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# Heliophysics at total solar eclipses

Jay M. Pasachoff[1,2]

**Observations during total solar eclipses have revealed many secrets about the solar corona, from its discovery in the 17th century to the measurement of its million-kelvin temperature in the 19th and 20th centuries, to details about its dynamics and its role in the solar-activity cycle in the 21st century. Today's heliophysicists benefit from continued instrumental and theoretical advances, but a solar eclipse still provides a unique occasion to study coronal science. In fact, the region of the corona best observed from the ground at total solar eclipses is not available for view from any space coronagraphs. In addition, eclipse views boast of much higher quality than those obtained with ground-based coronagraphs. On 21 August 2017, the first total solar eclipse visible solely from what is now United States territory since long before George Washington's presidency will occur. This event, which will cross coast-to-coast for the first time in 99 years, will provide an opportunity not only for massive expeditions with state-of-the-art ground-based equipment, but also for observations from aloft in aeroplanes and balloons. This set of eclipse observations will again complement space observations, this time near the minimum of the solar activity cycle. This review explores the past decade of solar eclipse studies, including advances in our understanding of the corona and its coronal mass ejections as well as terrestrial effects. We also discuss some additional bonus effects of eclipse observations, such as recreating the original verification of the general theory of relativity.**

The solar corona, normally too faint to be seen with the naked eye but revealed during total solar eclipses, has been known since at least its description by Kepler in 1605[1], though he thought it could be a lunar atmosphere. The discovery of emission lines in the spectrum observed during the eclipse of 1868, attributed to helium[2], and during the eclipse of 1869 (attributed to a new element called coronium)[3] led to the discovery of the high temperature of the corona. In the 1940s, W. Grotrian, B. Edlén and H. Alfvén[4] found that the supposed coronium is actually highly ionized iron gas at temperatures of about a million kelvin. Starting with the strong solar storm in 1859 – the Carrington event — scientists have known about the 'space weather' that permeates what is now known as the 'heliosphere' and affects us on Earth as well as the satellites around us. Even the discovery of thousands of comets with a camera on ESA's Solar and Heliospheric Observatory (SOHO) has led to an increased appreciation of the changing environment near the Sun and its link to objects from farther out in the heliosphere. NASA's plan to launch the Parker Solar Probe in 2018 to travel to within 6 million km of the solar surface (about 4% of an astronomical unit from the sun) will reveal *in situ* measurements of that portion of the heliosphere, a region crucial to the development of space weather. Overlapping observations of the total solar eclipses of 2019 and 2020 with the spacecraft's observations should allow improved mutual calibration.

In 2009 I summarized the latest eclipse science, largely about the solar corona but also including tests of relativity and biological effects, for the International Year of Astronomy[5] and in another review[6]. Total solar eclipses occur about every 18 months somewhere in the world, which has led to the scientific results of six total eclipses since those publications, as well as the associated results from spacecraft[7]. The forthcoming path of totality on 21 August 2017 that crosses the continental United States from west coast to east coast for the first time in 99 years (Fig. 1) has led to a plethora of books summarizing the history and human aspects of eclipse observing[8,9].

It has also led to plans for scientific expeditions with sponsorship from the National Science Foundation (NSF), NASA, National Geographic, and others, as well as citizen-science projects across the country. It is therefore appropriate that, almost a decade after my prior reviews, I summarize the recent scientific advances in coronal and other eclipse studies. The study of the Sun during eclipses is an international priority; authors of the papers cited in this review include scientists from the United States, Slovakia, China, Japan, France, Russia, Czech Republic, India and elsewhere.

## The relevance of eclipse science in the space era

Even if it sounds counterintuitive, considering recent advances in technology, we still need eclipses to study the Sun and its corona. In fact, current instruments in space cannot access the region (and thus the regime) that eclipses allow us to observe. In particular, the zone from the solar limb up to the lower edge of the C2 coronagraph on SOHO remains occulted up to 0.75 solar radii, as it has since the spacecraft's launch in 1995, and the zone remains unobserved from the points of view of the coronagraphs of NASA's Solar TErrestrial RElations Observatory (STEREO) mission. NASA's Solar Dynamics Observatory (SDO) has a full-disk field of view, whereas NASA's Transition Region and Coronal Explorer (TRACE) imaged only about 1/6 of the solar disk at a time, but the resolution is the same. The NASA/National Oceanic and Atmospheric Administration's Solar Ultraviolet Imager (SUVI) on the GOES-16 spacecraft launched in 2016 has a somewhat lower resolution, though a somewhat larger field of view and, importantly, a prospective longevity of two decades.

