The Magnetopause

Bringing Space Physics Into a Junior Lab

Jim Crumley, Ari Palczewski,and Steve Kaster

Physics Department, College of Saint Benedict / Saint John's University, Collegeville, MN 56321

jcrumley@csbsju.edu

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.

Magnetopause 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).

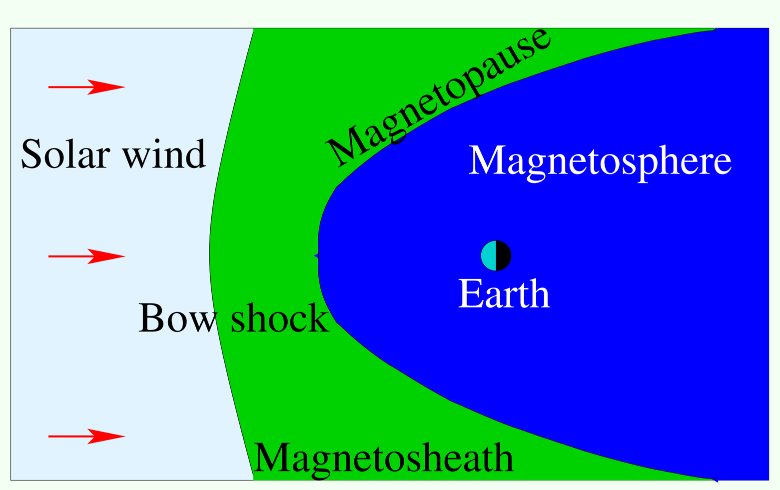

Figure 1: *A simple diagram of Earth's magnetosphere.*

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:

$$2\rho_{sw}v_{sw}^2\cos^2\theta = \frac{1}{2\mu_0}B_E^2 \qquad (1)$$

where the $\cos\theta^2$ term takes into account the fact that the solar wind may not be coming in normal to the magnetopause.

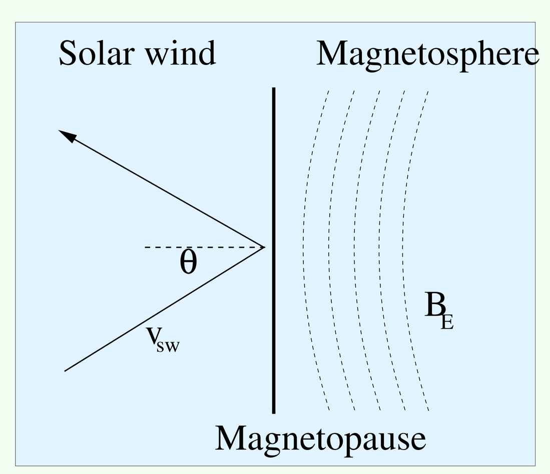

Figure 2: *The pressure balance between the dynamic pressure of the solar wind and the magnetic pressure of the magnetosphere.*

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:

$$r_o(R_E) = 107.4(n_{sw}v_{sw}^2)^{-\frac{1}{6}} \qquad (2)$$

where r_o is the standoff distance from the Earth to the magnetopause in R_E, n_{sw} is the number density of the plasma in the solar wind in cm^{-3}, and v_{sw} 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.

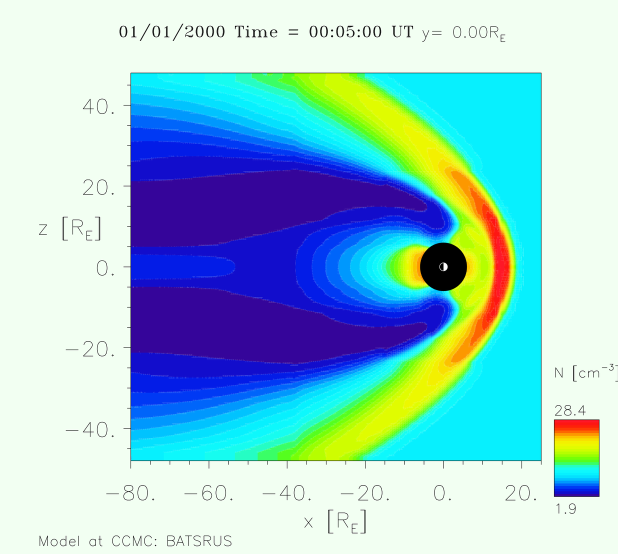

Figure 3: *Plot of number density showing the magnetosphere in simulation results. The number density is plotted in the XZ at a time 5 minutes into a typical simulation run.*

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.

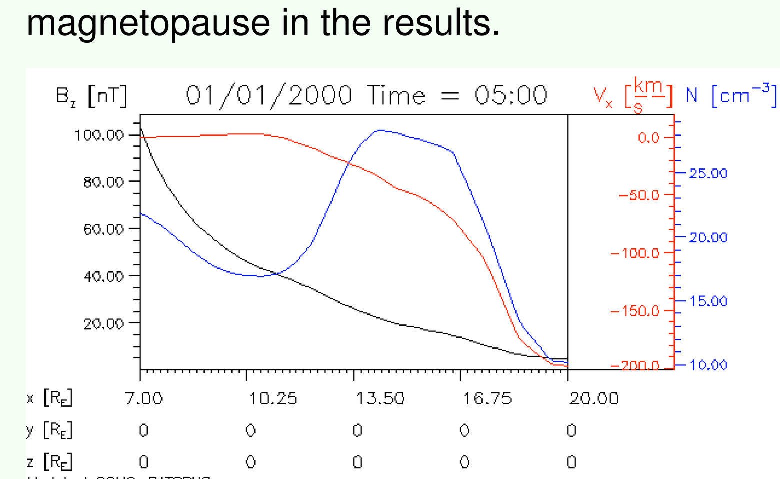

Figure 4: *Simulation results plot used to find subsolar point of the magnetopause. The z-component of the magnetic field, the number density, and the x-component of the plasma flow velocity are plotted for locations along the line from the Earth to the Sun.*

