THE SOLAR SPECTRAL IRRADIANCE 1200-3184 Å
NEAR SOLAR MAXIMUM: 15 JULY 1980

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ABSTRACT

Full-disk solar spectral irradiances near solar maximum were obtained in the spectral range 1200-3184 Å at a spectral resolution of approximately 1 Å from rocket observations above White Sands Missile Range, New Mexico, on 15 July 1980. Comparison with measurements made in 1979 and during solar minimum confirm a large increase at solar maximum in the solar irradiance near 1200 Å with no change within our measurement errors near 2000 Å. Irradiances in the range 1900-2100 Å are in excellent agreement with previous measurements, and those in the 2100-2500 Å range are lower than the Broadfoot results. We find agreement with previous values 2600-2900 Å, and then fall below those values 2900-3184 Å.

INTRODUCTION

Solar radiation at wavelengths shorter than 2980 Å is totally absorbed by the earth's atmosphere and provides the dominant source of energy for atmospheric heating, dissociation, and ionization. An accurate knowledge of the solar spectral irradiance in the ultraviolet is accordingly of fundamental importance for studies of the photochemistry of the upper atmosphere. Unfortunately, because of experimental difficulties, the available data are limited, and there are major uncertainties in many of the measurements.

We have begun a systematic sounding rocket program to study solar ultraviolet irradiance and its variation over the solar cycle. Results from the first flight in this study (Mount, Rottman, and Timothy, 1980), when compared to the solar minimum measurements of Rottman (1981) indicate a significant enhancement of irradiance below 1800 Å. Results from the 15 July 1980 rocket flight confirm these conclusions and indicate that the irradiance in the 2100-2550 Å spectral region is lower than the Broadfoot (1972) results, although not as low as reported in our 1980 paper. Results near 2800 Å are in close agreement with Broadfoot.

FLIGHT INSTRUMENTS

The full-disk solar spectrum from 1160-3184 Å was recorded by two spectrometers which scanned adjacent but overlapping spectral ranges. The spectrometers are designated by the spectral region covered; namely, a far-ultraviolet (FUV) Ebert-Fastie spectrometer with 1/8-m focal length to cover 1160-1850 Å, and a middle-ultraviolet (MUV) Ebert-Fastie spectrometer with 1/8-m focal length to cover 1600-3184 Å. The irradiance payload was not evacuated at launch but was maintained with a dry nitrogen purge for several days prior to launch. The important instrument characteristics are outlined in Table 1.

The irradiance instruments were carried piggyback on a solar rocket with a high-resolution EUV instrument dedicated to the study of coronal holes. The Nike-boosted Black Brant rocket (NASA 27.044 US) reached an altitude of 325 km above White Sands Missile Range, New Mexico, at 1705 UT on 15 July 1980. The solar zenith angle at time of apogee was 23°. All rocket systems performed well and the experiment was completely successful. Just prior to launch, the spectrometers were individually aligned with the Solar-Pointing Aerobee Rocket Control System (SPARCS) to ±1 arc minute. Mechanical alignment of the instruments was checked immediately after recovery and was found to be unchanged by the flight and recovery. The MUV spectrometer calibration was checked 63 days after the flight and was found to be unchanged from pre-flight values. The FUV spectrometer was damaged on impact. Impact during the recovery phase caused an internal misalignment of the FUV spectrometer optics and precluded a post-flight calibration.

INSTRUMENT CALIBRATION

The absolute efficiencies of the flight spectrometers were measured at the Johns Hopkins University as described in detail by Mount et al. (1980). Briefly, the Johns Hopkins calibration test equipment (CTE) compares the monochromatic response of calibrated reference photomultiplier tubes with the response of the instrument under test. The reference photomultiplier tubes are calibrated before and after instrument tests against National Bureau of Standards standard photodiodes 17195 and 17183 (Canfield et al., 1973). The FUV calibration was made with the same error budget as for the 1979 flight. The MUV spectrometer, however, was calibrated with a larger error budget as shown in Table 2.

The source of the larger over-all error for the MUV spectrometer was an instability in the Johns Hopkins CTE reference F photomultiplier tube. This instability has been noted previously (Brune, Mount, and Feldman, 1979) and resulted in a larger transfer error between the NBS photodiode and the reference photomultiplier tube.

The FUV spectrometer experienced no calibration difficulties during the pre-flight calibration. No direct post-flight calibration was possible due to damage on impact which misaligned the optics. The MUV spectrometer was recalibrated at Johns Hopkins after the flight with agreement to ±8%. The preflight calibration was used in the data reduction. The 1979 flight calibrations indicate no change before and after the flight on either of the two spectrometers flown to within ±5%.

In addition to the calibration at Johns Hopkins, the MUV spectrometer was calibrated with an NBS standard tungsten lamp in our laboratory. The overlap region of the two calibrations was approximately 2600-3000 Å and the spectrometer efficiencies derived from these two independent methods agree within 10% near 2700 Å and 20% near 3000 A. Figure 1 shows the calibration of the MUV instrument with associated absolute error bars (see Table 2). The adopted curve falls between the Johns Hopkins and the tungsten lamp calibrations.

A major source of calibration error occurs in the measurement of the small slit widths (approximately 50 μ) used on the spectrometers. Errors were ±4% and the slits were measured on three different engines and using diffracted red laser light.

The instruments were rotated ±5° about the incident beam at Johns Hopkins to provide a map of the grating and Ebert mirror. Non-uniformities were less than ±3%, insuring that a small misalignment in solar pointing does not introduce a calibration uncertainty.

