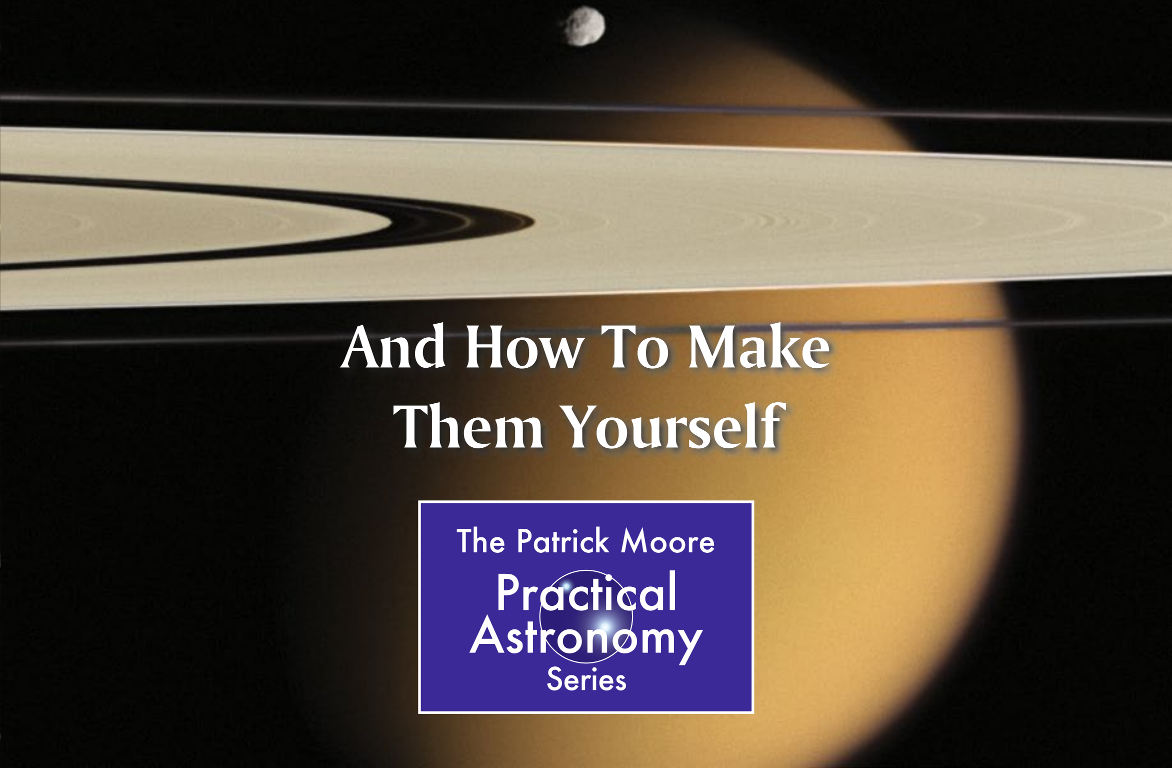
Michael Marett-Crosby

Twenty-Five Astronomical Observations That Changed the World



And How To Make Them Yourself

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Springer

Michael Marett-Crosby
Mon Plaisir
Route de la Haule
Jersey JE3 8BD
United Kingdom

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Preface

What This Book Is About

This book is about bringing the far-off close. It offers twenty-five observations that can be achieved using modest amateur equipment. Each of these observations has changed how we understand our world and its place in the universe. Some have made headlines, transforming how we think about ourselves. Others have caused quieter revolutions. But each of these observations has a place in history.

And you can see them for yourself. With the help of this book, you can follow in the footsteps of the great astronomers and connect with the science, the history and the changes that have flowed from them. You can share with others why astronomy matters for us all.

Each chapter contains observations that require fairly simple astronomical tools: binoculars, a telescope, a sense of where things are in the sky and lots of patience! Each observation is made from familiar starting points, so there is no need to have go-to software for your telescope.

We will cover the science that explains and illuminates the observations so as to understand what we are seeing. We will also witness the impact that each observation has made on human history and culture, and see why a planet or tiny spot in the sky has affected the world in which we live.

How to Use This Book

Readers who are beginning their astronomical explorations can follow this book in order. The early chapters contain straightforward observations and introduce key scientific tools that help to understand the planets and the stars. More experienced observers will be able to see familiar objects in a new way, as well as seeking out more challenging targets. Everyone will discover things that they can share with non-astronomers, so that we can talk about our passion in a way that builds connections.

The history of astronomy is enfolded within the observations. Great figures appear several times and sometimes in surprising ways, as we see for ourselves the observations that they made.

This is inevitably a personal selection. It is formed by my own observing experience in the northern part of the northern hemisphere and by my perception of great moments in astronomical history. I make some suggestions as to what might be the 26th observation in the last chapter of the book. I would welcome other ideas.

About the Pictures

Many images in this book are the work of amateur astronomers. The pictures taken by the Hubble Space Telescope and other instruments are magnificent, but they can also mislead. If we think we are going to see the Horsehead or Crab Nebula as Hubble does through our telescopes, we are going to be disappointed. But amateur astrophotographers can, with great patience and skill, achieve amazing images.

