CCDs versus traditional astrophotography

Introduction

The well known centenarian astrophotography technique has allowed average trained amateur astronomers to achieve excellent results since long time ago. However, from its irruption on the market about ten years ago, amateurs also have at their disposition another revolutionary imaging technique: the astronomical CCD camera.

Although CCDs are far more complicated to use than film cameras, the resulting digital images are simply astonishing. This explains why, despite the important required investments both in money and in time training, the CCD technique is nowadays becoming more and more popular among amateur astronomers.

This essay will compare both imaging techniques -traditional film versus CCD- from the perspective of an average amateur astronomer. Firstly, it will be succinctly described the characteristics and properties of both films and CCDs. Later on, a head to head comparison will show that each technique still has its pertinence regarding particular conditions and targets. Finally, an hybrid technique which joints both film and CCD strengths together will be presented.

1. Amateur film astrophotography

Basically, the photographic technique implies the exposition of a photosensitive chemical element (the *emulsion*) to an object's light for a while. The emulsion is made up of crystals of silver halide (the *grains*) which can change their structure when excited by light (*photons*), thus allowing to form a "latent" image of the exposed object [1]. After being developed, a dark deposit of metallic silver proportional to the amount of the photons that actually excited each grain is obtained, which becomes a "permanent" photograph.

The emulsion is deposited on a ribbon of cellulose acetate or polyester, simply referred to as the *film*. Its active width actually determines the image format, being by large the most popular the so called *"35-mm"* (24 mm x 36 mm) [2].

The main characteristics of a film are its *spectral sensitivity*, its *speed*, its *characteristic curve*, and its *reciprocity failure*. Success or failure in amateur astrophotography has a lot to do with the proper selection of the right film for the intended target [3].

The *spectral sensitivity* is the response that a film exhibits depending on the wavelength of the light that excites it. Typical films show a slightly variable response that notoriously decays at longer visual wavelengths, making that reddish objects appear too light. Special films can overcome this problem.

The *film speed* determines the length of the exposure for a given target. As it takes about the same number of photons to excite either a large or a small grain, larger grains (greater gathering areas) receive their full number of photons first. This implies that coarse grained films are faster (more sensitive) than fine grain film [4]. Film speeds are rated under (old) ASA or (current) ISO systems, being the greater the number, the faster the speed.

The *characteristic curve* is a plot that summarizes the way that a film responds to light (density versus exposure). When the logarithm of the exposure is selected as the horizontal axis, the characteristic curve typically becomes something like Figure 1 shows.

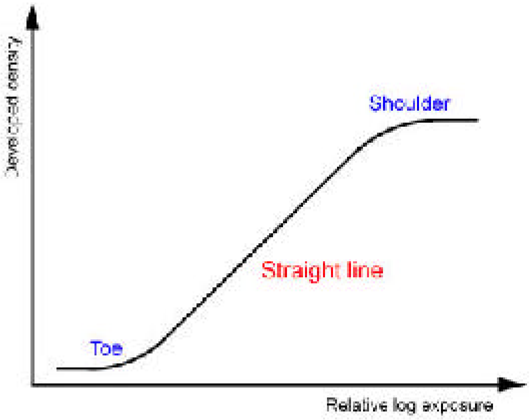

Figure 1
The characteristic curve of a film

The steeper the straight line portion is, the greater the change in density for a given change in the exposure factor, that is, the greater the image's *contrast*. In practice, black and white photographs are taken on the toe and the lower part of the straight-line portion, because longer exposures (approaching the shoulder of the curve) result in *"a very dense, grainy negatives, as well as a loss of effective speed since more light is required"* [5]. However, colour negative films become less grainy the higher up the curve they go.

The *reciprocity failure* is the intrinsic non-linearity response that films shows, becoming particularly insensible at very short or very large exposure times in responding to low light levels. In longer astronomical applications, after the initial period of image formation, the image density does not continue to build up at the same rate, independently that the density of the image could still be well below the saturation limit for that film [6]. The higher the reciprocity failure degree, the sooner the rate of further image build up slows down noticeably.

Having firstly chosen the celestial object to be photographed, the aficionado should then select the proper film, usually *a compromise between speed and grain*, which will determine the right exposure time. It could be also possible to apply in advanced some techniques to increase the film's response to faint light, like *preflashing* (pre-exposing it to a small amount of light) or *hypersensitizing* (eliminating the substances that reduce its sensitivity) [5].

