DIY GO-TO CONTROLLER

MOTORIZE YOUR TELESCOPES

ROBERT HORTON

2020/12/07

WHY GO-TO?

- Refiguring and Rebuilding my old 17.5” f/4.5 Telescope (Max II)
- My “Mental Map” of the Heavens is starting to show signs of degradation ☺
- Moore’s Law of computing power
- Discovered the OnStep program and community while building the DSC
- It’s kinda cool…

WHAT I’LL BE COVERING

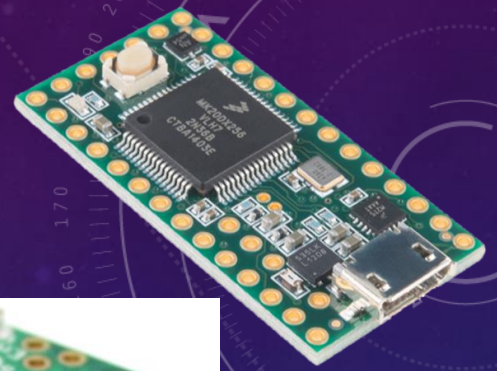
- The Electronics
- The Software
- The Mount Conversions
- The Telescope Construction

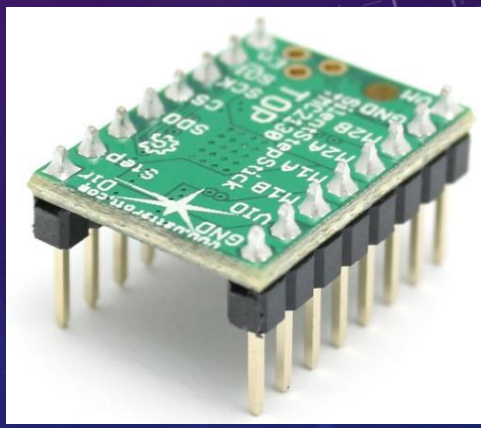
OnStep

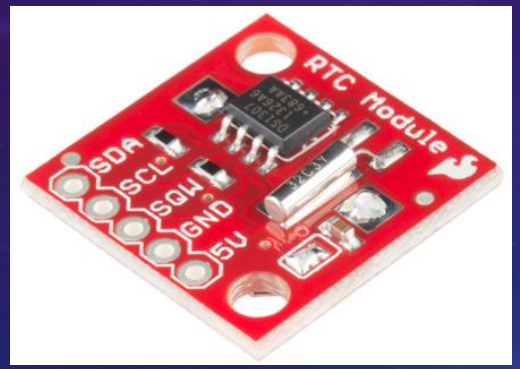
- https://onstep.groups.io/g/main/
- Started by Howard Dutton in 2017
- Supports a variety of mounts including Equatorial (GEM, Fork, etc.) and Alt/Azi (Dobsonian, etc.)
- Extensive Wiki that supports a wide variety of Hardware and Software Configurations
- Very active Message Forum with help from many experts (eg. Khalid Baheyeldin, Dave Schwartz)
- Large Showcase of people who have built or converted their telescopes to OnStep
- Low priced kits: Harold Cushing and others

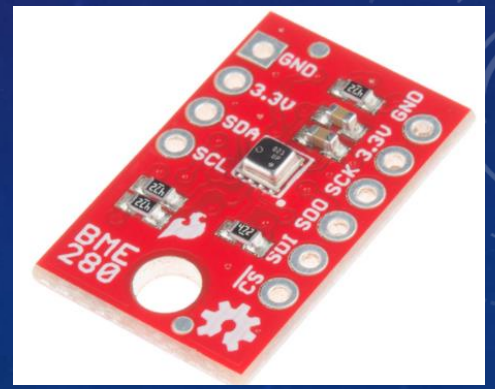
OnStep - Hardware Modules

- Microcomputers – Teensy3.2, 3.5, 4.0, Arduino Mega2560, ESP32, STM32F446…
- Stepper Motor Drivers - Pulolu A4988, LV8729, TMC2130, TMC5160
- WiFi – WeMos D1 Mini
- Ethernet – W5500ToMax2
- BlueTooth – HC-06
- Real Time Clock – Teensy, DS3231
- GPS – Neo-7m
- Weather – BME280



