THE ECLIPSES OF THE SUN *

BY

Dr. M. K. VAINU BAPPU

Director, Indian Institute of Astrophysics, Bangalore

Inaugural Address delivered at the Inaugural Function of the Seminar on 'The Total Solar Eclipse of February 16, 1980' held at the Centre of Advanced Study in Astronomy, Osmania University, Hyderabad on March 15 and 16, 1979.

Prof. Ramreddy, Prof. Abhyankar, Ladies and Gentlemen,

Thank you very much for your kind words Prof. Abhyankar. It gives one a good feeling, almost of home coming, when one visits Hyderabad and particularly the Department of Astronomy and the Nizamiah Observatory. It gives me great pleasure to be here today and to participate in this seminar sponsored by the Department of Astronomy to commemorate the sixtieth Anniversary of the founding of this University. My felicitations to you, Mr. Vice-Chancellor, on this occasion.

The passage of years enables institutions of learning to build up traditions of excellence and achievement. These are modest to begin with, but increase progressively with time. Age, therefore, accumulates these credits and especially so when successive generations of humanity pass through your portals. The credit is all the greater when one realizes that you have spent sixty years as a University with certain novel characteristics in your method of functioning: firstly with a very basic linguistic experiment and, secondly from the point of view of the audience present, with an astronomical bias to your functioning as the first University in India to have an Astronomy Department.

We are gathered here to talk about an astronomical event that we are all going to witness shortly, a total eclipse of the Sun, one of the grandest spectacles that nature can offer from its wide repertoirs. Such eclipses are notorious in having their tracks of totality pass over relatively inaccessible regions of the globe. It is a very rare event when such a track of total eclipse passes over a sizeable metropolis, and it is even more rare when it passes over an established facility for astronomical research. You will, therefore, agree with me that when Nature decides to stage such a grand display over your University's instruments at Rangapur, the heavens have really contributed an event which is a grand finale to your Diamond Jubilee Celebrations.

Eclipses of the Sun take place when the line of sight to the solar centre is intersected by the moon. You have a total eclipse of the sun when the moon completely blocks out the visible disc of the sun. It becomes an annular eclipse when it just falls short of this particular target and exposes a very small annulus around the moon's periphery. On such occasions the sunlight shines through the valleys of the moon causing the well known phenomenon of Baily's beads which were discovered, probably since annular eclipses were known, but were correctly interpreted as due to sunlight shining through the valleys, as long ago as 1836. Of course, when the moon does an improper job of covering up the sun, it is a partial eclipse that we witness, which has limited interest to astrophysical thought. Now, amongst these three varieties, the annular eclipse has some degree of utility. It is useful for planning out certain experiments that tell you about the uppermost layers of the sun, and I know of atleast two individuals in this audience who have had the opportunity of witnessing an annular eclipse of the sun. The total eclipses are more rare. They are really a grand spectacle perhaps, essentially by virtue of the fact that they are rare. In fact, the whole event is over before you realize it has started and all these may be contributory factors to the aspects of importance that we attach to an eclipse. One may go one step further and say that considerable information on solar physics has come about by a study of total eclipses of the sun and were it not for such events perhaps we would not have been as well–off today, as we are, on certain items of information relevant to this important branch of physics and astrophysics.

Eclipses must have been seen right from the beginnings of antiquity when human beings would have witnessed events in Nature that filled them with some degree of awe and terror. But the earliest recorded eclipse goes back to the year 2137 BC as listed in the Canon der Finsternisse by Oppolzer. This eclipse is also of interest to astronomers, partly because of the moral that it seems to provide. Eclipses must have been taken very seriously by the Chinese, specially their emperors, and on this particular occasion an eclipse came along unnoticed and without prior information, in the sense that the Royal Astronomers at the court had failed to predict it ahead of time, as a result of which perhaps they could not take care of the sequence of ceremonies necessary to drive away the supposedly evil spirits. And so when the eclipse came along it was found that the two astronomers were completely drunk and had to be penalised by being slain. I cannot promise that subsequent astronomers have taken a leaf from this story, but certainly, astronomers near the path of totality are not likely to repeat the experience of Hsi and Ho, and atleast it is a consoling fact that the rules of conduct are much more lenient today for handling situations of such lapses. The Chinese had it in their rule book that if the eclipse came before time, the astronomer had to be slain without respite and if the eclipse came a little later than predicted, then of course he had no chance of a reprieve. Fortunately that is all a story that happened four thousand years ago.

