Astrophys Space Sci (2012) 339:19–23
DOI 10.1007/s10509-012-1010-0

LETTER

Relaxed magnetic field structures in multi-ion plasmas

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Received: 27 September 2011 / Accepted: 31 January 2012 / Published online: 16 February 2012

Abstract The steady state solution of a three species magnetoplasma is presented. It is shown that relaxed magnetic field configuration results in a triple curl Beltrami equation which permits the existence of three structures. It is the consequence of inertial effects of the plasma constituents. One of the three vortices is of large scale while the remaining two relaxed structures are of small size of the order of electron skin depth. The magnetic field profiles are given for different Beltrami parameters. The study could be helpful to understand large magnetic field structures in three species plasmas found in space and laboratory.

Keywords Relaxation · Beltrami fields · Triple Beltrami fields · Space plasma

1 Introduction

Multi-ion plasmas are found in abundance in space and astrophysical objects. Ionosphere and magnetosphere of Earth, solar wind, bow shock in front of the magnetopause boundary layers, heliosphere, Saturn's magnetosphere and cometary tails contain multi-ion plasmas (Shemansky and Hall 1992; Hultqvist et al. 1999; Stasiewics 2004; Schwenn and Marsch 1990). The creation of fullerene and electron positron pairs in the laboratory have substantially increased the importance of multi-ion plasmas. The multi-ion plasmas have been studied extensively to investigate different modes such as nonlinear Alfvén waves (Faria et al. 1998), acoustic solitary waves (Verheest et al. 2008), solitons (Sauer et al. 2001) and electrostatic modes (Vranjes et al. 2008).

In the present work, we investigate the self-organization of multi-ion magnetized plasmas. Self-organization is a universal phenomenon and magnetofluids also self-organize to some preferred states. Self-organization of magnetofluids is also called as relaxation. It has been shown by the seminal work of Woltjer and Taylor (Woltjer 1958; Taylor 1974, 1986) that plasmas relax to force-free states. Such type of states occur when the field and its vorticity are parallel. The magnetic field structures observed in Reversed Field Pinch were explained using the Taylor's concept of relaxation. But the flow and pressure gradients being essential features of all practical plasmas are missing in the relaxation theory proposed by Taylor. Employing different types of constraints, the investigators in the field of plasma relaxation have presented different models mostly based on variational principle, which lead to relaxed states characterized by strong flow and pressure gradients. One of such models presented by Mahajan and Yoshida (Mahajan and Yoshida 1998; Yoshida and Mahajan 2002) is mathematically very simple and covers a large variety of solutions. This is a generalized model and a variety of relaxed structures that is paramagnetic, as well as diamagnetic could be obtained. Under certain conditions, one can see the glimpse of force free relaxed states and on the other hand, one can construct a non-force free, high β relaxed states of a plasma system (Yoshida et al. 2001; Iqbal et al. 2001; Iqbal 2005). The relaxed state of this Hall magnetohydrodynamics (HMHD) model is represented by double curl Beltrami equation. It has also been investigated that different multi-species plasma systems could relax to a

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