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Forecasting the Onset Time of the Second Maximum of Proton Enhancements Using Solar-Wind Kinematics and a Quantum Regression Neural Network (RQNN)

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The aim of this work is to forecast the onset time of the second maximum of proton enhancements associated with the transport of particles by solar-wind structures. The "zeroth-order" forecast is based on the kinematic parameters of the solar wind measured at the L1 Lagrange point, and is subsequently refined by machine-learning methods. The difficulty of this problem lies in the nonlinear, non-stationary relationships between proton-flux and solar-wind parameters, on the one hand, and the lack of a training base large enough to build a conventional regression or neural-network model, on the other. We therefore used a quantum regression model, RQNN, in which the input heliophysical parameters are encoded as phase shifts of the wavefunctions of emulated qubits. As an example, consider the prediction of the second maximum in the proton event of 10–11 May 2024, which involved the catch-up (cannibalization) of a slower CME (≈628 km/s, launched on 8 May at 22:24 UT) by a faster one (≈1711 km/s, launched on 9 May at 09:24 UT) at a distance of ≈0.31 AU. Advection of the merged structure to Earth at the OMNI solar-wind speed (684 km/s) predicts the onset of the second proton-flux maximum at about 09:33 UT on 11 May, whereas the actual (GOES-cross-validated ART-XC/Spektr-RG) maximum is observed at 07:33 UT on 11 May, i.e., about 2 hours earlier. RQNN, in turn, predicts the second maximum at 06:58 UT on 11 May, which is about 1 h 25 min (1.4 h) closer to the actual value, reducing the residual from ≈2.0 h to ≈0.6 h.

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