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MARK LITTMANN & FRED ESPENAK

A Complete Guide to the Most Amazing of Celestial Sights

TOTALITY

The Great American Eclipses of 2017 and 2024

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To Peggy, to our children Beth and Owen, and to our grandchildren Liam and Adele, with love.

Mark Littmann

To my wife Pat, and granddaughters Valerie and Maggie who will see their first total eclipse in 2017.

Fred Espenak

Contents

Foreword

I have never seen a total solar eclipse.

That is a peculiar confession for an astronomer, especially one who prides himself on observing the sky both dark and sunlit. I've seen rocket launches and space debris re-entering, stars exploding, galaxies cosmically proximate and distant, planets in alignment, and meteors by the thousands.

So how can it be that in my life I've never witnessed this one phenomenon, universally (if I may be so bold) acknowledged as the most glorious sight the heavens provide?

Well, y'know, *life*. Timing, schedules, finances, weather—these mundanities can interfere. But to be honest, none of these has been the issue personally. The real root of my lack of experience is *circumstance*: Eclipses are particular in where they occur. For people of Europe, the great eclipse of 1999 was a godsend, but not so much for a newly minted American father who couldn't possibly travel that far to see it.

South America in 1994, Africa in 2001, Asia in 2009 . . . all these were too distant or too logistically difficult for me to attend.

I'm sure penguins enjoyed the 2003 eclipse in Antarctica. Me, and the rest of us, not so much.

But all this is about to change. In August of 2017 the shadow of the Moon will sweep across my home country, and will pass just a few hundred kilometers north of my home, an easy day's drive. When the Great American Eclipse occurs, I will be there, to bask in over two minutes of non-sunlight.

And when it happens I will be prepared, because I have read the book you now hold in your hands. After you read it, you will be too. The information you're about to receive is both critically important to prepare for the eclipse as it is delightful to read.

Let me be clear: This book will prepare you *logistically* for the eclipse. You will know where to be, when to be there, where to look, what to look for, how to look, and why it's all happening.

But the book also does a good job preparing you *emotionally* too. The stories by people who have witnessed eclipses for themselves, especially first-timers, are moving (I particularly liked the "Moments of Totality" chapter interstitials), and the photographs will give you a taste of what it will be like. Of course, no number of words, no matter how exquisitely crafted, will have you understand what it is like to witness such magnificence for yourself, to have your soul touched by the experience.

Or so I've been told. I'll find out in August, just as I hope you will.

After reading the book, I thought carefully about what that day, that hour, those just-more-than two minutes will be like. And I have decided not to take any pictures of the eclipse, at least not directly. I may take a few photos of the people around me staring in awe, or the shadows of the eclipse on the ground should circumstances fall that way, or maybe even set up a telescope and camera to shoot pictures automatically.

But when the moment comes, I want to stand there, with nothing between me and the Sun but a thin slip of atmosphere and the depths of space as the Moon joins us in alignment. I don't want to worry about terrestrial mundanities, I just want to enjoy the show brought to us care of celestial mechanics.

. . . at least, for a while. Note this: Due to the complex and subtle dance of gravity, the Moon is slowly receding from the Earth, drawing away from us at a rate of about 4 centimeters per year. In the past it was much closer, and in the future it will be more distant.

This means that in the remote past it appeared much larger in the sky, and would have blocked the Sun to a much greater degree. Back then, hundreds of millions of years ago, the glory of the Sun's atmospheric corona would scarcely have been visible; the Moon's larger size would have blocked most of it.

Conversely, in the very distant future the Moon will appear *smaller* in the sky, and won't be able to completely cover the surface of the Sun. In some far-flung day, hundreds of millions of years from now, there will be a very last total solar eclipse, and then every one after that will be annular, partial.

We live in the middle of a billion-year-long eclipse season. You'd better catch them while they last. Your great-great-great^{nth} descendants won't have this luxury.

But that is a concern for them, not us. For now, I'm content to look forward to August 21, 2017, to my very first total solar eclipse. And when that's over?

For those of us in the States (and Mexico and Canada!), there's always April 8, 2024.

Phil Plait, Ph.D.
Astronomer, author, and host of
Phil Plait's Bad Universe on the Discovery Channel
and
Crash Course Astronomy on YouTube

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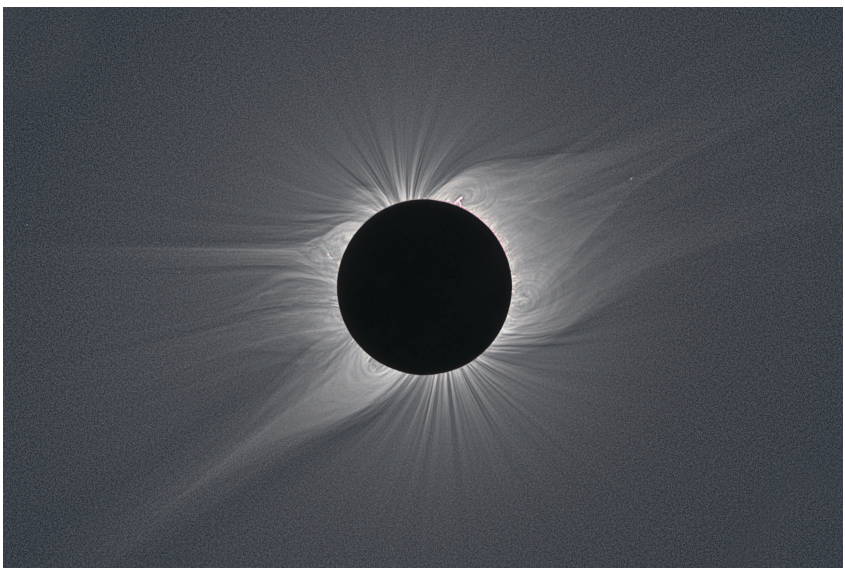
To everyone who helped with this book, our profound thanks and our hope that you will enjoy many total eclipses of the Sun.

