ORBITAL TILTS AND HIGH-FLYING MOONS

UNDERSTANDING THE GEOMETRY OF LUNAR AND SOLAR DECLINATIONS

By Bill Romanishin

Mention the words "tropical zone" and most people conjure up images of drinks with little paper umbrellas and bodies covered in sand and SPF-50 sunscreen. Astronomically, the tropical zone is defined as the area on Earth where the Sun can be seen directly overhead, at the zenith, at some time during each year. Outside this band, which spans the area between about 23.5 degrees north and south latitude, the Sun never reaches the zenith. No part of the continental United States is in the tropical zone, so even in the hottest deserts of the southwest U.S., the Sun can never be seen directly overhead.

In fact, the width of the tropical zone is shrinking very slowly, as the Earth's tilt, or obliquity, changes (*Sky & Telescope,* June 1 '98, p. 36).

What if, instead of asking where on Earth the Sun can be directly overhead, we ask where on Earth we can see the Moon directly overhead? We might call this the Earth's "lunar zenithal zone." If the Moon's orbit around the Earth were in the same plane as the Earth's orbit around the Sun (the ecliptic plane), then the tropical zone and the lunar zenithal zone would be exactly the same. However, the Moon's orbital plane is tilted by about 5 degrees to the ecliptic plane. Because of this 5-degree tilt, the two zones are quite different.

Two planes tilted with respect to one another always intersect in a straight line. In the Sun-Earth-Moon system, the line of intersection of the ecliptic plane and the plane of the Moon's orbit around the Earth is called the line of nodes. Solar or lunar eclipses can only happen when the Moon is near the line of nodes and thus near the ecliptic. Only at this time can the Sun, Earth, and Moon line up in the nearly straight line necessary for an eclipse to take place. If the line of nodes were fixed in space, then we could only have solar and lunar eclipses around the same two times each year, as the Earth's motion around the Sun would position the line of nodes near the Earth-Sun line regularly twice a year. Of course, eclipses do not follow such a seasonal pattern. This is because the line of nodes rotates in space, as seen by an outside observer, due to the "wobble" of the Moon's orbital plane. This rotation of the line of nodes takes about 18.6 years to complete.

The rotation of the line of nodes obviously has a critical role to play in determining the dates of eclipses. A less-well-known consequence of the rotation of the line of nodes is that the maximum and minimum, or the range, in declination that the Moon reaches each month varies with the same 18.6-year periodicity. Declination, of course, is the angle between a spot on the sky and the celestial equator, while latitude is the angle between a spot on the Earth and the Earth's equator, as seen from the center of the Earth. For a celestial object at the zenith, the declination of the object is equal to the latitude of the observer. If the Moon orbited in the Earth's equatorial plane (as many moons orbit their planets), the Moon would always have the same declination.

If the Moon followed the Sun's path in the sky along the ecliptic, the range in lunar declination would be the same as the Sun's, about 23.5 degrees north and south, for a total range of about 47 degrees. But because of the 5-degree tilt between orbital planes, the Moon is sometimes found up to 5 degrees farther from the Earth's equatorial plane than the Sun, and at other times up to 5 degrees closer. Thus, when the orbital planes are oriented so that the Sun is at maximum declination north or south, and the Moon's orbit is tilted so that the Moon is at a more extreme equatorial angle than the Sun, the Moon can be seen overhead at a latitude up to about 28.5 degrees north or south. When the Moon is closer to the equatorial plane than the Sun, the Moon's declination range can be as low as about 18.5 degrees north and south. These effects cause the lunar zenithal zone to vary significantly in width in latitude, from a minimum about of 37 degrees (twice 18.5) to a maximum of 57 degrees (twice 28.5) with an 18.6-year periodicity.

To illustrate the readily observable results of this phenomenon, I used the HORIZONS system provided by NASA's Jet Propulsion Laboratory to calculate the position in the sky of the Moon, the illuminated fraction of the Moon, and the Earth-Moon distance for every hour of every day between the start of 2014 and the start of 2034. This period spans a little more than one period of the nodal rotation. The sky ➡

positions are for a hypothetical geocentric observer located at the center of the Earth. The actual declination of the Moon as seen by any particular observer on Earth will differ from the geocentric positions by up to about 1 degree due to parallax. However, if we want to ask where the Moon passes directly overhead, the geocentric positions are fine, as an observer seeing the Moon directly overhead would be on the line between the center of the Earth and the Moon, so would have no parallactic correction to the Moon's position as compared with geocentric coordinates.

