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Total solar eclipse at ESO La Silla Observatory, July 2019

On 2 July 2019 a total solar eclipse passed over ESO's La Silla Observatory in Chile. The eclipse lasted roughly two and a half hours, with almost two minutes of totality at 20:39 UT, and was visible across a narrow band of Chile and Argentina. To celebrate this rare event ESO invited 1000 people, including dignitaries, school children, the media, researchers, and the general public, to come to the Observatory to watch the eclipse from this unique location.

Source European Southern Observatory (ESO).
https://www.eso.org/public/images/eso1912a/

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More Mooning Around

By Mike Frost

When I was a teenager, my favourite author was the American writer Isaac Asimov. Asimov wrote excellent science fiction, most famously the *Foundation* series and *I Robot*, but although I enjoyed these I felt he was better at science fact. Asimov was a prolific writer, and I have many of his books, but the ones I enjoyed most were his collected essays from the monthly science column he wrote for *Fantasy and Science Fiction* magazine. In this column, Asimov would range far and wide over the whole of science, but he himself wrote that his favorite topic was astronomy.

So my all-time top Asimov book was *"Asimov on Astronomy"*, his collected astronomy essays from F&SF. I re-read the book before writing this article.

Of all the essays in *"Asimov on Astronomy"*, the one I most enjoyed was called *"Just Mooning Around"*, which first appeared in the May 1963 edition of F&SF (and is therefore almost as old as me). As in many of Asimov's other columns, he managed to reach unexpected conclusions from a straightforward premise. His idea was to look at each Moon in the solar system, and compare the ratio of the gravitational attraction of the host planet on the Moon to the gravitational attraction of the Sun.

The fundamental equation used is Isaac Newton's theory of universal gravity – Einstein's theory of General Relativity is slightly more accurate but Newton is easily good enough for our purposes. The gravitational force F between two bodies of mass M and m, separated by distance r, is given by

F = - G M m / r^2

G is a universal constant.

So, if the moon has mass m, its host planet mass Mp, and the two are distance r apart, the force exerted between the two will be

-G Mp m / r^2

And if the Sun has Mass Ms, and the distance from Sun to moon R, the force exerted by the Sun on the Moon is

-G Ms m / R^2

What is the ratio of these two? Divide second quantity by the first and you get the relative strength of the Sun's pull to the planet's pull, as

Ratio = (- G Ms m / R^2) / (-G Mp m / r^2)

The minus signs, G and m all cancel out.

Ratio = (Ms / Mp) * (r^2 / R^2)

Asimov computed this ratio, which he called the "Tug-of-war" ratio, for each of the thirty-two moons known in the solar system in 1963. I have repeated the exercise, using up-to-date values for moon distances and planetary masses, and the values do not differ significantly from those which Asimov computed when he wrote the article. Here are the tug-of-war ratios for thirty-one of the thirty-two moons, excepting only our own Moon, which I'll come to shortly. Several of the smaller moons of Jupiter didn't have names in 1963, so I have put their official number (V -> XII) which Asimov used.

Planet	Moon	Tug-of-war Ratio	Asimov Value
Mars	Phobos	190.7	195
	Deimos	30.5	32
Jupiter	Amalthea (V)	17,582	18,200
	Io	3,253	3,260
	Europa	1,285	1,260
	Ganymede	505.3	490
	Callisto	163.2	160
	Himalia (VI)	4.46	4.4
	Lysithea (X)	4.20	4.3
	Elara (VII)	4.17	4.2
	Ananke (XII)	1.26	1.3
	Carme (XI)	1.07	1.2
	Pasiphae (VIII)	1.04	1.03
	Sinope (IX)	1.00	1.03
Saturn	Janus	25,570	23,000
	Mimas	17,075	15,500
	Enceladus	10,370	9,800
	Tethys	6,763	6,400
	Dione	4,123	4,150
	Rhea	2,113	2,000
	Titan	393.7	380
	Hyperion	267.6	260
	Iapetus	46.3	45
	Phoebe	3.5	3.5
Uranus	Miranda	21,550	24,600
	Ariel	9,891	9,850
	Umbriel	5,088	4,750
	Titania	1,899	1,750
	Oberon	1,060	1,050
Neptune	Triton	8,289	8,400
	Nereid	34.3	34

To re-iterate, the tug-of-war ratio says how much more strongly a planet pulls on its own moons than the Sun does. For example, the pull by Jupiter on Io, the innermost of the four large Galilean moons of Jupiter, is 3253 times stronger than the pull of the Sun. Io is clearly locked very tightly to Jupiter. But look too at the outer reaches of the Jupiter system. For two moons, Pasiphae and Sinope, the ratio is only just greater than unity. Jupiter only just holds onto these two moons. Asimov conjectured that Io and the Galilean moons of Jupiter might have formed at the same time as Jupiter, in pretty much the locations they reside today, whereas the much smaller outer moons might be captured asteroids.

Asimov's intuition on this was probably correct. There is other good evidence that the outer moons of the solar system's giant planets might be captured. Many of them are in retrograde orbits, going round the planet in the opposite direction to its spin (which would be difficult to explain if they formed at the same time as the planet). Many of them have orbits tilted to the equatorial plane of the planet, whereas the better behaved inner moons orbit around their planets' equators.

Asimov proposed a tug-of-war threshold: above thirty, and the moon was likely to have formed around the planet; below thirty, and the moon was likely captured. This is not a smooth transition - he claimed that Neptune's moon Nereid, with a tug-of-war ratio of 34, was likely to be captured, whereas Mars's moon Deimos, with tug-of-war ratio 32, formed in situ. We still think Nereid is a captured moon, but current science is ambivalent about the Mars moons, which show signs of being rubble piles left over from a collision and are probably drifting towards Mars, and, in the case of Phobos, likely to crash to the Martian surface in a few million years.

But all-in-all Asimov had created a very satisfying and illuminating synthesis, based on some easy-to-follow calculations. There remained one tiny loose end – the one remaining moon known in our solar system in 1963, our very own Moon. Do the tug of war calculation for the Moon, and you can add one final line to the table

Planet	Moon	Tug-of-war Ratio	Asimov Value
Earth	Moon	0.43	0.46

!!!!????
Or, to quote Asimov,
"WHAT IN BLAZES IS OUR OWN MOON DOING OUT THERE?"

This result is so extraordinary that I want to re-iterate it to you – the Sun attracts the Moon more than twice as strongly as the Earth does! I remember laughing out loud when I first read this – it is so completely counter-intuitive that I had to check the calculation to make sure Asimov hadn't made a mistake (he hadn't, check it yourself). Even today, it still comes up on forums such as the astronomy section of Yahoo Answers – I remember some poor soul asking why the Moon orbited the Earth instead of the Sun, and people were saying things like *"the Sun is much more massive than the Earth, but also further away"*, without ever bothering to do the calculation.

But the question remains valid – why does the Moon orbit the Earth rather than the Sun, if the Earth's grip on the Moon is so tenuous? Asimov's resolution to the problem was quite interesting. He suggested that the Earth-Moon system had formed as a double planet. However, his reasoning towards this struck me as a little shaky even when I read it the first time. His main line of evidence is the "well-known" fact that the Moon's orbit around the Sun is always convex. In other words, even though the Moon orbits the Earth, its orbit around the Sun never bends away from the Sun. I found that argument unconvincing: the Moon's orbit around the Sun is convex, so what?! I discuss this in more detail in the first appendix.

I'll take a different approach here. Since 1963, a lot has happened in the solar system. Interplanetary travel was in its infancy in 1963 – the first attempt to send a probe to Venus was in 1962. In the 55 years subsequently we have visited every planet in the solar system, plus some of the dwarf planets and some asteroids and these missions have discovered many more moons. Additionally we now have the Hubble space telescope, which is powerful enough to detect moons for itself.

So I wondered what the tug-of-war ratio was for these additional moons. Was our own moon still the only one in the solar system which "shouldn't be there"? For example, we now know that Pluto, which was simply a pinprick of light in 1963, is a much more complex system, having several satellites, including the unusually massive Charon. Pluto-Charon is actually a much better candidate for double-planet (double-dwarf!) than Earth and Moon are. The mass of Earth is 81 times that of the Moon, Pluto is only 8 times more massive than Charon. So what are the tug-of-war ratios for the moons in the Pluto system?

