

TOTAL SOLAR ECLIPSES THEN AND NOW

Jay Pasachoff

Williams College—Hopkins Observatory, Williamstown,
Massachusetts 01267-2565, USA.

E-mail: jmp@williams.edu

Abstract: I describe the new equipment and observations of the major total solar eclipse that passed from Mexico (where we observed it, in Miahuatlán, Oaxaca) on 7 March 1970, to the improved imaging and other capabilities we applied to the recent total solar eclipses of 2 July 2019 (from Chile), and 4 December 2021 (from on and near Antarctica, including airborne observations).

Keywords: Sun, total solar eclipses, corona, spectroscopy

1 THE 1970 TOTAL SOLAR ECLIPSE

A major solar eclipse swept across Mexico and through parts of the U.S. Atlantic Seaboard, including Virginia Beach and Nantucket, on 7 March 1970. Menzel, with Pasachoff as post-doc, mounted a major expedition to the small village of Miahuatlán, south of Oaxaca (Menzel and Pasachoff, 1970b). They later presented a paper at the 1971 meeting of the American Astronomical Society describing a motion picture record of the eclipse that they made (Pasachoff and Menzel, 1971). The abstract of this paper is shown here in Figure 1.

A major instrument during the Mexican eclipse was a new Littrow spectrograph designed by James G. Baker (1914–2005), arguably the foremost astronomical-instrument designer of the time (Menzel and Pasachoff, 1970a). It operated from a 16-inch coelostat, and each part was set up on concrete and brick piers (the orientations of which even led to an article in *Antiquity*; Pasachoff, 1970). The expedition was supported by the Committee for Research and Exploration of the National Geographic Society, and as clear weather approached, *National Geographic Magazine* sent one of their staff photographers (Menzel and Pasachoff, 1970b).

Preliminary results were described in a special issue of *Nature* that included many eclipse reports. Though radially-graded filter images from Newkirk had started to be taken at eclipses, the published coronal image was not so made. The spectrograph showed only the inner, brightest corona, in spite of its wide-field design. Menzel and Pasachoff (1968) had earlier evaluated the conclusion of the million-degree coronal temperature in terms of scattering by the high-temperature coronal electrons (see also Pasachoff, 1973).

The successful 1970 observations led to Menzel and Pasachoff's reconnoitering in Mali and Niger that summer to see if the 7 min 4 s totality of the 1973 eclipse could be observed from the Sahara. In the event, supplying an

expedition 100 km or so north of Timbuktu was evaluated to be too difficult, and in 1973 Menzel took a group with National Geographic Society support to Mauritania for 6 min 20 s of totality and Pasachoff joined the National Science Foundation expedition to northern Kenya, with almost 5 min of totality but a better chance of clear sky. A suggestion by Mercer and Pasachoff (1969) had perhaps been a motivation for the Concorde flight of 1973 that obtained 74 min of totality, as described by Lena (2015).

Motion Picture Record of the 7 March 1970 Total Solar Eclipse. JAY M. PASACHOFF, Hale Observatories, and DONALD H. MENZEL, Harvard College Observatory and Smithsonian Astrophysical Observatory. – A time-lapse motion picture of the total solar eclipse of 7 March 1970 is presented. It was taken in Miahuatlan, Oaxaca, Mexico by an expedition of the Harvard College Observatory, Smithsonian Astrophysical Observatory and National Geographic. Partial phases, second and third contacts, and totality are included. The 16-mm camera was mounted on the same auxiliary equatorial clock-driven mount that bore cameras that photographed coronal streamers to distances from the sun greater than 10 solar radii.

Figure 1: Jay Pasachoff's abstract from the first SPD, co-authored by Donald Menzel.

