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Highlights of observations of Total Solar Eclipse of October 24, 1995

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1. Introduction

The sky conditions during this eclipse along the whole of the totality path in India (Figure 1) were excellent. Hence most of the experiments (about 90 percent) conducted by Indian scientists, Foreign scientists, students and amateur astronomers were successful. Also, large number of people were made to understand about the happening of this rare celestial event of total solar eclipse.

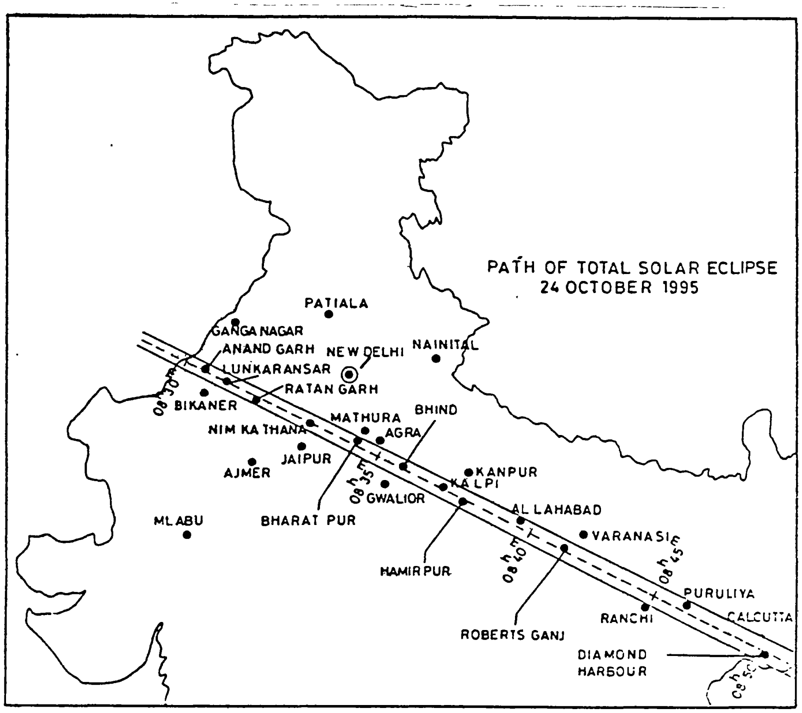

Figure 1. Path of totality in India during the total solar eclipse of Oct. 24, 1995.

Here we discuss the experiments and their scientific objectives conducted by Indian and foreign teams in India. The data collected from large number of experiments will help in finding answers to some of the open questions such as temperature structure, turbulence, large scale systematic mass motions, location of temperature maximum and high frequency oscillations in the solar corona. A definite answer to the above mentioned parameters will help in understanding the heating mechanism, the factors that contribute to the solar wind flow, and in building realistic models of coronal structures. Further, the study of solar corona at different phases of the solar cycle is required since the corona changes in shape, size and activity with the solar activity. We will also look at the preliminary results obtained from these experiments.

2. Experiments

To find answer to the above mentioned open questions, the following experiments were conducted during this eclipse :

A. Experiments by Indian Institute of Astrophysics, Bangalore

I. High resolution multi-slit spectroscopy of solar corona in two lines :

On an examination of the list of coronal emission lines in the visible part of the spectrum, one finds that the two lines 5303 Å (Fe XIV) and 6374 Å (Fe X) are best suited for these observations. The ionization temperature for Fe X ion is about 1.0×10^6 K and about 2.0×10^6 K for Fe XIV ion.

The experiment set-up consisted of two mirror 8 inch coelostat shown in figure 2, and f/10 objective of 10-cm aperture to form the solar image of 9.1 mm diameter on the multislit of the spectrograph. The field lens behind the multislit focused the objective onto the spectrograph lens. The Littrow spectrograph with f/10 lens of 14-cm aperture and a 600 lines per mm grating provided a dispersion of 4.7 A/mm in the 2nd order red. Thus 2nd order 5303 Å and coronal line at 6374 Å were separated by 228 mm. The 80 micron wide slit provided us a resolution of 11 arc secs. The spectrograph is capable of giving us a spectral resolution of 30 mA but the image tube resolution and emulsion grain of 15 micron restricts the resolution to 70 mA which corresponds to a velocity of 4 kms^{-1}. 25 mm diameter of the image intensifier allowed us to obtain the coronal spectra upto 2 solar radii from the center of the sun. The spectrum was recorded on kodak 2415 emulsion. These spectra have been scanned with PDS machine of the institute to get the line profiles of emission lines using standard photometric technique. These line profiles will be used to derive "turbulence" and in the modelling of the solar corona.

