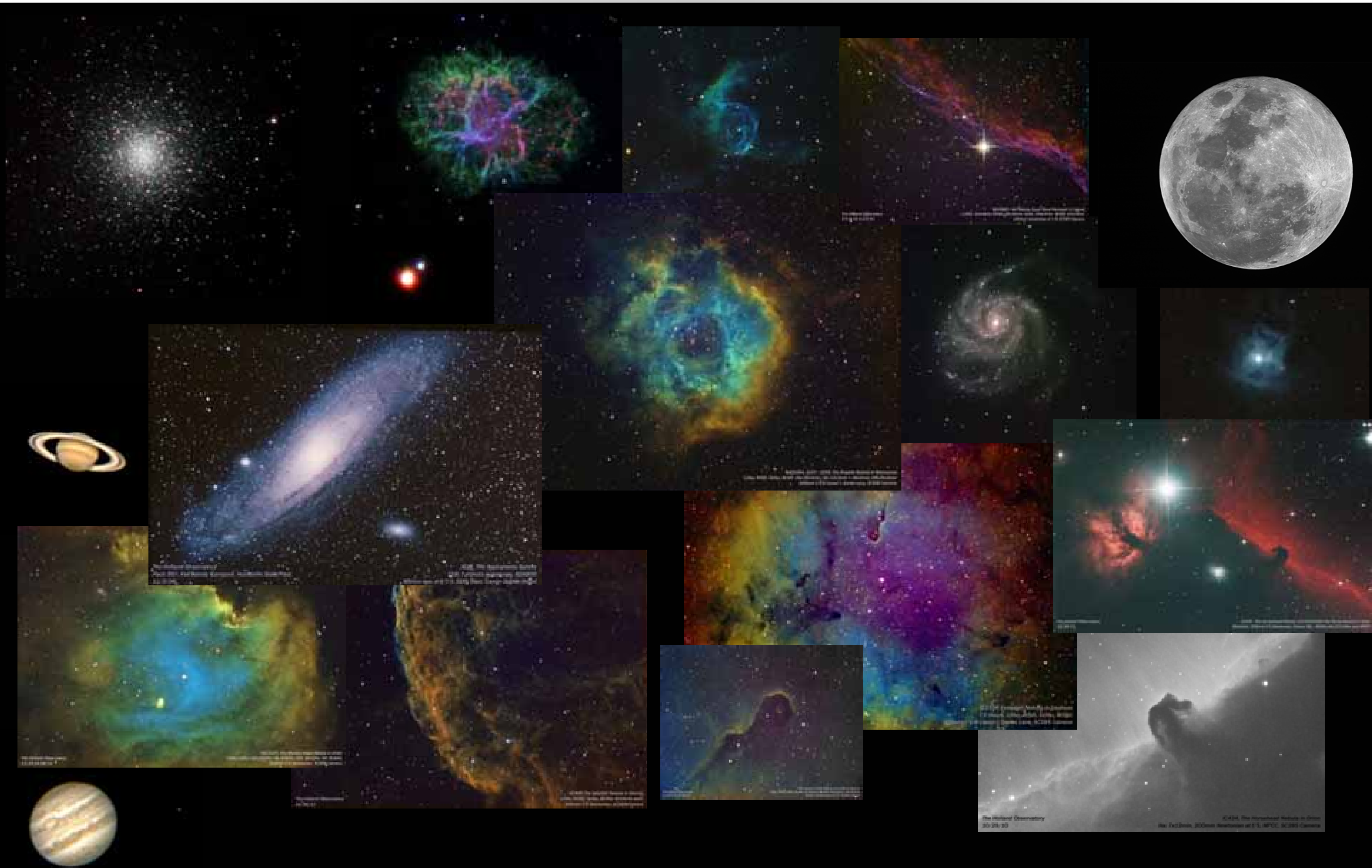
Astroimaging - Tutorial



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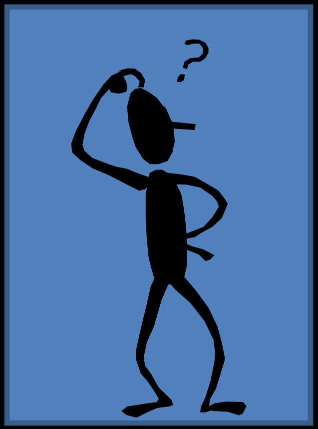

Who am I

&

Why am I talking to you?

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By day…





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But, by night…

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Outline

- What You Can Expect
- The Elements of an Astroimaging System, and Signal Flow
- Tracking
- Setting up Your Equipment
- Focus
- Finding Your Target
- Camera Options
- Filter Options
- Calibrating the Images
- Creating Color Images
- Post Processing
- What Else Will Effect Your Astroimaging Session
- A Collection of Images (and how they were taken)
- References

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- What You Can Expect: Types of celestial objects within reach

Planets

Galaxies

Nebulae

Comets

Star Clusters

Constellations

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- What You Can Expect: Proportional to how much effort you put in –

Easiest

- The Moon

- Bright
  - Short exposure, easy to find
- Can be shot with most any system

Moderate

- Planets

- Bright
  - Easy to find
  - Short exposures – many taken, stacked and combined
- Minimal tracking
- Increase image processing difficulty

Difficult

- Bright DSO & Comets

(Deep Sky Object)

- More difficult to find
- Accurate tracking
- Exposure times around 4 minutes
- Calibration images needed
- Complicated image processing

Most Difficult

- Dim DSO
- Difficult to find
- Accurate tracking
- Exposures > 4 minutes
- Accurate calibration images needed
- Most complicated image processing

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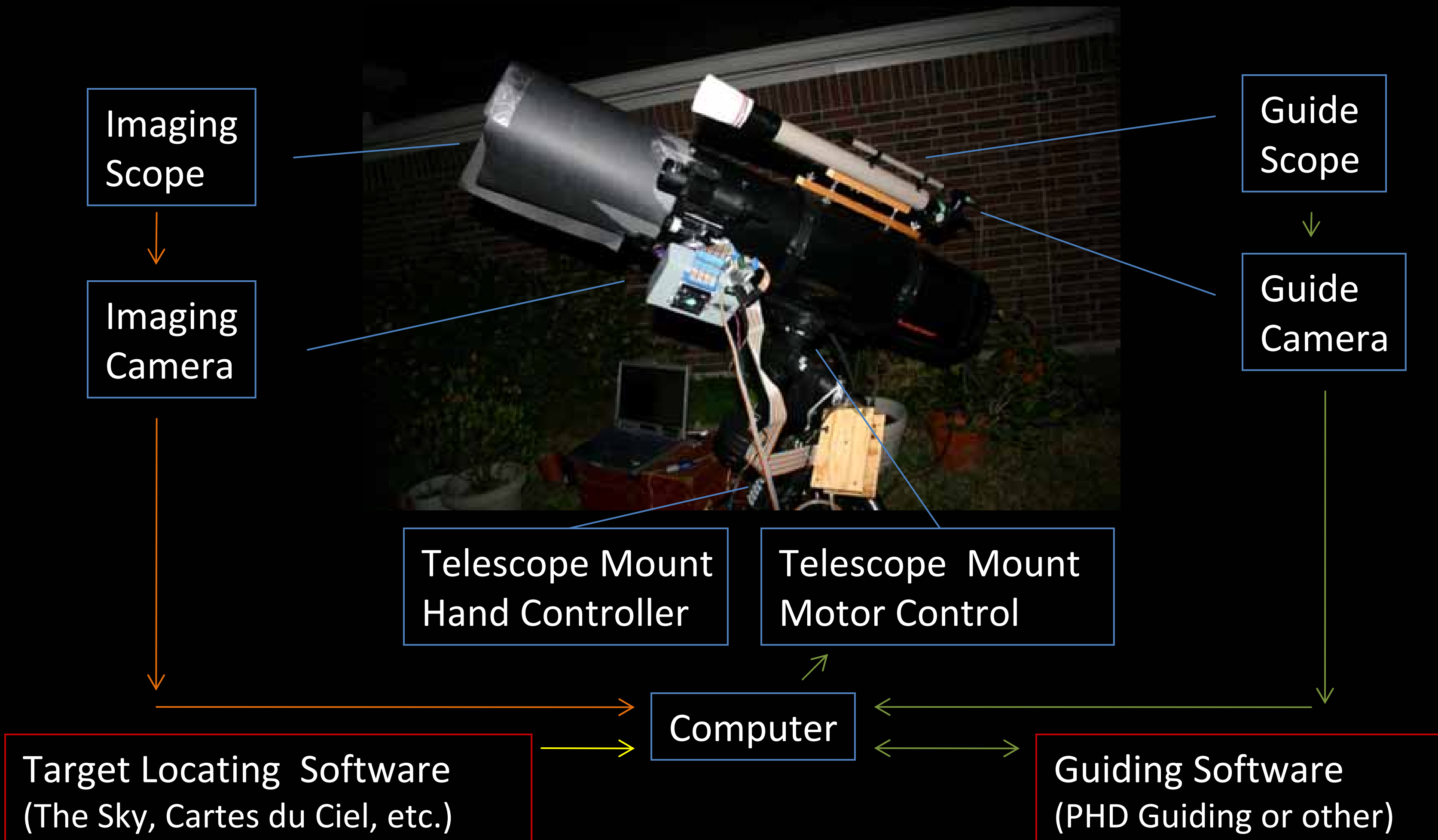
- The Elements of an Astroimaging System, and Signal Flow



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- Tracking
  - Problem: image pixel size corresponds to approx. 1 arc second (1”) of angle
  - It is difficult to get a mechanical telescope mount to track accurately for long exposure pictures within around 1” of accuracy. Otherwise, pixels are smeared due to tracking errors.
  - First step: Mount selection (periodic error PE figure of merit) –

Celestron ASGT
$575
35 lbs load
Light weight
Inaccurate
PE ~ 40”pp

Celestron CGEM & Orion Atlas
$1,400
40 lbs load
Smoother PE, still ~ 30”pp

Losmandy G-11
$3,200
60 lbs load
High quality
Users get ~ 10”pp

Astro Physics AP900
$8,750
70 lbs load
Guaranteed accuracy (7”pp)

