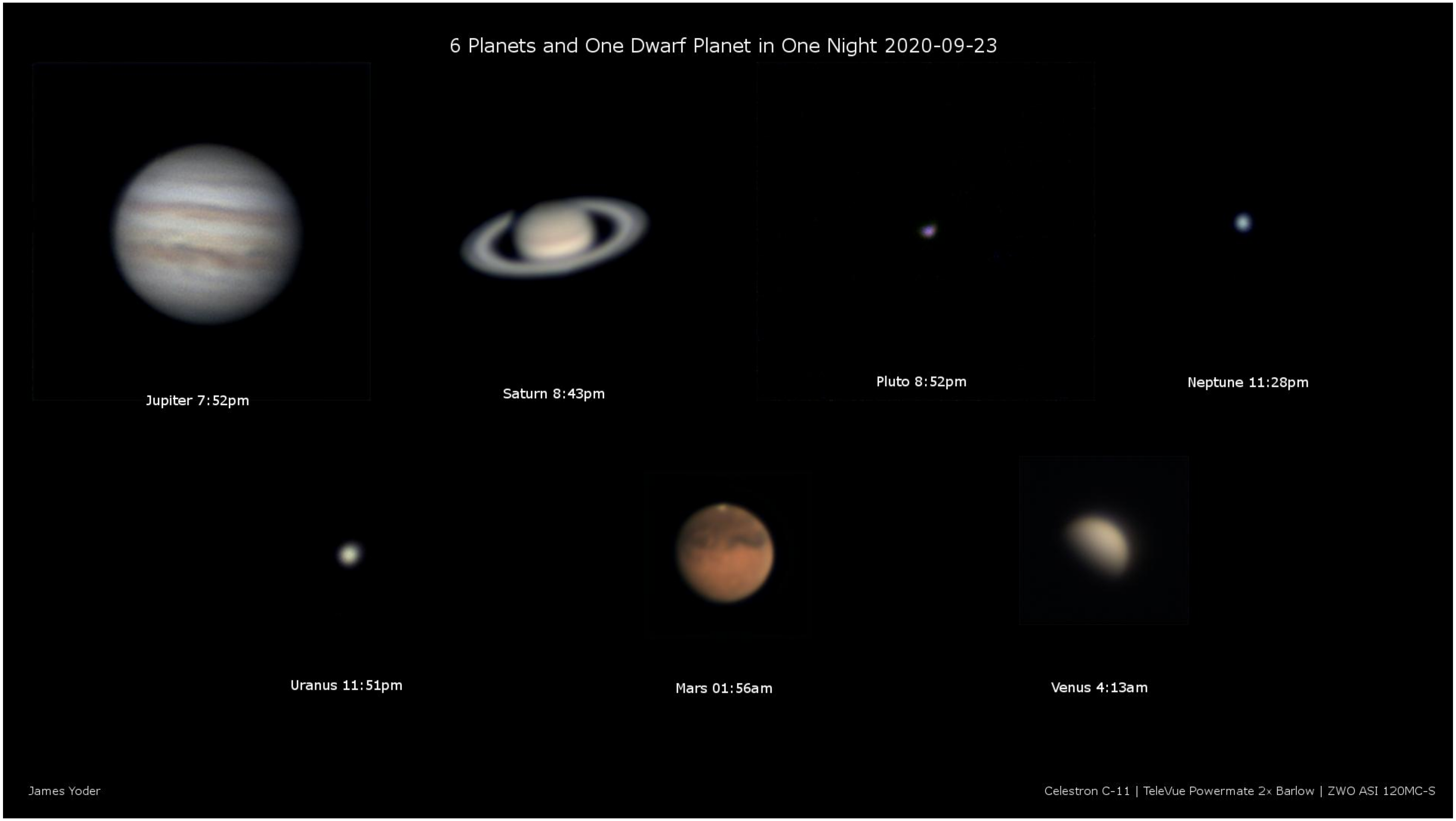
Planetary Imaging Primer



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Planetary Imaging Primer

Chapter 1: Introduction

Goals of this class
This class is targeted to individuals who are interested using their telescope to capture images of the Sun, the Moon, and planets. The intent is to introduce you to the various hardware, software and techniques that are used in capturing images of these type of objects. This class does not address landscape or deep sky (Galaxies, Nebula, etc.) photography.

Class Structure
Lectures - This course is presented as a set of three lectures each lecture lasting 60-90 minutes. It is recommended that you briefly review the chapter before each class so you can get familiar with the concepts and prepare any questions you may have. Attendance is strongly recommended, but lectures will be recorded and available for viewing at a later time if you are unable to attend or would like to review a lecture.

Demonstration – Due to the large size of the class, there will be no hands-on sessions with your equipment. However there will be at least one demonstration so students can be familiar with the process.

ArtCentrics Website
The ArtCentrics website has a number of different resources including:

- Planetary Imaging Primer - Webpage associated with this class.
- This Years Astronomical Events - Listing of events of interest for the calendar year.
- AstroPhotography: Solar System Objects – Photos of solar system objects and night scape photos.

Planetary Imaging Primer

Review of Class and Labs
Provided below is the outline of the ZOOM meetings and demonstration for this class.

Chapter 1: Introduction – In this chapter we discuss goals of the class hardware recommendations, set expectations and provide some examples of planetary imaging photos.

Chapter 2: Atmospheric Considerations – We discuss the impact of the atmosphere on imaging. Various atmospheric parameters are discussed and finally we have a discussion on how to optimize these parameters to get the most favorable conditions for imaging.

Chapter 3: Optical Train and Hardware – Discussion on the main configurations /combinations of telescope and camera are used for capturing images. We also discuss the various equipment and accessories that might be utilized.

Chapter 4: Calculations and Lucky Imaging – We discuss the calculations that can be utilized to determine the level of detail that can be obtained for a given optical train configuration and how this might be optimized. The technique of Lucky Imaging is introduced and discussed.

Chapter 5: Capture and Process – An example of an imaging session work flow is provided along with a discussion of checking collimation and focus check of your system before the process of capturing images is executed. An example processing workflow is introduced to discuss the various applications utilized to obtain a final image of the targeted object.

Hardware Recommendations
While taking this class does not technically require any hardware, it is assumed you will ultimately have access to a telescope, camera of some type that can be coupled to the telescope, computer, and appropriate software to perform planetary imaging processing. An ideal configuration for solar system imaging consists of the following:

- Telescope with a long focal length
- GoTo telescope mount
- Camera with small pixel size
- Flip Mirror Diagonal
- Laptop with SharpCap Pro application

Don't get discouraged if you don't have all of these components, the listed hardware is and ideal list, there are some modifications you can make to compensate for some short comings of some hardware, that's one of the main points of this class is to identify the various parameters show how they can be adjusted to get the best image possible for your equipment. Also, If you are a member of the East Valley Astronomy Club (EVAC) you may be able to rent the Planetary & Moon Imaging Kit that supplies everything you should need of imaging except the telescope, and that also could be rented from EVAC (The NexStar 8 would be recomened).

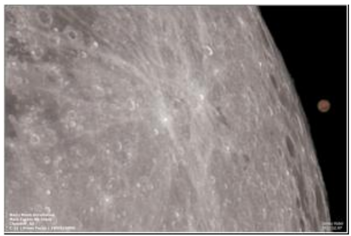
Planetary Imaging Primer

Setting Expectations

This class covers basic concepts and techniques, it can be considered a basis of information you need to begin your journey to planetary imaging, many advanced concepts may not be covered here. There are a huge number of configurations possible when it comes to the hardware used to image, we will focus on how what parameters to consider and run through a few samples so you can perform the calculations for your hardware.

Some Examples

Provided below are some examples of images taken with various telescopes and configurations and may be a realistic expectation of what may be possible with a decent telescope/mount and camera. (Select the thumbnail to view the full image in your browser)



Moon Occultation of Mars (2022.12.07)

Venus Transit of Sun (2012.06.05)

Partial Solar Eclipse (2014.10.23)

Jupiter & Io shadow (2018.06.29)

Saturn (202.05.12)

Mars (2018.08.03)

4 Planets (2018.06.06)

Lunar Eclipse (2015.09.27)

Montes Apenninus (2023.07.07)

References and Resources

Title	Type	Description
Planetary Astronomy	Website	Some details on planetary imaging
Planetary Imaging Primer	Website	Artcentrics website for this class. Contains class materials and recordings
Stellarium Web	Website	Free online Planetarium.
Go Astronomy	Website	Go Astronomy is a good general astronomy website
AZ Observing Group	Website	AZ-Observing groups is a great local group website covering a range of astronomy related topics for local astronomers.
East Valley Astronomy Club	Astronomy Club	East Valley Astronomy Club (EVAC) is one of the larger clubs in the phoenix metro area that meets monthly at the Southeast Regional Library in Gilbert • Club Equipment Rental page • Club Equipment Sales page
Saguaro Astronomy Club	Astronomy Club	Saguaro Astronomy Club (SAC) – Astronomy club in the Central Phoenix Area.
Superstition Mountain Astronomical League	Astronomy Club	Superstition Mountain Astronomical League (SMAL) is located in the East Valley
Cloudy Nights	Website	Place where astronomers share ideas get help share photos, advertise very robust and strong astronomy community here.
This Years Astronomical Events	Website	ArtCentrics web page listing some of the major astronomical events for the year.

Chapter 2: Atmospheric Considerations

Factors Impacting the Quality of the Image

In this class we will discuss many of the elements that go into capturing the best/highest resolution image possible for your particular setup. We will discuss each of these in more details throughout the class. These Include:

- Viewing Conditions
  - **Location of object in the sky**: The higher an object is in the sky the less atmosphere it travels through.
  - **Seeing conditions**: Atmospheric turbulence
- Hardware
  - **Optical quality of the imaging train:** Most decent telescopes these days are diffraction limited so this is not a big factor.
  - **Tracking accuracy:** Telescope alignment and tracking accuracy of the telescope mount. While Alt/Az mounts can technically be used for planetary imaging, equatorial mounts are better positioned for this task.
- Configuration
  - **Optimization of the imaging train:** Ensure that your optics are clean, collimated and in focus.
  - **Optimizing Sampling**: Configuring the imaging train to obtain the appropriate resolution based on the telescope, camera and seeing conditions.
- Capture
  - **Image capturing technique**: Utilizing the best optical train configuration to the best image possible from your setup and the best method to capture details of the target object.
- Processing
  - **Image processing technique**: Processing workflow of captured images to obtain the best final image possible.

Atmospheric Conditions Impacting Image Quality

There are a number of factors that can impact the quality of image that can be captured by your system. Most we don't have a lot of control over, but it is good to recognize what they are.

Dispersion: When light from a celestial object is broken into its constituent colors by the prismatic effects of the Earth's atmosphere. (Green flash at sunset).

Extinction: Extinction causes the brightness of celestial objects to diminish. Extinction is caused by absorption and scattering of light in the atmosphere. (Sun at sunset is much dimer than at noon).

Scattering: The diffusion of light in the atmosphere caused by particles such as atoms and molecules smaller than the wavelength of light scattered. It can be caused by atmospheric gasses as well as smoke and other particles.

Scintillation: Rapid changes in the brightness of a celestial object due to atmospheric turbulence. Like looking through heat waves rising off the hot pavement during the summer making the image shimmer and waver.

Seeing: A measure of the atmosphere's stability. Poor seeing makes object waver or blur when viewed in a telescope at high magnification. The best seeing often occurs on hazy nights, when the sky's transparency is poor. Poor seeing handicaps how sharp your images are.

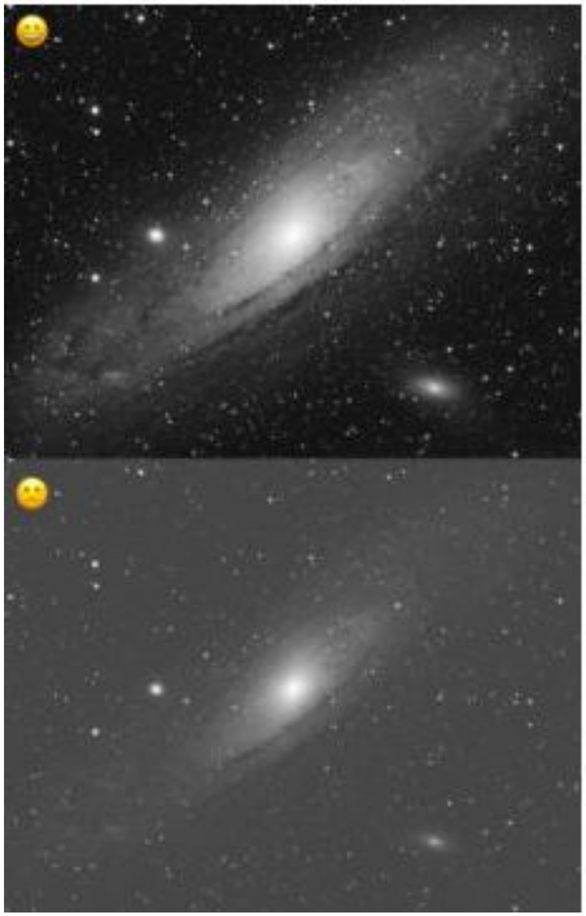
Transparency: The opacity of the Atmosphere, or how clear it is. Poor transparency washes out faint details and reduces contrast.

Reddening: Objects in the sky close to the horizon appear redder because of Rayleigh scattering. (Orange moonrise).

Refraction: The change in direction of a wave due to a change in the medium through which it is traveling. In astronomy, refraction is the angular amount which the apparent altitude of a celestial body is increased by refraction in the Earth's atmosphere.

[Seeing VS. Transparency: What's the Difference?]

Good/Bad Transparency



Bad Transparency = Loss in Contrast

Good/Bad Seeing

Bad Seeing = Loss in Resolution

What Can Be Controlled

There are a number of steps we can take to ensure environmental conditions are the best possible for taking images:

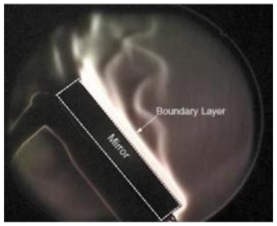
- **High in the Sky:** Try to image when the target is over 45° above the horizon. Light originating from objects high in the sky have less atmosphere to travel through, and as a result all of the atmospheric related issues will be minimalized. The amount of atmosphere light travels through based on the altitude is:

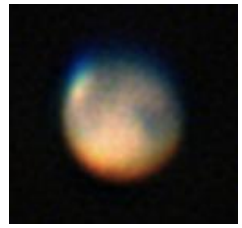
Altitude	**90°** (Meridian)	**45°**	**30°**	**0°** (Horizon)
AirMass	1.0	1.4	2.0	10

- **Thermal Equilibrium:** Many times, the main factor in poor seeing can be that the telescope has not yet reached thermal equilibrium with its surroundings. Make sure to give time for your telescope to reach thermal equilibrium with its surroundings. Open tube telescopes tend to cool quicker than closed tube telescopes like Schmidt-Cassegrain (SCT) that can take up to two hours to reach equilibrium. Some astronomers even purchase fans they can attach to their telescopes to help speed up this process.
- **Immediate Surrounding**: Try to position your telescope away heat sources in the immediate area. For open framework tubes, use a cloth shroud. Avoid cement, buildings etc. Select a grass field or a location close to a cool body of water if possible.
- **Atmospheric Dispersion**: Objects high in the sky don't suffer from this issue, but when this cannot be avoided a Atmospheric Dispersion Corrector (ADC) can be used to counter this problem.
- **Filters for Atmospheric Distortions**: Astronomik has developed a few IR-Pass filters that eliminate visible light and allow light in the infer-red spectrum (642nm to 842nm) reducing interference from the atmosphere. This may be particularly attractive when imaging the moon since color is not of any importance. However, it should be noted that lower frequency light has less resolution than higher frequency light, so there is a trade-off. More discussion on this in the Filters Section.
- **Try to Shoot with optimal atmospheric conditions**: The quality of images is highly dependent from the seeing and to a less extent to the transparency. Not all nights are ideal for planetary imaging and you can't observe every time: how can you anticipate the best ones? The experience of planetary observers reveals a few meteorological situations that favors the good seeing: a weak jet stream in altitude, the presence of a high pressure, the temperature inversion (in spring or fall), the moment of twilight and dawn. These situations are not always favorable but they are those you should be aware of.

Primary Mirror Heat

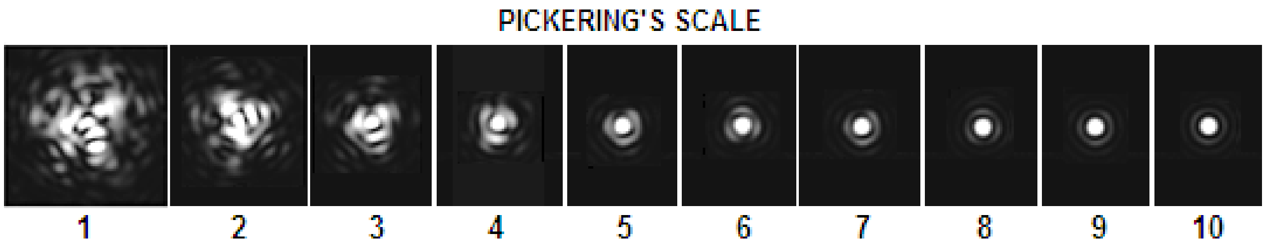
Atmospheric Dispersion





Evaluating Conditions

It is a good idea evaluate seeing conditions before each imaging session. There are a couple of techniques to do this. One of these methods is the Pickering Scale. Pickering used a 5-inch refractor. His comments about diffraction disks and rings will have to be modified for larger or smaller instruments, but they're a starting point



1 — Star image is usually about twice the diameter of the third diffraction ring if the ring could be seen; star image 13 arcseconds (13") in diameter.
2 — Image occasionally twice the diameter of the third ring (13").
3 — Image about the same diameter as the third ring (6.7"), and brighter at the center.
4 — The central Airy diffraction disk often visible; arcs of diffraction rings sometimes seen on brighter stars.
5 — Airy disk always visible; arcs frequently seen on brighter stars.
6 — Airy disk always visible; short arcs constantly seen.
7 — Disk sometimes sharply defined; diffraction rings seen as long arcs or complete circles.
8 — Disk always sharply defined; rings seen as long arcs or complete circles, but always in motion.
9 — The inner diffraction ring is stationary. Outer rings momentarily stationary.
10 — The complete diffraction pattern is stationary.

