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Neil English

Chronicling the Golden Age of Astronomy

A History of Visual Observing from Harriot to Moore

Springer

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A History of Visual Observing from Harriot to Moore

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Neil English
Fintry by Glasgow, UK

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Preface

Fig. 1 Tiberius, the author's 5-in. f/12 classical achromatic refractor. (Image by the author)

Do the words of a poem lose their poignancy once its author departs this world?
Can the limp of 'progress' outshine the 'grand procession' of great accomplishment?
Can a culture, basking in the glory of its own achievement, be made mute by a faithless generation of technocrats?
Can an optical bench test inspire more than a night spent behind the eyepiece of a grand old telescope?

Let us venerate that which is deserving of veneration!
Whose crown shall we adorn with a laurel wreath?
Let us sing again of old dead men
And clear the cobwebs from their medals.
For they have no equal in the present age
No muse to light their way.
—Neil English

It has been said that those who are ignorant of history are likely to make the same mistakes over and over again. But it is equally true that the same person is likely to underestimate the achievements of our forebears. This is particularly true of the history of astronomy, where dedicated men and women turned their telescopes skyward in an attempt to make sense of the universe in which they found themselves. The telescope has enjoyed four centuries of development, radiating into a veritable smorgasbord of form and function. For nearly two centuries, the slender tube of the refracting telescope dominated the astronomical world. And yet slowly but surely, adventurous individuals developed entirely novel means of observing the starry heaven using mirrors instead of lenses, and in the twentieth century, clever opticians combined the best properties of both, by bringing to market compound telescopes represented by the Schmidt-Cassegrain, Maksutov-Cassegrain, and other catadioptric forms enjoyed by amateurs today.

Fig. 2 Denis Buczynski, with his dear old Brashear achromatic refractor. (Image by the author)

On our journey through the maze that is the history of amateur and professional astronomy, we shall discover much about the personalities behind the most momentous discoveries made visually at the telescope, what motivated and inspired their prolonged study of the starry heaven, often with very modest equipment. On our journey through four centuries of time, we shall explore the discoveries made by countless individuals, many of which have long been forgotten by our contemporaries. If you have been guided only by discussions on modern forums on the Internet, chances are good that you will be kept completely in the dark about tips and techniques used by lesser known individuals that aided their study of the celestial realm. Who discovered the effects of colored filters? When was resolving power linked to the wavelength of light? Why did the long focus achromatic refractor do so well in the study of double and multiple star systems?

Studying the details of past lives dedicated to astronomy can also help dispel some myths perpetuated by some contemporary amateurs. Can modern apochromatic refractors resolve double stars better than the classical refractor? Historical investigation provides the answer – no. Are refractors better than reflecting telescopes in resolving double stars? Again the answer is: not necessarily. How impor-

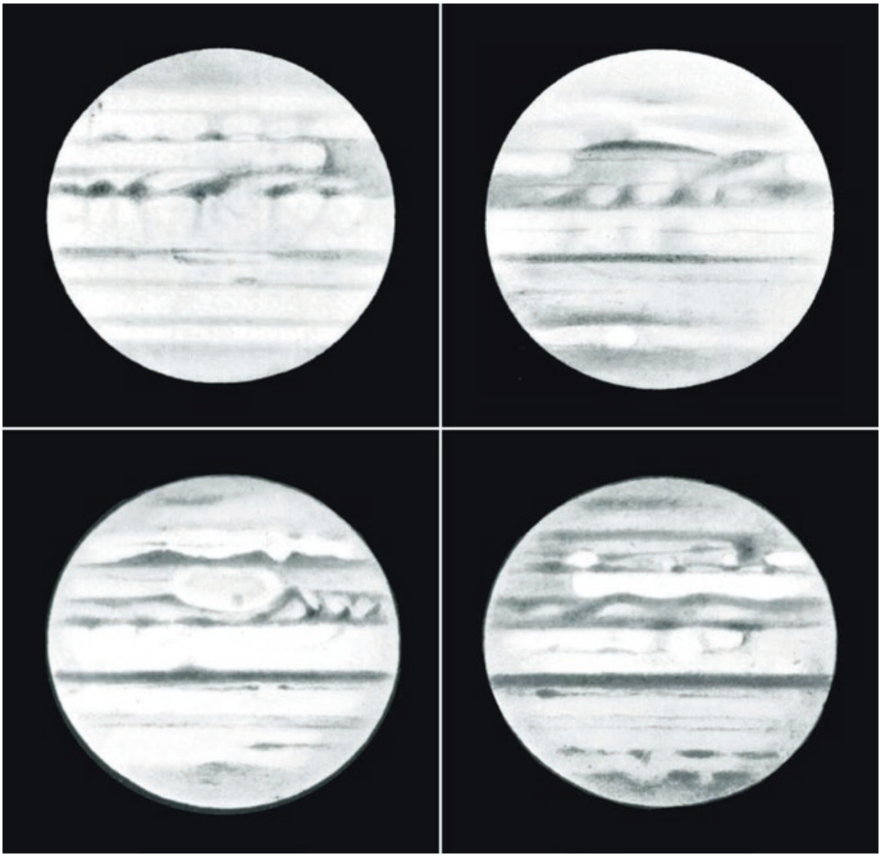

Fig. 3 Drawings of Jupiter made in 1908 and 1909 by the Reverend T.E.R Philips using a 12.5-in. Calver reflector. (Image courtesy of the BAA)

tant is the character of the individual and his or her level of training in seeing telescopically? As we shall discover, the answer is: very important! Many an individual is on record for stating that they hardly ever encounter clear skies. How true is this statement? As we shall discover, the study of history can shed much light on this question. In short, those that ignore the historical literature are prone to drawing erroneous conclusions of what can and cannot be achieved with a given telescope today.

A detailed look at what our astronomical forebears believed also has a bearing on what they allegedly saw through their telescopes. The most obvious example is the case of Percival Lowell, who sincerely believed that intelligent beings existed on our planetary neighbor, Mars. The "canals" he drew at the eyepiece of the 24-in. refractor he erected at Flagstaff, Arizona, reflected his mistaken worldview that life was an inevitability on other worlds, even those "next door" to us in space. But for others, the sensationalized findings of astronomers such as Lowell provided the impetus to launch their own delusional careers. One need only look at the dubious work of a one Leo Brenner to see how a colorful imagination can quickly run amok.

