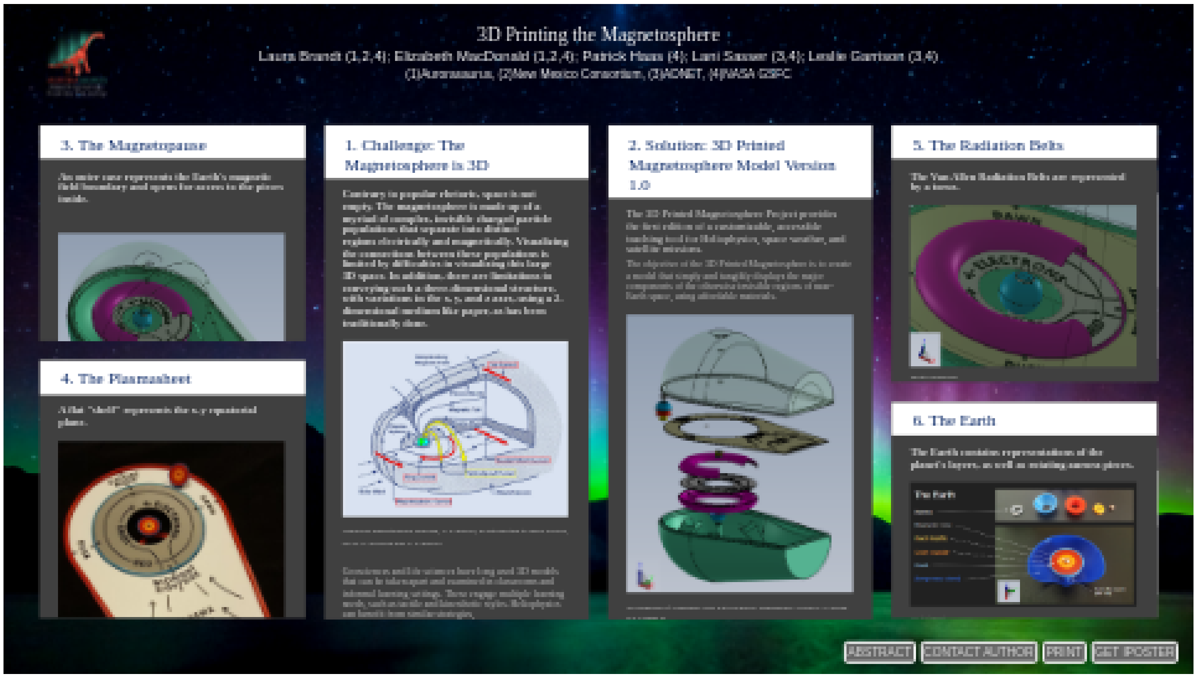
3D Printing the Magnetosphere



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(1)Aurorasaurus, (2)New Mexico Consortium, (3)ADNET, (4)NASA GSFC

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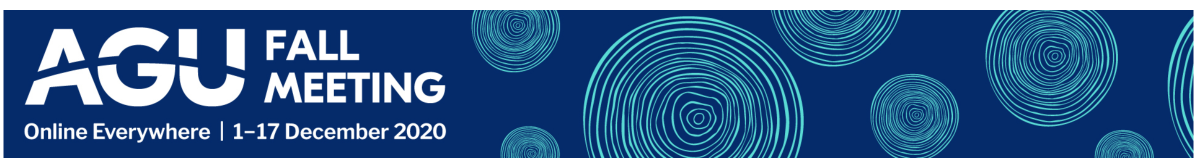
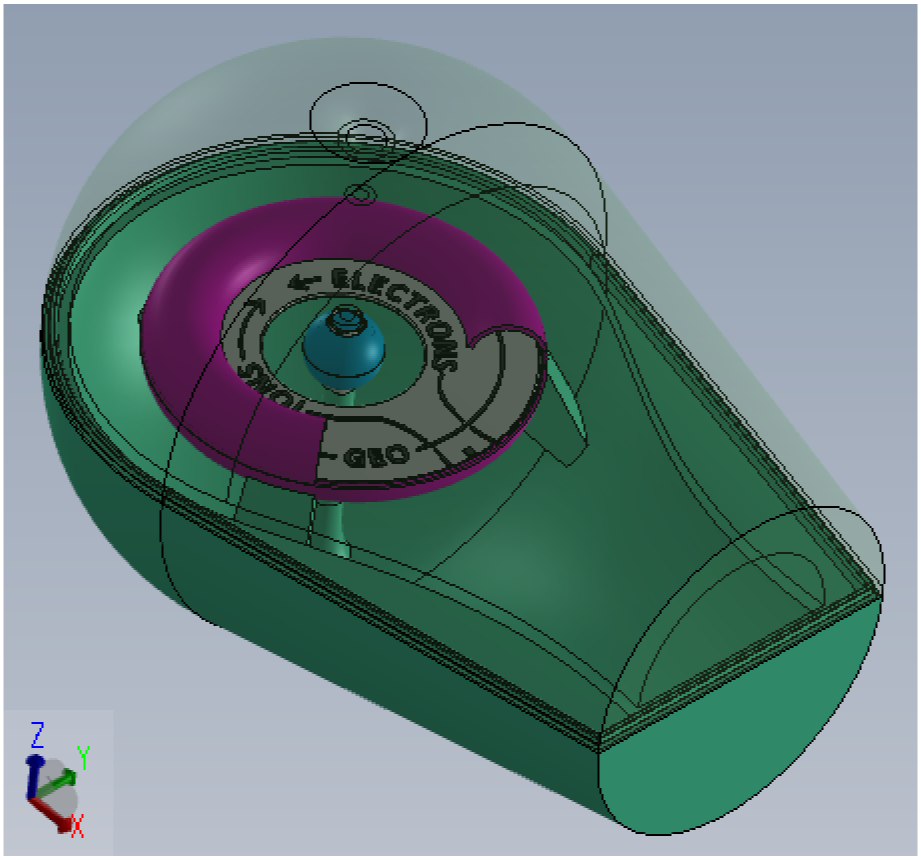


