

Chapter 3 Telescopes in England Before Hooke

We saw at the beginning of the last Chapter that Hooke contributed papers to *Philosophical Transactions* relating to telescopes and telescopic observations intensively in the 1660s. We also saw that Huygens's communication with the Royal Society on the same topics was very active up to 1675. These suggest that the Galilean Observation Paradigm was of major interest to the members of the Royal Society, especially in the early stages of that institution. Indeed Wallis's record, cited in the last Chapter, attests that the English natural philosophers who later met at the Royal Society had been interested in astronomy since the late 1640s. In this Chapter, we show how the Paradigm was adopted and developed in England.

The Dawn of Telescopes in England

Telescopic observations in England can be traced back to 1609, the same year that Galileo constructed his first telescope. Thomas Harriot (1560-1621) performed the earliest known telescopic observation in England in that year, and he made his first observation of sunspots the following year¹. Although he was in correspondence with Kepler, he did not publish his results and they did not become known until the end of the eighteenth century².

William Gascoigne (c. 1612-1644) of Middleton, near Leeds, made two important inventions for telescopes in about 1640: the eyepiece micrometer and the telescopic sight. The former was a measuring scale set in the visual field of the telescope. The latter allowed the use of telescopes in conjunction with other measuring instruments, such as the sextant or quadrant. Both were used to measure angular distances between celestial bodies. They were significant instruments for precision astronomical observations, and became essential for positional astronomy in the last quarter of the seventeenth century.

Gascoigne was the youngest member of a group of Northern England astronomers which included Jeremiah Horrocks (1618-1641) of Hoole, near Liverpool, and William Crabtree (1610-1644?) of Broughton, near Manchester³. Gascoigne met an early death at the battle of Marston Moor, but his inventions were passed on to natural philosophers in Oxford, notably through Oughtred to Wren⁴.

¹ North (1974), pp. 132 & 136; Vyver (1971a), p. 71.

² North (1974), pp. 129 & 138.

³ King (1955), pp. 93-94. Crabtree had contact with Samuel Foster, Gresham Professor of Astronomy **.

⁴ Bennett (1989), pp. 22-23; Bennett (1982), pp. 39-40. Jonathan Goddard, a member

Gascoigne wrote of his eyepiece micrometer in letters of the early 1640s to Oughtred (Fig. 3-1: A diagram of the eyepiece micrometer sent from Gascoigne to Oughtred)⁵. Although the illustration is not very clear, the text of the letter establishes that Gascoigne used parallel knife-edges moving along a screw for the micrometer⁶.

Wren was a 'pupil' of Oughtred in the 1650s⁷, and probably learned of Gascoigne's eyepiece micrometer through him. Indeed, Sprat recorded in *History of the Royal Society* that Wren 'has added many sorts of *Retes*, *Screws*, and other devises to *Telescopes*, for taking small distances and apparent diamet[er]s to Seconds'⁸.

The micrometer also reached the Royal Society by a different route in 1667, when the Society received a claim of Gascoigne's priority for the invention from Richard Towneley (often Townley, 1629-1707)⁹. He was a nephew of Christopher Towneley (1604-1674), a friend of Gascoigne¹⁰.

The Newcastle Circle

Eyepiece micrometers could be applied only to Keplerian telescopes, which have a positive focus. Of course, Gascoigne used Keplerian telescopes, as Fig. 3-1 clearly shows, but it is not certain how he became aware of them¹¹. It is known that at least two groups of natural philosophers in England, the 'Hartlib circle' and the 'Newcastle Circle', contacted Wiesel, who was a popular maker of Keplerian telescopes on the European Continent¹².

The Newcastle Circle was a small group of natural philosophers gathered under the patronage of William Cavendish, the second Earl (later Duke) of Newcastle

of the Oxford group (see the next section), might have known of Gascoigne's inventions in 1649 (Turnbull, 1952-3, p. 108).

⁵ W. Gascoigne to Oughtred, 2 December 1640 & c. February 1641, in Rigaud (1841), 1, pp. 33-59; King (1955), pp. 94-97.

⁶ Bennett (1982), pp. 39-40.

⁷ Cajori (1916), pp. 58-59; Bennett (1982), pp. 17-18. See Chapter 1, note 42 above. Oughtred was also close to Ralph Greateorex, an instrument-maker who made Boyle's first air pump (Bennett, 1982, p. 40).

⁸ Sprat (1667), p. 314.

⁹ Details of the priority dispute over the invention of the eyepiece micrometer are discussed in Chapter 5. Richard Towneley also set the basis for the formulation of Boyle's law. See Cohen (1964); Webster (1963); Webster (1965); Aggasi (1977).

¹⁰ Christopher Towneley was the hub of a circle including Crabtree, Gascoigne, and Horrox. See *Birch*, 1, p. 395, note b; Taylor (1954), p. 217.

¹¹ He mentioned the names of Galileo, Kepler, Descartes, &c, as predecessors in his letters. See for example, Rigaud (1841), 1, p. 33.

¹² For the Hartlib circle, see also the previous Chapter, p.**.

(1592-1676)¹³. Its membership included Charles Cavendish (1591-1654), elder brother of William and an important mathematical correspondent of Oughtred¹⁴; Margaret Cavendish (1624?-1674), William's wife; and Walter Warner (1550-1636), Kenelm Digby (1603-1665), and John Pell (1611-1685), among others. Thomas Hobbes (1588-1679) was a tutor both to William Cavendish and to his son (William, the younger), and also belonged to the Circle.

The Puritan Revolution forced the members of the Newcastle Circle to leave England for the Continent, where they communicated with the natural philosophers there. But even before that, Charles Cavendish was deeply interested in natural philosophy on the Continent. He exchanged mathematical letters with François Derand (1588-1644), a French Jesuit mathematician, in the 1630s, and by 1639 began a correspondence with Mersenne¹⁵.

During its exile, the activity of the Newcastle Circle was centred in Paris. Members were in close contact with Descartes and Gassendi¹⁶. Hobbes exchanged letters with Descartes via Mersenne. They discussed not only the inner structure of matter, but also optics. Hobbes maintained his priority on the theory of light against Descartes, who suspected that Hobbes had borrowed some concepts from him. Hobbes wrote to Descartes in March 1641 that 'this doctrine of the nature and production of light, of sound, and of all the images and ideas...I have explained to these two eminent brothers, William Earl of Newcastle, and the knight Charles Cavendish, our common friend, in the year 1630'¹⁷. But it was not until 1644, seven years after Descartes published *La Dioptrique*, that Hobbes published his work on optics, *Tractatus opticus*, in Paris as a part of Mersenne's *Universae geometriae* ¹⁸.

