Outer Wilds System Orerry

In this document I will list parts and equipment you need to build electromechanical Outer Wilds System Orerry. It will provide instructions with pictures of how to assemble it, but be warned, that this project is not simple when it comes to 3D printing, tinkering and electronics.

All the units used in this project are metric and STL files are encoded with [mm] as main unit. It should be possible to scale the model, but be aware of changes to diameters of all tubing, screws and bolts that need to be made for the assembly to be possible.

1. Main specs of model.
    - Real size: diameter 250mm, height 140mm.
    - Electrically powered using stepper motor.
    - Controlled with STM32 microcontroller.
    - Capable of playing music and sounds from game with build-In speakers.
    - The Sun is equipped with RGB LEDs inside, providing ability to change its color and simulate supernova explosion.
    - The front of the device has embedded OLED screen and rotary encoder for controlling functions of orrery.

2. What equipment and tools you will need to build this device:
    - FDM printer with minimum bed size of 230x230. Ender 3 and similar devices are sufficient.
    - (OPTIONAL) Any STL printer to print high quality models of planets.
    - Dremel-like tool. Any knockoff also will be fine. A set of tips, including drilling, and cutting discs will be required.
    - Standard set of Philips and flat-head screwdrivers.
    - Set of mini Hex screwdrivers.
    - Soldering iron. Preferably more powerful one, with temperature control. There is one part where soldering of brass pipes is required, can also be done with handheld torch (albeit requires more experience).
    - ST-Link or USB-TTL converter. Required for programming of STM32 board.

3. What parts you will need to buy to assemble mechanical part of the Orrery:
    - Around 1kg of PLA filament (could also be probably printed with other materials)
    - Small bit of transparent PETG filament for printing the sun. Can be omitted if using resin printer to print planets.
    - UV resin for FDM printing (if going for quality option)
    - 1m of 3x2.1 brass tube. This brass tube will be used as sliding bearing in almost all mechanical connections, so it is very important that the next part easily slides inside it.
    - 2m of 2mm brass rod. This one can be bought as pure brass rods used for hard soldering. Just make sure that its diameter is consistent and compatible with 3mm pipe.
    - 20cm of 4x3.1 brass tube. Required for sun assembly. 3mm tube must easily slide inside this one.
    - Two 4x11x4 ball bearings.

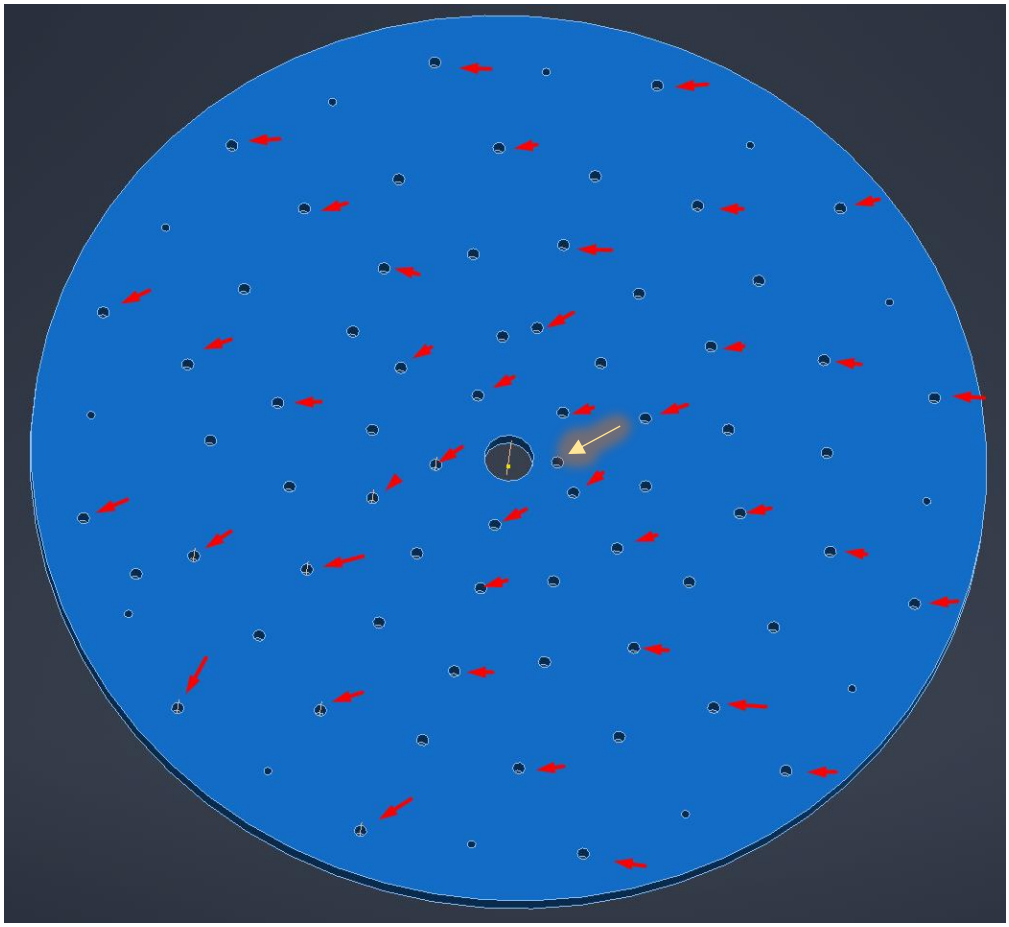
- M2 nuts. You will need around 25.
- Eight M2x3mm insert screws.
- Six M2x20 bolts.
- Around 30 M3 10mm wood screws.
- Around 20 M3 25mm wood screws.
- Five M3 40mm wood screws.

4. What you will need to buy to assemble the electronical part of the Orrery:
   - Small factor 4-wire stepper motor. SHP-35d or similar is best.
   - STM32F103C6T6 (known as blue pill). These boards come with many different designs and chips, but code for this project was developed for the weakest 32kb board, so it should be compatible with more advanced ones. It would require some changes in the code.
   - DF player mini module. These can be bought cheaply from aliexpress or ebay.
   - Two 3W 40mm speakers.
   - Micro SD card. Any size bigger than 64Mb should be good.
   - tmc2208 stepper motor driver. This is the quietest one I could find, others work too, but at the cost of increased noise when the motor is in operation
   - Three WS2812B LEDs. Those can be easily desoldered from the cheap strips that are available for sale everywhere. Be mind to apply heat from the bottom of the strip, otherwise you will melt their plastic housing.
   - Rotary encoder module. Should have a button built-in.
   - 0,96 OLED display SSD1306. I2C version, as it requires fewer wires.
   - Universal prototyping PCB board to solder all the components in place.
   - Some capacitors and resistors. More details in the assembly section.
   - USB C socket to provide power to the Orrery.
   - Lots of wires and optional connectors (more info in assembly section).

5. Some details about 3D printing.
   - Most of parts can be printed with 0.2mm layer height. For some of smaller gears printing with 0.12mm layer height could result in better meshing gears. It is not required through.
   - If you use ender 3 or similar bed sized printer, you will need to increase the working area to full 235x235mm. You must also disable printing of any nozzle priming lines or skirt loops.
   - Most holes are printed horizontally, so they should fit brass tubes without modifications. There are some printed vertically, and those could require some post-printing drilling.
   - STL files are contained in different folders, and prefixed with ID number, corresponding to the order in which they need to be assembled. Feel free to print them in any order you want. Also, at the end of the filename, a quantity number is present.

6. The first step of building the orrery, requires printing the main plate (1). To do this, please remember to increase the bed size limits if necessary.

Picture 1 depicts where to place 3mm brass tubes required for smooth motion of the gears. Red arrows show where tubes need to be hammered in. Please consider using a rubber head hammer to not crimp the ends of tubes.
For the correct orientation of front plate, look for a hole highlighted by yellow arrow. Its placement is not symmetrical so it can be used for alignment.
In total 43 brass tubes, each one 5mm in length, need to be inserted.



Picture 1: Placement of 3mm diameter brass tubes

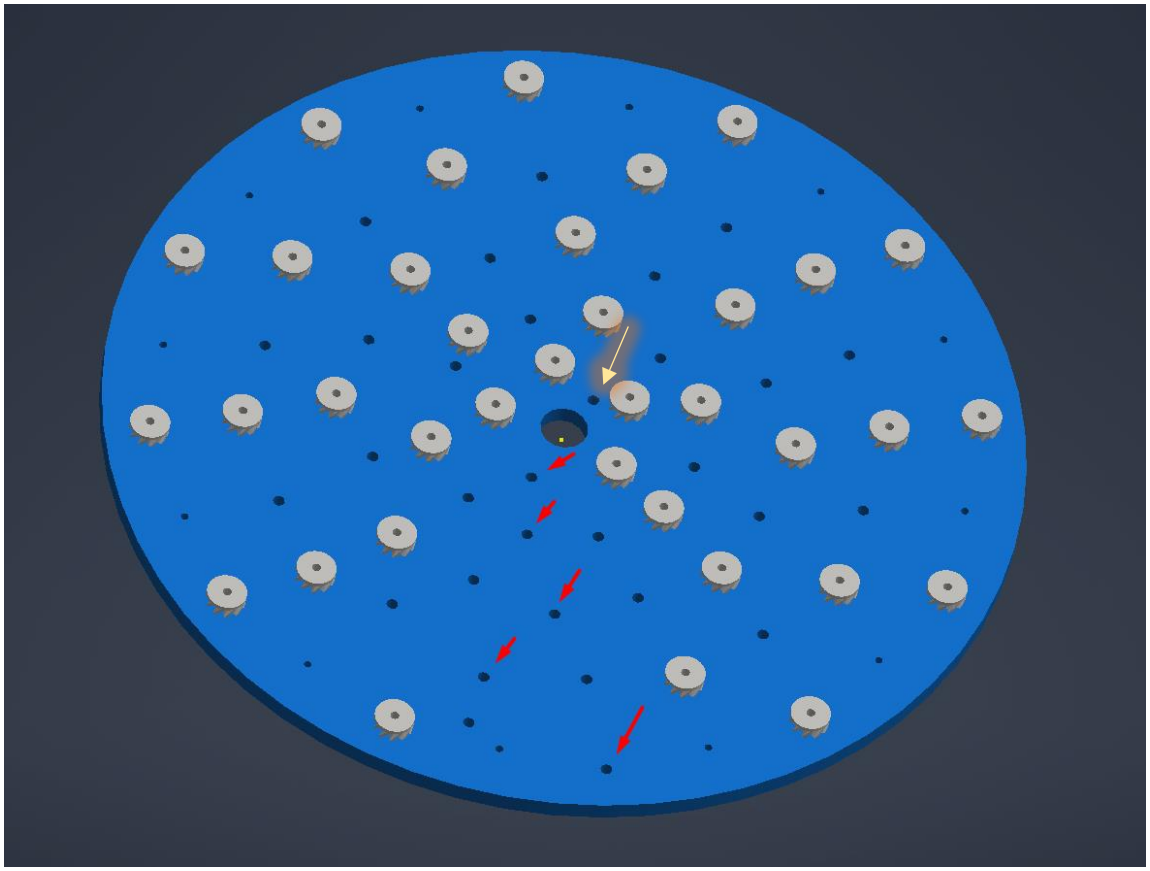
7. Next, you will need to print 38 (probably more for spares) guiding gears (2). For each of those, a 2mm diameter brass rod need to be cut at length of 12mm (Picture 2).

