Getting The Most From Your Imaging Equipment

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Key Factors

- Optical Alignment
- Image Sampling and Seeing
- Maximize Signal-To-Noise Ratio
- Focusing
- Guiding & Dithering
- Reliable Hardware Assembly

Optical Alignment

- Collimation
  - As precise as possible
  - Look at the image
- Stable Optical Path
  - Secure Threaded Connections
  - Minimize Tilt
  - Eliminate Draw Tube Sag

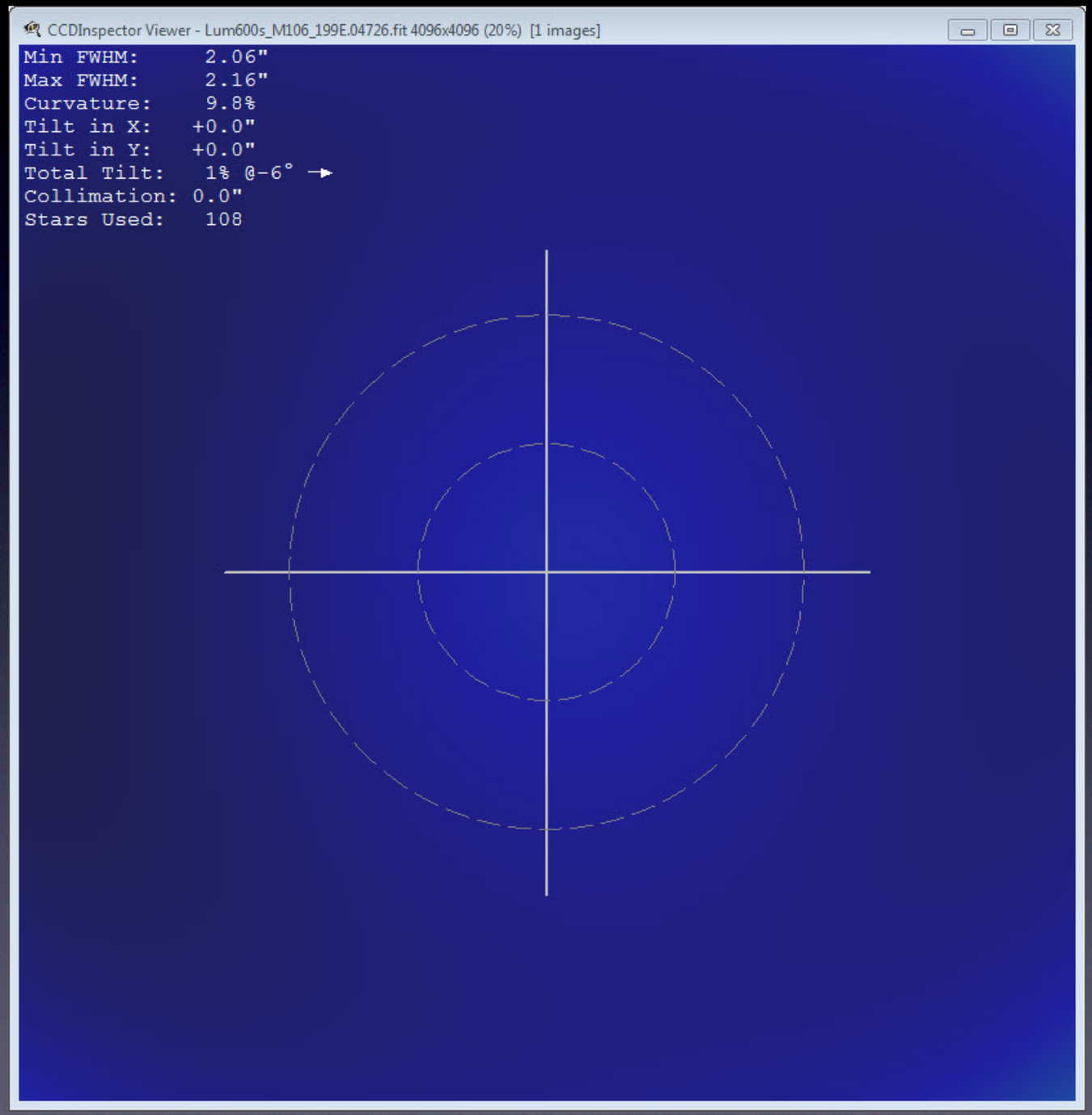
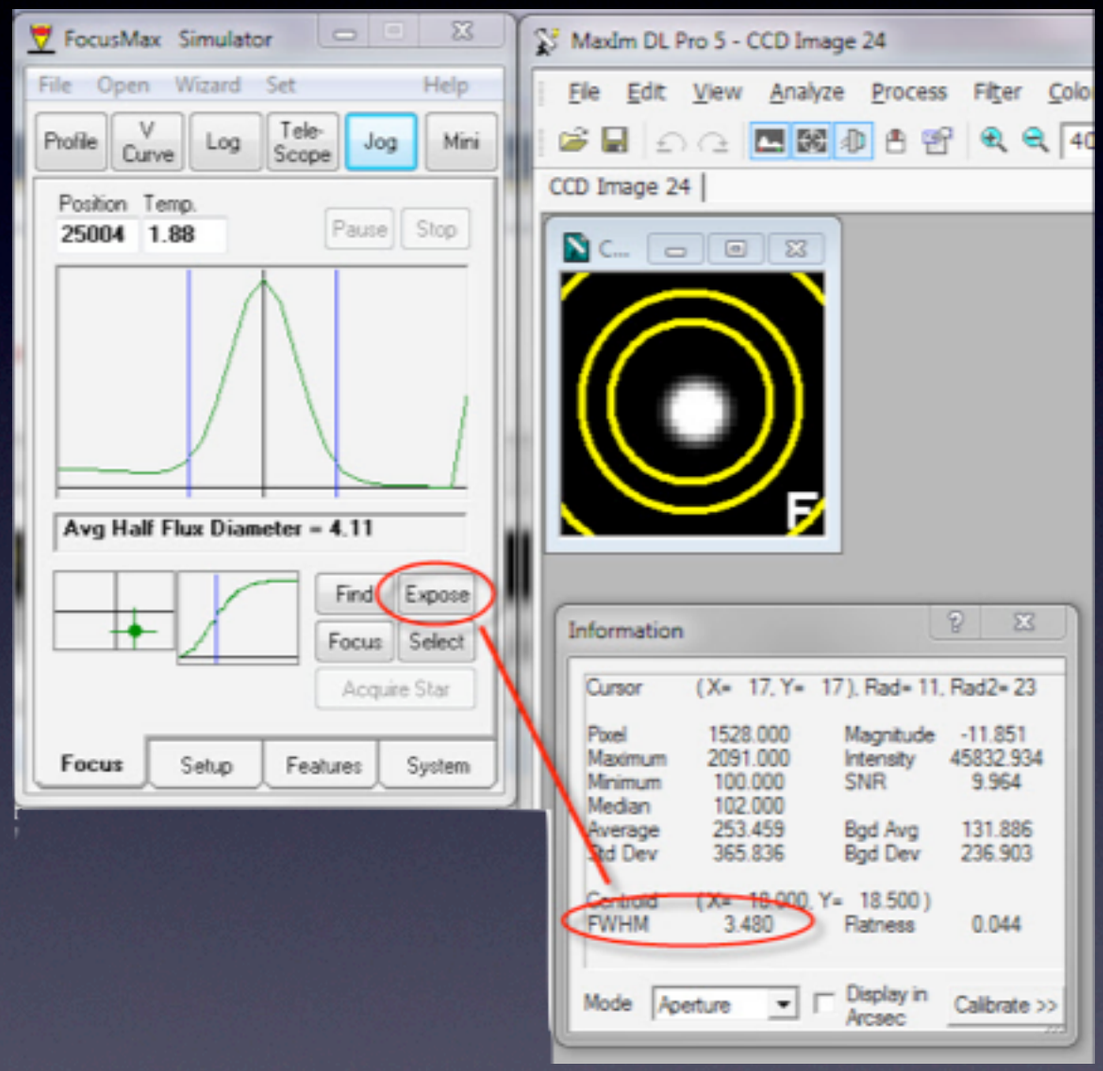


Image Sampling & Seeing

- Seeing is defined as the point spread function of a point source, as seen through the atmosphere.
- FWHM of a short exposure, measured in arc-sec,
- For high resolution imaging, sample seeing by 3 - 3.5
- 2 arc-sec. seeing = .58 - .67 arc-sec./pixel
- arc-sec./pixel = $\frac{206 \times \text{Pixel Size (micron)}}{\text{Focal Length (mm)}}$



Rough Seeing Test
Maxim & FocusMax

Some Noise about Noise

- Incoming light is fixed but faint - we count photons - this is our “Signal”
- For discussion purposes, signal is fixed
- Noise is what we can mitigate to some extent
- Signal-to-Noise Ratio is simply incoming light divided by all noise sources
- Noise sources combine like Pythagorean’s theorem:
  Square root of the sum of the squares
- Primary sources of noise:
  - Camera read noise
  - Sky glow noise
  - Dark signal noise
  - Noise from the signal itself!

