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Final Report

ASTRONOMICAL EXPERIMENTS PROPOSED FOR EARTH SATELLITES

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ABSTRACT

The following report lists and describes a number of astronomical experiments to be made from artificial earth satellites. Included are those experiments which, in the authors' opinion, should be given the highest priority in the immediate future. Each of Sections II-XII contains a discussion of a broad area of research, including reasons why observations from satellites would be of value. Then follow specific recommendations of the type of instrumentation to be used, the rate of data acquisition, the size and orientation of the satellite orbit, and other pertinent design specifications. It is the authors' hope that this work will be useful to those groups planning satellite launchings in the near future.

I. INTRODUCTION

The advent of earth satellites as a tool for research is the most important development in astronomy since the invention of the telescope. Astronomical observatories will, in the very near future, be located at altitudes of several hundred miles, where the universe may be surveyed far above the opaque and turbulent sea of air that has heretofore impeded the advance of astronomy. The pace of rocket technology is so rapid that instrumental payloads will soon be measured in tons rather than in pounds, and even the more modest weights of 100-300 pounds that will be available to astronomy within the next year or two make possible a variety of fresh and exciting experiments.

There are still many practical problems that must be solved before observatories in space can become a reality. The equipment must be sufficiently rugged to withstand the violent shocks and vibrations that attend the launching of satellite vehicles. Provision must be made for an adequate power supply, for the stabilization of the vehicle in space, for the accurate pointing and control of the telescopes, and for the recording, storage, and transmission to earth of the scientific data. The unexpected discovery by Van Allen of the intense radiation belt that surrounds the earth reveals a new hazard to the functioning of energy detectors that must be overcome, either by shielding or by the careful selection of working altitudes.

These engineering problems will certainly be overcome, but it is imperative that work in this direction be undertaken immediately if astronomers are to take full advantage of the opportunities that will soon be at hand. As a prerequisite, the astronomer must formulate his observational program in terms that will provide the engineer with a set of specifications from which he can proceed to design the necessary equipment. The report that follows represents such a formulation for a number of astrophysical problems that appear to the writers to be of highest immediate priority. It is recognized that priority ratings in scientific research must naturally be colored by the interests of the individual scientists who assign them, and hence a report by another group is likely to contain a wholly different set of experiments. It is our hope that this report will stimulate similar studies elsewhere in the astronomical community.

We wish to thank the McDonnell Aircraft Corporation and particularly Mr. Michael Witunski for their encouragement and financial support of this report as a service to astronomy.

II. THE SPECTRUM OF THE SUN IN THE FAR ULTRAVIOLET

Radio communication is strongly dependent on the state of ionization in the ionosphere. When a sudden ionospheric disturbance (S.I.D.) occurs, the level of ionization is enhanced and radio fade-outs occur. Observations have demonstrated a connection between solar flares and S.I.D.'s, but the correlation is not so well established that one can simply predict the magnitude of the ionospheric disturbance from the visual brightness of a flare and its position on the disk of the sun. Indeed, it is not possible to be sure that there will be any disturbance at all!

The visible flare is only a symptom of some mechanism (probably hydromagnetic in character) that releases a large amount of energy very suddenly. The radiation relevant to the production of an S.I.D. must be released in the region of the far ultraviolet and soft X-rays, and can be studied only by devices flown outside the atmosphere of the earth. The ionization in the normal or unperturbed ionosphere is controlled by the radiation from the solar chromosphere and corona.

The Fraunhofer spectrum which arises from the visible surface or photosphere of the sun has been traced as far as $\lambda 1500$. Shortward of this point it must become very weak, and the solar radiation in this region is contributed almost entirely by the outer envelope of the sun, the chromosphere, and the corona. Since these layers are responsive to the variations characteristic of the solar cycle, and the photospheric radiation is not, knowledge of the emission in this region and its time-dependent variation will play an important role in our understanding of the sun and solar-terrestrial relationships.

THE CORONA

Various lines of evidence indicate that the solar corona has a very high temperature. Considering for the moment only the "quiet" sun which is observed near the time of minimum solar activity, we may regard the corona as an envelope with an electron (gas kinetic) temperature of about a million degrees and with a density ranging from about 10^6 to 2×10^8 ions/cm^3 over the regions of greatest interest, i.e., from the top of the chromosphere out to about 2.0 solar radii. The density falls off very rapidly outwards, but the temperature is maintained at a high value as far out as the corona can be observed. Although this envelope is regarded as spherically symmetrical in the first approximation, it does show a pronounced asymmetry in the sense that the polar regions have a different density distribution from that of the equatorial region. Furthermore, the radiofrequency observations of the occultation of the Crab Nebula show that the outer corona has a structure that is far from being spherically symmetrical. In fact, this outer corona consists essentially of individual clouds and condensations. At the times

of high solar activity, the corona exhibits regions of unusually high excitation. The existence of such excited regions is indicated by the following: (1) the appearance of the corona itself in the disturbed region; (2) the enhancement of the green coronal line due to [FeXIV] (as well as to other high excitation coronal lines); (3) enhanced radio emission in frequencies emitted by the corona; and (4) enhanced X-ray emission in the region of the shortest X-rays.

In the visible region of the spectrum, the corona is about a million times fainter than the sun. On the other hand, in the region below 100Å, the solar spectrum is due almost entirely to the corona. First, there is a strong continuous X-ray spectrum produced by the highly ionized atoms. It has an intensity distribution roughly comparable with that of a black body at 700,000°K, but its total intensity is many times smaller. In other words, the layer is optically thin in the X-ray region as well as in the region of the visible radiation. According to the calculations of Elwert,[1] this continuous emission amounts to about 0.015 erg/cm^2/sec at the earth's distance. The intensity maximum falls at about 30Å at the temperature of a million degrees and at about 50Å at a temperature of 700,000°K. The largest contribution comes from the recombination continuous spectra of hydrogen and helium.

In terms of energy output, the X-ray line spectrum is much more important than the continuous spectrum. At a temperature of 700,000°K, the bulk of the X-rays fall in the region between 44Å and 120Å, the spectral domain observed by Friedman's group at the Naval Research Laboratory. The strongest X-ray lines tend to fall in the region 80-90Å and a few important transitions fall at longer wavelengths. Helium, neon, and oxygen produce the strongest lines, but there are also important contributions from iron, carbon, nitrogen, magnesium, silicon, and sulfur. Using the theory given by Elwert, and the abundances recently derived for the sun, we find, for the flux of the X-ray line radiation received at the top of the earth's atmosphere, the following figures (which differ slightly from those given by Elwert).

T_ϵ =	600,000°K	700,000°K	1,000,000°K	
	0.040	0.036	0.029	erg/cm^2/sec

The energy distribution with frequency changes as a function of the temperature. Figure 1 shows the positions and relative intensities of the strongest X-rays in the region 10-150Å for the three temperatures noted above. The intensities of the strongest lines have been corrected for self-reversal by the procedure given by Elwert.

When certain areas of the corona are disturbed, as at times of high solar activity, the character of the X-ray emission changes. A considerable contribution may now come from the shorter wavelengths, while the soft X-ray region λ40Å-100Å remains virtually undisturbed. Elwert[2] showed that this behavior of the X-ray spectrum could be understood if one supposed that, in the condensations, the temperature rose to about six million degrees, a value selected from the radio data. In these condensations there occurs a noticeable increase of the radiation intensity below about 30Å, but there is a short wavelength limit to the

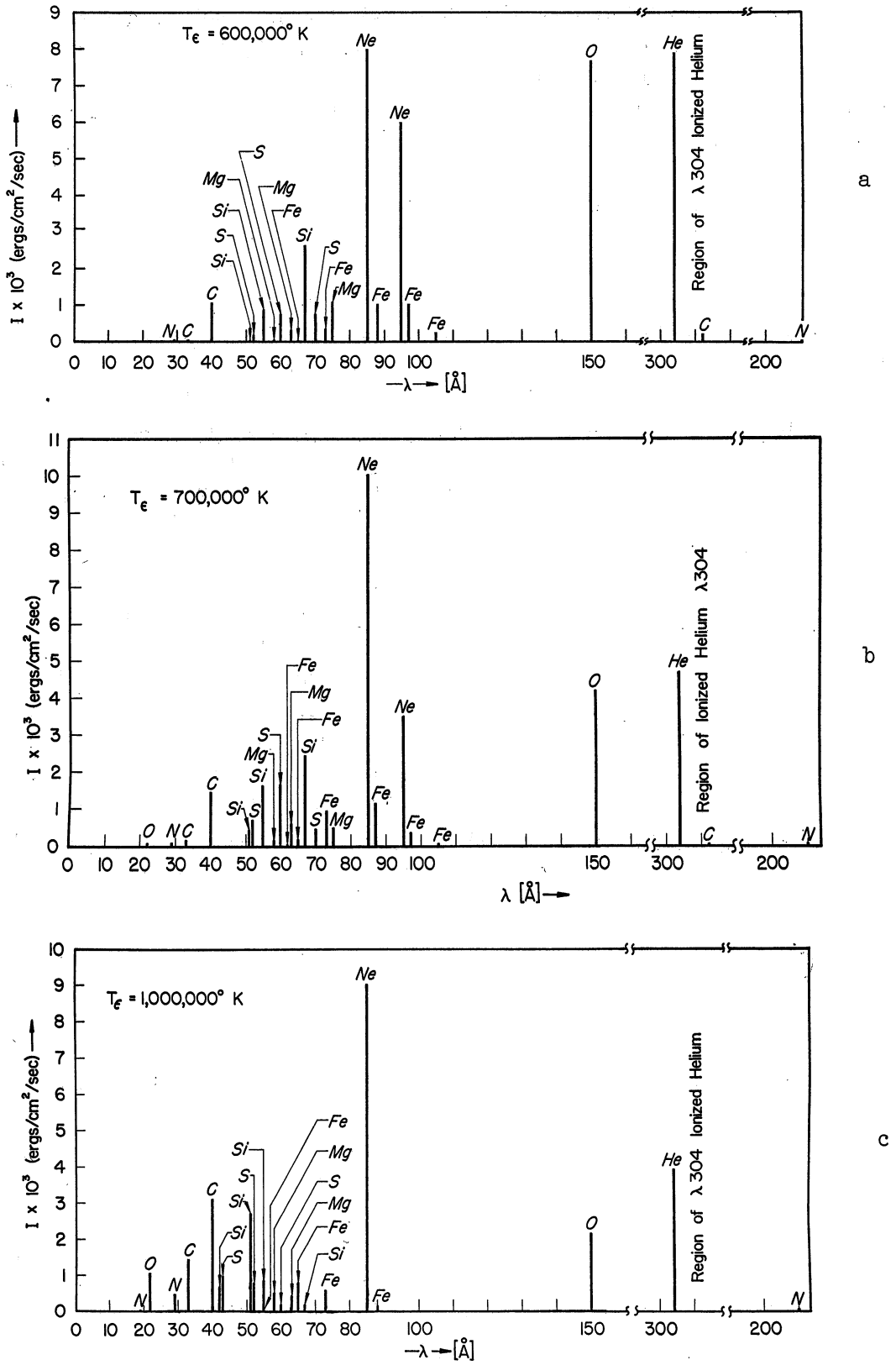


Fig. 1. X-ray radiation of solar corona. The flux received at the top of the earth's atmosphere for each X-ray line is exhibited. The insert gives the region λ300-320 which includes the resonance line of HeII. Note that the contribution of the chromospheric regions is not included.

radiation at about 607Å. The predictions of Elwert's theory seem to be in accord with the observations secured by Friedman's group with rockets.[3] The short wavelength limit of the spectrum is to be understood in terms of the character of the X-ray spectra, together with the abundances of the elements involved. The X-rays involving the K shells of the abundant elements (except iron) all fall on the long wavelength side of 6Å. Elements between sulfur and iron could contribute to the X-rays in the region shortward of 6Å, but Elwert presumed these elements to be so rare that they would not contribute very much. Chlorine and argon may contribute lines that are about ten times fainter than those of sulfur. The excitation of the K shell of iron gives a line at 1.9Å, but this line could be excited only at temperatures much higher than six million degrees.

The high-energy X-rays (those with wavelengths less than 8Å) provide a good index of solar activity. There is a good correlation between flares, radio fadeouts, and X-rays. The intensity of the X-rays depends on the importance of the flare, but even a flare of importance two produces an order-of-magnitude increase in the intensity of those X-rays with wavelengths less than 8Å. These hard X-rays produce an increased ionization in the D-layer of the ionosphere. The E region of the ionosphere is controlled by X-rays in the neighborhood of 40Å, while the D region is controlled only by the hardest X-rays, i.e., those with wavelengths less than 8Å, although Lyman-α may play some role in producing ionization. The highest (F2) layer of the ionosphere may be controlled by the radiation falling in the region between 100Å and Lyman-α, although not enough is known about the excitation mechanisms of the ionosphere to identify the responsible agent without ambiguity.

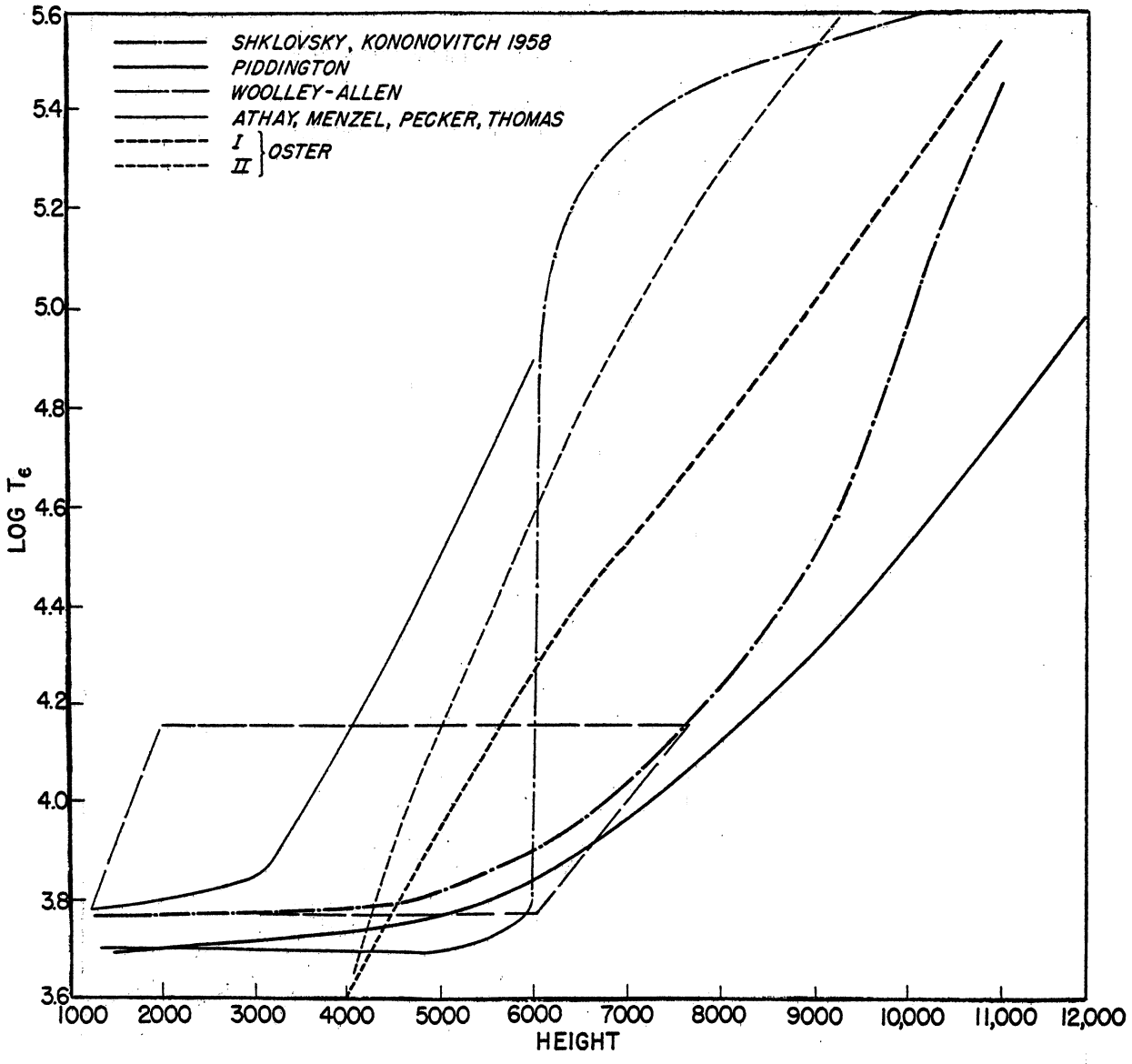
The emission spectrum of the sun from λ976Å to λ2000Å has been photographed from rockets fired above the earth's atmosphere.[4] The strongest line in this region is Lyman-α but there are also present emission lines of HeI, HeII, CI, CII, CIII, CIV, NV, OI, OVI, AlII, SiII, SiIII, SiIV, SII, FeII, and PII which originate in the chromosphere or more likely in the transition region between the corona and the chromosphere. The region between 100Å and 976Å remains to be explored but presumably it contains a number of important emissions.

The strong Lyman-α radiation probably contains more energy than all the rest of the emission lines in this spectral region put together. Photon counters, phosphors, and ionization chambers have been used to measure the intensity of the radiation. Friedman and his associates[3,5] have found Lyman-α fluxes at the earth ranging from 0.1 erg/cm^2/sec to 6 ergs/cm^2/sec. The flux in Lyman-α may be associated with the solar cycle, but no precise correlation has yet been established. There is no clear-cut evidence that the Lyman-α intensity is closely connected with flare activity, and this question can be settled only by satellite observations.

THE CHROMOSPHERE

The structure of the solar chromosphere is one of the most difficult problems in solar physics; in spite of a vast effort, we have not yet secured a satisfactory picture. The lower chromosphere has been investigated by means of the flash-spectrum observations at the time of solar eclipses and by examination of the cores of very strong lines. The simultaneous appearance of both low- and high-temperature phenomena, e.g., low-excitation metallic lines, indicating an excitation temperature of about 4000°K, and ionized helium lines suggestive of a temperature of 20,000°K, have only compounded the difficulties. In addition to the optical observations, measurements of the quiet sun in the radiofrequency region may also be made. Each volume element radiates in the radiofrequency region in accordance with Kirchhoff's law, and the emergent radiation is attenuated by absorption in the overlying layers. Models of the chromosphere have to satisfy both the radio and the optical data. Some chromospheric models have been based on flash-spectrum (optical) data (e.g., Athay and Menzel[6]), while others have been based primarily on radio data (e.g., Piddington[7]). Figures 2 and 3 exhibit the present confused state of chromospheric theories. We plot log T_e and log N_e against the height above the photosphere. In the Woolley-Allen model,[8] a sharp temperature rise is postulated at about 6000 km where, it is supposed, the transition from the low chromospheric temperatures to the high coronal temperatures takes place almost instantaneously. A curious discontinuity in the electron density is implied by this model. The Piddington[7] model gives a smooth temperature rise with height and a smooth electron density decrease. In the two models proposed by L. Oster,[9] relatively larger densities are postulated out to about 5000 or 6000 km and thereafter the density falls rapidly as the temperature climbs steeply.

