#236

EXTRATERRESTRIAL SOLAR SPECIAL IRRADIANCE

MS-11A
MS-11B

Table of Contents

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1. INTRODUCTION:

The documentation for this data set was originally on paper, kept in NSSDC's Data Set Catalogs (DSCs). The paper documentation in the Data Set Catalogs have been made into digital images, and then collected into a single PDF file for each Data Set Catalog. The inventory information in these DSCs is current as of July 1, 2004. This inventory information is now no longer maintained in the DSCs, but is now managed in the inventory part of the NSSDC information system. The information existing in the DSCs is now not needed for locating the data files, but we did not remove that inventory information.

The offline tape datasets have now been migrated from the original magnetic tape to Archival Information Packages (AIP’s).

A prior restoration may have been done on data sets, if a requestor of this data set has questions; they should send an inquiry to the request office to see if additional information exists.

2. ERRATA/CHANGE LOG:

NOTE: Changes are made in a text box, and will show up that way when displayed on screen with a PDF reader.

When printing, special settings may be required to make the text box appear on the printed output.

Version	Date	Person	Page	Description of Change
01				
02				

3 LINKS TO RELEVANT INFORMATION IN THE ONLINE NSSDC INFORMATION SYSTEM:

http://nssdc.gsfc.nasa.gov/nmc/

[NOTE: This link will take you to the main page of the NSSDC Master Catalog. There you will be able to perform searches to find additional information]

4. CATALOG MATERIALS:

a. Associated Documents — To find associated documents you will need to know the document ID number and then click here.
http://nssdcftp.gsfc.nasa.gov/miscellaneous/documents/

b. Core Catalog Materials

REQ. AGENT
DLB
DAD

ACQ. AGENT
JRJ

EXTRATERRESTRIAL SOLAR SPECTRAL IRRADIANCE

MS-11A
MS-11B

These data sets are contained on 2 files on one 9-track, 1600 BPI, ASCII magnetic tape created on the MODCOMP IV computer from card images. The first file contains solar spectral irradiance data covering the wavelength range 0.115 to 1000 micrometers. The second file covers the range 0.3 to 0.61 micrometers. These data were originally created at 556 BPI, 7-track, BCD on the IBM 7094 computer but were converted to 9-track ASCII because of the phasing out of 7-track tape drives. The document numbers for these data sets are B-15796-000A, B-15797-000A, and B-15798-000A. The D and C numbers follow below:

D#	C#
D-12248	C-09473

115796

SOLAR SPECTRAL IRRADIANCE

The data are in two card decks giving wavelength (λ) and spectral irradiance due to the Sun at 1 AU over a small bandwidth centered at λ (E_λ). The first deck has 211 pairs of values, 71 cards, in format (6 F 10.0), covering the wavelength range 0.115 to 1000 μm; the values of λ are at intervals of 5 nm for 0.225 μm < λ < 0.605 μm, and at wider intervals for the rest of the range. The second deck has 3101 pairs of values, 388 cards, in format (16 I 5), covering the range 0.3 to 0.61 μm; the values of λ are at intervals of 0.1 nm (1 A). The first deck is the extraterrestrial solar spectrum recommended for NASA Space Vehicles Design Criteria and adopted as standard for engineering use by the American Society for Testing and Materials (ASTM). The spectral irradiance values, as also the integral of the spectral curve, $\int_0^\infty E_\lambda \, d\lambda$, which is the solar constant, are based on high altitude measurements from CV 990, B-57B, X-15, balloon, and Mars Mariner made by different observers and the recommendation of an ad hoc Committee on Solar Electromagnetic Radiation. The solar constant is 1353 W m^{-2}. The second deck is based on the data of the Perkin-Elmer monochromator on board CV 990; the data have been normalized to the standard curve. The irradiance scales to which these values are referred are IPS '56 for the solar constant, NBS lamps for spectral irradiance in the range 0.25 μm < λ < 2.5 μm and high temperature blackbodies for λ > 2.5 μm. The estimated error is

1.5% for the solar constant, 5% for spectral irradiance for $0.25 < \lambda < 2.5$ μm. More details about these standards are given in NASA SP 8005; NASA TR R 351; M. P. Thekaekara and A. J. Drummond, Nature, Phy. Sc., 229, 6, 1971; Optical Spectra 6, 32, 72; A. J. Drummond and M. P. Thekaekara, Eds., "Extraterrestrial Solar Spectrum," IES, Mt. Prospect, Ill., 1973; NASA SP 298, Paper 82, p. 955; "Solar Constant and Solar Spectrum" in Encyclopedia of Physics, Van Nostrand Reinhold, 1973.

315797

PREPRINT

The Extraterrestrial Solar Spectrum, 3000-6100Å at One Ångström Intervals

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ABSTRACT

Standard values of the solar constant and extra-terrestrial solar spectrum are reviewed. In the visible and near UV, this listing of average irradiance over 100Å band-widths at 50Å intervals was found to be inadequate for many applications. A more detailed spectrum obtained from solar scans with a Perkin-Elmer, Model 112, monochromator was found to give sufficient detail. A normalization program was developed to make the Perkin-Elmer curve agree with the standard curve. Values of extraterrestrial solar spectral irradiance at one Ångström intervals in the range 3000 to 6100Å have been derived. The results are presented in tabular form and as spectral charts.

INTRODUCTION

One of the principal workers in solar constant studies during the past ten years was A. J. Drummond, as was observed by Howard and Garing in a recent review paper.[1] His measurements during the Eppley-JPL program [2,3,4] and his work in the ad hoc committee on Solar Electromagnetic Radiation were largely instrumental in developing the values of the solar constant and extraterrestrial solar spectral irradiance which are now currently accepted. These values have become the standard adopted by the American Society for Testing and Materials[5] and the design values for NASA space vehicles design criteria[6]. The value of the solar constant is 1353 W m^{-2}; it is the average of many series of measurements made at high altitude from CV 990, and B-57B aircraft, X-15 rocket aircraft, from balloons and the Mars Mariner spacecraft. The table of values of the extra-terrestrial solar spectral irradiance is based mainly on the data from the CV 990 flights made by NASA/GSFC[7] and from the aircraft flights of the Eppley-JPL program[2,3]. Details about the derivation of the standard solar spectrum are given in Reference 8 where an abridged version of the table was published. The complete version is given here in Table I. A project was undertaken recently to develop a more detailed spectral irradiance table for the wavelength range 0.3 to 0.61 μm. This paper discusses briefly how this table was developed and presents the results.

THE STANDARD TABLE

Table I follows closely the format of an earlier table published by the GSFC experimenters as Table III of Ref. (7), which is also available in the current edition of the American Institute of Physics Handbook[9]. Over a great part of the wavelength range the earlier spectral irradiance values have been retained. A comparison of the GSFC data with those obtained by Drummond showed that in the wavelength range of $\lambda > 0.7$ µm Drummond's integral value obtained from cut off filters was exactly the same as the GSFC value. In the wavelength range 0.3 µm $< \lambda < 0.7$ µm, the results from Drummond's band pass interference filters were in fairly close agreement with the integrals over the respective ranges from the GSFC curve, but there were a few differences. Hence a weighted average of the GSFC data and the Drummond data was taken to derive the standard curve of Table I. The maximum changes from the GSFC curve are +2.3% at 0.34 µm, -0.7% at 0.45 µm and +1.6% at 0.63 µm, and percentages varying between zero and these maxima at intermediate wavelengths of 0.3 µm $< \lambda <$ 0.7 µm. With these changes the integral under the spectral curve was raised from the GSFC value, 1351 W m^{-2}, to the revised solar constant, 1353 W m^{-2}. For the wavelength range 0.3 µm $> \lambda >$ 15 µm which was not adequately covered by the measurements of GSFC or Drummond the data of Hinteregger[10], Heath[11] and Shimabukoro and Stacey[12] were used.

For Table I the spectral irradiance values, E_λ, are averaged over finite bandwidths centered at λ, the bandwidths being (all units in μm) 0.01 for $0.3 < \lambda < 0.75$; 0.05 for $0.75 < \lambda < 1.0$; 0.1 for $1.0 < \lambda < 5$. The entries are at intervals of 0.005 for $0.22 < \lambda < 0.605$ and at wider intervals for the rest of the range. This mode of presentation was chosen in order to limit the Table to one page and to present the spectral irradiance independently of the Fraunhofer structure which different instruments show differently according to their wavelength resolution.

But for many practical applications this mode of presentation at wide intervals is inadequate, especially in the visible and near UV where line absorption in the solar atmosphere is most pronounced and the extraterrestrial solar spectrum is most widely applied. Thus, for example, in filter radiometry of the Eppley- JPL program or the Earth Radiation Budget experiment of Nimbus F, an important parameter is the filter factor F defined by[3]

$$F = \int_{\lambda_1}^{\lambda_2} E_\lambda \, d\lambda \Big/ \int_{\lambda_1}^{\lambda_2} E_\lambda \, \tau_\lambda \, d\lambda \qquad (1)$$

where E_λ is spectral irradiance, τ_λ is spectral transmittance and λ_1, λ_2 are the limits of non-zero transmittance. For an interference filter having τ_λ nearly constant over a range of a few hundred Ångströms but dropping rapidly to zero, the evaluation of F requires E_λ to be known to a few Ångströms. Other applications, as shown by feedback from the users of the spectral irradiance table, are atmospheric modelling, transmittance and scattering in the atmosphere, source and sink mechanisms of pollutants, radiation budget, chemical processes in the upper atmosphere, oceanographic surveys, night sky radiance, solar energy at ground level, etc.

The spectral irradiance values of Table I in the near UV and visible ranges are based on the data of four instruments, a Perkin-Elmer monochromator, Model 112, a Leiss quartz double prism monochromator, an Eppley Mark V filter radiometer (modified by GSFC, with 22 narrow band pass filters in the range 0.3 to 0.6 μm) and multi-channel filter radiometers. The first three were flown in the GSFC CV 990 program and the fourth in the Eppley-JPL program. Of these the Perkin-Elmer was the most complex and versatile instrument, had the best wavelength resolution, and yielded the most abundant data[13]. The data were recorded on strip charts and on magnetic tapes, the latter for computer analysis. Spectral curves based on these charts and tapes were published as Figures 13 and 14 of Ref.(7) but no detailed spectral irradiance tables were prepared or published. The curves are based on the data from about 70 scans. The wavelength resolution, while not sufficient to show the line shapes of the Fraunhofer lines is adequate for many computer programs; the value of $\lambda/\Delta\lambda$ varied from 1100 at 3000Å to 455 at 5000Å. A complete mapping of the Fraunhofer lines would require a resolution of 60,000 or better. Such data are available in the Minnaert atlas[14] and other sources. The spectral curve obtained from the Perkin-Elmer does not agree at all wavelengths with the standard curve of Table I, since the latter is a weighted average of the data from four instruments.