Without exception, those whom I approached gave permission for their pictures to appear in this book. They want their work to be enjoyed.

Acknowledgements

Many people have contributed to bringing together this book.

I would like first of all to thank John Watson and Maury Solomon at Springer, who between them helped me to hone a plan for this book that has remained robust and is, I hope, something like what they want.

It is a pleasure to thank all those who have contributed their images so willingly. Individuals are credited beneath their work. I would like here to acknowledge those who have provided multiple images and who gave me other assistance: John Ambrose, Dr Jean-Marc Bonnet-Bidaud, Paul Downing, Kathryn McKee, Dr Birgit Krummheuer, Jim Misti, Steven Ringwood, Professor Paul Schenk, George Tarsoudis, Christian Viladrich and Jimmy Westlake.

All maps have been created with the Cartes du Ciel software. The program makes use of the VizieR catalogue access tool, CDS, Strasbourg, France.

Throughout the writing of this book, I have been encouraged and inspired by members of the Highlands Astronomical Society, who have shared so willingly their interests and expertise: Arthur Milnes, Pat Williams, Paul Jenkins, Pauline Macrae, Pat Escott, Gordon McKenna, John Rosenfield for his infectious enthusiasm for Mercury, and Gerry Gaitens for the tutorial with the Lunt telescope.

I am particularly grateful to Eric Walker and Maarten de Vries for their help with images and to Antony McEwan for his advice on several of the observations.

My interest in astronomy began as a child when Adrian and Lucinda Phillips gave me my first telescope. I will always remain grateful for all that they have given me.

I would like to thank my family for all their support, in so many ways, during this last year and every year.

And also to thank James, without whom there is no way this book would even have started, let alone come to its end.

Contents

Chapter 1

The Eyes of the Moon

Observation: Tycho and Copernicus craters
Significance: The Moon has a history, the Copernican revolution
Science: Lunar orbit, phases, features

When your new telescope was unpacked and set up on its mount, what did you do? The answer to this question is the same for many – pointed it towards the Moon. Any telescope or pair of binoculars can do that awe-inspiring thing and take us, while we stand on Earth, to the surface of a different world.

The Moon is where our journey starts through these 25 observation that have changed human history. We will return to it in later chapters, where we will explore in detail its many types of craters, seas, mountains and ridges. We will look for evidence of water and, most transient of all, for human footprints. But in this first chapter we are going to do some more basic observations of the Moon, seeking to understand why it's there, why it matters and what forces account for the contrasting light and shade that forms the face looking back at us.

A Unique Sight

The Moon is so familiar that we forget it is exceptional, and that the Earth-Moon combination is something very special in our Solar System. As astronomers have learned more about the classical planets from Mercury to Neptune, about dwarf planets beyond and between them, about asteroids and comets and planets circling other stars, it has become increasingly clear that the Moon is an unusual companion.

The Moon is the only natural satellite of Earth. Since English was first spoken, "the Moon" has referred to that one companion in the sky. In the seventeenth

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century, the meaning of the word was expanded to include the natural satellites of other planets, but the capital letter distinguishes Earth's Moon from the moons of other planets. The adjectives used for things of Earth's Moon are *lunar*, from the Latin word *luna*, or rarely *selenian* or *selenic,* derived from Greek.

All the planets save two – Mercury and Venus – have natural satellites, two in the case of Mars, at least 64 for Jupiter. As new satellites are identified by remote probes around the giant planets, the population of our Solar System increases, and the Earth-Moon mini system seems to become more special. Earth is a little less than four times the size of the Moon, a pairing of near equals.

The largest other satellite of a planet in our Solar System is the moon Ganymede, in orbit around Jupiter. Ganymede is significantly larger than our Moon and larger than the planet Mercury as well, but its diameter is miniscule compared to the planet it circles. A similarly extreme relationship exists between Mars and its tiny moons Phobos and Deimos.

The only comparable configuration to the Earth-Moon lies far out in the icy edges of our Solar System, in a region called the Kuiper Belt. There we find the dwarf planet Pluto, whose largest satellite Charon has a ratio to Pluto much like that of our Moon to Earth, about 1:4. But the similarities end there. Both Pluto and Charon are small, and the Pluto system contains at least three other bodies.

