Making Beautiful Deep-Sky Images

Astrophotography with Affordable Equipment and Software

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*I dedicate this book to my wife **Helga**, who understands my obsession, and whose favourite image was M13, but is now the wide field version of the Rosette.*

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Preface

I have recently discovered the most satisfying hobby so far, and to be frank, I have pursued quite a few hobbies in my time! This one encompasses computers, optics, precision mechanics, digital image processing and artistic appreciation, and it therefore satisfies just about every major interest I have in one go. The hobby is taking photographic images of the deep-sky.

I have not met anyone, so far, that has not been moved, sometimes to a great extent, by the images you will find within the pages of this book. Some people will actually admit to being frightened by the vastness of space that these images depict. I am not frightened by these images, but I am certainly awe-struck by them, and they do make me feel rather insignificant regarding the grand scale of things. I am also still firmly in the grip of being totally amazed that the capability to take such awe-inspiring images is now available to anyone with sufficient time and effort to dedicate to this most rewarding of hobbies.

This book has two aims. The first is to show you the richness, wonder, and beauty of deep-sky objects. The second is to show you how you can take these images for yourself, using readily available commercial equipment.

I really envy those of you who will embark on this adventure for the very first time after reading the contents of this book. Savour and record every moment, it is truly a unique life-experience!

Greg Parker
Brockenhurst, Hampshire, U.K.
2007.

Acknowledgements

Firstly, I gratefully acknowledge the outstanding image processing work of PhotoShop guru Noel Carboni! Noel created all the marvellous deep-sky images you can see in Chapter 10 of this book, from my raw data acquired at the New Forest Observatory. In creating these works of art Noel has spent at least as much time bringing the best out of the data as I spent in collecting it – thank you Noel!!!

I was greatly helped in my early days of imaging by two people in particular, and both still continue to help me now. Many thanks go to Alan Chen on the Yahoo Starlight Xpress forum for showing me the way right back at the very beginning of my imaging work. Many thanks also go to Bud Guinn who can be found on the "Our Dark Skies" forum. Bud introduced me to ODS from the SX forum and has been a great help and inspiration ever since I started imaging – he has also offered me a great deal of encouragement, especially early on when I felt I was getting nowhere. Bud's introduction to the ODS group also led to my teaming up with Noel Carboni of course, and the rest as they say is history.

Last, but not least, many grateful thanks go to Dave Squibb of Tavistock in Devon, U.K. Dave was my "A" level Physics teacher at Tavistock Community College, and it was his dedication to the subject that subsequently led me to authoring a textbook on semiconductor device physics, and the book you now hold in your hands. Many, many thanks to you Dave!!

Greg Parker
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U.K. 2006.

CHAPTER ONE

How did I start?

This Chapter may help if you are just starting out in deep-space imaging. Personally I find it very useful to see how other people entered the hobby, because in that way you can see what their major mistakes were, and hopefully you can then circumvent the major problems.

I am fortunate enough to live in a semi-rural location with reasonably dark skies. I was also in the fortunate financial position of being able to buy myself a reasonable quality telescope. At this point in time, around January-February 2002, I was solely interested in carrying out visual work, I knew nothing about, and had very little interest in imaging of any sort at all. So, as I wanted a good telescope for visual observation, I went for the biggest refractor that my budget would allow. My first purchase was a beautiful 6-inch Helios refractor with motor drives for both axes, and no computer control. This was a considered choice on my part, I wanted the “fun” of finding all the deep-sky objects I’d read about, using my own skills, no computers! The scope performed admirably and gave beautiful bright, high-contrast views of the planets, and also of large galaxies and nebulae. On the other hand, I did not perform admirably; I was clearly pretty useless at finding where all these Messier and Caldwell objects were hiding. I did not properly polar align the telescope, and I did not properly use the motor drives, so objects, when I did find them, were always drifting out of the field of view. After returning to view the few objects I could find night after night I realised I had actually made a big mistake – I really did need the computer “goto” capability to get these evasive objects into my field of view. So, admitting defeat after around three months, I then bought the Celestron Nexstar 11 GPS Schmidt-Cassegrain reflector http://www.celestron.com/prod_pgs/tel/nx11gps.htm] with an Alt-Az computer-driven mount, and I spent the next two years happily carrying out visual observations. The Helios refractor is not totally unused however; I bring it out for photographing transits (Venus, Mercury) using the projection method.

The first couple of outings with the Nexstar 11 GPS were very disappointing indeed, mainly because I didn't really know what I was doing and I was only just beginning to get to grips with the basics of the system; a system that seemed incredibly complicated to me at the time. In addition, setting up the "goto" required me to know the position of two alignment stars, so I had to start learning my way around the sky anyway, even if it was just to know what the brightest stars were called, and where they were located.

Then the night of Thursday 2nd May arrived, a clear crisp evening with good viewing, and what subsequently happened is the subject of a "Lateral Thoughts" article in the September 2002 issue of Physics World. To cut a long story short, this was the first time I had set the telescope up properly, and armed with my copy of Norton's, I quickly logged up 24 of the 27 objects listed on one page! I had never seen any of these objects before, and it really was a defining moment in my life and a night I shall never forget. My first ever views of M13, the Great Globular Cluster in Hercules, and NGC3242 a planetary nebula in Hydra called "the Ghost of Jupiter" are now permanently etched into my memory. I still get a "tingle" of excitement when I recall the beauty of that crisp, crystal-clear night.

As I was primarily into observing, it wasn't too long before I invested in the superb Celestron Bino-Viewers [http://www.celestron.com/prod_pgs/accessories/optical_accessories.htm], which of course meant I then had to double up on all my eyepieces – an expensive move! This turned out to be a bit of a blow when I finally took the plunge and began CCD imaging, as I haven't looked through an eyepiece since! The first thing that I changed on the main scope was the totally abysmal holder for the little finder scope. I bought the Celestron "quick release" holder for the finder scope and to be honest this is the one Celestron should fit as standard as the supplied version simply isn't worth bothering with in my opinion. With the Celestron f#6.3 reducer/corrector and a few other optical accessories I was extremely happy observing for around two years. However, there are only a handful of objects that look truly spectacular through the eyepiece of an 11" reflector, and I found I was returning to these few objects time and time again. I was not searching out the less dramatic objects because, to be quite honest, I found them boring when I eventually did track them down. It was clear that I was rapidly approaching the time when I needed to image the skies rather than just view them, so that I could see both faint and bright objects in all their glory, and in colour.

The move to create an imaging setup meant that I had to go for a permanent mounting rather than carrying the scope in and out of doors for each observing session. I will discuss my observatory in another chapter, but on reflection, I think I was very lucky not to have dropped the rather heavy Nexstar 11 GPS on its many trips in and out of the lounge door, with the rather large step down into the garden. So, the acquisition of a fibreglass dome also meant the purchase of a pier, and the fixing of the pier to a large concrete block in the ground. Details are covered in the observatory chapter, but the first major change from observing to imaging was the construction of the observatory.

To start serious deep-sky imaging I bought the Starlight Xpress SXV-H9C colour CCD. I had already purchased the Hyperstar lens from Starizona [http://www.starizona.com/hyperstar/] that converts the f#10 Nexstar 11GPS into an f#1.85 imaging system. It was the availability of the Hyperstar lens assembly that led to my buying the Nexstar 11GPS over other similar makes of scope in the first place, just in case I wanted to move onto imaging at some later date. The decision to choose the Starlight Xpress SXV-H9C [http://www.starlight-xpress.co.uk/SXV/SXV-H9C.htm] was quite easy to make. I wanted a U.K. manufactured device in case it needed to be returned to base for repair. I also wanted a single shot colour camera as I was only interested in taking pretty pictures, and it seemed perverse to take monochrome images through at least 3 different filters and combine them all at the end when the job could actually be done in one go. So the final decision, for me, came down to either the massive SXV-M25C camera [http://www.starlight-xpress.co.uk/SXV-M25.htm] coming in at 6 Megapixels, or the smaller SXV-H9C http://www.starlight-xpress.co.uk/SXV/SXV-H9C.htm coming in at 1.4 Megapixels. Both Starlight Xpress (Terry Platt) and Starizona (Dean) suggested the H9C as it would be much better matched to the Hyperstar lens, and they have both been proved correct in practice. The M25C would have been far too large, and a lot of the chip's imaging capability would have been wasted due to the Hyperstar's small focal plane diameter. The SXV-H9C together with the Hyperstar lens [see Figure 1.1] gives me an extremely fast f#1.85 system with a field of view of 1 degree by three-quarters of a degree and a sampling of 2.57 arcseconds per pixel. For other "field reducer" systems, I found the Celestron f#6.3 reducer to be very nice, and the Meade f#3.3 to be unusable (due to vignetting and coma) at the lower f-numbers. It should be noted that all Starlight Xpress SXV imaging cameras are now designated SXVF, where the F indicates a very fast download capability.

So my initial imaging system was a standard Nexstar 11GPS in Alt-Az mode, SXV-H9C colour CCD imaging camera, and the Hyperstar lens. The first thing that had to be changed was the focuser on the Nexstar, which turned out to be far too coarse for f#1.85 imaging. The depth of focus for the Hyperstar system on the 11 GPS is only around 7 microns; where the diameter of a human hair is on average around 80 microns! The standard Celestron focuser was replaced by the "FeatherTouch" focuser [http://www.starizona.com/search.cfm?Category=0&Product=1&Keyword=microfocusser] from Starizona, a straight replacement that gives coarse and fine focusing options using an outer and inner focusing knob. This is a truly superb product and it is indispensable for fine focusing if you are moving the main mirror of a large reflector to micron accuracy! At this point I also changed from taking a little VAIO laptop into the observatory to having a home-built 1GHz mini-ATX machine in permanent residence. Not having the portable little laptop made it difficult for me to manually focus the scope whilst trying to look at an image on the display, so the next addition was a Celestron motorised focuser that I modified to go onto the FeatherTouch focuser [see Figure 1.2]. Now, whatever direction the telescope was pointing in, I could sit in front of the monitor and focus the scope with the hand-controller. At this point I could now start acquiring my first images! I was over the Moon (sorry) with my first efforts imaging M42, I thought they were fantastic, but I realise now of course that they were in fact very

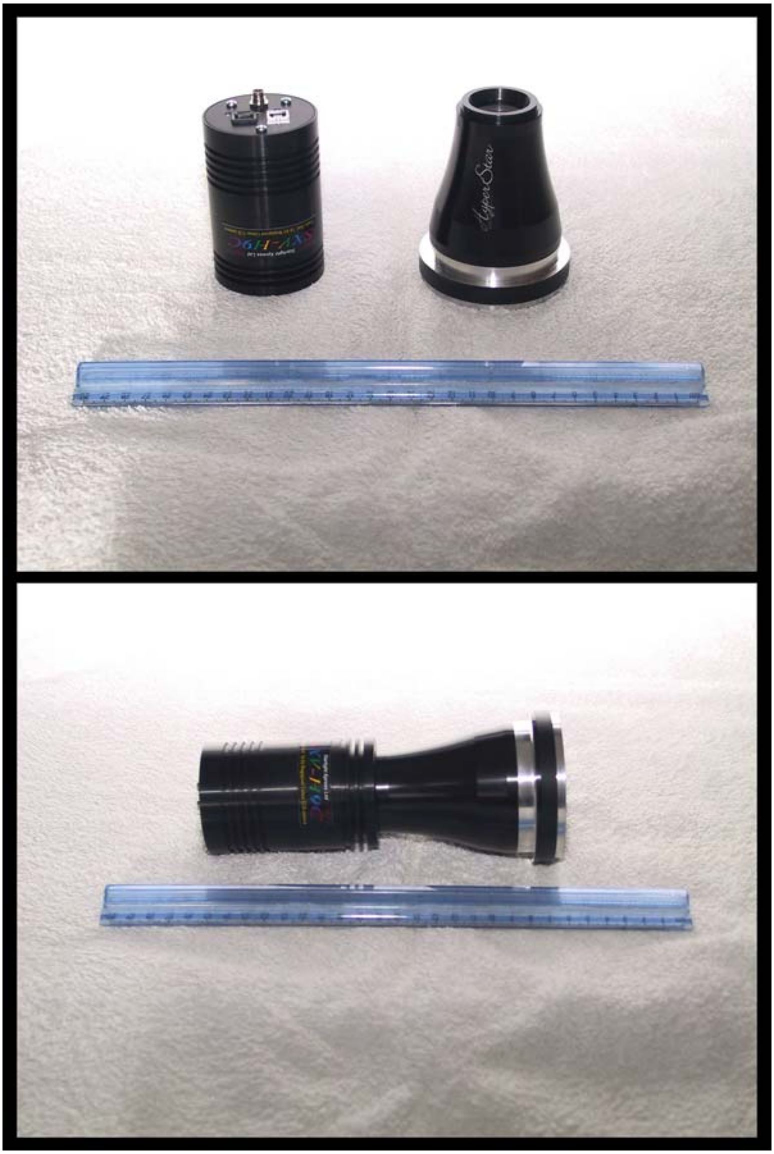

Figure 1.1. The Hyperstar lens assembly and the SXV-H9C one-shot colour CCD camera from Starlight Xpress. Bottom photo – the two elements connected.

poor images. For a start, I did not use (or understand the benefits of) stacking sub-exposures, and I didn't realise how extremely poor the star shapes were either. More of very poor star shapes and the Hyperstar lens assembly a little later.

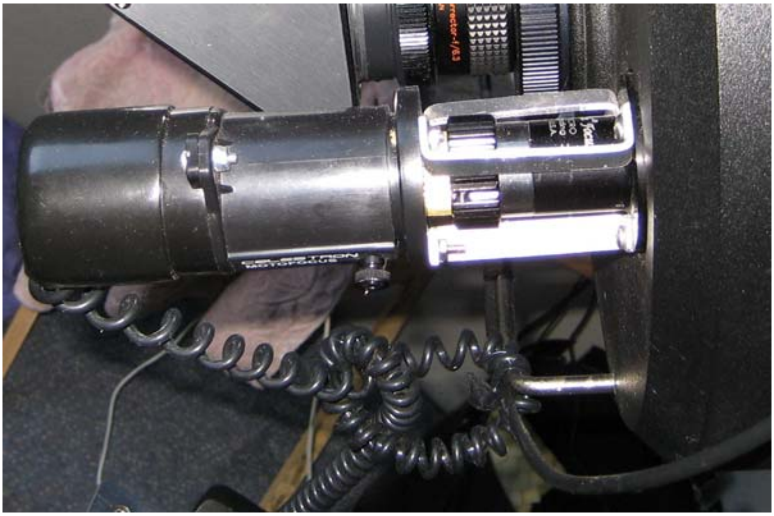

Figure 1.2. The standard Celestron electric focuser, mounted on home-built aluminium standoff pillars, to fit the Starizona "FeatherTouch" focuser.

Next I started to use stacking, remember the telescope was in Alt-Az mode, no problem, the fast Hyperstar system meant I could take short sub-exposures (less than 30 seconds to prevent field rotation problems) and stack the subs together to get a reasonable final image. Except the supplied Starlight Xpress software would not stack AND rotate as was necessary for my field-rotated series of subs. Although the field rotation on any one sub was undetectable, if you took an hour's worth overall you could get several degrees of rotation that needed to be accounted for in the stacking software. So the next excursion was into different software packages. At first I used AstroArt [http://www.msb-astroart.com/], a package I was very happy with, but I quickly moved onto Maxim DL for reasons I actually cannot now remember, and I have stayed with Maxim DL ever since [http://www.cyanogen.com/]. At this stage Maxim DL was used for data (image) acquisition, and for all the image processing.

At this point it would seem that things are entirely satisfactory, but of course the field rotation limitations of Alt-Az imaging finally got to me so I was forced to go equatorial. This required purchasing the Celestron heavy-duty wedge and adjusters (very naughty that the adjusters are bought separately Celestron!) and I then had to redesign my all-aluminium Alt-Az pier for the new Equatorial system. The redesigned aluminium pier can be seen in Figure 1.3. Another thing I noted was the so-called "heavy duty" wedge was not so heavy duty after all, and it would shift a little depending on how the very heavy Nexstar 11GPS was cantilevered, i.e. the telescope's imaging position in the sky. Fortunately a very simple modification could rectify this design fault in the wedge, and I found that I did not have to reposition the wedge, after carrying out the first drift alignment, for over a year. The wedge modification can be seen in Figure 1.4.

Figure 1.3. The custom-made all-aluminium Equatorial mode pillar.

As you can see the modification, using 2mm thick Aluminium basically closes off the open box-section at the end of the wedge that led to the "warping" and loss of alignment when the scope was slewed across the sky.

So, surely we must be there now? Equatorially aligned, fast imaging, large aperture scope, colour CCD and software that both acquires the CCD data and carries out powerful image processing. Not quite, we still have the problem with "funny-shaped" stars, and sorting this one out took many months of effort and much pain. You will see from the images presented in Chapter 10 of this book that the stars are pretty round, with the exception possibly of some coma at the extreme top corners of the field which is very hard to eradicate in any low f# optical system. I don't think you will find ANY other Hyperstar/Fastar images that can show you decent round stars (unless they have been nicely "rounded" in software) across the whole field of view. The reason for this is quite nasty. An

Figure 1.4. The modification made to the standard Celestron "heavy-duty" wedge. A 2mm thick aluminium sheet is used to close off the open-ended box section of the wedge. Right-hand photo, the wedge in-situ.

f#1.85 system is very unforgiving in alignment/focusing and the Hyperstar lens just sits in the secondary mirror cell. Now the secondary cell has some "slop" around the edge giving maybe +/- 1mm of movement of the cell. Absolutely no bother if you have the standard secondary mirror in the cell, you just use the adjustment screws to set your collimation, but what about the f#1.85 Hyperstar lens? There was no adjustment in the initial design (the one that I of course have), and the placement of the lens within the corrector plate is a very hit or miss affair. I won't bore you with the details that made me persevere with getting this system finely tuned – suffice to say I knew there was a "sweet spot" where a collimated Hyperstar system would give very good results – so I had an "existence proof". Problem was, how do you "collimate" a Hyperstar system?

I took a drill to my beloved Nexstar 11 GPS telescope, glued nuts to the outside of the secondary cell ring, and fitted four threaded rods that could physically push the Hyperstar assembly around within the corrector plate. The assembly can be seen in Figure 1.5. The collimation procedure is now exactly the same as for collimating the secondary mirror. Image an out of focus star and move the Hyperstar assembly to get symmetrical star patterns in the centre of the field of view; it is as difficult/easy as conventional reflector collimation. These four adjuster rods are the reason I get diffraction spikes around the brighter stars. I also got diffraction spikes before fitting the adjuster rods as the four cables from the back of the CCD need to somehow be routed out across the corrector plate. So, however you go about it, the Hyperstar assembly will give you some sort of diffraction pattern around bright stars.

Are we there yet? Sorry, not quite. It now became clear that for the fainter objects I wanted to image I needed to go for longer sub-exposures, I needed to move to auto guiding. This was a little more straightforward than I was expecting with only a couple of minor glitches to contend with. I bought the Starlight Xpress

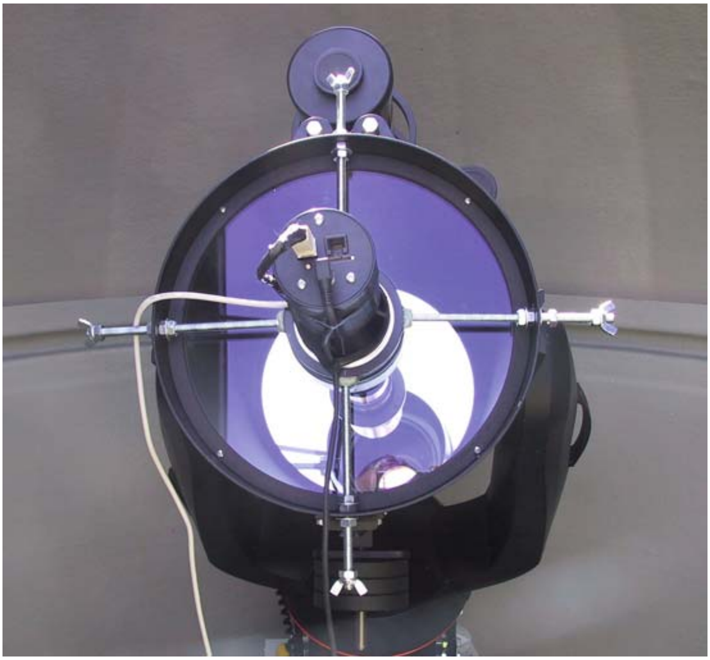

Figure 1.5. The threaded rod adjusters used to collimate the Hyperstar lens to the Nexstar 11 GPS. The threads are covered in black tape prior to imaging or you will get a very strange diffraction pattern around bright stars due to the fine threads.

SXV auto guider camera, as this was compatible with the SXV-H9C. Maxim DL was already set up to be able to handle an auto guider with the SXV-H9C, so it was just a matter of buying a suitable guide-scope and I'd be ready to take some long exposures. I chose the superb little Celestron 80 wide-field scope as a guide scope. This is extremely light at only 2kg and it operates at f#7.5, which meant that my auto guiding was very precise since I was only imaging at f#1.85. Typically during an imaging session the errors were less than 0.1 pixels! So what were the glitches? Well at first, the auto guiding simply did not work. It was fortunate that there was a "manual control" in the Maxim software as this allowed you to see if you could physically move the scope by clicking on direction buttons. The scope did not move! It turned out that you couldn't use a standard "telephone" cable connection between the imaging CCD and the Nexstar 11 GPS; it doesn't have enough connections! I put together my own home-built solution and at last the software "talked" to the scope and I could start to try auto guiding. My first auto guiding session was very disappointing! The stars were badly trailed and I actually had better results without the auto-guiding being enabled. This was due to incorrect parameters being used in the auto-guiding program. With a couple of nights of trial and error I iterated to a set of guider parameters that seemed to work rather well, as stated earlier, the R.M.S. errors for an evening's observing were typically less than 0.1 pixels. I now use auto guiding for all subs longer than about 30 seconds, and no auto-guiding if my subs are less than this.

There was still yet another addition to the system, in truth I don't think you ever finally end up with a final stable configuration. The very fast Hyperstar lens was not only unforgiving in the precision needed to set it up, it was also very unforgiving in showing you how much local light pollution (sky glow) you had. In order to try and cut down the sky glow in my location I made one of the best accessory acquisitions yet – the IDAS light pollution filter [http://www.sciencecenter.net/hutech/idas/lps.htm]. This filter together with the Hyperstar meant that I typically took sub-exposures of 120-seconds, without the filter I was limited to around 60 seconds before sky glow became intrusive. I did not properly recalibrate the system (with the filter in) to see just how far I could go before the sky glow became really intrusive again before I moved onto wide field refractor imaging; this was a big mistake on my part. However, from the experience gained with the refractor, I now estimate that I could have gone to 5 or 6-minute sub-exposures with the Hyperstar and IDAS filter before the light pollution once again reared its ugly head.

Now, we're just about there - surely! It's been a long fraught journey, and it's still far from over. I had to invest in a dehumidifier [http://www.screwfix.com/app/sfd/cat/pro.jsp?id=10204] for the observatory [http://www.pulsar-optical.co.uk/catalog/product_info.php?cPath=144&products_id=189as] [http://www.pulsar-optical.co.uk/catalog/product_reviews_info.php?products_id=189&reviews_id=6] as living in the New Forest gave me severe condensation problems during the last few months of 2005. Severe, and costly, the damp wrote off my nice little 15" CRT monitor, and I don't think it did much for the computer's life expectancy either.

After a great deal of painstaking deliberation I then finally opened my wallet (a painful experience) and invested in PhotoShop CS2, a worthwhile investment if you want to get the last 0.5% out of your images. I also use Noel Carboni's PhotoShop actions extensively [http://actions.home.att.net/Astronomy_Tools.html] and even better than that, Noel Carboni actually processes all of my images nowadays!

In terms of system reliability, it seems I have gained a couple of "hot-pixels" in the SXV-H9C that I can live with, and the azimuth motor of the Nexstar 11GPS simply stopped working a few months back. I know that this was due to leaving the scope totally unused for two months due to a spell of really bad weather. I replaced the motor assembly (surprisingly cheap considering what you get!) and found on close examination what the problem was. The motor and worm gear "floats " over the main gear cog due to a sprung loaded swivel mount. The mount had seized (simply an Allen screw that had pinched itself up), so I have fixed the old motor drive and now have a spare. Michael Swanson:

[http://www.nexstarsite.com/] was extremely helpful in showing me how to track down where the problem was (was it the motor, or the motor controller?) and if you have a Celestron scope you really should use his site and buy his book. Don't run into unnecessary trouble like I did, if you have a long spell of bad weather don't just leave the system untouched, go out and fire it up anyway a couple of times a week, it may just save you from severe grief when the skies finally clear!

So have we now finally got there? No of course not, there have been some further recent changes to the system. The Celestron wide field guide scope has been replaced with a Takahashi Sky 90 refractor and f#4.5 reducer/corrector for wide field imaging. In order to make full use of the Sky 90's imaging plane I now also have the large format CCD camera SXVF-M25C to give me those very big field-of-views (FOVs) necessary for imaging objects like M31 with a single frame. The trusty Starlight Xpress SXV-H9C workhorse camera has been sold to a UKAI forum colleague and has gone to a good home. The Hyperstar has been removed altogether from the Nexstar 11 GPS and now if I am wide field imaging using the Sky 90, the Nexstar 11 GPS is relegated to the role of guide scope, which sounds, and looks, rather perverse! However, if I want high-resolution images of the smaller galaxies, I can put the big SXVF-M25C camera on the 11 GPS with an f#6.3 reducer/corrector, and then use the Sky 90 as the guide scope at f#5 (i.e. I remove the Sky 90 reducer/corrector lens). Lastly, the Nexstar 11 GPS hand-controller started to play up (the buttons got "sticky"), so I moved to the NexRemote software and now drive the telescope through the computer keyboard and a "Gamepad" controller. This is the system I currently have in place, and I don't think there is much that can be done to improve the system overall now without going for a replacement for the Nexstar 11 GPS itself. You can see the piggybacked Sky 90 on the Nexstar 11 GPS in Figure 1.6, and the 7' 6" diameter fibreglass dome garden observatory itself can be seen in Figure 1.7.

Would I choose the same overall setup if I were starting from scratch again? Well, with the price limitations I was working to I probably would. I like the look of the all-refractor alternatives, but for me the big aperture of a reflector, and the potential of f#1.85 imaging really take some beating. Maybe the 14" Celestron with a Hyperstar lens, but then that wouldn't fit too easily in my 7 foot 6 inch glass-fibre dome observatory, so maybe a new observatory and then…. and then…and then. You get the picture.

Stop Press!!! Just when you thought it was safe to go back into the water! I have just found (September 2006) that there is a conflict between the NexRemote software and Maxim DL configured for the SXVF-M25C camera (there was no problem with the H9C camera??). My immediate solution to this was to purchase a new programmable hand controller as this doesn't seem to conflict with Maxim DL (I don't think the big camera likes anything else running on another USB port). There was also a camera firmware upgrade needed for the new M25C camera as the colour planes were shifted in a peculiar way. Terry Platt responded very quickly to get this particular problem sorted. Finally (?) there was a light smear towards the right of bright stars, and a dark band above bright stars in the red channel. These problems were overcome by me soldering a Tantalum bead capacitor onto the M25C circuit board as described by Terry Platt in a private communication. My advice – when you get a system sorted and fine-tuned, don't change ANYTHING!

Stop Press 2!!! I live in the New Forest, Hampshire, U.K. but at times I wonder if I'm in a 3rd World country. We seem to suffer more than our fair share of power outages, and these cause severe grief if you're in the middle of an imaging session, not to mention the possibility of line glitches and computer damage. It appears I did suffer computer damage from one of these outages

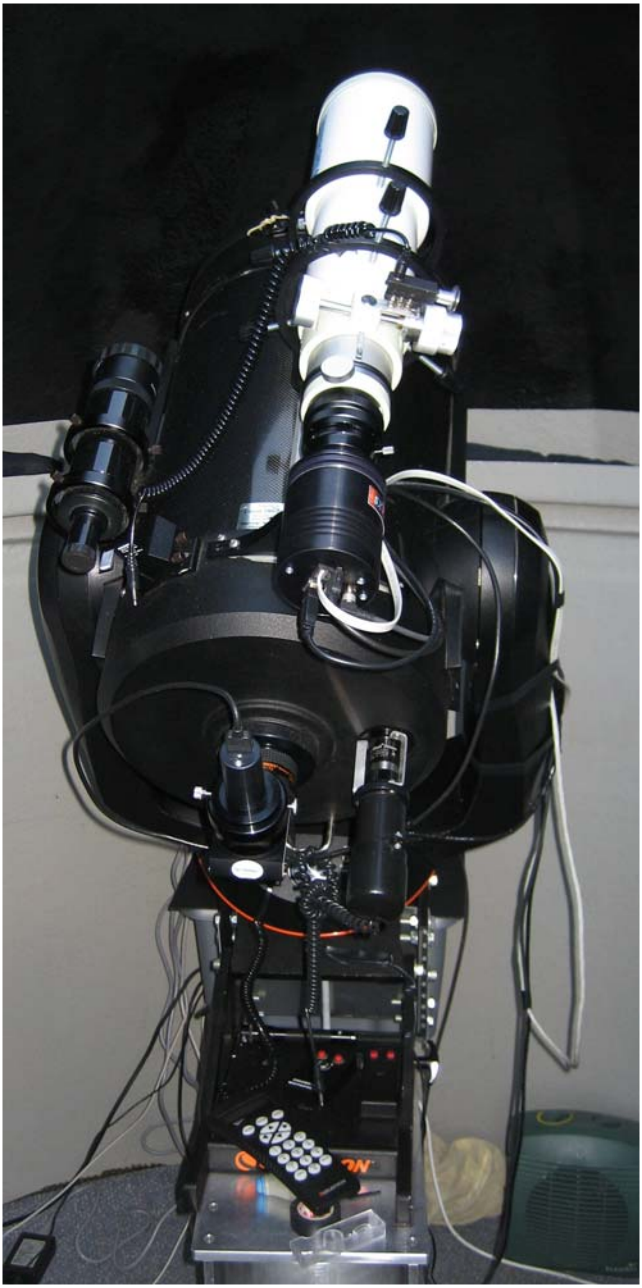

Figure 1.6. The Sky 90 f#4.5 refractor system mounted piggyback on the Nexstar11 GPS.

Figure 1.7. The Pulsar Optical 7 foot diameter fibreglass dome in its back-garden location in the New Forest, Hampshire, U.K. The dome sits on a hexagonal 10-foot diameter wooden decking.

and so there have been three more additions/changes to the observatory setup. From November 2006 my extension cables in the observatory are now the Belkin surge-protection type. I do not use the transformer to power my Nexstar 11 GPS telescope anymore, but instead I use the excellent Celestron "power tank" http://www.celestron.com/c2/product.php?CatID=51&ProdID=371 which makes the telescope totally mains independent, so that I don't need to go back to the two-star align and object location if I suffer a mains glitch! Lastly, I bought an uninterruptible power supply (UPS) for the computer/monitor, this gives an audible warning if mains power goes off, as well as giving that extra bit of buffer protection between any mains spikes and my delicate computer innards. I also get the benefit of a few tens of seconds to shut down the computer properly if it looks like mains power will be off for a while.

I am sure that in the months/years to come there will be the need for many more additions that I presently don't see any requirement for, such are the never-ending joys of this hobby.

Conclusions

When I first started imaging and posting my Hyperstar images on the forums, people were very complimentary, and there were often suggestions that it might be a good idea to move from Alt-Az to Equatorial if I wished to improve my images. People were extremely polite and helpful, they did not say, "You must go Equatorial if you want to take decent images"; they merely suggested it might be a good idea. Well, from what I've learnt I guess I won't be so polite. If you want to take excellent images with perfectly round stars with an amateur setup, you must go Equatorial – eventually. I'm not saying you can't get very good practice imaging in Alt-Az mode because you can, I've done it, and you can turn out reasonable quality images. But when the time comes to going up a notch in quality, there simply is no way of getting around an Equatorial mounting for your system (well there is but do you really want to go in for rotating camera systems?).

CHAPTER TWO

The Beginning – and a Serious Health Warning!

In writing an introductory book of this nature we need to assume some common starting point. I will assume the reader has a keen interest in astronomy, and that the only optical instruments currently to hand are a pair of eyes. The sequence of events as we progress with this Chapter need not be followed to the letter, if indeed at all, and if you have no interest in anything other than immediately starting to take deep-sky images please turn straight to Chapter 3. On the other hand, if you'd like to immerse yourself in this hobby at a more leisurely place, please continue here.

Before getting straight into imaging I strongly recommend you spend at least a year at your proposed imaging site, whether that is your garden, or some local dark location, simply observing the night sky using just your eyes or perhaps a pair of low power binoculars, 10×50s will be more than adequate. On reading this it may sound like a very boring way to start what is a very exciting hobby, but a great deal of useful information can be recorded during that year. You will need a notebook, a star map or star atlas, and a weak red light to see your map without destroying your night vision. Take good notes of what you see in the sky and where it is located, North, South, directly overhead etc., and also note what the viewing conditions are like, poor visibility, fog, exceptionally clear etc. This may sound a bit strange right now, but the value of this data will be made clear as we go on. What constellations are visible, what constellations are not visible, and in what direction is your view hampered by trees, or buildings, or hills? By observing and keeping good notes you will be able to carefully plan your future imaging sessions, you will find out that certain objects can only be imaged during certain months of the year (if at all), you will also see how the Moon badly interferes with your attempts to view faint objects, and you will discover how certain "wet" months will also interfere with viewing, and imaging. Is there any light pollution in your proposed location? By studying your proposed site carefully you may find that viewing is exceptionally good on most clear evenings, but becomes impossible on the Saturday nights when the local football team is playing, and the huge banks of halogen lights are turned on. Lastly, you will learn your way around the night sky, which is important on two counts. Firstly, if your first "real" telescope is of the "goto" variety, as it is very likely to be, then you will know where to look for the scope's alignment stars. Secondly, you will know what the faint fuzzy areas are that suddenly come into view as your eyes become dark adapted, and/or the seeing conditions become exceptionally good. Even though your "goto" scope will take you very close to the object you have keyed in, it is still a good idea to know in your mind where that object is actually located in the night sky.