Typical Noise Calculation

- Camera Read Noise: 12e
- Sky glow signal for a 10 min. exposure through a clear filter: 1440e
  Sky glow noise: 38e
- Dark signal noise (9 dark frames combined): 3e
- Total Noise = SQRT (12^2 + 38^2 + 3^2)
- Total Noise = SQRT (144 + 1440 + 9) = 40e (broadband)
- Total Noise = SQRT(144 + 100 + 9) = 16e (narrowband, little sky glow)

Note: Noise is measured in electrons (e). Multiply ADU by Gain (e/ADU) to get e.

What Can We Do?

- Ideally,
  - Use sensors with lowest possible read noise
  - Cool the sensor to reduce dark signal and its attendant noise
  - Go to a dark site to reduce sky glow
  - Get the most signal possible

- Practically,
  - Get the quietest camera *we can afford*
  - Cool the sensor *as much as necessary*
  - Bury the read noise in the sky glow noise
  - Multiple, sufficiently long sub-exposures

Sub-Exposure Duration

- Broadband - Sky Noise Dominant
  - Bury read noise in sky noise when possible
    - Sky noise = square root of sky glow
    - Sky glow = 10 x read noise squared for 5% read noise contribution
    - Expose so that sky glow ADU = 10 x (read noise)^2 / Gain
- Narrowband - Read Noise Dominant
  - Negligible sky glow
- Noise reduces as square root of sub-exposures
- Binning may *or may not* give improved SNR. Verify!

Sample Calculation

Read Noise = 12e
Gain = 1.4 e/ADU

Target Dark Subtracted Sky Glow:

10 x 12 x 12 / 1.4 = 1028 ADU
(Subtract pedestal if present)

Focusing

- Know your Critical Focus Zone
  - Approx. 1/3[1] of classical 2.2 x (Focal Ratio)[2]
  - Measure focus movement per count
  - Calculate CFZ in counts
- Repeatable Focuser
  - Heavy loads challenge draw tube focusers
- Focus Automation
  - FocusMax, CCCDSoft @Focus2, Maxim's Focus

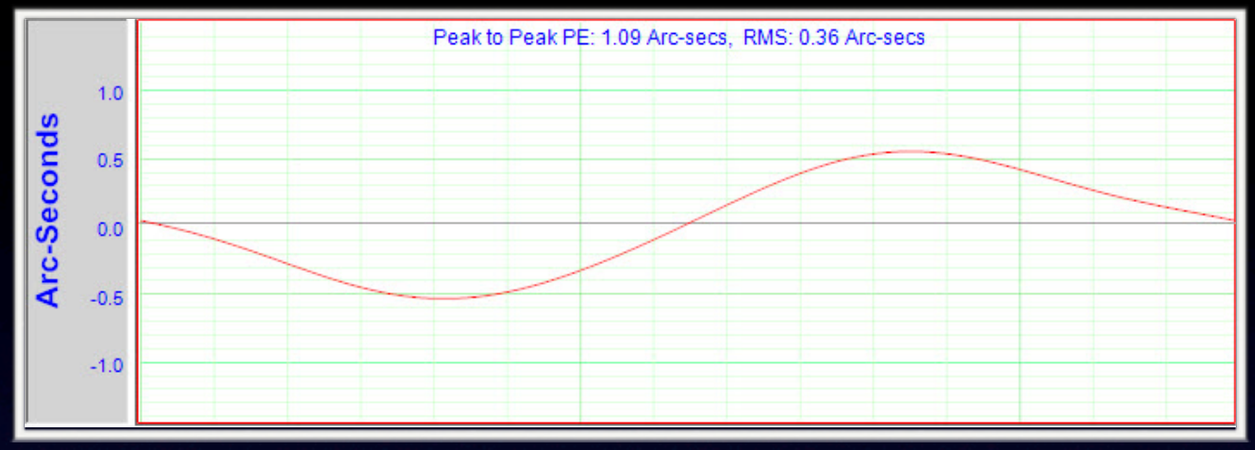
Sample Calculation
Optec TCF-S3: Moves 2.54 micron/count
CFZ for an F/5 system @ 450 nm: 18 microns
CFZ = 18/2.54 or 7 counts

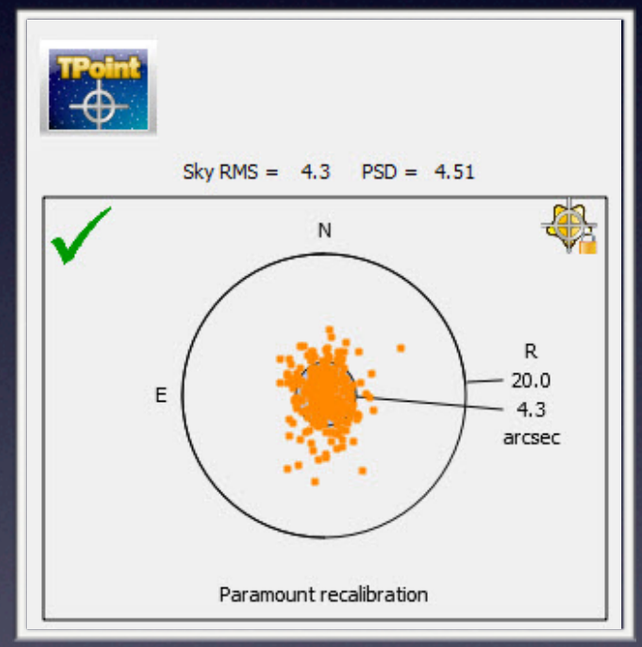
[1] Goldman, Magdal, *In Perfect Focus*, S&T, June 2010

[2] More precisely, classical CFZ = 4.88 x (Focal Ratio)[2] x (light wavelength)

Guiding

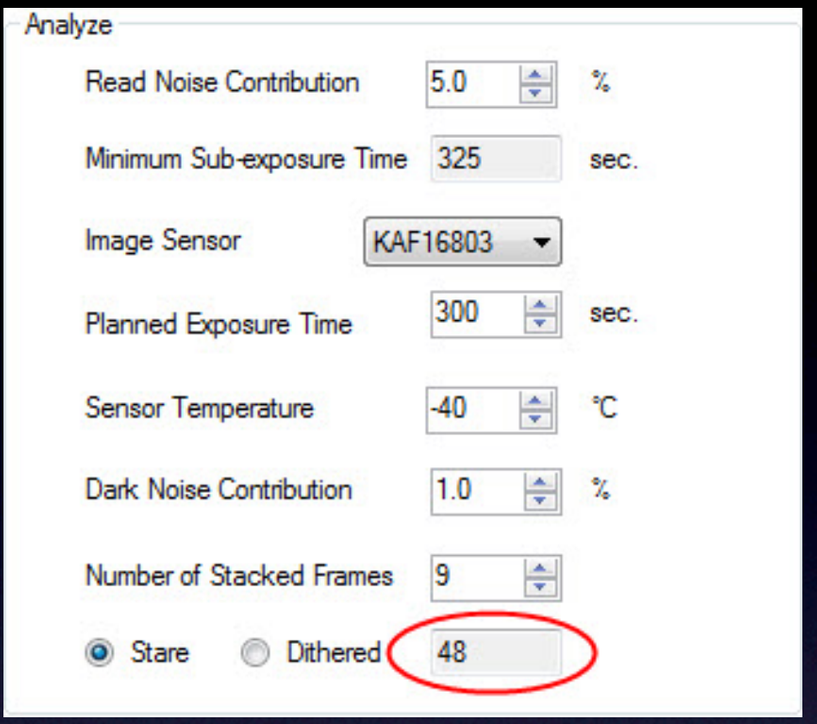
- Minimize Guider Work
  - Use Periodic Error Correction
  - Careful Polar Alignment
  - Pointing Modeling
- Guide Exposure Duration
- Adaptive Optics
- Common Optical Path Best
  - Differential Flexure with Guide Scope

