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THE ART OF ASTROPHOTOGRAPHY

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Good evening – thank you so much for coming. I would like to thank Gresham College for allowing us to have this book launch here and for me to give a talk on astrophotography.

I have been at Jodrell Bank since 1965 – that is my 52nd year. I still go out two days a week and I am doing a project there. But since I was 11 or 12, I was given some lenses by my optician. I had to wear these very thick glasses from then, and I made a little telescope out of cardboard tubes and toilet rolls, and I could certainly see the craters on the Moon and the moons of Jupiter. A lot of people tend to embroider their past a bit, and Sir Patrick Moore was a bit inclined to do that, but anyway, I know that I did have a real interest because I won the odd Physics prize, and actually the Music prize, at school over the years, and they were all astronomy books, like Everyman's Astronomy, so I must have still been interested, and I was able to do a little bit of Astronomy at Oxford University, before becoming a radio-astronomer. But in fact, I have been interested in amateur optical astronomy all my life really and I had a 10-inch telescope when I was about 27, which was quite a size telescope 50 years ago or so, and I helped found the Macclesfield Society way back about 26 years ago. I am now its patron, and I was President of the Society for Popular Astronomy in 2000. I still am on its Council and help people with their choice and use of telescopes. So, I have been very much involved in amateur astronomy, and a few years ago, perhaps about six now, I started trying to teach myself a bit about astrophotography, and that is what this book is all about. So, let us begin.

Starting initially with a camera and a tripod, the book tells you what you how to take the pictures, which is quite important, but most importantly of all, how to then process those pictures to produce a nice image. That is where a bit of the art comes.

A camera plus lens on a tripod – that is all you need, and one of the first things, and perhaps the easiest thing to do, is to take a star trail's image. They can look very lovely, if you go on the web. The place I went to is called Redesmere. It is looking north, and it has got a nice low horizon. I have taken astronomy groups there quite often because it is pretty dark. It is one of the darker places in North Cheshire. There is only a slight problem. There is quite a good car park here and I said it is dark, so, at night, when we have been there doing astronomy, you sometimes have quite a few cars where the occupants probably are not interested in either ornithology or astronomy. I must admit, I was a bit worried about going here to do what I am going to show you in case that was what was happening. In fact, luckily, it was nought degrees Celsius as I left home and it was minus four when I left Redesmere, so I thought I would be okay. There was still one car at the far end of the car park – how they kept warm, I do not know. So, what I did, I pointed my telescope directly at the Pole Star. Can anybody see the little dot here? That is the Plough. You see, this is light from Manchester, and up here is Cassiopeia, and I took 100 pictures before my lens – 30-second exposure – before the lens dewed up. The way to get round that is very, very simple and very cheap: you just take a nice thick sock, you cut the end off, you push it over the lens and stuff a couple of hand-warmers. Only costs you a couple of quid, and that will do it. But anyway, I was there for 50 minutes, I took 100 exposures, and that was the first one. So, the way to do it is so easy. There is a wonderful program called StarStax and all you do is put in all the pictures, you download them, it says here "Drop images here", and, cleverly, it has a thing called "gap-filling" because there is always a little gap between you pressing and taking one picture and the next one, and it just fills the gaps..

So what else can we do? Well, again, with a camera just on a tripod, looking up at the Plough I took 20 exposures, 10-seconds long. You cannot take too long exposures just on a tripod because, as the Earth rotates, the image, the stars will trail. There is a way round that we will come to. I then put them in something called DeepSkyStacker, more of which a bit later on, that looks at each image and it aligns them all. It even de-rotates them, which is something you get just on a tripod, and adds them all together, and I got a total of 200 seconds from it, which is not too bad. Now, what comes out of DeepSkyStacker does not really look any better than what you get with a single image. You need to stretch the image because the DeepSkyStacker has a lot of bit depth, and a lot of the information is way down below what you can see on a simple screen. So, you can go into another free program, called Iris, and that will actually stretch the images. Digital cameras are better than film. In film cameras, the brighter stars tended to look larger, because of what is called halation – they stand out more.

We can use small refractors, and the ones we use for astronomy tend to have at least one element of what's called ED-glass, extra-dispersive glass. Most camera lenses you buy now – have you seen the word "ED" on them, anybody? It basically helps reduce chromatic aberration.