The diamond ring effect just before second contact was photographed from Libya during the total solar eclipse of March 29, 2006. [Nikon D200 DSLR, 170–500 mm zoom at 500 mm, f/5.0, 0.8s, ISO 400. ©2006 Patricia Totten Espenak]



The solar corona's enormous dynamic range and wealth of fine structure requires multiple exposures and special computer processing as illustrated in this image of the total eclipse of August 1, 2008. [Canon 450D and 300 mm, Canon 35OD an b200 mm, ISO 100, large range of exposures, image processing by Hana Druckmullerova. ©2008 Arne Danielsen]

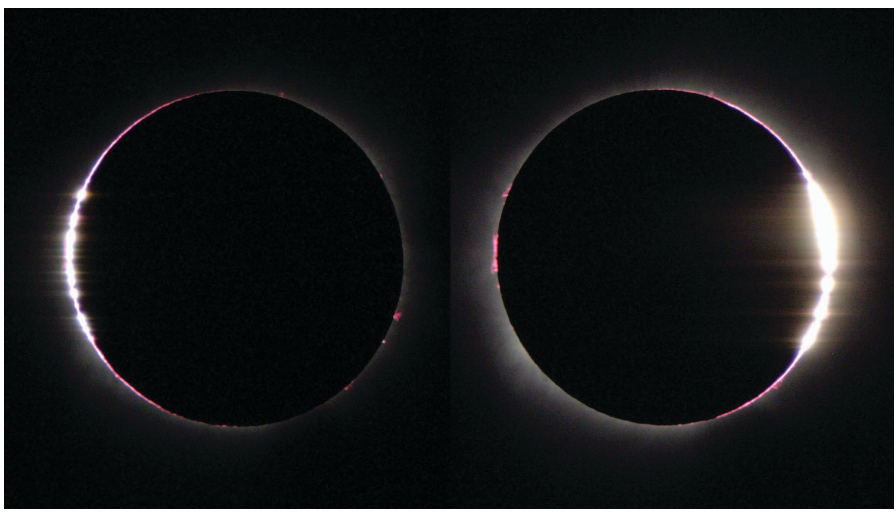
Observers gaze in wonder at the August 1, 2008 total eclipse as seen in this time lapse composite shot from the shore of the Novosibirsk Reservoir in Russia. [Nikon D200, 17 mm lens, stacked multiple exposures at five-minute intervals. ©2008 Ben Cooper]

The totally eclipsed Sun stands above threatening clouds on July 21, 2009. Taken from Northern Cook Islands, at sea on M/S Paul Gauguin. [Canon 20Da, 28–105 mm zoom at 60 mm, ISO 100, f/5, 1.3 seconds. ©2009 Alan Dyer]

The silhouette of an intrepid eclipse chaser stands high above the lights of EL Calafate and Lake Argentino during the total eclipse of July 11, 2010. This challenging eclipse barely cleared the distant Andes as totality began. [Olympus SP570UZ, lens at 8.9 mm, f/3.4 at 1/2 second. ©2010 Janne Pyykkö]

From the frigid landscape of Antarctica, an eclipse watcher is dramatically captured against the total eclipse of November 23, 2003. [Canon EOS D60 DSLR, 100–400 mm Canon F4.5–5.6 L IS, f/8, 1/60s ISO 100. ©2003 Fred Bruenjes]

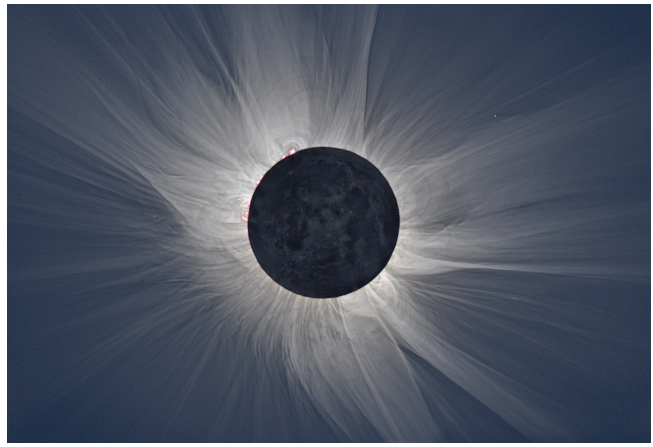
The wondrous sight of the diamond ring effect hanging 10° above the horizon is greeted by frozen eclipse chasers in the −20°C (−4°F) landscape of Svalbard on March 20, 2015. [Nikon D800, Nikon 14–24 zoom at 24 mm, ISO400, f/2.8, 1/8 second. ©2015 Stan Honda]



