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John Flamsteed and the turn of the screw: mechanical uncertainty, the skilful astronomer and the burden of seeing correctly at the Royal Observatory, Greenwich

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Abstract. Centring on John Flamsteed (1646–1719), the first Astronomer Royal, this paper investigates the ways in which astronomers of the late seventeenth century worked to build and maintain their reputations by demonstrating, for their peers and for posterity, their proficiency in managing visual technologies. By looking at his correspondence and by offering a graphic and textual analysis of the preface to his posthumous *Historia Coelestis Britannica* (1725), I argue that Flamsteed based the legitimacy of his life's work on his capacity to serve as a skilful astronomer who could coordinate the production and proper use of astronomical sighting instruments. Technological advances in astrometry were, for Flamsteed, a necessary but not a sufficient condition for the advancement of astronomy. Technological resources needed to be used by the right person. The work of the skilful astronomer was a necessary precondition for the mobilization and proper management of astronomical technologies. Flamsteed's understanding of the astronomer as a skilled actor importantly shifted the emphasis in precision astronomical work away from the individual observer's ability to see well and toward the astronomer's ability to ensure that instruments guaranteed accurate vision.

> The Certeinty of Astronomicall Determinations depends upon these three things, The accuracy of the Celestiall observations. and. the skill & diligence of the person that makes them.[1]

So began John Flamsteed at a lecture, the sixth in the series, delivered at Gresham College in London on 26 October 1681. The first Astronomer Royal went on to caution his listeners that

> some very ingenious & curious men … [who are] ill accommodated with the necessary helpes for observation … [and who have] slipt the principle opportunityes & so ill managed such others as have presented themselves that theire notes serve onley to perplex not to assist the Skilfull Astronomer …[2]

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1 Eric Forbes (ed.), *The Gresham Lectures of John Flamsteed*, London: Mansell, 1975, p. 147.

2 Flamsteed was likely trying to save face with these comments as this lecture followed a quarrel that took place between Flamsteed and Robert Hooke at Garraway's coffee house in which Flamsteed left the coffee house humiliated. Flamsteed used the opening remarks of this lecture to set himself apart not only from Hooke

This paper is about Flamsteed's notion of the skilful astronomer – what made a skilful astronomer, how one could recognize a skilful astronomer, and what differentiated a skilful astronomer from the curious and ingenious individuals whose pretensions to astronomical know-how undermined good astronomical work. Looking at Flamsteed's epistemology, scholars have typically stressed Flamsteed's emphasis on the importance of technological advances in astronomical praxis in the pursuit of advancing knowledge.[3] Scant attention has been paid to the sorts of behaviour that befitted the skilful astronomer according to Flamsteed.[4] The certainty of astronomical measurements, Flamsteed reminded the attendees at Gresham College, depended on the skill and diligence of the astronomer in addition to accurate observation. Individuals who failed to incorporate the technological advances ('principle opportunityes') of astronomy or who failed to properly mobilize those technologies served as counterpoints to Flamsteed and other individuals whose work merited the advance of astrometry.

The improvement of precision astronomy made specific demands of the skilful astronomer. Where independent verification could be used by Kepler to prove Galileo's claims regarding the existence of the moons of Jupiter, finding the exact location of celestial bodies, the metaphysical status of which were not in question, placed weightier demands on astronomers who held pretensions to exactitude in their observations.[5] This paper argues that Flamsteed justified his claims of achieving unprecedented accuracy in celestial measurements specifically on his capacity to manage various visual technologies. Rather than basing the veracity of his claims on the quality of his eyesight, Flamsteed saw the telescope as a way of elevating the quality of an observer's eyesight such that it rendered obsolete the importance of the individual's ability to see well. For Flamsteed, the telescope 'perfected' vision, making the real work of the astronomer the coordination of events that made an accurate observation possible. The coordinating activities of the astronomer may be broken down into at least three principal and overlapping categories: the ability (1) to incorporate instruments into one's research that could genuinely merit advances in astronomical knowledge, (2) to discriminate between good-quality instruments and bad ones, and (3) to calibrate instruments such that inherent mechanical errors, or errors that might develop in instruments over time, could be accounted for and, if possible, corrected. For Flamsteed this was the work of the

but also from Hevelius and Riccioli, all of whom he considered exemplars of poor astronomical work. See Forbes, op. cit. (1), pp. 147, 149, 160 n. 6.7; Adrian Johns, *The Nature of the Book: Print Knowledge in the Making*, Chicago: The University of Chicago Press, 1998, pp. 554–555; Johns, 'Flamsteed's optics and the identity of the astronomical observer', in Frances Willmoth (eds.), *Flamsteed's Stars: New Perspectives on the Life and Work of the First Astronomer Royal (1646–1719)*, Woodbridge: Boydell Press in association with the National Maritime Museum, 1997, 77–106, 81–90.

3 The clearest iterations of this are seen in Allan Chapman (ed.), *The Preface to John Flamsteed's Historia Coelestis Britannica (1725)*, London: Trustees of the National Maritime Museum, 1982, p. 1; Chapman, *Dividing the Circle: The Development of Critical Angular Measurement in Astronomy, 1500–1850*, Chichester: John Wiley & Sons, 1995, pp. 34–35, 49–59.

4 Johns's work is a notable exception. See Johns, 'Flamsteed's optics', op. cit. (2).

5 On the example of Kepler and Galileo see Albert van Helden, 'Telescopes and authority from Galileo to Cassini', *Osiris* (1994) 9, pp. 8–29, 11–13.

skilful astronomer, and it was in this role that he understood his ability to advance astronomical knowledge.[6]

In his essay on how early modern scientists dealt with discrepant results, Jed Z. Buchwald holds that, for astronomers,

> while instruments and measuring devices were often created by local craftsmen … [o]ne might think that disputes over numbers would … revolve in perpetuity [because of the non-standardization of instruments] with little possibility of resolution other than by social *fiat*. For the most part we find nothing of the kind. Astronomers for example did produce different stellar coordinates from the time of Tycho onwards, but we rarely find any disputes over whether or not observer *x* worked his apparatus correctly in producing number *y*. There was a great deal of discussion concerning ways to improve the accuracy and precision of instruments, and these did take into account what the later observer thought to be *the range of trust to be placed in previous results*.[7]

Buchwald, however, does not clarify that the 'range of trust placed in previous results' is of two sorts: first, the trust placed in the quality of an astronomer's instruments, and second, the trust placed in an astronomer's ability to operate, manage and maintain those instruments. Regarding the former, trust was not usually extended to the craftsmen who manufactured the astronomer's instruments. Instead, it is more accurate to say that there was an expectation that gentlemen-astronomers were capable of appropriately selecting skilled craftsmen and ensuring that their work resulted in sufficiently accurate instrumentation. This was an expectation about the quality of an astronomer's instruments, and it was an expectation that astronomers actively worked to fulfil; it was not a basic level of trust that was freely bestowed upon astronomers. Regarding the second sort of trust implied by Buchwald's statement, consider the warrant issued to Flamsteed in late 1710 on behalf of Queen Anne commanding the appointment of permanent interlopers to the Royal Observatory:

> Her Majesty commands … for the improvement of astronomy and navigation, to appoint the President, and in his absence the Vice-President of the Royal Society … to be constant *Visitors* of the Royal Observatory. And for the better enabling you to make the necessary observations for these ends, directions are likewise given for repairing, erecting, or changing Her Majesty's instruments in the said Observatory.[8]

6 According to Chapman, it was through improved instruments and methods of mathematical reduction that Flamsteed thought astronomical knowledge could be improved. By comparison, I argue that, for Flamsteed, a particular type of person with particular skills needed to put instruments and methods to work in order to genuinely advance astronomical knowledge. Chapman, *The Preface*, op. cit. (3), p. 1; Chapman, *Dividing the Circle*, op. cit. (3), pp. 34–35, 49–59.

7 Jed Z. Buchwald, 'Discrepant measurements and experimental knowledge in the early modern era,' *Archive for the History of Exact Sciences* (2006) 60, pp. 565–649, 590 (emphasis added).

8 Queen Anne's Warrant Appointing Visitors to the Royal Observatory, 12 December 1710, in Eric Forbes, Lesley Murdin and Frances Willmoth (eds.), *The Correspondence of John Flamsteed, the First Astronomer Royal* (hereafter *CJF*), 3 vols., Bristol: Institute of Physics Publishing, 1995, vol. 1; Francis Baily (ed.), *An Account of the Revd. John Flamsteed, the First Astronomer-Royal: Compiled from His Own Manuscripts, and Other Authentic Documents, Never before Published & Supplement to the Account of the Revd. John Flamsteed*, London: Dawson, 1966, p. 91.

As a consequence of Isaac Newton and Flamsteed's bitter rivalry, this order was issued at the behest of Newton, then president of the Royal Society, as a way of forcing Flamsteed to relinquish his autonomous management of the Royal Observatory. Significantly, 'repairing, erecting … [and] changing' the observatory's instruments were the main responsibilities that the Astronomer Royal lost as a result of Newton's intrusion. In this case, the range of trust placed in the Astronomer Royal did not extend to his ability to incorporate the appropriate instruments into his research, or to his ability to discriminate or calibrate the instruments at the Royal Observatory. Specifically, doubts about Flamsteed's ability to achieve those ends provided the pretence for Newton to impose the supervision of the Royal Society on Flamsteed's solitary bastion of uranology. The following study shows not only how Flamsteed tried to diminish this sort of doubt by working to create and maintain a public identity for himself based on fulfilling the expectations of the skilful astronomer, but also that it was specifically by fulfilling these expectations that Flamsteed advertised his capacity to produce a comprehensive star catalogue that could legitimately supplant the work of his astronomical forebears.

The technological cutting edge of late seventeenth-century astrometry and the privilege of information

> Between the *Object* and *Eye-glass*, at the focal distance of the *Eye-glass* … place two fine Hairs or Threads across, so as to be seen clearly when you look through the *Eye-glass*. Let there be an aperture near these cross hairs, that the light of a Candle may shine on them, in the night, when you look at a star. It is convenient that the *Eye-Glass* and Cross-Hairs or Threads should be lodged in a short lesser Tube by themselves, so as to go into, and slide backward and forward, in the end of the larger tube; whereby you may set the *Eye-Glass* and *Cross-Strings* nearer unto, or farther off from the *Object-Glass*.[9]

With the exception of a few fleeting passages relating to the installation of lenses into a tube, these lines constitute the instructions William Derham, a clergyman-cum-amateur-scientist, offered in an appendix to his book *The Artificial Clockmaker*, for the construction of a simple telescope.[10] Derham wrote these instructions with the intention of giving a lay audience a way of using 'a telescope for the governing of … Watch[s] by [observation of] the fixed stars'.[11] This was part of Derham's larger project of sharing his learning with 'those, whose business the Mechanik part is', about the 'Artificial [i.e. theoretical] part of … the Automatical Computation of time'.[12] What is most surprising about Derham's instructions for the construction of a simple telescope is that the installation of a crosshair features as the most important part of the device's

9 William Derham, *The Artifical Clockmaker: A Treatise of Watch and Clockwork*, 2nd edn, London, 1700.

10 The directions on how to build a telescope only appear in an appendix in the second edition of the book. The first edition of Derham's volume was published in 1696.

11 Derham, op. cit. (9).

12 Derham, op. cit. (9).

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construction. Indeed, the actual building of the tube and the installation of the lenses received scarcely any attention in Derham's account. Understandably, by the end of the seventeenth century when Derham was writing, those topics did not merit much attention as the basic construction of a telescope would have been well known. Derham, however, was not offering an account of how to simply observe the night sky; instead, he was offering the reader an opportunity to learn, albeit in an elementary way, how to measure the passage of celestial bodies through the night sky. This required a device, no matter how rudimentary, with which one could divide what one saw through a telescopic sight into different parts. Derham's instructions illustrate how, by the end of the seventeenth century, the telescope had moved from being an instrument of discovery to one of measurement.[13] This change came with the proliferation of micrometers among astronomers in the early 1670s, an event that was closely tied to the rise of an aspiring astronomer eager to build his reputation.[14]

When, in 1673, a little more than a quarter-century before Derham published his instructions for constructing a telescope, the Scottish mathematician James Gregory began establishing an observatory in St Andrews equipped with the most modern and sophisticated instruments, he contacted Flamsteed through their mutual acquaintance, John Collins. Writing to Flamsteed for the first time, Gregory confessed, 'There is nothinge I am more Curious for then Micrometers; For I perceive by some things, That I have seen of yours, that you understand Extroardinarilye to manage.'[15] Gregory was excitedly referring to a letter Flamsteed wrote to G.D. Cassini that was published in the *Philosophical Transactions* early in the summer of 1673.[16] In his letter, Flamsteed revealed the exceptional accuracy with which he could measure celestial bodies through the expert handling of a filar micrometer – a device that, when inserted in the focal plane of a telescope, can be used to measure the image viewed through the telescope by moving two reticles nearer or farther apart by means of the threading on a screw. He reported that by fastening his micrometer to a fourteen-foot telescope he could reliably divide 'a single … [inch] into 3507 parts'.[17] This unprecedented precision could be used,

13 I owe the wording of this sentence to Voula Saridakis, who writes, 'the development of the telescope dominated much of the seventeenth century, yet it was the invention and ultimate implementation of micrometers and telescopic sights that turned astronomy from a field of discovery into one of measurement'. See Voula Saridakis, 'Converging elements in the development of late seventeenth-century disciplinary astronomy: instrumentation, education, networks, and the Hevelius–Hooke controversy', PhD dissertation, Virginia Institute of Technology, 2001, OCLC 48543806, p. 10. Although not perfectly distinct, the difference between describing and measuring in astronomy is often tied to the kind of astronomical problems the astronomer is trying to solve. See Simon Schaffer, 'Herschel in Bedlam: natural history and stellar astronomy', *BJHS* (1980) 13, pp. 211–239.

