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CURRENT PROBLEMS IN RESEARCH

Solar Research from Rockets

The greatly broadened spectrum above the atmosphere opens a new realm for astrophysics.

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Study of the sun goes far back into history, but solar astrophysics is a relatively new and rapidly expanding field. The spectroscope is the key instrument. Although invented three centuries ago by Newton, its first important application to solar research was made in 1802 by Wollaston, who noted the presence of dark lines in the solar spectrum. Twelve years later Fraunhofer studied these lines in detail and showed that they are invariable in position. In 1861 Kirchhoff explained the Fraunhofer lines as produced by a cool reversing layer near the sun's limb, with temperature lower than that in the underlying bright photosphere. Only in recent years has this useful concept been shown to be an oversimplification, a better model being one where both Fraunhofer lines and continuum are formed together in a region whose temperature falls gradually to a minimum at the limb.

Photography, developed by Niepce and Daguerre in 1839, soon made possible the recording of the solar spectrum and especially of the ultraviolet. This was first accomplished by Becquerel in 1842, and was carried to great perfection by Rowland, in 1882, with the aid of his concave diffraction gratings. Then came the invention of the spectroheliograph in 1891, by Hale and by Deslandres independently, which has led to the daily recording of the changing conditions on the sun by monochromatic photography of the disc.

The corona has been studied intensively, over the last century, during the brief periods of total eclipse. Lyot's invention of the coronograph in 1930, however, has made the inner corona visible at any time when the sky is really clear. With coronographs at stations scattered widely over the earth, the million-degree coronal line emissions are now monitored on a 24-hour basis.

Perhaps the most important question concerning the sun is the process by which its energy, released deep inside by the conversion of hydrogen into helium, is transmitted out through its atmosphere and radiated to the earth. An understanding of the details of this process is needed for the explanation of many solar phenomena. For example, one of the most mystifying is the 11-year periodicity in the sun's radiation output, which affects our lives in many ways. Although the total energy radiated changes so little as to defy detection, there is a many-fold increase in x-ray emission at solar maximum, as has been discovered through rocket experiments. During flares, which become far more common at maximum, emission of hard x-rays takes place, causing ionization deep within our atmosphere and radio blackout. Though the periodicity must originate in the unseeable interior, a complete understanding of the outer regions whose radiations can be studied will surely go far toward providing the explanation.

The general nature of the sun's atmosphere is now understood from intensive study of its spectrum in the visible and near ultraviolet. There is no agreement as yet on the exact atmospheric model, and many types have been proposed. A suggested schematic model is shown in Fig. 1. The temperature falls, from the center outward, from a high value inside the sun to a minimum near 4700°K at the limb. This region is the photosphere, where the white-light continuum originates; the blue, near 4500 angstroms, is the most intense and comes from farthest inside, where the temperature is nearly 6600°K; the red and the ultraviolet come from regions closer to the limb, which are cooler. Superimposed on the continuum are the Fraunhofer absorption lines, explained by Kirchhoff's cool reversing layer.

It is now known that the temperature above the limb rises to a value of nearly one million degrees in the corona. Before the eras of rocketry and radio astronomy, this region could be studied in detail only during a solar eclipse. At the moment when an eclipse becomes total, the spectrum of the chromosphere, just outside the limb, flashes into view. In this flash spectrum the Fraunhofer lines appear as emission lines, because the photosphere and its brilliant continuum are cut out by the moon. However, lines of ionized helium, which are not present as Fraunhofer lines, are observed in the flash spectrum. Their existence requires temperatures in excess of 20,000°K. This was the first evidence that the temperature in the chromosphere rises with altitude. Farther out, the long unidentified green line at 5303 A in the corona was shown by Edlén in 1940 to be produced by Fe XIV. The presence of

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this highly ionized atom was indisputable evidence that the temperature must rise to about $10^{6\circ}$K in the corona, since lesser energies are not sufficient to strip 13 electrons from an atom of iron.

Thus arose a problem which is still unsolved: How can the corona sustain a temperature near $10^{6\circ}$K, unless energy is received from a region that is still hotter? The deep interior of the sun is indeed sufficiently hot, but the cool outer layer enveloping it acts as a screen to prevent radiation from transferring the energy.

It was clear that the inaccessible extreme ultraviolet would provide answers to many questions about the chromosphere and corona, because the resonance lines of atomic species that exist at these high temperatures lie at very short wavelengths. Observation of the sun in the extreme ultraviolet has been prevented, however, by the earth's atmosphere. From the ground, ultraviolet solar emissions can be detected only to about 2900 A. This abrupt termination of the spectrum was shown in 1913 by Fabry and Buisson to be caused by ozone in the earth's atmosphere. Despite attempt after attempt, this limit could not be exceeded, even through the use of stratosphere balloons, since the ozone layer is too high. All that was required to break through this impasse was a means of carrying equipment to still greater altitudes.

Rocket Spectroscopy

Through rockets, first made practical by the Germans during World War II, this dream of astronomers has been realized. It is now possible to study the solar radiations across the entire electromagnetic spectrum. The expense is high, but the rewards are great. The solar spectrum, in former times known hardly at all outside the frequency range 10^{14} to 10^{15} cycles per second, has now been observed all the way to 10^{19} in x-rays. A similar breakthrough has been made toward the red, where the spectrum is now observed to 10^{8} cycles per second by means of radio techniques, also resulting from developments of World War II. Thus, the width of the window has been increased from 1 power of ten to 11 powers of ten.

