Astronomers' Universe

Tony Buick

Orreries, Clocks, and London Society

With a Foreword by the Earl of Cork and Orrery

Springer

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Tony Buick

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The Evolution of Astronomical Instruments and Their Makers

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To Isabella, Abigail and Caitlin
and my great, great, great,
great, great grandchildren.
What will they think of us!

Foreword to the First Edition

Charles Boyle, the 4th Earl of Orrery, who gave his name to the marvel of mechanical engineering that is the subject of this book, grew up at Knole, the house in Kent where I now live. Tenuous though this connection might seem, it is one of many links and allusions that, for me, make this book so extraordinarily rich.

In the early chapters, Tony Buick expertly surveys developments in astronomy, mathematics, and the making of scientific instruments, that paved the way for the orrery, a machine which demonstrates the relative movements of the planets. Subsequent chapters read more like a detective story, as Tony Buick traces the origin of the prototype 'orrery' to the partnership in the early eighteenth century of Thomas Tompion, 'the father of English watchmaking', and George Graham. It was Graham's interest in astronomy that inspired his geared model of part of the solar system. The Earl of Orrery then commissioned a London instrument-maker called John Rowley to make him a copy of Graham's device—and that is how, by a stroke of patronage, the machine acquired its name.

As the illustrations in this handsome book show, orreries are things of great beauty, as well as miracles of precision. Tony Buick's text is equally precise, making complicated scientific and mechanical concepts clear. And yet he never loses sight of the personalities who made it all possible, and the social, cultural and intellectual milieus in which they moved: to such an extent that you sense the sights, sounds and smells of life in eighteenth-century London, as well as the broad sweep of scientific history.

Knole — Robert Sackville-West
January 2013

Foreword to the Revised Edition

Tony Buick has tackled a subject which, by definition, is without boundaries, encompassing Man's attempts to make sense of the complexities of the solar system and beyond. His first edition of 'Orrery' is a masterful rehearsal of the history of those efforts and provides a backcloth to the relatively small number of remarkable people who have played a central part in this journey. He chronicles their attempts to resolve finally one of the great questions of the Age of Enlightenment (approximately 1685 to 1800)—does the solar system revolve around the Earth or around the Sun?—and the use of models and instruments to prove their cases. The second, upon which we now embark, adds to the original, and extends the canvas into the past, but also into the future. In providing a new Preface, and new chapters on the History and Science of Astronomy and on the place of the Orrery in education and in space exploration, he has brought the whole treatise up to date and expanded it well beyond its original scope. He has even provided a wonderful set of instructions explaining how to build your own Orrery out of readily available materials! Finally, he has begun a discussion on climate change, the favourite subject of our present age, and has neatly related the thinking of Graham, Tompion and Rowley to that of both Ptolemy and Herschels. Being without borders, this leaves Dr Buick in a strong position to continue his future travels into space, to the benefit of us all.

It should also be mentioned that the founding of the Royal Society, formally *The Royal Society of London for Improving Natural Knowledge*, between 1660 and 1663, brought together many names represented elsewhere in this book. During its early years, the following, amongst others, were elected to the Society: Robert Boyle (Founder Member), Charles Boyle (nephew of Robert Boyle), Flamsteed, Halley, Hooke, Huygens, Maskelyne, Mercator, Moore and Newton. An early influence was the contemporary Italian mathematician and astronomer Cassini, himself influenced by Copernicus, Galileo and Brahe. Names such as these were at the root of the Enlightenment.

Tony has honoured me in asking me to write this foreword, for no other good reason than that I am a lineal descendent of Charles Boyle, 4thEarl of Orrery, collector of instruments, and of John, his son. As we heard from Robert Sackville-West, who wrote the foreword to the first edition, Charles grew up at Knole, the great Sackville family house in Kent. John was born in 1702, and Charles then inherited Marston, a majestic house in north Somerset, from his sister-in-law in 1714. Marston was originally bought by Richard Boyle, 1st Earl of Cork, in 1641 as a wedding present for his son Roger, who later became the first Earl of Orrery. Charles was Roger's grandson and, being born in 1674, was old enough to have known his great-uncle, Robert Boyle, before he died in 1691, and also Robert's equally famous assistant, Robert Hooke, who went on to become, amongst many things, an astronomer of importance with heliocentric beliefs. I have learned a great deal about the Science of the seventeenth and eighteenth centuries from this book, and even more about my own family! I commend it!

18 November 2019

Jonathan Cork and Orrery
15th Earl of Cork and Orrery

Preface

Tracing Back the Orrery's Story

Time and time again, the question pops up about the origin of the mechanical Solar System models that demonstrate the relative motions and often the sizes of the planets.

