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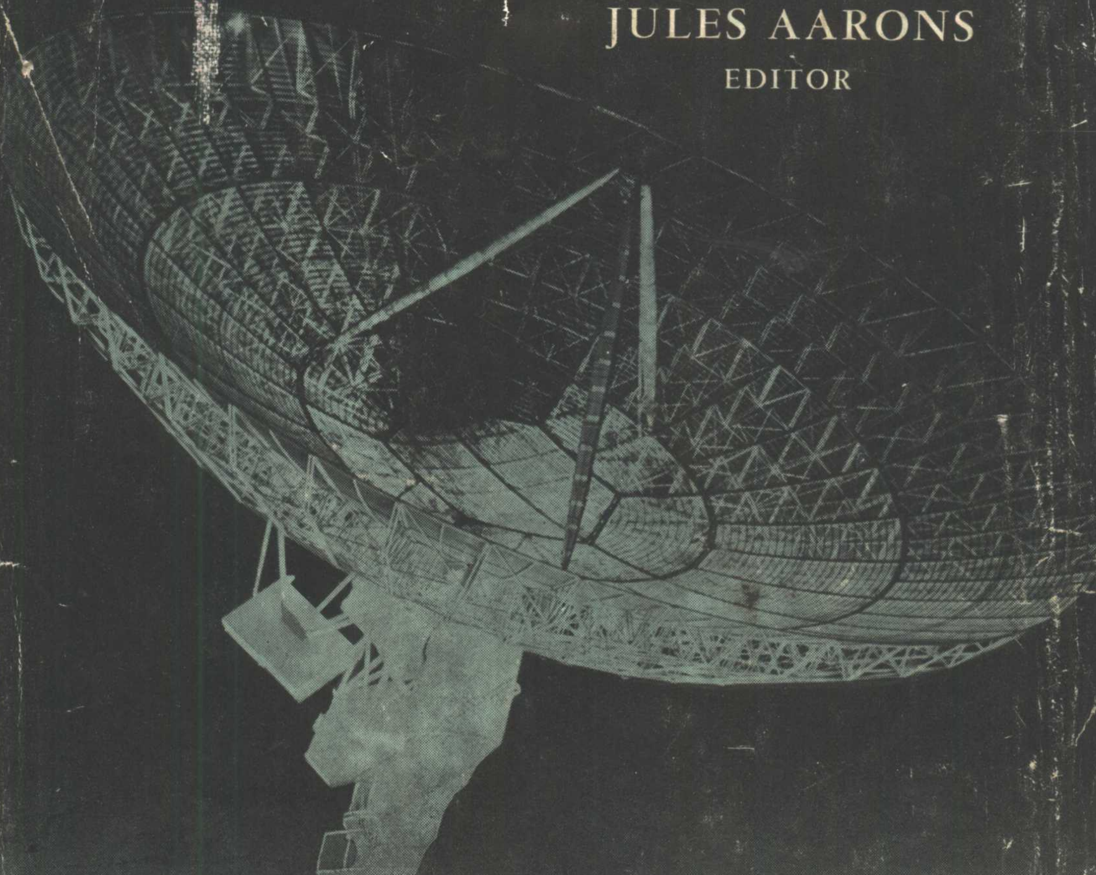

RADIO ASTRONOMICAL AND SATELLITE STUDIES OF THE ATMOSPHERE

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EDITOR

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Radio Astronomy Branch, Air Force Cambridge Research Laboratories,

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PREFACE

Michael ANASTASSIADES
Director, Corfu Advanced Study Institute, University of Athens

In order to summarize and discuss two subjects of increasing importance in the study of the earth's atmosphere and in radio wave propagation, the Advanced Study Institute of Corfu, Greece, which is under the direction of the University of Athens and sponsored by the Scientific Affairs Division of NATO, held a conference in June 1962 on Radio Astronomical and Satellite Studies of the Atmosphere.

The aim of the conference was twofold: First, to draw together those who had been active in the field and to have specialists summarize the work done to date; second, to present contributions in which recent results would be discussed in depth. It was hoped that on the basis of these presentations, it would be possible to outline the future directions of the field so that work could be concentrated on these areas which need emphasis as well as those that have been only partially explored.