Until coronal observations are available from the Moon, or from tandem spacecraft with a distant occulter, eclipse observations remain the only way to get white-light observations of the important regions of the lower and middle corona, in which the solar wind forms, of the lower parts of coronal streamers, and of polar plumes.

## Eclipse studies of the solar corona

The solar corona itself remains the main focus of scientific research performed during total solar eclipses (Fig. 2). There are two main directions for such studies. The first one concerns the time-domain

[1]Hopkins Observatory, Williams College, Williamstown, Massachusetts 01267, USA. [2]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California 91125, USA.
e-mail: jmp@caltech.edu

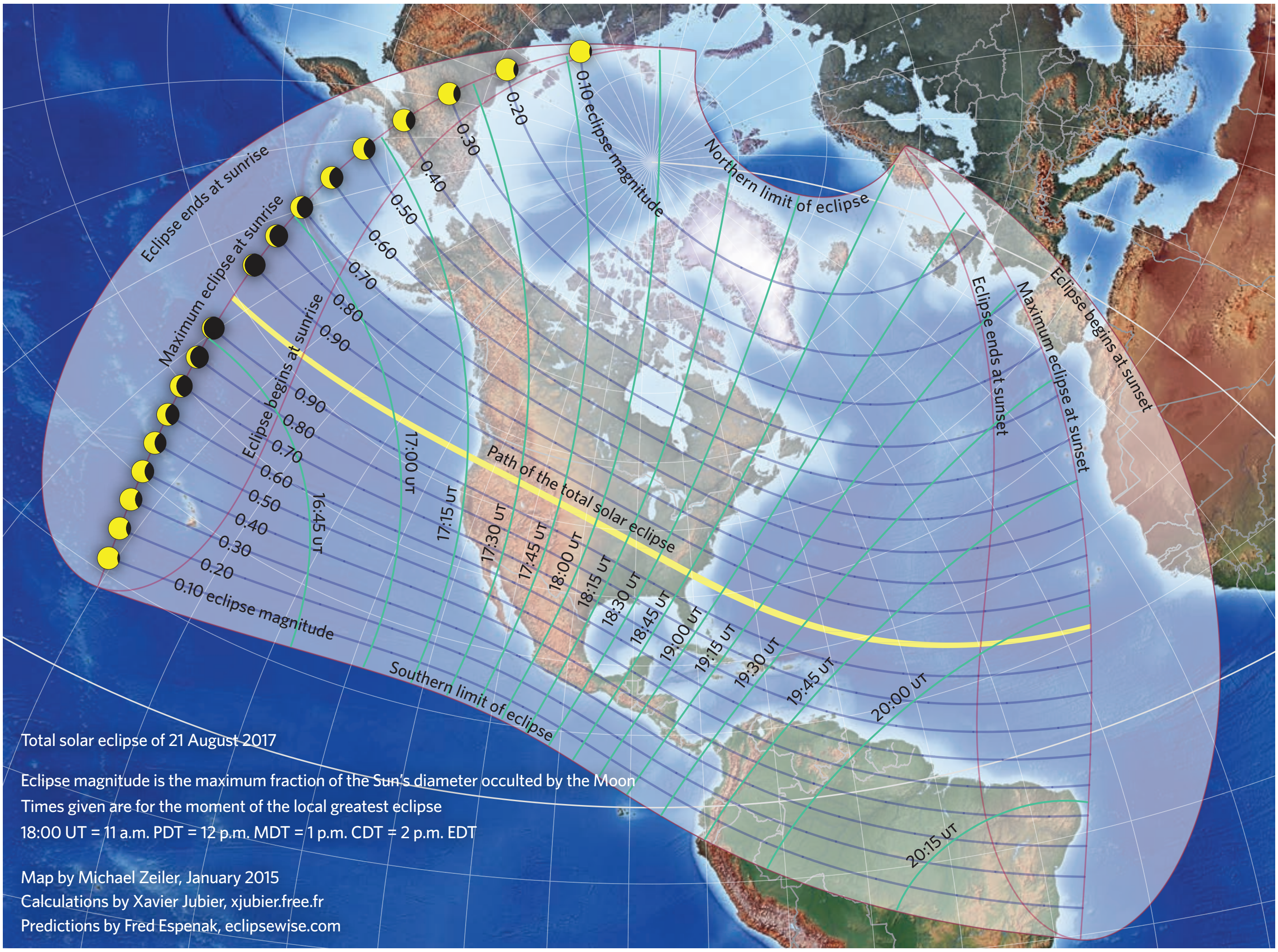


**Figure 1 | Stereographic map of the 21 August 2017 eclipse.** The path of totality (yellow) is surrounded by the locations from which the solar photosphere is partially visible. Note that since the solar corona is about one-millionth the brightness of the photosphere, when even 1% of the solar disk is visible (a so-called 99% partial eclipse), the sky is 10,000 times brighter than during totality and the most interesting eclipse phenomena, such as the solar corona, are not visible. PDT, MDT, CDT and EDT are Pacific, Mountain, Central and Eastern Daylight Time, respectively. Image courtesy of Michael Zeiler, www.greatamericaneclipse.com.

solar corona. In fact, the rhythm of approximately one total solar eclipse every 18 months allows a good sampling of the global-scale changes the solar corona undergoes within the 11-year solar cycle. The second important branch is about the characterization of coronal conditions and its spectrum.

**Dynamics of the solar corona.** The intricacies of the solar corona can now be imaged with electronic detectors at a cadence unavailable with film — especially the film sensitivities of a century ago, which necessitated drawing or painting the coronal configurations[10] — but also at cadences over ten times those available from any current solar spacecraft. At solar minimum, as it was in 2008 during the eclipse observed from Siberia, streamers are concentrated near the solar equator and polar plumes are visible[11]. As solar activity resumes, velocities in streamers become higher, as seen from Easter Island in 2010[12], and they remained high for the 2012 eclipse (visible from Australia and the Pacific Ocean). For the 2012 eclipse, a coronal mass ejection (CME) appeared in the 40-minute lapse between the observations of the eclipse from inland Australia and from a ship north of New Zealand, allowing