1115 Å FAR ULTRAVIOLET STELLAR PHOTOMETRY

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Résumé. — *Au moyen d'expériences menées depuis* 1960, *on a mesuré des brillances stellaires dans l'ultraviolet lointain à des longueurs d'ondes plus grandes que Lyman α. Les mesures de* 1960 *ont été obtenues au moyen de télescopes à miroirs et de chambres d'ionisation. Les brillances mesurées sont inférieures de* 1 *magnitude à celles que la théorie prévoit. Des observations ultérieures faites au moyen de compteurs de Geiger semblent en accord avec cette conclusion, mais la reproductibilité des mesures photométriques à bord de fusée est insuffisante pour donner une grande confiance dans les résultats.*

D'autres mesures dans la bande 1150-1180 Å *indiquent que le déficit en ultraviolet stellaire pourrait être encore plus grand au-dessous de Lyman α qu'au-dessus.*

Abstract. — *Stellar brightness measurements in the far ultraviolet at wavelengths above Lyman α have been obtained from several experiments beginning in* 1960. *The* 1960 *data were obtained using mirror telescopes and gas gain ion chambers. They indicated far ultraviolet stellar brightness about* 1 *magnitude lower than predicted by theory. Subsequent Geiger counter data appear to support this conclusion. The reliability of rocket far ultraviolet stellar photometry, however, is still insufficient, to place great confidence in the above conclusions.*

Stellar brightness measurements in the band 1150-1180 Å *indicate that there may be a considerably greater deficiency in far ultraviolet stellar emission at wavelengths below Lyman α than above.*

Резюме. — При посредстве опытов, проведенных начиная с 1960 г, были измерены звездные яркости в дальней ультрафиолетовой области на длинах волн превышающих лаймановскую α. Эти измерения 1960 г были получены при посредстве зеркальных телескопов и ионизационных камер. Измеренные яркости на 1 звездную величниу меньше предвиденных теорией. Последующие измерения, проведенные при посредстве счетчиков Гейгера, являются по-видимому в согласии с этим заключением, но воспроизводимость фотометрических измерений на борту ракеты недостаточна, чтобы дать большую уверенность в результатах.

Другие измерения, в полосе 1150-1180 Å, указывают на то, что недостаток в звездном ультрафиолетовом излучении может быть еще гораздо большим ниже лаимановской α, нежели выше ее.

One of the sets of data eventually expected from rocket and satellite astronomy is that of the brightness of stars in the far ultraviolet. An early experiment directed toward obtaining such data was described in the 1960 Liège meeting [1]. This experiment showed that early type stars radiate as point sources in the far ultraviolet, that the early B stars radiate more than late B and early A stars, and that stellar brightness in both the 1290-1350 Å and 1350-1550 Å bands is fainter than previously predicted by model atmosphere theory by about a stellar magnitude [2]. The reliability of the absolute photometry of the experiment was such, however, that the brightness discrepancy could not be considered certain.

Subsequent attempts to obtain photometric data in the far ultraviolet on the early type stars have supported the results described above [3]. The newer results have not, however, been of any greater reliability than those previously published ; hence, they have not increased the certainty with which one can state that the far ultraviolet brightness discrepancy is real. They have, however, extended our knowledge to a new wavelength band, namely, the band 1050-1190 Å. The data

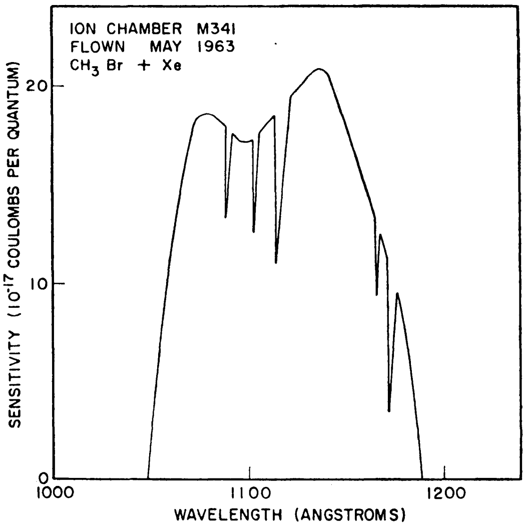

Fig. 1. — Spectral sensitivity of gas gain ion chamber used to detect stellar 1050-1190 Å radiation in the May 1963 rocket. The ion chamber was made with à LiF crystal window, and was filled with a gas filling of 3 mm CH_3Br and 97 mm xenon. A spectral sensitivity value of 10^{-16} coulombs per quantum means that at operating voltage the detector delivered 10^{-16} coulombs of charge to external circuitry for each quantum striking the front surface of the detector window.

