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AERONOMICA ACTA

A - N° 178 - 1977

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by

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FOREWORD

This paper is the result of a joint work between the "Laboratoire de Physique Stellaire et Planétaire (Verrières le Buisson, France)" et l' "Institut d'Aéronomie Spatiale de Belgique". It has been accepted for publication by Solar Physics.

AVANT-PROPOS

Ce travail est le résultat d'une collaboration entre le Laboratoire de Physique Stellaire et Planétaire (Verrières le Buisson, France, et l'Institut d'Aéronomie Spatiale de Belgique. Il a été accepté pour publication dans "Solar Physics".

VOORWOORD

Dit werk is het resultaat van een samenwerking tussen het "Laboratoire de Physique Stellaire et Planétaire (Verrières le Buisson, France)" en het Belgisch Instituut voor Ruimte-Aëronomie. Het werd ter publicatie in "Solar Physics" aanvaard.

VORWORT

Dieser Text ist das Resultat einer Mitarbeit zwischen des "Laboratoire de Physique Stellaire et Planétaire (Verrières le Buisson, France)" und das Institut für Belgische Raümte Aeronomie. Er wird in "Solar Physics" herausgegeben werden.

SOLAR FLUX DETERMINATION IN THE SPECTRAL RANGE 150 - 210 NM

by

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Abstract

Solar irradiation fluxes are determined between 150 and 210 nm from stigmatic spectra of the sun obtained by means of a rocket-borne spectrograph. Absolute intensities at the solar disk center with spectral resolution of 0.04 nm and spatial resolution of 7 arc sec. are presented. From center-to-limb variations determined from the same spectra, mean full disk intensities of the quiet sun can be deduced. In order to compare them with other measurements, the new solar fluxes have been averaged over a bandpass of 1 nm.

Résumé

Les flux solaires entre 150 et 210 nm ont été déterminés à partir de spectres stigmatiques du soleil obtenus à l'aide d'un spectrographe embarqué en fusée-sonde. Les intensités absolues au centre du disque solaire sont présentés avec une résolution spectrale de 0.04 nm et une résolution spatiale de 7" d'arc. A partir des variations centre-bord de l'intensité mesurées sur les mêmes spectres les intensités intégrées sur l'entièreté du disque ont été calculées. Ces nouvelles valeurs ont été moyennées sur 1 nm afin d'être comparées avec les résultats les plus récents.

Samenvatting

Zonnefluxen in het golflengtegebied 150 - 210 nm werden bepaald door middel van stigmatische spectra van de zon met behulp van een spectrograaf aan boord van een peilraket. De absolute intensiteiten in het centrum van de zonneschijf worden voorgesteld met een spectrale resolutie van 0-04 nm en een ruimtelijke resolutie van 7 boogseconden. Uitgaande van de intensiteitsverandering tussen het centrum en de boord, gemeten aan de hand van dezelfde spectra, werden de intensiteiten geïntegreerd over het totale oppervlak van de zonneschijf, berekend. Met het oog op het vergelijken met andere recente metingen werd van deze nieuwe waarden het gemiddelde genomen over een bandbreedte van 1 nm.

Zusammenfassung

Die Sonnebestrahlungsstärke zwischen 150 und 210 nm wird aus stigmatischen Spektren, die mit Hilfe einem Spektrograph tragenden Rakete empfangen wurde, festgestellt. Absolute Intensitäten in der Sonnenmitte werden mit einem Aufläsungsvermögen von 0.04 nm und einer Raumauflösung von 7" Bogen vorgestellt. Mittelwerte für der ruhigen ganzen Sonnenscheibe können aus den Zentrum - Randvariationen der Intensität gerechnet werden. Um eine Vergleichung mit anderen Messungen durchzuführen, werden diese Werten über 1 nm vermittelt.

