CHAPTER FIVE

Deep-Sky Imaging with a Digital SLR

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Introduction

Digital cameras (digicams) are now dominating the sales for general-purpose photography. In the past 2 years, besides the point-and-shoot cameras, digital SLRs have been replacing film SLRs, and at competitive prices. All types of digicams have begun to be used for shooting the Moon, the planets and the Sun (with appropriate filter) – and with great success. However, these objects can all be imaged with short exposures similar to those for daytime imaging. The use of digicams for deep-sky imaging has been very limited due to the fact that these cameras have uncooled CCD/CMOS chips. This design is very good for standard shooting conditions under available daylight but has proved very problematical for real long-time exposures. Most of the point-and-shoot cameras are limited to exposure times between 4 and 30 seconds. Even the presence of a "bulb" mode does not help much as the noise overwhelms the signal for most cameras. So only bright objects could be imaged successfully at that time.

The Arrival of (Affordable) Digital SLRs

In June 2002 Canon released its D60 D-SLR model, one of the first 6.3-megapixel cameras. Initial tests published for this camera showed much lower noise in long exposures than all previous models. I acquired one of the first available models.

Figure 5.1. Johannes Schedler in his observatory with his 4-inch TMB "Apo" and Celestron C11 Schmidt-Cassegrain.

Early trials soon showed a dramatic improvement in reducing noise for long exposures. For the first time, exposures of more than 60 seconds could be used and even at summer temperatures. What could be achieved with these new D-SLR cameras at that time was reviewed in the *Sky & Telescope* October 2002 and June 2004 issues, with the D-SLR results featured in the "Gallery" section. For the following year, I used the D60 extensively to image many of the brighter deep-sky objects, most of them at prime focus of my 4-inch TMB refractor and Celestron C11 (at f/6) telescopes (see Figure 5.1).

In June 2003 the Canon D60 was replaced with the new model 10D (see Figure 5.2). Although basically the same chip design, there were several key improvements introduced with it, namely:

- significantly better noise performance for long exposures for all ISO ratings;
- nearly complete elimination of the red amplifier glow on the right side of the image;
- higher ISO settings up to 1600 (3200 not really usable);
- higher review magnification of up to 10× for analyzing images via the integral display;
- improved remote capture software allowing multiple interval exposures up to a maximum of 30 sec each (but not in bulb mode!).

See Figure 5.3 for the noise comparison of the 10D compared to the D60 showing a 300-sec ISO800 dark at 22°C, cropped from the center to the right corner.

Figure 5.2. Camera Canon D60 and Canon 10D.

The new cheaper Canon Rebel (300D in Europe), built with a plastic casing, shows similar results for deep sky applications but two major drawbacks have to be noted:

1. No mirror lockup is possible, but a firmware update, available from the Canon homepage, enables a mirror lockup.
2. No direct connection to remote interval timer is possible – the plug for the timer TC80N3 must be exchanged to enable its use.

The SLR-type camera body provides an easy coupling to any telescope at prime focus. This connection is usually by means of a T-ring that attaches to typical telescope accessories. The large chips of the new D-SLRs offer better quality and wider coverage of the telescopic field than is possible with the smaller chips of most astronomical cameras. Field flatteners/reducers are very helpful in achieving the desired image quality into the frame corners.

What are the biggest advantages of such cameras compared to film SLRs? A clear advantage, especially for photographers with little experience, is the

Figure 5.3. Comparison image of the noise performance – Canon 10D vs. D60.

Figure 5.4. Star trails, imaged on a tripod with the Canon 10D and a 20mm lens.

immediate review of the image by getting the result quickly after the exposure. This allows problems related to focus, composition and sky background level to be resolved during the imaging session itself. A second advantage is the relatively low noise and high resolution compared to a typical slide or negative color film. New cameras like the 10D not only save the images in jpg mode but also in raw mode that utilizes the internal 12-bit-per-channel format. This can further be converted to 16-bit-per-channel tiff images. This is a big advantage for the wide contrast

Table 5.1. Overview on current D-SLR camera models (compared in early 2005 for DSO capability)