The first "rocket ultraviolet" solar spectrum was obtained by the U.S. Naval Research Laboratory (*1*) in 1946. For historical interest, and to point up the progress made in 15 years, it is reproduced in Fig. 2. This established indisputably the height of the ozone layer and the fact that little absorption by ozone remains at 55 kilometers. There was much excitement over this spectrum, and especially over the great absorption doublet of ionized magnesium (2802.7, 2795.5 A), corresponding to the well-known near-ultraviolet H and K lines of ionized calcium. Improved spectra, from which detailed

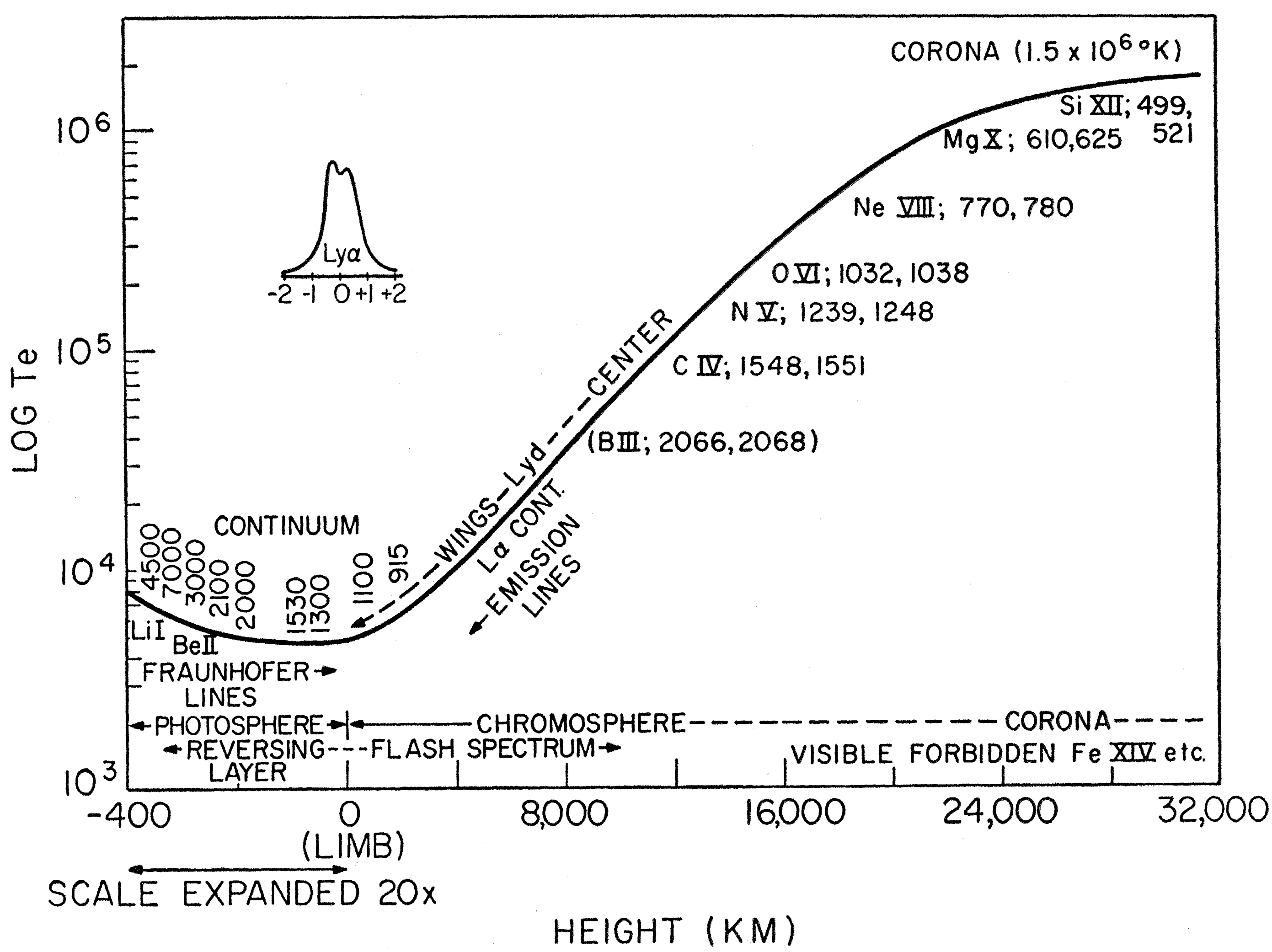

Fig. 1. A schematic model of the electron temperature in the solar atmosphere, showing the approximate positions from which the various radiations originate.

