Astronomical Adventures

Building, Outfitting and Operating a Remote Observatory

Manny Leinz

Nightfall Imaging Conference
November 11, 2023

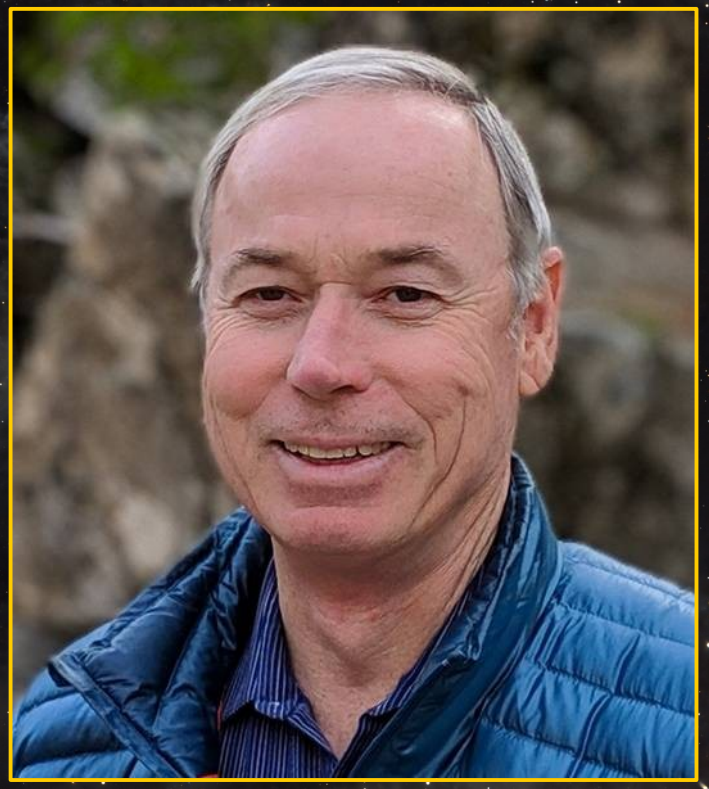
Cover and Background Image: LBN 406

We Will Talk About...

- A little about me
- Dreaming to Building – Selecting the Observatory Site
- Observatory Design/Build Details
- Initial and Current Imaging Configuration
- Observatory Control Strategy and Implementation
- Observatory Software
  - Home Assistant, Node-Red, Dashboards
- Observatory Hardware
  - Overview, Power Control, Backup Power
  - AllSky Camera, Cloud, Rain Sensors
- A Typical Night of Remote Imaging
- Limitations, Next Steps
- A Few Astro Images
- Resources
- Getting in Touch

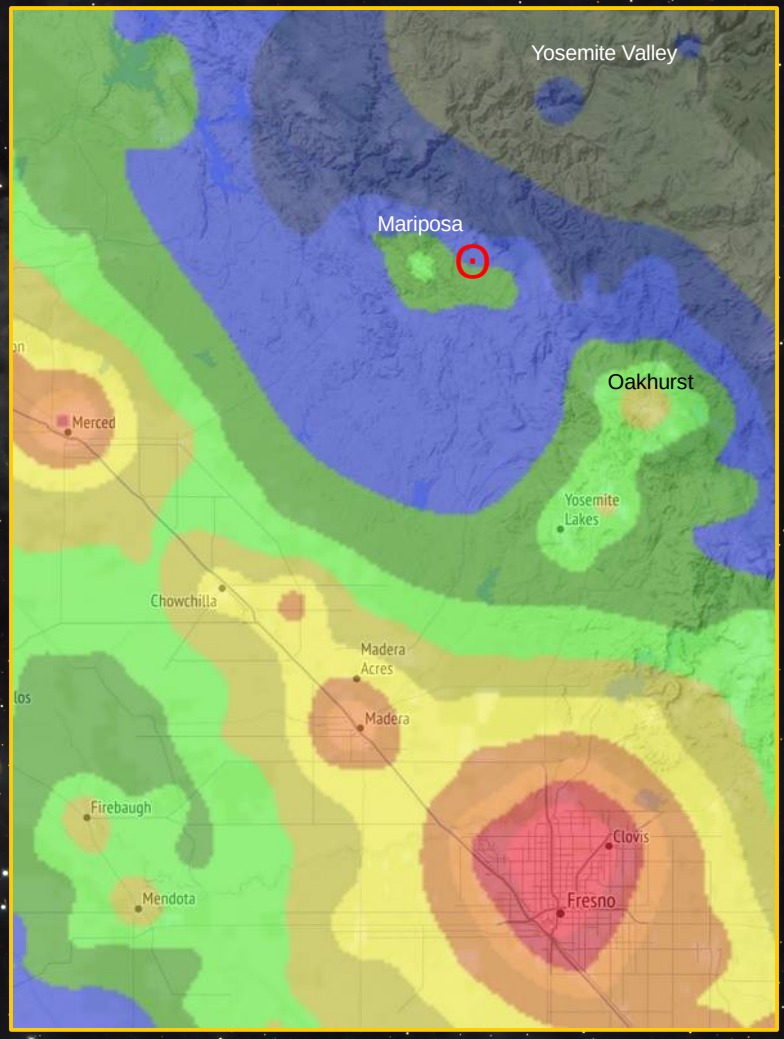
A Little About Me...

- Happily married husband and father
- Former Engineering Manager in Boeing Space business
  - Retired 2015
- Amateur astronomer for 30+ years
  - Observational and more recently astrophotography
  - RAS Member for several years
  - Dreamed of having an observatory for many years
- Enjoy travel, photography (including nightscapes), guitar, family history



Dreaming to Building - Selecting the Site

- Objective: Build an observatory far from city lights on the site that would double as a vacation home in the mountains
  - Visual Astronomy
  - Astroimaging
  - Electronically Assisted Astronomy – Outreach
  - Citizen Science
- We selected a property outside the Gold Rush town of Mariposa (Bortle class 3) – Purchased December 2014
- Pros:
  - Reasonably dark location
  - Comfortable sleeping arrangements on site – no warm room needed
  - Our favorite National Park nearby!
- Cons:
  - Long drive (No dark sites in the local mountains)
  - Autonomous systems need to be *very* robust
  - Not the cheapest option...



darksitefinder.com/maps

Observatory Design/Build Details

- Contractor build
  - 3 Days in November, 2017
  - Backyard Observatories *(www.backyardobservatories.com)*
- Roll-off roof design
  - Inconspicuous, simplified control
  - Roll-off to the east, away from the road
- Size: 15’ x 8’ (120 ft^2)
  - Avoids building permits)
  - External “plug-in” power
- Accommodates two piers:
  - Astroimaging (N), Observational (S) - TBD
  - Platform floor
    - Cheaper than concrete, simplifies cable runs underneath

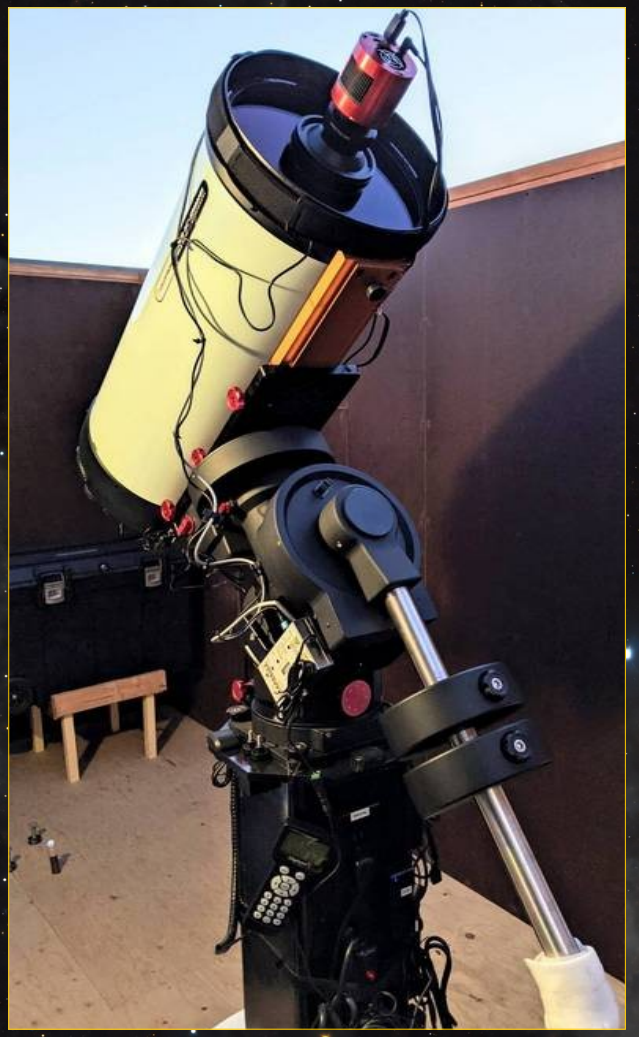
Observatory Build

Three Days in 60 Seconds...

Initial/Current Imaging Configuration

- **Telescopes**:
  - Celestron C-11
  - Stellarvue SV70ED 70 mm refractor
- **Mount**
  - CGEM
- **Imaging Camera**
  - Canon 60D DSLR, then...
  - ZWO ASI294 MC Pro (10.7 Mpixel Color Cooled)
- **Guide Camera/ Scope**
  - QHY5L-II 1.2 Mpixel mono
  - Astromania 60 mm Scope
- **Software:**
  - Nebulosity
  - PHD2
  - Deep Sky Stacker
  - Photoshop

2017 - 2020



2020 - Present

- **Telescope:**
  - Celestron RASA-11
- **Mount:**
  - Ioptron CEM120-EC2
- **Imaging Camera**
  - ZWO ASI294 MC Pro (10.7 Mpixel Color Cooled)
- **Guide Camera/Scope**
  - QHY5L-II 1.2 Mpixel mono
  - Astromania 60 mm Scope
- **Software:**
  - N.I.N.A.
  - PHD2
  - Pixinsight

