Camera Basics +

(How cameras work + useful info about DLSR's for astro-imaging and specialized Astro-Imaging Cameras)

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Goals of this presentation:

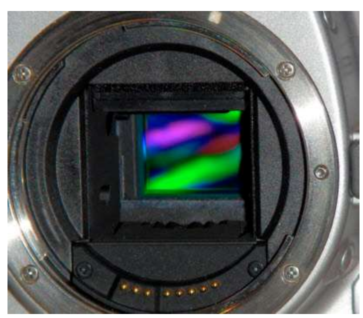
- Explain how cameras work.
- Introduce some key words and concepts used in photography and astro-imaging.
- Provide a starting point for asking questions

This presentation will cover- Concepts common to all cameras. Characteristics of DSLR (digital single lens reflex) cameras that affect their use in astro-imaging and touch on the more specialize astro-imaging cameras. The following questions will be answered.

- How do the imaging sensors in cameras work?
- What is focal length?
- What is f/ratio?
- How do these relate to taking pictures?
- What is exposure time?
- What is ISO setting?
- What is "noise"
- Does the size of the imaging sensor matter?
- Paul will discuss some of the trade-offs between choices of cameras.
- What about point & shoot cameras?
- Short list of resources

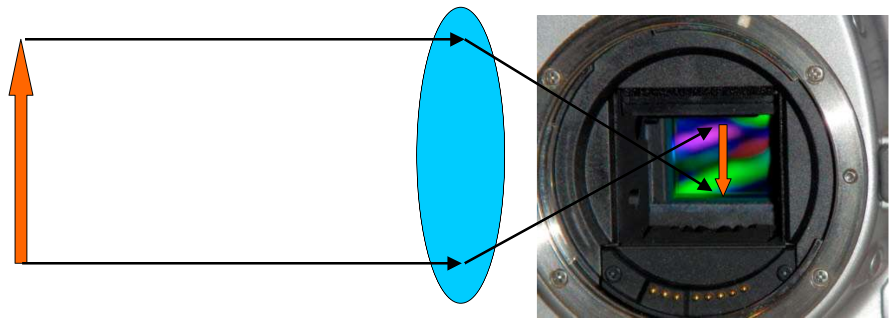
All cameras have a light sensitive device or sensor.

Now-a-days this is an electronic sensor, in the "old" days it was a thin piece of plastic coated with light sensitive chemicals.



All cameras need a lens (or mirror such as in a reflecting telescope).

The lens focuses the light from your subject creating an image on the light sensor.



How do the imaging sensors in cameras work?

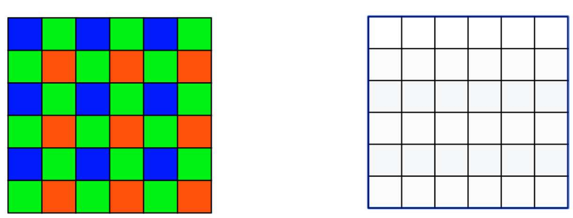
The **imaging sensors** in all modern digital cameras are electronic devices with a grid of tiny **photosensors**. Each photosensor corresponds to a **pixel** in the image.

Photons hitting these photosensors are converted into electrons. The number of electrons in each photosensor is measured and converted into a digital number and saved in the camera's memory card.

Below are representations of color and monochrome imaging sensors

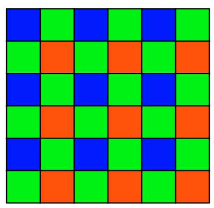
The examples are 6x6 or 36 pixel sensors

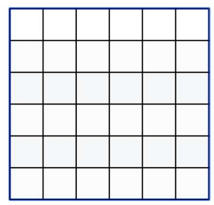
Typical imaging sensors have 10 - 24 million or more photosensors.



To make a **color image** we need **red, green and blue (RGB) color information**. For color sensors this is information is divided up among the photosensors by manufacturing them with tiny red, green and blue filters in front of the photosensors. In astro-imaging, cameras with color imaging sensors are called **"one shot color" cameras**.