INTRODUCTION

The photodissociation of molecular oxygen by ultraviolet solar irradiation flux ranging from 175 to 242 nm is the initial source of odd oxygen in the mesosphere and the stratosphere. This wavelength interval corresponds to the Schumann-Runge band system (204-175 nm) and to the Herzberg continuum (242-204 nm) of molecular oxygen. In this spectral region, solar fluxes are not sufficiently well known especially between 180 and 200 nm. The first complete measurements reported by Detwiler *et al.* (1961) are generally considered as being too high by an important factor. The other flux values covering also this whole spectral region which were published by Widing *et al.* (1970) correspond to values measured at the center of the solar disk and cannot be used in aeronomy which requires total disk solar flux values. The most recent measurements have been obtained by means of rocket-borne spectrometers by Rottman (1974) between 116 and 185 nm and by Heroux and Swirbalus (1976) between 125 and 194 nm. In addition, Brueckner *et al.* (1976) have deduced average disk intensities from a quiet sun spectrum between 175 and 210 nm. Other measurements have also been obtained by Simon (1974) by means of a balloon-borne spectrometer between 196 and 230 nm. Rocket measurements agree very well together below 180 nm leading to an equivalent blackbody solar temperature of the order of 4550 K in this spectral region. Simon's data lead to a brightness temperature of the sun of the order of 4700 K at 196 nm. There is therefore an important increase in the solar flux between 180 and 196 nm which must be determined to calculate accurate photodissociation rate coefficients of minor stratospheric constituents (Kockarts, 1976). Data published by Heroux and Swirbalus (1976) and by Brueckner *et al.* (1976) do not solve completely this problem since systematic difference of roughly 40% can be seen between these observations. Furthermore, high spectral resolution fluxes are needed to calculate, for example, the photodissociation rate coefficient of nitric oxide which has absorption bands with rotational structure in the Schumann-Runge band region (Cieslik and Nicolet, 1973).

The purpose of this work is to determine the solar irradiation fluxes between 150 and 210 nm from stigmatic spectra of the sun obtained by Samain *et al.* (1975) by computing the mean flux over the whole disk from the center-to-limb variations determined from the same spectra.

OBSERVATIONAL DATA AND CALIBRATION

The stigmatic spectra of the sun between 120 and 210 nm were obtained during a rocket flight, April 17, 1973, by means of a double Wadsworth mounting spectrograph. This experiment leads to the determination of solar disk intensities with a spectral resolution of 0.04 nm and to center-to-limb distributions with spatial resolution of 7 arc sec. Absolute intensities at the center of the disk have been published by Samain *et al.* (1975). For wavelengths below 168 nm, flux values reported in their figure 9 correspond to minima of the spectrum whiles beyond this wavelengths they correspond only to continuum peak intensities, excluding emission lines. Comparison with other measurements cannot be made directly since the spectral resolution of the instrument plays a role on the measured intensities. In the spectral range 150-210 nm, differences of ± 20% from the high resolved intensities can occur when the spectral intensities are smeared by a triangular function of 1 nm half width. This fact could explain the equivalent blackbody temperature of the sun of nearly 4900 K at 200 nm.

The absolute calibration which is described by Samain *et al.* (1975) was carried out at the Culham Laboratory (Abingdon, England) using standard detectors calibrated against ionization chambers as absolute standards (Burton *et al.*, 1973). The film absolute sensitivity was measured at 120, 130, 149, 164, 174, 202 and 206 nm. The instrumental transmission was determined at the same wavelengths, except at 164 and 202 nm. This determination is based on measurements at the instrument aperture of a calibrated light which is related to film densities by means of the film characteristic curve. Moreover, by another experimental method, the instrument sensitivity was determined every 5 nm between 120 and 190 nm. The instrumental response was also measured as a function of wavelength along the spectrograph slit. The average instrumental sensitivity curve is shown in figure 3 by Samain *et al.* (1975). Intensity calculations from the optical film densities are based on the relative film characteristic curves obtained from inflight calibration spectra and on absolute sensitivity curves obtained by interpolating between values measured at the aforementioned wavelengths. Except below 155 nm, only densities between 0.3 and 1.3 have been considered in our work. Figure 1 and 2 show the solar intensities measured at the disk center.

