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THE ENGLISH QUADRANT IN EUROPE: INSTRUMENTS AND THE GROWTH OF CONSENSUS IN PRACTICAL ASTRONOMY

J. A. BENNETT, University of Cambridge

The Meridian Programme

Two things that were important to the development of the discipline of astronomy are particularly characteristic of the eighteenth century. One is the growth in the number of official observatories across Europe — established by states, by universities, by scientific societies, by religious foundations.[1] The staff of these observatories represent a body of professional men that can scarcely be matched in number by any other branch of science in the period. The second is the consensus that these men achieved regarding the proper practice of their profession. Practical astronomy was a matter, it soon became clear, of taking prescribed angular measurements — fundamental measurement of, for the most part, stellar positions. The measurements were to be made in the celestial co-ordinates of right ascension and declination, which meant that, since stability and accuracy were increasingly prized, they had in practice to be confined to the meridian. Thus programmes of meridian measurement came to be pursued in all the active observatories of Europe, with the research goals of the individual enterprises subsumed in the broader consensus. Even if the measurements were unpublished, even if they remained unreduced to useful numbers, they were accumulated by the activity that became the *sine qua non* of an astronomical observatory.[2]

John Herschel questioned the purpose of this agreed and extensive programme of meridian observation when he presented the Gold Medal of the [Royal] Astronomical Society to Francis Baily, who had found his *métier* in the assessment and consolidation of these measurements. Herschel was speaking in 1827, by which time the programme was firmly established and had yielded a range of catalogues through effort and expense "which on a superficial view", as he put it, "must appear in the last degree lavish".[3]

> If we ask to what end magnificent establishments are maintained by states and sovereigns, furnished with master-pieces of art, and placed under the direction of men of first-rate talent, and high-minded enthusiasm, sought out for those qualities among the foremost in the ranks of science: — if we demand *cui bono*? ...[4]

Herschel's answer was not found in the astronomy that he, and more particularly his father, had made their own, though he was discreet enough not to personalize his comments: it was "not to settle mere speculative points in the doctrine of the universe ... to trace the path of our system through infinite space, or its history through past and future eternities". Neither did he remind his

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audience that the professional consensus was so well established that his father's extravagant speculations had confounded and bewildered his contemporaries, and they had judged him "fit for Bedlam".[5] The justification of the accepted programme of observation lay, he said, first of all in its practical utility — in establishing a system of reference for astronomy, geography, navigation and surveying. But utility alone could scarcely have excused the duplication of effort implied by the extent of the programme, and Herschel cited also a moral benefit from this quest for the absolute:

> The stars are the landmarks of the universe; and amidst the endless and complicated fluctuations of our system, seem placed by its Creator as guides and records, not merely to elevate our minds by the contemplation of what is vast, but to teach us to direct our actions by reference to what is immutable in his works. ... Once its [a star's] place has been thoroughly ascertained and carefully recorded, the brasen circle, with which that useful work was done, may moulder, the marble pillar totter on its base, and the astronomer himself survive only in the gratitude of his posterity: but the record remains ....[6]

The symbolic importance of the official observatory — a token of stability, integrity, order, permanence — must be part of our explanation of the programme. Thomas Romney Robinson would later see any compromise in the standards of measurement at Greenwich as a threat to the British Empire.[7]

George Graham and the English School of Instrument Making

Before the eighteenth century such a consensus across Europe could not have been formed, for it required two components that were not present. One was official observatories — institutions that did not depend on the vision, commitment and material resources of individuals, and so foundered with the astronomer's demise. The other essential ingredient concerns instrumentation. Such observatories as had been established had, for the most part, been equipped locally. Sometimes artisans principally engaged in other areas of mechanics were employed, such as Joost Bürgi by Wilhelm IV of Hesse, Willem Janszoon Blaeu by Willebrord Snellius, Elias Allen for instruments at Gresham College, or Thomas Tompion by John Flamsteed. Before George Graham, however, there was no such thing as a specialist in building large measuring instruments for observatories. No-one would ever make a living doing this alone, but Graham created a space for a new kind of presence in instrument making — a specialist to whom control of a commission might be granted, who gained credit from its outcome, whose reputation could be secured through celebrated design and construction, to whom complimentary references accrued in journals and textbooks, and who earned acceptance, respect and admiration within the mathematical community.

Graham's contribution was a comprehensive one; he produced an entire suite of designs for observatory instruments that lasted for most of the century, and sometimes beyond.[8] This comprised designs for mural quadrant, transit instrument, zenith sector, astronomical regulator and, the least commonly adopted member, equatorial sector. The export of astronomical instruments was itself a novelty, but examples from this group of designs — particularly the mural quadrant and transit instrument — were acquired by leading European observatories. While the designs were due initially to Graham, the export orders were gathered principally by his associates Sisson and Bird. Improvements were made by Bird, and the tradition was carried on to an extent by Ramsden, before he in his turn introduced radically new ideas.

The instrument at the centre of this development is the 8-ft mural quadrant by Graham (with Jonathan Sisson working under his direction), made for Edmond Halley and mounted at Greenwich in 1725.[9] It was first described in detail and illustrated by Robert Smith in his influential textbook on optics, published in 1738, and his information had been furnished by Graham himself. "The particular accuracy, whereby it excells all others, is owing", wrote Smith, "to the extraordinary skill and contrivance of Mr. George Graham Watch-maker in Fleet Street and F.R.S.".[10] Smith also revealed that Sisson was making to order a version of 4-ft radius, so already it was possible to acquire one of these quadrants.

Each of the other instruments in the Graham group of designs was added in turn to the equipment at Greenwich. Smith describes Halley's transit instrument, which was probably made by Graham.[11] Although a transit instrument as such was not new, Graham was principally responsible for the design — with its central telescope supported by a double-cone axis — that came into general use in the eighteenth century. The first of Graham's four Greenwich clocks was installed in 1721.[12] Though none seems to have had his form of compensation pendulum, the two technical improvements that made the longcase clock fit for use as an astronomical regulator — the mercury compensation pendulum and the dead-beat escapement — were both due to Graham. With such a clock, right ascension could be measured with the transit instrument or, it was hoped, the mural quadrant.