Who started all of those models? Who made the leap from static displays to clockwork mechanisms? When I followed these questions, I found that full and detailed answers were not easy to come by. This quest led to me thumbing through—virtually and physically—the archives of world history, no less, to extract and crystallise as much relevant knowledge as was available. Comparing sources often uncovered contradictions and so a judgement had to be made as to which facts were the most likely. Internet public encyclopaedias have had bad press, but unfairly so. Comparison between them and world-famous ones showed that they usually came out very well and even sometimes the best in terms of information and errors. There were certainly many real horrors, not just slips and misprints, in the classic volumes. Therefore, as many sources as possible had to be checked, including national and international museums, auction houses, personal and family websites, churches, stately homes, old newspapers online, Royal Society archives, ancient transactions of other societies, observatories, local councils (UK and other countries), London Guilds, Bank of England archives, libraries, commercial companies and much general browsing of the Internet.

It is a fact that a mechanical, clockwork model of a small part of the Solar System was first made around the early part of the eighteenth century, and it was made by George Graham. But did he make it on his own? Where did he get the money to do it? Was he commissioned? Who made the second one and the third, and where did they go before fortunately ending their days in the good hands of museums and other such care homes? Why did they become known as *orreries*?

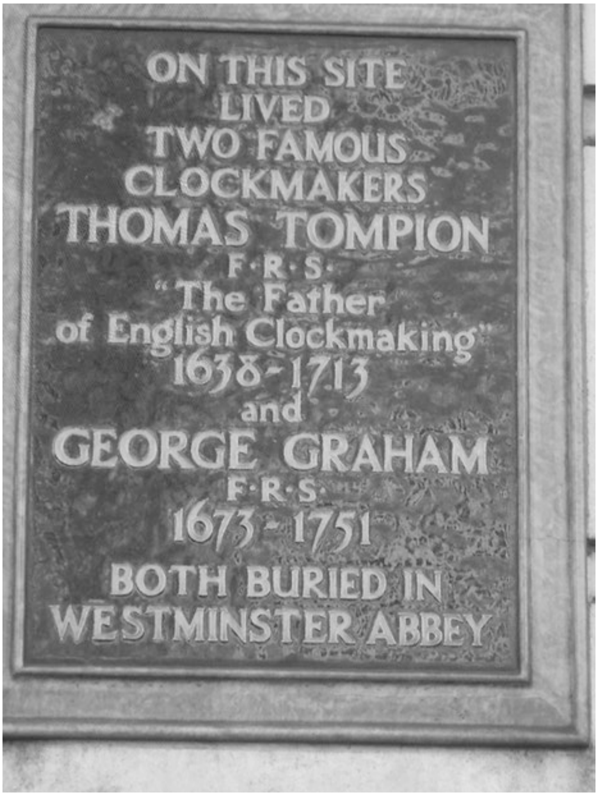


Fig. 1 Blue Plaque commemorating the dwelling place of George Graham and Thomas Tompion. (Photograph by the author)

The name of Eugene of Savoy kept cropping up, but what would an Austrian prince have to do with anything, and how were the Duke of Marlborough, his battles, a monastery and Irish nobles involved? So many questions! But there are answers, and the story had to start with scientific instruments and move on to clocks before focusing on the model itself. Surrounding the story are insights into the lives of revered scientists, Astronomers Royal, war leaders, monarchs and nobility, all of whom influenced the birth and life of the orrery.

The year 2013 marked the tercentenary of the death of Thomas Tompion, the master clockmaker who is such a crucial part of the story of the orrery. It is also the 340th anniversary of the birth of George Graham, 'Mr Orrery (Tellurion)' himself, and 320th of the birth of John Harrison, 'Mr Longitude'. All three were significant scientists of the Age of Enlightenment who joined with many others to make great contributions to the progress of science. A Blue Plaque commemorates Tompion and Graham at the corner of Fleet Street and Whitefriars (previously Water Lane) in London (Fig. 1). This year is also the 350th anniversary of the remarkable Prince Eugene of Savoy, who was linked with the commissioning of the second proto-orrery; he collected fine treasures and fought alongside the Duke of Marlborough.