On this scale 1 to 3 is considered very bad, 4 to 5 poor, 6 to 7 good, and 8 to 10 excellent.

The Pickering scale can be roughly mapped to seeing in Arcseconds as follows

P1 (Very Poor): > 5.0"	P2 (Poor): 4" - 5"	P3 (Fair): 2" - 4"	P4 (Good): 1" - 2"
P5 (Very Good): 0.5" – 1"	P6 (Excellent): <0.5"		

Close examination image created with the Defocus Star Test is not only useful for checking collimation, it might provide hints to heat currents within the OTA and the atmosphere.

References and Resources

Title	Type	Description
Clear Sky Chart	Website	Forecast Cloud Cover, Transparency, Seeing, Darkness, Smoke, Wind, Humidity, Temperature.
MeteoBlue	Website	Forecast website
How to Successfully Beat Atmospheric Seeing	Website	Sky & Telescope article
Atmospheric Effects: Extinction and Seeing	Website	Math model around effects
The Pickering Seeing Scale	Webpage	Examples of various degrees of seeing quality
Schlieren Optics	Video	Good demo showing how the defocus star test can show heat currents.

Chapter 3: Optical Train and Hardware

Basic Techniques of Capturing Images

There are three basic techniques for capturing images from a telescope presented below. The underlying principle to keep in mind when considering each of the methods is that generally, the less optical elements involved the better results we can obtain.

Afocal Photography – In this technique you basically put your camera up to the eyepiece in place of your eye to capture the image. You can also purchase adapters that will attach the phone/camera to the eyepiece to stabilize the camera and fix it rigidly to the telescope. This may be the lowest cost technique, but also will give the lowest quality results since there are a lot of glass surfaces the light has to travel through to get to the sensor capturing the image. This technique is used for single-shot photos, and may provide acceptable results for the moon, and possibly Jupiter and Saturn. We will not dive into this technique since anyone can do it and the results are basically the same. Cost of phone adapters range from $20 - $150.

Phone Adapter

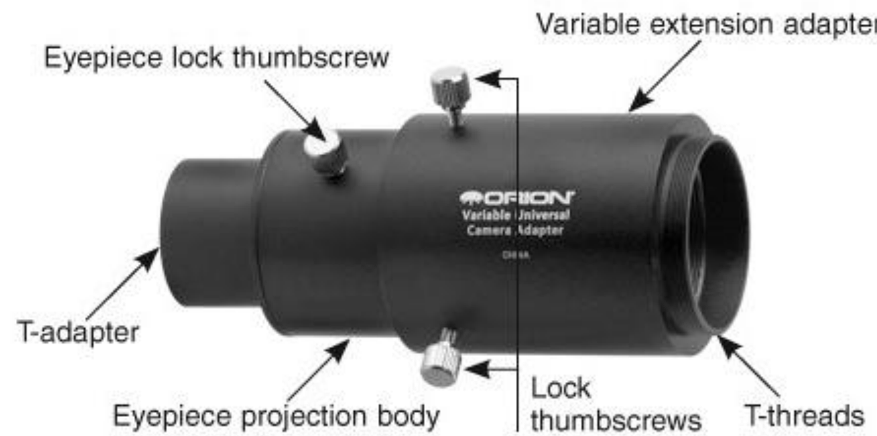
Hold and shoot

Camera Adapter

Eyepiece Projection Photography – In this technique we eliminate the lens associated with the camera and utilize the telescope eyepiece to project the image on the camera sensor. Since you probably already have the eyepieces you need for your telescope, cost is generally associated with purchasing the adapter used to house your eyepieces and adapt for the camera. Image quality is highly dependent upon the eyepiece utilized. One advantage of this technique is that it does allow for a wide range of magnification/field of view based on the eyepiece being used to capture the image. However, quality is still limited due to the number of glass surfaces light has to travel to reach the camera sensor. Also, for any given telescope/camera configuration there is a limited well-defined range of magnification that will give best results (to be discussed later).

Direct Thread onto eyepiece

Eyepiece holder and Camera adapter



Primary Focus Photography – Here we eliminate camera and eyepiece lenses and utilize the telescope as the primary lens for the camera. Optionally a focal reducer or multiplier may be used between the camera to increase or decrease the magnification the system. This configuration can ensure you get the best images possible for your telescope/camera when setup properly. This is the recommended method of capturing images.

Two examples of Prime Focus

Complex Prime Focus Configuration

Summary of Image Capture Techniques

Technique	Pros	Cons
Afocal	Easy, lowest cost, least work	Poorest results, generally good only for the moon
Eyepiece Projection	Highest flexibility for magnification, reasonable cost	Image quality not optimized for your system.
Prime Focus	Best quality possible for telescopes	Limited magnifications available.

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Optical Tube Assembly (OTA)

Most likely you already have your telescope, so we will not spend a lot of time discussing details on various telescopes. However, it should be pointed out the primary factors that impact getting good quality planetary images:

- **Aperture** - The light gathering power of the telescope. Aperture size has a direct impact on the useful magnification for the telescope up to a limit of about 350x (for really good seeing conditions). Aperture size decreases exposure time (a good thing) as aperture increases with no practical limit associated with aperture size. However, larger apertures are impacted by atmospheric turbulence more.
- **Focal Length** – The measure of the distance from the aperture of the telescope to the point of focus for light being gathered by the telescope.
- **Focal Ratio** – F-ratio is the focal length (in mm) of the telescope divided by its aperture (in mm). Telescopes with high F-ratio values (ie f/10 and higher) provide smaller fields of view, have greater native magnification and suffer less from optical distortion than telescopes with lower F-ratios; this makes them ideally suited for planetary imaging.

Telescope Mounts

For lucky imaging (a technique we will discuss later), we want to ensure the target planet will remain on the camera sensor for the entire time we are capturing the images; typically, this will be from one to five minutes, Ideally, we will have a mount that can do this on its own. However, manual intervention may still enable you to us a mount that might not typically be able to do this on its own. There are three mechanical designs to telescopes: Manual, Clock Drives and GoTo. GoTo and Clock drives are typically desired for planetary imaging. Within each of these mechanical designs there are two types of mounts:

- **Alt-Az mounts**: Including Dobsonian mounts, these mounts move in a horizontal and vertical movement. Tracking the planets/stars requires adjustments on both axes. Alt-Az mounts also suffer from field rotation, but this generally is not much of a concern for planetary imaging.
- **Equatorial mounts**: Have one of their axes, the Declination (DEC) aligned to the celestial north pole and as a result only require motion of the Right Ascension (RA) axis to track planets and the stars.

Cameras

The Ideal camera for planetary imaging is dependent upon the details of the telescope and accessories you have for capturing images. Having a camera with small pixel size will help ensure you can capture smaller details provided the imaging train is configured to support the pixel size of your camera. Assuming the telescope is fixed, one may consider what the smallest pixel size camera they can get for the telescope, keeping in mind Barlow lenses can help ensure you have a good pixel scale for your system (much more on this later). There are a number of camera manufactures but currently ZWO and QHYCCD seem to produce the widest range and cost effective cameras. Keep in mind for strictly planetary imaging a large sensor is not needed; However, if you plan on imaging the full disk of the sun or moon a larger sensor will be needed. Additionally, a large sensor is much more forgiving when it comes to locating the target on the camera sensor.

There are many elements to consider when picking a camera for planetary imaging. It is vital to have the specifications of the camera you will be using since this has a direct impact on optical train configuration required to obtain the Sampling you desire. The primary characteristics to consider are listed in the table below along with a brief description and importance indication.

Table 3.1: Key Camera Specifications

Parameter	Importance	Discussion
Mono Vs Color	N/A	Mono cameras have higher resolution but much more expense and effort than color cameras
Pixel Size	Very	The Size of a pixel on the camera. Vital for determining pixel scale and what magnification is required in the optical train to obtain the sampling desired for a target.
Download Rate	Very	Transfer Rates represents the speed an image can be transferred from a camera to the computer, provided the computer supports the speed the camera is pushing the data.
Frame Rate	High	Lucky imaging is trying to capture the very brief moment in time the atmosphere is ideal, having a high shutter speed/frame rate is one of the requirements to make this possible.
Bit Depth	Very	The number bits used to record the intensity of light a pixel experiences. Higher bit depth increases the number of possible brightness levels (grayscale) a camera can capture, providing more accurate representation. Not as important for the planets, but for the moon with a wide range of brightness levels this is very important.
Well Capacity	Very	Represents how much light a single pixel can collect before becoming saturated. Higher well depth (deeper well) allows for longer exposure times without losing detail in bright areas, and showing more details in darker areas due to the longer exposure time.
Dynamic Range	Very	A combination of Bit Depth and Well capacity, represents the range in brightness and the levels of brightness (grayscale) that can be distinguished in this range.
Sensor Resolution	Depends	The number of pixels in a sensor along the X and Y axis. Large sensors are best for full moon/sun imaging and ease of use. Smaller sensors are much more cost effective.
Cooled Vs uncooled	Low	Critical for Deep sky imaging, this is not important for planetary imaging since noise is not nearly as important to minimalize.
Quantum Efficiency	Low	The sensor efficiency at capturing photons, not as critical in planetary/lunar/solar imaging compared to deep sky imaging.
Amp Glow	Low	Unwanted signal from a sensor caused by the camera’s circuitry, that is usually only visible when taking extended exposures, something we are not doing when planetary imaging.

Bit Depth/Grayscale

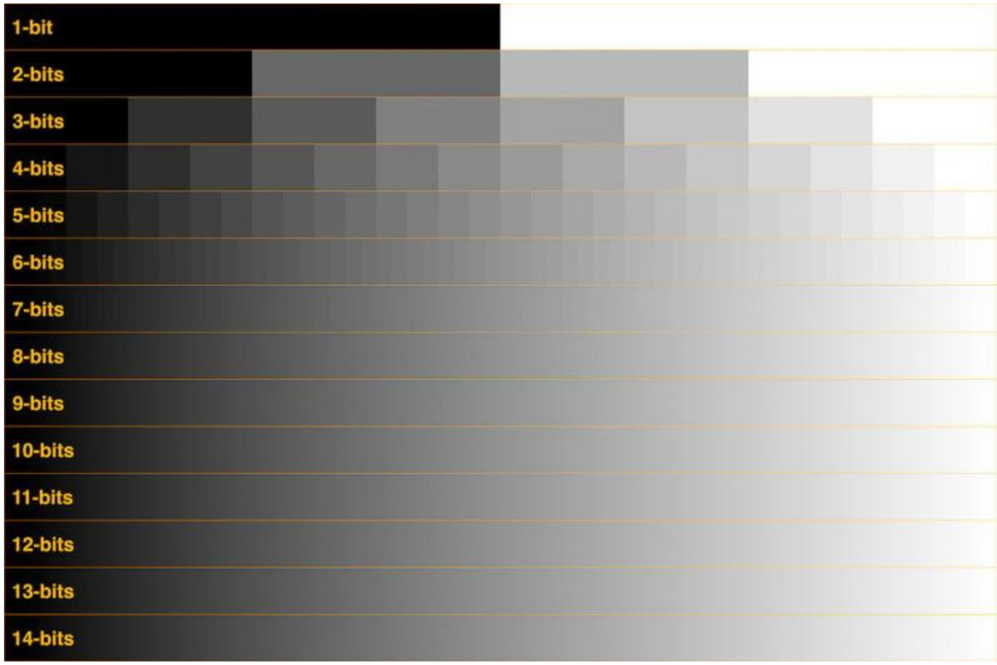
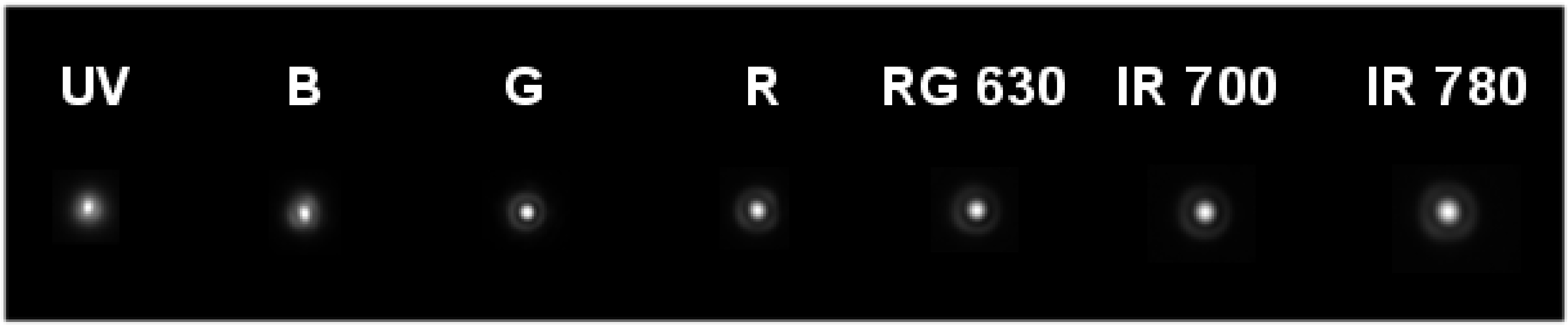


Table 3.2: Some Good Planetary Cameras

Camera	Cost	Pixel Size	Resolution Pixels	Fram Rate	Bit Depth	Well Depth	Comments
ZWO ASI715MC	$229	1.4um	3,864 x 2,192	45 FPS	12 bit	6,030e	Smallest pixel size camera on the market – Great for planet imaging.
ZWO ASI183MC	$499	2.4 um	5,496 x 3,672	19 FPS	12 bit	15,000e	Large sensor with small pixels a great camera Ideal for Moon & Sun
QHY5-III 462	$202	2.9um	1,920 x 1,080	*135 FPS	12 bit	12,000e	FPS at 8bit depth. Good for planet imaging.

Filters

Wavelengths matter: The various wavelengths of light can be isolated to highlight different aspects of some of the planets. Shorter wavelengths on the blue end of the spectrum are more subject to atmospheric interference, but have the potential for supporting finer details conversely; lower frequency light in the Red and Infer Red end of the spectrum have lower resolution, but are not impacted as much by the atmosphere. There is a wide selection of filters, we mention a few of the more popular ones along with the best applications. Utilization of filters for color cameras will mean many of the color pixels will not be utilized and convert the image to grayscale. This may not be an issue for some targets such as the Sun, Moon, Mercury and perhaps Venus. A green filter has the advantage of cutting out some of the shorter wavelengths and utilizing ½ of the pixels on a color camera if the camera has the standard Bayer Pattern.



Size Matters – The aperture size of your telescope should also be of consideration telescopes with smaller apertures <150mm are less impacted by atmospheric interference opening the opportunity to use a green filter allowing utilization of more pixels and providing decent resolution while larger aperture telescopes are more impacted by atmosphere, and may benefit more from a Red or CMOS Red filters to help stabilize the atmosphere better. The bottom line is that each situation needs to be evaluated based on the goal, target, seeing conditions, and hardware configuration.

References: Choosing a Color/Planetary Filter, The Optical Resolution and Wavelength

Table 3.2: Filters

Filter	Links	Application(s)
Baader Moon & Skyglow	1	While this filter may not be the best in any particular field it is quite effective in most applications including planetary imaging, visual astronomy and even deep sky imaging. If you can only purchase one filter this may be the one to purchase. It helps cut down on atmospheric issues and does not impact color to a great extent.
IR Filter	1,2,3	Less affected by the atmosphere, and improve seeing when compared to visible light Near IR wavelengths are also scattered less. IR filters also have greater penetration to atmospheric mists on gas planets that may highlight details barely discernable in visible light. On the downside, these filters may provide less resolution due to the lower transmission of light since sensors are not particularly sensitive at these wavelengths. Application of this filter is probably restricted to the following planets • Jupiter – Shows most of the details that can be seen on the planet • Saturn – Shows greater contrast on the planet's belts as well as its principal spots • Sun – Atmosphere tends to be more of a problem during the day, this may be a good filter to utilize when imaging the sun.
R+IR	3	This filter has the advantage of capturing the red component of the spectrum and the IR wavelengths to help stabilize the image against atmospheric effects while letting in more light than a dedicated IR or R filter. This has the advantage of allowing shorter image capture times. Sun – Atmosphere tends to be more of a problem during the day, this may be a good filter to utilize when imaging the sun.
CMOS Red	1, 2	The Red filters transmission is located within the maximum sensitivity of most sensors and will let through a large amount of light. Red is significantly less disturbed by the atmosphere and is scattered less to help ensure a sharp image provided the seeing is not too bad. • Jupiter – Shows most of the details that can be seen on the planet • Saturn – Shows greater contrast on the planet's belts as well as its principal spots • Uranus – Shows it most important cloud belts • Mars – Best for detect details visible on the surface • Venus – May reveal faint grey bands on condition of very good seeing.
CMOS Green	1	Not as sensitive to atmospheric effects as Blue, and provides better resolution than Red, this color also has the advantage of utilizing twice as many pixels than the individual red or blue pixels in a color sensor due to the Bayer pattern of utilizing two green pixels for every red and blue pixel. Additionally, most sensors are more sensitive in this region. This filter may be good for teasing out details of the moon while high in the sky.
Semi APO	1	Designed to eliminate or greatly reduce chromatic aberration of conventional two lens refractors. This filter also provides benefits of the Neodymium filter and has minimal impact on image color. This filter should be considered a must for mid-low-end owners of refractor telescopes.

