The influence of Alfvén Ionization on exoplanetary atmospheres

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Observations of continuous radio and sporadic X-ray emission from exoplanets and substellar objects suggest that such objects harbour atmospheric magnetized plasmas. This presents a powerful diagnostic tool, allowing us to characterize the local atmospheric environment if the nature of the source plasma and the plasma processes underpinning the emission can be identified. However, for low-mass objects such as brown dwarfs or exoplanets, the degree of thermal ionization is insufficient to qualify the ionized component as a plasma, posing the question: what ionization processes can efficiently produce the required plasma? We propose Alfvén ionization as a simple mechanism for producing localized pockets of ionized gas in the atmosphere, having sufficiently large degrees of ionization ($\geq 10^{-7}$) that they constitute plasmas. We carefully outline the criteria required for Alfvén ionization to occur and justify its applicability in the atmospheres of exoplanets and brown dwarfs. We find that Alfvén ionization is optimum at mid to low atmospheric pressures where the seed plasma is easier to magnetize and the pressure gradients required to drive the required neutral flows are the smallest. For the model atmospheres considered here, our results show that degrees of ionization ranging from 10^{-6} to as large as 1 can be obtained depending on the atomic and molecular species that are ionized. Furthermore, Alfvén ionization alters the atmospheric chemistry via the creation of new ionic species not normally available in current, thermally-driven atmospheric models. The presence of atmospheric plasmas opens the door to a multitude of plasma processes and radiation emission mechanisms that contribute to the observed radiation signature. We explore the observable consequences of Alfvén ionization, with the hope of identifying useful diagnostics to probe and characterize the nature of exoplanetary atmospheres, such as the magnetic field strength, the electron number density and the chemical composition.