The experience of an eclipse, even these days, is very dramatic: something which is very difficult to transmit and essentially is something that one should live through. It is worth travelling any distance, to go through such an experience. An hour before totality there is almost no change in the conditions where a person may be stationed. But as totality draws closer, say about twenty minutes before totality, you begin to notice a sizeable decrease in the intensity of the light. Ten minutes from totality you become more keyed up, everyone in an eclipse camp gets more tense, for one is not sure of how the equipment is going to behave. Sure enough the eclipse would come on at the scheduled instant within a second or so and that uncertainty is because of the uncertainty in our knowledge of the motion of the moon. So one goes along with this decrease in intensity until say about two, three minutes before totality when if one is located on a hilly terrain or if there are clouds near the western horizon you begin to notice the shadow approaching you. The shadow moves in at a speed of about 800 meters per second. So if you have the presence of mind to look out in the west, say about a minute before totality, you see it sweeping fast and coming towards you. A minute before totality you see another phenomenon, if the atmosphere is unsteady that day. You see what are known as shadow bands. These are equivalent to the scintillation effects that you notice because by that time the moon would have covered most of the sun and the last rays coming from the bright visible disc would be shining through the valleys and therefore would be as individual bright points equivalent to the stellar case. Each such source produces a scintillation pattern, with the result that if you are fortunate enough to see shadow bands, you find a kind of rippling motion on the ground coming towards you. The feeling, I had watching shadow bands at the 1970 eclipse was that, momentarily I was in a sort of snake pit with reptiles crawling all over me. It is then only that I realized that I was seeing shadow bands and because I was located out in the open and one of my tasks was to announce the commencement of totality, I was able to alert the other observer in the team, so that he could also take a look and see this interesting phenomenon. So then, we have reached one minute before totality, and we have seen the shadow bands and now you distinctly see the shadow pass in and come sweeping right over you. When that happens, if you are looking at the remaining crescent of the sun through a pair of binoculars or even through a monocular with a transmission grating ahead of it, you see the flash spectrum. The chromosphere blazes out in full glory and this is an indication that totality has commenced.

Now this is a task usually assigned to one person in an eclipse camp who counts down the seconds to totality. Probably this was the only occasion when people had a count down before the satellite era, for such count downs are quite common nowadays. When our eclipse observer declares 'flash', experiments on the chromosphere would already have been well underway by then. Experiments relating to the corona would probably be delayed by another five or ten seconds, so that chromospheric effects would be minimized and then the cameras would be working in full action. The duration of totality could be anywhere from thirty seconds to seven minutes depending upon the eclipse, depending upon your location within the track, depending on whether you are on the central line of totality or towards the edge, and before you realize what has happened the entire sequence of events is repeated in reverse. The flash spectrum appears at third contact followed by the shadow bands and then the transition to normal brightness is very rapid. Particularly you feel it more rapid, because you have just come out of darkness. Darkness during the totality depends very much upon sky conditions and also varies from event to event. If you are fortunate enough to witness totality through a hole in the clouds, then it is likely that it would be quite dark. If on the other hand you are witnessing an eclipse of the sun with an absolutely clear sky the sky is bright enough for you to read the time on your wrist watch, but may not be bright enough to do several other operations.

