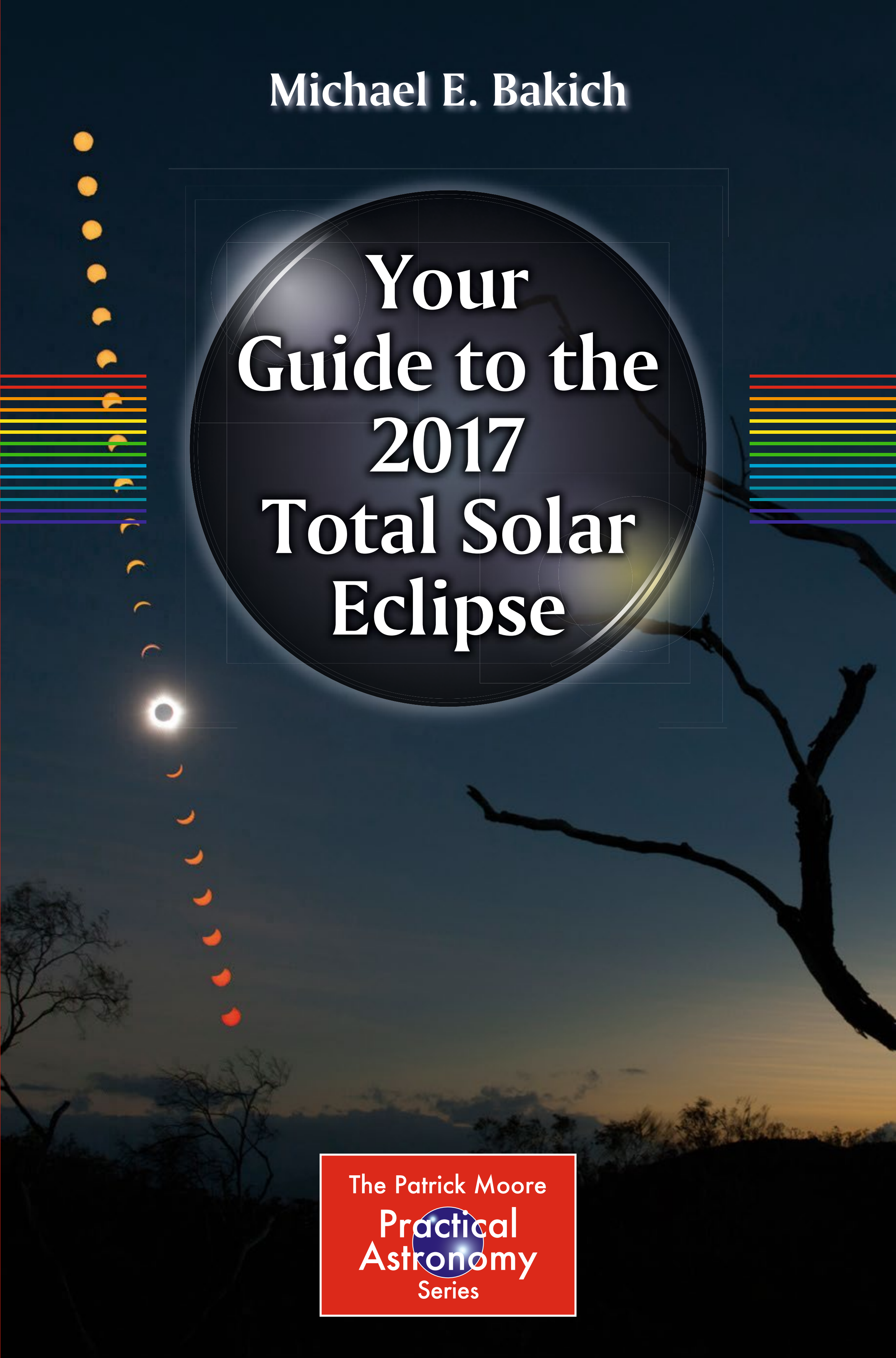
Michael E. Bakich

Your Guide to the 2017 Total Solar Eclipse

The Patrick Moore Practical Astronomy Series



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Preface

The original meaning of ἐκλειψη (the Greek word for "eclipse") is a forsaking, quitting, or disappearance. Hence the covering over of one object by another or the immersion of something into something else represents precisely the facts of an eclipse.

Earth and the Moon are solid bodies in space. Each casts a shadow as a result of the Sun's illumination. To understand eclipses, all we need to know is what results from the existence of these shadows. Total eclipses, be they of the Sun or the Moon, are examples of sublime celestial geometry. Each one is an exact lineup of the Sun, the Moon, and Earth for a total solar eclipse, or the Sun, Earth, and the Moon for a total lunar eclipse.

Our solar system is a group of a huge number of bodies, a few large and many small. The main one is the Sun. Its Latin name, *sol*, indicates why we call the collection a solar system. Now imagine a line between the Sun and any other body at a given time. Because everything in the solar system is in motion, that line will point in a different direction as time passes. Such a line shows the direction of the object's shadow, precisely opposite the Sun's position in space.

Every so often, an additional body comes into alignment with the other two. If the two non-solar bodies are close enough, the shadow from the closest one to the Sun may fall on the other. It may completely cover the second body or only partially cover it. Likewise, the first body may completely block out the Sun's disk or it may only partially obscure it. It is during these times that eclipses occur.

