J. Geophys. 44, 117–123, 1977

Journal of Geophysics

Intensity of Solar X-rays in the E Region Measured by Proportional Counters Carried on Rockets

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Abstract. The attenuation in the lower thermosphere of the solar X-ray spectrum from 0.1 to 10 keV (6 to 0.2 nm) was measured by Skylark rockets launched from El Arenosillo, Spain (37.10°N; 6.73°W), on 4 and 21 January 1976, at 16.30 UT. The X-ray spectrometers consisted of three proportional counters different in window material and filling gas. They were part of a complex rocket payload (BII).

The solar X-ray spectra and the electron-production rate obtained from the solar X-ray spectrum of 4 January 1976 are presented.

Key words: Attenuation – E region – Proportional counter experiment – Solar X-ray spectrum.

Introduction

In general, the electron- and ion-density profiles in the D-E region may be considered as a product of the attenuation in the lower thermosphere and mesosphere of hydrogen Lyman-α radiation and the X-ray flux from the Sun. In winter, however, also other important influences on the electron-density profiles have to be taken into account. This is suggested from the occurrence of the well known winteranomaly in radio-wave absorption which, in its particular features, cannot be explained by variations in the solar radiation, although its degree, in the average, depends on the solar cycle (Schwentek, 1971; Röttger and Schwentek, 1974). Nevertheless the solar X-ray spectrum should be observed simultaneously when measurements of essential parameters of the D-E region are made, because the solar X-ray flux is one of the main sources of electron production, and the hard component may be very much enhanced during solar flares.

Therefore, measurements were made of the 0.1 to 10 keV solar X-ray spectrum by X-ray spectrometers carried on two Skylark rockets, both launched from El Arenosillo, Spain, (37.10°N; 6.73°W), on 4 and 21 January 1976, at 16.30 UT. The X-ray spectrometer was part of a complex payload (B II).

Since the solar radiation and the Earth's atmosphere are always varying in space and time, such an observation can give only a spot check. But as a part of a complex experiment, and within a comprehensive aeronomy program, a simultaneous measurement of the solar spectrum at the same location was expected to give an useful contribution to the whole.

When planning the experiment it was hoped that the US Naval Research Laboratory would start the announced two Solar-Radiation Satellites in time, so that absolute solar X-ray data would also be available from satellites. Thus, a comparison and calibration of the spot-check measurements made by rockets with the continuous measurements on board satellites would have been possible in real time. Unfortunately, the SOLRAD Satellites 11a and 11b were not started earlier than 15 March 1976.

Equipment and Measurements

The X-ray spectrometers consisted of three proportional counters different in window material and gas filling (Table 1), and thus in sensitivity. The transmittivity of the window materials, and the sensitivity of the detectors were determined by means of a simple Bragg-crystall vacuum-monochromator which was constructed particularly for this calibration. The output pulses of the counters, which are proportional to the applied photon energies, were amplified by a charge sensitive amplifier, converted to voltage pulses, these separated by a 5-level pulse-height discriminator, then counted in 8-bit quasi-logarithmic counters for each period of measurement, and finally, stored in registers for the read out by the telemetry. The adjustment of the energy channels is shown in Table 2.

Before the rockets were launched, the detectors were turned to definite angles against the axis of the rocket by a remote control, depending on the actual solar zenith angle at the time of launching. Since the rockets were trajectory stabilized, the detectors had to be reversed near the apogee using a programmed timer in order to be directed towards the Sun also on the downleg. Triggered by a particular solar sensor (aperture 40°), at each rotation of the rocket, two measurements were made, one when the sensor pointed at the Sun, the other, when the sensor was opposite to the Sun. By the second measurement the scattered radiation from the background could be found and recorded. For both measurements, the solar sensor determined the (same) counting time of the detectors which was also telemetered.

A detailed description of the equipment is given in a technical report (Loidl and Boogaarts, 1976).

