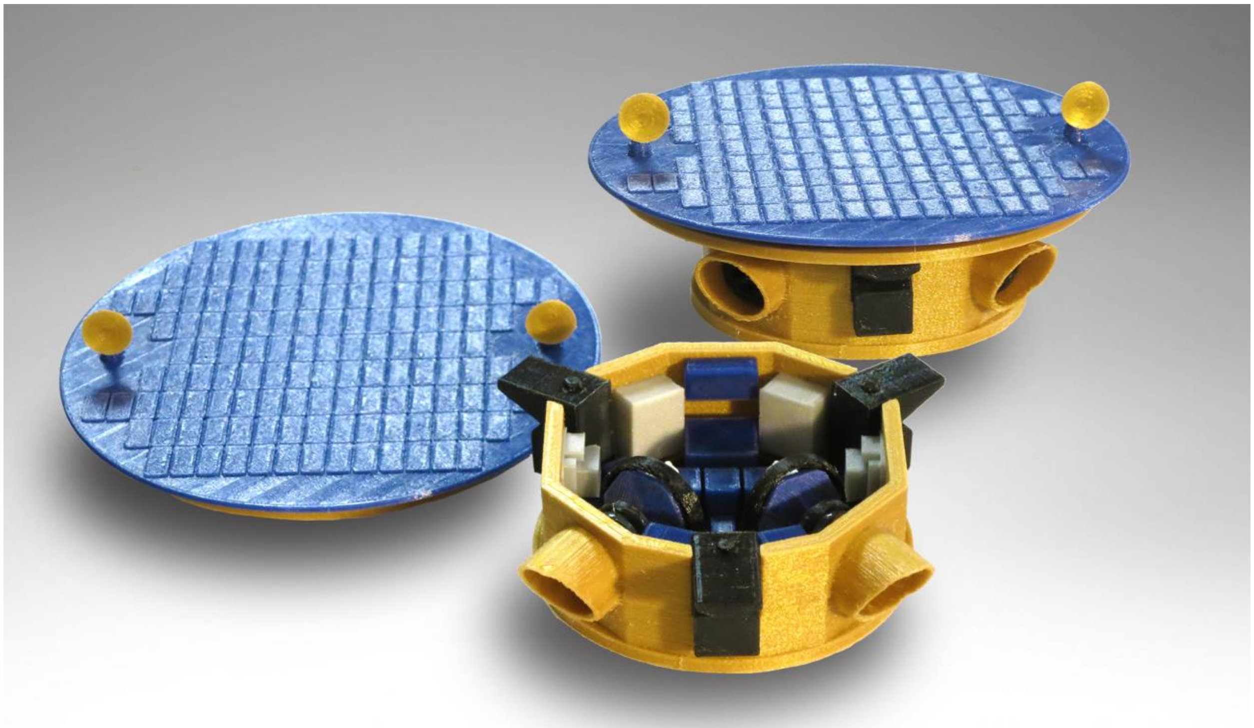
3-D Print the Laser Interferometry Space Antenna (LISA)

By Francis Reddy and Jeff Livas
Astrophysics Science Division
NASA's Goddard Space Flight Center, Greenbelt, Maryland



The LISA concept 1:20-scale model printed in PLA. The model is shown completely assembled (above) and with the top removed to reveal its internal parts.

The LISA mission is a concept for a future space-based gravitational-wave observatory now being developed. It consists of three spacecraft separated by millions of miles flying in a triangular formation that trails behind Earth as we orbit the sun. Each spacecraft transmits and receives laser beams linking it to the others, and these signals are combined to search for passing gravitational waves — ripples in space-time — as they pass through the formation.

This model is based on an early LISA concept. The design is now being refined and needed technologies are being developed, so the actual spacecraft may look quite different. NASA is a partner in the mission, which is being led by the European Space Agency. The observatory is expected to launch in the mid-2030s.