3. THE MAGNETOPAUSE

An outer case represents the Earth's magnetic field boundary and opens for access to the pieces inside.



Digital rendering with transparent magnetopause upper half

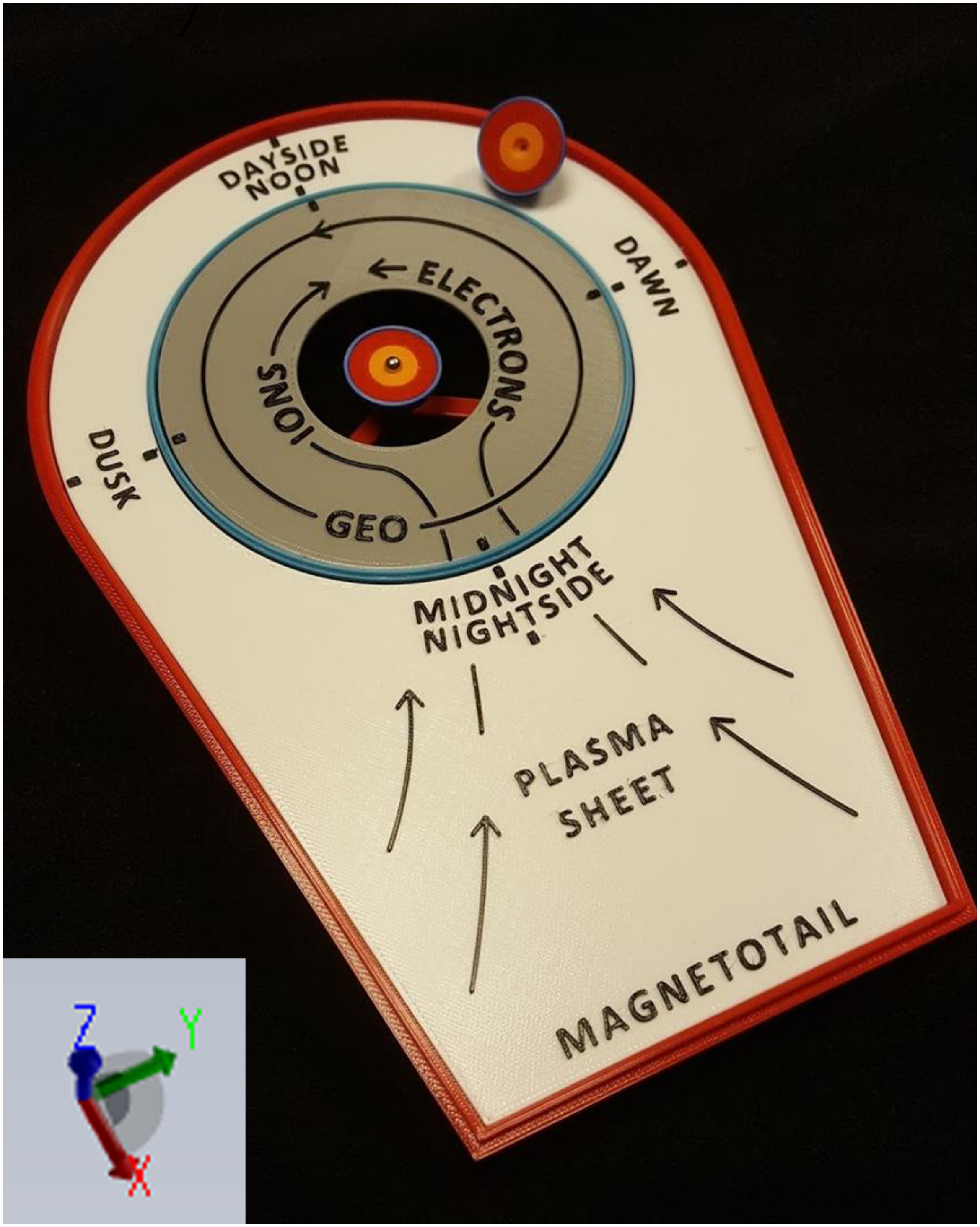
The **magnetopause** is the boundary between the Earth's magnetic field and particles that stream out from the Sun. It changes size and shape depending on the strength of that outflow, but is always rounded on the sunward side of Earth and is stretched into a long **magnetotail** away from the Sun. The shape is roughly similar to a tadpole. Our model truncates the magnetotail to allow for greater printability and detail in the interior structures.