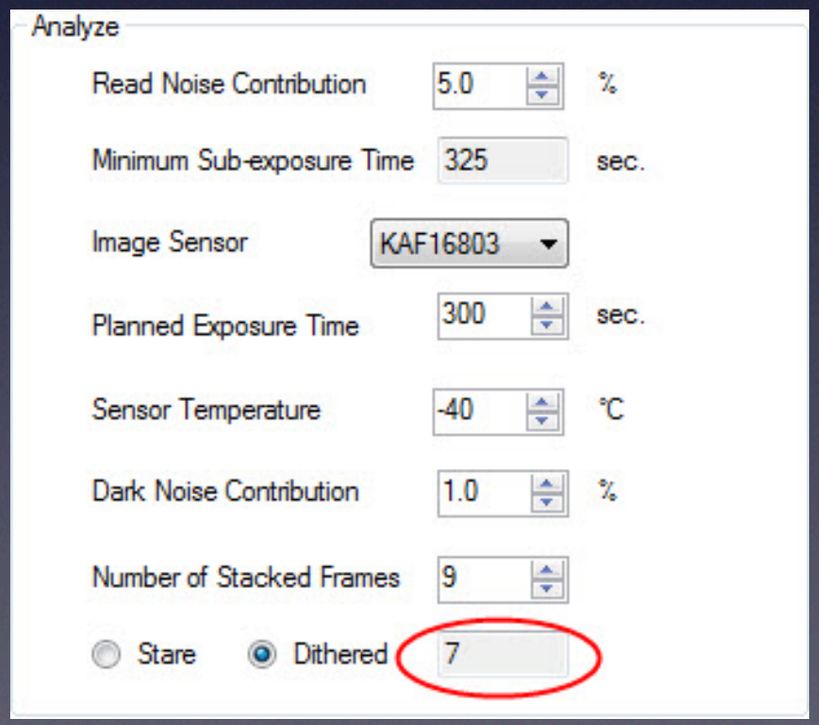




Dithering

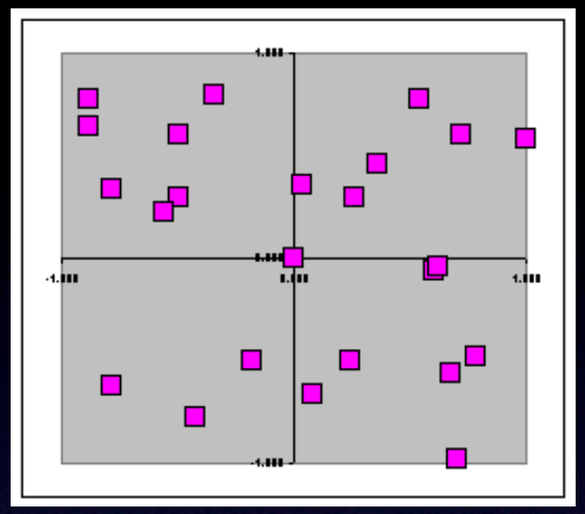
- Move guide star coordinates between sub-exposures
- Reduce pattern noise, hot pixels
  when properly aligned with rejection algorithm
- Fewer dark frames needed due to uncorrelated noise[3]



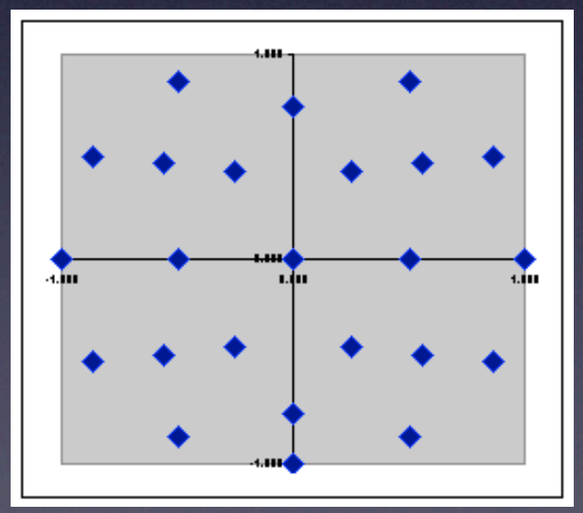


[3] Sub-Exposures and Dark Frames:
http://www.hiddenloft.com/notes/DarkSubExp.pdf