The larger a body is, the farther into space it will cast its shadow. At Earth's average distance from the Sun, any object casts an umbral shadow 108 times its diameter. This makes Earth's umbral shadow an average length of 855,000 miles and the Moon's umbral shadow approximately 255,000 miles long. Of course, these numbers vary because the distances of these bodies from the Sun change. Still, with them in mind it's easy to see why total lunar eclipses last much longer than total solar eclipses. The disk of Earth's shadow is much larger than the corresponding disk of the Moon's shadow at the average Earth-Moon distance of about 238,900 miles.

Most readers of this book will never have experienced a total solar eclipse and may therefore think that solar eclipses are rare. Actually, at least two and as many as five occur every year. During the period from 2000 B.C. to 3000 A.D., a total of 11,898 solar eclipses occurred. Of that number 3,173 (26.7 percent) were total. Within that span of five millennia, Earth experienced five solar eclipses in one calendar year only 25 times (0.5 percent). The most recent was in 1935, and the next time will not be until 2206.

Indeed the numbers surrounding eclipses, the scientific reasons they happen, and the way astronomers can predict—to a fraction of a second—where, when, and for how long a given eclipse will occur make these events fascinating. But all of this pales in comparison to actually witnessing totality at your location.

94.5 percent of the continental United States will experience a partial eclipse on August 21, 2017. Do you know the difference between a partial eclipse and a total one? It's the difference between a lightning bug and lightning. Between testing negative and positive with a pregnancy test. Between a paper cut and stepping on a land mine. In other words, there's no comparison.

Thankfully, comets and eclipses no longer generate the anxiety and alarm among uneducated populations that they did even as recently as a century ago. This means the upcoming total solar eclipse on August 21, 2017, will not only attract a good deal of attention from many millions of people, it may even induce a respectable number to think about the science and history of eclipses. And that's a good thing. Every now and then when something this remarkable happens—a great thunderstorm, an earthquake, a volcanic eruption, a bright comet, or an eclipse—it allows people who normally don't think of astronomy a chance to stop and appreciate the wonderful universe we live in.

Because this book is about a scientific event, it contains lots of facts. But it's also meant to appeal to astronomy newbies, people who certainly will be interested in this event, but who may not be well versed in science.

That said, my advice regarding how you use this book is to concentrate on the section or sections that mean the most to you when you're ready to deal with them. Your first order of business probably will be either to familiarize yourself with what's actually going to happen or to identify the ideal location you'd like to be at on eclipse day. Later, you may be interested in reading about eye safety. At some point, you'll want to cross-reference your ideal location with the discussion of weather prospects you'll read about here. And if you wish to enhance your viewing, the equipment chapters will speak to you as the event approaches.

However you choose to approach it, I cannot stress enough that you really should observe the eclipse. This is a must-see event. I think of it as "awesome" in the truest sense of that word: able to inspire or generate awe. Especially in the United States, people throw that word around like it's nothing "Your shoes are awesome!" "This crème brûlée is awesome!" "Little Julie's new crayon drawing is awesome!" Really? Do these things actually generate *awe*? On second thought, probably not.

But the eclipse on August 21, 2017, will be nothing short of awe-inspiring. I guarantee that if you stand under the Moon's shadow in the daytime you'll never forget it. Furthermore, it will stand out as one of the greatest—if not the greatest—sights you ever have or ever will behold. I'm smiling as I write this because I know some of you are thinking, "Wow, this guy should have worked for P. T. Barnum!"

Remember, however, that I've traveled to observe 13 total solar eclipses, and for 11 of those, I had groups accompanying me. I made passionate presentations to thousands of people before those events. And afterward, how many people thought I'd gone overboard? That I'd over-hyped the eclipse? That I'd set their expectations so high they could never reach them?

Zero.

Milwaukee, WI, USA Michael E. Bakich

Acknowledgements

First, as always, I want to thank my lovely wife, Holley, for both her emotional and real support with regard to this book. The latter manifests itself in the many illustrations she created, and the former because of her wonderful attitude of, "Sure, I can do that."

I also am indebted to David J. Eicher, editor of *Astronomy* magazine, for letting me cherry-pick all the "non-Holley" eclipse-related illustrations our magazine has produced over the years. This gold mine of gorgeous explanatory material goes back more than four decades.

As far as the actual photography of eclipses, I called on two of the best. Astronomy professor and *Astronomy* magazine Contributing Editor Mike Reynolds (coauthor of my most recent book) has seen 18 total solar eclipses and photographed them all. And I think he's sent every image he ever took to me to use as I please. Thanks, pal.

Ben Cooper, who maintains the excellent photographic website LaunchPhotography.com, started photographing total solar eclipses on August 1, 2008, during a trip he accompanied me on to Novosibirsk, Russia. His shots were great then and, to my surprise, they've actually gotten better. You rock, dude!

Thanks also to eclipse meteorologist Jay Anderson. His willingness to share his weather predictions for the 2017 eclipse made Chapter 24 far more accurate than it would have been. The entire cadre of eclipse chasers worldwide owes Jay a huge debt. Keep up the great work, sir!

I want to thank Kate Russo for sharing her "Community Eclipse Planning" white paper that I turned into Chapter 23. Want to talk eclipses? She is a wealth of information who offers her services as an eclipse planner. That's right, she not only talks the talk, she walks the walk, too.

