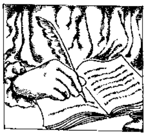


When The Sun Goes Out

M K V Bappu

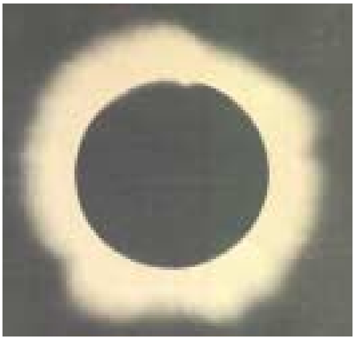


Photo of the solar corona taken in Miahuatlan, Mexico, by the eclipse team of the Indian Institute of Astrophysics. A 5.8-metre focal length camera was used.

One of nature's grandest displays, a total solar eclipse can be inspiring, even awesome.

There was an air of hushed expectancy in our camp as I saw the moon's shadow approach from the distant hills in the west. In a few seconds the last traces of the sun's brilliant disc would be covered by the moon brining into view the ruddy chromosphere and pearly white corona.

My first task was to announce this instant. Viewing the disappearance of the bright solar disk through a monocular with a transmission grating ahead of it, the bright lines of the chromosphere flashed into view replacing the dark absorption lines of the normally visible solar photosphere. For the next 203 seconds, my teammate and I were to carry out a programme of photographing the coronal form and its spectrum. We had travelled nearly 20,000 km to the village of Miahuatlan in Mexico, carrying along four tonnes of equipment, to observe this total solar eclipse of 7 March, 1970.

The few preceding weeks had made heavy demands on our reserves of energy and resourcefulness. But in those few seconds of totality, when a cloudless sky revealed the glorious spectacle of the corona, making our programme a success, we more than made up all the effort and investment.

On an average, there are about 66 total eclipses of the sun in a century, with the longest duration of totality being no more than 451 seconds. Many of these have tracks that are mostly over areas with little or no human habitation. Success in observing the remaining few depends heavily on the weather; the best plans of many expeditions in the past have

Reproduced from *Science Today*, February 1980.

been foiled by a stray cloud that happened to cover up the sun during the critical duration of totality. On the other hand, there are rare instances of extreme good luck, as the one I had at Maine, USA, on 20 July 1963, when a gap in the thick clouds, just when and where it was needed, enabled us witness the spectacle. Eclipse lore has much more to tell on the near escapes and disappointments that previous observers have experienced in this regard.

Why then do solar physicists attempt to make such eclipse observations when they are so fraught with uncertainty? The answer lies in the fact that total solar eclipses have hitherto been the only occasions when studies on the sun's chromosphere and corona could be made in great detail. With the bright light of the visible disc completely cut off, we can examine the characteristics of the faint distended outer atmosphere of the sun.

The physical processes at work in these regions are of great interest not only from the standpoint of the origin of excitation and extent of the solar atmosphere, but also for providing information on the radiative flux responsible for the formation of the earth's ionosphere as well as the charged matter that makes up the solar wind. Much of the basis of our understanding of these regions of the solar atmosphere has been the information collected during eclipses that would span a total observing time of just a quarter hour in almost a century.

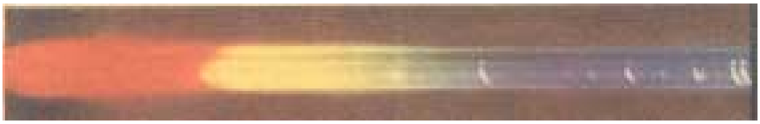
As I write this, numerous teams in different countries are busy preparing to observe such an event in India on 16 February 1980. This is the first occasion during the twentieth century when a total eclipse track will cross the Indian peninsula. Three eclipses during the last century, as observed from India, have already helped lay some of the foundations of solar physics.

The most important, historically, was the one of 18 August, 1868, which the British and French teams, together with the Madras Observatory team, studied. All teams used spectrometers and established that the prominences were gaseous in nature as inferred from the emission lines of hydrogen. The prominence spectrum also displayed a bright yellow line more refrangible than the well known D lines of sodium. This observation in India was the first ever made of helium. Recognised as a new element in the solar

Diagram of shadow bands. Reproduced from 'The story of eclipses' by G F Chambers published in 1902.

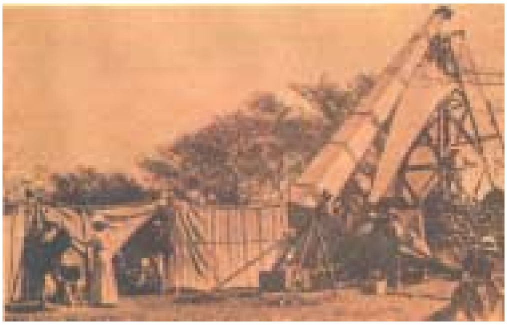
Flash spectrum of the chromosphere at second contact during the January 1898 eclipse at Jeur, Maharashtra.

