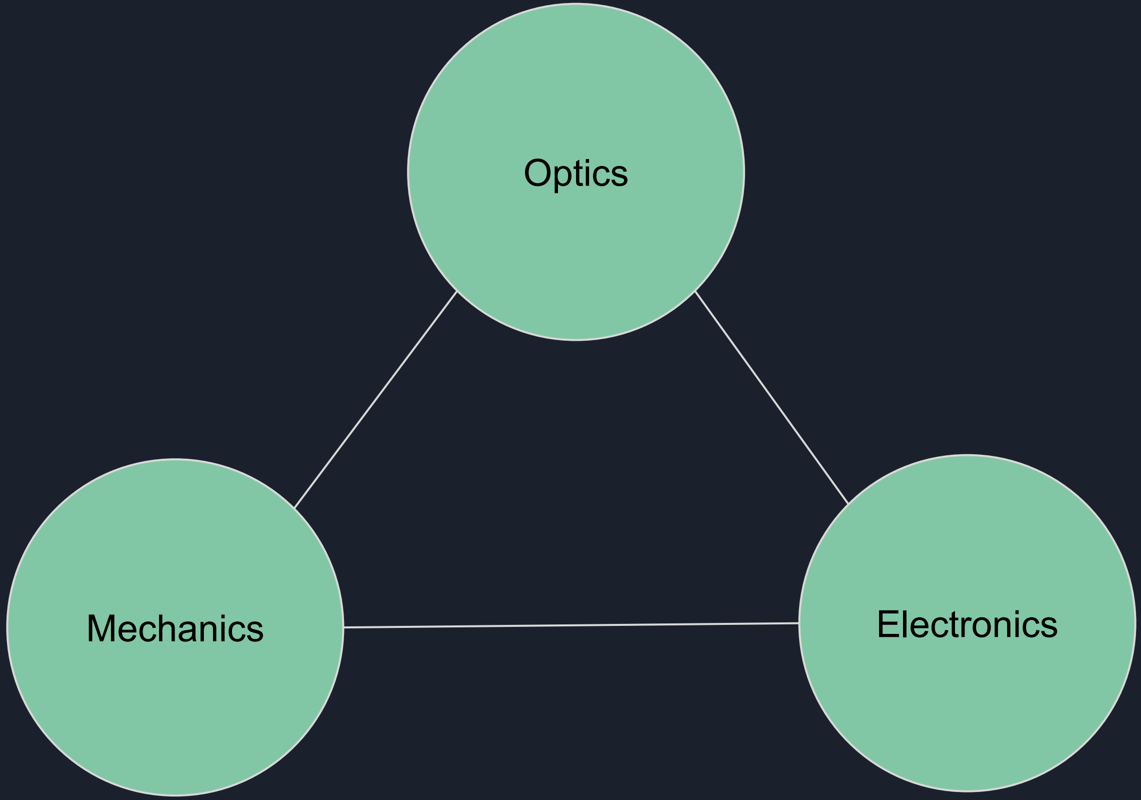
Deep Sky Imaging Acquisition Workshop: Rig Setup

Gabe Shaughnessy

What do you want to achieve?

- Pretty pictures!
    - Color: OSC, RGB, LRGB
    - False color: HaRGB, SHO, HOO, IR-RGB
- Advance what you can image
    - First images of common targets
        - M31, M27, M57, etc.
    - More challenging targets:
        - Veil nebula
        - Dark nebula: Iris nebula, Ghost nebula, etc
    - Pushing the limits of you, your system and your skies
        - Spaghetti nebula
        - Soap bubble nebula
        - Deep integration of galaxy tails
        - IFN
        - The sky is literally the limit
- Science!
    - SN detection, Variable stars, Spectra studies, Exoplanet transit, etc.

The Trinity of Imaging



Knowing your optical system

- Aperture and focal length
- Resolving power
- F-ratio
- Aberrations
  - Spherical aberration
  - Chromatic aberration
  - Field curvature
  - Coma
- Thermal stability
- Critical Focus Zone
- Central obstructions

Celestron EdgeHD 1400

SkyWatcher Esprit 80mm

Knowing your electronic system

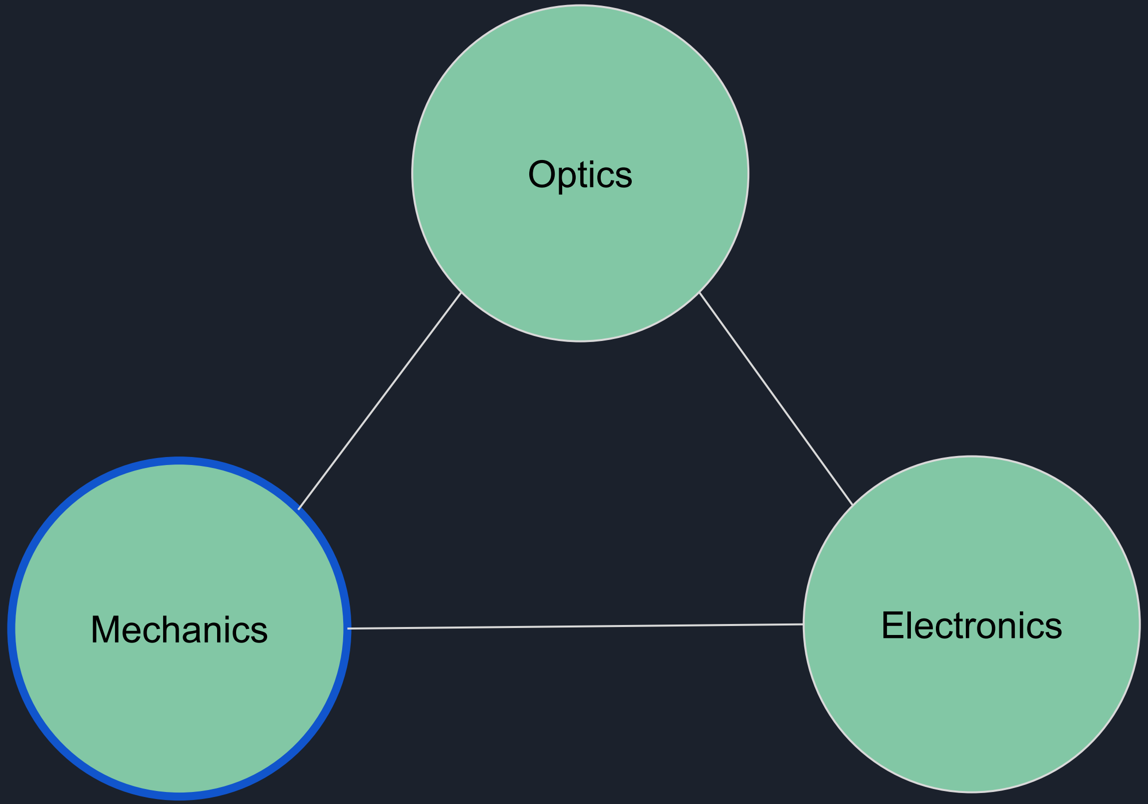
- Camera
  - Read noise
  - Dark current
  - Defects
  - Linearity
- Power management
  - Battery capacity
  - Interference
- Computer
  - USB settings
  - Entirely remote system?

Knowing your mechanical system

- Tripod/Mount Capacity
- Periodic Error
- Telescope Balance
- Counterweight Balance
- Cable management
- Backlash
    - Mount
    - Motorized Focuser
- Wind profile
- Vibration

This will be the focus of this session

The Trinity of Imaging



The Mount

"The single most important item for the imager is the mount. Next comes the mount. Then comes the mount.... Get the picture?"