an estimation of the CME velocity of over a million km hr$^{-1}$ (refs [13,14]). The 2013 total solar eclipse, observed from Gabon, showed two CMEs and an erupting prominence[15], which allowed the measurement of CME velocities of the order of 150 km s$^{-1}$ in the lower- and mid-coronal regions that are below the occulting disk of space coronagraphs. Chinese observers using a fibre-optic spectrograph detected coronal dynamics during the Gabon eclipse[16]. Though few papers have yet been published about the 2015 eclipse, whose totality was best studied from Svalbard in the Arctic, my team's composite images show a hybrid corona, with helmet streamers extending to the north solar pole but with no streamers in the extreme south and with visible south polar plumes[17]. The coronal configuration for the 2016 total solar eclipse, observed from Indonesia, was again transitional, with plumes visible at only one pole[18,19] (Fig. 3).

New image-processing techniques have provided a long-term-comparison set of images[20] and have revealed a wide variety of coronal features, including previously unmentioned ones[21]. Expanding loops and bubbles, twisted structures and smoke-ring-like features were discovered, probably traces of the dynamical evolution of instabilities. Such techniques also reveal details of the interface between prominences and the corona[22], including coronal cavities close to the solar limb and twisted helical structures farther out. These small-scale features may explain the origin of the twisted magnetic flux ropes that are sometimes detected in interplanetary

**Figure 2 | The most recent total solar eclipse, photographed from Ternate, Indonesia, in 2016.** Top: three images taken without filtering during totality are sandwiched between pairs of images of partial phases taken through a neutral density 5.0 filter. Bottom: the view of the solar corona through the clouds.

space, and may lead to a better understanding of the mechanism by which the Sun sheds its magnetic helicity.

**Narrow-band spectral imaging.** The development of narrow-band filters with a full width at half maximum of about 0.2 Å in the red and near infrared, using multiple-coat reflection and temperature-controlled systems, allowed imaging of the solar corona with each filter probing a different temperature. The Solar Wind Sherpas team based at the Institute for Astronomy of the University of Hawai'i has been a leader in this work. They use filters not only at the coronal green forbidden [Fe xiv] line at 530.3 nm and the coronal red [Fe x] line at 637.4 nm, but also the 789.2 nm [Fe xi] line and even the 1,074.7 nm [Fe xiii] line.