Picture 2: Brass shaft

Picture 3: Finished guiding gear assembly

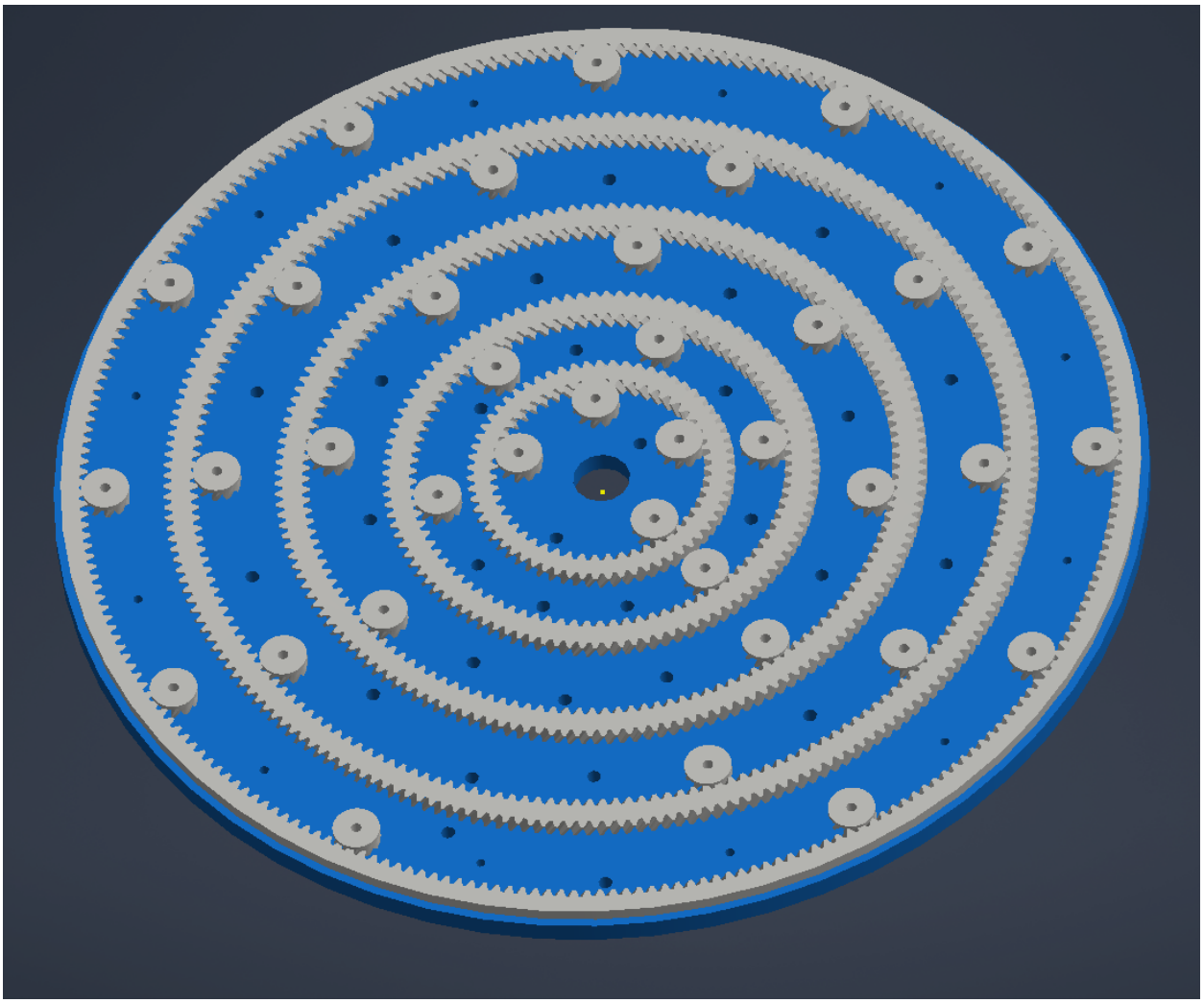
The brass rod is then inserted in guiding gear. (Picture 3) This step needs to be repeated for all 38 gears. Those gears can now be inserted into main plate (Picture 4). Red arrows mark holes you need to leave empty.

Again, yellow arrow shows the location of asymmetrical alignment hole.



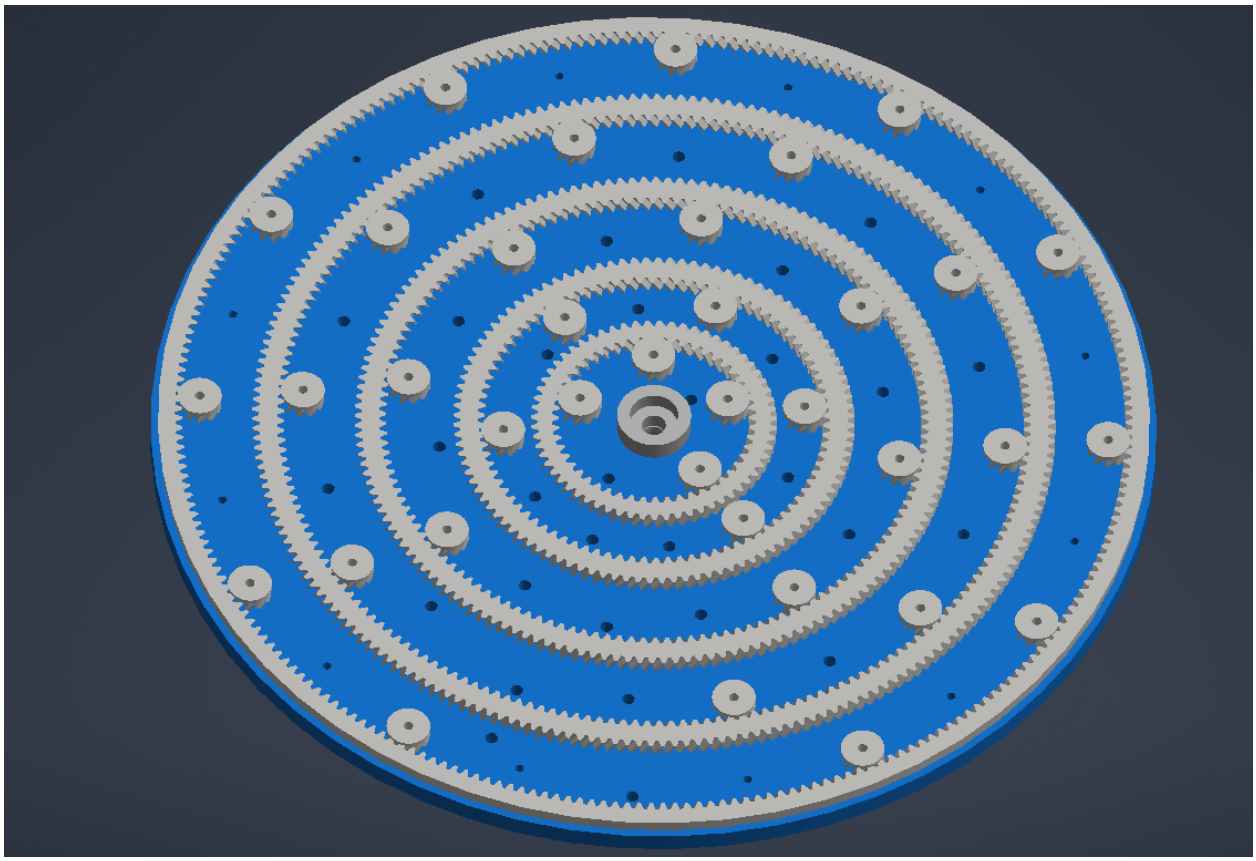
Picture 4: Guiding gears inserted into main plate

8. Now, you can print and insert main planet gears. For those assure you have good bed adhesion because they tend to delaminate during printing due to heat warping. After printing all 5 gears (parts 3 to 7) you can simply insert them on the main plate by lifting couple of guiding gears and then inserting them back.



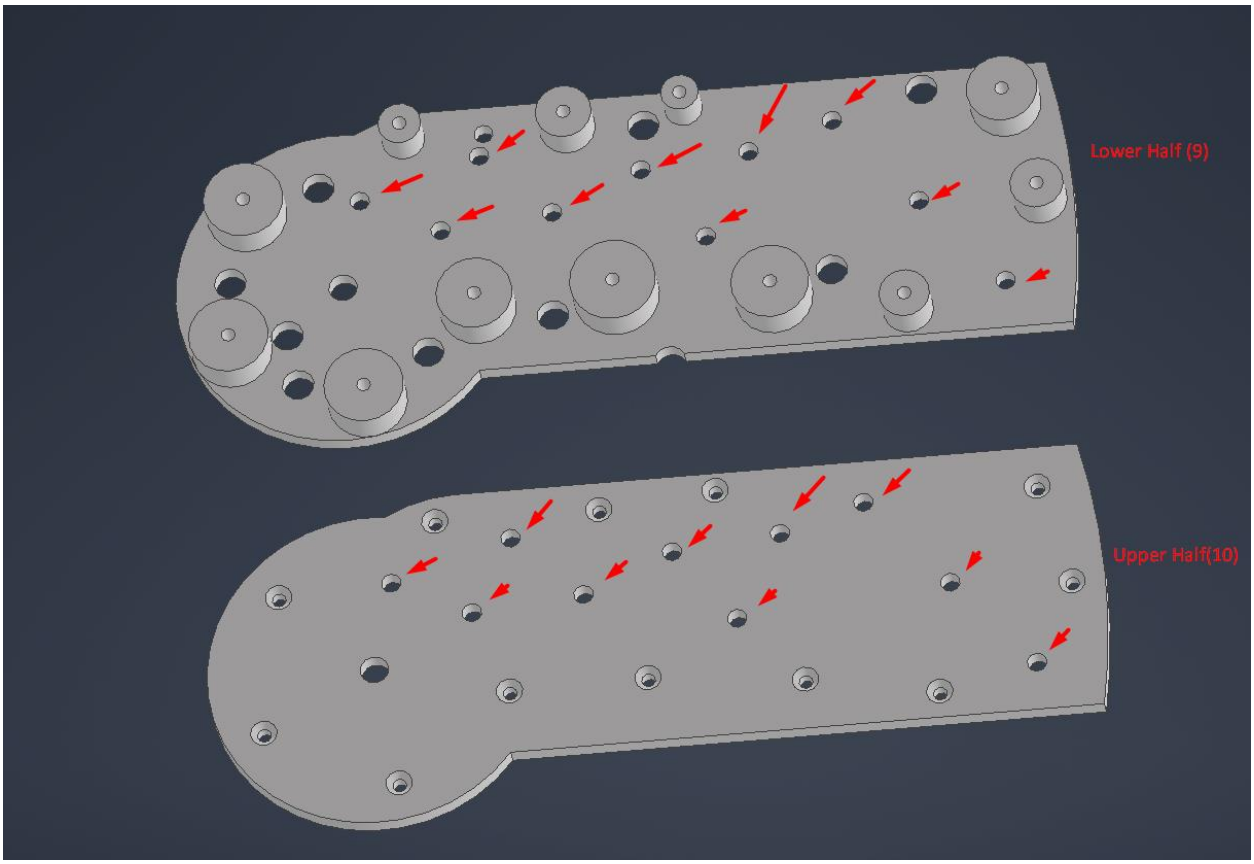
Picture 5: Placement of main planet gears