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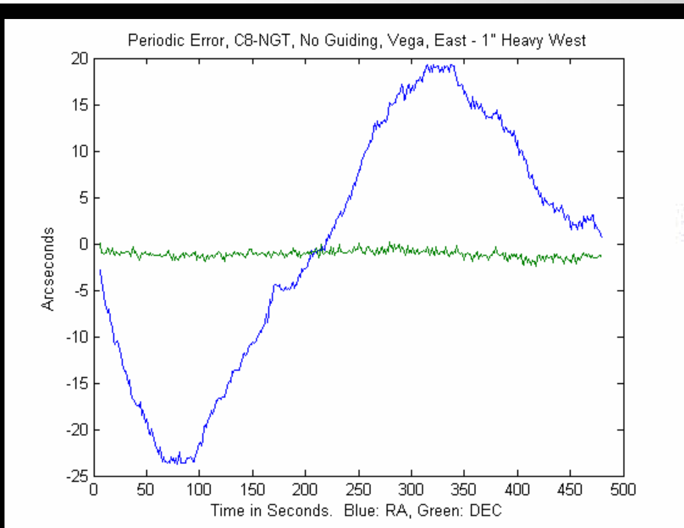
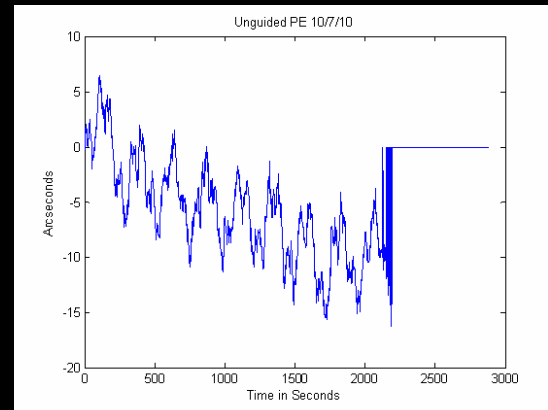
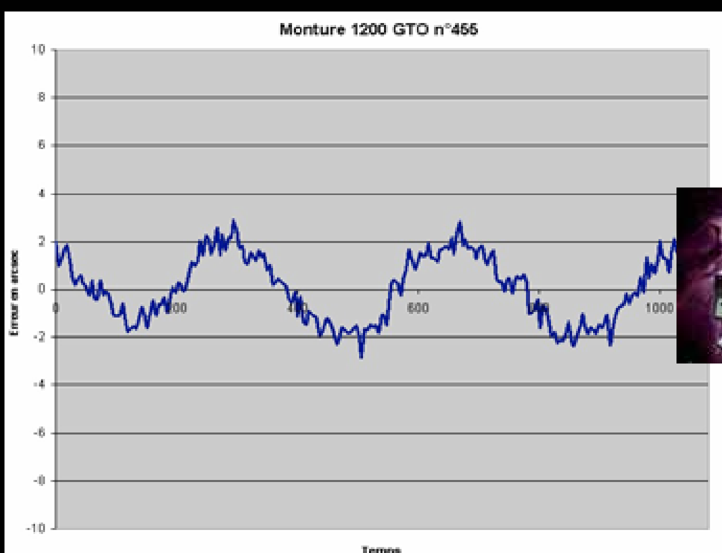


Celestron ASGT
$575
35 lbs load
PE ~ 40”pp

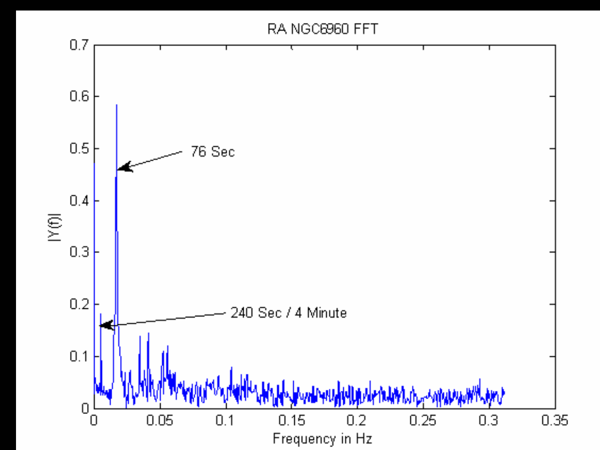


Losmandy G-11
$3,200
60 lbs load
Users get ~ 10”pp

Why is this happening???



Astro Physics AP1200
$9,950
140 lbs load
Guaranteed accuracy (5”pp)



Note – Not all error is periodic!

http://demeautis.christophe.free.fr/ep/ap1200gto.htm

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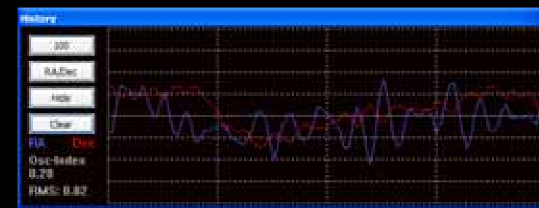
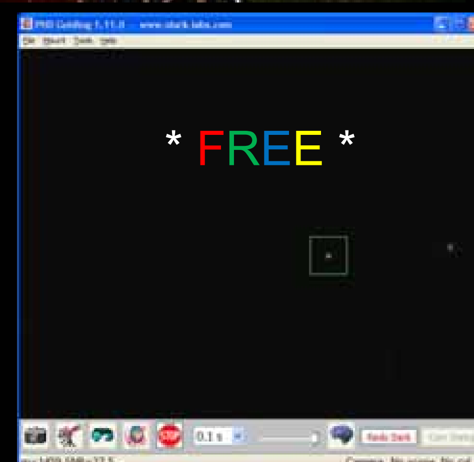
- Tracking (cont'd)
  - How accurate tracking is accomplished: Autoguiding



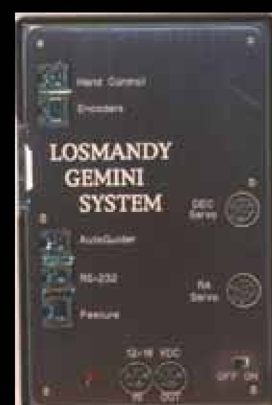
1. Guide camera is selected in guiding software
2. Guide camera with guide scope focuses on star
3. Telescope mount is selected in guiding software
4. Software calibrates mount
5. Autoguiding starts



Camera options:

Webcam style ::: or :::

Dedicated autoguide camera



Mount interface options:

RS-232 port (ASCOM drivers) ::: or :::

Mount Autoguiding Port (ST4)

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- Tracking (cont'd)
  - How accurate tracking is accomplished: Autoguiding (cont'd)

What are the guiding optical options?

Guidescope:
Pros –
Easy to find stars
Cons –
Flexing
Different optical axis (field rotation)

Self Guiding:
Pros –
Same optical axis
Cons –
Limits available stars
Behind filters

Off Axis Guider:
Pros –
Same optical axis
Cons –
Limits available stars
Behind filters

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- Tracking (cont'd)

- OR -

Barn Door Tracker

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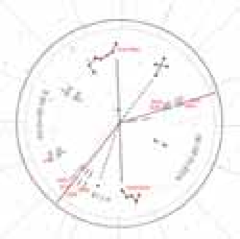
- Setting up Your Equipment
  - Polar Alignment Options:
    - North Celestial Pole Polar Alignment Scope
      - Quick, easy. Good enough for many targets
    - Declination Drift
      - More difficult, takes time. Best method



  - GoTo Alignment
    - User will center 2 or more bright stars allowing scope computer to create an accurate map of the sky.
      - Afterwards, targets can be entered into scope computer and scope will slew to them.
      - Some scopes have 'Accurate GoTo' features that aid in finding faint objects
  - Dew
    - Dew can form on scope, camera, filters, etc.
      - Just extending the length of the end of the scope will combat dew.

  - Stray Light
    - You will need to address any sources of stray light (same dew extensions help). Filter selector is a source of light leaks.

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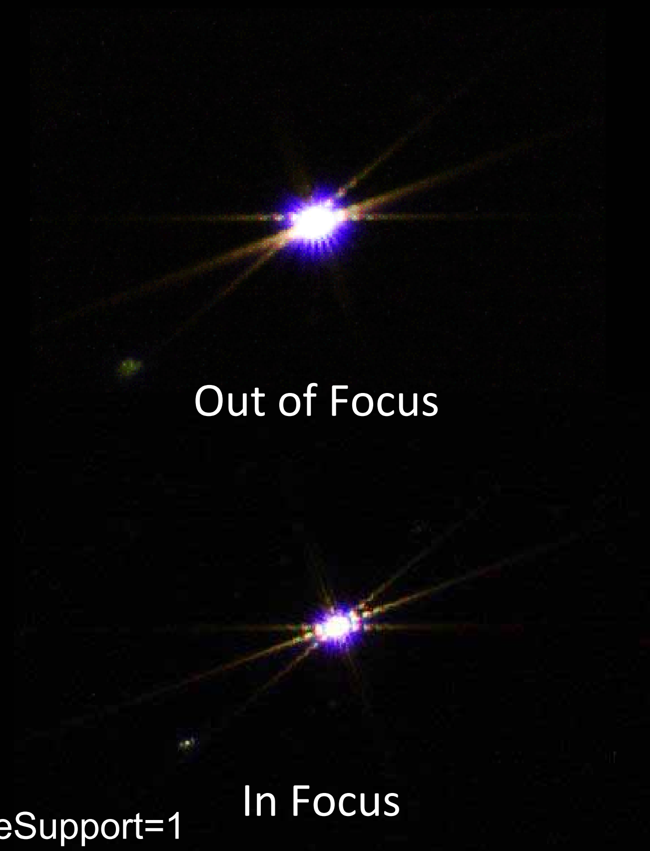
- Focus
  - There are many methods to obtain focus:
    - Hartman Mask, Measuring the Point Spread Function, Visual, Bahtinov Mask
      - Recommend Bahtinov Mask