The Solar Wind Sherpas have mapped the electron temperature and iron charge states for the 2006 and 2008 eclipses, pointing out that only in collisional plasmas do the emission-line intensities give temperatures, linking the solar wind to electron temperatures below $1.2 \times 10^6$ K (ref. [23]). They connect their observations to *in situ* measurements from NASA's Solar Wind Ion Composition Spectrometer (SWICS) on the Advanced Composition Explorer (ACE) and on Ulysses throughout solar cycle 23 (1998–2009)[24]. With observations of their four spectral lines from the same eclipse, they discovered that prominences are enshrouded in hot plasmas held in place by twisted magnetic fields[25]. For the 2010 eclipse, from Tatakoto in French Polynesia, they added filters at Hα, [Fe ix] at 435.9 nm, and [Ni xv] at 670.2 nm, which provide a temperature differentiation of 200,000 K, and compared them with extreme ultraviolet observations[26]. Concerning instrumental advances, they subsequently introduced a Fourier normalizing-radial-graded filter to enhance details during image processing[27] and suggested the possibility of studying the corona from satellites in lunar orbit thanks to advances in detector technology and image-processing techniques[28].

A team of Indian astronomers continues to analyse Fabry–Pérot narrow-band interferograms, including the images from the 2001 total eclipse observed from Zambia[29]. They found many components in the line profiles, perhaps related to coronal heating via type II spicules, jet-like bright structures that originate in the chromosphere and fade away rapidly in the corona, and they remark on the presence of a persisting blue-shift.

Narrow-band imaging can also be used to search for fast (>2 Hz) oscillations of coronal loops that could help discriminate among coronal heating theories. Such observations have been reported for the eclipses of 2006[30], 2009[31] and 2010[32]. Evidence exists in the power spectra for sub-second oscillations, which would be typical of surface Alfvén waves, whereas body Alfvén waves would be associated with oscillations with periods of tens of seconds for coronal loops, which are observed just above the solar limb. Perhaps both Alfvén-wave heating and nanoflare heating coexist[33].

**Coronal brightness and flattening index**. The brightness of the corona varies with the solar-activity cycle[34]. It has long been known[35] that the corona is fainter at solar minimum. Helmet streamer distributions over the sunspot cycle have been compared with solar polar magnetic fields[36]. The flattening index — the deviation of the lines of equal brightness from circular — have been shown to match the phase rather than the magnitude of sunspot cycles, though there seems to be no such correlation with the sunspot number[37].

**Polarimetry.** The inner solar corona, in addition to the emission lines, shows electron scattering, which is highly polarizing (and which obliterates the Fraunhofer lines[38,39], except potentially the broad and strong H and K lines). Russian scientists are using polarization studies to explore velocities in the corona[40] and study the structure of the lower corona in preparation for space observations[41], providing two-dimensional distributions of the polarization angle and of the relative colour index. They concluded that eclipse observations are an efficient method to measure the electron-scattering corona (the 'K-corona'). They have also used the Zeeman and Hanle effects to detect polarization in prominences[42]. They even detected the low fraction of neutral hydrogen that had previously



**Figure 3 | The 2013 total solar eclipse, observed from Gabon.** A composite image of the lunar silhouette surrounded by the pinkish (because of Hα emission) chromosphere and prominences (one of which is erupting) and the solar corona. The composite was made from original images by Jay M. Pasachoff, Allen B. Davis, and Vojtech Rusin with computer analysis by Miloslav Druckmüller.

been discovered from rocket observations[43]. New polarization-measuring technology will be tested at the forthcoming eclipse[44].

Imagine polarimetry and spectro-polarimetry techniques were used in all recent eclipses. With their prototype Fiber Arrayed Solar Optical Telescope (FASOT)[45], Chinese colleagues recently published spectro-imaging polarimetry results from the 2013 eclipse[46]. They highlighted a diverse set of mechanisms in the coronal green line, with polarization up to 3.2% above the continuum polarization on a spatial scale of 1,500 km. Polarization structure within a 7,500 km region led to the conclusion that coronal polarization is highly structured and variable even on such a small scale. A theoretical evaluation of using polarized light for eclipse coronal studies suggested the employment of the sulfur-like [Fe XI] 789.2 nm emission line with the Daniel K. Inouye Solar Telescope to measure coronal magnetic fields, complementing measurements made with the current Mauna Loa coronagraph[47].

**Spectrum of the solar corona.** Among the dozen or so coronal emission lines in the visible, the strongest are the coronal green line at 530.3 nm, from [Fe XIV], and the coronal red line at 637.4 nm, from [Fe X], The ratio of the coronal red line and the coronal green line vary over the solar-activity cycle, revealing that the overall corona is hotter at solar maximum than at minimum[48,49]. The 530.3 nm line is especially diagnostic in the middle corona[50]. Because of the temperature difference, loops appear in different places when viewed in the coronal red line and the coronal green line[51].

