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INVITED REVIEWS

Scientific observations at total solar eclipses

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Abstract The occasion of the longest totality of an eclipse in the 18 yr $11^1/_3$ d saros cycle leads to taking stock of the scientific value of ground-based eclipse observations in this space age. Though a number of space satellites from the U.S., Europe, Japan, and Russia study the Sun, scientists at eclipses can observe the solar chromosphere and corona at higher spatial resolution, at higher temporal resolution, and at higher spectral resolution than are possible aloft. Furthermore, eclipse expeditions can transport a wide variety of state-of-the-art equipment to the path of totality. Thus, for at least some years to come, solar eclipse observations will remain both scientifically valuable and cost-effective ways to study the outer solar atmosphere.

Key words: Sun: eclipses

1 INTRODUCTION

Sixty-eight times in the 21st century, the umbra of the lunar shadow sweeps across the Earth's surface, making a path of totality up to hundreds of kilometers wide and thousands of kilometers long. Such total solar eclipses provide unique opportunities for astronomers to study phenomena of the outer solar atmosphere from the ground, both at low levels and, when possible, from mountaintop observatories. Airplane observations are sometimes also necessary or, when instrumented airplanes are available, possible.

Over the last decades, scientific eclipse expeditions have varied in their coordination. Let us first consider the two previous long eclipses from the saroses prior to this summer's especially long eclipse, following the 18 yr $11^1/_3$ d saros interval. At the 1973 long eclipse that crossed Africa, for example, the U.S. National Science Foundation had a coordinated team that travelled in a chartered airplane and that split between sites in Mauritania and in Kenya; the peak of the eclipse duration at 7 min 4 s in the desert north of Timbuktu, Mali, and Agadez, Niger, was deemed too hard to support (National Science Foundation, 1973). The next saros interval later, in 1991, individual teams observed from Hawaii, Mexico, Brazil, and elsewhere. The NSF's last organized team effort was in East Java, Indonesia, in 1983. The International Astronomical Union's Working Group on Solar Eclipses coordinated a site in Putre, northern Chile, for the 1994 eclipse. Since then, the IAU Working Group coordinated some planning, publicity, and public information, and worked on duty-free temporary import of scientific equipment for the observations, but did not supervise expedition logistics. The IAU's Commission on Education and Development has a program group on Public Information at the Times of Eclipses, to take advantage of the attention that eclipses bring for a wide variety of scientific education (Pasachoff 1996; Pasachoff 2008b).

Observations of total solar eclipses are made by a select group of professional scientists and by increasing numbers of ecotourists. Observational aspects of eclipse paths and observing totality appear in such books as Pasachoff (2006), Pasachoff & Filippenko (2007), and Held (2005). Non-technical but substantial eclipse-expedition, eclipse-history and eclipse-science descriptions appear in Pasachoff & Covington (1994), Guillermier & Koutchmy (1999), Mobberley (2007), and Littmann, Espenak & Willcox (2008). Substantial, advanced texts on eclipse and coronal science include Golub & Pasachoff (2009), Aschwanden (2006), and Foukal (2004). Aschwanden's book is available free online. General books about solar astronomy include Golub & Pasachoff (2001) and Livingston & Bhatnagar (2005). A popular book about the sun, from a series for non-experts in technical fields who may be knowledgeable in their own fields, is Pasachoff (2003); it includes autobiographical and light-hearted information.

On the days of eclipses, we can supplement space observations of the sun to show a region not visible from spacecraft. Occulting disks on space coronagraphs have to over-occult because of internal scattering. In particular, we provided a preliminary image for that later purpose on eclipse day in 2006, and, linked with SOHO images by Steele Hill of NASA's Goddard Space Flight Center, it appeared as a SOHO Hotshot (*http://sohowww.nascom.nasa.gov/hotshots/2006_03_29/* and *http://soho.esac.esa.int/hotshots/2006_03_29/*) and, two days later, as Astronomy Picture of the Day (*http://apod.nasa.gov/apod/ap060331.html*). Our 2008 image was quickly linked with SOHO's and displayed as *http://soho.nascom.nasa.gov/pickoftheweek/old/01aug2008/*.

Several eclipse symposia have been published, including Raljevic, Zaratti & Pasachoff (1995) for the 1994 eclipse in Bolivia and Chile; Maris (1996) and Mouradian & Stavinschi (1997) for the 1999 eclipse in Romania; Livingston & Özgüç (2000) for the 1999 eclipse in Turkey; and Demircan, Selam & Albayrak (2007) for both solar and stellar eclipses.

Note that the Sun is a close-up example of the billions of stars that also have coronas (Peres, Orlando & Reale 2006). They are observed with the Chandra X-ray Observatory and other X-ray satellites. Their chromospheres can be observed from the ground, and surveys of the emission from the ionized-calcium K-line have shown solar-activity cycles on many stars.

2 ECLIPSE MAPS AND PATH CALCULATIONS

The most recent total solar eclipse crossed Siberia (Pasachoff, Babcock, Freeman, DuPré, Demianski, Nesterenko, Nesterenko & Schneider 2009) and China on 1 August 2008 (Stone 2008). The path of totality was generally clear, allowing observations. A longer totality is to be available on 22 July 2009, the longest totality to be available until the year 2132, so it has engendered particular interest worldwide. Totality will approach 6 min on mainland China, including very accessible observing locations, and is somewhat longer in the Pacific, including some small Japanese islands. A variety of maps, photographs, and expedition descriptions appear in the Chinese language in a special issue of Amateur Astronomer; Pasachoff (2008a) describes several of his past expeditions and shows photographs of what observers will encounter at total eclipses (Fig. 1). See also Bohannon (2008) for the value of eclipse observing and some comments on eclipse expeditions.

Maps of the eclipse paths, at various levels of detail, appear in NASA Technical Publications of Fred Espenak and Jay Anderson, such as Espenak & Anderson (2008) for the 2009 total solar eclipse that will cross India and China. Since Espenak is now retired from NASA's Goddard Space Flight Center, and Anderson is a retired meteorologist from Canada, it remains to be seen how long this arrangement will last. Xavier Jubier, an amateur astronomer from France, has put the Espenak calculations into Google Earth and Google Maps, both accessible from the IAU Eclipse Site at *http://www.eclipses.info*.

Espenak and Meeus have published both in print and on-line massive tomes containing information about eclipse paths over a 5000-year interval, their *Five Millennium Atlas of Solar Eclipses* (2006) and their *Five Millennium Catalogue of Solar Eclipses* (2008). Espenak's *World Atlas of Solar Eclipse Paths*, with twenty-year intervals of mapped-paths going back thousands of years, is online at *http://eclipse.gsfc.nasa.gov/SEatlas/SEatlas.html*, also accessible through *http://www.eclipses.info* (Fig. 2).

Solar eclipses occur periodically, with eclipses similar in latitude and duration appearing with an 18-yr $11^{1}/_{3}$-d interval, with the $^{1}/_{3}$ d allowing the Earth to rotate 120°. The period, known as the saros, was discovered by the Babylonians in terms of lunar eclipses but named by Halley. Though it was

Fig. 1 The solar disk and the corona look smaller in the sky than one would expect, based on the many close-up views that are seen. Here we see a wide-angle view of the 1995 total solar eclipse, viewed from India. Depending on how high in the sky the corona is during totality, lenses of different focal length are chosen to display both the corona and the horizon. (©1995 Jay M. Pasachoff, *http://www.williams.edu/astronomy/eclipse/eclipse1995/IMG350.jpg*.)

