# Magnetic flaring in the young Sun and implications for solar nebula solids

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## Abstract

To address the role of energetic processes in the solar nebula, we provide a detailed characterization of magnetic flaring in stellar analogs of the pre-main sequence Sun based on two 0.5-day observations of analogs of the young Sun in the Orion Nebula Cluster obtained with the Chandra X-ray Observatory. The sample consists of 41 stars with masses 0.7-1.4 $M_\odot$ and ages $< 1$ to $\simeq 10$ Myr. We find the X-ray luminosities are strongly elevated over main sequence levels, and decline during the pre-main sequence phase according to $\log L_x \simeq 29.7 - 0.6(\log t - 6)$, where $L_x$ is in erg $s^{-1}$ measured in the $2-8$ keV band and $t$ is in years. The X-ray emission is strongly variable in time in most solar analogs; about 20 flares with $29 < \log L_x(peak) < 31$ erg $s^{-1}$ on timescales from 0.5 to $> 12$ hours are seen during the Chandra observations. The ubiquity of the strong, hard and variable X-ray emission in this sample is strong evidence that the early Sun exhibited similar enhanced magnetic activity.

Comparison to the contemporary Sun shows that, at an age of 1 Myr, the Sun exhibited long duration events (LDE) with $10^2$ higher peak X-ray luminosities occurring $10^2$ times more frequently than the most powerful LDE flares seen today. MeV proton fluxes are inferred to have been $10^{5.5}$ times greater than current levels. The results support a local flare origin of various properties of pristine meteorites. The particles and shocks produced by the magnetic reconnection flares may have flash melted meteoritic chondrules, produced correlated excess $^{22}Ne$ and particle tracks in free-floating meteoritic grains, and generated at least some of the short-lived nuclides found in CAI inclusions by spallogenic nuclear reactions.

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