II. Narrow band photometry in emission lines :

To investigate the spatial variation of temperature and density within coronal structures, narrowband photometry in a number of coronal emission lines representing various temperatures was done.

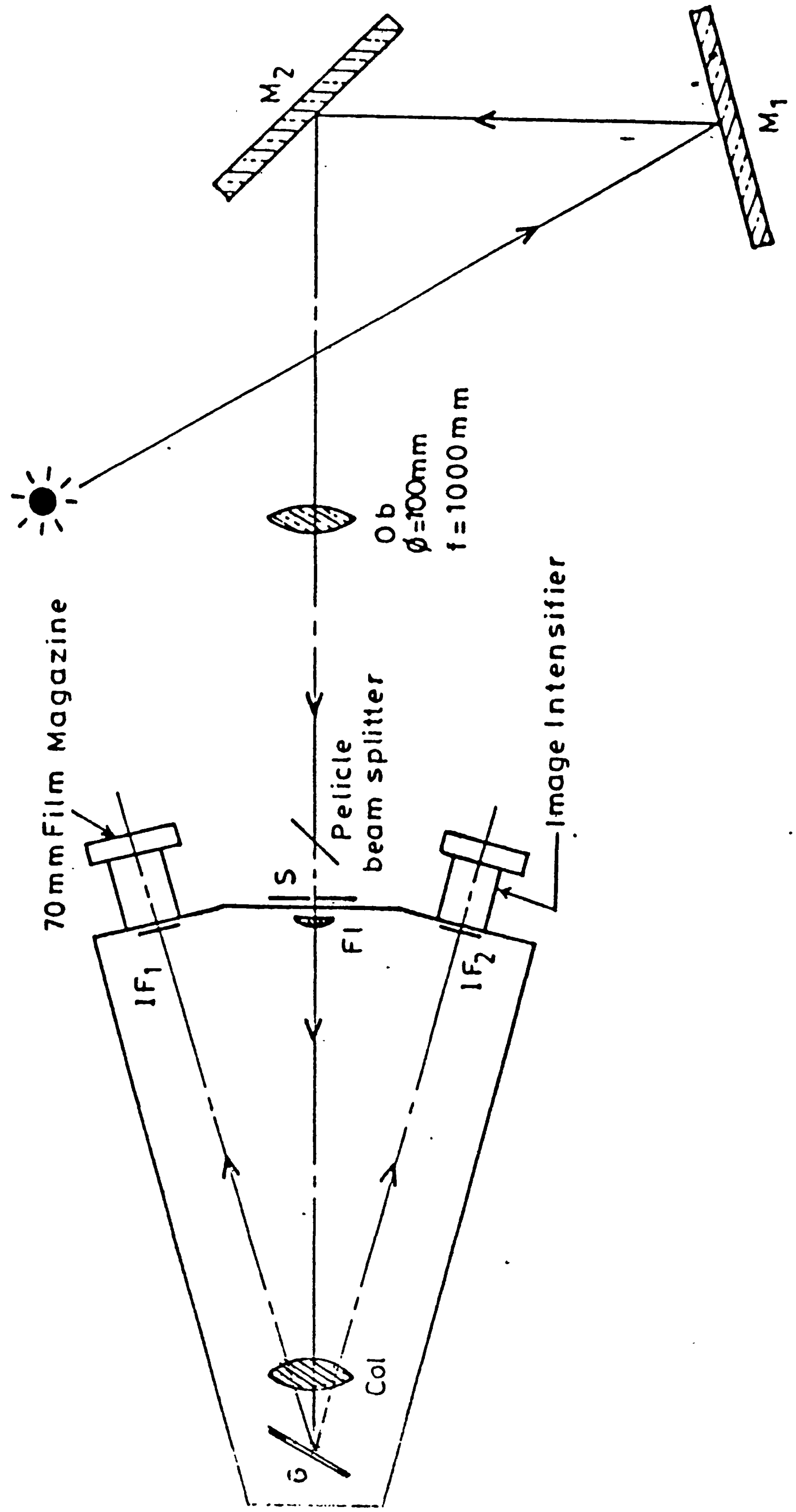

Figure 2. Optical layout of the multislit experiment. M_1 and M_2 are the flat mirrors of 8-inch coelostat system. Ob is f/10 objective of 1000 mm focal length. S = 5 slits with separation of 5 mm; F_1 = Filed lens; Col = f/10 collimator of 1400 mm focus; G = Grating with 600 lines per mm; IF_1 and F_2 are interference filters of 5 Å pass and centered around 5303 Å respectively.

The coronal emission lines which had been selected for narrow band photometry are : 6374 Å (Fe X), 7892 Å (Fe XI), and 5303 Å (Fe XIV). The coronal ions corresponding to these lines are dominant emitters at temperatures of 1.0 x 10^6 K, 1.20 x 10^6 K and 2.0 x 10^6 K, respectively. Since the emission lines considered cover a temperature range, the various line-intensity ratios would enable us to determine temperature, electron densities and relative abundances of elements within the coronal sturctures. Estimates of electron densities and temperatures are essential for understanding the energy balance of the coronal plasma.

A two mirror coelostat was used to direct the coronal light to an objective of 3 inch aperture and 16 inch focal length. Narrow band filters of central pass band 6374 Å, 7892 Å, 5303 Å and each of 5 A band width were kept near the front of objective on a rotating wheel. The coronal pictures were recorded using peltier cooled CCD. Filters of 5 A band pass are sufficient to isolate the coronal emission due to the lines from the backgroud corona.

III. Interference fringes in green coronal lines using Fabry-Perot etalon :

The multislit experiment provides information only at selected locations in the solar corona but yields data in two lines simultaneously emitted from the chosen locations. To obtain bi-dimensional information about temperature and velocity structure in a single line Fabry-Perot experiment in Fe XIV (5303 A), a strong emission in the visible spectrum, was performed.