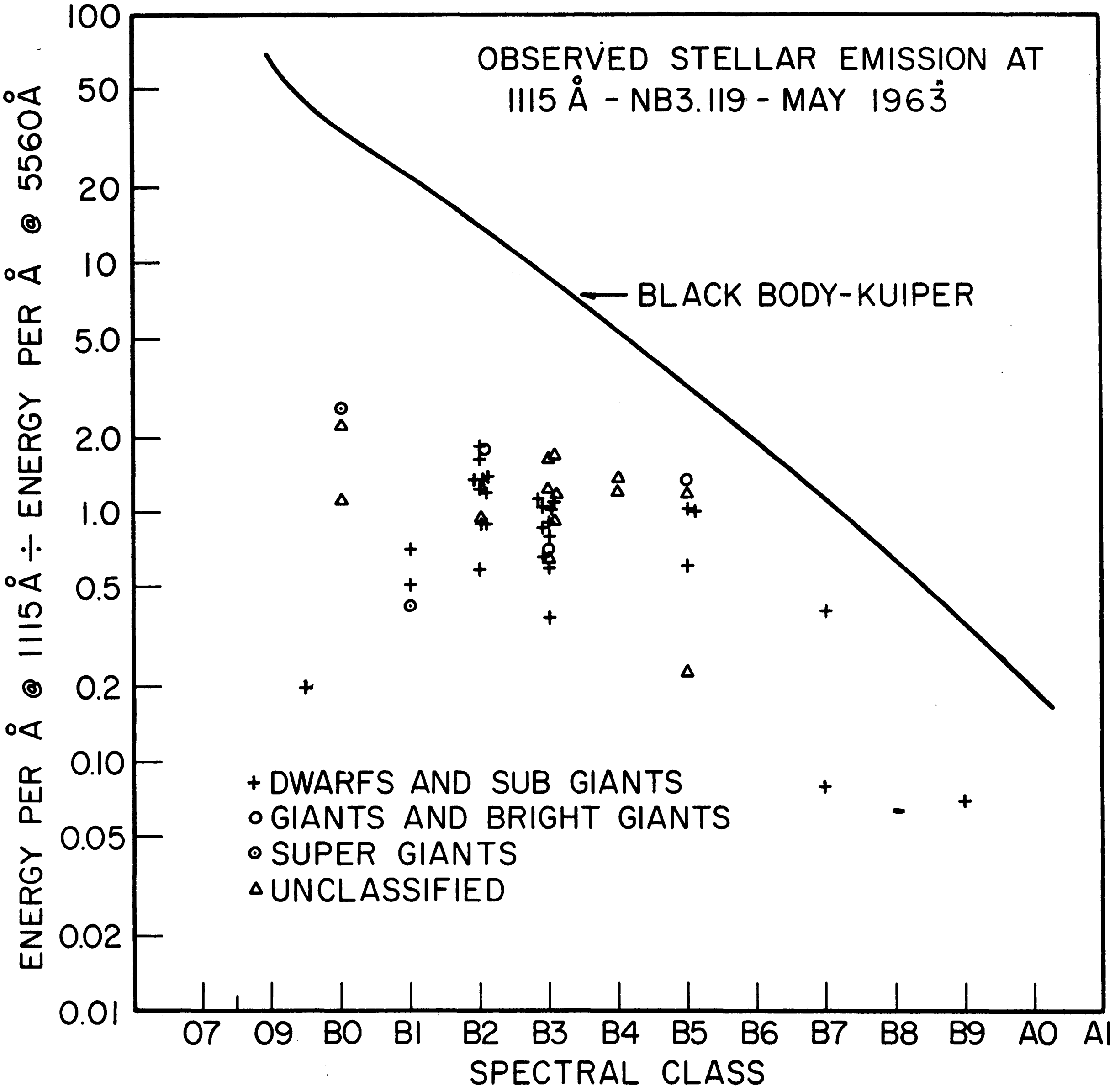

Fig. 2. — Brightness of stars at 1115 Å relative to their brightness at 5560 Å as a function of spectral class. Plotted in this figure are the observed ultraviolet to visible flux ratios for a set of 47 stars. The data are in terms of energy per Angstrom arriving at Earth, and no correction for interstellar absorption is included. The stars responsible for each data point can be identified from Table I. The solid line curve drawn on the figure is the brightness ratio which would be expected if the stars were black body objects at temperatures equal to the effective temperatures given by Kuiper [4].

indicate that in this band the ultraviolet deficiency of the stars may be far greater than that encountered at wavelengths above 1200 Å.

