PROTON TRANSPORT THROUGH SELF-GENERATED WAVES IN IMPULSIVE γ-RAY FLARES

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Energetic proton transport through self-generated Alfvén waves in impulsive (γ-ray) flares is studied using the method of Monte Carlo simulations. Protons are traced inside a flux tube after they are released from a point source located inside the loop until they hit the boundary of the 1D simulation box and escape. As they stream from the source towards the boundaries, the particles generate Alfvén waves through the streaming instability. We consider both open and closed field lines. In the closed field line case, the escaping particles precipitate and produce observable secondary emissions; for the open field line, particles precipitate only from one end of the field line, and escape freely to the interplanetary medium from the other end.
For a sufficiently large number of accelerated protons (per logarithmic momentum interval and unit area) the particle flux from the source produces a turbulent particle trap that expands at Alfvén speed to both directions from the source. The resulting γ-ray emission consists of a precursor, related to the quick diffusion of particles when the trap has not formed yet, and of a delayed brightening in the loop leg closer to the source, related to the opening of the turbulent trap as the self-generated waves reach the solar surface. For open field lines, our model is capable of producing the small ratio of the numbers of interplanetary-to-interacting protons typically observed in impulsive flares, if the proton source is located close to the Sun.