A Guide to Beginning and Advanced Astrophotography

Overview of Equipment and Techniques to begin Astrophotography and to Evolve to Advanced Astrophotography.

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A Guide to Beginning and Advanced Astrophotography

Astrophotography is taking photographs of objects in the sky

- Records the objects to see for history
- Records once in a lifetime celestial events
- Allows seeing dimmer objects that can not be seen with your eyes or visually with your telescope
- See objects in color

Astrophotography can be performed with

- Only a tripod with SLR or DSLR (digital camera), or any camera with tripod connector
- Telescope with SLR/DSLR, or just hold a point and shoot camera up to the eyepiece of a telescope
- Webcam, video or specialized digital camera can be used with a telescope
    - Computer may be required to capture the objects, and to combine or process the images

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Types of pictures that can be taken

- Star Trails
- Asteroids, Meteors and comets
- Eclipses
- Transits - Planet transits across Sun’s surface
- Celestial objects (stars, planets, clusters, galaxies, nebula, etc.)
- Occultation's
- Sun spots
- Moon and craters
- Meteor Planet impacts
- Constellations
- Aurora Borealis

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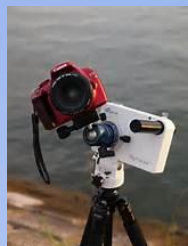
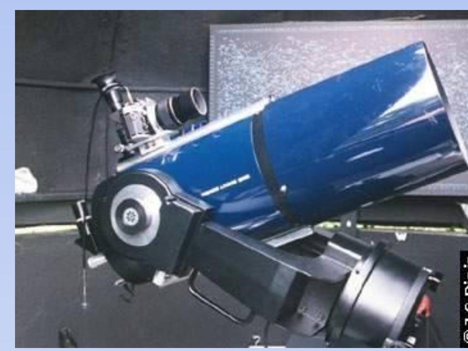
Example Astrophotography Equipment Setups





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Agenda

- Astrophotography with Camera and Tripod
- Astrophotography with Manual or motorized Mount
- Astrophotography with Telescope
- High End Astrophotography
- Planetary Imaging
- Image Processing
- Final Thoughts

Astrophotography with Camera and Tripod

- Astrophotography with a camera mounted on a tripod is very easy. Attach a camera to a tripod, point camera at sky, use the infinity focus, and snap the picture.
- Before choosing a sky target, let's decide on which camera lens to choose, how to focus in the dark, how long an exposure to take, and at what ISO should be used?
  - For the first attempt, a good choice would be to use a DSLR camera that has a bulb setting (shutter stays open while shutter button is depressed) with a 35 or 50mm lens. Best to use the camera timer, a shutter cable release or a camera wireless controller to take the picture

Cable release

Intervalometer

Wireless control to phone, tablet or computer

Note: manufacturer products are for reference only and does not recommend a specific product

Astrophotography with Camera and Tripod (continued)

- Focusing a camera at a night sky is difficult and will take pre-planning and a little practice.
    - Depending on camera type, one of the following focusing method (worse to best) can be used.

1) Do a manual focus at time of exposure
2) Determine the infinity focus setting during the daytime and mark the position on the lens with tape or mark
3) If camera has live view and magnify-the-image capability, use it to focus the best you can on the brightest star.
4) Same as option 3), except use auto focus mode then switch back to manual (beware this doesn’t always work depending upon camera. If it doesn’t work use option 3)

Astrophotography with Camera and Tripod (continued)

- The camera shutter speed is critical. If too fast, image will be blank, and if too slow stars will have tails and the image will appear blurry due to the rotation of the Earth. This is why it is best to use a 50mm or wider (<50mm) lens to reduce the noticeable effects of Earth rotation or errors in focus.
  - Remember the Earth is rotating at 15 degrees per hour, or 1 degree in four minutes, or 15 arc-minutes/minute or 15 arc-seconds/second

- A rule of thumb for defining the camera shutter speed is the "The 500 rule"

500 / (Crop-Factor x Focal Length) = Shutter Speed

where

- shutter speed expressed in seconds
- crop factor - the ratio between your sensor and a full frame one (35mm x 35mm.
  - example: with a camera sensor of 24mm, the crop factor would be 1.5
- focal length in millimeters.

https://astrobackyard.com/the-500-rule/

Astrophotography with Camera and Tripod (continued)

The "500 Rule" in table format

The 500 Rule

Lens Focal Length	Full Frame Camera	1.5 Crop (Nikon)	1.6 Crop (Canon)
14 mm	36 sec	24 sec	22 sec
16 mm	31 sec	21 sec	20 sec
20 mm	25 sec	17 sec	16 sec
24 mm	21 sec	14 sec	13 sec
35 mm	14 sec	10 sec	9 sec
50 mm	10 sec	7 sec	6 sec
70 mm	7 sec	5 sec	4 sec
85 mm	6 sec	4 sec	4 sec
135 mm	4 sec	2 sec	2 sec
200 mm	3 sec	2 sec	2 sec

- This table is not exact and it depends on the size of the image being viewed and the declination of the object.
- Star Trails are more likely at 0 deg declinations than at higher declinations.
- Also, the more an image is magnified, the more noticeable the star trails.
- But this table is a good starting point.

https://astrobackyard.com/the-500-rule/

Astrophotography with Camera and Tripod (continued)

- How much image smear is allowed is dependent upon the size of the final image being viewed. Image smear will be the least apparent if viewed on the camera screen and will be more apparent with increasing print size (5x7” or 8x10”) and most apparent on a computer screen.
- A more detailed analysis for different sizes of viewed images and assuming 3.5mm eye diameter (for daylight viewing of image), the following is obtained for a camera with 6 micron pixels.

- Some where between these exposures times and the “**500 rule**” should provide the best images with minimual star trails.

Exposure time based on a 8x10 photo, 3.5mm eye diameter

F(mm)	Dec(deg) 0	30	60
50	0.8sec	0.9sec	1.5sec
35	1.1	1.2	2.2
24	1.6	1.8	3.1
18	2.1	2.4	4.2
16	2.4	2.7	4.7

Exposure time based on a 5x7 photo, 3.5mm eye diameter

F(mm)	Dec(deg) 0	30	60
50	1.1sec	1.3sec	2.3sec
35	1.6	1.9	3.3
24	2.4	2.8	4.8
18	3.2	3.7	6.4
16	3.6	4.1	7.2

Exposure time based on camera for 3 pixels@6μm each

F(mm)	Dec(deg) 0	30	60
50	5.0sec	5.7sec	9.9sec
35	7.1	8.2	14.1
24	10.3	11.9	20.6
18	13.8	15.9	27.5
16	15.5	17.9	30.9

Astrophotography with Camera and Tripod (continued)

- The ISO camera setting is dependant on several factors that doesn't lend itself to be one answer. From an overall perspective , the lower the ISO, the more image detail will be seen due to lower noise, and the higher the ISO more noise will be visible in the image. However, if the object is not visible at an ISO of 400, then the ISO must be increased until it can be seen. Generally an ISO of 400 to 1600 is what would be expected in most cases. Although there will be times that 3200 or more may be needed.

- Which subject matter should be the first choice?
  - The easiest photo to take is of the Milky Way or a constellation. Point the camera at the Milky Way and take a series of pictures varying the exposure time and ISO.
  - Another first target can be taking a photo of the stars as the Earth rotates. Point the camera at the north star, and leave the shutter down for several hours. May also get some meteors trails!
  - Another option if your camera has an internal intervalometer or an external intervalometer can be attached, take images every couple of minutes for several hours. Afterwards make a time-lapse video.

Astrophotography with Camera and Tripod (continued)

Calculate Camera Lens Field-of-View

The field of view of a standard camera lens (valid for a telescope/camera also) is defined by

$$\alpha = 2\tan^{-1}\left(\frac{d}{2f}\right) \sim \frac{d}{f} \text{ in radians}$$

where

α = Camera lens field-of-view in radians or degrees, depending on $\tan^{-1}$ function

d = Width of camera focal plane chip (horizontal, vertical, or diagonal) in mm

f = Camera Lens or telescope focal length in mm

The field of view of a fisheye camera lens is defined by

$$\alpha = 4\sin^{-1}\left(\frac{d}{4f}\right)$$

Example:

Camera lens focal length (f) = 18 mm

Camera focal plane chip (d) = 36mm x 24mm (6000 pixels x 4000 pixels)

Angle of view (vertical) = 2 $\tan^{-1}$ (24/(2x18)) = 67 deg

Angle of view (horizontal) = 2 $\tan^{-1}$ (36/(2x18)) = 90 deg

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Astrophotography with Manual or Motorized Mount

- Adding a camera mount that is either manual or motorized to compensate for Earth's rotation allows longer exposures with a camera. But it also adds additional complexity and expense.
- Generally an equatorial mount would be used and could be manual or motorized. The camera mounts shown below would be placed on a tripod or pier and would have to be polar aligned (pointed at Polaris would be sufficient).

Manual Barn Door Tracker

iOptron Sky Tracker Pro

AstroTrac TT320X AG AutoGuiding Tracking Mount

Vixen Polarie

Star Adventurer Astro Package

Note: manufacturer products are for reference only and does not recommend a specific product

Astrophotography with Manual or Motorized Mount (continued)

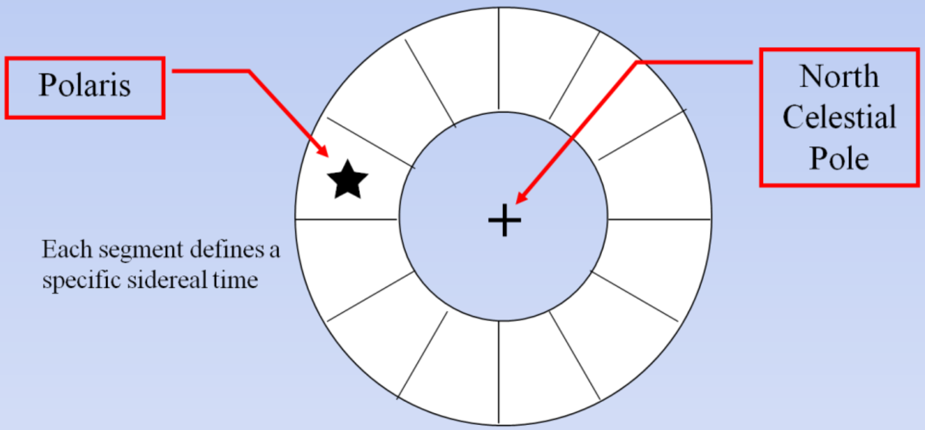
- A **equatorial mount** has two perpendicular axes, the right ascension (RA) axis is pointed at the Earth's rotation axis and is rotated at the apparent sky rate (15 deg/hr) to allow object tracking. The declination (DEC) axis provides a second axis that when combined together with the RA axis allows pointing at any object in the sky.
  - The one axis motion can be performed either by the user or can be motorized.
  - Most equatorial mounts come with an azimuth and altitude set of adjustments to precisely allow pointing the right ascension (RA) axis at the Earth's rotation axis (polar alignment).
    - To assist in polar alignment, some mounts come with a polar alignment scope in the mount

Astrophotography with Manual or Motorized Mount (continued)

- Polar alignment of an equatorial mount can be accomplished by the user depending on the polar alignment aid that is available.
  - If none is available, then user must use their eyes to sight along a reference straight edge to point the mounts RA rotation axis at Polaris.
    - Recommend that the camera tripod or pier be leveled first.
    - With the barn door hinge mount, the hinge is pointed at Polaris. A laser can be used to assist in alignment
  - Some of the camera mounts come with a crude polar alignment aid or in some cases this can be purchased at an additional expense.
- Focusing is the same as was discussed in the previous section

Astrophotography with Manual or Motorized Mount (continued)

- Polar alignment with a camera mount that has a polar align reticle
  - Level mount by adjusting tripod legs or pier bolts
  - If required, insert polar align reticule into the mount
  - Using date and time, confer with manual or App to determine which segment Polaris must be in for polar alignment.
  - Depending upon tripod/mount arrangement adjust the tripod legs, tripod head, or latitude/azimuth adjustment bolts/knobs on the mount until Polaris is centered in the polar align reticule quadrant/segment shown for current day and time (see picture).



