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Observations of $1s^2$–1s np and 1s–np lines in RESIK soft X-ray spectra

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Abstract

RESIK is the X-ray bent crystal spectrometer on the *CORONAS-F* satellite. Between 2002 and 2003, RESIK collected numerous spectra of active regions and flares in the wavelength range from 3.37 to 6.09 Å. This range includes many strong emission lines due to transitions $1s^2$–1s np and 1s–np, in He-like and H-like ions, respectively; the $n = 2$ and 3 lines are routinely observed for Si, S and Ar ions. For some flares RESIK has observed enhanced emission in spectral features coinciding with lines due to transitions for n up to 9 or 10. Identifications of these features, not previously observed in astrophysical spectra, are presented in this paper. Their observed intensities are compared with those from theory.

Keywords: Sun; X-ray; Spectra; High-*n* transitions

1. Introduction

The RESIK (in Russian – REntgenovsky Spektrometers Izognutymi Kristalami) spectrometer (Sylwester et al., 2005) aboard the *CORONAS-F* solar observatory collected spectra during hundreds of solar flares in the highly interesting spectral range 3.37–6.09 Å. In this wavelength range the high n Rydberg series for Al XIII, Si XIV, Si XIII, S XVI and S XV are observed (Sylwester et al., 2004). In this paper observed line intensities are compared with theory. In previous observations, the emission line ratio of the higher-n soft X-ray transitions of the type $1s^2$–1s np, have been reported by Keenan et al. (1985, 1986, 1987) for $n = 2, 3$ in O VII, Ne IX and Mg XI ions. The results of their observations are in good general agreement with the theory. Keenan et al. (1990) compared observed Si XIII emission lines ratios $[1s^2–1s\ np]/[1s^2–1s\ 2p]$ ($n = 3$–5) recorded by flat crystal spectrometer (FCS) aboard *Solar Maximum Mission* and obtained substantial discrepancy between the observed (too low) and calculated line intensity ratios only in case of $n = 4$ line for Si XIII. They ascribe this discrepancy to problems with the calibration of FCS Channel 4 sensitivity.

Generally, in previous observations, including the early data from *OV 1–17* (Walker et al., 1974) and *OSO-8* (Parkinson et al., 1978), the line intensity ratios corresponding to $1s^2$–1s np transitions appear in agreement with predictions of the theory, even in a simple isothermal approach.

In this work, we investigate the relative line intensity ratios again using data collected by RESIK. We use spectra obtained for 14 selected flares, where the higher-n lines are particularly well seen. For the theory, we calculate the

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respective emission functions from the work of Mewe and Gronenschild (1981) and Mewe et al. (1985).

2. The observed spectra

For the study of relative line intensities within particular resonance series – so-called "line decrements", we use the RESIK spectra collected during 14 flares (eight of them of *GOES* C class, six of *GOES* M class). All these spectra have been measured between 2003 January 1 and 2003 March 14. In this period, all important RESIK instrument settings (i.e., the high voltage and the energy discrimination thresholds) were set to optimum values. The relative accuracy of RESIK wavelength sensitivity calibration is expected to be better than 10% over this time. Our event selection criterion was that the higher-n transitions should be discernible by eye in respective spectral plots. The overall 14-event average spectra in individual RESIK channels with descriptions of important lines and marked positions of respective ionisation limits of important line series are shown in Fig. 1. In Channel 1, the K XVIII triplet, lines from Ar XVII, Ar XVIII and the lines of H-like ion S XVI corresponding to transition from $n \geqslant 4$ are observed. In Channel 2, one can see the Ar XVII triplet and lines of S XV He-like ions (from $n \geqslant 4$). In Channel 3, the lines of sulphur are prominent: S XVI 1s–2p (Lyα), S XV $1s^2$–1s 3p and the lines of H-like Si XIV ion corresponding to transitions from $n \geqslant 5$ are noticeable. In Channel 4, the S XV triplet and the lines of H-like ions (Si XIV and Al XIII) corresponding to the transitions from $n \geqslant 3$ are seen. In Table 1, we present the theoretical wavelengths for the corresponding transitions expected to be present within the spectral range covered by RESIK.

The wavelengths for Ar XVIII were taken from Rice et al. (1999), while for the remaining elements we used atomic data from Verner's tabulations (Verner et al.,

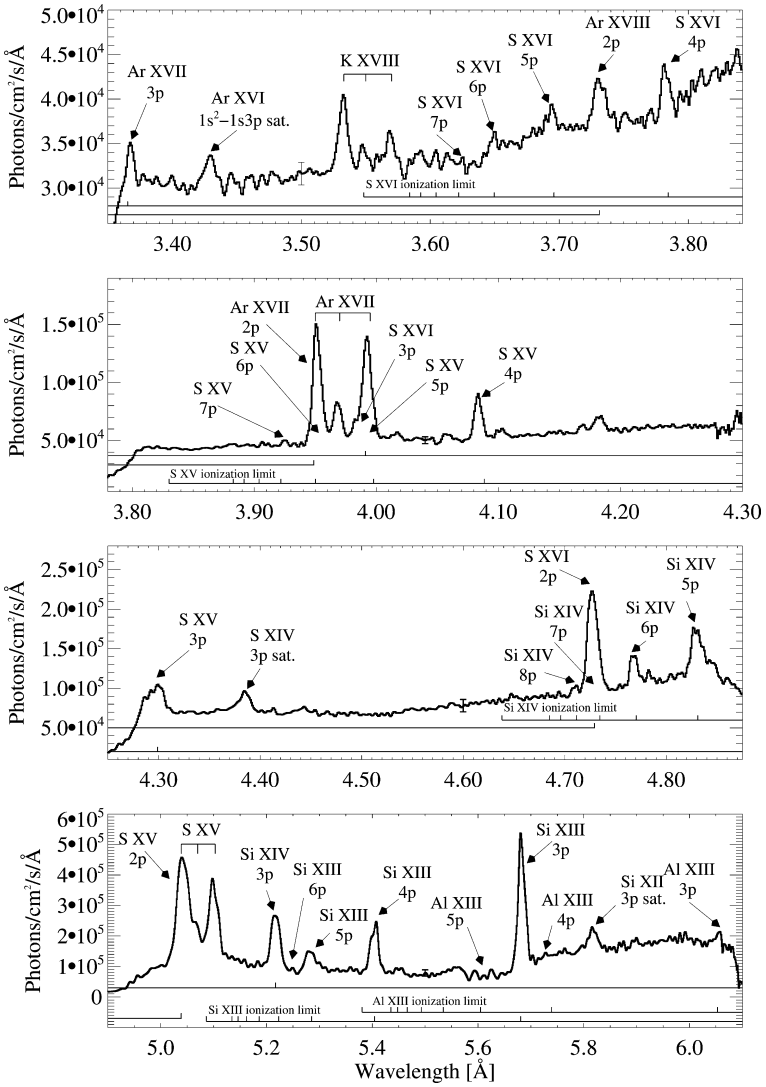

Fig. 1. Average spectra observed by RESIK for 14 flares (the total integration time amounts approximately to 9 h). In each panel, the formal, example uncertainty is presented, corresponding to r.m.s. error of the average for a given spectral bin.