Evidence of significant energy input in the late phase of a solar flare from NuSTAR x-ray observations

We present observations of the occulted active region AR 12222 during the third Nuclear Spectroscopic Telescope ARray (NuSTAR) solar campaign on 2014 December 11, with concurrent Solar Dynamics Observatory (SDO)/AIA and FOXSI-2 sounding rocket observations. The active region produced a medium-size solar flare 1 day before the observations, at ~18 UT on 2014 December 10, with the post-flare loops still visible at the time of NuSTAR observations. The time evolution of the source emission in the SDO/AIA 335 Å channel reveals the characteristics of an extreme-ultraviolet late-phase event, caused by the continuous formation of new post-flare loops that arch higher and higher in the solar corona. The spectral fitting of NuSTAR observations yields an isothermal source, with temperature 3.8–4.6 MK, emission measure \((0.3–1.8) \times 10^{48} \text{ cm}^{-3}\), and density estimated at \((2.5–6.0) \times 10^{8} \text{ cm}^{-3}\). The observed AIA fluxes are consistent with the derived NuSTAR temperature range, favoring temperature values in the range of 4.0–4.3 MK. By examining the post-flare loops' cooling times and energy content, we estimate that at least 12 sets of post-flare loops were formed and subsequently cooled between the onset of the flare and NuSTAR observations, with their total thermal energy content an order of magnitude larger than the energy content at flare peak time. This indicates that the standard approach of using only the flare peak time to derive the total thermal energy content of a flare can lead to a large underestimation of its value.

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