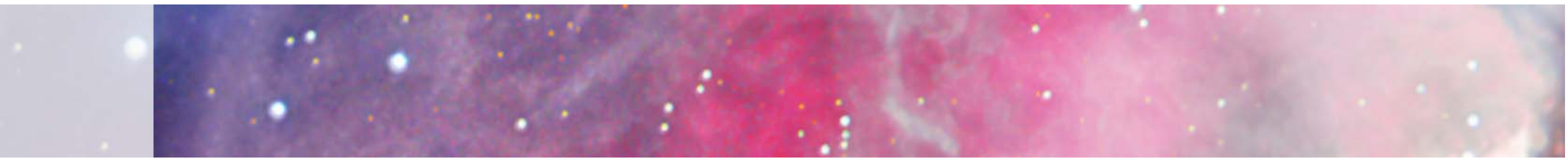

Tips for the Purchase of the Camera

The purchase of an astronomical CCD camera should be carefully considered since it does involve a noteworthy investment. The array of factors that are important for the selection of a specific model is quite complex. There is no such thing as the “ideal camera” that satisfies all needs - not even if money is not an issue. Just compare it with the purchase of an automobile: You will not be able to find an all-terrain sports car with a large loading capacity, four-wheel drive and excellent mileage.

This means, that each astronomical CCD camera is only suited perfectly for specific purposes and performs other tasks only with limitations. In order to make an informed decision it is therefore important that you first get to know the parameters that characterize an astronomical CCD camera and that differentiate the available models. Afterwards you need to consider the primary purposes of your camera. As difficult as this question may seem right at the beginning: do try to find an answer!

Many of the following parameters can be found in the technical data sheets of the respective cameras:

Characteristic	**Description**
Purchase Price	Of course the budget that is at your disposal is an essential criterion. Nevertheless, it is quite comforting to know, that the most expensive camera is not always the best choice. For example, if you are looking for a supernova or would like to measure the position of an asteroid, you can do this without any restrictions with a camera that has a relatively small sensor and is therefore comparatively cheap. Whereas the entry model starts at 1000 dollars, the sky’s the limit for the top models.
Sensor Size	Is specified in millimeter. The size of the image sensor usually correlates with the purchase price: large image sensors are therefore more expensive. Using the same focal length a larger image sensor connotes a larger field of view. However, a large image sensor also requires optics that can illuminate this large sensor size immaculately. The current range varies from 4.9 x 3.6 mm to 36 x 24.7 mm. The calculation of the field of view is described from page 8 onwards.
Light Sensitivity	An important parameter for any CCD sensor is it’s light sensitivity. It is also referred to as Quantum Efficiency (abbr. “QE”) and indicates the percentage of light that is actually recorded by the sensor. Since the QE varies with the different wavelengths of light, a graph indicating the wavelength on the x-axis and the QE on the y-axis is very helpful (e.g. http://www.sbig.com/sbwgifs/qe3200me.gif). Comparing some of these curves you will notice that light sensitivity can be very low for some wavelengths (QE < 10%), while others reach a QE of more than 90%. Some sensors only reach a QE of 50% as their maximum. Pay attention to the shape of the curve: a curve with a broad “peak” at a high level indicates a good QE across a large range of wavelengths (good overall sensitivity). A curve on a low level with a sharp maximum does not provide a good overall sensitivity. Attach special importance to a good QE in your preferred wavelengths. If your primary interest is to image hydrogen nebulae a good QE of the hydrogen-alpha line (656 nanometers) is important for you. The QE of the different sensors actually vary here between 25% and 85%. A QE that is twice as high reduces the necessary exposure time by one half.
Number of Pixels	Is usually indicated in “megapixel” (=one million pixel). A higher number of pixels in an image sensor allows you to present your image in a larger format, without the pixel pattern showing. A prerequisite for this is, that you have chosen the correct focal length, matching the size of the individual pixel (see page 9). A high-quality print requires 300 dpi. In order to print one page of a book (not a spread) in the format of 6.7 inch x 8.5 inch in first-class quality, you need 2000 x 2500 pixels (= 5 megapixel). But do keep in mind that a high number of pixels not also increases the size of the image file but also the requirements with regard to the performance of the PC that you are using for image editing. Entry level models have 0.15 megapixel, top level models more than 10 million megapixel.