So what did you discover during your observing year? The stars twinkled more, that is the "seeing" was poor, when there were very strong winds and when there was a lot of atmospheric water vapour. If it was slightly foggy, you could still observe directly overhead (the Zenith), but the stars became very faint as you approached your horizons where you are looking through a lot more atmosphere (and dust). Also with the slight fog, any light pollution was made very clear again as you approached the horizon, you may have even found the horizon in certain directions was actually "lit up" by the scattering of artificial lights by the water droplets in the air. All this information will be very important in planning your future imaging sessions.

What else did you find out? Certain stars were clearly coloured, but most were simply white, and any deep-sky object observed was in black and white. This is due to the physiology of the eye; things look black and white only (no colour) when the light intensity is weak. Colour appears "out of nowhere" when using your colour CCD camera as it is much more sensitive than your eye to the incoming photons (light particles). Disappointingly using the naked eye, there were far less stars to see than appeared to be on your map. Anything else? Well during your year's naked-eye observing you saw M31 the Andromeda galaxy, M42 the Great Nebula in Orion, you could just make out M33 the Pinwheel galaxy in Triangulum, and there was a clear patch of fuzzy light where the Double Cluster in Perseus is located. With binoculars things improved enormously, still no colour for faint objects, but the Double Cluster was an amazing sight, and M13 the Great Globular Cluster in Hercules was clearly a great glowing ball of stars. Many more stars appeared out of nowhere, and it looks like you can now actually see more stars than you have on your map. Virtually any reasonable pair of binoculars, or small telescope, greatly increases the number of stars and deep-sky objects you can see. Replacing you eye with a sensitive CCD camera improves the detection capabilities by further orders of magnitude, and it was this discovery in particular that moved me on from purely visual observing to CCD imaging. To be frank, when I saw the huge number of stars on my very first CCD image, orders more than I could see by simply looking through the eyepiece, I knew my observing days were over. I used to feel sorry for the professional astronomers in their huge observatories who never actually "looked through" these giant telescopes, but simply took pictures all the time. Now I know why, and I don't look through my telescopes any more either – but I do occasionally still use my binoculars!

Before we move on to look at the hardware and software requirements for carrying out deep-sky imaging, I feel it is my responsibility to provide you with a very serious Health Warning!! Deep-sky imaging has a tendency to become addictive/obsessive!!! Now maybe that is due to the sort of person that enters the hobby, or maybe it is the nature of the hobby itself, I don't know. However, I repeat, deep-sky imaging can become obsessive and it can have a negative impact on your family life if you allow it to take over all your free time!!! If you are a single nerd, great, revel in this hobby. If you are in a serious relationship, or married, then please try to maintain some sort of balance, because I warn you, after your first good image of the Heavens – you are likely to be hooked for life. If your partner is equally interested in your hobby, then you are very lucky person indeed and you can both share something wonderful. If however your partner is a far more "down to earth" character, and has no interest whatsoever in sitting outside, in the middle of Winter, for hours on end looking at dots in the sky, then be sympathetic, not everyone can understand what you get out of this hobby. Here ends the serious Health Warning.

CHAPTER THREE

Assembling your Imaging System

Refractor or Reflector, or Perhaps Both?

You will need a good quality telescope for deep-sky imaging and these come in two flavours, refractors or reflectors. Refractors are the ones with the objective lens at the front, reflectors utilise a big light-collecting mirror and come in several different configurations. So here's your first big decision, refractor or reflector, and what size? Also these telescopes seem to come with a variety of different mounting and control options, Altazimuth, equatorial and "goto". Which do you choose? Unfortunately these are very difficult questions from the outset, and I personally have oscillated between the two optical systems, so my compromise option would be to suggest that you eventually have both!

Modern day refractors are beautiful instruments, especially those with multi-element lenses that are designed to cut down chromatic aberration [http://www.opticstar.com/Run/Astronomy/Astro-Telescopes.asp?s=59855caf-a673-4aae-9084-4636fb905e7&p=0_10_1_2]. These refractors are often referred to as apochromatic, but the point is, by using different glasses in the multi-element lenses, the splitting up of light into its constituent colours (just as light does in passing through a glass prism) is minimised. If the refractor is to be your main imaging telescope you will need the more expensive three-element apochromat in order to eradicate "blue halos" around bright stars and "star bloating". If your telescope only had one type of glass in its construction, then it would split the light up into its constituent colours as it passed through the optical system, and finally the different colours would be focused in slightly different positions at the eyepiece end. There are filters you can use to cut down these unwanted effects, and these are usually referred to as "fringe-killers". These filters cut down the blue and infrared wavelengths passing through your refractor minimising the blue halos, and the bloated (oversize) stars caused mainly by the near infrared radiation your CCD camera will be sensitive to. Since your CCD camera is invariably based on Silicon technology, it will detect radiation up to near 1 micron (10^{-6} m) in wavelength. Very deep red extends to around 0.695 microns, so the CCD is sensitive well beyond the eye's visible wavelength limit and it extends your detection limits to the near infrared. The filter may sound like a good way of turning a "cheap" refractor into an effective apochromat for imaging purposes, but of course there is a catch. By severely attenuating any blue transmission you will find that your CCD simply cannot detect certain reflection nebulae such as the Iris nebula in Cepheus, or the reflection nebulae near the Horsehead nebula in Orion. By effectively cutting out the blue transmission you will also find that you cannot detect the faint wisps of nebulosity around the Pleiades (seven sisters, Subaru, or Messier 45) either. So I'm afraid you can't cheat here and it is not possible to turn a sow's ear into a silk purse by this approach. However, there really is one way you can win! We will discuss these issues in more detail a little later in this Chapter, but it is worth introducing H-alpha filters at this point. If you are forced to image in a heavily light polluted area, you will be forced to go down this route anyway, and these filters also allow you to image when the Moon is creating a lot of sky-glow [the sky is always beautifully clear when the Moon is full!]. A hydrogen alpha or H-alpha filter only allows through a very narrow range of light wavelengths in the red region of the visible spectrum. This narrow range of wavelengths corresponds to the emission of hydrogen atoms in most of the large emission nebulae we image. Moonlight, being reflected sunlight, means there will be some light at the H-alpha wavelengths present, but the filter bandwidth is so narrow that the amount of H-alpha that gets through from Moonlight is very small indeed, and of course all the other wavelengths are very severely attenuated. An H-alpha filter therefore means we can image emission nebulae (and other objects, like stars) in poor visibility skies caused either by light pollution or Moon glow. There is an added bonus. Since only one very narrow band of wavelengths is getting through the H-alpha filter we can now use our "cheap" refractor for very effective imaging! All the other wavelengths that would have been focused at different distances from the eyepiece, forming an out-of-focus image, are gone. We can get nice, pin-sharp, H-alpha images from the night sky with relatively cheap equipment, and with light pollution or Moonlight present. Sounds too good to be true, so what's the catch? The catch is the same as for the fringe-killer filter, but far more extreme. Instead of not being able to image just the blue region of the spectrum, now you cannot image any part of the spectrum, with the exception of a tiny band of wavelengths in the red. You cannot therefore take those pretty full-colour images of the night sky with just an H-alpha filter, but you can take very dramatic monochrome images, and it is easy to convert these into (red) colour images with image processing software that is readily available including Noel Carboni's astronomy tools for Photoshop http://actions.home.att.net/Astronomy_Tools.html.

I deviated a little from the most direct course there, but I felt it was necessary to point out some of the options, and the compromises, at this very important initial decision-making stage.

So if your main imaging system is to be a refractor, I am implying that you need to buy a good quality apochromat if your aim is to take those pretty full-colour images you see in the astronomy magazines, or in this book. A refractor has other advantages too over the alternative types of telescope. Since a refractor has no obstructing objects in the optical path, a refractor will give you better image contrast than a reflector; this is more important for planetary observation and imaging rather than for deep-sky work. The way a refractor is constructed also means that it tends to hold its alignment (of its optical elements) better than the reflectors, which means that (unlike with reflectors) you do not need to worry about collimation. Refractors also have disadvantages of course compared to reflecting telescopes. Depending on the region of sky you are working in, the eyepiece may be very awkward to get to, this is important only if you wish to view through the system, and it is totally irrelevant if you only want to image. However, if you want to both image, and occasionally view through your telescope, then this hindrance is worth bearing in mind. Light-grabbing power is all about aperture, which is down to the diameter of the objective lens in your refractor, or the diameter of the main primary mirror in your reflector. Per inch of aperture, the refractor is the most expensive telescope you can buy, especially so if we are considering apochromats. I have seen very good imaging work carried out with refractors of just 90mm (3.5 inch) aperture, but personally I would put this at the very minimum you should consider for serious imaging purposes. However, you also need to consider portability if you do not have the luxury of a permanent-base imaging site, so a large 6-inch refractor may not be feasible for your particular requirements, but as mentioned earlier, aperture is everything (provided the quality is there) so you would want the largest aperture apochromatic refractor you can afford, or carry.

One last little detail before we move on to consider reflectors specifically, and that is autoguiding. If we want to take individual images with an exposure time in the order of minutes, then not only do we need to be equatorially mounted and polar aligned, of which more later, but we will also need to guide our main imaging scope by optically locking on to a guide star somewhere in the image we are taking, and then moving the imaging scope so that the guide star remains fixed in the field of view. There are three main ways this can be achieved. You may either need a second CCD camera to act as the guide star detector, or there are some CCD cameras that allow you to both image, and have a separate area for the autoguiding function. If we consider the separate CCD camera first, then this needs to also see the same region of sky as the main imaging CCD, and this can be achieved in one of two ways. Either, the autoguiding CCD is connected to a separate guide scope, or you can fit what is called an "off axis guider" in the eyepiece position of the telescope which allows you to fit the main imaging CCD in-line with the telescope, and the autoguiding CCD at 90 degrees to the imaging CCD. Light is "split off" from the main light path to the imaging CCD by a prism that re-directs a small portion of the light to the autoguiding CCD.

If you are using a separate guide scope then it is clear that this must be rigidly mounted like the main imaging scope so that both track the sky in the same manner, this can turn out to be very much harder than it sounds. The third option is to use a CCD that combines both an imager chip and a guider chip in the one integrated package. I personally have no experience of using combined imaging/autoguiding CCD cameras but mention them here that for completeness and note that they do seem to operate very well. The only negative aspect I can see in having a combined imaging/guiding CCD is when you are imaging in H-alpha, or using narrowband filters. Under these conditions you severely limit the number of photons reaching the CCD, including the guider, and this means you may need very long integration times to see an appropriate guide star. Such long integration times will generally lead to poorer autoguiding.

Reflecting Telescope as the Main Imaging Scope

So now let us consider reflecting telescopes, which are telescopes with a mirror as the main light-collecting element. These come in lots of different flavours such as Newtonian, Schmidt-Cassegrain (S.C.), and Ritchey-Chrétien (R.C.) to name just three. Since the main collecting and focusing element is a mirror, the big advantage reflecting systems have over refractors is the much-reduced chromatic aberration (C.A.), and this is very important for imagers. There may well be chromatic aberration "downwind" of the mirror if you use glass elements (e.g. focal reducers or eyepieces), but these are usually very well designed and the C.A. is usually very slight if it is present at all. The Newtonian is a rather bulky instrument and was the most popular reflector, more compact, reflectors are of the S.C. and R.C. design which "fold" the optical path leading to a shorter instrument than a typical Newtonian. I think it can be stated without contradiction that it is the commercial competition between the big two manufacturers, Celestron and Meade, that has led to the possibility of providing amateurs with extremely high quality instruments at what must be considered very reasonable prices; I would go as far as to say "cheap" given the precision engineering involved in creating these instruments both in the optics and the drive mechanics. This commercial competition also leads to innovative and improved design that also greatly benefits the customers. In considering reflectors I will concentrate mainly on the Schmidt-Cassegrain, as this is the amateur scope of choice, but please do consider other designs as they may better suit your needs. For example, a well-designed R.C. will give a better edge-to-edge quality of viewing field image than a typical consumer S.C. and so it should, as it will be a lot more expensive!

Considering S.C. design reflectors we see there are computer-controlled "goto" instruments, those on Altazimuth mounts, those on Equatorial mounts, and they also come in a variety of mirror diameters from six inches to sixteen inches, the latter not falling into the portable category! I would say that if portability is a requirement you really shouldn't consider much beyond an eight-inch diameter mirror. Having said that, for the first two years of owning my eleven-inch S.C. scope I regularly used to carry it in and out of doors. However, as the outcome of this exercise (in both meanings of the word) was a double hernia and two hospital operations, I would rather you didn't go down the same route as me in this instance! I strongly advise that an 11" or greater reflector is mounted permanently at your observing site.

I purchased the Celestron Nexstar GPS 11, which is an S.C. design with an eleven-inch diameter mirror and GPS (Global Positioning System). It has a "goto" capability, a large database of objects on its in-built computer, and it sits on an Altazimuth mount (Equatorial mount options are available, but remember, initially I was only interested in observing and Altazimuth mounts are best for this). For visual observing, the Altazimuth mount gives the most comfortable viewing position, and also the fork arms and flat base lead to a rock-steady structure. When I started imaging with this beautiful scope I used the Altazimuth mounting it came with, but I soon discovered that this was not the ideal type of mounting for CCD imaging. At this point it makes sense to digress into a short discussion of telescope mounts.

The Altazimuth mount http://www.celestron.com/c2/category.php?CatID=9 is a very sturdy mount and ideal for visually observing objects as the eyepiece will be presented at a convenient height and angle for most objects you will observe. It must be a good mount; all the really big professional telescopes use this type of mount! However, when it comes to CCD imaging, this sturdy mount also gives us a major problem. If you look at the geometry of the mount it can of course pinpoint any object in the sky in an x-y kind of way, in that it can rotate on its base (rotational axis straight upwards) and move up and down to lock onto the object you want to view. But the Earth spins on its axis, and thus the stars appear to rotate as well, with the centre of rotation being somewhere near the Pole Star (Polaris) for us viewers in the Northern hemisphere, not straight up overhead. So what? Well our Altazimuth x-y coordinate system scope cannot rotate around the same axis as the stars, and this means that over a period of time, although your star (or other object) is still slap bang in the middle of your field of view and you can see it very well, all the other stars around it have rotated a bit, the rotation distance being greater as you move away from the centre of the field of view. This rotation is called "field rotation" it is the rotation of your field of view over time due to the Altazimuth mounting's inability to follow the rotation about the polar axis. So what again? Well, this field rotation doesn't matter at all when visually observing, that's why the Altazimuth mount is a great mount for observers. But if you are imaging, and if your exposure times are longer than say 30 seconds, then your final image captured by the CCD camera will show the characteristic trailing stars that accompany field rotation. So, one way around the problem is to take short exposures. This is fine provided you have a bright enough object that will allow you this luxury; normally you won't be able to take this way out. The reason I could take this option, for a short time at least, is that I had a "bolt-on" to the Celestron S.C. telescope called a Hyperstar lens. This lens takes the place of the secondary mirror in the S.C. design and turns the S.C. telescope into another design called a Schmidt camera. Technically the Hyperstar lens is a times one corrector lens assembly giving a flatter view in the imaging plane than would occur without the lenses. It also shortens the focal length of the

S.C. telescope and consequently reduces the f# considerably since f# is defined as the focal length of the telescope divided by the mirror diameter. Now, if you are into "ordinary" photography you will know that low f# lenses are called "fast" because they allow you to take pictures with a shorter exposure time than "slow" (large f#) lenses. The same is true to first order (if we want to get technical there is a difference between point objects like stars and extended objects like nebulae) in astrophotography. So my Hyperstar lens allows me to take much shorter exposures than using the telescope in its normal f#10 mode of operation, so short in fact that I can reduce the field rotation effects considerably – but only for relatively bright objects! Also, although the field rotation is reduced, it is not removed. When you start improving your imaging techniques and you become pickier you will find in fact that although small, the field rotation effects are not acceptable, even for exposure times of just a few seconds. You won't get "perfect" round stars – and perfect round stars are one of the main criteria we strive for in good astronomical images. So where does that leave us? Well the sad fact is that if you want to turn out good astronomical images you simply must have an Equatorial mount http://www.celestron.com/c2/category.php?CatID=15. There is no simple way around this problem. But wait a minute; didn't I just say a while back that all the big professional scopes were Altazimuth mounted? And aren't they used almost exclusively for photography? The answer is yes to both questions, and the no-expense spared big professional telescopes have no-expense spared solutions to the problem including very sophisticated software and cameras that can rotate to compensate the field rotation. Although such luxuries are available on the amateur market, the plain fact is that the Equatorial mounting solution is the simplest and most cost-effective solution to the field rotation problem.

If, like me, you have an Altazimuth mounted scope, you can now mount your scope on a wedge and set up the wedge so that the new rotational axis for the base points towards the same rotational axis as the stars. This can work fine, it certainly does for me, but there's no getting away from the fact that the whole system is far less sturdy and vibration-proof than the original Altazimuth mounting. Why should this be? You have cantilevered your scope over at some angle dependent upon your latitude, and it wasn't primarily designed to be as stable in this configuration. Far better that you buy an equatorially mounted scope in the first place if your ultimate intention is imaging and be done with all these annoying little problems!

Returning to the S.C. telescope itself. Focusing is usually afforded by moving the main primary mirror, and the secondary mirror must be accurately aligned (collimated) to the primary to get the best results from your scope. Remember that the optically more robust refractor keeps its collimation rather well – the S.C. doesn't. This once again does not actually matter, as it becomes a matter of routine to occasionally check your scope collimation and make the necessary adjustments to the secondary mirror as required. For the definitive account on collimating your S.C. telescope please visit: http://legault.club.fr/collim.html this says everything you need to know about collimating your S.C. Adjusting three Philips screws fitted to the secondary mirror affords collimation of the secondary mirror. Trying to follow the CCD image on a monitor, whilst adjusting screws using a Philips screwdriver, which of course is located precariously close to the precious corrector plate, simply isn't a fun experience. I very quickly invested in a set of Bob's Knobs http://www.bobsknobs.com/ which replace the Philips screws with a set of knurled knobs that can be finger tightened for collimation. Bob's Knobs are very good value for money, and basically an indispensable item if you want your reflector to be in tiptop collimation condition for crystal clear imaging.

So how far have we got in putting our imaging system together? We have either an equatorially mounted apochromatic refractor with an objective lens diameter of 90mm or more, or we have an S.C. reflector with a mirror diameter greater than six inches, on an Equatorial mount. I shall not describe the different Equatorial mounts available, they all do the job required to varying degrees of accuracy directly proportional to cost, and properly set up they will remove the field rotation problem. What they won't remove, and what will be apparent in the cheaper mounts is periodic error. Periodic error is due to the gears used to move the telescope in R.A. and Dec. not being absolutely precise. Consider the manufacturing difficulties here, precision gearing for very precise tracking and control, coupled with mass-production and a price affordable to the average income earner – we're looking at several mutually exclusive events here. Personally I have not found the periodic error of my Nexstar 11 GPS to be any problem at all in my imaging, something that I find amazing in a mass-produced scope and give full credit to Celestron's engineering department. Do realise that unless your periodic error is VERY bad, the autoguider will be able to take this error out. Periodic error should NOT be this bad in any good quality mount or complete system such as the Nexstar 11 GPS.

To summarise: As a beginner you will benefit from having the biggest aperture, smallest f-number system you can afford (or carry). This will be a "fast" system, and as such you can keep the sub-exposure (individual exposure) times down, which makes the autoguiding process much simpler. A smaller f-number also means a shorter focal length for a given aperture, and this will give you a wider field of view (than a large f-number system), which makes finding and framing your chosen object a lot simpler too. Large aperture, small f-number systems are a win-win in astronomical imaging; this is why I chose the Hyperstar option with the 11" diameter Nexstar 11 GPS reflector. This combination gives you a reasonable aperture with an incredibly fast f#1.85 imaging capability.

Refractor as the Main Imaging Telescope

Although it is nice to have as large an aperture as you can afford for your main imaging telescope, in the case of refractors they become very large (long) very quickly with increasing aperture. This means that for the larger aperture refractor you will almost certainly need to consider a permanent setup (observatory) and a portable system becomes impractical. Of course you can use smaller aperture refractors for imaging, but you will by necessity be using a "slow" system and your sub-exposure times will typically be very much longer than for a larger aperture reflector.

If the refractor really is to be your main imager, rather than the piggyback wide field scope sitting on a reflector, then you will want to invest in a 3-element apochromatic refractor so that you will not be bedevilled by unwanted coloured halos around very bright stars, or by "bloated" stars caused by the infrared region of the spectrum not being brought to the same focus as the rest of the colours (RGB). These refractors are expensive, but they also deliver the goods, it is a difficult decision to know which route to take when you begin your imaging career, and I feel loathe encouraging you one way or the other. I can however give you my personal experience on this subject.

After imaging for maybe 6 months using the 11 GPS and Hyperstar, I felt that maybe I had made the wrong decision. The 11 GPS was certainly a beautiful instrument for observing, but I was having second thoughts about its perfection as an imager. I outlined the problems encountered with the Hyperstar system in Chapter1, but even if you were eyepiece imaging at larger f-numbers, you would still have to make sure your collimation was spot on for the best images. Collimation is something you don't need to think about in a high quality refractor. Now although it is relatively quick and easy to collimate a SCT, it is still an unnecessary worry to consider every time you want to image. In the reflector's favour, you really don't need to worry about chromatic aberration with a good quality SCT, and your stars will always end up looking good (provided your collimation is good!). In maybe a further 6 months or so I decided that the advantage provided by the bigger aperture really made the reflector a better main imager choice than a refractor, that plus the lack of any chromatic aberration. But again, I must stress, this is a personal feeling only, and there are many top quality amateur imagers out there whose main scope is a refractor, Steve Cannistra [http://www.starrywonders.com/] being one of the best imagers I know who mainly uses refracting telescopes. One final point in favour of the reflector is the flexibility in choosing the f-number you can work at. The Celestron systems are a bit special in that the Hyperstar is available to produce very fast imagers, although Starizona [http://starizona.com/acb/] is now producing Hyperstar lens assemblies for Meade SCTs. But think on this a little, the native large aperture SCT is f#10, and by using various reducer/correctors you can also image at f#6.3, maybe at f#3.3 if you're lucky, and f#1.85 if you spend a lot of effort getting the Hyperstar properly collimated. You can also go the other way and image at f#20 or even f#30 using Barlow type adapters. This flexibility is simply not available with refractors. Yes, reducer/correctors are available, but the range of f-numbers at your disposal is nothing like that attainable using the SCTs. So, when considering what is to be your main imaging telescope, this is another factor you really must consider very carefully. The Schmidt-Cassegrain reflector is an immensely versatile imaging instrument.

Again, for autoguiding your refractor, you will have the same three options. A second guide scope (usually a smaller aperture refractor), an off-axis guider with its own guide CCD, or a combined imaging/guiding CCD mounted on your main imaging refractor. Recall that this last combination can cause you trouble when H-alpha, or narrowband filter imaging as you may need long integration times for the guider part of the CCD to detect stars, and this may give an incompatibility with good autoguiding. Terry Platt, the CEO of Starlight Xpress Ltd., makers of the U.K. produced CCD cameras, uses the two-refractor

Figure 3.1. A view of Terry Platt's all-refractor deep-sky imaging system.

configuration for his imaging work as can be seen in Figure 3.1. Terry is a World Class imager in his own right so I think we can all learn something from the route he has taken in putting his imaging system together.

Reflector/Refractor Imaging Combination

Unusually for this hobby there is actually a win-win combination you might like to consider, provided your finances will allow it. You can have the large aperture reflector as your main imaging telescope at the larger f-numbers, typically your scope's native f-number will be around f#10 and this can be reduced using refractive optics to a comfortable f#6.3. You can then piggyback a good quality, short focal length refractor on your reflector and use this either as a guidescope for the reflector, or as your main imaging scope. Clearly if your piggybacked refractor is being used for imaging, then your rather expensive large aperture reflector is being relegated to the role of a simple guidescope! It seems a little odd to do this, but it does allow wide field imaging using the refractor, and much narrower field imaging at high resolution for things like the smaller galaxies, with the reflector. As I mentioned, this is a very popular combination, I think it really does offer the best of both worlds, and it is the imaging system that I now currently use myself.

Polar Alignment

The drift method of polar alignment sounds like a very scary process, and I must admit to being pretty scared about the whole thing before trying it out for the first time. I was fortunate enough to have already found and downloaded Scott Tucker's excellent procedure for polar aligning a scope by the drift method from here http://www.darkskyimages.com/gpolar.html . By simply following this procedure to the letter, I successfully polar aligned my wedge-mounted Nexstar 11 GPS over two evenings. The first evening was really just getting used to the procedure to be followed, and finding stars in roughly the right position in the sky. The second evening, I knew what I was doing and nailed the alignment pretty accurately (I didn't need to re-align for a full year after this first go at drift aligning).

Are there any practical tips that can shorten this process a little? I have only one tip to offer from my experience of the procedure. You don't need to wait 5 minutes to see how the star is moving in the reticule eyepiece, the moment you see any movement, make the necessary adjustment to your wedge to bring the star back to position. You will only need to wait a few minutes when your polar alignment is coming close to a good polar alignment. When you're quite a long way away from alignment (as you are likely to be when you first start) the stars will drift rather quickly in the eyepiece. Also, unless you intend to take VERY long sub-exposures, don't bother to get so close to polar alignment that it takes tens of minutes to see any drift, there's no point in trying to get this accuracy if you never take subs more than 5 minutes long! And does any of this matter anyway if you are using an auto guider? Yes I'm afraid it does! If your polar alignment is way out, you will still seem to auto guide o.k., but the dreaded field rotation will rear its ugly head with long exposures and you will get some star trailing in your images.

One last tip on the drift alignment procedure. After checking for drift with your telescope pointing south with the OTA at right angles to the fork arms, move the telescope to the East using the R.A. control only (don't touch the DEC). You will then be at around the right declination for drift aligning the DEC axis.

Collimation of an SCT

As mentioned earlier, the definitive explanation for the precise collimation of a Schmidt-Cassegrain telescope is given here by Thierry Legault http://legault.club.fr/collim.html I cannot describe the procedure any better than this! However, there are a couple of practical tips that might make this process a little less tiresome for you. It is essential that the out of focus star you are trying to make symmetrical lies precisely in the centre of your field of view when carrying out the adjustments. If there is only one reasonably bright star in the FOV, then this can already start to be a painful process, as you will have to keep moving this star back into the centre of the FOV with each adjustment of the secondary mirror. Better to be collimating your telescope while pointing at an open cluster! This way it is likely that you do not need to move the telescope very far in order to bring another star into the centre of the FOV after moving the secondary mirror. Secondly, I recommend that you view the out of focus stars on your monitor using your CCD camera, rather than using an eyepiece. Why? Because if you are using an eyepiece you will need to move around to the front of the scope each time you make an adjustment, and then move back to the eyepiece again to see the outcome of the adjustment. If you move your monitor so that you can see it while working at the front of the scope, then the adjustment process becomes that much quicker, especially if you are using Bob's Knobs to make the adjustments!

Like all precision operations, the first time you try to collimate your S.C. telescope, it will take an inordinate amount of time. However, with practice, you will quickly get a "feel" as to how you need to move the secondary mirror to get the central out of focus star pattern looking symmetric.

The CCD Camera

There are a large number of CCDs suitable for astronomical imaging on the market. There are sub-mega pixel, multi-mega pixel, black and white, single shot colour, imaging and autoguiding CCDs. It is very bewildering; especially when there's all this talk about the field of view you get with different telescope/CCD combinations and the even more puzzling question of how many "arcseconds per pixel" your system delivers. Do we need to know the "numbers" involved in fine detail, or can we just trust to luck, buy a CCD and see if it works? Well, although it is a pretty bad idea I guess my decision strategy fell mostly into that last category – and I think I was very lucky to have come out relatively unscathed! I did receive (correct as it happens) advice on the best CCD in my list to go with the Hyperstar lens, but I think I should have been personally better informed. Nowadays you can download a superb "CCD calculator" that allows you to input your preferred telescope and CCD combination and see the performance for yourself: http://www.wodaski.com/newastro/downloads/ccdCalcFree.asp this program is provided by Ron Wodaski, and tells you everything you really need to know about the performance of your telescope/CCD combination.

Although the above program will give you the correct results for the correct input of telescope and CCD, it might be best if you can calculate at least two of the important values for yourself, the field of view of the combination, and the sampling. The formulae are quite simple to use and I'll run through some examples so you get a feel for what different combinations offer. By the way, these are the only formulae and maths you'll see in this book!

The sampling of your combination, which is the number of arcseconds per pixel resolution your system delivers, is given by:

Sampling = arctan [pixel size in metre / telescope focal length in metre]. For deep-sky work you want the sampling to be in the range of 1 – 4 arcseconds per pixel. For high resolution astrophotography you want to work in the range 0.1 – 1 arcseconds per pixel, although the highest resolution end of the scale will probably be better than your local "seeing" conditions, and the resulting image resolution will not be better than the seeing. Arctan is a trigonometric function, it doesn't matter what it is, just hit the right button on your calculator.

The field of view of your telescope/CCD combination is given by:

Field of view = arctan [length of side of CCD in mm./telescope focal length in mm.]

As the CCD is likely to be rectangular, rather than square, the lengths of the sides of the CCD will be different giving a field of view which is also rectangular.

Probably the best way to get a "feel" for what's going on here is to look at a couple of specific examples. Let's see what two different one-shot colour Starlight Xpress CCDs, the SXV-H9C and the SX-M25C do when hooked up to a Celestron Nexstar 11 GPS reflector, and a Sky 90 refractor. We shall also consider the 11 GPS working at different focal lengths by using either a reducer/corrector lens element, or the Hyperstar lens.

Celestron Nexstar 11 GPS SCT

For this reflector, the mirror diameter (11") is 280 mm, and the focal length in its normal mode of operation as a Schmidt-Cassegrain telescope is 2800 mm which gives us an f#10 system in the normal mode of operation.

We can put an f#6.3 reducer/corrector (R/C) on the eyepiece end of the telescope (Celestron make these R/C elements) and this will reduce the effective focal length to 1764 mm. There is also an f#3.3 R/C available (made by Meade) and this results in an effective focal length of 924mm. Finally, the Hyperstar lens operating at around f#1.85 will give a short focal length of only 518mm on the 11 GPS.

F# = Optical system focal length in mm./mirror diameter in mm.

The SXV-H9C colour CCD camera has the following parameters:

Physical size of the CCD array = 8.95mm×6.7mm.

Number of pixels in the CCD array = 1392×1040 pixels.

Size of individual pixels = 6.45um×6.45um, where a micron (um) is 10^{-6} m.

The SXV-M25C large format colour CCD camera has the following parameters:

Physical size of the CCD array = 23.4mm×15.6mm.

Number of pixels in the CCD array = 3024×2016 pixels.

Size of individual pixels = 7.8um×7.8um.

Putting all the above information together and using the two formulae given earlier, we can tabulate a set of results as follows:

CCD	F#	F.O.V. [arc minutes]	Sampling [arc seconds per pixel]
SXV-H9C	10	10.9×8.2	0.47
SXV-H9C	6.3	17.3×13	0.75
SXV-H9C	3.3	33.1×24.7	1.43
SXV-H9C	1.85	59×44.1	2.55
SXV-M25C	10	28.9×19.3	0.57
SXV-M25C	6.3	45.9×30.6	0.91
SXV-M25C	3.3	87.6×58.4	1.74
SXV-M25C	1.85	156.3×104.2	3.1

60 arc seconds = 1 arc minute.

60 arc minutes = 1 degree.

Although I have included a row for the SXV-M25C with the Hyperstar option, the CCD is actually too large for the diameter of the focal plane (20mm) that the Hyperstar can provide. Physically and experimentally, the SXV-H9C is just about the largest chip size that the Hyperstar can accommodate.

What can we deduce from the above Table? The SXV-H9C performs well at all f# ratios, at f#3.3 this would make an ideal “galaxy” imager for the smaller galaxies, and at f#1.85 (Hyperstar) there is a reasonably wide field of view with a good sampling for deep-sky objects. The fast optics, good field size, and respectable sampling makes the Celestron Nexstar 11 GPS with Hyperstar and SXV-H9C, an extremely powerful combination indeed, I would say an almost perfect imaging system for the beginner.

The SXV-M25C of course increases both the field of view, and the sampling, but the sampling remains good for all f# ratios. At f#6.3 this becomes an almost ideal galaxy imager with a good field of view for all but the largest galaxies, together with a sub 1 arc second per pixel sampling – a very nice combination.

The CCD/telescope combination also looks very good for f#3.3 imaging, and the numbers do indicate that this would make a great general-purpose imager. However, experimentally I have found a problem with the Meade f#3.3 focal reducer and the Nexstar 11 GPS scope combination. Although I spent a great deal of time trying out different spacer distances I could not get the reducer to work at f#3.3 without significant coma and vignetting. Coma is where star shapes become elongated and look like little comets at the edge of the field, and vignetting is where the edge of the field is significantly darker than the centre of the field due to "clipping" of the light by an aperture that is too small for the f-ratio. I did manage to get respectable results at f#5 from the f#3.3 R/C, but this was so close to the f#6.3 R/C that I simply ended up using the f#6.3 reducer for eyepiece-end imaging on the Nexstar 11 GPS.