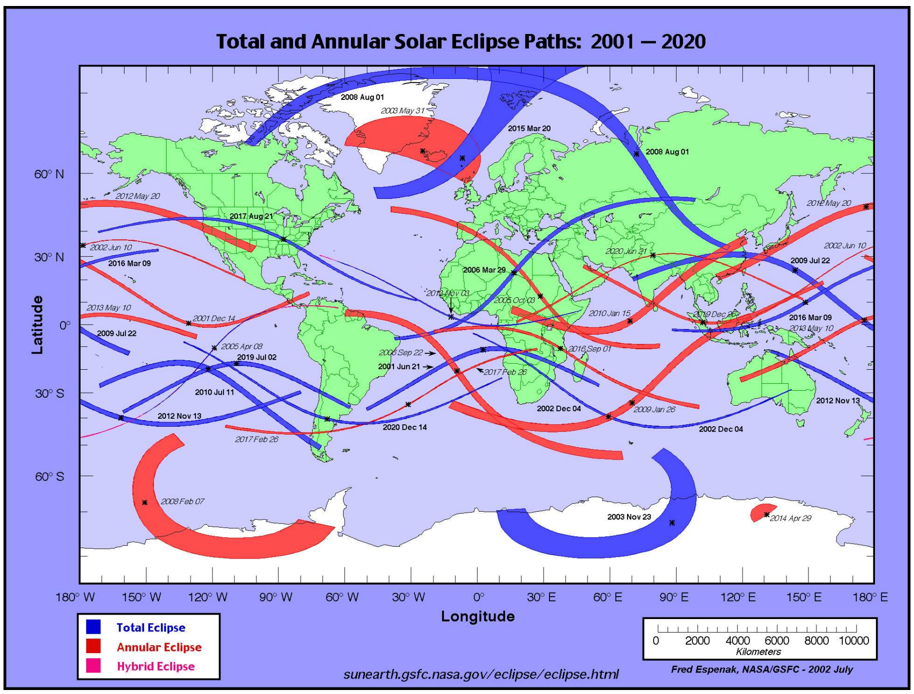

Fig. 2 Paths of totality and of annularity for solar eclipses between 2001 and 2020. In total eclipses, the Earth intercepts the lunar umbral cone. In annular eclipses, the umbral cone falls short of the Earth, and observers in the antumbra that hits the Earth see a ring of solar photosphere around the lunar silhouette. This ring is too bright to allow the corona to be observed, except in marginal cases. In hybrid eclipses, also known as annular-total eclipses, the curvature of Earth's surface allows some locations to see totality while others see only the annular phases. In all cases, partial eclipses extend thousands of kilometers away from the paths of totality or annularity. (Courtesy of Fred Espenak, NASA's Goddard Space Flight Center, *http://eclipse.gsfc.nasa.gov/SEatlas/SEatlas3/SEatlas2001.GIF*.)

properly used only for lunar eclipses, today's eclipse observers (who have worldwide knowledge of eclipses, which the ancients did not have) apply the interval to solar eclipses. The saros arises because of an astonishingly precise coincidence between 223 synodic months (a synodic month is the period of the lunar phases) = 6558.32 d; 242 draconic months (draconic months are also known as nodical months, the interval taken by the Moon to pass nodes of its orbit, intersections of the lunar orbit and the ecliptic) = 6585.36 d; 239 anomalistic months (an anomalistic month is the period by which the Earth-Moon distance varies) = 6585.54 d; and 19 eclipse years (an eclipse year is the interval at which the Sun returns to the nodes) = 6585.78 d. The nodes precess around the ecliptic with a period of 18.6 yr, making an eclipse year equal to 346.6 d. Successive eclipses in a saros series drift north or south, taking between 1244 to 1514 yr to move from pole to pole.

The longest possible totality is approximately 7 min 30 s. The longest eclipse in the current saros is declining in duration, from 7 min 4 s on 30 June 1973 in the Sahara, Africa, to 6 min 53 s on 11 July 1991, in Mexico, to 6 min 39 s on 22 July 2009 in the Pacific Ocean east of Shanghai, China. The lunar umbra moves through space at about 4000 km h^{-1} , and the Earth's rotation subtracts from that velocity. So an eclipse that occurs near the equator near noon has maximum rotational velocity with respect to the umbra, and the relative velocity can dip to 1200 km s^{-1}.

At the 1973 eclipse, this relatively low velocity was uniquely taken advantage of, and an experimental pre-production Concorde flew several scientific experiments along with the eclipse for an unprecedented 74 min (Beckman, Begot, Charvin, Hall, Léna, Soufflot, Liebenberg & Wraight 1973). Since the sun was high overhead, holes had to be cut in the top of the plane, and quartz windows inserted; the plane was retired after the eclipse. For the most part, ordinary airplanes flying to carry people to see eclipses do not extend totality significantly. A specific advantage of using airplanes is the availability of the infrared because of the high altitude. The infrared has also been observed from high-altitude mountain sites, when the 1991 eclipse went over Mauna Kea. The 2.5-m telescope on the Stratospheric Observatory for Infrared Astronomy (SOFIA), the NASA-German Space Agency instrumented airplane scheduled to start scientific observations in late 2009, should be valuable for eclipse studies.

In a given calendar year, there can be as many as five solar eclipses or as few as two. At a given spot on Earth, with a latitude dependence, an eclipse would be viewed only about every 350 yr, though paths of some successive eclipses overlap, and fortunate viewers at those locations could see two total eclipses with only a one-year interval. Now that travel is so convenient, ardent eclipse viewers travel to all total or even to all solar eclipses (Fig. 3).

At equal frequencies to total eclipses, when the umbral cone of the lunar shadow is intercepted by Earth's surface, are annular eclipses, when the umbral cone does not quite reach Earth. The percentage of solar photosphere that remains visible varies up to about 10%. Even a 1% remainder leaves the sky too blue from Rayleigh scattering for the corona to be seen, so annular eclipses do not have the same scientific benefits as total eclipses. Annularity can surpass 12 min in duration.

In the 21st century, out of 224 solar eclipses, there are 68 total, 72 annular, 7 hybrid (that is, total and annular at different locations along the path; also known as annular-total eclipses), and 77 merely partial eclipses. Still, even at partial eclipses using the Moon's limb as a knife edge crossing the sun outside of totality, sizes of radio-emitting regions on the sun have been measured, and space X-ray and ultraviolet telescope resolutions have been calibrated. One rare negative result of an eclipse was the loss of the Yohkoh solar X-ray satellite, which lost its bearings during the partial phase of an annular eclipse in 2001 when its guidance sensor got confused.

Rarely does a total eclipse cross a major observatory, so most eclipse observations are taken with portable telescopes. The last eclipse observed with a large telescope was the 1991 totality, which crossed the Mauna Kea Observatory in Hawaii, where scientists used the 3.6-m Canada-France-Hawaii telescope to study it. Among other discoveries was that of a very narrow coronal "thread" (Koutchmy, Belmahdi, Coulter, Demoulin, Gaizauskas, MacQueen, Monnet, Mouette, Noens, November, Noyes, Sime, Smartt, Sovka, Vial, Zimmermann & Zirker 1994; November & Koutchmy 1996). Precautions had to be taken to be very sure that no direct photospheric beam ever hit the telescope's mirror, since it would have dangerously focused the light and heat, causing damage in the system or a fire.

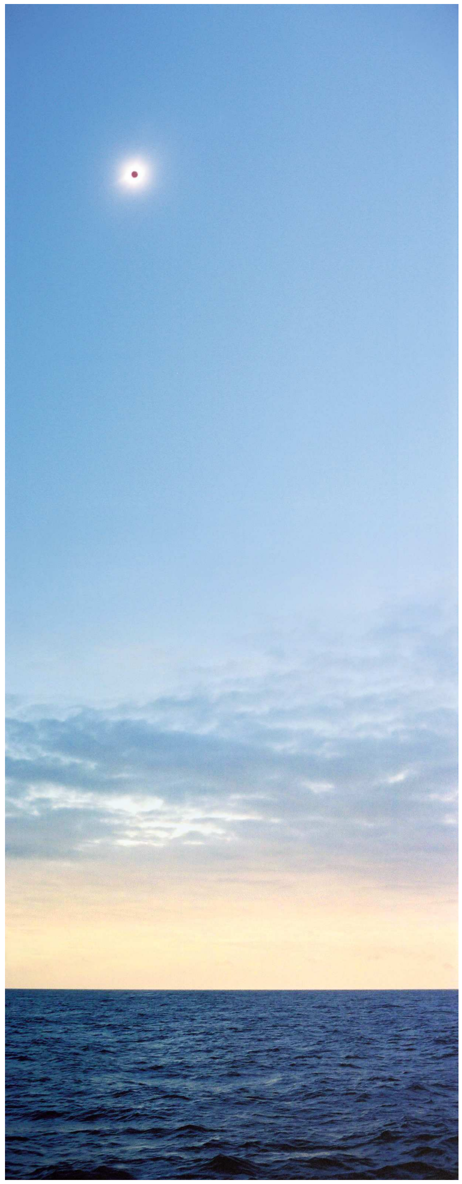

Fig. 3 The corona in the sky from mid-Pacific during the total phase of the hybrid eclipse of 2005, for which totality was visible only four days' travel by boat west of the Galápagos islands, Ecuador. The image is a composite of two exposures, one with the camera pointed high, for the corona, and the other pointed low, for the horizon. (©2005 Jay M. Pasachoff and Dava Sobel, *http://www.williams.edu/astronomy/eclipse/eclipse2005/2005hybrid/eclipse_composite_5.jpg*.)

