Localisation of 3D Kinetic Alfven wave and turbulence spectra in the solar corona region

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Abstract

Magnetic reconnections and the Kinetic Alfven Waves (KAW) are the keys to transferring the heat from the inner part of the Sun to the outer Solar atmosphere but the proper methodology to describe the heating of solar corona is still being browsed by the Solar physicist. Different magnetic structures interact with the KAW and the perturbation plays its role in the occurrence of this dramatic Corona heating. We proposed a 3D model of Kinetic Alfven wave which encounters the Harris current sheet profile of the magnetic field with taking into consideration of ponderomotive effects in the solar corona. This Model equation is solved numerically using the finite difference method in time and pseudospectral in spatial domain. The numerical simulation shows that the field structure feels a slow change without the nonlinearity whereas the presence of nonlinearity causes a rapid change. And approaching towards quasi-steady state, it generates a fully chaotic structure which are signals of turbulent filamentation with temporal evolution. We have also obtained the semi-analytical solution for these localized structures which shows the transverse scale size to be comparable to electron inertial length.

Introduction

Turbulence and magnetic reconnection have been observed to be the most important process which plays a very important role in cascading the energy from a larger scale to a subsequent lower scale in space plasma[1][2][4]. Turbulence plays an important role in the astrophysical events. Small perturbations can create turbulence in a given environment and this turbulence is very effective to transport and mix the energy from one scale to another. Turbulence is the prevailing phenomenon in Solar Corona. In Solar corona the interplay of the magnetic field lines paved the path to reconnection phenomenon and these reconnection sites are the very concerning topic for explaining the Solar corona heating problem. These two phenomena have been studied separately but their connection with each other is not fully understood. In inertial range, energy from a larger scale is cascaded towards smaller scales by Kolmogorov $5/3^{rd}$ law but to match with the observed temperature in Solar corona, this generated amount of energy does not satisfy the requirements. The dissipation range needs a steeper slope of energy cascading which can generates ample amount of heat to proceed the millions of temperature observed in the Solar corona. The reconnection sites have different type of magnetic structures in the vicinity. We have taken the Kinetic Alfven Wave (KAW) and studied its interaction with the Harris current sheet [5] profile in the vicinity of reconnection site. After developing the model equation, the numerical simulation have ben done to analyse the effects of this interaction.

Model Equation of dynamics

In the present work, we have developed three-dimensional model using MHD model to examine the effect of 3D KAW. In this analysis, we have assumed that kinetic Alfven wave having wave vector $\vec{k}_0 = \vec{k}_{0x} + \vec{k}_{0y} + \vec{k}_{0z}$ is propagating in a medium with equilibrium magnetic field $B = \vec{B}_{0z}\hat{z} + \tanh\left(\frac{x}{L}\right)\hat{y}$. using equation of motion for electron and ion, continuity equation

$$\frac{\partial \vec{v}_j}{\partial t} = \frac{q_j}{m_j}\vec{E} + \frac{q_j}{cm_j}(\vec{v_j} \times \vec{B}_0) - \frac{k_B T_j}{m_j}\vec{\nabla}\frac{n_j}{n_0} \tag{1}$$

$$\frac{\partial \vec{n}_j}{\partial t} + \vec{\nabla}.(n_j v_j) = 0 \tag{2}$$

and maxwell's equation by using wave equation to develop dyanamical equation of KAW.

$$(\vec{\nabla} \times \vec{E}) = -\frac{1}{c}\frac{\partial \vec{B}}{\partial t} \tag{3}$$

$$\nabla^2 \times \vec{E} - \vec{\nabla}(\vec{\nabla}\vec{E} = \frac{4\pi}{c^2}\frac{\partial \vec{J}}{\partial t} + \frac{1}{c^2}\frac{\partial^2 E}{\partial t^2} \tag{4}$$

Taking the x and y component and putting the velocities component of KAW ,we obtain the modified Kinetic Alfven wave equation which turns out to be-

$$(1-\lambda_e^2\nabla_\perp^2)\frac{\partial^2 A_z}{\partial t^2} - {v_A}^2(1-\rho_s^2\nabla_\perp^2)\left(\frac{B_{0y}}{B}\right)^2\frac{\partial^2 A_z}{\partial y^2} - {v_A}^2(1-\rho_s^2\nabla_\perp^2)\frac{\partial^2 A_z}{\partial z^2} = 0 \tag{5}$$

