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THE X-RAY LINE AND CONTINUUM EMISSION FROM A SOLAR ACTIVE REGION

Peter B. Landecker, et al

Aerospace Corporation

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5 March 1975

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The X-Ray Line and Continuum Emission from a Solar Active Region

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5 March 1975

Interim Report

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The x-ray spectrum of the quiet sun in the energy range 2.3 - 6.9 keV was observed from an Aerobee rocket using an uncollimated graphite crystal spectrometer. These results and spatial measurements made with an onboard modulation collimator are analyzed using solar models. Several methods of estimating coronal temperatures are used in this analysis and all yield results within the range $(4 \pm 1) \times 10^6$ K.

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PREFACE

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FIGURES

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I. INTRODUCTION

In a recent sounding rocket experiment (NASA 13.005 US) launched on 1972 June 27 at 1900 UT, we have observed the solar x-ray spectrum in the 1.8 - 5.3 Å region using a Bragg crystal spectrometer (Wolff, 1974). At the time of the measurements the sun was quiescent, and the spectrum obtained as shown in Figure 1 was primarily continuum with a broad line feature at 5.1 Å. In this paper we discuss these results quantitatively, comparing the x-ray data with other observations and solar models based on the assumption of thermal equilibrium. The spectrometer consisted of two panels of highly oriented pyrolytic graphite crystals (2d = 6.7 Å) and proportional counters to detect the diffracted photons. Further details of the instrument and the conversion between counting rate and energy flux are presented elsewhere (Wolff, 1974).

II. OBSERVATIONS

The emission feature observed at 5.1 ± 0.05 Å must be interpreted as either the convolution of several spectral lines, the superposition of lines from more than one active region, or both. This conclusion is necessitated by the 1.75° FWHM, which far exceeds the 1.2° FWHM response of the spectrometer obtained in laboratory calibrations. We consider both possibilities, using predicted line intensities for optically thin plasmas (Tucker and Koren, 1971; Mewe, 1972) and correlative optical and soft x-ray maps of the sun made on the same day. Additional data on the spatial distribution of the x-ray emitting regions was obtained from a modulation collimator and proportional counter which was aligned with the crystal spectrometer. Combining these data, we are able to construct models which can then be compared to the features in the observed spectrum to resolve the ambiguity.

The modulation collimator consisted of two planes of parallel wires of diameter 0.0254 cm separated by 0.0635 cm and spaced 7.62 cm oriented perpendicular to the scan path to yield transmission maxima at 0.48° intervals. With these parameters, the collimator would yield a purely trapaziodal response

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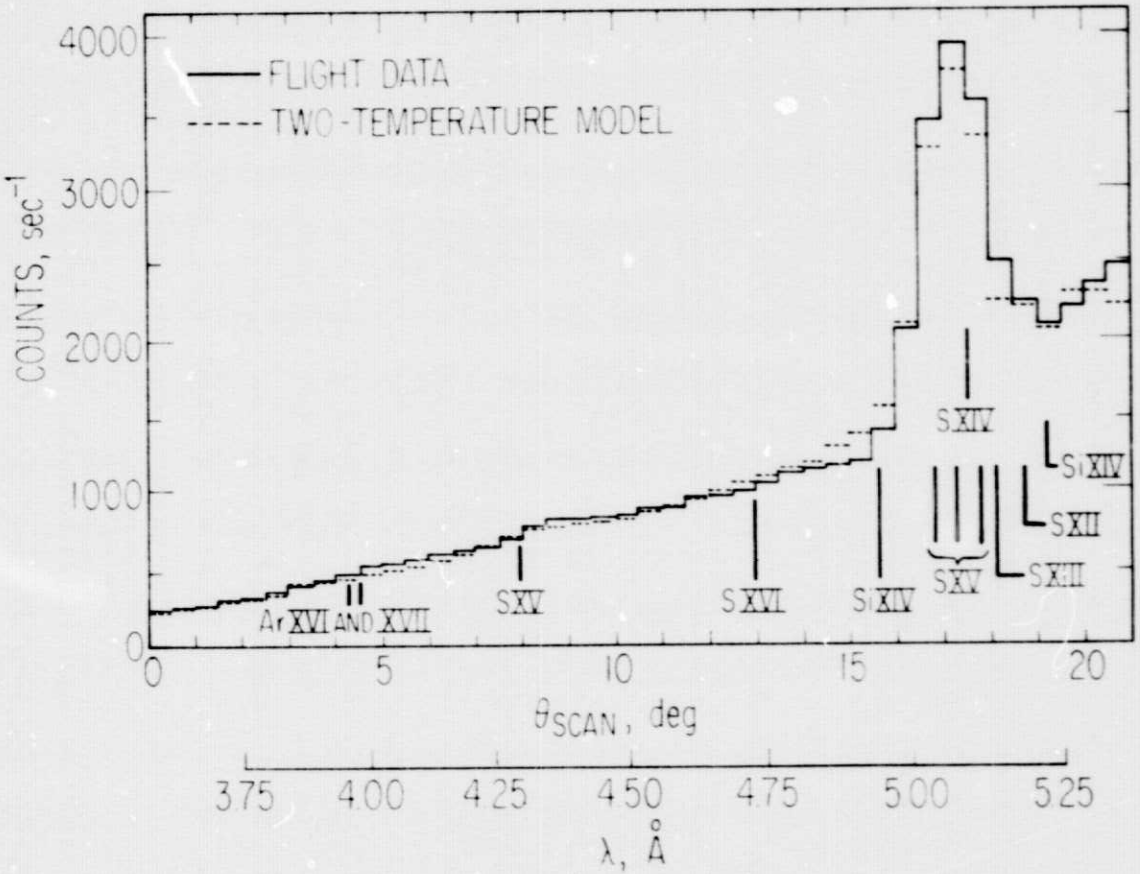

