

Estimation of Auroral Currents in Ultracool Dwarf Based on Magnetospheric 3D Global Magnetohydrodynamic Simulations

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Auroras occur when electrons in space are accelerated along planetary magnetic field lines by energy from stellar winds, planetary rotation, and intrinsic magnetic fields. These electrons subsequently collide with the atmosphere, producing auroral emissions. Detecting auroras from exoplanets would provide direct evidence of planetary magnetic fields and atmospheres, offering critical insights into exoplanetary habitability. Auroral emissions in the radio wavelength range are circularly polarized (Wu & Lee, 1979), distinguishing them from other astrophysical radio sources, such as stellar radio emissions, which typically lack circular polarization. To date, only one study has reported a reliable detection of exoplanetary auroras (Turner et al., 2021); however, the statistical significance remains uncertain, necessitating further observational efforts. To optimize target selection for future observations, theoretical and numerical models have been developed. For instance, a coupled magnetosphere-ionosphere model (Nichols & Milan, 2016) and a 3D magnetohydrodynamic (MHD) simulation (Turnpenney et al., 2020) have estimated that auroral radio emission from hot Jupiters could reach $\sim 10^{15}$ W. However, observational constraints remain limited, highlighting the need for further studies to validate and refine these models.

Some ultracool dwarfs (UCDs) with strong magnetic fields ($\sim$ several kG) and rapid rotation (with periods of a few hours) have been observed to emit strong radio signals ($\sim 10^{16}$ W) (e.g., Nichols et al., 2012; Turnpenney et al., 2017). The magnetospheres of these objects have been modeled using the Hill-Pontius equation (Hill, 1979), with results suggesting that radio emissions consistent with observations can be reproduced within this framework. These findings indicate that the magnetospheres of UCDs may resemble the rotating magnetosphere of Jupiter. While the magnetic field strength and rotation period of radio-emitting UCDs are known, their surrounding plasma environment remains largely unconstrained. Consequently, models based on the Hill-Pontius equation rely on assumptions regarding several undetermined parameters, such as the plasma's angular velocity and mass-loading rate.

Here, we estimate the auroral currents by simulating the magnetosphere of LSR J1835+3259, a well-studied UCD, using a 3D global MHD simulation (Fukazawa et al., 2005). Compared to the Hill-Pontius equation, the MHD approach reduces the number of assumed parameters, enabling a more self-consistent determination of key physical properties. Our results indicate that the total current associated with auroral radio emission is $\sim 9 \times 10^9$ A. In future work, we will quantitatively assess the validity of this model by estimating the auroral radio emission energy of LSR J1835+3259 and comparing it with observations (Hallinan et al., 2008). Furthermore, we aim to extend this modeling framework to hot Jupiters and terrestrial exoplanets. Here, we present the current progress of our research.

Keywords: exoplanet, ultracool dwarf, auroral radio emission