Moonbows over Yosemite

By Donald W. Olson, Russell L. Doescher,
and the Mitte Honors Students

The rainbow occurs by day, and it was formerly thought that it never appeared by night as a moon rainbow. This opinion was due to the rarity of the phenomenon: it was not observed, for though it does happen, it does so rarely. . . . The colors are not easy to see in the dark. . . . The moon rainbow appears white.

— Aristotle, *Meteorologica,* about 340 BC

More than mountain air and daytime scenery beckon visitors to Yosemite National Park each spring — many go for a chilly, damp, nighttime vigil.

Few sights evoke such spontaneous delight and wonder as a late-afternoon rainbow bursting into view in the eastern sky after a spring downpour. Even before it appears, you sense that it might, and you keep a lookout. Maybe you once fancied finding a pot of gold where the colorful arc ends.

Yet how many of us have seen a rainbow at night? While this is a fairly rare event, nature lovers as far back as Aristotle knew it was possible for a bright Moon, like the Sun, to produce a rainbow.

When rays of light from the Sun (or Moon) shine on spherical drops of water in a rain shower, a combination of refraction, internal reflection, and dispersion can produce a rainbow display. The primary bow forms a circular arc with a radius of 42°, and under good conditions a much fainter secondary rainbow can appear with a radius of 51° and with the sequence of colors reversed.

By day the center of the rainbow is the *antisolar point,* the point exactly opposite the Sun and therefore marked by the shadow of your head. It is located as far below the horizon as the Sun is above the opposite horizon. At night the geometry is the same except that the antilunar point (opposite the Moon) is the center for this display — known as a lunar rainbow, moon rainbow, or moonbow.

Time-exposure photographs show that the full palette of col-

Kim Steinbacher set up her tripod at the viewing area near the base of Lower Yosemite Fall to capture this double moonbow about 11 p.m. PDT on May 22, 2005. With mist and spray blowing down from the fall, she struggled to keep the camera and lens dry during the long exposure.

BRENT GILSTRAP

A reflected moonbow appears in this unusual scene captured by Brent Gilstrap near 1:20 a.m. PDT on May 15, 2006, from the edge of the parking lot next to Sentinel Bridge (some 900 yards farther back than the usual viewing area). The image is a four-frame vertical panorama made from three 30-second exposures and (at bottom) a 60-second exposure. The reflection is from Cook's Meadow, which was flooded by an unusually large spring runoff. Yosemite National Park had received about twice the normal snowfall during the preceding winter.

ors is present in lunar rainbows. The human eye loses most of its color sensitivity in dim light, and visual observers usually describe moonbows as gray, white, or silver. But under ideal conditions — clear air, abundant water drops, and bright moonlight from a full or nearly full Moon — some people have reported seeing the colors in lunar rainbows.

Mark Twain and Moonbows

In his 1872 travel narrative *Roughing It* (chapter 71), Mark Twain records such an observation that he made in 1866 during a trip to Hawaii:

> *Why did not Captain Cook have taste enough to call his great discovery the Rainbow Islands? These charming spectacles are present to you at every turn; they are common in all the islands; they are visible every day, and frequently at night also — not the silvery bow we see once in an age in the States, by moonlight, but barred with all bright and beautiful colors, like the children of the sun and rain. I saw one of them a few nights ago.*

The celebrated author was returning to America from a European tour in 1879 when he again experienced near-ideal conditions. He described what he saw in a notebook entry for August 31, 1879:

> *At sea in the "Gallia" . . . about 9 PM brilliant moon, a calm sea, & a magnificent lunar rainbow — a complete arch, the colors part of the time as brilliant as if it were noonday — some said not* quite *as brilliant, softened with a degree of vagueness, but to me it was not different from a daylight rainbow.*

Twain considered himself very fortunate to have seen this wonder twice in his life.

Ben Franklin at Sea

Another account of a lunar rainbow at sea comes from the young Benjamin Franklin, on a return voyage from London to Philadelphia in 1726. His journal entry for August 30th (Julian calendar), equivalent to September 10th (Gregorian calendar), reads:

> *Contrary wind still. This evening the moon being near full, as she rose after eight o'clock, there appeared a rainbow in a western cloud to windward of us. The first time I ever saw a rainbow in the night caused by the moon.*

Astronomers will find much of interest in Franklin's journal for this trip, including his observations of a partial solar eclipse and then, two weeks later, a partial lunar eclipse.

Moonbows and Waterfalls

Instead of waiting for a rain shower on a moonlit night, observers can find moonbows more reliably in the spray near waterfalls. At Victoria Falls, on the border between Zambia and Zimbabwe, tour companies offer "lunar rainbow tours." Moonbow observing is also a popular activity at Cumberland Falls in Kentucky, and early postcards show a hotel named the Moonbow Inn adjacent to the falls. Lunar bows were a great tourist attraction at Niagara Falls in the years before the installation of artificial night lighting, and two topographic features there (Luna Island and Luna Falls) took their name from the phenomenon.

