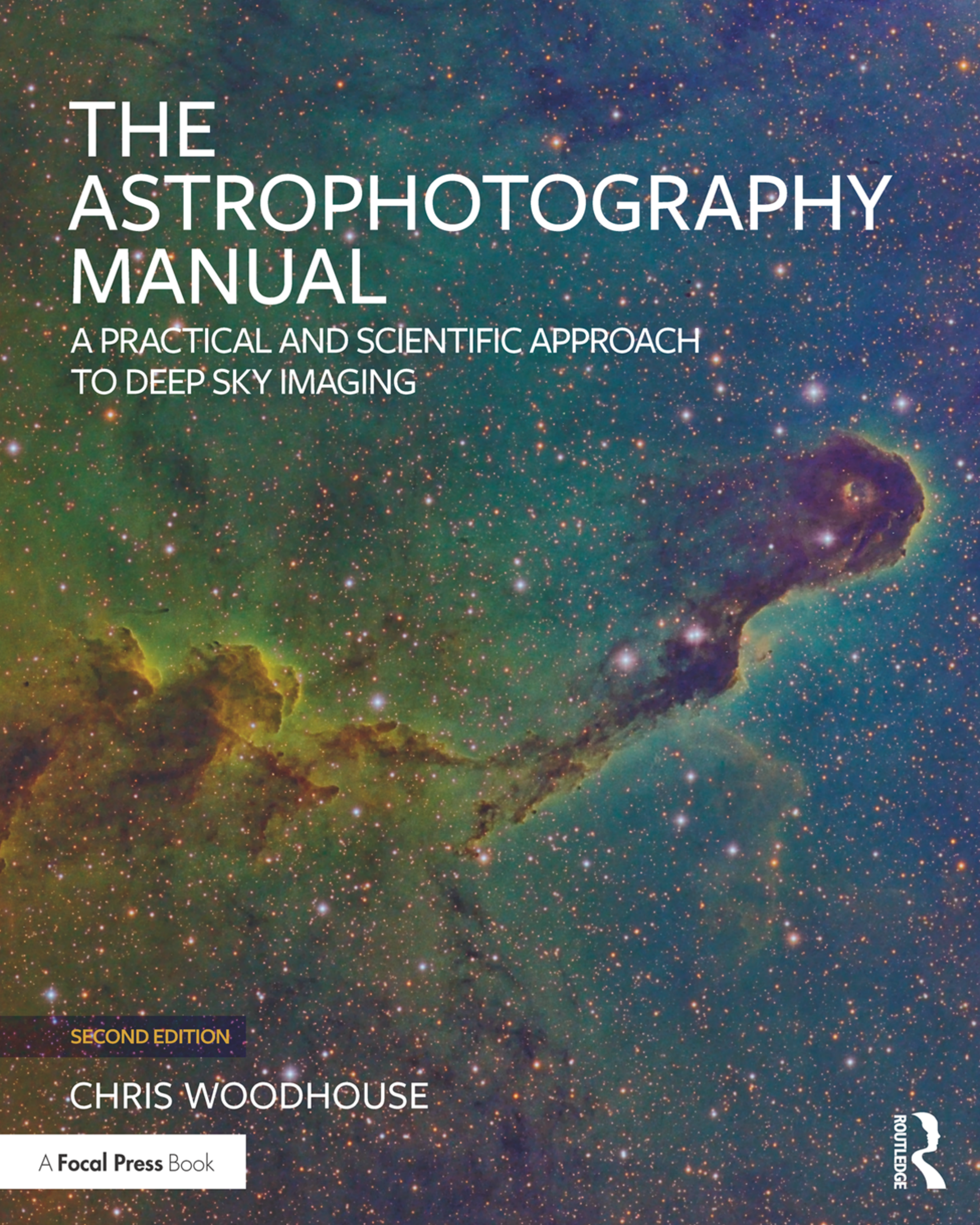

THE ASTROPHOTOGRAPHY MANUAL

A PRACTICAL AND SCIENTIFIC APPROACH TO DEEP SKY IMAGING

SECOND EDITION

CHRIS WOODHOUSE

A Focal Press Book

ROUTLEDGE

The Astrophotography Manual

A Practical and Scientific Approach to Deep Sky Imaging

2nd Edition

Chris Woodhouse

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Contents

I was once asked by a 7-year old,
“Why do you take pictures of space”?

After a moment’s reflection I replied,
“Because it is difficult.”

Preface to the Second Edition

An edition with further refinement, insights and to expand the hobbyist's horizons.

