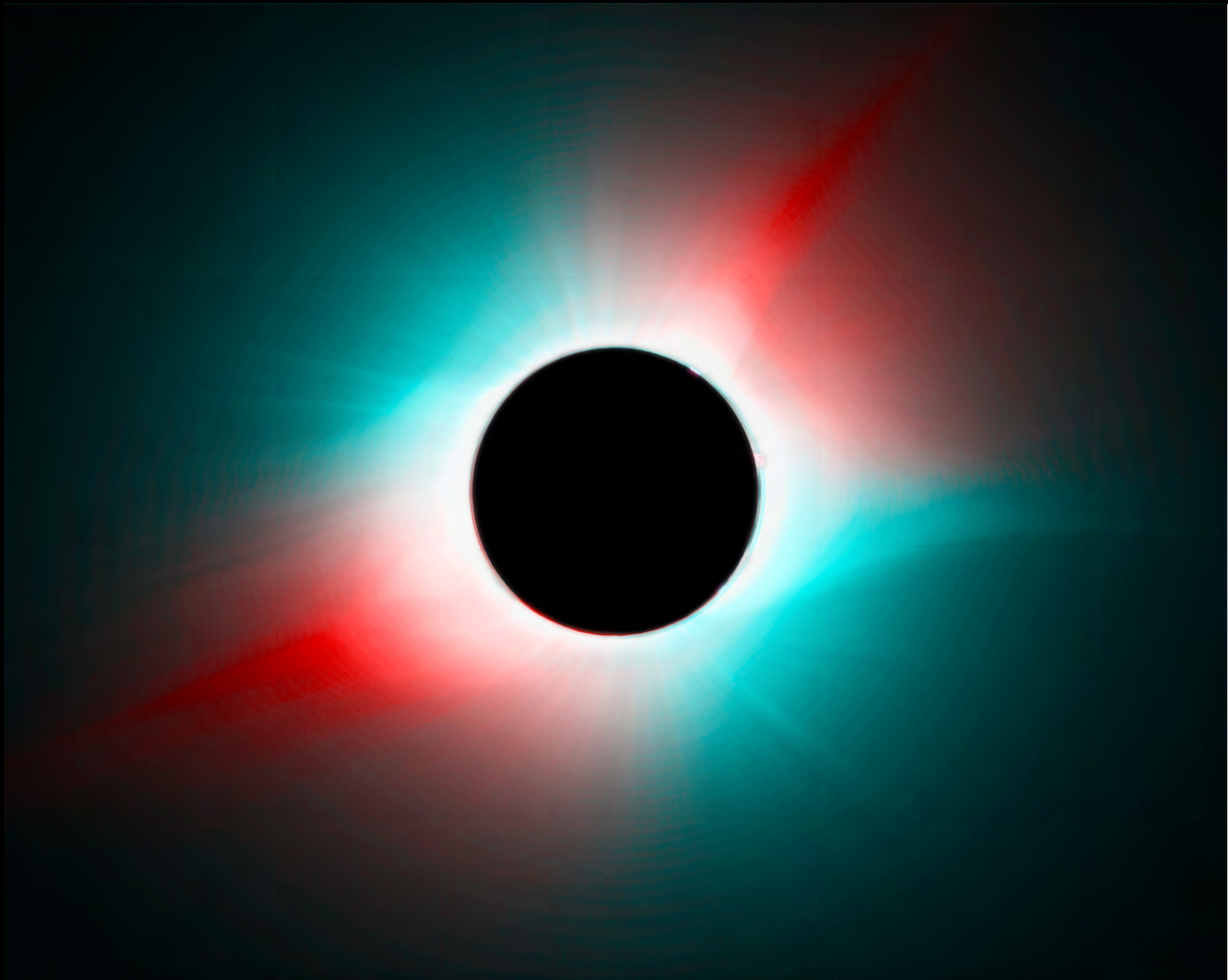

Nightfall

Newsletter of the ASSA

Deep-Sky Section

Special Report

Photographing the Polarisation of the Inner Solar Corona

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NIGHTFALL

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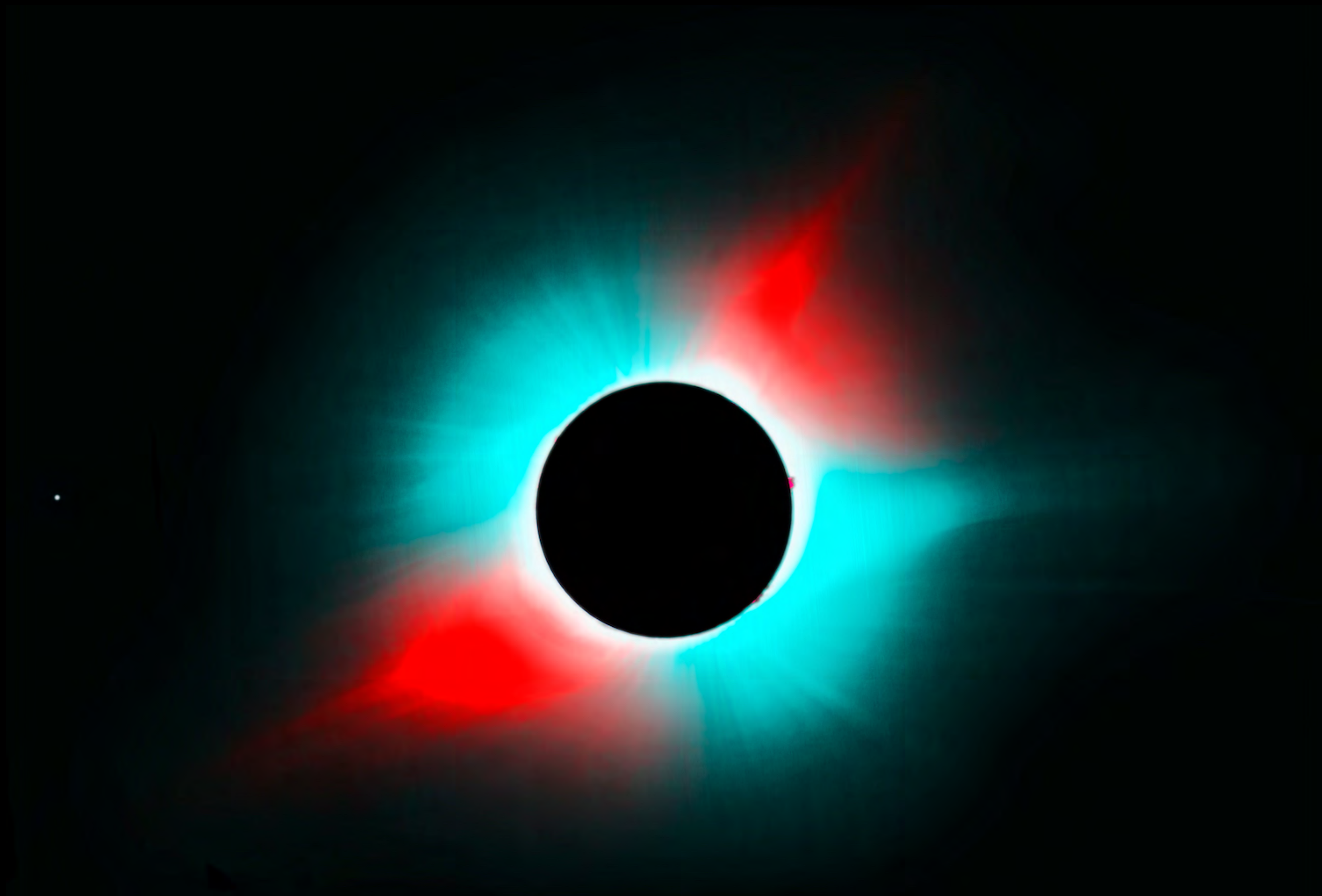
Canon 5D Mk II at ISO 100 with custom APM 115/805 operated at f/5.25. Effective image brightness is T/8. The image was constructed from frame sets running from 1/250th to 2 seconds followed by rotation of the polariser and then running from 2 seconds down to 1/250th. Those preceding the polarisation switch were coloured red and correspond to east-west polarisation while those following were coloured cyan and correspond to north-south. This was then set aside as a sub-frame. The same process was adopted for each set. These were then composited. This approach allowed the mapping between brightness and colour to be maintained so that the colour reflects the actual level of polarisation. The image reveals fine radial jets of north-south polarisation, which appear to be dominated by the Sun's background field. Two of the larger jets—corresponding to the Sun's active regions 12671 and 12672 that morning—hint at east-west polarisation. A third jet appears to emanate from active region 12671—though possibly from a different part of it.