Einstein's theory of relativity predicted the existence of gravitational waves in 1915. They are produced by massive orbiting objects, like black holes and neutron stars. In 1974, Russell Hulse and Joseph Taylor Jr. at the University of Massachusetts Amherst discovered B1913+16, a neutron star that is also a pulsar, producing radio signals nearly 17 times a second.

Hulse and Taylor later found that the pulsar was orbiting another neutron star, and in 1978 they showed that the pair's orbits are shrinking, that is, the two stars are orbiting ever closer.

According to Einstein's predictions, the neutron stars lose orbital energy by producing gravitational waves. The shrinking orbits indicated that a certain amount of orbital energy was leaving the system, and it matched the amount relativity predicts should be carried away by gravitational waves. This experimental evidence for the existence of gravitational waves won the scientists the 1993 Nobel Prize in physics.

Gravitational waves were first directly detected on Sept. 14, 2015, by the ground-based Laser Interferometer Gravitational-Wave Observatory (LIGO), located in Hanford, Washington, and Livingston, Louisiana, when two black holes merged. Since then, many other events have been detected. These discoveries won the architects of LIGO the 2017 Nobel Prize in physics.

But LIGO reveals only a fraction of the waves we could observe. The gravitational-wave spectrum spans a broad range of frequencies. LIGO can detect waves between 10 and 1,000 cycles per second, or hertz. LISA will operate at a much lower frequency range, from 0.0001 to 1 hertz. This means LISA will find waves with much longer wavelengths, corresponding to objects in much wider orbits and potentially with much greater masses than those LIGO can see. This will enable detections from a broader range of gravitational-wave sources.

To find gravitational waves produced by black holes hundreds of millions of times more massive than our sun, astronomers need a giant detector much bigger than Earth. That's what LISA will provide.

Notes on the model

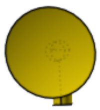
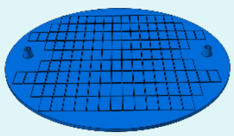
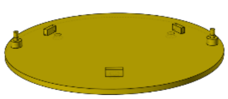
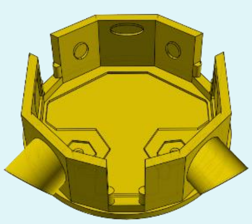
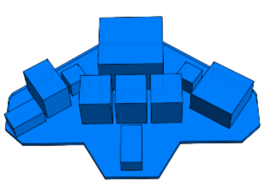
All of the parts were test printed in both ABS and PLA; in addition, the large solar panel piece was also printed in PETG, which tends to warp minimally during the printing process. ABS parts were printed on a Makerbot Replicator 2X, and a ZYYX printer was used for PLA and PETG.

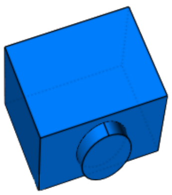
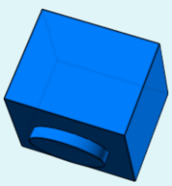
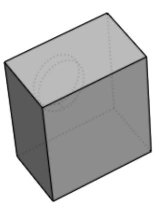
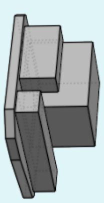
Most parts are designed to be glued together; the spacecraft top assembly, the antennas, the three thruster units and the telescope assemblies are intended to be removable. The part tolerances provide loose fits to accommodate use of either ABS or PLA; slight adjustments in scale may be necessary for the best fit, depending on printer specifics.

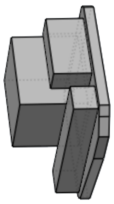
This project originated with 1:14 scale model created by Reddy for use at an exhibitor booth during scientific meetings. Our goal was to simplify that project to distribute a version that had fewer printed parts and that was small enough its solar panel could be produced on common printers without additional scaling. Summer intern Colin Yancey developed the 1:20 scale version, and the final model includes refinements by summer intern Tobias Eegholm and Reddy.

The rest of this document provides a description of the parts, tips for printing them and instructions for assembling your LISA model.

