Modeling non-thermal emission from SN 1987A

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The remnant of SN 1987A is the best-studied object of its kind. The rich data-set of its thermal and non-thermal emission across the electromagnetic spectrum poses a unique testbed for the elaboration of particle-acceleration theory. Recently, the detection of SN 1987A in high-energy gamma-rays was claimed for the epoch between 2016-2018. Despite the prediction that very young SNRs are the best candidates for the acceleration up to PeV-energies, there is no sign of very-high energy gamma-ray emission yet.

We use 2D MHD simulations of the progenitor's wind to obtain hydro-profiles for the medium around the supernova explosion. The model is based on an episode of enhanced mass loss, when the progenitor of SN 1987A transited on a red-to-blue loop about 25,000years prior to its explosion. We constructed two cones based on the MHD simulations and used these in our time-dependent acceleration code RATPaC to model the evolution of the gamma-ray emission of SN 1987A and compare it to the available observational data. The central cone has an opening angle of $\pm 2°$ and contains dense material, forming an equatorial ring approximately 0.2 pc from the center of the explosion. This dense equatorial ring is embedded an intermediate density Hii-region extending radially outward from 0.1pc away from the center of the explosion and to $\pm 35°$ around the equatorial plane.

We then solve the transport of cosmic rays and the gas-dynamical equations for the hydrodynamical flow, in the test-particle limit. We assume Bohm-like diffusion in an amplified magnetic field which reaches $B_0 = 125\mu G$ in the immediate upstream of the forward shock. We use the spatial and temporal information of the particle distribution to calculate the hadronic gamma-ray emission from SN 1987A.

We find that the increase in thermal X-ray emission, caused by the interaction with the dense equatorial ring, predates the increase in the low-energy gamma-ray brightness by several years. Low energy cosmic rays need to be accelerated freshly from the shocked dense ring material in order to boost the high-energy gamma-ray emission. The slow shock-speed of ~1000km/s in the dense ring is hindering efficient acceleration to TeV energies of CRs injected from the ring. As a consequence, the roughly tenfold increase of the gamma-ray brightness in the last 15years at very-high energies is mainly powered by the acceleration in the outer, less dense cone. Contrary, the brightening by a factor of ~100 at high-energy gamma-ray energies is powered by the interaction with the dense ring.

The superposition of the two components originating form the two considered cones results in a soft gamma-ray spectrum with a spectral index of s~2.6 above ~100GeV. The flux-increase at energies relevant for H.E.S.S. should make a detection of SN 1987A possible at a flux-level comparable to the published upper-limit derived from data taken between 2005-2012.