9. Next, print upper bearing holder (8), and insert it in the center.



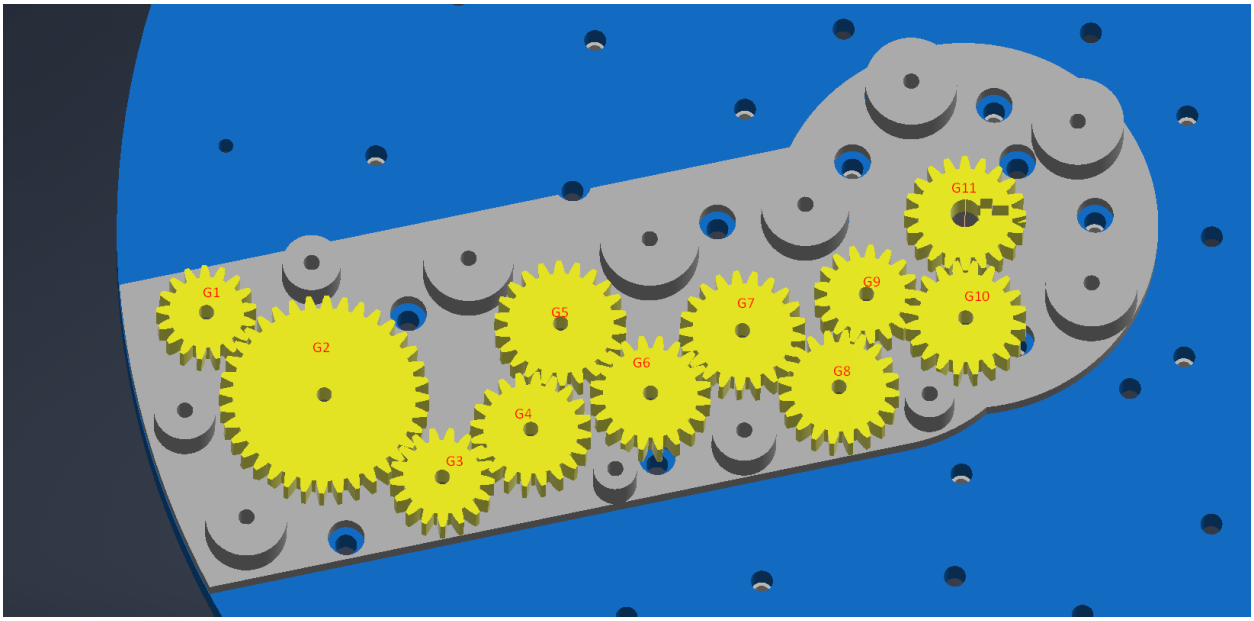
Picture 6: Placement of upper bearing holder.

10. Next you will need to flip the main board on the other side. To do this without risking all the moving parts falling out, use a piece of cardboard and support all the elements while you flip it.
    Print two halves of gear train assembly housing (part 9 and 10). Cut 20 3mm diameter brass tubes to the length of 3mm and insert them in holes marked by red arrows (Picture 7).



Picture 7: Placement of brass tubes in gear train housing

11. Print 11 gears from Gear Train folder. Keep track of their order, mark them with sharpie if necessary.



Picture 8: Gear train assembly

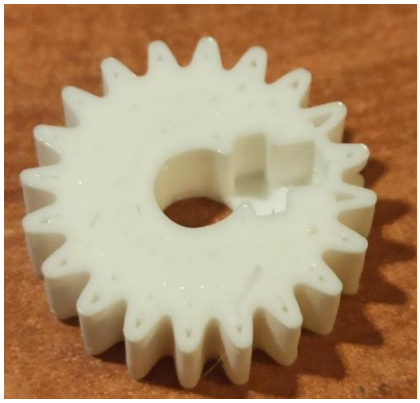
Gear ID	Shaft diameter	Shaft length
G11	4mm, locking	70mm
G10	2mm	11mm
G9	2mm	24mm
G8	2mm	11mm
G7	2mm	24mm
G6	2mm	11mm
G5	2mm	24mm
G4	2mm	11mm
G3	2mm	24mm
G2	2mm	11mm
G1	2mm	24mm

Table 1: Gear shafts lookup table

You need to cut brass rods to lengths presented in Table 1. Longer 2mm shafts are inserted asymmetrically, with one, shorter length always being around 3mm, so they don't stick outside of the housing. Other side is longer and should protrude from the main base when assembly is inserted into place. Shorter shafts are inserted symmetrically with 3mm protruding from both ends of the gear.

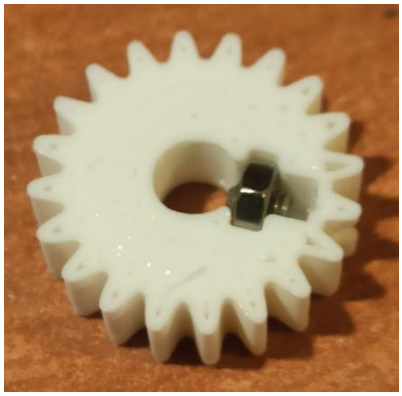
Main 4mm shaft is far longer, as it is the start of the mechanism and will contain the gear that is powered by stepper motor. It is 4mm in diameter so that another 3mm tube could be inserted inside, providing a stationary rod in which wires to the Sun's LEDs will be placed.

Because of high torque that will be placed on first gear it is locked in place with locking nut. Assembly instructions are depicted in pictures 9 through 11.



Picture 9: Printed locking gear

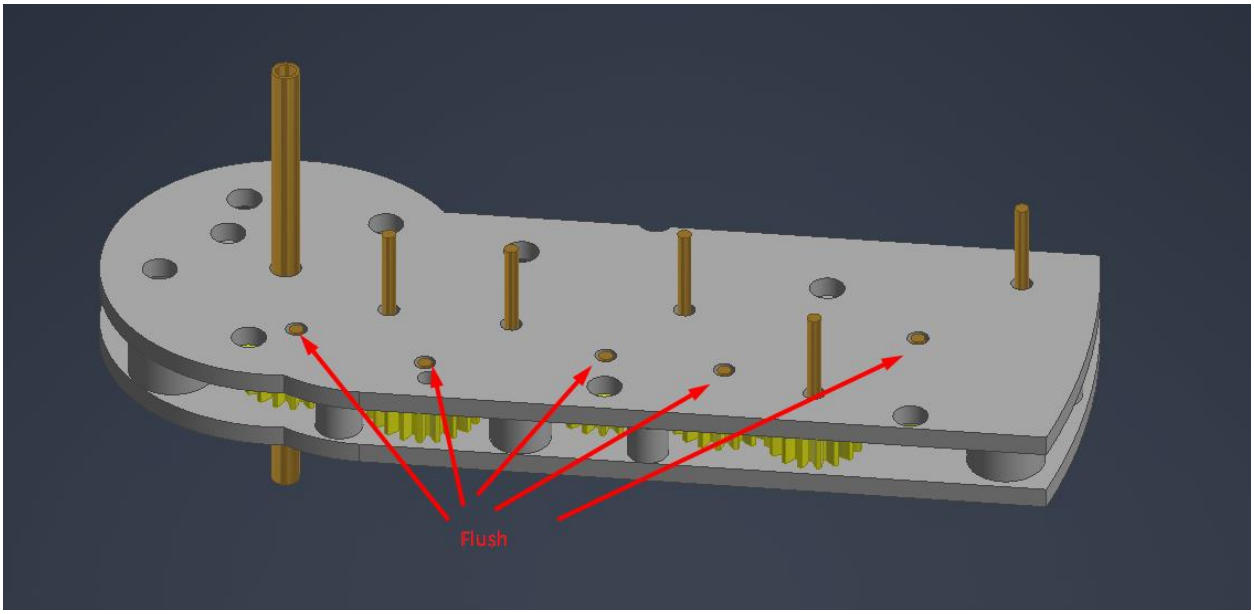
Picture 10: Assembly of M2 3mm hex insert bolt and M2 nut



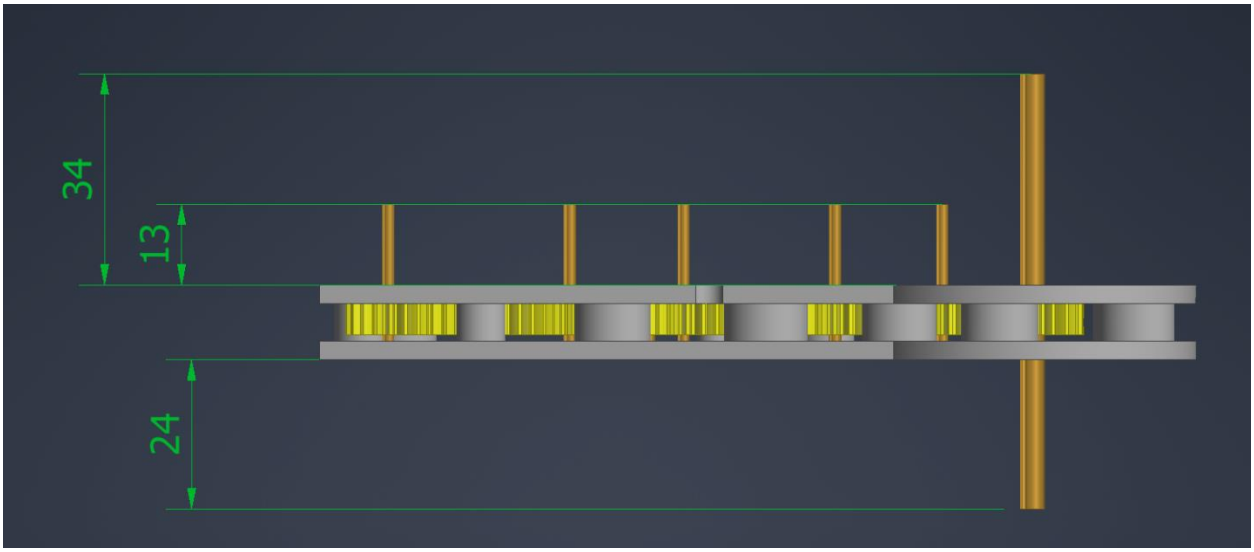
Picture 11: Screw assembly inserted into locking gear

There is a hole in side of locking gear in which a hex key can be inserted so that the gear can be locked on the shaft.