Perhaps most importantly, it is through the sheer dedication of humble individuals, often from obscure backgrounds, that can most inspire amateur astronomers today. In this capacity, we shall look in detail at individuals such as Edward Emerson

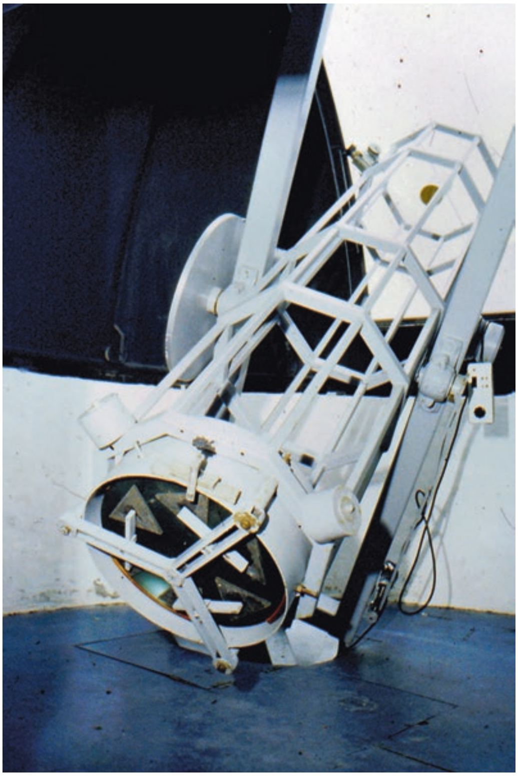

Fig. 4 An equatorially mounted Calver reflector dating to 1884 that sported a silver on glass reflector. Such technology revolutionized amateur astronomy. (Image courtesy of Denis Buczynski)

Barnard, Charles Grover, and William Denning, who rose from obscurity to become some of the most active and productive observers in history. And then there are those observers who displayed almost superhuman visual acuity. One need only look at the extraordinary careers of the Reverend William Rutter Dawes or Sherburne Wesley Burnham to see how exceptional eyesight can set new precedents in resolution and visual perception.

Finally, our exploration into the careers of the classical astronomers of old will help to teach us that there really is nothing new under the sun. Despite the drive to acquire telescopes that are more and more optically perfect, nothing of any substance has been discovered that was not seen by our illustrious telescopic ancestors. We still see the same belts and zones and spots and caps they saw on the planets using telescopes that many today would deem inferior.

Though the chapters are arranged chronologically as far as possible, the reader can enjoy each one independently of all the others. Of course, with any work of this magnitude, some errors are bound to have crept in and are entirely of my own doing. Feel free to contact me should you notice one. All that remains for me to say is that I hope you will enjoy this whistle-stop tour of our shared astronomical history and come to appreciate, as I do, the enormous contributions our forebears made to both amateur and professional astronomy.

Fintry by Glasgow, UK Neil English
July 2018

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Chapter 1
Thomas Harriot, England's First Telescopist

What is remarkable and possibly says much about Harriot's personality is that he expressed only admiration for Galileo without the slightest trace of jealousy.

–Allan Chapman

The mid-16th century was an era of profound social and political change in Europe; the Protestant Reformation swept across the kingdoms of the north, while in the southern reaches of the continent, Roman Catholicism still prevailed. The Renaissance juggernaut had introduced radical new ideas in the spheres of science, architecture, politics, art and literature, inspired by a palpable sense of nostalgia for the triumphs of classical antiquity. Knowledge, for so long the mainstay of the rich and powerful, was now being disseminated at a hitherto unprecedented rate to the 'lower' strata of European society, doubtless stoked by the invention of the printing press, which had empowered a new generation of scholars. And it was not just in Latin, the traditional language of the educated, but in the lingua franca of the various kingdoms, principalities and nation states of a new and self-confident Europe.

This was the world that Thomas Harriot was hurled into, born sometime in the year 1560, in the county of Oxfordshire, England. Though he likely had a sister, his ancestry remains somewhat of a mystery to modern historians, and the first we hear of Harriot comes from his matriculation on December 20, 1577, from St. Mary's Hall, a daughter house of Oriel College at the University of Oxford. In order to graduate, Harriot would have had to demonstrate a mastery of classical Latin and Greek, both spoken and written, as well as the Bible, the pillars of knowledge upon which all prospective Tudor scholars were required to assimilate. The contemporary reader can infer from this that Harriot's family placed great value in education for its own sake and that they had sufficient wealth to prepare their bookish son for such a career, a circumstance still quite beyond the means of the vast majority of children.

At St. Mary's College Harriot absorbed himself in what we might now be called a classical education, with its strict adherence to Latinity, supplemented by rhetoric

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Fig. 1.1 Thomas Harriot (1560–1621), England's first telescopic astronomer. (Image courtesy of Wiki Commons. https://en.wikipedia.org/wiki/File:ThomasHarriot.jpg)

and structured debate, as well as the elements of Protestant theology and civil law. Any graduate worth his salt would have been expected to be able to discuss the pros and cons of complex ideas, in order to excel in the three principal career options open to him – jurisprudence, the Church and Parliament. But quite unlike the education of the ancient Romans, this educational program would also have included a thorough grounding in mathematics, geometry and Ptolemaic cosmology. And it was in these latter studies that Thomas Harriot would excel.

It was very likely at St. Mary's College that Harriot first came to the attention of Walter Raleigh (1552–1618), 8 years his senior and himself a graduate of Oriel College. By his late twenties, Raleigh had established a name for himself, both at home and abroad, as a naval commander, scholar and public showman, having the ear of the Virgin Queen herself. In this age, England had become a formidable maritime power with a decidedly imperious outlook, and Raleigh had high ambitions for the English Crown, to colonize the eastern Atlantic seaboard of North America. To make this a reality, though, Raleigh was always on the lookout for young and enterprising officers with a mathematical penchant, to conduct the surveys, the proper execution of various censuses, as well as the creation of maps of the new colonial territories. It was in this capacity that Harriot entered the employ of Raleigh, who bequeathed him an opulent apartment annexed to his own mansion at Durham House, on the banks of the River Thames (Fig. 1.1).

