A new perceived reality: Thomas Harriot's Moon maps

Allan Chapman considers the impact of the first telescopic observation of the heavens, made by the Englishman Thomas Harriot in July 1609.

ABSTRACT

This article examines the world of the 17th-century mathematician Thomas Harriot, who first drew what he saw when he looked through a telescope, and, in doing so, changed the perception of the world in ways that reached far beyond astronomy.

1: For much of the 20th century this was believed to be the face of Thomas Harriot, but cleaning has revealed that the man depicted was 10 years too young for Harriot (Dudley 2000). Its status as a likeness is therefore thrown into serious doubt, although it has a resemblance to the man – supposedly Thomas Harriot – depicted in Francis Delaram's engraving of c.1620 in the British Museum. (By permission of the President and Fellows of Trinity College Oxford; image supplied by Max Alexander)

Four centuries ago, in 1609, the human race's capacity to perceive the natural world changed radically. And, in particular, on the night of 26 July 1609, the English astronomer and mathematician Thomas Harriot looked at the five-day-old Moon with his newly acquired "Dutch truncke", or telescope, and left a dated sketch of what he saw: the oldest known drawing of a telescopic body, made nearly four months before Galileo's first drawing.

Harriot, however, did not invent the telescope. The precise inventor, indeed, is still a matter for conjecture, for the patent or reward claim made by Hans Lippershey to the States General of Holland on 2 October 1608 was immediately contested by two other Dutchmen, and Lippershey, while obtaining a contract to supply some instruments to the government, received no major reward. As a result, the device variously called a "truncke", "cylinder", or "perspective", started to appear on sale in various parts of northern Europe and, in November 1608, the chronicler Pierre de l'Estiole – who mentioned that the device revealed stars not generally visible – gave a printed account of the Dutch instrument to the English Ambassador in Paris[1]. It was probably through the well-established channels of the book, luxury goods and novelty trades that Harriot acquired his instrument.

Yet even by the standards of 1609 the telescope was a fairly simple instrument to make, for all that one needed was a convex object-glass of 10, 20 or 30 inches focal length, and a concave eyepiece of a one or two negative power. And when aligned at the right distance apart, they made a distant object suddenly appear magnified, in the tiny field of view. All that was necessary to create a "telescope" was to mount the lenses in a simple tube, and make sure that the observer placed his or her eye at the correct spot to intercept the exit cone of light. And as for the lenses themselves, they would have been available "over the counter" in any major city in Europe by 1609, for the use of spectacles to aid human eyesight already went back well over 200 years by that date. Indeed, by 1629 London alone had enough spectacle-makers and glass-grinders living within the Square Mile to enable them to obtain a charter as a City Livery Company. After all, grinding and polishing small slips of glass or quartz had no doubt grown out of the ancient art of the lapidary or gemstone polisher, to whose craft the *Old Testament* and other ancient documents refer. And a couple of centuries before 1609, spectacles had even made their appearance in Western art, where portraits of learned men – including allegorical depictions of those long dead, such as St Jerome the fourth-century AD *Bible* translator – invariably showed them sporting a pair of glasses.

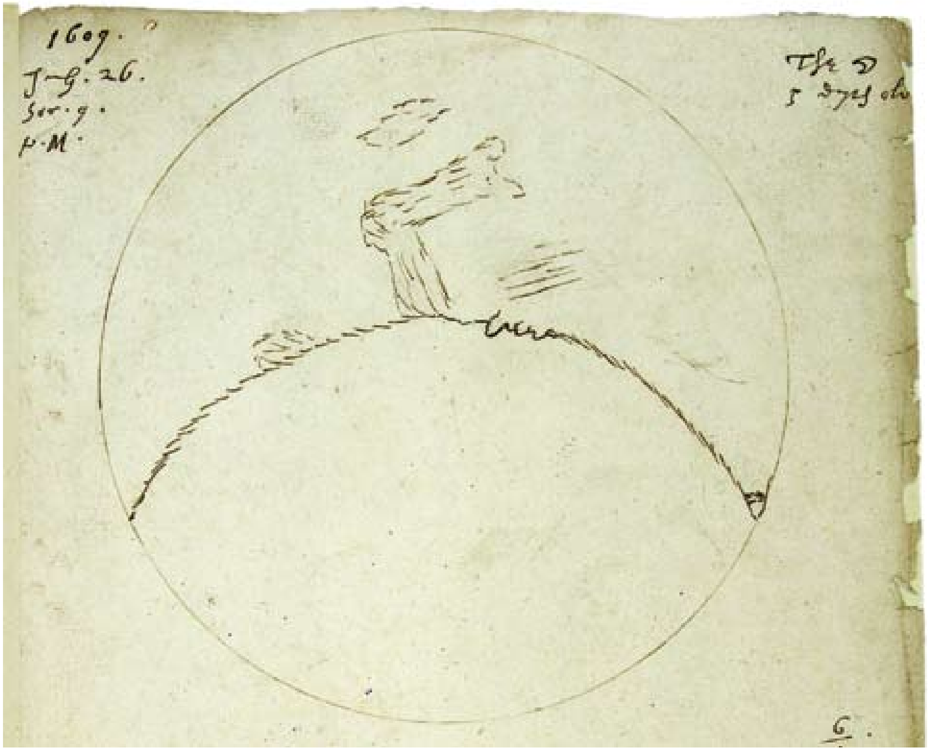
Telescopes, ships and new data

Indeed, what is genuinely surprising is that the optical configuration of the simple telescope had not been chanced upon centuries earlier, though I do not believe that a pre-1608 device had been known (Ronan 1991, 1993, Chapman 1995). For had the device any known historical provenance, the astronomers of Europe would not have been so amazed, perplexed and delighted with what they discovered with their newly contrived "cylinders" after July 1609.