Takahashi Sky 90 Refractor

For the Sky 90 refractor there is the native f#5.6 telescope, or with the Takahashi reducer/corrector we can convert this to an f#4.5 refractor. The parameters for the various combinations are as below:

CCD	F#	F.O.V. [arc minutes]	Sampling [arc seconds per pixel]
SXV-H9C	5.6	60.7×45.3	2.62
SXV-H9C	4.5	75.5×56.4	3.26
SXV-M25C	5.6	160.7×107.1	3.19
SXV-M25C	4.5	200×133.3	3.97

We can see that the short focal length of the Sky 90 makes for a nice wide field imaging system. Wide field imaging at reasonable sampling make these combinations look appealing for those large deep-sky objects that are too large to consider using the Nexstar 11 GPS combinations. The only negative comment would be that for the SXV-M25C camera at f#4.5 the sampling is getting a little close to our 4 arc seconds per pixel upper limit. This means our image may look a little "soft" and lack the sharpness of images taken at lower sampling. However, this is the trade-off we have to make; very wide field imaging implies larger sampling and these very wide field single frame images will always appear soft. The only way around this problem is to work with a smaller field and sampling, and then to build up a mosaic of the object by stitching together a number of separate frames. This is painstaking work to put it mildly, but some expert imagers out there, notably Rob Gendler [http://www.robgendlerastropics.com/], do precisely this in order to get beautiful high-resolution images of large deep-sky objects. This approach requires so much time, effort, and dedication, that it makes a clear differentiator for your work, as not many people are willing to invest so much time and effort into producing these images. Chapter 12 in this book discusses how you can differentiate your astronomical imaging from the mainstream.

Sub-exposure Times

I don't believe I have come across a topic that causes more contention (and tension!) on the various forums than the subject of optimum sub-exposure time, and with it the total exposure time needed for acquiring a great image!

For sub-exposure times there are two boundary conditions, the lower bound and the upper bound. The lower bound is the shortest sub-exposure you can take before the CCD noise becomes the predominant source of noise. For the Hyperstar system and SXV-H9C camera with IDAS LP filter, CCD noise was clearly apparent with 5-second subs. I would therefore suggest that for this imaging combination, 10-second subs are the absolute minimum you should consider. The upper bound is a little bit more difficult to quantify as it depends on you local sky glow conditions. The longest sub-exposure time you take is one where the CCD noise is just a few percent; say 5%, of the sky background noise. If you go much beyond this time with your sub-exposure times you do not gain much in the way of signal to noise ratio for the sub concerned.

However, with CCD imaging and digital processing we have a great weapon at our disposal, we can take LOTS and LOTS of subs and average them together in some way and we can then improve the signal to noise ratio of our final image by something like the square root of the number of subs we average. This means that if you average something of the order 100 subs you will end up with a very nice "smooth" looking image. Nothing contentious so far I hope.

Things only start getting contentious when we start discussing how long each sub-exposure should be. The sub-exposure length is an extremely important parameter for a number of reasons:

1) For longer subs, you will take fewer subs in an imaging session, so you may end up with a lower signal to noise ratio in your final image than if you used a large number of short subs (the image will not appear as smooth as one taken with a large number of shorter subs).
2) For longer subs it will become more inconvenient to lose an individual sub to a satellite, or plane, PEC or download glitch, or a bumped telescope.
3) For longer subs you will need to contend with the gradient (sky background) problem, which will become more apparent as the sub-exposure time increases.
4) For longer subs your polar alignment and guiding is much more critical than with short subs.
5) Conversely - for shorter subs you will not be able to go as deep as with longer subs, but don't forget your upper limit is defined by your local sky glow. You can't (unfortunately) image deeper and deeper objects by arbitrarily increasing your sub-exposure time; your sky background ultimately limits how deep you can go.

This final point (5) is a bit of a shame as it wrecks an otherwise "obvious" strategy. Points 1-4 suggest you take the shortest length subs you can get away with, and stack as many of them together as possible to get a good signal to noise ratio in the final image. This is in fact what I did with Hyperstar imaging. The Hyperstar is a "fast" f#1.85 system, so I can make my subs quite short, typically 60 seconds or even less. It doesn't take too long to collect 100 subs for averaging if the individual sub time is only 60 seconds, so the resulting images are smooth-looking with a good signal to noise ratio. However, your resulting "smooth" image doesn't go very "deep" if you stick to short sub exposure times, in other words you will not image the really faint stuff. I was actually disbelieving when a supernova hunting colleague commented on one of my Hyperstar images that he was surprised that it did not go particularly "deep" even though the total exposure time was a couple of hours or so. At first I thought he was just mistaken, but as I progressed with my imaging I realised he was absolutely correct, and the reason was I had used short subs of around a minute in acquiring the data!

So what then is the optimum sub exposure time for your optical imaging system? Since this is going to depend on your local viewing conditions, the "speed" of your optics, and the sensitivity and noise specification of your CCD, I cannot give you a simple numerical answer. This is something you need to determine for yourself experimentally. There are CCD "calculators" on the Internet that will calculate your optimum sub exposure time, for a given make of CCD and for your viewing conditions, but I personally have not found the calculators to be very useful. However, it is quite possible that you will do better than me, so a site can be found here http://www.ccdware.com/resources/subexposure.cfm. One reason I don't find such calculators useful is that your viewing conditions are likely to vary from night to night, so you will need to modify your sub exposure time dependent on the night's conditions (which of course may change while you are imaging!) so there is no single "good" value to be calculated. A guideline for your expected sub exposure time can be worked out using my Hyperstar results as a baseline. As mentioned, I typically used 60-second subs with the Hyperstar and SXV-H9C CCD given my local viewing conditions. If the sky clarity was particularly good I could go to 90 seconds and see an overall improvement in the final image. I did not see an improvement in final image quality in going to 120 seconds with the Hyperstar, although the image itself may have gone fractionally deeper. If this is used as a baseline, then you can calculate guideline values for your sub exposure times using:

$$\text{Time (seconds)} = 60 \text{ seconds} \times ([\text{f-number of your system}]^2/[1.85]^2)$$

Assuming that you are using an SXV-H9C camera and that your sky conditions are similar to mine. On a "good" night I can clearly see all the stars that make up Ursa Minor, on a "bad" night I can only make out Polaris! My Sky 90 refractor with focal reducer is an f#4.5 system, which if using the above equation implies that the optimum sub exposure time should be around 6 minutes, and experimentally this does indeed seem about right (within a factor of 2).

However, I do not recommend necessarily going to the maximum sub exposure time you can possibly manage for reasons 1-4 given in the list above. Also, it is possible to use sub exposures below the "optimum" time and simply stack more subs together to end up with an image of precisely the same signal to noise ratio. So my advice would be to use subs of less than the optimum exposure time and stack more of them together. Again, just how much below the "optimum" value you can get away with is a matter for experimentation. Also, remember that the f-ratio equation given above is only strictly true for extended sources and does not apply to point sources. This being the case, you will find in your imaging that you can use much shorter subs for imaging star fields and clusters than you can in imaging nebulae and galaxies.

As a final comment I need to discuss the most contentious issue of all, and that is the question of f# and the "speed" of an optical system. You will see in various places on the web that the "speed", basically meaning the f# of an optical system, does not apply to systems using a CCD. This is, in my opinion, complete nonsense I'm afraid. There are several reasons for my statement. Firstly, it is the definition of f# number, namely the photon density reaching the image plane, that spells out that f# really is the "speed" of an optical system, it's how f# is defined, so it seems a little perverse to state that f# does not relate to speed. Since we are talking about the photon density reaching the image plane, it matters not a jot whether the detector is film, a CCD, or a currant bun, the lower f# system will be "faster" because more photons per unit area are reaching the image plane – end of story. It really DOES NOT matter what the aperture of your system is, the f# number normalises out the aperture with respect to the focal length, so the Hubble space telescope with a 2-metre diameter mirror operating at f#24 really is very much slower than my Sky 90 3.5" diameter refractor operating at f#4.5. It might not seem logical, but it is a fact. Why on earth would the main selling point of the Hyperstar system be the fact that it is a "fast" system if it were not true? I think there might be a number of very aggravated customers calling up the manufacturer of the Hyperstar if it did not live up to its expected high "speed"! But of course it does! The f#1.85 Hyperstar on my Nexstar 11" GPS is a full twelve times faster than the same scope operating at f#6.3 using a reducer/corrector, and a full twenty-nine times faster than the 11" GPS operating at its native f#10. This is simple optics, and I have experimentally verified these figures at f#1.85 and f#6.3 (I have not ventured into the dizzy heights of f#10 imaging so far). But do consider the widely different fields of view you observe at these different f-ratios as well, maybe then it is not too surprising that f# really does equate to "speed"!

Enough of that particular diversion, what does all this mean for deep-sky imagers? It means that you would like the largest aperture at the smallest f# you can afford. This will give you a wider field than a longer focal length system, so a deep-sky setup will not be good for planetary imaging, and it will not give you good resolution on small deep-sky objects like planetary nebulae. You will need to very carefully select your CCD to match your optical imaging system. Remember, for reasonable resolution you will want to keep below about 4 arcseconds per pixel imaging scale, and you will want as big a CCD as you can afford to get the biggest field of view. Big apertures mean reflectors rather than refractors, and small f# reflector systems typically mean Schmidt cameras, Hyperstar systems, or Newtonians with lens reducer/correctors. These then are the tools of the deep-sky imager. High quality, large aperture refractors are also serious contenders, and they may give a flatter coma-free image over a bigger image plane diameter allowing the use of bigger CCD chips. But – they are invariably of smaller aperture than a similarly priced reflector and they will typically operate at a higher f-number. Reflector or refractor – it's a very difficult call – as you know, I side with the reflector.

So you have a low noise and highly sensitive CCD, and you have a large aperture low f-ratio imaging system, but what you don't have is particularly good sky glow conditions. Is this the end of CCD imaging for you? If your sky pollution is particularly bad, then yes it might be for that particular location, but we have one final set of weapons at our disposal that allows imagers to take quality pictures under quite poor sky conditions, and these are the narrowband filters and light pollution filters.

Narrowband Imaging and Light Pollution Filters

As mentioned previously, I always have an IDAS LP filter in the optical train. This filter cuts out emissions from common light-polluting sources (sodium and mercury vapour lamps) and as a bonus I find I do not need to radically alter the colour balance of my one-shot colour images. I have tried other "nebula" or "light pollution" filters and have found it necessary to make substantial colour balance changes to get a good colour-balanced image.

Also mentioned previously was the Hydrogen Alpha narrowband filter. The H-alpha filter works at a wavelength of 656.3nm, where a nanometre (nm) is 10^{-9}m. This is in the red part of the visible spectrum and it is the emission line associated with singly ionised hydrogen (HII), which is the main light emitting species in emission nebulae such as the Orion nebula, the Monkey Head nebula, and the Rosette nebula. Since we are using just a very narrow band of wavelengths we do not need to use refractors with a good degree of chromatic aberration compensation; this opens up the possibility of using good quality camera lenses instead of high cost apochromatic refractors! Also, since we are only collecting photons of a single wavelength, it becomes pointless to use a one-shot colour CCD for imaging, and we typically use monochrome CCD cameras for narrowband imaging. As an added bonus the monochrome camera provides higher resolution than a one-shot colour camera based on the same CCD chip.

Again recall that narrowband imaging allows us to image in areas that suffer from light pollution, providing that the pollution is not too severe, and we can also image with the Moon up! This narrowband imaging really seems like a win-win situation, and in many ways, it is. There are downsides however. If you want to create a false colour image, you need to take several sets of data of the same image using different narrowband filters, and this pushes up your total imaging time. You also need to use long sub-exposure times as you have severely cut down the number of photons reaching your detector with the narrowband filter. This also greatly increases your total imaging time on an object. You will not get those "true colour" pretty pictures that you get with film or one-shot colour CCDs, but you can create nice "false colour" images. You can create false colour images by combining the images from several different narrowband filters. Other readily available narrowband filters include:

Hydrogen-Beta filters operating at 486.1nm. This is in the blue region of the spectrum and this emission line is associated with doubly ionised hydrogen. Note this is NOT the blue emission you see from reflection nebulae which is a broadband blue associated with the scattering of starlight from a dust cloud. A classic example of reflection nebulosity is the blue nebulosity associated with the Pleiades star cluster M45.

Oxygen-III filters operating at 500.7nm in the green part of the visible spectrum. O-III emission is associated with doubly ionised oxygen atoms and is often the dominant emission line from planetary nebulae.

Sulphur-II filters operating in the deep red region of the visible spectrum at 672.4nm. Singly ionised sulphur is also a common emission line in deep-sky objects.

And finally Nitrogen-II filters operating at 658.4nm also in the red region of the visible spectrum (we have 3 narrowband filters all operating in the red!).

False colour images can be formed by using various combinations of the above narrowband filters as the Red Green and Blue channels of the image to be formed. These different possible "mixtures" are called palettes, and the Hubble "palette" is one of many possible alternatives. The Hubble tricolour palette assigns S-II to the Red channel, H-alpha to the Green channel, and O-III to the blue channel. There are a number of iconic Hubble images using this particular false colour scheme, the "Pillars of Creation" being one very well known example.

So there in a nutshell are the basics of what's involved in narrowband imaging. You can carry out high resolution, deep-sky imaging in a relatively light-polluted environment (you can of course always take even better images from a dark sky site!). You can use lower specification equipment than that necessary for single shot colour imaging, this allows the use of short focal length camera lenses for those really wide field shots. You can also differentiate your work by creating your own "custom" palette.

What I haven't discussed in any detail is the fun and games you will have in overlaying and combining the different narrowband channels. You will find the stars in your separate images will have slightly different diameters according to the narrowband filter used, and this will make the formation of the final false colour image quite a processing challenge.

CHAPTER FOUR

Computational Considerations – Data Acquisition and Image Processing

You will be acquiring and manipulating digital data in your new hobby, and this means you will need to use one or more computers as an integral part of your overall imaging system. There are many ways of handling the computer hardware and software issues and I will outline just a few.

Many people, myself included, start off by taking their laptop out to the observatory and using that to acquire the CCD data and to look after the scope driving and autoguiding. The software for downloading the CCD data, and autoguiding can be the native camera software, or it can be specialist software specifically written for carrying out the tasks, including image processing. I have used AstroArt [http://www.msb-astroart.com/] to great effect (AstroArt also has a great photometry package amongst many other goodies), but I currently use Maxim DL [http://www.cyanogen.com/] for all data acquisition, autoguiding, colour conversion and stacking. Returning to hardware considerations, any current model laptop is going to be good enough to carry out these tasks provided it has a fast USB 2.0 interface available for downloading the data from the CCD camera. Any reasonable size hard drive will also be more than adequate for storing a night's imaging data, the screen brightness is readily reduced to save your night vision, and it is very easy to carry a laptop around your observatory for the best access in what are usually cramped conditions. There is only one negative as far as I am concerned. I do not like taking a very expensive laptop out to a freezing observatory in the depths of winter and then bringing it back indoors to work on, or download the data. I know you can carefully wrap the laptop up in a plastic bag before bringing it indoors so that it can warm up slowly without filling itself with condensation, but I still feel it's a risky thing to do on a regular basis. I much prefer to have a very basic, small footprint computer, left full time in the observatory, and that is now my current arrangement. I also think that an LCD monitor is preferable over the CRT variety in the highly variable environmental conditions you get year round in an observatory. Again from experience, a little 15" CRT monitor didn't last one season before giving up the ghost, whereas my current 17" LCD doesn't seem to be suffering any problems at all. You can use a standard desktop (or server) configuration in the observatory, but space being a premium (especially if you also have a electrical greenhouse heater and a small dehumidifier unit taking up floor space as I have) means I use a mini ITX system with a 1GHz processor that has worked flawlessly – so far - http://www.mini-itx.com/store/ . The mini ITX system downloads the sub-exposures from the CCD, stores them in a file set up for the evening's imaging, and looks after the autoguiding of the Nexstar 11 GPS using Maxim DL software. With the SXV-H9C camera I also used the Celestron NexRemote software on the mini ITX to initialise the scope alignment and for the goto functions. An added bonus of using NexRemote is that you can connect up a wireless gamepad to control the scope movement. This makes life very easy during the star align routine, and when centring your object, since you are not tied to the Celestron keypad and its connection to the base of the telescope. I found the joystick gamepad control of the telescope movement much more intuitive (and enjoyable!) than the keypad, and I am not one for playing computer games. After acquiring the evening's data on the mini ITX, I transfer all the files onto a 4 GB USB pen and take that indoors for image processing on a separate desktop computer.

In the few weeks since writing the above, I had a nasty incident that has caused me to think a little more carefully about the observatory electrical system. The supply from the house has an earth leakage circuit breaker for safety, and you really must fit one of these as the last thing we want is for you to be incapacitated in a remote observatory after receiving an electrical shock, and nobody knowing you are in trouble! That wasn't the nasty incident by the way. The nasty incident was some power surges from a failing power supply spiking the mains supply. These spikes successfully took out the motor control board on the Celestron Nexstar 11 GPS telescope, and two complete sets of memory in two different computers! This as you can gather was a very expensive glitch. In order to minimise this potential problem occurring again in the future I have fitted the Celestron "Power Tank" to the telescope [http://www.celestron.com/c2/product.php?CatID=51&ProdID=371], this is basically a 12 volt rechargeable battery, so the scope is now completely isolated from the mains. By the way, the 12-volt connector to the base of the scope can become intermittent due to poor electrical contact, a fact that is well-documented on Mike Swanson's superb site http://www.nexstarsite.com/. I wrapped a single layer of aluminium foil around the outside (earth) part of the connector from the power supply and this seems to have improved things enormously, this is in addition to carefully "splaying" the +12V connector pins on the telescope connector using a small screwdriver. I have also hooked up the computer and monitor to an uninterruptible power supply (UPS) to add an extra bit of buffering protection between the mains and the computer system. Finally I have replaced the ordinary extension leads with Belkin surge protection extension cables. I'm not sure there is a great deal more I can do to try and protect the sensitive electronics from something nasty on the mains supply.

My main (desktop) processing computer is a 2.8GHz homebuilt system with 250Gb of internal hard drives, a further 1.0Tb of external networked hard drive, and 2Gb of RAM, which is located in the house. The main processor is dual core. I also use a dual 19" CRT monitor system so that I can pull all the software processing menus across onto one screen leaving the second screen completely clear for the image I am processing. Again, you don't need an enormously powerful computer for your image processing, but I have found that PhotoShop actions on the 2.8GHz system are carried out very much faster than on the 850MHz system I used previously for over a year. This isn't to say a sub-1GHz system isn't perfectly adequate – I believe it is – but processing an image takes quite a long time as it is and it can be quite frustrating having to wait a while for a simple processing action to be carried out. So the sequence of events on the indoor desktop computer is as follows. Download the previous evening's data from the USB pen into a named and dated file on the desktop computer. Convert the raw 16-bit FITS sub-exposures into FITS floating point IEEE format. Convert these FITS files into RGB (i.e. colour images) using the View/Command Sequence Window in Maxim DL. Manually look through each of the colour sub-exposure images and delete any that have satellite or plane trails, download glitches, or movement glitches. Combine the remaining (good) sub-exposures using SD Mask or Sigma Clip. Lightly crop the outer edge of the combined image and mirror the image (if necessary) in order to get the correct image orientation from the optical system. And that's about it. However, there are lots of variations and combinations you might want to try. My home computer system can be seen in Figure 4.1.

As I suggested originally, you can do all your astronomical work on a reasonable laptop computer, this could be your "observatory" computer and your indoor desktop computer for image processing. You can have a separate "observatory" computer and indoor desktop computer, the system I currently use, and transfer the data between the two using either a USB pen, or even by writing the raw FITS data to a CD/DVD in the observatory using a CD/DVD burner. This latter approach is a good idea, as you will automatically generate a "hard copy" of your night's imaging that won't be easily lost due to some electronic glitch in your computer system. For obvious safety reasons you should always burn your original FITS data onto DVD or CD so that you never lose this hard won data to something as trivial as a hard disk failure. Fine words, but lately I have not actually done this myself! I used to burn all original data to DVD, but with two 0.5Tb external networked hard drives I now pull all my data (processed and unprocessed) off the desktop computer's internal hard drive, and place all that data onto the huge network drive. The idea is to fill the network drive and then remove it from the system and install another network drive. However it is quite possible that at some point I turn "chicken" and spend a month or two burning all the original FITS data onto DVDs. I highly recommend you get into the habit of doing this from the beginning of your imaging career and do not follow the lazy route I have chosen, which I am sure will one day end in tears.

You can actually connect your observatory computer to your indoor desktop computer using either cable or wireless if the distance is not too great. This allows you to use your indoor computer as a remote desktop for your observatory computer so that you can see what is going on in the observatory from the luxury of your study armchair. The only reason I have not bothered to go this extra mile is that I have not automated the dome rotation of my observatory, so every half an hour I have to go outside to rotate the dome so that I am not restricting the FOV of my scope with the dome aperture. If I had automatic dome rotation I would probably remotely control the observatory computer from indoors and do all my imaging from my study with some nice appropriate music playing in the background. In fact that sounds so nice I think I'd better start looking into automatic dome rotation!

Most other computer system configurations for astronomical imaging and processing are variations on the above options. It really comes down to where your telescope is situated, and how far away it is from your home computer, that decides on the configuration that will work best for you.

To summarise my "observatory" and my indoor "image processing" computers are as follows:

The Observatory Computer System

An Epia 1.2GHz motherboard in a black Venus (beautiful!) case.

512 Mb of RAM (single card).

150 Gb single hard disk drive.

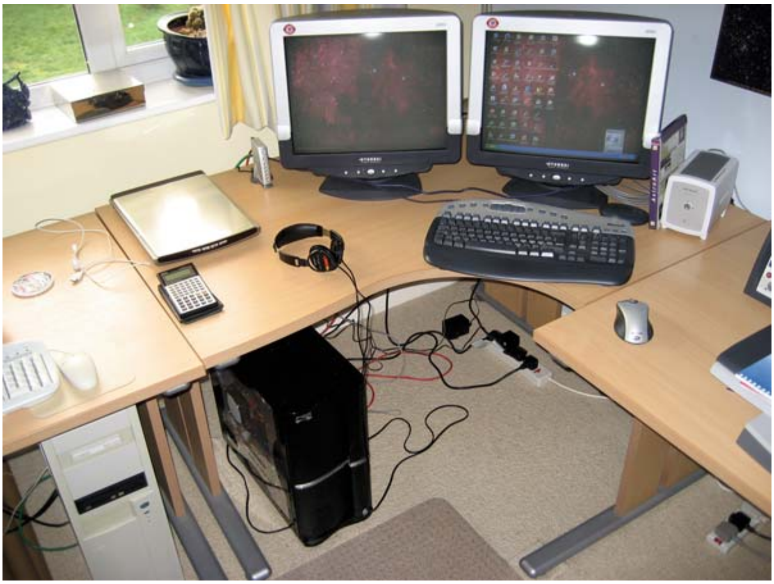

Figure 4.1. My home computer system for image processing. I have two monitors so that the image I am working on can be on one screen, whilst all the open processing menus sit on the other screen and do not block the image.

CD/DVD writer and single floppy drive.

17” LCD monitor with in-built speakers.

Standard keyboard and mouse.

Wireless Gamepad controller for joystick control of the scope movement – H9C camera only, not the SXVF-M25C.

Windows XP, Maxim DL, CCDInspector.

The main function of the observatory computer is for downloading the imaging CCD camera data, and for autoguiding.

The Indoor Image Processing Computer System

An ASUS motherboard with 2.8GHz dual-core Pentium 4 processor.

Silent 500W power supply.

2Gb of RAM (4×512 Mb).

An 8×AGP graphics card with dual monitor control.

2×150Gb internal SCSI hard drives.

Tsunami Dream Case (beautiful again!).

CD/DVD writer and floppy drive.

Wireless keyboard and mouse.

2×19” Hyundai CRT monitors.

2×0.5Tb external networked hard drives.

Internet access, Windows XP, PhotoShop CS2 plus Noel’s actions, Maxim DL, Neat Image, Paint Shop Pro 7, Rus Croman’s Gradient Xterminator, and a whole bunch of other processing software both freeware and purchased.

The main function of the indoor computer is to process the astronomical images and print the results on an A1 format inkjet printer [HP Designjet 130].

Always keep in mind that for what you get, computer power is exceptionally cheap. If you have a problem that can be solved by buying an extra computer, this is likely to be the quickest and cheapest way of solving your problem.

My long-term project goal is to create my own micro-WASP http ://www.super wasp .org/ observatory. This will consist of four imaging systems (short focal length) with four large format CCD cameras so that a large area of sky can be imaged at one time. For a Sky 90/SXVF-M25C micro-WASP array consisting of four imagers, an area of sky 4.5 by 6.5 degrees would be covered in each image! It is likely that I will hook each CCD up to its own computer so that I will avoid data conflicts from so much data transfer, and so that there is a certain amount of redundancy available. So, my future observatory is likely to be overrun with computers – at least they will keep me warm in winter.

CHAPTER FIVE

A Permanent Setup

You can have the greatest imaging system on the planet, but unless it can be up and running quickly, usually between breaks in the cloud, it may end up simply being a dust-magnet. The problems associated with not having a permanent base for your imaging system are huge, but they are certainly not insurmountable.

Many people do not have the luxury of an observatory in their garden, or at a local dark site. In these cases they have to limit themselves to smaller aperture telescopes so that they can carry the whole assembly in and out of doors, or to the local dark site. This in itself is a pain, and you will find that you can't be bothered to go to all the trouble of lugging all your equipment outside unless the viewing conditions are perfect, and are likely to remain so all evening. Such conditions are very rare in the U.K. and you will find that your expensive imaging equipment will spend a lot of its life sitting in the corner of the lounge, unused. There are further complications with a non-permanent setup. Every time you take your kit out you will need to do a polar alignment before imaging, and this takes up valuable imaging time. Make no mistake, many people do this, and I have the greatest respect and admiration for their skills, especially since I do polar alignment so rarely it takes me at least a couple of hours to get the alignment looking good. However, as stated, a lot of people do take this route, and many World-class images have resulted from their diligence.

The benefits of a permanent setup, given the above difficulties, are obvious. Your imaging system is already polar aligned just waiting for you to do the usual star alignment, and then you're ready to begin imaging. You can be up and running within ten minutes, so you don't need to wait for perfect conditions, you can be out and imaging at the first sign of a break in the clouds. You will also find yourself imaging through broken cloud, picking out those subs that imaged during the clear intervals – you don't normally do this when carrying the kit in and out of doors, just in case it decides to rain! Being outside the telescope is temperature stabilised, again ensuring a quick-start when you want to start imaging. There are very many advantages to having a permanent setup outside as you can see, and if your budget, and your location allow it, I strongly recommend that you construct some sort of observatory to house your gear.

There are many designs of observatory for housing your telescope and associated gear, and there is an excellent book you should refer to on the subject:

"More Small Astronomical Observatories", Patrick Moore's Practical Astronomy Series, Ed. Patrick Moore, Springer, 2002, ISBN 1-85233-572-6. There is the added bonus of a CD containing the first book "Small Astronomical Observatories" which is included. Within this book you will find just about every idea going for your observatory design. However, when all is said and done, the designs all usually fall into one of two categories, either a roll-off roof, or a dome construction. As its name implies, the roll-off roof is literally a shed where the roof can be rolled-off to one side, or temporarily removed altogether for the observing session. Domes look like the big observatories seen on top of Mauna Kea, except they are on a much smaller scale. You will need to think very carefully about which design best suits your location, and your own particular requirements. The dome is much more compact than a roll-off roof in that you don't need to find floor area (well, roof area actually) next to your observatory to accommodate the rolled-off roof! However, completely removing the roof means that you do not have to consider rotating the dome every half an hour or so as your telescope tracks the stars (unless you have the added luxury of a motorised dome!). The decision is not at all easy to make, and I personally spent over a year making many designs of my own before finding the above book. All my ideas had already been considered before (unsurprisingly) and mine were certainly no better than many others in the book. I considered modifying sheds to give me a roll-off roof observatory and felt that for what I wanted to do the cost involved would not be very different from buying a purpose-built fibreglass dome. In addition, the fibreglass dome was guaranteed waterproof and weather proof, and even more importantly needed no construction time. For these reasons I chose the 7 foot Pulsar Optical fibre glass dome http://www.pulsar-optical.co.uk/catalog/ which I am extremely happy with. You can find my review of this dome on Pulsar's website, but I will also make a few comments here. First, I was a little worried the Nexstar's GPS wouldn't work through the fibreglass dome as it certainly doesn't work indoors. Unsubstantiated worry, the GPS system works without any problem at all within the dome. The dome is very well constructed and is certainly waterproof and has been tested as gale proof! The major environmental problem I had with my location within the New Forest area was with condensation. This was minimised by placing water absorbing "Water Snakes" all around the dome runner region, these are Silica Gel filled fabric "sausages" that simply reduce the amount of damp air entering the observatory through the opening between the rotating dome and the main wall. In addition to these I also run a dehumidifier in the observatory that keeps the interior quite dry. Without the dehumidifier I found that water vapour would enter the Hyperstar optics necessitating a session with the hair dryer to expel the condensed vapour, and occasionally a spell in the oven at 40 Celsius. Are there any negative aspects associated with the 7-foot dome design? Well the aperture width is a little tight for an 11" reflector with a 90mm refractor piggybacked. When the refractor is either directly above or below the reflector (south or north pointing) there is no problem at all. If however the reflector is facing east or west, then the refractor lies to the side of the reflector and the aperture width then becomes a little on the tight side. This means you may need to physically move the dome a little more often to ensure you don't block the field of view of the imager, or the guider. That really is my only very minor quibble, and that is very quickly sorted out by buying the 10-foot version of the dome!

There are two other things you can learn from my mistakes. I put the dome down at the far end of my garden, which was not the best location with regard to the local street lighting, but it had to be down the end if I was to see Polaris over the roof of my house. I thought I needed to see Polaris in order to do a proper Polar alignment – this was in fact incorrect! Since the method you will use to get good Polar alignment is the drift method http://www.darkskyimages.com/gpolar.html all you really need to do is to get your setup roughly pointing north with the R.A. adjustment on your wedge, and the Dec angle set at your latitude (there is normally a vernier scale on the side of your wedge to facilitate this). This very rough "Polar alignment" is sufficient for you to now image stars to the south and to the east for precise Polar alignment. You really do not need to be able to see Polaris at all!

The second thing that you can learn from my own mistake is where to position the door of the dome. With the 7-foot Pulsar Optical dome there are runners that take the dome aperture down the back of the dome to leave the aperture clear, these can be seen in Figure 5.1. It can also be seen from Figure 5.1. that the runners extend below the rim of the dome and that they will prevent the door from being opened or closed properly if they are in front of the door! So this defines where you should place your door before bolting the dome down to its base. I did this all wrong! I wanted to be able to see the door from my house, so the door faces north. This means that when I am imaging close to due south, i.e. most of the time, I am unable to easily open or close the door – this is a great nuisance. As I cannot image to the west due to neighbouring trees, I should have placed the door opening facing the east. If I can summon up the energy and enthusiasm, one day I will remove the screws holding the observatory in position, remove the sealant that I have applied all round the base perimeter (internally and externally) and physically rotate the dome so that the door faces east. I think it will be quite some time before I undertake this exercise, and you can side step the problem by facing the door in the right direction first time off.

You can see from Figure 1.7 that my dome sits on raised wooden decking, so that I didn't need to pour a large concrete base. The aluminium pier is mounted on an eighteen-inch by eighteen-inch concrete slab that extends 3 feet into the ground. The decking does not touch the slab or pier so that vibration isolation is quite good, but it is by no means perfect. If you walk around the observatory you will see the autoguider trying to compensate!

Figure 5.1. Illustrating how the dome aperture guiding rails can block the opening and closing of the door on the Pulsar Optical 7-foot dome. In this photograph I have the door facing north, and the aperture facing south where most of my imaging takes place.

In summary, a permanent setup will ensure good usage of your telescope, and will prevent a rather expensive investment from collecting dust. It will allow a fast turn-on time so that you can maximise your observing/imaging time. It will prevent you from injuring yourself, or the equipment, by the repeated carrying in and out of doors of your gear. But most important of all, I think a dome in your garden looks really cool.

CHAPTER SIX

First Light – Choosing your Objects

I cannot stress how important it is to prepare properly before any imaging session. If, by some miracle you have a clear Moonless night, then you really must get the most out of the evening as these are such rare occurrences, especially in the U.K.

Since we are discussing your very first images, we need to consider the "easier"subjects so that your initial results are positive ones. This being the case I really recommend that you do not try to image things like the Owl nebula (M97), the Bubble nebula (NGC7635), or the Iris nebula (Caldwell 4) in your initial outings as you are likely to end up feeling despondent and unhappy with your hard-won results. A difficult winter object such as the very dim Witch Head nebula (IC2118) is completely out-of-bounds! Leave the tough stuff to later sessions when you have learnt more about your system and are more proficient with your kit. So for now, let's look at objects that should give you a good result with your very first imaging session, your "first light".

Clearly, the objects that are going to be visible to you will depend upon the time of year and your location. You will need to know what is "up there" in the sky at the time, and to this end you will need a good quality star map. It is also a good idea to subscribe to an astronomy magazine such as Astronomy Now, or the Sky at Night, in the U.K. or Sky & Telescope in the U.S.A. as these will give you a star map for the month, together with information on the best objects for viewing or imaging during that month. These magazines will also tell you the phase of the Moon, which is very important, as you want Moonless nights for the best imaging results (and please remember, a full Moon ALWAYS means clear skies).

