SISIR KUMAR MITRA MEMORIAL LECTURE

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(*Delivered on May 5, 1967*)

We have met here today to honour the memory of Sisir Kumar Mitra, pioneer of modern scientific radio in India. I would have said 'the pioneer', but I remember the earlier work of Acharya Jagadish Chandra Bose, whose investigations on electromagnetic waves in the centimetre-wave length region and the coherer were the forerunners of microwave radio and transistors. Today, there is hardly any branch of science which is unaffected by radio and electronics. Prof. Mitra's interests were versatile, and in his preface to the first edition of his book on 'The Upper Atmosphere', he wrote, 'In spite of the many and varied contributions to its study by theoretical and solar physicists, geomagneticians, meteorologists and others, there hardly existed a book dealing with the subject as a whole and in a comprehensive manner.' My own interest in the subject of 'The Earth and Its Environment' being somewhat similar to Prof. Mitra's, it gives me particular pleasure to have this opportunity of paying my tribute of admiration to Acharya Sisir Kumar Mitra as an erudite scholar, investigator and writer and as a great teacher and organizer of radio and related sciences in India.

Sisir Kumar Mitra was born in Calcutta on 24 October 1890, and after a bright school and college career took his M.Sc. in Physics from the Presidency College, Calcutta, in 1912. He served for a few years as a Lecturer in Physics in Colleges at Bhagalpur and Bankura and, being anxious to find his career in science, returned to Calcutta. He worked for a short time under Sir J. C. Bose, and later joined Prof. Raman who was building up a vigorous school of Physical Optics at 210 Bowbazar (Indian Association for the Cultivation of Science) and at the University College of Science. Working on problems of diffraction, Mitra obtained his doctorate degree (D.Sc.) from the Calcutta University in 1919 and was appointed Lecturer in Physics in the University College of Science.

Shortly after, the Calcutta University deputed Dr. Mitra to France for further work, and there he continued his optical studies under Prof. C. Fabry and in 1922 obtained the D.Sc. of the Paris University with a thesis on 'Spectroscopic standards in near ultraviolet'. While in France, Mitra got interested in thermionic valves and radio frequency oscillations in discharge tubes and worked for some months with Prof. Gutton in the University of Nancy. Realizing that radio had a great future, both for exploring the upper atmosphere and as the most important technique for communications, Mitra decided that his main work in India should be to build up a School of Radio Science. He wrote about his desire to Sir Ashutosh Mukherjee, the farseeing Vice-Chancellor of the Calcutta University, who promptly sent him the following characteristic reply. 'The course of investigation you suggest as to signals by wireless telegraphy is very attractive. Do please draw up a scheme and make it as inexpensive as possible. I shall see what we can do. But you may rest assured that there will be plenty of opposition. That need not frighten us, we shall have to fight our way through.' On his return to India in 1923, Dr. Mitra was appointed Khaira Professor of Physics in the Calcutta University and he immediately set about building up a Wireless Laboratory with the assistance of post-graduate students. By 1925, Mitra set up an Amateur Broadcasting Station at the Khaira Laboratory. At about the same time a group of radio enthusiasts had organized a Radio Club in Calcutta and with the assistance of a private company called 'The Indian States and Eastern Agency' had set up a broadcast receiver and transmitter to receive BBC broadcasts from England and transmit evening broadcasts for the local public. A similar club was started at Bombay also. These continued to function till the Indian Broadcasting Company took over the transmissions and installed more powerful transmitters at both Calcutta and Bombay.

In 1925 Appleton and Barnett in the U.K. and Breit and Tuve in the U.S.A. demonstrated the existence of stratified layers in the atmosphere from reflections of vertically incident radio waves. Mitra was greatly excited by this discovery and wanted to find out whether similar layers existed over the tropics. Making use of the Indian Broadcasting Company's transmitter at Calcutta which could transmit on 4 MHz, he installed receiving and recording equipment at a place 75 km from Calcutta, and showed that he could receive echoes from the *E* layer. Similarly, using 800 kHz transmission from the Khaira Laboratory, he could obtain reflections from the *D* layer. The diurnal and seasonal variations of the virtual heights of the *D* and *E* layers were then studied. This was in 1930. As the second International Polar Year was to come off in 1932-33, Dr. Mitra and his colleague, Mr. H. Rakshit, built up a pulse reflection equipment in time to take part in the second Polar Year. Between 1930 and 1936, various other experimental and theoretical investigations were started. Among these were the diurnal and seasonal variations of the ionospheric layers and attempts to explain the formation of the layers by the dissociation and ionization of atmospheric constituents by solar ultraviolet radiation.

