THE STRUCTURE OF THE QUIET PHOTOSPHERE AND THE LOW CHROMOSPHERE

PROCEEDINGS OF THE 'BILDERBERG' CONFERENCE
HELD NEAR ARNHEM, HOLLAND, APRIL 17–21, 1967

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PREFACE

From 17 to 21 April 1967 a Study Week was held in the hotel 'De Bilderberg' near Arnhem, Holland, with the purpose to establish a new, and if possible, generally acceptable working model for the quiet parts of the solar photosphere and low chromosphere.

The organizers of the conference hoped that even if this latter goal appeared too far to be reached, such a meeting would still be useful, if only for enumerating the crucial problems in solar photospheric research, and for defining future subjects of research. About twenty solar physicists from outside the Netherlands participated in the Study Week, while some others, though prevented from actively attending, submitted their comments before the meeting.

The two above-mentioned goals were reached: a working model *could* be established; yet it became clear that not everyone would agree about this model, and it became obvious too that future research is strongly needed, in particular in the field of line formation (coherence, or non-coherence; local thermal equilibrium), while also the motion field of the photosphere and chromosphere is insufficiently known, and its influence on the formation of spectral lines hardly understood.

After the Study Week the preliminary results were circulated and provisionally presented in a meeting of Commission 12 of the International Astronomical Union in Prague. This preprint circulation offered one the opportunity to modify the model in certain respects, while it also provoked some post-Bilderberg discussions, the results of which may also be found in the present proceedings of the Study Week, reprinted from *Solar Physics* **3** (1968), No. 1.

We gladly mention that the Study Week has been made possible by a grant of the Leids Kerkhoven-Bosscha Fonds. We remember with thankfulness the efficient help in the practical organization by Miss C. E. Boot and Mr. J. B. Vogel.

C. DE JAGER

First row (left to right): J.-C. Pecker; J.T. Jefferies; Carla E. Boot; Marijke Burger; R.W. Noyes; Edith A. Müller; R.M. Bonnet; Simone Dumont; D.L. Lambert; Yvette Cuny. *Second row (left to right)*: J.E. Blamont; J. Houtgast; R.G. Athay; Christiane Grevesse-Guillaume; N. Grevesse; O. Namba; C. de Jager. *Third row (left to right)*: J.P. Mutschlecner; O. Gingerich; G. Withbroe; M.G.J. Minnaert; T. de Groot; H. Holweger; A. Sauval; H. Vesters; P. Souffrin; H. Hubenet; M. Herse; R.J. Rutten; P.J. Léna; A. Skumanich; P. Delache; J. B. Vogel.

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THE BILDERBERG MODEL OF THE PHOTOSPHERE AND LOW CHROMOSPHERE

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Abstract. From 17 through 21 April 1967, an international study week was held in the 'Bilderberg' near Arnhem, Netherlands, with the aim of obtaining an internationally acceptable model of the solar photosphere and low chromosphere. It was found that such a model, based on observed intensities and center-to-limb observations of the solar continuous spectrum, could indeed be established. This model, henceforth called the Bilderberg Continuum Atmosphere (BCA), is shown in Table I, which gives the temperature, gas and electron pressures, and other data as functions of the continuous optical depth at 5000 Å between $\tau_{5000} = 10^{-7}$ and 25. The model is characterized by a flat temperature minimum of 4600°K between $\tau_{5000} \approx 10^{-2}$ to 10^{-4}. The model is homogeneous, and in hydrostatic equilibrium. A hydrogen-helium ratio of 10 has been assumed.

Much divergence remains in the interpretation of line-profile observations with regard to the establishment of a photospheric model (Section 4). It proved to be as yet impossible to obtain reliable information on the variation with depth of the following functions: temperature fluctuations, turbulence velocities, convective velocities, and vibrational velocity amplitudes (Section 5). Provisionally, it is assumed that $v_{\mathrm{macro}} = 2$ km/sec and $v_{\mathrm{micro}} = 1$ km/sec, isotropic and independent of depth.

1. Introduction

In the course of the last twenty years, many models of the solar photosphere have been constructed. These have been used with more or less success in predicting certain aspects of the solar spectrum or for interpreting observations. Gradually it became obvious that a generally acceptable model of the solar photosphere and low chromosphere that could be used as a reference model by all the workers in the field might be useful.

It was with a view to this need that the so-called Utrecht Reference Model of the Photosphere and Low Chromosphere (URP; HEINTZE, HUBENET, and DE JAGER, 1964) was established. It fulfilled this requirement in the sense that it has been used by several solar physicists for the intercomparison of results of their computations based on their own photospheric model with the URP model; this proved to be valuable.

However, after three years of service, it became obvious that the URP model needed revision in several respects. To arrive at a model acceptable for many solar photospheric workers, and in particular to take account of the heterogeneous mass of observations of various kinds and their implications for our knowledge of solar structure, a study week was convened for the construction of a new and possibly internationally acceptable model of the photosphere and low chromosphere. This study week was organized by the Utrecht Observatory and held at the Hotel 'De Bilderberg' near Arnhem, Netherlands, from 17 through 21 April 1967.

2. Program of the Meeting

The general schedule of the meeting was as follows:

In a period of about five months before the meeting, many participants formulated their opinions about the solar model. These contributions, in the form of some 30 preprints, were distributed prior to the meeting.

In the first two days of the conference, the participants discussed their preprints for 10 to 15 minutes, and general discussions followed. On the third day, the results of the previous sessions were reviewed and a first attempt was made to synthesize the various contributions into a model of the photosphere.

