On the acceleration of low-β plasma in magnetic fields

Sur l'accélération des plasmas ayant un bas β dans des champs magnétiques

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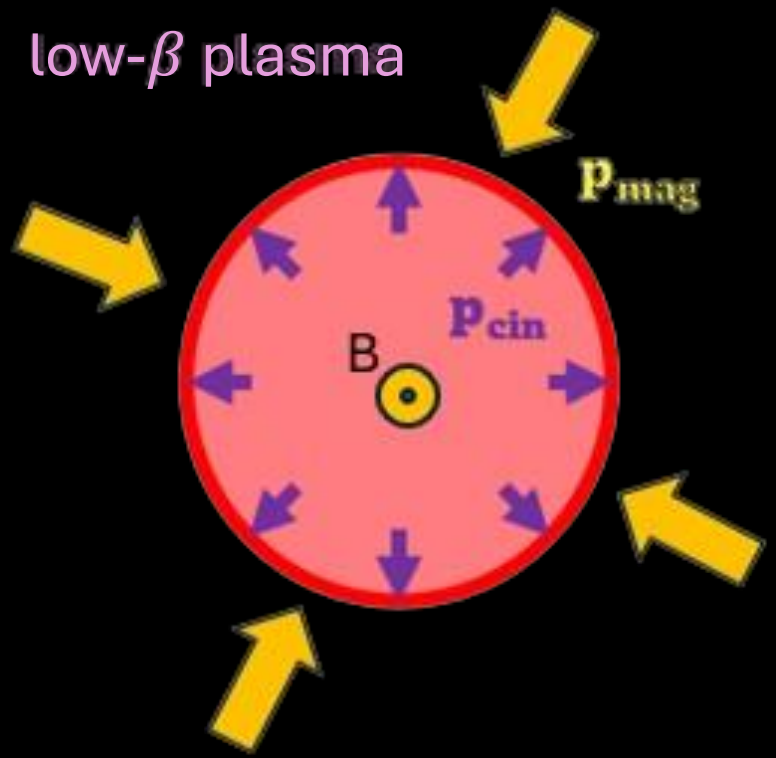
Introduction

low-β plasma



$$\beta = \frac{p}{p_{mag}} = \frac{nk_BT}{B^2/2\mu_0}$$

=

Magnetic confinement

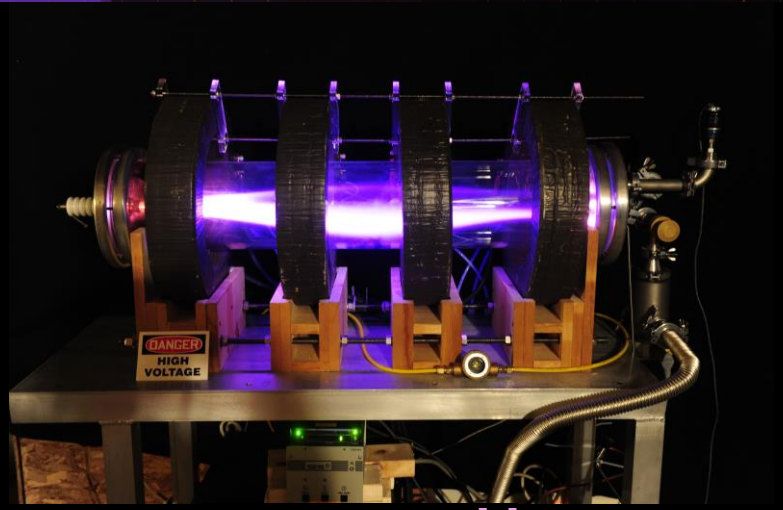
Introduction

Acceleration

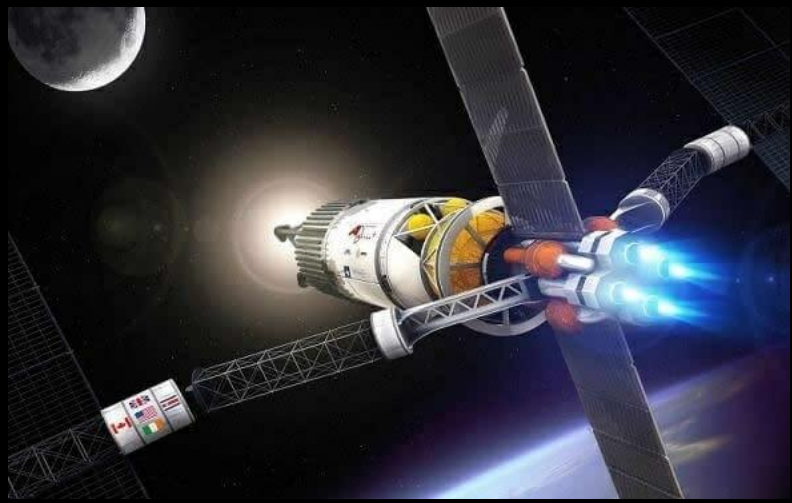
Lorentz force

Pressure gradient

$$mn\left(\frac{\partial}{\partial t}+\vec{v}\cdot\nabla\right)\vec{v}=\vec{J}\times\vec{B}-\nabla p$$



Magnetic bottle [1]



Space propulsion [2]

De Laval nozzle

De Laval nozzle [4]