Several interesting things happen in Nature during these few moments of totality and a few minutes before and after totality. If you look at the plant and animal kingdom, many plants that close up for the night, close up during the phases of total eclipse. The crocus, the anemone, and wattle leaves that close up for the evening, behave as they would at nightfall. Violets which give out their very agreeable smell only in darkness and which were probably unnoticed before totality, give out an agreeable perfume. The animal kingdom responds in much the same fashion. Birds get confused. The owls and bats come out. Pigeons go to roost and as soon as total phase is over they come out again. The fowls sit down where they are. A cock may even crow, soon after totality. Ants however, continue their work unperturbed by what has happened. The famous French physicist, Arago, at the eclipse of 1842 carried out an experiment on his dog. He did not give it food for twenty four hours and started giving it pieces of bread at different phases of the eclipse. While the animal greedily grabbed at the pieces of bread well before totality, during totality it refused to eat. And this is much the same I suppose, if one looks at homosapiens. If the ants were to write a parable on homosapians, I suppose they would point out that the entire clan would be very keen to huddle expectant mothers into darkened rooms, throw out all their old food and as soon as the event is over, make a beeline for the nearest river or tank or whatever be the source of water and have a bath to eliminate the supposedly evil effects of the astronomical event that they have recently witnessed.

This is more or less the general situation that prevails during a total eclipse. In fact, it is inspiring: it is partly awesome. It is a grand spectacle, because when you cut off the entire photospheric radiation of the sun, you see the corona in all its splendour, a corona which changes its structure from epoch to epoch depending upon the solar cycle. There may be red prominences standing out: the chromosphere can be seen as a sort of a ruddy ring around the edge of the sun. I suppose by and large, the awesome aspect of it must be essentially dictated by the fact that the event is rare; that it lasts for a very short time and that before you realise what has happened, it is relegated into history. So much so, that there are recorded instances, when nations known to continuously battle over simple problems of boundary disputes, when unexpectedly confronted by a total solar eclipse have decided to compromise and draw up a peace treaty and to ensure that the peace treaty is continued for ever, they cement it by a double marriage that minimises the risk of a fresh recurrence of battle. This has happened in the past and probably is not one of those repititions that is likely to occur in the future.

