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Wet Mars, Dry Mars

Matt Fillingim,[1] David A. Brain,[2] Laura M. Peticolas,[3] Darlene Yan,[3] Kyle Fricke,[3] and Leitha Thrall[3]

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

[2]*Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, Colorado 80309, USA*

[3]*Center for Science Education, Space Sciences Laboratory, University of California, 7 Gauss Way, Berkeley, California 94720, USA*

Abstract. The magnetic fields of the large terrestrial planets, Venus, Earth, and Mars, are all vastly different from each other. These differences can tell us a lot about the interior structure, interior history, and even give us clues to the atmospheric history of these planets. This paper highlights the third in a series of presentations that target school-age audiences with the overall goal of helping the audience visualize planetary magnetic field and understand how they can impact the climatic evolution of a planet.

1. Introduction

The magnetic field of the large terrestrial planets, i.e., 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. We are developing a series of presentations that examine these differences and explain how they arose. These presentations are given on visually engaging spherical displays in conjunction with hands-on activities and scientifically accurate models of planetary magnetic fields. The overall goal of this work is to help the audience visualize planetary magnetic fields and understand how they can impact climatic evolution.

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Our collaborators include science and education professionals from the Space Sciences Laboratory (SSL), the Center for Science Education (CSE@SSL), and the Lawrence Hall of Science (LHS) at the University of California, Berkeley, and from the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado in Boulder.

Below, we will briefly describe our three presentations, emphasizing the third and final presentation, our related activities, and our future plans

2. Presentations

2.1. Goldilocks and the Three Planets

Our first presentation, entitled “Goldilocks and the Three Planets,” is targeted to an elementary school age audience. This presentation focuses on the differences in the atmospheres of Venus, Earth, and Mars, and why, of the three, only Earth currently supports life. The presentation stresses the role of liquid water. Water plays the role of Goldilocks in the familiar story of Goldilocks and the Three Bears: Venus is too hot, Mars is too cold, but Earth is just right for liquid water to exist. Liquid water removed much of the carbon dioxide from Earth’s early Venus-like atmosphere; it is the presence and stability of liquid water that made Earth habitable. The carbon dioxide removed from the atmosphere by liquid water went into carbonate rocks found on Earth’s surface.

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 where it still is today.

2.2. Lost on Mars (and Venus)

Our second presentation, entitled “Lost on Mars (and Venus),” is targeted to a middle school age audience. This presentation focuses on differences in the magnetic fields of Venus, Earth, and Mars. These differences are illustrated by “global compass maps.” Examples of these maps are shown in Figure 1. These maps show the direction a compass would point on the surface of the planet and the color of the arrows represents the strength of the magnetic field. In this format, it is very easy to see the differences between the magnetic fields of the planets. At Earth, all of the compass arrows point north and, since the field strength doesn’t change significantly over the surface (by a factor of two between the pole and equator), the colors are similar. At Mars, the compass arrows point in many different directions, particularly near crustal magnetic anomalies, and there is a large variation in the magnetic field strength which is apparent as a change in color. Finally, since there is no measurable surface magnetic field at Venus, there are no arrows on the Venus map. These maps also illustrate that a compass would not help you if you were lost on Mars or Venus.

This presentation also stresses the role of interior activity and conditions of the planets in creating the different magnetic fields. Earth has a global magnetic field which is created by a planetary dynamo in the deep interior. For a planetary dynamo (and, likewise, a global magnetic field) to exist, a planet must satisfy three conditions: 1) it must have a conducting (for example, a metal) layer, 2) that conductor must be rotating, and 3) the rotating conductor must also be convecting. Earth’s magnetic field arises from a planetary dynamo operating deep inside 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 convection because it is a liquid being heating from the bottom (the inner core). Mars does not have a global magnetic field, so it does not have a working planetary dynamo. However, the magnetic field we measure at Mars comes from surface rocks that trap or remember the magnetic field from a long time ago. This tell us that Mars used to have a planetary dynamo operating in its interior that the rocks remember, but that it has since turned off (it is estimated to have turned off a few billion years ago). Mars is smaller than Earth, so its interior has cooled off faster. Its core is too cool for

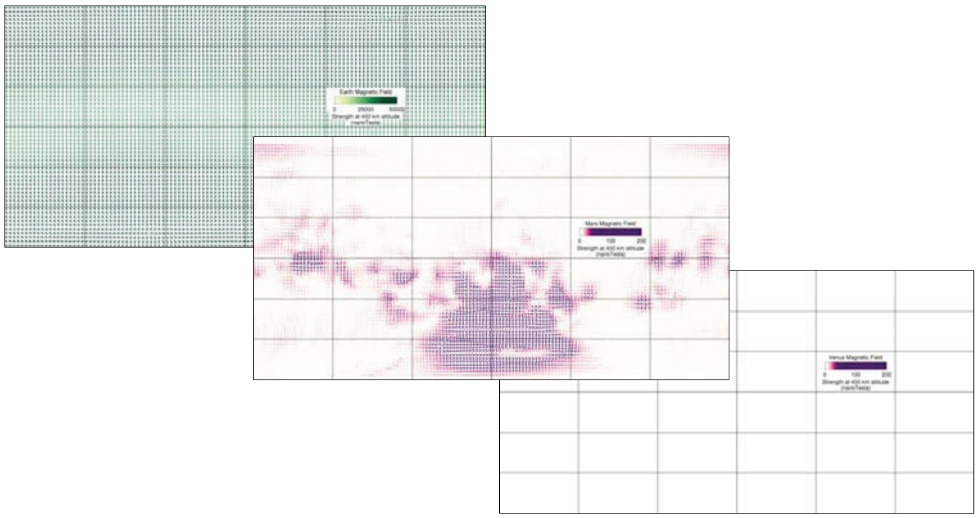

Figure 1. Examples of "global compass maps" for Earth, Mars, and Venus (from left to right).