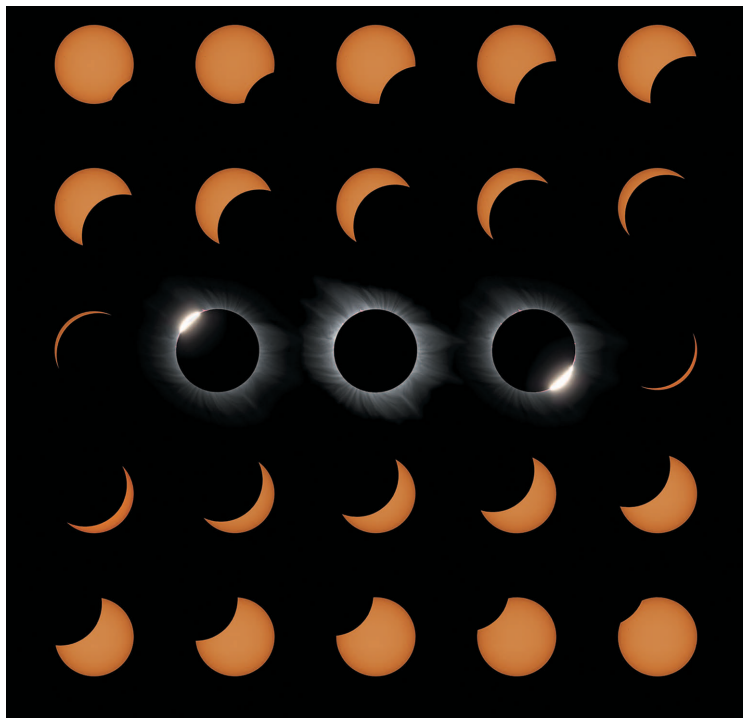
Short eclipses have fewer seconds of totality, but they offer fantastic views of Baily's beads. These two images were shot 34 seconds apart during the total solar eclipse of December 4, 2002 from Koolymilka, Australia. [Canon EOS D60 DSLR, Takahashi FS-60C w/ Extender-Q, fl = 568 mm f/9.5, exposures: 1/4000s and 1/1000s, ISO 800. ©2002 Arne Danielsen]

Just minutes after annularity, an oddly shaped crescent Sun sets behind giant wind turbines of a wind farm near Elida, New Mexico on May 20, 2012. [Nikon D90, Sigma 170–500 zoom at 500 mm, no solar filter, ISO 200, f/8, 1/500 second. ©2012 Fred Espenak]

A wide-angle view of totality captures eclipse chasers in a sugarcane field in North Queensland, Australia on November 14, 2012 [Canon 550D, Tokina 11–16mm zoom, ISO 3200, f/2.8, 1/25 second. ©2012 Stephen Mudge and Adam Poplawski]

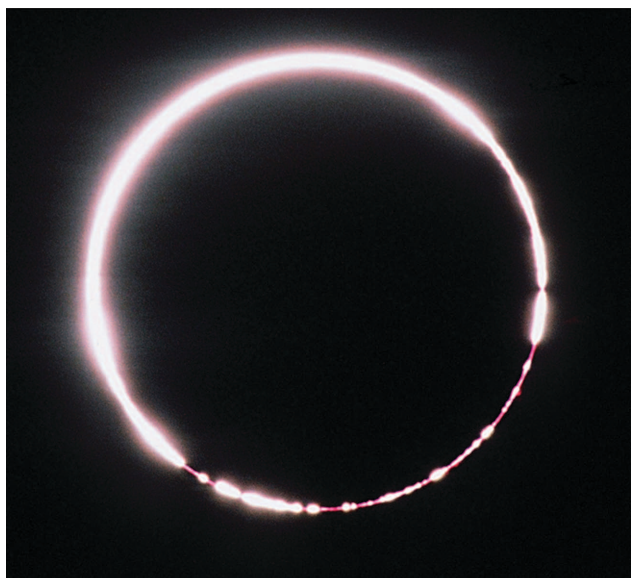


A stunning view of the March 20, 2015 total eclipse from Svalbard was created from 29 individual exposures combined with custom software. In addition to the wealth of fine structure seen in the corona, lunar surface features are also revealed. [Nikon D810, TS Photo Line refractor, fl = 800 mm, f/6.9, exposures: 1/1600 to four seconds. © 2015 Miloslav Druckmüller, Shadia Habbal, Peter Aniol, Pavel Starha]



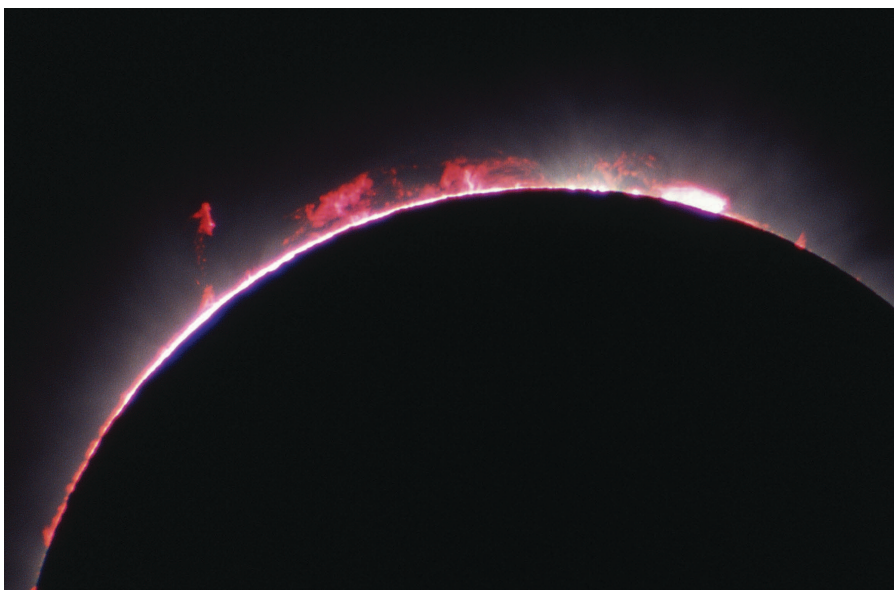
All stages of the March 29, 2006 total eclipse are captured in a mosaic of 25 images taken every seven minutes throughout the event. The diamond ring at each contact is included while the corona has been computer enhanced to show subtle details and prominences. [Nikon D200, Vixen 90 mm fluorite refractor, fl = 820 mm, f/9, ISO 400. ©2006 Fred Espenak]