Model	Effective Pixel	Deep-Sky Capability	Street Price Approx. in $ (€)	Comment
Canon 1DS	11 MP	+++	7000	Top model, 24 × 36mm chip. Replaced with MKII model with 16.7 MP
Canon 10D	6.3 MP	+++	1500	Best all-round performance. Replaced by 20D model with 8.2 MP
Canon Rebel (300D)	6.3 MP	+++	1000	Best price/performance ratio, limited functions
Fuji S2 Pro	6.3 MP	++	1800	Good all-round performance. Replaced by S3 model with 6 MP (×2)
Kodak DSC Pro14	13 MP	+	6000	Bad noise behavior at higher ISO
Nikon D100	6.3 MP	++	1500	Good all-round performance
Nikon D2H	4.1 MP	++	3000	Good all-round performance
Nikon D70	6.3 MP	++(+)	1000	Low noise, but amplifier glow, best alternative to Canon
Olympus E1	5 MP	++	2200	Good all-round performance, some noise
Pentax *ist D	6.1 MP	++	1350	Good all-round performance, some noise. DS model similar at lower cost
Sigma SD9	3.5 MP per color	–	1100	Foveon X3 sensor, weak low-light performance, no bulb mode
Sigma SD10	3.5 MP per color	+	1600	Foveon X3 sensor, improved performance at ISO400

Note: The noise behavior at long exposures is not comparable to daytime behavior. All the listed cameras are excellent for use during daytime.

range that has to be accommodated with many deep-sky images, e.g., faint nebula structures embedded in bright foreground stars. Compared to 35mm film, when using lenses, the focal length has to be multiplied by a factor of 1.6 to get the equivalent field coverage. See Table 5.1 for an overview of current DSLR cameras.

As expected, the noise behavior very much depends on the ambient temperature. As is the case with cooled CCDs, the sensors of digicams are subject to dark current, which doubles for every 6°C increase in temperature. However, some of the dark noise is compensated for by the internal calculations of the CMOS chip. During the warm season a well-matched dark frame subtraction is essential to get the best results out of the raw images. During wintertime, even at high ISO ratings, the dark current and noise are reduced to a minimum so that a dark frame subtraction is not as essential, since the residual noise is basically of a random structure.

The graph (Figure 5.5) illustrates the standard deviation for 300-sec darks at two different temperatures (22°C vs. –4°C). These darks have been taken in raw mode, converted to 16-bit-per-channel images by ImagesPlus and examined in Astroart.

The values in Figure 5.5 demonstrate that there is little advantage in using higher ISO ratings for achieving maximum signal to noise (S/N). For my typical semi-rural sky conditions, I use ISO 200–800 for unfiltered images and ISO 400–1600 for narrowband filtered images. For long exposures, I use 5 minute

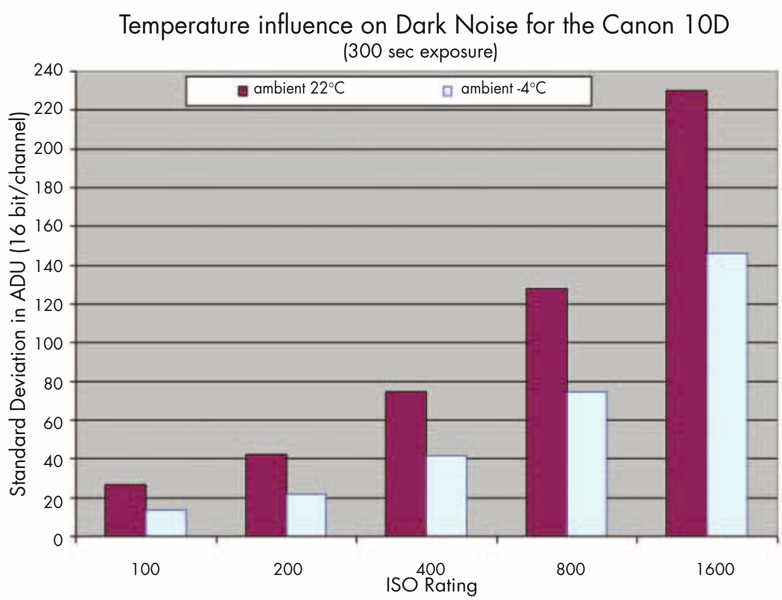

Figure 5.5. Standard deviation of darks at 22°C vs. –4°C.