Moon of Pluto	Tug-of-war Ratio
Charon	595.6
Styx	125.6
Nox	96.4
Kerberos	68.5
Hydra	54.6

Perhaps surprisingly, all the moons in the Pluto system are attracted more strongly to tiny Pluto than they are to the Sun. Pluto may not be big enough to count as a planet, but its moons lie close and Pluto's great distance from the Sun means that it can hold on to them.

The majority of the new moons found in the solar system since 1963 are small moons around giant planets. For the most part, these still tend to orbit with tug-of-war ratios close to, but just above unity. For example, although a lot of new moons have been found orbiting at a great distance from Jupiter, they are in the same "family" and at similar distances as the already-known Pasiphae and Sinope so there are certainly no moons of Jupiter in the anomalous position that our own Moon is to us.

Saturn is a little more interesting. Again, dozens of moons have been discovered since 1963. Some are in the inner part of the Saturnian system, many are associated with the rings, the so-called shepherd moons. But once again there are a lot of moons with tug-of-war ratios narrowly exceeding unity, which we could infer are captured asteroids. Just one moon, Fornjot (named, like many of Saturn's outer moons, from Norse mythology) has a tug-of-war ratio of 0.978, just less than unity. Perhaps Saturn might be losing its grip on this outer moon.

Things become more interesting still for Uranus and Neptune. The outermost moon of Uranus is called Ferdinand (named from Shakespeare, not for Rio), and it has a tug-of-war ratio of 0.826, substantially less than unity. The outermost moon of Neptune is called Neso, and its tug-of-war ratio is 0.426, even less than the Moon's.

So it appears that our own Moon may not be alone in occupying an anomalous, some might say inexplicable, position. It may have partners in crime in the darker outer reaches of the solar system . Had Asimov known about these tiny moons around Uranus and Neptune, he might have reached different conclusions. Actually, I'm glad he didn't know about them, because the Moon's stark refusal to fit Asimov's rules made his original essay so much more entertaining.

So do I have an explanation for the location of the Moon, so far away from Earth? Well yes, I do, although I'm aware it may be as unconvincing as Asimov's attempts in 1963. First, we have to accept that a tug-of-war ratio of less than unity does not stop a moon from orbiting its parent planet. That's maybe how it looked in 1963, with just one "minor" exception, but now we have more examples. The zone of gravitational stability is more complicated than that given by Asimov's ingenious calculation – the zone is called a "Hill Sphere" and the more complicated calculations for such a zone do allow stable orbits which fail Asimov's tug-of-war criterion.

But Asimov's arguments are still powerful. How could our Moon possibly have formed where it did? The answer to that is that we don't think it did. Instead, we believe that it migrated outwards from where it formed, much closer to the Earth. I wrote about this in my article *"Receding Moon"* in MIRA 84, explaining that the tidal pull of the Moon of the Earth tends to slow the Earth down, and that the conservation of angular momentum in the Earth-Moon system then implies that the Moon will recede, very slowly, from Earth. I write more about this in the second Appendix.

Here's what I think Asimov missed. He implicitly assumed that there were only two ways for a moon to end up in orbit around a planet. Either it formed there at the same time as the planet, or it was captured at a later date. But we now know that there is a third possibility – catastrophic formation by collision. The current theory for the formation of the Moon has it that a Mars-sized object, Thea, collided with the Earth. The collision threw off debris which went into orbit around the Earth and eventually coalesced into the Moon. The Moon is thought to have formed at around 30,000 km from the earth, and has now receded to over ten times this distance. Pluto's moons, and possibly Mars's too, might have formed the same way.

So, here's my revised version of Asimov's threshold. Tug-of-war ratios above 30 may mean that the moon formed at the same time as the planet; ratios below 30 might mean the moon was captured. But there's a third population – moons which formed from the debris of collisions of a larger object with the planet. I'm not sure how small the tug-of-war ratio can get for these moons, but it can definitely drop below one.

"Asimov on Astronomy", Isaac Asimov (Coronet, 1976)

Appendix 1 – Convex Orbits

It is commonly stated that, even though the Moon orbits around the Earth, its orbit around the Sun is always convex to the Sun. Even though the distance to the Sun can vary by up to 800,000 km over the course of two weeks (at New Moon the Sun is on the Sun side of the Earth, two weeks later at Full Moon it is the other side of the Earth). (Ivor writes about this in MIRA 84 in *"The Earth and Moon System"*).

Figure 1 - Moon and Earth

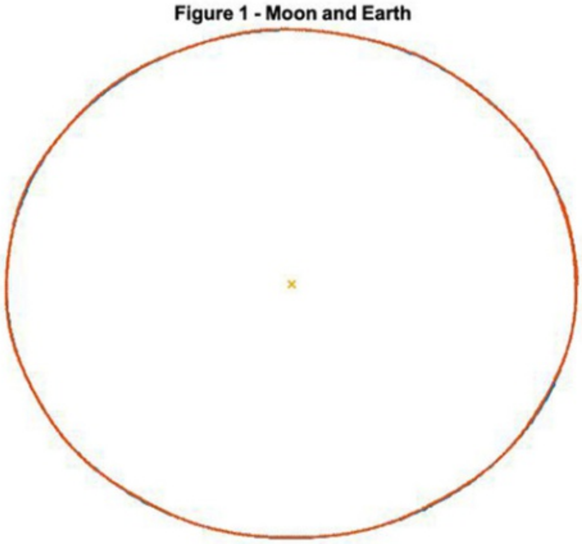


Figure 2 - Moon and Earth (detail)

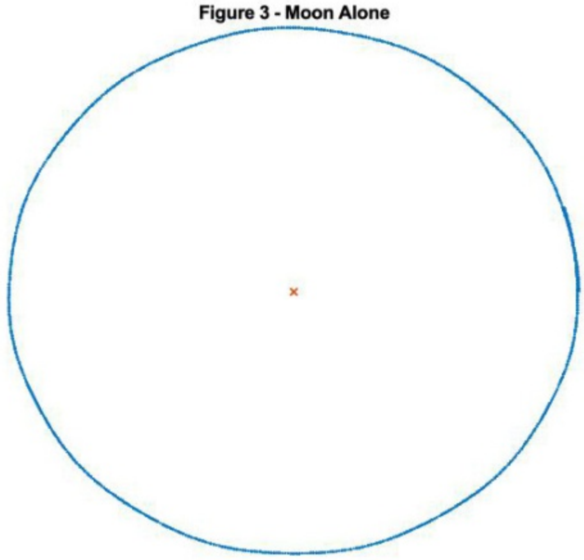
It is also commonly stated that our Moon is the only object in the Solar System for which this is true – every other moon's orbit around the Sun bends away from it at some point.

I ask – are these two statements true? And if so, why?

I have plotted some sample orbits for moons in the Solar System. For simplicity, I assume that both planet orbits around the Sun and moon orbits around the planet are circular; actually all orbits are elliptical, but circular doesn't much affect my conclusions.

Figure 1 shows the orbits of the Earth and the Moon around the Sun; figure 2 is a close-up. Figure 3 shows just the Moon's orbit, and. You might expect to see the Moon's orbit oscillate, Spirograph style, around the more circular orbit of the Earth. You can also see that this doesn't noticeably happen.

Figure 3 - Moon Alone



Why not? I thought about this, and realised that the root cause is that the Moon goes around the Sun a LOT faster than it does around the Earth. The circumference of the Earth's orbit is around 1,000 million kilometres, which the Moon and Earth traverse in a year. During that time, the Moon orbits the Earth about twelve and half times; the circumference of this orbit is around 4 million kilometres, so whilst the Moon is traversing a billion kilometres of solar orbit, it is superimposing only 50 million km of Earth orbit over the top.

As we go further out into the solar system, the speed of orbiting the Sun diminishes, because of the diminished force of gravity from the Sun.

Additionally, many of the moons in the outer solar system travel a lot faster around their parent planets, either because these planets are a lot more massive, or because the moons are much closer to their parents. Or both.

I'll give a few examples. Figure 4 shows the actual

Figure 4 - Phobos and Mars (detail)

path of Phobos, largest moon of Mars, around the Sun. You can see a clear back-and-forth oscillation – the orbit is not convex.

Figure 5 - Io and Jupiter (detail)

Figure 5 shows Io, innermost Galilean moon. Relative to the Sun, the orbit looks like a Spirograph plot

But what about the recently discovered outer moons of the giant planets? They travel much more slowly around their parent planets.