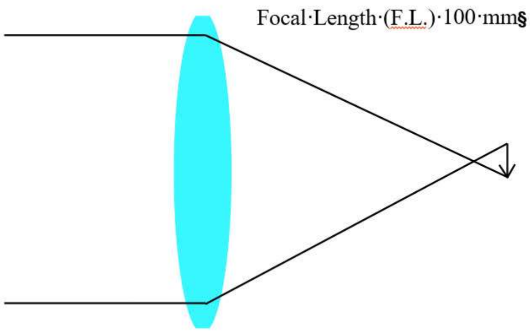
For **monochrome** sensors, **3 separate images are taken**. One with a red filter in front of the whole image sensor, one with a green filter and one with a blue filter. Most cameras used on space probes use this method and typically use other filters as well. For astro-imaging a 4th image is typically taken with no filter. This is called a luminance (L) image (we won't go into details about this here).



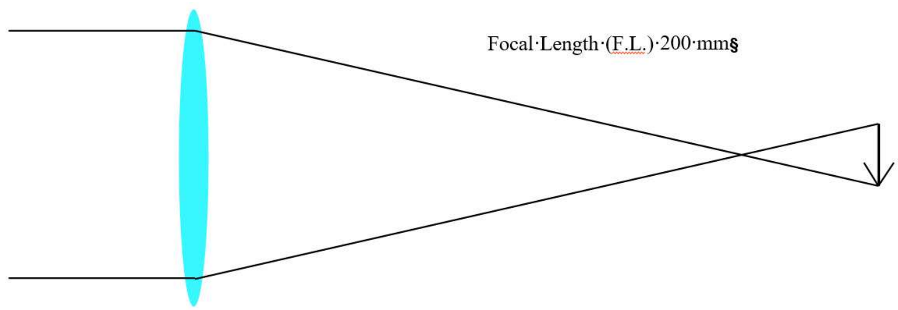


Focal Length and Focal Ratio

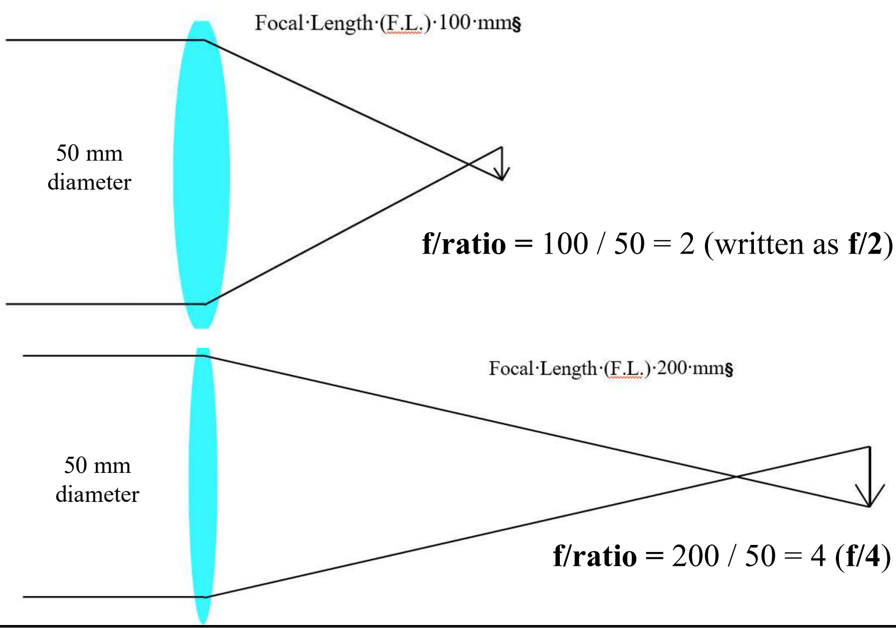
The **focal length** of the lens **determines** the **size of the image** or scale of the image (called **image scale**).



Doubling the focal length doubles the size of the image and doubles the image scale (magnification).