An computer, smart phone or tablet app, or manual alignment dial can be used to indicate which segment to put Polaris as a function of day and time

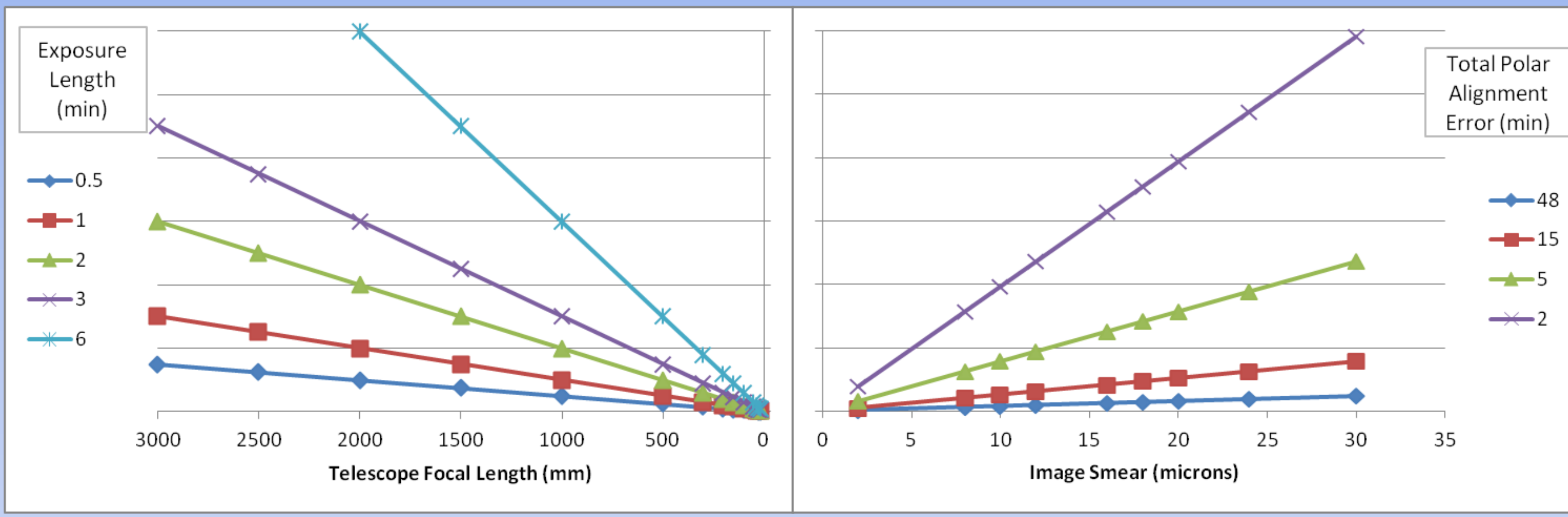
Astrophotography with Manual or Motorized Mount (continued)

- Another Polar Alignment method for an equatorial mount is the Star Drift method
  - The star drift method can be used to align your telescope/camera to any accuracy. First, level your tripod (not necessary, it just helps) and coarsely aim the telescope RA axis to Polaris. If you have a polar align reticle in the mount, use it to get a better starting alignment.
  - Look at a star near the Equator, South. Track the star in RA only, and look if the star goes up or down in your eyepiece (supposing your are looking straight at south with your head vertical). Rotate the azimuth of your telescope to adjust it until the star is not moving anymore.
  - Then, move to a star at East (West works also). Do the same, but adjust the altitude this time (the angle between your telescope RA axis and the horizon). By switching several times from South to East (West), you should be able to adjust your polar alignment quite quickly. Of course, the first time you will spend a lot of time; take notes of what you are doing, and it will be much quicker the next time you do it.
  - Continue star drift process until the star does not move for the time you want to take an exposure

Astrophotography with Manual or Motorized Mount (continued)

Estimated Image Smear due to Polar Alignment Errors

Nomograph



$$t = \frac{787.872\, I_s}{f\ P_e}$$

where

t = Exposure Length, min

I_s - Image Smear, microns

f = Focal Length, mm

P_e = Polar error, arc-min

<u>Example how to use a nomograph</u>: pick a focal length, draw an imaginary line vertically until hitting an exposure length line is reached. Then draw an imaginary horizontal line until hitting the total polar alignment error line. Then draw an imaginary vertically line down to the image smear horizontal axis.

http://articles.adsabs.harvard.edu

“Polar axis alignment requirements for astronomical photography”, Hook, Richard N., 1989 volume 99 page 19-22, British Astronomical Association provided by NASA Astrophysics data system

Astrophotography with Manual or Motorized Mount (continued)

Estimated Image Smear due to Polar Alignment Errors (continued)

Examples

Smear Allowed – 6 microns

		Polar Error (arc-min)				
		1	**2**	**5**	**10**	**60**
	50	94.5	47.3	18.9	9.5	1.6
Focal	150	31.5	15.8	6.3	3.2	0.5
Length	300	15.8	7.9	3.2	1.6	0.3
(mm)	500	9.5	4.7	1.9	0.9	0.2
	1000	4.7	2.4	0.9	0.5	0.1
	1500	3.2	1.6	0.6	0.3	0.1
	2000	2.4	1.2	0.5	0.2	0.0

Allowed Exposure time (min)

Smear Allowed – 18 microns

		Polar Error (arc-min)				
		1	**2**	**5**	**10**	**60**
	50	283.6	141.8	56.7	28.4	4.7
Focal	150	94.5	47.3	18.9	9.5	1.6
Length	300	47.3	23.6	9.5	4.7	0.8
(mm)	500	28.4	14.2	5.7	2.8	0.5
	1000	14.2	7.1	2.8	1.4	0.2
	1500	9.5	4.7	1.9	0.9	0.2
	2000	7.1	3.5	1.4	0.7	0.1

Allowed Exposure time (min)

Astrophotography with Manual or Motorized Mount (continued)

DIY Barn Door Tracker

- At the simplest, a barn door hinge mount can be bought or made that will allow camera exposures up to a couple of minutes.
- A very simple way to track is to use two pieces of wood, a hinge, and a ¼ - 20 bolt. A quarter turn of the bolt every 15 seconds matches Earth rate. It is both cheap and fun to build, and you can have very nice results. Adding a rotating head between the barn door tracker and your camera will help orienting the camera to get the field of view you want. You may even add a one rev/min DC motor to make the tracking more automatic.
- Do need to point the hinge at the North Star (Polaris)
- Can allow exposures up to about 2 to 2 ½ minutes

http://ridetheclown.com/BarnTracker/ https://www.jjrobots.com/projects-2/startracker/

https://garyseronik.com/build-a-hinge-tracker-for-astrophotography/

Astrophotography with Manual or Motorized Mount (continued)

- The next possible upgrade or growth would be to use an equatorial telescope mount in place of the camera mount.
  - The advantages are
    - A telescope can be added later
    - Better tracking
    - Better payload capability and balancing allowing use of a longer lens
    - Most have a polar align telescope in the mount
  - The disadvantages are
    - Higher cost
    - Higher weight
    - Additional power is required

Note: manufacturer products are for reference only and does not recommend a specific product

Astrophotography with Manual or Motorized Mount (continued)

- Polar alignment software using camera with a Go-To equatorial mount
  - There are many software programs to help in polar alignment using a web cam or camera with a computer
    - Some mimic the star drift method by displaying the star drift over time.
    - Others require precise star alignments and the software computes the polar error by comparing the star coordinate to what the telescope mount measured.
    - Also some continuous displays the error as the polar axis is being modified by the user to provide real time updates and to know when complete.
  - Here is an incomplete list;
    - Alignmaster, EQAlign, APT, PoleAlignMax, PemPro, WCS, Polar finder, StarTarg2.0. , SharpCap Pro polar alignment. Also PHD2 has a polar alignment capability

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Astrophotography with Manual or Motorized Mount(continued)

DSLR Camera Control

- Complete camera control can be accomplished using DSLR image capture software on a computer.
  - Some of the image capture software is Prism, Sequence generator Pro 3, Astro Photography Tool, Backyard EOS, Nebulosity 4 and Voyager 4.5.

AstroDSLR

Cascable

Note: A sky planetarium program is required for image capture computer control , some of the above programs have one included, but some require a separate planetary program to be purchased. TheSky X is one of many that can be used. Sequence Generator Pro requires a tracking program such as PHD2.

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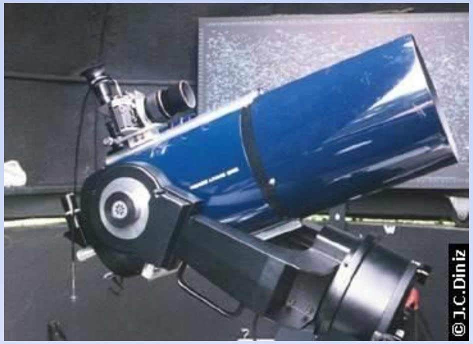
Astrophotography with a Telescope

- Astrophotography with a telescope is a giant step in both equipment and knowledge, not to mention cost
  - Two categories:
    1) Telescope replacing DSLR camera lens
    2) Using a DSLR with an existing visual telescope system



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Astrophotography with a Telescope (continued)

1) Replacing a DSLR camera lens with a telescope is easy, but there are several considerations including using a different mount
   - Mount must be of sufficient size to handle the telescope/camera weight
   - Depending on size of camera, balancing the scope/camera system become more important.
   - Attaching a DSLR to a telescope requires T-ring (specific to camera) that will allow attaching the camera to a telescope
   - Telescope usually has a longer focal length than a camera lens requiring the mount to be able to track well.
     - Field-of-view (FOV) will be smaller (see equation from previous section)
     - Polar alignment needs to be better
     - More difficult to get subject on the center of the camera sensor
       - Finderscope, on-axis or off axis guider is a must

On–axis guiding with coated lens that reflects infra-red light to an eyepiece (same guider Field-of-view as main camera, but fewer infra-red light stars)

Piggy-backed finderscope (can have large guider FOV)

Off –axis guiding with small pickoff mirror for manual guiding with an eyepiece (smaller guider FOV)

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Astrophotography with a Telescope (continued)

1) Replacing a DSLR camera lens with a telescope is easy, but there are several considerations including using a different mount (continued)
   - Focusing will also be more difficult as the focus aid from a DSLR is not available
     - The simplest and cheapest is a simple aperture mask over the front of the telescope that has two holes cut 180 degrees apart. The size of these holes varies depending on the aperture of the scope you are using (about 2" diameter for an 8 inch aperture and maybe 3" for a 10").
       - Once in place on telescope, move the scope to a bright nearby star and look through the camera. You should see two stars. Move the telescope focus in or out and you will notice the stars will begin to converge or diverge. What you want is to converge them into a single stellar image as accurately as you can. After doing so, you are in focus.
       - Now move the telescope to the object to be photograph and take the shot.

Bahtinov Mask

Hartmann Mask or Scheiner Disk

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Astrophotography with a Telescope (continued)

Focault method

Focault method - A razor edge to cut a star beam.

- Use a "knife edge focuser" to get a precise focus. This employs the fact that a well focused star makes a small pinpoint of light on the focal plane of the camera. The knife edge focuser in simple terms is a very thin edge that when placed at the precise prime focus of the scope will cause a well focused star to quickly vanish from view when the scope is moved in a direction that will cause the knife edge to occult the star. An out of focus star will not quickly vanish but will appear to slowly dim out as it is occulted.

Mitsuboshi knife-edge focusers

http://www.sciencecenter.net/hutech/mitsub/focuser.htm

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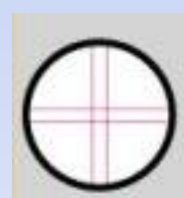
Astrophotography with a Telescope (continued)

- Guiding is the act of continuously correcting track errors in real-time to eliminate image smearing and minimize elongated stars in capturing images.
  - Track errors can consist of polar alignment errors, Earth rotational rate errors, and induces errors, such as refraction, atmospheric, wind, and mount/telescope.
  - Although the purpose of guiding is to remove errors, it can also add errors by just the act of guiding, such as sensitivity to telescope vibration, and the interaction with guiding exposure rate, atmosphere fluctuations, and mount periodical tracking errors.
  - Only manual guiding will be discussed here. Automated guiding will be discussed in the High End Astrophotography section
- Manual Guiding
  - Consists of using a crosshair reticule as an eyepiece in either the finderscope, telescope or off-axis guider that is attached between telescope and camera. The objective is to maintain the guide object in the center of the crosshair by using mount hand controller.



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Astrophotography with a Telescope (continued)

1) Replacing a DSLR camera lens with a telescope is easy, but there are several considerations including using a different mount (continued)
   - Focusing will also be more difficult as the focus aid from a DSLR is not available (continued)
     - If the telescope has spider vanes that hold the secondary mirror. Point the telescope at a very bright star and look for the refection of the spider vanes in the camera. Adjust the focus until the spikes are as small as possible.
     - During the daytime, point the telescope/camera a far distance object and focus. Use tape to hold the focus or tape to mark the infinity focus.
2) Using a DSLR with an existing visual telescope system
   - Most visual telescope system (i.e., Celestron or Meade) for visual use have an mount that is alt-az. Mounts support the telescope by either 1 or 2 arms
   - However, there are some different skills needed and limitations
     - Need to be able to a 2 to 3 star alignment, although if was used for visual this skill should already be known
     - Alt-Az mounts because of their design is susceptible to image field rotation
     - 2 arm mounts are required to support a DSLR properly

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Astrophotography with a Telescope (continued)

Using a DSLR with an existing visual telescope system (continued)

- An **altitude-azimuth (alt-az) mount** has two perpendicular axes, one axis that rotates 360 degrees around the horizon from north, to east, to south, to west and back to north, and one axis that is perpendicular to the other that rotates from horizontal (0deg) to vertical (90deg) and back to horizontal.
    - Types: Tripod, Tripod with manual alt-az adjustment, and manual or motorized alt-az mount
  - The alt-az mount must mimic the apparent sky motion using two axes and over time an unwanted rotation occurs, called field rotation.
  - The alt-az mount needs to be aligned with the sky to perform tracking. This is performed by performing a star alignment.
    - Star alignment consists of pointing the telescope at 2 or 3 stars and telling the computer which star(s) it is. The computer can then determine the angular transformation between the sky and telescope. This allows the computer to point the telescope at the correct location to see the desired object in the sky.

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Astrophotography with a Telescope (continued)

Using a DSLR with an existing visual telescope system (continued)

Field Rotation

- If watching a object through a telescope that is being driven with an Alt-Az mount, the object will appear to rotate over time. This is called field-rotation.
    - An example of this effect is watching the motion of a constellation from rising to setting. The constellation rises in the east, but by the time it sets in the west it has rotated a little less than 180 degrees. So assuming a 12 hour time period, that is an average of a little less than 15 deg/hr.
    - This is one reason equatorial mounts are preferred over Alt-AZ mounts in astrophotography. Although, if many short exposures are taken over a period of time, there are post processing methods that can be performed to rotate each picture back on top of each other to remove this field rotation effect.