The 1050-1190 Å stellar photometry experiment was carried out by mounting a narrow band photometer at the focus of a four inch diameter parabolic mirror. The mirror telescope looked out the side of an Aerobee rocket in a direction perpendicular to the long axis of the rocket. The rocket was unguided, and executed an almost rigid body motion characterized by almost constant roll rate and by experimentally constant precession rate about a free precession cone fixed in inertial space. Analysis of the rocket motion was made possible from signals of auxiliary orientation sensors (magnetometers and photomultipliers), with the result that a time history of the telescope view direction was eventually obtained. This time history permitted verification of the stars responsible for each response peak observed by the 1050-1190 Å photometer, except where clustering of early type stars created possible ambiguity.

TABLE 1

STARS SEEN BY 1115 Å PHOTOMETER IN MAY 1963 AEROBEE

HD	STAR	SPECTRAL TYPE	m_v	F_{1115} (erg cm^{-2} s^{-1} A^{-1})	F_{1115}/F_{5560}
3360	17 ζ Cas	B2 V	3.7	1.57×10^{-10}	1.25
5394	27 γ Cas	B0 IV var	1.6-3.0	> 4.9	
10516	φ Per	B0 *ne* var	4.4	0.74	1.12
11241	1 Per	B2 V	5.49	0.40	1.67
11415	45 ε Cas	B3 IV*p*	3.44	0.60	0.38
20336	GC 3947	B2 V*e*	4.76	0.43	0.91
32630	10 η Aur	B3 V	3.3	1.10	0.60
48879	42 Cam	B3 IV	5.04	0.39	1.05
74280	7 η Hya	B3 V	4.3	0.63	0.88
83754	38 ϰ Hya	B4	4.96	0.48	1.23
87901	32 α Leo	B7 V	1.3	0.93	0.081
91316	47 ρ Leo	B1 Ib	3.9	0.45	0.43
98718	π Cen	B5 V*n*	4.3	0.76	1.06
105435	δ Cen	B2 V*e*	2.9	3.22	1.22
109387	5 ϰ Dra	B7 V	3.88	0.43	0.40
111123	β Cru	B0III	1.5	> 4.9	> .51
113791	ξ^2 Cen	B21V	4·4	0.90	1.39
116087	J Cen	B5IV	4.62	0.57	1.06
116658	67 α Vir	B1 V	1.21	> 4.9	> .39
118716	ε Cen	B1 V	2.56	> 4.9	> 1.76
120315	85 η Uma	B3 V	1.91	4.33	0.66
121263	ζ Cen	B2 IV	3.06	> 4.9	> 2.16
122451	β Cen	B1 II	0.86	> 4.9	> 0.28
125823	*a* Cen	B5 III	4.8	0.64	1.39
127972	η Cen	B3 V*p*	2.7	3.25	1.03
129056	α Lup	B2 II	2.89	> 4.9	> 1.85
129116	*b* Cen	B2 V	4.1	0.79	0.91
132058	β Lup	B2 V	2.81	> 4.9	> 1.71
138890	γ Lup	B3 *n*	3.0	4.04	1.68
139365	40 τ Lib	B3 V	3.8	0.92	0.8
142669	5 ρ Sco	B2 V	4.02	1.28	1.36
143118	η Lup	B2 V	3.6	2.58	1.87
144217	8 β^1 Sco	B0.5 V	2.90	> 4.9	> 1.86
147165	22 σ Sco	B1 V	3.08	1.14	0.52
147394	τ Her	B5 IV	3.9	0.64	0.61
148708	N Sco	B3	4.3	1.23	1.71
149438	23 τ Sco	B0 V	2.91	> 4.9	> 1.88
149757	13 ζ Oph	09.5 V	2.70	0.64	0.20
150898	GC22549	B0 *n*	5.8	0.40	2.22
155763	22 ζ Dra	B5	3.22	0.45	0.23
156633	68 *u* Her	B3 *be*	4.9	0.53	1.26
157056	42 θ Oph	B2 IV	3.4	2.23	1.34
157246	γ Ara	B1 V	3.5	1.08	0.72
160578	ϰ Sco	B2 IV	2.51	> 4.9	> 1.30
160762	85 ι Her	B3 V	3.8	1.05	0.91
164402	GC24526	B0 I	5.73	0.50	2.63
166182	102 Her	B2	4.3	0.71	0.98
169022	20 ε Sgr	B9 IV	2.0	0.43	0.07
169467	α Tel	B3 V	3.76	1.04	0.87
175191	34 σ Sgr	B3 V	2.14	> 4.9	> 0.93
187811	12 Vul	B5 *ne*	4.91	0.49	1.19
190993	17 Vul	B4 *n*	5.08	0.49	1.40
192685	GC 28140	B3 V	4.82	0.48	1.07
202904	66 υ Cyg	B3 *ne*	4.4	0.43	0.64
205021	8 β Cep	B2 III	3.3	3.58	1.96
207330	81 π^2 Cyg	B3 III	4.26	0.53	0.71
208057	16 Peg	B3	5.05	0.41	1.14
213420	6 Lac	B2 IV	4.54	0.34	0.59
221253	AR Cas	B3	4.7-4.8*pe*	0.43	0.90

