ESP Heavy Ion Property Variations in Solar Cycles 23 and 24

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Abstract

Solar Cycle (SC) 24 was the weakest solar cycle since SC 14. Comparing energetic storm particle (ESP) events observed during a weak solar cycle in SC 24 and a relatively stronger solar cycle in SC 23 will provide insight into any effects the strength of a solar cycle has on ESP properties. In this study, we examine variations in ESP heavy-ion peak intensities and energy spectra, between ~0.1 to 75 MeV/nucleon at CME-driven interplanetary shocks for events observed at the ACE spacecraft during SC 23 and SC 24. We find that the number of clearly defined heavy-ion ESP events at ACE during SC 23 is about twice as that observed during SC 24 (75 vs 42). The distribution of peak intensities for energies below ~1 MeV/nucleon are consistent between both solar cycles. However, for higher energies (~10 MeV/n), the intensity distributions are broader for SC 23, resulting in an increase in the roll-over energy (E_0) for their spectra profiles.

Background and Motivation

Solar Cycle (SC) 24 continues a trend of weakening solar cycles that began with SC 21, which peaked in 1980. SC 24 has been the weakest sunspot cycle since SC 14 which peaked in 1906 according to data from the Space Weather Prediction Center of the National Oceanic and Atmospheric Administration (NOAA). Average pressure in the heliosphere is reduced by about 40% in SC 24 compared to SC 23, leading to wider CMEs with diminished effectiveness to accelerate particles and produce magnetic storms (Gopalswamy et al. 2014).

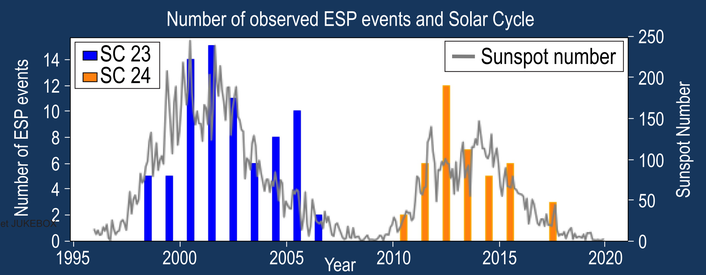

Figure1. Heavy ion ESP events histogram during SC 23 (blue bars) and SC 24 (orange bars). The events are grouped by year. the grey line is the plot of monthly number of Sunspots during SC 23 and SC 24.

Observations

We use data from instruments on board NASA's Advanced Composition Explorer (ACE; Stone et al. 1998) mission, which is located at the Sun–Earth L1 Lagrange Point. The Suprathermal Ion Telescope (SIS; Stone et al. 1998), and the Ultra-Low Energy Isotope Spectrometer (ULEIS; Mason et al. 1998) on ACE are used to survey ~0.1 – 35 MeV/nucleon energetic helium (He), ~0.1 – 76 MeV/nucleon Oxygen (O), and ~0.034 – 31 MeV/nucleon Iron (Fe) ion observations during ESP events identified between August 1996 and December 2019. We used the solar wind plasma and magnetic field instruments (SWEPAM; McComas et al. 1998 and MAG; Smith et al. 1998) on ACE to identify the associated IP shocks and their properties and the solar wind conditions upstream and downstream of these structures. Ace has been observing ESP events during both SC 23 and SC 24 providing an opportunity to study the variability in ESP properties for events observed during solar cycles of different strength.

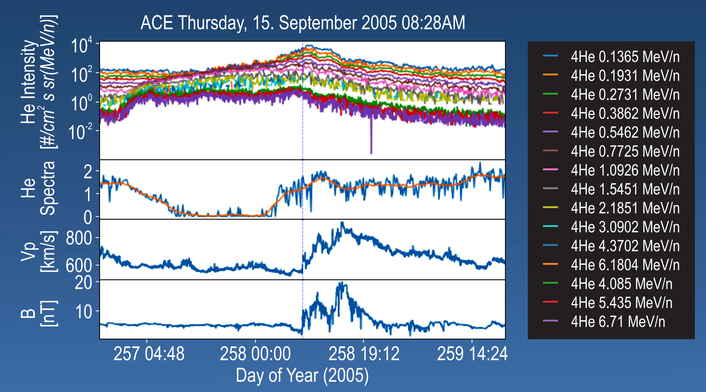

Figure 2. An ESP event observed by ACE on September 15, 2005. The time profiles of energetic He intensities, He spectral index), solar wind speed, and magnetic field strength are also shown.

CME Speed Distribution

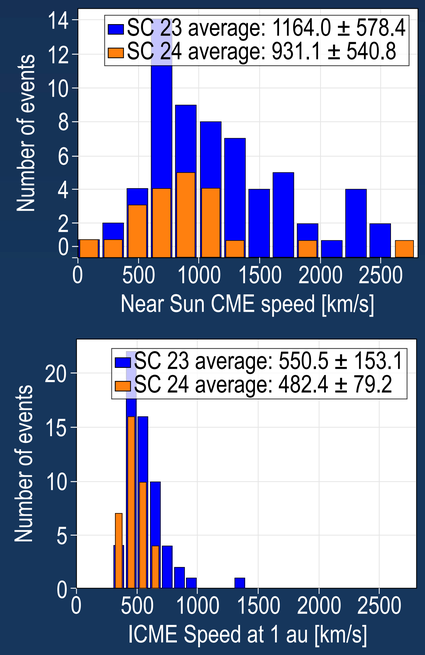

Figure 3. The distribution of near Sun and 1 au CME speeds for the ESP events in our study. The near-sun speeds show a grater difference between SC23 and SC24 events; however, as the CME approaches 1 au, the difference is drastically reduced. Which we interpret as a stronger deceleration for events in SC23 than in SC24.

