Magnetohydrodynamic (MHD) Waves in Earth’s Magnetosphere

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Overview

1. Introduction - Magnetospheres and Waves
2. Magnetohydrodynamics
3. Numerical Analysis
4. What does a PhD student actually do?
5. Solar Research at St Andrews
What is a Magnetosphere?

- Extent of the influence of a planetary magnetic field.
- Generated, for the Earth, by the geodynamo.
- Protects us from high energy particles in the Solar Wind.
Magnetospheric Structure

- Solar Wind
- Van Allen Radiation Belts
- Plasma Sheet
- Tail Lobe
- Current Sheet
- Plasmasheet Boundary Layer
- Plasma Mantle
- Magnetopause
- Magnetosheath
- Bow Shock
- Southward IMF
What are Magnetospheric Waves/Pulsations?

- Low frequency oscillations in the Earth’s magnetic field, detected by ground and space magnetometers.
- Named Ultra Low Frequency (ULF) waves - 1 mHz to 1 Hz.
- Generated in various ways, from the Solar Wind to magnetosheath instabilities.
- Important to understand the dynamics of the magnetosphere, a lot of the motion governed by waves.
- How can we study these waves theoretically?
Equations of Magnetohydrodynamics - MHD

\[ \rho \frac{\partial \rho}{\partial t} + \rho (u \cdot \nabla) u = -\nabla p + j \times B + \rho g \quad \text{(Momentum)} \]

\[ \frac{\partial \rho}{\partial t} + \nabla \cdot \rho u = 0 \quad \text{(Continuity)} \]

\[ \frac{\partial p}{\partial t} + u \cdot \nabla p = -\gamma p \nabla \cdot u \quad \text{(Energy)} \]

\[ \frac{\partial B}{\partial t} = \nabla \times (u \times B) + \eta \nabla^2 B \quad \text{(Induction)} \]

\[ \nabla \cdot B = 0 \quad \text{(Solenoidal)} \]

A lot of assumptions made to get here! But MHD is a good approximation for large scale, long lived phenomena of speeds much less than c.
How to Solve PDE’s numerically?

- We solve PDE’s numerically on a grid by *finite difference* methods.
- Approximate the derivative terms appearing in the PDE’s using rearranged Taylor series expansions.
- Many different methods, all of which have different strengths for different problems.
- After assuming a geometry for the magnetosphere, together with yet more assumptions, can reduce the MHD equations down to a set of PDE’s.
Read papers, then read some more papers. There are always more papers to read!

It can take a lot of time to get into a field (e.g. I have no physics background!).

Write fortran code to use finite difference equations to numerically solve a simplified version of the MHD equations.

Develop simulation ideas based on observations in order to test our theory against the physical results.

Use IDL (Interactive Data Language) to visualise results.
Solar Research at St Andrews

- Theoretical and observational, analytical and numerical.
- Global 3D MHD simulations to study coronal loop motions and flux emergence.
- Magnetic reconnection.
- Coronal loop heating.
- MHD Waves.
- Analytical treatment of MHD.
SDO Data

Image credit: SDO website.
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Numerical Simulations from our department

Paolo Pagano: Ejection of a Magnetic Flux Rope
Numerical Simulations from our department

Archontis & Hood: Coronal Jets
Numerical Simulations from our department

K. Meyer & D. Mackay: Storage and dissipation of Magnetic Energy
Thanks!

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