Autonomy Phases

Crawl → Walk → Run

	Phase 1	Phase 2a	Phase 2b	Phase 3a	Phase 3b
Control Location	**Observatory**	**Mariposa Home**	**Mariposa Home**	**SoCal Home**	**SoCal Home**
Capabilities	• Local Manual Startup, Shutdown • Manual Operation	• Manual Startup/Shutdown • Tele-Operation Imaging	• TeleOp Startup/Shutdown • Remote Autonomous Imaging	• TeleOp Startup/Shutdown • Remote Autonomous Imaging • Manual safety monitoring	• Full Remote Autonomy • Remote Autonomous Imaging • Automated Safety Monitoring
Observatory Control					
Roof Motor Control	Manual (Hand Controller)	Manual (Hand Controller)	HA/Node-Red Software Control	HA/Node-Red Software Control	HA/Node-Red Software Control
Control Hardware/ Operating System	None	None	Raspberry Pi/Linux	Raspberry Pi/Linux	Raspberry Pi/Linux
Control Software	None	None	Home Assistant/Node-Red	Home Assistant/Node-Red	Home Assistant/Node-Red
Safety Systems					
Situational Awareness Cameras	None	None	Two 5 MP PoE Reolink Cameras	Two 5 MP PoE Reolink Cameras	Two 5 MP PoE Reolink Cameras
Roof Clearance Detect	TBD	TBD	N/A (No Interference Possible)	N/A (No Interference Possible)	N/A (No Interference Possible)
Rain Detect	None	None	None	None	Rasp Pi/HA/Mode-Red Software
Network Loss Detect	None	None	Rasp Pi/HA/Mode-Red Software	Rasp Pi/HA/Mode-Red Software	Rasp Pi/HA/Mode-Red Software
Power Loss Detect	None	None	Rasp Pi/HA/Mode-Red Software	Rasp Pi/HA/Mode-Red Software	Rasp Pi/HA/Mode-Red Software
Backup Power	None	None	None	Renogy Inverter/Battery Backup	Renogy Inverter/Battery Backup
Lighting					
	Red, white w/wall switch control	Red, white w/wall switch control	Red, White with Smart Switches	Red, White with Smart Switches	Red, White with Smart Switches
Weather					
Indoor/Outdoor Temperature, Wind, Rain, Barometric Pressure	None	Ambient Weather WS-0900	Ambient Weather WS-0900	Ambient Weather WS-0900	Ambient Weather WS-0900
AllSky Camera	None	None	None	Custom - Rasp Pi, Jacquin AllSky Software	Custom - Rasp Pi, Joaquin AllSky Software
All Sky Cloud Sensor	None	None	None	None	Custom – Integrated w/AllSkyCam
Rain Sensor	None	None	None	None	Hydreon RG-9
Imaging System					
Telescope	Celestron C-11	Celestron RASA-11 V2	Celestron RASA-11 V2	Celestron RASA-11 V3	Celestron RASA-11 V4
Mount	CGEM	Ioptron CEM120-EC2	Ioptron CEM120-EC2	Ioptron CEM120-EC2	Ioptron CEM120-EC2
Imaging Camera	ZWO ASI294-MC Pro	ZWO ASI294-MC Pro	ZWO ASI294-MC Pro	ZWO ASI294-MC Pro	ZWO ASI294-MC Pro
Filters	IDAS-LPS-D1	IDAS-LPS-D1	IDAS-LPS-D1	IDAS-LPS-D1, IDAS-NBZ	IDAS-LPS-D1, IDAS-NBZ
Focuser	None – Manual	None – Manual	Celestron Focus Motor	Celestron Focus Motor	Celestron Focus Motor
Guide Scope	Astromania 60 mm	Astromania 60 mm	Astromania 60 mm	Astromania 60 mm	Astromania 60 mm
Guide Camera	QHY5L-II	QHY5L-II	QHY5L-II	QHY5L-II	QHY5L-II
Guide Software	PHD2	PHD2	PHD2	PHD2	PHD2
Computer	Desktop PC	Desktop PC	Desktop PC	Mini-PC (Intel NUC)	Mini-PC (Intel NUC)
Operating System	Windows 10	Windows 10	Windows 10	Windows 11	Windows 11
Interface	ASCOM	ASCOM	ASCOM	ASCOM	ASCOM
Remote Desktop Control	None	Teamviewer	Teamviewer	AnyDesk	RustDesk
Planetarium	Stellarium	Stellarium	Stellarium/NINA	Stellarium/NINA	Stellarium/NINA
Guiding	PHD2	PHD2	PHD2/NINA	PHD2/NINA	PHD2/NINA
Image Acquisition	Nebulosity	Nebulosity	NINA	NINA	NINA
Plate Solving	None	None	ASTAP/NINA	ASTAP/NINA	ASTAP/NINA
Image Processing	Photoshop	Photoshop	Pixinsight	Pixinsight	Pixinsight

Nov 2017 July 2020 Nov 2023

Observatory Control Strategy

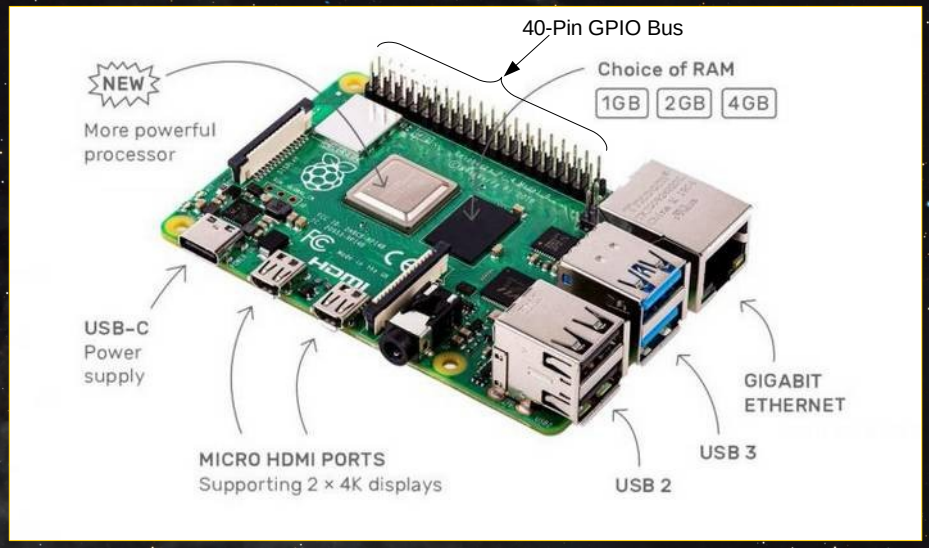
Observatory Control Strategy

Observatory Control Strategy

- Controller based on small, low power, low cost computer
  - Responsible for monitoring and controlling observatory roof, power, and all safety systems
  - Operates 24/7 with battery backup
  - Reliable, lightweight operating system (avoid MS Windows)
  - Open source software solution preferred
  - Minimal interface to imaging computer (which remains off except during imaging)
- Ethernet or hard-wire interface to all observatory subsystems
  - Avoid wifi for critical systems

Observatory Control Implementation

- Raspberry Pi 4B Single Board Computer
  - Developed by the UK non-profit Raspberry Pi Foundation
  - 64 Bit, 1.8 GHz Quad-core processor, 4 GB RAM
  - Gigabit ethernet, USB 2, USB 3
  - 128 GB SSD (more reliable than SD card)
  - Interface to observatory sensors and control via GPIO bus
  - (Not used): Wifi, Dual HDMI, Camera port
- Home Assistant (HA)
  - Open source Home Automation Software
  - Linux-based OS
  - Supported by a large online user community
- Node-Red
  - ‘Low-code’ graphical software add-on for HA

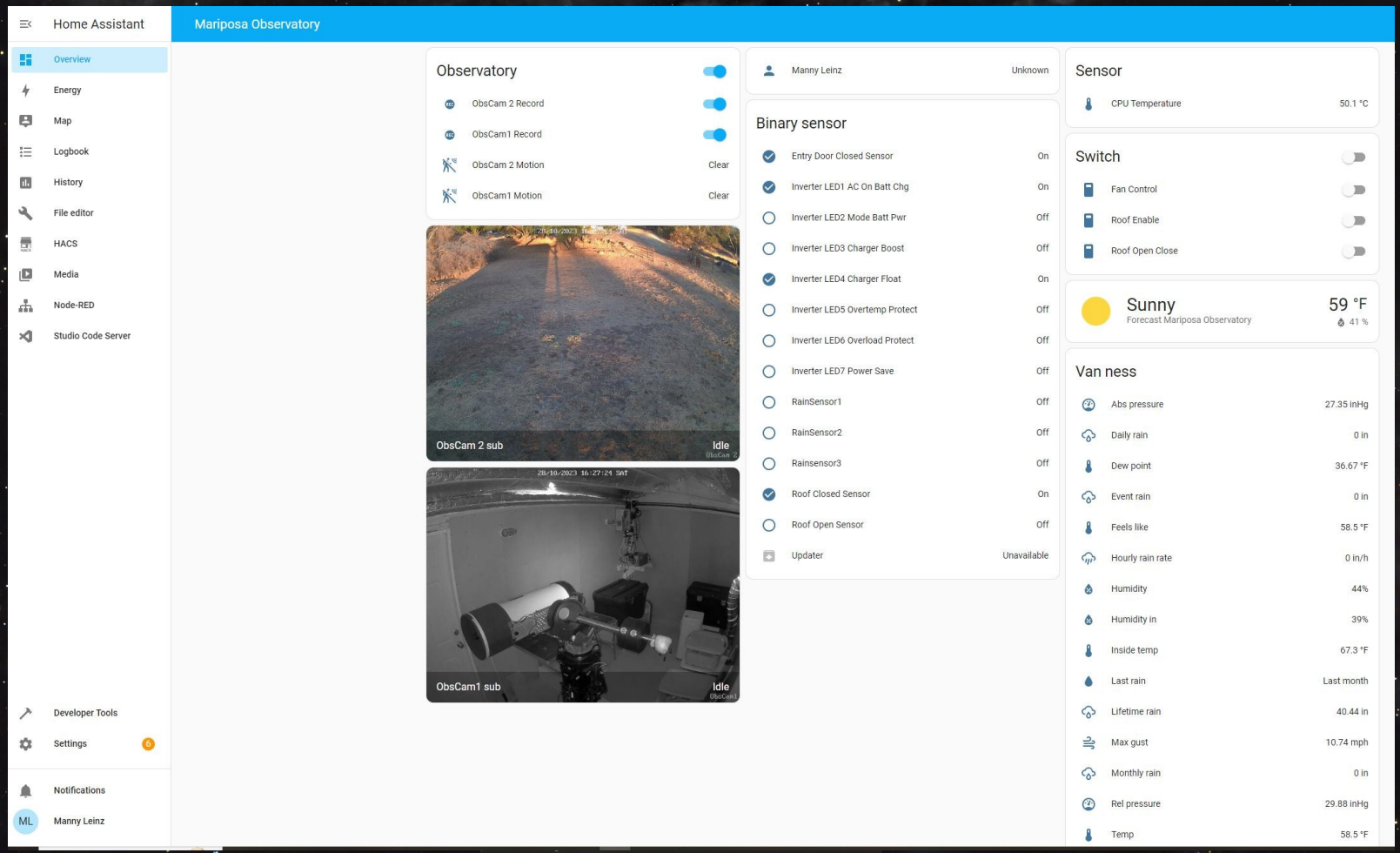


Home Assistant

Node-RED

Home Assistant

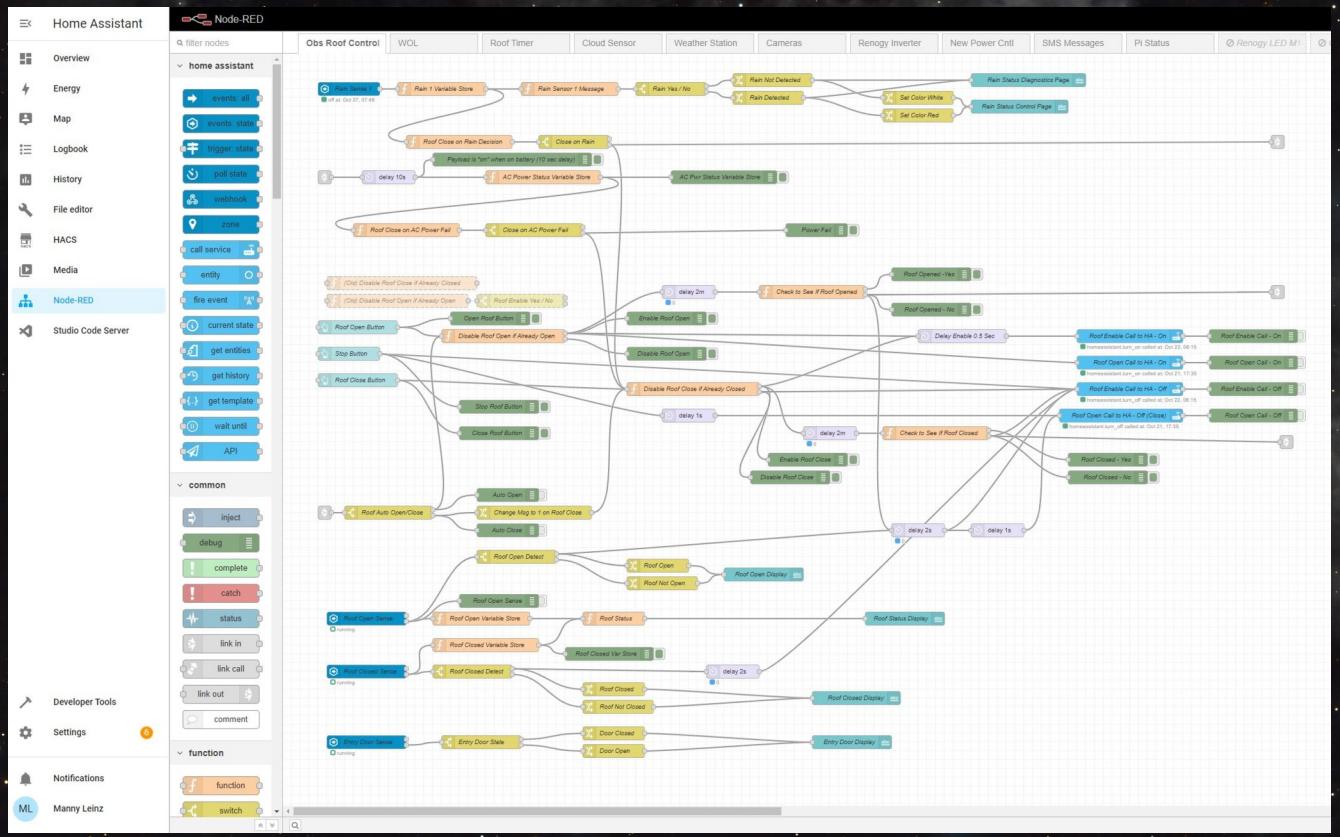
- Runs on Raspberry Pi (or other computer) host
- Integrates a wide range of Home Automation products, sensors and effectors
- Enables creation of custom routines and scripts based on trigger events, conditions and actions



