Best Possible Astroimaging for the Beginner on the Cheap

Abstract

The objective for this project is to analyze the different imaging alternatives currently at the reach of any novice amateur astronomer. Considering that each one of the three possible astroimaging options -that is, film, CCD, and webcam imaging- has its own pros and cons, to know in advance which one becomes particularly appropriate for a given target becomes the ineludible very first step in the right way to achieve success.

The selected technique has also to be applied at field with properness. Despite the apparent rudimentary of simple astroimaging gear, serious information can be inferred as long as it is rightfully used. What does "rightfully used" actually mean and which "serious information" can be particularly obtained will be the main discussed topics along this report. Finally, a head to head comparison will summarize the obtained results.

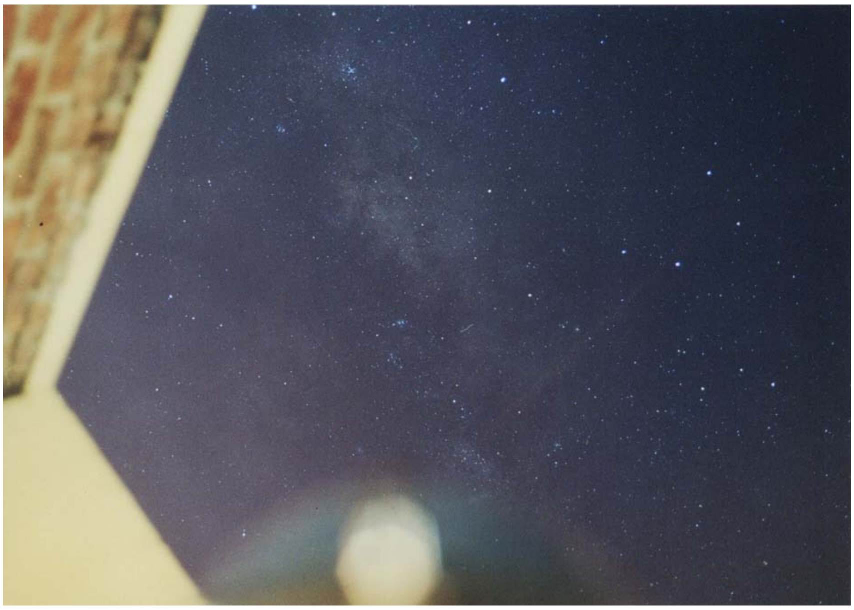

Figure 1
Despite suburban skies, the glory of the Milky Way's centre can still be easily imaged, as this not-neat framed shot proves. As for all remaining images in this report, south is up.

1. Introduction

There are two basic possibilities for imaging: either analog or digital. Each one intrinsically achieves very different characteristics regarding linearity, dynamic range, spectral sensitivity, efficiency, etc. Being both techniques nowadays equally accessible to any amateur astronomer, the plain knowledge of their theoretical potentialities and practical complexities of use becomes fundamental if serious field work is really intended to be performed.

1.1 Film photography basics

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 (*grains*) of silver halide which can change their structure when excited by light (*photons*), thus allowing to form a "latent" image of the exposed object. After being developed, a dark deposit of metallic silver proportional to the amount of the photons that actually excited each grain is finally obtained, resulting in a "permanent" photograph [**1**].

The emulsion is deposited on a ribbon of cellulose acetate or polyester, referred to as the *film*. Its active width actually determines the image format, being 24 mm x 36 mm for the most popular (the so called *"35-mm"* film[1]).

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

The *spectral sensitivity* is the response that a film exhibits depending on the wavelength of the light that excites it. Typical monochrome films show a slightly variable response that notoriously decays at longer visual wavelengths, making that deep reddish objects appear too light [**2**]. Special films 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 [**3**]. Film speeds are currently rated under an ISO system (replacing the old ASA numbers), 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 2 shows.

The steeper the straight line portion, 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"* [**4**]. However, colour films[2] become less grainy the higher up the curve they go.

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[1] 35-mm is the overall wide size of the ribbon, including the tracking perforations at both edges.
[2] Colour films have three sensitive layers of emulsion.

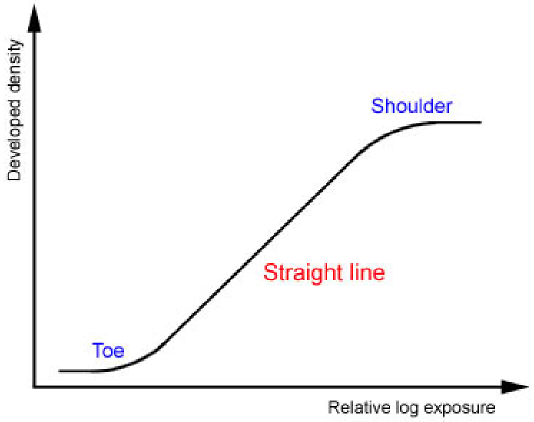

Figure 2
The characteristic curve of a film

The *reciprocity failure* is the intrinsic non-linearity response that films show, becoming particularly insensible at very short or very large exposure time in response 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, even if the density of the image could still be well below the saturation limit for that film [**5**]. 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), *cooling*, or *hypersensitizing* (eliminating the intrinsic substances that reduce its sensitivity).

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-processing"*. There are other particular techniques of developing[3] and the amateur should be well aware about their respective potentialities [**6**].

1.2 CCD imaging basics

The *charge-coupled device* (CCD) works by converting light received by multiple tiny cells (*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 [**7**].

CCDs are high *quantum efficiency* devices, that is, they are very efficient in turning the input energy (light) into a measurable signal, as Figure 3 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 [**8**]. Smaller exposure times reduce the demands on accurate tracking, one of the major problems in imaging faint objects.

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[3] Like *dodging, unsharp masking, image stacking, double exposure, tri-colour photography,* etc.

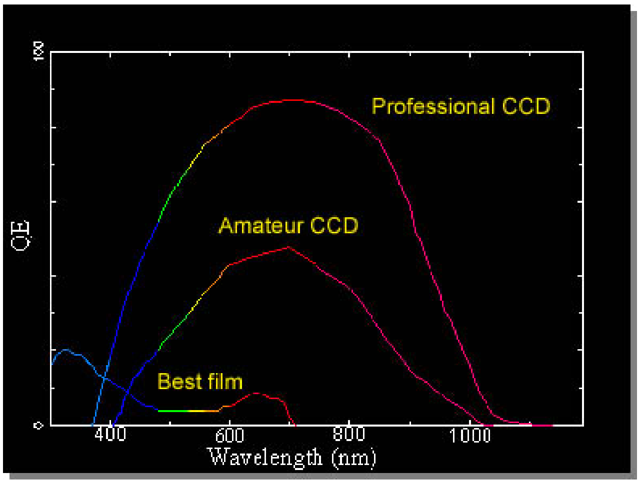

Figure 3
Comparison of relative quantum efficiency

Unlike films, CCDs do have a linear response to light over a large range of data values (wide *dynamic range*) [**9**]. This peculiarity turn 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 [**10**].

The drawback with CCDs is that electrons can be generated inside a pixel either by absorption of incoming photons (*signal*) or by just thermal motion of the silicon atoms (*noise*)[4]. Electrons produced by these two effects are indistinguishable. Obviously, the lesser the noise, the better the CCD, and this becomes the great difference between professional and amateur CCDs.

Likely enough, most of the noise in the CCD images can be lately reduced by simply performing a proper digital processing technique, on condition that specific images can also be taken at field.

As CCDs are just "black and white devices", colour imaging is still possible at the price of taking at least three different shots using three different colour filters (although a fourth non-filtered shot called *luminance* is highly recommended), and composing them digitally on the final image. The digital enhancement of raw CCD images is a relative easy procedure by means of several powerful software tools, some of them available even for free [**11**].

CCD technology has allowed the current digital astroimaging revolution, which nowadays includes many other devices than the "traditional" cooled camera, like *webcams* (inexpensive video cameras), *integrating video cameras* (video cameras that can take long exposures due to having new supersensitive CCD chips [**12**]), or *consumer standard digital cameras.* All this CCD-based devices[5] are capable of taking at least dozens of short colour shots to be integrated lately by digital processing [**13**].

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[4] Technically, CCDs endure other sources of noise (*pixel non-uniformity, read noise, photon noise*), but at the amateur level the thermal noise (*"dark current"*) is by far the most important one.

[5] Although in truth, some of them actually have CMOS chips (another digital technology very close to CCDs).

2. Project execution

All the imaging activities were executed from the author’s terrace, under suburban skies. Each new session implied to perform the reassembling and proper polar alignment of the telescope and related gear, as no fixed mount was available. No other person collaborated with him at field, and all the images were taken without any further assistance.

Two last introductory considerations are well worth mentioning: (a) the astroimaging learning curve had to be started from zero, as the author had no previous practical experience at all, and (b) the impossibility to obtain any special developing service or stuff other than common supplies, as the author’s living region imposed such constraints.

2.1 Technical Description

As the title states, this project has been done by means of modest equipment at the current reach of any average amateur astronomer. Specifically, the used telescope was an 20-cm Schimdt Cassegrain (*Meade LX-90*), and the imaging gear basically included a small sized CCD astronomical camera (*Meade 216XT*), some unsophisticated SLR 35-mm film cameras (*Nikon EM, Nikon N4004s,* and *Yashica FR*) with several interchangeable lenses, and a CMOS webcamera (*Meade LPI*).

The tried lenses were: *Chinon* 28-mm (f/2.8-16), *Nikon* 50-mm (f/1.8-22), *Chinon* 135-mm (f/2.8-22), *Quantaray* 500-mm (f/8 fixed, mirror), and a teleconverter 2X [6]. The cameras were used either fixed on tripods, piggybacked on the telescope, or mounted on a variable-projection camera adapter through the telescope. External (cable connected) triggering shutters became indispensable, and a digital beeper cooking timer resulted very convenient.

The optical used accessories were a flip mirror system (*Meade 644*), an off-axis guider (*Meade 777*), an f/6.3 focal reducer (*Meade series 4000*), and a 12-mm reticle eyepiece (*Meade MA*).

The film images were digitalized by using a standard scanner of 600 dpi (*Genius ColorPage-Vivid 3XE*) , and lately processed with the aid of *Adobe Photoshop 6.0* software. Astronomical data extraction was performed by applying the *AIP4WIN* software tool.

The imaging targets had been selected from the brightest objects in each one of the wanted categories -solar system, standard fields, nebulae- on condition that they would appear particularly high from the observing site. Each expected altitude was found out with the assistance of the *Starry Night Pro* software.

No image has been shot with a lower altitude than 45° (that is, airmasses under 1.4 were always satisfied), with the only exception of the initial pictures of the Moon on occasion of the lunar eclipse of October 28th, 2004.

Twenty three photography rolls have been taken along this work. The films were either Kodak or Fuji, for regular non-specific use. The rolls were automatically developed at the local Kodak

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[6] With exception of the *Yashica FR* camera, all the film photography stuff was temporarily borrowed to the author for this project.

shop (no special development process was possible to be performed). The used film sensibilities varied from ISO 100 to 1,600.

About 300 CCD images were taken at field (besides all those images shot while testing the CCD camera indoors), and some dozens of different webcam images.

A detailed description containing the technical background of the images presented in this report has been included in Appendix A. The shown images have been compacted at low resolution levels in order to minimize as much as possible the final size of this document. No digital process was performed on the film images other than their digitalization from printed photos (except for those few images presented as negatives).

2.2 Project Schedule

The overall period to perform this project spanned little more than two months, from late August to early November, 2004. Taking into account that weather conditions at the observing site were highly variable especially for the considered period, imaging sessions had been properly planned to optimize the occurrence of favorable nights.

