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The Filamentation of the TLE's

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Abstract

The small scale structure of TLE's is discussed in the context of the filamentation processes. The discussion is focused around 3 mechanisms –pinch instability, filamentation of kinetic Alfven's waves and ionization instability.

1. Introduction

Plasma turbulence is one of the most significant features of the space plasma. Alfven, lower hybrid, electron and ion cyclotron waves and higher frequency waves at Langmuir and upper hybrid frequencies are always observed in the ionospheres, magnetospheres, solar wind.

Another general feature of a magnetized plasma is a tendency to create filamentary structures in the field aligned currents [1]. This filamentation can be seen by optical and X-ray observations of the solar chromosphere and corona, in the cometary's tails and on the Earth in the aurora. Magnetospheric plasma indicates also a tendency to form subtle structures in the current flowing along magnetic field line.

Prognoz-8, Magion-4, Interball Tail Probe and CLUSTER registered crossings of many small scale structures in different magnetospheric plasma domains. Examples of observation of these types of structures which we assumed are plasma filaments in the polar, magnetospheric cusp [2] are shown in Figures 1 and 2. The observed subtle structure of the TLE's indicate subtle structure which can be also identified with the plasma filaments.

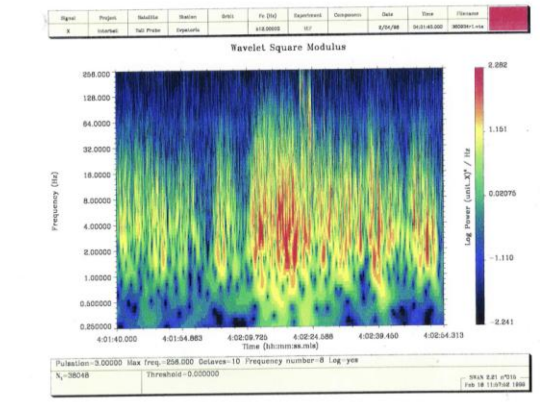


Figure 1: Wavelet spectra from Interball 1taken in the polar cusp. The variability of the wave intensity indicate crossing small scale structures within cusp.

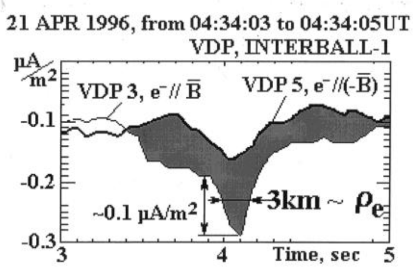


Figure 2: Filament of the electric current in the polar cusp registered by Interball 1 [2].

2. Transient Luminous Events (TLE's)

Transient Luminous Events (TLE) are upper atmospheric optical phenomena associated with thunderstorms. First suggestion on the existence of such phenomena was given by Scottish physicists C.T.R. Wilson in 1920's, but only 70 years later these phenomena were registered. The experimental discovery of these events was done accidentally in 1989 by Robert Franz . These first registrations were related to phenomenon which now is called red sprite [3],[4].

Since then thousands of observations of different types of TLEs have been done from the aircrafts, space shuttle, space station and satellites. The observations up to now are mainly related to optical phenomena. There are some different types of TLE- red sprites, blue jets, elves, halos and trolls. All of them are of the electromagnetic nature and are triggered by a rapid significant change in electric filed above the cloud level reaching to the ionosphere. The first proof that the electromagnetic effects observed in the mesosphere are generated by sprites and can be registered in the ionosphere has been done by DEMETER satellite observations [5] . These events are associated with the intense energy transfer between the atmospheric layers and have a strong influence on the ionosphere. Figure 3 presents the variety of the Transient Luminous Events.

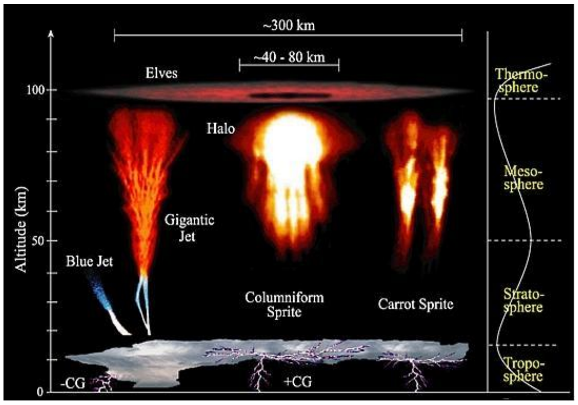


Figure 3: The view of the different phenomena called Transient Luminous Events

Sprites are associated with giant storm clouds with dimensions over 1000km producing strong electric field in the mesosphere. Sprites are massive but weak luminous flashes, appearing at altitudes 40-90 km.