As the conference proceeded it became apparent that there was need for a specially tailored satellite designed to yield total electron density data. Other scientific satellites in the field of ionospheric physics were also envisioned by the participants. Cooperative programs were planned for the future involving simultaneous measurements at different geographical areas.

The conference succeeded in drawing together specialists who compared their methods. It also provoked an interchange across specialist lines. The papers delivered at the conference were organized and written with the reader of this book in mind. It is hoped they will aid the student of atmospheric physics in understanding techniques explored in this volume.

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WHITE DWARFS

CONTENTS

INTRODUCTION

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1. *The radio stars*

Shortly after the study of astronomy by radio techniques began in earnest, a basic problem arose. Three "sources" of radio flux had been delineated: 1. the sun, 2. the cosmic noise background, and 3. the discrete sources which are called "radio stars". Initial measurements seemed to indicate that these discrete sources varied in intensity much in the same manner as the sun. It seemed as though they were exhibiting intrinsic fluctuations in intensity with a period of several seconds. The question soon arose as to whether these were true variations in the source itself, or if it actually was the atmosphere that was modulating the signals from fixed flux sources. Studies in Australia and England, utilizing spaced receivers, indicated that it was the earth's ionosphere and troposphere that was producing effects similar to the "twinkling" of visible stars. The study of "twinkling" or scintillation was the first of the upper atmospheric effects to be investigated in detail. Shortly thereafter ionospheric refraction and absorption studies were conducted that paralled those already made in the optical region of the spectrum. As early as World War II the M. I. T. Radiation Laboratory conducted absorption studies in the microwave region. At the present time, one of the most constant scientific pressures in radio astronomy is to find a discrete source that is inherently variable, such as the sun. No such fluctuating discrete source has been discovered with certitude.

The very absence of variable discrete sources has allowed the field of radio astronomical studies of the atmosphere to flourish. It means that since the source is constant, all the variables are found in the intervening atmosphere of the earth.

The use of the sun as a source for atmospheric studies has been for the most part dispensed with, except in the millimeter region. The reason for this is that the three components of solar radiation: 1. the quiet sun, 2. the slowly varying component, and 3. the component attributed to solar bursts are all varying. Therefore, the sources most frequently used for transatmospheric studies are the two strongest discrete sources, Cygnus A and Cassiopeia A. These two strong "radio stars" are the obvious choices for use since atmospheric studies are of necessity long term, and a strong non-varying source is required. If the equipment used for observation is sensitive enough and is devoid of internal fluctuation, any variation large or small can be ascribed to the atmosphere.

The types of atmospheric studies made have included measurements of 1. amplitude and phase scintillation of discrete source signals, 2. ionospheric and tropospheric absorption, and 3. vertical and horizontal refraction. The vertical measurements were made by following the risings and settings of discrete sources, whereas, the work in the horizontal plane involved interferometers. The emphasis in the atmospheric studies was placed on determining the irregularity structure of the ionosphere. Wind studies could be made by noting the ground pattern as the structure moved through space.

However, atmospheric studies of irregularities using Cygnus A and Cassiopeia A have certain limitations: 1. Since both sources are in the northern sky, only a limited area of the atmosphere is investigated. 2. Neither Cassiopeia or Cygnus is polarized. 3. As both Cassiopeia and Cygnus provide any observatory in northern and middle latitudes with an extremely long observation time each day, the ionospheric parameters change considerably as a function of solar zenith distance, as well as with the more dramatic solar flares and magnetic storms. Thus, only long term records (covering many months) can show diurnal effects. 4. The separation of geomagnetic latitude of the sub-ionospheric point from the elevation of the source poses a difficult problem. Each source at a distinct elevation goes through the ionosphere at two very similar geomagnetic latitudes. Therefore, separation of these two factors is possible only by comparing many simultaneous records taken at different observatories.

2. *Radar astronomy*

Historically, the next development was the study of lunar reflections. Again, as in the earlier measurements of discrete sources, the variations in the returned signal were an enigma. Only with the sorting out of the two causes of the lunar echo fading could progress be made. Frank Kerr of CSIRO in Australia showed that the cause of one type of fluctuation was the apparent rocking or libration of the moon as seen from the transmitting and receiving station. Scientists of the Jodrell Bank Station, England, showed that the second type of fluctuation was caused by the rotation of the plane of polarization of the signal. As the signal traverses the ionosphere, the plane of polarization is rotated because of the electron density structure within the earth's magnetic field. The rotation due to the Faraday effect allows a means of studying the integrated electron density beyond the limit of 400 kilometers, which had been the previous limit imposed by the conventional ionosounding techniques.

