Multiradionuclide evidence for an extreme solar proton event around 2610 BP

Recently it has been confirmed that extreme solar proton events (SPE) can lead to significantly increased production of cosmogenic radionuclides (Mekhaldi et al. 2015). The evidence of these events can be recorded in tree rings (^{14}C) and ice cores (^{10}Be, ^{36}Cl). The IntCal13 calibration curve, which is a continuous tree ring record of ^{14}C fluctuations throughout the Holocene, was used to locate two potential spikes in radionuclide production (~7510 and ~2610 BP).

The primary aim of this study was to establish whether these potential spikes have counterparts in other radionuclide records. The secondary aim was to determine whether the spikes in radionuclide production could be attributed to extreme solar events, and to define the parameters of these events.

Cosmogenic ^{10}Be, ^{14}C and ^{36}Cl are produced in the atmosphere through a series of reaction pathways. The individual production rates for these radionuclides are differently sensitive to the energies of incident particles. This varying energy sensitivity can theoretically be used to determine the energy spectrum and therefore the source of sharp peaks in cosmogenic radionuclide production. However, high resolution radionuclide records are required to determine individual radionuclide production rates over short time periods. Therefore, new annually-resolved ^{10}Be was measured from the NGRIP ice core for the two periods of interest and analysed in addition with available records of ^{36}Cl. The results from this analysis are shown in figure 1.

New sub-annually to annually-resolved ^{10}Be measurements from the NGRIP ice core have led to the discovery of a sharp peak in ^{10}Be deposition around 2610BP, with an estimated integral increase of 240% relative to annual background ^{10}Be deposition. Existing measurements indicate a synchronous ^{36}Cl deposition peak in the GRIP ice core, with an estimated increase of 457% relative to annual background ^{36}Cl deposition.

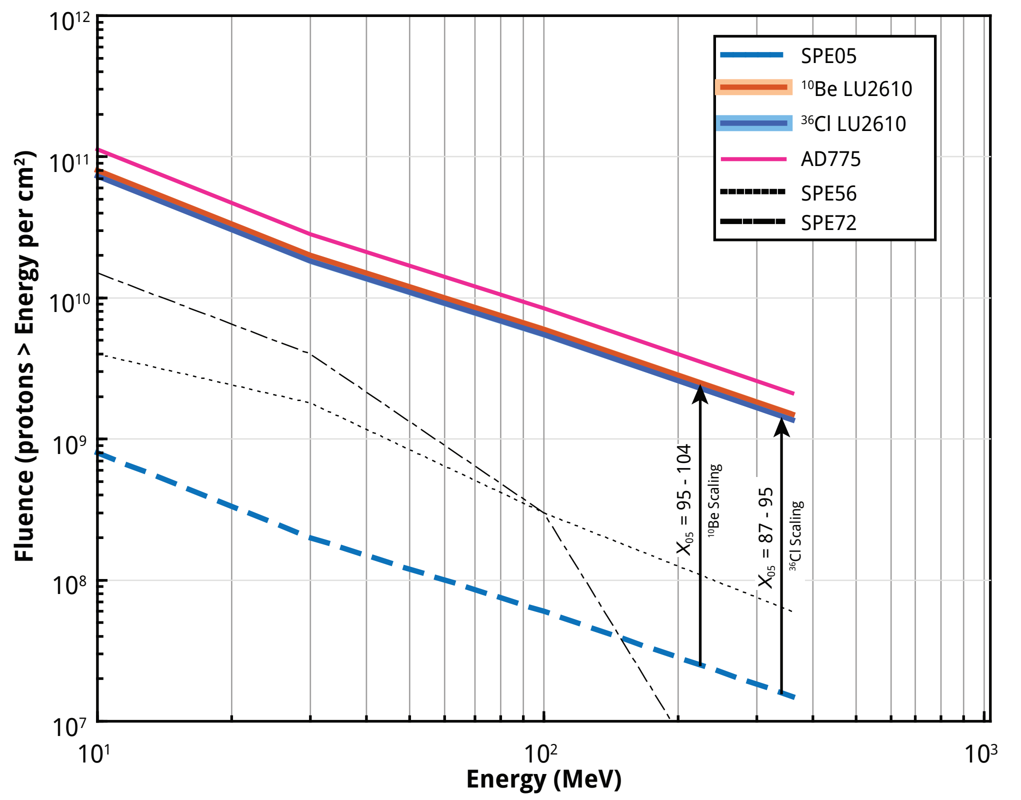

Figure 2. Fluence spectra of LU2610. *Estimated fluence spectra of the extreme SPE associated with the LU2610 event based on ^{36}Cl and ^{10}Be and scaled against the fluence spectrum of SPE05 (dashed blue line). Scaling factors for both radionuclides are shown, with shading representing upper and lower uncertainty boundaries. The estimated fluence spectra for AD775 is shown for reference (red line). Dashed black lines indicate spectra for hard (SPE56) and soft (SPE72) events.*