Prof. Mitra and Prof. M. N. Saha realized the importance of building up a network of ionospheric observatories in different regions of the world. In 1935, shortly after the inauguration of the National Institute of Sciences, Mitra presented a 'Report on the present state of our knowledge of the ionosphere' at a symposium organized by the National Institute. In 1936, after he became Rash Behari Ghosh Professor of Physics, Mitra went on a visit to England and, while there, took the opportunity to interest Prof. Appleton and other leading ionospheric scientists of Britain in the setting up of a Radio Research Board in India. It has to be remembered that India was still a part of the British Empire. However, it was only World War II that made the U.K. and other countries realize the importance of ionospheric data in the tropics for planning world-wide communications and the C.S.I.R. in India agreed to set up a Radio Research Board. This was in 1942. Prof. Mitra was appointed the first Chairman of the Board and remained in that capacity till 1948. By 1946, both the British and Japanese scientists made the surprising discovery that the maximum noon and afternoon values of f_0F_2 were found not in the sub-solar region where the maximum ion production may be expected, but at two latitudes on either side of the magnetic (dip) equator. As soon as the discovery was announced, Mitra suggested the following explanation. At the magnetic equator, the magnetic lines of force are highest and slope towards the north and south. High above the F_2 layer, the collision frequency of electrons and ions is small and they will be free to spiral round the lines of force. They will be guided to move along the lines of force and move downward to lower levels and contribute to increased ionization at two latitudes on either side of the dip equator. He showed that electrons and ions at 600–1,200 km above the magnetic equator would reach the F_2 region at the appropriate latitudes. D. F. Martyn (1955) supplemented this explanation by showing that, over the dip equator, there will be increased conductivity due to Hall effect and upward movement of plasma by electro-dynamic lift and that this will be followed by diffusion down the lines of magnetic force.

Mitra's 1935 'Report on the present state of our knowledge of the ionosphere' formed the basis of his well-known treatise on the Upper Atmosphere which was published by the Asiatic Society of Bengal in 1947 and even now forms an outstanding introduction to Aeronomy. The effort of Prof. Mitra and his team of research workers in preparing the book proved very helpful in channelling radio-associated geophysical studies in India and abroad. The growing needs of Communication Engineering and Broadcasting required a large number of young men with sound knowledge of radio physics, and Mitra's book served as a good comprehensive introduction to this subject. A second edition of the book was published in 1952.

In 1949, Prof. Mitra induced the University of Calcutta to establish a separate Institute of Radio Physics and Electronics where post-graduate students could be systematically trained. The Calcutta School of Radio Physics and the Department of Communication Engineering in the Indian

Institute of Science, Bangalore, have been responsible for training the majority of senior Telecommunication Scientists and Engineers now working in the country.

Dr. Mitra was happy when in 1949 the University of Calcutta with the assistance of the C.S.I.R. and the Ministry of Education agreed to transfer the Ionospheric Field Station from the electrically disturbed Upper Circular Road to Haringhata. Although arrangements for the transfer of the station were started in 1949, systematic work could begin at Haringhata only in 1955. In the same year, Dr. Mitra retired from the Ghosh Professorship of the University and his student, Professor J. N. Bhar, succeeded him. This did not, however, mean any cessation of Dr. Mitra's scientific activities. He continued as Emeritus Professor in the University and could give more attention to the editing of '*Science and Culture*', an activity which was after his heart. The Government of West Bengal requisitioned his services as Administrator of the Board of Secondary Education. In this capacity, he was able to impress on the authorities the need for raising the standard of teaching of science in schools.

Prof. Mitra held many important Offices such as the Secretaryship of the Indian Science Congress (1939–1944). He was its General President in 1955. Prof. Mitra was a founder-member of the National Institute of Sciences and was its President in 1959-60. He was elected a Fellow of the Royal Society in 1958 and appointed National Professor in 1962. In the same year, he received the Presidential award of Padma Bhushan.

Dr. Mitra chose an exciting new field for his work, and devoted himself whole-heartedly to its development. He achieved a highly respected position among his colleagues both in India and abroad. He had his trials in life, losing his wife in 1939 and his eldest son in 1961, but knowing his duty (*swadharma*), and intent on doing it well, I believe he was able to find consolation and fulfilment in life. Mitra's example of devoted service in the cause of Science and Education should serve as an inspiration to younger workers. The band of active scholars whom he trained, and who are today continuing his work, are to my mind his greatest contribution to the country.

