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Visualizing Planetary Magnetic Fields (and Why You Should Care)

Matt Fillingim,[1] Dave Brain,[1,3] Laura Peticolas,[2] Darlene Yan,[2] and Kyle Fricke[2]

[1]*Space Sciences Laboratory, University of California, 7 Gauss Way, Berkeley, California 94720, USA*

[2]*Center for Science Education, Space Sciences Laboratory (CSE@SSL), University of California, 7 Gauss Way, Berkeley, California 94720, USA*

[3]*Now at the Laboratory for Atmospheric and Space Physics and Department of Astrophysical and Planetary Sciences, University of Colorado, Boulder, Colorado 80309, USA*

Abstract. Since they are invisible to our eyes, planetary magnetic fields are difficult to visualize. However, we can learn much about a planet, its interior, and its history from studying its magnetic field. A challenge, then, is how can we effectively communicate the structure of planetary magnetic fields to the public, i.e., how can we help the public visualize planetary magnetic fields. An additional challenge is how can we effectively communicate the importance of studying planetary magnetic fields to the public, or why should they care. We address these challenges by developing a series of presentations about magnetic fields and their importance given on visually engaging spherical displays. We are also creating scientifically accurate three-dimensional models of planetary magnetic fields.

1. Introduction

The magnetic fields of the large terrestrial planets, Venus, Earth, and Mars, are all vastly different from each other. These differences can tell us about the interior structure, interior history, and even give us clues to the atmospheric history of these planets. Unfortunately, unless space can be permeated with tiny iron filings, magnetic fields are invisible. As the saying goes, "out of sight, out of mind."

This leaves us with two questions. How can we best communicate the structure of these planetary magnetic fields to the public? How can we best communicate the importance of studying planetary magnetic fields?

We address these questions in two different ways: 1) by developing (and evaluating) a series of presentations given on visually engaging spherical displays in conjunction with hands-on activities, and 2) by creating scientifically accurate three-dimensional models of planetary magnetic fields.

This work is part of a larger effort entitled "Seeing the Invisible: Educating the Public on Planetary Magnetic Fields and How they Affect Atmospheres" funded through a NASA ROSES Supplemental Education Grant. Our collaborators include science and education professionals from the Space Sciences Laboratory (SSL), the Center for Science Education at the Space Sciences Laboratory (CSE@SSL), and the Lawrence Hall of Science (LHS) at the University of California, Berkeley.

We will describe our presentations, 3D models, and future plans below.

2. Presentations

Our presentations are a combination of planetary images on engaging spherical displays, coupled with visual demonstrations. Our first presentation, entitled "Goldilocks and the Three Planets," is targeted to an elementary school age audience. The focus of this presentation is mainly on differences in the atmospheres of Venus, Earth, and Mars, and why Earth can support life. We employ an analogy with the familiar story of Goldilocks and the Three Bears: Venus is too hot, Mars is too cold, Earth is just right for liquid water to exist. It is the presence and stability of liquid water that made Earth habitable; liquid water helped remove the carbon dioxide from Earth's early atmosphere. To illustrate this point, we employ a demonstration. We take an ordinary rock, something like limestone works best, and place it in a container of vinegar. Bubbles begin to appear in the vinegar. These are bubbles of carbon dioxide. This shows that carbon dioxide is present inside rocks. Chemical reactions that take place in water take carbon dioxide out of the air and put it in rocks.

We tested and evaluated this presentation during the spring of 2010 on the six-foot diameter "Science on a Sphere"™ at the Lawrence Hall of Science in Berkeley, California. As a result of this testing and evaluation, we decided to remove the original demonstration illustrating the phases of matter with the rock, vinegar, carbon dioxide demonstration mentioned above. The earlier demonstration did not effectively communicate the importance of liquid water in changing the atmosphere early in Earth's history.

Our second presentation is targeted to a middle school age audience. It is entitled "Lost on Mars (and Venus)." This presentation focuses on differences in the magnetic fields of Venus, Earth and, Mars. To do this, we developed "global compass maps" to be shown on the Science on a Sphere. These maps show the direction a compass would point on the surface of the planet. In this format, it is very easy to see the differences between the magnetic fields of Earth (all compass arrows point north), Mars (compass arrows point in many different directions, particularly near crustal magnetic anomalies), and Venus (no arrows since there is no measurable magnetic field).

Differences in the "global compass maps" are due to differences in how the magnetic fields are formed. First we discuss the idea of a planetary dynamo. A planetary dynamo can create a planetary magnetic field if there is 1) a conducting (metal) layer in the planet that is 2) rotating and 3) convecting (churning). Earth's magnetic field arises from a planetary dynamo operating deep inside the Earth in its liquid iron outer core. It is made of iron, so it is a conductor. It is rotating because Earth is rotating, and it is convecting because it is a liquid being heated from the bottom.

