The relativistic solar particle event on 28 October 2021: evidence on particle acceleration in and escape from the solar corona

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Particle, radio and X-ray observations during the first relativistic proton event detected on Earth during solar cycle 25 are analysed. The aim is to gain insight into the relationship between relativistic solar particles detected in space and acceleration processes in solar eruptive events. To this end ground-based neutron monitor measurements of relativistic nucleons and space borne measurements of electrons with similar speed are used to determine the arrival times of the first particles at 1 AU, and infer their solar release times. The release times are compared with the time histories of non thermal electrons in the solar atmosphere and their escape to the interplanetary space, as traced by radio spectra and X-ray light curves and images. As in other events, the first relativistic protons detected at Earth are released more than ten minutes after the start of the radio emission. We report evidence for the co-existence of both confined and escaping non-thermal electrons, and identify two features at the origin of electrons escaping to the interplanetary space: a shock wave that accelerates electrons on open field lines, and radio signatures of the reconnection between the confining magnetic field lines within a CME (flux rope, flare loops) and ambient open magnetic field lines, which allows confined electrons to escape. We discuss the relationship between these signatures and the late release of relativistic protons, and compare two scenarios: the acceleration of relativistic protons by a coronal shock wave vs. the gradual escape from closed magnetic structures though successive events of magnetic reconnection with ambient open magnetic field lines.