To reconcile optical data that are contradictory to any uniformly stratified, plane-parallel model, various investigators have proposed two-stream models of various types. In some models such as that by Woltjer,[10] the hot regions are identified with the spicules; in others such as that by Athay, Menzel, Pecker, and Thomas,[11] Athay and Menzel,[6] or Coates,[12] the spicules are identified with the cool regions. The Woltjer model does not appear to agree with the better optical observations; we have not plotted it in Figs. 2 or 3. Perhaps one of the most promising models is the one proposed by Shklovsky and Kononovitch,[13] using both radio and optical data. The hot regions, which have a temperature of about 12,000°K, extend to a height of about 8000 km and cover less than 10% of the solar surface. The cool regions extend to heights of about 6000 km, and have temperatures appropriate to the boundary of the sun, i.e., about 4000°K. The extremely high excitation phenomena, such as the HeII λ4686 line are presumably excited by radiation originating within the corona. The two-fluid model proposed by Coates[12] is closely identified with the visible spicule phenomenon, but is derived to satisfy the radio observations at 4 and 8 mm. The spicules are taken to have a temperature of 6400°K and the interspicular gas is hot, somewhat hotter than in the model of Shklovsky and Kononovitch. It remains to be seen if this model will reproduce the observed optical data.


SHKLOVSKY, KONONOVITCH 1958
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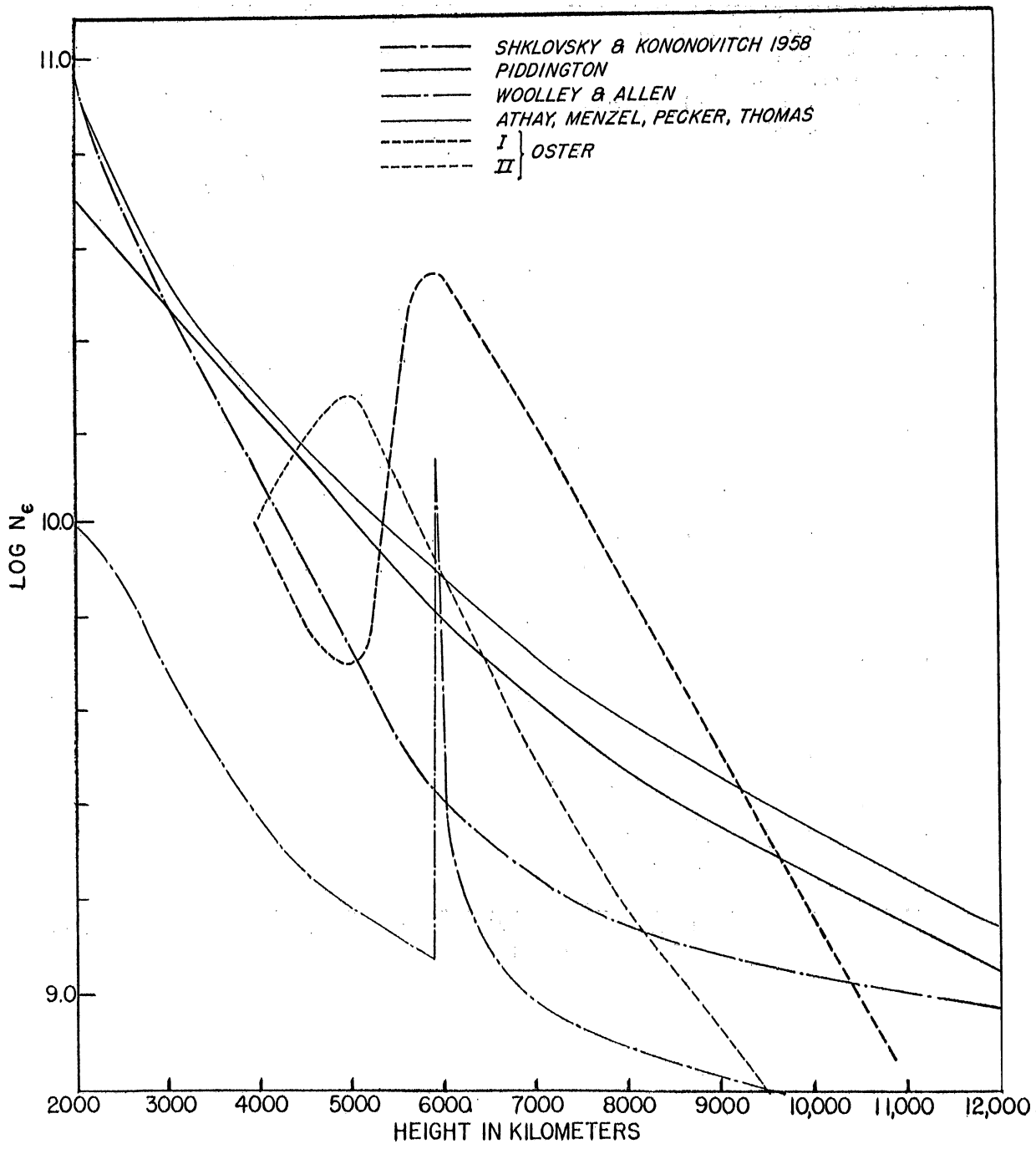

Fig. 3. The electron density in the chromosphere. The logarithm of the electron density expressed in particles per cm^3 is plotted against the height in km.

A very sharp temperature rise must occur between the lower chromosphere and the corona which has a temperature of about a million degrees. The nature of this transition region poses one of the most engaging problems in solar physics. Some authors have computed the temperature gradient on the assumption that heat is conducted inwards from the corona, while others have discussed the dissipation of the energies of shock waves. The continuous absorption which sets in at the head of the Lyman series λ912 might provide important clues about the structure of this region. Since the radiation reaching the observer originates, on the average, at an optical depth, τ, of about 1, photographs of the sun obtained with a band-pass filter transmitting between 800 and 900Å might clearly distinguish between the hot and cold regions. One difficulty is that a very high resolving power, of the order of a second of arc, might be required to separate the hot and cold regions if current ideas on the spicules are to be accepted.

The high excitation lines of CIII, OVI, and SiIV, etc., observed by the Naval Research Laboratory rocket spectroscopists, almost certainly originate in this transition region, and we might expect other lines that fall in the region 100-1000Å likewise to originate there. Until the structure of this transition region is elucidated, many critical problems concerning the outer envelope of the sun cannot be solved.

Oster attempted to calculate the intensity of the strongest lines and the continua due to hydrogen and helium, but his model of the chromosphere appears to be in need of revision.

Table I lists the principal atomic lines to be expected in the region λ100Å-λ1000Å. The data are abstracted from Mrs. Sitterly's list (Bur. Stds. Circular 488). In many instances the lines of a given multiplet fall closely together. Under these circumstances, we give a mean wavelength, $\overline{\lambda}$, and the spread $\Delta\lambda$ of the multiplet. Since practical requirements may limit the spectral resolution in this region to something between 0.1 and 0.5Å or perhaps even 1Å, many of these multiplets will appear as single, fuzzy lines.

We first summarize some of the technical difficulties that make a study of the region 100-1000Å very difficult. First, atmospheric extinction is particularly persistent in this region and probably persists (in the lines) at least as high as 200 km. It may be necessary to go to a height of 300 miles to secure observations sufficiently free from distortion by the line spectrum in the earth's atmosphere (particularly by nitrogen). Secondly, the efficiency of the spectrographic equipment is almost certain to be very low. As a rough estimate, the Naval Research Laboratory suggested that one might expect an efficiency of about a third as great as that obtained in the spectrographs working above 1000Å. Film speeds are low, and the possibility of using some other type of detector should be examined. Finally, the intensity available in this region is very low. Friedman, from a consideration of soft X-ray intensity (λ below 100Å), and from the observed level of ionization of the E and F layers, suggested that the helium resonance lines at λ304 and λ584 might contribute about 0.05 erg/cm^2/sec, and that the whole intensity in the region λ100-λ1000 would not amount to more than about

TABLE I

PRINCIPAL ATOMIC LINE TO BE EXPECTED IN REGION λ100-λ1000Å

	λ	Δλ	I_{LAB}	
H				
Ly-β	1025.7		972	
Ly-γ	972.5		417	
Ly-δ	949.7		216	
Ly-ε	937.8		126	
Ly-ζ	930.7		79	
Ly-η	926.2		53	
Ly-θ	923.1		37	
HeI	584.3		10	
	537.0		7	
	522.2		5	
	516.6		4	
	512.1		3	
	510.0		2	
HeII				
Ly-α	303.8		490	
Ly-β	256.3		155	
Ly-γ	243.0		67	
Ly-δ	237.3		34.5	
Ly-ε	234.3		20	
Ly-ζ	232.5		12.6	
Ly-η	231.4		8.5	
Ly-θ	230.7		6	
Ly	230.1		4	
CII	1335.1	1.2	27	
	1036.8	0.7	27	
	904.0	0.9	43	
	858.3	0.5	17	
	687.2	0.3	21	
	1010.1	0.5	29	
	806.3	0.3	29	
	651.2	0.1	36	
CIII	977.0	S*	18	
	386.2	S	14	
	310.2	S	7	
	1175.7	1.1	74	
	538.2	0.2	36	
	459.5	0.2	42	
	371.7	0.1	28	
CIV	1549.5	2.6	39	Observed
	312.4	0.05	29	
	244.9	S	10	
	419.6	0.2	27	
	384.7	0.1	33	

	λ	Δλ	I_{LAB}	
CIV (conc.)	296.9	0.1	13	
	289.2	0.1	19	
	259.5	0.1	13	
NII	1084.8	1.7	55	
	916.2	1.2	66	
	671.5	1.0	40	
	649.9	0.5	27	
	533.6	0.3	25	
NIII	990.7	1.8	47	
	763.8	1.0	29	
	685.7	1.3	59	
	451.2	0.2	21	
	374.3	0.2	23	
NIV	765.1	S	17	
	247.2	S	10	
	923.1	2.3	(62)	
NV	1238.8		8	Observed
	1242.8		6	
	209.3	0.03	13	
	162.6	S	4	
OI	1302.2		10	Observed
	1304.8		10	Observed
	1306.0		10	Observed
	1335.6		8	Observed
	1358.5		5	Observed
	1039.2		8	
	1040.9		8	
	1041.7		7	
	1025.8		9	
	1027.4		8	
	1025.2		7	
OII	834.5		15	
	833.3		15	
	832.7		14	
	539.4	0.8	23	
	430.0	0.3	17	
	718.5	0.1	33	
	538.1	0.5	26	
OIII	835.3		16	
	833.7		16	
	835.1		14	

	λ	Δλ	I_{LAB}	
OIII (conc.)	832.9		14	
	703.85		18	
	702.9		17	
	702.8		16	
	702.3		16	
	507.9	0.5	51	
	374.0	0.5	50	
	305.7	0.3	47	
	303.5	0.4	44	Blend HeII
	599.6	S	18	
	525.8	S	18	
	395.6	S	12	
	328.4	S	10	
	321.0	S	12	
	597.8	S	15	
	435.0	S	10	
	345.3	S	10	
OIV	790.15	0.1	28	
	787.7	S	15	
	609.8		15	
	608.4		14	
	554.5		18	
	554.0		17	
	555.3		16	
	553.3		16	
	279.8	0.3	21	
	238.4	0.2	29	
OV	629.7		15	
	172.2		12	
OVI	1031.9		10	Observed
	1037.6		9	Observed
	150.1	0.3	19	
NeI	743.7		12	
	735.9		30	
NeII	462.7		15	
	462.4		14	
	456.0	2.0	21	
NeIII	489.5		10	
	489.6		4	
	488.1		8	
	488.9		7	
	491.0		9	

*The symbol "S" denotes that the line is sharp.

TABLE I (Concluded)

	λ	Δλ	I_{LAB}	
NeIII (conc.)	490.3		7	
	283.4	0.7	9	
NeIV	543.9		15	
	542.1		10	
	541.1		8	
	208.7	0.4	28	
	469.8	0.05	40	
NeV	572.3		80	
	569.8		50	
	568.4		40	
	572.1		25	
	569.8		25	
	483.0		50	
	481.4		25	
	359.4		50	(OIII)
	358.5		50	(NIII)
NaII	376.4		3	
	372.1		6	
MgIII	234.2		12	
	231.7		14	
	187.2		8	
	186.5		9	
AlIII	696.0	0.4	9	
Si - Strongest lines lie above λ1000Å. No prominent lines are found below λ1000Å for any stage of ionization.				
SII	1259.5		5	Observed
	906.9		3	
	910.5		3	
	912.7		3	
SIII	1200.97		4	Not observed
	1194.02		4	
	735.2		4	
	732.4		5	
All other lines λ< 1000Å are weak.				
SIV	1073.0		6	Not observed
	1062.7		6	
	1073.5		4	
	816.0		5	
	809.7		4	
	750.2		5	

	λ	Δλ	I_{LAB}
SIV (conc.)	748.4		5
	753.8		5
	744.9		5
	661.4		6
	657.3		5
SV	786.5		8
	854.8		7
SVI	933.4		5
	944.5		4
	249.2	0.3	4
ClII	1071.0		20
	1071.8		10
	1063.8		10
ClIII	1015.0		7
	1008.8		6
	1005.3		5
	556.6	0.9	15
AI	1066.6		15
	1048.2		25
AII	919.8		15
	932.0		10
	740.3		12
	723.4		14
	661.9		15
AIII	878.7		12
	871.1		10
	887.4		10
	637.3		20
AIV	850.6		25
	843.8		20
KII	612.6		4
	600.8		5
	607.9		5

0.1 erg/cm^2/sec. That is, the anticipated intensity would be about two orders of magnitude lower than the intensity in Lyman-α!

It seems clear that the exploration of the 100-1000Å region will have to be a satellite experiment, since the trajectories of rockets are limited to only a few minutes above the earth's atmosphere. Of particularly great interest for the understanding of the solar atmosphere are observations just to the shortward (low λ edge) of the Lyman continuum, λ912, of the λ584 line of HeI, of the λ303.78 line of HeII, and of other resonance lines of abundant elements. The relative intensities of these lines should enable us to make a critical evaluation of conditions in the transition layer.

X-rays have been measured only with the aid of ionization chambers, although Friedman and his group have shown how fairly narrow band-pass filters may be made for this region. Observations with a grazing-incidence X-ray spectrograph would be needed to resolve the lines in this spectral region, but the same instrument could perhaps serve for both the far ultraviolet and the X-ray regions. If the spectrum of the 100-1000Å region could not be observed in detail, it would be very valuable to obtain measurements of the radiation with broad band-pass filters. The only difficulty is that such filters have not yet been prepared.

THE OBSERVATIONS MOST URGENTLY NEEDED FROM SATELLITES IN THE REGION OF THE SOLAR SPECTRUM SHORTWARD OF λ1500

Rocket measurements have provided invaluable data concerning the ultraviolet and X-ray solar radiations. There are certain limitations to the rocket data that are inherent in this type of experiment. (1) Continuous surveillance of the sun is not possible; only sporadic observations can be obtained. (2) The durations of the flights are such that only snapshots of the solar radiation are obtainable; hence long photographic exposures or tracing of the spectrum cannot be made. (3) For certain regions of the spectrum, it is difficult to get above the troublesome parts of the earth's atmosphere. The types of experiments that can be performed with satellites fall into two broad categories: (a) patrol observations of certain spectral regions to maintain a check on solar activity; and (b) detailed measurements of the radiation and spectra of the ultraviolet solar spectrum.

In the first type of experiment, we want to compare the solar radiation in one spectral range with that in another, with respect to both absolute intensity and relative variations. Thus it is important to compare, say, X-rays in the region shortward of 10Å, X-rays in the 60-100Å region, the Lyman-α radiation, and the radiation in the Lyman continuum at the times of flares with the same radiations from the quiet sun. The emission in each of these domains is to be patrolled continuously, and the information telemetered back to earth. Techniques are available for each of these spectral regions except the Lyman continuum, and since this falls in the region of low intensity, some difficulties might be encountered. The counting or ion chamber equipment could be sturdy, simple, and of relatively low weight so that it could be flown in an early satellite experiment.

The broad band-pass observations should be carried out continuously, since we have no a priori knowledge about when a flare will actually occur. Suitable ionization chambers have been described by Friedman,[5] who lists the following combinations.

Window	Thickness	Ionizable Gas	Wavelength Range
Beryllium	0.005 in.	Neon	1 - 8Å
Aluminum	0.00025 in.	Neon	8 - 18Å
Mylar	0.00025 in.	Helium	44 - 60
Glyptal	0.00006 in.	Helium	44 - 100
Lithium Fluoride	2 mm	Nitric Oxide	1180 - 1340
Calcium Fluoride	2 mm	Nitric Oxide	1225 - 1340
Sapphire	1 mm	Xylene	1425 - 1500

The ion chamber required for measurements of Lyman-α is simple and reliable. Since 95% of the radiation between 1100Å and 1340Å is concentrated in this line, there is no difficulty in the interpretation.

To identify the individual radiations in the far ultarviolet and the X-ray region, we must have spectroscopic observations. A suitable spectrograph for making worthwhile observations in this region would probably weigh about 200 lb in addition to the data-recording and telemetering equipment. Spectroscopic work in this spectral region is more difficult than in the ordinary regions because of the following difficulties.

(1) Scattered light must be avoided. The solar radiation is so much more intense in ordinary spectral regions than it is in the far ultraviolet that only a fraction of one percent of scattered light from the 4000Å region injected into the region 1000-1500Å would vitiate the results. The problem has been handled by:

(a) Choosing surfaces that have a relatively high reflectivity in the far ultraviolet as compared with the region near λ4000. Al_2O_3 appears to be the best material so far.

(b) Elimination of imperfections in gratings. If one groove is not the same as the next, light will be scattered along the spectrum.

(c) Predispersers. A good predisperser will involve several reflections and hence will lower the efficiency.

In rocket work where speed is essential, item (a) has been emphasized, but in observations from a satellite, one could take advantage of all three methods since the time available for making the observations would be of the order of hours.

(2) Detectors.

(a) Photographic materials. The Schumann film is sensitive down to about 100Å, but the film is very thin and difficult to handle. Although photographic film has been used successfully in rockets, it is doubtful that it would be the best material to use in a satellite, particularly since the film sensitive to the wavelength regions of interest is so capricious in behavior.

(b) Ion chambers. It should be possible to use ion chambers and photon counters as detectors for a spectrograph as well as for a broad band-pass filter device. The entrance slot would have to be very narrow and the counting rate would be low except in the neighborhood of strong emission lines.

(c) Photoelectric cells. Since the experiment would be flown in a vacuum, a photocell arrangement would be very simple in principle. We need surfaces of high photoelectric efficiency in the ultraviolet. The advantage of a photoelectric detector is that it could be made "blind" to all wavelengths shorter than, say, 2000A by a suitable choice of cathode material.

(3) Spectrographs.

