STNOs non-stationary dynamics and multi-GHz spin-wave generation

Mateusz Zelent,[1] Abbas Koujok,[1] Abbass Hamadeh,[1] and Philipp Pirro[1]

[1] *asas*

Spin-torque nano-oscillators (STNOs) offer compact, electrically driven access to nonlinear magnetization dynamics, making them promising candidates for reconfigurable signal-processing hardware and neuromorphic computing. A central challenge in developing spintronic–magnonic interfaces is the controlled, energy-efficient generation of broadband, high-frequency (multi-GHz) excitations and propagating spin waves, extending beyond narrow-linewidth steady-state oscillations. Here, we propose and numerically demonstrate a route to sustain non-stationary soliton dynamics in vortex-based STNOs by applying a time-modulated current drive in the low-frequency range (hundreds of KHz to a few MHz).

Micromagnetic simulations reveal that under harmonic pumping, the vortex trajectory avoids relaxing into a single stationary orbit. Instead, it remains persistently non-stationary, enabling repetitive energy accumulation and release within each modulation cycle. This regime promotes nonlinear mode coupling between low-frequency gyrotropic motion and higher-order azimuthal modes, resulting in pronounced spectral features and emission in the multi-GHz range. Importantly, the intensity and characteristic frequencies of this high-frequency response can be precisely tuned via the modulation protocol and drive amplitude. We discuss how the resulting time-sampled nonlinear spectrum represents a high-dimensional dynamical state, positioning vortex-based STNOs as tunable magnonic resonators and candidate nodes for analogue fading-memory processing and reservoir computing architectures.

MZ acknowledges that this project has received funding from the European Union´s Framework Programme for Research and Innovation HORIZON-MSCA-2024-PF-01 under the Marie Sklodowska-Curie Grant Agreement Project 101208951 – CNMA.