http://astrojargon.net/MaskGen.aspx?AspxAutoDetectCookieSupport=1

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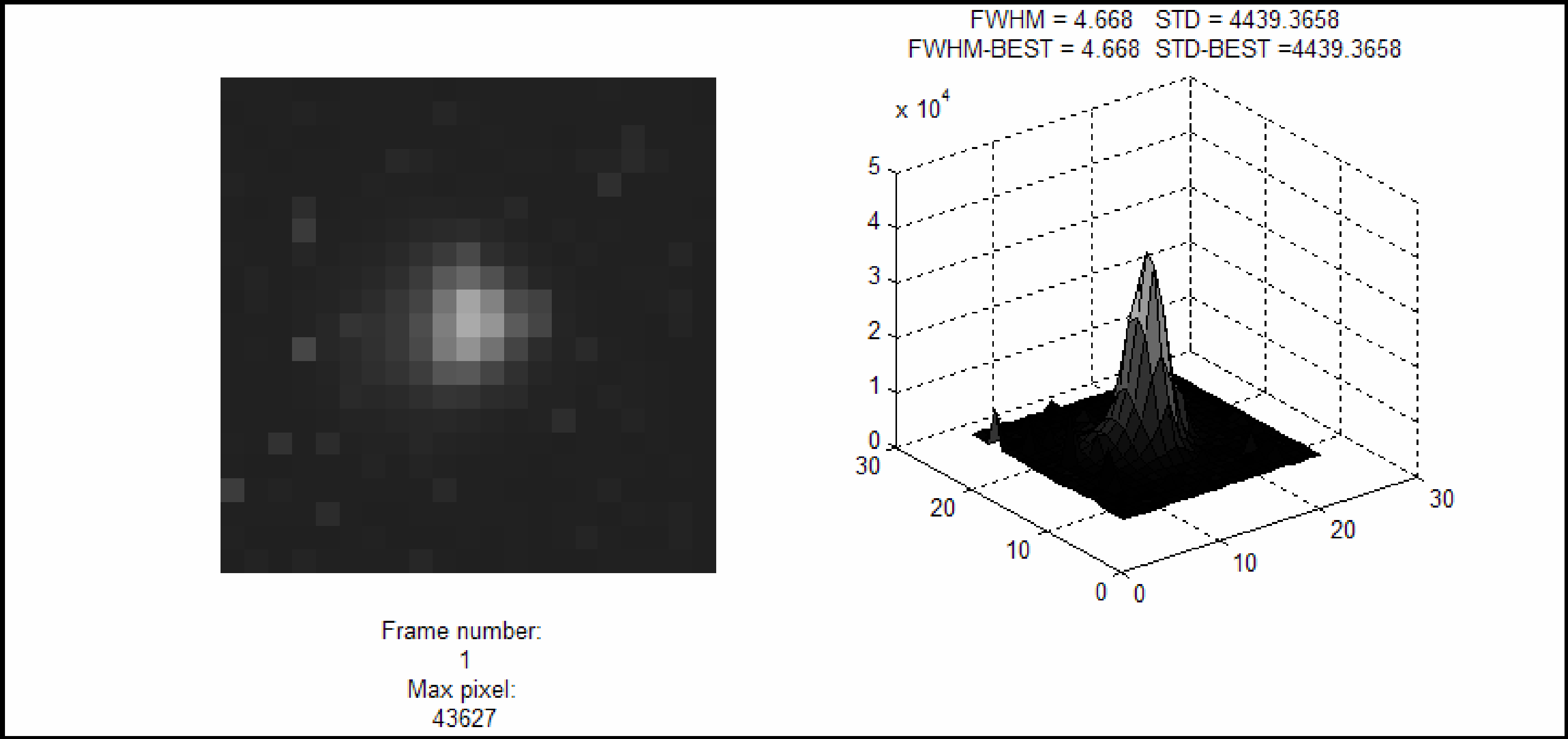
- Focus (cont'd)

Another method – Measuring Point Spread Function:
Full Width Half Max – minimum
Standard Deviation - maximum



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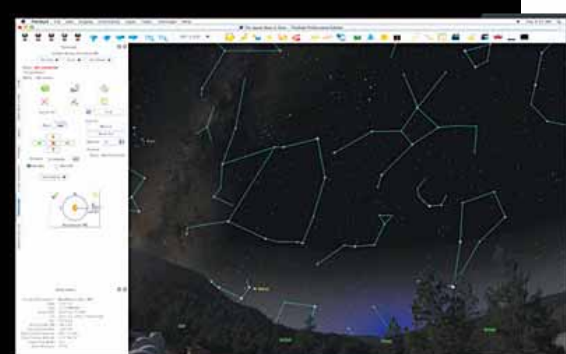
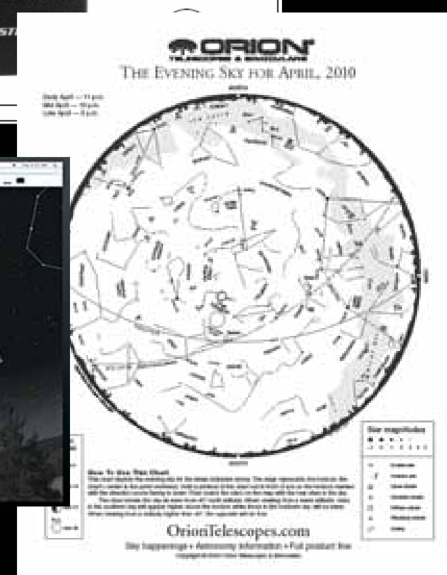
- Finding Your Target
  - At Least Three Options
    - GoTo Scope – select from list
      - Accurate GoTo function
    - Computer Control
      - Via scope RS-232 interface
      - ASCOM drivers
      - Planetarium Programs
        - » The Sky
        - » Cartes du Ciel
    - Star Hopping
      - Star charts
        - » Free Monthly charts:
        - » www.telescope.com
        - » www.skymaps.com
      - Planetarium Programs
        - » The Sky
        - » Cartes du Ciel
  - Note: Best results when target near Zenith due to atmosphere





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- Camera Options

1. Webcam style camera

Meade LPI

Orion Star Shoot Solar System Color Imager

Celestron NexImage

What can be accomplished?

1. Planetary imaging
2. Use as guide camera (but noisy)

How it is done:

1. Focus is critical
2. Mounts in place of eyepiece
3. Use high magnification (barlow lens)
4. Nights of good seeing (low air turbulence) are required
5. Hundreds of images taken, best selected, stored as video
6. Aligned and stacked (e.g. Registax software)
7. Enhanced in Photoshop, or other

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- Camera Options (cont'd)

2. Digital Single Lens Reflex (DSLR)

What can be accomplished?

1. Images of the Moon
2. Bright Deep sky objects (DSO): Nebulae, Galaxies, Super Nova Remnants, Star Clusters, etc.
3. Not optimal for planetary (unless movie mode)
   a) Vibrations from shutter
   b) Long download time (planet features move)

How it is done:

1. T adapter acquired for specific DSLR
2. Shutter release cable required for specific DSLR or control via USB
   - Note – mirror lockup requires shutter release cable
3. Long exposures can be taken (miraculously)
4. Calibration frames are required (more later)
5. Exposure control manual or software controlled (EOS Utility, Backyard EOS, APT)
6. Remote image capture and download (e.g. EOS Utility, Backyard EOS, APT)
7. Images calibrated, aligned and stacked (e.g. Deep Sky Stacker or AIP4WIN)
8. Final processing in Photoshop or other (more later)

M42, The Orion Nebula Center, NGC1977, Running Man Nebula Right

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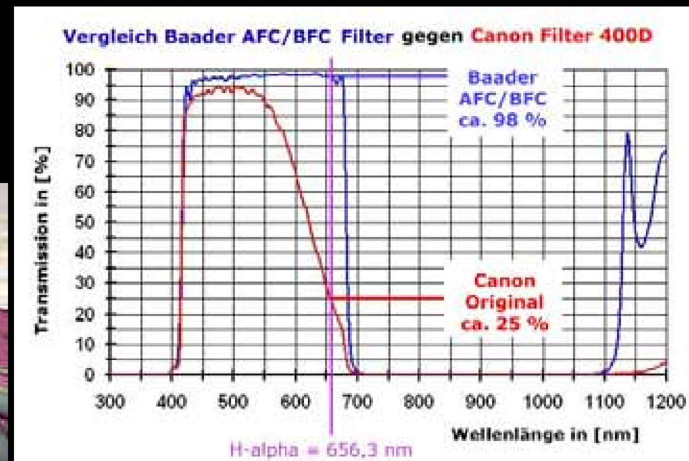
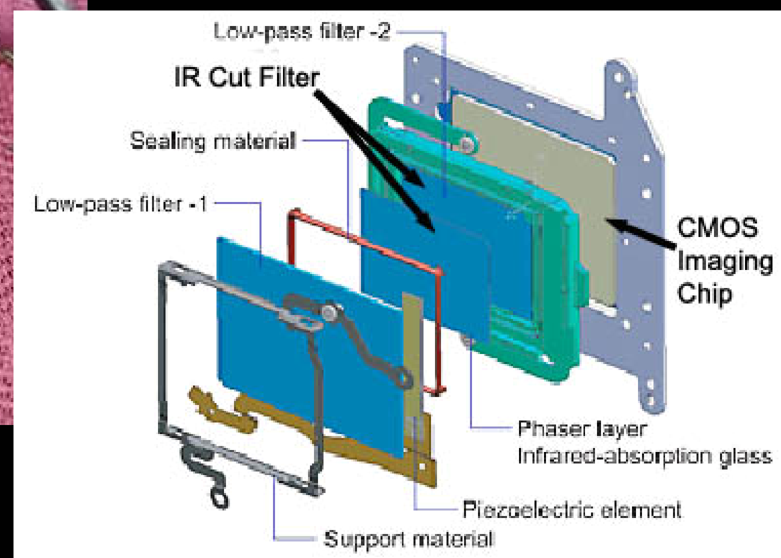
- Camera Options (cont'd)

2. Digital Single Lens Reflex (DSLR) (cont'd)





Replacing IR Cut Filter improves performance for Astrophotography.