Special Report:

August 21, 2017 solar eclipse

by Bruce Dickson

PART I A GREAT SILENCE

Some people take eclipses for granted. Not me.

Years ago, I was amazed to learn that a useful, empirical eclipse model existed as far back as the time of the Chaldeans (500–800 BCE). How many eons did people gaze in fright or prayer at the sun suddenly blotting out or the moon becoming fiercely warlike red, only to recover soon after? What could it all mean? According to the Greek and Roman writers Strabo, Pliny, Barossus, and Cicero, Chaldean astrologers deduced that every 241 lunar cycles (6585.32 days) the Earth-Moon-Sun alignments would be nearly identical with a similar set many years before.

August 21, 2017 eclipse in unpolarised light taken by Bruce Dickson at Lost Springs, Wyoming, USA. Camera: Canon 5D Mk II on the APM 115/805. (*Full details below.*)

They adopted the Babylonian word "*sāru*" (the word for the number 3600) to describe the cycle — perhaps because no one had ever needed a word for 6585.32. How —and *why* — did the Chaldean astrologers determine that every 18 years and 11 days, the Moon would be in the same phase, at the same node, and at the same distance from the Earth, as it passes in front of the Sun. In those days the average life span was only about 35 to 40 years. Many people lived long enough to witness one *Sār* (the singular of S*āros*) but few lived long enough to experience two complete *Sāros*. Who was the first to think of recording the Moon's cycles?

That was then, this is now. Computers whip out the exact times and geographic positions of any *Sār* we wish in less time than it takes us to pull the atlas off the shelf. In early 2016 our local astronomy club decided on a group project to observe and photograph the 2017 eclipse. The shadow would race along the waistline of the United States like a belt made of shadow.

We scrutinized the weather patterns like *tesseomants* scrutinize tea leaves. The best weather prospects would lie in eastern Wyoming. We put in our deposits in May 2016. Club founders Andreas Gada & Bonnie Bird went location scouting (this would be their 16th eclipse expedition!) We dreamed of arriving with bags packed, scopes cleaned, mounts checked, credit cards paid up, and our Club's guitar ready for sing-alongs.

The Canuck Contingent. Bonnie Byrd and Andreas Gada hold the club flag, lower left front. Dave Cotterell is in the back with a white hat & matching moustache. The author is wearing a blue tee-shirt in back row centre, sporting a sunburned face beneath his hat and wearing a Starfest name tag. Lodge owners Brad & Heather Reese and family are on the right of the centre and back rows. The kiddie at the front is Jordan—three years old and already an eclipse specialist, eager to explaining eclipses to anyone who would listen. *Photo courtesy of Ramesh Poornan (front left).*

Then work and daily life turned busy and I forgot about the eclipse — until *Starfest*. Fred Espenak, now retired from NASA Goddard, came up from his home in Arizona to deliver the keynote address. As we chatted it dawned on me that I was totally unprepared for a 6000 km road trip looming barely a month away. I checked the route again, suddenly daunted at the logistics of a sojourn equivalent to Cape Town to Malawi and back, albeit on better roads.

The club bestirred itself like bats at dusk. We made lists, bought supplies, checked equipment, packed boxes. My lounge filled. Then filled some more. I did a dry-run pack into my SUV. *Uh-oohh*. So I bought a roof rack and tried again. *Hmmm*. I bought a box for the roof rack. *Bingo*.

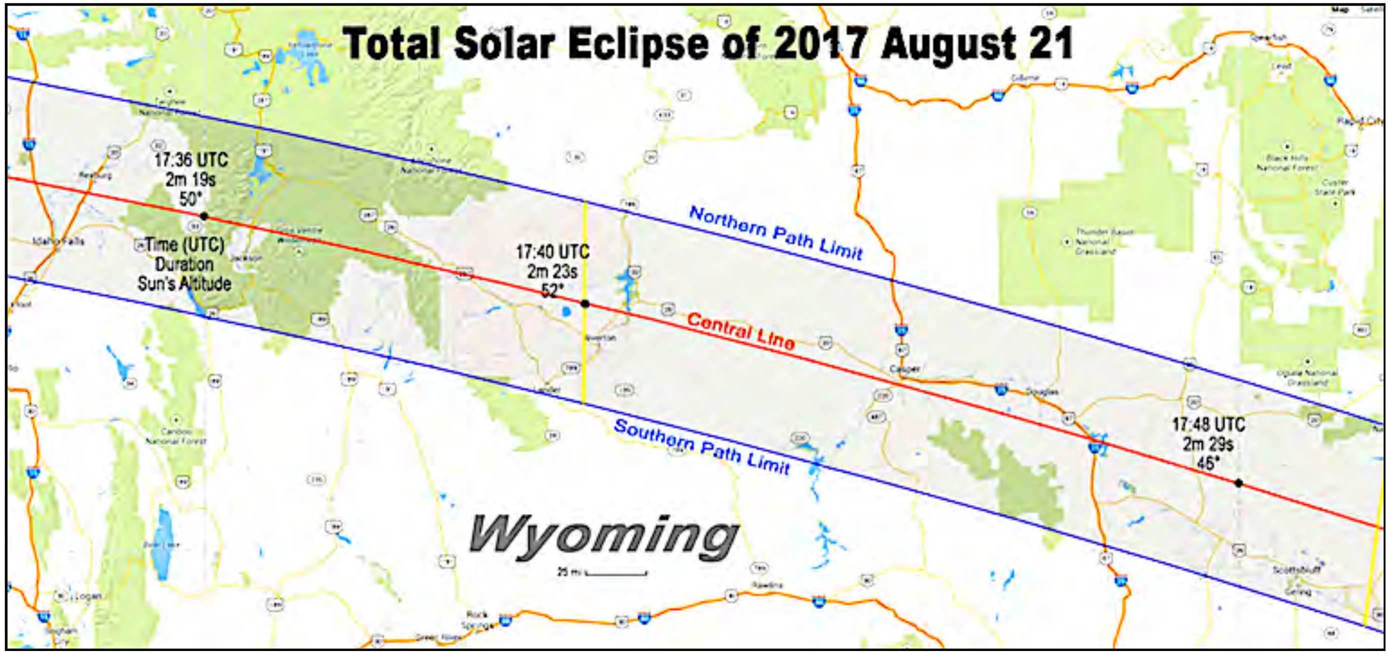
Departure Day. My companion was a northern skies observer named Dan Driscoll. He arrived, parked his Chevy pickup, became lost in the underground parking, escaped a street over and hopped into my SUV. A three-hour drive and two-hour wait at the border later, we entered the USA.