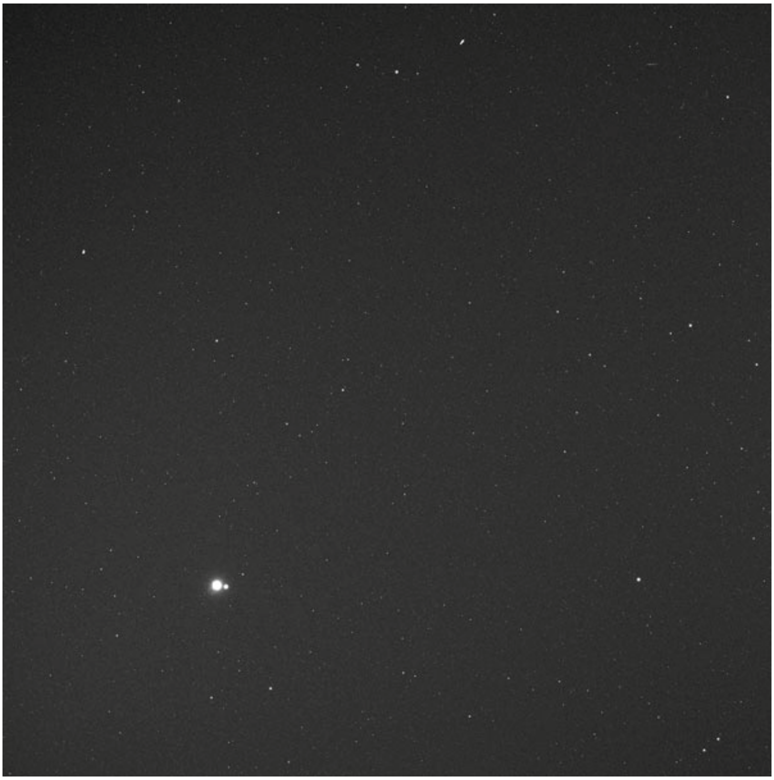

Fig. 1.1 This is who we are. The Earth and the Moon as seen by Messenger, 17 August 2010 (Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington)

At the moment, and until our studies of planets around other suns offer this kind of detail, Earth and the Moon will remain a unique pair.

This image makes the point. Taken in March 2011 by the Messenger spacecraft as it prepared to enter orbit around Mercury some 114,000,000 miles away, it shows Earth and the Moon as two merging spots of light separated from each other by a tiny strip of darkness.

First Observation

Just looking at the Moon on a reasonably clear night is where astronomy starts. It was the beginning of humanity's encounter with the skies. And it revealed some important facts about our satellite.

First of all, the Moon follows a predictable course from east to west, different every night, growing in apparent size from a thin sliver to full, when a whole disk is on show. Second, this disk contains a pattern of brighter and more shaded areas – these have for many centuries been identified as either a face or a full human figure. "I was the Man i' the Moon, when time was," Stephano says in Shakespeare's *The Tempest*.

This pattern on the lunar surface makes an important scientific point. It enables us to distinguish between the darker areas, lunar seas or maria, and the rest of the terrain.

Fig. 1.2 Full Moon (Credit: Jim Misti, http://www.mistisoftware.com/astronomy/)

We are going to focus now on the Tycho Crater, the bright white mark towards the bottom of the lunar disk as we look at it with the naked eye. It's probably easiest to explore first with binoculars because with them, the crater will appear in the same place as it does to the naked eye. This is not true when using telescopes, most of which invert images. For the majority of astronomical targets this does not matter, but on the Moon, our sense that north is at the top becomes confused.

Tycho is one of few features to survive the glare of a full Moon. The shape of the crater is visible and so, too, are the bright white lines emerging from it. But in these conditions there is too much light to reveal the detail. Tycho shows much more when it is emerging from the darkness on an eight- or nine-day Moon.

This is a key skill in lunar observing. The lunar day lasts about 29½ of our Earth days, and so the line between dawn and dusk moves quite slowly as we observe it. At this line, the terminator, shadows are lengthened by the angle of sunlight, making features stand out much more clearly. It's possible to watch the lunar morning in real time.

The lunar surface is a complicated place, but Tycho is a large crater some 86 km in diameter and nearly 5 km deep. Depending on what time of night you are viewing, you should be able to see the long shadow cast by the crater wall that faces the rising Sun. These ramparts are 4.8 km high, nearly six times higher than the tallest skyscraper on Earth. The shadows will slowly reveal Tycho's central peak standing 2.25 km

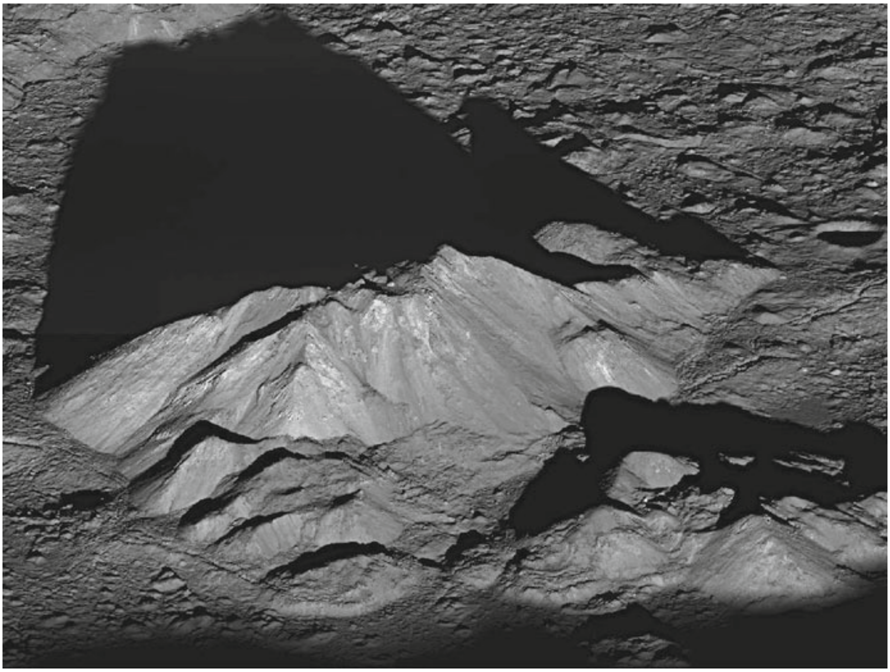

Fig. 1.3 (Credit: NASA Goddard/Arizona State University)