The first Skylark rocket was launched at 16.30 on 4 January 1976 at a solar zenith angle of 73°22′, the second at 16.31 UT on 21 January at 70°02′. The real flight trajectories of both rockets deviated considerably from the nominal trajectory for which the experiment was adjusted. The rockets did not reach the projected apogee, and the windows were ejected at heights which

Table 1. Characteristics of the detectors in the X-ray spectrometer

Number of X-ray detector	Energy band (keV)	Window material and thickness (mm)	Gas filling and pressure (Bar)	Wire ∅ (mm)	Window area (mm^2)
1	0.1–0.5	Hostaphan 0.005 Alu; 0.00012	Ne; 0.72 CH_4, 0.08	0.15	2
2	0.4–2.0	Alu; 0.0064	P 10; 0.8	0.15	4.5
3	2.0–10	Be; 0.0508	Xe; 0.88 CH_4; 0.04	0.04	350

Table 2. Adjustment (by a suitable choice of the discriminator levels) of the energy channels used for the three X-ray detectors. The upper energy level of channel 5 of detector 1 was not defined; this channel was only used to detect a possible disturbance of the detector by electrons during the rocket flight

Channel	Detector 1 keV (nm)	Detector 2 keV (nm)	Detector 3 keV (nm)
5	-0.42 -2.94)	2.0–1.68 (0.62–0.73)	10.0–8.40 (0.12–0.15)
4	0.42–0.34 (2.94–3.63)	1.68–1.36 (0.73–0.91)	8.40–6.80 (0.15–0.18)
3	0.34–0.26 (3.63–4.75)	1.36–1.04 (0.91–1.19)	6.80–5.20 (0.18–0.24)
2	0.26–0.18 (4.75–6.86)	1.04–0.72 (1.19–1.71)	5.20–3.60 (0.24–0.74)
1	0.18–0.10 (6.86–12.34)	0.72–0.40 (1.71–3.09)	3.60–2.0 (0.74–0.62)

were lower than planned. Thus, at the first flight, the thin window of the low-energy detector 1 was destroyed. At the second flight, unfortunately, one of the high-voltage converters failed, and detector 3 (2–10 keV) did not produce data.

Results

The measured solar X-ray spectrum, as a function of height, is presented in Figures 1–3.

On 4 January 1976 detector 1 failed; measurable fluxes were obtained from channel 1 of detector 3, and channels 1 to 4 of detector 2. Measurements were made on the upleg and downleg of the rocket, but on both legs not at each height. At heights where two values were obtained, these values were equal within the limits of accuracy, and a mean value was calculated on January 21, 1976 detector 3 failed.

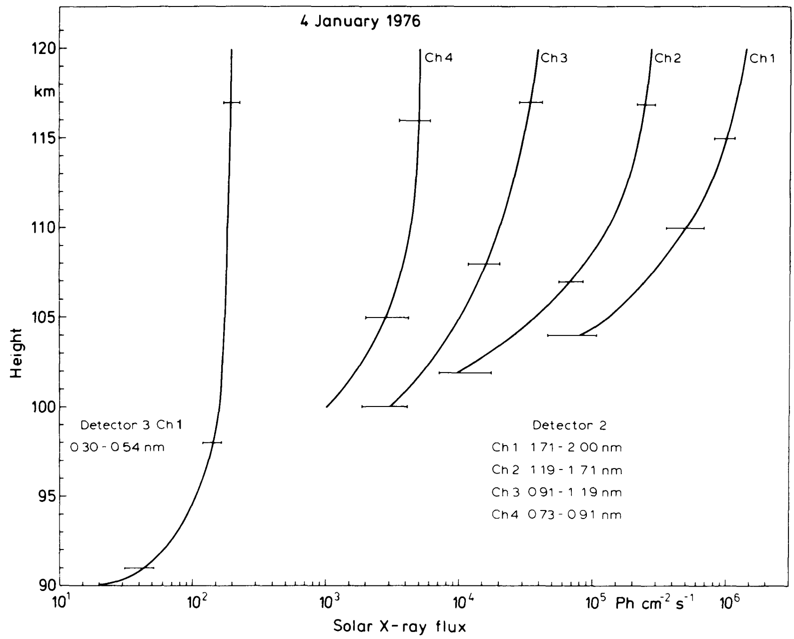

Fig. 1. Measured X-ray flux in channel 1 of detector 3 and in channels 1–4 of detector 2 on 4 January 1976 (the deviation from the wavelengths given in Table 2 are due to a change in gas gain) (channel 1, at wavelengths >2 nm, no signal was obtained due to the window material); (1 nm = 10 Å; 1 keV 1 1.234 nm)