NORMALIZATION PROGRAM

A normalization program was undertaken to shift the Perkin-Elmer curve up or down parallel to the y-axis, so that the curve remains everywhere continuous, wavelengths of flexion points are not shifted, and the integrals over 50A intervals are the same as in the standard table.

The normalization procedure is briefly reviewed. An enlarged version of the Perkin-Elmer curve was produced. It was traced manually with a cross hair locator and the y-coordinate (irradiance) was punched on IBM cards. Let these values be designated e_λ. Let A_p be the average of 50 consecutive values of e_λ from λ-24 to λ+25 (λ in Ångströms), and let b be the difference $E_\lambda - A_p$, where E_λ is the standard spectral irradiance at λ in Table I. Let a and c be the corresponding values of the difference in two 50 A ranges just below and above λ, that is in ranges centered at λ-50 and λ+50. A correction factor D is added to each e_λ from λ-24 to λ+25 such that (1) for the first e_λ, D is $\frac{a+b}{2}$, (2) for the 50th e_λ, D is $\frac{b+c}{2}$, and (3) the average of D's for all 50 e_λ's is b.

These conditions can be satisfied if D is of the form

$$D_n = \alpha + \beta n + \gamma n^2 \qquad (2)$$

Thus, for

$$n = 1, \quad \alpha + \beta + \gamma = \frac{a+b}{2}, \qquad (3)$$

$$n = 50, \quad \alpha + 50\beta + 50^2\gamma = \frac{b+c}{2} \qquad (4)$$

$$n = 1, 2, \ldots 50,$$

$$\frac{1}{50}\left[\,50\alpha + \left(\sum_{1}^{50} n\right)\beta + \left(\sum_{1}^{50} n^2\right)\gamma\,\right] = b \qquad (5)$$

Equation (5) can be simplified as

$$\alpha + 25.5\beta + 858.5\gamma = b \qquad (6)$$

From equations (3), (4) and (6),

$$\gamma = \frac{c+a-2b}{1568}\ ;\ \beta = \frac{c-a-4998\gamma}{98}\ ;\ \alpha = \frac{a+b}{2} - \beta - \gamma \qquad (7)$$

Using equations (2) and (7) the correction factor D_n is computed for each wavelength at one Å intervals and added to e_λ to give the normalized value of the spectral irradiance.

This procedure proved satisfactory over the whole range 3000 to 6100Å, except between 3926Å and 4025Å, where the E_λ values of Table I, which are averages over 100Å band, fail to show the sharp discontinuity of the Perkin-Elmer curve. Here the first computer output showed a spurious inflection around 3970Å. Values of E_λ at 3950Å and 4000Å were adjusted by subtracting a small amount from the first and adding the same to the second, and new values of the difference $E_\lambda - A_p$ were computed.

RESULTS

The results are presented in Table II and Figures 1 and 2. Table II is in the format of trigonometric tables. Wavelengths are in Ångströms and irradiance in W m^{-2} μm^{-1} or

$mW\ m^{-2}\ nm^{-1}$. The accuracy is estimated to be ± 5%, the same as in the stahdard table. In Figures 1 and 2 the dashed curve gives the standard values of Table I.

The spectral irradiance data of Tables I and II are available in the form of punched cards to any organization which has need of this type of data. The cards give λ and E_λ, three pairs per card for Table I and eight pairs per card for Table II. They can be obtained from National Space Science Data Center, Code 601, NASA/GSFC, Greenbelt, Md. 20771.

ACKNOWLEDGMENTS

The author acknowledges his indebtedness to R. Stair who helped in the early analysis of the Perkin-Elmer data; to A. J. Drummond discussions with whom showed the need for more detailed spectral data; to J. DeLuisi of the National Center for Atmospheric Research, Boulder, Colorado, for tracing the Perkin-Elmer curves and punching the values; to L Bieberman of the Institute for Defense Analysis, Arlington, Virginia, for the main part of the computer aided normalization and to W. Mocarsky and R. Mitchell of Goddard Space Flight Center for help with the GSFC computers.

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CAPTIONS FOR TABLES AND FIGURES

Table I (No extra caption is needed if the whole 8x10 is reproduced. If only the table is reproduced, type set the legend given on top of the table).

Table II The extraterrestrial solar spectrum, 3000 to 6100Å, at one Ångstrom intervals. Wavelength in Å; spectral irradiance in mW m^{-2} nm^{-1}. Spectral irradiance values are given in the format of trigonometric tables.

Both Tables I and II should be given a full page each.

Figure 1. Solar spectral irradiance, 3000 to 4000Å; dashed line shows standard values of Table I.

Figure 2. Solar spectral irradiance, 3600 to 6100Å; dashed line shows standard values of Table I.

λ = Wavelength in micrometers

E_λ = Solar spectral irradiance averaged over small bandwidth centered at λ, in W m^{-2} µm^{-1}

$E_{o-\lambda}$ = Integrated solar irradiance in the wavelength range o to λ, in W m^{-2}

$D_{o-\lambda}$ = Percentage of solar constant associated with wavelengths shorter than λ

Solar constant = 1353 W m^{-2}

Note: lines indicate change in wavelength interval of integration

λ	E_λ	$E_{o-\lambda}$	$D_{o-\lambda}$	λ	E_λ	$E_{o-\lambda}$	$D_{o-\lambda}$	λ	E_λ	$E_{o-\lambda}$	$D_{o-\lambda}$
.115	.007	.0025	.0001	.510	1882	324.976	24.018	1.55	267	1188.109	87.869
.120	.900	.0048	.0003	.515	1833	334.214	24.701	1.60	245	1198.909	88.611
.125	.007	.0070	.0005	.520	1833	343.379	25.379	1.65	223	1210.609	89.479
.130	.007	.0071	.0005	.525	1852	352.591	26.059	1.70	202	1221.234	90.261
.140	.030	.0073	.0005	.530	1842	361.826	26.742	1.75	180	1230.784	90.967
.150	.070	.0078	.0005	.535	1818	370.976	27.418	1.80	159	1239.259	91.593
.160	.230	.0093	.0006	.540	1783	379.979	28.084	1.85	142	1246.784	92.149
.170	.630	.0136	.0010	.545	1754	388.821	28.737	1.90	126	1253.484	92.644
.180	1.250	.0230	.0016	.550	1725	397.519	29.380	1.95	114	1259.484	93.088
.190	2.710	.0428	.0031	.555	1720	406.131	30.017	2.00	103	1264.909	93.489
.200	10.7	.1098	.0081	.560	1695	414.669	30.648	2.1	90	1274.559	94.2024
.210	22.9	.2778	.0205	.565	1705	423.169	31.276	2.2	79	1283.009	94.8269
.220	57.5	.6798	.0502	.570	1712	431.711	31.907	2.3	69	1290.409	95.3739
.225	64.9	.9858	.0728	.575	1719	440.289	32.541	2.4	62	1296.959	95.8580
.230	66.7	1.3148	.0971	.580	1715	448.874	33.176	2.5	55	1302.809	96.2903
.235	59.3	1.6298	.1204	.585	1712	457.441	33.809	2.6	48	1307.959	96.6710
.240	63.0	1.9356	.1430	.590	1700	465.971	34.439	2.7	43	1312.509	97.0073
.245	72.3	2.2730	.1680	.595	1682	474.426	35.064	2.8	39	1316.609	97.3103
.250	70.4	2.6306	.1944	.600	1666	482.796	35.683	2.9	35	1320.309	97.5838
.255	104.0	3.0666	.2266	.605	1647	491.079	36.295	3.0	31	1323.609	97.8277
.260	130	3.6516	.269	.61	1635	499.284	36.902	3.1	26.0	1326.459	98.0383
.265	185	4.4391	.328	.62	1602	515.469	38.098	3.2	22.6	1328.889	98.2179
.270	232	5.4816	.405	.63	1570	531.329	39.270	3.3	19.2	1330.979	98.3724
.275	204	6.5716	.485	.64	1544	546.899	40.421	3.4	16.6	1332.769	98.5047
.280	222	7.6366	.564	.65	1511	562.174	41.550	3.5	14.6	1334.329	98.6200
.285	315	8.9791	.663	.66	1486	577.159	42.657	3.6	13.5	1335.734	98.7238
.290	482	10.9716	.810	.67	1456	591.869	43.744	3.7	12.3	1337.024	98.8192
.295	584	13.6366	1.007	.68	1427	606.284	44.810	3.8	11.1	1338.194	98.9056
.300	514	16.3816	1.210	.69	1402	620.429	45.855	3.9	10.3	1339.264	98.9847
.305	603	19.1741	1.417	.70	1369	634.284	46.879	4.0	9.5	1340.254	99.0579
.310	689	22.4041	1.655	.71	1344	647.849	47.882	4.1	8.70	1341.1641	99.12521
.315	764	26.0366	1.924	.72	1314	661.139	48.864	4.2	7.80	1341.9891	99.18618
.320	830	30.0216	2.218	.73	1290	674.159	49.826	4.3	7.10	1342.7341	99.24124
.325	975	34.5341	2.552	.74	1260	686.909	50.769	4.4	6.50	1343.4141	99.29150
.330	1059	39.6191	2.928	.75	1235	699.384	51.691	4.5	5.92	1344.0351	99.33740
.335	1081	44.9691	3.323	.76	1211	711.614	52.595	4.6	5.35	1344.5986	99.37905
.340	1074	50.3566	3.721	.77	1185	723.594	53.480	4.7	4.86	1345.1091	99.41678
.345	1069	55.7141	4.117	.78	1159	735.314	54.346	4.8	4.47	1345.5757	99.45127
.350	1093	61.1191	4.517	.79	1134	746.779	55.194	4.9	4.11	1346.0049	99.48299
.355	1083	66.5591	4.919	.80	1109	757.994	56.023	5.0	3.79	1346.3999	99.51219
.360	1068	71.9366	5.316	.81	1085	768.966	56.834	6	1.8200	1349.2049	99.71950
.365	1132	77.4366	5.723	.82	1060	779.694	57.627	7	.9900	1350.6099	99.82335
.370	1181	83.2191	6.150	.83	1036	790.174	58.401	8	.5850	1351.3974	99.88155
.375	1157	89.0641	6.582	.84	1013	800.419	59.158	9	.3670	1351.8734	99.91673
.380	1120	94.7566	7.003	.85	990	810.434	59.899	10	.2410	1352.1774	99.93920
.385	1098	100.3016	7.413	.86	968	820.224	60.622	11	.1650	1352.3804	99.95420
.390	1098	105.7916	7.819	.87	947	829.799	61.330	12	.1170	1352.5214	99.96462
.395	1189	111.5091	8.241	.88	926	839.164	62.022	13	.0851	1352.6224	99.97209
.400	1429	118.0541	8.725	.89	908	848.334	62.700	14	.0634	1352.6967	99.97758
.405	1644	125.7366	9.293	.90	891	857.329	63.365	15	.0481	1352.7524	99.98170
.410	1751	134.224	9.920	.91	880	866.184	64.019	16	.037100	1352.7950	99.98485
.415	1774	143.036	10.571	.92	869	874.929	64.665	17	.029100	1352.8281	99.98730
.420	1747	151.839	11.222	.93	858	883.564	65.304	18	.023100	1352.8542	99.98923
.425	1693	160.439	11.858	.94	847	892.089	65.934	19	.018600	1352.8751	99.99077
.430	1639	168.769	12.473	.95	837	900.509	66.556	20	.015200	1352.8920	99.99202
.435	1663	177.024	13.083	.96	820	908.794	67.168	25	.006170	1352.9454	99.99596
.440	1810	185.706	13.725	.97	803	916.909	67.768	30	.002970	1352.9683	99.99765
.445	1922	195.036	14.415	.98	785	924.849	68.355	35	.001600	1352.9797	99.99850
.450	2006	204.856	15.140	.99	767	932.609	68.928	40	.000942	1352.9860	99.99897
.455	2057	215.014	15.891	1.00	748	940.184	69.488	50	.000391	1352.9927	99.99946
.460	2066	225.321	16.653	1.05	668	975.584	72.105	60	.00019000	1352.9956	99.99967
.465	2048	235.606	17.413	1.10	593	1007.109	74.435	80	.00006160	1352.9981	99.99986
.470	2033	245.809	18.167	1.15	535	1035.309	76.519	100	.00002570	1352.9990	99.99992
.475	2044	256.001	18.921	1.20	485	1060.809	78.404	120	.00001260	1352.9994	99.99995
.480	2074	266.296	19.681	1.25	438	1083.884	80.109	150	.00000523	1352.9997	99.99997
.485	1976	276.421	20.430	1.30	397	1104.759	81.652	200	.00000169	1352.9998	99.99999
.490	1950	286.236	21.155	1.35	358	1123.634	83.047	250	.00000070	1352.9999	99.99999
.495	1960	296.011	21.878	1.40	337	1141.009	84.331	300	.00000034	1352.9999	99.99999
.500	1942	305.766	22.599	1.45	312	1157.234	85.530	400	.00000011	1352.9999	99.99999
.505	1920	315.421	23.312	1.50	288	1172.234	86.639	1000	.00000000	1353.0000	100.00000