Accessories

There are many accessories to consider for planetary imaging. Provided below are some of the more relevant tools and accessories:

- Bahtinov mask: A Bahtinov mask is used to check focus and can be used to refine collimation on telescopes (not refractors).
- Barlow Lens: A Barlow lens can be used to help obtain the optimal pixel scale for your optical train and camera combination. Make sure to purchase a high quality one.
- Variable Eyepiece Projection Adapter: While primary focus with a Barlow lens is the preferred method of setting up the optical train, this method can occasionally prove useful. When using this configuration, it is vital a high-quality eyepiece be utilized. The Baader Hyperion Mark IV 8-24mm Zoom eyepiece with Barlow ($490) is an interesting eyepiece and Barlow.
- Electronic Focuser: There are two types of electronic focusers, Crayford type adjust the focus tube (these have limited travel) and focuser motors that attach to the focuser knob of a telescope and manually rotate the knob (these are less accurate, generally less expensive, but do not have travel limits). Each type of focuser has its pros and cons. Focusers enable the astronomer to adjust focus without having the telescope wobble every time it is touched.
- IR-pass Filter: Used to reduce seeing effects and enhance contrast when used for lunar imaging, especially useful for day imaging. However, these filters do cut out quite a lot of light, so will be restricted to the moon or telescopes with large apertures. Note: this will produce a grayscale image.
- Telescope Fan: Used to help the telescope reach thermal equilibrium with the surroundings. SCT Cooler, Dobsonian Cooler.
- Atmospheric Dispersion Corrector: Used to reduce the effect of atmospheric dispersion on lunar and planetary images. Perhaps most useful on objects less than 60° above the horizon. The lower in the sky the object the more this helps. Video Link.
- Flip Mirror: Provides an easy way to re-direct the light exiting the telescope to either an imaging camera or eyepiece. Quite convenient when trying to locate and center an object on a small sensor.
- Broadband Solar Filter – Can be used to view and image sunspots and solar events such as eclipses.
- Specialized Solar Telescopes – Can be utilized for viewing various features on the sun that may not be visible with a broadband solar filter (1,2,3). These filter systems tend to be quite expensive; some are dedicated telescopes with strictly solar application.
- Parfocalizing Rings – Are used to normalize your set of eyepieces to a common focus. When eyepieces differ as to the location of the field stop with respect to the field stop (position of focus), they require focusing adjustments when switching. With parfocalizing rings, all are made to focus at the same (or nearly so) focus position, thus negating or minimizing focus adjustments when swapping between eyepiece and camera. 1,2

References and Resources

Title	Type	Description
Telescope Aperture Explained	Website	Detailed discussion on telescope aperture size and impact on what you can see
Choosing the best planetary camera	Website	High Point Scientific website reviews planetary cameras (2021)
Using the ZWO ADC to image Venus	Video	Video demonstrating how to use the ZWO Atmospheric Dispersion Corrector
Imaging Planets with a Dobsonian Telescope	Website	BBC Sky at Night Magazine
Astromart	Website	Great website for picking up used equipment
PetaPixel: 8, 12, 14 vs 16-Bit Depth: What do you really need?		PetaPixel: 8, 12, 14 vs 16-Bit Depth: What do you really need?
Agena Astro: ZWO Astronomy Cameras Buying Guide		Agena Astro: ZWO Astronomy Cameras Buying Guide
Bit Depth, Full Well and Dynamic Range		Bit Depth, Full Well and Dynamic Range

Chapter 4: Sampling

Apparent Size of the Moon, Sun and the Planets

When discussing the size of objects in the sky (ie moon, planets, etc) we typically use units of degrees, arc minutes and arc-seconds. These are related as follows.

360° in a full circle **1° = 60' (arc minutes)** **1' = 60" (arc seconds)**

How small is an arcsecond? The average human hair held 32.8 feet away would cover one arcsecond of sky! With this in mind, we can discuss how the apparent size of the planets and moon can change over time.

Apparent Minimum and Maximum Size of Planets

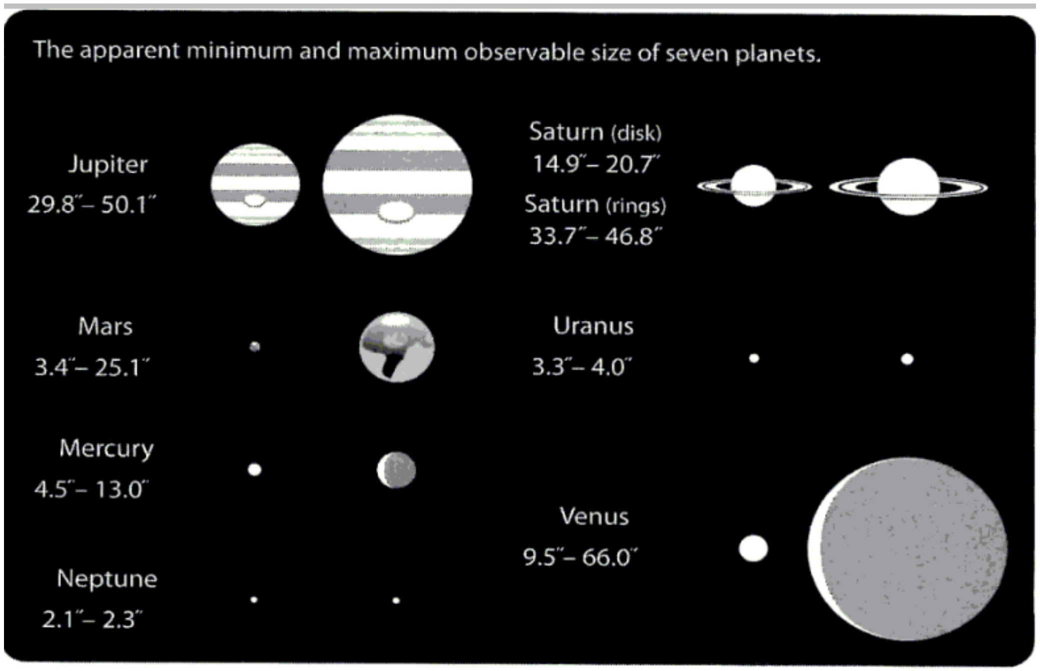
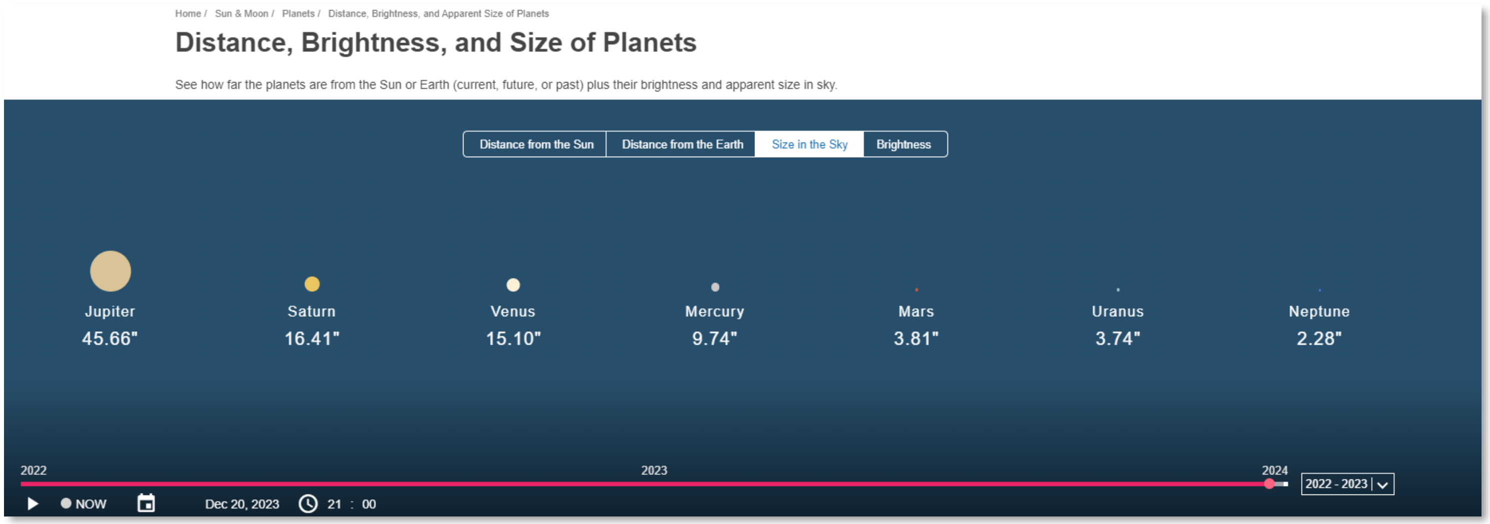


Illustration by Michael Gatto

Moon Average Angular size is 31' and ranges from 29.3' to 34.5'



Timeanddate.com has a nice tool that gives the current apparent size of planets

Magnification and Sampling

So how do we make sure we get the best quality image possible for our equipment? The first step is to make sure we have the optical train configured to provide the most resolution possible. We don't want to confuse this with the **Highest Useful Magnification** (HUM), since this application would be for the human eye, but let's discuss this topic anyway since it introduces some common elements.

NOTE: The Conversation on Highest Useful Magnification is for visual observation, it does not apply to imaging. In imaging we are more concerned with getting proper Sampling.

Highest Useful Magnification (HUM): is an estimation of the most magnification that can be utilized for a given telescope based on seeing conditions. This is directly related to the aperture size of the telescope and the seeing conditions. First, we will address the seeing conditions limit. For average seeing conditions the practical magnification limit for planetary imagine is about 250x, while exceptional seeing conditions may allow up to 350x.

Turning our attention to the telescope, the HUM for a telescope is based on the aperture size (assuming excellent optics). For smaller telescopes with aperture of 5” or less this is 60 times the measured aperture size in inches. For telescopes with an aperture greater than 5”, the HUM is 50 times the aperture size in inches.

We can see from this relationship that an ideal telescope planetary viewing will have an aperture size of about 7” to ensure the atmosphere is the limiting factor in reaching the highest useful magnification. That all being said, increasing aperture size beyond this will increase the amount of light collected, generally making it easier to see details of the target.

Equation 4.1: Seeing Constraints on HUM

$$100x < HUM < 350x$$

Equation 4.2: HUM Calculation (Small Scopes)

$$HUM = (60 \times Aperture^{"})$$

Equation 4.3: Telescopes Aperture >5”

$$HUM = (50 \times Aperture^{"})$$

Some Examples (Assuming optics of the telescope are diffraction limited)

Telescope	Aperture	Calculated HUM	Practical HUM
Questar 3.5”	3.5”	210x	**210x**
Celestron C-6SE	6”	300x	**300x**
Meade 7” Maksutov	7”	350x	**350x**
Celestron C-11 HD	11”	550x	**350x**

Okay, but how does this all relate to how I configure the optical train? There are arguments that magnification shouldn’t be utilized for imaging; We need to talk about Sampling.

Determining the Limiting Factor for Sampling

A quick side note before we begin this conversation, Sampling, Magnification and Pixel Scale are all very closely related and can be used in the same context, for example when you decrease the pixel scale you are increasing magnification. Selecting the correct magnification may be interchanged with obtaining the correct pixel scale. Sampling is the required Pixel Scale to record the smallest detail possible for a given telescope under ideal seeing conditions ON A SENSOR you will see below this is roughly ¼ of calculated magnification.

Sampling: Is the Targeted Pixel Scale required to record the most detail possible given the current seeing conditions and telescope being used. Pixel Scale is the measure of how much area of the sky is captured on an individual pixel on a camera sensor. Systems that have a lower pixel scale than the seeing conditions supports are said to be “Oversampled”, while systems that have higher pixel scale, and are thus losing details are said to be “Undersampled”. Pixel scale calculation along with what the targeted pixel scale should be based on the telescope aperture and seeing condition. There are online calculators that calculate pixel scale of a given system configuration. There are two main factors that determine what the best resolution possible to obtain when imaging a planet, the Moon or the Sun. The seeing conditions and the telescope resolving power.

The Seeing Conditions is based on the atmospheric conditions and was mentioned earlier in the Evaluating Conditions section and are recapped in the table below. Telescope resolving power is approximated by the Dawes' Limit, the resolution limit of a telescope given its aperture. Some common telescope apertures and resulting resolution values (Dawes' Limit) are provided below. Keep in mind these calculations are based on hypothetical best conditions; telescope has perfect optics and collimation.

Equation 4.4: **Dawe's Limit**

$$\boldsymbol{Dawes'Limit}\ (Arcsec) = \frac{116}{ApetureSize(mm)}$$

Table 4.1: Seeing Conditions

Pickering Scale	Seeing Condition	Angular Resolution Limit
P1	Very Poor	>5.0"
P2	Poor	4.0" – 5.0"
P3	Fair	2.0" – 4.0"
P4	Good	1.0"– 2.0"
P5	Very Good	0.5"– 1.0"
P6	**Excellent**	**< 0.5"**

Table 4.2: Dawe's Limit

Aperture	**Resolution**		**Aperture**	**Resolution**
2.5" (62mm)	1.80"		**9.25" (235mm)**	**0.49"**
3.5" (89mm)	1.30"		10.0" (254mm)	0.46"
4.5" (114mm)	1.02"		11.0" (279mm)	0.42"
6.0" (152mm)	0.76"		14.0" (356mm)	0.33"
7.0" (178mm)	0.65"		18.0" (457mm)	0.25"
8.0" (203mm)	0.57"		20.0" (508mm)	0.20"

Reviewing the two tables above we can identify the limiting factor by comparing the telescopes Dawes' Limit to the best-case Seeing conditions (0.5") and pick the higher of the two values as our targeted resolution. It can be seen that the limiting factor is generally the telescope aperture size for telescope up to about 10" (254mm) in diameter, after that the seeing conditions becomes the limiting factor.

Chart 4.1: Aperture vs Dawes' Limit

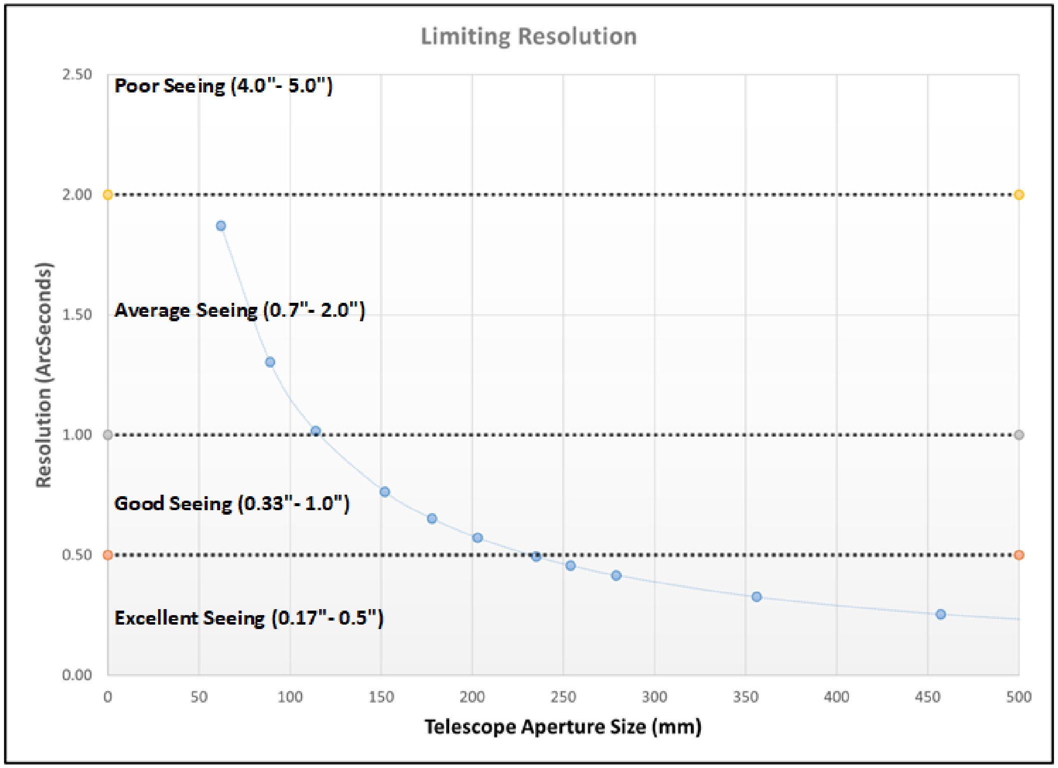


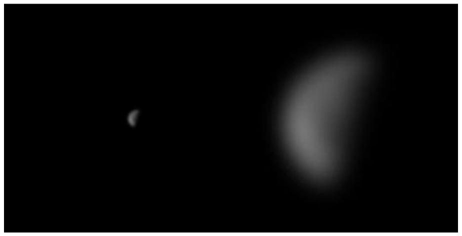
Table 4.3: Calculated Sampling Target

Aperture		Resolution	Sampling
Inches	mm	ArcSec	ArcSec
2.5	63.5	1.83	**0.46**
3.5	88.9	1.30	**0.33**
4.5	114.3	1.01	**0.25**
6.0	152.4	0.76	**0.19**
7.0	177.8	0.65	**0.16**
8.0	203.2	0.57	**0.14**
9.25	235.0	0.49	**0.12**
10.0	254.0	0.50	**0.13**
11.0	279.4	0.50	**0.13**
14.0	355.6	0.50	**0.13**
18.0	457.2	0.50	**0.13**
20.0	508.0	0.50	**0.13**

Now that we have identified the angular resolution for our telescope for best resolution, we need to translate that to a Targeted Pixel Scale (Sampling) that will ensue we can record the best detail possible. The Nyquist sampling theorem indicates the sampling required to be able to produce angular resolution we desire would the angular resolution divided by a factor of two. When taking into consideration the topography of a camera sensor that factor changes to a value between 3.5 and 4 (we will use 4) to get the best sampling. The Calculated Sampling Target table above indicates the Sampling we should target for various telescope aperture sizes. The values in the Sampling column represent our Targeted Pixel Scale to ensure we are able to capture the most detail possible if the optics and seeing conditions are at the absolute best possible. For a more in-depth discussion on this check out ASTROPIX: Sampling and Pixel Size.

