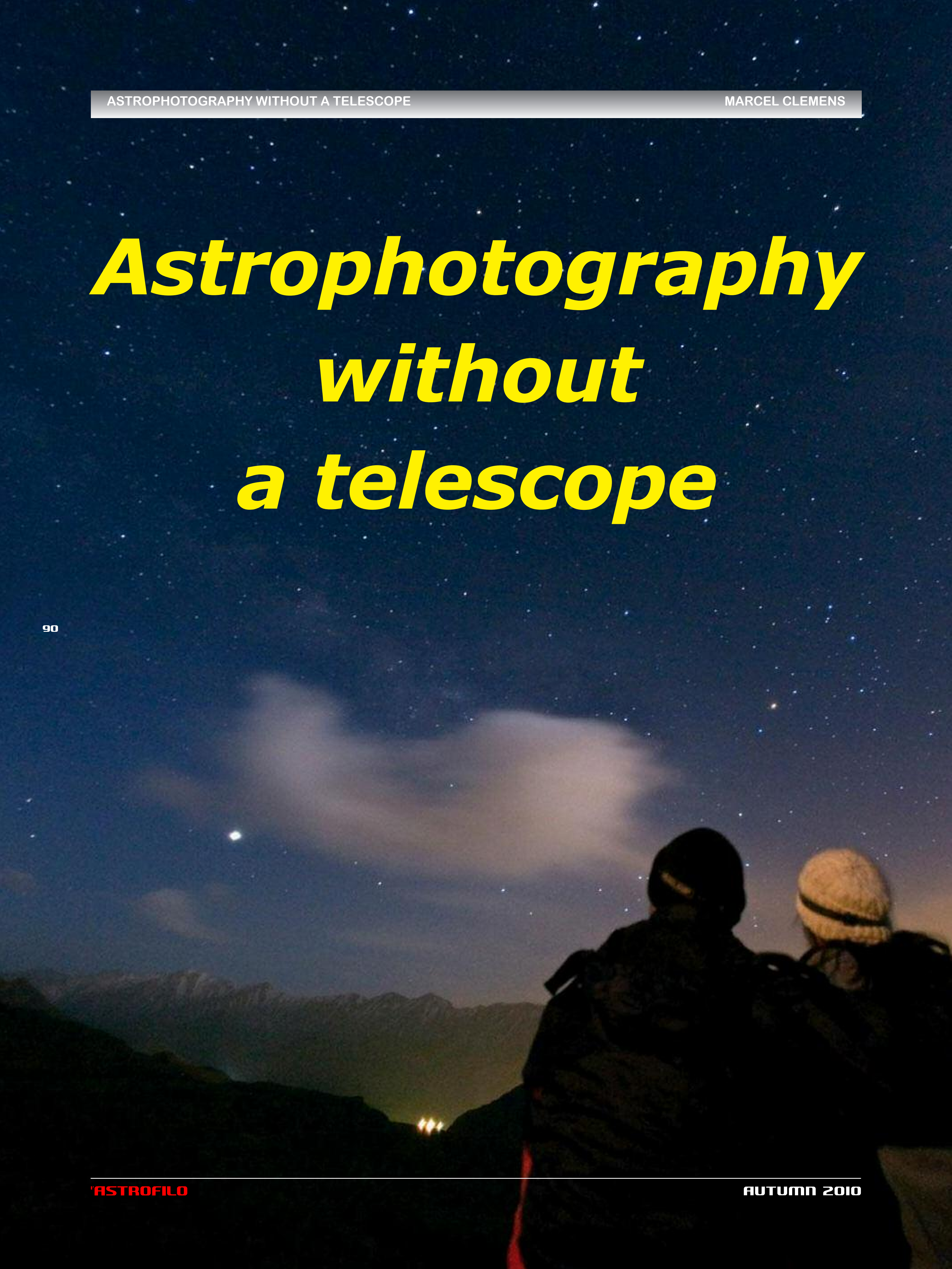
Astrophotography without a telescope

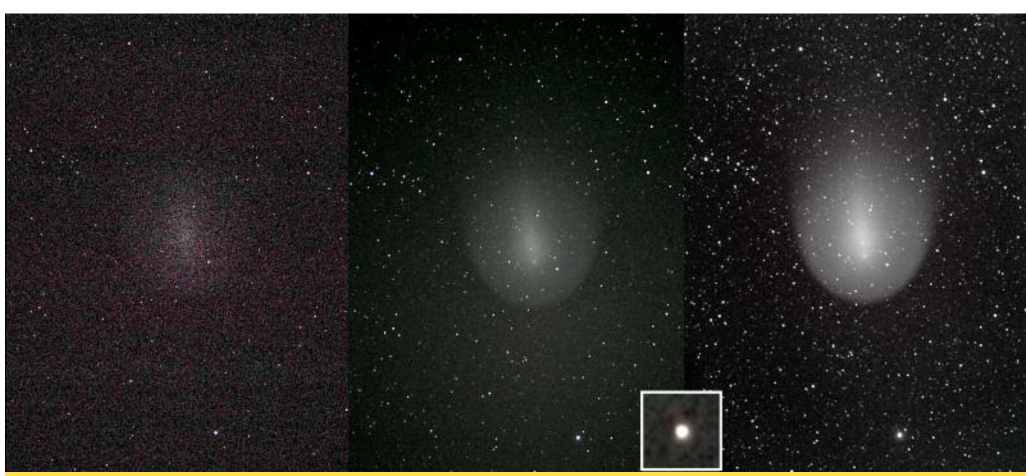


An everyday digital camera, when used with the right software, can be used to produce quite respectable images of astronomical objects.

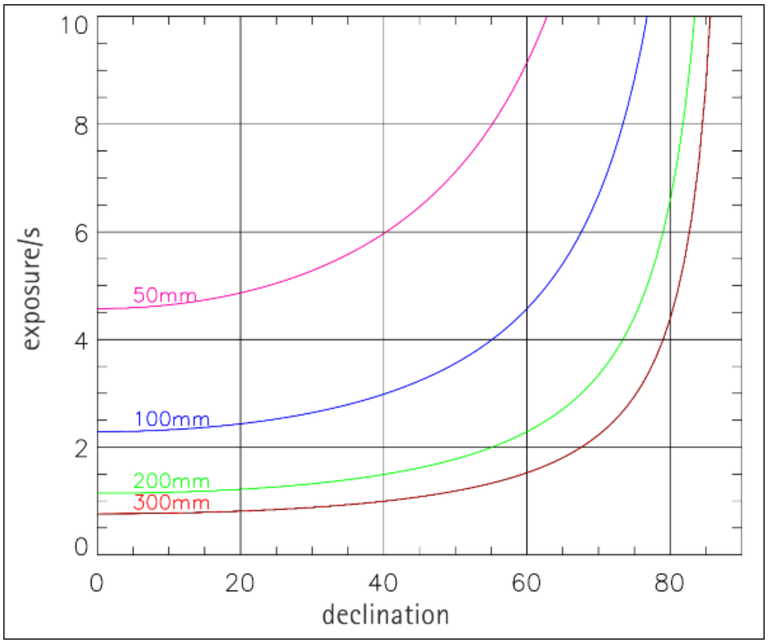
We all know, more or less, what is needed to take the best images of deep sky objects; you just have to look on the Internet or in the gallery of any astronomy magazine. A 40-50 cm Ritchey-Chrétien telescope, a wide-field, cooled CCD camera, a stable mount and a dark site (in a desert or in the mountains) would be a good start. Okay, but let's suppose that you wanted to spend that 50,000 euro on a new BMW 5 series. Then what? Well, you can also take beautiful astrophotos with a (good quality) small telescope, an astronomical mount and a normal digital camera. But what if you have neither telescope nor astronomical mount? In the old days of film cameras you would be pretty much limited to taking pictures of star trails; not exactly the apex of astrophotography! However, nowadays, if you have a digital camera this article gives a few examples of what can be achieved.

The problem is clear: in order to record the faint light from astronomical objects long exposures are needed, but the rotation of the Earth transforms stellar images into elongated trails in a few seconds. Exactly how many seconds depends on the lens used, the size of the sensor's pixels and the declination of the object. Typically, with a 200-300 mm lens, the motion is already noticeable in exposures of 1-3 seconds.

The solution is simply to take many exposures of a few seconds and then add them together. Adding together images after observation is by now common practice in astrophotography, but here we include examples of photos composed of more than 1000 single images!



Comet 17P/Holmes photographed on 3rd December 2007 with a Nikon D200 at ISO 1600, and a 300mm f/2.8 lens. From left to right: Single exposure of 1 second, sum of 100 exposures, sum of 1,100 exposures for a total of 18.5 minutes. Each image has been scaled to maximise the detail visible. The comet was at a declination of about 45 degrees, but despite the movement of about 10" during each exposure the stellar images are not visibly elongated (see the enlarged star image).