KARA TABLE I

SOLAR SPECTRAL IRRADIANCE, 3000 TO 6100A, 1 A INTERVALS

WAVELENGTH IN A, IRRADIANCE IN MW PER M SQ AREA NM BAND

	---0	---1	---2	---3	---4	---5	---6	---7	---8	---9
3000	576	566	557	549	543	535	527	522	519	516
3010	511	502	490	477	463	461	462	467	481	499
3020	513	527	576	560	561	561	560	535	523	508
3030	498	488	477	470	466	465	466	477	496	523
3040	519	544	546	549	562	596	611	616	652	653
3050	647	626	591	567	567	566	559	565	616	617
3060	623	628	640	658	666	706	720	735	740	771
3070	777	775	772	770	772	770	787	791	791	790
3080	787	776	732	691	684	689	676	666	661	660
3090	560	559	558	556	553	549	545	543	542	544
3100	553	649	674	743	765	799	810	810	805	790
3110	701	760	746	775	760	722	709	706	707	713
3120	719	727	735	746	751	757	762	763	762	760
3130	757	756	751	751	756	761	771	768	768	795
3140	804	800	727	713	711	713	714	730	742	752
3150	761	766	765	749	730	725	705	694	689	687
3160	688	697	712	730	739	794	816	822	839	857
3170	865	870	882	879	859	766	739	738	761	755
3180	776	793	801	803	861	795	783	772	772	775
3190	789	800	814	830	843	854	863	868	895	911
3200	915	910	910	918	915	903	892	880	868	861
3210	858	866	863	865	868	858	851	850	847	835
3220	825	807	786	777	771	771	770	782	796	808
3230	817	824	836	842	856	866	873	884	893	899
3240	904	908	912	911	908	908	898	902	915	927
3250	962	971	995	1022	1047	1066	1102	1111	1112	1116
3260	1129	1135	1139	1139	1124	1115	1112	1111	1110	1108
3270	1102	1079	1068	1063	1015	996	947	982	979	975
3280	971	967	963	966	980	1003	1071	1086	1109	1112
3290	1119	1127	1140	1147	1150	1151	1149	1142	1135	1118
3300	1103	1086	1061	1036	1015	1011	1013	1020	1022	1021
3310	1023	1030	1041	1056	1065	1073	1077	1076	1062	1040
3320	1065	1078	1086	1091	1096	1103	1076	1049	1037	1031
3330	1035	1049	1064	1080	1090	1105	1137	1145	1145	1144
3340	1151	1161	1175	1182	1165	1165	1163	1155	1120	1074
3350	1039	1033	1037	1045	1050	1030	1021	1017	1020	1042
3360	1076	1084	1089	1090	1067	1079	1070	1056	1044	1041
3370	1036	1031	1026	1031	1052	1096	1103	1100	1094	1084
3380	1065	1059	1055	1066	1094	1125	1135	1137	1136	1131
3390	1110	1089	1074	1072	1070	1067	1049	1033	1013	984
3400	980	975	973	975	981	990	1015	1058	1069	1073
3410	1076	1048	1066	1095	1104	1114	1122	1126	1128	1127
3420	1125	1120	1104	1091	1079	1066	1036	1023	996	956
3430	921	923	927	933	961	969	1056	1073	1083	1093
3440	1103	1110	1115	1118	1120	1121	1119	1117	1112	1105
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3480	1010	1008	1004	1006	1012	1027	1037	1060	1096	1123
3490	1169	1186	1201	1204	1206	1207	1201	1182	1128	1127
3500	1127	[illegible]	[illegible]	1138	1136	1126	1100	1075	1044	1032
3510	1024	[illegible]	[illegible]	1023	1027	1039	1059	1086	1096	1132
3520	1116	[illegible]	[illegible]	1155	1159	1163	1171	1184	1200	1216
3530	1213	[illegible]	[illegible]	1231	1237	1241	1244	1246	1247	1248
3540	1244	[illegible]	1251	1236	1238	1215	1191	1183	1181	1184
3550	1167	[illegible]	1026	1017	1013	1012	1019	1024	1026	1028
3560	1024	1007	991	967	908	891	872	856	843	833
3570	838	[illegible]	827	827	828	829	841	855	874	926
3580	966	1050	1074	1122	1150	1178	1191	1195	1197	1198
3590	1196	1192	1188	1182	1168	1139	1119	1100	1086	1060
3600	1047	1035	[illegible]	1015	1016	1022	1031	1039	1039	1035
3610	1017	1007	1001	997	996	999	1031	1074	1107	1127
3620	1131	1131	[illegible]	1103	1075	1068	1070	1074	1085	1094
3630	1095	1090	1081	1067	1038	1016	993	966	941	979
3640	992	1008	1016	1019	1027	1046	1057	1080	1096	1115
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3670	1234	1237	1238	1234	1228	1207	1191	1168	1148	1134
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3740	1051	1063	1074	1100	1104	1104	1100	1067	1066	1068
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3780	1355	1355	1351	1342	1328	1312	1294	1256	1163	1139
3790	1122	1107	1096	1087	1080	1075	1072	1070	1069	1071
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3810	1140	1106	1086	1075	1066	1056	986	952	926	903
3820	888	874	835	826	825	830	826	832	842	852
3830	862	876	887	901	922	944	965	999	1075	1101
3840	1145	1167	1190	1204	1214	1219	1219	1217	1214	1218
3850	1206	1203	1200	1196	1191	1188	1187	1187	1186	1185
3860	1186	1182	1180	1177	1171	1161	1150	1140	1129	1121
3870	1115	1111	1103	1096	1100	1105	1114	1120	1121	1120
3880	1136	1141	1152	1152	1171	1171	1169	1167	1165	1161
3890	1150	1156	1156	1155	1157	1160	1165	1171	1177	1182
3900	1186	1192	1199	1202	1203	1202	1199	1196	1189	1176
3910	1156	1125	1104	1079	1032	1012	978	961	946	928
3920	869	832	815	789	778	754	731	706	693	667
3930	686	721	800	832	898	921	991	1032	1036	1038
3940	1039	1039	1038	1036	1032	1026	1022	1016	1004	980
3950	976	959	944	923	911	871	757	734	730	731
3960	736	758	803	813	893	971	1017	1043	1083	1122
3970	1135	1161	1171	1245	1325	1347	1376	1429	1454	1515
3980	1529	1557	1597	1595	1624	1649	1666	1680	1689	1698
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4460	1967	1969	1970	1971	1973	1974	1975	1975	1976	1976
4470	1977	1977	1976	1976	1974	1972	1969	1968	1967	1966
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4540	2095	2093	2091	2088	2086	2082	2078	2074	2069	2065
4550	2061	2056	2050	2041	2035	2028	2022	2016	2013	2012
4560	2011	2011	2012	2012	2013	2013	2013	2013	2013	2013
4570	2014	2015	2017	2021	2026	2033	2039	2044	2050	2055
4580	2059	2062	2065	2067	2069	2071	2073	2074	2076	2076
4590	2077	2077	2077	2077	2077	2077	2076	2076	2075	2074
4600	2074	2073	2073	2072	2071	2070	2069	2068	2067	2066
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4620	2060	2060	2060	2060	2060	2060	2061	2062	2062	2063
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4680	2019	2021	2022	2024	2025	2026	2028	2030	2032	2034
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4710	2039	2038	2037	2035	2034	2032	2031	2030	2029	2029
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4770	2054	2055	2055	2055	2055	2056	2055	2054	2052	2051
4780	2051	2050	2051	2051	2053	2054	2055	2057	2059	2060
4790	2062	2063	2065	2067	2069	2070	2072	2073	2075	2076
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4850	1980	1973	1966	1958	1951	1943	1937	1932	1923	1915
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4910	1987	1987	1986	1986	1984	1983	1981	1980	1978	1976
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5010	1924	1922	1920	1918	1915	1912	1909	1906	1904	1902
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5060	1935	1934	1935	1935	1934	1934	1933	1933	1931	1930
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5080	1907	1904	1901	1898	1895	1893	1891	1888	1886	1884
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5100	1870	1869	1869	1869	1869	1869	1869	1869	1870	1870
5110	1871	1872	1873	1875	1876	1877	1878	1878	1879	1879
5120	1879	1879	1879	1878	1878	1879	1876	1875	1875	1874
5130	1876	1876	1876	1873	1872	1871	1866	[illegible]	1866	1861
5140	1859	1857	1855	1856	1852	1850	1847	1840	1840	1837
5150	1834	1831	1829	1825	1822	1820	1817	1818	1812	1824
5160	1858	1803	1803	1799	1797	1795	1796	1792	1790	[illegible]
5170	1788	1786	1785	1786	1786	1783	1782	1782	1786	1786
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5220	1879	1879	1880	1881	1882	1881	1882	1883	1885	1886
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5870	1708	1708	1707	1707	1707	1706	1706	1705	1705	1705
5880	1705	1705	1704	1704	1704	1704	1704	1704	1704	1703
5890	1703	1703	1703	1703	1702	1702	1702	1702	1702	1701
5900	1701	1701	1701	1700	1700	1700	1699	1699	1698	1698
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5970	1675	1675	1674	1674	1674	1674	1673	1673	1673	1672
5980	1672	1672	1672	1671	1671	1671	1671	1670	1670	1670
5990	1669	1669	1669	1668	1668	1667	1667	1666	1666	1666
6000	1665	1665	1664	1664	1664	1664	1663	1663	1663	1662
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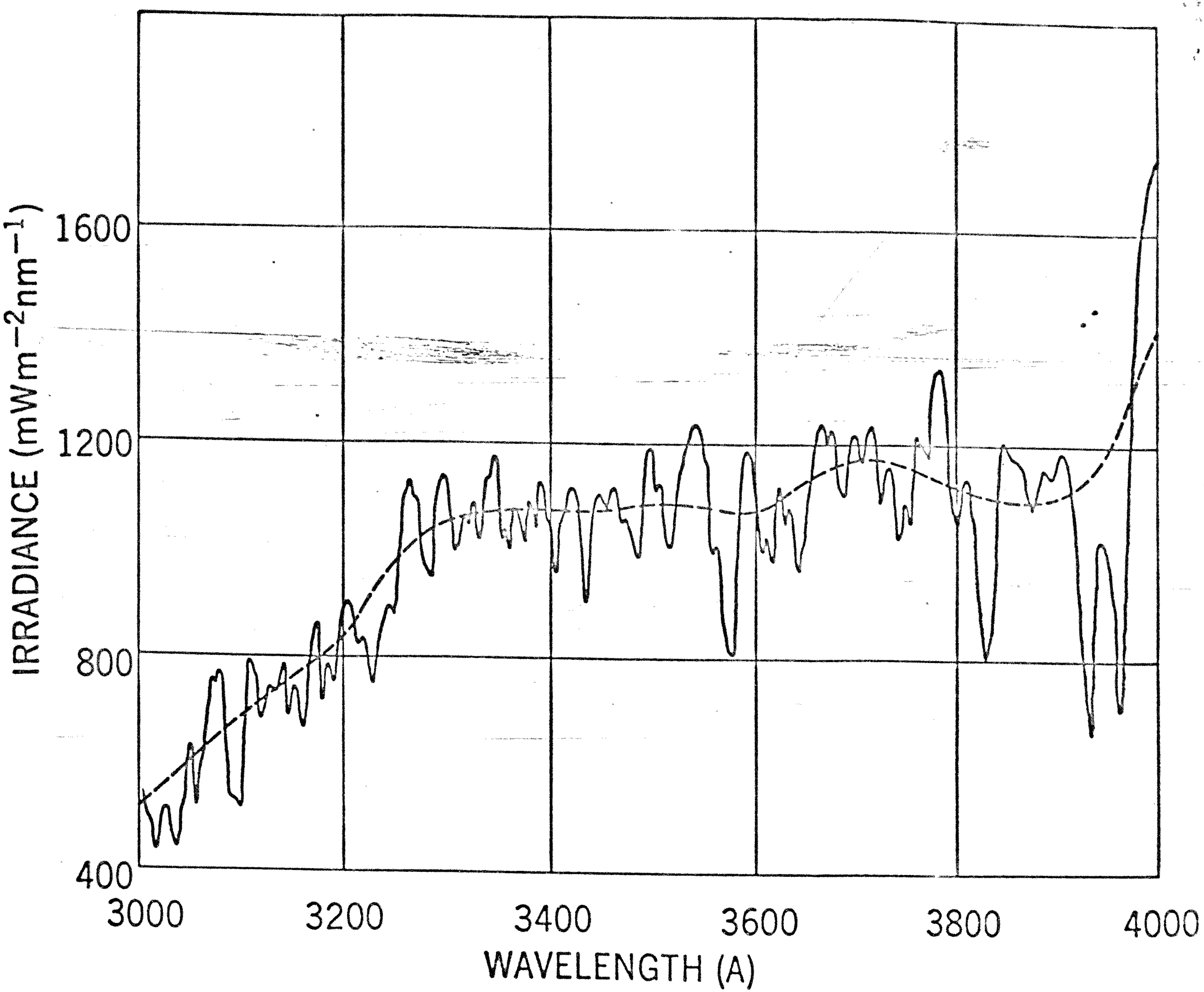
6020	1660	1660	1660	1660	1659	1659	1658	1658	1657	1657
6030	1657	1656	1656	1655	1655	1654	1654	1653	1653	1652
6040	1652	1651	1651	1650	1650	1649	1649	1648	1648	1647
6050	1647	1646	1645	1645	1645	1644	1644	1643	1643	1643
6060	1641	1641	1641	1640	1640	1640	1639	1639	1639	1638
6070	1638	1637	1637	1637	1636	1637	1636	1636	1636	1635
6080	1635	1635	1635	1634	1634	1634	1633	1633	1634	1633
6090	1633	1632	1633	1632	1631	1631	1630	1631	1631	1630
6100	1630									