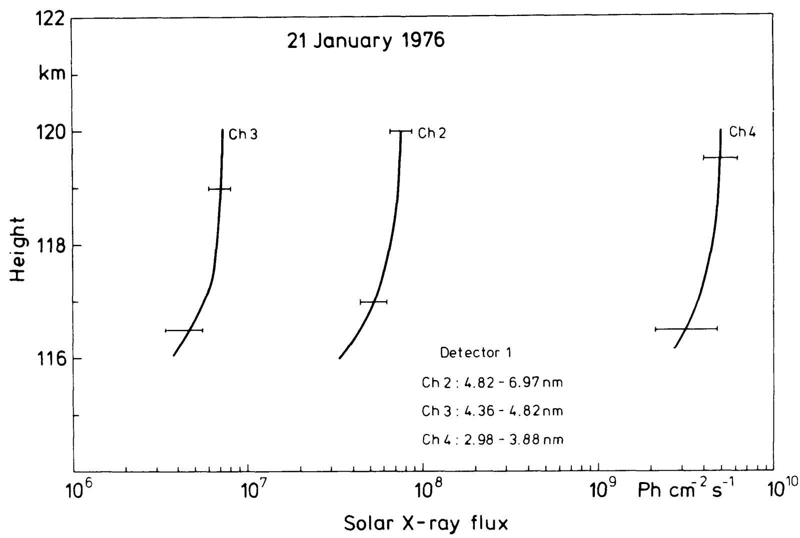

Fig. 2. Measured X-ray flux in channels 2–4 of detector 1 on 21 January 1976. Channel 1, at wavelengths >2 nm, no signal was obtained due to the material of the window. Channel 5 was only used to detect electrons which possibly could penetrate the windows; the result was that electrons did not disturb the measurement by the other channels

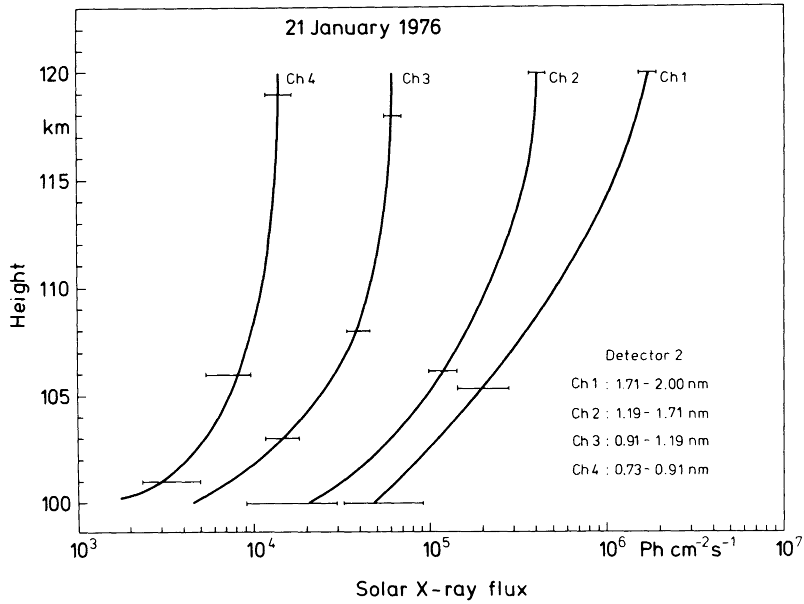

Fig. 3. Measured X-ray flux in channels 1–4 of detector 2 on 21 January 1976. Concerning channels 1 and 5 see legend of Figure 2

On January 1976 Detector 3 Failed

During both flights the solar activity was low, but slightly increased on 21 January 1976, as can be seen by comparing Figures 1 and 3.

