NOTE ON THE ENERGY SCALE OF THE MICHIGAN OSO III ION CHAMBER

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Abstract. The energy scale of the Michigan OSO III soft X-ray ion chamber has been assessed by using realistic theoretical X-ray spectra. Multiplicative factors by which the data may be corrected are proposed. The factors are only slightly temperature-dependent. A test of the proposed energy scale indicates it is still somewhat uncertain.

1. Introduction

Solar X-radiation has been monitored for many years by means of rocket- and satellite-borne ion chamber detectors. The method of reduction of the ionization current recorded by these devices to an X-ray flux value was early worked out by the pioneers in the field at the Naval Research Laboratory (Kreplin, 1961). In this method, the spectrum shape is fixed by assumption to be that of a black body at some temperature T. Upon justifiable observational and theoretical grounds, the temperature defining the spectral shape appropriate to the 8–20 Å data was selected by them to be $T=2\times10^6$ deg (Friedman, 1960). This value has been used ever since, although the data so reduced have been treated carefully in the full realization of their approximate nature (e.g. Kreplin *et al.*, 1962).

The Michigan soft X-ray ion chamber on OSO III was adapted from an NRL design. Solar soft X-ray fluxes were conventionally determined from the telemetered data by adopting the $T=2\times10^6$ deg grey-body assumption in order to provide a continuity of the observations with those made by NRL. In previous papers concerning our results we have extensively quoted X-ray flux values between 8–12 Å for many observed phenomena on basis of that assumed spectrum. Thomas (1970) concluded that the quoted fluxes were reasonably independent of spectrum, but that they might be systematically a factor of two or three too high.

We have re-investigated the question of the energy scale of the Michigan instrument and find support for Thomas. The results of our calculations provide correction factors which may be applied to the quoted Michigan fluxes. These correction factors depend upon theoretical spectra, which are not yet completely perfected. A test of the proposed energy scale, described below, indicates that the suggested correction factors are still to some extent uncertain.

2. Calculations

Culhane (1969) has calculated free-free and free-bound continua for thermal plasmas

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at a variety of temperatures. We directly adopted his spectra for coronal abundances.

Tucker and Koren (1971) have calculated the power emitted in spectrum lines between 0.5 and 70 Å, using coronal abundances, for a wide variety of temperatures. We superposed these emission lines upon Culhane's continua for the calculations which are discussed below.

The ionization current that would be produced when the ion chamber is exposed to the fluxes described by the superposition of emission lines and continua is

$$\frac{i'}{\int N_e^2 \mathrm{d}V} = \frac{1.078 \times 10^{-8}}{\int N_e^2 \mathrm{d}V} \int_0^\infty F(T, \lambda)\, \varepsilon(\lambda)\, \mathrm{d}\lambda \ \mathrm{A\ cm}^3, \tag{1}$$

where $\varepsilon(\lambda)$ is the band-pass of the detector. The flux of X-rays between 8 and 12 Å would be

$$\frac{F(8, 12)}{\int N_e^2 \mathrm{d}V} = \frac{\int_8^{12} F(T, \lambda)\, \mathrm{d}\lambda}{\int N_e^2 \mathrm{d}V} \ \mathrm{erg\ cm\ s}^{-1}. \tag{2}$$

In carrying out our actual data reductions, the quoted fluxes were calculated from (c.f. Kreplin, 1961)

$$E(8, 12) = 7.75 \times 10^8 i \ \mathrm{erg\ cm}^{-2}\ \mathrm{s}^{-1} \tag{3}$$

In Table I we list the electrical currents which would be produced (per $N_e^2 V$) by exposing the ion chamber to a 'realistic' flux of X-rays (from Equation (1)), the 'realistic' flux $F(8,12)$ as calculated from Equation (2) and the flux value that would have been quoted by us had we observed the electrical current i' (from Equation (3)). In the last column is given the correction factor which converts the quoted flux to the 'realistic' flux.

