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Galaxy formation with cosmic rays: the importance of the gamma-ray window

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Star formation in galaxies appears to be self-regulated by energetic feedback processes. Among the most promising agents of feedback are cosmic rays (CRs), the relativistic ion population of interstellar and intergalactic plasmas. In these environments, energetic CRs are virtually collisionless and interact via collective phenomena mediated by kinetic-scale plasma waves and large-scale magnetic fields. The enormous separation of kinetic and global astrophysical scales requires a hydrodynamic description. We develop a new macroscopic theory for CR transport in the self-confinement picture, which includes CR diffusion and streaming simultaneously. The interaction between CRs and electromagnetic fields of Alfvénic turbulence provides the main source of CR scattering. We account for energy exchange of CRs and Alfvén waves via the gyroresonant instability and include other wave damping mechanisms. These theoretical advances enable us to simulate CR physics with the three-dimensional magneto-hydrodynamical simulation code AREPO, which employs an innovative moving mesh geometry. I will demonstrate that CRs play a decisive role on all scales relevant for galaxy formation, from individual supernova remnants, to the multiphase medium in our Galaxy up to scales relevant for galaxy formation. In particular, I will show how TeV shell-type supernova remnants can be used to infer the in-situ coherence scale of Galactic magnetic fields. Finally, I will discuss the non-thermal gamma-ray emission of Milky-Way like galaxies and how the next-generation instruments such the Cherenkov Telescope Array (CTA) can be used to infer properties relevant for galaxy formation.

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