(a) The NRL type of instrument described by Johnson *et al.*[4] offers many advantages, but a higher dispersion instrument would be even more worthwhile as many of the details in the absorption spectrum cannot be studied in a satisfactory way with a spectral purity as low as 0.65Å.

(b) Eschelle; useful for high-dispersion studies in the region of the Fraunhofer spectrum λ3000-1500, and in particular for detailed studies of line profiles, such as the profiles of the MgII lines near λ2800, (emission components) and Lyman-α.

(c) Crystals might be used as dispersive elements in the region of soft X-rays. Probably for wavelengths greater then, say 10Å or 20Å, it would be better to use a grating spectrograph at grazing incidence, but for a study of the hard X-rays observed at times of solar flares, etc., crystals might be used.

SPECTRAL RESOLUTION REQUIRED

Compromises with respect to the resolution may be required in the spectroscopic observations. We list here some of the desired features. As noted elsewhere in this report, it would be informative to observe the Lyman-α line with a resolving power of 25,000. Such high resolution presumably would not be needed, nor practicable for other lines. For the region from λ1000 to λ1500, a resolution of 0.1Å would be excellent, but much valuable information could be obtained with

a resolution of 0.3Å; lower resolutions than this would not represent a substantial improvement over earlier work. For the emission lines in the range from 100Å to 1000Å, a resolving power of about a thousand at the lower end and three thousand at the upper end would be desirable, whereas for the continuum a resolution of 1-2Å or even less would suffice. With a spectrographic camera of a given f-ratio, the efficiency for photographing emission lines does not decrease with increasing resolution until the width of the image becomes less than the width of the line itself. The continuous spectrum, however, suffers attenuation with each increase in resolving power.

In the X-ray region from 10Å to 100Å, a resolution of at least 1Å is required and 0.05Å is desired. For X-rays of wavelengths less than 10Å, the resolving power should be further increased, to as much as 0.01Å if possible. These desiderata with respect to resolution have to be weighed against the practical requirements of weight, sensitivity of detectors, etc. It is clear that a low intensity may impose acceptance of a relatively low resolution at least in some of the earlier phases of the work. If we accept Friedman's estimate concerning the intensity of the radiation from 100Å-1000Å, we may have to be content with a relatively low dispersion in this region.

TYPE OF ORBIT

For the study of the far ultraviolet spectrum of the sun, an orbit will be required that passes above the bulk of the earth's atmosphere. Possibly a height of at least 250 or 300 miles would be necessary. At these elevations, continuous absorption by the earth's atmosphere would cease to be important, but line absorption might yet be significant, although it probably would be confined to the lines of nitrogen, oxygen, and hydrogen. Hence observations secured at different points in the satellite orbit would give information on the earth's atmosphere as well as on that of the sun. This question is discussed in Section IV, "Density of the Earth's Atmosphere," where it is pointed out that the integration times required for terrestrial atmosphere experiments are small compared with the time required to trace the solar spectrum. Accordingly, tracings primarily intended for a study of the sun should be obtained when the satellite is on the sunward side of the earth and not when it is passing into or out of the twilight zone.

FREQUENCY OF OBSERVATIONS

The frequency of data collection, spectral resolution, etc., will depend on whether we are concerned with observations of the "quiet" or of the "active" sun. Consider first the observations of the "quiet" sun. Our problem here is to get as complete a tracing of the solar spectrum from the X-ray region to λ3000 with as high a spectral resolution as we can employ. If spectral scans are used, each scan would require from about five minutes to about half an hour, depending on the intensities involved. Enough complete scans would be required to give reliable measurements of the intensities and wavelengths of the features in the ultraviolet and X-ray solar spectra. Unless the satellite is moving outside the earth's atmosphere, we would need scans at several points in the orbit to allow for the ef-

fects of atmospheric extinction. Furthermore, several orbital passages around the earth would be required before this information could be secured.

Observations of the active sun entail a different emphasis. Except for the cores of the MgII lines, and the SiII lines at λ1808 and λ1817, we would not expect the solar activity to affect the spectrum very much above λ1700. The most engaging features might well be the behavior of Lyman-α, HeI λ584, and HeII λ304, and the "harder" X-rays. Accordingly, it would be desirable to have the spectral scanner linked with the Lyman-α and hard (shorter than 10Å) X-ray counters so that, when unusual enhancements of these radiations occurred (as during a solar flare), the spectrum could be rapidly and repeatedly scanned from about 5Å to about 1700Å. If possible, the duration of each trace should be between 2 and 5 minutes. When the flare subsides, and the Lyman-α or X-ray intensities fall below a certain preassigned value, the cycling would cease and the observational program would return to its original schedule.

To summarize, the plan would be to get a good series of observations of the quiet or normal sun covering the ultraviolet and X-ray regions. When this objective had been accomplished, further measurements of the quiet sun would be superfluous, and emphasis would be shifted to the active sun. If flares occurred while the original program was in progress, the latter would be discontinued so that rapid scans of the quickly changing ultraviolet and X-ray spectra could be made. The original program would be resumed after the solar activity had died down.

OBSERVATIONS OF THE SOLAR CORONA WITH AN OCCULTING DISK

For the spectral region below λ1500, the solar radiation is virtually all contributed by the corona and the chromosphere. No occulting disk is necessary to cut out the photosphere in this spectral region, but accurate tracking is necessary if we wish to separate the emission of the chromosphere from that of the corona.

At wavelengths longer than λ1500, the photospheric light overpowers that of the corona and it is necessary to use an occulting disk. The energy in the continuous spectrum of the corona falls off in proportion to the energy in the photospheric spectrum at the same wavelength, since it is produced by electron scattering. Hence it should fade out more rapidly than the line spectrum; we might expect a few lines of coronal origin in the region λ1500-λ3000. Term analyses of highly ionized, abundant atoms are not sufficiently complete to enable us to predict just what transitions will be observed.

For the coronal lines and continuum at wavelengths greater than 1500Å, a resolving power of 1Å or 2Å would appear to be sufficient. We would need tracings covering the region λ1500-λ3000 both for the quiet sun and for the disturbed sun at times of high solar activity. Since the intensities involved are likely to be rather low, either relatively long exposures with a photographic plate (10-30 min) or relatively long integration times with the scanner will be needed.

III. LYMAN-ALPHA SPECTROHELIOGRAMS

Spectroheliograms, or monochromatic photographs of the sun, made from the surface of the earth in the line radiations of ionized calcium (H and K lines) and of hydrogen (Hα), have revealed a great variety of transient disturbances in the solar atmosphere. These disturbances, together with the sunspots observed in white light, comprise what is referred to as "solar activity," or "solar phenomena." Solar phenomena are exceedingly diversified and complex and it is difficult even to give an organized account of them. The more striking among them include (a) the sunspots; (b) the so-called "plages," which are relatively stable formations that usually but not always occur near sunspots, and appear perhaps 50-100% brighter than their surroundings; (c) the solar flares, the most catastrophic of all events on the sun, which always break out in plage regions; (d) the prominences, great clouds of gas, which jut out beyond the limb of the sun, and are frequently in violent, turbulent motion; and (e) the dark flocculi and filaments, which are prominences seen in projection against the solar disk.

Except for some types of prominences, solar activity is generally confined to sunspot regions, and indeed the level of activity roughly parallels the sunspot cycle. The lifetimes of solar phenomena are highly variable. Some types of activity, e.g., the surge prominences ejected at the limb, and the high-speed dark flocculi that accompany flares, are exceedingly ephemeral, lasting but a few minutes. Great flares may persist for several hours, some types of prominences for weeks, and plages and sunspots for months.

The flare phenomenon is probably the most spectacular of all solar events because of its complexity, its abrupt commencement, relationship to other solar phenomena, and its often immediate and dramatic impact upon the earth. It is characterized by a sudden increase in the radiation intensity from relatively small areas up to 2-3 tenths of a percent of the total area of the solar disk. The enhanced radiation is almost always in the form of emission lines, and only rarely does the intensity of the continuous spectrum increase. The most prominent emissions are the Hα line of hydrogen and the H and K lines of ionized calcium, but other lines, particularly hydrogen and neutral and ionized helium, are also likely to be strong. After the initial brightening, the excess radiation intensity dies out slowly in times of from one-half to three or four hours.

The flare is not an isolated phenomenon on the sun in the sense that it often interacts with and is accompanied by other phenomena. Thus, dark filaments in the vicinity of flares, previously quiescent, may suddenly become active. High-speed gas clouds are sometimes ejected from flares at several hundred kilometers per second. The localized emission from highly ionized atoms such as CaXV in the corona high above the sun's surface is sometimes greatly

increased at the time of solar flares. Bright flares are almost always accompanied by great bursts of radio noise, particularly in the low-frequency band 20-600 Mc. The absolute intensity of these bursts at the lowest frequencies is sometimes as high as that which would be radiated by a black body at a temperature in excess of 10^{12} degrees. Some of the brightest flares observed in recent years have also given rise to rather extraordinary increases in the intensity of cosmic rays from the sun. It has been calculated that the total energy of high-speed particles emitted by the cosmic ray flare of February 23, 1956, was about 10^{31} ergs, which exceeds by a factor of about 1000 the radiative energy content previously estimated. The energy content of a solar flare is not always revealed by its brightness in the visible spectrum. A relatively minor flare, seen in Hα on March 20, 1958, was accompanied by a short but intense burst of gamma radiation, which was observed during a balloon flight.[14] Thus it is apparent that solar flares are tremendously energetic phenomena, and hence it is understandable that the elucidation of their origin and physical nature should be one of the fundamental problems of astrophysics.

Solar activity initiates various events on the earth, chiefly in the upper atmosphere, and hence its study has very important practical consequences for the human race. These events fall into two categories: (1) sudden ionospheric disturbances (S.I.D.'s), which are initiated almost immediately upon the onset of a flare and must therefore be caused by radiation from the flare, and (2) geomagnetic storms, which begin about one day later, and hence must be triggered off by high-speed particles.

Sudden ionospheric disturbances are caused by increases in the degree of ionization of the upper atmosphere in the height range 50-100 km, presumably as a consequence of increased ultraviolet emission from the regions of solar flares. The S.I.D.'s are manifested in a variety of ways, the most dramatic of which is the sudden fade-out of short-wave radio communications on the earth, in the band 1.5 to 30 Mc. The lower frequencies in this band are most strongly affected, although at much lower frequencies (about 50 km) the transmission is actually improved. The fade-outs may last for a few minutes or for as long as eight hours, and hence can cause serious disturbances in an important phase of everyday life.

Geomagnetic storms appear to be caused by streams of solar protons and electrons that impinge on the earth's atmosphere and are carried along the lines of force of the earth's magnetic field. The streaming of electric charges induces a magnetic field opposite to that of the earth and consequently reduces its magnitude. The practical consequences are that changes in the earth's magnetism cause increases in the electric currents in power, telephone, and telegraph lines, with resulting damage to equipment and disruption of channels of communication.

Daily observations of the sun, in the form of Hα spectroheliograms, are collected from several U.S. observatories by the Central Radio Propagation Laboratory at Boulder, Colorado, and used as a basis for forecasting sudden ionospheric disturbances and geomagnetic storms. The economic value of these forecasts is very high, but unfortunately the predictions are far from accurate. Thus what

may seem to be a relatively minor flare in Hα light may cause a very great S.I.D., and conversely a sizable event in the sun may have no obvious terrestrial effects.

The reason is that the visible radiation from the sun does not by itself produce terrestrial events, which are caused by the increased flux of ultraviolet radiation that is presumed to accompany increases in visible light. Unfortunately, the mechanism of the emission of radiation by solar flares is very poorly understood and we cannot at present predict their ultraviolet radiations from observation of the visible light. To obtain comprehension of the physical nature of flares and a better understanding of the causes of disturbances to the earth's atmosphere, it is necessary to observe directly the solar ultraviolet radiation that is screened from observation on the ground by the earth's atmosphere.

The wavelengths of ultraviolet solar radiation which can cause S.I.D.'s are severely restricted because of the absorbing properties of the earth's atmosphere and because the radiation must penetrate the atmosphere to the level of the D-layer of the ionosphere at a height of 70 km or less. Such penetration can occur only for wavelengths of about 5Å, 1200Å, or 1900Å. The 1900Å radiation would not ionize any known constituent of the atmosphere, and hence the choice is narrowed to the two shorter wavelengths. By a coincidence, what is probably the strongest emission line in the entire ultraviolet spectrum, the so-called Lyman-alpha line* of hydrogen, falls at 1216Å, and has been observed in rocket experiments at heights as low as 60 km. By its ionization of the molecule nitric oxide, the Lyman-alpha radiation is thought to be responsible for the normal ionization of the D-layer of the ionosphere, which then becomes reflecting for short radio waves propagated from the ground. The excess ionization during solar flares causes this layer to absorb short radio waves and thus causes the fade-outs. At present it is uncertain whether the excess ionization can also be caused by excess Lyman-α radiation during flares, or whether it is due to X-rays.

To resolve the question whether the Lyman-alpha radiation is directly responsible for sudden ionospheric disturbances, it would be sufficient to monitor continuously the total flux of the radiation from the whole solar disk that strikes the top of the earth's atmosphere. Observations of this type have been made during short time intervals from rockets and now for extended periods from satellites. But such observations can yield little information concerning the origin and basic physics of the flare phenomenon and its interactions with other related solar activity. Nor, on the practical side, can the integrated flux observations serve as a basis for the refined prediction of sudden ionospheric disturbances. For these broader purposes we require spectroheliograms of the sun in Lyman-α radiation, similar to and concurrent with those now being obtained in the Hα line from the ground. We shall now discuss some of the instrumental requirements for Lyman-α spectroheliograms.

ALTITUDE AND ORBIT OF SATELLITES

The absorption of Lyman-α in the lower 100 km of the earth's atmosphere is

known to be caused chiefly by molecular oxygen. Rocket measurements made at the Naval Research Laboratory[15] suggest that the absorption by O_2 vanishes above a height of about 120 km. This does not rule out the possibility that there may be some additional attenuation by neutral hydrogen in the earth's atmosphere at greater heights. Unfortunately, the neutral hydrogen content of the air has not been experimentally determined, and there is no reliable theoretical basis for its computation. Illustrative calculations by Bates and Nicolet[16] and by Chapman[17] suggest that at very high altitudes neutral hydrogen becomes the major constituent of the air, but its quantity cannot be estimated even roughly for satellite engineering purposes. One can only say that it is theoretically possible that it exists in sufficient quantity to cause some attenuation of Lyman-α even up to heights of 2000 km. The experiment described in this section is designed to measure the attenuation by neutral hydrogen and, until it is carried out, it is impossible to say whether there is any advantage in performing the Lyman-α spectroheliogram experiment at an altitude greater than, say, 200 km. Sufficient information is at hand from rocket experiments to make it certain, however, that most of the goals of the experiment can be attained from any altitude greater than 120 km.

It is extremely important that the sun be kept under more or less constant surveillance during the period of the experiment, owing to the transient character of flares and related solar activity. This suggests a more nearly polar rather than an equatorial orbit. The possibility should be investigated of minimizing the duration of "dark" periods by devising an orbital inclination and direction of rotation that would cause the precession due to the equatorial bulge to compensate at least partially for the revolution of the earth about the sun.

THE SOLAR IMAGE

The design of the telescope imaging system should be based on the requirements (1) that the time taken to record the sun's image either photographically or by scanning should not exceed 20 seconds, and (2) that the resolving power of the image be not less than 5 seconds of arc. These requirements may have to be compromised if the pointing accuracy of the telescope is insufficient. Much valuable information could be obtained even if the resolution were no better than one minute of arc and the exposure times on the order of two or three minutes. But the more rigid specifications are desirable to avoid time integration of solar activity and to compare ultraviolet details with those observed in visible light.

An important design factor is the expected intensity of the radiation incident at the top of the atmosphere. The measurements made to date have been summarized by Bates and Nicolet.[16] The values for the whole sun from 10 different rocket flights vary over a very large range from 0.10 erg cm^{-2} sec^{-1} to 10 ergs cm^{-2} sec^{-1}. The fluctuations may reflect a dependence of Lyman-α intensity upon the sunspot cycle. It seems wise, however, either to assume the lowest value for design purposes or better still to provide for a sequence of graduated exposures.

DISPERSING SYSTEM

The total width of the Lyman-α line has been estimated to be less than 0.3Å.[4] Ideally, therefore, the spectral purity of the image should be about 0.1Å to avoid contamination from neighboring emission lines or a possible continuous spectrum. However, on the basis of the rocket spectrum obtained by Johnson[4] on February 21, 1955, the Lyman-α line appears to be at least 50 times stronger than any other emission line distant within ± 100Å. This suggests the utility of employing a slitless spectrograph of the type used for the spectroscopy of planetary nebulae.

FREQUENCY OF DATA COLLECTION

The most valuable collection of Lyman-alpha spectroheliograms would be those covering the life histories of a series of flare outbursts, such as might be expected to appear during the 14-day period when a large and active sunspot group transits the solar disk. Considering the rapidity with which flares develop, successive photographs should be taken at intervals of one minute. Longer intervals are acceptable, but every effort should be made to keep them shorter than about five minutes.

IV. DENSITY OF THE EARTH'S ATMOSPHERE

L. Spitzer[18] has proposed an interesting experiment designed to yield the particle densities of the major constituents of the earth's atmosphere. The method is of particular interest for altitudes above 100 km, where data from rockets and satellites have been obtained on the total particle densities but not on the chemical composition. Thus the precise heights at which molecular oxygen and nitrogen became completely dissociated are not known and although neutral hydrogen is believed to be the major constituent of the atmosphere above levels on the order of 1000 km, its amount and vertical distribution are unknown. The measurement of individual particle densities, when combined with total densities derived from drag measurements, would make possible the calculation of temperatures above 300 km and so answer the question about the extent of the thermosphere. This is the region above the mesopause in which the temperature increases with height from about 200°K at 100 km to about 1100°K at 300 km. It is not known whether, above 300 km, the atmosphere becomes isothermal, or whether, as Chapman suggests, the temperature continues to rise until the earth's atmosphere merges with the very hot gas of the solar corona at a distance of several earth radii.

Spitzer suggests that the energy absorbed from solar radiation by spectral lines of atmospheric constituents would provide a very sensitive measure of the number of absorbing atoms in the line of sight, particularly when the line of sight between satellite and sun passes tangentially through the atmosphere. The geometry of the experiment is illustrated schematically in Fig. 4 for the case of a circular orbit. R is the radius of the orbit, measured from the center of the earth, and r is the radius of the earth. Radiation from the sun passes through and is absorbed by the atmosphere along the direction SS' before reaching the satellite. h_o is the minimum altitude at which absorption takes place.

The amount of energy absorbed depends upon the total number of absorbing atoms along the line of sight SS' and upon the absorption coefficient for the line in question. The number of absorbing atoms in turn depends upon the composition of the atmosphere and upon its density gradient. The density distribution is exponential but its scale height increases with altitude. However, the absorption along the tangential column SS' is determined chiefly by the density at height h_o. In the analysis of observational data, the precise form of the density distribution will have to be taken into account, but for this preliminary discussion of the experiment it should be sufficient to assume that the scale height above height h_o is constant and equal to its value at h_o.

