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STATIC GALACTIC HALO AND GALACTIC WIND

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1. INTRODUCTION

Although the exact state of the interstellar medium (ISM) in our Galaxy (other galaxies as well) is not clear at all, the "common consensus" is a rough pressure balance (or equipartition of energy) exists between different components and phases, say, cold, warm, hot phases of the ISM, magnetic field, cosmic rays, etc. If the halo of a galaxy is taken to be an extension of the ISM, then its structure is influenced by various ISM components. A "complete" description of the halo is evidently very complicated. This contributed paper gives a brief account on cosmic ray halo, which emphasizes the role played by cosmic rays. The interaction between cosmic rays and thermal plasma is facilitated by magnetic field. The cosmic rays are scattered by hydromagnetic waves (e.g., Alfvén waves) which in turn can be generated by cosmic ray streaming instability. This constitutes a self-consistent picture. Since we are interested in the structure of the halo, we adopted a hydrodynamic model in which the cosmic rays and waves are described by their pressures (see e.g. Ko 1992). In general there are two classes of halos: static and dynamic.

2. STATIC GALACTIC HALO

The basic model includes magnetohydrostatic equilibrium and energy exchange between cosmic rays and Alfvén waves. Magnetohydrostatic equilibrium is achieved when the total pressure gradient (which includes thermal plasma, cosmic rays and Alfvén waves) is balanced by the Lorentz force and the gravitational force. Cosmic rays and Alfvén waves are described by their energy flux equations. Energy exchange is simply the work done on the waves by the cosmic rays. To further simplify the model, we consider the so called *flux-tube formulation* (see e.g., Ko 1991). In this formulation, the background magnetic field is assumed to be a nice smooth vector field without any singularities so that we can form a flux tube. Moreover, assume that the Alfvén waves travel along the field line and there are no cross field line diffusion of cosmic rays. Under this formulation the model is essentially one dimension (along the flux tube).

Take our Galaxy as an example. The "base" of the halo is taken to be at 1 kpc above the mid-plane. At this level, the thermal plasma density and pressure are about 10^{-3} cm^{-3} and 0.25 eV cm^{-3}, respectively. The cosmic ray pressure is about 0.16 eV cm^{-3} and the pre-existing wave pressure is negligible. The density (and pressure) of the halo exhibits two scale heights. Close to the disk, the thermal plasma pressure (small scale height) dominates. At large distances the halo is supported by cosmic rays and self-generated waves (large scale height). In the case of our Galaxy, the coupling between the cosmic rays and background plasma is strong. The cosmic rays lift the halo to large distances and give rise to a pressure (about 6×10^{-3} eV cm^{-3}) too large to match the intergalactic medium (IGM) pressure. In addition, stability analysis on this kind of static halo shows that the halo is very susceptible to overturning instability. In the case of our Galaxy the growth time is of the order of 2×10^{7} yr (see e.g., Ko et al. 1991; Ko 1991). As a result, at least in the case of our Galaxy, a dynamic model is needed.

GALACTIC WIND

The large pressure difference between the static halo and IGM at large distances initiates an outflow, namely, galactic wind (if the material falls back to the disk afterwards, it is called a fountain then). A cosmic ray driven wind model can be constructed from the above static cosmic ray halo model by simply replacing the magnetostatic equilibrium condition by the mass, momentum and energy fluxes equations. The model can also be formulated along the flux tube provided that the flow and Alfvén waves follow the field line and no cross field line diffusion of cosmic rays. For steady state, the problem reduces to analysing a wind equation. To match the small IGM pressure, a transonic solution (from subsonic near the disk to supersonic far away) is required. In our Galaxy, the cosmic ray is able to push the plasma through the critical point and forms a supersonic cosmic ray driven galactic wind (see Breitschwerdt et al. 1991).

Finally, a few words about galactic rotation. When galaxy rotates, the magnetic field line forms Parker's spiral type helix (assume the flow dominates the field at large distances). Suppose the wind speed is about $250 \sim 500$ km s^{-1}. In our Galaxy the helical structure is important when we are interested in distances larger than $50 \sim 100$ kpc. Helical field line complicates the above formulation. Of course, there is no problem if we consider an isolated rigid thin flux tube. If we consider an extended region, then we must modified the above formulation simply because we can't use a helical curve as one of the coordinate curves. When axisymmetry is assumed, a formulation closely resemble the above one can be constructed and is called *projected flux-tube formulation* (c.f. Ko 1991).

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