On the fourth day, some general problems of methodology were discussed; in the afternoon, three working groups were convened to discuss:

(a) the establishment of a photospheric model based on continuum measurements;

(b) the establishment of a photospheric model based on observations of line profiles and equivalent widths;

(c) the variation with optical depth of the following functions: temperature fluctuations, turbulent velocities, convective velocities, and vibrational velocities.

On the fifth day, the three chairmen of these groups reported, and a model of the photosphere was established. This model appeared essentially to be based on the continuum observations and hence was named the Bilderberg Continuum Atmosphere (BCA).

The detailed program of the study week is given in Addendum I. The composition of the three working groups is shown in Addendum II.

3. The Bilderberg Continuum Atmosphere

In this and the two following sections, we briefly summarize some of the main conclusions of the three working groups. The establishment of a solar photospheric model based on continuum observations proved feasible, and, in fact, the participants were surprised to see how well the observations of the various parts of the solar spectrum, including the ultraviolet and infrared ranges, agreed in producing one uniform model of the solar photosphere. This model is outlined in detail here. A brief summary of the results from line-profile observations is given in Section 4; in Section 5, a summary of the meeting's opinions on the temperature and pressure variations and on the velocity fields in the photosphere will be given.

To determine empirically the run of temperature in the sun, we must examine the emergent intensities that arise from various depths. This is accomplished in three ways:

(a) by investigating absolute intensities over an extended spectral range, exploiting changes in opacity to cause different effective depths of formation;

(b) by measuring the intensities close to the extreme limb of the sun;

(c) by studying the profiles of strong lines where great differences in the absorption take place within a few angströms.

Although the first method permits the simplest interpretation (provided the theoretical absorption coefficients are linked without systematic error throughout the wavelength range), the ordinary visual continuum does not provide much leverage on the solar temperature distribution, because the opacity changes very little between 4000 Å and 10000 Å. However, in both the micron and millimeter regions, as well as in the ultraviolet, the absorption increases enormously and the emergent radiation originates in higher layers of the sun's atmosphere.

Until recently, there were too few observations to sketch a systematic picture of the region of the solar temperature minimum and the low chromosphere by this method, but in the past few years more observations from this extended wavelength range have become available, and their significance for a solar model has been more clearly appreciated. As a result, a number of new measurements were collected and reported for the first time at the Bilderberg Conference and incorporated in the BCA. This new empirical solar model defines the temperature throughout twice as many orders of magnitude in optical depth as the previous URP.

Although the observations considered fall into place with remarkable consistency, solar physicists should be aware that conflicting results from line-profile analyses were completely ignored in the formulation of this model. Furthermore, the agreement of the far-ultraviolet and infrared observations may point more toward the meagerness of the data than to the certainty of our deduced temperature distribution.

Before the particular observations and the temperature regions they define are discussed, some general remarks about the different spectral regions are in order.

In the far ultraviolet, calibrations rest primarily on the rocket results of DETWILER *et al.* (1961). The ultraviolet opacities, although now much better understood through the work of GINGERICH and RICH (1966, 1968), are still comparatively poorly known. Nevertheless, they point to the spectral region between 1525 Å and 1683 Å as arising from the solar temperature minimum, and since the minimum region is apparently rather broad, even large errors in the opacity will not appreciably affect the emergent intensity. Furthermore, because the Planck function is extremely sensitive to temperature in this wavelength region, an order-of-magnitude error in the absolute intensity calibration will make only a 400° difference in the emergent brightness temperature.

In the visible spectrum violetward of 4500 Å, marked discrepancies still exist between the observed intensities and the model-atmosphere predictions, as reported to the Bilderberg Conference by CARBON, GINGERICH, and KURUCZ (1968). In the absence of any truly convincing explanation for this disagreement, it is best to omit these wavelengths in constructing an empirical solar temperature distribution. This near-ultraviolet region is increasingly blanketed by absorption lines, but these seem to account only partially for the discrepancy.

The wavelength region extending from about 5000 Å onward into the infrared provides several distinct advantages for determining the solar temperature distribution. The comparative paucity of absorption lines eliminates the difficulty of establishing the true continuum. The opacity is well known, arising in the infrared regions from the free-free absorption of negative hydrogen ions. Finally, at least some of the non-LTE effects haunting the ultraviolet regions are absent here. Undoubtedly, future models will place increasing reliance on this spectral region as more observations become available.

The run of temperatures in the BCA can be roughly divided into three sections: the *photosphere*, below $\log \tau_{5000} = -1$, the *temperature minimum* from $\log \tau_{5000} = -2$ to -4, and the *low-chromosphere* temperature rise above $\log \tau_{5000} = -4$.

3.1. The Photosphere

A great wealth of limb-darkening data from the visible regions of the spectrum delineates the shape of the temperature distribution between optical depth 0.1 and unity. The models of Sauval (1968), Holweger (1967), Mutschlecner (1968), Lambert (1967), and Elste (as presented by Withbroe, 1968) differ from each other or from the URP by less than 200°. Much of the existing disagreement derives from the various values adopted for the absolute intensities of the continuum at various wavelengths. It is clear that not all the values in the literature can be taken with equal weight, and it should be noted that averages including the original, high results of Labs (such as those given in Allen's Astrophysical Quantities) are less trustworthy than the more recent values given by Labs and Neckel (1962).