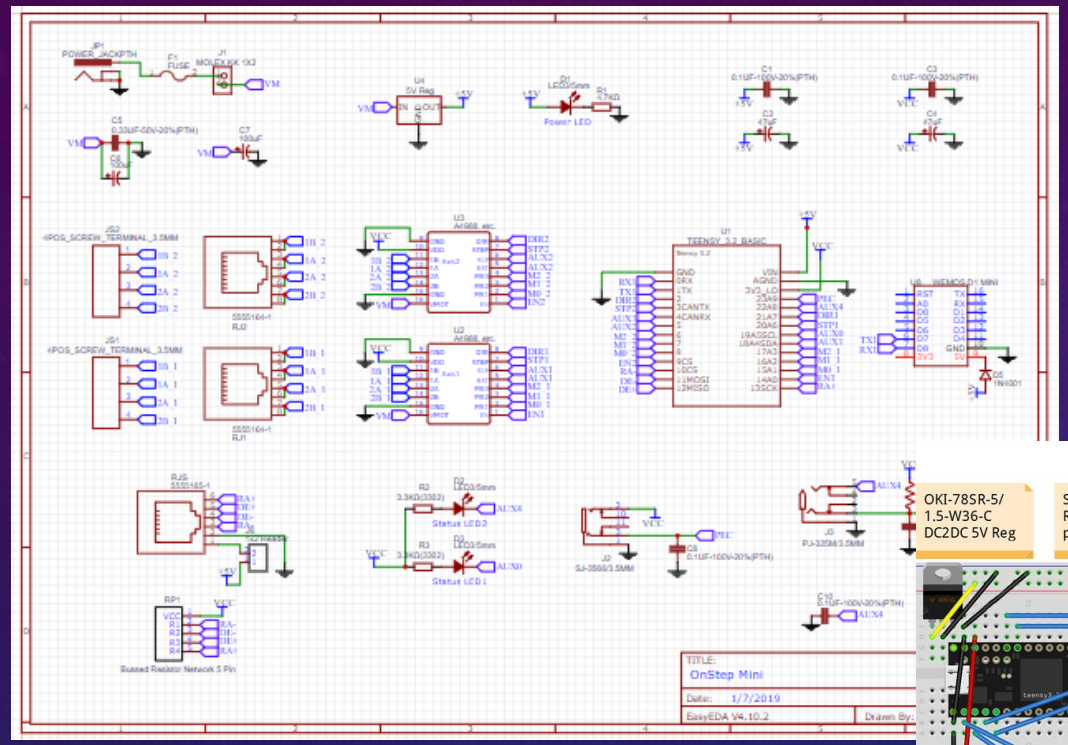




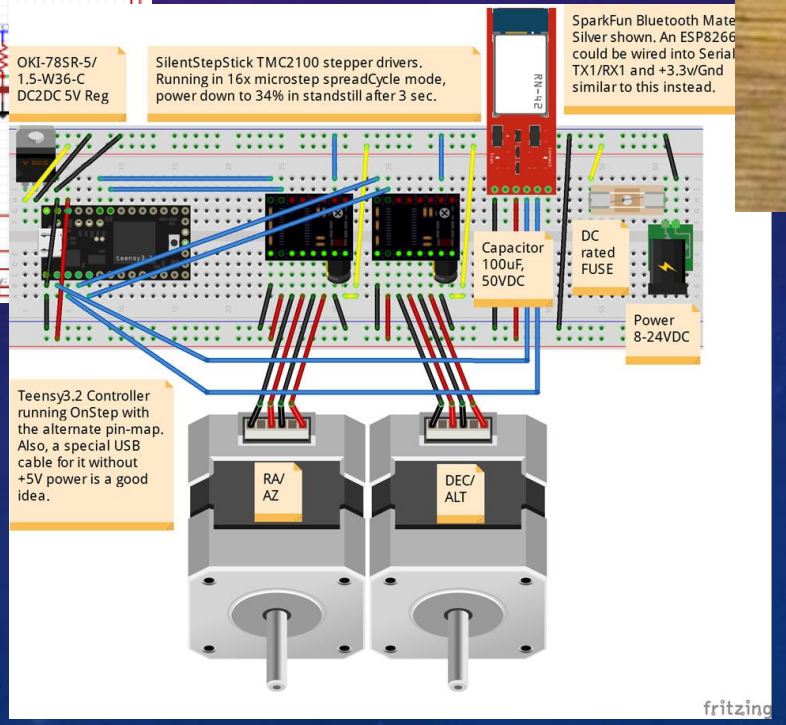


OnStep - Hardware Assemblies : Simple

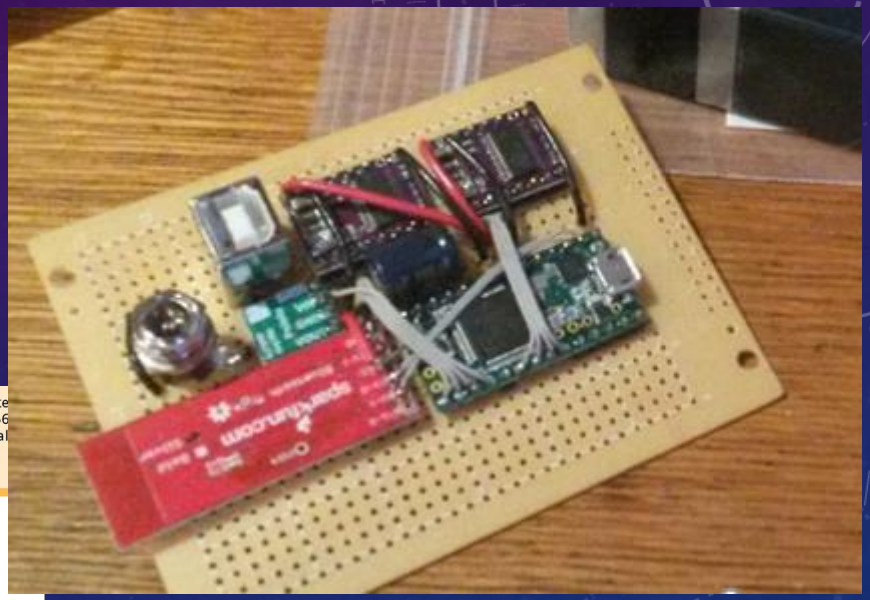
Schematic



Solderless Breadboard



Proto-Board

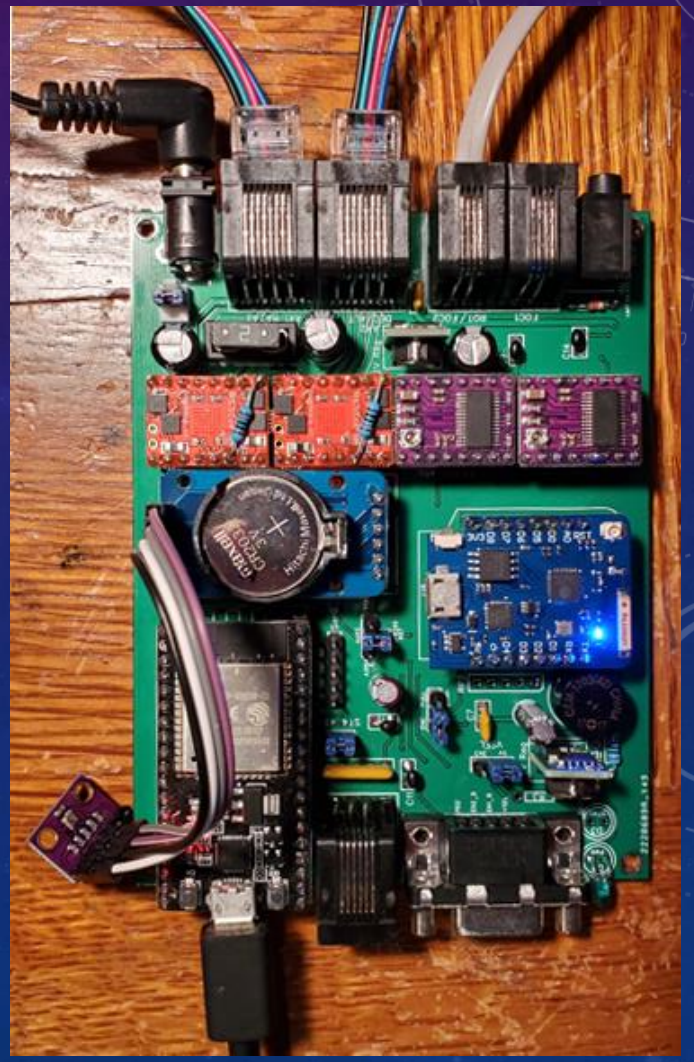


Onstep – Hardware Assemblies : Custom PCBs

MiniPCB2 ($40 + 2 Motor Drivers)

MaxPCB

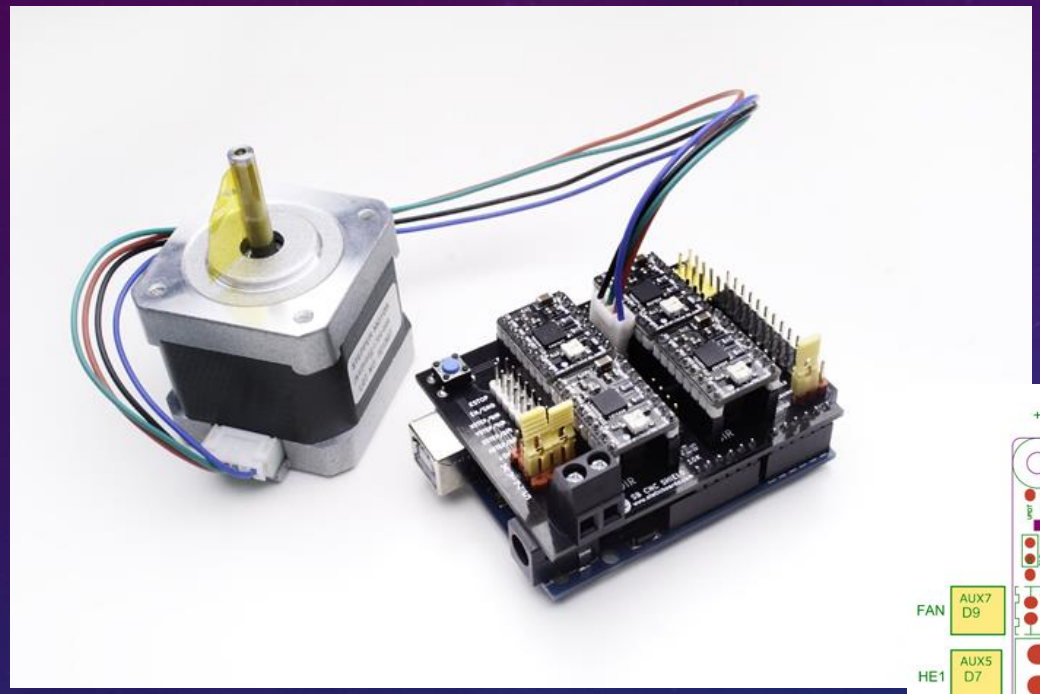
MaxESP3 ($45 + 4 Motor Drivers)



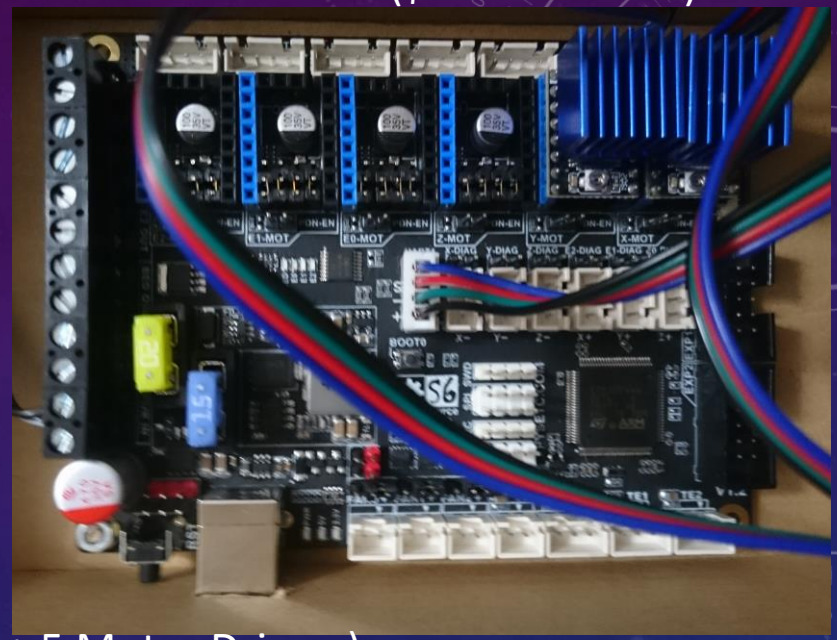
Onstep - Hardware Assemblies :

3D Printer Controllers

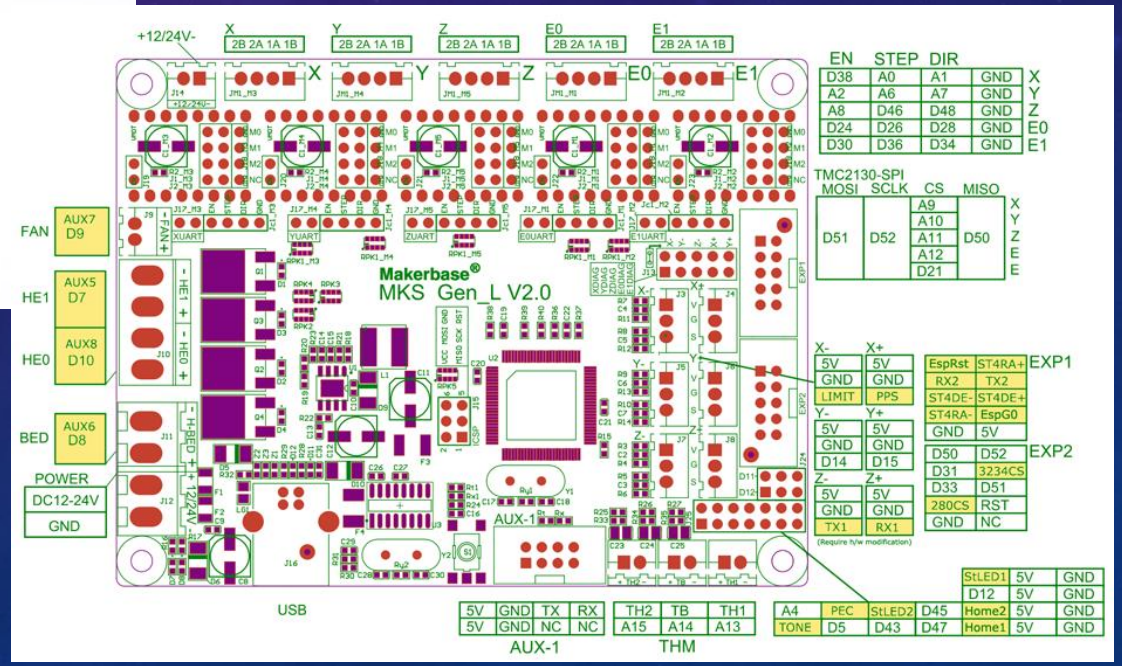
Wemos R32 + CNC V3 ($5 + $7 + 4 Motor Drivers)



FYSETC S6 ($40+ 6 Drivers)



MKS Gen_L & RAMPS ($30 + 5 Motor Drivers)