HA Overview Screen

Node-Red

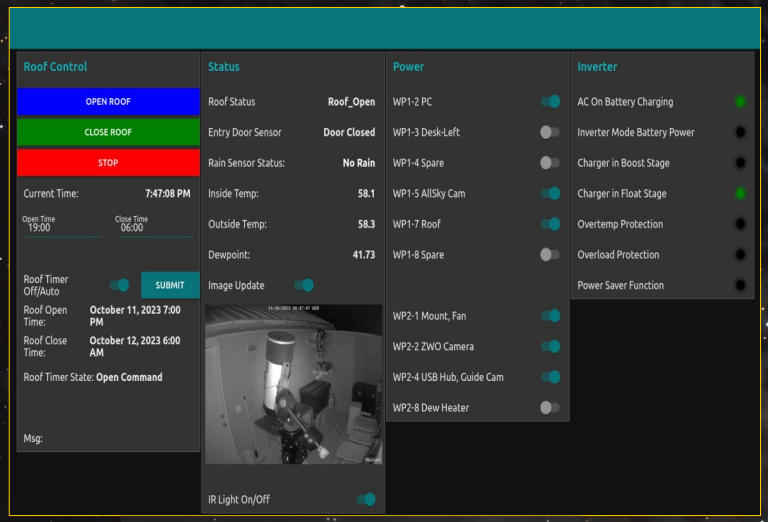
- Initially developed by IBM as a in-house project, made available open-source in 2016
- Available as a software add-on for Home Assistant
- Provides “drag and drop” block diagram type interface
- Javascript-based function nodes provide increased flexibility for more complex operations
- Individual “flows” provide control of individual observatory subsystems (roof, cameras, power inverter, weather station, etc.)



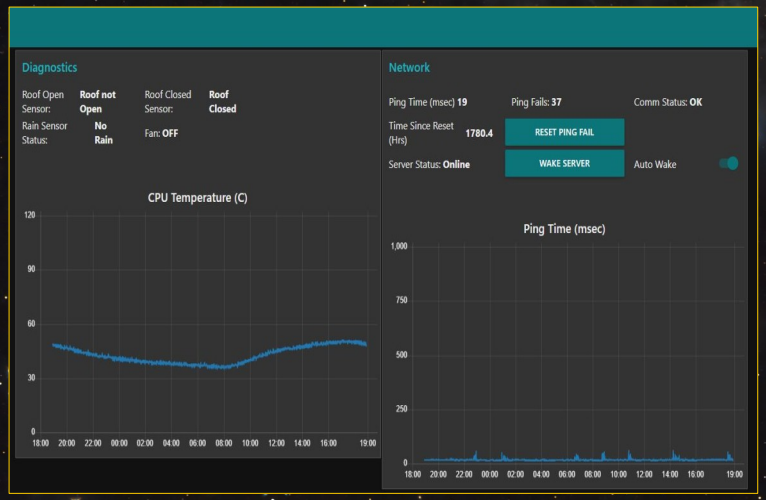
Observatory Roof Control Flow

Node-Red

- A key Node-Red capability is the straightforward creation of web-based “dashboards”



