Statistical Analysis of a Solar Energetic Particle Event: Fractional Brownian Motion or Not?

Dionissios Hristopulos[1,2], Lengying Khoo[2], Manuel E. Cuesta[2], Spyros Kasapis[2], George Livadiotis[2], Sungmin Pak[2], David J. McComas[2], Jamie S. Rankin[2], Christina Cohen[3]

[1]School of Electrical and Computer Engineering, Technical University of Crete, Chania, Greece, [2]Department of Astrophysical Sciences, Princeton University, Princeton, USA, [3]Space Radiation Lab, California Institute of Technology, Pasadena, USA

Solar energetic particle (SEP) events exhibit complex variability, making their statistical characterization essential for constraining physical models and accurately modeling SEP dynamics. SEP transport is commonly modeled as a diffusive process. However, recent studies reveal persistent correlations in SEP propagation, suggesting that fractional Brownian motion (fBm) provides a suitable framework for representing non-diffusive transport because it accounts for correlated increments. In this work, we perform the first detailed evaluation of whether SEP flux time series conform to the fBm model, using ISOIS data from the Parker Solar Probe mission. Specifically, we test three defining properties of fBm: Gaussianity and stationarity of flux increments, and power-law scaling of the structure function. Our analysis of LET-A measurements across SEP phases and energy channels reveals phase- and energy-dependent behavior inconsistent with fBm, including nonlinear drift, volatility clustering, and heavy-tailed distributions. Consequently, stochastic generators based on fBm cannot reliably reproduce SEP fluxes. While structure functions exhibit power-law scaling with Hurst exponents $H < 0.5$, indicating anti-correlated increments, H varies with phase and energy without a consistent trend. Overall, SEP fluxes behave as stochastic processes with self-similarity, non-Gaussian statistics, and intermittent volatility—yet a unified statistical model that integrates these properties remains elusive.