2 THE 2017, 2019, AND 2020 TOTAL SOLAR ECLIPSES

Not only instruments—with the gain in efficiency by ~100× in the change from film to CCDs—but also data-reduction computer techniques had greatly advanced by the 50th anniversary of the 1970 eclipse (Pasachoff and Fraknoi, 2017; Pasachoff, 2017a, 2017b). The 21 August 2017 total solar eclipse whose path of totality crossed the continental United States and the 2 July 2019, total solar eclipse whose path of totality crossed Chile and Argentina, including major observatories such as the Cerro Tololo Inter-American Observatory and the La Silla Observatory, saw the most modern equipment and computer techniques applied to studies of the solar corona (Pasachoff and Fraknoi, 2017; Pasachoff et al., 2020a, 2020b).

The contrast in abilities since the 1970 eclipse stood out in many ways. For example, the Baker wide-field spectrograph in 1970 was used with film, and the slit was placed radially.

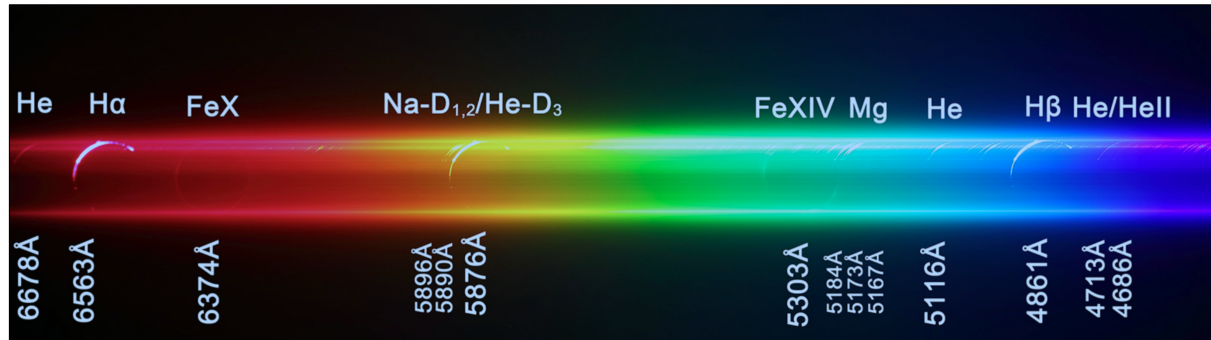


Figure 2: A slitless spectrum by A. Voulgaris of our team from the 2017 eclipse in Oregon, showing chromospheric emission lines at 3rd contact plus forbidden coronal lines of Fe X at 6374 Å and Fe XIV at 5303 Å (after [Pasachoff et al., 2018](#)).



Figure 3: A stack of 646 individual images taken by N. Lefaudeux from Cerro Tololo Inter-American Observatory during the 2 July 2019 totality. The coronal streamers are visible even beyond the distance of SOHO's LASCO C3 coronagraph (after [Pasachoff et al. \(2019\)](#), at the Fiftieth SPD, and [Lockwood et al. \(2020\)](#)).

In the event, only the innermost coronal emission lines showed. Fifty years later, the electronic-imaging capability allowed spectra to show at higher levels in the corona, as can be seen even in the slitless spectra of [Figure 2](#). [Dennefeld et al. \(2019\)](#) used a wide slit with the New Technology Telescope (NTT) at ESO's La Silla Observatory in 2019. The gain in speed even allows spectroscopy from airplanes, such as Samna's observations and the forthcoming eFlight for the 4 December 2021 totality that is otherwise limited to Antarctica.

Another advance in the 50 years of the Solar Physics Division is infrared imaging capability. [Williams et al. \(2020\)](#) observed in the 3–5 μm range from a pair of NASA WB-57 research aircraft flying at 52,000 feet altitude and the Airborne Infrared Spectrometer (AIR-Spec) on the NSF Gulf-stream V flying at

47,000 feet altitude. [Judge et al. \(2019\)](#), for example, observed spectra and broad-band polarized light from an altitude of 14.3 km with ground-based backup from Oregon.