The endless flat horizons of the Wild West beckoned. Nerves tingled. We were on our way. We ran the gamut of eastern Michigan's barely drivable washboards (which may explain the most disciplined drivers I've ever encountered). We got lost in the south side of Chicago, met some wonderful people, then crossed the border and slept in Bettendorf.

The author's eclipse imaging configuration – Custom APM 115/805 with 3" Feather Touch focuser and Takahashi flattener-reducer. This normally produces an effective f/5, but here the polariser slightly constricts the aperture so the system aperture was f/6. The mount is an Astro-Physics 900GTO. The primary camera is a Canon 5D Mk II. The piggy-back camera mounted on top of the refractor is an unfiltered Fujifilm X-Pro2 with OM 500/8 mirror-lens and Metabones focal reducer. The backup camera was only exposed during totality.

Hollywood's version of America would have us believe that the speed limit is 55 mph (90 km/h), but the reality is that most places allow 70 mph (110 km/h). It's a good thing — America is big. Iowa's green rolling hills proclaimed their farmsteads with really red RED RED barns, all tarted up with white trim and Z-barred doors.

The highways were threaded with truckers drafting each other's big rigs in caterpillar-like convoys. With tips of the hat to Iowa City, Omaha (the city with a railway bridge and an oracle) we rushed by Grand Island, and made it to a man sized beer in North Platte and bed.



Eclipse path courtesy of Fred Espenak, www.EclipseWise.com

Ranch Hands

Finally we made it to Lost Springs, Wyoming. Population 4."It's a bit quiet 'round these parts," allowed Brad Reese, owner of the lodge where we stayed.

Lost Springs is, well, lost. There is an exit sign with that name at the highway off-ramp. Once off, the town is a clapboard City Hall, a post office annex (no clerks, two rows of mailboxes), a general store. Ask someone and "The Lodge" (i.e., the only one) is 25 km down a dirt road. The Google Maps location is wrong by miles—go where Google tells you and you'll find yourself in a large field. You have to ring Brad for instructions. When we finally arrived Brad & Heather's place was a 150 000 acre (60,740 hectares) spread called Rockin' 7. Ask the Reese kids Cody, Shelby, Paige, or Chase where the name came from and they'll spin an elaborate but true yarn that a Rocking 7  branding iron was the only one in the store when Brad came in to buy his first branding iron for his first small herd in their first corral. The place has grown a mite since then, to 607 square kilometres.

Brad and Heather's kids deserve a special mention all their own. Eclipse happened right in the middle of their school holidays, when their usual summer entertainments like swimming in the ranch's water reservoir and evenings with Netflix were simmering along with the sun. The temps reached 40° C while we were there, but the air is so dry it wasn't bothersome. Farm kids are a breed all their own—no goofing off when there are chores to do. "Chores" included kitchen duties. The kids did most of the food prep under Heather's (semi)supervision. Kids like the Reese's are why the term"ranch hands" is a by-word for "reliable".

Solar Zoo

We were not to be lonely very long. Wyoming's notional population is about six hundred thousand. If the eclipse centre line was a ship's Plimsoll line, the state would have capsized on Eclipse Day. Two million umbraphiles descended on I-25. We twenty-two Canucks from North York, Toronto were a tiny islet in a vast archipelago of campers, trailers, fifth-wheelers, RVs, and pup-tents.

My first night was spent polar aligning my mount. It was so easy it seemed like cheating – Polaris is bright and polar scopes allow instant alignment to within a few arc minutes. On E-Day minus 1 I checked and corrected scripts, mounted the scope and focussed the camera, balanced the mount, checked and rechecked that cables would not tangle, that the backup camera was aligned and focussed. Then I did it all over again. When evening arrived and I used Polaris to achieve the best focus possible—my first (and last) observing session devoted to looking at just one star. Everything was locked down, batteries were put on charge, nerves twitched. I recalled the feeling I had as a varsity lad when entering an exam hall – I've prepared as well as I could. Now it was time to "Do or do not. There is no 'try'."

Boom & Gloom

Then . . . ***OH NO!*** At 10:00 pm pillars of clouds rolled in. It was one of those sky-inking monster storms that had people running for the root cellars in the old days. The air was a cacophony of crackles and thunder. We convened an emergency club meeting to decide if this really warranted Plan B.

Months earlier we had a Plan B session to crystal-ball what we should do if the morning weather looked bleak. Now, on Eclipse eve, we broke out our pre-marked maps to guide us to the nearest cloud-free back road. Foreseeing that everyone else would have the same idea, we were on hair-trigger alert for the unthinkable: leave before everybody else and drive like hell.

The Darkness After the Dawn

The Toronto contingent was up before dawn. 21 August 2017 arrived sky-high and cloud-perfect. I played "Dark Side of the Moon"to a rousing chorus of groans and eye-rolls from everyone eating breakfast.

