22E04

Fluid modeling of Short Large Amplitude Magnetic Structures (SLAMS) near the earth's bowshock

SLAMSの流体モデル

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The so-called Short Large Amplitude Magnetic Structures (SLAMS) are one of the most outstanding features frequently observed upstream of the earth's bowshock. Although the properties of these structures have been studied extensively using spacecraft observations, the mechanism leading to their formation still remains unclear. Since the SLAMS grow in a region with a gradient of energetic ions, the ion heat flux is likely to be the main energy source for their growth. We model their evolution using the Landau-fluid type framework, by including a nonlocal interaction between the ion heat flux and the magnetic envelope modulation. Numerical simulations show that, in the presence of inverse Landau interaction, a series of magnetic pulsations similar to the SLAMS grow rapidly. The growth is nonlinear and singular.

1. Introduction

From *in-situ* spacecraft observations we have learned that the collisionless quasi-parallel shocks are associated with a wide variety of wave activity and an abundance of supra-thermal particles. Among them are the short large amplitude magnetic structures, or "SLAMS" [1], which are also often grouped with longer structures and referred to collectively as "pulsations" [2,3].

Figure 1 gives a few examples of the SLAMs detected by four-spacecraft Cluster experiment [4]. Plotted is the total magnetic field amplitude versus time, and different colors correspond to different spacecraft. Three panels show examples for three different spacecraft separation scales (shown at the upper left corner of each panel). These observations suggest that the overall extent of the SLAMs is a few hundred to a few thousand kilometers, *i.e.*, much larger than the typical ion Larmor radius, and that the structure can grow within a very short period of the order of seconds, *i.e.*, about the same order as (or even shorter than) the ion gyro-period.

The rapid growth and the apparently "nonlinear" shape of the SLAMs suggest that they are generated by some external energy injection, rather than internal plasma instabilities. From early days of observations it was inferred that foreshock ULF waves (MHD waves often found in a region upstream of the bowshock) provide the seeds of the SLAMs[1,3]. Also, a superimposed epoch analysis of suprathermal ion data around the SLAMs clarified that the background energetic ion flux, presumably of the bowshock origin, is responsible for feeding energy to the SLAMs growth [5]. Hybrid simulation (super-particle ions + a massless electron fluid) of a quasi-parallel shock and its upstream region suggests that the foreshock ULF waves are amplified as they interact with energetic ions backstreaming from the shock, and they nonlinearly steepen and form a pulsation-like wave packet [6].

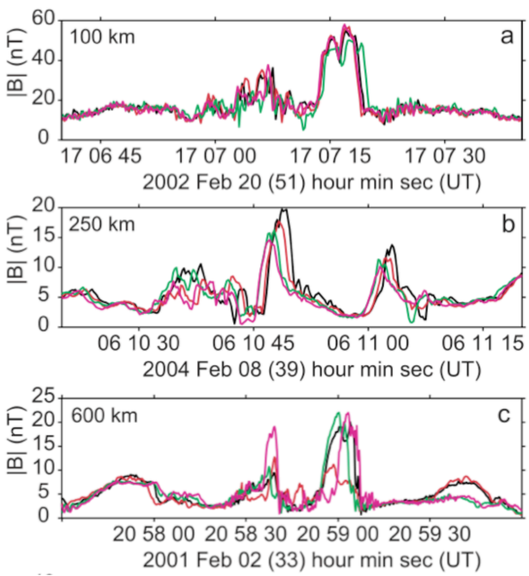

Fig. 1: Examples of SLAMs observed by Cluster

2. Fluid Model

In order to study the growth and nonlinear evolution of the SLAMs from the fluid point of view, we employ a Landau-fluid type formulation [7,8],

$$\rho\frac{\partial u}{\partial t}+\rho u\frac{\partial u}{\partial z}+\frac{\partial p}{\partial z}+\frac{\partial S}{\partial z}+\frac{\partial}{\partial z}(\frac{\mathbf{b}^2}{8\pi})=0 \tag{1}$$

$$(\frac{\partial}{\partial t}+u\frac{\partial}{\partial z})(\frac{p}{\rho^\gamma})+\frac{\partial q}{\partial z}=0 \tag{2}$$