above the crater's floor. Walls and a central peak are characteristic of complex lunar craters – the peak is shown in exceptional detail in this image taken by NASA's Lunar Reconnaissance Orbiter on June 10, 2011.

In the area immediately around the crater, you should also be able to spot a dark band. This feature, called an annulus, circles the crater – its name is drawn from the Latin for *little ring*.

With the crater in the center of a binocular image, we can move from Tycho to its neighborhood, a broken landscape of shattered craters. Just beneath Tycho lies the crumbling crater Street, while to Tycho's east it is worth exploring Pictet through a telescope. It has a fine pattern of hills at its center. The rays of Tycho have fallen over Pictet, giving it a mottled appearance under the right light.

These rays are Tycho's most distinctive feature. They are lines of material thrown out when the crater was gouged out of the lunar surface. They act as useful pointers to other features. Beginning with Tycho's clear double ray, follow it to the Mare Nubium, the Sea of Clouds.

Continuing anticlockwise, the next ray points almost directly at the Moon's south pole, bisecting the crater Clavius, while the next and longest ray stretches across as far as the Mare Nectaris, the Sea of Nectar. This mare lies between two much larger seas that show up as dark patches under the naked eye: Fecunditatis (Fertility) and Tranquilitatis (Tranquility). It was on the southern 'shore' of Mare Tranquilitatis that Apollo 11 landed on July 21, 1969.

It is well worth repeating the Tycho observation on successive nights. It helps in acquiring a sense for lunar topography, and it is possible to watch the advancing terminator create new shadows across features. Find Tycho at the other end of the lunar cycle, the last quarter of the Moon, for as Tycho slides into the night, you can watch the dusk fall for yourself.

There are two items that really help with lunar observing, be it a straightforward or a tricky target that you are seeking. One is a lunar map. This is easy to obtain and makes navigating across the lunar surface much easier. Take one out with you, protected from the dew or ice in a sealed plastic wallet. There are excellent lunar maps available for handheld tablets, and these show where the terminator lies, making lunar navigation easier than it has ever been.

It's also worth investing in a lunar or planetary filter. The Moon shines very brightly, and a quick way of reducing glare is to screw an appropriate filter onto the eyepiece. The effect is to make details and lunar shadows come alive under an altogether more kindly light.

We cannot end our look at Tycho without acknowledging something will be a disappointment. However hard you look, you will not be able to observe AMT1, the black monolith that appears in the crater in the opening of Arthur C. Clarke's and Stanley Kubrick's film *2001: A Space Odyssey*. If Tycho seems familiar, that is where you have seen it before, for the film does a good job of making crater feel real. If it rains every time you try to look at the Moon, you can always watch the film instead.

Understanding What You've Seen

One of the central themes of this book is that understanding the science increases the pleasure and interest you can derive from observing. This way, too, you can connect with the ways in which astronomical discoveries have transformed our perception of where we belong in the cosmos.

We have just made use of the fact that the Moon is predictable. This is because it is in a stable orbit around Earth. But the Moon's orbit does not describe a perfect circle through the sky. Rather, it rotates in an ellipse with two focal points, with an average distance from Earth of 384,401 km and a maximum of 406,700 km. This lunar orbit takes 27.3 Earth days, the sidereal month, and some of its details, as we shall see, are very complex to measure.

That the Moon is regular and can be predicted was one of the earliest discoveries of recorded astronomy. It appears in lunar 'diaries' compiled by priest-astronomers of Babylon in the eighth century BCE – some of their observations still survive. Later observers continued to make meticulous observations of the westward arc described by the Moon, but aspects of its behavior remained puzzling until Johannes Kepler (1571–1630) made sense of planetary orbits, that of the Moon as well, by way of elliptical mathematics. His *Astronomia Nova* ("The New Astronomy") of 1609 devotes a quarter of its length to exploring and explaining the ellipse model, which is now expressed in Kepler's first law of planetary motion – all planets move in ellipses, with the Sun as one focus. This law achieved precision in the 1687 *Principia Mathematica* of Isaac Newton (1642–1727). Newton explained: "The irregularity of the Moon's motion hath been all along the just Complaint of Astronomers; and indeed I have always looked upon it as a great Misfortune that a Planet so near us as the Moon is…should have her Orbit so unaccountably various, that it is in a manner vain to depend on any calculation…though never so accurately made."

We have also made use of another basic feature of lunar science, the Moon's phases. The Moon emits no light of its own and shines by virtue of reflected sunlight. Its phases are produced by the relative angles of the Sun, the Moon and Earth between them.

