Indian Journal of Radio & Space Physics
Vol. 15, October & December 1986, pp. 348-355

Progress of Laboratory Aeronomy and Airglow Research in India during the Last Fifty Years: Part III—Airglow Research in India

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Airglow observations carried out in different parts of the country are reviewed. The photometers used by the investigators and the observations made by them are described. From the results obtained from the investigation, upper atmospheric phenomena are interpreted.

1 Introduction

The light from the sky on a dark moonless night is composed of star, scattered, galactic and zodiacal light and also light due to the self-luminescence of the upper atmosphere. About 40% of the total light is contributed by the last source. This source of radiation was used to be called as the 'light from the night sky'. It is now called the 'night airglow'. Such emission is also observed during twilight and is known as the twilight airglow. Nothing definite was known about the source of the sodium although radiation from it was detected in the upper atmosphere—whether it is of terrestrial or extra-terrestrial origin. Ghosh and Mitra[1] first showed that sodium comes into the atmosphere from outer space. They also determined its incoming flux.

The lines and bands in the night airglow spectrum, which were known around fifties, are given in Table 1 (Ref. 2).

The first observation of OH emission in the night airglow was made by Slipher[3]. He reported maxima at 6530, 6870 and 7270 Å. However, this radiation was finally established only after the work of Meinel[4]. Previously, OH bands were misunderstood as due to N_2 molecules.

After World War II, two new techniques of airglow research were developed. First, to send instruments during daytime above the scattering region of the lower dense atmosphere and observe airglow from there—the so-called day-airglow emission which is much more intense than night or twilight airglow radiation. Secondly, to send instruments through the airglow emitting layers and make direct measurements of emission.

Table 1—Lines and Bands in the Night Airglow Spectrum (Reproduced from Ref. 2)

Origin	Transition	Remarks
O atom	$^1S \rightarrow {}^1D$ (λ 5577)	Green oxygen line. Permanently present in the night airglow spectrum. Strong intensity. Transition forbidden.
	$^1D \rightarrow {}^3P$ (λ 6300) (λ 6363) (λ 6392)	Red oxygen lines. Permanently present, but of lesser intensity than λ 5577. Transition forbidden. Considerably enhanced in twilight spectrum
N_2^+ ion	$^2\Sigma_u \rightarrow {}^2\Sigma_g$ ($0 \rightarrow 0$ λ 3914)	First negative bands of N_2^+. Absent or very faint in the night airglow; but observed when the slightest trace of aurora is present and also in the twilight.
Na atom	$^2P \rightarrow {}^2S$ (λ 5894)	Sodium *D*-line. Strong; always present. Greatly enhanced in twilight spectrum.
O_2 molecule	$B^3\Sigma_u \rightarrow X^3\Sigma_g$ (blue and ultraviolet region)	Runge-Schumann bands. There is a fair probability of the occurrence of this band system.
	$A^1\Sigma \rightarrow X^3\Sigma$ (infra-red region)	Atmospheric band system. Identified by Meinel
	$^3\Sigma_u^+ \rightarrow {}^3\Sigma_g^-$ (ultraviolet region)	Herzberg bands identification almost certain.
OH radical	Vibration-rotation bands of the ground state $X^2\Pi$ (red and near infra-red)	Meinel bands. Very strong.

2 Experimental Arrangement of Kulkarni

Figs 1 and 2 show the complete photometer used by Kulkarni[5] at Mt Abu, except the paper chart recorder. The turret box T at the top contained Geneva gear assemblies which positioned the filters and the light from a standard source on the optical system O, which is seen in the left half of the turret box. Light was allowed to fall on the optical arrangement through the