EXTRA TABLE I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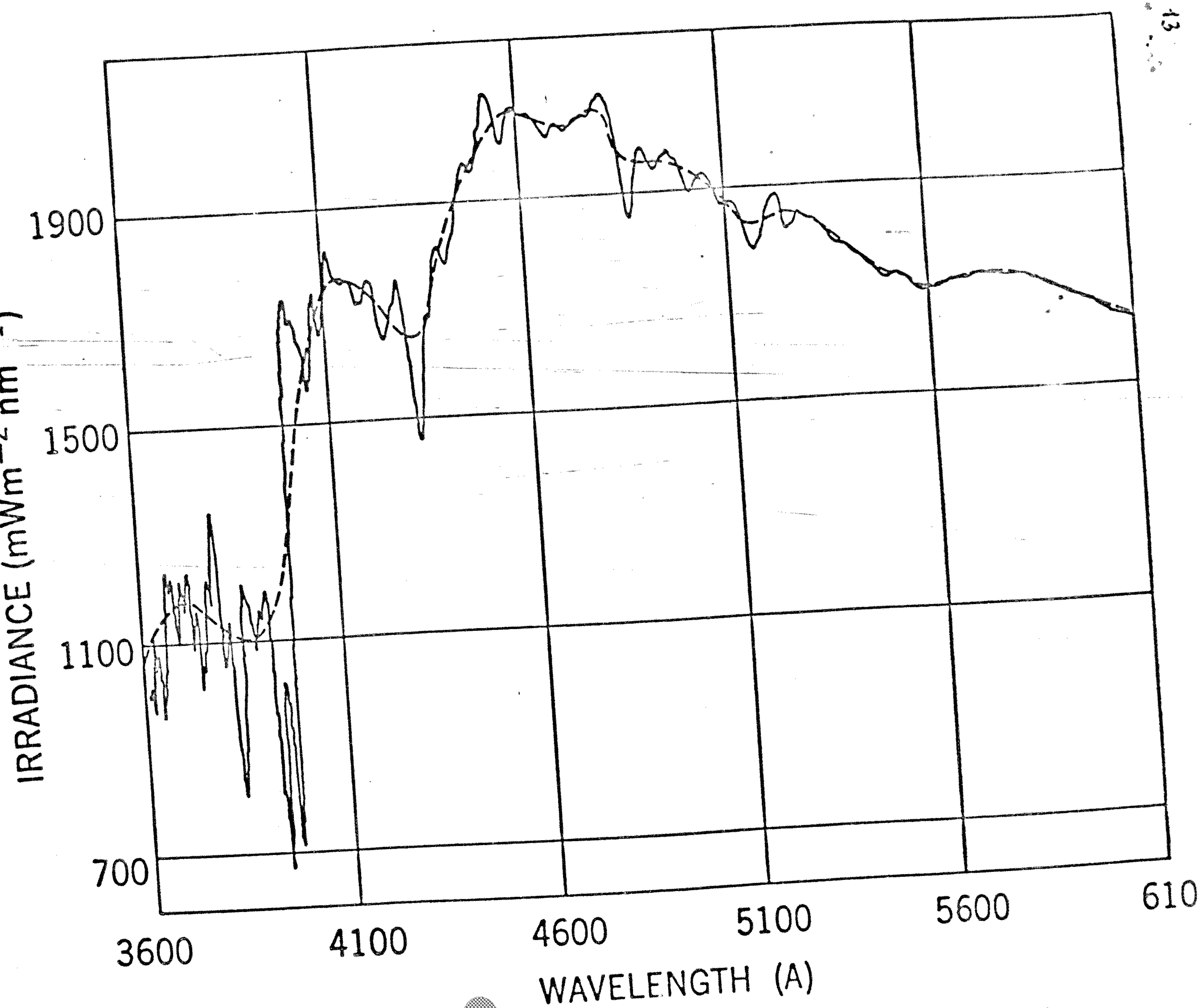
800
400
3000
3200
3400
3600
3800
4000
WAVELENGTH (A)


IRRADIANCE (mWm^{-2} nm^{-1})
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1500
1100
700
3600
4100
4600
5100
5600
6100
WAVELENGTH (A)

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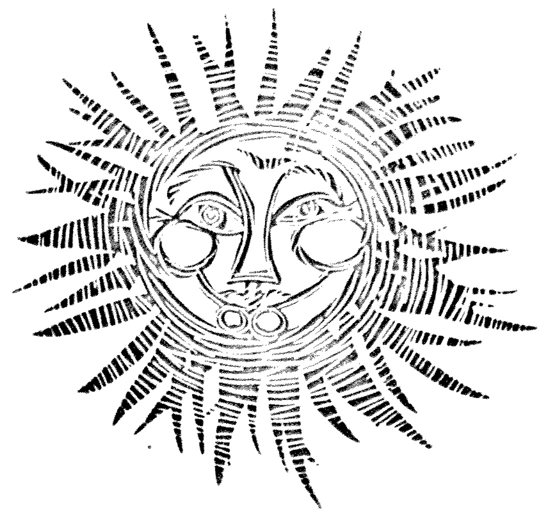
EVALUATING THE LIGHT FROM THE SUN



High-altitude observations, made in response to space-age needs, indicate the need for reassessing some long-accepted values based on previous ground-based measurements of the sun's energy and spectral distribution.

by Matthew P. Thekaekara

OPTICAL SPECTRA AS A FIELD OF RESEARCH began with the discovery by Sir Isaac Newton that the white light of the sun is made up of many different colors. The energy from the sun and its spectral distribution has been and still is a fruitful and elusive field of research

Recent measurements from high altitude observing platforms have produced converging evidence that the values accepted earlier need significant revisions. The values most commonly accepted in the United States had been those proposed in 1954 by Francis S. Johnson.[1] These values were based mainly on an analysis of the ground-based data of the Smithsonian Institution, supplemented for the ultraviolet by rocket data of the Naval Research Laboratory.