Some concept of the internal accuracy of measurements can be formed by comparing the temperatures derived from different wavelengths. For example, the results of Sauval and Holweger show that either the opacities or their adopted continuum intensities are incorrect in parts of the near-infrared. Since any opacity errors would probably show their most conspicuous anomalies in the relatively transparent region of the H^- absorption minimum at 16400 Å, and since the results of Sauval and Holweger were quite smooth in this particular spectrum region, we conclude that their adopted intensities beyond 20000 Å contain errors. The work of Lambert, which was based primarily on the absolute intensities of Labs and Neckel and the relative intensities of Pierce scaled to the intensities of Labs and Neckel, did not show any such anomalies in the infrared. Because the model of Lambert not only appeared internally consistent but closely resembled the model of Mutschlecner and the middle column of Elste's three-column model, his model was adopted for the region $\log \tau_{5000} = -1$ to 0. At the same time, the value for $I_{5000}(0,0)$ of 4.05×10^{14} ergs cm^{-3} sec^{-1} ster^{-1} was adopted from the work of Labs and Neckel.

The temperature distribution below optical depth unity is rather poorly determined by the observations, since there is no particularly transparent region of the spectrum that permits unambiguous observations of these depths. Models constructed with the mixing-length theory of convection give some guidance to plotting the temperature in this vicinity, and since the URP already reflected these convective trends, the temperatures at greater depth were simply scaled from that model. In retrospect, it appears that the temperatures below $\tau_{5000} = 2$ were pressed too low. It is perhaps this decision that has produced the lower predicted $I_{5000}(0,0)$ of 3.91×10^{14} ergs cm^{-3} sec^{-1} $ster^{-1}$ in the BCA rather than the desired value of 4.05×10^{14}.

3.2. THE TEMPERATURE MINIMUM

The value of 4600° adopted for the temperature minimum in the BCA rests on two lines of evidence. First, this is close to the color temperature found by TOUSEY (1963) and his colleagues for 1600 Å; the reasons for believing that radiation from this wavelength region emerges from the temperature minimum have been given by GINGERICH and RICH (1968). Second, the work of RICH (1966) on the carbon monoxide spectrum in the solar ultraviolet presents a consistent picture if the lowest temperatures lie in the vicinity of 4600°. Because the carbon monoxide is formed preferentially and with great sensitivity on the high-pressure side of the temperature minimum, it provides a delicate indicator. Should a minimum of 4400° have been adopted, the predicted carbon monoxide spectrum would have been much too strong.

With the temperature placed at 4600°, it was easier to draw a smooth transition both to the deeper photosphere layers and to the overlying chromosphere than if the minimum were 4400°.

Limb-darkening measurements both in the infrared and in the ultraviolet provide evidence for the broadness of the temperature minimum. The observations by LÉNA (1968) at 20.4 and 24.2 μ and by NOYES, BECKERS, and LOW (1968) at 22.5 and 24.3 μ show a center-to-limb intensity variation going from definite darkening at 20 μ to an essentially flat distribution at 24 μ. This is in distinct contradiction to the URP, which predicts definite limb brightening because its temperature-minimum region is too narrow. The BCA model, on the other hand, yields infrared predictions in satisfactory agreement with the observations. Unfortunately, these infrared measurements are as yet only relative, and consequently, they offer no information about the actual temperature in the minimum region.

In the ultraviolet, the spectral region between 1525 Å and 1683 Å shows neither darkening nor brightening toward the limb. As pointed out in the paper by Gingerich and Rich, the URP predicts considerable limb brightening throughout this region, whereas the BCA is much more satisfactory in this regard.

The transition between the photosphere and the temperature minimum (i.e., the region between -1 and -2 in log τ_{5000}) is comparatively poorly determined. The URP reaches a minimum value of 4500° at an optical depth of 0.025, whereas the models of Lambert and Mutschlecner show at the same point a temperature of about 4800°. The evidence for a comparatively sharp dip in this region comes largely from intensity measurements at the extreme limb made during eclipses (HEINTZE, 1965). Such measurements inevitably carry a rather low degree of confidence because of the difficulties in correcting for the geometry of the eclipse and because of the rough and spiculed nature of the sun's limb. It would be far preferable to determine the temperatures in this transition region from absolute intensities and limb-darkening measurements in some suitably opaque spectral region, for example, from 1900 Å to 2800 Å. The BCA satisfactorily represents the central intensities determined by BONNET and

BLAMONT (1968), but it has not been possible to achieve a satisfactory interpretation of their limb-darkening observations. Consequently, in the BCA the temperature distribution in this transition region is simply a smooth curve connecting the points at $\log \tau_{5000} = -1$ and -2.

3.3. THE LOW CHROMOSPHERE

Absolute-intensity measurements from the millimeter region as compiled by NOYES, BECKERS, and LOW (1968) and from the far ultraviolet as interpreted by SAUVAL (1968) established the temperature rise from $\log \tau_{5000} = -5$ to -6. The results from these two extremely diverse spectral regions showed such remarkably good agreement as to border on the unbelievable. If the interpretation of these observations is correct, then inhomogeneities must have comparatively little influence on the model in this region – otherwise, the temperatures derived from the ultraviolet should have been higher than those derived from the infrared because of the non-linear increase in the Planck function for high frequencies.

Given the run of temperatures established for the vicinity of the low chromosphere, an interpolation between this region and that of the temperature minimum was comparatively unambiguous. For shallower layers, however, the millimeter-region observations implied a steeper rise in temperature. Although these temperatures are not well determined, we decided to specify them in the BCA as a warning that the temperature distribution between $\log \tau_{5000} = -5$ and -6 should not simply be extrapolated outward.

