PhD Open Days

Turbulent MagnetoRotational Instability in large scale PIC simulations

Advance Program in Plasma Science and Engineering (APPLAuSE)

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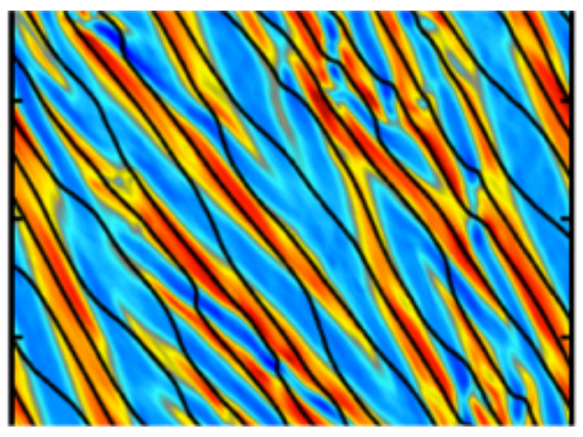
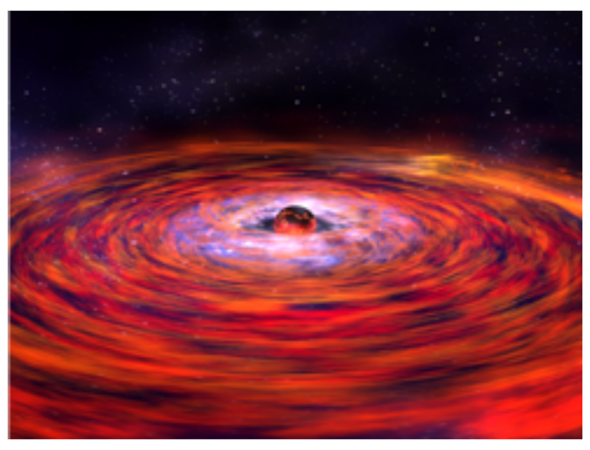
Introduction

The **MagnetoRotational Instability** (MRI) [1,2] is essential to understand the **growth of B** in astrophysical scenarios characterized by a state of differential rotation along central masses, like **accretion disks**.



Magnetic filaments characteristic of the Mirror Instability [3]



Artistic representation of accretion disk (NASA)

A **kinetic analysis** is required for collisionless systems in order to study the influence of **pressure anisotropies** (Firehose & Mirror instabilities [3]) to MRI.

We modified our PIC (Particle In Cell) code OSIRIS 3.0 to observe the kinetic effects in a rotating system on **large scale** simulations.

Analysing the evolution of the MRI on large scale, we observed the comparison of a **turbulent regime**, that plays a crucial role for the **saturation of the instability**.

Shear co-rotating frame

Maxwell's equations

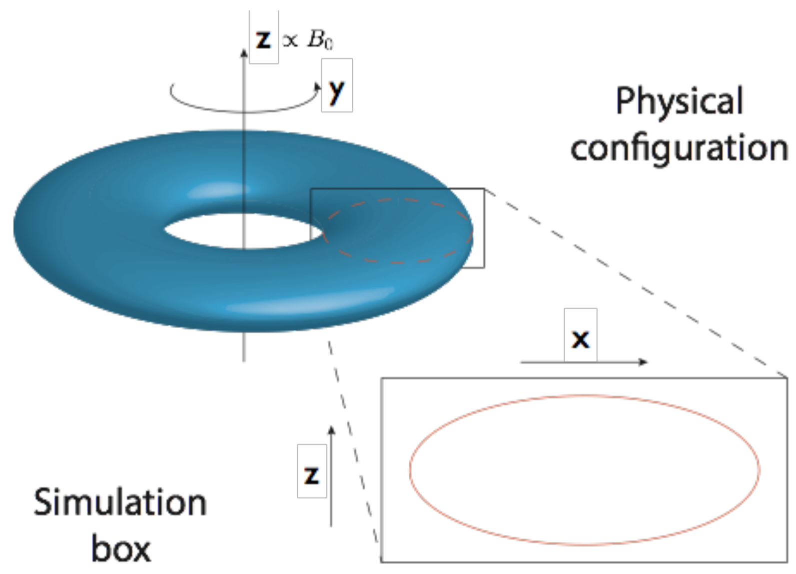
$$\frac{\partial \vec{B}(\vec{r},t)}{\partial t} = -\nabla \times \vec{E}(\vec{r},t) - \frac{3}{2}\alpha B_x \hat{y}$$

