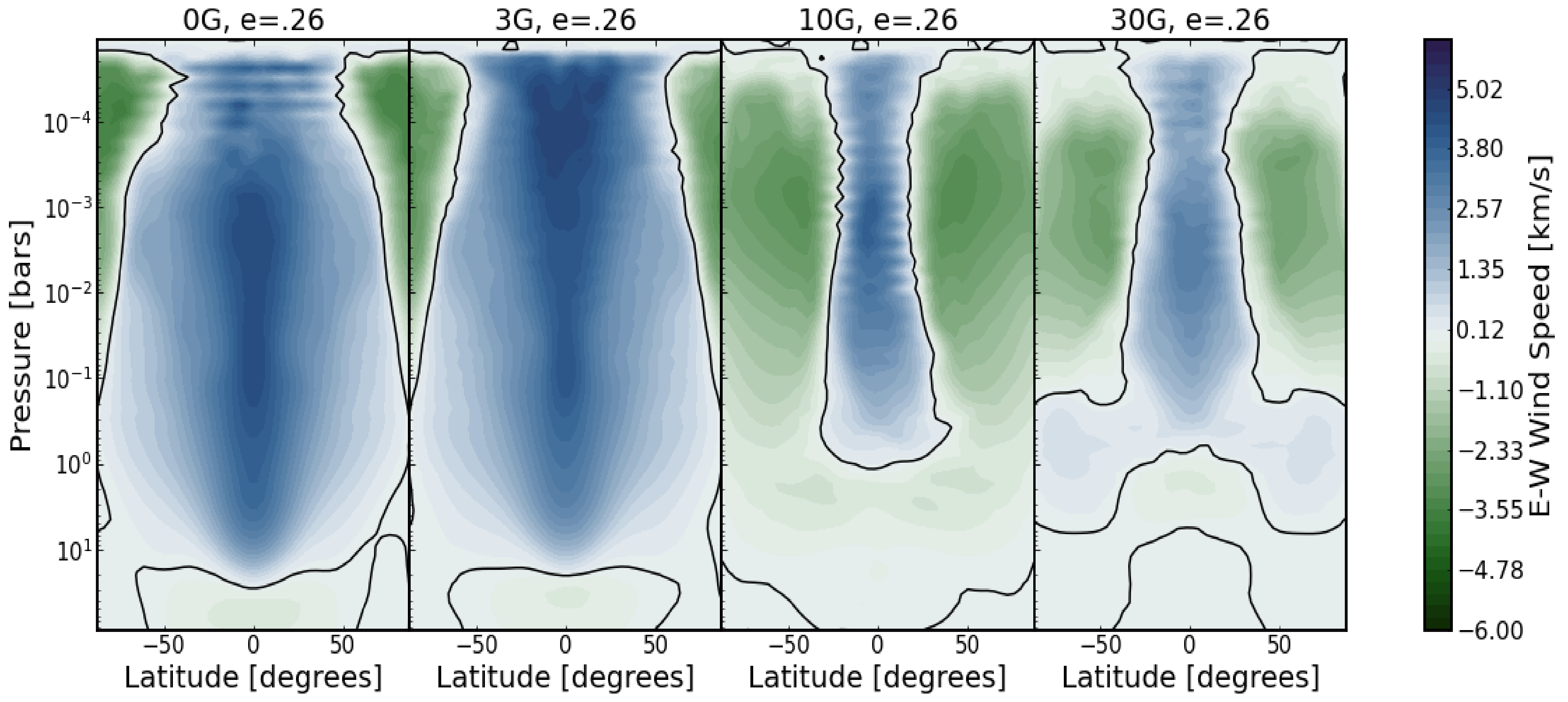

Figure 2: To demonstrate the affect magnetism and eccentricity have on wind structure, we displayed zonal mean zonal winds as a function of latitude. We generated these over a range of pressure levels. Here we time-averaged the winds over the course of the planet's entire orbit.

- When a **low magnetic field strength** is applied (i.e. 3G), the **superrotating equatorial jet** becomes slightly **stronger** at lower pressure levels and slightly **weaker** at higher pressure levels. However, at **higher field strengths** (i.e. 10 and 30G), the superrotating equatorial jet **weakens** substantially at all pressure levels as the dayside flow is primarily meridional.
- Eccentric orbit results in the presence of **westward** wind motion that is not present when the orbit is circular. This motion gets weaker as magnetic field strengths increase.