Oversampling (having a smaller pixel scale than what the seeing will support) doesn't have any huge disadvantages; Conversely, we should avoid Undersampling, because the resulting image will not have as good of resolution that is possible given the seeing conditions. Because of this it is probably a good idea to configure your system for exceptional seeing conditions knowing that you may be oversampling, but you will not lose any resolution if seeing conditions improve.

Oversampled images don't provide more details, just makes the image larger



Managing Your Light

Now that we have the targeted Pixel Scale/Magnification it's just a matter of configuring the optical train, right? Well, it's not quite that simple you may find that you are unable to utilize the targeted pixel scale and capture the object you are trying to image because at this magnification the object is just too dim. This is more of an issue the smaller your telescope aperture, there is a minimal amount of light each pixel must obtain in order to actually register any details on the target. Generally, the histogram is used to guide you on this lower limit (this will be discussed more later). The parameters listed below have a direct impact on how much light each pixel gathers for a given exposure.

Table 4.4: Factors Impacting Light Collection

Parameter	Comments
Aperture Size	How big the opening of the telescope is for capturing light.
Target Brightness	How bright is your target? For example, the Moon is much brighter than Saturn and Saturn is brighter than Mars.
Magnification	The more magnification the dimmer the features will appear.
Filters	More aggressive filters will cut a certain percentage of light from hitting the sensor.
Exposure Time	The higher the gain on a camera the brighter the object will appear. Unfortunately, as the gain is increased, so is the noise and noise needs to be kept to a manageable level. Additionally increased gain will decrease the grayscale dynamic range the camera is able to capture.

Determining what parameters to tweak and how much to adjust them is the great challenge and takes a lot of trial and experience to get the best fit.

Chart 4.2: Relative Light Gathering Power

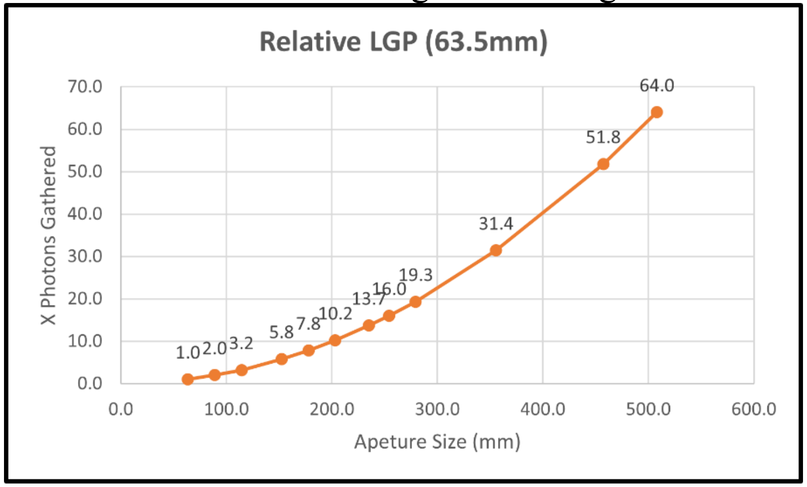
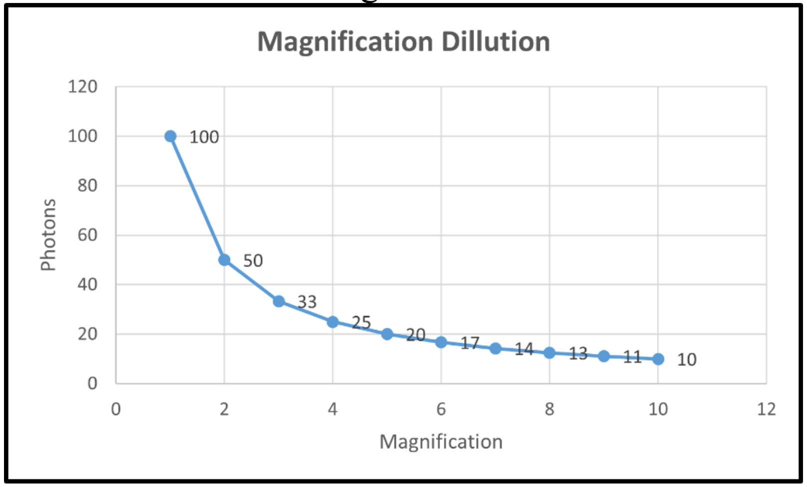


Chart 4.3: Magnification Dilution



This chart is a graphical representation of how the light gathering power increases as the aperture size is increased. The comparison is to a 2.5" (63.5mm) telescope. A 3.5" telescope gathers 2x the light a 2.5" telescope, while a 20" telescope gathers 64x of a 2.5" telescope.

In this chart we see how increasing the magnification decreases the number of photons each pixel will receive. Here we are taking an arbitrary number of photons (100) as the number of photons entering the telescope.

References and Resources

Title	Type	Description
Arcminutes and Arcseconds	Webpage	Discussion on how these two measurements relate to each other.
Distance, Brightness and Size of Planets	Webpage	Give these parameters for the current date.
CCD Suitability	Webpage	Calculate the resolution in arc seconds per pixel of a camera with a given telescope.
Telescope Capabilities calculator	Webpage	Calculate Dawes' Limit, Rayleigh Limit, Limiting Magnitude and Ligh Grasp Ratio for a telescope you specify
Sampling and Pixel Size	Website	A discussion on how sampling and pixel size are related

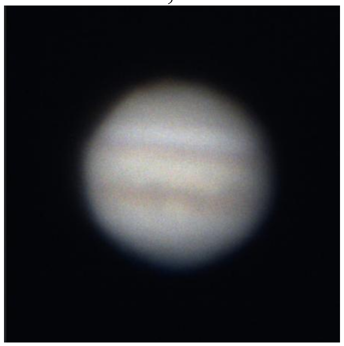
Chapter 5: Calculations and Lucky Imaging

Lucky Imaging

Planetary imaging technology and techniques have come a long way in the last decade. Lucky Imaging is currently the most effective way of getting the best image possible for most systems. The concept behind this technique is instead of taking a single photo of the targeted object we take a high-resolution video to gather as many individual frames as possible. The hope is that we can throw out the frames with poor atmospheric conditions and combine the photos with good conditions to help increase the signal and reduce the noise for features we are trying to capture. Speed is vital in this process; the goal is to maximize the frame capture rate so we can gather as much "good frames" as possible in the time we have to image the target (The capture duration discussed shortly).

Recently this technique has been brought to a new level by the windows-based application called SharpCap Pro with the Live Stacking function. The user is able to perform lucky imaging on-the-fly and get immediate results. In the past one would capture a recording and process the recording at a later time, so the impact of making various changes were generally not immediately apparent.

Best 1 of 1,044 frames



261 frames of 1,044 Stacked

Final Sharpen Image

Frame Capture Rate (Frames Per Second – FPS)

The speed at which you are capturing images is one of the most important parameters in Lucky Imaging. The parameters that impact frame capture rate that need to be checked to make sure they are not limiting factors are listed below.

Table 5.1: Factors Impacting Capture Rate

Parameter	Comments
Data Transfer Speed	This is a combination of the speed the camera sensor can pass information and the connection type between the camera and the computer. For instance, USB2.0 transfer speeds peak at 480 Mbps while USB 3 transfer speed peaks at 5 Gbps, over 10 times that of USB 2.0.
Image Cropping	Cropping the sensor to just a little larger than the target can greatly improve the number of frames that can be captured and saved in a given time period.
Exposure Time	Ideally, exposures of about 1/10 second or less is desired, but this may be adjusted up to as much as a second, faster is always better. This technique naturally favors telescopes that have larger apertures (to allow us to minimalize exposure time) and still have a properly exposed image.
Save Time	We need to try to make sure the amount of time it takes to store each frame on the computer does not exceed the exposure time otherwise some frames will be dropped. Having a camera that supports fast data transfer (i.e. USB3) and a computer that is able to write this data to the data storage media (i.e. hard drive, solid state drive or flash drive) will also play into this. • Drive Speeds: It is difficult to have exact numbers here but the latest solid-state drives (7,000 Mbps) can be up to 28 times faster than the typical hard drive (250 Mbps). The solid-state internal drive is by far currently the fastest means of storage available. • External Storage: Write speeds on external devices such as thumb drives, SSD cards, etc. vary greatly depending on the device and interface being used. Currently the fastest speeds in optimal conditions seem to top off at about 10 Gbps with the average speed probably being much lower for most media. You will need to review the specifications of the media and your computer you plan on using if you go this route.

Rotation and Detail Smearing

All planets, the moon and the sun have a rotation. This limits the amount of time you have for capturing the details of the object you are imaging before clarity of the final image will be degraded. Things that impact the amount of time before detail smearing becomes an issue include:

- **Imaging Train Resolution**: What is the pixel scale for your imaging train? This may be further limited by your seeing conditions.
- **Detail Travel Speed**: How fast the detail is moving due to rotation of the object in reference the resolution of you imaging system.

Provided below is a conservative estimate on how long you can image the various targets before rotational smearing may become an issue. This is assuming a pixel resolution of 0.5”/pixel. Usually seeing conditions limit resolution to about 1.0”/pixel, so you may be able to increase these values depending on your system, and seeing conditions.

Table 5.2: Capture Duration Rules of Thumb

Target	Detail of Interest	Capture Duration
Sun	Sunspots	180s (3min)
Moon	Moon features	600s (5 min)
Mercury	Phase	720s (12 min)
Venus	Cloud features	120s (2 min)
Mars	Planetary features	90s (1.5 min)
Jupiter	Planetary features	45s (0.75 min)
Saturn	Planetary features	600s (10 min)
Uranus	Disk of planet	No practical limit
Neptune	Disk of planet	No practical limit

Guidelines

Provided below are some main parameters that should be reviewed and optimized when utilizing Lucky Imaging to capture an image of an object. These are general guidelines that I have found work for me. Your milage may vary.

Table 5.3: Guidelines and Considerations

Parameter	Target Range	Comments
Accumulated Frames	750 – 2,500 frames	More frames will cut down on noise in the final image.
Histogram	40% - 75%	Utilization of the histogram is key to make sure you are capturing as much detail (signal) as possible without losing any detail (clipping).
Gain	5% - 70%	Different cameras use different scales, so this is just a percentage of the maximum gain allowed for that camera. Increase gain limits dynamic range and increases noise, but also allows shorter exposure times.
Exposure	250ms max	Shorter exposure rates are always better, but you need to make sure your pc can handle the faster capture rates, check the dropped frames. Also, the exposure must be long enough to see the target, check the histogram.
Filters		Choose the appropriate filter for the target. See filters section.

Table 5.4: Target Parameters Considerations

Target	Parameters	Comments
Sun	• Dynamic Range: The sun can have a fairly large dynamic range depending on what features and what part of the spectrum you are imaging. You should probably try to maximize the Bit Depth and Well Capacity and decrease the Gain if possible. Make sure to save the video in a color space (i.e. Raw 16) that will keep all of this information for future processing. • Frame Filtering: With an upper limit of 3 minutes, for capture duration, we need to balance the need to capture good frames with the need to accumulate enough for processing. 30% retention? • Filters: Atmospheric conditions when imaging during the daytime can be problematic, Utilization of IR or a R + IR filter may help counter the atmospheric turbulence encountered during the day. A Green filter may also be beneficial to increase the number of pixels utilized on the sensor.	There are many different wavelengths to examine different features of the sun, so the approach to capturing images will also vary
Moon	• Dynamic Range: The moon has the greatest dynamic range of all the solar system targets. Maximize the Bit Depth and Well Capacity and decrease the Gain if possible. Make sure to save the video in a color space (i.e. Raw 16) that will keep all of this information for future processing. • Frame Filtering: With an upper limit of 5 minutes capture duration you can afford to be more selective on the quality of frames you wish to retain (provided you mount will track the target). 20% retention? • Filter: Utilization of an IR filter will help reduce atmospheric effects, and should not impact the FPS much since the moon is so bright.	One of the brightest targets for imaging
Jupiter	• Dynamic Range: While Jupiter exhibits more color than the sun or the moon, the dynamic range of the sensor required to capture these colors are not nearly as demanding so you can be more generous with the gain, and using color space of Raw 8 may not impact the quality of the final image. • Maximize FPS: With an upper limit of 45 seconds, it is vital you have maximized the FPS capture rate of your system. Make sure to crop your image, adjust your gain to cut down on exposure time, and relax your frame quality requirements. 40% retention? • Filter: An IR filter may help with atmospheric effects. Since Jupiter is one of the brightest planets exposure FPS may not be impacted to a critical level.	

Target	Parameters	Comments
Venus	• Filter: Venus tends to be lower on the horizon, and is very bright so this object will greatly benefit from an IR filter. • FPS: Target increased FPS to help counter atmospheric conditions	Size and brightness of this target have a large range, so capture methods and parameters will need to change accordingly
Mars	• Filter: Baader Moon & Skyglow? Should help stabilize atmosphere, doesn't cut much light and should be pretty good with retaining color and showing different regions on mars. • Maximize FPS: You only have 90 seconds to capture images, so you will need to get as many FPS as possible.	Size and brightness of this target have a large range, so capture methods and parameters will need to change accordingly

References and Resources

Title	Type	Description
Planet Angular Size, Brightness and Distance	Website	Timeanddate.com
Picking Your Pixels	Website	Sky & Telescope
How to Capture the Clearest Astro Images	Website	Sky & Telescope – Discussion on Pixel Scale
Magnification in Astrophotography	Website	Cloudy Nights - Discussion
CCD Suitability Calculator	Website	Astronomy Tools – Will calculate the resolution of your telescope/camera combination.
Planetary Imaging with an AltAz Dob	PDF	Details on methods to correct for field rotation and imagine with a Alt/Az mount
Digital Camera Database	Website	Specifications for various cameras
Sampling and Pixel Size	Webpage	Jerry Lodriguss explains equations associated with sampling

Chapter 6: Working Examples

In this chapter we take the knowledge we have gained from so far and apply it to help plan for imaging sessions.

Handy Equations

In the examples below we will utilizing the following equations. Don't panic if math scares you, there are online calculators such as the Astronomy Tools website that will many of these calculations for you.

Equation 6.1: Telescope **Dawe's Limit**

$$\boldsymbol{Dawes'\,Limit}\ (Arcsec) = \frac{116}{ApetureSize(mm)}$$

Equation 6.2: Telescope **Pixel Scale** **(Resolution)**

$$\boldsymbol{PixelScale}\ \left(\frac{Arcsec}{pixel}\right) = 206.3 \times \frac{CameraPixelSize\ (\mu m)}{Telescope\ FL\ (mm)}$$

Equation 6.3: Needed Barlow Lens

$$\boldsymbol{Barlow\ Lens} = \frac{Telescope\ Resolution\ ("/pixel)}{Telescope\ Target\ Sampling\ \ ("/pixel)}$$

Equation 6.4: **Target Object Size in Pixels**

$$\boldsymbol{ObjectSize}\ (Pixels) = \frac{ObjectSize(Arcsec)}{ImagingPixelScale\ (\frac{Arcsec}{pixel})}$$

Equation 6.5: **Sensor Diagonal Measured in Pixels**

$$\boldsymbol{SensorDiagonal}(pixels)\ = \sqrt{(Lenth^2 +\ Width^2)}$$

Equation 6.6: **Percent Target Object Takes of Sensor Diagonal**

$$\boldsymbol{ObjectPercentDiagonal}\ = 100\ \times \frac{ObjectSize(pixels)}{SensorDiagonal(pixels)}$$

Working Example1: Calculating Pixel Scale and Optical Train Configuration

Determine best optical train configuration to obtain proper sampling. In this example we will review a number of OTA's (Table 6.2) and a couple of cameras (Table 6.1) and determine what the best configuration would be to obtain proper sampling (Table 6.3). Table 6.1 shows specifications for three cameras, we will do analysis for two of the cameras (QHY5-II 462 and ZWO ASI715MC).