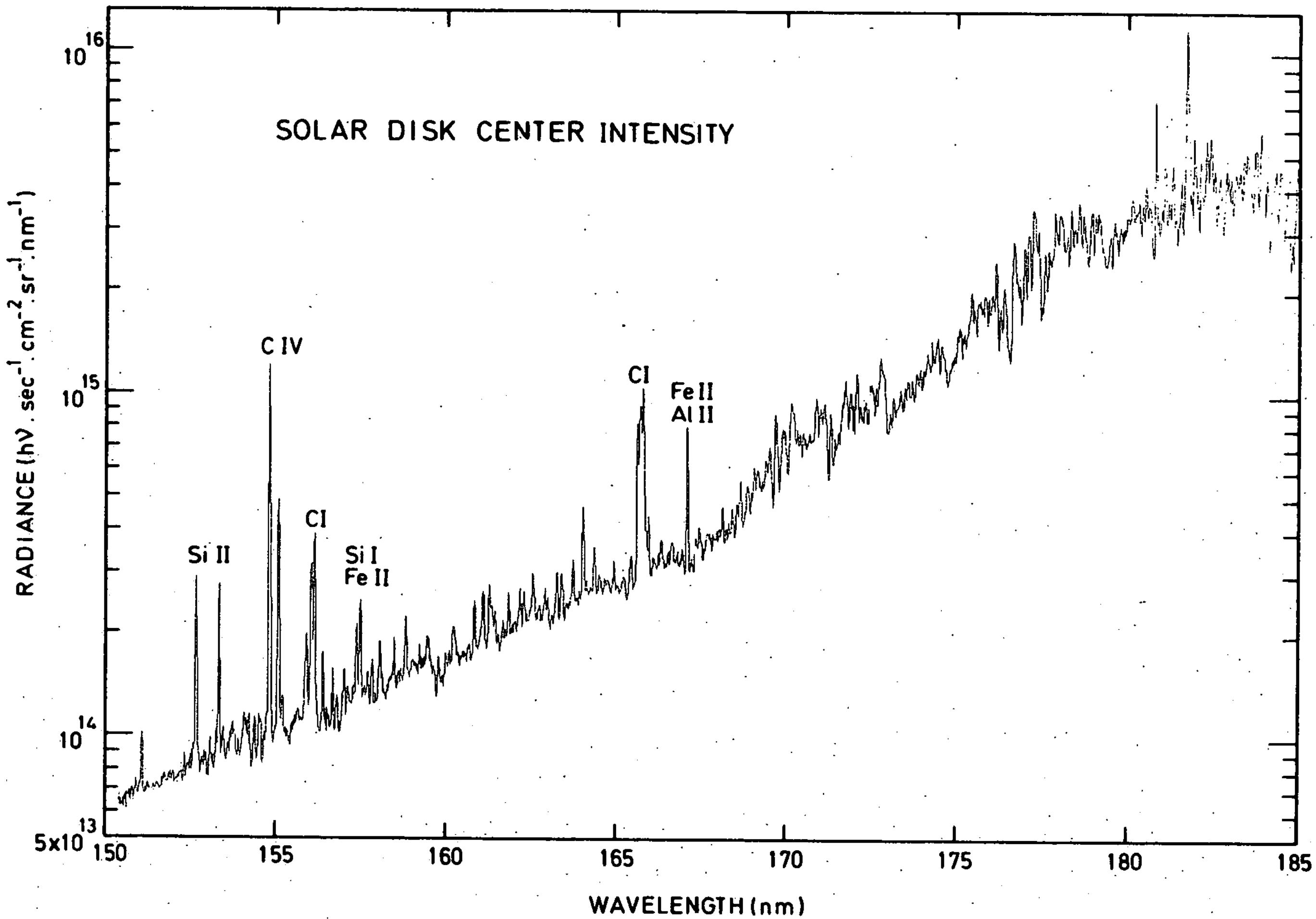

Fig. 1.- Absolute intensities for the solar disk center between 150 and 185 nm with a spectral resolution of 0.04 nm and a spatial resolution of 7 arc sec.