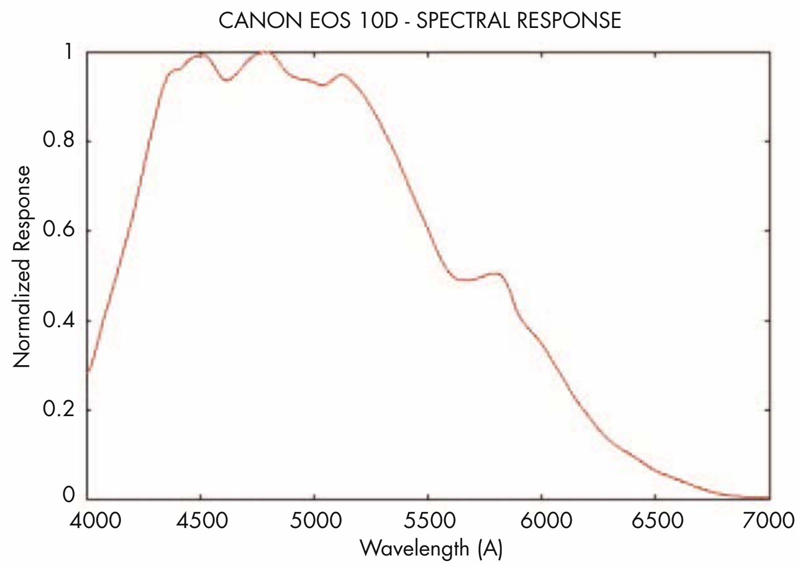

Figure 5.6. Relative spectral response of the Canon 10D. Note the low response at the important 6563Å H-alpha emission line.

exposure for raw frames with the white balance set to "sunny." For shorter exposures (less than 2 minutes), the lower ISO settings prove the best.

There is one major disadvantage for the D-SLRs compared to film imaging: the limited sensitivity in the far red where the H-alpha emission line at 6563 Å reveals most detailed structures in the majority of emission nebulae (see Figure 5.6). The spectral sensitivity investigations from Christian Buil on the 10D are showing that the normalized sensitivity falls off from 100% in the green to approximately 6% at 6563 Å. Considering a 40% average absolute quantum efficiency for ABG chips, the absolute quantum efficiency at 6563Å will be near 2%.

The integral IR blocking filter of the 10D reduces the far red end of the visible spectra and therefore is the main reason for the poor red response. Preliminary tests on D-SLR cameras with the IR filter removed showed a significant increase of the red response. However, carrying out this modification cannot be recommended because the filter is an important part in the optical path. Removal will make the auto-focus useless and the color balance will be severely disturbed for daylight imaging. Hutech is now marketing a modified Canon Rebel camera, with an exchanged IR-cut filter optimized for dedicated astro-imaging purposes, for approximately $1500. Because the Bayer color filter pattern used on the chip contains 50% green pixels and 25% for both blue and red pixels, the expected absolute sensitivity without the IR-cut filter will not exceed 10% at 6563 Å over the total chip area, even for the modified cameras.

