Machine Learning-Based Disruption Diagnosis and Prediction: From Fusion in Tokamaks to Solar Flares in Space Plasmas

Carlos Eduardo Falandes[1], Reinaldo Roberto Rosa[1], Rubens Andreas Sautter[2], Luan Orion de Oliveira Baraúna Ferreira[1], Jiro Kawamura[3], Mirelly Silveira[1], Pablo Alexander Medina Sanchez[4], and Juan Alejandro Valdivia[5]

[1]*National Institute for Space Research (INPE), Brazil*

[2]*Federal University of Technology (UTFPR), Brazil*

[3]*International Thermonuclear Experimental Reactor (ITER), França*

[4]*University of Los Andes, Colômbia*

[5]*University of Chile, Chile*

Plasma instabilities can exhibit a variety of structural patterns known as loops, kinks, constrictions, wrinkles, and disruptions. When disruptions occur, a small disturbance in the magnetic field can amplify, increasing the instability. In the case of solar plasma, this instability can trigger a flare and associated extreme events. In the tokamak, such instabilities can complicate plasma confinement and can lead to energy losses and serious damage to the vacuum vessel by releasing significant amounts of energetic particles from the plasma column towards the vessel wall. A special type of disruptions are the so-called edge-localized modes (ELMs), which are almost always associated with a filament-like structure. Based on simulated data from the p-model (multiple cascades generate time series with endogenous and exogenous disruptive fluctuations), we test the performance of a disruption prediction algorithm (DPA) based on LSST-Autoencoder machine learning models. Our results present a probability mapping associated with the predictions and discuss the achievements and delays of disruption prediction in terms of triggering performance, simulating alarms at each discharge in a plasma control system. We discuss which prediction performance levels should be met to predict disruptions that may occur in the International Thermonuclear Experimental Reactor (ITER) experiment scheduled to enter test operation in the next decade. We extend the methodology to predict possible successive X-class solar flares that may occur on the Sun within a space weather perspective. In solar physics, the analysis is accompanied by the characterization of filaments in the magnetohydrodynamic (MHD) turbulence pattern observed in images captured by the Solar Dynamics Observatory (SDO) observatory.