Figure 6 - Pasiphae and Jupiter

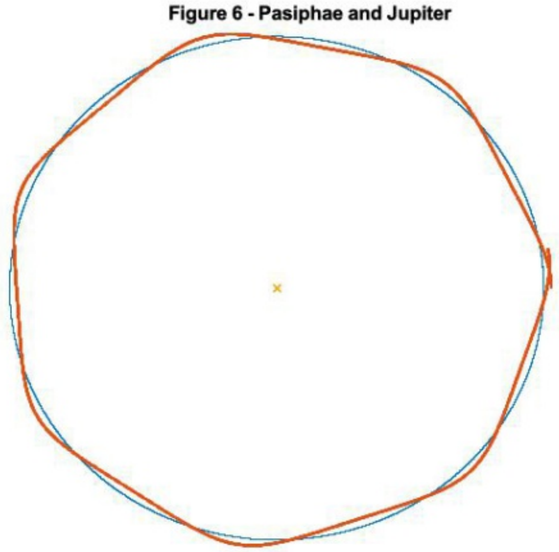


Figure 6 is for Pasiphae, outermost(ish) moon of Jupiter, which orbits Jupiter in retrograde fashion. Pasiphae's orbit relative to the Sun is extraordinary, almost polygonal.

Figure 7 - Neso and Neptune

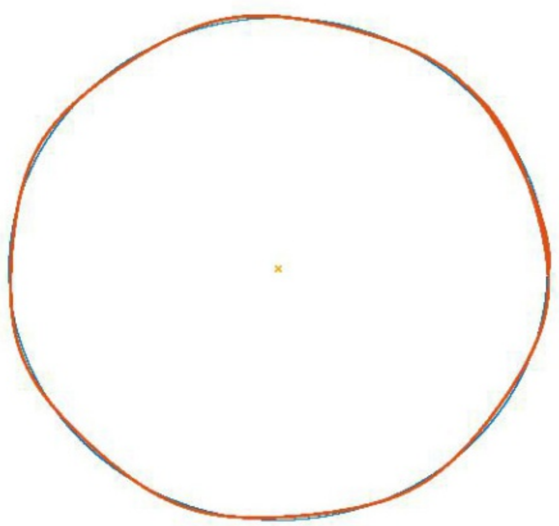


Figure 7 is for Neso, outermost moon of Neptune, which orbits Neptune, also in retrograde fashion.

Conclusion – the Moon definitely has a convex orbit around the Sun. Io and Phobos definitely don't. Pasiphae and Neso look like they might.

Appendix 2 – Approaching Moon

You might have noticed two apparently inconsistent statements in the main article. Earth's Moon, I tell you, is receding from the Earth (and I've told it you before, so it must be true). But later on I mentioned, in passing, that Phobos, largest moon of Mars, is approaching Mars, and will probably eventually crash into it.

So why is the Moon receding, and Phobos approaching? And what are all the other moons in the solar system doing?

Well, the reason for the behaviour of both moons is tidal friction. And this gets complicated, so bear with me.

The root cause of tidal effects is that gravity drops off with distance, so the gravitational pull by a moon on the near side of its planet is stronger than the pull on the far side. If our moon was orbiting a planet made entirely of fluid, the effect would be to stretch out the planet into an ellipsoid. But planets are not made entirely of fluid. For the Earth, the effect of the Moon's gravity is to stretch the rock of the Earth by a small amount and the fluid of the oceans by a rather larger amount. We can conceptualise these as "tidal bulges" on either side of the Earth.

There is something else to worry about. The tidal bulge never has time to form fully, because the Earth is rotating and spinning any newly formed bulge "out of the way". The Earth spins faster (once per day) than the Moon orbits around the Earth (once per month). Again, conceptually, we can view the tidal bulge as having been "spun out of the way". And the Moon exerts a pull on this bulge, very slightly slowing down the Earth. See Figure 8.

(I'll emphasise that this explanation simplifies reality considerably).

The slowing down of the Earth's rotation is tiny – just a few microseconds per year – but it is genuine, and is has been measured. Moreover, angular momentum has to be conserved in the Earth-Moon system, so as the Earth is losing angular momentum, the Moon has to move further away to conserve it. Again, this is a tiny effect, of just a few centimetres a year, which is absolutely swamped by the thousands of kilometres by which the Earth-Moon distance changes in just a single month-long orbit. But over billions of years, it means that the Moon will recede slowly from the Earth, and will only stop when the Earth slows down so much that it rotates at the same rate as the Moon's orbit.

This gives us a clue to why Phobos behaves differently. The largest Moon of Mars is so close to the planet that it goes round the planet more quickly (7 h 39 min) than the planet rotates (24 h 37 min). Yes, that really does mean that Phobos rises in the west and sets in the east! (There's a famous story told by, I think, Ray Bradbury – *"A fan comes up to me and says 'you know that story where Phobos rises in the east'? I said 'Yeah?' He said 'Nah'. So I hit him.")*.

So what happens now, conceptually, is that Phobos overtakes Mars's tidal bulge, and so "pulls the bulge along with it", speeding it up (see figure 9.). To conserve angular momentum, the distance from Mars to Phobos decreases. And so Phobos approaches Mars.

It's a quite neat division, isn't it? Considering a single moon orbiting a planet - if that moon rotates around a planet faster than the planet itself rotates, it approaches. If the moon rotates around its planet slower than the planet rotates, it recedes. And if the two speeds coincide, it stays where it is. There's one other case to consider, when the moon's orbit is retrograde, so that the moon's orbit and

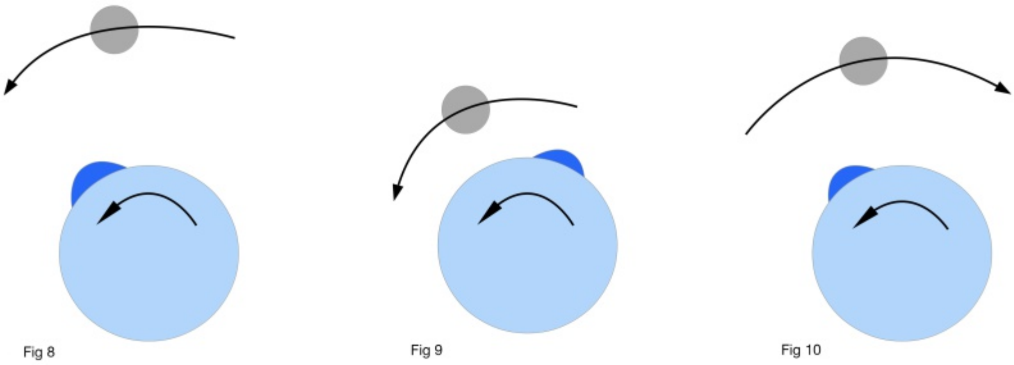


Figure 8 Planet spins faster than moon orbits.   Figure 9 Moon orbits faster than planet spins.
Figure 10 Moon orbits in opposite direction to the planets spin (retrograde motion).

planet's rotation are in opposite directions – this also leads to a receding moon, in all cases. See figure 10.

So, apart from Phobos, are there any other moons in the solar system which orbit quicker than their parent planets rotate? Yes. Metis and Adrastea, the two innermost moons of Jupiter, rotate in under eight hours, an hour quicker than Jupiter. Several of the innermost moons of Uranus orbit in less than the 17 hours Uranus takes to rotate. Neptune rotates in 16 hours, slower than five of its innermost moons.

However, each of these tiny moons is too small to force the slowing down of its host planet. We have to consider the net effect of all the moons orbiting a planet. For each of the giant planets, the innermost moons are small and will have little effect; moreover, there are much larger moons a little further out, which will tend to slow down their host planets, causing all the moons to recede.

Phobos, by contrast, is the largest moon to orbit Mars, and so forces the planet to speed up, and its moons to approach. When Phobos crashes into Mars, if Deimos is still orbiting slower than Mars, then it will then recede, and slow Mars down; but if Deimos has got close enough to orbit faster than Mars, it will continue to approach and then later collide with Mars itself.

So I think that Phobos, and possibly Deimos, may well be the only "at-risk" moons in the solar system.