Astrophotography with a Telescope (continued)

Using a DSLR with an existing visual telescope system (continued)

Field Rotation (continued)

The formula for calculating the amount of field rotation of the celestial sphere relative to an Alt-Az coordinate system (in degrees per hour) is:

Angular rate of field rotation (deg/hours) = AR_E x *cos*(lat) x *cos*(az) / *cos*(alt)

where:

- AR_E = Earth Sidereal Rotation Angular Rate = 15.037662 degrees/hour
- lat (deg) = Observer’s Latitude
- az (deg) = target’s azimuth angle from North
- alt (deg) = target’s altitude angle from horizon

http://calgary.rasc.ca/field_rotation.htm

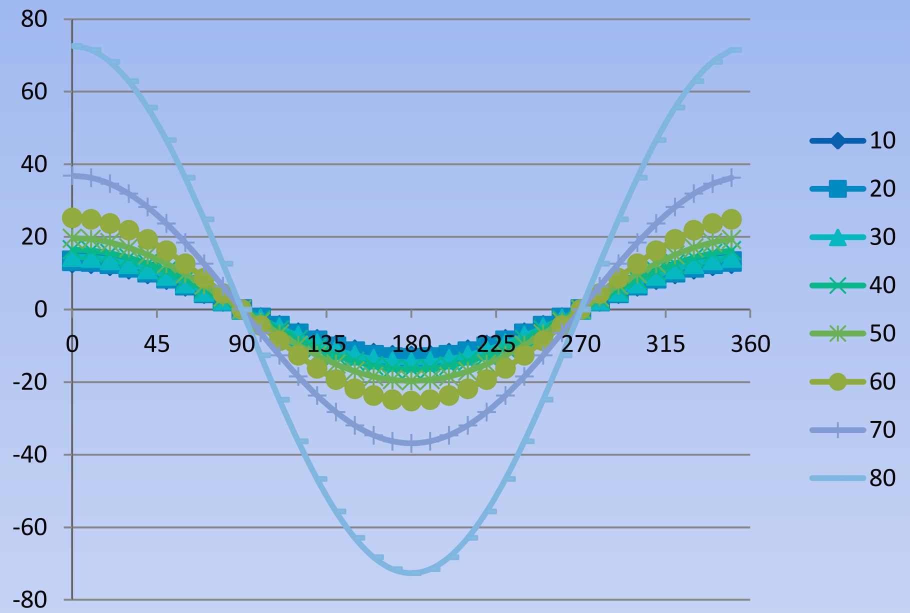
- Note that the Earth’s rotation about its rotation axis is 360 deg/24 hrs or 15 deg/hr. However, the Earth is also revolving around the sun at 360 deg in 365.25 days or 0.041068 deg/hr, but at a slightly different rotation angle because the Earth is tilted 23.5 deg from the Earth rotation axis around the sun. This creates a 2D rate vector of 0.037662 deg/hr in the Earth’s rotation axis rate direction and 0.016376 deg/hr in the direction perpendicular to the Earth’s rotation axis rate. Over a 12 hour period this is less than a 0.5 deg effect, so using AR_E = 15 deg/hr is a good approximation, or to be a better approximation, a value of 15.037662 deg/hr could be used.

Astrophotography with a Telescope (continued)

Using a DSLR with an existing visual telescope system (continued)

Field Rotation (continued)

Field Rotation Rate (deg/hr)



Alt (deg)

Field Rotation for Latitude 33 deg

Notice the higher up the camera is pointed, the worse the field rotation

Astrophotography with a Telescope (continued)

Using a DSLR with an existing visual telescope system (continued)

- A one arm mount that supports the telescope can be used for photography although limited.
  - Use a smart phone with camera to snap pictures through eyepiece
    - There are devices that can be purchased to assist in aligning the phone camera to eyepieces
  - Small 1 ¼ inch diameter video cameras can be used to capture bright objects (i.e., moon, planets, sun with solar filter). Processing will be required with a computer

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High End Astrophotography

- High end astrophotography starts with a great support platform to support the weight of all equipment while in motion or stationary
  - Generally, this is accomplished using a pier or tripod.
    - A Pier is usually permanently mount but can also be made portable especially if for lighter weight equipment
      - A Pier is generally made of wood, metal or concrete
    - A Tripod is generally made of wood or metal

Note: manufacturer products are for reference only and does not recommend a specific product

High End Astrophotography (continued)

- High End Astrophotography generally is performed using a computer to control the mount, camera, focuser and a separate camera that is used to guide on a star (auto guiding)
  - Mounts are usually German-equatorial Go-to mounts, but there are also some direct drive mounts starting to appear

LOSMANDY® ASTRONOMICAL PRODUCTS

PlaneWave™ INSTRUMENTS

Dedicated to Craftsmanship! ASTRO PHYSICS State-of-the-Art Instruments for Discriminating Astronomers

SB SOFTWARE BISQUE

Some mounts have option of adding absolute encoders

Note: manufacturer products are for reference only and does not recommend a specific product

High End Astrophotography (continued)

- High end astrophotography cameras are usually CCD with either a 1 or 2 stage cooler.
  - CCD camera can be cooled below the ambient outside temperature which reduces the noise and allows dimmer objects to be exposed with the same exposure duration.
    - 1 stage cooler reduces sensor temperature to about 30 deg C below ambient
    - 2 stage coolers reduces sensor temperature to 50-60 deg C below ambient

SBIG

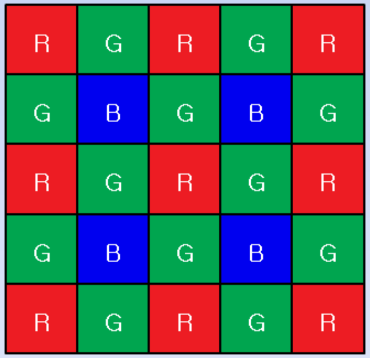
ATIK

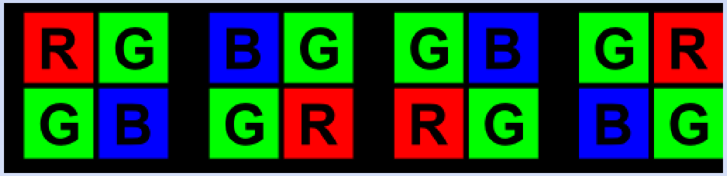
- Using an astrophotography CCD or DSLR without a lens on a telescopes fixes the field-of-view and magnification. Therefore depending on the image or object to be capture, the object size needs to be matched to the telescope field-of-view or telescope focal length

Note: manufacturer products are for reference only and does not recommend a specific product

High End Astrophotography (continued)

- High end astrophotography cameras are either a Color or a mono camera
  - Color cameras are easier to use, less expensive, less weight, and a DSLR is a color camera. Disadvantages are resolution is less, and will require longer exposures to obtain same signal-to-noise(https://en.wikipedia.org/wiki/Signal-to-noise_ratio) as a mono camera. Image capture and Image processing takes a shorter time as there are less images to capture and process.
  - Why does color cameras have lower resolution?
    - Color cameras (sometime called one-shot color) require only one exposure to create a color image. However, to achieve this requires four side-by-side pixels to be combined, each with a different color filter sitting over the pixel (called a Bayer matrix). This technique to obtain color images comes at some loss of resolution in exchange for the ability to capture color in one exposure.

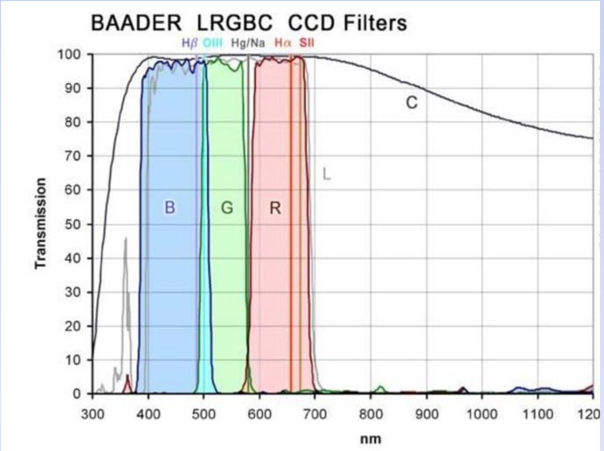




RGGB BGGR GBRG GRBG

High End Astrophotography (continued)

- How does mono cameras get color?
- Mono cameras get color by shooting through a Red, Green, and Blue filters. Then through combination and processing converts the 3 images into one color image.
  - Professional astronomers use mono more than color, because adding color doesn't produce shaper images. They use color to help highlight differences in the images.
    - Mono cameras produce the highest signal-to-noise ratio because the entire visual waveband contributes (~300nm). Whereas each color filters is only about 100nm across and each signal is about 1/3 less than mono. Although the signal is recoped when combined, each color image has camera electronic noise so when combined there are 3 times the electronic noise of an image without the color filter.



- The total signal-to-noise of the combined color images is about ~15% less than using a (clear) filter (with a KAF-8300 sensor) assuming 16 exposures for each of the R, G, B and clear images.
- Because of the benefits of mono, images are usually also shot with a clear filter, making a total of 4 filters to produces a color image with the greatest detail. This is called LRGB imaging.

High End Astrophotography (continued)

- How does mono cameras get color? (continued)
  - Additional filters can be used: Narrow band filters.
    - Narrow band filters are filters that only allow a narrow band of wavelengths of light to enter. Typically 2-10 nano-meters.
    - Besides being used to show objects in a different light, they can also help exclude the urban lights from ruining a image taken in a light polluted environment.
    - The more popular Narrowband filters are Silicon 2, hydrogen alpha, and Oxygen 3.
      - These are called the "Hubble Palette" or SHO

High End Astrophotography (continued)

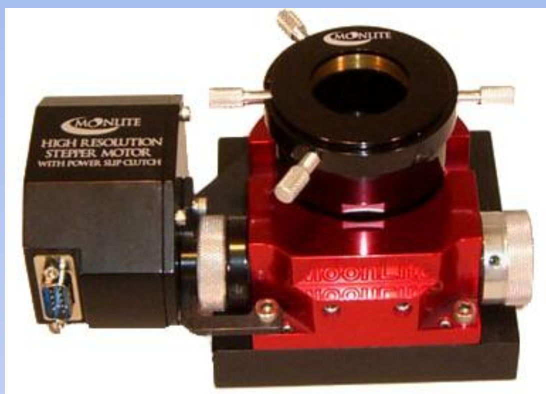
- CCD Camera filterwheels are attached to a CCD mono-chromic camera to hold the filters used to obtain color images, whether Red, Green and Blue (RGB), or narrow band.
- The computer controls the filterwheel to ensure the correct filters is being requested.

- Remember to capture the images in “RAW” format when using DSLR or CCD cameras. The “RAW” format is best if image processing is to performed.

Note: manufacturer products are for reference only and does not recommend a specific product

High End Astrophotography (continued)

- High end astrophotography use focusers that need a controller to be controlled by a computer



MoonLite Focusers

Crayford Design
2" And 2.5" Format
For Refractors, SCTs,
RCs, And Newtonians

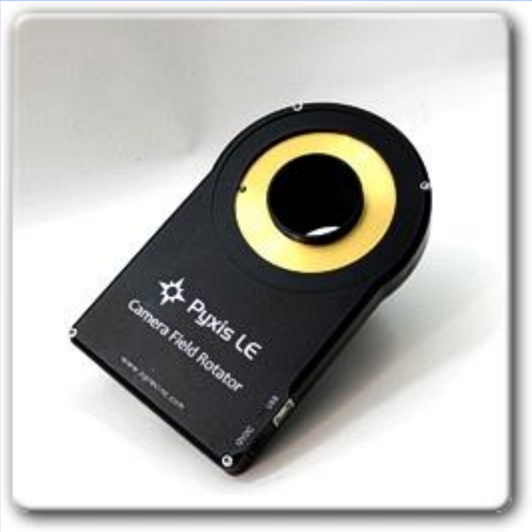
2", 2.5", 3" and 3.5" format

Note: manufacturer products are for reference only and does not recommend a specific product

High End Astrophotography (continued)

- An available option to assist in "Image Framing" is to rotate or position the intended object on the camera focal plane to frame the object the best. For example, placing the object in the center would look better than if placed in a corner. This of course is entirely up to the astroimager discretion.
  - Generally this is accomplished by rotating the camera or pointing the telescope in a slightly different sky position by hand.
  - More advanced and expensive method is to use a camera rotator.

For a SLR or DSLR



For an astro CCD or CMOS camera

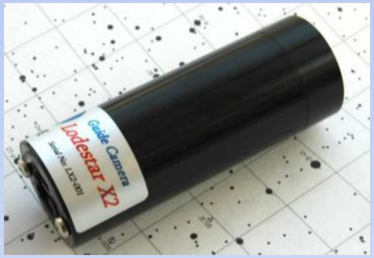
Note: manufacturer products are for reference only and does not recommend a specific product

High End Astrophotography (continued)

- To allow longer exposures, manual guiding or auto guiding is required. Manual guiding was used before the computer, however, with today's technology auto guiding is the best way to extend image exposure durations.
  - Auto guiding uses a second camera to image a smaller star field and send the image to image control processing which then keeps the chosen star centered reducing image blur in the presence of polar alignment errors, and other errors such as axis non-orthogonality, mount rate and gear symmetric errors. Auto guiding can also reduce some of the image smear due to wind or cable drag.
    - The larger the guiding camera sensor, the larger the field-of-view(FOV) and therefore, easier to find a guide star

SBIG STi
(4.8x3.6 mm)

Starlight xpress Ultrastar
(8.98x6.71 mm)



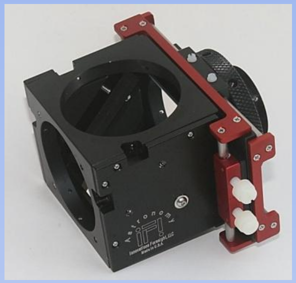
Starlight xpress Lodestar
(6.47x4.81 mm)

  - Another more expensive option is adding precise digital encoders to a telescope mount. This allows the computer and mount to track to a precise RA and DEC set of coordinates and almost eliminate the need to auto guide for exposures up to about 20 minutes. This option also prevents loss of the knowledge of the home position.