Using slitless spectroscopy from Siberia in 2008 and French Polynesia in 2010, during and after solar minimum, 3 Mm helium shells were detected in ionized helium at 468.6 nm and neutral helium at 471.3 nm[52]. The flash spectra obtained during the 2010 eclipse were compared with images taken with the Sun Watcher using Active Pixel System Detector and Image Processing (SWAP) on ESA's PROBA2 mission, finding many low-excitation emission lines in addition to the helium lines just mentioned, with analysis of prominence cavities in the corona as one result[53].

## Effects of eclipses on the Earth

Eclipse phenomena also have a direct impact on Earth, scientific and otherwise. This section describes some Earth-related topics that use eclipse results in various ways.

**Terrestrial atmospheric studies.** A special issue of the *Philosophical Transactions of the Royal Society A* was devoted to the effects of the 2015 eclipse on the UK, presenting it as a natural meteorological experiment that can improve weather-prediction models and can lead to improved plans for extra electricity to be generated during solar eclipses, given the reduction in solar incident energy[54]. They found that UK electrical energy demand increased by about 4% (3 GWh = 11 TJ) with wind and photovoltaic electrical energy reduced by 1.5 GWh = 5.5 TJ.

One of the dozen papers in the issue analyzed the ionospheric response (decay and recovery) with 1 min time resolution, using SDO observations to follow the fraction obscured at its nine ultraviolet emission wavelengths. Given the varying spatial distributions, the Sun was obscured differently at each wavelength, showing coronal spatial structure[55]. The eclipse was total over Svalbard, during which a temperature drop from −13 °C to −22 °C was measured. The thermal lag was about five minutes to the minimum temperature after the depth of totality in unshielded observations, and much less in shielded observations[56].

**Measuring variations in Earth's rotation.** Measurements of eclipse locations continue to update[57] the epochal evaluation of Earth's rotation period from historical eclipses over thousands of years[58]. In addition to the tidal effects of the Earth–Moon system on the rotation period, current estimations indicate an average increase in the length of the mean solar day of 1.8 ms per century between 720 BC and AD 2015[59].The rotation period depends on Earth's moment of inertia, which is affected by such matters as the distribution of polar caps and the Antarctic ice sheet.

**Eclipses in history and art.** Though solar eclipses have been seen for millennia, they are depicted in few major works of art. The brilliant diamond-ring effect painted by Cosmas Damian Asam in 1735 may well be the first oil portrait of an eclipse made by someone who was painting the effect as observed in nature[60]. A trio of early-20th-century eclipse paintings graced the entrance to New York's Hayden Planetarium for decades, reaching out to students and the general public[10,61].

A further survey of art including solar eclipses joined a themed issue of *Philosophical Transactions of the Royal Society A* otherwise about terrestrial meteorological studies[62]; it dwelt on the advance from iconography to rational learning to helping scientists record data.

## Future artificial eclipses from space

Total solar eclipses observed from the ground remain important even in the 21st century, since no current space coronagraph can observe the inner or middle corona (nor can views from ground-based coronagraphs match the quality of eclipse imaging). This situation is true for the 1995 set of nested C2 and C3 coronagraphs on ESA's SOHO as well as for the pair of SECCHI (Sun Earth Connection Coronal and Heliospheric Investigation) coronagraphs on NASA's STEREO mission, launched in 2006, with STEREO-A (ahead) and STEREO-B (behind) drifting in opposite directions with respect to the Earth's orbit around the Sun. Their occulting disks must block out much of the inner and middle corona because of the corona's extreme dynamic range. At the time of the 2017 total solar eclipse, they will each be about one-third of the way around Earth's orbit. STEREO-A's view will join SOHO's from the direction of Earth in our planet's solar orbit to provide 3D information; contact has been lost with STEREO-B.