Now let us examine the state of solar physics before we consciously took advantage of a series of eclipses, specially after the mid-nineteenth century. Well, spectrum analysis did not exist until 1859, when Kirchoff and Bunsen came out with their celebrated laws of spectrum analysis. Many of the big minds in Europe had skirted very close to these ideas but had missed the fundamental point involved in it until Kirchoff came through with his ideas. The eclipse of 1842 was visible in southern Europe and therefore several individuals, physicists and astronomers had obviously taken advantage of witnessing this phenomenon. There were several prominences on the edge of the sun and these were correctly interpreted as gaseous clouds floating around in the solar atmosphere. But they were not sure about the corona. Some were of the opinion that perhaps it was a kind of lunar atmosphere. But by then. there were very few adherents of such a hypothesis. Some were of the opinion that it was some complicated diffraction phenomenon in the earth's atmosphere. Soon thereafter, in 1851 there was another eclipse in Europe and this time the photographic technique was used for the first time and showed the advantages of capturing the fleeting phenomenon for ever, by taking a time exposure during the total eclipse phase. Besides this, they had talked about the chromosphere as a red burning sierra. The prominences of course were correctly identified, and of course, the corona, looked a little different from what eclipse goers nine years previously had seen. So it became all the more important to look at total eclipse because those were the few occasions when one could see the prominences, one could see the corona of course, and one could speculate on phenomena in the solar atmosphere. Then came the laws of spectrum analysis and the stage was set for observation of a series of eclipses, which starting in 1868 until 1919 have revolutionised our knowledge of the subject. Many of these eclipses were observed on Indian soil, and many of these striking discoveries that originated from these observations, were made at locales five hundred to six hundred miles from Hyderabad. Take the case of the eclipse of 1868. It was in the month of August when skies in India are usually cloudy except for the region around the east-coast. There were many teams of observers from England, from France, from Germany and of course from the Madras Observatory which was represented by Pogson at Masulipatnam and by the first assistant Raghunathachari at a place called Wanaparti, not very far from Hyderabad. The expedition from the Madras Observatory and another from England were located at Masulipatam. The one under Jansen of the Meudon Observatory was located at Guntur. The Englishmen were also close by. Fortunately eclipse day dawned with a clear sky. One of the main tasks that the observers had was to find out the constitution of the prominences. Were the prominences going to give out a spectrum which was continuous in nature or was it going to be an emission spectrum or an absorption line spectrum? You can visualize yourself these several teams with small telescopes, with high dispersion visual spectroscopes attached to the end; you can imagine the feverish state of tension that must have prevailed in the few moments before totality, because one did not know where one could see these prominences. Then totality comes along, the prominences are located and then the telescope moved around so that the slit bisects the prominence, and lo and behold, all five teams that were fortunate enough to have good weather, discovered that the prominence spectrum was essentially one of emission lines, that most of these emission lines coincided in position where hydrogen lines are known to exist in absorption. All the teams that were favoured with this good luck also discovered the presence of a bright yellow line somewhere where the normal sodium lines are commonly seen. Of these several individuals one, in particular, Jansen, used his wits immediately following the eclipse; he concluded that the prominence spectrum was so bright that he should be able to see it even without an eclipse. But by then the clouds had come in and the sky was cloudy for the rest of the day. The next morning Jansen pointed his spectroscope to the limb of the sun. and sure enough, he was able to trace out prominences where he had seen them the previous day. These were glowing in the light of the red line of hydrogen-alpha and the green line of hydrogen-beta. He was also able to immediately note that the yellow line did not coincide with the familiar position of the D-lines of sodium, but instead it was shifted more towards the violet. He did not realise the significance of this at the time, but then a few months later it was obvious that this was due to some unknown element on the surface of the sun. Since this was first seen on the sun it was named after Helios, the sun and that is how Helium came to be discovered.

This set of observations carried out at Guntur really opened up the wide vistas in solar physics, because one could then examine at will on any day several aspects of solar behavionr, except for the case of the corona. One could examine all these different aspects without waiting for a total eclipse of the sun. And, therefore, in a sense, one can say that solar physics was born on the 17th of August 1868, in the tobacco fields of Guntur.

The year 1869 had another total eclipse of the sun, this time on the North American continent, and an individual by the name of Harkness discovered the green coronal line which at that time, or for quite sometime after, was identified with an iron line normally noted in the photospheric spectrum of the sun. It was only much later, when a higher dispersion was used, that one came to realize the nature of its true origin, that it was due to something else, which was unknown on the surface of the earth. Following the example of the helium, it was called coronium and it was only in 1942 that we realized that the green line originated from a forbidden transition in the iron atom that has lost thirteen of its outer electrons. In 1870 there was another total eclipse, this time in southern Spain and the northern coast of Africa and this figures very prominently because it was at this eclipse that Young discovered the flash spectrum. He observed that during those five or six seconds before totality, there was this bright flash when emission lines were seen in the spectrum almost exactly where the absorption lines were and therefore this eclipse goes down in history as the first occasion when the flash spectrum was discovered. In 1871 the stage is again set in India. This time the path of totality passed over Ootacamund, southern Tamilnadu and the northern portion of Ceylon, and Jansen who had made his discoveries in 1868 was present at the little village of Sholur which is about twenty miles west of Ootacamund. To this place he had brought along a sixteen-inch aperture telescope, which gave him considerable light gathering power, and it was at this eclipse that he discovered what we now know as the Fraunhofer corona. The next eclipse in India was in 1898 when the path of totality intersected west of India, south of Ratnagiri in Bombay presidency and went up through Vindhyapradesh into southern China. On this occasion there were several teams all over the track. The Kodaikanal Observatory, which was just then formed, had its team located near Rewa. Norman Lockyer was present at Ratnagiri. Negamwala from Poona was at Jeur in Maharashtra close to Dhond. The Americans from Lick Observatory were also closeby. The most significant results of this particular eclipse were achieved by a bright young amateur, John Evershed, who has his name carved in the annals of Solar Physics history. A decade later he became Director of the Kodaikanal Observatory. Evershed brought along with him an ultra-violet spectrograph with quartz optics that allowed him to obtain the flash spectrum and the coronal spectrum down to about 3000A. As a result of this attempt, he was able to show for the first time that the continuous emission in the spectrum of prominences were caused by the Balmer continuum of hydrogen. He was also able to detect a new strong coronal line at 3388A which we now know as due to a forbidden transition of iron.