Based on the fluxes measured at the apogees, *the solar X-ray spectrum beyond the Earth's atmosphere* was calculated by numerical integration using a model with a number of thin layers of 1 km thickness, and assuming for the small region of concern constant atmospheric density. The atmosphere density data were taken from the CIRA 1972 reference atmosphere, the absorption coefficients from Henke et al. (1967). The results obtained from the calculation are presented in Figure 4. For comparison, the dashed lines indicate the solar fluxes determined by Hinteregger (1965). The agreement is rather good, and reasonable since both measurements were made near sunspot-minimum conditions, those by Hinteregger in July 1963 (sunspot minimum in 1964), and those presented in this paper, in January 1976 (sunspot minimum in 1977).

A main purpose of the described experiment was to find the *ionization production rate,* q, due to solar X-rays, for comparison with the production due to other ionization sources during winteranomalous conditions. This was done by measuring the attenuation of the X-ray flux as it is absorbed in the lower thermosphere, calculating the effective spectrum as a function of height, and from that calculating electron production.

Solar X-rays with wave-lengths up to 10 nm can produce electrons in the lower thermosphere, and thus contribute to the electron-density distribution of the E region. Since there are no window materials being transparent for

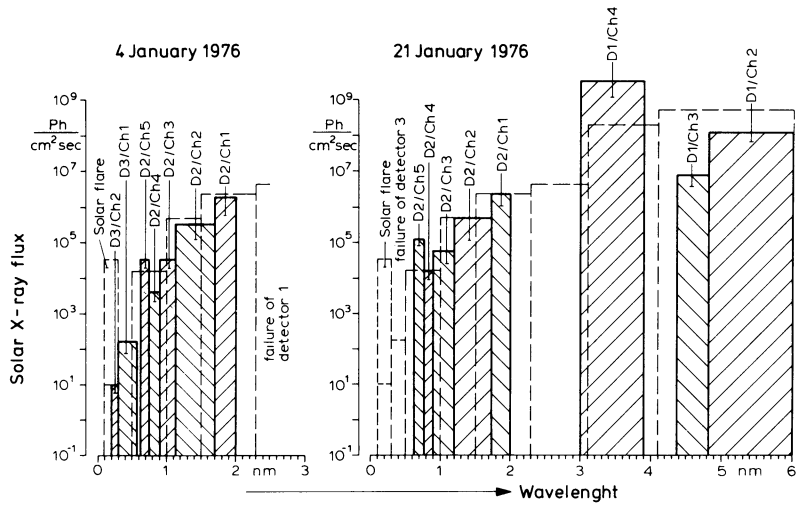

Fig. 4. Comparison of solar X-ray spectrum calculated from the measurement in the apogee on 4 and 21 January 1976 for conditions outside the Earth's atmosphere (solid lines) and the solar X-ray spectrum given by Hinteregger et al. (1965) which is valid for essentially quiet solar conditions (dashed lines)

X-rays above 7 nm, a measurement of the whole solar X-ray spectrum would only be possible beyond the Earth's atmosphere by use of windowless detectors. Therefore, in order to calculate the electron-production rate, it was necessary to complete the measured curves of solar X-ray flux vs. height (range 0.2 to 2 nm) by curves obtained from measurements outside the Earth's atmosphere made by other authors (range 2 to 10 nm) (Hinteregger et al., 1965).

The calculation of the electron-production rate as a function of height was also based on the CIRA 1972 reference atmosphere, and on absorption coefficients published by Henke et al. (1967).

The X-ray spectrum was divided into energy ranges, and for each of these, the effect of the radiation on N_2 and O_2 was calculated from the ratio $n(N_2)\sigma(N_2):n(O_2)\sigma(O_2)$, where σ is the absorption coefficient.

From the set of curves of X-ray flux vs. height, the differential attenuation of flux was determined. This differential attenuation was splitted up according to the ratio given above. From the average energy per wavelength range, the energy of the threshold of ionization was subtracted taking the threshold energies of the K and L edges into account, and the energy thus calculated was divided by 35 eV, because 35 eV were assumed to produce an electron ion pair (Valentine and Curran, 1958; Nicolet and Aikin, 1960). Since the product of absorbing cross-section and atmospheric density of the other atmospheric constituents is small, only N_2 and O_2 were considered.