Harriot's first overseas expedition was to accompany Sir Richard Greenville to Virginia in the New World on board the *Tiger*, which departed from England in the spring of 1585. Greenville himself was under the auspices of Raleigh. Harriot's duties included the thorough survey of the hinterland of the small, white settlements that had sprung up around the territory of the native Roanoke people, to learn the

Fig. 1.2 Dancing Secotan Indians in North Carolina, very much like those encountered by Thomas Harriot. Watercolor painted by John White in 1585. (Image courtesy of Wiki Commons. https://en.wikipedia.org/wiki/Thomas_Harriot#/media/File:North_carolina_algonkin-rituale02.jpg)

language and customs of these native Americans and, if possible, to purchase land from them. This was not to be a bloody enterprise, however, with the usual spate of rapine pillaging. The land would be honorably acquired with a spirit of honesty and fair treatment, a circumstance that was aided substantially by the vastness of the New World and its sparse indigenous population. Raleigh had already brought two young men from the Algonquin nation, Wanchese and Manteo, back to England to immerse them in the cultural nuances of Elizabethan London, and, while there, they were given the freedom of Durham House before being repatriated under the aegis of Harriot, in their native Virginia.

By all accounts, Harriot carried out his duties with great diligence and enthusiasm, learning the 'queer' tongue of the Algonquin and immersing himself in their rich culture and religious beliefs. Although one of the goals of such a mission was to take the Christian faith to the native Americans, it was not to be imposed on them. That said, Harriot found no shortage of Algonquins who embraced the new religion, finding that their beliefs were seamlessly assimilated into Christian doctrine (Fig. 1.2).

Harriot produced a famous treatise, *A Briefe and True Report of the New Found Land in Virginia*, published in 1588, chronicling his dealings with the peoples of this new territory, and marking him out as arguably the father of modern ethnology.

According to Dr. Allan Chapman, a renowned historian of science at the University of Oxford, Harriot could also be said to be the founding father of scientific education in North America. In his *True Report*, Harriot gave a lecture, presumably in the Algonquin language, to a native American audience, who were dumbstruck by the cleverness of the scientific instruments he brought with him from England:

> *Mathematicall Instruments, Sea Compasses, the virtue of the Loadstone in drawing yron, a Perspective Glasse which shewd manie strange sightes. Burning Glasses, wide fire woorkes, Gunnes…Spring Clocks that seem to goe of themselves, and many other things that we had.*

Some historians have used the accounts of the various optical devices described in his *True Report* as evidence that there may have been a 'Tudor telescope,' significantly predating those eventually acquired by Harriot (see below for more on this). Yet, as Chapman points out in his book, *Stargazers, Copernicus, Galileo, the Telescope and the Church*, this may be a classic case of reading too much into the literature:

> *The strange sights and images which seemed to perplex and even alarm the Roanoke locals, I suspect, were probably no more than the facial and other distortions that anyone can see in a convex or concave mirror.*

Thomas Harriot was an accomplished mathematician, one of the finest in England by all accounts. Most notably, perhaps, he introduced the symbols for less than (<) and greater than (>), which are used to solve equations. Harriot also did original work on the binomial theorem, which is an eminently useful technique for the expansion of algebraic expressions raised to any power.

When Raleigh asked Harriot to investigate the science of gunnery in the 1590s, he applied a vector-based technique to resolve the projectile's velocity into horizontal and vertical components and was able to deduce that its path fitted that of a parabola, an essentially modern analysis. He did however retain some outdated (and completely incorrect) ideas on motion, adhering to the ancient Aristotelian idea that heavier objects fall to Earth faster than lighter objects, for example.

Having a lifelong interest in optics, Harriot formulated a theory of refraction in 1601, noting that when a ray of light passes from a thinner to a denser medium, the angle to which it is refracted from the point at which it enters the glass is always in the same proportion to the angle at which the ray first strikes the glass. This result, known more generally as Snell's law, was independently discovered by the Dutch scientist Willebrord Snellus (1580–1626) in 1621.

After Queen Elizabeth I died in March 1603, ending the line of the Tudors, James VI of Scotland ascended to the throne as James I, uniting the crowns of England and Scotland in the process. The new king, unlike Elizabeth before him, strongly disliked Sir Walter Raleigh. Indeed, just a few short months after the passing of Elizabeth, James I had Raleigh put on trial for treason. Though many scholars now consider the evidence against him to be specious at best, he was found guilty, sentenced to death, inexplicably reprieved from the gallows and condemned to spending the rest of his days under arrest in the Tower of London. Despite this change of events, Harriot visited Raleigh at the Tower on many occasions, remaining loyal to his friend and patron.

It is important to remember that though Raleigh was imprisoned in the Tower, he still enjoyed considerable liberties, uncannily similar to Galileo's 'house arrest.' A far cry from the dark, dank and rat-infested dungeons used for commoners, they were given comfortable lodgings, enjoying fine food and drink and freedom to roam within its walls, attend Church and carry out day to day investigations and studies. Even their families were permitted to live there. So, despite his 'imprisonment,' it was still possible for Raleigh to live out a reasonably fulfilled life from day to day.

Harriot himself was not immune to the suspicions of the new regime, having been imprisoned in the Tower himself for 3 weeks, but after cross examination was summarily released in November 1605. Harriot's loyalty was rewarded when Raleigh recommended him to Henry Percy, the Ninth Earl of Northumberland (1564–1632), who was also imprisoned for 17 years in the Tower for being a Catholic sympathizer and for his alleged involvement in the plot to destroy the Houses of Parliament in 1605. Fabulously wealthy, the 'exotic' Percy was rumored to have spent an unprecedented £50 a year on books (an enormous sum by today's standards) and employed Harriot to carry on his scientific investigations. For this he was given a very generous stipend and access to Percy's stately southern residence at Syon Park, Brentford, London, as well as a comfortable residence at Threadneedle Street in the city. Overnight, Harriot not only became financially independent but was now the richest mathematician in Europe, commanding a salary estimated to be ten times greater than the best paid university dons of the age!