These have been some of the major disooveries in solar physics at eclipses in the 19th century. The next major discovery is one of considerable interest to physics. The eclipse of 1919, when Einstein's predicted gravitational light deflection near the limb of the sun was observed at Principe on the west coast of Africa and at Sobral in Brazil. The Einstein value of 1.75 seconds of arc was obtained, and was sufficient to indicate that here was a concept that came through with the fullness of vigour in its entire validity. Subsequent observations of the Einstein deflection have never been as convincingly accurate as this first one was, and to some extent, I think it was a fortuitous coincidence of circumstances that permitted it to be so. One camera gave values of $1.69 \pm 0.2''$, seconds of arc. Another camera gave results of $1.98 \pm 0.2''$. The third one came to the Newtonian value about $0.9 \pm 0.1''$. This indicates the significance that one can attach to the error determination. The consistency of the internal error is not something that one should take at face value and it is essentially this aspect that has been a severe problem for measurement of the Einstein shift in subsequent years.

Let us look a little bit at the human element in this aspect of eclipse observation. I suppose in someways those who have a few eclipses to their credit, one eclipse or more, would say that this is an occasion when you really separate the men from the boys. This is to some extent partially true, even if it is an acceptance of human ego. It is true, because you repeat experiments calling for considerable accuracy under field conditions which are far from ideal, conditions wherein you have thermal problems by solar radiation, you have human problems, logistic problems, all kinds of difficulties. In 1898 certain locations had to be changed in the last minute because of the bubonic plague. So you see, there is a considerable amount of hazard, risk and uncertainty, associated with eclipse experiments, and one should be able to face some of these crises. Equipment may cease to function at the crucial moment and it takes everything on the part of the experimenter to keep cool and set it right quickly. There is no guarantee that, even if you have gone through several of these experiences, you are likely to make no mistakes at future eclipse. I know of one individual who at his fourteenth eclipse, of which nearly eleven were successful, forgot to take out the neutral filter during the critical phase of totality and therefore, hardly got a spectrum of the corona, because it was well absorbed by a neutral filter of density five.

On the other hand there are several other individuals who have many of these problems even before they stir out from home. Some have started on these expeditions after having forgotten to take the main lens of the camera. Some have been so awestruck watching the corona that they have forgotten the next item of the sequence of operations planned for them. At the 1970 eclipse a neighbouring camp had its own diesel generators for electricity because they were located out in the wilderness, and in this camp five to ten minutes before totality, the generator decided to call it a day. It took the best of everyone participating on the occasion to cajole it back into activity. It was more so embarrassing because the President of the country was seated in the same camp watching his boys go through an experience of a total eclipse of the sun. At the same eclipse, much later during totality, one of the several chains of the students who had to pass on the appropriate plate holder at the appropriate time, forgot to do so, and he had to be prodded by the next man in the chain in order to set the cycle going. These are happenings that occur at an eclipse and add to the overall excitement of the experience, one lives through. Then there is the uncertainty about the weather. There are some individuals who have been extremely lucky. Sir Frank Dyson, the Astronomer Royal, went to seven eclipses and had seven clear occasions of totality. I have a friend of mine, who shall remain nameless, who went to seven eclipses and could see a total eclipse only on the last occasion. There are two of us in the room who were very fortunate in 1963, when the first phase of the eclipse was completely lost in a tremendous downpour that ceased just about twenty minutes before totality came through. We knew the eclipse was proceeding on schedule because we could see the darkness prevail in the vicinity. But then just about two minutes before totality, a hole in the clouds appeared in the direction of the eclipsed sun, of the extent of about 3 to 4 degrees. And thus we saw the entire total phase which lasted 58 seconds and then, bang in the next minute, the clouds covered it. You con imagine how fortunate we were, because those located barely twenty or thirty miles away from our site had only cloudy skies to talk of. Well these are some of the things that one should be prepared for, at the time of the total eclipse of the sun.