Component list

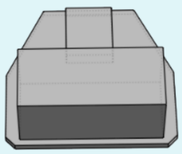
Part	Description	Printing tips
	The **High-gain Antenna** is used for communications with Earth. Its base inserts into the top of the solar panel. Part name: Satellite_dish.stl Suggested color: Gold	Two parts needed; print with support. Layer height: 0.2 mm or less
	The **Solar Panel** generates electrical power for the spacecraft. Part name: Solar_panel.stl Suggested color: Blue	Layer height: 0.25 mm or greater. Infill: 10 percent Low infill helps prevent warping during the print; adding a brim may also be needed.
	The **Spacecraft Top** provides support for the solar panel and antennas and inserts into holes beneath the solar panel. Part name: Spacecraft_top.stl Suggested color: Gold	Print with support. Layer height: 0.25 mm Infill 15 percent
	The **Spacecraft Base** is the main body of the spacecraft. Part name: Spacecraft_base.stl Suggested color: Gold	Print with support. Layer height: 0.25 mm Infill: 15 percent
	This piece combines numerous elements, including a phase meter, laser units, electronics for the caging system that secures the test masses during launch, and more. It mounts on the aft floor of the spacecraft body. Part name: Combined_bottom_boxes.stl Suggested color: Blue	Layer height: 0.25mm or lower Infill: 25 percent or lower These will be default values for the remaining parts unless otherwise noted.

	The **Charge Management System** keeps the test masses electrically neutral. It mounts on the aft wall of the spacecraft base, between the gamma-ray spectrometers. Part name: Charge_mngt_system.stl Suggested color: Blue	
	The **LISA Control Electronics** lead spacecraft operations. The unit mounts on the forward wall of the spacecraft body. Part name: LISA_control_electronics.stl Suggested color: Blue	
	The **Command and Data Handling Unit** mounts on the forward wall of the spacecraft body. Part name: Cmd_and_data_handling.stl Suggested color: Blue	
	Two **Gamma-ray Spectrometers** provide environmental monitoring. They mount on both sides of the charge management system on the aft wall of the spacecraft body. Part name: GRS_unit.stl Suggested color: Silver or gray	Two parts needed.
	The **Left Side Panel** contains a transponder and other electronics. It fits into the left side (as viewed from the telescope side) of the spacecraft body. Part name: Left_side_panel.stl Suggested color: Silver or gray	



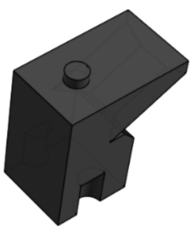
The **Right Side Panel** contains a transponder and other electronics. It mounts on the wall opposite the left unit.

Part name: Right_side_panel.stl
Suggested color: Silver or gray



This unit carries the **Power Supply Electronics** and a lithium-ion **Battery** for backup power. It mounts on the forward floor of the spacecraft.

Part name: PSE_and_battery.stl
Suggested color: Silver or gray



Micronewton **Thrusters** provide LISA with ultra-fine maneuvering capability with ultra-low noise. Each thruster slides into slots in the walls of the spacecraft.

Part name: Thruster.stl
Suggested color: Black

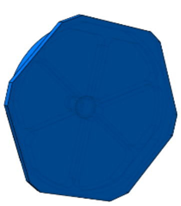
Three parts needed; print with support.

Two optical **Telescopes** are used to transmit and receive laser beams linking each of the three LISA spacecraft.

Part name: Telescope.stl
Suggested color: Black

Two parts needed; print with support.

Layer height: 0.2 mm or lower
Infill: 20 percent

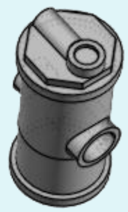


The **Optics Bench** mounts into the rear of the telescope. It enables laser interferometry to measure slight changes in the separation of test masses contained in spacecraft separated by 2.5 million km.

Part name: Optics_bench.stl
Suggested color: Blue

Two parts needed.

Layer height: 0.2 mm or lower
Infill: 15 percent



The **Gravitational Reference Sensor** is a vacuum chamber that houses a test mass shielded from all forces except gravity. This part mounts onto a pin on the rear of the optics bench.