- Focusers & Field Rotators
- Fans & Dew Heaters
- Limit Switches
- Expansion Interfaces (GPS, Weather, etc)

Onstep - MiniPCB2

- Ordered Kit from George Cushing ($40)
- Includes everything except the Motor Drivers
- SilentStepStick TMC2130 Drivers ($13 each)
- Easy Pin-Through-Hole solder assembly

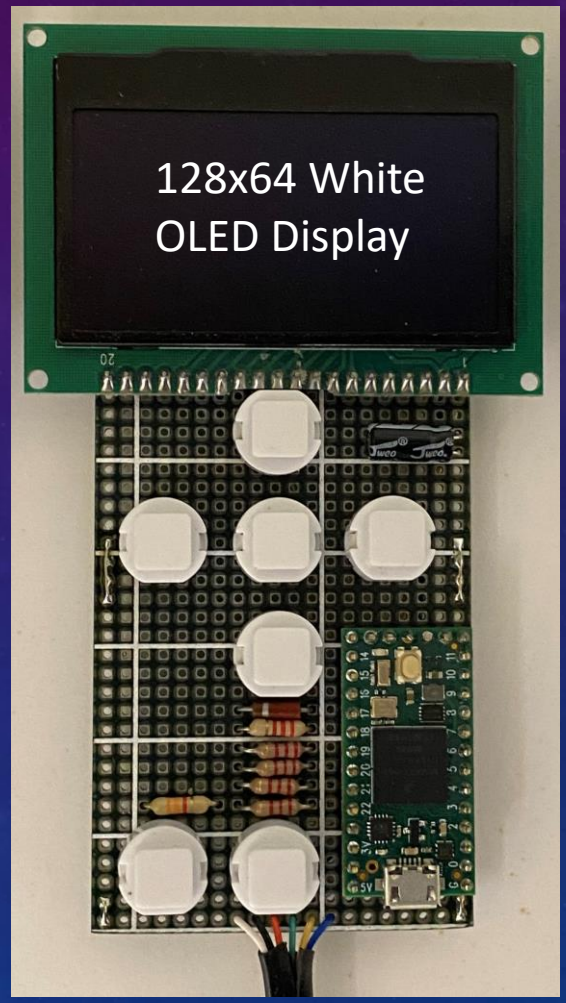
Onstep - Smart Hand Controller (SHC)

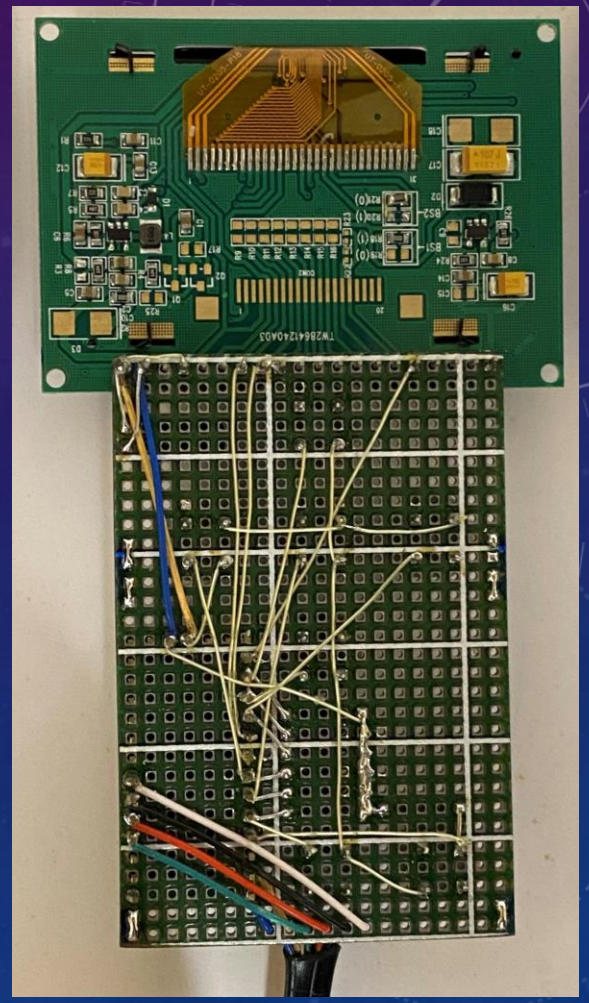
- Teensy 4.0 Microcontroller ($19.95) – Aug 2019
  - 32-bit ARM Cortex-M7 running at 600 MHz
  - 2048KB Flash, 1024KB RAM, 64KB EEPROM
  - Hardware IEEE Floating Point
  - 40 Digital I/O (3.3 Volt only)
  - 14 Analog Pins, 2 ADCs
  - Real Time Clock
  - USB, SPI, Serial, I2C, CAN, I2S Communication
  - Arduino compatible IDE (C, C++)

- Compared to Teensy 3.2
  - 14X Performance
  - 4X Flash
  - 16X RAM
  - 32X EEPROM
  - $0.15 more expensive ☺

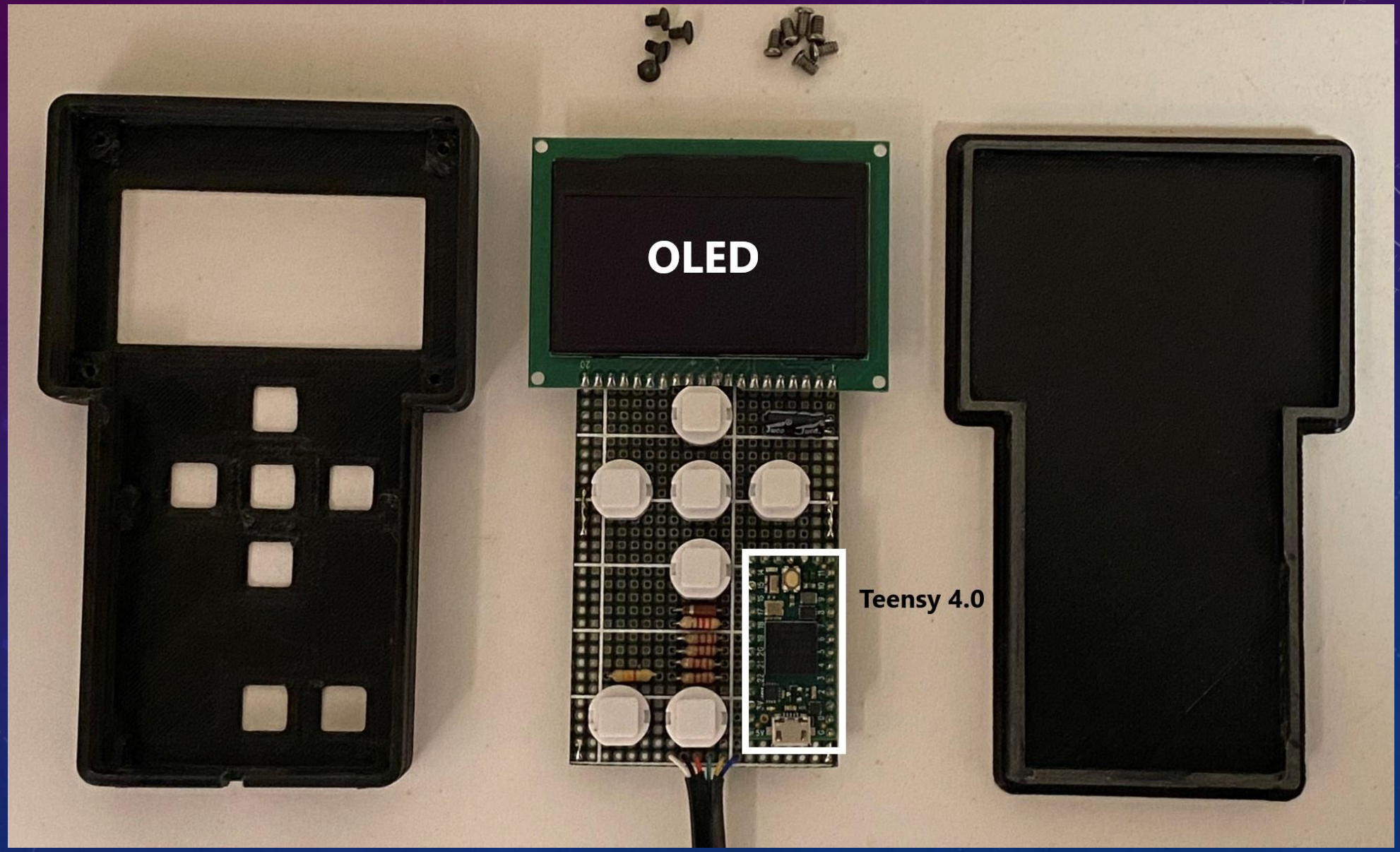
- Plugs into the ST4 Connector

- Catalogs
  - 408 Bright Stars
  - 5079 Struve Double Stars
  - 4478 Variable Stars
  - 109 Messier Objects
  - 109 Caldwell Objects
  - 400 Hershel Catalog
  - 471 Collinder (open clusters)
  - 8154 NGC Objects
  - 5400 IC Objects
  - Sun, Moon and Planets

