Multiradionuclide Evidence for a Solar Energetic Particle Event at 14,300 BP

Solar Energetic Particle (SEP) events, resulting from intense solar eruptions, can cause short-term increases in the production of cosmogenic radionuclides such as ^{10}Be, 14C, and ^{36}Cl. This study investigates whether such events occurred around 14,300 and 14,700 BP, intervals where pronounced spikes were previously observed in ^{10}Be and ^{14}C records.

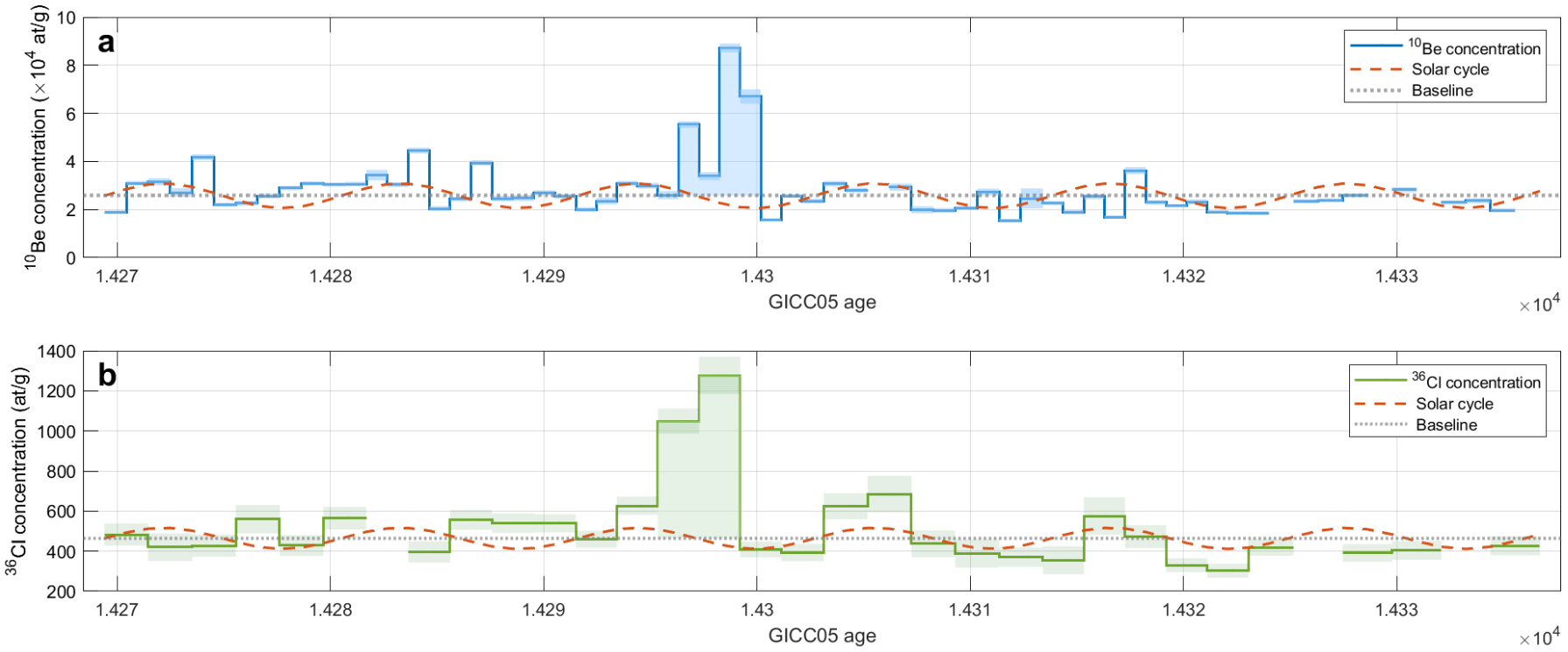

Fig. 1. *NGRIP2 ^{10}Be and ^{36}Cl concentrations plotted against GICC05 age for the time interval 14,269.4-14,336.7 BP.* ***(a)*** *and* ***(b)*** *show ^{10}Be and ^{36}Cl concentrations, respectively, with associated uncertainties represented by shaded bars. The peak region is also shaded. Baselines and a reconstructed solar cycle are overlain.*

To explore this further, high-resolution ^{10}Be and ^{36}Cl data from the North Greenland Ice Core Project was analysed. The results reveal one of the largest production peaks identified to date in both ^{10}Be and ^{36}Cl at 14,300 BP (Fig. 1). This peak coincides with a sharp rise in modelled ^{14}C production. This consistent signal across three radionuclide records provides strong evidence for an extreme SEP event. Variations in the ^{10}Be and ^{36}Cl concentrations exhibit an ~11-year sinusoidal periodicity, consistent with modulation by the solar cycle. This places the event within a period of high solar activity, aligning with modern observations that they are most common near solar maxima. The event's ^{36}Cl/^{10}Be ratio suggests a hard energy spectrum dominated by very high-energy particles. Fluence estimates indicate the event was of an exceptional magnitude (F_{30}: 8.85 (± 0.86) × 10^{10} particles/cm^2), far exceeding any events observed during the instrumental era. These offer new insights into the timing, magnitude, and characteristics of extreme solar storms.