The last four years have been a whirlwind of activity. From a complete newbie to a credible amateur has been both challenging and huge fun. The first edition was constrained by time and economics. I'm glad to say the feedback has been extremely encouraging; the pitch of the book was just right for the aspiring amateur and intermediate astrophotographer and in particular, readers liked the cogent write-ups on PixInsight, the fact it was up to date with the latest trends and, oh, by the way, please can we have some more? Some topics and imaging challenges were left untold in the first edition and since new developments continue to flourish in astrophotography, there is now sufficient content to fill an effectively "new" book.

When I authored my original photographic book ,*Way Beyond Monochrome*, it was already 350 pages long. The second edition, with considerable new content, pushed that to over 530 pages. That took 6 years to write, which was acceptable for the mature subject of classical monochrome photography. The same cannot be said of astrophotography and I thought it was essential to reduce the project time to a few years, in order to preserve its relevance.

I only write about things I have direct experience of; so time and money do limit that to some extent. Fortunately I have owned several systems, in addition to many astronomy applications for Mac OSX, Windows and Apple iOS. As time goes by, one slowly acquires or upgrades most of your equipment. There comes a point, after several years, that the cumulative outlay becomes daunting to a newcomer. As a result I have introduced some simpler, lower-cost and mobile elements into the hardware and software systems.

In the first edition, I deliberately dedicated the early chapters to the fundamentals. These included a brief astronomy primer, software and hardware essentials and some thought-provoking content on the practical limitations set by the environment, equipment and camera performance. I have not edited these out as these are still relevant. In the second edition, however, the new content concentrates on new developments; remote control, imaging techniques and an expanded section on PixInsight image processing.

Many readers of the first edition particularly liked the practical chapters and found the processing flow diagrams very useful. You should not be disappointed; in the second edition, after the new PixInsight tutorials, there are several case studies covering new techniques, again featuring PixInsight as the principal processing application. These illustrate the unique challenges posed by a particular image, with practical details on image acquisition, processing and from using a range of equipment.

Astrophotography still has plenty of opportunity for small home-made gizmos and there are additional practical projects too in this edition to stretch the user, including software and hardware development. After some further insights into diagnostics, there is an extensive index, glossary, bibliography and supporting resources. The website adds to the book's usefulness and progression to better things:

www.digitalastrophotography.co.uk

Clear skies.

chris@digitalastrophotography.co.uk

"Supermoon" Lunar eclipse, September 2015 (This is not a book on solar system astrophotography and any resemblance is purely coincidental.)

About the Author

My wife is resolved to the fact that I do not have "normal" hobbies.

Chris was born in England and from his teenage years was fascinated by the natural sciences, engineering and photography, all of which he found more interesting than football. At the weekend he could be found building or designing some gadget or other. At school he used a slide-rule and log books for his exams at 16. Two years later, scientific calculators had completely displaced them. He studied Electronics at Bath University and by the time he had completed his masters degree, the computer age was well under way and 8-bit home computers were common. After a period designing military communication and optical gauging equipment, as well as writing software in Forth, Occam, C++ and Assembler, he joined an automotive engineering company.

As a member of the Royal Photographic Society, he gained LRPS and ARPS distinctions and pursued a passion for all forms of photography, mostly using traditional monochrome techniques. Not surprisingly, this hobby, coupled with his professional experience led him to invent and patent several highly regarded f/stop darkroom meters and timers, still sold throughout the world. During that time digital cameras evolved rapidly and photo ink-jet printers slowly overcame their annoying limitations. Resisting the temptation of the early optimistic digital promises, he authored a book on traditional monochrome photography, *Way Beyond Monochrome*, to critical acclaim and followed with a second edition to satisfy the ongoing demand.

Digital monochrome appeared to be the likely next avenue for his energy, until an eye-opening presentation on astrophotography renewed a dormant interest in astronomy, enabled by the digital cameras. Astrophotography was the perfect fusion of science, electronics and photography. Like many before, his first attempts ended in frustration and disappointment, but he quickly realized the technical challenges of astrophotography responded well to a methodical and scientific approach. He found this, together with his photographic eye and decades of printing experience, was an excellent foundation to produce beautiful and fascinating images from a seemingly featureless sky. The outcome was *The Astrophotography Manual*, acclaimed by many readers as the best book on the subject in the last 15 years and he was accepted as a Fellow of the Royal Astronomical Society, founded in 1820.

