Evidence of quasilinear and nonlinear precipitation of radiation belt electrons into Earth's atmosphere from the ELFIN CubeSats

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ELFIN[1] is a satellite mission launched in 2018 consisting of two, identical 3U CubeSats in circular, polar low-Earth orbit (LEO) at altitudes ~450 km; ELFIN deorbited and reentered Earth's atmosphere in late 2022. Onboard each spacecraft, the ELFIN prime payloads consisted of energetic particle telescopes and boom-deployed fluxgate magnetometers. Each orbit, ELFIN observed energetic electrons ranging from 50 keV to 7 MeV precipitating from Earth's radiation belts and plasma sheet. ELFIN offered the opportunity to study radiation belt and relativistic electron precipitation losses with unprecedented energy resolution and multipoint observations that enable some disambiguation of spatiotemporal evolution. Furthermore, the ELFIN spacecraft were spinners, revealing for the first time details of electron pitch angle distributions within the atmospheric loss cones. In this talk, we focus on multipoint observations from the two ELFINs plus the two Van Allen Probes (RBSP) and Magnetospheric Multiscale (MMS) during the last months of the RBSP mission in 2019. With this unique array of near-equatorial and low-Earth orbiting observatories – combining science products from billion-dollar-scale missions with million-dollar-scale CubeSats – we examine signatures of both quasilinear and nonlinear scatting and precipitation of relativistic electrons from Earth's outer radiation belt and slot region. With full equatorial pitch angle and energy distributions afforded by the combined RBSP and ELFIN datasets, we estimate atmospheric loss rates during storm and non-storm magnetospheric conditions due to quasilinear diffusion (stochastic pitch angle scattering) into the atmospheric loss cones. We also highlight several cases showcasing distinct evidence of nonlinear interactions that result in short-lived/localized, intense bursts of precipitating electrons into Earth's atmosphere. We argue that those nonlinear interactions are consistent with scattering by a combination of electromagnetic ion cyclotron and whistler-mode chorus waves, each presenting distinctive signatures in the precipitating electron fluxes. Finally, we highlight how this relativistic electron precipitation deposits significant amounts of energy from Earth's inner magnetosphere into the bottomside ionosphere (E- and D-regions) and even lower into the mesosphere and even stratosphere of Earth's neutral atmosphere. All told, ELFIN represents a textbook example of how small, targeted science missions with affordable (i.e., million-dollar-scale) missions can be used in coordination with larger, more expensive (i.e., 100M- to billion-dollar-scale) missions and enhance our overall science return.

References

[1] V. Angelopoulos et al., "The ELFIN Mission", *Space Science Reviews*, **216**:103, 30 July 2020, doi:10.1007/s11214-020-00721-7.