One solution for supersonic acceleration

- Hydrodynamic model (neutral fluid)
- Transonic
- Driven by pressure

$$mn(\vec{v} \cdot \nabla)\vec{v} = -\nabla p$$

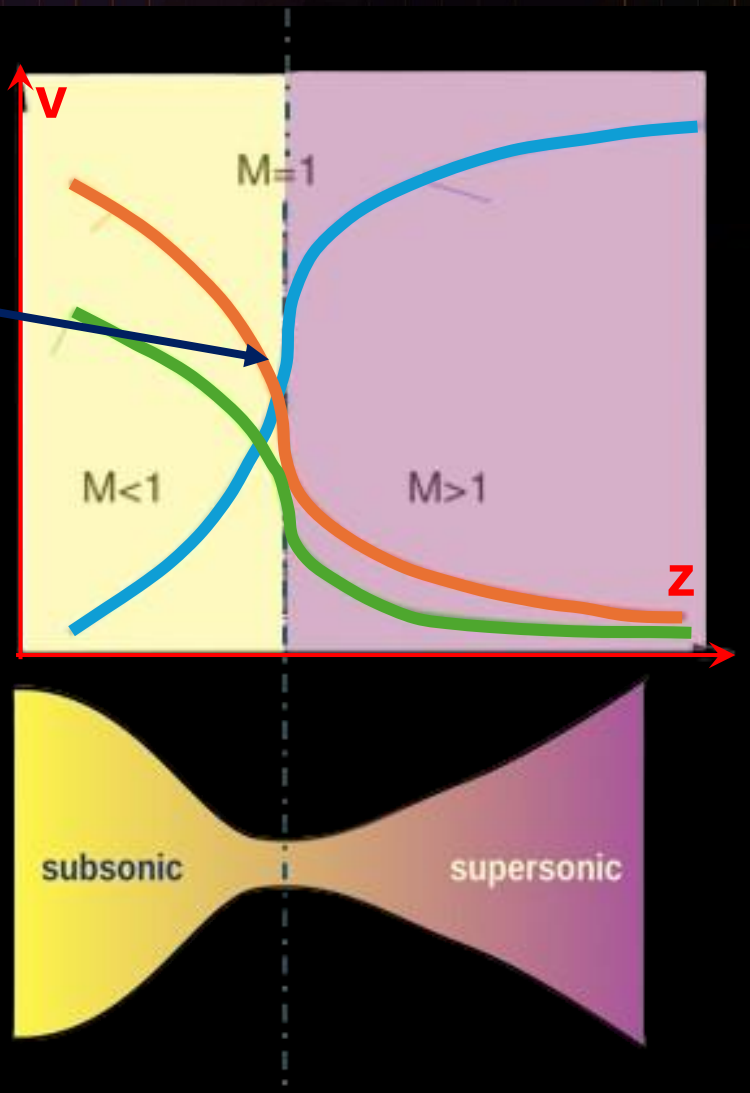


Fig.1 Axial velocity of the fluid in the de Laval nozzle [5]

