

Development of Analytical Model Generalized for Exoplanetary Auroral Radio Emission

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Planetary aurora is believed to play a key role in the direct detection of planetary magnetic fields and atmosphere. The circular polarization of the auroral radio emissions (Wu & Lee, 1979) enables them to be easily distinguished from other radio sources, and their emission frequency is theoretically proportional to the magnetic flux density in the radio source region. Therefore, auroral radio observations can directly constrain the magnetic field flux density without relying on complex model assumptions. However, auroral radio emissions have not yet been observationally detected from any exoplanet, except for a marginal detection (Turner et al., 2021). Modeling of auroral radio emission is needed to predict which exoplanets are suitable for auroral detection. Modeling of exoplanetary aurora has been conducted by several studies, focusing on the Magnetosphere-Ionosphere (M-I) coupling (Nichols, 2011) and the Star-Planet Interaction (SPI) mechanism (Saur et al., 2013), but they have not been able to generally explain emissions from a variety of exoplanets simultaneously.

Here, we developed a new generalized analytical model of the M-I coupling that predicts the exoplanetary auroral radio power, based on the pioneering exoplanetary M-I coupling model by Nichols (2011). We use only the magnetospheric velocity distribution as a measure of radio power to allow for generalization, ignoring unobservable variables in exoplanets, such as the flux function and the mass loading rate. Validation of our model with Jupiter and Saturn suggests that our model successfully describes the total auroral energy dissipated through Joule heating in the planet's ionosphere (Jupiter: ~450 TW; Saturn: ~5 TW). The results align with observations within an uncertainty of one order of magnitude and are consistent with past modeling. We believe that our results on the total auroral power will help us understand the thermal atmospheric escape associated with the auroral Joule heating (Cowley et al., 2004; Gronoff et al., 2020) when we apply our model to exoplanets in the future. Analysis of past models suggests a 0.01% conversion efficiency of energy dissipated through auroral Joule heating into radio emission (Cowley et al., 2004; Zarka, 2007). Applying this conversion efficiency to our results suggests that the radio emission from Jupiter and Saturn is consistent with observational results within an uncertainty of one order of magnitude (Jupiter: ~50 GW; Saturn: ~0.5 GW; Zarka, 2007). Furthermore, the application of our model to ultracool dwarfs (UCDs) shows that the observed UCD auroral radio emission, up to ~1000 GW (Hallinan et al., 2008; Kao et al., 2023), suggests that UCD atmospheres are weakly ionized. We are currently modifying our model to understand the dependence of auroral power on the corotation breakdown location in the magnetosphere. We also attempt to apply our model to recent unverified observations from Tau Boö b (Turner et al., 2021) to investigate the plasma and magnetic conditions around hot Jupiters. Here, we present the current status of our modeling and validation.

Keywords: Exoplanets, Aurora, Radio waves, Magnetic field, Habitability