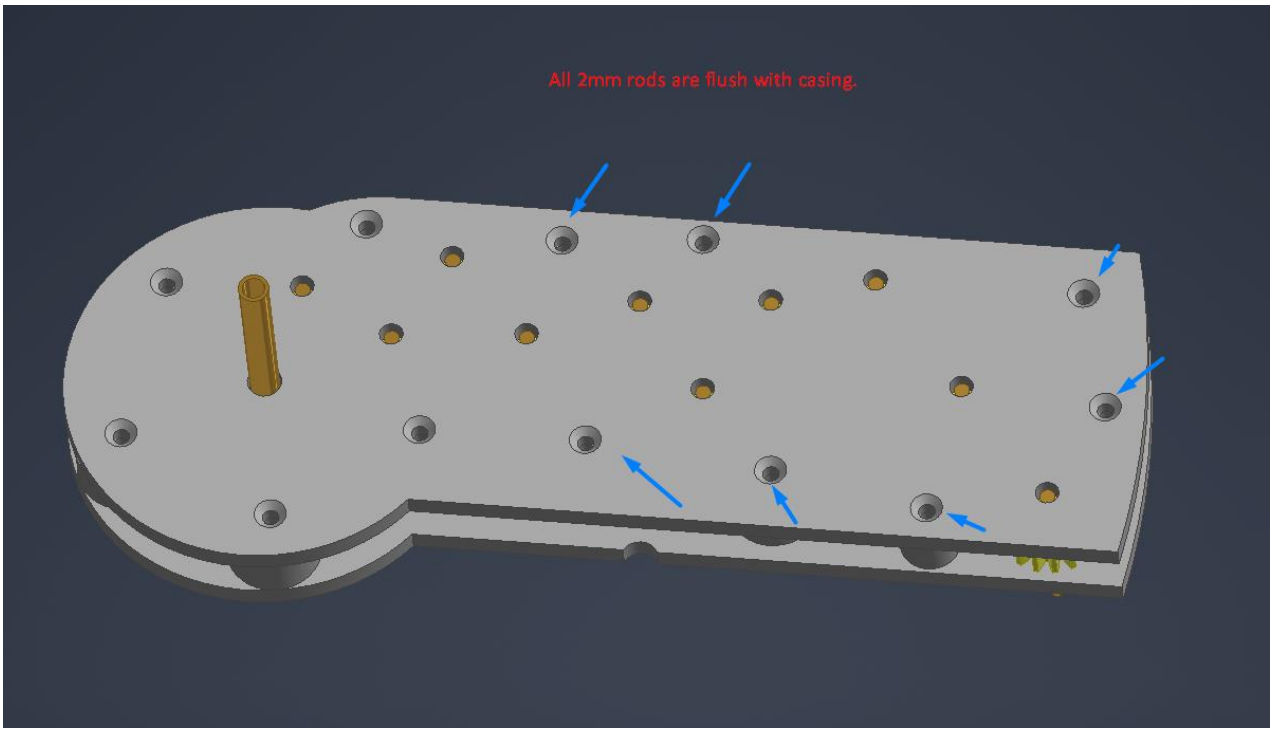
Pictures 12-14 depict how to assemble the gear train.



Picture 12: Upper side of gear train assembly



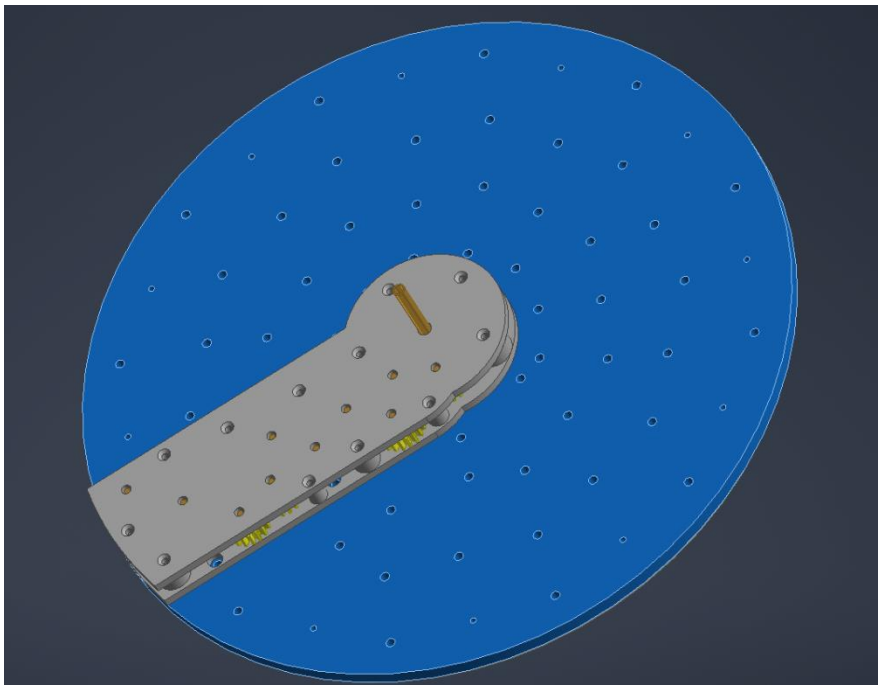
Picture 14: Correct lengths of brass shafts



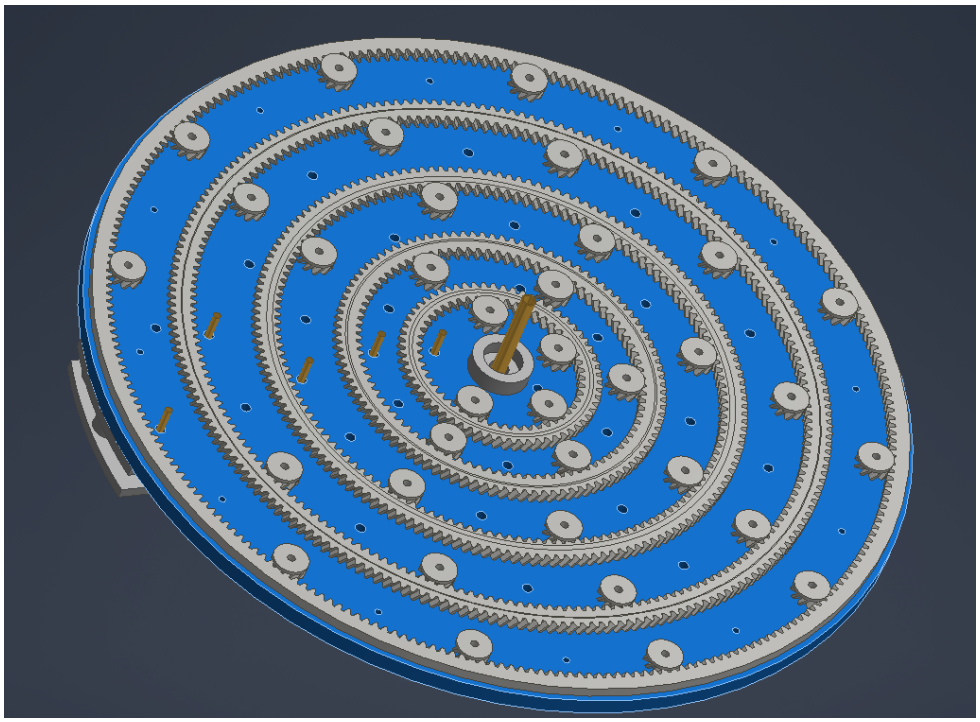
Picture 13: Bottom side of gear train assembly

Looking at Picture 13, you will need to screw both side of the casing with 10mm M3 brass wood screws. Blue arrows depict which holes are correct. Be carefull to not tighten them too much, the mechanism should move freely when 4mm brass tube is rotated.

12. After assembly of gear train it can be then inserted into main plate.

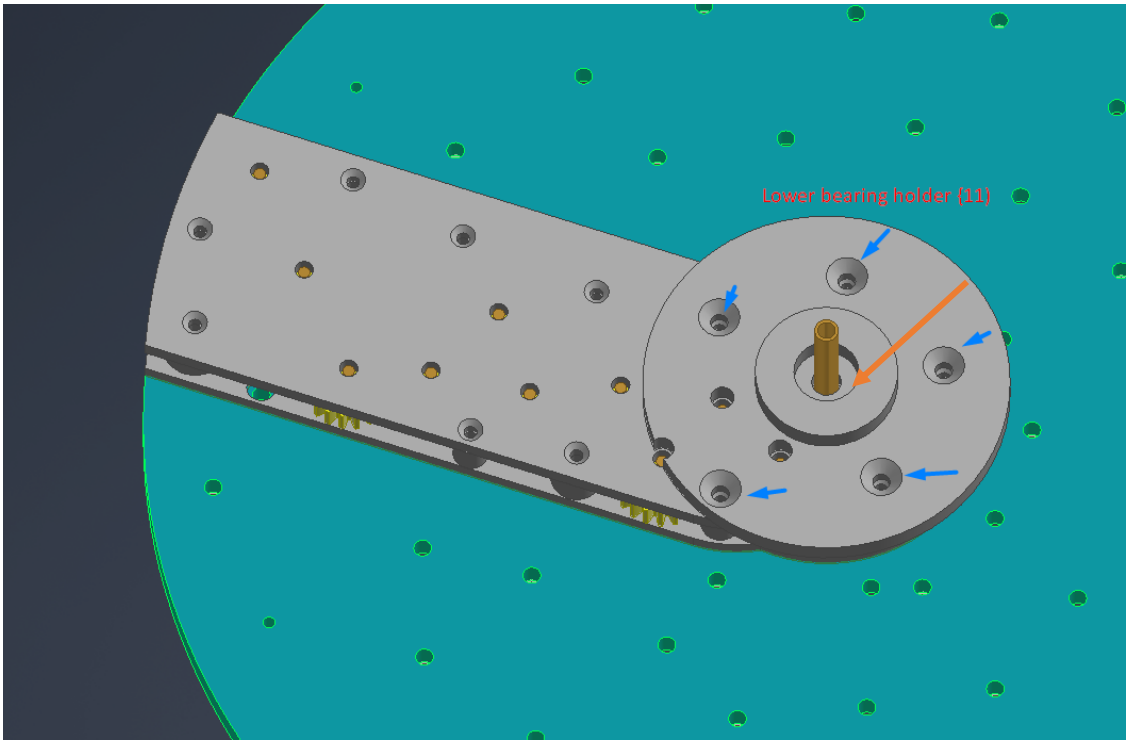


Picture 16: Gear train assembly inserted in the main plate (view from below).



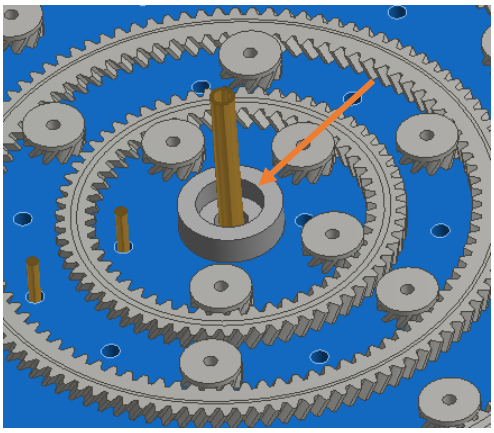
Picture 15: Gear train assembly inserted in the main plate (view from above)

13. Print lower bearing holder (11). Place five M3 20mm wood screws in holes designated by blue arrows.



Picture 17: Lower bearing holder placement.