Dither Patterns



Random

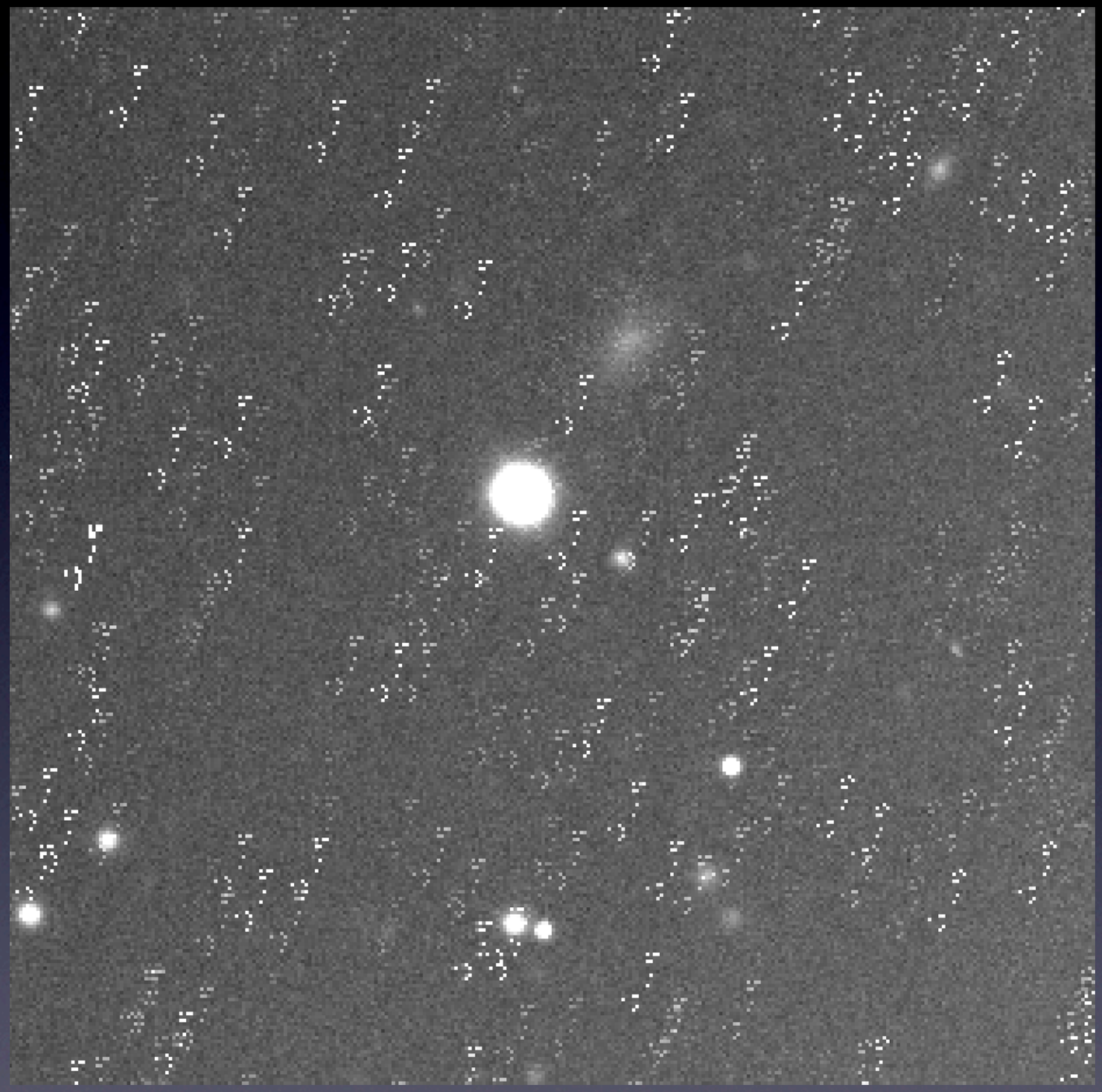


Unique

Single Frame

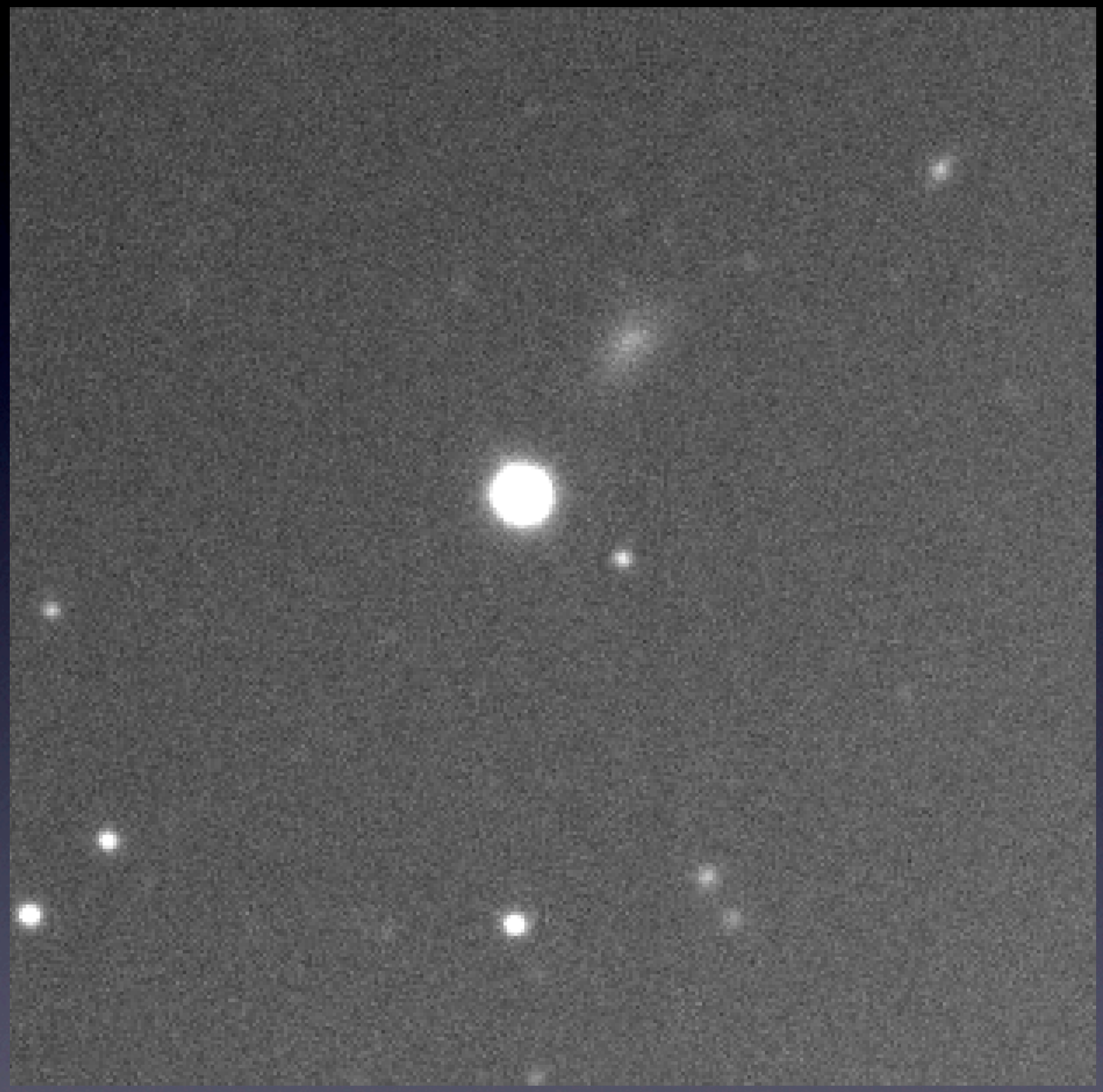
Aligned and Combined

- 12 Frames
- No Rejection
- Visible Pattern
- Varying Hot Pixel Levels