3.4. NOTES ON THE COMPUTATION OF THE MODEL

The model is homogeneous, and is in hydrostatic equilibrium. The abundances are those of GOLDBERG, MÜLLER, and ALLER (1960), except that the ratio of hydrogen to helium by number is 10. The electron contributions of six elements (Si, Mg, Fe, C, Na, and Al) have been considered explicitly; as can be seen in Table I, these elements contribute over 80% of the electrons throughout the intermediate regions of this model. It is necessary to perform detailed calculations of the ionization of these elements that contribute significantly to the electron pressure, because throughout the intermediate regions of the model the negative hydrogen ion is the predominant opacity source at 5000 Å. Our studies show that the six elements considered explicitly constitute a sufficiently extensive set.

Tables I to IV have been calculated on the Control Data Corporation 6400 computer at the Smithsonian Astrophysical Observatory with the program described by GINGERICH (1963). In Table I, the monochromatic opacity at 5000 Å is tabulated. The sources of opacity used in the calculation are neutral H, H^-, H_2^+, metals, and Rayleigh and electron scattering. The abundances of Si, Mg, and Al affect the opacity, and they play a very important role in the ultraviolet rather than at 5000 Å. The treatment of the opacities has been described by GINGERICH (1964) and GINGERICH and RICH (1966).

The optical depth/geometrical depth relation has been independently calculated by Linsky, with the conclusion that this integration is quite stable, even at shallow optical