At any given frequency in the absorbing line, radiation from the sun will be attenuated by the factor $e^{-\tau\lambda}$, where $\tau\lambda$ is the optical thickness of the absorbing column at wavelength λ in the line. The optical thickness per unit wavelength is given by

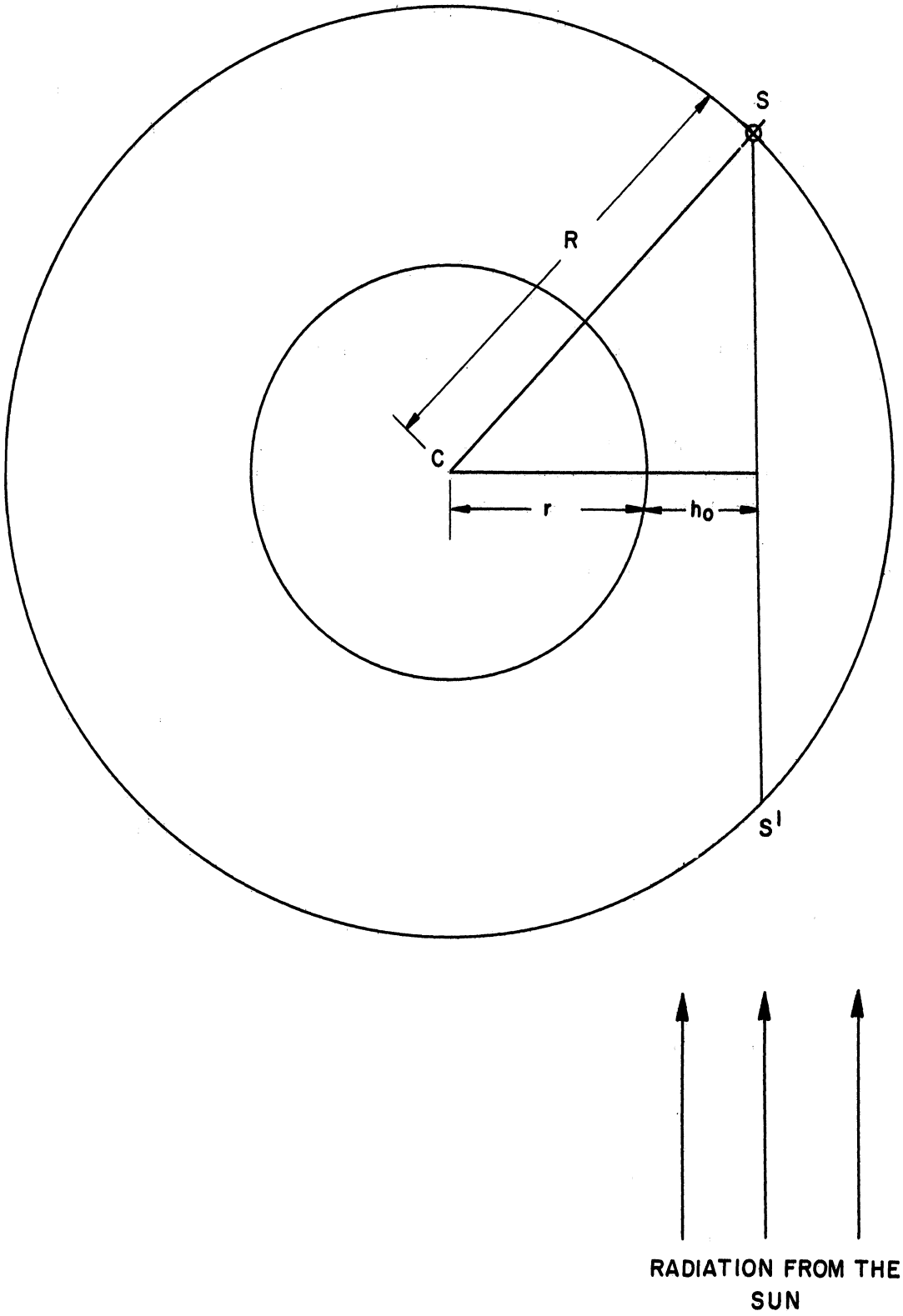

Fig. 4. Geometry of atmospheric absorption experiment.

$$\tau_\lambda = \alpha_\lambda \cdot N \ , \qquad (1)$$

where N is the total number of atoms in unit cross section along the column. If it is assumed that the thickness of the atmosphere is small compared with the radius of the earth, the optical depth is given by

$$\tau_\lambda = \alpha_\lambda \cdot n_{h_o} (2\pi \ r \cdot H)^{1/2} \ , \qquad (2)$$

where n_{h_o} is the number density of absorbing particles at height h_o and H is the scale height.

The atmospheric constituents whose densities at high altitudes are desired are atomic nitrogen, oxygen, and hydrogen. Since the temperatures are relatively low, atmospheric absorption by these atoms will take place only by transitions from their low-energy states, i.e., in their resonance lines and continua. We shall consider first the resonance lines, beginning with oxygen.

OXYGEN I

Atomic oxygen gives rise to a triplet, as a result of the transition $2p^4\ {}^3P - 2p^3 3s\ {}^3S^\circ$, at the following wavelengths:

J	E.P. (Volts)	λ (Ångstroms)	Intensity
2 - 1	0.00	1302.2	5
1 - 1	0.020	1304.9	3
0 - 1	0.028	1306.0	1

In the above table, the first column gives the J-values for the transitions, the second the excitation potential in volts of the lower level, the third the wavelength, and the fourth the theoretical intensity. At λ1300, the solar continuous spectrum is extremely weak and has in fact not yet been observed in rocket experiments. On the other hand, the resonance triplet of OI has been photographed from an altitude of 115 km with fairly high intensity in emission.[4] It is interesting to note that the intensity ratios of the solar emission lines are inverted as compared with the theoretical intensities. The inversion is probably due to atmospheric absorption as noted by Johnson et al. They also point out that, in principle, intensity measurements as a function of altitude would provide information on the vertical distribution of oxygen and possibly the temperature, but that information is also needed on the profiles of the solar lines and on the shape of the atmospheric absorption coefficient.

It is interesting to try to estimate the optical depth in the center of the line λ1302 as a function of h_o. For this purpose we shall first estimate the number densities of OI. The second column of the following table gives the air

densities at 220 and 368 km, derived by Sterne[19] from drag measurements on Explorer I.

h(km)	ρ(gm cm^{-3})	n(O+N)
220	4.0×10^{-13}	1.60×10^{10}
368	1.4×10^{-14}	5.6×10^{8}

If we assume that the atmosphere at these heights is composed entirely of atomic nitrogen and oxygen, with a mean atomic weight of 15, the number density of the particles is as given in the third column of the table above. The scale height corresponding to the above data is 44 km. We now suppose that the scale height remains constant at 44 km up to a height of 500 km, and further that the oxygen density is 20% of the total number density. This leads to the values of the oxygen number density given in the second column of the following table:

h_o	n(OI)	$n(2\pi\ rH)^{1/2}$	$\tau_o = \alpha_o : N$
220	3.20×10^{9}	4.3×10^{17}	8.6×10^{4}
300	5.24×10^{8}	7.0×10^{16}	1.4×10^{4}
400	5.42×10^{7}	7.2×10^{15}	1.4×10^{3}
500	5.62×10^{6}	7.5×10^{14}	1.5×10^{2}

According to Nicolet,[20] the number of oxygen atoms at h = 500 km depends on the temperature gradient in the thermosphere and varies between 10^7 and 2×10^8 for gradients between 1° and 5° km. These are larger than the values given above, but it will turn out that even these low values give substantial line absorption at h_o = 500 km. The third column gives $N = n \cdot (2\pi\ rH)^{1/2}$, the total number of oxygen atoms along the tangential line of sight.

We must now estimate α_o, the absorption coefficient per atom at the center of the λ1302 line. Its value for Doppler broadening may be calculated from

$$\alpha_o = \frac{\pi\, e^2\, \lambda^2\, f}{mc^2} \frac{1}{\pi^{1/2}\, \Delta\lambda_D} , \qquad (3)$$

where f is the usual absorption f-value and $\Delta\lambda_D$ is the Doppler half-width. The f-value is not known but a value of 0.1 is a reasonable lower limit. The Doppler width is calculated from

$$\Delta\lambda_D = \frac{\lambda}{c} \sqrt{\frac{2kT}{M}} , \qquad (4)$$

with T = 1000°K and M, the mass of the oxygen atom, equal to 2.67×10^{23} gm. The result is $\Delta\lambda_D = 0.43 \times 10^{-10}$ cm = 0.0043Å. We obtain $\alpha_o = 2.0 \cdot 10^{-13}$ cm^{-2}, by which we multiply the values of N in the table to get τ_o in the fourth column. The results suggest that there may be substantial absorption at the center of the λ1302 line even at heights well above 500 km. The total amount of energy sub-

tracted from the solar line will, as pointed out earlier, depend on the precise shape of the atmospheric absorption coefficient in relation to that of the solar profile, but the rough calculations given above suggest that the atmospheric absorption experiment is certain to yield valuable information on the oxygen densities above 200 km.

NEUTRAL HYDROGEN

Chapman's[17] calculations suggest that atomic neutral hydrogen may be the principal neutral constituent of the air above a level that may be of the order of 1000 km. Numerical values of the hydrogen density cannot be given even roughly with any certainty. The values in the first four columns below are given by Chapman for illustration:

h	n(H)	T	H(km)	N	T_o
160	8×10^5	560	490	3.5×10^{14}	230
520	1.6×10^5	2000	1850	1.4×10^{14}	50
2000	2.75×10^4	7920	7330	4.9×10^{13}	4.4

If we multiply the values of n by the factor $(2\pi \cdot rH)^{1/2}$ we obtain the values of N in the fifth column. The central optical depths may now be calculated with f = 1 and with $\Delta\lambda_D$ computed according to the temperatures in column 3. The results are given in column 6. Once again, they demonstrate the desirability of performing the experiment. One difficulty is the probable intrinsic variability of the solar Lyman-alpha line, which, according to rocket experiments, may vary by a factor of 100. On the other hand, the solar variations can probably be separated from those due to atmospheric absorption during the course of numerous satellite revolutions.

NITROGEN I

The following lines of NI have a high probability of occurrence in the ultraviolet solar spectrum:

Electron Transition	J	Wavelength
$2s^2\ 2p^3\ {}^4S^\circ$ - $2s\ 2p^4\ {}^4P$	3/2-5/2	1135.0
	3/2-3/2	1134.4
	3/2-1/2	1134.1
$2s^2\ 2p^3\ {}^4S^\circ$ - $2s^2\ 2p^2\ 3s\ {}^4P$	3/2-1/2	1200.7
	3/2-3/2	1200.2
	3/2-5/2	1199.5

As between these two triplets, the first is likely to be the stronger, since it includes the ultimate line at λ1135.0. According to Johnson et al.,[4] none of the lines appears in the solar spectrum photographed from a height of 115 km.

Their suggestion that atmospheric attenuation may account for the absence of these lines is reasonable in view of the evidence for substantial absorption by OI at this altitude and the probably much greater abundance of NI. In view of the great likelihood that the 1135Å line does appear in the solar spectrum, we suggest that an experiment be designed to reveal the atmospheric height distribution of NI from observations of the intensity variations in this line.

As a check on the densities of OI and NI derived from the attenuation of their respective lines, the sum of their densities may be determined from intensity measurements on the resonance line of HeI at λ584, which is expected to be a strong emission line in the solar spectrum. This line is strongly absorbed in the earth's atmosphere, both as a result of continuous absorption beyond the series limits of NI and OI, and at lower altitudes by continuous absorption in the ionization continua of N_2 and O_2. The molecular absorption seems to be of no consequence, since the radiation would be completely absorbed by the atomic constituents higher up. According to Bates and Seaton,[21] the peaks in the continuous absorption of both N and O occur in the vicinity of λ600 where the absorption coefficients are on the order of 300 cm^{-1}.

SATELLITE ORBIT

The geometry of the experiment requires that the orbit of the satellite lie as nearly as possible in the plane of the ecliptic, although the exact orientation is not at all critical. The line of sight between the satellite and the sun will, during the course of a half revolution, traverse all values of h_o between zero and the orbital radius. For a circular orbit, this would require that the radius be no less than 2000 km since the density of neutral hydrogen should be investigated to this altitude at least. An alternative possibility would be an elliptical orbit with major axis roughly perpendicular to the line of sight to the sun.

INSTRUMENTATION

The experiments require the formation of monochromatic images of the sun at wavelengths 1135Å, 1302Å, 1216Å, and possibly 584Å. The desired spectral purity will depend on the proximity of neighboring lines in the solar spectrum. In the case of Lyman-alpha, a band of wavelengths 100Å wide would probably exclude all other radiations of any consequence. For the OI triplet at 1302Å, the band 1270-1330Å could probably be admitted. For NI, the photograph of Johnson et al.[4] shows no emission lines between 1050Å and 1150Å. However, since the NI lines are themselves totally absorbed by the atmosphere on the NRL photograph, the possibility that other nearby solar lines may have been similarly absorbed should be investigated.

ANALYSIS OF DATA

As pointed out in the Introduction, the analysis of the data will require knowledge of the shapes of the solar line profiles and of the absorption coefficients in the earth's atmosphere. In principle, the solar line profiles may be determined from spectroscopic observations with very high resolving power from satellites above the absorbing layers of the earth's atmosphere. If the solar line profiles are known with accuracy, it is possible that the atmospheric absorption coefficients could be derived as a byproduct of the analysis by a modification of the curve of growth technique. Until the solar profiles are determined, however, it would be useful to calculate them theoretically on the basis of plausible solar models to explore the sensitivity of the analysis to the assumed solar model. We suggest that such calculations be undertaken as soon as possible, preferably in advance of the engineering design of the instruments.

INTEGRATION TIMES AND RATE OF DATA ACQUISITION

The integration time of the recording system must be short enough so that the total number of atoms along the line of sight does not vary greatly during the exposure. The important parameters here are the variation of h_o with time and the scale height. The former may be controlled by the size and shape of the orbit and by its orientation with respect to the sun. Calculations should be made for a variety of different orbital parameters to ascertain the optimum value of dh_o/dt in relation to the scale height and to the sensitivity of the recording system. We shall merely illustrate the problem with reference to a circular orbit at a height of 1000 km.

For a circular orbit, the variation of h_o with time is given by

$$h_o = R \cos 2\pi \left(\frac{t}{P}\right) - r , \tag{5}$$

where P is the period and R the radius of the satellite orbit, and t is taken to be zero when ϕ is zero. The derivative of h_o with time is

$$\frac{dh_o}{dt} = - \frac{2\pi R}{P} \sin \frac{2\pi T}{P} . \tag{6}$$

The time derivative of h_o therefore varies between zero and $2\pi R/P \, [1 - (r^2/R^2)]^{1/2}$. As an example, consider an orbit at an altitude of 1000 km and a period of 102^m. Then R = 7370 km, and the maximum value of dh_o/dt turns out to be about 4 km/sec. With a scale height of 40 km, the density of h_o would change by about 10% in one second and hence integration times on the order of a second would be quite satisfactory. At high altitudes the scale height increases and dh_o/dt decreases, thus permitting much longer integration times.

The rate of data acquisition should be designed to yield the densities at intervals of about every 10 km at altitudes near 200 km. Since the scale height increases with altitude, the intervals may also be lengthened, up to perhaps 50-100 km in the range 1000-2000 km. Since observations would undoubtedly be made over a larger number of orbital revolutions, it should be possible to take data at a relatively slow rate. On the other hand, there is a real possibility that the hydrogen density and its gradient may be variable, and if this is true, a complete set of data should be taken during one or two orbital revolutions.

V. SPECTROHELIOGRAMS IN HELIUM LINES

The chromosphere is a region of the solar atmosphere, about 15,000 km in thickness, that lies between the visible surface below, where the temperature is about 6000°K, and the corona above, in which the temperature is on the order of a million degrees. It is thus a transition region in which the temperature rises steeply and through which are propagated the hydrodynamic and magneto-hydrodynamic waves that originate in the layers below and supply the energy that maintains the corona at its very high temperature.

Most of our information on the chromosphere is derived from the analysis of emission-line spectra taken during the times of solar eclipses, and from radio measurements at centimeter wavelengths. Although many such data have been taken, there is sharp disagreement among different investigators on the detailed physical state of the chromosphere, particularly as regards the variation in temperature through the atmosphere. The ambiguities arise both because the eclipse observations entail a double integration of the emission in the tangential and radial directions and because the chromosphere is in neither hydrostatic nor thermodynamic equilibrium, and hence the theoretical interpretation of the data is extremely complex.

From the evidence of both the emission spectra, which show low-excitation lines of metals, together with high-excitation lines of neutral and ionized helium, and the radio measurements, there is now general agreement that the chromosphere is nonhomogeneous and that it consists of heterogeneous hot and cold columns with widely differing temperatures. It is also clear that the metallic lines are formed in the cold regions and the helium lines in the hot regions, but there are sharp differences of opinion concerning both the origin of the hydrogen emission, and the temperature gradients in the respective regions.

An important advance toward understanding of the structure of the chromosphere would result from spectroheliograms of the sun in ultraviolet lines of other elements in addition to Lyman-α of neutral hydrogen. The most significant lines for this purpose would be the resonance lines of HeI, λ584.3, and of HeII, λ303.78, both of which should be very intense. Since the excitation potentials of the HeI and HeII lines are very high, about 20eV and 40eV, respectively, the distribution of intensity over the disk should reveal the temperature fluctuations among the hot and cold regions, especially when the spectroheliograms are compared with those taken simultaneously in Lyman-α and on the ground in the K-line of CaII. Furthermore, the averaged variation in the brightness of the image from the center of the disk to the limb should give quantitative information on the gradient of the temperature with height. Also, correlation studies of the brightness and sizes of the fine structure would provide information on the hydrodynamics of the chromosphere.

Apart from the problem of the fine structure of the chromosphere, the helium-line spectroheliograms would be of very great value for the study of solar activity. There should be significant differences in the appearance of flares when seen in ionized helium, as compared with hydrogen, which should be most revealing with regard to the physical nature and origin of flares.

SATELLITE ORBIT

For the study of the fine structure of the chromosphere, the shape and orientation of the orbit are not critical; the only requirement is that the altitude be high enough to eliminate all atmospheric absorption at 584Å. The absorption at 304Å is expected to be smaller. For the study of solar activity, however, continuity of observation is important and hence a polar orbit is preferred, particularly since it may be possible to combine the helium-line and Lyman-α spectroheliogram experiment.

INSTRUMENTATION

It is recommended that every effort be made to obtain simultaneous records in the three lines 304Å, 584Å, and 1216Å, perhaps with a single slitless spectroscope. Whether or not this type of instrument can be used depends on the presence or absence of other strong lines in the vicinity of 304Å and 584Å. This question is being investigated and calculations are also in progress to estimate the expected intensities of the helium lines for engineering design purposes.

