SOLAR PHYSICS AT KODAIKANAL

(Report from Solar Institute)

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(Received 28 September, 1966)

1. Introduction

A little over sixty-five years ago, regular observations of the sun were started at the newly established Kodaikanal Observatory (lat. 10° 14′ N; long. 77° 5′ E). Located on the Palni hills at an elevation of 2343 metres above mean sea level, it has been one of the earliest of the several mountain observatories that have come into operation during the present century. A successor of the Madras Observatory, which contributed effectively to astronomy of position for over a century since 1792, the Kodaikanal Observatory was erected to enable those classes of observations to be made which came under the terms of "Astronomical physics" and "Solar physics". Its location near the southern tip of India, on a hilly range, was prompted by the belief that the climate and atmospheric conditions are specially favourable for research in solar physics, and six decades of almost daily observations have well justified this belief.

2. Observing conditions

Kodaikanal experiences the effects of both the monsoons. We have a wet season from July through November and a dry season from mid-December to May. Very often there is a gap in September of about three weeks' duration, when the general direction of monsoon winds changes from southwest to northeast. This brief spell of clear September weather is characterised by good coronagraphic skies near mid-day, and good solar definition until three to four hours after sunrise. There are also a few rainy days interspersed during the dry season. We welcome these occasional showers, for apart from eliminating the dust in the air, they are usually followed by spells of good to excellent seeing. The discovery of the Evershed effect was made "on 5th January 1909 with two large spots on the Sun and excellent definition after heavy rain storms" (Evershed, 1955). The diffusive widening (Evershed, 1916) of lines near the outer edges of penumbra seen on present-day high dispersion spot spectrograms with good image resolution, and the "innumerable small displacements of the lines equivalent to velocities of the order of a few tenths of a kilometre per second" (Evershed, 1922) when "the slit lies across a well-defined image of the sun", are the observational first findings of a skilled astronomer working with a small solar image, of excellent definition during the dry season.

As is common among many mountain solar observatories, the best seeing for the day exists during the period within three or four hours after sunrise. On some occasions good definition of the solar image is seen even in the early afternoon, but these are seldom. From May until December, clouds usually gather before noon, and flare patrol observations are usually made only through gaps in the clouds. During the wet season the maximum chance of having clear skies is early in the morning when the definition is the best for the day. This happy circumstance considerably offsets the handicap of a cloudy period for the rest of the day, on most days. The solar observations extending over a half century indicate that white-light photoheliograms, needing only a few minutes of clear sky, are obtained on an average of about 310 to 320 days in the year. Calcium flocculus and Hα disc spectroheliograms are obtained on about 290 days, while K-prominence spectroheliograms are exposed on about 270 days. The number of daily prominence spectroheliograms obtained are a good index of the total number of days on which the skies have been clear for more than forty-five minutes. In general, while it is possible to execute any programme at any time of the year at Kodaikanal, we have often preferred to make observations demanding continuity of good definition and transparency, during the winter months of good seeing and plentiful sunshine.

3. Solar instrumentation

The principal facility for high spectrographic dispersion as well as solar image resolution is the instrumentation in the solar tower. Built in 1959 and commissioned in early 1960, it went into regular operation in 1962, after several modifications had been made to the tower and spectrograph. A two-mirror fused quartz coelostat 61 cm diameter, mounted on an 11 m tower, reflects light onto a third quartz flat, which sends the beam in the horizontal direction into a 60 m long underground tunnel. The parallel light falls on a 38 cm achromatic objective of 36 m focal length. This yields a 34 cm diameter solar image that has a scale of 5.5 seconds of arc/mm. Both the coelostat mounting and optics as well as the image-forming objective were manufactured by the well-known firm of Grubb Parsons in U.K. The spectrograph is of the Littrow type and utilizes a 20 cm aperture, 18.3 m focal length, Hilger achromat in conjunction with a 600 lines/mm Babcock grating of ruled area 200×135 mm and blazed in the fifth order at 5000 Å. Examinations of the iodine absorption spectrum near 5330 Å in the fifth order show, from the separation of the doublets, that the theoretical resolution has been attained.

