Reflected fractional Brownian motion as model of serotonergic axons in the brain

Thomas Vojta[1], Ralf Metzler[2], and Skirmantas Janusonis[3]

[1]*Department of Physics, Missouri University of Science and Technology, 1315 North Pine Street, Rolla, MO 65409, USA*

[2]*Institute of Physics and Astronomy, University of Potsdam, D-14476 Potsdam-Golm, Germany*

[3]*Department of Psychological and Brain Sciences, University of California, Santa Barbara, Santa Barbara, California 93106, USA*

Fractional Brownian motion (FBM), a non-Markovian self-similar Gaussian stochastic process with long-time correlations, is a widely applied model of anomalous diffusion. In confined geometries, the interplay between the long-time correlations of FBM and the reflecting boundaries leads to striking deviations of the stationary probability density from the uniform density found for normal diffusion. Particles accumulate at the boundaries for superdiffusive FBM while their density is depleted at the boundaries for subdiffusion [1,2].

Reflected FBM has recently emerged as a promising model for the self-organization of serotonergic axons in vertebrate brains. These fibers form a dense matrix that releases serotonin, a neurotransmitter that modulates a wide range of neural processes. We employ large-scale computer simulations to model serotenergic fibers as FBM-paths in realistic brain-shaped geometries. We demonstrate that the resultant steady state distributions approximate the fiber distributions in physical brain sections of several vertebrate species. This suggests that this framework supports predictive descriptions of the serotonergic matrix that can be further extended by incorporating details of the fibers and their environment [3,4.5].

This research was supported by an NSF-BMBF (USA-Germany) CRCNS grant (NSF no. 2112862 and BMBF no. STAX).

[1] A.H.O. Wada and T. Vojta, Fractional Brownian motion with reflecting wall, Phys. Rev. E 97, 020102(R) (2018)

[2] T. Vojta, S. Halladay, S. Skinner, S. Janusonis, T. Guggenberger, and R. Metzler, Reflected fractional Brownian motion in one and higher dimensions, Phys. Rev. E 102, 032108 (2020)

[3] S. Janusonis, N. Detering, R. Metzler and T. Vojta, Serotonergic Axons as Fractional Brownian Motion Paths: Insights into the Self-organization of Regional Densities, Front. Comp. Neuroscience 14, 56 (2020)

[4] S. Janusonis, J.H. Haiman, R. Metzler and T. Vojta, Predicting the Distribution of Serotonergic Axons: A Supercomputing Simulation of Reflected Fractional Brownian Motion in a 3D-Mouse Brain Model, Front. Comp. Neuroscience 17, 1189853 (2023)

[5] S. Janusonis, R. Metzler and T. Vojta, The Organization of Serotonergic Fibers in the Pacific Angelshark Brain: Neuroanatomical and Supercomputing Analyses, Front. Neuroscience 19, 1602116 (2025)