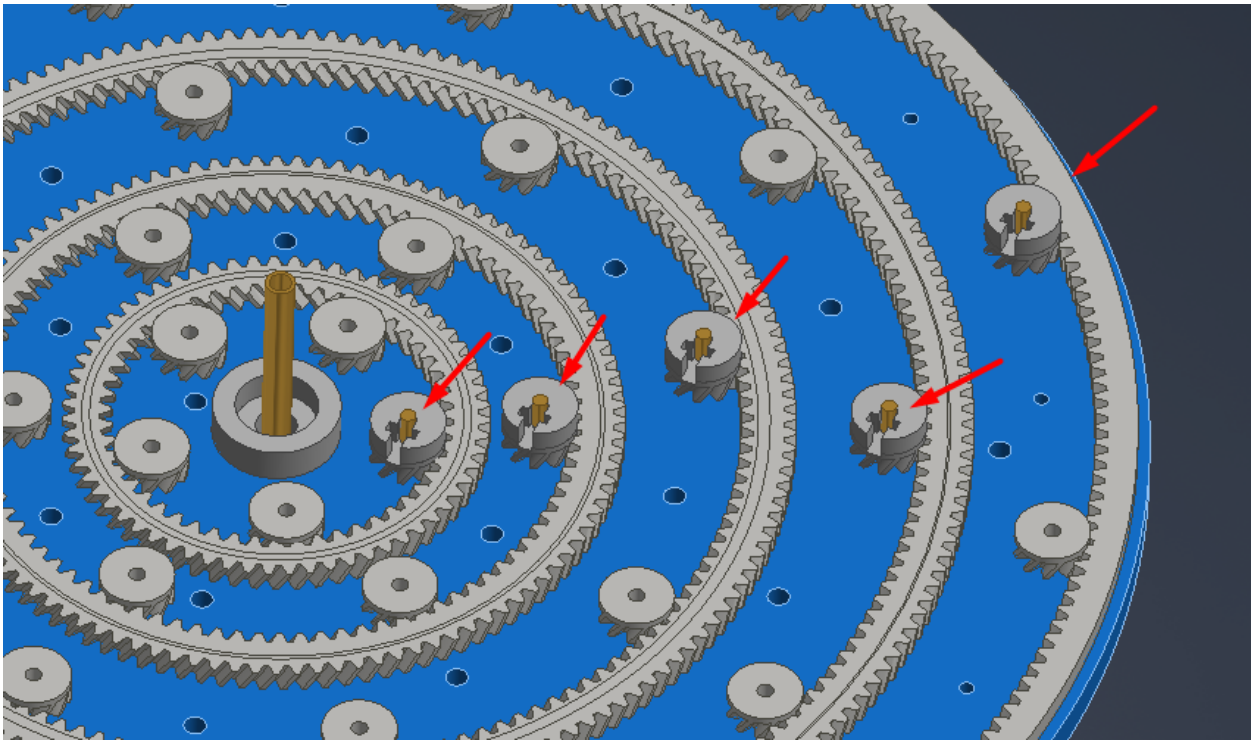
Picture 18: 4x11x4 ball bearings



Picture 19: Placement of upper bearing

Place two 4x11x4 ball bearings in places marked by orange arrows (Picture 17 and 19)

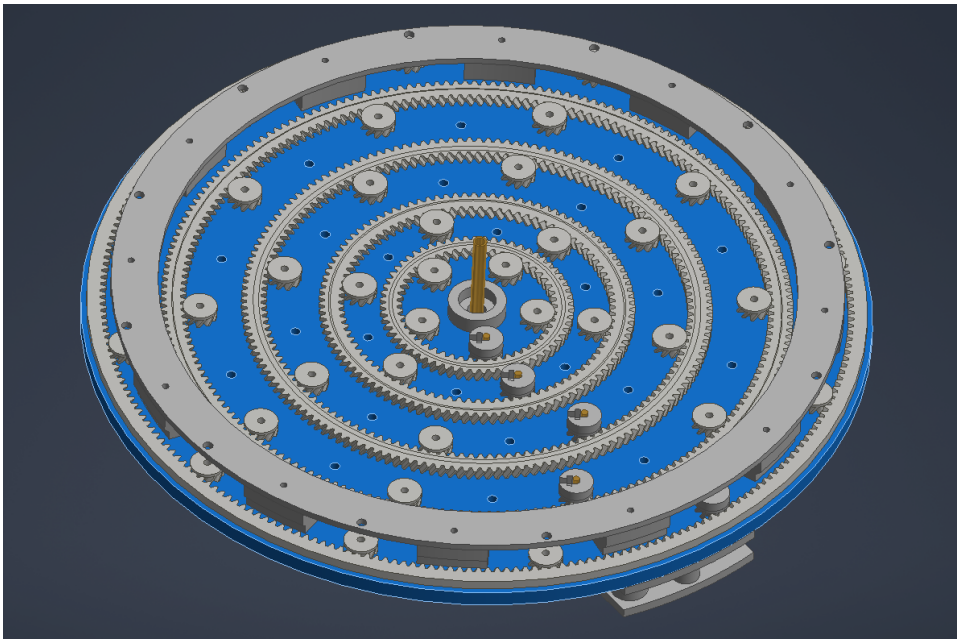
14. Print five locking torque gears (12). Insert 5 locking bolts and nuts similar as in the locking gear depicted in pictures 9 – 11. After that affix them to the empty rods on main plate. Use a hex key to lock them in place.



Picture 20: Locations of locking gears

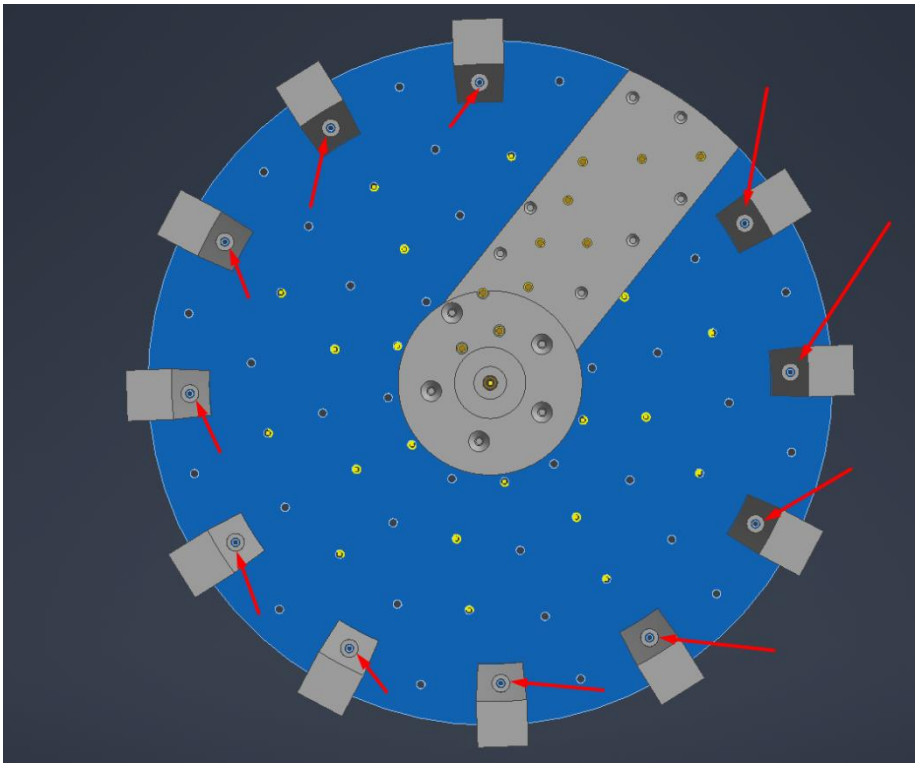
Now the mechanism should work and all five main planet gears should rotate when the main 4mm shaft is rotated. Check mechanism for smooth movement, file gear tooths that snag or catch.

15. Print eleven structural legs (13) and Giant-bramble stationary guide (14).



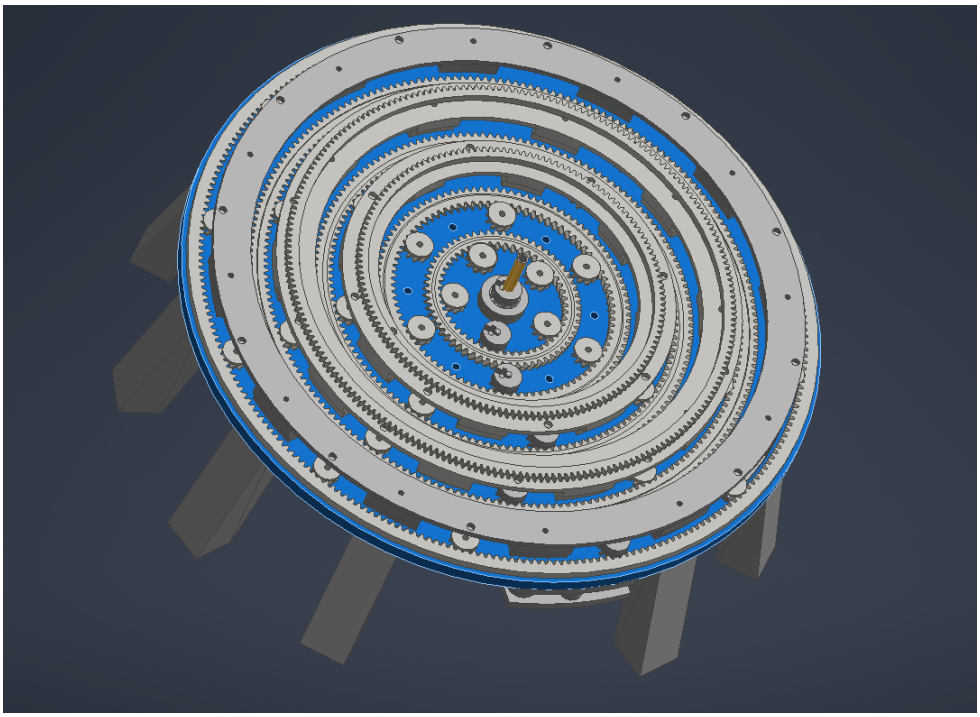
Picture 21: Placement of Giant-Bramble stationary guide (14)

Mount eleven legs with M3 25mm wood screws. Do it one after another ensuring that the stationary guide won't touch the moving gears.

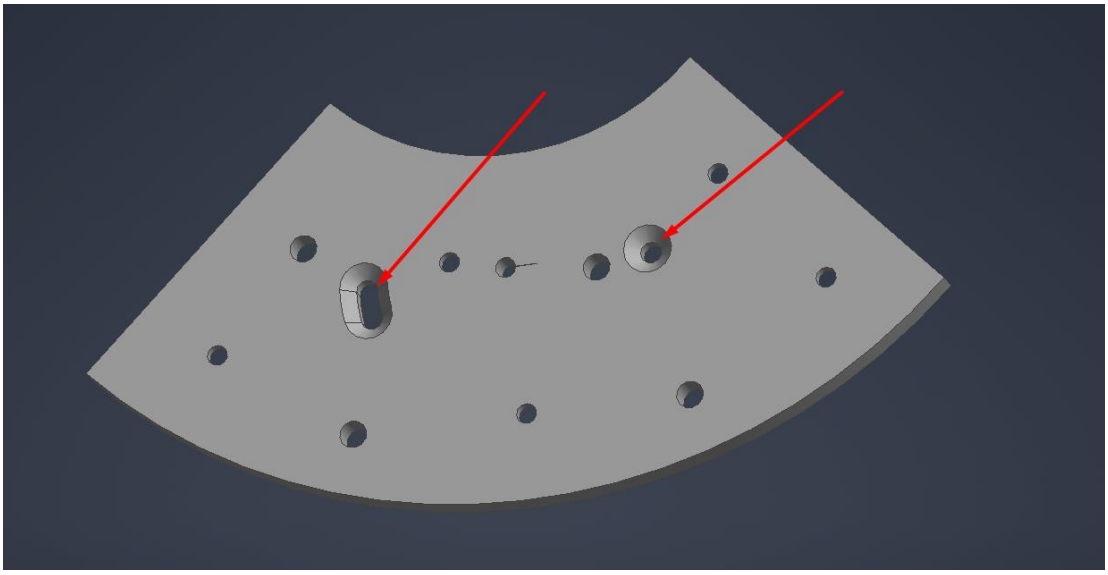


Picture 22: Placement of leg screws

16. Print Timber Hearth Stationary Gear (15) and Brittle Hollow Stationary Gear (16). Also print Stepper motor mount plate (17). At this point you can either install the motor, or finish the rest of the mechanism. Be warned that you will have to unscrew the plate to install motor if you want to do it later.