There are many ways to look at this huge list of numbers. The maximum northerly declination reached by the Moon occurs on March 7, 2025, when the Moon is at declination of +28.71 degrees and is about 60 percent illuminated. (All dates are given in Universal Time, so they may differ one day from local dates.) For southern hemisphere observers, the maximum southerly declination is −28.72 degrees on March 22, 2025, with the Moon 52 percent illuminated. However, these are not particularly unusual occurrences, as there are many dates when the Moon reaches almost as far north or south.

Undoubtedly the greatest visual effect of the Moon's changing declination occurs when the Moon is full. So I plotted the times and Moon declinations for the 247 full Moons between the beginnings of 2014 and 2034. During 2015 and 2016 there is a broad minimum in the Moon's declination range, as the declination of the full Moons range from roughly 18.5 degrees north to 18.5 degrees south. During the 2024–2025 period the nodal rotation next brings the Moon to its farthest point from the equator, and the full Moons range in declination up to about 28.5 degrees north and south. During the current year, 2018, the maximum lunar declination starts to increase noticeably. The full Moon on January 2, 2018, was the first full Moon above +20 degrees declination in about 5 years. Over the next 7 or 8 years the full Moons near the December solstice will pass a little higher in the sky each year for northern hemisphere observers.

I present two plots, each of which shows the declinations of full Moons and the declination of the Sun.

The first figure is for years 2015, 2016, and 2017. The date and declination of each full Moon is shown as a filled circle. The solid line is the declination of the Sun as a function of time. As the full Moon is always opposite in the sky from the Sun, the declination of the full Moon and Sun are roughly mirror images of each other.

For northern hemisphere observers, the middle of each year brings summer, and the Sun rides high in the daytime sky and the full Moon rides low in the nighttime sky. Near the end of each year, close to the December solstice, the positions are reversed. Note that the range in declination of the full Moons is less than the range of declinations for the Sun during the years 2014 to 2016. The second plot shows the same data for the years 2024, 2025, and 2026. The range of declination for the full Moons is now clearly larger than that for the Sun. For the years between these plots (more plots can be found on my website), the early northern winter full Moon will cross the meridian a little higher in the sky each year. Thus the width of the lunar zenithal zone is smaller than the tropical zone in 2014–2016 and larger than the tropical zone in 2024–2026.

The northernmost full Moon will occur on December 15, 2024, at a declination of +28.22 degrees. In the continental United States, southern parts of Florida and Texas will be able to see the Moon pass directly overhead, and the Moon will pass the meridian as close to the zenith as is possible for most U.S. observers. The closer an object is to the zenith, the less atmosphere it is seen through, and the brighter it appears, so the full Moon should appear a little brighter than usual for people in the continental U.S. But of course the brightness of the full Moon depends primarily on its distance from Earth. The Earth-Moon distance varies from about 357,000 to 405,000 km. The distance varies in a complicated way that is not in sync with the phase or declination of the Moon. The full Moon of December 15, 2024, will be at a distance of 370,400 km, which is somewhat closer than average, but certainly not a particularly close approach.

Are there any upcoming particularly close full Moons that will also be at extreme northerly or southerly declination? The term "supermoon" has been applied to full Moons that are particularly close to Earth. There are various definitions of supermoon, but one is that the full Moon is closer than 90 percent of all full Moons.

I made a list of the closest 10 percent of full Moons over the 2014–2034 period and compared

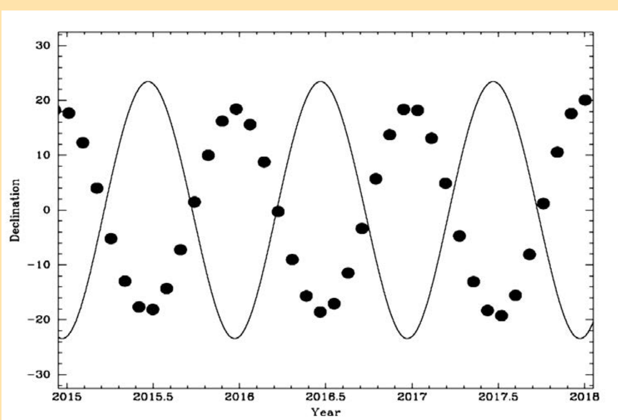

Figure 1: Sun and full Moons, 2015–2017. The date and declination of each full Moon is shown as a filled circle. The line is the declination of the Sun. During these years, the declination range of the full Moons is at its minimum. The full Moons do not reach as far north and south as does the Sun.