A log of all practical activities actually performed for this project has been included in Appendix B.

2.3 Tasks not performed

Despite the author's best intention, three planned tasks could not be actually performed:

(a) CCD guiding: Even though several attempts were executed along different sessions, the author was unable to make his CCD camera to guide the telescope for more than a few minutes. No matter how careful all related parameters were set, what calibration was previously tried, or which brightness level for the target star was selected, the CCD always ended up by losing its target star after performing only a few corrections.

(b) Colour CCD imaging: This technique, which certainly had been planned to be included, was not even tried in spite of having at reach a colour filter wheel. The disappointing performance of the tracking system of the LX-90 telescope was the only reason explaining why the author decided that trying this interesting technique with such deficit would have been a waste of time.

(c) Webcam planetary imaging: Although not preliminary considered, the author decided to try some planetary shots encouraged by the excellent initial results of lunar webcam imaging. The selected target was Saturn (who other!). The first attempt failed due to human errors (the taken images, actual satisfactory colour images, were not properly stacked and became lost). On revenge, Nature did not allow new opportunities for the remaining days.

3. The imaging techniques at field

All specialized literature emphasizes that prior to attempt any serious astroimaging activity, there are two major topics that must be checked:

(a) the right collimation of the telescope's optics
(b) a stiff equatorial mount properly polar aligned

The necessity of as-good-as-possible collimation is self explicatory. Imaging through an alt-azimuthal telescope, or doing it supported by an equatorial misaligned one implies the inevitable appearance of *field rotation.* If the mount is not sufficiently rigid and/or the telescope not properly balanced, gravity will make that the imaging gear will change its pointing direction as the telescope moves.

The third factor in importance, although there is little action that an amateur can do for improving it (unless a major surgery could be considered) is the tracking accuracy of the telescope. Nevertheless, there is no perfect drive system, and excellent ones only assure a little more margin in exposition times. Figure 4 shows a prime focus image spoiled due to a noticeable erratic response of the telescope's tracking.

Figure 4
A palpable prove of the inaccuracy tracking of the used telescope

Therefore, the first task performed at field after checking the collimation (only a slight adjust was needed) was the drift polar alignment sequence. The method was straightforwardly applied without any problem after correctly resolving its translation to the southern hemisphere (almost all trustworthy published information describes the method just for northern observers).

Next, time came to start trying the different imaging techniques at field. The first objective was to get familiar with their different peculiarities and potentialities. The qualitative analysis of achieved results as a function of different combinations of the involved imaging variables, either benefiting or degrading them, is immediately presented.

3.1 Film astroimaging

Independently of the particular camera mounting technique, two fundamental topics are fully responsible of the light amount that reaches the film during the imaging process: the exposure time, and the optical focal ratio (just the aperture diaphragm for usual film cameras).

The consequences of different exposure times become quite understandable. Longer exposures means that the light density will also grow, but up to certain point (as shown in Figure 2). The series of photos of Figure 5, where only the exposure times varied, show this achieved saturation effect, as the 4-minute exposure certainly shows less stars than the 2-minute one due to the "accumulation" of the sky background brightness.

The focal ratio of an optical device is the focal length divided by its corresponding diameter, and this ratio determines its "speed" (those having comparatively larger ratios are called "slower", as opposed to "faster" devices of smaller ratios). Obviously, the faster the lens, the lesser time is required to excite the film at a given brightness level.

The following pictures in Figure 6 were obtained with the same lens, the same exposure time, and the same film, but at different f/ values[7]. Despite the dirtiness of both images, which makes to confuse impurities with non-existing stars, the second one contains much more stars.

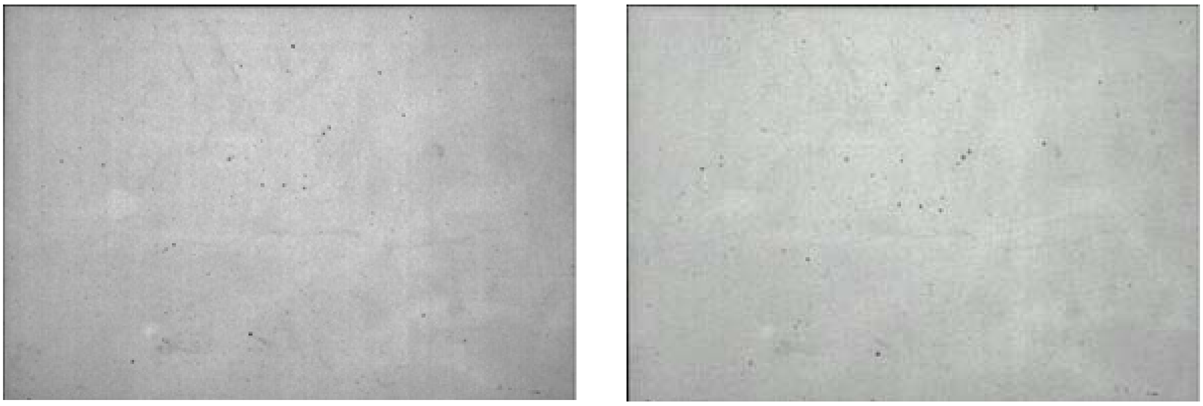

Figure 6
Two photos taken with all same parameters except aperture diaphragm:
the one at the left (at f/5.6) shows many less stars than the other (at f/2.8)

The final image is the transformation of the overall received light accordingly to the film characteristics, where *speed* and *reciprocity failure* are the most important factors regarding astrophotography.

There are several methods for obtaining film astroimages. The usual ones are: fixed camera, piggyback, prime focus, and positive projection. Each technique has its own pros and cons, so that their respective suitability greatly depends on the considered target.

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[7] In photography jargon, the aperture diaphragm is usually referred to as "f/ something".

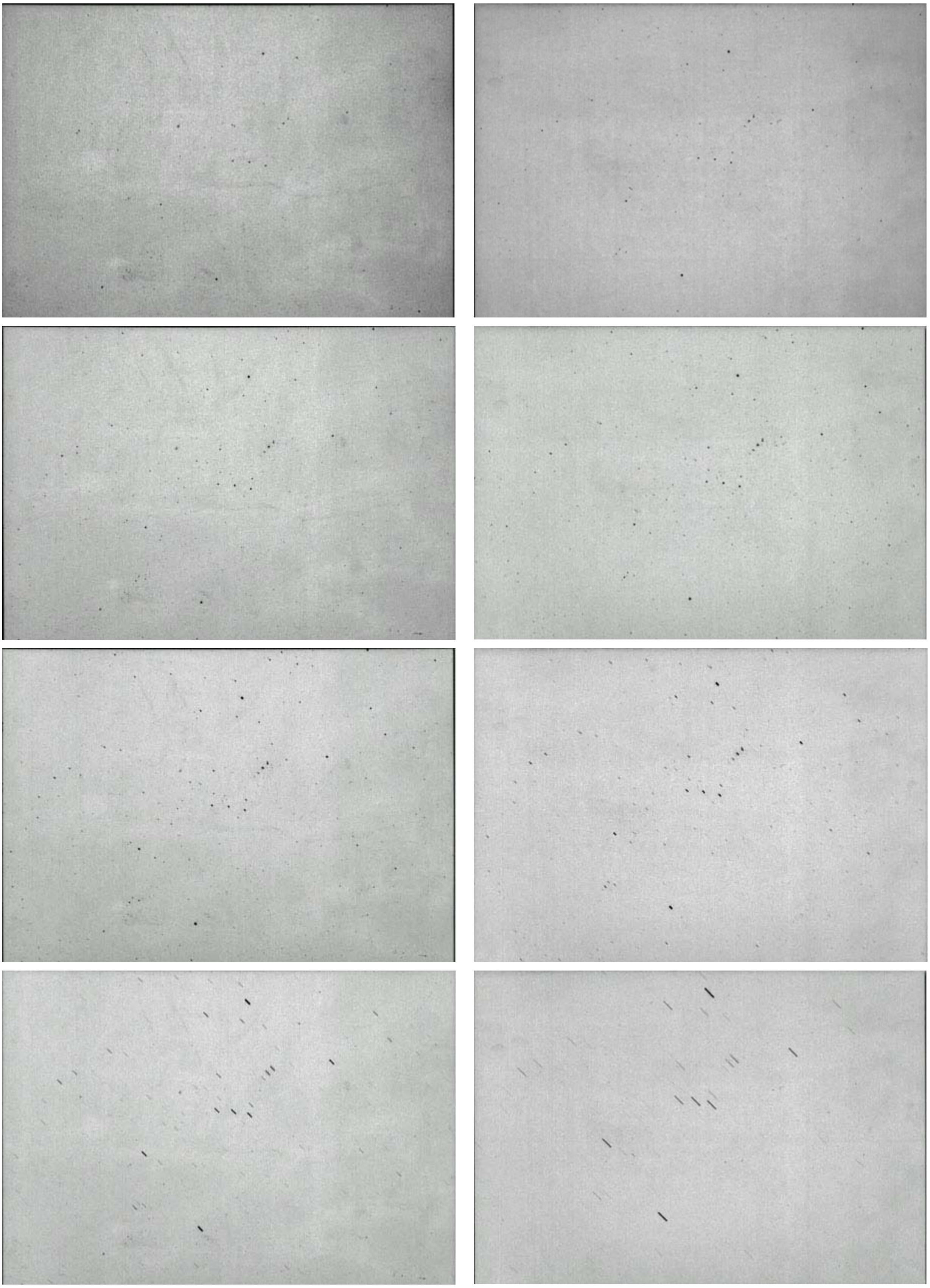

Figure 5
Fixed camera at the Orion constellation
Exposure times: 2s, 4s, 8s, 16s, 32s, 1m, 2m & 4m

The most important factor that distinguishes each method is its associated field of view, that is, the angular field that becomes imaged in a single frame. Deriving from the small-angle formula, the field of view (*FOV*, in arcseconds) becomes

$$FOV = \frac{206{,}265w}{F} \tag{1}$$

where *w* is the considered width of the film (24 mm for the short side, or 36 mm for the long one), and *F* is the focal length of the used optics (expressed in the same units as *w*).

The composition shown if Figure 7 exemplifies about the notorious differences in field of view typically achieved by each imaging method.