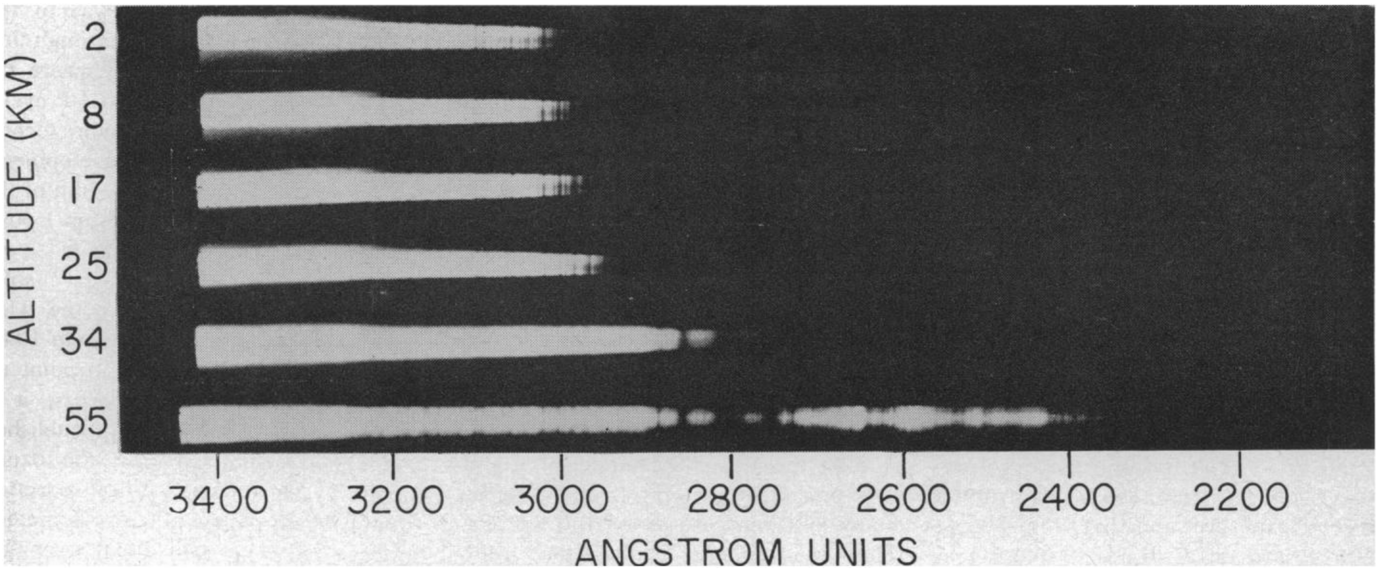

Fig. 2. The first spectrum of the sun obtained from a rocket, as photographed from a V-2 rocket by the U.S. Naval Research Laboratory (*1*), 10 October 1946. When the spectrograph was above the ozone layer the spectrum extended far into the ultraviolet.

studies of these emissions could be made, were eagerly awaited.

From the beginning it was apparent that rocket-borne laboratories would present many special problems not encountered in ground-based spectroscopic laboratories. The greatest difficulty is the shortness of the time available for observing. The Aerobee-High rocket, now in common use for astrophysical research, provides but 5 minutes of time above 100 kilometers, and only 2 to 3 minutes above 200 kilometers, the altitude above which there is very little absorption. Satellites now offer a possible means of surmounting this time limitation, and we may expect many advances to be made during the next 5 years, from orbiting solar observatories.

A second difficulty encountered with rockets is their unpredictable roll, yaw, and pitch. The spectrograph must be directed accurately at the sun if useful records are to be made in the short time of flight. The solution of this problem lay in the development of a solar pointing control with which a spectrograph could be aimed continuously at the sun during flight. The University of Colorado (*2*) succeeded in making the first practical biaxial pointing control. This device will point 40 pounds of equipment at the sun with an accuracy within 1 minute of arc and has made it possible to obtain excellent solar spectra.

At White Sands, recovery of photographic records has turned out not to be difficult. Almost always the film casette has been located undamaged, even after the most severe impact. More recently, however, parachute recovery of equipment has become feasible, and this offers the possibility of saving the entire instrumentation for recalibration and re-use.

The sun itself, however, continues to be a challenge to spectroscopists. Even if it were available in the laboratory, with none of the problems associated with rockets or satellites, the sun would still be extremely difficult to study, for the reason that its spectrum becomes fainter and fainter with shorter and shorter wavelengths but is extremely intense in the visible. Since most detectors of extreme ultraviolet radiation also respond well to the visible and near ultraviolet, and since only one-millionth of the sun's total energy falls in the spectral region below 1000 A, the problem of suppressing instrumental stray light is critical. It is not difficult, in principle, to reduce the stray light by as large a factor as is necessary, but this must be accomplished without reducing the intensity of the short wavelengths themselves, which are already faint.

Many advances have been made in stray-light suppression. An excellent method is the detection of the radiation by a photomultiplier with a metal cathode. Metals have extremely low photoelectric yields for wavelengths greater than about 1300 A, but at shorter wavelengths the yield becomes high; thus, they are relatively blind to the intense long-wavelength portion of the solar spectrum which produces most of the stray light. Using such a photomultiplier, combined with a grazing incidence spectrograph in which the stray light intensity is extremely high, Hinteregger (*3*) has succeeded in reaching 65 A with a resolution of the order of 5 A.

For obtaining spectra of the greatest resolution, photographic film must be used, and this is highly sensitive to the stray light. In the most recent experiments by the U.S. Naval Research Laboratory (*4*) the stray light has been suppressed by combining two spectrographs in series. The first spectrograph consists of a concave grating which receives the sunlight, and which is arranged to disperse the spectrum up and down the slit. A second concave grating located behind the slit disperses the light at right angles to the slit and forms a spectrum in the usual fashion. Spectra obtained with this instrument are reproduced in Fig. 3. The combination of the two dispersions at right angles makes the spectrum look strangely distorted. However, double dispersion proved to be a successful method of freeing the spectrum from contamination by stray light, at least to wavelengths as short as 800 A.

For recording the very faintest emissions it was necessary to make use of the most sensitive photographic emulsions, and of reflecting coatings and diffraction gratings of the highest efficiency. Contributing to the success of the spectrograph were the special Schumann-type, gelatine-free photographic film of Kodak-Pathé in France, produced by a centrifuging process described by Audran (*5*); the high-reflectance coating, magnesium fluoride over fresh aluminum, described by Hass and Tousey (*6*); and the blazed tripartite replica diffraction gratings ruled by Richardson at Bausch and Lomb.

The spectrum reproduced in Fig. 3 is a composite of several exposures selected to present as wide a range as possible in a single reproduction. The spectrum at the bottom was the best exposure, covering the range 950 to 1400 A. The spectrum at the top consists of three parts; the region from 1550 to 1170 A is from one exposure, that from 1170 to 805 A is from a second exposure, and that from 805 to 500 A is from a third. The portion at upper left was produced by the second-order image from the external grating and the first-order image from the main grating, while the portion near 600 A at the bottom of the left-hand area was from the first-order image of the first grating. There is a trace of fog at the short-wavelength end, produced by light from a small leak which opened during flight, but except for this, there is no contamination of the spectrum by stray light. The region from 1500 to 2300 A is shown in Fig. 4 (photographed with a single-dispersion spectrograph); it is pieced together from the best spectra obtained on several earlier flights.