What area of the sky will you be imaging in? This depends on your location and your local sources of light pollution, but it's true to say that often the best (darkest) place to image is directly overhead - the Zenith. This also has the best "seeing"as you are going through the thinnest amount of light-disturbing atmosphere. As you go to lower and lower declinations, you will be imaging through greater and greater thicknesses of the Earth's atmosphere, and you will be more susceptible to things like dust, fog and water vapour, which will end up giving you a poor final image. You are also more likely to start seeing the effects of local light pollution at lower declinations as well! So my advice on your first imaging session is to check what can be seen at the Zenith of the evening you wish to image.

Next we need to consider the class of object that would be best for our first imaging attempts. We want large, bright objects (the Moon is too bright!) and we would like them to fit the field of view of our imaging system nicely so that we don't get either an indiscernible point in the centre, which was meant to be a galaxy, or a general region of uniform red, that was meant to be the North America nebula. Initial subjects that are good to image would be open or globular clusters, and any large bright nebula that might be in your sky at the time that fits your optical system's field of view. The most ideal bright nebula to experiment with is the Great Nebula in Orion M42, but you are restricted to the winter months only for that one.

To summarise, we are looking for a bright object, galaxy, nebula or cluster, that nicely fits our imaging system's field of view, and that is almost directly overhead during the time we wish to image it.

Some Possible Examples

For general examples of suitable targets I will consider two imaging setups, one will be a wide field imager like the Sky 90 and SXVF-M25C camera, and the second will be a smaller field of view as provided by the Nexstar 11 GPS scope at f#6.3, but again using the SXVF-M25C camera. The Sky 90 system will give a large field of view approximately 3.33 by 2.22 degrees at 3.96 arcseconds per pixel, and the Nexstar 11 GPS at f#6.3 will cover a smaller 0.5 x 0.75 degrees at 0.91 arcseconds per pixel which makes it an ideal galaxy imager. Let's look at what will be available in the 4-quarters of the year imagers working in the Northern Hemisphere.

Spring

Spring is known as the "galaxy season"for astronomers in the Northern Hemisphere, as it is at this time of the year that many galaxies are well placed for imaging and observing. As galaxies are going to be our main targets during the spring, our galaxy imaging system will be seeing more action at this time of year than our wide field setup.

So, some nice bright targets that will fit the field of view of the Nexstar 11GPS at f#6.3 and SXVF-M25C will be:

1) M51, the Whirlpool galaxy in Canes Venatici. A pair of interacting galaxies with lots of nice structure, and the subject of a Hyperstar image (see Chapter 11).
2) The famous "Leo Trio"– NGC3628, M65 and M66 (see Chapter 11). You won't get all three objects in the F.O.V. but you could make a nice mosaic.
3) M106 is a beautiful bright galaxy in Canes Venatici that to me looks like it is made from Mother-of-Pearl. You can also see M106 in Chapter 11. Many other smaller galaxies surround M106 and you should pick these up easily in your imaging system.
4) M100 is a nice bright spiral galaxy in Coma Berenices.
5) M104 is the rather small, but surprisingly bright Sombrero galaxy in Virgo, which would look great in with this imaging system's field of view.
6) M63, the Sunflower galaxy in Canes Venatici is a spectacular sight, reasonably bright with very nice fine structure.
7) M64, the Black Eye spiral galaxy in Coma Berenices is not as bright as M63 but has an interesting structure, with a clear dust lane running right through it.
8) M3 is a spectacular globular cluster in Canes Venatici, it is very bright and a good beginner's object.
9) Similarly M5 in Serpens is another bright globular cluster, perfect for the beginner.
10) M101, the Pinwheel galaxy in Ursa Major is a large, classic-looking spiral galaxy, but a little bit on the dim side. Not so easy to image as it has a low surface brightness. This is however an object that is worth persevering with as a beginner, just to learn how to deal with the slightly more difficult subjects.

I would suggest starting with 5-minute sub exposures for the above objects, and getting as many of them as you can. Move upwards from 5-minutes if you do not seem to be achieving sufficient depth.

For the Sky 90/SXVF-M25C combination there is a smaller selection to choose from.

1) Although it will come out a little on the small side, it would still be worth imaging the M101 area, as there are other small galaxies you will pick up in the wide field that would make a very nice frame overall.
2) The Leo Trio will be a very easy single frame using the wide field system.
3) The main spring target would have to be the Virgo Cluster region around Markarian's Chain! There are more than 2,500 galaxies in this region, and the tail end of Markarian's chain would make an ideal single frame object for the wide field imager. It would certainly be worth your while spending

the time building up a 4-frame mosaic of this area which would allow you to capture the whole of Markarian's Chain, and a good bit of the surrounding galaxy-filled area.

I would suggest starting with 6-minute sub exposures, and again go for as many as you can obtain.

Summer

Summer is an extremely difficult time of the year for the astronomical imager at the latitude I work from [50 degrees 49 minutes 10 seconds North], especially for those of us that have day-jobs. In peak summer it never really gets dark and you find you cannot start imaging much before 11.00 p.m. (it's just too light), and you have to pack up around 3.00 a.m. as the rising Sun will again start to cause you problems. It is a very frustrating time of the year, probably better spent in maintaining your observatory and equipment rather than imaging. Having said that, one of my finest Hyperstar mosaics was taken in those few available hours – a 4-frame mosaic of the North America/Pelican nebula region.

There are lots of narrow-field as well as wide-field targets you can obtain during the summer, and it is fortunate that you can still get many of them during the autumn months as well when the dark evenings start a little earlier.

For the 11GPS at f#6.3/SXVF-M25C combination, you could try:

1) M13 and M92, two absolutely stunning globular clusters in Hercules. M13 is often quoted as the best globular cluster in the Northern Hemisphere, and it is certainly an amazing sight.
2) M27 is a nice reasonably bright nebula in Vulpecula with distinct blue and red regions.
3) IC5146 is the Cocoon nebula in Cygnus. Reasonably bright and with a nice surrounding dark nebulosity, which enhances the Cocoon.
4) NGC6946 is a beautifully coloured spiral galaxy in Cepheus, and it is unfortunately a little on the dim side. However, as it is the site of a number of supernova discoveries, it is probably also worth imaging occasionally, just on the off-chance :

All the above objects can be seen in Chapter 11.

For the Sky 90/SXVF-M25C combination, you are spoilt for choice! You have all the Cygnus goodies at your disposal – and they're BIG.

1) As mentioned in the introduction above, you have the spectacular North America nebula (NGC7000) and the Pelican nebula (IC5070) in Cygnus. This is a massive H-II region (ionised hydrogen emission at 656nm in the deep red) and is truly beautiful, as well as being truly huge. The wide field imager will get the whole of NGC7000 in one frame if used in portrait mode, and will easily get the whole of the Pelican region in one frame as well. So in order to get the whole region imaged you will need to do a 2-frame mosaic – but it's well worth it. My original 4-frame Hyperstar mosaic covers less area than

a single frame wide field mosaic using the Sky 90, such is the high price you pay for not having the best gear for the job at the time.

2) There is another superb huge nebulosity in Cygnus that is ideal for the wide field system, and that is the Veil nebula, NGC6960/6992/6995. Again, this is so big it will require a mosaic, even with the wide field imager. I took a nice image of part of the Veil (the Witch's Broom, NGC6960) with a narrow field, but have not imaged the whole object yet; so this is a future project for me. I estimate it will take 3-frames to capture the whole of this supernova remnant using the wide field setup.
3) There's even bigger stuff to be had in Cygnus, believe it or not. The Gamma Cygni nebulosity IC1318 surrounding the bright star Sadr at the centre of Cygnus is truly immense. Centre Sadr in the FOV and you will capture the whole of the Butterfly nebula, a fascinating H-II region with plenty of nice dark nebulosity. Move up to the NGC6914 region of IC1318 and you will get some blue reflection nebulosity breaking up the rather monotonous red that makes up the huge IC1318. A 4-frame mosaic will be insufficient to capture the whole of the Gamma Cygni nebula, you will need at least 6 and more likely 8 frames to get the whole thing in – this is a major project.
4) There's another huge H-II region in the summer skies, IC1396, and strangely enough it doesn't have a "common name". It does however contain a region of dark nebulosity that does have a common name, namely the "Elephant's Trunk"nebula vdb142. I estimate that IC1396 is just about possible as a 2-frame mosaic using the wide field system, or a very easy 4-frame mosaic using the same setup.

Several of the above objects can be seen in Chapter 11.

Autumn

Autumn has a good mixture of narrow field and wide field objects to image.
For the 11GPS at f6.3/SXVF-M25C try the following:

1) M15, a nice bright globular cluster in Pegasus.
2) While you are in Pegasus move across to NGC7331 a very nice spiral galaxy with plenty of structure. It has the added bonus of a group of nearby smaller galaxies (the Deer Lick group) that gives a very nice frame.
3) You can get the core region of the massive Andromeda galaxy, M31, in Andromeda.
4) You can also get a large part of the Triangulum Galaxy, M33 in Triangulum, but will need at least a 2-frame mosaic to get the whole thing. Be warned – the Triangulum galaxy has quite a low surface brightness, which makes it a lot more difficult to image than it first appears.
5) M74 in Pisces is a very nice spiral galaxy, but it is a little on the dim side.
6) The famous Double Cluster in Perseus, NGC 884 and NGC 869, makes a very fine image. This is likely to be a 2-frame mosaic with the narrow field imager.

7) NGC891 is a nice bright spiral galaxy that is almost edge-on to us, so it shows a dominant dark dust lane running right across its diameter. Very photogenic.

The wide field targets duplicate some of the narrow field objects suggested above.

1) M31, the Great Andromeda galaxy, can be framed along the diagonal of the wide field imager. M31 is surprisingly big at 3 degrees along its major axis. M31 benefits from LOTS of medium-length subs, so something like 100 subs of 6 minutes each would give a very good image of M31.
2) Another one from the above list, M33, the Triangulum galaxy is a very easy single frame object for the wide field imager.
3) NGC281 the Pacman nebula in Cassiopeia is an almost perfect size for a wide field single frame image.
4) This next target I suggested was not for the beginner, but it may well be worth having a go at it, even if it's just to see why it is a little tough. Try to get NGC7635, the Bubble nebula centred in the frame. If you do, you will also have the little open cluster M52 clearly visible in the frame, and if you go deep enough with your sub-exposures, you'll see the whole area is covered in H-II regions. I think you'll need a minimum of 10-minute subs to get anything meaningful out of this one, that's why I don't think it's a good beginner's object. But it is very pretty!
5) Finally, the Double Cluster again. Very easy in the wide field, but not as impressive-looking as the 2-frame narrow field image.

Most of the above objects can be seen in Chapter 11.

Winter

Winter is the best time of year for us deep-sky imagers. Long nights, crisp dark crystal-clear skies (when you can see them), and of course the piece-de-resistance – Orion! Winter is a good time, and a bad time for me personally. It's good for the reasons given above, it's bad for one of the reasons given above – Orion. With Orion up in the sky I rarely want to look at, or image, anything else. It has a magical power. It also contains just about every different type of deep-sky object you want to image. Orion is the ultimate playground for the deep-sky imager. I will try to include objects other than those just in Orion :

For the 11GPS at f#6.3/SXVF-M25C combination:

1) We may as well start with the winter showpiece, the Great nebula in Orion, M42 (and the closely associated M43). This region is bright. Take many short subs of 3-4 minutes each, and enjoy the result. It is almost impossible not to get something you like when you image Orion. I clearly remember the first few images I ever took with my brand new Hyperstar/SXV-H9C combination, of course they were all of Orion. I also remember how excited I was at the results which I thought were fantastic. Looking back I realise they were actually pretty miserable with extremely poor star shapes – but under all the blemishes, M42 shines through looking quite beautiful. You won't get the whole of M42 in a

single narrow field frame, so pick bits of it; they all look good. If you feel ambitious enough, build up a mosaic, it will take around 3-4 frames.

2) Go slightly north of M42/M43 to get the famous "Running Man"nebula NGC1977 and associated open cluster. This is a little tough for the beginner, but should do well with as many 6-minute sub exposures as you can muster.
3) Move west towards Monoceros and get the core of the Rosette nebula (Caldwell 49, the Great nebula in Monoceros, or Swift's nebula) and the associated open cluster at its centre NGC2244. You will only get the central region of the Rosette, but this alone is worth it. A lovely deep-red H-II region that really lives up to its name.
4) Move across to the Pleiades (M45) in Taurus. It is of course very easy to image the bright stars that make up the Pleiades, and much more difficult to capture the faint blue reflection nebulosity that fills the whole region. You won't get the whole of the Pleiades in your FOV, but you can take some stunning images with each of the major stars centred in your FOV.
5) Move to the leftmost star in Orion's belt, Alnitak, and there you'll find the most imaged region of the sky. Here resides the Horsehead nebula B33. Your narrow field will get a nicely framed Horsehead, and you should be able to keep the ultra-bright Alnitak out of your field of view.
6) Move north of the Horsehead and you will come across the Flame nebula (NGC2024) and the associated bane of the astronomical image processor's life, Alnitak. The flame nebula is another H-II region but with an appearance nearer that of orange/burnt umber rather than the usual deep red.
7) Your narrow FOV should get most of the open cluster M35 and the little old cluster off to one side NGC 2158 in Gemini. This is one of those nice, rarely encountered, "double objects"where you get two for the price of one.
8) Another "double whammy"can be found in Puppis, this is the nice open cluster M46 and the pretty little planetary nebula NGC2438.
9) Although you won't get both galaxies together in the narrow field, M81 and M82 in Ursa Major are well worth spending some time on. M81 and M82 need a lot of exposure time, so they are probably not good beginner's objects, but if you can get the accumulated time on these objects you will be very well rewarded.

For the wide field combination, you are really spoilt for choice.

1) Orion again! M42, M43 and the Running Man – you'll get the lot in a single, wide field frame, and they look great together. Go for as deep an image as you can manage and you will see the whole area surrounding M42 is covered in nebulosity.
2) The Rosette nebula. Once again, your wide field imager will capture the whole thing. Go for as many 6 to 10 minute subs as you can manage.
3) The Horsehead and Flame region near Alnitak. Yet again, the wide field imager will capture the lot. Go as deep as you can to pull out as much of the huge sheet of H-II region as you can that lies behind the horse's head.

4) M45, the Pleiades or Subaru! The whole thing fits easily into your wide field FOV. Blue reflection nebulosity fills the whole region but it is very difficult to capture nicely. Go for as many 10-minute subs as you can get.
5) Finally M81 and M82 in Ursa Major. You will easily get this pair in your single frame FOV. Again, go for, as many long subs as you can manage for this region, there are lots more things to see than just M81 and M82 if you go deep enough. I'll let you discover what they are for yourself!

Other Things to Image

In the above sections I have discussed imaging nebulae (dark, emission and reflection), clusters (open and globular) and galaxies of all types. The objects chosen have been suggested as good first targets for the beginner. Is there anything else? If you take a look at the Chapter 11 images, you'll see there is something else, but it takes a lot of image processing practice to make these objects look as good as they do in that Chapter. These objects are single (or double) bright stars, with a nice background star field.

This type of image will look far better using the narrow field setup. A well-centred very bright star with a nice background star field can make a really stunning image. The other good thing about these images is that the sub-exposure times can be reasonably short, say 3-minutes with a total of 50 subs altogether.

Single star images of Polaris, Aldebaran, Vega, Altair and Deneb can look very stunning indeed. A well-processed image of the double star Albireo, in Cygnus, can be really striking.

If your sky conditions are not optimal one evening, or the Moon is being intrusive and you cannot do H-alpha imaging, don't forget the possibility of taking some nice single star images!

CHAPTER SEVEN

First Light – your First Objects

I really envy you this moment! It doesn't matter how good, or bad, this first image of yours turns out, it is your first light with your new system and you will always remember this evening as something special.

For your first image I strongly recommend you pick the largest, brightest object in the sky at the time as discussed in the previous Chapter. This might be a cluster, globular or open, or a bright nebula, Orion if it is up is ideal.

Go through your star alignment routine if you are using a goto telescope and then move to your chosen object. Carefully centre the object in the middle of the screen using the crosshairs if you have Maxim DL as the image capture software (right click on the image box and check crosshairs).

You will already have excellent polar alignment so there is just a short checklist to sort out before you start imaging. Having centred your object you should then carry out the following:

1) Make sure the object is in good focus using the acquisition software. Check the FWHM of the star chosen for focusing is the minimum you can get on this particular evening. Viewing conditions can vary greatly from night to night, on a very good night you might obtain an FWHM of 1.5 pixels or less, on an average night you may have difficulty getting below 2.0 pixels. Take your time over this step, it is the most important step of the evening, and you may need to do it again if conditions change during your imaging session (i.e. temperature, viewing, humidity, mirror shift, etc.)
2) Choose a guide star using the guiding routine in your software and calibrate to it as the software describes. You will want to choose a relatively bright

guide star close to the centre of the field of view if at all possible. There should not be any other bright stars in close proximity to the one chosen or the calibration routine can get confused. Choose an integration time of around 1 or 2 seconds for the image acquisition for your guide CCD. Go to the options settings for your guide parameters; you will need to experiment with x-speed and y-speed settings to get the best guiding. You will also need to experiment with the aggressiveness settings for best guiding as well. Open up the tracking error graph so you can see how well your system is guiding and set the guide to track. If your guiding is good you will be able to be on +/- 0.5 pixels full scale and all your tracking points will lie between +/- 0.2 pixels. Unfortunately this may take quite a bit of experimentation with your new system, and you may find your whole first session is spent just getting the autoguider calibrated without even taking an image. You may find the following program helpful in iterating to the best autoguider parameters http://www.ccdware.com/resources/autoguidercalcv4.cfm Again, take your time over this step, once you have sorted out the best settings for your system you will use these for all future imaging sessions for the same arrangement of kit. Set the autoguider to track and now open the sequence window, as we will want to store a sequence of images.

3) With the sequence window open choose options and set up the sequence. If you are using a one-shot colour camera choose "light"and then you will need to choose an exposure time for your sub-exposures, and a figure for the total number of exposures. I simply put a large number in for the number of exposures (300 or more) as I will terminate the sequence manually at some point, usually dictated by poor weather turning up! Your main concern will be the length of the sub exposures. Now there is a good calculator for working out how long your sub exposures should be and it can be found here: http://www.ccdware.com/resources/subexposure.cfm It is well worth using this as a good first guide for your best sub-exposure times, but nothing beats experience. As you get more and more used to the quirks of your system you will get to know what the best length of sub-exposure to use is for the given object under the given "seeing"conditions. Faint objects will require longer sub-exposures, but if the Moon is up you will want to reduce sub-exposure times as much as possible to minimise gradient problems. This is very much a "black art"area where experience counts. For ballpark figures, if you are using a low f# system like my Hyperstar, try for 30 second sub-exposures. If you are using a short focal length refractor like the Sky 90 at f#4.5, try for a sub-exposure time between 180 and 300 seconds. If you are imaging at f#6.3 using an 11" Schmidt-Cassegrain, try experimenting using sub-exposures between 240 and 420 seconds. Choose a file location to place your sub-exposures in and you are ready to use the auto-sequencer.
4) Before starting off the auto-sequencer, return once more to the expose window and take a quick exposure of your chosen sub-exposure length. Check that everything looks o.k. that it is in good focus, and that the brightest parts of the object you are trying to image are not "burnt out". You can check to see whether you have burnout by calling up the "Information Window"and placing the cursor over the region of concern. Don't worry about bright stars, they will

be burnt out, check the core region of globular clusters, or the bright regions in nebula (especially the Trapezium region in the Orion nebula). Once you are satisfied that the sub-exposure looks reasonable, return to the Sequence Window and start off the sequencer.

5) Now all you need do is go away if you have your scope in an observatory, and only return to rotate the dome every half an hour or so if you don't have a roll-off roof or a motorised dome.
6) Once all your sub-exposures have been taken, download all the saved FITS files to bring indoors for image processing.
7) Shut down your system and leave the telescope in its usual resting position.

For your first image, I wouldn't worry too much about the fine detail you will be concerned with once you gain more experience. So, for this first image I would try to aim for a total exposure time of around an hour. You will discover that the absolute minimum total exposure time to get any of those "good"images is always around an hour, and that is for bright objects using a fast f# imaging system! As you go hunting for dimmer, more difficult objects, two, three and even four hour total exposure times will become common. As an example using my Hyperstar system, I can obtain reasonably good images of the Orion nebula and NGC7000 (the North America nebula) using total imaging times of only 40 minutes using sub-exposures of 30 seconds or less. For bright clusters a total imaging time of only half an hour can be sufficient, so these are good subjects to go for on those nights when you are bothered with background Moonlight. To get the nebulosity around the Pleiades I would need at least an hour total exposure using subs of around 60 seconds. Now let's move onto the dimmer stuff. Something like the Bubble nebula, or the Iris nebula needs at least 2 hours total exposure and 3 hours (or more) is preferable. The Jellyfish nebula shown in this book was over four hours total exposure, and clearly this was still insufficient with the sub-exposure times I was using! You will have to experiment carefully in order to understand how to get the best out of your system, and quite often when I am imaging a new object, the first imaging session is usually only an experiment to see what the best imaging parameters should be in order to image the object properly at a later time. Treat all objects as entirely new cases, and carefully log all the conditions and parameters used for your imaging session; this will be an invaluable resource for you as you progress and improve.

You should be aware of a "trick"that you need to employ on these long total exposures. If you have very good tracking you will find that you will get CCD artefacts feeding through into the final image, especially in the darker (low photon signal) parts of the image. This can manifest itself as bright and dark vertical bands (not the same as the Venetian blind effect which appear horizontally if the CCD is used in the normal "portrait"mode), which can be caused by different columns having slightly different read-out characteristics. With good sub-pixel tracking each sub with its own "CCD signature"will add together giving pronounced banding. To prevent this you can simply turn off the autoguiding and auto-sequencer after say an hour, slightly move the telescope using the X-Y controls, then reconfigure the autoguider and start imaging again using the auto-sequencer. I would follow this routine after each hour of total exposure time. The same effect can be achieved using the "dither"function in

Maxim DL. When you combine all the individual sub-exposures using either sigma clip combine, or SD mask combine, the vertical banding will be removed in the combine process.

Reading the above it is apparent that a whole evening's imaging should be dedicated to just one object if you want to obtain a really good image. In fact you will find that you may actually need to dedicate several evenings imaging to just one object, especially if it is faint. At the beginning of your imaging career you are unlikely to want to do this, there's just too much up there you want to see and capture. After all, if you spend less than an hour on an object you have the possibility of getting three or more objects "done"in one night. That's fine – get it out of your system as early as possible, because the results will not be the images that you admire from the likes of Rob Gendler or Steve Cannistra. To move into the big league you have to go the extra mile, and spending many hours imaging a single object is the price you have to pay to get those great images.

Stop Press!!

Here's yet another late addition to the imaging armoury, only brought on board in the last few weeks. The SXVF-M25C is a large chip to be sure. It is so large that there is provision for adjusting the flatness of the chip to the optical system using three adjuster screws. Now if the chip isn't quite square to the imaging scope's optical axis you will see central stars nicely focused, and stars towards an edge of the field of view will be out of focus to varying degrees. Practically, how do we square up the chip to the scope? Well one way I suppose is to take an image, slightly adjust the CCD, take another image and see if it looks any better. I am sure this approach will work, eventually, but I don't fancy my chances of ending up with a perfectly flat chip even after much iteration.

It is very fortunate that there is some powerful software out there, purpose-built to take all the pain out of this exercise. Produced by CCDWare the software is called CCDInspector http://www .ccdware.com/products/ccdinspector/features.cfm and it makes big-chip alignment a doddle! It gives a lot more information about your optical system as well (see the above website), and will be as invaluable on the Schmidt-Cassegrain for collimation adjustment as it is on a wide field refractor setup for squaring up a big CCD chip. Until I had actually used this product I didn't believe for a second it would turn out to be as useful, in fact invaluable, as it has done.

CHAPTER EIGHT

Hyperstar Imaging

Basing your deep-sky imaging on the Hyperstar lens assembly from Starizona [http://www. starizona.com/] is sufficiently differentiating that I feel the subject deserves its own Chapter. Figure 1.1 shows the Hyperstar lens assembly for an 11" Celestron Nexstar GPS scope. This is an earlier model that does not incorporate collimation screws as part of the Hyperstar lens. The Hyperstar lens replaces the secondary mirror in a Schmidt-Cassegrain type reflector and turns the SCT into a Schmidt Camera http://www.schursastrophotography.com/schmidt.html. Although this lens assembly was initially designed for Celestron telescopes only, recently Starizona have started producing Hyperstars for some of the Meade range of SCTs. The Hyperstar is basically an x1 field corrector, in other words it does not reduce at all, but it does flatten the curved field that results from just using the primary mirror alone to form an image. Let's be frank here, this was an amazingly bold move for Celestron to take, and I am highly impressed that the company tried to get this advanced optical engineering into the hands of the amateur imager. Turning an f#10 SCT into an f#1.85 Schmidt Camera is inspired thinking, and it creates an immensely powerful imaging tool. But there is a problem, and it could well be the reason that Celestron themselves no longer offer the Fastar option*. An optical system operating at f#1.85 may be an extremely fast system, allowing objects to be imaged in a very short period of time, but it is also a very unforgiving system in terms of any misalignment of the optical elements.

* The Starizona "Hyperstar" was originally the Celestron "Fastar". Celestron never made a "Fastar" for the 11" GPS scope; this is why I bought my Hyperstar directly from Starizona in the States.

To give you some idea of how precise some of the requirements are, using the Hyperstar at f#1.85 on the Nexstar 11 GPS scope with the SXV-H9C colour CCD, your depth of focus (critical focus zone) is 7.53 microns, that is 7.53 x 10^{-6}m. The diameter of a human hair by comparison is something like 80 microns! I think you can probably see where the trouble is going to be found when trying to use the Hyperstar for high quality imaging.

As stated above, the Hyperstar replaces the secondary mirror in an SCT; you remove the secondary mirror completely and place the Hyperstar in the secondary mirror cell. This cell actually has something close to 1mm of clearance between it and the corrector plate, so the positioning of the cell in the X-Y plane (the plane of the corrector plate) is only good to about 1mm in each perpendicular direction. Now it doesn't matter that the position of the secondary mirror is only good to about a millimetre because the secondary mirror comes with those collimation screws mentioned earlier, so the optical system can be precisely collimated. The original "Fastar" and the earlier "Hyperstar" assemblies did not have collimation screws, so it was a hit and miss affair where your lens assembly sat within the corrector plate. Now recall that your depth of focus is only 7.5 microns, and your possible error in the X-Y position of your Hyperstar is 1,000 microns – and you begin to see a major problem looming. You are very unlikely to have a collimated system when you fix your Hyperstar in the "randomly positioned" secondary cell. The outcome of this is terrible star shapes across the whole field of view, and extremely bad coma at the field edges. I do not know if the "collimation screws" on the later Hyperstar models are able to properly collimate the system, as I have had to work with the earlier model that had no adjustment, so I had to find another solution to this problem.

How did I know there *was* a solution to this problem? This is one example of such an unbelievable stroke of luck that I should probably play the lottery on a regular basis! When I used the Hyperstar for the very first time, indeed the star shapes were terrible, and the coma was completely unacceptable at the field edges, although the nebulae themselves seemed to come out very well. I then took off the Hyperstar as I didn't like the star shapes and did some f#6.3 imaging at the eyepiece end. After the speed of the Hyperstar I quickly became frustrated at the slowness of f#6.3 imaging and the fact that dust doughnuts now became a problem (something else I didn't have to worry about with the Hyperstar) – so I replaced the Hyperstar. Now here's where the unbelievable luck comes in – I must have, at odds of millions to one, put the Hyperstar back in smack bang on the "sweet spot"!

I obtained good round stars across the whole 1 degree by three-quarters of a degree field of view, and there was no coma to be seen. At the time I thought nothing more of this and simply assumed that I had done something wrong the first time I fitted the Hyperstar.

Fast-forward four months. I am trying to get M81 and M82 into the single Hyperstar frame, but I need to use the diagonal, and this means rotating the Hyperstar assembly by 45 degrees. No bother, I reach into the end of the 11 GPS and give the assembly a twist, the cell can be rotated within the corrector plate reasonably easily. Absolute disaster! I am back to terrible shaped stars and unbelievable coma – what had I done? Well even for me I fairly quickly understood what had happened. By some miracle I had put the Hyperstar right on the collimation point for the system, and in rotating the assembly I had shifted it off this position and lost collimation completely. I felt physically sick for around two days. However, after the panic had started to subside and logic started to kick in again something became apparent. At least there *was* a "sweet spot" position for the Hyperstar in the corrector plate where everything is perfectly collimated – I had an existence proof. Now all I needed to do was position the Hyperstar once again in the "sweet spot" and I'd be off imaging again in no time. It wasn't quite so easy of course. My first attempt was to use the usual technique for collimating an SCT, defocus a star, check the star shape on the monitor, and then manually move the Hyperstar by sliding the assembly around the corrector plate until the star shape looked good. Within a couple of minutes it became clear that even the smallest movements I could make manually were far too coarse to be able to collimate the system. Once again the odds against me putting the Hyperstar right on the "sweet spot" that second time hit home. O.K. so I cannot manually move the Hyperstar around, I am going to have to build some sort of precision cell-shifter.

My solution to the problem of precision-shifting the secondary cell within the corrector plate can be seen in Figure 1.5. Taking this route you can appreciate took a great deal of faith that what I was about to do would work! It meant taking a drill to my beloved Nexstar 11 GPS that I had only used for imaging for 4 months now. I could call it a day and give up the imaging and go back to visual observation (the thought did cross my mind) and I wouldn't have to take a drill to the scope. Figure 1.5 shows you that I was foolish enough to believe my idea would work, and I did take a drill to the scope. I drilled four 8mm clearance holes in the end ring of the 11 GPS to take four 8mm diameter threaded rods. I used Araldite to stick four 8mm nuts at right angles to the corrector plate to accept the ends of the 8mm threaded rods. The nut threads were drilled out for this purpose. I then threaded nuts to the inside of the scope end ring, onto the threaded rod, and I would screw up against these to physically push the secondary cell, and the Hyperstar lens, around on the corrector plate.

Again I went back to the "classical" method of collimating an SCT by defocusing a star and then moving the Hyperstar with the push rods to try and get a nice symmetrical star shape. After a little experimenting I began to get a "feel" for how I should move the Hyperstar to get collimation, and after a couple of nights, unbelievably, my Hyperstar setup was once again collimated!!! Hooray!!! So I quickly went back to imaging and found a further problem. There were now strange rectangular boxes of very fine lines around very bright stars looking like some sort of strange diffraction pattern. It was some sort of strange diffraction pattern; it was the threads of the push rods! Some black insulating tape wrapped around the push rods eradicated the diffraction pattern, and I was back in business.

Four push rods across the corrector plate will of course produce diffraction spikes around bright stars, that's O.K. I like diffraction spikes anyway. However, this was nothing new to me as a Hyperstar imager as I had to get four cables from the back of the SXV-H9C out to the scope, the computer and the autoguider anyway, so I was used to diffraction spikes. It just meant that now I needed to tape the cables down to the push rods to make sure I only got one set of spikes.

There are further fine-tuning details to attend to in order to create fine Hyperstar images. The system is fast, which is very good, but this also means that sky glow quickly becomes a problem; there was also a problem with "star bloat" due to imaging the infrared. The sky glow problem could be significantly reduced, and the infrared bloating eradicated, by using an IDAS light pollution (LP) filter. This beautiful filter cuts out the main sources of light pollution (Sodium and Mercury lines) as well as attenuating the infrared wavelengths that cause bloating http://www.sciencecenter.net/hutech/idas/lps.htm. There is another added bonus of using this filter, it doesn't upset colour balance like many other LP filters do so there is less image processing for you to do to get the colours looking right.

Another "fine-tune" I carried out that I believe had some positive effect, was to very carefully tighten up the corrector plate retaining screws by about half a turn each. Why would I want to do this? Remember, the depth of focus is a tiny 7.5 microns, and you have a weighty Hyperstar plus CCD cantilevered off this corrector plate. I don't think it will take much to get 7.5 microns of movement as you pan around the sky, and I wouldn't be surprised if the plate itself did not deform to the order of a few microns.

Finally, there's that 7.5-micron depth of focus! You are shifting that huge 11" diameter mirror up and down a shaft for focus, and you have to control its movement to just a few microns. You are not going to do that with the as-provided manual focuser! Remove the Celestron manual focus knob and fit a "FeatherTouch" focuser http://www.starizona.com/search.cfm?Category=0&Product=1&Keyword=microfocuser for very fine focus control. One further addition; if your fingers are as clumpy as mine you will still have trouble getting good focus. Just touching the focuser shifts focus and it becomes difficult trying to see the FWHM focus numbers on the monitor whilst fiddling around with a focus knob. The solution to this problem is to fit an electric focuser to the FeatherTouch such as those supplied by JMI http://www.jimsmobile.com/ also see Figure 1.2. Now you're finally done!

Solving all these rather difficult technical problems makes Hyperstar imaging more of a Black Art than a true science.

But what if you persevere until you get your Hyperstar system tuned and finely collimated – what then? Well, personally, I believe you have one of the finest amateur imaging systems available on the planet. You have ultra-fast imaging, a wide field of view, and a big aperture scope – all the ingredients to have a pretty amazing time imaging deep-sky objects.