Two types of sector by Graham were brought to Greenwich by James Bradley, when he became Astronomer Royal in 1742. Along with the mural quadrant and transit instrument, the equatorial sector had been described in detail by Smith in 1738.[13] The celebrated 12.5-ft zenith sector had been used by Bradley in 1727 to confirm an annual displacement in stellar positions, which he and Samuel Molyneux had previously detected with an even longer zenith sector by Graham, and which Bradley explained in 1729 as deriving from the cycle of change in the apparent velocity of light from a star as the Earth's orbital velocity varies through the year.[14] It was this discovery of aberration that brought Graham to international attention and established him as a source of the finest instruments and the prizes they might yield. It was not just that this was the first empirical proof of something that everyone by then believed, namely that the Earth has a planetary orbit; there was also the contribution the instrument had made to fundamental measurement. The discoveries of aberration and later of nutation with the same instrument, provided the science of stellar position with two of its most fundamental parameters, used daily by practitioners in the reduction of their measurements, and were seen as having introduced the whole enterprise to a new age of precision. It was no coincidence that the instrument that marked Graham's entry into Continental astronomy was a large, but portable, zenith sector, displacing the traditional French portable quadrant. It was also in connection with the zenith sector that Bradley himself confirmed the cult of the great mechanic, by acknowledging in the *Philosophical transactions* that whatever success he had had in astronomy "has principally been owing to the Advice and Assistance given me by ... Mr. George Graham".[15]

Although introduced piecemeal to Greenwich, this group of Graham designs was seen as a suite of observatory instruments. When the next important observatory was established in Britain, the Radcliffe Observatory in Oxford, its foundation instruments, ordered by the astronomer Thomas Hornsby from John Bird in 1771, comprised two mural quadrants, a transit instrument, a zenith sector and an equatorial sector.[16] Improvements had been made to some of these by Bird, but the basic designs were all due to Graham.

If influential publicity for the English instruments had been provided by Smith and by Bradley, the message was reinforced by Edmund Stone in his "Supplement" on English instruments to the 1758 edition of his translation of Bion's *Traité de la construction et des principaux usages des instrumens de mathematique*. Graham is now cited as "one of the greatest Masters of Mechanicks in the World",[17] and the whole Supplement is justified on blunt claims for the superiority of English production, over the French in particular. "The mural Quadrant at the Royal Observatory at Greenwich", for example, and here Stone may be referring to Bird's 1750 version of the Graham design, "far exceeds that of the Royal Observatory at Paris".[18] He describes and illustrates the Graham quadrant in sufficient detail for gentlemen, workmen being referred to Smith, and makes a play for the kind of dominance that the London makers would in fact achieve in the second half of the century: "The making of good Mathematical Instruments is", he claimed, "almost peculiar to the English".[19]

More influential than Stone were Bird's own accounts of dividing astronomical instruments and of constructing mural quadrants, published respectively in 1767 and 1768.[20] Not only did they carry the immediate authority of the maker, the tracts served to announce official recognition, endorsement and financial reward from their publishers, the British Board of Longitude. Reverence for Graham continued. Bird had carefully studied the Graham mural quadrant before building a second one for Greenwich, and had judged it "a lasting testimony of his great skill in mechanicks".[21]

English Instruments in Europe

By the time of Bird's tracts, the European dimension to the rise of the English school was clear to all concerned. Roger Long wrote in 1764 that the work of John Bird was "the ornament and most valuable furniture of the capital observatories in Europe".[22] In the same year Lalande described the English quadrant in his *Astronomie* of 1764, and said that Bird had made three of 8-ft radius for Greenwich, Paris and St Petersburg, and two of 6-ft for Göttingen and Cadiz.[23]

The intrusion of the English instruments into continental Europe began with the celebrated 1736 expedition to Lapland, led by Maupertuis and sponsored by the Académie des Sciences, to measure a degree of latitude, which, by comparison with a degree measured in Peru, was intended to settle the controversy over the shape of the Earth. The principal instrument was a 9-ft zenith sector by Graham, which Maupertuis points out in his published account was of the same design as the instrument Bradley had used to discover stellar aberration. They also had a clock and a transit instrument by Graham. *La figure de la terre* by Maupertuis, published in 1738 with its detailed account of the sector, was an influential advertisement for Graham and his designs. An English translation appeared in the same year.[24]

The Continental reputation of the English makers was advanced further by another French Fellow of the Royal Society, admirer of London instruments, and former member of the Lapland team, Pierre-Charles Le Monnier. In his *Histoire céleste* of 1741, an account of the observations made in France since the founding of the Académie, it is clear that, like Maupertuis, he sees Bradley's discovery as a watershed in precision astronomy.[25] He deals with the history of quadrants, from moveable to mural, and with their use for measuring right ascension. The mural quadrant has the advantage of stability, but for the adjustments necessary to a successful instrument for right ascension he recommends the transit instrument, which he calls a new instrument despite being familiar with precursors, such as the instrument of Roemer. The transit instrument he illustrates (Figures 1 and 2) and describes in detail is by Graham.[26]

Le Monnier's demonstrated familiarity with the history of French quadrants makes his choice of an English mural quadrant on the Graham pattern soon after the publication of the *Histoire céleste* all the more telling. Indeed he became one of the principal champions of the English quadrant, and his magnificent *Description et usage des principaux instruments d'astronomie* of 1774 was a French equivalent of the tracts by Bird: much of the content was similar and it performed a parallel role in publicising and endorsing the quadrant. Endorsement for the Bird account came from its official character; in France, however, no-one could speak with more authority in this field than Le Monnier.