Table 6.1: Camera Specs

Camera	Pixel Size	Resolution (Pixels)	Diagonal (Pixels) [6.4]
QHY5-III 462	2.9um	1,920 x 1,080	2,203
ZWO ASI715MC	1.4um	3,864 x 2,192	4,442
~~ZWO ASI183MC~~	~~2.4 um~~	~~5,496 x 3,672~~	~~6,610~~

A few cameras for examples, diagonal column calculation is based on Equation 6.4, Sensor Diagonal Measured in Pixels.

Table 6.2: Telescope Sampling

Telescope	Aperture (mm)	F.L. (mm)	Ideal Sampling (ArcSec)
ZWO SeeStar S50	50 mm	250	1.05”
Celestron AZ 130DX	130 mm	650	0.33”
C-6 SCT	150 mm	1,500	0.19”
7” Maksutov	178 mm	2,670	0.16”
C-8 SCT	203 mm	2,032	0.14”
10” F3.9 Astrograph	254 mm	990	0.13”
C-11 SCT	279 mm	2,800	0.13”

Ideal Sampling Based on Dawe’s Limit (Equation 4.4) divided by 4 for telescope with apertures smaller than 10”. Telescopes with apertures larger than 10” are assumed limited by atmospheric seeing at 0.5” divided by 4 = 0.13”.

One Calculation Walkthrough: C-6 SCT with both cameras

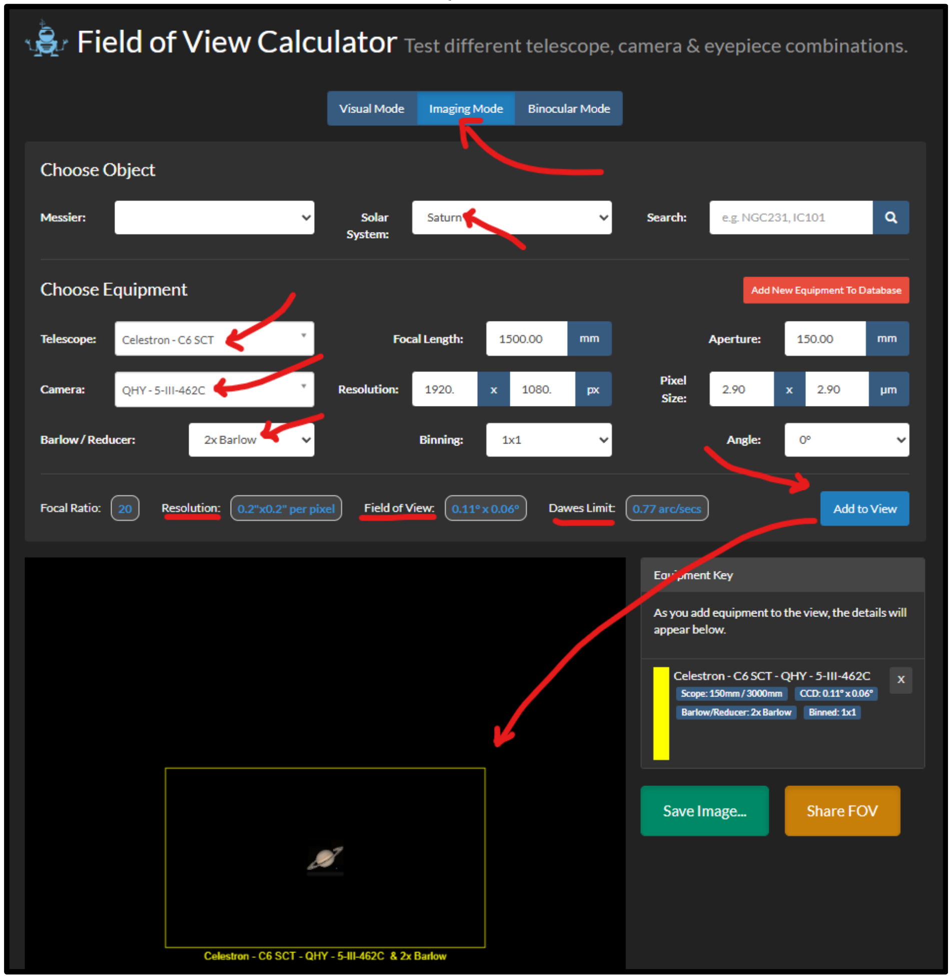
- C-6 SCT Target Sampling Pixel Scale (Table 6.2) = **0.19”/pixel**
- Camera = QHY 5-III 462 | Telescope Pixel Scale (Equation 6.2) = 206.3 x (2.9um/1,500mm) = 0.399”/pixel (to high)
  - Needed Barlow Lens (Equation 6.3) = (Telescope Pixel Scale)/(Target Sampling) 0.399”/0.19” = 2.1 → 2x Barlow required, will increase the FL of the optical train to 3,000mm
  - 2x Barlow Pixel Scale (Equation 6.2) = 206.3x(2.9um/3,000mm) = 0.20”/pixel (Great!)
- Camera = ZWO ASI715MC | Telescope Pixel Scale (Equation 6.2) = 206.3 x (1.4um/1,500mm) = 0.19”/pixel (Great!, not changes needed)
  - Observation: having a camera with roughly ½ the pixel size is the same as having a 2x Barlow lens in the imaging train.
- Calculating Object Size (In Pixels) of Saturn (20”) – Equation 6.4
  - Camera: QHY 5-II 462 with 2x Barlow
    - Object Size (pixels) = (Object Size)/(Optical Train Pixel Scale) = (20”)/(0.20”/pixel) = 100 pixels
  - Camera ZWO ASI715MC
    - Object Size (pixels) = (Object Size)/(Optical Train Pixel Scale) = (20”)/(0.19”/pixel) = 105 pixels
- Percent Target Takes of Sensor Diagonal (Equation 6.6) = 100x (Object Size in pixels)/(Sensor Diagonal in pixels)
  - Camera: QHY 5-II 462 with Barlow
    - Percent of Diagonal = 100 x (100pixels) / (2,203 pixels) = 4.5%
  - Camera: ZWO ASI715MC
    - Percent of Diagonal = 100 x (105 pixels) / (4,442) = 2.4 %

Table 6.3: OTA Configuration Calculations

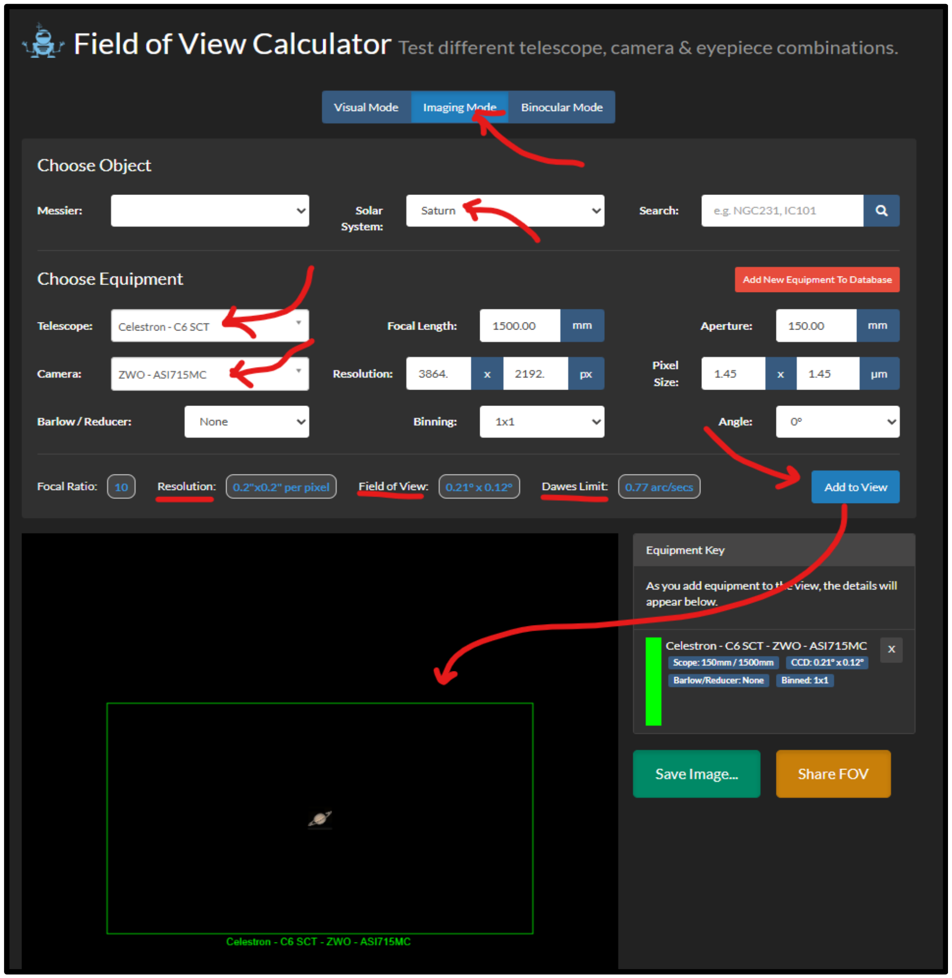
Telescope/Camera	**Target Sampling**	**Camera Pixel Size**	**Native Pixel Scale[1]**	**Barlow**	**Barlow Pixel Scale[1]**	**Saturn # Pixels**	**% Diagonal**
ZWO SeeStar S50	1.05”		5.28”/pixel	N/A		4 pix	
Celestron AZ 130DX	0.33”						
QHY5-III 462		2.9um	0.92”/pix	2.5x	0.36”/pix	56 pix	2.5%
ZWO ASI715MC		1.4um	0.44”/pix	1.25x	0.35”/pix	57 pix	1.3%
C-6 SCT	0.19”						
QHY5-III 462		2.9um	0.40”/pix	2.0x	0.20”/pix	100 pix	4.5%
ZWO ASI715MC		1.4um	0.19”/pix	N/A	N/A	105 pix	2.4%
7” Maksutov	0.16”						
QHY5-III 462		2.9um	0.22”/pix	1.5x	0.15”/pix	133 pix	6.0%
ZWO ASI715MC		1.4um	0.11”/pix	N/A	N/A	182 pix	4.1%
C-8 SCT	0.14”						
QHY5-III 462		2.9um	0.29”/pix	2.0x	0.14”/pix	142 pix	6.4%
ZWO ASI715MC		1.4um	0.14”/pix	N/A	0.xx”/pix	143 pix	3.2%
10” F3.9 Astrograph	0.13”						
QHY5-III 462		2.9um	0.60”/pix	5.0x	0.12”/pix	167 pix	7.6%
ZWO ASI715MC		1.4um	0.29”/pix	2.5x	0.11”/pix	182 pix	4.1%
C-11 SCT	0.13”						
QHY5-III 462		2.9um	0.21”/pix	1.5x	0.14”/pix	143 pix	6.5%
ZWO ASI715MC		1.4um	0.10”/pix	N/A	N/A	200 pix	4.5%

We all love doing these calculations. However, the Astronomy Tools website has a tool that will do this for you if you. Go to the Field of View Calculator page, select the Imaging Mode tab and enter your equipment, and the target of interest to see what it will look like in your system.

C-6 with QHY 5-III 462

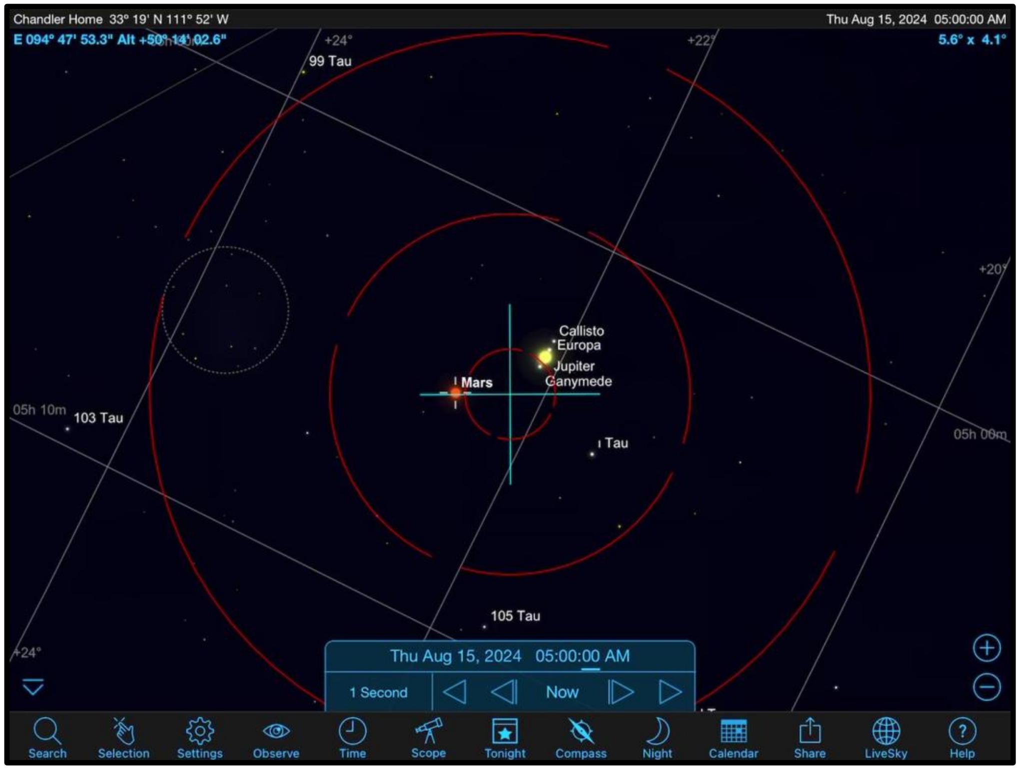


C-6 SCT with ZWO ASI715MC



Working Example 2: Planning for Jupiter/Mars Appulse

In this example, we identify an event we would like to capture and determine the best configuration to for our system. On 2024-08-14 at 5am Mars and Jupiter came within 19’ (0.32°) of each other (known as an Appulse)



Assuming the following Hardware:

- **Telescope**: SCT 11” | FL=2,800mm | Aperture=279.4mm | FR=10.0 |
- **Camera**: ZWO ASI462MC | Pixle Size=2.9 | Xres=1,936 | Yres=1,096 |
- **Calculations**: PixelScale= 0.21”/pix | Field of View=6.9’ x 3.9’ | → Hmm, FOV is too small!

What elements can we play with to see if we can get these to fit in the same picture?

- Get a camera with a larger sensor size
- Get a shorter focal length (Reducer or different telescope).

Let's take a look at both options and see what we can do

- Camera

  The current camera has a fairly small senor on it. If we bump this up to a full frame camera size (ZWO 6200MC) with

  Camera Specifications (ZWO 6200MC): | PixSize=3.76um | Xres=9,576 | Yres=6,388 |

  Calculations: | PixelScale=1.44"/pix | Field of View=44' x 29' |

  That works!

- Focal length

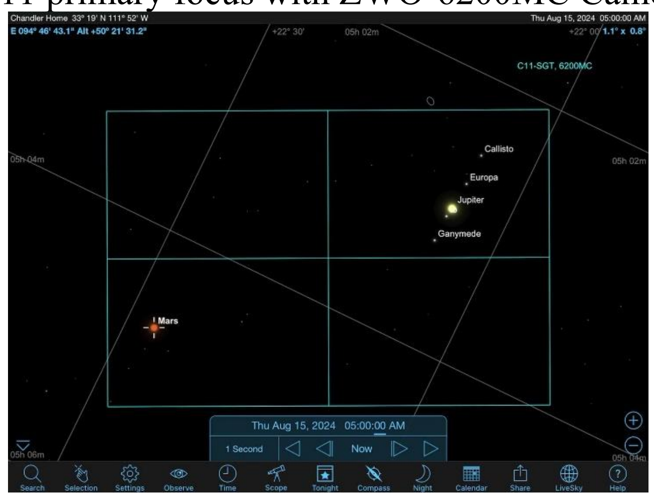
  Currently the longest axis of the field of view is 6.9', lets round that off to 6' since we will need a bit of tolerance. And let's also assume instead of 19' that the planets are apart that we are shooting for 30' (0.5°) distance to give us some wiggle room and it's an easy number to remember. This means we need to decrease our magnification from 6' to 30' so by about 5x. Not sure if you can get a 0.2 focal reducer. However, we may be able to utilize the HyperStar configuration that gives us a 540mm focal length. So going from 2800mm to 540mm = 2800/540 = 5.2 reduction! Hey just about perfect to get these two guys in the same field of view with a bit of wiggle room, so we might even be able to get a few of the moons of Jupiter in the shot!