Often, eclipse observers use coelostats, mirrors that track in right ascension at a 48-hour rotation rate (given a reflection) to allow large or long telescope tubes and/or spectrographs to be stationary. A second coelostat mirror in permanent installations allows adjustment for declination, but since eclipses are on fixed days, the second mirror can be dispensed with on eclipse day if telescopes are set up at the suitable angle (Pasachoff 1970). Techniques of aligning coelostats in the field for eclipses, and general discussions of coelostats and heliostats, are discussed by Pasachoff & Livingston (1984) and Demianski & Pasachoff (1984).

The configuration of the corona varies with the solar-activity cycle, which is now as low as it has been in decades (Fig. 4). We therefore expect few streamers, and those mainly equatorial. One can always hope for a coronal mass ejection during totality at some set of sites. Coronal mass ejections were discussed in Beijing at an International Astronomical Union Symposium edited by Dere, Wang & Yan (2005). See also Pasachoff (2008c) for a report on coronal mass ejection observations from NASA's STEREO spacecraft.

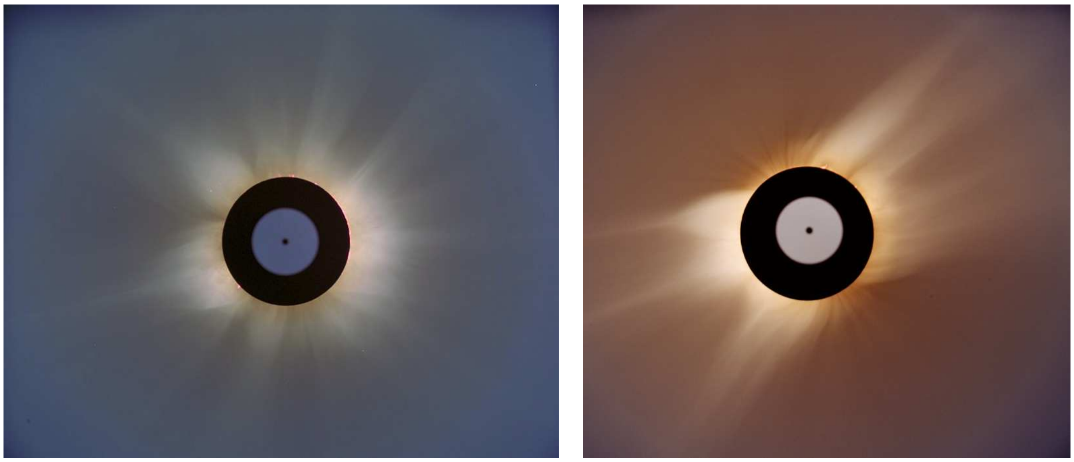

Fig. 4 Single images made (a) in 2001, and (b) in 2006, showing the contrast between the solar-maximum corona of 2001, with streamers silhouetted in all directions, and the declining activity of 2006, with streamers localized toward the solar equator. Both images were made by Jonathan Kern with his radial-filter camera, whose filter's density was maximal at the solar limb and declined outward to match the overall decline of coronal intensity. A transparent part of the center of the filter in each case allows the lunar disk to be seen, for calibration. (©2001, 2006 Jonathan Kern, Observatories of the Carnegie Institution of Washington, as part of the Williams College Expedition.)

Because of the low level of magnetic activity, the corona during the 2009 total eclipse is expected to be relatively weak. It is studied not only in white light but also, in particular, in spectral lines known to come from high-temperature ions. The longest known, and strongest in the visible spectrum, are the green line from 13-times-ionized iron (530.3 nm) and the red line from 9-times-ionized iron (637.4 nm). Singh, Ichimoto, Imai, Sakurai & Takenda (1999), with a ground-based coronagraph, and Takeda, Kurokawa, Kitai & Ishiura (2000), from the 1991 eclipse, are among those who have shown variations in their spatial distribution and differences between the red-line and green-line structure.

3 ECLIPSE OBSERVATION TEAMS

The main eclipse research teams in recent years include those of Jay Pasachoff at Williams College in the United States; Serge Koutchmy of l'Institut d'Astrophysique and Luc Damé of the LATMOS (Laboratoire Atmospheres, Milieux, Observations Spatiales) Laboratory, both parts of CNRS (Centre National de Recherche Scientifique) in Paris, France; Jagdev Singh of the Indian Institute of Astrophysics in Bangalore, India; Iraida Kim and V. Popov of the Sternberg Astronomical Institute of the State University of Moscow, Russia; and Vojtech Rušin, Metod Saniga, and Miloslav Druckmüller of Slovakia and the Czech Republic.

The International Astronomical Union's Working Group on Eclipses now includes Iraida Kim of the Sternberg State Astronomical Institute, Moscow State University, Russia; Hiroki Kurokawa of the

Kwasan Observatory, Kyoto University, Japan; Jagdev Singh of the Indian Institute of Astrophysics, Bangalore, India; Vojtech Rušin, Slovak Academy of Sciences, Tatranská Lomnica, Slovakia; in addition to its chair, Pasachoff. Atila Özgüç of the Kandilli Observatory, Bogazici University, Istanbul, Turkey, was added for the 2006 eclipse. Yihua Yan of the National Astronomical Observatories of the Chinese Academy of Sciences, Beijing, China, was added for the 2008 and 2009 eclipses. Espenak, formerly of NASA's Goddard Space Flight Center, Greenbelt, Maryland, USA, and Anderson, formerly of Environment Canada and now living in Manitoba, were members because of their valued predictive work and publications. Michael Gill, U.K., is a member because of his much appreciated maintenance and supervision of the Solar Eclipse Mailing List, a listserve that brings together hundreds of amateur and professional umbraphiles (*SEML@yahoogroups.com*). Another member is Glenn Schneider, Steward Observatory, University of Arizona, Tucson, Arizona, U.S., who has supervised several airborne expeditions, arranging and navigating airplanes over the Antarctic in 2003 and the Arctic in 2008.

The International Astronomical Union's Commission on Education and Development has a Program Group on Public Education at the Times of Eclipses. Its members include Pasachoff, Julieta Fierro of Mexico, and Ralph Chao, a professor of optometry from Canada and an expert on eye safety at solar eclipses.

4 HIGH SPATIAL-RESOLUTION IMAGING

The many problems in high-resolution imaging of the solar corona at eclipses include terrestrial atmospheric turbulence and the extremely wide range of coronal brightness. The corona at the solar limb is almost 1000 times brighter than the corona two solar radii above the limb. So no film or electronic detector can satisfactorily cover that whole brightness range on a single image.

One method of reducing the range of coronal brightness to fit on a single exposure is to have a filter with high neutral density at a circle to match the solar diameter and with neutral density diminishing radially outward. Such methods were pioneered in France by Marius Laffineur, and elaborated on together with Serge Koutchmy (Koutchmy 2004); and in the United States by Gordon Newkirk of the High Altitude Observatory. Whole series of eclipses imaged with Newkirk's camera are available online. Jonathan Kern, now of the Carnegie Observatories (Pasadena, California), as an amateur astronomer associated with the Williams College Expedition, has continued imaging eclipses with radially graded filters; Wendy Carlos has composited some of his images, improving the result further (Fig. 5).

Morgan, Habbal & Woo (2006) describe their own method of observing the corona in white light and processing their images by making the equivalent of a radially graded filter.

Various amateur astronomers have used current imaging techniques to provide high-resolution coronal images in recent years. Notable among them is Fred Espenak (*http://mreclipse.com*).

