Lunation Rumination

by Bruce McCurdy (bmccurdy@freenet.edmonton.ab.ca)

Pop quiz: How long is a month?

This decidedly tricky question has a virtual infinitude of answers: a (western) calendar month can be anything from 28 to 31 days, menstrual cycles differ from woman to woman and from one month to the next, while the drought between pay cheques can seem to stretch on interminably.

For the purposes of this exercise, I will stick to the astronomical definition(s). The *Observer's Handbook 2001* lists no fewer than five separate periods:

Draconic month (node to node)	= 27.212 221 d
Tropical (equinox to equinox)	= 27.321 582 d
Sidereal (fixed star to fixed star)	= 27.321 662 d
Anomalistic (perigee to perigee)	= 27.554 550 d
Synodic (New Moon to New Moon)	= 29.530 589 d

The six significant digits in each case suggest that these periods are known to something like a tenth of a second; indeed, other sources list as many as nine decimal places, reducing the period in question to the nearest "nano-day." However, what is typically left unstated is that in all cases these figures are *averages* derived over very long periods. Individual months are actually like the proverbial snowflakes, no two exactly alike.

The Sun-Earth-Moon system is the classic manifestation of the three-body problem, with the tiny Moon showing the most easily measurable influences of its two larger neighbours. Add in the infinitesimal gravitational effects of the other planets, Earth's equatorial bulge, and tidal friction, and the lunar orbit is in a permanent state of evolution. Fortunately, for the purpose at hand, we need look only at the effects caused by the eccentricity of both the Moon's and Earth's orbits.

The primary focus of this rather elliptical exercise is the synodic month, also known as a lunation, defined as the interval from one New Moon to the next. Using a spreadsheet, I entered the times of all New Moons for the period 1990–2020, as listed in Jean Meeus' *Astronomical Tables of the Sun, Moon and Planets*. In the period under review, lunations varied from a minimum of 29 days 6 hours 46 minutes (May 25 to June 24, 2017) to a maximum of 29 days 19 hours 50 minutes (January 4 to February 3, 1992: more on this below). Rather than jumping about randomly, these periods followed a regular curve. Figure 1 details this curve in the short term, namely the three year period 2000–02. One can immediately see that the "long months" are grouped together, with the peaks occurring some 14 lunations apart, and the valleys of "short months" occurring at the intervals midway between the peaks.

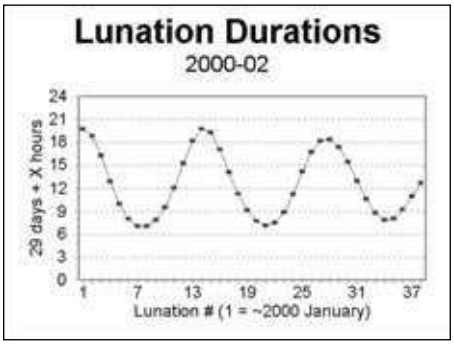


Fig. 1 — Variations in the duration of a synodic month over the period 2000-02. The effect is a rough sine curve with a wavelength of 14 months and an amplitude of about 13 hours. Bear in mind the variance appears exaggerated due to the scale of the graph; *i.e.*, the day represented here is actually the thirtieth day, so the curve should resemble a turret atop a tower 29 days high.

What's going on? I quickly determined that the primary influence is the distance of the Moon from Earth around the time of each successive New Moon. The Moon can be up to 50,000 km closer at its perigee, or closest approach to Earth, than at apogee. The Moon's orbital speed is at its fastest at perigee; also, its relative proximity to Earth effectively gives it a tighter turning radius to the Earth-Sun line, further speeding the change in phase angle. Indeed the careful naked-eye observer can actually see the Moon move further than normal from one day to the next when near perigee. As the anomalistic month from one perigee to the next is some two days shorter than the synodic, the Moon achieves perigee at an earlier phase each month. Therefore a lunation which begins near a perigee will include two "extra" days of the Moon moving at its fastest, which thus reduces the amount of time required to catch up with the Earth-Sun line. The shortest of all lunations are those that include two perigees, one just after New Moon and one just before the next. The longest lunations are those that include two apogees.