According to his 17th century biographer, John Aubrey, Harriot waded into all of the pressing astronomical questions of his day. "He had seen nine Cometes," wrote Aubrey, "and had predicted Seaven of them, but did not tell how." Intriguingly, according to Dr. Chapman, Harriot may have co-discovered the elliptical nature of the planetary orbits traditionally ascribed to the work of the German astronomer and mathematician Johannes Kepler. According to his friend and protégé, Sir William Lower, while pressing his master to compile a list of notable scientific achievements later in his life, left this tantalizing snippet: "…long since you told me as much [of Kepler], that the motions of the planets were not perfect circles," and that the planets made their "revolutions in Ellipses."

What is certain, however, is that Harriot, being a geometer of some reputation and so intimately acquainted with the mathematics of orbits, would have had extensive correspondence with the other great intellectuals on the European continent, Johannes Kepler included. Furthermore, there is no evidence that Harriot promulgated the notion that he had arrived at the formula of the ellipse to explain the orbit of Mars. Indeed, in striking contrast to the vast majority of scientists of his time, Harriot never published anything after his *True Report* of 1588, which came as a source of considerable irritation to his patrons, who wished only to advance their own prestige on the back of his accomplishments, as well as to his friends, who watched in anguish as others trumpeted their 'discoveries,' many of which were probably best attributed to Harriot himself. This was a characteristic that was to set him apart from his contemporaries, who almost invariably conflated knowledge with power.

Despite vigorous research efforts over many decades and centuries, historians of science cannot unequivocally attribute the invention of the first refracting telescope to any one individual. And though rumors abounded that there were telescopic devices significantly earlier than those that came on the scene in the early 17th century, it is undoubtedly the case that the enterprising spectacle maker, Hans Lippershey, based in the Dutch town of Middleburg, tried but ultimately failed to secure what would have been a lucrative patent in 1608 from the Dutch States General for the simple telescopes he constructed.

As a result, the device, which consisted of a matched pair of convex and concave lenses arranged in a long, slender tube, could be fashioned and sold by anyone once the proverbial cat was let out of the bag. It is likely that Harriot acquired an early "dutch *trunke*" or "cylinder" from one commercial source in Holland early in the year 1609.

A Curious Aside: The Telescope of Leonard Digges

Rumors have been circulated since the mid-16th century that the telescope was not invented in early 17th century Holland but in Elizabethan England, some half a century before. A telescopic device appears to have been constructed by the noted English polymath Leonard Digges (1515–c. 1559) as early as the first half of the 1500s and later reiterated by his son, Thomas Digges, in a communication dated to 1571:

> *[H]is divine mind aided with this science of Geometrical mensurations, found out the quantities, distances, courses, and strange intricate miraculous motions of these resplendent heavenly Globes of Sun, Moon, Planets and Stares fixed, leaving the rules and precepts thereof to his posterity. Archimedes also (as some suppose) with a glass framed by revolution of a section Parabolicall, fired the Roman navy in the sea coming to the siege of Syracuse. But to leave these celestial causes and things done of antiquity long ago, my father by his continual painful [painstaking] practices, assisted with demonstrations Mathematical, was able, and sundry times hath by proportional Glasses duly situate in convenient angles, not only discovered things far off, read letters, numbered pieces of money with the very coin and superscription thereof, cast by some of his friends of purpose upon downs in open fields, but also seven miles off declared what hath been done at that instant in private places.*

This intriguing tract, which appears on page 5 of the preface to his posthumously published book *Pantometria* (1571), provides the modern reader with an intriguing glimpse of a telescopic device made with lenses and mirrors. In a lively debate that took place in March 1993 organized by the Scientific Instrument Society (SIS) and held at Burlington House, London, Colin Ronan spoke in favor of the existence of such an early telescope, while the late Professor Gerard Turner, based at the Museum for the History of Science, Oxford, UK, provided a robust counterpoint. During the debate, a replica of the alleged Digges telescope was presented to all in attendance.

Fig. 1.3 The author's 6× achromatic spyglass used to corroborate Harriot's observations. (Image by the author)

The device consisted of a simple biconvex objective lens, the light of which was incident to a focusing mirror that relayed the image to the eye. Mounted inside a wooden tube, the device magnified 11 times and did produce an enlarged image, but with a very narrow field of view, and was additionally plagued by chromatic aberration – a consequence of using a singlet lens as an objective. There is, as yet, no consensus on whether such a telescope ever saw the light of day.

Harriot and his assistant, Christopher Tooke, set up a telescope magnifying 6 times on the grounds of Syon Park, and on the clement evening of July 26, 1609, turned it on a five-day-old crescent Moon, immediately sketching what he saw. Various lunar 'seas' are included in these lunar portraits, including the Mare Crisium, Tranquilitatis and Fecunditatis, as well as some rugged lunar features situated along the terminator, which modern scholars have identified as Theophilus and Cyrillus. Curiously, this first sketch does not record any craters, although 6× is certainly large enough to resolve several of the more prominent ones.

Out of sheer curiosity, in a separate investigation, this author used a modern spyglass with an uncoated, 1-inch diameter object glass, also having a magnification of 6×, in the wee small hours (01:30 h UT) of January 1, 2016, to record observations of the last quarter Moon and Jupiter, as they cleared the treetops in the eastern sky. Like Harriot's telescope, the spyglass gave an erect, correctly orientated image but enjoyed a much larger field of view (approximately 4 angular degrees). Nonetheless, this author could confirm that many lunar craters can indeed be observed with a steady hand, as well as clearly showing various maria. Turning to Jupiter, then just a few degrees above the Moon, the telescope could clearly reveal four Galilean satellites all to one side of the planet (Fig. 1.3).