ESA is preparing an externally occulted coronagraph for their PROBA-3 mission, composed of two spacecraft in formation about 150 m apart, allowing the occulting disk to just barely cover the solar photosphere. ASPIICS (Association of Spacecraft for Polarimetric and Imaging Investigation of the Corona of the Sun), at the Centre

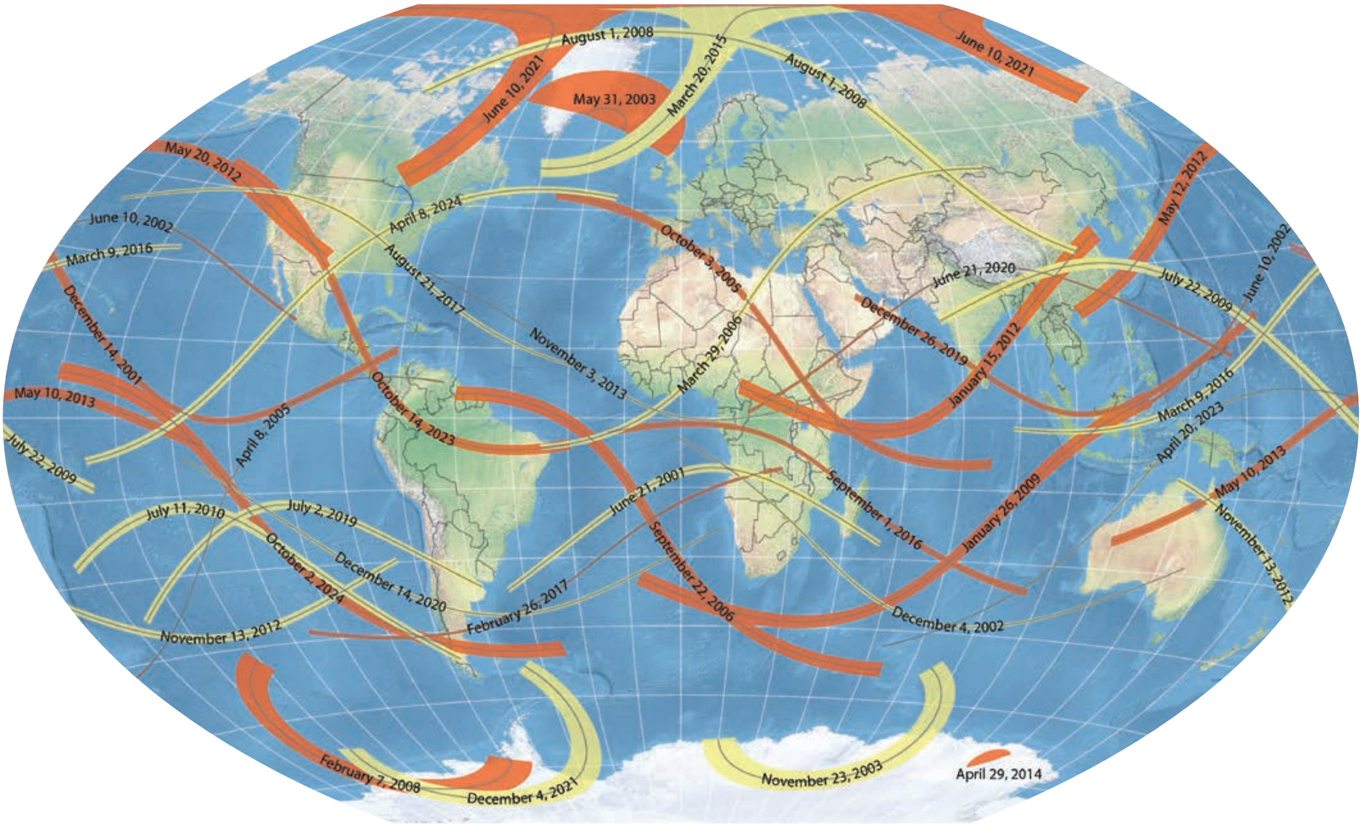


**Figure 4 | The paths of total and annular solar eclipses between 2001and 2025.** Total solar eclipses are in yellow, annular eclipses are marked in orange. Image courtesy of Michael Zeiler, www.greatamericaneclipse.com; adapted from ref. 66, Cambridge Univ. Press.

Spatial de Liège, is responsible for the optical design of PROBA-3[63], as part of a big European consortium. The main scientific objective of PROBA-3's coronagraph is to occult outward from a technical 1.08 solar radii in design to usefully occult from better than 1.2 solar radii with a resolution of 6 arcsec. PROBA-3 is in its preparatory phase; its launch into a high Earth orbit is planned for 2019.

ESA's Solar Orbiter mission is planned for launch in late 2018, and in 2022 after gravity assists from Earth and Venus will reach at least one perihelion between 0.20 and 0.25 au with an inclination >30°, to view the poles and other high solar latitudes with a resolution substantially improved over even current spacecraft resolution. It will match the solar rotation for a few days at perihelion, allowing continuous coverage of an active region. Its additional priorities will be to measure solar-wind plasma and high-energy particles, but it will also include a coronagraph with a polarimeter (Metis, named after the titan who in Greek mythology presided over all wisdom and knowledge) to study the corona and the early propagation of CMEs. Metis will create annular images between 1.6 and 3.0 solar radii from disk centre.

