Ultra-high Energy Inverse Compton Emission from Galactic Electron Accelerators: Summary

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With the detection of sources above energies of 100 TeV by the HAWC and the LHAASO observatories, we are close to answer the very old question about the sources of the cosmic rays until the knee feature at $\sim$ PeV. We investigate here, if hard γ-ray spectra from inverse Compton emission of leptonic origin can be maintained until 100 TeV. Due to the Klein-Nishina suppression of the emission, hard spectra can only be achieved, if hard enough electron spectra can counterbalance the Klein-Nishina softening of the γ-rays. Such electron spectra can naturally be achieved in equilibrium situations in environments, where the cooling is dominated by inverse Compton losses.

In such environments, increased cooling times in the Klein-Nishina regime lead to a hardening of the electrons. Above a critical energy E_{X}, synchrotron cooling will inevitably dominate, which leads to a softening of the electron spectrum at energies above. Because of this, hard γ-ray spectra can only be maintained until energies slightly below E_{X}. E_{X} depends on the ratio between the energy density of the radiation field U_{rad} and of the magnetic field U_{B}, which we define as $\Xi_{\mathrm{IC}} \equiv U_{\mathrm{rad}}/U_{\mathrm{B}}$. The temperature of the radiation field plays a crucial role, because for lower temperatures, the Klein-Nishina transition occurs at higher energies, making it possible to maintain dominance by inverse Compton losses with lower values of Ξ_{IC}. For the CMB, the required Ξ_{IC} for $E_{\mathrm{X}} = 100\,\mathrm{TeV}$ is only ~ 3, implying, that for $B < 1.8\,\mu\mathrm{G}$ dominance of IC losses until 100 TeV is ensured.

Additional constraints on the system arise, because particles have to be able to be accelerated and confined long enough. For small sources, this requires a minimum magnetic field value, implying sufficiently large Ξ_{IC} to ensure IC loss dominance. Strong radiation fields will in turn lead to significant $\gamma\gamma$ absorption, which imposes an upper limit on the source size. For magnetic field values between 1 and $\sim$20 μG, the estimated sizes of the three sources above 100 TeV detected by HAWC fulfil these constraints up to temperatures of the radiation field of 50 K. Absorption by large scale galactic radiation fields can be ignored in many cases at 100 TeV, but at higher energies it should be taken into account. Pulsars with high spin down powers $> 10^{36}\,\mathrm{erg\,s^{-1}}$ are potential PeV accelerators. If the termination shock is not far away from the pulsar and B-fields are too high to allow $\Xi_{\mathrm{IC}} > 1$, the accelerated electrons could diffuse to larger radial distances and fill the surrounding volume where radiation energy dominance holds.

While the required conditions for hard leptonic γ-ray spectra at 100 TeV are highly unlikely to be met on large scales in the galactic disk, except at large galactic radii or high above or below the disk, they could be fulfilled in local regions with enhanced radiation fields and/or low B-fields. Star forming regions or super-bubbles provide ideal conditions, and suitable environments could potentially exist along any line of sight through the inner galaxy.

The three HAWC sources are all plausibly associated to powerful pulsars. We find that for $B = 3\,\mu\mathrm{G}$ and enhancements of the large scale galactic radiation fields below a factor of 5, all γ-ray spectra above 10 TeV can be explained with equilibrium inverse Compton scenarios. For two of these sources, data from the LHAASO observatory was published recently, and is explained by the models as well. The enhancements of the radiation fields are compatible with data from IRAS. However, there is a redundance between model parameters, and knowledge about the local radiation fields and B-fields, and a time dependent modelling including multiwavelength data is necessary to constrain the models further.