The first edition of Prof. Mitra's book on the Upper Atmosphere was published by the Asiatic Society of Bengal in 1947 and the second edition in 1952. In the concluding remarks of his book, Mitra wrote, 'The greatest obstacle to the study of the upper atmosphere is undoubtedly the lack of our direct and precise knowledge of the energy distribution in the near and extreme ultraviolet radiation of the sun.' He hailed the advent of instrumented rockets for sounding the upper atmosphere which began in 1946 after World War II. The next important advance came in October 1957 when the Russians sent up their first Sputnik, and this was closely followed by the launching of Explorer I by the U.S.A. A tremendous amount of knowledge regarding the earth and its environment and, in particular, the wave and particle radiations, which continually reach the earth from the sun and space, has accumulated since then. Prof. Mitra himself summarized some of the advances made after 1952 in three important lectures:

1955—*Science and Progress, the Study of Radio-electronics.* Presidential Address at the Baroda Session of the Indian Science Congress.

1960—*Upper Atmosphere and Space Exploration.* Anniversary Address to the Silver Jubilee Session of the National Institute of Sciences.

1963—*Physics of the Earth's Outer Space.* Seventh Meghnad Saha Memorial Lecture.

I shall now give a brief summary of a few important recent developments in some aspects of ionospheric physics and aeronomy in which Prof. Mitra was deeply interested.

From the information gathered at different levels in the atmosphere by instrumented rockets and satellites supplemented by ionospheric and solar radiation observations made at ground stations, we have now a fairly clear idea of the densities, temperature and composition of the earth's atmosphere and of the radiations which are responsible for the ionosphere and its variations. Fig. 1 shows a picture of the variation of air density with height derived

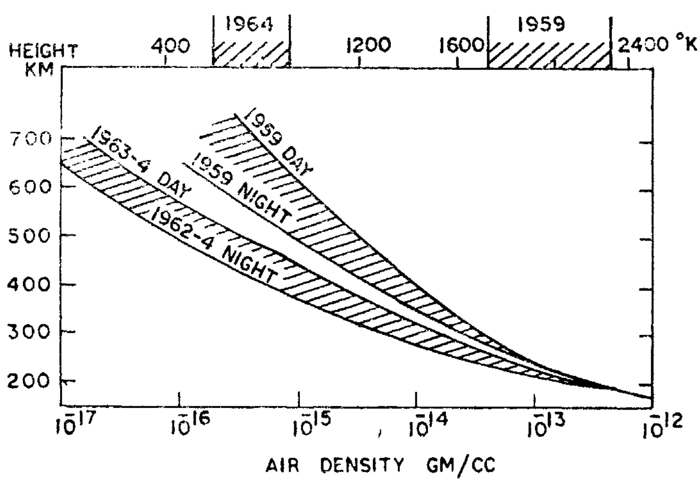

Fig. 1. Variation of air density with height from satellite drag observations for the years 1959 and 1962–64. Also thermosphere temperatures above 400 km (after King-Helle and Quinn (1965) and Jacchia (1965)).

from observations of the decelerations of satellites caused by the viscous drag of the atmosphere. The density above 200 km has a strong diurnal variation and also variations with solar activity as manifested by the changes in the intensity of solar radio waves of wavelength 10·7 or 8 cm and of the geomagnetic index of activity. There are also corresponding variations in the temperature of the thermosphere which are shown at the top of the figure. These have been elucidated by the work of Nicolet, Harris and Priester, Jacchia, King-Helle and their collaborators.

A good summary of solar radiation in the ultraviolet and X-ray regions is available in a paper by Hinteregger *et al.* (1965). Fig. 2 shows the mean solar flux outside the atmosphere in ergs cm^{-2} sec^{-1} $(10A.)^{-1}$ from 3000 to