At field, colour or special filters could be used to enhance or reject selected wavelengths.

After the photographs have been taken, the particular development process applied to the film can actually vary the response (density) of the final image, just for a selected area or for the overall picture. The most easy and direct way to increase the effective speed and contrast of any film is by just extending the development time –the so called *"push-proccesing"*. There are other several particular techniques of developing[1] and the amateur should be well aware about their respective potentialities.

2. Amateur CCD imaging

The *charge-coupled device* (CCD), works by converting light received by multiple tiny cells (the *pixels*) into a pattern of electronic charge inside a single silicon chip. This pattern of charge is then converted through a complex process into a video waveform, digitized and stored as an image file on a computer.

CCDs are high *quantum efficiency* devices, that is, they are very efficient in turning the input energy (light) into a measurable signal, as Figure 2 depicts. Greater efficiency means that either more data can be gathered in a shorter time, or that fainter signals can be measured in the same time. Smaller exposure times reduce the demands on accurate guiding, one of the major problems in imaging faint objects.

Unlike films, CCDs do have a linear response to light, implying that the measured signal is directly proportional to the amount of light which has been received, over a large range of data values (wide *dynamic range*) [7]. This condition turns CCDs especially suitable to measure both very faint and very bright targets captured in a single exposure.

The *resolution* attainable by CCDs is actually controlled by the angular field of view of each individual pixel, and thus by the pixel's physical size [8].

The drawback with CCDs is that electrons can be generated inside a pixel either by absorption of incoming photons (the *signal*) or by just thermal motion of the silicon atoms (the *noise*). Electrons produced by these two effects are indistinguishable. Obviously, the lesser the noise, the better the CCD, and this becomes the very great difference between professional and amateur CCDs.

As CCDs are just "black and white devices", colour imaging is still possible at the price of taking at least three different -although shorter- shots using three different colour filters, and digitally composing later on the final image.

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[1] Like *dodging*, *unsharp masking*, *image stacking*, or *double exposure*.

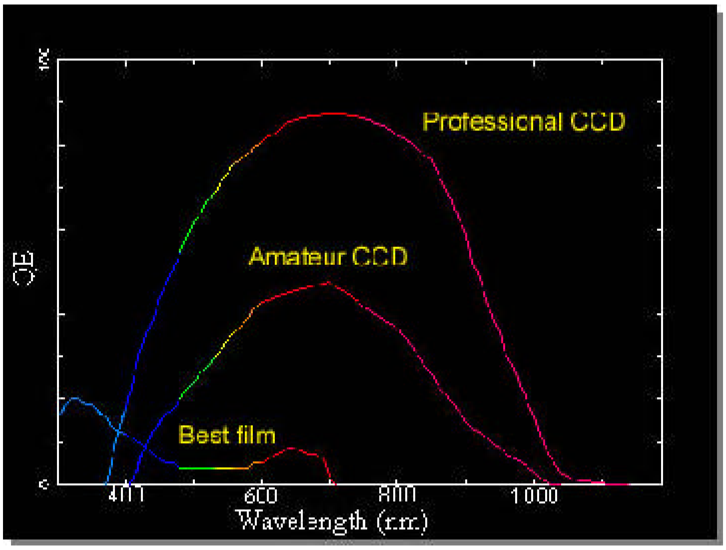

Figure 2
Comparison of relative quantum efficiency

The digital enhancement of raw CCD images is a relative easy procedure by means of several powerful software tools currently available, some of them even for free.

A special mention deserves the increasing use of inexpensive webcams for astrophotography, in particular for lunar and planetary imaging. Depending on the used resolution, webcams are capable of capturing from hundreds to several frames per seconds. Despite being intrinsically "noisy" devices -they lack any kind of thermoelectric cooling- webcams can easily obtain many hundreds of coloured frames in a couple of minutes, which afterwards can be digitally stacked. This process significantly improve the final image quality, as the *signal-to-noise ratio* is proportional to the square root of the number of frames that are combined [9].

Besides dedicated CCD astronomical cameras and webcams, aficionados are also using *integrating video cameras* and standard consumer *digital cameras*. Integrating video cameras are equipped with new supersensitive CCD chips that can take exposures longer than usual video cameras (1/60 second) [10]. Consumer standard digital cameras can either be artificially cooled (when air temperature is not low enough) or used to take dozens of shots to be integrated later by digital processing [11].

