Gravity-Darkened Atmospheric Modeling of Exoplanets: Insights From KELT-9b

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The ever-present search for extraterrestrial life on exoplanets requires a comprehensive understanding of their atmospheric properties. However, research in this area is sparse, leaving the door open to test the effects of many physical parameters on these models. In this work, I incorporate the phenomenon of stellar gravity darkening into an atmospheric model of the ultra-hot Jupiter (UHJ) KELT-9b, which orbits the rapidly-rotating early-A-type star KELT-9. I develop a gravity-darkened spectral energy distribution of KELT-9 and numerically derive a time-dependent irradiation temperature of the planet. With the non-constant irradiation notably being a novelty, I modify an MIT General Circulation Model (MITgcm) to perform a variable-irradiation two-stream approximation of radiative transfer over a drag timescale of 1E7 days, comparing simulated results with a control simulation possessing the accepted equilibrium planet temperature of 4050˚K. I average data over the last 500 simulated time-steps and observe significantly different zonal and meridional wind speeds of the gravity-darkened model as compared to the control. I find that the gravity-darkened data predict an observed flux that corresponds more closely with observations. Although KELT-9b is tidally locked, gravity darkening improves model accuracy and drives significant changes in climate and wind patterns, establishing the phenomenon as an important factor in atmospheric research of strongly inclined UHJs and other exoplanet types. With the KELT-9 system acting as a proof-of-concept, this work establishes a more robust, precise exoplanet atmospheric model that can be adopted for any planet -- Earth-like or not -- to improve the search for life everywhere.