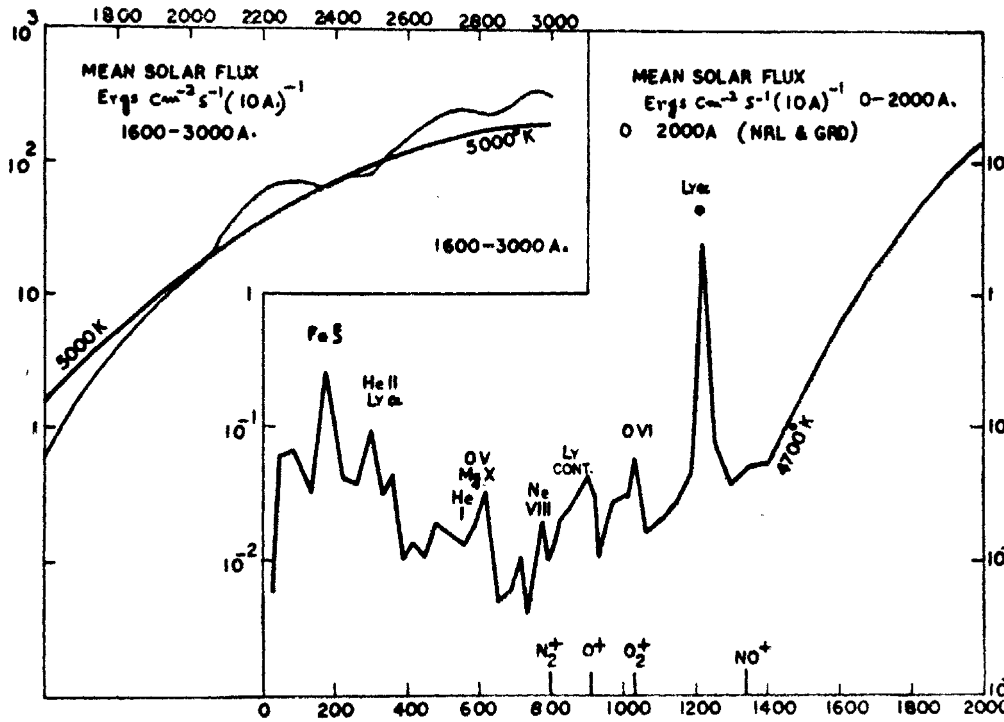

Fig. 2. Mean solar flux outside the atmosphere in ergs cm^{-2} sec^{-1} $(10A.)^{-1}$ from 3000 to 30A. as for epoch 1963 (after Hinteregger *et al.* (1965)).

30A. as for epoch 1963. While the continuous electromagnetic radiation near 1400 A. corresponds to black body radiation of about 4700° K, the radiations at higher frequencies are mainly line emissions from the chromosphere and corona and correspond to steadily increasing temperatures. At wavelengths shorter than 400 A., the emission varies considerably with solar activity. Large increases in X-ray flux at 0–20 A. occur during solar flares.

Fig. 3 shows the heights at which the intensity of solar radiation of wavelengths below 3000 A. fall to $1/e$ of its extra-terrestrial value due to absorption by the constituents of the atmosphere, O_3, O_2, NO, O and N_2. Ly α radiation and X-rays of wavelength 1–20A. are responsible for the D region of the ionosphere.

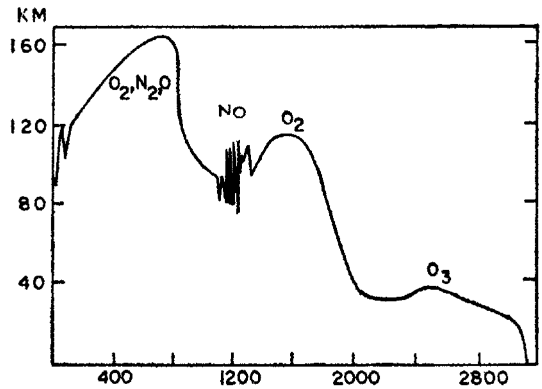

FIG. 3. Heights at which the intensities of solar radiation of wavelengths 3000–30A. fall to $1/e$ of their extra-terrestrial values at normal incidence (Friedman 1960).

Fig. 4 shows examples of two solar flares on 1-5-62 and 3-5-62 which were accompanied by strong X-ray emissions as recorded by OSO I and Ariel satellites and produced characteristic disturbances in the field strength record of 164 kHz radio transmissions from Tashkent received at Ahmedabad. In some flares, as in the one on 1 May 1962, the field strength undergoes an initial sharp fall and rapid recovery indicating that ionization is produced at low levels in the atmosphere where the collision frequency is high. Normally, the sudden commencement in the field strength record is followed by increased field strength, a comparatively slow fall lasting half to one hour and recovery. Recently, it has been observed at Ahmedabad that, on a number of successive days, the daytime intensity of low frequency radio waves is enhanced and this is followed by some days of decreased intensity. It has also been found that the decrease in field strength is associated with an increase in solar X-ray flux on 0–8A. and 8–20A. as recorded by NRL satellites. The approximate inverse relationship between solar X-ray flux and the daytime field strength of 164 kHz waves from Tashkent is shown in Fig. 5.

The absorption of UV- and X-rays is accompanied by dissociation of O_2, ionization of molecules and atoms, dissociative recombinations, and conversion of the excess energy of photo-electrons into heat by collisions with ions and neutral molecules.

The dominant positive ions in the ionosphere are:

Below 95 km	$H_5O_2^+$, NO^+ and O_2^+
95–140 km	O_2^+, NO^+ and O^+
150–700 km	O^+
Above 700 km	O^+, H^+, He^+

N_2^+ and N^+ are minor constituents

In the upper part of the ionosphere, the particles tend to be distributed according to diffusive equilibrium. The movements of electrons and ions are largely controlled by the geomagnetic field.