Revd Dr William Pearson and the Foundation of the RAS

By Mike Frost

The Revd. Dr William Pearson, co-founder of the Royal Astronomical Society, was the rector of South Kilworth, Leicestershire, for the last three decades of his life. He built two observatories in the village to allow him to pursue his research interests and published estimates of the obliquity of the ecliptic, and a catalogue of stars occulted by the Moon, as a result of observations from the village. As the two-hundredth anniversary of the RAS approaches, I and other historians of astronomy in the Midlands are taking the opportunity to honour the memory of one of the RAS's founding fathers.

Jacky Harrison, the current owner of the Rectory, has had a long-standing interest in Pearson's life in South Kilworth. We teamed up to secure funding to renovate Pearson's grave in the village graveyard. I acknowledge with gratitude a grant from the RAS historical committee. This matches funds that Jacky secured from the South Kilworth Parish Council, and the restoration took place earlier this summer.

In parallel, I and Carolyn Bedwell, assistant librarian at the Society for the History of Astronomy and secretary of Leicester Astronomical Society, both nominated Pearson for the Green Plaque program run by Leicestershire County Council. Leics CC invites nominations of eminent residents of the county into a popular vote to receive a plaque. Despite being up against stiff competition (including a recipient of the Victoria Cross, and the illustrator of Thomas the Tank Engine), Pearson placed high in the popular vote and so will be commemorated by the county, with a plaque on the gates of the Rectory, right in the centre of the village.

The dedication of William Pearson's plaque will take place on the afternoon of Jan 16th 2020, two hundred years and four days after the first meeting of the society that he did much to found and to nurture. RAS President Mike Cruise has been invited to unveil the plaque and there will be a short dedication ceremony in St Nicholas' church. I hope some of you may be interested in attending; I'll give you more details when I know them.

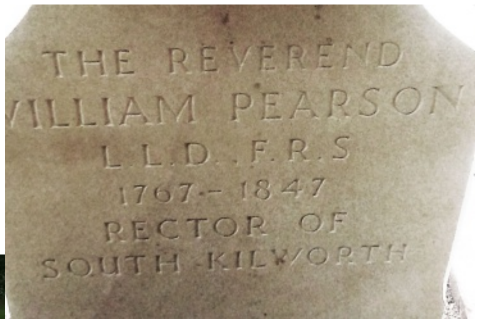


*Photo credits
Jacky Harrison*

The Ionosphere Ten Years On

by Mark Edwards

About ten years ago I wrote two articles for Mira, one in MIRA 85 called SIDs and Pings about observing the ionosphere using very low frequency (VLF) radio and the other in MIRA 89 called Modelling the Ionosphere about how those observations could be interpreted. Those articles dealt with observations of the phenomena of Sudden Ionospheric Disturbances (SIDs) caused when bursts of X-rays from active regions on the Sun increase the ionisation in the D-layer of the ionosphere and lower its effective reflecting height. This article reports on ten years of such observations plus other interesting events revealed by the same observing technique.

The Atmosphere as Detector

In our normal experience of observing the heavens at optical wavelengths we use a piece of glass or mirror to gather the light emitted by the astronomical object of interest and detect it directly by using our eyes or the light sensitive chip in a digital camera.

However, in the case of active VLF observations the collector and detector of the radiation of interest is the Earth's atmosphere itself. The use of VLF radio is just the readout mechanism of that detector. More specifically, any form of ionising radiation that impinges on the many thousands of cubic kilometres of atmosphere lying in the path of the radio waves from a remote VLF transmitter to a receiver will affect its reflection properties and will be read out as a change in the received strength of the transmission.

There are a number of sources of Ionisation, the main ones of which are:-

1. Ultra-violet light from the Sun
2. X-rays from the Sun
3. The Solar Wind
4. Supernovae
5. Gamma Ray Bursts
6. Soft Gamma Repeaters

My observations reported here to date are of the first three, of the others:-

Supernovae

We are all waiting for a supernova! One did occur in the Large Magellanic Cloud in 1987 which it has been calculated should have had a measurable effect on the ionosphere, but no observations of it were made. If we do have one, I shall be hoping that it explodes during the day rather than the night so that I can see its effects on the ionosphere.

Gamma Ray Bursts

Several observers have reported that Gamma Ray Bursts (GRBs) have produced detectable SIDs in particular GRB 830801 in 1983 which so far is the brightest event known. I am still waiting to see one, however my system uses a 10s integration time to help reduce the system noise level and improve its sensitivity, so is not really suited to seeing rapidly changing effects.

Soft Gamma Repeaters

Soft gamma repeaters are magnetars (neutron stars with a high magnetic field) that emit large amounts of X and gamma rays at irregular intervals. On 22nd January 2009 observers in Brazil detected changes to the ionosphere caused by a series of flares from magnetar SGR J1550-5418.

As the ionosphere is near the top of the Earth's atmosphere, any motion of the atmosphere itself has the potential to move ionisation in the D-layer around and cause observable changes in the received VLF signal. Such motion can be caused by:-

1. Weather systems
2. Earthquakes
3. Bolides
4. Nuclear Explosions

Of these I have seen the effects of the first one, of the others:-

Earthquakes

On 11th March 2011 there was a powerful magnitude 9 earthquake off the coast of Japan which triggered a tsunami. Another effect of the ground shaking was to send waves up through the atmosphere into the ionosphere which were detected by their effects on GPS propagation delays.

Bolides

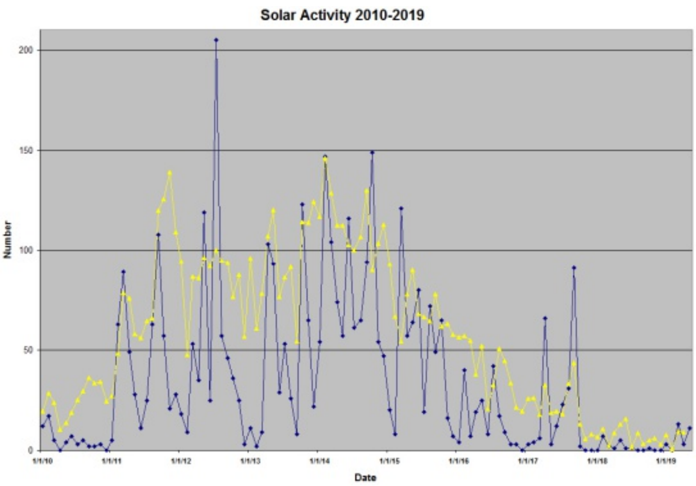
Bolides are extremely bright meteors that explode in the atmosphere, the most notable example being that of the Chelyabinsk meteor of 25th February 2013. Russian observers reported seeing the effects on the ionosphere from gravity waves triggered by the explosion, but as it happened at 03:20 UTC it was unfortunately too early for me to see.

Nuclear Explosions

On 25th May 2009 North Korea exploded a nuclear device underground and as with an earthquake it produced a wave in the ionosphere which was detected in South Korea.

The Observations

SID numbers and the Sunspot Cycle



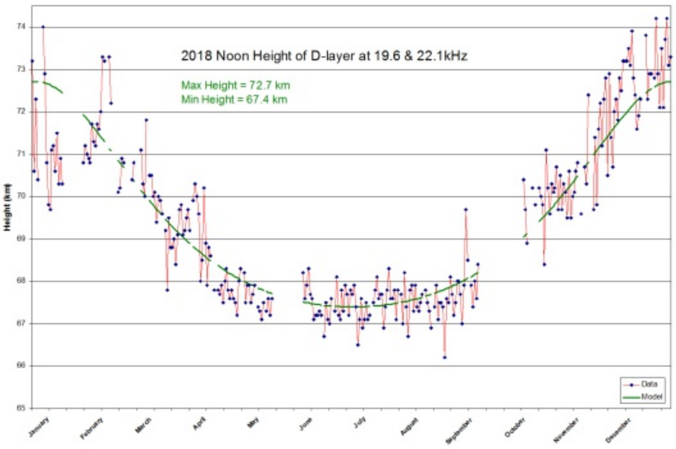
The current sunspot cycle (number 24) started on 4th January 2008, but without much activity until 2010. As my continuous observations of SIDs started on 1st January 2010 they allowed me to track the cycle's progression up to and through sunspot maximum towards the next minimum.