Figure 1. Counting rate vs scan angle for the low-energy crystal panel. The solid line indicates flight data from eight scans superimposed in 0.5° angle bins. The dashed line is the counting rate calculated for a two-component solar model characterized by $T = 5 \times 10^6 °K$, $Ne^2V = 10^{47}$ cm^{-3} and $T = 2.5 \times 10^6 °K$, $Ne^2V = 10^{49}$ cm^{-3}. Conversion between counting rate and energy flux is given in Fig. 2 of Wolff (1974). The 1σ statistical uncertainty in 1000 counts sec^{-1} is 11 counts sec^{-1}; it scales with the square root of the counting rate.

to a single point source, a convolution of trapaziods to several point sources, and an almost unmodulated response to a uniformly luminous disk. The detector, sensitive to 1.5 - 8 keV x-rays, showed a modulation consistent with more than one point source superimposed on a disk continuum. A study was performed to simulate the amplitude and phase of the modulation collimator data with different solar models. A least squares analysis yielded a best fit with two point sources and a uniform disk contribution, with the point sources located at 0.11° and $+ 0.125^{\circ}$ relative to the solar center as seen from the earth along the scan path, which passed through the disk center and was 24.5° east of heliocentric north. The relative intensities of the two-point sources and disk were 1 : 3 : 2.4 respectively. The fit was significantly worse if either source was shifted by 0.02°. The rocket data and model calculation are given in Figure 2. Comparison of these results with the Fe XVII 14.44 - 15.83 Å OSO-7 spectroheliogram taken on the same day (Neupert, 1972) and observations at even longer wavelengths indicates that two active regions on the west limb are probably responsible for the emission seen at 0.125° in the scan path and that two regions on the east limb project to the $- 0.11^{\circ}$ point on the scan path. A comparison of the relative intensities of the regions shows that the two pairs make comparable contributions, but extrapolation to the shorter wavelengths observed by the Columbia spectrometer is not necessarily valid.

The structure of the line feature in the spectrometer data was examined as the superposition of a series of emission lines from two active regions separated by 0.23°. Spectral lines considered in the analysis, obtained from tables given by Kelley and Palumbo (1973), Mewe (1972), Tucker and Koren (1971), and Walker (1974a), were S XV (5.04, 5.07, 5.11 Å), S XIV (5.09 Å), S XIII (5.13 Å), S XII (5.18 Å) and Si XIV (5.22 Å). The temperature dependence of the line intensity calculated by Mewe (1972) was also used. A subtraction of the continuum was necessary, as the line emission is superimposed on a steeply rising base line (Figure 1). On the short wavelength side of the 5.1 Å feature the continuum is quite flat, but at longer wavelengths there are possible contributions from unresolved Si XIII lines at 5.28 and 5.41 Å. We

