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Astronomical Cybersketching

Observational Drawing with PDAs and Tablet PCs

Peter Grego

Springer

Peter Grego

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To Mike James, teacher of art.

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About the Author

Peter Grego has been a regular watcher of the night skies since 1976 and began studying the Moon in 1982. He observes from his garden in St. Dennis, Cornwall, UK, using a variety of instruments, ranging from a 100 mm refractor to a 300 mm Newtonian, but his favorite is his 200 mm SCT. Grego's primary interests are observing the Moon and bright planets, but he occasionally likes to 'go deep' during the dark of the Moon.

Grego has directed the Lunar Section of Britain's Society for Popular Astronomy since 1984 and has been the Lunar Topographical Coordinator of the British Astronomical Association since 2006. He edits four astronomy publications: *Luna* (Journal of the SPA Lunar Section), *The New Moon* (topographic journal of the BAA Lunar Section), the *SPA News Circular*, and *Popular Astronomy* magazine. He is also the layout editor for the Society for the History of Astronomy's *Newsletter*.

He has written and illustrated the monthly *MoonWatch* column in *Astronomy Now* magazine since 1997 and is the observing Q&A writer for *Sky at Night* magazine. Grego maintains his own web site at www.lunarobservers.com and is webmaster of the BAA Lunar Section web site at www.baalunarsection.org.uk.

Grego is also the author of 15 books, including *The Moon and How to Observe It* (Springer, 2005), *Venus and Mercury and How to Observe Them* (Springer, 2007), *Moon Observer's Guide* (Philips/Firefly, 2004), *Need to Know? Stargazing* (Collins, 2005), *Need to Know? Universe* (Collins, 2006), and *Solar System Observer's Guide* (Philips/Firefly, 2005). He is a Fellow of the Royal Astronomical Society and a member of the SPA, SHA, and BAA. He has given many talks to astronomical societies around the UK and has been featured on a number of radio and television broadcasts.

Introduction

Sketching the Skies

Suddenly and without warning, a new star appeared in the night sky, and everyone in the community was alarmed. Nobody could remember having seen its like before. Dazzling to look at, this unexpected intruder in the heavenly vault gave off a light that almost rivaled that of the full Moon, drowning out the familiar patterns of stars with its glare. The new star's steady white light penetrated deep into the sacred cave, illuminating an age-old patchwork of intricately drawn pictographs; some of these depicted terrestrial objects and events, from mundane sketches of bison to vast and sweeping panoramic images of wild galloping horses. Other scenes showed celestial phenomena, such as the phases of the Moon and prominent asterisms, or star patterns.

The next morning, accompanied by solemn chanting in which the entire community participated, an elderly shaman entered the sacred cave by the light of a fiery brand and selected a suitable area upon which to depict the new star. Once the artwork was finished, the shaman reappeared at the cave entrance; he held out his arms wide to the slowly brightening morning skies and announced that the powerful magic of the new star had been captured and could now be used to ensure the continuing prosperity of his tribe.

About 30,000 years later, in the same beautiful part of southwestern France, the entrance to the famous world heritage-designated caves at Lascaux was illuminated by another striking celestial spectacle – a piece of midsummer midnight magic which was every bit as compelling to sketch as that shaman of old. Across the fertile plain of the Jurançon, and above the distant silhouetted peaks of the Pyrenees Mountains, a full Moon shared the same section of low southern sky as the planet Jupiter. Unlike our distant ancestor, a torch was not needed to illuminate the artwork. The backlit illuminated screen of a touchscreen handheld computer gave the image a perfect and even illumination; nor was the palette of colors from which to choose limited, or the range of effects to apply to the artwork. The only limiting factors were artistic competence and the amount of artistic license to take with the sketch (Figure 2).

