MEASUREMENT OF SOLAR X-RAY SPECTRUM BETWEEN 13 AND 26 Å

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Résumé. — *Le N. R. L. a tenté en juillet 1963 d'obtenir un spectre de l'émission X du Soleil avec une fusée Aerobee équipée d'un spectromètre à cristal de* Bragg. *L'engin comportait un dispositif de pointage automatique sur le Soleil. On a enregistré environ 12 raies entre 12 et 25 Å, principalement dues à O VII, O VIII, N VII et Fe XVII. Alors que les raies de O VII et N VII semblent émises par le disque en son entier, les raies de Fe XVII sont produites presque uniquement par une seule région active.*

Abstract. — *In July 1963, the U. S. Naval Research Laboratory flew an Aerobee rocket equipped with a Bragg Crystal Spectrometer in an attempt to record an x-ray spectrum of solar emission. A pointing control was used to keep the device accurately pointed at the Sun. A spectrum of about 12 lines between 12 and 25 Å was recorded, made up mainly of lines from O VII, O VIII, N VII and Fe XVII. The O VII and N VII lines appeared to come from the entire solar disk. The Fe XVII lines originated almost entirely in a single plage region.*

Резюме. — Н. И. Л. попыталась в иоле 1963 г получить спектр излучения X солнца с ракетой Aerobee снабженной кристаллическим спектрометром Брагга. Снаряд содержал устройство автоматической наводки на солнце. Было зарегистрировано около 12 линий между 12 и 25 Å, происходящих главным образом от O VII, O VIII, N VII, и Fe XVII. В то время как линии O VII и N VII по-видимому излучены всем диском, линии Fe XVII произведены почти только одной активной областью.

One of the most exciting products of the use of rocket borne instrumentations in exploring our universe has been the continuing extension of our knowledge concerning the radiation spectrum of the Sun. Most of our detailed knowledge of solar emission below 3000 Å has been obtained with grating spectrographs and spectrometers [1], [2]. In the very short wavelength region, below 30 Å, studies have been largely confined to use of broad band detectors, which have provided interesting time histories of solar emission, but have contributed little to our knowledge of the solar X-ray line spectrum. The present note concerns a study of the solar X-ray spectrum between 13 and 25 Angstroms, carried out with a Bragg crystal X-ray spectrometer.

On 25 July 1963, an Aerobee rocket equipped with an X-ray spectrometer and a University of Colorado solar pointing control was launched from White Sands, New Mexico. The Bragg crystal spectrometer used the 1/2 degree solar disk as the X-ray source and a thin window Geiger counter as X-ray detector. The spectrum was scanned back and forth a single time during the high altitude portion of the flight by rotating a KAP analyzing crystal between grazing angles of incidence of 20 and 140 degrees. The Geiger counter was mounted on an arm, which was moved during the spectrum scan so that the counter window would always intercept radiation reflected from the crystal. A photograph of the spectrometer and accompanying experiments is shown in Figure 1.

The counter itself used a very thin gauze-supported window of nitrocellulose film, and it was operated during flight with a counting gas mix of 10 % isobutane and 90 % argon, which was maintained at an internal pressure of 100 mm. Troublesome ultraviolet sensitivity was minimized by use of an external filter made up of four thicknesses of aluminium-coated nitrocellulose. Total window and filter thickness was equivalent to 0.061 mg cm^{-2} of Al plus 0.093 mg cm^{-2} nitrocellulose. Satisfactory spectrometer operation was achieved throughout flight. However, some difficulty was encountered with the pointing control. During the scan from short to long wavelengths pointing was adequate except for occasional small