Two other spectrographs will shortly be accommodated in the observing tunnel, fed by the 61 cm coelostat. One is a double monochromator for the photoelectric determination of solar line profiles. This instrument functions on the principle of the conventional laboratory double monochromator, and utilizes two 6.5 m grating spectrographs in tandem. Each of the two dispersing units functions in the Czerny-Turner mode with an aperture ratio of *f*/50. Both gratings are mounted on the same scan-assembly, thus ensuring perfect synchronization during a scan. The grating table is held to a massive base by horizontal steel shims and the controlled elastic deformation of the shims provides the fine scan mechanism. Such a principle for spectrum scanning has been used with remarkable success by Dunn at Sacramento Peak. The grating assembly rides against an optical flat which is driven by the precision screw of a measuring engine. An almost continuous change in the angle of contact with the optical flat provides for a wide choice of suitable scanning speeds. A first model of such an instrument by Raheem and the author has shown that the features of high resolution and a minimum of scattered light are easily achieved.

Besides the 38 cm Grubb achromat, auxiliary reflecting systems in the Newtonian or Gregorian arrangements, utilizing optics figured at Kodaikanal by Jayarajan, are used in conjunction with the 18 metre spectrograph. A solar magnetometer of the Babcock type has been designed and brought into use in 1965 by Bhattacharyya. It operates at a chopping frequency of 50 cycles/sec and is in use for the study of weak longitudinal magnetic fields on the solar surface.

Adjacent to the solar tower is the spectroheliograph building, which houses three spectroheliographs, the Lyot filter camera and the Hale spectrohelioscope. The spectroheliographs function with a 60 mm image formed by a 30 cm Cooke photovisual triplet. A Foucault siderostat with a 46 cm diameter mirror reflects sunlight onto the 30 cm lens. The K-spectroheliograph is a two-prism instrument with a dispersion of 7 Å/mm near 3930 Å. The exit slit admits 0.5 Å about K_{232}. The daily disc and prominence spectroheliograms obtained with this instrument date back to 1904. The Hα spectroheliograph is a Littrow grating instrument. The exit slit isolates 0.35 Å about Hα, and the daily series of pictures with this instrument go back to 1911. A third spectroheliograph, recently built by Raheem, is a Littrow arrangement of 4.3 m focus with a 1200 lines/mm grating blazed at 7500 Å in the first order. This instrument has very fine optical definition and is currently being adapted for the study of solar magnetic fields using Leighton's spectroheliographic technique.

The Lyot Hα camera housed in the same building operates in conjunction with a 30 cm Foucault siderostat. The filter is one of the O.P.L. series with a pass band of 0.75 Å. This instrument, together with the spectrohelioscope, constitutes the main instrumentation for the Observatory's optical flare patrol programme. This chromospheric patrol is carried out between 0200 hours and 1130 hours UT every day.

In addition to the above there is the photoheliograph for white light solar pictures, 20 cm in diameter. A 20 cm coronagraph is being rebuilt on a spar mounting. This, in conjunction with a high-dispersion spectrograph, will be used as a scatter-free system. A Yagi interferometer with spacing of 7λ at 100 Mc/sec, and a 2 m dish for solar flux recording at 3000 Mc/sec also augment the solar instrumentation facility. Gopala Rao has under construction a radio spectrograph in the frequency range 20-200 Mc/sec, which will become operational in 1967.

Kodaikanal's participation in the study of solar-terrestrial relationships is of comparatively recent origin. While a magnetic observatory controlled by the Survey of India existed at Kodaikanal from 1902 to 1923, systematic work in this field was commenced only from 1949 onwards. The old magnetic observatory was revived, and in addition, since 1952, systematic ionospheric soundings were undertaken with a C3 ionosphere recorder. The location of Kodaikanal in the vicinity of the magnetic equator renders these observations of considerable interest in the study of the equatorial ionosphere. In recent years, regular measures of Faraday fading using the Beacon satellites are made.

4. Research Programmes

Solar magnetic fields. – Strong magnetic fields in sunspots are measured regularly since 1963 by means of the compound quarter-wave-plate technique and using the 6303 Å line. For medium to large spots several slit settings are made at different locations on the spots in order to evaluate the spatial distribution of the longitudinal field. Two extensions of this programme which we hope to undertake shortly are: measures of plage magnetic fields by Leighton's technique and the spatial orientation of the magnetic field in spots. Weak fields, in the polar regions and elsewhere, are under study by Bhattacharyya with the magnetometer. This technique will also be utilised for a study of flare effects in the magnetic regions during the current cycle.

Solar velocity fields. – A recent study of the Evershed effect has been completed by BHATNAGAR (1966). The spectra utilised for this purpose have a dispersion of 8 mm/Å and cover two successive passages of the same spot group. The velocity configurations have been derived on different days from measures of the Zeeman insensitive lines 4912.027 Å of Ni I, 5576.101 Å of Fe I and 5691.508 Å of Fe I. Mean depths of line formation, with the aid of Makita's penumbra model, have been used in obtaining a value of 4.0×10^{-3} km/sec/km as the gradient of maximum radial velocity with depth. The observations show the presence of sizable tangential velocities in the spot penumbrae. A maximum tangential component of the order of 0.6 km/sec was observed on six disk positions. Bhatnager has also studied the asymmetry in the lines in the penumbral region, observed first by EVERSHED (1916). This asymmetry varies with line strength and the magnitude of the maximum asymmetry decreases as the spot position gets closer to the centre of the disc.

