DERIVATION OF THE IONIZATION BALANCE FOR IRON XIV/XXV AND XXIII/XXIV USING SOLAR X-RAY DATA

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The relative concentrations of different ionization stages of iron are measured using the spectral emission of plasmas formed during solar flares. This is an extension of a study on the ionization balance of heavy elements, initiated with the analysis of calcium solar spectra (Antonucci et al., 1984). The data consist of a large set of iron spectra in the wavelength range from 1.84 to 1.88 Å, detected during the recent maximum of activity with the X-ray Polychromator Bent Crystal Spectrometer (BCS) on the NASA Solar Maximum Mission satellite and on the Soft X-ray Crystal Spectrometer (SOX) on the Hinotori satellite.

At the low densities typical of the solar corona, in the steady state the ionization balance of an element is a function of the plasma electron temperature. Hence, it can be measured for plasmas of known temperature and in slowly varying physical conditions, and in most cases, solar flare plasmas can be considered to be in such conditions.

The flares have been chosen to cover a wide range of temperatures. The iron spectra at flare onset have not been included in the analysis. A set of 273 spectra detected with the BCS and 54 spectra detected with the SOX spectrometer have been studied. The flare emission has been accumulated for periods varying from 60 to 120 seconds.

One example of iron spectrum, used in the analysis is shown in Figure 1; it has been obtained with the SOX spectrometer. At the longer wavelength side of the Fe XXV resonance line, well-resolved satellite lines are observed. The use of dielectronic satellite spectra to derive a number of plasma parameters is discussed in Gabriel (1972). The ratio of j to w, the resonance line, depends only on the electron temperature T_e, while the ratio of q to w depends predominantly on the Li-like to He-like ion concentration, N (Li)/N (He), and the ratio l to w depends almost entirely on the Be-like to He-like ion concentration, N (Be)/N (He). The notation of Gabriel (1972) is used for lines. The electron temperature and ion concentrations are determined by computing the synthetic spectrum which best fits the data. The method of analysis is described in Antonucci et al. (1982) and the atomic theory used to compute the intensity of the emission for the He-like and Li-like ions is by Bely-Dubau et al. (1982) and for the Be-like ions is by Dubau (private communication).

The results of the fitting procedure are displayed in Figure 2 and 3, where the N (Li)/N (He) against Te and the N (Be)/N (Li) against T_e curves are plotted. The dots denote BCS data points and the crosses SOX data points. In the same figures, the theoretical ionization balance curves from Doyle and Raymond (1981), Shull and Van Steenberg (1982), Jordan (1969), Jacobs et al. (1977) and Urnov et al. (1981) are shown. The experimental results differ from the theoretical predictions by an amount which is larger than random errors.

The experimental curves are a measure of ionization balance, provided the flare plasma is in steady state and isothermal conditions. The steady state is ensured since the flare analysed have rise and decay times of minutes. Moreover,

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the data points obtained in different flare phases define the same ionization balance curves.

In the case of non-isothermal plasmas the derived electron temperature and ion concentrations are average values. The effect of the weighting involved in the averaging on the definition of these quantities can be tested by constructing different model flare plasmas, with different non-isothermal distributions. The procedure is explained in more detail in Antonucci et al. (1984). A range of plasma temperature distributions from isothermal to almost flat distributions is considered. In this way it is possible to determine the uncertainty in the derivation of the Fe XXIII, Fe XXIV and Fe XXV ion abundances, due to temperature distributions substantially deviating from isothermal conditions. In Figure 4, the ion abundances experimentally measured (E) are compared with the theoretical curves (S-V) computed by Shull and Van Steenberg (1982).

The experimental continuous curves are derived for isothermal conditions, while the dashed ones are derived by considering the observed line ratios as produced by a non-isothermal plasma with temperature distributions of exponential form. The discrepancy between the experimental and theoretical values, in Figure 4, is considerably larger than the uncertainty in the derivation of the experimental values, due to possible deviations of the plasma from isothermal conditions. The discussion of the experimental ionization balance for iron will be presented in more extended form in a paper in preparation.