$$\frac{\partial \vec{E}(\vec{r},t)}{\partial t} = \nabla \times \vec{B} - 4\pi \vec{J} - \frac{3}{2}\alpha E_x \hat{y}$$

$$\vec{B} = B_0 \hat{z} \qquad \vec{v}_{shear} = -\frac{3}{2}\alpha x \hat{y}$$

Equation of motion

$$\frac{d\vec{p}}{dt} = 2\alpha p_y \hat{x} - \frac{1}{2}\alpha p_x \hat{y} + q\left(\vec{E} + \frac{\vec{u}}{c} \times \vec{B}\right)$$

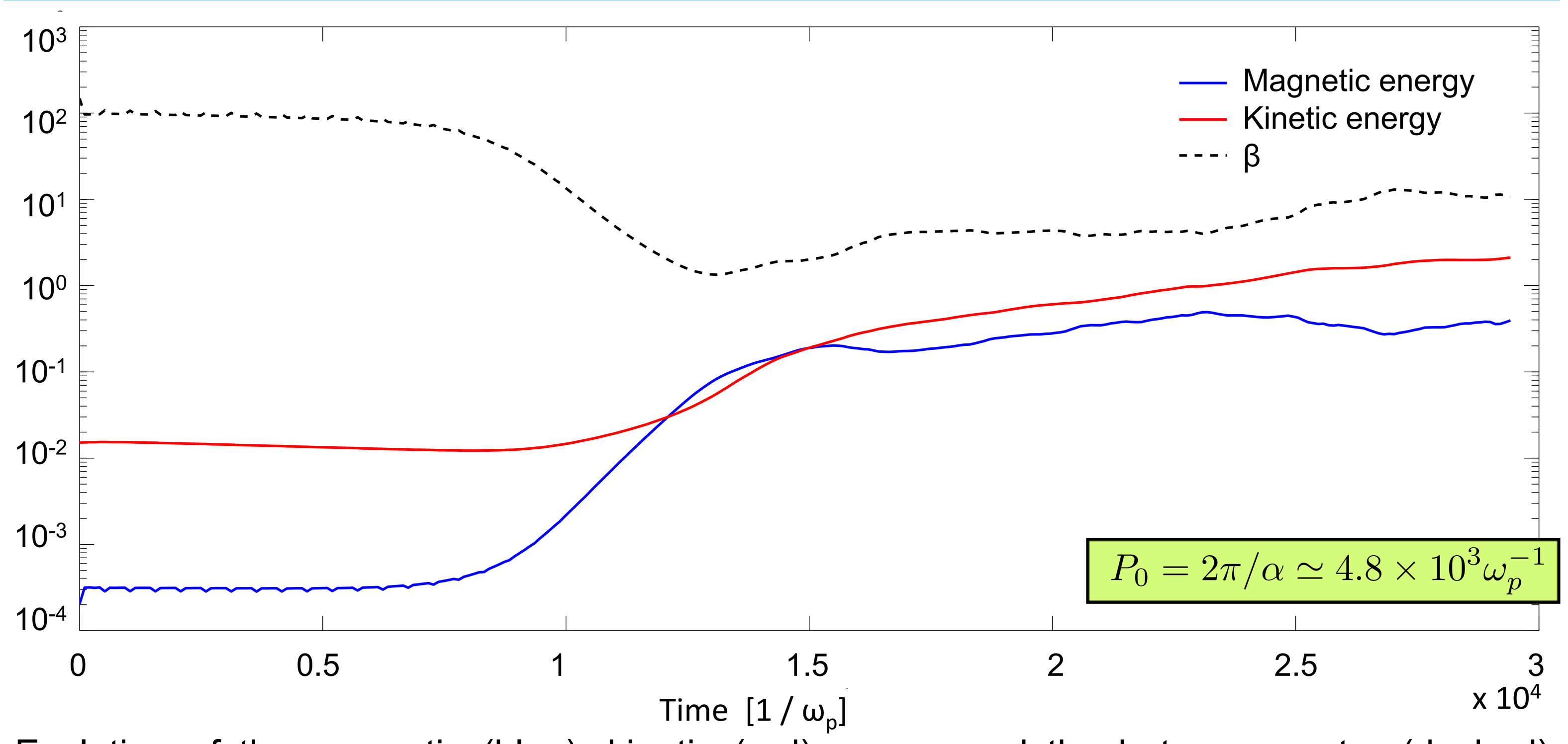


Weak magnetic field	Non-relativistic limit	Small box approximation
$\frac{\omega_{ci}}{\alpha} << 1$	$v_0 = \alpha \times r_0 << c$	$L << r_0$