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Pixel Size	Measured in microns (symbol “µ“, is equivalent to one millionth of a meter). Small pixels allow the use of short focal lengths. The resolving power then matches that of a camera with larger pixels and a longer focal length. But small pixels have disadvantages too: Their relatively small surface area leads to a low light sensitivity. In addition, a smaller pixel can store fewer electrons, i.e. saturation (overexposure) occurs faster in smaller pixels than larger ones (q.v. full well capacity). Small pixels have an edge length of about 6 µ, large ones 24 µ. Pixels are not always square. Rectangular pixels always require a correction of the proportions in an image editing program. Otherwise the image will be distorted. You can find formulas for the calculation of the “ideal” pixel size on pages 10 and 11.
Full Well Capacity	Is indicated in electrons (e-) and is a measurement for the “storage capacity” of a pixel. It specifies how many electrons (produced by photons hitting the surface) a pixel can store, before it is saturated. The more electrons a pixel can store, the better. If you are imaging an object with a high range of contrast (e.g. a faint galaxy with a bright core) the full well capacity determines at what exposure time the brighter areas of the image will be saturated and thus will be overexposed (q.v. dynamic range). For the most part smaller pixels have a lower full well capacity than larger ones. Values around 50.000 e- are rather modest, 100.000 e- and more are excellent.
Dark Noise	Is measured in electrons (e-) and characterizes the number of electrons that are created in each pixel per time unit and temperature even when the sensor is not exposed to light. A typical specification is e.g. e- per second at 0° C. Lower values, i.e. lower dark noise, are preferable. The cooling of the sensor reduces the dark noise (see page 97). Good values are below 1 e-, high values are around 25 e- per second at 0° C.
Read-Out Noise	The number of electrons that are stored in a pixel after the exposure cannot be determined one hundred per cent. System-inherent limitations can be indicated by an average square deviation from the real value (measurement: e- rms). A lower read-out noise is preferable. The read-out noise and the full well capacity (q.v.) determine the dynamic range (q.v.) of a camera. Excellent values are 7 e- rms and smaller, modest values are around 20 e- rms and more.
Dynamic Range	A value without unit which indicates the maximum range of brightness that the camera can record without overexposing the brightest image areas, while still capturing the darkest image areas. The dynamic range is calculated by dividing the full well capacity by the read-out noise. For example (Kodak Sensor KAI-11000M): Full well capacity = 50.000 e-; read-out noise 13 e-. Dynamic Range ≈ 3846. A 12-bit A/D converter would be sufficient for this sensor since it can differentiate between 2^{12} = 4096 brightness levels.
Guiding Technique	Many astronomical CCD camera models offer a device to monitor the tracking accuracy of the mount and to control the correction movements, if necessary. This monitoring and correcting is called guiding (see page 115). For bulb exposures guiding is mandatory. The company SBIG exclusively offers cameras with two CCD sensors (patent-protected). Next to the image sensor a small guiding sensor is located, which monitors the position of a guide star. The advantage of this technique is that you only need one camera for the exposure and the guiding. However, it is a disadvantage that filters employed also reduce the brightness of the guide star. Moreover, you cannot use this technique to track objects that have a proper motion relative to the stars, which you would like to image at the same time (e.g. comets or asteroids). The manufacturer Starlight-Xpress offers models in which the image sensor is read-out partially during the exposure, in order to analyze the position of stars or other objects for guiding purposes. This comes at the expense of 50% loss of light sensitivity but does allow imaging and guiding the same object. The alternative is a second telescope that is mounted parallel to the exposure optics and is only used for guiding. You can either hook up a separate camera to this telescope (guiding camera) or a remote “guiding head” that is detached from the main camera. SBIG as well as Starlight-Xpress offer these guiding heads for some of their camera models. An advantage of the separate guiding head: Light-absorbing filters in the optical path of the exposure camera do not affect the brightness of the guide star. Find out before the purchase which guiding techniques the respective cameras offer and which methods are possibly available as accessories.