Let's do some simple math (the only kind I know how to do). The ratio of the synodic to anomalistic month is 29.530:27.554 = 1.071714. A good

approximation of this is 15:14, or 1.071429. So there are almost exactly 15 anomalistic months per 14 lunations. The effect is a rotation of the major axis of the Moon's orbit, known as the line of apsides. Every 206 days this major axis is directed towards the Sun, resulting in particularly close perigees and distant apogees of the Moon. 206 days equals about seven lunations but 7.5 anomalistic months, meaning that in this period the line of apsides has completed *half* a rotation with respect to the Sun. If perigee occurs at New Moon on one occasion, 206 days later New Moon will be at apogee. This effect therefore accounts for both the peaks *and* the valleys in Figure 1.

If the Moon's orbital speed around Earth affects the duration of a lunation, so too must Earth's around the Sun. This too varies due to the ellipticity of Earth's orbit, which, while less eccentric than that of the Moon, is still significant. Earth achieves perihelion in early January each year, at which point it's about 5 million km closer to the Sun than at aphelion in early July. When Earth is moving at its fastest, it follows that the Moon will have to travel a little further to again line up with the Sun, making for a longer lunation. The reverse should hold true at aphelion. (See Figure 2 and caption.)

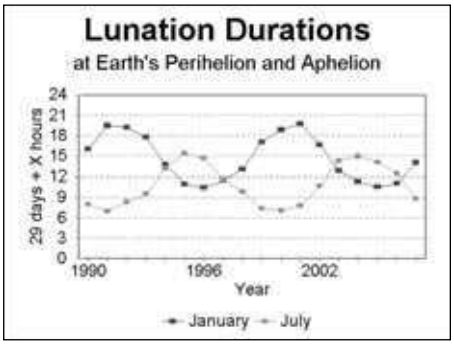


Fig. 2 — The effect of the Earth's eccentricity on lunation durations. The (usually) upper curve is comprised of the first lunation for each year from 1990-2007, the lower curve of the seventh. The two curves overlap because the effect of the Moon's own orbital eccentricity is greater than that of the Earth. Still, on average lunations are two hours longer than the mean in January and two hours shorter in July. The curves depicted here are less smooth than in the other figures because the data points are at slightly irregular intervals (either 12 or 13 lunations).

Now that we have introduced a second-order effect, it pays to look at longer-term patterns. Figure 3 graphically displays the changing durations of lunations for the period 1990–2020. The resulting curve is a fascinating representation of two separate effects gradually moving into and out of phase with each other.

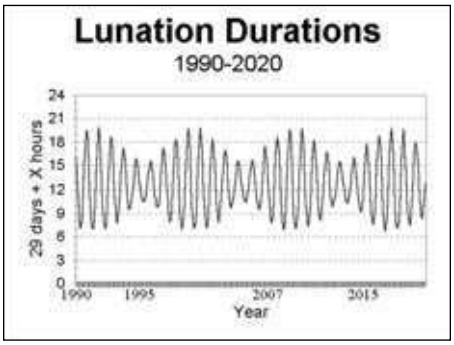


Fig. 3 — Variations in the duration of synodic months for the period 1990–2020 show a fascinating ebb and flow effect caused by the combination of the eccentricity of both the Moon's and the Earth's orbits. In general terms the Moon's distance from the Earth can affect the duration of a lunation by roughly plus five, or minus four hours, and that of the Earth from the Sun by plus or minus two. When the two effects are complementary, the amplitude of the wave is roughly 13 hours, but when they are in interference, the amplitude is reduced to about five hours.

The highest peaks occur when New Moon happens at apogee while Earth is at perihelion: the Moon's slower orbital speed in combination with Earth's greater one makes for an especially long lunation. The lowest valleys occur roughly a half-year later (or earlier) when New Moon is near perigee and Earth is at aphelion and both effects are again synchronized. However, in subsequent years the two effects gradually move out of phase and actually start to interfere with one another. Things are again back in synch after about nine years, an interval that is pleasingly consistent with the 8.85-year period known as the advance of perigee.

And if 15:14 is a good approximation of the ratio between synodic and anomalistic months, an even better one is 239:223 (1.071749), which not coincidentally is the number of each that occurs in one Saros cycle. The Saros period of 18 years plus 10 or 11 days (depending on the fall of leap years) is familiar to eclipse chasers, but it is manifest in virtually any application of lunar cycles.