Yet how did the telescope transform mankind's sense of physical reality? Of course, it showed hitherto unseen craters on the Moon, the satellites of Jupiter, sunspots, and a host of new astronomical phenomena. But I would suggest that it did something much more profound. For up to 1609, humanity's capacity to perceive Nature had been firmly bounded by our five natural senses, which had imposed strict limits upon physical knowledge. The simple telescope, on the other hand, broke through this boundary. Even the earliest observers, such as Harriot, and some months later Galileo, soon mastered the technique of making their "cylinders" more powerful, and by 1610 or 1611 magnifications had risen from ×6 (which was the power of Harriot's 26 July 1609 instrument) to ×30 and even ×50 (Rigaud p34). And as magnifications increased, so more and more things became visible in the universe. It seemed that for the first time in scientific history, knowledge was expanding exponentially alongside a new technology.

Once the telescope had shown the way, other instruments – optical and physical – began to open up entirely new domains of Nature: the microscopic world by 1665; the atmosphere, meteorology and combustion, explored by means of the thermometer, barometer, hygrometer and airpump by 1660; and the geomagnetic properties of our planet by 1700, to name but a few. And what made these once unimaginable realms real and physically accessible to scientific study was a new generation of instruments, each one capable of accessing a particular domain of Nature and showing how unit improvements in the technology could yield abundant new harvests of data. For after 1609, astronomical research ceased to be exclusively concerned with measuring celestial angles, and came instead to pay increasing attention to the physical characteristics of objects. For as Robert Hooke (1665) aptly styled the telescope, microscope and other new instruments, they were "Artificial Organs" that added to and strengthened the natural: "By means of Telescopes there is nothing so far distant but may be represented to our view."

Indeed, one of the most powerful defining features in the rise of post-Renaissance Western science was the swelling tide of new data that had started to pour in to Europe in the wake of the great geographical discoveries of Columbus and Magellan, and of which scholars had been trying to make sense since around 1500. For classical and medieval science had been largely concerned with the taxonomic, mathematical and philosophical understanding of *Scientia*, or rational knowledge. It had not, generally, been concerned with a radical investigation into the very inner fabric and structure of Nature. I have long argued that Europe's great geographical discoveries after c.1460 unexpectedly began this investigative approach, by presenting new and hitherto unimagined oceans, continents, peoples and objects for the puzzled delectation of Western scholars – objects for which there were no parallels in the annals of classical and medieval learning and which demanded a fundamental rethink about the bounds of intellectual inquiry. These geographical discoveries, moreover, could not be accessed by pure geometry, logical syllogisms, or the authority of ancient writers: access to them came only via men in ships. Yet when these explorers had charted and reported their discoveries, so that they entered the domain of public knowledge, then any other man with a ship could sail forth and confirm them and add yet more to the original discovery. One can, therefore, see the deep-sea sailing vessels of Renaissance Europe as scientific instruments in their own right, in so far as they were physical tools that took an observer to terrestrial places that his eyes and perceptions could not otherwise reach or see. Just as the telescope would do for the heavens, in fact. It is hardly surprising, therefore, that in this Elizabethan and Jacobean world of maritime images and analogies, Harriot himself had been a scientist on a major voyage of exploration, that many of his friends and patrons were intimately bound up with the sea, and that so many 17th-century scientific writers, including Robert Hooke, connected the great modern instrument-based discoveries in astronomy, physiology, microscopy, aerostatics and mechanics, with the achievements of the great navigators.



2: Harriot's 26 July 1609 sketch of the Moon – the first known drawing of a telescopic body – approximately six inches in diameter with the Mare Crisium shaded at the top. Turn the drawing to the right for the correct orientation. The oddly curved shape of the terminator may mean that in his small "Galilean" telescope of x6 magnification, Harriot could not see the whole of the crescent and therefore only sketches the central, interesting, parts. (Reproduced by kind permission of Lord Egremont, Petworth House Archives HMC 241/9 fol 26. West Sussex Record Office, Chichester)

Who was Thomas Harriot?

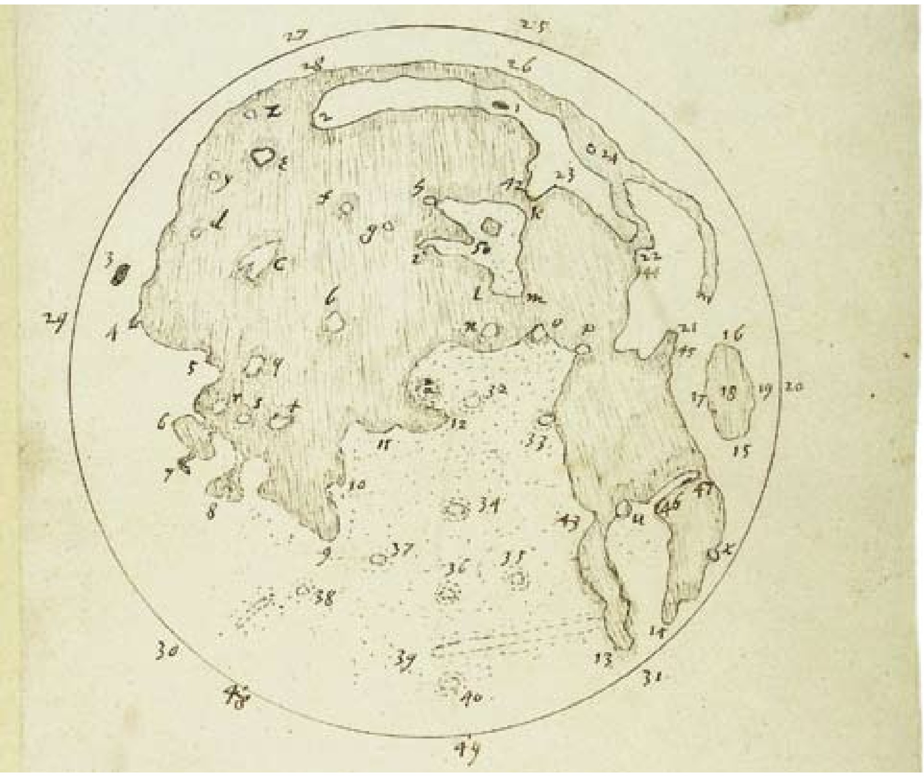
In 1609, Harriot was a comfortably off 49-year-old bachelor with residences at Syon Park, near Kew, and probably in Threadneedle Street in the City of London, and was rightly ranked among the eminent astronomers and mathematicians of the age (Stevens 1900, Shirley 1983, Roche 2004a). In particular, he was a leading force in English mathematics and was known on the continent, where he corresponded with Kepler, then living in Prague. Like most mathematicians of that age, Harriot was a geometer who was fascinated by the flawless elegance of Euclid, Apollonius and their successors, and by the way in which the conceptual realm of intellective mathematics synchronized with the observed motions of the heavens. But he was also a highly original pioneer of the new mathematics of algebra and the theory of equations. On the other hand, he was a practical observer of the heavens, which he did by means of a large "Astronomical Radius", which could read planetary and stellar angles to within a few arc minutes (Roche 1981).

