Printing Instructions

Introduction

The 3D Printed Magnetosphere Model was created by citizen science project Aurorasaurus in collaboration with NASA's STEAM Innovation Lab and the Magnetosphere Multiscale Mission (MMS). This Version 1.0 is an intermediate-level print project intended to be expanded upon by Makers, educators, subject matter experts (SMEs), and the general public. You can read more on the Aurorasaurus blog. A list of resources geared toward educators is provided here. **Safety note: This model contains small pieces and may contain neodymium magnets. Use caution with younger learners.**

Summary

The complete model requires a total of 14 different 3D-printed parts, plus an optional display stand and assembly alignment tool. There are also two magnetic non-printed parts: the Earth Core and Upper Magnetic Pole. Dimensions with all pieces assembled are 231mm long x 155mm wide x 152mm high. All pieces have been designed and tested for fit and printability by a NASA engineer. On-demand printing of the model costs approximately $350+, but we provide instructions below to print yourself.

Materials

- **3D Printer**
  The designer used a Prusa i3 MK3S.
  - Print Bed volume of 240mm x 200mm and 80mm high
  - 0.2mm layer height ("z resolution") minimum
  - Heated print bed preferable (60°C)
- **Filament**
  Amounts may vary slightly by printer, be sure you have enough for the larger parts. Colors the designer used are in parentheses, but you can choose your own. For safety, cost efficiency, and ease of use, the model is designed to be printed using standard 1.75 mm PLA material. Results may vary if using other materials.
  - Magnetosphere_Upper_Half: 355g (blue)
  - Magnetosphere_Lower_Half: 295g (blue)
  - Plasma_Sheet: 30g (white) plus 1g optional (black) to emphasize text
  - Radiation_Belt_Upper_Half and Radiation_Belt_Lower_Half: 35g total (turquoise)
  - Ring_Current: 12g (grey) plus 1g optional (black) to emphasize text
  - 2 Aurora pieces: less than 1g (white)