Because the Earth's magnetic field is similar to a dipole magnet and contains funnel-like "cusps" at the poles, there are divots in the magnetopause model above the Earth's magnetic poles. Future editions will add more realism to these structures.

On the model, the magnetopause piece acts as a case which opens along the x axis to provide access to the elements it contains. Its interior is contoured to represent magnetic fields and particle flow in the magnetotail.

4. THE PLASMASHEET

A flat "shelf" represents the x-y equatorial plane.



3D test print

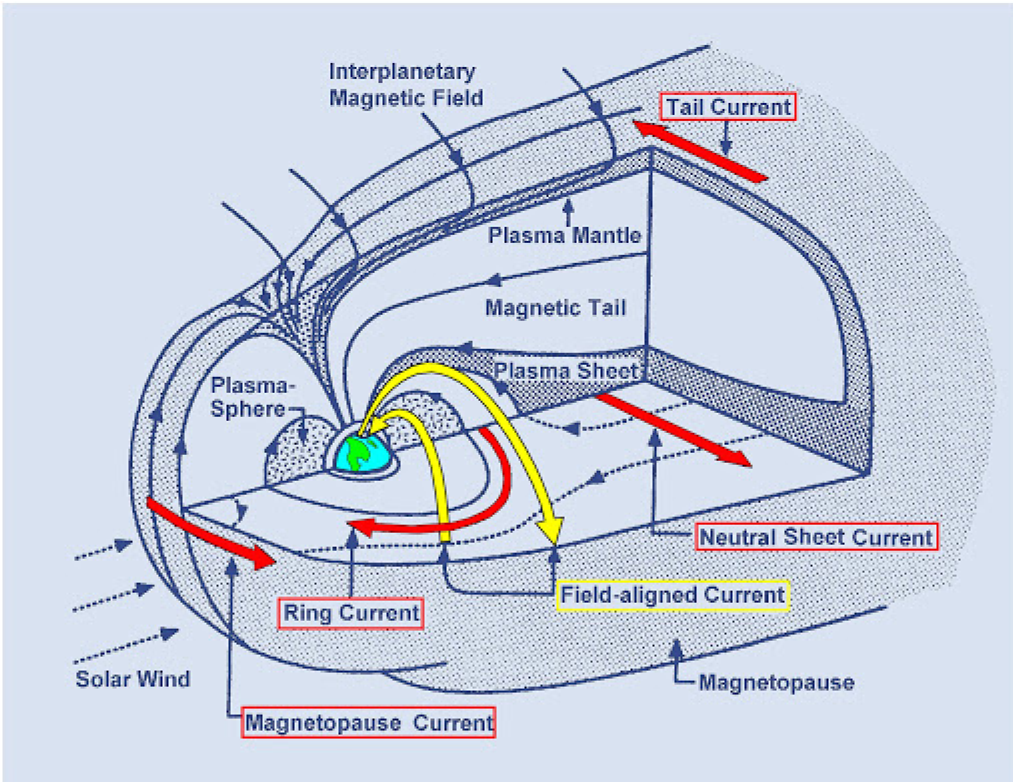
The **plasmasheet** is a flattish equatorial plane of denser plasma and weaker magnetic field. Plasma from the dayside is convected to the nightside and stored in the stretching magnetotail. When it comes back to Earth negative electrons and positive ions follow different drift paths due to their differing electric charge.

On the model, a shelf representing the plasmasheet equatorial plane (cream) is labeled with important structures and concepts, including the flow of plasma and directions relative to the Sun. This piece surrounds and connects with the inner ring current (brown).

We anticipate working with NASA Space Science Education Consortium DEIA partners and the Maker community to add texturing for accessibility to this and other structures.

1. CHALLENGE: THE MAGNETOSPHERE IS 3D

Contrary to popular rhetoric, space is not empty. The magnetosphere is made up of a myriad of complex, invisible charged particle populations that separate into distinct regions electrically and magnetically. Visualizing the connections between these populations is limited by difficulties in visualizing this large 3D space. In addition, there are limitations to conveying such a three-dimensional structure, with variations in the x, y, and z axes, using a 2-dimensional medium like paper, as has been traditionally done.



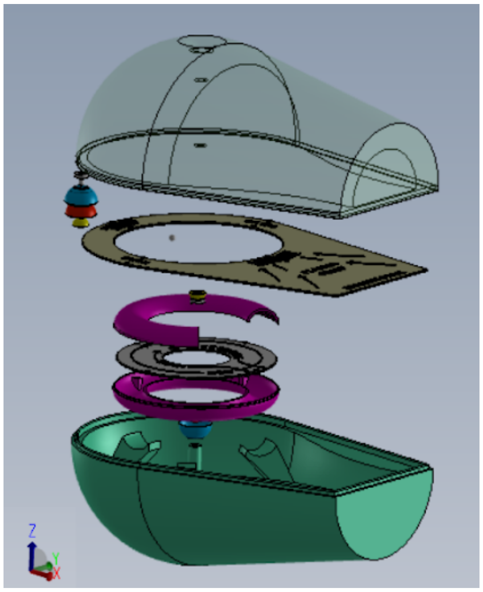
Canonical magnetosphere diagram, C. T. Russell, in Introduction to Space Physics, ed. M. G. Kivelson and C. T. Russell

Geosciences and life sciences have long used 3D models that can be taken apart and examined in classrooms and informal learning settings. These engage multiple learning needs, such as tactile and kinesthetic styles. Heliophysics can benefit from similar strategies, and employ the new accessible technology of 3d printing to create an accurate educational model.