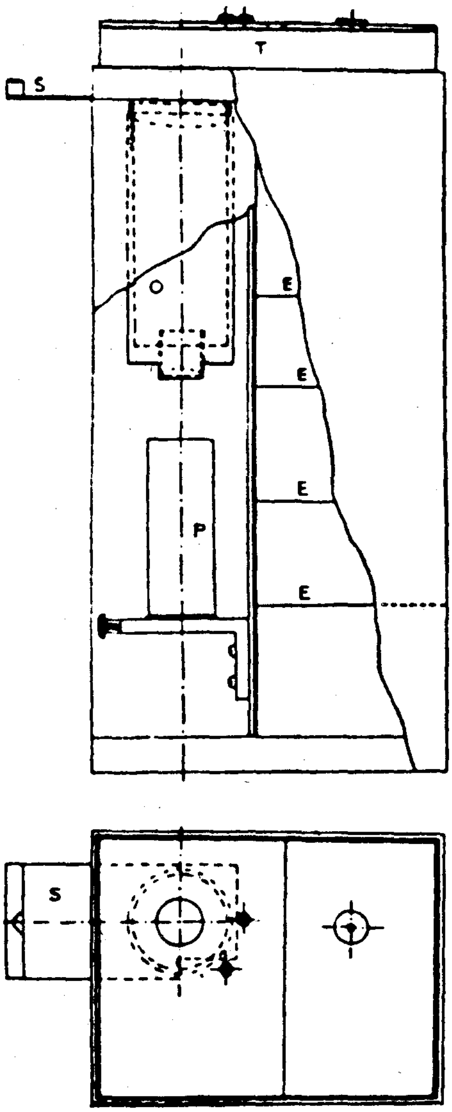

Fig. 1—Complete photometer of Kulkarni (except the recorder) [T, Turret Box; S, Shutter; O, Optical system; P, Photomultiplier tube; E, Shelves for electronic cards]

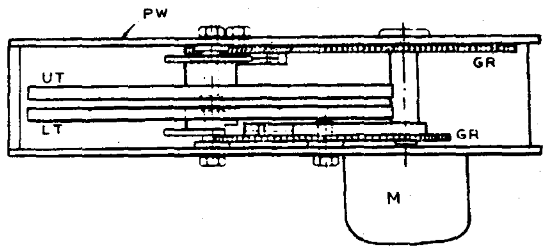

Fig. 2—Details of the turret box [PW, Plastic window; GR, Gear assembly; M, Motor; UT, Upper turret; LT, Lower turret]

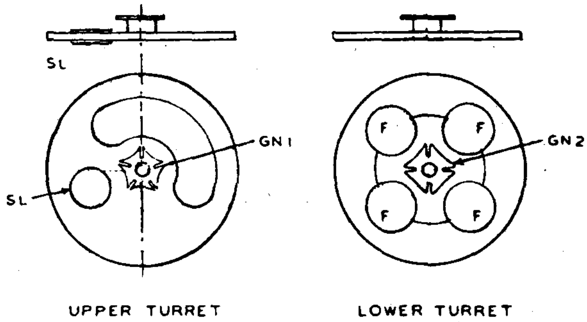

Fig. 3—Details of the upper and the lower turrets [GN 1, Five sector Geneva; SL, Standard light (the ^{14}C radio activated source); GN 2, Four sector Geneva; F, Filters]

photomultiplier P. The right half of the photometer had shelves E in which electronic cards were fitted. A plastic window PW on the top of the turret box allowed sky light to enter the photometer. There were two turrets which were driven through gears by a single Hurst motor M mounted under the box. Fig. 3 shows the Geneva GN arrangements of the turret box. Upper turret UT was driven by a five-sector Geneva GN 1 in such a manner that each sector stayed on for 36 s, so that one rotation of the turret was completed in $36 \times 5 = 180$s. One sector, that is 1/5 of the turret held the ^{14}C-activated phosphorescent source SL. One sector was blank to zero light and three sectors had holes through which sky light was admitted. The lower turret LT (Fig. 3) was driven by a four-sector Geneva GN 2 and the speed was such that each sector remained steady for 3 min (time required for one revolution of the upper turret). Thus the lower turret completed one revolution in 12 min. Therefore, through each filter an airglow reading for 108 s was obtained. It was immediately followed by the ^{14}C-light reading for 36 s and a zero reading for 36s. In 12 min, four such sets with four filters were obtained. Light going through a filter either from the sky or the ^{14}C-light fell on an achromatic objective which was focussed by a Fabry lens on the cathode of the photomultiplier. The photocurrent was then amplified by an electrometer-type amplifier. The output of the amplifier was directly given to a 0-1 mA paper chart recorder.

3 Experimental Arrangement of Ghosh

Taking advantage of the blackout condition of the city during World War II, Ghosh[6] made night airglow observations at Calcutta. He used a simple apparatus as follows. A telescope with objective and eyepiece was pointed towards the region of the sky to be studied. The objective was achromatic, 4 in diameter and 57 cm in focal length. In its focal plane, a circular opening was placed. The eyepiece placed behind the opening was double convex lens of focal length 3 cm. A single lens was used as the eyepiece in order to reduce the absorption of light. The eyepiece threw on the photographic film an image of the exit pupil of the objective. The telescope received the light from a solid angle at 1.5×10^{-3} radian of the sky. It is clear that the circular opening being in the focal plane of the objective, the image on the photographic film had uniform illumination. The film-holder could be moved up and down by a rack and pinion arrangement so that different parts of the film could be exposed when necessary.