Note: manufacturer products are for reference only and does not recommend a specific product

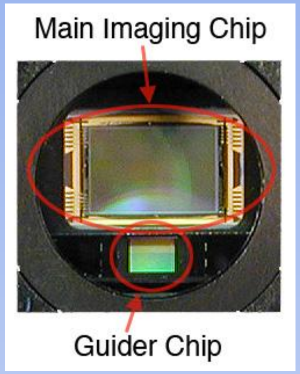
High End Astrophotography (continued)

- The guide camera is attached to a guider which is placed between the focuser and camera/filter wheel.



on-axis guider

off-axis guider



Guiding Port

- The use of a guiding telescope/camera attached piggy back is best when used with a short focal length telescope. For long focal length telescopes, the in-line guide camera is best with the use of an off-axis guider, inline-axis guider, or a imaging camera that has a build-in guiding port or sensor.

Piggy-back or differential guiding

Off –axis guiding with small pickoff mirror for auto guiding with a camera connected to a computer
(smaller guider Field-of-view)

- There are numerous Guiding software available, such as Maxim DL, PHD2, CCDSoft and MetaGuide.

Note: manufacturer products are for reference only and does not recommend a specific product

High End Astrophotography (continued)

Astrometry Plate Solving to Improve Imaging

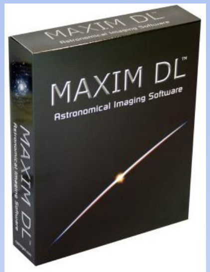
- **From Wikipedia, "Astrometry** is the branch of astronomy that involves precise measurements of the positions and movements of stars and other celestial bodies"….."A fundamental aspect of astrometry is error correction. Various factors introduce errors into the measurement of stellar positions, including atmospheric conditions, imperfections in the instruments and errors by the observer or the measuring instruments. Many of these errors can be reduced by various techniques, such as through instrument improvements and compensations to the data."
- Astrophotographers uses Astrometry with the use of "Plate Solving". Plate solving is a technique that measures precisely where the telescope is pointing by taking a CCD image and then using various pattern matching techniques to match the stars in the image to a given star catalog. Knowing approximately where the telescope is pointing and the system image scale, plate solving algorithms can calculate the center of the image to sub-arc-second accuracy. In order to be successful, three things are required: telescope coordinates, known image scale and sufficient catalog stars in the image. (www.CCDware.com)
- Plate Solving makes life of an astrophotographer so much easier. Assists in aligning telescope coordinates to the sky, putting the image at the center of the camera focal plane(essential for smaller camera focal plane dimensions), calibrating images for white balance point using CV2 stars, and can be used to assist in aligning (registrating) subs (images).
- Plate Solving sources, but not limited to : MaximDL w PinPoint LE(light edition), PinPoint FE(full edition), and CCDAutoPilot.

Note: manufacturer products are for reference only and does not recommend a specific product

High End Astrophotography (continued)

Telescope Control

- Complete camera control, along with mount and focus control requires an image capture software program on a computer.
  - Some of the image capture software is Prism, Maxim DL, Sequence generator Pro 3, Astro Photography Tool, Backyard EOS, Nebulosity 4 and Voyager 4.5.



Sequence Generator Pro v3.0

Note: A sky planetarium program is required for image capture computer control , some of the above programs have one included, but some require a separate planetary program to be purchased. TheSky X is one of many that can be used. Sequence Generator Pro requires a tracking program such as PHD2.

Note: manufacturer products are for reference only and does not recommend a specific product

High End Astrophotography (continued)

Image Capture Scripting

- Scripting is the process of automating the steps in operating your telescope and camera in taking astrophotographs. There are several computer programs available that automate the steps of focusing, changing filters, taking and saving pictures, guiding, roof control, weather/cloud, camera on/off, slewing to objects and determining where the camera is pointed.
  - CCDCommander, CCDAutoPilot and ACP are some standalone packages, and some of the image capture programs come with script capability.

Note: manufacturer products are for reference only and does not recommend a specific product

High End Astrophotography (continued)

Telescope and Camera sizing

- In the two previous major sections, it wasn't as important to talk about how the telescope/lens should be match to the camera. The reason is usually the camera is a DSLR with one or two lens purchased to take pictures to memorialize life events. At some time afterwards, it is decided to take pictures of the night time sky.
  - So the first step is to take the available DSLR and use it. Later a telescope or a camera mount is purchased to improve the quality of the images.
  - Or maybe a telescope was purchased to look visually at the night time sky. And later it was decided to capture pictures using an existing DSLR to memorialize the images.
  - There is nothing wrong with either approach.
- But as the desire to really capture better pictures and to really get into high end astrophotography begins, the cost outlay now becomes very large. To keep from wasting money and time, several considerations must be considered in sizing a telescope and camera to obtain the desire outcome.
  1) The expected observing site seeing conditions define the image resolution which defines the Camera pixel size and telescope focal length
  2) The object sizes that will be photograph help decide the telescope focal length and the camera sensor size.

High End Astrophotography (continued)

Telescope and Camera sizing (continued)

1) The expected observing site seeing conditions define the image resolution which defines the Camera pixel size and telescope focal length

- Looking through a telescope at a night time object requires us to look through the atmosphere. Because the atmosphere is very turbulent and may not be very clear, the images can appear to be blurry.
- Here are two examples: one looking at the moon and the other looking at a star with different levels of seeing conditions

https://en.wikipedia.org/wiki/File:Seeing_Moon.gif
http://weather.gc.ca/astro/images/seeing.gif

- The amount of apparent blurriness defines the resolution of the object to be viewed.

High End Astrophotography (continued)

Telescope and Camera sizing (continued)

- The major terms that define Image Resolution are

  Image Resolution = sqrt(scope^2 + tracking^2 + seeing^2)

  where

  - Scope - is the airy disk size (https://en.wikipedia.org/wiki/Airy_disk) plus telescope optics imperfections that affect the image resolution (Mirror/lens quality, mirror/lens collimation), typically less than 1 arc-sec error Peak-to-Peak(PP)
  - Tracking - is the ability of the mount to stay pointed at the object (i.e., polar align errors, earth rate errors, mount axis non-orthogonality errors, wind, cable drag, vibration), typically less than 1 arc-sec error PP for good mounts.
  - Seeing - is how stable the atmosphere is during the exposure. More atmosphere usually means more motion. So higher the telescope pointing altitude the better. <2 arc-sec good, 2-3, OK, 3-4 poor, >4 very poor

- For most observers with a good mount, the seeing term dominates if seeing is > 2

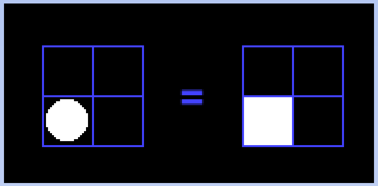
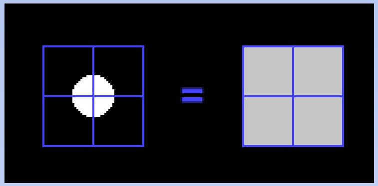
- To determine the resolution required image scale, take the average seeing at your observing location and divide by 3.

High End Astrophotography (continued)

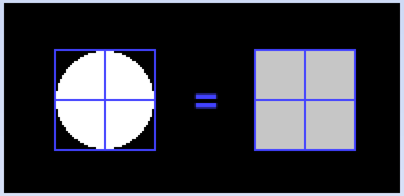
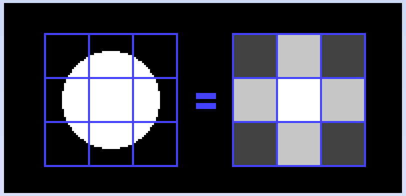
Telescope and Camera sizing (continued)

Why divide by the value of 3 to determine resolution or image scale?

- Take a look at the x-y plot of a star image on a CCD
  - *If a star is the same size as a pixel (say, 4"/pixel from a typical site), the star can be reproduced as a square.*
  - *This is not a very accurate reproduction of the star*
  - *If the star falls on the corner of a group of pixels, the star is still square, just larger and dimmer (since the light is now split among 4 pixels).*

- *Making the pixels 50% smaller to 2"/pixel (double the sampling frequency), the star is still a square if it falls on just four pixels.*
  - *If the star is centered on a pixel, it is reproduced as a (somewhat) round image.*
  - *This is a better approximation to the original image, but only for those stars that fall in just the right spot on the CCD.*

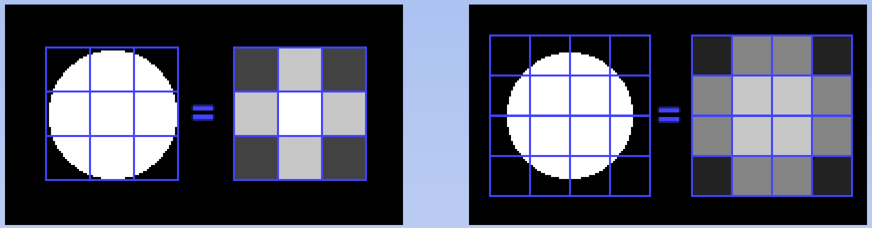



http://starizona.com/acb/ccd/advtheorynyq.aspx

High End Astrophotography (continued)

Telescope and Camera sizing (continued)

- By increasing the sampling to 3 times or 1.33"/pixel, the star is now more circular in both situations where the star image is centered on a pixel (left) and centered on an intersection of pixels (right). Also, the individual pixels can take on various intensity values to more accurately reproduce the original star image.



http://starizona.com/acb/ccd/advtheorynyq.aspx

- The above implies that using higher and higher sampling will improve resolution. But unfortunately there is a disadvantage and it has a name, "'Read Noise".
  - **Read noise** is the amount of **noise** generated by electronics as the charge present in the pixels is transferred to the **camera**. It is a combination of all the **noise** generated by system components which convert the charge of each CCD pixel into a signal for conversion into a digital unit (ADU or grey-scale value). https://www.photometrics.com/resources/whitepapers/read-noise
  - Every downloaded pixel will have Read Noise. The more pixels the more noise. With a image sampling of 3, that means the above star image will have 9 read noises. To reduce noise on an image when increasing sampling, choose a camera with low read noise or reduce the effects of read noise.

High End Astrophotography (continued)

Telescope and Camera sizing (continued)

A very important idea is that of *sky limit*. An exposure in which the primary limiting factor is the background sky flux is called *sky limited*. In such an exposure the sky background flux is the primary factor in determining SNR. Astroimager Stan Moore states, "sky limit is the zone where the sky noise overpowers the readout noise". Just where this point occurs is somewhat arbitrary but there is a generally accepted guideline:

Stan Moore recommends keeping the readout noise contribution to just 5% of the total noise, the point where the sky noise is 3 times greater than the readout noise.

John Smith's excellent article on the subject also adopts this 5% readout noise rule. The equations which follow are from that article.

A little rearranging of the SNR equation gives us an equation for determining what John Smith calls the exposure time to overwhelm readout noise, t_{ORN}:

$$t_{ORN} = \frac{R_{on}^2}{[(1+p)^2 - 1]E_{sky}} \qquad E_{sky} = \frac{(ADU_{bkg} - 100)g}{t_{test}}$$

t_{ORN} – time to achieve sky limited exposures(min)
R_{ON} – Read noise (e^-)
p – 0.05
E_{SKY} – sky background flux (e^-/min)
g – camera gain
t_{test} – test exposure time (min)
ADU_{bkg} – background signal (ADU or DN)

http://starizona.com/acb/ccd/advtheoryexp.aspx

High End Astrophotography (continued)

Telescope and Camera sizing (continued)

Sky Limited Exposures

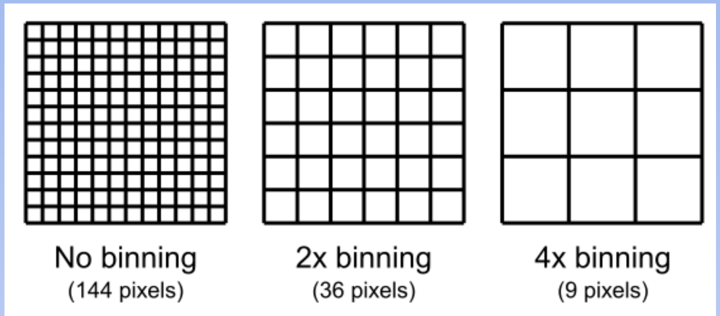
John C. Smith also says. A "statistically significant" number of frames should be taken, at least for the luminance data, to allow successful non-random artifact reduction. If your prior practice was to take n sub-exposures of t_{ORN} duration, instead take 2n+1 sub-exposures of $t_{ORN}/2$ duration. 3. Dither your sub-frames with sufficient movement such that non-random noise occurs in different locations on the registered sub-frames and therefore can be greatly reduced.