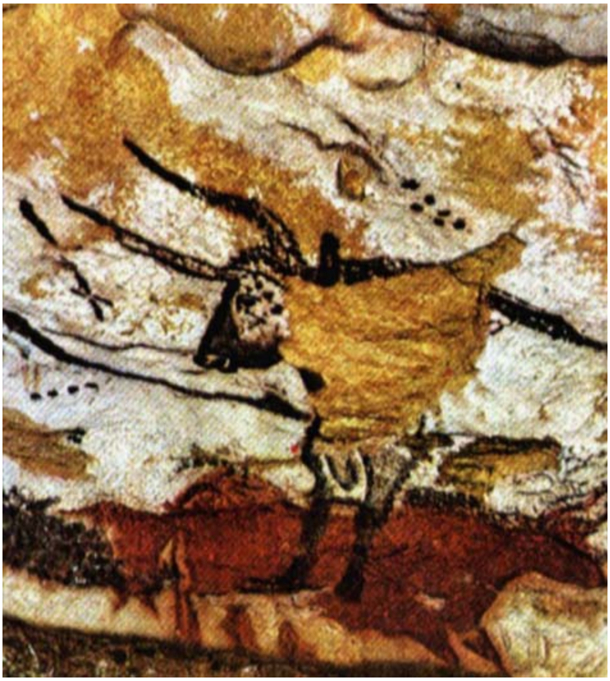

Figure 1. Anyone familiar with the constellations might be tempted to think that this vivid portrayal of the front of a bull, taken from a depiction on the cave walls at Lascaux, represents the constellation of Taurus the Bull, its head and horns marked by the Hyades open cluster. It might even be imagined that the smaller Pleiades star cluster is depicted to its upper right; compare it with a picture of the constellation (Peter Grego).

Of course, the story about the ancient shaman and the unexpected supernova is purely a product of the imagination – at least, its details are – but it is true that our remote ancestors sketched representations of a wide variety of terrestrial and celestial phenomena on the walls of their cave homes and sacred places. The appearance of bright supernovae – stars that explode as they reach the end of their lives – must have been alarming to our superstitious ancestors, to say the least. Some of the celestial depictions were of unexpected spectacles, like the intense blaze of a supernova or the appearance of a brilliant sky-spanning comet; other sights were more predictable, 'routine' heavenly events, such as the rising and setting of the midsummer or midwinter Sun, the patchwork of spots on the Moon's face, and the familiar configurations of certain star patterns. Archaeoastronomers have identified all these celestial representations in cave paintings, petroglyphs, and carvings from various sites around the world that date back many tens of thousands of years to the dawn of humanity.

Figure 2. The Moon and Jupiter over the French Pyrenees, based on a painting done on a PDA (photo by Peter Grego).

It is thought that these portrayals of celestial happenings were not simply art for art's sake; they actually served a vital purpose in the minds of the folks who skillfully executed them. Functional representations of the heavens include minutely carved bones and antlers, among which are thought to be records of the Moon's cycles and portrayals of certain constellations. Keeping a tally on the Moon's phases was one way that our ancient ancestors were able to mark the passage of time throughout the year; indeed, many early civilizations based their calendars upon lunar cycles.

Ever since those ancient times, humans have striven to record the world around them and the heavens above in drawings and paintings. Astronomers have been drawing for centuries, ever since the Englishman Thomas Harriot (1560–1621) turned his newly invented little telescope toward the Moon in the summer of 1609 and attempted to sketch the features that were brought into view through his 'optick tube.' Until the invention of photography in the mid-nineteenth century, drawing at the eyepiece was the only way that astronomers could make a visual record of the view through the eyepiece. We have to go back much further in time, long before the telescope was invented, to find the first fairly accurate representations of the starry skies – back to ancient China, where paper maps of the night skies were in use from at least the seventh century CE (Figure 3).

Why Draw?

This author has been a visual observer and an avid at-the-eyepiece sketcher for nearly 30 years. In the following chapters we will argue the case for making observational drawings of a variety of astronomical phenomena. Every amateur