As discussed earlier, my Nexstar 11 GPS sits on a modified Celestron wedge, and a Celestron 80mm wide field refractor is used with the SXV autoguider CCD for guiding the system. Since you are imaging at f#1.85 and you are autoguiding at f#5 using the lightweight Celestron refractor, it is quite easy to achieve extremely tight autoguider control. I had no difficulty in maintaining 0.2 pixels RMS error in X and Y all through an imaging session, and very often the error would be 0.1 pixels or less RMS! You will find this level of accuracy has both plus and minus points. On the plus side, your stars certainly come out round! On the minus side, you will start to see CCD noise feeding through into the darker areas of your image as some rows may have a slightly higher gain than others and this becomes very apparent when you have such very high guiding accuracy.

However, even this problem is very easily resolved in Maxim DL, you activate the "dither" function in the "Sequence" menu and you make the scope move a little after each sub-exposure. In this way you can eradicate the CCD noise. If you don't want to have the scope move after each sub-exposure, you can simply physically move the scope a little bit after say an hour's imaging, reset the autoguider and start up the sequencer again.

Sub-exposure Times with the Hyperstar

There are an upper and lower bound to consider when considering the optimum sub-exposure time to use. The lower bound is governed by the shortest sub you can take before CCD noise becomes intrusive. For the SXV-H9C camera, with the Hyperstar, and my typical imaging conditions, this would typically be around 5 seconds or so. The upper bound is where sky glow limits your integration time so that your dim deep-sky objects get lost in the sky background. You must clearly operate well below the time when your image is completely "washed out" by sky glow, but at the same time it is good to maximise your sub-exposure time in order to obtain "deep" images – that is images that are able to pick up very faint objects.

Now I will readily admit that I got into a lot of arguments over the "optimum" sub-exposure time with people on imaging Forums, and the main reason for the disagreements I had was that they were not familiar with very fast systems like the Hyperstar, and I was not familiar with "bog-standard" i.e. the depressingly slow imaging that most conventional imagers suffer. Eventually we did iterate to some sort of agreeable conclusion and it all proved to be a very interesting exercise. I will try to get the main points across in a logical fashion, but it is a very confusing business.

Because you are using a very "fast" optical system, your sub-exposure times can be very short – this after all is the main selling point of the Hyperstar. If your sub-exposure times are very short, then your tracking doesn't need to be very precise and yet you will still get good round stars. Also, if your sub-exposure times are very short, then you will take a very large number of sub-exposures during your imaging session, and when you stack these together to form your final image it will have a very high signal to noise ratio and the image will be as smooth as glass! Excellent, that's just what we want, but it's not a win-win situation. I was surprised when a supernova hunting colleague of mine examined one of my Hyperstar images (composed of more than a hundred sub-exposures) and he said that although it was a very nice low-noise image, it didn't go particularly deep, i.e. it didn't pick up very faint stars or galaxies, and that he could go deeper with a similar aperture scope using a higher f#. He also used a longer sub-exposure time of course, that goes naturally with the bigger f#, but why could he image deeper than me even if I used a much larger number of sub-exposures? The answer really is just the sub-exposure time. I typically used short sub-exposure times of less than a minute and this basically limits how deep you can go. On Moonless nights with good seeing I could approach nearly two minutes for sub-exposures, but I was always fighting against the intrusion of sky glow and the associated problem of removing gradients from my images, as well as having the problem of saturating (and therefore losing information) bright parts of objects.

So the power of the Hyperstar is the ability to collect a large number of subs in a reasonably short time so that the resulting low-noise (high quality) image can be obtained in a matter of only an hour or two. However, if the discussion above is true, I am going to find I run into trouble when trying to image very faint objects and the speed of the Hyperstar will not help me much in these instances. Does this agree with experiment? The answer is yes it does seem to. I was very surprised to find that even with very long total exposure times I couldn't get the quality of image I was used to when imaging rather faint objects like the Crescent Nebula and the Jellyfish nebula – I was running into the problem of not being able to take long enough sub-exposures to image these faint objects without simultaneously increasing my noise level to the point where I didn't gain – because I was coming up against sky glow. I was starting to find the imaging limitations with the seemingly limitless Hyperstar system. A way around this problem, with the emission nebulae at least, is to take narrowband H-alpha images of the region and combine them with the RGB data. The narrowband filter will cut back the sky glow enormously allowing you to use much longer sub-exposure times and giving you a much greater contrast image at the H-alpha wavelengths. You could also image in this way with other narrowband filters and combine the different narrowband images to give a colour image of great depth. Many imagers follow this approach, and narrowband imaging is very popular, especially in regions with bad light pollution. Since you are only imaging one wavelength at a time with narrowband filters you can use higher resolution black and white imagers and there is no need to consider the one-shot colour cameras for narrowband filter imaging. You do however have a problem with trying to use these filters with the Hyperstar! The only place to put a filter in the Hyperstar system is the gap between the end of the Hyperstar and the CCD camera. Physically that is fine, optically it is not so good. The very fast Hyperstar optics means that the cone angle of the light rays passing through the filter is pretty sharp. Now you will find that interference filters have very good specifications for parallel light rays striking the filter surface perpendicularly, but that as the angle moves away from the perpendicular, then not surprisingly, the filter characteristic changes. This is why filter manufacturers often quote the lowest f# system you can use their filters with. Unfortunately, the f#1.85 Hyperstar is not particularly useful for working with narrowband filters, a filter specified with a bandwidth of 6nm would have a much greater bandwidth if used with the Hyperstar with the associated loss in contrast.

So how long were my typical sub-exposure times using the Hyperstar and the IDAS LP filter? If seeing conditions were average there was little to be gained in using sub-exposure times in excess of 60 seconds. Under good clear dark skies, a 90 second sub-exposure time seemed to work well for me. I saw no improvement in final image quality, or depth, if I used 120-second sub-exposure times for the same total length of time under good seeing conditions. However, these are parameters you must work out for yourself (experimentally) under your own local viewing conditions.

The Images

The majority of the full-colour deep-sky images presented in this book in Chapter 11 are from the Hyperstar setup, and many have been published in either "Astronomy Now" or "The Sky at Night" magazines. Details of the imaging parameters accompany the corresponding image. There are some images from the Sky 90 with the SXV-H9C camera included for comparison with the Hyperstar work. You will see that the Sky 90 with SXV-H9C colour CCD combination gives a 40% larger F.O.V. than the Hyperstar with SXV-H9C, and that longer total exposure times are required with the Sky 90 as it is a slower f#4.5 system. The very latest work was carried out using the Sky 90 at f#4.5 with the massive SXVF-M25C one-shot colour camera from Starlight Xpress. This combination gives a massive field of view of 2.22 x 3.33 degrees! Couple this huge field of view with 6-mega-pixel capability and you can appreciate the power of this imaging system.

CHAPTER NINE

Wide-Field Imaging with a Short Focal Length Refractor

A very popular combination used in DSO imaging is a long focal length reflector, usually a Schmidt-Cassegrain, with a good quality short focal length refractor piggy-backed on the reflector. This system allows high-resolution images of small objects, such as galaxies, to be taken using the reflector, and wide-field images of large nebulae to be acquired by the refractor. Clearly when the refractor is being used for imaging, the reflector is relegated to the role of guidescope which may appear a little perverse considering the cost of the "guidescope"! When the reflector is being used for imaging the piggybacked refractor is used in its "normal" mode as a guidescope.

There are a number of things to consider when choosing the imaging refractor, not least the added weight that you are going to put on your reflector's drive train. On the Nexstar 11 GPS I initially used a Celestron 80mm wide field telescope as a guidescope. At f#5 and weighing in at only 1.8kg this was an almost ideal telescope to use for guiding the f#1.85 Hyperstar. The extremely light weight meant that the 11 GPS barely noticed it was there, and f#7.5 guiding with f#1.85 imaging meant that standard deviations in both R.A. and DEC. were typically below 0.2 pixels throughout an imaging session. All this changes when a high-quality refractor is to be piggybacked for imaging.

For a number of reasons I chose to piggyback the Takahashi Sky 90 refractor for guiding and wide field imaging as shown in Figure 1.6. The native Sky 90 comes in at 3.2kg, has a 90mm objective lens, is a doublet, and has an f-number of 5.6. The Takahashi reducer/corrector brings the f-number down to 4.5, giving a focal length of 405mm and provides superb wide-field coverage. Add to this the fact that the reducer/corrector gives a nice clean field over a 35mm film frame and you can see that this is an imager to be reckoned with. The only slight negative is being a doublet rather than a triplet means that some very slight chromatic aberration must be suffered, though this is typically minimal away from very bright stars, or planets. At 3.2kg the Sky 90 is no heavyweight, but I still needed to add another 1.5kg counterweight and this made the counterweight look decidedly "clunky". Things were a little worse than just looking clunky however. On trying to autoguide the new system I found the autoguider couldn't handle it, the system simply wouldn't iterate to a stable control point, and this at first seemed very strange. I had of course re-balanced the telescope in the horizontal and vertical directions as previously described, so the balance was not in question. It was only when I looked at the telescope from the side that I saw a possible problem. The counterweight was sitting towards the front end of the reflector. Well, what does this matter if the whole thing balances nicely? It means that the counterweight lies quite some distance from the DEC axis bearings, so that there is quite an inertial mass sitting away from the DEC axis. I then pulled the counterweight back until it sat exactly underneath the DEC axis bearings and pushed the whole refractor assembly forward to regain balance. By manually pushing the system up and down in the DEC direction I could "feel"that the inertia around the DEC axis bearings had been considerably reduced! When I then tried to autoguide the system, once again things behaved normally and once again I had good control of the system. So please keep this in mind, there are in fact **three** things to take into account when balancing your telescope system:

1) Balance the system in the horizontal direction.
2) Balance the system in the vertical direction.
3) Make sure the counterweight lies directly beneath the DEC axis bearings (or as close to this position as possible) in order to minimise the inertia about the DEC axis.

As things were clearly becoming a little bit heavy for the 11GPS drives to handle I would suggest that somewhere around the 3.5kg is the maximum refractor weight you should consider mounting on a reflector such as the 11 GPS. This weight limit consideration automatically reduces the number of options of suitable refractors considerably.

What else do you require of the refractor? Well, you want the biggest objective diameter you can afford, bearing in mind the weight limitation, and you want the shortest focal length to get the biggest field of view. Taking all the parameters into account there are very few refractors that will actually fit the bill, but the Sky 90 is one that does the job admirably. It is also comforting to see that one of the World's finest amateur imagers, Steve Cannistra http://www.starrywonders.com/ uses a Sky 90 extensively for his work.

With the reducer/corrector fitted to the Sky 90 and a reduced focal length of 405mm, we now have a system with a shorter focal length than the 500mm of the Hyperstar, and thus we have an imager with a 40% bigger imaging area! This is clearly quite a powerful imager. However, let us not forget that the Sky 90 is an f#4.5 telescope whereas the Hyperstar was a very fast f#1.85 optic, so we can expect the sub-exposures, and total exposure time of the Sky 90 to be greater than those of the Hyperstar. This is the main drawback of all non-Hyperstar systems, they are incredibly slow by comparison, but, you gain a much bigger useful focal diameter, so you get perfect shaped stars across the whole field of view of a large CCD with little vignetting. This is then the “swings and roundabouts”compromise you have to consider between using these systems.

The Sky 90 being slower than the Hyperstar has several knock-on effects that you must consider seriously:

1) Your subs and total imaging time will be dramatically increased.
2) This means that the time required to image an object will now, more than likely, require several night’s work on the one object! So your rate of image production per year will decrease seriously from the production-line days of Hyperstar imaging.
3) The increased sub-exposure time means your autoguiding precision needs to be far greater than you were used to with f#1.85 imaging.
4) The increased sub-exposure time means that you will suddenly discover you have a great deal more hot pixels than you thought you had.
5) Dust doughnuts become a problem once again.

Let’s face it, low f-number imaging makes life very easy, and if you want an easy life you want a low f-number optical system. However, you may not want the large field of view that accompanies a fast system, especially if you want to take high-resolution images of small galaxies. So once again there are practical imaging issues to consider depending on the sort of imaging you want to do. This is why we often see the short focal length refractor piggy-backed on the larger f-number larger aperture reflector, using this combination you can address wide-field imaging and high resolution imaging of small galaxies using the one setup.

CHAPTER TEN

Basic Image Processing

Let me come clean before we even begin this Chapter – I am not an image-processing expert, in fact I just about get by. However, what you will learn from this section of the book should provide you with the basis of getting some very good-looking results from your hard won data. I will also give you the process by which I transform the raw FITS data into a file ready for image processing. This procedure is by no means meant to be definitive. I have found that it works well for me, but I am sure that there are better procedures to follow, and better ways of processing your images. There is however one very important observation I have made that should help you in getting the best out of your data and it is this: **there is no set processing sequence that you can apply for all your images**! You must treat every image as unique and worthy of its own special attention, because it is unique. The noise characteristics will be different from any other image you take, the background signal will be different, the light pollution (gradients) if any will differ, in fact just about every aspect of every image you take will differ from every other image in some subtle (or not so subtle) way. This inability to apply a "wrote procedure" for processing images is, I find, very annoying. It means there is no formal "scientific approach" to deep-sky image processing; it is very much a black art. This is fine if you are blessed with some artistic talent, and an eye for what looks good to the general public, and it is a curse if you are not so blessed. This is why you will find that an American collaborator based in Florida, Noel Carboni, has processed all but one of the deep-sky images in this book. Noel has probably used Photoshop on a daily basis for the past 10 years and therefore has more practical knowledge of the use of this package than I can ever achieve. He has also created a set of "actions" to be used in conjunction with Photoshop that allows the user to run complex sequences of image processing functions at the click of a mouse button. For example, a couple of mouse clicks will remove background light pollution effects (gradients) by setting off a sequence of Photoshop actions that effectively create an inverse background which is subtracted from the light polluted background to give a final resulting flat background. Digital image processing is the present day equivalent of yesterday's photographic darkroom. It is in this digital dark room that your hard won images are turned into awesome works of art, or are effectively destroyed! It is an unpleasant fact of life that the image processing side of deep-sky imaging is every bit as important as getting the photon data in the first place.

Creating the Image Processing File

You have finished your image session and you have brought the valuable sub-exposure data indoors to be processed into a wondrous deep-sky image. There are a number of hurdles to be overcome before we end up with a pretty picture. The first thing to do is to convert your individual FITS sub-exposures into IEEE floating point format using Maxim DL's "Batch Save and Convert" routine. This step is not entirely necessary if you do not have the software to carry out the conversion. You now need to convert the files to colour RGB files. Assuming you have the SXV-H9C (or similar) one-shot colour camera, you run the "Convert RGB" function as a batch conversion using the "Command Sequence Window". The Command Sequence Window allows you to convert all your subs into RGB frames using the Convert RGB command. For the SXV-H9C camera you need to have both the X-offset and the Y-offset boxes ticked in the Convert RGB dialog, you will also use the "High Quality" deBayer mode. If you are using the SXVF-M25C camera you will only need the Y-offset box ticked, but you will still use the High Quality deBayer routine. Having created a set of RGB colour-converted FITS files from your sub exposures, you now put all these files into their own separate folder on your computer for further processing. Using your acquisition/processing software, open up each of the RGB converted subs in turn and check them out carefully for defects, you may want to screen stretch the data just to see if there are any problems lurking in the shadows. With Hyperstar/H9C data I delete all subs that have say a satellite trail, a plane trail, a download glitch, or a movement glitch (uncompensated PEC glitch). I am told that this is unnecessary as the Sigma combine process will remove the satellite and plane trails, and the download glitches, but once again, I have personally never found this to work in practice, so I take the easy option and I delete the offending files. I cannot afford to throw away sub-exposures so easily with the Sky 90 M25C combination, as there are far fewer of them in an imaging session due to the longer sub-exposure times I must use. For this data, I bite the bullet, and spend a lot more time during the image processing stage removing all these annoying defects. You may also have some subs with poor, or no data, due to clouds. Again, these files should be deleted. If your subs are say 5 minutes each, then it can be a wrench deleting any of them as you feel you are throwing away something valuable. You feel that if there is 5 minutes worth of data there, even if it is not top quality, then surely it is worth adding in. It is not worth adding in! All sub-optimal data will actually detract from the quality of the final image, which is why I prefer to go to shorter length subs (so there is less chance of an unwanted glitch occurring during the sub-exposure), and you don't lose so much valuable imaging time in deleting shorter exposure subs. Finally of course the signal to noise ratio of your final image improves as the square root of the number of subs you take, so a larger number of shorter subs is in my opinion the best route to take (though many experienced astrophotographers will disagree with this approach). It is true that using a larger number of shorter sub-exposures will lead to a "shallower" image, but does it really matter that your image's limiting magnitude is 20 rather than 21? Usually it does not.

So you now have a file containing all your high-quality (i.e. sifted) RGB converted FITS files, the next step is to combine all these separate files into a single file. To do this you use the "Combine Files" function of your acquisition/processing package. I prefer to use the SD mask combine, although many experienced astrophotographers use the Sigma combine. Having created this single large combined file, my combined files tend to be around 16.5Mb in size using the SXV (F)-H9C camera; you are now ready to start processing the data.

To summarise, for the H9C camera:

1) Convert the raw 2.76Mb FITS data files (the sub-exposures) into IEEE floating point format files using "Batch Save and Convert"
2) Convert the 5.52Mb floating point files into RGB colour-converted files using "Convert RGB" and the "High Quality" deBayer routine. Remember to check both X-offset and Y-offset for the SXV (F)-H9C camera, other cameras may need different combinations of offset checked.
3) Check each colour-converted file to see if there are any defects in the image, if there are delete the image.
4) Combine the remaining 16.5Mb RGB files into a single 16.5Mb file using either the SD mask or the Sigma combine function.

For the M25C camera I take a slightly different approach.

1) Colour-convert the raw 11.6Mb FITS data files (the sub-exposures) into RGB files using "Convert RGB" and the "High Quality" deBayer routing. The Y-offset box should be ticked. Each RGB colour-converted file will now be 34.9Mb in size, these are getting rather large!
2) Check each colour-converted file and delete any that have defects that you feel you cannot fix in the processing software.

3) Combine the remaining individual 34.9Mb files into a single IEEE floating point file using either the SD mask or the Sigma combine function. The resulting single file will be 69.9Mb in size.

Processing the Combined File Dataset

There are many good tutorials and some books available on processing your astronomical images. I have Jerry Lodriguss' "Photoshop for Astrophotographers" and I also check out Rob Gendler's http://www.robgendlerastropics.com/ processing tips, as well as Steve Cannistra's http://www.starrywonders.com/ on a regular basis. Ron Wodaski http://www.newastro.com/wodaski/ also has some very nice image processing tutorials on his website.

However, when all is said and done, there is no substitute for getting the colour-converted raw image into an image-processing package and simply having a go at some digital image processing. There are probably more than 3 "Golden Rules", but I find these three must be adhered to at all times.

Golden Rule number 1:
Do not clip the light point.

Golden Rule number 2:
Do not clip the dark point.

Golden Rule number 3:
When (nonlinearly) stretching your data using "curves" to bring out the faint stuff – use the "Magic Curve".

I think the only way to see how to use the available tools is by practical example. So you will be able to download some raw data and try these things out for yourself. Be advised, the data I will provide you with isn't too bad, so you will not be plagued by gradients or terrible vignetting in these examples, I don't want you to be scared off too early : I will also supply you with two basic processing routes, the first a "cheap and cheerful" i.e. reasonably quick route that will give good overall results without using Photoshop at all, but it will result in non-optimal stars. The second route will be a little more "formal" using Photoshop for all the main digital image processing and which will end up with a better overall result. Lastly, we shall have a try at putting together a 5-frame Hyperstar mosaic!

Before getting on with the practical work I should say that the consensus of opinion is that you should get your stacked image file out of the acquisition package (Maxim DL or AstroArt) and into a "proper" processing package such as PhotoShop as quickly as possible. In other words, any pre-processing (beyond colour-conversion and stacking) should be minimal or even zero in the non-PhotoShop packages. Having looked at the alternative processes quite extensively, I have to agree with the consensus opinion on this occasion. That being the case, this first "quick and dirty" processing routing is really only for initial practice, and to get an image out as quickly as possible with minimal effort. It is not recommended for creating an astronomical work of art.

A "Quick" Process of a Single Frame of the Pleiades

This first example will use stacked, colour-converted data from a single Hyperstar frame of the Pleiades. Please download the unprocessed .jpeg file from http://img156.imageshack.us/my.php?image=frame270filessdmaskcropbi9.jpg where you will find an unprocessed image of Merope and its associated nebulosity as the central part of the frame. This image is made up from 70 sub-exposures of 1 minute per sub taken with the Hyperstar/SXV-H9C combination. Having a reasonable number of subs means the final stacked image will have a pretty good signal to noise ratio, although the image may not go that "deep". However I think you will find the image does go fairly deep, as a faint galaxy [PGC1396, mag.17.89] will appear towards the top right hand corner of the frame as you process the image.

Having downloaded the file from the "Image Shack" site, and saved it into a folder on your computer, now open the file in Maxim DL using File/Open. Zoom out once using View/Zoom Out so that you can see the whole frame on your screen.

What we are going to do with this image is to split it up into separate Luminance (L), and Red (R), Green (G), and Blue (B) files. We will then do a little image processing on the L file only before recombining all four files back into a colour image.

With the Pleiades file opened up in Maxim DL, go to Colour/Convert to Mono and click o.k. Save the monochrome image to a new file with the filename ending in MONO.jpg so that you can remember what it is. Minimise the file. Now open the original Pleiades file again and this time split it up into its RGB components using Colour/Split Tricolour and click o.k. You will get three monochrome images appearing on the screen, which are the RGB channels of your data. Minimise these three files. Maximise the MONO.jpg file. We shall now use just button clicks to bring out the faint nebulosity. Go to Filter/Digital Development/FFT – Low Pass/Mild and click o.k. This process will carry out a Fast Fourier Transform low-pass filtering of the data, which will pull out the faint parts of the data (the nebulosity) without completely blowing out the bright parts (the stars). Save this processed file as _MONO_FFT.jpg and open up the Screen Stretch window – View/Screen Stretch. Pull the left tab (red) to the far left and move the right hand tab (green) to about three-quarters of the way along to the right. You will see that the DDP filtering process, like magic, has brought out all the faint nebulosity. We now need to reform the colour image by recombining the LRGB files.

Go to Colour/Combine Colour – conversion type is LRGB, conversion colour space is RGB, tick allow resize and tick Bgd Auto Equalize. Put your _MONO_FFT.jpg file into the Luminance box and put the RGB files into the Red, Green and Blue boxes and click o.k. Save the file as Pleiades_RGB_process.jpg. Close Maxim DL and open up PaintShopPro. Open up your RGB process file within PaintShopPro, go to Effects/Automatic Contrast Enhancement/Darker, Mild, Bold and click o.k. Save this file as Pleiades_RGB_process_PSP.jpg and you're finally done with this cheap and cheerful process.

Figure 10.1 shows the raw unprocessed data, in 10.2 the DDP processed luminance file, in 10.3 the recombined LRGB file, and in 10.4 the final processed image. I have not cloned out any hot pixels, lens flare or other defects in this simple process. You can take the processing of this image further by doing that, and by carrying out some noise reduction as well as some further contrast enhancement.

PhotoShop Processing of the Pleiades Data and Use of Noel Carboni's Actions

Before we begin there are two things about PhotoShop and astronomical imaging processing. One, PhotoShop is plain scary, it looks big and intimidating and it is big and intimidating. Some people can have a day job based on the fact that they can run PhotoShop – it's that big. The second thing we need to know is the shape of the "Magic Curve" mentioned in the Golden Rules. We shall use a nonlinear stretching routine in PhotoShop called "curves" to pull out the faint stuff in the same way that we used the DDP FFT function above in Maxim DL. However, you need to get the shape of the curve you are going to use correct, or you will blow up the stars as well as bring out the faint stuff, this is where the "Magic Curve" comes in. The shape of the curve can be seen in Figure 10.5. The steep rise at the beginning of the curve is what we are using to bring the faint detail out of the darkness. We then use a second point on the curve (by clicking and dragging on the curve) to start bringing the curve over from its steep initial rise. We then finally add the last long straight section using a 3rd point on the curve, which keeps the star blowout under control. I believe this last part of the curve called "the long straight ride home" is due to Ron Wodaski.

With those preliminaries taken care of, let's try and get a reasonable looking image using the image processing power of PhotoShop and Noel Carboni's PhotoShop actions http://actions.home.att.net/Astronomy_Tools.html alone. I recommend you save the image file you are working with after **every** step as you proceed with the processing so that you can easily backtrack, or take different routes at any stage to see what happens.

Open up the original Pleiades file in PhotoShop, and click on Image/Adjustments/Curves. Drag the curve into the Magic Curve shape shown in Figure 10.5 and note as you do so that the nebulosity brightens up without losing control over the star brightness. Make sure you also have the all-channels histogram open, Window/Histogram/RGB so that you can keep an eye on the luminance channel as well as the individual RGB channels. Remember the Golden Rules at the beginning, we don't want clip the black or white ends of the histogram data, clipping loses you information, and you will see clipping if your dark data ends in a sheer vertical wall rather than a steeply falling curve.

Next we are going to carefully adjust the levels. Go to Image/Adjustments/Levels and note that you get a luminance histogram in this window too (it's that important!). Adjust the black level by moving the left hand pointer slightly to the right to where the data is about to rise steeply, keep a close eye on the histogram to make sure you do not "clip" any data. Do not touch the right hand (white point) pointer, but instead move the centre (gamma) pointer slightly to the left to brighten up the whole image a touch. When you are happy with your level (linear stretching) changes, click o.k. and save the file again.

The colour looks a little washed out. Go to Image/Adjustments/Hue/Saturation and increase the saturation by 20% and click o.k.

You will see some lens flare and a few hot pixels (maybe the odd green star too) in the image that you wish to "clone out". Click on the Clone Tool (the one that looks like a rubber stamp) with mode normal, opacity 100% and flow 100% and with a brush size to suit the object you wish to remove. At this point it is worth zooming in a couple of times [View/Zoom In] so you can see what you're doing. To grab a piece of the background that you want to place over the defect, hit the Alt button and simultaneously left-click – this will "pick up" what's behind the cursor. Now move the cursor over the defect you wish to remove and left click – the defect is now buried beneath the piece of background you picked up elsewhere. It clearly makes sense to pick up the background in a region as close as possible to the defect so that it all merges in nicely afterwards. Proceeding in this way, clone out all the defects that you find detract from the image – remember, this is not scientific work, this is creating a pretty picture, and you cannot use this image for "scientific" purposes.

We like to be able to concentrate on nebulosity and not have stars overpowering the image – time to use some of Noel Carboni's actions. Simply click on Make Stars Smaller, and then click on Make Stars Smaller again.

The curves process has brightened things up, but also shows us quite a bit of noise in the image. Click on Space Noise Reduction followed by Deep Space Noise Reduction. Next click on Enhance DSO and Reduce Stars.

I now want to darken things down a little in a controlled way, so first apply the "lazy S" curve as shown in Figure 10.6. Now go back into levels and move the gamma point slightly to the right making sure, once again, that you don't clip the black point at all.

Finally apply the "downward curving bow" curve as shown in Figure 10.7 to finish off processing this image. Your image should look something like that shown in Figure 10.8 which I hope you find reasonably satisfactory.

Remember, this is all very basic stuff and over time you will refine these basic steps to fulfil your own needs. We haven't removed light pollution, or colour gradients from this image, but using Noel's Tools these are simple one, or two-step operations anyway.

Please find here http://img141.imageshack.us/my.php?image=ngc1977both datasetssdmaut6.jpg some rather nice data for the Running Man nebula (NGC1977) in Orion taken with the Hyperstar and the SXV-H9C one-shot colour camera. Use a combination of PhotoShop and Noel's actions to see if you can turn Figure 10.9 into Figure 10.10. I took 28 steps to get this result – happy processing.

Forming a Mosaic

The last basic thing I would like to show you to do is how to create a mosaic. If your field of view is just too small for the object you would like to capture, then one way of imaging the object is to create a mosaic of the region by taking several frames and stitching them together. I shall tell you about my "4-frame mosaic" technique that allows you to do this easily. Another reason for creating a mosaic is to get a high-resolution image of a region by stitching together several lower resolution (overlapping) images. If you simply "cheat" by getting the whole region in your field of view by working at shorter focal lengths, then your resolution (arcseconds per pixel) will suffer accordingly. By working at longer focal lengths you can keep a good resolution in terms of arcseconds per pixel, and image an object larger than your field of view, by forming a mosaic.

To get a good mosaic of the region you're after takes quite a bit of preparation. You will need to use planetarium software, or wide field images taken by someone else (again, Davide de Martin's SkyFactory site is invaluable for this purpose) to plan how you are going to take your mosaic images. Remember, you will need to overlap the edges of your images to some extent so make sure you don't go "right up to the edge" when moving on to your next frame, or the software will have nothing to work on when it comes to matching one frame's stars with the next frame's stars. I have a very simple method to make sure I will get overlapping frames for a mosaic. Having checked the planetarium software to see what an overlapping 4-frame mosaic will look like, I carefully note what star pattern or object appears in the centre of the 4-frame region. When I go out to image, I place the same object or star pattern dead centre in the field of view. Now if I am to take a 5-frame mosaic for the Hyperstar, this will form the first frame. I shall explain a little later why I take 5-frames for the Hyperstar/H9C, and 4-frames for the Sky 90/M25C. Now having taken this first frame, move the object or star pattern that is currently in the centre of your frame to just inside the top left hand corner of the field of view, and take the next frame. Continue the process by moving the object to the top right, bottom right and bottom left of the field and taking frames. If you have the object sufficiently inside the corners of your field of view, you are guaranteed that your images will overlap sufficiently to make a mosaic at the end of the process. If your imaging system gives good-shaped stars right the way across the field of view, then you will only need to take the 4-frames as described above, you won't need the central frame. As you will recall, even a well-collimated Hyperstar gave slightly dodgy stars at the corners of the field, so it is not a good idea to take just a 4-frame mosaic as each frame will have poorly-shaped stars right at the corner of the field of view and these will be obvious in the final mosaic right in the centre of the image, precisely where it is most noticeable! By placing the 5th frame in the centre of the field of view you overcome the poorly shaped stars that would have been grouped near the centre of the image during the mosaic forming process. We shall now put together a 5-frame Hyperstar mosaic by following the procedure below.

First download your data files from the following locations:

http://img241.imageshack.us/my.php?image=pelican1zy1.jpg
http://img241.imageshack.us/my.php?image=pelican2yf1.jpg
http://img241.imageshack.us/my.php?image=pelican3mv3.jpg
http://img241.imageshack.us/my.php?image=pelican4mk5.jpg
http://img241.imageshack.us/my.php?image=pelican5ui2.jpg

These are the 5 files you will need in order to assemble a 5-frame Hyperstar mosaic. Each file (frame) is approximately 50 sub-exposures of 40 seconds per sub. I worked right through the night one summer's evening to get this data, and I've only done two "all-nighters" since I started imaging. The second all-nighter was on M31 when I first got the M25C camera. The individual subs have been colour-converted and stacked, and that is all, no other processing has been carried out.

Start up Maxim DL and open up the 5 NGC7000/Pelican files as listed above. Zoom out on each file twice so that you can see all 5 frames on your monitor at once. Each frame will need to be very slightly cropped and then mirrored to get the right orientation. Open up the Screen Stretch window and move the white (right hand) pointer to the left to brighten up one of the images so you can see what you are doing. Depending on the frame you are working on, you may see a thin black line along one or more edges of the image that will need cropping out. Click on Edit/Crop and alter the box size so that it sits just inside any black edge. Do not make the box too small or you will not be able to overlap the images at the mosaic stage. When the box is the correct size click o.k. to crop the image and the click Edit/Mirror to mirror the image. Save this cropped and mirrored frame under a new filename to work with later. Now carry out exactly the same procedure on the other 4 frames.

You now have the 5 frame of a 5-frame mosaic all neatly cropped and correctly orientated. Move the frames around on your monitor so you can see what the final mosaic is going to look like. Frame 1 is central, Frame 2 is top-left, Frame 3 is top-right, Frame 4 is bottom-right and Frame 5 is bottom-left. Each frame is a little less than the full 1392 by 1040 pixels as we cropped a bit off the edges. Your screen should now look like that shown in Figure 10.11.

The next thing we need to do is equalise the stretching of all the frames so that we can match them together more easily. I have found that it is usually best to select the dimmest frame of the mosaic as the reference image in this process, which in this instance is Frame 2. Click on Frame 2 to select it and then click View/Equalize Screen Stretch.

In creating the mosaic we first need to form the background onto which we are going to paste the individual frames. Click File/New. Give yourself plenty of room to work with, choose width 3,500 and height 2,500 and choose Image Color Type/Color, then click o.k. Move the frame positioners at the edge of the screen to their mid-positions so that you can work out from the centre of the mosaic. Now click Edit/Mosaic – and this is where the fun really starts!

Background equalisation should be auto, choose blend area 50, XY step 1, and change Angle Step to 0.1, and tick Frame Active Tile. In the top box make sure you have Frame 1 selected; click Place, followed by Blend. Now we need to place the next frame in position. Put the second frame name in the top box of the mosaic menu and then click Place. The second frame will be put down over the first frame. Place the cursor over the new frame and left click-and-drag the frame into as good a position to match the stars on the first frame as you can manage. You will find that some stars are just about spot-on, but as you move away from these well-matched stars you will see the field is rotated – don't worry! Click Snap and all the stars should now overlap nicely, click Blend to finish. Don't worry if there is a big change in brightness of the image, that's just the software matching the two frames. Add the other 3 frames to the mosaic following exactly the same procedure as above. When you have finished assembling your mosaic click Close. Zoom out twice to see the result of your work; it should look like the screen dump shown in Figure 10.12. Save this file under a new name and carefully crop around the ragged edge to make it look neat. Save this cropped image and then close the 5 original frames **without** saving the changes, which were the screen, equalise stretches we applied at the beginning.