High End Astrophotography (continued)

Telescope and Camera sizing (continued)

Another option to reduce the effects of read noise is to “BIN” the pixels

- If a camera focal plane is binned, the read noise is reduced as only one pixel read is performed



https://postacquisition.wordpress.com/2017/08/03/in-the-bin/

  - No binning – every pixel contributes one read noise value
  - 2x2 binning – one read noise value per 4 pixels, resolution is 1/2x
  - 3x3 binning – one read noise value per 9 pixels, resolution is 1/3x

- Example: Assume average seeing is 3 arc-sec. To get that resolution, the camera image scale is chosen to be 3/3 or 1 arc-sec/pixel
  - Read noise to obtain this resolution is 9 units
  - Idea: use 2x2 binning with the 1 arc-sec/pixel camera
    - Every 4 pixels has read noise of 1 unit
    - Therefore, with 2x2 Binning the read noise is 9 divided by 4 or 2.25 units of read noise, but image scale is 2 arc-sec/pixel. With 3x sampling the resolution is 6 arc-sec or twice that of not binning.

Is this better or worse?????

High End Astrophotography (continued)

Telescope and Camera sizing (continued)

- On the last chart a question was asked about whether in the Binning example the results were better or worse. The answer depends on a lot of different factors that would require many pages of discussion which is really outside the scope of this package

- However, generally most imagers bin to increase the signal from a dim object being photography. They would rather lose resolution than not see the object. Also binning produces a higher object signal-to-noise ratio than not binning for the same amount of exposure time. A 10-30% reduction in the exposure time when binning with a mono camera with red, green and blue filters, ends up in reducing the total time spent in image capture compared to the time spent if not binning.

- Last, notice if a camera is chosen to provide an image scale of 1/3 the seeing condition. But the actual seeing conditions are 2x over the design seeing condition, than the overall resolution is the same whether binning is used or not. But binning in this example, reduces the read noise contribution by one-fourth.

  - Remember read noise effects can be minimized by choosing a low read noise camera or by ensuring the exposures are sky background limited.

High End Astrophotography (continued)

Telescope and Camera sizing (continued)

- In summary and written in an equation format, the camera resolution is derived by the seeing with are related to the pixel size and focal length.

  - Seeing (arc-sec)/sampling= Image scale (arc-sec/pixel) = 206.265*pixel size(microns)/telescope focal length (mm)

    (206.265= 180/π degrees/radian*3600 arc-sec/deg/ 1000 microns/mm)

High End Astrophotography (continued)

Telescope and Camera sizing (continued)

2) The object sizes that will be photograph help decide the telescope focal length and the camera sensor size.

- In equation format, maximum object size is related to the sensor size and focal length.

  - Max object size (arc-min) = $(60*180/\pi)$*sensor size(mm)/telescope focal length (mm)

High End Astrophotography (continued)

Telescope and Camera Sizing (continued)

- Below are several examples of the apparent sizes of deep sky objects

"Astroplanner" April 1 - object database used (M, NGC, IC, + others

Field-of-View (arc-min)	# of Objects
30	1604
60	5
90	0
120	0
150	1
180	0
210	0
240	0
270	0
300	3

Orange County Astronomers AstroImaging Starting object database

Field-of-View (arc-min)	# of Objects
≤30	310
>30-60	21
>60-120	13
>120-180	2
>180-240	2
>240-300	0
>300-360	1

(DSO_sizes.xls)

Planetary Nebulas – NGC, M, IC, DSHJ,DMSH, Abell catalogs

Field-of-View (arc-min)	# of Objects
20<FOV<=25	2
15<FOV<=20	5
10<FOV<=15	6
5<FOV<=10	6
2<FOV<=5	41
1<FOV<=2	55
<= 1	187

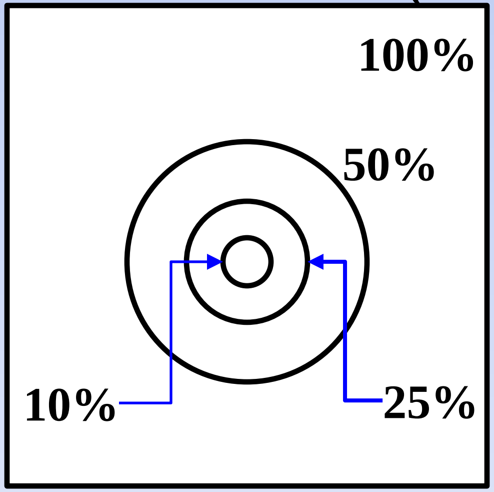
- Note from table: 86% of objects with diameters less than 30 arc-min
- 75% of planetary Nebulas are less than 2 arc-min in diameter
- Galaxies comes on all sizes
- Clusters are medium sizes, generally between 5 and 20 arc-minutes in diameter
- Moon and Sun are approximately 30 arc-min in diameter

High End Astrophotography (continued)

Telescope and Camera Sizing (continued)

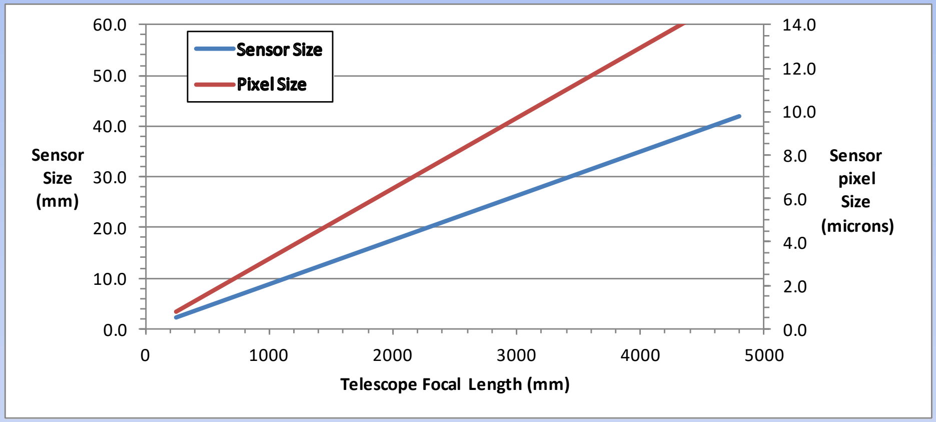
- So the largest object that is to be photograph define the camera sensor size.
  - Although a multiple image mosaic can be used to photograph a larger object
- But don't forget about the smallest object. Generally, the smallest object to be photography should be about 10% of the full camera field-of-view.
  - You can shoot images smaller than 10% but to see any detail will have to magnify the image and therefore lose resolution allowing any imperfections to be more apparent
- So may have to balance the desired largest and smallest object to size the camera sensor

Camera field-of-view (FOV)



High End Astrophotography (continued)
Telescope and Camera Sizing (continued)

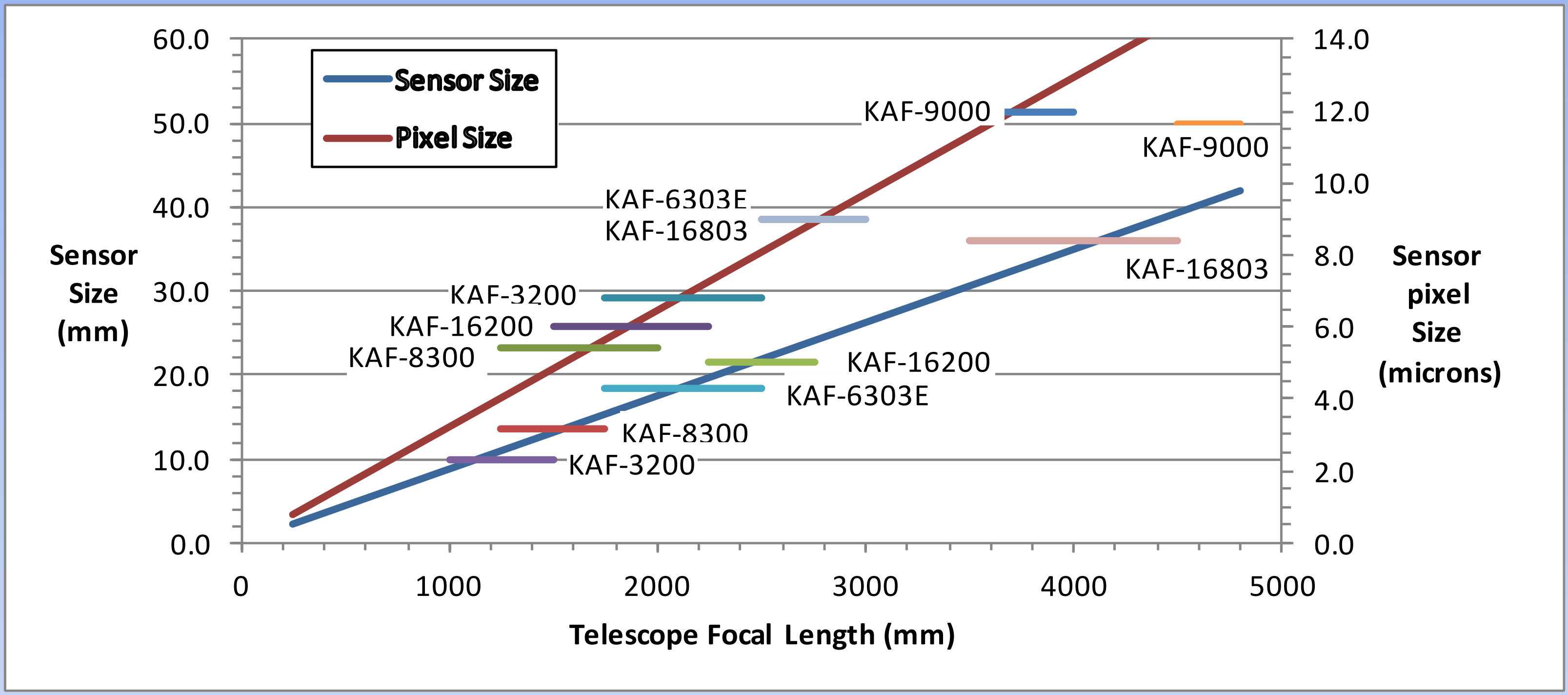
- Several charts ago, it was shown that image scale and object size is a function of focal length.
  - Example: below is a chart showing how sensor size (mm) and Sensor Pixel size (microns) vary with telescope focal length (mm) for an object size of 30 arc-min and seeing of 2 arc-sec.



    - This would be great if any combination of sensor and pixel size could be obtained
    - However, there are a very limited number of camera sensors, so it would be better to start with the available camera sensors and by varying the telescope focal length determine which object sizes and seeing conditions the sensor is compatible.

High End Astrophotography (continued)

Telescope and Camera Sizing (continued)



Min Sensor Size (mm) = π *focal length(mm)*FOV*(arc-min) /(60*180)
= 0.000291*focal length(mm)*FOV(arc-min)

Sensor Pixel Size (microns) = Seeing (arc-sec)*focal length (mm)/(Sampling*206.265)

Assumes:
•Seeing = 2 arc-sec
•Max object size = 30 arc-sec
•Sampling (Nyquist) = 3

- Notice that there is not one focal length that satisfies one sensor for both size and pixel size at the same time.
- One simple method is to look at a sensor and determine the focal length for the sensor size and the pixel size. Then divide by two. Then see what telescopes are available

High End Astrophotography (continued)

Telescope and Camera Sizing (continued)

- If focal length is solved to meet the specific pixel and sensor size based on sampling and seeing, the following is obtained. Using available manufacturing focal ratios, telescope aperture diameter can also be determined

Table of FOV, focal lengths and diameters meeting assumed sampling/seeing conditions for a specific camera sensor

		Pixel Size (micron)	Min Sensor Size (mm)	Sampling = 3			Focal Ratio =10 (i.e., Schmidt-Cassegrain)								
				Seeing (arcs-sec)											
				1			2			3			4		
				FOV(')	FL(mm)	D (inch)	FOV(')	FL(mm)	D (inch)	FOV(')	FL(mm)	D (inch)	FOV(')	FL(mm)	D (inch)
Sensors	KAF3200	6.8	10.0	8.2	4208	16.6	16.3	2104	8.3	24.5	1403	5.5	32.7	1052	4.1
	KAF-8300	5.4	13.5	13.9	3341	13.2	27.8	1671	6.6	41.7	1114	4.4	55.6	835	3.3
	KAF6303E	9.0	18.5	11.4	5569	21.9	22.8	2785	11.0	34.3	1856	7.3	45.7	1392	5.5
	KAF-16200	6.0	21.6	20.0	3713	14.6	40.0	1856	7.3	60.0	1238	4.9	80.0	928	3.7
	KAF-16803	9.0	36.0	22.2	5569	21.9	44.4	2785	11.0	66.7	1856	7.3	88.9	1392	5.5
	KAF-9000	12.0	50.0	23.1	7426	29.2	46.3	3713	14.6	69.4	2475	9.7	92.6	1856	7.3

		Pixel Size (micron)	Min Sensor Size (mm)	Sampling = 3			Focal Ratio =8 (i.e., Plane-wave, TPO, AstroTech, RCOS)								
				Seeing (arcs-sec)											
				1			2			3			4		
				FOV(')	FL(mm)	D (inch)	FOV(')	FL(mm)	D (inch)	FOV(')	FL(mm)	D (inch)	FOV(')	FL(mm)	D (inch)
Sensors	KAF3200	6.8	10.0	8.2	4208	20.7	16.3	2104	10.4	24.5	1403	6.9	32.7	1052	5.2
	KAF-8300	5.4	13.5	13.9	3341	16.4	27.8	1671	8.2	41.7	1114	5.5	55.6	835	4.1
	KAF6303E	9.0	18.5	11.4	5569	27.4	22.8	2785	13.7	34.3	1856	9.1	45.7	1392	6.9
	KAF-16200	6.0	21.6	20.0	3713	18.3	40.0	1856	9.1	60.0	1238	6.1	80.0	928	4.6
	KAF-16803	9.0	36.0	22.2	5569	27.4	44.4	2785	13.7	66.7	1856	9.1	88.9	1392	6.9
	KAF-9000	12.0	50.0	23.1	7426	36.5	46.3	3713	18.3	69.4	2475	12.2	92.6	1856	9.1

Focal reducers can be used to obtained different focal lengths(FL) and field-of-views (FOV)

High End Astrophotography (continued)

Telescope and Camera Sizing (continued)

- To use the previous table, assuming a sampling of 3

1) Look at the FOV column for the expected seeing condition at the observing site to be used, and see which sensor can provide a FOV close to the desired value

2) Note the corresponding focal length that provides the desired FOV

3) Note the aperture diameter for both the focal ratio tables.