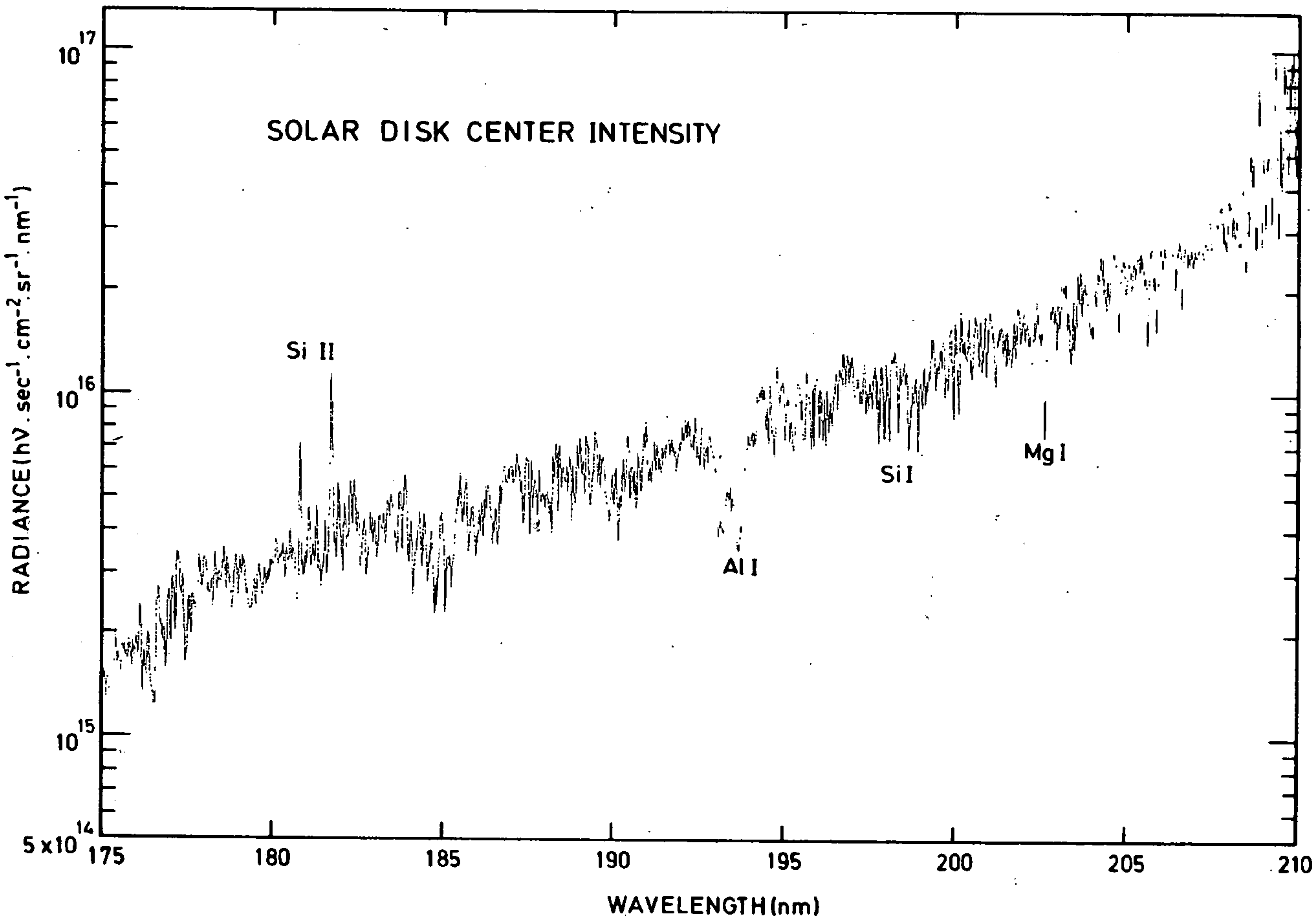

Fig. 2.- Absolute intensities for the solar disk center between 175 and 210 nm with a spectral resolution of 0.04 nm and a spatial resolution of 7 arc sec.

CENTER-TO-LIMB VARIATIONS

Center-to-limb intensity variations which were initially determined in bandpass of 0.05 nm of the solar continuum from the stigmatic spectra for 25 wavelengths (Samain *et al.*, 1975) have been extended between 146 and 210 nm in order to determine accurate mean full disk intensities of the quiet sun versus wavelength each 1 or 2 nm whenever possible. The mean intensity $\overline{I}(\lambda)$ integrated over the whole disk can be deduced from the variation of the solar intensity $I(\mu,\lambda)$ from the center ($\mu = 1$) to the limb ($\mu = 0$) trough the relation :

$$\overline{I}(\lambda) = 2 \int_0^1 \mu I(\mu,\lambda)\, d\mu$$

Ratios between mean solar Intensities $I(\lambda)$ and specific intensities at the center of the disk $I(0,\lambda)$ have been calculated for many wavelengths and shown in figure 3. where each point corresponding to the continuum is an average over 6 observed values in most cases. The error on $\overline{I}(\lambda)/I(0,\lambda)$ is deduced from the errors on the center-to-limb intensity variations and has been estimated to be of the order of 6 to 8% between 150 and 210 nm and larger than 10% below 150 nm.