The result of the calculations is presented in Figure 5. Curve 1 was determined only from the values in the range 0.2–2 nm, measured on 4 January 1976; curve 2 shows the electron production by the entire range 0.2–10.2 nm where

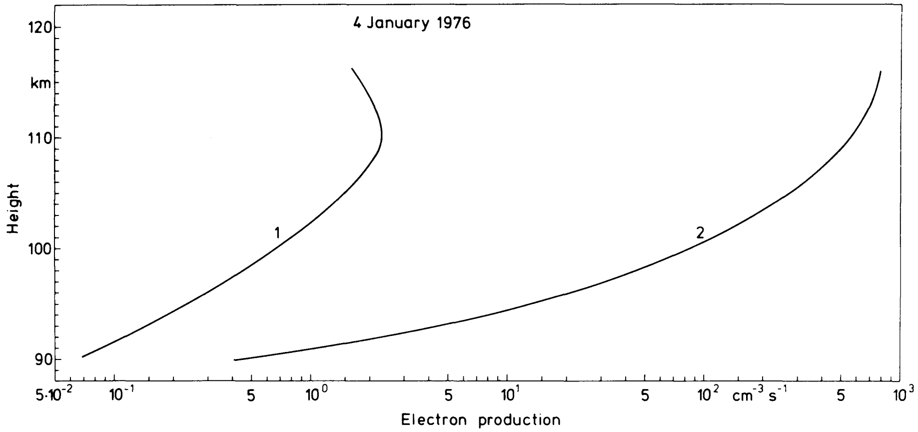

Fig. 5. Electron production from measurement of solar X-ray flux on 4 January 1976 (1), and including data from Hinteregger et al. (1965) of the spectral range 0.2–10.2 nm (2). The curves are for a solar zenith angle of 73°

the part 0.2 to 2 nm is based on our curves of X-ray flux vs. height, and the part 2 to 10.2 nm on calculations using data taken from Hinteregger (1965).

Acknowledgements. Both experiments were developed by A. Loidl assisted by W. Boogaerts who also contributed to the data reduction. The experiments were mainly funded by the "Bundesministerium für Bildung und Wissenschaft" of the Federal Republic of Germany in the framework of a German Aeronomy Programme carried out in 1976 at El Arenosillo/Spain.

The authors acknowledge also the various supports of all who contributed to the success of this experiment, particularly, Dr. A.J.F. den Boggende, Laboratorium voor Ruimteonderzoek, Utrecht (The Netherlands), Mr. A.S. Rate, University of Leicester (England); last, not least, they like to mention the encouragement obtained from Prof. W. Dieminger, the former director of the Max-Planck-Institut für Aeronomie.

References

CIRA 1972, COSPAR International Reference Atmosphere 1972, Akademie-Verlag, Berlin, 1972.

Henke, B.L., Elgin, R.L., Lent, R.E., Ledingham, R.B.: X-ray Absorption in the 2 to 200 Å-Region. Norelco Reporter **XIV**, 112–134, 1967

Hinteregger, H.E., Hall, L.A., Schmidtke, G.: Solar XUV Radiation and Neutral Particle Distribution in July 1963 Thermosphere. Space Research XII, S.A. Bowhill, L.D. Jaffe, M.J. Rycroft, eds., pp. 1175–1190. Amsterdam: North-Holland Publ. Co., 1965

Loidl, A., Boogaerts, W.: Internal Report. Experiment DL5. Röntgenspektrometer. Max-Planck-Institut für Aeronomie. Lindau 1976

Nicolet, M., Aikin, A.C.: The formation of the D-region of the ionosphere. J. Geophys. Res. **65**, 1469–1482, 1960

Röttger, J., Schwentek, H.: A numerical description of the winter anomaly in ionospheric absorption for a sunspot cycle. J. Atmospheric Terrest. Phys. **36**, 363–366, 1974

Schwentek, H.: The sunspot cycle 1958/70 in ionospheric absorption and stratospheric temperature. J. Atmospheric Terrest. Phys. **33**, 1839–1852, 1971

Valentine, J.M., Curran, S.C.: Average energy expenditure per ion pair in gases and gas mixtures. Reports on progress in physics, Vol. **XXI**, A.C. Stickland, ed., pp. 1–29. London: The Physical Society, 1958

Received May 2, 1977