You now have a basic 5-frame mosaic of the NGC7000/Pelican region as shown in Figure 10.13, which you can open up in PhotoShop, or your own image processing package, for final processing. Eventually you should end up with something looking like Figure 10.14.

That exercise concludes this section on basic image processing. I hope that I've provided you with enough information to at least get started. You can now begin to appreciate the effort involved in getting a nice mosaic together; it is not a trivial task. You will also see in Chapter 11 that the Sky 90/M25C gives a bigger field of view in a single frame than the 5-frame Hyperstar/H9C image we just created! Sometimes life just isn't fair:

Figure 10.1. The raw unprocessed Merope nebulosity data.

Figure 10.2. The DDP processed luminance image.

Figure 10.3. The recombined LRGB image.

Figure 10.4. The final processed image of the Merope nebulosity.

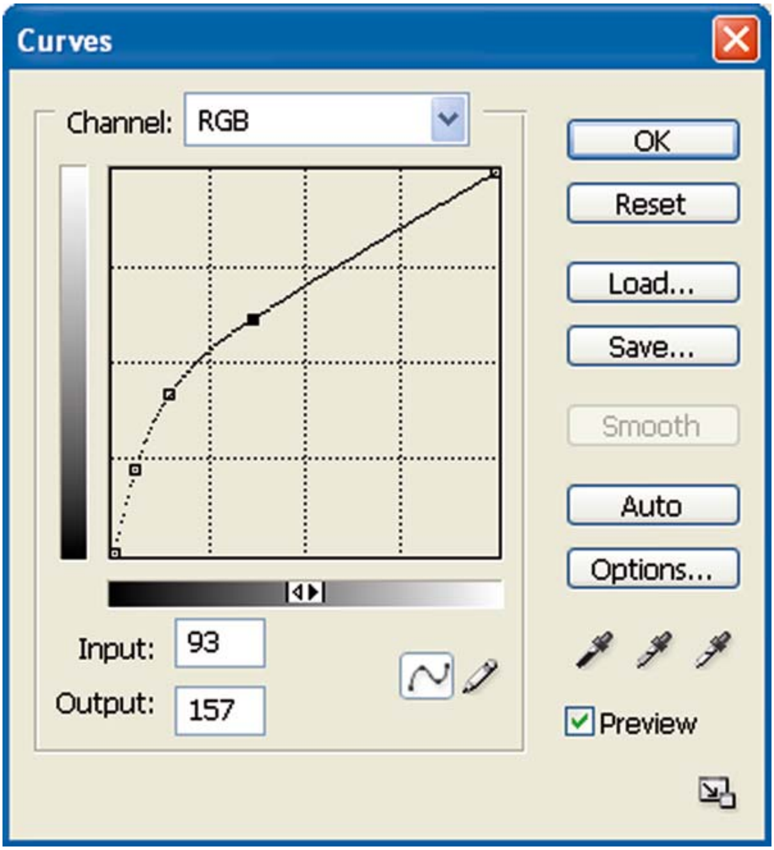

Figure 10.5. The shape of the "Magic Curve".

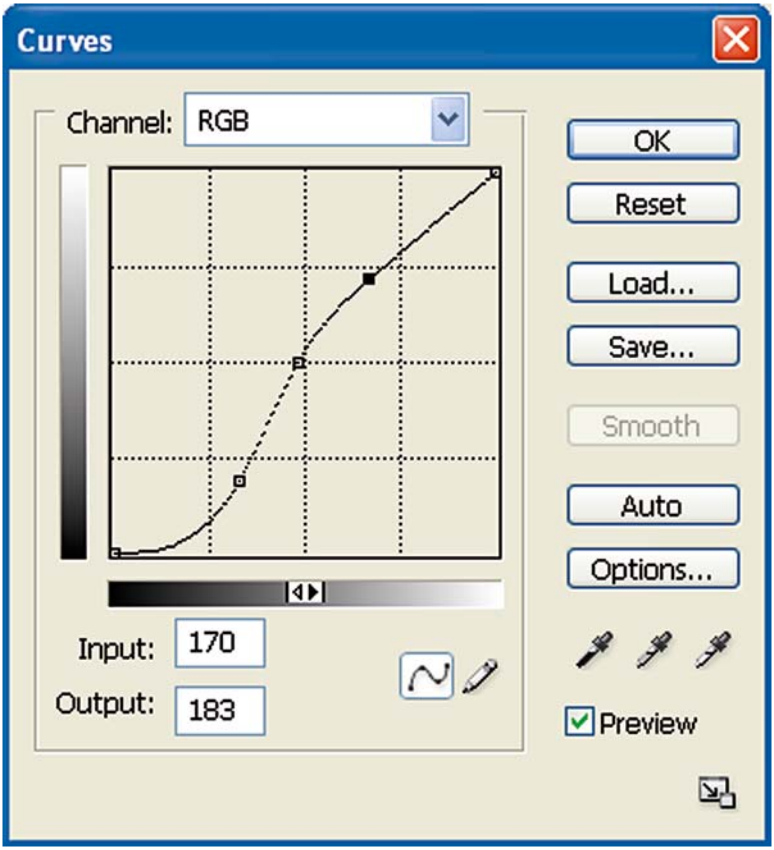

Figure 10.6. The "Lazy S" curve.

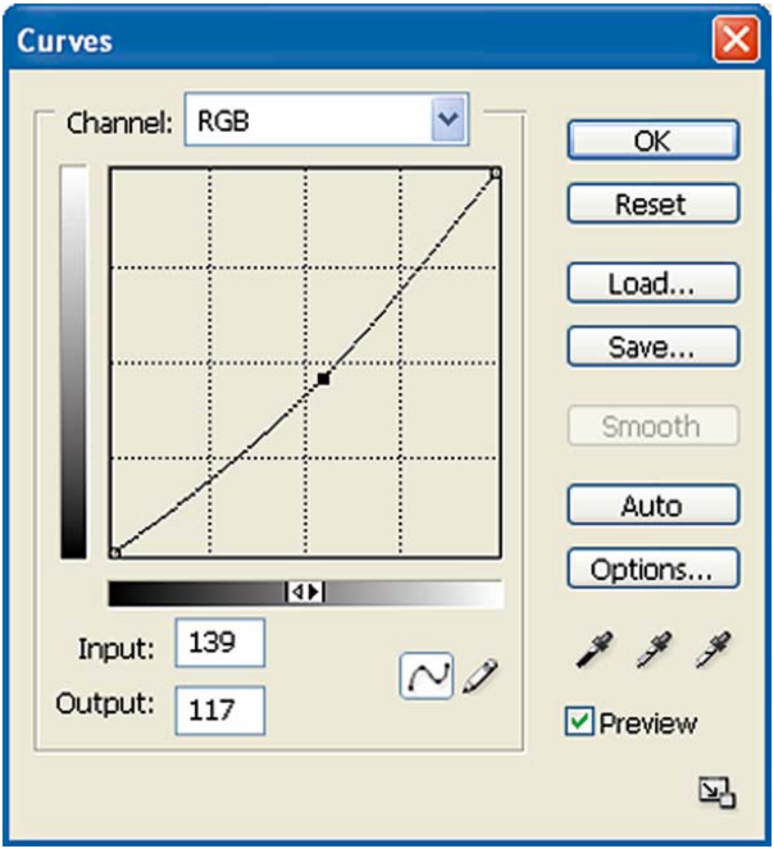

Figure 10.7. The "Downward Bow" Curve.

Figure 10.8. The Merope nebulosity processed in PhotoShop.

Figure 10.9. The Running Man nebula, basic raw data.

Figure 10.10. The Running Man nebula, processed in PhotoShop.

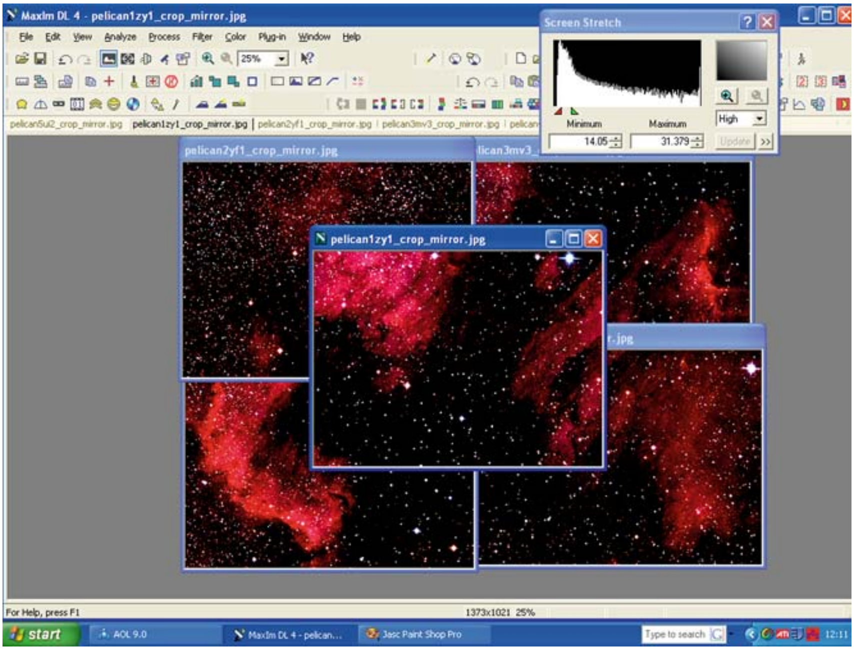

Figure 10.11. Five raw data frames ready to form into a mosaic.

Figure 10.12. The uncropped and unprocessed 5-frame mosaic.

Figure 10.13. NGC7000/Pelican 5-frame mosaic cropped and ready for processing.

Figure 10.14. The 5-frame mosaic of NGC7000/IC5070 processed using PhotoShop.

CHAPTER ELEVEN

The Deep-Sky Images

This Chapter is unashamedly the "pretty picture" Chapter of the book. Its aim is three-fold. One is to show you what can be achieved in a relatively short amount of time, if you are able to commit serious effort to the hobby. Two is to inspire you to go out and do this for yourself, and to amaze your friends with these beautiful "Starscapes" that are on show every night of the year (even if most nights they are beyond the clouds). And finally it is to make yourself think, "Well, I reckon I can do better than that", which would be really great.

I recently appeared on a B.B.C.1 programme called "Inside Out" presented by Chris Packham, and the inevitable question came up - which is my favourite image? This doesn't take much thought for me, although it is not the technically "best" or "most difficult" shot of the lot, for other reasons the 3-frame Hyperstar mosaic of the Horsehead nebula region is my favourite. Why should this be so? For a number of years I had the most amazing picture of the Flame and Horsehead region as Wallpaper on my processing computer. I used to look at this wonderful image on a daily basis and think to myself, "I will never, ever, be able to take an image as good as that!" The truth is, the 3-frame Hyperstar mosaic in this book is, in my opinion, a little better overall than that wallpaper image I drooled over for so many years. I didn't think it was possible, but everything came together on the few nights it took to take the data, and you can see the results for yourself. It's this sort of thing that spurs me on, so it would be great if someone reading this book felt the same about the images in this Chapter, and then went out and did **better** themselves - I would then feel this book has done its job:

Figure 11.1. Single frame Hyperstar image of Albireo. Possibly the most beautiful double star in the Northern hemisphere is Albireo in the constellation Cygnus, the Swan. Albireo forms the "tail" of the Swan, and Deneb forms the "head". Particularly nice are the very distinctive colours of the double, the blue and orange making a very striking contrast with one another. This Hyperstar image is composed of 76 sub exposures with 25 seconds exposure time per sub, and it shows what a striking image a single (or double) star can make as the main subject.

Figure 11.2. Single frame Hyperstar image of Aldebaran. Beautiful Aldebaran, the eye of the bull in Taurus, seemingly glowing red/orange even to the naked eye (it is so bright). Only 60 light years away this is the 14th brightest star in the sky (omitting the Sun). This image is composed of 30-second subs totalling approximately 45 minutes.

Figure 11.3. Single frame Hyperstar image of the "Thundercloud" region between M43 and NGC1977 in Orion. The turbulent "thundercloud" region lying between M43 and the Running Man fascinates me. So, in order to see this area more clearly I took this very long total exposure of the region. This image is a single Hyperstar frame using 204 sub exposures at 50 seconds per sub, which represents a total exposure time of just less than three hours; quite a lot for the "fast" Hyperstar system! See how extensive the dark nebulosity is in this image, blotting out all the stars in the perimeter regions away from the emission nebulae. Not a beginner's target, but certainly within the capabilities of a second season imager.

Figure 11.4. Single frame Hyperstar image of the Cocoon Nebula in Cygnus. The Cocoon nebula [Caldwell 19] in Cygnus is an emission nebula whose beauty is enhanced by the surrounding dark nebulosity, and the fact that the whole object sits in the Milky Way, so it is surrounded by a very high density of stars. This object is relatively bright and makes a reasonably good target for the beginner. The distance to this nebula is 3,300 light years, and the nebulosity is about one-sixth of a degree in diameter.
This is a single Hyperstar frame consisting of 159 sub exposures at 55 seconds per exposure giving a total exposure time of nearly two and a half hours.

Figure 11.5. Two-frame Hyperstar mosaic of the Coma Cluster of galaxies in Coma Berenices. Sitting below the handle of the plough (Ursa Major) is this glittering region full of galaxies. In the image everything that is not obviously a star (i.e. all the orange/brown "faint fuzzies") are galaxies. For galaxies, this is definitely one of the densest regions in the sky. Look at the two large elliptical galaxies towards the centre of this image – the giant elliptical galaxy on the left is NGC4889, 300 million light years distant and 240,000 light years across (about two and a half times the size of our own Milky Way). The elliptical galaxy on the right is NGC4874.
The 2-frames were made up from 83 subs per frame at 30 seconds exposure per sub.

Figure 11.6. Wide field refractor image of the Cone Nebula & Christmas Tree in Monoceros: It is appropriate that this is a winter object often imaged during December. The Christmas tree and Cone nebula region is very pretty emission/reflection nebulosity with an open cluster lying in Monoceros, just north of the Rosette nebula. Towards the bottom left of this image you can also see Hubble's variable nebula, and centre-bottom that nice little golden open cluster I had trouble identifying, Trumpler 5 (or OCL494, or Collinder 105). This image is composed of 37 subs at 6-minutes per sub using the Sky 90 refractor and M25C camera.

Figure 11.7. Single frame Hyperstar image of the Crescent Nebula in Cygnus. The Crescent nebula is an extremely faint emission nebula in the constellation Cygnus. In order to get the fine filamentary structure within the bulk of the nebula requires extreme measures, very long exposure times, and if possible narrowband-imaging using an H-alpha filter. This is therefore definitely not a beginner's object.
The Crescent nebula [NGC6888, Caldwell 27] lies at a distance of about 4,700 light years. Why are there so many stars seen in this image? This is because it is not only a very long exposure, but also that the Crescent lies in the star-rich Milky Way. This emission nebula has its material thrown out by the Wolf-Rayet star HD 192163 you can see within the nebulosity itself. This image consists of 3 hours of RGB data and 2 hours of H-alpha data. The RGB data used 90-second subs and the H-alpha data used 200-second subs. You can see from the final image that it could have easily used a great deal more exposure time both in the RGB and H-alpha data – and that's with a Hyperstar!!!

Figure 11.8. Two-frame Hyperstar mosaic of the "Cygnus Wall" region of the North America nebula in Cygnus. This is the "Gulf of Mexico" region of the massive North America nebula [NGC7000, Caldwell 20], also popularly known as the "Cygnus Wall". This huge HII region in Cygnus lies quite close to the bright star Deneb see next image), and is at a distance of 1,800 light years from us.
The image is a two-frame Hyperstar mosaic of the region with each frame being a total exposure time of 1 hour using 60-second subs.

Figure 11.9. A single frame Hyperstar image of Deneb. The brilliant star Deneb in the constellation Cygnus is one of the Summer Triangle of stars, together with Vega and Altair. Deneb shines at magnitude 1.25 and is at a distance of 1,500 light years. The single frame Hyperstar image of Deneb was taken in June 2006 and is made up from 73 sub exposures with an exposure time of only 20 seconds per sub.

Figure 11.10. A wide field refractor image of the Double Cluster in Perseus using the SXV-H9C camera. NGC869 & NGC894 are a magnificent pair of open clusters in the constellation Perseus. Also known as Caldwell 14, the 14th entry in Patrick Moore's list, the Double Cluster in Perseus is one of the most amazing sights in a pair of low power binoculars. This image does no justice to the view in even very modest optical instruments – "diamonds in black velvet" is the term most often used for these celestial gems. These objects do not form part of the Messier catalogue, so he must have considered them most un-comet like! The Double Cluster lies at a distance of 7,300 light years.This image was acquired using the Takahashi Sky 90 at f#4.5, and the diffraction spikes are therefore software generated! The whole image is a mixture of 30second and 120-second subs with a total exposure time of 137 minutes.
If your optical system can capture the whole field, then this is a nice object (pair of objects) for the beginner. It does seem very hard to process however, and to be honest, however good the processing, the final image never seems to look as good as the view you get through the eyepiece!

Figure 11.11. A single Hyperstar frame of the Flaming Star nebula in Auriga. The beautiful Flaming Star nebula [Caldwell 31, IC405] lies at a distance of 1,600 light years in the constellation Auriga. This image shows the bright red emission nebulosity together with bright blue reflection nebulosity. Towards the right is a fainter vertical bar of emission nebulosity that continues quite a distance below the field of view. There is a strange story behind AE Aurigae, the very bright star in this image that is lighting up the nebula. Apparently this star was thrown out of the Trapezium (core) region of the Great Nebula in Orion some 2.5 million years ago, so AE Aurigae is just "passing through" IC405, and perhaps in another 20,000 years time the Flaming Star nebula will "go out" as AE Aurigae continues on its journey through space. This single frame Hyperstar image consists of 86 sub exposures of 70 seconds per sub.

Figure 11.12. Wide field refractor (with M25C camera) image of the Horsehead nebula region in Orion. The massive 3.33 by 2.22 degree field of view of the Sky 90/M25C camera combination really pays off in images such as this. More details about the Horsehead nebula can be read in Figure 11.28, but this image consists of only 22 sub exposures of 5 minutes per sub, so the result isn't too bad for a fairly "slow" f#4.5 system.

Figure 11.13. Single frame Hyperstar image of the Iris nebula in Cepheus. NGC7023, also called Caldwell 4, or the Iris nebula in Cepheus is beautiful reflection nebulosity. Its dimensions are given as only 10 by 8 minutes of arc, where 60 minutes of arc is one degree. But now look carefully at the image and notice that there is a huge clover-shaped dark nebula region surrounding the Iris itself, bringing out the colour, and greatly extending the boundaries of the nebula itself. Given that the distance to the Iris nebula is about 1,400 light years means the diameter of the dark nebulosity is something in the order of 4 light years, or basically the distance to the nearest star beyond our Sun!

This single frame Hyperstar image comprises 160 sub exposures at 40 seconds per sub giving a total exposure time of just over one and three-quarter hours.

This object is very faint and a difficult one to image, it is not recommended at all for the beginner.

Figure 11.14. A two-frame Hyperstar mosaic of the Leo Trio of galaxies. This is a very famous galaxy grouping in the constellation Leo. In the U.K. "galaxy season" is during the springtime when the Leo/Virgo galaxies are in the best position for imaging. NGC3628 is a large edge-on galaxy separated from the other galaxy pair, and you can clearly see the dark dust lane running through its centre. Messier 65 is a spiral galaxy lying at a distance of 24 million light years, and M66 which has the appearance of Mother-of-Pearl is another spiral galaxy lying 21.5 million light years away.
This is a 2-frame Hyperstar mosaic with the NGC3628 side of the image composed of 74 sub exposures at 90 seconds per sub, and the M65/M66 side composed of 71 sub exposures again at 90 seconds per sub. The total imaging time for this picture was therefore just over three and a half hours. This is rather a long total exposure time for the Hyperstar and shows that this grouping is rather faint, as well as occupying a large region of space. It is therefore not recommended as a beginner's imaging object.

Figure 11.15. A single frame Hyperstar image of the incredible Great Globular Cluster in Hercules. Globular clusters and open clusters are relatively bright objects and are very good subjects to begin your imaging career as they are relatively easy targets. Also, being bright, you can image these objects successfully even if the Moon is up, provided the Moon is not too full, or too close to your target cluster.
Messier 13 is rated as the finest globular cluster in the Northern Hemisphere, and it certainly makes a stunning sight in any reasonably sized telescope. I can clearly recall the awe I felt when I saw this object for the very first time through the Nexstar 11 GPS scope with a binocular adapter and 32mm eyepieces, and I still feel the same way every time I look at it! This immense globular cluster lies in the constellation Hercules at a distance of about 23,400 light years and it contains around half a million stars. This is yet another naked eye object, where good viewing conditions will reveal a faintly glowing ball of light. Note the bright galaxy NGC6207 towards the top left of the image.
This image is a single Hyperstar frame using 10 and 30 second sub exposures with a total exposure time of approximately 1 hour at f#1.85. If I were to use the Sky 90 f#4.5 for this object I would choose 120-second subs and a total exposure time of around two and a half hours provided the viewing conditions were good.

Figure 11.16. A single frame Hyperstar image of the Dumbbell nebula in Vulpecula. Messier object 27 is the Dumbbell nebula in the constellation Vulpecula. M27 is a bright planetary nebula, the result of the final stages of stellar evolution with the 48,000-year-old white dwarf star at its centre. M27 is rather close to us at only 815 light years distance and it measures 1.2 light years across. The several colours seen in this nebula are due to ionised Hydrogen, Nitrogen and Oxygen.This is a single Hyperstar frame with 100 sub exposures of 55 seconds per sub giving a total exposure time of just over an hour and a half.
Being bright, and reasonably sized at 8 by 6 arc minutes, this is a pretty good object for the beginner. It is however quite a difficult object to process properly as the colours are very subtle and there is a bright patch running through the nebula that is very easy to saturate during the "curves" stretching routine.

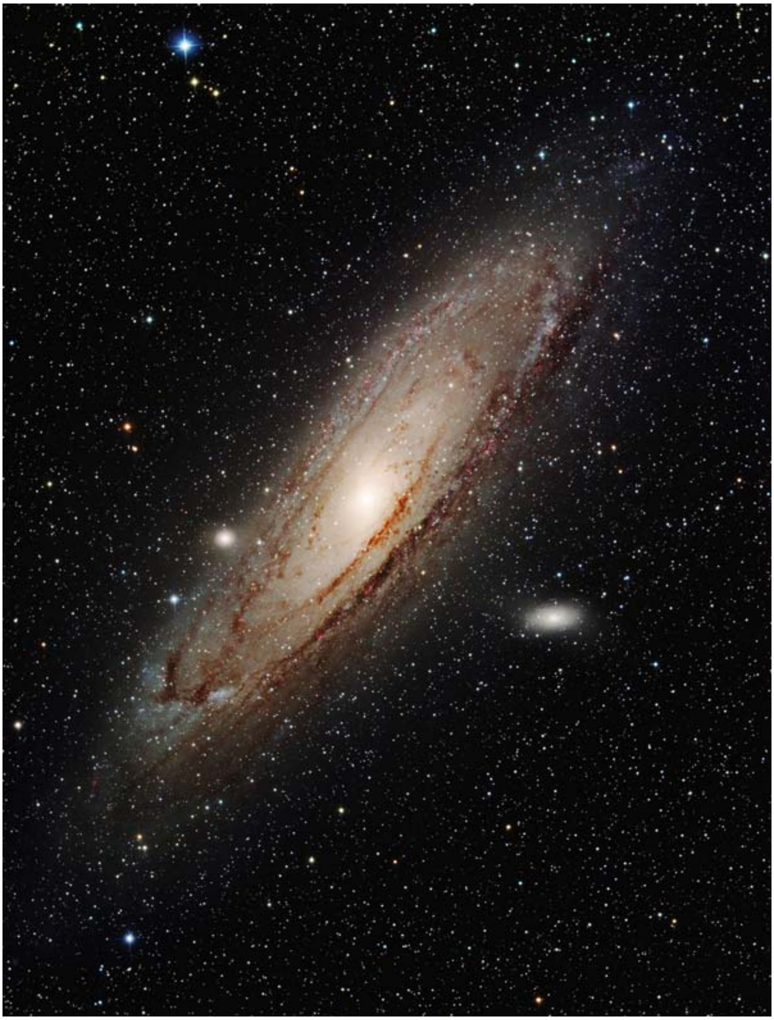

Figure 11.17. Wide field refractor image of the Great Andromeda galaxy M31 in Andromeda. The huge spiral galaxy M31 lies in the constellation Andromeda, and is around 3-degees along its major axis! You need a big field of view to get this in one frame, and fortunately the Sky 90 with M25C camera is just about big enough. This image shows not only the dark dust lanes circling the very bright core region, but also bright red HII regions in the outer arms. M31 lies at a distance of 2.3 million light years, and as it can be seen (as a fuzzy glowing region) with the naked eye, it is one of the most distant objects that we can see with the unaided eye. This single frame wide field refractor image is composed of 5 and 10-minute sub-exposures totalling approximately 8 hours. It still needs more data!

Figure 11.18. Two-frame Hyperstar mosaic of the Triangulum galaxy. M33 is a pretty large galaxy and is naked eye under very good skies. This gives the false impression that this object is bright, and therefore easy to image, both are incorrect assumptions. The low surface brightness of M33 makes it quite an imaging challenge, especially so if you approach it thinking it will be an easy target!
M33 is in the constellation Triangulum that lies just below Andromeda. M33, the Triangulum (or Pinwheel) galaxy is just a bit too large for a single Hyperstar frame, so this image is a mosaic of two frames. You can clearly see lots of bright red HII regions (ionised hydrogen emitting light at 656.3nm in the red part of the spectrum, HI is neutral hydrogen) and these are associated with star generating regions. M33 lies at a distance of about 2.3 million light years (like the Andromeda galaxy).
Each frame of this image was a total exposure time of about 1 hour using 65-second sub exposures and the Hyperstar at f#1.85.

Figure 11.19. Single frame Hyperstar region of open cluster M35 in Gemini. Here's another image where the large field of view of the Hyperstar bags two objects in a single frame with a good resolution of 2.55 arcseconds per pixel. In this image we can see two open clusters in the constellation Gemini, M35 full of bright blue stars, and the much smaller NGC2158 full of old red stars. Although NGC2158 appears smaller in the image than M35, they are both roughly the same size, it's just that NGC2158 is six times further away than M35 which lies at a distance of 2,800 light years.
This single frame Hyperstar image consists of 70 sub exposures with 45 seconds per sub.
M35 is quite bright and a good target for the beginner, NGC2158 is a lot fainter and requires a reasonable total integration time to come out well. For the Sky 90 working at f#4.5 I would recommend subs of around 180 seconds and a total exposure time approaching 3 hours to get a good result.

Figure 11.20. Four-frame Hyperstar mosaic of the Pleiades. This famous open cluster of stars is M45 - The Pleiades, or seven sisters, or Subaru, or Soraya (Persia), or Mataariki (Maori), the Vikings called the Pleiades "Freya's Hens", it has many names around the World! The Pleiades lie in the constellation Taurus and are about 2 degrees in diameter (the full Moon is about half a degree in diameter).

The Pleiades are the stars that form that well-known constellation of the winter skies that looks like a question mark. As you can see in this 4-frame Hyperstar mosaic, a beautiful blue reflection nebula that extends well beyond this star group surrounds the Pleiades. A reflection nebula is basically a dust region, and the dust is of such a size that it scatters short wavelength (blue) light very effectively. The Pleiades lie at a distance of only 407 light years, so in astronomical terms, they are pretty close to us.

This is a 4-frame Hyperstar image where each frame is composed of around 70 sub exposures at 60 seconds per sub.

Being a 4-frame Hyperstar image immediately tells you that this is a large object to capture, and this is always difficult with conventional gear. However, these big objects are perfect for short focal length lenses as found in standard camera telephoto lenses. So, quite often, imagers adapt a good quality telephoto lens to fit to their CCD cameras. The lens needs to be of good quality if you're not to get too much chromatic aberration - but if you use the lens with narrowband filters and a monochrome camera, then you don't need to worry about the chromatic aberration of the telephoto lens at all. You can see a very deep wide field refractor image of the Pleiades in the next image.

Figure 11.21. Wide field refractor image of the Pleiades. A lot of the pain of imaging this large region of space is removed if you go to short focal length, wide field imaging systems. This image is composed of 6-minute, 10-minute and 20-minute sub exposures totalling some 5 hours and 48 minutes in all. You can begin to see the faint reflection nebulosity that flows out well-beyond the perimeter of the Pleiades star cluster itself.

Figure 11.22. A single frame Hyperstar image of the open cluster M46 in Puppis. This is a very difficult object for me to image in the southern U.K., as it is so low down on the horizon I have to catch it as it passes between two tall Oak trees that lie on my southern horizon. But the wait is worth it, for open cluster Messier 46 holds a little gem, a tiny planetary nebula NGC2438 that you can see glowing towards the top of the cluster. M46 lies at a distance of 5,300 light years and is about a third of a degree in diameter.
This single frame Hyperstar image is composed of 31 sub exposures with 60 seconds per sub. If you have a good southern horizon this object is well worth a try for the beginner.

Figure 11.23. A single Hyperstar frame of the nebula M78 in Orion. I find it strange that this beautiful, awe-inspiring, region of space doesn't have its own name but is only known by its Messier [78] and NGC [2068] numbers. M78 is a beautiful reflection nebula surrounded by a large region of dark nebulosity. An associated nebula to the northeast is NGC 2071. M78 lies in the constellation Orion at a distance of 1,630 light years.
This is a single Hyperstar frame comprising 114 sub exposures of 60 seconds per sub.
M78 is not only pretty faint, but from the U.K. it is also pretty low in the sky, this makes it quite a difficult target and it is not recommended to the beginner.

Figure 11.24. A single frame Hyperstar image of the spiral galaxy M81 in Ursa Major. Messier 81 [Bode's Galaxy] is a beautiful spiral galaxy lying 4.5 million light years away in the constellation Ursa Major. The tiny immensely bright core is thought to contain a supermassive black-hole powerhouse. You may just about see a very faint blue blob of light to the West of M81; this is Holmberg IX, an extremely faint galaxy, and a very good indicator that the image has gone very "deep".
This is a single frame Hyperstar image – but the total exposure time to create this image was very nearly 6 hours using both RGB and H-alpha filtered sub-exposures. This is an enormous length of time using a fast f#1.85 system like the Hyperstar.

Figure 11.25. A single Hyperstar frame of the globular cluster M92 in Hercules. Another highly impressive globular cluster, and strangely enough this one is also in the constellation Hercules just like its very famous cousin M13. M92 doesn't get much press as it is overshadowed by M13 that lies close by. This is a shame as M92 is pretty spectacular in its own right and is only a little smaller in apparent diameter (14′) than M13 (21′). M92 lies at a distance of around 25,400 light years from us.
This single frame Hyperstar image is composed of 139 exposures with 30 seconds per exposure, so this image goes pretty deep. This is apparent if you look very carefully at the image, you will find several "faint fuzzies" lying in the dark background.

Figure 11.26. Single frame Hyperstar image of spiral galaxy M106 in Canes Venatici. Here's another spiral galaxy with lustre like Mother-of-Pearl. This one is Messier 106 lying at a distance of 22 million light years in the constellation Canes Venatici (the Hunting Dogs). This single frame Hyperstar image is only 34 exposures of 55 seconds per exposure!

Figure 11.27. A single frame Hyperstar image of the Monkey Head nebula in Orion. This rather faint emission nebula in Orion has been printed upside-down (north is downwards in this image) so that the "Monkey Head" can be more clearly seen. Often mistakenly called NGC2174 (which is in fact a smaller nebulosity within the Monkey Head itself), this is a region of strong H-alpha emission, and its size is an almost perfect match for the field-of-view of the Hyperstar lens with the Nexstar 11 GPS scope and SXV-H9C camera.
This single Hyperstar frame consists of 157 sub exposures at 60 seconds per sub, giving a total exposure time of over two and a half hours, which was still not long enough to capture this very faint object.
Clearly this is not a beginner's target, and the limitations of the Hyperstar are also being made apparent here. Sixty-second subs are usually enough for most targets with the Hyperstar, but they simply aren't capturing enough photons from NGC2175 to give a very deep looking image. This object needs at least 120-second subs from the Hyperstar, which would equate to a massive 12 minutes for the Sky 90 operating at f#4.5!!

Figure 11.28. Three-frame Hyperstar mosaic of the Horsehead region in Orion. This image is a 3-frame Hyperstar mosaic with each frame having a total of 1-hour exposure using 55-second subs. Note that with even 3 Hyperstar frames stitched together the field of view is still very much smalller than the single Sky90/M25C image shown in Figure 11.12.

Figure 11.29. Single Hyperstar frame of NGC188 in Cepheus. This open cluster has the honour of being the first object listed in the Caldwell catalogue - it is therefore the most northerly at a declination of 85 degrees 14.5 arc minutes, and is very difficult to image using a wedge-mounted Alt-Az scope of conventional design. NGC188 lies at a distance of 4,800 light years and resides in the constellation Cepheus. It is also old - very old. At an estimated 5 billion years of age this open cluster is about 1 billion years older than M67 in Cancer, but is still 2 billion years **younger** than NGC6791 in Lyra.
This single Hyperstar frame was assembled from 169 sub exposures of 50 seconds exposure per sub, making a total exposure time of nearly two and a half hours.
Being a cluster, this is a good beginner's object, provided your system allows you to image close to the Pole! Also, if you are imaging near the Pole, you will find the autoguiding a doddle!