Parker model of solar wind

- 1D model
- Hydrodynamic equations
- Transonic
- Driven by pressure and gravity

$$mn(\vec{v}\cdot\nabla)\vec{v} = -\nabla p - \nabla\Phi_G$$

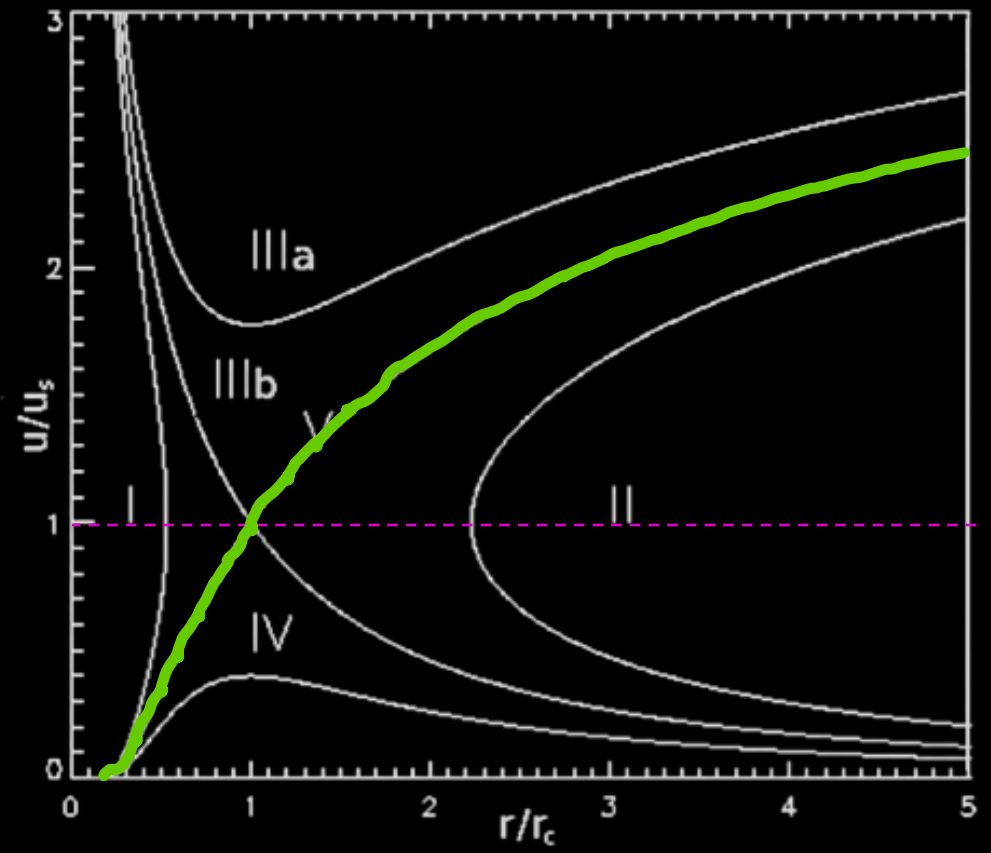
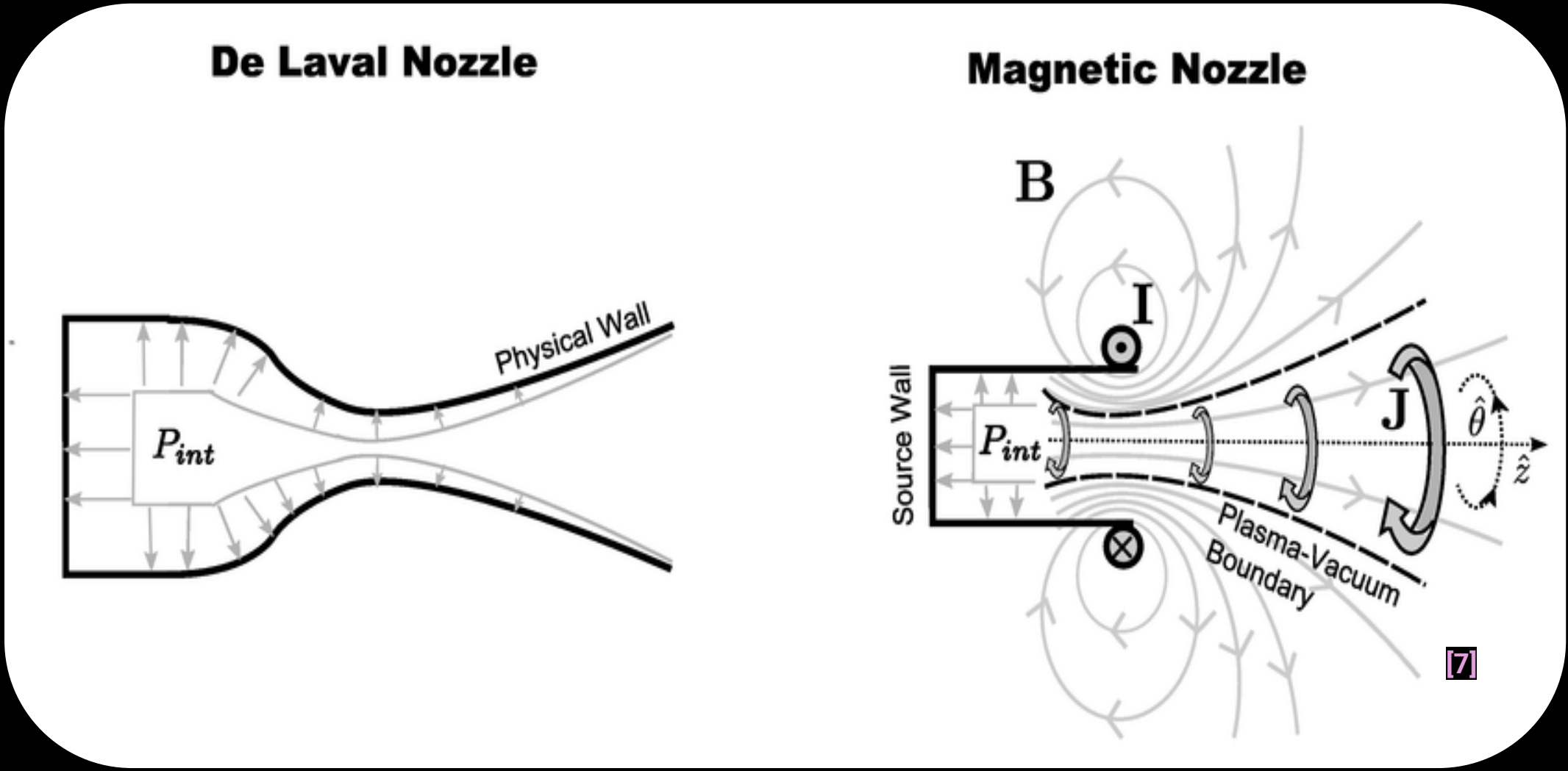
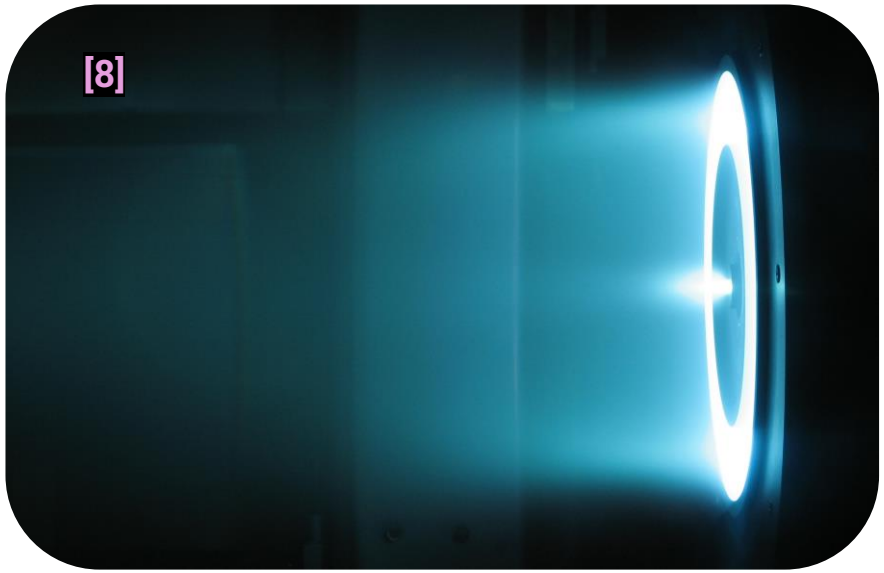


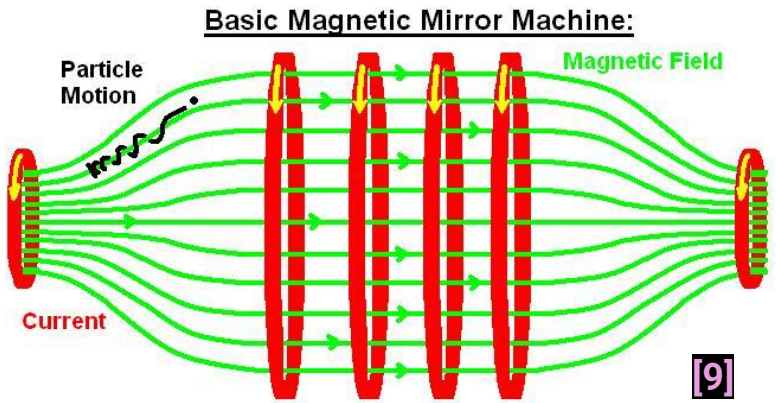
Fig.2 Five classes of solutions of the Parker solar wind model [6]