Later on, Ghosh and Kundu[7] used an automatic portable Dunn-Manring type photometer at Allahabad to measure nightglow intensity of 5577 Å line due to atomic oxygen. The experimental arrangements are given in Figs 4 and 5. In this type of photometer, the flux of light from the line emission was incident on the cathodes of the photoelectric detector. Integrated over a fraction of a second, the flux yields a measurable photocurrent. The entire sky could be surveyed several times within a few minutes. Narrow passband interference filter was used for the selection of 5577 Å line. The photometer was operated by a portable motor generator.

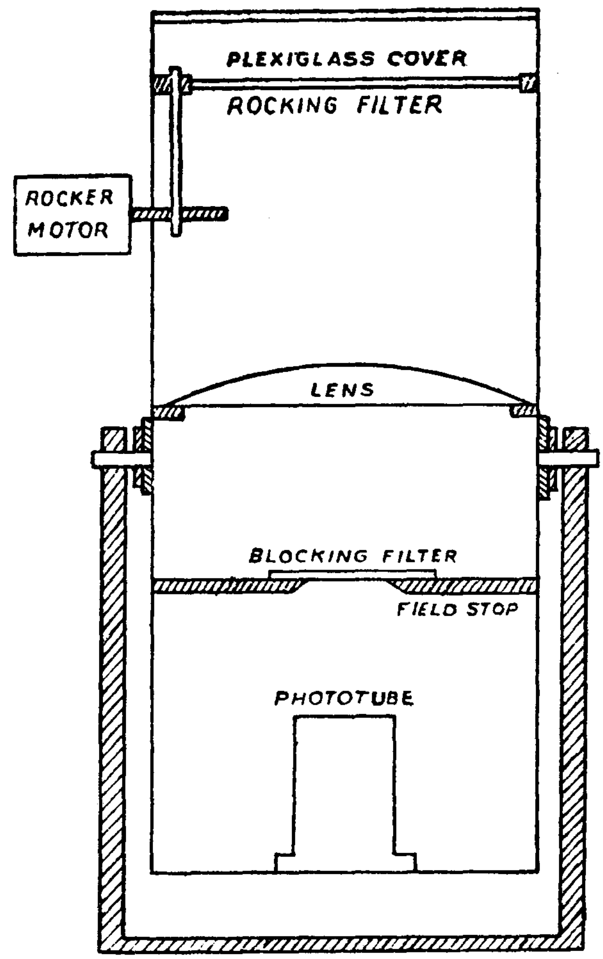

Fig. 4—Optical arrangement of the photometer telescope used by Ghosh

Recently, Ghosh and Midya[8,9] have been carrying out work on airglow at Narendrapur near Calcutta. It is also a Dunn-manring type of photometer as detailed above. The instrument is operated at 45°W to observe the intensities of 5577, 5893 and 6300 Å line emissions of airglow.

4 Experimental Arrangement of Choudhary and Tillu

The telescope and the scanner of the photometer used by these investigators are shown in Fig. 6. The optical system was designed to work at 50 mm clear aperture and with a focal length of 216 mm. Lenses L_1 and L_2 form the objective and L_3 the field lens. A circular patch of sky about 4° in diameter was focussed by the objective near the field lens, which imaged the objective on the photomultiplier. The objective was carefully shaped to give minimum spherical aberration. The use of the field lens eliminated the possibility of change in photocurrent, if any, due to the unevenness of the image of a bright star. With the present arrangement, the portion of the sky covered was controlled by the diaphragm S near the field lens.

A beam of light entering through filter F above the objective was successively reflected at mirrors M_1, M_2, M_3 and M_4, each mounted at an angle of 45° to the

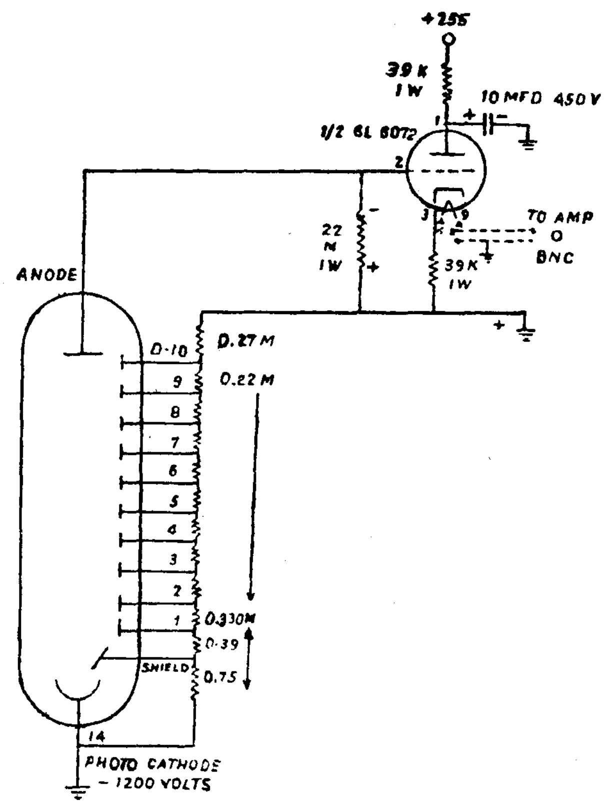

Fig. 5—Phototube and cathode follower preamplifier circuit of the photometer telescope (Fig. 4)