In his *Description*, Le Monnier tells how in 1743 he had Jonathan Sisson, whom he rightly associates closely with Graham, make him a 5-ft mural quadrant.[27] Le Monnier's experience with mural quadrants has persuaded him that transits can be taken with them, making the mural quadrant, accompanied by a clock, the complete astronomical instrument for right ascension and declination.[28] In 1751 Le Monnier lent his quadrant to the Berlin Academy, so that observations could be made close to the meridian established by Lacaille at the Cape of Good Hope in a collaborative effort to measure lunar parallax. With the instrument he sent "un de mes deux Eleves du College Royal", whom he instructed in the method of setting up the quadrant.[29] This pupil was

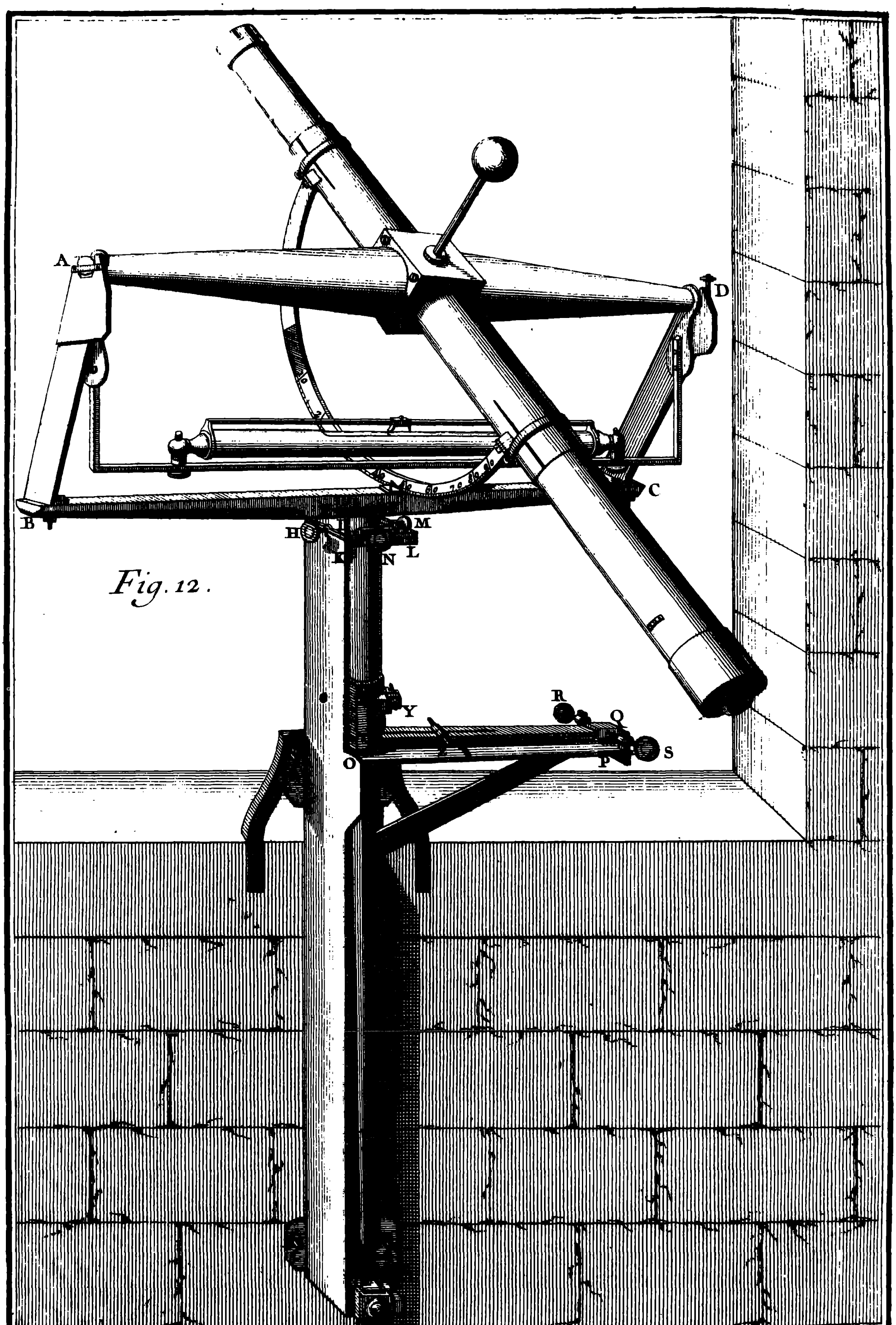

FIG. 1. Le Monnier's transit instrument by Graham, from P. C. Le Monnier, *Histoire céleste* (Paris, 1741).