14 Derham himself was in direct contact with Flamsteed, and on at least one occasion visited the Royal Observatory. He received explicit instructions from the Astronomer Royal on how to conduct his micrometer, which Derham refered to as 'Flamsteedian' in design. See Derham to Flamsteed, 15 October 1706, *CJF*, vol. 3; Derham to Flamsteed, 29 October 1706, *CJF*, vol. 3.

15 Gregory to Flamsteed, 19 July 1673, *CJF*, vol. 1.

16 Flamsteed to Cassini, 7 July 1673, *CJF*, vol. 1; John Flamsteed, 'Johannis Flamstedi … Novas Observationes …', *Philosophical Transactions* (1673) 8, pp. 6094–6100.

17 Micrometers were typically graduated by determining how many parts an inch could be divided into. Normally, this was done by counting how many revolutions of the screw were required to create the space of an

Flamsteed showed, not only for accurately locating fixed stars, but also for determining planetary parallax.[18] When asked about the device by Gregory, Flamsteed responded with a detailed description of the micrometer, explaining different design flaws and the best techniques for calibrating the device. He stressed that the micrometer was utterly essential for any astronomical work that aspired to correct what 'Ticho has often misplaced'.[19] He insisted, 'Your Pendulums you will finde exceedeing usefull, but not for Measuring small distances, in which I am confident they will not performe neare soe exactly as the Micrometer.'[20] The instrument in this case, along with Flamsteed's capacity to successfully manage its production and its use, would come to be central to how he presented his astronomical praxis to others.

Flamsteed's work with the micrometer, and more importantly the ways in which he communicated information about the device, demonstrate how the astronomer engaged in a sophisticated process of scientific identity formation by strategically publicizing and restricting information about his instruments and his methods of producing, managing, and calibrating those instruments. When it was to his tactical advantage, Flamsteed openly and readily shared his expert knowledge of the micrometer in order to ward off doubts about the extraordinary accuracy he claimed to be able to achieve with the device. This meant that he had to show that his privileged understanding of the micrometer made him acutely aware of the differences between adequately and inadequately manufactured devices and of the methods by which one could skirt the errors that might creep into one's use of the device. On other occasions, Flamsteed was more tight-fisted with information about the micrometer, strategically guarding his reputation as a skilful astronomer or throwing into relief the differences between his work and the work of those 'very ingenious & curious men … [who are] ill accommodated with the necessary helpes for observation'.[21]

Flamsteed and the micrometer

William Gascoigne, writing to William Oughtred in 1639, reported that after a spider cast its web in the field of view of his telescope, it came upon him to devise a mechanism that he could insert into his telescopic sights so as to be able to measure

inch between the dividers of the instrument. Degrees of arc where then determined trigonometrically. Flamsteed to Cassini, 7 July 1673, *CJF*, vol. 1.

18 Later in his career Flamsteed held that the micrometer even created the possibility of measuring stellar parallax. Johns, 'Flamsteed's optics', op. cit. (2), pp. 93–100, 104–106, describes the lengths Flamsteed went to to convince his community that he was actually observing stellar parallax; also see M.E.W. Williams, 'Flamsteed's alleged measurement of annual parallax for the Pole Star', *Journal for the History of Astronomy* (1979) 10, pp. 102–116.

19 Gregory to Flamsteed, 19 July 1673, *CJF*, vol. 1; Flamsteed to Gregory, 2 August 1673, *CJF*, vol. 1.

20 Flamsteed to Gregory, 2 August 1673, *CJF*, vol. 1.

21 Following Mario Biagioli, the approach outlined here centres on geographical distance and time as factors that limit access to information and on how these factors serve as a function of identity construction in an economy of social and epistemic legitimacy. On this and as a useful comparison to the present study see Mario Biagioli, *Galileo's Instruments of Credit: Telescopes, Instruments, Secrecy*, Chicago: The University of Chicago Press, 2006, Chapter 1; Forbes, op. cit. (1), p. 147.

celestial distances.[22] Although Gascoigne developed and put his invention to use, none of his work was published, and after his death in 1644 the invention was all but forgotten. The first published account of a micrometer appeared independently of Gascoigne's discovery when Christiaan Huygens described in his *Systema Saturnia* (1659) how he inserted objects of measured apertures into the viewing field of his telescope in order to determine the diameter of celestial bodies. The micrometer, however, only received serious attention when in 1666 Adrian Auzout sent a letter to Henry Oldenburg, the secretary of the Royal Society and editor of the *Philosophical Transactions*, describing his invention of an instrument that could be inserted into the field of view of a telescope in order to measure celestial distances with exceptional accuracy.[23] When this letter was published in the *Philosophical Transactions*, it sparked a number of vehement responses proclaiming the English priority of the invention. Robert Hooke and Christopher Wren both argued that the invention was theirs, but Richard Towneley was ultimately able to establish Gascoigne's priority when he presented the inventor's manuscripts.[24] When Flamsteed informed Cassini in 1673 that 'by the aid of … [the Townelian micrometer] a single … [inch] is divided into 3507 parts' (Figure 1), he was showing that it was through his work with the instrument that he improved significantly on Auzout's vague claim six years previously that 'Monsieur [Jean] Picard et moy … pouvons, prendre les diametres jusques aux secondes, parceque nous pouvons diviser un pied en 24 000 [*sic*] ou 30 000 parties'.[25] Gregory's excitement about the micrometer is understandable considering that Flamsteed's early work with the device was the technological cutting edge of the early 1670s, when the micrometer's capacity for precision was a promising yet largely unfamiliar advancement in astronomical technology.[26]

It was a fortunate and enviable circumstance for Flamsteed, an aspiring astronomer in the early 1670s, to have been able to work at first hand with Gascoigne's recently resurfaced invention. By way of contrast, Hevelius, far removed from Paris and London,

22 On the invention and early dissemination of micrometers see Randall C. Brooks, 'The development of micrometers in the seventeenth, eighteenth and nineteenth centuries', *Journal for the History of Astronomy* (1991) 22, pp. 127–173, 129–130; Brooks, 'Origins, usage and production of screws: an historical perspective', *History and Technology* (1991) 8, pp. 51–76, 57; Chapman, *Dividing the Circle*, op. cit. (3), pp. 35–45; Saridakis, op. cit. (13), pp. 36–40; Jim Bennett, *The Divided Circle: A History of Instruments for Astronomy, Navigation, and Surveying*, Oxford: Phaidon, 1987; R.M. McKeon, 'Les débuts de l'astronomie de précision: I. Histoire de la réalisation du micromètre astronomique', *Physis* (1971) 13, pp. 225–288.

23 Auzout to Oldenburg, 18 December 1666, in A.R. Hall and M.B. Hall (eds.), *The Correspondences of Henry Oldenburg* (hereafter *CHO*), 13 vols., Madison: University of Wisconsin Press, 1965–1986, vol. 3; [Adrian] Auzout, 'An Extract of a Letter … by M. Auzout … Concerning a Way of his, for Taking the Diameters of the Planets …', *Philosophical Transactions* (1665) 1, pp. 373–375.

24 Richard Towneley, 'An Extract of a Letter … Touching the Invention of Dividing a Foot into Many Thousand Parts …', *Philosophical Transactions* (1666–1667) 2, pp. 457–458.

25 In his original letter to Cassini and in the published version in the *Philosophical Transactions*, Flamsteed recorded that 'a single *foot* is divided into 3507 parts' (emphasis added). The unit of feet in this passage is almost certainly a typographical error. When Flamsteed wrote to Moore about the calibration of his micrometer nearly a year after he wrote to Cassini (see below), he reported that he could divide a single *inch* into 3507 parts. Flamsteed to Cassini, 7 July 1673, *CJF*, vol. 1; Flamsteed to Moore, April 1674, *CJF*, vol. 1.

26 Brooks, 'The development of micrometers', op. cit. (22), pp. 132–135.

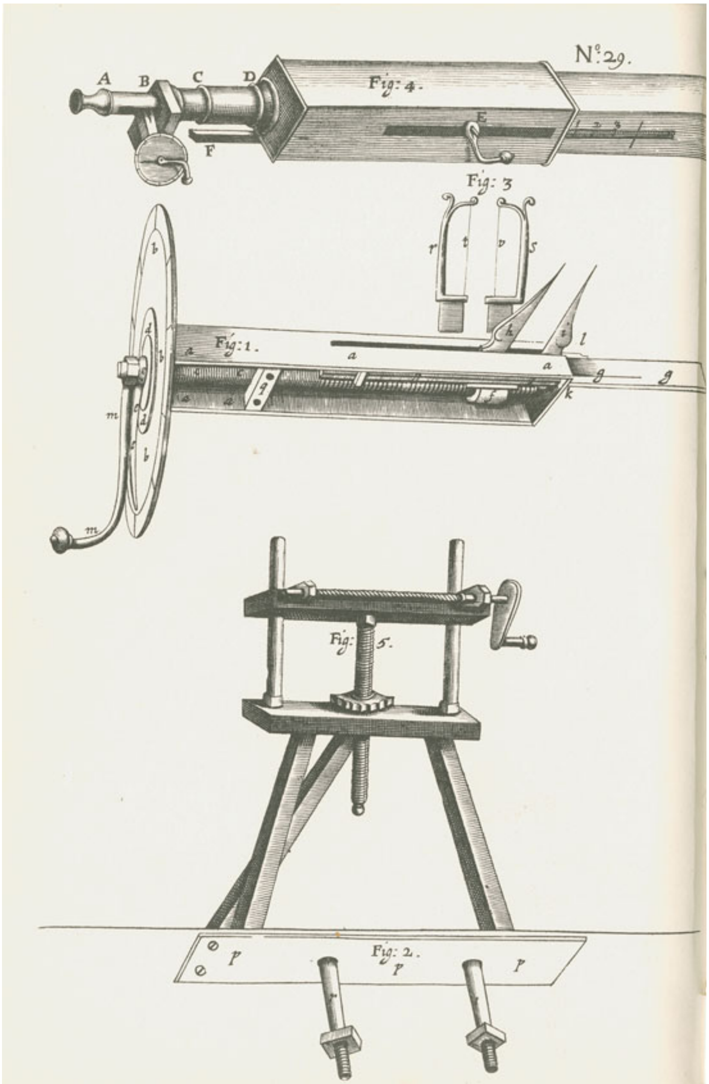

Figure 1. Towneley's micrometer. Robert Hooke, *Philosophical Transactions* (1667) 2, frontispiece. ©The Royal Society.

tried to acquire a micrometer for his observatory in Danzig from as early as November 1668.[27] Despite his persistent requests to Oldenburg, Hevelius was still unacquainted with the device by the early 1680s.[28] The importance of Flamsteed's early acquisition of the micrometer did not escape the young astronomer. Even much later in his life when Flamsteed recalled the events that led to his rise to the position of Astronomer Royal,

27 Hevelius to Oldenburg, 19 November 1668, *CHO*, vol. 5.
28 See below.

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his early acquisition of the micrometer did not fail to feature in his recollections.[29] In the spring of 1670, upon his first visit to London to meet the ingenious gentlemen with whom he had been corresponding about astronomical matters, Flamsteed received the Towneley–Gascoigne micrometer as a gift from Sir Jonas Moore, His Majesty's Surveyor of the Ordnance.[30] The significance of Moore's gift exceeded simple material support for Flamsteed's gestating research programme. As the inheritor of the Towneley–Gascoigne micrometer, Flamsteed was also to become the heir to Gascoigne's technical legacy. The mantle of Gascoigne's achievements (along with the achievements of other northern astronomers from earlier in the century, such as William Crabtree and Jeremiah Horrocks) was, as it were, picked up by Flamsteed. Moore's gift was thus not only important for its material contribution to Flamsteed's work; it also held immense symbolic value and, as Frances Willmoth maintains, 'confirmed Flamsteed's position in the line of succession from the "Northern Astronomers"'.[31] Moore's gift was a significant step forward for the legitimization of Flamsteed's work as an astronomer. Following Peter Dear's claim that 'the legitimacy of the knowledge claimed by astronomy [in the early modern period] depended on the discipline's continuing practice', we are reminded that continuity was based on 'customary praxis' and 'routine'. However, Dear continues, 'innovation … [was] the highest expression of creative continuity'.[32] It was not enough, therefore, for Flamsteed to be the recipient of the Towneley–Gascoigne micrometer if he wanted his work to advance beyond the accomplishments of earlier astronomers – Moore's gift was saddled with the responsibility of improvement.

Writing to Collins in 1672, the mutual acquaintance of Moore and Flamsteed, Flamsteed enthusiastically held, 'I am much indebted to Mr. Jonas Moore for that micrometer, where with I have made those observations, which in your opinion I beleive never had theire equalls.'[33] Despite his enthusiastic acclaim of Moore's gift, Flamsteed's early impressions of the Towneley–Gascoigne micrometer were not completely laudatory. Writing a few months earlier to Oldenburg, Flamsteed remarked how he failed to make an observation of a star crossing behind the moon, because 'Mr. Townley's micrometer was not convenient for the observeing [*sic*] this transit by reason of the shortnesse of his pointers [i.e. the reticles]'.[34] This failing of the Towneley–Gascoigne micrometer, Flamsteed went on to explain, could be remedied by the design he envisaged

29 Flamsteed recalled in two different accounts of his life and work that the micrometer was an important part of his rise as an astronomer. See Baily, op. cit. (8), pp. 28–29; Chapman, *The Preface*, op. cit. (3), p. 113.