The high-resolution imaging has reached a peak with the work of Miloslav Druckmüller, a computer scientist from Brno Technical University, Czech Republic (Fig. 6). He carefully aligns images taken by himself and also often by Peter Aniol, his daughter Hana Druckmüllerová, Vojtech Rušin, and others. He has sometimes also improved images of others, including those of my own team. He uses his own software for the purpose (Druckmüller, Rušin & Minarovjech 2006). Many of his eclipse images are posted at *http://www.zam.fme.vutbr.cz/∼druck/Eclipse*.

Among resulting technical papers are those using images from the 2005 total eclipse observed from a ship in the mid-Pacific Ocean (Pasachoff et al. 2006); from the 2006 eclipse in Libya, Greece, and Turkey (Pasachoff et al. 2007); and from the 2008 eclipse in Mongolia and Russia (in preparation). The range of 2006 data from Libya to Turkey allowed motion in a polar plume to be followed and measured (Pasachoff et al. 2008).

We match our image of the corona at eclipse with the Solar and Heliospheric Observatory's images of the corona on the disk in the Extreme Ultraviolet and above about 1.8 solar radii from its coronagraphs (Fig. 7).

Fig. 5 The 2006 total solar eclipse, with several of Jon Kern's images composited by Wendy Carlos. Such an image more closely matches what the human eye sees of the corona, when looking through binoculars or a telescope during totality. (©2006 Wendy Carlos and Jonathan Kern. All rights reserved. *http://users.ociw.edu/jkern/Eclipse1998/; http://users.ociw.edu/jkern/Eclipse1999/; http://users.ociw.edu/jkern/Eclipse2001/; http://users.ociw.edu/jkern/Eclipse2002/; http://users.ociw.edu/jkern/Eclipse2006/*.)

Fig. 6 The solar corona from Bor Udzuur, Mongolia, during the 2008 total solar eclipse, the result of image processing by Miloslav Druckmüller using 52 eclipse images and 663 calibration images. We see the extended equatorial streamers typical of this inactive phase of the solar-activity cycle and extensive polar plumes. Stars are also visible. (©2008 Miloslav Druckmüller, Peter Aniol, Martin Dietzel & Vojtech Rušin, *http://www.zam.fme.vutbr.cz/∼ druck/Eclipse/Ecl2008m/Tse2008_400_mo1/0-info.htm*.)

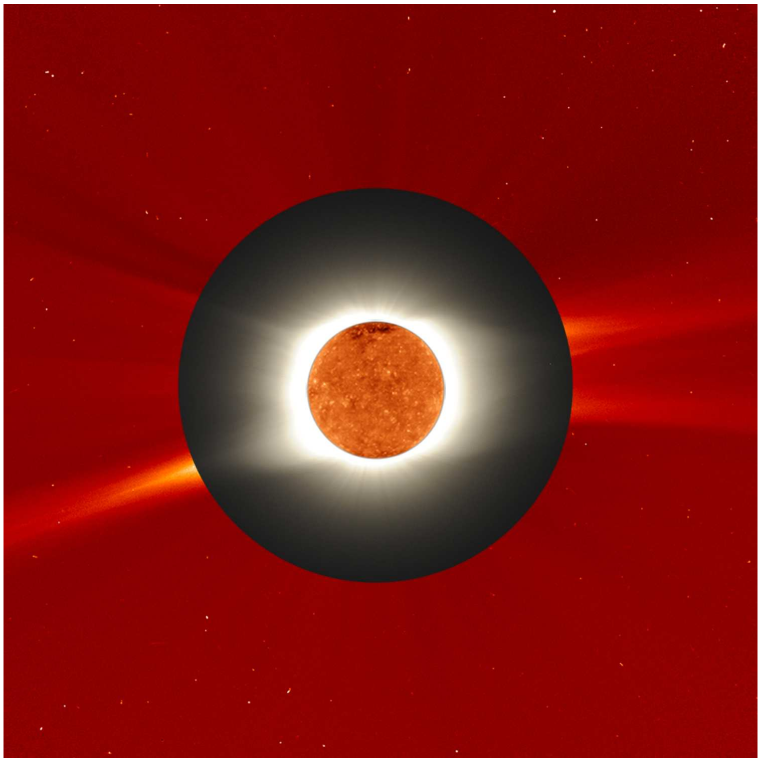

Fig. 7 The 1 August 2008 eclipse from Siberia and with the European Space Agency/National Aeronautics and Space Agency (ESA/NASA) Solar and Heliospheric Observatory (SOHO). The single, uncomposited eclipse image taken in Akademgorodok, near Novisibirsk, Siberia, Russia, is sandwiched between an image from SOHO's Extreme-ultraviolet Imaging Telescope (EIT) in helium radiation at 30.4 nm in the extreme ultraviolet, and an outer-corona image from one of SOHO's two coronagraphs from the Large-angle and Spectroscopic Coronagraph C2 (LASCO C2). (Eclipse image from Williams College Expedition: Jay M. Pasachoff, Bryce A. Babcock, William G. Wagner, Matthew Baldwin, Katherine DuPré, Marcus Freeman, Marek Demianski, Paul Rosenthal, with Alphya Nesterenko and Igor Nesterenko, State University of Novosibirsk; inner image from the EIT Team, NASA's Goddard Space Flight Center; outer image from the LASCO Team, Naval Research Laboratory; composited by Steele Hill, NASA's Goddard Space Flight Center, *http://soho.nascom.nasa.gov/pickoftheweek/old/01aug2008/2008eclipse.tif*.)

5 HIGH TIME-RESOLUTION IMAGING

5.1 The Williams College Oscillation Experiment

It is clear that the convectively turbulent, relatively dense, high plasma-beta photosphere must be the source of the energy to heat the corona (as well as the chromosphere). The main mystery is really which of the many temporal scales and modes of upward propagation present in the photosphere play an important role in the heating of the higher levels. It was formerly thought that acoustic waves with periods of a few hundred seconds, which are involved in the heating of the chromosphere, might also serve to heat the corona. However, their observed energy flux through the transition region is inadequate to explain the enhanced heating in the coronal active regions. The observations strongly suggest that the solar magnetic field plays an essential role in the coronal heating process. Thus, the principal energy flux is the Poynting flux.

The question of what kinds of waves may heat the corona incites heated debate. Koutchmy, Zhugzhda & Locans (1983) had discussed coronal oscillations, though with periods of 43 s and longer. Among the many reviews are Gómez (1991), Hudson & Kosugi (1999), Gómez, Dmitruk & Milano (2000), Harra (2001), Moore, Falconer, Porter, Hathaway, Yamauchi & Rabin (2004), Priest (2004), Klimchuk and López Fuentes (2006), and Priest (2006a, 2006b), and treatments in the texts listed above. The reports of the discovery of coronal Alfvén waves from a spacecraft (Erdélyi & Fedun 2007; Tomczyk, McIntosh, Keil, Judge, Schad, Seeley & Edmondson 2007; summarized by Pasachoff 2007) gained widespread publicity, though the periods measured are minutes compared with seconds of time sought in the eclipse studies soon to be described. The report of the apparent discovery of Alfvén waves from a ground-based observatory, and their possible role in coronal heating, was also widely reported (Jess, Mathioudakis, Erdélyi, Crockett, Keenan & Christian 2009, summarized by Kerr 2009). See also Li & Ding (2009) for Hinode ultraviolet spectral measurements relevant to coronal heating.

There are two classes of models that invoke the magnetic field to heat the corona, with the difference between the two classes mainly being in the timescale of the photospheric velocity field which drives the motion of the coronal field lines. The driving timescale can either be assumed to be longer than the Alfvén transit time across a coronal structure (the DC models) or shorter (AC).

See "On solving the coronal heating problem" (Klimchuk 2006) for a comparison of coronal-heating mechanisms and a discussion of how the problem might be solved with a warning about potential obstacles. See also the framing of the debate by Cranmer (2008).

Our basic experiment is to observe the corona in two different wavelengths in order to detect coronal intensity fluctuations while eliminating terrestrial atmospheric effects by monitoring a continuum channel. Our 10 Hz measurements, meant to be able to detect 1 Hz oscillations, are meant to be a contribution to the newly termed field of coronal seismology, some aspects of which are described by Klimchuk, Tanner & Moortel (2004). See also Aschwanden (2003) for a review.

We also measure the position of the solar limb and align the series of images, taking out periodic and atmospheric variations and any drift. We will calculate Fourier transforms for various intervals and for various parts of the image, comparing on-band and off-band images (where the off-band images monitor non-coronal contributions). Any signs of excess power in the 1-Hz range will be interpreted in terms of loop models and their adjustable parameters.