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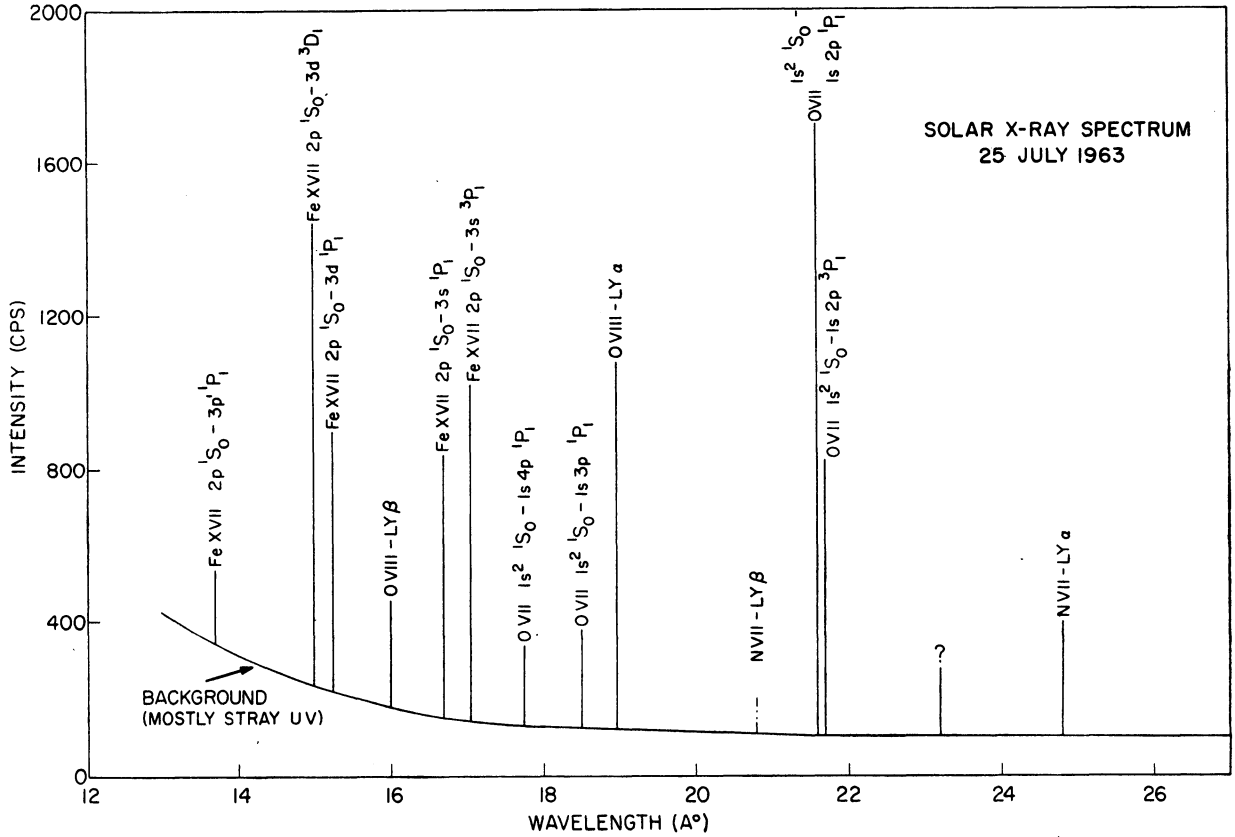

FIG. 2. — Solar X-ray spectrum as recorded by BRAGG crystal spectrometer. The peak counting rates for each line are shown on the curve. The data shown have not been corrected for crystal reflectivity or for filter and counter window transmission. The lines of O VII are broad and appear to come from the whole solar disk. They contain most of the energy in the spectral region covered.

pointing excursions ; most of the scan from long to short wavelengths was lost because of pointing failure.

