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CURRENT GENERATION IN EXTRAGALACTIC JETS BY MHD WAVES

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Resumen. Varias observaciones indican que chorros extragalácticos (CE) intensos parecieran necesitar confinamiento que sea magnéticamente auxiliado para que la presión externa total (cinetica más magnética) equilibre la presión interna total del chorro. Por otro lado, del movimiento de CE altamente ionizados en un campo magnético se espera, en general, que excite olas MHD en los bordes de los CE por la inestabilidad Kelvin-Helmholtz. Estudiamos el amortiguamento magnético por tiempo de tránsito de olas magnetosônicas y superficiales en esos plasmas esencialmente acolisionales, y mostramos que esas olas MHD compresivas de baja-frequencia producen apreciables corrientes eléctricas, I, las cuales pueden ser dinâmicamente importantes. Usando valores indicados de observaciones de CE intensos, obtenemos $I \sim I_c$ para $\xi^2 = \xi_c^2 \sim 10^{-10}$, siendo I_c la corriente necesaria para confinar esos chorros y $\xi \equiv |B_{MHD}/B_o|$ el nivel de perturbación MHD, con $B_{MHD}(B_o)$ siendo el campo magnético de la ola MHD (de fondo). Sugerimos que $\xi \sim \xi_c$ puede ser auto-regulador, con perturbaciones $\xi > \xi_c$ sofocando el chorro, exigiendo que ξ retorne a $\xi \sim \xi_c$. El modelo tiene además la ventaja de admitir un generador distribuido que actúa al largo de la longitud del chorro y evita problemas de modelos anteriores que exigen un generador de corriente en el núcleo galáctico para mantener un circuito gigantesco con longitud $\sim$ de la longitud del CE.

ABSTRACT: Several observations indicate that strong extragalactic jets (EJ) appear to need magnetically aided confinement in order for the total (kinetic plus magnetic) external pressure to balance the jet total internal pressure. On the other hand, the motion of highly ionized EJ in a magnetic field is, in general, expected to excite MHD waves on the borders of EJ by the Kelvin-Helmholtz instability. We study transit-time magnetic damping of magnetosonic and surface waves in these essentially collisionless plasmas, and show that these low-frequency compressive MHD waves produce appreciable electric currents, I, which can be dynamically important. Using indicated values from observations of strong EJ, we obtain $I \sim I_c$ for $\xi^2 = \xi_c^2 \sim 10^{-10}$, where I_c is the current required for confining these jets and $\xi \equiv |B_{MHD}/B_o|$ is the MHD perturbation level, with $B_{MHD}(B_o)$ being the MHD wave (background) magnetic field. We suggest that $\xi \sim \xi_c$ may be self-regulating, perturbations $\xi > \xi_c$ choking-off the jet, requiring ξ to return to $\xi \sim \xi_c$. The model has also the advantage of admitting a distributed generator which acts along the jet length and avoids problems of previous models requiring a current generator at the galactic nucleus to maintain a huge circuit with length $\sim$ EJ length.

Key words: GALAXIES-JETS — HYDROMAGNETICS

I. INTRODUCTION

We study here the electric current generation due to Cherenkov damping, particularly the magnetic component of Cherenkov damping which is the transit-time magnetic pumping (TTMP) of MHD waves.

It is well known that in the absence of trapped-electron effects (i.e., in cylindrical geometries) a high current-drive efficiency is attained by low-frequency waves (e.g. Fisch 1987). For the geometry, plasma, and wave conditions considered for astrophysical jets, one has thus a very favorable scenario for a high efficiency of the current generation process discussed.

Shear-flowing magnetized plasmas are likely to be important in many astrophysical situations, such as in jet-ambient plasma medium interactions. Such interactions are expected to be intense sources of the MHD waves considered here (section II) mainly through the Kelvin-Helmholtz instability.

The present model is discussed in a more detailed form in Jafelice et al. 1990.

II. THE PHYSICAL SCENARIO STUDIED

We consider a power-law relativistic electron distribution function with a mean energy $\overline{E} \sim \overline{E}_e \sim \overline{E}_i \sim 10$ MeV, where $\overline{E}_e$ ($\overline{E}_i$) is the electron (ion) mean energy. Our calculations are valid for $1 \lesssim \overline{E} \lesssim 50$ MeV.

The MHD waves considered have the following properties:

1) Low-Frequency: $\omega << \omega_{ci}$ (ion gyrofrequency) } Magnetic moment
2) Long-wavelength: $\lambda >> \rho_i$ (ion gyroradius) } (μ) is an adiabatic invariant.
3) Small amplitude: $\xi \equiv |B_{MHD}/B_o| << 1$, where $\vec{B}_{MHD}$ is the magnetic field associated with the wave and $\vec{B}_o$ is the background unperturbed magnetic field.
4) Small damping rate: $\nu_{eff} << \mathrm{Im}(\omega) << \omega$, where ν_{eff} is the effective collision frequency including anomalous effects.
5) Compressiveness.

The plasma is considered to be approximately collisionless.

The waves satisfying all of these conditions are the magnetosonic waves (MS) and surface waves (S). These waves are therefore the modes we study here, generically called MHD waves.

We treat a cylindrical geometry with the plasma flow in the z-direction, the same as $\vec{B}_o$. The shear-flowing plasma interfaces are parallel to $\vec{B}_o$ and are magnetically dominated (i.e., the plasma parameter $\beta \lesssim 1$ in the interfaces).

For the case studied here of discontinuous interfaces (with width a<<b, the plasma flow radius), low-β plasmas ($\beta \lesssim 1$), and low-frequency waves ($\omega << \omega_{ci}$), TTMP is the only collisionless damping mechanism for S (Assis and Busnardo-Neto 1987). This result can be shown to be valid for MS.