Our equipment for searching for coronal oscillations is much improved and much more sophisticated than the version used for the earlier experiments, which led to our previously published results. We found indications of excess Fourier power near 1 Hz in the 1980 experiment (Pasachoff & Landman 1981; Pasachoff, Schierer & Landman 1981; Pasachoff, Schierer, Landman & Miller 1981; Pasachoff & Landman 1984) and again found excess power in the 1983 observations (Pasachoff & Ladd 1987). Our conclusions were restrained, given that we had data only from single channels: our results "are consistent with theories of fast mode waves in a magnetically dominated regime," but we added that "Further observations are necessary to completely confirm and quantify these coronal oscillations, to assess atmospheric and other contributions."

At the 1999 eclipse (Pasachoff, Babcock, Russell & Seaton 2002), we digitized at 10 Hz for 140 s. Our 530.3 nm filter had a full width at half maximum of 0.36 nm, and we also monitored with a 10-nm filter in the nearby K-corona continuum. Compared with our observations at the 1998 eclipse (Pasachoff et al. 2000), we benefited from the brighter corona at solar maximum.

Our Monte Carlo model of the data suggests the presence of enhanced power, particularly in the 0.75–1.0 Hz range. Our results indicate that magnetohydrodynamic waves are a viable source of coronal heating.

Our latest observations are with our new POETS frame-transfer charge-coupled device (Souza, Babcock, Pasachoff, Gulbis, Elliot, Person & Gangestad 2005). We are still studying our results from the 2006 and 2008 eclipses, with the precise alignment of the images from frame to frame as our major stumbling block.

Our results are pointed toward resolving differences between predictions of methods for the sources of coronal heating (Golub & Pasachoff 2009). Alternative methods invoke nanoflares, which are small impulsive events (Krucker & Benz 2000; Gómez, Dmitruk & Milano 2000; Klimchuk 2006).

5.2 The British Oscillation Experiment

Kenneth J. H. Phillips and colleagues in the U.K. (Williams, Phillips, Rudaway, Mathiodakis, Gallagher, O'Shea, Keenan, Read & Rompolt 2001; Williams, Mathiodakis, Gallagher, Phillips, McAteer, Keenan, Rudawy & Katsiyannis 2002) have carried out a series of observations of coronal oscillations similar to ours. They built an apparatus called SECIS: The Solar Eclipse Coronal Eclipse Imaging System, which is similar to our own; we described it together (Phillips, Read, Gallagher, Keenan, Rudawy, Rompolt, Berlicki, Buczylko, Diego, Barnsley, Smartt, Pasachoff & Babcock 2000; Rudawy, Phillips, Read, Gallagher, Rompolt, Berlicki, Williams, Keenan & Bucylko 2002). Their most successful run, in 2001, led to discussions pro and con as to whether they had detected waves in the 1 Hz region (Katsiyannis, Williams, McAteer, Gallagher, Keenan & Murtagh 2003; Nakariakov, Arber, Ault, Katsiyannis, Williams & Keenan 2004; Nakariakov, Roberts & Wright 2004b). Williams reviewed the topic at a meeting based on the Solar and Heliospheric Observatory spacecraft (Williams 2004). Nakariakov and Verwichte (2005) reviewed the topic "Coronal Waves and Oscillations" in an online, updatable posting in *Living Reviews in Solar Physics*. Van Doorsselaere, Andries, Poedts & Goossens (2004), and Van Doorsselaere, Nakariakov & Verwichte (2008) continue to discuss just what kind of waves may have been detected.

5.3 The Indian Oscillation Experiment

Jagdev Singh and colleagues reported on continuum-light oscillations during the 1995 and 1998 total solar eclipses (Singh, Cowsik, Raveendran, Bagare, Saxena, Sundararaman, Krishan, Naidu, Samson & Gabriel 1997; Cowsik, Singh, Saxena, Srivivasan & Raveendran 1999), reporting periods of 6.9, 25.2 and 90.1 s from the latter. They plan further observations on the subject in China in 2009. They hope eventually for a spacecraft to observe forbidden emission coronal lines with faster cadences to look for oscillations at higher frequencies.

6 HIGH SPECTRAL-RESOLUTION IMAGING

At the 2006 eclipse in Kastellorizo, Greece, we brought a high-spectral-purity Fabry-Perot filter built at the Johns Hopkins University Applied Physics Laboratory by David Rust and colleagues. Its passband was only 0.016 nm wide, 1/60 nm. It had previously been used in an Antarctic balloon-borne telescope (Rust, Murphy, Strohbehn & Keller 1996).

We tuned the Fabry-Perot with applied voltages. Our observations of a coronal streamer found velocities of $\sim$ 10 km s^{-1} at two of the eight locations that we measured. We coordinated our observations at the eclipse with pointed observations from space from NASA's Transition Region and Explorer Spacecraft (TRACE), to get high-spatial-resolution images of the same region for which we were obtaining high-spectral-resolution data (Rust, Noble, Pasachoff, Babcock, Bruck & Wittenmyer 2006; Pasachoff & Bruck 2007; Noble, Rust, Bernasconi, Pasachoff, Babcock & Bruck 2008).

Coronal motions measured with Fabry-Perots have given varying radial velocities, as summarized by Kim (1994, 2000). For example, Chandrasekhar et al. (1984) and Chandrasekhar et al. (1991) found velocities of 40 km s^{-1} at the 1983 eclipse with photographic methods, while others, such as Kim (1994), found lower velocities, closer to 10 km s^{-1}. Fabry-Perot techniques were extended to CCD imaging (Chandrasekhar et al. 2006) at the 2001 eclipse. The 2001 data are still being reduced; line-width temperatures have been measured ranging from 2.4 to 3.7 million kelvins but velocities are not yet available though many asymmetric profiles were detected.

At the 2006 eclipse, velocities were measured in an apparently rising polar plume by comparing white-light brightness observations made from stations spaced over a 1-hour 9-minute interval (Pasachoff et al. 2008), showing a velocity of $\sim$ 65 km s^{-1}. See also the discussion of DeForest, Lamy & Llebaria (2001) about coronal motions and velocities in plumes and otherwise.

Wang, Biersteker, Sheeley, Koutchmy, Mouette & Druckmüller (2007) comment on three kinds of long, fine "rays", including polar and low-latitude plumes, helmet-streamer rays, and rays that separate coronal holes of the same polarity.

Fabry-Perot measurements provide unique opportunities to measure widespread velocities during the rare eclipse opportunities, and the observations reported here provide encouragement for wider use of Fabry-Perot measurements on such occasions in order to resolve the question of the disparities between velocities in the $10\,\mathrm{km\,s^{-1}}$ range, matching the results of this paper, and velocities $> 40\,\mathrm{km\,s^{-1}}$ measured on some occasions from both Doppler and imaging methods. The discrepancies may be resolved when a sufficiently wide field of view has all its velocities measured.

7 INFRARED CORONAL OBSERVATIONS

Traditional eclipse observations were in the visible, but advances in technology now allow observations in the infrared. As far back as the 1970s, electronic technology allowed the infrared triplet of [Fe XIII] to be observed at 1074.7 and 1079.8 nm (Pasachoff, Muzyka & Schierer 1976; Pasachoff & Muzyka 1976; Pasachoff, Sanford & Keller 1978). Since that time, there have been great advances in infrared imaging. Habbal, Arndt, Nayfeh, Arnaud, Johnson, Hegwer & Ene (2003) reported on their polarization measurements from the 2001 eclipse in the 1074.7 nm line, which they interpreted both in terms of interplanetary dust and as an expansion of coronal holes.

Observing from Libya at the 2006 total eclipse, Habbal, Morgan, Johnson, Arndt, Daw, Jaeggli, Kuhn & Mickey (2007) obtained for the first time a coronal image in the [Fe XI] emission line at 789.2 nm. They observed emission out to at least 3 solar radii, with localized intensity enhancements at particular locations between 1.2 and 1.5 solar radii, which they interpret in terms of localized increases in the ion density compared with electron density . They extended their work on coronal imaging at the 2008 eclipse (Habbal, Daw, Morgan, Johnson, Druckmüller, Scholl, Arndt & Pevtsov 2008). For logistic and funding reasons, we do not plan to repeat this experiment at the 2009 eclipse.