Magnetic nozzle

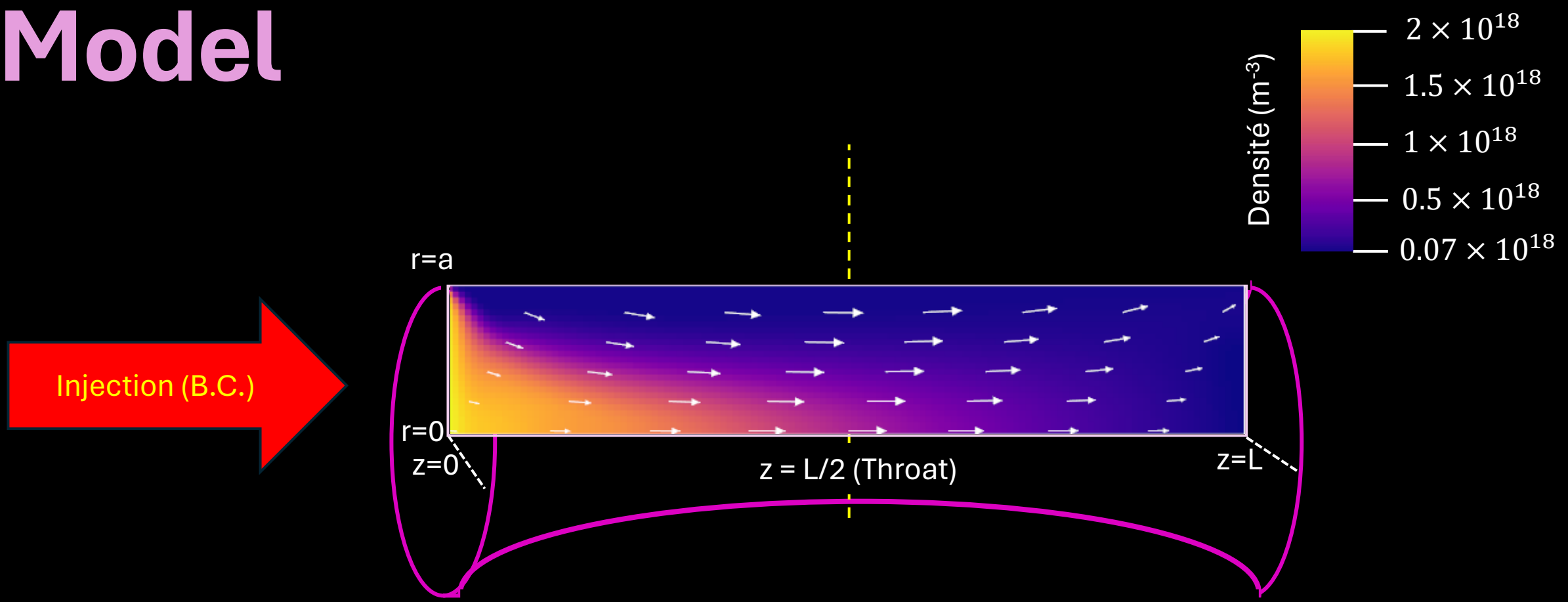


Magnetic nozzle





Model



- Density ~ 10^{18} particles/m^3
- Beta ~ 0.01
- Mirror ratio = 10

Effect of . . .