4) Check manufactures website to find aperture, focal length and focal ratio that is closest to desired FOV

5) Another knob to turn…Focal reducers can be used to obtained different focal lengths(FL) and field-of-views (FOV)

Note equations have been provided in previous charts to make a different telescope and camera sizing table

High End Astrophotography (continued)

Telescope and Camera Sizing (continued)

Example:

- Desired: FOV 30 arc-min with seeing of 2 arc-sec
- From table:
  - KAF-8300 sensor provides 27 arc-min with focal length of 1671
  - Diameter with f/10 = 7" and at f/8 = 8"

- Closest example telescopes are

1) Schmidt-Cassegrain 8" f/10 w 2032 FL, focal reducer needed = 0.82 @ f/#=8.2
2) TPO RC 8" f/8 w 1626 FL, No focal reducer needed
3) TPO RC 10" f/8 w 2032 FL, focal reducer needed = 0.82 @ f/#=6.6
4) TPO RC 12" f/8 w 2438 FL, focal reducer needed = 0.69 @ f/#=5.5

Analysis:

- Telescopes 1 and 2 are basically the same, although 1 needs focal reducer
- Telescope 4 has largest diameter, fastest optics, and 0.68 focal reducer exists
- 0.80 focal reducers exist
- Larger the telescope the larger the price, and the mount must have the payload capacity

My decision was TPO RC 12", meets desired FOV with faster focal ratio, which reduces exposure time, and my existing mount can handle

High End Astrophotography (continued)
Telescope and Camera sizing

There are several considerations in selecting a telescope and camera combination.

1) Objects sizes that will be photograph help decide the telescope focal length and the camera sensor size.

2) Camera pixel size and telescope focal length define image resolution.

3) Guide camera sensor size and guide telescope focal length define guide camera field-of-view

High End Astrophotography (continued)

Guide camera sensor size and guide telescope

- The sizing of the guide camera sensor and guide telescope follows in a similar method as was done for the main telescope and camera with a few changes.

- To perform guiding, a guide star must be available. This can be accomplished by a guide camera and using a separate guide telescope, an off-axis guider or an on-axis guider. Each has been discussed previously, but not how to size.

- The larger the guide camera field-of-view the easier it is to find an acceptable guide star to use for tracking.
- Using a separate telescope and camera will allow a large field-of-view by far than any other methods. Remember the major disadvantage is flexure between the guide telescope and the main telescope requiring only short focal length main telescopes or the very expensive RCOS telescope (although there may be other manufactures that could be used that I am not aware)
  - The on-axis guider comes in second with a field-of-view equal to the main telescope
  - The off-axis guider has the smallest field-of-view of the three.

  - Guider field-of-view (radians) = guide camera sensor size (mm) divided by the guide telescope focal length(mm).

    Note: The guide telescope focal length for the on/off axis guider is the main telescope focal length. Some off-axis guiders have added a focal reducer to improve guide star brightest and field-of-view

A Guide to Beginning and Advanced Astrophotography

Agenda

- Astrophotography with Camera and Tripod
- Astrophotography with Manual or motorized Mount
- Astrophotography with Telescope
- High End Astrophotography
- Planetary Imaging
- Image Processing
- Final Thoughts

Planetary Imaging

Planetary imaging is quite different than deep sky astrophotography. Different cameras and different techniques are needed. However at the basic level, the field of view, resolution, and image brightness still need to be balanced to obtain the image with the best resolution and image size that can be achieved with the equipment available. Also the atmosphere is still a limiting factor, but in a different way.

With deep sky astrophotography, the images being captured are dim and require extended exposures to capture the required detail and brightness. However, the planets are a lot brighter than deep sky images and therefore require very short exposures (less than 1 second). This is an advantage and a disadvantage.

<u>Advantages</u>

- Uncooled cameras can be used, including not only astrophotography video cameras but regular inexpensive web cameras.

<u>Disadvantages</u>

- The images from a video camera are susceptible to atmospheric turbulence which can create image blurring

Also planets are small. To be able to capture any detail, the planet image must large on the camera focal plane which demands long focal length telescopes.

Planetary Imaging (continued)

Cameras and imaging software

- To capture planet, moon or solar images with a video camera, the best free package is FireCapture

- The mono or color video cameras used are generally higher speed astro video camera with greater than 300 frames per second.

ZWO Cameras

QHY Cameras

Note: manufacturer products are for reference only and does not recommend a specific product

Planetary Imaging (continued)
Image resolution/Field-of-view/camera/aperture

- Defining the field-of-view for planet image capture is somewhat easier to define in that planets are all small with a lot less size variability than deep sky objects. To see a lot of planet detail, the planet must be large in the field-of-view and therefore large on the camera focal plane. This is achieved with a long telescope focal length.
  - The disadvantage with long telescope focal lengths is getting the planet on the center of the camera chip and keeping it centered!
- Atmosphere and Camera Frame Rate
  - When a star is observed through the Earth's atmosphere it appears to "Twinkle". This is because Earth's atmosphere is very turbulent and not steady.
  - So when a planet is being observed with a telescope through the atmosphere, the image will vary in intensity and size at some frequency and appear to be blurred. However, there is some probability that for a very short period of time, the image will be steady and appear to be in focus.
  - So in theory, if a camera could capture an image of a planet at a faster frequency than the atmosphere frequency, then a steady planet image would occur at some probability. Given a sufficient amount of image capture time, a number of stable images could be collected.

Planetary Imaging (continued)
Atmosphere and Camera Frame Rate (continued)

- These good, stable images could be combined or stacked to improve the planet's signal-to-noise ratio and then be processed to obtain the best planet images for the equipment being used.
- So to maximize the collection of stable images, the atmosphere frequency must be compensated.
  - The professional telescopes measure the atmosphere frequency using lasers, and using adaptive optics deform the mirrors to compensate for the moving atmosphere.
  - Unfortunately, this is outside the capability of most amateurs.
  - However for us amateurs, the atmosphere motion can be compensated by using fast frame rate video cameras to obtain the necessary large number of frames to achieve good planet resolution in an image.

Planetary Imaging (continued)
Atmosphere and Camera Frame Rate (continued)

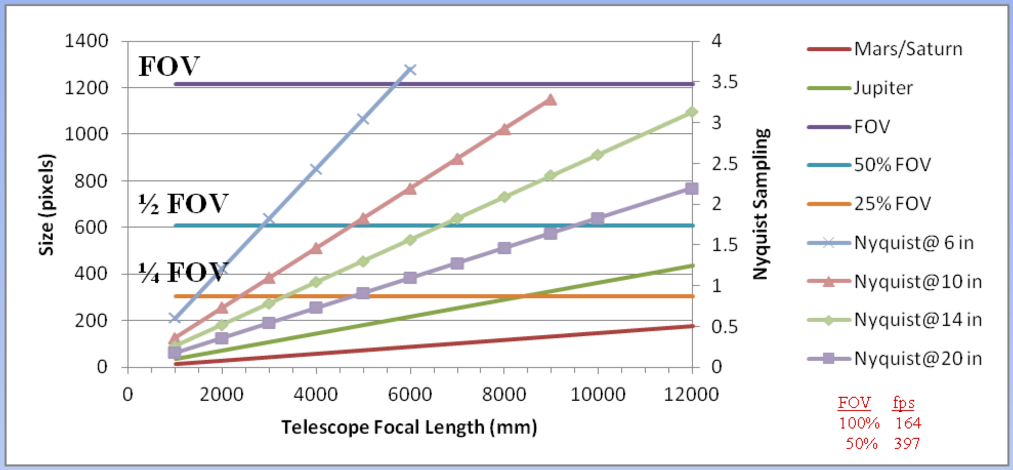
- According to https://en.wikipedia.org/wiki/Astronomical_seeing" the atmosphere can vary at rates of over 100 times a second. To have a good probability of capturing a stable image, a video camera should be at 200-300 frames per second.
  - However, there are only a few astrophotography videos camera (>$350) that have the capability of high rate and be sensitive enough to capture a planet image at that rate.
  - However, a lower frame rate camera can be used, but will have to use "Lucky Imaging" to capture planetary images.
  - "Lucky Imaging" is as implied, take a series of images (>5,000-10,000) and hope a few are not blurred .
- Video cameras frame rate is a function of size of the imaging window frame. Most camera control software has the capability to decrease the image window frame to increase frame rate.
  - The disadvantage of smaller frame size is it is more difficult to keep the planet inside the frame.
  - Auto guiding can help keep the planet inside the camera frame. To auto guide, the camera needs to have a guide port and the camera control software must have that capability.
  - Achieve a frame rate of greater than 30fps for fair to good results, 50-100fps is better and over 100fps is best.

Planetary Imaging (continued)

Atmosphere and Camera Frame Rate (continued)

- In the next chart a sensitivity analysis is shown that shows the relationship of focal length, aperture, planet size on camera chip, and image sampling ratio (Nyquist) for Mars, Jupiter, and Saturn.
  - Camera frame rate is provided as a function of planet size on the camera chip or focal plane for two different video cameras.
    - Note the image scale was arbitrary set at 0.1 arc-sec/pixel.
    - The only reason, to limit image scale is that the planet get larger than the camera field-of-view for the majority of amateur video cameras at the high focal lengths which may reduce available camera frame rates.
    - Also technical design limitations with the camera and being to track the objects at very high focal lengths may also limit image scale.
    - Some sources say that an image scale of 0.1 arc-sec/pixel is the oversampling (https://en.wikipedia.org/wiki/Oversampling) limit.

Planetary Imaging (continued)
Parameter Sensitivities



Note: Data for Image Scales ≤ 0.1 arc-sec

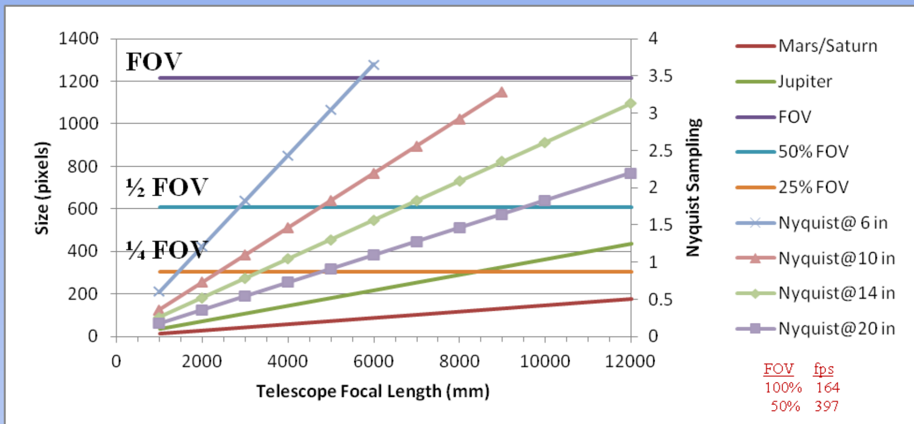
Camera:
USB 3 ZWO ASI-174
(5.86 micron pixels)

How to read chart:

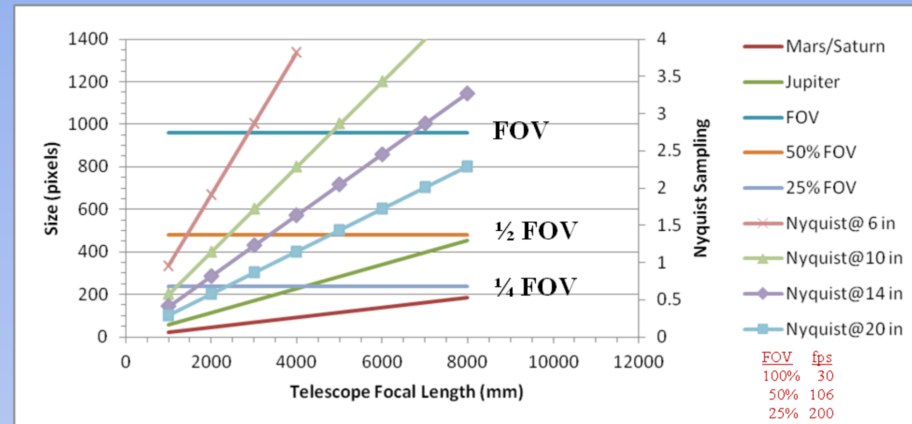
- The horizontal lines defines the FOV in number x number of pixels for the referenced camera.
- Red text is the frame per second (fps) of the referenced camera depending on FOV window size
- The solid red and green lines are the corresponding planet size in pixels x pixels as a function of focal length for the reference camera
- The lines with symbols provides the sampling number of pixels versus telescope focal length for different telescope diameters using reference camera

Planetary Imaging (continued)

Parameter Sensitivities



Camera: USB 3 ZWO ASI-174 (5.86 micron pixels)



Camera: USB 2 QHY5L-II (3.75 micron pixels)

Example Comparison: Assume a 6" diameter telescope viewing the planet Jupiter

• Camera provides @ /full FOV	1216 x 1216 pixels	960 x 960pixels
• Sampling of 3 requires a FL	5000mm	3500mm
• Jupiter Size	180 x 180 pixels	200 x 200 pixels
• 50% window size provides	~400fps w 237% FOV margin	~100fps w 140% FOV margin
• 25% window size provides	~400fps w 68% FOV margin	~200fps w 20% FOV margin

Conclusions from example and chart:

1) Faster Frame rates (fps) with USB 3 cameras
2) Smaller pixels sizes reduce required Focal length to achieve a sampling of 3
3) Smaller pixels sizes provide more pixels on planet for better resolution
4) More pixels provide additional FOV margin to keep planet in imaging window
5) Increasing the diameter of the telescopes requires a smaller "Barlow" magnifier (1.5x to 5x) to achieve the required focal length with a sampling of 3

Planetary Imaging (continued)

Exposure Time

Planet rotate fairly fast, which require short exposures to prevent image smearing.