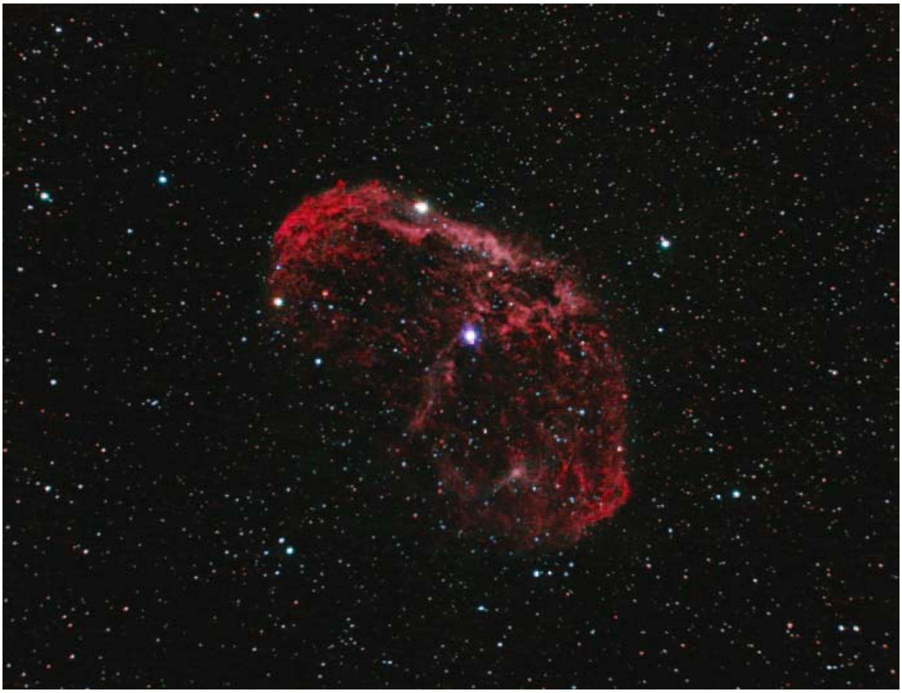

Figure 5.7. The Crescent Nebula NGC6888 imaged with a Canon 10D and Celestron C11.

The biggest disadvantage of CCDs compared to film, until now, has been the much smaller chip size compared to the film format (typical 36 × 24mm). This has changed, however, in the past two years. Like the previous D60, the Canon 10D uses the same 22.7 × 15.1mm 6.3 megapixel CMOS sensor (3072 × 2048 final image size). This corresponds to the size of APS film format. The big chip size compensates for the reduced red sensitivity and the noise at high ambient temperatures.

The already mentioned limitations of the D-SLRs are valid again when comparing them to dedicated astronomical CCD cameras. These typically monochrome cameras are cooled to a constant low temperature of approximately 30°C below ambient. They are optimized for quantum efficiency and they can reach between 50% and 80% over the visible wavelengths. In a monochrome CCD camera every imaging pixel contributes for maximum resolution as no interpolation between the different colors filters has to be performed. CCD astro cameras show real 16-bit-per-pixel resolution and are close to ideal, even under heavily light-polluted skies. My opinion is that for the foreseeable future, dedicated astronomical cameras will have significant advantages for narrowband imaging and for reaching the faintest structures. Additional features that D-SLRs cannot provide are binning, subframe readout, focus support routines, integrated guiding and automated image acquisition, as well as links to other astronomical programs and hardware.

What features should one look for in a digital SLR for astrophotography? The camera must have a bulb mode and connectivity to a remote interval timer, either hardware like the TC80N3 for the Canon D-SLRs or software based via the PC connection for long controlled exposures. One should select a model with low noise design, as shown in Figure 5.3. I would recommend the current standard line of D-SLRs; the top-end models will not repay the high investment, as technical progress will push forward the features like chip size, transfer speed and sensitivity in high speed.

The model should be able to use existing high-quality lenses. Focal lengths between 20 and 300 mm are able to frame most of the possible deep-sky targets. Figure 5.8 shows my typical setup for deep-sky imaging using the C11 with a reducer for f/6, mirror lock and helical fine focuser for the D-SLR. A 4-inch TMB refractor at f/12.5 is used as a guide scope with the MX7C autoguiding. The setup is also used with the telescope roles reversed. The D-SLR is permanently connected to the PC to control focusing, while the timer TC80N3 automatically takes the exposure sequence.

Imaging and Processing

Focusing is the first critical step for any imaging session. To avoid focus shifting caused by the main mirror of SCTs, the mirror should be locked. First I calibrate my go-to mount and use a bright star to focus the D-SLR. Visual focusing is easier when using the 2.5× angle viewer. A Hartmann mask or two parallel tapes across the lens improve the judging of the best focus. After determining the best focus it is essential to prove the focus by taking a test image of say 30 seconds and then checking it on the PC. At the optimum focus, sharp spikes and interference patterns on bright stars can be seen from the tapes. The freeware *DSLRFOCUS* helps with this procedure. Then the scope can be slewed to the desired object and the imaging can begin. Fast lenses should be stopped down one or two steps after focusing. During the night, as the temperature is typically dropping, a refocusing should be considered every one to two hours.