Changing Character of the Spectrum

The spectra reproduced in Figs. 3 and 4 show the dramatic change that takes place in the character of the solar spectrum as one looks deeper and deeper into the ultraviolet. At wavelengths longer than 2085 A the spectrum is a continuum crowded with dark Fraunhofer lines, not greatly different from the visible spectrum. Below 1530 A the character is completely changed. Here the continuum is smooth; no Fraunhofer lines are present, but in their place there are many intense emission lines.

With the aid of the model of Fig. 1 it is possible to interpret, qualitatively, many of the features of the spectra. The photospheric continuum with Fraunhofer lines becomes less intense, and originates closer to the limb, at the shorter wavelengths; at 2100 A the brightness temperature of the continuum is 5500°K, and the Fraunhofer lines dip down to about 5000°K. Below 2085 A the spectrum suddenly becomes weaker and the Fraunhofer lines almost vanish, as may be seen from Fig. 4. The cause is continuous absorption of some kind, which makes it impossible to see between the Fraunhofer lines into the deeper layers. The emission level is at 5000°K. Below 2050 A the Fraunhofer lines become a bit more conspicuous again but remain far weaker than above 2100 A. The Mg I line at 2026.5 A is intense, as is the double broad feature at 1935 A, produced by autoionization transitions of Al I.

It is tempting to ascribe the onset of continuous absorption at 2085 A to the ionization continuum of aluminum, whose ionization limits lie at 2076.1 and 2071.3 A. The great depth of the aluminum autoionization lines, which reach a temperature level of 4700°K, and the presence in the spectrum above 2100 A of a number of the Al I absorption lines in the series leading up to these limits, support this explanation. This portion of the continuum, therefore, can be interpreted as arising from a region close to that of minimum temperature, with the aluminum autoionization lines arising from the minimum-temperature region.

The spectral region from 1850 to 1550 A, shown in Fig. 4, is most interesting because it arises from the region of minimum temperature and has contributions from the photosphere below and the chromosphere above. It is the transition region between the normal Fraunhofer spectrum and the extreme ultraviolet emission-line spectrum. Here all three types of spectrum are present together—the continuum, Fraunhofer lines, and emission lines. At the resolution presently obtainable it is not easy to determine which features are emis-

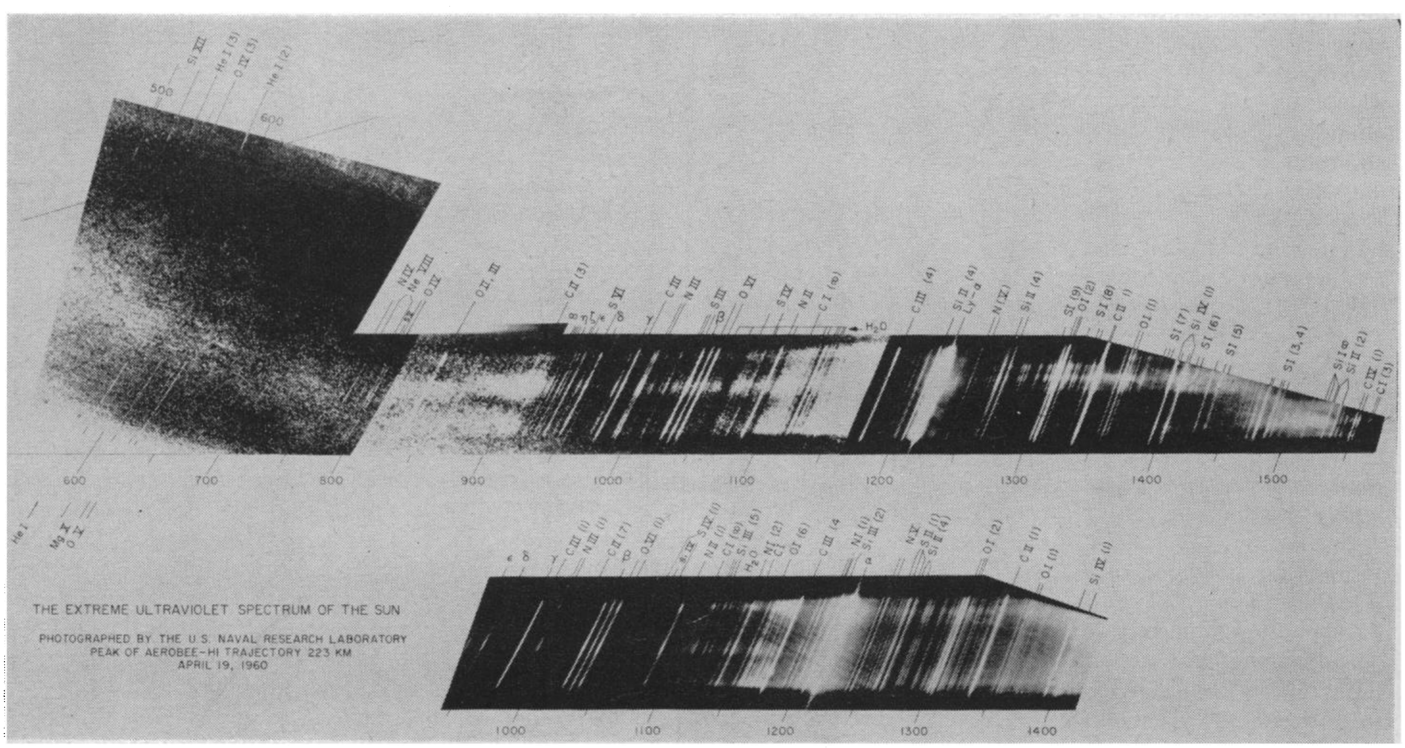

Fig. 3. The extreme ultraviolet spectrum of the sun, photographed with a double-dispersion spectrograph from an Aerobee-High rocket by the U.S. Naval Research Laboratory on 19 April 1960 (*4*). The upper spectrum is pieced together from three exposures, with joints at 805 and 1170 A.

