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Lines in the range 3.2–6.1 Å observed in RESIK spectra

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Abstract

RESIK is a Bragg bent crystal X-ray spectrometer on board the *CORONAS-F* satellite. Between 24 August 2002 and 22 May 2003 RESIK collected a large number of solar X-ray spectra in four energy bands covering the range 3.2–6.1 Å. A recent absolute calibration has allowed us to make detailed identification of observed spectral features, and from observed line and continuum fluxes to get temperature, emission measure, etc. The lines were identified using spectra averaged over periods of various solar activity levels. These averaged spectra contain a number of strong lines with transitions in H- and He-like ions of K, Ar, S and Si. Some of them are resonance parent lines and their satellites which were observed with other spectrometers and have been described elsewhere. Here, we report detection of several lines not previously observed in solar spectra, including lines of H-like and He-like S and Si ions with transitions 1s–*n*p and $1s^2$–1s*n*p, *n* up to 10. In addition we provide identification of the He-like Cl (Cl XVI) triplet in the range 4.43–4.45 Å. The feature at 4.182 Å, which is the wavelength of the H-like Cl (Cl XVII) Lyα line, is probably a blend of S XIV satellites from cooler plasma.

Keywords: Sun; X-ray; Spectra; Line identification

1. Introduction

The RESIK (REntgenovsky Spektrometr es Izognutymi Kristalami) instrument is an uncollimated bent crystal X-ray spectrometer on the Russian *CORONAS-F* solar spacecraft. It operated from mid-August 2001 to mid-May 2003. The four channels of RESIK cover the wavelength range 3.3–6.1 Å. The RESIK wavelength coverage is at present unique as concerns the time and spectral resolution in soft X-ray band. Previously, the *P78-1* (Doschek et al., 1980), FCS and BCS on *SMM* (Acton et al., 1980) as well as *Hinotori* (Tanaka et al., 1982) and *Yohkoh* (Culhane et al., 1991) observed in the soft X-ray bands with high spectral resolution. The *OSO-8* (Parkinson et al., 1978) carried Bragg spectrometers with a similar energy coverage, however the spectral resolution was inferior. Among these experiments launched up until now, RESIK takes measurements of the spectra in the wavelength range 3.3–6.1 Å in the most comprehensive way. Brief descriptions of RESIK and initial observations have been given by Sylwester and Kordylewski (2002), Sylwester et al. (2002, 2003), Phillips et al. (2003, 2005) and Kepa et al. (2005). The instrument is described in detail by Sylwester, Gaicki, et al. (2005), and Sylwester, Sylwester, et al. (2005). Preliminary analysis of the spectra indicates the presence of many spectral features which until recently have not been identified. Among the known lines seen by RESIK are strong emission lines of highly ionized Si, S, and Ar, together with lines from the

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low-abundance, odd-Z elements K and Cl. Some of these lines are also seen in the spectra of bright, non-flaring active regions. We have calibrated the spectra (Sylwester, Gaicki, et al., 2005), established an absolute wavelength scale, and determined absolute photon fluxes. By analyzing the pattern of temperature behaviour of the lines observed, several spectral features observed for the first time from astrophysical plasmas can now be identified. In particular, we observe lines due to highly ionized chlorine (Sylwester et al., 2004). The absolute intensity calibration is now considered to be better than ~20% (Sylwester, Gaicki, et al., 2005), allowing an accurate absolute coronal abundance of Cl (Sylwester et al., 2004).

In this paper, we summarize the analysis of spectra collected between January 1 and March 14, 2003 with optimum instrument settings (high voltage and amplitude discriminator). In Fig. 1 (left panel) the distribution of analyzed events according to their *GOES* importance is shown (histogram). A total number of 1163 time intervals have been selected covering 388.2 h of time integration. There was a moderate level of activity during this period, though no single X-class and only few M-class flares were seen by RESIK. Fig. 1 (right panel) shows the summed spectrum for this period. The (logarithmic) flux scale is in units of photons $cm^{-2}\,s^{-1}\,Å^{-1}$. The temperature indicated in this plot is the value derived from the ratio of total emission in channels 1 and 2. The thin line below the spectra is the continuum level as calculated from the derived temperature ($T = 6.7$ MK) and emission measure ($EM = 1.6 \times 10^{51}\,cm^{-3}$) corresponding to the summed spectrum. The vertical dotted lines indicate spectral ranges covered by individual channels. Grey area is the spectral region not covered by RESIK.

The RESIK wavelength range (3.3–6.1 Å) is ideal for studying the abundances of a wide variety of elements with low (<10 eV) and high (>10 eV) first ionization potentials (FIPs). Emission lines of Ar (FIP = 15.76 eV, the highest value among the RESIK observed elements) around 4 Å, S (FIP = 10.4 eV) at 4.3, 4.73 and around 5.1 Å, and Si (FIP = 8.2 eV) at 5.21, 5.29, 5.4 and 5.69 Å are present and some are strong. The He-like Ar (Ar XVII) line triplet near 4 Å was observed even at low activity levels with no flares in progress. Weaker lines due to K, having the lowest FIP of any cosmically abundant element (4.3 eV), are seen in channel 1 between 3.5 and 3.6 Å. Also chlorine which is observed both in the photosphere and the corona (FIP = 12.97 eV) gives lines visible in channel 3 between 4.4 and 4.5 Å (cf. Fig. 3).