Finally, I want to thank everyone at Springer involved with this project. To Maury Solomon, who replied to my initial enquiry in less than a day, thanks for realizing this event was going to be so huge and that we needed to get this project going quickly. And if anyone rates an even bigger thanks, it's my point-of-contact editor, Nora Rawn. She answered every one of my questions immediately, thereby saving me any wasted effort. Nora also performed a meticulous edit on the manuscript. That said, I accept all responsibility for any factual errors. This book contains lots of numbers. Let's hope I got them all correct.

Contents

Chapter 1

What's All the Fuss About?

Drama is coming to the United States. But it won't be in the form of an economic collapse, a papal visit, or a political upheaval. On August 21, 2017, Sun-watchers along a thin curved line that stretches for thousands of miles from Oregon to South Carolina will experience nature's grandest spectacle: a total solar eclipse.

It's not a stretch to say that this might prove to be the most viewed sky event in history. That's why prior to the eclipse, astronomy clubs, government agencies, cities—even whole states—are preparing for the unprecedented onslaught of visitors seeking to experience darkness at midday.

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Fig. 1.1 The path of totality across the U.S. (Courtesy of *Astronomy* magazine: Richard Talcott and Roen Kelly)

One thing you may hear when the media starts to hype this eclipse is the name they ascribe to it. You'll hear it called "America's eclipse," "the United States' eclipse," "our eclipse," and similar monikers. Why? Does the U.S. have some special connection to this eclipse? Believe it or not, the answer is yes. The Moon's dark inner shadow, which is the only place the eclipse will be total, touches no other land on Earth outside the United States for this eclipse. It speeds along thousands and thousands of miles of open ocean waters—in the Pacific before it contacts land in Oregon, and then in the Atlantic after leaving land in South Carolina—but if you want to stand on solid ground and look up at the wonder in the sky, you'll need to be in America.

This will be the first total solar eclipse crossing the continental U.S. in 38 years. One did cover Hawaii in 1991, but in the 48 states the last one occurred February 26, 1979. Unfortunately, not many people saw it because it was visible from just five states in the Northwest. Making matters worse, that winter's weather for the most part was bleak along the path of totality. Before the 1979 eclipse, you have to go back to March 7, 1970, when a total solar eclipse traveled up the East Coast of the United States, again occurring in a scant five states. More people certainly saw that one—I'm one of them!—but because it happened 45 years ago, the percentage of people that you'll encounter who saw it will be essentially zero.

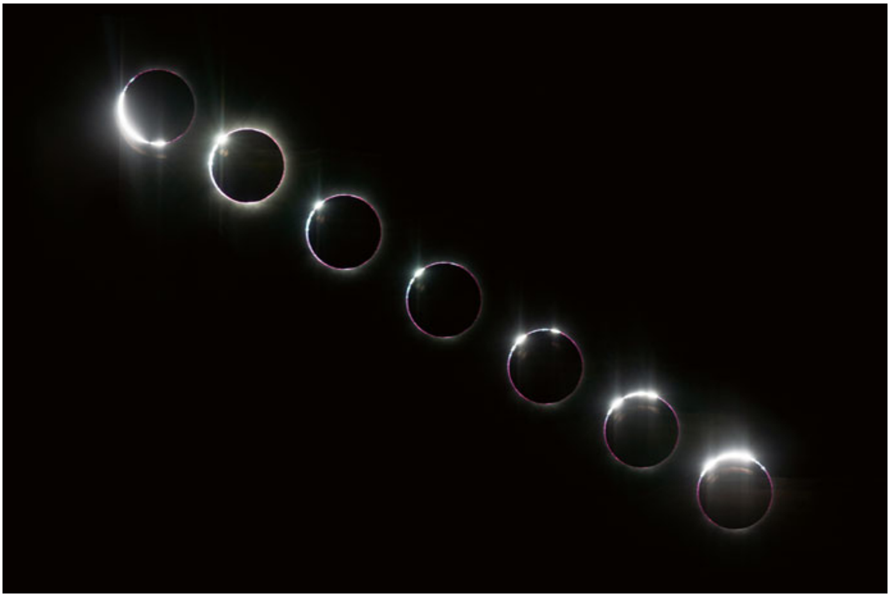

Fig. 1.2 This spectacular photographic sequence around totality shows some of the features you'll see August 21, 2017. (Courtesy of Ben Cooper)

Although total solar eclipses occur more often than total lunar ones, more people—actually, pretty much everyone—have seen a total eclipse of the Moon. Few, on the other hand, have seen a total solar eclipse. The reason is quite simple. We live on Earth, and it's our perspective that interacts with the geometry of these events. During a lunar eclipse, anyone on the night side of our planet under a clear sky can see the Moon passing through Earth's dark inner shadow. That shadow, even as far away as the Moon, is quite a bit larger than the Moon, so it takes our satellite some time to pass through it. In fact, if the Moon passes through the center of Earth's shadow the total part of the eclipse can last as much as 106 minutes. Usually totality doesn't last that long because the Moon passes either slightly above or below the center of the shadow our planet casts.