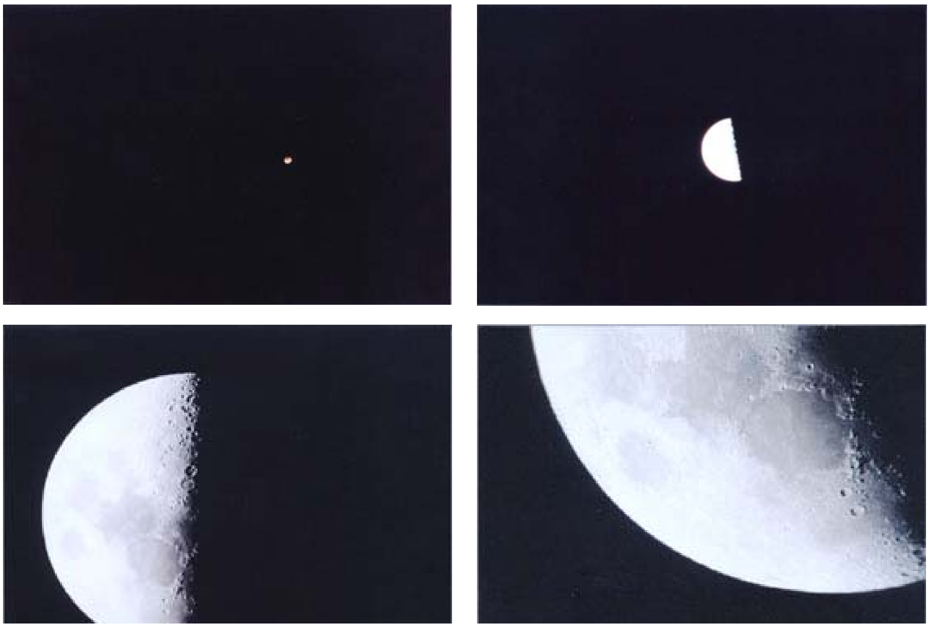

Figure 7
Four images covering very different fields:
upper left: 40° x 27° (50-mm lens); upper right: 4.0° x 2.7° (500-mm lens);
bottom left: 60’ x 40’ (prime focus); bottom right: 24’ x 16’ (positive projection)

3.1.1 Fixed camera technique

The fixed camera imaging technique is the easiest one. The obvious drawback is that star trails appear if the exposition becomes greater than a few tens of seconds, depending on the declination of the star field (the lower, the worse). The empirical formula for the longest acceptable exposure (*t*, in seconds) is

$$t = \frac{1000}{F\cos\delta} \tag{2}$$

where *F* is the focal length of the lens (in millimeters), and δ is the declination of the centre of the star field [**14**].

The Orion constellation sequence seen in Figure 5 represents the worst case, as δ = 0°. Star trails appear noticeably longer as the exposure time was increased. As the used lens has a focal length of 50-mm, the formula (2) gives 20 seconds as the longest acceptable exposure without annoying trails. The pictures provide fact of its empirical correctness.

3.1.2 Piggyback on telescope technique

Using the sidereal motorized tracking of telescope to accordingly move the piggybacked camera is the simplest way -at least in theory- to eliminate star trails. In practice, there will be no noticeable star trails only on condition that the unguided tracking would have been very good during the overall exposure period, on a properly polar aligned telescope. Those conditions are usually achieved imaging with lenses lesser than about 300-mm, exposing not longer than 10-15 minutes, with decent equatorial mount and clock drive.

If either larger lenses are going to be used, or bigger expositions applied, guiding will be necessary (at least, some guiding that assures not big tracking errors during the imaging period). Assuming an overall blur of 1/40 mm on the film to be acceptable, the guiding tolerance (*GT*, in degrees) can be derived from

$$GT = 2arctg\frac{1}{80F} \tag{3}$$

where *F* is the focal length of the used lens, in millimeters [**15**].

The following image set of the Milky Way around the Trifid Nebula in Sagittarius includes shots of 8m & 16m taken with a 135-mm lens without any special guiding. Both photos do show some star trails, denoting a noticeable inaccuracy in the telescope tracking system.

Figure 8
Despite being taken mounted on a motorized telescope, these respective 8m and 16m 135-mm photos do show some star trails (more obvious on the longer one)

Both images of Figure 9 have been obtained with manual guiding, forcing that a target star never drifted out of the central box formed by the double crosshair of a 12-mm reticle eyepiece during the full guiding period. For the f/10 used telescope, that central box equals a square of 22.5 arcsec of side. The left image, although it took 7 minutes, shows almost no star trails while the

one at the right, of only 90 seconds of exposition, suffered notorious drifting. The simple explanation lays in the different covered fields, as the first one was shot with a 500-mm piggybacked lens, while the second one was taken directly at the telescope'focus (4 times longer, and thus demanding a much more accurate tracking).

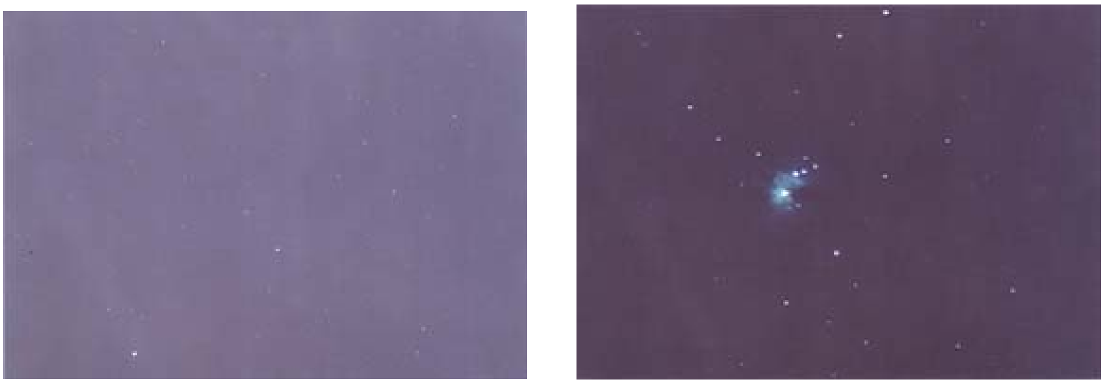

Figure 9
Both images have been manual guided with the same reticle eyepiece, but the 7-minute shot through a 500-mm lens shows almost no drifting errors compared to the 90-second at prime focus

Incidentally, it is interesting to observe the excellent response that the emission nebula has promoted in the used colour film, in just 90 seconds of exposition.

3.1.3 Prime-focus technique

The film has to be placed at the telescope's focus, so that the telescope behaves like a large telephoto camera lens. The required rigid mechanical coupling of the camera is obtained by means of a special piece known as a camera *T-Mount* (which is specific for the particular camera brand).

Two factors concur to make almost imperative the need of guided expositions for prime-focus deep sky photography. Not only the field of view has become much more reduced compared to those achieved through usual camera lenses, but at the same time the fixed focal ratio of the telescope is also normally larger -that is, less "luminous", often refer to as "slower"- than lenses. Both conditions imposed greater exposure times compared to the aforementioned techniques, and this explains the certainty that any tracking inaccuracy will appear materialized in the final deep sky image.

However, prime focus photography becomes a necessity when the magnification obtained from the largest available lens is still not enough. This is the usual case for lunar or planetary surface imaging, but being bright objects as they are, they do not demand large expositions at all (forgiveness about tracking errors becomes directly proportional to target brightness).

3.1.4 Positive projection technique

The last step in the staircase of film astroimaging magnification is positive projection. Here the film is placed after an eyepiece that enlarges even more the focal image –which makes this technique been also known as *eyepiece projection*. It becomes necessary an adaptor accessory

that holds the eyepiece inside and the film camera at its rear side, preferably of variable length in order to permit a continuous range of projection magnifications.

The smallest field of view implies the greatest demand in tracking performance. Regarding tracking errors, positive projection photography operates an almost "zero-tolerance" policy.

To find out the achieved field of view it is necessary to replace F in formula (1) by the *effective focal length*, which becomes the original focal length of the telescope multiplied by the projection magnification M. This magnification is

$$M = \frac{s_2 - F_2}{F_2} \tag{4}$$

where s_2 is the real distance from the eyepiece to the film, and F_2 is the focal length of the eyepiece [**16**].

Summarizing, the logical process for selecting the right parameters in film astroimaging is:

(a) To determine the target going to be imaged (the first and most important topic);
(b) To choose the technique and elements to apply (basically derived from the desired magnification at which the target has to be imaged);
(c) To opt for an available film speed (an equilibrium between the desired quality of the final image -more or less density grained-, spectral response, expected exposure time and reciprocity failure);
(d) To select the right exposure time and focal ratio (which necessarily have to be derived in accordance with the previous options).

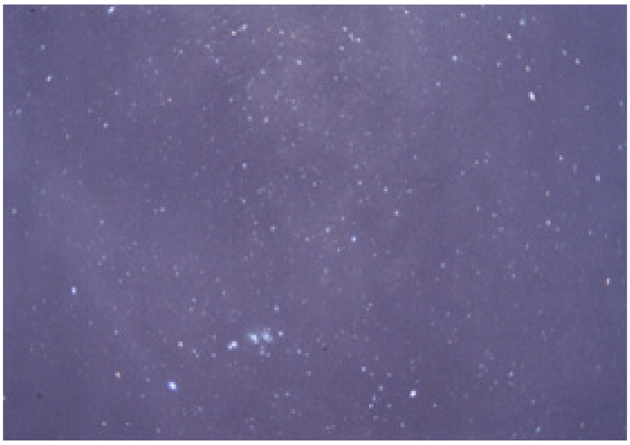

Figure 10
The noticeable arcs that seems to be centered at the precise centre of this 2x135-mm image of 4 m of exposure are only due to the inferior optical quality of the used teleconverter

Although necessary, the right selection of the appropriate elements is no guarantee of final success. It still remains its proper manipulation at field. Besides, equipment or materials that lack of a minimum acceptable quality will certainly prevent from good results. Figure 10 shows the effects of the bad optics of a tried 2x teleconverter, making it unable for astroimaging purposes.

Lastly, if there is something that experience has shown to be fundamental in film astroimaging, is that *bracketing* becomes a must. In practice, theory is not enough. There is a lot of variables

that simultaneously concur, and astronomical phenomena can be very rare or non repetitive at all. The astrophotographer must image insured, and the only insurance at field is taking many photos with slightly different settings, especially in exposure times.

Proceeding with a minimum care, film astrophotography can be very rewarding for even the novice amateur, as the following picture exemplifies.

Figure 11
The Lagoon Nebula (center, at left) and the globular cluster M28 (center, at far right) become easily detected in this suburban 4-minute shot of the magnificent Milky Way at Sagitarius

3.2 CCD astroimaging

Generally speaking, CCD astronomical cameras cover tiny field of view compared to film cameras. Regarding the aficionado level, cheap astronomical CCD cameras means even minuscule field of views. Figure 12 dramatically depicts such situation.

This basic restriction imposes two inherent problems to amateur CCD astroimaging: the proper centering of the desired target, and the correct focusing. Both tasks can be (usually are) a real challenge at field. A lot of patience at first, and practice at last, are the inevitable required conditions if all known benefits of CCD imaging (linearity, dynamical range, sensibility, spectral response) are pursuit.

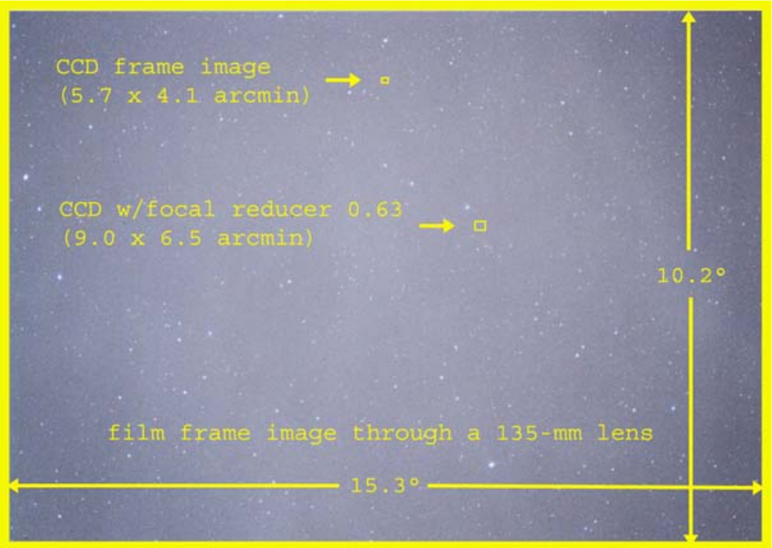

Figure 12
The field of view actually covered by the used CCD camera compared to the potentiality of a 135-mm film camera

The use of a flip mirror device does help a lot, as the simplest technique of replacing the camera by a parafocal eyepiece has the inconvenient that usually the difference in weights makes the telescope to flex and hence to lose the aiming[8].