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3. *Satellite studies*

With the advent of transmissions from satellites, distinct capabilities were added to ionospheric studies. Transmissions from the satellites are coherent narrow-band signals whereas wideband noise is observed from radio stars. Narrow-band signals when shifted in frequency by motion of the satellite relative to the ground observer as well as by electron density variations can be measured by simple techniques. Once the motions of the source are calculated, that is the Doppler effect, the remainder of the frequency shift is due to the intervening ionosphere. Doppler techniques are thus readily available for studying total electron density and gradients of the electron concentration. Multifrequency techniques have helped to remove the ambiguities from the observations.

The antenna in a satellite is often linearly polarized. In a manner similar to that of moon reflections, the plane of polarization is rotated. The number of rotations varies with the magnetic field, the total number of electrons in the path, the geometrical parameters, and the square of the wavelength. The total rotation leads to the determination of the total number of electrons.

Many of the techniques for measuring the electron column variations (diurnal, magnetic storm, etc.) by Faraday rotation as well as by Doppler measurements are outlined in the review paper by Mass and in the contributions. By the time this volume is published, a satellite designed to eliminate the ambiguities in many of the methods described will be near launch. The design of this satellite has been made with both the previous knowledge and the present needs of the ionospheric physicists in mind.

The use of polarization rotation for study of total electron content as a function of latitude, diurnal variation, and magnetic storm conditions has already contributed distinctly to ionospheric and exospheric studies. The extension of the electron density work into computer programs will allow for synoptic studies over large geographic regions, for more extensive measurements of horizontal gradients, and for longer period precision measurements.

Conversely, the fund of knowledge obtained to date has reoriented the satellite instrumentation program so that planned experiments are set up to advance our knowledge beyond presently available observations.

4. *Intercomparisons*

In the field of atmospheric studies, it has been axiomatic that the less the data, the greater the number of hypotheses. Coordinating the work of many observatories or many types of observations is a complicated operation. Calibration techniques, antenna patterns, the interpretation of specific experiments, etc. all enter into a coherent picture. Nevertheless, the trend must of necessity be away from isolationism and toward the understanding of the totality through mutual effort. This statement appears trite, but intercomparison of observations of a single flare and of a magnetic storm in all of its ramifications is rare in the literature.

Within the field of transatmospheric studies a new technique has been evolved, that of incoherent scatter. Scattering from individual electrons in the range of perhaps 100 per cubic centimeter is now possible, thus offering a method for determining the electron density structure out to several thousand kilometers. The method holds many possibilities for studying not only electron density, but also constituent ions, and variations in the earth's magnetic field at these distances, as well as other parameters. The equipment needs are considerable: high power transmitters, extremely large aperture antennas, and sophisticated receiver and data handling equipment. The contrast to the simple needs of the satellite observatories is great, but the combination of methods can yield world-wide observations which can be fully interpreted.

In principle, therefore, one can make simultaneous measurements of electron density structure, variations, and gradients by ionosounders (to the maximum height of the F-layer), by satellite transmissions (to the height of the satellite), by incoherent scatter (to the height determined by the parameters of antenna-transmitter-receiver combination), and by lunar reflections and lunar pulse dispersion techniques (from ground level to the moon). In practice, however, these measurements remain to be made over a sufficiently long period of time to ascertain their validity.

5. *Absorption by cosmic noise techniques*

Not only do we receive radio frequency energy from point sources such as Cygnus A and Cassiopeia A, but also the cosmic noise background radiation provides us with a high level signal in the radio spectrum up to approximately 100 Mc/s that allows us to study the intervening terrestrial atmosphere. When receiving signals from the discrete sources (usually < 5' of arc) the radio observatory has need of a highly directive antenna and receivers that are extremely sensitive and stable. However, the detection of the signal emanating from the broad sky pattern is such that simply attaching an antenna to a reasonably good receiver will produce a signal level much higher than that created in the receiver itself. The only real problem for studying the absorbing medium between earth and sky is the stability of the receiving equipment. By using one of several modern radio techniques, the required stability may now be achieved, and thus means for studying absorption in the D-, E- and F-layers of the ionosphere now exist.

