Modeling of MHD waves in the solar corona

Bachelor project 2019-2020

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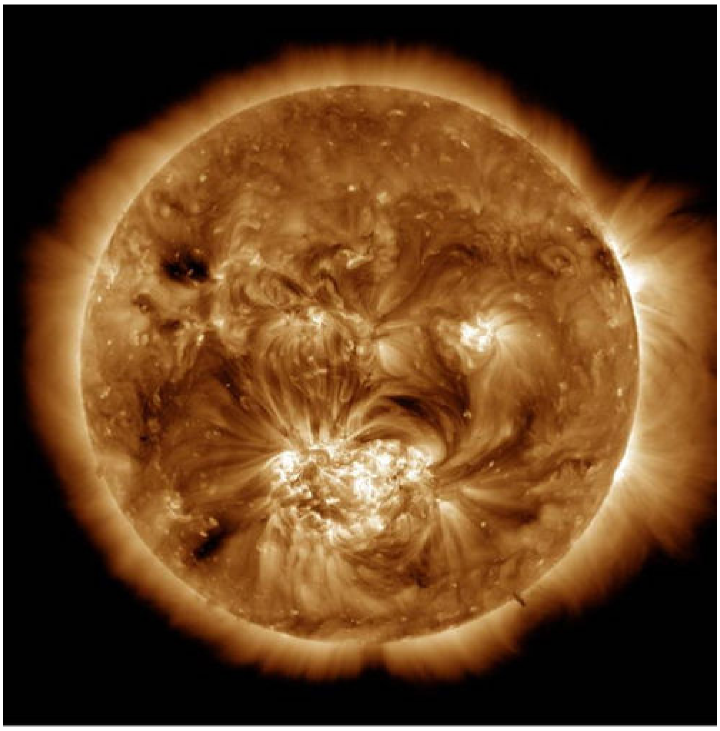

Figure 1: Image of corona from NASA's Solar Dynamics Observatory showing features created by magnetic fields. Image credit: NASA

The solar corona is the outer layer of the solar atmosphere. The temperature of the solar corona is very high (10^6 Kelvin) so that the material is fully ionized to the plasma state. The coronal plasma can be readily described by the magnetohydrodynamic (MHD) equations, which combine the fluid dynamic equations and the Maxwells equations. Due to the involvements of electric and magnetic fields, wave behaviors in plasma are more complex than in neutral gas. Satellites observations have shown that MHD waves are ubiquitous in the solar atmosphere. These MHD waves can be used as diagnostic tools to measure some coronal physical parameters that are difficult to measure directly. MHD waves also have the potential to heat the corona plasma to the temperature of million Kelvin.

Computer modeling (or simulation) provides an effective tool studying waves in the solar corona. Computer modeling solves numerically the governing equations, and thus can solve some problems that are not easily solved analytically.

This project aims to investigate these MHD waves in the solar corona, via performing numerical simulations using an open source code PLUTO. A basic knowledge of C language is required to modify the source code. A Linux computer is preferred to run simulations.

Through this project, you will learn some basic knowledge of MHD waves in the solar corona and be familiar with MHD simulations and data analysis. The detailed tasks are as follows:

- **Sound waves in hydrodynamic fluids**

  In the neutral gas, sound waves are driven by the gradient of gas pressure. In a uniform medium, sound waves are isotropic. With this task, you will learn to use an open source code PLUTO and perform 2-dimensional hydrodynamic (HD) simulations on the propagation of sound wave.

  - Download and install the PLUTO code. [1]
  - Read Chapter 0 of the code userguide and run the test problems.
  - Setup the initial condition (e.g., a circle region with higher pressure) to trigger sound waves.
  - Run simulations, visualize and analyze the wave properties, e.g., the propagation speed.

- **Waves in magnetohydrodynamic (MHD) fluids**

  The involvements of electric and magnetic field make wave properties in the solar corona more complex than in neutral fluids. These waves are called MHD waves. This task is similar to the previous one but in the case of MHD.

  - Choose the MHD module of PLUTO and implement a uniform magnetic field.
  - Setup the initial condition (e.g., a circle region in the domain center with higher pressure) to trigger waves.
  - Run simulations, visualize and analyze the wave properties.
  - Refer to books or academic articles to understand the simulation results.

[1] `http://plutocode.ph.unito.it/index.html`

- **Interaction of MHD waves with large scale structures**

  The solar corona is not a uniform medium, instead, large scale structures are clearly seen from observations. This task thus aim to investigate the interaction between waves and these large scale structures through simulations.

  - Understand normalization and transformation between physical quantities and dimensionless code quantities.
  - Setup the initial and boundary conditions following the paper by [Afanasyev & Zhukov(2018)]
  - Analyze the interaction of MHD waves with large scale structures.

- **MHD waves in a slab geometry**

  In solar corona the magnetic force is dominant over the pressure force, so that the plasma is structured by the magnetic field and coronal loops are formed. In structured coronal loops waves are often dispersive, that is, waves with different frequencies have different propagation speed. This task aims to explore the propagation of MHD waves in a 2-dimensional slab.

  - Setup initial condition following the paper by [Nakariakov et al.(2004)].
  - Run simulation and analyze the results.
  - Refer to academic papers and try to understand the simulation results.

References

[Afanasyev & Zhukov(2018)] Afanasyev, A. N., & Zhukov, A. N. 2018, Astronomy & Astrophysics, 614, A139

[Nakariakov et al.(2004)] Nakariakov, V. M., Arber, T. D., Ault, C. E., et al. 2004, Monthly Notices of the Royal Astronomical Society, 349, 705