These correction factors indicate that the quoted energy scale for the Michigan data is too high by about 30% for the quiet Sun and by about 40% for phenomena that reach $T_e = 20 \times 10^6$ deg. In general, however, the *relative* fluxes quoted from our data

TABLE I

Proposed correction factors for Michigan OSO III ion chamber data

$\log T_e$	$\frac{i'}{\int N_e^2\, \mathrm{d}V}$ (A cm^3)	$\frac{F(8, 12)}{\int N_e^2\, \mathrm{d}V}$ (erg cm s^{-1})	$\frac{E(8, 12)}{\int N_e^2\, \mathrm{d}V}$ (erg cm s^{-1})	Correction factor
6.3	2.99×10^{-62}	1.82×10^{-53}	2.32×10^{-53}	0.78
6.5	3.23×10^{-61}	1.92×10^{-52}	2.50×10^{-52}	0.77
6.7	1.26×10^{-60}	7.57×10^{-52}	9.72×10^{-52}	0.78
7.0	3.59×10^{-60}	2.08×10^{-51}	2.78×10^{-51}	0.75
7.3	2.42×10^{-60}	1.30×10^{-51}	1.87×10^{-51}	0.70

are independent of spectrum shape, between $2 \times 10^6 \leqslant T_e \leqslant 20 \times 10^6$ deg, to within 12%.

Horan (1970) and other NRL observers (Kahler *et al.*, 1970) have found that at the X-ray maximum in flares the appropriate T_e for soft X-rays is in the neighborhood of 10×10^6 to 20×10^6 deg. Thus the relative flux amplitudes quoted by us for flares are perhaps correct to about 7% or better, and time-integrals of energy relatively correct to about 10%.

We especially note that the instrumental ion chamber current produced per unit emission measure on the Sun is nearly independent of temperature (to within 50%) between $10 \times 10^6 \leqslant T_e \leqslant 20 \times 10^6$ K. Thus, during flares the instrument responded chiefly to variations of emission measure. Relative flux data quoted for flares (e.g. Teske, 1969; Thomas and Teske, 1971) thus principally depict the differences in emission measure which characterize the soft X-ray source in various flares.

These conclusions support Thomas's (1970), which were based upon semiartificial spectra. The corrections proposed here, however, require a test of their acceptability.

3. A Test of the Calculated Response

The above calculations may be tested upon published observations that were made at the same time as our own. One such test may be made using the spectrum recorded on 9 Nov., 1967, by a proportional counter and reported by Culhane *et al.* (1969). This spectrum is shown as the full line in our Figure 1. At the time of their observation, our OSO III ion chamber current was 2.58×10^{-12} A.

Culhane *et al.* used Culhane's (1969) continuum calculations and fitted their observed spectrum by a coronal model containing two components described by (i) a component at 5×10^6 deg, $N_e^2 V = 1.7 \times 10^{47}$ cm^{-3} and (ii) a component at 3×10^6 deg, $N_e^2 V = 5 \times 10^{48}$ cm^{-3}. Their model failed to fit the observed spectrum longward of 6 Å wavelength, and they concluded that there must have existed 'substantial volumes of plasma at temperatures below 3×10^6 deg'.

We have attempted to fit Culhane *et al.*'s observed spectrum by a three-component model based upon the theoretical continua and lines utilized in this study. A constraint upon the model is that it must reproduce the observed ion chamber current. The parameters of a three-component model which fits the data are listed in Table II and the resulting fit to the observed spectrum, averaged over one-angström intervals, is shown in Figure 1. Although the spectrum fit is good and the model reproduces the observed ion chamber current, an emission measure of 7.1×10^{49} cm^{-3} is required.