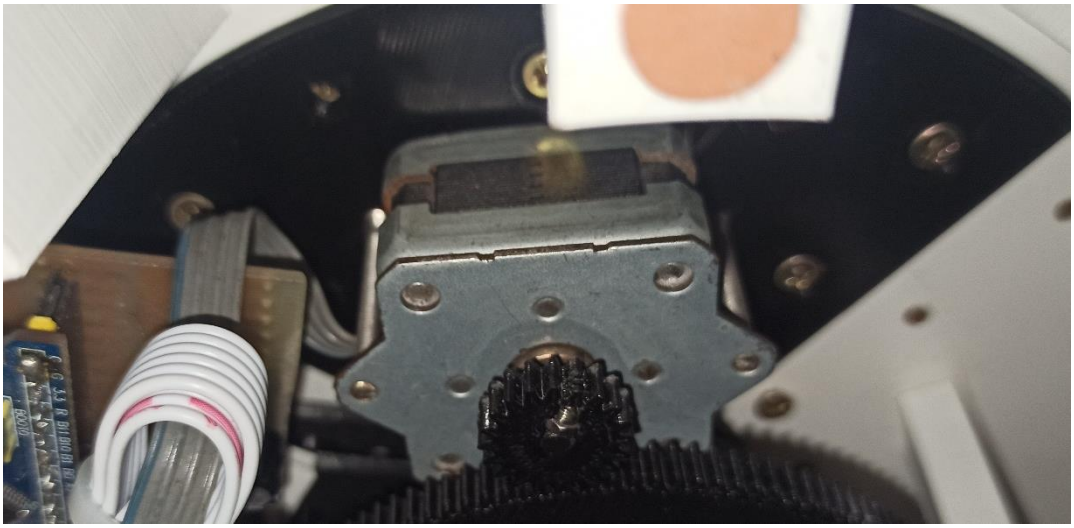


Picture 24: Timber and Brittle stationary gears.

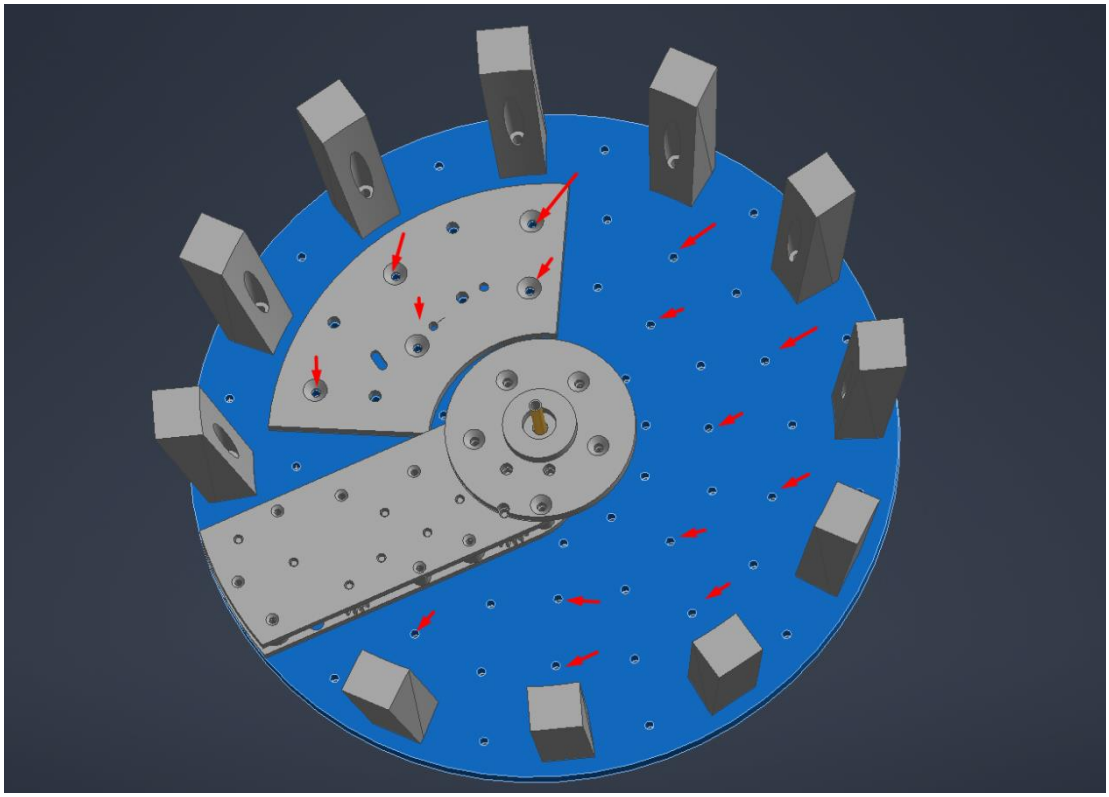


Picture 23: Places to insert motor screws on Stepper motor mount plate (17).

Use 30mm M3 bolts to screw the motor to its mounting plate. One of the mounting holes is wider and can be used to adjust the motor's position, so the gears meshes correctly.

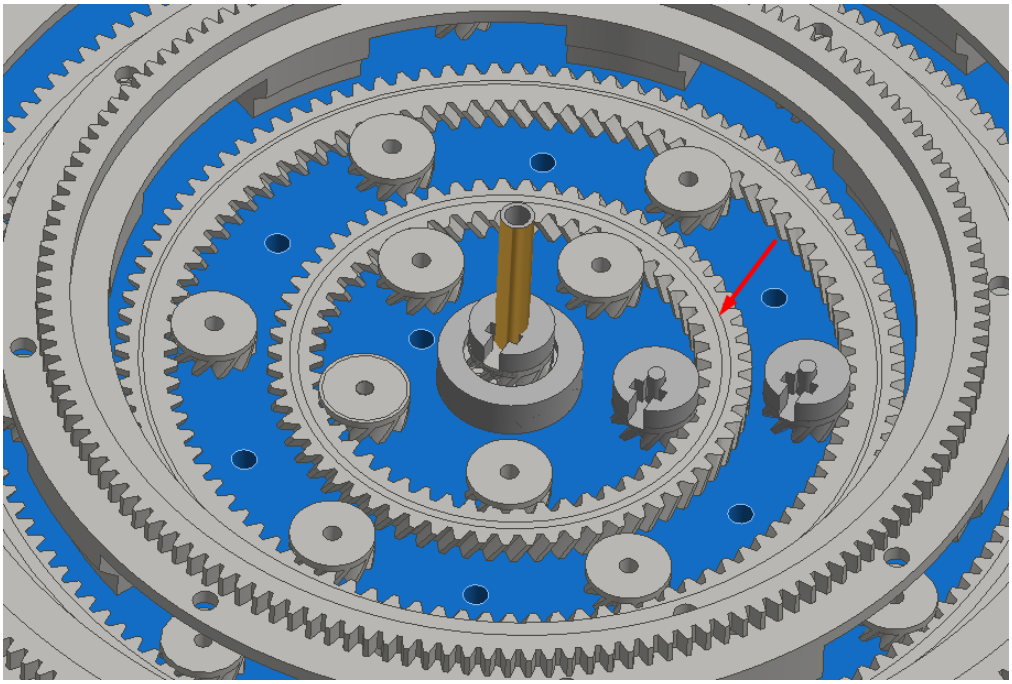


Picture 25: Motor mounted using two bolts.



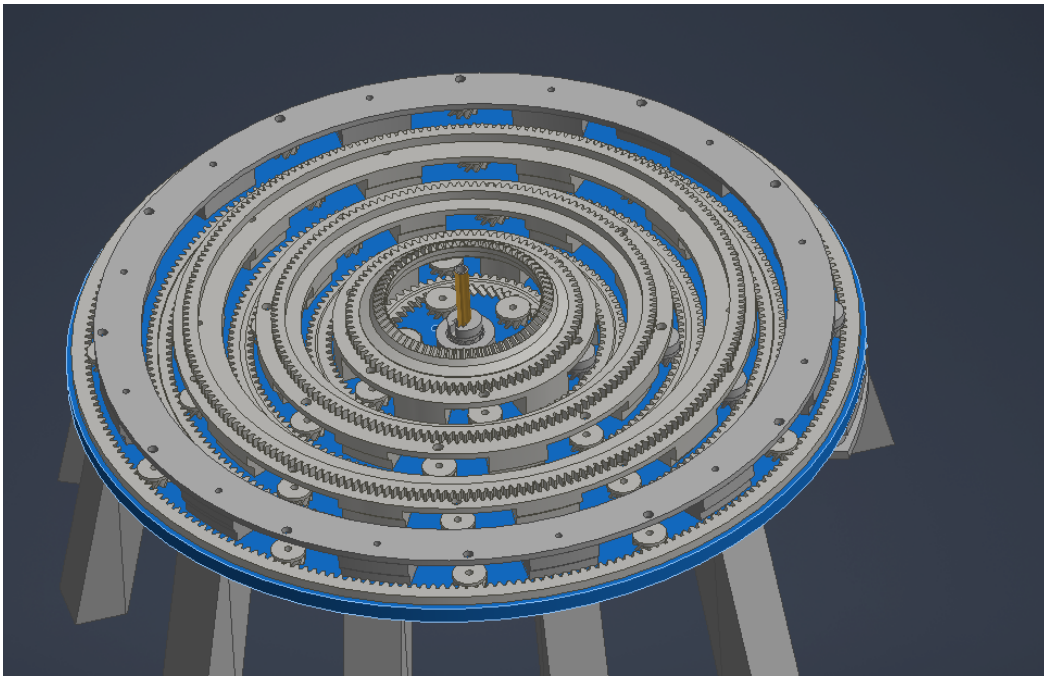
Picture 26: Securing the motor plate and stationary gears with screws.