2. RESIK spectra

For each of the 1163 spectra we calculated the temperature and emission measure (isothermal approximation). These T_i and EM_i values have been derived from the ratio of total fluxes in the most energetically separated RESIK channels (1 and 4), covering the 3.4–3.8 and 5.0–6.05 Å regions, respectively. Based on T_i and EM_i values it has been possible to calculate the expected continuum level and subtract it from observed spectra in order to better see the line contribution. In the following, the spectra have been grouped into five temperature classes: "4.5 MK" contains the spectra with $T_i < 5$, "5.5 MK" ($5 < T_i < 6$), "7 MK" ($6 < T_i < 8$), "9 MK" ($8 < T_i < 10$), and "11 MK" ($T_i >$ 10 MK). The averaged spectrum in each group is shown in Fig. 2. These instructive plots show clearly the temperature dependence of various lines. Some lines are relatively strong at higher temperatures (e.g., the K XVIII triplet in the range 3.5–3.6 Å, 1s–2p lines of Ar XVIII at 3.73 and S XVI at 4.72 Å), while others are strong when the temperature is low. The latter include dielectronic satellite lines of Li-like Si XII ion at 5.565 and 5.818 Å. They are on the long wavelength side of their respective parent lines emitted by He-like Si ions (Si XIII) at 5.384 and 5.681 Å, and serve as a diagnostic for low-temperature plasmas (see Phillips et al., 2005). The triplet of lines due to He-like Ar (Ar XVII, 3.95–4.02 Å and S (S XV, 5.00–5.13 Å) are present in the spectra of all temperature groups.

In addition, three bumps occur towards the long-wavelength ends of spectra in channels 1, 3 and 4. The bumps in channels 1 and 4 are more pronounced at higher temperatures while that in channel 3 is observed to be stronger at lower temperatures. Their origin is unknown at present. To

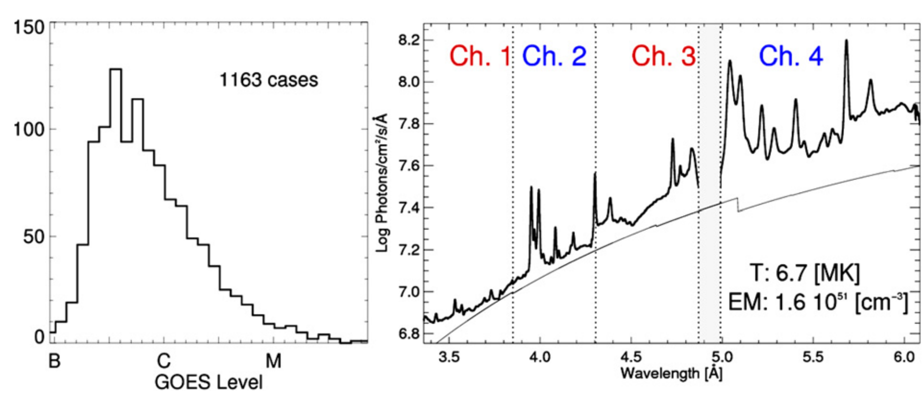

Fig. 1. *Left*: Histogram showing the distribution of flares according to their *GOES* importance. *Right*: The summed spectrum as obtained for ~400 h of integration (1163 individual spectra). The intensity scale is logarithmic. The thin line below the observed spectrum is a calculated continuum level (see text for details).