Even by human standards, eclipses are fleeting. I had volunteered myself for a number of experiments to fill 147 seconds of totality — "Look at the black sun!", "Did the wind drop?", "Did wildlife behave differently?", "How bright was the sky during totality?" Having failed with two previous attempts, I wanted a photographic record of the eclipse. My real goal was an image sequence of the corona's polarisation. This required a fair bit of automation. Our group's preferred automation packages are *Eclipse Maestro* for Mac and *Eclipse Orchestrator* for Windows

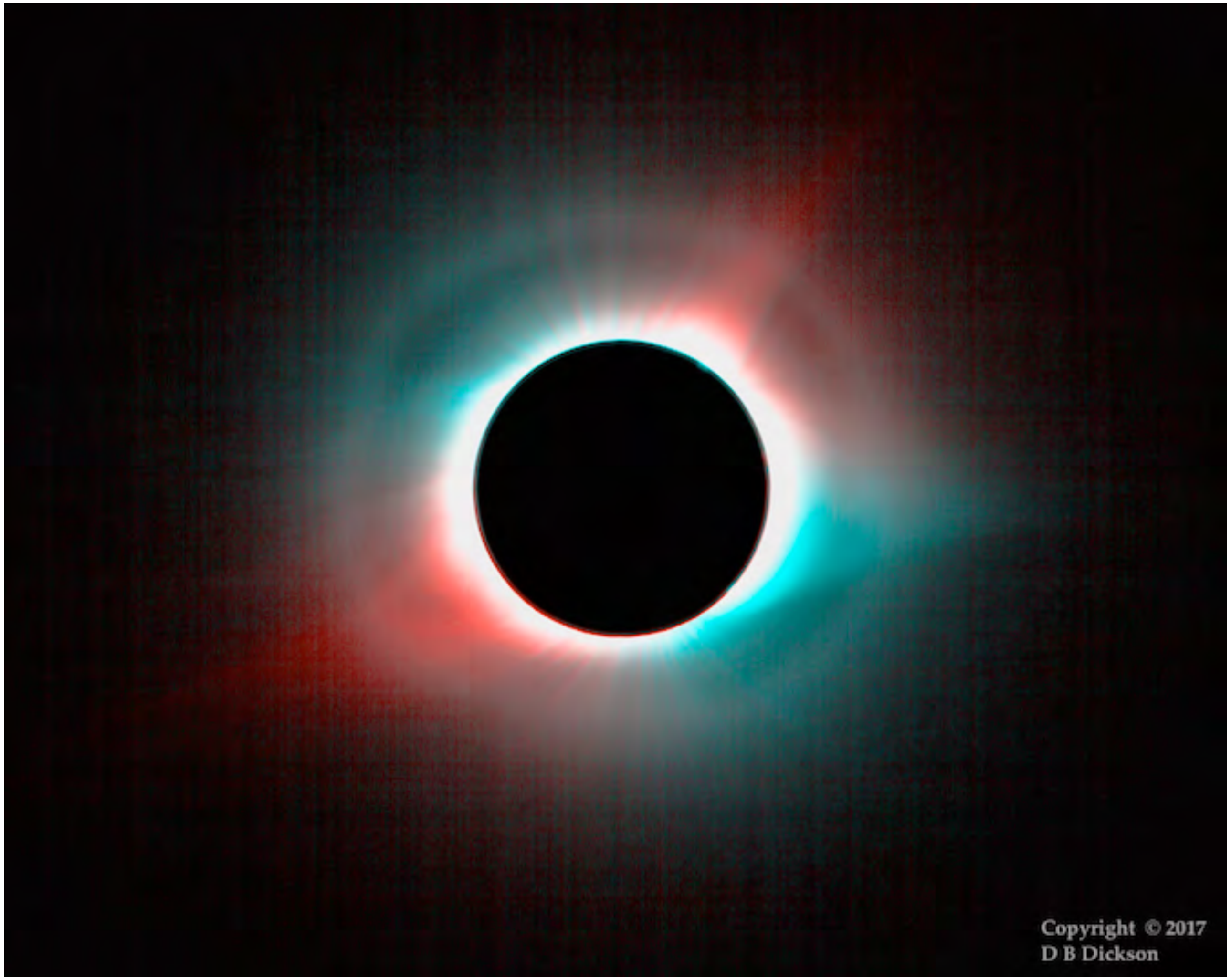
At 11h 45m 13s Mountain Daylight Time, the sky went dark. I could have taken time out to ponder the myth of the dragon eating the sun, but nope. No frivolities. I was busy with the cameras, *snap-snap-snap fast-fast-fast*. It was varsity exams all over again, only this time for real. Only as Baily's Beads speckled into dazzle did I step away to behold the entire sky turned into a spectacle so overpowering I could only mutter a line from the poet Rumi: *"**A great silence overcame me, and I wondered why I ever used words.**"*

Our hosts, Brad Reese and his wife Heather, were as awed by Nature's grandest spectacle as we. At dinner the previous night, Brad confided that he thought we were all crazy driving so far just to see the Sun go dark in the middle of the morning.

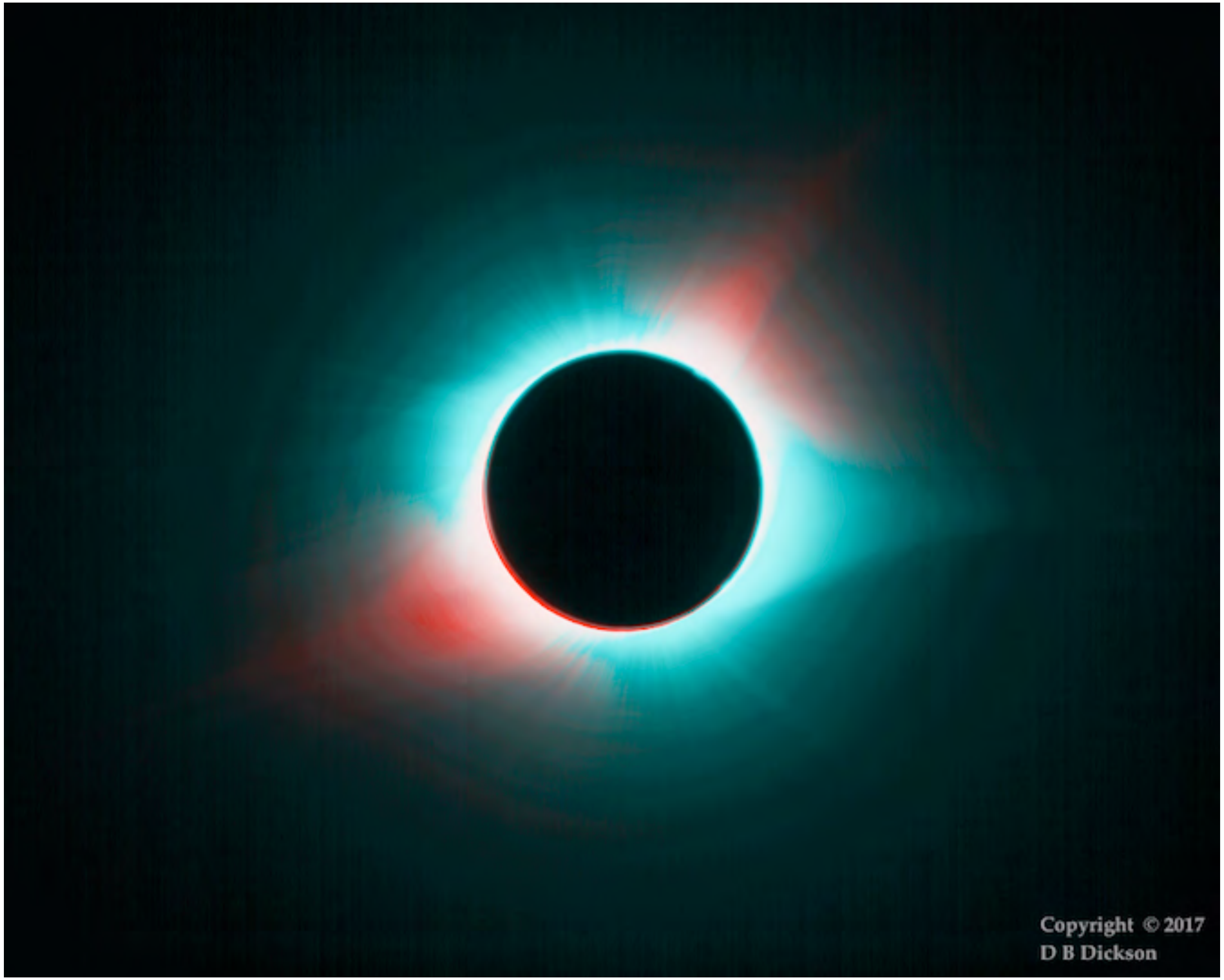
But by the time we departed, his tune had changed. "When's the next eclipse due in?" he asked us by way of farewell.