One of the most beautiful consequences of this interaction between the three celestial objects is called Earthshine, 'the old Moon cradled in the young Moon's arms.' Earthshine describes the glow of the unillumined portion of the Moon dimly visible beyond the shining crescent. It is produced by sunlight reflected from Earth onto the Moon and then back to Earth again. Nothing demonstrates more clearly the intimacy of the relationship between the two bodies. As Galileo Galilei (1564–1642), whom we will meet many times in this book, expressed it in 1610: "In an equal and grateful exchange the Earth pays back to the Moon with light equal to that which she receives."

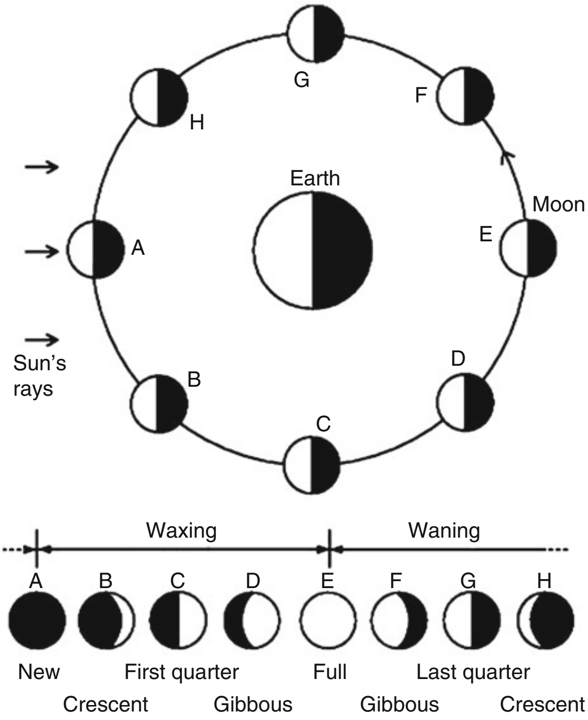

Fig. 1.4 The phases of the Moon. This simplified diagram represents the view from above the Earth's north pole (http://www.springerimages.com/Images/Physics/1-10.1007_978-3-642-14805-7_1-9)

Glimpsing Earthshine

Relatively few artists are remembered in the names given to features on the Moon, but one exception is Leonardo da Vinci (1452–1519), whose inconspicuous crater lies on the edge of the Mare Tranquilitatis. He has earned his place there, not only for being the first observer whose drawings of the Moon have survived, three in all, but also for explaining how Earthshine happened. Always interested in the way sunlight reflected off mirrors, glass and water, here are his own words, written beside the sketch of the three bodies that he drew in a manuscript now known as the *Codex Leicester:* "Some have believed that the Moon has some light of its own, but this opinion is false, for they have based it upon that glimmer visible in the middle between the horns of the new moon…this brightness at such a time being derived from our ocean and the other inland seas."

In fact, Earth's water is not a primary source of the reflected light, which comes mostly from clouds. But this is a small point compared to how Leonardo perceived the relationship between Earth and Sun and Moon. Take a look at his sketch, drawn around 1510.

Fig. 1.5 Leonardo's sketch of the crescent Moon with Earthshine, as it appears in the Codex Leicester

Da Vinci's achievement is all the more spectacular because, at the time he was drawing, prevailing orthodoxy held that Earth was the fixed center of the cosmos. The idea that Earth might be in motion around the Sun had been suggested in Greek antiquity, but in Leonardo's time this seemed almost inconceivable.

To explain how that started to change, we must return to the telescope.

Meeting Copernicus

The second half of this first observation takes us to the northern hemisphere of the Moon and another naked-eye crater, Copernicus. We can follow the same pattern as we established with Tycho and begin once again at full Moon. Under these conditions, Copernicus appears as something like a sibling to Tycho. Look further to the north of Tycho and a little 'off center.' Like with Tycho, the full Moon is the best time to notice the crater's spider's web of rays, less extended but denser than those we observed around Tycho.

It is also clear, even under these bright light conditions, that Copernicus is situated in a darker region of the lunar surface. Its surrounding terrain is flatter, and binoculars expose this as a characteristic mare landscape, in this case, the Mare

Insularum, or Sea of Islands. Through binoculars, it also becomes clear that Copernicus is an imperfect circle, more of an octagon, formed out of what seem to be separate sections of straight walls, reminiscent of a castle. Signs of landslips are visible as well as secondary craters formed from debris impact. The terraces themselves rise some 1,000 m above the surrounding terrain, and the crater itself is some 93 km wide.

The last quarter of the lunar cycle is a good time to observe Copernicus in detail. On the Moon's 24th day – an astronomical calendar or an online resource will identify this – observe with binoculars or through a small telescope the progress of nightfall up the slopes of Copernicus' central peaks until, as you watch, they vanish into the dark.