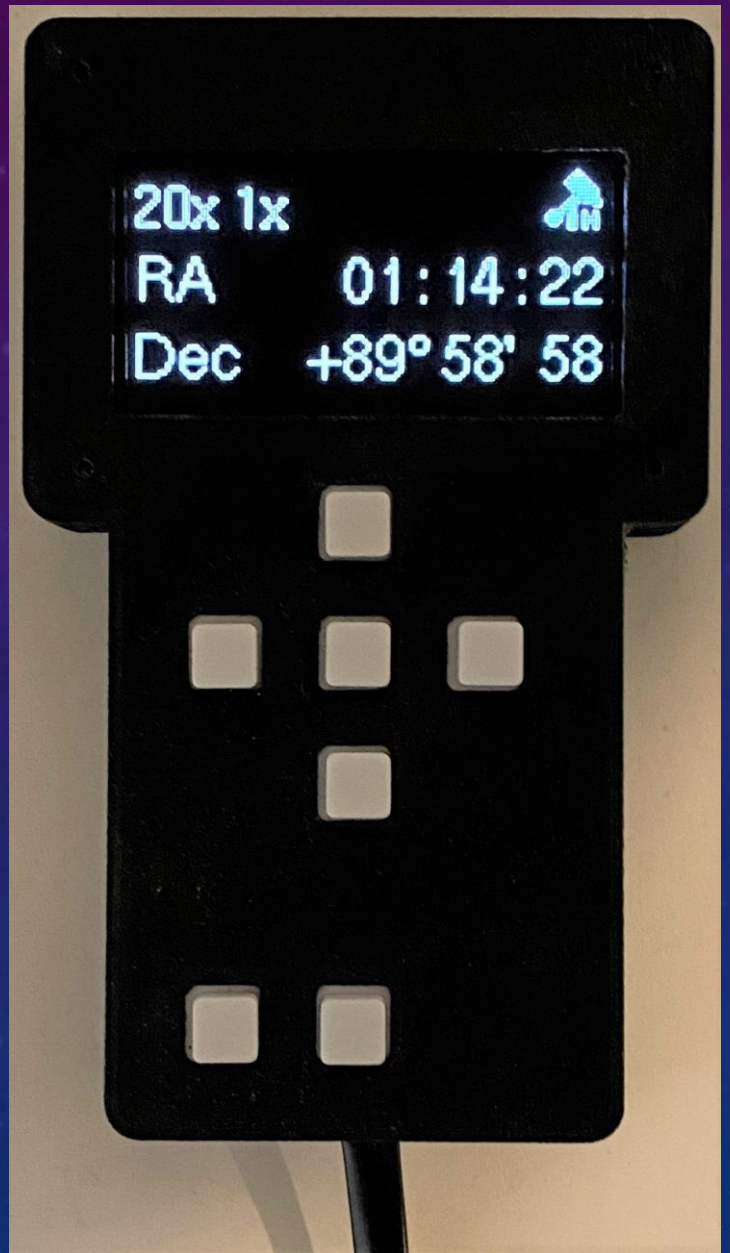




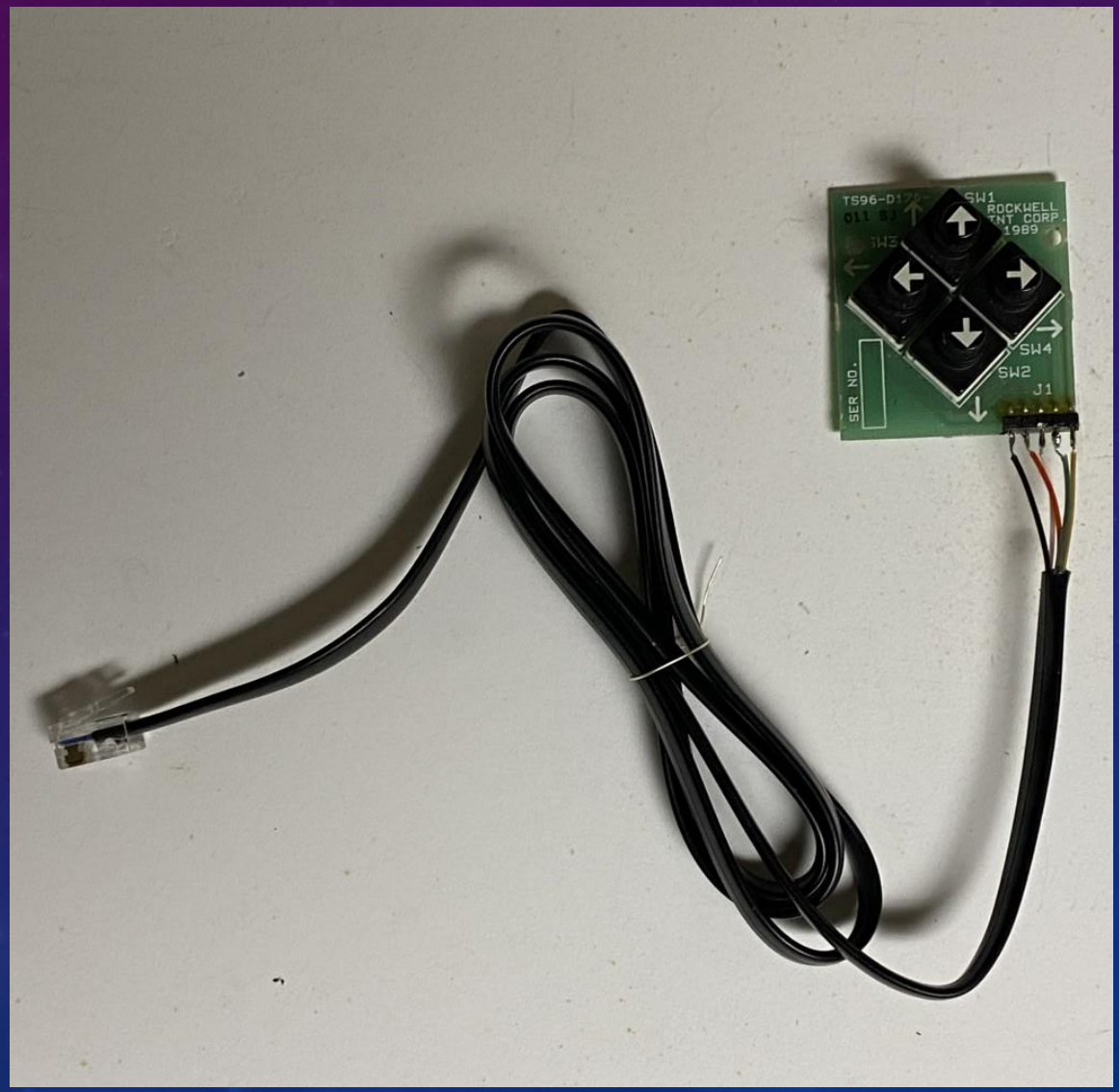
Onstep - Smart Hand Controller (SHC)



Onstep - Smart Hand Controller (SHC)



Onstep - Dumb Hand Controller (DHC)



OnStep - Software (by Howard Dutton)

- Open Source C/C++
- Arduino Programming Tools
- Highly Configurable
- Under Continuous Development

OnStep - Goto.ino | Arduino 1.8.12

File Edit Sketch Tools Help

OnStep | Align.h | AlignEq | AlignHor | Astro | Command | Config.h | Constants.h | Globals.h

```
16 CommandErrors validateGotoCoords(double HA, double Dec, double Alt) {
17   // Check coordinates
18   if (Alt < minAlt)                          return CE_GOTO_ERR_BELOW_HORIZON;
19   if (Alt > maxAlt)                          return CE_GOTO_ERR_ABOVE_OVERHEAD;
20 #if AXIS2_TANGENT_ARM != ON
21     if (Dec < AXIS2_LIMIT_MIN)               return CE_SLEW_ERR_OUTSIDE_LIMITS;
22     if (Dec > AXIS2_LIMIT_MAX)               return CE_SLEW_ERR_OUTSIDE_LIMITS;
23 #endif
24   if ((fabs(HA) > AXIS1_LIMIT_UNDER_POLE))   return CE_SLEW_ERR_OUTSIDE_LIMITS;
25   return CE_NONE;
26 }
27
28 CommandErrors validateGoToEqu(double RA, double Dec) {
29   double a,z;
30   double HA=haRange(LST()*15.0-RA);
31   equToHor(HA,Dec,&a,&z);
32   CommandErrors r=validateGoto(); if (r != CE_NONE) return r;
33   r=validateGotoCoords(HA,Dec,a);
34   return r;
35 }
36
37 // syncs the telescope/mount to the sky
38 CommandErrors syncEqu(double RA, double Dec) {
39   double a,z;
40
41   // Convert RA into hour angle, get altitude
42   // hour angleTrackingMoveTo
43   double HA=haRange(LST()*15.0-RA);
44   equToHor(HA,Dec,&a,&z);
45
46   // validate
47   CommandErrors e=validateGoto();
```

OnStep - Config.h | Arduino 1.8.12

File Edit Sketch Tools Help

OnStep | Align.h | AlignEq | AlignHor | Astro | Command | Config.h | Constants.h | Globals.h | Goto | Guide | Home | Initialize | MoveTo | Park | Pec