There are two basic ways of using a telescope with a camera. The simplest is to use a compact camera with a little zoom lens on it. You set up the telescope with an eye-piece, just as you'd use it visually. You can buy a little stage that mounts the camera so the lens of the camera is on the optical axis of the eye-piece – you get the idea, so it's all lined up. You can actually hold it by hand, but it's easier with one of those. And you can take a picture of the Moon.

Typically, images of the Moon tend to look a bit flat. The contrast is not very high. There are techniques to make it somewhat better. Again, it is not actually black and white, it is not monochrome, it is actually slightly coloured, but often they look better as on the right-hand side when you take the colour away.

The other thing you can do is to use a proper DSLR or one of these Micro Four Thirds cameras. What you have is a barrel that goes into the focuser of your telescope, and then a specific little adaptor that screws on there and has the right bayonet, to go into your own camera, so the two of them are called a T-mount. The trouble is you nearly always need to have the camera further away from the telescope objective than the focuser will let you do, so you often need to have a little barrel extender – it just makes the focuser a bit longer. Again, if you are looking at the Moon, the images, if it is a small telescope, are not very big, and there are things called Barlow lenses that basically two-times – they double the size of the image. So, I have had a go with those. That is just one image that I took, using a 70mm, quite a small telescope.

Another lovely thing you can do is to try and image the Moon when it is a very, very thin crescent, which normally you do it in the evening when it is a waxing crescent. for example, from the Isle of Wight, where it is pretty dark, I took one picture exposed for the bright part, the bit that was lit, a much longer exposure for this, and I was using a really lovely telescope, so the light from this did not really scatter too much, and then I put those together to make a composite. So, that is Earth Shine, and that is done quite well in competitions.

Another thing you can do, every so often, we get a lunar eclipse, do we not? Sometimes people say, "Why do they look red?" How many people know why they look red? If you were on the Moon and you looked at the Earth at a time of lunar eclipse, the Earth's disc would look black, would it not?, but around it, you would see a red rim, which is the sunlight that is being refracted around the Earth's atmosphere, so that is what illuminates the surface of the Moon, why it looks that colour. If you have had a major eruption – do you remember Mount St Helen's, quite a few years ago? Well, for a couple of years after that, you hardly saw the Moon during an eclipse – there was so much dirt in the atmosphere, it just cut all the light out.

Here is another example, imaging the Pleiades - the Pleiades cluster? I mentioned it slightly earlier – done with a 72mm telescope. For these things, you do not need big telescopes because the bigger the telescope, the smaller the field of view. That is what you get with a single exposure. So, you can see the main star of the Pleiades but not much else.

What you can do is to add many of these images together and that helps you reduce the noise, and here is an example. This actually is M51, a little galaxy. That is 48-seconds, 96, 192, and 384. Would you agree, the amount of noise goes down quite considerably?

So, what we do is we take lots of short exposures and then we put them into a program I mentioned called DeepSkyStacker. That takes them all and you just put them all in and it will then align them all and rotate them if necessary, add them together to give you the result. If, disappointingly, the result that comes out of DeepSkyStacker does not look any better than a single exposure the cheapest, simplest solution is to use a program called Iris. You put them into Iris, and use [logarithmic] view, and it stretches it to make some of the nebulosity in the Pleiades show up, and you can play a little bit with that.

I had another go at the Pleiades just a few months ago, using a slightly bigger telescope. And we capture a little streak, an asteroid that was in fact passing in front of the Pleiades, and knowing the time when it first exposed and the time when it last exposed - we knew the time very accurately – you could work out which particular asteroid it was and also in fact how far away it is. It is about three astronomical units from the Sun. It is called 769 Tatjana. And I could measure the number of pixels across, so I knew precisely how far it had moved. Each pixel is three arc seconds and I think that total length was 27 arc seconds, and from that, we could work out quite a bit. That is a bit of astronomy just taken from a pretty picture.

Have you all heard of the Orion Nebula? It is a lovely region. It glows a rather deep red colour, it is a really difficult thing to image, partly because a lot of the light is in the deep red. It is called H-alpha emission. We have a problem: that camera, normal cameras, cut off virtually all, well, all but 25% of the light at that wavelength. It is so the image from a DSLR matches what our eye sees. Our eyes are not very sensitive as you go down the spectrum. So, what one can do is to modify a camera. There are firms that do it for you, is they take out the filter in the cameras and replace it with a filter made by Baader, which means you can see a lot more of that lovely colour.

I was able to image the Orion Nebula with a relatively cheap Canon camera which has been modified for about £220, which isn't too bad.