Figure 11.30. Single frame Hyperstar image of NGC2276 & NGC2300 in Cepheus. The strange-shaped galaxy towards the centre of this image [NGC2276] is an example of an Arp galaxy, a galaxy that has had a close gravitational encounter with another galaxy. In this case NGC2276 has had an interaction with the giant elliptical galaxy NGC2300 lying towards its lower left. In this region of space very close to the pole there are over half a dozen other small faint galaxies, can you spot them? I like imaging in this region, as it is very difficult for equatorially mounted scopes to image here as the CCD may strike the base of the telescope in a conventional (wedge) system. As the Hyperstar is actually mounted on the front of the telescope I don't meet this restriction.
This image is a single Hyperstar frame consisting of 151 sub exposures of 30 seconds per sub.

Figure 11.31. A single Hyperstar frame of NGC6791 in Lyra. This faint-looking, very red, open cluster has the look of age about it, and old it is. NGC6791 in the constellation Lyra is perhaps the oldest open cluster in our Milky Way galaxy with an estimated age of 7 billion years!
This single frame Hyperstar image consists of 54 sub exposures with 50 seconds exposure per sub, needing a little longer total exposure for a cluster than usual, as this one is rather faint, in fact this object needed quite a lot more total exposure time. For a system like the Sky 90 working at f#4.5 I would recommend 5-minute subs for at least a total exposure time of 3 hours.

Figure 11.32. A wide field refractor image using the SXV-H9C camera showing NGC6914 in the huge Gamma Cygni nebulosity in Cygnus. This image was acquired using the Sky 90 and the old SXV-H9C camera before the SXVF-M25C was purchased. Gamma Cygni can be a bit boring as it is a huge field of red emission nebulosity, but just occasionally you can find a few bright gems amongst the uniform red. Here's one such region, NGC6914 a very nice blue reflection nebulosity with some noce fine detail. This image is only 36 exposures of 3 minutes per sub at f#4.5.

Figure 11.33. A wide field refractor image using the SXV-H9C camera showing the Witch's Broom nebula in Cygnus. This beautiful nebula is part of the massive "Veil nebula" in Cygnus, a supernova remnant. This one is faint and needs a lot of exposure time. This image is composed of 35 exposures at 150 seconds and 53 exposures at 300 seconds giving a grand total of nearly 6 hours (and it still needs more!). This is definitely not a beginner's object.

Figure 11.34. Wide field refractor image using the M25C camera showing NGC7000 and IC5070 regions in Cygnus. Also known as the "North America" and "Pelican" regions, a more detailed description can be read against Figure 11.36. However, the huge field of view of the Sky 90/M25C camera combination is simply not enough to capture all that is going on here. To get the whole of NGC7000 and the Pelican together in the one image I would need to put the M25C into "portrait" mode and take a 2-frame mosaic – it's that big! This is clearly an imaging project to be continued in another year. This image is composed of 59 subs at 4-minutes per sub and 8 subs at 5 minutes per sub.

Figure 11.35. A two-frame Hyperstar mosaic of the Great nebula in Orion. Of all the deep-sky objects, the Great Nebula in Orion is the most highly recommended for the beginner, as just about any capture you make will look great. This was the very first deep-sky object I imaged with the Hyperstar/SXV-H9C, and although those first images are very poor in comparison with those I take today, I was completely over the Moon with these first attempts, and they gave me the enthusiasm to continue with this amazing hobby.
This "busy" region of emission nebulosity is in the constellation of Orion. The large central region is M42, and the smaller circular region at the top with a notch taken out of it is M43. Together these are known as the Great Nebula in Orion, and I have a problem with this object. When Orion is high in the winter sky I rarely want to look at, or image anything else. Every time I return to this object there is something more to see, or something more to learn, and it has a great advantage over many other deep-sky objects in that it is very bright, and therefore very easy to image well.

Figure 11.35. (Continued) This nebula lies just below Orion's belt, and it is lit up by the Trapezium group of stars which you can just see in the brightest part of the nebula's core (near M43). Laying at a distance of 1,500 light years the Great Nebula in Orion measures a massive 1.5 degrees by 1 degree.
Being over a degree in one dimension means that this image is a 2-frame Hyperstar mosaic. Each frame is composed of around 120 subs at 20 seconds per sub; each frame therefore represents about 40 minutes of total imaging time.
Take a look on the Internet at all the images you can find of the Great Nebula. What do you see? Just about every one is different in detail, and they all look pretty good. It is very bright, so you don't need to image all night to get a very respectable image. There are lots of subtle colours and hues in the region, so it looks very pretty and responds well to your processing experiments. It is large, which means you may have trouble fitting the whole region in one frame, but then it makes an ideal subject for forming a mosaic.
I am so enthusiastic about the Great Nebula as your first imaging object that I would say hold back on buying your CCD camera and starting your imaging career until Orion and its glories are well-placed in your sky. The ease with which you can generate very nice looking images of this object will spur you on to greater things. If you try to start imaging on more difficult subjects, you may be discouraged, and we certainly don't want that happening.

Figure 11.36. A 5-frame Hyperstar mosaic of the NGC7000/IC5070 region in Cygnus. If you carried out the 5-frame mosaic exercise in the previous Chapter, this image will certainly be familiar to you. This is a huge area of emission nebulosity in the constellation Cygnus close to the bright star Deneb (one of the Summer triangle of stars along with Vega and Altair). The North America nebula (to the left) is also Caldwell object 20, and the much dimmer Pelican nebula (to the right) is designated IC5070. This image is a 5-frame Hyperstar mosaic, so the effective size of this picture is 2 degrees by 1.5 degrees. For comparison, the diameter of the full Moon is just half a degree. Distance to the North America nebula is 1,800 light years. See the "Weasel" with his one blue eye lying between the North America nebula and the Pelican?
This image was taken one late summer evening in 2005. Each sub exposure was 40 seconds and each frame was a total exposure time of 40 minutes. Imaging this object finished around 3.00 a.m. – don't forget you need to set up the autoguider for each individual frame and there is the download time for each image, plus a five second delay between images.
Clearly this is a difficult object to image using conventional equipment – because it is so large! Also, the Pelican nebula really is quite a lot dimmer than NGC7000, so you will need to make relatively long total exposures. The speed of the Hyperstar makes the total imaging time bearable, but being a Summer object means that you cannot begin imaging much before 11.00 p.m. in the U.K. so this is a sleep-killer target!
Note how a single frame using the wide field refractor system gave me a bigger field of view than assembling 5 Hyperstar frames!! This business can be very disheartening at times. However there's one very important thing to consider about the two different imaging systems – they're just about the same. What do I mean by this? Well, the wide field system is slower than the Hyperstar by about a factor of 6. However, the field of view of the Sky 90 with SXVF-M25C is about 6 times greater than the Hyperstar with the SXV-H9C – so overall, the time needed to cover the same (wide field) area of sky is about the same in both cases. Not only is this very interesting, but I also considered the maths and the outcomes very carefully before changing imaging systems so that I wouldn't effectively "lose out".

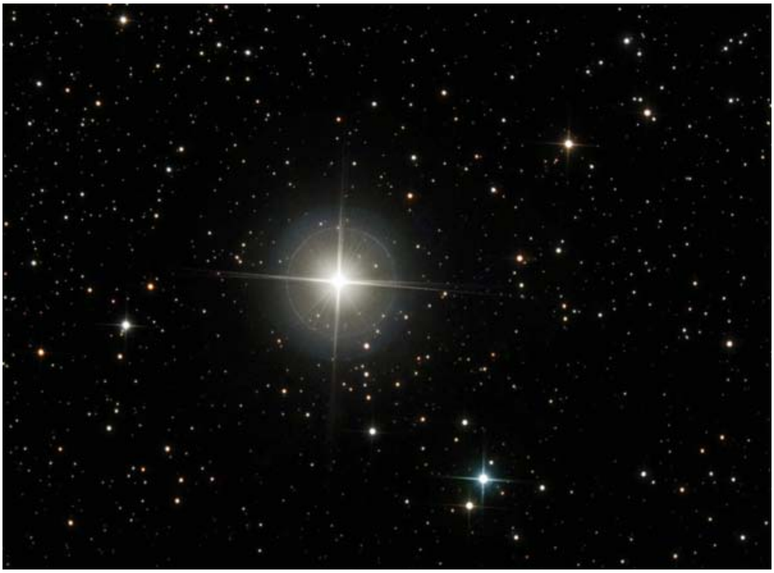

Figure 11.37. A single frame Hyperstar image of Polaris. Another single bright star image, this time the one that shows us the way home, the Pole Star or Polaris in the constellation Ursa Minor. Polaris is in fact a double star (the double is lost in the glare from Polaris in this image). This single frame Hyperstar image is composed of 30 subs with a very long exposure time of 120 seconds per sub. I was hoping to pick up a faint nebulosity in the area called an "Integrated Flux Nebula" which is very faint and blue in colour. Unfortunately the nebulosity doesn't show up at all and needs far longer integration times even at f#1.85!

Figure 11.38. A single frame Hyperstar image of the core of the Rosette nebula in Monoceros. The Rosette nebula in Monoceros is a huge emission nebula with a nice open cluster, NGC2244, at its centre. You can see many dark regions in this nebula known as "Bok globules". The Rosette nebula is a massive 1-degree by 1.33 degrees in size, with a full Moon only coming in at half a degree in diameter! The Rosette lies at a distance of 4,900 light years over three times further away than the Great Nebula in Orion, and yet the Rosette is of a similar apparent size in the sky. This of course means that in fact the Rosette nebula is considerably larger than the Orion nebula, it spans something like 115 light years!
This is a single Hyperstar frame of the central core region of the Rosette and is made up from 84 sub exposures of 60 seconds per sub.
Capturing part of the Rosette is well within the reach of the beginner, but once again, this is a very large object and short focal length optics, plus a large CCD chip are required to capture the whole thing in a single frame.

Figure 11.39. Wide field refractor image of the Rosette nebula in Monoceros. It was too big for the Hyperstar and SXV-H9C, but it is just about perfect in the Sky 90/SXVF-M25C combination! Once again the Rosette nebula, but this time the whole thing, rather than just the core region. There are plenty of wide field targets to occupy the wide field refractor system throughout the year, and some of them will require mosaics as well!

Figure 11.40. A single frame Hyperstar image of the Running Man nebula in Orion. This region of rich nebulosity to the north of the Great Nebula in Orion is aptly named the Running Man nebula - can you see him? With three NGC designations, this region has nebulae and a very pretty open cluster that can be seen towards the top of the image. See how the whole region is surrounded by a dark nebula cutting out the background stars all around the edge of the image.This is a single Hyperstar frame with a total exposure time of approximately two hours using 55-second subs.
The Running Man is not too bright an object, that's why 2 hours of Hyperstar time have been used. It's size however is convenient for most imaging setups being neither too large nor too small. Although this is not an object for the beginner, it should certainly be within the capabilities of someone in their second season.

Figure 11.41. Wide field refractor image using the M25C camera showing the Sadr region of Cygnus and the Gamma Cygni nebulosity. This is just a tiny part of the massive Gamma Cygni nebulosity IC1318 that lies in Cygnus. The region you see here has the star Sadr centralised in the frame (Sadr is also the central star in Cygnus). The image is composed of 33 subs using 6-minute sub exposure times. Can you see the little open cluster NGC6910 towards the top of the frame?

Figure 11.42. Wide field refractor image using the M25C camera showing the whole of the M42 region in Orion. The Orion region is full of interesting objects, one of the brightest and most imaged being M42 the Great Nebula in Orion. The huge FOV of the wide field refractor system not only gets the whole of M42/M43, but the Running Man as well, and plenty of the surrounding space too! Notice how the "empty" region surrounding M42 is actually full of "brown-looking" nebulosity. This image is a composite of H-alpha, RGB and earlier Hyperstar RGB work and is a total of over 12 hours of exposure.

CHAPTER TWELVE

Differentiating your Work

Now that you have mastered the basics of astronomical imaging with your setup, how are you going to differentiate your work from others? Why should you even bother? If you are happy to take very nice images that you are personally pleased with, there's nothing wrong with that at all. But, the people that seem to get involved with this hobby are typically pathfinders rather than followers. So you will find if you sit on the Forums long enough, that there is always someone who pushes the envelope that little bit further, which gives you (and all the others of course) a big incentive to improve your own imaging technique, and to try just that little bit harder to acquire that really stunning, and unusual image.

With so many people engaged in this hobby, how can it be possible to differentiate your work? If I drop the false modesty for a second, I think that during the period late 2004 until mid-2006 my work was highly differentiated by being just about the only person on the planet getting high quality images from the Hyperstar lens assembly. We have seen the reasons for the difficulty in obtaining good images from the Hyperstar, and those difficulties remain. So a very easy way to differentiate your work is to become a "good" Hyperstar imager. But there are LOTS of other possibilities of course. One way of being able to differentiate your work is to throw more money at the hobby than most people can afford. I have no strong feeling as to whether this is a good or a bad thing for amateur astrophotography, but would suggest that if an extremely wealthy person has the high intelligence to want to take up this fascinating hobby, it can only be a good thing. So, you can differentiate your work, providing you have the funds, by buying the biggest aperture, fastest telescope your budget will allow, setting it up in a permanent dark site, and sticking the biggest most efficient CCD system you can find on the back end. Couple this with a nice powerful workstation to grab the data and run the observatory for you and you'll have done a good job in differentiating your work from the rest of us that suffer from permanent thin-wallet syndrome. But is it at all possible to differentiate your work nowadays without having access to large reserves of cash? Of course it is, and one answer is, as it is with most things, is to work really hard.

Mosaics as we have already seen take a great deal of time effort and patience to produce, especially big ones, i.e. mosaics with a large number of individual frames. That's a very good differentiator to start with. There are a few stalwarts out there, who make this type of imaging their forte, but their numbers are very low indeed, so there's plenty of room for more to join them. Push the envelope, take things that bit further, make a mosaic of a large object, for example the North America and Pelican nebula region, *and do so at very high resolution!* Now you will have differentiated you and your work even further, even less people form high-resolution mosaics than those that create mosaics in the first place. One expert in creating large, high-resolution mosaics is the astrophotography innovator Rob Gendler http://www.robgendlerastropics.com/ check out some of his iconic masterpieces including his mouth-watering rendition of M31, the great Andromeda galaxy. I hope you are beginning to get the picture; the possibilities really are almost endless and virtually untapped.

What else can we do? Well, it's a good idea to get off the Messier and Caldwell lists, useful as they are, and find objects that have been imaged to a much lesser extent. The NGC list is a good place to hunt down rarely imaged objects, but so are the Arps (peculiar galaxy) lists and the Abell list of galaxy groups. We then have all the dark nebulae out there (check out the Sharpless list), the strange integrated flux nebulae http://www.galaxyimages.com/UNP_IFNebula.html and many other little-studied wonders. Do some Internet research and see what you can find, there's plenty of stuff out there that's hardly ever been imaged at all! What I am saying here is to find objects that you can't get at by simply hitting the goto on your computer controlled telescope – anyone can do that! What you need to do is find some relatively obscure list with a nice looking object on it (and not duplicated on one of the other well-known lists), get the R.A. and Dec. co-ordinates, then use your scope's "goto R.A./DEC" function to go to the object for imaging.

This is precisely what I did when I imaged the "brightest object in the Universe", according to the Guinness Book of Records anyway. That object was APM08279+5255, which can be found at R.A. 08hours 31 minutes 41.60 seconds, and DEC. +52 degrees 45 minutes 16.80 seconds. Any telescope with "goto" capabilities can be easily programmed to slew to this object. The object is of course a quasar, or quasi-stellar object, but it appears to be just a dim, very red star. Nobody really knows what quasars are but it is hypothesized that they are black holes emitting tremendous amounts of energy (from beyond the event horizon!) as they capture huge quantities of matter from nearby stars. APM08279+5255 is a very deep red and was a candidate for a so-called carbon star that was thought to lie within our own galaxy. The reason this quasar is so red is due to its enormous red shift of 3.87, which basically means that it lays a very long way away from us. To be more precise APM08279+5255 lays 12.9

billion light years away in the constellation Lynx in the Northern Hemisphere. Consider that our Universe erupted out of the big bang only something like 13.7 billion years ago and you can start to appreciate what a totally amazing object this quasar is, and how incredible it is that you can image something this far away from your own backyard using amateur equipment.

Although APM08279+5255 only appears to be a magnitude 15.2 star, far too dim to be seen with the naked eye, it was still bright enough for people to think it was in our own galaxy. The reason it appears "so bright" to us is due to yet another strange coincidence regarding this object. Between the quasar and Earth lies a large galaxy with the huge gravitational field usually associated with such a collection of stars, and it is the "gravitational lensing" provided by this galaxy that "magnifies" the weak light from the distant quasar making it more easily detected by our Earth-bound telescopes.

I took a colour image of this quasar on the Celestron Nexstar 11 GPS reflecting telescope using the Hyperstar lens attachment with 46 sub-exposures of 50 seconds each, giving a total imaging time of only 38 minutes; see Figure 12.1. This is a very nice object to differentiate your work! Get a really long focal length image of this one in colour; it hasn't been done yet (2006). An object 12.9 billion light years away, captured as a colour image, by an amateur astrophotographer using commercially available equipment. It is mind-boggling really, isn't it!

Is there anything else? Well, move away from thinking about the type of objects you want to image and go back to the hardware, but without moving into the megabuck region. You can specialise in filtered imaging, using narrow bandwidth filters to look at specific emission lines from objects. You may need to do this anyway if you have to image from a light polluted site, but how

Figure 12.1. The Quasar APM08279+5255. Brightest object in the Universe laying 12.9 billion light years away in the constellation Lynx.

about getting your own (blue) broadband filters specially designed so that you could image the integrated flux nebulae mentioned above? Increase the budget requirement somewhat, but not beyond the realms of a high end Ritchey-Chrétien scope and what about putting together your own micro-WASP facility? This is nowhere near as way-out as it sounds. Buy the same Canon lenses as in the Super-WASP array http://www.superwasp.org/, couple them into large CCD cameras like the SBIG 11000 or the SXV-M25C, add a cheap guide scope and guider CCD and off you go. Huge field imaging and a resource that could be used for serious near earth object research. Your micro-WASP array will also require a substantial computational resource as well to download and handle the vast amounts of data you will generate in an observing session. Check out this site to see the type of data handling problem you will need to address http://www.star.le.ac.uk/~pjw/wasp/wasp_escience.html. This is a perfect differentiator for the amateur imager if ever I saw one!

What about imaging in the Polar region? As stated in Chapter 3, it is not easy for wedge-mounted Alt-Az scopes to work near the Pole, and for this reason, the Pole region is relatively “un-imaged”. The Hyperstar allows you to image at the Pole, as there is no large optical train at the eyepiece end that will strike the base when the scope is pointing towards the Pole. However, by judicious use of a high-quality diagonal, you should also be able to fit your optical train at the eyepiece end and still clear the base when imaging near Polaris. German Equatorial mounts don’t suffer from this particular problem, but many large scopes are wedge-mounted Alt-Az designs, so there are not very many high-quality images of the Polar region to be found. Check out how many good images you can find of Caldwell 1 [NGC188], surprisingly few I think you’ll find. Now look for images of Polarissima Borealis, a little galaxy and the NGC object closest to the Pole – how many images of this one can you find?

As another possible suggestion, instead of building your own imaging array, what about putting together your own unique telescope? A big aperture, low f number telescope, with a large flat focus field designed specifically for very fast CCD imaging. Design it, and build it. It is far too specialised an instrument for the major manufacturers to get involved in, simply because the market isn’t there for the manufacturer to get a good return on their investment. But that doesn’t stop a dedicated amateur with lots of perspiration and dedication from building the “perfect” CCD imaging system!

Then if you have the luxury of a really dark site, you could go for the longest possible integration times and hunt down the faintest objects in the Universe. You could even have a crack at the amateur record for the faintest object ever imaged; currently I believe this is around magnitude 24.5.

What about very long focal length imaging, that is imaging at f #10, f #20, or even f #30 with a large aperture telescope? This is something that I haven’t covered in this book as the mount and guiding problems become very severe, and it is usually the realm of the planet or comet imager, rather than the deep-sky imager. The planet or comet imager does have one major advantage over the long focal length deep-sky imager, their objects are very bright by comparison and the sub-exposure integration times are very short. This seriously reduces the accuracy constraints on the guiding for planetary and comet imaging. However, long focal lengths are also required for some of the tiny distant galaxies, and the smaller planetary nebulae, and for imaging these objects long sub-exposure integration times will be required. This becomes a good differentiator for your work as the accuracy in the guiding requirements really does become very difficult to achieve, once long integration time sub-exposures, at very long focal lengths are attempted.

Finally, rather than just creating new pretty images that nobody else has seen before, what about searching out new objects? How about trying to find a new asteroid, or a supernova? Your imaging system should be capable of this work, and AstroArt as well as Maxim DL come along with comparator software so you can compare two frames of the same region taken at different times to see if something has moved, or if something new has appeared. You will find asteroids in some of your deep-sky shots simply by chance anyway. Go to an asteroid/near Earth object Internet site listed in Chapter 13 and see if your asteroid is a new one or not. I should probably recount to you the first asteroid a colleague discovered in one of my images as it may help you NOT to do what I did!

I had been imaging the Merope nebulosity in the Pleiades with the Hyperstar and had obtained a very deep shot – fairly long sub-exposure time, and lots of them. It was getting late in the evening, but I wanted to see what I had captured, so I started some image processing. Remember, it's getting very late, and I'm not in a very good mood, when I see this stupid annoying little rod of light – slap bang in the middle of the Merope nebulosity, see Figure 12.2. Now this really did annoy me, more work to be done in order to clone out that glitch!!! So I cloned

Figure 12.2. Asteroid 162 Laurentia on its way through the Merope nebulosity just as I was imaging this region for 4-frame Hyperstar mosaic.

out the light glitch and thought no more about it that evening. The next day I sent an image of the Merope nebulosity to Ron Arbour, a well-known U.K. supernova hunter, but I hadn't realised at the time that I'd sent an earlier version of the image without the light glitch cloned out. I think you can see it coming can't you? Ron e-mails me back almost immediately – "You realise you've caught an asteroid on here don't you?" he says. I'm a bit taken aback as I saw no asteroid on the image, and only realise after a while that Ron must be talking about the light glitch that I thought I'd cloned out. To cut a long story short we traced this one down to asteroid 162 Laurentia, unfortunately not a "new" asteroid, but certainly a new one for me. There is a sequel to this story. Fast forward to November 2006. I am imaging the Pleiades again, this time with the Sky 90 and the huge SXVF-M25C camera, so it's a nice big wide field image containing the whole of the Pleiades constellation. It's also a deep image, 10-minute sub-exposures and plenty of them. This time it is Noel Carboni, the guy who processed the image that gets back to me by e-mail. "You realise we caught two asteroids in that image don't you?" he said. Once again, no, I had no idea there were any moving objects in the image until Noel pointed out where they were. Using the Lowell asteroid site with a lot of trans-Atlantic e-mail chatter we soon found out these asteroids were 1193 (Africa) and 5063 (Monteverdi). Again, both asteroids were known, but a lot further down the food chain than the initial Laurentia find.

Having a closer look at the Lowell asteroid site I found that there were asteroids passing through the Pleiades region on a very regular basis, I had no idea that the Pleiades were the "Grand Central Station" for asteroids. Also note, the "Micro-WASP" project I mentioned a little earlier would be a great asteroid-hunting imaging system with its very large field of view and reasonable resolution (image scale)!

Finally we arrive at the specialist/obsessive sport of supernova hunting. Now this is something that doesn't actually ring my bell, but I know several people who have made this their life's work. Nowadays this is not a particularly good area to be in for differentiating your work, as there are professional institutes whose sole purpose is to use custom-built wide field imaging systems, under extremely good dark sky conditions, to go on "supernova patrols" every clear evening. As an amateur you are therefore up against some very heavy-duty competition, but despite this amateurs still manage to bag their fair share of supernovae each year.

I know very little about the art and science of supernova hunting, but what little I do know consists of the following. You don't look for supernovae in our own galaxy, as they would usually appear so bright that they would be immediately obvious; this of course also makes them very rare events. A good idea is to look for supernovae where there are lots of stars about. Now globular clusters have lots of stars, but as the majority of the bright globular clusters we know of are in our galaxy, this is actually once again not a good place to look. Other places that have high concentrations of stars are of course other galaxies, and it is in other galaxies that the supernova hunter generally looks for these highly elusive events.

So, supernova hunting differs from normal deep-sky imaging in several fundamentally important ways.

1) The supernova hunter is not after a pretty picture; lots of sub-exposures are not a requirement.

2) The supernova is likely to be a dim event if it is not to be readily picked up by one of the professional teams, and it is likely to be in a non-Messier non-Caldwell galaxy, apart from Caldwell 12 of which more a little later, if it is not to be discovered by hundreds of people at the same time! This means the supernova hunter takes one longish sub-exposure of a galaxy, with the biggest aperture scope he can afford, before moving quickly on to the next galaxy.
3) The imaging time is spent quickly taking sub-exposures of galaxies that are in the supernova's list for that particular evening. The idea is to cover as many potentially interesting galaxies as possible in the imaging time available. Some galaxies are well-known supernova grounds, Caldwell 12 being one of them, and these will be on the supernova hunter's search list. Some, very surprisingly have no supernova history at all, examples being M31 and M33 and these galaxies are unlikely to be searched by professionals.
4) After collecting the evening's data, the daylight hours are spent blink-comparing the evening's images against reference images taken at an earlier date and keeping an eye out for "new stars". Some advanced software with pattern recognition will take the legwork out of this stage for you as well.

As I mentioned above, this aspect of astronomical imaging does not interest me in the same way that taking pretty pictures does, but it might be an aspect of our imaging hobby that appeals to you greatly. If this is an area that does interest you, then firstly read up the enormous amount of information available on this subject before starting. Secondly, get yourself involved in a group who are already doing the same thing. In this way you can look at galaxies the rest of the group are not already looking at and thus prevent not only duplicate imaging of the same galaxy, but also reduce the chance of multiple people discovering the same supernova at the same time.

Happy differentiating!

Asteroid 162 Laurentia

162 Laurentia is a large, dark, main-belt asteroid discovered by brothers Paul and Prosper Henry on April 21st 1876. The asteroid is named after A. Laurent, an amateur astronomer who discovered the asteroid 51 Nemausa.

Orbit	Main Belt
Semi-major axis	3.027 A.U.
Perihelion distance	2.503 A.U.
Aphelion distance	3.551 A.U.
Orbital period	5.27 years
Inclination	6.08 degrees
Eccentricity	0.173
Diameter	99.1 km
Rotational period	11.87 hours
Absolute magnitude	8.83
Albedo	0.053

CHAPTER THIRTEEN

Your Largest Resource

It probably goes without saying, but the largest resource to support your new hobby is the Internet. Where do I begin to even start thinking about the possibilities? What resources are there for the amateur? It might be useful to start with a far from comprehensive list of useful topic areas, and then delve a little deeper into some of these. We have, in no particular order:

- Up to date deep-sky images readily available from Hubble and large Earth-based telescopes.
- Photographic sky maps.
- Catalogues, including images, of the NGC, Messier, Caldwell, IC, Arps and just about any other deep-sky object you can think of.
- Free planetarium software.
- Free image processing software.
- Sites dedicated to Supernovae.
- Many amateur deep-sky, and planetary, imaging sites. Don't be put off by the word "amateur" here. Many of these skilled astrophotographers are able to create images that rival those coming from the World's largest telescopes!
- Sites dedicated to asteroids and near Earth objects.
- Sites listing the World's astrophotographers.
- Pay-for astronomical imaging software sites.
- Pay-for CCD download and control software sites.

- Sites for purchasing your astronomical telescope.
- Sites specialising in CCD cameras.
- Specialist forums dealing with specific telescope manufacturers, specific CCD manufacturers, specific telescope add-ons (e.g. Hyperstar), and specific image processing software, astronomical imaging in general, and in fact just about any topic you can imagine in astronomy.
- Sites where you can actually take your own images on a large observatory-based telescope!

And so it goes on, and on, and on.

This is your near infinite reference library, your market survey department, your purchasing department, your means of immediate communication with like-minded friends. This is a truly amazing resource; it is your Encyclopaedia Galactica.

So we return to the initial question again, where do I start? I will start with the sites I initially started with, and I'll progress in the way that I progressed. Before proceeding I should say I have no affiliation, or personal interests (beyond learning) with regard to any of the sites I will mention.

I decided to buy the Celestron Nexstar 11 GPS scope for my main imaging instrument. As mentioned before the reasons for this were several, but for me the main reason was the Hyperstar capability. So I needed to be in touch with other Nexstar users. What could be better than?

http://groups.yahoo.com/group/NexStarGPS/

A very active group that covers just about every question you will ever have regarding Nexstar GPS scopes. Michael Swanson is author of the NexStar User's Guide, and his site can be found here,

http://www.nexstarsite.com/

This is an extremely useful site for the NexStar owner, and Michael has personally helped me out of sticky problems on several occasions. Clearly if you are a Meade, or Takahashi, or other brand-name owner, you will be able to Google all your own specific community links, be assured, they are out there in large numbers. As I also used a Hyperstar, and still use Starlight Xpress cameras, the Starlight Xpress Yahoo Group http://tech.groups.yahoo.com/group/starlightxpress/ and the Fastar Group http://tech.groups.yahoo.com/group/fastar/ are both also on my "Favourites" toolbar.

You will find Celestron at,

http://www.celestron.com/main.php

and the main U.K. distributor of Celestron products can be found at,

http://www.dhinds.co.uk/ or more recently http://www.celestron.uk.com/catalogues/browse_content.asp?catalogueID=272&page=home

David Hinds also hosts a Photo Gallery on which you can display your newly acquired astronomical images and compare them with other amateur astrophotographers.

My imaging CCD was a Starlight Xpress SXV-H9C because it was an almost perfect match to the Hyperstar lens, and is currently an SXVF-M25C. The Starlight Xpress range of CCD cameras can be drooled over here,

http://www.starlight-xpress.co.uk/

The Managing Director, Terry Platt, is an accomplished deep-sky imager in his own right, and has turned his hobby into a business. Terry is very responsive on both his site, and the Starlight Xpress user's site,

http://groups.yahoo.com/group/starlightxpress/

You will find many top class amateur imagers on this site who are always willing to help you improve your technique.

The first CCD download, autoguiding, and image processing package I bought was AstroArt3 (AA3),

http://www.msb-astroart.com/

As mentioned in the image processing section, I found this software extremely useful and easy to use, and I really like the photometry package it offers. Also AA3 makes you work a little harder (than Maxim DL) in carrying out tasks such as mosaic formation. At first sight this may appear to be of little use, but it allows you to understand more about what's "going on behind the scenes" of the software, so if and when you move to a more sophisticated package you will know the little tricks you need to carry out in order to bring the best out of the process. Within a couple of weeks of buying AA3 I downloaded the (one month free) software package Maxim DL. Being a lazy character, this was exactly what I was looking for, and when my free month was over I purchased the full image-processing package. Up until this point I was still using AA3 for image acquisition, but having moved to Maxim for processing, I also bought the Maxim DL CCD control software that has been very easy to use with both the Starlight Xpress imaging camera, and the associated SXV autoguider camera. You can see what Diffraction Limited; Maxim DL's creators have to offer here,

http://www.cyanogen.com/

I also really liked being able to upgrade the software, at no extra charge, for one year after purchase. Not all image processing software costs you hard cash. There is a very powerful freeware package called Iris, that if you get proficient, will do everything you want http://astrosurf.com/buil/us/iris/iris.htm. This looks like very good software indeed (especially as it's free!). When I looked at it some time ago the only problem I had was that the user interface was difficult for me, so being lazy I went for the commercial packages that spent a lot of resource getting the user interface just right. Don't be lazy like me give Iris a try.

I needed more external input for my imaging questions and got invited to join the Our Dark Skies forum by one of the initial members of the group, Bud Guinn. ODS can be found at,

http://forum.ourdarkskies.com/

this is the forum where Noel Carboni can be found, image processing expert and creator/developer of a set of actions for Photoshop,

http://ncarboni.home.att.net/PhotoshopActionsForSale.html

these actions are indispensable for the amateur astrophotographer saving a great deal of time and pain. Being a resident in the U.K. I soon joined a local group of imagers,

http://ukastroimaging.co.uk/forums/index.php who are really scary in the rate at which they turn out astroimages. It seems we only need half an hour's clear sky and a whole new bunch of images appear out of nowhere [get a life guys].

As I image in the U.K. it's a good idea to keep an eye on what the weather might be up to http://www.metcheck.com/V40/UK/HOME/ is as good as any, although nothing beats looking out the window from time to time just to see what's really happening.

We now move on to resources/databanks for astrophotographers. Probably the resource I use the most is the superb complete listing (with images!) of all the NGC objects, the NGC/IC project homepage http://www.ngcic.org/default.htm. This definitive database and the accompanying images really help you out when you are hunting down a new object. The images also give you a very good idea if the object is worth going for both in terms of its size and brightness.

It seems whenever I image the Pleiades; a new (for me) asteroid turns up in the image! This was most amazing to me at first, but I now realise on looking at the following sites, that asteroids are moving through M45 all the time. If you discover a moving object on your images, check out the Asteroid Data Services by Lowell Observatory http://asteroid.lowell.edu/ or the IAU Minor Planet Centre at http://cfa-www.harvard.edu/iau/mpc.html or the Near Earth Objects – Dynamic Site at http://newton.dm.unipi.it/cgi-bin/neodys/neoibo to see if your moving object really is a new one, or not.