A multiple-exposure time sequence records the partial phases and totality during the total solar eclipse of March 29, 2006 from Side, Turkey. [Zenith, 50 mm lens, Kodak Ektachrome, multiple exposures at f4. ©2006 Alex Tudorica]

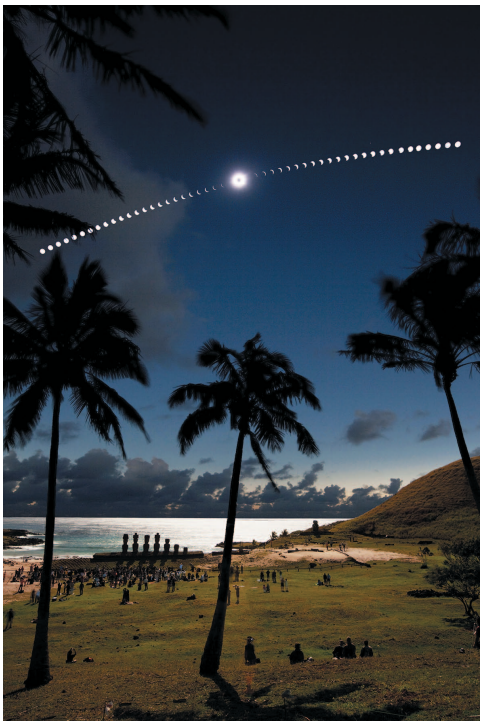


The Moon's disk was surrounded by a diamond necklace during the beaded annular eclipse of May 30, 1984 from Pendleton, SC. At beaded annular eclipses, the Moon is very nearly the same size as the Sun so the Moon's higher mountains break the annular ring into a series of beads and crescent segments. [35 mm SLR, 3 inch F/15 Jaegers refractor, fl = 1140 mm, no solar filter, f/15, 1/500, ISO 64 slide film. ©1984 Johnny Horne]

Eclipse chasers gaze up at the totally eclipsed Sun from the Libyan desert on March 29, 2006. [Nikon N90s, Nikkor 16 mm Fisheye lens, f/5.6, auto (ISO 200). ©2006 Fred Espenak]



A forest of red prominences appears before third contact during the total solar eclipse of August 11, 1999 from Lake Hazar, Turkey. [Pentax ZX-M SLR, 94 mm Brandon refractor, f/30, 1/60s, Ektachrome V100 film pushed to ISO 200. ©1999 Greg Babcock]



Easter Island's Anakena Beach offered a surreal landscape of Maoi statues and palm trees for this time-lapse sequence of the total solar eclipse of July 11, 2010. [Canon 5D Mark II, Canon 16–35 zoom at 24 mm, solar filter for partial, no filter for total. ©2010 Blanchard Guillaume]

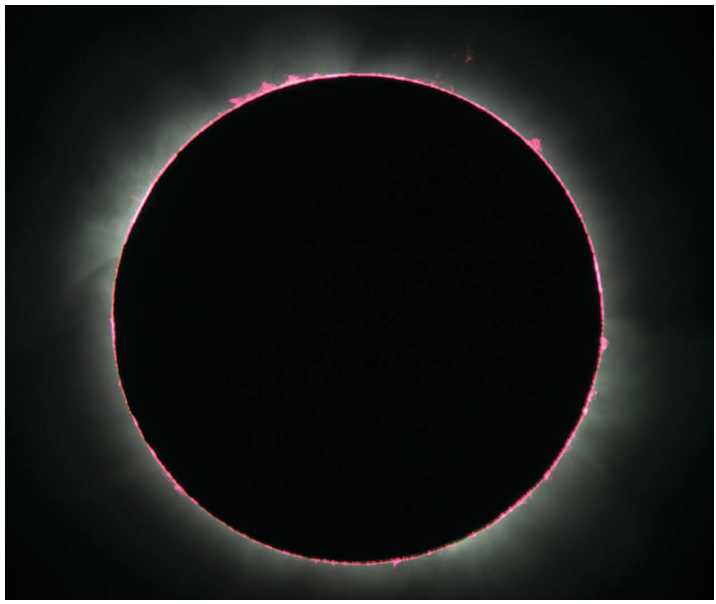
A stunning composite of the total solar eclipse of August 1, 2008 was produced using 28 exposures. Features on the dark side of the Moon are also visible. The images were processed and combined using Photomatix and Photoshop. [Nikon D300, Borg 77 mm ED refractor, fl = 500 mm, f/6.5, exposures: 1/4000 to two seconds. ©2008 Alson Wong]

Thin clouds provide a screen for the projection of shadow bands during the third contact diamond ring of the Australian eclipse of November 14, 2012. [Canon 50D, 70–200 mm zoom, ISO 400, exposure 1/1000 second. ©2012 Stephen Mudge]

The Great Wall of China at Jiayuguan Fort frames the sky during the total eclipse of August 1, 2008. A composite of eight exposures reveals the Sun's corona as well as the planets Mercury, Venus, Mars, and Saturn. [Canon 450D, Canon 10–22 mm, exposures: 1/125 at f8 to one second at f5.6. ©2008 Terry Cuttle]