The beginning of the Age of Enlightenment is credited to Benedict de Spinoza (1632–1677), a Jewish-Dutch philosopher who sacrificed much in life to develop his thoughts about reason, refusing rewards, honours and prestigious appointments and giving his family inheritance to his sister. To him, everything must be looked at from an impartial perspective without coercion from religious scriptures or other preconceived ideas. Because of this approach, the age is also known as the Age of Reason. Spinoza, in addition to being a business man, was also a master grinder of lenses of such quality that Constantijn Huygens (1628–1697; Christiaan Huygens' older brother) ground a 'clear and bright' 42-ft telescope lens from one of Spinoza's grinding dishes 10 years after his death. John Locke (1632–1704) and Pierre Bayle (1647–1706) were also early influences for the progression of enlightenment, or reason, followed by Newton and Voltaire. These men developed their ideas often at considerable risk to themselves.

To lay out the history of the orrery and mechanical clocks beginning solely with the seventeenth century, or maybe two centuries earlier, would be to ignore the elephant in the room. This would be the Antikythera mechanism. The mechanism's precision and wealth of understanding boggle the mind with its complexity of wheels, teeth and cogs and mathematics related to the known Solar System. Questions remain. Why has only this one mechanism been found? Will many more pop up out of chance discoveries and fill in 2000 years of hitherto unknown advanced technology? The phrase 'it will rewrite history' is often used to describe minor discoveries, but the uncovering of a plethora of Antikytheras and their successors really would put the cat amongst the pigeons!

Fig. 2 A fine red umbra of an eclipse of the Moon. (Photograph by the author)

Rarely does one invention pop out of the blue with no previous gradual progression, and the orrery is no exception. Moving machines have fascinated scientists from time immemorial, albeit with a smaller number of parts (except possibly the Antikythera mechanism). Hence, the story must begin with primitive instruments like shadow sticks, sundials and water-driven clocks, from where it moves on to instruments requiring the precision engineer to meet ever-increasing demands. Einstein is quoted as having said, 'Imagination is more important than knowledge. Knowledge is limited; imagination encircles the world'. Also, 'When I examine myself and my methods of thought, I come close to the conclusion that the gift of fantasy [imagination] has meant more to me than my talent for absorbing absolute knowledge'. And so it must have been that, with George Graham's imagination firmly spread throughout the heavens above, it eventually came back down to Earth with a design for an educational model to indicate the regular and relative motions of the Sun, Earth and Moon. Not least amongst the demonstrations available from an orrery is the eclipse of our Moon and the time of its arrival. It is a beautiful sight, as illustrated in Fig. 2. The eclipsed Moon can be very dark, almost invisible, or a stunning red in colour.

Fig. 3 A modern view of Fleet Street. (Photograph by the author)

During the eighteenth century, many scientists and astronomers recognised the attraction of producing orreries, not just as an educational tool, but to show off their talents and increase their business prospects. Instruments were produced with extraordinary complexity and precision, some having extravagant adornments to enhance their appeal.

A gizmo needs a catchy label to popularise, and adopting the title of a revered nobleman, 'Orrery', for the name was brilliant! So, who was Orrery exactly? The answer reveals the amazing histories of the Earls of Cork and Orrery and their influence on science, battles, politics and philosophy. Although the family had their roots in Ireland, they spread throughout Britain with some concentration in the southern counties of England. They became so involved in top-class academic squabbles that Charles Boyle ended up figuring prominently in the Phalaris question.

London was an acknowledged centre of excellence for clockmakers in the seventeenth and eighteenth century and the epicentre of that excellence was Fleet Street. A modern view is shown in Fig. 3. Not only did some of the best clockmakers live and work there, but famous scientists constantly visited the artificers and coffee houses to discuss science and business. Notable among them were giants such as Newton and Hooke from whom much history is gleaned through his diaries. While the excellence of precision clock mechanics was honed in Fleet Street, the other main site of events was Greenwich, where a concentration of politics and practical application of astronomy was being played out.

The skills of the clockmakers were in great demand to serve the aspirations of those who wished to accurately study the stars or pursue their fortunes, recognition and, just maybe, the solution to the longitude problem. Even here, the greatest scientists squabbled sometimes, slowing down the progress of science.

It is hard to imagine what life was like for the inhabitants of Fleet Street (and the rest of the ordinary folk of the country), not just scientifically, but every day with the squalor of the streets, crime and the lack of medicine that was accepted as the norm. Many would have witnessed major natural events such as storms and aurorae that could not be accounted for at the time. Scientists did their best to explain anything that occurred, even on one occasion proposing a hollow Earth with inhabitants!

Although the orrery's story is a great story to tell simply by itself, some of the technicalities are addressed for those who wish to delve a little deeper, such as meshing cogs, the equation of time and an explanation for the relative positions of the Solar System bodies.

Above all, the travails of the first orreries themselves form the centrepiece around which the other histories hang. One cannot hope to cover every detail surrounding every relevant fact, especially as historical and scientific archives, events and artefacts are constantly being revealed or discovered. Hopefully, this work will stand as an overview for some and an introduction for those who wish to know more.