ESP Intensity Distribution

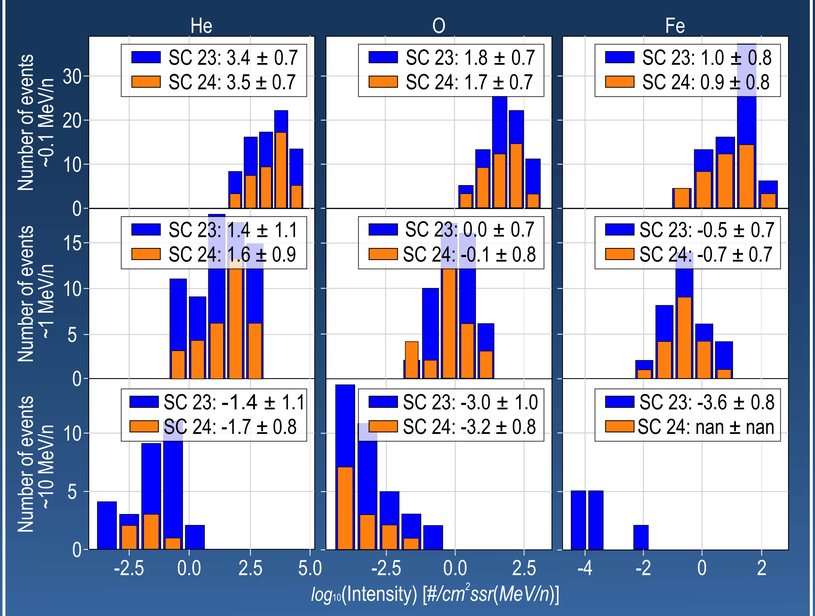

Figure 4. The distribution of energetic particle (He, O and Fe) intensities show similar mean and standard deviation values for both SC23 and SC24.

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ESP Spectral Fitting (Example Event)

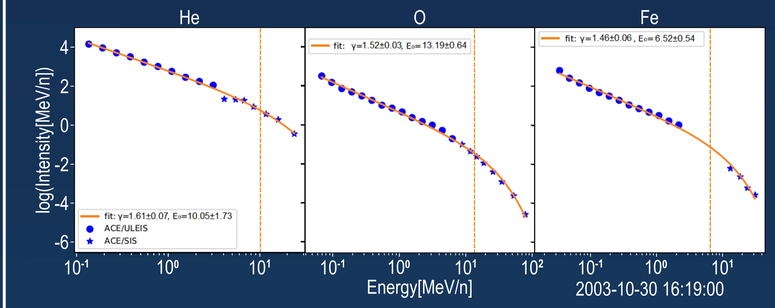

Figure 5. We used the average intensity for each energetic bin in the ESP time interval, to fit the ~0.1 – ~70.0 MeV/nucleon He, O, and Fe spectral profile of the ESP events with the Jones and Ellison (1991) expression of $j(E) = j_0 E^{-\gamma} e^{(-E/E_0)}$, where j is the differential intensity, E is the particle energy in MeV/nucleon, γ is the spectral index, and E_0 is the e-folding energy. This figure shows an example of the fits and their parameters using the described technique.

ESP Spectral Index Distribution

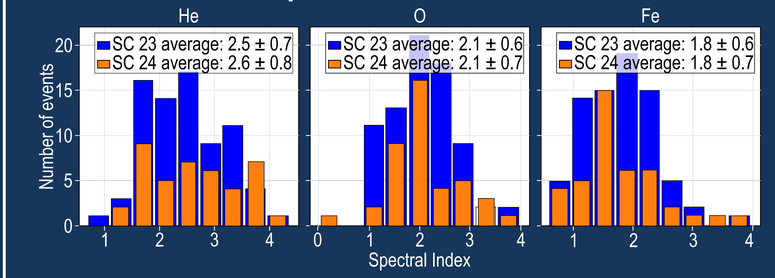

Figure 6. The spectral index distribution of the ESP events show similar mean and standard deviation values for both SC23 and SC 24.

ESP Roll-over Energy (E_0) Distribution

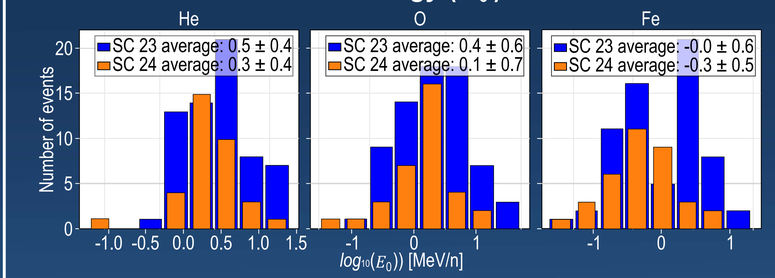

Figure 7. The roll-over energy (E_0) distribution of the ESP events have higher mean values in SC23 than in SC 24; however, the standard deviation values are similar.

Summary

- The number of heavy ion ESP events observed by ACE during SC23 is higher than those of SC24 (75 vs 40).
- The near Sun and 1 AU CME speeds are on average faster for SC23 than for SC24.
- The heavy ion peak intensities show similar mean values for SC23 and SC24 but the SC24 events are less likely to accelerate heavy ions to energies above 10 MeV/nucleon.
- The spectral index distributions are similar in both SCs.
- The roll-over energy (E_0) in the spectral profile is higher for SC23 ESP events than for SC24, suggesting that heavy ions were accelerated more efficiently to higher energies in SC23.