Muir and Yosemite Moonbows

John Muir, the naturalist largely responsible for the creation of Yosemite National Park, eloquently described moonbows in waterfalls:

> *Lunar rainbows or spray-bows also abound in the glorious affluence of dashing, rejoicing, hurrahing, enthusiastic spring floods, their colors as distinct as those of the sun and regularly and obviously banded, though less vivid. Fine specimens may be found any night at the foot of the Upper Yosemite Fall, glowing gloriously amid the gloomy shadows and thundering waters, whenever there is plenty of moonlight and spray. Even the secondary bow is at times distinctly visible.*

US MINT

In his 1912 book *The Yosemite,* Muir urged visitors

S&T: ROGER W. SINNOTT

RUSSELL DOESCHER

S&T: ROGER W. SINNOTT

Left: In September 2005, the authors use rulers, plumb bobs, and a laser level to make a topographic survey at the viewing area near the base of Lower Yosemite Fall. Left to right are Kellie Beicker, Russell Doescher, and Don Olson. *Center:* Joined by *Sky & Telescope* senior editor Roger Sinnott (left), the group determines the direction of the geometric horizon and the distance to the base of the fall, which was nearly dry at this season. Ashley Ralph is at right. *Right:* Olson and Doescher plan the sky photographs they would need to take from the base of the fall at night.

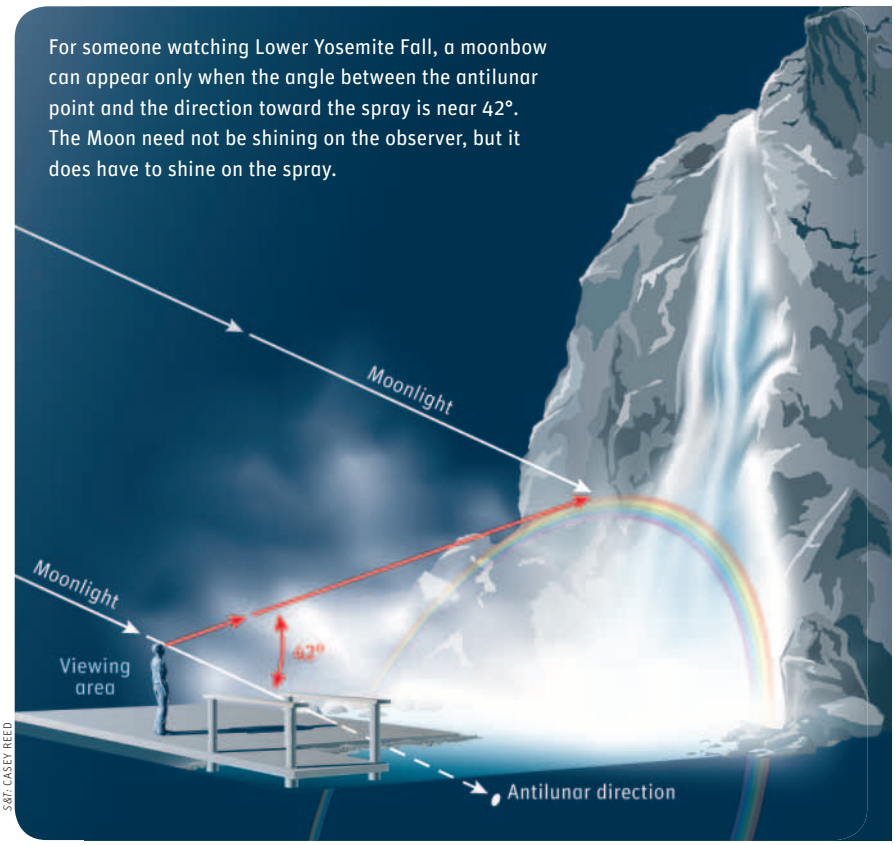
to explore Yosemite Valley at night and to look for the moonbow:

> *This grand arc of color, glowing in mild, shapely beauty in so weird and huge a chamber of night shadows, and amid the rush and roar and tumultuous dashing of this thunder-voiced fall, is one of the most impressive and most cheering of all the blessed mountain evangels.*

Standing alone in the night near the north rim of the valley, Muir delighted in the magical sights that have drawn pilgrims to this place on moonlit nights for more than a century:

> *The moonbeams were pouring through. . . . I saw a well-defined spray-bow, beautifully distinct in colors . . . while pure white foam-waves beneath the beautiful bow were constantly springing up out of the dark into the moonlight like dancing ghosts.*

Four decades earlier, in April 1871, Muir had written in a letter to Mrs. Jeanne S. Carr, "Silver from the moon illumines this glorious creation which we term 'falls,' and has laid a magnificent double prismatic bow at its base. The tissue of the fall is delicately filmed on the outside like the substance of spent clouds, and the stars shine dimly through it."