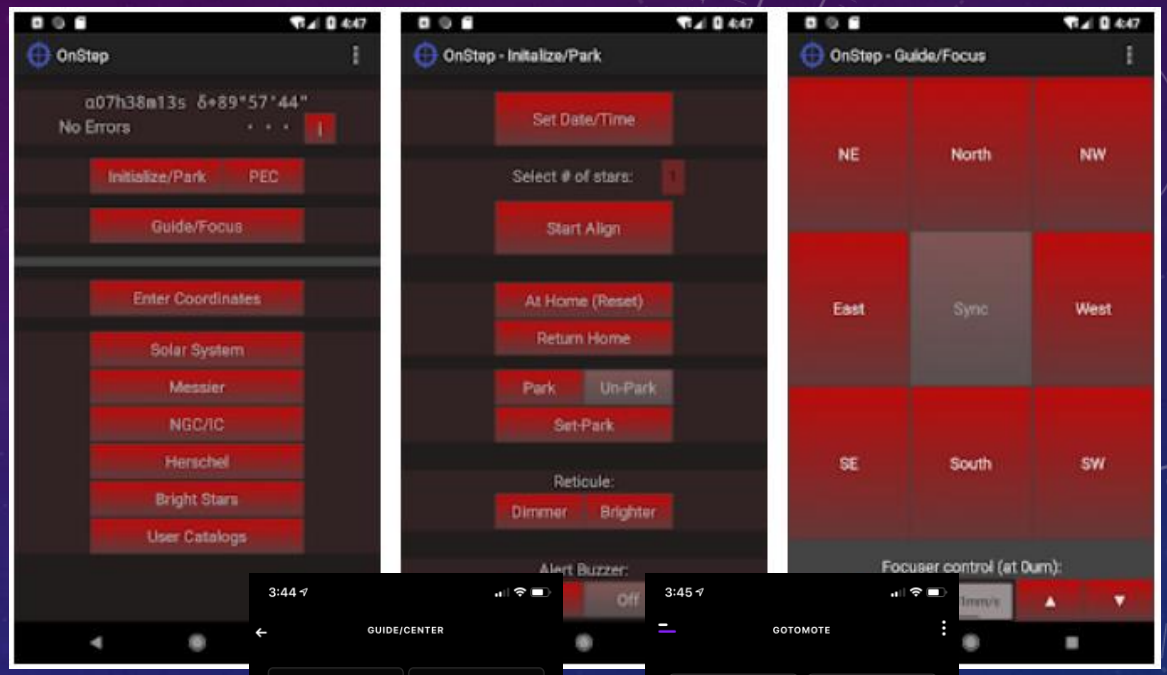
```
115                                          //        n = (stepper_steps * micro_steps * overall_gear_reduction)/360.0
116 #define AXIS1_STEPS_PER_WORMROT     12800 //  12800, n. Number of steps per worm rotation (PEC Eq mode only:)          <-Req'd
117                                          //        n = (AXIS1_STEPS_PER_DEGREE*360)/reduction_final_stage
118
119 #define AXIS1_DRIVER_MODEL  TMC2130_QUIET //    OFF, (See above.) Stepper driver model.                                  <-Often
120 #define AXIS1_DRIVER_MICROSTEPS        32 //    OFF, n. Microstep mode when tracking.                                    <-Often
121 #define AXIS1_DRIVER_MICROSTEPS_GOTO  OFF //    OFF, n. Microstep mode used during gotos.                                 Option
122 #define AXIS1_DRIVER_IHOLD            100 //    OFF, n, (mA.) Current during standstill. OFF uses IRUN/2.0                Option
123 #define AXIS1_DRIVER_IRUN             300 //    OFF, n, (mA.) Current during tracking, appropriate for stepper/driver/etc. Option
124 #define AXIS1_DRIVER_IGOTO            600 //    OFF, n, (mA.) Current during slews. OFF uses same as IRUN.                Option
125 #define AXIS1_DRIVER_REVERSE          OFF //    OFF, ON Reverses movement direction, or reverse wiring instead to correct. <-Often
126 #define AXIS1_DRIVER_STATUS           OFF //    OFF, TMC_SPI, HIGH, or LOW.  Polling for driver status info/fault detection. Option
127
128 #define AXIS1_LIMIT_UNDER_POLE        180 //    180, n. Where n=150..180 (degrees.) Max HA hour angle + or - for Eq modes.  Infreq
129 #define AXIS1_LIMIT_MAXAZM            360 //    360, n. Where n=180..360 (degrees.) Max Azimuth + or - for AltAzm mode only. Infreq
130
131 // AXIS2 DEC/ALT
132 // see https://onstep.groups.io/g/main/wiki/6-Configuration#AXIS2
133 #define AXIS2_STEPS_PER_DEGREE    15222.2 //  12800, n. Number of steps per degree:                                    <-Req'd
134                                          //        n = (stepper_steps * micro_steps * overall_gear_reduction)/360.0
135
136 #define AXIS2_DRIVER_MODEL  TMC2130_QUIET //    OFF, (See above.) Stepper driver model.                                  <-Often
137 #define AXIS2_DRIVER_MICROSTEPS        32 //    OFF, n. Microstep mode when tracking.                                    <-Often
138 #define AXIS2_DRIVER_MICROSTEPS_GOTO  OFF //    OFF, n. Microstep mode used during gotos.                                 Option
139 #define AXIS2_DRIVER_IHOLD            100 //    OFF, n, (mA.) Current during standstill. OFF uses IRUN/2.0                Option
140 #define AXIS2_DRIVER_IRUN             300 //    OFF, n, (mA.) Current during tracking, appropriate for stepper/driver/etc. Option
141 #define AXIS2_DRIVER_IGOTO            600 //    OFF, n, (mA.) Current during slews. OFF uses same as IRUN.                Option
142 #define AXIS2_DRIVER_POWER_DOWN       OFF //    OFF, ON Powers off 10sec after movement stops or 10min after last<=1x guide. Option
143 #define AXIS2_DRIVER_REVERSE          OFF //    OFF, ON Reverses movement direction, or reverse wiring instead to correct. <-Often
144 #define AXIS2_DRIVER_STATUS           OFF //    OFF, TMC_SPI, HIGH, or LOW.  Polling for driver status info/fault detection. Option
145 #define AXIS2_TANGENT_ARM             OFF //    OFF, ON +limit range below. Set cntr w/[Reset Home] Return cntr w/[Find Home] Infreq
146
```

1 Teensy 3.2 / 3.1, Serial, 96 MHz (overclock), Faster, US English on usb:0/140000/0/4

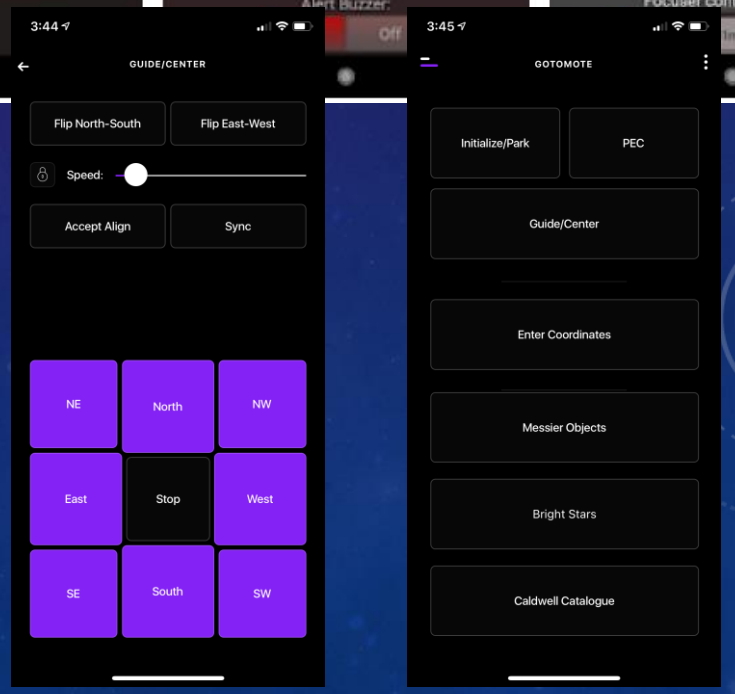
OnStep - Software Capabilities

- Controls up to 5 Stepper Motors (GoTo, Guide, Track)
  - RA (Azi), DEC (Alt), Field Rotator, Focuser 1 & 2
- ST4 Interface for autoguiding and hand controllers
- Status Indicators
  - Tracking LED, Reticle LED, Buzzer
- Time and Location Sources
  - Teensy, DS3231, GPS, Smart Phone
- Weather and Temperature Sensors
  - BME280, DS1820
- Switch Sensors
  - Home Position, Limit Switches, PEC, PPS
- Tracking
  - Refraction, Backlash, Sidereal/Solar/Lunar Rate
- Initialization
  - Up to 9-Star Alignment
  - Sync to Current Object
- Meridian Flip for GEMs
- WiFi, Bluetooth, Ethernet
  - Web Server (http://192.168.0.1/)
  - Android/iOS Apps – Hand Controls
  - LX200+ Protocol to Planetarium Programs