Charles Cavendish took refuge first in Hamburg in July 1644, then in Paris and The Hague. His interest in optics and telescopes had manifested itself before his exile. He had exchanged letters on optics with the mathematician Walter Warner in the mid-1630s and discussed, for example, the location of the image in concave and

¹³ Jacquot (1952); Hervey (1952); Kargon (1966), pp. 40-42 & 63ff. The name 'Newcastle Circle' was coined by Kargon. Sometimes he also called it the 'Cavendish Circle'. Charles Cavendish has been often mistakenly identified as a younger brother of William, a Cavalier hero at the battle of Marston Moor. Aubrey made this mistake in Aubrey (1898), 1, p. 153.

¹⁴ See for example, Rigaud (1841), 1, pp. 22-23 & 87-88.

¹⁵ Jacquot (1952), pp. 14-15.

¹⁶ Kargon (1966), p. 63.

¹⁷ Translated from the Latin original in the edition of Adam & Tannery by Jacquot (Jacquot, 1952, p. 17).

¹⁸ For Hobbes's optics, see Shapiro (1973), pp. 143-172; Brandt (1928); Chap III & IV. On Hobbes' face-to-face meeting with Descartes, see Hervey (1952), p. 69.

convex lenses. Hobbes, then in Paris for the grand tour of William Cavendish's son, intervened in their correspondence. Hobbes became the intermediary between Charles Cavendish, Warner and Mydorge in the exchange of information on research of refraction, lenses and telescopes¹⁹.

In 1641 and 1642, Charles while still in England corresponded with Pell about Richard Reeve (often Reeves, *d.* 1666)²⁰, and from him they ordered lenses including one of hyperbolic section. They planned to construct Galilean telescopes with hyperbolic objective lenses²¹. Charles believed, as his letter from Hamburg in exile later in 1644 shows, that a telescope with 'a concave on that side next the eye would doe better' than one with 'convex on both sides'²².

It is certain that Charles Cavendish knew Gascoigne, because he wrote in the same letter in 1644:

'I am well acquainted with Mr. Gascoine, whoe was providore to oure armie: he is an ingenious man and hath shewed me howe perspectives maye be much improved; I onelie mislike his glass²³ next the eye which he makes convex on both sides; I tolde him it woulde make confused sight, if De Cartes his doctrine be true, but upon triall it proved more distinct than I expected, yet I thinke a concave on that side next the eye would doe better'²⁴.

During his Hamburg period, Charles Cavendish became interested in Keplerian telescopes. He heard about Rheita's celestial discoveries and his new Keplerian-type telescopes. In 1644 he made inquiries about how he could obtain 'Rheita's glass' from Wiesel at Augsburg²⁵. Charles was able to meet Rheita in March 1645, at Antwerp on his way to Paris²⁶. He wrote to Pell:

¹⁹ Jacquot (1952), pp. 19-20.

²⁰ See six letters from Cavendish to Pell dated between 26 June 1641 and 5 February 1641/42 (O.S.) printed in Halliwell (1841), pp. 72-74. For Halliwell's systematic confusion of dating years in the Old Calendar, see Helden (1977b), p. 35, note 10 & 15.

²¹ Helden (1977b), p. 27.

²² Charles Cavendish to John Pell, 16/26 August 1644, Halliwell (1841), p. 83.

²³ The word 'glass' was often applied to the lens, the mirror and the telescope in the seventeenth century. See North (1974), p. 140.

²⁴ Halliwell (1841), p. 83. The letter clearly shows that he knew of both Galilean and Keplerian telescopes.

²⁵ Helden (1976), p. 32; Helden (1977b), pp. 27-28; Halliwell (1841), pp. 85-88. In his letters, Charles repeatedly mentioned his inquiry to 'Auspurge' (Augsburg) on 'Rheita's glass'. For Wiesel's price list, which might have been sent to Charles, see Court & Rohr (1930-1), pp. 117-120.

²⁶ Helden (1977b), pp. 27-28.

'Wee met here with the famous Cappuchin Rieta [*sic*], his booke is nowe in the press here allmost finished. Hee solves the aparences of the planets by excentricks, without æquants or epicycles, and yet not according to Copernicus system of the worlde. He teaches allso in this booke the making of his newe telescope; his tube for his best glass was spoiled so that wee could not see it, but wee sawe another made by his directions'²⁷.

Richard Reeve

We saw in the previous Chapter that professional telescope-makers appeared in about 1640, as the telescope developed into an elaborate instrument. Italy was at the forefront of telescope production, because good glass was available from Venice. In Rome from 1650, Divini and then Campani earned a high reputation as professional telescope-makers.

Although it was not until the mid-1660s that high quality glass was produced in England²⁸, makers of telescopes and optical instruments nevertheless emerged in England as early as on the Continent, as is illustrated by the case of Richard Reeve²⁹. His name first appeared in 1641 in the previously mentioned correspondence between Charles Cavendish and Pell³⁰. They asked Reeve to grind a hyperbolic lens for them.

In the event, however, the improvement of telescopes was not achieved by grinding aspheric lenses. In his discourse in 1692, which was published in *Philosophical Experiments*, Hooke pointed out that:

'Thence many Attempts have been made by divers ingenious Men, as *Descartes, Hevelius, Sir Paul Neile, Divini, Mr. Smethwick*, and others, to make Object-Glasses and Eye-Glasses of elliptical Figures, but all without Success. However, of the spherical Figure they made good Improvements, by making Object-Glasses of much greater Lengths, and truer Figures, than they were at first able to do'³¹.

²⁷ Charles Cavendish to John Pell, 26 March [1645] (O.S.), Halliwell (1841), pp. 77-78.

²⁸ Simpson (1981), p. 15. Hooke wrote 'For, as to the possibility of getting Plates of Glass thick and broad enough without veins, I think *that* not now so difficult here in *England*, where I believe is made as good, if not much better Glass for *Optical Experiments*, than ever I saw come from *Venice*' (*Phil. Trans.*, 1, 1665, p. 65).