  Telescope (SCT-11 w HyperStar): | FL=540mm | Aperture=279.4mm | FR=2.0 |

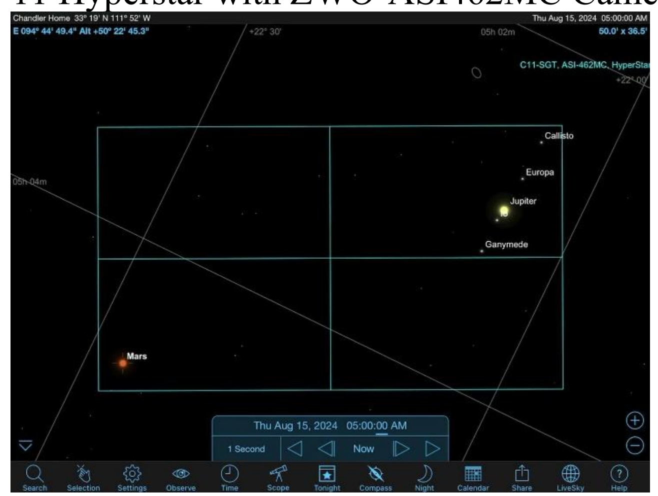
  Calculations: | PixelScale=1.11"/pix | Field of View=36' x 20' |

We can put our hardware specifications in a planetarium program to get an idea of how things should fit.

C-11 primary focus with ZWO-6200MC Camera



C-11 Hyperstar with ZWO-ASI462MC Camera



Chapter 7: Capture and Processing

Introduction

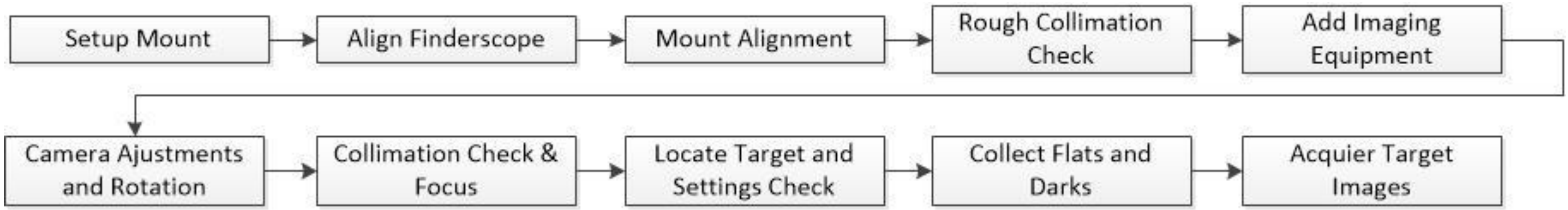
In this chapter we outline the basic steps for setting up and capturing images for processing. The steps outlined below in theory seem pretty straight forward. However, in practice this process can be very challenging. Locating and placing the target object on the camera sensor (especially smaller size sensors) can be very challenging. Usually, the focus point for an eyepiece compared to the camera sensor is quite different, so even if you have the target on the sensor, you may not notice it since the light can be so spread out over the sensor due to the focus being so far off. Increase the exposure time to see if you can see the familiar doughnut pattern of defocused stars. This is why having the finder scope alignment very close to the main telescope is critical. Your first target when starting imaging should be the moon since it will be the easiest target to locate. Using the moon to image, you can refine your technique. Another tool that may prove helpful is the flip mirror, allowing you to change from visual configuration to imaging configuration with the flip of a lever.

Planning Workflow

It is important to make proper preparations for an imaging session to ensure you have all of the required gear and plan how you would like to configure your optical train to ensure you get the best image possible for the evening. Planning location, time and what hardware will be required for the imaging session will help increases the changes of having a successful imaging session.

- **Identify Target(s):** Decide what your imaging targets will be for the upcoming imaging session and what sequence you would like to images the targets if you plan on imaging more than one.
- **Optical Train Configuration:** Understand what pixel scale you can obtain with your hardware and decide how you will configure your optical train to accomplish this. Utilize the to verify Field of View Calculator in your expectations.
- **Location and Time:** Using whatever applications or programs like Stellarium Web you have to determine when the targeted object will be best placed in the sky. Ideally the target to be as close to the meridian as possible to minimalize atmospheric interferences.
- **Choose a Location:** Select a location that will minimize ground and local sources of turbulence. Avoid shooting over roof tops, cement surfaces and other heat sources. Ideal locations might be in a large field or possibly close to an open body of water.
- **Software Updates:** Make sure you have the latest operating system and software updates for the application you will be utilizing.
- **Organize and Pack:** Have a checklist with all the gear you need and make sure to pack it all before you leave. Make sure you have enough storage space on your PC for the imaging session.

Imaging Session Workflow



- **Mount Setup**: Make sure you have all equipment needed for the imaging session. Locate a suitable location for the imaging session where there will be no obstructions when imaging. Make sure the mount is level and attach the Optical Tube Assembly (OTA). Balance the mount.
- **Align Finder Scope**: Make sure the finder scope is precisely aligned with the OTA.
- **Mount Alignment**: If you have an equatorial or GOTO mount you will need to perform an alignment procedure to ensure the telescope will track the object being imaged.
- **Rough Collimation Check**: Before attaching and utilizing the camera a collimation check should be performed to make sure the telescope is collimated. This is also a good time to check seeing conditions by defocusing the star and doing a visual evaluation of the defocused star.
- **Addition of Imaging Equipment**: Add camera and any associated equipment to the telescope and re-balance the mount.
- **Camera Adjustments and Rotation**: Startup the imaging software and connect to the camera make adjustments to settings, and slew to a bright star so you can fine tune any adjustments you may need to make to make sure the finder scope is aligned with the camera. Next synchronize the telescope axis with the camera axis. This is accomplished by centering the target star in the image and then slewing the telescope in one direction and take note of the movement of the star. Rotate the camera to orient it so the star moves either in the horizonal or vertical axes to match the telescope slew. Re-center the star and perform this process again until you are happy with the alignment.
- **Collimation & Focus Check**: Make sure the telescope has had time to cool down. Fine tune the collimation, check inside and outside focus. Perform focus on a star close to the target.
- **Locate Target and Settings Check**: Locate target. Review and adjust settings you will use to acquire images/video. Make sure not to have any areas over or under exposed.
- **Flats/Darks Acquisition**: Based on settings determined for the target collect flats/darks if needed.
- **Acquire Target Images**: You may want to recheck focus before acquiring the video or images of your target. Remember there may be limitations on how long you can collect images based on your system focal length and the rotation of the target being imaged.

Additional Techniques and Tricks

- **Locating Targets** – Can be particularly trick on small sensors near perfect alignment between the finder scope and the Optical Tube Assembly (OTA) is more critical the smaller the camera sensor since the area of sky covered by the camera is smaller on smaller sensors.
- **Initial Focus** – When switching from eyepiece to camera the focus point will most likely be quite different, and as a result the system may be so much out of focus that you may not initially see anything when viewing the image from the camera. This is because the cone of light from the target is spread out over the sensor in the form of a highly defocused doughnut. Try these steps to help obtain your initial focus:
    - **Gain and Exposure** - Raising the Gain and the exposure time drastically may help to bring the doughnut into view so you can begin to bring the image into focus.
    - **Use An Easy Target** – Use a large, bright target such as the moon or even a distant terrestrial target such as a street light to obtain initial focus.
    - **Parfocalizing Rings** – May be able to be employed to help address or reduce the issue of having a drastic difference in focus between eyepiece and camera.
- **Focus Mask** – Focus mask can help with ensuring you have the best focus possible. Utilize this on a bright star just before moving to the imaging target.
- **Flip Mirror** – Use of a flip mirror can be especially helpful if your camera sensor is rather small.
- **Histograms** – It is important to pay attention to the histogram to ensure you obtain as much detail as possible when imaging a target. Histograms can identify underexposure (Shadow Clipping) and underexposure (Highlight Clipping).
- **Optimizing Capture Parameters** – These parameters all interplay with each other, it is important to obtain the best combination between these to ensure as successful image session.
    - **Telescope Aperture size** – Most of us don't have much control over this parameter, just remember larger aperture means more light gathering power, allowing higher resolution and shorter exposures.
    - **Region of Interest** – For camera with large sensors it may be beneficial to define a sub section of the sensor for image capture (Region of Interest) to minimalize download time and decrease the file size associated with the image.
    - **Gain** – Increasing gain will allow you to decrease shutter time, but at the expense of introducing more noise into the image.
    - **Exposure Time** -Decreasing exposure time down to about between 0.5 to 0.1 second will allow you to capture the brief moments of exceptional seeing. The shorter the exposure time the better.

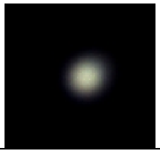
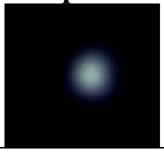
Additional Considerations for Various Targets

Provided below are some general guidelines for settings and considerations for imaging the specified targets. These should be considered strictly as a starting point for consideration; The actual values that work best for you may by quite different based on your equipment and preferences.

- **Dynamic Range for the Moon & Sun** can have a large dynamic range. Camera settings need to be adjusted to capture this range
  - Camera Gain: Should be low (*Note: the newer low-noise cameras can still have relatively high gain without serious impact to the noise introduced*)
  - Bit Depth: Should be set high if possible (ie 12 or 16)
- **Dynamic Range for the planets** generally is generally low, so Gain and Bit dept can be relaxed to help lower exposure time and file save time
  - Camera Gain: Can be adjusted upwards
  - Bit Depth: 8-bit dept is generally adequate.
- **Save File format**: SER video format is preferred for size, bit depth support and speed considerations and are most commonly utilized, however AVI is the most flexible in that it is supported by most video players.
- **More is Better**: The signal to Noise (S/N) ratio of a combined image increases with the square root of the number of stack images
- **Filters**: The listed filters below are possible recommendations for teasing out more details of the target. If a colored camera is utilized many of these filters will result in a monochrome image. Filters that transmit shorter wavelengths (i.e., the UV/Blue end of the spectrum) allow for higher resolution but are more impacted by atmospheric conditions. Filters that transmit longer wavelengths (i.e., the Red/IR end of the spectrum) are less impacted by atmospheric conditions but provide lower resolution. Additionally, smaller telescopes are less impacted by atmospheric conditions relative to larger telescopes. REF: The optical resolution and the wavelength.

Object	Filters	References	Comments
Sun 	Solar Film H-alpha Ca-K	SOHO SpaceWeather.com	• Apparent size of disk ranges from 4.5” to 13” • Max Capture Duration: 720s • Average Exposure Time: 5-10ms • Sun Information including upcoming events
Moon 		TheSkyLive Moon Atlas Moon Globe HD	• Apparent size of disk ranges from 4.5” to 13” • Max Capture Duration: 720s • Average Exposure Time: 5-10ms • Moon Information including upcoming events • Small aperture telescope may consider a CMOS green filter

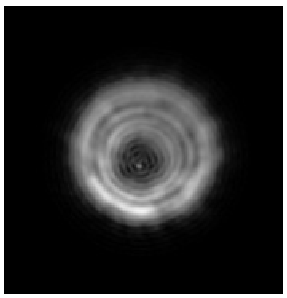
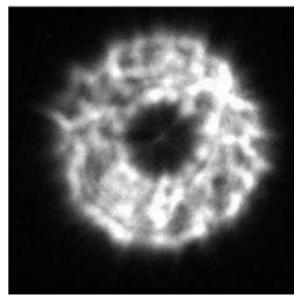
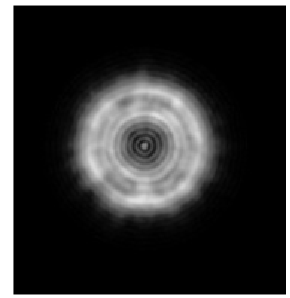
Object	Filters	References	Comments
Mercury 	IR Pass R+IR	USGS Maps Location & Size	• Apparent size of disk ranges from 4.5" to 13" • Max Capture Duration: 720s • Average Exposure Time: 5-10ms • Mercury Information including upcoming events • Only rises a few degrees above the horizon for an observer outside of the equatorial latitudes of the tropics. • Utilization of R+IR filters may help counter atmospheric effects due to the low angle of Mercury. • Most favorable viewing/imaging conditions in evening spring and morning autumn. • Color variations on disk may be visible for larger size telescopes.
Venus 	Blue IR	USGS Maps Location & Size Venus Filters	• Apparent size of disk ranges from 9.5" to 66" • Max Capture Duration: 120s • Average Exposure Time: 5-10ms • Venus Information including upcoming events • No surface details visible on this planet due to the clouds. However, Utilization of Ultraviolet, Violate and IR filters may provide cloud details; best with a monochrome camera.
Mars 	Blue R+IR	USGS Maps Location & Size	• Apparent size of disk ranges from 3.4" to 25.1" • Max Capture Duration: 90s • Average Exposure Time: 10ms • Mars Information including upcoming events • Blue and Ultraviolet filters for capturing clouds R+IR for planet details
Jupiter 	Methane	Location & Size	• Apparent size of disk ranges from 29.8" to 50.1" • Max Capture Duration: 45s • Average Exposure Time: 10ms • Jupiter Information including upcoming events • Methane (CH_4) filter of limited use for identifying some storms
Saturn 		Location & Size	• Apparent size of disk ranges from 14.9" to 20.7" • Max Capture Duration: 600s • Average Exposure Time: 10ms • Saturn Information including upcoming events

Object	Filters	References	Comments
Uranus 		Location & Size	• Apparent size of disk ranges from 2.1” to 2.3” • Max Capture Duration: 720s • Average Exposure Time: 100-200ms • Uranus Information including upcoming events
Neptune 		Location & Size	• Apparent size of disk ranges from 3.3” to 4.0” • Max Capture Duration: 720s • Average Exposure Time: 100-200ms • Neptune Information including upcoming events

Defocus Star Test

It is vital that your telescope is collimated to ensure that this doesn't limit the quality of the images you capture. The collimation process varies from telescope type to telescope type. Some telescopes such as reflectors may not need collimation, while others such as Schmidt-Cassegrain (SCT) and refractors may need collimation quite often. A quick check on collimation can be performed either with the GoldenFocus Plus Collimation Mask, or a Defocus Star Test. For Schmidt-Cassegrain telescopes, make sure to check both the inside and outside focus of the star.

Defocus Star Test

Collimation Needed	Turbulent Conditions	Good Collimation
		

Golden Focus & Defocus Star Test – Good Collimation

The collimation process details dependents upon the type of telescope being collimated. Ref: Five tips to know to better collimate your telescope.

Software and Applications

There are many applications and software packages available to help telescope setup, image capturing and processing. Luckly most software is either free or very reasonably priced.

- Planning
  - ASCOM Drivers: Many mounts, cameras, and other hardware require utilize the ASCOM protocol for communicating with software. Make sure to have the latest platform installed on your computer if you use ASCOM.
  - SkySafari 7 application: Probably the best planetarium app available for your smart phone.
  - Stellarium Web: Online planetarium, you can also download the app on your smartphone
  - SOHO website: Feed from the Solar & Heliospheric Observatory to see what's is happening on the sun.
  - MoonGiant website: Good information on the moon
  - Virtual Moon Atlas: Software has mor details on the moon than you could ever want.
  - JupiterMoons app: (Apple) application shows where the moons of Jupiter at a given time.
  - This Years Astronomical Events webpage: List major astronomical events for the year.
- Imaging Session
  - Polar Scope Align Pro: Great tool for equatorial mounts to help with the polar alignment procedure. This app installs on your apple or android phone.
  - Sharpcap: Great application for capturing images with your camera. Main advantage of this application is it's easy to use interface.
  - FireCapture: Another application for capturing images, probably has some more features than Sharpcap, but has a more complex interface.
  - PHD2 Guiding: Telescope guiding software that tracks objects for long exposures. You should have a ASCOM compactable mount with appropriate drivers for best performance, but it may not be needed depending on what your imaging target is and the performance of your mount.
- Processing
  - Planetary Imaging Pre-Processor (PIPP): This software pre-processes your video to prepare it for processing.
  - WinJupos: Used for processing and analyzing planetary images, but it's much more than this and is actually the software equivalent of a Swiss Army Knife for the Solar System.
  - AutoStakkert!: Sofware used for stacking images together to create one image from many.
  - WaveSharp: Used for sharpening images. This is new software to replace Registax
  - GNU Image Manipulation Program (GIMP): Free replacement for Photoshop.
  - IrfanView: Another image manipulation software.

Processing Workflow

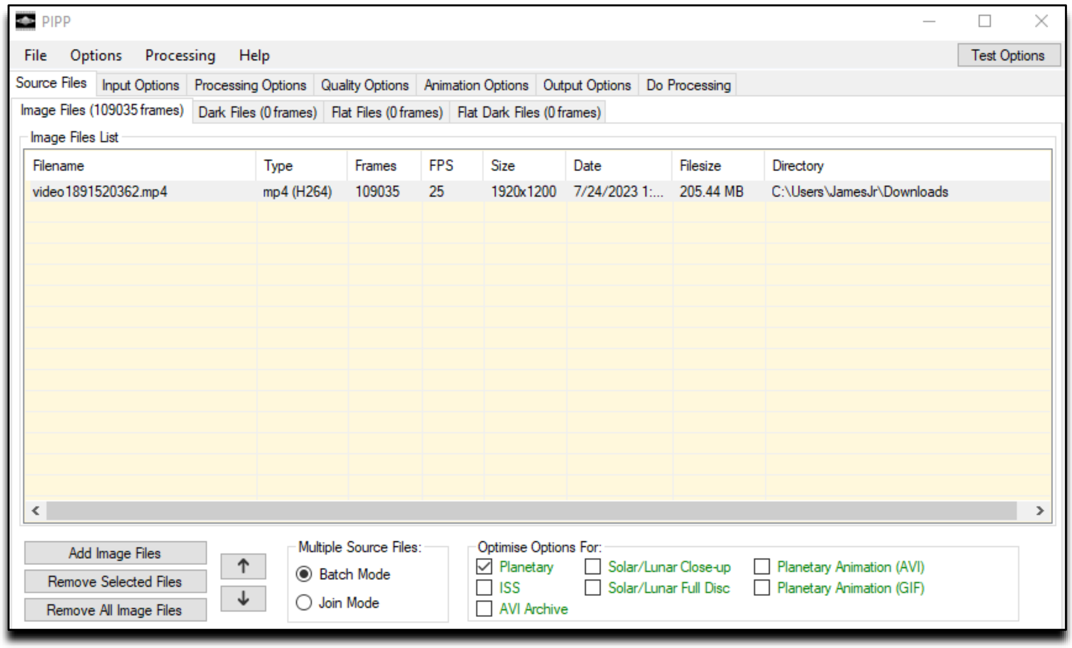
There is no one size fits all workflows when it comes to processing images. Provided below is the workflow that I have found works well for me.