Notes on the Second Edition

The innocuous-looking model described in the first edition has grown up. It is now possible to stand within one kind of orrery, a lunarium, to study a meticulously detailed 7-metre replica Moon up close and personal. More walk-around large-scale displays have been created hundreds of metres across, with planets being marked by rocks and/or posters. Even larger-scale models occupying many square kilometres are drive-around attractions often taking full advantage of the natural hills and beautiful scenery, or even the whole country. They are sometimes called orreries and sometimes planetaria; in popular talk, the distinction between the two has become blurred. *Planetarium* is often the term used for an auditorium with a projector displaying wonderful images onto a dome or screen, taking advantage of the huge increase in computing power and imagination. There have been great leaps in projector technology from the early twentieth century carbide lamps to the high-power light sources and optics of today. Such equipment is and will be required to display the intricacies of astounding astronomical discoveries from deeper and deeper into space, and further back in time. Are there limits of how far back we can go? Maybe the new gravitational wave detectors and telescopes could take us back to before the microwave map, even to the Big Bang itself. How would the planetarium display such a thing? This is one such question tackled in this revised edition.

Modern orreries demonstrate the positions of planets, moons and other bodies as they revolve around the Sun. This edition travels much further back in time, considering a mechanical model designed in the second century AD when geocentrism still reigned supreme.

While being much fun to use, the orrery is far from being just a toy. A new emphasis on education is threaded through the chapters. Building on this theme is the approach to the orrery's technological successor, the planetarium, which takes up that duty in a big way, making full use of its educational and entertainment potential. Also included is a glossary of terms (excluding ones frequently used throughout the book, like orrery) for the reader's convenience.

Orpington, Kent, UK
2020

Tony Buick

Acknowledgements

I am most fortunate to have had a great friend who knows just about everything astronomical to read through the final manuscript. Gilbert Satterthwaite had many associations with the Royal Observatory, Greenwich, not least having been employed there under the tenth Astronomer Royal, Sir Harold Spencer Jones, during the 1950s. He was for many years very active in the history of astronomy, including serving 7 years as chairman of the Society for the History of Astronomy (later vice chairman). I am most grateful for his generous comments and the huge amount of his valuable time spent in indicating improvements and making some corrections. Any errors that may remain are entirely my responsibility.

As the first edition of *Orrery* was about to go to print, I received the sad news that Gilbert Satterthwaite had died. My gratitude for his support is deep. Gilbert was a true expert and friend and generous with giving his valuable time to astronomers of every level. He read and thoroughly checked every one of my astronomy books, including *Orrery*, for which he gave a glowing report: ‘This is a book that needed to be written’. I, and others around the world, will miss him greatly.

I am grateful and honoured that Robert Sackville-West, a descendant of those who cared for the young Charles Boyle, the 4th Earl of Orrery, after whom was named the mechanical model, has been kind enough to provide the foreword to the first edition. Robert and his ancestors have resided in and maintained the stunning Knole House that is mentioned and illustrated in the following chapters.

I am grateful to Dr Stephen Johnston of the Museum of the History of Science, University of Oxford, England, for leads into some vital proto-orrery references.

While many images have been acquired for use at some expense, a few critical ones were freely provided or provided at reduced rates. I am grateful to the Chicago Adler Planetarium, the Oxford Museum of the History of Science, the Armagh Planetarium in Northern Ireland, Knole House, the National Maritime Museum (Royal Observatory) and the British Museum. Many have allowed me to reproduce my own photographs of their treasures including the London Science Museum; the Collegiate Church in Youghal, County Cork, Ireland; and St. Paulinus Church, Crayford, England.

Without the encouragement of Springer's John Watson, this work would not have been written. Many thanks go to John for always being available for advice and consultation and Maury Solomon and Nora Rawn who patiently and professionally supported me through the final stages of the first edition manuscript.

Support and patience from family and friends has been crucial. Tim, Kat, Chris, Jo, Caitlin and Abigail have been wonderful. And finally, Eileen has held cameras, steadied tripods, toured 'interesting' places with me, scoured books in libraries, spotted great subjects for photographs, given down-to-earth advice and criticism, and generally supported all of the work from start to finish.

For this newest edition, I have more names to thank. It was fortunate that at an astronomical presentation, I was introduced to Professor Stuart Malin, now a great friend, an expert astronomer and horologist, who also made orreries. In particular, he revealed that he was making a Ptolemaic one. Was it possible to make such a machine? It certainly was, and I am grateful to Stuart for introducing me to not only his amazing geocentric model, but also to his designs and models of other novel Copernican models. I greatly appreciate being able to call on Stuart's advice for many other aspects of the book.

