EARLY RESULTS FROM RESIK AND DIOGENESS SOFT X-RAY SPECTROMETERS ABOARD CORONAS-F SATELLITE

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ABSTRACT

We present examples of early, unreduced results obtained from the instrument package dedicated for spectroscopic studies of coronal flaring plasma composition. The package consists of two Bragg spectrometers, RESIK and Diogeness. These instruments have been launched aboard the Russian Coronas-F solar observatory on 31 July 2001. The data being received from these two spectrometers allow for determining the absolute abundances of several important elements including that of low and high first ionization potential (FIP). Based on the data which have been (and hopefully will be) obtained, we will investigate fast temporal variations ($\sim$ 1 min) of the plasma composition in flares and hotter active regions. The analysis of spectra obtained will certainly allow for spectroscopic studies of several, so-called "triplet" lines forming in He-like, highly ionized plasma since the spectra received are apparently of unprecedented quality.

The Coronas-F Mission is expected to be supported for at least two years.

Key words: X-rays; solar flares, spectra, instruments.

1. INTRODUCTION

The Coronas-F mission has been successfully launched around 08:00 (local time) on 31 July 2001 from Plesetsk northern Russian range. The booster used was the Ukrainian made Cyclone-3 rocket (184 tones) which put the satellite (2260 kg) on nearly circular (539.7 km x 498.5 km), 95 min, semi Sun-synchronous orbit of 82.5 degree inclination. From such an orbit, unocculted observations are possible for periods of up to 20 days (this situation was met at the time of writing). The payload (350 kg) includes several solar and magnetospheric instruments. It is pointed towards the centre of Solar disc with few arcmin accuracy. Its absolute orientation (roll angle) may slowly drift in time (few degree/hour). Since mid-August we are receiving about 15 MB of data per day from both spectrometers. The data are being recorded by dedicated IZMIRAN ground based station (twice daily) and can be accessed from Coronas-F data server by internet. In the following, we will shortly describe our spectrometers placed aboard Coronas-F and present examples of reformatted, raw, unreduced data received. For more details concerning the instrument's construction and operation see Sylwester and Kordylewski (2001).

2. DIOGENESS

Diogeness is a scanning flat crystal spectrometer and photometer. The instrument consists of three functional blocks: the spectrometer (BS), photometer (BF) and onboard computer (PRAM). The scanning range of the spectrometer covers 140 arcmin. Details concerning the crystal used and wavelength ranges covered are given in Table 1. During intense flares we sample the spectra about twice faster than normally (0.4 s). Two of the crystals used in Diogeness are identical Quartz, mounted in the so-called Dopplerometer configuration. Such arrangement of the crystals allows us to precisely measure expected flare related Doppler shifts of X-ray lines. For the source plasma being at rest, the maxima of lines scanned in opposite directions would be measured nearly simultaneously. If any radial motions are present, the lines are off-set in time. The relative off-set can be directly translated to the velocity. The spectrometer is composed of four crystals. A special construction of double Archimedean cam driving the

Figure 1. The launch of Coronas-F, early morning 31 July 2001 from northern Russian range Plesetsk.

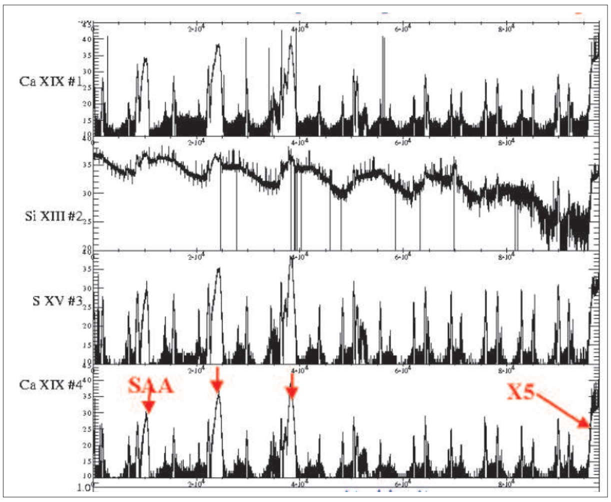

Figure 2. Example of 12 hours of Diogeness time records obtained on 25 August 2001 in the four spectral channels of the spectrometer. Vertical arrows point to the signal rise due to passage through the SAA. Other regularly repeating spike patterns are related to passages of the satellite through the polar fringes of Van Allen belts. The inclined arrow in the bottom panel points to the rise of the signal due to the X5 solar flare ∼16:00 UT. The "real" X-ray spectra are represented by "noise" seen atop the modulated pattern.

scanning motion of the crystals allows two phases of scanning.