- **Review Video**: Review the captured video to make sure it is what you expected before starting to work on it.
- **PIPP**: Utilize this program to generate an AVI video. This program can be used to track, crop and select the best images of the source video.
- **AutoStakkert!**: This application will be used to stack all individual frames from the AVI video into a single TIFF image.
- **WaveSharp**: Taking the TIFF image apply wavelets to sharpen the image and bring out details.
- **Microsoft Photos**: Used for fine tuning brightness of the image.
- **GIMP**: Used to add notation to the image.
- **IrfanView**: Utilized to resize photo and generate thumbnails of the photo.

Planetary Imaging Pre-Processor (PIPP)

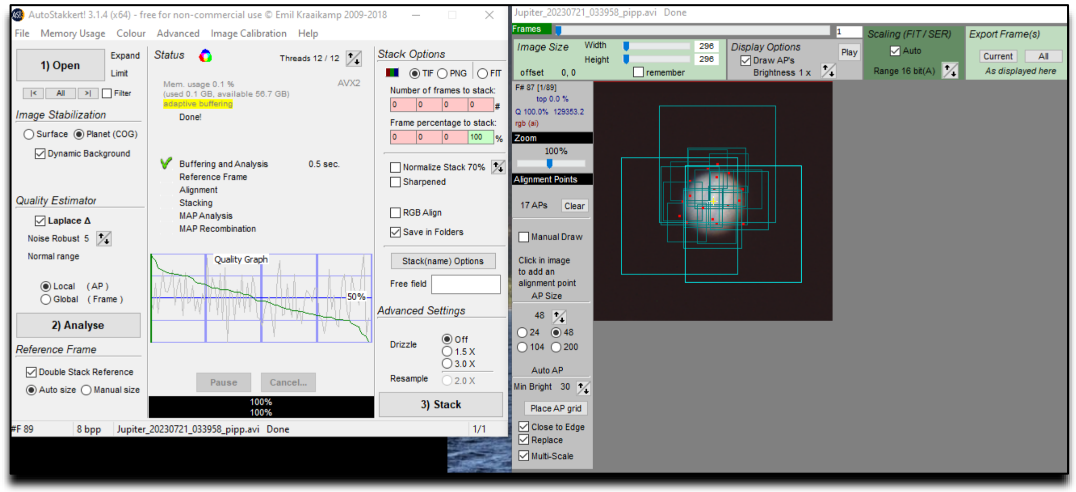
This program is very effective in combining image files, darks and flats and performing various preprocessing actions to output an AVI file that is has the target object centered, cropped and rotated to your needs.

- **Source Files** tab
  - Image Files tab
    - Add Image File
    - Optimise Options section
  - Dark Files tab – Add files
  - Flat Files tab – Add files
  - Flat Dark Files tab – Add files
- **Processing Options** tab
  - Histogram Equalisation section
    - Stretch Histogram White Point to 85%
  - Flip And Rotate section
  - Cropping section
- **Quality Options** tab
  - Quality Estimation section
  - Quality Limiting section
- **Output Options** tab
  - Output Forma section: AVI
  - Output Directory section
  - Output Subdirectory section
  - AVI File Options section
- **Do Processing** tab
  - Test Options
  - Start Processing



AutoStakkert!

AutoStakkert! Inspects each frame in the video and will stack them and generate a single TIFF image.

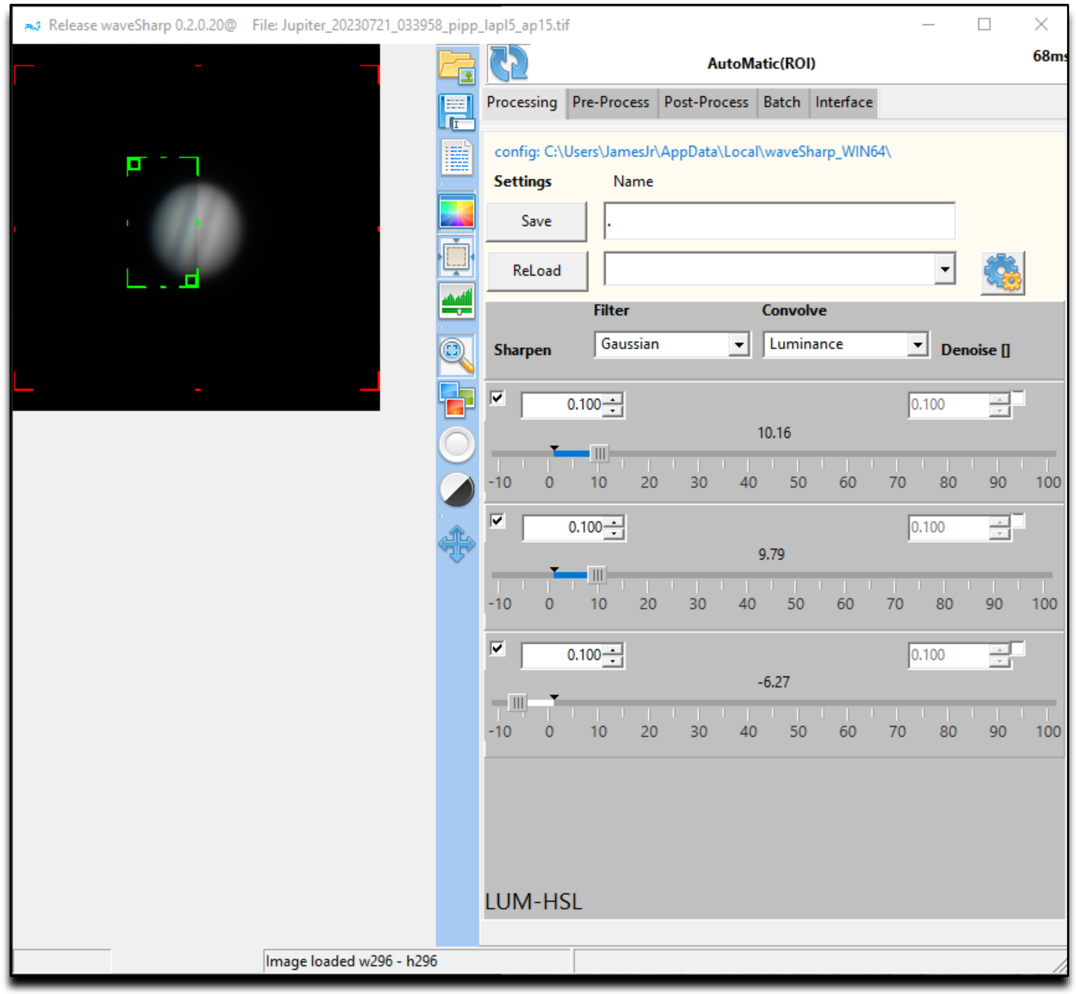


- **Program** window
    - **Open** button
        - Open the AVI file created by PIPP
    - **Image Stabilization** section
        - Surface: Moon & Sun
        - Planet: Planets
    - **Analyse** button
        - Review Quality graph
    - **Stack Options** section
        - TIF output format
        - Percent of frames
- Image window
    - **Alignment Points** section
        - Select size and place AP in grid (10-50) points should work

WaveSharp

WaveSharp replaces RegiStax for performing sharpening operations on the TIFF image.

- **Image** frame
  - Shows photo being processed
  - Red frame indicates zoom-in region for preview pop-up window.
  - Green frame is used to define preview area for sharpening operations.
- **Tools** strip
  - This vertical strip straddles the Image frame and the Where selection of various tools is available.
- **Actions** frame
  - **Processing** tab: Perform sharpening
  - **PreProcess** tab: Rotation and color enhancements
  - **Pors-Process** tab: Trim and resize.
  - **Batch** tab: Batch operations
  - **Interface**: Application Preferences



References and Resources

Title	Type	Description
A Guide to Planetary Imaging and Processing	Website	The London Astronomer website
Five tips to Collimate your Telescope	Website	Provides hints on making collimation easier
No-Tools Telescope Collimation	Website	Details on how to collimate telescopes using a star
How to star test a telescope	Webpage	Sky at Night Magazine
SCT Collimation Guide	Webpage	Celestron

Appendix

Measuring Field of View for a Telescope/Eyepiece Combination

Most eyepieces have not only the **Focal Length** (FL) printed on them but also the **Apparent Field of View** (AFOV). Although, not all manufactures provide the **Apparent Field of View** (AFOV) for their eyepieces. This is especially true for lower cost packages where the telescope comes with a number of eyepieces. If this information is not provided, you can manually measure the field of view and back-calculate the **Apparent Field Of View** (AFOV) for an eyepiece by following the procedure below:

- Locate any star near the celestial equator (ie +/- 10 degrees DEC).
- Center the star in your eyepiece.
- If you have a clock drive turn it off or if you have a computer controlled drive disable tracking.
- Using the RA control only, move the star to the edge of the field of view so it will track across into the eyepiece when observing it.
- Record the number of seconds it takes for the star to travel across the field of view until it is no longer visible in the eyepiece (**Recorded Time**).

$$\boldsymbol{FOV Measured} = \frac{(Recorded\ Time)}{(240)}$$

Where

$FOV_{Measured}$ = Measured Field Of View in units of degrees °
$Recorded\ Time$ = Time in Seconds it take the star to travel across the field of view

Now we can back-calculate the **Apparent Field Of View** (AFOV) for the eyepiece

$$\boldsymbol{AFOV_{Eyepiece}} = (FOV_{Measured}) \times (\frac{FL_{Telescope}}{FL_{Eyepiece}})$$

Where

$AFOV_{Eyepiece}$ = Calculated Apparent Field of View in units of degrees °
$FOV_{Measured}$ = Measured field of view in units of degrees °
$FL_{Telescope}$ = Focal Length of Telescope in units of millimeters
$FOV_{Measured}$ = Focal Length of Eyepiece in units of millimeters

Glossary

This section contains many terms associated with planetary imaging. The following resources were used for these definitions:

- A Guide to DSLR Planetary Imaging (Jerry Lodriguss)
- Sky & Telescope: Astronomy Terms

Afocal photography – Placement of a camera or smartphone up to the eyepiece of a telescope and taking an image.

Angular Resolution - The angular size of detail that is resolved in an image.

Aperture – The diameter of a telescope's objective lens.

Atmospheric Prismatic Dispersion - When light from a celestial object is broken into its constituent colors by the prismatic effects of the Earth's atmosphere.

Averaging - Adding together a number of frames and dividing by the total. Averaging many frames together increases the signal-to-noise ratio in an image by the square root of the total number of images used. It works because the sign

Barlow Lens - Barlow lenses are the most versatile telescope accessory you can get. A Barlow lens is a device you can use in a telescope before an eyepiece to increase the magnification you would normally get. They do this by decreasing the focal length of your optical chain by the number of times they are rated for (1.5x, 2x, 3x, etc).

Bayer Array/Pattern - Color astrophotography camera sensors have a filter system over the imaging sensor that converts data into color. The Bayer filter system creates a color image by using tiny color filters over each pixel. The filters comprise of red, green, and blue (RGB) colors, with only one color per pixel. To best match what our eyes see, the Bayer filter uses two green pixels for every one red and blue pixel (e.g., RGGB). This pattern then repeats in 2×2 pixel blocks throughout the entire photo, which to our eyes, forms a color image.

Bit Depth - Describes the number of steps of tonal resolution, or brightness levels, that the dynamic range is divided into when it is quantized by the Analog to Digital converter. Bit depth is specified in base 2 notation. Eight bits is 28 or 2 raised to the 8th power. 8 bits equals 256 steps or levels of information. 12-bits is 212 and equals 4,096 levels. 16-bits is 216 and equals 65,536 levels.

Black Point - The darkest area of an image that is mapped to level 0 (completely black) when setting the dynamic range during a levels adjustment in image processing.

Color Filter Array (CFA) - An arrangement of individual color filters over individual pixels in a CCD or CMOS detector designed to synthesize color from a grayscale sensor. A Bayer array using red, green and blue pixels is the most common type of CFA. A CFA image is a monochrome (black and white and grayscale) image containing data from the Bayer array in the CCD or CMOS sensor in the DSLR camera that has not yet been interpolated into color. It presents the data from each individual filter, which ha

Clip, Clipping - To lose, cut off, or saturate data at either end, black or white, of the dynamic range by overexposure or incorrect manipulation of data.

Codec - A mathematical algorithm that compresses and decompresses, or encodes and decodes data into a digital format.

Collimation - Collimation is the precise aligning of the optical elements in a telescope so that it performs as well as it can.

Color Depth - The number of steps or levels of tone that each primary color of the total dynamic range is divided into. In 24-bit color, 8 bits of color depth are assigned to each color channel of red, green and blue is represented by 256 steps. This yields more than 16 million total colors (256 * 256 * 256 = 16,777,216).

Dawes Criterion - Derived by William Rutter Dawes, this empirical measure of the resolving power of a telescope for two stars of similar brightness observed in a modestly sized telescope. The formula is $\theta = (1.02 * \lambda / D) * 206,265$ where θ is the angular separation in arcseconds, λ is the wavelength in millimeters, and D is the diameter of the aperture of the telescope in millimeters.

Deconvolution - Deconvolution is a process that attempts to remove the effects of convolution. For example, deconvolution was used to attempt to restore the aberrated images in the Hubble Space Telescope that were caused by spherical aberration.

Detail Smearing - High resolution detail on planets that are smeared in long exposures by planetary rotation.

Diffraction- High resolution detail on planets that are smeared in long exposures by planetary rotation.

Diffraction Limited - A telescope is said to be "diffraction limited" if its optics are made with enough accuracy so that all the light rays from a star fall within that star's Airy disk and diffraction rings, with no excess light being scattered out of the disc and rings by defects in the mirrors. Optics that bring all light rays to a focus within 1/4th of a wavelength of light of each other at the final focus are considered to be diffraction limited.

Dispersion - When light from a celestial object is broken into its constituent colors by the prismatic effects of the Earth's atmosphere.

DPI - Dots Per Inch. A measure of resolution that refers to the number of dots a printer can print in an inch of output. Higher resolution means more dots per inch. Often mistakenly used for PPI, or pixels per inch. It more correctly applies to output devices that print with dots, such as inkjet printers.

DSLR - Digital Single Lens Reflex. A camera that uses a mirror to intercept the light from the camera's lens and send it to a focusing screen for inspection by the photographer's eye. The reflex mirror swings up and out of the way when the picture is taken, allowing the light to reach the digital sensor.

Dynamic Range - The range of brightness from light to dark in which detail can be recorded.

Planetary Imaging Primer

Equatorial Mount - A telescope mount designed with two axes, one of which (the Polar axis) is made parallel to the Earth's axis of rotation. Movement in this single axis allows celestial objects to be followed to compensate for the Earth's rotation. Any object in the sky can be found by a combination of movements in the two axes. The polar axis corresponds to right ascension, and the other axis to declination.

Exposure - The length of time that the shutter is open and light is hitting the sensor in the camera.

Extinction - Extinction causes the brightness of celestial objects to diminish. Extinction is caused by absorption and scattering of light in the atmosphere.

Eyepiece Projection - A method of photography where the image is formed at the focal plane of the camera by projection by the eyepiece in a telescope. No camera lens is used on the camera, only the telescope's eyepiece is used in the scope.

Field of View (FOV) **-** The circle of sky that you see when you look through a telescope or binoculars. Generally, the lower the magnification, the wider the field of view.

Finderscope - A small telescope used to aim your main scope at an object in the sky. Finderscopes have low magnifications, wide fields of view, and (usually) crosshairs marking the center of the field.

Field Rotation - Rotation of the field of view around the center of the field in an altazimuth mount tracking the stars, or around a guidestar tracking the stars on a misaligned equatorial mount.

Filter - 1.) A piece of glass or gelatin placed in the optical path that modifies the wavelength or light that ultimately reaches the sensor. An example would be a hydrogen-alpha filter that only allows the light of the hydrogen-alpha wavelength to pass. 2.) A piece of software that performs particular algorithms on digital data. An example would be a Gaussian blur filter in Photoshop that blurs an image.

Frames Per Second (fps) - The number of frames that are recorded or played back per second.

F/Stop - The designation marker on a lens that indicates the focal ratio that is being created by stopping down the aperture of the lens with an internal diaphragm inside of the lens. The f/stop is same thing as the focal ratio or f/ratio. It is defined as the ratio between the aperture and focal length of an optical system. For example, a 125 mm aperture telescope with a focal length of 1,000 mm has a focal ratio of 1,000 / 125 or f/8.