"We'll leave the light on for ya'."

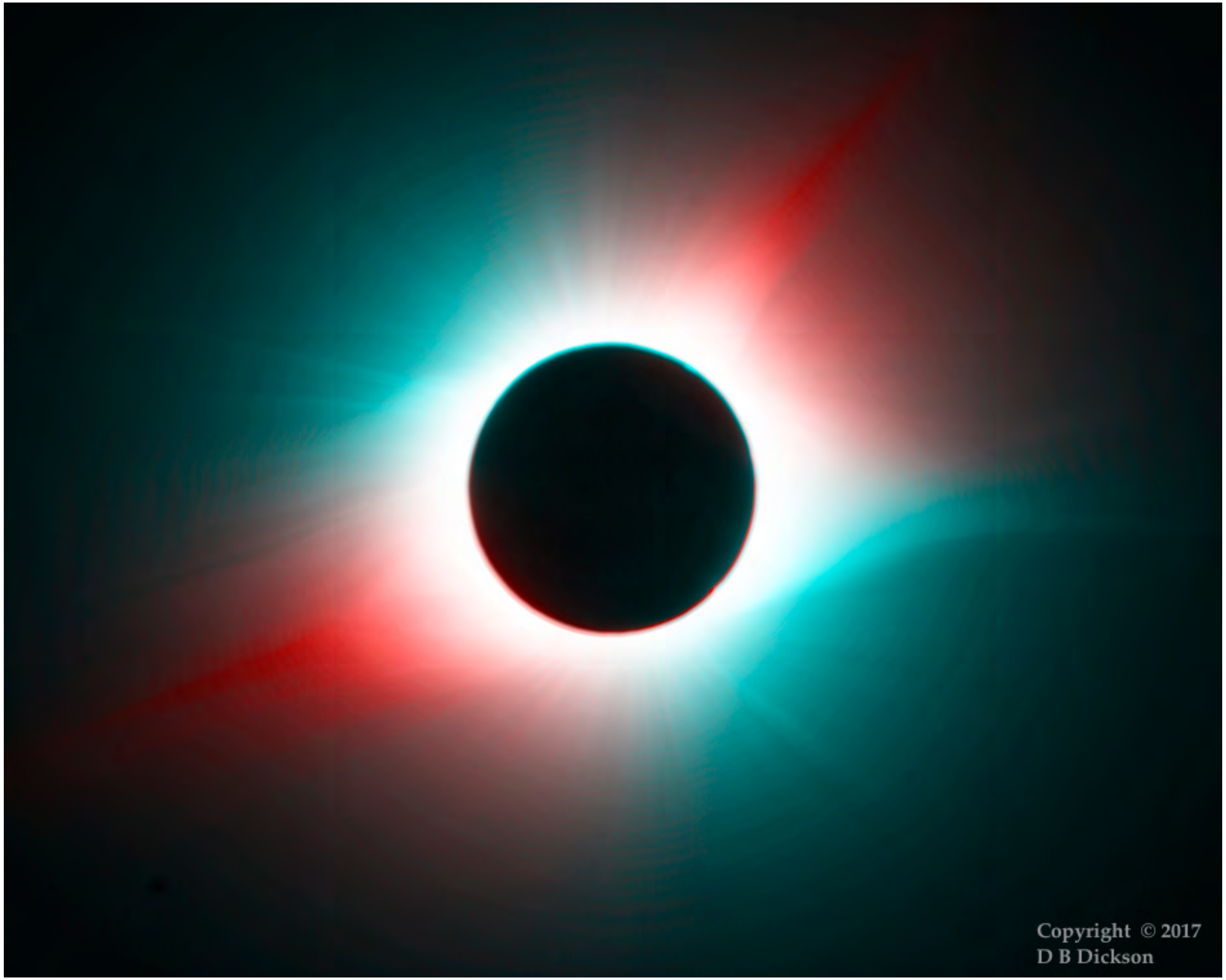
Part II Photographing the Solar Polarisation



Inner Corona – a composite of two polarisations with exposures spanning 1/250 to 1/60 second. The bright ring is an artefact that appeared when the structure was boosted. It was hidden for the final composite. The white areas are where the inner corona saturates the detector.



Middle Corona – a composite of two polarisations with exposures spanning 1/30 to 1/4 second. Note how light from this part of the corona appears to be strongly polarised in the N/S direction. The red and cyan edges to the moon are artefacts caused by the sensor saturation during the before and after sequences.



Outer Corona – a composite of two polarisations with exposures spanning 1/2 to 2 seconds. As can be inferred from the inner and middle corona polarograms above, the white region represents sensor saturation.

Coronal Polarity Imaging

As far back as 1879 Arthur Shuster had reported polarisation of coronal light.[1] Although the outer corona is accessible from spacecraft observations,[2] total solar eclipses offer a rare opportunity for the amateur astronomer to study the behaviour of the inner corona.