Injection radius

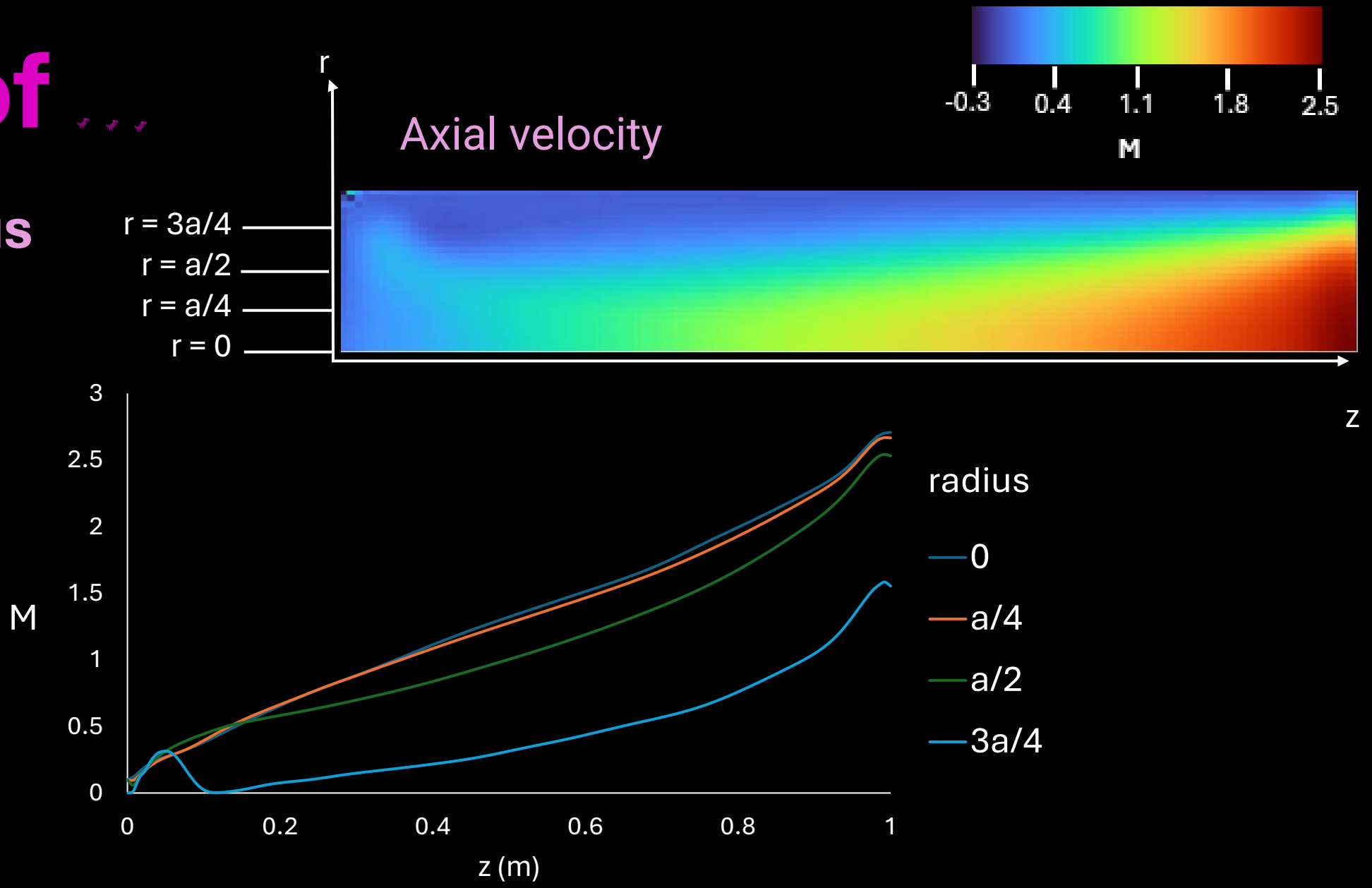


Fig.3 Axial velocity for different radius with an injection velocity of 0.1M

Effect of …

Injection velocity

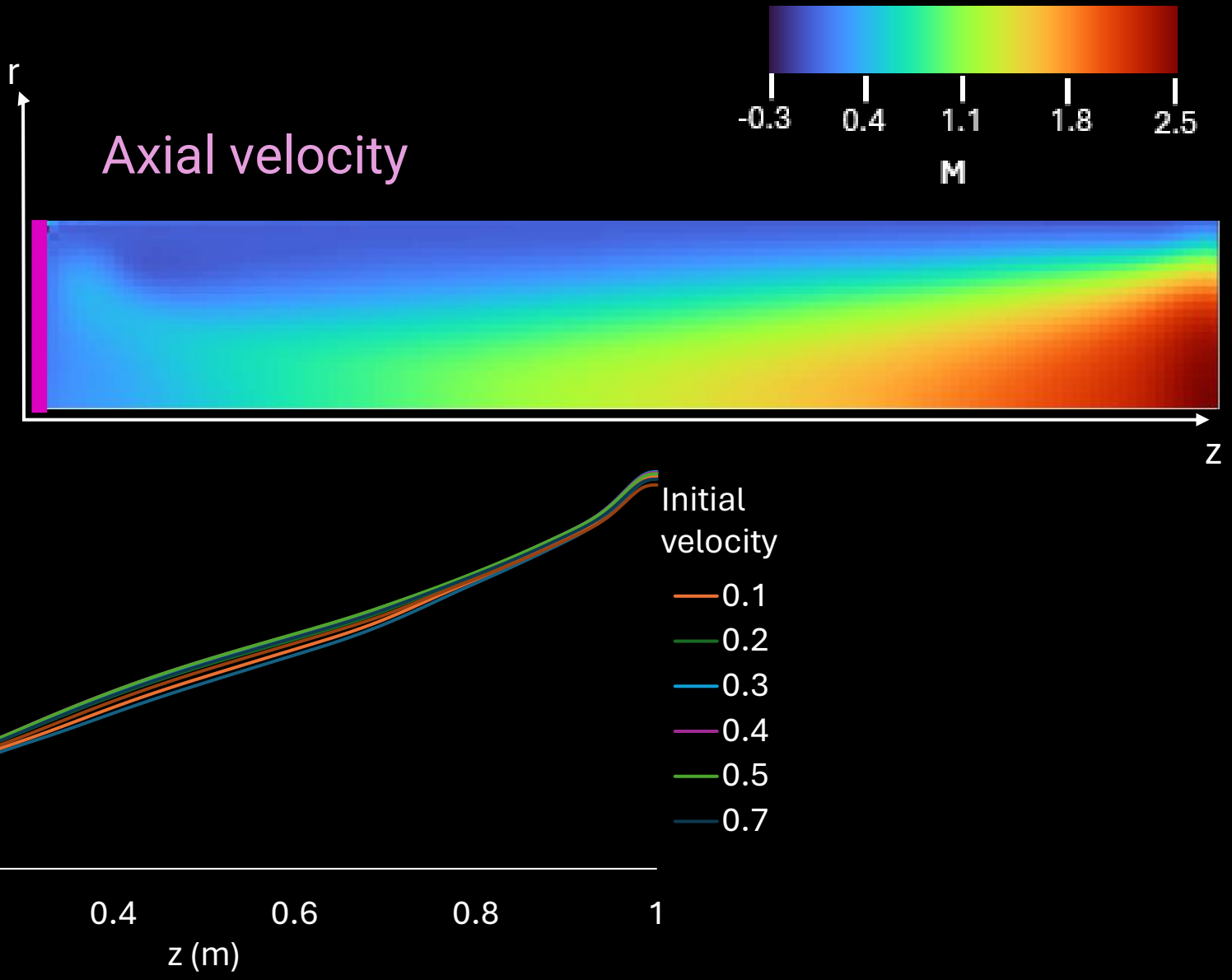
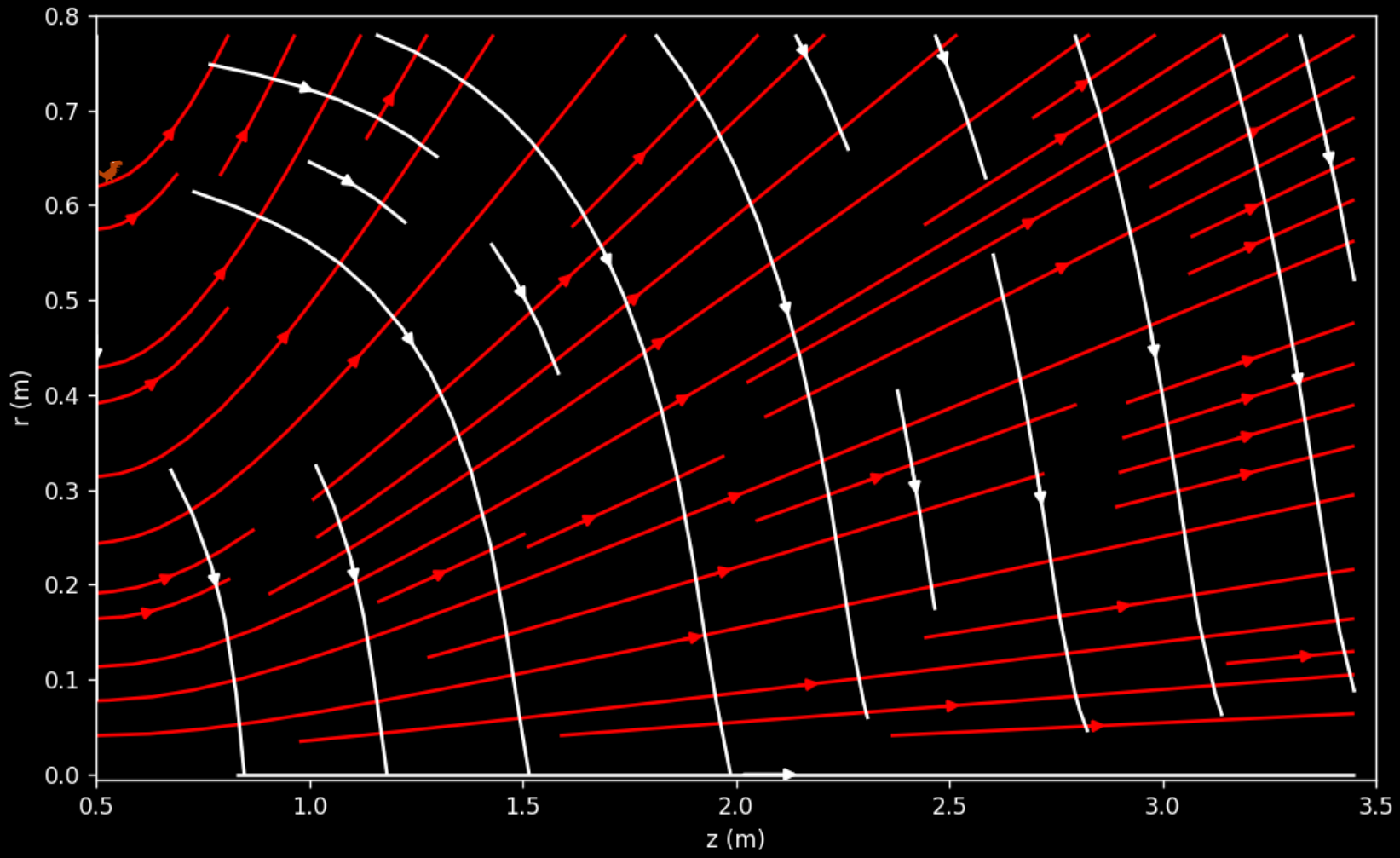