What are the important aspects that one should look for at future eclipses? We have been odserving eclipses for well over a century, but even so have had a total amount of only about 30 minutes of observing time during this one century of the total phase. We have built instruments that can simulate a total eclipse of the sun, the coronograph, that tell us many things but never is a complete substitute for a genuine total eclipse with the moon doing the blocking way out beyond the earth's atmosphere. And so there are still several problems which need to be tackled, which can be tackled only at a total eclipse of the sun, even in these days when skylabs and other facilities exist for observing the manifestation of the corona over the disc of the sun or the limb of the sun. But then these aspects of the corona are seen in permitted lines of highly ionised atoms like Iron or Magnesium or whatever it is and it takes a prodigious effort on the part of individuals to have facilities of this kind available at beck and call and so one really still depends upon eclipses to provide much of the information, because a greater number of individuals, with carefully chosen experiments, can certainly accomplish a considerable amount in the limited time. And this is where one has to be careful in the choice of experiment. There are certain experiments which must be done to give us the synoptic feeling of what the corona looked like on that particular day. I suppose almost every expedition would take a white light picture of the corona, study the polarization of the corona, obtain a typical spectrum of the corona and study the distribution of the emission corona. All these are standard experiments Perhaps the non-standard ones are rather difficult to visualize and perhaps I should not anticipate the flow of ideas that we will experience later this afternoon, that will cover this particular sphere. But I think everything points out to the fact that this eclipse, like previous eclipses in the past, will have large numbers of professional and amateur astronomers widely distributed over the entire track, so that the uncertainties of clouds and weather are minimised and that much will be accomplished in the form of adding to our information on the behaviour of this aspect of the solar atmosphere.

There is one other aspect that I would like to cover. So far I have talked of essentially the activities of the professional and of the serious amateur who is keen to obtain results that pertain to the solar atmosphere. I now think of the man who enjoys some of the nice sights of Nature, one who has got the aesthetic sense of feeling of appreciation of beauty, who enjoys a good sunset, who finds a feeling of delight at hearing the roaring waters of a water-fall or of a gurgling stream as it passes by, who delights in a good rainbow or takes a fancy for seeing the well-spun cobweb of a spider on a dewy morning; in short an individual who is alert to his environment and who enjoys different aspects of it. I think there is much for him in witnessing one of these rare sights of the total eclipse of the sun. I hope that he would just travel down not very far, just even twenty miles south of Hyderabad and take with him, probably a minimum of equipment, just his own eyes, and go through this delectable feast that is really only a feast of the Gods. I hope Mr. Vice-Chancellor you will be one of those who will not miss this opportunity, next February.

And so, I come to the end of what I had to tell you about eclipses of the sun in general and of some of the problems associated with eclipsiana and of its achievements in the past. The seminar that you are going to have later today will tell you very many more different aspects of problems that we are going to grapple within the coming year and in the coming years. I wish your deliberations considerable success because it would not only be an indication of a successful seminar but it would also lay the foundations for a successful spell of experimentation next February, in southern Andhra Pradesh or northern Karnataka, and I hope that you will all enjoy this occasion when Nature comes forth in all its blazing glory.