Sprites are predominantly red. The brightest region lies in the altitude range 65-75 km, above which there is often a faint red glow structure that extends to about 90 km. Below the bright red region, blue tendril-like filamentary structures often extend downward to 40 km. Sprites rarely appear alone, they usually occur in groups - two, three or more

The duration of sprites is of the order of ms. Currents associated with sprites have intensity above 1 kA.

Blue jets are another high altitude optical phenomena, observed above strong thunderstorms. Blue jets are seen as an optical ejections from the top of the electrically most active regions of thunderstorms. Following their emergence from the top of the thundercloud, they typically propagate upward in narrow structure in form of cones of about 15 degrees full width at vertical speeds of roughly 100 km/s (Mach 300), fanning out and disappearing at heights of about 40-50 km. The giant blue jets can reach the ionospheric altitude . Their intensities are on the order of 800 kR near the base, decreasing to about 10 kR near the upper edge. These correspond to an estimated optical energy of about 4 kJ, a total energy of about 30 MJ, and an energy density on the order of a few mJ/m^3. Blue jets are rather rare events. Their appearance is much lower than sprites. Blue jets are not aligned with the local magnetic field.

The described above events are strongly electromagnetic events and its activity has direct influence on the conditions in the ionosphere.

3. Filamentary Structure of TLE's

Filamentary structures are found in the many cases of space plasmas, all of them are observed or are likely to be associated with electric currents: In the aurora filaments parallel to the magnetic field are often observed. These can have dimensions down to 100m; inverted V events (10^5 -10^6 A) and in situ measurements of the electric currents in the magnetosphere demonstrate the existence of the filamentary structures; in the ionosphere of Venus „flux ropes" or „magnetic ropes", whose filamentary diameter are typically 20km, are observed; on the Sun, prominences (10^{11}A), specula's, coronal streamers, polar plumes etc. show filamentary structure whose dimensions are in order 10^7-10^8m; the cometary tails often have a pronounced

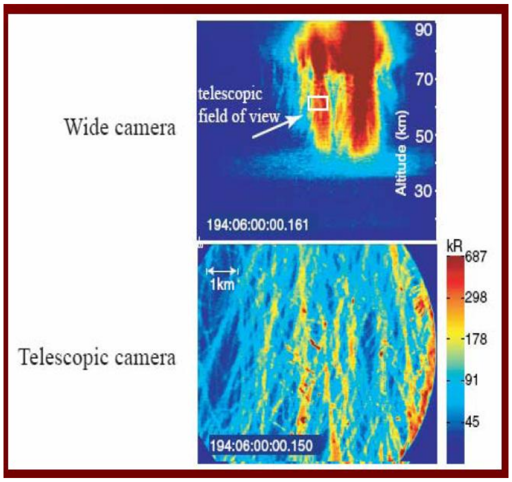


Figure 4: Subtle structure of the sprite [6]

filamentary structure, sprites and blue jets show the subtle structure along the current with spatial scales of the order tens to hundreds meters . Figure 4 shows the subtle structure of the sprite [6].

4. Physical Mechanisms of Filamentation

There are two fundamental physical mechanisms trying to explain a creation of the filamentary structure in the space plasmas. Both are associated with currents and ambient magnetic field.

1.Pinch instability of the field aligned electric current [7]. Galperin et al. suggested this mechanism as a source of the subtle structure of the aurora. Current layer is decomposed into small scale magnetic islands by this instability. The size of these islands is given by:

$$L \approx \frac{c}{\omega_p} \approx \frac{10^4}{\sqrt{n_e}} [m.]$$

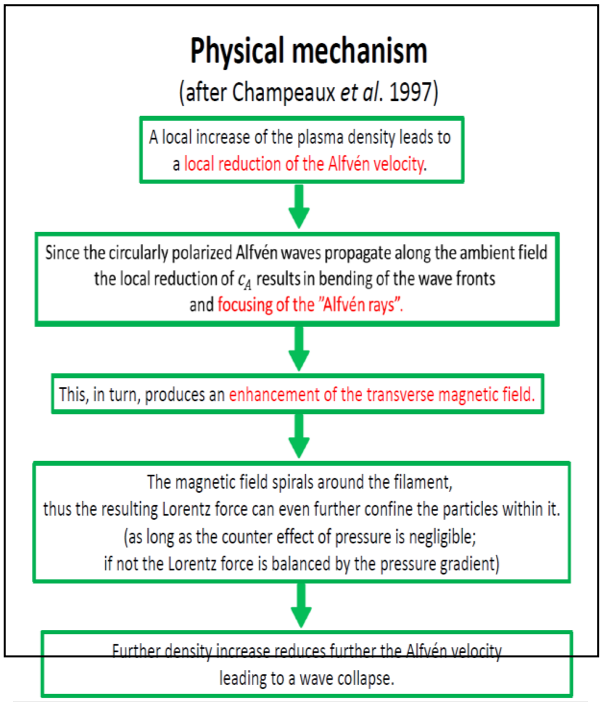
The characteristic time of formation of these structures is given by:

$$\tau^* = 4\sqrt{\frac{m_i}{m_e}} \frac{m_e}{eB_{perp}}$$

2.Filament instability of the dispersive Alfven waves [8], [9], [10]. Magnetohydrodynamic description of the plasmas concentrates on length scales that are much longer than ion inertial length $L \approx \frac{c}{\omega_{pi}}$ and time scales much longer than inverse ion gyrofrequency Ω_i^{-1}.

The solution of these equations are dispersive Alfven waves. These waves are circular polarized and propagate along the magnetic field. Shukla and Stenflo find that transverse perturbation of these waves leads to formation of the paralell to the magnetic field alongated structures (filaments) due to so called filametation instability. The numerical simulation of the disturbances of the MHD Hall's equations done by Laveder et al. [8] fully confirm this result. The scheme of the physical mechanism of this instability is shown in Figure 5. The scale of generated structures can be determine by the local density as:

$$\lambda \geq \frac{2.2 \times 10^8}{n_e} [m.]$$



Physical mechanism

(after Champeaux *et al.* 1997)

A local increase of the plasma density leads to a local reduction of the Alfvén velocity.

Since the circularly polarized Alfvén waves propagate along the ambient field the local reduction of c_A results in bending of the wave fronts and focusing of the "Alfvén rays".

This, in turn, produces an enhancement of the transverse magnetic field.

The magnetic field spirals around the filament, thus the resulting Lorentz force can even further confine the particles within it. (as long as the counter effect of pressure is negligible; if not the Lorentz force is balanced by the pressure gradient)

Further density increase reduces further the Alfvén velocity leading to a wave collapse.

Figure 5: Physical mechanism of the filamentation instability.

5. Summary and Conclusions

The characteristic time scales of the fine structures in TLE correspond to characteristic time scales of TLE's and can be up to tens of miliseconds and the spatial scales are in order of tens to hundreds meters. The structures observed in the aurora have similar size ([7]and references given there).

The non-linear analysis of the kinetic Alfven waves shows the possibility of the filamentation of these waves with a minimum characteristic scale corresponding to characteristic scales of Alfven soliton [11]. The characteristic scale is of the order of the Alfven wave length. Its minimum value can be expressed by the local electron density: $\lambda_a \geq 2.2 \text{ x}10^{8} / n^{1/2}$[m] if the plasma density n is measured in m^{-3}.

Another non-linear mechanism which can lead to the filamentation is pinching of the field aligned electric current [7]. This mechanism can generate structures with a smallest size given by $L > c/\omega_p$ (c is the light velocity and ω_p the plasma frequency). It can be also expressed by the electron local density as $10^7/n^{1/2}$ [m].

Both characteristic scales depend strongly on the altitude. Assuming that proton density at the altitudes where TLE's appear 10^9-10^{10} m^{-3} what corresponds to Alfven wavelengths of 2.2-7 km and pinch generated structures of 100- 300 m. The application of these mechanisms to TLE's needs a further studies and we are currently doing that.

Another mechanism which is well known in laboratory plasmas and has been applied for explanation of the small scale irregularities of the electron concentration in the ionospheric electrojets (equatorial and auroral)- the ionization instability [12] can be also discussed as a source of subtle structure of TLE and we will discussed it in our further work.

Acknowledgements

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