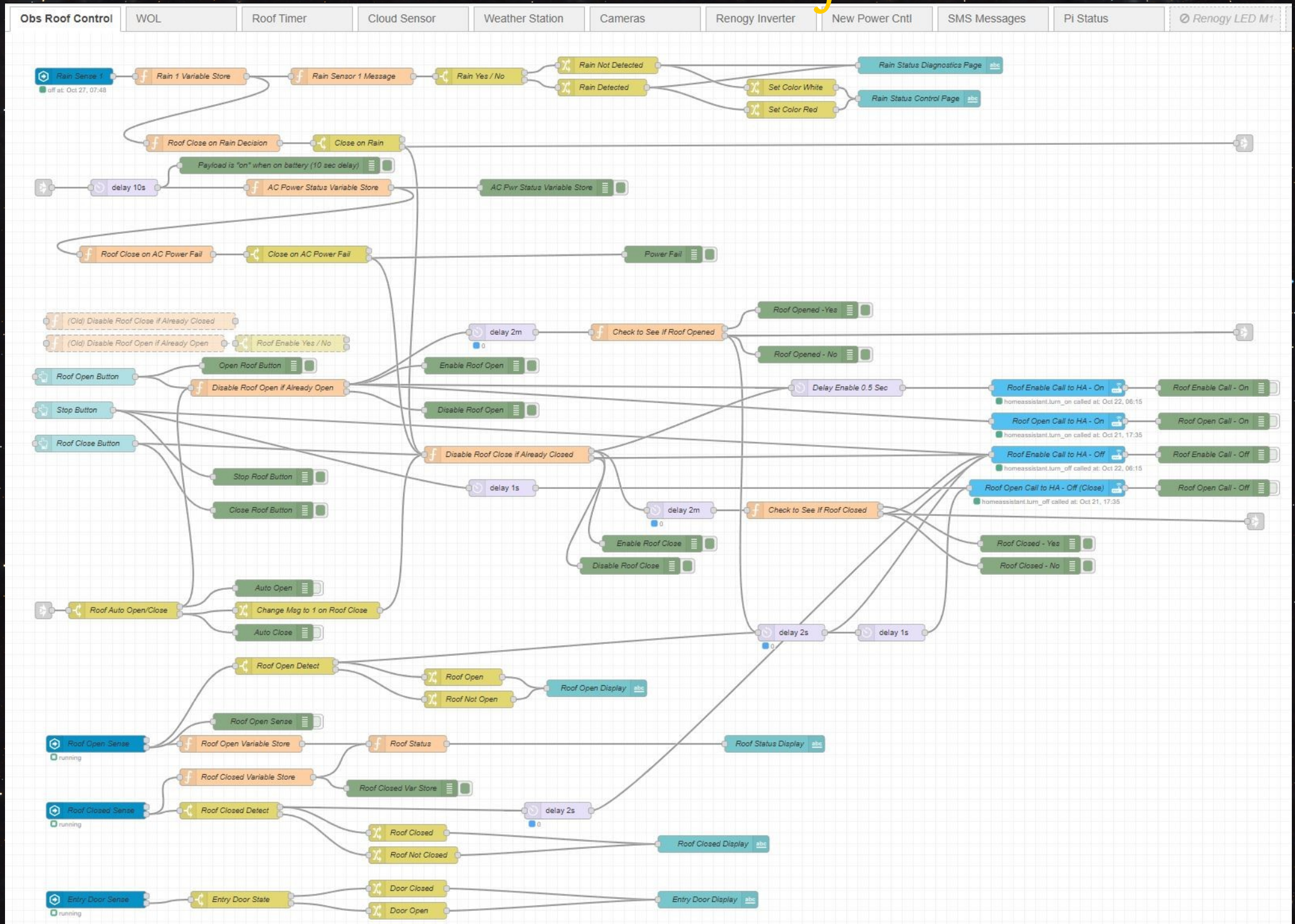
Observatory Control



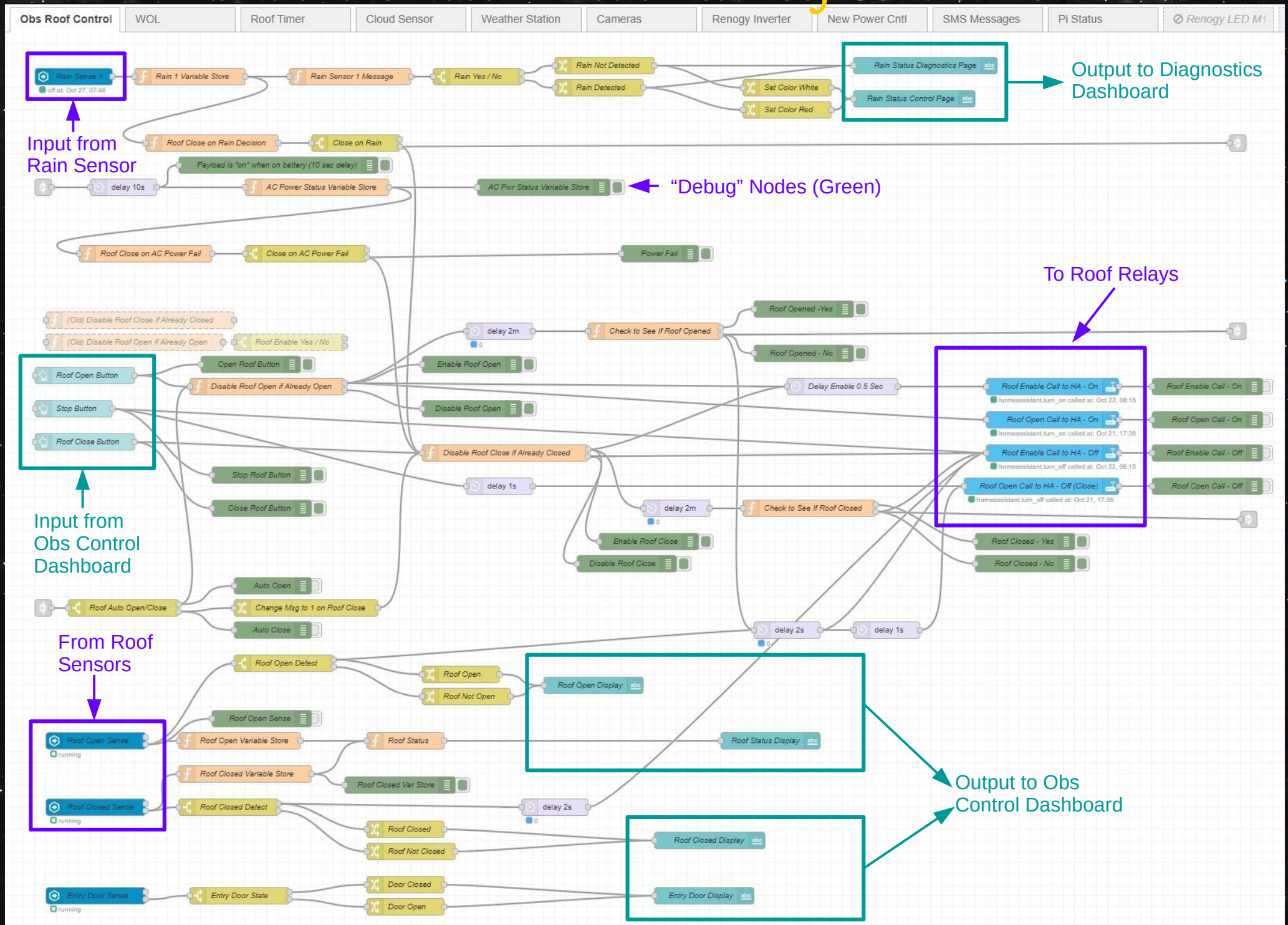
Diagnostics

Weather

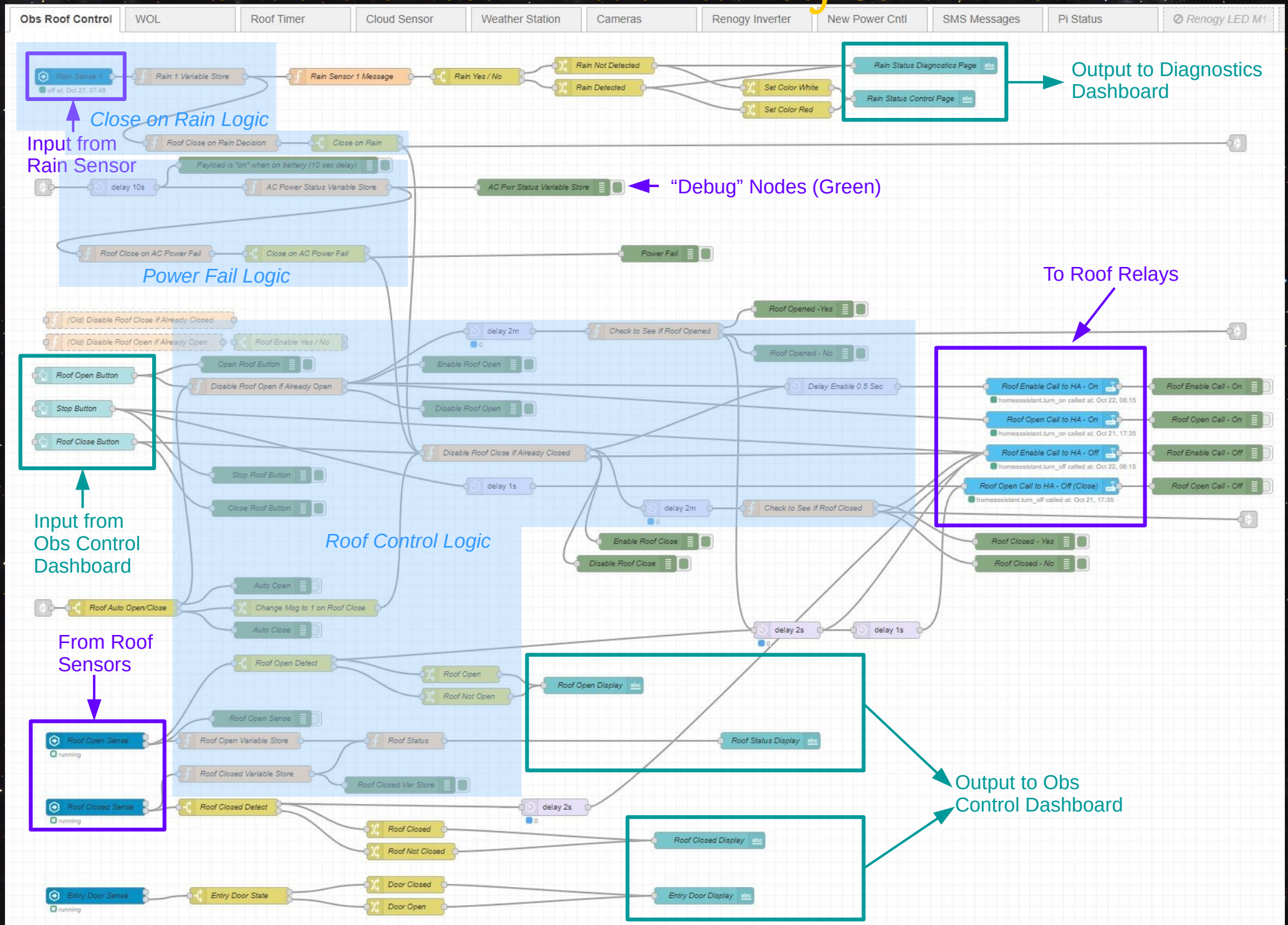
Under the Hood — Node-Red Roof Control Flow



Under the Hood – Node-Red Roof Control Flow



Under the Hood – Node-Red Roof Control Flow



Observatory Control Dashboard

Roof Control

OPEN ROOF

CLOSE ROOF

STOP

Current Time: **7:47:08 PM**

Open Time 19:00

Close Time 06:00

Roof Timer Off/Auto

SUBMIT

Roof Open Time: **October 11, 2023 7:00 PM**

Roof Close Time: **October 12, 2023 6:00 AM**

Roof Timer State: **Open Command**

Msg:

Status

Roof Status	**Roof_Open**
Entry Door Sensor	**Door Closed**
Rain Sensor Status:	**No Rain**
Inside Temp:	**58.1**
Outside Temp:	**58.3**
Dewpoint:	**41.73**

Image Update

IR Light On/Off

Power

- WP1-2 PC
- WP1-3 Desk-Left
- WP1-4 Spare
- WP1-5 AllSky Cam
- WP1-7 Roof
- WP1-8 Spare

- WP2-1 Mount, Fan
- WP2-2 ZWO Camera
- WP2-4 USB Hub, Guide Cam
- WP2-8 Dew Heater

Inverter

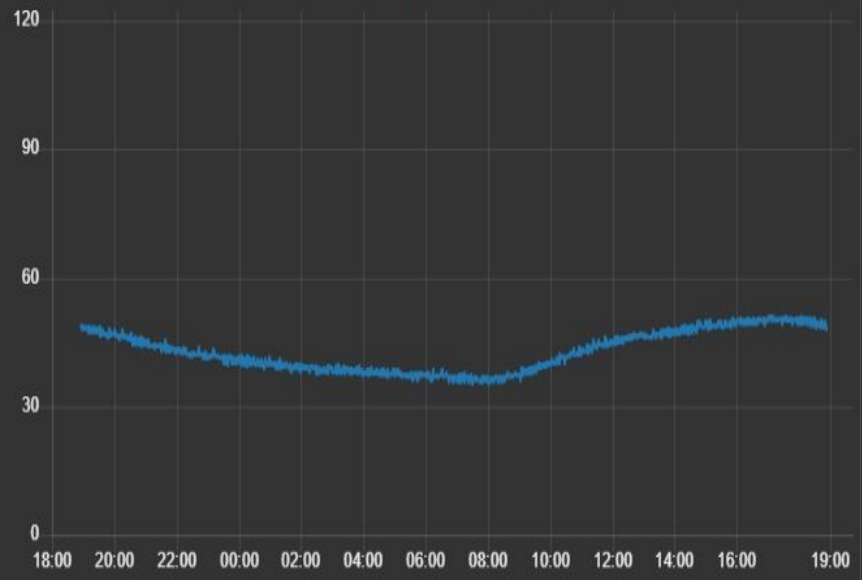
- AC On Battery Charging
- Inverter Mode Battery Power
- Charger in Boost Stage
- Charger in Float Stage
- Overtemp Protection
- Overload Protection
- Power Saver Function

Observatory Dashboard - Diagnostics

Diagnostics

Roof Open Sensor:	**Roof not Open**	Roof Closed Sensor:	**Roof Closed**
Rain Sensor Status:	**No Rain**	Fan: **OFF**	

CPU Temperature (C)



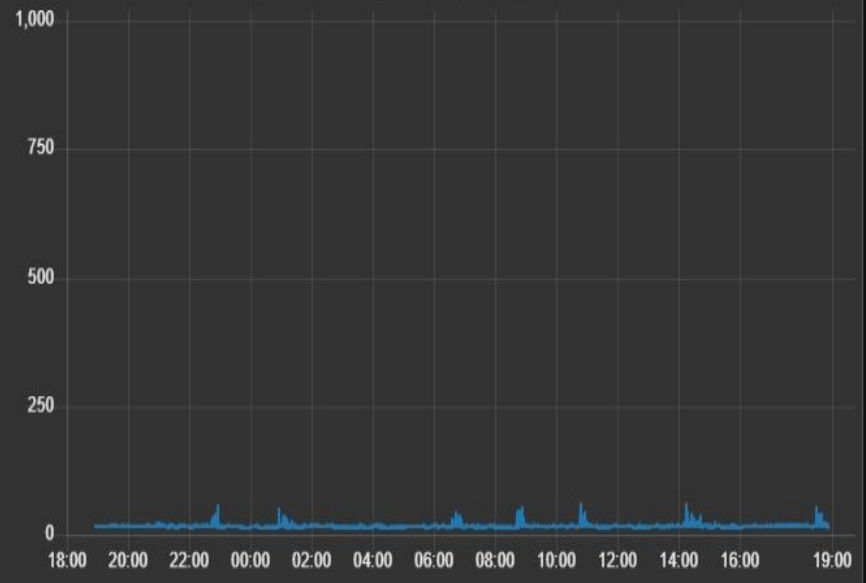
Network

Ping Time (msec) **19** | Ping Fails: **37** | Comm Status: **OK**

Time Since Reset (Hrs) **1780.4** | RESET PING FAIL

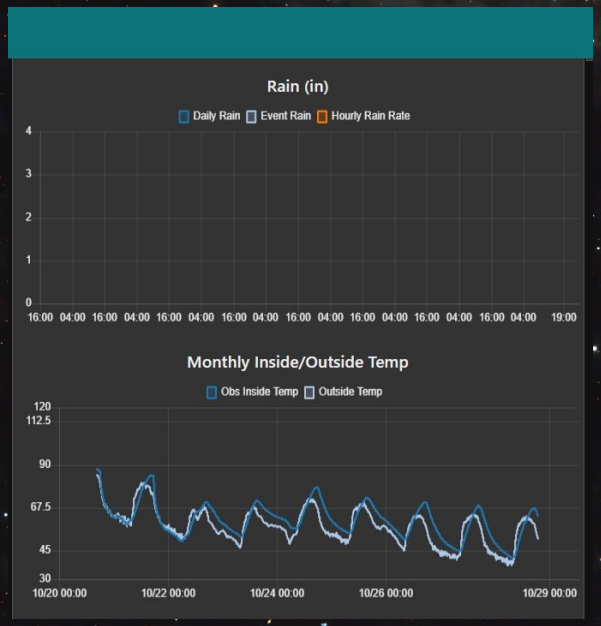
Server Status: **Online** | WAKE SERVER | Auto Wake