In all ground-based measurements, the dust, haze, and smoke of the atmosphere, the permanent gases and, above all, the highly variable and absorbent water vapor are a source of uncertainty. These measurements are made at varying zenith angles of the sun and the readings are extrapolated to what they would have been in the absence of the earth's atmosphere. Since the extinction due to the atmosphere varies with wavelengths, the spectral irradiance is determined in narrow wavelength ranges and the integral energy is computed to give the solar constant. The solar constant, as is well known, is the energy due to the sun incident on unit area exposed normally to the sun's rays at the average sun-earth distance in the absence of the earth's atmosphere. The solar spectral irradiance is the distribution of this energy as a function of wavelength.

Evaluations of the solar constant derived from ground based measurements cover a wide range from 1323 $W \cdot m^{-2}$ of Parry Moon (1940) to 1428 $W \cdot m^{-2}$ of Stair and Johnston (1954) and 1418 $W \cdot m^{-2}$ of Makarova and Kharitonov of USSR (1969). F. S. Johnson's value was 1395 $W \cdot m^{-2}$. All earlier observers have also derived zero air mass solar spectral irradiance curves based on their data. The differences between authors for spectral irradiance values are even greater than for the solar constant. In the ultraviolet range discrepancies are as high at 40%. In the wavelength range longer than 0.7 μm, which contains more than half of the solar energy, the water vapor of the atmosphere is a strong absorbent and most authors, following the lead of Parry Moon, had assumed the solar spectrum to be that of a 6000K blackbody.

Space-age requirements

With the advent of the space age the need for a more reliable set of values of the solar constant and the solar spectrum began to be realized. The temperature equilibrium of satellites and space probes, the electrical output of solar cells, the degradation of surface coatings, the torques due to radiation pressure, the irradiance levels to be maintained in solar simulation chambers for pre-launch testing of satellites, all require design values about the sun's energy, both total and spectral. These are also necessary in many areas of astronomy, astrophysics, meteorology, optics, spectroscopy, geophysics, illumination engineering, etc.

A group of experimenters from NASA Goddard Space Flight Center made extensive measurements of the solar constant and solar spectrum from a research aircraft, NASA 711 Galileo, at 11.6 km[2,3]. They made six flights in August 1967, had about 15 hours of observation and used 11 different instruments, five for total and six for spectral irradiance. The instruments represented different measuring techniques and incorporated some of the best available techniques in radiometry. Their results, as well as data from other independent observers in the U. S. and abroad, were reviewed by a Committee on Solar Electromagnetic Radiation sponsored by the Space Vehicles Design Criteria Program of NASA and by the Solar Simulation group of the Institute of Environmental Sciences. The results of the committee's findings were published in May, 1971, as a monograph in the NASA Space Vehicles Design Criteria series, entitled "Solar Electromagnetic Radiation." (NASA SP 8005).[4] They are also being proposed for engineering use in general by the American Society of Testing Materials and the Institute of Environmental Sciences,[5] and are currently being used for design and testing in many laboratories. This paper will present these values and review briefly how they were derived.

The committee's values

The value of the solar constant is 1353 $W \cdot m^{-2}$. The estimated error is ± 21 $W \cdot m^{-2}$. In units of calories $\cdot cm^{-2} \cdot min^{-1}$ the value is 1.940. This is 3% lower than the Johnson value. The independent measurements o[n] the basis of which the solar constant was derived a[re] shown in Table I. They are all values based o[n] measurements from high altitude observing platform[s,] aircraft or balloons, or from spacecraft. The instru[-]ments were total radiation detectors. The radiati[on] scales to which these values are referred are that of [a] blackbody radiator for the Hy-Cal pyrheliometer, th[e] scale of absolute electrical units for the GSFC cone an[d] JPL cavity radiometer, and the international pyrheli[o-]metric scale IPS '56 for the five other instruments. Th[e] three scales are in agreement within the limit o[f] accuracy of these measurements.

The zero air mass solar spectral irradiance curve i[s] given in tabular form in Table II and graphically i[n] Figure 1. In the wavelength range of 0.3 to 15μm[,] which contains nearly 99% of the energy of the su[n,] these values are based mainly on the measurement[s] made by the GSFC team from the research aircraf[t.] The instruments used were a Perkin-Elmer model 11[2] spectrometer with a lithium fluoride window, a Lei[ss] double quartz prism monochromator, a filter radio[-]meter, a polarization type interferometer and, for th[e] infrared range beyond 4μm, a Michelson typ[e] interferometer. In the wavelength range 0.3 to 2.6μm an independent set of data are available from th[e] Eppley-JPL measurements, made with a filter radio[-]meter during several series of flights of Convair 99[0] and B57B and one flight above the ozonosphere by th[e] X-15 rocket aircraft.[6] In the wavelength range abov[e] 0.7μm the Eppley-JPL integrated value was practicall[y]

Table I

Measurements from which solar constants were derived.

Platform	Detector	Year	Solar Constant $W \cdot cm^{-2}$
NASA 711 Aircraft	GSFC Hy-Cal Pyrheliometer	1967	1358
NASA 711 Aircraft	GSFC Ångström 7635	1967	1349
NASA 711 Aircraft	GSFC Ångström 6618	1967	1343
NASA 711 Aircraft	GSFC Cone Radiometer	1967	1358
Soviet Balloon	U. of Leningrad Actinometer	1961-1968	1353
U. of Denver Balloon	Eppley Normal Incidence Pyrheliometer	1969	1338
X-15, B57B, CV990 Aircraft	Eppley Normal Incidence Pyrheliometer	1966-1968	1360
Mariner VI & VII Spacecraft	JPL Cavity Radiometer	1969	1353
JPL Balloon	JPL Cavity Radiometer	1968-1969	1368
		Average	1353

TABLE II

SOLAR SPECTRAL IRRADIANCE - PROPOSED STANDARD CURVE

λ - Wavelength in micrometers

E(λ) - Solar spectral irradiance averaged over small bandwidth centered at λ, in $W{\cdot}m^{-2}{\cdot}\mu m^{-1}$

E(o-λ) - Area under the solar spectral irradiance curve in the wavelength range 0 to λ in $W{\cdot}m^{-2}$

D(o-λ) - Percentage of the solar constant associated with wavelengths shorter than λ