OnStep Android App



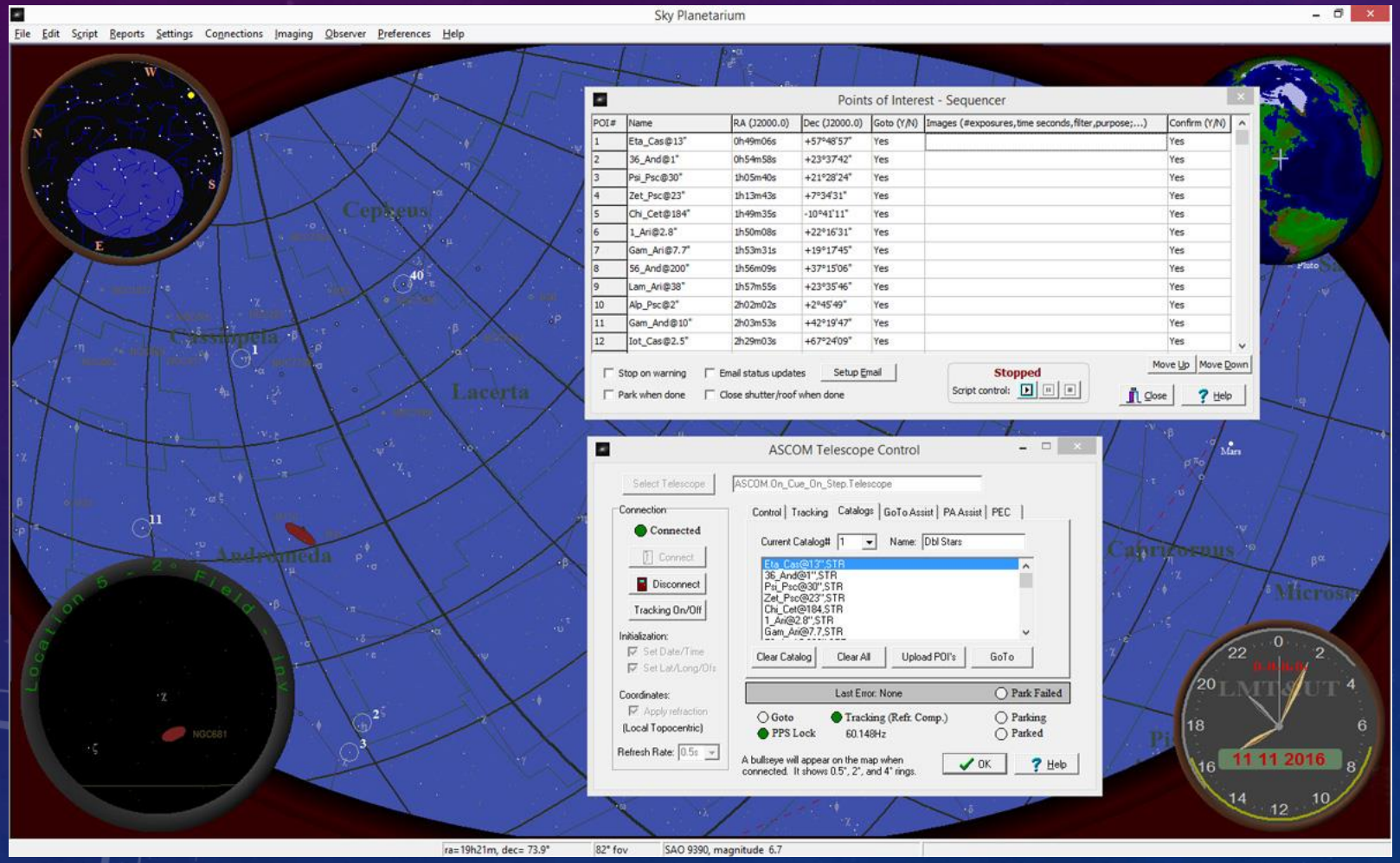
GoToMote iOS App



OnStep - Planetarium Programs

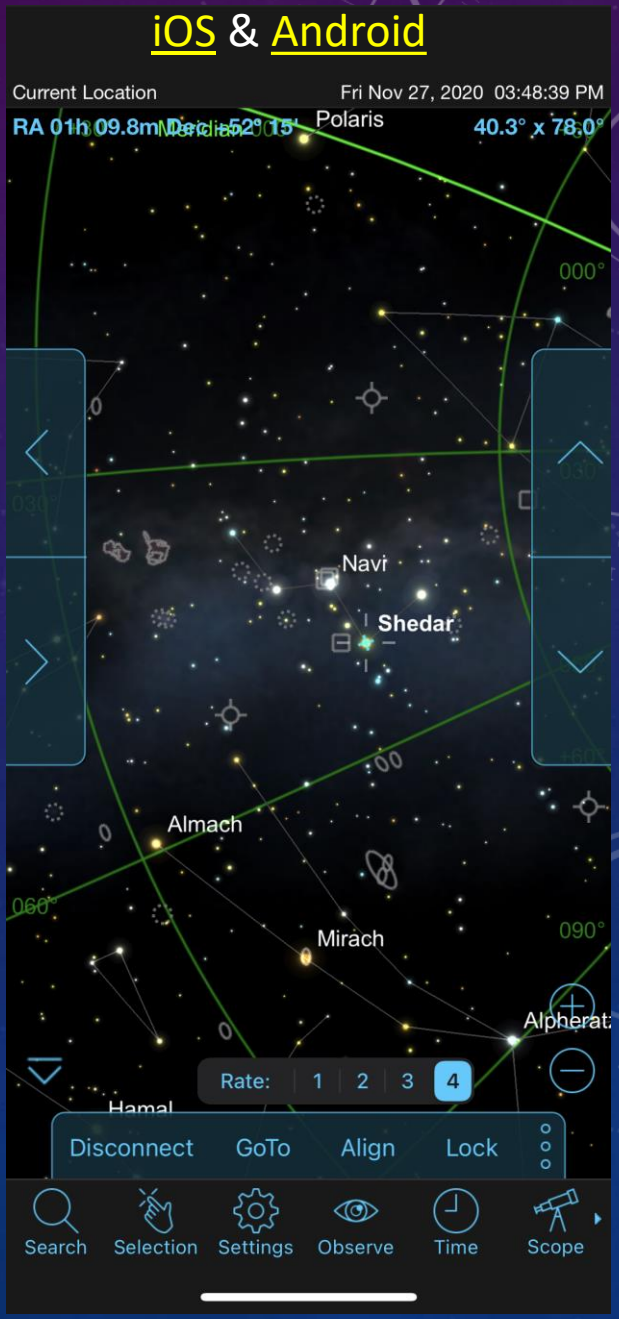
- Stellarium (Windows, Mac OS X, Linux, iOS, Android)
- Cartes du Ciel (Windows, Mac OS X, Linux, RPi ARM)
- KStars (Linux, Windows, Android)

Sky Planetarium – Windows (by Howard Dutton)



Sky Safari 6 Plus/Pro

iOS & Android



Onstep – Telecope Mount Conversions

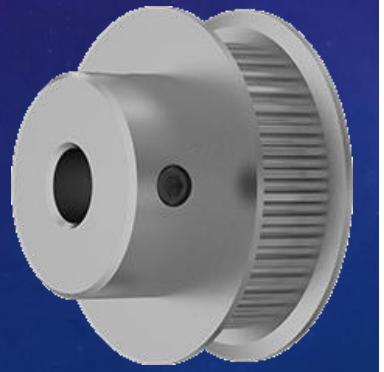
OnStep Showcase Page

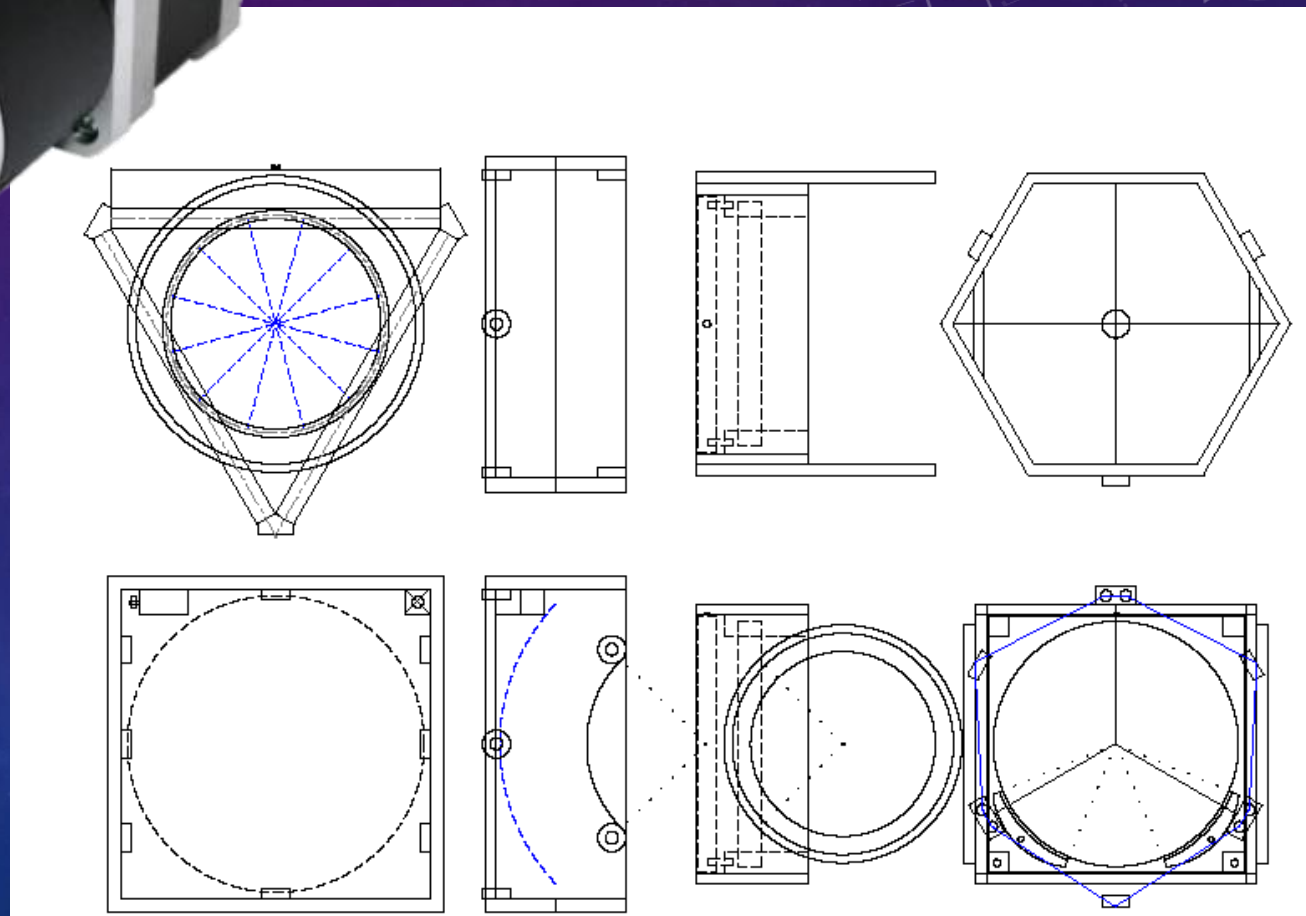
- Equatorial & Fork
  - SkyWatcher EQ3, EQ5, NEQ5, EQ6
  - Celestron CG4, CG5, CGE, CGE Pro, CGEM
  - Vixen Super Polaris, Great Polaris, SXD
  - Orion AstroView, SkyView Pro
  - Meade LXD 75, LXD 600, LXD 650
  - Bresser EXOS1
  - Losmandy GM8, G11
  - Celestron CI700, CG11
  - iOptron iEQ30, EQ45, SmartStar PR EQ
  - Takahashi NJP
  - Astro-Physics AP400, AP1200
  - Meade LX200, LX3
- Dobsonian & AltAzi
  - Orion XT10, XT10 Plus, XT12, StarFinder
  - SkyWatcher Stargate 500
  - Celestron NexStar
  - Vixen Porta II
  - Custom DIY Mounts (like mine)