It is a very difficult thing to image well because there's an incredible brightness difference between the central part, around the Trapezium, and the outer parts of the nebula – you can't see them at all. So, in order not to over-expose the centre, I had to have only 12-seconds exposure. I took a large number of images and added them all together in DeepSkyStacker and, again, what comes out of DeepSkyStacker looks terrible, but you put it into Iris? Then I used the program called GIMP, which is free to highlight, to enhance it somewhat, and then I produced the image, but the trouble is that the outer parts of the nebula are so faint, they were very noisy. The central parts of the image were fine; the outer parts really didn't look very good. So, I spent quite a long time to cope with that. What I did, I basically masked the areas here which were not noisy, okay, the good bits, and then, with a little pen, in effect, a little paintbrush, I spotted out every star in the whole field. That probably took me a little while. And then you can essentially just reduce the noise level by smoothing everything but the stars in the central part, so it leaves the stars sharp but gets rid of all the noise.

To take longer exposures, we tend to do something called auto-guiding. The idea is very simple: you have a second telescope, this one, with its own camera, and that's linked up to a piece of software in your computer, and that then sends commands to this camera, and out of the camera through a cable into the mount, so, what the guide camera does, and the guide-scope, it sees if the guide star is moving a bit from where it should be, rock-solid, and it then sends commands to your main driving mount just to tweak it to keep it in the right place. That means you can take much longer exposures and possibly sharper images.

I took a picture of Orion in the winter. I tried to do it again in late-spring, and the result wasn't at all good. The problem is thermal noise – it's called dark current. The amount of noise that the actual sensor generates is a function of temperature, and it varies quite a bit, and the problem is that, when you actually have a DSLR camera taking continuous pictures, the sensor temperature goes up perhaps by 12 degrees Celsius, and it gets quite noisy. So the problem I needed to tackle was can we cool our camera to keep the sensor a bit colder? There is one very cheap way of doing it. I took a 1.7 litre food box with a cover that stops the air getting in. You put some insulation in, and I have actually done it with layers of net, very fine net, mesh, and also silver foil,

from space-blankets which are very good at stopping heat transfer by radiation. The little net in between them, makes lots of little areas, little pockets of air, and that actually acts as quite a good insulator. I cooled the camera in the fridge for a bit – you put it in a plastic bag with some desiccant so it does not get stuff condensing on it – put it into here, and then surrounded it by some of these somewhat flexible ice-packs. That takes the temperature down, and then, when you start observing, it goes up again, but you have gone down by quite a number of degrees. For every six degrees, you get a doubling of the noise.
The other way of doing it is to Peltier-cool it, and you can actually buy Peltier Cooling Boxes for about £150, but in fact, what I did was to buy a £15 Peltier unit from eBay and, same type of box – you have to slightly alter how it goes. I have not got the insulation in. The trouble is, this takes six amps at 12 volts, so you need quite a big power supply, but that will then cool things down just as well as the thermal ice-packs but it will do it for longer, and of course, if it is much colder, it will actually get below zero, so that's quite a nice thing to do.

I have had a go, using that, imaging what is called M27, which is a lovely planetary nebula, one of the brightest in the sky. I live in Macclesfield, about a mile from the centre, and it is somewhat light-polluted. So, what can you do about it? Well, you can actually play a trick, and I think I worked this trick out a few years ago. What you do is you make a second copy – I am just going to show you a second copy. On the second copy, there's a wonderful filter in Photoshop called "Dust and scratches". It's meant to restore, you know, old pictures. What do you think it thinks stars are? Dust. So, it gets rid of them! Now, it can't get rid of the nebula because that's quite big, but you can clone that out, so you've then got a pretty good image of the light pollution. Do you see the point? You've got rid of everything else. So, if you then difference that with your original image, you get rid of the light pollution, you can begin to see the nebula, and you can play around a bit and that's what you get. This is the central star. It is the remnant of the star. It was the nuclear fusion reactor – it's the core. It's probably about the size of the Earth now, still very hot. It is called a "white dwarf".

There are other things you can do about light pollution. You can buy a number of different filters.

Panets are a problem to photograph because they're quite small. I imaged Mars, a couple of years ago, when it was closest. It was only 15 arc seconds across. The trouble is that the atmosphere, the turbulence, typically mucks things up by at least two arc seconds. Well, what can we do about it? Quite a few years ago now, Philips brought out a very sensitive webcam, called the Toucam Pro II, and when they discovered that lots of astronomers were buying it, they put the price up by quite a bit! But the idea is this: it's a webcam and you take a whole video stream, of the planet, and there's then a wonderful piece of software that looks at all those images, it finds the sharpest parts – it is called lucky imaging. It picks the best ones, it lines them all up, and can give you a much better image than even you could see with your eyes.