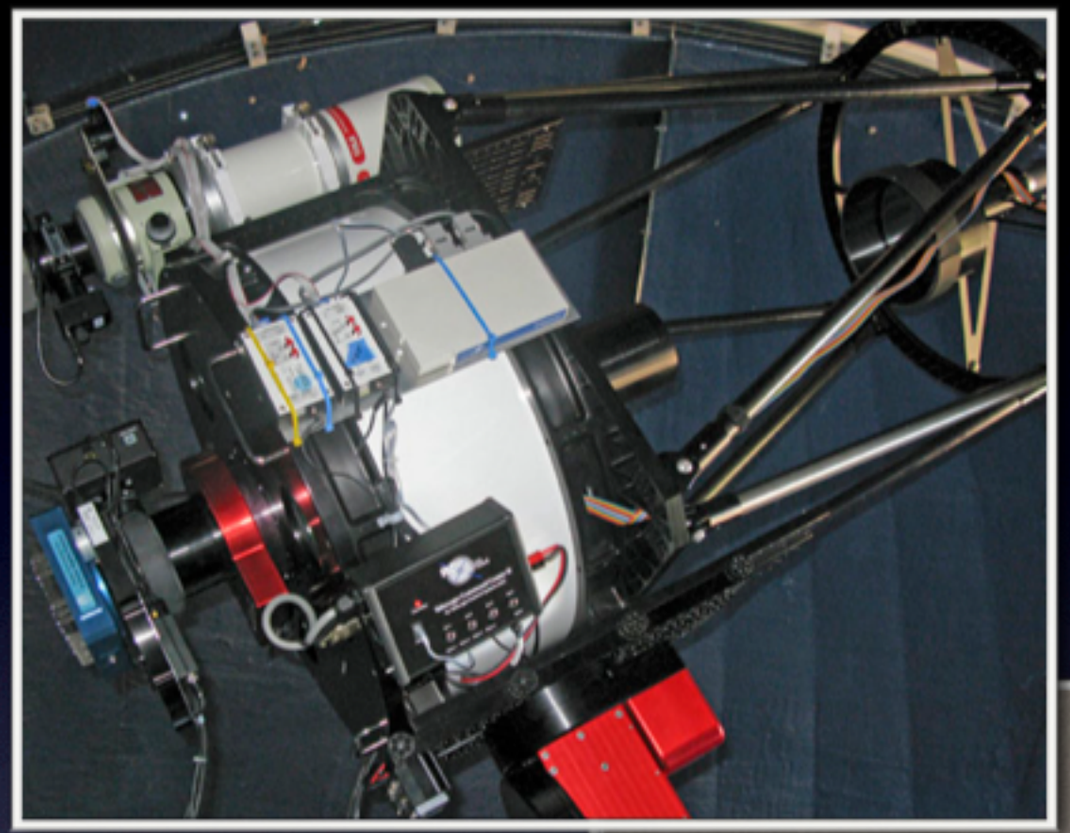
Combined With Data Rejection

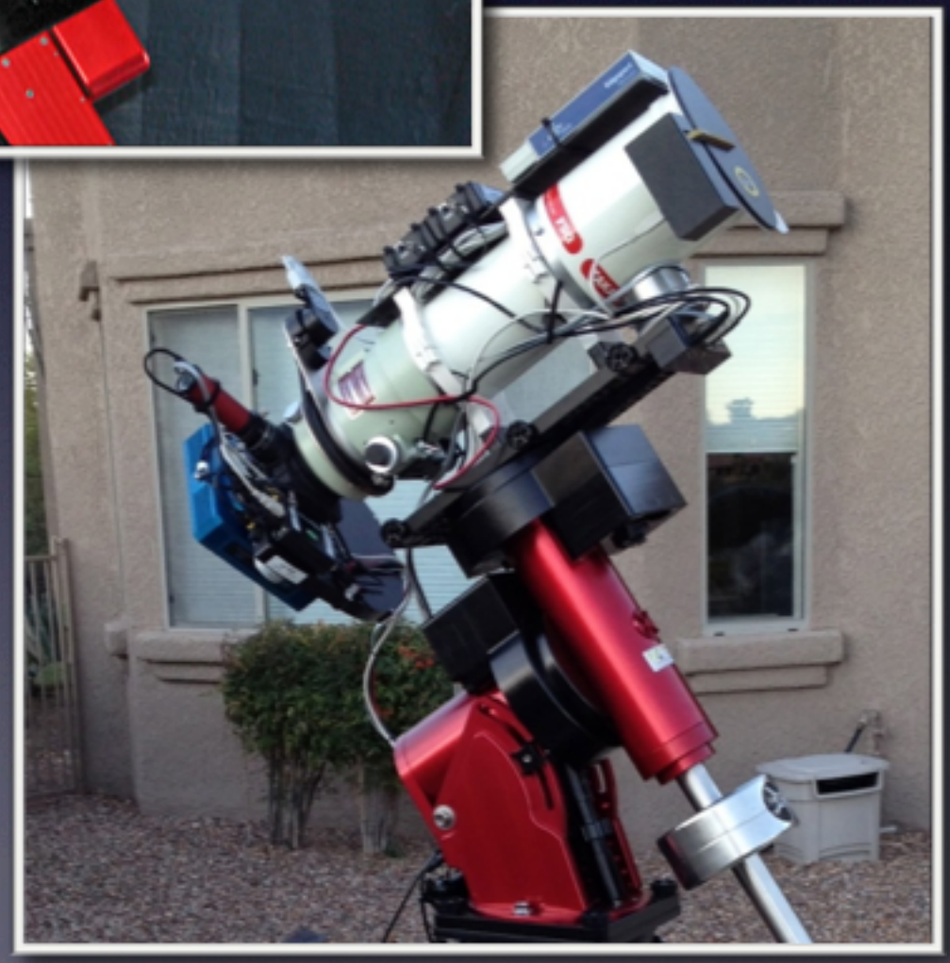
- 12 Frames
- Sigma Reject
  - As few as 3-4 Frames
  - More Is Better
- Nearest Neighbor Combine
- Smooth Background
- Faint Details Preserved