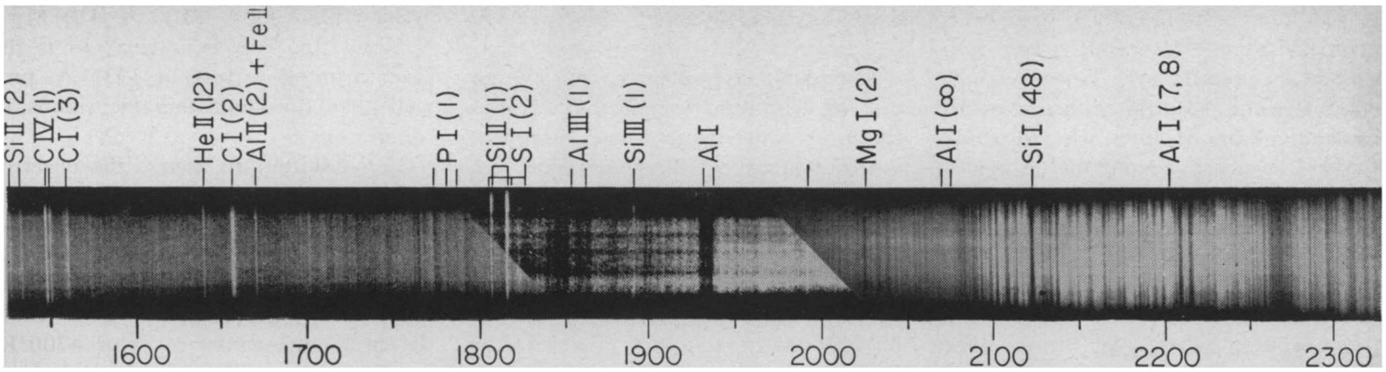

Fig. 4. The solar spectrum from 1500 to 2300 A, photographed with a single-dispersion spectrograph by the U.S. Naval Research Laboratory. The three sections were obtained with different instruments.

sion and which are absorption, in many instances. The Fraunhofer lines can be traced toward short wavelengths to 1770 A. The longest emission line appears at 1993 A, but the first strong emission lines are those of Si II, at 1808.0 and 1816.9 A.

Much of the faint structure between 1700 and 1600 A appears to be produced by emission lines of Fe II, and from Fe II, of course, arise many strong absorption lines above 2000 A. If the Fe II emission comes principally from a region just above the temperature minimum, at the very bottom of the chromosphere, it would be expected to appear as emission lines above the 1600-A continuum, which arises from the lowest temperature region, and as Fraunhofer lines against the higher-temperature continuum for wavelengths greater than 2100 A. The situation is similar for neutral sulfur, whose multiplet containing the raie ultime near 1800 A is seen faintly in absorption. The higher multiplets of the series appear at wavelengths below 1500 A in emission. Thus, neutral sulfur lines also appear to be radiated from the bottom of the chromosphere, just slightly above the region of minimum temperature. In order to complete a study of the distribution of atoms in this region it will be necessary to obtain spectra at higher resolution and also to determine in the laboratory the absorption cross sections for the various atomic lines involved.

The continuum below 1530 A has no Fraunhofer lines (see Fig. 3). There are a few regions where absorption is evident—for example, near 1120 A. These absorptions are not solar but are produced by water vapor carried with the spectrograph and rocket.

The absence of any Fraunhofer lines at wavelengths shorter than 1530 A means that there can be no region in the line of sight at a temperature lower than that of the region from which the continuum arises. Since the brightness-temperature level varies between 4700° and 4750°K from 1530 to 1280 A, the radiation must arise from the region extending from the temperature minimum a short way outward into the chromosphere.

The ending of the Fraunhofer region at 1530 A may be the effect of the capture continuum leading to Si I, whose ionization limits are 1526.26, 1522.86, and 1521.07 A. Silicon is an abundant element, and many lines of Si II in emission, and of Si I in absorption, are intense; therefore the capture continuum would be expected to be important.

The Lyman-α line of hydrogen, 1215.67 A, is the most intense feature of the extreme ultraviolet spectrum. Below 1280 A the continuum rises rapidly as the Lyman-α line is approached, then falls on the short-wavelength side. Here the emission is produced by hydrogen in the broad wings of the Lyman-α line. The continuum is surprisingly intense below 1150 A, however, and in the original spectrum it can be traced all the way through the Lyman series of hydrogen. Its brightness temperature never falls below 5100°K.

The origin of the continuum below 1200 A is not entirely understood. A considerable portion must be produced by the wings of the higher members of the Lyman series of hydrogen. Still another contribution appears to come from the capture continuum leading to C I, whose ionization limits lie near 1101 A, and a similar contribution may be attributed to S I beyond its ionization limits near 1200 A. This radiation must come mainly from the chromosphere, perhaps within 2000 kilometers of the limb.

Emission Lines

The most exciting features of the extreme ultraviolet spectra obtained with rockets are the emission lines. The various lines arise from different layers in the chromosphere and corona, and thus they may provide a great deal of information about the distribution of material and the physical processes occurring in this little understood region, where local thermodynamic equilibrium does not exist. Perhaps the best example is the lithium-like isoelectronic sequence of resonance lines, which produces line pairs extending throughout the entire spectrum, as may be seen in Fig. 3. These lines are entered on the temperature model of Fig. 1 in accordance with calculations made on the basis of the method of Woolley and Allen (7). Each succeeding element in the isoelectronic sequence requires greater energy to strip the electrons down to one in the L-shell. Therefore each must be produced farther out in the region leading to the corona, where the temperature is sufficiently high to furnish the appropriate energy.