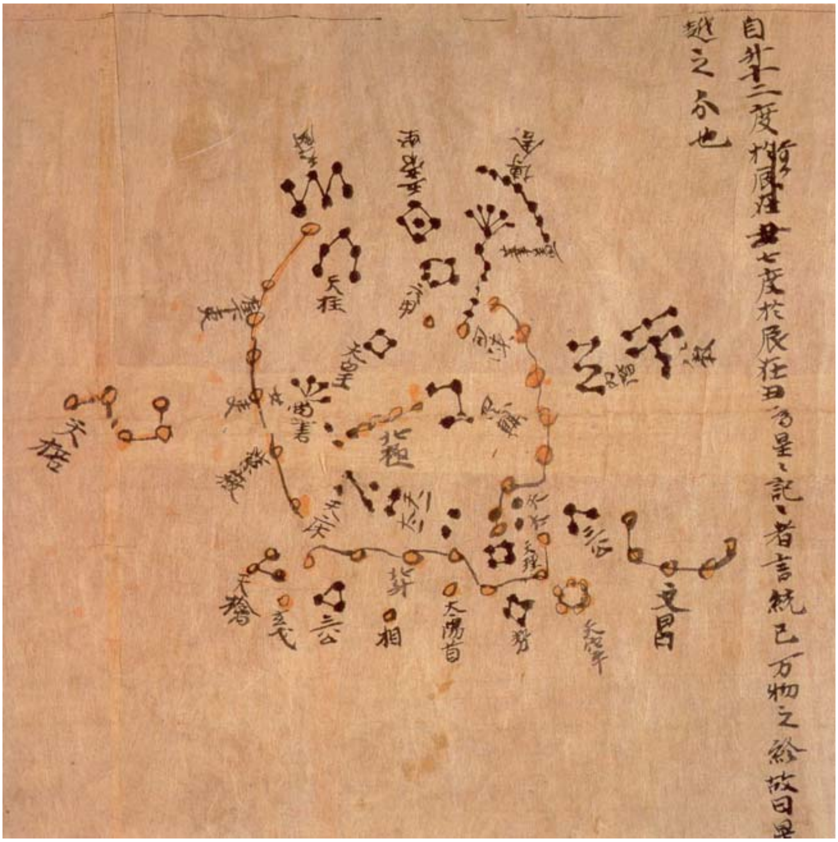

Figure 3. The oldest flat map of the night skies, known as the Dunhuang manuscript, is an ink on paper chart dating back to the seventh century CE. Most of the Chinese constellations depicted are unrecognizable, but the familiar shape of the Plough in Ursa Major is obvious (British Library, London).

astronomer – regardless of his or her own drawing skills – can benefit from being well-versed in various drawing and recording techniques. Drawing is by no means an outmoded and arcane practice. Making observational drawings concentrates and focuses the observer's attention on the subject at hand, enabling the observer to take advantage of moments of good seeing to tease fine, elusive detail out of the image presented in the eyepiece. By attending to the subject in view, those who carefully sketch objects discover more and enjoy observing more than cursory viewers.

Making regular observational drawings improves observing skills all round. When observing and drawing the Moon, with its moving shadows that reveal gloriously detailed topographical scenes of sublime majesty, the lunar landscape is transformed from a confusing jumble of light and dark to a familiar place. After becoming competent at observing and recording planetary detail, what were once tiny bright-colored blobs to the untrained eye become fascinating worlds with ever-changing albedo and cloud variations that can be captured in a drawing. The visual observer who makes the effort to draw deep sky objects will find that nebulae aren't all faint blurry smudges but delicate, subtly detailed wisps of nebulosity whose detail can be sketched.

It's not uncommon to hear disgruntled visual observers complain that drawings can never hope to 'compete' with CCD images. Yet this misses the point. For example, no sane visual observer has ever claimed to have been able to capture all the lunar detail visible through the telescope eyepiece on a single observational drawing. There's simply too much detail discernable on the Moon, even through a small telescope, so visual observers can only hope to produce a drawing that gives a general impression of the appearance of any particular area. No serious visual observer has ever felt that they are in some sort of competition with the image they can see through the eyepiece, so why feel that an image captured by electronic means provides any sort of competition? The root of the problem is a psychological one. Visual observers – especially those with a keen eye and a good drawing ability (either natural or learned) – ruled supreme for more than three centuries. Their drawings were the only means of recording astronomical objects, and amateur astronomers of yesteryear were familiar with books full of drawings by astronomers, rather than high-resolution CCD images. Nowadays, books are full of spectacular full-color CCD images from amateur and professional astronomers; although these are visually pleasing, such images tend to raise the novice's expectations of what they might see through the eyepiece to unrealistic levels, often leading to disappointment and disengagement with observing.

Nevertheless, here are a number of reasons why visual observing is as valid now as it ever was, and will remain valid in the future:

- Drawing is a supremely enjoyable pursuit. If you don't think that you enjoy drawing or were put off drawing by your art teacher at school, give it a go and stick at it for a while.
- Drawings provide a uniquely personal record of observations.
- Attending to detail through drawing allows the observer to concentrate on an object's finer points.
- Drawing enhances every aspect of your observing skills. Making written (or spoken) notes, along with technical aspects of recording features (noting UT, seeing, and other salient details), is also learned in the process.
- Drawing improves your chances of making a scientific discovery.
- Drawing improves your visual skills and enables you to become a better, more accurate observer.

Technological Aids

Now that we have established that drawing is a valid (and perhaps essential) pursuit for the visual observer, let's come to the nitty-gritty of this book – replacing paper and pencil with the computer. We'll call it 'cybersketching' – the prefix *cyber* referring to all things electronic.

Computers and digital imaging technology can do nothing but help the visual observer in many important respects. We shouldn't regret that the so-called Golden Age of visual observation is long gone; that era began to fade away when astrophotography came along and had all but disappeared during the Space Age. We have now entered a more exciting age of visual observation, where we can learn from the great telescopic observers and apply new technology to our hobby.

These days, people are increasingly 'digitizing' their lifestyles, and an increasing number of amateur astronomers of the future will not willingly put up with damp paper and smudgy pencils while juggling with a red torch at the eyepiece. This is where modern technology – in the form of PDAs (personal digital assistants, or handheld computers), UMPCs (ultra-mobile portable computers), and tablet PCs (flat, lightweight, touchscreen portable computers) – provides some neat solutions.