CCD imaging has a powerful advantage: its (almost) immediate result. The possibility of obtaining a rapid feed-back about the correctness of the imaging procedure being performed becomes invaluable. It represents an important plus point in the comparison to film imaging.

3.2.1 CCD Calibration

As previously mentioned, besides the target images it becomes imperative to obtain some other specific images in order to permit the later elimination of inevitable gathered noise. This includes the so-called dark frames, flat-field frames, and bias frames.

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[8] In the particular case of the used CCD camera, which happens to have its sensitive chip off axis due to a failed factory assembly, the flip mirror device could only be partially helpful.

At the amateur level, which implies CCD cameras operating at temperatures always above minus 30°C, the larger collected noise comes from “dark currents”. This noise can be easily removed just by subtraction. Hence, it is only necessary to obtain an image of it, and this is what dark frames are: just an image of the dark current that the CCD camera auto generates when takes images of determinate exposure time at determinate operating temperature.

The imaging system also introduces noise due to non-uniform responses originated by optical irregularities or randomly distributed dirties. Since the imaging of a perfect uniformly illuminated field through a perfect imaging system should achieve a perfect evenly brightened result, it becomes simple to remove all the introduced non-uniform responses by the real imaging system, just by dividing any considered image by the image of an evenly illuminated frame. That is what flat-field frames are: just an image of a uniform source obtained in identical optical conditions as the considered image.

The bias level is a voltage added to the CCD output to keep its minimum always positive. It is possible to obtain a map of its different distributed values and thus subtracting it lately from any image. That is what bias frames are: just an image of a zero-exposure time taken with the camera shutter closed [9].

A very handy accessory for obtaining flat frames is a “lightbox”. It is a light box that can be easily mounted over the front of the telescope, with the fundamental feature that it presents an evenly illuminated screen, which brightness level can be adjusted –usually, in order to obtain a half-full-well level. Also dark frames can be obtained through it, on condition that the illumination source remains turned off. Figure 13 shows the lightbox specially constructed for this project.

Figure 13
The constructed lightbox at field, and a detail showing its translucent layer that results evenly illuminated by twelve colour LEDs, strategically placed under it

As the use of a focal reducer, Barlow lens, or any coloured filter actually means a different overall optical system (each optical device has its own irregularities), a flat field for each different situation must be obtained.

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[9] By “definition”, a bias frame is included in any considered frame, and thus any dark frame always contain it.

The logical procedure for calibrating an amateur CCD image becomes as follows:

a) Obtain a master dark (a combination of several dark frames that will reduce dark noise more accurately than from any single dark frame[10]) of the same integration time of the considered image;

b) Subtract the master dark from the considered image;

c) Obtain a master flat-field frame;

d) Obtain a master dark-flat frame, that is, a master dark of the same integration time as the flats;

e) Subtract the dark-flat frame from the master flat-field frame;

f) Finally, divide the master dark subtracted image by the dark-corrected master flat.

An alternative is to obtain a master bias that allows to compose "scalable" master darks of different integration times. This means that it is no longer necessary to obtain dark frames of the same integration time of both the original image and the flat-field frames.

The noticeable improvement achieved by the calibration process can be observed in the images of Figure 14. This image of only 5 seconds of integration also examples about the great sensibility of CCD astronomical cameras, as the "medium" bright stars that appear are 12th magnitude, and even very fainter stars (of at least 2 magnitudes more) can be observed.

Figure 14
The Great Orion Nebula CCD imaged
The raw image and the final result after calibration (both images have the same resolution)

3.3 Webcam astroimaging

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[10] It will result uncontaminated by any possible transitory effect (as the frequent appearing of *cosmic rays*).

This represents the newer player appeared in the amateur astroimaging game. Besides the pros of digital imaging features, webcams add an almost instant feedback that helps a lot during focusing and centering initial times. Another attractive feature is that webcams specifically designed for astroimaging are currently colour devices.

Despite being an inexpensive imaging device compared to CCD cameras, webcams achieve quite satisfactory results in particular for lunar and planetary imaging, as Figure 15 certainly proves it. Both images were truly obtained in the author's very first attempt of webcam imaging. Considering the easiness of this imaging proceeding, the achieved quality became frankly unexpected.

Webcams are intrinsically "noisy" devices, as they lack of any kind of cooling. They base their astroimaging potentiality due to being capable of the continuous capture of individual frames. Depending on the used resolution, the capture rate usually varies from several to hundreds of frames per second, which afterwards can be digitally stacked.

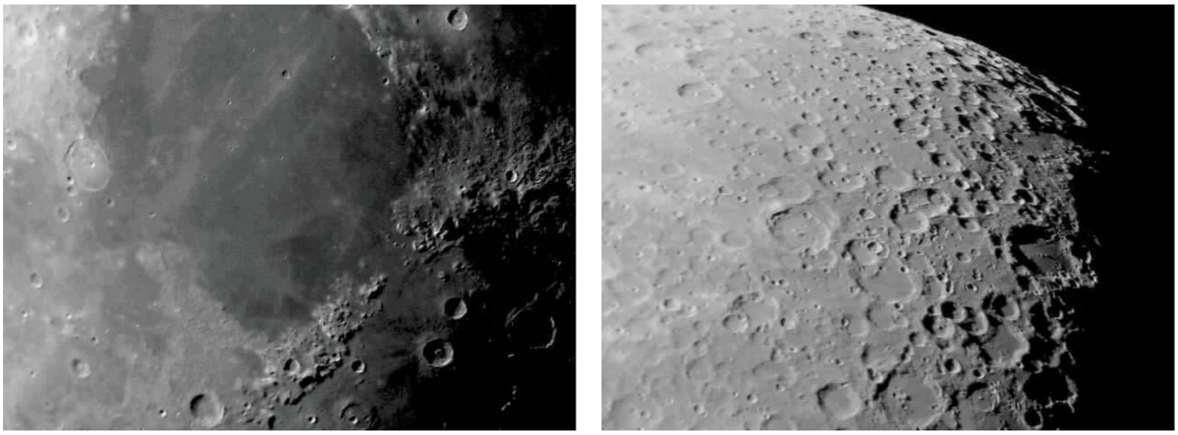


Figure 15
The Moon imaged by a webcam
At left, the northern side of Mare Serenatis; at right, a region near the South Pole

This stacking process significantly improves the final image quality, as the *signal-to-noise ratio* is proportional to the square root of the number of frames that are combined [**17**]. Besides, noisy frames under a minimum of standard quality set at will be rejected, letting "pass" only those frames shot when the atmospheric turbulence just happened to be particularly steady.

Astrowebcams also allows the possibility of guiding, although only from bright stars at the current state-of-the-art. Such procedure was certainly intended at field, but insoluble tracking problems of the telescope made it fail. Nevertheless, the guide setting at field was a lot easier compared to usual CCD guiding operation, encouraging next attempts.

Regarding amateur astroimaging, not long ahead colour webcams will be option #1 as their current single handicap -the lack of high sensitivity for deep sky targets- is becoming permanently minimized as technology improves.

4. Quantitative analysis performed on some obtained images

The potentiality of amateur astroimages can go far beyond the mere aesthetic satisfaction, on condition that they were careful captured, and that the aficionado actually knows what data is capable to be obtained, and how to get it. Some examples of objective data just extracted from typical amateur images are now presented.

4.1 The measurement of the exact focal length of the used telescope

From Figure 14 (Orion Nebula) image it is possible to measure the pixel distance between two well-separated pointlike stars: the bright one most at the top, and the bright one most at the left. Respectively, their data appears in the following table:

Star	*Coordinates (J2000.0)*	*Magnitude*	*Pixel location*
TYC 4774-849-1	5h 35.164m -5° 27.887’	8.53	(216, 44)
TYC 4774-935-1	5h 35.524m -5°25.273’	8.43	(22, 152)

The pixel distance (d_{px}) between those stars becomes

$$d_{px} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)} = 222 \text{ pixels}$$

As the pixels of the used camera measure 0.01mm, the image separation at the telescope’s focus results 222 times 0.01, that is, 2.22 mm. Therefore, knowing that the angular separation is 358 arcsec (extracted from the *Starry Night Pro* planetarium software), and considering that a 6.3 focal reducer was used, from equation (1) it becomes that the exact focal length (F) of the telescope is

$$F = \frac{206{,}265 x 2.22}{358 x 0.63} = 2{,}030 \text{ mm}$$

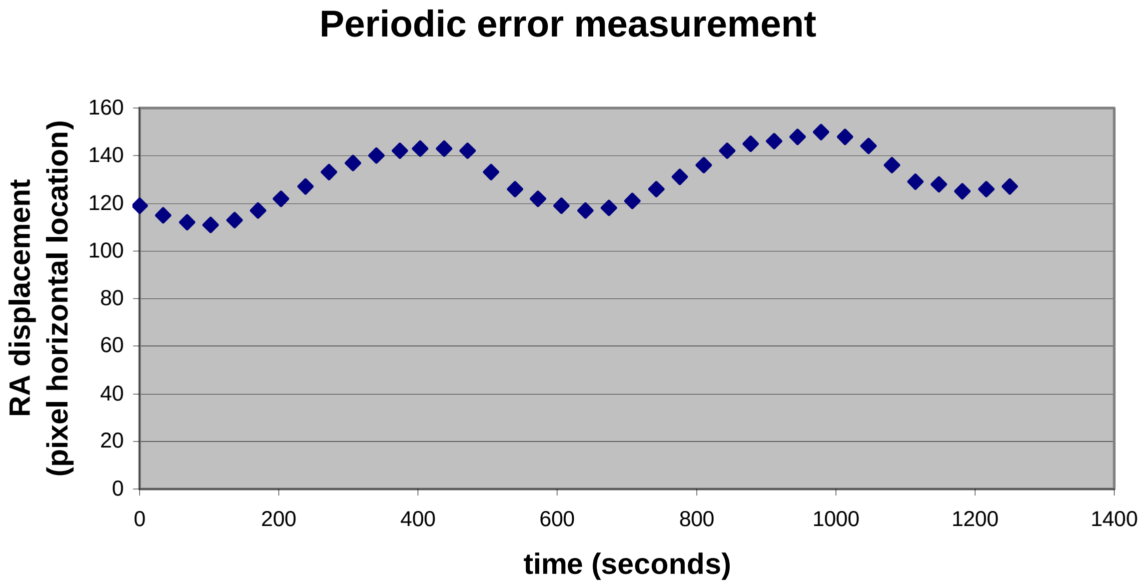
This result confirms that the LX-90 telescope is an exact f/10, as its diameter is 203 mm.

4.2 The measurement of the periodic error of the used telescope

Periodic errors occur because the tracking system of the telescope advances at a changing rate as the worm wobbles against the drive gear. An easy test field can measure this cyclic error, by taking images of a star during at less 20 minutes.

The following graph plots the measured drift in right ascension. The long axis of the CCD camera was placed parallel to RA, and 38 images were obtained during almost 21 minutes (fortunately, the selected star was a bright one that allowed to achieve data for all the considered period despite thin passing clouds). Each image was 5 seconds, and automatically shot one after another at the fastest possible rate (34 seconds with binning on).

The resulting curve clearly shows up its typical cyclic characteristic, with a period of about 550 seconds (9.2 minutes). The vertical tendency is due to a slight misalignment of the horizontal axis of the camera with respect to the true RA direction.