TABLE I

BILDERBERG CONTINUUM ATMOSPHERE

T EFF = 5780, LOG G = 4.440, HELIUM/HYDROGEN BY NUMBER= .100, ABUNDANCES G-M-A

OPTICAL DEPTH	TEMP (K)	PRESSURE (CGS)	ELECTRON PRESSURE	OPACITY (PER GM)	HYDROGEN IONIZED	METAL TOTAL	ELECTRON CONTRIBUTORS SI	MG	FE	C	DENSITY (GM/CC)	GRADIENT RADIATIVE	ADIABATIC	DEPTH (CM)
.0000001	9500.0	1.922E-02	9.204E-03	2.87E-01	1.00E+00	.1	.0	.0	.0	.1	1.63E-14	-1.41E+14	1.90E+10	-2.21E+08
.0000001	8780.0	2.173E-02	1.035E-02	2.84E-01	1.00E+00	.1	.0	.0	.0	.1	2.01E-14	-2.25E+10	1.55E+10	-2.16E+08
.0000002	8220.0	2.489E-02	1.184E-02	2.84E-01	9.99E-01	.1	.0	.0	.0	.1	2.46E-14	-1.44E+10	1.20E+10	-2.10E+08
.0000002	7740.0	2.887E-02	1.371E-02	2.84E-01	9.94E-01	.1	.0	.0	.0	.1	3.03E-14	-1.01E+10	7.84E+09	-2.05E+08
.0000003	7300.0	3.392E-02	1.594E-02	2.79E-01	9.75E-01	.1	.0	.0	.0	.1	3.81E-14	-7.33E+09	3.52E+09	-2.00E+08
.0000003	6900.0	4.055E-02	1.819E-02	2.57E-01	8.95E-01	.1	.0	.0	.0	.1	5.02E-14	-5.21E+09	1.44E+09	-1.94E+08
.0000004	6550.0	5.044E-02	1.920E-02	1.96E-01	6.76E-01	.1	.0	.0	.0	.1	7.38E-14	-3.59E+09	9.83E+08	-1.88E+08
.0000005	6250.0	6.960E-02	1.801E-02	1.12E-01	3.84E-01	.2	.0	.0	.0	.1	1.28E-13	-2.38E+09	1.08E+09	-1.81E+08
.0000006	6010.0	1.167E-01	1.662E-02	5.38E-02	1.82E-01	.3	.0	.0	.0	.3	2.58E-13	-1.48E+09	1.35E+09	-1.72E+08
.0000008	5830.0	2.437E-01	1.705E-02	2.49E-02	8.22E-02	.7	.0	.0	.0	.6	6.02E-13	-8.67E+08	1.63E+09	-1.61E+08
.0000010	5700.0	5.807E-01	1.968E-02	1.22E-02	3.81E-02	1.3	.1	.1	.0	1.2	1.52E-12	-4.90E+08	1.82E+09	-1.48E+08
.0000013	5610.0	1.387E+00	2.444E-02	6.85E-03	1.93E-02	2.4	.2	.1	.0	2.0	3.76E-12	-3.43E+08	1.85E+09	-1.36E+08
.0000016	5500.0	3.153E+00	2.763E-02	4.02E-03	9.34E-03	4.1	.3	.3	.0	3.4	8.80E-12	-2.48E+08	1.94E+09	-1.26E+08
.0000020	5435.0	6.485E+00	3.332E-02	2.99E-03	5.35E-03	5.8	.6	.4	.1	4.7	1.84E-11	-1.42E+08	1.59E+09	-1.16E+08
.0000025	5370.0	1.176E+01	3.754E-02	2.49E-03	3.25E-03	7.7	.9	.7	.1	5.9	3.38E-11	-1.13E+08	1.24E+09	-1.09E+08
.0000032	5305.0	1.940E+01	4.018E-02	2.24E-03	2.06E-03	9.9	1.4	1.1	.2	7.1	5.65E-11	-8.97E+07	9.45E+08	-1.02E+08
.0000040	5240.0	2.987E+01	4.142E-02	2.09E-03	1.34E-03	12.3	2.1	1.6	.2	8.1	8.81E-11	-7.12E+07	7.10E+08	-9.71E+07
.0000050	5175.0	4.376E+01	4.154E-02	2.01E-03	8.88E-04	15.1	3.0	2.4	.4	9.0	1.31E-10	-5.46E+07	5.33E+08	-9.24E+07
.0000063	5115.0	6.177E+01	4.148E-02	1.97E-03	6.04E-04	18.4	4.3	3.4	.5	9.6	1.87E-10	-4.15E+07	3.98E+08	-8.83E+07
.0000079	5055.0	8.476E+01	4.087E-02	1.95E-03	4.13E-04	22.3	5.9	4.7	.7	10.1	2.59E-10	-3.17E+07	3.01E+08	-8.45E+07
.0000100	5000.0	1.138E+02	4.055E-02	1.96E-03	2.87E-04	26.8	8.0	6.4	.9	10.4	3.52E-10	-2.30E+07	2.27E+08	-8.10E+07
.0000126	4950.0	1.500E+02	4.066E-02	1.99E-03	2.03E-04	32.0	10.5	8.4	1.2	10.4	4.69E-10	-1.58E+07	1.71E+08	-7.78E+07
.0000158	4910.0	1.943E+02	4.190E-02	2.06E-03	1.49E-04	37.3	13.1	10.6	1.6	10.2	6.12E-10	-1.10E+07	1.28E+08	-7.48E+07
.0000200	4870.0	2.479E+02	4.316E-02	2.15E-03	1.09E-04	43.2	16.2	13.1	1.9	9.8	7.88E-10	-7.78E+06	9.66E+07	-7.20E+07
.0000251	4840.0	3.121E+02	4.578E-02	2.28E-03	8.26E-05	48.8	19.2	15.5	2.3	9.2	9.98E-10	-5.21E+06	7.24E+07	-6.94E+07
.0000316	4810.0	3.880E+02	4.865E-02	2.44E-03	6.25E-05	54.7	22.3	18.2	2.7	8.5	1.25E-09	-4.14E+06	5.46E+07	-6.69E+07
.0000398	4780.0	4.773E+02	5.191E-02	2.61E-03	4.69E-05	60.8	25.6	20.9	3.1	7.6	1.55E-09	-3.29E+06	4.14E+07	-6.46E+07
.0000501	4750.0	5.817E+02	5.572E-02	2.82E-03	3.49E-05	66.9	28.9	23.7	3.5	6.7	1.90E-09	-2.61E+06	3.14E+07	-6.24E+07
.0000631	4720.0	7.029E+02	6.022E-02	3.08E-03	2.58E-05	72.7	32.0	26.5	3.9	5.8	2.31E-09	-1.77E+06	2.38E+07	-6.03E+07
.0000794	4700.0	8.419E+02	6.660E-02	3.40E-03	2.00E-05	77.0	34.3	28.7	4.2	5.0	2.77E-09	-1.10E+06	1.79E+07	-5.83E+07
.0001000	4680.0	9.999E+02	7.382E-02	3.77E-03	1.55E-05	81.0	36.3	30.7	4.5	4.2	3.31E-09	-7.76E+05	1.36E+07	-5.64E+07
.0001259	4665.0	1.179E+03	8.249E-02	4.20E-03	1.23E-05	84.0	37.7	32.4	4.7	3.6	3.91E-09	-5.20E+05	1.03E+07	-5.46E+07
.0001585	4650.0	1.381E+03	9.215E-02	4.69E-03	9.81E-06	86.7	38.9	33.9	5.0	3.1	4.60E-09	-3.52E+05	7.87E+06	-5.29E+07
.0001995	4640.0	1.608E+03	1.035E-01	5.25E-03	8.07E-06	88.6	39.7	35.1	5.1	2.7	5.36E-09	-2.19E+05	6.03E+06	-5.12E+07
.0002512	4630.0	1.864E+03	1.160E-01	5.87E-03	6.66E-06	90.3	40.2	36.2	5.3	2.3	6.23E-09	-1.74E+05	4.65E+06	-4.96E+07
.0003162	4620.0	2.152E+03	1.298E-01	6.57E-03	5.50E-06	91.7	40.6	37.3	5.4	2.0	7.21E-09	-1.38E+05	3.59E+06	-4.81E+07
.0003981	4610.0	2.476E+03	1.450E-01	7.34E-03	4.54E-06	92.9	40.8	38.3	5.5	1.7	8.32E-09	-8.53E+04	2.79E+06	-4.65E+07
.0005012	4605.0	2.841E+03	1.625E-01	8.19E-03	3.90E-06	93.8	40.7	39.1	5.6	1.5	9.55E-09	-4.35E+04	2.18E+06	-4.51E+07
.0006310	4600.0	3.254E+03	1.818E-01	9.13E-03	3.35E-06	94.6	40.6	40.0	5.7	1.3	1.10E-08	-1.93E+04	1.70E+06	-4.36E+07
.0007943	4600.0	3.720E+03	2.039E-01	1.02E-02	2.98E-06	95.0	40.3	40.6	5.8	1.2	1.25E-08	0.	1.34E+06	-4.21E+07

Table I (continued)