17. Drill 2 mm hole somewhere in the middle of the smallest planetary gear (between the teeth).



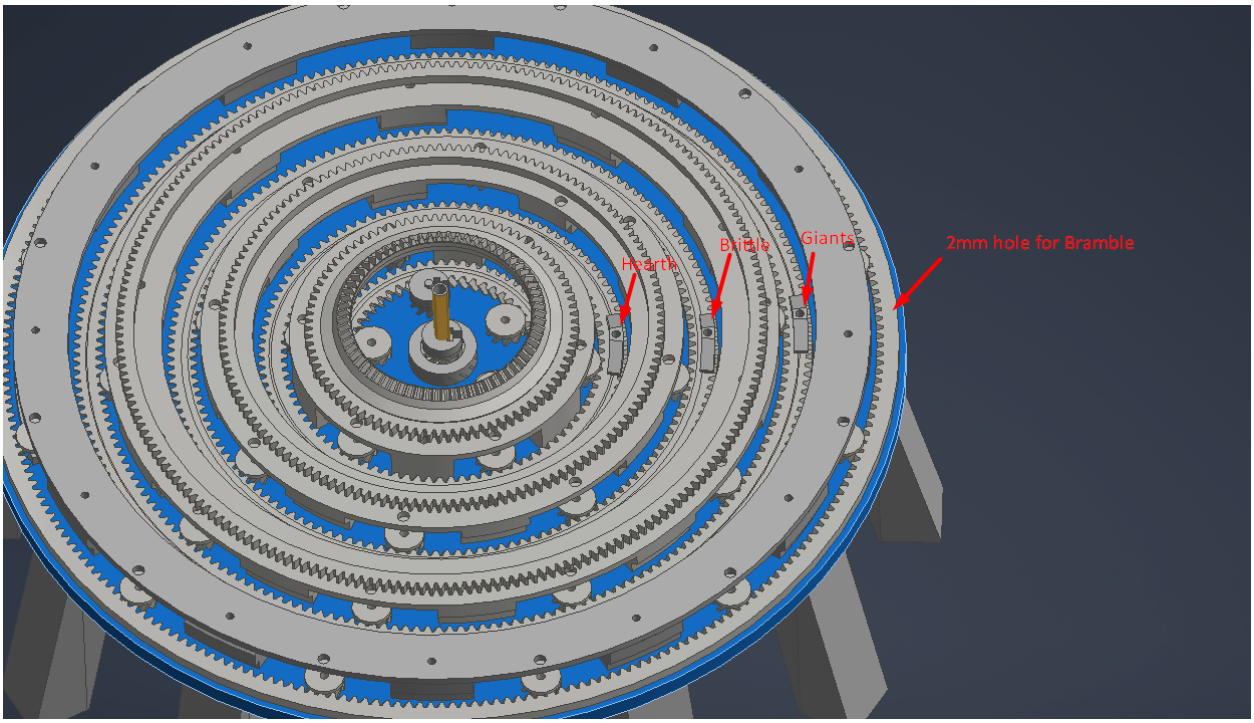
Picture 27: Place for a 2mm hole

Print and mount Twins stationary gear. Secure it with wood screws from the bottom side of main plate.



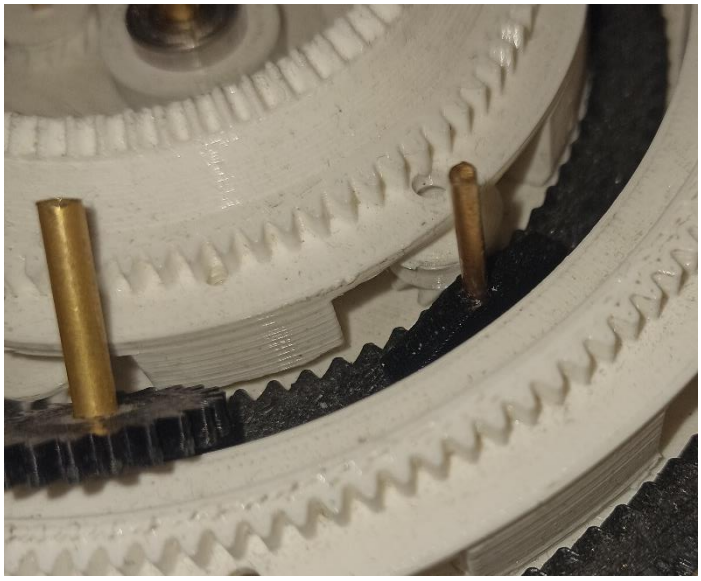
Picture 28: All stationary gears mounted

18. Print three planetary stabilizers (19), and Hearth, Brittle and Giant's planetary gears (20, 21, 22). Using those planetary gears, mark positions where they freely mesh with stationary gears. Drill out those marks with 2mm drill.

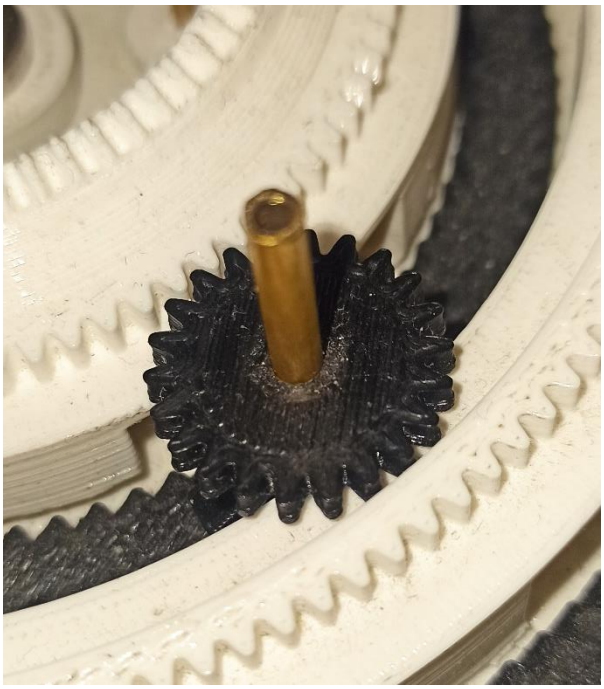


Picture 29: Drilling holes for planets

Insert 2mm brass rods in holes on main planetary gears. Insert 3mm brass tubes in secondary planetary gears (20-22).

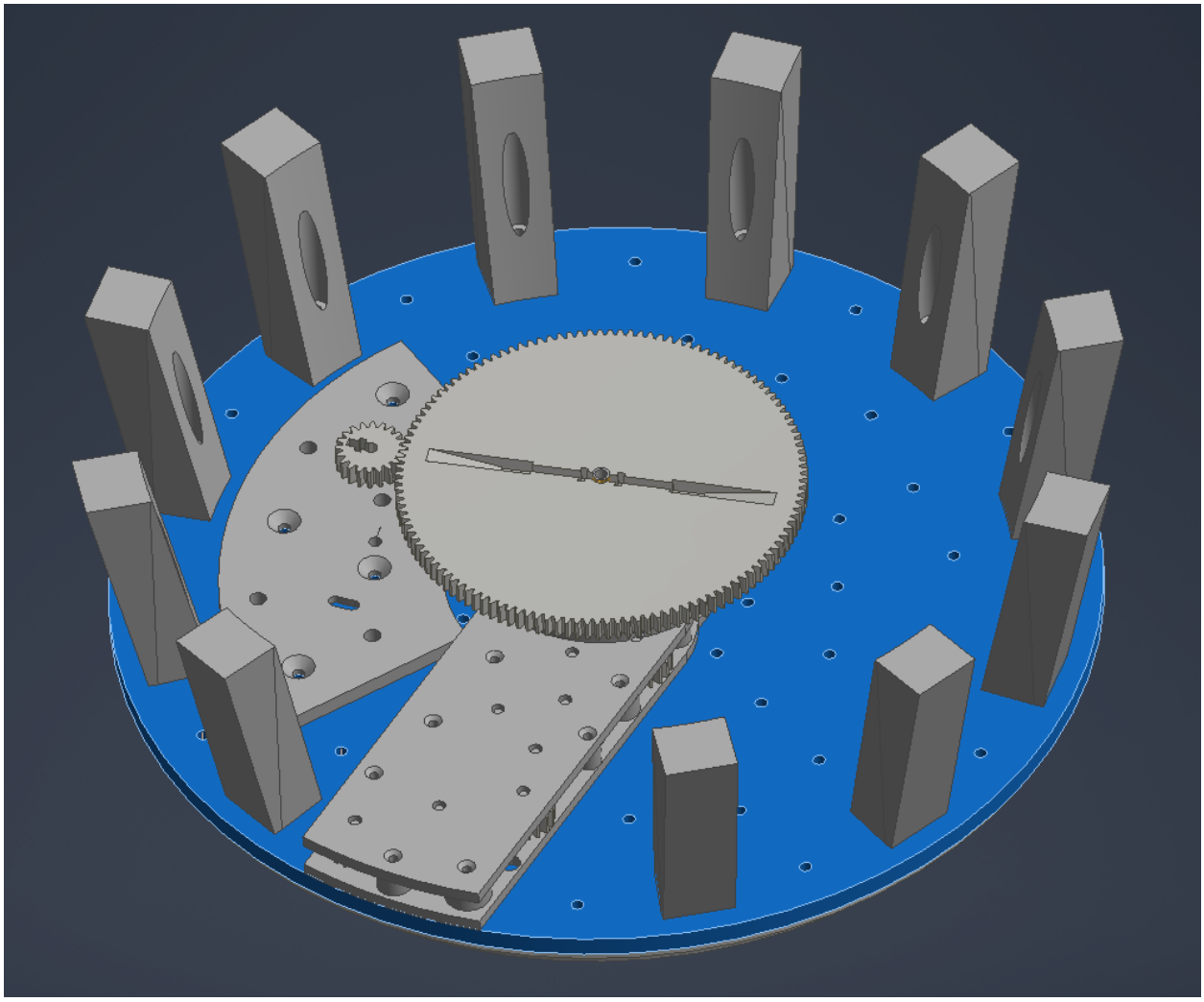


Picture 30: Planetary gears assembly



Picture 31: Finished gear.

19. Print Main Torque gear (23) and Stepper motor gear (24). Insert those on the main shaft from the bottom of assembly, and lock them in similar manner to that described previously.

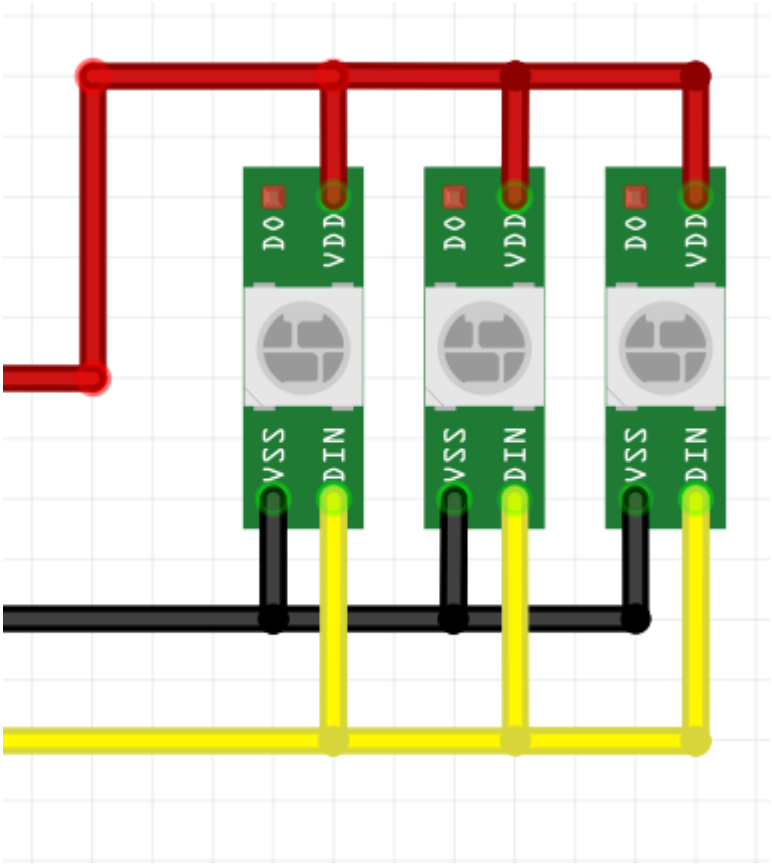


Picture 32: Two stepper motor gears.