Fig.4 Axial velocity of the fluid in the magnetic nozzle at r=0

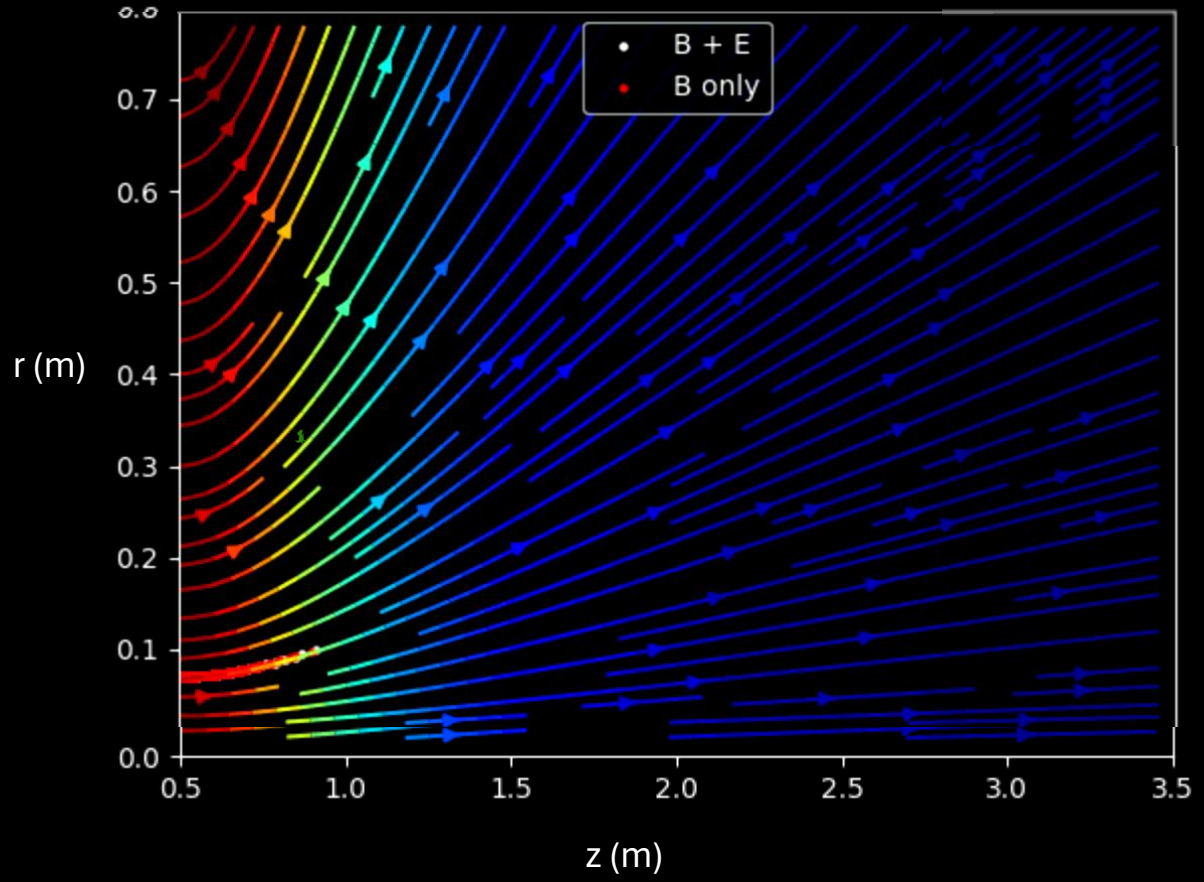
Plasma Detachment from MFL and centrifugal confinement