Solar Constant - 1353 $W{\cdot}m^{-2}$

λ	E(λ)	E(o-λ)	D(o-λ)	λ	E(λ)	E(o-λ)	D(o-λ)	λ	E(λ)	E(o-λ)	D(o-λ)
.120	.100	.005999	.00044	.525	1852	352.591	26.059	1.70	202	1221.23	90.261
.140	.030	.007299	.00053	.530	1842	361.826	26.742	1.75	180	1230.78	90.967
.150	.07	.00780	.00057	.535	1818	370.976	27.418	1.80	159	1239.25	91.593
.160	.23	.00930	.00068	.540	1783	379.979	28.084	1.85	142	1246.78	92.149
.170	.63	.01360	.00100	.545	1754	388.821	28.737	1.90	126	1253.48	92.644
.180	1.25	.02300	.00169	.550	1725	397.519	29.380	1.95	114	1259.48	93.088
.190	2.71	.04280	.00316	.555	1720	406.131	30.017	2.00	103	1264.90	93.489
.200	10.7	.10985	.00811	.560	1695	414.669	30.648	2.10	90	1274.55	94.202
.210	22.9	.27785	.02053	.565	1705	423.169	31.276	2.20	79	1283.00	94.826
.220	57.5	.67985	.05024	.570	1712	431.711	31.907	2.30	69	1290.40	95.373
.225	64.9	.98585	.0728	.575	1719	440.289	32.541	2.4	62.0	1296.95	95.8580
.230	66.7	1.31485	.0971	.580	1715	448.874	33.176	2.5	55.0	1302.80	96.2903
.235	59.3	1.62985	.1204	.585	1712	457.441	33.809	2.6	48.0	1307.95	96.6710
.240	63.0	1.93560	.1430	.590	1700	465.971	34.439	2.7	43.0	1312.50	97.0073
.245	72.3	2.27385	.1680	.595	1682	474.426	35.064	2.8	39.0	1316.60	97.3103
.250	70.4	2.63060	.1944	.600	1666	482.796	35.683	2.9	35.0	1320.30	97.5838
.255	104	3.05660	.2266	.605	1647	491.079	36.295	3.0	31.0	1323.60	97.8277
[illegible]	130	3.65160	.2698	.610	1635	499.284	36.902	3.1	26.0	1326.45	98.0383
[illegible]	185	4.43910	.3280	.620	1602	515.469	38.098	3.2	22.6	1328.88	98.2179
[illegible]	232	5.48160	.4051	.630	1570	531.329	39.270	3.3	19.2	1330.97	98.3724
.275	204	6.5716	.4857	.64	1544	546.899	40.421	3.4	16.6	1332.76	98.5047
.280	222	7.6366	.5644	.65	1511	562.174	41.550	3.5	14.6	1334.32	98.6200
[illegible]	315	8.9791	.6636	.66	1486	577.159	42.657	3.6	13.5	1335.73	98.7238
[illegible]	482	10.9716	.8109	.67	1456	591.863	43.744	3.7	12.3	1337.02	98.8192
.295	584	13.6366	1.0078	.68	1427	606.284	44.810	3.8	11.1	1338.19	98.9056
.300	514	16.3816	1.2107	.69	1402	620.429	45.855	3.9	10.3	1339.26	98.9847
.305	603	19.1741	1.4171	.70	1369	634.284	46.879	4.0	9.5	1340.25	99.0579
.310	689	22.4041	1.6558	.71	1344	647.849	47.882	4.1	8.7	1341.16	99.1252
.315	764	26.0366	1.9243	.72	1314	661.139	48.864	4.2	7.8	1341.98	99.1861
.320	830	30.0216	2.2188	.73	1290	674.159	49.826	4.3	7.1	1342.73	99.2412
.325	975	34.5341	2.552	.74	1260	686.909	50.769	4.4	6.50	1343.4141	99.291507
.330	1059	39.6191	2.928	.75	1235	699.384	51.691	4.5	5.90	1344.0341	99.337331
.335	1081	44.9691	3.323	.76	1211	711.614	52.595	4.6	5.30	1344.5941	99.378721
.340	1074	50.3566	3.721	.77	1185	723.594	53.480	4.7	4.80	1345.0391	99.416045
.345	1069	55.7141	4.117	.78	1159	735.314	54.346	4.8	4.50	1345.5641	99. .50413
.350	1093	61.1191	4.517	.79	1134	746.779	55.194	4.9	4.10	1345.9941	99.482195
.355	1083	66.5531	4.919	.80	1109	757.994	56.023	5.0	3.83	1346.3906	99.511500
.360	1068	71.9366	5.316	.81	1085	768.965	56.834	6.0	1.75	1349.1806	99.717708
.365	1132	77.4366	5.723	.82	1060	779.694	57.627	7.0	.99	1350.5506	99.818965
.370	1181	83.2191	6.150	.83	1036	790.174	58.401	8.0	.60	1351.3456	99.877723
.375	1157	89.0641	6.582	.84	1013	800.419	59.158	9.0	.380	1351.8356	99.913939
.380	1120	94.7566	7.003	.85	990	810.434	59.899	10.0	.250	1352.1506	99.937221
.385	1098	100.3016	7.413	.86	968	820.224	60.622	11.0	.170	1352.3606	99.952742
.390	1098	105.7916	7.819	.87	947	829.799	61.330	12.0	.120	1352.5056	99.963459
.395	1189	111.5091	8.241	.88	926	839.164	62.022	13.0	.087	1352.6091	99.971108
.400	1429	118.0541	8.725	.89	908	848.334	62.700	14.0	.055	1352.6801	99.976356
.405	1644	125.7356	9.293	.90	891	857.329	63.365	15.0	.049	1352.7321	99.980199
.410	1751	134.2241	9.920	.91	880	866.184	64.019	16.0	.038	1352.7756	99.983414
.415	1774	143.0366	10.571	.92	869	874.929	64.665	17.0	.031	1352.8101	99.985964
.420	1747	151.8391	11.222	.93	858	883.564	65.304	18.0	.024	1352.8376	99.987997
.425	1693	160.4391	11.858	.94	847	892.08	65.934	19.0	.02000	1352.8596	99.989623
.430	1639	168.7691	12.473	.95	837	900.50	66.556	20.0	.01600	1352.8776	99.990953
.435	1663	177.0241	13.083	.96	820	908.79	67.168	25.0	.00610	1352.9328	99.995037
.440	1810	185.7066	13.725	.97	803	916.90	67.768	30.0	.00300	1352.9556	99.996718
.445	1922	195.0366	14.415	.98	785	924.84	68.355	35.0	.00160	1352.9671	99.997568
.450	2006	204.8566	15.140	.99	767	932.60	68.928	40.0	.00094	1352.9734	99.998037
.455	2057	215.0141	15.891	1.00	748	940.18	69.488	50.0	.00038	1352.9800	99.998525
.460	2066	225.3216	16.653	1.05	668	975.58	72.105	60.0	.00019	1352.9829	99.998736
.465	2048	235.6066	17.413	1.10	593	1007.10	74.435	80.0	.00007	1352.9855	99.998928
.470	2033	245.8031	18.167	1.15	535	1035.30	76.519	100.0	.00003	1352.9865	99.999002
.475	2044	256.001	18.921	1.20	485	1060.80	78.404	1000.0	.00000	1353.0000	100.000000
.480	2074	266.296	19.681	1.25	438	1083.88	80.109				
.495	1976	276.421	20.430	1.30	397	1104.75	81.652				
.490	1950	286.236	21.155	1.35	358	1123.63	83.047				
.495	1960	296.011	21.878	1.40	337	1141.00	84.331				
.500	1942	305.766	22.599	1.45	312	1157.23	85.530				
.505	1920	315.421	23.312	1.50	288	1172.23	86.639				
.510	1882	324.926	24.015	1.55	267	1186.10	87.665				
.515	1833	334.214	24.701	1.60	245	1198.90	88.611				
.520	1833	343.379	25.379	1.65	223	1210.60	89.475				

SOLAR SPECTRAL IRRADIANCE

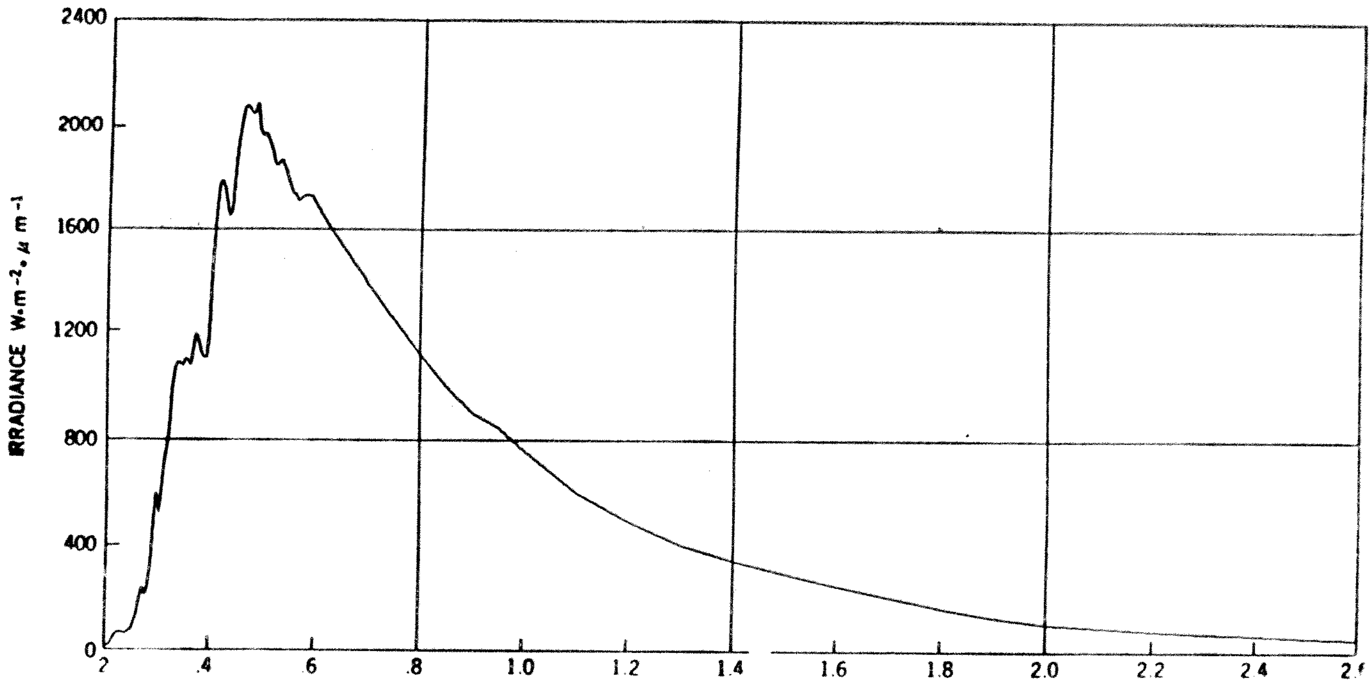


Figure 1. The solar spectral irradiance curve for zero air mass (also given in tabular form in Table II).

the same as that of GSFC, and there was very close agreement in the range 0.3 to 0.7μm. The GSFC values were modified slightly in the light of the Eppley-JPL values, thereby raising the solar constant from the GSFC value of 1351 $W \cdot m^{-2}$ to 1353 $W \cdot m^{-2}$ as given earlier on the basis of total irradiance data.

Practically all the other spectral irradiance curves available in literature are derived from ground-based measurements, and were not considered sufficiently significant to alter the mutually confirming data of GSFC and Eppley-JPL. The radiation scales to which these values are referred are that of the NBS standards of spectral irradiance for the GSFC data and the IPS 56 for the Eppley-JPL data. The wavelength ranges below 0.3μm and above 15μm were not covered in the GSFC and Eppley-JPL measurements. The values given in Table II for these ranges are based on Hinteregger, Parkinson and Reeves and Heath for X-ray and UV regions and on Shimabukoro and Stacey for IR and microwave regions. For more detailed information on the sources on which values of the solar constant and its spectral components are derived and for comparison of these values with earlier estimates, References 2, 3, 5 and 6 as also the bibliography given there should be consulted. □

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Meet the author

Matthew P. Thekaekara received his Ph.D. in physics from Johns Hopkins University in 1956. In 1957 he joined the faculty of Georgetown University, where he was associate professor of physics and astronomy and later acting chairman of the department of physics. Since 1962 he has been associated with NASA Goddard Space Flight Center, doing research in solar irradiance and space simulation radiometry. He received the NASA/GSFC Exceptional Performance Award in 1970 and the Space Environment Award of the Institute of Environmental Sciences in 1971 for his work on the solar constant and solar spectrum.