²⁹ Simpson (1989), p. 36. For Reeve, see also Simpson (1985); Taylor (1954), pp. 223-224.

³⁰ See note 20 above.

³¹ *Philosophical Experiments*, p. 260. Though Hooke favoured aspheric lenses of

In a response to Cassini's discourse on the history of astronomy, which was also printed in *Philosophical Experiments*, Hooke argued that the making of longer and better telescopes:

'was first performed here by Sir *Paul Neile*, Sir *Christopher Wren*, and Dr. *Goddard*, who instructed and employed Mr. *Reives* [*sic*] in the manual Operation; and, by that Means, it was carried to the Perfection of making Object-Glasses of 60 and 70 Foot long, very good, before any Mention was made of such being made in *France*'³².

It is informative to compare this quotation with the description below, which Wallis left in his autobiography, and which has already been referred to in the previous Chapter. Natural philosophers had meetings in London in about 1645, and

'These meetings we held sometimes at *Dr. Goddards* lodgings in *Woodstreet* (or some convenient place near) on occasion of his keeping an Operator in h[is] house, for grinding Glasses for Telescopes and Microscopes'³³.

Putting these quotations together, it is highly probable that Reeve was engaged in lens making in about 1645 under Jonathan Goddard (1616-1675), physician and later Gresham Professor of Physic.

Soon after, some members of the London group moved to Oxford. Seth Ward and John Wallis were appointed Savillian Professors of astronomy and geometry respectively at Oxford in 1649. In that year or the next, Christopher Wren went to Wadham College from Westminster School. Goddard was made Warden of Merton College, Oxford, in 1651 by Parliament³⁴. Thus 'major astronomers' gathered at Oxford.

In about 1651, Seth Ward, astronomy professor, built 'a slight observatory for the matter of my profession' in the tower of Wadham College³⁵. Helden argued that

elliptical section, Descartes recommended hyperbolic lenses.

³² *Ibid.*, p. 390.

³³ Scriba (1970), p. 39. John Ward wrote that Seth Ward observed particularly that Goddard 'was the first Englishman, who made telescopes' (Ward, 1740, p. 271).

³⁴ *DNB*, 'Goddard'.

³⁵ Seth Ward to Justinian Isham, 27 February 1652, transcribed into Robinson (1950), pp. 69-70 (p. 70). Ward was then a fellow commoner of the College (*ibid.*, p. 68). Later in 1669, Oldenburg praised Ward as 'your Lordship Geometrized *Astronomy*'

the observatory was 'almost certainly' equipped with telescopes by Paul Neile (c. 1613-1686) of '6, 12, 22 and even 35 feet long', with which Wren performed many observations of Saturn³⁶. Neile hired the 'best workmen' and supervised their work from his house at White Waltham³⁷. Simpson confirmed from Hartlib's paper of 1655 that one of the telescopes at Wadham was made by Reeve, and that it was used by Wren³⁸.

Reeve's name was firmly established by 1652, when John Evelyn mentioned him as 'famous for Perspectives' in his diary³⁹. His position as a popular optical instrument-maker did not change after the Restoration. In 1661 Huygens visited London. On 23 April, with Thomas Streete (1621-1689) and others, he watched a transit of Mercury across the sun with a telescope at Reeve's shop. He chose to miss Charles II's coronation at Westminster for the observation⁴⁰.

Reeve was 'the most accomplished optical worker in the capital' at that time⁴¹. He sold not only advanced long telescopes, but also short telescopes of less than a foot length. They were for a broader 'virtuoso' market, which gave him commercial security⁴².

Reeve made a long telescope of 60 feet in 1664 for the use of some members of the Royal Society. Oldenburg wrote to Hevelius in November that:

'you will be aware that we have constructed a telescope 60 feet long, recently finished by our countryman Reeves, whose object glass of about five inches

(*ibid.*, p. 68).

³⁶ Helden (1968), pp. 215 & 221. See also Wallis à Huygens, 1 avril 1656 (N.S.) (written at Oxford, 22 March 1656, O.S.), *Oeuvres*, 1, pp. 396-397; Wallis à Huygens, 17 avril 1656, *ibid.*, pp. 401-403 (p. 401). Sir Paul Neile was Usher of the Privy Chamber to Charles I, and after the Restoration he resumed his position as a Gentleman-Usher of the Privy Chamber. He, like Sir Robert Moray, often relayed messages between the King and the Royal Society. See Ronan & Hartley (1960), p. 160.

³⁷ Helden (1968), p. 221; *Oeuvres*, 3, p. 420.

³⁸ Simpson (1989), p. 37, note 13. The relevant part of the original manuscript (Sheffield University Library, Hartlib MS 29/5/46B) was transcribed into the note. Simpson reasonably said that 'There is some difficulty in distinguishing the telescopes at Wadham from those available to Wren at Neile's nearby home' (Simpson, 1989, p. 37, note 13).

³⁹ Simpson (1989), p. 37; E.S. de Beer (ed.), *The Diary of John Evelyn* (Oxford, 1959), p. 319.

⁴⁰ Huygens's travel record on 3 May (N.S.) in his 'Voyage et séjour à Londres &c' printed in *Oeuvres*, 22, pp. 566-576 (p. 575). See also Taylor (1970), p. 224; *Oldenburg Corresp.*, 2, p. 189. See also Huygens à [Ism. Boulliau], 13 juin 1661 (N.S.), *Oeuvres*, 3, pp. 278-281 (pp. 279-281).

⁴¹ Simpson (1992), p. 84.

⁴² Simpson (1985), p. 359; Court & Rohr (1930-1), p. 121.

diameter bears an aperture of 2 1/5 inches. It is still in the hands of its maker'⁴³.

The manufacture of the telescope seems to have begun in about 1662, because, in 1665, Hooke 'positively affirms that it was three years ago that Mr. Reeves made his first sixty-foot lens, convex on both sides'⁴⁴. But it took some time to make the telescope practical.

Boyle bought the sixty-foot telescope in 1666, the only 60-foot telescope that 'the maker of it, or any man that I hear of, hath perfected of that bignesse'⁴⁵. He recorded 'which [telescope] the Ingenious Artist that made it, Mr. Reeves, prized constantly at no lesse than an hundred pounds'⁴⁶.