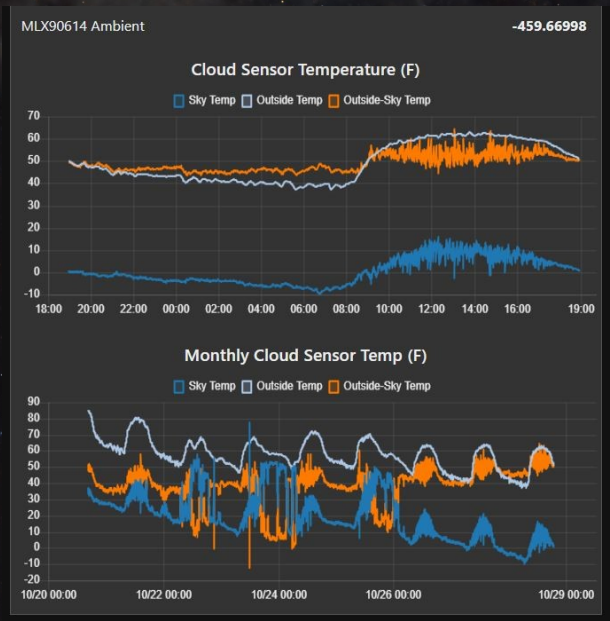
Ping Time (msec)



Observatory Dashboard - Weather

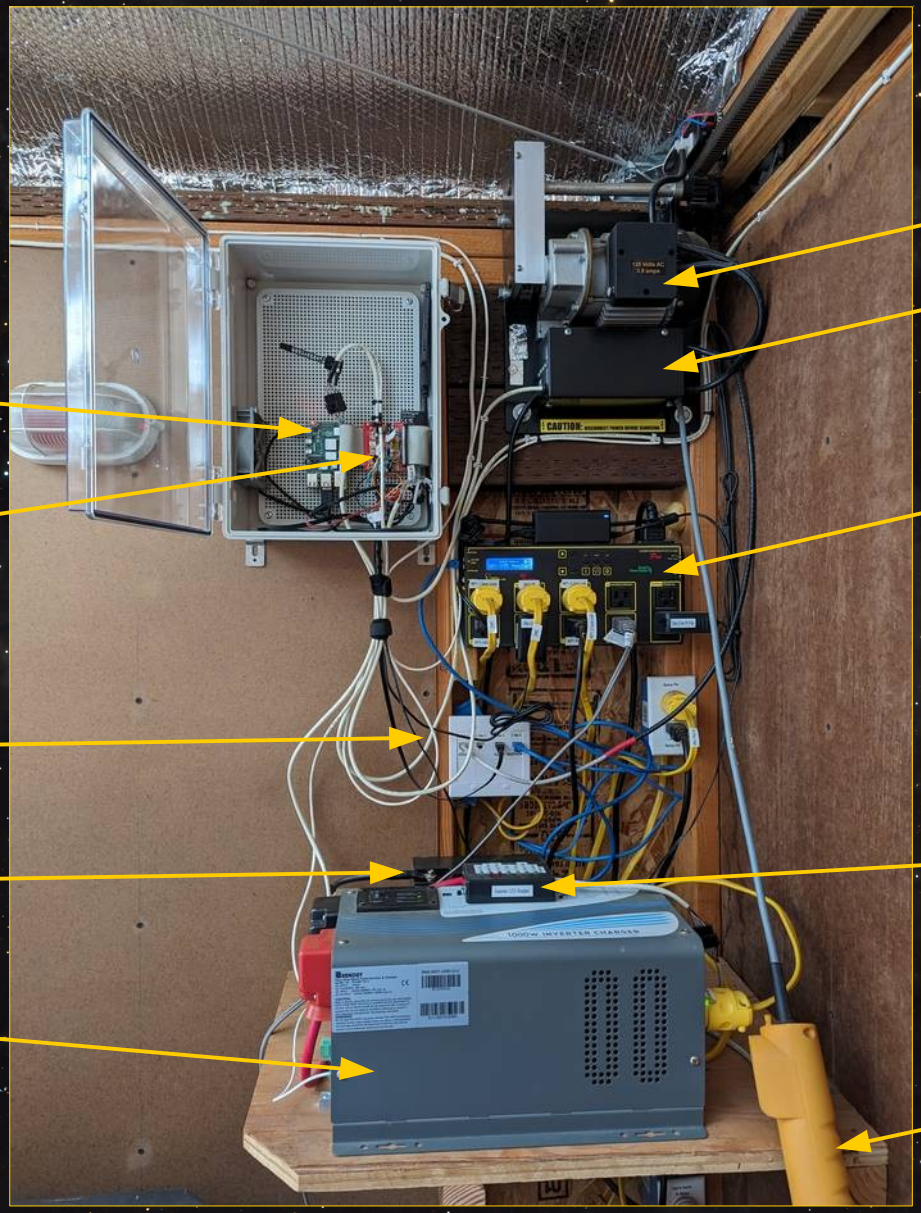
Wireless Receiver / Access Point



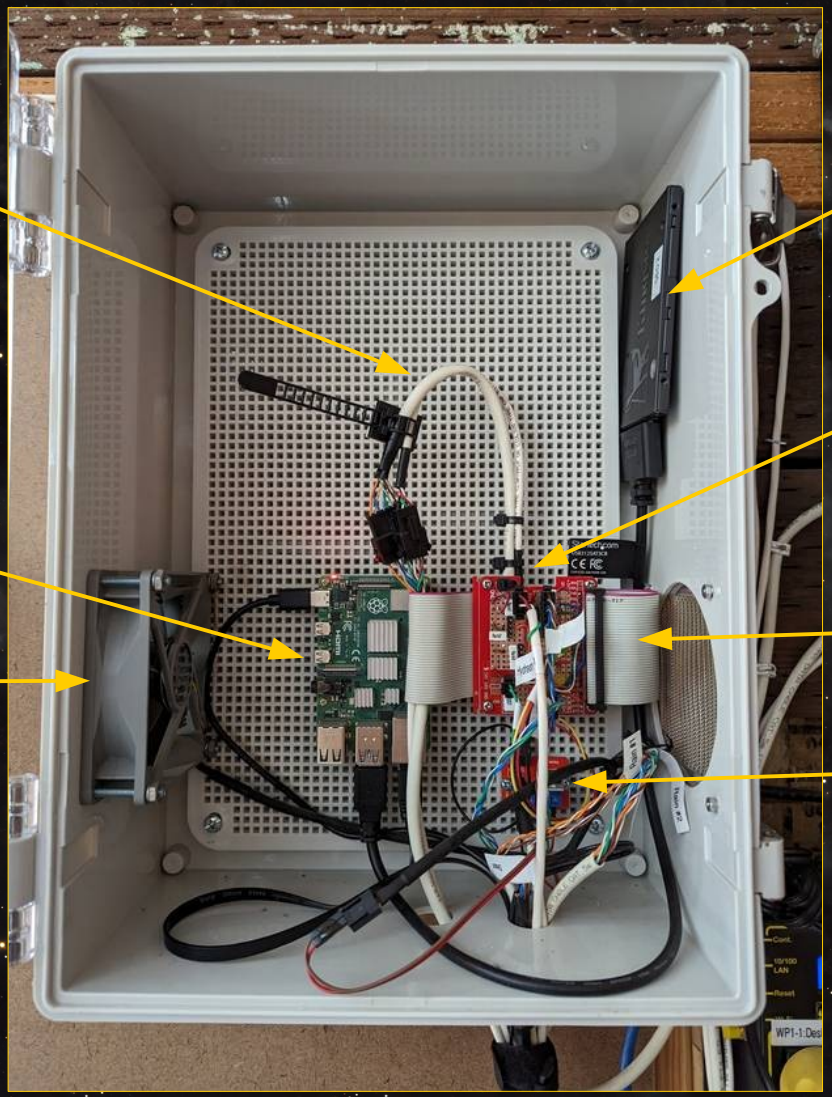


Ambient Weather WS-0900

Observatory Control Hardware



Observatory Control Hardware

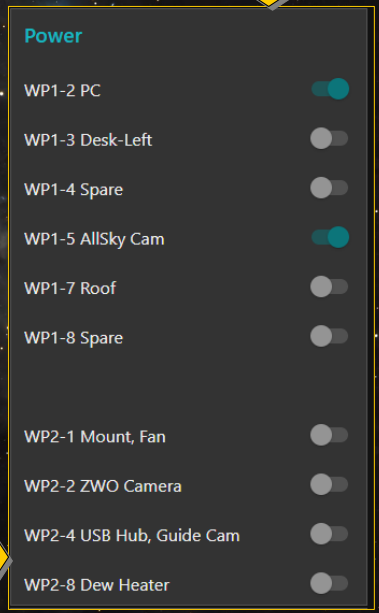


Power Control

- Based on Digital Loggers Inc. (DLI) Web Power Switch Pro
  - Enables control of individual observatory subsystems over the Internet
  - Eight web switchable AC outlets
  - 40 Amp relays
  - Supports Ethernet (or if you must), Wifi
  - Web GUI interface
  - Optionally remembers last state on power loss
  - Ability to ping, restart modems/routers
  - Economical
- Used to control Roof Power, PC, Monitors, secondary power ‘bricks’

Main Power Distribution (WP1)

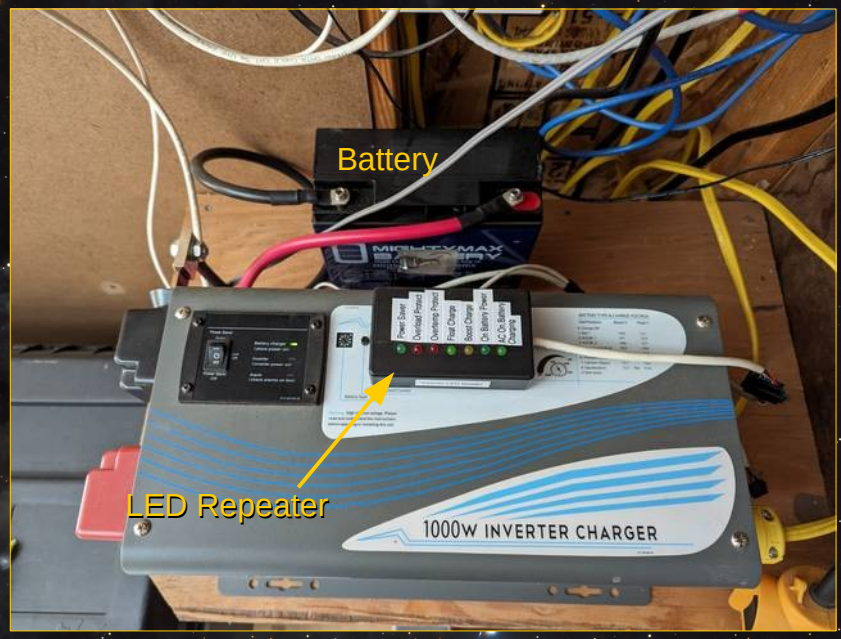
Pier Power Distribution (WP2)

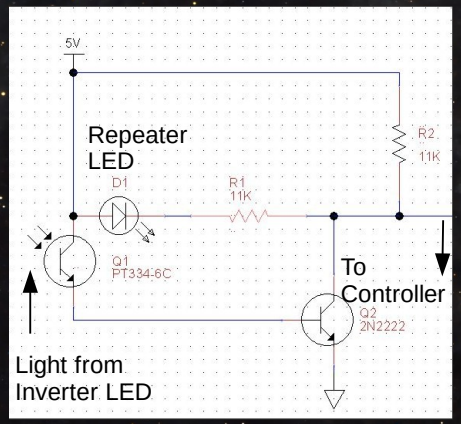


Controller GUI

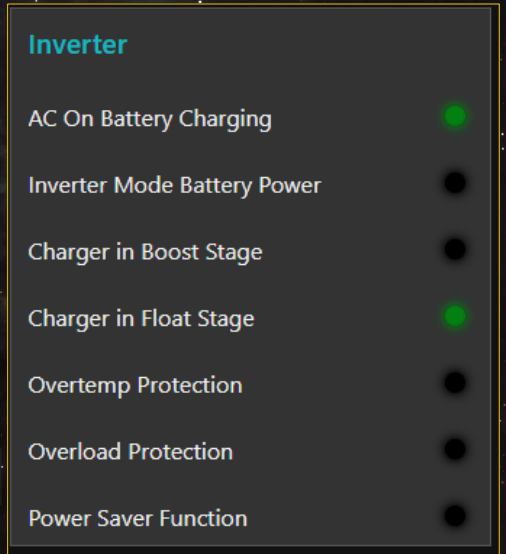
Backup Power

- Renogy 1000 W Inverter
  - Combines 12V-115VAC Inverter, Battery Charger, Transfer Switch
  - Automatic switchover in event of line power loss
  - Automatic text message to my phone in the event of power loss
- 12V, 22 Ah Gel backup battery
  - Provides ample power to close the roof in the event of AC line outage
  - Worst-case 15-30 minute run time with all observatory systems powered on
- Custom ‘LED Repeater’
  - Provides Inverter LED Status to Observatory Controller
  - Photodiode/Optocoupler interface to GPIO
  - Controller sends text message, automatically closes roof on power failure