From the plot it comes out that the maximum RA displacement (that is, peak to peak)is about 25 pixels. From equation (1), replacing *w* by the pixel width (its actual size times two, due to the 2x2 binning) and considering that a 0.63 focal reducer was used, the angular width of a pixel (υ_{pixel}, in arcsec/pixel) results

$$\upsilon_{pixel} = \frac{206{,}265x0.010x2}{2{,}030x0.63} = 3.2 \text{ arcsec/pixel}$$

Therefore, the periodic error is 3.2*x*25 = 80 arcsec, which certainly is a very big one. As the telescope was perfectly balanced when the test was performed, there is no easy solution for correcting this serious drawback[11].

4.3 The measurement of the parameters of the used CCD camera

As mentioned before, regarding linearity CCD cameras achieve in theory a fantastic response. However, there are only imperfect cameras in this imperfect world -and at the amateur level “imperfections” always get worse. Therefore, it becomes very important to know the real potentiality of the particular CCD camera intended for collecting scientific data.

Luckily, the performance of a CCD camera can be accurately appraised at the price of carefully following a simple test. All that it is required is a closed illuminated box, where the brightness level can be precisely adjusted at will. Just a series of images taken with the CCD camera on different conditions (actually two flats and one dark for each integration time) will be enough to test its linearity as well as two other important parameters: the conversion factor and the readout noise [**18**].

Figure 16 depicts the construction of such box, usually referred to as the *low-level light source* [**19**], following the detailed referred instructions.

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[11] Either a major surgery or, much better, a telescope replacement will have to be attempted.

Figure 16
The low-level light source has a LED that brights at a very stable level; the amount of light reaching the CCD is adjusted by introducing different calibrated holes

The adjoined table summarizes the measurements performed in order to obtain the linear response of the considered CCD camera. All the images were obtained at the same CCD operating temperature, in a dark room with no other electrical appliance switched on in order to minimize interferences[12]. The mean pixel value (PV) column corresponds to dark subtracted flat images, the variance column to the result of both flat images being subtracted, and the count rate column to the mean PV divided by the integration time.

Integration time (sec)	**Mean PV (ADU)**	**Variance of flat1-flat2 (ADU)**	**Count rate (ADU/sec)**	**Variance / 2 (ADU)**
0.5	124.87	25111.72	249.74	12555.86
1	148.30	25766.35	148.30	12883.18
2	250.53	25917.88	125.27	12958.94
3	365.76	25398.65	121.92	12699.33
4	979.96	27320.12	244.99	13660.06
5	945.61	26843.34	189.12	13421.67
6	1255.03	27898.67	209.17	13949.34
9	2023.84	29044.06	224.87	14522.03
12	2183.56	30356.87	181.96	15178.44
15	2767.35	31604.56	184.49	15802.28
20	3951.36	34870.88	197.57	17435.44
25	4874.02	35974.04	194.96	17987.02
30	5804.52	39994.57	193.48	19997.29
45	8088.85	43325.01	179.75	21662.51
60	10952.06	52608.53	182.53	26304.27
80	14625.94	62057.75	182.82	31028.88
100	18258.13	69061.48	182.58	34530.74
120	22041.98	73679.90	183.68	36839.95
150	27503.68	80501.67	183.36	40250.84
180	33099.42	87510.08	183.89	43755.04
210	37016.47	93089.54	176.27	46544.77

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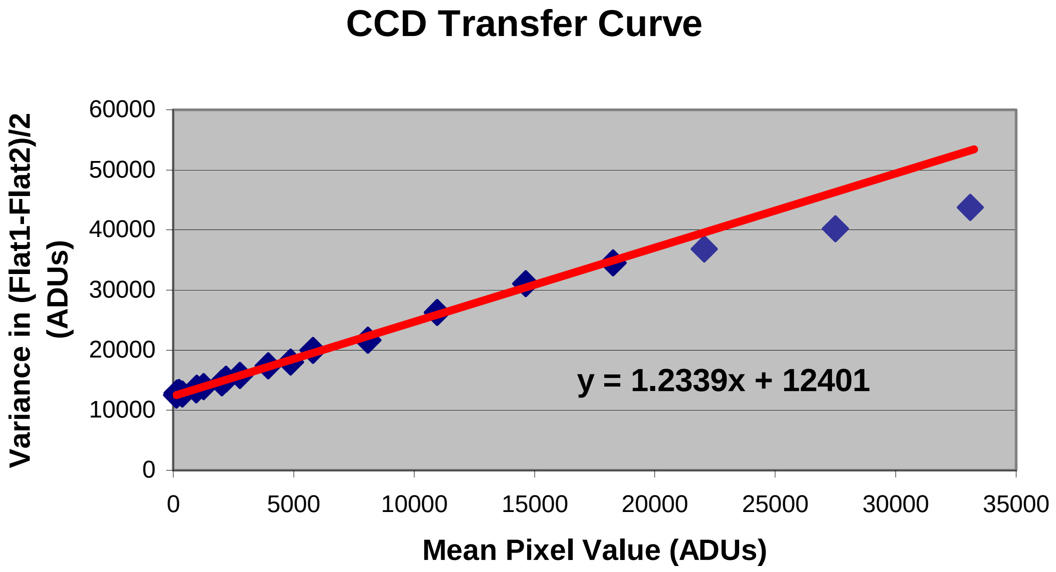
[12] Electrical interferences must not be underestimated, as they certainly affect the electronics of the CCD camera, and thus altering its performance. This long test had to be completely redone due to interference originated in other two table PCs that were operating in the same room as the CCD camera under test.

The *CCD transfer curve* is a graph of the variance (last column) as a function of the mean pixel value (column 2) [**18**], resulting the following plot:



From the transfer curve it comes out that the CCD's *conversion factor*, usually simply referred to as the *gain* (*g*) and given by the inverse of the angular coefficient, becomes

$$g = \frac{1}{1.2339} = 0.81\ \mathrm{e^-/ADU}$$

and the readout noise (σ_{ron}), being equal to the gain multiplied by the square root of the independent term, results

$$\sigma_{ron} = 0.81 \text{ x } \sqrt{12{,}401} = 90.2\ \mathrm{e^-_{rms}}$$

Both measured values are very modest, even for an amateur astronomical camera (unquestionable proof that the specimen under test was a cheap one[13]). Usual values for the gain of a 16-bit CCD camera are between 1 and 10 e$^-$/ADU, while the readout noise (the lesser the better) is somewhere between 15 and 60 lays e$^-_{\mathrm{rms}}$ [**20**].

The *CCD linear response* can be analyzed by plotting integration times (column 1) versus mean pixel values (column 2), resulting:

A preliminary analysis of the CCD response indicates that it does behave quite linearly only up to 35,000 ADUs, that is, it comes into saturation at such level. This imposes the limit for the achievable dynamic range, as it restricts how much signal can be obtained from the CCD before it saturates.

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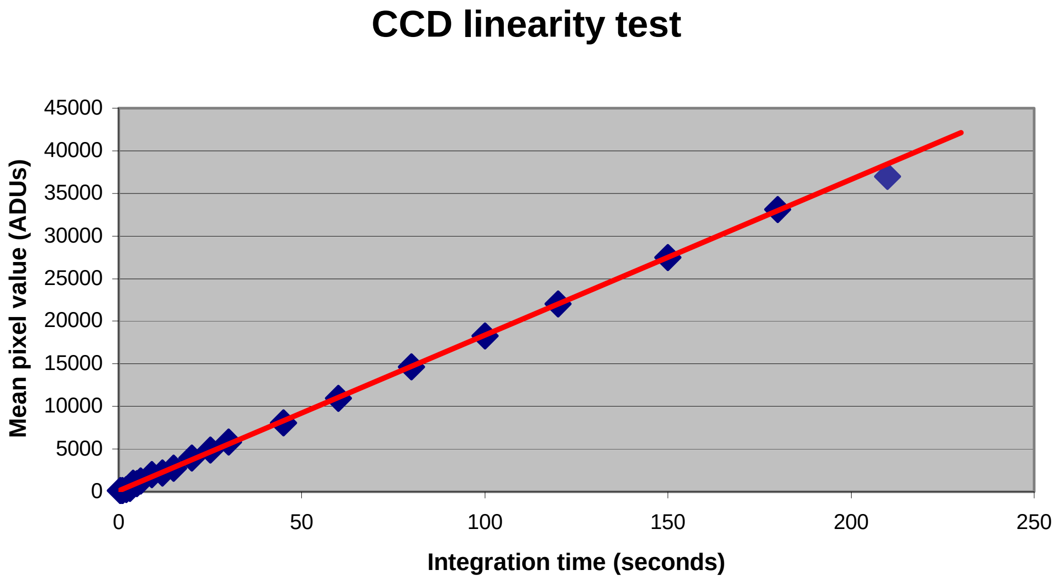
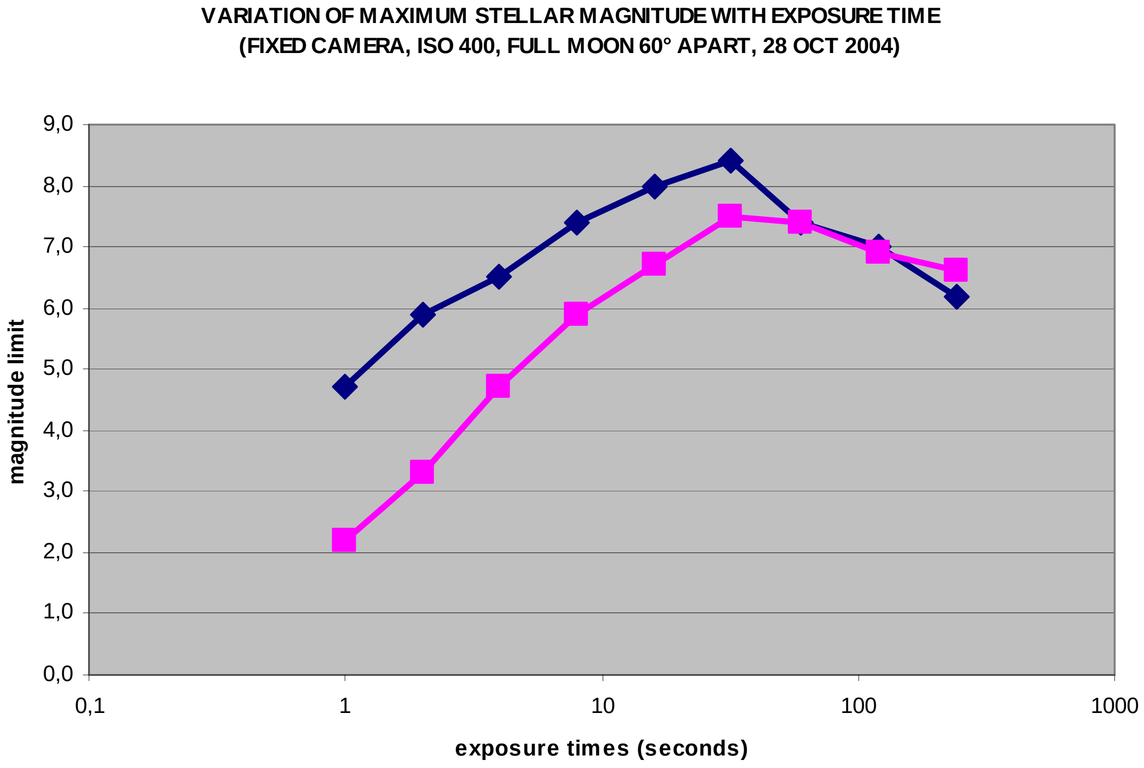
[13] The *Meade 216XT* actually is the cheapest one at the current market of CCD astronomical cameras.

