Stabilizing Influence of Magnetic Fields in Magnetohydrodynamic (MHD) Shear Flows

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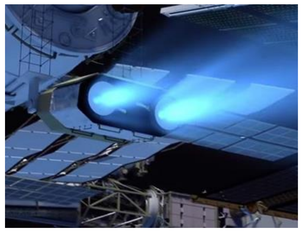
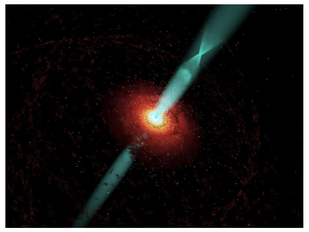
Introduction

Why are astronomical jets collimated and stable for so long? How do magnetic fields affect instabilities? To enhance our understanding of these, we investigate the behavior of homogeneously sheared MHD flows subject to perturbations in various directions. Using direct numerical simulations (DNS), we examine the interplay between magnetic and kinetic energies. These numerical simulations have applications in more complex cases such as propulsion, astronomical flows, and nuclear fusion.

Experimental x-ray radiographs showing collimation of jets (Yurchak et al.)



VASIMR Engine (Ad Astra Rocket Company)

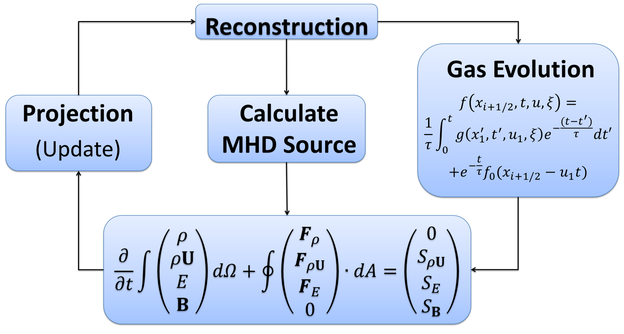


Symmetrical jets from a black hole (Wolfgang Steffen)

Methodology & Set Up

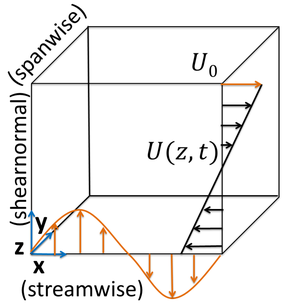
Magneto Gas Kinetic Method (MGKM) solves fluid equations with the simplified Boltzmann equation and the magnetic field equations *separately.*

MGKM Flowchart:



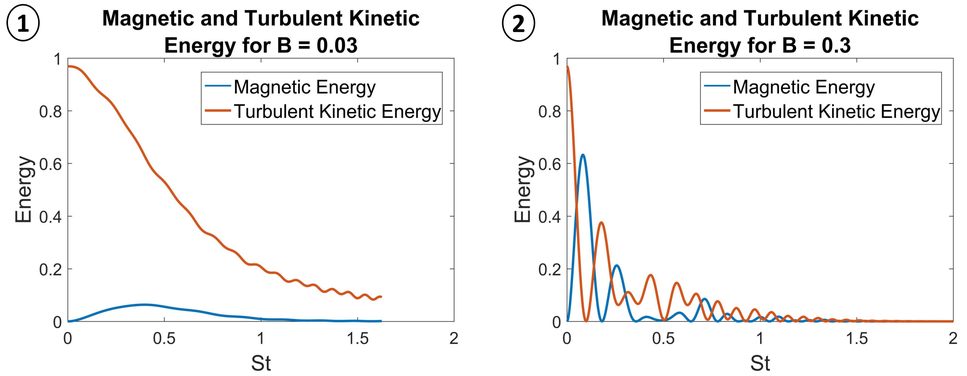
Directionality and Parameters:

M_g = 0.3
Re = 15,823
Re_m = 61,625
Molecules = Argon
Molar Mass = 39.948 kg/mol

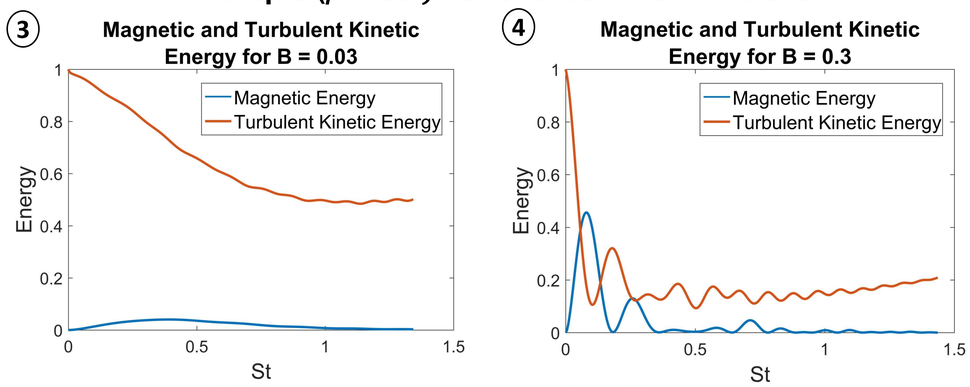


Results

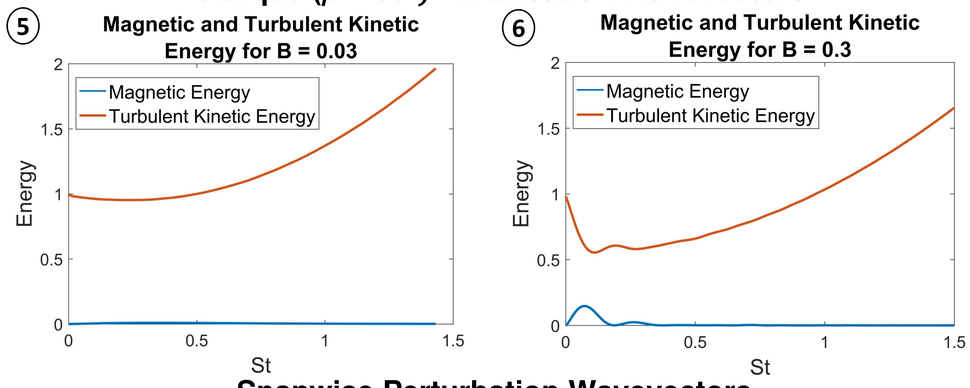
Streamwise Perturbation Wavevectors



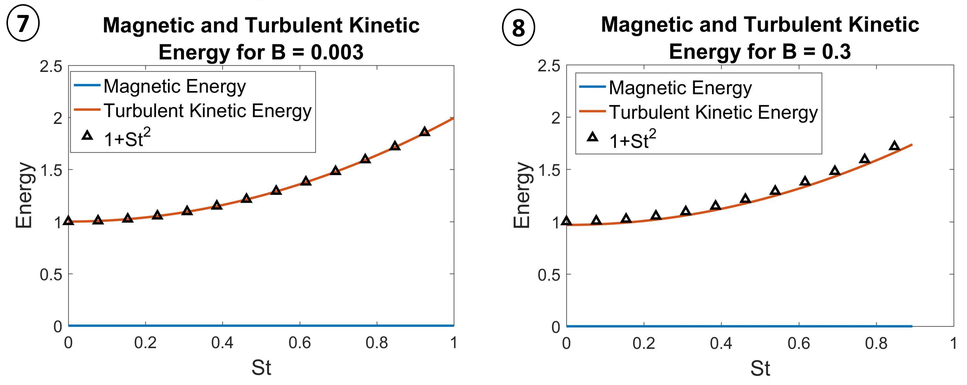
Oblique ($\beta = 30°$) Perturbation Wavevectors



Oblique ($\beta = 60°$) Perturbation Wavevectors



Spanwise Perturbation Wavevectors



Analysis

Streamwise:

- Magnetic and velocity fields are tightly coupled and "harmonic" in nature

Low Magnetic Fields:

- Evolution becomes predominantly oscillatory as time increases

High Magnetic Fields:

- Oscillatory behavior intensifies as magnetic field strength increases, indicating strong harmonic exchange

Oblique (30°):

- Turbulent kinetic energy does not decay to zero as the spanwise component exerts influence at later times

Oblique (60°):

- Monotonic increase in turbulent kinetic energy as spanwise component dominates
- Magnetic field effects no longer dominant
- Strong enough magnetic fields still create some oscillatory interactions

Spanwise:

- Magnetic and velocity fields are decoupled
- Turbulent kinetic energy increases monotonically
- Behavior is impervious to magnetic field

Conclusions & Future Work

For perturbations with streamwise wavevector component, a significant decrease in kinetic energy is observed. *This demonstrates the ability of the magnetic field to inhibit growth of instabilities.*

Future Work:

- Homogeneous MHD shear is a simple case that can be extended to jets and mixing layers.
- We want to investigate how multiple wave numbers influence energy interactions using fully turbulent initial conditions.

Acknowledgements

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