2. SOLUTION: 3D PRINTED MAGNETOSPHERE MODEL VERSION 1.0

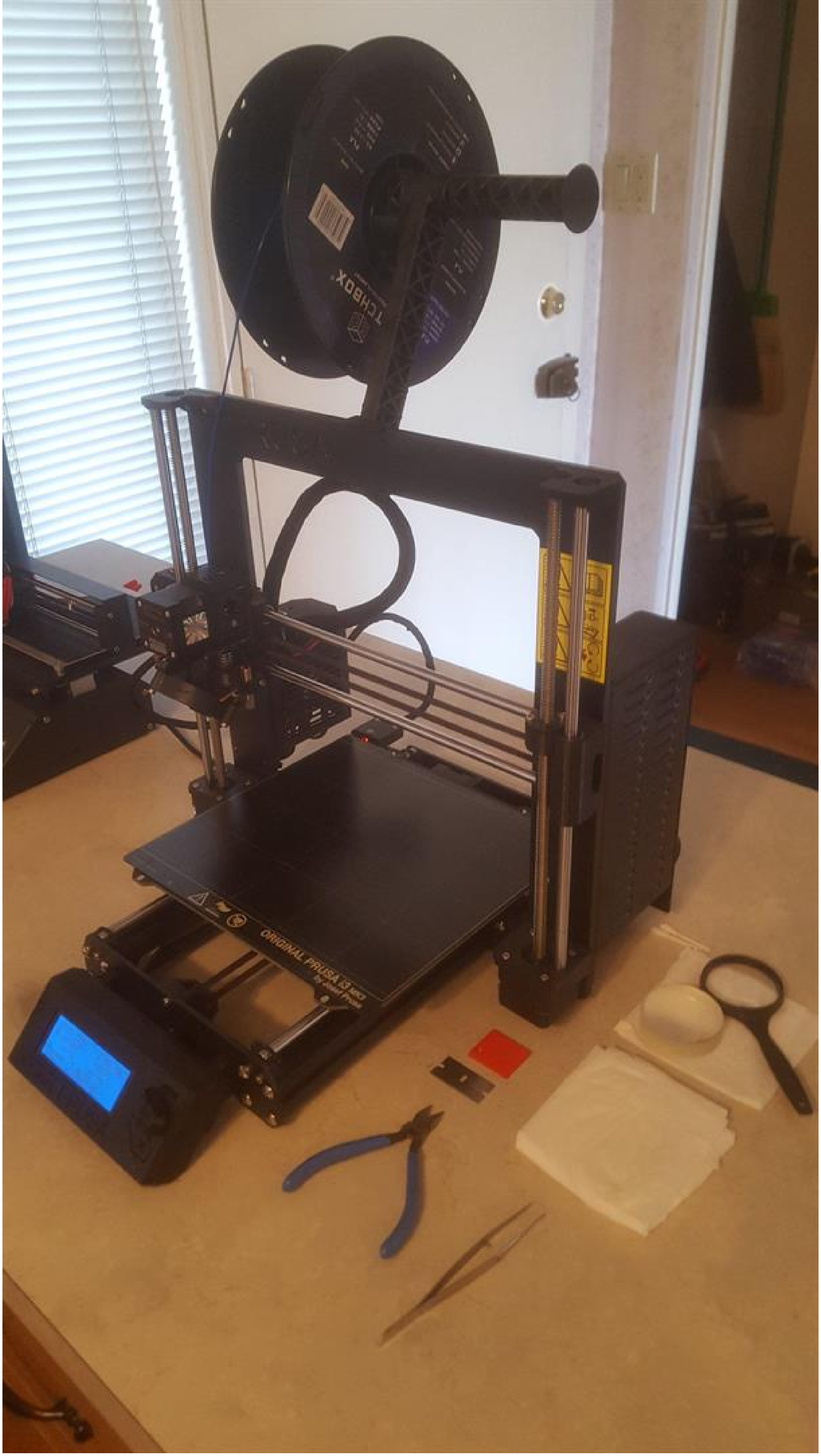
The 3D Printed Magnetosphere Project provides the first edition of a customizable, accessible teaching tool for Heliophysics, space weather, and satellite missions.

