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From Non-Resonant to Resonant Cosmic Ray Driven Instabilities

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ABSTRACT

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1. ANALYTIC

We consider the dispersion relationship for a plasma composed of 4 different populations: A cold ion and electron background population, a low density, high energy drifting (CR) ion population and a cold electron population drifting so that there is no net current. The dispersion relationship for this system is discussed in Zweibel (2003) and is given in the background rest frame as

$$(\omega + kv_D)^2 + \omega_{ci}\omega\frac{n_{cr}}{n_i}\zeta_{lr}(k) - k^2 v_{Ai}^2 = 0 \qquad (1)$$

where ω_{ci} is the gyro-frequency of the background ions, n_{cr} and n_i are the number density of the background and CRs respectively, v_A is the Alfvén speed and ζ_{lr} is defined as

$$\frac{i\pi}{2}\int_{p_1}^{\infty} p_1 p\phi dp - \frac{p_1}{4}\mathscr{P}\int_0^{\infty}\left[(p^2 - p_1^2)\ln\left|\frac{1\mp p/p_1}{1\pm p/p_1}\right| \mp 2pp_1 \pm \frac{4}{3}\frac{p^3}{p_1}\right]\frac{d\phi}{dp}dp \qquad (2)$$

where $\mathscr{P}$ denotes the principle part of the integral, $p_1 \equiv m_i\omega_{ci}/k$, i.e. the minimum momentum resonant with a wave number of k, and ϕ is the distribution of CRs, such that $f_{CR} = n_{cr}\phi(p)$ and $\int_0^\infty 4\pi p^2 \phi dp = 1$.

2. INTRODUCTION

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3. SIMULATIONS

To investigate these we use the code *dHybridR* (cite to come?) to run relativistic hybrid simulations (kinetic ions/ fluid charge neutralizing electrons). Simulations are quasi-1D but account for the three spatial components of the particle momentum and of the electric and magnetic fields. Lengths are normalized to the proton skin depth, c/ω_p, where c is the speed of light and $\omega_p \equiv \sqrt{4\pi n_p e^2/m}$ is the proton plasma frequency, with m, e and n_p the proton mass, charge and number density. Time is measured in units of inverse proton cyclotron frequency, $\omega_c^{-1} \equiv mc/eB_0$, where B_0 is the strength of the initial magnetic field. Velocities are normalized to the Alfvén speed $v_A \equiv B/\sqrt{4\pi mn}$, and energies and temperatures are given in units of mv_A^2. Fluid electrons are initialized with the same temperature as ions, and have a adiabatic equation of state with an effective index. The computational box measures $[L_x, L_y] = [10^4, 5]c/\omega_p$, with two cells per ion skin depth, An effective speed of light is set to $c/v_A = 100$, which ultimately sets the condition for the simulation time step $\Delta t = 0.0025\omega_c^{-1}$.

The simulations are periodic in all directions with two over-lapping populations; a thermal background population and a variable cosmic ray (CR) population with different densities and initial distribution functions. We examine two different distributions of CRs: a "hot" distribution that follows a power law with an index of -4.5

drifting with a velocity of $10v_A$ parallel to the magnetic field,

$$f(p) = \begin{cases} \frac{3n_{cr}}{8\pi p_{\min}^{3/2}} p^{-4.5}, & p > p_{\min}. \\ 0, & \text{otherwise.} \end{cases} \tag{3}$$

and "beam" distribution that is a Gaussian in momentum space peaked around some beam momentum p_b with a range of positive pitch angels μ with a linear increase from 0 to 1, $f(p, \mu) = F(p)g(\mu)$ where

$$F(p) = e^{-(p-p_b)/2\Delta p} \tag{4}$$

$$g(\mu) = \begin{cases} 0, & \mu < 0. \\ \frac{1+\mu}{3/2}, & 0 \geq \mu. \end{cases} \tag{5}$$

4. NUMERIC

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5. NON-LINEAR

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6. CONCLUSION

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7. BODY

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REFERENCES

Zweibel, E. G. 2003, ApJ, 587, 625, doi: 10.1086/368256