OPTICAL DEPTH	TEMP (K)	PRESSURE (CGS)	ELECTRON PRESSURE	OPACITY (PER GM)	HYDROGEN IONIZED	METAL ELECTRON CONTRIBUTORS TOTAL	SI	MG	FE	C	DENSITY (GM/CC)	GRADIENT RADIATIVE	GRADIENT ADIABATIC	DEPTH (CM)
.0010000	4600.0	4.247E+03	2.283E-01	1.13E-02	2.66E-06	95.5	40.0	41.3	5.9	1.1	1.43E-08	0.	1.05E+06	-4.07E+07
.0012589	4600.0	4.844E+03	2.554E-01	1.26E-02	2.38E-06	95.9	39.6	42.0	6.0	1.0	1.63E-08	0.	8.31E+05	-3.93E+07
.0015849	4600.0	5.520E+03	2.853E-01	1.40E-02	2.13E-06	96.2	39.1	42.6	6.0	.9	1.86E-08	0.	6.56E+05	-3.79E+07
.0019953	4600.0	6.286E+03	3.184E-01	1.55E-02	1.91E-06	96.6	38.6	43.4	6.1	.8	2.12E-08	0.	5.19E+05	-3.65E+07
.0025119	4600.0	7.156E+03	3.550E-01	1.72E-02	1.71E-06	96.9	38.0	44.1	6.2	.8	2.41E-08	0.	4.11E+05	-3.51E+07
.0031623	4600.0	8.143E+03	3.954E-01	1.91E-02	1.54E-06	97.1	37.4	44.8	6.3	.7	2.74E-08	0.	3.26E+05	-3.37E+07
.0039811	4600.0	9.264E+03	4.402E-01	2.11E-02	1.38E-06	97.4	36.7	45.6	6.3	.7	3.12E-08	0.	2.59E+05	-3.23E+07
.0050119	4600.0	1.054E+04	4.896E-01	2.34E-02	1.24E-06	97.6	35.9	46.3	6.4	.6	3.55E-08	0.	2.05E+05	-3.09E+07
.0063096	4600.0	1.199E+04	5.441E-01	2.59E-02	1.12E-06	97.8	35.1	47.1	6.4	.6	4.04E-08	1.53E+03	1.63E+05	-2.95E+07
.0079433	4605.0	1.363E+04	6.074E-01	2.87E-02	1.04E-06	97.9	34.4	47.7	6.5	.5	4.59E-08	2.75E+03	1.30E+05	-2.81E+07
.0100000	4610.0	1.551E+04	6.777E-01	3.17E-02	9.72E-07	98.0	33.7	48.4	6.5	.5	5.21E-08	5.08E+03	1.03E+05	-2.67E+07
.0125893	4630.0	1.764E+04	7.673E-01	3.51E-02	1.01E-06	97.9	33.5	48.5	6.5	.5	5.90E-08	8.46E+03	8.22E+04	-2.53E+07
.0158489	4660.0	2.007E+04	8.772E-01	3.90E-02	1.11E-06	97.7	33.5	48.3	6.5	.5	6.67E-08	9.48E+03	6.56E+04	-2.39E+07
.0199526	4700.0	2.282E+04	1.012E+00	4.32E-02	1.32E-06	97.3	33.9	47.7	6.5	.6	7.52E-08	9.71E+03	5.25E+04	-2.25E+07
.0251189	4750.0	2.593E+04	1.179E+00	4.80E-02	1.65E-06	96.7	34.4	46.8	6.4	.7	8.46E-08	8.68E+03	4.20E+04	-2.11E+07
.0316228	4800.0	2.946E+04	1.373E+00	5.34E-02	2.06E-06	96.0	34.8	45.8	6.3	.8	9.51E-08	7.51E+03	3.36E+04	-1.97E+07
.0398107	4860.0	3.346E+04	1.614E+00	5.95E-02	2.71E-06	94.9	35.2	44.6	6.2	.9	1.07E-07	6.57E+03	2.69E+04	-1.83E+07
.0501187	4920.0	3.797E+04	1.897E+00	6.63E-02	3.53E-06	93.6	35.5	43.2	6.0	1.1	1.20E-07	5.61E+03	2.15E+04	-1.68E+07
.0630957	4990.0	4.307E+04	2.254E+00	7.42E-02	4.83E-06	91.6	35.6	41.5	5.8	1.3	1.34E-07	4.84E+03	1.72E+04	-1.53E+07
.0794328	5060.0	4.879E+04	2.681E+00	8.32E-02	6.51E-06	89.2	35.3	39.7	5.6	1.6	1.49E-07	4.09E+03	1.37E+04	-1.39E+07
.1000000	5140.0	5.518E+04	3.234E+00	9.40E-02	9.12E-06	85.9	34.6	37.5	5.3	1.9	1.66E-07	3.59E+03	1.09E+04	-1.24E+07
.1258925	5225.0	6.228E+04	3.940E+00	1.07E-01	1.28E-05	81.6	33.4	34.9	5.0	2.2	1.85E-07	3.10E+03	8.58E+03	-1.09E+07