It will come as somewhat of a surprise to the contemporary reader not acquainted with a Galilean telescope that, despite its very low magnifying power, its field of view was very restrictive – typically just over half the diameter of the full Moon! As a result, Harriot could not have seen the entire countenance of the lunar crescent even at the low magnifications his telescopes delivered. Incredibly, though, Harriot made many more drawings of the Moon, some of which display finer cartographic details than Galileo's later drawings, but they were frustratingly left undated. When we take into account the radically different personalities of both Galileo (explored in the next chapter) and Harriot, we can see that both men had entirely different modi operandi. Harriot, having spent time in Virginia, was a draughtsman and well acquainted with mapmaking. His methods were slow and methodical. Harriot was categorically not seeking fame and fortune in the same way that Galileo was, and, according to Dr. Chapman, because Harriot had two high profile friends on 'death row' in the Tower, he had little desire to make himself conspicuous.

By the closing weeks of 1609, Harriot dispatched Tooke, his able technician, to the residence of Sir William Lower at Trefenti, Carmarthenshire, South Wales, instructing him to fashion several other Galilean cylinders in order that he and his philosophical chums, a one Mr. Vaughan and Mr. Protheroe (and possibly a few others), could begin their own telescopic investigations of the Moon and other celestial bodies. The surviving exchanges between Harrriot and the 'Carmartenshire philosophers,' clearly unveil their avowed acceptance of the Copernican system, as well as Kepler's elliptical theory of planetary orbits. This meeting may well be first known record of an astronomical society, the members of which were to confirm Galileo's monumental telescopic work by observing the large Jovian satellites and the erstwhile "invisible" stars in the Pleiades.

Over the next few years, Harriot was to complete his now famous Moon maps, as well as embarking on a detailed study of the Sun. His method involved observing the intensely bright solar disk, when it was near the horizon and veiled behind mist and thin cloud (the reader should, under no circumstances, attempt such an observation!). Harriot is credited as the co-discover of sunspots, recording them at or about the same time as Galileo, and possibly earlier than Christopher Scheiner (1573–1650) and Johannes Fabricius (1587–1616), who themselves yielded additional evidence against the time-honored cosmology of Ptolemy (Fig. 1.4).

Over the next 2 years, Harriot was to carry out some 450 observations of the Sun and its dark spots, never once claiming their discovery for himself, studying how they moved across its otherwise brilliant face, breaking up and sometimes even disappearing. Indeed, modern scholars were able to establish a solar rotation period of 27.154 days from Harriot's drawings – uncannily close to the modern accepted value of 27.2753 days. This affirms the accuracy and attention to detail so central to Harriot's methodology.

According to Dr. Chapman, Tooke may have made improvements to the basic Dutch *trunke,* and referring to a study conducted by the distinguished historian of astronomy and cosmology, the late Professor John North (1934–2008) identified no less than six telescopes associated with Harriot and the 'Trefentine' philosophers, which ranged in power from 6× up to 50×. Tooke is likely to be among the first bona fide telescope makers in Britain, a tradition that was to be continued over the following centuries.

Although Harriot embraced the Christian message from his youth, even writing the Lord's Prayer in the Algonquin language, some scholars have suggested that he may have experienced a brief religious hiatus as he approached middle age.

Fig. 1.4 Christoph Scheiner (1573–1650), the Jesuit priest and astronomer, with his telescope shown on his left. (Image courtesy of Wiki Commons. https://en.wikipedia.org/wiki/Christoph_Scheiner#/media/File:Scheiner_christoph.gif)

Doubtless, the revolution heralded by the application of the telescope to the celestial realm had raised new questions in the minds of his learned contemporaries. Why were the astronomical bodies puckered and imperfect? How did God create everything from nothing? Was His divine hand needed at every stage, from the formation of atoms to the completion of worlds? Was the allegory of the universe even attributed to a personal God or was it merely blind chance? These questions weighed heavily in the mind of Thomas Harriot.

Dr. Chapman acknowledges that nothing firm can be adduced from Harriot's surviving notes and correspondences, but he is inclined to the view that the world's first telescopic astronomer re-embraced his Christian heritage in the final decade of his life, as evidenced by his 1615 correspondence with the king's physician, Sir Theodore Mayerne, who assured Harriot of the certainty of the existence of one all-powerful God. From his days in Virginia, Harriot had taken to 'drinking' tobacco smoke, as his contemporaries had referred to it. Earlier physicians had hailed the new wonder drug as an effective remedy to counter the "dangerous moist humors of the body." But three decades of heavy inhalation of tobacco smoke was to take its toll on Harriot's health, and he developed a cancerous lesion on his nose.

Because many tumors of this sort have a tendency to metastasize, spreading to other organs of the body via the lymph nodes, Harriot was arguably history's first clearly attested tobacco-induced cancer victim, dying on July 2, 1621. He was laid to rest at his local Parish Church of St. Christopher-le-Stocks, located in the heart of the city of London. And while the church was razed to the ground by the Great Fire of 1666 and another resurrected on the original site by none other than Sir Christopher Wren (1632–1723), this too was eventually demolished in 1781 in order to make way for a grand new building that would became the headquarters of the Bank of England. In the 1970s, however, the gravestone dedicated to Thomas Harriot was recovered, and, in his honor, a new plaque carrying his gravestone inscription was unveiled inside the bank.

It is difficult to crystallize the legacy of Thomas Harriot, being so far removed from him in time, but these words come to mind; learned, diligent, enterprising, kind, loyal, uncompetitive, humble and God-fearing. Despite not marrying and raising children, he lived a fulfilled life without a bad word to say about his fellow men, rendered all the more remarkable owing to his great wealth and lifelong connection with the rich and powerful.

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Chapter 2
The Legacy of Galileo

It is undoubtedly true that while there may have been a number of observers who had employed the telescope before Galileo, it is to him that we habitually turn to as the great pioneer of early telescopic astronomy. Galileo Galilei was born in the city of Pisa to his parents, father Vincenzo and mother Giulia Galilei, on February 15, 1564. A once independent city-state, Pisa had by now come under the administration of the so-called Florentine Diaspora of Tuscany and flourished throughout the Renaissance. The city enjoyed great wealth as a magnate for some of the richest merchants and bankers of the day. And as a university town, Pisa had also attracted some of the finest minds in Europe from the realms of art, architecture, theology, medicine and the natural sciences. Indeed, the other northern Italian cities, including Milan, Florence, Bologna, Venice and Genoa, enjoyed more or less equal status as self-governing city-states – much like the classical period of ancient Greece, but ruled by a curious assortment of dukes, kings, and prince bishoprics (Fig. 2.1).