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Cooling System	In order to reduce the amount of noise the image sensor of astronomical CCD cameras is actively cooled. The higher the cooling power, the lower the image noise. Ideally the camera has a controlled cooling power that allows you to set the cooling to a specific temperature. This permits you to take your dark frames at a different time than the actual exposures (dark frames should always be taken using the same sensor temperatures as the actual exposures). With this you can realize downright dark frame libraries that can be reused time and again. With an uncontrolled cooling system the sensor is always cooled to the minimum temperature possible, which is dependant upon the ambient temperature and therefore varies. Dark frames should then always be taken close to the time of the actual exposures. An uncontrolled cooling system is not a disadvantage if the image sensor has such a low dark noise that dark frames are superfluous.
Color Filter Wheel	There are two methods to produce color images with an astronomical CCD camera. Either you decide to select a model with a color sensor, or you employ a monochrome camera with which you take subsequent exposures through a red, green and blue filter respectively and later use an image editing program to combine these images to a color picture. Some cameras have a color filter wheel integrated into the camera body, where the filter change is controlled by the camera software – undoubtedly the most elegant solution. If you are planning the purchase of an astronomical CCD camera you should check if a color filter wheel with a motor-driven filter change is offered at least as accessory and how much this upgrade would cost. A separate filter wheel comes at the expense of the optical path length, which can lead to the fact that the focus on “infinite” is no longer attainable, in particular if Newton telescopes and camera lenses are employed. It is very helpful if the filters used are “parfocal”, i.e. a filter change does not require re-focussing.
Read-Out Rate and Transfer Rate	Theoretically an image can be read-out very quickly after the exposure. However, this causes a strong read-out noise. But long read-out times are not desirable either, since a lot of imaging time is lost. Therefore, for astronomical CCD cameras a comprise must be found between read-out noise and read-out transfer rate. In addition, the read-out data must be transferred to the computer. A USB port offers a distinctly faster data transfer than a parallel port. The serial interface (RS-232) is even slower, but is hardly used anymore. Depending on the amount of pixels (q.v.) the read-out and transfer of a single image can take several seconds. This does not matter with regard to bulb exposures, but does play a role with short-lived events. For example, if the read-out and transfer rates take 20 seconds, you can only take six images during a solar eclipse that lasts two minutes.
Blooming Characteristics	If a pixel is overexposed and reaches its limit for storing electrons (q.v. full well capacity), it can happen that the remaining electrons “spill over” into adjacent pixels and cause some unattractive “rays” there (example: http://www.sbig.de/universitaet/bilder/blooming.jpg). Image information that is covered by these rays is irretrievably lost. In particular bright stars are affected by this “blooming”. It is especially bothersome when imaging faint objects that include a rather bright star in the field of view (e.g. Pleiades Nebula, Great Orion Nebula, Horsehead Nebula). Many sensors in CCD cameras thus contain so-called “Anti-Blooming-Gates”: These are conductor paths on the sensor that discharge the excessive charge from the overexposed pixels and thus prevent, delay or mitigate the blooming. The conductor paths are located in the optical path length and do lead to some loss of light sensitivity. For photometry, where maximum measuring accuracy is required, sensors without an Anti-Blooming-Gate are preferable. If “pretty pictures” are the objective, a camera with an Anti-Blooming sensor is better suited. A few camera models are optionally available with or without Anti-Blooming-Gate.
Technical Support	An astronomical CCD camera is not a mass product. If you have specific questions regarding the handling or if the camera is out of order you have to rely on the service of the dealer and/or manufacturer. The expertise of the dealer before and after the sale as well as the handling and duration of repair or maintenance jobs with regard to the camera can play an important role.