.1584893	5320.0	7.007E+04	4.893E+00	1.24E-01	1.86E-05	75.9	31.4	31.7	4.5	2.7	2.04E-07	2.80E+03	6.71E+03	-9.48E+06
.1995262	5430.0	7.846E+04	6.263E+00	1.46E-01	2.78E-05	68.4	28.5	27.9	4.0	3.2	2.24E-07	2.50E+03	5.16E+03	-8.05E+06
.2511886	5550.0	8.731E+04	8.233E+00	1.77E-01	4.19E-05	59.7	24.9	23.7	3.4	3.6	2.44E-07	2.12E+03	3.91E+03	-6.68E+06
.3162278	5675.0	9.644E+04	1.102E+01	2.17E-01	6.19E-05	50.8	21.0	19.6	2.8	3.9	2.63E-07	1.79E+03	2.93E+03	-5.37E+06
.3981072	5810.0	1.057E+05	1.511E+01	2.73E-01	9.13E-05	42.0	17.2	15.7	2.3	4.1	2.82E-07	1.50E+03	2.17E+03	-4.14E+06
.5011872	5950.0	1.149E+05	2.096E+01	3.46E-01	1.32E-04	34.1	13.7	12.3	1.8	4.2	2.99E-07	1.26E+03	1.59E+03	-2.98E+06
.6309573	6100.0	1.240E+05	2.959E+01	4.46E-01	1.91E-04	27.1	10.6	9.4	1.4	4.1	3.15E-07	1.08E+03	1.16E+03	-1.91E+06
.7943282	6265.0	1.328E+05	4.278E+01	5.84E-01	2.80E-04	21.1	7.9	7.0	1.0	4.0	3.28E-07	9.30E+02	8.40E+02 C	-9.15E+05
1.000000	6440.0	1.412E+05	6.239E+01	7.72E-01	4.07E-04	16.3	5.8	5.1	.7	3.7	3.39E-07	7.73E+02	6.05E+02 C	0.
1.258925	6620.0	1.493E+05	9.065E+01	1.02E+00	5.85E-04	12.6	4.3	3.7	.5	3.4	3.49E-07	6.24E+02	4.38E+02 C	8.46E+05
1.584893	6800.0	1.570E+05	1.298E+02	1.33E+00	8.21E-04	9.9	3.2	2.7	.4	3.1	3.57E-07	5.02E+02	3.21E+02 C	1.64E+06
1.995262	6985.0	1.644E+05	1.846E+02	1.72E+00	1.14E-03	7.8	2.4	2.0	.3	2.8	3.64E-07	4.14E+02	2.35E+02 C	2.39E+06
2.511886	7180.0	1.716E+05	2.629E+02	2.25E+00	1.58E-03	6.2	1.7	1.5	.2	2.6	3.70E-07	3.42E+02	1.72E+02 C	3.10E+06
3.162278	7380.0	1.786E+05	3.712E+02	2.91E+00	2.18E-03	5.0	1.3	1.1	.2	2.3	3.74E-07	2.76E+02	1.26E+02 C	3.78E+06
3.981072	7580.0	1.854E+05	5.156E+02	3.73E+00	2.94E-03	4.1	1.0	.8	.1	2.1	3.78E-07	2.24E+02	9.29E+01 C	4.44E+06
5.011872	7790.0	1.921E+05	7.155E+02	4.80E+00	3.98E-03	3.4	.7	.6	.1	1.8	3.80E-07	1.44E+02	6.79E+01 C	5.08E+06
6.309573	7900.0	1.990E+05	8.516E+02	5.50E+00	4.59E-03	3.1	.6	.5	.1	1.7	3.88E-07	1.10E+02	5.63E+01 C	5.74E+06
7.943282	8120.0	2.062E+05	1.171E+03	7.07E+00	6.13E-03	2.5	.5	.4	.1	1.5	3.91E-07	9.65E+01	4.08E+01 C	6.41E+06
10.00000	8240.0	2.137E+05	1.396E+03	8.14E+00	7.07E-03	2.3	.4	.3	.1	1.4	3.99E-07	7.17E+01	3.35E+01 C	7.09E+06
12.58925	8460.0	2.214E+05	1.876E+03	1.04E+01	9.22E-03	1.9	.3	.3	.0	1.3	4.02E-07	7.62E+01	2.43E+01 C	7.80E+06
15.84893	8680.0	2.291E+05	2.486E+03	1.31E+01	1.19E-02	1.7	.3	.2	.0	1.1	4.04E-07	6.06E+01	1.77E+01 C	8.49E+06
19.95262	8900.0	2.368E+05	3.250E+03	1.65E+01	1.51E-02	1.4	.2	.2	.0	1.0	4.06E-07	4.81E+01	1.30E+01 C	9.17E+06
25.11886	9120.0	2.445E+05	4.197E+03	2.07E+01	1.90E-02	1.2	.2	.1	.0	.9	[illegible]	8.80E-01	9.58E+00	9.86E+06