An analysis have also been undertaken for several absorption and emission lines of the solar spectrum in order to determine their influence on the mean intensity integrated over 1 nm. Since weak lines are generally narrow in comparison with the spectrograph resolution, the center-to-limb measurements lead to same values deduced for the nearby continuum. For broader or stronger lines, the center-to-limb variations are different from continuum values but their differences are much less important than the possible error in the absolute intensity measurements. Limb darkening is weaker in absorption lines than in the continuum, while limb brightening is more intense in emission lines. In both cases, the effect of smearing is to increase the level of the mean intensity and thereby the level of the solar flux. If the detailed structure of the spectral intensity may be slighly modified at a few wavelengths, this effect is generally less than 3% and negligeable when irradiation flux values are averaged over spectral range of 1 nm. However, special care has be taken for the very broad auto-

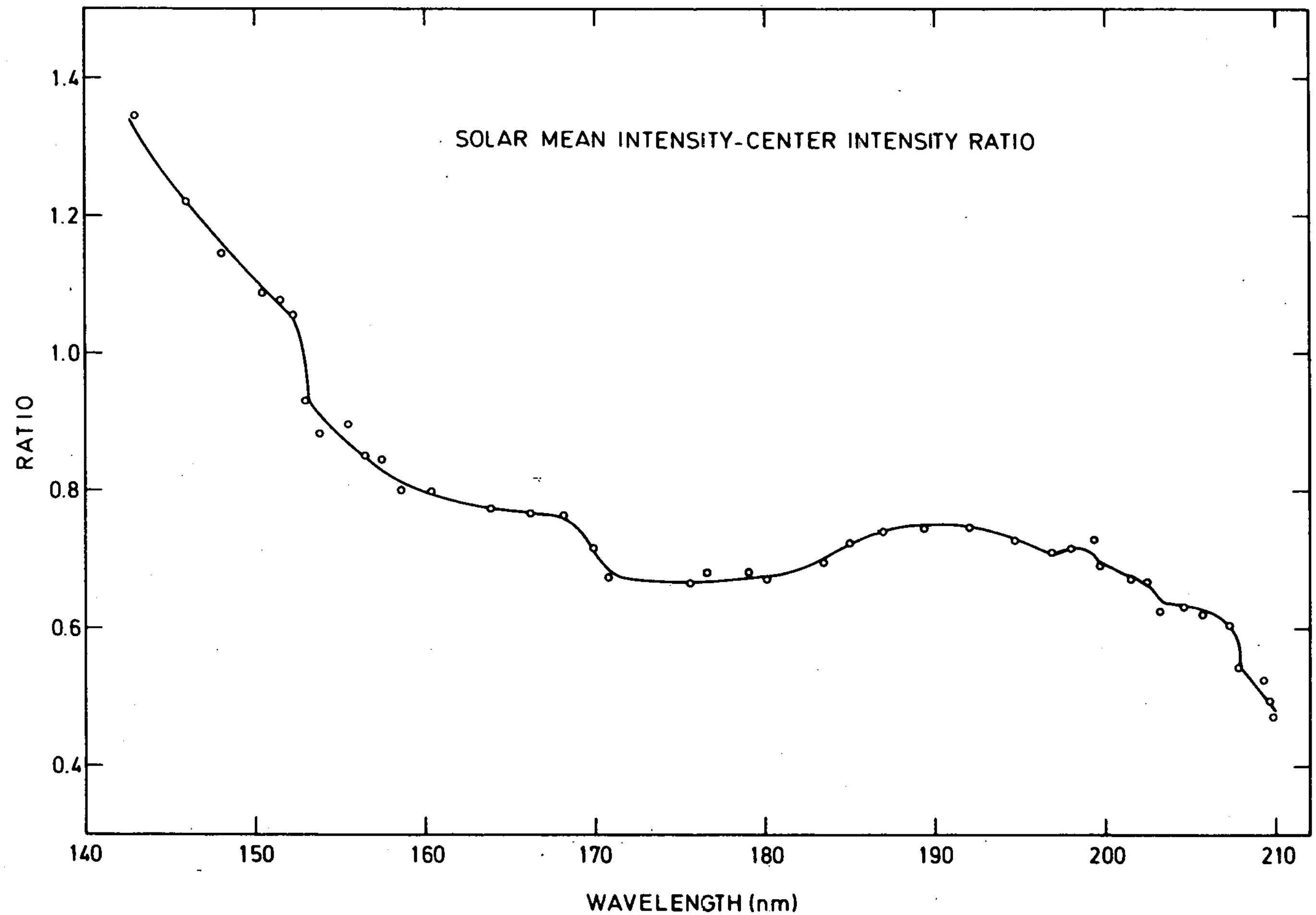

Fig. 3.- Ratios between mean full disk intensities and specific intensities at the center of the disk versus wavelength. Only wavelengths corresponding to the continuum have been plotted.

ionization lines of aluminium at 193.2 and 193.6 nm, and for lines with intense emission or very large limb-brightening such as the lines of CIV at 154.82 and 155.08 nm, SiI/FeII at 157.49 nm, FeII/HeII at 164.02 nm, CI at 165.7 nm and of Si II at 181.69 nm for which differences vary between 4 and 12%. The solar fluxes for intervals of 1 nm including these lines have been corrected consequently by introducing the correct center-to-limb variation in the calculations.