For the Messier objects, check out the SEDS database http://www.seds.org/messier/ and for the Caldwell catalogue SEDS gives us this http://www.seds.org/ messier/xtra/similar/caldwell.html.

What about the astrophotographer community itself? Key players can be found on a site maintained by Michael Stecker http://mstecker.com/pages/app.htm, you may even find something on the Author here. There are many, many, great astroimagers out there and it is difficult to provide a list of the "best" without omitting some truly great work. However, I was initially motivated by the work of Steve Cannistra http://www.starrywonders.com/ and Rob Gendler http://www.robgendlerastropics.com/ whose images, in my opinion, still rank amongst the best in the World. Perhaps not so well-known, but with an impressive portfolio of images is Wolfgang Promper http://www.astro-pics.com/. Why I like these images so much is that Wolfgang seems to have the same eye as me as to how these objects should be portrayed, especially with regards to colour. Axel Mellinger has carried out some amazing widefield work http://canopus.physik.uni-potsdam.de/~axm/images.html and his piece-de-resistance is the totally incredible all-sky panorama which can be found here http://home.arcor-online.de/axel.mellinger/. As far as a differentiator project goes, that one surely wins the prize! The man who started and pioneered all this long before the CCD camera came along was of course David Malin with his state-of-the-art film work http://www.davidmalin.com/, pioneering, and highly inspirational, and remember this was using film!

What other titbits do I have on my "Favourites" bar? Well, there is some nice data on astronomy filters here http://www.astrosurf.org/buil/filters/curves.htm#Badder%20UV/IR, my "Starscapes" Exhibition brochure can be downloaded from here http://www.ecs.soton.ac.uk/about/pdfs/starscapes.pdf, and you can read up all about noise and sub-exposure calculations here http://www. hiddenloft.com/notes/noise_and_sub.htm.

For more inspiring astronomical images, try looking at the "Sky Factory" here http://www.skyfactory.org/ and of course at the Hubble images here http://hubblesite.org/gallery/.

Your favourites toolbar will of course become populated by addresses that you find useful or helpful, not by my suggestions. So the last few addresses are likely to be found on my toolbar only, but are included here out of modesty. First there is my observatory http://hometown.aol.co.uk/mobiusltd/myhomepage/photopersonal.html, then my CCD imaging site http://hometown.aol.co.uk/mobiusltd/myhomepage/computer.html. I have done work at completely the other end of the time spectrum here http://hometown.aol.co.uk/mobiusltd/myhomepage/photo.html and you can read a bit more about me here http://hometown.aol.co.uk/mobiusltd/myhomepage/business.html. It will be worth keeping an eye on the CCD imaging site, as this will reference a more complete "New Forest Observatory" site that is currently under construction. You will also be able to download un-processed data files from this new site, so that you can practice your own data processing techniques.

CHAPTER FOURTEEN

Book Recommendations

Although anyone starting in astrophotography today might be forgiven for thinking that "everything is on the WEB", books still have a very important role to play in our education.

My library consists of close on a thousand books, with maybe a hundred specialising in astronomy and astronomy related subjects. I certainly do not rate all 100 books as indispensable, but there are a few that most certainly are.

1) This being a book recommendation section, I shall start off with something that is NOT a book! It is a star map. You will need a nice large star map in order to see where all those objects you will be imaging lie with respect to one another. There are a huge number of star maps on the market, but there's only one I personally like, it is the Hallwag International space map, "Die Sterne, Les Etoiles"by Hallwag, www.swisstravelcenter.com This is the nicest uncluttered star map I have come across that has all the major objects listed.
2) For star charts in a booklet form that you can carry out to your observing site, I have a single recommendation, and that is the superb "Sky Atlas 2000, 2nd edition"by Wil Tirion and Roger W. Sinnott. Very detailed and beautifully presented, this is a "must-have"publication, ISBN 0-933346-87-5.
3) It is probably a good idea to become accustomed to the well-known Messier and Caldwell objects before venturing off to find the less commonly known galaxies, nebulae and clusters. To this end I use the two books by Stephen James O'Meara extensively. First we have "Deep-Sky Companions: The

Messier Objects", Cambridge University Press 1998, ISBN 0-521-55332-6. And secondly there is "Deep-Sky Companions: The Caldwell Objects", Cambridge University Press 2002, ISBN 0-521-82796-5. Every object in both books is accompanied by a black and white image, and the descriptions to go with each object are both descriptive, and in my opinion, beautifully written. I treasure these two books!

4) Stephen O'Meara is not unique, fortunately, in writing beautiful prose to go with deep-sky objects. Walter Scott Houston has also produced outstanding descriptions of these objects in his own book, edited by Stephen James O'Meara! The book is called "Deep-Sky Wonders", by Walter Scott Houston, edited by Stephen James O'Meara, Published by Sky & Telescope (Stargazing Series), 1999, ISBN 1-931559-23-6. This is truly a superb book, full of many black and white images, and plenty of objects that are not in the Caldwell or Messier lists – it's invaluable.
5) The next book I bought not knowing what I was going to get! I just saw the title on Amazon.co.uk and bought it. The book is "Observing Handbook and Catalogue of Deep-Sky Objects"by Christian B. Luginbuhl and Brian A. Skiff. Published by Cambridge University Press 1990, ISBN 0-521-62556-4. I'll be honest; when I first opened this book I was extremely disappointed. Very few pictures, many hand-drawn images, and at first sight not very interesting at all. This simply shows my early ignorance, I did not even realise at the time that this was one of the definitive works, often referred to on the NGC-IC Project Homepage http://www.ngcic.org/default.htm This book is a mine of data! Sectionalised by constellation, all the interesting objects associated with each constellation are discussed from an observer's point of view. Many faint objects that are not "popular"are described making this an excellent source of material if you want to go "off road"with your imaging and observing. I am embarrassed to say this book remained untouched on my shelves for something like 6 months before I realised what I had sitting there.
6) Already mentioned earlier in this book is the reference for constructing your own small astronomical observatory. Called "More Small Astronomical Observatories"this book also contains a CD with "Small Astronomical Observatories", the earlier publication. This book is one of Patrick Moore's Practical Astronomy Series, edited by Patrick Moore, published by Springer-Verlag London Limited 2002, ISBN 1-85233-572-6. As already mentioned, if you have thought about your own small observatory design, it's probably in this book.
7) Ultra wide angle full-page colour maps of the constellations are given in "The Photographic Atlas of the Stars". Published by IOP Publishing Ltd. 1999, HJP Arnold, Paul Doherty & Patrick Moore, ISBN 0-7503-0654-8. The huge wide field photographs in this book are an excellent reference for finding your way around the heavens and for locating the brighter deep-sky objects.
8) If you decide to go the Celestron Nexstar route like me you will need THE reference book for your telescope. "The Nexstar User's Guide"by Michael Swanson is another in the Patrick Moore's Practical Astronomy Series. Published by Springer-Verlag London Ltd. 2004, ISBN 1-85233-714-1, this book contains everything you need to know about your Nexstar telescope, it is an invaluable reference.

9) A very large, encyclopaedic volume is "The Cambridge Atlas of Astronomy"Cambridge University Press and Newnes Books 1985, ISBN 0-521-26369-7. An immense work with each section written by a World expert in the field. Covers The Sun, the Solar System, The Stars and the Galaxy, The Extragalactic Domain and The Scientific Perspective. Another mine of information, full of beautifully drawn colour images, and colour photographs. A great book to sit down with on a rainy afternoon.
10) An astronomy data book, pure and simple is "The Data Book of Astronomy"by Patrick Moore. Published by the Institute of Physics Publishing 2000, ISBN 0-7503-0620-3. This data book will save you a great deal of legwork, or nowadays I suppose mousework.
11) For an astronomy encyclopaedia, try the "Philip's Astronomy Encyclopaedia", edited by Patrick Moore, Philip's 2002, ISBN 0-540-07863-8. Very broad coverage of all things astronomical with excellent colour drawings and photographs.
12) This recommendation has a superb quotation on the back cover from James Michener's "Space". "This is one of the loveliest books in the world, the Professor had said, still clinging to the large flat volume. Norton's Star Atlas. Half the great astronomers living in the world today started with this as boys". I have "Norton's 2000 Star Atlas and Reference Handbook"edited by Ian Ridpath, Eighteenth Edition, Longman Group UK Limited 1989, ISBN 0-582-03163-X. I NEVER write in my books, yet I have pencilled in my own observations next to some of the star maps, this book invites you to personalise it in this way.
13) We mortals all aspire to take images like Robert Gendler, so why not buy his book and look at his images for inspiration? "A year in the life of the Universe"by Robert Gendler, with a Foreword by Timothy Ferris, published by Voyageur Press 2006 in association with Sky & Telescope, ISBN-13: 978-0-7603-2642-8. Beautifully produced, beautiful pictures, and very reasonably priced.
14) If you are interested in Cosmology and want an introduction into everything, then why not try "Bang! The complete history of the Universe"by Brian May (yes the Queen lead guitarist), Patrick Moore and Chris Lintott. Published by Carlton 2006, ISBN 1-84442-552-5. I am particularly fond of my copy, as Brian May has signed it for me himself! Thank you Bri!

The above list is anything but exhaustive, I have not included the interminable collection of "Hubble Space Photograph"books, for no other reason than I think you could choose any of these and be blown away by the images, no work in my personal opinion stands head and shoulders above the others. However, the books listed above are useful for both the beginner and the expert alike, so they should withstand the test of time in your ever-growing astronomical book collection.

APPENDIX 1

The Angular Size of Objects in the Sky

We measure the size of objects in the sky in terms of degrees. The angular diameter of the Sun or the Moon is close to half a degree. There are 60 minutes (of arc) to one degree (of arc), and 60 seconds (of arc) to one minute (of arc). Instead of including – of arc – we normally just use degrees, minutes and seconds.

1 degree = 60 minutes.

1 minute = 60 seconds.

1 degree = 3,600 seconds.

This tells us that the Rosette nebula, which measures 80 minutes by 60 minutes, is a big object, since the diameter of the full Moon is only 30 minutes (or half a degree).

It is clearly very useful to know, by looking it up beforehand, what the angular size of the objects you want to image are. If your field of view is too different from the object size, either much bigger, or much smaller, then the final image is not going to look very impressive. For example, if you are using a Sky 90 with SXVF-M25C camera with a 3.33 by 2.22 degree field of view, it would not be a good idea to expect impressive results if you image the Sombrero galaxy. The Sombrero galaxy measures 8.7 by 3.5 minutes and would appear as a bright, but very small patch of light in the centre of your frame. Similarly, if you were imaging at f#6.3 with the Nexstar 11 GPS scope and the SXVF-H9C colour camera, your field of view would be around 17.3 by 13 minutes, NGC7000 would not be the best target. In this case you would likely see just a general red glow of this massive H-11 region over the whole frame, with very little structure apparent. It is for these reasons why it is a good idea to get a "feel" for the relative size of objects compared to your field of view.

It is also a good idea to get a feel of the size of your night sky, and how big or small objects will appear in your whole hemisphere of night sky. For example, let's say you have a telescope imaging system with a relatively large field of view of 1 degree by 1 degree and you point your telescope randomly in the sky. What is the chance that you will land on a chosen object? In other words how many square degrees of sky are there in a hemisphere?

I need to use radians measure to easily make the link to square degrees and compare with a hemisphere. So for an ordinary planar angle (not a solid angle) we find that Pi radians are equivalent to 180 degrees. In terms of solid angle (square degrees, or Steradians), 4Pi Steradians are the solid angle subtended by a whole sphere, and so a hemisphere subtends 2Pi Steradians.

Let's go through the maths:

1) 4π Steradians = Whole sphere.
2) $180/\pi$ = degrees per radian.
3) $(180/\pi)^2$ = square degrees per Steradian.
4) $2\pi \text{ x } (180/\pi)^2$ = square degrees for a hemisphere = 20,626 square degrees.

So the whole hemisphere of the night sky covers 20,626 square degrees, and our large field of view covers only 1 square degree, so randomly pointing our telescope at the sky with the hope of finding an object gives us a one in 20,626 chance of stumbling upon it. The sky is a BIG place to hunt for small objects.

APPENDIX 2

The Designation of Deep-Sky Objects

I have no hesitation in letting you all know that I am totally and utterly confused by the designations used to name deep-sky objects.

This was clearly brought to my attention literally only a few days ago when I had just imaged the Christmas tree and Cone nebula area NGC2264 with the wide field setup. In the lower centre part of the image there is a very nice golden coloured open cluster – what is the name of this cluster? I looked everywhere and finally came upon it on Davide de Martin's absolutely superb "SkyFactory" site http://www.skyfactory.org/index.htm. Davide listed this open cluster as OCL494, didn't help too much as I had never heard of OCL either. What on Earth does OCL stand for?? Well I was a bit slow there I guess, but OCL stands for "Open Cluster" which I suppose makes sense. Still, I had never heard of this designation before, so it still wasn't very enlightening.

I put the same question out on the Forums and got two further replies back! One said it was Cr 105, and another said it was Tr 5 or Trumpler 5. Now I thought at first that the guy who had answered Cr 105 had got it completely wrong since if you "Google" Cr 105 you get back something that is the 3rd furthest object from the Sun. But then if you persevere and delve a little deeper you find out that Cr also stands for "Collinder" and Collinder 105 is indeed this nice little open cluster in NGC2264. Mind you, so is Trumpler 5 or Tr 5, so OCL494, Cr 105 and Tr 5 are all the same thing, the pretty little golden coloured open cluster in the Christmas tree region of Monoceros. I find this all unbelievably confusing, so in order to help myself as much as you, I have put together the very brief list below which includes some of the designations you will have seen associated with my deep-sky images in Chapter 11. This list is nowhere near comprehensive, it probably doesn't cover a 5th of the catalogues out there, but it may give you an idea where some of these obtuse names have come from. I have put the designations together in object list form.

General Deep-Sky Objects

There are only four designations that we come across on a regular basis for this category.

1) **M:** The well-known Messier catalogue named after Charles Messier who didn't want us confusing these vermin for precious comets. Total number of objects either 109 or 110, as an example M45 is the designation for the Pleiades open cluster in Taurus.
2) **Caldwell:** The Caldwell catalogue is named after Patrick Alfred Caldwell-Moore. Patrick came up with his own list of interesting objects not included in Messier's catalogue, and unlike the M objects, the Caldwell objects cover both hemispheres. Patrick did not use "Moore" as there would have been confusion with the Messier (M) objects. There are 109 Caldwell objects for you to discover. Caldwell 1 (the most northerly Caldwell object) is NGC 188 an open cluster in Cepheus.
3) **IC:** The "Index Catalogue". Most of the objects in this catalogue had been discovered photographically, and Dreyer created this list from two indexes between 1884-1894 and 1895-1907. IC1318 is the huge Gamma Cygni nebulosity in central Cygnus.
4) **NGC:** The well-known "New General Catalog". Again a Dreyer masterpiece, with most of the objects having been discovered visually. Go to this fantastic resource http://www.ngcic.org/default.htm to find every NGC object listed with an accompanying black and white photo and data! NGC7000 is the huge North America nebula in Cygnus.

Diffuse Nebula

Again there are four designations that I have come across with the diffuse nebulae, but many more exist.

1) **Ced:** "Cederblad" from S. Cederblad "Catalog of Bright Diffuse Galactic Nebulae" 1946. Ced 214 is a nice emission nebula in Cepheus.
2) **Gum:** From C.S. Gum, "A survey of Southern HII regions". THE Gum nebula (Gum 56) is a huge supernova remnant in the constellations Puppis and Vela. This huge region is something like 40 degrees across, and extremely faint.
3) **Sh2:** The "Sharpless" catalogue from S.Sharpless "A Catalogue of HII regions" 1959. Sharpless 2-155 is the Cave Nebula (also Caldwell 9).

4) **vdB:** From “van den Burgh” 1966 “A study of reflection nebulae”. The Elephant’s Trunk Nebula is vdB142 in the massive HII region IC1396 in Cepheus.

Dark Nebulae

There’s one very-well known catalogue here due to Barnard.

1) **B:** “Barnard”. From “Catalogue of 349 Dark Objects in the Sky”, 1927. The most famous member of this listing is of course B33, the Horsehead Nebula in Orion.

Open Clusters

This is the category that caused me all that confusion with the open cluster in NGC2264.

1) **OCL:** Now this actually took a lot of tracking down! It is apparently from “The Catalogue of Star Clusters and Associations”. OCL494 is that nice open cluster in NGC2264 in Monoceros.
2) **Tr:** From Trümpler “Preliminary results on the distances, dimensions and space distribution of open star clusters” 1930. Trumpler 14 has one of the highest concentrations of massive, luminous stars in the Galaxy. Situated towards the edge of a large molecular cloud Trumpler 14 is part of the Eta Carina complex, which contains eight star clusters.
3) **Cr:** “Collinder” From P.Collinder “On structured properties of open galactic clusters and their spatial distribution” 1931. A catalogue of 471 open clusters. Collinder 470 is the cluster associated with the Cocoon nebula [IC5146, Caldwell 19].
4) **Mel:** P.J. Melotte, “A catalogue of star clusters shown on the Franklin-Adams chart plates” 1915. Mel 111 is the Coma Berenices star cluster.

Galaxies

1) **Arp:** Halton Arp, “Atlas of Peculiar Galaxies”, 1966. My favourite Arp galaxy is NGC2276 (Arp 25) in Cepheus.
2) **Holm:** “Holmberg”. There are 9 Holmberg galaxies, 1,2,3 & 9 are in the M81 region and 4 & 5 are in the M101 region. You can just about make out Holmberg IX in the image of M81 in Chapter 11, it lies very close to M81 itself.
3) **Mrk:** “Markarian”. A catalogue of 1515 galaxies by B.E.Markarian et al. Markarian 421 is an active galaxy (blazar) in Ursa Major.

Galaxy Clusters

1) **Abell:** G.O. Abell, "The distribution of rich clusters of galaxies" 1958. Abell 2065 is a group of galaxies in Corona Borealis lying at a distance of 1.5 billion light years.

As I mentioned in the Introduction, this is a far from complete listing, and much more information can be found at http://www.gis.net/~vickers/images/Prefixes.pdf and at http://www.sctscopes.net/Glossaries/DSO_Database_Notations.pdf.

Physics World Article

The article that appeared in the September 2002 issue of Physics World was fairly heavily edited, to the extent that some of the meaning was lost entirely. Below you will find something a little closer to the original manuscript.

The Most Amazing 2½ Hours of my Life – So Far!

If you have been fortunate in your choice of day job, there comes a time around middle-age, when if you're very lucky you can afford to buy the toys you wished you'd had as a child. Some people at this crisis point in their lives opt for sports cars, or even powerful motorbikes – I on the other hand decided to buy a lovely 6-inch refracting telescope. This Helios branded telescope was incredibly powerful and gave me great views of the Planets, as well as nice views of the Orion nebula and the Andromeda galaxy. This was not a "goto" telescope, although it did come with a motor-controlled German Equatorial mount. The lack of computer-controlled "goto" was a firm decision on my part. I didn't want a computer finding all these wonderful deep-sky objects, I wanted to do that all by myself and have the "fun" of being able to hop from object to object without any computer-aided help. I have to admit I didn't have much fun! I was too inexperienced to find my way around the Heavens, and all those Messier and Caldwell objects still remained quite elusive. So after a couple of months I admitted defeat and bought a Celestron Nexstar 11 GPS telescope, computer-controlled and an on-board GPS system for accurate position location and for setting up the local time. This advanced telescope also tells you which stars you should align against to set it up for an evening's observing.

When the telescope finally arrived I could not wait to start observing. As with all new astronomical gear it was the proverbial "cloud-magnet" so it was a week or so before I could take it outside for its initial trial run. On the first clear evening I took it outside and followed the instructions (to the best of my ability at the time) and was quite disappointed with the instrument. The telescope couldn't even locate Jupiter even though it was blazing away up there for all with a pair of eyes to see. I later realised that this was due to me wrongly calibrating the telescope by mistaking Capella for Procyon and therefore invalidating the two-star align (I cannot remember what the second alignment star was, or how I could have possibly got "align success" with one guide star being completely wrong, but that's what happened).

After a few more days of overcast weather the evening of Thursday 2nd May 2002 finally fell clear. Out came the telescope, which I managed to set up properly this time by using the correct alignment stars. By 9.30 p.m. I had observed Jupiter and its moons for half an hour and it was now time to try the handset again to see if I could find those elusive Messiers and other deep-sky objects.

Not knowing what would be visible that night I simply typed in "M3" and off the telescope went. The motors whirred for maybe a minute, the last little whir being used to take up the gears' backlash. Expecting to see nothing through the eyepiece I was totally amazed to see a fuzzy ball of light glowing right in the middle of the eyepiece. Never having seen this object before [M3 is in fact a very nice example of a globular cluster], or anything like it, I thought this must have been a fluke and just a lucky "hit".

Pushing my luck I typed in another number: M88. Off went the telescope again and this time there was a galaxy right in the middle of the eyepiece! Now although several decades of scientific training should have told me that I couldn't have been so lucky twice in a row, I was not entirely convinced that this still wasn't just chance. However, I was very excited by all this and got my wife to take a look through the eyepiece. She was not too impressed – and I guess that for £3,000 you might expect to see at least the Starship Enterprise come into view.

I was not daunted. I went indoors and brought out my Norton's 2000.0 star atlas – I knew its day would come, and today was the day! It was about 10.00 p.m. when I opened the page on "Interesting Objects Maps 9 and 10, clusters, nebulae and galaxies". I typed in the name of the first object on the page – NGC 3132 – and set the telescope running. As in the early classic computer game – nothing happened! The handset indicated that the object was below the horizon and so it would not slew the telescope. I then went to the second object on the list – NGC 3242 – a planetary nebula in Hydra called the "ghost of Jupiter" – I'd never even heard of this one before. This time the motors whirred into life and the stars flew across the field of view. The motors wound down and I looked through the eyepiece just as the gear backlash was being taken up. An amazing glowing object quickly locked itself into the centre of the eyepiece. It was indeed the ghost of Jupiter, and a marvellous sight in the eyepiece!

Like a kid in a sweetshop, I now had this whole mass of clusters, nebulae and galaxies all ready to be viewed. All I had to do was type in the Messier or NGC number. This was so good it seemed unreal. During the next hour I worked my way down the list in Norton's and logged 27 out of the 34 objects on that page. It was an incredible experience. Getting greedy I turned to a different page in Norton's and started on another list of objects. If you have not seen M13 – the great globular cluster in Hercules – through a reasonably sized telescope, you must, it is simply breathtaking.

Just after midnight the sky clouded over and I had to stop. It was just as well really as I may have perished outside from the cold if I had not been forced to give up the evening's viewing. With regards to new discoveries [for me at least], it was, at the time, the most amazing two and a half hours of my life.

So how can I possibly summarise an experience like that? It is very difficult of course, but I can offer a comparison. A few years ago I bought a sub-notebook computer (a Libretto) that was a little larger than a videocassette and weighed just one kilogram. I fitted a 40Gb hard drive to this machine, which meant that I could carry in one hand – and have access to – not just the whole Encyclopaedia Britannica, but actually something like twenty times the data content of the whole of the Encyclopaedia Britannica. Even Star Trek (First Generation) was not that bold.

Now I have a computer-controlled telescope that can take me accurately to any object in the night sky just by typing the coordinates into a handset. This is a totally amazing piece of technology, and it is available to the general public at effectively very low cost, thanks to mass-production techniques. We may live in "interesting" times, but as Physicists we also live in truly amazing times.

Greg Parker is professor of photonics at the University of Southampton. He lives in the New Forest with his Wife, Son and Nexstar 11 GPS telescope.

Greg Parker

B.Sc. (1st Class Hons), Ph.D. C.Phys. C.Eng. F.Inst.P.

Greg is currently Professor of Photonics, and Head of the Nanoscale Systems Integration Group at the University of Southampton, Hampshire, U.K.

He was born in Barking, Essex (U.K.) on April 20th 1954. His first life changing experience was moving to New Zealand with his parents for a couple of years at age 12. This has led to a lifelong love of sandy beaches and good surf.

On leaving school he joined the Harwell and Culham laboratories and started a life in research. In 1975 he went to the University of Sussex to take his first degree in Physics, Mathematics, and Astronomy, he graduated in 1978 with 1st Class Honours. He then joined the Philips Research Laboratories at Redhill, Surrey, U.K. where he carried out research into new Silicon-based electronic devices. At the same time he enrolled for a Ph.D. at the University of Surrey on the work he was undertaking at Philips. He was awarded the Ph.D. in December 1982 and spent a further 5 years in different industries until he joined the University of Southampton in April 1987.

His University research is primarily into nanoscale optical devices and circuits, called Photonic Crystals, and in December 2000 he was made Professor of Photonics having begun his Academic career as a Junior Lecturer. In July 2001 he span out the photonics company Mesophotonics Ltd. based on his Photonic Crystal research. He has also created three other successful companies, one of which is his Consultancy business Parker Technology - http://hometown.aol.co.uk/mobiusltd/myhomepage/business.html

He has published over 120-refereed scientific papers, an undergraduate textbook on the physics of semiconductor devices, and has 14 filed Patents.

Greg's interest in Astronomy goes back to his very early childhood, but took a major boost when he lived within the Dartmoor National Park and had crystal clear skies (virtually no light pollution) for many nights of the year. He will never forget the awesome sight of a completely light pollution free sky as he looked out of his tent flap somewhere in the middle of Dartmoor on a warm Summer's evening in 1970. Today he is a CCD imager [http://mstecker.com/pages/appparker.htm] taking images of deep-sky objects with a technology that he never dreamed would exist in his lifetime. Since any sufficiently advanced technology is indistinguishable from magic (pace Clarke!) – he is clearly a firm believer in magic. His observatory can be seen at http://hometown.aol.co.uk/mobiusltd/myhomepage/photopersonal.html and his CCD imaging page can be found here http://hometown.aol.co.uk/mobiusltd /myhomepage/computer.html.

Greg lives in the New Forest, Hampshire, U.K. with his wife, son, cat, dog, Celestron Nexstar 11 GPS reflecting telescope, Sky 90 refractor, and Sony VAIO PCG-C1MHP. He is a fully certified nerd, Star Trek fan (original series), and very proud of it.

University Website Biography

Light has always been a defining factor in the life of Greg Parker, Professor of Photonics at the University of Southampton's School of Electronics and Computer Science.

It began with a young boy's love of the stars in the night sky and his fascination with his father's photographic collection, taken whilst he served in the First World War in Afghanistan & Egypt - he was actually in Luxor at the time

Howard Carter discovered Tutankhamen's tomb. This followed through to Greg's internationally acclaimed career in photonics and his own passion for capturing images of deep-sky objects. "These things go into your subconscious mind and make a really big impact although you don't realise it at the time. Then, years later, they resurface".

He vividly remembers the year the Daily Express featured the world's first ruby laser on its front cover. "It was around 1963–1964, three or four years after the laser was invented by Maiman in America," he recalls. This groundbreaking invention featured a ruby rod in the middle of a spiral Xenon flash tube and resulted in the 10-year-old disembowelling old watches to retrieve the rubies from their mechanisms.

"I dug the rubies out and got a magnifying glass to shine the Sun on them, hoping to make a laser. Of course I never did but I must have spent a year trying to do this and it was a big letdown", he says. The disappointment, however, didn't put him off: "That was when laser and light and flashtubes all started for me," he adds.

His early career was spent studying and working in industry. On leaving school he joined the Harwell & Culham laboratories, also taking an HNC in applied physics at Oxford Polytechnic. Having gained a taste for study, he went to Sussex University to read maths, physics and astronomy, graduating with first class honours in 1978. He then joined the Philips Research Laboratories in Redhill and enrolled for a PhD at the University of Surrey.

Greg joined Southampton's Department of Electronics, as it was then, in 1987. The move was partly prompted by the onset of change in the big research labs. "The grass was beginning to look a lot greener on the other side," he says. "Over the last 20 years a lot of those places have gone. You just can't play anymore and they've become very commercial. It's difficult to be inventive and innovative in industry, it doesn't accommodate free thinkers very well whereas a university will".

He steadily climbed the ranks at Southampton, specialising in novel growth systems for Silicon compatible materials and Silicon-based optoelectronics, and was appointed Chair of Photonics in 2000. During his time, Greg has designed, built and developed four LPCVD systems for the Microelectronics Group, published over 120-refereed papers, created three successful companies and is now group leader for the Nanoscale Systems Integration Group.

Around 1994 Greg had a Eureka moment with the creation of the world's first photonic crystal to work at optical wavelengths. The cry, however, didn't come until many months after their unintentional fabrication. "I had an EPSRC grant to make very thin, tall wires of single crystal Silicon," he says. "One of the early steps in the process is a sheet of Silicon with very deep holes going down into it. This was just a precursor to the process and didn't mean anything to me at the time."

The project was successfully completed and the samples were stored on the shelf. Six months later he was reading an article on photonic crystals - something he'd never heard of before but he now suspected the precursors could be linked to them. At a colleague's suggestion he took some careful measurements and realised he had created the world's first photonic crystal to work in the infrared region.

Greg convinced BTG plc to invest in the new photonic crystal technology and they invested £2.8 million in the spin out company Mesophotonics Limited in 2001. The technology allows light to be bent, routed and processed at a sub-millimetre scale resulting in a low cost, high volume production of integrated optical devices. "They are no more than an array of holes in an optical wave guide but by placing the holes in a certain manner you can create lots of different functionality," says Greg. A second round investment of £5.5 million was attracted in late 2003.

Another dimension to Greg's career in light is his interest in photography, first sparked by his father. "Dad was born in 1900 in the squalor of the East End and to get away from a pretty grim existence he joined up very early in World War I," he says, "for some reason he decided he was going to do photography out in Afghanistan." As a result the Parker boys grew up in a house surrounded by boxes of old photographs. "It obviously had a big impact on me and my older brother. He was a forensic photographer in Scotland Yard for 33 years," he adds.

In 1985 Greg created the first portable high-power, high-speed flash unit with a 1/40,000 second duration for his older brother Alan. A design that, 20 years after development, remains virtually unchanged and is still in use by award-winning nature photographer Andy Harmer.

Greg's own photography necessitates a slightly longer exposure time; he needs two to three hours for his deep-sky imaging work. In July 2006 he will stage his first exhibition of astrophotography at the University of Southampton library. The work will be entirely his own from beginning to end; all images on display will have been photographed, printed, mounted and framed by Parker himself.

He readily admits it can be an addictive obsession but one he is keen to share, and use to inspire others. He says, "I want other people to come in and see what a guy off the street did within a year with something you can buy commercially that someone with an ordinary job can afford. I wouldn't have believed it!"

Although Greg has been stargazing for over 40 years and has his own mini dome observatory in his New Forest garden, he only started imaging the skies in November 2004.

"CCD cameras with long exposure times have only been around for about ten years and it's only in the last five or six years you could get them at a reasonable price to do the job," he says. "I started imaging literally one year ago but the technology allows you to do it as long as you're au fait with computers".

The camera downloads the data which Greg then processes digitally using Adobe Photoshop. This enables him to manipulate the picture and bring out the faint detail. The result is a galaxy of prints that bring the splendours of the cosmos to life.

"That's why it's a great one for me," he says, "it brings together optics, the stars, photography and the computational processing. It's got the lot in the one hobby." And helps provides light relief to an academic career immersed in luminescence.

Postscript – and a Tiny Admission

I really hope you have found many useful tips and items in perusing this book that will help you on your way to create those spectacular "Gendler" type images. I am of course quite proud of the images you see within the pages of this book, and I was also quite proud, and very excited by, my very first images – which to be blunt were pretty hopeless in comparison with the ones you see reproduced here. But history has also taught me that given sufficient time and effort, the images in this book will also be relegated to the bin as I continue to learn and develop this fascinating hobby.

So to the admission – as I write these words, I have only been imaging for around 2 years! Some of the images you see will have been taken a few weeks later than 2 years, but the bulk will have been taken within 18 months of starting the hobby. This gives you a baseline reference of what can be done given sufficient dedication to the task of sorting out your complete system out; that is your imaging system, and your digital darkroom.

It might seem a little presumptuous to write a book such as this with so little "real" imaging experience, and I am very well aware of the gaping holes in my understanding of astronomical imaging, and astronomy in general, but I am also aware of the pitfalls of trying to write an Introductory book from the perspective of an "expert". I have written a top-selling introductory text on Semiconductor Physics, and I wrote this book within two years of giving the first lectures on the subject. The book has been extremely well received by students around the World, and I have many letters of thanks from students who were struggling with the subject until they discovered my book. Why should this be so? It is because I *did* write the book so soon after teaching the subject. I could still clearly remember all those silly little problems that come along when studying a new subject for the first time, and I could answer those problems in a simple and straightforward way that appealed to new students of the subject. Also, in writing the book so soon after teaching the Physics, I was still very far from being an “expert” in the subject, and still had clear recollections of all those irritating little things that had me scratching my head for hours at a time. I know that if I had left writing the book for a few more years I would not have been able to help the beginner as much as I have done, simply because I would have forgotten about all those silly little things that caused me so much trouble, they would have become “obvious” with the passing of time. How do I know this? Because I am at that stage now, I know semiconductor physics well enough that already some of the topics that caused me great difficulty are now trivial and not worthy of my time – this in turn makes me less useful to the new student who is finding difficulty with the subject – I am already beginning to “dismiss the base rungs by which we ascend”.

So, that’s why I moved so quickly to get this book written. I hope it has been instructional and answered some of the basic questions that you might have had burning inside you. I have certainly really enjoyed writing it.

It only leaves me to wish you clear, dark skies, and many, many hours of happy deep-sky imaging!

All the best,
Greg Parker
Brockenhurst
U.K. 2006.

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