Harriot had been born in Oxford in 1560, and while we know nothing about his parents or family, we do know that he went up to St Mary's Hall, on Oxford's High Street, facing the University Church of St Mary the Virgin, in 1577, and took his BA in 1580 (à Wood 1721, Roche 2004a). St Mary's Hall no longer exists, having been incorporated into its neighbour, Oriel College, in the late-Victorian period. Oriel now claims Harriot as one of its own. He clearly displayed outstanding talents as a mathematician, for soon after graduation he entered the household of Sir Walter Raleigh – an Oriel graduate eight years his senior – as a mathematical teacher and companion.

Harriot spent the year 1585–6 in the new colony of Virginia, as a scientist and surveyor, where, incidentally, I suggested that he became the first person to teach Western science and technology on the North American continent, when he demonstrated to the local Algonquian Indians: "Mathematicall Instruments, Sea-Compasses, the vertue of the Loadstone, in drawing yron, a Perspective Glasse, whereby was shewed manie strange sightes, Burning Glasses, Wilde-Fire woorkes, Gunnes … Spring Clocks that seem to goe by themselves, and many other things" (Stevens 1900).

Could his "Perspective Glasse" have been a form of "Tudor telescope", as some people have proposed? Frankly, I doubt it, for "perspective" devices were part of the stock-in-trade of 16th-century "natural magick", and besides, as I indicated above, I suspect that he would have been less impressed by the telescopic image of the Moon after 1609 had he already possessed a viable telescope in 1585 (Ronan 1991, 1993, Chapman 2008).

On his return to England, Harriot lived comfortably on Irish rentals settled upon him by Raleigh. And when Sir Walter fell from grace with Queen Elizabeth I in the 1590s, and was imprisoned in the Tower of London under



3: The best of Harriot's two whole-Moon maps, perhaps built up from phase drawings. The wealth of small details in this six-inch diameter map indicates how quickly Harriot's seleographical draftsmanship had improved. This is undated but probably made between 1610 and 1613. (Reproduced by kind permission of Lord Egremont, Petworth House Archives HMC 241/9 fol 30. West Sussex Record Office, Chichester)

sentence of death by the new King James I in 1603, then Raleigh generously passed him over to the patronage of Henry Percy, the Ninth, or "Wizard", Earl of Northumberland (Roche 2004a, Stevens 1900, Tanner 1974). And when the learned Earl, after being implicated in the Gunpowder Plot, joined Raleigh in the Tower in 1605, where he was detained until 1621, he continued to maintain his ace mathematician in fine style at Syon Park, Kew. Of course, detention in the Tower for high status prisoners such as Raleigh and Northumberland did not involve dungeons, for they could use their wealth to rent decent sets of rooms and come and go within the Tower precincts. Raleigh's wife and servants moved in as Sir Walter pursued alchemy and wrote great works of scholarship, while Northumberland not only enjoyed the freedom to entertain Harriot and his other philosophical friends, but also to run his vast northern estates from within the Tower. On the other hand, one never knew which day would be one's last.

I would suggest that the political turmoil through which he had lived – for Harriot himself had been imprisoned for three weeks following the Gunpowder Plot – may go some way towards explaining his reluctance to publish and draw further attention to himself once he was at liberty and well in funds. For the remarkable thing is, that while Thomas Harriot seems to have made the first recorded telescopic observations of an astronomical body, he made no public claim for this achievement. Indeed, apart from his *True Report of a New Found Land* (1588) which dealt with his Virginia voyage, he published nothing whatsoever, and what we now know of Harriot comes from modern scholarly researches into his substantial surviving manuscript remains.

When Harriot died in 1621, he left his papers to the Earl of Northumberland, who had recently been released after his long detention in the Tower (Roche 2004a, Stevens 1900, Tanner 1974). This bequest was fortuitous, for it ensured the documents' survival. They came to be lodged at Petworth House, Sussex, and in 1810 the then title-holder of Petworth, Lord Egremont, deposited the greater part, but not all, in the British Museum. Part of the archive was retained at Petworth, including Harriot's lunar drawings and maps, and the Petworth material is now housed in the West Sussex Record Office, Chichester. Although short "lives" of Harriot were written in the 17th century by John Aubrey and Antony à Wood, it was not until the visiting German Baron Franz Xavier von Zach worked on the Petworth papers in 1784 and published some of his findings in Berlin thereafter, that Harriot's astronomical significance became known. Then in 1832–3 Stephen Peter Rigaud, Savilian Professor of Astronomy in Oxford, published his own study of the Harriot papers, complete with letters and extracts from notes, dealing in particular with Harriot's observations of the Moon, sunspots and Jupiter's satellites. Modern Harriot studies really began in 1900, when the American scholar Henry Stevens posthumously published his biography of Harriot and his circle, while from the 1960s onwards, Thomas Harriot became a focus for many distinguished historians of mathematics and astronomy, most notably Prof. John W Shirley, as well as for seminars and lectures held at Durham and Oxford universities.