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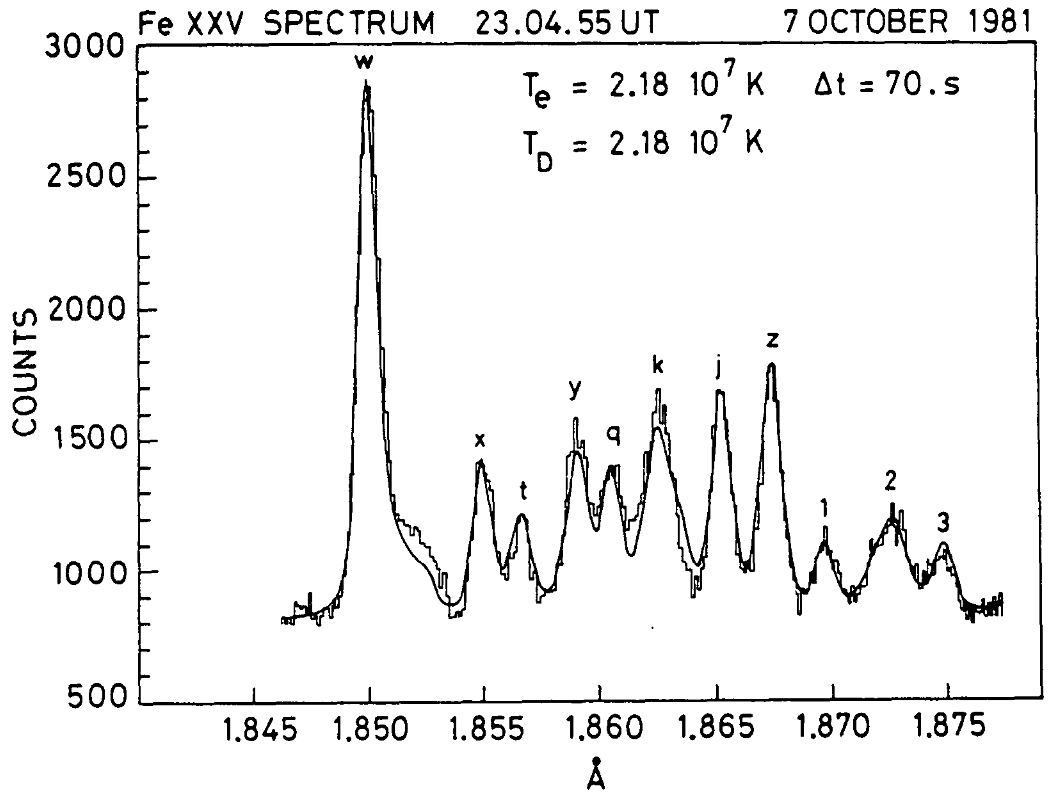