Observations from the ground suggest that the chromospheric fine structure has a scale on the order of 2 seconds of arc, and hence a resolving power in this neighborhood should be a design goal.

RATE OF DATA ACQUISITION

The requirements here are similar to those for the Lyman-α experiment, if the study of solar activity is included as a primary goal. The lifetime of the chromospheric fine structure is believed to be on the order of hours rather than of minutes, and for this purpose one record per satellite revolution would be sufficient.

VI. PROFILE OF LYMAN-ALPHA

The survey of the ultraviolet solar spectrum to be conducted in the experiment described in Section II envisages the measurement of the total intensities of the emission lines. However, the ultimate goal of satellite spectroscopy should be the precise determination of the shapes, or profiles, of the lines. The instrumental requirements for line-profile measurements are much more severe than for total intensity measurements. The degree of spectral purity that is needed is extremely high for narrow, weak lines, whose half-intensity widths would be approximately 1.6 times the Doppler half-width. In the low chromosphere, for example, the Doppler half-width of a metallic line at $\lambda 4000$ is about 0.6Å. The half-intensity width of a weak line would therefore be 0.096Å. This means that the delineation of the profile would require a resolving power in the neighborhood of 100,000, which is probably too high for the first satellite experiments but not beyond reach in the near future.

On the other hand, profile measurements are probably immediately practicable for strong lines and for weak lines of very light elements, whose Doppler widths are relatively large. For example, the Doppler width of the Hδ line at $\lambda 4100$ in the low chromosphere is about 0.2Å. This suggests that a resolving power of about 25,000 should be ample to define the profiles of the Lyman-α line, especially in view of its great intensity.

Relatively crude data bearing on the profile of Lyman-α in the sun have been obtained from rocket experiments. Thus photon counter measurements[22] suggest that more than 90% of the energy in a 100Å band falls within $\pm$0.5Å of the line, and photographs[4] of the line made with a resolving power of about 1Å indicate that the true width of the line must be less than 0.3Å. These order-of-magnitude results on the width of the line have been employed to deduce the nature of the temperature gradient in the chromosphere. The conclusions have been highly conflicting. Thus Goldberg[23] suggests that the line width is consistent with the formation of the line in the region of the chromosphere between 4000-6000 km, where the temperature apparently increases outward from about 4500° to about 6000°K. de Jager[24] believes that the Lyman-α data require that the center of the line be found at a height of 9500 km where the temperature is about 66,000°K. Athay and Thomas[25] find the Lyman-α data consistent with a wide range of chromospheric models and conclude that detailed observations of the line profile, with resolution better than one Doppler width, are needed to specify the correct temperature model. From our estimate of 0.2Å for the Hδ Doppler width given above, the Lyman-α value would be 0.06Å and the desired resolving power greater than 20,000, which agrees with our own figure of 25,000.

VII. THE CONTINUOUS SOLAR ENERGY DISTRIBUTION AT WAVELENGTHS BETWEEN 100Å AND 3000Å

INTRODUCTION

The continuous spectrum of the sun and the Fraunhofer absorption lines have been photographed down to approximately 1550Å by Tousey and his co-workers.[4] Scattered light in the spectrograph and the rapid fall-off of the energy curve combined to prevent detection of this component of the spectrum at shorter wavelengths. With filters placed in front of photon counters or ion chambers, the continuum probably has been reached at 1450Å and at 1250Å,[22] but here the contribution of emission lines is not well-known. In particular the strong Lyman-α emission line at 1216Å interferes quite seriously with the 1250Å measure, and the continuum intensity can only be inferred from the nature of the absorption by the earth's atmosphere. It is estimated that the intensity of Lyman-α is some ten times that of 200Å of the underlying continuum.

In the best Naval Research Laboratory (Tousey et al.) spectra, which have a resolution of the order of an Angstrom, the Fraunhofer spectrum shortwards of 3000Å is exceedingly rich, with the absorption lines giving a most jagged appearance to densitometer traces. At approximately 2085Å, there is an abrupt drop in intensity, which, according to Goldberg, may be caused by quasi-continuous absorption by diatomic molecules, such as NO, CO, and H_2.

A sharp increase in the intensity of the continuous spectrum should occur at 912Å, where the continuous emission of the Lyman series of hydrogen sets in. Probably in the vicinity of 500-700Å, a minimum of the energy curve will be reached. At shorter wavelengths the continuous emission of the solar corona will become important (see Section II, "The Spectrum of the Sun in the Far Ultraviolet").

Figure 5, reproduced from a summary article by H. Friedman,[5] conveniently represents our present knowledge and theory of the solar spectrum below 3000Å.* It should be emphasized that the X-ray rocket measures include the effects of emission lines, and the continuum lies well below the depicted curves. The extremely rapid drop-off of continuous intensity between 1000Å and 2000Å should be particularly noted.

THE PROBLEMS AND THEIR IMPORTANCE

The state of the ionosphere of the earth is controlled almost entirely by ultraviolet and X-ray solar radiation. In the accompanying table are listed three

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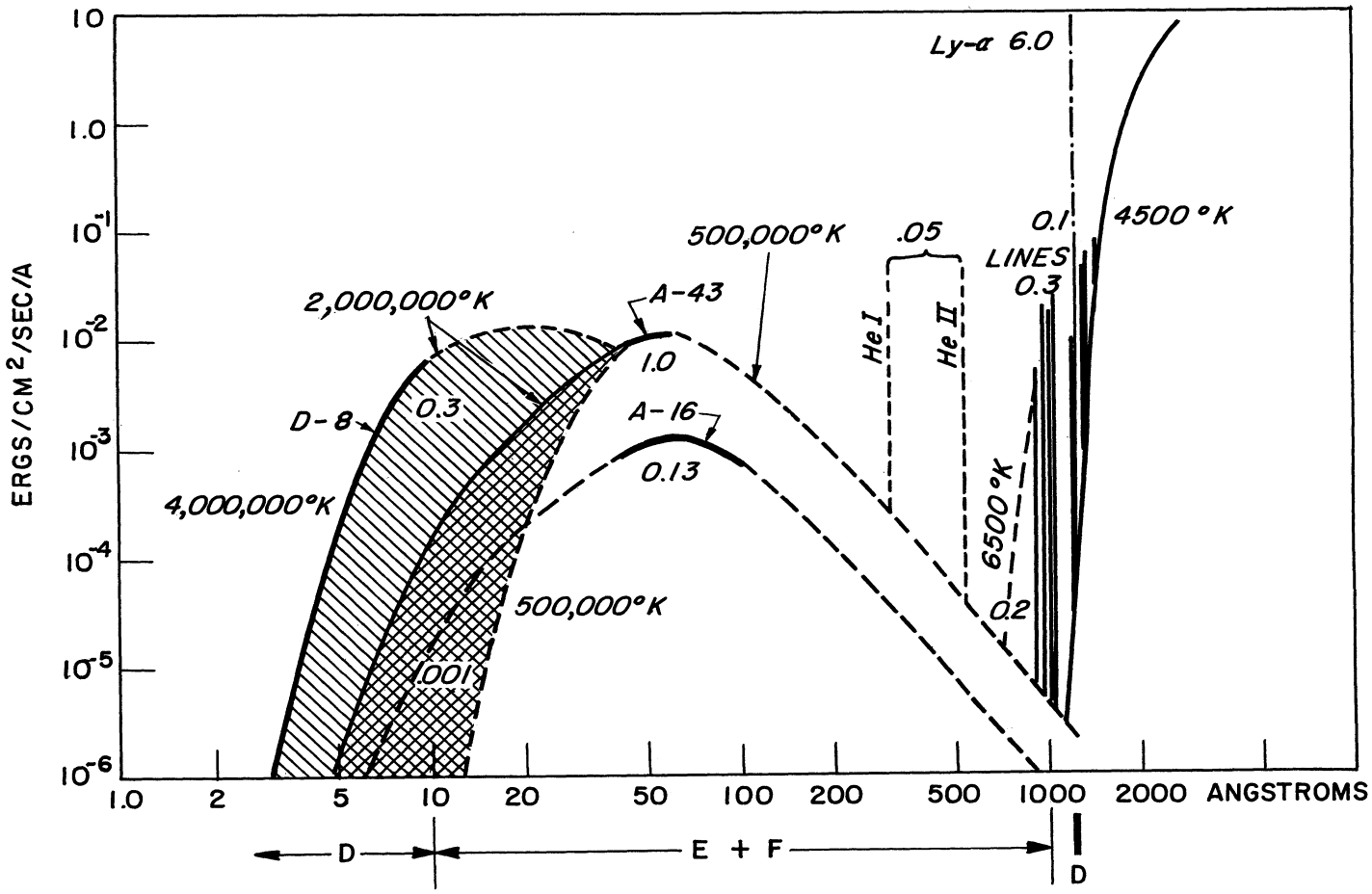

Fig. 5. Solar spectrum from rocket measurements. Solid line portions of curves are derived from measurements. Dashed curves are extrapolations. X-ray spectrum is represented as 500,000°K gray body for two different total intensities corresponding to N.R.L. Aerobees 16 and 43. Shaded areas represent short wavelength X-rays originating in hot coronal condensations. D-8 is data obtained by Rockoon during Class 1-space flare. Total flux under each curve is indicated: D-8, 0.3 erg/cm^2/sec; A-43, 1.0 erg/cm^2/sec; A-16, 0.13 erg/cm^2/sec. Measured intensity of Lyman-α line has varied from 0.1 to 6.0 erg/cm^2/sec over past seven years. Lines in neighborhood of Lyman-α obtained from the spectrogram obtained by Johnson et al.[4] Helium resonance lines are estimated for purposes of ionosphere calculation. Effective ionosphere regions of absorption are indicated along abscissa.

layers of the ionosphere and the radiation which is believed to be responsible for each. This information has been found by comparing the amount of energy needed to form each layer with both the transmission properties of the atmosphere above that layer and the available solar energy thought to exist at the appropriate wavelengths. Much of the information on the atmospheric transmission as a function of height above the earth's surface and the energy distribution of the sun at short wavelengths has been measured or inferred from rocket observations. As yet, little of it is precise, particularly the quantity of solar energy as a function of wavelength.

Ionospheric Layer	Controlling Radiation
D	$\lambda < 8$Å (active sun); Lyman-α (quiet sun)
E	$\lambda < 100$Å
F2	100-1000Å (helium lines)

As far as the continuous spectrum of the sun is concerned, very little is known about it below 1800Å. From 100 to 1000Å, no direct observations of any sort have yet been made. Although the solar continuum becomes relatively weak below 2000Å, its contribution is probably not negligible. Measurements of the strength of this radiation will give us a better understanding of the upper atmosphere not only of the earth, but also of the sun.

The measurement of the complete energy curve of the sun will allow a precise determination of the solar constant, the rate of energy received from the sun just outside the earth's atmosphere. The solar constant is perhaps the most important single solar physical quantity.

It would be desirable to obtain energy curves of the sun at several points on the sun's disk between the center and the limb. Such information would lead to a better idea of the physical structure of the solar atmosphere.

The rich absorption-line spectrum of the sun below 3000Å should be studied with high-resolution instruments. Although the crowding is considerable and there is much overlapping of line wings, these lines are mostly of low excitation, making them particularly suitable for studies of abundance as well as of the physical characteristics of the sun. The Lyman-α absorption component has not yet been observed, and its effects may spread over a wide range of the spectrum.

INSTRUMENTATION

Because of the crowding of both absorption and emission lines in the ultraviolet regions of the solar spectrum, high resolving power is most desirable. In general, the higher the resolution, the more useful will be the resulting spectrum.

Wilson, Tousey, Purcell, and Johnson[26] have shown that instrumental blending of only 0.6 or 0.8Å distorts the spectrum of the sun around 3400A to such a degree that, at wavelengths where there are absorption lines of moderate intensity, "emission" peaks can actually appear under certain circumstances.

It is strongly recommended that when photographic techniques are to be used, the long exposure times possible from an artificial satellite be utilized to acquire the highest quality observations. Charge integration or counting techniques should likewise be used whenever photoelectric detectors are employed. Rocket observations have been limited to only a few minutes of time at the most; with satellites, exposure times of hours or even days will be feasible, making high-resolution work possible. The accompanying table can be used as a guide in determining the maximum desirable band-pass. A coarser resolution would still be useful. At the longer wavelengths, this would, however, only duplicate earlier work. The value of using narrow slit widths must be emphasized.

Wavelength Interval	Desired $\Delta\lambda$
2000-3000Å	0.1Å
1000-2000	0.3
100-1000	0.5

Because the intensity of the continuous spectrum of the sun at short wavelengths is so poorly known, a wide margin of error must be provided when designing the receiving equipment.

The desired precision of the final solar energy curve is ±1%.

RATE OF DATA ACQUISITION

The continuous spectrum of the sun in the ultraviolet above 1000Å is not expected to have any detectable variability. Therefore, a single good exposure of this region of the spectrum of the sun is all that is needed. However, additional spectra would be useful in verifying the presence of faint features and determining the precision of the final results.

Naval Research Laboratory rocket observations of Lyman-α have shown it to have considerable variation. Hence it is expected that the Lyman continuum will also show fluctuations. If it is possible to obtain a spectral scan of this region in less than five or ten minutes, it would be most interesting to cover the life histories of a series of flare outbursts (see Section III, "Lyman-Alpha Spectroheliograms"). Monitoring the continuum brightness at one wavelength during a period of solar activity would be a valuable substitute for spectrum scans, if they prove too difficult to obtain in a short period of time.

SATELLITE ORBIT

The most important requirement of the satellite orbit is that it be at an altitude such that the atmospheric absorption is less than 1% at all wavelengths. Until experiments such as that described in Section IV have been performed, it is difficult to estimate this height. Past rocket flights indicate that an altitude of at least 300 km will be necessary. Friedman[5] gives a graph (here shown as Fig. 6), which should be useful in planning satellite launchings.*

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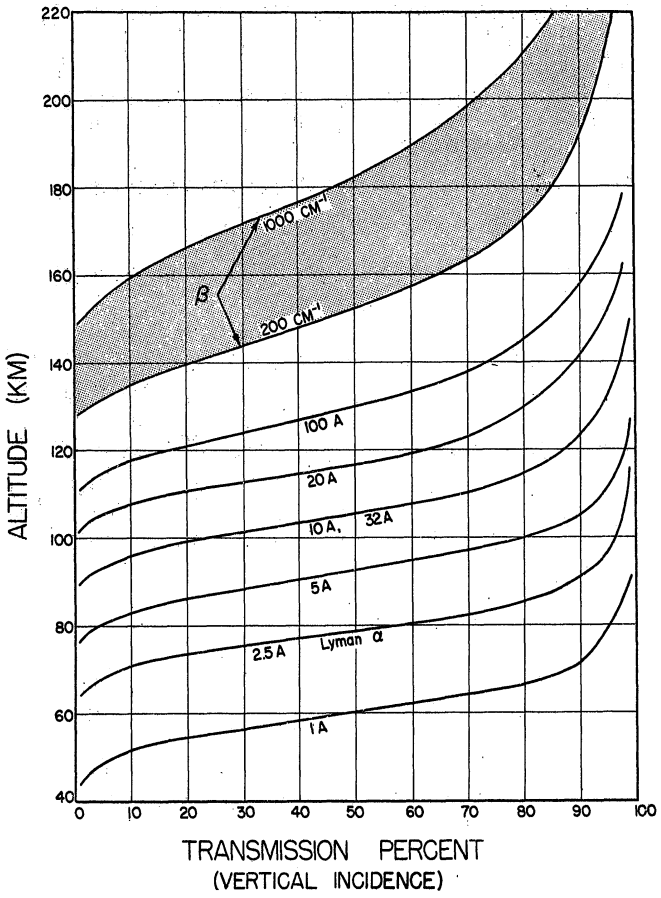

Fig. 6. Penetration of solar radiation into upper atmosphere. The density of the atmosphere was obtained from the Rocket Panel. The shaded band corresponds to wavelength from 100Å to 1000Å.

VIII. SOLAR ENERGY DISTRIBUTION IN THE INFRARED

In Fig. 7a is shown part of the infrared solar spectrum, as measured by Langley.[27] Essentially all the broad absorptions shown are terrestrial in origin. However, unlike the ultraviolet, the infrared solar spectrum can be observed at numerous points through atmospheric "windows." Therefore, today we have a reasonably accurate knowledge of the distribution of energy at long wavelengths.[28] Figure 7b presents a plot of the smoothed energy curve, as determined by Adel and by Abbott et al.[29]

However, the fraction of the solar spectrum blocked out mainly by the absorptions of H_2O and CO_2 is considerable. Numerous atomic and molecular lines and bands which are formed in the solar atmosphere cannot be observed. The lines are of high excitation and are usually quite weak. However, they are not crowded, and it would be possible to measure their shapes and sizes quite accurately.

Presented in the table below is the calculated effectiveness of the absorption of the H_2O band at 1.9μ and of the CO_2 at 4.3μ at different altitudes above the earth's surface. The quantity tabulated is the optical depth, τ, defined by

$$\frac{I}{I_o} = e^{-\tau} ,$$

where I and I_o are the absorbed and unabsorbed intensities, respectively. The listed quantities refer to the integrated effect of the entire band. The H_2O band is much narrower than the CO_2 band, and therefore produces a more striking discontinuity in the spectral trace reproduced in Fig. 7a.

h (km)	τ (H_2O)	τ (CO_2)
0	3.0×10^{4}	8.0×10^{5}
30	6.3×10^{2}	1.7×10^{4}
100	1.9×10^{-1}	5.0
200	2.6×10^{-4}	7.5×10^{-3}

As the table clearly shows, much radiation will still be blocked at even the highest balloon elevations (30 km). Even at low satellite altitudes, some effects will still be noticeable, since individual lines in a band system can be highly efficient at blocking small regions of the spectrum.