In his classic work *Astronomical Algorithms*, Meeus lists the two longest lunations from 1900–2100 as follows: December 14, 1955 to January 13, 1956 (29 days 19 hours 54 minutes) and December 24, 1973 to January 23, 1974 (29 days 19 hours 55 minutes). The longest in my sample was January 4, 1992 to February 3, 1992 (29 days 19 hours 50 minutes). Note that all three occur at intervals of exactly one Saros.

In order to confirm the correctness of the mean period of a synodic month recorded in The *Observer's Handbook*, I averaged several randomly chosen samples of 14 consecutive lunations which were consistent to two decimal places *(i.e.*, 29.53 days), and a few of 223 consecutive lunations which were consistent to at least three.

Finally, for your added amusement, how long is a lunar phase? While the length of a full lunation can vary by only around 13 hours, there is a *much greater* variability in the duration of a quarter, as the same factors noted above still apply without being moderated by the rest of a full orbit. For example, have a look at the *RASC Observer's Calendar* for 2001 February, which indicates that Full Moon occurs on February 8th, Last Quarter on the 14th, and New Moon not until the 23rd, implying one phase of six days immediately followed by another of nine. While the difference is not the full three days — following the calendar's usage of Eastern Standard Time to emphasize the point in this instance — it clearly has to be greater than one. I did a quick analysis of the 2001 calendar year and found that quarters range from a maximum of 8 days 5 hours 10 minutes (New Moon on December 25, 2000 to First Quarter on January 2, 2001) to a minimum of 6 days 14 hours 24 minutes (New Moon on July 20 to First Quarter on July 27), a difference of over 38 hours (20%). Note the two extremes cited occur exactly seven lunations apart: July 27 is 206 days after January 2. In the first instance apogee

occurs on December 28 and Earth is virtually at perihelion, and in the second case perigee occurs late on July 21 and Earth is still near aphelion.

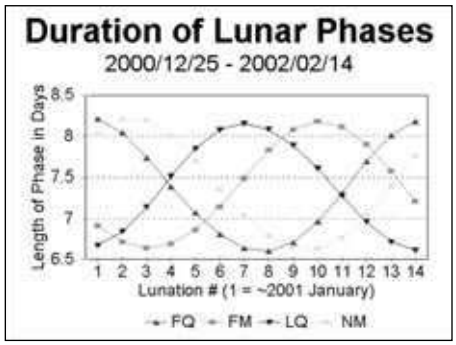


Fig. 4 — The duration of a given lunar phase, or quarter, varies dramatically due to the gravitational influences described in the text. When represented graphically, the interrelationship among them becomes obvious.

In figure 4, I have plotted the duration of all lunar phases for the 14 lunations commencing at the end of 2000. Each of the four phases follows a very similar curve, with the opposing phases (New *versus* Full, First Quarter *versus* Last) casting virtual mirror images peak-to-valley. Over the 14 lunations each of the phases averages out to about 7.38 days, each almost exactly one quarter of the synodic average of 29.53.

The intricacies of the lunar orbit can be a subject of endless fascination for those with an appreciation of nature's details and can be approached from many more angles than I have room to describe here. No doubt this topic will be raised again in this space in the future.

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A Past President of the Edmonton Centre RASC, Bruce McCurdy is also the resident "semi-pro" astronomer at the Edmonton Space & Science Centre's Public Observatory, where he has provided volunteer service for 14 years and has enjoyed paid employment for the past five summers. He has had a particular interest in the Moon since the Apollo missions and recently completed a project in which he observed every named feature on the lunar nearside. As anybody who has visited his house can attest, Bruce has a natural affinity for chaotic systems.

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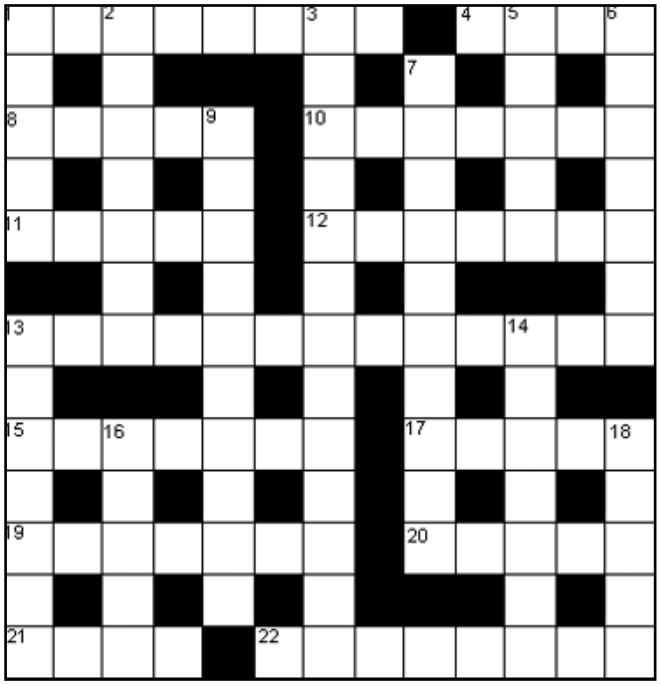
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Rajiv Gupta
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Astrocryptic #9