The I.G.Y. emphasis on large scale geographical deployment of these instruments has led to a clearcut separation of the various types of absorption. Polar cap absorption, the proton produced absorption after some large flares, is the most drastic decrease of signal. The time of flight of protons from the flare eruption on the sun to the start of the slowly increasing absorption is readily seen. Day-night variations, geomagnetic extent of the polar cap and relationship to flare parameters have been some of the factors studied by the network of simply instrumented receiver-recorder combinations. Auroral absorption, as well as the relationship of the D- and F-layers to absorption in middle latitudes, is also subjected to scrutiny by the continuously operated multi-frequency stations. The observational material is making possible a more accurate interpretation of recombination mechanisms.

6. *Planetary studies*

The radio astronomer studies the planets both by reflection techniques and by passive observations, perhaps in some cases only measuring energy from the planetary atmospheres. Sampling radiation from the planets across the radio spectrum has produced some exciting observations. Interpretation of these observations is not complete at this time as the science of planetary atmospheres is still in its infancy. However, the radiation from Jupiter, its burst-like character in the decameter wavelength portion of the spectrum, the polarization of the signal evidenced in decimeter measurements, and the equivalent black body temperatures in the microwave region has given us the opportunity to build up a reasonably clear picture of Jupiter's atmosphere.

7. *The summary and the future*

It is a necessity for any study group to conclude the formal program of a discussion session with the topic of "Whither?". A review must be made of the direction of present research, as well as a speculation on future work. The Advanced Study Institute, therefore, held informal discussions on needed research, as well as the possibilities of different avenues of approach to transatmospheric studies. A summary of the directions indicated by the participants follows.

In reviewing the work to date on radio astronomical and satellite techniques for atmospheric study one is struck by the advantage gained when one technique or type of measurement is supplemented by a second. The frozen picture of the ionosphere when a satellite passes from horizon to horizon in a few minutes can be contrasted to the slow atmospheric changes recorded by radio star and moon reflection techniques. The instrumental complexity and enormity of the incoherent scatter station is in sharp contrast to the simplicity of satellite ground receiving equipment. The minimum data for any ionospheric study are supplementary solar and magnetic observations; the needs for the total picture include many simultaneous measurements of the same phenomena.

Many suggestions for future satellite instrumentation for ionospheric studies were put forth. Most scientists in the field anxiously await the ionosphere beacon units with their closely spaced frequency transmissions, coherent oscillations and multi-frequency output. Using this instrument, many of the problems brought to the fore in the chapters on electron density measurements will be eliminated and the data analysis will be relatively simple and unambiguous.

In addition to the presently planned satellites, C. G. Little suggested measuring differential absorption of the ordinary and extraordinary modes at frequencies not too far from the critical frequency of the F2-layers. The technique would be comparison of depth of Faraday fading nulls to determine the ratio of 0 to E-modes. J. Warwick emphasized the needs for a 1 - 2 Mc/s radiometer placed in a polar orbit satellite, whose purpose would be to attempt to detect emission at the gyro frequency of electrons in the earth's magnetic field. The importance of the inclination of the satellite was stressed since observations of cosmic noise in the 1 - 10 Mc/s portion of the radio spectrum are being planned. T. Hartz pointed out, for example, that the Canadian topside sounder will monitor cosmic noise in this range at the 1 000 kilometer height level.

In reviewing the transatmospheric studies at middle and equatorial latitudes there appeared to be many avenues of research that have relatively small efforts attached to them. The small number of observatories working in these geographical regions, many of them inadequately equipped compared to auroral zone geophysical institutes, could well be better instrumented during the International Quiet Sun Year. M. Anastassiades outlined the sparcity of riometer sites, particularly of the multi-frequency variety at middle latitudes. The International Geophysical Year with its emphasis on solar activity stressed auroral research; the IQSY could well put its resources behind middle latitude and equatorial region research. E. Golton described future work in Singapore, designed to emphasize the variation of upper F-regions profiles in equatorial regions.