30 Flamsteed to Collins, 19 September 1670, *CJF*, vol. 1.

31 Frances Willmoth, *Sir Jonas Moore: Practical Mathematics and Restoration Science*, Woodbridge: The Boydell Press, 1993, p. 166. Willmoth also discusses the significance that the influence of the so-called 'northern astronomers' made on Flamsteed early in his career. See Willmoth, 'Models for the practice of astronomy: Flamsteed, Horrocks and Tycho', in Willmoth, op. cit. (2), pp. 49–75.

32 Peter Dear, *Discipline and Experience: The Mathematical Way in the Scientific Revolution*, Chicago: The University of Chicago Press, 1995, pp. 95–96. On the importance of historical continuity in early modern astronomy also see Nicholas Jardine, *The Birth of History and Philosophy of Science: Kepler's* A Defence of Tycho against Ursus *with Essays on Its Provenance and Significance*, Cambridge: Cambridge University Press, 1984, esp. Chapter 8.

33 Flamsteed to Collins, 23 July 1672, *CJF*, vol. 1.

34 Flamsteed to Oldenburg, 8 March 1671/2, *CJF*, vol. 1.

for an improved device. Less than two years after receiving the Towneley–Gascoigne micrometer Flamsteed wrote to Oldenburg about these improvements:

> Not findeing that Mr. Townlys Micrometer is so devised as to be convenient for some observations I intend I have devised a new one in which I can have threed [i.e. thread] sights or others as I please and parallel threeds disposed perpendicular to the ostensors . . . and I hope by it to escape some inconveniences and faults which in the use of our micrometer at present wee frequently undergoe and commit.[35]

Flamsteed's early work with the micrometer thus involved differentiating what he perceived to be the useful from the frustrating qualities of the instrument. And, as is clear from his correspondences with Oldenburg, and later with Towneley, Flamsteed was not bashful about sharing his findings. Improving upon Towneley's device, however, proved more difficult for Flamsteed than expected. In the same letter to Oldenburg, Flamsteed explained that the thread pitch of the screws that were manufactured for Towneley's device were of such outstanding fineness that 'our smith despaires of makeing mee such good screwes as Mr. Townlys are'.[36] Nearly all screws at this time were manufactured by hand using some combination of lathes, chasers, dies (called screw-boxes or screw-plates), and files. The fineness and axial dimensions of thread pitch were thus the direct result of the skill of the manufacturer.[37] Still in Derby at the time, Flamsteed's access to skilled artisans was limited, retarding his work on improving the Towneley–Gascoigne micrometer. Eventually, Flamsteed went to the same artisan Towneley himself used, Humphrey Adamson, in order to acquire screws of a similar quality.[38] Flamsteed recognized early on from his experience with Towneley's micrometer that the upper limit of accuracy that his micrometer was capable of achieving was a direct consequence of the thread pitch of the screws used to draw the pointers across the field of view of the telescope in which the device was installed.[39]

The micrometer became equivalent to the screws that were use to move the reticles, making the problem of thread pitch a central concern for Flamsteed.[40] His ability to distinguish between fine and coarse thread pitches became his chief preoccupation in distinguishing between micrometers of superior and inferior quality. Since Flamsteed's claims of extraordinary accuracy rested on his use of the micrometer, showing the

35 Flamsteed to Oldenburg, 2 December 1671, *CJF*, vol. 1.

36 Flamsteed to Oldenburg, 8 March 1671/2, *CJF*, vol. 1.

37 For an especially illustrative description of screw and nut production techniques from the time see Joseph Moxon, *Mechanick Exercises: or, The doctrine of handy-works*, London, 1693–1694, pp. 29–32; for secondary literarture on premodern screw production techniques see Randall C. Brooks, 'Standard screw threads for scientific instruments: Part 1: Production techniques and the filière suisse', *History and Technology* (1988) 5, pp. 59–76, 61–62; Brooks, 'Origins, usage and production', op. cit. (22), pp. 57, 60–65; Brooks, 'The precision screw in scientific instruments of the 17th–19th centuries: with particular reference to astronomical, nautical and surveying instruments', PhD dissertation, University of Leicester, 1989, OCLC 806501987, pp. 23–30, 56–75.

38 Flamsteed to Collins, 23 July 1672, *CJF*, vol. 1.

39 Brooks, 'The development of micrometers', op. cit. (22), pp. 130–134, offers an examination of the different thread pitches of different early filar micrometers.

40 In his Gresham lectures, Flamsteed told his listeners that 'M^{r} Gascoigne . . . tooke his measures by the help of a Micrometer or payre of screws placed in y^{e} inner focus of his telescope'. See Forbes, op. cit. (1), p. 197.

scientific community that his devices were made with screws of an exceptionally fine pitch became a critical aspect of maintaining his credibility. In late 1676, Flamsteed received a letter from Towneley on behalf of Cassini, who charged the newly appointed Astronomer Royal with the task of sending a micrometer to Paris of equal quality to the one with which he reported to have made his observations. Knowing that this was not a simple task and that if he failed his credibility would be tarnished, Flamsteed hesitated at first and suggested to Towneley,

> it were better to send one of yours then of my contrivance for I would not have a bad one sent over into France and I am confident yours are much better made then mine . . . for Humphrey [Adamson] has not made the screws of mine so good as I would have them and I can not at this distance from London procure him to follow my directions.[41]

In spite of his protests, Flamsteed eventually agreed to oversee the manufacture of Cassini's micrometer. At first the process faltered as the Astronomer Royal reported that he could not find a suitable artisan to craft the device according to his precise instructions.[42] Adamson did not see fit to try his hand again since Flamsteed thought that he did not manufacture the screws for his own micrometer as well as those made for Towneley's.[43] Thomas Tompion, the famous clockmaker, was backed up with work and could not offer to complete the project in a reasonable amount of time. Flamsteed found a third option, Mr Thomas Fowle, who was responsible for Halley's instruments on his expedition to St Helena. Fowle's work, however, did not proceed apace, frustrating Flamsteed. Fowle's first attempts to manufacture the fine screws needed for the micrometer 'fayled', which Flamsteed reported 'a little discouraged him [Fowle]'.[44] It is significant that Flamsteed reported Fowle's failure to Towneley as it shows that Flamsteed portrayed the difference between success and failure as a decision – one which he imposed upon the craftsman. Failure was thus represented to be the fault of the artisan whereas success was the result of Flamsteed's ability to distinguish a satisfactory product from one that was inadequate.[45] Flamsteed's attitude toward artisanal labour echoes a common tension between natural philosophers and artisans: artisans tended to want to raise their social rank through their work, and natural philosophers tended not to want to have their scientific reputations tied to artisanal labour.[46]

41 Flamsteed to Towneley, 11 December 1676, *CJF*, vol. 1. Flamsteed was in Greenwich – at the time a considerable distance from London.

42 Flamsteed to Towneley, 31 December 1676, *CJF*, vol. 1.

43 See, for example, Flamsteed to Moore, April 1674, *CJF*, vol. 1.

44 Flamsteed to Towneley, 15 February 1676/7, *CJF*, vol. 1.

45 This was not an uncommon form of assuming authorship for artisanal successes. In his *Micrographia* (1665), Hooke ascribed all of the failures in the engravings in his book to the engravers but maintained that in all other cases the engravers' work was merely that of copyists. See Michael Aaron Dennis, 'Graphic understanding: instruments and interpretation in Robert Hooke's *Micrographia*', *Science in Context* (1989) 3, pp. 309–364, 314.

46 A fine example of this tension in Flamsteed's career is that in the manuscript of his preface to the *Historia Coelestis Britannica* Flamsteed referred to his assistants as 'Domestiks'. In preparing his manuscripts for publication after his death, Flamsteed's assitants, A. Sharpe, J. Hodgson and J. Crosthwaite, changed their titles to 'Contubernalis', 'which translates as comrade, companion, associate or colleague'. See Chapman, *The Preface*, op. cit. (3), p. 206 n. 138. The fraught relationship between Descartes and Ferrier is a good example of

Under Flamsteed's attentive supervision, the micrometer was finally made ready and sent to Cassini. Flamsteed's considerable anxiety over the production of this instrument is understandable if we consider that it was his responsibility to ensure the quality of the instrument. There was a typical expectation placed on the person who oversaw the construction of an instrument for a distant colleague. Molyneux, for example, expressed to Flamsteed, who offered to oversee the construction of the instruments for an observatory in Dublin, that 'I doubt not but you will take Care that the Instrument[s] be made accurately, and for this I shall wholy reley upon you'.[47] There is good reason to think that Flamsteed's work with the micrometer was being carefully scrutinized by his colleagues abroad. In a letter to Oldenburg, Henri Justel pressed the editor of the *Philosophical Transactions* to explain 'how Mr. Towneley's device was made'.[48] Sceptical of the ability to move the reticles with a high level of accuracy, Justel stressed his concern that if, as he understood it, the reticles are moved 'by means of gearing', then it would follow that the screw controlling the 'two needles' would have to be 'exceptionally accurate [for] the slightest inequality would be greatly magnified'.[49] The difficulty in manufacturing threads of an exceptionally fine pitch that did not deviate from the axis of the screw-pin was thus apparent to Flamsteed's French colleagues. They were sufficiently doubtful about the ability to manufacture such a screw that they regarded such a device as the one that Towneley described in the *Philosophical Transactions* as 'impossible'.[50] If, therefore, Flamsteed delivered a second-rate instrument to Cassini with screws of a considerably inferior thread pitch, it would have cast into doubt the quality of Flamsteed's ability to judge the quality of his own instruments and thereby put into question the credibility of Flamsteed's celestial measurements.

Availing artisans to craft screws of an adequate thread pitch was not Flamsteed's only concern in maintaining the credibility of his claims regarding the micrometer. Fortifying the credibility of his claims demanded that Flamsteed account for the exceptional precision of his device by explaining his manner of reliably graduating the fine threads of the screw. Flamsteed, ever the skilful astronomer, proudly advertised his technique of graduating the screw of his micrometer by featuring it in an early draft of his 'Praeface to my caelestiall Observations', sent to Moore in 1674, shortly before Flamsteed was appointed to the position of Astronomer Royal.[51] This draft foreshadowed the grand preface that Flamsteed would later write for his *Historia Coelestis Britannica* that would only be published posthumously. Echoing its younger cousin in its grandiose vision of the place of Flamsteed's work in the history of astronomy, Flamsteed began by writing to his patron that since Kepler 'the Restitution of Astronomy [has] gone but

this pattern outside Flamsteed's career. See D. Graham Burnett, *Descartes and the Hyperbolic Quest: Lens Making Machines and Their Significance in the Seventeenth Century*, Philadelphia: American Philosophical Society, 2005, pp. 41–69, esp. 52; Jean-François Gauvin, 'Artisans, machines, and Descartes's Organon', *History of Science* (2006) 44, pp. 98–201; William R. Shea, *The Magic of Numbers and Motion: The Scientific Career of René Descartes*, Canton: Science History Publications, 1991, pp. 191–201.

47 Molyneux to Flamsteed, 3 December 1681, *CJF*, vol. 1.

48 Justel to Oldenburg, June 1667, *CHO*, vol. 3.

49 Justel to Oldenburg, June 1667, *CHO*, vol. 3.

50 Justel to Oldenburg, June 1667, *CHO*, vol. 3.

51 Flamsteed to Moore, April 1674, *CJF*, vol. 1.

slowly forward'.[52] Flamsteed continued by revealing that this pace would soon quicken as a result of his work with the micrometer, thus basing the extraordinary accuracy of his work on Moore's contribution to his research programme.[53] 'I have attained', Flamsteed claimed, 'to the praeciseness of 5 seconds, which what proportion it beare to the praecisenesse attaineable in the ancient or moderne instruments'.[54] Holding that he had reliably achieved the preciseness of five seconds was a bold claim, and it was one that Flamsteed used a considerable portion of this early preface to explain by describing his method of graduating the screw of his micrometer. After determining how many revolutions of the screw were required to open and close the dividers an inch, Flamsteed recounted, he found that the fineness of his screw differed significantly from Towneley's, whose screw was cut from the same 'box' and thus could not be naturally suspected of such a great discrepancy.[55] Flamsteed then calculated afresh the number of turns required to open the dividers an inch, but found that the screw for his micrometer was still somewhat more precise than Towneley's. Not wanting to rely on these results since the discrepancy might appear to be the result of ineptitude or negligence, Flamsteed took to a more rigorous form of calibration:

> And therefore August the 5th following haveing chosen a level place in the open feild I setled my bigger tube [telescope] upon it and from the object glasse forward with a surveyors chaine I measured 908 feet, 7 inches, at which distance exactly a crosse to the chaine I placed a very substantiall ruler with black marks in white upon it, at 1, 3, 6, 36, 72, and 108 inches distance: I drew out the tube to 165½ inches long [i.e. focusing the telescope] where I could best see the object.[56]

Counting the number of revolutions of the screw it took to place each of the different measurements on the ruler between the dividers of the micrometer, Flamsteed reasoned trigonometrically how many revolutions would result in the dividers of the micrometer opening to an inch. This was a way of cross-referencing his earlier method of counting the number of revolutions of the screw it took to open the dividers of the micrometer an inch, and from this Flamsteed confirmed that the screw of his micrometer was indeed of a finer pitch than the one used by Towneley. The implication was that the error belonged to Adamson, the craftsman who manufactured the screws from the same die. It was the

52 Flamsteed to Moore, April 1674, *CJF*, vol. 1.

53 On the connection between patronage and scientific identity formation in the context of astronomy in the early modern period and as an interesting contrast to Flamsteed see Mario Biagioli, 'Galileo's system of patronage', *History of Science* (1990) 28, pp. 1–62; Biagioli, *Galielo, Courtier: The Practice of Science in the Culture of Absolutism*, Chicago: The University of Chicago Press, 1993, Chapter 1.