Acknowledgements

This book and the intensive research that it demands would not have been possible without the ongoing support of my wife Carol (who even dug the footings for my observatory) and the wider on-line community. Special thanks go to Sam Anahory and Lawrence Dunn for contributing a guest chapter each on their respective specialty.

This edition is dedicated to Jacques Stiévenart, who piqued my interest in photography and astronomy. In the 1970s, he showed me how to silver a mirror and print a small black and white picture of the moon, taken through his home-made 6-inch Newtonian using a Zeiss Ikonta held up to the eyepiece. It was made all the more exotic since we only had a few words of each other's language. Such moments often inspire you when you are a kid.

It is one of the pleasures of this hobby to share problems and solutions with other hobbyists and this edition builds upon the knowledge and wisdom of many astrophotographers. This hobby is a never-ending journey of refinement, knowledge and development. It is a collaborative pursuit and I welcome any feedback or suggestions for this book or the next edition.

Chris Woodhouse ARPS, FRAS

Introduction

It is always humbling to consider the great achievements of the ancients, who made their discoveries without access to today's technology.

Astronomy is such a fascinating subject that I like to think that astrophotography is more than just making pretty pictures. For my own part, I started both at the same time and I quickly realized that my knowledge of astronomy was deficient in many areas. Reading up on the subject added to my sense of awe and also made me appreciate the dedication of astronomers and their patient achievements over thousands of years. A little history and science is not amiss in such a naturally technical hobby. Incredibly, the science is anything but static; in the intervening time since the last book, not only has the general quality of amateur astrophotography improved greatly, but we have sent a probe 6.5 billion km to land on a comet traveling at 65,000 km/h and found firm evidence of water on Mars. In July 2015 the New Horizons space probe, launched before Pluto was downgraded to a minor planet, grazed past the planet 12,000 km from its surface after a 9.5 year journey of 5 billion km. (It is amazing to think that its trajectory was calculated using Newton's law of universal gravitation, published in 1687.)

From the earliest days of human consciousness, mankind has studied the night sky and placed special significance on eclipses, comets and new appearances. With only primitive methods, they quickly realized that the position of the stars, the Moon and the Sun could tell them when to plant crops, navigate and keep the passage of time. Driven by a need for astrology as well as science, their study of the heavens and the belief of an Earth-centric universe was interwoven with religious doctrine. It took the Herculean efforts of Copernicus, Galileo and Tycho, not to mention Kepler, to wrest control from the Catholic Church in Europe and define the heliocentric solar system with elliptical orbits, anomalies and detailed stellar mapping.

Astronomers in the Middle East and in South America made careful observations and, without instruments, were able to determine the solar year with incredible accuracy. The Mayans even developed a sophisticated calendar that did not require adjustment for leap years. Centuries later, the Conquistadors all but obliterated these records at a time when ironically Western Europe was struggling to align their calendars with the seasons. (Pope Gregory XIII eventually proposed the month of

Year [Circa]	Place	Astronomy Event
2700 BC	England	Stonehenge, in common with other ancient archaeological sites around the world, is clearly aligned to celestial events.
2000 BC	Egypt	First Solar and Lunar calendars
1570 BC	Babylon	First evidence of recorded periodicity of planetary motion (Jupiter) over a 21-year period.
1600 BC	Germany	Nebra sky disk, a Bronze age artifact, which has astronomical significance.
280 BC	Greece	Aristarchus suggests the Earth travels around the Sun, clearly a man before his time!
240 BC	Libya	Eratosthenes calculates the circumference of the earth astronomically.
125 BC	Greece	Hipparchus calculates length of year precisely, notes Earth's rotational wobble.
87 BC	Greece	Antikythera mechanism, a clockwork planetarium showing planetary, solar and lunar events with extraordinary precision.
150 AD	Egypt	Ptolemy publishes *Almagest*; this was the astronomer's bible for the next 1,400 years. His model is an Earth-centered universe, with planet epicycles to account for strange observed motion.
1543 AD	Poland	Copernicus, after many years of patient measurement, realizes the Earth is a planet too and moves around the Sun in a circular orbit. Each planet's speed is dependent upon its distance from the Sun.
1570 AD	Denmark	Tycho Brahe establishes a dedicated observatory and generates first accurate star catalog to 1/60th degree. Develops complicated solar-system model combining Ptolemaic and Copernican systems.
1609 AD	Germany	Kepler works with Tycho Brahe's astronomical data and develops an elliptical-path model with planet speed based on its average distance from the Sun. Designs improvement to refractor telescope using dual convex elements.
1610 AD	Italy	Galileo uses an early telescope to discover that several moons orbit Jupiter and Venus and have phases. He is put under house arrest by the Inquisition for supporting Kepler's Sun-centered system to underpin his theory on tides.

fig.1a An abbreviated time-line of the advances in astronomy is shown above and is continued in fig.1b. The achievements of the early astronomers are wholly remarkable, especially when one considers not only their lack of precision optical equipment but also the most basic of requirements, an accurate timekeeper.