RESULTS AND DISCUSSION

Full disk solar irradiation fluxes deduced between 150 and 210 nm from the intensities at the center of the disk and from the center-to-limb intensity variations have been integrated for the spectral range of 1 nm (figure 4 and 5). Table 1 which gives also the flux values for 1 nm intervals in photon.sec^{-1}.cm^{-2}.nm^{-1} and in mW.m^{-2}.nm^{-1}, allows a direct comparison with other published values. A good agreement with data reported by Rottman (1974) and Heroux and Swirbalus (1976) is obtained around 160 nm and at 175 nm, and with values deduced by Brueckner *et al.* (1976) over their whole wavelength range (175 - 210 nm). For wavelengths greater than 180 nm our mean values are roughly 50% higher than those published by Heroux and Swirbalus (1976). Nevertheless, they are not different from the recent measurements of Simon (1974) around 200 nm which were obtained in the stratosphere near 40 km of altitude by means of a balloon- borne spectrometer and photo-electric detector with a spectral bandpass of 0.6 nm.

Discrepancies of the order of 50% of in the spectral region between 180 and 194 nm are difficult to explain. The results of Heroux and Swirbalus (1976) were obtained by means of a rocket-borne spectrometer and a photon counter and have a general accuracy of ± 20%. The CsI photocathode which was used in their instrument shows a rapid decay in efficiency for wavelengths greater than 180 nm (see figure 1 in Heroux and Swirbalus, 1976) which sets an upper limit at 194 nm to their spectra. On the other hand, Rottman (1974), who also has used a photomultiplier tube with the same photocathode gives results only below 185 nm with an accuracy of ± 15%. Therefore, it seems that such measurement lead to less