An eight inch coelostat mirror driven by electronically stepper motor, collects the light from the sun and feeds the fixed telescope objective of 100 mm aperture and 1000mm focus which makes 9.1 mm size image of the sun. A collimator of 102 mm focus makes the beam parallel which passes through an interference filter of 5 A band width cenetered around 5303 Å and a Fabry-Perot etalon of 4 Å free spectral range (see Figure 3). The etalon has a di-electric coating to yield 92 percent reflectivity in green to provide sharp fringes and high spectral resolution. The etalon is kept at a plane where the collimator focuses the objective lens of the telescope. Then the camera lens of 135 mm focal length provides the solar image of 12 mm diameter. Finally the liquid nitrogen cooled CCD camera of 1024 x 1024 format recorded intereference fringes in the corona. The pixel size of 24 x 24 micron provided a spatial resolution 8 x 8 arcsec^2. An assembly of mercury lamp operating at 600 volt, flat mirror and ground glass plate was inserted in the experimental set to take the calibrated fringes in 5461 Å.

The optical layouts for other experiments are similar with variations in the specifications of the optical components and detectors.

IV. Narrow band of solar corona in H-alpha line :

An eight inch coelostat mirror driven by a stepper motor feeds the sun-light to second mirror which makes the light beam horizontal. The fixed telescope objective of 150 mm aperture and 2250 mm focal length forms the solar image of about 20 mm diameter. 0.75 Å pass band Daystar filter centred around H-alpha line kept before the image plane isolates the red light due to hydrogen. Then the image is recorded using 1024 x 1024 Photometrics liquid cooled CCD camera. The pixel size of 24 x 24 microns provided a spatial resolution of 4 x 4 arcsec^2. The CCD camera mounted on the eastern edge of the solar image recorded the part of the solar corona.