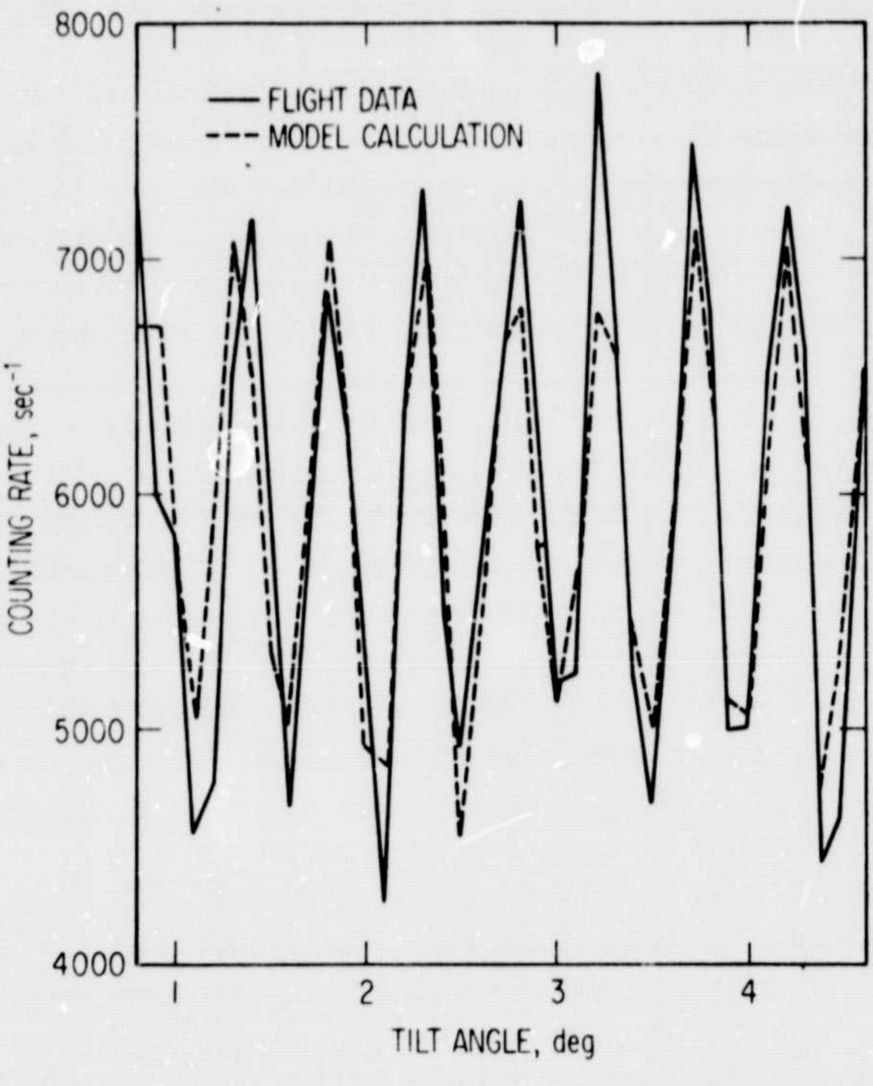

Figure 2. Modulation collimator proportional counter data giving counting rate as a function of rocket tilt angle. Counting rate is average number of events per second per 0.1° bin for all energies and the first two inward scans. Model data is superimposed and corresponds to point sources at 0.125° SW and 0.11° NE of the center of the disk and a disk contribution of 3 : 1 : 2.4 intensity ratio.

therefore considered a range of possible continuum fluxes, taking as one extreme that none of the long wavelength flux is due to other lines, and as an alternative, an estimate of the continuum based on an extrapolation of the short wavelength data only. These two possibilities establish upper and lowerlimits on the continuum flux, corresponding to line-to-continuum ratios of 0.24 and 0.20 respectively in the range 4.5 - 5.5 Å. Line-to-continuum ratios for optically thin plasmas have been calculated by Mewe (1972) in 1 Å wavelength intervals for various temperatures and are in agreement with those of Landini and Fossi (1970). Comparing our results with Mewe's calculations at 5 Å, we find that our data can best be fit by a temperature between 3.8 and 4.3×10^6 °K, the larger number corresponding to the higher line-to-continuum ratio.

The width, shape and wavelength centroid of the emission feature are determined by both the spatial separation of the emitting regions and the temperature. A model was constructed on the basis of the analysis of the spatial data, and the temperature and emission measure were varied until a best fit to the observed spectrum was obtained. Since the mosiac spread of the graphite crystals was greater than the separation of the source regions, the major contribution to the observed width is due to the various emission lines. For the same reason, the fit of the model of the data was found to be quite insensitive to the relative intensities of the two regions. The temperature of the emission plasma was the most important parameter, determining both the width and centroid of the emission feature through the rapid variations in the intensities of the various lines with small changes in temperature. Small increases in temperature result in a large shift to shorter wavelengths due to increasing strength of the S XV triplet. The absolute accuracy of the spectrometer angle to energy calibrations was ±0.05 Å at 5 Å and was determined by preflight laboratory measurements with a monochromatic, collimated x-ray beam. On the basis of these considerations, we find that a best fit to the data is obtained with a plasma temperature of $(3.8 \pm 1) \times 10^6$ °K where the two emitting regions have the same temperature, but the emission measures differ by a factor of two. The contribution to the emission feature due to the disk is negligible due to its lower temperature. If we assume the least or greatest continuum subtraction, as previously discussed, the best fit temperature ranges from 5 to 3×10^6 °K, respectively.