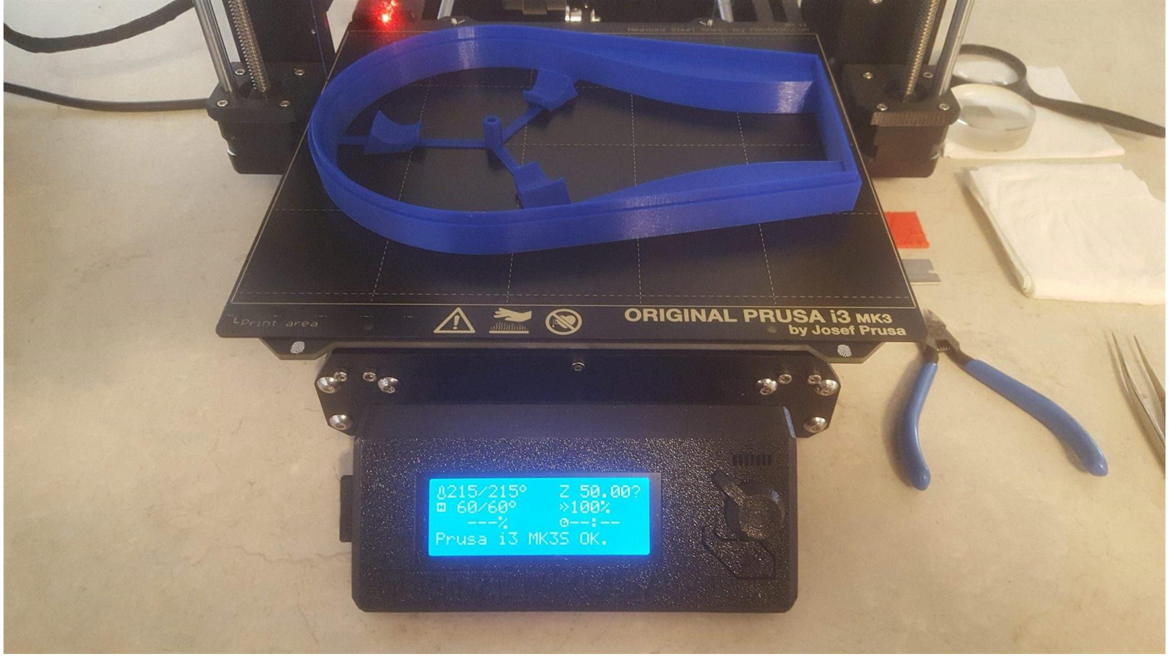
The objective of the 3D Printed Magnetosphere is to create a model that simply and tangibly displays the major components of the otherwise invisible regions of near-Earth space, using affordable materials.



3D rendering of "exploded" view with all pieces. Dimensions: 231mm L x 155mm W x 152mm H

3D printers extrude material and build up a print layer by layer.


ORIGINAL PRUSA i3 MK3



The print was created on a Prusa i3 MK3.

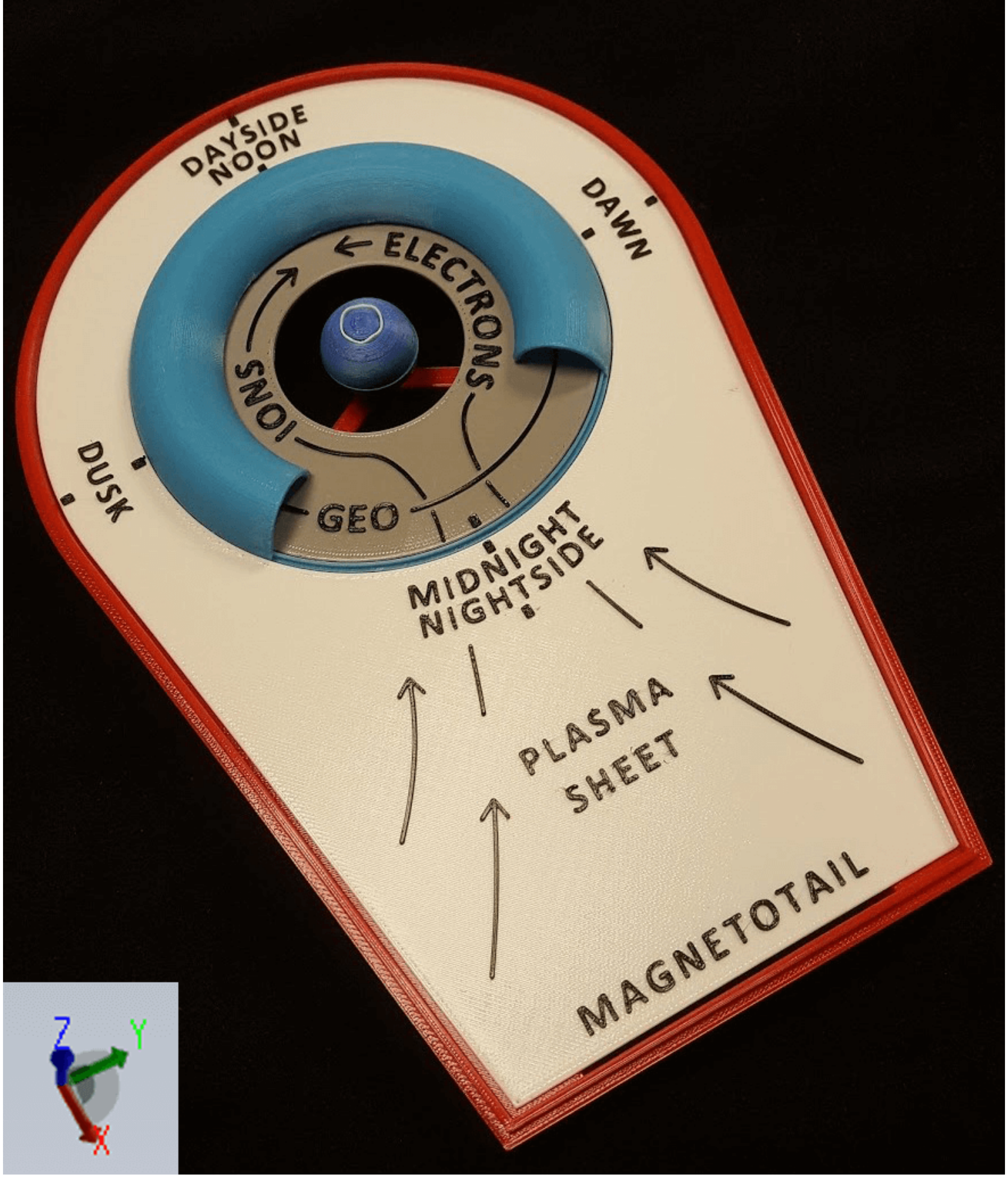
While this design appears simple, the 3D print required innovation to meet challenges, which included:

- Scaling for the model required some compromises. Maximum size is limited by 3D printer beds, while minimum size is limited by printability. It was a priority for this model to be accessible to a range of printers, and parts were sized with this in mind. Most importantly, the long magnetotail was cut off to allow for this. The largest pieces of the model require a printer that has print volume of 240mm x 200mm and at least 80mm high, with 0.2mm layer (z resolution) minimum, and heated print bed preferable.

- The shapes of the magnetosphere are "non-prismatic geometry," comprising asymmetrical curves and solids. These pose challenges for current 3D printing technology. We plan to refine these shapes in the next version, so that they more closely represent snapshots of magnetospheric structures. Modern 3d printing design allows new design tools to carve out space in a totally different way than traditional metal milling methods, thus the CAD (computer-aided-drawing) design tools are freer as well.

- This project requires a large number of parts (16+) that must fit into one another with fairly tight tolerances. Lead Designer Patrick Haas has created novel, printable interfaces and geometries, and done test prints to ensure successful prints for the Maker audience. To keep the parts looking smooth on the critical inside and outside surface, both the top and bottom curved magnetopause pieces are designed to be printed in place.

- Due to safety, cost efficiency, and ease of use, the model is designed to be printed using PLA material. However, PLA is brittle and does not stand up to high stress. In the next version, we will include a printable hinge mechanism that would prove sturdy enough for classroom use.



3D test print

3D printing provides customizability options that allow makers to tailor the model to specific lessons and expand upon the basic template presented here. 3D printers are commonplace in many schools, libraries, and other public institutions, and free software options provide low-cost methods for obtaining and editing this magnetosphere model.

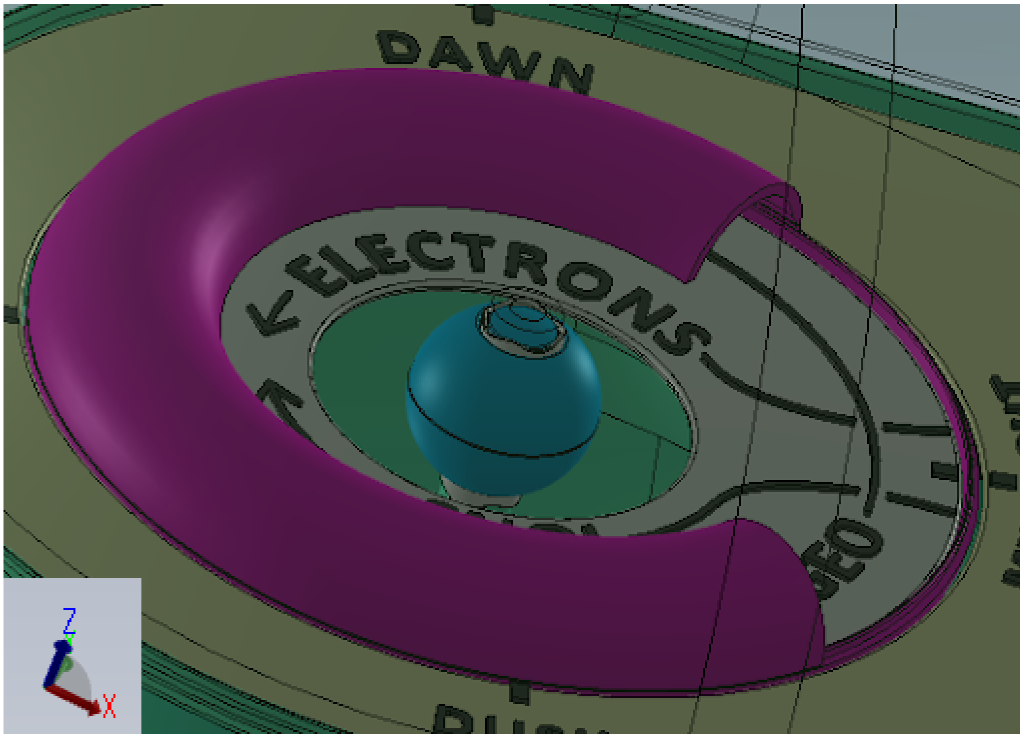
Version 1.0 of the model will be released as open source files for crowdsourced upgrades, remixing, and beta testing as well as posting on major platforms and distribution through the NASA STEAM Innovation Lab (http://www.steminnovationlab.org/) and NSSEC partners.