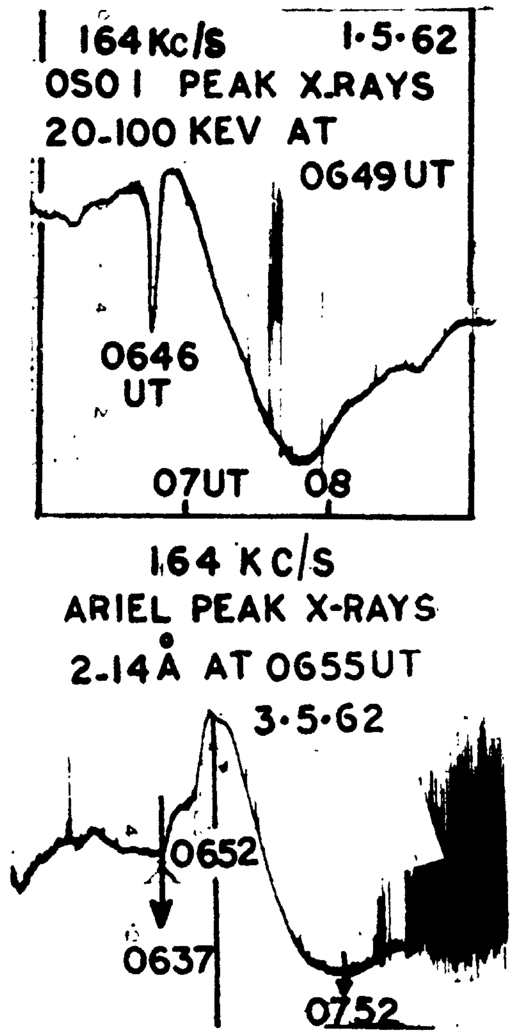

Fig. 4. Effect of solar X-ray flares on the field-strength of low frequency (164 kHz) radio waves propagated from Tashkent to Ahmedabad (Ramanathan and Ananthakrishnan 1967).

I have already referred to the equatorial anomaly in the F_2 region of the ionosphere whose explanation was first suggested by Prof. Mitra. Fig. 6 shows the mean annual noon values of f_0F_2 at stations with magnetic dip ranging from 90° N to 80° S in the years 1957-58 and 1953-54. The anomaly is more pronounced in years of low solar activity. The apparent diffusion of f_0F_2 peaks in 1957-58 is due to the fact that, in high sunspot years in winter,