Even while the telescope was still with Reeve, it was used by Hooke. Hooke wrote to Boyle in September 1664 about his observation of Jupiter with 'Mr. Reeves's threescore feet glass'⁴⁷. In *Micrographia* (1665), Hooke referred to its lens:

'I have experimentally observ'd in one of that length [60 feet] made by Mr. Richard Reives here at London, which will bear an Aperture above three inches over, and yet make the Object proportionably big and distinct'⁴⁸.

Hooke performed observations of Jupiter and Saturn in 1666, with the telescope now in Boyle's possession⁴⁹.

Reeve supplied both telescopes and microscopes. He sent a price list of telescopes on 11 March 1660/61 to Henry Power. To it, he attached a list of 'Microscopes of several sizes' costing from 3 to 6 pounds⁵⁰. Samuel Pepys recorded

⁴³ Oldenburg to Hevelius, 13 November 1664, *Oldenburg Corresp.*, **2**, pp. 300-309 (pp. 302 & 306). For the sixty-foot telescope, see Simpson (1989), note 20.

⁴⁴ Oldenburg to Auzout, July 1665, *Oldenburg Corresp.*, **2**, pp. 439-443 (pp. 440 & 442). In the note to this claim by Hooke, the editors insisted that 'this assurance hardly concurs with Oldenburg's report to Hevelius' above (*ibid.*, p. 443). But the author disagrees with this view, because Hooke said simply that the 'first sixty-foot lens' was made in 1662, not that the 'telescope' was completed.

⁴⁵ Hooke to Boyle, 21 March 1666, *Boyle Correspondence*, **3**, pp. 119-121 (p. 120); *The Usefulness of Natural Philosophy*, II, sect. 2 (1671), in *Boyle Old Works*, **3**, p. 399; *Boyle New Works*, **6**, p. 399.

⁴⁶ *Boyle Old Works*, **3**, p. 399; *Boyle New Works*, **6**, pp. 399-400.

⁴⁷ Hooke to Boyle, 15 September 1664, *Boyle Correspondence*, **2**, pp. 324-326 (p. 326).

⁴⁸ *Micrographia*, sig. e1v.

⁴⁹ *Birch*, **2**, pp. 98 & 103. The result was reported in *Philosophical Transactions*. For details, see Chapter 4 'Hooke's Early Observations' below.

⁵⁰ Court & Rohr (1930-31), p. 121.

that he paid '£5 10s., a great price' to Reeve on 13 August 1664 for a microscope he brought with him⁵¹. Simpson argued that Hooke's microscope illustrated in *Micrographia* 'is clearly a commercially-made product', even though 'Reeve is not actually distinguished as its maker'⁵². Reeve made good microscopes for Hooke, Power, Wren and Boyle⁵³.

Reeve's work suddenly came to an end in 1664. Hooke wrote to Boyle on 21 October:

'Perhaps you may have heard of it; if not, in short, he [Reeve] has, between chance and anger, killed his wife, who died of a wound she received by a knife flung out of his hand, on Saturday last. The jury found it manslaughter, and he and all his goods are seized on; and it is thought it may go hard with him'⁵⁴.

Though Reeve was granted a King's pardon and was discharged, he died shortly afterwards in early 1666. His son, Richard the younger, took over the business, but his ability was not comparable to that of his father⁵⁵. Thus Christopher Cock, who was trained by Reeve, was to emerge as the leading optical instrument-maker, as we see in the next Chapter.

Wren and Telescopes

Christopher Wren is known as a distinguished architect, who designed prominent buildings such as St. Paul's Cathedral. After the Great Fire, he did a great deal of work for the rebuilding of London. He was also a leading natural philosopher of his time⁵⁶. His chief contribution to mathematics was the rectification of the cycloid (quadrature). In mechanics, Wren formulated a theoretical solution to the collision of elastic bodies, independently from Huygens.

Wren also did research with telescopes and microscopes. He intended to

⁵¹ Henry B. Wheatley (ed.), *The Diary of Samuel Pepys*, 10 vols. (Cambridge, 1899-1920), 4, p. 215. The edition sometimes confuses Reeve with his son, especially in its index.

⁵² Simpson (1989), p. 41.

⁵³ *Ibid.*; Simpson (1985), p. 359.

⁵⁴ Hooke to Boyle, 21 October 1664, *Boyle Correspondence*, 2, pp. 362-364 (p. 362).

⁵⁵ Simpson (1985), pp. 359-360; Simpson (1989), p. 47.

⁵⁶ Bennett (1982) is the best work on Wren's scientific research. See also Bennett's papers on Wren listed in the bibliography at the end of this paper.

publish a book of microscopic observations and selenography in 1655⁵⁷. In 1667 Sprat mentioned in *History of the Royal Society* Wren's inventions for astronomical observations, his telescope making, theory of refraction, observations of Saturn, selenography and theory of the moon's libration, and other researches⁵⁸. Nevertheless, Wren's commitment to improvements in optics has not been analysed in detail by historians of science.

Wren was led to natural philosophy by his father, Dean Christopher Wren, and his brother-in-law, William Holder (1616-1698)⁵⁹. Holder was a cleric and a practical mathematician, and gave Wren 'his first instructions in geometrie and arithmetique'⁶⁰. Holder had known Seth Ward and Charles Scarborough (often Scarburgh, 1616-1694) at Cambridge, and later joined the natural philosophers at Oxford.

Scarborough was a member of the group of natural philosophers in London around 1645⁶¹. He was interested in mathematics, navigation and astronomy. It was Scarborough who introduced Wren to the work of Oughtred. At Scarborough's suggestion, Wren translated the appendix of Oughtred's *Clavis Mathematicae* into Latin in 1646, at the age of sixteen⁶².

Wren entered Wadham College, Oxford, in 1649⁶³. In the same year, John Wallis came to Exeter College, and Seth Ward to Wadham, as Savillian Professors. Two years later, Goddard was appointed Warden of Merton. Lawrence Rooke became a fellow of Wadham in 1650. They began to hold meetings, first at the lodgings of William Petty. When Petty left Oxford in late 1651 or early 1652, they transferred to the lodgings of John Wilkins, who had been made Warden of Wadham in 1648⁶⁴.