The 17.5” f/4.5 Telescope Construction : Max III

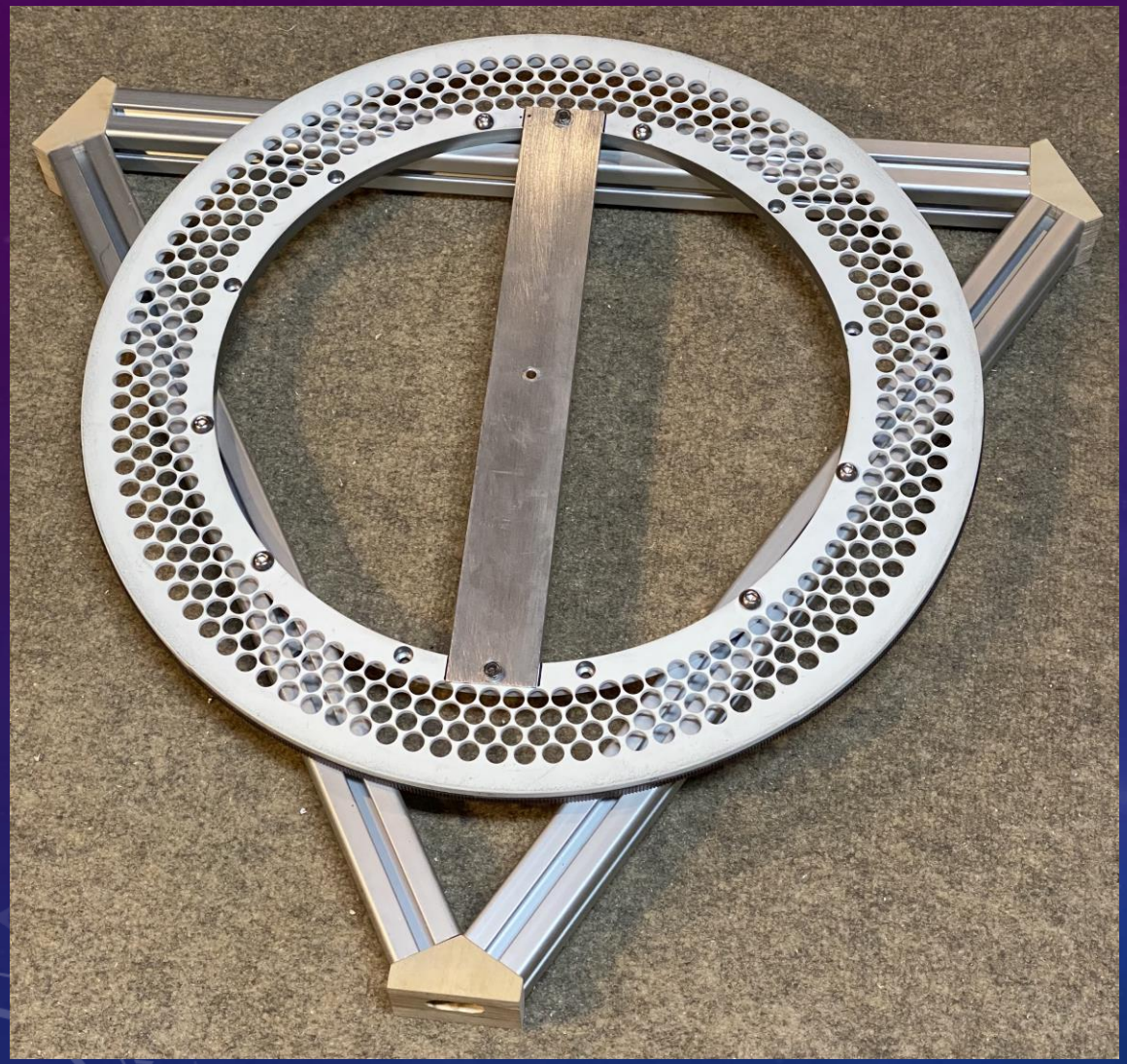
200*50*32*(848/40)/360 = 18844

- Sky Optical Mirror (1980’s)
  - Currently being Re-Figured…!
- Rough design in LibreCAD ->
- Uses Bearings instead of Teflon/Formica
- 3 Truss Tube Pairs
- Lightweight Focuser/Diagonal Cage
- Stepper Motors (Stepper Online)
  - 200 Full Step NEMA-17 Motors
  - 50:1 Precision Planetary Reduction Gear
  - Running at 32 Microsteps per Full Step
- GT2 Timing Gears/Pulleys and Belts (McMaster-Carr)
  - Azimuth
    - 40 Tooth Gear on Motor
    - 848 Tooth Belt on Axis Ring
    - 18844 Steps per Degree
  - Altitude
    - 40 Tooth Gear on Motor
    - 686 Tooth Belt on Axis Ring
    - 15222 Steps per Degree





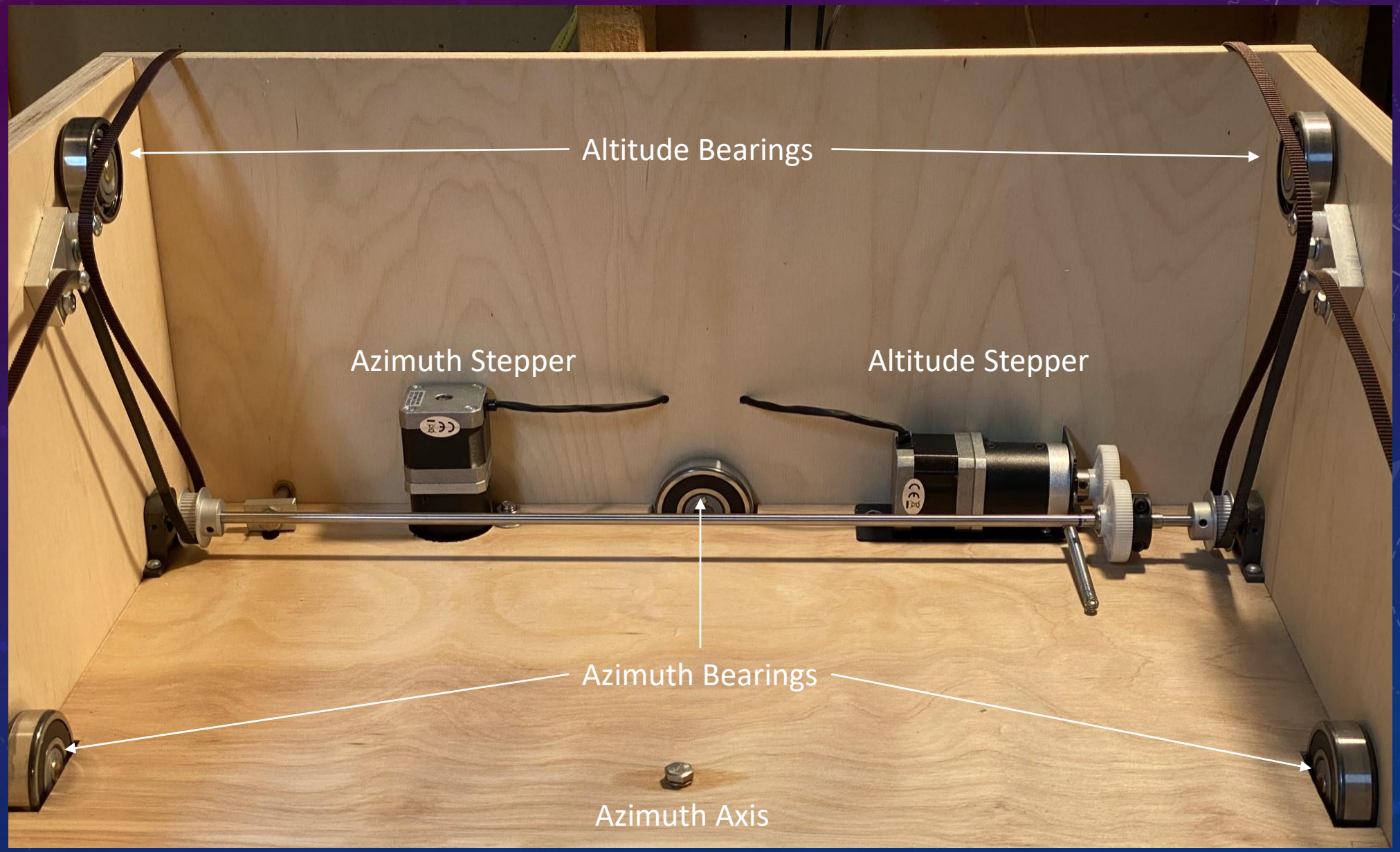
The 17.5” f/4.5 Scope : Ground Triad & Azimuth Gear