Year [Circa]	Place	Astronomy Event
1654 AD	Holland	Christiaan Huygens devises improved method for grinding and polishing lenses, invents the pendulum clock and the achromatic eye-piece lens.
1660 AD	Italy	Giovanni Cassini identifies 3 moons around Saturn and the gap between the rings that bear his name. He also calculates the deformation of Venus and its rotation.
1687 AD	England	Isaac Newton invents the reflector telescope, calculus and defines the laws of gravity and motion including planetary motion in *Principia*, which remained unchallenged until 1915.
1705 AD	England	Edmund Halley discovers the proper motion of stars and publishes a theoretical study of comets, which accurately predicts their periods.
1781 AD	England	William Herschel discovers Uranus and doubles the size of our solar system. Notable astronomers Flamsteed and Lemonnier had recorded it before but had not realized it was a planet. Using his 20-foot telescope, he went on to document 2,500 nebular objects.
1846 AD	Germany	Johann Galle discovers Neptune, predicted by mathematical modelling.
1850 AD	Germany	Kirchoff and Bunsell realize Fraunhofer lines identify elements in a hot body, leading to spectrographic analysis of stars.
1908 AD	U.S.A.	Edwin Hubble provides evidence that some "nebula" are made of stars and uses the term "extra-galactic nebula" or galaxies. He also realizes a galaxy's recessional velocity increases with its distance from Earth, or "Hubble's law", leading to expanding universe theories.
1916 AD	Germany	Albert Einstein publishes his *General Theory of Relativity* changing the course of modern astronomy.
1930 AD	U.S.A.	Clyde Tombaugh discovers planet Pluto. In 2006, Pluto was stripped of its title and relegated to the Kuiper belt.
1963 AD	U.S.A.	Maarten Schmidt links visible object with radio source. From spectra realizes quasars are energetic receding galactic nuclei.
1992 AD	U.S.A.	Space probes COBE and WMAP measure cosmic microwaves and determines the exact Hubble constant and predicts the universe is 13.7 billion years old.
2012 AD	U.S.A.	Mars rover *Curiosity* lands successfully and begins exploration of planet's surface.
2014 AD	ESA	*Rosetta* probe touches down on comet 67P after 12-year journey.
2015 AD	ESA	*New Horizons* probe flies past Pluto

fig.1b Astronomy accelerated once telescopes were in common use, although early discoveries were sometimes confused by the limitations of small aperture devices.

October be shortened by 10 days to re-align the religious and hence agricultural calendar with the solar (sidereal) year. The Catholic states complied in 1583 but others like Britain delayed until 1752, by which time the adjustment had increased to 11 days!)

The invention of the telescope propelled scholarly learning, and with better and larger designs, astronomers were able to identify other celestial bodies other than stars, namely nebula and much later, galaxies. These discoveries completely changed our appreciation of our own significance within the universe. Even though the first lunar explorations are over 45 years behind us, very few of us have looked at the heavens through a telescope and observed the faint fuzzy patches of a nebula, galaxy or the serene beauty of a star cluster. To otherwise educated people it is a revelation when they observe the colorful glow of the Orion nebula appearing on a computer screen or the fried-egg disk of the Andromeda Galaxy taken with a consumer digital camera and lens.

This amazement is even more surprising when one considers the extraordinary information presented on television shows, books and on the Internet. When I have shared back-yard images with work colleagues, their reaction highlights a view that astrophotography is the domain of large isolated observatories inhabited with nocturnal Physics students. This sense of wonderment is one of the reasons why astrophotographers pursue their quarry. It reminds me of the anticipation one gets as a black and white print emerges in a tray of developer. The challenges we overcome to make an image only increase our satisfaction and the admiration of others, especially those in the know. When you write down the numbers on the page, the exposure times, the pointing accuracy and the hours taken to capture and process an image, the outcome is all the more remarkable.