As we saw in the last section, Goddard had been working on the improvement of the long telescope around 1645. Seth Ward built a small observatory at Wadham College in about 1651. In this environment it was natural that Wren, who was highly commended by Wilkins⁶⁵, was introduced to astronomical observation: his interest in

⁵⁷ Turnbull (1952-3), p. 114.

⁵⁸ Sprat (1667), pp. 314-315. Wren's interest in refraction and the properties of lenses was exhibited in his letter in mid-1650, probably to Petty, which was transcribed by Bennett (Bennett, 1973, p. 146). Details of his theory are not known.

⁵⁹ The description in this paragraph mainly depends on Bennett (1982), pp. 14ff.

⁶⁰ Aubrey (1989), 1, p. 403; Wren (1750), p. 181.

⁶¹ Wallis (1678), p. 7.

⁶² Bennett (1982), pp. 17-18; Wren (1750), p. 184. See, Chapter 1, note 42**.

⁶³ Bennett wrote that Wren joined 'Wadham College as a gentleman commoner in 1650' (Bennett, 1982, p. 16). See also Hutchison (1976), p. 22.

⁶⁴ Frank Jr. (1980), pp. 52-53.

⁶⁵ Turnbull (1952-3), p. 110. Wilkins himself was interested in cosmology. Even

astronomical theory was already established, and according to his son, Wren had devised a lunar theory '*secundum Rationes Tyconianas*' in 1648⁶⁶.

Although we do not know when Wren began his own astronomical observations, it would be reasonable to suppose that he made them at Seth Ward's small observatory built around 1651. It is certain that in 1654 Wren, now fellow of All Souls' College, assisted Wallis's observations of Saturn and a solar eclipse⁶⁷. On 17 September 1655, Wren told Hartlib that he was preparing a better selenography and theory of lunar libration than Hevelius's⁶⁸. Before that, Hartlib had reported that, at Oxford, Wilkins and Wren were making a telescope of eighty feet to see the whole moon at once⁶⁹.

Wren continued his research of the moon after the Restoration. He made a pasteboard model of it by command of Charles II in 1661⁷⁰. It was completed in August, and presented to the King. 'His Majesty received it with particular Satisfaction, and ordered it to be placed among the Curiosities of his Cabinet'⁷¹.

In his younger years at Oxford, Wren performed astronomical observations not only at Seth Ward's observatory. He probably made observations also at Paul Neile's home at White Waltham, Berkshire, because they were collaborating in 1655 and 1656⁷². From Wren's letter produced at the Royal Society in 1661, it is clear that Wren and Neile observed Saturn from Neile's home in December 1657⁷³, four months after Wren's appointment as Gresham Professor⁷⁴.

Sir Paul Neile was one of the new members of the group of natural philosophers in London, like William Ball (or Balle, c. 1627-1690) and Lord Brouncker, who joined the group toward the end of the Civil War⁷⁵. Neile was associated with

before the outbreak of the Puritan Revolution, he published *The Discovery of a World in the Moon* (London, 1638). Bennett wrote that Wilkins's book on mathematical sciences, *The Mathematical Magick* (London, 1648), had immense influence on Wren. Wilkins's works were later republished in *The Mathematical and Philosophical Works of the Right Rev. John Wilkins* (2nd ed., London, 1802, repr., 1970).

⁶⁶ Bennett (1982), p. 15; Wren (1750), p. 184.

⁶⁷ Bennett (1982), pp. 18 & 28; Helden (1968), pp. 215 & 221.

⁶⁸ Bennett (1982), pp. 19-20; Turnbull (1952-3), p. 114.

⁶⁹ Bennett (1982), pp. 18; Turnbull (1952-3), p. 116.

⁷⁰ Bennett (1982), p. 40; *Birch*, 1, p. 21; Wren (1750), pp. 210-211.

⁷¹ *Ibid.*, p. 212. The model was 10 inches in diameter. The Royal Society asked Wren to make bigger version for them, but it is not known whether it was completed. See Bennett (1982), pp. 40-41.

⁷² *Ibid.*, p. 20.

⁷³ *Birch*, 1, p. 47.

⁷⁴ To be exact, Wren retained College affiliation at Oxford until 1662.

⁷⁵ Hartley (1961), p. 130.

Seth Ward⁷⁶.

Neile's telescopic research was well known in the latter half of the 1650s. For example, Evelyn recorded in his diary on 8 May 1656 that 'I went to visite Dr Wilkins at Whitehall, where I first met with Sir P: Neale [*sic*] famous for his optic-glasses'⁷⁷.

We have already seen Hooke's discourse of 1692, which mentioned Neile's vain attempt to make elliptical lenses (see, p. **). The improvement of telescopes was achieved by making long telescopes, not by aspheric lenses. Indeed in the same discourse Hooke wrote that 'Sir *Paul Neile* made some of 36 Foot pretty good, and one of 50, as I have informed, but not answerable'⁷⁸.

This report corresponds to Wren's description in 1658:

'And therefore, since it was granted to us to have the use of very well worked telescopes of 6, 12, 22 and even 35 feet long,...we have not hesitated to unveil at last the hypothesis of Saturn which for a long time has been kept secret from learned men; especially lest the stars would seem to have granted to us the friendship of that very distinguished man, Sir Paul Neile, in vain. This is the man who, having hired the best workmen, ordered the making of these above mentioned celestial devices, and even greater ones, of 50 feet in his own house'⁷⁹

Wren's letter, probably to Petty around 1656, two years earlier than the description, recorded his observations with Neile's telescopes, again up to 36 feet long:

'thô we have no[t] yet arriv'd to a good 50 ft. Glass, yet we have very long ones from 12 to 36ft. by which we have drawn many exact Pictures of Saturn not only of his Ansulæ but his Spots, and attain'd to a Theory of his Rotation & various inclination of his Body; and have drawn the spots [of] Mars'⁸⁰.

Neile donated a 36-foot telescope to Gresham College. It was erected in the

⁷⁶ Bennett (1982), p. 20.

⁷⁷ *The Diary of John Evelyn* (1959), p. 369; Ronan & Hartley (1960), pp. 159-160. Neile's telescope was alluded to in Hartlib's paper in 1657 (Turnbull, 1952-3, p.120).

⁷⁸ *Philosophical Experiments*, p. 260.

⁷⁹ Helden (1968), p. 221; *Oeuvres*, 3, p. 420.