Plotting monthly SID numbers (blue line) together with monthly sunspot numbers (yellow line) produces the figure above. One thing is obvious, as the number of sunspots increases so does the number of active regions, the number of X-ray flares and so the number of SIDs.

However, there are distinct differences in the two plots. The number of sunspots showed a double peak as first the northern hemisphere of the Sun reached a maximum, followed over two years later by the southern hemisphere. Secondly, although the second peak was matched by a peak in the SID numbers, the peak SID numbers overall occurred 9 months after the northern peak.

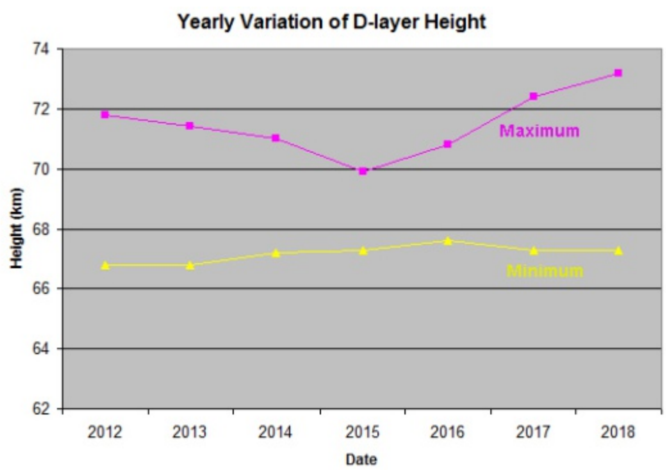
In addition there is a pattern present in the SID numbers and not in the sunspot numbers, that of a certain periodicity over timescales of a few months. Such a periodicity has been noted in previous cycles and a theory put forward that they are multiples of 25.5 days. However, there is still no coherent theory on the source of the oscillations.

Seasonal Height Changes



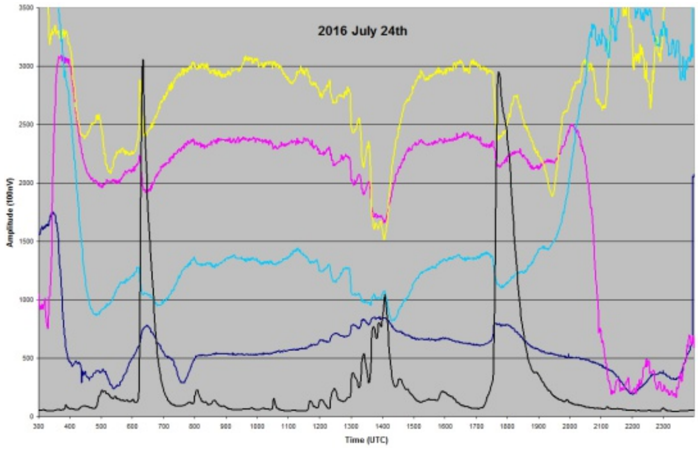
The periodic nature of the occurrence of SIDs leaves plenty of days where none occur, but that does not mean the data for such quiet days should be thrown away. As every day's data allows the height of the D-layer at noon to be calculated and when gathered over a long time interval reveals some interesting results as shown in the example above from the year 2018.

The green line is an attempt to fit a simple model of the dependence of the height with the declination of the Sun and reveals that the minimum height of the ionosphere is 67.4km at the summer solstice (when the Sun is at its highest) and the maximum height 72.7km at the winter solstice (when the Sun is at its lowest).



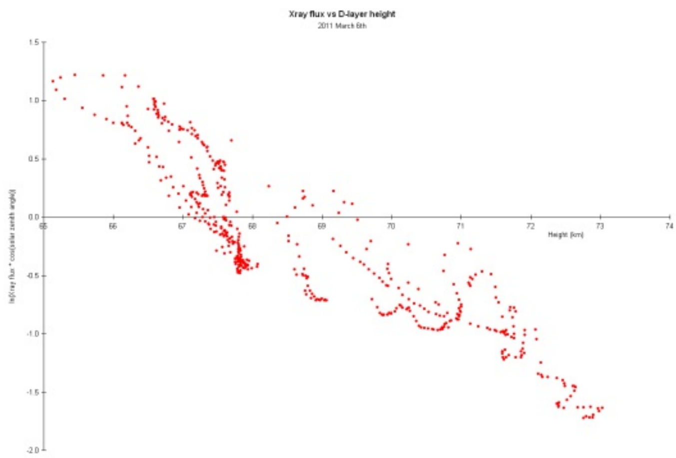
Using these maximum and minimum values from each year it is possible to produce a graph of the variation from year to year. Here it is tempting to equate the lowering of the maximum height around 2015 with the progression of the sunspot cycle, so it will be interesting to see if that pattern continues into the next cycle.

Why SIDs are Sudden



On 24th July 2016 we had an unusual set of X-ray flares from the sun. The figure shows the intensity of those flares as measured by the GOES satellite (black line) and their effects on a number of VLF frequencies. What is immediately apparent is that the received amplitude follows the X-ray flux. As the X-ray flux builds up to a maximum through a series of pulsations so does the VLF amplitude (or a minimum depending on the phasing between the received sky and ground waves) and as the X-ray flux gradually decays so does the VLF amplitude.

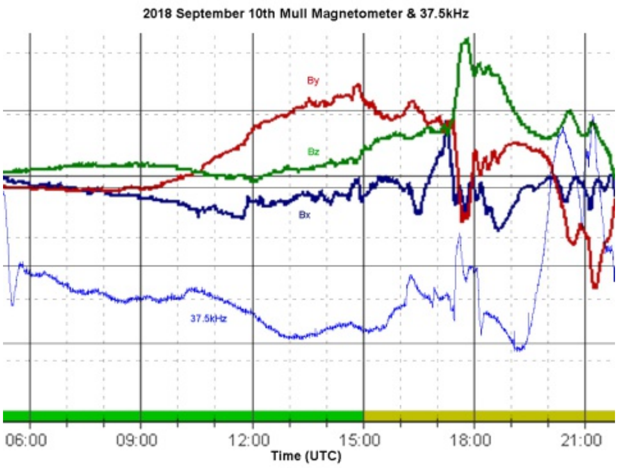
Here then lies the reason why SIDs are sudden, they are sudden because the X-ray flux of a flare usually rises suddenly and decays gradually, no more than that. If the X-ray flux rises gradually they should be called GIDs (Gradual Ionospheric Disturbances)! In fact we can go more and produce a plot of received X-ray flux against ionosphere height, as shown for 6th March 2011 when there were continuous SIDs throughout the day. The plot shows an inverse logarithmic relationship as predicted by ionisation theory.



Magnetic Effects

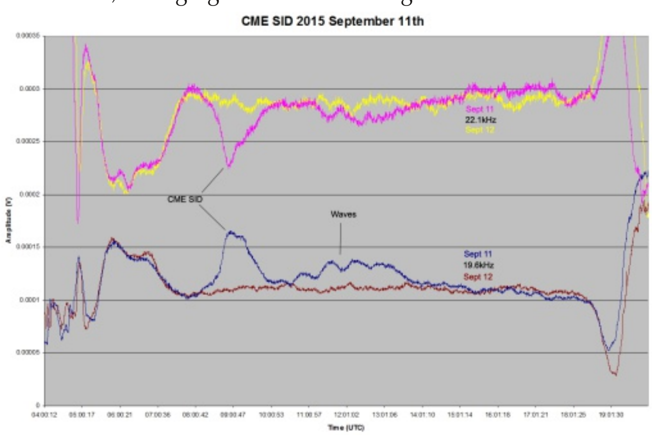
At the end of 2010 I gave myself a Christmas present and upgraded the PC I had been using to log the VLF data. The new PC (a Zotac Zbox) had a soundcard that doubled the received frequency range from 24kHz to 48kHz and as it turned out significantly expanded the range of phenomena that I could observe.

The increase in bandwidth gave the ability to receive the NRK transmissions on 24.0kHz from Cutler on the east coast of the USA. This had two effects. The first being caused by its position to our west which extended the daylight time (remember that the D-layer all but disappears during the night). The second being caused by its much greater distance away from my location (about 8 times the distance to the transmitters in the UK). Such a distance requires more than one reflection from the ionosphere for the radio waves to reach us and as a consequence it is more sensitive to the weaker X-ray flares. Other paths generally require a C-class flare to produce a noticeable effect, but the Cutler path often shows an effect with B-class flares.