Chromosphere photographed in white light. The samll jet-like features are the spicules. At the far right is a small prominence (Lick Observatory Expedition, Jeur)



Flash spectrum of the sun at eclipse showing the arc shaped emission lines of the chromosphere. The thin full circle of light in the green part is the green coronal line.

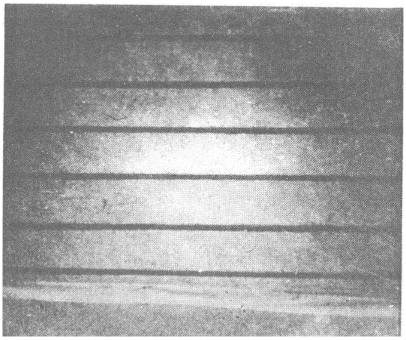
The 26 February 1979 total solar eclipse. This one-second exposure at f/4 on Kodachrome 25 film was made about 30 seconds after totality began.



The eclipse of 22 January 1898 at Jeur in Maharashtra. Photo shows the Lick Observatory's eclipse team with their coronal camera. The camera was not guided; it had to be pointed ahead of time to the position where the sun and moon would seem to meet.

The chromosphere can be seen only for a few seconds just as the last bit of the sun is being covered by the moon.

Photograph of the shadow bands; see the periphery of white area.



spectrum, it was 27 years later that Ramsay isolated it from the mineral cleveite.

The next eclipse in India was on 12 December 1871 with the track of totality passing through Ooty and Pudukotah, in Tamil Nadu. This eclipse is memorable for the French astrophysicist Janssen's discovery of the Fraunhofer corona by the observation of weak and shallow Fraunhofer lines, especially those of sodium; Janssen also saw weak hydrogen emission in the corona.

The eclipse of 22 January 1898, the path of which cut across the country from Ratnagiri through Rewa, had observing teams all along the path of totality. Evershed obtained ultraviolet spectra of the chromosphere and prominences, and found continuous emission shortward of the Balmer limit, a feature which is most usefully exploited in present day studies for the determination of electron temperature and density.

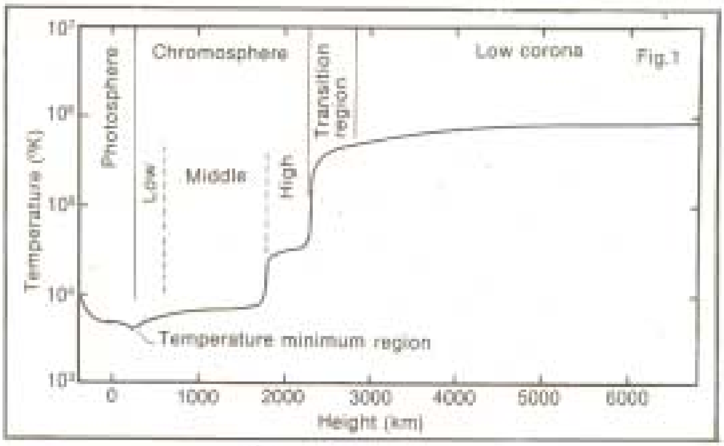
The recurrence of a similar event 82 years later in the same region of the world quite naturally evokes considerable interest. The shadow will enter the west coast of India at Ankola and leave at Puri on the east coast. The shadow cone will first touch the earth's surface in the mid-Atlantic and after sweeping over the continent of Africa, the southern part of India, Bangla Desh and Burma, will leave the earth at location in southern China. The maximum duration of totality will be 252 seconds near the east African coast. In India, totality will be of the order of 170 seconds on the west coast and 136 seconds at Puri. The altitude of the sun above the horizon will be 39° and 24° at the two respective places. February, with its clear skies, is one of the best months for astronomical observation in India. Here is then an occasion of the greatest interest not only to both professional and amateur astronomers, but also to anybody who appreciates beauty in nature.

The red annulus seen just adjacent to the bright vanishing disk of the eclipsed sun is termed the chromosphere. The emission line spectrum of this layer, which in some places can be as high as 3,000 km, constitutes the flash spectrum discovered in 1870 by Young of Princeton. The spectrum of the chromosphere is best observed at a total eclipse, although Pogson of Madras Observatory had demonstrated in 1872 that it could be viewed even during an annular eclipse. The eclipse is necessary to block out the normally intense photospheric radiation. Otherwise, the scattered light will reduce the chromospheric lines to near invisibility. A coronagraph, which is a telescope that produces artificial eclipses of the sun, can be used to some advantage to study the higher regions of the chromosphere. But for quantitative researches involving photometric studies of continua, emission line intensities and spectral line profiles, which are essential for an understanding of the chromosphere, a total solar eclipse is best.

