USE OF Al xII AND Mg xI LINES AS SOLAR PLASMA DIAGNOSTICS

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Abstract. We present three sets of observations of n = 1 to n = 2 lines due to helium-like aluminium (Al xII), made during two solar flares (25 August, 1980 and 19 October, 1986), using the X-Ray Polychromator on the SMM satellite. The observed temperature-sensitive line ratio G is shown to be consistent with the close-coupling calculations of Keenan and McCann (1987), although the ratio R, which is both temperature and density-sensitive for lower-Z elements, is not sufficiently well determined from these data to say more than that the observed values of R are not inconsistent with the theoretical calculations. This region of the spectrum also includes the helium-like magnesium (Mg xI) 1S - 3P line, and it is shown that the ratio of this line to the Al xII resonance (1S - 2P) line is a more sensitive indicator of electron temperature than are the Al xII G and R ratios. We demonstrate that the three ratios may be used together in order to derive values of emission measure, electron temperature and electron density during these flares.

1. Introduction

Lines due to helium-like ions in the soft X-ray spectrum of solar active regions and flares have been studied extensively over the past twenty years with the aim of using the diagnostic capability of their intensity ratios. The principal n = 1 to n = 2 lines are referred to as the resonance (r) 1S 1S - 1S 2P transition, the intercombination (i) 1S 1S - 1S 2P transition, and the forbidden (f) 1S 1S - 1S 2S transition. Gabriel and Jordan (1969) showed that, for lower-Z elements, such as oxygen and neon, the intensity ratio R = f/i is a strong function of electron density (N_e); there is also an electron temperature (T_e) dependence, which in principle may be found from the flux ratio G = (f + i)/r, a weak function of T_e. For heavier elements in solar plasmas, the R ratio is observed to be nearly equal to a low density limit. A number of theoretical calculations of these ratios as functions of T_e and N_e have been made since Gabriel and Jordan's paper (see, for example, Keenan et al., 1987, and references therein). The most accurate calculations are currently those using the close-coupling method (Burke and Robb, 1975), and these include the effect of auto-ionising resonances in the collisional excitation cross-sections which, in particular, make large contributions to the i and f line intensities. Recently, Keenan and McCann (1987) presented the results of their calculations of the G and R ratios for Al xII, comparing them to observations of two solar flares (Phillips et al., 1982; McKenzie et al., 1985). The measured G ratios were seen to be consistent with the theoretical value at the temperature of maximum Al xII.
emissivity of $7.9 \times 10^6$ K. However, Keenan and McCann point out in their paper that the value of $R$ ($\approx 2.0$) obtained by Phillips et al. would imply that $\log N_e \approx 12.7$ (in c.g.s. units) yet Phillips et al. deduce from the absence of certain Fe XXI and Fe XXII lines that $\log N_e$ must be $\leq 12$. In this paper we look again at the flare of 25 August, 1980; the region of the spectrum between 7.6 and 8.0 Å is examined closely and compared with simulations (see Figure 4 and Section 4) generated assuming the theoretical $G$ and $R$ ratios presented by Keenan and McCann together with line emissivities published by Mewe, Gronenschild, and van den Oord (1985).

A line due to the transition $1s^21S_0 - 1s3p^1P_1$ in helium-like magnesium (Mg xi) is also present in this region and it became apparent in the course of producing these simulations that the intensity ratio of the resonance line of Al xii and this Mg xi line was sensitive to $T_e$ (see Section 3). In order to study the simulation more objectively, a program was written to fit Voigt profiles to the lines present using an automatic least-squares curve-fitting algorithm (see Section 4). As expected, it was found that the Mg xi/Al xii ratio could be derived with greater precision than the Al xii $G$ and $R$ ratios and yielded more precise values of $T_e$. The next step was to employ the Mg xi/Al xii ratio in conjunction with the $G$ and $R$ ratios in a program which fitted for emission measure, $T_e$ and $N_e$ simultaneously, combining the information provided by all three ratios to give well-determined electron temperatures and emission measures, together with a (poor) estimate of electron density (this might be better determined in cases where $R$ is below the low density limit, corresponding to densities above about $10^{12}$ cm$^{-3}$).

2. The Observations

The three spectra examined here were recorded by the Flat Crystal Spectrometer (FCS), part of the X-Ray Polychromator instrument, on board the Solar Maximum Mission (SMM) satellite. Instrument details are given by Acton et al. (1980). The region under discussion was covered on a channel which uses an ADP crystal ($2d = 10.64$ Å) as dispersing agent, and covers the range 7.3–10.1 Å. The first spectrum was recorded during the decay of an M1 flare which occurred on 25 August, 1980, with the FCS scanning and accumulating data for 0.512 s at every point, with a step size of $\sim 0.0017$ Å. The total time taken to scan the region 7.6–8.0 Å was $\sim 2$ min.

The other two spectra were recorded in the early stages of the decay of a long-lived M5 flare which occurred on 19 October, 1986. In these two cases the spectrum was sampled in wavelength steps of $\sim 0.0010$ Å, accumulating counts for 0.256 s. The total time taken to scan 7.6–8.0 Å was approximately 100 s. The time which elapsed between recording these two spectra was approximately 14 min.

The region of the spectrum containing the lines which were measured spanned about 0.15 Å. This took about 40 s to record, during which time the flare intensity declined only slowly; any change in the plasma parameters which would have occurred between recording the first and last lines in the 7.6–8.0 Å region was considered small enough to be neglected in the data analysis.