Harriot's lunar observations

More than a dozen pen and ink lunar drawings by Thomas Harriot survive, the first and crudest being that dated 26 July 1609 (figure 2). The rather oddly misplaced terminator line is done so as to suggest its unevenness, but no specific craters or mountains are visible, though a particular roughness in the terminator could perhaps represent the region around the crater Theophilus. Light shading, however, is used to suggest the position of what we now call the Mare Crisium, Mare Tranquillitatis, Mare Foecunditatis and perhaps the Lacus Somniorum. The drawing offers no commentary upon what Harriot saw, nor does he say why he made and recorded the observation. It is possible that he intended to use the telescope to establish the exact quadrature of the Moon more precisely than could be done with the naked eye, as a way of calculating the Earth–Moon–Sun distances in accordance with Aristarchus's "Diagram", although for this he would have needed a seven- not a five-day Moon. On the other hand, he did make very exact lunar quadrature observations (Rigaud p17), such as on 9 April 1611, when "Sir Nicholas Sanders and Christopher [Tooke, Harriot's technician] were with me and also observed in my garret". Yet as his first "truncke" only seems to have had a magnification of ×6, it is hardly surprising that he did not record much detail.

Harriot did not draw the Moon again, at least as far as the surviving documentary record is concerned, for nearly a year, on 17 July 1610. This second drawing, and those that quickly followed, show an increasing amount of detail. Within an unspecified period afterwards, but probably by 1613, after which Harriot's telescopic observations seem to have ceased, he was to produce two, tantalizingly undated, whole-Moon maps (figure 3) showing intricate detail in the edges of the "seas", and plenty of craters that we can easily identify. One is left to wonder whether the best of his whole-Moon maps were composites, made from phase and terminator drawings, for many of the formations shown on his best maps would have been "washed out" in the glare of a full Moon.

It has been suggested by Terrie F Bloom (1978), and perhaps even implied by Rigaud, that Harriot's new collection of Moon drawings, made after 17 July 1610, could have been inspired and guided by Galileo's lunar drawings of December 1609 to January 1610, published as engravings in *Sidereus Nuncius* in Venice, in March 1610, and also mentioned by Kepler in his *Dissertatio* (1610) (Bloom 1978, Whitaker 1978). We know from independent sources that Galileo's discoveries were being discussed in England by June 1610, and it is hard to imagine that Harriot had not seen a copy by 17 July, when he made his next lunar drawing.

I accept Terrie Bloom's point about Harriot and the Galileo drawings, but I would suggest two caveats. First, while none of Harriot's letters to his scientific friends for the crucial year 1609–10 seem to have survived, we do know from letters sent to him that he had friends who were using telescopes to observe the heavens and, judging from the internal evidence within the letters, the telescopes had probably been sent to them by Harriot himself. The foremost of these correspondents was the Cornish–Welsh landowner, MP and mathematical gentleman Sir William Lower (Roche 2004b). For on the "Longest Day, 1610", probably 11 June in the Julian calendar, Lower wrote from his estates at Traventi, Carmarthenshire, expressing admiration for both Galileo and Kepler (news of whose discovery of the elliptical orbit of Mars was beginning to spread across Europe), as well as reporting his own telescopic observations of the stars below Orion's Sword, and of the stars in the Pleiades (Rigaud p25–26). Yet by June, these asterisms would long since have vanished into the light of spring, and must therefore have been observed between October 1609 and March 1610, for Orion and Taurus are winter constellations. What is clear, however, is that Lower – and perhaps his friend the young Mr Protheroe, to whom he sometimes refers, and who could see detail on the Moon with the naked eye – must have been making telescopic observations of astronomical bodies "with my cylinder" from south Wales "this last winter" of 1609–10. And considering Lower's known friendship – even "pupil–teacher" relationship – with Harriot, it is not unreasonable to assume that Harriot was continuing to make telescopic observations as well from Syon House, near Kew. As all this would have happened weeks or months before Galileo's book could have reached England, or even before it was published, I suggest that the practice of observing, and trying to make sense of, telescopic images was already well under way in the British Isles by the summer of 1610, by the time that Harriot made his second and subsequent drawings of the Moon, rather than that Harriot's interest had suddenly been aroused and his perceptions influenced by a reading of *Sidereus Nuncius*, or by Kepler's comments upon Galileo's discoveries. What I do believe, however, from evidence in his subsequent writings, is that Harriot was most likely inspired afresh to undertake further telescopic researches after reading Galileo. Yet one tantalizing thing alluded to in Lower's "Longest Day, 1910" letter (Rigaud p26) is how much modern astronomy was being actively cultivated in South Wales. For, as Lower told Harriot in that letter, "We Traventine [Traventi] philosophers were [already] a consideringe of Kepler's reasons" when Harriot's latest letter arrived, and elsewhere in his letters Lower mentions Mr Protheroe and Mr Vaughan. So, did South Wales already have a "club" of men discussing elliptical orbits and which, in turn, became early users of telescopes and fans of Galileo?

> **"Could Lower have been the first person to have had a telescope for a Christmas present?"**

Secondly, I would argue, on the basis of his surviving papers, that Harriot's telescopes – like Galileo's – were getting more powerful between 1609 and 1612. About eight individual instruments are referred to in his manuscripts dealing with telescopic astronomy, ranging in power from ×6 or ×8 up to ×50, with the telescopes most commonly mentioned being around ×10 or ×20 (Rigaud p34). And this in itself furnishes us to some extent with an explanation for why he records increasingly fine data, and then produces the beautiful and very detailed whole-Moon map of c.1613 (figure 3).

