LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO-T1500335-v2 *LIGO* August 8, 2016

3D Printing LIGO

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1 Introduction

The purpose of this document is to present information and ideas for the 3D printing of a miniature model of the LIGO telescope.

2 What is 3D Printing?

3D printing is a process used to produce a three-dimensional object.

2.1 Types of 3D Printing

2.1.1 Chemicals

This method uses a pool of chemicals that turn solid in the presence of light.

2.1.2 Molten Ink

This method uses molten ink that becomes solid when it emerges from the printer head.

2.1.3 Continuous Liquid Interface Production (CLIP)

This method works by projecting a series of ultraviolet images through a special window located below a bath of liquid resin. The light causes the resin to harden into the projected shape; the resin solidifies just above the “dead zone” at the bottom of the container. As the printed object is lifted out of the bath, fresh resin is pulled towards the window below, making it a continuous process.

2.1.4 Polyactic Acid

This method uses a material called polyactic acid (PLA) that is loaded into the 3D printer as a spool of filament. The PLA is made from field corn, creating a sweet smell when heated. Once the spool is loaded, the filament is drawn out layer by layer starting with the outside and working inwards until the finished product is completed. PLA is around $20-30 a spool.

2.2 Process of 3D Printing

2.2.1 Virtual Design

The process of 3D printing starts with a file made with CAD, or computer aided design, software. The design is to be made using a 3D modeling program or a 3D scanner. (*Caltech uses SolidWorks 2015). Once the design is completed, the 3D modeling software “slices” the final model into hundreds or thousands of horizontal layers. The file then needs to be converted to fit the 3D printer’s requirements. Once the file is uploaded to the 3D printer, the object is created using the process of layering.

2.2.2 Layering

3D printers work like regular printers. Only instead of ink, it uses a spool of either plastic, rubber, or metal. Most printers have differing build volumes, so the length, width, and height of the object needs to be planned according to the ability of the printer. Once the dimensions are set and the PLA is loaded, a series of two-dimensional layers will print that eventually become a three-dimensional object.

3 3D Printers

3.1 Types of 3D Printers

Printer	Color	Build Size (in)	Reliability	Availability	Price*
Cube	Yes	6 x 6 x 6	Yes	Sold	$999.00
Mcor IRIS	Yes	9.39 x 6.89 x 5.9	Yes	Sold	RFQ
LulzBot TAZ 5	Yes	11.7 x. 10.8 x 9.8	Yes	Sold	$2,200.00
MakerGear M2	Yes	10 x 7.99 x 7.99	Yes	Sold	$1,775.00
Makerbot Replicator 2	Yes	11.2 x 6.0 x 6.1	Yes	Sold Out, Chandler School	$2,899.00
Makerbot Replicator Z18	Yes	11.8 x 12 x 18	Yes	Sold	$6,499.00

*2015 prices listed. See spreadsheet "3D Print Comparison" LIGO-T1500335 for a more information and printers.

4 Scale of Model

4.1 Original

The LIGO chamber is a round cylinder with a lower part and an upper cap. The chamber is 115 inches in diameter, making it 361.28 inches in circumference. The overall height of the chamber is 200 inches, separating into a lower part of 130 inches and an upper cap of 70 inches.

The LIGO pipes connect the 5 chambers. There are two longer pipes connecting the end chambers and 4 smaller pipes connecting the inner chambers with the middle chamber, the laser table, and the photodiode. The pipes are 49 inches in diameter.

The LIGO laser table and photodiode will be modeled as the same size. The two tables are 192 inches in length and 59 inches in width. Need dimension for height.

4.2 Lego

Lego uses a scale of 1:48.

4.2.1 Lego LIGO Chamber

The LEGO Ligo Chamber would be 2.4 inches in diameter, making it 7.54 inches in circumference. The height of the LEGO Ligo would be 4.17 inches. Considering the Makerbot Replicator 2's build volume of 11.2 x 6.0 x 6.1 inches, this size is applicable to the printer's capabilities. Given that we want to split the lower part of 130 inches and upper cap of 70 inches, the Lego size dimensions would be 2.71 inches for the chamber's lower part and 1.46 inches for the upper cap.

4.2.2 Lego LIGO Pipes

The Lego LIGO Pipes would be 1.02 inches in diameter, making it 3.21 inches in circumference. The lengths of the pipes are determined by the restrictions created in using a 4 foot in diameter rounded table. There will be 2 longer pipes and 4 shorter pipes. Ratio of lengths to be determined.

4.2.3 Lego LIGO Laser Table/Photodiode

The Lego LIGO Laser Table/Photodiode would be 4 inches in length and 1.23 inches in width. Height to be determined.

4.3 Playmobil

Playmobil uses a scale of 1:24.