54 Flamsteed to Moore, April 1674, *CJF*, vol. 1.

55 There is an interesting contradiction to be pointed out here. When Towneley asked Flamsteed to construct a micrometer for Cassini, the Astronomer Royal declined at first, insisting that Humphrey Adamson did not construct the screws for his micrometer as well as those Adamson had produced for Towneley's micrometer (see above). If in his letter to Moore Flamsteed was referring to the same screws he acquired from Adamson that he later tells Towneley are not so well made, it may be the case that Flamsteed exaggerated to Moore the accuracy he could achieve with his micrometer, or Flamsteed was downplaying the quality of Adamson's work when he was asked to manufacture a micrometer for Cassini.

56 Probably, 908′ 7″ was the complete length of Flamsteed's surveyor's chain. This method was not of Flamsteed's invention; he learned it from Towneley. Flamsteed to Moore, April 1674, *CJF*, vol. 1.

work of the astronomer to discover and account for the discrepancy, and it was his work in this capacity, Flamsteed assured Moore, that credited his claim that he could reliably measure five seconds of arc.

From the micrometer's re-emergence in the late seventeenth century, Hevelius, operating his observatory in Danzig, was curious about the degree of precision that Western European astronomers boasted about achieving through their use of the instrument. From as early as 1668, Hevelius began requesting that Oldenburg organize the manufacture of such a device and have it sent the breadth of Europe to Hevelius's observatory. Hevelius's demands fell on deaf ears, and it was only once Edmond Halley arrived in Danzig to settle the dispute that had arisen between Hevelius and Hooke over the benefits of telescopic sights that Hevelius first became acquainted with the device.[57] After Halley's visit, however, Hevelius confessed to Flamsteed that he was not sufficiently acquainted with the device to know how to properly affix a micrometer to his telescopes:

> I would very much like to know of what length the telescope is into which you are accustomed to insert that micrometer, and by what method it is secured into the tube; I noticed 4 screws but I do not understand how this ought to be done.[58]

By the time Hevelius was writing this letter early in 1682, Flamsteed, who had been working with and advocating the use of the micrometer for more than a decade, considered Hevelius's questions an exercise in banality. The tone of Flamsteed's response to Hevelius's questions about what were to Flamsteed commonplace astronomical practices was appropriately snarky and supercilious: 'I [am] accustomed to apply the micrometer', Flamsteed began, 'I reply of any [length] whatever … This I first learned by experience and then proved by optical reasoning.'[59] Questioning even the didactic efficacy of sending Hevelius a telescope with a micrometer properly fitted, Flamsteed sardonically pressed Hevelius to excuse his apparent inability to do the necessary work of the skilful astronomer:

> Mr. Halley, having returned from Danzig, reported to me that he had left such an instrument with you there, fitted to a tube and eye glasses in the customary manner. I thus had no doubt that you would correctly understand how (or more conveniently) it can be fixed to a telescope of any length whatever.[60]

57 Hevelius to Oldenburg, 19 November 1668, *CHO*, vol. 5. Hevelius struggled to get his hands on a micrometer. Three years after he first requested a micrometer from Oldenburg in the autumn of 1668, Hevelius reprimanded Oldenburg for persistently failing to send him the device. See, for example, Hevelius to Oldenburg, 27 September 1671, *CHO*, vol. 8.

58 Hevelius to Flamsteed, 9 January 1681/2, *CJF*, vol. 1. Hevelius also asked Dethlef Cluver in London for instructions on how to install his newly acquired micrometer in 1681. See Hevelius to Cluver, 1681, in Peter Damian-Grint (ed.), *Translations of Edmond Halley's Latin Correspondence* (tr. Alice Stainer), Oxford: Electronic Enlightenment Project, 2009, available at www.e-enlightenment.com/item/halledEE0010191_1key002cor.

59 Flamsteed to Hevelius, 28 March 1682, *CJF*, vol. 1.

60 Flamsteed to Hevelius, 28 March 1682, *CJF*, vol. 1.

It was not for lack of the necessary resources that Hevelius did not understand how to use the device, Flamsteed pushed Hevelius. The fault was that of the astronomer. Specifically, it was Hevelius's technical ineptitude that barred him from successfully incorporating the device into his work. After finally indulging Hevelius's requests with a full account of how to install the instrument and how to calibrate it, Flamsteed teasingly closed his description of the micrometer by admitting that he was 'fearful of dwelling too much upon such a simple matter'.[61]

The condescending tone of Flamsteed's response to Hevelius should be thought of in the context of Hevelius's stubborn reluctance to use the telescope for positional astronomy. Only six months before writing to Hevelius, Flamsteed recounted in his lectures at Gresham College how 'the World was almost persuaded to believe that all observations made with glasses [are] more doubtfull & uncerteine' than those made with the naked eye.[62] The micrometer, or Gascoigne's development of including 'a needle third [thread], or point placed into common Focus [with a telescope]', permitted that 'the diameters & distances of the planets might be … exactly measured'.[63] Flamsteed saw Hevelius's rejection of telescopic sights as a rejection of the micrometer as well.[64] By condescending to Hevelius because of his ignorance regarding the micrometer, Flamsteed was rebuking Hevelius by highlighting the differences in their astronomical praxis. Where Hevelius was bound to the 'customary praxis' of the Tychonic tradition, Flamsteed understood himself to be 'the highest expression of creative continuity' in the history of astronomy since Tycho, because of his ability to excel beyond the 'routine' of tradition.[65] In this sense, Flamsteed saw his work as being both continuous and discontinuous with Tycho's. Tycho was one of Flamsteed's principle role models, and Flamsteed was always quick to pardon the Noble Dane's errors based on the difficulty Tycho had in aligning the sights of his instruments.[66] Where, however, Flamsteed claimed that his own work surpassed Tycho's because of his use of telescopic sights and micrometric devices, the implication for Flamsteed was that Tycho would have adopted the same technologies as a way of ameliorating his own observational techniques should he have been in Flamsteed's position. In this sense, Flamsteed figured himself as the legitimate heir of Tycho's legacy, both continuing and surpassing Tycho's work.

61 Flamsteed to Hevelius, 28 March 1682, *CJF*, vol. 1.

62 Forbes, op. cit. (1), p. 149.

63 Forbes, op. cit. (1), p. 148.

64 Consider the following passage: 'Especially a famous p[er]son [Hevelius] found himselfe p[ar]ticualrly touched by my recommendations of them [the micrometer and telescope] when I had published some new observations or measures taken with glasses & screws placed in their focus. Hee was pleased to urge me much against their use.' Forbes, op. cit. (1), p. 149.

65 That Flamsteed considered Hevelius to be problematically entrenched in the 'Tychonic tradition' of astronomy is clearly articulated in several of Flamsteed's works. See, for example, Chapman, *The Preface*, op. cit. (3), pp. 105–109; Forbes, op. cit. (1), pp. 119, 132 n. 4.2, 149, 160 n. 7.7. All of the quotations refer to Dear, op. cit. (32), pp. 95–96.

66 Chapman, *The Preface*, op. cit. (3), p. 101.

In 1698, when Flamsteed confidently wrote to John Wallis, the Savillian Professor of Geometry at Oxford, that he had successfully detected stellar parallax, he grounded his certainty specifically on his use of telescopic and micrometric technology:

> the shape of the sights in Tycho's and [Giovanni Battista] Riccioli's instruments (constructed according to their standard) was such, and the breadth or aperture of the slits (through which the sighting took place) was so great, that it was difficult to avoid an inaccuracy of a whole minute … The invention of the telescope … introduced a useful remedy for this deficiency of sights. As far as we know, the first to use it for recording distances was an ingenious young man, William Gascoigne … Following in his footsteps, I used his inventions in conjunction with my own instruments … [to demonstrate that] the parallax of the earth's great orbit is perceptible.[67]

Convinced that Flamsteed had succeeded, Wallis published Flamsteed's letter in his *Opera Mathematica*.[68] Later, however, after Jacques Cassini decisively refuted Flamsteed's claim, the Astronomer Royal grudgingly admitted his error in a letter to Christopher Wren. This letter remained private during Flamsteed's lifetime, suggesting that Flamsteed did not want to publicly admit that his theory of parallax was wrong.[69] Such an admission would have seriously jeopardized Flamsteed's larger astronomical project because it would have necessarily called into question Flamsteed's capacity to satisfy the role of the skilful astronomer. Writing to Wren, Flamsteed claimed that his error must have stemmed from his instruments, and as a consequence he committed, 'I shall return to my stock of night observations to seek out such as are most proper for discovering the Error of the Instrument.'[70] As Williams points out, however, although Flamsteed assured Wren that he would return to the issue of stellar parallax once he had discovered and corrected the error in his instruments, 'there seems to be no evidence that he ever did return to the problem of detecting parallax. A likely explanation is that he could not find an instrumental cause for the systematic discrepancy because it did not exist', or because he was unable of detecting it.[71] This episode offers a particularly acute example of Flamsteed's general strategy of self-fashioning. Where at first Flamsteed defended his claim to have detected stellar parallax based on his work as a skilful astronomer, Cassini's refutation of his claim led him to draw on the same kind of strategy as a way of licking his wounds. However, as Flamsteed could not discover how his instruments had led to the error, he suppressed his failing as a skilful astronomer by keeping his letter to Wren from the public eye and by otherwise ignoring Cassini's refutation of his theory of parallax.

Salvaging reputations with visual rhetoric

Janet Vertesi, in her recent study of the images in Johannes Hevelius's *Machina Coelestis Pars Prior* (1673), argues that Hevelius used the illustrations in this volume to represent

67 Flamsteed to Wallis, 20 December 1698, *CJF*, vol. 2.

68 John Wallis, *Opera Mathematica*, 3 vols., Oxford, 1699, vol. 3, pp. 701–708.

69 His letter to Wren was, however, published posthumously in Stephen Wren, *Parentalia: or, memoirs of the family of the Wrens*, London, 1750, pp. 248–252; Williams, op. cit. (18), pp. 112–113.

70 Flamsteed to Wren, 19 November 1702, *CJF*, vol. 2.

71 Williams, op. cit. (18), pp. 113.

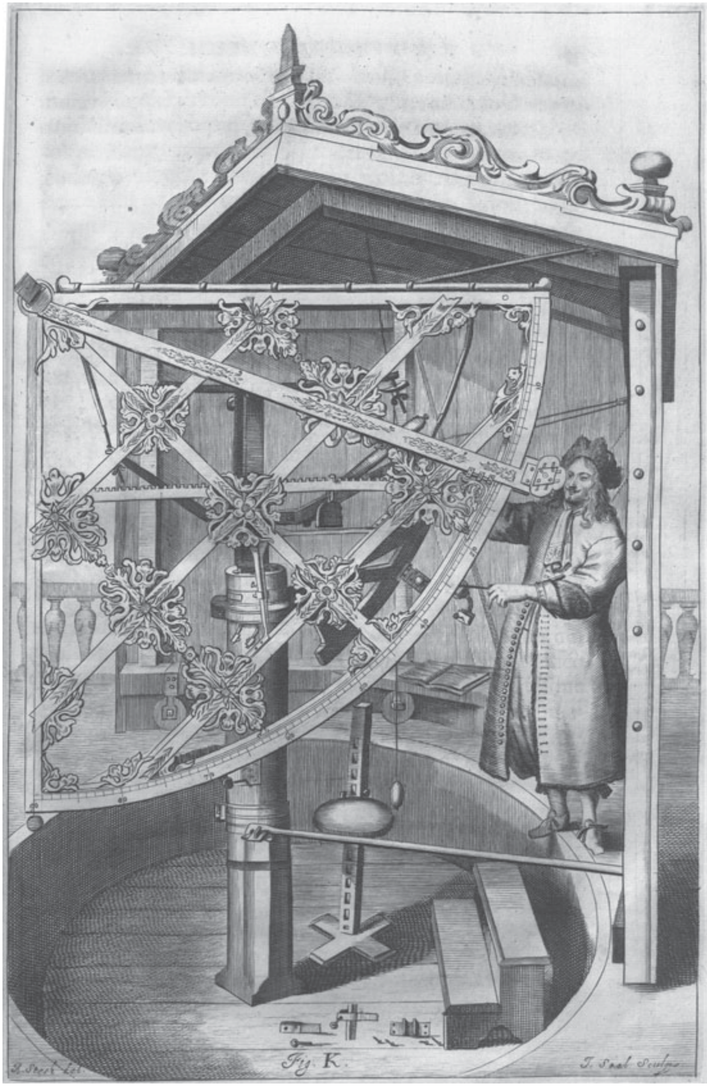

Figure 2. Hevelius peers through his quadrant. Hevelius, *Machina Coelestis Pars Prior* (1673). Courtesy of Posner Memorial Collection, Carnegie Mellon University Libraries, Pittsburgh, PA.

himself as a 'keen-eyed' observer as well as an adept and authoritative technician who could be seen 'at [his] instruments in the process of repair, assembly, or slight alignment' (see Figures 2 and 3).[72] Following in the tradition established by Tycho of licensing one's astronomical authority through the publication of detailed textual and visual

