Simulating solar cell degradation from proton flux during major solar storms

Abstract

Satellite solar cells tend to degrade when exposed to energized protons in particular. Solar storms increase the amount and intensity of proton fluxes, especially in the radiation belt. The historic Carrington Event has been a focus of interest due to its extreme severity—a storm of such intensity may have complex geomagnetic effects. In this thesis, the estimation of Carrington Fluxes using Extreme Value Theory (EVT) is described, and damages to solar cells are estimated using Geant4-based simulations.

Displacement damage dose (D_d) is the most significant damage type for solar cells, for which calculations utilize non-ionizing energy loss (NIEL) analysis. MULASSIS is the Monte Carlo simulation used in this thesis to simulate solar cell damage based on an input flux. It is able to calculate the wattage loss directly for a simple model of a solar cell. MULASSIS runs on Geant4—an extensive particle simulation toolkit.

Carrington Fluxes are difficult to estimate due to the complex nature of magnetosphere interactions. Additionally, very few points of real measurements exist for space weather events, and considering a data distribution of particle energies—they are commonly not Maxwellian. For this reason, EVT is used to extract data for the extreme "tails" of distributions. These fluxes obtained from EVT are used as a basis for this thesis.

The Carrington Event occurred in 1859, meaning that any results cannot be validated against real data. For this reason, the several-times-weaker 2003 Halloween event is used for the method validation. For the Halloween event, solar panel output wattage is known to have fallen around 2% for the NASA Cluster spacecraft, and proton fluxes were measured at a few energy channels. Using these fluxes, MULASSIS is run to confirm the output degradation for a given exposure time, allowing for further simulations for Carrington fluxes to be run with greater confidence.

The main challenges to this research involve the plethora of simplifying assumptions. Notably, the fluxes used are practically spatially-averaged estimations, meaning that damage must be estimated based on exposure time to the fluxes rather than considering particular orbits. Additionally, solar cells must be modeled within the simulation in a way which is both simple and involved enough to cover all cases to a significant extent. Furthermore, EVT assumes independence between events, implying that fluxes of new storms are decoupled from previous ones. The decay of fluxes, therefore, is often obtained numerically from the diffusion equation—involving more assumptions and conditions.

Please note that my thesis work is still ongoing and I do not have results yet.
I plan to focus on some theory and mainly the challenges in my seminar.