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MS - 11A
File 1
D-12248
C-09473


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STANDARD EXTRATERRESTRIAL SOLAR SPECTRUM, M.  P. THEKAEKARA, CODE 322, G.S.F.C.
FORMAT (6F10.0) WAVELENGTH IN MICROMETERS, IRRADIANCE IN WATT/(M.SQ.,MICROMETER)
  211 THEKAEKARA STANDARD SOLAR SPECTRAL IRRADIANCE
 .03       .0528823  .115           .007      .12          .9
 .125       .007     .13            .007      .14          .03
      .1500     .0700     .1600     .2300     .1700     .6300
      .1800    1.2500     .1900    2.7100     .2000   10.7000
      .2100   22.9000     .2200   57.5000     .2250   64.9000
      .2300   66.7000     .2350   59.3000     .2400   63.0000
      .2450   72.3000     .2500   70.4000     .2550  104.0000
      .2600  130.0000     .2650  185.0000     .2700  232.0000
      .2750  204.0000     .2800  222.0000     .2850  315.0000
      .2900  482.0000     .2950  584.0000     .3000  514.0000
      .3050  603.0000     .3100  689.0000     .3150  764.0000
      .3200  830.0000     .3250  975.0000     .3300 1059.0000
      .3350 1081.0000     .3400 1074.0000     .3450 1069.0000
      .3500 1093.0000     .3550 1083.0000     .3600 1068.0000
      .3650 1132.0000     .3700 1181.0000     .3750 1157.0000
      .3800 1120.0000     .3850 1098.0000     .3900 1098.0000
      .3950 1189.0000     .4000 1429.0000     .4050 1644.0000
      .4100 1751.0000     .4150 1774.0000     .4200 1747.0000
      .4250 1693.0000     .4300 1639.0000     .4350 1663.0000
      .4400 1810.0000     .4450 1922.0000     .4500 2006.0000
      .4550 2057.0000     .4600 2066.0000     .4650 2048.0000
      .4700 2033.0000     .4750 2044.0000     .4800 2074.0000
      .4850 1976.0000     .4900 1950.0000     .4950 1960.0000
      .5000 1942.0000     .5050 1920.0000     .5100 1882.0000
      .5150 1833.0000     .5200 1833.0000     .5250 1852.0000
      .5300 1842.0000     .5350 1818.0000     .5400 1783.0000
      .5450 1754.0000     .5500 1725.0000     .5550 1720.0000
      .5600 1695.0000     .5650 1705.0000     .5700 1712.0000
      .5750 1719.0000     .5800 1715.0000     .5850 1712.0000
      .5900 1700.0000     .5950 1682.0000     .6000 1666.0000
      .6050 1647.0000     .6100 1635.0000     .6200 1602.0000
      .6300 1570.0000     .6400 1544.0000     .6500 1511.0000
      .6600 1486.0000     .6700 1456.0000     .6800 1427.0000
      .6900 1402.0000     .7000 1369.0000     .7100 1344.0000
      .7200 1314.0000     .7300 1290.0000     .7400 1260.0000
      .7500 1235.0000     .7600 1211.0000     .7700 1185.0000
      .7800 1159.0000     .7900 1134.0000     .8000 1109.0000
      .8100 1085.5000     .8200 1060.0000     .8300 1036.0000
      .8400 1013.0000     .8500  990.0000     .8600  968.0000
      .8700  947.0000     .8800  926.0000     .8900  908.0000
      .9000  891.0000     .9100  880.0000     .9200  869.0000
      .9300  858.0000     .9400  847.0000     .9500  837.0000
      .9600  820.0000     .9700  803.0000     .9800  785.0000
      .9900  767.0000    1.0000  748.0000    1.0500  668.0000
     1.1000  593.0000    1.1500  535.0000    1.2000  485.0000
     1.2500  438.0000    1.3000  397.0000    1.3500  358.0000
     1.4000  337.0000    1.4500  312.0000    1.5000  288.0000
     1.5500  267.0000    1.6000  245.0000    1.6500  223.0000
     1.7000  202.0000    1.7500  180.0000    1.8000  159.0000
     1.8500  142.0000    1.9000  126.0000    1.9500  114.0000
     2.0000  103.0000    2.1000   90.0000    2.2000   79.0000
     2.3000   69.0000    2.4000   62.0000    2.5000   55.0000
     2.6000   48.0000    2.7000   43.0000    2.8000   39.0000
     2.9000   35.0000    3.0000   31.0000    3.1000   26.0000
     3.2000   22.6000    3.3000   19.2000    3.4000   16.6000
```

```
      3.5000   14.6000    3.6000   13.5000    3.7000   12.3000
      3.8000   11.1000    3.9000   10.3000    4.0000    9.5000
      4.1000    8.7000    4.2000    7.8000    4.3000    7.1000
    4.4    6.5          4.5    5.92         4.6    5.35
    4.7    4.86         4.8    4.47336      4.9    4.11
    5.0    3.79         6.     1.82         7.     .99
    8.0    .585         9.     .367        10.     .241
   11.0    .165        12.     .117        13.     .0851
   14.0    .0634       15.     .0481       16.     .0371
   17.0    .0291       18.     .0231       19.     .0196
   20.0    .0152       25.     .00617      30.     .00297
   35.0    .00160      40.     .000942     50.     .000391
   60.0    .000190     80.     .0000616   100.     .0000257
  120.0    .0000126   150.     .00000523  200.     .00000169
  250.0    .000000701 300.     .000000342 400.     .000000110
 1000.     .000000003
```

MS-11B
File 2
D-12248
C-09473