I am honoured and delighted that Jonathan Cork, the 15th Earl of Cork and Orrery, kindly agreed to write a very relevant foreword to this book.

I am greatly indebted to Springer's Hannah Kaufman for her patience and expert guidance, without whom this edition would not have been possible. Thank you.

Contents

About the Author

Tony Buick, PhD, CChem, FRSC, before retirement, was an analytical chemist by profession specialising in several aspects of chromatography, High Performance Liquid Chromatography, (HPLC) in particular, with international pharmaceutical, veterinary and agricultural companies. He is the author of the first and second editions of *How to Photograph the Moon and Planets with your Digital Camera* (Springer, 2006 and 2011) and *The Rainbow Sky* (Springer 2010) that reflected his career interest in many aspects of spectroscopy including magnetic and electron spin resonance.

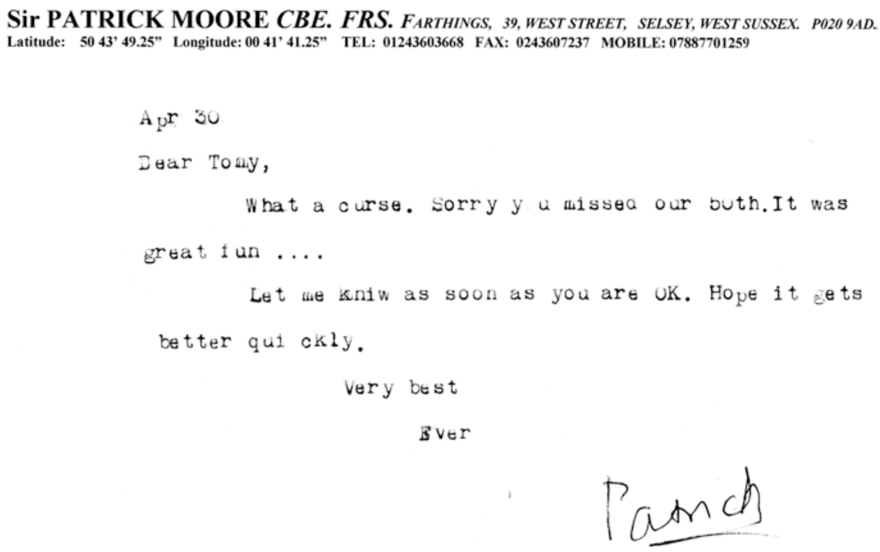
Buick has had articles published in astronomy and various other magazines such as *The Sky at Night* and the *Society for Popular Astronomy* with regard to capturing photographs of the ISS and Iridium satellite trails, transient lunar phenomena and lunar landscapes. He entered retirement by realising his ambition of teaching and has encouraged young and old to observe and understand the sky, especially while teaching science, computing and geography at a local school. Indeed, it was at that school where he showed the children at his science club how to make a human orrery and demonstrated the construction of an orrery from bits and pieces found around the house.

Buick's fascination with the orrery led to the research that forms the foundation of this book. His passion covers not only the infinite, looking through a telescope, but also the infinitesimal, looking through a microscope, and he has published articles on tardigrades, robust microscopic animals that can even survive in space. The photography of wildlife is a recent pursuit, and he has published articles and photographs in wildlife magazines. He has a tame blackbird, Dusty, who returns from migration each autumn to be fed and rear little Dusties each spring. He, Buick, not Dusty, likes playing the piano and the clarinet and plays golf to keep his feet firmly on the ground. With the pressures and restrictions of the current coronavirus pandemic, and ever further into retirement, he has enjoyed gardening as a pleasant and healthy pastime.

Sir Patrick Moore, CBE, FRS, FRAS: A Personal Memory

It is with much sadness that as the first edition of this book was being prepared, Sir Patrick Moore died on the 9th of December 2012. He must have had a million loyal and grateful friends and I feel honoured to be amongst that million. We were with him, Eileen and I, in his garden just a few weeks before when he was making sure we would be attending his usual New Year's Eve party. Each such gathering, party or one of the many celebrations of his achievements was marked by learning from so many how Patrick had changed or rescued their lives. They were not just astronomers but all sorts of people, including scientists and non-scientists, who had been treated badly by life and were grateful to Patrick for his help. He never asked for thanks but he appreciated loyalty. His generosity was immense and it was common for him to publish a book with all proceeds going to charities or local services.