Coronal infrared spectroscopy is most recently notable for the probable discovery at 3.93 μm of a forbidden Si IX line by Kuhn, MacQueen, Streete, Tansey, Mann, Hillebrand, Coulter, Lin, Edmunds & Judge (1999), following a survey article by Kuhn, Penn & Mann (1996). The field would benefit from new infrared eclipse spectroscopy.

8 ULTRAVIOLET K-CORONA TEMPERATURE MEASUREMENTS

The traditional method of determining the million-kelvin coronal temperature was the discovery that the coronium lines were highly ionized heavy atoms. However, the discovery could have been made earlier from realizing that high temperature and therefore high Doppler shifts is the the explanation of the absence of absorption lines in the K-corona spectrum. (The "K" is from the German word for "continuous".) Since that continuum is scattered photospheric light, the lack of detectable lines—especially of the strong ultraviolet lines including Ca II H and K as well as absorption lines at somewhat higher ultraviolet wavelengths—can be interpreted in terms of Doppler scattering by high-speed coronal electrons.

Menzel & Pasachoff (1968) reported that the slight dip earlier reported in the ultraviolet was within the uncertainties of the film calibration then used. Cram (1976) made calculations that showed optimum wavelengths at which to measure the coronal intensity with high precision, given the existence of nodes that are temperature-independent and of ultraviolet wavelengths that are temperature-dependent.

Ichimoto, Kumagai, Sano, Kobiki & Sakurai (1996) measured the ultraviolet spectroscopically between 390 and 430 nm. They found a coronal streamer with temperatures 1.5–1.7 MK and a coronal hole with temperatures 0.9–1.1 MK. They found an acceleration of the solar wind's expansion by $80\,\mathrm{km\,s^{-1}}$ in a streamer. (See Pasachoff 2008b, for a summary of a new idea of how the solar wind forms.)

Reginald & Davila (2000), Reginald, St. Cyr, Davila & Brosius (2003), and Reginald, Davila & St. Cyr (2004), have repeated and enlarged on Cram's calculations to include the effect of the expanding solar wind. They imaged through filters at selected ultraviolet wavelengths during several eclipses to measure electron temperature and solar-wind flow. Most recently, as yet unpublished, they observed from the desert in China.

9 2009 PLANS OF RESEARCH TEAMS

9.1 The Williams College Team's Plans

The team from Williams College, Williamstown, Massachusetts, USA, is headed by Jay Pasachoff and Bryce Babcock. They plan observations from Tianhuangping, northwest of Hangzhou.

The first of their experiments is to continue their 10-Hz imaging of the coronal green line, in a search for high-frequency oscillations. Their goal is to provide information about coronal seismology that can be used as a discriminator among theories of coronal heating from various forms of magnetic waves.

They are also imaging in the coronal green line, in collaboration with Robert Lucas of the University of Sydney, Australia. They will have on-band and off-band observations, the subtraction of which reveals the emission-line image.

They are also imaging with a variety of telephoto lenses to provide raw observations for the magic of the image-processing of Miloslav Druckmüller and Hana Druckmüllerová in the Czech Republic, as well as that of Wendy Carlos in New York.

We will again coordinate with the Solar and Heliospheric Spacecraft to fill in the gap in their spatial coverage.

The Williams College team has been joined since their observations on the Greek island of Kastellorizo in 2006 by that of John Seiradakis from the Aristotle University of Thessaloniki. On his team, Aris Voulgaris also carries out high-spectral-purity coronal green-line imaging, on-band and off-band (Voulgaris, Athanasiadis, Seiradakis & Pasachoff 2009). See Pasachoff, Babcock, Souza, Bruck, Hess, Kimmel, Levitt, Steele, Tsykalova, Rust, Noble, Wittenmyer, Kern, Hawkins, Seiradakis, Voulgaris, Pistikoudis, Nestoras & Demianski (2006) for a summary of the overall expedition.

9.2 The French Team's Plans

The team from various universities, institutes, and observatories in France is headed by Luc Damé of the LATMOS (Laboratoire Atmospheres, Milieux, Observations Spatiales) and Serge Koutchmy of IAP (Institut d'Astrophysique de Paris), both institutes being part of CNRS (Centre National de la Recherche Scientifique). Their team includes Philippe Lamy, Jean-Marie Malherbe, Thierry Legault, Christian Viladrich, Claude Frelat, Jaime Vilinga, Marie-France Balestat, Jean Mouette, Jean-Marie Munier, and Denis Fiel from France. Russian and Chinese collaborators are associated: Sergey Kuzin and Andrey Pertsov from the Lebedev Physics Institute; Boris Filippov and Yuri Platov from IZMIRAN; Valery Nagnibeda, from Saint-Petersburg University; and Hongqi Zhang, Xingming Bao, Sen Wang and Xiyang Fu from the National Astronomical Observatories/Beijing, Chinese Academy of Sciences.

They plan a wide range of observations including spectroscopy to measure line profiles to search for velocities and wide ultraviolet bands to measure electron temperature from the broad dips resulting from highly-scattered strong absorption lines. They are also looking for short-period waves. Their infrared observations, including imaging from Jacques-Calir Noéns of the Pic-du-Midi Observatory jointly with a Chinese team and spectroscopy from the Chinese, include studies of the [Fe XIII] infrared spectral lines, which are sensitive to the coronal magnetic field. At the contacts of the moon with the solar limb, they will be observing the chromospheric flash spectrum, to study especially the height of formation of the ionized helium emission line at 468.6 nm. They will be measuring coronal polarization to separate the contributions by coronal electron scattering of photospheric light from dust scattering of photospheric light that occurs higher above the photosphere, that is, farther out in the solar system.

Additional details are available at *http://solarnet.obspm.fr/hirise/Eclipse2009/Eclipse2009-ExperimentsTable.pdf*.

Damé points out that, in the future, to address near-limb observations with spatial resolution, there are space missions proposed involving two satellites over 100 m apart to create an artificial eclipse. The satellite pointed to the Sun is carrying an occulting disk for the second, aligned on the shadow. A large external occulted coronagraph is formed based on formation flying of the satellites (Fig. 8). They hope to observe down to the transition zone between the chromosphere and corona and, as well, address both the IR [Fe XIII] coronal emission line and UV ones [Lyman-alpha, O VI] for direct magnetic-field measurements, from only 1.01 times the radius of the solar limb out to 3–4 solar radii, with a very low level of scattered light (since it linearly depends on the distance between the occulter and the coronagraph entrance pupil). An ESA Cosmic Vision proposal, HiRISE (High Resolution Imaging and Spectroscopy Explorer, a new generation ultrahigh resolution, interferometric and coronagraphic, Solar Physics mission) was proposed in 2007 by Damé (Coordinator) with a large Chinese involvement, and encouraged by ESA to re-propose in 2012 (2nd Cosmic Vision Call) following further feasibility demonstration of the Formation Flying control of the two satellites. In that respect, ESA is developing, for 2012, the PROBA-3 Technology Demonstration Program which will carry, on two microsatellites, a 2D coronagraph, ASPIICS (Association de Satellites Pour l'Imagerie et l'Interférométrie de la Couronne Solaire), developed by Philippe Lamy and collaborators (Lamy, Vivès, Damé & Koutchmy 2008).