III. CURRENT GENERATION

The MHD energy and momentum transfer to relativistic electrons through TTMP generates an electric current density $\vec{J}$ (parallel to $\vec{B}_o$) along the interfaces (Jafelice et al. 1990).

The electric current calculations for the present case are those made by Jafelice and Opher (1987) for kinetic Alfvén waves. To apply these results for the wave modes discussed here, we need essentially to substitute in their work for the perturbing electric potential energy e ψ (with e for the electric charge and ψ for the electric potential associated to the kinetic Alfvén wave) by the perturbing magnetic energy μB_{MHD}, which we assume to be much smaller than $\overline{E}$.

Using typical mean values for EJ it is possible to show (Jafelice et al. 1990) that the TTMP damping rate (γ_{TTMP}) prevails over: 1) the non-linear ion Landau damping rate (γ_{NL}), with $\gamma_{TTMP}/\gamma_{NL} \gtrsim 1$ for $\xi^2 \lesssim 11$; 2) the cascade rate (γ_{casc}) for the cascading conversion process of long to short wavelengths when shear Alfvén waves are present, with $\gamma_{TTMP}/\gamma_{casc} \gtrsim 1$ for $\xi^2 \lesssim$ [illegible] and 3) the modulation instability rate of magnetosound waves (γ_{MIMS}), with $\gamma_{TTMP}/\gamma_{MIMS} \gtrsim 4$.

The electric current density (J) exists in a layer (around an interface) where the MHD wave is effective in generating it. For the case of MS and S such a layer can be considered as having a lateral (i.e., transverse to $\vec{B}_o$) extend $\sim$ b. We take therefore the total current carrying area as $A_I \sim \pi b^2$ (see Jafelice et al. 1990 for further discussion).

Thus, the estimate for the total electric current generated by compressive low-frequency MHD waves in collisionless plasmas is:

$$I = JA_I \sim \pi b^2 J \quad (1)$$

For the physical scenario studied we obtain (Jafelice et al. 1990):

$$J \cong e\,c\,2^{4/(s-4)} \frac{(s-4)(s+1)}{16s} \left(\frac{c}{V_{ph}}\right)^2 n_e\, \xi^3 , \quad (2)$$

here c is the velocity of the light, s is the power-law index, V_{ph} the MHD wave phase velocity ere taken to be $V_{ph} = 2^{1/2} V_A$ for both MS and S (with V_A for the Alfvén velocity), and n_e is he relativistic electron number density.

We assume there exists a return current external to the observed plasma flow ssuming circuit closure. Such a return current can have important consequences. One of them an be in the generation of the large-scale intergalactic magnetic field as discussed elsewhere n these proceedings by Jafelice and Opher (1989).

V. THE CASE OF EJ

Observations indicate that strong jets appear to require magnetic confinement; they lso appear to have axial magnetic fields. Theoretical work, treating MHD Kelvin-Helmholtz nstabilities in flows with shear layers, indicates that strong jets are characterized by lows with sharp boundaries which have a peak instability for wave numbers $kb \sim 1$.

The basic problem of extragalactic jet collimation is to explain the high jet degree f collimation from their origin $\lesssim$ 0.01pc to distances > 10kpc. Hydrodynamic models have been nable to explain the over six orders of magnitude collimation. Magnetic fields have thus been uggested for confining jets, but the origin of the currents producing the magnetic field has ot been investigate in detail.

We consider a generic EJ with a mean radius $b \equiv R_J \sim 1$kpc. Typical values for such jet is a magnetic field $B_o = 5.5\times10^{-9}$T and a pressure $P_o = 10^{-11}$ Nm^{-2}. Using for the ions $_i = n_i k_B T_i \cong 10^{-11}$Nm^{-2}, $\bar{E} = (3/2) k_B T_i = 10$MeV, we obtain $n_e \cong n_i \cong 9$ m^{-3} and $V_A/c \cong 0.13$, espectively, where V_A is the Alfvén velocity at the denser of the two regions of the interface long which the wave travels.

An EJ with the adopted radius and pressure, can be magnetically confined if it arries a current (e.g., Begelman et al. 1984):

$$I_c \sim 2\times10^{18} \text{ A} . \quad (3)$$

Using the above physical parameters and the typical value $s \cong 4.3$ for these sources, e obtain from (2):

$$J \cong 3\times10^{-6}\, \xi^3 \text{ A m}^{-2} . \quad (4)$$

From (1), (3) an (4) we see that $I \sim I_c$ for:

$$\xi^2 = \xi_c^2 \sim 4\times10^{-11} . \quad (5)$$

If we calculate the electric current density for a Maxwellian distribution of elativistic electrons (J_M) we find $J/J_M \sim 100$.

. CONCLUSIONS

We may summarize the main conclusions as follows:

1) $I \sim I_c$ for $\xi^2 \sim 10^{-10}$.

2) In the present model the value of ξ^2 arises directly from the theory used to xplain observational features (e.g., confinement) of EJ contrary to previous studies dealing ith weak MHD turbulence where the value of ξ^2 is assumed .

3) We suggest that $\xi \cong \xi_c$ may be self-regulating. Perturbations with $\xi > \xi_c$ choking off the jet, requiring ξ to return to $\xi \cong \xi_c$.

4) This current generation process is independent of short-circuiting effects along

the jet. If I is shorted out, perturbations $\xi^2 \cong \xi_c^2$ reestablish $I \cong I_c$.

5) The model suggests the possibility that the generator needed to generate I_c is distributed along the jet length. This avoids problems of previous models requiring a localized generator in huge circuits of hundreds of kiloparsecs.

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