Conversely, the Moon and its shadow at the distance of Earth are much smaller; so small, in fact, that the shadow barely reaches our planet's surface. Anybody in the lighter outer region of the shadow will see a partial solar eclipse. The lucky individuals under the dark inner shadow will *experience*—a much better word than "see"—a total solar eclipse. But not for long. Solar totality lasts a maximum of 7½ minutes. In fact, the longest totality in the 5,000-year span from 2000 B.C. to 3000 A.D. is 7 minutes and 29 seconds. That eclipse will occur July 16, 2186.

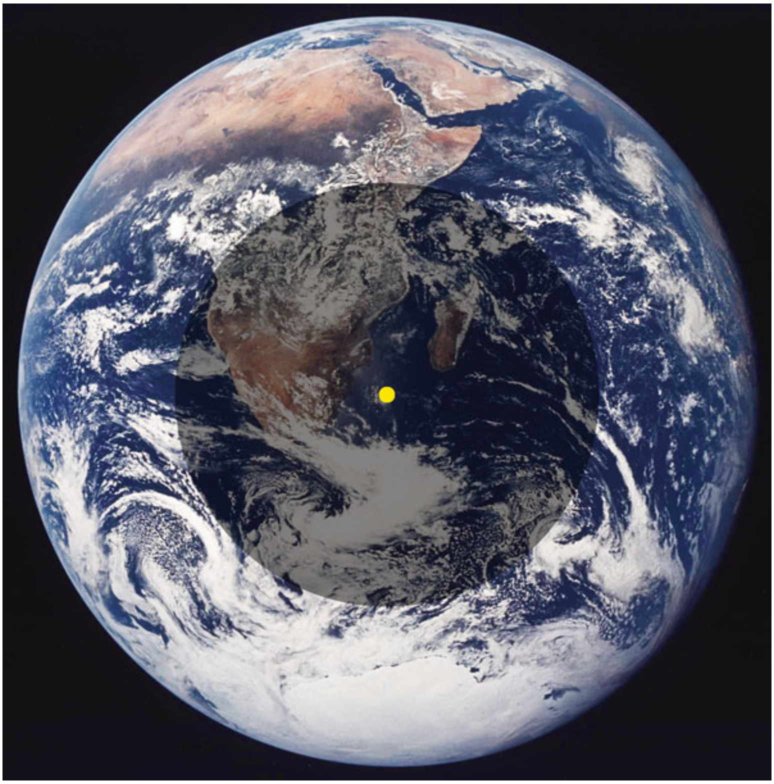

Fig. 1.3 The Moon's penumbra (*lighter outer circle*) has an average diameter of approximately 4,350 miles (7,000 kilometers) at Earth's distance The umbra (here represented by the *small yellow circle* to make its size easier to see) has a maximum diameter of 166 miles. (Earth image courtesy of NASA; graphics: Holley Y. Bakich)

We won't be nearly that fortunate August 21, 2017. The maximum duration of totality then will be 2 minutes and 40 seconds. Ah, but what a span it will be!

Now, I do want to say a few words about the importance of totality. ***It's all about totality.*** Everyone in the continental U.S. will see at least a partial eclipse. In fact, if you have clear skies on eclipse day, the Moon's shadow will cover at least 48 percent of the Sun's surface. And that's from the northern tip of Maine. Although the Moon covering part of the Sun's disk sounds cool, you need to aim higher.

Likening a partial eclipse to a total eclipse is like comparing almost dying to dying. If you are outside during a solar eclipse with 48 percent coverage, you won't even notice your surroundings getting dark. And it doesn't matter whether the partial eclipse above your location is 48, 58, or 98 percent. Only totality reveals the true celestial spectacles: the two diamond rings, the Sun's glorious corona, 360° of sunset colors, and stars in the daytime. So, remember, to see any of this you must be in the path of totality.

Knowing that, you want to try to be on the centerline. The fact that the Moon's shadow is round probably isn't a revelation. If it were square, it wouldn't matter where you viewed totality. People across its width would experience the same duration of darkness. The shadow is round, however, so the longest eclipse occurs at its centerline because that's where you'll experience the Moon's shadow's full width.

Oh, there's something else. This event will happen! As astronomers (professional or amateur), some of the problems we deal with are due to the uncertainty and limited visibility of some celestial events. Comets may appear bright if their compositions are just so. Meteor showers might reach storm levels if we pass through a thick part of the stream (and generally the best views occur after midnight). A supernova as bright as a whole galaxy may be visible, but you need a telescope to view it. In contrast to such events, this solar eclipse will occur at the exact time astronomers predict, along a precisely plotted path, and for the lengths of time given. Guaranteed. Oh, and it's a daytime event to boot.

The next total solar eclipse that causes the Moon's shadow to fall across the continental U.S. occurs April 8, 2024. It's going to be a good one, too. Depending on where you are on the centerline, the duration of totality will last at least 3 minutes and 22 seconds on the east coast of Maine and stretches to 4 minutes and 27 seconds in southwestern Texas. After that eclipse, it's a 20-year wait until August 23, 2044 (and, similar to the 1979 event, that one is visible only in Montana and North Dakota). Total solar eclipses follow in 2045 and 2078. You can read about these upcoming events in Appendix A.

But it's 2017 that's causing all the excitement now. And you've got the right reference for it in your hands. I'll discuss trip planning, how to observe the event, top locations for activities and viewing, and much more. I'll weave interviews in, too, with people who are experts on photographing eclipses and others who will be conducting major observing events across the country. This book will keep you informed so that you can approach the eclipse without a shadow of doubt.