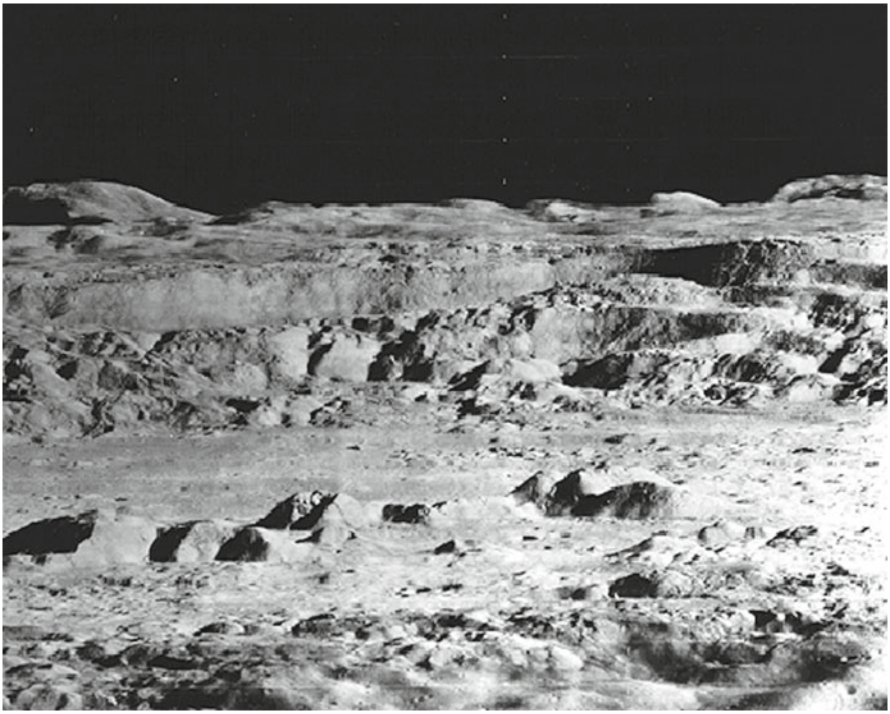

Fig. 1.6 Copernicus' wild topography has never been captured more powerfully than by NASA's Lunar Orbiter 2 on 10th November, 1966 (Credit: NASA)

The area around Copernicus is worth exploring. Just north of the crater rise the Carpathian Mountains (Montes Carptus), a fine line of peaks bounded at each end by the craters Gay-Lussac and Tobias Mayer. Continuing west from the end of the mountains and moving a little south to the level of Copernicus is the crater Kepler dug into a wild terrain of older, degraded crater rims. It presents an obviously different aspect to the flat lands of the maria terrain, an important distinction for understanding lunar processes.

The Moon Has a History

The Copernicus crater demonstrates another element of lunar science. All that decay and collapse, those multiple and overlapping craters, reveal that the Moon has a history. Some of the craters, the ones with broken walls and smaller craters within, must predate the impacts that have deformed them. Similarly, the rays emerging from the Tycho crater overlie the features all around them and therefore must have been formed after them.

Brightness is another clue. Both of our craters are substantially whiter than the gray terrain around them. But what darkens the older features of the Moon? There is no wind or rain on the Moon, so they have not ‘weathered,’ as on Earth, but the lunar surface has been subjected to the power of the solar wind, unmediated by any protecting atmosphere as exists on Earth. The Moon is also peppered with a hail of micrometeorites.

The area around Copernicus was the first to be studied in detail for its geological chronology. Eugene Shoemaker (1928–1997) and Robert Hackman established the relative ages of the craters, mountains and seas, in part by observing, exactly as we have just done, the overlay of ejecta from the Copernicus impact. It is now possible to identify broad periods in the lunar past of which the most recent is named, in honor of the crater, the Copernican.

The dating of the Tycho crater has been determined in two ways. The first is by a count of the smaller craters within the Tycho envelope. Older features will on average have more evidence of cratering than the younger – the older have been around to be hit for longer. Some data about the crater was also collected by NASA’s Surveyor 7 unmanned lander, which touched down on the rim of Tycho in January 1968. After Apollo 17 astronauts brought back samples of Tycho’s ray ejecta, it became possible to date the event precisely. The Tycho crater was formed 109 million years ago and is the youngest large feature on the lunar surface.

Giving a history to lunar features is important because, until relatively recently in human history, many people asserted that the Moon was an unblemished sphere outside the reach of change, part of a concentric system of spheres with Earth at its center. The decline of this system of thought was, a little like has happened at Copernicus, a gradual collapse, but there are definite moments when aspects of the paradigm failed. The two men remembered in these two craters played central roles in the story of reshaping the human understanding of the universe.

The Moon Is Made of Alabaster?

Medieval European astronomers were not stupid. Built upon the foundations laid by Greek philosophy, astronomy gained a new repository of insights from Islamic thinkers by way of Moslem kingdoms in southern Spain. The subject was part of the curriculum taught at medieval universities.

We get a glimpse of this astronomy in the basic textbook used throughout medieval Europe, John de Sacrobosco's *De Sphaera*, *On The Spheres.* Written around 1230, it was the basis for lectures and commentaries up to the end of the sixteenth century.