The total error budget was ±13% for the FUV spectrometer and ±18% for the MUV spectrometer (see Table 2).

RESULTS AND DISCUSSION

The data were analyzed as described in Mount et al. (1980). Figure 2 (FUV) and Figures 3-6 (MUV) show the results (including all line fluxes) averaged into 10-Å bins and compared with other measurements. Absolute error bars are indicated. Table 3 lists the data corrected to 1 AU, averaged into 10-Å bins, and including all line fluxes. The daily Zurich sunspot number, R_z, was 207 for the 1979 flight and 165 for the 1980 flight. Of the 35 complete scans obtained by each spectrometer during the flight, only 10 scans were used, all recorded above 275 km. Statistical uncertainty was less than ±2% for each wavelength bin.

Comparison of the 1979 and 1980 flight results (Figure 2) indicates essentially no change in the solar irradiance 1200-1900 Å within our measurement accuracy. The relative irradiance values of the 1979 and 1980 flights are of particular significance since the same FUV spectrometer was flown. The instrument was not dismantled or disturbed in the intervening year and was stored in a clean, dessicated environment. The calibration values obtained for the 1980 flight from the same calibration facility were within 10% of the 1979 values, with the largest difference below 1350 Å. This difference is almost certainly calibration error and not a change in actual instrument sensitivity. Thus, comparison of the 1979 and 1980 results with the solar minimum results of Rottman (1981) (also taken with the same instrument) confirm our earlier conclusion (Mount et al., 1980) that there is significant variability in the solar spectral irradiance from solar minimum to solar maximum at wavelengths short of 1800 Å and that the change varies from less than the measurement error at 2000 Å to a factor of 2.5 near 1200 Å. The effective brightness temperature of the atmospheric temperature minimum calculated at 1600 Å is 4654°K.

The important comparison to be made in Figure 2 is between Rottman's solar minimum results and our solar maximum results, since the same instrument was used to take both data sets. The solar minimum data and its comparison to (e.g.) Heroux and Swirbalus (1976) are discussed in detail by Rottman (1981). Briefly, it seems clear that most of the difference between the Rottman results and those of Heroux and Swirbalus is caused by a calibration problem and not an intrinsic change in solar irradiance during solar minimum.

The MUV results are shown in Figures 3-6. Below 2100 Å we find agreement with the many measurements made in that spectral region (Brueckner et al., 1976; Samain and Simon, 1976; Simon, 1975). The 1980 measurements are higher than the average by about 14%, and the 1979 results are lower by about 14%.

In the spectral region 2100-2550 Å, we find a large difference (40%) between our 1979 and 1980 results with agreement closer to, but still 20% below, the Broadfoot (1972) values. Figure 6 shows the comparison with a 20 Å running average. Since the MUV instrument was rebuilt for the 1980 flight to extend the spectral coverage from 2550 Å to 3184 Å, a true relative comparison of the results is not possible. The same phototube and electronics were used on both flights; however, in addition to replacement of the grating, an 1800 Å broadband interference filter was included to reduce the dynamic range requirement on the detector. The calibration of the filter is shown in Figure 1. Since its calibration is a relative measurement, errors are only a few percent. The measurements made in our laboratory agreed to within 3% of the manufacturer's (Acton Research Corp.) results.

We have continued laboratory testing of the MUV instrument since the 1980 flight in order to locate the source of the discrepancy between the two data sets. We have found a temperature effect in the detector electronics that produces a decreasing count rate with increasing temperature for constant light input. At 60°C this effect is approximately 15%. Summing total counts per scan on the 1979 flight indicates a 14% sag in count rate later in that flight. Only a 3% effect was observed on the 1980 flight. Since the temperatures of the instruments were not monitored during the flight, we do not know their exact temperatures. However, based on detailed temperature measurements of the solar coronal hole instrument, it is not unreasonable to expect the temperature on the MUV instrument to have reached 60°C. Temperature tests made immediately after the 1979 flight did not go to 60°C. Thus, we may conclude that the data from the MUV instrument on the 1979 flight could be raised approximately 15%. This reduces the difference between the two sets of flight data to approximately 25% and raises the MUV data to the average of the many 1900-2100 Å measurements. The residual difference is attributed to calibration and slit measurement errors, assuming a variation in the solar irradiance much smaller than the ±18% error bars. The 1979 MUV data below 1900 Å were merged with the FUV data at 1800 Å. Thus we recommend make no change in the 1979 results below 1800 Å, but would increase those results 15% above 1900 Å.

From 2550 Å - 2900 Å we find close agreement of our results with Broadfoot (1972). Above 2900 Å we once again fall below the Broadfoot results. Our calibration above 2800 Å is not as reliable as below that wavelength (see Figure 1) due to disagreement between the CTE and tungsten lamp calibrations. We have placed our calibration curve between the two measured calibration curves above 2600 Å. The reader is referred to a recent review by Kohl _et al_. (1980) for a comparison of the Broadfoot results with other investigators.

It is very important to note that all the data taken on both flights were full solar disc measurements. Thus, no assumptions about limb darkening have been introduced into the analysis as would be required on data obtained with a solar instrument with a restricted field of view.

In addition to measuring the continuum irradiance, we measured the absolute intensities of several strong emission lines of atomic species. Results are given in Table 4 along with ratios to solar minimum. In all cases the appropriate continuum background was subtracted before the integral of the line profile was calculated.