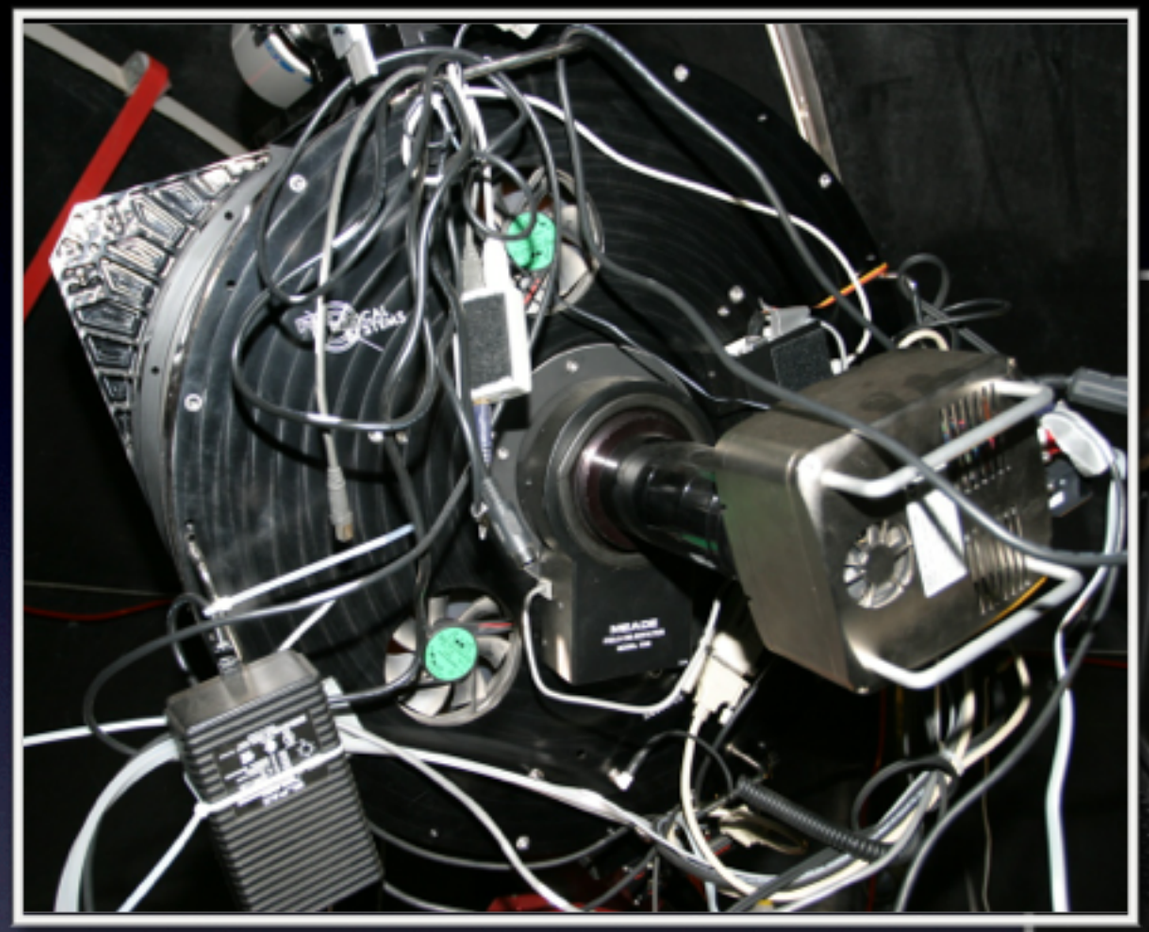
Repeatable Imaging

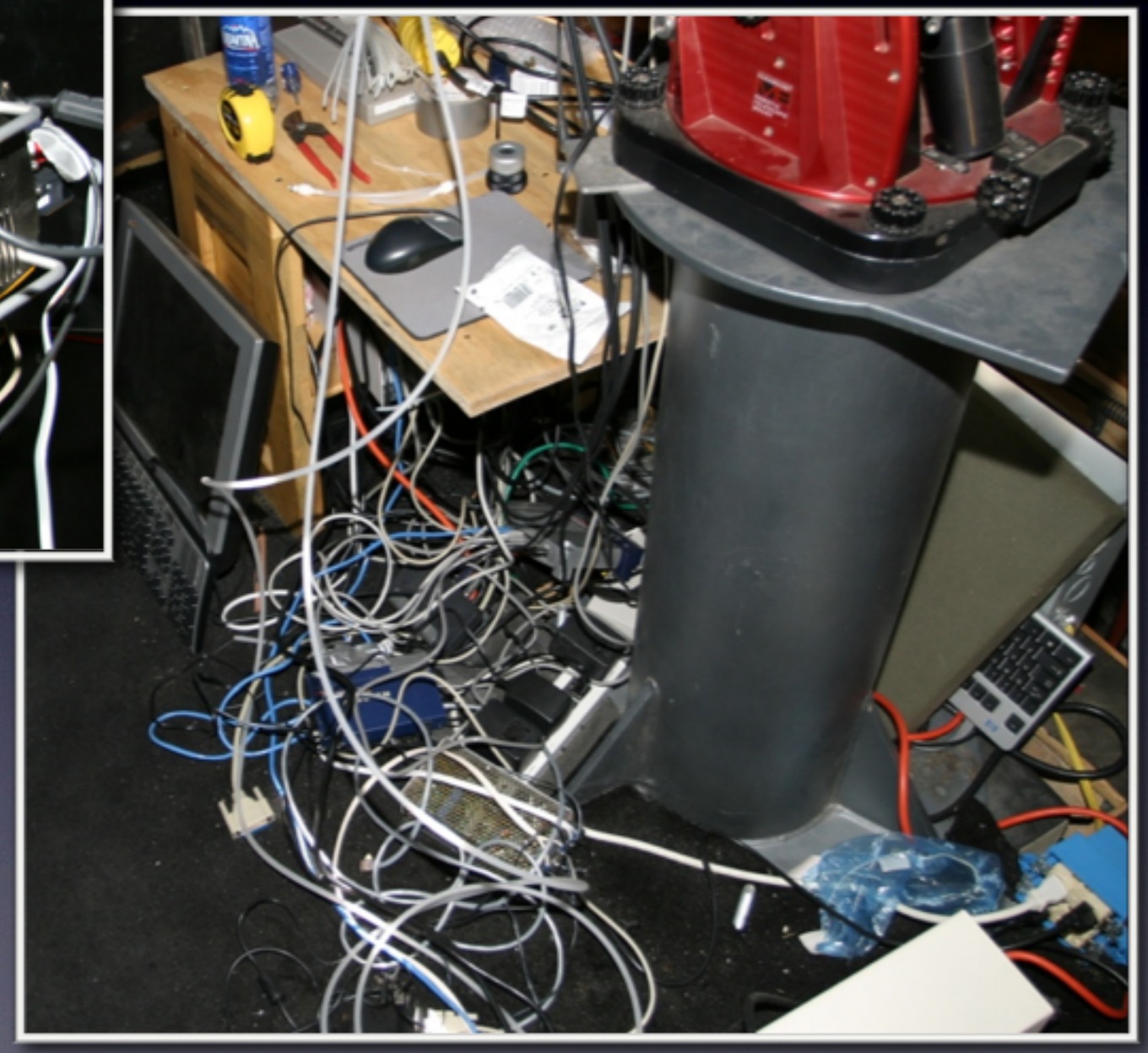
- Automated Acquisition
- Repeatable Protocol
- Automatic Logging
- Backyard or Across the World
- Reliability Is Key





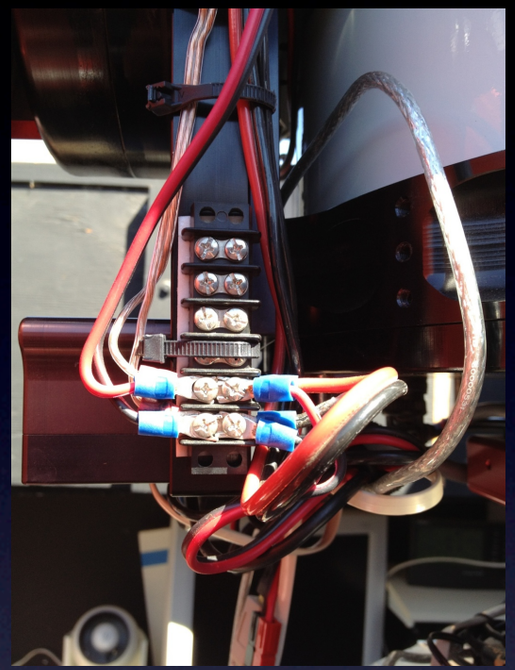
Wiring





Wiring

- Neatness counts
- Minimize connections between OTA and PC
- USB hub(s) and Power Distribution on OTA
- Strain Relieve All Connections
  - Cable Clamps, Ties
- Strain Relieve Through-The-Mount Wiring at Exit
- After wiring, check for interference and binding during the day
  - Move Rotator Through All Angles
  - Move Mount Through All Orientations



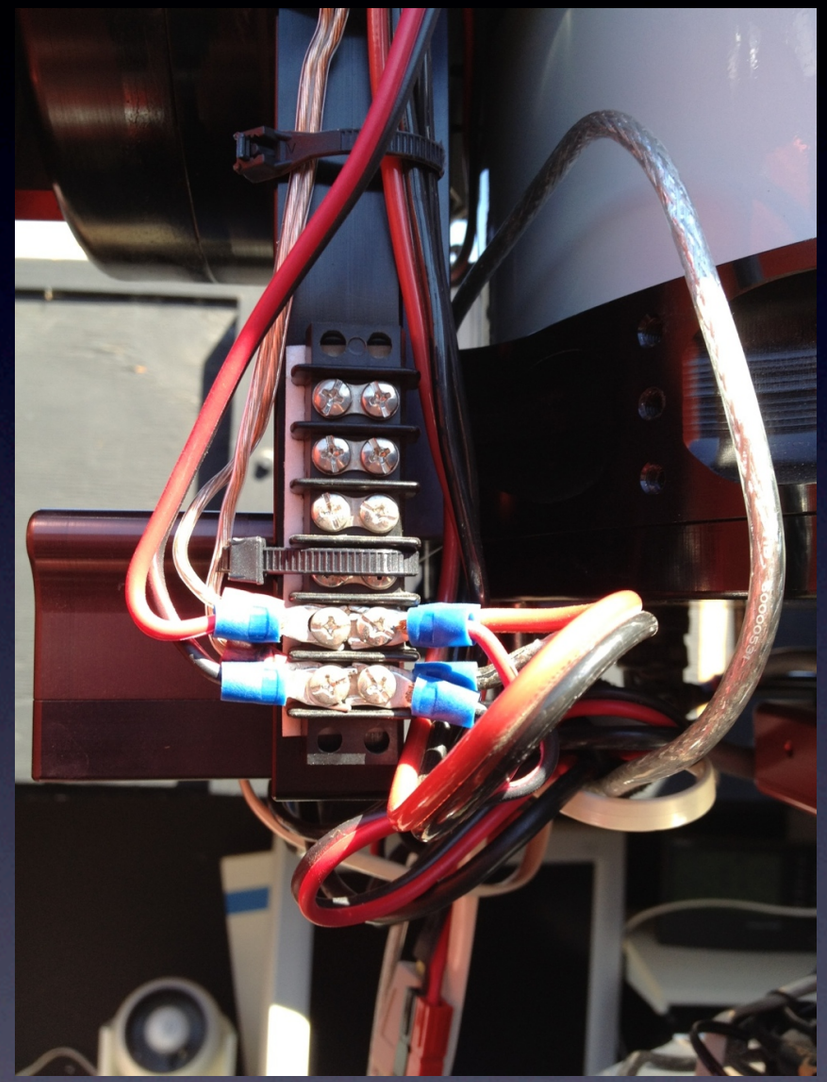
USB & Serial Converters

- Commercial hubs, serial-to-USB converters
  - Better temperature range, components
  - 12-volt powered hubs are ideal
- Office-class hubs can be a problem
  - Limited temperature range, unexplained hangs
- Locate hubs and serial-USB converters on OTA
- Single USB Cable from OTA to PC
  - Don't use PC's front panel USB connection