So, what makes PDAs, UMPCs, and tablet PCs so special? Well, for a start, they carry their own source of illumination. This is a big bonus because they obviate the need for a separate source. Computers are supremely versatile, as images can be stored and retrieved, zoomed-in on, modified, and enhanced at will. Most good drawing programs for PDAs and tablet PCs allow the properties of the stylus stroke to be modified in terms of its thickness, shape, intensity, color, texture, and transparency, so that a range of pencil, pen, brush strokes, and other artistic media (such as spray cans, paint rollers) can easily be replicated. The experience is fairly intuitive, in that the user is inputting data onto a screen using a stylus; because it's very much like drawing onto paper with a pencil, using a stylus requires little special skill or expertise to get the hang of. Indeed, virtual sketching is in many ways easier than 'real' sketching, and it can provide a more pleasant experience. First-time users find it a remarkable experience – a kind of 'eureka' moment that one can compare to seeing Saturn through a telescope eyepiece the first time.

This book outlines the techniques involved in astronomical cybersketching – making observational sketches and more detailed 'scientific' drawings of a wide variety of astronomical subjects using modern digital equipment, specifically PDAs, UMPCs, and tablet PCs. Various items of hardware and software are discussed, although with such an ever-growing range of products available on the market, the discussion is necessarily kept to its essentials. Once observational drawings are made at the eyepiece, we move on to deal with the process of producing finished or enhanced drawings at the user's main PC.

Contrary to 'assimilating the masses' in a mundane digital world, new technology can really only serve to liberate people by expanding their knowledge and unleashing the potential of their creativity. As astronomical cybersketching gains in popularity over the coming years, it will produce graphic works whose makers' individuality is as apparent and palpable as that in physical artworks. Hopefully, this modest book will help to further that end.

It is hoped that the techniques revealed in this book encourage many people to try cybersketching for themselves. Whether it represents the future of making records of visual observations of astronomical subjects remains to be seen. Having taken computer in hand into the field, it is hard to imagine what might induce someone to return to the exclusive use of pencil and paper.

Part I

Hardware: Past, Present, and Future

CHAPTER ONE

From Carefully Tooled Gears to Totally Cool Gear

Rather than launching headlong into the subject of personal computers, laptops, tablet computers, ultra-mobile computers, and palmtop devices, it's perhaps a good idea to take time to peruse a broad historical overview of the subject of machine-assisted computing. This will help us to remind ourselves how generations of humans with an interest in the machinations of the heavens have benefited from computers of various sorts.

Ancient cultures in all corners of the globe developed an amazing variety of cosmologies that granted the untouchable occupants of the heavens – the Sun and Moon, the stars, and the planets – a variety of supernatural powers over Earth and over the affairs of humanity. It appeared perfectly clear that the sky gods had their own unique personalities; no two looked the same, and each moved through the sky at its own speed and in its own special way. Most powerful among the sky gods were the Sun and the Moon, which were sometimes interpreted as an endlessly competing pair of deities because of the phenomena of solar and lunar eclipses.

Our ancestors might have imagined that it was possible for mere mortals to understand the intentions of the sky gods if their movements and phenomena were carefully noted. It followed that careful observation over extended periods of time enabled distinct patterns to be recognized, allowing some events to be predicted in advance. Having the ability to predict celestial phenomena gave the watchers of the skies great power, as events on Earth were thought to be affected by them and thus possible to predict as well. This was a pretty handy skill to possess for any ruling class.

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Archaeological evidence tells us that humans have been systematically watching the skies and recording celestial events for at least 6,000 years. The remains of megalithic constructions such as Stonehenge, whose stones are aligned with specific celestial points, such as the rising and setting points of the midsummer/midwinter Sun, are impressive evidence of how important people once thought it was to maintain an awareness of celestial phenomena (Figure 1.1).

Great leaps forward in understanding the workings of the cosmos took place in ancient Greece, where philosophers used their intellects to define the universe in