Part name: GRS_tank.stl
Suggested color: Silver or gray

Two parts needed; print with support

Layer height: 0.2 mm
Infill: 20 percent

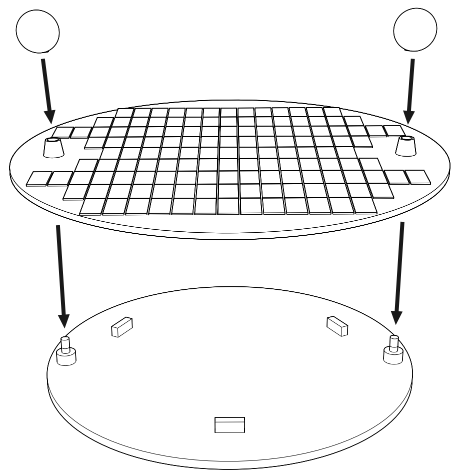
Assembling LISA

Most parts on this model should be glued together. Adhesives used for jewelry and craft projects, such as E6000 or various instant glues, work well.

1. Align pins on the **Spacecraft Top** to holes on the bottom of the **Solar Panel.**

Apply a small amount of glue to the top pins and the tops of the rectangular supports. Gently press the solar panel onto them.

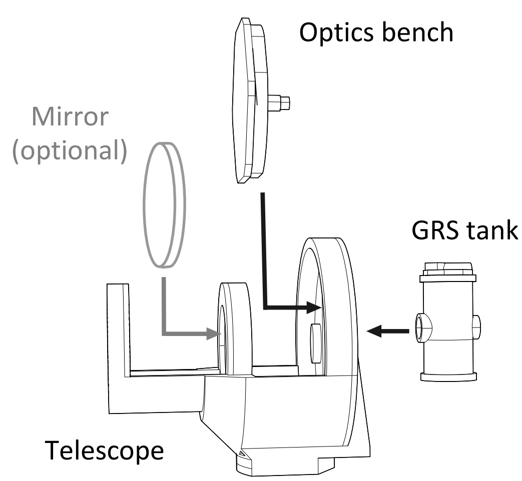
Insert the bases of the **Antennas** into holes on the top of the **Solar Panel**; it is not necessary to glue them.



2. Assemble the **Telescopes.** Apply glue to the small tabs on the inside rear of the telescope, where the **Optics Bench** mounts.

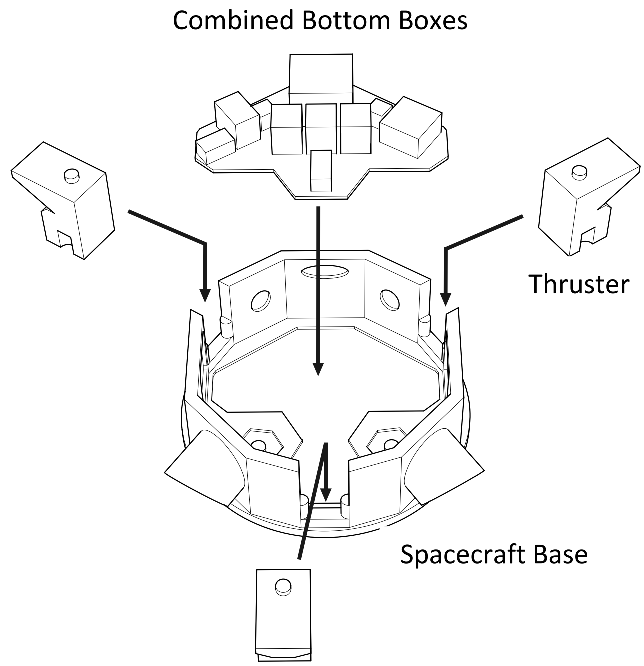
Insert the **Optics Bench** so it fits over the tabs. Let dry. Then carefully glue the **GRS Tank** onto the pin at the rear of the **Optics Bench.**

Optional: Add a mirror to each **Telescope.** Glue the back of a half-inch round craft mirror (found in hobby or craft stores) to the mirror support in the center of each **Telescope**.