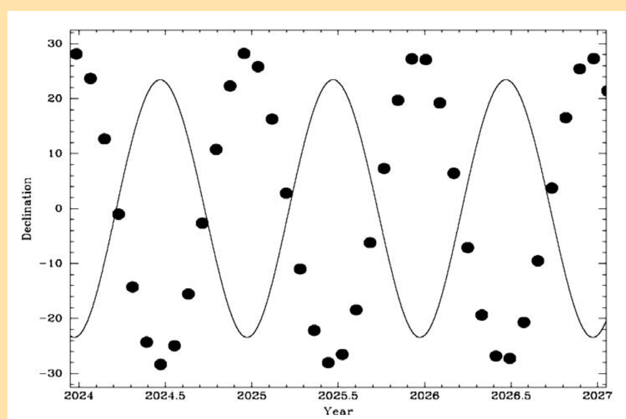

Figure 2: Sun and full Moons, 2024–2026. During these years, the declination range of the full Moons is at its maximum. As seen from the Earth, the full Moons clearly range farther north and south than does the Sun.

this to the list of high-declination Moons. Four full Moons stand out. The full Moon of December 24, 2026, will be not only the third most northerly full Moon (+27.29 degrees) but will also be the fifth closest of the 247 full Moons between 2014 and 2034! This full Moon will come within a scant 304 km (0.09 percent) of the closest the Moon approaches Earth in the entire 21st century. The closest approach between the Moon (any phase) and the Earth in the 21st century will occur on December 6, 2052, at a center-to-center distance of 356,421 km (*Sky & Telescope*, August 1981, p. 110). The full Moon on December 4, 2025 (+27.25 degrees) will come within 800 km (0.22%) or so of the closest Moon. For observers in the southern hemisphere, the full Moon of July 13, 2022, (−26.20 degrees) will be about 1000 km (0.27%) farther than the closest Moon, and the full Moon of June 14, 2022 (−25.88 degrees) will be within 1200 km (0.36 percent) of the closest the Moon comes in the 21st century. These combinations of particularly high (or low) declination and close distance should make these full Moons just about the brightest possible for northern or southern hemisphere observers at mid-latitudes.

The full Moon closest to Earth during the 2014–2034 period was that of November 14, 2016. This full Moon was only about 101 km (0.03 percent) farther than the closest 21st-century Moon approach. The full Moon of January 2, 2018, was the second closest full Moon of the 2014–2034 period, only about 90 km farther from Earth than the November 2016 full Moon.

These nights of bright, high-flying full Moons would be particularly bad nights to look for faint galaxies or nebulae. They would even be poor nights to look at the Moon through a telescope, as the lack of shadows of lunar features near full Moon makes the Moon look flat and uninteresting. These nights would be good for some nighttime hiking or cross-country skiing, and for contemplating the many motions of our magnificent Moon.

More detailed plots and various lists of full Moons and hourly lunar positions can be found at my website, *hildaandtrojanasteroids.net*. ★

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GALLERY

More GALLERY can be found on pages 29–30

NOTE:
We can't do this image justice at this size in the magazine. At full size, mapped to 300 pixels per inch, the Moon's diameter would be over 17 inches!

Thomas Spirock
(Springfield Telescope Makers)

Full Moon, July 28, 2018, taken with the Warner & Swasey / Brashear 6-inch refractor at Mt. Wilson Observatory, operating at f/15, with a ZWO ASI1600MM camera and a wide-band red filter.

Initial data was twelve 30 second (~200 images) videos – four sections of the Moon each captured with 2, 4, and 6 millisecond exposures. Each video was converted to a single image with AutoStakkert!, using the best 32 images.

RegiStax was used for wavelet processing.

Each group of four images was stitched together with Adobe Photoshop, to make three complete images of the full Moon, at 2, 4, and 6 millisecond exposures.

The three images were then combined into one HDR image using Photomatix Essentials.