72 Janet Vertesi, 'Instrumental images: the visual rhetoric of self-presentation in Hevelius's *Machina Coelestis*', *BJHS* (2010) 43, pp. 209–243, 213, 228–229. Although Vertesi does not mention it, there is an important theoretical parallel to her work in Marcus Popplow's 'Why draw pictures of machines? The social

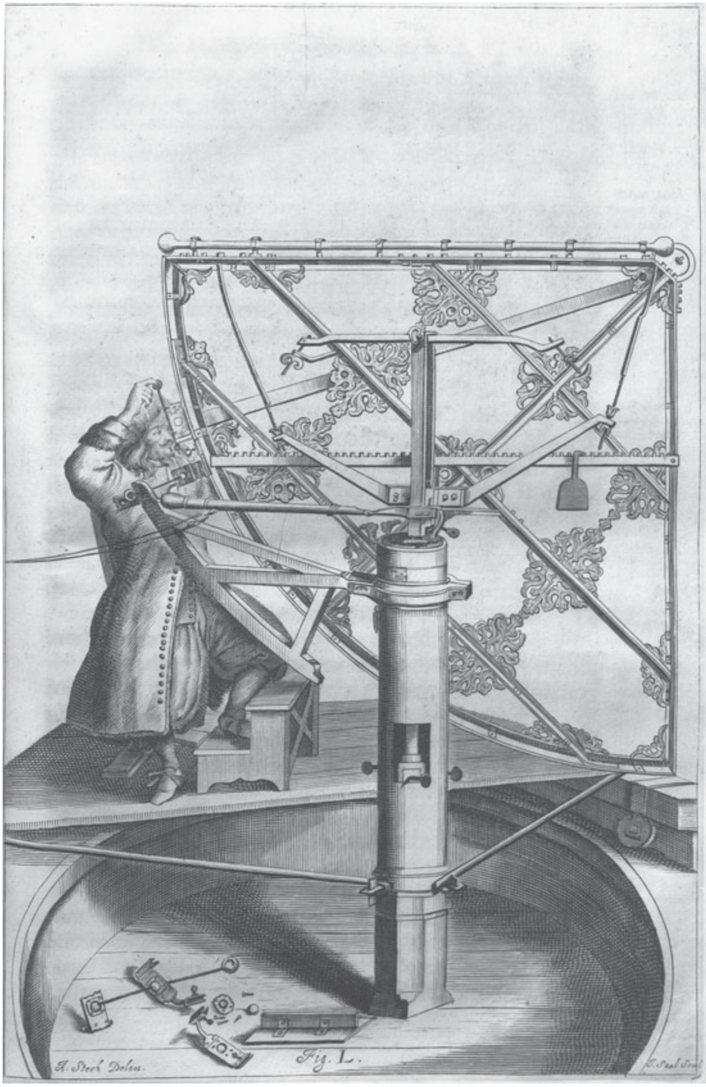

Figure 3. Notice the agreement between Hevelius's body and the quadrant. Their shapes complement one another – it is not clear where Hevelius's body ends and the machine begins. Also notice how the buttons on Hevelius's coat echo the teeth on the quadrant. Hevelius, *Machina Coelestis Pars Prior* (1673). Courtesy of Posner Memorial Collection, Carnegie Mellon University Libraries, Pittsburgh, PA.

descriptions of one's observatory and instruments, the images in Hevelius's *Machina* were meant to give 'a glimpse into Hevelius's distant observatory, with a stunning visual catalogue of his instruments and detailed descriptions of their construction and his

contexts of early modern machine drawings', in Wolfgang Lefèvre (ed.), *Picturing Machines, 1400–1700*, Cambridge, MA: The MIT Press, 2004, pp. 17–48.

observational techniques'.[73] Although Hevelius's actual star catalogue, *Machina Coelestis Pars Posterior*, only appeared in 1679, the publication of the first volume of his *Machina* six years earlier was a strategic move. After Hevelius's observations of the positions of a comet in 1665 became highly contested by Auzout, Hevelius's instruments and observational techniques came increasingly under the suspicion of the European astronomical community.[74] The early publication of the first part of Hevelius's *Machina* was meant to resuscitate Hevelius's public image. The images in *Machina Coelestis Pars Prior* were accordingly employed as a 'programme of visual rhetoric' that 'produced and supported [Hevelius's] authoritative persona'.[75] Hevelius used the early publication of the first volume of his *Machina*, in other words, as an extended preface meant to legitimate his observations by creating and maintaining his identity as an authoritative and credible witness to the night sky.[76]

Operating within the same tradition of publishing detailed visual and textual descriptions of his instruments and observational techniques as a strategy for rebuilding his credibility, the preface to Flamsteed's posthumous *Historia Coelestis Britannica* (1725) was designed to serve a similar restitutive function for the public image of the Astronomer Royal. In the latter stages of his career, Flamsteed became increasingly obsessed with delivering his reputation from the indignities it had suffered as a result of the heightening antagonism between himself, Newton and Newton's cohort in the years before the publication of his long-awaited star catalogue. In 1709, Flamsteed's name alone was left off the register of members who would continue their fellowship with the Royal Society for the following year. Officially, the reason for Flamsteed's ousting was 'on account of his not having paid up his [dues in] arrears'.[77] This was, as Feingold explains, particularly damning for Flamsteed because in the same year eighteen other fellows of the Royal Society were granted an exemption on the need to settle their past dues, an exemption that Flamsteed himself had benefited from for 'more than thirty years!'[78] Later, in 1712, Flamsteed's public image suffered another injury when his observations from countless nights' work, the very *materia* of his star catalogue, were wrested from him and published out of his control. Further, the 1712 edition of Flamsteed's star atlas was prefaced with a notoriously pejorative account of the

73 Vertesi, op. cit. (72), p. 210; Van Helden, op. cit. (5), p. 10; Tycho Brahe, *Tychonis Brahe Astronomiae instauratae mechanica*, Noribergae, 1602.

74 For a detailed account of this episode see Steven Shapin, *A Social History of Truth: Civility and Science in Seventeenth-Century England*, Chicago: The University of Chicago Press, 1995, pp. 266–291.

75 Vertesi, op. cit. (72), pp. 212, 211.

76 Hevelius's *Machina* followed his *Selenographia* (1647), which, it has been argued, was the first early modern astronomical publication to develop a comprehensive and meticulous visual language for astronomical observation and instrumentation. See Mary G. Winkler and Albert van Helden, 'Johannes Hevelius and the visual language of astronomy', in J.V. Field and Frank A.J.L. James (eds.), *Renaissance and Revolution: Humanists, Scholars, Craftsmen, and Natural Philosophy in Early Modern Europe*, Cambridge: Cambridge University Press, 1993, pp. 97–116.

77 Baily, op. cit. (8), p. 90.

78 On Flamsteed's history with and expulsion from the Royal Society see Mordechai Feingold, 'Astronomy and strife: John Flamsteed and the Royal Society', in Willmoth, op. cit. (2), pp. 31–48.

Astronomer Royal drafted by his once-friend, Edmond Halley.[79] In his preface, Halley applauded his own efforts to amend Flamsteed's mistakes, saying, 'Not infrequently he [Halley] had to correct and amend errors in the positions of fixed stars made through the fault of the writer [Flamsteed].'[80] Halley haughtily assured readers that his contribution was 'by far the most important part of the whole work'.[81] In response, Flamsteed maintained not only that it was 'a malicious preface of Halley's that was wrote', but also that Halley's role as editor of his work resulted in the catalogue being 'absolutely spoyled, [and] the Abstracts of my Observations are very sorrily done, so that it will become a Shame to our Nation to have them seen in any *Publick Library*'.[82] The preface to the 1725 edition of his star catalogue, which was meant to supersede the corrupted 1712 publication, was 'expressly drawn up [by Flamsteed] for his own vindication'.[83] Similar to Hevelius, Flamsteed used the preface of his star catalogue to rebuild the credibility of his research and of himself in the eyes of his peers and for posterity.

In the following section, I contrast the visual strategies employed by Hevelius in his *Machina* with those used by Flamsteed in the preface to his *Historia* in order to demonstrate how Flamsteed used visual rhetoric as a way of distinguishing his work – the work of the skilful astronomer – from the work of those astronomers who have 'slipt the principle opportunityes' offered by technological advancement and, as a result, have been unable to deliver themselves from the limitations of Tychonic astronomy.[84] Where Hevelius hinged the rhetorical efficacy of his images (and of his larger strategy of self-fashioning) on his body and his ability to see well, Flamsteed's strategy shifted the responsibility of making an accurate observation from the individual observer's ability to see well to the astronomer's ability to coordinate the circumstances in which anyone (at least hypothetically) could make and record an accurate observation. Telescopic technology was central to Flamsteed's strategy because, for Flamsteed, the telescope regularized vision, effectively rendering an individual's ability to see with exceptional accuracy an obsolete consideration. For Flamsteed, the ability to genuinely surpass Tycho's achievements hinged not on the individual observer's visual acuity, but on the astronomer's ability to coordinate, manage and organize his instruments.[85]

79 On the 1712 publication of the *Historia Coelestis Libri Duo* and Halley's pejorative preface see Johns, *The Nature of the Book*, op. cit. (2), pp. 598–611.

80 Chapman, *The Preface*, op. cit. (3), Appendix II, p. 192.

81 Chapman, *The Preface*, op. cit. (3), Appendix II, p. 192.

82 In the spring of 1716 Flamsteed collected all of the remaining copies of Halley's abridged version of his Historia, and on Greenwich Hill he burned all of the sheets he considered to be corrupted by Halley's intervention. This was, as he put it, a 'sacrifice to TRUTH'. See Adrian Johns, *The Nature of the Book*, op. cit. (2), pp. 607–609; Flamsteed to Lowthorp, 3 February 1715/16, *CJF*, vol. 3; Baily, op. cit. (8), pp. xlii, 320–321.

83 Baily, op. cit. (8), p. xix.

84 Forbes, op. cit. (1), p. 147.

85 It is important to note that although this reading emphasizes the way in which the images in Flamsteed's preface and his rhetoric in the preface try to show how Flamsteed's work surpasses the Tychonic tradition, Flamsteed was still working within a general scheme of credit based on instrumentation that originated with Tycho. Another way to say this is that although Flamsteed was trying to base his credibility on the discontinuity between his astronomical praxis and that of the Tychonic tradition, his general rhetorical strategy was still operating within the Tychonic paradigm. I owe this point to an anonymous referee.

Hevelius, Flamsteed and different ways of picturing astronomical machines

As Vertesi points out, one of Hevelius's chief visual strategies was to strike an analogy between himself and Tycho, raising his own status to a mythical level similar to that of the Noble Dane. Hevelius effected this analogy by rendering himself extravagantly dressed and his instruments impressively decorated, reminding viewers of his high social rank.[86] This strategy also harked back to the famous image of Tycho working with his mural quadrant in his *Astronomiae instauratae mechanica* (1598) (Figure 4). More signicantly, however, the mythology articulated in the images in *Machina* was rooted in Hevelius's omnipresence and his powerful gaze. In each of the images that prominently feature human figures, Hevelius is seen physically and visually engaged with his machines. His hands tinker while his eyes peer steadfastly through the eyepiece of the instruments. These images articulate a mythology about Hevelius by depicting Hevelius minding his instruments and engaging in observation. The centralized action of his body animates the devices. The ornamentation on the limb of his quadrant gives a ballistic quality to Hevelius's vision. The embossed flourishes on the alidade appear as if they are almost being emitted from Hevelius's gaze. The power of his vision passes beyond the threshold of his body and activates the instruments. Astronomical work proceeds from Hevelius's body to the machines without pause. The two figures, machine and astronomer, are elaborately intertwined: the machines are, as it were, extensions of Hevelius's body. The long line and frequency of buttons on Hevelius's coat, for instance, are echoed by the long series of teeth on the instrument (see Figure 3). Similarly, the angle of Hevelius's bent knee is traced by the metal curves of the instrument, and the angle of his upraised arm encloses his face in the instrument, giving the impression that there is no break between body and apparatus. Associations between these images and Hevelius's body would only have been heightened for early modern audiences, because it was widely known that Hevelius drew and engraved the plates for his *Machina* himself. Thus not only was Hevelius's body graphically at the centre of each image, but each image was an index of the gestures of Hevelius's labour. Hevelius's individuality is central to each vignette. The images impress upon the viewer that Hevelius, the particular individual, is trustworthy because he is technically competent and of honourable social rank, and that his observations are to be trusted by virtue of the extraordinary acuity and resolving power of his eyes.[87] He was, as it were, a sage-observer whose embodied skills justified the legitimacy of his celestial measurements.[88] This mythology earned Hevelius a number of flattering epithets: 'the sharp-seeing Hevelius', 'the Prussian Lynx', and the 'keen-eyed [Hevelius]'.[89]

86 Vertesi, op. cit. (72), pp. 221, 227–230.

87 Hevelius was, of course, not the first to base the legitimacy of his observations on the quality of his eyes. Arguing about the true shape of Saturn, Galileo held that his observations were indeed correct because his eyesight and instruments were superior to those of his challengers. Stillman Drake (ed.), *Discoveries and Opinions of Galileo: Including The Starry Messenger (1610), Letter to the Grand Duchess Christina (1615), and Excerpts from Letters on Sunspots (1613), the Assayer (1623)* (tr. Stillman Drake), New York: Anchor Books, 1957, pp. 101–102.

88 The typology of the early modern scientific observer as a sort of sage is borrowed from Lorraine Daston and Peter Galison, *Objectivity*, New York: Zone Books, 2007, pp. 55–113.