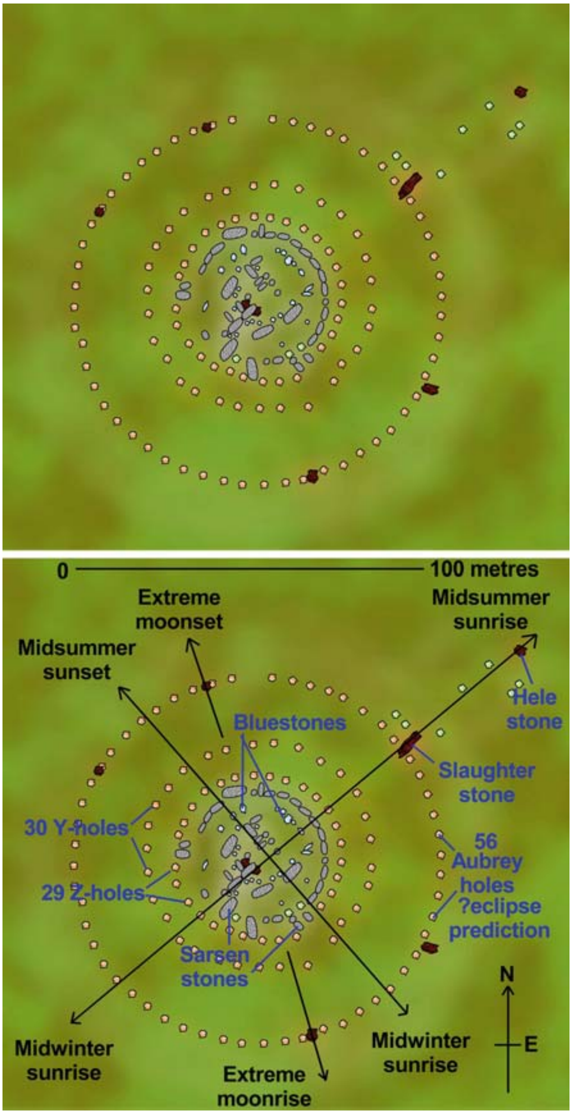

Figure 1.1. Rising from Salisbury Plain in southern England, the ancient, intricately arranged carved rocks of Stonehenge are thought to be some form of astronomical computer (photo by Peter Grego).

physical terms. In the fourth century BCE the philosopher Eudoxus of Cnidus (410–355 BCE) devised a complete system of the universe; in his model Earth lay at the very center of a series of concentric crystal spheres upon which were fastened the Sun, Moon, individual planets, and stars. As for the scale of the universe, mathematics and geometry proved invaluable tools with which to understand realms that were unimaginably vaster than our own planet. Careful observation combined with trigonometry enabled Eratosthenes of Cyrene (276–194 BCE) to accurately measure the circumference of Earth around 240 BCE.

A century later, Hipparchus (190–120 BCE) made the first fairly accurate determinations of the distance and size of the Moon. At around the same time Ptolemy took care to compile an encyclopedia of ancient Babylonian and Greek knowledge, including a definitive atlas of the stars – no fewer than 1,022 of them, contained within 48 constellations. Expanding on Eudoxus's idea of an Earth-centered universe, Claudius Ptolemaeus (around 83–161 CE) explained that the odd looping motions (called 'retrograde motion') of the planets at some points along their paths were produced when the planets performed smaller circular movements, or 'epicycles,' as they orbited Earth. Although the idea of epicycles answered a lot of problems and appeared to explain the clockwork of the cosmos, careful observation over extended periods of time was later to prove their downfall – but the story of modern astronomy and the heliocentric (Sun-centered) universe is far beyond the scope of this chapter.

The Antikythera Mechanism

Around the year 150 BCE, a cargo ship plying the waters near the little island of Antikythera, half way between mainland Greece and Crete, met with disaster. For some reason unknown to us – probably the result of a sudden storm – the vessel capsized and sank some 50 m to the bottom of the Kithirai Channel, where it remained along with its cargo to gather the usual organic submarine exoskeleton until it was discovered almost 2,000 years later. Shipwrecks are not uncommon in this part of the world, as trading between the myriad of islands in the region has been going on since time immemorial. It is thought that this particular ship was laden with loot, en route from the island of Rhodes to the burgeoning city of Rome. Small items soon began to be recovered from the wreck by sponge divers; among the concreted debris, which included fragments of pottery, sculptures, and coins, several items appeared that were markedly different from anything that had been previously found at any archaeological site of such antiquity.

Close examination revealed the fragments of a heavily encrusted, corroded, geared device measuring around 33 cm (13 in.) high, 17 cm (6.7 in.) wide, and 9 cm (3.5 in.) thick (Figure 1.2). Constructed of bronze and originally contained within a wooden frame, the device was engraved with a copious text (more than 3,000 characters in length), which appears to be the device's operating manual. With references to the Sun and Moon, along with the motions of the planets Aphrodite (Venus) and Hermes (Mercury), it is thought that the instrument could have been used to predict various astronomical cycles, such as the synodic month (the interval between full moons) and the metonic cycle (235 lunar months between exact phase repetitions) along with some of the phenomena displayed by the inferior planets. As such, this amazing piece of engineering represents the first portable, programmable computer, demonstrating that the ancient Greeks were far more technologically advanced than they are sometimes given credit for.

Figure 1.2. The main fragment of the Antikythera mechanism, on display at the National Archaeological Museum of Athens. Despite its condition, the great complexity of the device can clearly be seen. Credit: Marsyas, Wikimedia Commons.