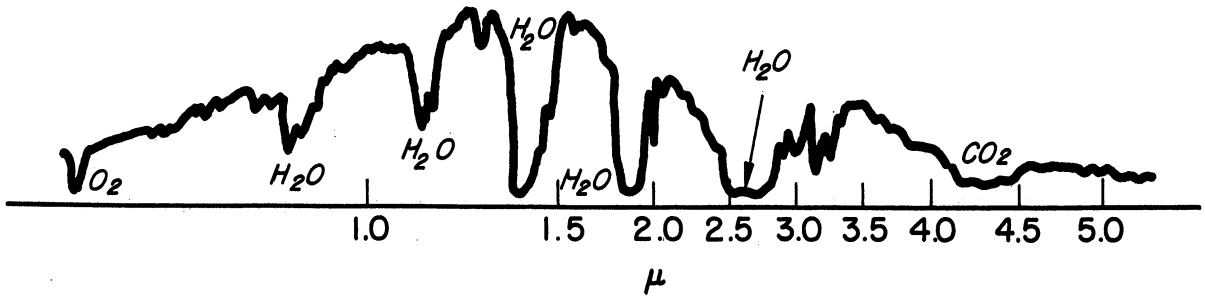

Fig. 7a. The infrared spectrum of the sun to 5 microns, according to Langley.[27]

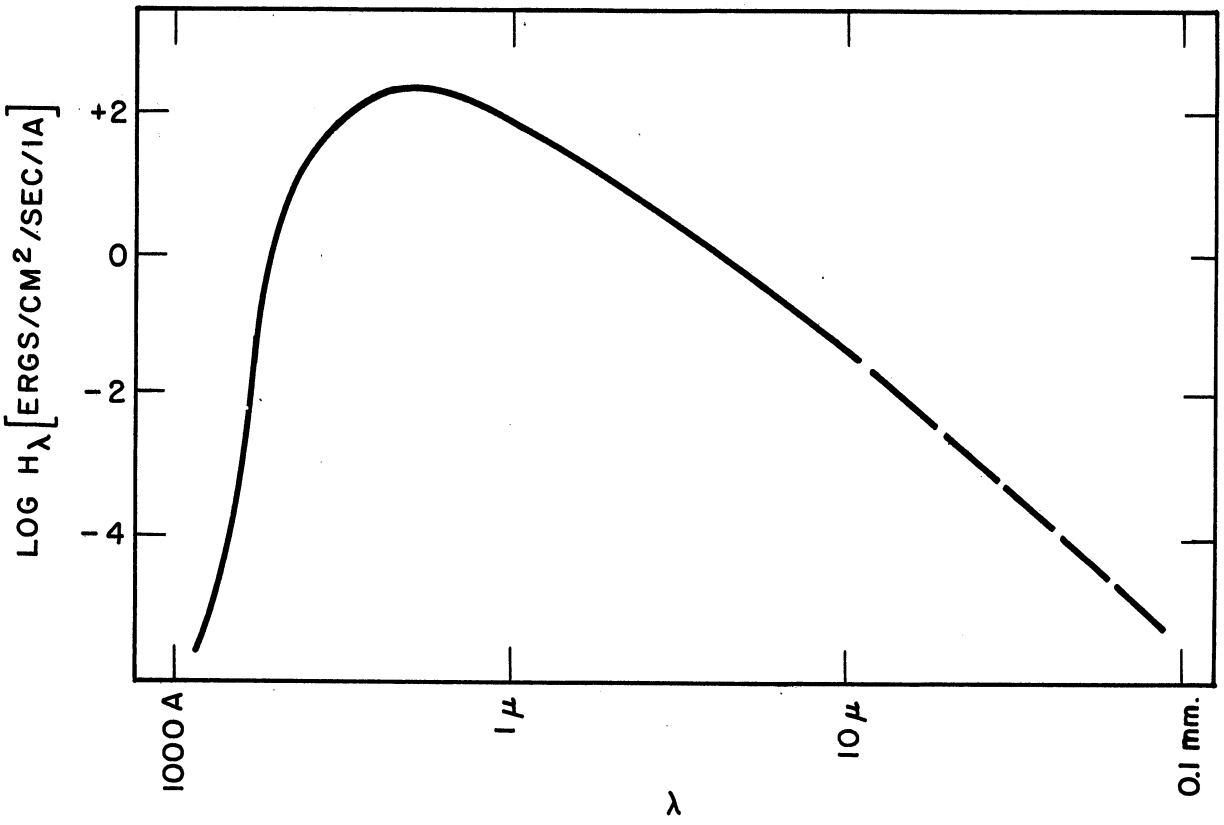

Fig. 7b. The distribution of energy of the spectrum of the sun from 1000Å to 0.1 mm. The dashed portion of the curve represents an extrapolation. The ordinate gives the amount of energy reaching the top of the earth's atmosphere.

SUGGESTED OBSERVING PROCEDURE

From an altitude of at least 200 km, a recording of the infrared spectrum with high resolution is needed. The resolving power ($\lambda/\Delta\lambda$) should be at least as high as 50,000, so that faint lines can be detected. The possibility of using long exposures to achieve even higher resolution should be considered seriously.

High-precision ($\pm 1\%$) measurements of the intensity of the continuous spectrum are desirable, so that a complete energy spectrum of the sun will be available. As no variability is expected, only one reliable observation is needed. Additional spectra would be valuable, however, as a means of verifying the presence of faint lines, and increasing the precision of the final energy curve.

Center-to-limb variations would be of value, but since the effects should be small, they are not of the greatest importance.

IX. DIRECT PHOTOELECTRIC AND PHOTOGRAPHIC OBSERVATIONS OF PLANETS

Although many of the problems of planetary photography will be solved when high-altitude balloons carry large telescopes above the turbulent regions of the atmosphere, there still exist a number of interesting questions which may be answered through the use of satellite observations. One of these is the determination of the characteristics of the scattering particles in the atmospheres of the planets. The opacity of Venus' atmosphere is probably due to the presence of solid or liquid particles; perhaps dust or sand is blown about by strong, persistent winds, or maybe ice crystals in a complete overcast of extremely high cirrus clouds. By observing the planet photoelectrically through filters and polarizers at a number of wavelengths extending from the ultraviolet to the far infrared, it should be possible to learn much about the size, shape, and composition of these particles. The same applies to photographs of the sand storms often recorded on Mars. A similar approach should be made to the rings of Saturn.

The distribution over a planet's surface of various substances—solid, liquid, or gaseous—which have characteristic absorption patterns in what are now the inaccessible portions of the spectrum could be determined. Often such absorption patterns have led to the determination of the composition of solid material, such as the polar caps of Mars. Ultraviolet photographs should prove most useful in such projects.

OBSERVATIONAL PROCEDURE

Photoelectric observations should be quite simple to make, since most of the planets are relatively bright and the pointing accuracy required is low. However, photographs would require rather precise guiding; a resolution of better than one second of arc is essential to show even the broadest features of surface detail.

It is therefore suggested that two separate programs be set up. In the first, photoelectric measurements of the integrated light from Mercury, Venus, Mars, Jupiter, and Saturn should be made at four or five selected wavelengths between 1800Å and 3000Å. Observations at shorter wavelengths would be most valuable but probably exceedingly hard to make because of the faintness of the solar continuum. Band-passes of no more than 100Å should be employed. Measurements of the percent of polarization at each wavelength should also be included. Either a rotating polarizer or a set of three suitably oriented polarizers would be required. A tracking accuracy of 1° would be sufficient.

The second program would lead to detailed photographs of the surfaces of these five planets at different ultraviolet wavelengths and in different planes

of polarization. The procedure would be identical to that of the first program, except that a tracking accuracy of at least one second of arc is necessary. Obviously, a moderately large telescope would be required to obtain the specified angular resolution. Either photographs or spectral sweeps of the planetary image would be suitable.

SATELLITE ORBIT

As long as the observations are to be restricted to wavelengths longer than 1800Å, satellite altitudes of no more than 150 km will suffice.

X. DIRECT PHOTOELECTRIC AND PHOTOGRAPHIC OBSERVATIONS OF THE ZODIACAL LIGHT

It is now believed that sunlight scattered from both free electrons and interstellar particles produces the zodiacal light, the faintly luminous band of light seen in the plane of the solar system. However, little is known about the abundance of either of the scattering agents. Following the procedure outlined in Section IX, "Direct Photoelectric and Photographic Observations of Planets," the properties of the light-scattering particles could be learned by treating the zodiacal light as an extended atmosphere of the sun. Here, of course, the pointing accuracy and angular resolution can be low. If both are of the order of two or three degrees, much desirable information will become available.

XI. MEASUREMENTS OF ULTRAVIOLET ENERGY FROM STARS, NEBULAE, AND THE SKY BACKGROUND

INTRODUCTION

Radiation impinging on the earth's atmosphere from celestial sources other than the sun has been measured by rockets fired at night by Friedman's group at the Naval Research Laboratory.[30] The problem is complicated by the fact that no guiding system is possible. As the rocket rolls, the detectors sweep out a broad band across the sky, and one must find the region of the sweep by identifying known stars or objects likely to emit characteristic radiations in the frequencies involved. The rockets carry counters sensitive to radiation in the visible region so that the stars may be more readily identified and the aspect of the rocket determined. In addition, the rockets usually carry counters sensitive to the radiations of the night sky for the study of the permanent aurora as a function of height above the earth's surface. All this information is telemetered back to the experimenter.

In the experiments of particular interest to us, the rocket was equipped with a photocell sensitive to a 300Å interval of the spectrum near λ2700, and photon counters and ion chambers sensitive to the 1040Å to 1350Å regions. With one kind of filter, it was possible to isolate a region from 1040 to 1225Å (which includes Lyman-α), and with another kind of filter the region from 1225 to 1350Å could be observed.

For the near ultraviolet, the experimenters used a 1P28 photo-multiplier tube (which is similar to a 1P21 tube with a quartz envelope), together with a chemical filter which transmitted a band-pass of about 350Å longward of λ2530 and had a maximum at λ2700. With this arrangement, Boggess and Dunkelmann[30] observed a number of stars in the near ultraviolet, and were able to construct plots of B-V (Blue-Visual) stellar colors against (λ2700) -V far ultraviolet-visual colors. These investigators concluded that the U "ultraviolet" colors of the Johnson-Morgan photometric system may be unsatisfactory as they presumably contained the influence of the Balmer discontinuity. The results obtained are difficult to interpret in terms of existing theories of model stellar atmospheres and emergent radiation. Further work will have to be done on this problem before the results can be considered final. Boggess is planning to observe the region from λ1700-1800 in an effort to remove the discrepancy.[30] The difficulty with the rocket work is that one has no control over the orientation of the observing vehicle and has to make the best of such observations as he can get.

The counter centered on the 1300Å region yielded some of the most puzzling and exciting results. Some of the hot, bright stars seemed to be much too faint

in this spectral region if current calculations of their energy fluxes in the ultraviolet are accepted. For example, if we adopt an effective temperature of 28,000°K for Spica, as recent studies of the excitation of its line spectrum would suggest, this star should be about thirty times brighter than it is observed to be. Qualitatively similar results are observed for other stars.

Most remarkable, however, are the brilliant ultraviolet emission nebulae observed in Virgo and in Orion by Kupperian, Boggess, and Milligan.[30] The Orion emission appears to be connected with the nebulae in that region, although it may fill all the area out to the outer loop. The Virgo nebula, which is centered on Spica, is especially remarkable since it is connected with no emission in the visible region at all! The average diameter of this feature is 22°; its surface brightness ranges from 10^{-4} to about 10^{-3} ergs/cm^2/sec with an average around 5 x 10^{-4} ergs/cm^2/sec. Until a spectrum of this radiation has been obtained, speculations concerning its atomic or molecular origin must be rather tentative. The fact that the emission entails no radiation in the visible region makes the problem extremely tantalizing but serves to rule out at once a great many suggested interpretations. There is no abnormal radiofrequency radiation from this region of the sky.

Kupperian, Boggess, and Milligan[30] tentatively suggest that the Lyman bands of H_2 in the region from 1000-1500Å may be responsible for this emission. There is probably no substantial amount of radiation beyond the limit of the Lyman series escaping from the α Virginis system; this phenomenon may be confined to HI regions.

Hence one of the most urgent problems would be to obtain spectrograms of this radiation. To obtain a complete understanding of this remarkable radiation, devices must be provided for measuring the total amount of radiation, its spectrum, and its surface distribution in known regions of the sky.

The radiation measured with the Lyman-α detector has been described in some detail in a preprint entitled "Extreme Ultraviolet Radiation in the Night Sky" by Kupperian, Byram, Chubb, and Friedman.[30] The Lyman-α appeared to fill the entire upper hemisphere with a glow continuous over all solid angles and amounting, on the average, to 0.003 erg/cm^2/sec/sterad. Directional intensity contours measured from the skyward hemisphere when the rocket was above 130 km show that this Lyman-α surface brightness is lowest in the direction of the antisolar point. Of equal interest is that there is a considerable amount of Lyman-α scattered back by the earth's own atmosphere. The fraction of the incident Lyman-α radiation scattered at night is far greater than the fraction scattered in the daytime, indicating that the bright Lyman-α profile in the sun is much broader than in the narrow range of frequencies scattered by the hydrogen atoms in the earth's atmosphere. This diffuse Lyman-α radiation is presumed to come from scattering by atoms in the solar system, although some external interstellar hydrogen may contribute. Clearly, the observation of stars or nebulae in the region of Lyman-α, if possible at all, will be extremely difficult!

RECOMMENDATIONS

Sky Survey

It would be of considerable value to have complete maps of the sky at several selected wavelengths in the ultraviolet and X-ray regions. These would then serve as guides to future work by locating those regions in the sky which are of particular interest. Already a number of extremely interesting discoveries have resulted from the Naval Research Laboratory rocket observations described in the Introduction (Section I).

The method of survey might be either by scanning the sky in parallel bands of latitude or by taking wide-angle photographs. Regardless of the technique, high angular resolution and high receiver sensitivity are of the greatest importance. Scanning apertures of one minute of arc diameter would be desirable; however, a resolution as coarse as 1° would be useful.

Below are listed a number of suggested band-passes, together with a priority rating of each (in parentheses). Following each are a few remarks giving the reasons for selecting that particular spectral region. The width of each band-pass may be as much as 100Å, except, of course, at the X-ray wavelengths.

λ2700 (A). Rocket observations at this wavelength have been made by the Naval Research Laboratory group. Such measurements enable determination of fluxes below the Balmer discontinuity.

λ2100 (B). This region is just above the point where heavy molecular absorption begins in the solar spectrum. Many of the brightest stars in the sky have the maxima of their predicted energy curves near this wavelength. It is also desirable to ascertain if the 1300Å emission in nebulae, discovered by the Naval Research Laboratory group, extends into this region.

λ1600 (B). This wavelength falls below the region of heavy band absorption in stars of solar type. Here chromospheric emission lines begin to dominate the solar spectrum. In nebulae, the extent of the 1300Å emission can be checked.

λ1300 (A). A map of the sky at this wavelength would be most valuable in locating and measuring the extent of emission regions. The techniques used by the Naval Research Laboratory group are well-developed.

λ1216 (B). Lyman-alpha. The results of Friedman et al.[30] indicate the radiation here from the interplanetary hydrogen is intense, but it may be confined to a narrow region of the spectrum. Hence if the spectroheliograph technique of observing just off line center were used, objects with sufficient radial velocity might be detectable. Such observations would be of the greatest importance, but would require equipment with high spectral resolution.

λ800 (B). It is possible that very little of this radiation can penetrate the neutral hydrogen in the solar system. Observations of planets would allow a

determination of the distribution of hydrogen as a function of solar distance. Perhaps a shorter wavelength would be more useful.

λ10-100 and λ1-10 (A). Observations here with collimated X-ray counters would be most interesting, because so little is known about this high-energy radiation coming from cosmic sources.

Spectral Traces

A moderately accurate guiding system will be needed before spectral traces of stars and nebulae can be made. Tracking to within ten minutes of arc will be necessary for most objects.

For scanning the spectra of the brighter stars, a band-pass of 2Å should be possible and would be highly desirable. For faint stars, scans with a resolution of ten times this amount would still yield much valuable information. For emission nebulosities a band-pass of 5Å would be desirable, but their faintness will probably require wider slits. A resolution even as low as 50Å would produce interesting results.

Since interplanetary and interstellar hydrogen will absorb much radiation below 912Å, the initial scans should cover only the region from 900Å to 3000Å. However, it would be most valuable to include counters in the same pointing system to obtain the total amount of energy in the X-ray region.

Listed below are a number of the brightest extended sources (Table II) and representative stars (Table III). Observations of these objects at an early date would be highly advisable since, in addition to providing much extremely valuable new data, they would make the programming of future work more efficient.

TABLE II

BRIGHT EXTENDED SOURCES

Object	Type
Orion Nebula	Emission
Spica Nebula	Emission
"Gum" Nebula	Emission
Eta Carina Nebula	Emission
Magellanic Clouds	Galaxy
Milky Way Clouds	Galaxy

TABLE III

REPRESENTATIVE BRIGHT STARS

Name	Spectrum	Visual Magnitude
Gamma Velorum	WC7	1.9
Zeta Puppis	O5	2.2
Beta Centauri	B1	0.9
Spica	B2	1.2
Archernar	B5	0.6
Rigel	B8	0.3
Sirius	A0	-1.6
Deneb	A2p	1.3
Canopus	F0	-0.9
Procyon	F5	0.5
Capella	G0	0.2
Arcturus	K0	0.2
Aldebaran	K5	1.1
Antares	M1	1.2

SATELLITE ORBIT

For all these observations it will be necessary to make the measurements at altitudes above which there is little absorption of radiation at the selected wavelengths (see Fig. 6, page 38).

FREQUENCY OF DATA COLLECTION

None of the objects listed in Tables II and III is variable. Therefore no more than two or three traces of the spectrum of each object are required. The speed of the trace should be no greater than that needed to achieve the desired resolution.

XII. RADIO ASTRONOMY OBSERVATIONS FROM A SATELLITE

During the past decade or so extensive radio astronomy observations have been conducted at many frequencies ranging principally from 10 Mc to 10,000 Mc.* The earth's lower atmosphere strongly absorbs and emits radio waves above a frequency of 10,000 Mc, thereby limiting higher-frequency observations. But since this observational limitation can be largely overcome by flying the receiving equipment in balloons or high-altitude aircraft, satellite experiments at these frequencies are not yet urgent. At frequencies from about 10 Mc to 10,000 Mc, the vertical atmosphere is usually highly transparent. However, the ionosphere and troposphere, by distorting the phase fronts of incoming waves, limit the measurement of size and position of radio sources and the radio emission detail that can be seen on the sun and planets. Satellite observations would also overcome this limitation in resolution but would require very large antennas or interferometers. For example, to resolve one minute of arc at 100 Mc, one would need an antenna system extending over 10 km.

On the other hand, satellite observations at frequencies below about 30 Mc, even with low-gain antennas, would be extremely valuable. It would be possible to extend the dynamic radio spectra of solar bursts and bursts from Jupiter down to 5 Mc or lower and to check and extend the work of Reber and Ellis,[31] who extended the spectrum of the general cosmic radio background emission to 1 Mc by observing through occasional "holes" in the ionosphere. It would also be possible to determine the free-electron density distribution in the earth's atmosphere above the F-layer of the ionosphere and determine how this distribution blends into that of interplanetary space or the solar corona. These are important and basic experiments which hold promise of greatly increasing our knowledge of solar flares, corpuscular streams, the sun's outer atmosphere, and the atmosphere of Jupiter, as well as of providing valuable design data for future satellite experiments relating to ambient radio noise levels (both steady-state and transient), the characteristics of the radio transmission through the solar system, and the leakage of natural static and man-made signals up through the ionosphere.

When more elaborate and highly directional satellite antennas are developed, it will be possible to extend the radio spectrum of the brighter radio sources. The determination of the spectra of radio sources at low frequencies is required to specify the physical parameters of the radiation process in the wide variety of interesting radio sources, such as the colliding galaxies in the constellation of Cygnus, the peculiar nebulosity in Cassiopeia, the supernova remnant in Taurus, the galactic center source, etc. In short, satellite observations make it possible to extend the radio astronomy spectrum downward by several octaves, to

*Mc is the wave frequency in megacycles per second. A frequency of 10 Mc corresponds to a vacuum wavelength of 30 meters.

a limit determined only by the free electron in the interplanetary medium or solar corona.