Focal Length - The distance (usually expressed in millimeters) from a mirror or lens to the image that it forms. In most telescopes the focal length is roughly equal to the length of the tube. Some telescopes use extra lenses and/or mirrors to create a long effective focal length in a short tube.

Focal Ratio (F/ratio, F/number) - A lens or mirror’s focal length divided by its aperture. For instance, a telescope with an 80-mm-wide lens and a 400-mm focal length has a focal ratio of f/5.

Full Width Half Maximum (FWHM) **-** A measurement of the diameter of a star where the intensity is 50 percent of the star's maximum brightness value.

GOTO Mount - A computerized telescope mount with a database of objects that will automatically point the scope to an object when selected.

Greatest Elongation - The largest angle between the Sun and an inferior planet as viewed from Earth.

Histogram - A plot of the number of pixels in an image at each brightness level. It's a useful tool for determining the optimum exposure time; the histogram of a properly exposed image generally peaks near the middle of the available brightness range and falls to zero before reaching either end.

Image Scale - The size on an image formed by a lens or telescope based on the magnification of the optical system in relation to the sky. Image scale is usually measured in a digital camera as arcseconds per micron, or arcseconds per pixel.

Inferior Conjunction - When the two planets lie in a line on the same side of the Sun, the planet closest to the Sun is in inferior conjunction and the outer planet is at superior conjunction, relative to each other.

Inferior Planet - One of the planets inside of the orbit of another planet. Mercury and Venus are inferior planets to the Earth.

Infrared (IR) **-** Long wavelengths of light beyond the visible portion of the spectrum, typically between 770 nanometers and 1 millimeter.

Integration - Collecting photons for a given exposure time to accumulate a charge or signal in a digital sensor. Integration time is essentially equivalent to exposure time.

Interpolation - A mathematical procedure for increasing resolution by up-sampling, or decreasing resolution by down-sampling. Up-sampling creates new data from existing data and increases file sizes. It is not real data though, it is the algorithm's best guess at what the real data would have been if it had actually existed. Down-sampling lowers resolution and decreases file size by throwing away real data in existing pixels and creating new pixels.

ISO - An international standard published by the International Organization for Standardization. In the field of photography, the term ISO is used as a shorthand name for the standard defined by the specification for determining the sensitivity to light of film or a digital camera sensor. In film, a higher ISO number means the film is more sensitive to light. Digital camera sensors really only have one sensitivity to light though. Changing the ISO on a digital camera changes the gain in the camera, seemingly changing the sensitivity. For dedicated astronomy camera's Gain is considered the equivalent.

Jet Stream - A fast moving, narrow current of air found in the upper atmosphere near the tropopause on Earth.

Light Pollution - A glow in the night sky or around your observing site caused by artificial light. It greatly reduces how many stars you can see. Special light-pollution filters can be used with your telescope to improve the visibility of celestial objects.

Limb - The edge of a celestial object's visible disk.

Linear Resolution - The linear size of detail that is resolved in an image.

Linear Response - A response in a digital sensor where the output directly corresponds to the input signal. Most CCD and CMOS sensors have a linear response to light, that means that a doubling of exposure time results in a doubling of brightness in the recorded image.

Live View - The display of a near real-time video feed from the sensor of a camera to an LCD screen

Lossless Compression - A compression method, such as LZW, where the original data is completely preserved and no information is thrown away. Lossless compression usually only results in a modest saving in file size for images.

Lossy Compression - A compression method, such as JPEG, where data is thrown away to gain increased compression ratios and smaller file sizes.

Lucky Imaging - Shooting many frames in a video in the hope of getting lucky and capturing high-resolution planetary detail in moments of good seeing. The frames are then graded for quality, and "stacked" or averaged together either as a whole frame, or with multiple alignment points to produce an image with higher quality than a single image.

Magnification (power)- The amount that a telescope enlarges its subject. It’s equal to the telescope’s focal length divided by the eyepiece’s focal length.

Magnitude - A number denoting the brightness of a star or other celestial object. The higher the magnitude, the fainter the object. For example, a 1st-magnitude star is 100 times brighter than a 6th-magnitude star.

Meridian - The imaginary north-south line that passes directly overhead (through the zenith).

Mosaic - 1.) In digital sensors, an arrangement of non-overlapping tiles or pixels that constitute the sensor array, such as a Bayer pattern in a DSLR CCD or CMOS sensor. 2.) In an astrophotography, a mosaic is a wider-angle picture made up of a series of narrower-angle pictures. Each individual tile in the larger picture is shot so that there is some overlap with the tile next to it so that individual images can be correctly aligned. When the individual images are put together like a puzzle to form the larger image, the edges of the tiles that overlap are blended together seamlessly so that the edges are invisible. This creates a higher-resolution images with wider fields of view than would normally be possible.

Mount - The device that supports your telescope, allows it to point to different parts of the sky, and lets you track objects as Earth rotates. A sturdy, vibration-free mount is every bit as important as the telescope’s optics. A mount’s top, or head, can be either alt-azimuth (turning side to side, up and down) or equatorial (turning parallel to the celestial coordinate system). “Go To” mounts contain computers that can find and track celestial objects automatically once the mounts have been aligned properly.

Movie Crop Mode - A special high-definition movie recording mode found on Canon T2i (550D), 60D and 60Da DSLR cameras that records the central 640 x 480 pixels in the camera sensor at 60 frames per second.

Native Resolution - The natural or optical resolution of a sensor or image where the original number of pixels is not changed.

Noise - Technically, random and non-repeatable signal in an image. In common use in digital photography, any unwanted or undesirable signal that does not convey useful information. For example, a dark frame is composed of thermal current signal, thermal signal noise (and bias). Thermal and bias signals are technically not noise because they are consistently repeatable, and this is how we are able to remove them by subtraction with a calibration frame. Thermal signal noise is random and cannot be removed. However many people refer to thermal current as "noise".

Normalization - Applying a mathematical function like multiplication to data from one image to make it match another. For example, multiplying each pixel's brightness value by 2x in a 30 second exposure to make it match the pixel values in a 1 minute exposure.

Nyquist Sampling Theorem - A theorem in communications theory, formulated by Harry Nyquist in 1928, that says when converting an analog wave form to digital data, the sampling must be at two times the highest frequency of the original to preserve all of the information in the original. The theorem can also be applied to spatial information such as high-resolution detail in an image that is sampled by the pixels in a digital sensor.

Objective - A telescope’s main light-gathering lens or mirror.

Occultation - When the Moon or a planet passes directly in front of a more distant planet or star. A grazing occultation occurs if the background body is never completely hidden from the observer.
One-Shot Color

Opposition - When a planet or asteroid is opposite the Sun in the sky. At such times the object is visible all night — rising at sunset and setting at sunrise.

Oversample - To use more resolution than is necessary to correctly sample the high-resolution detail in an image.

Photon - A quantum of electromagnetic energy usually associated with light. Photons appear to be both waves and particles simultaneously.

Pixel - A "Picture Element". In a digital camera, it refers to an individual photo site on the CCD or CMOS sensor. In the image it refers to the smallest building block out of which the image is made. A pixel on the sensor corresponds one to one with a pixel in the final image.

Pixel Array - A grid or rectangular arrangement of pixels in the CCD or CMOS sensor in a digital camera.

Pixel Size - The physical size of the pixel in the pixel array in the sensor. Usually measured in microns. For example, the size of each individual pixel in the Canon 20Da camera is 6.4 microns square.

Pixel Well - An area in a photo site where electrons are stored that are released from the silicon surface by the energy of impacting photons through the photoelectric effect. Also called a potential well.

Pixelization - Pixelization occurs when an image is enlarged so much that individual pixels become visible.

Pixels Per Inch (PPI) - Pixels Per Inch. A basic measurement of resolution. More pixels per inch yield higher resolution images.

Point Spread Function (PSF) **-** A mathematical description of how the light from a theoretical point source like a star is spread out by seeing, diffraction, optical quality, tracking accuracy, and the resolution of the sensor.

Polar Alignment - Making the polar axis of an equatorial mount parallel to the Earth's axis of rotation by pointing it accurately at the North Celestial Pole in the Northern Hemisphere, or the South Celestial Pole in the Southern Hemisphere.

Prime Focus - Prime focus describes a camera attached to a telescope without any other eyepieces or camera lenses in the optical path. The telescope then acts as the camera lens.

Prismatic Dispersion - When light from a celestial object is broken into its constituent colors by the prismatic effects of the Earth's atmosphere.

Rayleigh Criterion - Derived by Lord Rayleigh (John William Strutt), The Rayleigh criterion says that two stars are resolved when the brightest part of the center of one star (the maxima) is centered over the first interspace (the minima) between the disk and the first ring of the other star. The formula is $\theta = (1.22 * \lambda / D) * 206{,}265$ where θ is the angular separation in arcseconds, λ is the wavelength in millimeters, and D is the diameter of the aperture of the telescope in millimeters.

Reddening - Objects in the sky close to the horizon appear more red because of Rayleigh scattering.

Reflector -A telescope that gathers light with a mirror. The Newtonian reflector, designed by Isaac Newton, has a small second mirror mounted diagonally near the front of the tube to divert the light sideways and out to your eye.

Refractor - A telescope that gathers light with a lens. The original design showed dramatic rainbows, or “false color,” around stars and planets. Most modern refractors are achromatic, meaning “free of false color,” but this design still shows thin violet fringes around the brightest objects. The finest refractors produced today are apochromatic, meaning “beyond achromatic.” They use expensive, exotic kinds of glass to reduce false color to nearly undetectable levels.

Retrograde - When an object moves in the reverse sense of “normal” motion. For example, most bodies in the solar system revolve around the Sun and rotate counterclockwise as seen from above (north of) Earth’s orbit; those that orbit or spin clockwise have retrograde motion. This term also describes the period when a planet or asteroid appears to backtrack in the sky because of the changing viewing perspective caused by Earth’s orbital motion.

Refraction - The change in direction of a wave due to a change in the medium through which it is traveling. In astronomy, refraction is the angular amount which the apparent altitude of a celestial body is increased by refraction in the Earth's atmosphere

Resampling - Resizing an image by mathematical algorithms that examine neighboring existing pixels and create new ones based on this analysis.

Resolution - 1.) Producing separate images of close objects such as stars or fine details in a subject. 2.) Spatial Resolution is the number of pixels that we have in an image, and the size of the space that these pixels are contained in. Two parameters are necessary to specify resolution: the number of pixels per inch or centimeter and the total number of inches or centimeters. More pixels in a given space mean higher resolution. Tonal resolution specifies the number of steps of tone that the dynamic range is divided into.

Resolution, Angular - The angular size of detail that is resolved in an image.

Resolution, Linear - The linear size of detail that is resolved in an image.

Resolving Power - The ability to resolve fine detail in an image.

RGB - Red, Green and Blue. These are the three primary colors, out of which all other colors can be created, in the additive color model.

Sampling - Measurement in discrete, regular intervals. Spatial sampling in a digital camera is done by the number of pixels in a given sized area sensor. Tonal sampling is determined by the bit-depth of the analog to digital converter. Correct spatial sampling in high-resolution astrophotography matches the sample size (pixel size) to the size of the Airy disk and seeing, based on the Nyquist sampling theorem.

Saturation - 1.) Tonal or pixel values on the bright end of the dynamic range that are maxed out and contain no detail. 2.) The purity or vividness of a color.

Scaling - 1.) Changing the black or white endpoints in image histogram to modify the data so that it changes its distribution in the dynamic range. 2.) Enlarging or reducing the size of an image.

Scattering - The diffusion of light in the atmosphere caused by particles such as atoms and molecules smaller than the wavelength of light scattered. It can be caused by atmospheric gasses as well as smoke and other particulates

Scintillation - Rapid changes in the brightness of a celestial object due to atmospheric turbulence.

Seeing - A measure of the atmosphere's stability. Poor seeing makes objects waver or blur when viewed in a telescope at high magnification. The best seeing often occurs on hazy nights, when the sky's transparency is poor.

Seeliger Effect - The brightening of an object when the Sun lies directly behind the observer at opposition. Also known as the opposition surge.

Sensor - Usually refers to the CCD or CMOS chip in the camera that senses photons of light and turns them into electrons which ultimately end up as digitized numbers that represent the light that hit the sensor.

Sidereal Time - A measure of time by the stars, sidereal time marks the right ascension of stars on your local meridian at any moment.

Signal - In a digital camera, the signal is an electric current or voltage, whose variations represent information. For example, the number of electrons released through the photoelectric effect from photons from a star forms a current that represents the brightness of the star. Signals can be interesting, such as those from astronomical objects, or not interesting, such as that from thermal current.

Signal-to-Noise Ratio - A measure of the quality of a signal, expressed as the ratio of the signal to the noise present.

Smearing - The loss of high resolution detail on planets caused by planetary rotation in long exposures.

Sparrow Criterion - Derived by C. M. Sparrow for the resolution of double stars, the Sparrow criterion that said an observer could detect duplicity when two equally bright stars were elongated. The formula is $\theta = (0.95 * \lambda / D) * 206{,}265$ where θ is the angular separation in arcseconds, λ is the wavelength in millimeters, and D is the diameter of the aperture of the telescope in millimeters.

Spatial Resolution - The amount of detail contained in a given space. In digital imaging, spatial resolution is defined by the number of pixels per unit area.

Spot Size - The size of the Airy disk.

Stack, Stacking - To align and average multiple images to improve detail and the signal-to-noise ratio in the resulting image. Derived from the days of film when two pieces of film were physically stacked on top of each other.

Star Diagonal - A mirror or prism in an elbow-shaped housing that attaches to the focuser of a refractor or compound telescope. It lets you look horizontally into the eyepiece when the telescope is pointed directly overhead.

Stretching - Redefining the black or white points in an image to increase the contrast.

Superior Conjunction - When the two planets lie in a line on the same side of the Sun, the planet closest to the Sun is in inferior conjunction and the outer planet is at superior conjunction, relative to each other.

Sufficient Sampling - Having enough pixels at a size smaller than the detail to be recorded so that all of the detail present is captured.

Summing - Mathematically adding together individual shorter-exposure images to create the equivalent of a longer-exposure image.

Target - The astronomical object of interest.

Telecompressor (Focal Reducer) - An optical component made of a lens or glass elements that decrease the focal length (and focal ratio) of a telescope. For example, a 0.75x telecompressor will make a 1,000 mm focal length f/8 optical system into a 750 mm f/6 optical system.
Tele-extender - An optical component made of a lens or glass elements that increases the focal length (and focal ratio) of a telescope. For example, a 2x tele-extender will turn a 1,000 mm focal length f/8 optical system into a 2,000 mm f/16 optical system.

Terminator - The line on the Moon or a planet that divides the bright, sunlit part from the part in shadow. It's usually the most exciting and detailed region of the Moon to view through a telescope.

Tonal Range - The range of tones present in an image from black to white. Also known as the dynamic range.

Tonal Resolution - The number of steps that the dynamic range is divided into as specified by the bit-depth of the analog to digital converter.

Tracking - Following a star with a telescope to compensate for the Earth's rotation.

Transparency- A measure of the atmosphere's clarity — how dark the sky is at night and how blue it is during the day. When transparency is high, you see the most stars. Yet crystal-clear nights with superb transparency often have poor seeing.

Transit - When Mercury or Venus crosses the disk of the Sun, making the planet visible as a black dot in silhouette, or when a moon passes across the face of its parent planet. Transit also refers to the instant when a celestial object crosses the meridian and thus is highest in the sky.

Transparency - A measure of the atmosphere's clarity — how dark the sky is at night and how blue it is during the day. When transparency is high, you see the most stars. Yet crystal-clear nights with superb transparency often have poor seeing.

Twilight - The time after sunset or before sunrise when the sky is not fully dark. Astronomical twilight ends after sunset (and begins before sunrise) when the Sun is 18° below the horizon.
Undersample

Unit Power Finder - A device for aiming your telescope that shows the sky as it appears to your unaided eye, without magnification. The simplest type is a pair of notches or circles that you line up with your target. Other versions use an LED to project a red dot or circle onto a viewing window (Telrad, Red dot, laser finders).
Universal Time (UT) - Also called Greenwich Mean Time, expressed in the 24-hour system. For example, 23:00 UT is 7:00 p.m. Eastern Daylight Time (or 6:00 p.m. Eastern Standard Time). Astronomers use Universal Time to describe when celestial events happen in a way that is independent of an observer's time zone.
Vignetting

Waning - The changing illumination of the Moon (or other body) over time. The Moon waxes, growing more illuminated, between its new and full phases, and wanes, becoming less illuminated, between its full and new phases.

Waxing - The changing illumination of the Moon (or other body) over time. The Moon waxes, growing more illuminated, between its new and full phases, and wanes, becoming less illuminated, between its full and new phases.

Wavelets - Wavelets break an image down by frequency information so that details can be independently sharpened based on their scale, or size, in the image.

White Balance - Adjusting the color in an image to compensate for the color temperature of the illumination source.

White Point - The brightest area of an image that is mapped to the highest level available (pure white) based on the bit-depth of the image (Level 255 for an 8-bit image) when setting the dynamic range during a levels adjustment in image processing.

Zenith - The point in the sky that's directly overhead.

Zodiac - Greek for "circle of animals." It's the set of constellations situated along the ecliptic in the sky, through which the Sun, Moon, and planets move.