The magnetic field of Mars, on the other hand, comes from surface rocks that trap or remember the magnetic field from long ago. This tells us that Mars does not currently have a planetary dynamo operating in its interior, but that it used to. Mars is smaller than Earth, so it's interior has cooled off faster. It no longer satisfies the third condition necessary for a planetary dynamo. Mars once had a planetary dynamo that the surface rocks remember, but it is no longer operating. We've learned something about the history of Mars!

Venus lacks any measurable magnetic field, so it does not have an operating planetary dynamo. However, Venus is about the same size and mass as Earth, so we expect the internal conditions to be similar. Clearly they are not. Additionally, the surface rocks don't appear to remember a past planetary dynamo. This is attributed to the surface being very young (as evidenced by its many volcanic features) and hot (the hottest planetary surface in the Solar System). The interior of Venus must be different than the interior of Earth, but we are not entirely sure how. This is a topic of current planetary science research.

As part of the presentation, we have small balls (several inches in diameter) with magnets placed at the poles (Earth), magnets scattered around the surface (Mars), or no magnets (Venus). These balls are designed to be used with small pieces of metal, small washers, and bent staples to trace out the magnetic field configuration.

We tested and evaluated this presentation during the spring of 2011 on the LHS's Science on a Sphere. The evaluation results showed that the target audience did gain understanding in the differences between the magnetic fields of Venus, Earth, and Mars as well as the origin of these differences.

Our final presentation will be targeted to a high school age audience. This presentation is still a work in progress. However, we plan to focus on the effects of the differences in the magnetic fields of Venus, Earth, and Mars. In the absence of a global, planetary dynamo driven magnetic field (such as is the case at Venus and Mars), the solar wind can slowly strip away the upper atmosphere. A strong, global planetary magnetic field (such as at Earth) can protect the atmosphere from the solar wind. The presence (or absence) of a planetary magnetic field is important for the long term atmospheric climate evolution of a planet.

In addition to finalizing this third presentation, our future plans include adapting this series of presentations from the six-foot Science on a Sphere format to a portable, table top spherical display system for traveling presentations. Through this project, in conjunction with other projects at the Center for Science Education, we have purchased a "Magic Planet"™ portable digital video globe from Global Imagination. This video globe will allow us to take these (and other) presentations into classrooms to reach students who do not traditionally go to the Lawrence Hall of Science.

3. 3-D Models

Recently, we finished construction of a scientifically accurate, three-dimensional scale model of the magnetic field of Mars interacting with the interplanetary magnetic field (IMF). We use rigid wires to represent magnetic field lines. Three types of magnetic field lines are present: lines (wires) which intersect the surface of Mars at two points ("closed" magnetic field lines emanating from the crust), lines which intersect the surface of Mars at one point while the other reaches the edge of the box (magnetic field lines that are "open" to the IMF), and lines which intersect the box at both ends (IMF lines). This model can be used in conjunction with the presentations as an additional visualization tool.

The pictures below show the views of the front and back of the model. The front of the model shows surface features of Mars (volcanoes and canyons); the back of the model shows a cut-away view of the interior of Mars. The crustal magnetic field lines are shown to be originating near the surface rather than deep in the interior. For scale, the length of the case is approximately 2 feet.

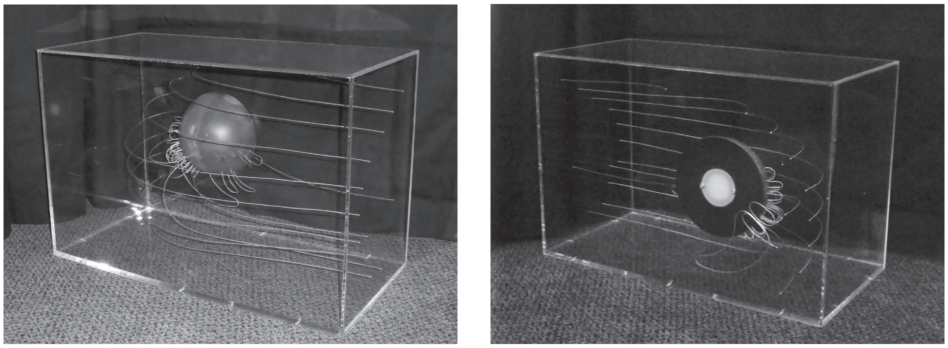

Figure 1. Photographs of the front (left) and back (right) of our 3-D wire model of the magnetic field of Mars

Finally, our future plans also include constructing similar wire models of the magnetic fields of Venus and Earth. These display models will be part of the traveling presentations and will show scientifically accurate representations of each planet's magnetic field. These models will be important in communicating the shape and scale of the magnetic field in relation to the planet.

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