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- Camera Options (cont'd)

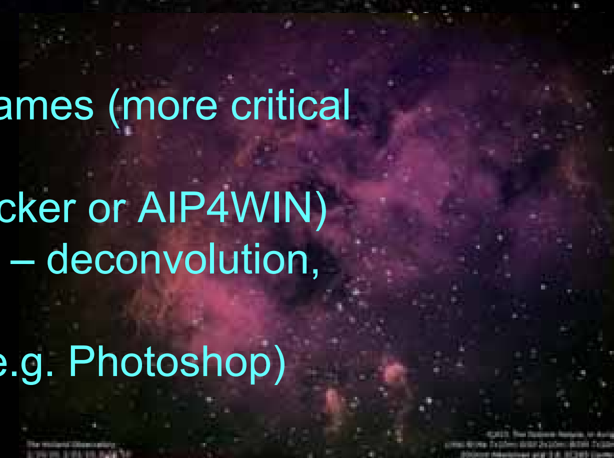
3. Dedicated Astroimaging Camera

What can be accomplished?

1. Pretty much everything: Planetary, Moon, Solar, Bright & Dim DSOs, etc.
2. Advantages: highest quality, meaningful scientific data
3. Disadvantages: most complicated

How it is done:

1. T adaptor required between scope and camera
2. Some cameras are monochrome so filters and filter exchanging mechanism is required
3. Cameras are cooled to reduce thermal noise
4. Images are taken along with closely matched calibration frames (more critical than DSLR)
5. Images are calibrated, aligned and stacked (Deep Sky Stacker or AIP4WIN)
6. The individual color channels preprocessed (e.g. AIP4WIN – deconvolution, background smoothing, etc.)
7. The individual channels are combined into a color image (e.g. Photoshop) and then post processed (Photoshop)



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- Camera Options (cont'd)

What are the trade offs?

CAMERA	EASE OF USE	WIDE SPECTRAL RANGE	SINGLE SHOT COLOR	NOISE	DARK CURRENT	SCIENTIFIC RESULTS (Linearity)	DOWNLOAD SPEED
Webcam	Easy	No	Yes	Very high	High	No	High (many frames per second)
DSLR	Moderate	No Yes – if modified	Yes	Moderate	Moderate	No – linearity, tough to calibrate	Low to High (up to 2 minutes)
Astroimager	Difficult	Yes	Yes or No	Very low (down to 1 electron)	Very low	Yes	Moderate (a few seconds)

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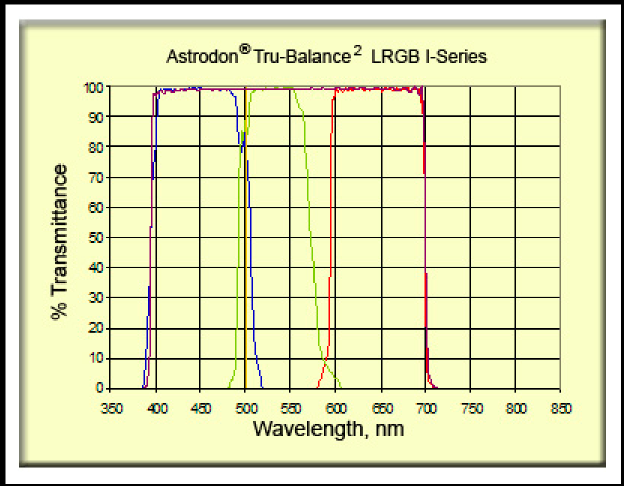
- Filter Options

For dark sky areas or moderate light pollution, Luminance, Red, Green, Blue (LRGB) filters work well



Some type of filter exchange mechanism is needed.

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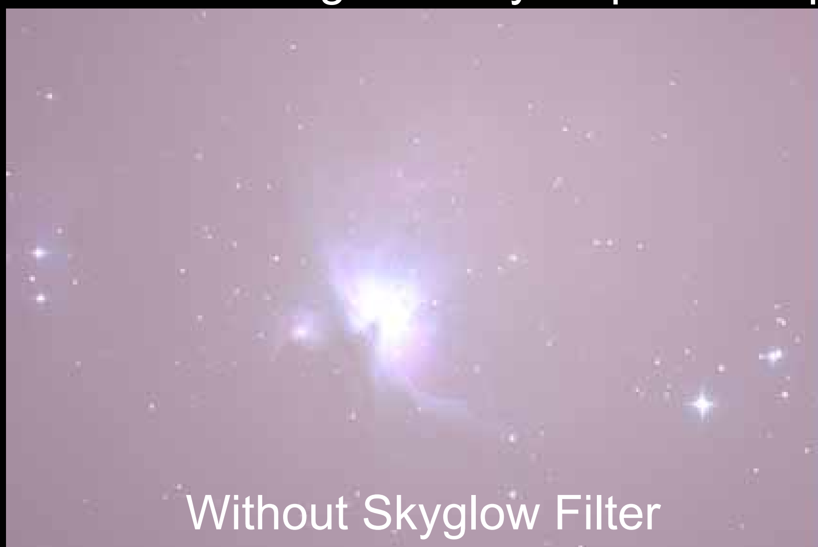
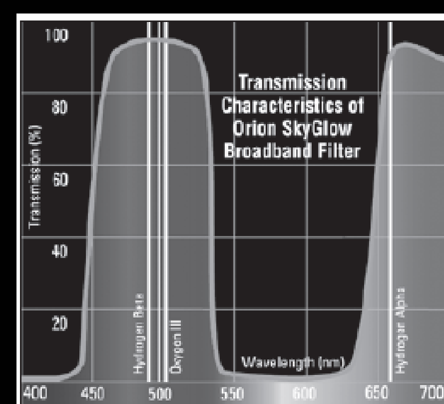
- Filter Options (cont'd)
  - Light pollution reduction filters
    - Can significantly help – example 4 minute exposures





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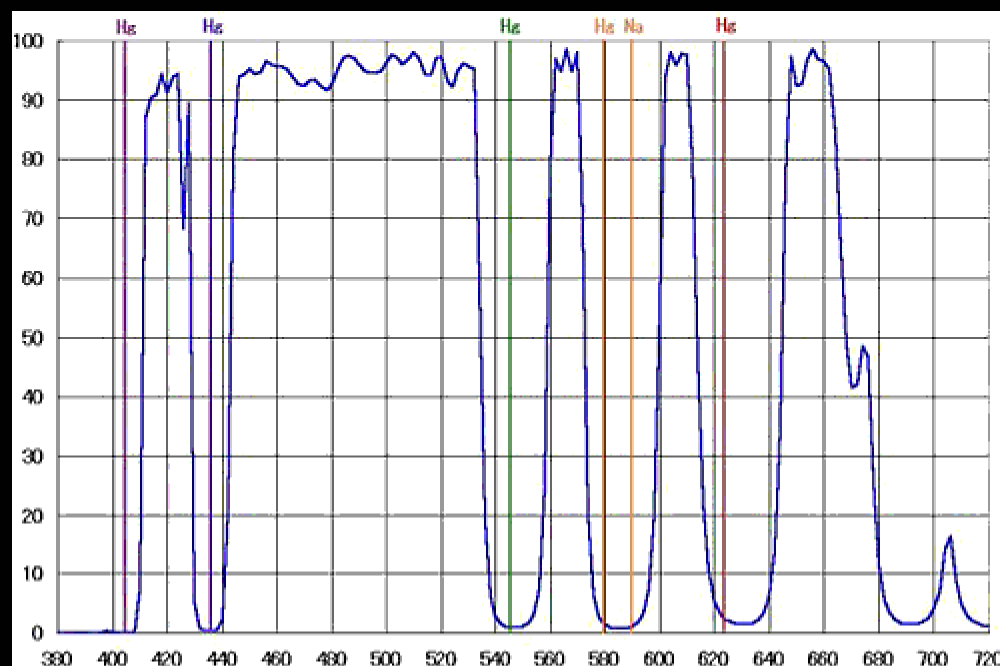
- Filter Options (cont'd)
  - Other light pollution filters like the Hutech IDAS filter pass more total light, and have narrow rejection bands for specific light pollution wavelengths.
  - Results in truer colors, than filters that cut larger sections out of spectrum



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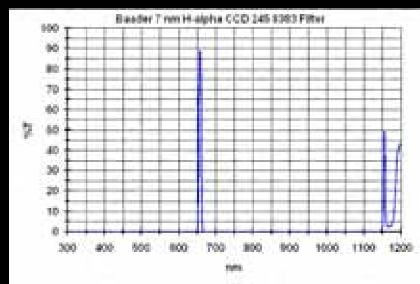
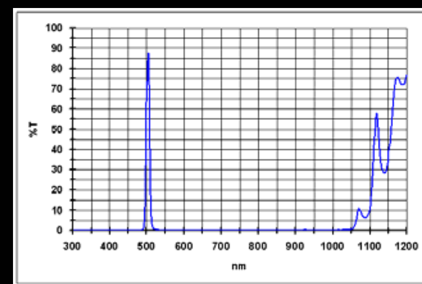
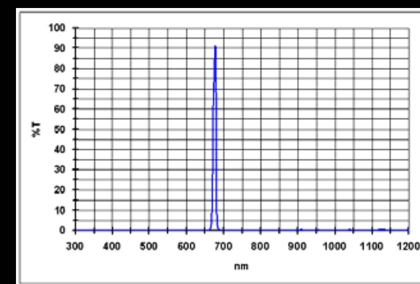
- Filter Options (cont'd)

Narrowband Imaging – Cuts all wavelengths except narrow bandwidth around desired wavelength.

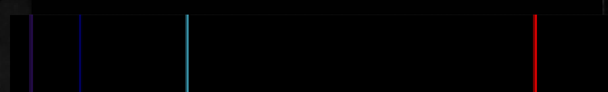






Most common: Hydrogen Alpha (Ha), 656.3nm; Sulfur (SII), 672.4nm; Oxygen (OIII), 500.7nm.