Table 2—Experimental Arrangements for Observing Night Airglow

Investigator	Observed line or band (Å)	Remarks
Kulkarni (1969)	5577 6300 5893 OH bands	The instrument was automatic and sensitive. Simultaneous observation of any three emissions could be taken.
Ghosh (1946)	Total visible region	Using the instrument which was very simple, the total airglow intensity in the visible region could be observed.
Ghosh and Kundu (1975)	5577	It was a Dunn-Manring type photometer. The instrument was automatic, sensitive and could survey the whole sky within a few minutes.
Ghosh and Midya (1982)	5577 5893 6300	It was also a Dunn-Manring type photometer, but not automatic. The instrument could be pointed towards any direction of the sky and at any angle of elevation. Singh and Chatterjee used a similar type of instrument.
Chaudhuri and Tillu (1972)	5577 6300	The instrument was very sensitive. The objective was carefully shaped to give minimum spherical aberration.

beam before it was incident on the photomultiplier. The telescope mount T was rotated about the vertical axis during the azimuthal motion. The mirror M_1, the objective and the filter disc were rotated together with the mount through pre-determined angles for different zenith distances. The photomultiplier was held stationary during the complete scanning programme.

A synchronous motor drive SMD having 10 revolutions/min was used for driving the scanner and chart recorder. A speed of 1 revolution/min was then achieved for the telescope mount T for the azimuthal motion through a bevel gear BG having a reduction ratio 10:1. A seven-sector Geneva wheel G_1 got engaged to the telescope mount after one revolution of the mount by a pin P on the guide ring GR. This wheel operated through a can C and rotated the assembly of mirror M, objective and filter-disc through a desired angle at the end of each azimuthal revolution.

A comparison of the photometers used by the above investigators is given in Table 2.

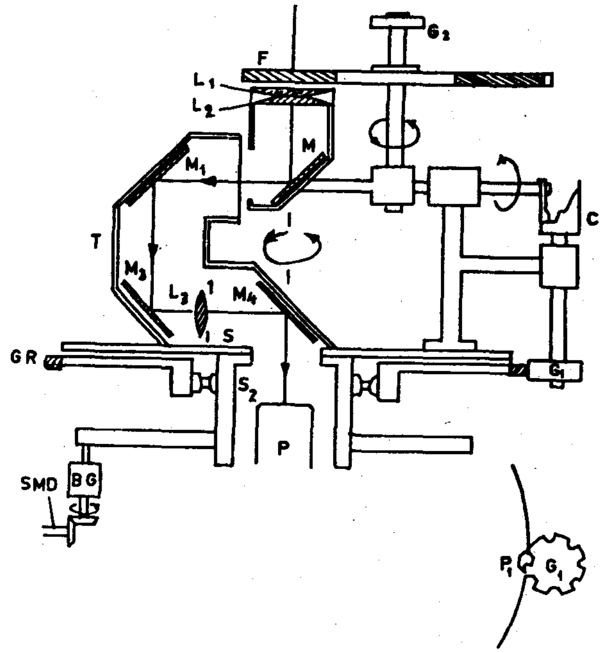

Fig. 6—An automatic photometer of Choudhary and Tillu for measuring night airglow intensity

5 Results and Discussion

Kulkarni *et al.*[10,11] summarized their night airglow observations of O I 6300 Å, O I 5577 Å, NaI 5893 Å and OH (8, 3) bands at Mt Abu (Fig. 7). On a number of occasions they observed covariation of OH (8, 3) and Na (5893 Å); OH (7, 2) and OH (8, 3) bands; O I (5577 Å) and seasonal variation of 5577 Å and OH (8, 3; 7, 2) (Fig. 8). From ionospheric parameters and electron density profiles, they showed that Barbier-type relation fitted well for the 5577 Å observations.

From rocket measurements of O I 5577 Å emission at night over the magnetic equator, Kulkarni[12] obtained the height of maximum emission as 102 ± 2 km, and the half thickness of the layer as 11 ± 2 km (Fig. 9).