- ○ Crust_Upper_Half and Crust_Lower_Half: 3g total (light blue)
  - ○ Mantle_Upper_Half and Mantle_Lower_Half: 3g (red)
  - ○ Outer_Core_Upper_Half and Outer_Core_Lower_Half: 1g total (orange)
  - ○ Stand_Rotatable: 80g (black)
  - ○ Guide_Tool: 1g (any color)
- **Non-Printed Magnetic Pieces**
  Using magnetic materials for these pieces allows the assembled Upper and Lower halves of the Earth to stick together firmly (See: Assembly Section).
  - ○ **Earth Core**
    - ■ Can be a spherical magnet (low-cost options can be purchased online using the search terms: "4mm magnetic sphere 5/32") or a 4mm (5/32") bead or ball bearing.
  - ○ **Upper Magnetic Pole**
    - ■ Can be a cylindrical magnet (low-cost options can be purchased online using search terms: 4mm x 3mm cylinder magnet).
- **Optional Tools**
  - ○ File
  - ○ Sandpaper
  - ○ Penknife
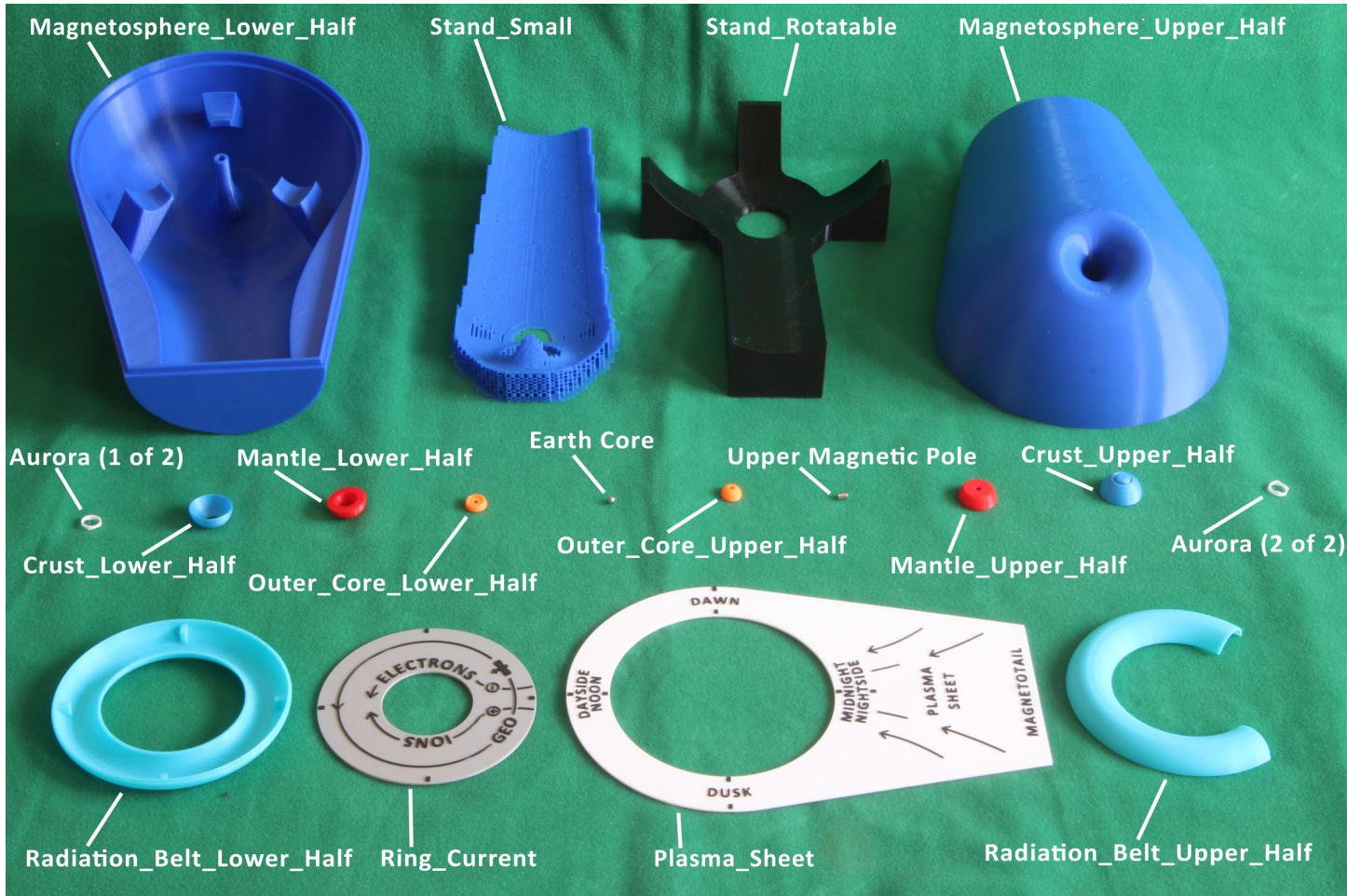 - ○ Magnetic compass
  - ○ Bar magnet with labeled poles

General Setting Recommendations

All parts were designed in Solidworks and successfully printed using the following settings, unless otherwise noted in the "Individual Piece Setting Recommendations" section.
- No rafts, brim, or supports
- 0.2mm layers
- 15% infill
- Heated bed (60°C)
- Best results are achieved when parts are printed in the orientation as saved in the STL files.
- (Optional) If your software contains a setting like "Horizontal Shells", set fields to "2 perimeter".
- (Optional) If your software contains a setting like "Top Shell", "Bottom Shell", set fields to 3 top and bottom shells.

As printer settings may vary, you may need to experiment with Process settings to achieve best results. Examples of settings to experiment with include "detect thin walls" and "ensure vertical shell thickness" for small and/or thin parts such as Earth's Crust and Aurora. This will help configure the file to your individual printer.

Parts

Parts of the 3D Printed Magnetosphere Model, not yet assembled. Note that all parts are shown in their print orientation.