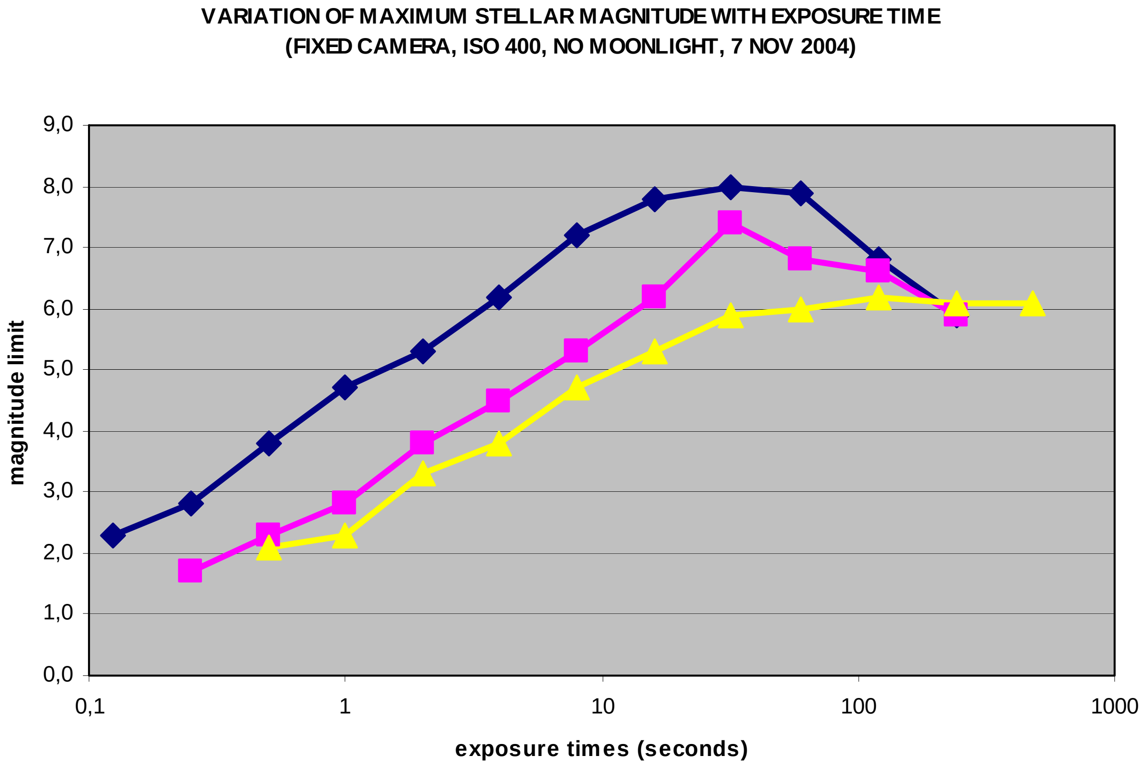


4.4 Analysis of the incidence of exposure times on film images

A test of the achievable magnitude limit depending on exposure times for differing conditions was performed for an ISO 400 film. The same constellation at the same altitude was shot on two different occasions, with and without moonlight (Figure 5 is a partial example). The respective limit magnitudes were found out by analyzing the dimmest stars in each printed photos with a magnification glass, and obtaining its value from a planetarium software. (The variable colour-response of the film has been considered that do not greatly affect this test).



The blue curve corresponds to f/2.8, and the fuchsia to f/5.6. The overall shape of the obtained responses are pretty much like the theoretical curve of Figure 2. As expected due to the sky background fog, the curves achieve a maximum and then began to descent. The f/2.8 curve gradually loses its better initial response compared to f/5.6, and it seems like the latter would become even better for very long exposures.



Here the blue, fuchsia, and yellow curves correspond to f/1.9, f/4, and f/5.6. The suspected fact of better long-exposure response for slower lens seems to be confirmed. However, there is something very strange. For the same f/5.6 condition, the maximum reached magnitude was more than a full magnitude greater for the full-Moon session than for no moonlight. The same can be said comparing the responses of the faster lens, even though the fastest lens was used with no moonlight at all. The only possible explanations for this counter intuitive result might be that the latter specimen film was particularly less sensitive than the first one.

4.5 Astrometric measurements

Astrometry refers to the measurement of the apparent location of objects in the celestial sphere. Having determined the exact position of a body for a particular moment, by comparison to further measurements it becomes possible to determine its relative displacement through the sky.

High precise astrometry can be currently done at the aficionado level (i.e. the detection of displacements as tiny as 0.2 arcseconds are at well the reach of a modest 20-cm f/10 telescope [**21**]), only on condition that accurate astrometric databases[14] can be accessed.

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[14] Like the Hubble *Guide Star Catalogue (GSC)*, the *US Naval Observatory A2.0* database, or the *MegaStar* CD-ROM, to mention just a few examples.

Lacking of such accurate information, a basic astrometric measurement has been done for this project, just by a “graphic” comparison to the position of nearby stars. The performed procedure was executed according to the following sequence:

(a) from a planetarium software (*Starry Night Pro*) it was firstly obtained the celestial chart corresponding to approximately the same star field of the image where the astrometric measurement had to be performed;
(b) with the aid of an imaging processing software (Adobe Photoshop), the celestial chart was roughly overlapped to the corresponding pictures after making the sky transparent (that is, appearing only stars and grid lines);
(c) after several precise rotations and enlargements of the celestial chart in order to make its stars to perfectly coincide with the imaged stars, the equatorial grid was accurately incorporated to the picture;
(d) astrometric coordinates were finally obtained by measuring the relative separation of the considered object to the nearest equatorial axes.

Figure 17 shows a photography of the *Landolt SA113 standard field* where it has been properly overlapped a celestial chart, referred grid included. The stars of the chart appear in black, and they are in perfectly coincidence with the white stars of the real image.

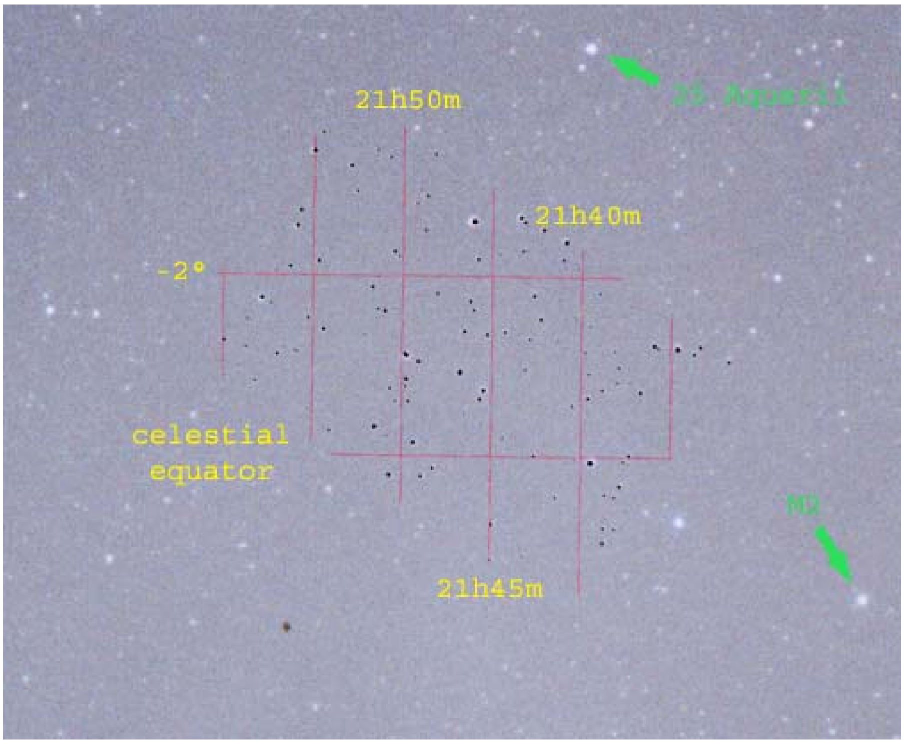


Figure 17
The corresponding equatorial grid has been properly applied over this photography of the Landolt SA113 standard field

The selected target for the astrometric measurements was the asteroid Vesta, which happened to move high enough through the (southern) spring skies. It was imaged on three different occasions, spanning a 45-day period. Figure 18 shows the obtained images, where yellow arrows point at each location of Vesta. Following the described method, Vesta’s celestial coordinates were obtained referred to present values (Eq JNow) and then compared to the corresponding data presented by the *Starry Night Pro* planetarium software:

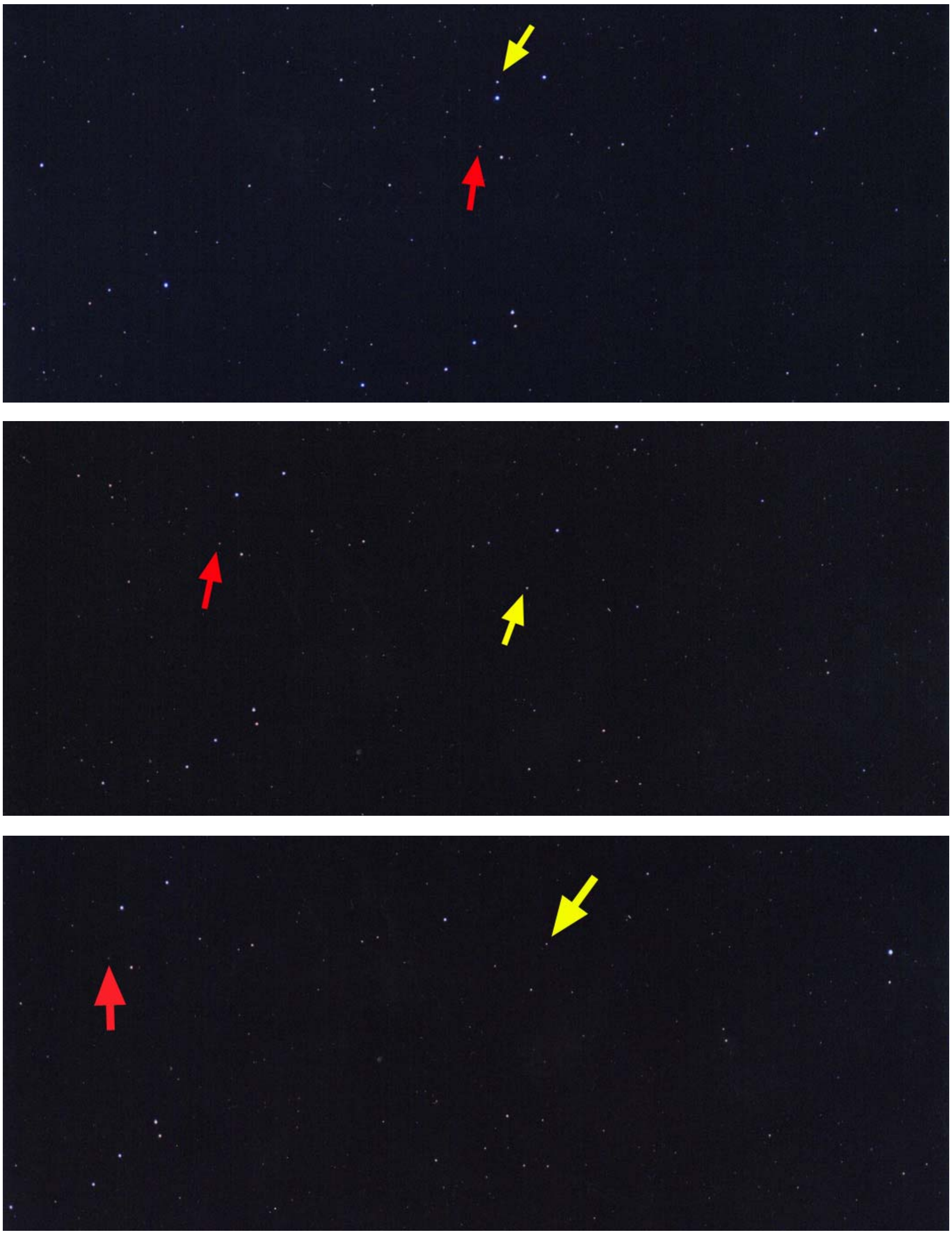


Figure 18
Three different shots of Aquarius where Vesta (pointed by yellow arrows) appears noticeably displaced (red arrows point to the variable R Aquarii)