We know very little about John of Sacrobosco (John of Holywood). He taught in Paris and, aside from astronomy, was interested in the measurement of time. He was among the first scholars to argue for a reform of the calendar.

Sacrobosco presented astronomy as a mathematical science. He opened his work with geometric definitions of a sphere, and he went on to describe the heavens in terms of a series of spheres radiating outwards, as it were, from Earth. "The earth is held immobile in the midst of all," he wrote. This was a spherical Earth, though; the idea that all medievals thought Earth was flat is incorrect, and Sacrobosco went to some pains to prove this.

Sacrobosco explained the way the Moon, planets and stars moved through the sky by reference to more circles. It was complicated stuff:

> *Every planet except the sun has three circles, namely, equant, deferent, and epicycle. The equant of the moon is a circle concentric with the earth and in the plane of the ecliptic. Its deferent is an eccentric circle not in the plane of the ecliptic – nay, one half of it slants toward the north and the other toward the south – and the deferent intersects the equant in two places, and the figure of that intersection is called the dragon.*

Dragons aside, this is an attempt to explain the observable facts with reference to interlocking circles, something Sacrobosco derived from the Claudius Ptolemy, whose *Almagest* was written in Greek in the second century CE. The geocentric or Earth-centered view of the universe was referred to as Ptolemaic, after Ptolemy.

It's interesting to note the evidence Sacrobosco used to demonstrate his points. It was almost all from classical authors of the Roman and Greek periods, not astronomers but historians and poets. This gives a clue to the kind of authorities that underpinned his astronomy. He wanted the support of antiquity much more than observation.

It was the same with the theory of the perfect Moon. It was never based on observation but drawn from principles espoused by Aristotle. It later acquired a significance in Roman Catholic theology as a metaphor for the Immaculate Conception of the Virgin Mary.

There were always two problems with this account. The first was obvious – the Moon had some areas that were darker than others. The second was a piece of scientific reasoning. If the Moon was perfect, then as a spherical mirror it would presumably act like other mirrors and reflect the Sun as light is caught on a billiard ball, showing one brilliant spot. This was not the case. It led observers to wonder what the Moon was made of and whether there was a property on its surface, however perfect, that led to this effect. Some wondered if the Moon might be made of alabaster, and this became the accepted explanation by the thirteenth century. As Albert of Saxony (c. 1320–1390), another significant figure in medieval astronomy, explained: "The portions of alabaster that are very dense and non-transparent appear very white; those that are transparent like glass are obscure and tend towards black. If one asks why the Moon exhibits such differences between its various parts, one must reply that this is its nature."

New Ways of Thinking

The Ptolemaic system lasted. Commentators wrote commentaries upon commentaries and on it went. Anyone who argued differently, whether for a Moon that displayed evidence of change or for a Solar System where everything, including Earth, revolved around the Sun, was calling for a revolution in thought. And not just thought. Upheavals in astronomy touched upon theology and astrology, threatening to undermine the sense of where human beings fitted into the cosmos. This was not a small thing to undertake.

We will meet many of those who did this, though, during the course of this book. Here, we will touch upon two. They are the astronomers whose names are attached to the two craters we have observed, Nicolas Copernicus (1473–1543) and Tycho Brahe (1546–1601). Both offered different models for an alternative reality.

Copernicus' universe is contained in two books, his *Commentariolus* ("Little Commentary"), written before 1514, and then the more famous *De Revolutionibus Orbium Coelestium* ("On the Revolutions of the Celestial Spheres"), published in 1543. In these books, Copernicus argued historically, framing his new model in the familiar and comforting terms of what came before him. "To be sure," he wrote in his preface dedicated to Pope Paul III, "Claudius Ptolemy…brought this entire art almost to perfection…. Nevertheless very many things, as we perceive, do not agree with the conclusions which ought to follow from his system." In place of the complex Ptolemaic system, Copernicus proposed something simple, one system applying to all. He proposed that Earth and the planets revolved around the Sun because "the Sun occupies the middle of the Universe."

Like Sacrobosco, Copernicus' used a mathematical argument. Copernicus' title page carried the warning, "Let no one untrained in geometry enter here," said to have been the motto inscribed over the gateway to Plato's academy in ancient Greece. The text lives up to this, punctuated with tables and diagrams of interlocking triangles. It was a careful, almost reluctant piece of work.

Copernicus' publications did not immediately dissolve the Ptolemaic consensus. But his works were read, and some of those who thought it through came to agree with what he was saying. This, for example, is Michael Maestlin (1550–1631), tutor and mentor to Johannes Kepler, writing in the margin of his copy of Copernicus' *De Revolutionibus*: "Unless the common hypotheses are reformed…I will accept the hypotheses and opinion of Copernicus." Maestlin would live to see the gathering of evidence that Copernicus was right.

Others thought through the problems of the Ptolemaic system differently. One of the greatest astronomers to turn over the evidence was Tycho Brahe. In his own view he was a prince among observational astronomers, and he worked from the Danish island of Hven in the Baltic Sea to amass vast quantities of data with every kind of instrument he could create. He used this to propose a different model.