Then there is the fascinating letter sent to Harriot by Lower from Traventi, dated 6 February 1610 (Rigaud p42–45). Its date, however, is somewhat ambiguous. Did he mean 6 February 1610 Old Style Julian Calendar, or 6 February 1611 New Style Gregorian? As the Julian was the legal calendar in Great Britain at the time, with its New Year beginning on Lady Day, 25 March, the conventional way to write a February date would have been "1609/10" or "1610/11", with the forthcoming, post-25 March New Year date following the slash. So could Lower have been referring to 6 February 1610 (1609/10), just seven months after Harriot's first lunar phase drawing of 26 July 1609?

Evidence in the letter

But what can be learned from internal evidence contained in the letter? The following points are significant. (a) Lower begins his 6 February 1610 letter by thanking Harriot for the "perspective cylinder" which Harriot had promised, and which had arrived safely in Wales. He next mentions choosing two or three other telescopes, all of which seem to be of English rather than Dutch manufacture, with a comment about paying the "work man". (b) Lower goes on to say "I have observed the moone in all his changes", or phases, including earthshine at new Moon. To have observed a whole lunation by 6 February, therefore, one is left to assume that the telescopes must have arrived in South Wales at the beginning of January 1610 if not before. Could Lower have been the first person to have had a telescope for a Christmas present? (c) He next gives what has become the classic early description of the Moon when, near gibbous: "[It] lookes like unto the description of coasts in the dutch bookes of voyages. In the full she appears like a tarte that my cooke made me the last week. Here a vaine of bright stuffe, and there of darke, and so confusedlie al over. I must confesse I can see none of this without my cylinder" (Rigaud p42). (d) The rest of this long letter is devoted to discussing the newly announced elliptical orbits of Kepler. Lower tells Harriot that he has already read Kepler "twice over", and he is clearly fascinated and somewhat nonplussed by Kepler's "revolutions in Ellipses". Lower does not give a title to Kepler's book, but it was probably *Astronomia Nova* (1609), in which Kepler first discusses elliptical orbits.

And very importantly, (e) Lower's 6 February 1610 letter makes no mention whatsoever of Galileo and his discoveries. This, I suspect, is because Lower's letter predates the publication and arrival in England either of Galileo's *Sidereus Nuncius* (March 1610) or Kepler's own *Dissertatio* on Galileo's book, published in Prague in May 1610. So while, by February 1610, both Harriot and Lower were discussing Kepler's elliptical orbits, published the previous year, neither seems to have been aware of Galileo's lunar work, and hence they appear to be talking about entirely original telescopic researches, conducted at Syon House and in South Wales. (f) Yet by his "Longest Day 1610" letter, Lower is not only mentioning Galileo, but even discussing the Italian astronomer's "three discoveries" – the rough lunar surface, the telescopic visibility of otherwise invisible stars, and Jupiter's satellites – making it clear that news of Galileo's discoveries had reached the British Isles by midsummer 1610 (Rigaud p24–27). Yet as Lower is requesting Harriot to "send me also one of Galileus bookes" one suspects that copies of *Sidereus Nuncius* had not yet reached Carmarthenshire and that Lower so far knew the Galilean discoveries only as had been reported to him at second hand, probably by Harriot himself.

Of course, this suggested sequence would fall down if one could demonstrate conclusively that the letter dated from what we would call 1611, though if that were the case, one would expect to find references to Galileo's discoveries. For as shown above, both Harriot and Lower were undoubtedly inspired by Galileo's telescopic discoveries by the time of the "Longest Day 1610" letter.

But in our concern with early telescopic observations of the Moon, it is all too easy to overlook what was most likely the real contemporary interest of Harriot and Lower: celestial mechanics and the mathematical significance of Kepler's elliptical orbits. For both men were mathematicians at heart, and Kepler's elliptical orbits represented a radical departure from the pure circular orbits of Greek cosmology, and presupposed an abandonment of the classical crystalline spheres. I would even suggest that the "strange spottednesse" of the Moon as seen through a telescope would have been less intellectually challenging than the nature and causal influences behind elliptical orbits, which idea in itself was replete with philosophical questions such as what was the nature of the force that produced such orbits, if space was a void? This is perhaps why Lower's letters to Harriot devote much more attention to discussing Kepler's orbits than they do to telescopic viewing (Apt 1982, especially p98).

Observing with a 'Galilean' telescope

To help me make sense of what Harriot was observing and trying to interpret on and after 26 July 1609, I began my own study of the Moon with a "Galilean" telescope during the brilliantly clear (from Oxford) waxing lunation in early December 2008. I had long owned a "Galilean" refractor of ×20 magnification of my own manufacture, which I had built with a companion "Keplerian" instrument of similar optical specification. I had originally made this pair of telescopes many years before, partly to test their respective optical performances upon heavenly bodies, and partly for teaching.

The first thing that strikes any observer using a Galilean optical system, as it had Stephen Ringwood in his 1994 study of Galilean telescopes, is the very tiny field of view, encompassing 20 arcmin at most. Indeed, the field of view is about as big, in the words of the late Prof. John D North, as that seen down the barrel of a Colt 45 revolver held at a distance of two feet (North 1974). Now, not only does this make the finding and tracking of an object a feat in itself, but one can never see the whole, or whole *crescent*, Moon at any one time – which would have made it hard for Harriot (and by December 1609, Galileo) to gain an integrated spatial comprehension of the Moon as a whole. And this could indicate why Galileo himself sometimes drew the very conspicuous crater Albategnius (probably) in slightly different positions on the terminator, and vastly exaggerated in size, in his depictions of the quadrature Moon in *Sidereus Nuncius*.