Estimate of the maximum usable exposure time for various lenses as a function of declination. For example, for an object with a declination of 40°, with a 50mm lens the longest exposure that can be used is about 6 seconds. If it were longer the star images would start to appear elongated. (Calculations based on a 10 Mpixel sensor with dimensions 23.6 x 15.8 mm).

The effect of summing images

Each image made with a digital camera is composed of an image of the object and noise (this is what causes the "graininess" of photos taken at high ISO values). This noise has contributions from the electronics of the camera when it "reads" the image (read noise), from the material of the sensor (dark current), and from the sky. Without going into too much detail the critical point is that the astronomical object remains the same during each exposure while the noise is random, a little different in each frame. If I take photos of the same object and then sum (or average) them, the noise is reduced with respect to the object of interest.
The images on the previous page show the result of this process when applied to many photos (1,100 to be precise) of comet 17P/Holmes. In a single 1 second exposure the comet can barely be seen, and the image is totally dominated by noise. Combining a large number of frames, the resulting image shows cometary light in regions where, in the single photo, absolutely nothing can be seen.

How long should each exposure be?

This depends on the focal length of the lens, the declination of the object and the dimensions of the sensor's pixels. For example, on my camera with a 300 mm lens a pixel covers 3.8". Therefore, in theory, if the movement of the star exceeds this the stellar images will start to appear elongated. In practice, however, I find that movement of up to about 10" is tolerable with a lens of this focal length (this is actually the case for the example on page 91).
This means that the stellar image on the sensor is larger than a single pixel. Using this empirical result as a starting point, the graph above shows the longest exposures that can be used for a given focal length and declination. I should stress that the values will depend also on the pixel size and quality of the lens so I would recommend a little testing with your given setup. Nonetheless, I would not expect the values to change much.

(60 x 1 s) = (1 x 60 s)?

Unfortunately not. In the images on page 94 we see the difference between a single 20 second exposure (guided with an astronomical mount) and the sum of 20 exposures of 1 second each. There is more detail and more intense colours in the single exposure (also in the light pollution!). Why? An important difference is that in the case of multiple exposures the sensor is read 20 times, which means that the contribution from read noise is greater. This contribution

Comet 17P/Holmes by the author taken on 13th December 2007. Nikon D200 at ISO 1600, 300mm f/2.8 telephoto lens. Sum of 76 exposures of 20 seconds each (astronomical tripod with motorised drive).

can be minimised by subtracting bias frames (using, for example, "DeepSky-Stacker"), but I have found (at least with exposures of 1 second) that this doesn't actually change the result much.
There is another problem: the limited "bit depth" of the images produced by the camera. Most digital cameras produce 12 bit (raw) files, but various tests show that the actual dynamic range is typically 1000:1 (corresponding to about 10 bits). This value is also a function of the ISO value used, and in the case of my camera body, is only 7EV (7 bit) at 1600 ISO, because the read noise is higher. This is why there is a loss of faint detail and colour in the multiple exposure case. In a 1 second exposure the pixel values are often close to the bias value. If in 1 second the photons that arrive on a pixel are not sufficient to raise the value by one, then those photons are not detected (at least in that exposure). The same goes for the colours. To detect that an area is red, for example, the value of a red pixel must be higher than that of adjacent blue pixels. So for a red object, red photons arrive more frequently than blue ones, but if, by the end of the exposure, the difference in the number of red and blue photons collected is not enough to change the value of a red pixel relative to that of a blue pixel, then no colour is registered. With a long exposure there is more time to accumulate a difference.
This problem, however, only seems to present itself for very short exposures, of around 1 second, while for 4 second exposures, for example, colours are detected without any problem. This might be one of the considerations when deciding which lens to use for the declination of the chosen object.
There is, however, one advantage to using short exposures. Brighter areas in the image are less likely to be saturated (image values that reach the maximum value attainable in which no detail can be seen). In the above example, it can be seen that the central area of M42 is saturated in the single 20 second exposure, while in that composed of 20 separate images detail can be seen all the way to the centre of the nebula.

The difference between one 20 s exposure and 20 exposures of 1 s. From the left, the first is a single exposure of 1 second, the second is the sum of 20 images in jpeg format, while the third is the same but using raw files. The last image is a single exposure of 20 s (tracked using an astronomical mount).

