

# The Probability of Satellite Anomalies by a Disastrous Solar Flare

\*Daikichi SEKI<sup>1,2,3</sup>

1. Graduate School of Advanced Integrated Studies in Human Survivability, Kyoto University, 2. Centre for the Study of Existential Risk, University of Cambridge, 3. Astronomical Observatory, Kyoto University

The Sun has a potential risk of various socioeconomic impacts on our human society. It often produces various eruptive phenomena such as a solar flare and a coronal mass ejection, which sometimes bring adverse effect to us like satellite anomalies, radiation exposure, and huge blackouts. For example, in 2003 October 28, X17-class flares (roughly once-in-10-year level severity) occurred and more than 60 % of NASA scientific satellites were affected.

Similar to other terrestrial disasters like an earthquake, the solar eruptive phenomena also follow the power-law distribution between frequency and severity, and low-frequency-high-impact solar disaster could also happen. Recently, it was revealed that a “super-flare”, a flare whose energy is 100 times larger than X10-class flare, can occur once in 1000 years from statistical and theoretical points of view [Maehara et al. 2012, Shibayama et al. 2013, Shibata et al. 2013].

However, though there are many assessment studies of “moderate” solar eruptive phenomena, the assessment of “disastrous” solar eruptive phenomena like a super-flare has been little conducted. For this reason, this research aims to evaluate the frequency (or probability) and the possible socioeconomic damage of a super-flare, especially focusing on satellite anomalies.

Using various data sets about satellites, their anomalies, flares, and plasma environment around the Earth\*, 154 X-class flare events with 9 relating parameters (peak flux of X-ray (0.1–0.8 nm), integral fluxes of electron (> 2 MeV) and of proton (> 1, 5, 10, 30, 50, 60, 100 MeV)) were selected. To avoid multi-collinearity, Ridge regression model was used to compute the regression to the satellite anomaly rate (1/satellite/event). Also 10-fold cross validation was performed. After obtaining the model, the possible plasma parameters in case of X1000-class flare assumed by Takahashi et al. 2016 were input into the model.

As a result, we obtained the model with its coefficient of determination of 0.607 and its Pearson correlation coefficients of  $0.691 \pm 0.212$  (for 100 times randomly chosen dataset). Assuming that electron and proton follow the same scaling law, with applying scaling law by Takahashi et al. 2016, 0.573 satellite anomaly rate (57.3% per satellite per event) was obtained. It should be noted that the scaling law provided by Takahashi et al. 2016 is upper limit, so in the actual case, rate should be lower. The validity of assumption, the comparison between this research and others (Pilipenko et al. 2006; Iucci et al. 2005; Odenwald et al. 2006, 2007), and the possible socioeconomic loss will be also discussed.

\* NOAA NGDC Spacecraft Anomaly Data, Satellite Catalogue (<https://www.celestrak.com/satcat/search.php>), NOAA GOES flare report (<https://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-features/solar-flares/x-rays/goes/xrs/>), and OMNI 2 database

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