Majumdar *et al.*[13] measured the intensities at two fixed wavelengths in the OH bands at Mt Abu to estimate the neutral temperature in the altitude range 80-90 km. It was observed that sometime the temperature in this region showed periodic oscillations throughout the night. It was found that the periods of fluctuation are comparable to the theoretically predicted periods of internal gravity waves.

Utilizing van Rhijn method, Singh and Chatterjee[14] determined the height of the layer emitting the green line 5577 Å at Dumka, Bihar. They showed that the measured height of 174 km may be taken as the optical centre of gravity of two emitting layers, one located near 100 km and the other near 250 km.

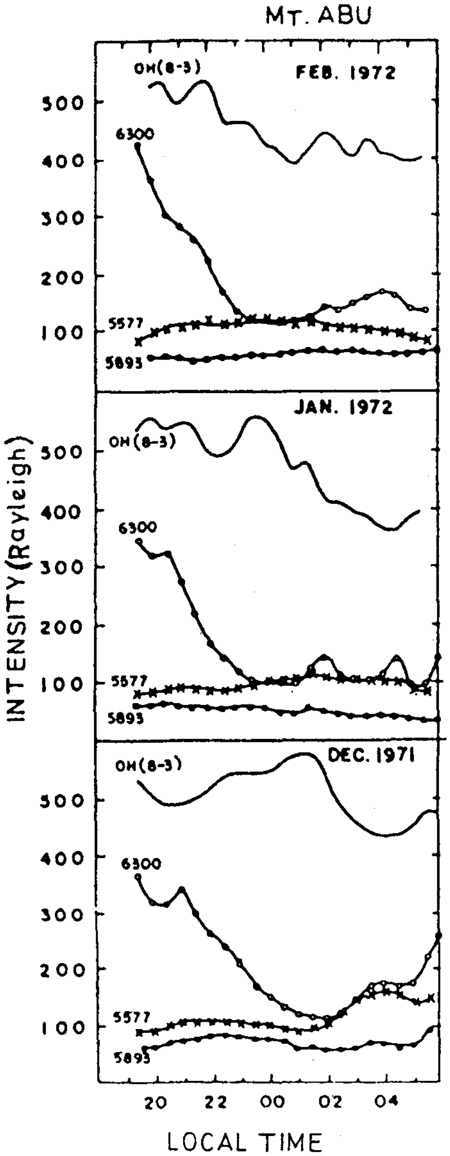

Fig. 7—Average night airglow diurnal variation of OH (8, 3), 6300, 5577 and 5893 Å at Mt Abu

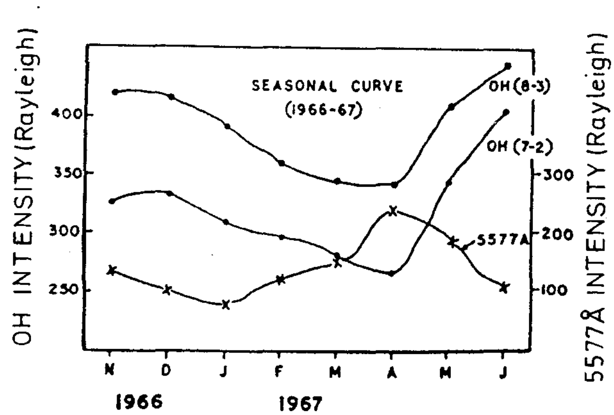

Fig. 8—Seasonal variation of OH (8, 3), OH (7, 2) and 5577 Å line intensities

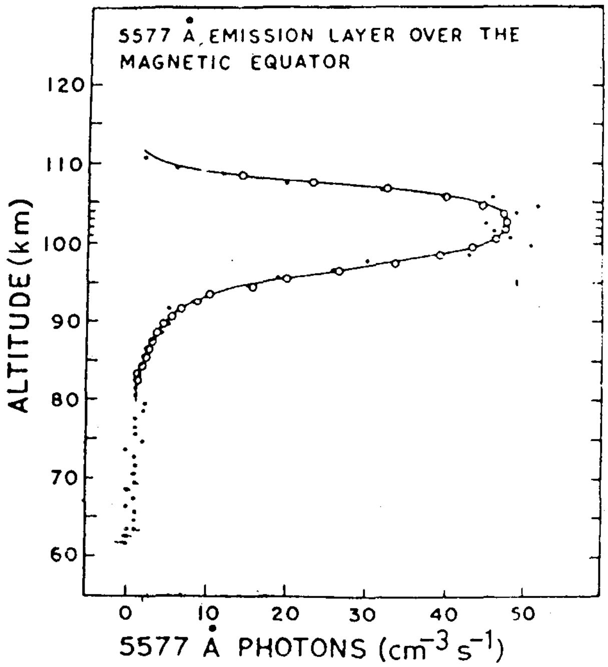

Fig. 9—Altitude variation of 5577 Å photon emission rate

Ghosh[6] measured the night sky intensity variation at Calcutta for the period 1943-1945. It was found that on undisturbed nights, the intensity decreased with advance of night, attained a minimum near about local mid-night and then again increased. On normal nights, the night sky intensity and the electron density of F region did not follow the same trend. For abnormal nights, a co-variation (Fig. 10) was reported by Ghosh[6]. These observations showed that the upper layer emission involves a reaction with ions.