Roland Christen

The Mount

Specs:

- Type:
    - Equatorial
    - Alt-Az
- Payload capacity
    - Visual or imaging rated?
    - Most imaging rated typically overinflated by 2x
- Periodic Error
    - Amplitude
    - Smoothness
    - Periodic error correction
- Interface:
    - Hand paddle
    - Computer connection
        - ASCOM
        - Indi
    - Smartphone app

Periodic Error

Small inaccuracies in gear fabrication/assembly can lead to error in RA tracking

Typical PE values:

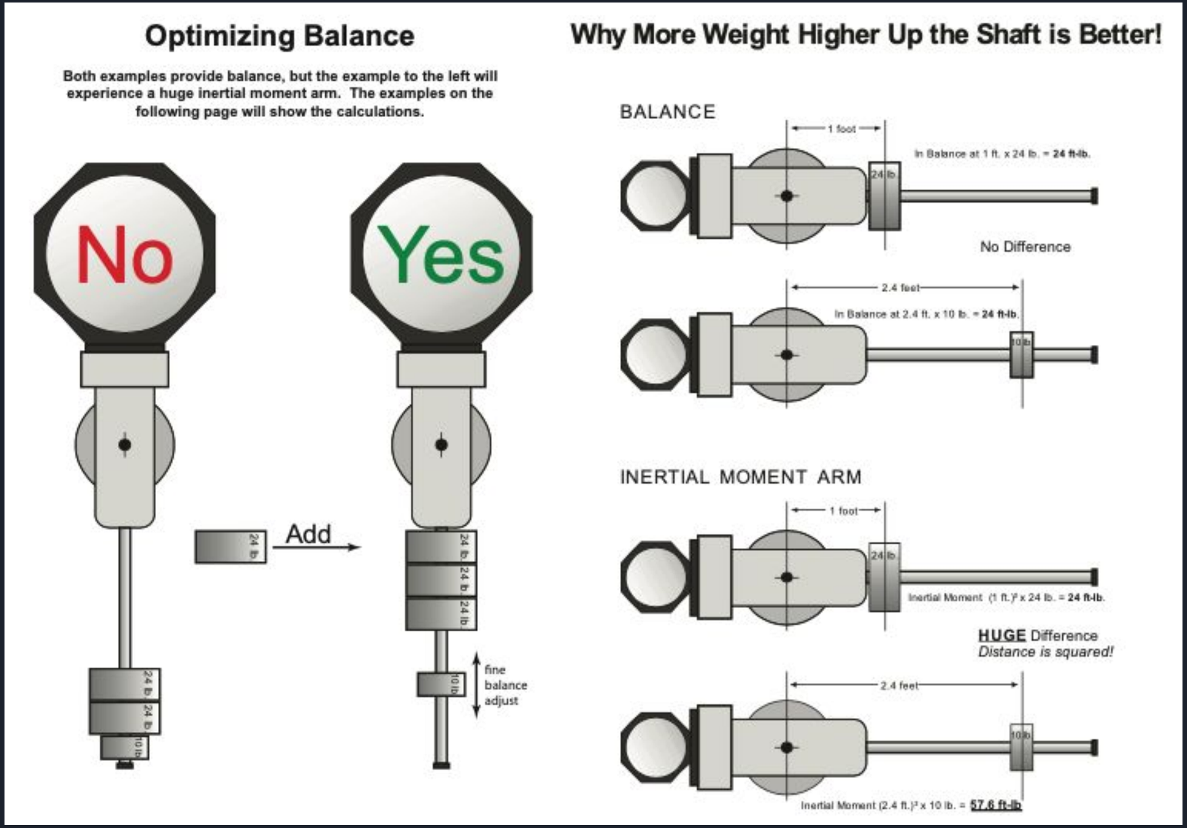
- Good mounts < 30” peak-to-peak
- Excellent <7” peak-to-peak

Choices to get better guiding:

- If smooth enough, can sometimes ignore
- Add PE Correction

Some mounts have encoders that make PEC unnecessary

Counterweight arrangement



Why?

The balance of forces (Newton's second law) for damped harmonic oscillators is then

$$F = -kx - c\frac{\mathrm{d}x}{\mathrm{d}t} = m\frac{\mathrm{d}^2x}{\mathrm{d}t^2},$$ [1][2][3]

which can be rewritten into the form

$$\frac{\mathrm{d}^2x}{\mathrm{d}t^2} + 2\zeta\omega_0\frac{\mathrm{d}x}{\mathrm{d}t} + \omega_0^2 x = 0,$$

where

$\omega_0 = \sqrt{\frac{k}{m}}$ is called the "undamped angular frequency of the oscillator",

$\zeta = \frac{c}{2\sqrt{mk}}$ is called the "damping ratio".

The value of the damping ratio ζ critically determines the behavior of the system. A damped harmonic oscillator can be:

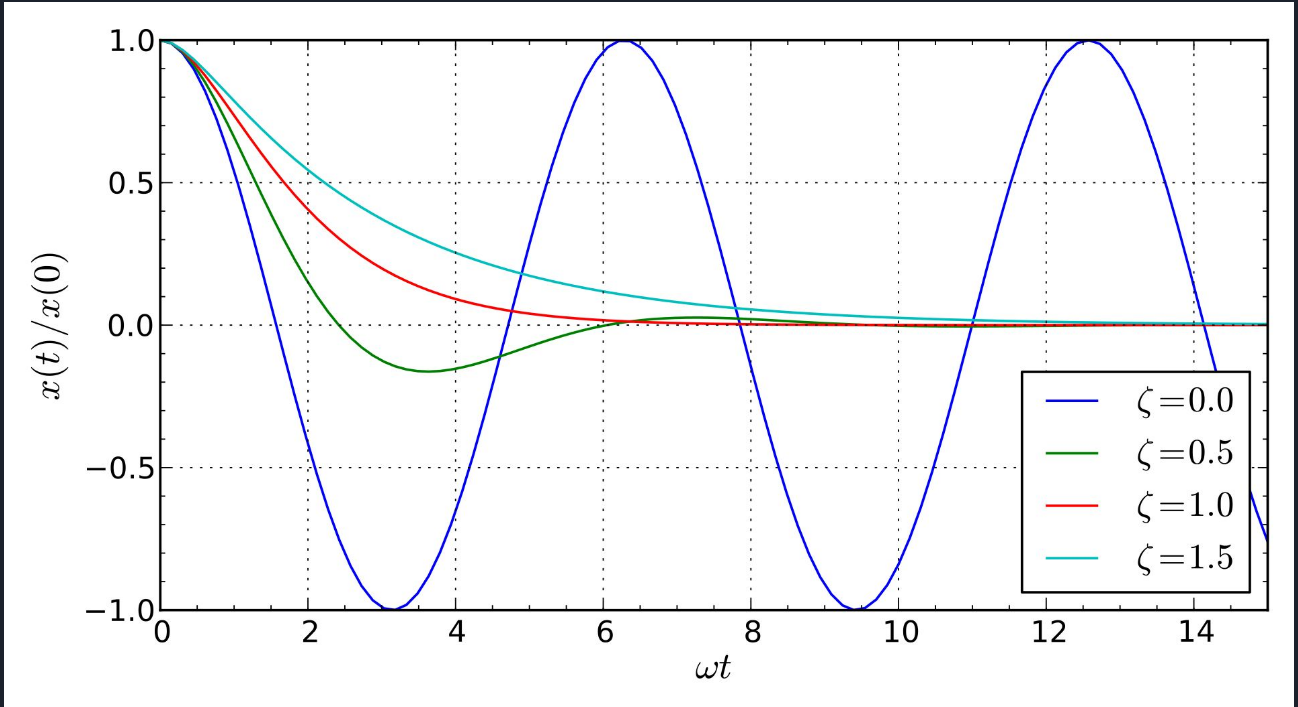
- *Overdamped* ($\zeta > 1$): The system returns (exponentially decays) to steady state without oscillating. Larger values of the damping ratio ζ return to equilibrium more slowly.
- *Critically damped* ($\zeta = 1$): The system returns to steady state as quickly as possible without oscillating (although overshoot can occur). This is often desired for the damping of systems such as doors.
- *Underdamped* ($\zeta < 1$): The system oscillates (with a slightly different frequency than the undamped case) with the amplitude gradually decreasing to zero. The angular frequency of the underdamped harmonic oscillator is given by $\omega_1 = \omega_0\sqrt{1-\zeta^2}$, the exponential decay of the underdamped harmonic oscillator is given by $\lambda = \omega_0\zeta$.