It was also interesting to see, when I compared the five-day Moon of 3 December 2008 with Harriot's drawing of 26 July 1609, that there were few outstanding features to be seen other than the *maria*, which might go towards explaining why Harriot's first drawing is relatively devoid of detail. Indeed, in a low-power, aberrated Galilean optical system, much of the broad lunar crescent seemed a mixture of grey and white areas, with very few sharply defined details. By the 7th, 8th and 9th-night Moon, however, the terminator had become much more interesting and variegated, with craters such as Albategnius, then Clavius, appearing very distinctly: perhaps one reason why both Galileo and Harriot made them look so conspicuous. Geoff Burt of the South Downs Planetarium, Sussex, has done valuable work in identifying craters and other features on Harriot's maps and I am indebted to him for the drawings and feature identification lists he has sent me[2].

What is truly astonishing by the time Harriot made his 6-inch-diameter whole-Moon map in c.1613, however, is how he managed to get so many key features, both *maria* and crater formations, in the right places, and even numbered in accordance with what might have been a trigonometrical grid or system of nomenclature (figure 3). Of course, as Ewen A Whitaker (1999) has demonstrated, there was an already well-established artistic tradition of naked-eye man-in-the-Moon lunar drawing by 1609, though Harriot's whole-Moon map goes well beyond anything up to that date. For not only are the *maria* drawn with a remarkable level of accuracy, but there are numerous crater and other topographical features included as well. Indeed, the phase drawings of Galileo and whole-Moon maps of Scheiner (1614), Biancani (1620), and even Fontana (1630) are crude by comparison, and not until the published maps of Claude Mellon (1635–7) and Hevelius (1647) is Harriot's manuscript whole Moon equalled as far as precise detail is concerned (Whitaker 1999).

It is important to remember, moreover, that it is not possible to delineate precise parts or fractions within the field of view of a Galilean telescope, for its optical configuration does not allow the insertion of clearly defined reticules or measuring points within its field. Galileo and others attempted to put obscuring bars across their lenses as a way of dividing up the field of view, but such bars only produce vague shadow lines and nothing like the sharp fiducial edges that are necessary for making proper measurements within a telescopic field. (I speak from personal experience, having experimented with obscuring bars to divide up the field of my own Galilean refractor.)

I am confident, therefore, that Harriot could not have had any micrometric device for measuring the sizes or relationships of lunar features, for in 1610 the micrometer still lay 30 years in the future, when William Gascoigne of Leeds would invent the screw micrometer used in conjunction with a positive, Keplerian, eyepiece (Chapman 1990). Harriot, therefore, must have made his phase- and whole-Moon maps by a combination of eye-estimate and skilled draughtsmanship.

"Galileo, I suggest, had the instincts of an artist, whereas Harriot had the precise skills of a draughtsman or a surveyor."

I would take issue, therefore, with Terrie Bloom's suggestion that Harriot's post-17 July 1610 lunar drawings are explained by his being influenced by Galileo's drawings published in *Sidereus Nuncius*. For while it is true that Galileo seemed more interested in big craters, mountains, and shadow-casting formations that emphasized the rough character of the lunar terrain, and Harriot in delineating the *maria*, nonetheless the details and proportions displayed in Harriot's whole-Moon map of c.1613 are, I argue, much more advanced as a piece of detailed topographical draughtsmanship than anything ever drawn or published by Galileo or his contemporaries. And that stands despite the fact some of Galileo's watercolour pictures of the rough lunar surface indicate that he may have been more artistically gifted than Harriot (Whitaker 1999). Galileo, I suggest, had the instincts of an artist, whereas Harriot had the precise skills of a draughtsman or a surveyor.

Harriot's other telescopic observations

Of course, the Moon was not the only astronomical object that Harriot looked at with his early telescopes. He also made an original and quite independent discovery of sunspots, as the following MS entry indicates: "1610, Syon. December 8th [♄]. The altitude of the sonne being 7 or 8 degrees. It being frost & a mist I saw the sonne in this manner," which observation he accompanies with a solar drawing depicting three large sunspots (Rigaud p32). It cannot be claimed, however, that Harriot was the first astronomer to observe sunspots, as Galileo had probably seen them in the summer of 1610, while Johannes Fabricius and Christopher Scheiner saw, and published accounts of them, probably independently, in 1611. But at the time of Harriot's first seeing the spots, Galileo had neither published nor openly communicated anything on the subject, so that Harriot's can be considered an independent, albeit slightly delayed, discovery. On the other hand, Harriot made no attempt to interpret the spots, and though observing them occasionally in the interim, such as on 19 January 1611, when he noted that the spots seen previously had now gone from the disc, he did not begin to regularly observe sunspots until 1 December 1611, by which time he had almost certainly learned of Galileo's, Johannes Fabricius', and other continental sunspot observations. To Galileo, however, the sunspots were valuable Copernican ammunition, in so far as they contradicted the Aristotelian theory of an unblemished Sun, but as Harriot was not vociferously advancing a Copernican agenda, we can understand why he was less quick in delivering an opinion on them, even in his private notes. In all likelihood, Harriot was more interested in sunspots, along with other newly discovered telescopic phenomena, as curious and hitherto unknown natural phenomena in their own right, rather than as potential ammunition in Copernican scientific politics. Over the next two or three years after 1610, Harriot made some 200 observations of sunspots, recorded on 73 foolscap sheets in his papers (Rigaud p32). He watched spots form and break up, as Galileo was to discuss in his *Letter on Sunspots* (1613), and subsequent analyses of his sunspot observations have shown that the Sun had a rotation period of 27 days.154 days. Of course, Harriot knew nothing of the latitude dependency of sunspot rotation periods, though his values were much more precise than those of any of his contemporaries (North 1974).

Surprisingly, Harriot seemed to prefer to observe the Sun by direct vision, through "thick ayer & thin cloudes", as he put it in January 1613, using mists and clouds as natural filters (Rigaud p34). He was, however, acquainted with the projection method, as employed by Galileo, Scheiner and others, but does not appear to have used it. There is no reference, though, to his suffering any eye damage, unlike his younger contemporary John Greaves (1602–1652), whose direct-vision sunspot observations left the retinal impression of "a company of crows flying together in the air at a good distance" (Greaves 1737, Rigaud p33).