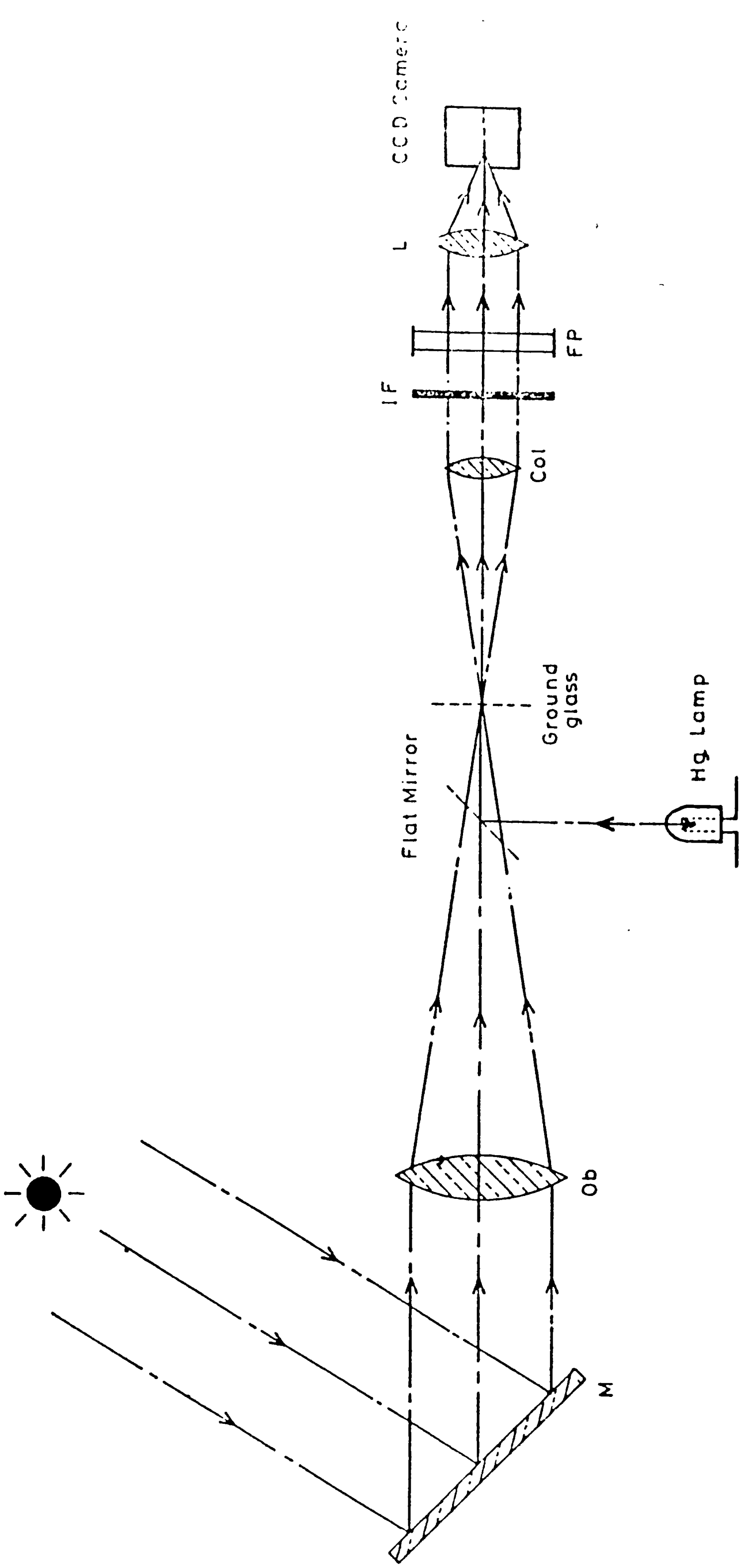

Figure 3. Optical layout of the Fabry-Perot experiment. M = 8 inch flat of the coelostat; Ob = f/10 objective of 1000 focus; col = collimator of 102 mm focus; IF = interference filter of 5 Å pass band centered around 5303 Å; FP = Fabry-perot etalon with free spectral range of 4A; L = camera lens of 135 mm focus.

