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KINETIC ALFVÉN WAVES AND THE DEPLETION OF THE THERMAL POPULATION IN EXTRAGALACTIC JETS

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RESUMEN. Chorros Extragalácticos (CE) y Fuentes Radio Extendidas (FRE) son locales de ricos y complejos procesos de plasma magnetizado. Recientes observaciones indican que esas fuentes son estructuradas en filamentos. Nos concentramos aqui en el análisis de dos problemas: 1) el problema de injección, que es propuesto por las teorias de aceleración de partículas en plasmas de CE e FRE, que necesitan partículas que ya tengan energías moderadamente relativísticas para que los procesos de Fermi sean efectivos; y 2) la reciente evidencia observacional de la ausencia de partículas térmicas en CE. El presente modelo pone en evidencia que ambos problemas están íntimamente relacionados uno con el otro. Jafelice y Opher (1987a) (Astrophys. Space Sci. 137, 303) muestram que es esperada una abundante generación de olas Alfvén cinéticas (OAC) en CE y FRE. En el presente trabajo estudiamos la cadena de procesos: a) OAC aceleran electrons térmicos al largo del campo magnético de fondo produciendo electrones supratérmicos fugitivos; b) que generan olas Langmuir; y c) las cuales por su vez aceleran una fracción de los electrones fugitivos hasta energias moderadamente relativísticas. Mostramos que suponiendo que no haya otra fuente de población térmica a no ser la original, la secuencia de procesos arriba puede encargarse del consumo de los electrones térmicos en una escala de tiempo $\lesssim$ que el tiempo de vida de la fuente.

ABSTRACT: Extragalactic Jets (EJ) and Extended Radio Sources (ERS) are sites of rich and complex magnetized plasma processes. Recent observations indicate that these sources are filamentary structured. We concentrate here on the analysis of two problems: 1) the injection problem, faced by theories of particle acceleration in EJ and ERS plasmas, which need particles with already moderately relativistic energies for the Fermi processes to be effective; and 2) the recent observational evidence of the abscence of thermal particles within EJ. The present model makes evident that both problems are intimately related to one another. Jafelice and Opher (1987a)(Astrophys. Space Sci. 137, 303) showed that an abundant generation of kinetic Alfvén waves (KAW) within EJ and ERS is expected. In the present work we study the chain of processes: a) KAW accelerate thermal electrons along the background magnetic field producing suprathermal runaway electrons; b) which generate Langmuir waves; and c) which in turn further accelerate a fraction of the runaway electrons to moderately relativistic energies. We show that assuming that there is no other source of a thermal population but the original one, the above sequence of processes can account for the consumption of thermal electrons in a time scale $\lesssim$ the source lifetime.

Key words: GALAXIES-JETS — HYDROMAGNETICS

I. INTRODUCTION

Recent observations (e.g., Perley 1989) confirm previous results (e.g., Bridle and

Perley 1984) that observed Faraday rotations associated with extragalactic jets (EJ) and extende radio sources (ERS) are due to a magnetoionic medium located outside the source, surrounding the radio-emitting plasma. On the other hand, entrainment from galactic or intergalactic material and/or electron energy decrease due to synchrotron radiation are examples of sources of thermal plasma within EJ and ERS. Why EJ and ERS should be, therefore, so depleted of a thermal population? This is the called depletion problem of extragalactic radio sources.

The Fermi processes of first and second order, associated with shocks or hydromagn tic turbulence, are the reacceleration processes which can generate relativistic electrons i EJ or ERS (inferred to exist from the observation of emitting knots in the radio, optical and X-ra range in many jets)(e.g., Melrose 1980; Eilek 1989). These processes just work with the needed efficiency if the electrons to be accelerated are already moderately relativistic($\gtrsim$1MeV What is the mechanism which effectively acts in the first-phase acceleration in EJ or ERS? Thi is the called injection problem of extragalactic radio sources.

We address here the depletion and injection problems in EJ and ERS, and we show th they are intimately related to one another.

II. KINETIC ALFVÉN WAVES IN EXTRAGALACTIC RADIO SOURCES

It has been shown by Jafelice and Opher (1987a) (JOI) that conditions in ERS or EJ are very propitious to copiously generate kinetic Alfvén waves (KAW).

JOI predicted that the wealth of filamentary structure discovered in radio lobes (Perley et al. 1984) would also be discovered in jets. Improved accuracy in observation techniques in recent years reveal that EJ and ERS are highly inhomogeneous plasmas, constituting filamentary structures (Owen et al. 1989; Eilek 1989; and references therein), which confirm the predictions of JOI.

A possible explanation for the formation of these filaments is that electric curre flows along them (Jafelice and Opher 1987b (JOII); Jafelice et al. 1990; Eilek 1989).

JOI showed that given typical conditions in EJ or ERS, KAW can directly act as a first phase acceleration mechanism, taking thermal electrons and, through Landau damping, bring them to moderately relativistic energies.

Here we consider the possibility that KAW participate as the link which drives a chain of processes which end up with the electrons being accelerated to energies of the order of several MeV.