Filters are very effective against light pollution – can even image during full Moon.



Hydrogen Spectral Series
{ Ha: red line at right}

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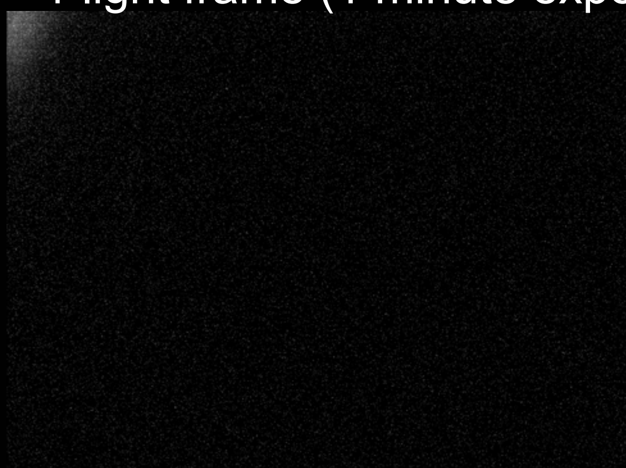
Desired Wavelengths (nm):		Undesired & Light Pollution Wavelengths (nm):	
OII	372.7	Hg	405
Hγ	434	Hg	436
Hβ	486.1	Airglow Auroras	463
OIII	495.1	Hg	546
OIII	500.7	High Pressure Sodium, Na	466, 475, 498, 515
C2	511	Hg	546
C2	514	O (skyglow)	557
NII	654.8	NaII / Hg	570
Hα	656.3	Hg	579
NII	658.4	High Pressure Na(D) / NO_2	583
SII	671.6	Na	600
SII	673.1	NaII / Hg	617
		O (skyglow)	630
		O (skyglow)	636

Astroimaging - Tutorial

- Calibrating the Images

Thermal noise present in both light & dark frames

1 light frame (1 minute exposure)



1 dark frame (1 min)

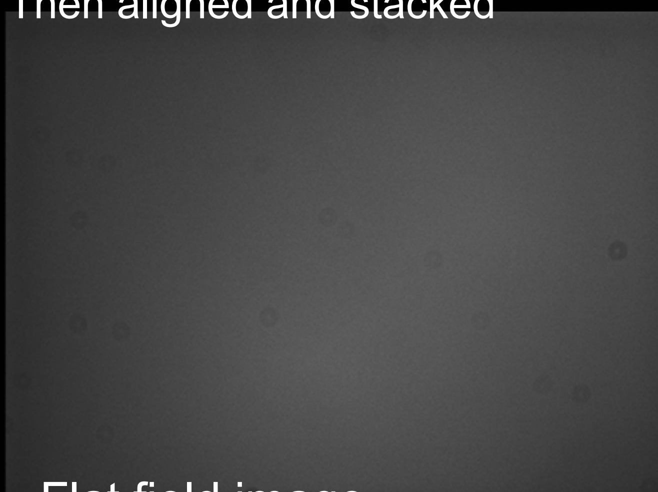
With dark frame subtraction only, Imperfections remain (dust donuts, vignetting)

(42 x 1 minute lights) – (10 x 1 minute dark), Then aligned and stacked

Astroimaging - Tutorial

- Calibrating the Images (cont'd)

(42 x 1 minute lights) – (10 x 1 minute dark),
Then aligned and stacked



Flat field image

((42 x 1 minute lights) – (10 x 1 minute dark))
7 flat field images

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- Calibrating the Images (cont'd)

Why does aligning and stacking images increase the signal to noise ratio?

Answer – The signal adds linearly, the noise (being uncorrelated / orthogonal) adds as the square root of the sum of the squares.

Example: Take an image that has a signal of 2 and a noise level of 2. Its initial signal to noise ratio (SNR) is 2/2 = 1.

When we combine (2) images: signal = 2 + 2 = 4, noise = sqrt ($2^2 + 2^2$) = 2.828, SNR = 4/2.828 = 1.414.

When we combine (4) images: signal = 2 + 2 + 2 + 2 = 8,
noise = sqrt ($2^2 + 2^2 + 2^2 + 2^2$) = 4,
SNR = 8/4 = 2.

*** So, the more images we combine, the better the signal to noise ratio.

- Calibrating the Images (cont'd)

Do you believe it?

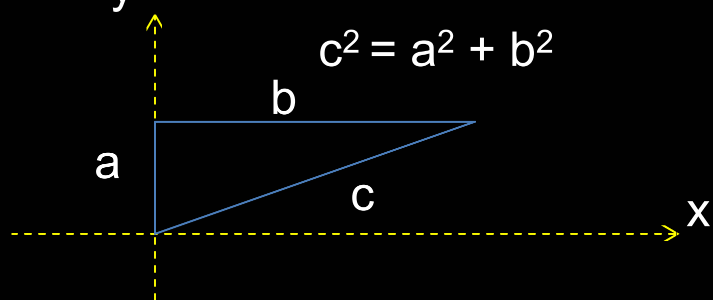
Answer - The signal adds linearly, the noise (being uncorrelated / orthogonal) adds as the square root of the sum of the squares.

Why is this true?

Uncorrelated Noise

Pythagorean Theorem

$c^2 = a^2 + b^2$



Noise a has no x value
Noise b has no y value
→ uncorrelated

correlated Noise

Note – there is correlated noise!!

- Combining images does NOT decrease correlated noise.
  - Example: Fixed Pattern Noise
    - Use dithering

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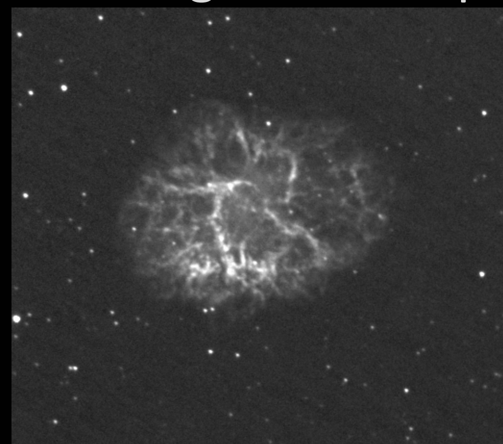
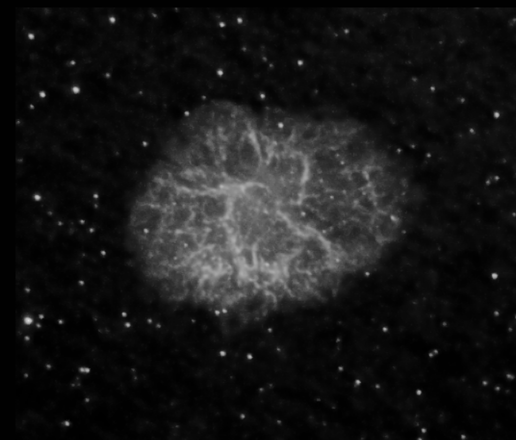
- Creating Color Images – using Photoshop

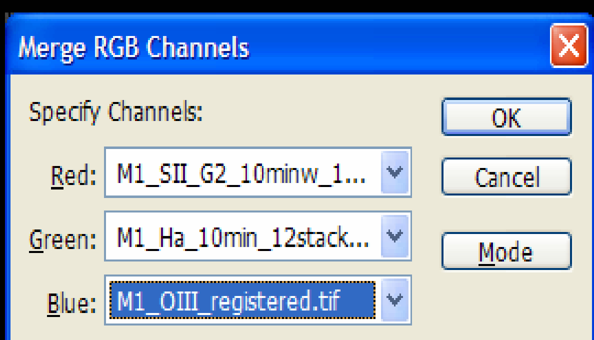
SII, 672nm, Red



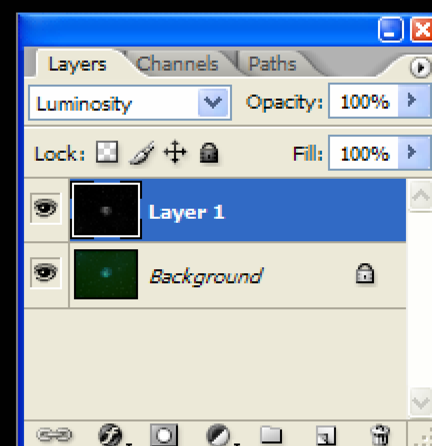
Ha, 656nm, Green & Luminance



OIII, 501nm, Blue



Combined: SII, Ha, OIII: LRGB Image



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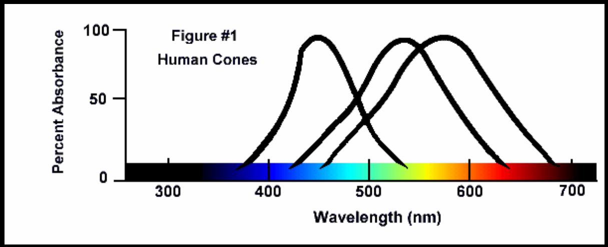
- Creating Color Images – using Photoshop (cont'd)

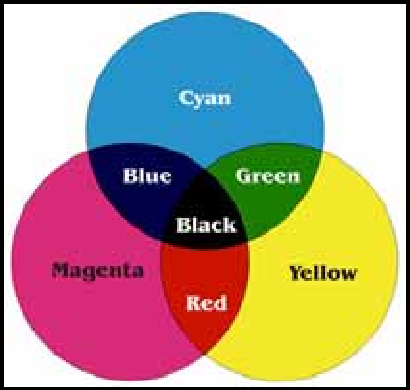
Alternate Color Mapping

SII, 672nm: Red
Ha, 656nm: Green
OIII, 501nm: Blue



SII, 672nm: Magenta
Ha, 656nm: Gold
OIII, 501nm: Turquoise

RGB Color Space
(Red, Green, Blue)