The quality of a deep-sky image proportionally increases with the S/N ratio. Doubling the exposure time improves the S/N by $\sqrt{2} = 1.4$ and so on. Taking many raw images is the key to deep and high-quality images. Find out what maximum exposure time your mount is capable of. My setup with separate guide scope achieves 5- to 10-minute subexposures. If combining say 16 raw images, you should also collect 10 to 16 dark frames under the same conditions. They can be taken automatically with the telescope or lens closed.

For processing large raw files, *ImagesPlus* image processing software is very capable and reliable, able to perform all the necessary steps. First, average the darks and make a master dark of them. Then load the master dark as reference in the calibration setup and calibrate your raw images. If you have vignetting in your optical system, you should also include a flat for calibration. Next step is aligning the calibrated images, easily performed by "Image File Operations/ Align File/ Translate, Scale, Rotate" by marking reference stars. When using Canon raw files, convert them to 16-bit tiff files first, then align and average them in 16 bit. When using 8-bit jpg files, you should use the "extended add" for combining.

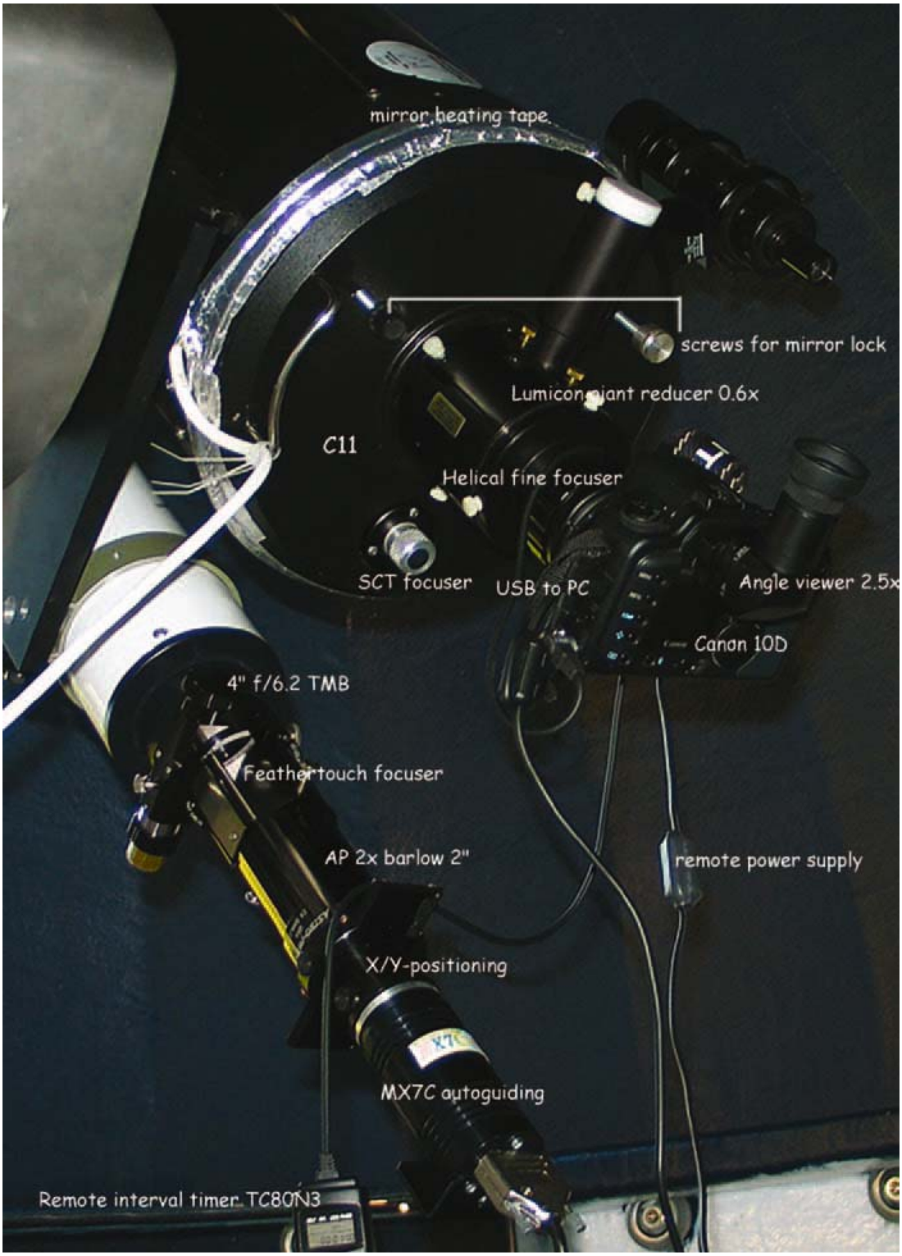

Figure 5.8. Johannes Schedler's imaging setup. In this case the Celestron C11 is being used to image with the Canon 10D and the TMB refractor for autoguiding.

Figure 5.9. The Globular cluster M13 imaged with a Canon 10D and 4-inch APO refractor. Note the faint galaxy recorded in the top left-hand corner.

I have found that combining a large number of jpg-fine images does not show a major disadvantage compared to using the raw mode. "Extended adding" of 16 calibrated 8-bit images in the 16-bit-per-channel space increases the dynamic range of the final image from 8 to 12 bits. This compensates for the limited dynamic range of the 8-bit-per-color jpg files. A second advantage of the "extended adding" is the combining of different exposure times, i.e., for M42 exposures of 20 sec, 60 sec and 300 sec can be added together in one step. This procedure is much easier than difficult masking procedures for the burned-out areas (see Figures 5.10 and 5.13). The calibrated combined images should be saved in 16 bit tiff format, then a DDP processing (i.e., in ImagesPlus) supplies the desired nonlinear stretching. Further processing steps, like removing gradients and adjusting the color balance, I prefer to do in Photoshop. In most