The existence of H-alpha in emission in the higher atmosphere of the sun was first discovered by Bappu and Bhattacharya at the Mexico eclipse in 1970. This indicated the presence of cooler pockets of gases in the hot ambient plasma of solar corona. The data will be used to verify the above finding and detect if there exists small knots of coller material in the hot corona at million degrees.

V. Broad band photometry of solar corona with high spatial resolution :

A 12-inch coelostat fed the sunlight to a fixed telescope of 6 inch aperture and 90 inch focus. A red filter kept in front of the objective and kodak 2415 film permitted the coronal light in the wavelength range of 6000-7000 Å to be recorded on the film. An electrically controlled film magazine containing 70 mm film was used to obtain a sequence of pictures of the solar corona with exposure times ranging between fraction of a second to 20 seconds. The short exposure gives detailed information about prominences and inner corona whereas longer exposure provides about outer coronal structures extending upto 2 solar radii.

VI. High frequency aperture photometry at a location in the solar corona :

A fixed telescope f/10 objective of 10 cms aperture formed an image of the sun of 9.1 mm diameter. A circular aperture of 0.5 mm size isolated the coronal light at 1.25 solar radii. This light falls on a photomultiplier tube. The fast photon counting system controlled by a PC sampled the coronal intensity at the rate of 20 Hz. The system provided the data with a photometric accuracy of 0.02 percent. The power spectral analysis of the data shows the existence of periodic intensity oscillations in the corona.

VII. Ultra low spatial resolution photometry in deep red to detect dust ring :

A telephoto objective of 210 mm focus collected the sun light through a coelostat and formed an image of 3.8 mm diameter. A deep red filter with pass band from 9000 A onwards was kept near the focal plane. The liquid nitrogen cooled CCD camera having 1024 x 1024 chip with pixel size of 24 micron enabled us to record the coronal images upto 10 solar radii. The high dynamic range and low dark noise data are being analysed to detect the dust ring around the sun, if any. A dust ring at 4 solar radii has been predicted and there are conflicting views about its existence.

VIII. Polarization measurements in solar corona :

A 75-mm refracting telescope of 800 mm focus from Zeiss with a drive unit to follow the sun was used to image the sun. An OG 1 filter and a polaroid assembly was mounted in front of the objective. The polaroid was rotated in predetermined steps of 30 degree each. The coronal images were recorded on 35 mmmm Kodak 2415 film using an SLR Camera.

IX. High temporal resolution photmetry of solar corona :

A 500 cms focus Schmidt telescope collected the light from stepper motor driven coelostat. An EEV peltier cooled CCD camera was mounted onto the telescope at the focus. Time sequence of coronal photographs was obtained with time interval of 40 milliseconds. The data is being analysed to study periodic intensity variations in the solar corona.

X. Solar corona in radio emission :

Mapping of solar radio emission at 3.8 and 4.2 GHz was done using the lunar occultation technique during the eclipse. The data is being analysed to study the oscillations in the solar corona.

XI. Photography of solar corona using Indian Air Force aeroplane :

The teams of the Indian Air Force participated actively in the programme. They made several supersonic flights to follow the shadow zone of the moon on earth along the path of totality, thereby extending the duration of totality. Another aircraft AN-32 was dedicated to acquire airborne imaages of the sun through filters attached to photographic cameras. These experiments were planned with the help of NCSTC and Vigyan Praasar.

XII. Photograph of solar corona by Students and Amateur Astronomers

A coordinated effort was made to obtain the time sequence of coronal photographs from 30 different locations in the path of totality extending from Rajasthan to West Bengal using similar telescopes and same kind of film. The data will help to study the gross dynamics of coronal structures over a period of about 15 minutes.

B. Foreign Teams

(1) NASA, US Team : Prof. Paul D. Maley (12 members)
Location : Near Agra, Uttar Pradesh.
Experiment to measure the solar diameter and study long term variations in solar diameter was conducted.