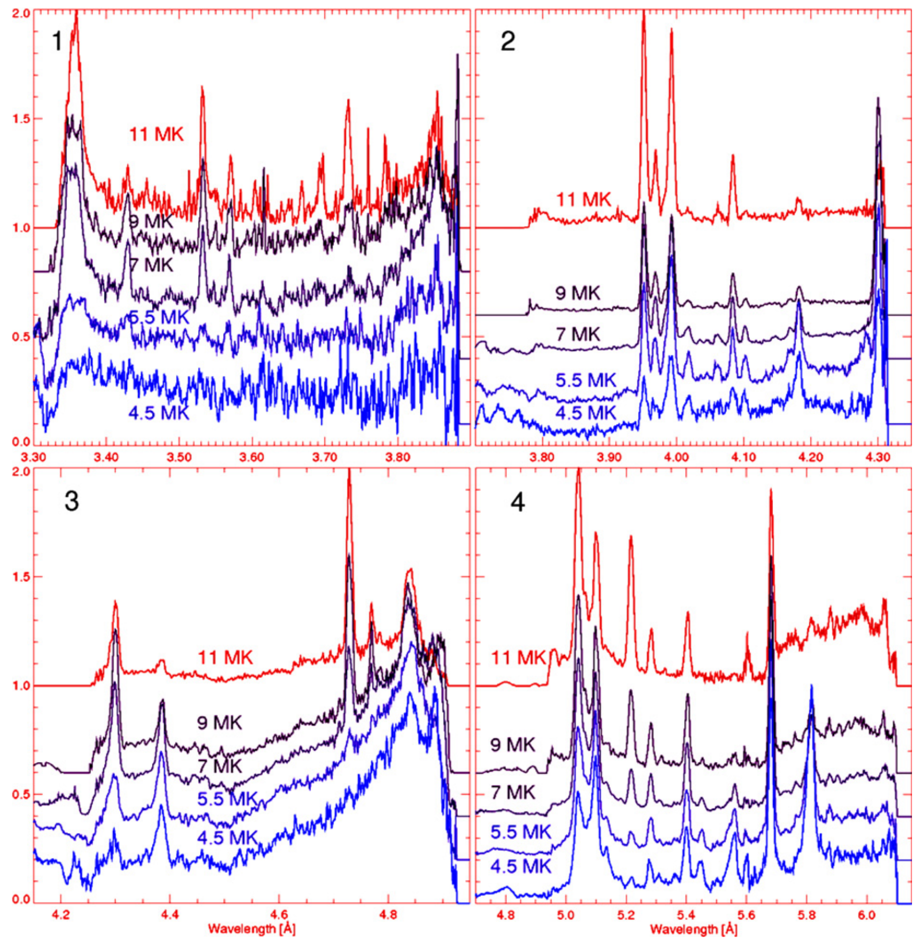

Fig. 2. The observed spectra (based on 1163 individual spectra) arranged according to their temperature class for the four RESIK channels (indicated in the top left-hand corner of each plot). On the vertical axis the line intensity (above the continuum) is indicated in relative units. The spectra for individual temperature classes have been shifted vertically for clarity.

make identifications of all line features, we took a "grand" summation of spectra in the temperature groups 7, 9, and 11 MK (channels 1 and 2) and of spectra in the temperature groups 4.5, 5.5, and 7 MK (channels 3 and 4). These spectra are shown in Fig. 3 with line identifications indicated.

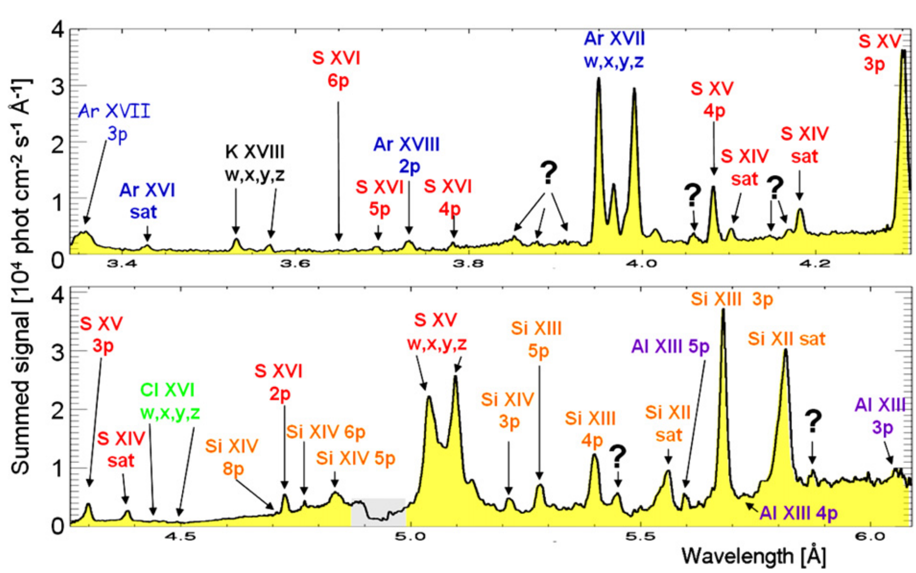

Fig. 3. Summed spectra (linear scale) for channels 1 and 2 (upper panel) and channels 3 and 4 (lower panel) with the continuum contribution subtracted. In grey the spectral area is indicated, where the uncertainty of the spectral shape determinations is rather large.

The RESIK range includes ~20 strong emission lines due to $1s^2$–$1snp$ and $1s$–np in He-like and H-like ions, respectively. The lines corresponding to the transitions for $n = 2$ and 3 are routinely observed for Si, S and Ar ions. For some flares we observe significant emission in these line series having n up to 9 or 10 (Kepa et al., 2005). On the summed spectrum shown in Fig. 3 one can see a number of lines corresponding to $n = 5$ transitions in H- and He-like ions and also a small peak corresponding to $n = 8$ transition in Si XIV ion at 4.71 Å.

3. Concluding remarks

The wavelength coverage of RESIK is suitable for a number of research projects which include:

- Identification of the remaining weaker lines in the RESIK range. Preliminary analysis indicates presence of many satellite lines and numerous lines with higher n transitions in H-like and He-like ions.
- Determination and analysis of line series decrements and corresponding theoretical calculations for thermal and non-thermal plasma.
- Determination of absolute element abundances in flare and active region plasmas and their possible time variations from line-to-continuum ratios.
- Investigation of FIP dependence of coronal plasma composition.
- Determination of the temperature structure and its variation of emitting regions – some ~20 lines with well known emission functions can be used in this respect (Kepa et al., 2004).

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