Easter Island statures (maoi) bare mute testimony to the spectacle of totality from Anakena Beach during the total solar eclipse of July 11, 2010. [Canon 5D Mark II, 14 mm lens. ©2010 Stephane Guisard]

A time sequence of seven images captures the breakup of the crescent Sun into Baily's beads immediately preceding second contact. The total eclipse of March 29, 2006 was photographed from Jalu, Libya. [Nikon D200, Vixen 90 mm fluorite refractor, fl = 810 mm, f/9 1/1000s, ISO 200. ©2006 Fred Espenak]



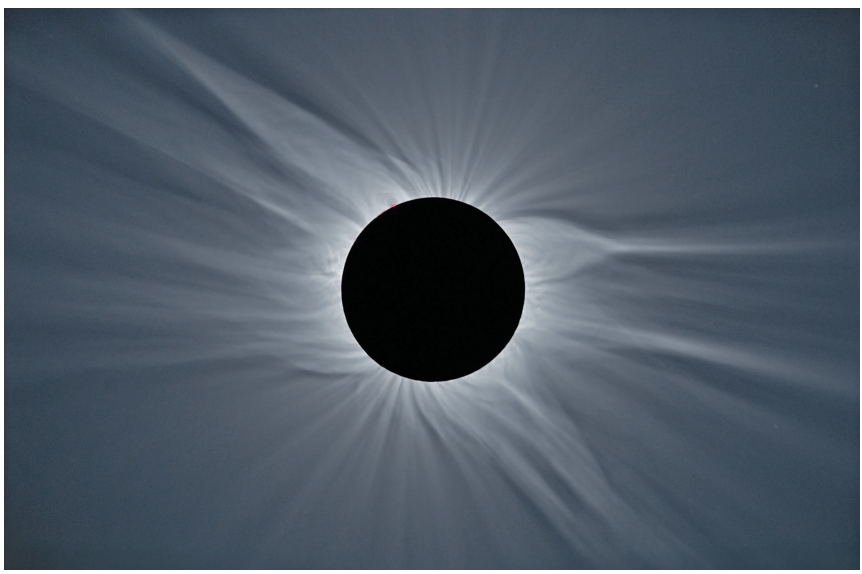
The Moon barely covered the Sun during the total eclipse of November 3, 2013 from Pokero, Uganda. This offered photographers the rare chance to record prominences and the chromosphere surrounding the entire limb of the Moon. [Nikon D800, Televue 102 refractor, fl = 1500 mm, f/15, 1/800 second. ©2013 Jaime M. P. Vilinga]

A low-altitude total eclipse offers the perfect opportunity for a "selfie" with totality. The total eclipse of August 1, 2008 was photographed from the deserts of northern China. [Canon G9, ISO 400, f/5.6, autoexposure. ©2008 Fred Espenak]

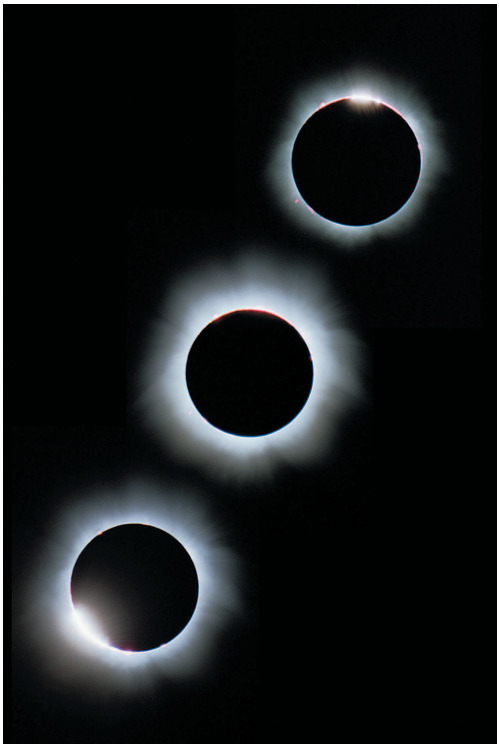
The Altiplano of Chile offered a unique landscape complete with volcanoes for the total solar eclipse of November 3, 1994. [35 mm SLR, 28 mm lens, f/2.8, 2s, Ektachrome 100 slide film. ©1994 Alan Dyer]

Amazing detail in the prominences and chromoshpere are visible in this high-magnification image of the July 11, 2010 total eclipse from Easter Island. [Nikon D700, Borg 100ED and 2x teleconverter, fl = 1280 mm, ISO 800, f/12.8 at 1/5000 second. ©2010 Dave Kodama]

The diamond ring effect is photographed with the Sun just clearing the high Andes Mountains. Excited eclipse watchers are seen in the foreground of this dramatic image of the July 11, 2010 total eclipse from near El Calafate, Argentina. [Nikon D300, Nikon 24–120 zoom, auto-exposure. ©2010 Charles Fulco]