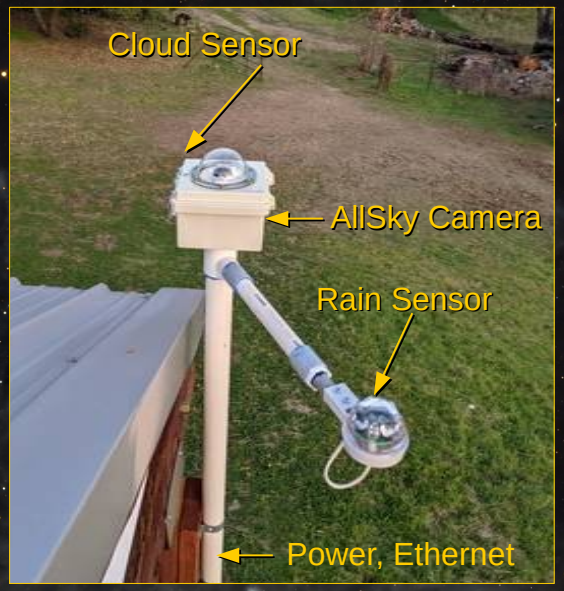
LED Repeater – One Channel

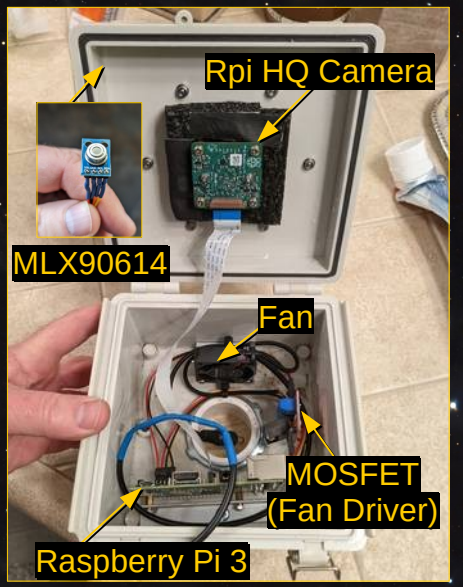


Controller GUI

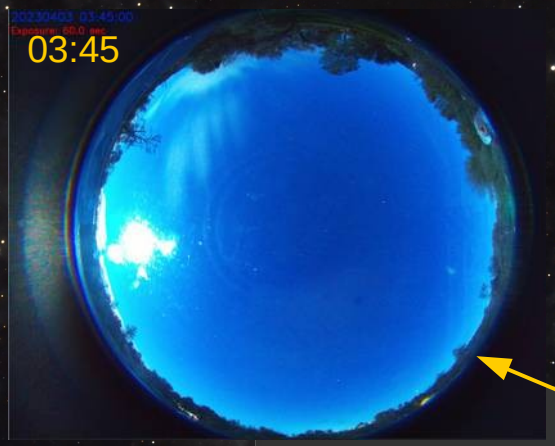
AllSky Camera, Cloud, Rain Sensors

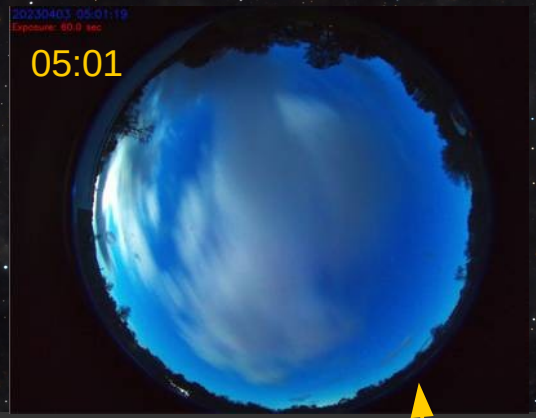
- AllSky Camera
  - Thomas Jacquin design – now maintained by Open Source Community
  - Raspberry Pi 3/Rpi HQ camera
  - Super useful before, during and after imaging runs to assess sky quality
  - Ethernet Interface to Observatory Controller
  - Integrated web server
- Cloud Sensor
  - MLX 90614 Infrared Thermometer
  - 90º Field of View (pointed to zenith)
  - Interface via I2C bus on AllSky Raspberry Pi
- Rain Sensor
  - Hydreon RG-9 Optical Rain Detector
  - Single wire (Rain/No Rain) interface to Observatory Controller GPIO
  - Controller automatically closes roof on rain detection