	Rotation Period	Apparent Diameter
Mars	24.6 hours	18 arc-sec
Jupiter	9.9 hours	44 arc-sec
Saturn	10.5 hours	18 arc-sec

Example – Jupiter, 3.75 micron pixels, 4000 mm focal length

Motion = 44 arc-sec/(0.5 rotation period*9.9 Hrs*60min/hr)

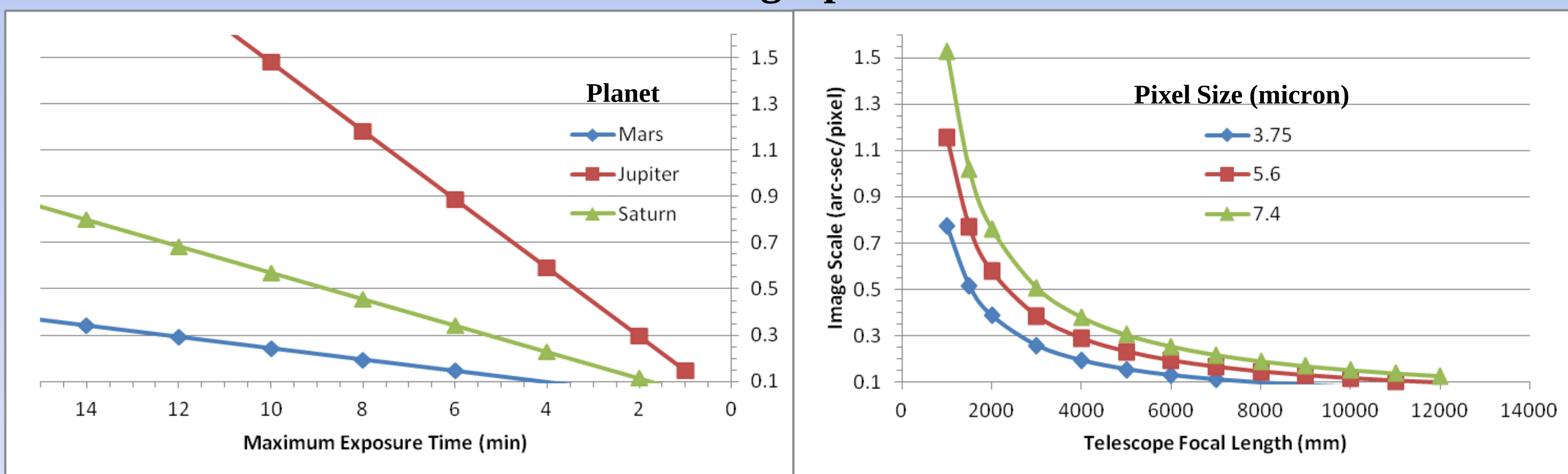
= 0.148 arc-sec/min

Image Scale = 206.265*3.75/4000 =0.193 arc-sec/pixel

Maximum exposure to prevent 1 pixel smear = 0.193/0.148

= 1.3 min/pixel

Nomograph



Planetary Imaging (continued)
Exposure Time (continued)

- As shown previously, to obtain the best resolution requires a small image scale in comparison to the airy disk size. Also, the smaller the image scale the shorter the time to take an exposure without a 1 pixel image smear. Using a color video camera would minimize the time required to obtain an image, but at the expense of a lower resolution. Even though the pixel sizes are the same between color and mono cameras, the added Bayer matrix on the color camera in effect reduces the color resolution. To be able to use a mono camera with red, green and blue filters each filter total exposure time will have to be less than 1/3 the total time to prevent a 1 pixel image smear.

- However, with a processing method called planet de-rotation(Winjupos, http://jupos.org/gh/download.htm), the disadvantage of using a mono camera with filters can be reduced by taking longer exposures then rotate the image back to a single time to reduce the smear effect. Just keep track of the red, green and blue exposure time and rotation all images to the middle of the total imaging time. Of course this process can also be applied to long color camera exposures.

Planetary Imaging (continued)

Getting the Planet on Camera Chip and Focusing

One of the most difficult task with planetary imaging is to put the planet on the camera chip and to focus. A video camera has a small chip and a Barlow will be required to get the required focal length to make the planet large enough to see good detail. The choices are a trade between time, cost and available equipment.

1. If a finderscope is not available, a wide field eyepiece can be used to get a bright planet in the center of the telescope field-of-view, then switch to a lower focal length eyepiece (higher magnification) and again center the planet in the telescope field-of-view. Repeat by changing eyepieces to keep increasing magnification and keep the planet at the center of telescope field-of-view. Stop the process when going to higher magnification does not require re-centering.

- Now remove the eyepieces and insert the barlow. Use eyepieces again to repeat the centering process. Again, stop the process when going to higher magnification does not require re-centering.
- Use the telescope/camera focuser to get the sharpest star image.
  - If you are having trouble getting a good planet focus, do the previous steps on a bright star to get it centered. If you have a Bahtinov focusing mask, put it on the end of the telescope and focus on the star. If you don’t have a focusing mask do the best you can. If your scope is a reflector, focus on spider vane light spikes. Then go to the planet and repeat the steps from above that was done with the star.

Planetary Imaging (continued)

Getting the Planet on Camera Chip and Focusing

2. If a finderscope is available, first get a bright star in the telescope (star at high elevation > 30deg, >60 deg better) and center. Adjust finderscope to center star. Switch to a shorter focal length eyepiece (higher magnification) and again center the planet in the telescope field-of-view. Again adjust finderscope to center. Repeat by changing eyepieces to keep increasing magnification and keep the planet at the center of telescope field-of-view. Each time re-adjust finderscope. Stop the process when going to higher magnification does not require re-centering.

- Now remove the eyepieces and insert the Barlow. Use eyepieces again to repeat the centering process along with centering finderscope. Again, stop the process when going to higher magnification does not require re-centering.
- Remove the eyepiece and insert the camera. Hopefully the star is visible, if it is, then center the star in the camera, and center star in finderscope. If it is not, repeat the previous process with the eyepieces and/or barlow. Try going to a higher magnification than was used previously.
- If you have a Bahtinov focusing mask, put it on the end of the telescope and focus the star. If you don’t have a focusing mask, use the telescope/camera focuser to get the sharpest star image in the camera.
- Now using the finderscope, move telescope to planet. Hopefully planet is visible and in center of camera, if not adjust telescope and re-adjust finderscope. If not visible, either do a search or redo previous steps.

Planetary Imaging (continued)
Getting the Planet on Camera Chip and Focusing

3. This option uses a video camera attached to a finderscope.
   - Use the steps defined previously to align finderscope and camera.
   - Take a picture near the planet to be imaged.
   - Then using astrometry software, compare known stars to those in the image to determine where the center of the camera is pointing(plate solve).
   - Now tell the computer where it is currently pointed by doing a sych
   - Move or command the scope to go to a bright star and focus using one of the previously defined techniques
   - Move or commanded scope to point a planet

   - To make this work, a finderscope/camera field-of-view greater than 0.5 deg is preferred. A 50mm finder at 250mm focal length works well with a typical video camera (3.6mm X 4.8mm chip).

Planetary Imaging (continued)
Image Capture

- Planetary image capture is a series of trade-offs. First, whether to use a color camera, or a mono camera with RGB color filter wheel.
  - Color Camera
    - No RGB color filter wheel needed – reduced cost
    - Reduced effort in not controlling color filter wheel
    - Resolution with color camera is less than mono
  - Mono Camera with RGB color filter wheel
    - Additional cost – filter wheel and filters
      - Manual filter wheels are not usually sealed like motorized filter wheels - clean filters more often
    - Best resolution
    - Capture time will be less with the necessity of changing color filters
- Second, whether to extend capture time beyond 1 pixel smear time and use planet de-rotator software to correct – worse with color filter wheels as additional processing required for each filter.
- Large computer harddrive storage is necessary to store video data captured at high frame rates. Because of "Lucky Imaging" need lots of data and a harddrive with a capability of many tens of Gigibytes.

Planetary Imaging (continued)
Planet Tracking

Planetary tracking can be a challenge.

- To achieve good planet resolution
  1) telescope focal length must be large
  2) smaller camera pixel size
  3) fast camera frame rate

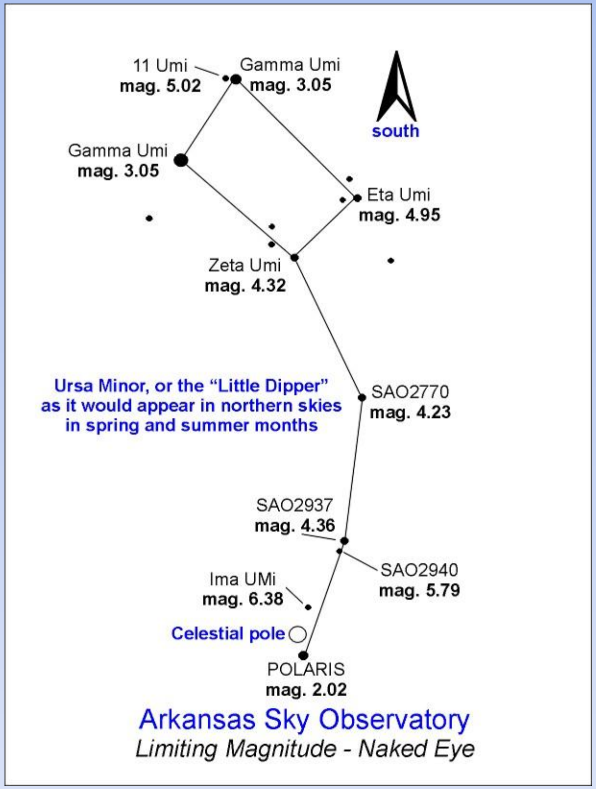
- To give the mount the best chance of keeping the planet on the camera chip, a good polar alignment is necessary.
  - For a 4mm camera chip and 4000mm focal length, a full frame field-of-view will be 3.4 arc-min.
  - If the field-of-view must be reduced to 25% to achieve a fast frame rate, that leaves a field of view of 0.86 arc-min or 52 arc-sec.
  - It will be difficult to keep the planet in the field-of-view, without a good polar alignment, and auto or manual assisted guiding for 1-7 minutes depending on the planet.

- The best option is to use planetary guiding software that will allow auto guiding to keep the planet within the camera frame. Currently the best software is “FireCapture”. This software will control the camera, mount, color filter wheel and perform auto guiding.

Seeing and Transparency

http://www.weasner.com/etx/buyer-newuser-tips/seeing.html

The best method to improve planet resolution is to photograph the planets during good seeing and transparency of the sky. Here is a handy guide to determine seeing conditions using the stars in the little dipper as a guide.



"transparency" is a measure of how clear the sky is; this will allow you to see fainter stars and deep sky objects, but will NOT necessarily allow you to use more than about 25x per inch aperture, and then only for deep sky objects. Typically speaking (there are exceptions) the CLEAREST NIGHTS are the most UNSTEADY.

Imagine it this way: "transparency" relates to how DEEP you can see in space through the obstacle of the earth's air. The better the transparency, the fainter the object or star that you might be able to see.

On the other hand, "seeing" has absolutely NOTHING to do with transparency; it is a gauge of how PERFECT, or steady, the image remains while you view it.

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- Image Processing
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Image Processing

- Image Processing takes your original raw data and enhances the brightness, contrast, and color, to make faint deepsky objects more visible as well as correcting for things such as the ugly red color of the sky from light pollution, vignetting, and sky gradients. http://www.astropix.com/bgaip/index.html
  - Complete imaging processing generally includes Image Calibration
    - Image Calibration consists of taking calibration images to account for camera noise/artifacts that when subtracted from the original picture improves image quality.
  - Can be preformed by camera or phone, although usually it performed in photo processing software on a computer
- Image processing comes in at least three categories:
  1) None or limited to what the camera can do
  2) Limited or minimal processing of an DSLR image
     - Can be as simple as using photoshop (or similar) to remove a blemish or enhance the contrast in a single image
  3) High end image processing of color or mono images using computer software

Image Processing (continued)

- Getting the most from Image Processing
  - It begins, with collecting multiple calibration and subject (sometimes referred to as light images or frames) image in "RAW" format when using DSLR or CCD cameras. The "RAW" format is best if image processing is to performed.
    - It has been proven that taking multiple images of a single dim object allows the noise in the image to be reduced making the image appear brighter by making the signal-to-noise ratio larger.
      - Noise reduces by the square-root of the number of frames, and therefore, the signal-to-noise ratio also increases by the square-root of the number of frames

Image Processing (continued)
Calibration Frames

Calibrating CCD images involves removing noise artifacts and uneven illumination. This is done by taking dark frames, bias frames, and flat field images.