Power Distribution

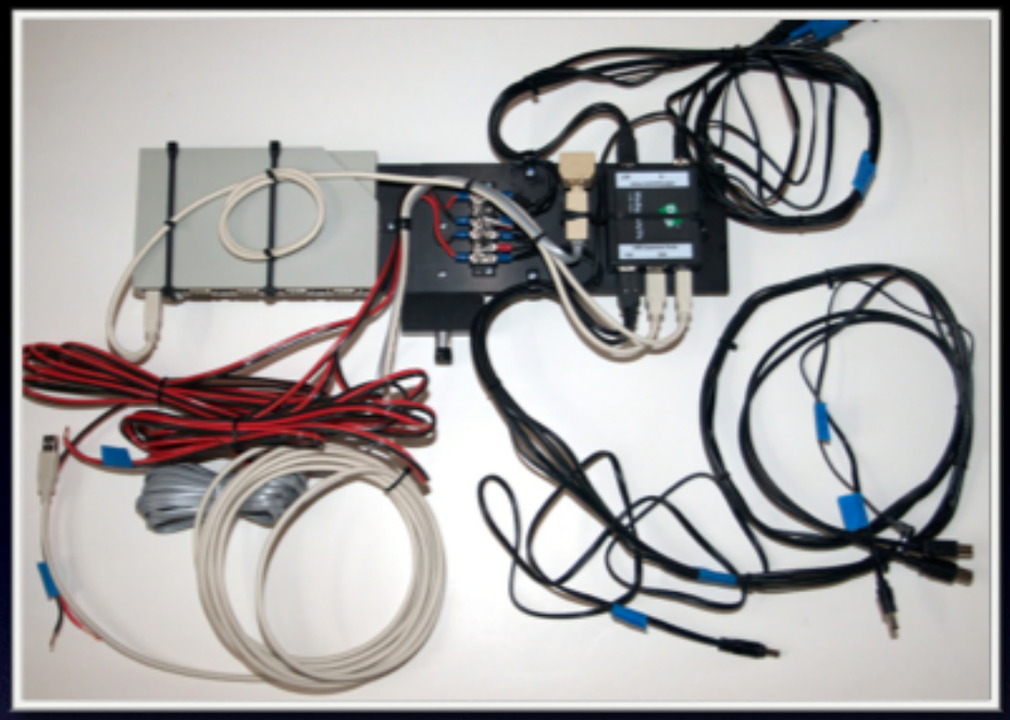
- Most Equipment is 12-volt Powered
- Use Common Power Supply
- Minimize Cables to OTA

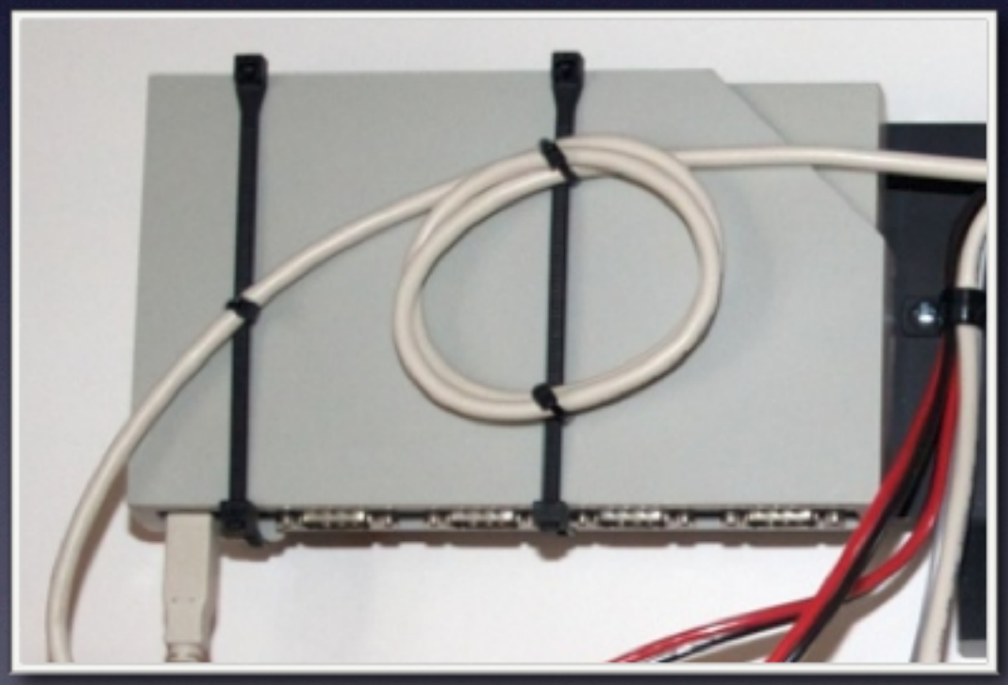
- 1 or 2 16 gauge pairs
- Distribute Power on OTA
- Barrier Strips, Crimp Terminals



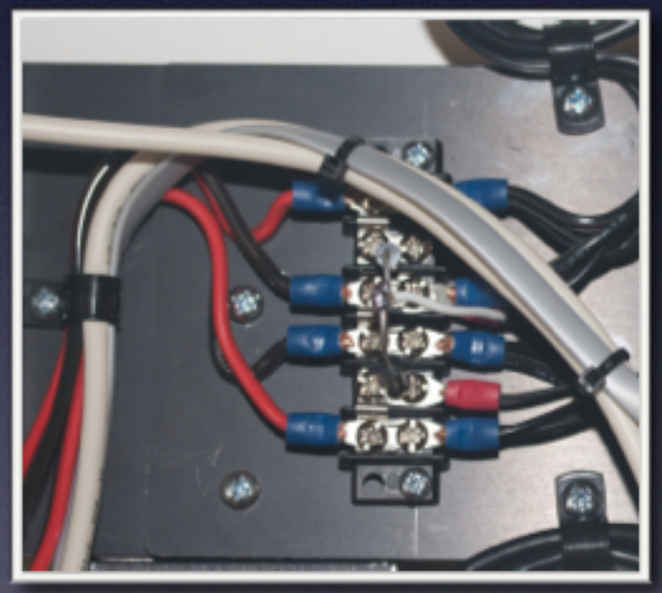
An Electronics Panel

- Mounts to OTA via Dovetail Adapter
- All cables strain relieved
- Electronic assemblies redundantly mounted
- Designed for single power per system
- Supports 2 systems on OTA