Galileo's ancestors and surviving relatives were accomplished intellectuals, and the young man grew up to be a self-confident individual, receiving an excellent grounding in mathematics, musical theory and astronomy at the nearby monastery of Vollombroso. Although Galileo appears to have had an early calling to the religious life, intending at one time to be dedicated as a priest of the Roman Catholic Church, his father seemed to have other ideas about his eldest son's future and removed him from the monastery so that he could prepare him for a career in medicine. But it was not at all to the tastes of this young son, who found the writings of the classical scholar of the Roman physician Galen to be strange and substantially outdated, seeing as 1,400 years had passed since the works of this revered scholar of classical antiquity were penned. Neither was Galileo's argumentative nature much use to him in an intellectual environment that went out of its way to resist the march of progress. Truth be told, medical knowledge at that time was a hodgepodge of good science and quackery, and all the dissecting and overuse of flowery language probably bored the young Galileo senseless, whose mind was more cut out for precise calculation and mathematical certainty than any of his medical peers.

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Fig. 2.1 Galileo Galilei holding his telescope, portrait by Justus Sustermans (1636). (Image courtesy of Wiki Commons. https://en.wikipedia.org/wiki/File%3AJustus_Sustermans_-_Portrait_of_Galileo_Galilei%2C_1636.jpg)

But medicine was a lucrative career and Vincenzo was quite displeased when he learned that his son had expressed a distaste for it. Instead, Galileo, now in his early twenties, longed to carve out an uncertain career as a mathematician. But in the end, Vincenzo, an accomplished musician in his own right, respected his son's wishes and supported his retraining for a career in the 'exact' sciences. His progress was rapid, however, with him quickly distinguishing himself as the best mathematician in his class and being awarded a professorship at the University of Pisa in 1589 at only 25 years old!

Being such a towering figure, it is easy to see why so many stories were cultivated about him, such as the famous tale where he became mesmerized by a swinging lamp in Pisa Cathedral that led him to deduce that the period of its swing was independent of the mass of the pendulum but only depended on the length of the string. Another story recounts how Galileo dropped cannon balls of different weights off the Leaning Tower of Pisa, discovering that they hit the ground at the same time, in sharp contradiction to the tenets of the time-honored Aristotelian physics. We have no idea about the veracity of these claims, since it was his devoted student, a one Vincenzo Viviani, who later became his biographer, and who first brought our attention to them. What is certain, though, is that Galileo was one of the greatest experimental physicists of his era, making valuable contributions to our knowledge of motion. Indeed, it was this experimental approach that distinguished

Galileo from the medieval physicists who tended to analyze physical problems using Aristotelian 'thought experiments.' In this way, Galileo could rightly be called the father of the modern experimental method.

Though of professorial rank, Galileo's academic stipend was meager, and he resorted to supplementing his income by extending his tutelage to fee-paying private students. One of his patrons, a one Marchese Guido Ubaldo del Monte, used his influence to recommend Galileo to the vacant chair of mathematics at the more prestigious University of Padua, a post he enthusiastically took up in 1592, remaining there for the next 18 years. Here, in the Most Serene Republic of Venice, he enjoyed new freedoms that were not available to him at Pisa, as well as acquiring a circle of new and powerful friends. He also had access to the steady stream of new technological devices constantly streaming in from the nearby port of Venice, located only 24 miles from Padua. After studying their construction, he would often improve on the designs and sell them to interested parties, including the navy and military, which were always on the lookout for new gadgetry.

A minor crisis precipitated in Galileo's life in 1591, with the death of his father Vincenzo. Overnight he became the major breadwinner for his family, with a dependent mother, two unmarried sisters each requiring dowries, as well as funding the musical education of his younger brother, Michelangelo. But he made ends meet with his various technical enterprises as well as his role as a consultant to many private ventures. It was in Padua that Galileo met the love of his life, an attractive redhead from Venice, Marina Gamba. Although he never married her, she did bear him three children – two girls, Virginia and Livia, born in 1600 and 1601, respectively, and a younger son, Vincenzo (born 1606), named after his paternal grandfather.

By the time he reached his fortieth birthday in 1604, it was becoming clear that Galileo was somewhat discontented. He had an uncanny knack of annoying and insulting people who didn't see eye to eye with him, and as a consequence burned more than a few bridges. And despite having some very influential friends in high places, he could never rise above his station because of his seemingly endless financial difficulties. What's more, he began to tire of his university teachings and having to deal with mostly mediocre students. What he truly longed for was financial independence so that he could get on with more 'elevated' themes allied to his eclectic research interests.

This middle age discontentment with life was probably exacerbated by his first brush with the Holy Office in 1604, when he was accused of practicing a dangerous type of astrology. The debacle probably had its origin in his relationship with a Signor Silvestro Pagnoni, who had at one time been employed by Galileo as his secretary. For reasons that remain obscure, Pagnoni reported him to the Inquisition for casting so-called fatalistic horoscopes. Normal horoscopes were perfectly acceptable and indeed part of the cultural tradition of his times, but Galileo used his astrological knowledge to predict the death date of certain individuals. Such an activity was viewed as a type of divination in the eyes of the Inquisition and a distraction from worshiping the 'true' God. From that time on, Galileo's work was never far from the scrutinizing eyes of the ecclesiastical authorities, as we shall see later.

Galileo's fortunes changed utterly and forever after the summer of 1609, when he heard of a curious new invention from Holland, an optical novelty that made distant objects appear closer. As we have seen earlier with the telescopic work of the English astronomer, Thomas Harriot, a great deal of mystery surrounded the invention of the telescope, and no one individual can legitimately lay claim to its discovery. Though the technology to contrive a telescopic device was available since ancient times, it was probably not conceived from any consideration of optical theory and most likely discovered serendipitously, perhaps during the idle investigations of childhood curiosity.

When Galileo received news of the new optical marvel, he at once set to work reproducing his own. His first attempts yielded a device consisting of two lenses mounted at either end of a lead pipe, a device he called a *cannocciale* (little tube) but thereafter sought to make the instrument more powerful. The objective consisted of a convex lens, thicker in the middle and thinner at its edges, while the eye lens was concave in shape, thinner in the middle than at its edges and working in a similar way to modern opera glasses. The convex lens, with an aperture of slightly more than an inch, needed to have a focal length of 2 or 3 feet. Galileo used simple methods to arrive at this focal length by measuring how far from the eye the lens needed to be positioned in order to give a sharp image of a distant object.