New Technology

The explosion of interest and amateur ability fuels the market place and supports an increasing number of astro-based companies. Five years on after writing the first edition, the innovation and value engineering continue to advance affordable technology in the form of mechanics, optics, computers, digital cameras and in no small way, software. The digital sensor was chiefly responsible for revolutionizing astrophotography but it itself is now at a crossroads. Dedicated imaging cameras piggy-back off the sensors from the digital camera market, typically DSLRs. At one time CCDs and CMOS sensors were both used in abundance. Today, CMOS sensors dominate the market place and are the primary focus of sensor development, increasing in size and pixel density. Their pixel size, linearity and noise performance are not necessarily ideal for astrophotography. New CCDs do emerge from Sony but these are a comparative rarity and are typically smaller than APS-C. It will be interesting to see what happens next; it may well drive a change in telescope optics to move to small field, shorter focal length and high resolution imaging. At the same time, the CCD sensor in my QSI camera has become a teenager.

It was not that long ago that a bulky Newtonian reflector was the most popular instrument and large aperture refractors were either expensive or of poor quality and computer control was but a distant dream. The increasing market helps to make advanced technology more affordable or downsize high-end features into smaller units, most noticeably in portable high-performance mounts and using the latest manufacturing techniques to produce large non-spherical mirrors for large reflector telescopes.

At the same time computers, especially laptops, continue to reduce in price and with increased performance and battery life. Laptops are not necessarily ideal for outdoor use; many are switching to miniature PCs (without displays or keyboards) as dedicated controllers, using remote desktop control via network technologies. New software required to plan, control, acquire and process images is now available from many companies at both amateur and professional levels. Quite a few are free, courtesy of generous individuals. At the same time, continued collaboration on interface standards (for instance ASCOM weather standards) encourages new product development, as it reduces software development costs and lead-times. If that was not enough, in the last few years, tablet computing and advanced smart phones have provided alternative platforms for controlling mounts and can display the sky with GPS-located and gyroscopically-pointed star maps. The universe is our oyster.

Year [Circa]	**Astrophotography Event**
1840	First successful daguerreotype of Moon
1850	First successful star picture
1852	First successful wet-plate process
1858	Application of photography to stellar photometry is realized
1871	Dry plate process on glass
1875	Spectra taken of all bright stars
1882	Spectra taken of nebula for first time
1883	First image to discover stars beyond human vision
1889	First plastic film base, nitro cellulose
1920	Cellulose acetate replaces nitro cellulose as film base
1935	Lowered temperature was found to improve film performance in astrophotography applications
1940	Mercury vapor film treatment used to boost sensitivity of emulsion for astrophotography purposes
1970	Nitrogen gas treatment used to temporarily boost emulsion sensitivity by 10x for long exposure use
1970	Nitrogen followed by Hydrogen gas treatment used as further improvement to increase film sensitivity
1974	First astrophotograph made with a digital sensor
1989	SBIG release ST4 dedicated astrophotography CCD camera
1995	By this time, digital cameras have arguably ousted film cameras for astrophotography.
2004	Meade Instruments Corp. release affordable USB controlled imaging camera. Digital SLRs used too.
2010	Dedicated cameras for astrophotography are widespread, with cooling, combined guiders; in monochrome and color versions. Consumer digital cameras too have improved and overcome initial long exposure issues.
2013	New low-noise CCDs commonly available with noise levels below 1 electron per square micron
2015-	Low-noise CMOS chips starting to make inroads into popular astrophotograhy cameras.

fig.2 A time-line for some of the key events in astrophotography. It is now 30 years since the first digital astrophotograph was taken and I would argue that it is only in the last 5 years that digital astrophotography has really grown exponentially, driven by affordable hardware and software. Public awareness has increased too, fuelled by recent events in space exploration, documentaries and astrophotography competitions.

Scope of Choice

Today's consumer choice is overwhelming. Judging from the current rate of change, I quickly realized that it is an impossible task to cover all equipment or avenues in detail without being variously out of date at publishing. Broad evaluations of the more popular alternatives are to be found in the text but with a practical emphasis and a process of rationalization; in the case of my own system, to deliver quick and reliable setups to maximize those brief opportunities that the English weather permits. My setup is not esoteric and serves as a popular example of its type, ideal for explaining the principles of astrophotography. Some things will be unique to one piece of equipment or another but the principles are common. In my case, after trying and using several types of telescope and mount, I settled on a hardware and software configuration that works as an affordable, portable solution for deep sky and occasional planetary imaging. By choosing equipment at the upper end of what can be termed "portable", when the exertion of continual lifting persuaded me to invest in a permanent observatory, I was able to redeploy all the equipment without the need for upgrading. Five years on, astronomy remains a fascinating subject; each image is more than a pretty picture as a little background research reveals yet more strange phenomena and at a scale that beggars the imagination.