Chapter 2

An Illustrated Eclipse Glossary

So that we're all speaking the same language about solar eclipses, this chapter will provide a brief list of the most popular terms you'll encounter, many of them with illustrations. You should get familiar with them because you will see them again.

Altitude—the height, in degrees, of a point or celestial object above the horizon. We measure altitude from 0° (on the horizon) to 90° (at the zenith, which is the overhead point). Consider the following sentence as an eclipse-related example: At Rosecrans Memorial Airport in St. Joseph, Missouri, on August 21, 2017, the Sun will stand 61.9° high in the south at mid-eclipse.

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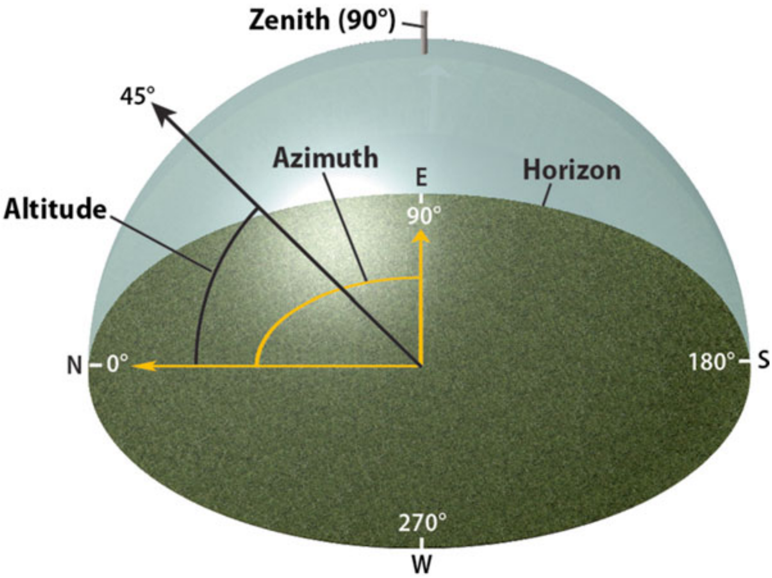

Fig. 2.1 Altitude and azimuth. (Courtesy of *Astronomy* magazine: Roen Kelly)

Angular diameter—the apparent size of a celestial object, measured in degrees, minutes, and/or seconds, as seen from Earth. OK, let's define the three words in that sentence. A degree is 1/360 of a circle. Said another way, a circle contains 360°. A minute (short for minute of arc or arcminute) is 1/60 of 1°. A second (short for second of arc or arcsecond) is 1/60 of 1 minute of arc. So, 1° contains 3,600 arcseconds. An example of use might be something like, "The average angular size of the Sun or the Moon, as seen from Earth, is 31 arcminutes, or 0.52°."

Angular distance—this is the same thing as angular diameter except that we're measuring the distance between two objects, not the size of a single object; so the definition would be the distance between two celestial bodies expressed in degrees, minutes, and/or seconds of arc.

Aphelion—the position of an object in solar orbit when it lies farthest from the Sun. Similarly, **apogee** is the position of the Moon or other object in Earth orbit when it lies farthest from our planet. Aphelion has two approved pronunciations: a FEEL ee on and ap HEEL ee on.

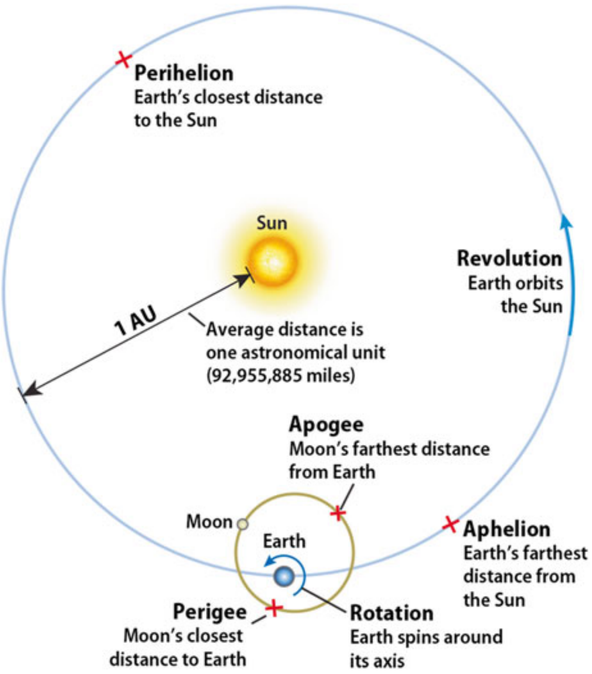

Fig. 2.2 Aphelion and perihelion. (Courtesy of *Astronomy* magazine: Richard Talcott and Roen Kelly)

Azimuth—the angular distance (from 0° to 360°) to an object measured eastward along the horizon starting from north; so the azimuth of an object due north is 0°; due east would be 90°; south would be 180°; and a due-west azimuth equals 270°. Well, that's if the object is on the ground; for a celestial object, the measurement is to a line that passes through the object and makes a right angle to the horizon.

Baily's beads—during a total solar eclipse, the effect often seen just before and just after totality when only a few points of sunlight are visible at the edge of the Moon. This effect is caused by the irregularity of the lunar surface. At our satellite's edge, mountains block out the Sun's disk, but valleys permit it to shine through. Scientists named this phenomenon after English astronomer Francis Baily, who first explained it in 1836.