$$\rho\frac{\partial \mathbf{v}}{\partial t}+\rho u\frac{\partial \mathbf{v}}{\partial z}-\frac{B_0}{4\pi}\frac{\partial \mathbf{b}}{\partial z}=0 \tag{3}$$

$$\frac{\partial \mathbf{b}}{\partial t}+u\frac{\partial \mathbf{b}}{\partial z}+\mathbf{b}\frac{\partial u}{\partial z}-B_0\frac{\partial \mathbf{v}}{\partial z}=0 \tag{4}$$

where all the notations are standard, except that **b** is the transverse magnetic field, u and **v** are the longitudinal and the transverse plasma velocity components, and that S and q are the nonlocal momentum and heat flux defined via their Fourier counterparts,

$$\hat{S}_k=-\sqrt{2}mn_0v_t\mu\frac{ik}{|k|}\hat{u}_k \tag{5}$$

$$\hat{q}_k=-\sqrt{2}n_0v_t\chi\frac{ik}{|k|}\hat{T}_k. \tag{6}$$

The transverse dynamics (such as propagation of Alfven waves) in a medium specified by the longitudinal variables is described by (3) and (4), while (1) and (2) describe the longitudinal dynamics modified by the ponderomotive force and the nonlocal flux contributions. The latter is independent of the spatial gradient scale (factor $k/|k|$ in (5) and (6)), characteristic of the Landau type interaction.

If the interaction between two oppositely propagating waves (or structures) can be ignored, (1)-(5) may be written in a way similar to the DNLS equation,

$$\frac{\partial \mathbf{b}}{\partial t}+\frac{1}{2}\frac{\partial}{\partial z}(U_{NL}\mathbf{b})+\mathbf{e}\times\frac{v_A^2}{2\Omega}\frac{\partial^2\mathbf{b}}{\partial z^2}=0 \tag{7}$$

where v_A is the Alfven speed, Ω is the ion gyrofrequency, **e** is the unit vector along the z-axis. The nonlinear response due to finite amplitude magnetic field is given by

$$U_{NL}=\frac{v_A}{2}(c_1(|b|^2-|\bar{b}|^2)+c_2\mathrm{H}(|b|^2-|\bar{b}|^2)) \tag{8}$$

where the bar indicates the average, and H stands for the Hilbert transformation. The first and the second terms in the r.h.s. of (8) represent the fluid and the Landau response, and their magnitude is specified via coefficients c_1 and c_2, which are further determined by the plasma states (such as the distribution function).

Figure 2 shows time evolution of seed magnetic fluctuations (upper panel) when they are immersed in a plasma with normal (red)/zero (black)/inverse (blue) Landau interactions. Energetic ions from the shock are able to grow the initial magnetic fluctuations to a very large amplitude. In addition, as Figure 3 shows, the growth is intrinsically nonlinear, and is associated with a (almost) blow-up at a certain finite timescale.

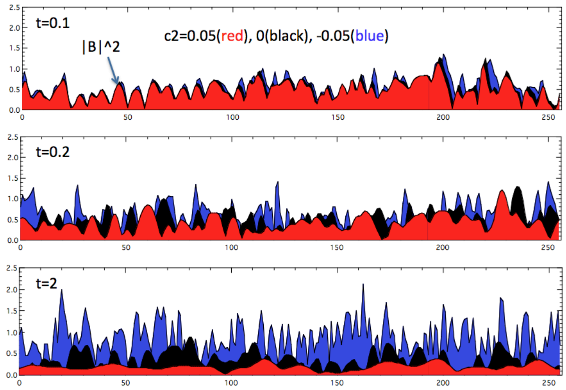

Fig.2. Time evolution of finite amplitude magnetic fluctuations in a plasma with Landau interations

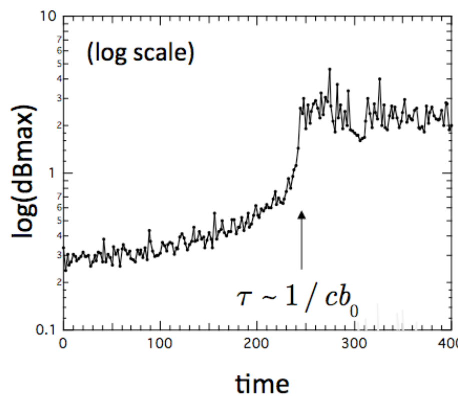

Fig. 3. Nonlinear growth of the magnetic field

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