Deus Ex Machina

Mechanical devices have always formed part of the astronomer's armory; since mathematics is essential to understanding and predicting celestial events, the abacus was among the first such mechanical devices because it made arithmetic a great deal easier. Abaci were used in ancient Sumeria more than 4,000 years ago, and the earliest Greek abacus in existence has been dated to 300 BCE.

In pre-Columbian Central America, from around 1,000 BCE, the complicated calculations involving the 260-day festival calendar was made easier by the use of calendar wheels. The festival calendar, known as a tzolkin, was based on physical objects, animals, and deities, and it revolved around the numbers 20 (the digits of the 'whole person') and 13 (in their philosophy there were 13 directions in space). Rotations of meshed wheels of 20 and 13 spaces enabled each day to be associated with a different object, and the whole cycle with respect to the 365-day solar calendar repeated itself every 52 years. Calendar wheels were therefore useful for planning events and for telling the future.

Simple naked-eye cross-staffs enabling the measurement of celestial angles have been used since antiquity. More complicated astronomical instruments that permitted calculations to be made in advance included the planisphere and the astrolabe, both of which first appeared in ancient Greece. Consisting of a map of the stars and an overlay that could be rotated to approximate the position of the horizon at any given date and time, the planisphere is an elegant, though rudimentary, device that allows the operator to calculate the rising and setting times of the Sun and stars and their elevation above (or below) the horizon at any given time. Planispheres are still beloved by amateur astronomers; indeed, most modern astronomical computer programs contain a facility to create a planisphere display. Astrolabes are a potent combination of the planisphere and a sighting device called a dioptra; thought to have been invented by Hipparchus, astrolabes permitted calculations to be made on the basis of observations, enabling numerous problems in spherical astronomy to be solved. Perhaps the most prolific and proficient exponents of the astrolabe were astronomers of the medieval Islamic world, where they were employed for astronomy, navigation, and surveying, in addition to being put to use as timekeepers for religious purposes.

Planispheres and astrolabes were used extensively by astrologers in medieval Europe to construct horoscopes (Figure 1.3). Although we now know that astrology is pseudoscience, without any scientific merit, there was no shortage of eminent

Figure 1.3. A superb brass astrolabe manufactured by Georg Hartmann in Nuremberg in 1537, now in the Scientific Instruments Collection of Yale University (Ragesoss, Wikimedia Commons).

practitioners in the West who combined astrology with their more serious astronomical pursuits. For example, Johannes Kepler (1571–1630), brilliant mathematician and originator of the laws of planetary motion, was convinced of the merits of astrology and devised his own system based upon harmonic theory. Some 800 horoscopes formulated by Kepler are still in existence, and certain lucky predictions for the year 1595 – including foretelling a peasants' revolt, forebodings of incursions by the Ottoman Empire in the east, and predictions of a spell of bitter cold – brought his astrological talents into great renown.

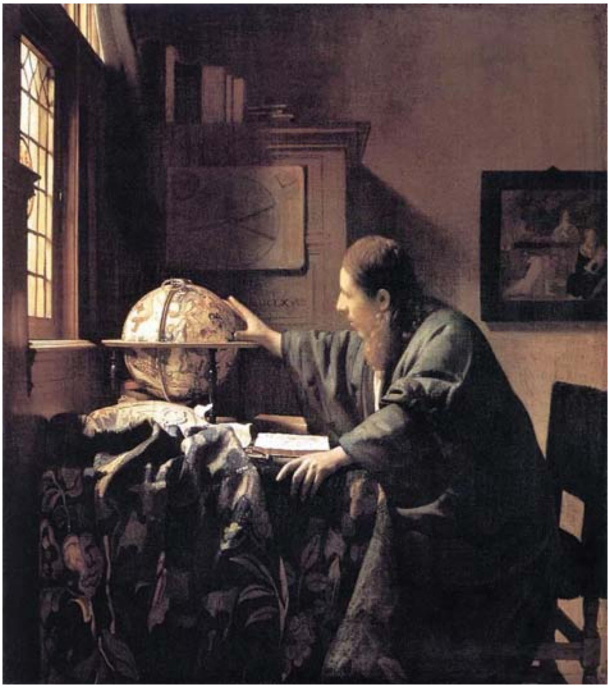

Figure 1.4. A celestial globe and a copy of Adriaan Metius' book *Institutiones Astronomiae Geographicae* feature in Johannes Vermeer's painting *The Astronomer* (1668). The book is open at Chapter Three, where it is stated that along with knowledge of geometry and the aid of mechanical instruments, there is a recommendation for 'inspiration from God' for astronomical research. Nowadays many amateurs echo this sentiment by praying that the battery on their laptop or PDA holds out during a night's observing session.