Figure 4 shows a typical plot used by students to find the subsolar point of the magnetopause, which is located at located at roughly 11 R_E in this case. This is shown by:

- N - the magnetopause is just to the left of the bump.
- V_x - speed stagnates inside magnetopause.
- B_z - has a subtle kink in shift from B_E to B_{sw}.

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 GEOS satellites, and the L satellites) and several events.

Example: Geotail - 10/31/2003

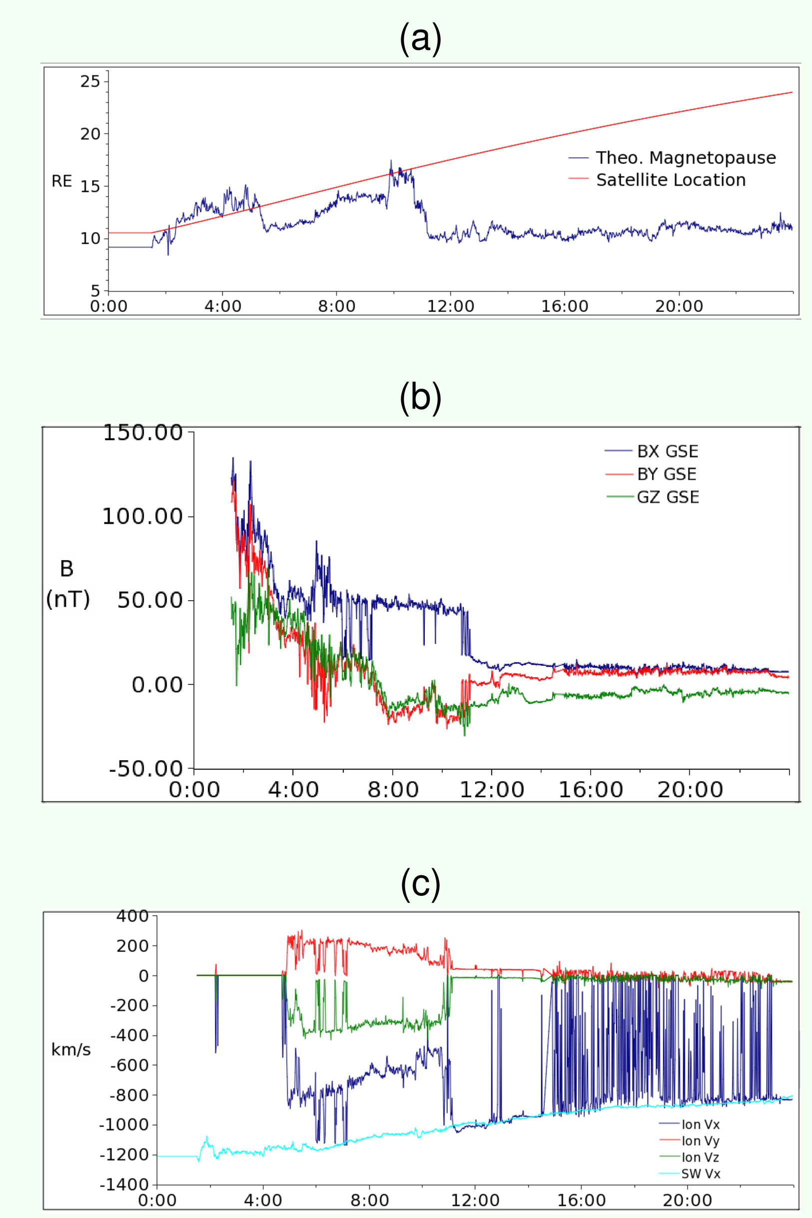

Figure 5: *Geotail's magnetopause crossings on 10/31/2003. Plot (a) shows predicted location of the magnetopause and Geotail's actual position. Plot (b) shows the Geotail's magnetic field measurements. Plot (c) shows Geotail's ion speed measurements, as well as the GSE x-component of the solar wind speed.*

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, but the most notable crossings are at roughly 5:00 and 10:00. On either side of this time range Geotail is outside the magnetosphere, while for most of the rest of this time period it is inside the magnetosphere.

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
  - Help 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.

References

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Kivelson, A., M. G. Kivelson, and C. T. Russell, *Introduction to Space Physics*, Cambridge University Press, London, 1995.

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Acknowledgements

I would like to thank Kristi Keller from NASA Goddard Spaceflight Center. Conversations with Kristi led to the development of this lab. Simulation results have been provided by the Community Coordinated Modeling Center at Goddard Space Flight Center through their public Runs on Request system (http://ccmc.gsfc.nasa.gov). The Spacecraft key parameter data provided by CDAWeb (http://cdaweb.gsfc.nasa.gov/). This research was supported by an award from Research Corporation.