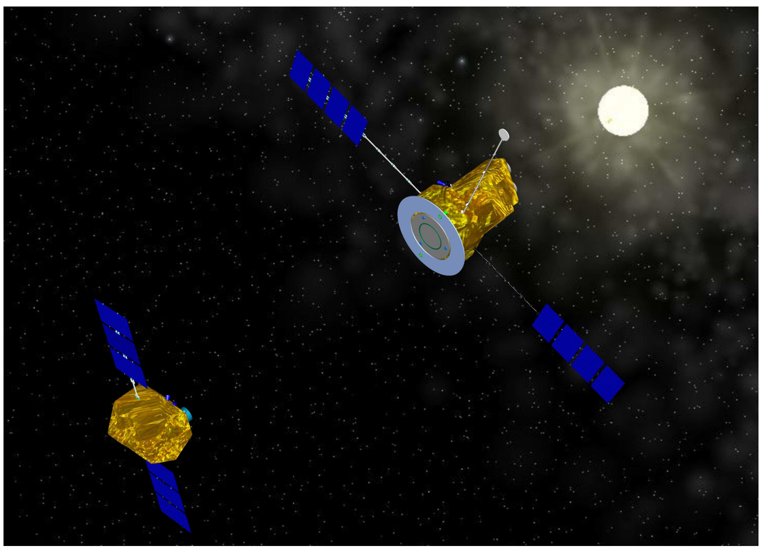

Fig. 8 An artist's conception of the proposed mission for the European Space Agency to fly two spacecraft in formation so that one can act as an external occulter for the telescope on the other. (courtesy of Luc Damé, LATMOS, CNRS, France)

9.3 The Indian Team's Plans

The team from India will come from three Institutes: Indian Institute of Astrophysics (IIA), Bangalore; Udaipur Solar Observatory (USO), Udaipur; and Aryabhatta Research Institute of Observational Sciences (ARIES), Manora Peak. The 15 or so Indian scientists will be located with American and Chinese scientists at Tianhuangping, near Hangzhou.

Their main observations will be devoted to the study of waves in the solar corona. They will carry out spectroscopy of the solar corona simultaneously in the green and red emission lines with a cadence of about 8 Hz. They will also image the corona in the same emission lines with a cadence of about 1.5 Hz.

Prof. Jagdev Singh advises me that their experimental setups will be as follows:

Spectroscopy of the Solar Corona: A 30-cm two-mirror system (coelostat) will be used to direct the sun and coronal light to a 10-cm objective to form an image of the corona on the slit of the Littrow-type spectrograph. A 14-cm objective will collimate the beam and image the spectrum on the two CCD cameras. Broad band filters will be used to separate the orders. A grating with 600 lines per mm blazed at 2 μm will provide a reasonable dispersion (0.2 nm/mm) to determine the emission line profiles. Two CCD cameras of 1 K$\times$1 K format with pixel size of 13.5$\times$13.5 μm will be used to take the images. The CCD chip will be back-illuminated for high efficiency, and the camera will operate in frame-transfer mode to obtain data with high frequency. The readout will be in 14-bit format at 8 Hz.

Photometry of the Solar Corona: Two 40-cm telescopes with effective focal length of 200 cm each will be used to image the solar corona. A 5-cm narrow-band (0.3 nm) filter centered around the coronal red line (637.4 nm) kept near the focal plane in one of the telescopes will permit red-line imaging. The second telescope fitted with a corona green-line narrow-band filter (530.3 nm) will take images in the green line. The CCD cameras of 2 K$\times$2 K format with 13.5$\times$13.5 μm pixel size will cover the solar corona up to 1.5 solar radii, where most of the emission occurs. The 16-bit readout at 5 MHz rate will provide a high dynamic range and fast kinetic series (1.5 Hz). The back-illuminated chip will yield more than 90% efficiency at the wavelengths of interest.

Magnetic mapping: Udaipur Solar Observatory (USO) plans to map magnetic topology of the solar corona by measuring the polarization of the green emission line using spectroscopy and imaging.

Emission-line imaging: Aryabhatta Research Institute of Observational Sciences (ARIES), Manora Peak, Nainital, plans to carry out photometry of the solar corona in the two emission lines (530.3 [Fe XIV] and 789.2 nm [Fe XI]) using two independent telescopes. They plan to take images in the range of 2–4 Hz, depending on the exposure time.

9.4 Czech and Slovak Teams' Plans

Vojtech Rušin of the Slovakian Academy of Sciences' Tatranská Lomnica coronal station in the High Tatras is one of history's major eclipse observers, and he has also observed the corona over time with his coronagraph (Rušin 2000). In recent years, he has been working with Miloslav Druckmüller of the Brno Institute of Technology, Czech Republic, on high-resolution imaging. Druckmüller has developed his own methods of alignment, compositing, and image-enhancement, and has produced an amazing series of detailed coronal images. They are available for view at *http://www.zam.fme.vutbr.cz/∼druck/Eclipse/*.

I have been fortunate to work with Druckmüller; his daughter, Hana Druckmüllerová; and Rušin and Metod Saniga of Tatranská Lomnica to describe the ramifications for coronal structure and motions of several of the past eclipses, including Pasachoff, Kimmel, Druckmüller, Rušin & Saniga (2006) for the 2005 eclipse; Pasachoff, Rušin, Druckmüller & Saniga (2007) for the 2006 eclipse; Pasachoff, Rušin, Druckmüller, Druckmüllerová, Bělík, Saniga, Minarovjech, Markova, Babcock, Souza & Levitt (2008) for motions of a polar plume at the 2006 eclipse; and Pasachoff, Rušin, Druckmüller, Aniol, Saniga & Minarovjech (2009), now in preparation, for the 2008 eclipse.

It goes without saying that Druckmüller, his colleague Peter Aniol, Rušin and Saniga will be observing the 2009 eclipse from suitable sites.

9.5 Chinese Teams' Plans

The total solar eclipse of 22 July 2009 will be one of the most widely viewed in history, since it will pass over major cities, including Shanghai, Hangzhou, and Wuhan. Of course, many Chinese scientists will observe it. I am pleased that some of them, in a group headed by Yihua Yan of the National Astronomical Observatories, Chinese Academy of Sciences, will be observing alongside my own group and that of Dr. Singh at Tianhuangping.

Much of the eclipse work will be related to the topics discussed at the 2004 Beijing International Astronomical Union symposium on *Coronal and Stellar Mass Ejections* (Dere, Wang & Yan 2005).

Prof. Yan sent the following report of related research activities organized by the Chinese solar-physics community for the 2008 and 2009 total eclipses:

During the 2008 total solar eclipse, the coronal emission lines were observed with an optical-fibre spectrograph and polarization imaging system in a near infrared waveband. The profiles of the coronal emission lines including [Fe XIII] 1074.7 nm and 1079.8 nm, as well as chromospheric He I 1083 nm, were obtained with dispersion of 0.05 nm/pix. The intensity of [Fe XIII] 1074.7 nm is the strongest among the three lines in the regions away from the prominence while the intensity of He I 1083 nm is considerably increased in the location where the prominence appeared. The coronal linear-polarization images were observed at [Fe XI] 789.2 nm with a bandpass of 3 nm in a series of exposure times (Bao, Zhang, Deng, Hu, Xuan, Liu, Zhang, Deng, Wang & Wang 2009).

The linear-polarization signals of the flash spectrum ranging from 502.5 nm to 528.5 nm were measured after the second contact of the total solar eclipse. A large group of spectral lines (especially those lines produced by neutral iron, neutral copper, and as carbon molecules) are found with a very high degree of polarization relative to the continuum polarization, and the linear-polarization spectrum is more abundantly structured than the flash spectrum itself. According to the observational result, it is concluded that coherent scattering and scattering geometry as well as other mechanisms may together play a very important role in producing the high polarization amplitudes (Qu, Zhang, Xue, Dun, Zhong, Liang, Yan & Xu 2009).

Based on the joint observations of radio broadband spectral emissions of the solar eclipse of 1 August 2008 at Jiuquan (total eclipse) and Huairou (partial eclipse) at the frequencies of 2.00–5.60 GHz (Jiuquan), 2.60–3.80 GHz (Chinese solar broadband radiospectrometer, SBRS/Huairou, Fu, Ji, Qin, Xu, Xia, Wu, Liu, Yan, Huang, Chen, Jin, Yao, Cheng, Xu, Wang, Pei, Chen, Yang, Tan & Shi 2004), and 5.20–7.60 GHz (SBRS/Huairou), a successive series of broadband spectra with frequencies of 2.60–7.60 GHz was assembled to observe the solar eclipse synchronously. Based on these data, a semiempirical model of the coronal plasma density of the quiet Sun is obtained and compared with the classic model (Tan, Yan, Zhang, Tan, Huang, Liu, Fu, Chen, Liu, Chen & Ji 2009). Radio observations at 8.6 mm and 2.5 cm wavelengths were taken by a Purple Mountain Observatory team following their previous solar eclipse recordings.