The Q factor of a damped oscillator is defined as

$$Q = 2\pi \times \frac{\text{energy stored}}{\text{energy lost per cycle}}.$$

Q is related to the damping ratio by the equation $Q = \frac{1}{2\zeta}$.

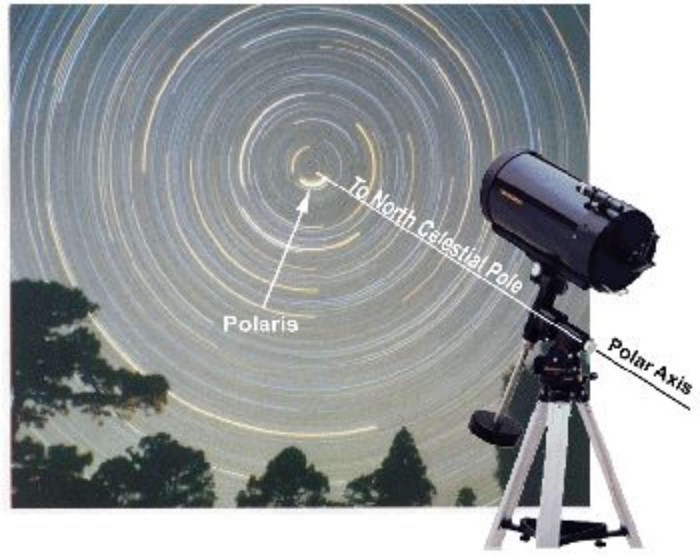
Why?



1.0
0.5
0.0
−0.5
−1.0
0
2
4
6
8
10
12
14
$x(t)/x(0)$
ωt
$\zeta = 0.0$
$\zeta = 0.5$
$\zeta = 1.0$
$\zeta = 1.5$

Counterweight bias

Polar Alignment

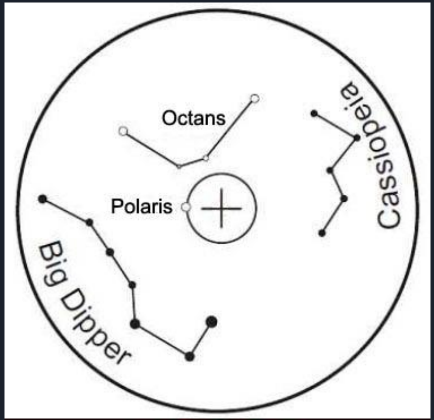


Polar alignment methods

1. Align on polaris
   a. Polar scope: RAPAS, etc.
   b. Polemaster

2. Drift-align methods
   a. PHD2 has easy method

3. Model your mount
   a. Build model of pointing/tracking inaccuracies to know polar alignment error



Direct Polaris alignment: Polemaster

Camera fixed to mount

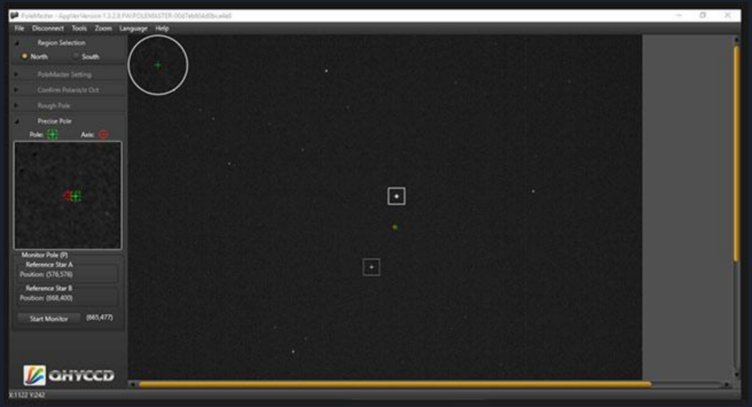
Initial alignment of stars to template

Rotation of mount in RA to fine tune alignment

Fairly fast and easy

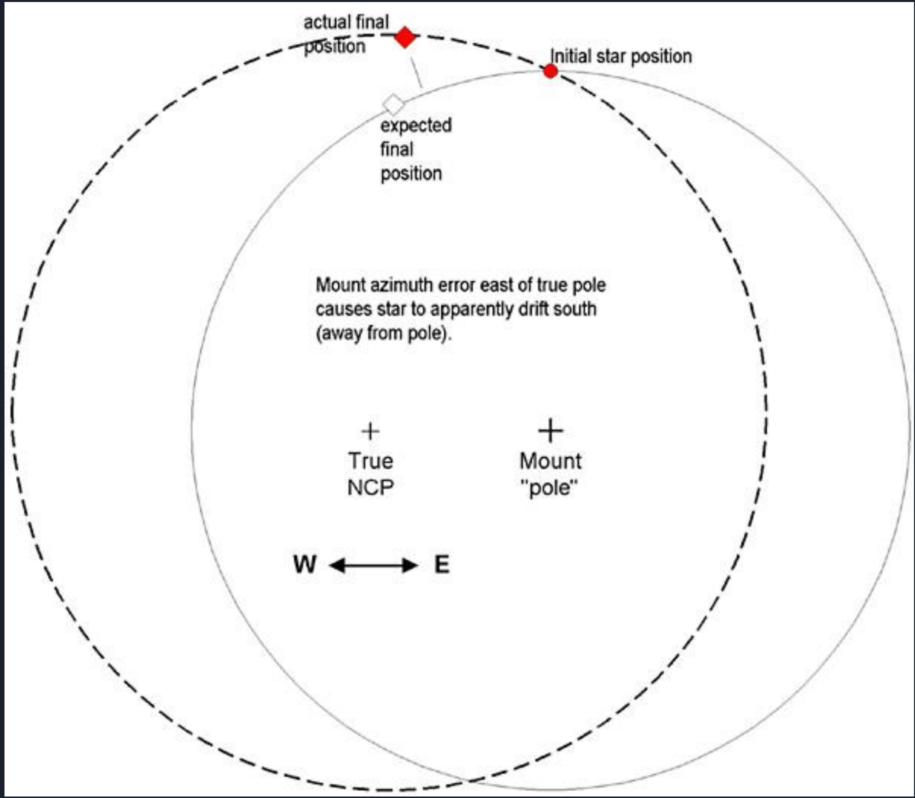
Alternative: Sharpcap

https://www.sharpcap.co.uk/sharpcap/features/polar-alignment



Drift alignment

Polar Alignment - Northern Hemisphere	
Star Direction	**Description**
Meridian	Star drifts NORTH, rotate telescope azimuth EAST Star drifts SOUTH, rotate telescope azimuth WEST
Eastern Horizon	Star drifts NORTH, adjust telescope altitude LOWER Star drifts SOUTH, adjust telescope altitude HIGHER
Western Horizon	Star drifts NORTH, adjust telescope altitude HIGHER Star drifts SOUTH, adjust telescope altitude LOWER

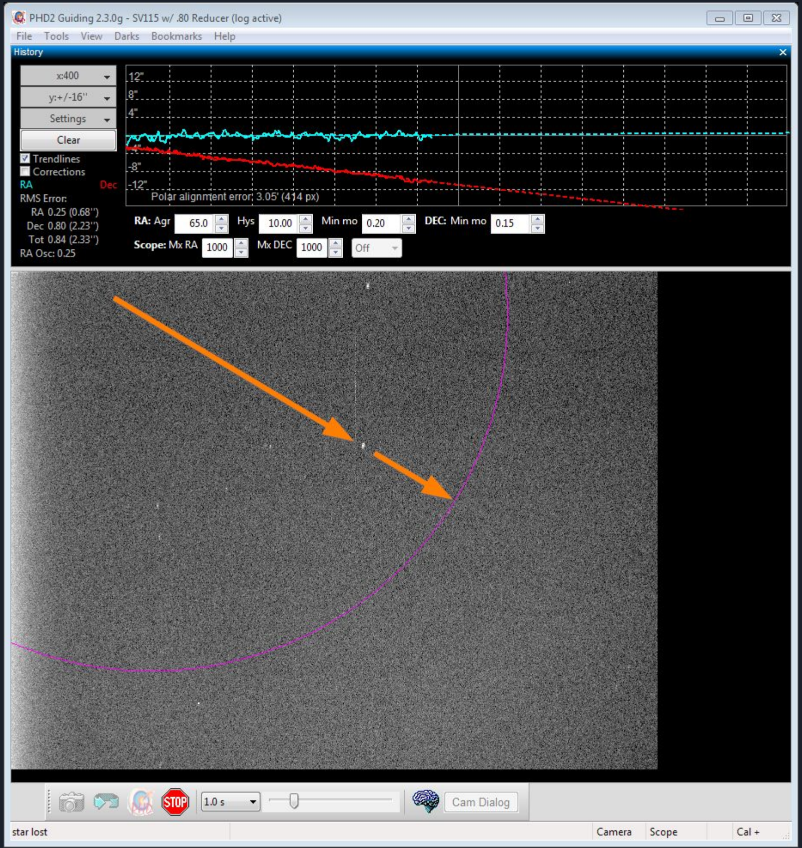


PHD2: drift align

Faster than it sounds!