CYM Color Space
(Cyan, Yellow, Magenta)

http://bf-astro.com/hubbleP.htm

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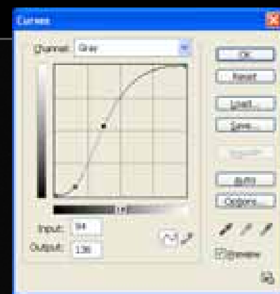
- Post Processing
  - A very large field. Example tools: Photoshop, Matlab, IRIS, GIMP, PixInsight

NGC2244 / NGC2237 (7 x 10 min) Ha Original



NGC2244 / NGC2237 (7 x 10 min) Ha Processed

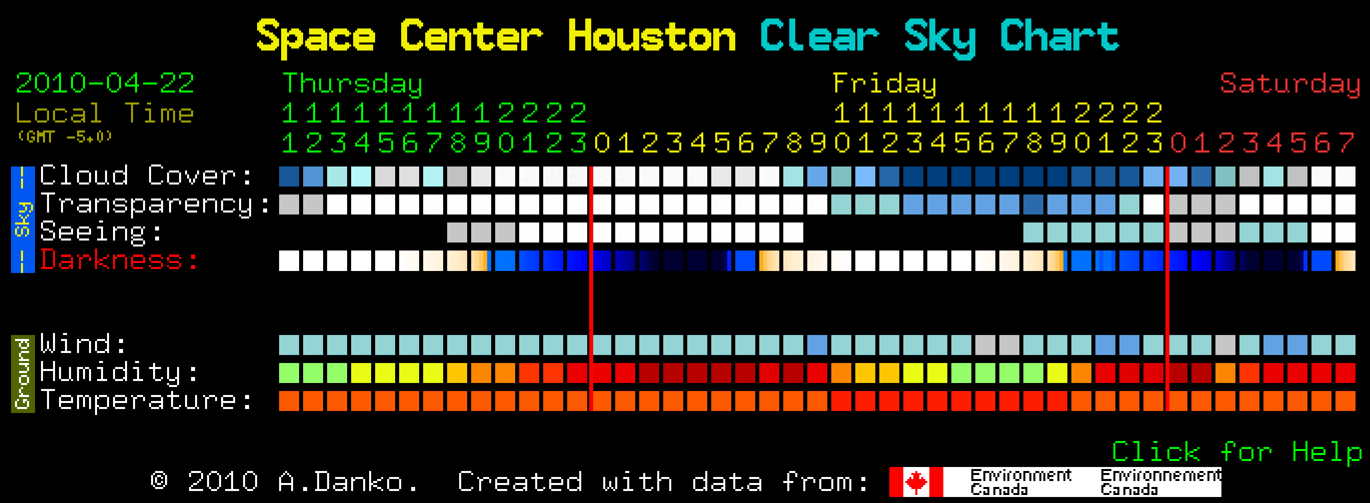
Example of the power of image processing –
• Image on left has had its dynamic range stretched via Photoshop curves, and noise reduced using Selective Gaussian Blur Noise Reduction (SGBNR) in PixInsight.

Astroimaging - Tutorial

- What Else Will Effect Your Astroimaging Session?

Cloud cover, transparency (humidity + particles in atmosphere), seeing (turbulence), phase of the Moon

How can you find the conditions for your area?
=> Clear Sky Clock home page: http://cleardarksky.com/csk/



Astroimaging - Tutorial

- What Else Will Effect Your Astroimaging Session? (cont'd)

f stop – vs. – aperture – vs. – focal length – vs. – tracking accuracy – vs. – seeing conditions – vs. – exposure length – vs. – polar alignment – vs. – wind – vs. planes flying through your picture – vs. – a large truck driving down your street – vs. – etc., etc., etc.

Exposure Length –

- For planets, shorter is better - capture during moments of good seeing
- DSOs, in general longer is better to bring out subtle detail

⇒Trade offs:

- ⇒ Lower f-stop allows shorter exposure times
  - ⇒ f-stop = focal length / aperture
  - ⇒ Example: At f/5.6, only half the exposure time is required as compared to f/8 for the same resulting image brightness
- ⇒ Longer exposure lengths require accurate mount tracking for longer periods of time
  - ⇒ Periodic and non-periodic error due to quality of mount
  - ⇒ Field rotation due to poor polar alignment
- ⇒ Longer exposures require other ideal conditions
  - ⇒ Wind vibrating scope, airplanes, meteors, trucks

Astroimaging - Tutorial

- What Else Will Effect Your Astroimaging Session? (cont'd)

Scope Focal Length –

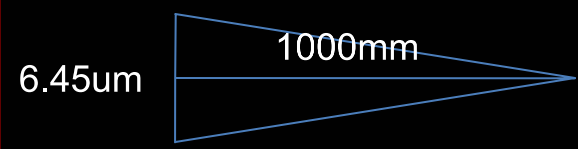
- Image Scale: the angle subtended by one pixel
  - Example: a 6.45um pixel (ICX285) with a 1000mm fl telescope has an image scale of 1.33".
- Image Scale – vs. – Tracking Accuracy – vs. Seeing
  - Seeing limits results to be between 2" to 4"
  - It is challenging to get a telescope mount to track to 1" and below.
  - Without good polar alignment, image will rotate around guide star – field rotation.

⇒So, what is the point?

⇒ A shorter focal length telescope:

1. Leads to a lower f-stop, short exposure (f-stop = fl/ aperture)
2. Does not show seeing effects as much
3. Is more forgiving of guiding errors
4. Is more forgiving of polar alignments
5. Is in general easier to image with

How to calculate image scale:



$$2 \bullet \arctan\left(\frac{6.45um/2}{1000mm}\right)$$

Astroimaging - Tutorial

- What Else Will Effect Your Astroimaging Session? (cont'd)

How to fit target within image –

- Field of View: the angle subtended by an image sensor's horizontal and vertical dimensions
  - Example: ICX285 sensor measures 8.98mm x 6.71mm. With a 1000mm fl telescope has a horizontal field of view of .50° , and a vertical field of view of .38°.
- How can I change the field of view?

⇒Focal reducer

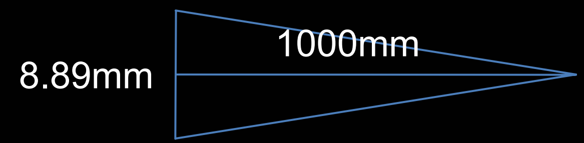
⇒ Will decrease f-stop thus allowing shorter exposure times

⇒ Can cause vignetting (bright in middle, dark on edges)

⇒Will change where scope comes into focus

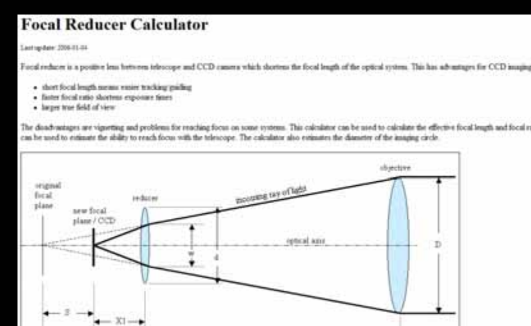
⇒ Or just use scope with shorter focal length

How to calculate field of view:



$$2 \bullet \arctan\left(\frac{8.89mm/2}{1000mm}\right)$$

Focal Reducer



http://timosastro.1g.fi/tools/focalreducer.html

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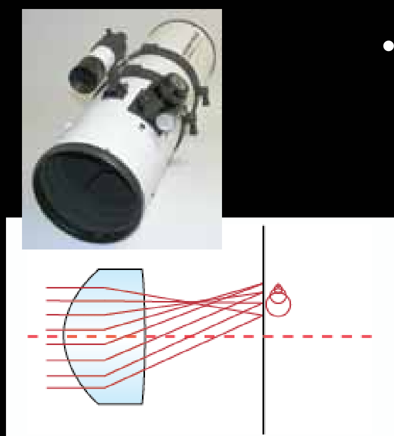
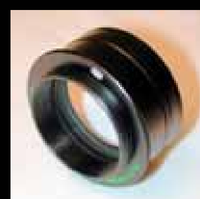
Astroimaging - Tutorial

- What Else Will Effect Your Astroimaging Session? (cont'd)

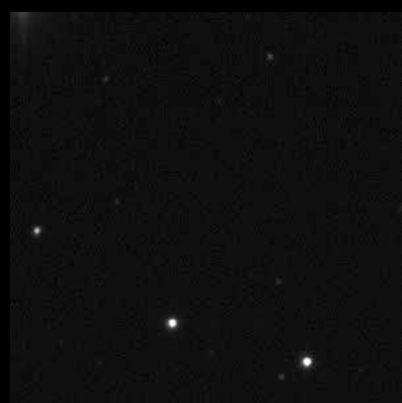
In general, telescopes perform better on axis (middle) than off axis (edges).