Harriot also observed Jupiter's moons, though no claim of priority can be advanced for him on this front, for his interest in, and observations of, the Jovian moons only got under way after the summer of 1610, by which time he would have had ample opportunity to read about them in *Sidereus Nuncius*, or learn of them via Kepler in Prague. On the other hand, Harriot made very careful timings of the periods of the Jovian satellites, the accuracy of which has been confirmed by modern scholarly analyses of his surviving manuscripts (Roche 2004a).

Harriot's telescopic observations of the heavens seem to have come to an end after a few years – his last solar observations, for instance, date from January 1613. And one suspects that this was because Harriot, like Galileo in Italy, had pushed the simple Galilean telescopes of the day, with their small, often aberrated, lenses and tiny fields of view, as far as they could go by 1615 or so. Of course, over the next two or three decades astronomers and opticians strove to improve lenses and images, but it was not really until the 1640s, when glass-makers and grinders such as the Huygens brothers Christiaan and Constantijn in Holland, Giuseppe Campani and Eustachio Divini in Italy, and Johannes Hevelius in Poland, had succeeded in significantly improving the optical technology, that a new generation of telescopes, and telescopic discoveries, became possible. The fruits of these endeavours were the very-long-focus "aerial" telescopes which, between 1650 and 1700, revolutionized our physical knowledge of solar system bodies, to reveal Saturn's ring structure, new satellites, more detail on the Moon, Jupiter's belt systems, cometary nuclei and half-a-dozen mystifying "lucid spots" or nebulae. And by 1660, the weight of observational evidence had undoubtably shifted in favour of the Copernican system, though it was not until James Bradley's discovery of the aberration of light in 1728, backed up by the measurement of star parallaxes in the 1830s, that Copernicus's theory of 1543 found its conclusive physical proof.

> **"Galileo was a 46-year-old professor who did not especially enjoy his university job … he wanted fame, comfort and security, and the telescope opened up such possibilities."**

But this was well after Harriot's, and even Galileo's, time, and Harriot's other astronomical observations tended to be of the more traditional "Tychonic" variety, painstaking geometrical measurements of naked-eye bodies against the fixed stars, such as his meticulous observations of the paths of the brilliant comets of 1607 (Halley's) and 1618. Most of these were made by large "Astronomical Radii" or cross-staves (Roche 2004a, Roche 1977). John Aubrey in his "Brief Life" of Harriot records that Sir Francis Stuart had told him that Harriot had seen no less than nine comets, and – more dubiously – that he had predicted seven of them!

A new perceived reality

It is hard for 21st-century persons, however, to think themselves back into the visual world of 1609. For since time immemorial the naked eye had been the sole and natural adjudicator of things celestial, aided by the geometry of the 360° circle, as seen at its most refined in the instruments of Tycho Brahe, with a one-arc-minute resolving power asserting a perceptual barrier beyond which no vision could pass. But all of a sudden, ancestral wisdom had been turned topsy-turvy: a ×6 telescope showed hitherto unimagined shoals of stars in the Milky Way, and ×10, ×20 and so on magnification telescopes revealed more and more objects in the planetary and stellar heavens. Could the universe be infinite, as certain medieval philosophers had speculated (Grant 1994)? And the once smooth, albeit tarnished, silver ball of the Moon now seemed strangely rough, with topographical features that reminded Sir William Lower of the bays, headlands and seas of a Dutch atlas. For I would suggest that Harriot was not only the first person to record seeing an astronomical object through a telescope, he was also the first to wrestle with the problem of interpreting and making sense of what he saw. And while I fully concede that Harriot's reading of Galileo's *Sidereus Nuncius* in the early summer of 1610 may have influenced his subsequent thinking and perceptions, I find it hard to believe that the sophistication of the best of the two whole-Moon maps which he produced two or three years later, is not the fruit of a great deal of observing, interpreting and fresh understanding of what he saw through his original "Dutch truncke", and its more powerful successors as fabricated by Christopher Tooke. Indeed, it should also be remembered that Christopher Tooke, Harriot's craftsman and sometimes fellow-observer, was the first recorded Englishman to make telescopes.

For having personally struggled with a "Galilean"-type telescope of similar specification to Harriot's "Dutch truncke", tried to make sense of the small and badly aberrated image that it produces, and having suspended, as far as possible, all that a 21st-century observer routinely knows about the lunar surface, I could not help but be amazed by the quality of the detail on Harriot's whole-Moon map. For it is a staggeringly original production by any standards and, I would suggest, a significant milestone in mankind's attempt to understand the cosmos.

Yet quite apart from any cautions about keeping a low profile in dangerous political times, I would argue that unlike Galileo, Thomas Harriot was not an agenda- or career-driven individual. For in 1610, when Galileo published his undoubtedly epochal telescopic findings, he was a 46-year-old Italian professor who did not especially enjoy his job at the University of Padua. He was not very well paid, not particularly respected, did not seem fond of having to deal with students, and had a rather dysfunctional family to maintain, with three illegitimate children. He wanted fame, comfort and security, and the telescope opened up such possibilities to him, as witnessed by his demonstration of his "perspective" as a way of seeing distant ships to a group of Venetian senators in the summer of 1609. A far-seeing device would be very handy for the Venetian maritime Republic, and Galileo got a reward from the Venetian authorities, though not as big nor as grand a one as he had hoped for. Curiously enough, what Galileo desired was a job just like that which Thomas Harriot already had: to be the well-maintained star philosopher to a great and wealthy nobleman. Galileo won this status, to some extent, in 1610, after naming the four satellites of Jupiter the "Medicean Stars", following which his former pupil Cosimo II de Medici, Grand Duke of Tuscany, one of the most powerful and munificent princes in Italy, brought him back to Tuscany and gave him a well-paid research chair at Pisa. A vastly more desirable position, for a man of Galileo's ambition, than being a mere teacher of Euclid and Ptolemy to fractious students for a modest salary of 180 florins a year. And to live up to his new status in Tuscany, Galileo dismissed his long-standing mistress, the Venetian Marina Gamba, had his son legitimized by Ducal decree, and obtained an ecclesiastical faculty enabling him to hide away his two little girls in a convent. One of them, who took the religious name Sister Maria Celeste, would win posthumous historical fame as *Galileo's Daughter* (Broderick 1964).