A few spot spectra obtained under excellent conditions of seeing show continuum brightness fluctuations in the penumbral region. A correlation study of continuum brightness and equivalent width indicates that the darker regions of the penumbra show larger equivalent width while the brighter (hotter) regions show smaller width.

Velocity fields in spot-free regions on the solar disc are under study with the 18 m spectrograph utilising two techniques of measurement. The 5-minute oscillation for localised areas, for extended time intervals, are studied with the magnetometer in the velocity mode. Measures of this kind are in progress for different lines that have a mean depth of formation at different heights in the solar atmosphere. The spatial variation of the oscillation characteristics are studied by the photographic method, following Evans and Michard.

The velocity structure in the uppermost solar photosphere and the very low chromosphere has been studied by Miss SUBRAHMANYAM (1965) utilising photoelectrically determined line profiles of the molecular lines of CN 3864 Å and 4207 Å, and of C_2 5094 Å for different centre-limb positions. A satisfactory fit with the observations is obtained for a value of 3 km/sec radial turbulent velocity at the disc centre. For other positions on the disc, the most reasonable fits obtained are for a tangential turbulent velocity of 3.6 km/sec. The mean value of τ for these lines range in the interval 0.04 to 0.10.

Chromospheric features on the disc and at the limb. – A study is in progress by Sivaraman and the author of the mottling characteristics of the chromosphere, as seen in the first four lines of the Balmer series, and in the H and K lines. This study based on spectrograms with the large spectrograph makes an attempt to evaluate the intensity fluctuations for different $\Delta\lambda$ from the line centre, and hence chromospheric heights. Simultaneous spectra in H and K are used to study the identity in mottling characteristics in the two lines. Autocorrelation techniques applied to K spectroheliograms have been utilized for a study of the sizes of the coarse Ca^+ network. These measures are being extended to cover a whole solar cycle. Simultaneous spectra of chromospheric spicules in D_3 and K as well as Hα and K are under study by Sivaraman for evaluating spicule properties in the different lines.

Sunspot spectra. – This field of endeavour will command much attention from us during the next three to four years. The evaluation of sunspot fluxes at different wavelengths and the study of both atomic and molecular lines in sunspot spectra will constitute our main approach to the problem.

Solar Terrestrial relationships. – Several studies relating to the ionosphere over Kodaikanal and the electrojet have been completed by Bhargava and his colleagues in recent years. Among these may be mentioned the study of radio star scintillations and associated properties of the F-region, the temporal changes of foF2 at Kodaikanal and Huancayo, the variation over a solar cycle of ionic densities at different levels of the equatorial ionosphere, and the spatial, seasonal and solar cycle variations in the lunar semi-diurnal oscillations in the ionospheric F-region. Two recent studies of direct interest to solar physicists are: an analysis of magnetic crochets associated with relativistic flares (SUBRAHMANYAN, 1964) and the amplitude characteristics of geomagnetic sudden commencements with energetic proton events (BHARGAVA and SUBRAHMANYAN, 1966).

5. Publications

The *Kodaikanal Observatory Bulletin* has long been the medium of publication of research results at Kodaikanal. The *Bulletins* contain, apart from research contributions, the results of the daily solar, geomagnetic and ionospheric observations carried out at Kodaikanal. Shorter research contributions are published in the standard astronomical and geophysical journals of the world, and are circulated to the various institutions on our mailing list of publications as *Kodaikanal Reprints.*

References

BHARGAVA, B. N. and SUBRAHMANYAN, R. V.: 1966, *Planet. Space Sc.* (in press).
BHATNAGAR, A.: 1966, *Kodaikanal Observatory Bulletin* (in press).

Evershed, J.: 1955, *Vistas in Astronomy* **1,** 36.
Evershed, J.: 1916, *Kodaikanal Observatory Bulletin* **51.**
Evershed, J.: 1922, *Monthly Not. Roy. Astron. Soc.* **82,** 392.
Subrahmanyam, N.: 1965, Doctoral Thesis, University of Madras.
Subrahmanyan, R. V.: 1964, *J. Atm. Terr. Phys.* **26,** 1119.