⁸⁰ Transcribed in Bennett (1973), p. 147.

courtyard⁸¹, and was to be used by Hooke. Charles II, who visited the College in October 1660, was taken with the telescope and asked Neile to provide one for Whitehall Palace.

Indeed, we have some records of Neile's telescopes at Whitehall⁸². For example, Evelyn wrote in his diary on 3 May 1661 that Brouncker, Moray, Neile, Huygens, Ball &c. met the King, and they observed handles of Saturn, satellites of the planet and Jupiter's 'through the greate Telescope of his Majesties, drawing 35 foote'. Saturn was then 'very neere eclipsed by the Moone'⁸³. Huygens also recorded that, on that day, they observed the conjunction of Saturn with the moon with Neile's telescopes in the garden of Whitehall Palace⁸⁴

Wren's *De Corpore Saturni*

Wren was made Gresham Professor of Astronomy in August 1657. He continued his astronomical observation which he began while he was at Oxford. The research environment of Gresham College was no less fertile than that of Oxford. Goddard, Warden of Merton, had been appointed Physic Professor of Gresham in 1655. Rooke moved from Professor of Astronomy to Geometry on Wren's arrival. With them in residence, 'Gresham College continued its traditional role as a centre for research'⁸⁵.

The problem of Saturn, or its changing appearance through telescopes, was an important research topic for Wren at this time. He began observing the planet around 1654, while he was still at Oxford, and his observation and theoretical consideration continued until at least 1659⁸⁶.

There are two good sources of information on his studies during this period.

⁸¹ *Birch*, 1, p. 48. Simpson ascribed a series of Neile's successful 36-foot telescopes to Reeve (Simpson, 1989, pp. 37-38). This is highly probable, but lacks decisive evidence.

⁸² Simpson (1989), p. 38, note 17.

⁸³ *The Diary of John Evelyn* (1959), pp. 422-423.

⁸⁴ His travel record on 13 May 1661 (N.S.) printed on *Oeuvres*, 22, p. 576. Before that, on 6 April (N.S.), Huygens observed the moon, Jupiter and Saturn from Whitehall with a 35-foot telescope. He wrote that the instrument did not produce as distinct an image as his 22-foot telescope (*ibid.*, pp. 569-570).

⁸⁵ Bennett (1982), p. 23.

⁸⁶ *Ibid.*, p. 28; Helden (1968), pp. 214ff. In his inauguration speech at Gresham College in 1657, Wren summarised the astronomical discoveries made with telescopes. He wrote that 'So large a Field of Philosophy is the very Contemplation of the *Phases* of the *coelestial* Bodies, a true Description of the Body of *Saturn* only, were enough for the Life of one Astronomer; how much more the various Motions of them; which I am not now to descant on, but reserve for the continual Subject of my future Discourses in this Place' (Wren, 1750, p. 205).

One is a Latin tract, *De Corpore Saturni*⁸⁷, which Wren composed from his astronomy lectures at Gresham College in the spring of 1658⁸⁸. Wren did not publish it, but he sent it to Neile and copies were made without Wren's consent⁸⁹. The other source of information is a letter from Wren to Neile of 1 October 1661, which accompanied the copy of the tract for Neile⁹⁰.

At the beginning of *De Corpore Saturni*, Wren praised Galileo 'who was the first to direct a telescope to the sky'. Galileo discovered not only the fact that the Milky Way and nebulas are comprised of innumerable stars, but also the earth-like surface of the moon, the phases of Venus, sunspots, and the triple-bodied nature of Saturn.

'His successors are envious because they believe that there can scarcely be any new worlds left, about which they can boast, and believe that only to succeeding Lyncei is it granted to add to the discoveries of Galileo. And, indeed, it did not seem useless or inglorious (because it still remained to be done) to describe the lunar appearance more accurately, or to show the more than lunar fickleness of Saturn in a variety of figures, as the mathematicians improved the theory of dioptrics and craftsmen daily promoted the art of working big lenses. For which reason distinguished men of nations everywhere, even now, eagerly apply themselves to the production of longer telescopes'⁹¹.

Here we see a clear presentation of the 'Galilean Observation Paradigm'. Wren argued that the remaining task of significance for astronomers was to refine Galilean discoveries concerning the moon and Saturn with long telescopes.

Wren emphasised the special importance of Saturn for the programme, writing that 'Saturn is proposed as the greatest test of skill' because that planet alone 'shows so many discrepant phases'⁹². He referred to earlier hypotheses on the real

⁸⁷ *Oeuvres*, 3, pp. 419-424. Helden translated it into English (Helden, 1968, pp. 219-226).

⁸⁸ *Ibid.*, p. 216. The fact that Wren's tract was composed in 1658 is clearly shown by this statement: 'Almost three years ago, the illustrious Mr Balle first saw this belt [of Saturn]' (*ibid.*, p. 223-224). For the discovery of the 'belt' in 1655, see Armitage (1960), p. 167; *Oeuvres*, 2, p. 305.

⁸⁹ Helden (1968), p. 216; *Birch*, 1, p. 43.

⁹⁰ *Birch*, 1, pp. 47-49. The letter is also transcribed in Ronan & Hartley (1960), pp. 162-164.

⁹¹ Helden (1968), pp. 219-220.

⁹² *Ibid.*, p. 220.

shape of Saturn: 'a globe connected to two smaller globes', 'a spheroid provided with two conspicuous cavities', 'a kind of vessel with handles on both side'. One reason why very different figures had been proposed by Galileo, Fontana, Gassendi, Riccioli, Hevelius and others, was that 'observers did not often use very long tubes and absolutely perfect lenses'⁹³. Thus good, long telescopes were a prerequisite for Wren to resolve the confusion:

'And therefore, since it was granted to us to have the use of very well worked telescopes of 6, 12, 22 and even 35 feet long, together with a supply of all sorts of lenses of English manufacture, and to have at hand many observed appearances of Saturn in a continuous series from 1649 onward (some of which, from the last four years, we have depicted with the greatest care) we have not hesitated to unveil at last the hypothesis of Saturn which for a long time has been kept secret from learned men'⁹⁴

The telescopes concerned were offered by Neile (see, p. **) for the use of 'his chosen astronomical friends' including Wren⁹⁵.