Figure 5.10. Adding exposures of different lengths preserves the detail that would otherwise be burnt out in the brightest areas. This image comprises crops of 3 raws from the left to right that have been added in the following way: 2 × 20 sec, 8 × 60 sec and 26 × 5 min. The final combined result is shown in the image crop at right. The telescope was the 4-inch TMB refractor with reducer at f/5.

cases a noise reduction program like *Neatimage* helps in smoothing the final image.

Hints and Tips

Using fast telescopes or lenses with large and flat illuminated fields makes imaging much easier. Try tripod shots for star trail images. Start with piggyback images and short focal lengths. Constellation images are very forgiving of imperfect tracking. M31 with a 50mm lens is an impressive target. With more experience, longer focal lengths can be used. High-quality fast refractors with flat field like the Televue NP101 and imaging dedicated telescopes like the Takahashi Epsilon are best suited for use with D-SLRs. Above 300 mm focal length, an autoguider is highly recommended.

In many situations we have to live with light-polluted skies. Because of the 8-to 12-bit resolution of the D-SLRs, they are more sensitive to light pollution than astro cameras. Filters are a big help in overcoming these effects. The Hutech LPS filter and high-quality UHC filters allow us to reveal faint nebula structures even under magnitude 4.5 skies, while star colors can be preserved. Narrowband filters like the Astronomik 15 nm H-alpha filter need very fast lenses (< f/2.8) and low temperatures for optimum results. The better your raws and the more raws you have, the less effort will be needed to achieve the best final image quality.

As we all have to live with the given sky conditions, I select the objects to fit best with the prevailing conditions:

- Under moon-lit skies, small bright planetary nebulae and globular clusters can be imaged. Narrowband filters allow nebula imaging even with a bright sky background.

Figure 5.11. Lagoon and Trifid Nebulae, M8 and M20.

