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Electron and proton peak intensities as observed by a five-spacecraft fleet in solar cycle 25

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Solar energetic particle (SEP) events are major outbursts of energetic charged particle radiation from the Sun. These events are related to solar flares and fast coronal mass ejections (CMEs). Flares are presumed to accelerate particles in magnetic reconnection processes, whereas fast CMEs drive shock waves through the corona that are known to be able to accelerate particles. Electron acceleration has traditionally been ascribed to reconnection in flares whereas proton acceleration is believed to be efficient in CME-driven shocks. Recent observational evidence [1], however, suggests that shocks may be important in electron acceleration as well. Almost all major eruptions are related to both flares and CMEs so the association of the accelerated particles to these eruptive phenomena is often subject to debate. Using novel spacecraft observations of strong SEP events detected in solar cycle 25, we aim at identifying the parent acceleration region of the observed electron and proton events. We have analyzed a set of 45 SEP events between Nov 2020 and May 2023 using data from multiple spacecraft including Solar Orbiter, near-Earth spacecraft (SOHO and Wind), STEREO-A and BepiColombo. We make use of peak intensities of >25-MeV protons and ~100-keV and ~1-MeV electrons and perform correlation studies of these peak intensities with each other as well as with the associated flare intensity. We separate the events into those that are well-connected (angular separation $\leq 35°$) or poorly-connected (angular separation $> 35°$) to the flare by the interplanetary magnetic field. We find significant correlations between electron and proton peak intensities. While events detected by poorly-connected observers show a single population of events, consistent with the idea that these particles are all accelerated by the spatially-extended CME-driven shock, events observed in well-connected regions show two populations: One population has higher proton peak intensities that correlate with electron peak intensities similarly to the poorly-connected events. These are most likely shock associated. The other population has low proton intensities that are less well correlated with electron peak intensities. This population is suggested to show a dominant contribution of the flare.

References

[1] Dresing, N., Kouloumvakos, A., Vainio, R., Rouillard, A., Astrophys. J. Lett., 925, L2