Another transmission that fell within the wider bandwidth was that from TFK in Grindavik, Iceland on 37.5kHz. This was especially important as looking at the plots each day it seemed that even on days when there were no solar flares sometimes 37.5kHz showed what looked like SIDs whereas the other frequencies showed nothing at all. It was only when such SIDs were compared to the magnetometer data from the Isle of Mull for the same day (an example from 10th September 2018 is shown in the figure) that a correlation with rapid changes in the Earth's magnetic field was seen.

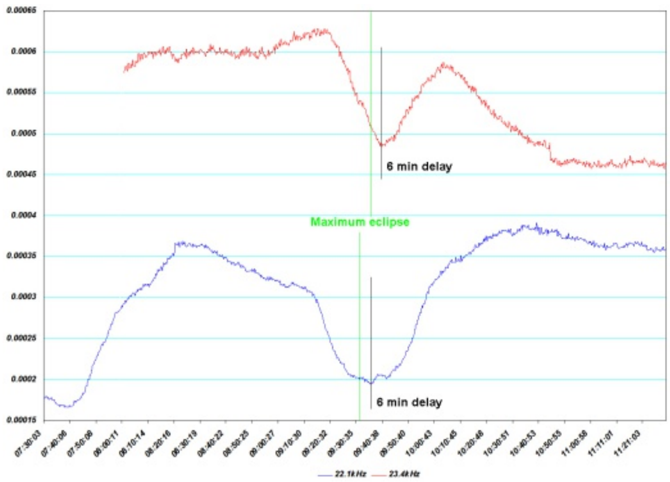
These rapid variations are caused by density and velocity changes in the solar wind (often coming from coronal holes on the Sun) changing its associated magnetic field which then interacts with the Earth's magnetic field. At the same time the particles are funnelled into the polar regions and change the ionisation of the ionosphere affecting the path to Iceland. By pure chance the path from my home to Iceland passes close to the Isle of Mull.



Coronal Mass Ejections

An extreme example of a density change in the solar wind is caused by a Coronal Mass Ejection (CME) from the Sun. If a CME is directed towards the Earth and impinges on its atmosphere it often produces an aurora and substantially increases the ionisation of the D-layer. One such case occurred on 11th September 2015 and its effects are shown in the figure on the paths to Skelton (upper traces) and Anthorn (lower traces) compared with the following day. Interestingly, a slow wave in the ionosphere was provoked by the CME.

Solar Eclipse



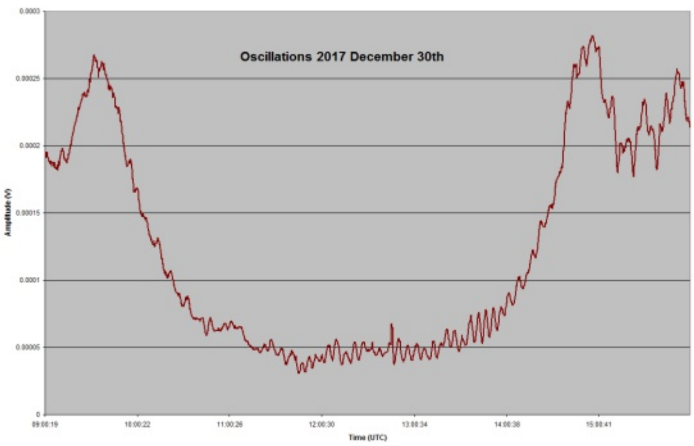
On 20th March 2015 a total eclipse took place with the path of totality passing between Iceland and the UK with a considerable partial eclipse being visible over Europe. This gave an opportunity to see the effects of the reduction of the Sun's radiation on the ionosphere. The figure shows what happened on the paths to Skelton, Cumbria on 22.1kHz (blue trace) and Rauderfehn, northern Germany on 23.4kHz (red trace). Both show an expected dip towards maximum eclipse as shown by the green lines (Rauderfehn is further east than Skelton so its time is later). However, what was not expected was that in both cases there was a six minute delay between the time of maximum eclipse and the time of maximum effect on the ionosphere.

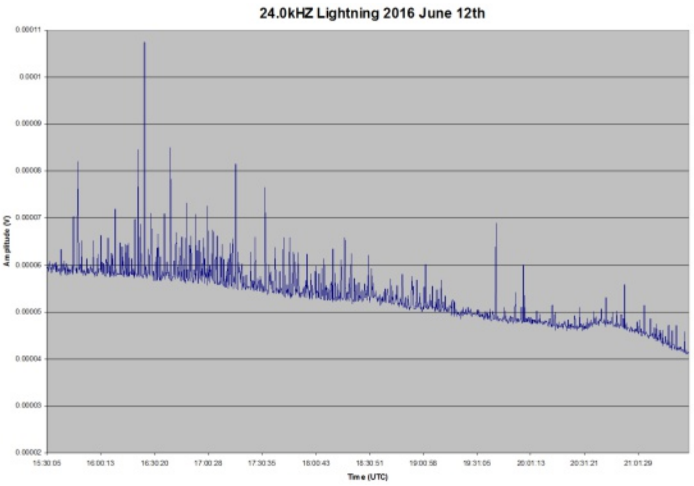
It would appear that other eclipses have produced the same effect and it seems that it is due to the rate at which ions recombine with the arrival of the shadow and the rate at which they are produced again when the shadow passes. They do not happen instantly, hence the delay.

Travelling Ionospheric Disturbances (TIDs)

On occasions the ionosphere appears disturbed and the VLF amplitudes received vary chaotically, however, occasionally it exhibits regular rapid oscillations.

They can last for hours and generally show a period of about 5 minutes as shown in this example from 30th December 2017. These TIDs are produced by gravity waves (not to be confused with gravitational waves) in the atmosphere travelling up to the ionosphere and probably had their origins in a low pressure system that was around at the time. It is interesting to note that noctolucent clouds which





occur around the same height as the D-layer of the ionosphere also show the evidence of such waves, except that as they are only seen at night and we can only observe the ionosphere during the day correlating the two is very difficult!

Lightning

When lightning occurs nearby the radio waves generated by the strikes spread across a broad spectrum of frequencies including those VLF frequencies that I monitor. An essential part of the loop of wire I use to receive them are the protection diodes wired across it. These limit the maximum voltage induced by the lightning that can be sent to the PC's soundcard. They do not however stop lightning from showing its effects, it just stops any damage from occurring.

This example from 12th June 2016 shows how the lightning appears as spikes of noise on a 24.0kHz plot, the number far exceeding any that can be counted visually.

Although not something that I monitor, with a more sensitive receiving system it is possible to observe the radio waves generated by more distant lightning strikes. When such radio waves come via the Earth's magnetosphere from one hemisphere to the other the lower frequencies arrive later than the higher frequencies giving them their characteristic "whistler" sound.

Conclusion

Although I originally set out to see if I could detect those mysterious SIDs I had heard about, it soon became obvious that days can go by with no observable activity, but one of the principles of observational astronomy is that you have to take note of the usual to be able to recognise what is unusual. You never know when that unusual event might indicate that elusive supernova!

So I would encourage everyone to start making their own continuous observations and not to be disheartened if they do not see anything at this time of sunspot minimum.

Editors Bit

Since MIRA 29, the February 1993 issue, I have been the editor of MIRA and have produced, with this one, 77 issues over the last 26 years, about 3 per year as members submitted drawings and written copy. In the beginning most of the issues sold out within a short while and most issues were about 25 to 30+ copies per issue. At the time most members bought a copy as the income boosted the clubs funds. So at a rough guess I will have produced over the years nearly 2000 copies of MIRA’s with most of them with 12 pages but many going up to 16 or 18. So at a very rough estimate I have over the years churned out about 26,000+ pages!

A lot of the early ones contained many observational reports and drawings of lunar craters and planets. By November 1993 I had a new Acorn computer and was getting to grips with a DTP (Desk Top Publishing) program and went on to format MIRA into a two column format which continues today.

All the printing was when done on Xerox copiers in glorious Black & White. When we got to MIRA 50 we had the first colour cover, it was the 1999 August 11th Total Eclipse edition with members writing their memories of this event in a special 16 page issue from across the UK and Europe. From MIRA 86 in 2009 many pictures and captions started to be in colour and this helps to show more complex diagrams and all photographs always look better in colour than B&W. The last few MIRA’s have been printed by myself as the cost to print outside rose to silly levels for such a short print run of 20+ copies. But even these don’t all sell at the monthly meetings anymore.