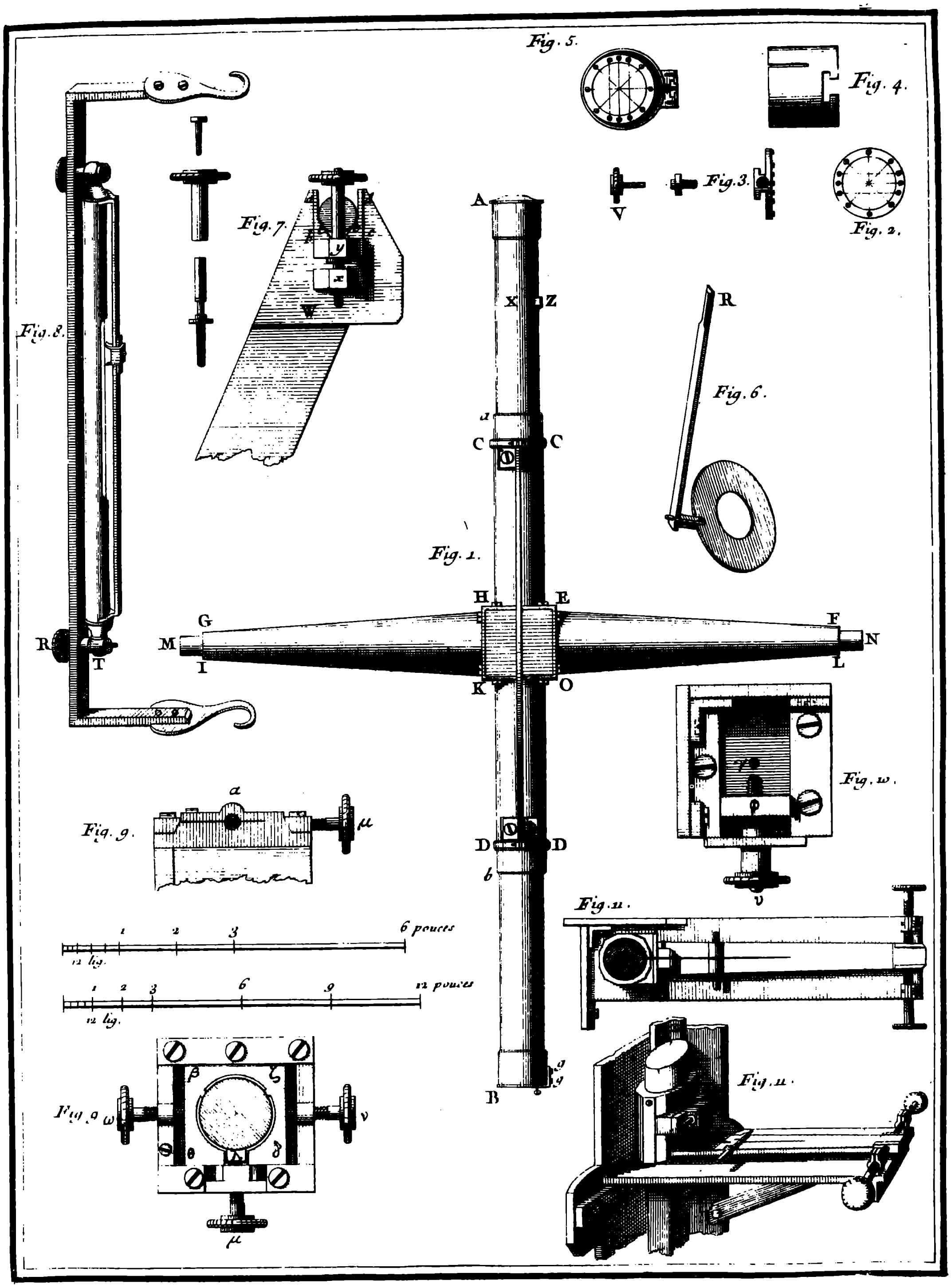

FIG. 2. Components of Le Monnier's transit instrument by Graham, from P. C. Le Monnier, *Histoire céleste* (Paris, 1741).

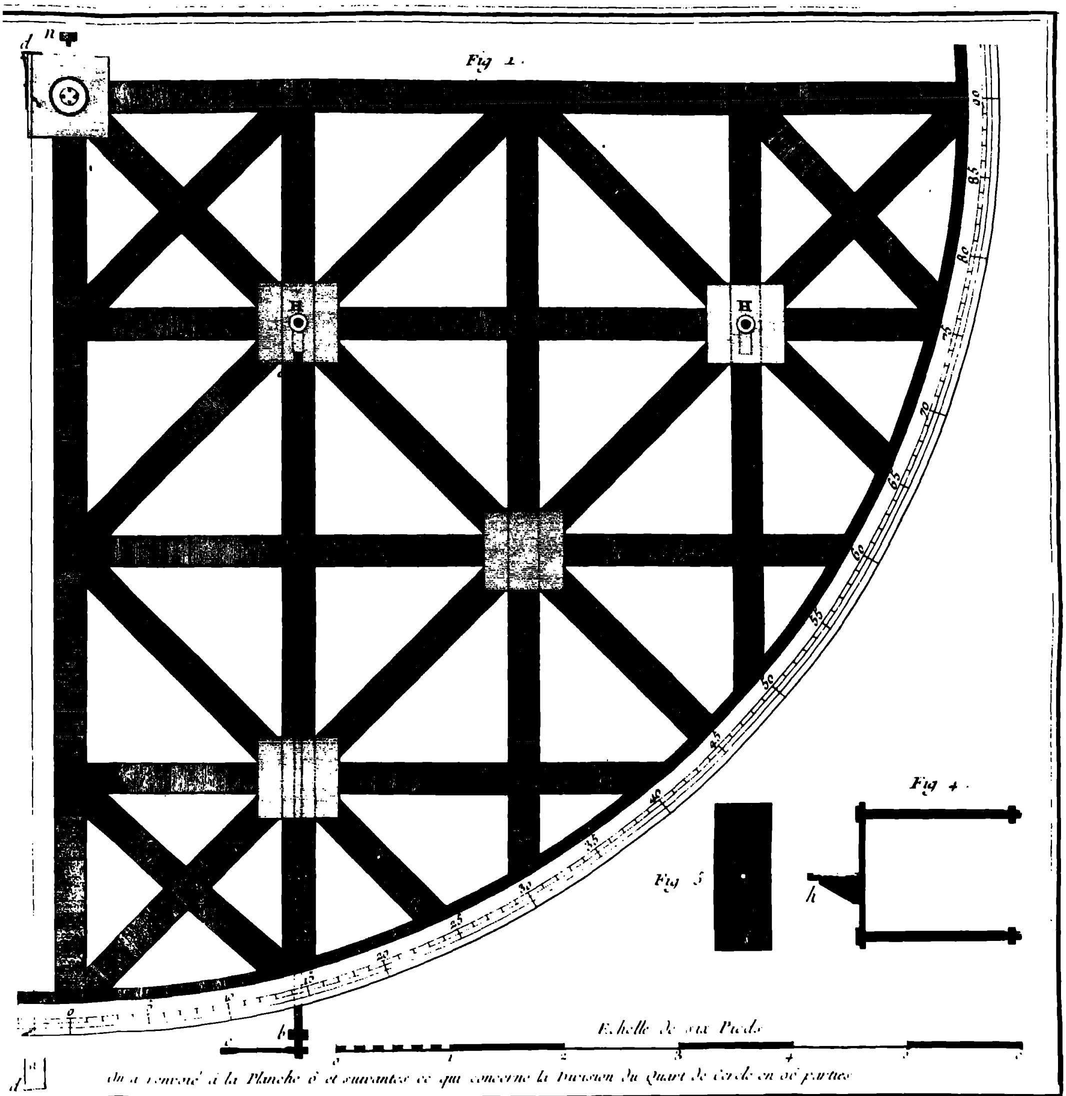

FIG. 3. Le Monnier's 8-ft mural quadrant by Bird, from P. C. Le Monnier, *Description et usage des principaux instruments d'astronomie* (Paris, 1774).

Lalande, who made the observations in Berlin, where the quadrant stayed till 1799.[30] The transfer of this quadrant, accompanied by an observer trained in its use, was important to the introduction of the measurement programme, and its increasingly English instrumentation, to Germany.

