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Mutual impedance experiments as a diagnostic for magnetized space plasmas

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Mutual impedance experiments are active electric instruments that provide in situ diagnostic in space plasmas, such as the plasma density and electron temperature. The instrumental technique is based on the coupling between electric antennas embedded in the plasma, and characterizes the local properties of the plasma dielectric.

Different versions of mutual impedance instruments are present onboard past and future planetary missions, such as Rosetta, BepiColombo, JUICE, and Comet Interceptor. Recently, the interest of the scientific community is shifting from large satellite platforms with single-point measurements concepts to small satellite platforms, to enable multipoint measurements for the spatial mappings of planetary outer environments. Therefore, instruments previously designed for large platforms are now miniaturized and adapted to small satellites. In this context, instrumental efforts are devoted to adapting mutual impedance experiments to small satellites, such as in the case of the CIRCUS CubeSat or the SPEED SmallSat missions projects.

Current state-of-the-art quantitative instrumental models of mutual impedance experiments are based on the assumption of an unmagnetized plasma. However, for planetary environments within which the magnetic field is not negligible, such as intrinsic planetary magnetospheres (e.g. Mercury, Ganymede) significant modifications of mutual impedance measurements are expected.

The goal of this work is twofold: (i) support the preparation of mutual impedance instruments for small satellites and (ii) extend current mutual impedance instrumental models to take into account the effects of the magnetic field on the plasma diagnostic.

This investigation is performed by combining two complementary approaches. First, numerical simulations are used to quantify the impact of the plasma magnetization on the mutual impedance measurements and, therefore, improve its diagnostic. In particular, we have developed and validated a new instrumental model, based on the numerical calculation of the electric potential emitted by an electric antenna in a magnetized, homogeneous, collisionless, Maxwellian plasma. This new instrumental model is used to compute synthetic mutual impedance spectra and assess the impact of electron magnetization on the instrumental response. Using this new model, we provide diagnostics for the plasma density, electron temperature, and magnetic field amplitude. Second,

laboratory experiments are used to test and validate our numerical model. We use the controlled plasma environment of the PEPSO plasma chamber at LPC2E laboratory in Orléans. This plasma chamber offers the possibility to test the performances of space plasma instruments and CubeSats in realistic planetary ionospheric conditions. A model of CubeSat is present inside the plasma chamber, and is equipped with a set of electric antennas that are used to perform mutual impedance measurements in the same configuration as a CubeSat. The measurements obtained by this setup are compared with the instrumental model, to validate the plasma diagnostic of the instrument prototype on a CubeSat.