Lookers and Optick Tubes

In most textbooks on astronomy credit for the invention of the telescope goes to the Dutch–German lens maker Hans Lippershey (1570–1619) of Middelburg, Zeeland, in the Netherlands. One version of the traditional story says that children playing in his workshop stumbled upon the fact that the combination of a negative (concave) and a positive (convex) lens will magnify a distant image, provided that the negative lens is held near the eye and the lenses are firmly held at the right distance from each other; why Lippershey's children would be allowed to play in his workshop full of delicate and expensive glass items is not explained, and of course the story is utterly unverifiable. Regardless of whether the discovery was made by accident or by careful experiment, Lippershey presented his invention – a device that he called a kijker (a 'looker,' which magnified just three times) – to the Dutch government in October 1608, with the intention of obtaining a patent, stating that such an instrument would have enormous military potential. However, it was thought that there was little chance of successfully keeping the invention a secret or preventing others from making their own telescopes, and the patent was declined. Nevertheless, Lippershey was well rewarded for his design, and he went on to make several binocular telescopes for the government.

Two other Dutch opticians later claimed to have come up with the idea of the telescope prior to Lippershey – Jacob Metius (1571–1628) of Alkmaar in the Northern Netherlands, who actually filed his patent application just a few weeks after Lippershey, and the notorious counterfeiter Sacharias Jansen of Lippershey's hometown of Middelburg, who claimed to have made a telescope as early as 1604. However, Lippershey's patent application represents the earliest known documentation concerning an actual telescope, so the credit rightly remains with Lippershey. Interestingly, the surnames of all three pioneering opticians have been given to craters on the Moon – Lippershey, a fairly insignificant 6.8 km diameter pit in southern Mare Nubium (Sea of Clouds); Jansen, an eroded 23 km crater in northern Mare Tranquillitatis (Sea of Tranquillity); and 88 km diameter Metius in the southeastern corner of the Moon (although the latter is actually named after Jacob's brother, Adriaan).

Before proceeding to the telescopic era, it's worth pointing out that the first and only known pre-telescopic map of the Moon based on naked-eye observations was made by the Englishman William Gilbert (1544–1603) in the early seventeenth century (Figure 1.5). Gilbert's drawing is by no means the most detailed depiction of the lunar surface, nor is it the most expertly drafted. In fact, one of the most prominent ink strokes on it is an obvious error in positioning. The map is, however, unique in that it designated a set of names to the Moon's features. Among the quaint nomenclature on Gilbert's map is 'Britannia,' designating the dark oval patch we now call Mare Crisium (Sea of Crises) and 'Insula Longa' (Long Island) for the region now called Oceanus Procellarum (Ocean of Storms). It's true that the great Leonardo da Vinci (1452–1519) sketched the Moon way back in the early sixteenth century – and the fragment showing the eastern half of the Moon extant today is a good representation – but he was content not to name the features he saw (Figure 1.6). Leonardo considered the Moon an Earth-like world, the bright areas representing seas and the dark areas continents (contrary to common belief at the time, which imagined that the dark areas were seas). Leonardo also correctly deduced the true cause of Earthshine – that faint illumination of the dark side of the Moon when it is a crescent phase – ascribing it to sunlight reflected onto the Moon from Earth. Still, it's incredible that Gilbert's map is the only surviving pre-telescopic lunar map – incredible, considering that the Moon displays such obvious features when viewed with the average unaided eye.

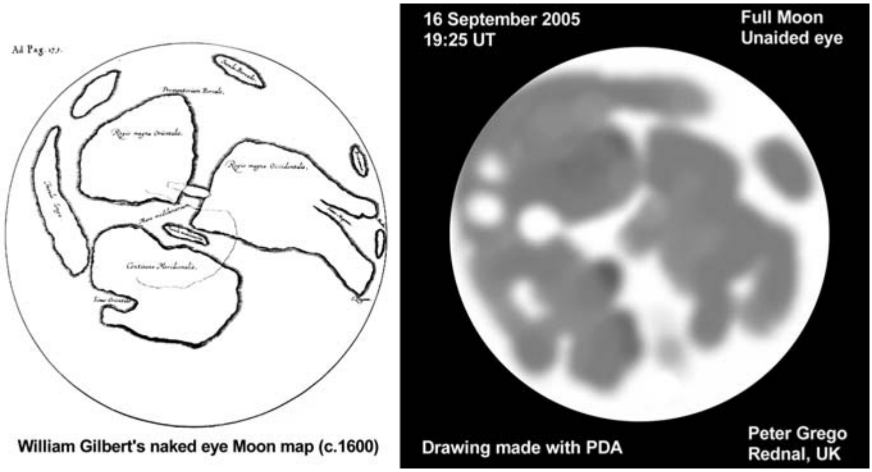

Figure 1.5. William Gilbert's naked-eye map of the Moon, circa 1600, compared with a sketch by the author using a PDA in 2005.