convection to take place, so Mars no longer satisfies the third condition necessary for a planetary dynamo. Venus lacks any measurable magnetic field, so it also does not have an operating planetary dynamo. Venus does not satisfy at least one of the three conditions necessary for a planetary dynamo to exist (and recent calculations suggest that the slow rotation of Venus is NOT to blame). Since Venus is about the same size and mass as Earth, we would expect the internal conditions to be similar. Clearly they are not. 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. Additionally, the surface rocks don't appear to remember a past planetary dynamo. This is attributed to the surface being very young and covered with demagnetizing lava flows, as evidenced by its many volcanic features.

We have developed a hands-on activity to accompany this presentation. The activity is a modification of the "Terrabagga" activity.[1] Instead of giving the students an Earth-like planet for the activity, the students are given one of three types of planets: an Earth-like planet with a large bar magnet in the center, a Mars-like planet with several small magnets placed just under the surface, or a Venus-like planet with no magnet. With a small compass, their orbiting magnetometer, the students are to determine which type of planet they have.

2.3. Wet Mars, Dry Mars

Our third and final presentation, entitled "Wet Mars, Dry Mars" (which is nearly complete), is targeted to a high school age audience. This presentation focuses on the causes and effects of differences in the magnetic fields of Earth and Mars in particular. Again, we note that differences in the magnetic fields are caused by differences in internal ac-

[1]Which is described at `http://www.windows2universe.org/teacher_resources/magnetism/teach_terrabagga.html`

tivity. Differences in the magnetic field affect climatic evolution contributing to differences in the atmospheres. Based on feedback from our initial testing, the presentation stresses the complete story (at least as we think we understand it currently). There is ample evidence that Mars was once warmer and wetter with a significant atmosphere, internal activity, and a global magnetic field. As the interior of the planet cooled, internal activity slowed and eventually stopped. Volcanic activity slowed and stopped, removing a significant atmospheric source. Once the planetary dynamo turned off, the global magnetic field, which acted as a protective shield for the atmosphere, disappeared. Without its global magnetic shield, the atmosphere of Mars began to be eroded away by the solar wind. As the atmosphere was slowly eroded away, the atmosphere and surface became colder and drier until they reached the conditions we see today. This story suggests that in the absence of global magnetic fields, atmospheres can be eroded away. Earth, on the other hand, still exhibits significant internal activity, still has a global magnetic field, and still possesses a warm, wet atmosphere. This contrast suggests that global planetary magnetic fields can protect atmospheres. An important message of this presentation is that planetary magnetic fields are important for long tern atmospheric evolution.

All of these presentations have been designed to be given on spherical displays. We tested and evaluated the first two presentations on the six-foot diameter Science on a Sphere® at the Lawrence Hall of Science in Berkeley, California. We have also given these presentations (or slight variants thereof) using a portable, table top spherical display system (the Magic Planet® portable digital video globe from Global Imagination®) at different venues including schools and science centers.

3. Future Work and Related Activities

In addition to the series of presentations, we are creating scientifically accurate models of the magnetic fields of Venus, Earth, and Mars. These models will augment the presentations. Recently we finished construction of the 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). The photographs in Figure 2 show 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 two feet.

Currently the model of Earth's magnetic field is in progress, and the model of the magnetic field of Venus is forthcoming.

The next steps we plan to take in this project include finishing, testing, and evaluating our third presentation. We are in the final stages of developing graphics illustrating the evolution of the surface and interior of Mars for the spherical display systems. Once this is done, our final presentation will be ready for evaluation.

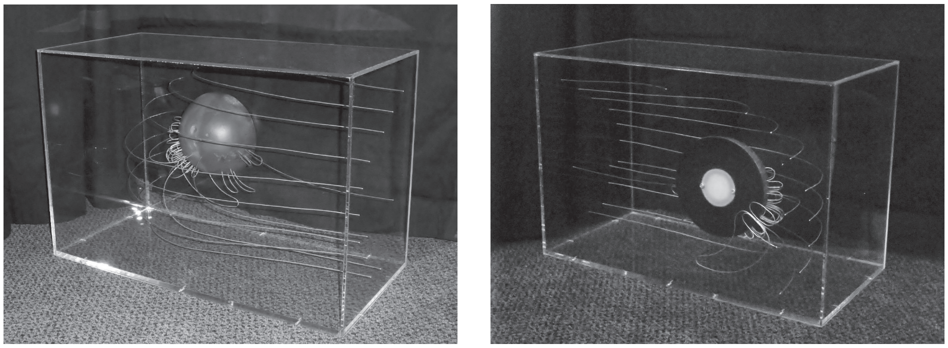

Figure 2. Photographs of the front (left) and back (right) of our 3-D wire model of the magnetic field of Mars

A final product of this work may be printed supplemental material or handouts succinctly showing the differences in the magnetic fields of Venus, Earth, and Mars. One possible example would be lenticular cards to show the global compass maps of Venus, Earth, and Mars (similar to Figure 1) for a direct comparison of the three.

Finally, although this project is schedules to end very soon, the presentations, activities, and products are anticipated to continue as we explore and cultivate synergies with the upcoming MAVEN mission EPO efforts occurring at both SSL and LASP.

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