Printed Piece Setting Recommendations

- **Magnetosphere_Lower_Half** and **Magnetosphere_Upper_Half** and **Stand_Rotatable** - add support with angles greater than 40° from horizontal, and if your software contains a setting like "horizontal shells", "Top Shell", "Bottom Shell", etc set the fields to 3 vertical shells for strength. These are very large and long prints. Best results occur when a single spool is used for each. For aesthetics and functionality, the Magnetosphere_Lower_Half is designed to be printed with the curved side on the print bed, like a bowl; and Magnetosphere_Upper_Half is designed to be printed with the curved side up, like a turtle shell. The pieces should display in this orientation in the STL files.
- **Ring_Current** and **Plasma_Sheet** - For maximum text contrast, printer should be paused at or above 1.6mm and filament color changed, if available. If using a single color, then raised text can be marked with roller, or by hand with marker or paint
- **Radiation_Belt_Upper_Half** - If your software contains a setting like "horizontal shells", "Top Shell", "Bottom Shell", etc set the fields to Vertical, top, and bottom shells = 2, 20% infill, add support and raft (can print upper and lower together with this setting, just more material to remove) Support should have angles greater than 40° from horizontal.
- **Radiation_Belt_Lower_Half** - If your software contains a setting like "horizontal shells", "Top Shell", "Bottom Shell", etc set the fields to Vertical, top, and bottom shells = 2, 20% infill, add support with angles greater than 40° from horizontal

- **Aurora** - Print 2 copies
- **Crust_Upper_Half** - Use perimeter shell = 1, add support with angles greater than 40° from horizontal
- **Crust_Lower_Half** - Use single perimeter "Vase" setting if available—if not, use perimeter shell=1
- **Mantle_Upper_Half** and **Mantle_Lower_Half** no specific recommendations
- **Outer_Core_Upper_Half** and **Outer_Core_Lower_Half** no specific recommendations
- **Stand_Small** - A simple stand can be created by carefully removing the support material from Magnetosphere_Lower_Half in one piece, if possible
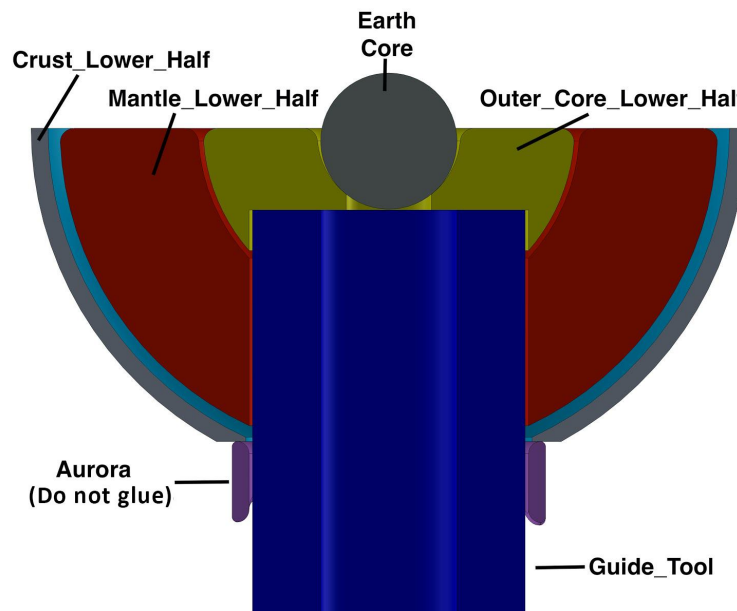
Assembly

Earth

1. We have provided a Guide Tool to make aligning and gluing together the Earth's lower half pieces easier. You can use the Upper Magnetic Pole in a similar way for the upper pieces.

Guide_Tool (left); Earth lower half pieces (center); Earth upper half pieces (right).
Auroras are pictured for reference but should **not** be glued into the assembly.

Place the Crust_Lower_Half piece onto the Guide_Tool as shown below. Add the Mantle_Lower_Half and Outer_Core_Lower_Half pieces, as shown in the diagram. The Guide_Tool should ensure they are aligned.
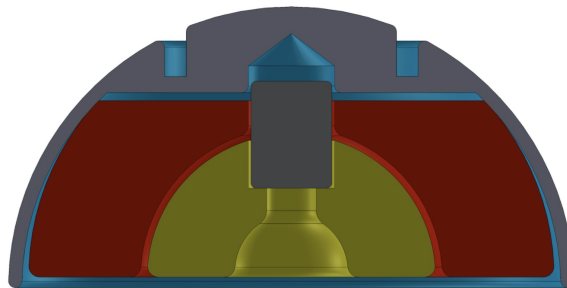

Rendered cross-section of Earth lower half assembly with Guide_Tool inserted.
Aurora is pictured for reference but should **not** be glued into the assembly.