Center line—the midpoint of the width of the Moon's shadow on Earth; the centerline is the location for the maximum duration of totality. You'll hear the cry throughout this book: "Get to the center line!"

Chromosphere—the region of the Sun's atmosphere between its visible surface and its corona; sometimes briefly visible just before or after totality as an intense red glow at the Moon's edge.

Conjunction—a point on the sky where two celestial bodies appear to line up; the lineup may be an exact one, as in the case of a total eclipse, or it may be a near one, as in the case of New Moon (when our satellite is "in line" with the Sun).

Corona—the shell of thin gas that extends out some distance from the Sun's surface normally visible only during totality; "corona" is the Latin word for "crown." Well put.

Fig. 2.3 The Sun's corona becomes visible during totality. (Courtesy of Mike Reynolds)

Fig. 2.4 The diamond ring is visible just before and just after totality. (Courtesy of Mike Reynolds)

Diamond ring—the effect just prior to or just after totality of a solar eclipse when a small portion of the Sun's disk plus its corona produce an effect similar to a ring with a brilliant diamond.

Disk—the visible surface of any heavenly body.

Ecliptic—the circle described by the Sun's apparent annual path through the stars; the plane of Earth's orbit around the Sun. You may not know it by this name, but the ecliptic traces the Sun's path through the constellations of the zodiac.

First contact—during a solar eclipse, the moment that the Moon makes contact with the Sun; this moment marks the beginning of the eclipse.

Flare—a sudden burst of particles and energy from the Sun's photosphere; through a Hydrogen-alpha filter, flares often appear brighter than the surrounding area.

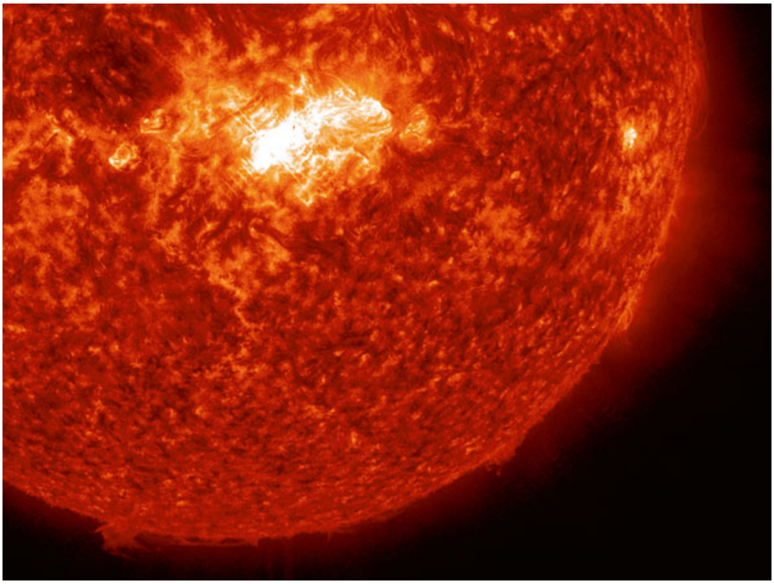

Fig.2.5 Solar flares are huge explosions on the Sun’s surface. (Courtesy of NASA/SDO)

Fourth contact—during a solar eclipse, the moment that the disk of the Moon breaks contact with the Sun; this moment marks the end of the eclipse.

Hydrogen-alpha filter—a filter that passes only light with a wavelength of 656.28 nanometers (or 6,562.8 Angstroms); a simpler definition is a filter that allows you to observe the Sun’s chromosphere, flares, prominences, and more; abbreviated H-alpha filters, these accessories are expensive but impressive.

Magnitude—the amount of the Sun's diameter the Moon covers during an eclipse; this is not the same as “obscuration.”

New Moon—the phase where the Moon seems completely unlit from our perspective on Earth; the phase where the Moon is between Earth and the Sun; solar eclipses can occur only at New Moon.

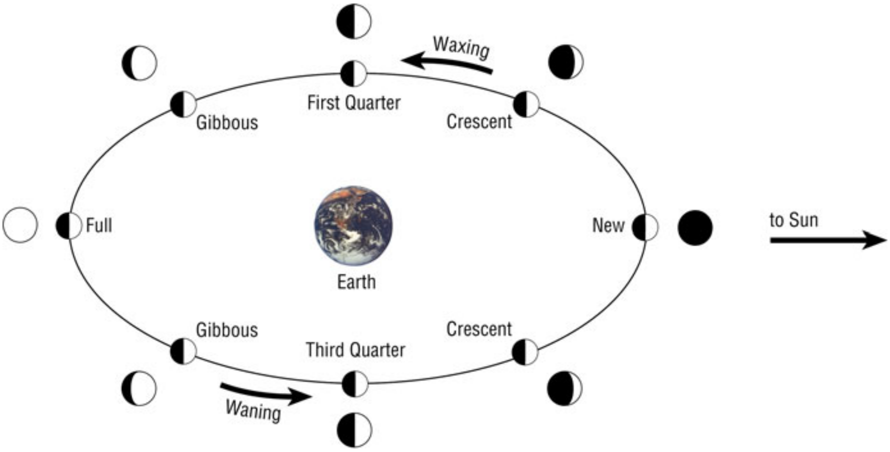

Fig. 2.6 Lunar phases. Solar eclipses occur only at New Moon. (Courtesy of Holley Y. Bakich)