Focal Ratio (f/ratio) is simply the ratio of the focal length of the lens divided to the diameter of the lens, **(focal length / diameter).**



f/ratio = 100 / 50 = 2 (written as **f/2**)

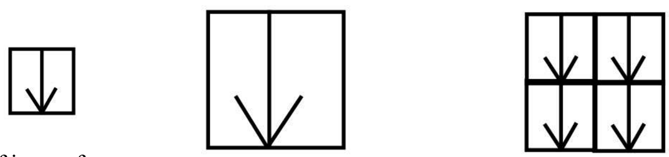
f/ratio = 200 / 50 = 4 (**f/4**)

Image Brightness and F/ratio

As the f/ratio increases the image gets dimmer. (this is true for extended objects like nebulae and galaxies, not true for “point sources” like stars.

f/4 is dimmer than f/2

One way to visualize this is, since the upper and lower lenses are the same size they let the same amount of light through. The image formed by the 2nd lens **(200mm f.l., f/4)** is **twice as large as** compared to the 1st lens **(100mm f.l., f/2)**. Because it is spread out in 2 directions, it is spread over **4 times the area** and is **4 times dimmer**. (The math 4x4 / 2x2 = 4) It is the same thing that happens when you increase the magnification when viewing say, Jupiter. As you increase the magnification Jupiter gets bigger and dimmer, unless you switch to a telescope with a larger objective and use the same magnification.



Size of image from 100mm, f/2 lens

Size of image from 200mm, f/4 lens

Image from the f/4 lens covers 4 times the area of the f/2 image

How does focal length and f/ratio relate to taking pictures?

The following applies regardless, whether the “lens” is a camera lens or a telescope.

Focal length is pretty obvious. **The longer the focal length the larger the subject will appear in the image.** If you are trying to image a small object you would typically want use a longer focal length. However, a large object won’t fit onto your cameras sensor if the focal length is too large.

The bigger the f/ratio number the dimmer the subject will appear. **The dimmer the subject the longer the exposure time needed** to make the image the same brightness as a smaller f/ratio (to collect the same number of photons per pixel)

That brings us to **Exposure Time,** that is, how long the **shutter** is open exposing the imaging sensor to light.

In deep sky astro-imaging exposure times can be several minutes long.

Focal length (f.l.) does not affect the needed exposure time but **f/ratio does** (for extended objects like nebulae).

You may say, "But earlier you showed that the image from the longer focal length lens was bigger and dimmer than from the shorter focal length lens". You are right, I did.

The key point is - why it is dimmer? It is dimmer because the focal length is 200mm **and** the lens diameter is 50mm, making it an f/4 lens (200mm/50mm). If the lens had a diameter of 100mm it would be an f/2 lens (200mm/100mm) and be as bright as the short f.l. lens.

A "trick" I use to remember how to calculate f/ratio is the f/ratio is almost always bigger than 1. If you get a number less than 1, you probably need to switch the two numbers. Unless, perhaps, you have a very expensive lens.

ISO Settings

ISO stands for International Standards Organization.

The ISO setting on cameras is an arbitrary system for indicting the gain setting on cameras. It is linear, so ISO 400 is 2x the gain of ISO 200. Increasing the ISO setting on a camera will make an image ***look*** brighter. A short exposure can be made to ***look*** just as bright as as longer exposure. However, looks are deceiving. **Increasing the ISO is not the same as increasing the exposure time**.

An analogy for understanding the effect of the ISO setting- Take a radio and tune to a nearby radio station (strong signal) adjust the volume (gain) to a comfortable level. Now tune to a distance station (weak signal). Adjust the volume to the same level. There is also some auto gain adjustment happening when the signal is weak so you may not have move the knob much. Notice how you hear more static **(noise)**. When you turn the volume up to amplify a weak signal you also amplify the background noise. This is what happens when you "turn up" the ISO to brighten (amplify) a weak (dark) image, the brightness and noise go up.

Noise

Noise is also the term used for visual noise in images. It shows up as graininess in an image. It is also unwanted light and any other "signal" that is not produced by light coming from the subject.

Sources of noise in cameras are:

"Hot" and "warm" pixels (show up as brighter pixels on every image) due to minor defects in photosensors on the imaging sensor. This is normal. **Temperature affects the brightness of hot and warm pixels**.

The **electronics that "reads" the signal** from the photosensors.

The **electronics that amplifies the signal**

Conversion of the analog readout to a digital number (changes the "smooth" analog signal to a stepped signal) which adds noise by rounding up or down to the nearest step.

Cosmic ray strikes (show up as occasional randomly located "hot" pixels).

Vignetting - light blocked from the corners (or other areas) of the sensor making them darker than the middle of the picture.