The first members of the lithium sequence are, of course, the resonance pair of Li I, the well-known laboratory lines in the red. Because lithium is easy to ionize, these lines are not seen as Fraunhofer lines in the light of the photosphere but can be seen in sunspots, where the reduced temperature increases the concentration of neutral lithium. Next in the sequence is Be II. These lines, at 3130.4 and 3131.1 A, are observed as faint Fraunhofer lines against the photospheric continuum. They originate in the reversing layer. Twice-ionized boron has its resonance lines at 2066.4 and 2067.9 A, and according to calculation should arise from a region well out in the chromosphere. However, since boron is probably at least four times less abundant than silicon, whose lines are present in this spectral range, it is not surprising that its lines do not show above the nearby moderately intense photospheric continuum. The resonance lines of C IV, however, show strongly in the spectrum at 1548.2 and 1550.8 A; according to calculation, these should arise from a region of the chromosphere where the temperature is close to 80,000°K. Next in the sequence is N V, which can be seen at 1238.8 and 1242.8 A. These lines are followed by the O VI lines, at 1031.9 and 1037.6 A, which are very intense because oxygen is an abundant element in the sun. They arise from near the top of the chromosphere, where the temperature has reached 200,000°K. Next in the sequence would be F VII, but this line is not seen because fluorine is a rare element. The resonance lines of Ne VIII, however, are present in the spectrum, at 770.4 and 780.3 A. These are the first lines of neon to be discovered in the spectrum of the sun and the first direct proof that neon is present in the sun. Their discovery was not unexpected, since neon has been identified in stars and its cosmic abundance is equal to that of carbon. The lines of neon arise from a region very high in the chromosphere or low corona, where the temperature is of the order of 500,000°K. As yet, the lines of Na IX have not been found, but the cosmic abundance of sodium is 40 times less than that of neon. Magnesium, however, is quite abundant, and the resonance lines of Mg X are clearly present, at 609.7 and 624.9 A. These lines may be considered coronal, since a temperature of almost 1 million degrees is required for their production. Next in the sequence would be Al XI, but aluminum, like sodium, is less abundant. Finally, there are the resonance lines of Si XII, at 499.3 and 521.1 A. Still higher temperatures are required for their excitation, and they must originate at a temperature level well over 1 million degrees in the corona.

In addition to these lines, many others can be seen in Fig. 3. Most are from low states of ionization of the abundant light elements, such as carbon, nitrogen, and silicon. They arise in the low chromosphere. Almost all the emission lines have been identified, but there are perhaps 25 whose origin is not known.

Hydrogen and Helium

The most abundant element in the sun is hydrogen. A knowledge of its distribution in the chromosphere is essential to an understanding of the physical processes which sustain the high temperature in the chromosphere and corona. The resonance lines of hydrogen lie in the extreme ultraviolet,