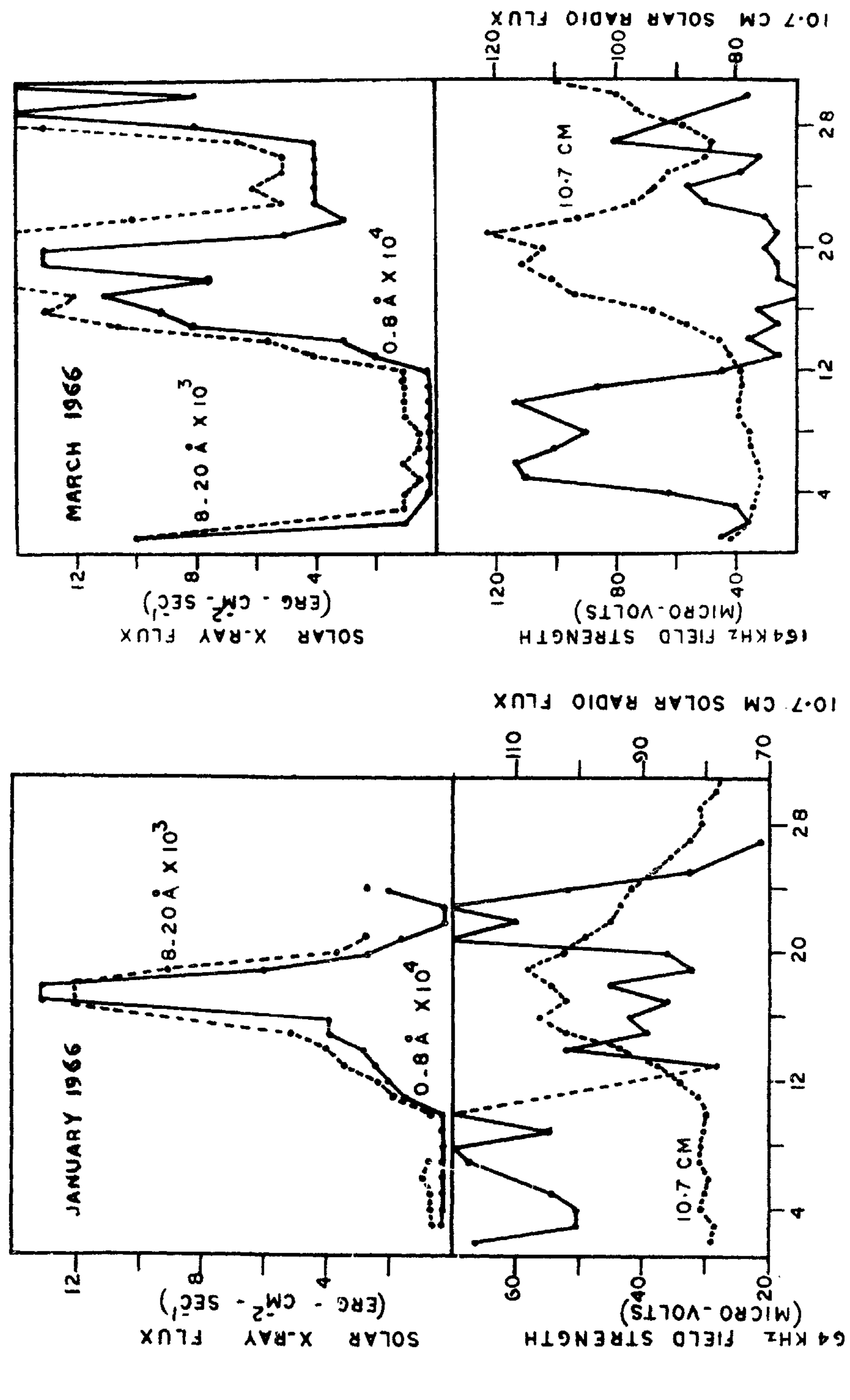

Fig. 5. 0–8 and 8–20A. X-ray emissions, 10·7 solar radio waves field strengths of 164 kHz transmissions from Tashkent received at Ahmedabad (Ramanathan and Ananthakrishnan 1967).

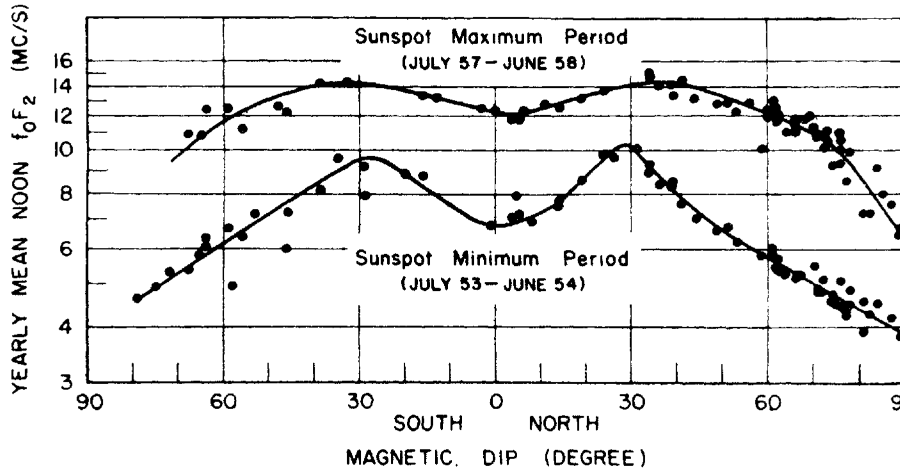

FIG. 6. Equatorial anomaly in f_0F_2 at local noon in high and low sunspot years (Rastogi 1966).