4.3.1 Playmobil LIGO Chamber

The Playmobil LIGO Chamber would be 4.79 inches in diameter, making it 15.05 inches in circumference. The height of the Playmobil Ligo would be 8.33 inches. Considering the Makerbot Replicator 2's build volume of 11.2 x 6.0 x 6.1 inches, we would need to break up the height into pieces. The LIGO chamber's lower part would be 5.42 inches and the upper cap would be 2.92 inches. Considering the Makerbot Replicator 2's build volume of 11.2 x 6.0 x 6.1 inches, this size is applicable to the printer's capabilities.

4.3.2 Playmobil LIGO Pipes

The Playmobil LIGO Pipes would be 2.04 inches in diameter, making it 6.41 inches in circumference. The lengths of the pipes are determined by the restrictions created in using a 4 foot in diameter rounded table. There will be 2 longer pipes and 4 shorter pipes. Ratio of lengths to be determined.

4.3.3 Playmobil LIGO Laser Table/Photodiode

The Playmobil LIGO Laser Table/Photodiode would be 8 inches in length and 2.46 inches in width. Height to be determined.

5 Plan for Model

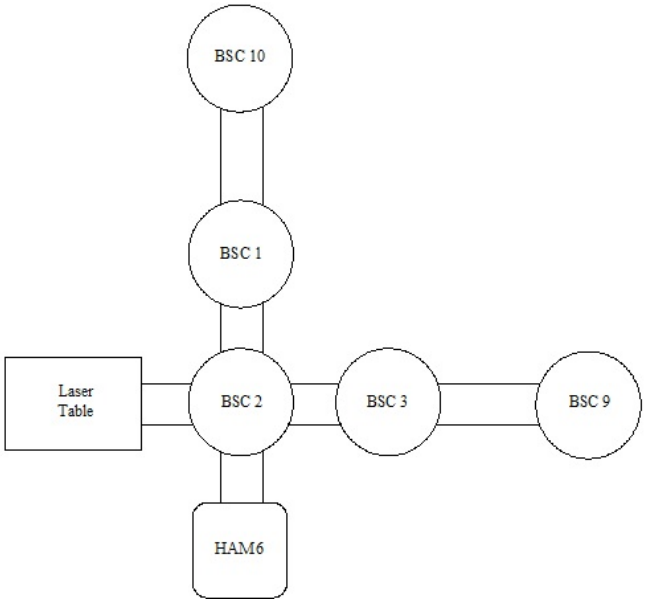
5.1 Chandler School

Chandler School in Pasadena has offered for Caltech to use their Makerbot Replicator 2 this summer free of charge. Our only responsibility is to create the file (*.stl; .obj; .thing) and buy the materials needed (*PLA).

5.2 Modeling the Model

Two paper models of the LIGO chamber will be made in both the Lego scale and the Playmobil scale in order to determine which scale we like best. A drawing of the 3-5 chambers with the laser table and piping will give us an idea of how big the final product will be and if it will fit on a 4 foot table.

5.2.1 2D Model



5.3 Cost of Model

Because Chandler School has offered for Caltech to use their Makerbot Replicator 2 free of charge and the California Institute of Technology has offered the usage of their MakeIt and Deezmaker 3D printers, the other costs to calculate are minimal. The PLA printing filament, which will depend on the scale of the model and the amount of material needed, costs around $20-30 per spool.

5.4 Cost of Maintenance Service

5.4.1 The Makerbot Industry offers a Makerbot Makercare Service. Makercare will cover support via e-mail, phone, and live chat during the coverage period (1, 2, or 3 years from delivery depending on your plan). Makercare will also cover the cost of damaged parts that occurs during normal use and any in-house repair of a device if the repair is found to be necessary by a Makerbot representative, as well as the shipping of that device to the service and repair department. It will not cover any damage resulted from unrecommended use or use outside of Makerbot specific directions for use.

5.4.2 Makerbot Service Plan

Makerbot Replicator		Makerbot Replicator Z18	
One-year plan	$350.00	One-year plan	$750.00
Two-year plan	$720.00	Two-year plan	$1,540.00
Three-year plan	$1,105.00	Three-year plan	$2,365.00

6 3D Printing at the California Institute of Technology

The California Institute of Technology (CalTech) currently has seven 3D printers in their technology lab of the following types: MakeIt Pro-M, Deezmaker Bukito, and New Matter MOD-t. They are all available for use, free of charge, to CalTech students and faculty.

7 Conclusion

Of the many 3D printers available for purchase, the ones best suited for an individual depends on how they will be used. For example, in an elementary or high school setting, the Polar 3D printer, MakerBot Replicator, Lulzbot Taz 5, or Lulzbot Taz Mini would be the best fit. The Polar 3D is small, has educational resources available, and is easy to connect to. It also uses polar coordinates, which high school students would be learning about as part of the curriculum. The MakerBot Replicator is high quality, has a larger print space, and is partially enclosed, to prevent younger students from accidentally touching the nozzle. The two Lulzbot printers are the same except the Mini is less expensive, but has a smaller bed size. If the school was to purchase a Lulzbot, it would depend on their budget and need for a larger printer.