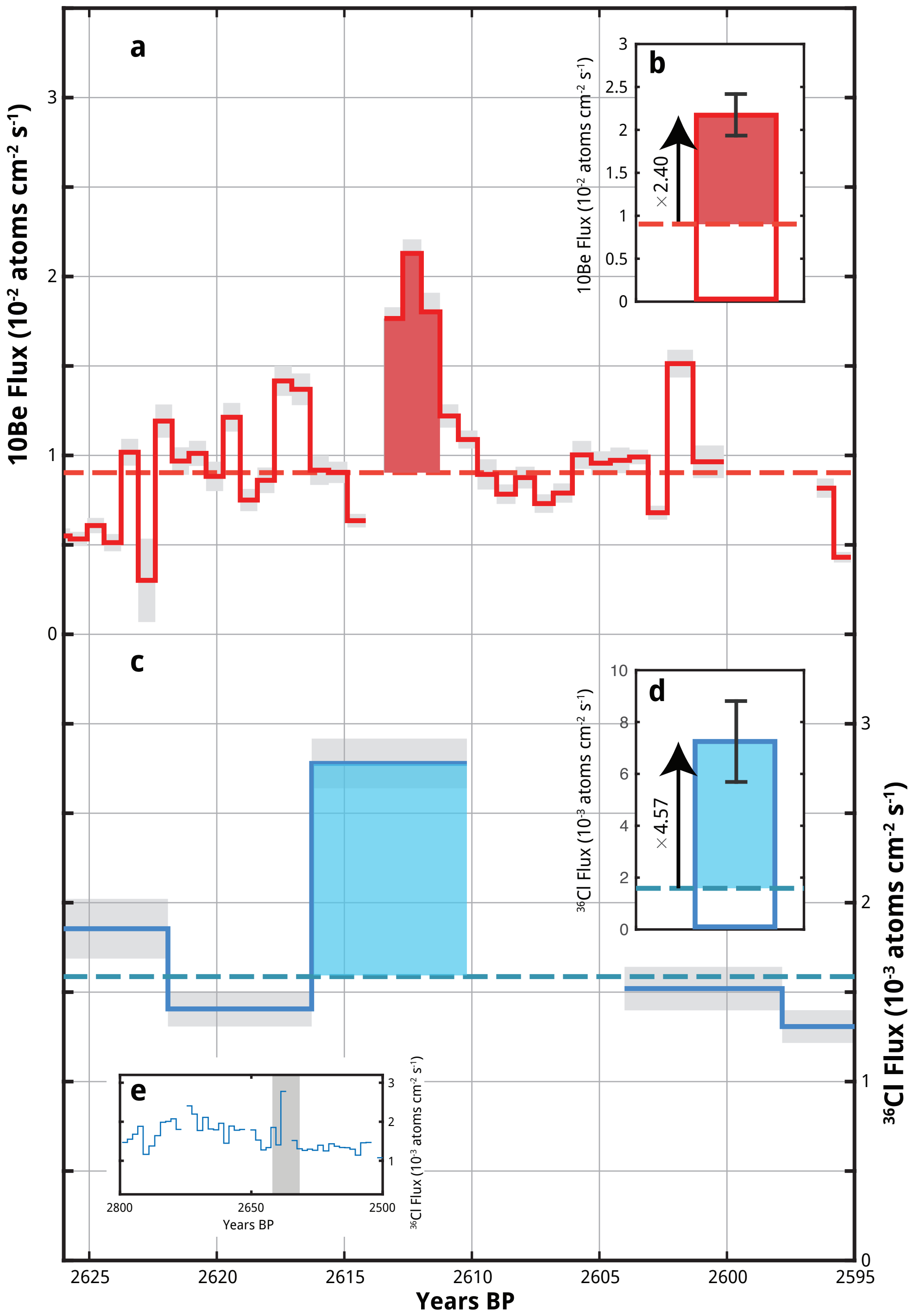

Figure 1. LU2610 event view of ^{10}Be and ^{36}Cl. (a) *Time series for newly measured NGRIP ^{10}Be flux (red line), along with corresponding measurement error margins (grey shading).* ***(c)*** *Time series for existing ^{36}Cl GRIP measurements, displayed as flux (blue line). Filled areas represent estimated production enhancements relative to background production (dashed lines). Inset* ***(e)*** *is an extended time series for ^{36}Cl flux in the GRIP core, with the investigated period shown in grey. Sub figures* ***(b)*** *and* ***(d)*** *show radionuclide production enhancement fluxes in atoms cm^{-2} s^{-1} for the LU2610 event, integrated into 1 year for ^{10}Be and ^{36}Cl respectively. The radionuclide increases are indicated with arrows relating to the ratio between the inferred flux/production enhancements stacked over 1 year (filled rectangles) and estimated background levels (white rectangles). Error bars represent measurement uncertainty for the period of integration.*

This synchronous peak in both records is consistent with the increased radionuclide production expected due to an extreme SPE. Calculations based on the production yields of ^{10}Be and ^{36}Cl suggest that the hypothesised SPE at 2610 BP was characterised by a hard spectrum and a remarkably high fluence of 1.92 x 10^{10} protons.cm^{-2} (fig. 2). Furthermore, this event was at least an order of magnitude more energetic than the so far assumed strongest hard SPE of February 1956, and similar in magnitude to the remarkably strong hard AD775 paleo-SPE event. This and prior studies should therefore motivate the investigation of similar events in order to better ascertain the occurrence rate of extreme solar events.

References:

Mekhaldi, F., Muscheler, R., Adolphi, F., Aldahan, A., Beer, J., Mcconnell, J. R., Possnert, G., Sigl, M., Svensson, A. & Synal, H.-A., 2015: Multiradionuclide evidence for the solar origin of the cosmic-ray events of AD774/5 and 993/4. Nature communications 6.

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