Very accurate with current camera sensors

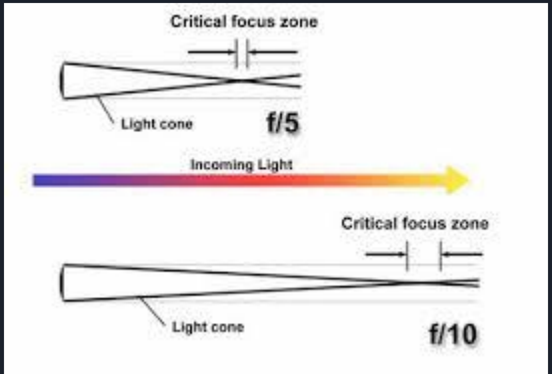
I use this method to calibrate my RAPAS



Nailing Focus

Nailing Focus - The Critical Focus Zone

- Describes how accurate focus position must be to be within acceptable focus
- Highly dependent on focal-ratio
- Very tight for fast optical systems
-



Critical Focus Zone

Calculate the length of the zone in which the focused image of a star is smaller than the size of its Airy disk.

$$\mathit{critical\ focus\ zone} = 2 \times \text{focal\_ratio} \times \text{Airy\_disk}$$

which simplifies to:

$$\mathit{critical\ focus\ zone} = 4.88 \times \text{focal\_ratio}^2 \times \lambda$$

For CCD cameras, if we take a 2x sampling ratio:

$$\mathit{ccd\ focus\ zone} = \text{focal\_ratio} \times \mathit{pixel\_size}$$

where:

λ = wavelength of light

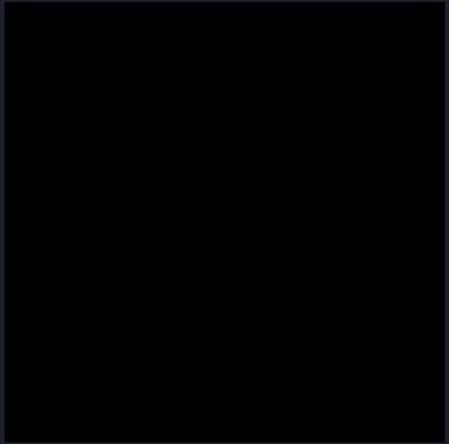
Light Colour	Green
Wavelength of light	510
Focal Ratio	4.6
Camera pixel size (microns)	3.69
Pixel binning	1x1
Calculate Reset	
Critical Focus Zone	53 microns
CCD Focus Zone	53 microns

Note that because at low f/ratios the size of the Airy disk becomes significantly smaller than typical CCD pixels sizes I have introduced a value for the CCD Focus Zone. The value for the CCD focus zone takes the larger value of the CFZ, or where the Airy disk is half the effective pixel size (2x under sampling ratio) the CCD focus zone value defined above. For small focal ratios the CFZ gives a misleadingly small figure for imagers.

http://www.wilmslowastro.com/software/formulae.htm

Nailing Focus - A Manual Method

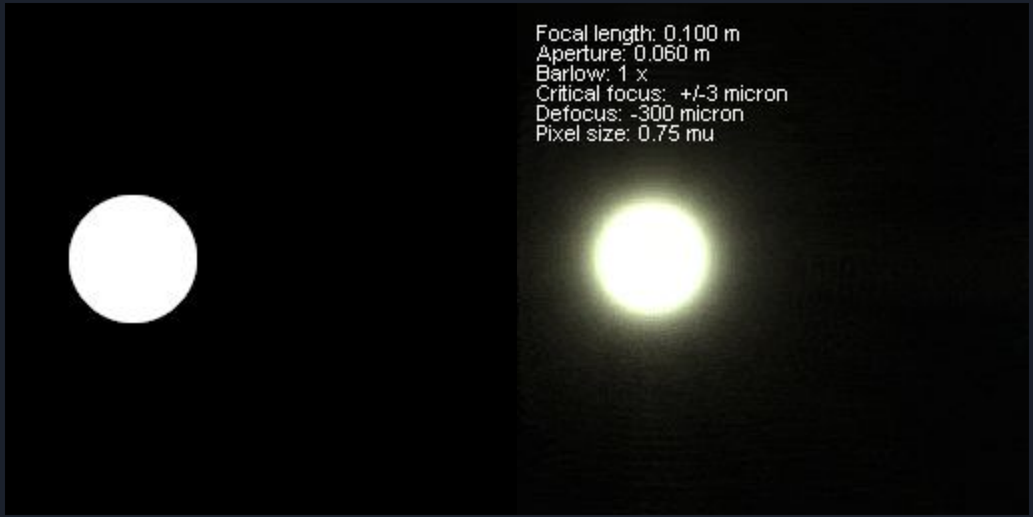
- As night cools, optical properties change - need to refocus
  - OTA contraction
  - Lens deformation
- Need some way to monitor changes
  - FWHM
  - Number of stars in image
  - Mask
- Bahtinov Masks



The Bahtinov Mask - How does it work?

Credit **cprobertson1**:
https://www.pentaxforums.com/forums/groups/135-astrophotography/9078-bahtinov-masks-basic-visual-guide-how-they-work.html

The Bahtinov Mask - How does it work?



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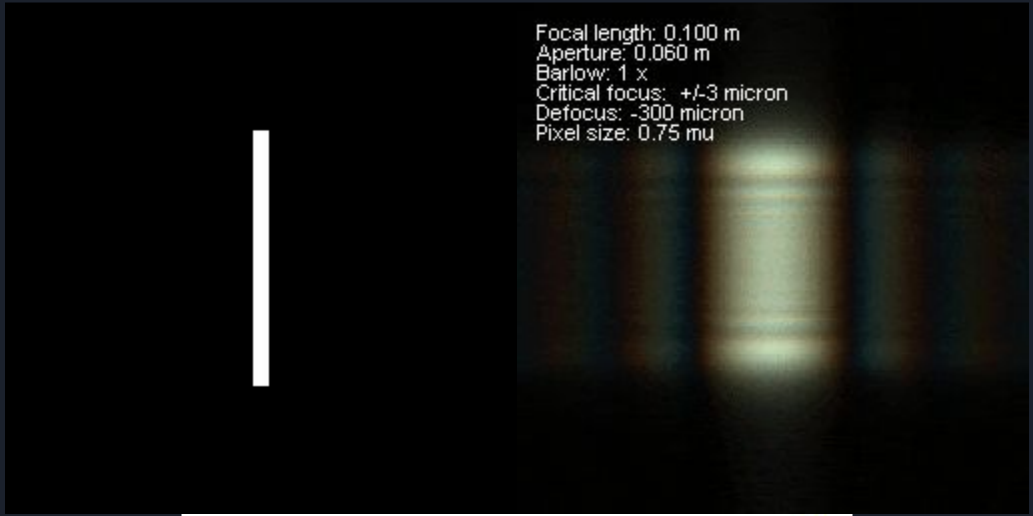