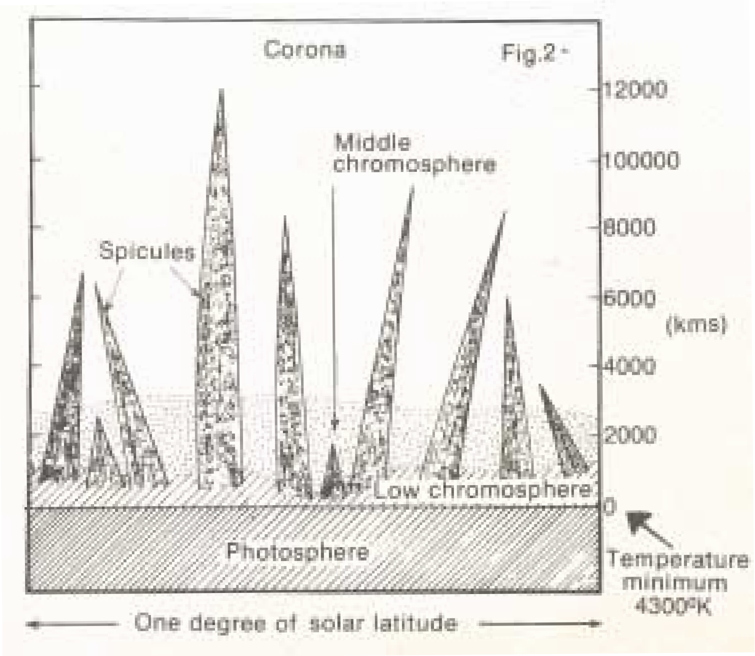
The chromospheric spectrum consists primarily of emission lines of the excited atoms as well as those from which one or more electrons have been stripped. A continuum is present, the characteristics of which depend on wavelength as well as height in the chormosphere. Farther outward from the limb, as one leaves the chromosphere and examines the coronal spectrum, we see a weak emission spectrum of a few lines superposed over a continuous spectrum. Those coronal emission lines are forbidden lines of highly ionised atoms; the brightest line in the green region of the spectrum, first seen in 1869 by Harkness, was identified only in 1942 as being due to the iron atom stripped of 13 of its electrons.

We, therefore, conclude that the solar atmosphere, instead of becoming cooler with increasing distance from the limb, actually experiences a sharp increase in temperature; from a temperature minimum of 4,300° K tentatively located at a height of 200 km beyond the limb, the value increases to 6,000° K in the low chromosphere, 20,000°K in the upper chromosphere at heights of 2,000 km, and a very sharp increase into the million degree domain in the corona thereafter. A temperature profile of these outer layers of the solar atmosphere can be seen in *Figure* 1 with the transition to coronal temperatures confined to a few hundred kilometres.

These phenomena indicate the strong contribution of non-radiative energy sources that are responsible not only for the abnormal excitation, but also for the density gradients indicative of distension. Direct evidence for such forces comes from a scrutiny of the upper chromosphere boundary either during eclipse or otherwise, when one sees numerous jet-like features of short duration known as spicules. These jets penetrate the chromosphere-corona transition boundary and exist in the low coronal regions. Many of them go up to



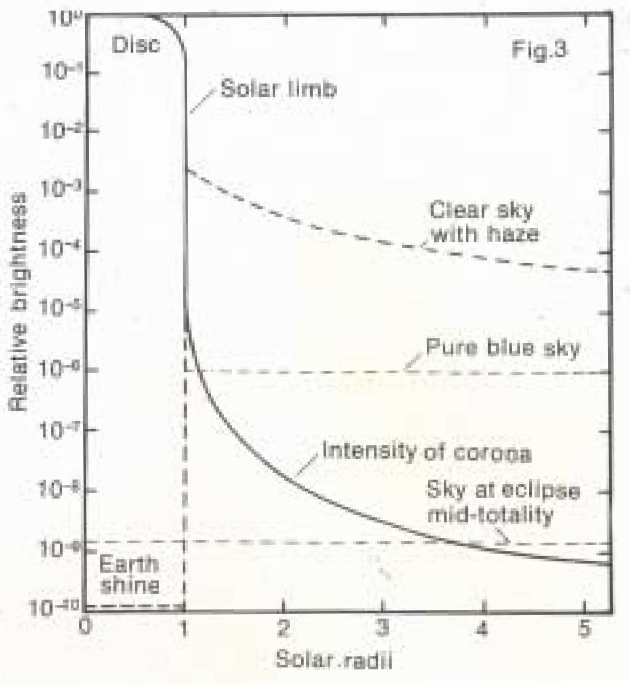
The mean temperature variation with height in the chromosphere and corona.