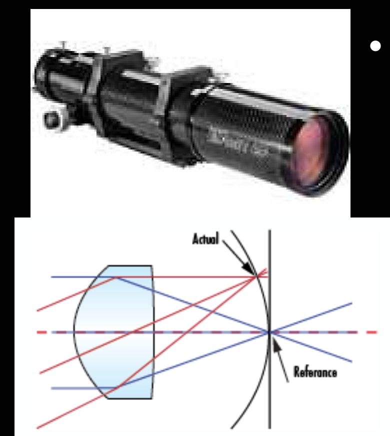
- Newtonians have issues with coma



Coma Corrector



WITHOUT WITH



- Refractors have issues with field curvature

Field Flattener

WITHOUT WITH

- <u>A Collection of Images</u>

➢ *And how they were taken*

- Unmodified Canon DSLR -

Astroimaging - Tutorial

- Camera: Unmodified Canon 300D
- Telescope: Celestron 80ED Refractor
- Mount: Celestron ASGT

NGC6992: The Waterfall Nebula (Super Nova Remnant)

NGC7000: The North American Nebula

Astroimaging - Tutorial

- Camera: Unmodified Canon 300D
- Telescope: Celestron 80ED Refractor
- Mount: Celestron ASGT

M31: The Andromeda Galaxy

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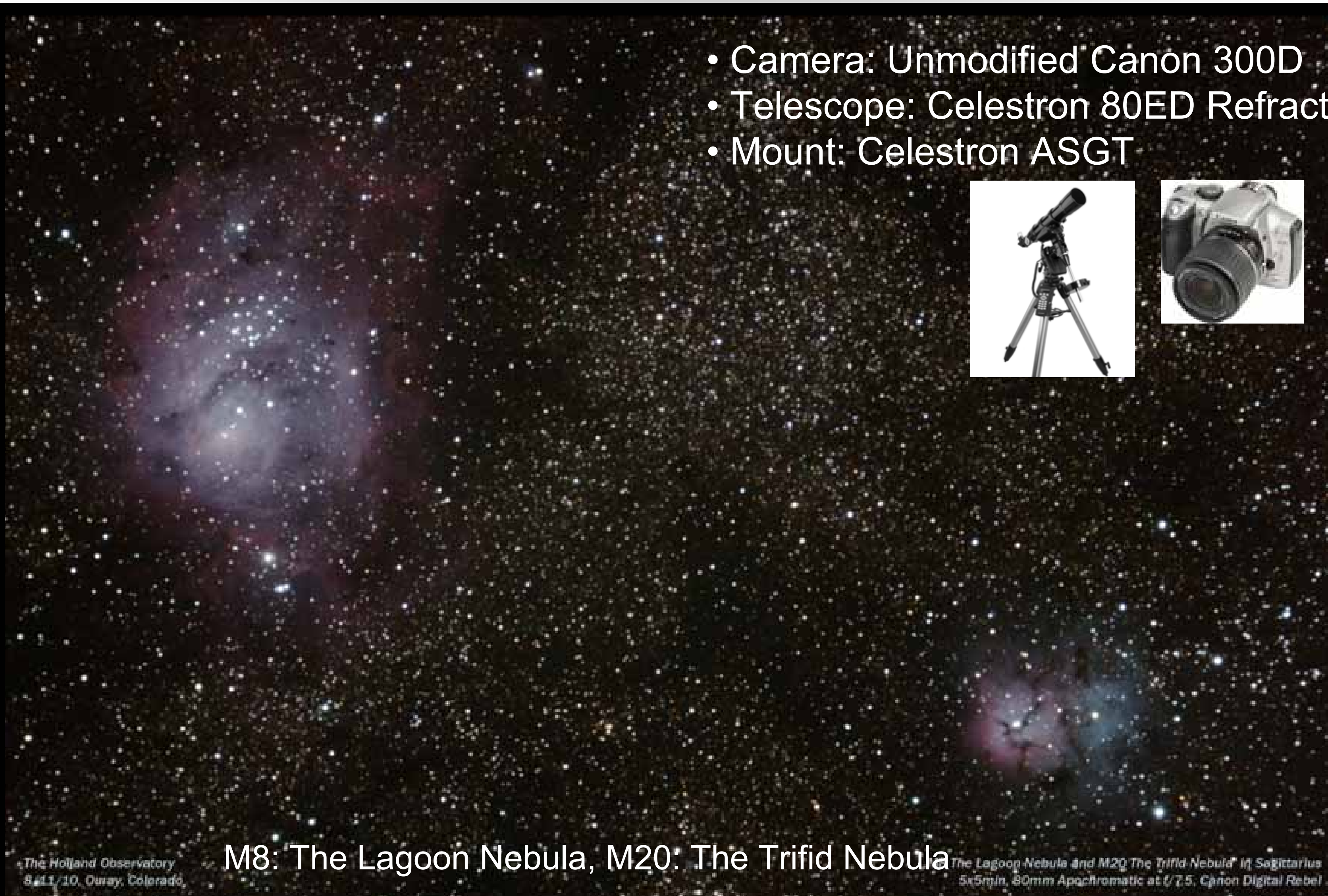

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- Camera: Unmodified Canon 300D
- Telescope: Celestron 8” Newtonian
- Mount: Celestron ASGT

Astroimaging - Tutorial

- Camera: Unmodified Canon 300D
- Telescope: 18-55mm kit lens
- Mount: Barn Door Tracker

The Center of the Milky Way Galaxy

- Modified Canon DSLR -

Astroimaging - Tutorial

- Camera: Modified Canon 450D
- Telescope: Celestron 8" Newtonian
- Mount: Losmandy G-11
- Filter: Astronomik CLS

NGC2174: Monkey Head Nebula

IC434: Horsehead, NGC2024: Flame Nebula

IC410: The Tadpole Nebula

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- CCD LRGB -

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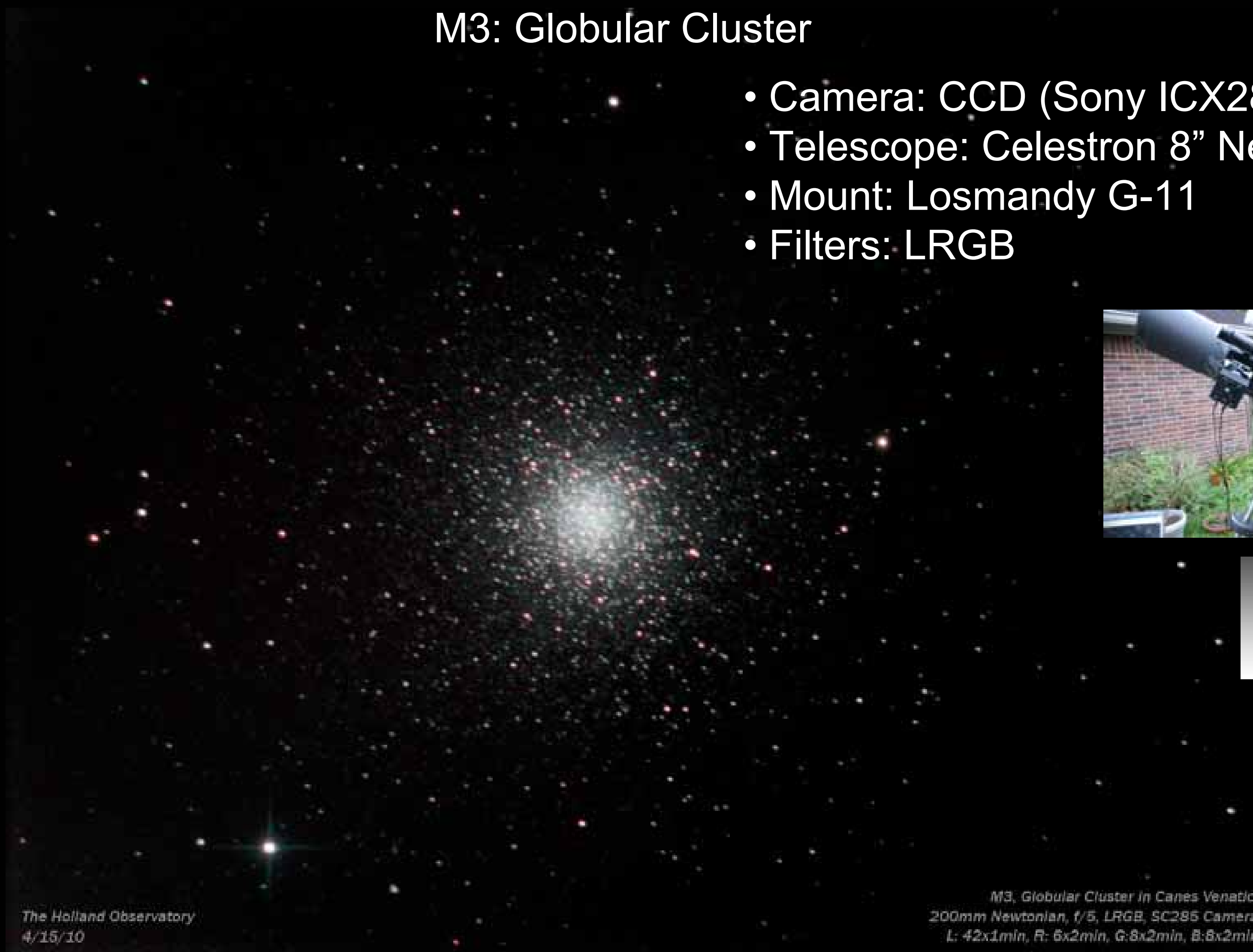
M3: Globular Cluster

- Camera: CCD (Sony ICX285 Sensor)
- Telescope: Celestron 8” Newtonian
- Mount: Losmandy G-11
- Filters: LRGB



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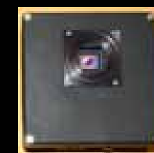
- Camera: CCD (Sony ICX285 Sensor)
- Telescope: Celestron 80ED Refractor
- Mount: Celestron ASGT
- Filters: LRGB

M101: Spiral Galaxy



- CCD Narrowband -

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- Camera: CCD (Sony ICX285 Sensor)
- Telescope: Canon 200mm f/2.8 L Lens
- Mount: Celestron ASGT
- Filters: Narrowband (SII, Ha, OIII)

NGC2244, 2237 - 2239: The Rosette Nebula

IC1805: The Heart Nebula

NGC1499: The California Nebula

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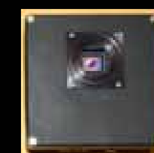
NGC2359: Thor’s Helmet

- Camera: CCD (Sony ICX285 Sensor)
- Telescope: Celestron 8” Reflector
- Mount: Celestron ASGT
- Filters: Narrowband (SII, Ha, OIII)