Meanwhile Le Monnier was setting about acquiring another and better English quadrant, this time even closer to the Graham original. Le Monnier had examined the Graham quadrant very carefully on a visit to Greenwich in 1748,[31] and its maker is revered and complimented whenever he is mentioned in the *Description.* The new instrument was an 8-ft (English feet) mural quadrant (Figure 3), made in 1753 by Bird, who had completed his 8-ft quadrant for Greenwich, again on the pattern established by Graham, in 1750.[32] Le Monnier tries to demonstrate that improvements have been made to the instrument in

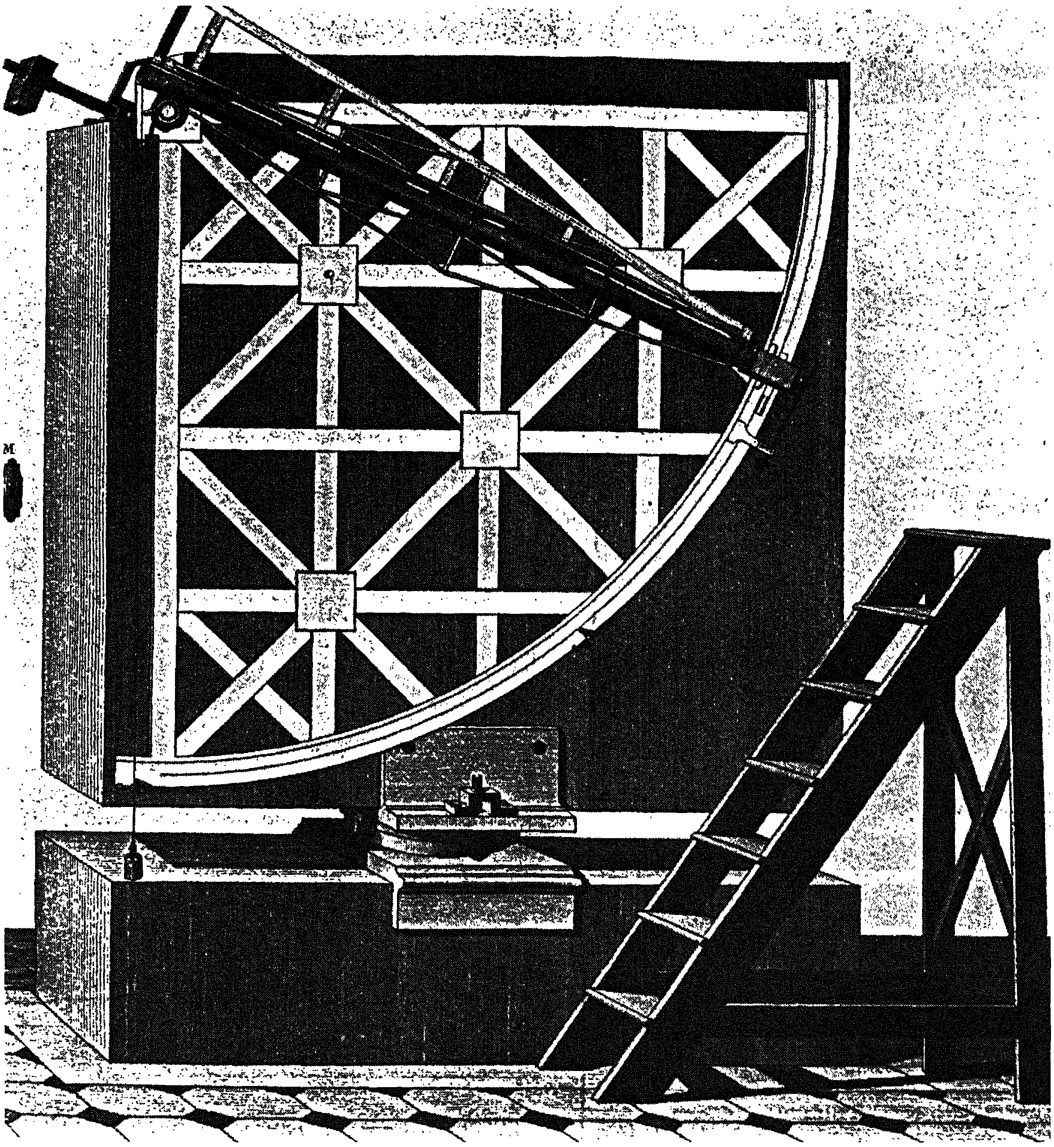

FIG. 4. Le Monnier's mural quadrant mounted on a reversible wall, from P. C. Le Monnier, *Description et usage des principaux instruments d'astronomie* (Paris, 1774).

France, but he does not disguise his great regard for the basic design. Indeed the most significant change — arranging for the wall to be rotated, so as to allow the quadrant to face north (Figure 4), was not really a success, and compromised the instrument's accuracy.

Further significant accounts and illustrations of the English instruments appear in the French literature. Lalande describes and illustrates the Sisson quadrant taken to Berlin (Figure 5) in his *Astronomie* of 1764.[33] He also describes Graham's sectors and transit instrument, and illustrates an English transit instrument (Figure 6) made for Lacaille and now used by himself.[34] In 1768 Lalande obtained permission to establish an observatory at the École