Modeled High-Resolution Emission Spectra

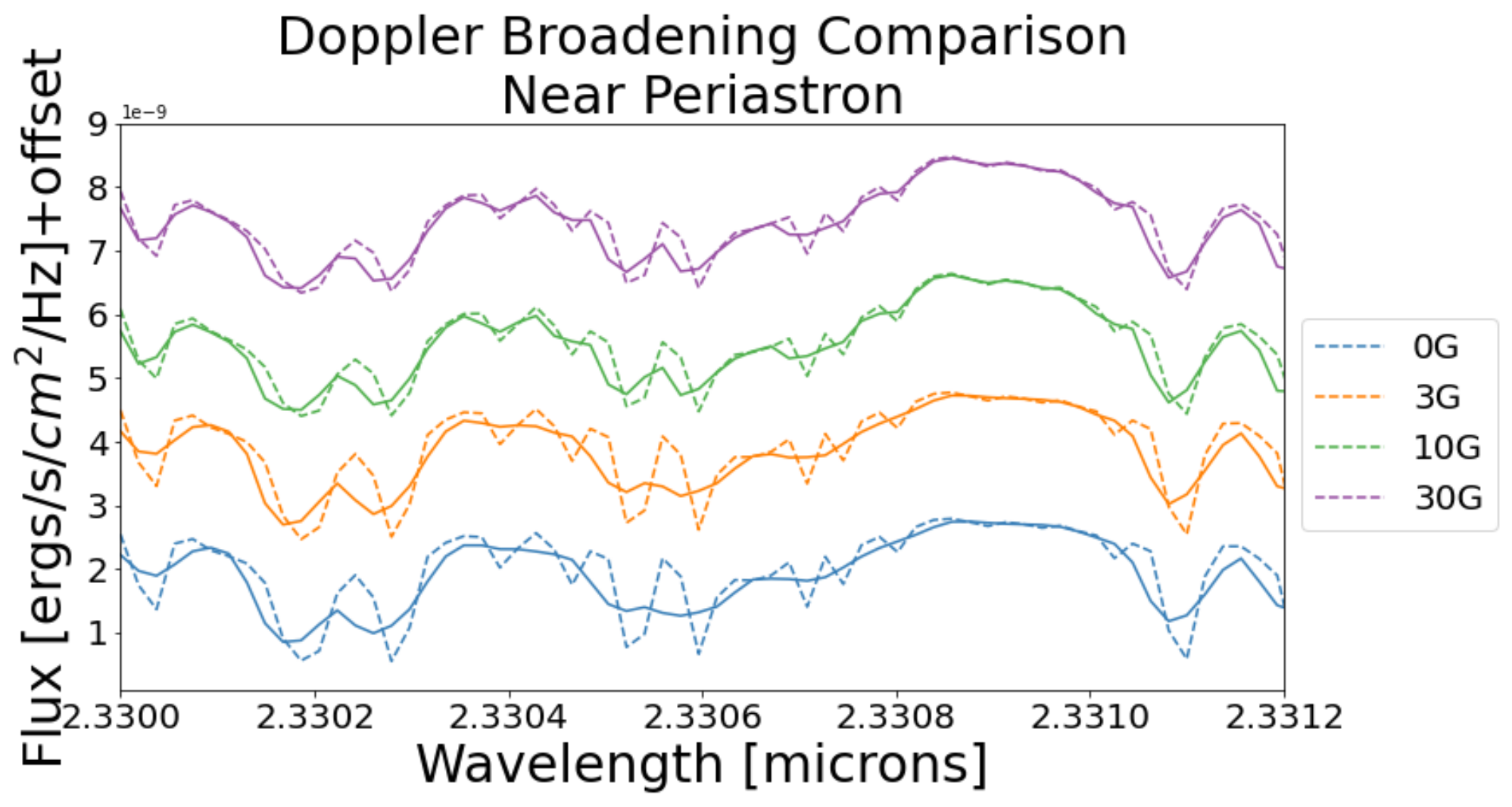

Figure 4: Here we display all the eccentric model at phase near periastron. We contrast the doppler broadening effects by applying an offset to the spectra. The spectra with doppler effects applied is shown in the solid line, and the spectra with the doppler effects not applied is shown in the dashed line.

- The spectra with doppler effects applied is **broadened** and **shifted** due to the effects of wind and rotation
- Because the spectra is high-resolution (R~100,000), we are able to probe into the atmospheric motion at km/s
- There are clear differences between the doppler broadening effects at lower magnetic field strengths vs. those at higher magnetic field strengths
- As magnetic field strength increases and subsequent wind strength decreases, the magnitude of the doppler broadening effect **decreases**

Future Works

We have many plans to utilize these models even further in the future. We plan to:

- Generate transmission spectra to determine the molecular composition of the planet at different temperatures
- Post-process other models with different magnetic field strengths
- Through cross-correlation, calculate a phase-dependent doppler shift as a probe of atmospheric structure
- Propose to observe spectra of TOI-150b using JWST or ground-based high-resolution Instruments and compare to the results of the model

References: [1] Beltz, H., Rauscher, E., Brogi, M., & Kempton, E. M. R.,2021, AJ, 161, 1 [2] Cañas, C. I., Stefansson, G., Monson, A. J., et al. 2019, ApJL, 877, L29 [3] Hut, P. 1981, A&A, 99, 126 [4] Kataria, T., Showman, A. P., Lewis, N. K., et al. 2013, ApJ, 767, 76 [5] Kossakowski, D., Espinoza, N., Brahm, R., et al. 2019, MNRAS, 490, 1094 [6] Perna, R., Menou, K., & Rauscher, E. 2010, ApJ, 719,1421 [7] Rauscher, E., & Menou, K. 2012, The Astrophysical Journal, 750, 96