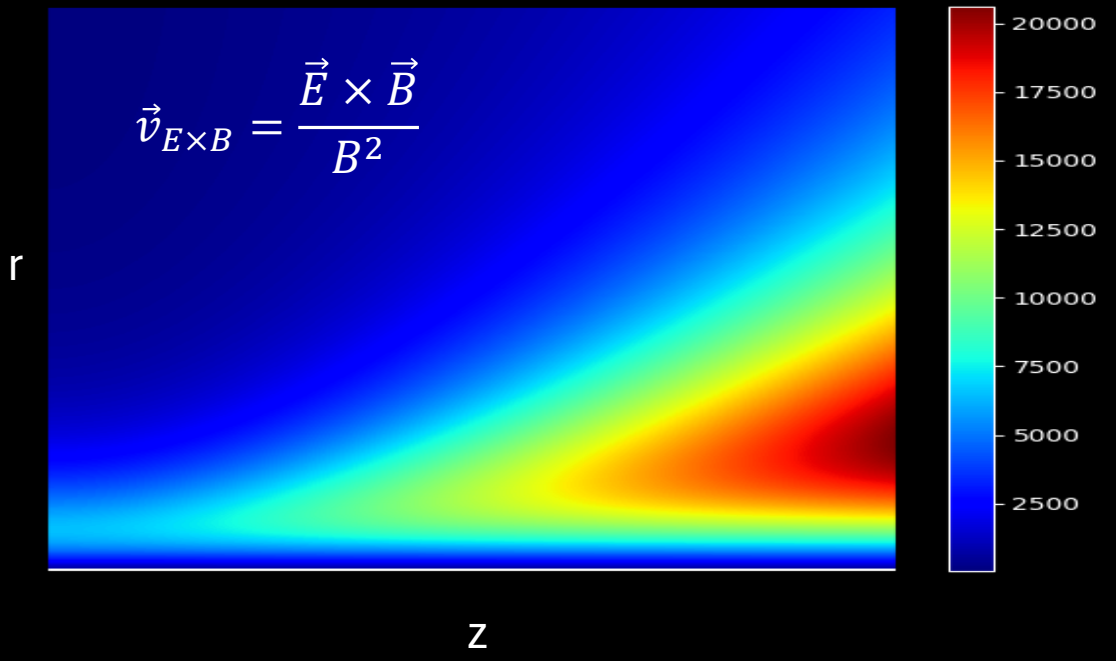


Electric field

Magnetic field

Plasma Detachment from MFL and centrifugal confinement





We want to accelerate plasma with pressure and electromagnetic fields to supersonic velocities for space propulsion and nuclear fusion

Plasma must be confined in high magnetic fields (magnetic confinement)

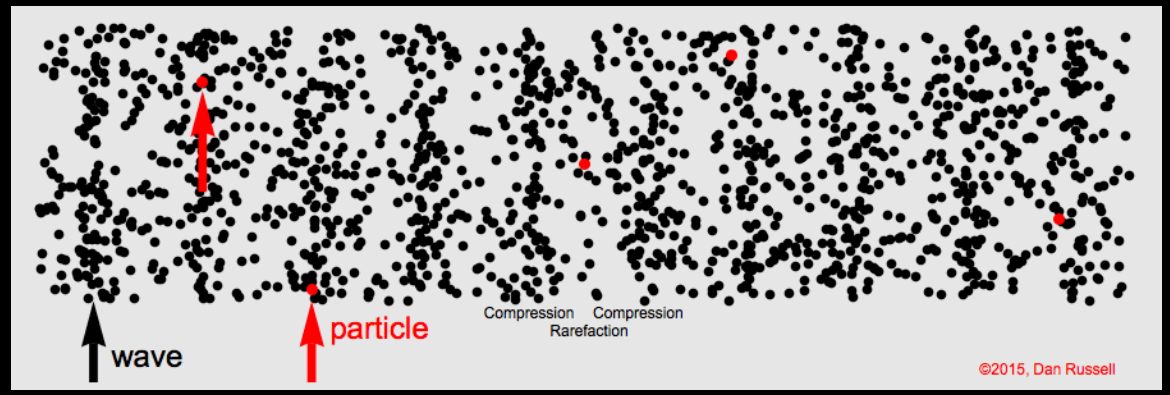
Transonic acceleration solution is robust close to the axis

Centrifugal confinement used in Hall-effect thrusters is used to obtain higher acceleration and better confinement

Thank you! - Merci!

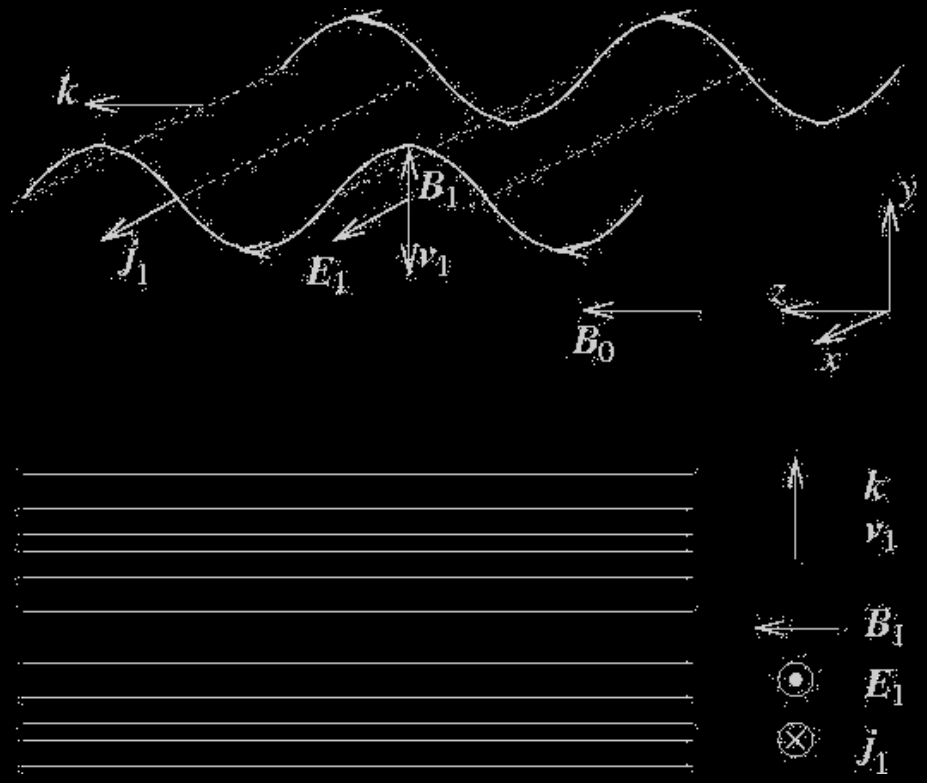
Je reconnais que mes recherches se sont déroulées sur le territoire du traité 6 et sur la terre natale des Métis. Je rends hommage aux ancêtres des Premières nations et des Métis de la Saskatchewan