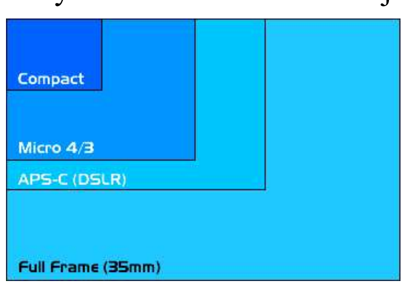
"Stacking" images reduces the noise from most of these sources. It does not reduce vignetting, but that is a topic for another talk.

Does the size of the imaging sensor matter?

The short answer is yes. There are other parameters to consider as well.

The most obvious thing is the size determines how much of the sky the camera will cover using a particular lens or telescope. 3 common sizes for DSLR cameras are, Full-Frame, APS-C and Micro Four Thirds. Their relative sizes are shown below. Compact is what point & shoot camera use and generally is not considered suitable for deep sky images.

A camera with the Micro 4/3 sensor on a smaller, lighter telescope can cover as much sky as a camera with a Full-Frame sensor on a much larger, heavier telescope and mount. Also on any given scope, a Micro 4/3 camera will effectively "zoom-in" on small subjects compared to a Full-Frame camera.



Does the Size of the Pixels Matter?

Yes, some. Smaller imaging sensors (like the Micro 4/3) have smaller photosensors (pixels) than a larger sensor of the same "mega-pixel" size which have more noise than larger ones. Based on some recent reading, not much more until you get down to the Compact sensors and may not be worth factoring into what camera to get.

Sensor technology has improved considerably over the years so even small photosensors today have much lower noise levels than large photosensors from 10 years ago.

If you are interested in calculating the photosensor (or pixel) size, it is actually fairly easy to calculate. Take the long (or short) dimension of the imaging sensor and divide by the number of pixels.

Full-Frame 25Mp, 35.9mm / **6048** pixels = 0.00593mm, X 1000 = **5.93 microns (µm)** (millionths of a meter, the units used in stating pixel size).

APS-C 24 Mp, 22.2mm **/ 6000** pixels **=** 0.00370mm, X 1000 = **3.70 µm**.

Mirco 4/3, 20 Mp, **17.3** x 13mm, **5184** x 3888 px = **3.34 µm**.

Compact 1/2.3", 20 Mp, 6.17mm x4.55mm, 5184 x 3888, = **1.19 µm**.

Another Factor: Cost

The cost of DSLR cameras range from a few hundred to a few thousand dollars with cameras popular for astro-imaging in the $600 and up range (price new).

Currently (as of 2020) cameras with APS-C sensors are the least expensive (starting at ~$600 for the body only), the Micro 4/3 cameras run a little more (starting at ~$850 for the body only), Full Frame is the most expensive (starting at ~$1200 for the body only).

If you want a lens, add $150 or more. Lenses for Micro 4/3 are generally a little less then those for APS-C cameras and those for Full-Frame cameras the most expensive.

You can save up to 50% or more if you look for a deal on a used camera. However, buyer beware.

You may already have a DSLR that you can start with and save some money. I used a 2005 model, Canon Rebel XT (modified) for almost 10 years and have a Canon Rebel XTi (unmodified) that I still use.

Making a DSLR into a Better Asto-Camera

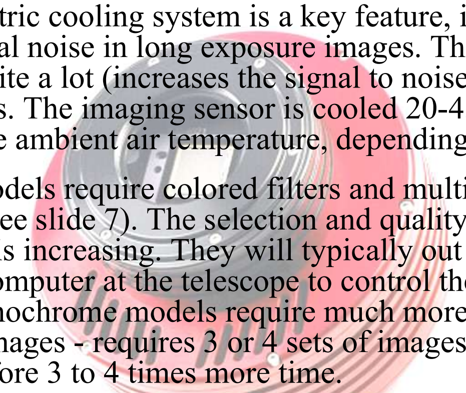
For about $300 you can get many DSLR’s modified for improved astro-imaging. This is done by having the built-in UV/IR blocking filter (right in front of the imaging sensor) replaced with a filter that lets more of the red light from glowing hydrogen gas clouds reach the sensor.

There are 2 types of conversion, Full Spectrum and Visible + H-alpha with the latter being perhaps the more common but the first more versatile (I am on my 2nd visible + H-alpha modified camera). When using the full spectrum conversion with a refractor or camera lens it will need a visible + H-alpha or a UV/IR blocking filter in front of a camera lens or between it and the telescope. In addition, for astro-images both conversions work best when used with a broad band light pollution filter.

