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The Magnetopause
Bringing Space Physics Into a Junior Lab
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1. Introduction

Motivation
Exposing students to current areas of research, as well as classic labs, helps students broaden their interests in and deepen their understanding of physics. There are hurdles to using current research techniques and topics in labs in every subdiscipline, but bringing Space Physics into the undergraduate lab is especially difficult because:
- most students get little exposure to space and plasma physics.
- advanced E&M, which is key to understanding space plasma, is often late in the curriculum.
- applications are often complex, defying simple treatment in lab.

Magnetoopause Lab
This project describes our attempt to introduce physics students to Space Physics by using the magnetopause as the topic of a sophomore/junior physics lab. As shown in Figure 1, the magnetopause is the boundary between the region of space dominated by the solar wind and the region dominated by the Earth’s magnetic field (the magnetosphere).

Figure 1: A simple diagram of Earth’s magnetosphere.

The magnetopause is an apt topic to use to expose students to Space Physics because it can be introduced at a fairly elementary level, after which more complicated models can also be examined. This approach to introducing the magnetopause allows students to use their existing physical intuition, but also gain experience with more advanced methods.

2. Theory

Pressure Balance
At the simplest level, the location of the magnetopause can be considered to be due to the pressure balance between the dynamic pressure of the solar wind and the magnetic pressure of Earth:

\[ 2 \mu_0 \rho_w v_w^2 \cos^2 \theta = \frac{1}{2} \mu_0 B_n^2 \]  

where \( \cos \theta \) term takes into account the fact that the solar wind may not be coming in normal to the magnetopause.

Magnetopause Subsolar Point
Substituting the expression for the Earth’s magnetic dipole moment into equation 1 and assuming that the solar wind is coming in normal leads to the following equation for the distance from Earth to the subsolar point of the magnetopause:

\[ r_{sl}(R_E) = 107.4(v_w \cos \theta)^{-1/2} \]  

where \( v_w \) is the standoff distance from the Earth to the magnetopause in \( R_E \), \( \rho_w \) is the dynamic density of the plasma in the solar wind in \( \text{cm}^{-3} \), and \( B_n \) is the speed of the solar wind in km/s [Kivelson et al., 1995].

Fitting Spacecraft Observations
Recent work on the magnetopause location has focused on fitting the spacecraft observations of the magnetopause location under various conditions to empirical expressions. In the satellite data portion of this lab, students compare predictions from Shue et al. [1998] to their interpretations of the satellite data.

3. Simulation

In this section of the lab, students run the BAT-R-US [Hansen et al., 2002] simulation on supercomputers at the Community Coordinate Modeling Center. Students find subsolar points for a dozen solar wind conditions and fit their data to equation 2.

Figure 2: The pressure balance between the dynamic pressure of the solar wind and the magnetic pressure of the magnetosphere.

Finding the Magnetopause Location
Students upload parameters describing variations in the solar wind conditions. They plot the simulation results and search for signs of the magnetopause in the results.

Figure 3: Plot of number density showing the magnetopause in simulation results. The number density is plotted in the XZ at a time 5 minutes into a typical simulation run.

Figure 4: Simulation results plot used to find subsolar point of the magnetopause. The \( \psi \) component of the magnetic field, the number density, and the \( x \)-component of the plasma flow velocity are plotted for locations along the line from the Earth to the Sun.

Finding the subsolar point in simulation results
Students are exposed to Space Physics because it exposes them to using current research techniques and simulation results, the struggles that the students have are good experiences for the students.

In research results are often ambiguous, and scientists make their own judgements in consistent ways. In this lab students get practice making their own judgements and dealing with ambiguity.

4. Spacecraft Data

In this section of the lab, students search for magnetopause crossings for three sets of data chosen from several spacecraft (Geotail, Polar, the GEOES satellites, and the L satellites) and several events.

Example: Geotail - 10/31/2003

Figure 5: Geotail’s magnetopause crossings on 10/31/2003. Plot (a) shows predicted location of the magnetopause and Geotail’s actual position. Plot (b) shows the Geotail’s magnetic field measurements. Plot (c) shows Geotail’s ion speed measurements, as well as the GSE \( z \)-component of the solar wind speed.

Finding the Magnetopause Location under extreme solar wind conditions, 

On October 31, 2003, a large Coronal Mass Ejection (CME) hit Earth, causing auroras that were visible throughout much of the United States. Figure 5 shows data from this CME used by students to search for spacecraft crossings of the magnetopause.

Figure 5(a) predicts several magnetopause crossings of the magnetopause. These predicted crossings are confirmed by both Figure 5(b) and 5(c), which show very different conditions between 5:00 and 10:00.

5. Discussion

The results of this lab are promising. In this lab students:
- are exposed to some basic concepts of Space Physics.
- explore a realistic Space Physics problem.
- use real Space Physics data and tools.

Though the students have some difficulties interpreting the spacecraft data and simulation results, the struggles that the students have are good experiences for the students.

In research results are often ambiguous, and scientists make their own judgements in consistent ways. In this lab students get practice making their own judgements and dealing with ambiguity.

6. Future Improvements

Students have gotten reasonable results from the current lab, but there are still difficulties with:
- Finding the subsolar point in simulation results
- Students deal with lack of certainty — the answers are not always clear.
- Interpreting ion data
- Find events where the boundary crossings are more clear in the ions.

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References