(2) Hopkins Observatory, US Team : Prof. Jay M. Pasachoff (14 members)
Location : Mukundgarh Fort, Rajasthan.

The prime experiment is a study of the method by which the corona is heated to 2,000,000 K through a search for rapid (1 second) oscillations in the coronal green spectral line at 5303 Å, using a princeton Instruments CCD detector controlled with a Macintosh Quadra computer.

A scond experimment cosntructed a map of the coronal temperature by making observations of the corona through a set of ultraviolet and polarising filters chosen to maximize the effect of the broadening of the ultraviolet coronal spectrum when underlying sunlight bounces off rapidly moving coronal electrons. The data was recorded using a Photometrics PM 512 CCD provided to the Keck Northeast Astronomy Consortium.

(3) Russian Team - 1 : Prof. V.I. Makarov (2 members)
Location : Neem ka Thana
Photometry and polarization of solar corona was done.

(4) Russian Team - 2 : Prof. I.S. Kim (2 members)
Location : Neem ka Thana
Interference fringes were obtained using a Fabry-Perot etalon to determine the temperature and velocity structure in the solar corona.

(5) Brazilian Team : Dr. Matsura Oscar (4 members)
Narrow band photometry and polarization measurements were made.

(6) Japanese Team - 1 : Prof. Hiei (38 members)
Location : Dundload castle
Polarisation, emission line photometry, continuum photometry of soalr corona using CCD cameras and longer focal length telescopes were done.

(7) Japanese Team - 2 : Prof. M. Ueno (6 members)
Location : Neem ka Thana
Infrared observations and spectroscopy of solar corona was done.

(8) German Team : Dr. Daniel Fischer, In-charge, Bonn Eclipse Task Force (6 members)
Location : Neem ka Thana
Photography of the solar corona was done.

3. Preliminary Results

Analysis of the data has indicated that the solar corona oscillated with time periods of about 5, 6, 8, 13, 19 and 56 seconds as seen in Figure 4 and listed in Table 1. This kind of oscillations could not be detected earlier due to small amplitude of these variations. The use of highly sensitive photometer made it possible to detect these oscillations. The data obtained in radio wavelength does not show oscillations in the solar corona.

The data also indicated that the emission corona was very weak at the time of eclipse. This may be due to the minimum phase of the solar cycle. The preliminary look at the photographs taken from An-32 aircraft indicates that one can observe the solar corona for larger distances from the sun by aeroplane in comparison with observations from the ground levels using simmilar telescopes with same f-ratios.

The data obtained from other experiments is being analysed and will help understand the differences in closed magnetic field and open field regions.