CONCLUSIONS

We confirm our conclusion from the 5 June 1979 flight that there is significant variability in the solar spectral irradiance from solar minimum to solar maximum at wavelengths short of 1800 Å with the change varying from less than the measurement error near 2000 Å to a factor of 2.5 near 1200 Å. We find good agreement among recent investigations in the 1900-2100 Å region. We conclude that the irradiance values of Broadfoot (1972) from 2100-2500 Å lie within our mutual error bars although both 1979 and 1980 results fall somewhat below Broadfoot's results, and we find reasonable agreement with the measurements of both Broadfoot (1972) and Simon (1980) above 2600 Å.

The next flight of the irradiance payload (September 1981) will include a 2400-4000 Å spectrometer to connect the results with ground-based measurements. We are presently testing a new ultraviolet calibration facility which will improve our understanding of the flight instrument, especially at longer wavelengths.

ACKNOWLEDGMENTS

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FIGURE CAPTIONS

Figure 1. The absolute calibrations of the MUV interference filter and the MUV spectrograph. Note the difference in calibration above 2800 Å between the Johns Hopkins CTE (based on NBS standard photodiodes) and an NBS tungsten lamp source.

Figure 2. Solar irradiance in the spectral range 1200-1900 Å averaged into 10 Å bins including line fluxes and compared with our 1979 flight results and those of Rottman (1981) at solar minimum. The data have been corrected to 1 AU. Present results are listed in Table 3.

Figure 3. Solar irradiance in the spectral range 1900-3200 Å averaged into 10 Å bins and compared with previous results. The data have been corrected to 1 AU. Present results are listed in Table 3.

Figure 4. Same as Figure 3 except 1900-2600 Å.

Figure 5. Same as Figure 4 except 2600-3184 Å.

Figure 6. A 20 Å running sum comparison of our 1979 and 1980 flight results and those of Broadfoot (1972).

TABLE 1

INSTRUMENT CHARACTERISTICS

PARAMETER	FUV	MUV
Spectrometer Type	Ebert-Fastie	Ebert-Fastie
Focal Length, mm	125	125
Spectral Range, Å	1160-1850	1600-3184
Grating		
Ruled Area, mm	26 x 26	26 x 26
Ruling Frequency, g/mm	3600	2400
Coating	Al-MgF_2	Al-MgF_2
Manufacturer	Bausch and Lomb.	Hyperfine, Inc.
Scan Period, s	12	12
Detector	EMR 510G MgF_2 Window	EMR 510F MgF_2 Window
Field-of-view	$11^{\circ}.5$	$11^{\circ}.5$
Slits		
Entrance Area, mm^2	0.048 x 0.752	0.048 x 1.00
Exit Area, mm^2	0.056 x 3.00	0.071 x 3.00
Filter (Interference)	None	1800 Å Broad Band
RMS Grating Drive Jitter	±0.3 Å	±0.3 Å
Spectral Resolution	1.15 Å @ Ly α	2.10 Å @ 2500 Å
Step Size	0.28 Å @ Ly α	0.45 Å @ 2500 Å

TABLE 2

ERROR BUDGETS

PARAMETER	FUV	MUV
NBS Standard Diode	±6%	±6-10% (1600-3000 Å)
CTE Transfer to PMT	±8%	±12%
Slit Width:		
Entrance	±4%	±4%
Exit	±4%	±4%
Efficiency Variation Across Field-of-view	±3%	±3%
Geometrical Errors Estimate	±5%	±5%
Difference: JHU Calibration - LASP NBS Tungsten Lamp Calibration	---	10% (at 2700 Å)
Interference Filter	---	3%
Instrument Scattered Light	<0.3% of peak signal	<0.3% of peak signal
Quadrature Sum	13%	16-21%

TABLE 3

SOLAR IRRADIANCE IN UNITS OF 10^{10} ph cm^{-2} s^{-1} Å^{-1} AVERAGED IN 10 Å INTERVALS AT 1 AU FOR ROCKET FLIGHT 27.044, 15 JULY 1980

	00-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
1200 Å	0.236	5.64	0.052	0.035	0.028	0.031	0.041	0.021	0.022	0.021
1300 Å	0.154	0.036	0.026	0.251	0.025	0.053	0.041	0.041	0.041	0.128
1400 Å	0.105	0.060	0.066	0.076	0.074	0.079	0.104	0.125	0.122	0.119
1500 Å	0.136	0.143	0.187	0.212	0.327	0.315	0.258	0.244	0.223	0.223
1600 Å	0.253	0.280	0.326	0.404	0.411	0.634	0.491	0.542	0.554	0.745
1700 Å	0.900	0.953	0.999	1.02	1.05	1.22	1.39	1.42	1.54	1.60
1800 Å	1.63	2.01	1.94	2.05	1.80	2.05	2.37	2.77	2.91	3.31
1900 Å	3.41	3.86	4.15	3.31	4.85	5.25	5.62	6.13	6.07	6.54
2000 Å	7.23	7.93	8.26	9.44	10.5	11.2	11.5	13.4	15.2	21.2
2100 Å	23.1	33.3	35.6	34.6	43.4	42.2	36.1	36.6	51.7	54.4
2200 Å	58.1	42.9	59.9	77.9	70.7	62.9	45.1	49.1	65.3	57.5
2300 Å	68.8	59.4	65.4	54.2	48.7	67.8	61.8	61.5	53.6	58.5
2400 Å	51.0	70.0	93.9	84.9	77.3	64.6	67.9	75.0	54.3	81.8
2500 Å	76.6	56.9	55.5	71.6	81.7	112	146	169	161	120
2600 Å	119	129	135	251	324	342	317	330	318	324
2700 Å	357	293	260	286	182	212	321	346	249	133
2800 Å	131	289	401	440	339	226	469	457	444	639
2900 Å	816	771	683	739	692	681	736	611	640	644
3000 Å	508	593	635	777	749	735	719	790	764	585
3100 Å	785	879	789	853	746	665	778	1050		