Ghosh and Kundu[7] took observations of 5577 Å line intensity at Nainital. In general, two maxima were obtained during a night (Fig. 11). They also showed that the diurnal variations of 5577 Å intensity depends on latitude and longitude (Fig. 12).

Kundu and Ghosh[15] investigated the effect of solar flare and the sunspot numbers on the intensity of 5577 Å line emission. They determined the time lag between the occurrence of a flare and the enhancement of 5577 Å line intensity and made day-to-day analysis of the variation of intensity of the 5577 Å line emission and sunspot number and obtained high correlation (Fig. 13). Correlation was also observed between the intensity of 5577 Å line with change of sunspot number from the preceding night of observations to the day following it. The intensity appears to vary with magnetic field produced by the sunspot and not with the sunspot area.

Ghosh and Midya[8,9] performed the experimental observations of the diurnal variations of 5577, 5893

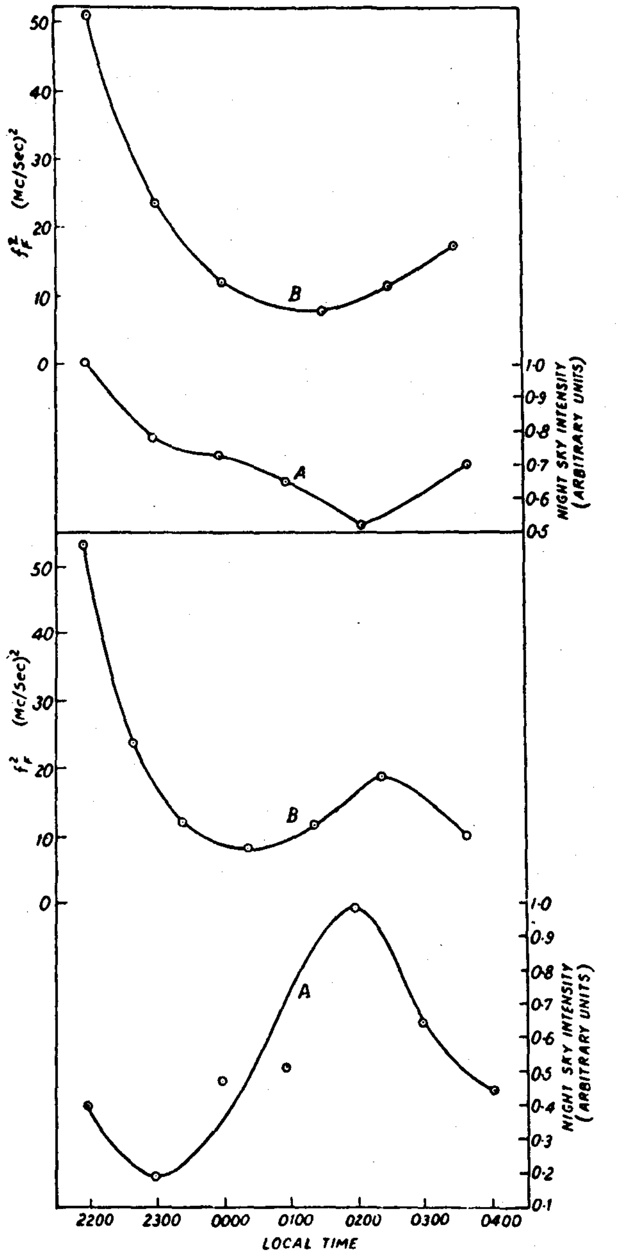

Fig. 10—Comparison of the variations of the night sky intensity (A) with that of f_F^2(B) for two abnormal nights with magnetic disturbances [The upper curves are for Feb. 14-15, 1945 and the lower curves for Feb. 15-16, 1945. It is to be noticed that the variation of the night sky intensity follows the same trend as that of f_F^2.]