Visible + H-alpha modified Cameras can be used for regular photography by using the custom white balance feature in the camera or by placing a special filter in front of the camera lens that blocks the extra red light that the modification allows onto the sensor. There is also a filter for use with full spectrum converted cameras.

Specialized Astro-Imaging Cameras

The monochrome versions of these are full spectrum. Most have a thermal electric cooling (TEC) system. They are not designed to be used with camera lens, though adapters are available.

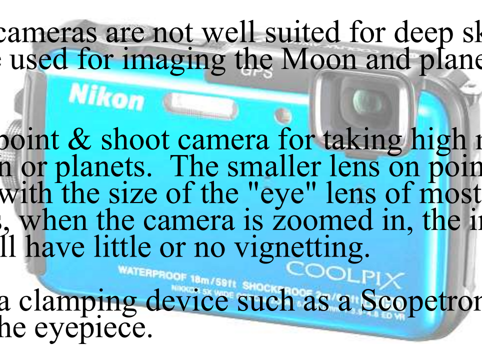


The thermal electric cooling system is a key feature, it reduces the amount of thermal noise in long exposure images. This improves the image quality quite a lot (increases the signal to noise ratio), especially on warmer nights. The imaging sensor is cooled 20-45 degrees C (36-81 deg. F) below the ambient air temperature, depending on model.

Monochrome models require colored filters and multiple images to make a color picture (see slide 7). The selection and quality of color imagers (one shot color) is increasing. They will typically out perform DSLR’s. Both require a computer at the telescope to control the camera and store the images. Monochrome models require much more time acquiring and processing the images - requires 3 or 4 sets of images to make 1 color image and therefore 3 to 4 times more time.

Prices start at about $700 for small CMOS sensors and go up to $20,000. CCD sensors range from $350 - $45,000. CMOS is becoming more popular while CCD technology is being phased out.

Point & Shoot Cameras

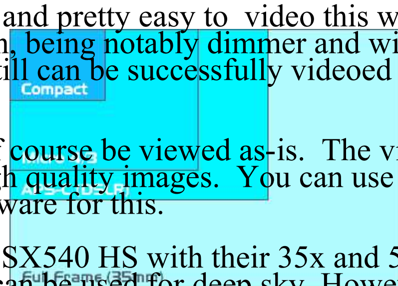


Point & shoot cameras are not well suited for deep sky astro-imaging they but can be used for imaging the Moon and planets through telescopes.

One can use a point & shoot camera for taking high magnification video of the the Moon or planets. The smaller lens on point & shoot cameras match up well with the size of the "eye" lens of most 1 1/4" eyepieces. Because of this, when the camera is zoomed in, the image on the camera view screen will have little or no vignetting.

You will need a clamping device such as a Scopetronix EZ-Pix II to hold the camera to the eyepiece.

The Moon is bright and pretty easy to video this way. Jupiter is fairly easy as well. Saturn, being notably dimmer and will not take as much magnification but still can be successfully videoed this way with a large enough telescope.



These videos can of course be viewed as-is. The video frames can be stacked to make high quality images. You can use Registax or other image stacking software for this.

Canon SX40 HS & SX540 HS with their 35x and 50x zoom and reasonable f/ratios can be used for deep sky. However, the imaging sensor is a compact size sensor and therefore relatively noisy.

A partial list of resources:

dpreview.com - Good site for info and specs on most DSLR cameras.

lifepixel.com - Site for purchasing modified cameras and getting you camera modified.

lifepixel.com/tag/h-alpha - Informational page on above site about camera modifications.

spencerscamera.com - Another site for purchasing modified cameras and getting you camera modified and information about modifications. (**Note**: at least 2 club members have dealt with this company, one had an acceptable experience, the other a 1 good experience and 1 very poor experience.)

Try Googling “camera modifications for astrophotography” or “camera modifications” and “DSLR’s for astro-imaging” to find information on popular cameras.

Most companies that sell astronomy equipment carry the special astro-imaging cameras and associated equipment: Orion Telescopes and Binoculars, telescope.com; OPT Corporation, optcorp.com; High Point Scientific, highpointscientific.com; Anacortes Telescope & Wild Bird, buytelescopes.com; Astronomics, astronomics.com;