The following important radio astronomy satellite experiments that can be made with simple long-wire, short-stub, or loop antennas with conventional radio receivers will now be discussed individually:

(1) dynamic spectra of solar radio bursts,
(2) dymanic spectra of radio bursts from Jupiter,
(3) the spectrum of cosmic radio background radiation, and
(4) the distribution of electron densities outward from the F-layer.

(1) DYNAMIC SPECTRA OF SOLAR RADIO BURSTS

A description of solar activity and flares, how they are related to events on the sun and earth, and their scientific and practical importance has been presented in the proposal of this series "Lyman-Alpha Spectroheliograms" by L. Goldberg.[32] Certain of the greater solar flares are accompanied by large bursts of radio emission which begin at the higher frequencies (above about 200 Mc) and appear progressively later at the lower frequencies. The observed rates of this downward drift in frequency fall into two broad but distinct classes, as first noted by J. P. Wild and L. L. McCready[33] in 1949 from their first sweep-frequency measurements of solar radio bursts. They denoted the fast drift-rate bursts [of the order of 20 (Mc/s) sec^{-1}] as type III and the slower drift-rate bursts [of the order of 0.25 (Mc/s) sec^{-1}] as type II bursts. They denoted as type I the narrow spectrum (a few Mc wide), short duration (less than 1 sec to 20 sec) impulsive "noise storm" bursts. J. P. Wild[34] has interpreted the type III and II bursts as caused by corpuscular streams shot out from the region of a solar flare, at velocities of the order of 50,000 km/sec for type III and 500 km/sec for type II. The streams excite plasma oscillations of decreasing frequency as they pass through successively more rarefied layers of the corona. The approximate heights of different plasma levels are known for optical eclipse determinations of coronal electron densities; hence the outward radial component of velocity can be estimated from the frequency drift. Wild further noted that the velocities of particles presumed to cause great geomagnetic storms following great flares is of the same order as the type II burst velocities, and that the time-of-flight velocities computed for the rare solar cosmic ray increases following very great flares correspond to the type III burst velocities.

Now not all radio bursts of type II or III give rise to a magnetic storm or a cosmic ray increase. There is some evidence that a number of type II and type III events start at a high frequency, reach only a certain limiting frequency (because of a lack of kinetic energy in the stream), and are turned back or stopped. It has been tentatively noted that type II and type III bursts which appear to terminate at a low frequency are not associated with geomagnetic index increases.[35] In general, the type II bursts do show some correlation with the geomagnetic increases. Therefore it is important to make observations of solar spectra in a band below about 40 Mc. This is difficult even at these frequencies

which normally penetrate the ionosphere because the ionosphere is disturbed at the very time these observations are required. The satellite data can be correlated with observations from the ground to help identify the particular event observed and also to identify bursts from the planet Jupiter and terrestrial interference.

The importance of this experiment is twofold: it would make possible the further checking of the above hypothesis for the cause of the great bursts of radio emission from the sun; and it would also make possible, under the above hypothesis, the determination of the decrease of electron density with distance from the sun, and perhaps the acceleration or deceleration of the corpuscular stream in the initial phase of its flight from the sun to the earth.

The observation would consist of measuring the burst intensity as a function of frequency and time over the band of 5 Mc to 30 Mc with a receiver band-pass of 0.2 Mc while the receiver is tuned over the band one or more times a second (a rate proportional to frequency is desired but not necessary). The receiver response should be proportional to the logarithm of the input signal and the gain should be stable within one or two decibels for several hours.

The sweep-frequency receiver covering the range of 5 Mc to 30 Mc can have a maximum noise figure of 10 db over this band provided that the ratios of the antenna ohmic loss resistance to its radiation resistance are not greater than the following values: 0.75, 4, 8, 21, and 124 at frequencies of 30, 20, 15, 10, and 5 Mc, respectively. These values are based on the cosmic background brightness temperatures plotted in Fig. 10 and on the criterion that the externally limited signal-to-noise ratio is not reduced more than 10% by the receiver-antenna system.

Since a 25% reduction in signal-to-noise ratio is allowable and a 3-db receiver noise figure could be used, the maximum ratios of antenna ohmic loss resistance to radiation resistance are 16, 50, 90, 225, and 1250 at frequencies of 30, 20, 15, 10, and 5 Mc, respectively. This is an important consideration in the receiver design because it permits the resistive loading of the antenna circuit to lower the "Q" and to aid impedance matching over a wide frequency band. The dynamic range of response to input signals should be at least 60 db above the ambient noise level in the orbit to record the greatest bursts. If each intensity is measured to within an accuracy of 1 db, the data link must handle 7200 readings per second; this could be reduced by decreasing the accuracy, if required. The data should be stored on magnetic tape or film and telemetered to the ground station when requested. Since large radio bursts occur (with an hour or so duration), usually in groups, several times a month during active years, the storage could be emptied automatically every 3 or 4 hours, if necessary.

It is expected that some type III and type II burst spectra will be recorded over the entire 5-Mc-to-30-Mc band and would correlate with geomagnetic storms, aurorae, and perhaps solar cosmic ray increases. Some will be detected only at the higher frequencies and will not be correlated with terrestrial events.

If the experiment is successful and produces expected results, then subse-

quent observations should be planned at even lower frequencies perhaps from 0.8 Mc to 5 Mc.

Altitude and Orbit.—The perigee should be sufficiently high to eliminate radio propagation disturbances of the solar signal by the earth's ionosphere. The critical electron density for 5 Mc is 3.1×10^5 cm^{-3}. This is about 10 times less the maximum over England at noon during November, 1957. Since the sun cannot be observed from the dark side of the earth, the F-layer is likely to interfere with observations unless the perigee is above 600 to 1200 km. The electron densities are not well known in this region. This is a reason for the ambient electron density experiment proposed in this report.

The most desirable orbit would have a polar inclination to keep the sun under continuous surveillance for days at a time, since a given active region on the sun may produce a number of great radio burst events during its two-week passage across the solar disk.

Instrumentation.—Figure 8 displays the variation with frequency of flux density at the earth (in MKS units) for average peak solar burst intensities.[35,36] The flux density from the quiet or undisturbed sun, from the strongest cosmic radio source (Cassiopeia-A), and from the integrated intensity of the cosmic background radiation (labeled G=1) is also shown.[31]

It can be seen that the average burst level is only about 10 times greater than the cosmic background. This is also true of the ratio of the solar burst signal to background noise if a dipole antenna (G=1.5) is used, but if a long-wire antenna of several wavelengths (a few hundred meters), terminated in a lossy wire load, were used to obtain a directive gain of 15 or more, then the ratio of signal to noise would be 10 times greater than for a dipole.

The antenna must be broadband or tunable over the band and have a directive gain toward the sun of 1.5 or greater. The antenna could be extended after launching; a long-wire antenna must be extended after the satellite is stabilized. A short tunable stub or loop antenna could be used if the antenna size is large enough to obtain a sufficiently low ohmic-resistance-to-radiation-resistance ratio. Maximum permissible values for this ratio were given above.

A long-wire Vee antenna, having its beam fixed in space and directed toward the sun from a satellite stabilized about three axes, would give a large increase in signal-to-noise ratio and thereby make it possible to detect weaker solar radio bursts. However, such an antenna must be sufficiently stiff to withstand the tidal force from the earth to prevent its alignment along the earth-satellite radius vector unless the satellite is in a planetary orbit around the sun. The maximum acceleration due to the tidal force near the earth is about $5 \times 10^{-8}\ \ell$ of surface gravity, where ℓ is the distance (in meters) from the satellite center of gravity. The payload consisting of the receiver and an antenna necessary for covering this wide band of frequencies with a good impedance match would be less than 20 lb. The priority of this experiment and of the cosmic radio background

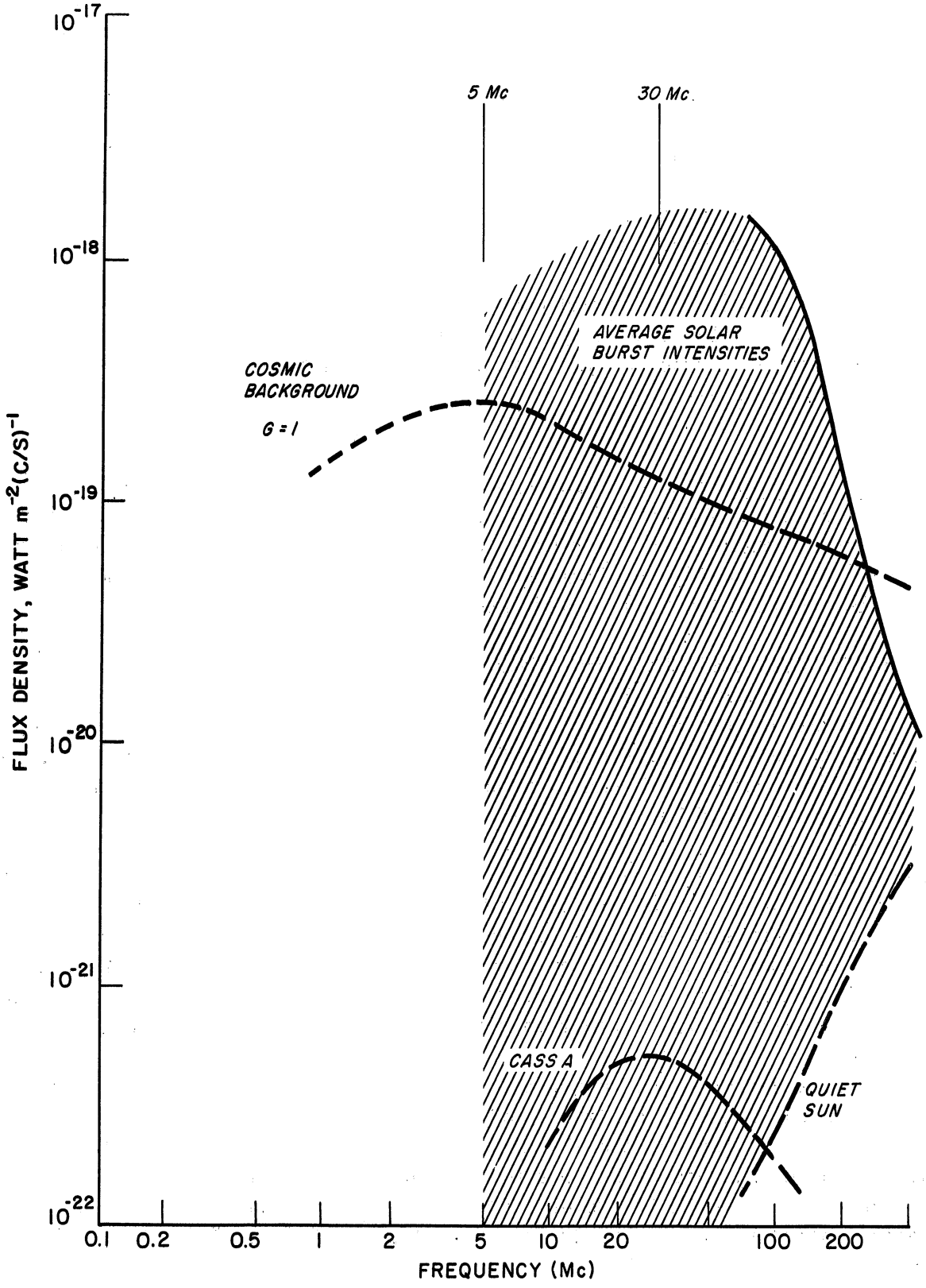

Fig. 8. Radio flux density spectrum at the earth of the sun and the galaxy.

measurement are the highest in the radio astronomy group.

It would be highly important to have a number of related experiments operating concurrently in the same satellite and on the ground. For example, experiments for measuring UV, X-rays, cosmic rays, geomagnetic stream particles, Lyman-α spectroheliograms, geomagnetic perturbations, etc., should be in the same vehicle, or other satellites while the standard I.G.Y. experiments are conducted more intensively on the ground.

(2) DYNAMIC SPECTRA OF RADIO BURSTS FROM JUPITER

In 1955 Burke and Franklin[37] unexpectedly discovered emission of intense bursts from the planet Jupiter at 22 Mc. Since then a number of very interesting and important facts have emerged.[38] It has been known for several years that about 20% of the time the planet Jupiter emits very intense bursts of radio emission in the frequency band of 14 to 27 Mc. Each individual burst has a rather narrow band width of the order of 1 Mc. They occur independently at different frequencies and last for 0.1 to 15 seconds. The bursts are most numerous at about 18 Mc; observations below 18 Mc are rare perhaps because of interfering signals and disturbance or blocking by the earth's ionosphere. The detection of bursts at frequencies above 30 Mc has not been confirmed. Therefore the spectra of the radio bursts from Jupiter have an extremely sharp high-frequency cutoff. Nothing definite is known about the low-frequency cutoff; however, if a jovian ionosphere controls the duration of burst activity, then low-frequency cutoffs from 8.5 to 20 Mc are indicated. On the other hand, this concept has been criticized by Carr et al.[38] R. Gallet has suggested that corpuscular streams are ejected from the "surface" of Jupiter through a jovian ionosphere, creating plasma oscillations and radio bursts.[38]

A fact bearing on the importance of the radio bursts from Jupiter is that the intensity of a large burst is about 10^{19} ergs, or of the order of the energy expended in an average volcano. The overall significance of radio bursts from Jupiter can be appreciated when it is noted that the radio observations to date strongly suggest the existence of an ionosphere on Jupiter, a magnetic field with a strength of at least two gauss, or four times that of the earth, and that the energy sources for the radio bursts are fixed to the surface of a solid rotating body. Recently it has been shown by Carr et al.[38] that the period of rotation of this body is 11.8 sec shorter than the period observed in the nonequatorial atmosphere of Jupiter. The determination of the energy source of bursts from Jupiter may bear on the composition and physical state of the invisible solid body of Jupiter.

The observation of Jupiter could employ the same receiver and antenna as proposed for the solar burst experiment. The dynamic range of the receiver could be reduced, however, to 40 db. The data handling and transmission could also be the same as for the solar equipment, but because of the small bursts, less information needs to be stored or telemetered.

It is expected that numerous bursts will be found over the band of 18 Mc to 30 Mc. However, knowledge of the range and frequency of occurrence of bursts below 18 Mc will provide new and valuable data for testing hypotheses of the emission process and influence of the jovian ionosphere on the bursts. Correlation of this range and frequency with solar induced effects in the earth's ionosphere can also be studied. It will be especially important to observe Jupiter during an S.I.D.* in the earth's ionosphere.

If the experiment is successful in obtaining strong, clear records of individual bursts, it would subsequently be important to record jovian bursts throughout a year to probe the outer corona of the sun by measuring the frequency dispersion and absorption of jovian bursts. If the low-frequency cutoff is not reached by 5 Mc, then a subsequent experiment should be made to extend the low-frequency range, perhaps down to 0.8 Mc. The measurement of the polarization of bursts at different frequencies would be valuable in elucidating burst generation and in determining the strength of the jovian magnetic field.

Altitude and Orbit.—The same comments apply here that were made for the solar burst proposal. The shielding of the satellite receiver from the sun by the earth may be of value, although the increased leakage of terrestrial noise from the night side of the earth may more than offset the reduction of solar interference.

Instrumentation.—Figure 9 is the same as Fig. 8 except that the solar burst spectrum has been replaced by the jovian burst spectrum. Note that the intensity of jovian bursts is less than that for solar bursts. Increased antenna gain would be desirable but the orientation of a directive antenna toward Jupiter increases the difficulty of this experiment. The payload is the same as the solar burst equipment.

The priority of this experiment is third in the four radio astronomy experiments. It would be important to have a number of concurrent ground observations of Jupiter and the sun during this experiment.

(3) THE SPECTRUM OF COSMIC RADIO BACKGROUND RADIATION

The determination of the low-frequency radiofrequency spectrum of the cosmic background radiation at low and high galactic latitudes is required to separate the components of radio emission (both galactic and extragalactic), and thermal and nonthermal emission. The thermal and nonthermal emission processes that contribute to the cosmic background spectrum should produce a maximum brightness temperature at some frequency in the band of 1 to 20 Mc, which then rapidly decreases at lower frequencies.[39] Because of the intervention of the earth's ionosphere, it is not possible to make reliable observations bearing on this critical point; therefore observations made from a satellite would make possible direct observation without

*A sudden ionospheric disturbance caused by a solar flare.

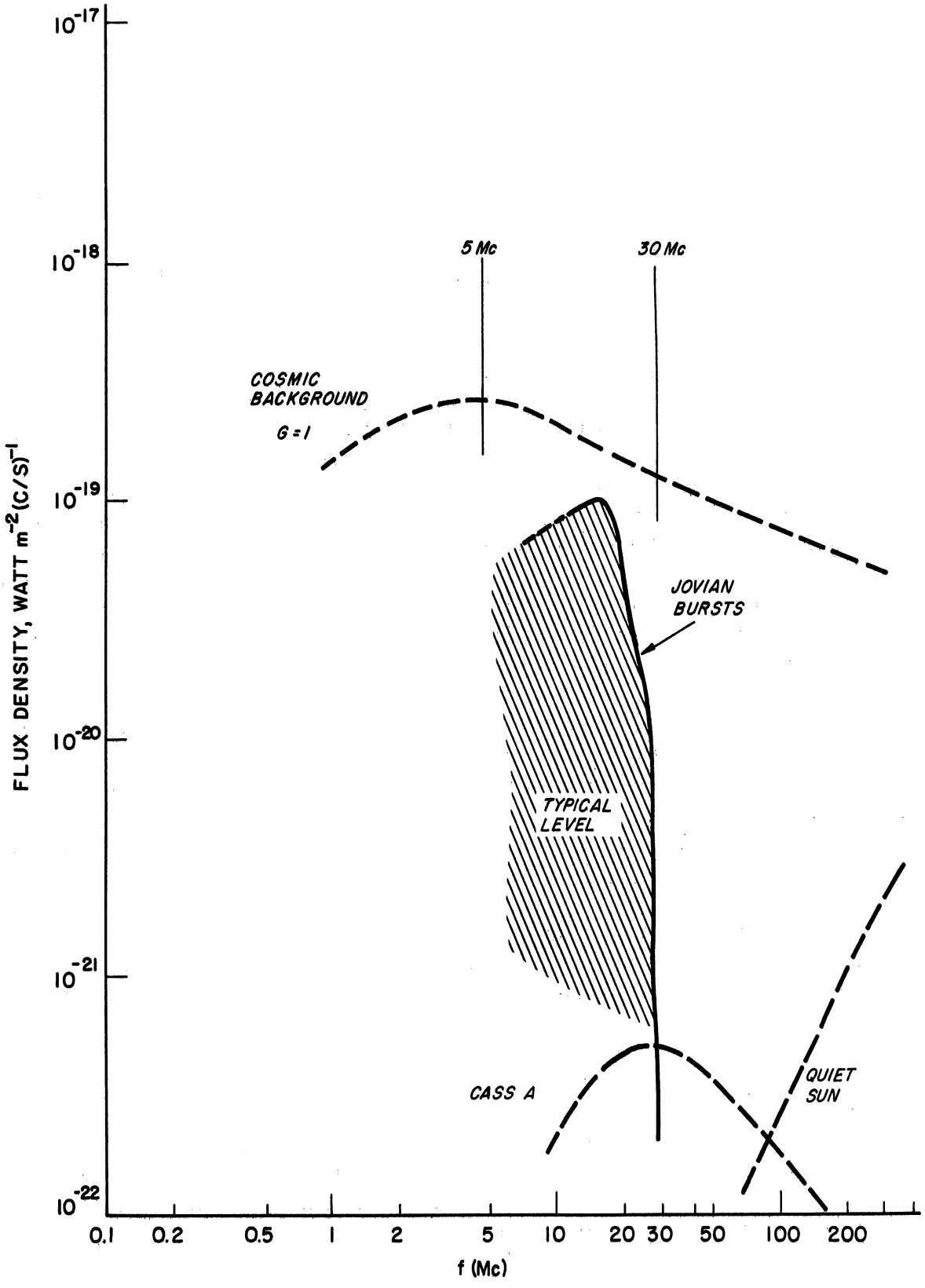

Fig. 9. Radio flux density spectrum at the earth of the planet Jupiter and the galaxy.

absorption and reflection by the earth's ionosphere. The principal value of the experiment is the determination of important parameters involved in the process of cosmic background emission. The source of the cosmic background radiation is important from the point of view of cosmology, galactic structure, the origin of radio sources and cosmic rays.