Simulation parameters

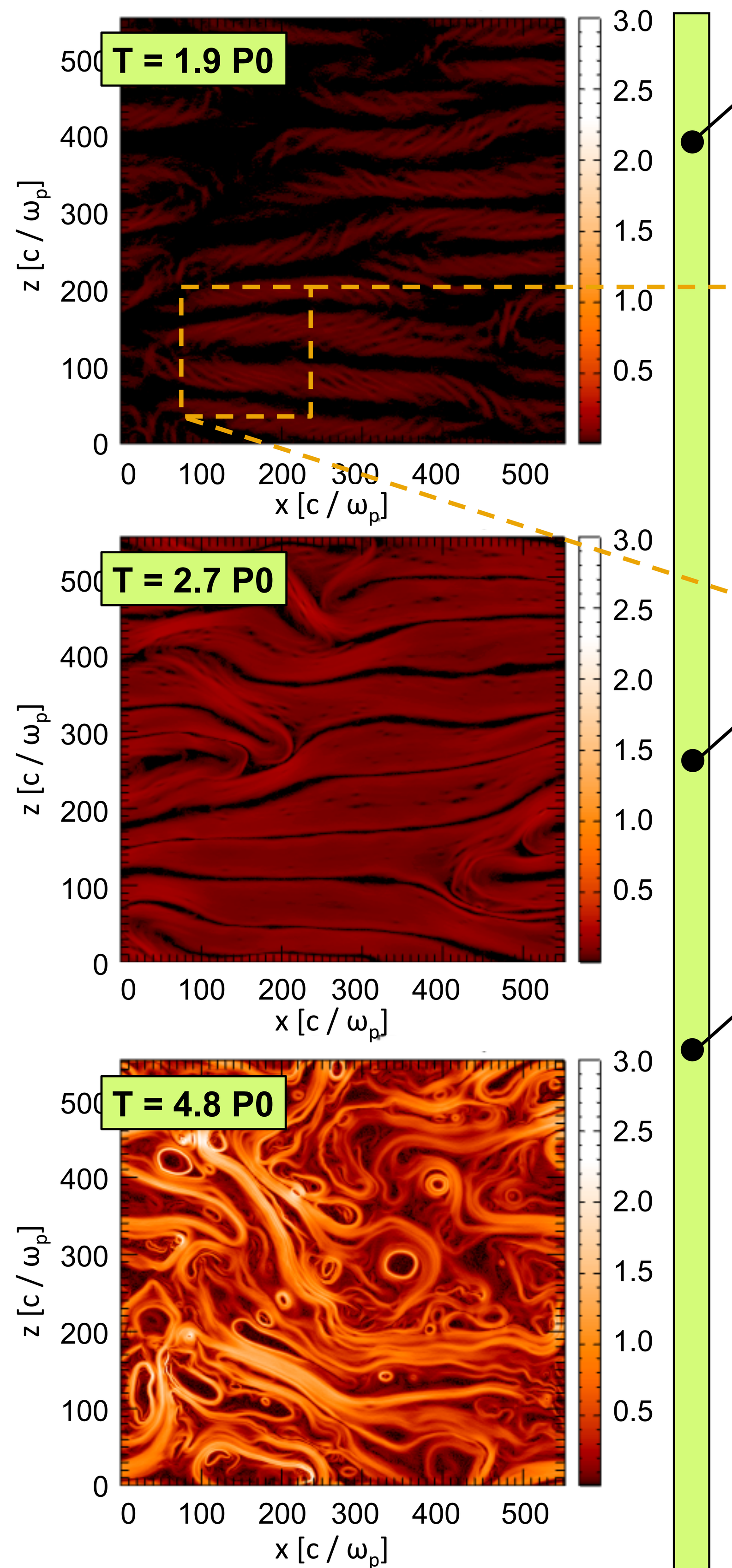
Mass ratio $\frac{m_i}{m_e} = 1$ — Alfén velocity $\frac{v_A}{c} = 0.0143$ — Box size $8 \times 8\ \lambda_0^2$

Beta parameter $\beta_0 = 100$ — Magnetization $\frac{\omega_{ci}}{\alpha} = 11$ — $\left(\lambda_0 = \frac{2\pi v_A}{\alpha}\right)$



Evolution of the magnetic (blue), kinetic (red) energy and the beta parameter (dashed) throughout the simulation.