Wren then proceeded to his hypothesis of Saturn; the spherical body of Saturn surrounded by a thin elliptical ring (Fig. 3-2). The ring, which Wren called the 'corona', touched the planet at two points along the minor axis of the ellipsis⁹⁶. He argued that the changing appearance of Saturn could be explained 'solely on the rotation or inclination of the body'⁹⁷. Wren believed the ring to be made of a fluid or vapours emitted from Saturn. It could not be solid matter, because it would not be possible to sustain a thin ring with great mass over the body of Saturn⁹⁸.

Wren concluded *De Corpore Saturni* with a description of a model of Saturn, illustrated in Fig. 3-2. The planet was represented in copper and could be rotated about the axis DF, which was supported by a semicircular mount able to be set at various angles on its pedestal⁹⁹.

In the letter which accompanied his tract, Wren introduced other physical models of Saturn by Neile and himself. One was a wax model made in about January 1655/6. Another model was made of two pieces of pasteboard 'upon the observation of

⁹³ *Ibid.*

⁹⁴ *Ibid.*, p. 221.

⁹⁵ *Ibid.*

⁹⁶ *Ibid.*

⁹⁷ *Ibid.*, p. 222.

⁹⁸ *Ibid.*, p. 225.

December 1657, when first we had an apprehension, that the arms of Saturn kept their length'¹⁰⁰.

'The hypothesis made more durable in metal was exposed on the top of that obelisk, which was erected at Gresham College in May, 1658. (if I mistake, be pleased to rectify me) to raise the thirty-five feet telescope of your donation'¹⁰¹.

However, when they raised the model, they did not know that Huygens had already reached a correct hypothesis of Saturn.

Huygens's Theory of Saturn

Huygens developed his theory of Saturn independently from Wren, but almost simultaneously. His insight was the modern ring hypothesis. This, and the invention of the balance spring, were his early achievements.

Huygens began his study of geometrical optics in 1652¹⁰². He soon discovered properties of lenses and lens systems which would contribute to the improvement of telescopes and microscopes. He was able to acquire two of Wiesel's telescopes and examine them: they had four and five lenses¹⁰³.

Huygens's own first telescope was finished in February 1655. He and his elder brother Constantijn (Constantijn Huygens, 1628-1699) ground the lenses themselves, because local craftsmen could not supply them to the required standard.

In March of the same year, Huygens trained the telescope on Saturn and discovered a satellite, now called Titan. It was the first major astronomical discovery since Galileo¹⁰⁴.

Huygens announced the discovery the following March in a pamphlet, *De*

⁹⁹ *Ibid.*, p. 226.

¹⁰⁰ *Birch*, 1, p. 47.

¹⁰¹ *Ibid.*, p. 48. Sprat wrote to Wren in 1658, when 'the College was garrison'd by the Rebels', that 'if you should now come to make Use of your Tube, it would be like *Dives* looking out of Hell into Heaven' (Wren, 1750), p. 254. The tube was probably the 36-foot telescope in the courtyard.

¹⁰² The description below mainly depends on Helden (1980).

¹⁰³ Helden (1977b), p. 29. Therefore, Huygens was familiar with compound eyepieces.

¹⁰⁴ Helden (1980), p. 149. Helden here pointed out that Titan, Saturn's largest satellite, 'was the obvious candidate for discovery with the new astronomical telescopes, after about 1645, which magnified from 40 to 60 times'. Galilean satellites, all of which have stellar magnitudes of about 5 or 6, could be seen with the naked eye if they were not hidden by the glare of Jupiter. Titan has a stellar magnitude of slightly over 8, and can be observed only through a telescope.

*Saturni luna observatio nova*¹⁰⁵. Huygens wrote in this short paper that the telescope he used was 12 feet long, and magnified about 50 times¹⁰⁶. With it, he found that the period of the satellite's orbit of Saturn was sixteen days. He stressed that his discovery was confirmed by observation for over a year, because he knew that when Rheita had reported the discovery of six satellites of Saturn he had been contradicted by Hevelius's thorough observations¹⁰⁷.

In this paper Huygens alluded to a hypothesis of the shape of Saturn. But he concealed his ring hypothesis in an anagram annexed to the paper¹⁰⁸. The hypothesis was made public in *Systemata Saturnium*, published in July 1659¹⁰⁹. In its preface, Huygens stressed the importance of Saturn as a system that supported arguments for a Copernican concept of the universe¹¹⁰. He began the main text with a description of his telescopes. First, he had used a 12-foot telescope with two convex lenses, with which he discovered a satellite of Saturn. On 19 February 1656 he started using a longer telescope of 23 feet with a magnifying power of about 100 times¹¹¹. It was about then that he arrived at the ring hypothesis of Saturn¹¹². Huygens went on to describe his telescopic observations of the satellite and the changing appearance of Saturn. He showed his calculations for the position of the satellite¹¹³. He compared previous hypotheses on the true shape of Saturn, which had been proposed over four decades by Galileo, Riccioli, Hevelius, Fontana, Gassendi, and others¹¹⁴. Finally he unscrambled his anagram attached to *De Saturni luna* three years previously: Saturn is surrounded by a ring which is thin, plane, not touching the body, and inclined toward the ecliptic¹¹⁵.

¹⁰⁵ *Oeuvres*, 15, 172-177.

¹⁰⁶ *Ibid.*, pp. 176-177.

¹⁰⁷ *Ibid.*, pp. 174-175.

¹⁰⁸ For the reason why Huygens postponed the announcement of his ring hypothesis for three years, see Helden (1980), p. 150.

¹⁰⁹ *Oeuvres*, 15, pp. 209-353.

¹¹⁰ *Ibid.*, pp. 214-215.

¹¹¹ *Ibid.*, pp. 228-231. Huygens's 23-foot telescope was sometimes confused with his brother's well-known 123-foot telescope of 1686, which was given to the Royal Society in 1692. See Helden (1974a), pp. 46-47, note 44.

¹¹² Helden (1980), p. 150. Also its note 25.

¹¹³ *Oeuvres*, 15, pp. 238ff.

¹¹⁴ *Ibid.*, pp. 270ff.

¹¹⁵ *Ibid.*, pp. 298-299. Huygens believed that the ring was solid. But alternative ideas, such as that the ring consisted of numerous small satellites orbiting together, were soon presented by other astronomers. See Helden (1980), p. 153 and its note 40.