TABLE 4

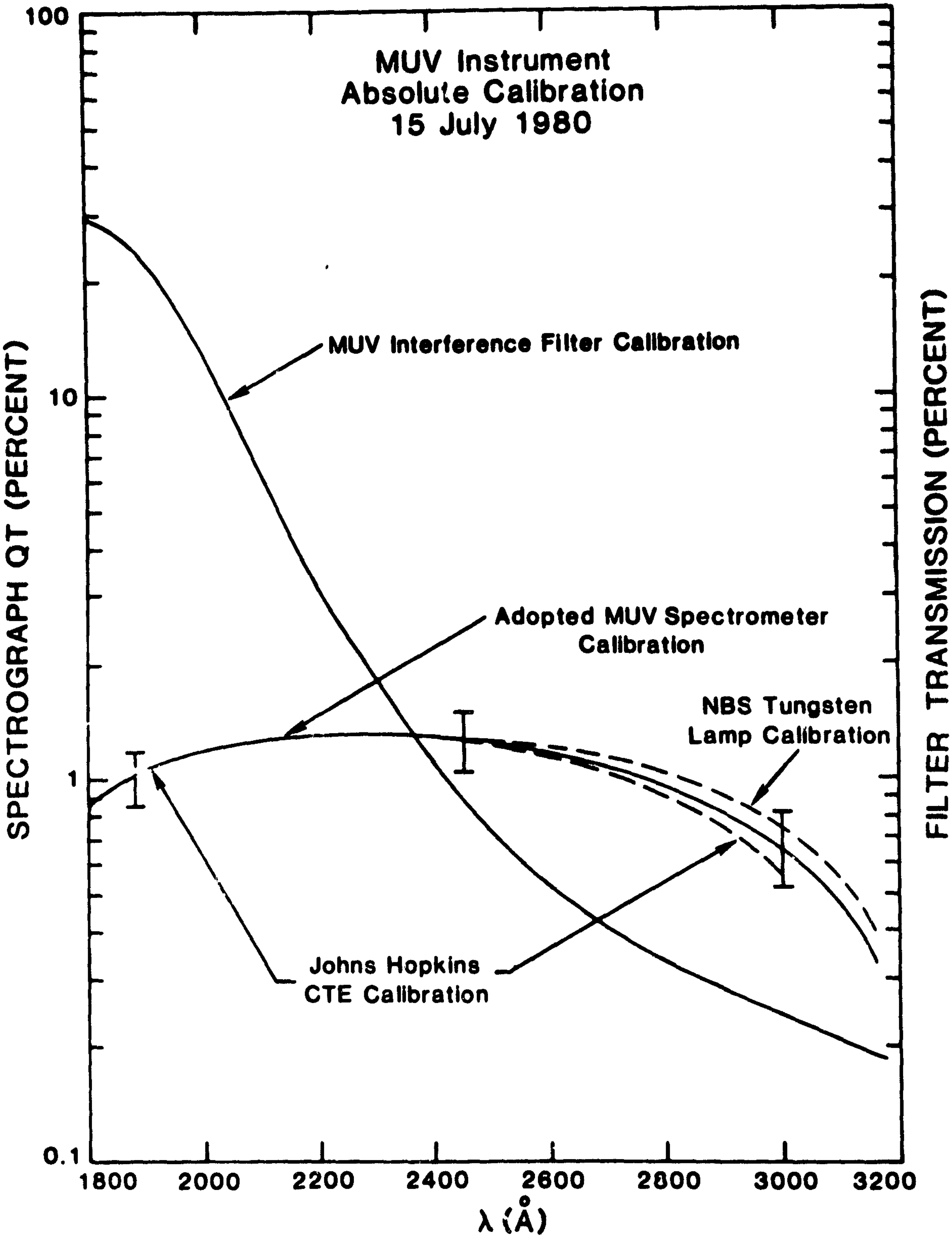
ABSOLUTE LINE FLUXES

[ph cm^{-2} s^{-1}]

SPECIES	WAVELENGTH (Å)	5 JUNE 1979	15 JULY 1980	RATIO [SOLAR MAXIMUM/SOLAR MINIMUM]	
				5 JUNE 1979[2]	15 JULY 1980
Si III	1206.53	1.7E10	1.50E10	3.1	2.7
H Ly	1215.68	4.36E11	5.01E11	1.4	1.6
N V	1238.82	7.1E8	8.7E8	-	-
	1242.80	5.3E8	5.6E8	-	-
Si II	1260.42	4.9E8	6.9E8	-	-
Si II	1264.74	9.2E8	1.5E9	-	-
O I	1302.17	4.7E9	3.4E9	1.9	1.4
O I	1304.86	9.3E9	9.8E9	1.7	1.8
O I	1306.03				
C II	1334.53	2.2E10	2.6E10	2.2	2.7
	1335.66				
O I	1355.60	9.6E8	1.0E9	1.5	1.6
Si IV	1393.76	7.4E9	7.3E9	2.2	2.2
Si IV	1402.77	3.3E9	3.4E9		
Si II	1526.71	4.20E9	2.3E9	-	-
C IV	1548.20	1.6E10	1.5E10	2.2	2.1
C IV	1550.77	6.9E9	7.4E9	1.7	1.9
C I	1561 (multiplet)	6.8E9	1.0E10	1.4	2.1
He II	1640.33 (Fe II blend?)	9.4E9	5.1E9	-	-
C I	1657 (multiplet)	2.7E10	2.1E10	1.8	1.4
Si II	1808.01	1.3E10	1.3E10	-	-
Si II	1816.93, 1817.45	2.6E10	4.5E10	.8	1.3