Sign up here (https://forms.gle/JcNnMi11NpK6SM4m6) to receive a link to the files as soon as they are published.

Be sure to check out the STEAM Innovation Lab's other poster: "NASA STEAM Innovation Lab ED TECH Showcase - Explore, Create, Share! (https://agu.confex.com/agu/fm20/meetingapp.cgi/Paper/764203)"

5. THE RADIATION BELTS

The Van Allen Radiation Belts are represented by a torus.



Digital rendering

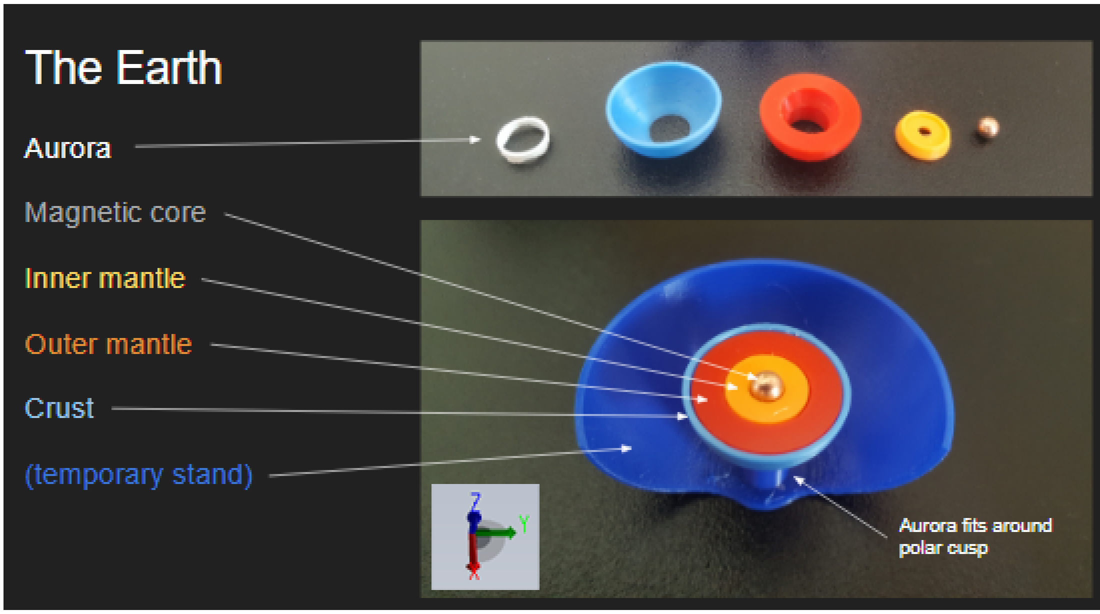
The Van Allen Radiation Belts (https://youtu.be/iujKSv9XOYE) are dynamic areas of charged particles that surround the Earth. The Outer Radiation Belt is represented in the model by a torus containing a cross-section in magenta.

The Radiation Belts are zones created by charged particles that become trapped in the Earth's magnetosphere.

The Radiation Belts can damage satellites in geosynchronous orbit (marked GEO on the model) and present radiation hazards to astronauts. Their intensities are affected by solar geomagnetic storms. In order to learn more about them, the NASA Van Allen Probes Mission studied these regions using satellites from 2012-2019.

6. THE EARTH

The Earth contains representations of the planet's layers, as well as rotating aurora pieces.



3D test print

The Earth is represented not just by a sphere, but as a dynamic, complex element with removable layers that represent the crust, outer mantle, inner mantle, and core. Convection in the mantle layers generates the Earth's magnetic field or **magnetosphere** by an internal dynamo. The Earth's core is designed to fit a 4mm ball magnet, giving educators the additional option to use this model in illustrating magnetic fields using iron filings or other materials.

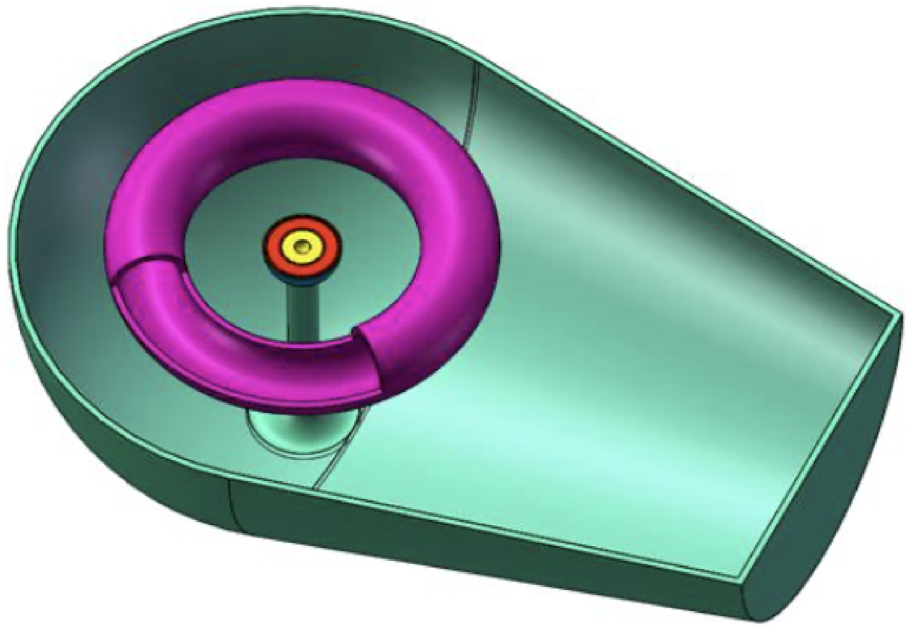
Representations of the auroral ovals fit around the northern and southern magnetic poles at the cusp insertion points discussed in Element 1. Since the Earth rotates underneath the auroral oval, the aurora piece is able to rotate separately. This configuration demonstrates that auroras are visual manifestations of the processes in the Earth's magenetic field, and provide educators with opportunities to draw parallels between the model and other experiential resources such as animations.