Galileo soon set about engineering and making improved versions of his telescopes. His earliest instruments only magnified eight times, but over time they became progressively more powerful. Soon he began grinding his own lenses and changing his arrays, extending their magnifying powers up to about 30 times more than normal vision, but, as we saw in the previous chapter, they all had a very narrow field of view.

Fortunately for later scholars, Galileo had the presence of mind to leave a very detailed description of his telescopes in the opening pages of his first great work, the *Sidereus Nuncius* (Starry Messenger) in 1610, as he would again in his later work, *Il Saggiatore* (The Assayer), which was first published in 1623.

In August 1609, Galileo ventured to Venice to show off one of his better telescopes to the dignitaries of the city, arranging for them to view the cityscape from the elevated vantage of the roof of St. Mark's Cathedral and other high towers, where it apparently caused untold wonder among the viewers. The distinguished guests observed ships that were far out to sea a full 2 h before they became visible to the unaided eye. As a gesture of good will, he presented his *cannocciale* to the Venezia Serenissima as a gift. It was a clever move, for soon his professorship was confirmed for life and his salary increased to 1,000 florins. But others, more aware of day to day matters in the city, were rather dismayed at Galileo's promotion, especially since a similar device was sold in Venice by a Frenchman for just a few lire (Fig. 2.2).

Sometime in the late autumn of 1609, Galileo turned his *cannocciale* on a four- or five-day-old Moon. Though a precise date was never recorded, most modern scholars think this occurred around November 30. What Galileo observed shocked him; the Moon was not smooth as was believed since time immemorial but was jagged, broken and spotted with craters, mountains and deep valleys. His drawings

Fig. 2.2 Galileo shows the Doge of Venice how to use the telescope. Fresco by Giuseppe Bertini (1858). (Image courtesy of Wiki Commons. https://en.wikipedia.org/wiki/File%3ABertini_fresco_of_Galileo_Galilei_and_Doge_of_Venice.jpg)

were made as sepia wash paintings or as a printed woodcuts, the accuracy and attention to detail of which clearly revealing his advanced skills as an artist.

The physical nature of the Moon as revealed by Galileo's telescope flew in the face of the classical position of the lunar orb, which was believed to be a smooth, though tarnished, silvery ball. Galileo was not slow to make noise about this incongruity, later claiming in his *Sidereus Nuncius* that these lunar features were "never seen by anyone before me" and that a "great number of philosophers" had been flatly wrong in their belief that the Moon was "smooth, uniform and precisely spherical."

It is a curious historical fact that Galileo never made a comprehensive mapping of the Moon, a task he left to others. He was only concerned with revealing the salient features of the orb as it progressed through its phases. Perhaps he was too pressed with examining other objects to get pinned down on details. What we do know is that during the Christmas period of 1609 through January of 1610 he began systematic observations of the planet Jupiter, which was bright and well placed in the skies over northern Italy. Using his finest instrument delivering a power of about 30 diameters, what he saw was truly remarkable and, as he put it himself, was "never before seen since the creation of the world to our own time."

On his first night of observation he found Jupiter to be an oblate sphere, slightly stouter at the equator than at its poles, with three stars close to it, two to the east and one to the west. Enjoying a spell of clear winter nights, he watched in amazement as these stars appeared to change their positions with respect to the planet. He quickly deduced that they were circling Jupiter at various distances. Then on January 13, 1610, he observed a fourth 'star.' As the weeks went by, Galileo noted that the star nearest Jupiter appeared to be circling the planet faster than the others, with those located further out moving more slowly. What's more, the satellites appeared to be moving in a plane that aligned itself with the planet's equator. Galileo quickly grasped the astronomical and philosophical implications of such a discovery and how it was destined to change our perceptions of the nature of the planetary bodies forever after (Fig. 2.3).

Firstly, no one had ever imagined that the planets might present themselves as sharp globes. The disk-like appearance of Jupiter as seen through Galileo's telescope showed that Jupiter was a bona fide world in its own right. Secondly, and perhaps much more importantly, philosophers from classical antiquity until now had assumed, based on the best naked-eye evidence, that either Earth or the Sun (if you were a follower of Copernicus) was the sole center of rotation in the universe. Doubtless, the Copernicans had already accepted that the Moon had a rotation independent of the Sun-orbiting Earth, but the idea that the planets had satellites of their own seemed patently absurd to them, and yet anyone with a telescope curious enough to take the time to look would have been convinced of the truth of Galileo's discovery.

After the publication of *Sidereus Nuncius* in March 1610, Galileo returned to the telescope, but this time his attention shifted to a variety of other astronomical bodies. He recorded spots on the face of Sun and watched them slowly move across its face over time. In his *Letter on Sunspots,* dated to 1613, he reported his observations of Venus and how it underwent phases much in the same way as the Moon. It appeared largest as a thin crescent, gradually diminishing in angular diameter as it went through its phases and presented itself as a perfectly circular disk when it was at its smallest.

To Galileo the changing angular size of Venus was related to its varying distance from Earth and, as such, provided powerful evidence in support of the Copernican theory that the planets orbit the Sun and not Earth. He also reported the curious appearance of Saturn. Unlike Jupiter and Venus, which did show a sharp disk, his telescope sometimes revealed to him a strange, elongated oval. At other times, Galileo saw a sphere with ansae (handles or 'ears') at either side of the planet. And occasionally, these Saturnian appendages completely disappeared!