by Curt Nason, Moncton Centre

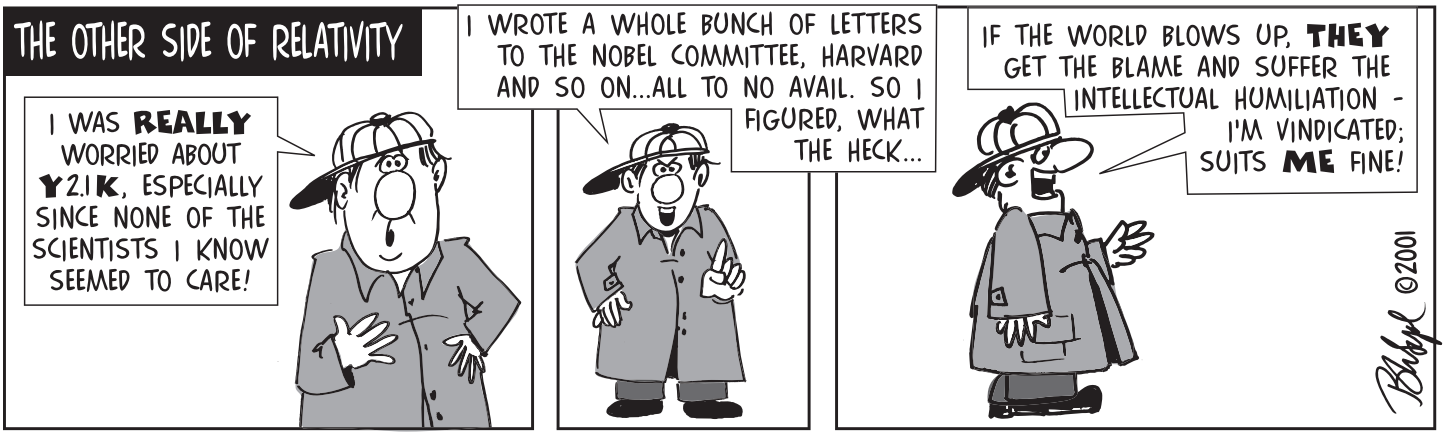


ACROSS

1. In effect, some see red when ripe junk is scattered (8)
4. RASC reorganization leaves its mark (4)
8. Southern Indian resolved from meteor train dust (5)
10. They do not shop around at the speed of light (7)
11. Jean's alignment predictions made Sky&Tel's centrefold girl return to me (5)
12. It might be an alignment phenomenon, but it isn't art somehow (7)
13. Rogue Type A red star captured on old film (13)
15. A significant fraction of #1 hydrogen alpha light filters (3-4)
17. Elizabethan author was named in the Columba constellation (5)
19. Tangible cometary train seen around Connecticut to the east (7)
20. It lies in brown haze around Saturn (5)
21. This bird can't fly around Saturn (4)
22. Isn't key C different when played on Phobos? (8)

DOWN

1. Sirius partly rises in the afternoon after a light bender (5)
2. Oddly dry mass of ice is a constant feature of H spectra (7)
3. Gribbin's planetary influence was not all it was cracked up to be (7,6)
5. Having one in each hemisphere makes one angry (5)
6. A nebula appears flipped in cassettes or in Monoceros (7)
7. Pilot or bar mix can take a satellite over the top (5,5)
9. Methodic solar one at the Index Catalogue (10)
13. Lens measurement used since the beginning of time in an uncertain period (7)
14. Peninsular home of the dinosaur killer (7)
16. Comet Kohoutek initially seen in the east northeast as a ring division (5)
18. Capella's mother or a surrogate mother (5)



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