Harriot, on the other hand, had no known offspring or dependents, and seems to have had no especial yearning for fame, nor to have nursed any higher worldly ambitions. In fact, Harriot seems to have deliberately avoided fame, for on 6 February 1610, Lower almost berated him for his "to[o] great reservednesse", especially regarding his algebraic and mathematical discoveries, which "hath robd you of these glories", for recognition had gone to others, before exhorting him, for "your counties & frinds" sake to set about "publishing some of your choice workes" (Rigaud p43). Yet not only had Harriot an aversion to the limelight, but he does not appear to have had any specific duties as the Earl of Northumberland's star "wise man", beyond talking with his master on visits to the Tower of London, and being what Prof. Shirley styles an "intellectual companion" (Shirley 1983 p364). He had ample creative space, perhaps two homes (Syon House and Threadneedle Street), a specially provided observing chamber on top of Syon House, and a salary variously cited, between £120 and £300 per annum: a sum between twice and six times the salary of a Gresham College Professor, and up to three times that of the Warden of Wadham College, Oxford. Indeed, the smaller sum, in 1600, would have been handsome, and the larger downright munificent, especially for a man in Harriot's circumstances[3] (Chapman 2007). How could he have done better?

Like Galileo, Thomas Harriot seems to have been a convinced Copernican though, unlike his Italian colleague, he was in no way "evangelical" about the heliocentric theory. This came, moreover, not from any fear of religious persecution, for while the authorities in Tudor and Stuart England were forever vigilant regarding the activities of political subversives or pro-Spanish or Catholic sympathizers (which were seen as one and the same), the scientific realm was very largely an open house, with no obvious barriers, provided that there was no threat to the Queen's Peace. What rotated around what was left to the mathematicians, and by 1609 England and Wales had had half a century of untroubled Copernican speculation, starting with the Welshman Dr Robert Recorde in the 1550s, followed by Thomas Digges' English language essay and solar system diagram explaining the Copernican theory in 1576, and then the early Gresham College Professors, such as Harriot's contemporaries Henry Briggs and Henry Gellibrand, and even the "Magnetic Philosopher" and Queen Elizabeth I's physician, Dr William Gilbert (Chapman 2007). Most people, including educated ones, probably thought that Copernicans were a little deranged for believing something which ran so much against commonsense experience, but there was certainly no persecution, and the Church of England had no official policy of any kind as far as astronomy and cosmology were concerned. But as a well-circumstanced, quiet, private gentleman, with his first patron Raleigh on "death row" between 1603 and his beheading in 1618, and his second, Lord Northumberland, detained at His Majesty's pleasure from 1605 to 1621, one can fully understand that Harriot was not willing to draw the world's attention to himself.

Conclusion

I began this article by arguing that the telescope radically changed the nature of human perception by showing how a progressive technology could open up hitherto unimagined realms of Nature to scientific enquiry. I believe that the radical analogy of the telescope still holds today: not only for instruments such as the Hubble Space Telescope, the Mars Rovers and fly-past images of the outer planets, but for every branch of science and science-based technology that depends upon images of any kind, from surveillance cameras to medical scanning machines. For all images, in fact, that go beyond what the natural eye can see.

Thomas Harriot died on 2 July 1621, in Threadneedle Street, London. The cause of his death was a cancerous tumour growing in his nose, and one wonders whether it may have been connected with the tobacco-smoking that Raleigh and his friends encountered during their youthful Virginia connections, and which they introduced into England. He was buried in the Church of St Christopher-le-Stocks, Threadneedle Street, but the church was destroyed in the Great Fire of 1666 (Seltman and Mizzi 1997). The Bank of England now stands on the site of Harriot's grave. ●

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Notes

1: For a definitive scholarly study on the origins of the telescope, see: Albert van Helden 1977 "The Invention of the Telescope" *Trans. American Phil.Soc.* **67** pt4. Also, H C King 1955 *The History of the Telescope* (London) Cht 2. Also, *Memoires-Journaux de Pierre de l'Estoile* (Paris, 1883), **tome IV** 164; **tome IX** *Journal de Henri IV*, 164, 168. Also, John J Roche 1982 "Harriot, Galileo, and Jupiter's Satellites", *Archive Internationales d'Histoire de Sciences* **32** 8, 9–51.

2: Geoff Burt "Harriot's Moon Catalogue", produced for the Hampshire Astronomical Group as part of the 26 July 2009 commemoration event (see box "Telecope400" below). I am indebted to Dr Robin Gorman DSc of the Hampshire Group for a copy of the Catalogue, which can be viewed at http://www.hantsastro.org.uk/resources/moonecatalogue/index.php.

3: Estimates of Harriot's income vary considerably. Antony à Wood (*Athenae* I p460) cites £120 p.a. Aubrey (*Brief Lives* p123) gives £200. FX von Zach (Rigaud p61) says "by some of his receipts, I found among his papers, it appears he had 300L". Shirley (*Thomas Harriot, Renaissance Scientist* ref. 5 p30) opts for £100.

Telescope400

Thomas Harriot's achievements will be celebrated at an event at Syon Park, Middlesex, on 26 July 2009, as part of IYA2009 and sponsored by the RAS. All are welcome.

http://telescope400.org.uk