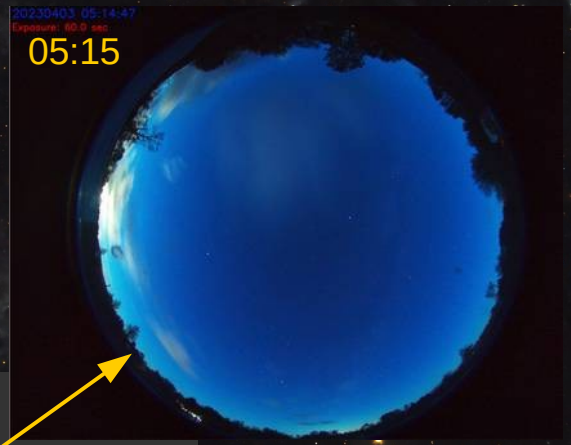


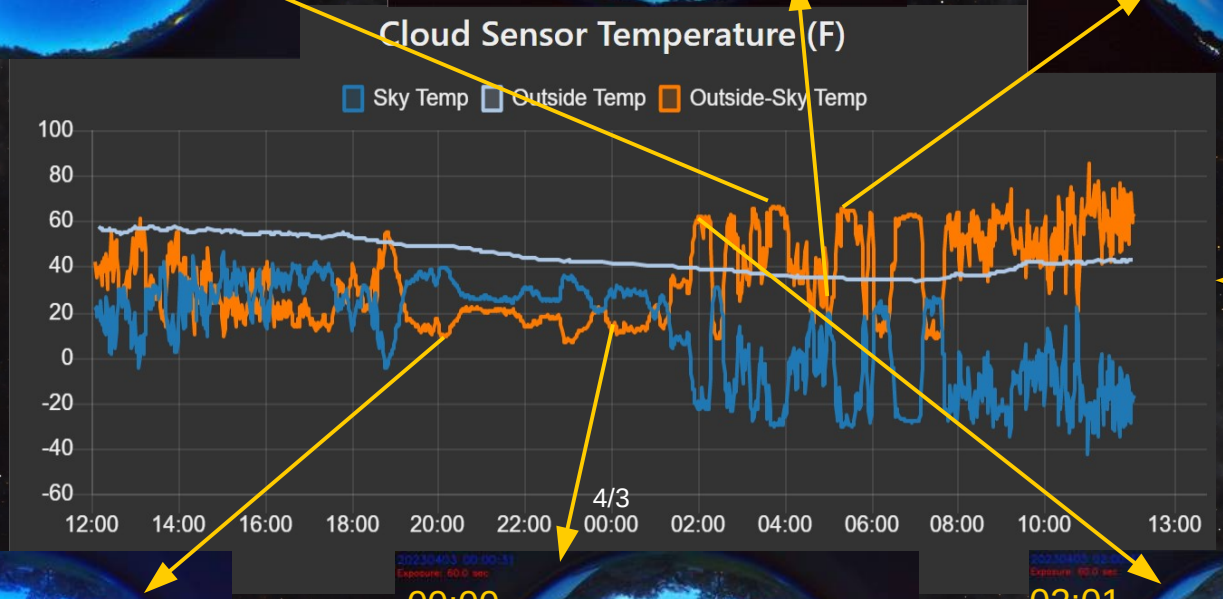


Cloud Sensor Testing

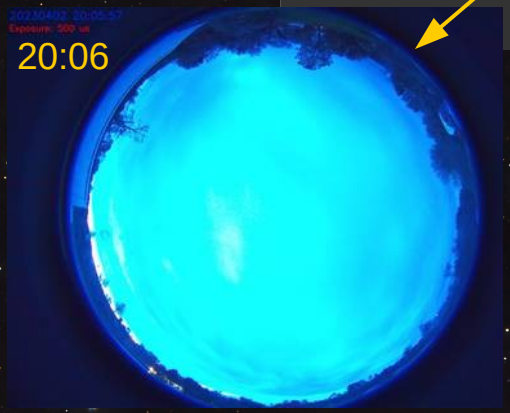


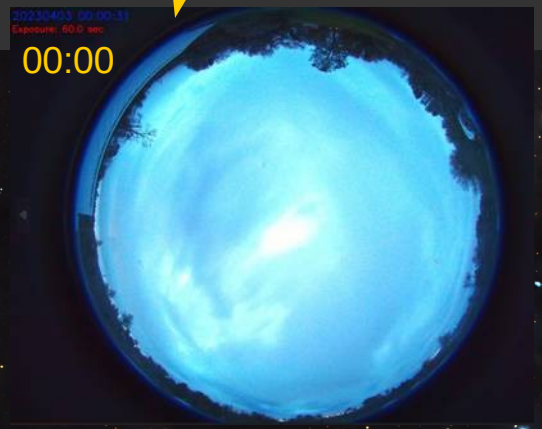


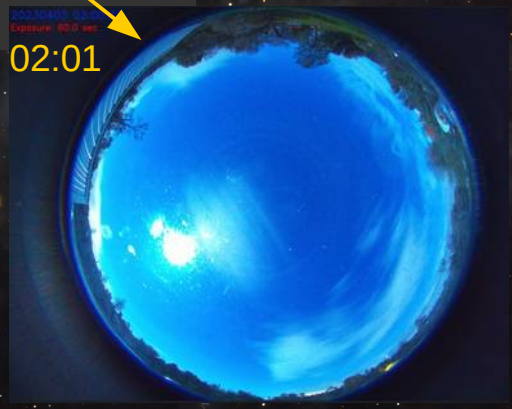




Controller GUI







Data from Noon 4/2 tp Noon 4/3/23

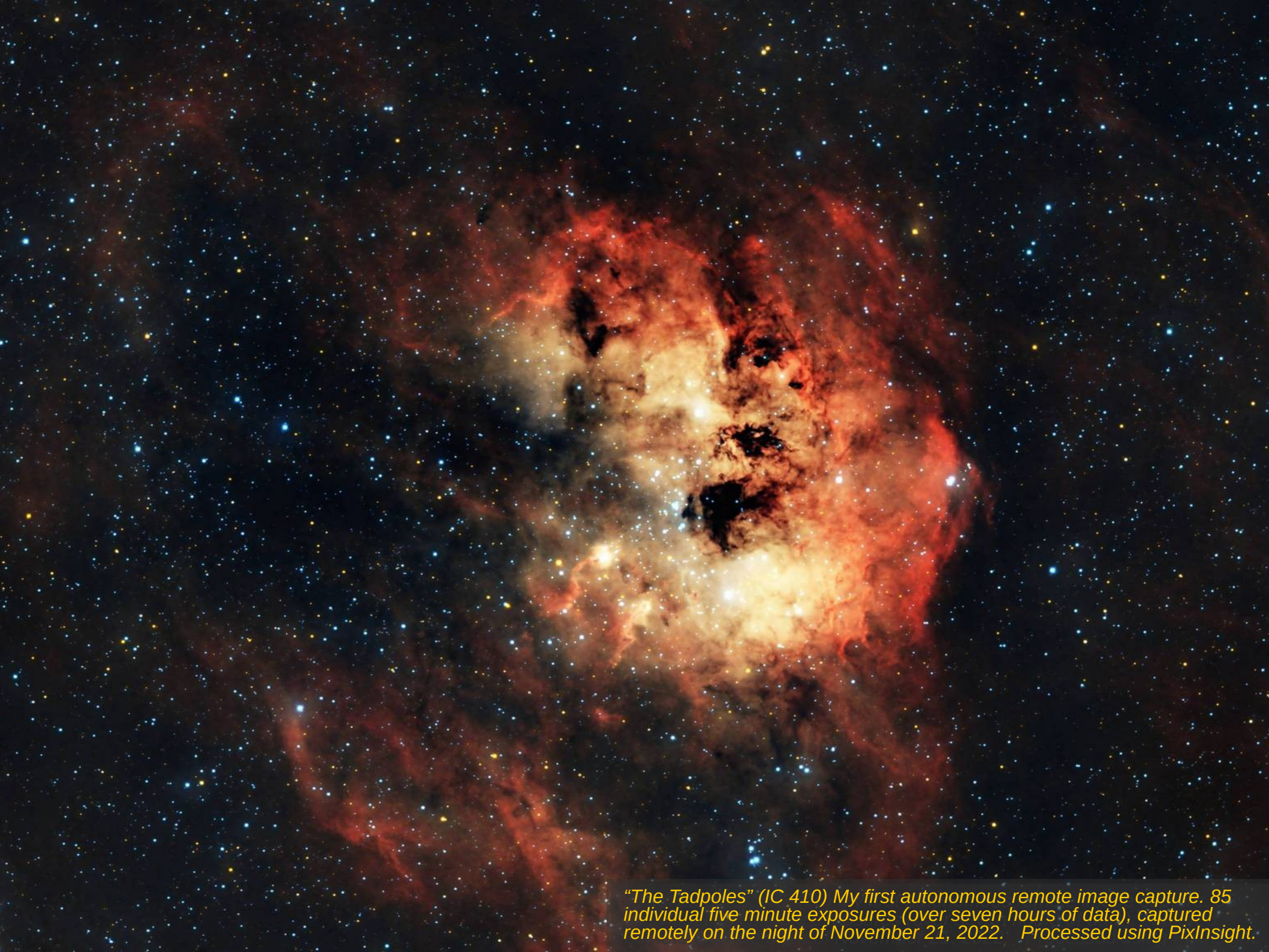
A Typical Night of Remote Imaging

- Select target(s) and prepare N.I.N.A. imaging sequence
- Go-No Go: Check weather status/forecast
- Turn on roof power, set times for roof auto open/close
  - Typically open at sunset, or at least one hour before imaging start
- Turn on secondary power supplies
  - USB hub, cameras, telescope mount
- Turn on PC, connect via RustDesk Remote Desktop
- Start N.I.N.A., connect equipment, load imaging sequence
  - Set sequence to automatically start at astronomical dusk
- Log in to AllSky camera
- Periodically monitor AllSKy, PHD Guiding, N.I.N.A. images, or…
- Go to bed!

Limitations, Next Steps

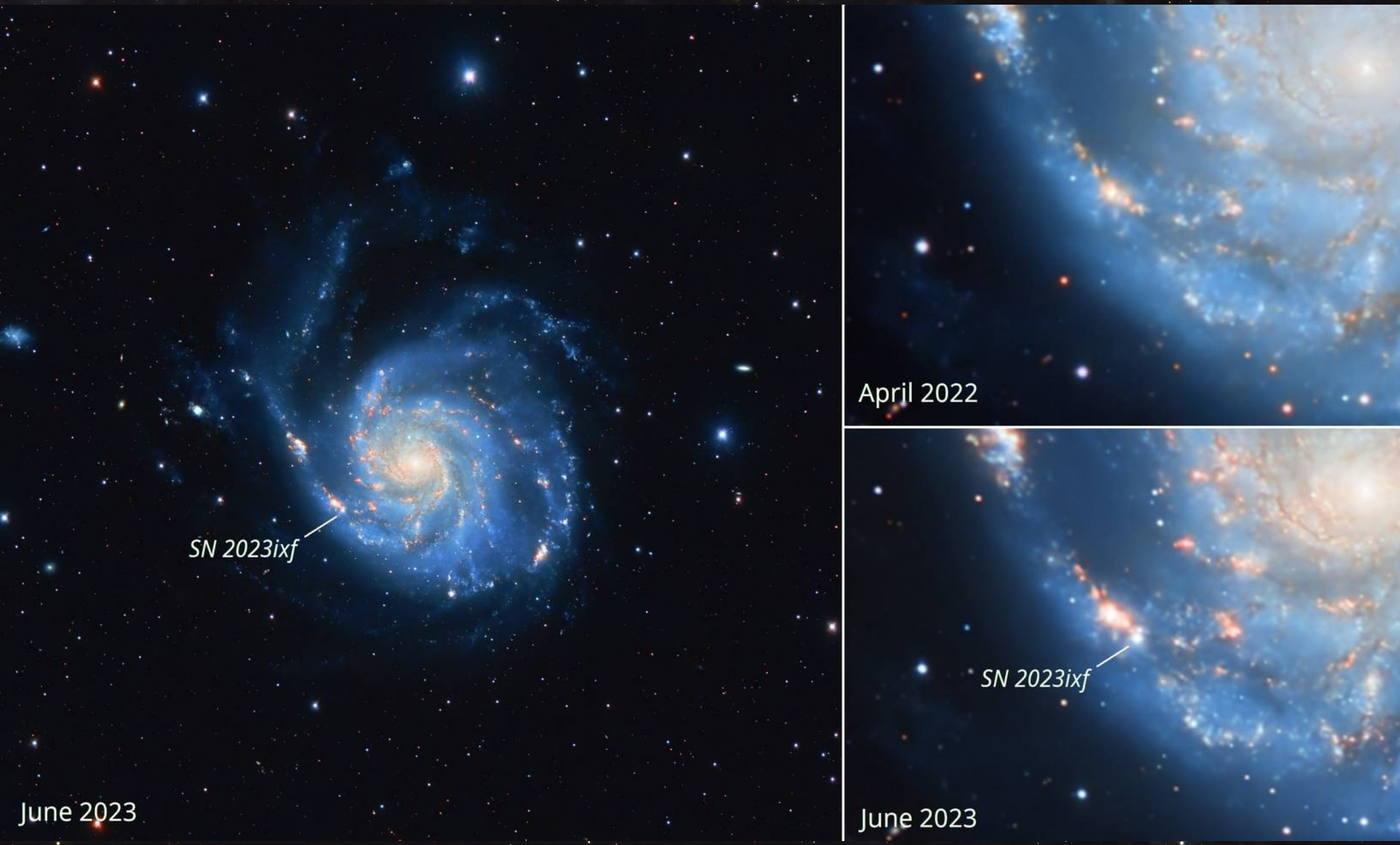
- Current (mostly acceptable) limitations
  - Observatory requires semi-manual start-up, shut down
    - Power sequencing, N.I.N.A., end of night file transfer
    - Not suitable for multi-day autonomous imaging campaigns
  - Filter switching is a manual process (RASA limitation)
    - Use Light Pollution filter (IDAS-LPS-D1) when on site, around New Moon
    - Narrow band (IDAS-NBZ) when remote imaging, and Moon is in the sky
- Next Steps
  - Implement Reverse Proxy for improved security
  - Integrate control software with N.I.N.A.
    - Pause or terminate imaging sequence due to an unsafe condition (clouds, rain, power or network loss)
  - Add web power timers for scope, guide/imaging cameras
  - Automate dew heater power
  - Complete Observatory Interior
    - Wallboard, cabinets, flooring, paint
  - Install second (south) pier for visual observing
    - Considering “split level” design to see over walls


A Few of my Astroimages...



“The Tadpoles” (IC 410) My first autonomous remote image capture. 85 individual five minute exposures (over seven hours of data), captured remotely on the night of November 21, 2022. Processed using PixInsight.

"Icy Visitor" - Comet Leonard (C/2021 A1) passes by the globular cluster M3 in this image that I captured on December 3, 2021. 29 individual two-minute exposures. Processed using PixInsight.



"Exploding Pinwheel" – Supernova SN 2023ixf explodes in M101 in this image that I captured from June 14-17, 2023. 204 individual five-minute exposures (17 hrs of data) shot through broadband (IDAS-LPS-D1) and narrowband (IDAS-NBZ) filters. Reprocessed zoomed and cropped 2022 broadband image is six hours of data, captured on April 17-19, 2022. Individual images processed using PixInsight. Composite annotated image created using GIMP 2.10.30

"Cosmic Cataclysml" – (Supernova remnant Abell 85, CTB-1 Medulla Nebula) This is an "HOO" image, combining 223 individual five minute exposures (18.6 hours of data), shot through an IDAS-NBZ narrow band filter for the nebula, with 4.8 hours of RGB data shot through an IDAS-LPS-D1 filter for the stars. Data captured in on site and remotely August and September, 2023. Processed using Pixinsight.

Resources

- Observatory build contractor: Backyard Observatories *www.backyardobservatories.com*
- Raspberry Pi Computer: *www.raspberrypi.org*
- Home Assistant Software: *www.home-assistant.io*
- Node-Red Software: *www.nodered.org*
- Node-Red Add-on for Home Assistant: *community.home-assistant.io/t/home-assistant-community-add-on-node-red/55023*
- Nextcloud server software: *www.nextcloud.com/athome/*
- AllSky Camera: *www.github.com/thomasjacquin/allsky*
  - Rpi HQ camera (for AllSky): *www.raspberrypi.com/products/raspberry-pi-high-quality-camera/*
  - TAIC Presentation by Linda Thomas-Fowler (10/3/2021): *https://www.youtube.com/watch?v=oc7W53umCTY*
  - Helpful installation video (some aspects out of date): *https://www.youtube.com/watch?v=7TGpGz5SeVI&t=1642s*
- Cloud Sensor:
  - Amazon: *www.amazon.com/gp/product/B07YZVDWWB/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1*
  - MLX 90614 Datasheet: *www.melexis.com/en/documents/documentation/datasheets/datasheet-mlx90614*
  - Connecting to Raspberry Pi: *www.olegkutkov.me/2017/08/10/mlx90614-raspberry/*
  - Code repository: *https://github.com/cmleinz/MLX90614-pi/tree/main*
- Rain Sensor: *https://store.hydreon.com/shop/rain-sensor/RG-9.html*
- N.I.N.A. Astroimaging Software: *www.nighttime-imaging.eu/*
- RustDesk Remote Desktop Software: *www.rustdesk.com/*
- DLI Web Power Switch: *www.digital-loggers.com/lpc.html*
- Renogy Power Inverter/Charger/Transfer Switch: *www.renogy.com/1000w-pure-sine-wave-inverter-charger/*
- Weather Station: *www.ambientweather.com/*
  - WS-0900 is discontinued
- Reolink situational awareness cameras: *www.reolink.com/us/product/rlc-410/*

If You'd Like to Get In Touch...