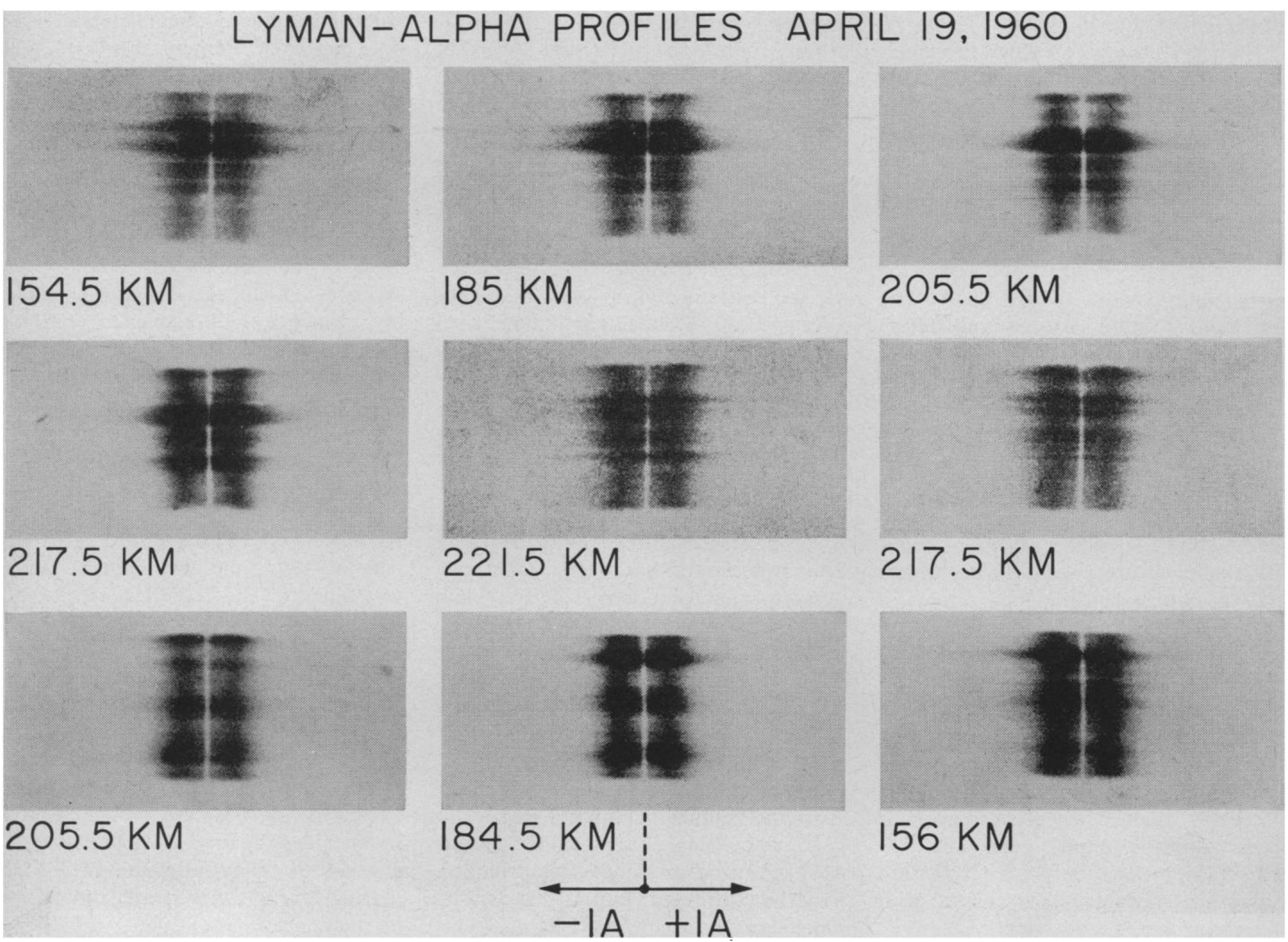

Fig. 5. Images of the Lyman-α line of hydrogen, obtained at high dispersion by the U.S. Naval Research Laboratory (*8*) on 19 April 1960. The narrow center absorption core is produced by hydrogen between the rocket and the sun. The bright streaks are the spectra of solar plages.

and a great deal is now known about them from the spectra obtained from rockets.

Nearly the entire Lyman series of hydrogen can be seen in Fig. 3, commencing with Lyman-α whose intensity is far higher than that of any other emission line in the extreme ultraviolet, and continuing with ten higher members of the Lyman series. Beyond the last resolved line the unresolved high members of the series build up with the appearance of a continuum to the series limit at 912 A; this is followed by the Lyman continuum itself, which can be traced to about 800 A.

The profile of the Lyman-α line has been studied by the U.S. Naval Research Laboratory (*8*) with a high-resolution spectrograph. Nine high-dispersion images of the line, obtained on 19 April 1960, are shown in Fig. 5.

The first immediately obvious feature is the extremely narrow absorption core at the center of the line. Its width is approximately 0.04 A. This narrow absorption line is produced by hydrogen in the region between the spectrograph and the sun. The presence of hydrogen in the upper atmosphere and exosphere has been detected with rockets, from the intense Lyman-α emission from the sky when it is

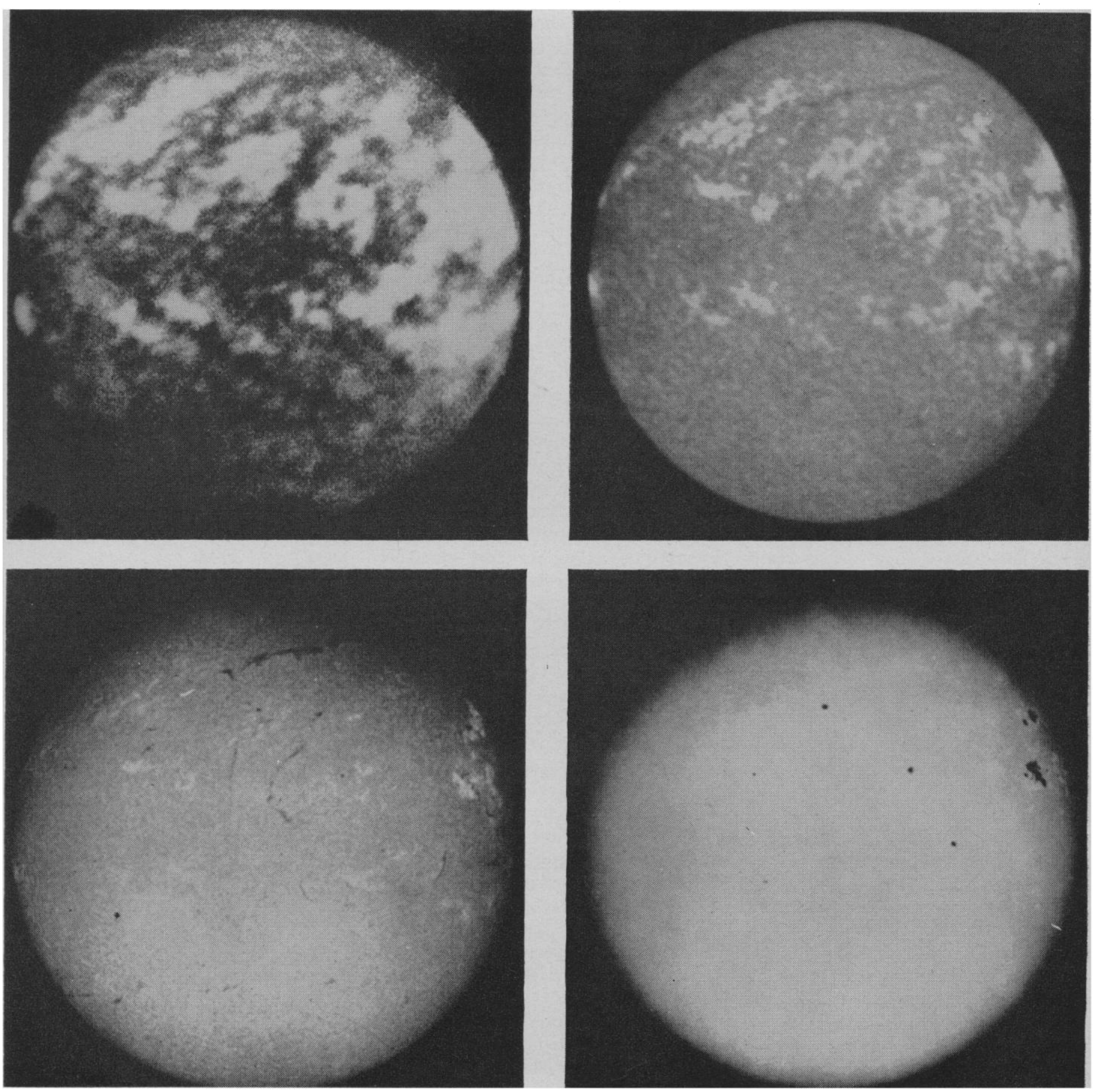

Fig. 6. Images of the sun on 13 March 1959. (Top left) Photograph taken in the light of the Lyman-α line of hydrogen from an Aerobee-High rocket; (upper right) $CaK_{2,3,2}$ spectroheliogram; (bottom left) photograph taken in the light of the hydrogen-α line with a 0.7-A monochromatic filter; (bottom right) photograph taken in white light. [U.S. Naval Research Laboratory, McMath-Hulbert Observatory, U.S. Naval Research Laboratory, and Naval Observatory, respectively]