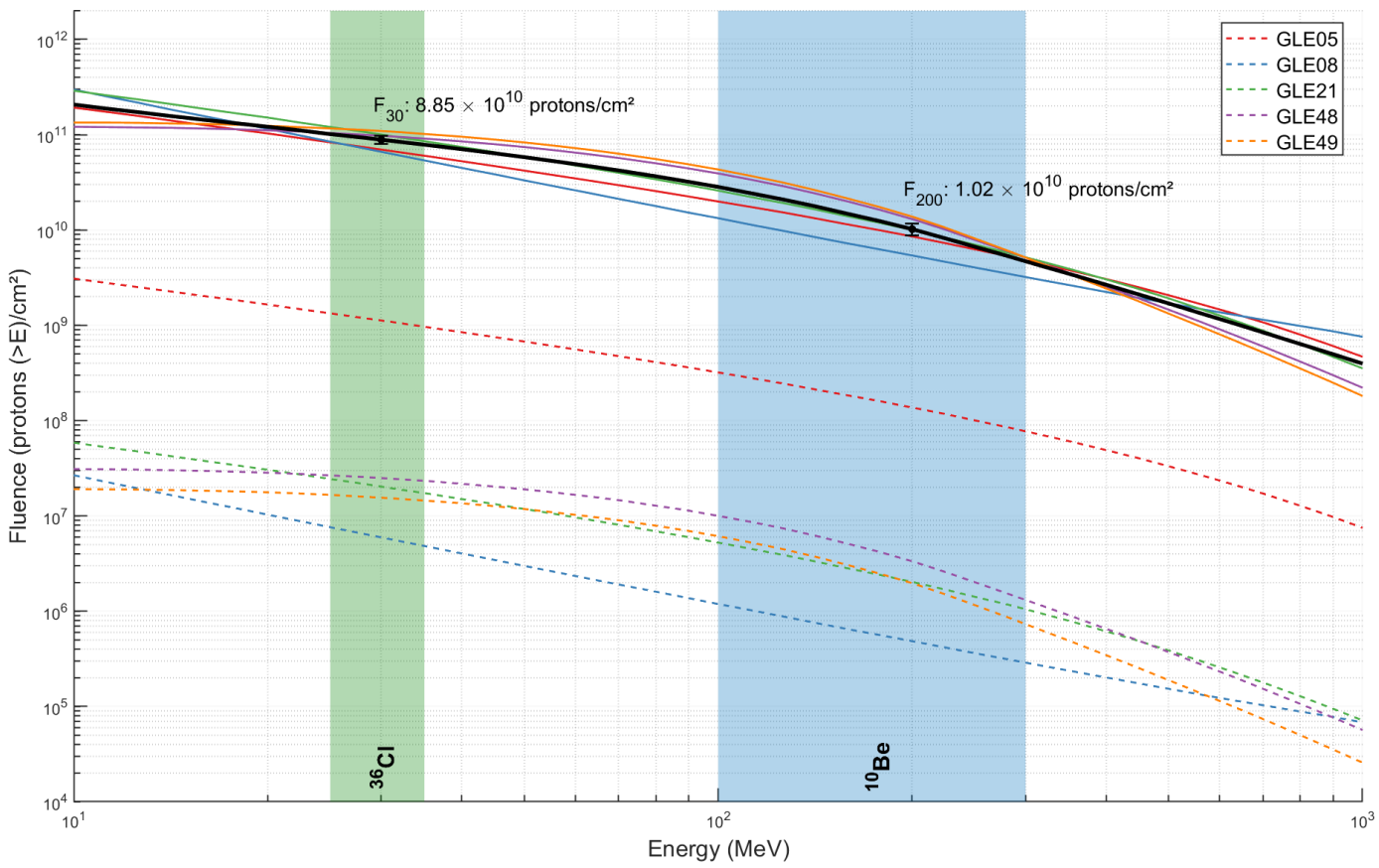

Fig. 2. *Estimated fluence spectrum of the 14,300 BP event. Dashed lines show original GLE spectra that fall within the uncertainty range of the ^{36}Cl/^{10}Be ratio. Solid lines represent scaled versions of these spectra. The black solid curve indicates the average scaled spectrum (with F_{30} and F_{200} displayed), interpreted as the best estimate for the 14,300 BP event. Adapted from Koldobskiy et al., 2021; F. Mekhaldi (personal communications, April 25, 2025).*

In contrast, the interval around 14,700 BP exhibits greater variability and lacks an unambiguous excursion. A significant correlation with δ^{18}O implies that these fluctuations are likely driven by climatic variability than solar activity.

Reference*:* Koldobskiy, S., Raukunen, O., Vainio, R., Kovaltsov, G.A., & Usoskin, I. (2021). New reconstruction of event-integrated spectra (spectral fluences) for major solar energetic particle events. *Astronomy & Astrophysics*, *647*, A132.

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