- Email: manny.r.leinz@gmail.com
- Astrobin: www.astrobin.com/users/Starrider55/
- My website: www.space.leinz.io

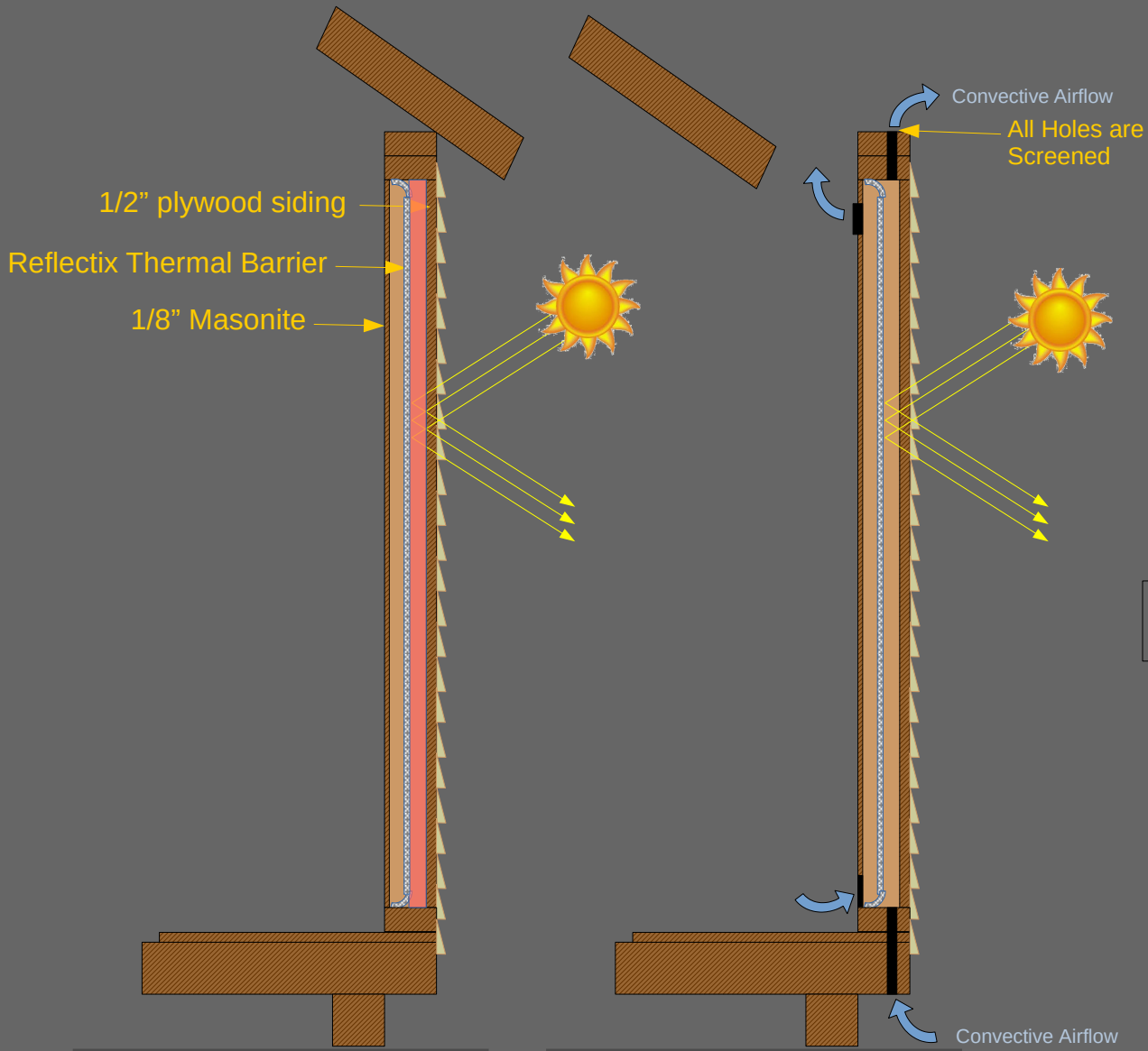

Questions?


Backup

Initial Imaging Configuration

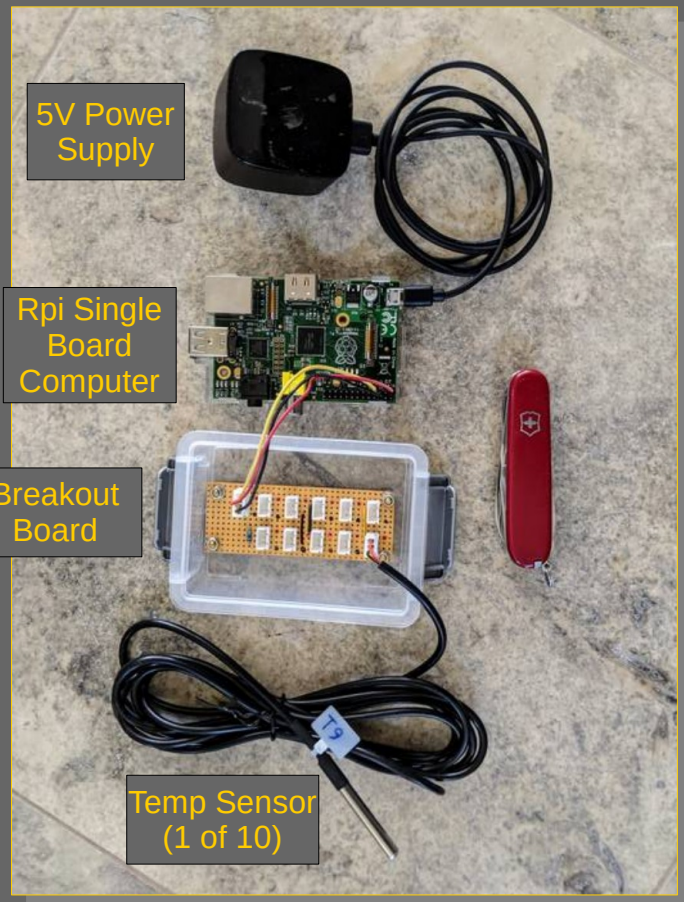
- Telescopes:
  - Celestron CGEM-1100
  - Stellarvue SV70ED 70 mm refractor
- Imaging Camera
  - Canon 60D DSLR, then...
  - ZWO ASI294 MC Pro (10.7 Mpixel Color Cooled)
- Guide Camera/Scope
  - QHY5L-II 1.2 Mpixel monochome
  - Astromania 60 mm Scope

Thermal Considerations



Baseline Wall Thermal Management

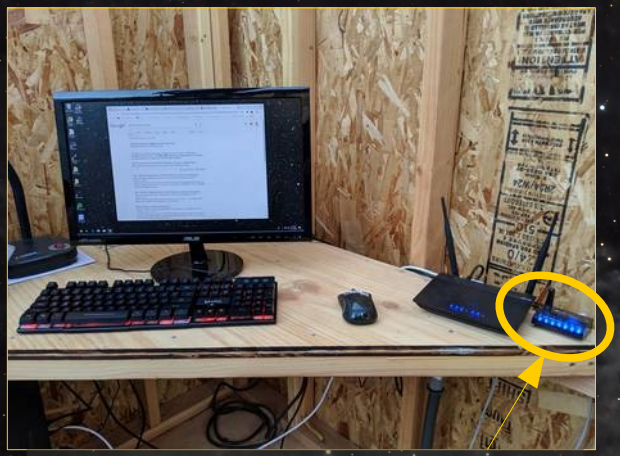
West, South Wall Option – If Needed



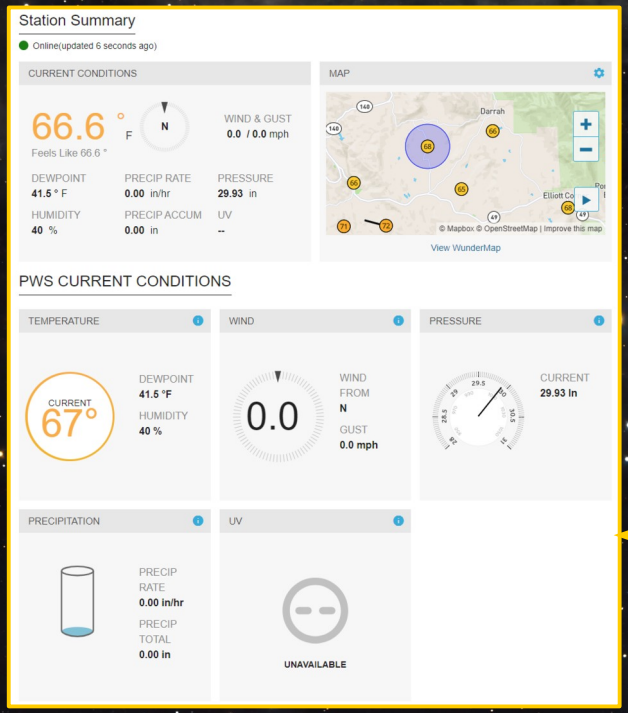
Raspberry Pi Temperature Data Logger

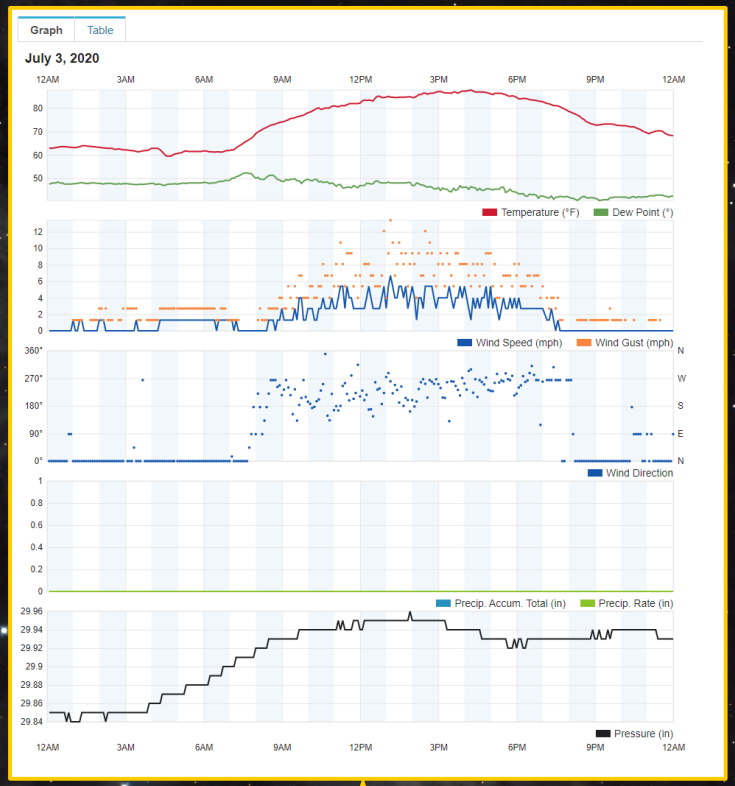
Weather

Ambient Weather WS-0900



Wireless Receiver / Access Point





Weather Underground App

Observatory Status as of July, 2020

- Observatory structure complete, including roof motor
- Wall power, internet installed
- PC located in observatory
- Weather station operational
- Insulation, Wallboard in progress
- Ability to control observatory from our home on the property
  - Except manual roof control
- No situational awareness, backup power, or safety systems
- Imaging setup (same as today):
  - RASA-11 V2 scope
  - Ioptron CEM120-EC2 Mount
  - ZWO ASI294MC-Pro camera
  - Astromania 60 mm Guide Scope, QHY 5L-II Guide camera