TABLE II

Three-component model to fit spectrum by Culhane *et al.* (1969)

$\log T_e$ (deg K)	$N_e^2 V$ (cm^{-3})	Ion chamber current (A)
6.3	7×10^{49}	2.09×10^{-12}
6.5	1×10^{48}	0.32×10^{-12}
6.7	1.5×10^{47}	0.19×10^{-12}

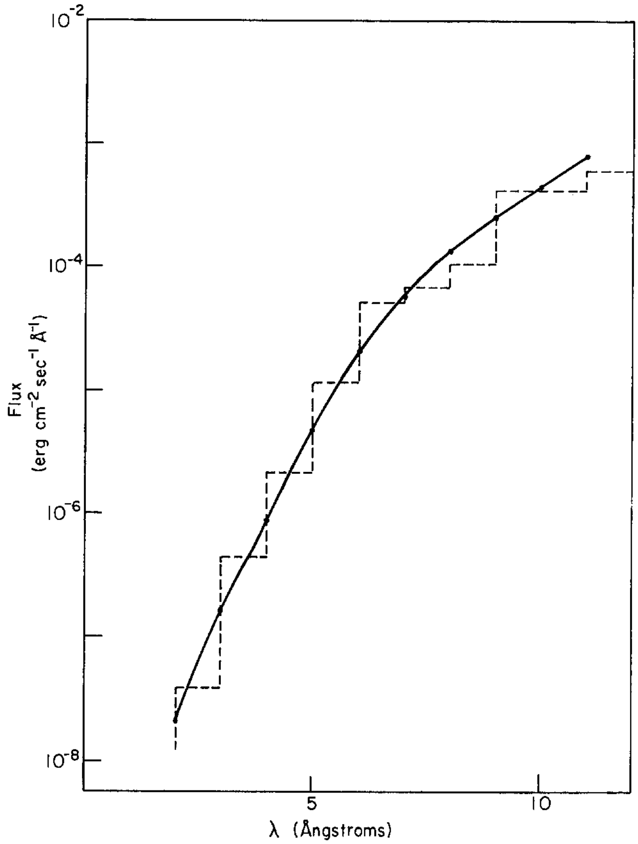

Fig. 1. The full line is the X-ray spectrum observed 9 Nov., 1967, by Culhane *et al.* The dashed histogram is the theoretical spectrum fitted to it using the energy scale for the Michigan ion chamber which is proposed in this paper.

This seems rather excessive. From the model of an active region by Christiansen *et al.* (1960), we obtain a representative columnar electron surface density squared in active regions of

$$\int N_e^2 \mathrm{d}h \sim 9 \times 10^{28}\ \mathrm{cm}^{-5}.$$

On 9 Nov., 1967, the total plage area was 15300×10^{-6} of a solar hemisphere, yielding

$$\sum A \int N_e^2 \mathrm{d}h \sim N_e^2 V \sim 4 \times 10^{49}\ \mathrm{cm}^{-3}.$$

We consider this test of the proposed energy scale for our instrument to be a partial success, since the energy required to explain the ion chamber current leads directly through the proposed calculations to a good fit of the observed spectrum. However, the required emission measure appears to be about 80% larger than an acceptable value. If we wish to make the derived emission measure match that predicted from Christiansen's model, we must increase the 'realistic' fluxes per unit emission measure of Table I above those given by the theoretical spectra which were employed, thereby increasing the correction factors and making them closer to unity.

4. Conclusions

Use of 'realistic' X-ray spectra rather than the standard grey-body approximation in calculating ion chamber response leads to the conclusion that flux values quoted for the Michigan OSO III ion chamber are semi-independent of the shape of the thermal spectrum over a temperature range $2\times10^6 \leqslant T_e \leqslant 20\times10^6$ deg, to within 12%, on a relative energy scale. For flares in the range 10×10^6 to 20×10^6 deg, the relative flux values are correct to 7%.

A multiplicative factor which corrects the quoted fluxes to the 'true' fluxes is temperature-dependent, and may be calculated from a suitable theoretical spectrum. The correction factors cannot yet be stated with certainty, but they lie in the range 0.7–1.0. If Culhane's (1969) continua and Tucker and Koren's (1971) emission line powers correctly represent the Sun, the correction factors of Table I may be applied directly.

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