At one of my visits, an amateur filming crew asked Patrick to read from a card that took about 5 minutes. Unbeknown to all (although I was aware), his lovely black cat Ptolemy pawed at a cable, resulting in an absence of sound on the final video. Patrick agreed to repeat it but rejected the card since he had memorised it at one reading and seamlessly repeated the clip with the same enthusiasm. Such a good example of his intellectual brilliance! Oftentimes, while at his house, I would witness him giving impromptu and eloquent interviews over the phone. He always knew what to say and had the facts at his fingertips. One of his favourite moments to relate was when he played the piano accompaniment for Albert Einstein on his violin. He loved telling this story, ending with, 'How I wish I had a video of that'.



Sir PATRICK MOORE *CBE. FRS.* *FARTHINGS, 39, WEST STREET, SELSEY, WEST SUSSEX. P020 9AD.*
Latitude: 50 43' 49.25" Longitude: 00 41' 41.25" TEL: 01243603668 FAX: 0243607237 MOBILE: 07887701259

Apr 30

Dear Tomy,

What a c urse. Sorry y u missea our buth.It was great fun ....

Let me kniw as soon as you are OK. Hope it gets better qui ckly.

Very best

Ever

Patrick

Fig. 4 A note from Patrick to the author

To some who didn't know him he gave the impression of being curt and xenophobic. Although he was fiercely patriotic, I constantly saw him being hospitable, kind and helpful to so many from every part of the world. I got to know him when I cheekily wrote, over a decade ago, to say there were things that he missed in his programme, *The Sky at Night*. He responded by inviting me to his home to discuss my photographs of the Moon. I have a pile of letters he wrote to me over the years, but the original ones tapped out on his Woodstock typewriter were favourite. The note in Fig. 4 was typical, when I couldn't attend one of his celebrations due to a sore throat. He showed his concern, as always.

I was honoured when he used my photographs of his two cats modelling his antique orrery for his book *Miaow*, of which he was very proud. My copy was signed by him at our visit, Fig. 5, just a few weeks before he died.

Fig. 5 At Patrick's home in late September, 2012, sharing orrery discussions with Ptolemy. (Photograph by the author)

If Patrick's belief in a life hereafter is correct, he will now be enjoying paradise with his fiancée, Lorna, who has been waiting for him since they were young. This story was often queried but I hope it's true.

Thank you, Patrick, for support for all my books and being such a friend to a minion of the astronomical world!

Ever,

Tony.

1

Setting the Scene

What Is an Orrery?

The answer to that question has become less straightforward than when it was described in the first edition. As will become clear through the revised sections, modern technology and an increase in awareness of science and global concerns have led to the development of at least five types of illustrative sources of information and education that could be classified as orreries, which will be described and explained. Original chapters from the first edition are included to retain the context, although revised where appropriate, and are followed by new material.

An *orrery* is a working model that demonstrates the movement of the planets, often with their moons, within our Solar System. Although the principle of making one or two spheres revolve around another seems simple by modern-day standards, the first ones were works of technical and imaginative brilliance, Fig. 1.1. The early to mid-eighteenth century was driven by the imperative to produce the most accurate clocks for seafarers and their navigation; some of these clockmakers became orrery makers. But the first such devices were not called orreries! They were tellurions, telluriums or planetaria, only later named after the fourth Earl of Orrery.

So how did nobility become involved enough for the tellurion to be forever labelled orrery? We will investigate that question throughout this book. On its own, the model was a small development in the quest for better craftsmanship, accuracy and plain showing-off. Yet, the orrery's rich history sits at a key point in the greater story of astronomy and is worth telling.

T. Buick, *Orreries, Clocks, and London Society*, Astronomers' Universe,
https://doi.org/10.1007/978-3-030-61777-6_1

Fig. 1.1 A closer look at the details of a W&S Jones eighteenth-century orrery. (Photograph by the author with permission of Sir Patrick Moore)

Astronomy in Ancient Civilizations

Human curiosity fuelled civilizations throughout the world. Many of them struck out in the same direction, pushing their knowledge to account for the movement of the stars, planets, Sun and Moon. This study was often seen as intertwined with their local religions, destiny, survival, and personal power. Many structures were built to assist with their observations and predictions. Outstanding among the ancient monuments is the World Heritage Site of Stonehenge in Wiltshire, England, built around 3100 BC. Its possible use at the time was to define the summer and/or winter solstices through the alignment of particular stones with the Sun and the Moon. Does this count as an orrery? Possibly it was an astronomical observatory or maybe a religious monument; it might even have been a place of healing or a burial site. Recent studies suggest the possibility that the orientation of the stones had more to do with access to a river than alignment with the Sun. Figure 1.2 is from the *Atlas van Loon 1649*. But even earlier than this, celestial objects proved to be fascinating for the very first high cultures we know of.