At the present time there are only a small number of observatories working in low latitude regions and they are performing measurements over a very limited range. Closely spaced riometer studies, differential mode absorption experiments and ELF-VLF observations all hold possibilities for future middle and low latitude work.

On the subject of multi-discipline interrelationship research, the increased needs for "relating" were apparent to all. Fitting a total picture to an individual observation requires consistent long term solar measurements. Satellite observations are needed to go beyond the present measurements of density variations, a very significant and needed addition to atmospheric physics. H. Kallmann-Bijl outlined ideas of needed measurements on ion and neutral particle densities as a function of height, diurnal variation, and solar ionospheric conditions. Future space programs should include rocket measurements in addition to satellite observations for low altitude data, as well as information on fluctuations in the 200 km region and beyond.

On the subject of absorption, B. Landmark and B. Hultqvist both agreed on the need for additional observations using both balloon and rocket techniques to supplement ground measurements. Within the sphere of ground measurements, comparison of data from the cross modulation and the riometer techniques are needed. The expansion of absorption measurements at low latitudes is certainly of importance in understanding the mechanism of absorption in detail.

The radar reflection technique, with both man-made targets and natural satellites, is not outmoded by satellite transmissions. G. Millman advocated the use of high frequencies (400 Mc/s) for Faraday rotation studies emphasizing the ease in eliminating ambiguities from single frequency measurements by use of this band. He stressed the need for total refraction studies through the earth's atmosphere. The possible future of incoherent scatter was outlined. Valuable contributions from this field would yield a better understanding of geomagnetism, the constitution of the atmosphere, and of electron and ion physics.

N. Taylor suggested the extension of the Faraday technique to other planets. The possibilities of planetary atmosphere exploration by Faraday rotation observations are quite exciting. This research would lead to an increased understanding of the magnetic field of the planets, the ionized atmosphere, and solar control data.

8. *Conclusion*

Coming away from an intensive session of this type, two divergent ideas seem to be present: one that everything is done and done well and conversely the nagging thought that only a rough beginning has been made. Even if atmospheric physicists look backward, they must explore the available data more fully. As C. Dieter pointed out, the systematic exploration of a known technique to obtain synoptic information calls for observations made with automatic data analysis equipment and a computer program.

Certainly once an end is in sight, tedious data analysis is archaic. However, even in space physics the role of the computer, despite its enormous capability, never can completely replace the creativity and ingenuity of a trained analyst who personally checks over his data.

STRUCTURE AND COMPOSITION OF THE ATMOSPHERE

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Abstract: The structure and composition of the atmosphere are discussed. Numerical values of atmospheric parameters are presented in the form of tables and graphs. Average values of density, pressure and temperature for both daytime and nighttime atmospheres were calculated for a time of medium solar activity. Numerical data are given for the hourly variations of density, pressure, scale height, heat flow, molecular weight, and temperature at 350 and 650 km in 2-hour intervals over a 24-hour period. These values also refer to medium solar activity. It is shown that at an altitude of 650 km, the density during minimum solar activity at night, may differ by a factor of 200 from the daytime density at solar maximum.
Major and minor constituents were calculated for a model atmosphere at 120 km. Between 90 and 400 km, number densities of molecular nitrogen and oxygen and atomic oxygen and argon were determined under the assumption that molecular oxygen begins to dissociate at 90 km, and that diffusion becomes effective at 110 km. It is shown that around 110 km, the number density of atomic oxygen is comparable to the number density of argon and that argon cannot be neglected in studies of composition at these altitudes. Neither can helium or hydrogen be neglected, although their number densities are considerably smaller than nitrogen and oxygen, and especially this is true at higher altitudes, where helium and hydrogen play a leading role in the atmosphere.

1. INTRODUCTION

Results obtained in recent years, primarily by means of rockets, satellites, and space probes, are summarized here. Great efforts have been made in various countries to obtain these results, but it is well to emphasize the great difficulties involved in analyzing and interpreting these new observations. Therefore, it must be stressed that the results presented here are neither perfect nor final. They are subject to changes when more systematic and accurate observations become available.

The subject has been divided into two parts.

1. Density, pressure, and temperature.
2. Composition of the atmosphere.

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