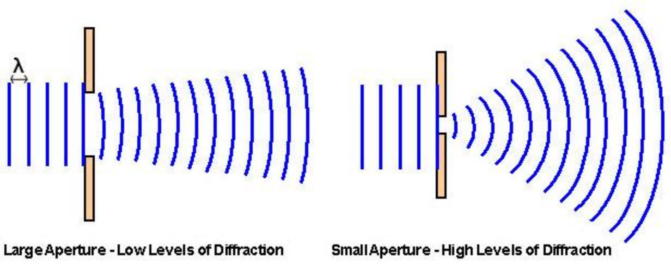

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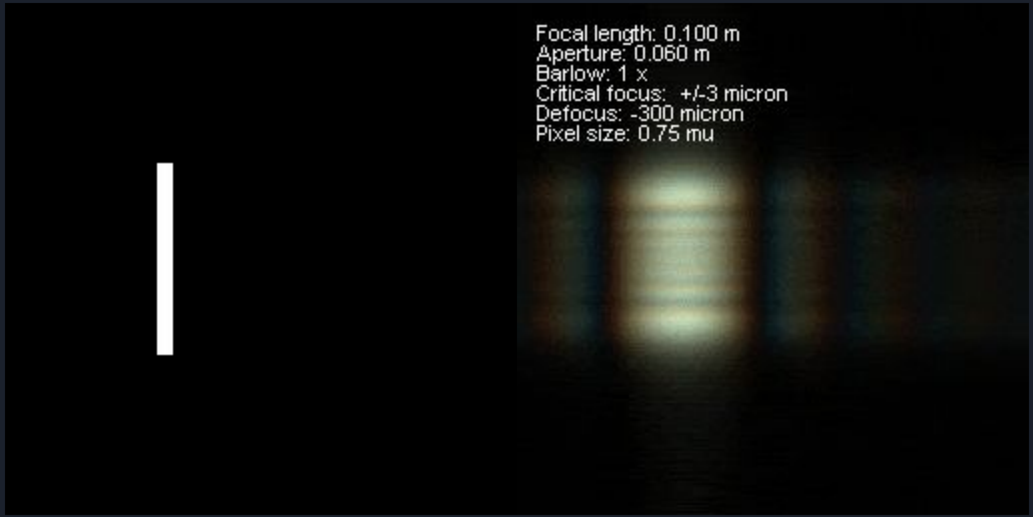

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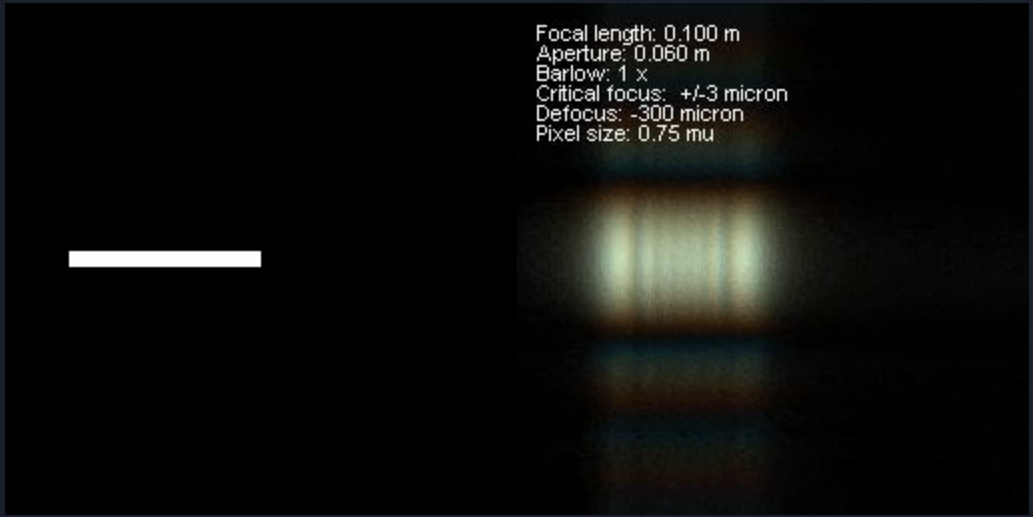

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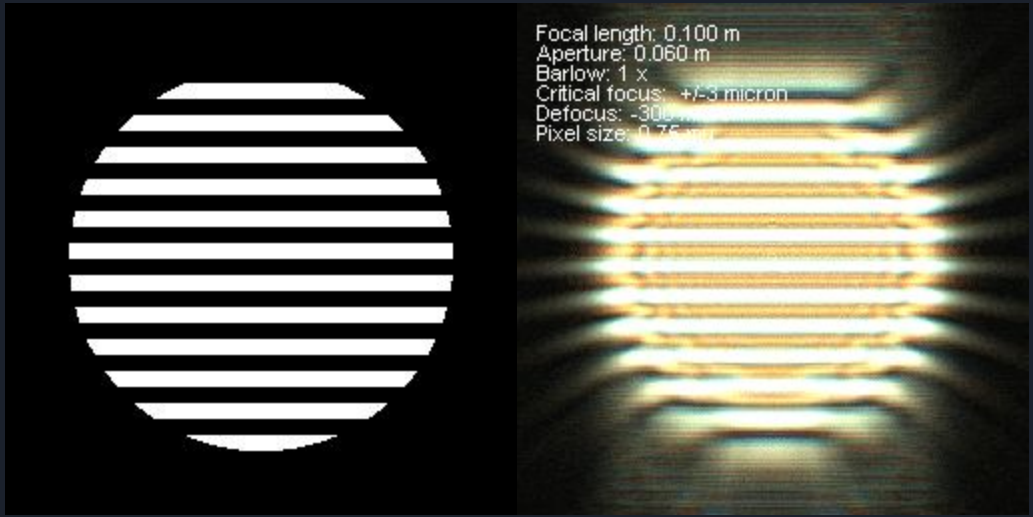

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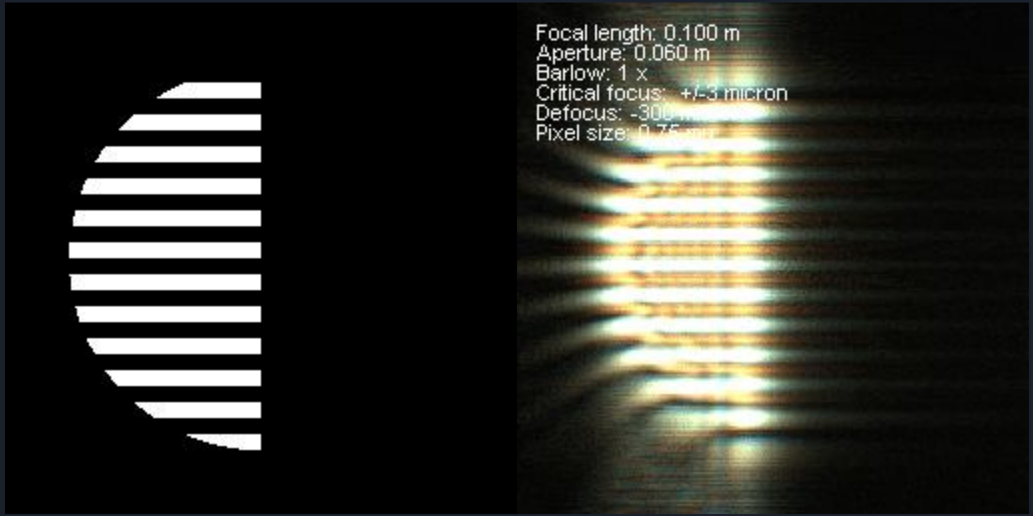