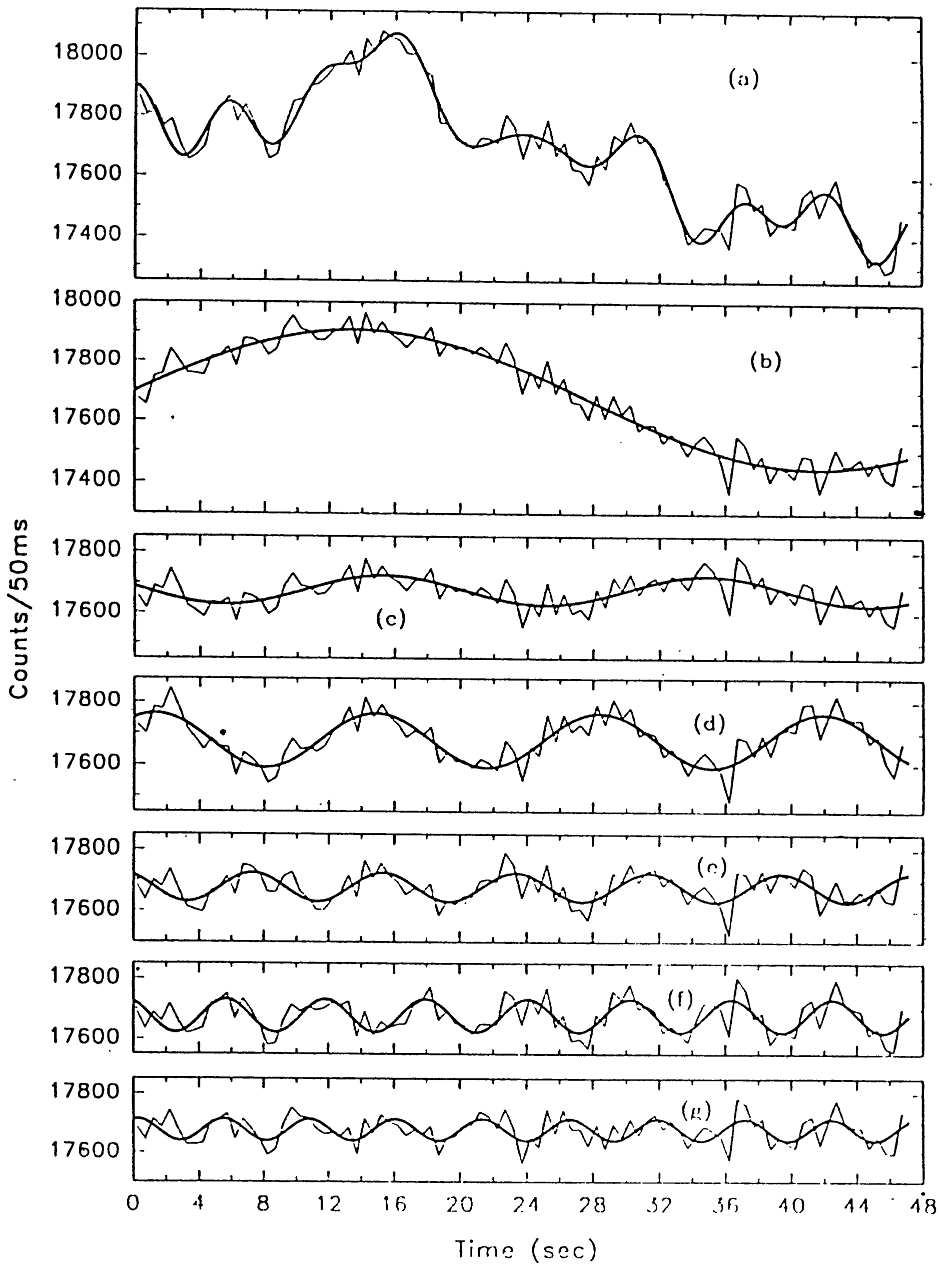

Figure 4a. Thin line shows the plot of observations after re-binning over 0.5 sec and the thick line, the computed curve, using the 6 frequency components listed in Table 1.

4b. Thick line shows the contribution of the 56.5 sec component computed using its parameters given in Table 1 and the thin line, the residuals obtained after removing the contributions from all the other components. The residuals are re-binned over 0.5 sec before plotting.

4c. g same as 4b, but for the 19.5, 13.5, 8.0, 6.1 and 5.3 sec components, respectively. The time plotted along the x-axis is reckoned from 3:06:31.2 UT.

Table 1. Periodicities identified in the data.

Mean of input data = 17677 ± 5 counts / 50cms

No.	Frequency (Hz)	Period (sec)	Amplitude (Counts / 50cms)	Amplitude % coronal brightness	Time of Maximum (sec)
1	0.0177 ± 0.0004	56.48 ± 1.44	232 ± 4	1.31 ± 0.02	13.4 ± 1.4
2	0.0512 ± 0.0017	19.52 ± 0.66	48 ± 4	0.27 ± 0.02	15.3 ± 0.6
3	0.0738 ± 0.0009	13.54 ± 0.17	85 ± 4	0.48 ± 0.02	14.8 ± 0.2
4	0.1246 ± 0.0012	8.02 ± 0.08	47 ± 4	0.26 ± 0.02	7.2 ± 0.1
5	0.1629 ± 0.0013	6.14 ± 0.05	54 ± 4	0.30 ± 0.02	5.7 ± 0.1
6	0.1896 ± 0.0020	5.27 ± 0.06	36 ± 4	0.20 ± 0.02	5.5 ± 0.1

Acknowledgements

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