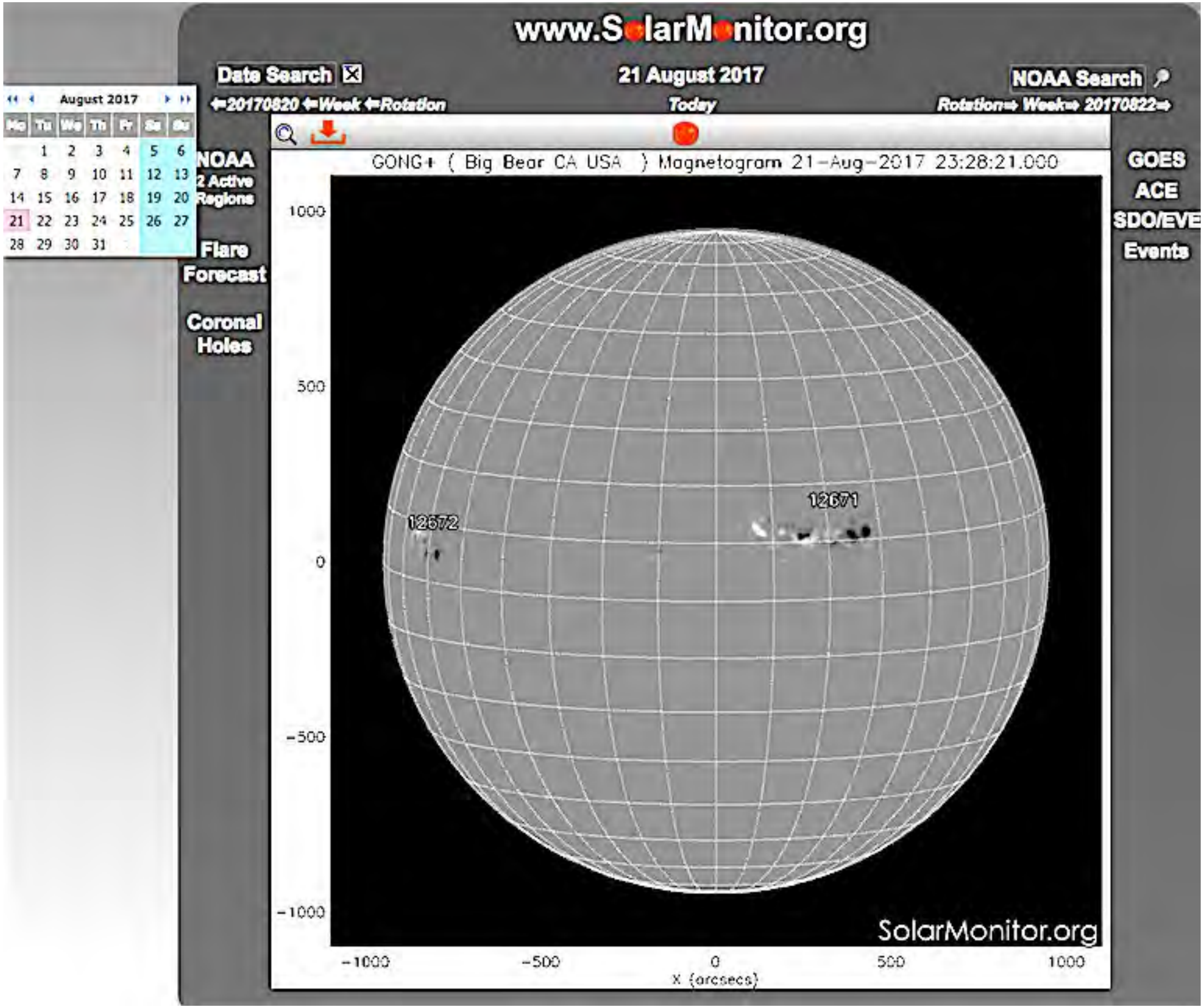
This report describes my attempts to measure the corona polarisation during the eclipse of 21 August 2017. I equipped my equatorially mounted, 115 mm refractor operating at f/5.25 with a polarising filter made by adapting one normally used with large aperture camera lenses. Its cell did not fit the lens on my APM refractor, so a friend obliged by creating a custom adapter on his 3D printer. (The adapter design and a couple of images can be found here.) This stopped down the objective to 100 mm, and introduced a filter factor of 1.7 stops. Accounting for slight loss in the lenses, the telescope effectively operated at f/6 and $T/7.85$.

I used *Eclipse Maestro* to provide scripting for camera control. I selected a script suitable for f/8 optics and increased the number of frames so that the full 147 seconds of totality could be recorded. The imaging sequence spanned 1/1000 to 2 seconds in 1-stop increments, followed by a brief pause to allow for polariser rotation. After that, the totality sequence was continued by running the image sequence down from 2 to 1/1000 seconds. At least two frames were recorded in each sequence; the shorter images allowed up to four frames.

A light wave can only be polarised along one plane. By making intensity measurements in two directions, we can identify the components in each direction and thus calculate the plane's inclination unambiguously. In this case, I chose to use planes that were parallel with and at right angles to the sun's axis. My printed adapter was designed with indexing marks and these can be referenced to manufacturer's labels on the front of the polariser so that it's relatively easy to see how the polariser is oriented. Of course, since you're measuring a plane, it doesn't matter whether you rotate the focuser clockwise or counter-clockwise; the plane it gets to is the same.

Physicists recognise a second form called circular polarisation. With this type, the electric field will either lead or lag the magnetic field. Rotating a polariser cannot separate these; even though the measurement is more robust, it's inconvenient and expensive to go chasing circular polarisation.

Self-described photographic "circular polarisers" are misnamed. These do not separate circularly polarised light. Instead, they have a linear polariser sandwiched with an optical quarter wave plate. This converts plane polarised light into circularly polarised, which is better suited to a camera's exposure meter. Thus my polarisation experiment could be performed using either a plane or circularly polarised photographic filter.



A large flare had erupted from AR12671 in Hydrogen alpha light immediately before the eclipse. Effects of the violent magnetic line reconnections were visible in the three-image set on pp. 11–13 above.

Source: www.solarmonitor.org.

The *Eclipse Maestro* scripting system also gives users the ability to insert verbal cues to remind the user when to remove solar filters, rotate the polariser, or other tasks during a fast-moving event. The value of an audible instruction cannot be overstated in situations where timing is critical. I also inserted cues to prompt me to conduct other, unrelated observations during totality. Among these, I had instructions to press the shutter release on my backup camera, measure the sky brightness using my SQM-L, look for stars and planets and observe the horizon. I was on a mission to squeeze everything I could from totality!

Shortly after dawn I aligned the polariser with the expected east-west orientation of the sun's equator. I then recorded a flat field sequence against the sky. I started the drive, aligned the scope with the sun verified the solar tracking rate. The camera was placed under automated computer control just before first contact (C1). Images were made every 2 minutes to record the partial phases starting at C1 until just before C2. For this sequence I had mounted an auxiliary full-aperture white-light solar filter to normalize exposure times and keep the camera cool. (A full-strength solar image from the 100 mm T/8 objective would have fried the shutter and perhaps also the sensor.) The filter reduced the incoming light by 99.999 % or 16.6 f/stops. The filter was removed a few seconds before C2 so I could capture images of Baily's Beads and the Diamond Ring effect. Keep the exposures short (1/4000 second) and you can produce excellent images this way.

Halfway through totality, I heard my cue to rotate the polariser. Incomprehensibly, I had already forgotten. I had difficulty squeezing my fingers in between the lens hood and the filter so rotating the polariser took longer than expected. This cost me one 2-second exposure. Not so good but not a calamity either.

The white light filter was returned 10 seconds after C3. I continued the earlier sequence of one frame every two minutes until the eclipse ended at C4. A second set of flat frames was then recorded to baseline the post-rotation frames.

Done. No sighs of relief. No slow exhale. Just that big stunning slice of light in the sky, getting brighter.

Wow.