About This Book

I wrote the first edition with the concept of being a fast track to intermediate astrophotography. This was an ambitious task and quite a challenge. Many astrophotographers start off with a conventional SLR camera and image processing software like Photoshop®. In the right conditions these provide good images. For those users there are several excellent on-line and published guides that I note in the bibliography. It was impossible to cover every aspect in detail, limited by time, page count and budget. My aim in this book is to continue where I left off: covering new ideas, advanced image processing, more advanced practical projects and fresh practical examples that cover new ground. This book is firmly focused on deep-sky imaging; my own situation is not ideal for high magnification work and any references to planetary imaging are made in passing.

The book is divided into logical sections as before: The first section covers the basics of astronomy and the limitations of physics and the environment. The second section examines the tools of the trade, brought up to date with new developments in hardware and software, including remote control, automation and control theory. The third section continues with setting up and is revised to take advantage of the latest technology. In the following section we do the same for image capture, looking at developments in process automation, guiding, focusing and mosaics.

The PixInsight content in the first book was very well received and several readers suggested I write a PixInsight manual. I am not a guru by any means and it would take many years of work to be confident enough to deliver an authoritative tome. Writing for me is meant to be a pleasure and the prospect of a software manual is not terribly exciting to either write, or I suspect, to read. Bowing to this demand, however, the image calibration and processing section provides further in-depth guides to selected processes in PixInsight and additionally uses PixInsight to process the new practical imaging assignments.

The assignments section has been revised and expanded: A couple of case studies have been removed, including the solitary planetary example. Some specialize in this field and they are best suited to expand on the extreme techniques required to get the very best imaging quality at high magnifications. As before, each case study considers the conception, exposure and processing of a particular object that, at the same time, provides an opportunity to highlight various unique techniques.

A worked example is often a wonderful way to explain things and these case studies deliberately use a variety of equipment, techniques and software. More recently these use my software of choice, namely Sequence Generator Pro, PHD2, PixInsight and Photoshop. The subjects are typically deep-sky objects that present unique challenges in their acquisition and processing. Practical examples are even more valuable if they make mistakes and we learn from them. Some examples deliberately include warts and present an opportunity to discuss remedies.

On the same theme, things do not always go to plan and in the appendices before the index and resources, I have updated the chapter on diagnostics, with a small gallery of errors to help with your own troubleshooting. Fixing problems can be half the fun but when they resist several reasoned attempts, a helping hand is most welcome. In my full-time job I use specialized tools for root-cause analysis and I share some simple ideas to track down gremlins. Astrophotography and astronomy in general lends itself to practical invention and not everything is available off the shelf. To that end, new practical projects are included in the appendices as well as sprinkled throughout the book. These include a comprehensive evaluation of collimation techniques for a Ritchey Chrétien telescope and ground-breaking chapters on designing and implementing an observatory controller, its ASCOM driver and a Windows Observatory controller application. It also includes a chapter on setting up a miniature PC as an imaging hub, with full remote control.

As in the first edition, I have included a useful bibliography and a comprehensive index. For some reason bibliographies are a rarity in astrophotography books. As Sir Isaac Newton once wrote, “If I have seen further it is by standing on the shoulders of Giants.” The printed page is not necessarily the best medium for some of the resources and the supporting website has downloadable versions of spreadsheets, drawings, program code, videos and tables, as well as any errata that escaped the various editors. They can be found at:

www.digitalastrophotography.co.uk

Share and enjoy.

Astronomy Primer

M45 (Open Cluster) or Pleiades, showing reflection nebulosity of interstellar medium

The Diverse Universe of Astrophotography

A totally absorbing hobby, limited only by your imagination, patience and weather.

Amateur astrophotography can be an end in itself or a means of scientific research and in some cases, a bit of both. It might be a surprise for some, but amateur astronomers, with differing degrees of patronage, have significantly contributed to our understanding of the universe, in addition to that from the scientific institutions. As an example, Tom Boles in Suffolk, England has identified over 149 supernova with his private observatory; these brief stellar explosions are of scientific importance and their spectra help determine the size and expansion of the universe. The professional large observatories cannot cover the entire sky at any one time and so the contribution from thousands of amateurs is invaluable, especially when it comes to identifying transient events. I might chance upon something in my lifetime but I have less lofty goals in mind as I stand shivering under a mantle of stars.