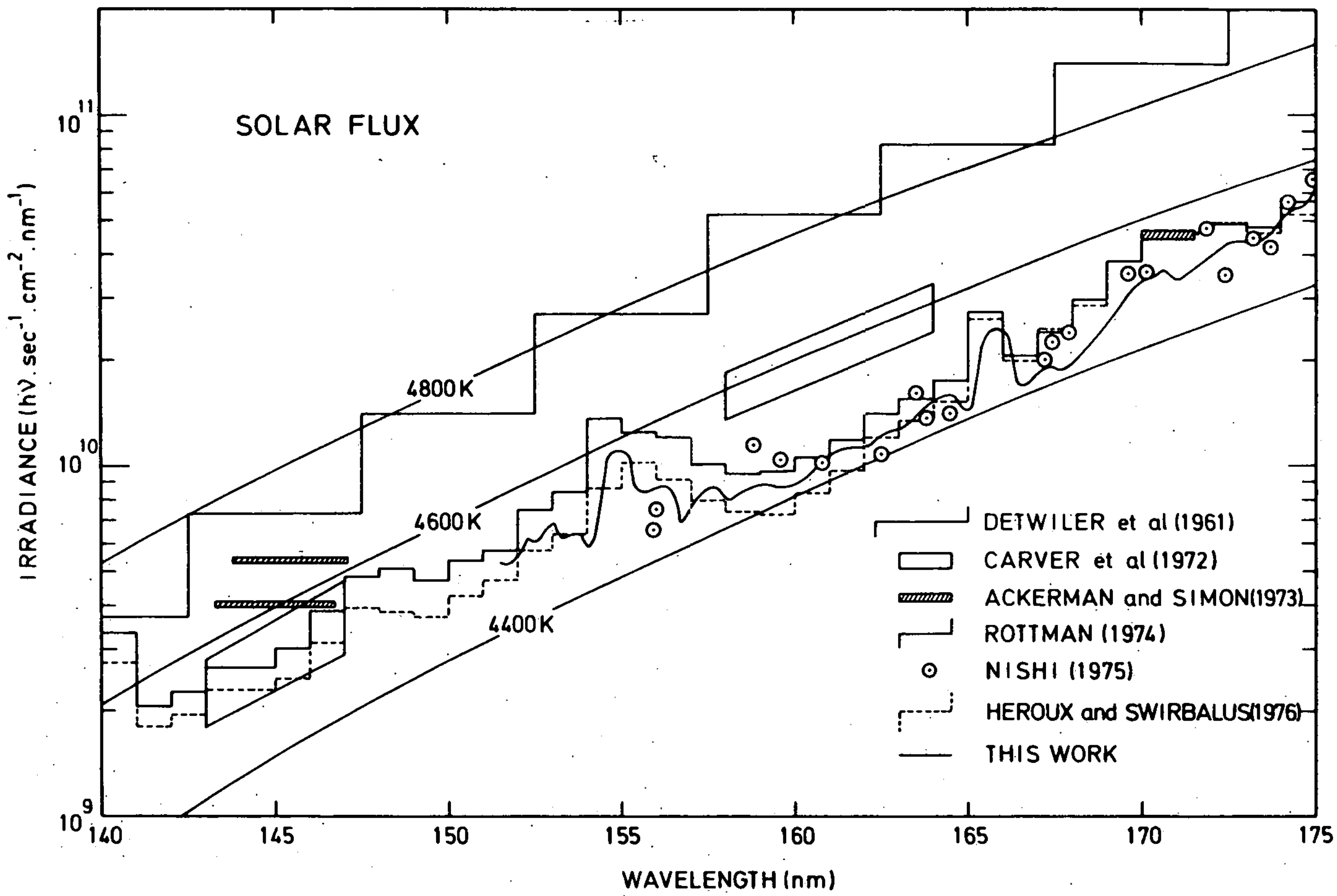

Fig. 4.- Comparison of the present solar irradiation flux determination integrated over 1 nm with various flux measurements from 130 to 175 nm and with different curves of the blackbody temperatures.