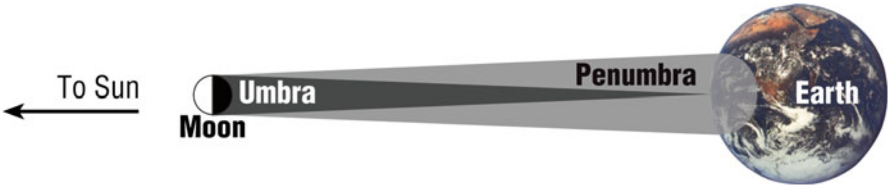

Fig. 2.7 The Moon's umbra is its dark inner shadow; its penumbra is the lighter outer shadow. (Courtesy of Holley Y. Bakich)

Nodes—with regard to solar eclipses, the two points at which the Moon's orbital plane intersects the plane of the ecliptic; in other words, the two places the plane of the Moon's orbit crosses the plane of Earth's orbit; eclipses can occur only near nodes.

Obscuration—the amount of the Sun's area the Moon covers during an eclipse; this is not the same as "magnitude."

Orbit—the path of one celestial body around another; examples: Earth orbits the Sun, and the Moon orbits Earth.

Penumbra—the less dark outer region of the Moon's shadow; an observer under the penumbra sees a partial solar eclipse.

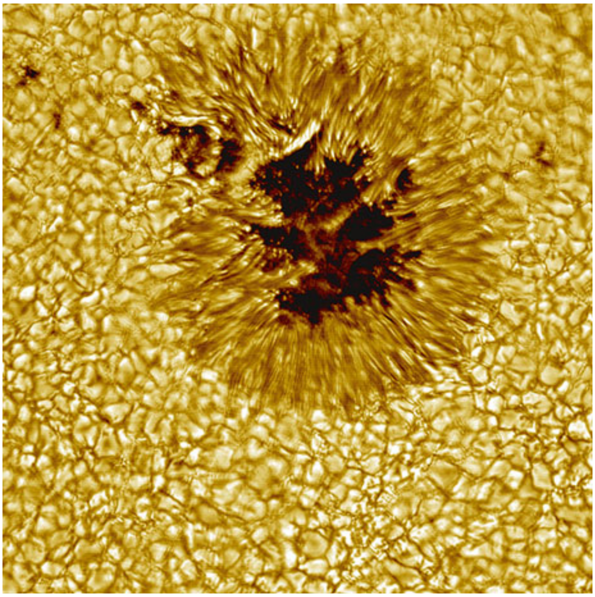

Fig. 2.8 Close-up view of a sunspot. (Courtesy of Vacuum Tower Telescope/NSO/NOAO)

Perigee—the position of the Moon or other object in Earth orbit when it lies closest to our planet.

Perihelion—the position of an object in solar orbit when it lies closest to the Sun.

Photosphere—the visible surface of the Sun; where our star emits visible light; the Sun's disk.

Prominence—a large-scale, gaseous formation above the surface of the Sun usually occurring over regions of solar activity such as sunspot groups; during totality observers often see prominences seeming to erupt from the Moon's dark edge.

Revolution—in astronomy, the orbiting of one body around another; the Moon revolves around Earth.

Rotation—the spinning of a celestial body on its axis; Earth rotates once a day.

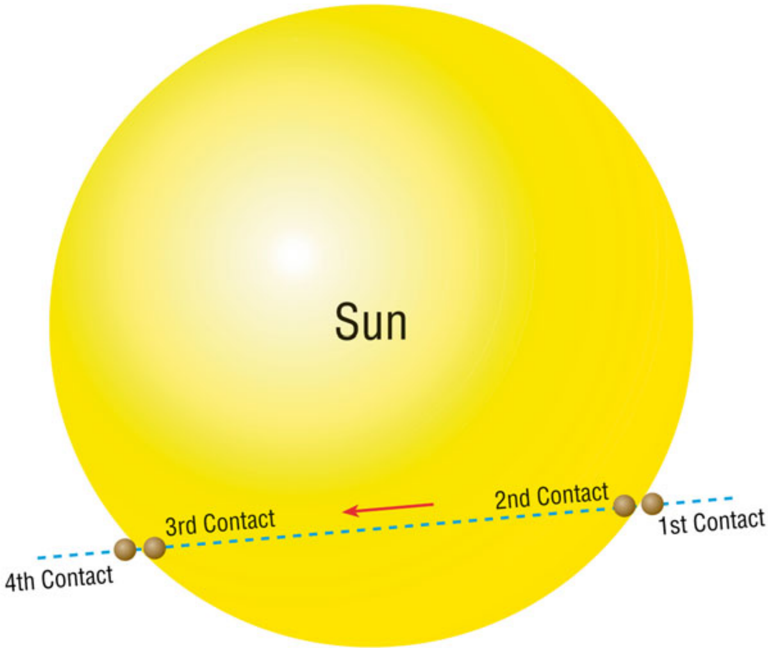

Fig. 2.9 First, second, third, and fourth contacts during a total solar eclipse have the same geometries as the planet pictured crossing the Sun in this illustration. (Courtesy of *Astronomy* magazine: Roen Kelly)

Saros cycle—a time period equal to 6,585.3 days between which similar eclipses occur.