Incidentally, the new coming product to be embraced by amateur astronomers seems to be the CMOS camera, which have many of the properties of CCDs but with less drawbacks (minimum power supply demand, more integration).

3. Pros and cons of each imaging alternative for amateur astronomy

The most important advantage of films over CCDs, at the aficionado level, is that *they cover larger fields of view at the same satisfactory resolution*. This becomes quite obvious just from comparing their respective photosensitive areas, as Figure 3 shows[2]. Therefore, films are ideal for the imaging of objects that are larger than a few minutes of arc across, like survey works or for most astrometric works of reasonably bright objects.

Conversely, the worst drawback of films is their comparatively long exposure times, not only because long exposures always partially record the night sky air glow as image fog, but for the increasingly higher demands on proper tracking as well.

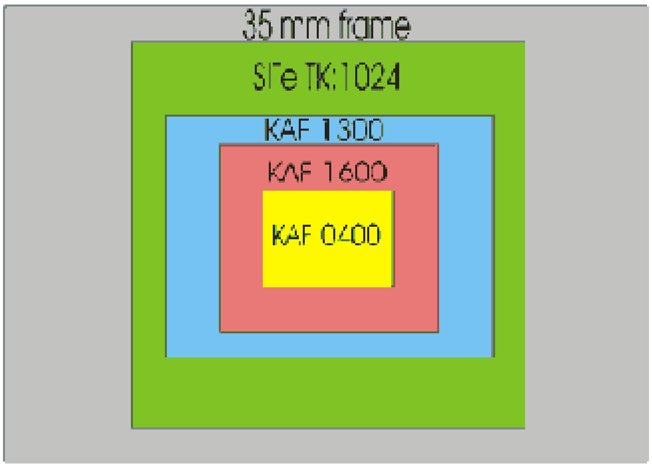

Figure 3
Comparison of photosensitive areas
A 35-mm frame versus several amateur CCD chips

The most important advantages of CCDs over films are *their great sensibility and linearity* (*not reciprocal failure at all*), thus making possible to image with comparatively shorter exposure times or even dividing the required exposition time in several partial shots that will be simply added on later. Shorter exposure times reduce requested tracking accuracies, becoming a major benefit in order to achieve success. Therefore, CCDs are ideal for imaging very faint objects and for photometric applications where their linearity and digital data format is a great asset. Also, for planetary work where their speed can take advantage of very brief episodes of excellent seeing in optical systems.

Apart of the main already mentioned comparative features, there are several other topics that differentiate the use of films or CCDs. A brief comparison follows up.

[2] As a matter of fact, a respectable CCD chip size for the amateur level, like the 9.2 mm x 13.8 mm of the KAF 1600, only covers about 1/9th of the 35-mm film size (24 mm x 36 mm).

In order to be clearly visible, the image size of the target must be proportionally large enough compared to the image format. Fortunately, there are several ways to obtain such required image sizes working with film cameras[3]. On the other hand, CCD cameras basically work coupled to a telescope at *prime-focus*, constraining image size variability[4]. Thus, regarding this topic, the film technique offers much more versatility.

Unlike films, CCDs are digital. That means that the all the powerful tools of digital imaging techniques can be straightforward applied to CCD images, while photographs necessarily require a prior *analogue-to-digital* conversion (involving inevitable added *noise*).

The film technique is also straighter forward at field. To take the photograph, the aficionado simply gets the proper focus, centres the frame (both relative easy tasks) and shots. If necessary, manual guiding could be applied, and that is the tiresome part, as the exposure could be very long (up to one hour, without any interruption). On the other hand, a typical amateur CCD imaging session implies:

a) taking many *dark frames* and *flat field* exposures;
b) proper focusing (tedious, to say the least);
c) proper centering (the desired target must be correctly framed, which is not so easy as it seems);
d) shooting many frames (mosaic, tri-colour) with the required guiding (although for shorter periods than for films); and
e) permanent verification that each shot has been properly transferred and loaded.

After a photography session, there is no way to know in advanced whether it was time (and resources) well used or wasted. Even a proper work could be ruined by other people at the development process. On the other hand, the feedback with CCDs is instantaneous and the merits or blames are just one's own responsibility.