The flash spectra in the He I D_3 line were successfully obtained. The average integrated intensity of the line at h = 1100 km above the photosphere was measured. The result confirms that the He I D_3 emission might be negatively correlated with the level of solar activity (Li, Ji, Ni, Zhang, Zhang, Liu, Deng, Wang, Du, Zhou, Li & Shen 2009). They also obtained a set of chromosphere spectra for a prominence during the total solar eclipse. It is found that the prominence had a red-shifted feature. The results support the idea that the material forming prominences is from the chromosphere (Ji, Li, Ni, Zhang, Zhou, Shen, Du, Li, Jin, Ding, Cao, Su, Fang & Wang 2009).

Complex dynamic structures in quiet regions were observed in the white-light inner corona during the total solar eclipse observation. It may throw light upon the study of the dynamics and the magnetohydrodynamics of the inner corona. A modified 25-cm (10-inch) telescope installed with an EMCCD was used to take all the white-light speckle images. The high-resolution image was reconstructed with a speckle masking technique (Liu 2009).

Similar observations and measurements will be carried out at the 2009 total solar eclipse by solar physicists from National Astronomical Observatories (NAOC/Beijing and NAOC/Yunnan) and Purple Mountain Observatory (PMO/Nanjing), all of the Chinese Academy of Sciences. From NAOC/Beijing, the team headed by Hongqi Zhang and Yuanyong Deng will continue coronal spectral observations in near-IR wavelengths and low-coronal images at optical wavelengths, and the solar radio group led by Yihua Yan will continue joint observations of microwave spectra at Tianhuangping (total eclipse) and Huairou, Beijing (partial eclipse). From NAOC/Yunnan, the team headed by Zhong Liu will take the white-light speckle images to obtain high-spatial-resolution images of the inner corona at Haining, Zhejiang, and the team led by Zhongquan Qu will pursue linear-polarization measurements of the flash spectrum in visible light. From PMO/Nanjing, the team led by Haisheng Ji and Hui Li will take flash spectra near the D_3 line using a spectrograph fed with a heliostat near Suzhou, Jiangsu, and a team led by Zongjun Ning will pursue radio observations at 8.6-mm and 2.5-cm wavelengths.

9.6 Russian Teams' Plans

The group of Iraida Kim from Moscow, in addition to their Fabry-Perot spectral work, has been studying coronal polarization, which is used to separate the polarized K-corona, from electron scattering, from the largely unpolarized F-corona ("Fraunhofer corona"), from scattering off interplanetary dust (Popov, Kim & Popova 2007).

We are trying to arrange for Alphya Nesterenko of the physics department of the State University of Novosibirsk and Igor Nesterenko of the Budker Institute of Nuclear Physics of the Russian Academy of Sciences to join us in Tianhuangping. They were the hosts for the Williams College group in Akademgorodok for the 2008 eclipse.

9.7 Japanese Teams' Plans

The path of totality passes over some small islands in the south of Japan as it proceeds toward the eastern Pacific Ocean. Included in totality are the Tokara islands in the northern part of the Ryukyu islands and the island of Iwo-jima. *Y. Suematsu, K. Ichimoto, and colleagues report the following plans:*

A team (Y. Suematsu, N. Tanaka, M. Saito & T. Kobiki) from the Solar Observatory, National Astronomical Observatory of Japan (NAOJ), will be dispatched to Iwo-jima with special visiting permission from the Japan Ministry of Defense. They plan to carry out spectroscopic observations in the wavelength band of 360–460 nm to derive the electron temperatures and radial expansion velocities of various coronal structures, aiming at advancing the previous study of Ichimoto, Kumagai, Sano, Kobiki & Sakurai (1996). They will also take high-resolution photometric images to elucidate fine-scale magnetic structures of the corona and their electron-density distributions using a 25-cm-aperture telescope.

Another team from NAOJ, the Japan Aerospace Exploration Agency (JAXA), and other institutes, plans to broadcast live eclipse images with high-definition television (HDTV) quality from Iwo-jima via the internet through the WINDS satellite of JAXA (the Wideband InterNetworking engineering test and Demonstration Satellite, nicknamed KIZUNA). Some teams are expecting eclipse observations coordinated with X-ray observations by XRT and EIS aboard the Hinode satellite and coronal emission-line observations at the Norikura Solar Observatory.

Since these Japanese islands cannot or will not readily accept expedition teams, most Japanese teams plan to use ships (i.e., one from Kagoshima University) or observe from China to carry out filter-imaging, photometric, and flash-spectrum observations of the corona using portable instruments. Kagoshima University (Principal Investigators: Y. Sofue and A. Nishina) is organizing a voyage to the east of the Ryukyu islands in the Pacific Ocean with the training vessel Kagoshima-maru (international gross tonnage, 1539 tons). The most important value of observations with a ship is to improve the promise of favorable weather conditions, because a ship can move to a cloudless area. Scientific observations planned in this voyage cover a wide range of subjects. A team from NAOJ/Kyoto University (PI: Y. Hanaoka) will take high signal-to-noise images of the white-light corona to measure the electron column density distribution. A joint team of Kobe University, JAXA, Hokkaido University, and NAOJ (PI: T. Mukai and H. Okuda) is planning to study the structure of dust around the Sun by observing the F-corona. They will carry out photo-polarimetric observations in the visible light and imaging observations in the H and K bands with an IR camera. Radio observations are planned by Kagoshima Univ. (PI: M. Nishio), with 9 small antennas to study 12 GHz radiation, and they will study the detail of the stratified chromospheric structure. A team from Sendai Astronomical Observatory (PI: M. Tosa) plans to take white-light movies with HDTV cameras, and also they will try to take a movie in the [Fe X] 637.4-nm red coronal line with a super high-sensitivity video camera. Variations of meteorological parameters during the eclipse will be measured by a joint team of Kinki University (PI: I. Sano)/Kagoshima Univ. (PI: A. Nishina).

Besides the observations conducted by professional astronomers, the corona will be imaged in white light by many amateur astronomers, and such observations will be carried out from a wide variety of sites along the eclipse path. A set of such images will show some short-term variations in the corona.

Therefore, we have proposed that a professional-amateur collaborative network be organized for extensive observations of the white-light corona.

10 TERRESTRIAL INFLUENCES OF ECLIPSES

Anyone who has seen the sky clear completely as the partially eclipsed sun results in atmospheric cooling (with the 2008 observations from Akademgorodok, Siberia, as an example) respects the eclipse's influence on weather (Setty 1960; Krumov 2007). See also Krezhova, Yanev & Krumov (2007) for the effect of changing solar radiation at the 1999 eclipse; and Eckermann, Broutman, Stollberg, Ma, McCormack & Hogan (2007) for simulations of the atmosphere's response to the 2002 eclipse and Emde & Mayer (2007) similarly for the 2006 eclipse. Peñaloza-Murillo (2002) discusses the optical response of the atmosphere during two eclipses, from 1998 and 1916, evaluating sky brightness and the role of aerosols.

Shadow bands, no doubt from upper atmospheric motions refracting the solar crescent just before or just after totality, are often seen (Codona, 1986, for the basic theory; Gladysz, Redfern & Jones 2004, for recent observations; earlier observations by Jones, Miseldine & Lambourne 1992; Jones & Jones 1994; Jones 1996, 1999a, b).

On or near Earth's surface, responses of animals can also be studied (Ferrari 1976; Tramer 2000; Rutter, Tainton, Champion & Le Grice 2002). I would be glad to have some new studies during the 2009 eclipse in China on the response of animals, which would be especially interesting at its time of day in early- to mid-morning.

11 FUTURE TOTAL ECLIPSES

The 22 July 2009 starts at sunrise in India, where it is the season of the monsoon; passes parts of Nepal, Bhutan, and Bangladesh; and then crosses China very extensively (Espenak & Anderson 2006). Major cities are involved, so tens of millions of Chinese citizens will be able to see the eclipse, weather permitting. Because of low-altitude haze that is common, we are choosing to observe from the mountains, at an altitude of 900 m.

The 11 July 2010 total solar eclipse will almost entirely cross water, touching very little land in the Pacific (Espenak & Anderson 2008). Aside from uninhabited islands and atolls, it crosses Easter Island, also known as Rapa Nui, where most ground-based observers will attempt to be, lodging and airplane logistics permitting. Several cruise ships could be based in French Polynesia. Totality ends at Chile, but the eclipse is then almost on the horizon, mountains would interfere with the horizon from the end of the path, and the winter-season weather forecasts are unfavorable.

Cloud statistics based on past years are available at *www.eclipser.ca*.

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