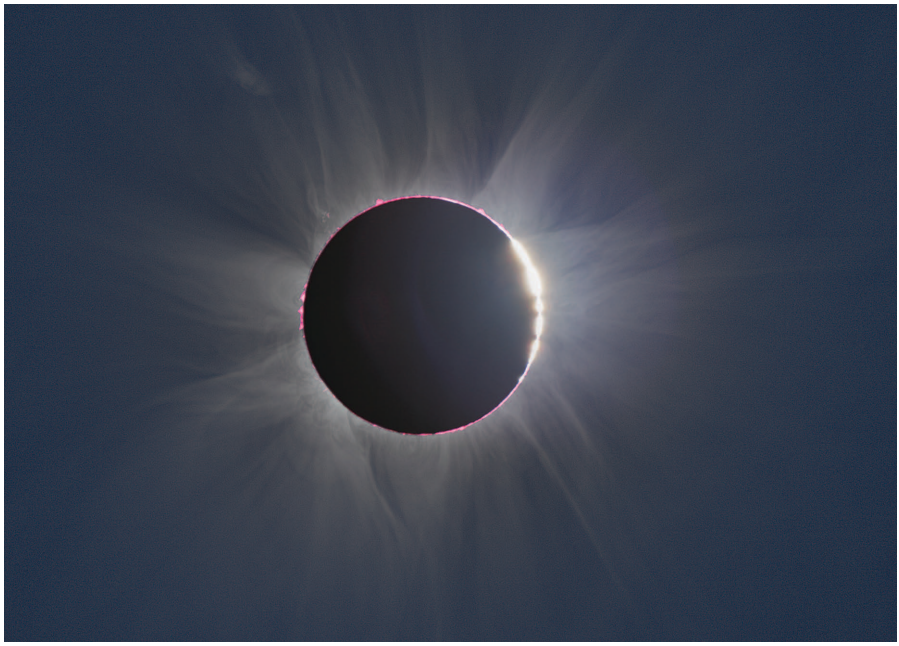


Details in the corona are revealed in this Photoshop composite that was processed to bring out fine structure. The images were obtained during the March 29, 2006 eclipse from the Sahara Desert in northern Libya. [Nikon D200 DSLR, TeleVue Ranger 70 mm refractor, fl = 476 mm, f/6.8, composite of 22 exposures: 1/1000 to two seconds, ISO 200. ©2006 Fred Espenak]



Totality is framed by two diamond rings in this composite of three images shot from Lake Hazar, Turkey during the August 11, 1999 total eclipse. [Nikon 6006 SLR, Celestron C90 Maksutov, fl = 1000 mm, f/11, auto-exposure, Kodak Royal Gold 400 negatives. ©1999 Patricia Totten Espenak]

Sometimes a hole in the clouds appears at just the right moment as in this photo shot from a sailing ship in the Atlantic during the total solar eclipse of November 3, 2013. [Canon 5D Mark II, 19 mm, f/2.8, 1/60 second. ©2013 Alan Dyer]



Baily's beads are captured as totality ends during the November 3, 2013 total solar eclipse from Uganda. This complex photo was produced from images shot with two cameras and processed with custom software. [Canon 6D and 350D, lenses: Rubinar 10/1000 mm, 3M-5CA 8/500 mm, ISO 250 and 100, 23 exposures: 1/500 to one second. © 2014 Miloslav Druckmüller]

The frigid landscape of Svalbard served as the backdrop for this wide-angle image of the March 20, 2015 total eclipse of the Sun. [Sony A550, Sigma 10–20 zoom, f/4.5, 1/10 second. ©2015 Sarah Marwick]

1

The Experience of Totality

In rating natural wonders, on a scale of 1 to 10, a total eclipse of the Sun is a million.

An observer who has seen 27 total eclipses[1]

First contact. A tiny nick appears on the western side of the Sun.[2] The eye detects no difference in the amount of sunlight. Nothing but that nick portends anything out of the ordinary. But as the nick becomes a gouge in the face of the Sun, a sense of anticipation begins. This will be no ordinary day.

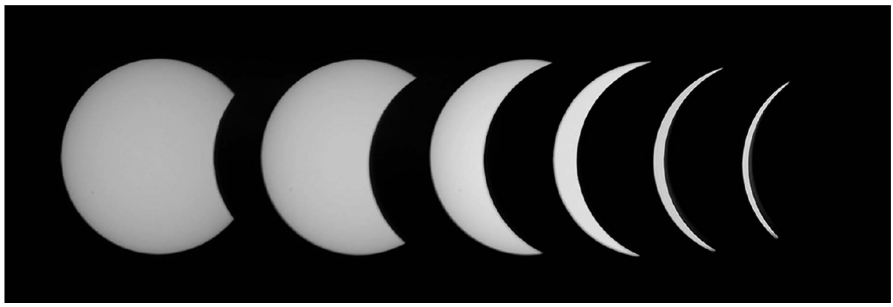
Still, things proceed leisurely for the first half hour or so, until the Sun is more than half covered. Now, gradually at first, then faster and faster, extraordinary things begin to happen. The sky is still bright, but the blue is a little duller. On the ground around you the light is beginning to dim. Over the next 10 to 15 minutes, the landscape takes on a steely gray metallic cast.

As the minutes pass, the pace quickens. With about a quarter of an hour left until totality, the western sky is now darker than the east, regardless of where the Sun is in the sky. The shadow of the Moon is approaching. Even if you have never seen a total eclipse of the Sun before, you know that something amazing is going to happen, is happening now—and that it is beyond normal human experience.

Less than 15 minutes until totality. The Sun, a narrowing crescent, is still fiercely bright, but the blueness of the sky has deepened into blue-gray or violet. The darkness of the sky begins to close in around the Sun. The Sun does not fill the heavens with brightness anymore.

Five minutes to totality. The darkness in the west is very noticeable and gathering strength—a dark, amorphous form rising upward and spreading out along the western horizon. It builds like a massive storm, but in utter silence, with no rumble of distant thunder. And now the darkness begins to float up above the horizon, revealing a yellow or orange twilight beneath. You are already seeing through the Moon's narrow shadow to the resurgent sunlight beyond.