Writing to his friend Marcus Wesler at Augsburg, a high-ranking Roman Catholic intellectual, Galileo expressed concern that what he was seeing couldn't possibly be true. Indeed, he wryly commented that it was as if Saturn had indeed consumed his

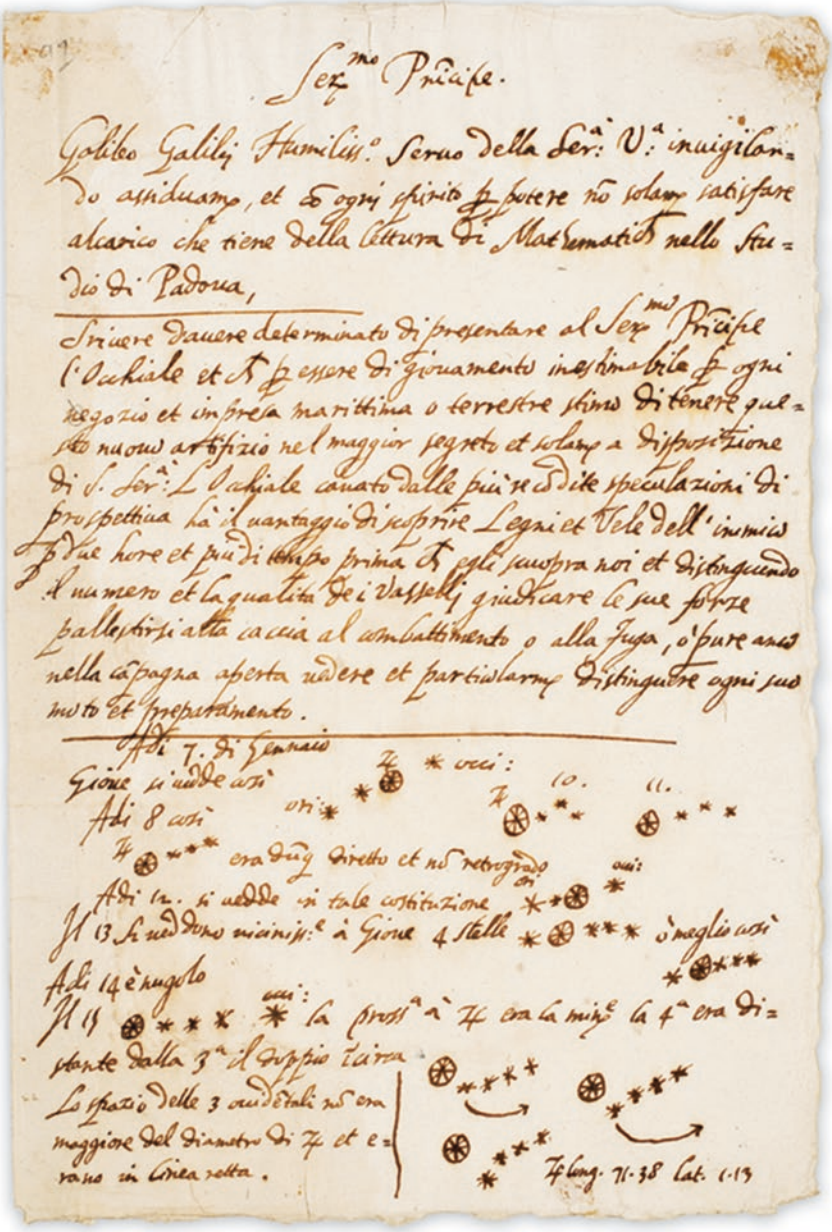

Fig. 2.3 An excerpt of Galileo's early notes on the wandering moons of Jupiter. This observation upset the notion that all celestial bodies must revolve around Earth. Galileo published a full description in *Sidereus Nuncius* in March 1610. (Image courtesy of Wiki Commons. https://en.wikipedia.org/wiki/File%3AGalileo_manuscript.png)

own children, just as the ancient Roman myths recounted. What is more, the whole affair with Saturn raised the thorny question of whether the telescope could be a superior tool to pure deduction in the establishment of truths about the workings of the universe. Indeed, it was one of the issues used as ammunition against him in his later clash with officials of the Roman See. For now, though, the mystery surrounding Saturn had to wait until more powerful telescopes (Huygens, 1675) were able to resolve the issue.

The ancient Greek astronomer Hipparchus (B. C. 190–120) had divided the stars in the firmament into six divisions of glory – what we now know as the magnitude scale. The brightest stellar luminaries were placed in the first magnitude, while those on the precipice of visibility were assigned to the sixth magnitude. But when Galileo turned his primitive telescope on the heavens, vast new shoals of stars came into view, far more than anyone had even thought possible. In particular, when he examined the Milky Way, or the *Via Lactica* as the ancient Romans had come to call it, he reported that it resolved into a "tight mass of stars." Furthermore, his 6× telescope revealed less stars than one of 30×. Although it was true that some medieval theologian astronomers had openly speculated that the Milky Way was made up of innumerable stars, it could only remain a speculation until the advent of the telescope. In one fell swoop, the universe known to humankind was extended beyond measure.

Galileo also visited a few well-known star clusters visible to the naked eye. When he examined the region known to us as the Sword Handle of Orion, he estimated that his telescope picked up about 600 new stars that were invisible to the naked eye, and when he scanned the belt stars in the Celestial Hunter he added a further 200 stars to the naked eye tally. Next he examined the Pleiades Cluster in Taurus, of which six or seven members can be clearly seen by the naked eye from a typical town. But his spyglass showed him about 40 new members. These he recorded in a sketch published in his *Sidereus Nuncius*. The same was true when he examined the Beehive Cluster (Praesepe) in Cancer.

The philosophic and theological implications of Galileo's telescopic adventures proved to be very unsettling for the Aristotelian academics, but not for Christians in the strictest sense. The trouble from the Church arose from those men within its ranks who had borrowed too heavily from the ancient Greek tradition, using it to inform their theological beliefs. Moreover, it must be stressed that none of what Galileo saw with his telescopes in any way contradicted Holy Scripture. What Galileo's discoveries openly questioned was the perfection of the astronomical bodies themselves.

Galileo was a keen observer of the solar surface, though he was almost certainly not the first telescopic observer to record dark spots on the Sun. That honor probably should go to the German astronomer, Johann Fabricius (1587–1616), who recorded them as early as the summer of 1611.

An elaborate myth has been cultivated over the years that Galileo went blind from looking at the Sun through his telescope, but his own records of sunspot observations conducted over many years show that this was not so. His sight failed in his seventies after he had conducted several decades of solar observations. And unlike