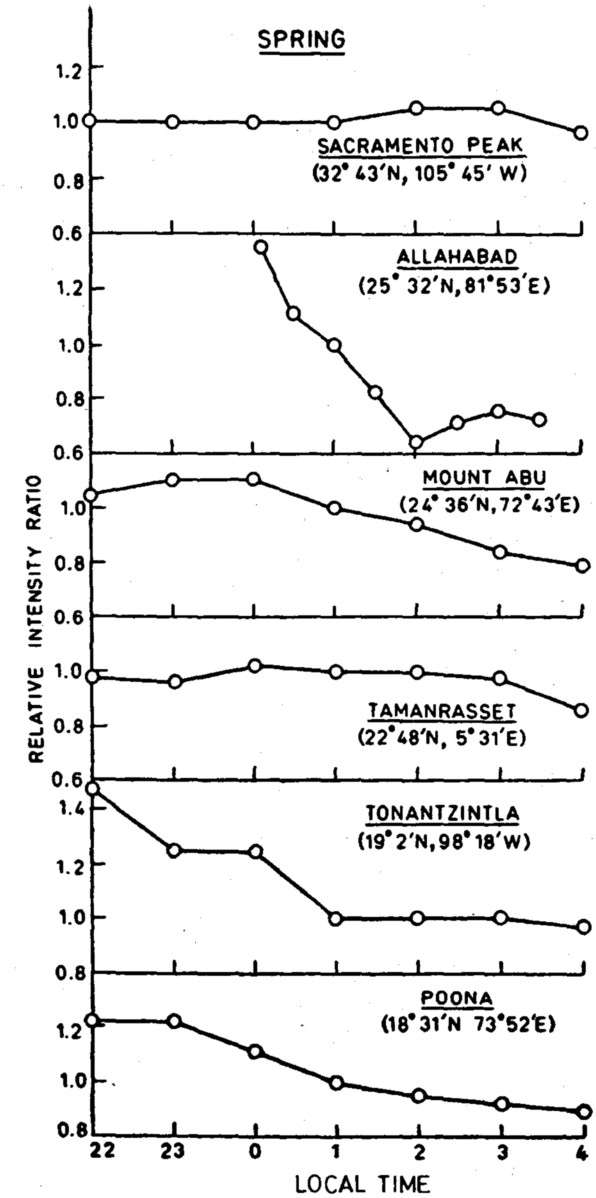

Fig. 11—Diurnal variation of 5577 Å line intensity during spring season for Sacramento Peak, Allahabad, Mt Abu, Tamanrasset, Tonantzintla and Poona

and 6300 Å line emissions at Narendrapur near Calcutta. They obtained the enhancements of 5577 and 5893 Å emissions during evening and morning twilight periods.

Saxena[16] observed the nocturnal behaviour of the red lines of O I at Nainital (Fig. 14) and showed that photoelectrons from the magnetic conjugate point may produce the predawn enhancement of the line O I 6300 Å.

At the University of Poona, after Chiplonkar's work on night airglow around 1950, the diurnal variation of sodium day airglow was observed recently under the guidance of Tillu[17]. This detection is difficult in the presence of large background intensity. A special type of photometer (Zeeman photometer) was used. The diurnal variation of sodium day airglow intensity was deduced which showed a symmetric pattern around noon. The variation of 5577 and 6300 Å with sunspot number was also obtained (Fig. 15).

Ground-based measurements of $O_2(^1\Delta g)$ were carried from the campus of University of Poona and also from Garad in Karnataka during the 1981 total