The accuracy of the "graphic" performed astrometric measurements has been estimated in ± 0.2 minutes in RA and ± 3 arcmin in DEC. However, the planetarium data greatly differs from the obtained values (the RA differences are 1.6, 1.3 and 1.0 arcmin, and the DEC are 9, 9 and 8' respectively for each observation). The following table summarizes all the performed measurements:

Date	**September 15th**	**October 7th**	**November 1st**
UT time	02:12 hs	04:29 hs	00:31 hs
Measured RA	23h 42.9m	23h 24.8m	23h 16.8m
Planetarium data RA	*23h 44.5m*	*23h 26.1m*	*23h 17.8m*
Measured DEC	-14° 16’	-15° 55’	-15° 30’
Planetarium data DEC	*-14° 07’*	*-15° 46’*	*-15° 22’*

4.6 Photometric measurements

Photometry refers to the measurement of the brightness of any object. Specifically considering astronomy, there is a lot of objective information that can be infer just by measuring the amount and type of light that reaches us from any considered celestial body, at any given time.

From digital images it becomes easy to perform photometry measurements by applying a specific imaging processing software called *aperture photometry*. This tool automatically measures the counts from pixels only belonging to the desired object, given a comparative value technically called its *raw instrumental magnitude*. This name underlines that the obtained value has not been corrected for the particular atmospheric absorption at the time of the image, neither for the particularities of the used telescope and imaging system.

The values obtained from the basic aperture photometry can be either used as differences in magnitudes respect to stars of constant brightness appearing in the same images (*differential photometry*), or transform them into objective values independently of the distortions introduced by the proper imaging system and by the atmosphere as well (*standard system*).

For this project, some raw instrumental magnitudes have been measured from digitalized photos. In particular, taking advantage that Vesta happened to appear near the variable star R Aquarii, as shown in Figure 18, both objects were photometrically measured.

Object	***Coordinates (J2000.0)***	***Actual Magnitude***	***Measured raw instr. Magnitudes***		
			Sep 15th	***Oct 6th***	***Nov 1st***
HIP 116957	23h 42.5m -15° 27’	5.25	15.633	15.894	15.975
Omega 2 Aquarii	23h 42.7m -14° 33’	4.46	15.095	15.894	15.418
Omega 1 Aquarii	23h 39.8m -14° 13’	4.96	15.413	15.488	15.753
HIP 117222	23h 46.0m -15° 08’	7.96	17.615	18.138	18.619
TYC5828-1006-1	23h 23.7m -14° 30’	8.06	17.930	17.512	17.820
Vesta	-	-	16.118	16.695	17.173
R Aquarii	23h 43.8m -15° 17’	-	16.771	17.274	17.656

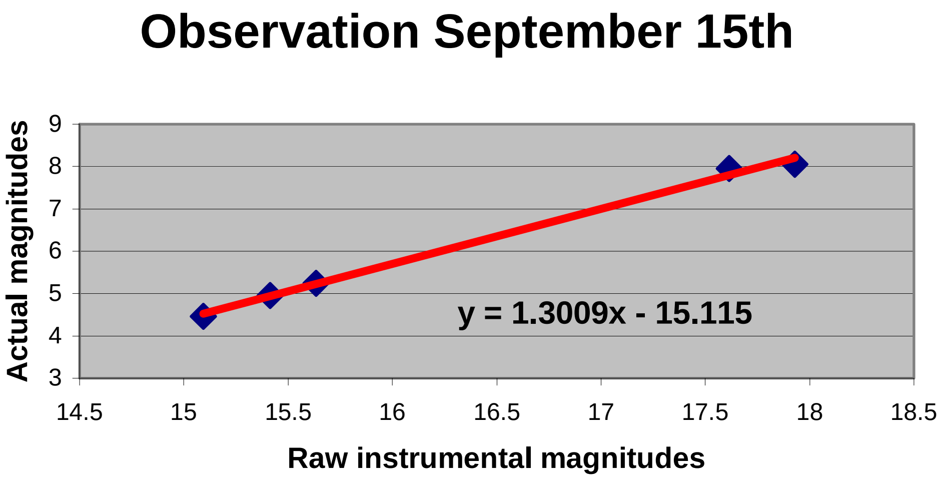
For finding out the actual magnitudes of Vesta and R Aquarii at the time of each observation, five nearby stars were selected, three brighter and two dimmer. The magnitude of each star was obtained from the *Starry Night Pro* planetarium software.

Plotting actual magnitudes versus measured raw instrumental magnitudes (as it is shown for the observation of September 15th), it was possible to obtain the conversion equation for each particular image. Specifically for the first observation, it resulted

$$y = 1.3009\,x - 15.115$$

Replacing x by the aperture photometry values (16.118 for Vesta or 16.771 for R Aquarii) it was possible to find out the actual magnitudes (respectively 5.85 and 6.70).

According to published data, Vesta reached opposition on September 13th, brightening at magnitude 6.1 [**22**], and R Aquarii achieved 6.5 of peak brightness on September 14th [**23**]. Therefore, both calculated values are 0.2 magnitudes lower than actual values, which results quite acceptable, especially considering that (a) only five stars were taken into account for obtaining the conversion equation, (b) data was derived from digitalized photos.



Proceeding in the same way, it was measured the magnitudes values for the two remaining images. The results for the three observations are listed in the following table:

	Sep 15th	***Oct 6th***	***Nov 1st***
Vesta	5.85	6.34	6.68
R Aquarii	6.70	7.16	7.26

This has proved that raw instrumental magnitudes can be easily derived from digitalized film images, with an acceptable accuracy.

4.7 Data from the lunar total eclipse of October 28th, 2004

The favourable occurred lunar eclipse allowed to obtain a single multiple-exposition frame actually containing 31 shots (Figure 19). The shots were taken at five-minute interval. Both the diaphragm aperture and the exposure times had to be permanently changed in order to compensate the dramatic changes in lunar brightness.

Figure 19
The totality phase of the lunar eclipse of October 28th, 2004
The displacement of the Moon is shown from the lower right to the upper left

From the image it is possible to actually visualize how the Moon cut across the umbra cone as the eclipse developed, given by the relative inclinations of the shadow.

Also, a composition has been done integrating eleven single pictures, as Figure 20 shows. Each lunar frame has the original surface colours as they appeared in the corresponding printed photos. From this image it is possible to objectively give a raw value in the five-point Danjon Scale for the particular lunar brightness occurred during this eclipse: level 3 (which corresponds to a *"brick-red eclipse, usually with a bright or yellow rim to the umbra"* [**24**]).

Figure 20
A composition of the development of the lunar eclipse, with its corresponding UT times

5. Head to head comparison of the tried imaging alternatives

The most important advantage of film astrophotography is the large field of view covered at the same satisfactory resolution as CCD cameras. Considered both at prime focus, the 35-mm film format covers 109 times more area than the CCD camera used for this project. Therefore, the imaging of any object larger than a few minutes of arc across in practice becomes only possible through the film camera[15].

The most important advantage of any astronomical CCD camera over films is its inherent great sensibility and wide-range 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. Regarding the usual poor tracking accuracy at aficionado's disposal, shorter exposure times are highly welcome.

As a matter of fact, the 7-minute guided film image of Figure 9[16] achieved magnitude 11.2, while, as said before, the 5-second CCD image of Figure 14 easily went under the 14th magnitude. This is palpable proof of what Figure 3 had prophesized.

The film technique is far more straightforward at field. To take the photograph, the aficionado simply gets the proper focus, centers the frame (both relative easy tasks) and shots. If necessary, manual guiding could be applied, becoming the only tiresome part (although the exposure could be very long). On the other hand, a typical amateur CCD imaging session implies: (a) proper focusing (tedious, to say the least); (b) proper frame centering (which is not as easy as it could sound); (c) shooting many frames (using different filters) with the required guiding (although for shorter periods than for films); (e) verification of each transferring and storing process; (f) shooting many dark and flat frames (at least one set for each image, where each used filter counts as different images).

Strictly based on the author's own experience, the potential imaging benefits of a small sized CCD camera becomes totally eclipsed by its set up complexity, and exiguousness of the surveyed area. For instance, after obtaining over than 80 CCD images of the *Landolt SA113 standard field* in order to perform accurate photometry, the later task of identification of the appearing stars demanded about 20 minutes per image, and that just for those images where some particular pattern had facilitated the search. The natural epilogue was the definitive abortion of the intended CCD photometry task after the fifth image.

On the other hand, as previously shown, interesting amateur analysis can be done from film astrophotography. Digitalized film photos, although much more "noisy" than original digital images, still have a great scientific potential at the aficionado level. And the price to pay for the acquisition of the required photos is just proficiency. No sophisticated or expensive equipment is needed. Just a lot of practice and wise feedback.

At the very beginning of this project, the author considered that film astroimaging was just a dying technique, with almost no future ahead. Having tried it, experiencing its simplicity, acknowledging its potentially, and particularly realizing the practical difficulties that the

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[15] Although is technically possible to construct a CCD image mosaic, its practical application demands proper equipment that certainly exceeds the possibilities of the beginner amateur astronomer.

[16] Considering stars appearing only as pointlike sources, this was the longest successful shot taken for this project using a focal length greater than 135-mm.

operation of small sized astronomical CCD camera implies, he has become now an enthusiastic astrophotography aficionado.

The right application for a small sized astronomical CCD camera seems to be the automatic guiding while film photography is been taken. This proceeding would joint together the strengths of both films and CCDs. The fact that the automatic guiding attempts been performed during this project were unsuccessful only means that the author still requires some extra tuning for it. But its suitability is generally recommended by all expert astroimagers.

The following table summarizes the respective pros and cons of the film and CCD options for amateur astroimaging.

	Amateur traditional film	***Amateur CCD imaging***
Exposure times for a particular target	Much more longer	Very short 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
Quantum efficiency	Very low (less than the eye)	Very high
Spectral response	Variable (depends both on the film and on wavelength)	Even over visible spectra
Basic equipment	Standard photographic SLR (*“reflex”*) 35mm camera	Astronomical CCD cooled camera, laptop, software
Possibilities of optical coupling through a telescope	Many ways (*prime-focus*, *eyepiece projection*, etc), even without it (*piggyback*)	Only at the telescope’s focal plane (*prime-focus*)
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	A single direct shot (with colour film)	At least three shots, each with different colour filters
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
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 must be composed
Recommended targets	Larger bright objects (Moon, constellations, nebulae, big galaxies, parts of the MWG)	Very faint and small objects, photometry, high contrast targets, planetary imaging
Cost (minimum investment)	Low	Expensive

Conclusions

Three basic imaging alternatives -films, CCDs, and webcams- are nowadays at the reach of any novice amateur astronomer. Each one has its own pros and cons. Attempting the best possible astroimaging result requires firstly to select the right tool for the intended job, and secondly to apply it with correctness.