In the Tychonic account, the Moon orbited Earth and so did the Sun, with the other planets then in orbit around the Sun. This geo-heliocentric model made sense of his voluminous observations, on the basis of which, in Tycho's view, "the position of Copernicus on the motion of Earth and the immobility of the Sun is weakened." Tycho was a giant among astronomers, and his model gained support during the seventeenth century.

Return now to the craters that carry these two names. There, on the surface of the Moon, cartographers recalled two systems vying for prominence over a period of revolution in astronomical thought. The outcome was never obvious, and there are also astronomers remembered on the lunar surface who supported the Ptolemaic system and the Aristotelian philosophy that underpinned it. What we take as self-evident is not so until you look. The telescope has changed the way we see the universe, so use it carefully. It may change you.

Chapter 2

How to See the Sun

Observation: The Sun, the solar corona, auroras
Significance: Astronomy beyond the visible, the rotating Sun, solar wind
Science: How the Sun works, sunspots

The Sun is a star, and all stars are suns. The word *Sun* is the name we give to our local star. Its first recorded use in English comes from the hand of King Alfred in the ninth century, but most Indo-European languages have similar-sounding words for it based around a root syllable *su*- or *so*-. We have been talking about the Sun for a long time.

The Sun is, right now, the most important thing in your life. Its power created the Solar System, and its gravity holds it together. It is far and away the largest astronomical body in our local environment. Just 150 million kilometers away and 1.4 million kilometers across it dominates the daytime skies. With the correct apparatus, it reveals an awesome glory. We can watch its power at work.

In this chapter we will, after taking due precautions, observe the Sun. We will also see how those observations have changed history. It was upon the face of the Sun that astronomers saw blemishes, spots that overturned another element of the ancient view of the heavens and demonstrated that the Sun was in motion. It was by dissecting sunlight that astronomers first stretched the boundaries of their science beyond the visible. It has been by identifying and studying the solar wind that we have been able to understand our Solar System as the realm where the Sun's power rules.

These have mostly been quiet revolutions. When Galileo saw the moons of Jupiter, it was obvious to many that the classical account of the sky was incomplete. The same was true for sunspots, which provoked a furious debate in the seventeenth century. But spectroscopy, the dividing of light, and the nature of the solar wind are huge advances in the human understanding of our world that have remained hidden. Seeing the Sun is a chance to make them shine.

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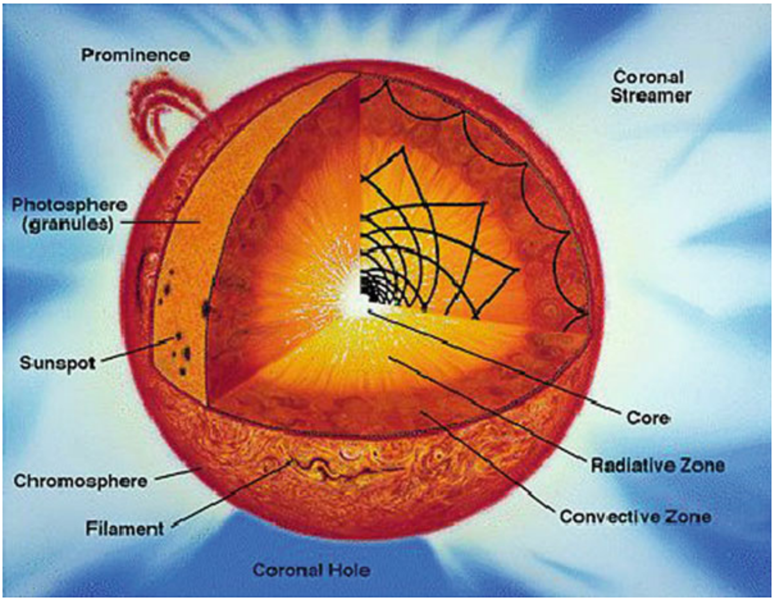

Fig. 2.1 A cutaway diagram showing the structure and zones of the Sun (Credit: NASA)

How to Look at the Sun

Here is a basic rule – don't look at the Sun.

To put it more precisely – don't observe the Sun using any telescope, binoculars or other optical instrument that has not been fitted with a safe appliance that is specific to solar astronomy. Don't stare at the Sun with your unaided eyes, unless you are using a recognized and tested solar filter. Why? Because human sight is precious and fragile, and the Sun can cause immediate and irreversible damage to the eyes.

This means avoiding home-made pieces of smoked glass, color film or whatever else seems like a clever idea and isn't. This means never using photographic solar filters as a sunshield for the eyes because, as their name suggests, they are for cameras.

This means, above all, not taking risks. If you are unsure of a piece of equipment, then do not use it to look at the Sun.

If you observe these warnings, then solar observing will become one of the pleasures of astronomy. Daytime viewing can be plagued by weather, but the Sun is much more available than any other astronomical target. It is also changing all the time, and we can see that for ourselves. This is rare in astronomy, where the timescales are usually far longer than the span of many human lives. The Sun provides a chance to understand and use fantastic online data provided by satellites that are watching it all the time. Finally, learning about the Sun informs our observations of other, much more distant stars.