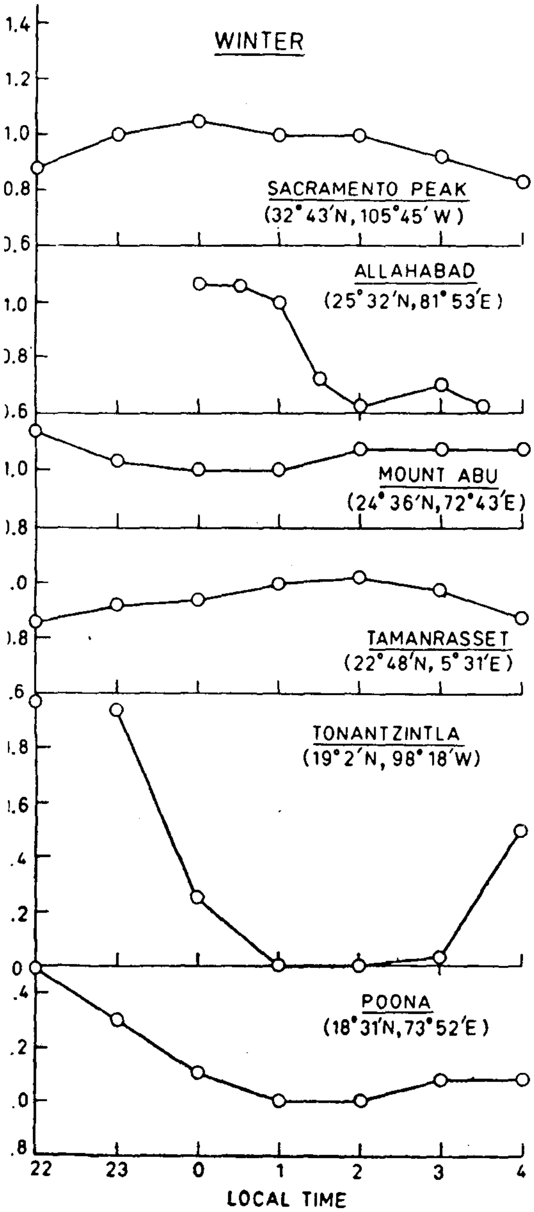

Fig. 12—Diurnal variation of 5577 Å line intensity during winter season for Sacramento Peak, Allahabad, Mt Abu, Tamanrasset, Tanantzintla and Poona

solar eclipse. Such observations provide a sensitive method of determining ozone at mesospheric altitudes. Again, from Mt Sinhagad near Poona, night airglow OH (7, 2) band intensities were measured at different zenith angles to obtain mesospheric neutral temperature and its variation.

On the theoretical side, Ghosh and Sharma[18] first showed that the dissociative recombination of O_2^+ ions with electrons accounts for the excitation of 6300 Å line. Ghosh and Mitra[19] explained the enhancement of Li line (6708 Å) in the twilight airglow due to thermonuclear explosion.

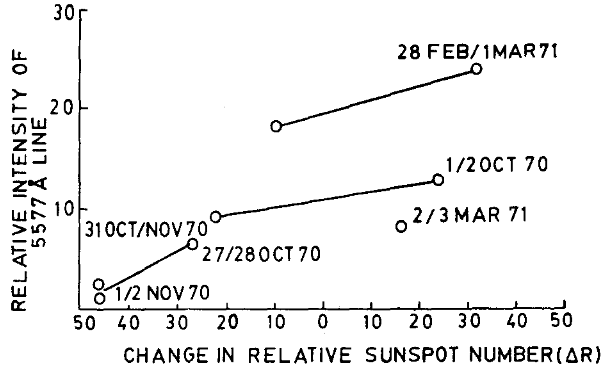

Fig. 13—Illustration of the strong correlation of 5577 Å line intensity with solar cycle

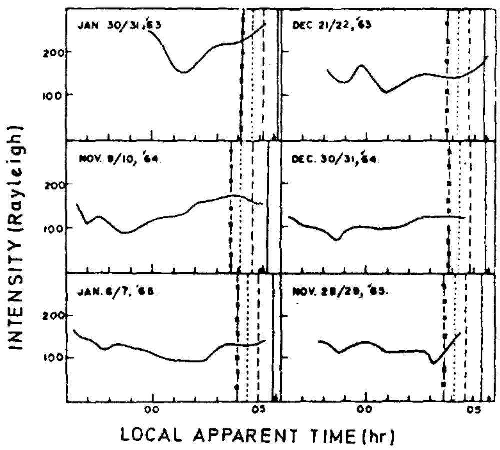

Fig. 14—Nocturnal behaviour of the red lines of O I and the pre-dawn enhancement at Nainital

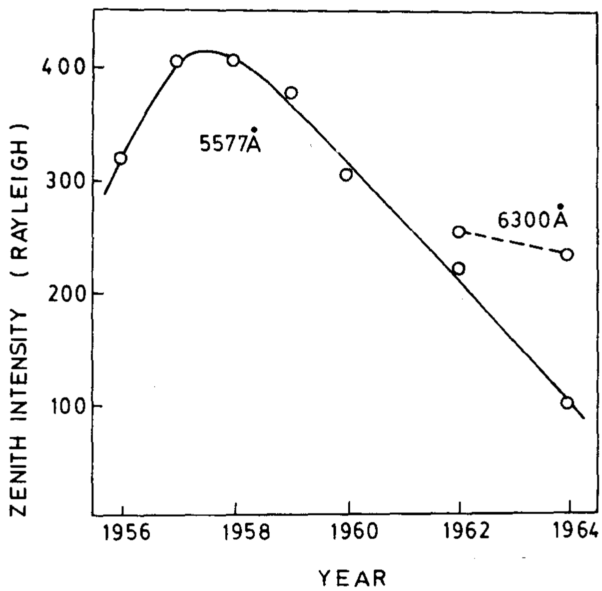

Fig. 15—Illustration of the strong correlation of 5577 Å line intensity with solar cycle [6300 Å maintains nearly a constant value]

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