Such a chain of acceleration processes can be summarized as follows: a) KAW accelerate thermal electrons along the background magnetic field producing suprathermal runawa electrons; b) which generate Langmuir waves (LW); and c) which in turn further accelerate a fraction of the runaway electrons to moderately relativistic energies. It is to be noted that the case of the solar corona plasma, LW efficiently accelerate non-relativistic electrons in the first-phase acceleration inferred to exist there from observations (Melrose 1980).

We assume cylindrical geometry (r, ϕ, z) with an axial background magnetic field $\vec{B}$ permeating an already formed filament. The treatment is linear in the sense that it satisfies $e\psi/k_BT_e < \beta^{-1}$ (e.g., section 4 in JOI), where ψ is the electric potential parallel to $\vec{B}_o$ associated with the KAW, β is the plasma parameter, and the other symbols have their usual meanings. We take initially $T_e \sim T_i$, which rules out, at least initially, the development of t ion-acoustic instability.

The constraints of KAW and runaway electron production are: 1) KAW must satisfy $k_r \sim \bar{\rho}_i^{-1} \gg k_\phi \gg k_z$, where $\bar{\rho}_i$ is the mean ion gyroradius and k is the KAW wavenumber; 2) Electron runaway occurs if the applied electric field (here taken to be that of the KAW, $E\sim\psi k_z$ exceeds the anomalous Dreicer field $E_D^* = m_e V_{T_e} \nu_{eff}/e$. We consider the anomalous resistivity due to the KAW, and so $\nu_{eff} \sim \omega_{ci} \beta^{-1}$ (JOII); and 3) Electrons with velocities $V_R \gtrsim (E_D^*/E)^{1/2}V_T$ will suffer runaway. In terms of the resonant wavelength in the z-direction, λ_z, these three conditions become: 1) $\lambda_z \gg 2\pi\bar{\rho}_i$; 2) $\lambda_z \lesssim 6.5\ \bar{\rho}_i$; and 3) $\lambda_z \gtrsim 6.1\ \bar{\rho}_i$. Remembering that even wit $E < E_D^*$ one can have runaway production with relevant consequences (e.g., Kaplan and Tsytovich 1973 (KT)), the second condition can be relaxed to $\lambda_z \lesssim 6.5\ \bar{\rho}_i$. Satisfying all the three conditions, we analyze energetic consequences of generated waves with $10\pi\bar{\rho}_i \leq \lambda_z \leq 30\pi\bar{\rho}_i$.

III. CALCULATIONS

For the calculations we take observed typical parameter values $T_e\sim10^7$K;$B_o\sim5.5\times10^{-5}$G $n_e\sim n_i\sim n_i\sim10^{-4}cm^{-3}$. The values of ψ and other KAW parameter are obtained from JOI and Jafelic and Opher (1987b)(JOII). From equations (2b) and (3), from JOI, one obtains $e\psi/\bar{E}\sim0.5\,\zeta\,\beta^{1/2}$, where $\bar{E} = (3/2)k_BT_e$ and $\zeta\equiv|B_{KAW}/B_o|$, with B_{KAW} the magnetic field amplitude of the KAW. We take

$\zeta \sim 1$. Therefore, $e\psi/\bar{E} \sim 13.9 < \beta^{-1}$.

Assuming runaway electrons have a Maxwellian distribution, their number density $n_r \sim n_e \exp[-(1/2)E_D^*/E]$ (KT, p. 135). Here $E_D^*/E \sim 9.7$ and $n_r \sim 8\times10^{-7}$ cm^{-3}.

The Langmuir wave (LW) density production due to runaways is $W^L \sim (1/2)\, n_r\, n_e\, V_{Te}^2 (E_D^*/E-1)$ (KT, p. 136). Here $W^L \sim 5\times10^{-15}$ erg cm^{-3}.

The scenario we suggest is that the LW can complete the last stage in the acceleration chain by taking a fraction (fn_r, with $f \ll 1$) of the suprathermal electrons generated by the KAW and accelerate them to the moderately relativistic energies necessary for Fermi-type acceleration mechanisms to work. For the adopted values of λ_z, and for $10^{-3} \leq f \leq 10^{-2}$, the energy gain per electron $0.2 \leq \varepsilon\ (\equiv W^L/fn_r) \leq 6$ MeV.

The time scale necessary for the entire thermal population of the filament to be transformed into a moderately relativistic population can be estimated by $t_o \sim (a/2fV_A) \exp[(1/2)E_D^*/E]$; where $a \sim 1$pc is the mean radius of the filament and V_A is the phase velocity of KAW. Taking the conservative value $f \sim 10^{-3}$, we obtain $5\times10^5 \lesssim t_o \lesssim 6\times10^7$ years, which are of the order, or less than, typical source lifetimes.

IV. CONCLUSIONS

Surface Alfvén waves generated at the border of EJ, or of filaments inside EJ or ERS, are converted to KAW (JOI) which are Landau damped parallel to $\vec{B}_o$ producing a suprathermal runaway population of electrons. The runaway electrons generated LW which further accelerate a small fraciton, f, of the runaways to moderately relativistic energies (where Fermi processes can operate). The entire thermal population of a filament can be consumed through these processes in a time scale $\lesssim$ source lifetime.

The present model relates for the first time the injection problem in EJ and ERS plasmas with the problem of the depletion of thermal particles within these sources. The model suggests a possible solution of both problems at the same time.

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