Fortunately, the sky was clear for most of the path of both those recent eclipses. [Lockwood et al. \(2020\)](#) summarizes exceedingly wide-field imaging by N. Lefaudeux from the altitude of Cerro Tololo with stacking of hundreds of images from standard Digital Single-Lens Reflex (DSLR) cameras (see [Figure 3](#)). Our slitless spectrographic imaging over an extended period prior to the recent eclipses shows the ratio of the Fe XIV coronal green line to the Fe X coronal red line reversing with the solar cycle, showing detail in how the overall coronal temperature is cooler near solar minimum. [Bemporad \(2020\)](#) shows the derivation of coronal electron densities, also from imaging with

DSLR cameras and including polarimetric measurements. No spectrographic observations succeeded in the overall-cloudy conditions on the ground in Chile and Argentina during the 14 December 2020 total eclipse, under COVID-limited observing conditions (Pasachoff, 2021).

A major experiment for us over the years has been an attempt at finding high-frequency (>1 Hz) coronal oscillations in the coronal forbidden lines. Our attempts with our high-frequency cameras that are used also for stellar occultations by Pluto and other objects had successful observations from the 2017 eclipse that we observed from Salem, Oregon (Pasachoff, et al., 2018). The low altitude of the eclipsed Sun from Chile in 2019 (the peak of totality was over the Pacific; we participated in a charter 787 flight that got 8 m 27 s of totality there) led us to worry sufficiently about atmospheric oscillations that we did not attempt the observations in 2019. Though COVID-19 travel restrictions prevented us from using our upgraded cameras to try to observe the high-frequency (>1 Hz) coronal oscillations again in 2020, we made such observations from Union

Glacier, Antarctica, during the 4 December 2021 total solar eclipse, and from an airplane at 12,000 m altitude near the sunrise point east of Punta Arenas, Chile. Cramer has listed over a dozen alternate models for coronal heating, and the Parker Solar Probe has reported 'campfires' of miniflares or nanoflares, so the quest remains to make observations to distinguish among models to explain coronal heating.

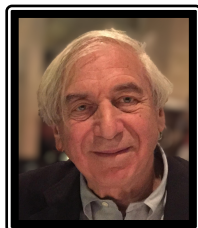
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Jay Pasachoff is the Field Memorial Professor of Astronomy at Williams College in Williamstown, Massachusetts, and Director of the College's historic Hopkins Observatory.

His passion and dedication to the field of astronomy goes beyond his main role as a Professor and researcher, touching numerous people across all generations. He wrote, in the Peterson Field Guide series, the popular *A Field Guide to the Stars and Planets*, now in the 17th printing of its 4th edition; is lead author of *The Cosmos: Astronomy in the New Millennium*, now in its 5th edition; is co-author with the art historian Roberta J.M. Olson of *Cosmos: The Art and Science of the Universe* (2019) on the intersection of artistic works over many centuries and astronomy; is co-author with Jay Anderson of a new *Peterson Field Guide to Weather* (2021); and has written textbooks and hundreds of articles and conference-series contributions, instilling a love of astronomy among laypersons and students all over the world.

His solar eclipse expeditions, including 36 total eclipses, and primary research on solar eclipses, has led to not only scientific papers but also popular articles in *National Geographic*, *Scientific American*, and elsewhere, as well as media appearances before and after the 21 August 2017 and 4 December 2021 solar eclipses. He is Chair of the International Astronomical Union's Working Group on Solar Eclipses.

Apart from his solar eclipse research Jay is interested in the history of astronomy, and has published papers on solar physics, historic transits of Venus and historic telescopes and observatories. Indeed, his hallmark paper on the history of the Hopkins Observatory at Williams College featured in the inaugural issue of the *Journal of Astronomical History and Heritage* back in 1998, and he has been a strong supporter of the *Journal* ever since.

Jay's leadership roles within the profession have brought him distinction and acknowledgment, such as the 2019 Klumpke-Roberts Award of the Astronomical Society of the Pacific; the 2017 Richtmyer Memorial Lecture Award from the American Association of Physics Teachers; the 2012 Prix-Jules-Janssen of the Société Astronomique de France; and the 2003 Education Prize of the American Astronomical Society. He is one of only fifteen honorary members of the Royal Astronomical Society of Canada. In addition, Asteroid 5100 Pasachoff is named for him.