89 Vertesi, op. cit. (72), p. 227; Winkler and Van Helden, op. cit. (76), p. 98.

Figure 4. Tycho Brahe, *Tychonis Brahe Astronomiae instauratae mechanica* (1602). Reproduced by permission of the Osler Library of the History of Medicine, McGill University.

Hevelius's fantastic visual skill became all the more certain for his contemporaries once Halley visited Hevelius's observatory in Danzig in order to settle the dispute between Hevelius and Hooke over the usefulness of telescopic sights in positional astronomy. According to Hooke, it was impossible for normal human vision to descry

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any angle greater than half a minute of arc.[90] In 1674, Hooke published the experiment that he used to determine this optical threshold in a tract he wrote condemning Hevelius's rejection of telescopic sights for positional astronomy. The dispute between Hooke and Hevelius only came to an end five years later when Halley arrived in Danzig and reported to Flamsteed, 'But as to the distances measured by the sextants, I assure you I was surpriz'd to see so near an agreement in them, and *had I not seen*, I could have scarce credited the relation of any.'[91] According to Halley, the greatest discrepancy between his observations and Hevelius's was no greater than 10″. Similar to the images in the first part of Hevelius's *Machina*, Hevelius had to be seen in the act of observation in order to conclude that there should be 'no more doubt about his Veracitye'.[92] Although he may have been a competent technician and of high social rank, the credibility of his astronomical measurements rested on the grounds that Hevelius, the individual, possessed exceedingly powerful visual skills.

Flamsteed, who vociferously disagreed with Hevelius's arguments against the use of telescopes for positional astronomy, worked hard to emphasize the differences in astronomical praxis between himself and the controversial 'star of Danzig'.[93] The few images published in Flamsteed's 1725 *Historia* speak to this cleavage (Figures 5–7).[94] Most strikingly, there are no people, let alone explicit representations of the Astronomer Royal, in the images published in the *Historia*. The machines depicted in these images rest unused and unaccompanied. They soberly represent Flamsteed's two most successful

90 Robert Hooke, *Animadversions*, London, 1674, p. 8; Buchwald, op. cit. (7), pp. 613–622, offers an excellent analysis of Hooke's experiment.

91 Halley to Flamsteed, 7 June 1679, *CJF*, vol. 1 (emphasis added).

92 Halley to Flamsteed, 7 June 1679, *CJF*, vol. 1 (emphasis added); Derek Jensen points out that the major difference between the images in Hevelius's *Selenographia* and those in his *Machina Coelestis Pars Prior* is that the images in the latter feature Hevelius's assistants working with him in order to heighten the analogy between Hevelius and Tycho. To this we can add that the reason for the assistants in these images was also to show that the credibility of Hevelius's visual skills was supported by local witnesses. Derek Jensen, 'The science of the stars in Danzig from Rheticus to Hevelius', PhD dissertation, University of California, San Diego, 2006, UMI 3236816, p. 237; Vertesi, op. cit. (72), p. 216.

93 Saridakis argues that the controversy that arose between Hooke and Hevelius about the benefits of naked-eye sights versus telescopic sights forced the scientific community to take sides and thereby distinguish 'the appropriate characteristics of astronomical practice and the appropriate activities of the astronomer'. See Saridakis, op. cit. (13), p. 10.

94 It is important to note that Flamsteed began drafting his preface as early as 1716, and he died at the end of 1719, making the second publication of his star catalogue posthumous. Although Flamsteed obviously did not have control over the publication of the 1725 *Historia*, its compilation and publication, which were organized by Flamsteed's wife, Margaret, and his two former assistants, Joseph Crosthwait and Abraham Sharp, who earned no recompense for their efforts, were very much devoted to the vindication of his reputation, and it was certainly published in the spirit of Flamsteed's research by the people who were the most intimately acquainted with it. In the spring of 1726, after the publication of the 1725 *Historia*, Margaret Flamsteed persisted in trying to vindicate her late husband. She wrote to Dr Mather, the vice chancellor at Oxford, asking for his copy of Halley's 1712 abridgement of Flamsteed's *Historia*, saying, 'I am under an obligation not only to do justice to the memory of Mr. Flamsteed, but also to prevent the world's being imposed on by a false impression.' See Baily, op. cit. (8), pp. 364 for the preceding quotation, 332–364 for relevant letters concerning the publication of Flamsteed's *Historia* following his death, 321 for Flamsteed beginning seriously to draft his preface in 1716. For a general account of the publication of the 1725 *Historia* see Johns, *The Nature of the Book*, op. cit. (2), pp. 611–617.

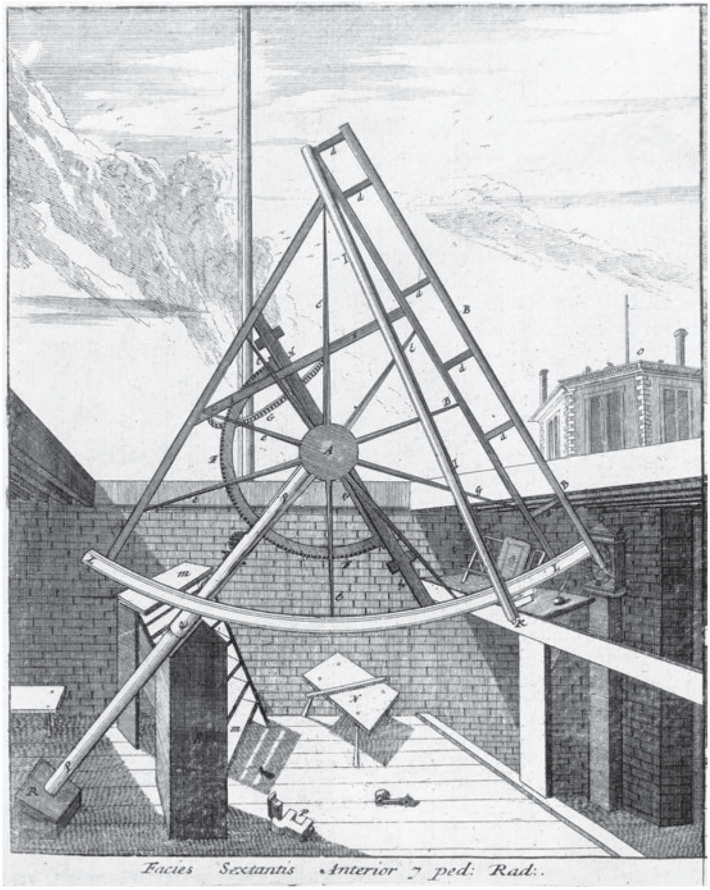

Figure 5. Flamsteed's seven-foot sextant, built by Thomas Tompion in 1676. Notice the instruments strewn on the floor and the pen resting in the inkwell. Francis Place, 'Facies Sextantis Anterior', in Flamsteed, *Historia Coelestis Britannica*, vol. 3 (1725), facing p. 164. Courtesy Archives and Special Collections Department, New Mexico State University.

observing apparatuses. Two of the three images were etched by Francis Place (Figures 5 and 6). They depict the anterior and posterior views of the sextant built from Flamsteed's own design by 'Master Tompion, the most outstanding craftsman of his age'.[95] Place's etchings are part of a larger series that was commissioned by Jonas Moore (Flamsteed's friend and patron) to visually celebrate the establishment of the Greenwich Observatory shortly after Flamsteed began his work there.[96] The etchings were completed by 1680,

95 Forbes, op. cit. (1), p. 113.

96 The only real attention these etchings have received is by Derek Howse, in whose book there is a nearly complete reproduction of the whole series (only the original frontispiece is known to be missing). Derek Howse, *Francis Place and the Early History of the Greenwich Observatory*, New York: Science History Publications, 1975.

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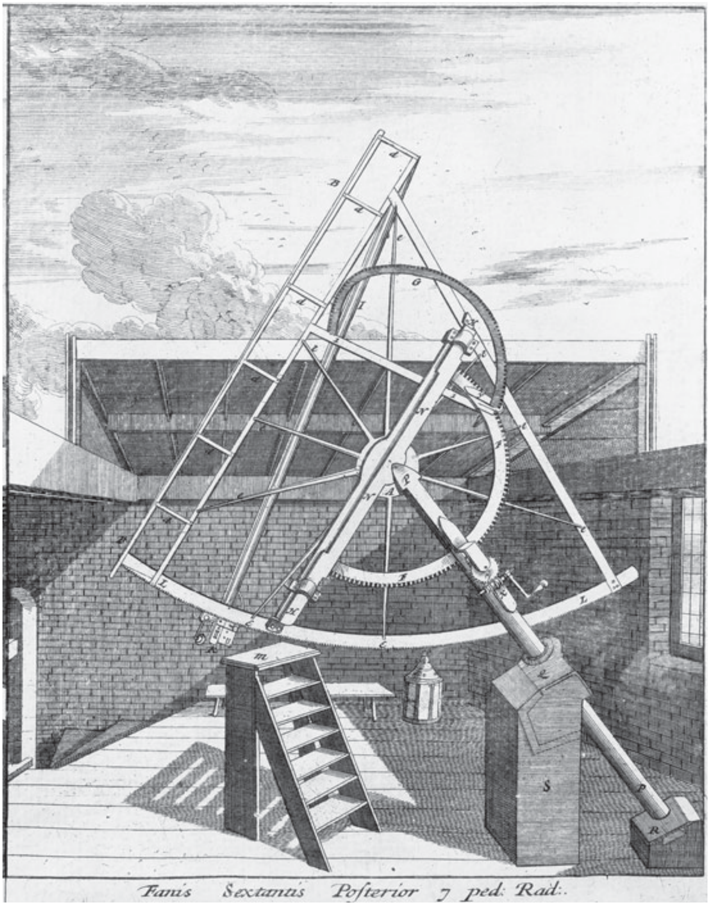

Figure 6. Flamsteed's seven-foot sextant, built by Thomas Tompion in 1676. Francis Place, 'Fanis Sextantis Posterior', in Flamsteed, *Historia Coelestis Britannica*, vol. 3 (1725), facing p. 164. Courtesy Archives and Special Collections Department, New Mexico State University.

about forty-five years before the 1725 publication of Flamsteed's *Historia*. None of the other Place etchings were published with the 1725 *Historia*, however. Of Places's original twelve etchings, only four were of instruments; the others were of plans or views of the newly built Greenwich Observatory. The exact reason for the exclusion of the other ten etchings is unknown, but we can reason that their omission was either deliberate or because they were simply thought to be unimportant.[97] In either case, we can say

97 We can be quite certain that at least some, if not all, of the other Place etchings were among Flamsteed's possessions when he passed away. Similarly, at the time Joseph Crosthwait was working on transcribing Flamsteed's preface and sending it off to be translated into Latin he was also certainly in possession of some of the Place etchings that were not included in the 1725 *Historia*. Howse, op. cit. (96), pp. 25–26; Baily, op. cit. (8), p. 343 for Crosthwait's possession of the place etchings, 333–338 for the letters concerning the transcription and translation of Flamsteed's preface.

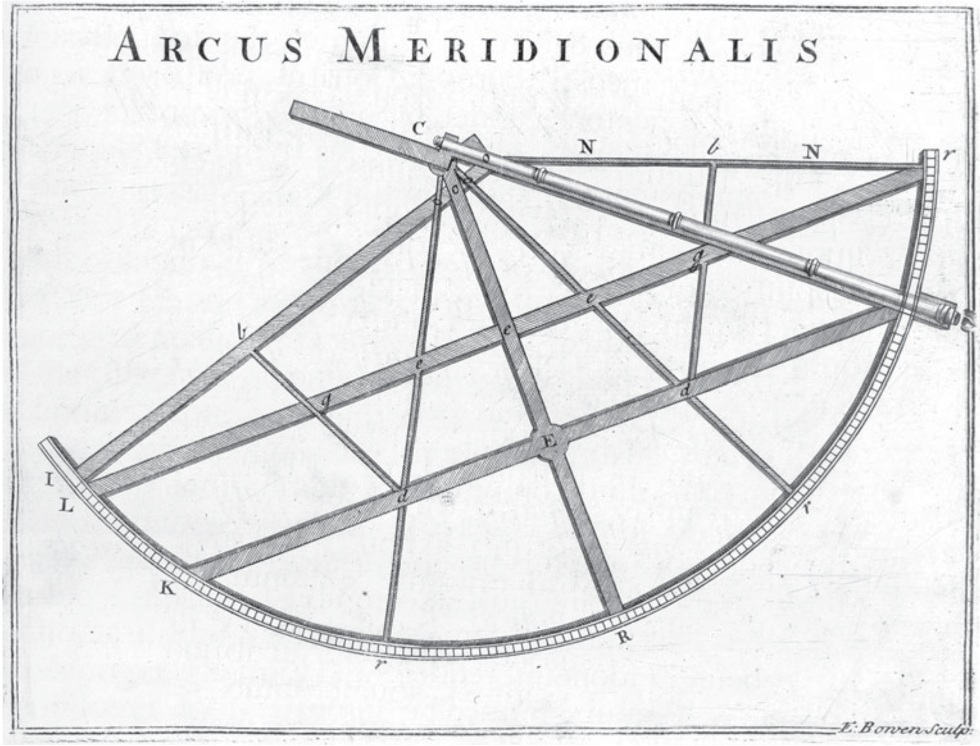

Figure 7. Flamsteed's mural arc, made by Abraham Sharp in 1668. 'Arcus Meridionalis', in Flamsteed, *Historia Coelestis Britannica*, vol. 3 (1725), facing p. 164. Courtesy Archives and Special Collections Department, New Mexico State University.

that the idea of including the other Place etchings was at best deemed to be irrelevant and at worst harmful to the project of vindicating Flamsteed's scientific identity. In any event, it is significant that the only two of the original twelve Place etchings that were published with the 1725 publication of Flamsteed's star catalogue were of the instruments that Flamsteed professed in his preface to have used earnestly as a part of his research at Greenwich. These were also among the few etchings in Place's series for which Flamsteed wrote descriptions.[98] Moreover, the images that were included in the 1725 *Historia*, in contrast to the images in Hevelius's *Machina*, depict no human figures. In fact, the implied observer is conspicuously absent, with the instruments scattered almost carelessly on the ground and the pen resting ready in the inkwell. The Place etchings suggest that someone is moments away from walking into the frame to make an observation and record it.