PROCESSING TECHNIQUES

Images made to reveal polarisation direction must be intensity-mapped from RGB luminosity into a single-colour brightness. Success requires quite a bit of planning and calculation. To begin with, coronal brightness spans about three orders of magnitude (10 stops). The obvious approach would be to construct a high dynamic range image using routines that are built into Photoshop. While these algorithms can create creditable white light images, I found they also created artefacts in the image and all information indicating polarisation was lost.

A more controlled approach was required. I divided the exposures into two frame sets – before rotation and after rotation. Each exposure was stacked and averaged into one of three range sets: *Frame Set A* (1/250 to 1/60 second), *Frame Set B* (1/30 to 1/4 second) and *Frame Set C* 1/2 to 2 seconds). This resulted in three set of composite frames, which then had to be normalized to each other. I averaged each new composite frame across the three frames that generated it. This way, every frame was weighted equally within the exposure range of that particular image set. The only non-linear variable was the exposure lengths. Since the frame sets were now matched to the radial drop-off in the corona brightness, the image preserves the polarisation information.

Finally, the images corresponding to the east-west and north-south channels were mapped to red and cyan respectively and again the images were averaged. I then adjusted the saturation of each image to reveal the faint structures.

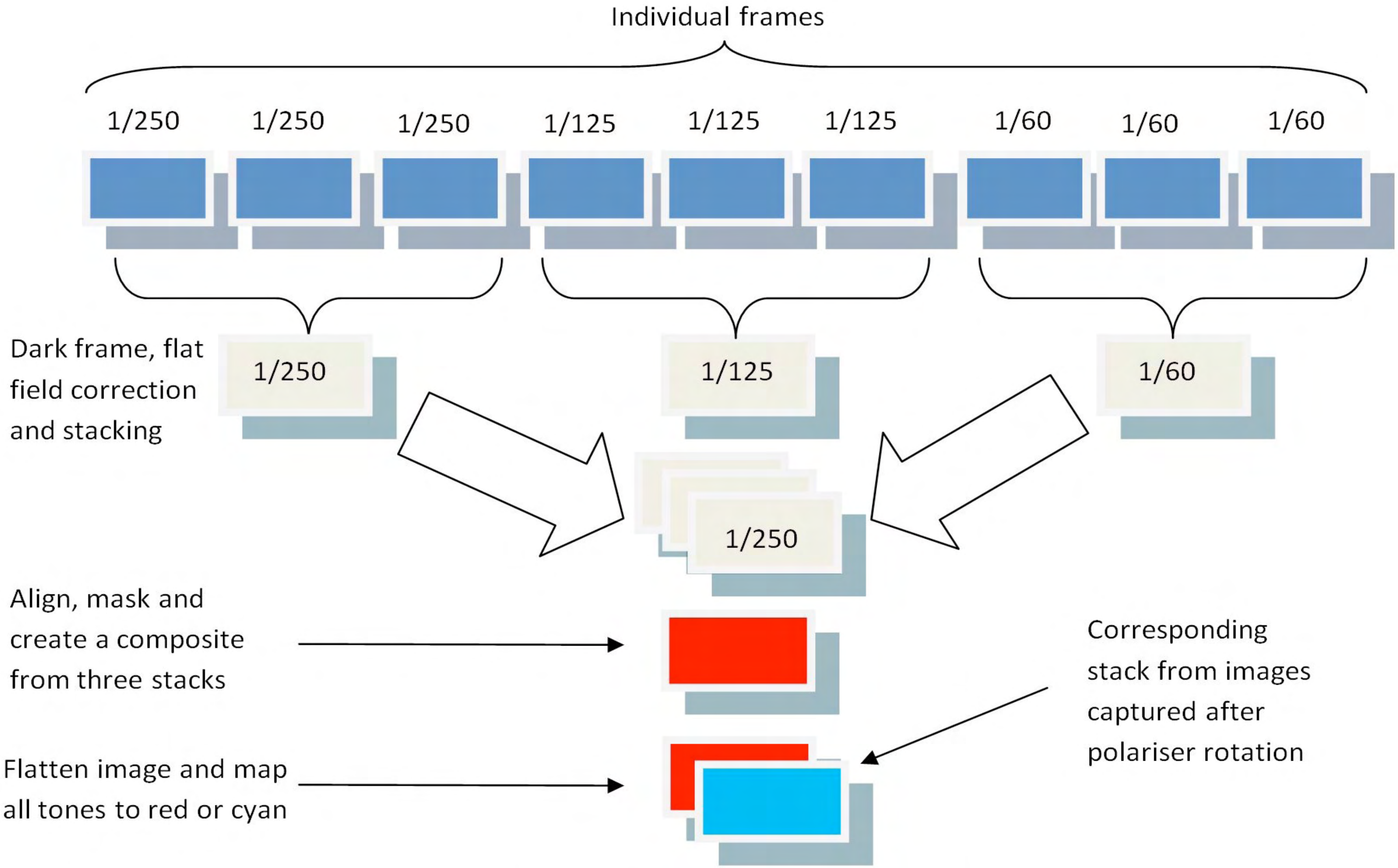
The sequence may be easier to follow using the chart on the next page. This details the creation of the polarogram for the inner corona (*Frame Set A*).

As the images above suggest, coronal light is strongly polarised, an effect which persists into regions very close to the solar disc. Since polarisation direction is a proxy for the magnetic field, cyan appears to map the normal solar magnetic field while red traces streamers with a different polarity axis.

The asymmetric streamer to the south-west (3:00 o'clock in the images) appears to be dominated by the regular solar dipole field. This may have been caused by a large active region AR 12671, as shown on page 15, near the middle of the disc on eclipse day.[3] The actual source of the streamer must remain a matter of conjecture. The photosphere is so bright that we can only view the inner corona during an eclipse. Unfortunately this means the moon will always be in the way.

Obtaining perfect focus is always challenging. Under ideal conditions, the observer could focus using a sunspot, but sunspots can be entirely absent (especially during a solar minimum). Granulation on the solar disc may be considered but this is low contrast and is usually only visible once images are processed. I decided to use a star. The afternoon before the eclipse, I insulated my telescope to keep its temperature reasonably stable. That night, I focused and locked things down. The trick was trusting that during the day my scope would return to perfect focus.

Polarisation Workflow



One third of the polarisation image processing workflow

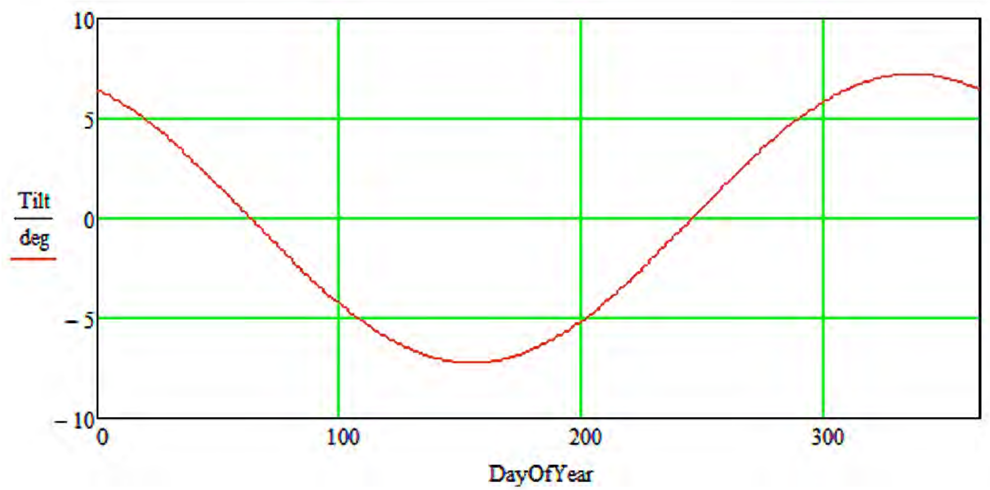
This approach worked well with the large aperture polariser. An internal polariser near the focal plane would not have compromised things beyond requiring longer exposures.