The only information available on the cosmic background intensity below 9 Mc is from observations made by Reber and Ellis[31] in Tasmania at times when the ionosphere was transparent (at times of low solar activity and at night). They were able to obtain estimates of the brightness of the cosmic background in the range of from 1 to 10 Mc. However, the accuracy of their measurements depends upon estimating the size of the transparent hole in the ionosphere. Therefore it is proposed that experiments with eight single-frequency receivers operating on separate or the same antenna be performed. The frequencies should cover uniformly the range of about 65 kc to about 6 Mc. This would make possible the determination of electron densities over a wide range of values and would make a great stride toward extending information on electron densities in the solar corona at large distances from the sun or in the interplanetary medium. The observation would consist of the continuous recording of the intensity on each channel. It would be desirable to scan the antenna beam over a great circle perpendicular to the galactic plane at a rate which depends upon the gain stability of the receiver. It would be valuable to continue the observations to note changes at the time of solar events and to record bursts from the sun and Jupiter.

We would expect to find that the intensity of the cosmic background emission peaks at higher frequencies in the galactic plane than at the poles because of absorption by interstellar electrons which are concentrated in the galactic plane. The peak intensity of emission will occur near 0.5 Mc in the plane, depending on the antenna directivity, whereas at the galactic pole the peak of emission may occur between 0.02 Mc, and 0.2 Mc.

It appears likely that ambient electrons will block a clear view of the galaxy at the lowest frequencies, even with the orbit at heights of 1000 km or greater. In such a case, subsequent experiments should be made at greater apogee heights.

Altitude and Orbit.—The orbit should have as great an apogee height as possible to avoid a low-frequency cutoff by local electron concentrations near the earth. If a density of 600 cm^{-3} exists around the earth-moon system, as is generally believed, then the galaxy is blocked from view below about 0.22 Mc. An orbit inclination perpendicular to the plane of the Milky Way is desirable only for the directive-beam measurement. Some directivity is always obtained by the earth occulting part of the background.

Instrumentation.—A low-directivity measurement of the radio background intensity can be accomplished with a small loop or stub antenna since antenna "radiation efficiency" is not very important because of the high background noise level. For example, with a receiver noise figure of 3 db and a permissible increase of one-third in the ultimate inaccuracy of the background intensity meas-

urement, the antenna ohmic-resistance-to-radiation-resistance ratio can be as large as 2500 at 65 kc and 140 kc; 25,000 at 300 kc, 650 kc, and 1.4 Mc; 5,000 at 3 Mc; and 750 at 6.5 Mc. These values are halved for a noise figure of 6 db.

A valuable directive-beam measurement of background radiation can probably be made by using a very-long-wire antenna (at least ten wavelengths in each half) released from a satellite stabilized in 3 axes, orientated and locked onto the earth, in an orbit more or less perpendicular to the plane of the Milky Way—the two halves of the antenna being aligned by tidal forces with the earth-satellite vector, one toward the earth and one away, each 45 km long (90 lb of AWG No. 30). This antenna would have a directive gain of 9 at 65 kc and somewhat higher at the higher frequencies. It is possible to obtain a sufficiently low ohmic-to-radiation-resistance ratio if a receiver noise figure is less than 3 db. The natural pendulum frequency of this long-wire antenna is independent of length and is sufficient to keep the wire aligned with the earth and satellite. Two wires are required because the electrical capacity of the present size of satellites is too low to act as a ground plane for efficient operation.

The receiver band width is not critical and can be in the range of from 10 to 50% of the center frequency of the pass band. These receivers should be calibrated occasionally to ensure an absolute noise-level measurement accurate to within 1 db. The receivers should recover rapidly from impulse interference and record data of background intensity every few seconds. The dynamic range should be at least 60 db with a logarithmic response.

Figure 10 displays the spectrum of cosmic radio background intensity, in temperature units, as extrapolated from higher-frequency measurements,[40] and as measured at a number of frequencies from 1 Mc to 4 Mc by G. Reber and G. R. Ellis.[31] The shaded area is a rough speculation of sudden decrease in intensity at low frequencies. The decrease can be intrinsic to the emission process or, more likely, to absorption or reflection by the electrons in the sun's outer corona, by interplanetary electrons or an extension of the earth's ionosphere.

It is expected that a sudden drop will be found in the background brightness around 0.14 Mc to 0.3 Mc.

The payload for the antenna and receivers should be less than 20 lb, unless a long-wire antenna is used.

This experiment has top priority in the list of four radio astronomy experiments contained in this report, along with the solar radio burst experiment.

(4) THE DISTRIBUTION OF ELECTRON DENSITIES OUTWARD FROM THE F-LAYER

For the radio astronomer, knowledge of the electron density surrounding the earth is important since electrons prevent cosmic radio waves from reaching an earth satellite at all frequencies below a certain critical value. If a present estimate of 600 electrons per cm^3 is correct, it is not possible to observe the

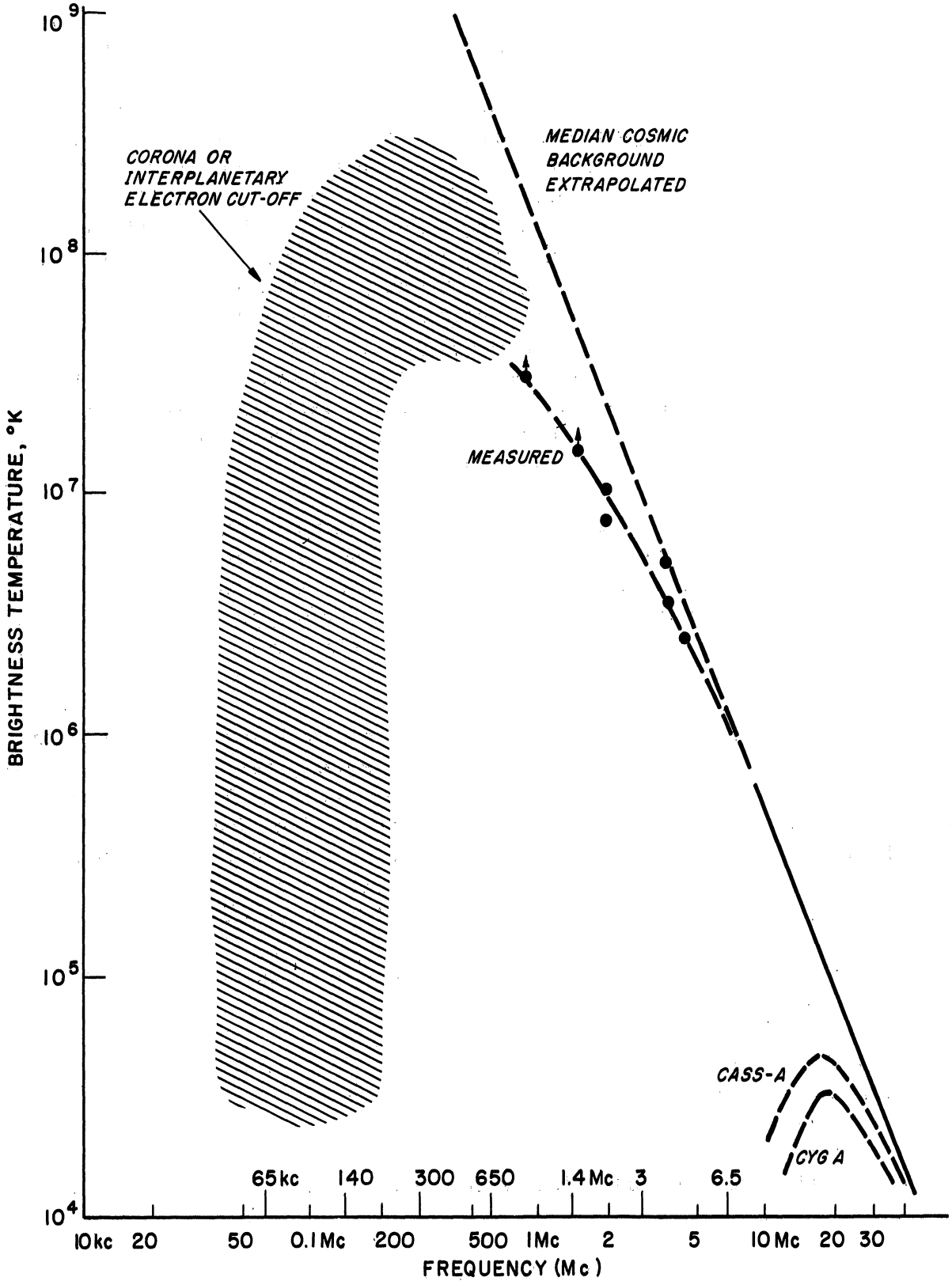

Fig. 10. Cosmic radio background brightness.

galaxy, or even planets, with frequencies below 220 kilocycles. It may be, however, that interstellar electrons will obscure our view of the cosmos at frequencies above this.

The electron-density distribution around the earth is important for a number of geophysical and astrophysical problems. It bears directly on studies of the earth's ionosphere and upper atmosphere. It is important for studies of the earth's magnetic field and the interplanetary magnetic field, for the nature, origin, and heating of the sun's corona, the conduction of heat from the sun to the interplanetary medium, and the nature of zodiacal light.

The electron-density distribution above the F-layer can be estimated from ionospheric theory, from the faraday rotation of radio waves from moon radar echoes, and from radio transmissions by rockets or satellites. These determinations, however, involve, or are affected by, the dense regions of ionization and therefore are not as attractive as a direct determination of the density surrounding a satellite as it travels from dense to the distant tenuous regions.

It is true that studies of audio-frequency atmospherics, propagating by a magneto-ionic-duct mode ("whistlers") to several earth radii and back, give values for electron density at these large distances. However, it is not easy to determine the variation of density with height.

A Langmuir probe method for the determination of electron temperature and density has been demonstrated on rockets in the E-layer of the ionosphere and has been considered for earth-satellite measurements.[41] This method should be considered for the measurements recommended in this proposal and compared with the following suggestion for measuring ambient electron densities; it is an r-f probe technique, which may have certain advantages over the d-c Langmuir probe method.

This technique consists of tuning a radiofrequency oscillator, attached to a matched long-wire antenna extending from the satellite, over a frequency band from 20 kc to about 10 Mc at a rate determined by the rate of change of altitude of the satellite. For a circular orbit this sweep rate could be rather slow; for an eccentric orbit the sweep period should be short compared to the time it takes a satellite to change its altitude by 10 or 20%. As the oscillator is swept over the frequency range, the change in the impedance of the oscillator circuit is recorded. When the oscillator frequency approaches the critical frequency of the ambient electrons, there should be an abrupt change in the record. With appreciable geomagnetic fields at oblique angles with respect to the antenna, a detailed analysis would be needed to interpret the results. It may be possible that changes in aspect of the antenna with the earth's field will give additional information about the field. The rate at which information must be telemetered to earth for this experiment depends largely on the orbit. The only data needed would be measurements of the change in the impedance with position of the satellite, and perhaps the antenna orientation. It may also be useful to record the phase of impedance as well as its magnitude. It would be extremely important to determine the change in magnitude and distribution of the electron density, following a flare or radio burst, and during a geomagnetic storm or aurora.

It is expected that the electron density will be found to decrease from the F-layer maximum near 10^6 cm^{-3} (depending on local time, season, solar activity, and latitude) to several thousand cm^{-3} at an altitude of 1000 km to 2000 km, and then gradually to decrease to a few hundred at several earth radii.

Subsequent observations should be devoted to refining the accuracy and speed of the measurement to record the fine scale structure of the electron-density distribution and its variations in time.

Altitude and Orbit.—The perigee should be about 250 km to 300 km and the apogee several thousand km. A polar orbit is preferred to determine the effect of the geomagnetic field on the distribution. The requirements due to the long-wire antenna were given in the description of the cosmic radio background experiment.

Instrumentation.—Figure 11 illustrates schematically a possible distribution for the electron density above the F-layer and how it blends into the interplanetary medium. The right-hand ordinates are the critical plasma frequencies for the corresponding electron densities on the left-hand ordinates. The dashed line on the left represents the decrease above the F-layer maximum. Its slope is based on an article in Pravda[42] on Sputnik I and II and a recent Russian paper.[43] The solid curve is based on a model by Dungey[44] which represents the electron-density decrease with the distance R from the earth's center by 600 exp $(2.5\ R_e/R)$ cm^{-3}, where R_e is the radius of the earth. The various horizontal lines on the right are values of electron density at the earth's distance from the sun. The values labeled C1, C1.1, and C1.2 are from a recent paper by S. Chapman[45] on the solar corona for the three assumed values of the base temperature of the solar corona; namely, 1, 1.1, and 1.2 million degrees Kelvin. The two values labeled H represent the range of values given by van de Hulst[46] from a study of the polarization of zodiacal light. Six hundred cm^{-3} is the asymptotic value given by Dungey's model and was adjusted to this because it fits both the zodiacal light determination and the results obtained from magneto-ionic-duct propagation studies ("whistlers").[47] However, some recent studies of "whistlers" require an electron density of 300 cm^{-3} at a distance of 3 earth radii.[47] It appears, then, that the electron density surrounding the earth lies between 300 cm^{-3} and 800 cm^{-3}, corresponding to critical frequencies of 15.5 kc and 25.5 kc.

The data should be recorded continuously, stored, and telemetered when requested.

The payload required should be less than 20 lb, excluding a long-wire antenna.

The priority of this experiment is fourth in the list of four radio-astronomy experiments.

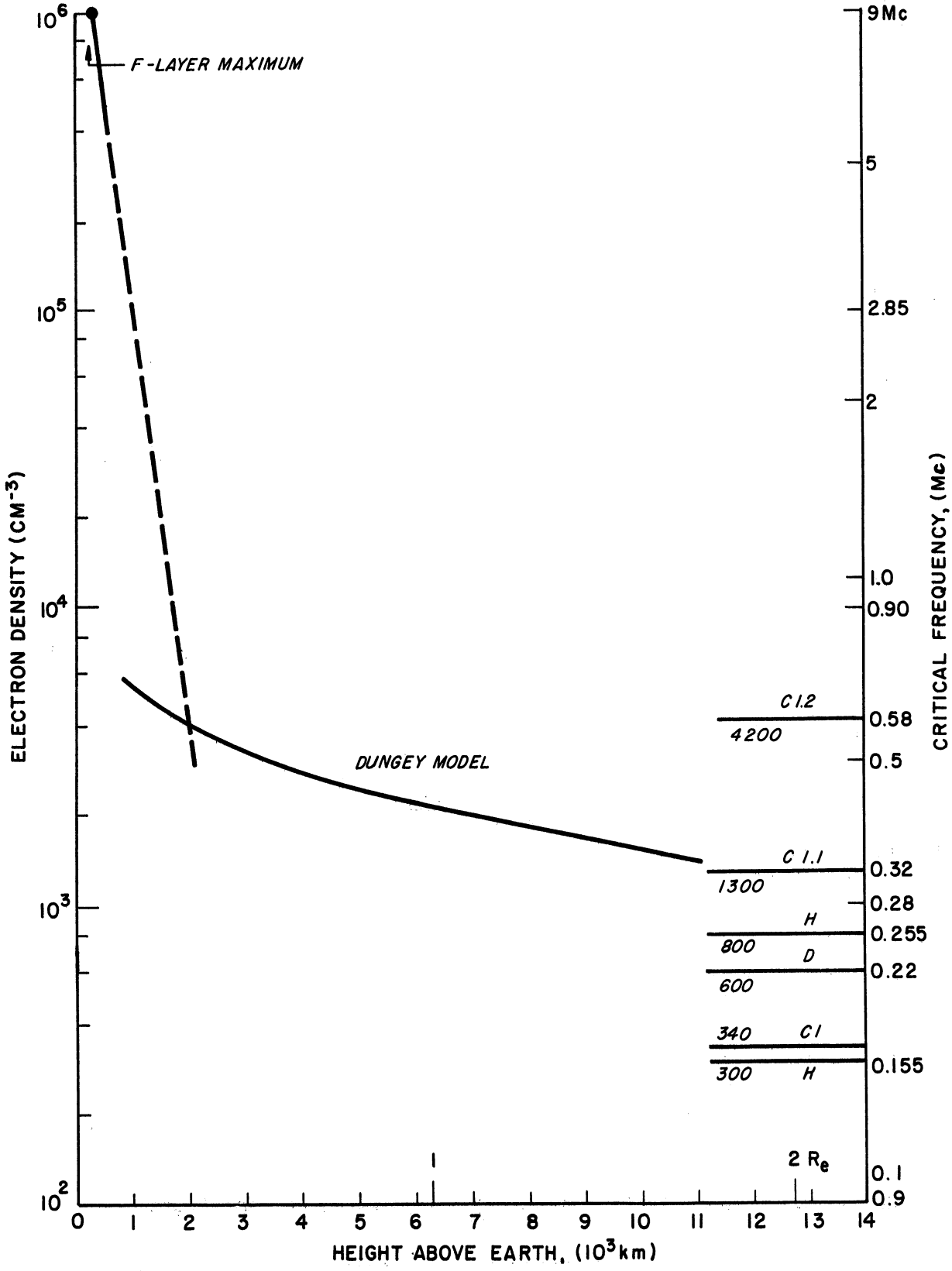

Fig. 11. Schematic representation of electron-density distribution above F-layer.

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