Figure 1. Fe XXV flare spectrum obtained with the SOX spectrometer

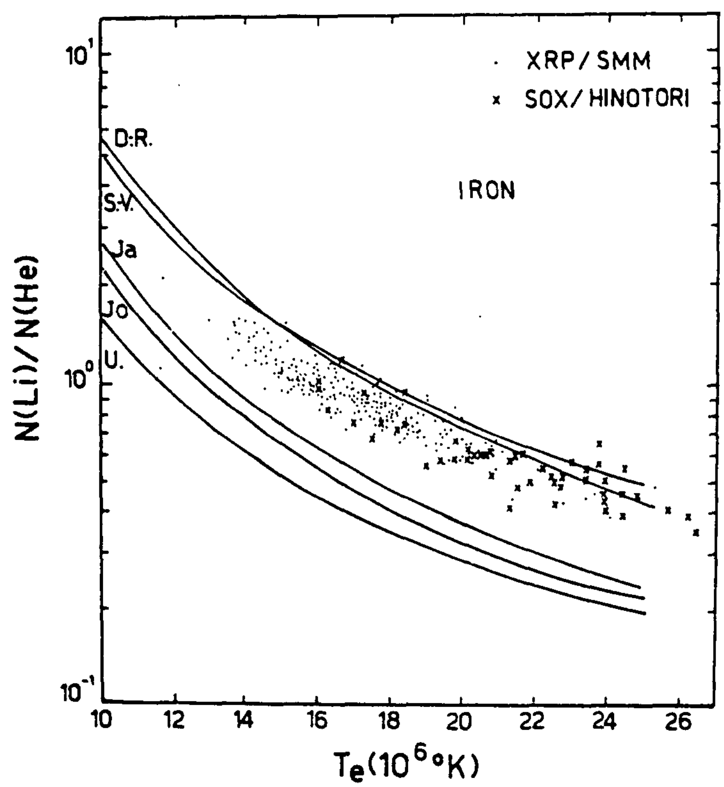

Figure 2. Ionization balance versus temperature for flare spectra

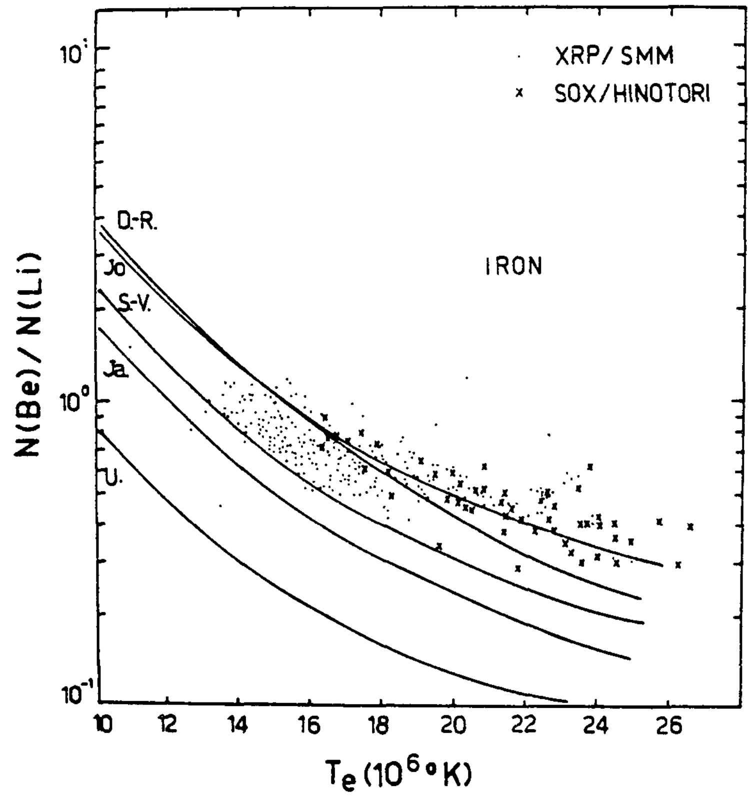

Figure 3. Ionization balance versus temperature for flare spectra

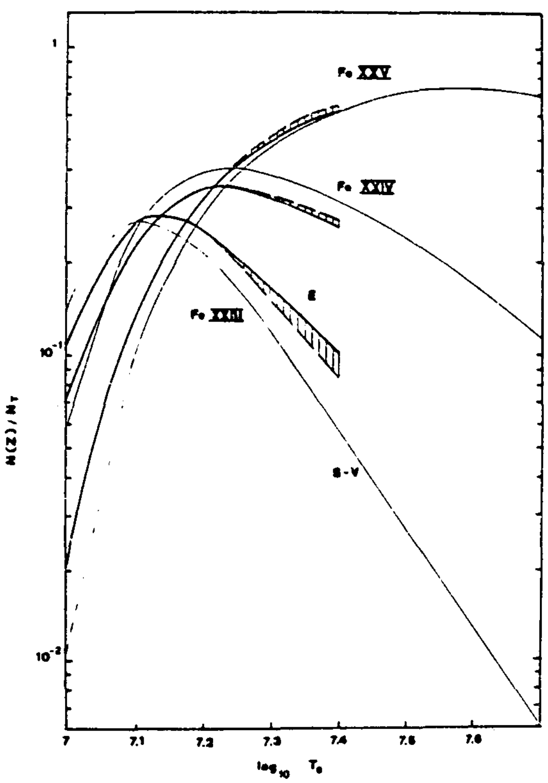

Figure 4. Fe XXIII, Fe XXIV and Fe XXV ion abundances versus temperature.