Stepper motor gear is designed to be locked onto 3mm stepper motor shaft. If you use different style of motor, you will need to redesign this part accordingly.

That is the end of main mechanism assembly. Now you can make a choice; how complex do you want your orrery electronics to be. Most functions are easy to implement, but nevertheless they can be skipped. In next chapter I will outline different functions, and what parts are needed for each one.

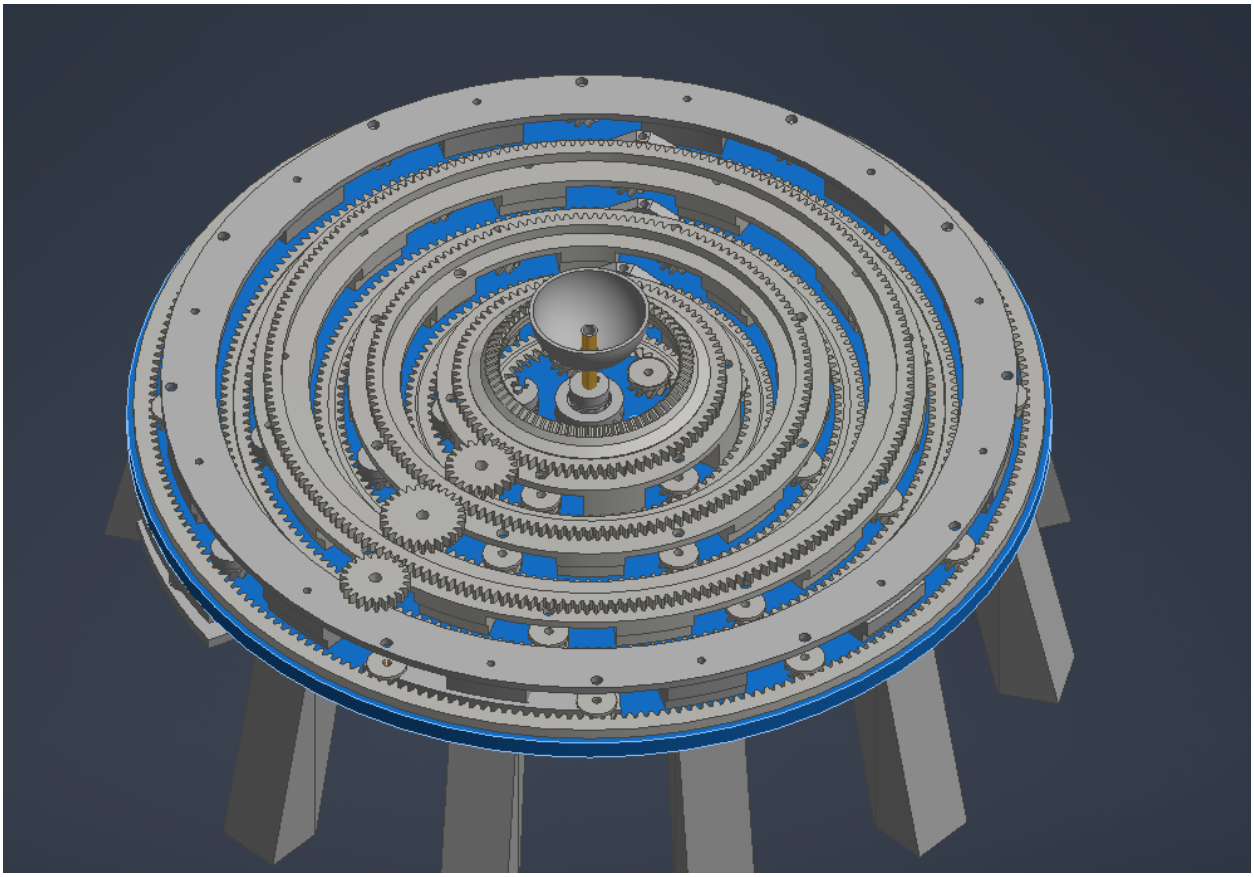
20. Skippable – RGB sun.
    To build the realistic, color changing sun you will need four WS2812B LEDs. Three are used as light source for the sun and one is necessary as voltage logic level converter.



Picture 33: Part of LED schematic

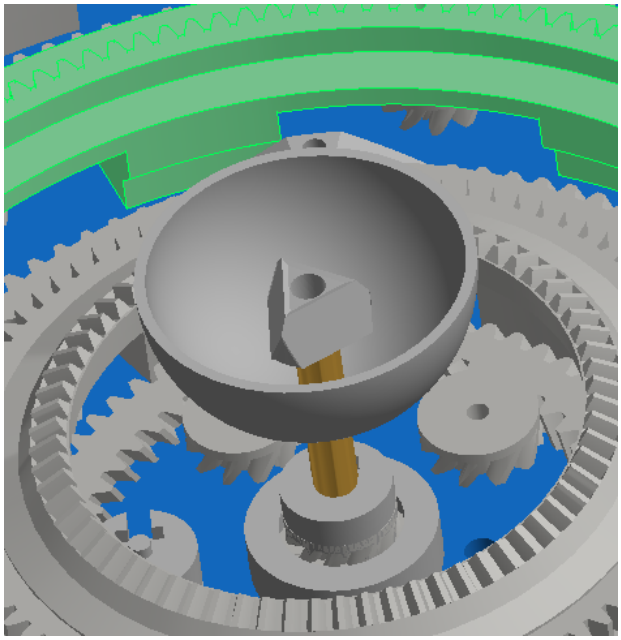
Picture 33 depicts internal LED connections that need to be build inside the shell of the Sun. You can insert 3mm brass tube inside the 4mm tube that makes the main shaft of the mechanism. This smaller tube should be stationary and not rotate with the rest of mechanism. You can use this tube as the negative terminal for the LED power. This means that only 2 wire (positive and signal) will need to be inserted inside the tube.

At the top of the tube, LED holder will need to be placed. Firstly the lower shell of the sun must be put on the tube. Print the lower half of the sun (25).

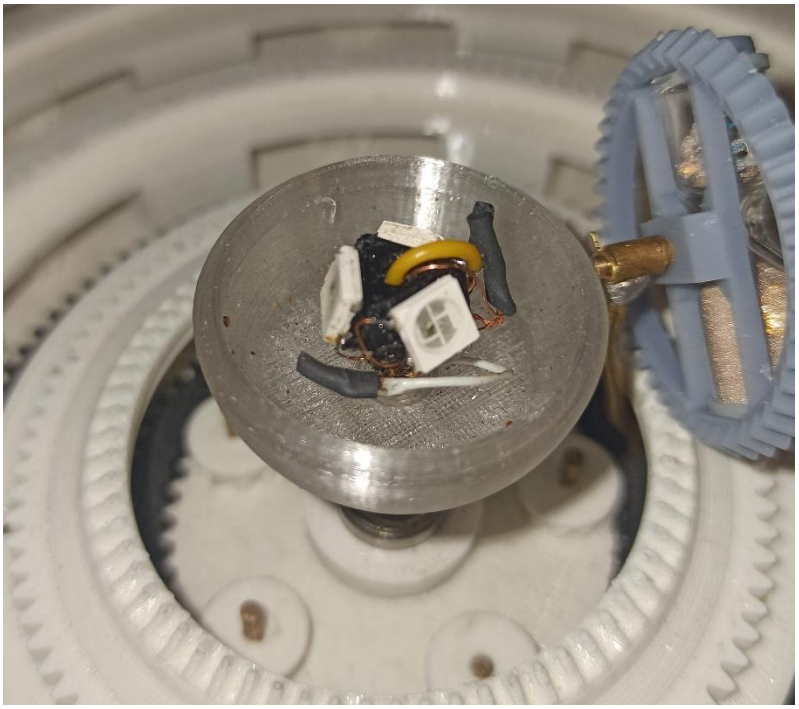


Picture 34: Lower half of the sun inserted.

Next, glue three WS2812B on to the three angled surfaces of LED bracket (26). Solder the wires between LEDs according to the schematic (Picture 33). Solder or clamp with screws the ground wire to 3mm tube (not rotating one). Then thread other two wires inside the tube, and guide them under the orrery. Insert the LED bracket onto the 3mm tube so all wires are coming out of top of it (look at pictures 35 and 36).



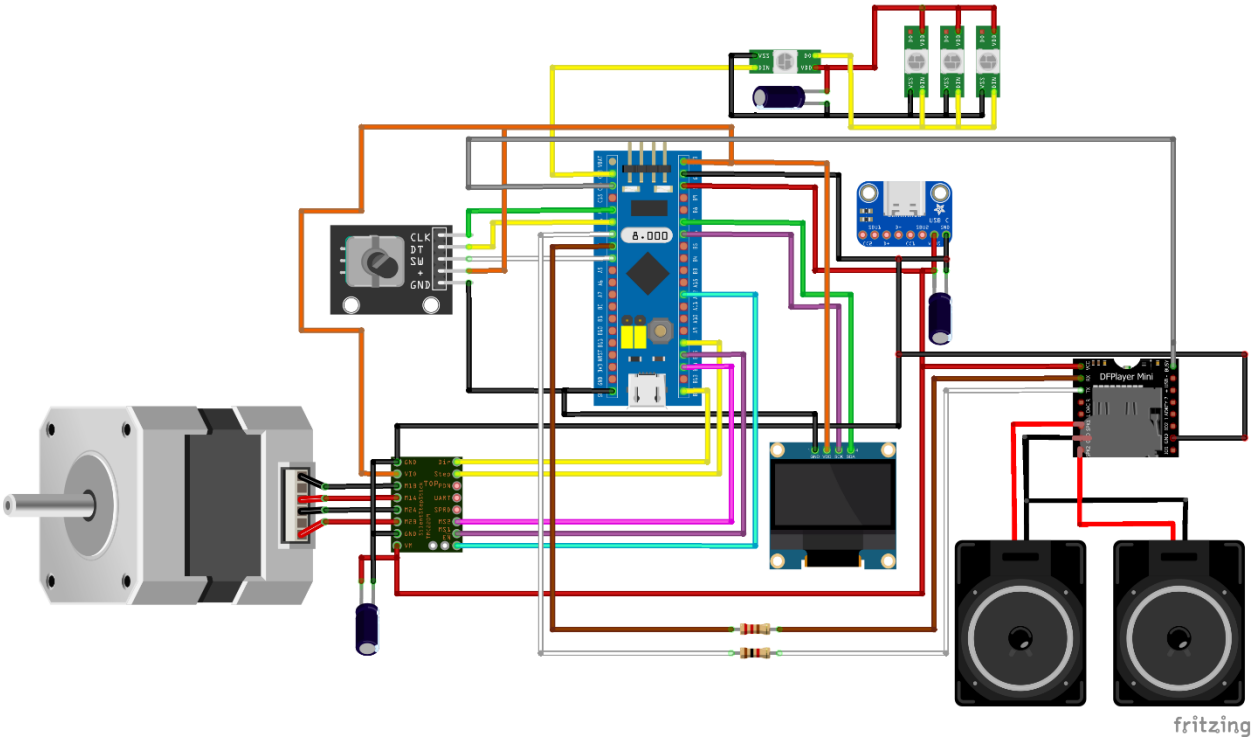
Picture 35: Inserting the LED bracket.



Picture 36: Correctly wired LED bulb

Next, you can print upper part of the sun (27). Both parts should clip and hold with friction.

21. Electronics and display.



Picture 37: Quick schematic of the electronics