Time Variability in 3D Atmospheric Models of Hot Jupiters

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An exoplanet is a planet that orbits a star outside our solar system. Among these, Hot Jupiters are a distinct class of gas giant exoplanets that are physically similar in mass and size to Jupiter, but orbit often under 10 days.[1] Due to this, they experience extreme levels of stellar irradiation, which leads to highly dynamic and exotic atmospheric conditions.

The atmospheres of Hot Jupiters are characterized by extreme temperatures - with temperatures ranging anywhere from over 1,000 to several thousand Kelvin. For example, NASA'S Scientific Visualization Studio reports that on WASP-121B, temperatures can reach approximately 2100 K (3320 degrees Fahrenheit) on the dayside and drop to around 1450 K on the nightside. This variation is because of the planet's close proximity to its host star - causing intense stellar irradiation and strong day-night thermal contrasts .[2]

This project is focused on analyzing the time variability of atmospheric features in Hot Jupiters using General Circulation Models (GCMs). These 3-Dimensional models simulate planetary atmospheres by solving the fundamental equations that govern fluid motion, along with radiative transfer calculations to account for heating and cooling. The simulation data generated using mitGCM includes variables like temperature, wind velocities, and tracer concentrations across different pressure levels, longitude and latitude.

In past analyses, researchers have primarily examined the atmospheric structure at a single timestamp. However, due to the complexity of these models, the atmosphere never reaches a 'final' state. For this project we are trying to examine how the atmosphere changes over a series of timestamps, which will allow us to trace the evolution of atmospheric dynamics which help us inform and refine observational predictions.

To do this, we are using a set of existing MATLAB scripts that process the simulation output at each timestep. These scripts read and manipulate large 3D arrays and apply physical transformations to prepare the data for analysis. My role in this project includes reading and debugging the post processing scripts, identifying which parts of the code can be optimized or translated, and developing visualizations that show how atmospheric quantities evolve over time.

Working under Dr. Beltz, I am building technical skills including but not limited to scientific programming and planetary data analysis, all while learning and contributing to a broader effect to understand the dynamic atmospheres of distant worlds.

References

[1] Jonathan J. Fortney, Rebekah I. Dawson, and Thaddeus D. Komacek. Hot Jupiters: Origins, Structure, Atmospheres. *Journal of Geophysical Research (Planets)*, 126(3):e06629, March 2021.

[2] Quentin Changeat (ESA/STScI) Mahdi Zamani (ESA/Hubble) NASA, ESA. Weather on exoplanet wasp-121b (tylos), 2024.