[1] Rottman (1981)

[2] Revised - See Rottman (1981)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15 July 1980
MUV Interference Filter Calibration
Adopted MUV Spectrometer Calibration
NBS Tungsten Lamp Calibration
Johns Hopkins CTE Calibration
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FILTER TRANSMISSION (PERCENT)
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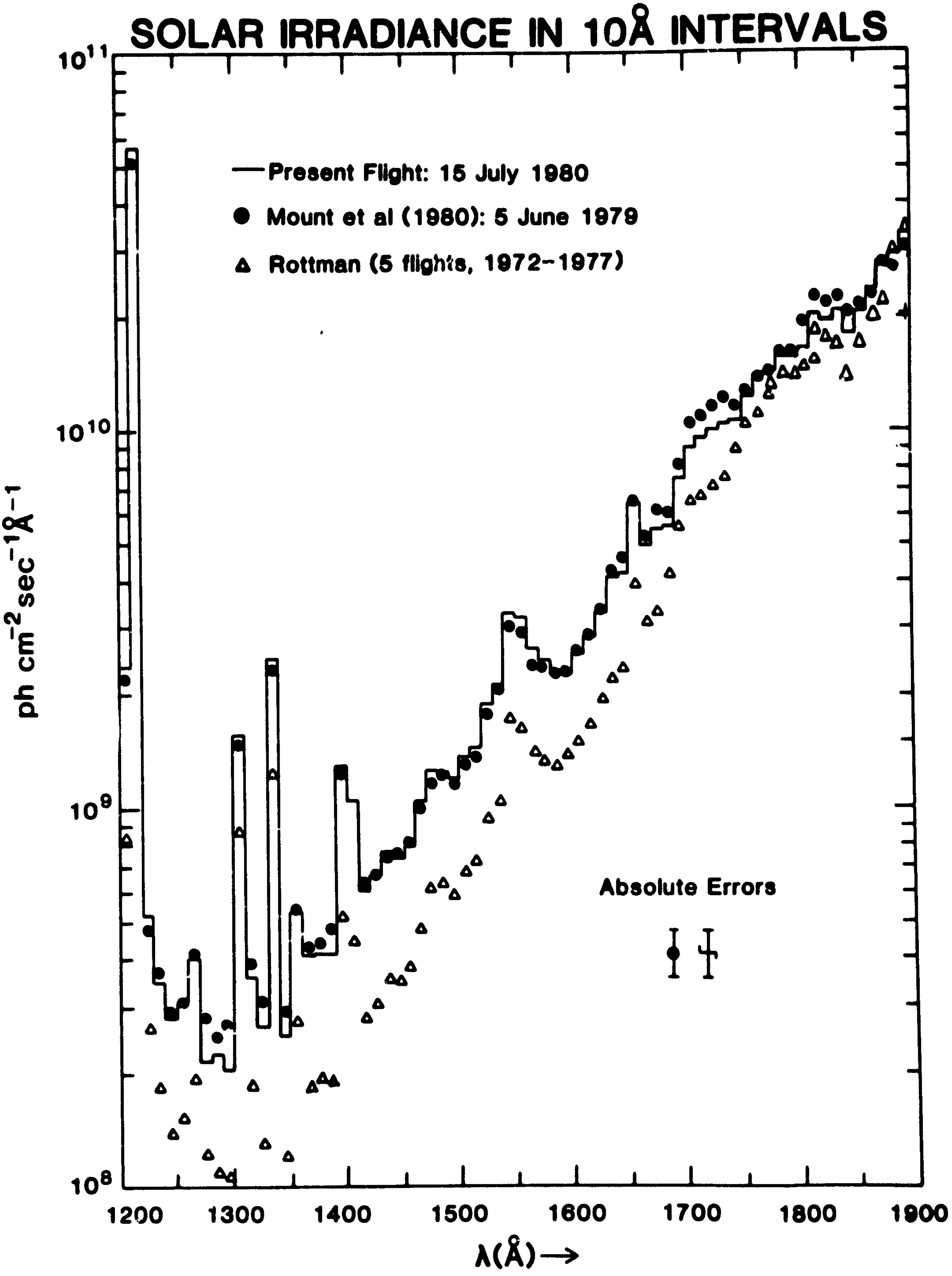
1
0.1
1800
2000
2200
2400
2600
2800
3000
3200
λ (Å)