Carefully remove each layer of the Earth and add a tiny amount of gel superglue (cyanoacrylate). Make sure that the Crust_Lower_Half is glued to the Mantle_Lower_Half, and the Mantle_Lower_Half is glued to the Outer_Core_Lower_Half. Be sure that the Guide_Tool is **not** glued into the assembly. Press the layers together for a few seconds to set, then remove the Guide_Tool.

Glue Earth Core into center mounting hole. As the mounting hole is a very small feature, you might have to trim and/or enlarge its mounting hole, depending on your printer. If so, remove just enough material around the edges and/or inside the hole so the sphere sits halfway in. Set aside to dry.

Since it is a cylinder that inserts through multiple parts, you can use the Upper Magnetic Pole in a similar way to align and glue the upper pieces (Crust_Upper_Half, Mantle_Upper_Half, and Outer_Core_Upper_Half). However, the Upper Magnetic Pole **should** be glued into the assembly as pictured below. Set aside to dry.

CAD cross-sections showing the Earth's upper half (Crust_Upper_Half, Mantle_Upper_Half, Outer_Core_Upper_Half, and Upper Magnetic Pole pieces).

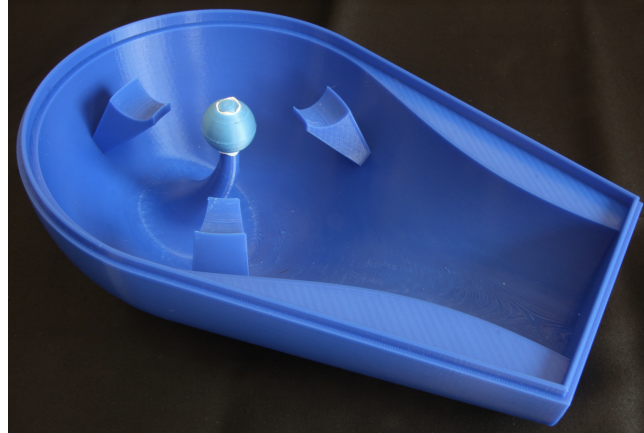**NOTE:** Make sure the magnets are aligned to attract each other.

Earth lower (left) and upper (right) halves, assembled.

2. **Do not** glue the Aurora pieces onto the poles; they are meant to be movable and removable. The lower Aurora piece should fit with a bit of friction over the polar cusp of the Magnetosphere_Lower_Half. The polar cusp is the funnel-like part of the Earth's magnetic field that curves into the Earth's magnetic pole. The aurora piece can be pushed down when you mount the Earth lower half. If the Aurora is too loose, add some clear tape to the insides and slip it up towards the bottom of the Earth. The upper Aurora piece should drop down into the slot on the top of the upper half Earth assembly. If too tight, try to remove any burrs or thin out the bottom with a precision knife or file/sandpaper.

Aurora pieces (left); Aurora pieces fitted into Earth assembly (right).