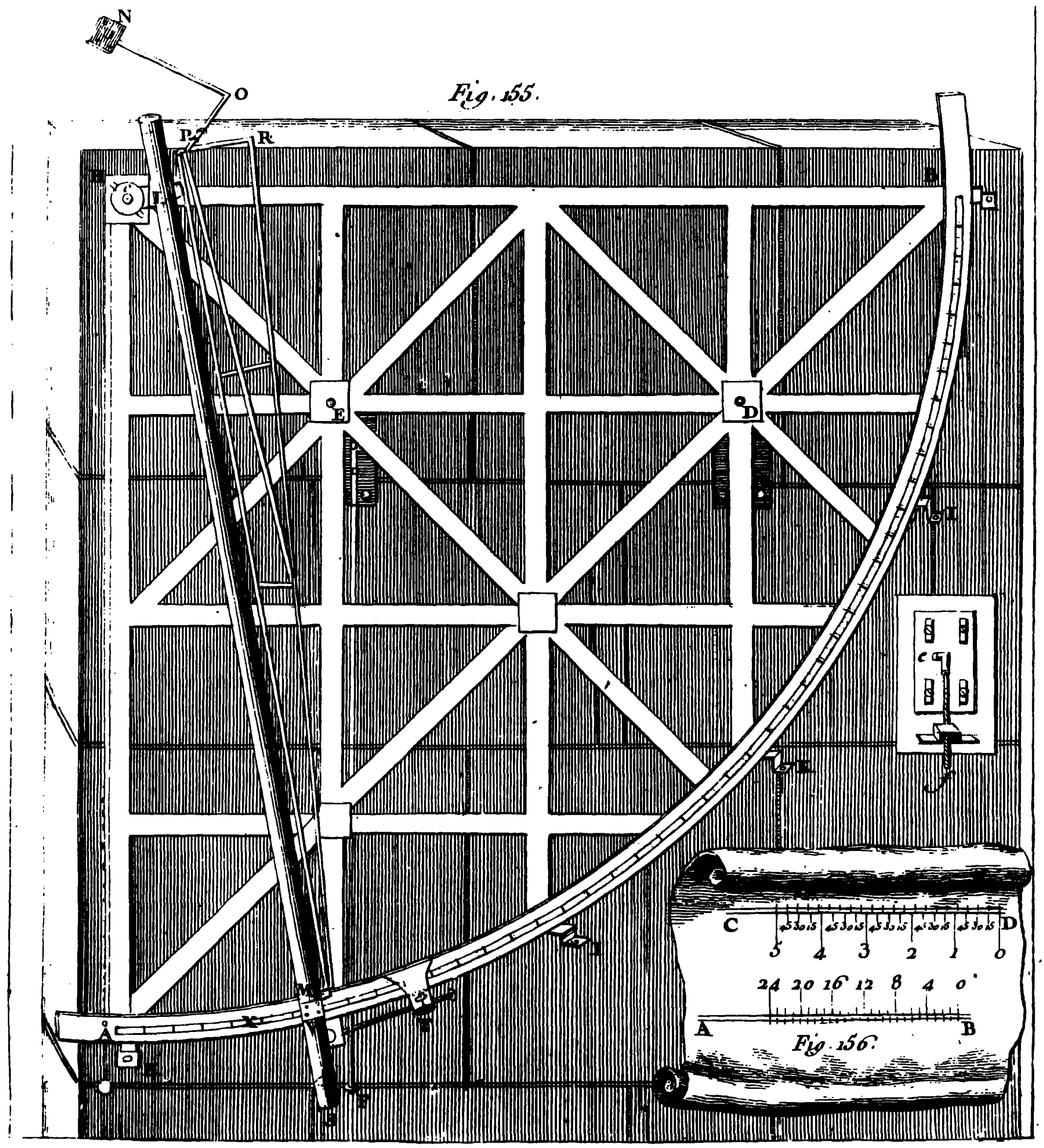

FIG. 5. The 5-ft mural quadrant by Sisson used by Le Monnier and Lalande, from J. J. Le F. de Lalande, *Astronomie* (Paris, 1764).

Militaire, and in his *Histoire céleste française* he tells of his efforts to obtain a mural quadrant, eventually acquiring an 8-ft instrument (Figure 7) by Bird in 1774.[35]

The Observatoire de Paris had not been involved with this influx of English instruments, and Lalande points out that its equipment had cost fifteen hundred thousand francs, whereas his observatory was better equipped for the needs of astronomy, having cost less than eighty thousand.[36] In particular the Observatoire did not have such a quadrant—now necessary for building a stellar catalogue.