Waves in plasma



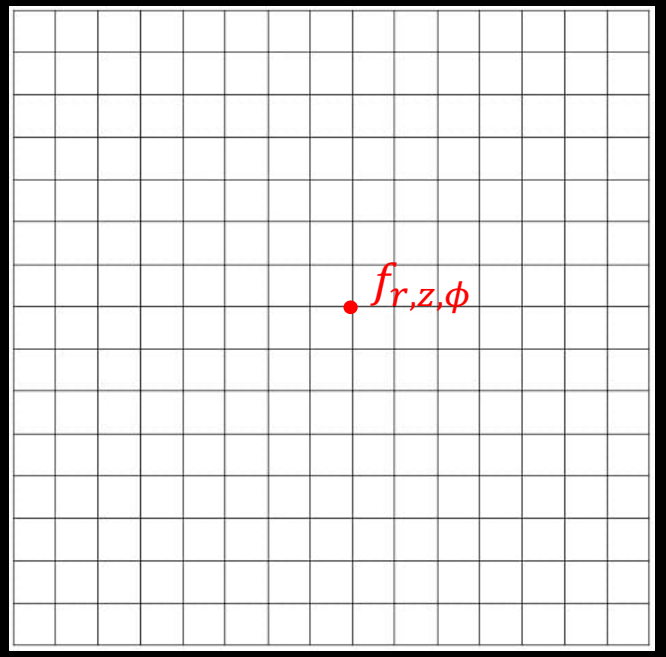
Sound wave (perturbation in the **pressure/density**) [3]

$$\sqrt{\frac{B^2}{\mu_0 mn}} = V_A > c_s = \sqrt{\frac{\Gamma p}{\rho}}$$



Alfvén wave (perturbation in the **tangential magnetic field/velocity**) [4]

Magnetohydrodynamics code



[10]

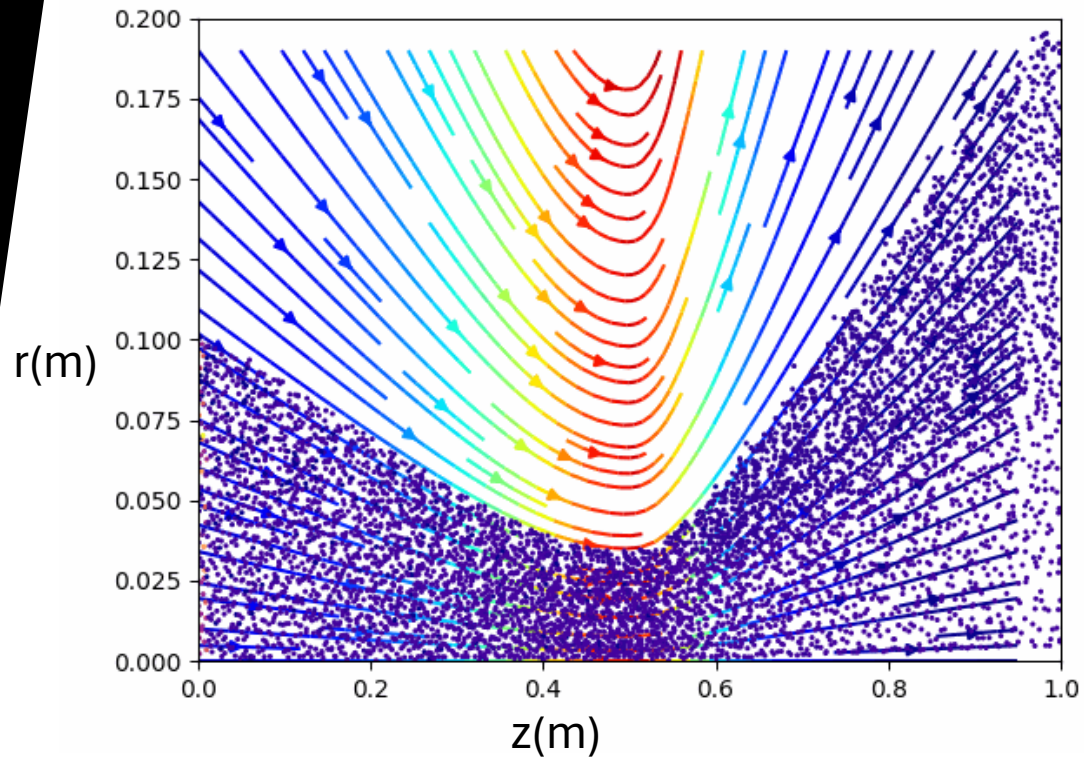
$$\vec{f} = \begin{pmatrix} \rho \\ p \\ \vec{v} \\ \vec{B} \end{pmatrix}$$

Magnetohydrodynamics (PLUTO, Athena)

- Fluid code
- Eulerian mesh
- Based on the MHD equations

Particle-in-cell (VSim)

- Injection of lagrangian particles in an eulerian mesh
- External magnetic field
- External electric field
- Particle dynamics



Particle-In-Cell