So from the next MIRA, number 106, all forthcoming articles and photographs will be entered onto the C&WAS web page in the MIRA part of our web site. So please keep the contributions coming.

Therefore this will be the last printed MIRA. Thanks to all the contributions from the many members over the years, especially to Mike Frost for all his interesting travel stories and the Dangerous Sports Club escapades he reported on. Without all of your efforts very few MIRA's would have seen the light of day.

Thank you all
Ivor Clarke Ed.

The Great Argentinian Eclipse

By Mike Frost

Has it really been two years since the Great American eclipse? The average interval between total eclipses of the Sun is about eighteen months, so there are years which are totality free, and 2018 was one of them.

However, 2019 did see a total eclipse, on July 2nd. This time it crossed the Southern hemisphere, starting at dawn to the east of New Zealand. Apart from one tiny atoll in the Pitcairn Islands, the first place that the totality track touched land was the Chilean coast to the north of Santiago. The eclipse rapidly progressed across the Andes into northern Argentina, concluding at sunset just south of Buenos Aires.

You might remember that I have worked in Argentina in the recent past – I spent several months working at a steel rolling mill in San Nicolas de Los Arroyos, one hundred and fifty miles west of Buenos Aires on the banks of the Parana River. Although I visited the cities of Buenos Aires and Rosario, I didn't have much chance to see the Argentinian hinterland. I enjoyed my work visits to Argentina, so this eclipse was an opportunity to see more of the country. Additionally, the Astro-Trails holiday I signed up for also included a couple of days in Chile, a country I had not previously visited.

So, I turned up at Heathrow for the flight to Buenos Aires. It's always fun to meet up with friends old and new at the airport. It was considerably less fun to see the advertised departure time slip by without any sign of the plane being boarded. Our flight was scheduled to leave at 10:30 PM and by midnight it was clear we weren't going anywhere – the weather radar on our plane wasn't working ("WE don't want to fly if the weather radar isn't working" one of the flight crew later told me). We were taken back through passport control, collected our luggage, and were taken to a hotel – I was relatively lucky, being in bed by 2 AM, but some poor souls were still up two hours later.

The next morning we discovered that our flight was being delayed until the next evening. Both Heathrow and Ezeiza airports close at night, so the "launch window" for flying to Buenos Aires is actually quite narrow. We spent most of the afternoon in the airport, submitting compensation claims to British Airways (paid in full, a few weeks later). The flight to Buenos Aires took off twenty two and a half hours late, wiping out the first day of my holiday – the one allocated to "jet-lag recovery". Oh well.

For the flight I was set next to a very beautiful young Argentinian lady who told me that she had been on a modelling trip to India. She might have hoped to be seated between two hunky gauchos; instead she got two old-fogey eclipse chasers. The other chap turned out to be my room-mate for the holiday – Peter, retired from a job in the Science Museum, now working as a volunteer at an industrial museum near Marlborough.

We got to the hotel in Buenos Aires just in time to join the first day trip I had signed up to; a boat tour around the Tigre Delta. The city lies in one of the world's largest river deltas, fed by the River Plate and the River Parana. The Parana threads its way through multiple channels, separated by swampy islands. In the suburb of Tigre, these islands have been colonised, partly as summer homes for those living in the metropolis, but also as a vibrant river-based community, with its own schools, libraries and museums. We passed a riverboat which delivered the mail, and another which was a floating supermarket. There was plenty of birdlife to observe. A fascinating trip, spoilt only by rain. The residents were used to it; there is frequent flooding, and all the houses are built on stilts. We were more worried about the weather prospects for the next few days – would the skies clear, or was the southern hemisphere winter going to defeat us?

We were soon to find out. The next morning we flew west from Buenos Aires to Mendoza, deep in the pampas hinterland of the country. Things didn't initially look good – at Mendoza airport, it had stopped raining, and it was warmer, but there was still cloud. However, as our buses headed north, the cloud broke and then disappeared altogether.

Our destination, and base for the next three days, was the city of San Juan. This city of around a hundred thousand people is a regional capital for the province of San Juan and was just inside the totality zone – I always relax once I know I'll see something even if the bus breaks down on eclipse day. Our hotel was close to the city centre, on the opposite side of the park from the cathedral.

San Juan dinosaur museum

The day before the eclipse was one to explore town. The cathedral, like much of the city, is modern. This is because of several catastrophic earthquakes, which levelled San Juan; most particularly that of 1944. There was a fundraising drive to rebuild the city, and at one charity event, a performer called Eva Duarte met her future husband, Juan Peron. San Juan is also famous for its dinosaur discoveries and so I wanted to visit the natural history museum – but it was Monday, so it was shut. No matter that the city was full of people who'd really appreciate visiting! The art museum was also shut, but somehow I managed to find that the opera house was open. Along with two fellow eclipse chasers, Judy and Adele, I was taken on a tour by a very enthusiastic member of staff. The opera house and adjoining theatre are impressive, very large for a city the size of San Juan and clearly a source of civic pride.

In the evening, we had the traditional pre-eclipse briefing by fellow BAA stalwarts Nick James and Nick Hewitt (Nick-Nick if you're a Jim Davidson fan, James-Hewitt if you prefer Lady Di), followed by a stargazing session in an out-of-town location, a basketball court by a reservoir. I was of course looking forward to exploring the southern skies from a dark location, but was somewhat thwarted by mist on the lake and more light than I would have wished for. Still, it was good to re-acquaint myself with the Southern Cross, Omega Centauri, and other lovely sights I rarely get to see.

Eclipse day started early for me. I was woken by what turned out to be an earthquake. Not exactly one to generate fundraising gigs by Evita, it was magnitude 4 on the Richter scale. We did have time for a leisurely breakfast before our convoy of coaches set of north-west into the hills.

An unfazed llama

Up-country from San Juan, with the Andes in the background

San Juan is an arid state; there are vineyards in the valleys, but the hills are treeless and barely populated. By heading up country, we would reach the centreline and see 150 seconds of totality, but also drop into the next valley, which had the best weather prospects of anywhere in South America. Our destination, two hours away, was on the outskirts of the small town of Bellavista.

Bella Vista, of course, translates as "beautiful view" and indeed we had a glorious backdrop of the Andes. Our viewing site was a llama farm. The animals watched unfazed from their paddock as hundreds of eclipse chasers, from several tour groups, set up their equipment. The organisers had set out bales of hay for people to sit on, although the serious photographers congregated at the back for more space and fewer disruptions. Along the side of the paddocks several enterprising retailers had set up; I bought some souvenirs, and had a generous steak sandwich for lunch, washed down with a glass of the local Malbec wine. There was also a wooden stage, on which a local troupe performed traditional Argentinian dances and drum routines.

The eclipse started mid-afternoon, under cloudless skies. As often, the early phases of the eclipse were unspectacular, but as the light thinned and the temperature dropped, excitement rose. A drone buzzed over the audience until Nick James, master of ceremonies, took a microphone to ask the owner, whoever it was, to stop flying it. A drone in shot would have been bad enough for most eclipse photographers; but the hot air balloon, inflating in the next field, threatened the worst possible interruption to the eclipse. Fortunately, it never got off the ground. Perhaps there was a fault. Perhaps someone sabotaged it. Not me, guv. . . The usual photographs were taken of shadow and pinhole phenomena. No-one round where I was sat seemed to have brought a colander, but fortunately the young woman just in front of us began to feel the cold and brought out a lace shawl. I pointed out that it would produce lots of beautiful pinhole images of the eclipsed sun; so the poor girl was deprived her top layer for a few minutes as we snapshot the pinholes.

As is customary at recent eclipses, I used my tablet to take a video of the two minutes leading up to totality. Fans of my over-excited attempts to video "unfilmable" shadow bands will not be disappointed. For the third time in four eclipses, there was an excellent display of them in the seconds immediately before and after totality. "Shadow bands!" I yelled, delighted, as the low contrast bands flickered across a sheet of paper. "They're not shadow bands" declared the lady to my left, a little grumpily. "SHADOW BANDS!" boomed out Nick, so everyone could hear. "They're not shadow bands" repeated the lady, "it's too early. . ." She was wrong. There was a great display for a minute or more either side of totality. Groups watching from up in the hills could see them sweeping across the valley.