The spectrum scan of the Sun provided three types of information. First, it provided data on the wavelengths and strengths of the X-ray emission lines making up the solar spectrum. Second, it provided evidence on each line as to whether the line originated mainly from the entire solar disk or mainly from the single strong plage region which happened to be present at the time of launch. Third, it established an upper limit to the strength of the solar X-ray continuum. A plot of uncorrected line strengths is shown in Figure 2. Table I shows wavelengths and probable identifications of the observed lines together with the computed energy contained in each line. The wavelengths are believed accurate to about $\pm$ 0.1 Angstroms. The final column describes the line shape. The broad lines have approximately the width of the solar disk and appear to come from the disk as a whole. The narrow lines have a width equal to the estimated rocking curve width of the KAP crystal used in the spectrograph. They are believed to have come from the isolated plage, which was the only significant activity center on the Sun at the time of firing. Calculations of the energy content associated with narrow lines were based on LIEFELD's [3] double crystal reflectivity values for KAP ; the energy content for broad lines was calculated from laboratory reflectance measurements made with an X-ray beam of 1/2 degree divergence. Line identifications were based on work by SAWYER *et al.* [4], EDLÉN [5] and TYREN [6].

Examination of Table I shows that emission from O VII and N VII comes from the disk as a whole, while emission from Fe XVII comes from the active plage. The line shape of the O VIII Lyman α lines is somewhat uncertain because of pointing control excursions which occured during its recording ; however, the O VIII Lyman β line