You can buy specialised webcams but there's a real problem: their sensor is tiny. It is just a few millimetres across. You have got to get the planet onto it and that's hard work. So, what we do is we use what's called a flip-mirror. You have to have a fairly sturdy mount because you do not want Jupiter to drift off the sensor while you're taking perhaps 2,000 frames.

Registax is one version of it. You show it one picture and it analyses it. Then it goes through all of those 2,000 images and aligns them and ranks them according to their quality. And then you stack them. Registax has got a wonderful method of sharpening – it's called wavelets, and no one else has done anything. That gives you a better, sharper image, which you can then export. .

How do you image a moon with a DSLR? You can do it with a webcam, and because you get rid of the atmospheric effects, to some extent, your images can be sharper. You take a webcam sequence, a video, and then you need to analyse it. Registax does it, and also a program called AutoStakkert 2. You can take these individual segments – we call them "panes" – and there's a wonderful program, which is free, called Microsoft ICE, Image Composite Editor, and all you do is you pop your frames in, and it puts them together, perfectly.

You have got to be very careful if you want to take images of the sun because it is the one thing that can really hurt you – you can lose your eyesight if you do not do it properly. We need to vastly reducing the Sun's brightness. For example, a Mylar filter, metallised, that cuts out,99.9 percent of the sunlight, and then, with a DSLR, you can simply take a whole image of the Sun

There is another way of doing it, called a Herschel Wedge. mIn here is a prism that reflects only about 5% of the light this way, towards your camera, and 95% goes into a sort of a heat-trap down here, but actually, this one has got a little imager on it so you can use it as a finder. I have got another solar-finder here. You can use neutral density filters to cut the light down by quite a bit, and also what they call a solar continuum filter, which is a very narrow band, in the lime green, and that's the image you get with a camera. You can also observe the Sun in the light of H-alpha, that lovely deep-red colour, and you get to see a lot more detail in the surface. You have to have a special type of camera, a solar camera. They use some very clever optics, a thing called an etalon, to basically cut out all the light except for the very narrow band where the H-alpha emission is, and you have to tune them to get them just right, and then you can take pictures showing a lot more detail.

When you start out you may want to work with a DSLR or a compact camera or with those little webcams you can get for a couple of hundred pounds or so. As you advance, you may want to use a CCD cameras, and the major difference is that they have Peltier cooling attached to the sensor, and that means you can get the sensor down to about minus 20 to minus 30, so the noise level, can you see, goes way down, and that makes your camera much more sensitive. There are two types.

The first type is called a one shot colour camera, and it is basically a colour camera

You can also buy, at some expense monochrome cameras, and the one I have is 8.3 megapixels and I cool it to about minus 30.

Some people, because they're in light-polluted locations, use three very narrow band filters to do their imaging because that cuts out all the light pollution, and something that's become very popular, and initiated by the Hubble Telescope, is what is called Hubble Palette. They make S2, the line, a very, very deep redbut H-alpha, which is really red, make that green, and O3, which is green, they make blue. It does give you some beautiful images but astrophysically, it is not really right.

The final thing I am going to show you is called LRGB imaging, which a lot of people do. "L" stands "luminance". You tend to take a higher resolution, a high-resolution image in white light, expose it for quite a long time to get lots of detail – you want a high resolution, high detail image. You then use R, G and B to take individual images, through the red, green and blue filters, and you combine those, as I've done here, to make a colour image. The resolution of that does not need to be so high, so there are some tricks you can play to make the camera more sensitive. What you then do is to take the luminance image and the colour image, luminance and colour, and combine those together to make an LRGB image.

Why am I offering advice in this book on the Art of Astrophotography? A colleague of mine, David Tolliday, in my Macclesfield Camera Club, which I have been involved with for a long time, who is very good with nature photography, decided he would like to do some astrophotography. He has got a very nice lens, 500ml lens, and he asked for my advice, and I told him precisely, and I mean precisely, how to go about imaging and processing the Orion Nebula – he did that. He entered it into the astrophotography award run by the Royal Greenwich Observatory, and they get thousands of superb images, and with that image, he won the Sir Patrick Moore Newcomers' Best Image Award!