Fig. 1.2 World Heritage Site of Stonehenge in Wiltshire, England. (Image from the *Atlas van Loon* of 1649, public domain)

The wonderful and ancient civilization of Mesopotamia began to be pieced together as archaeological evidence was unearthed dating from 5000 BC onward. This evidence revealed a culture very different from our own, with cities and a complex society rightfully dubbed the Cradle of Civilization. Mesopotamia, is a toponym for the Tigris-Euphrates river system, corresponding to modern-day Iraq.

The earliest language used in Mesopotamia was Sumerian, and the early writing was cuneiform, or wedge-shaped, script. In fact, as early as 8000 BC, with the development of pictograms (picture writing), clay token records were kept, which eventually led to the development of cuneiform writing. Three wedges, then a drawing of a bird meant three birds. Ten was represented by a corner wedge. It was found by the Sumerians that wet clay could be neatly and accurately imprinted to replace scratching on stones, and since the cut reeds used as styluses best produced the shape of a triangle, or wedge, this became the basis for writing.

Cuneiform texts and artefacts that date back to about 6000 BC have been found in the valley of the Euphrates. These are the earliest known attempts to catalogue the stars and show star groupings such as the Lion and the Bull. Baked clay was hard and very durable, hence the huge number of artefacts that have been unearthed. Figure 1.3 shows one such cuneiform tablet. The text is a list of gifts from the High and Mighty of Adab (an ancient city located in modern-day Iraq) to the High Priestess on the occasion of her election to the temple. It has clearly been written by an expert scribe.

The ancient Sumerians and Babylonians developed great skills in mathematics, astronomy and, essential for that time, astrology. Their mathematics and science were based on a sexagesimal numerical system, i.e., to the base of

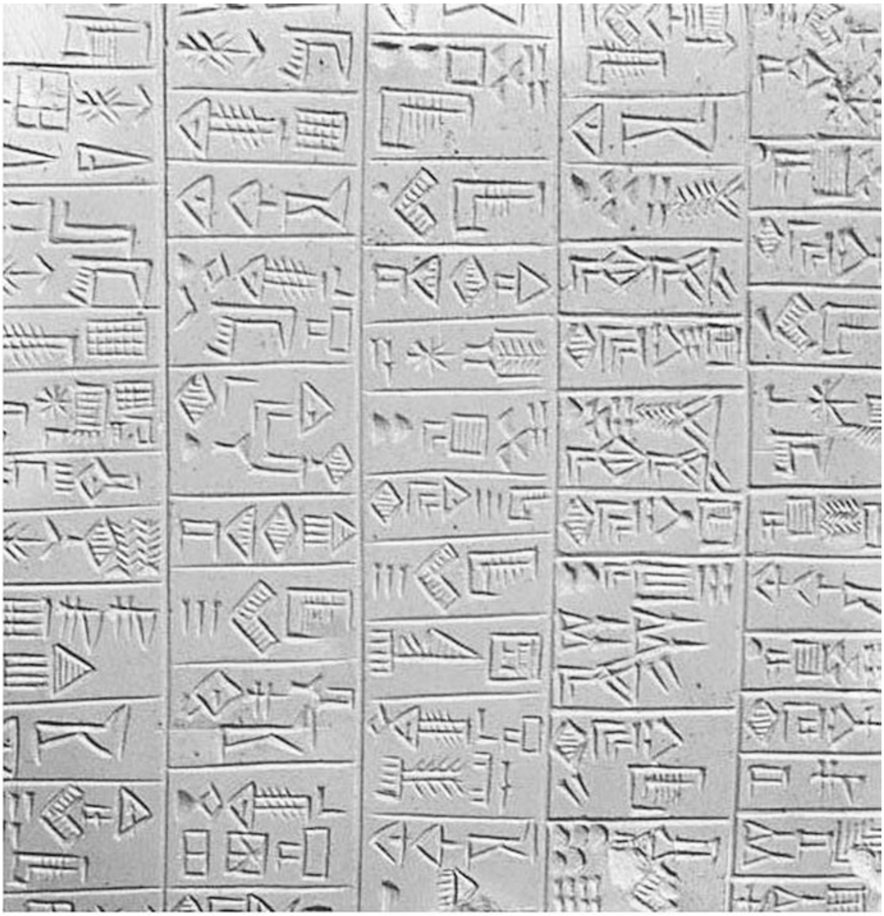


Fig. 1.3 Sumerian inscription on an ancient cuneiform tablet. (Courtesy of the Schoyen Collection)

60. They multiplied 60 by 10, then multiplied 600 by 6, and so on. The number 60 has the advantage of being divisible by 2, 3, 4, 5, 6, 10, 12, 15, 20, and 30. The Sumerians also divided the circle into 360°. From these early people came the word 'dozen' (a fifth of 60) and the division of the clock to measure hours, minutes, and seconds. Hence the 60-minute hour, 24-hour day and the 360° circle.