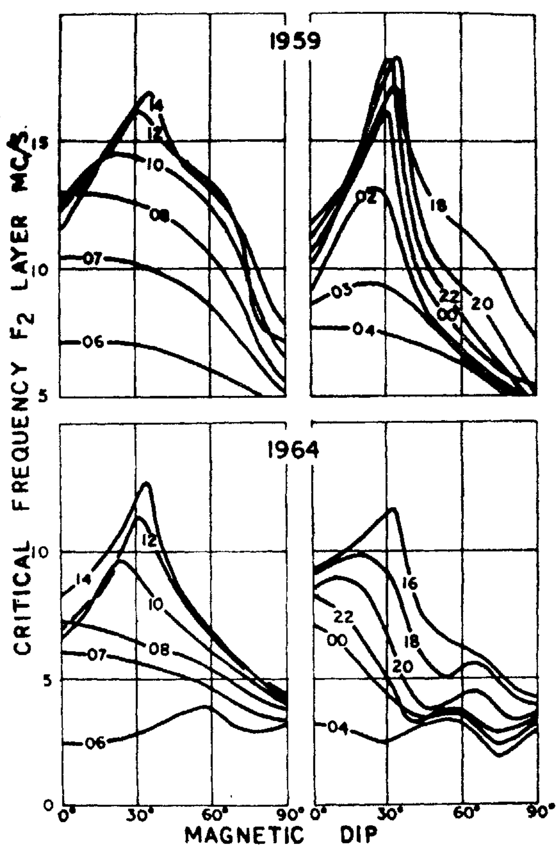

FIG. 7. Daily growth and decay of the equatorial anomaly in f_0F_2 over the northern hemisphere in years of high (1959) and low (1964) solar activity (Rastogi 1966).

another spur develops during the day at 60° to 70° dip, and this is superposed on the two symmetrical humps on either side of the equator (Thomas 1963) averaging the data over the whole year smooths out the humps. The daily growth and decay of the equatorial anomaly over the northern hemisphere in 1959 and 1964 are shown in Fig. 7. The peaks are not noticeable at 04 to 06 hr. They develop first over the magnetic equator and move towards the poles. They decay after 16–18 hr, but persist much later in the night in years of high solar activity. In 1964, a wave of high electron density could be seen to be moving from higher latitudes towards the equator.

The daytime equatorial anomaly exists not only at the f_0F_2 level but also at lower and higher levels. Fig. 8 shows the mean noon electron density distribution over Singapore longitude in the equinoctial months of 1957. The anomaly can be seen at all levels between 200 km and 360 km.

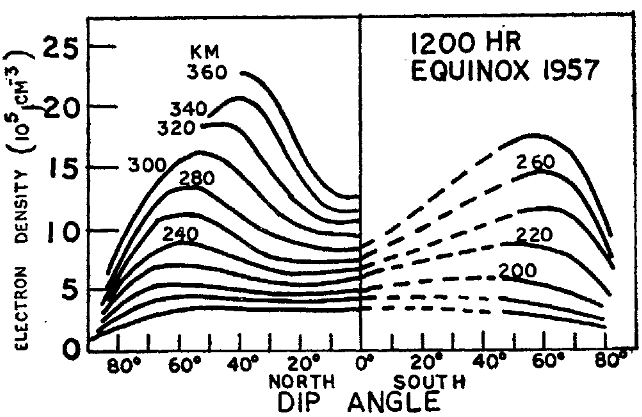

FIG. 8. Noon electron density profiles below F_2 peak calculated from ionograms (Croom *et al.* 1959).

An important development took place in 1962 when ionosondes were installed in the U.K. Ariel satellite and in the Canadian Alouette satellite. Sweep-frequency radio-waves are transmitted downward from a level of about 1000 km and the reflections are recorded continuously as the satellite moves in its orbit. They are relayed to command stations located in different parts of the globe. The electron density distributions on the top side of the F_2 peak can be calculated from the ionograms. A sample electron density distribution obtained from observations over Singapore longitude in 1964 is shown in Fig. 9. The curved line running through the electron peaks at different levels from 390 to 650 km represents the geomagnetic field line. The anomaly persisted up to about 600 km. Similar field-aligned ducts have been observed to occur temporarily at higher levels also.

An important new technique which has been introduced for studying movements in the ionosphere is by injecting from rockets vapours of substances

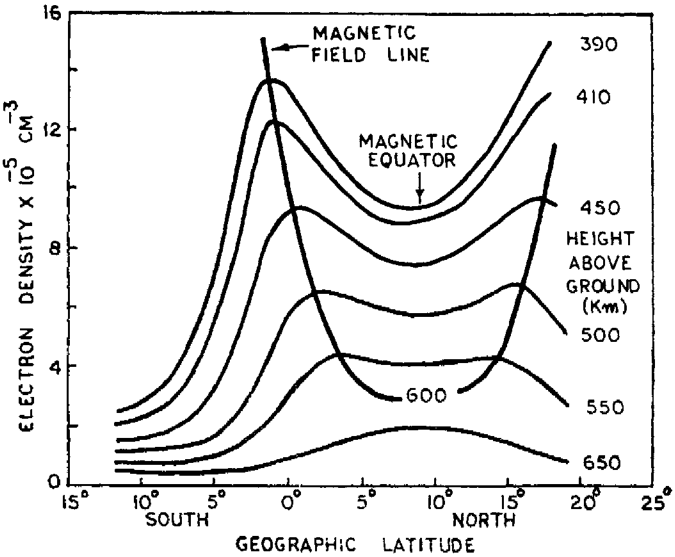

FIG. 9. Electron density profile above f_0F_2 over Singapore longitude Alouette satellite data (King 1963).