SOLAR IRRADIANCE IN 10Å INTERVALS
Present Flight: 15 July 1980
Mount et al (1980): 5 June 1979
Rottman (5 flights, 1972–1977)
Absolute Errors
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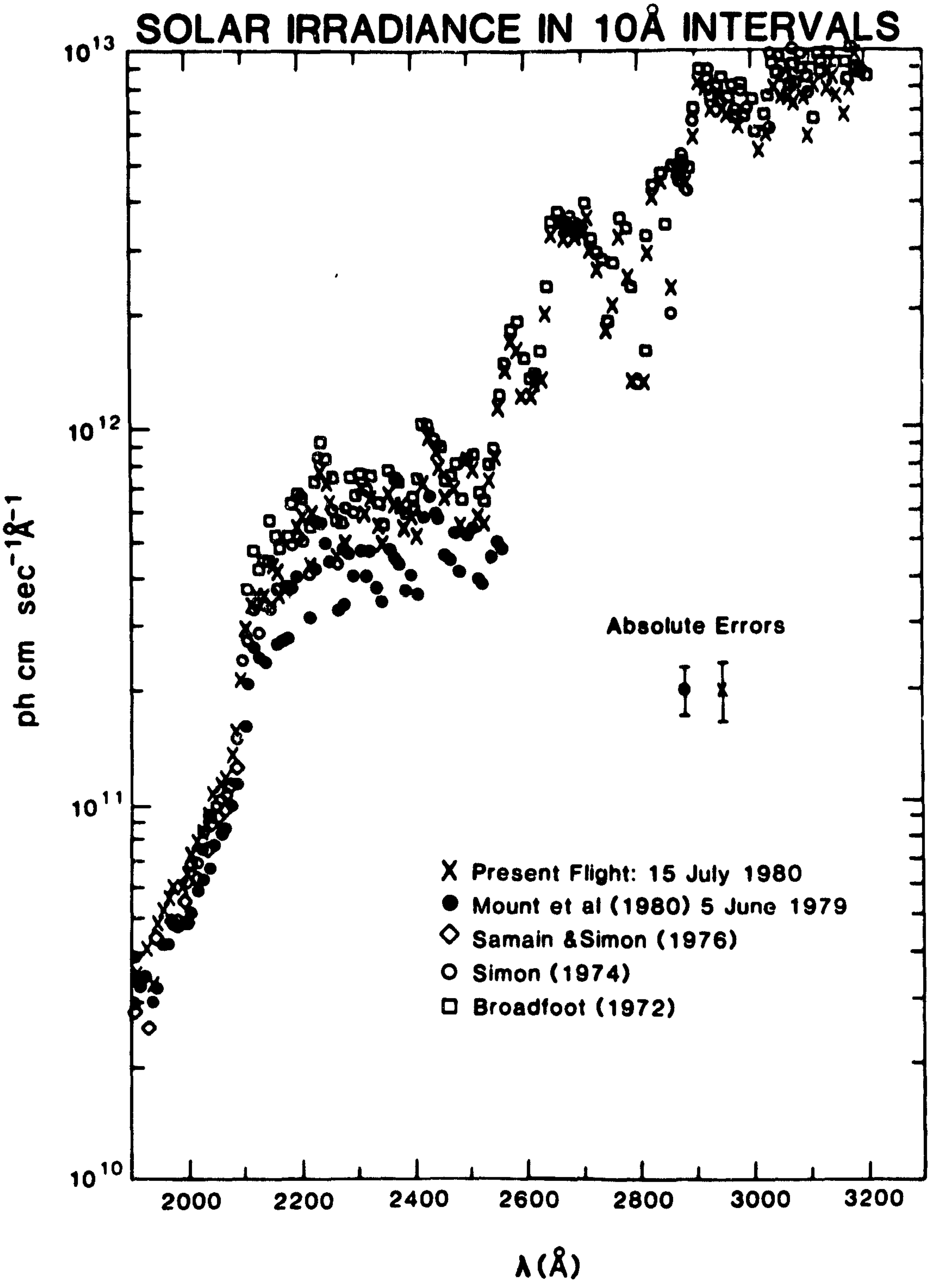
10^{10}
10^{9}
10^{8}
ph cm^{-2} sec^{-1} Å^{-1}
1200
1300
1400
1500
1600
1700
1800
1900
λ(Å)→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10^{13}
10^{12}
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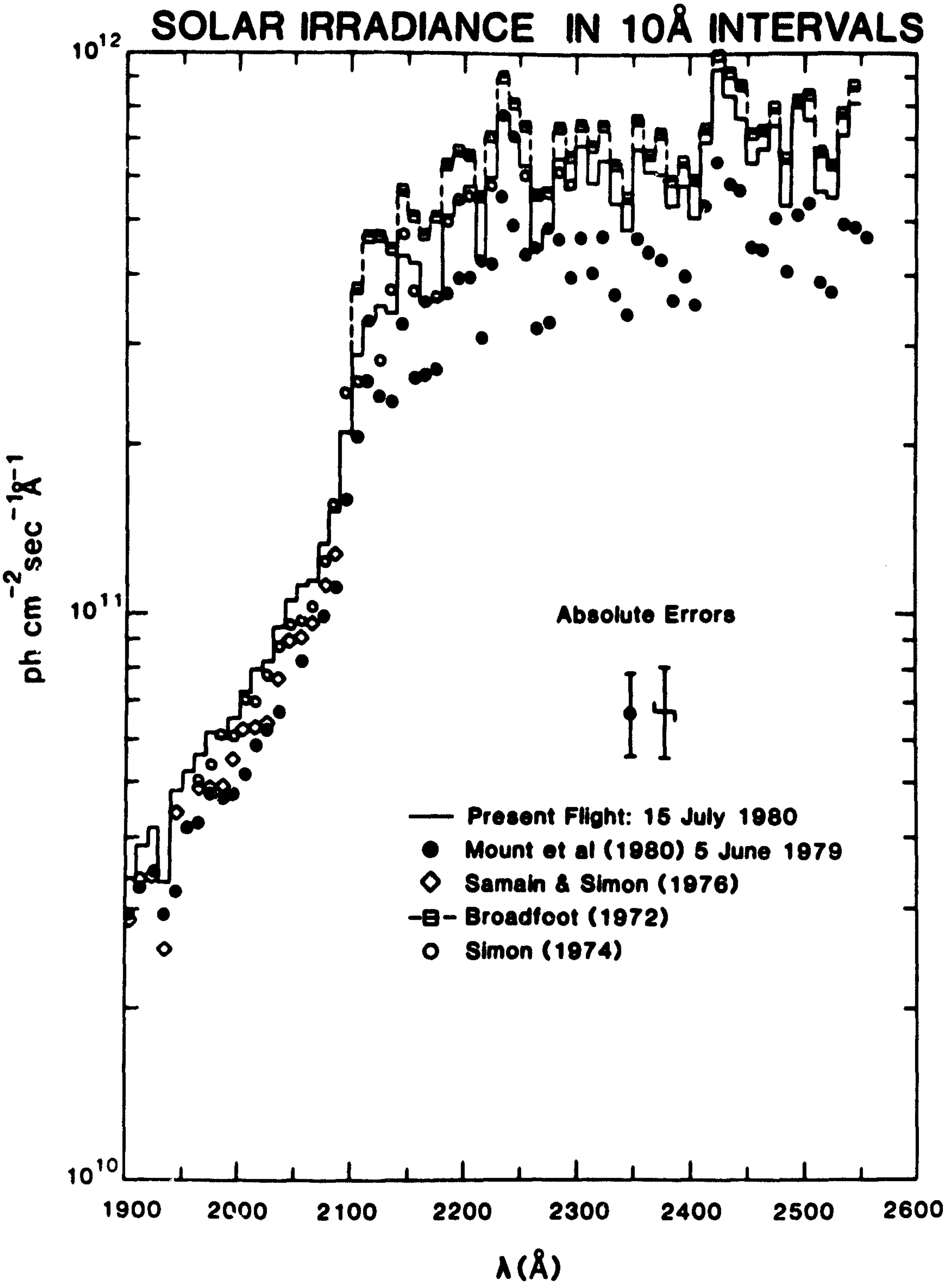
ph cm sec^{-1}Å^{-1}
2000
2200
2400
2600
2800
3000
3200
λ(Å)
Absolute Errors
X Present Flight: 15 July 1980
● Mount et al (1980) 5 June 1979
◇ Samain &Simon (1976)
○ Simon (1974)
□ Broadfoot (1972)