Wren and Huygens

Wren came to know of Huygens's hypothesis of Saturn around the beginning of 1659, just six months before the publication of Huygens's *Systemata Saturnium*. He probably learned of it through a letter from Huygens to Wallis¹¹⁶. Huygens and Wallis had been exchanging letters on Saturn, for example Huygens's discovery of a satellite of Saturn was communicated to Wallis in an anagram in June 1655¹¹⁷, and Wallis reported to Huygens that, although Neile and Wren 'saw' the satellite, they thought it was a fixed star¹¹⁸.

Wren knew of Huygens's discovery of a satellite of Saturn, because he mentioned it in his inauguration lecture for Gresham College in 1657¹¹⁹. But he did not know of Huygens's ring hypothesis even when he lectured on *De Corpore Saturni* in the spring of 1658¹²⁰.

When Wren eventually heard about Huygens's ring hypothesis, he abandoned his own hypothesis. He wrote of Huygens's model in his letter to Neile in 1661 that 'I confess I was so fond of the neatness of it, and the natural simplicity of the contrivance agreeing so well with the physical cause of the heavenly bodies'¹²¹.

Despite Wren's preference for Huygens's hypothesis, his *De Corpore Saturni* was made public after the publication of Huygens's ring hypothesis in *Systemata Saturnium*¹²². On 4 September 1661, Kenelm Digby read a letter at the Royal Society from Bernard Frenicle de Bessy, a French mathematician, on his hypothesis of Saturn¹²³. The hypothesis was so similar to Wren's that Neile, who knew Wren's hypothesis well, announced that Wren's hypothesis predated Frenicle's by some years. Wren confirmed this, though he was reluctant to talk about his old theory. But 'Mr. WREN was desired likewise to deliver a copy of his observations and hypothesis of Saturn to the amanuensis, to be transmitted by SIR KENELME [*sic*] DIGBY to Monsieur FRENICLE'¹²⁴.

¹¹⁶ Helden (1968), p. 217; Huygens à Wallis, 31 janv. 1659, *Oeuvres*, **2**, pp. 329-331 (pp. 330-331).

¹¹⁷ Huygens à Wallis, 13 juin 1655, *ibid*, **1**, pp. 331-333 (p. 332).

¹¹⁸ Huygens à Wallis, 1 janv. 1659, *ibid*, **2**, p. 306. Huygens mentioned this also in *Systemata Saturnium* (*ibid.*, **15**, pp. 254-255). See also note 120 below.

¹¹⁹ Wren (1750), p. 205.

¹²⁰ Even in the tract, Wren did not forget to praise Huygens's discovery of the satellite. He wrote 'As regards the companion or moon of Saturn, which has very often been observed by me, I leave it completely to the most illustrious and most ingenious inventor, Christiaan Huygens' (Helden, p. 225).

¹²¹ *Birch*, **1**, p. 48.

¹²² For the detail of the process, see Helden (1968), pp. 216-217.

¹²³ *Birch*, **1**, p. 43.

¹²⁴ *Ibid*.

Wren sent a copy of *De Corpore Saturni* to Neile in October 1661 with an accompanying letter. Copies of *De Corpore Saturni* were reproduced from it without Wren's consent, as has been mentioned. Huygens was given a copy by Digby, and having read it in 1662 was impressed by it. He was astonished that Wren had not shown it to him when they had met in London the previous year¹²⁵.

In February 1661, Wren was appointed Savillian Professor of Astronomy at Oxford. He left his position at Gresham College the following month. He kept the Savillian professorship until 1673. However, his main interest was redirected to architecture after the Great Fire of London in 1666.

Of course, Wren did not completely abandon his study of astronomy. For example, he produced 'the model of an engine...for the grinding hyperbolic glasses' at the meeting of the Royal Society on 3 June 1669¹²⁶. But it was not a new field for Wren; Sprat had recorded in *History of the Royal Society* in 1667 that Wren 'has attempted, and not without success, the making of Glasses of other forms than Spherical'¹²⁷.

At that meeting, Wren reported to the Society only the theory of an engine to grind hyperbolic lenses. At the next meeting:

'It was ordered, that the paper containing the demonstration of this should be registered, and an engine be made by the care of Mr. HOOKE, to try the principle in matter'¹²⁸.

In astronomy as in the case of microscopy, Hooke was to take over Wren's research.

We can identify another example of this as early as 1665. On 15 December 1664, Hooke wrote to Boyle that 'We had yesterday in several parts of *England*, an account of the appearance of a very great comet in the south south-east, with a very long tail'¹²⁹. When Hooke produced his observation of the comet to the Royal Society, he was asked to compile and present 'an history'¹³⁰. But during January, Wren became active in the argument on the shape of the orbit of the comet. Adrian Auzout

¹²⁵ Bennett (1982), p. 31; Huygens à Moray, 3 fév 1662, *Oeuvres*, 4, pp. 23-25 (pp. 23-24).

¹²⁶ Bennett (1982), pp. 36-38; *Birch*, 2, p. 377. Wren's research was published in *Phil. Trans.*, 4 (1669), no. 48, pp. 961-962 & no. 53, pp. 1059-1060.

¹²⁷ Sprat (1667), p. 314.

¹²⁸ *Birch*, 2, p. 379.

¹²⁹ Hooke to Boyle, 15 December 1664, *Boyle Corresp.*, 2, pp. 441-442 (p. 441). The description below depends on Bennett (1982), pp. 65ff.

¹³⁰ *Birch*, 1, p. 511.

and Wren favoured a rectilinear path, while Wallis defended Crabtree's idea that it should be elliptical. It was necessary to perform additional observations to confirm Wren's opinion. However, his interest soon faded, and in March he was occupied in planning a visit to France. The Royal Society 'turned once again to Hooke, and on 17 March Moray told Huygens that Hooke had take over the task from Wren'¹³¹. By February, Hooke had already included the comet in his lectures at Gresham College. When he published *Cometa*, a book on the comet, in 1678 a considerable part of it was taken from the lectures and papers of 1665-1666¹³².

¹³¹ Bennett (1982), p. 66; Moray to Huygens, 27 March 1665 (N.S.), *Oeuvres*, **5**, pp. 284-288 (p. 286). When the new comet appeared at the end of March, Wren's interest revived and he started collaborative work with Hooke.

¹³² Bennett (1982), p. 68; *Gunther*, **8**, p. 260.