Both PROBA-3 and Metis observations will still be complementary to ground-based solar eclipse observations, as their occulting disks allow them to observe only the higher regions that are seen to expand as the identifiable solar wind, preventing access to the region of the corona where the solar wind actually originates**.**

Fred Espenak's *Thousand Year Canon of Solar Eclipses, 1501-2500* provides information about many future eclipses[64] (Fig. 4). The next total eclipse after 2017, on 2 July 2019, will cross the Pacific Ocean and end above Cerro Tololo and other major observatories in Chile before crossing Argentina. The 14 December 2020 total solar eclipse crosses Chile and Argentina, with very accessible observing locations on the Argentine Atlantic coast. The 4 December 2021 total eclipse's totality will be visible from land only from Antarctica, so only those at the Chinese research station in the path may see it. Overflights may be possible, as happened for the 2003 eclipse, or a ship could carry observers east of Tierra del Fuego. The 20 April 2023 total eclipse's narrow band of totality will be visible from the US National Solar Observatory's Global Oscillation Network Group (GONG) station in Learmonth, Western Australia, before it goes over East Timor and West Papua, Indonesia. The 8 April 2024's totality path will travel from Mexico across the United States from Texas to Maine and into eastern Canada. The next total eclipse viewable from Europe will cross Spain near sunrise at an altitude of 5–10° on 12 August 2026 and be higher in the sky from western Iceland and eastern Greenland. The 2 August 2027 total solar eclipse will cross southern Spain and Gibraltar before crossing northern Morocco, Algeria, Tunisia, Libya and Egypt; and then Saudi Arabia, Yemen and Somalia[65].

Observers on the sides of these totality bands will be able to see partial phases, as they will for annular eclipses with annularity crossing India, Indonesia and Sri Lanka on 26 December 2019; East Africa, the Middle East, Pakistan, India, China and Taiwan on 21 June 2020; Canada on 10 June 2021; the US on 14 October 2023; and southern Argentina and Chile on 2 October 2024[66.]

## 2017 eclipse plans

A wide variety of scientific studies will be carried out across the United States on the ground, from balloons and from aircraft. Though aircraft observations will prolong the 2017 eclipse from a maximum of about 2 minutes 40 seconds when viewed from the ground (that is, from a stationary position) to as much as 4 minutes, no supersonic aeroplane eclipse expedition is foreseen as happened for instance with Concorde in 1973[67.] NASA's 2017 range of funded proposals include 6 projects for studies of the Sun and 5 for studies of the effects of the eclipse on Earth[44].

**Infrared studies.** Several aeroplanes and some ground-based sites will attempt to collect infrared observations during the 2017 total eclipse. The NSF will support one aeroplane campaign and NASA another two. Scientists using the NSF-sponsored plane will use its stabilized platform to observe the coronal spectrum in the near infrared, from 1.4 to 4 μm, in search of one of the spectral lines that are theoretically predicted to be magnetically sensitive and strong enough for future polarization measurements of the coronal magnetic field. They will also search for high-frequency waves, candidates for heating and accelerating coronal gas including the solar wind, and identify large-scale flows, especially in coronal holes[68].

**Citizen science and outreach.** Plans are afoot to involve the general citizenry in scientific research, such as those carried out in Japan at the 2012 annular eclipse[69]. Here I mention just the most expansive, with a more complete list described in the websites below (see 'Resources'). A 90 min cross-continent set of images of Baily's beads (variations in luminosity along the Sun's rim at totality due to the irregular topography of the Moon) and coronal observations are to be made by the Eclipse Megamovie Project[70], as well as by Citizen Continental America Telescopic Eclipse Experiment (Citizen CATE)[71]. The former, based at the Space Sciences Laboratory of the University of California, Berkeley, will provide an archive of eclipse images for analysis by citizen scientists. Citizen CATE, based at the National Solar Observatory, will have 68 identical telescopes imaging the corona from sites along the whole US eclipse path.

Pinhole camera images will be readily available to the general public during partial phases[72], though the widespread, inexpensive availability of Mylar and polymer filters has led to the distribution of millions of 'eclipse glasses' through libraries and other institutions across the United States prior to the 2017 total eclipse. A vast number of public talks and seminars will be given across the country around the eclipse date, and there will be several observing stations with experts available along the eclipse path during the event. A citizen-science balloon project with launches from about 25 along the totality path is planned[73].