SOLAR IRRADIANCE IN 10Å INTERVALS
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ph cm^{-2} sec^{-1} Å^{-1}
1900
2000
2100
2200
2300
2400
2500
2600
λ(Å)
Absolute Errors
— Present Flight: 15 July 1980
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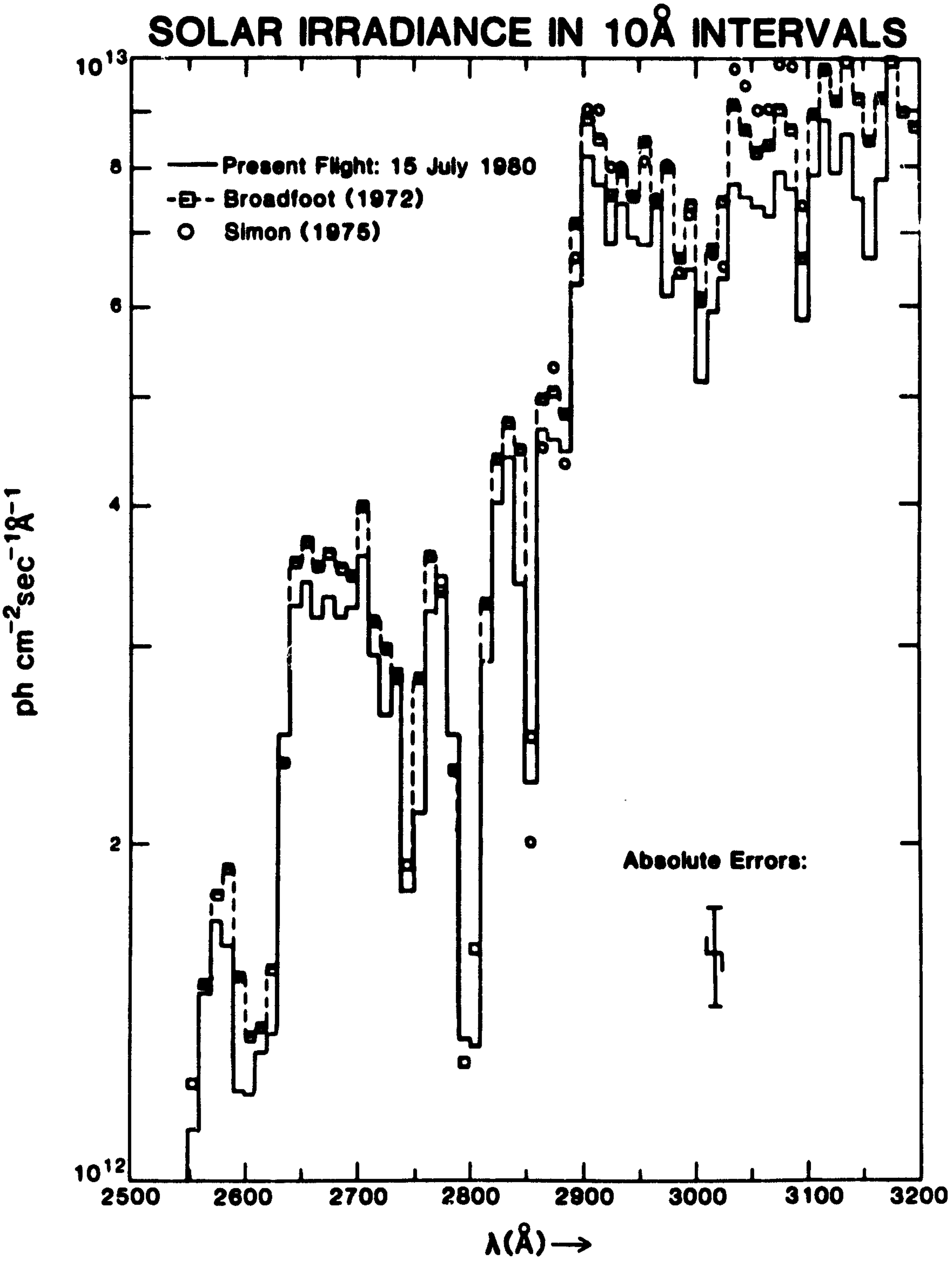
SOLAR IRRADIANCE IN 10Å INTERVALS
Present Flight: 15 July 1980