Astrophotography is not one hobby but many: There are many specialities and individual circumstances, as well as purpose. Depending on viewing conditions, equipment, budget and available time, amateur astronomers can vary from occasional imagers using a portable setup, to those with a permanent installation capable of remote control and operational at a moment's notice. The subjects are just as numerous too; from high magnification planetary, and deep sky imaging, through medium and wide-field imaging in broad or selective wavelengths. Then there is lunar and solar photography as well as environmental astrophotography, which creates wonderful starry vistas. As with any hobby, there is a law of diminishing returns and once the fundamentals are in place, further enhancements often have more to do with convenience and reliability than raw performance. My own setup is fit for purpose and ultimately its limiting factor is my location. Any further purchase would do little to increase my enjoyment. Well, that is the official line I told my better half!

fig.1 The lunar surface is best shown with oblique lighting, in the area between light and shadow. A different part of the Moon is revealed on subsequent nights. This picture and the one below were taken with a micro 4/3rds camera body, fitted to the end of a modest telescope.

A Public Health Warning

The next few pages touch on some of the more common forms of astrophotography and the likely setups. Unlike digital photography, one-upmanship between astrophotographers is rare but even so, once you are hooked, it is tempting to pursue an obsessive frenzy of upgrades and continual tuning. It is important to realize that there is a weak link in the imaging chain and that is often your location, light pollution, weather, stable atmosphere, obscuration and family commitments. Suffice to say, I did warn you!

Lunar Imaging

The Moon is the most obvious feature of the night sky and easily passed over for more sexy objects. Several astronomers, including the late Sir Patrick Moore, specialized in lunar observation and photography. Being a large and bright object, it does not mandate extreme magnifications or an expensive cooled CCD camera. Many successful lunar photographs use a modest refractor telescope with a consumer CCD-based webcam adapted to fit into the eyepiece holder. The resultant video image jumps around the screen and

fig.2 A full moon has a serene beauty but the reflected illumination adds considerably to any light pollution. This is likely to restrict any other imaging to bright planets or clusters. I have a theory that full moons only occur on clear nights.

fig.3 The Rosette Nebula appears as a small cluster of stars when observed through a short telescope. The nebula is almost invisible, even in a dark sky. Our eyes are the limiting factor; at low intensities, we have monochromatic vision and in particular, our eyes are less sensitive to deep red wavelengths, which is the dominant color for many nebulae.

fig.4 By way of comparison, if a digital camera is substituted for the human eye, we are able to record faint details and in color too. The above image has been mildly processed with a boost in shadow detail to show the detailed deep red gas clouds in the nebula. This is a large object, approximately 3x wider than the Moon.

many frames are blurred. The resulting video is a starting point; subsequent processing discards the blurred frames and the remainder are aligned and combined to make a detailed image. Increasingly, digital SLRs are used for lunar photography, either in the increasingly popular video modes or take individual stills at high shutter speeds. The unique aspect of the Moon, and to some extent some planets too, is that their appearance changes from night to night. As the Moon waxes and wanes, the interesting boundary between light and shade, the terminator, moves and reveals the details of a different strip of the lunar surface. No two nights are precisely the same.

Planetary Imaging

The larger and brighter planets, Jupiter, Saturn, Venus and to a lesser extent Mars, have very similar challenges to that of lunar imaging. These bright objects require short exposures but with more magnification, often achieved with the telescope equivalent of a tele-converter lens. A converted or dedicated webcam is often the camera of choice in these situations since its small chip size is ideally matched to the image size. Some use digital SLRs but the larger sensors do create large video files and only at standard video frame rates between 24 frames per second (fps) and 60 fps. I have made pleasing images of Jupiter and Mars using just a refractor with a focal length of just over 900 mm combined with a high-quality 5x tele-converter and an adapted webcam.

These and the smaller planets pose unique challenges though and are not the primary focus of this book. Not only are they are more tricky to locate with portable setups but to show sufficient surface detail requires high magnification. At high magnification, every imperfection from vibration, tracking errors, focus errors and most significantly, atmospheric seeing is obvious. The work of Damian Peach sets the standard for amateur imaging. His astonishing images are the result of painstaking preparation and commitment and his website (*www.damianpeach.com*) is well worth a look.

Solar Imaging

Solar imaging is another rewarding activity, especially during the summer months, and provided it is practised with extreme care, conventional telescopes can be employed using a purpose-designed solar filter fitted to the main and guide scope. Specialist solar scopes are also available which feature fine-tuned filters to maximize the contrast of the Sun's surface features and prominences. The resulting bright image can be photographed with a high-speed video camera or a still camera.