Colour images are straightforward obtained from colour films, but require at least three shots with different colour filters from astronomical CCDs.

Finally, as the amateur's own telescope does matter (its focal length will determine the image scale, and its focal ratio will determine the image brightness) it also has to be considered when the time comes to choose between the film or the CCD camera.

The following table succinctly summarizes all the already discussed features, as well as comparing other new ones (power supply, cost, etc).

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[3] The normal lens of the camera can be changed to the proper one, or even a telescope can be used, with or without eyepieces (thus varying the magnification as much as needed). Therefore, in order to get the right frame there are several ways to use a film camera, either alone just mounted on a telescope (*piggyback*) or through a telescope (*prime-focus*, *afocal*, *positive* or *negative projection*).

[4] For a given telescope and CCD camera, the angular object size that can be encompassed by the CCD chip can only be adjusted by the use of a focal reducer or focal extender (Barlow lenses). Most of the times there will be no such devices at hand with the required relationships, and so more work will be necessary (a mosaic of several frames, digital processing, etc).

Head to head features comparison of film and CCD imaging techniques at the level of amateur astronomy

	Amateur traditional film	*Amateur CCD imaging*
Exposure times for a particular target	Much larger	Much shorter for monochrome pictures
Resolution (at micro level)	Depends on the film grains (of intrinsic variable size)	Depends on the pixels size (of intrinsic uniform size)
Resolution (at macro level)	From good to excellent	Normally satisfactory
Spectral response	Variable (depends both on the film and on wavelength)	Even over visible spectra
Very faint objects suitability	Moderate (due to Reciprocity failure)	Always well suited
Great contrasted objects suitability	Acceptable	Always well suited
Large objects suitability	Just a single shot required	A mosaic of several frames should be composed
Power supply requirements	Minimum	Great consumption
Guiding method (if needed)	Could be manual	Only by another CCD
Tracking accuracy required	Can be very demanding for long exposures	Moderate (it increases with the length of the exposure)
Colour imaging	Just a single shot	At least three shots
Verification of good results	Only after development	Immediate at field
Other people "involved"?	Yes, usually for the development and printing	Not other people required
Stacking	Possible but complicated	Simple and direct
Digital enhancement	Possible, after digitalization	simple and direct
Operational difficulty at field	moderate	large
Recommended targets	Larger bright objects (constellations, nebulae, big galaxies, parts of the MWG)	Very faint and small objects, photometry, high contrast targets, planetary imaging
Cost (initial investment)	Low to moderate	Expensive to very expensive

4. Why not joining strengths together?

The current limitation of the small size of the CCDs normally used by amateurs make them quite inefficient for imaging purposes, but they are full capable of automatically guiding a telescope without any problem. On the other hand, any average aficionado would take excellent film pictures just by providing that the proper tracking has been achieved for all the exposure time long. So, the immediate idea is to put to work together both the film camera and the CCD.

This "mixed" technique is already affordable and, properly applied, guarantees excellent results. It could be applied either with the film camera piggybacked on the telescope (the CCD guiding on any selected star), or with the CCD mounted on an *off-axis guider device* between the telescope and the film camera (the CCD guiding on a star that should be close enough to the imaged frame).

At the aficionado level, this "transactional" solution assures a possible and reasonable truce in the current *CCDs vs film* controversy. Surely, how both techniques will proximately evolve in the coming years will determine which one will be the preferred one, although chances are that CCDs finally wins and relegates films just to old books and museums.

Conclusions

At the amateur level, both traditional astrophotography and CCDs currently have their respective niche assured. Each technique has comparative pros and cons over the other, and this necessarily implies that there are particular targets more suited to be imaged either by CCDs or by film cameras.

Film astrophotography is still ideal for the imaging of relative bright objects that are larger than a few minutes of arc across, like constellations, bright nebulae, big galaxies, parts of the Milky Way. Besides, colour images are straightforward obtained.

CCD imaging becomes more suitable for very faint and small objects (like tenuous and small galaxies), when linearity is a must (like in photometric applications), or when high contrast images are required (like for spiral galaxies, or planets). Particularly in planetary imaging, CCDs make it possible to eventually get rid of the usual atmospheric blurring.

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Figure 3 "*The role of CCD Cameras in Amateur Astronomy*", by *R. A. Greiner*, 2000, at http://www.mailbag.com/users/ragreiner/ALPaper.html