Calibration Images (Dark Frames)

- CCD cameras are so sensitive that the heat generated by their electronics can cause noise to appear in the image.
  - For this reason, CCD cameras are cooled, typically between 10 and 50 degrees C below ambient temperature. This minimizes the thermal noise, but doesn't completely eliminate it.
  - The remaining noise is easily eliminated by subtracting a dark frame. A dark frame is simply an image taken with the camera covered, which detects only the noise inherent in the CCD.
  - A dark must be taken at the same temperature and duration as the light frame. The dark is then subtracted from a regular light frame

Example: single 600 sec dark frame

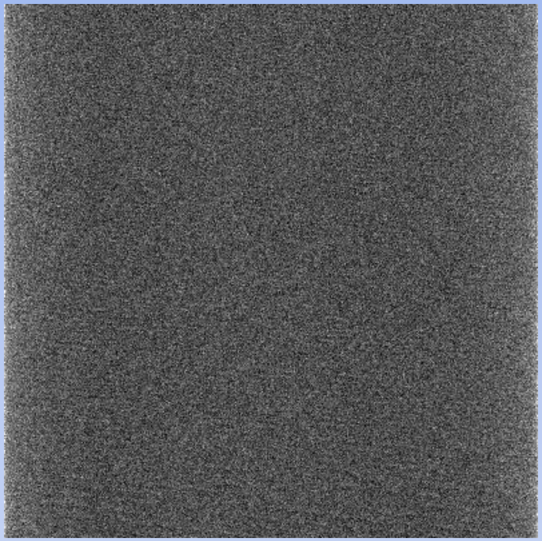
http://starizona.com/acb/ccd/software/maxim_calibrate.aspx

See more info at https://pixinsight.com/forum/index.php?topic=8839.0

Image Processing (continued)
Calibration Frames (continued)

Calibration Images (Bias Frames)

- To properly calibrate a flat field image, another calibration image must be taken, called a bias frame.
    - This is effectively a zero-second exposure and it detects purely the read-noise from the camera.
    - This is noise generated when the pixels are read out of the CCD. In a low-dark-current camera, a bias will look almost just like a dark frame. This image is used to normalize the flat field.



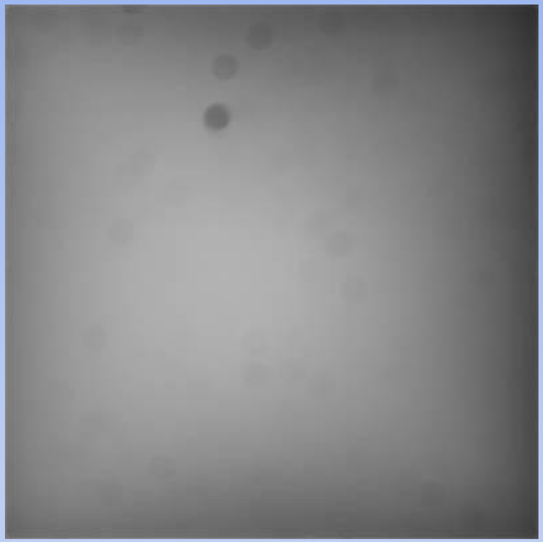
Example: Bias Frame

http://starizona.com/acb/ccd/software/maxim_calibrate.aspx

Image Processing (continued)
Calibration Frames (continued)

Calibration Images (Flat field)

- Uneven illumination of the field normally results from vignetting in the optical system. Dust on the CCD sensor or filters can also cause dark spots in an image. These artifacts are removed using a flat field image.
    - A flat field is simply an exposure of an evenly-illuminated light source. This is often the twilight sky, but flat field panels are also made that use artificial light sources and can be used any time.
        - A flat field image detects the uneven illumination of the field and any dust specks.
        - Flats are filter-dependent, so if you are using a monochrome camera with red, green, and blue filters, you must take separate flats for each filter.



Example of twilight flat field image taken through a luminance filter.

http://starizona.com/acb/ccd/software/maxim_calibrate.aspx

See more info at http://www.skyandtelescope.com/wp-content/uploads/documents/Flatfields+Mar11.pdf

Image Processing (continued)

Calibration Frames (continued)

- Therefore, generally with high end image processing, 8-16 or more calibration frames are taken, along with 8-16 or more frame of the light images
- Since multiple images are taken of the subject of interest, then each image must be align with each other using stars, this is called “registration”.
- The final two steps to image processing is to 1) combined all the images, and 2) to process the resulting image so it can be seen in detail with appropriate brightness, contrast, range of grayscale, and (if applicable) color balance.
- A very limited list of Image processing computer programs, are photoshop and PixInsight

Note: manufacturer products are for reference only and does not recommend a specific product

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Final Thoughts

There are several considerations in selecting a telescope and camera combination.

- Telescope type and size is user preference based on weight, cost, portability and storage and type of objects that will be photograph.

  However, Things to consider for deep sky object photography

  Telescopes

  1) Faster the optics (f ratio), the short the exposure to achieve a given signal
  2) Fast optics are usually the shorter focal length telescopes, which usually has a larger field-of view and are better suited to nebula or large scale objects.
  3) Longer focal length telescopes are great for galaxies and planetary nebulas, but does make tracking more difficult, usually requiring a better, more expensive mount used with auto guiding or encoders.
  4) 80-100mm diameter refractors are a good choice for wide field photography
  5) As telescope diameter increases, the airy disk size decreases which improves resolution
  6) Telescope back focus distance is critical to allow devices such as focuser, camera, on or off-axis guiders and rotators to be attached on telescope rear bulkhead.

Final Thoughts (continued)

Things to consider for deep sky object photography (continued)

Cameras

1) Larger the camera sensor dimensions the larger the telescope field-of-view and higher the cost
2) Cameras with a cooler reduce camera electronic noise more than non-cooler cameras (single stage ~ -30deg C, two stage ~ -50-60 deg C below ambient)
   - Two stage coolers are about twice as expensive as single stage
3) Binning increases signal, reduces total read noise by undersampling (https://en.wikipedia.org/wiki/Undersampling), and doubles image scale reducing resolution
4) Mono camera require filters to get color images (i.e., R, G, B)
   - Luminance (clear) filter is used to improve image detail
   - Can shoot narrow band images (i.e., Sii, Ha, Oiii (Hubble palette))
5) Color cameras have reduced resolution from mono camera
6) Total time shooting images with a color camera (1 color filter) is less than that of mono camera with 4 filters
   - Color camera require either longer image exposures or more light frames than mono camera with R,G, B filters to achieve same signal-to-noise ratio. Thus total time shooting with a color camera can only expect to save only half total shooting time of a mono camera.

Final Thoughts (continued)

Things to consider for deep sky object photography (continued)

<u>Mounts</u>

- Most important performance parameters is payload capacity and Periodic Error
  - Try to keep payload to 50-60% of the mount capacity
  - Periodic error and the ability to correct
    - Periodic Error is a small mechanical error in the accuracy of the tracking in a motorized mount …even if the mount is perfectly polar-aligned and appears to be tracking perfectly…It is called *periodic* because it repeats at a regular interval… the amount of time it takes the mount's drive gear to complete one revolution. (https://themcdonalds.net/richard/wp/astrophotography-mounts-periodic-error-correction/)
    - Low end mounts can not correct for periodic errors and can be 30-100 arc-sec PP
    - Mid-level mount has periodic error correction
    - High end mounts has periodic error correction and can achieve arc-sec PP periodic error and sub arc-sec PP error with auto guiding
    - Axis encoders can be added to mount to achieve sub arc-sec PP errors without guiding for about 20 minutes

Final Thoughts (continued)

Things to consider for deep sky object photography (continued)

Mounts (continued)

- Mounts come in different performance levels, each with different payload capacity
  - Each improvement is almost twice as expensive as the level below it.
    - Camera mounts ($300)
    - Celestron/Meade total package mounts ($900-$3600)
    - Ioptron like mounts ($2000-$3000)
    - Losmandy type mounts ($3000-$4000)
    - Astrophysics/Paramount type mounts ($6000-$9000)
    - Max capacity mounts ($15,000 and up) (encoders add about $6000)

Final Thoughts (continued)

There are several considerations in selecting a telescope and camera combination.

- Objects sizes decide the telescope focal length and the camera sensor size.
  - Mosaics can be used to increase image field-of-view beyond camera Field-of view
- Seeing is generally the dominate term in defining resolution
- Camera pixel size and telescope focal length define image resolution for seeing conditions
- Because camera sensors are limited with finite focal length telescopes, best to start with what is available and determine which configuration gets closes to desired maximum object size for observing site seeing conditions achieving an imaging sampling of at least 3
  - Focal reducers can be used to fine tune desired focal length telescopes
- Areas of performance versus cost
  1) Entry level – DSLR on tripod
  2) DSLR on camera tracking mount with tripod
  3) Telescope/Mount with DSLR with tripod
  4) Telescope/mount with CCD camera with single/duel stage coolers
  5) Telescope/mount with CCD camera with single/duel stage coolers and auto guiding

Final Thoughts (continued)

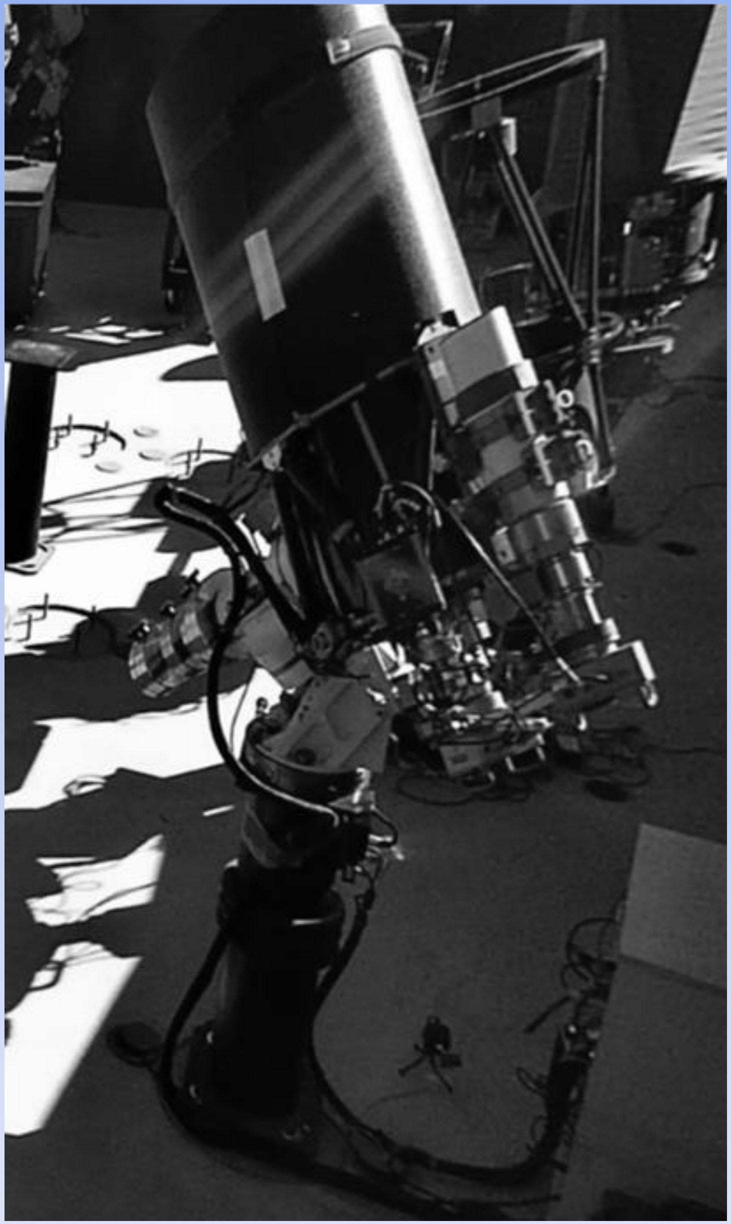
- Things to consider for planetary or solar/moon photography
  1) Generally need a barlow to increase telescope focal length sufficiently to achieve sampling and image scale
  2) Use a video camera with a fast frame rate capability > 100fps
  3) Exposure duration limited to planet rotation speed
     - Using derotating software can extend exposure duration(winjupos)
       - Especially helpful if using mono camera with filter wheel
  4) Use finderscope with large field-of-view to get planet on center of camera focal plane.
     - Best if can use camera with finderscope to see both images at same time to get aligned
     - Using plate solve is the best after finderscope and main telescope aligned.
  5) Use an alignment mask to get best focus
  6) Best free software: FireCapture

Final Thoughts: Subscriptions

New idea is instead of purchasing all the required hardware and software to perform high end astrophotography is to sign up with a company that provides raw images to you to process

- Advantage is a lot lower cost
- Disadvantage you don’t get to capture the images, just have to do all the image processing

My two Remote Scopes



- AP-1200 GTO mount CP4 w Radio Shack 10A, 12v Power Supply
- Pegasus Ultimate USB/Power Hub with 10A, 13.8v Astron Power Supply derated to 12.8v

Scope 1:

- TPO RC 12”
- Moonlite Focuser w Robofocus controller
- SBIG STF-8300m, filter wheel and OAG
- Ultrastar guide camera

Scope 2:

- WO 81 3 element Gran Turismo APO
- Moonlite Focuser w Ultimate Pegasus Focuser
- SBIG ST-8300c with OAG
- SBIG STi guide camera

My Planetary Scope

Planetary Scope

- Ioptron iEQ-45 Mount
- Intes MK-66 150mm Mak-Cassegrain fl=1800mm w 1.6x Barlow
- Borg 50 w ZWO ASI-174
- Moonlite Focuser w Robofocus Controller
- ZWO ASI-290

Solar Scope (not shown)

- Coronado SolarMax II 60 Solar Telescope modified for moonlite focuser w robofocus controller
- ZWO ASI-174

My 20” Go-to Dob

Wireless

Argo Navis

Servos

Includes 10k/32k optical encoders