98 In spite of this, the general point I am about to make also holds for others of the Place etchings when compared with the images in Hevelius's *Machina*. For Flamsteed's descriptions of the Place etchings that were included in the 1725 *Historia* see Chapman, *The Preface*, op. cit. (3), pp. 113, 116, 118.

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The same is not exactly true for the third image (Figure 7) that was included in the 1725 *Historia*. This image is of the seven-foot mural arc built for Flamsteed by Abraham Sharp. After Sharp completed the arc, Flamsteed maintained 'that when even the most skilled craftsmen saw and examined it, they acknowledged that they themselves could not have executed it with greater precision'.[99] Like the other two images of Flamsteed's seven-foot sextant, the image of Sharp's mural arc does not include any embodied observers. Instead, on the far right-hand edge of the image there is a single eye, making an observation through the telescope affixed to the mural arc (Figure 8). The significance of the disembodied eye, like the conspicuous absences in the Place etchings, is that these images do not imply any particular observer. Where for Hevelius the credibility of his observations was predicated on him, the 'keen-eyed' observer, witnessing the night sky, for Flamsteed credibility as a reliable witness did not rest on the quality of his eyesight in particular. For Hevelius, who refused to use telescopes for positional astronomy, credibility was necessarily predicated on the quality of his eyes and of his body. Flamsteed, whose conviction in the efficacy of telescopes was steadfast, freed, as it were, his body and his visual acuity from the responsibility of seeing correctly. To be sure, Flamsteed's unrelentingly poor health was well known to anyone who communicated with him. This reputation was no doubt accompanied by the knowledge that Flamsteed's observations were regularly made by his assistants, making the telescope and his fixation on the mechanical precision of his instruments a convenient way of rendering his body inessential to the acts of observing and recording. Even in Flamsteed's letter to John Wallis that described what Flamsteed claimed to be the veritable measurement of stellar parallax and that was later published in Wallis's *Opera Mathematica*, Flamsteed readily admitted that even his assistant, Abraham Sharp, 'had keener eyesight than I have'.[100] Flamsteed's readiness to diminish the quality of his eyesight in relation to the eyesight of his assistant, who, Flamsteed was careful to point out, was responsible for the construction of his mural arc, is a telling example of Flamsteed's broader strategy of self-fashioning. Flamsteed, who was engaging in the same enterprise as Hevelius – to improve upon the observations made by Tycho – held that 'the majority of errors in Tycho's catalogues quite indubitably arose from the difficulty from aligning stars accurately through plain sights'.[101] This problem, for Flamsteed, could be overcome by fitting telescopic sights to one's observing arcs. The telescope was, therefore, not only a way of ensuring that Flamsteed himself could measure the night sky with greater precision, but also a way of ensuring that any able-bodied observer could, at least hypothetically, see the same thing.

The mode of visual self-presentation in Flamsteed's *Historia* rejected the example set by Hevelius in favour of a scientific identity that displaced the burden of seeing correctly and measuring accurately from the astronomer's body. For Flamsteed, credibility as an astronomer was not predicated on superhuman perceptual skills. The identity that Flamsteed worked to create for himself was based on his understanding

99 Chapman, *The Preface*, op. cit. (3), p. 124.

100 Flamsteed to Wallis, 20 December 1698, *CJF*, vol. 2; Wallis, op. cit. (68), vol. 3, pp. 701–708.

101 Chapman, *The Preface*, op. cit. (3), p. 111.

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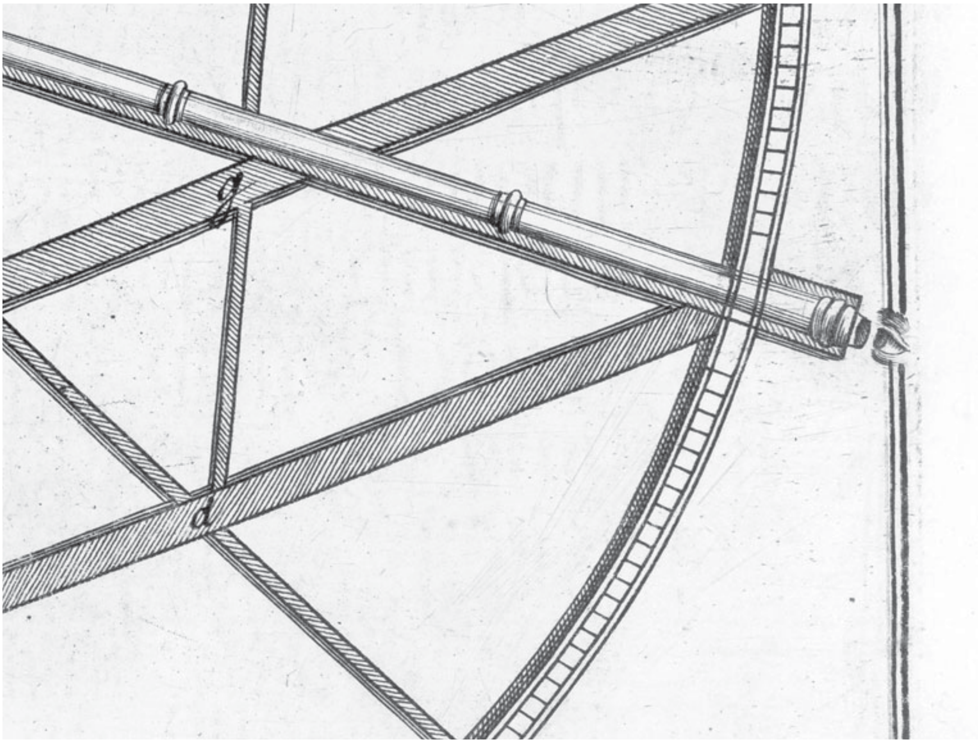

Figure 8. Detail of the eye peering into the telescope mounted on Flamsteed's mural arc. 'Arcus Meridionalis', in Flamsteed, *Historia Coelestis Britannica*, vol. 3 (1725), facing p. 164. Courtesy Archives and Special Collections Department, New Mexico State University.

of the astronomer as a skilful technician rather than as a sage-observer. The technical know-how and labour of the skilful astronomer supplanted the hyper-accurate vision of the mythical sage whose vision was occult and thus unreliable.[102] Since, for Flamsteed, 'telescopes particularly provide the means of achieving ultimate perfection', the issue raised by the variable quality of different individuals' eyesight was resolved by the introduction of the telescope into observational astronomy.[103] Machines superseded the fallible body of the observer as the vehicle through which observations were made. Consequently, machines, rather than perceptual skills, figured at the centre of Flamsteed's praxis.

102 For some of the problems associated with making astronomical observations publicly accessible in the seventeenth century see Mary G. Winkler and Albert van Helden, 'Representing the heavens: Galileo and visual astronomy', *Isis* (1992) 83, pp. 195–217; Van Helden, op. cit. (5); on the importance of the activities of natural philosophers being considered publicly accessible in general in the seventeenth century see Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life*, Princeton: Princeton University Press, 1985, pp. 55–60.

103 Chapman, *The Preface*, op. cit. (3), p. 116.

Mechanical uncertainty and metal instruments

The problem of seeing correctly thus became one of technical skill insofar as the certainty of one's observations rested on the quality of one's instruments and the ability to adroitly manage those instruments. To this effect, Flamsteed held that

> it would not be too hard to measure an angle or a distance in the heavens, to a high degree of accuracy, if we could establish with certainty that an arc of a circle can be divided with sufficient accuracy by human artifice. But there remains doubt as to whether this can be done.[104]

Instruments, for Flamsteed, were characteristically untrustworthy.[105] As was common among natural philosophers in the period, Flamsteed did not want to have his reputation 'bound to the manual skill of a hired craftsman'.[106] Certainty rested on the astronomer's ability to find and correct the errors of his instruments.[107]

Writing to William Molyneux, who was to come under the informal tutelage of the Astronomer Royal, Flamsteed encouraged the work of his admittedly inexpert apprentice by instructing him that when taking the height of celestial bodies short of the meridian, he should

> note also the time when they comes to the same height againe past it and to calculate the apparent houres from both for if the errors are not found the same by both (as it seldome happens they are where the Latitude is not exactly knowne or if the instrument you use be faultily divided) however the meane amongst them shall be the true error at the Middle time betwixt both observations.[108]

Flamsteed even admits that 'this method I have frequently used to be sure of my times'. Although, 'Now', he assures Molyneux, 'I find I need not, haveing [*sic*] both gotten the exact latitude of this place, and error of my Instrument.'[109] While Flamsteed acknowledged that averaging several observations is less preferable than knowing the error of

104 Chapman, *The Preface*, op. cit. (3), p. 116.

105 Flamsteed's scepticism about whether or not artisans could actually contrive a device that was not inherently flawed can be compared to Descartes's reluctance to trust lens makers to craft lenses that would not create optical distortions. According to Burnett, 'Descartes made the artisan responsible for the gap between theory and praxis, and then tried to close the gap by a mechanical device' – i.e. lens-grinding machines. See Burnett, op. cit. (46), p. 125. It is, however, interesting to point out that Flamsteed doubted the ability of artisans to manufacture mechanical devices in general (and graduated arcs in particular) of sufficient quality to eliminate instrumental errors in observation. That Flamsteed refers to telescopes as the means of achieving 'ultimate perfection' seems to ignore the fact that lenses too were contrived by human artifice. Flamsteed does acknowledge that the work of lens grinders is too imperfect, but this does not seem to inhibit his convictions about the perfection of telescopic sights. See Forbes, op. cit. (1), pp. 151–152; Chapman, *The Preface*, op. cit. (3), p. 116.

106 Burnett, op. cit. (46), p. 52.

107 Buchwald makes a similar observation: Flamsteed 'was from the outset deeply concerned with locating and minimizing the "errors" in his instruments ... In fact, Flamsteed seems to have attributed most differences between observational values taken at different times with the same device to errors of this sort'. See Buchwald, op. cit. (7), p. 578.

108 Flamsteed to Molyneux, 2 September 1681, *CJF*, vol. 1. On Flamsteed and Molyneaux's relationship see Johns, 'Flamsteed's optics', op. cit. (2), pp. 87–93.

109 Flamsteed to Molyneux, 2 September 1681, *CJF*, vol. 1.

your instruments and thereby being able to make single observations with certainty, his confession of having taken the 'meane' of past observations illustrates how, in the absence of sufficient mechanical expertise, one did not have adequate reason to prioritize one observation over another.[110] Being able to determine the coordinates of a celestial body with confidence was not, in other words, a matter of making a judgement about the quality of one observation over another. Certainty required the astronomer to demonstrate the ability to find the errors that would inevitably arise in their instruments, regardless of how well they were constructed, and compensate for those errors in a systematic way.

As opposed to Flamsteed, Hevelius never took averages of his observations, despite the fact that he normally recorded no less than four different positions for the same star.[111] Although the specific criteria that Hevelius used in order to prioritize one measurement over another are not available, it is certain that when Hevelius published his *Machina Coelestis Pars Posterior* (1679) and his *Prodromus Cometicus* (1665) the numbers he decided to use were 'the direct result of a *singular* observation and accordingly required an act of judgment on Hevelius' part rather than the rote application of a numerical algorithm'.[112] Before publishing his star coordinates, Hevelius, or possibly one of his assistants, would exercise his or her sage judgement by marking off in red ink the best measurements that were recorded for each star. Determining the coordinates of a star with certainty was, for Hevelius, something that could be judged by reason. Conversely, for Flamsteed, to be certain of the position of a star was to be certain of the deviation of one's instruments. Observing the precise location of a star was thus something that became self-evident when looking through the properly adjusted sights of a telescope. We might therefore think of the dis-analogy between Hevelius and Flamsteed sketched out above to be one wherein the role of the observer changed from one who *reasons* data to one who *registers* it.[113] Flamsteed was thus left to exercise his ability as a skilful astronomer in order to uncover and compensate for the mechanical errors that inevitably appeared in his instruments.

Wooden instruments, Flamsteed explained in his preface, were liable to 'distortions and contractions' due to the effects of weather on wood.[114] Using metal instruments, however, created new problems that Flamsteed needed to discover for himself. After using his seven-foot metal sextant (Figures 5–6) for some time, Flamsteed 'found that the thread on the screws had worn down the edge of the limb'.[115] This presented a problem for Flamsteed because he used a graduated screw to determine the degrees of arc on his sextant. Once he found that the screw had worn down the teeth on the alidade,

110 Buchwald, op. cit. (7), p. 580, has also noted that Flamsteed took averages of his observations.

111 Buchwald, op. cit. (7), p. 585.

112 Buchwald, op. cit. (7), pp. 589–590 (emphasis in original).

113 The wording for this sentence is anachronistically borrowed from Claude Bernard, the nineteenth-century physiologist, who is quoted saying, 'the observer no longer reasons; he registers', in Lorraine Daston and Elizabeth Lunbeck, Introduction to Daston and Lunbeck (eds.), *Histories of Scientific Observation*, Chicago: The University of Chicago Press, 2011, pp. 1–9, 4.