Evolution of the poloidal magnetic field (B_1,B_3)

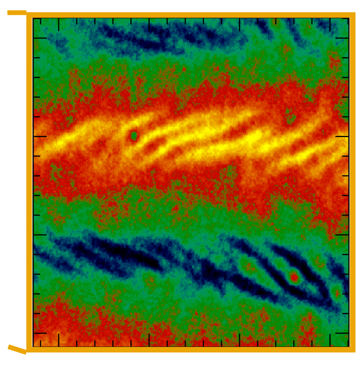


Poloidal magnetic field (B_1,B_3) at different time steps where we can see the evolution from the linear regime of the MRI to the turbulence.

Linear regime

Mirror Instability [3]

$$\frac{p_\perp}{p_\parallel} - 1 > \frac{1}{\beta_\perp}$$



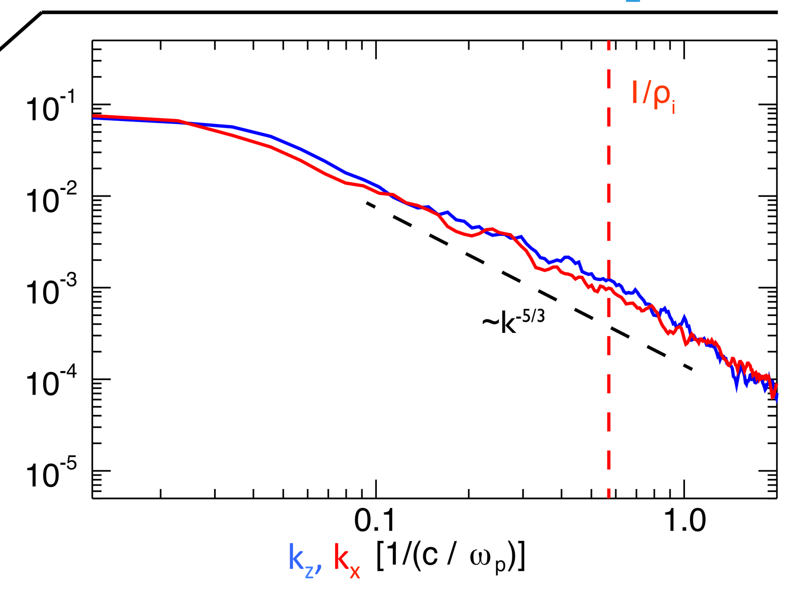
Zoom of the toroidal magnetic field (B_2) where it's possible to observe the oblique magnetic filaments typical of Mirror Instability.

Non linear regime

Channel flows [4]

Parasitic Instabilities [5]

Turbulence spectrum of $B_2 \sim k^{-5/3}$



Fourier spectrum of the toroidal magnetic field (B_2) for both radial (red) and vertical (blue) directions. The dashed red line represents the scale of ion Larmor radius.

Conclusions & Future works

- Evolution of the MRI for **large scale e-p plasma**
- Linear regime: pressure anisotropies that activate the **Mirror Instability on kinetic scale**
- Non linear regime: **channel flows**
- End of the non linear regime: **parasitic instabilities** that stop the growth of the MRI destroying the channel flows
- Activation of **turbulence** that characterize the **saturation of the MRI**

Future works

- Characterization of the different parasitic instabilities
- Evolution of turbulent regime using the **3D version of the code** (currently under development)
- Extend the analysis to **different mass ratio**, to understand the influence of **electron scale pressure anisotropies** on linear evolution of the MRI

References

[1] S. A. Balbus, J. F. Hawley, ApJ, 376, 214 (1991)
[2] S. W. Davis, et al., ApJ, 713, 1 (2010)
[3] M. W. Kunz, et al., PRL, 112, 20 (2014)
[4] H. N. Latter, et al., MNRAS, 394, 715 (2009)
[5] J. Goodman, G. Xu, APJ, 432, 213, (1994)

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