Schematic diagram of the chromospheric features. Note spicule heights and the relative heights of low and middle chromosphere.

heights of 10,000 km or more with velocities of the order of 20 km per second and lifetimes of five to ten minutes. They are associated with the boundaries of the large-scale convective network where vertical magnetic fields tend to be concentrated. Their temperatures are near 15,000°K. Further study can improve these values.

A schematic diagram of the solar chromosphere can be seen in *Figure* 2. A complex situation prevails in terms of energy balance. Spicules occupy about one percent of the solar surface at any time and the energy flux averaged over the sun is comparable to the energy needs for heating the chromosphere and corona. In addition we have the role of magnetic fields that contribute to both energy balance and structural detail. Energy losses in the corona are principally by inward thermal conduction through the transition region as well as by radiation. The loss by means of the solar wind (a continuous outflow of particles from the sun) is less by a large factor. In the chromosphere, the losses are mostly by radiation. Three sources of dominant radiation loss in the chromosphere are the Lyman alpha in the upper chromosphere; the line emission of singly ionised and neutral elements in the middle chromosphere; and the continuum radiation in the form of emission by negative hydrogen ions in the low chromosphere.



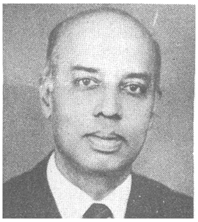
Coronal intensities and sky brightness values.

Eclipses have been the primary source of data for studying the sun's corona. The development of the coronagraph has greatly aided such study with regard to time variant aspects of coronal forms and emission line intensities. In recent years space observation in the extreme ultraviolet have transformed this feature considerably by making it possible to study the corona over the disk. A dramatic new era of observation thus ushered in enables us to discuss x-ray emission over active regions, the presence of coronal holes, and association of these features with limb phenomena seen at eclipses or with the aid of coronagraphs. In combination with high resolution radio astronomical techniques, we have powerful new possibilities of studying coronal physics. In this repertoire, ground-based eclipse observation still forms a valuable means to study the coronal form, its spectrum and structural inhomogeneities.

The relative brightnesses of the solar disc, solar corona and sky brightness can be seen in *Figure* 3. The corona near the limb can be examined with a spectroscope attached to a coronagraph in a "pure blue sky", the kind one can have occasionally at mountain location, higher than 2,500 metres. On rare occasions when the sky brightness near the limb is as low as 10^{-5} or less of the value on the disc, as it can be at altitudes of 3,000 metres or greater, coronal structures can be photographed by an instrumental combination of narrow band filter and coronagraph. On the other hand, when the moon blocks out the photospheric light, the sky brightness near the limb at mid-totality falls to such low levels that coronal intensities, a billionth in brightness of the solar disc, can be photographed out to almost four solar radii. It's no wonder why so many individuals with the instinct for adventure have numerous odds and have travelled far to capitalise on these few moments of totality. Janssen's effort of escaping with his equipment, in a balloon from a besieged Paris, to observe the 22 December, 1870 eclipse has almost the dramatic aspects of an Alexander Dumas tale.

There are many interesting happenings to observe during the few moments around totality. First, a minute before totality, the shadow of the moon sweeps by the observer at 800 m/sec, and the shadow bands appear. The bands can be photographed on an extended white surface (a few linen sheets spread on the ground or on a white wall). These shadows arise because of scintillation effects on the bright bead-like points on the vanishing or reappearing crescent of the sun. Many plants that close up before sunset do so as totality approaches, and open up again for the day as normal brightness is restored. The eclipse evokes a similar response in the animal kingdom. Pigeons go to roost, owls and bats come out of hiding, and cocks may crow. Only the ants seem unperturbed by the event.

This month's total eclipse will provide a fine opportunity for the study of spicule spectra, and profiles of both absorption and emission lines from near the temperature minimum to the upper chromosphere. Freedom from photospheric scattered light will make observation of high spectral and good spatial resolutions a distinct possibility. A slit-spectroscopic rapid scan of the chromospheric layers, determination of the scale height of the atmosphere by the use of limb darkening effects, and white light photography of sun's limb on the slit are other possibilities of leading to new knowledge. The eclipse will also undoubtedly be used to clarify many points regarding coronal rotation, spatial variation of coronal temperatures and the subtle excitation differences associated with coronal form. And today's sophisticated instrumentation is expected to make many of the endeavours a success.



Prof. Bappu, 52, Director of the Indian Institute of Astrophysics, Bangalore, since 1960, is well known for his 'Wilson–Bappu effect' that is extensively used for the determination of stellar distances. He is the first Indian to be elected President of the International Astronomical Union for the term 1979-82. A member of several other international scientific bodies. Prof. Bappu was the recipient of the Shanti Swarup Bhatnagar Prize in 1970.