TABLE II

BILDERBERG CONTINUUM ATMOSPHERE

T EFF = 5780, LOG G = 4.440, HELIUM/HYDROGEN BY NUMBER= .100, ABUNDANCES G-M-A

OPTICAL DEPTH	TEMP (K)	RAYLEIGH /TOTAL	ELECTRON /TOTAL	OPACITY PER NEUTRAL H (*E26) A(H-)	A(H)	A(H2+)	NEUTRAL H PER GM	MEAN WEIGHT	FRACTIONAL IONIZATION OF METALS SI	MG	FE	C		
.0000001	9500.0	.0000	.9981	6.188E-03	2.552E+03	5.902E-04	2.178E+19	.671	1.000	1.000	1.000	1.000	1.000	1.000
.0000001	8780.0	.0000	.9970	9.015E-03	7.397E+02	8.233E-04	1.164E+20	.674	1.000	1.000	1.000	1.000	1.000	1.000
.0000002	8220.0	.0000	.9954	1.288E-02	2.435E+02	1.127E-03	5.337E+20	.675	1.000	1.000	1.000	1.000	1.000	1.000
.0000002	7740.0	.0000	.9931	1.835E-02	8.280E+01	1.542E-03	2.350E+21	.676	1.000	1.000	1.000	1.000	1.000	1.000
.0000003	7300.0	.0000	.9896	2.623E-02	2.724E+01	2.122E-03	1.060E+22	.683	1.000	1.000	1.000	1.000	1.000	1.000
.0000003	6900.0	.0002	.9845	3.669E-02	8.778E+00	2.862E-03	4.473E+22	.710	1.000	1.000	1.000	.998	1.000	1.000
.0000004	6550.0	.0007	.9784	4.693E-02	2.914E+00	3.543E-03	1.378E+23	.798	1.000	1.000	1.000	.994	1.000	1.000
.0000005	6250.0	.0024	.9721	5.250E-02	1.027E+00	3.850E-03	2.621E+23	.955	1.000	1.000	1.000	.984	1.000	1.000
.0000006	6010.0	.0066	.9624	5.631E-02	4.143E-01	4.028E-03	3.477E+23	1.104	1.000	1.000	1.000	.963	1.000	1.000
.0000008	5830.0	.0161	.9411	6.498E-02	1.998E-01	4.552E-03	3.903E+23	1.198	1.000	1.000	1.000	.924	1.000	1.000
.0000010	5700.0	.0344	.8960	8.195E-02	1.147E-01	5.630E-03	4.091E+23	1.244	1.000	1.000	1.000	.856	1.000	1.000
.0000013	5610.0	.0625	.8158	1.084E-01	7.691E-02	7.307E-03	4.171E+23	1.265	.999	1.000	1.000	.762	1.000	1.000
.0000016	5500.0	.1076	.6858	1.326E-01	4.638E-02	8.692E-03	4.213E+23	1.276	.999	1.000	1.000	.628	1.000	1.000
.0000020	5435.0	.1450	.5376	1.678E-01	3.408E-02	1.073E-02	4.230E+23	1.281	.999	1.000	1.000	.506	1.000	1.000
.0000025	5370.0	.1744	.4001	1.985E-01	2.485E-02	1.235E-02	4.239E+23	1.284	.998	1.000	1.000	.397	1.000	1.000
.0000032	5305.0	.1948	.2892	2.232E-01	1.799E-02	1.348E-02	4.244E+23	1.285	.997	1.000	.999	.307	1.000	1.000
.0000040	5240.0	.2083	.2067	2.419E-01	1.291E-02	1.413E-02	4.247E+23	1.286	.996	1.000	.999	.235	1.000	1.000
.0000050	5175.0	.2172	.1475	2.554E-01	9.197E-03	1.435E-02	4.249E+23	1.286	.995	1.000	.999	.178	1.000	1.000
.0000063	5115.0	.2214	.1063	2.676E-01	6.671E-03	1.438E-02	4.250E+23	1.287	.994	.999	.999	.136	1.000	1.000
.0000079	5055.0	.2238	.0771	2.769E-01	4.803E-03	1.408E-02	4.251E+23	1.287	.993	.999	.998	.103	1.000	1.000
.0000100	5000.0	.2231	.0568	2.876E-01	3.530E-03	1.370E-02	4.251E+23	1.287	.991	.999	.998	.078	1.000	1.000
.0000126	4950.0	.2194	.0425	3.008E-01	2.652E-03	1.326E-02	4.252E+23	1.287	.988	.999	.998	.059	1.000	1.000
.0000158	4910.0	.2114	.0326	3.207E-01	2.101E-03	1.299E-02	4.252E+23	1.287	.986	.999	.997	.046	1.000	1.000
.0000200	4870.0	.2029	.0252	3.420E-01	1.658E-03	1.249E-02	4.252E+23	1.287	.983	.998	.996	.036	1.000	1.000
.0000251	4840.0	.1910	.0200	3.723E-01	1.385E-03	1.222E-02	4.252E+23	1.288	.979	.998	.996	.028	1.000	1.000
.0000316	4810.0	.1791	.0160	4.063E-01	1.154E-03	1.176E-02	4.252E+23	1.288	.975	.998	.995	.022	1.000	1.000
.0000398	4780.0	.1669	.0130	4.452E-01	9.598E-04	1.113E-02	4.252E+23	1.288	.969	.997	.994	.017	1.000	.999
.0000501	4750.0	.1545	.0106	4.909E-01	7.962E-04	1.035E-02	4.252E+23	1.288	.962	.997	.992	.013	1.000	.999
.0000631	4720.0	.1418	.0087	5.451E-01	6.589E-04	9.448E-03	4.252E+23	1.288	.953	.996	.990	.010	1.000	.999
.0000794	4700.0	.1283	.0072	6.140E-01	5.801E-04	8.926E-03	4.252E+23	1.288	.943	.995	.988	.008	1.000	.999
.0001000	4680.0	.1157	.0061	6.932E-01	5.101E-04	8.336E-03	4.252E+23	1.288	.932	.994	.986	.007	1.000	.999
.0001259	4665.0	.1038	.0052	7.855E-01	4.629E-04	7.926E-03	4.252E+23	1.288	.919	.992	.983	.005	1.000	.999
.0001585	4650.0	.0929	.0044	8.897E-01	4.198E-04	7.484E-03	4.252E+23	1.288	.904	.991	.980	.004	1.000	.998
.0001995	4640.0	.0831	.0038	1.008E+00	3.932E-04	7.237E-03	4.252E+23	1.288	.889	.989	.976	.004	1.000	.998
.0002512	4630.0	.0743	.0033	1.141E+00	3.681E-04	6.975E-03	4.252E+23	1.288	.872	.988	.972	.003	1.000	.998
.0003162	4620.0	.0664	.0029	1.289E+00	3.446E-04	6.705E-03	4.252E+23	1.288	.852	.985	.968	.003	1.000	.997
.0003981	4610.0	.0594	.0025	1.454E+00	3.225E-04	6.432E-03	4.252E+23	1.288	.831	.983	.962	.002	1.000	.997
.0005012	4605.0	.0533	.0022	1.637E+00	3.119E-04	6.357E-03	4.251E+23	1.288	.811	.981	.957	.002	1.000	.996
.0006310	4600.0	.0478	.0019	1.839E+00	3.017E-04	6.280E-03	4.251E+23	1.288	.789	.978	.951	.002	1.000	.996
.0007943	4600.0	.0429	.0017	2.063E+00	3.017E-04	6.401E-03	4.251E+23	1.288	.769	.975	.945	.001	1.000	.995