The acceleration of events intensifies. The crescent Sun is now a blazing white sliver, like a welder's torch. The darkening sky continues to close in around the Sun, faster, engulfing it.



Partial phases of the total solar eclipse of March 29, 2006, from Jalu, Libya. [Nikon D200 DSLR, Sigma 170–500 mm at 500 mm, f/11, 1/500 s, ISO 200, Thousand Oaks Type 3 solar filter. ©2006 Patricia Totten Espenak]

Minutes have become seconds. A ghostly round silhouette looms into view. It is the dark limb of the Moon, framed by a white opalescent glow that creates a halo around the darkened Sun. The corona, the most striking and unexpected of all the features of a total eclipse, is emerging. At one edge of the Moon the brilliant solar crescent remains. Together they appear as a celestial diamond ring.

Suddenly, the ends of the bare sliver of the Sun break into individual points of intense white light—Baily's beads—the last rays of sunlight passing through the deepest lunar valleys. The beads flicker, each lasting but an instant and vanishing as new ones form. And now there is just one left. It glows for a moment, then fades as if it were sucked into an abyss.

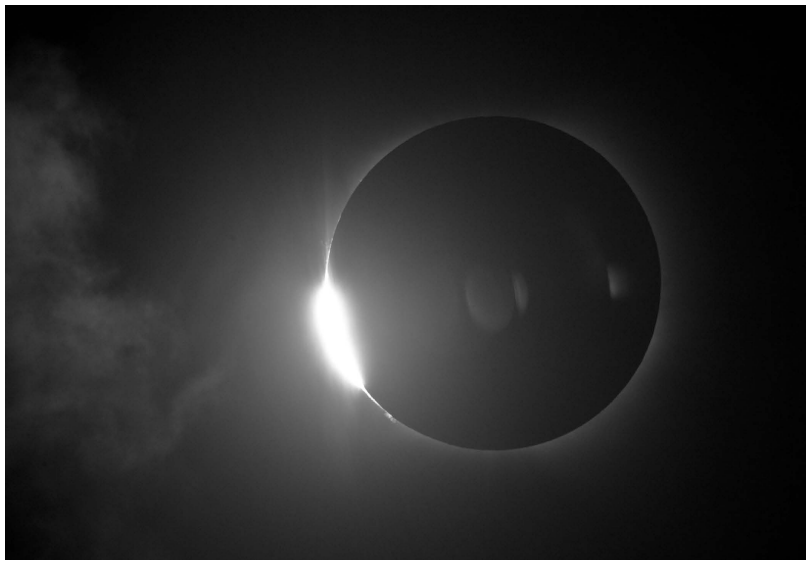
Totality.

Where the Sun once stood, there is a black disk in the sky, outlined by the soft, pearly white glow of the corona, about the brightness of a full moon. Small but vibrant reddish features stand at the eastern rim of the Moon's disk, contrasting vividly with the white of the corona and the black where the Sun is hidden. These are the prominences, giant clouds of hot gas in the Sun's lower atmosphere. They are always a surprise, each unique in shape and size, different yesterday and tomorrow from what they are at this special moment.

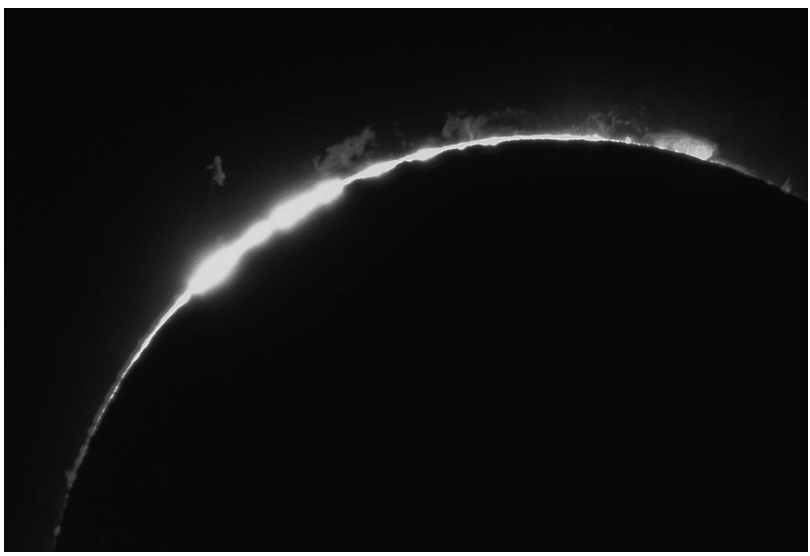
You are standing in the shadow of the Moon.

It is dark enough to see Venus and Mercury and whichever of the brightest planets and stars happen to be close to the Sun's position and above the horizon. But it is not the dark of night. Looking across the landscape at the horizon in all directions, you see beyond the shadow to where the eclipse is not total, an eerie twilight of orange and yellow. From this light beyond the darkness that envelops you comes an inexorable sense that time is limited.