```
      M. P. THEKAEKARA, STANDARD SOLAR CURVE, 3000 TO 6100 A, AT 1 A INTERVALS
   FORMAT (16I5),WAVELENGTH IN A, IRRADIANCE IN MW PER M SC AREA NM BAND AT 1 A.U.
   3000  576 3001  566 3002  557 3003  549 3004  543 3005  535 3006  527 3007  522
   3008  519 3009  516 3010  511 3011  502 3012  490 3013  477 3014  463 3015  461
   3016  462 3017  467 3018  481 3019  496 3020  513 3021  527 3022  536 3023  540
   3024  541 3025  541 3026  540 3027  535 3028  523 3029  508 3030  498 3031  488
   3032  477 3033  470 3034  466 3035  465 3036  466 3037  477 3038  494 3039  523
   3040  539 3041  544 3042  546 3043  549 3044  562 3045  594 3046  611 3047  636
   3048  652 3049  653 3050  647 3051  626 3052  591 3053  567 3054  547 3055  544
   3056  559 3057  595 3058  614 3059  617 3060  623 3061  628 3062  640 3063  658
   3064  686 3065  704 3066  720 3067  735 3068  748 3069  771 3070  777 3071  775
   3072  772 3073  770 3074  772 3075  778 3076  787 3077  791 3078  791 3079  790
   3080  787 3081  776 3082  732 3083  691 3084  646 3085  609 3086  575 3087  564
   3088  561 3089  560 3090  550 3091  559 3092  558 3093  556 3094  553 3095  549
   3096  545 3097  543 3098  542 3099  544 3100  553 3101  649 3102  674 3103  743
   3104  765 3105  799 3106  810 3107  810 3108  805 3109  798 3110  791 3111  788
   3112  784 3113  775 3114  748 3115  722 3116  709 3117  706 3118  707 3119  713
   3120  719 3121  727 3122  735 3123  744 3124  751 3125  757 3126  762 3127  763
   3128  762 3129  760 3130  757 3131  754 3132  751 3133  751 3134  754 3135  761
   3136  771 3137  780 3138  788 3139  795 3140  804 3141  800 3142  727 3143  713
   3144  711 3145  713 3146  719 3147  730 3148  742 3149  752 3150  761 3151  766
   3152  765 3153  749 3154  738 3155  725 3156  705 3157  694 3158  689 3159  687
   3160  688 3161  697 3162  712 3163  730 3164  739 3165  794 3166  816 3167  822
   3168  839 3169  857 3170  865 3171  878 3172  882 3173  879 3174  859 3175  744
   3176  739 3177  738 3178  741 3179  756 3180  774 3181  793 3182  801 3183  803
   3184  801 3185  795 3186  783 3187  772 3188  772 3189  775 3190  789 3191  800
   3192  814 3193  830 3194  843 3195  854 3196  863 3197  884 3198  895 3199  911
   3200  915 3201  918 3202  918 3203  918 3204  915 3205  903 3206  892 3207  880
   3208  868 3209  861 3210  850 3211  844 3212  843 3213  845 3214  848 3215  850
   3216  851 3217  850 3218  847 3219  835 3220  825 3221  809 3222  786 3223  777
   3224  771 3225  771 3226  770 3227  782 3228  796 3229  808 3230  817 3231  824
   3232  834 3233  842 3234  854 3235  866 3236  873 3237  884 3238  893 3239  895
   3240  904 3241  908 3242  912 3243  911 3244  906 3245  900 3246  898 3247  902
   3248  915 3249  927 3250  962 3251  971 3252  995 3253 1022 3254 1047 3255 1086
   3256 1102 3257 1111 3258 1112 3259 1116 3260 1129 3261 1135 3262 1139 3263 1139
   3264 1122 3265 1115 3266 1112 3267 1111 3268 1110 3269 1108 3270 1102 3271 1079
   3272 1068 3273 1043 3274 1015 3275  994 3276  987 3277  982 3278  979 3279  975
   3280  971 3281  967 3282  963 3283  964 3284  980 3285 1003 3286 1071 3287 1086
   3288 1109 3289 1112 3290 1119 3291 1127 3292 1140 3293 1147 3294 1150 3295 1151
   3296 1149 3297 1142 3298 1135 3299 1118 3300 1103 3301 1085 3302 1061 3303 1034
   3304 1016 3305 1011 3306 1013 3307 1020 3308 1022 3309 1021 3310 1023 3311 1030
   3312 1041 3313 1054 3314 1065 3315 1073 3316 1077 3317 1076 3318 1062 3319 1060
   3320 1065 3321 1078 3322 1086 3323 1091 3324 1096 3325 1103 3326 1076 3327 1049
   3328 1037 3329 1031 3330 1035 3331 1040 3332 1048 3333 1068 3334 1080 3335 1105
   3336 1137 3337 1145 3338 1145 3339 1146 3340 1151 3341 1161 3342 1175 3343 1182
   3344 1185 3345 1185 3346 1183 3347 1155 3348 1120 3349 1074 3350 1039 3351 1033
   3352 1037 3353 1045 3354 1050 3355 1030 3356 1021 3357 1017 3358 1020 3359 1042
   3360 1074 3361 1084 3362 1089 3363 1090 3364 1087 3365 1079 3366 1070 3367 1058
   3368 1049 3369 1041 3370 1036 3371 1031 3372 1028 3373 1031 3374 1052 3375 1096
   3376 1103 3377 1100 3378 1094 3379 1086 3380 1065 3381 1059 3382 1055 3383 1066
   3384 1094 3385 1125 3386 1135 3387 1137 3388 1136 3389 1131 3390 1110 3391 1089
   3392 1074 3393 1072 3394 1070 3395 1067 3396 1049 3397 1033 3398 1013 3399  989
   3400  980 3401  974 3402  973 3403  975 3404  981 3405  990 3406 1015 3407 1058
   3408 1069 3409 1073 3410 1076 3411 1080 3412 1086 3413 1095 3414 1104 3415 1114
   3416 1122 3417 1126 3418 1128 3419 1127 3420 1125 3421 1120 3422 1104 3423 1091
   3424 1079 3425 1066 3426 1036 3427 1023 3428  996 3429  956 3430  921 3431  923
   3432  927 3433  933 3434  941 3435  969 3436 1054 3437 1073 3438 1083 3439 1095
   3440 1103 3441 1110 3442 1115 3443 1118 3444 1120 3445 1121 3446 1119 3447 1117
```

$mW/(M^2, nM)$

bandwidth is 1 nanometer.

3448	1112	3449	1105	3450	1096	3451	1091	3452	1091	3453	1094	3454	1100	3455	1108
3456	1115	3457	1122	3458	1129	3459	1131	3460	1129	3461	1124	3462	1111	3463	1095
3464	1078	3465	1069	3466	1067	3467	1066	3468	1069	3469	1072	3470	1073	3471	1073
3472	1071	3473	1068	3474	1062	3475	1055	3476	1047	3477	1036	3478	1028	3479	1018
3480	1010	3481	1006	3482	1004	3483	1004	3484	1012	3485	1027	3486	1037	3487	1060
3488	1096	3489	1125	3490	1169	3491	1182	3492	1201	3493	1204	3494	1206	3495	1207
3496	1201	3497	1182	3498	1128	3499	1127	3500	1127	3501	1131	3502	1136	3503	1138
3504	1136	3505	1126	3506	1100	3507	1075	3508	1044	3509	1032	3510	1024	3511	1022
3512	1021	3513	1023	3514	1027	3515	1039	3516	1059	3517	1086	3518	1096	3519	1102
3520	1116	3521	1126	3522	1140	3523	1155	3524	1159	3525	1163	3526	1171	3527	1184
3528	1200	3529	1206	3530	1213	3531	1220	3532	1226	3533	1231	3534	1237	3535	1241
3536	1244	3537	1246	3538	1247	3539	1248	3540	1248	3541	1246	3542	1241	3543	1236
3544	1230	3545	1215	3546	1191	3547	1183	3548	1181	3549	1180	3550	1167	3551	1057
3552	1024	3553	1017	3554	1013	3555	1012	3556	1019	3557	1024	3558	1026	3559	1026
3560	1024	3561	1007	3562	981	3563	967	3564	908	3565	891	3566	872	3567	856
3568	843	3569	833	3570	830	3571	828	3572	827	3573	827	3574	828	3575	829
3576	841	3577	855	3578	894	3579	926	3580	966	3581	1058	3582	1074	3583	1122
3584	1150	3585	1178	3586	1191	3587	1195	3588	1197	3589	1198	3590	1196	3591	1192
3592	1188	3593	1182	3594	1164	3595	1139	3596	1114	3597	1100	3598	1086	3599	1060
3600	1047	3601	1035	3602	1021	3603	1015	3604	1016	3605	1022	3606	1031	3607	1039
3608	1039	3609	1035	3610	1017	3611	1007	3612	1001	3613	997	3614	996	3615	999
3616	1031	3617	1079	3618	1107	3619	1127	3620	1131	3621	1131	3622	1118	3623	1103
3624	1075	3625	1068	3626	1070	3627	1074	3628	1085	3629	1094	3630	1095	3631	1090
3632	1081	3633	1067	3634	1038	3635	1016	3636	993	3637	986	3638	981	3639	979
3640	982	3641	1008	3642	1016	3643	1019	3644	1027	3645	1044	3646	1057	3647	1080
3648	1096	3649	1115	3650	1127	3651	1138	3652	1160	3653	1172	3654	1188	3655	1206
3656	1213	3657	1221	3658	1233	3659	1241	3660	1245	3661	1247	3662	1248	3663	1248
3664	1243	3665	1227	3666	1214	3667	1216	3668	1220	3669	1227	3670	1234	3671	1237
3672	1238	3673	1234	3674	1220	3675	1207	3676	1191	3677	1168	3678	1148	3679	1134
3680	1128	3681	1124	3682	1121	3683	1120	3684	1120	3685	1123	3686	1131	3687	1144
3688	1171	3689	1194	3690	1210	3691	1221	3692	1227	3693	1228	3694	1230	3695	1229
3696	1224	3697	1213	3698	1195	3699	1185	3700	1180	3701	1179	3702	1181	3703	1186
3704	1198	3705	1211	3706	1224	3707	1232	3708	1237	3709	1240	3710	1243	3711	1245
3712	1244	3713	1233	3714	1222	3715	1211	3716	1178	3717	1167	3718	1107	3719	1109
3720	1113	3721	1118	3722	1125	3723	1133	3724	1142	3725	1150	3726	1152	3727	1161
3728	1169	3729	1170	3730	1170	3731	1167	3732	1135	3733	1105	3734	1056	3735	1040
3736	1037	3737	1039	3738	1042	3739	1046	3740	1051	3741	1063	3742	1094	3743	1100
3744	1104	3745	1104	3746	1100	3747	1067	3748	1066	3749	1068	3750	1076	3751	1087
3752	1130	3753	1166	3754	1197	3755	1213	3756	1227	3757	1228	3758	1228	3759	1226
3760	1225	3761	1222	3762	1218	3763	1213	3764	1207	3765	1202	3766	1198	3767	1193
3768	1190	3769	1190	3770	1249	3771	1263	3772	1311	3773	1319	3774	1327	3775	1333
3776	1347	3777	1349	3778	1351	3779	1353	3780	1355	3781	1355	3782	1351	3783	1342
3784	1328	3785	1312	3786	1294	3787	1256	3788	1183	3789	1139	3790	1122	3791	1107
3792	1096	3793	1087	3794	1080	3795	1075	3796	1072	3797	1070	3798	1069	3799	1071
3800	1077	3801	1089	3802	1100	3803	1113	3804	1133	3805	1144	3806	1148	3807	1150
3808	1151	3809	1148	3810	1140	3811	1104	3812	1086	3813	1075	3814	1064	3815	1006
3816	984	3817	952	3818	924	3819	903	3820	888	3821	874	3822	835	3823	824
3824	825	3825	830	3826	824	3827	832	3828	842	3829	852	3830	862	3831	874
3832	887	3833	901	3834	922	3835	944	3836	965	3837	999	3838	1075	3839	1101
3840	1145	3841	1167	3842	1190	3843	1204	3844	1214	3845	1219	3846	1219	3847	1217
3848	1214	3849	1210	3850	1206	3851	1203	3852	1200	3853	1196	3854	1191	3855	1188
3856	1187	3857	1187	3858	1186	3859	1185	3860	1184	3861	1182	3862	1180	3863	1177
3864	1171	3865	1161	3866	1150	3867	1140	3868	1129	3869	1121	3870	1115	3871	1111
3872	1103	3873	1094	3874	1108	3875	1105	3876	1114	3877	1120	3878	1121	3879	1128
3880	1138	3881	1141	3882	1152	3883	1162	3884	1171	3885	1171	3886	1169	3887	1167
3888	1165	3889	1161	3890	1158	3891	1156	3892	1156	3893	1155	3894	1157	3895	1160
3896	1165	3897	1171	3898	1177	3899	1182	3900	1186	3901	1192	3902	1199	3903	1202
3904	1203	3905	1202	3906	1199	3907	1196	3908	1189	3909	1176	3910	1156	3911	1125

```
5768 1718 5769 1718 5770 1718 5771 1718 5772 1718 5773 1718 5774 1718 5775 1718
5776 1717 5777 1717 5778 1717 5779 1717 5780 1717 5781 1717 5782 1717 5783 1717
5784 1717 5785 1717 5786 1716 5787 1716 5788 1716 5789 1716 5790 1716 5791 1716
5792 1716 5793 1715 5794 1715 5795 1715 5796 1715 5797 1714 5798 1714 5799 1714
5800 1714 5801 1714 5802 1714 5803 1714 5804 1714 5805 1714 5806 1713 5807 1713
5808 1713 5809 1713 5810 1713 5811 1713 5812 1713 5813 1713 5814 1714 5815 1714
5816 1714 5817 1714 5818 1714 5819 1714 5820 1714 5821 1714 5822 1714 5823 1714
5824 1714 5825 1714 5826 1713 5827 1713 5828 1713 5829 1713 5830 1713 5831 1713
5832 1713 5833 1713 5834 1713 5835 1714 5836 1714 5837 1714 5838 1714 5839 1714
5840 1714 5841 1714 5842 1714 5843 1714 5844 1714 5845 1714 5846 1714 5847 1714
5848 1714 5849 1714 5850 1714 5851 1713 5852 1713 5853 1713 5854 1712 5855 1712
5856 1712 5857 1712 5858 1711 5859 1711 5860 1711 5861 1711 5862 1710 5863 1710
5864 1710 5865 1710 5866 1709 5867 1709 5868 1709 5869 1708 5870 1708 5871 1708
5872 1707 5873 1707 5874 1707 5875 1706 5876 1706 5877 1705 5878 1705 5879 1705
5880 1705 5881 1705 5882 1704 5883 1704 5884 1704 5885 1704 5886 1704 5887 1704
5888 1704 5889 1703 5890 1703 5891 1703 5892 1703 5893 1703 5894 1702 5895 1702
5896 1702 5897 1702 5898 1702 5899 1701 5900 1701 5901 1701 5902 1701 5903 1700
5904 1700 5905 1700 5906 1699 5907 1699 5908 1698 5909 1698 5910 1698 5911 1697
5912 1697 5913 1696 5914 1696 5915 1695 5916 1695 5917 1694 5918 1694 5919 1694
5920 1693 5921 1693 5922 1692 5923 1692 5924 1691 5925 1691 5926 1691 5927 1690
5928 1690 5929 1690 5930 1690 5931 1689 5932 1689 5933 1688 5934 1688 5935 1688
5936 1687 5937 1687 5938 1687 5939 1686 5940 1686 5941 1685 5942 1685 5943 1684
5944 1684 5945 1683 5946 1683 5947 1682 5948 1682 5949 1682 5950 1681 5951 1681
5952 1680 5953 1680 5954 1680 5955 1680 5956 1680 5957 1679 5958 1679 5959 1679
5960 1678 5961 1678 5962 1678 5963 1677 5964 1677 5965 1677 5966 1676 5967 1676
5968 1676 5969 1675 5970 1675 5971 1675 5972 1674 5973 1674 5974 1674 5975 1674
5976 1673 5977 1673 5978 1673 5979 1672 5980 1672 5981 1672 5982 1672 5983 1671
5984 1671 5985 1671 5986 1671 5987 1670 5988 1670 5989 1670 5990 1669 5991 1669
5992 1669 5993 1668 5994 1668 5995 1667 5996 1667 5997 1666 5998 1666 5999 1666
6000 1665 6001 1665 6002 1664 6003 1664 6004 1664 6005 1664 6006 1663 6007 1663
6008 1663 6009 1663 6010 1662 6011 1662 6012 1662 6013 1662 6014 1662 6015 1662
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