The Egyptians were developing scientific and mathematical awareness at the same time, from around 5000 BC. Both the Babylonians and the Egyptians worked with the 365-day year. It is not unexpected that both Mesopotamians and Egyptians would look to the night sky to predict events. Stars were grouped into patterns, and their orderly appearance seemed clearly related to observations of the natural cycles of events throughout the year. Models, structures, stone circles and drawings were all created to assist in the correct prediction of natural events and timing of festivals. In many cases the astronomer's/astrologer's reputation and life depended on the accuracy of these predictions.

The ancient Egyptians made many great advances in the sciences, especially in medicine and alchemy. As with the Mesopotamians, their society was reliant on agriculture, which in turn largely depended on the Nile. Predicting its annual flooding was thus the driving force behind the development of Egyptian astronomy and religion.

The way the Egyptians built their magnificent pyramids (in a sense, their orreries or planetaria) and accurately aligned them with stars they were familiar with is a testament to the relationship they had with the sky and its mysteries. They seemed to be obsessed with true alignment with north/south, and a plethora of studies over many years have suggested how it was achieved from the position of the Sun and stars, allowing for the various precessions of Earth since Egyptian times. The mathematical methods of the time, such as multiplication and division, involved basic empirical processes that were used by mathematicians without really knowing why they worked.

Turning to the Indian subcontinent, its history of science and technology begins with prehistoric human activity at Mehrgarh (one of the most important Neolithic sites, 7000–2500 BC, in archaeology). Mehrgarh was located in present-day Pakistan and continued through the Indus Valley. The oldest extant text of astronomy is the treatise by the Indian astronomer Lagadha, possibly dating to the last millennium BC or a little earlier. It describes rules for tracking the motions of the Sun and Moon. This was soon supplanted by the knowledge of the Greeks.

The ancient history of India revolves around the Indus Valley civilization, 2500–1800 BC, in the northwest. Many meticulously planned and constructed cities were found around the valley of the Indus River, where its people, the Harappans, evolved some new techniques in metallurgy and worked with copper, bronze, lead and tin. The engineering skill of the Harappans was remarkable, especially in their dock-building, which required careful study of tides, waves and currents. They had their own script, the Indus Valley script, which is as yet undeciphered and may eventually reveal more of their secrets and science.

By the sixth century AD, Indian astronomy and mathematics had become quite sophisticated. One of the main contributors was Aryabhata, a mathematician and astronomer who introduced the decimal point, arithmetic and geometric progressions, a method for determining the positions of the planets and the rotation of Earth on its axis. He possibly even suggested heliocentricism. He gave a value of π as

$$100 + 4, \times 8, \text{add } 62{,}000, \text{divide by } 20{,}000 = 3.1416.$$

This was a pretty accurate value. A statue of Aryabhata is shown in Fig. 1.4, although we don't know how true to life it is as there is no known information regarding his appearance.

Moving now to Asia, the Chinese believed that the happenings in the sky were linked to their destiny. Almost every dynasty from the sixteenth century BC to the nineteenth century AD retained an official astronomer to observe and record changes in the heavens. Because of this, there is a huge legacy of observational accounts, most of which have been verified as accurate.

One early and tantalizing observation was that the Sun sometimes became much dimmer, and there was concern that the brightness might not return. So, meticulous records of time and size of the shadow were maintained. The earliest solar eclipse record that has been verified appears in a bone inscription dating back to the Shang dynasty, which ruled in the Yellow River valley in the second millennium BC. Studies have proved that the solar eclipse recorded there actually did take place on May 26, 1217 BC, thus proving that it was the first extant, reliable record of a solar eclipse.

Records of lunar eclipses, however, date back to an even earlier time. Bone and tortoise shell inscriptions record five lunar eclipses that took place during the fourteenth and thirteenth centuries BC. It is possible that the earliest records of sunspots were made by the Chinese in 28 BC. Even a record of a solar prominence has been found inscribed on tortoise shell. Other observations within the records include novae, supernovae and comets, notably one that has been confirmed as Halley's Comet.

Fig. 1.4 Aryabhata, an Indian mathematician and astronomer of the sixth century AD. (Creative Commons, author unknown. Public domain. Obtained from wicki-media.org)