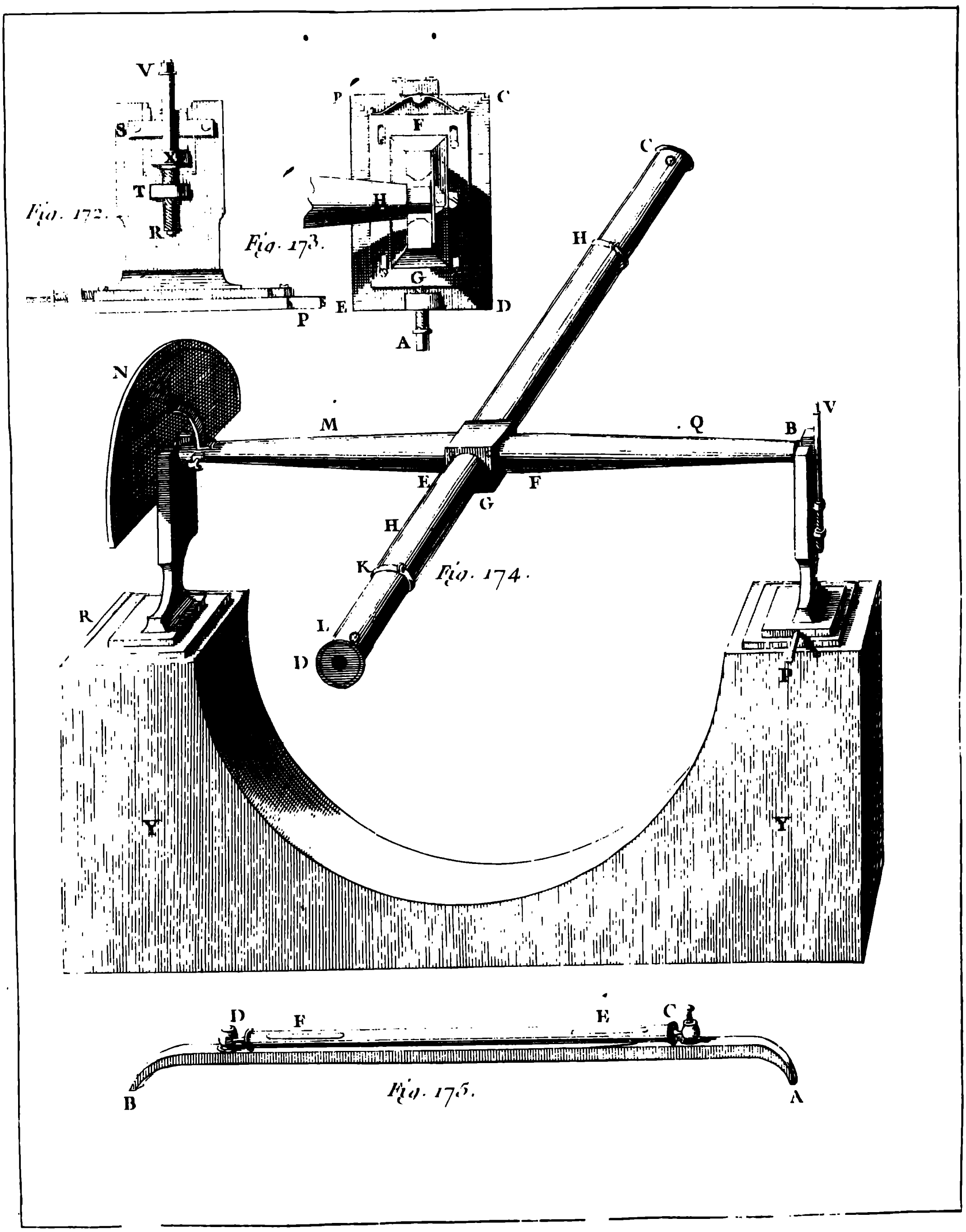

FIG. 6. A transit instrument used by Lacaille and Lalande. It has been attributed to Graham (see, for example, A. Wolf, *A history of science, technology and philosophy in the eighteenth century* (London, 1952), 132) but although the telescope and axis follow the English pattern, Lalande says it was made in 1760. From J. J. Le F. de Lalande, *Astronomie* (Paris, 1764).

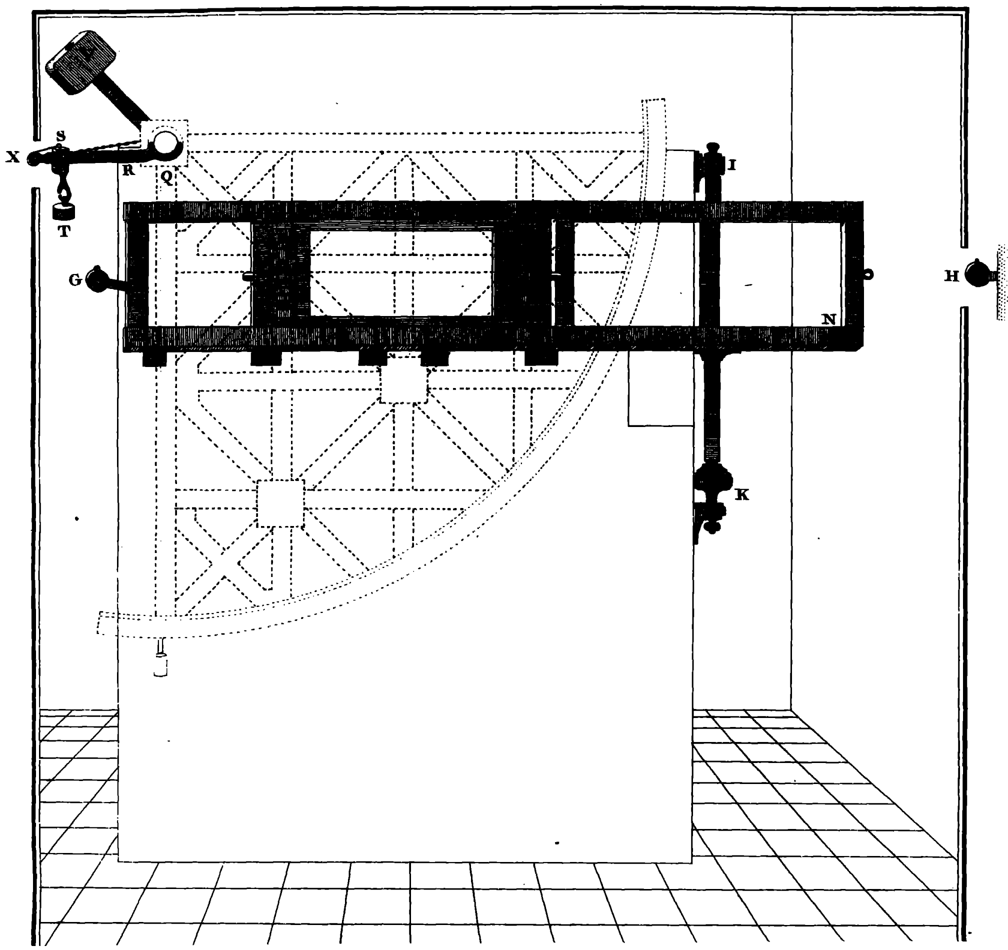

FIG. 7. The reversing apparatus for Lalande's 8-ft mural quadrant by Bird, from J. J. Le F. de Lalande, *Histoire céleste française* (Paris, 1801).

In Germany, the Berlin Academy, after their experience with the Sisson quadrant, added one by Bird, of 6-ft radius, in 1768. Göttingen University Observatory had acquired a similar one from Bird in 1755. The Royal Observatory in Mannheim acquired an 8-ft Bird quadrant in 1775, and later a transit instrument by Ramsden.[37] It was at Göttingen, with the observations of Tobias Mayer, who had close links with the English astronomical community, that the German contribution to this programme was most effective. His observations were later published by the Board of Longitude, and his catalogue was greatly esteemed. He too published an account of his mural quadrant.[38]

The spread of the English instruments extended beyond France and Germany. In Italy significant examples were acquired in Bologna, Florence, Milan, Padua and Pisa, and further afield we can add Eger in Hungary, Vilnius, St Petersburg and Cadiz.[39] We need to know more about the programmes of work they stimulated, but from the cases of England, France and Germany, we can already see the instruments as a vital ingredient in the astronomical consensus.

Instruments and the Discipline of Astronomy

Who were the observers from this central eighteenth-century period whose stellar measurements were valued into the nineteenth century and came to be included in such general catalogues as those compiled by Baily for the Royal Astronomical Society and for the British Association for the Advancement of Science?[40] They were Bradley, Lacaille, Lalande and Mayer. Le Monnier's influence also was central to the star catalogue industry, even though his own measurements were not so much used. Each of these astronomers — to a greater or lesser extent (though the only one in the lesser category is Lacaille) — was involved with introducing, publicising and using the English instruments. By extending the view just a little forward in time, we would include Piazzi and Zach, both of whom were principally equipped by Ramsden.