illuminated by sunlight. This absorption line gives a quantitative measure of the amount of hydrogen present. Photometry of the absorption core has shown that the total quantity of hydrogen required to produce the line is 3×10^{12} atoms per square-centimeter column between the spectrograph, at 100-kilometer altitude, and the sun; from the width of the line it has been determined that the temperature of the hydrogen lies between 1000° and 2000°K.

The second important aspect of the Lyman-α line is its great width. The streaks crossing the line are the spectra of different regions of the sun, of plages, and of areas of less activity. The top and bottom edges correspond to the solar limb. In the strongest plages the spectrum can be followed to more than 1 A from the center, and, of course, it must merge smoothly into the far wings, which may be seen in Fig. 3. The center of the emission line, apart from the narrow absorption core, is broadly self-reversed, with the most intense emission occurring about ¼ A on either side.

The width and shape of the central part of the Lyman-α line have been shown by Morton and Widing (*9*), in accordance with the theory of Jefferies and Thomas (*10*), to require emission in a region of the sun where the temperature is of the order of 80,000°K. The wings, however, are formed lower in the atmosphere, and the extreme wings, perhaps 50 A from the center of the line, come from close to the limb. The Lyman continuum, whose radiation temperature is approximately 6700°K, arises from low in the chromosphere, where the electron temperature is of the order of 10,000°K. Continued study of the Lyman-α profile and observation of the profiles of the higher members of the Lyman series will eventually give us detailed knowledge of the distribution of hydrogen throughout the chromosphere.

In another type of study the sun's disc was photographed by the U.S. Naval Research Laboratory (*11*) in the light of the Lyman-α line of hydrogen by flying a monochromatic camera. This produced an image of the type generally obtained by spectroheliographs. Figure 6 shows four images of the sun obtained on 13 March 1959. The photographs were taken, respectively, in (i) the light of the Lyman-α line; (ii) the light of the calcium K line; (iii) the light of the red line of hydrogen (this image was obtained with a Lyot filter); and (iv) ordinary white light. The Lyman-α emission pattern over the sun shows more contrast and is coarser than any of the others. According to the result obtained from the profile of the center of the line, the Lyman-α emission shown in Fig. 6 must arise from the level in the sun near 7000 kilometers, where the temperature is nearly 100,000°K. The red line of hydrogen, however, comes from a lower region of the chromosphere, where the temperature is approximately 10,000°K—perhaps from 4000 kilometers above the limb—and the calcium-K emission is thought to originate even lower down. In future experiments it is planned to photograph the sun in the light of other emission lines, thus securing maps of the atmosphere for many different levels. It would be especially interesting to obtain images with the various lines in the lithium sequence.

The solar lines of helium in the extreme ultraviolet are of great importance, since a detailed study of their intensities and profiles would lead to a better determination of the abundance of helium in the sun's atmosphere and of its distribution in the chromosphere. This is of interest in connection with the origin of the sun. It is believed that the sun's atmosphere has the same composition as the original cloud of gas from which the sun was formed by condensation. Although the heat produced by the sun is produced by the conversion of hydrogen into helium deep inside the sun, it appears that little or none of the helium so formed leaks to the surface to change the composition of the sun's atmosphere.

Two helium lines are present in the spectrum shown in Fig. 3, the 584.3-A resonance line of neutral helium and the second line of the series, at 537 A. The resonance line of He II at 303.8 A has been photographed by Rense (*12*) and observed photoelectrically by Hinteregger (*3*); a trace of the third-order image of this line, at 911.4 A, appears near the head of the Lyman continuum in Fig. 3. The Balmer series of He II is clearly present in the spectra of Figs. 3 and 4. Its first line, at 1640.5 A, is conspicuous. The higher lines in the series should be present in Fig. 3. However, every second line is blended with a line of the Lyman series, and several of the lines lying between members of the Lyman series happen to be blended with other emission lines. Traces of several of the high lines of the series have been identified. It appears that it will eventually be possible to apply the techniques of high-resolution spectroscopy and monochromatic photography to the He I line at 584 A and the He II line at 304 A and so to obtain detailed knowledge of the distribution and abundance of helium in the atmosphere of the sun.

Plans for solar research from rockets and satellites include many new and interesting experiments. With control of rocket orientation during flight it will soon be possible to study in greater detail many aspects of the solar spectrum in the extreme ultraviolet—to study changes in the spectrum very close to the limb; to make line identifications from 500 A even into the x-ray region; and, by monochromatic photography, to study the pattern of emission over the disc of the different lines in the lithium-like sequence. Satellites, on the other hand, offer the possibility of studying the outer corona, which is now visible only at total eclipse, on an hour-to-hour basis. This region contains the strange streamers that may, indeed, stretch to the earth itself, sending to us the charged particles that become trapped to form the Van Allen belts. Observation of changes in these weird forms from day to day, or even from hour to hour, may well provide the key to many of the effects taking place in the earth's atmosphere, and may possibly throw new light on the problem of changes in the earth's weather.

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