848 Teeth (Yes, I counted them !)

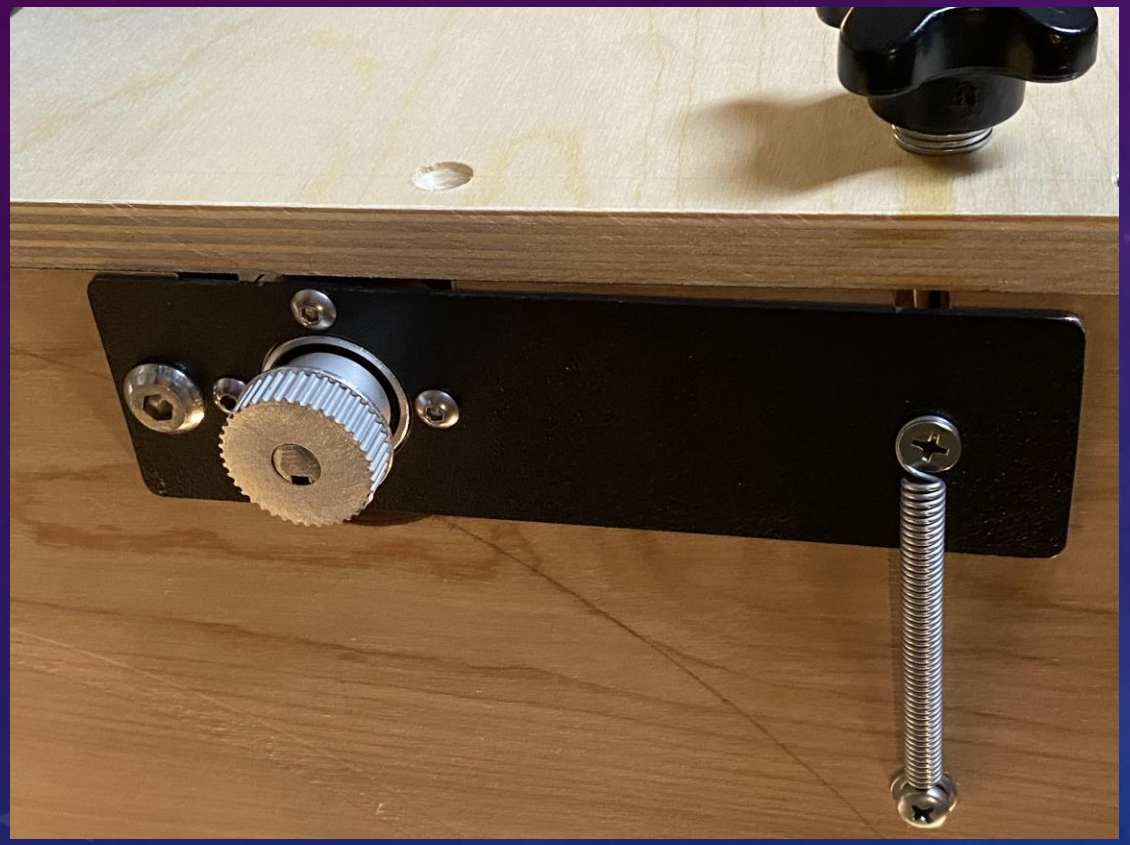
Timing Belt attached to ring with Scrapbooking Tape

The 17.5” f/4.5 Scope : Rocker Box & Stepper Motors

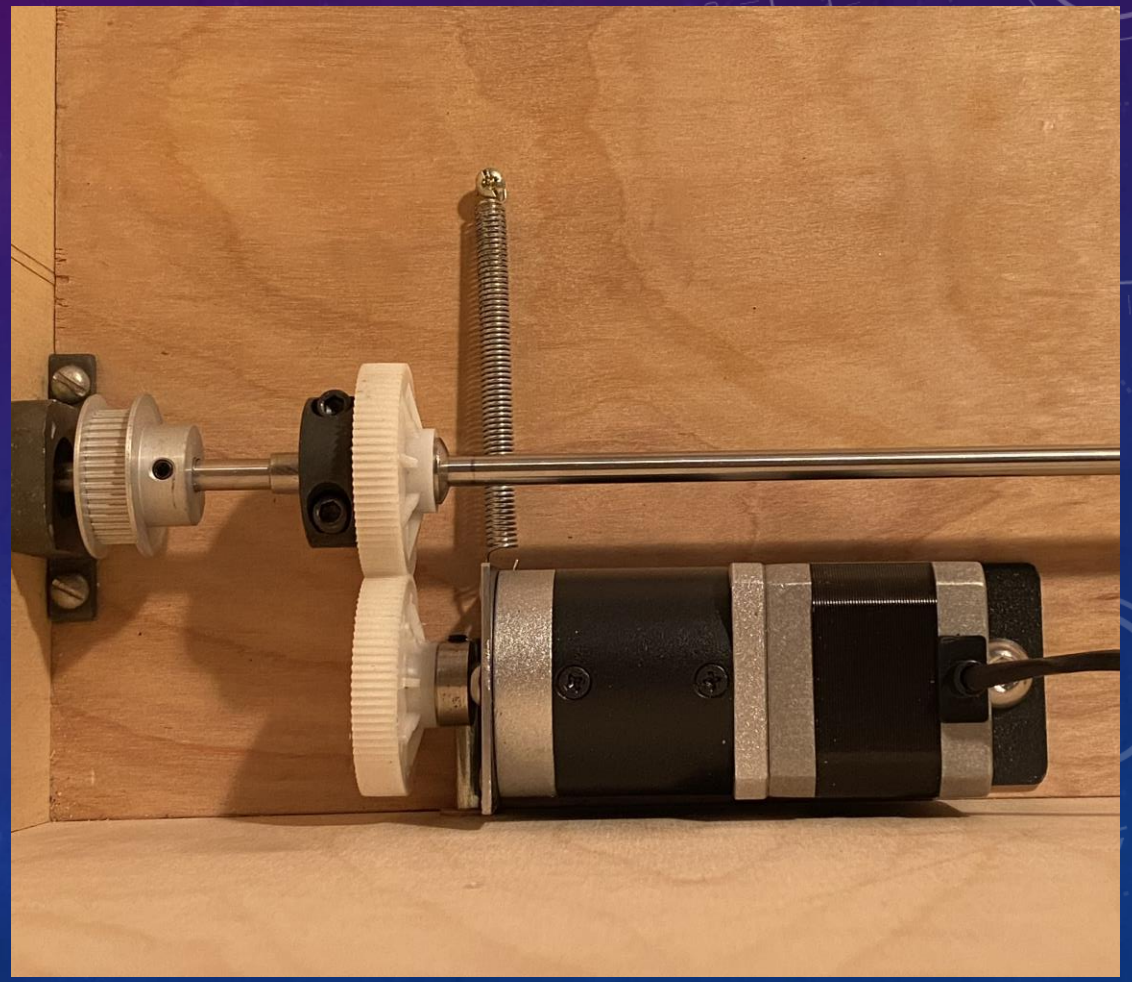


The 17.5” f/4.5 Scope : Motors & 40-Tooth Gears

Azimuth Motor Gear

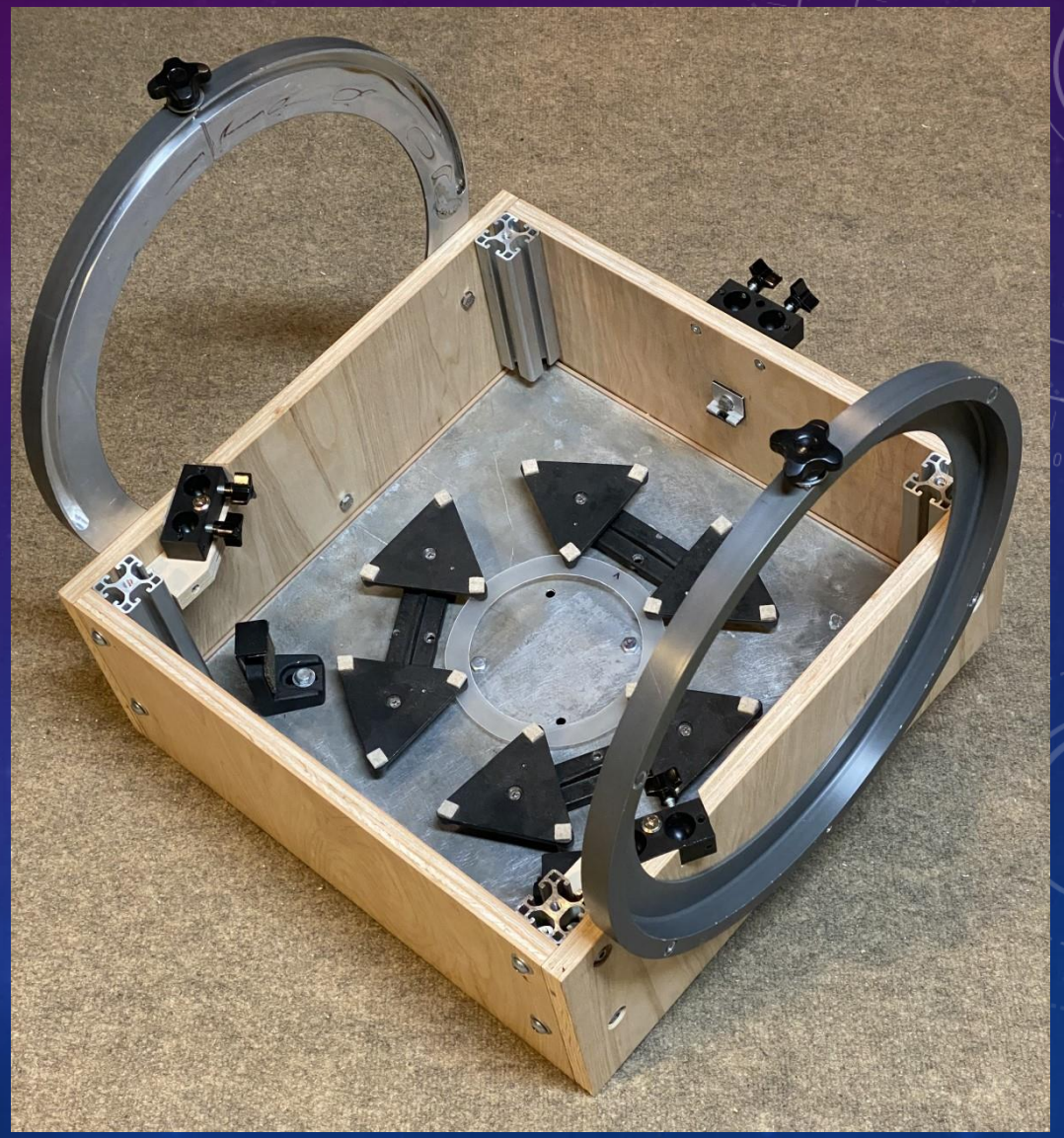


Altitude Motor Gear



The 17.5” f/4.5 Scope : Mirror Box & Altitude Rings

- 18 Point Flotation Cell
- Ball & Socket mounts for Truss Tubes
- Plan to add Fans to equalize mirror temp



The 17.5” f/4.5 Scope : Trusses