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Heating of the Intergalactic Medium Induced by Streaming Cosmic Rays

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In the current Universe, cosmic rays (CRs), which are nonthermal charged particles, are believed to be accelerated in the supernova remnants.[1] The energy density of CRs is as high as those of the other components of the Universe, such as thermal particles, turbulence, and magnetic fields, thereby affecting a lot of astrophysical phenomena.

As in the current Universe, previous studies show that CRs are also accelerated in the early Universe, in the supernova remnants of the first stars.[2] However, the influence of the accelerated CRs on the evolution of the early Universe is poorly understood. In this study, we propose that the resistive heating induced by streaming CRs is important for the temperature evolution of the intergalactic medium (IGM).

Here we consider the system where CRs stream radially away from a galaxy. Then, in order to cancel out the CR current and to maintain current neutrality, return current of the thermal electrons is induced. Since the collisions between thermal electrons and thermal ions are negligible, a resistive electric field is produced to maintain the return current. This resistive electric field causes the Joule heating.

In the standard scenario, the global heating of the IGM is caused by X-rays from galaxies. Here we consider local heating around a galaxy. We compare the heating rates of CR heating and X-ray heating and calculate the temperature evolution of the IGM gas. For CR heating, we also consider direct heating, which is caused by Coulomb interactions with free electrons and by ionization of neutral hydrogens. We conclude that CR resistive heating is dominant in the early stage of the heating up to $T \lesssim 10^{3.5}\,K$, as shown in Figure 1.[3] Since the propagation of the CRs depends on the intergalactic magnetic field and it can be also generated by CRs,[4] a more realistic treatment including the detailed structure around a galaxy is needed in future work. The heating of the IGM can be tested by future radio observations of the $21\text{-}cm$ line of neutral hydrogen.

References
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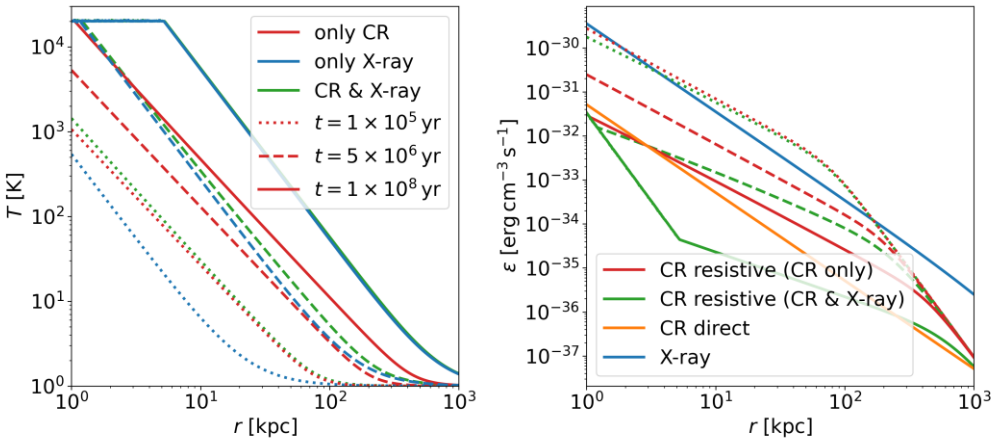

Figure 1. Temperature evolution of the intergalactic medium as a function of the distance from a galaxy (left) and the instantaneous heating rates (right).