Multipoint Perspectives on Radiation Belt Electron Precipitation from the Van Allen Probes, MMS, and ELFIN Missions: New Insights on Loss Rates and Energy Inputs to Earth's Ionosphere and Atmosphere

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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. Onboard each spacecraft, the ELFIN prime payloads consist of energetic particle telescopes and boom-deployed fluxgate magnetometers. Each orbit, ELFIN observes energetic electrons ranging from 50 keV to 7 MeV precipitating from Earth's radiation belts and plasma sheet. ELFIN offers 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 are spinners, revealing for the first time details of electron pitch angle distributions within the atmospheric loss cones. In this talk, we will present new results from ELFIN highlighting several enlightening features of relativistic electron precipitation. With simultaneous, 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, we quantify quiet-time and storm-time losses of Earth's radiation belt electrons due to atmospheric precipitation. With the combination of RBSP and MMS in the near-equatorial region and ELFIN observing losses at LEO, we estimate the relative contribution of atmospheric losses as a function of L-shell during quiet and stormy magnetospheric conditions. Furthermore, for those events and others using a combination of ELFIN and MMS only, we employ the excellent energy and pitch angle coverage of the ELFIN data to quantify energy input as a function of altitude from relativistic electrons precipitating into Earth's ionosphere and neutral atmosphere. These cases highlight how relativistic electron precipitation penetrate deep into the ionosphere (D-layer) and further into the neutral atmosphere, with direct energy deposits down to < 40 km altitude and that these energy deposits can far exceed those from auroral precipitation at higher altitudes (E-region ionosphere and thermosphere, ~100 km), even during active times. We stress that relativistic electron precipitation must be considered for ionospheric D-region activation and stratospheric and mesospheric chemistry and energy budgets.

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