**The size of the Sun.** The International Occultation Timing Association (IOTA) is organizing a citizen-science effort to determine the exact location of the edge of the path of totality near the southern limit near Minden, Nebraska[74], with similar measurements elsewhere. They continue to assess the size of the Sun[75]. A measurement of the size of the Sun is possible from eclipse light curves, evaluating the limb-darkening function[76,77]. An analysis that covers eclipses from 2010 through 2015 has been reported[78] and the average value is 959.99 ± 0.06 arcsec, slightly higher than the IAU-recommended value.

The accurate measurement of the size of the Sun with eclipses can also be carried out using the recently obtained 3D mapping of the Moon by the Japanese spacecraft Kaguya and the American Lunar Reconnaissance Orbiter spacecraft[79], modeling the results with the camera-control eclipse-calculation program Solar Eclipse Maestro[80].

**Testing general relativity.** Perhaps the best-known eclipse result to the general public is the 1919 confirmation of Einstein's general theory of relativity by detecting slight deflections of several stars near the Sun, though that important result in the history and philosophy of science is no longer of interest to heliophysicists. Still, advances in instrumentation are leading several professional and citizen scientists to attempt an improved version of the observations at the 2017 total solar eclipse.

One of Einstein's three major predictions from 1916 was that the mass of the Sun would warp space enough that a slight displacement in the positions of stars might be visible. Arthur Eddington arranged expeditions to Principe, off the coast of Africa, and to Brazil for the 1919 eclipse, following a failed expedition for the total solar eclipse of 21 August 1914 that would have disagreed with Einstein's prediction based on his then current version of his theory[81]. The results announced in 1919 both verified Einstein's theory to scientists and made Einstein an internationally popular figure. The observations were improved with the eclipse of 1922 and occasionally since, and verified as valid[82], but general relativity is better tested in several other ways now, including by the 2015 detection of gravitational waves. Though an attempt to detect the deflection of light with DSLR images from the 2006 eclipse failed, probably because of pixel size, careful amateur and professional attempts are being carried out at the 2017 eclipse[83], with particular attention to observational details[84]. The 2017 report of the detection with the Hubble Space Telescope of general relativistic deflection by a white dwarf, with an effect 1,000 times smaller than the result of the Eddington detection for the Sun, confirms the historic eclipse measurements to high accuracy[85,86].

**Resources.** Many eclipse-related observation resources are available from the International Astronomical Union (http://www.eclipses.info), the American Astronomical Society (http://eclipse.aas.org) and NASA (http://eclipse2017.nasa.gov). Information on the 2017 total eclipse is also available in print[87,88]. Detailed maps[89,90] and meteorological information based on decades of past satellite and other observations[91] are available. My *Field Guide to the Stars and Planets* has been updated[65]. The former NASA eclipse site has migrated to www.EclipseWise.com. A Braille/raised-outline book is available[92]. The AAS task force has a handout on eye safety[93].

## Final thoughts

Only on the days of total solar eclipses is a complete view of the solar atmosphere visible, from the photosphere to the outer parts of the heliosphere through the chromosphere and the lower and middle corona. Heliophysicists have such occasions available about every 18 months somewhere in the world. But the logistic advantages of the 2017 total solar eclipse's 100-km-wide path crossing the United States, with associated special funding from US organizations, is leading to tremendous amounts of equipment being constructed or updated, to better test prior ideas of the solar corona's dynamics and heating as well as new theoretical models. Still, just as Tycho Brahe was inspired by a solar eclipse in the 16th century to make the more accurate pre-telescopic observations that later allowed Johannes Kepler to formulate his laws of orbital motion, perhaps the most lasting effect of the 21 August 2017 total solar eclipse will be the inspiration given to young students. The 12 million people living in the totality path, not to mention the huge number of 'eclipse tourists', will be exposed to this show. This will probably be the most observed and studied solar eclipse ever, and the impact will be correspondingly proportional, as eclipses were in earlier eras[94]. The dramatic nature of the darkening of the sky by a factor of about a million over 75 minutes, including a factor of about 10,000 over the last minute before totality, will impress all who see it. We can hope that clear skies allow many tens of millions of people to see the eclipse phenomena, especially the chromospheric and coronal views between the Baily's beads and the diamond-ring effects.

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**Correspondence** should be addressed to J.M.P.

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## Competing interests
The author declares no competing financial interests.