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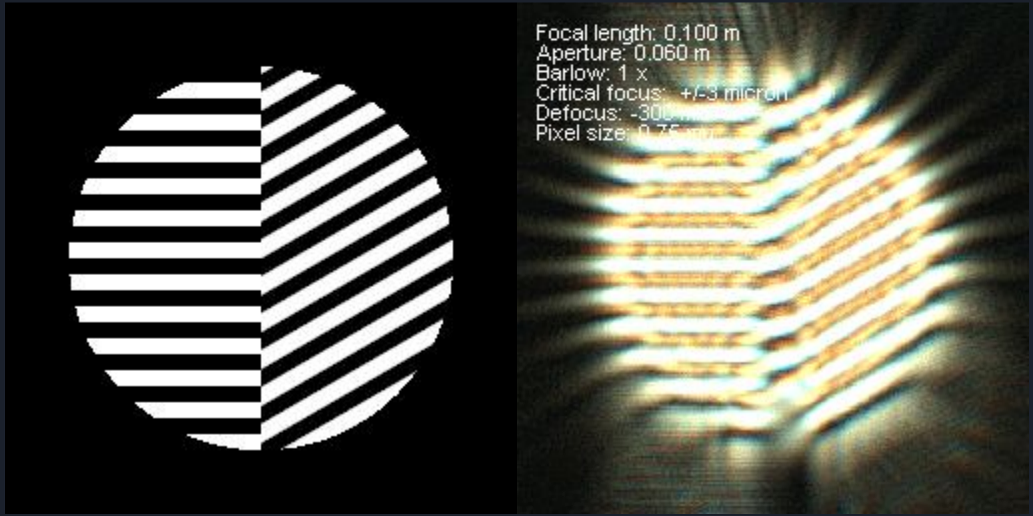

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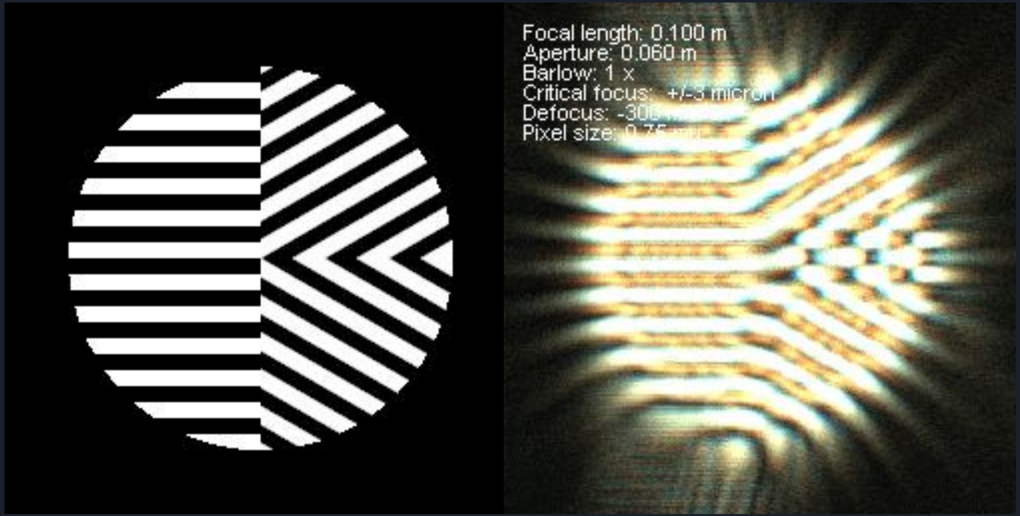


Autofocus

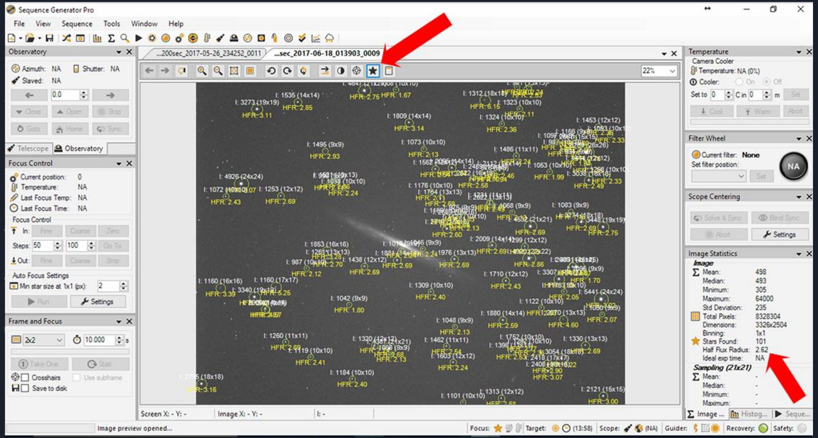
- Need focus motor and controller
  - Feathertouch
  - Moonlite
  - Pegasus Astro
  - Robofocus

- Telescope systems
  - High accuracy

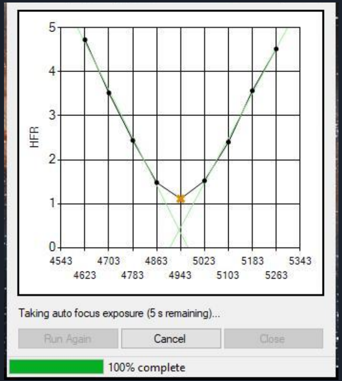
- Camera lens system
  - Belt driven
  - Can have significant backlash
  - Can pull lens laterally

Autofocus

- Single star method:
  - Fast if using ROI
  - V-curve is intuitive
  - Only one portion of FOV - bad for field with high curvature
  - Great for optically flat systems



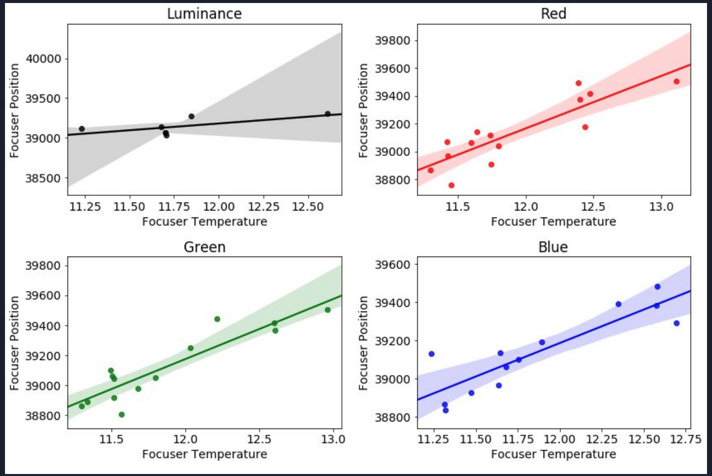
- Multi star method:
  - Can be slower - full frame download
  - Good for systems w/ some curvature
  - Method used in SGP



Keeping focus

Some telescopes are more susceptible to focus drift with changing environment temperatures

- May depend on tube construction, optical design, speed of optics
- I refocus every 0.5C change in ambient temp



- Temperature compensation another option **

Cable Management

Cable Management

Why ?

- Better guiding/tracking
- No cable snags
- Less impact from wind gusts

How?

- Bundle cables together
  - Cord Wrap
- Provide enough slack to slew to all parts of sky
- Attach bundle to low-moment arm areas of mount
  - I often use saddle plate

Cable Management: Side vs. Top mount

Side mount (my preference)

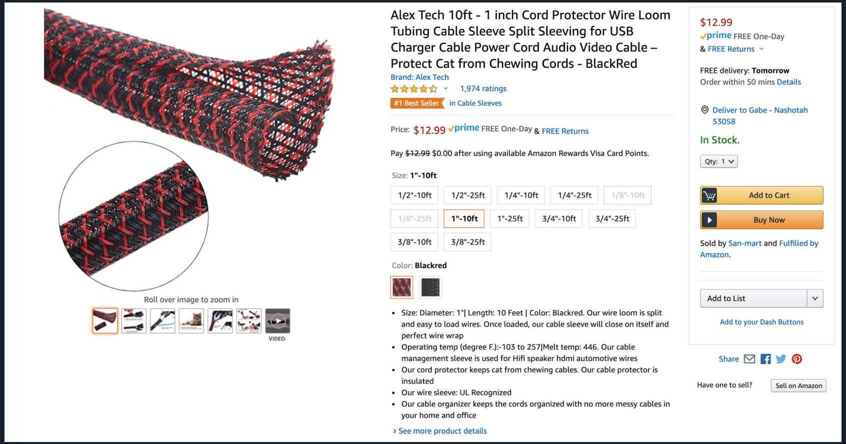
- \+ Less weight
- \+ Forces better cord management
- \- Longer cables

Top Mount

- \+ Fewer cables running up (sometimes just power and mount)
- \+ Shorter cable runs to peripherals
- \- More weight and moment arm