Auroras and Earth assembly fitted onto polar cusp of Magnetosphere Lower Half. Note: the three parts that angle in from the sides are supports for other pieces of the model and are **not** magnetospheric structures.
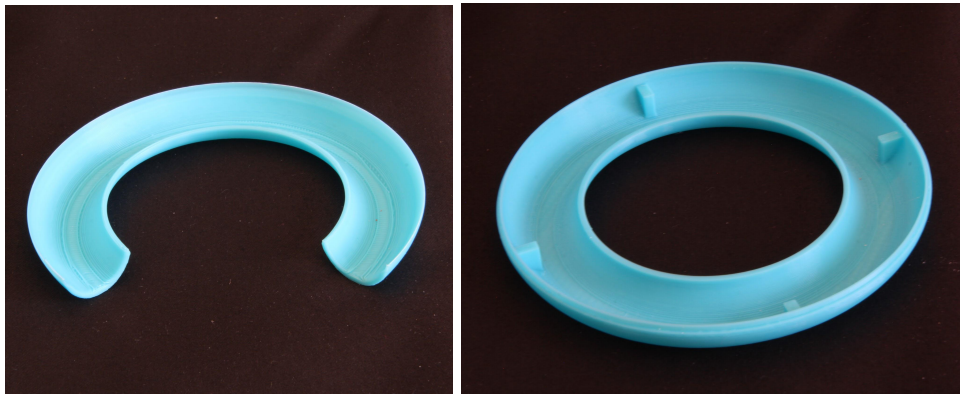
Radiation Belt and Ring Current

3. The Ring Current should drop freely into the Radiation Belt Lower half and be able to rotate. Its proper arrangement is as shown in the figure. If not, try cleaning and/or trimming its outer edge. Place the Radiation Belt Upper Half back onto the assembly.
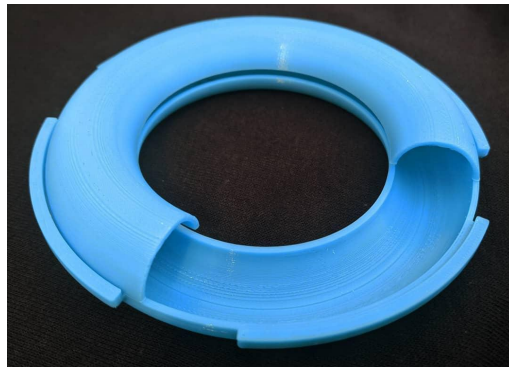

Upper and lower halves of Radiation Belt with Ring Current.

4. The upper and lower halves of the Radiation Belts should fit easily and be just loose enough to rotate. If not, you may have to adjust your printer settings or remove burrs and material at the interface areas.

Upper (left, pictured upside down) and lower (right) halves of the Radiation Belt.

We also have a version of these with looser tolerances that would be better for printers with less precision (below). The files are Radiation_Belt_Upper_Half_V2 and Radiation_Belt_Lower_Half_V2.

Optional alternate version of Radiation Belt, with halves assembled. The lower half rests on top of the Plasma_Sheet piece, with the tabs enabling it to be suspended.

Magnetopause

5. The Magnetosphere halves should friction fit together with some force—this is by design. If you want them to be looser, you can adjust the friction by filing down some or all the friction ribs located on the inside of the mounting lip on the Magnetosphere_Upper_Half. Do a little at a time, since adding them back is much harder if you take off too much. Also, note that over time they should naturally become looser and the fit may vary by temperature and filament type.

Magnetosphere_Lower_Half (left) and Magnetosphere_Upper_Half (right). Magnetosphere_Upper_Half is shown upside down for detail. Note: On Magnetosphere_Lower_Half, the three parts that angle in from the sides are supports for other pieces of the model and are **not** magnetospheric structures.

Full Assembly

6. Remove the upper Magnetosphere half and place the Plasma_Sheet piece into the assembly. Rotate the Ring_Current so that the markings match up to the Plasma_Sheet. Then, add the upper Magnetosphere half.

Plasma_Sheet inserted into assembly (left).
Magnetosphere_Upper_Half fits over full assembly (pictured with stand, right).

7. Show off your new miniature magnetosphere masterpiece! The pieces can be disassembled to emphasize different aspects, or moved/rotated to display different orientations, motion, and information.

Thank you for participating in this project!

Version 1.0 is only the start for the 3D Printed Magnetosphere Model! Check out our blog post for more ideas, and stay tuned to Aurorasaurus and NASA's STEAM Innovation Lab for future updates!

We hope that the 3D Printed Magnetosphere Model helps you share the science and wonder of our planet, and welcome feedback! How are you using your model? If you have any ideas that we could implement in future versions, please let us know by filling out this survey. If you have created an alternate or refined version, please post your make and tag us on Twitter @TweetAurora, @NASAHEAT, and hashtag #3DMagnetosphere!