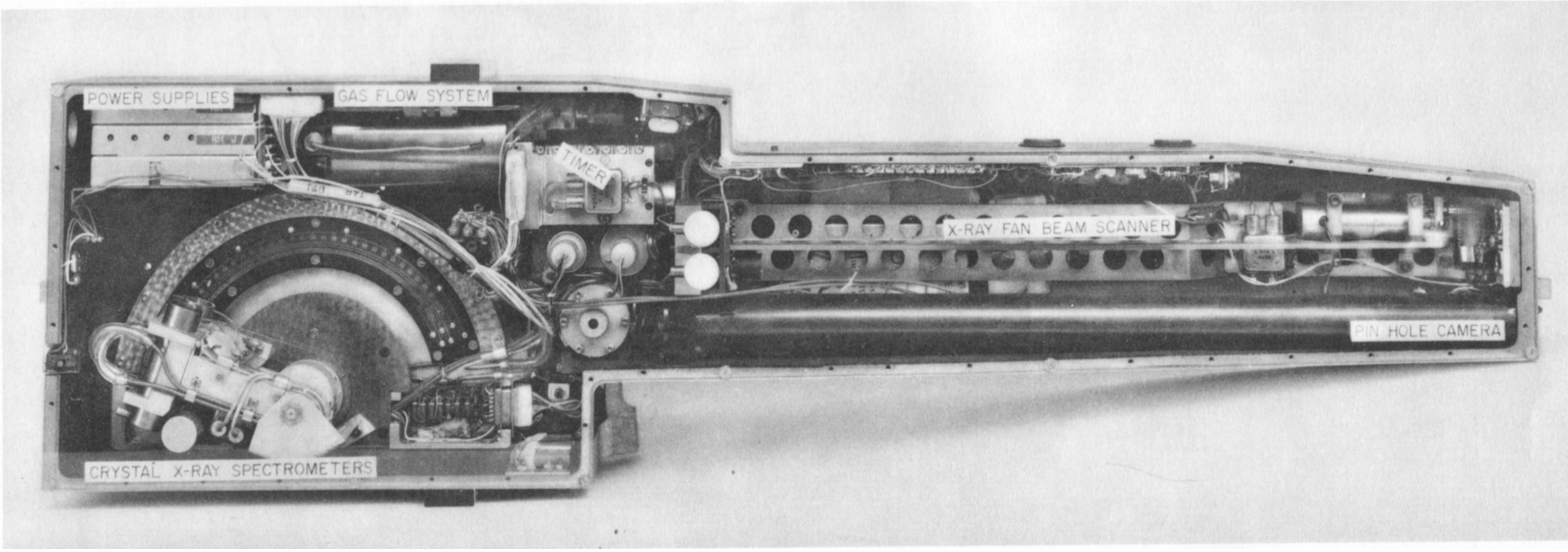

Fig 1 — Photograph of pointed portion of rocket instrumentation flown on July 1963. The crystal x-ray spectrometers, which constituted the main experiment, form the assembly located in the left half or back of the box. A rocket pointing control kept the right face of the box directed normal to the sun. The diffracting crystals are mounted on the rotation axis of the spectrometer. Each crystal is viewed by a separate Geiger counter mounted on a movable arm in such a fashion that the counter is always in position to record energy reflected from the crystal. Spectrum scanning is accomplished by rotating the analyzing crystals. The angle through which the analyzing crystals have been rotated is determined from signals generated by passing a wiper contact over a coded printed circuit board. Three x-ray spectrometers were mounted above each other and utilized the same mechanics drive, but only the spectrometer utilizing a KAP analyzing crystal recorded a solar spectrum. The locations of electronic assemblies, counter gas supply, sequencing timer and two auxiliary solar experiments are also shown.

TABLE I

WAVELENGTH OBSERVED Å	LAB. MEAS. OR PREDICTION Å	INTENSITY ABOVE ATMOSPHERE Photons cm^{-2} s^{-1}	ELEMENT	TRANSITION	NOTES
13.7	13.820	2.1×10^4	Fe XVII	$2p\ {}^1S_0 - 3p'\ {}^1P_1$	Possibly also Ne IX. Narrow.
15.0	15.012	16.3	Fe XVII	$2p\ {}^1S_0 - 3d\ {}^3D_1$	Narrow.
15.25	15.261	10.1	Fe XVII	$2p\ {}^1S_0 - 3d\ {}^1P_1$	Narrow.
16.0	16.006	5.0	O VIII	$1s\ {}^2S_{1/2} - 3p\ {}^2P_{1/2,\ 1/2}$	Lyman β. Narrow.
16.72	16.774	15.1	Fe XVII	$2p\ {}^1S_0 - 3s\ {}^1P_1$	Narrow.
17.01 and 17.05	17.051	20.1	Fe XVII	$2p\ {}^1S_0 - 3s\ {}^3P_1$	Doubled by excursion of pointing control. Both peaks narrow.
17.65 and 17.72	17.768	22.6	O VII	$1s^2\ {}^1S_0 - 1s4p\ {}^1P_1$	Doubled by pointing control excursion.
18.54 and 18.61	18.627	32.2	O VII	$1s^2\ {}^1S_0 - 1s3p\ {}^1P_1$	Doubled by pointing control excursion.
18.8 and 18.9	18.969	36.0	O VIII	$1s\ {}^2S_{1/2} - 2p\ {}^2P_{3/2,\ 1/2}$	Lyman α. Doubled Broad wings.
20.8	20.910	.....	N VII	$1s\ {}^2S_{1/2} - 3p\ {}^2P_{3/2,\ 1/2}$	Lyman β. Very weak line.
21.55	21.602	374.0	O VII	$1s^2\ {}^1S_0 - 1s2p\ {}^1P_1$	Broad.
21.70	21.804	169.0	O VII	$1s^2\ {}^1S_0 - 1s2p\ {}^3P_1$	Broad.
23.2	......	56.5	....	....	Broad. Unidentified. Possibly N VI.
24.8	24.781	50.9	N VII	$1s\ {}^2S_{1/2} - 2p\ {}^2P_{3/2,\ 1/2}$	Lyman α. Broad.

appears narrow. Total line energy content amounted to about 7.7×10^{-3} erg cm^{-2} s^{-1} in the 10-25 Angstrom band.

There is no clear evidence of continuum X-ray emission in the 10-25 Angstrom band. A rising background response occurred at short wavelengths, however, this background is believed to be a result of either reflected ultraviolet or incoherently scattered X-rays, rather than real continuum emission. It appears that an upper limit to X-ray continuum emission in the solar spectrum equal to about 1.4×10^{-3} erg cm^{-2} s^{-1} or roughly one-sixth of the solar line intensity can be established for the 10-25 Angstrom band covered.

A more complete description of this work has been published in the *Astrophysical Journal* [7].

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