The other thing I was looking for was the Moon's shadow. The geometry of this eclipse, from this location, in late afternoon, was that the shadow would come across the Andes directly towards us. (Contrast with Oregon and Australia, morning eclipses, where the shadow arrived over our shoulders). In the last few seconds before totality, the sky in front of us darkened from the horizon upwards and, as the darkness reached the Sun, the last few beads of light were extinguished and totality began.

The corona around the Sun was even, displaying none of the long rays which so marked the Oregon eclipse two year ago. I took a few seconds to wheel around and look at the horizon, but the gorgeous fake-sunset glows which characterised the Tidore eclipse of 2016 were nowhere to be seen. Venus and Jupiter were somewhere around, but I didn't spot either and wasn't really bothered. Initially I couldn't see any prominences, but it's always worth checking later in the eclipse because, as the trailing edge of the Moon approaches third contact with the Sun, it sometimes uncovers prominences on the edge of the Sun where the diamond ring is about to appear. This caught me out in Oregon, where I barely saw a beautiful string of red flames on the trailing side; but in Argentina I was ready, and saw two prominence groups at six and nine o'clock on the Sun. Unfortunately this meant that the diamond ring was about to appear and, indeed, so it did seconds later, to whoops of joy. The Moon's dark shadow departed the top of the Sun and shot off over our heads towards Buenos Aires.

I did what I usually do just after eclipses; find someone with alcohol. My very good friend Henryk always brings a bottle of champagne to an eclipse (in 2003, off the Antarctic coast, it froze in the glass), so I sought him out and enjoyed a tipple. Henryk usually brings his family too; I know his children well, but this time round he came with his sister and her husband for their first eclipses.

The Moon began its journey off the solar disk. I always feel a little saddened, in part because all the things which were so thrilling in the partial phases leading up to totality are still going on – but who photographs the pinhole pictures and the peculiar shadows in the latter phases? This time, however, there was something exciting to watch out for. Because it was a later afternoon eclipse, the Sun set whilst still in eclipse, into a mountain backdrop. The photographers had a field day; double or even triple "eclipses" by the Moon and foreground peaks; multiple sunsets as the Sun slid diagonally into a jagged horizon. Of course I watched for green flashes, but if there was one, I didn't see it. (In 2002, photographers at Woomera captured a green flash within the eclipsed Sun as it set, impossible to see with the naked eye. If that happened at Bellavista, I haven't yet seen the evidence).

As sunset turned to twilight, we made our way back to the buses and joined a surreal traffic jam on the mountain road back to San Juan. Nose to tail traffic in one direction; a completely empty road in the other. Back in San Juan the locals, who had seen a short eclipse in cloud-free conditions, were more concerned with the Argentina vs Brazil football game in the Copa Libertadores semi-final. The only mention I found of the eclipse on the TV was an astrologer explaining its importance to horoscopes – I changed channel quickly.

We didn't hang around long in San Juan, the next day – no time to revisit the dinosaur museum. Instead, we drove back to Mendoza airport for our flight to Santiago de Chile. The distance as the condor flies from Mendoza to the Chilean capital is only a hundred miles, but the road goes over the highest part of the Andes. After taking off, our plane had to circle the airport several times whilst it gained altitude. I had a window seat on the north-facing side of the plane, and was rewarded with a stunning vista over the mountains, including the summit of Aconcagua, the highest mountain in South America. We joked that the in-flight movie would be *"Alive"*, the true story of a group of Uruguayan rugby players whose plane crashed in the Andes; the survivors were stranded so long that they resorted to cannibalism.

No choice of meal ("chicken or beef or human. . .") was offered during the short flight, which concluded with us dropping down the western side of the Andes. Santiago, a city of seven million people, has a spectacular location with the Andes as a backdrop to the east and steep hills scattered through the city. Immediately on leaving the airport, I joined the city tour group, so instead of going to the hotel, we headed for the city centre.

Our tour guide started by sympathising with Argentina for losing their game against Brazil – "now they will not play Chile in the final" – as Chile were due to play Peru in the other semi-final that evening. We toured the city centre on foot, visiting the presidential palace, where Salvador Allende died in mysterious circumstances in the military coup of September 11th 1973, which ushered in the brutal junta of General Pinochet; and the curious cathedral, long and narrow. Like San Juan, Santiago is in an earthquake zone, and our guide told us about the earthquake which hit the city in 2010, of a barely believable magnitude 8.8, one of the largest ever recorded. The quake hit at 3:30 AM as he was walking home from a party – "what have I been drinking?" was his first thought. Santiago has many tall skyscrapers – our hotel was next to the largest in South America – but, by law, none of the windows are glass.

We had lunch in a street café and I joined a table with Stuart and Kim, from California and Adam, from Arizona. There were a lot of Americans in our group; perhaps not surprisingly given that half the population of America saw the 2017 eclipse and were smitten, and the other half wanted to know what they had missed. Stuart was a doctor and Kim, originally from England, did political volunteering for the democrats – the majority of the Americans on our group seemed to be anti-Trump. The exception was Adam, who held some surprisingly extreme views – he told us,

The Andes, with Aconcagua in the far distance

"We are not hippies, we are happies" – my tour group in Valparaiso

quite matter-of-factly, that at least three Democrat presidents had been Ku Klux Klan members (I was tempted to ask if one of them was Obama, but held my tongue). On the other hand, Adam was able, quite unexpectedly, to introduce me to a chap called Dr. Donald Kennerly. Prior to the 2017 eclipse, Donald had traveled the eclipse track, making videos of observing locations and it was Donald's video of the Snake River/Burnt River confluence which persuaded me to observe from there. It was a real pleasure to chat to Donald and I have corresponded with him subsequently.

Whilst I was enjoying the city tour, my room-mate Peter was doing a lightning tour of the museums of Santiago, an impressive feat of logistics and forward planning. We met up for a pizza in the evening, then joined the locals in watching the football. Alas, Chile too lost, to Peru this time. The English lionesses had just lost a semi-final, too, so for the second time in as many days we were able to empathise with grieving fans.

For my final day in Chile, I joined a day-trip to the coast, to the extraordinary city of Valparaiso, a world heritage site. This port tumbles into the sea from steep hills and there are many inclined railways which take people up and down the slopes. Creativity and individuality are encouraged, and so the city is a riot of street art. Our guide had us pose for a group photo at an intersection between a road open to traffic and one of several open only to pedestrians, with gardens where cars would normally pass. Only when we walked a little further downhill did we realise he had posed us above a slogan reading "We are not hippies – we are happies". How true.

From Valparaiso, we took the short journey to the neighbouring resort of Vina del Mar, a much more elegant and restrained location, for a lunch stop. We could have dined at the buffet in the casino, but instead chose one of the nearby restaurants. The menu looked appetising, but as Peter tried to order, problems became apparent. His first choice, a meat dish, wasn't available. The waitress too his order for a pasta-based dish but came back a few minutes later to tell him that the pasta hadn't yet been made that day. All that remained on the menu were the fish options and he didn't like fish. After some to-ing and fro-ing he settled on the most palatable option remaining and we sat back to wait for lunch. Trouble was, the menu vagaries meant we were way behind schedule. Our coach departure time of two o'clock approached, with no food in sight. Finally, at five to two, our meals arrived. They were absolutely delicious! Easily the best meal of the week (and I ate well all week) – bolted down at speed. We were fifteen minutes late back for the coach, but I think our guide wasn't too worried; he knew Chilean lunch breaks can overshoot.

Our final stop was, of course, a vineyard. Chilean wines, like Argentina's, are world-renowned. We stopped at the Casas del Bosque, in the Casablanca valley, through which Route 68 from Valparaiso to Santiago passes. A very enjoyable saunter through the vines and the winery concluded with a tasting of Casas del Bosque's Cabernet Sauvignon and two very nice red wines.

The party continued with an evening meal out in a Chilean/Japanese fusion restaurant. Sushi was a house speciality but I really didn't want to eat raw fish the night before flying, so instead I settled for a delicious steak and rice option, delicately cooked and presented. But the best part of the evening was the company.

And that was that. Back to the airport, flights on time, back to England. Four days later I was in Chicago. But that's another story. . .

Casas del Bosque vineyard, Casablanca Valley, central Chile