Second contact—during a total solar eclipse, the moment the Moon covers 100 percent of the Sun's disk; the instant totality begins.

Shadow bands—faint ripples of light occasionally seen on flat, light–colored surfaces just before and just after totality.

Solar telescope—a telescope whose design lets you safely observe the Sun.

Sunspot—a temporarily cooler (and therefore darker) region on the Sun's visible disk caused by magnetic field variations.

Syzygy—the lineup of three celestial bodies; for a solar eclipse, the lineup is the Sun, the Moon, and Earth.

Third contact—during a total solar eclipse, the instant totality ends.

Umbra—the dark inner region of the Moon's shadow; anyone under the Moon's umbra will experience a total solar eclipse.

Universal Time (UT)—also known as Greenwich Mean Time (GMT); standard time kept on the Greenwich meridian (longitude = 0°); astronomers use UT to coordinate observations of celestial events.

Chapter 3

Frequently Asked Questions Answered About Eclipses

The purpose of this chapter is to answer some of the most important questions for both the general public and the media. Yes, the eclipse is a year away, but it's never too early for knowledge, right? Plus, these are the facts, and they won't change.

As described earlier, a solar eclipse is a lineup of the Sun, the Moon, and Earth—in that order. The Moon, directly between the Sun and Earth, casts a shadow on our planet. If you're in the dark part of that shadow, called the umbra, you'll see a total eclipse. If you're in the light part, the penumbra, you'll see a partial eclipse.

Now the most-popular follow-up question: since the Sun larger than the Moon, how does this work? While our daytime star's diameter is approximately 400 times larger than that of the Moon, it also lies roughly 400 times farther away. This means both disks appear to our eyes to be the same size.

The next question is a frequent one: When do solar eclipses occur? A solar eclipse happens at New Moon. The Moon has to be between the Sun and Earth for a solar eclipse to occur. The only lunar phase when that happens is New Moon.

So then, why don't solar eclipses happen at every New Moon? The reason is that the Moon's orbit tilts 5° to Earth's orbit around the Sun. Astronomers call the two intersections of these paths nodes. Eclipses only occur when the Sun lies at one node and the Moon is at its New phase for solar eclipses or Full phase for lunar eclipses. During most lunar months, the Sun lies either above or below one of the nodes, and no eclipse happens.

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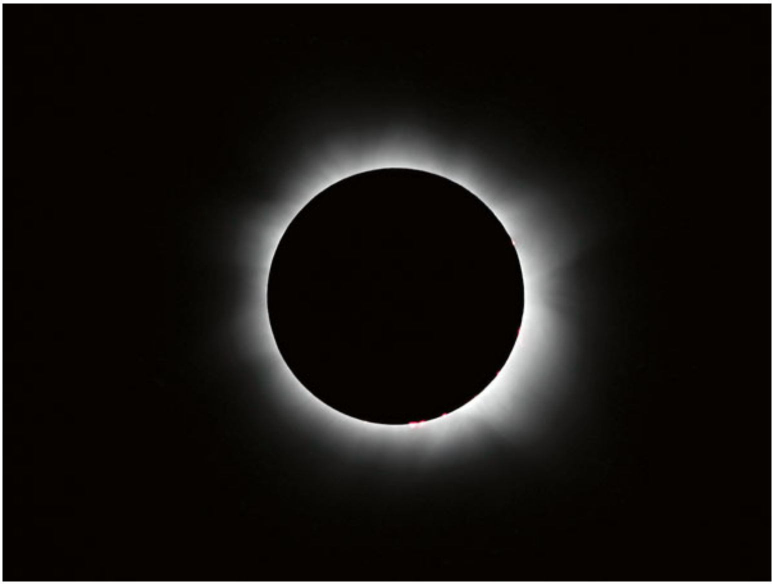

Fig. 3.1 Stand under the Moon's umbra during a total solar eclipse, and you'll experience the awe of totality. (Courtesy of Mike Reynolds)

Fig. 3.2 Although solar eclipses occur at New Moon, our satellite must lie at one of its nodes for the lineup to produce the event. (Courtesy of Holley Y. Bakich)

Another question people ask a lot is "Why are some eclipses longer than others?" The reason the total phases of solar eclipses vary in time is because Earth is not always at the same distance from the Sun, and the Moon is not always the same distance from Earth. The Earth-Sun distance varies by as much as 3 percent. That may not sound like much, but it's nearly 3 million miles. The Moon-Earth distance, meanwhile, can change by as much as 12 percent. The result is that while the Moon retains the same size at all times, the Moon's apparent diameter—that is, the disk that we see—can range from 7 percent larger than the Sun to 10 percent smaller than the Sun.

Next we have one about wording: What do magnitude and obscuration mean? Astronomers categorize each solar eclipse in terms of two properties, its magnitude and the percentage of obscuration, and I don't want you to be confused when you encounter these terms. The magnitude of a solar eclipse is the percent of the Sun's diameter that the Moon covers during maximum eclipse. The obscuration is the percent of the Sun's total surface area covered at maximum.

Fig. 3.3 This image shows the Moon covering half the Sun's diameter. The magnitude of the eclipse at this time would be 0.50, or 50 percent. The obscuration, however, that is, the percentage of the Sun's area covered, would be only 39.1 percent. (Courtesy of Ben Cooper)