It is possible to derive the temperature from the slope of the continuum if there are no resolved or unresolved lines in a wavelength region. For example, after folding in the instrument efficiency, the slope of the curve in Figure 1 from 4.0 to 4.5 Å is 5.6 $Å^{-1}$. When the continuum processes of bremstrahlung, radiative recombination, and two photon emission were added (Walker, 1974), this slope was found to correspond to a temperature of 3.1×10^6 °K.

III. DISCUSSION

Analysis of the x-ray spectrum at 5 Å, first on the basis of the line-to-continuum ratio and then by the shape and position of the line profile, yield similar results. The line-to-continuum comparison results in a higher plasma temperature than the absolute wavelength and line profile would indicate. This slight discrepancy could be due to a compact but hotter core in one or more of the active regions contributing relatively little continuum. At temperatures of 3.1 and 3.8×10^6 °K, we would expect line-to-continuum ratios of 0.14 and 0.20, indicating that our data contains a line excess of approximately 50% and 10%, respectively.

An upper limit of 5×10^6 °K, to the temperature of such a hot core, is given by the absence of the S XV lines at shorter wavelengths (Wolff, 1974). An additional check on the consistency of the analysis is obtained by examining the data for Ar XVII lines at 3.99 Å which have been observed under quiescent solar conditions (Walker et al., 1974a). There is a slight indication of such a feature in our data at 4 Å, which contains a flux of 50 counts sec^{-1} or less. Using the ionization equilibrium tabulations of Mewe (1972), we find that a plasma temperature of 4.3×10^6 °K and emission measure of 10^{49} cm^{-3} would produce such a flux. The absence of a more pronounced Argon line then sets an upper limit on the temperature consistent with the line-to-continuum ratio.

Recent high spatial resolution x-ray images of the sun taken with the Skylab x-ray telescope (Golub et al., 1974) have revealed the presence of a network of bright points distributed uniformly over the solar disk. Although the number of emission regions visible is quite large, their estimated temperature of $1.3 - 1.7 \times 10^6$ °K is too low to produce sufficiently highly ionized species to contribute to the x-ray flux observed in this experiment. An alternative interpretation of these results is that the predicted line intensities are incorrect due to either insufficient atomic data or inaccuracies in the solar abundances used. As the principal species responsible for the emission feature are S ions, a small shift in the ionic equilibrium would give rise to a large variation in the expected line profile. If the calculations used to derive the temperatures for these models are accurate to only 30%, the apparent discrepancy is resolved. Intensities for common lines calculated by Tucker and Koren and by Mewe in general agree to within a factor of two. We also note that a strong Si line at 5.22 Å could influence our results. Although the contribution of this line was taken into account, an overabundance of Si would enhance this line and shift the profile to longer wavelengths and yield correspondingly lower temperatures. Such a possible overabundance has recently been reported in observations of spectra from stellar x-ray sources (Burginyon, 1974). However, the solar abundance of silicon to sulphur has been determined to be 3.9 (Walker et al., 1974b) and therefore an extreme solar overabundance of silicon can be discounted.

The more detailed analysis of the structure of solar active regions necessitates both greater spectral and spatial resolution in order to establish whether the line and continuum emission are originating in the same volume, and which lines are the major contributors to the observed profile. High resolution PET crystals are used in conjunction with high sensitivity graphite crystals on the Columbia OSO-I experiment due to be launched in 1975.

REFERENCES

Burginyon, G. A.: 1974, Proc. Int. Conf. on X-Rays in Space, Univ. of Calgary, Aug. 14-21, (in preparation).

Golub, L., Kreiger, A. S., Silk, J. K., Timothy, A. F., and Vaiana, G. S.: 1974, Astrophys. J. Letters 189, L93.

Kelly, R. L. and Palumbo, L. J.: 1973, "Atomic and Ionic Emission Lines Below 200 Angstroms," NRL Report 7599.

Landini, M. and Fossi, B. C. M." 1970, Astron. and Astrophys. 6, 468.

Mewe, R.: 1972, Solar Phys. 22, 459.

Neupert, W.: 1972 (private communication).

Tucker, W. H., and Koren, M.: 1971, Astrophys. J. 168, 283.

Walker Jr., A. B. C.: 1974 (private communication).

Walker Jr., A. B. C., Rugge, H. R., and Weiss, K.: 1974a, Astrophys. J. 188, 423.

Walker Jr., A. B. C., Rugge, H. R., and Weiss, K.: 1974b, Astrophys. J. 192, 169.

Wolff, R. S.: 1974, Solar Phys. 34, 163.

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