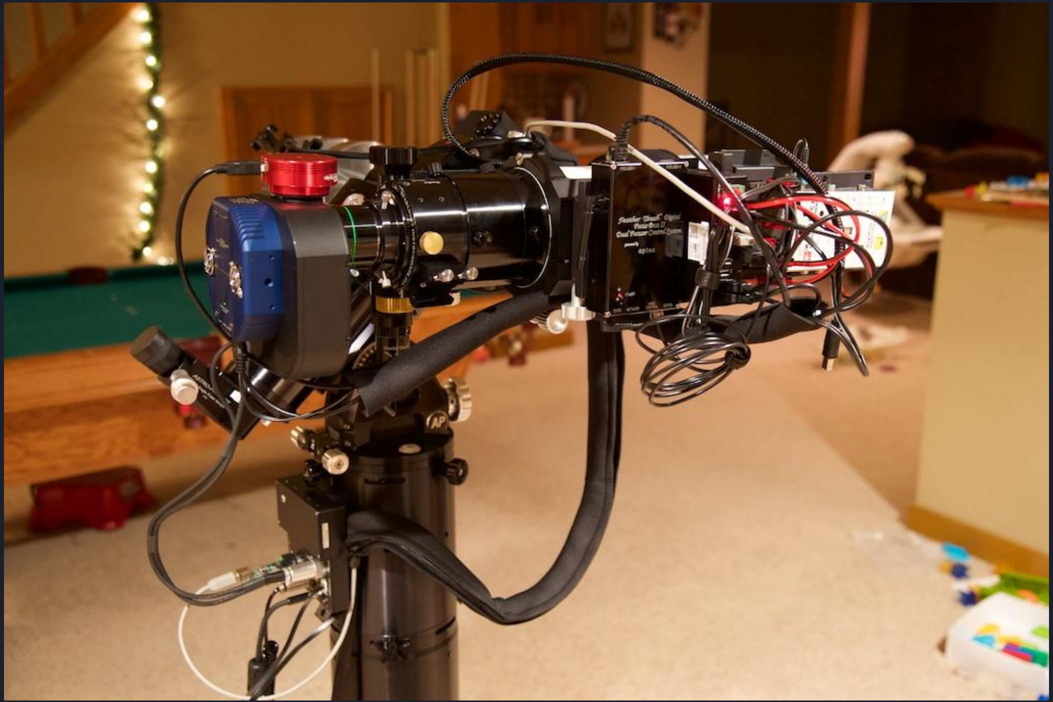
Cable Management

- Bundle cables together
    - Cord Wrap
    - Zip ties
- Crucial: Provide enough slack to slew to all points in the sky
- Be aware of pinch-points
    - Cable pinching can cause tracking inaccuracies at best, damaged cables or even mount at worst