Edgeport/4
Foam tape and cable ties

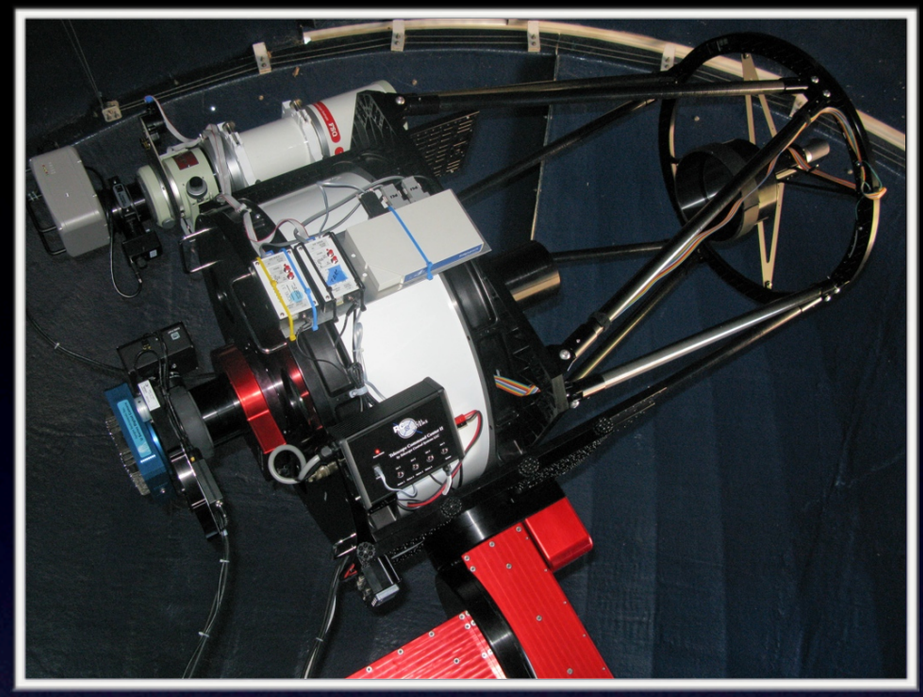


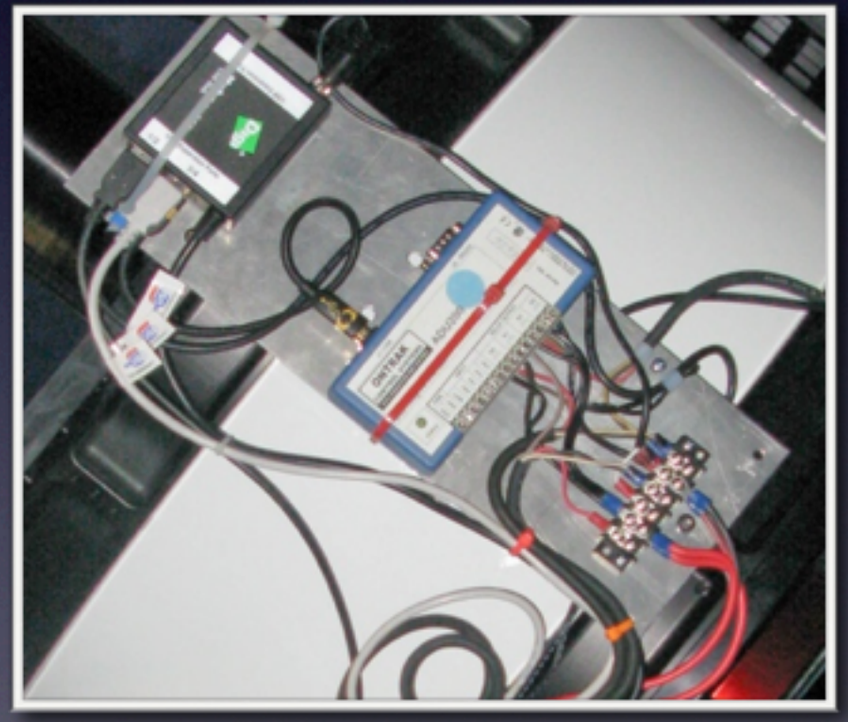
Power
Barrier Strips
Crimp Terminals
Cable Clamps

Digi Electronics
12 volt, 7 port hub

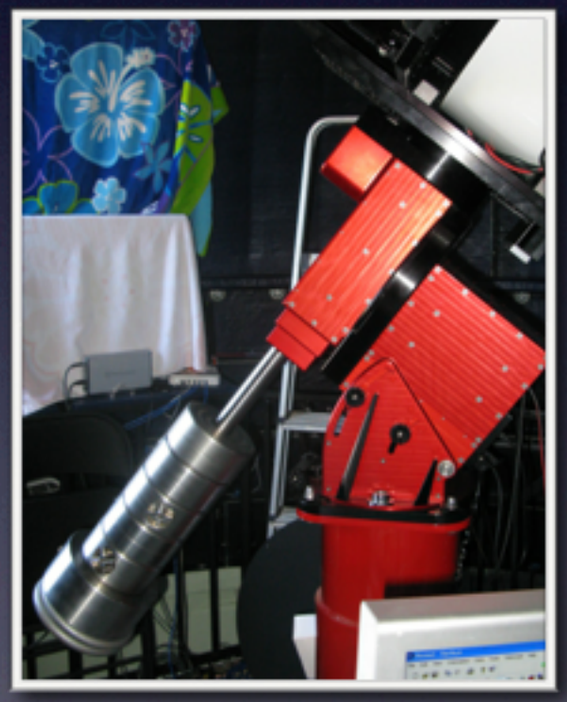
A Serious System

- 20” RC and FSQ on one mount
- Electronics side mounted
- Single power supply
- Remote system switching





12 volt hub
USB Power Controller
Power Distribution



225 lb. (!)

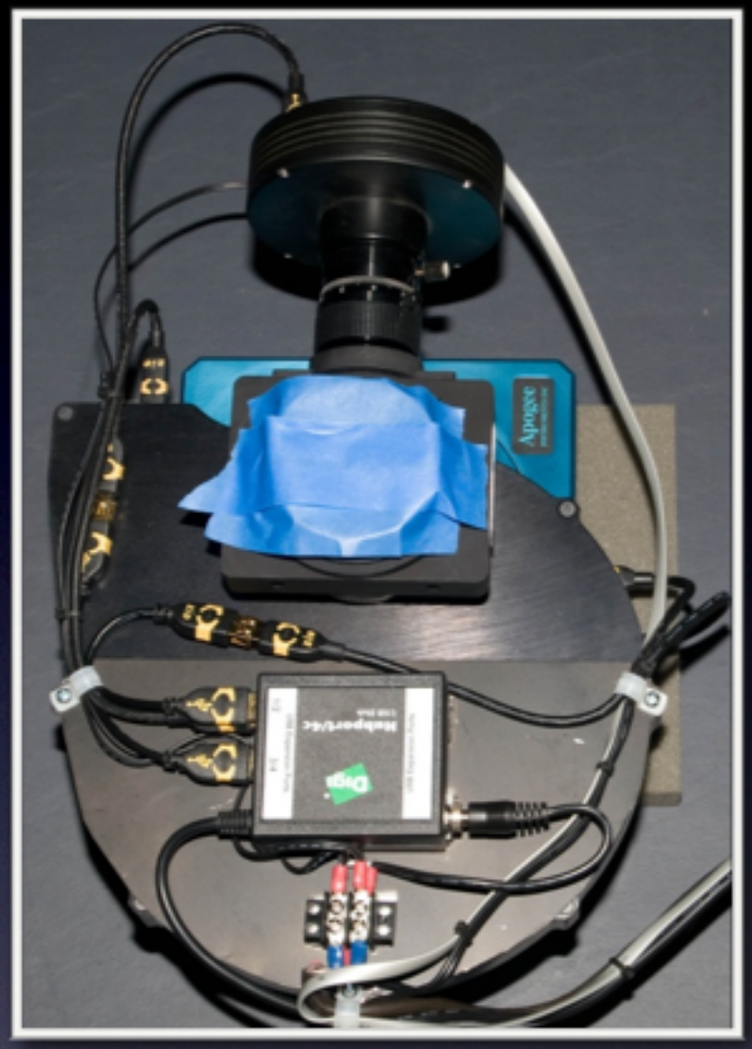
2 RFCP
Edgeport/4

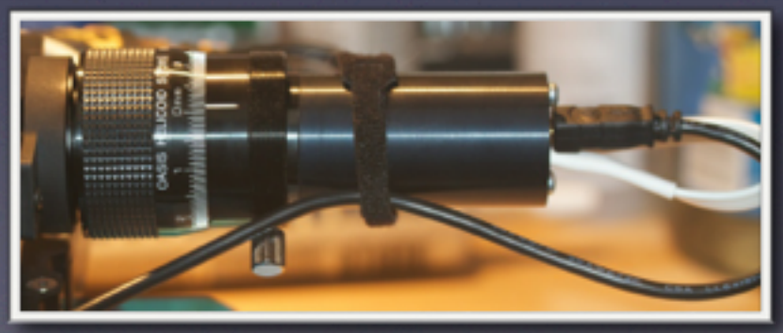
Backyard Widefield

- FSQ-106/U16M/AFW50-7S, ST-i, MMOAG, TAKometer, RoboFocus, FlipFlat, MX mount
- 16 lb. imaging train requires special coupler - no slip clutch.
- 4° x 4° FOV
- Electronics on top of FSQ
- Through-the-mount power and signal wiring sufficient.

Imaging Trains

- Short USB Cables
- Strain Relieve all - especially delicate connectors
- Power Distribution on Filter Wheel
- Hub on Filter Wheel
- Single power and USB cable from Imaging Train





Resources

- Digi Electronics USB hubs:301-1010-44 (4-port) and 301-1010-74 (7-port)
- Digi Electronics 4-port serial-USB Converter: Edgeport/4
- Pyramid Power Supplies
- OnTrak ADU200 USB Relay I/O Interface (custom software required)
- Short USB cables: www.cyberguys.com Ziotek
- Molded power cables: www.digikey.com CP-2187-ND (2.1/5.5 mm), CP-2186-ND (2.5/5.5 mm)
- DC Power wire: www.powerwerx.com 16 gauge minimum
- Cable ties and cable clamps from Home Depot
- System evaluation software: www.ccdware.com :
  PEMPro, CCDInspector, CCDAutoPilot

Final Thoughts

- Understand what's behind the data
- Make your systems stable and repeatable
- Enjoy the complete process
- Have fun!