Large Deep Sky Objects

One of the biggest surprises I had when I first started imaging was the enormous size of some of the galaxies and nebulae; I once thought the Moon was the biggest object in the night sky. Under a dark sky one may just discern the center of the Andromeda Galaxy with the naked eye but the entire object span is six times the width of our Moon. It is interesting to ponder what ancient civilizations would have made of it had they perceived its full extent. These objects are within the grasp of an affordable short focal-length lens in the range 350-500 mm. At lower image magnifications accurate star tracking is less critical and even in light polluted areas, it is possible to use special filters and reduce the effect of the ever-present sodium street light. Successful imagers use dedicated CCD cameras or digital SLRs, either coupled to the back of a short telescope or with a camera telephoto lens. Typically, the camera system fits to a motorized equatorial mount and individual exposures range from a few 10s of seconds to 20 minutes. Short focal length telescopes by their nature have short lengths and smaller diameters with correspondingly lightweight focus tubes. The technical challenges associated with this type of photography include achieving fore-aft balancing and the mechanical performance of the focus mechanism and tube as a result of a heavy camera hanging off its end. If you live under a regular flight path, a wide field brings with it the increased chance of aircraft trails across your images.

Small Deep Sky Objects

The smaller objects in the night sky require a longer focal length to make meaningful images, starting at around 800 mm. As the magnification increases, the image brightness reduces, unless the aperture increases at the same rate. This quickly becomes a lesson in practicality and economics. Affordable refractor telescopes at the time of writing have typically a 5-inch or smaller aperture and at the same time, reflector telescopes have between 6- and 10-inch apertures. Larger models do exist, to 16 inches and beyond, but come with the inherent risk of an overdraft and a hernia. The longer exposures required for these highly magnified objects benefit from patience, good tracking and a cooled CCD camera. At higher magnifications, the effect of atmospheric turbulence is noticeable and it is usually the weakest link in the imaging chain.

Environmental Imaging

I have coined this phrase for those shots that are astronomy-related but typically involve the surrounding landscape. Examples include images of the Northern Lights or a wide-field shot of the Milky Way overhead. Long exposures on a stationary tripod show the customary star trails, but shorter exposures (or slow tracking) with a wide-angle lens can render foreground and stars sharply at the same time. Digital SLRs and those compacts with larger sensors make ideal cameras for these applications and a great place to start with no additional cost. At a dark field site, a panorama of the Milky Way makes a fantastic image.

Other Activities

Spectroscopic analysis, supernova hunting, asteroid, minor planet, exoplanet, comet and satellite tracking are further specializations for some astrophotographers. Supernova hunting requires a computer-controlled mount directing a telescope to briefly image multiple galaxies each night, following a programmed sequence. Each image in turn is compared with prior images of the same object. The prize is not a pretty image but the identification of an exploding star. Each of these specialities have interesting technical challenges associated with object location, tracking and imaging. For instance, on *Atlantis*' last flight it docked with the International Space Station. Thierry Legault imaged it with a mobile telescope as it transited the Sun. The transit time was less than a second and he used a digital SLR, operating at its top shutter speed and frame rate to capture a sequence of incredible images, paparazzi-style. His amazing images can be seen at *www.astrophoto.fr*.

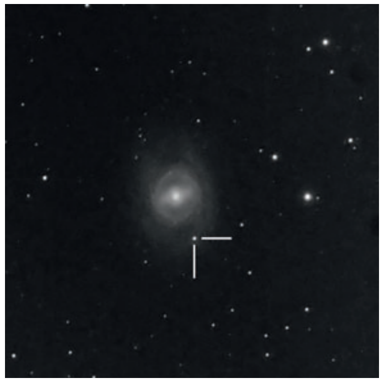

fig.5 A few months after I started using a CCD camera for astrophotography, a supernova was announced in the galaxy M95. I recorded an image of the dim galaxy (top) and used the Internet to identify the supernova position. The color image below was taken a few years later by which time the supernova has disappeared.
I now have software that allows one to compare two images taken of the same object from different nights. This automatically identifies any "new" stars or, as in the case of a supernova in our own galaxy, a star that just becomes suddenly very much brighter. Galaxies are the favorite location for likely supernova, as they contain the most stars.
A friend was imaging a galaxy as a supernova exploded. His series of unprocessed images proved useful to NASA since they showed the event unfolding between the separate image captures.