S&T: CASEY REED

SIMONE RIVERS

Above: The arrow points to the Lower Yosemite Fall viewing area, a paved terrace at the west end of the wooden bridge over Yosemite Creek. The viewing area, a popular spot for moonbow observing and photography, is 180 yards from the base of the fall.

Inspired by Muir's dramatic accounts, we decided to write a computer program to predict dates and precise times when moonbows would appear in the Yosemite waterfalls.

Missing Moonbow in 2005?

While searching for moonbow-related messages in the archive of Calphoto, a Yahoo Groups discussion forum about nature photography in California, we ran across an incident that made us realize how useful our program's predictions might be.

On the evening of June 22, 2005, the Moon was just slightly past full with 98% of its disk illuminated. Accordingly, about 50 photographers gathered under a clear sky at the viewing area near the base of Lower Yosemite Fall to await the moonbow. As the evening wore on, the temperature dropped toward freezing, and mist blowing down from the waterfall made it impossible to stay dry. By about midnight the gathering broke up in disappointment.

On the discussion list the next day, group members wondered why the moonbow had failed to appear, even with "all obvious conditions in place." One message ended with the words: "What has changed to eliminate this other unique feature of Yosemite?"

Computing Moonbow Visibility

We realized that six conditions must be simultaneously met for a moonbow to be readily visible at Lower Yosemite Fall. The first two conditions are weather dependent, but the last four are astronomical and can be modeled by a computer program:

- **CLEAR SKY AROUND THE MOON.**
- **ABUNDANT MIST AND SPRAY AT THE BASE OF THE FALL.** The best moonbows at Yosemite occur during the snowmelt runoff season of April, May, June, and sometimes early July.
- **DARK SKY.** Our program requires that the Sun be more than 9° below the geometric horizon.
- **BRIGHT MOONLIGHT.** The Moon's brightness depends on its phase, distance from Earth, and altitude. Our program requires that the moonlight be brighter than a cutoff value corresponding to a Moon at an altitude of 25°, at its mean distance, and with an illuminated fraction of 95%.
- **MOONLIGHT NOT BLOCKED BY MOUNTAINS OR CLIFFS.** For moonlight to strike the spray at the base of Lower Yosemite Fall, the Moon must have risen above the nearby mountains, domes, and cliffs. To determine the profile of the local horizon, we needed to visit Yosemite and take photographs from the base of the fall.
- **CORRECT RAINBOW GEOMETRY.** The Lower Yosemite Fall viewing area is a paved terrace at the west end of a wooden bridge over Yosemite Creek. For an observer at this spot, a moonbow will appear only when the angle between the antilunar point and the direction toward the base of the fall is near the rainbow angle of 42°. Understanding this topography provided another reason to travel to Yosemite.

WWW.CALVINBRADSHAW.COM

A spectacular moonbow forms in the mist from Victoria Falls as the stars of Orion set behind it. Calvin Bradshaw was visiting Africa from Brisbane, Australia.

Trip to Yosemite

Fortunately, our Texas State group already had a Yosemite trip scheduled! In a previous *Sky & Telescope* article (October 2005, page 40) we predicted that on September 15, 2005, the Moon's position would recreate the scene in a famous Ansel Adams photograph from Glacier Point. That moonrise event was a great success, with hundreds of photographers in attendance (*S&T:* January 2006, page 93), but we actually spent most of our time in the park near Lower Yosemite Fall.

The flow of water was reduced to a trickle in September, which worked to our advantage. We could stand right at the base of the fall, something impossible in the thundering torrents of the spring runoff season. We took photographs at night with the nearby mountains and cliffs silhouetted against brilliant star fields. The known altitudes and azimuths of the stars allowed us to accurately map the local horizon.

By day we did conventional surveying with rulers, plumb bobs, and a laser level. Websites had informed us that Lower Yosemite Fall would be about 100 yards from the viewing area, but our survey found that this distance is actually 180 yards (165 meters). We also determined values for two important angles. A person at the center of the viewing terrace would see the densest part of the spray by facing toward azimuth 325° (that is, 35° west of north) and looking somewhat upward at an altitude of 12°. We now had all the information we needed.

Case of the Missing Moonbow: Solved!