One might assume the Sun's equator aligns with the ecliptic. The planets all rotate in a thin plane, which in turn reflects the thin pancake of planet-forming accretion disks spinning around the rotational axis of their star. We assume the Sun condensed from the same cloud and conservation of angular momentum would keep things aligned. Nope. Nature is ever full of surprises.

The Sun's axis is in fact inclined at 7.25° with respect to the ecliptic.[4] Its north pole points toward the earth in the first week of September and its south pole is pointed earthward in the first week of March. This means that viewed from the earth's perspective, the sun appears to precess with its north pole going clockwise. It's easy to estimate the axis inclination with respect to the ecliptic from the graph below in which a positive value implies the sun's axis lies to the east of a line perpendicular to the ecliptic.

Several explanations have been advanced to explain this oddity. Most are based on sound orbital dynamics but none is truly compelling. The most recent suspect is the indicated "Planet 9".[5] A number of extra-solar systems exhibit even greater obliquity.

The bottom line: when planning to image the corona in polarised light, the polariser should be aligned relative to the Sun's axis or equator. Failure to do this will blend the channels together. In principle the polarity components could be separated using proportionate sums and differences but this adds a layer of unnecessary complexity to the processing.



A LESSON LEARNED THE HARD WAY

I've played guitar with varying levels of enthusiasm for 35 years. Early on, I learned that amateurs practice until they get things right, professionals practice until they can't get things wrong. This should be taken to heart, especially when there's no opportunity for a "do-over".

The excitement of an eclipse is distracting. Everything must be readied and rehearsed. I had a detailed check list but I didn't practice running through it. Inevitably, I forgot to clean the sensor on my camera. When I did remember I was out of time. The result was a lot more time in post-processing. I was lucky — other things could have gone wrong which could have wrecked my efforts.

IMPROVEMENTS FOR NEXT TIME

I was surprised to record *any* polarisation with a 4” telescope, let alone a clear signature. It might have been better.

Accuracy – My Heath-Robinson contraption allowed me to orient the polariser to within a few degrees. The result was channel crosstalk of a few percent. As in so many things, reasonable is easy, perfection takes effort. More care in equipment design might have rendered ten-fold improvement.

Ease of Use – Because I had to grab the polariser to rotate it, I disturbed the pointing direction of the scope by about 1 arc-minute. This wasn’t the end of the world but it could have been a lot worse. Would I have noticed if the sun was completely out of the field? Would I have been able to re-acquire the sun if it was? Having experienced the mental compost that totality delivered, I can answer “No to both.”

Orientation – It is similarly important that the camera is oriented correctly to the solar magnetic field axis. The latter, as we saw above, can be anywhere between –7.25° and +7.25° relative to the ecliptic.

***Aesthetics* –** The solar equator should align with the camera’s wide dimension — or at the very least the long side of the frame should align with the ecliptic. A brief glance at the cover image of this *Nightfall* issue shows an image rotated about 45° relative to the frame. The camera was half-wrong. I did dodge a second bullet though — on 21 August the Sun’s obliquity was about –1.7°and it seems my errors cancelled each other out. As they say, it’s better to be lucky than good.

Exposure time – I found that 2-second exposures gave relatively small improvements in detail. At T/8 and ISO100, the camera chip became saturated and there was a lot of bleeding around the moon’s disc. This introduces artefacts and makes alignment extremely difficult. Since exposures that long occupy a significant fraction of totality, my next session will employ many more ½ second exposures which can be stacked to obtain sufficient depth.

Cameras – My 10-year old Canon 5D Mk II DSLR was not the ideal choice. Its frame rate – something like 4 per second – is not quick enough to record the Diamond Ring or Baily's beads. Irrespective of whether I try for white light images or I have another go at polarisation, a more modern camera would make sense.

The Wrap

All things considered, my eclipse expedition was a tremendous experience. I had great company, great weather, a great place to stay *and* a black sun. Even though I'm a hard-nosed physicist, I experience totality as bordering on the mystical. It truly is the greatest show on Earth.

Come next eclipse, I'll be chasing the Moon's shadow. I hope I've inspired you to chase it too.

References

1. Arthur Schuster, Ph.D., F.R.S., *On the Polarisation of the Solar Corona*, MNRAS, v.40, no.2, 35–57, 12 December 1879

2. See for example the LASCO instrument on the SOHO spacecraft which is limited to observing streamers 5 solar radii from the Sun's surface.

3. See for example the magnetogram for 21 August 2017.

4. A near-contemporary of Galileo accused him of having plagiarised the observation in *Dialogues concerning the two chief world systems* as further evidence supporting the heliocentric theory. Christoph Scheiner in 1626/7 reported the accusation in *Rosa Ursina (1630)*. [See C. Schofield in *Planetary Astronomy from the Renaissance to the Rise of Astrophysics*, Part A, Ch. 3 pp 33-37, Cambridge 1989.] The matter was discussed in Documenta Ophthalmologica, March 1992, v.81, no.1, 27–35, which quotes Franz Daxecker, "*Christoph Scheiner was born in 1573 or 1575. In 1595 he entered into the Order of the Jesuits; he died in 1650. In 1619 his book* Oculus, *dealing with the optics of the eye, appeared in Innsbruck. The invention of the telescope was of utmost importance for progress in astronomical and physical research. Scheiner himself built telescopes and discovered the sunspots. As a result, an unpleasant priority dispute with Galilei ensued. From 1624 onwards, Scheiner was in Rome, where his main work* Rosa Ursina *was published in 1630.*" See bottom of p.28 for factual review.

5. It was recently suggested that the suggested Planet 9 may have tilted the plane of the ecliptic relative to the sun. See New Scientist 19 July 2016, Bailey, Batygin, Brown 2016, and Gomes & Morbidelli et al 2016.

About the author

Until his transfer to Toronto, Bruce was a long term member of the Johannesburg Centre. He is now Chief Scientist at Gedex Technologies based in Mississauga, Ontario. He is a Fellow of the Royal Astronomical Society and director of the ASSA Cosmology Section. An active observer with almost 45 years' experience, with Toronto being Toronto Bruce mostly spends his evenings glaring at clouds.