114 Chapman, *The Preface*, op. cit. (3), p. 106.

115 Chapman, *The Preface*, op. cit. (3), p. 118.

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Flamsteed could no longer accurately calculate degrees of arc by the number of times he rotated the screw. In order to correct this problem, Flamsteed found a way of cross-referencing his measurements:

> I dismantled the sextant, engraved the degree scale along the rim . . . And I further calculated the table of 'revolves' for the screw and divided the arcs of the corresponding parts into degrees and minutes. With these, I was more readily able to investigate whether the parts of the revolutions of the screw matched the degrees and minutes marked off on the limb, and if any error crept in, I was able to correct it.[116]

Using independent ways of measuring arc, Flamsteed explained to his readers that he found that on occasion the measurements he made with the screw 'erred by almost a whole minute'.[117] Having identified the discrepancy, Flamsteed then recalibrated the screw to correct for this error.[118] Despite his efforts, Flamsteed eventually found that the weight of the alidade moving back and forth had 'changed the position of the perpendicular [arm] by an indefinite quantity'.[119] The difficulties that arose due to the weight of metal instruments was to become a persistent problem for Flamsteed.

The following sextant that Flamsteed had built also proved to be fragile, and its structure required constant reinforcement. This problem continued until Abraham Sharp built for Flamsteed a seven-foot mural quadrant, which, according to Flamsteed, was reputed by the most skilled craftsmen to be unequalled in its precision (Figure 7).[120] By dividing the rim of the instrument and graduating the screw that moved the alidade, and by checking these graduations against each other, Flamsteed was confident in the accuracy of the instrument's graduations. After three months, however, Flamsteed explained that he found that the 'distances of those stars crossing the meridian from the zenith to the South are much too great, and those to the North are much too small'.[121] Although the discrepancy was slight, Flamsteed noticed that over time the problem increased at the same rate. Before long, Flamsteed told his readers, he reasoned that the south part of the wall on which the mural quadrant was placed 'subsided every year, and that the errors of the instrument grew a little each year'.[122] Confronted with the dilemma of choosing between instruments that were either too weak and warped or ones that gradually shifted their foundations due to their great weight, Flamsteed measured over the course of a year the rate at which the wall sank, allowing him to predict the changing error of the sextant over time. From this he recalculated the error of the instrument on a regular basis, and he recorded in his *Historia*, 'at the head of each page of observations performed with the instrument', the changing error of the mural arc (Figure 9).[123] This was meant to be both a testament to Flamsteed's honesty and a mark of his skill in

116 Chapman, *The Preface*, op. cit. (3), p. 118.
117 Chapman, *The Preface*, op. cit. (3), p. 119.
118 Flamsteed also used a similar strategy with his micrometer. See, for example, Flamsteed to Hevelius, 28 March 1682, *CJF*, vol. 1.
119 Chapman, *The Preface*, op. cit. (3), p. 119.
120 Chapman, *The Preface*, op. cit. (3), p. 124.
121 Chapman, *The Preface*, op. cit. (3), p. 125.
122 Chapman, *The Preface*, op. cit. (3), p. 141.
123 Chapman, *The Preface*, op. cit. (3), p. 141.

46 OBSERVATIONES *Fixarum & Planetarum.*

ANN. CHR. 1690. *Menſe Die Styl. Vet.*	*Tempora per Horologium oſcillatorium* h ′ ″	*Tempora vera apparentia.* h ′ ″	ANNO MDCXC.	*Diſt. a Vertice numerata.* *per Lineas Diagonales.* ° ′ ″	*per Strias Cochleæ.* Revol. Cent	*Diſt. a Vertice correcta.* ′ ″ Er. 01 30
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	58 38		remotus ———	29 20 20	664 74	29 18 50
	59 25		primus tranſit, centro	29 04 20	658 78	29 02 50
♄ 24	00 00 33		centrum tranſit, remoto ———	29 20 15	664 74	29 18 45
	01 42		limbus ſequens tranſit, centro	29 03 35	658 57	29 02 05
	02 25		proximus ———	28 48 20	652 77	28 46 50
	03 04		remotus ———	29 20 10	664 73	29 18 40
	7 53 39		Cor Caroli ———	11 29 20	259 95	11 27 50
	9 13 44		Arcturus ———	30 40 35	695 10	30 39 05
			Diſt.aVert.Cent.aVert.Hor.ſup.Er.Hor. ° ′ ″ ° ′ ″ h ′ ″ ′ ″			
☉ 25	19 23 55		*Solis* limb. prox. 59 29 40 | 59 46 50 | 19 22 27 | +1 28			
	26 03		59 09 40 | 59 26 50 | 24 35 | +1 28			
	28 30		58 47 00 | 59 04 10 | 27 01 | +1 29			
	30 35		58 27 50 | 58 45 00 | 29 04 | +1 30			
	32 25		58 10 30 | 58 27 40 | 30 56 | +1 29			
	34 15		57 53 30 | 58 10 40 | 32 46 | +1 29			
	36 18		57 34 20 | 57 51 30 | 34 49 | +1 29			
	23 58 15		*Solis* limbus proximus ———	28 34 50	647 63	28 33 20
	59 04		remotus ———	29 06 30	659 63	29 05 00
	59 50		primus tranſit, centro	28 50 30	653 58	28 49 00
☽ 26	0 00 58		centrum tranſit, remoto ———	29 06 20	659 56	29 04 50
	02 07		limbus ſequens tranſit, centro	28 50 30	653 53	28 49 00
	02 43		proximus ———	28 34 50	647 64	28 33 20
	03 33		remotus ———	29 06 40	659 61	29 05 10
			Diſt.aVert.Cent.aVert.Hor.ſup.Er.Hor. ° ′ ″ ° ′ ″ h ′ ″ ′ ″			
	4 27 09		☉l.ſu. 57 34 20 | 57 51 30 | 4 25 23 | -1 46			
			Mane ———	1 29		
			Err. in Merid.	1 37 ½		
			Sol tranſit ———	0 58		
			Err. Inſtrum.	0 39		
			Ad grad. limb.	28 ,		
☽ Junii 2	0 00 08		*Solis* limbus remotus ———	28 31 35	646 44	28 30 05
	01 02		primus tranſit, centro	28 15 40	640 41	28 14 10
	02 09		centrum tranſit, proximo ———	28 00 05	634 51	27 58 35
	03 20		limbus ſequens tranſit, centro	28 15 30	640 36	28 14 00
	03 52		remotus ———	28 31 35	646 44	28 30 05
	04 27		proximus ———	28 00 05	634 52	27 58 35
	9 10 50		*Libræ* Lanx Auſtrina ———	65 11 10	1500 54	66 09 40
	22. 15		*Saturni* centrum ———	64 53 40	1471 33	64 52 10
	37 16		Lanx Borea ———	59 41 10	1352 73	59 39 40

Figure 9. This table gives the locations of the fixed stars that Flamsteed recorded with Sharp's mural arc. Notice that the top of the far-right column of the table includes the deviation Flamsteed calculated for his sextant at the time of these observations. The right-hand column gives the corrected locations. Flamsteed, *Historia Coelestis Britannica*, vol. 2 (1725), p. 46. Courtesy Archives and Special Collections Department, New Mexico State University.

calibrating instruments by finding and accounting for the errors that inevitably appeared in all instruments. Whether or not the south side of Flamsteed's meridional wall was actually sinking at a fixed rate is unimportant. That Flamsteed proudly advertised the problems he discovered in his instruments in his preface shows that he based the credibility of his astronomical work on his ability to successfully both account and correct for the errors in his instruments.

Conclusion

The debate that arose between Hevelius and Hooke over the effectiveness of using telescopic sights for positional astronomy forced the scientific community to take sides and define what Voula Saridakis has termed 'the appropriate characteristics of astronomical practice and the appropriate activities of the astronomer'.[124] In this context, Flamsteed's reliance on the telescope as a means of seeing correctly, twinned with his attempts to legitimate the unprecedented accuracy of his work by emphasizing his proficiency in managing astronomical instruments, should be seen as his way of taking sides in this controversy. More heuristically, however, we might think of Flamsteed's emphasis on the importance of the technical literacy of the astronomer to be gesturing to a sort of mechanical turn in the history of astronomical observation. This is not to say that demonstrating a sort of technical proficiency was not a crucial component of legitimating the work of Hevelius as well as other, earlier astronomers. Rather, Flamsteed's character-building campaign merely shifted the emphasis onto the sorts of behaviour that actually counted toward the positional astronomer's ability to generate new knowledge. The originality of the scientific persona that Flamsteed worked to project was that it offered the telescope as a mechanical vehicle through which different individuals' eyesight could be regularized, thereby disassociating the body of the observer from the responsibility of seeing correctly and shifting the praxis of astronomy from the act of seeing to the organization of events that made seeing possible.

This was the inheritance of the Greenwich Observatory in the eighteenth century. When, in 1774, Nevil Maskelyne attempted to observe Newtonian gravitation by measuring the 'attraction of mountains' in Scotland, he was also, as Nicky Reeves has shown, demonstrating the accuracy of his zenith sector.[125] For Maskelyne, however, not only was this a demonstration of the accuracy of his zenith sector, but also his descriptions of the exercise served to demonstrate his ability to detect and correct slippages in the accuracy of his device. Commensurate with Flamsteed warning his readers of the way in which Abraham Sharp's seven-foot mural quadrant sank gradually into its foundations, demanding the utmost caution of the astronomer, Maskelyne warned his readers of the attention one must pay to his instrument on a boggy Scottish hillside to adjust 'for gradual changes of the wooden frame'.[126] In 1796, however, when Maskelyne discovered the 'personal equation', he also decisively overturned the

124 Saridakis, op. cit. (13), p. 10.

125 Nicky Reeves, '"To demonstrate the exactness of the instrument": mountainside trials in Scotland, 1774', *Science in Context* (2009) 22, pp. 323–340.

126 Quoted in Reeves, op. cit. (125), p. 332.

assumption that the telescope regularized the act of observing astronomical phenomena, leading to a more rigorous process of mechanizing observation. While the discovery of the personal equation invalidated Flamsteed's assumptions about the relationship between the telescope and the body of the observer, it also enlarged the range of responsibilities of the skilful astronomer to include the bodies of the individuals conducting observations.[127] The incorporation of the body of the observer under the jurisdiction of the skilful astronomer, the so-called 'mechanization of observation', in the period that followed the discovery of the personal equation was thus more the augmentation of a pre-existing historical process than the inauguration of a new historical process.[128]

Flamsteed's specific approach to licensing his astronomical authority suggests that there may be something of a prehistory to what Daston and Galison have called the emergence of 'mechanical objectivity' in the mid- to late nineteenth century, a historical process that was closely tied to the rise of photography in scientific image-making practices.[129] Simon Schaffer's, and more recently Jimena Canales's, work on the personal equation in the late eighteenth and early nineteenth centuries demonstrates the connection between astronomy and the pre-photographic process of the 'mechanization of observation'.[130] Flamsteed's attitude toward the work of the positional astronomer – trying to observe and record discreet moments in time by divesting the act of observation of the individuality of the person making the observation – is suggestively parallel to Daston and Galison's treatment of 'mechanical objectivity' as a kind of epistemic virtue or regime.[131] The two terminologies are similarly parallel – mechanical objectivity versus the mechanization of observation – and their difference may very well be rooted more in the idiosyncratic vocabularies of different subdisciplines than in their

127 Simon Schaffer, 'Astronomers mark time: discipline and the personal equation', *Science in Context* (1988) 2, pp. 115–145; Jimena Canales, *A Tenth of a Second*, Chicago: The University of Chicago Press, 2009, Chapter 2.

128 Although not using the terminology of the 'mechanization of observation', Ofer Gal and Raz Chen-Morris have argued that a similar process was taking place in the early seventeenth century. See 'Empiricism without the senses: how the instrument replaced the eye', in Charles T. Wolfe and Ofer Gal (eds.), *The Body as Object and Instrument of Knowledge: Embodied Empiricism in Early Modern Science*, Dordrecht: Springer, 2010, pp. 121–148.

129 Daston and Galison, op. cit. (88), pp. 115–190. Although Daston and Galison limit their discussion of objectivity to the images produced in scientific atlases, there is no reason to think that the concept of objectivity that they idenitfy as well as the concept's historical precursors should be limited to strictly visual representations in science: 'In this book, we trace the emergence of epistemic virtues through atlas images – by no means the only expression of truth-to-nature or objectivity or trained judgement'. Daston and Galison, op. cit. (88), p. 27.

130 Schaffer, op. cit. (127), pp. 115, 119, is responsible for the expression 'mechanization of observation' in relation to the events following the discovery of the personal equation. See also Canales, op. cit. (127), Chapter 2.

131 Compare the foregoing analysis of Flamsteed's attitude toward the appropriate behaviour of the positional astronomer with Daston and Galison's characterization of mechanical objectivity: 'By *mechanical objectivity* we mean the insistent drive to repress the willful intervention of the artist–author, and to put in its stead a set of procedures that would, as it were, move nature to the page through a strict protocol, if not automatically.' Daston and Galison, op. cit. (88), p. 121 (emphasis in original).

identification of different historical trends. Where the former focuses on photography and image making, the latter focuses on the problem of recording observed astronomical phenomena in time. If we wish to find a precursor to the rise of mechanical objectivity in the nineteenth century, the process of the mechanization of observation looks to be a promising, yet sorely under-researched, candidate. The cultural and epistemic investment in the telescope, pendulum clock and micrometer may very well have more in common with photography than we think.