An example will help explain the geometry. On June 23, 2005, at 1:30 a.m. Pacific Daylight Time, a bright, nearly full Moon had risen above the south rim of Yosemite Valley and stood in the sky at azimuth 169° and altitude 23°. Trigonometry shows that the antilunar point (azimuth 169° + 180° = 349°, altitude –23°) was then separated from the densest spray at the base of Lower Yosemite Fall by an angle of exactly 42°. Conditions were perfect for a moonbow.

Given that the mist occupies a rather large region, extending from roughly 8° above to 5° below the densest spray near the base of the fall, our program finds that a moonbow would have been visible from 12:45 to 2:00 a.m.

Rob Ratkowski captured a moonbow, stars, and three planets in this spectacular image looking west near Kahului, Maui, after sunset on May 4, 2004. Behind the photographer a full Moon was rising into the eastern sky. In the west the brightest object was Venus, inside the moonbow and close to Beta (β) Tauri. Above and left of Venus are Mars (inside the bow) and Saturn (outside the bow, among stars of Gemini).

PDT on June 23, 2005. As the Moon rose higher and moved westward, the bow first appeared near the top of the spray and slowly drifted downward and eastward.

We now had an explanation for the disappointing experience of the Calphoto group on the evening of June 22, 2005. The Moon *did* finally clear the local horizon, and a bright moonbow *did* eventually appear, but not until the early hours of the next morning! We realized that our calculations of dates and precise times could save people from long and disappointing waits in the cold and wet.

2006 and 2007

During the snowmelt runoff season of 2006, we tested our program by circulating predicted dates and times to the Calphoto list and to other interested photographers. The photographic results verified the program's accuracy.

The table here gives our moonbow predictions for 2007. Our Texas State website, http://uweb.txstate.edu/~do01, contains more detailed descriptions of the position of the Moon and appearance of the moonbows in 2007, along with links to moonbow photographs from 2006.

Our program typically predicts moonbows on four or five nights near each full Moon during the snowmelt runoff period. This is perhaps slightly conservative. But it's in general agreement with the conclusions of the sharp-eyed John Muir, who judged, "Magnificent lunar bows may be found for half a dozen nights in the months of April, May, June, and sometimes July" (*New York Tribune,* May 7, 1872).

Rain showers and waterfalls are not the only settings where this phenomenon takes place. Anyone can make a moonbow with a garden hose! With a bright Moon high in the sky, direct a fine mist toward a spot 42° away from the shadow of your head. The bow is much easier to see against a dark background, such as a dark bush or wall. Once seen, the ethereal silver-white of the moonbow is not easily forgotten. ✶

Moonbow Predictions for Lower Yosemite Fall

Evening Date in 2007	Pacific Daylight Time	Lunar Phase
April 29 (Sunday)	8:32 p.m. (Sun.) to 9:20 p.m. (Sun.)	96%
April 30 (Monday)	8:33 p.m. (Mon.) to 10:40 p.m. (Mon.)	99%
May 1 (Tuesday)	10:05 p.m. (Tues.) to 11:50 p.m. (Tues.)	100%
May 2 (Wednesday)	11:25 p.m. (Wed.) to 1:00 a.m. (Thurs.)	99%
May 3 (Thursday)	12:37 a.m. (Fri.) to 2:00 a.m. (Fri.)	96%
May 29 (Tuesday)	9:10 p.m. (Tues.) to 10:50 p.m. (Tues.)	97%
May 30 (Wednesday)	10:26 p.m. (Wed.) to 11:50 p.m. (Wed.)	99%
May 31 (Thursday)	11:33 p.m. (Thurs.) to 12:55 a.m. (Fri.)	100%
June 1 (Friday)	12:39 a.m. (Sat.) to 1:50 a.m. (Sat.)	98%
June 28 (Thursday)	10:35 p.m. (Thurs.) to 11:25 p.m. (Thurs.)	98%
June 29 (Friday)	11:30 p.m. (Fri.) to 12:20 a.m. (Sat.)	100%
June 30 (Saturday)	12:20 a.m. (Sun.) to 1:05 a.m. (Sun.)	99%
July 1 (Sunday)	12:55 a.m. (Mon.) to 1:45 a.m. (Mon.)	96%

All calculations are for the prime viewing area, the terrace at the west end of the wooden bridge near the base of Lower Yosemite Fall.

Don Olson *and* Russell Doescher *teach physics at Texas State University.* *They are grateful for support from the Mitte Honors Program, which made it possible for students Kellie N. Beicker, Ashley B. Ralph, and Hui-Yiing Chang to work on this project during the 2005–06 academic year. They also appreciate research assistance from Margaret Vaverek of Texas State's Alkek Library and from moonbow photographers Matt Asai, Mark Bright, Carl Bruce, Brent Gilstrap, Grant Johnson, Jia Liu, Robert Stavers, Kim Steinbacher, and Keith Walklet.*