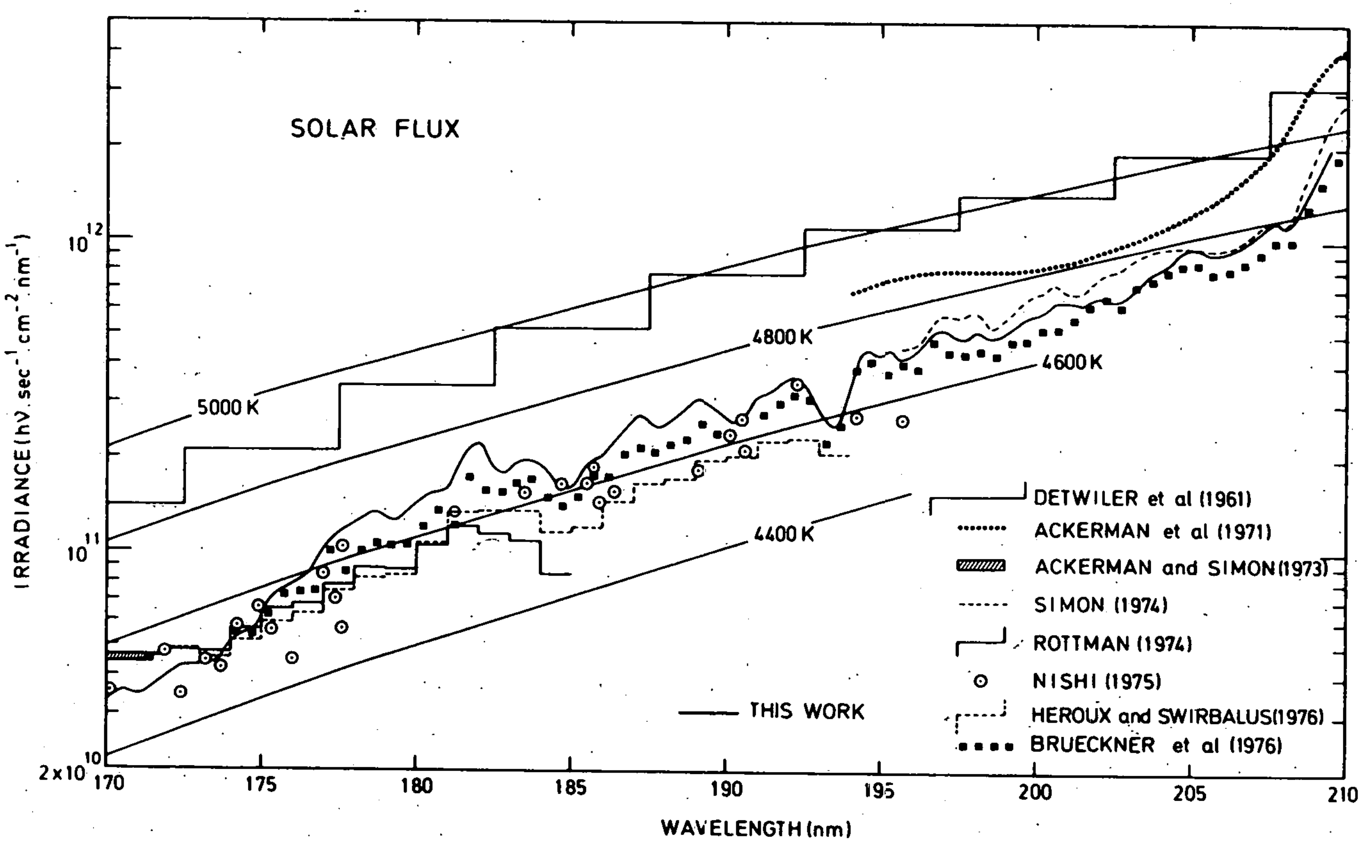

Fig. 5.- Comparison of the present solar irradiation flux determination integrated over 1 nm with various flux measurements from 170 to 210 nm with different curves of the blackbody temperatures.

precise values of the solar flux in the neighbourhood of 190 nm because of the lower detector efficiencies.

Our results have an accuracy of ± 30%, taking into account all possible sources of error on the photographic intensity calibration, instrumental sensitivity and center- to-limb variation. Consequently, we consider that there is a strong need for aeronomic purposes for further and more precise measurements, especially between 180 and 200 nm, since our results should give an upper limit while those of Heroux and Swirbalus (1976), should give a lower limit for the solar irradiation flux between 180 and 194 nm.

TABLE 1 : Solar irradiation fluxes integrated over 1 nm between 151 and 209 nm at one astronomical unit.

Wavelength interval (nm)	Irradiance $h\nu.sec^{-1}.cm^{-2}.nm^{-1}$	Irradiance $nW.m^2.nm^{-1}$
151 - 152	5.29×10^9	6.94×10^{-2}
152 - 153	6.04	7.86
153 - 154	6.28	8.13
154 - 155	9.62	1.24×10^{-1}
155 - 156	8.44	1.08
156 - 157	8.42	1.07
157 - 158	8.44	1.06
158 - 159	8.47	1.06
159 - 160	8.69	1.08
160 - 161	9.62	1.19
161 - 162	1.11×10^{10}	1.37
162 - 163	1.23	1.50
163 - 164	1.38	1.67
164 - 165	1.59	1.92
165 - 166	2.32	2.78
166 - 167	1.69	2.01
167 - 168	1.91	2.26
168 - 169	2.21	2.60
169 - 170	2.98	3.49
170 - 171	3.53	4.11
171 - 172	3.70	4.28
172 - 173	4.30	4.95
173 - 174	4.39	5.03
174 - 175	5.49	6.25
175 - 176	7.37	8.53
176 - 177	8.51	9.58
177 - 178	1.15×10^{11}	1.29×10^0
178 - 179	1.32	1.47

TABLE 1 : (Contd.)

Wavelength interval (nm)	Irradiance	
	$h\nu.sec^{-1}.cm^{-2}.nm^{-1}$	$nW.m^{2}.nm^{-1}$
179 - 180	1.29×10^{11}	1.43×10^{0}
180 - 181	1.54	1.69
181 - 182	2.00	2.19
182 - 183	1.86	2.02
183 - 184	1.97	2.13
184 - 185	1.66	1.79
185 - 186	1.91	2.04
186 - 187	2.37	2.53
187 - 188	2.66	2.81
188 - 189	2.80	2.95
189 - 190	2.93	3.08
190 - 191	2.94	3.06
191 - 192	3.33	3.45
192 - 193	3.48	3.59
193 - 194	2.54	2.61
194 - 195	4.46	4.56
195 - 196	4.27	4.34
196 - 197	4.86	4.91
197 - 198	4.87	4.90
198 - 199	4.92	4.93
199 - 200	5.53	5.50
200 - 201	6.25	6.19
201 - 202	6.30	6.21
202 - 203	6.42	6.30
203 - 204	7.63	7.45
204 - 205	8.96	8.70
205 - 206	9.20	8.89
206 - 207	9.65	9.28
207 - 208	1.13×10^{12}	1.08×10^{1}
208 - 209	1.27	1.21

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