Broadfoot (1972)
Simon (1975)
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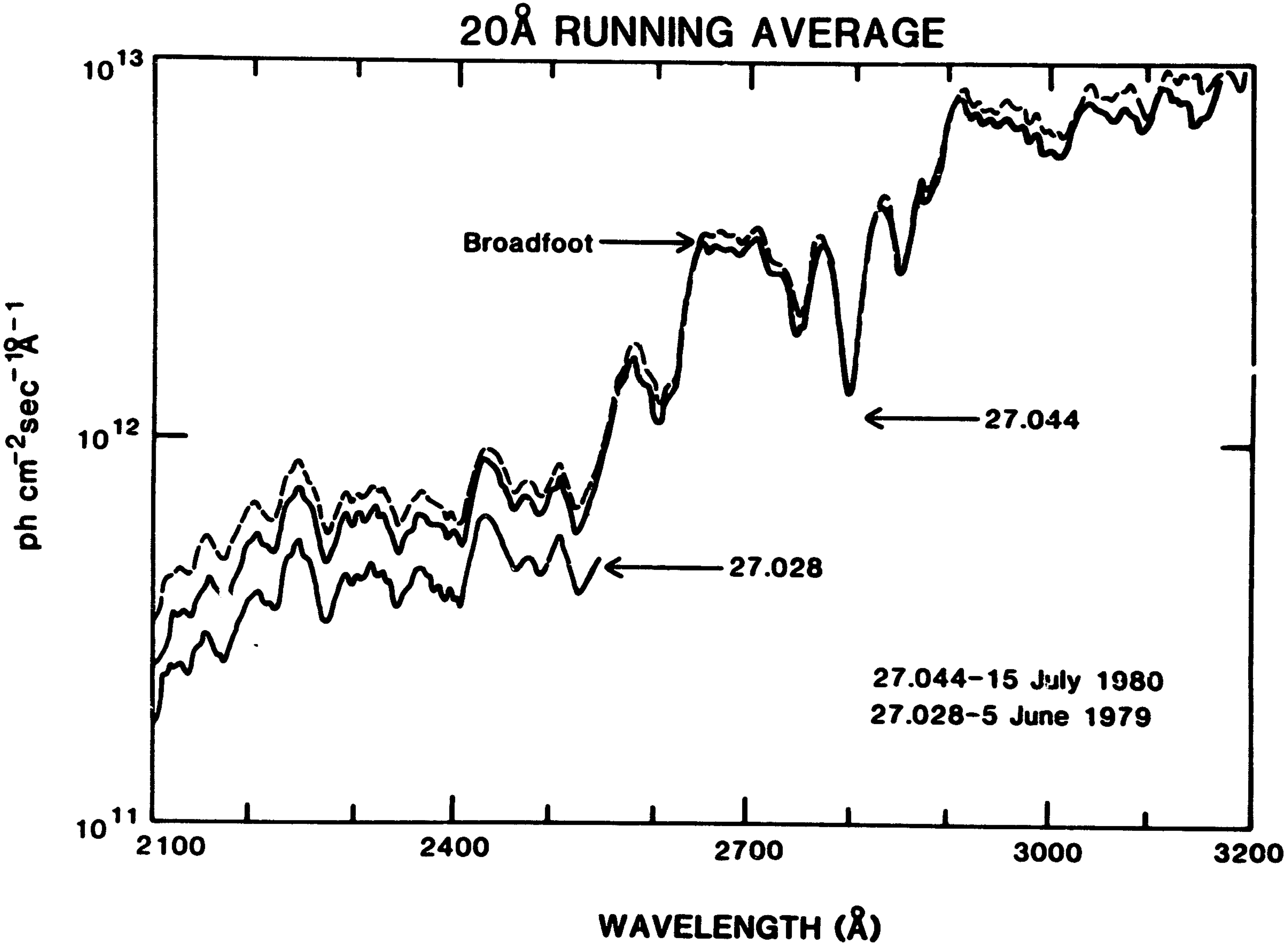
4
2
10^{12}
2500
2600
2700
2800
2900
3000
3100
3200
λ(Å)⟶


20Å RUNNING AVERAGE
10^{13}
10^{12}
10^{11}
ph cm^{-2}sec^{-1}Å^{-1}
Broadfoot
27.044
27.028
27.044-15 July 1980
27.028-5 June 1979
2100
2400
2700
3000
3200
WAVELENGTH (Å)