The photometer used in this study was a gas gain ion chamber filled with a gas mixture of 3 mm CH_3Br and 97 mm xenon. The spectral sensitivity curve for the photometer is shown in Figure 1. The effective wavelength of the detector was 1115 Å. The average detector sensivity over the 140 Å band between 1050 Å and 1190 Å was 8.4×10^{-6} coulomb erg^{-1}.

The experimental results of this study are shown in Table I. Useful data were obtained on 59 stars, of which 12 were seen more than one time. Star HD 160762 (ι Her) was viewed eight times and HD 166182 (102 Her) was observed four times. Saturated responses were produced by twelve of the stars ($F_{1115} > 4.9 \times 10^{-10}$ erg cm^{-2} s^{-1} $Å^{-1}$). The on-scale data are plotted vs. stellar spectral class in Figure 2. Specifically Figure 2 is a plot of the ratio of stellar brightness (ergs cm^{-2} s^{-1} $Å^{-1}$) at 1115 Å to stellar brightness at 5560 Å vs. spectral class. For comparison, brightness ratios have been computed for hypothetical black body stars of effective temperature T_e as listed by **Kuiper** [4]. These values are shown by the solid curve. The observed brightness ratios are typically more than two stellar magnitudes below the black body curve, and may be suggestive of the presence of severe line blanketing [5] in this spectral region.

The photometric validity of the above data is subject to question to about the same extent as that published for longer wavelength far ultraviolet bands. The data are internally consistent to within about 25 % error, hence the relative photometry may be considered to have about this degree of error most cases. The absolute photometry is subject to more question. An earlier flight using the same photometric principles, but internally less consistent, gave 1115 Å brightnesses about one-half the values listed here. The authors estimate that there is a 50 % probability that the absolute photometry is good to a factor of two.

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Discussion (*)

S. E. **Strom**. — Do most recent **Stecher**'s and **Boggess**' colors agree down to 2 000 Å ? If so, then the models would appear to agree well with observations both in the visual and the ultraviolet, at least down to 2 000 Å.

M. J. **Seaton**. — We have heard little about the **Gulledge** and **Pecker** models. Can anyone comment on it ? And could **Heddle** comment on whether he believes his results indicate a real discrepancy ?

D. W. O. **Heddle**. — I think some of our results are more reliable than others because they represent repeated observations. For example, we have four observations of Sirius which agree with the models and seven observations of ε CMa which shows a differing of 2 to 3 compared with an **Underhill** model selected by Balmer discontinuity. On the other hand, we have only one observation of ζ UMa and it will be instructive to compare this with the observations reported here by Dr. **Stecher**. I would like to echo Dr. **Boggess** remarks on the need of selective study of the observations, but I would suggest that it is important at this stage to disseminate one's observations so that comparisons can be made between the work of different observers.

M. J. **Seaton**. — At one moment in the afternoon, I had the nightmare thought that everyone was going to work too hard and that we would finish with the theory U. V. being reduced by a factor of 4, the observed U. V. increased by 4 and the discrepancy being inverted but just as bad as it was before.

More seriously, I would express the opinion that the theoretical work seems to be going rather well and is giving rather definite answers, but that there are real discrepancies in the observations. By far the most important problem now is to obtain more observational results, so that we can really be sure about what we are talking about.

Y. **Ohman**. — One phenomenon which struck me in the interesting relationship between the U. V. color index and temperature was the small scattering when using in this way a colour index instead of extrapolating the Planckian curve and measuring the depth at the Balmer limit. When measuring many years ago the Balmer continuum of Pleiades stars, I found a similar effect by comparing only two different wavelength

L. H. **Aller**. — Anyone who has tried to do spectrophotometry is aware of the difficulties produced by the irregularities in atmosphere extinction. Therefore, fundamental spectrophotometry should be done *above* the earth's atmosphere for at least a few stars which can serve as primary standards.

(*) This discussion is relevant to the communications by D.W. O. **Heddle**, by A. **Boggess**, by T. P. **Stecher**, by E. T. **Byram**, T. A. **Chubb** and M. W. **Werner**.