ABSTRACT

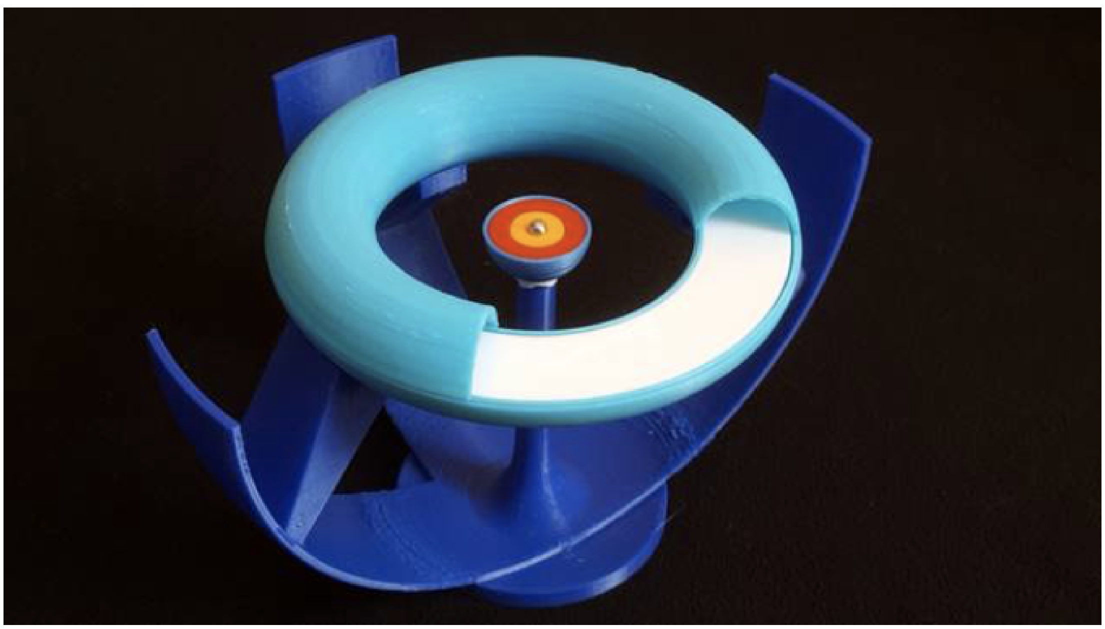
The 3D Printed Magnetosphere Project is a collaboration between Aurorasaurus and the NASA STEAM Innovation Lab, both partners of the NASA Space Science Education Consortium (NSSEC). The Earth's magnetosphere is a complex, multifaceted, and intangible system that poses unique challenges to science communication and education. Two-dimensional diagrams inherently oversimplify its structure and processes, leading to misunderstood or incomplete understandings of the physics involved. In addition, diagrams lack tactile accessibility, excluding some learners. While three-dimensional tactile models with nested components are classic tools for illustrating biological and geophysical concepts, similar models have not yet been created for the magnetosphere.

This project is an effort to create the first physical, open-source, customizable, three-dimensional, and 3D-printed model of the magnetosphere. We provide a NASA STEAM Lab Exploration Idea Profile detailing the current scope and future potential for the product. Our preliminary model is intended to provide a starting template that illustrates the following basic structures: the magnetosheath; an equatorial cross-section; a torus representing the outer radiation belt; the ring current; and Earth, including the crust, mantles, core, and aurora. The magnetosheath will be hinged and open on the x-axis like a case or shell, revealing the other structures nested inside. The components will be removable, and the radiation belt and Earth will have the capability of opening to reveal interior structures. The printable model will be shared with the Maker community, enabling customization to illustrate specific concepts, add classroom features, and provide tactile accessibility for learners with low vision. In addition, crowdsourced expertise from the space physics and Maker communities will contribute greatly to further refinements. This presentation will provide an overview of the model and explore its potential applications. These could include better contextualizing not only physics concepts, but missions like the NASA Magnetospheric Multiscale Mission (MMS) launched in 2015 to study the Earth's magnetosphere, using four identical spacecraft flying in a tetrahedral

formation. It is currently exploring magnetic reconnection, one of the mechanisms that causes aurora.



Preliminary rough sketch of model. Design by James Patrick Haas.



Earth and Outer Radiation Belt torus preliminary components in temporary frame. Design by James Patrick Haas.

(https://agu.confex.com/data/abstract/agu/fm20/0/5/Paper_683850_abstract_653171_0.png)