After considering the envelop solution as $A_z = A_0(x,y,z,t)\exp\imath(k_{0x}\hat{x} + k_{0y}\hat{y} + k_{0z}\hat{z} - \omega t)$ and using the Harris sheet profile along the y direction

$$\begin{aligned} &-\frac{2\imath\omega(1+k_{0z}^2\lambda_e^2}{v_A^2k_{0z}^2}\frac{\partial A_z}{\partial t} + \frac{2\imath k_{0z}(v_A^2-\omega^2\lambda_i^2)}{v_A^2k_{0z}^2}\frac{\partial A_z}{\partial z} - \frac{2\imath k_{0z}^2v_A^2\rho_s}{v_A^2k_{0z}^2}\frac{\partial A_z}{\partial x} \\ &-\left(\frac{2\imath k_{0z}^2v_A^2\rho_s}{v_A^2k_{0z}^2}\right)\frac{\partial A_z}{\partial y} + \frac{1}{k_{0z}}\left(\frac{B_{0y}}{B}\right)^2\frac{\partial^2 A_z}{\partial y^2} + \frac{1}{k_{0z}^2}\left(1-\frac{\delta n}{n_0}\right) = 0 \end{aligned} \tag{6}$$

Normalizing parameters are used to make equation (6) in dimensionless form

$$-2\imath\frac{\partial A_z}{\partial t} + 2\imath\frac{\partial A_z}{\partial z} - 2\imath\frac{\partial A_z}{\partial x} - 2\imath\frac{\partial A_z}{\partial y} + C_1\left(\tanh\left(\frac{x}{L}\right)\right)^2\frac{\partial^2 A_z}{\partial y^2} + C_2\left(1-\frac{\delta n}{n_0}\right) = 0 \tag{7}$$

Results and Discussion

The model equation is solved numerically for solar corona region parameters using pseudo spectral method and finite difference method. In numerical simulation periodic domain of $10\pi \times 10\pi \times 10\pi$ and grid point $(32 \times 32 \times 32)$ used.The typical parameters applicable in the solar corona [3].

$$B_0 = 32G, \quad n_0 = 10^8 cm^{-3}, \quad T_e = 37eV, \quad T_i = 235eV \tag{8}$$

The simulation of the KAW interacting with the Harris sheet profile near reconnection sites shows that the coherent structures evolves with the time and became chaotic. The generation of the localized structures of the KAW in the magnetic field plays an essential role in the turbulence generation. From the simulation results, the magnetic field amplification up to 3-4 times has been observed, as shown in the figure 1. The figures 2 depict the time-averaged magnetic turbulence generation with power-law scaling ($k^{-3.3}$) observed from the simulation results. This generates the turbulent behaviour with a more irregular and more energy dissipating power spectra. As in the classical Kolmogroff turbulence power spectra the energy transfers from a larger scales to the next scale size by 5/3 power law but this interaction enhances the energy cascading rate and the steepening of the power spectra confirms the role of this interaction in the solar corona heating.

Conclusion

Simulation results represent the 3D-KAW which interact with Harish sheet through which chaotic structures formed which indicates the generation of turbulence.KAW breaks up into localized structures. In inertial range it shows $k^{-5/3}$ power law and in dissipation range it shows $k^{-3.3}$.

Figures

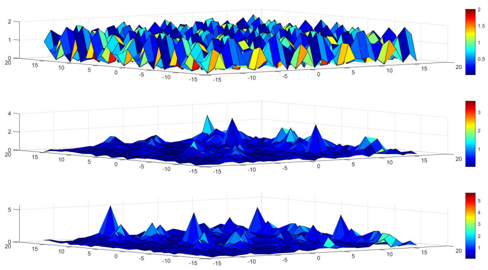

Figure 1: coherent structures of kinetic Alfvén wave in presence of nonlinearity and field perturbation at (a) $t = 0$, (b) $t = 10$, and(c) $t = 20$.

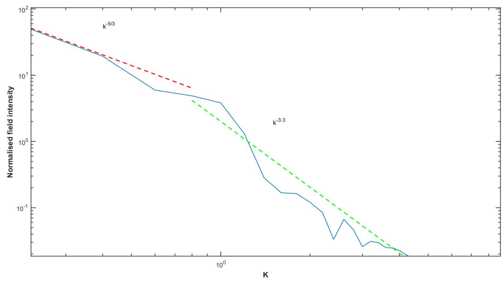

Figure 2: The averaged power spectra of the Magnetic field.

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