Alignment and summation of images

Given that we haven't followed the motion of the object during the exposures, we have to do it later, by aligning the star positions in each image. For a few images one could do this in Photoshop or

M45, the Pleiades. Top: sum of 600 exposures of 1 second; bottom: single 1 second exposure.

just to sum small groups of images without the flat field correction and to save the result in tiff format. Then this series of tiff files can be combined including the flat image (in tiff format).
This slightly unorthodox method would make a real astronomer cry, but if the motion of the object within each group of images is minimal, it works just fine.
The final summed (or averaged) image displayed in DeepSkystacker is actually often quite disappointing, but this is only because of how the result is displayed, there is more information hidden away. A little work is required to produce the final result and see if all those photos were worth the effort! The best thing to do is just to save the result as a tiff file and import it into Photoshop (or other photo editing software). Here, looking at the so called "levels" I normally find that about 95% of the pixel values are very low (histogram shifted to the left). The main correction then, is simply to move the maximum display value in the image to lower values, saturating the stars. From here one can then apply whatever modifications are needed, just as for any other image.

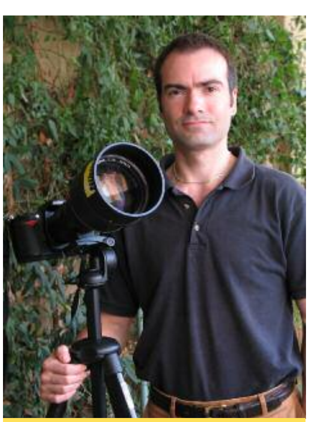
Gimp, but here we are dealing with large numbers of images. There are various programs that do it automatically by searching for patterns in the distribution of star images (e.g. DeepSkystacker, CCDStack, IRIS, Astromix). To be honest I've only tried DeepSkystacker (downloadable from http://deepskystacker.free.fr/english/index.html), it's free, works well and is available in several languages.
I won't describe here how to use it because it's very simple. Rather, I'll just describe one trick I used. In order to carry out the flat field correction DeepSkystacker requires non-jpeg images, both of the object and of the sky. (Flat field correction, in our case, remedies the tendency of any lens to produce images that are brighter in the centre than at the edges. The flat image should be a photograph of a very uniform light distribution, such as a clear blue sky, taken with the same lens at a low ISO value.)
The problem was that I often only have images in jpeg format (because more of them will fit on a single memory card with respect to raw files and because it doesn't actually seem to make much difference with my camera). The trick is

The next step?

This is simple; buy an astronomical mount with an RA drive. It doesn't need to be particularly good quality and polar alignment can be fairly approximate, just good enough to stay within 10" or so if using a 300mm lens (the longer the focal length the better the drive would need to be; all else equal). Now we can do just as before, but instead of using exposures

of 1 or 2 seconds we can use exposures of 10 or 20 seconds (again testing the given setup will give you more precise working values). The picture of comet Holmes on page 93 was, in fact, made with the use of an astronomical mount, and as such represents the "next step".
At this point, however, we're starting to get serious; better stop here!
The technique of summing a number of images to obtain the final image is quite standard practice in astrophotography (both amateur and professional). Here we have seen how the technique can be pushed to an extreme to take astrophotos with neither telescope nor astronomical mount, using simply a digital camera on a photographic tripod.
Here is what we can conclude: 1) the improvement in image quality obtained by summing hundreds of photographs is almost miraculous! 2) It works very well for large fields (focal lengths < 100mm). 3) There's a tendency to loose colours with very short exposures, around 1 s; it's perhaps best to use a lens that allows exposures of at least 2 seconds. 4) It even works if the individual images are in jpeg format.
Following the motion of the object in the sky with an astronomical mount is certainly a better way to take serious astrophotos, but if you want to try photographing some celestial objects before buying a mount (or if you're in the mountains on holiday when the comet "explodes") then this technique allows you to take proper astrophotos without any specialised equipment. For the examples in this article I used a Nikon D200 (not purchased with astrophotography in mind!). Almost certainly, more recent models of camera will be able to produce better results, as the ISO values available continue to rise, thus lowering the required exposure times.

A slightly more challenging subject; the M81 group of galaxies (from a terribly light polluted site in a city centre). Sum of 312 exposures of 2.5 seconds (13 minutes in total), 300mm f/2.8 lens at ISO 1600. The high declination of this group (+69°) allows for exposures in excess of 2 s even with a rather long lens.



The author, with the simple equipment used for the images in this article.

Marcel Clemens, was born in Cornwall in the UK in 1973, and graduated in 1994 from Southampton University with a degree in Physics with Astronomy. 4 years later he completed his Ph.D. thesis on interacting galaxies at the University of Cambridge. After 3 more years as a Research Fellow at the Cavendish Laboratory he moved to Padua, Italy as a "Marie Curie Research Fellow". He currently works at the Astronomical Observatory in Padua in the field of galaxy evolution, mainly at infrared and radio wavelengths. He has been taking astrophotos for many years, especially of comets.