It was the instrument industry that made this identity of astronomical purpose across Europe possible. We have seen the initial group of related and integrated designs by Graham, their production by the members of the school of Graham, and the development by these makers of an export trade, as well as the cultivation of what would become the cult of the great mechanical expert within the English community. Leading members of the specialist trade Graham had invented came to have European reputations. This spread of an instrument technology and an accompanying research programme illustrates some of the features detected by Shapin and Schaffer in the earlier case of the air-pump.[41] For the instrument successfully to mediate the programme of work requires more than the dissemination of written accounts — observers must themselves transfer a practical facility: Maupertuis, Le Monnier or Mayer must come to London, Lalande must take the Le Monnier quadrant to Berlin, and so on.

Our view of the influence of these celebrated instruments has generally been occupied with standards of accuracy and precision. But they did more than enforce such technical norms. They helped create a working community, a unified programme of astronomical effort, a consensus about the proper conduct of an observatory and a detailed regimen for the daily routine of astronomical life.

REFERENCES

1. D. Howse, "The Greenwich list of observatories: A world list of astronomical observatories, instruments and clocks, 1670–1850", *Journal for the history of astronomy*, xvii (1986), part 4.
2. The question of the reason for the widespread acceptance of the meridian observation programme was raised in D. W. Dewhirst, "Meridian astronomy in the private and university observatories of the United Kingdom: Rise and fall", *Vistas in astronomy*, xxviii (1985), 147–58.
3. J. F. W. Herschel, "An address delivered at a special general meeting of the Astronomical Society of London", *Memoirs of the [Royal] Astronomical Society*, iii (1829), 123–36, p. 124.
4. *Ibid.*, 124–5.
5. S. Schaffer, "Herschel in Bedlam: Natural history and stellar astronomy", *The British journal for the history of science*, xiii (1980), 211–39.
6. Herschel, *op. cit.*, 125.
7. J. A. Bennett, *Church, state and astronomy in Ireland: 200 years of Armagh Observatory* (Armagh and Belfast, 1990), 109–10.

8. J. A. Bennett, *The divided circle: A history of instruments for astronomy, navigation and surveying* (Oxford, 1987), 88–91, 113–19; A. Chapman, *Dividing the circle: The development of critical angular measurement in astronomy 1500–1850* (Chichester, 1990), 66–71.
9. D. Howse, *Greenwich Observatory*, iii: *The buildings and instruments* (London, 1975), 21–24.
10. R. Smith, *A compleat system of opticks* (Cambridge, 1738), ii, 321–7; quotation from p. 332.
11. *Ibid.*, 321– 7. Lalande's attribution to Hooke can apply, at most, to the telescope (Howse, *op. cit.* (ref. 9), 32–34).
12. Howse, *op. cit.* (ref. 9), 126–30.
13. *Ibid.*, 79–81; Smith, *op. cit.* (ref. 10), ii, 350–4.
14. Howse, *op. cit.* (ref. 9), 60–64; Michael Hoskin, *Stellar astronomy: Historical studies* (Chalfont St Giles, Bucks, 1982), 31–35.
15. J. Bradley, "A letter to the Rt. Hon. George, Earl of Macclesfield, concerning an apparent motion in some of the fixed stars", *Philosophical transactions*, xlv (1748), 1–43, p. 6.
16. R. T. Gunther, *Early science in Oxford* (Oxford, 1920–67), ii, 311, 319–25, 336, 394–6.
17. N. Bion, *The construction and principal uses of mathematical instruments*, trans. and ed. by E. Stone (London, 1758), 278.
18. *Ibid.*, Supplement, Advertisement.
19. *Ibid.* The mural quadrant is described at pp. 275–8.
20. J. Bird, *The method of dividing astronomical instruments* (London, 1767); *idem*, *The method of constructing mural quadrants* (London, 1768).
21. Bird, *The method of constructing mural quadrants*, 7.
22. J. Long, *Astronomy, in five books* (Cambridge, 1764), ii, 723.
23. J. J. Le F. de Lalande, *Astronomie* (Paris, 1764), ii, 854–6.
24. P. L. M. de Maupertuis, *La figure de la terre* (Paris, 1738), 38–39, 83–84, 94–100; *The figure of the Earth* (London, 1738), 65–67, 109, 123–9.
25. P. C. Le Monnier, *Histoire céleste* (Paris, 1741), "Discours Préliminaire", p. iii.
26. *Ibid.*, pp. lxxv–lxxxvii.
27. P. C. Le Monnier, *Description et usage des principaux instruments d'astronomie* (Paris, 1774), 5, 12, 33.
28. *Ibid.*, 2. This opinion did not become generally accepted.
29. *Ibid.*, 34.
30. Howse, *op. cit.* (ref. 1), 28.
31. Le Monnier, *op. cit.* (ref. 27), 39.
32. *Ibid.*, 6 and *passim*; Howse, *op. cit.* (ref. 1), 24–26.
33. Lalande, *op. cit.* (ref. 23), 854–6.
34. *Ibid.*, 877–88.
35. J. J. Le F. de Lalande, *Histoire céleste française* (Paris, 1801), pp. ii, viii.
36. *Ibid.*, p. iii.
37. Howse, *op. cit.* (ref. 1), 24, 26, 29.
38. *Tobias Mayer's Opera inedita*, ed. by E. G. Forbes (London and Basingstoke, 1971), especially pp. 62–70; E. G. Forbes, "Tobias Mayer (1723–62): A case of forgotten genius", *The British journal for the history of science*, v (1970–71), 1–20; *The unpublished writings of Tobias Mayer*, i: *Astronomy and geography*, ed. by E. G. Forbes (Göttingen, 1972); E. G. Forbes, *The birth of navigational science* (London, 1974); T. Mayer, *Astronomical observations made at Göttingen, from 1756 to 1761* (London, 1826); F. Baily, "Mayer's Catalogue of Stars corrected and enlarged", *Memoirs of the [Royal] Astronomical Society*, iv (1831), 391–445.
39. Howse, *op. cit.* (ref. 1).
40. F. Baily, "On the construction and use of some new tables for determining the apparent places of nearly 3000 principal fixed stars", *Memoirs of the [Royal] Astronomical Society*, ii (1826), Appendix; F. Baily, *The catalogue of stars of the British Association for the Advancement of Science* (London, 1845).
41. S. Shapin and S. Schaffer, *Leviathan and the air-pump: Hobbes, Boyle, and the experimental life* (Princeton, 1985), chap. 6.