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Particle accelerations, plasma instabilities, and collisionless shocks in partially ionized plasmas

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Cosmic rays are thought to be accelerated by shocks propagating to the interstellar medium, which is driven by a supernova. The interstellar medium in our galaxy is not always completely ionized. In fact, the existence of neutral hydrogen atoms around supernova remnants has been identified by observations of H-alpha emission. Therefore, cosmic rays are accelerated by shocks in partially ionized plasma. However, early studies about cosmic ray accelerations and collisionless shocks implicitly assumed that plasmas are fully ionized. In this talk, I'd like to talk about particle accelerations, plasma instabilities, and collisionless shocks in partially ionized plasmas. I'll introduce the standard model of cosmic ray acceleration and its problems, then I'll show results of hybrid plasma simulation with ionization of hydrogen atoms.

We performed the first hybrid simulations of nonrelativistic collisionless perpendicular shocks in partially ionized plasmas [4]. In the hybrid code, protons and hydrogen atoms are treated as nonrelativistic particles and electrons are a massless fluid. For ionization processes, we considered charge exchange of hydrogen atoms with protons and collisional ionization of hydrogen atoms with electrons, protons, and hydrogen atoms. We took into account the velocity dependence of their cross sections. The simulations showed the following.

1. The upstream hydrogen atoms are not dissipated at the collisionless shock because they do not interact with electromagnetic fields. After penetrating the shock front, some of them are ionized by the charge exchange process in the shock downstream region, while at the same time, hot protons dissipated at the shock become hot hydrogen atoms by the charge exchange process.
2. Some of the hot hydrogen atoms are leaking into the shock upstream region because they have a velocity larger than the shock velocity and they do not interact with magnetic fields. The leaking hydrogen atoms are ionized in the upstream region and picked up by the upstream magnetic field [3, 4].
3. The upstream plasma flow is decelerated by the pickup ions before the upstream plasma interacts with the shock front because the pickup ions push the upstream plasma when they are picked up.
4. The pickup ions generate a temperature anisotropy in the shock upstream region, which excites the Alfven ion cyclotron instability [1, 2, 4, 6]. In addition, the injection of hot pickup ions makes a sound wave unstable [5].
5. The instabilities in the shock upstream region generate density fluctuations in the upstream region. The interaction between the upstream density fluctuations and the shock generates strong turbulence in the downstream region. Then, magnetic fields are strongly amplified in the downstream region by the turbulent dynamo [6].
6. The pickup ions are preferentially accelerated by the diffusive shock acceleration because they have a larger velocity than one of upstream cold protons [7]. The momentum spectrum of accelerated particles is steeper than p^{-2} because the shock structure is modified by the pickup ions.

Therefore, our simulations showed that the upstream ionization fraction is a important parameter to decide the number of accelerated particles, the spectrum of the accelerated particles, the magnetic field strength in the downstream region, and the shock structure.

References

[1] Y. Ohira, T. Terasawa, and F. Takahara, ApJL, 703, 59 (2009)
[2] Y. Ohira and F. Takahara, ApJL, 721, L43 (2010)
[3] Y. Ohira, ApJ, 758, id. 97 (2012)
[4] Y. Ohira, PRL, 111, id. 245002 (2013)
[5] Y. Ohira, MNRAS, 440, 514 (2014)
[6] Y. Ohira, ApJ, 817, id. 137 (2016)
[7] Y. Ohira, ApJ, 827, id. 36 (2016)