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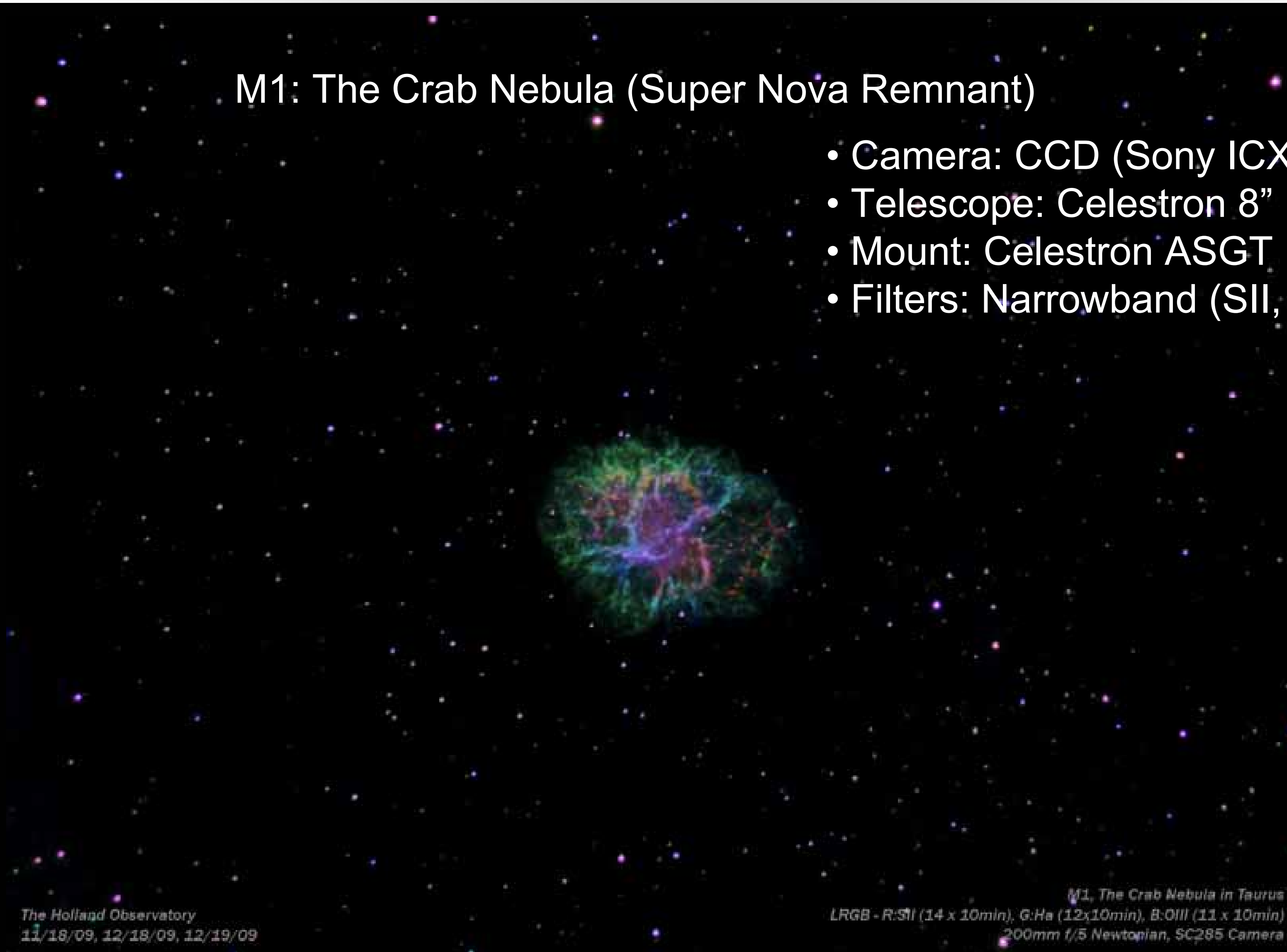
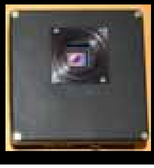
M1: The Crab Nebula (Super Nova Remnant)

- Camera: CCD (Sony ICX285 Sensor)
- Telescope: Celestron 8" Reflector
- Mount: Celestron ASGT
- Filters: Narrowband (SII, Ha, OIII)





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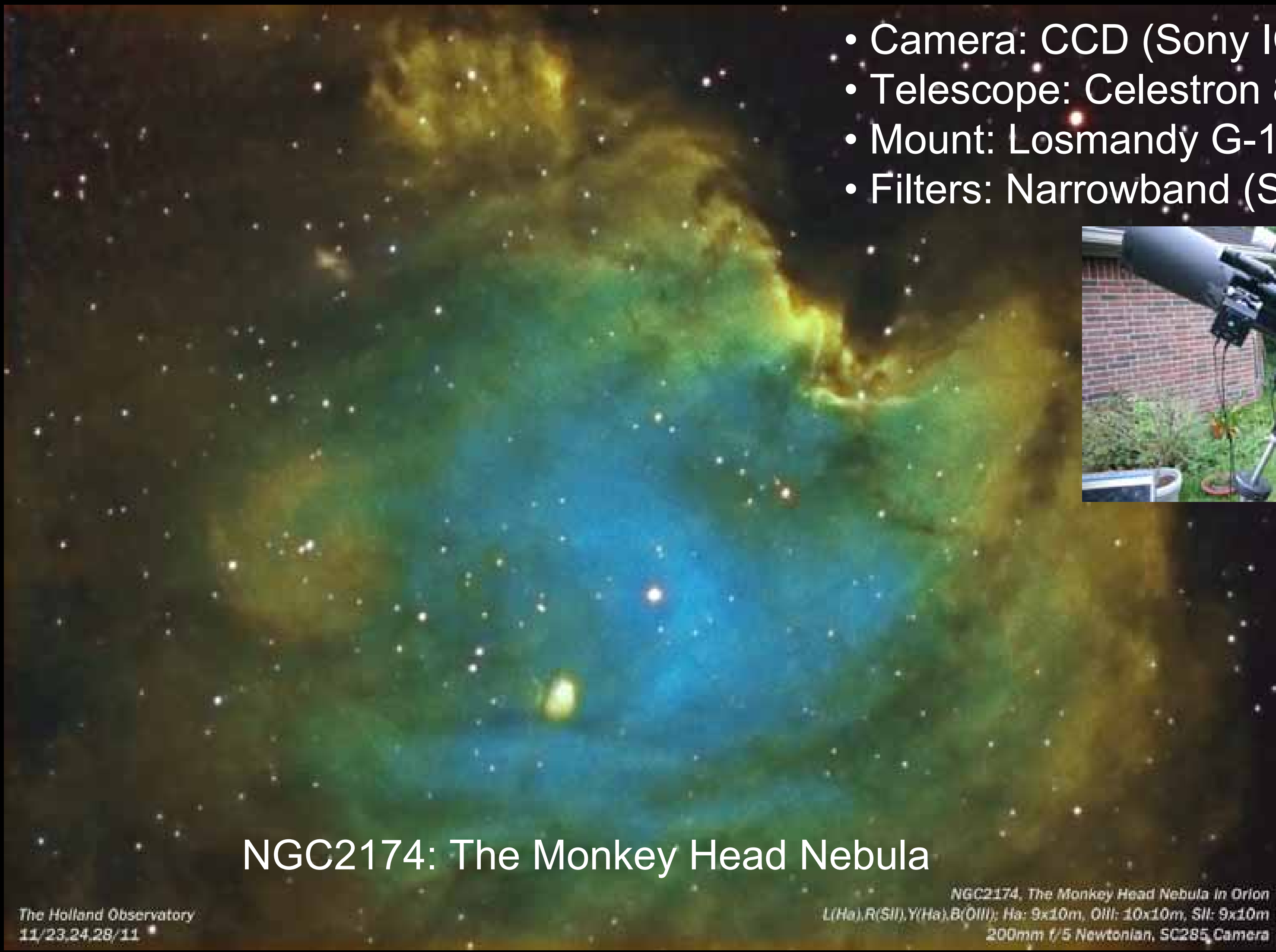
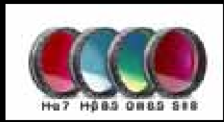


NGC2174: The Monkey Head Nebula

- Camera: CCD (Sony ICX285 Sensor)
- Telescope: Celestron 8” Reflector
- Mount: Losmandy G-11
- Filters: Narrowband (SII, Ha, OIII)



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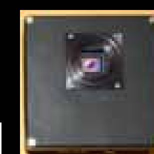
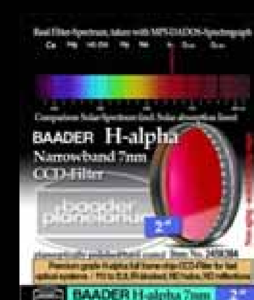
Monoceros Area with Rosette Nebula
in Hydrogen Alpha (Ha)

- Camera: CCD (Sony ICX285 Sensor)
- Telescope: Canon FD 50mm Lens
- Mount: Losmandy G-11
- Filters: Narrowband (Ha)





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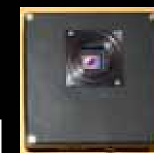
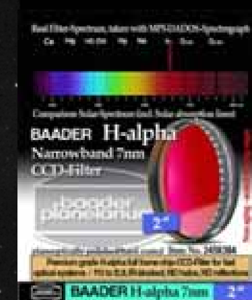
Orion Area with Orion, Horsehead, Flame Nebula, and Barnard's Loop in Hydrogen Alpha (Ha)





- Camera: CCD (Sony ICX285 Sensor)
- Telescope: Canon FD 50mm Lens
- Mount: Losmandy G-11
- Filters: Narrowband (Ha)

- CMOS Image Sensor -

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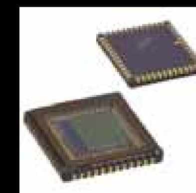
$18



Images taken with low cost Micron / Aptina MT9M001 CMOS Image Sensor based cameras

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- Unmodified Canon DSLR -

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The Moon
Single Shot Image

- Camera: Unmodified Canon 300D
- Telescope: Celestron 8” Netownian
- Mount: Celestron ASGT

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M42: The Orion Nebula, NGC1977 The Running Man Nebula

- Camera: Unmodified Canon 300D
- Telescope: Celestron 8” Netownian
- Mount: Celestron ASGT

Astroimaging - Tutorial

- References
  - The New CCD Astronomy by Ron Wodaski
  - The Handbook of Astronomical Image Processing by Richard Berry and James Burnell
    - Best book to understand theory of image calibration, comes with AIP4WIN software
  - The 100 Best Astrophotography Targets by Ruben Kier
  - Photoshop Astronomy by R. Scott Ireland
- Visit our web page:
  - www.holland-observatory.net