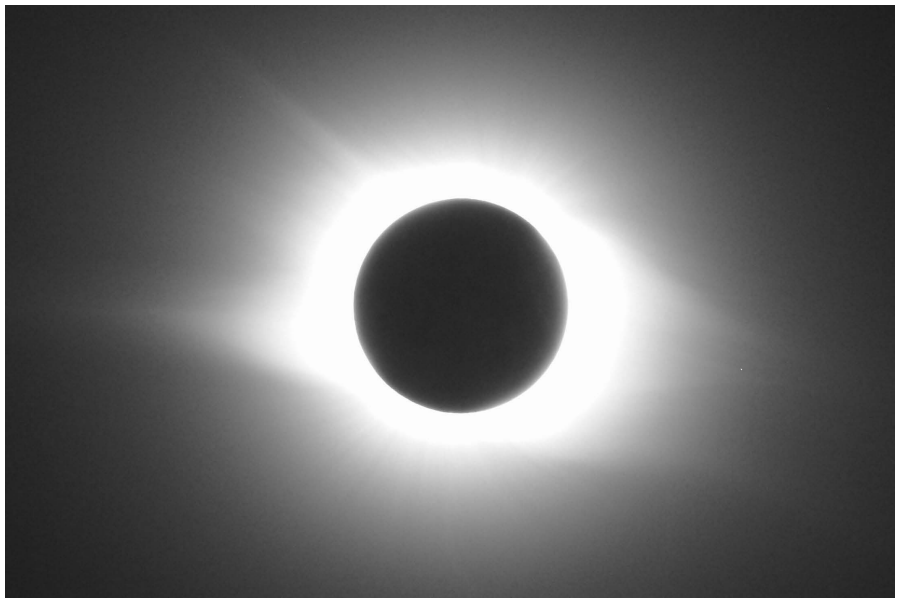
Now, at the midpoint in totality, the corona stands out most clearly, its shape and extent never quite the same from one eclipse to another. And only the eye can do the corona justice, its special pattern of faint wisps and spikes on this day never seen before and never to be seen again.



Diamond ring effect at the total solar eclipse of July 11, 2010, from Easter Island. [Nikon D700, Borg 100ED & 2x teleconverter, fl = 1280 mm, ISO 800, f/12.8 at 1/4000 second. ©2010 Dave Kodama]



Baily's beads are seen amid a forest of prominences during the total solar eclipse of August 11, 1999, from Lake Hazar, Turkey. [Pentax SLR, 94 mm Brandon refractor, f/30, 1/125 s, Ektachrome V100 film pushed to ISO 200. ©1999 Greg Babcock]



The outer corona is revealed during the total eclipse of August 1, 2008, from Novosibirsk, Russia. [Canon 450D, 300 mm, ISO 100, f/8, 1/2 second. ©2008 Arne Danielsen]

Yet around you at the horizon is a warning that totality is drawing to an end. The west is brightening while in the east the darkness is deepening and descending toward the horizon. Above you, prominences appear at the western edge of the Moon. The edge brightens.

Suddenly totality is over. A point of sunlight appears. Quickly it is joined by several more jewels, which merge into a sliver of the crescent Sun once more. The dark shadow of the Moon silently slips past you and rushes off toward the east.

It is then you ask, "When is the next one?"[3]

NOTES AND REFERENCES

1. Epigraph: Fred Espenak, October 24, 2014.
2. In sky observations, the western side of the Sun or Moon refers to the edge of the Sun or Moon closer to the western horizon. For observers in mid-northern latitudes, the Sun is usually to the south. When facing south, east is to the left and west is to the right. This south-looking orientation can briefly confuse readers who are used to maps that are oriented north, so that east is to the right and west to the left.
3. Special thanks to John Beattie of New York City, upon whose experience and description this chapter is based.

A MOMENT OF TOTALITY

Reaction to Totality

Eclipse veteran Sheridan Williams says that at the end of totality, the usual reaction of a first-time eclipse observer is "It was so short," "That was the most amazing thing I've ever seen," "I never realized it could be so beautiful," and "When is the next one?" Often they have tears in their eyes. There are not enough superlatives.

"After seeing a total eclipse," Sheridan says, "I have never, never heard anyone say, 'I don't see what all the fuss was about' or 'Why bother to see another one?'"[1]

[1] Sheridan Williams is a British rocket scientist (retired) and a Fellow of the Royal Astronomical Society.

2

The Great Celestial Cover-Up

If God had consulted me before embarking upon creation, I would have recommended something simpler.

Alfonso X, King of Castile (1252)[1]

A total eclipse of the Sun is exciting and even profoundly moving.

But what causes a total solar eclipse? The Moon blocks the Sun from view. And that is all you absolutely need to know to enjoy a solar eclipse. So you can now skip to the next chapter.

If however you are reading this paragraph, you are right: there is more to tell—about dark shadows and oblong orbits and tilts and danger zones and amazing coincidences. Yet before you venture further, promise yourself one thing. If for any reason your eyes begin to glaze over, stop reading this chapter immediately and go right on to the next. You must not let celestial mechanics, or this explanation of it, stand in the way of your enjoyment of the wild, wacky, and wonderful things people have thought and done about solar eclipses.

Moon Plucking

How big is the Moon in the sky? What is its angular size?

Extend your arm upward and as far from your body as possible. Using your index finger and thumb, imagine that you are trying to pluck the Moon out of the sky ever so carefully, squeezing down until you are just barely touching the top and bottom of the Moon, trapping it between your fingers. How big is it? The size of a grape? A plum? An orange?

It is the size of a pea. (You can win bets at cocktail parties with this question.) The Moon has an angular size of only half a degree.

Now, how large is the Sun in the sky? Your friends will almost all immediately guess that it is bigger. Before they damage their eyes by trying the Moon pinch on the Sun, just remind them that a total eclipse is caused by the Moon completely covering the Sun, so the Sun must appear no bigger