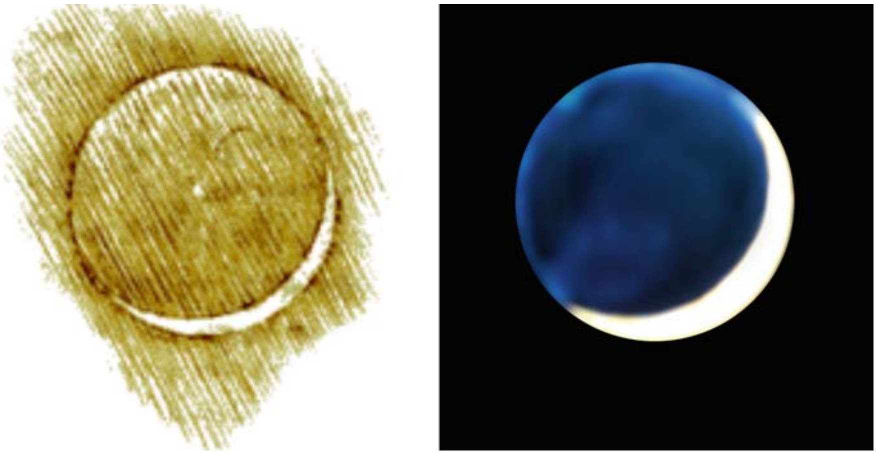

Figure 1.6. **a** Leonardo da Vinci's drawing of the Moon, made around 1500. Leonardo may have depicted the other half of the Moon, but the drawing has never been located. **b** Leonardo da Vinci's sketch of an Earthshine-illuminated young crescent Moon compared with a sketch of the Moon at a similar phase by the author using a PDA.

In the year 1609, news of the invention of the telescope and the principles involved in its construction rapidly spread throughout Europe. A series of astonishing observational discoveries by Galileo Galilei (1564–1642), commencing in late 1609, ushered in the era of observational astronomy. Squinting through a homemade instrument barely more sophisticated than a child's toy telescope of today, Galileo observed that the surface of the Moon displayed majestic highland regions packed full of craters and mountains, along with vast smooth gray plains pockmarked by numerous bright spots surrounded by light streaks. In his book *Sidereus Nuncius* (*The Starry Messenger*, 1610) the scientist wrote, '. . . the surface of the Moon is neither smooth nor uniform, nor very accurately spherical, as is assumed by a great many philosophers . . . it is uneven, rough, replete with cavities and packed with protruding eminences.'

Galileo's original inkwash drawings of the Moon show that he was an accurate and competent artist. His telescope was not powerful enough to discern any detail on Jupiter's disk, although he did find that the giant planet was attended by four large satellites; in fact, we still call Io, Europa, Ganymede, and Callisto the 'Galilean moons.' Among numerous other major astronomical discoveries, he saw that the surface of the Sun occasionally displayed sunspots, that Saturn was surrounded by mysterious 'appendages' (later found to be a ring system), and resolved the misty band of the Milky Way into countless faint stars. In 1612 Galileo also noted the planet Neptune in the same field of view as Jupiter but thought that it was merely a background star. Hence, this most distant of the major planets had to wait until 1846 to be discovered by Urbain Le Verrier, Johann Galle, and Heinrich d'Arrest.

The Clockwork Universe

In the Age of Enlightenment, humanity was gradually beginning to feel at ease with the fact that Earth was a relatively small globe in orbit around the Sun – one planet of many – rather than being an immovable rock anchored at the very hub of the universe. From the time of Galileo up until the telescopic discovery of Uranus by William Herschel in 1781, the known Solar System extended out as far as the orbit of Saturn.

Not content with having those fortunate enough to own a telescope able to appreciate the wonders of the Solar System, the clockmaker George Graham (c. 1674–1751) decided to build his own small mechanical Solar System for the purpose of instructing and enlightening its viewers. With Graham's consent, his first model Solar System was copied by the instrument maker John Rowley, who made one for Prince Eugene of Savoy and another for his patron Charles Boyle, 4th Earl of Orrery. This mechanical marvel – now known as an 'orrery' – demonstrated the orbits of the planets around the Sun, their axial rotation, and the orbits of their satellites, all in the correct ratio of speed (Figure 1.7). The finest orreries could be used as computers to determine the positions of the planets with respect to each other at any time in the past or future, although their predictive accuracy fell with the interval of time before or after the date to which it was originally set. For example, an orrery might be geared so that 12 Earth rotations around the Sun matched one of Jupiter's; however, Jupiter's orbital period is in fact 11.86 years long, so after several orbits there would be a big discrepancy between the actual and predicted position of Jupiter with respect to Earth.