Energetics of Star Planet Magnetic Interactions

Arghyadeep PAUL, Antoine STRUGAREK & Victor RÉVILLE

A key goal in modern astrophysics is to understand exoplanets in detail, including their size, composition, and magnetic fields. Among these, exoplanetary magnetic properties are particularly challenging to constrain, yet they are crucial for understanding a planet's evolutionary history, potential habitability and internal structure. Current insights into planetary magnetism are largely derived from observations within our own solar system, leading to inherent limitations and biases. Within the Jovian system, Alfvén wave-mediated magnetic interactions between Jupiter and its moons, such as Io, Europa, and Ganymede, have been shown to influence Jupiter's auroral ultraviolet and radio emissions. Analogous star-planet magnetic interactions (SPMI) are expected to occur in exoplanetary systems, where planets are immersed in the sub-Alfvenic stellar wind plasma. There is an ongoing lack of consensus in the scientific community regarding the quantification of energy generated by SPMI and the constraints on this energy imposed by tentative observations. Current theoretical models of SPMI energetics often also produce results that vary by a few orders of magnitude. To investigate this discrepancy, we employ magnetohydrodynamic (MHD) simulations to quantify the energy transferred back to the host star via SPMI, as a function of stellar and planetary magnetic field strengths and orbital parameters. Additionally, we model the transfer of Alfven-wave mediated energy through the stellar atmosphere by calculating a frequency-dependent transmission coefficient. This allows us to assess the efficiency of wave energy transmission, potentially leading to localized emission hotspots on the stellar surface, similar to features tentatively detected in several exoplanetary systems. Our simulations aim to evaluate both the viability and longevity of such hotspots driven by Alfvén wave energy injection and to delineate regions in stellar and planetary parameter space where SPMI is most effective.

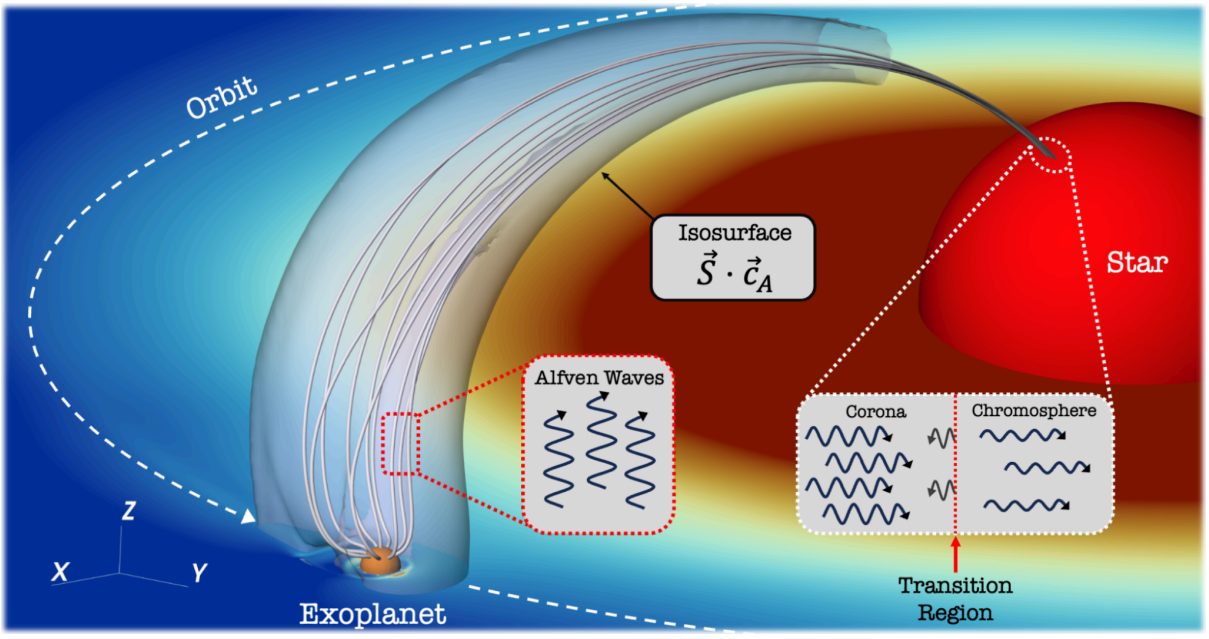

Figure: *A snapshot from an MHD simulation illustrating the key features and underlying framework of Alfvén wave-mediated star–planet magnetic interactions. (Paul, Strugarek & Reville, 2025: https://doi.org/10.1051/0004-6361/202452719)*