In the case of film photography, the imaging method, the selected film speed, the applied exposure time, the optical characteristics of the used lenses, and the application of proper guiding greatly affect the resulting image. For CCD photography, such user-variables as integration time, operating temperature, number of images to be stacked, filters, and correct image processing are directly responsible for the achieved final quality.

Film astrophotography is particular suitable for imaging larger objects, for attempting survey works, or for most astrometric measurements of reasonably bright objects. CCD astroimaging is ideal for imaging very faint objects or for photometric applications where their linearity becomes indispensable. Webcams, whose potentiality is growing very fast, are very convenient for lunar and planetary work where their speed can take advantage of very brief episodes of excellent seeing in optical systems.

Equipped with even modest astronomical gear, the serious aficionado can still infer useful data from his own images. Typical astrometric tasks, like finding out the proper motion or parallax of nearby stars, or the determination of the orbits of comets and asteroids are nowadays at his reach. Even for the novice amateur, astroimaging can be a very rewarding experience, not only by aesthetical considerations but for scientific results as well.

Finally, despite our present state-of-the-art “digital world”, where new appliances daily change -and improve- our way of living, the old film astroimaging technique should not be discarded at all. It certainly has a great potentiality, it is simple to apply, old good SRL cameras are easy to find, and one can achieve proficiency by his own. Film astrophotography still is an excellent alternative *for the beginner on the cheap*.

References

[**1**] *“Astrophotography for the Amateur”* by *Michael A. Covington*, 2nd ed, Cambridge University Press, 1999, page 174
[**2**] *“Astrophotography for the Amateur”* by *Michael A. Covington*, 2nd ed, Cambridge University Press, 1999, page 176
[**3**] *“A Brief, Simple and Approximate Explanation of Photographic Film and Reciprocity Failure”* at http://www.mailbag.com/users/ragreiner/filmrecip.html
[**4**] *“Astrophotography for the Amateur”* by *Michael A. Covington*, 2nd ed, Cambridge University Press, 1999, page 177
[**5**] *“Advanced Amateur Astronomy”* by *Gerald North*, 2nd ed, Cambridge University Press, 1998, page 87
[**6**] “*Developing and Printing*” (module 6, activity 2, slides 8-19), by *SAO* at CD-ROM HET 609, 2004
[**7**] “*Introduction to CCDs*” (module 8, activity 1, slide 4), by *SAO* at CD-ROM HET 609, 2004
[**8**] “*What is a CCD?*” (module 10, activity 1, slide 5), by *SAO* at CD-ROM HET 606, 2003

[**9**] *“Handbook of CCD Astronomy”* by *Steve B. Howell*, Cambridge University Press, 2001, page 40
[**10**] *“The role of CCD Cameras in Amateur Astronomy”*, by *R. A. Greiner*, 2000, at http://www.mailbag.com/users/ragreiner/ALPaper.html
[**11**] *“The New CCD Astronomy”* by *Ron Wodaski*, New Astronomy Press, 2002, page 163
[**12**] *“Deep-Sky Imaging with Integrating Video Cameras”*, article by *Adrian R. Ashford*, Sky & Telescope, December 2003 issue, pages 131-132
[**13**] *“Deep-Sky Imaging with Digital Cameras”*, article by *Edwin L. Aguirre*, Sky & Telescope, October 2002 issue, pages 114-115
[**14**] *“Astrophotography for the Amateur”* by *Michael A. Covington*, 2nd ed, Cambridge University Press, 1999, page 10
[**15**] *“Astrophotography for the Amateur”* by *Michael A. Covington*, 2nd ed, Cambridge University Press, 1999, page 131
[**16**] *“Astrophotography for the Amateur”* by *Michael A. Covington*, 2nd ed, Cambridge University Press, 1999, page 77
[**17**] *“Shooting the Planets with Webcams”* article by *Michael Davis*, Sky & Telescope, June 2003 issue, page 119
[**18**] *“The Handbook of Astronomical Image Processing”* by Richard Berry & James Burnell, Willmann-Bell, Inc., 2000, page 209-212
[**19**] *“The Handbook of Astronomical Image Processing”* by Richard Berry & James Burnell, Willmann-Bell, Inc., 2000, pages 199-203
[**20**] *“The Handbook of Astronomical Image Processing”* by Richard Berry & James Burnell, Willmann-Bell, Inc., 2000, page 198
[**21**] *“The Handbook of Astronomical Image Processing”* by Richard Berry & James Burnell, Willmann-Bell, Inc., 2000, page 238
[**22**] *“Observer’s Handbook 2004”*, editor *Rajiv Upta*, The Royal Astronomical Society of Canada, 2003, page 211
[**23**] *“Variable Stars for September”*, Sky & Telescope magazine, September 2004, page 84
[**24**] *“October’s Ideal Lunar Eclipse”* by *Alan MacRobert*, Sky & Telescope magazine, October 2004, page 74

Appendix A

Technical background information about the particular parameters of all images presented in this report.

Figure	***Technical background information***
1	Piggyback, Kodak Gold ISO 200, 28-mm, f/2, 1m, on 6 oct 04
2	Drawn by the author, copied from *"So Many Films … Which Should I Choose?"* (module 5, activity 1, slide 5), by *SAO* at CD-ROM HET 609, 2004
3	Drawn by the author, adapted from *"What is a CCD?"* (module 10, activity 1, slide 5), by *SAO* at CD-ROM HET 606, 2003
4	Prime focus, Fuji Superia ISO 800, 2000-mm, f/10, 4m, on 31 oct 04
5	Fixed camera on tripod, Kodak Ultra ISO 400, 50-mm, f/2.8, eight different exposure times (2s, 4s, 8s, 16s, 32s, 1m, 2m & 4m), on 6 oct 04, lately converted to negatives
6	Fixed camera on tripod, Kodak Ultra ISO 400, 50-mm, both shot at 16s, the first one at f/5.6 and the other at f/2.8, on 28 oct 04
7	Fixed camera on tripod, Kodak Ultra ISO 400, 50-mm, f/4, 0.5s, on 27 oct 04
	Piggyback, Kodak Gold ISO 100, 500-mm, f/8, 0.5s, on 20 oct 04
	Prime focus, Kodak Gold ISO 100, 2000-mm, f/10, 2s, ND filter, on 20 oct 04
	Positive projection, Kodak Gold ISO 100, eyepiece 26mm, f/10, 2s, ND filter, on 20 oct 04
8	Piggyback, Kodak Ultra ISO 400, 135-mm, f/2.8, 8m & 16m, on 14 sep 04
9	Piggyback guided manually, Fuji Superia ISO 800, 500-mm, f/8, 7m, on 20 oct 04
	Prime focus guided manually, Fuji Superia ISO 800, 2000-mm, f/10, 90s, on 20 oct 04
10	Piggyback, Kodak Gold ISO 100, 2x135-mm (teleconverter), f/1.4, 4m, on 15 sep 04
11	Piggyback, Kodak Ultra ISO 400, 135-mm, f/2.8, 4m, on 14 sep 04
12	Piggyback, Kodak Max ISO 800, 135-mm, f/2.8, 1m, on 14 sep 04
13	Digital consumer camera
14	CCD, 0.63 focal reducer, -10°C, 5s, no antiblooming, on 06 nov 04
15	Webcam, single monochrome shots, 0.384 s, on 21 oct 04
16	Digital consumer camera
17	Composition based on a partial area of Figure 12 (Piggyback, Kodak Max ISO 800, 135-mm, f/2.8, 1m, on 14 sep 04) plus the grid and chart imported from Starry Night Pro
18	Piggyback, Kodak Max ISO 800, 135-mm, f/2.8, 1m, on 14 sep 04
	Piggyback, Fuji Superia ISO 800, 135-mm, f/3.3, 2m, on 7 oct 04
	Piggyback, Fuji Superia ISO 800, 135-mm, f/3.3, 2m, on 1 nov 04
19	Fixed camera on tripod, Kodak Ultra ISO 400, 50-mm, varying from right to left as follows: the first eight at f/8 (0.002s, 0.004s, 0.004s, 0.004s, 0.008s, 0.008s, 0.02s & 0.07s), the following 17 at f/4 (0.25s, 0.5s, 0.5s, 0.5s, 1s, 1s, 1s, 1s, 1s, 1s, 1s, 1s, 1s, 0.5s, 0.5s, 0.5s & 0.25s), the last six at f/8 (0.07s, 0.02s, 0.008s, 0.008s, 0.004s & 0.004s), on 27 oct 04
20	Piggyback, Kodak Gold ISO 100, 500-mm, f/8, eleven different exposure times (0.0005s, 0.001s, 0.001s, 0.004s, 15s, 8s, 8s, 0.002s, 0.004s, 0.001s & 0.0005s), on 27 oct 04

Appendix B

Log of the principal practical activities performed for this project. The dates of the executed tasks are all referred to local time.

Date	***Executed tasks***
August 23rd	Colimation of the LX-90 telescope
August 24th	Parafocal eyepiece with CCD at flip mirror
August 25th	First mounting of the LX-90 on equatorial edge and raw polar alignment First attempt (spoiled) of film astroimaging CCD imaging on the Moon
August 27th	Drive training of motors of the LX-90 Drift polar alignment Permanent marks on ground for each leg of the LX-90's tripod
August 29th	Check of the accuracy of polar alignment after reassembling
September 4th	First success in film piggyback imaging (1x24 ISO400, different lenses at different apertures and exposures), several targets
September 14th	Piggyback imaging (1x25 ISO400 and 1x24 ISO800), very clear skies
September 15th	Piggyback imaging (1x25 ISO100)
September 19th	Determination of infinite-focus position for lens of 500-mm Parafocal eyepiece with webcam Alignment of SRL camera with RA axis (reposition of screws of T-mount)
September 23rd	CCD imaging trying to obtain best focus on stars with a Hartmann disk
Sep 24th to 26th	Construction of a lightbox
Sep29th to Oct12th	Construction of a low-level light source
Oct 3rd, 4th and 5th	Flat field frames on lightbox, varying exposure and brightness level of colour LEDs
October 6th	Basic CCD testing Piggyback imaging (1x24 ISO200 and 1x25 ISO 800) CCD images (first images plus corresponding flats and darks)
October 7th	CCD imaging (attempt to frame on Landolt SA113 field)
October 11th	CCD imaging (Landolt SA113 area)
October 13th	Prime focus film imaging (first attempt, 1x26 ISO 100) CCD imaging (careful sweep of all area of Landolt SA113)
October 16th	Advanced CCD testing with low-level light source (first attempt)
October 17th	CCD imaging attempts with flip mirror device and off axis guider on Moon
October 18th	Prime focus and positive projection (first attempt) of the Moon at day (1x24 ISO 100) Piggyback (1x24 ISO 100) with first (failed) attempts of guiding Determination of coincidence between eyepiece and CCD camera centers at flip mirror
October 20th	Prime focus, positive projection and piggyback imaging of the Moon (1x24 ISO 100) Manual guiding while piggyback imaging (first attempt, 1x12, ISO 800)
October 21st	Webcam lunar imaging (first attempt)
October 27th	Lunar total eclipse imaging (fixed and piggyback, 3x24 ISO 400, 5x24 ISO 100)
October 31st	Prime focus and piggyback imaging (1x24 ISO 800)
November 4th	Advance CCD testing with low-level light source (final attempt)
November 6th	Fixed film imaging (1x36 ISO 400) CCD imaging Piggyback imaging (1x9 ISO 1600), first attempt with webcam guiding Webcam (failed) Saturn imaging
November 11th	CCD imaging (periodic error test) Prime focus (1x9 ISO 1600)