3. Insert each Thruster into the side of the **Spacecraft Base** as far as it can go. **Do not glue** them in place so they can be adjusted if needed for **Step 6**.

Glue the **Combined Bottom Boxes** to the **Spacecraft Base**.

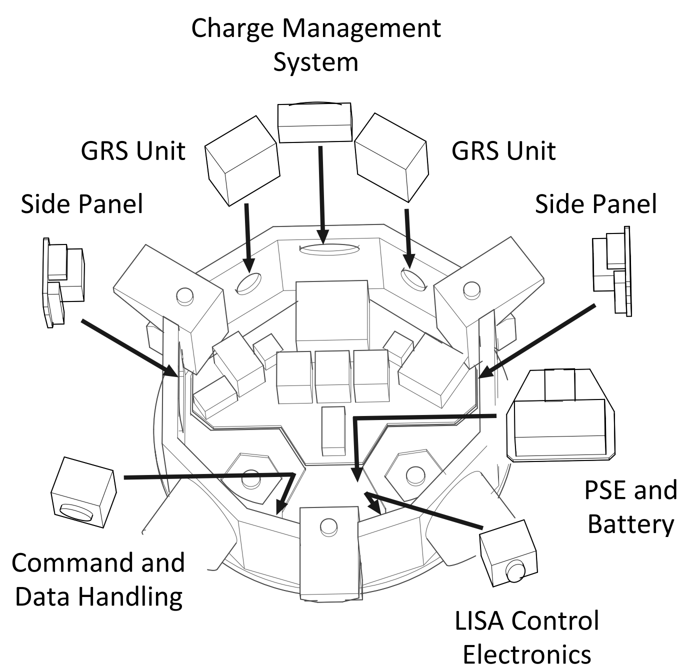


4. Glue the **Charge Management System** and **GRS Units** into matching holes on the aft interior of the **Spacecraft Base**.

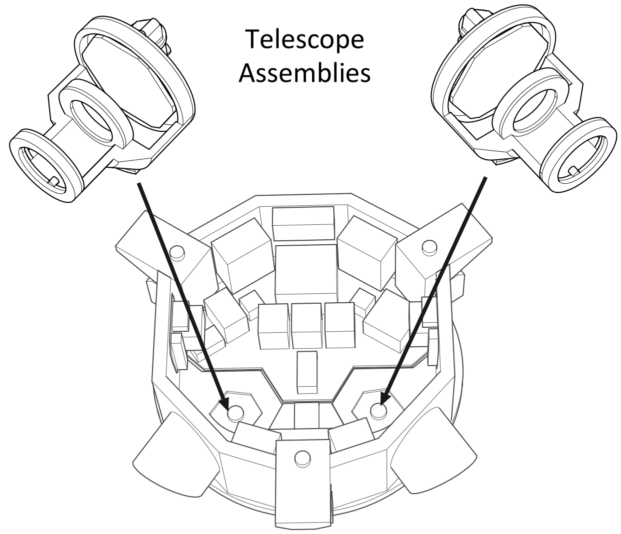
Glue the **PSE and Battery** unit to the forward floor of the **Spacecraft Base**.

Glue the **Left** and **Right Side Panels** into their locations.

Glue the **Command and Data Handling Unit** and the **LISA Control Electronics** to matching locations on the forward interior of the **Spacecraft Base**.



5. Insert both assembled **Telescopes** into the **Spacecraft Base**. They fit snugly into the base by friction, so glue is not needed.



6. Place the **Spacecraft Top Assembly** onto the assembled Spacecraft Base. Align the pin on the forward **Thruster** with the forward hole under the top. Then rotate the top so the remaining two holes align with the pins on the other thrusters. If needed, adjust the thruster positions to fine-tune the alignment.

Do not glue the top in place so it can be removed to look inside.

Your 1:20-scale LISA concept model is complete.