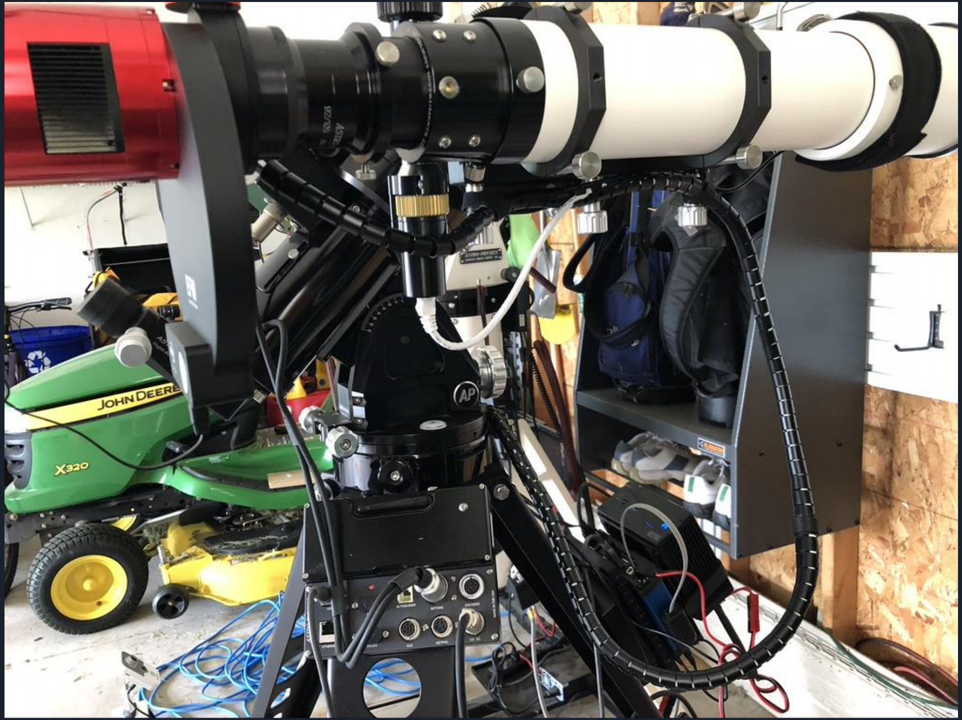


Cable Management examples

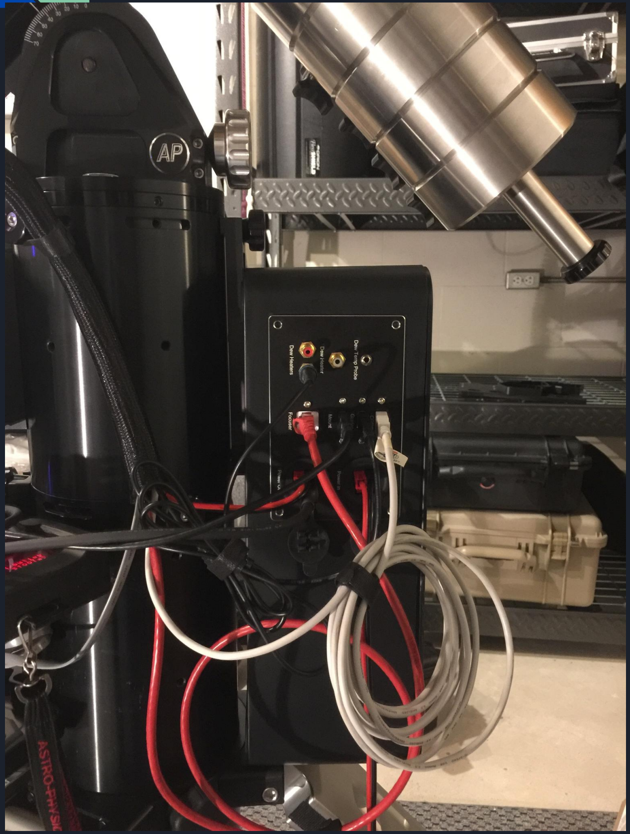
Cable Management examples

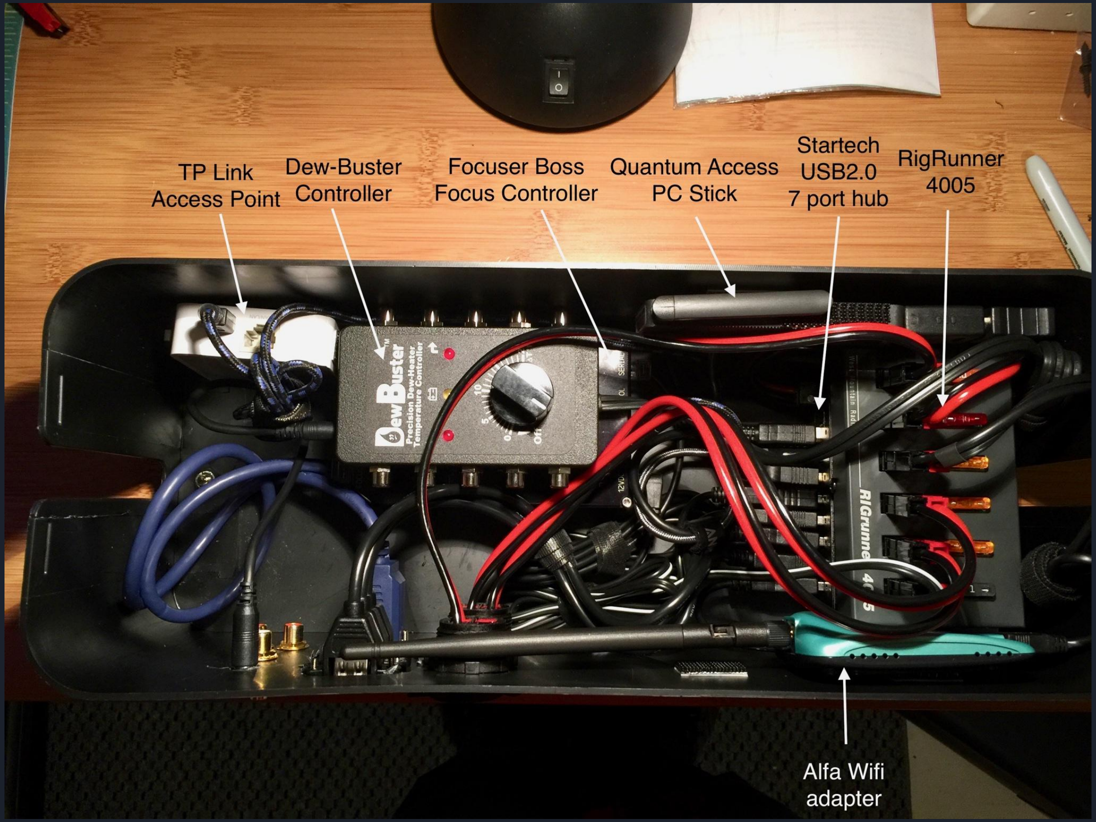


Cable Management examples



Cable Management: Assemble an Astro-box





Guiding setup: to OAG or not to OAG

To OAG (my preference)

- If significant flexure/mirror flop
- Sensitive guide CCD
  - Pick off prism can give small FOV
- Simpler focus
  - Set and forget

No OAG

- Mount can handle extra guide scope
- No flexure
- Not enough backfocus to get OAG
- Large FOV

Environmental Sensors

Tracking environmental conditions

- Temperature
  - Proactive tracking for focus changes: can be in focus motor on scope
  - How much to push TEC for camera
- Humidity
  - Sense level of dew prevention needed
- Wind
  - Knowing if the wind is too much for your rig
- Rain sensors
- Cloud sensors

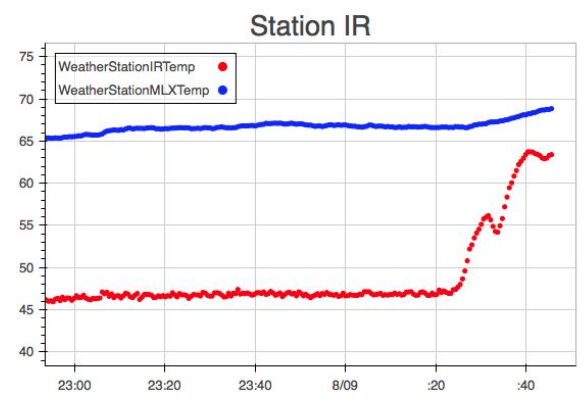
ASCOM drivers available to also connect with OpenWeather or other sources to get local conditions

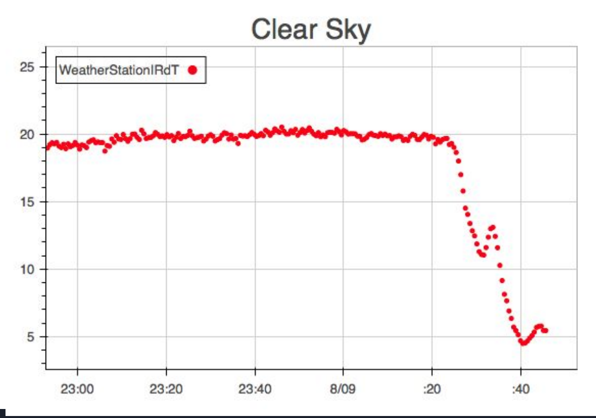
Cloud sensors

Main method of detection

- IR signature of cloud vs. open sky

Can alert to clear skies or when conditions are deteriorating





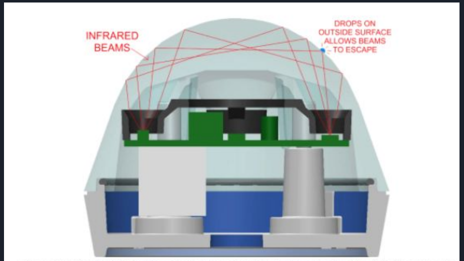
Rain sensors

Hydreon RG11

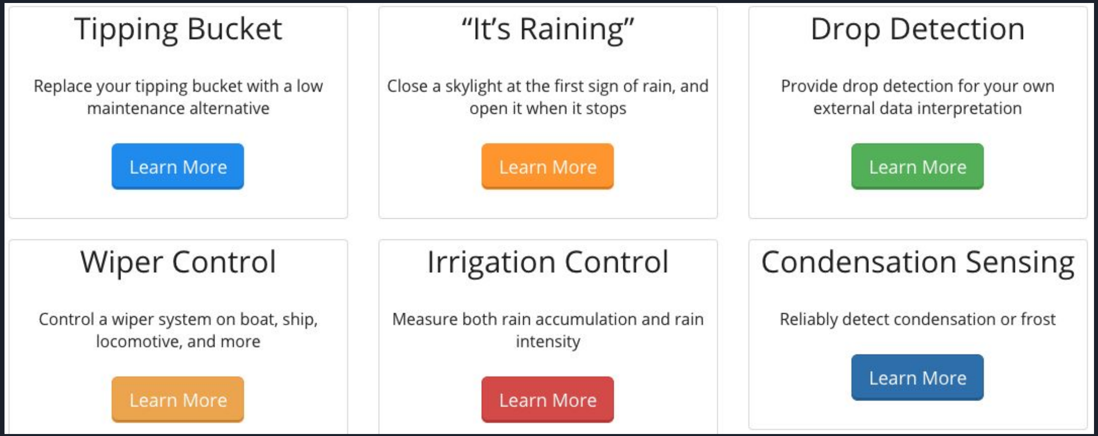
- Uses IR light to measure beads of water on transparent cover
- Configurable sensitivity

Tip-bucket

- Typically 0.01” increments



The patented Rain Gauge optical design keeps the beams inside the sensor, away from the influences of falling leaves and spiderwebs.



Dew Control

Need a heater to put on objective to keep dew away on humid nights

PWM of some controllers can affect electronics

Last resort: hairdryer

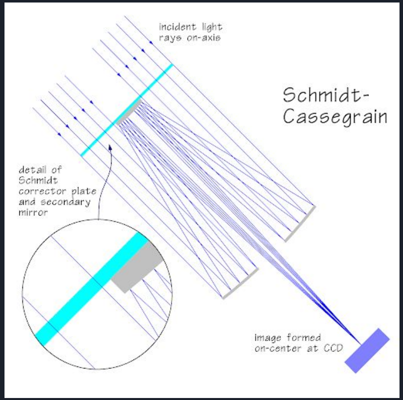
Next time:

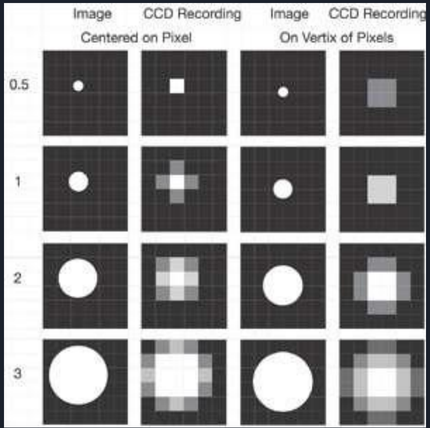
Me (September 9):

- Optical system
- Electronic system

Jeff (October 14):

- All about guiding





Down the road

- Cameras and settings
- Calibration frames
- Acquisition software (SGP, etc.)
- Target planning/sequencing
- Data management
- Weather resources
- Observatory topics
- More processing topics
    - PS/PI

Looking for volunteers for some of these topics