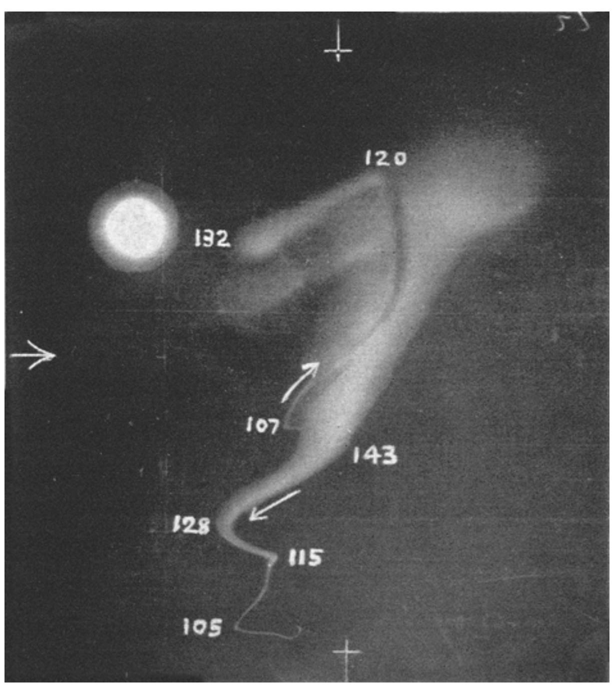

FIG. 10. Sodium vapour trail released from Thumba during evening twilight of 23-11-63 and photographed at Palayamkottai 500 sec after the launch of the rocket. Both upward and downward traces can be seen (Bhavsar and Rao 1965).

like sodium, barium and aluminium oxide. When sunlight falls on sodium vapour in the rarefied atmosphere, the vapour emits resonance radiation and can be photographed. Fig. 10 shows a photograph taken at Palayamkottai 500 sec after the launch of the rocket which released sodium vapour in the atmosphere over Thumba when the rocket was coming down after reaching its summit. The sharp changes in the trail indicate wind shears at about 105 km, 115–120 km and 130 km. The diffusion above 140 kms is rapid. The bright disk is that of the moon. When, instead of sodium vapour, barium vapour is released during twilight in the ionosphere, some of the atoms get ionized. While the neutral atoms of strontium (which is also present) diffuse symmetrically round the place of release, the ionized atoms of barium move along the lines of magnetic force and also drift perpendicular to the magnetic field. Sr and Ba^+ can be distinguished by the difference in their wavelengths. The elliptical cloud seen in the picture (Fig. 11) is the glow of ionized barium (Max Planck Institute).

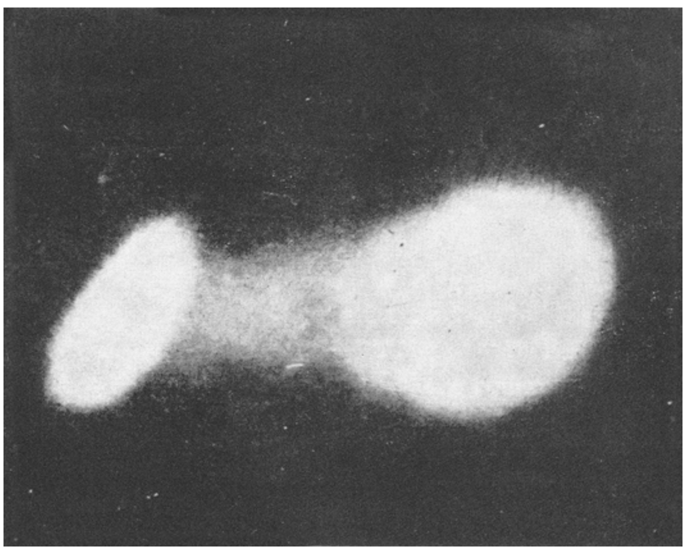

FIG. 11. Photograph of barium vapour clouds at 160 km, 500 sec after release. Note the elongated patch of Ba^+ separated from the neutral Sr patch (Haerendel *et al.* 1967).

The time is too short to say anything about the many other developments of great interest, such as incoherent scatter technique by which electron densities and electron and ion temperatures up to more than 6,000 km have been determined with the help of powerful radars or of aurorae, radiation belts and the magnetosphere.

I am indebted to articles by Prof. S. R. Khastgir, Prof. J. N. Bhar, Shri S. N. Mitra and others for some of the informations contained in the above sketch.

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