- When seeing is unsteady, I use the shorter focal length refractor and lenses for extended nebulae, open clusters and star fields (see Figure 5.11).
- The best dark and steady nights should be reserved for long focal lengths to image faint distant targets like galaxies. If possible, we should try to image difficult targets near the meridian, the point of highest elevation.

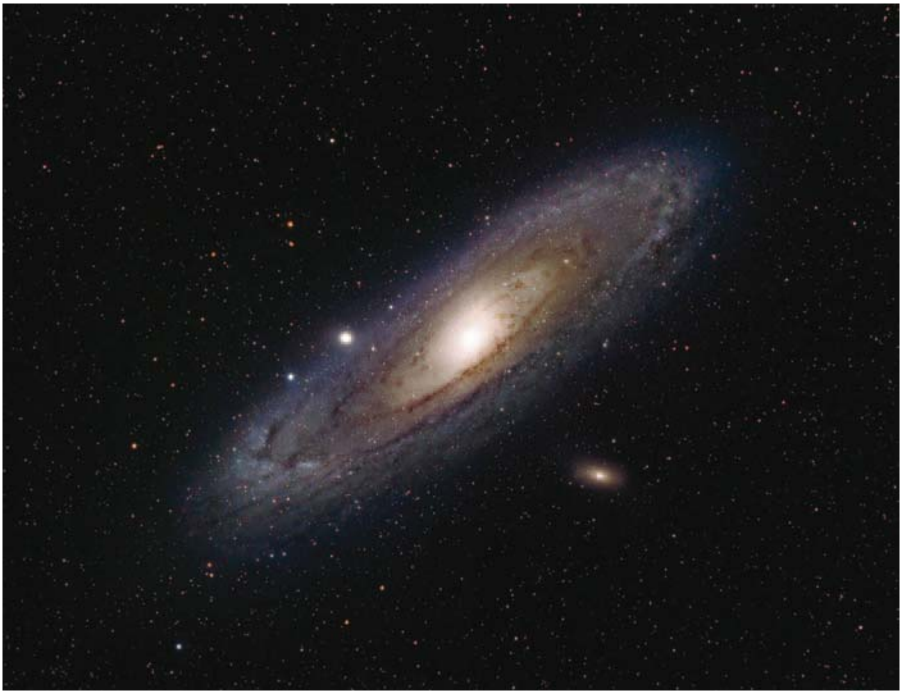

Figure 5.12. The Great Andromeda Galaxy, M31.

Conclusion

Modern D-SLRs are now available from $1000, which represents a much lower cost than most of the cooled astro cameras. They are multipurpose cameras usable for both daytime and nighttime imaging. They are well suited for gaining experience in the fascinating world of deep-sky imaging because they can provide stunning results on many of the brighter deep-sky objects and all in a simple one-shot color technique. However, the higher noise (compared to most dedicated astro cameras) must be compensated for by more effort and expertise in the image processing stage. In my opinion, astronomical cameras will always be some steps ahead in terms of sensitivity and versatility, especially for narrowband imaging, but at a much higher investment cost.

Figure 5.13. The Great Orion Nebula M42, M43 and NGC1977.

Useful related links

Yahoo Group DIGITAL_ASTRO:
http://groups.yahoo.com/group/digital_astro/

FAQ–Digicams for Astronomical Use:
http://www.szykman.com/Astro/AstroDigiCamFAQ.html

10D Spectral Sensitivity Charts (French):
http://astrosurf.com/buil/us/digit/spectra.htm

S/N comparisons by Roger Clark:
http://clarkvision.com/astro/canon-10d-signal-to-noise/

ImagesPlus Image Processing Software: *http://www.mlunsold.com/*

Al Kelly's guide to Acquiring and Processing:
http://www.ghg.net/akelly/procccd.htm

Photoshop for Astrophotographers by Jerry Lodriguss:
http://www.astropix.com/PFA/INTRO.HTM

The new CCD Astronomy by Ron Wodaski:
http://www.newastro.com/newastro/default.asp

DSLRFOCUS for Canon DSLRs:
http://www.dslrfocus.com

Section 2

Getting Serious