Table 1: Diogeness Characteristics

Channel	1	2	3	4
Crystal	Quartz	ADP	Beryl	Quartz
Plane	$10\bar{1}1$	101	$10\bar{1}0$	$10\bar{1}1$
$2d_1$ Å	6.6855	10.5657	15.9585	6.6875
λ_{obs} [Å]	3.1779	5.0348	6.6492	3.1779
λ_{theor} [Å]	3.1781	5.0374	6.6488	3.1781
Line	Ca XIX	S XV	Si XIII	CaXIX
λ_{min} [Å]	3.1436	4.9807	6.1126	2.9601
λ_{max} [Å]	3.3915	5.3721	6.7335	3.2123
R_C [μrd]	91	91	15	90
FWHM [arcsec]	24.1	68.1	94.1	25.6

R_C – The total reflection coefficient.

The first phase lasting approximately 120 s constitutes the slow scan with the angular velocity of the scanning arm of ∼ 1 arcmin/s. As the arm moves further-on, the reciprocal fast scan is usually executed with the angular velocity about twenty times faster. The observed widths of spectral lines reflect the intrinsic line widths (thermal and non-thermal broadening) since the instrumental rocking curves widths are much smaller. They are actually smaller (Fig. 5) than that characteristic of the preceding spectrometers. The source brightness profile along dispersion axis was thought to be obtained from the multi-grid 10" (FWHM) slit collimator records (2 keV - 4 keV and 4 keV - 8 keV). However, we have noticed from inspection of the early data, that the collimator signal appears to be absent in the data stream. In Fig. 2, we show examples of Diogeness spectral signal obtained over 12 hours period preceding the 25 August 2001 X5 flare. It is seen that the record for Si XIII channel is modulated with a period of satellite orbit which may suggest some, yet not well understood instrumental factor(s). In Fig. 3 we present the blow-up of the portion of the records related to the rise phase of the mentioned X5 flare. Besides Ca XIX spectra shown in Fig. 2 - 4, Diogeness is measuring important line complexes including the helium-like "triplets" of S XV (also observed by *Yohkoh*) and Si XIII. This latter triplet (not observed in solar spectra from the SMM era) contains the "coolest" lines (T > 5 MK) in the set of RESIK and Diogeness spectra. In this latter range, there are diagnostically important lines of H- and He-like ions

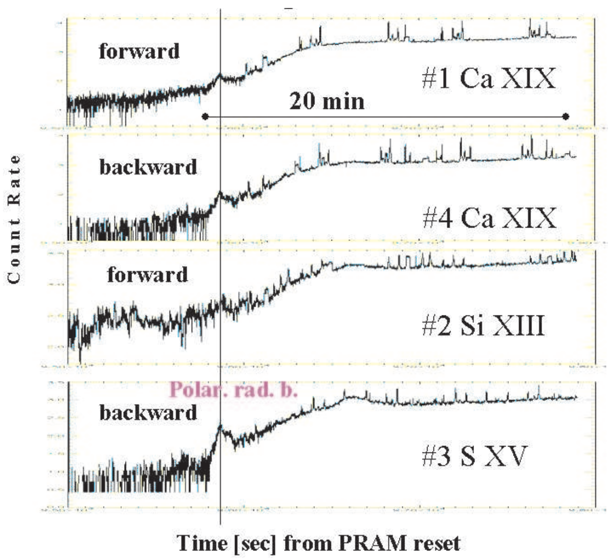

Figure 3. Diogeness spectral records for the rising portion of X5 flare on 25 August 2001. The sharp rise is seen in the "continuum" emission as well as the scanned spectral lines on top of it.

Table 2. RESIK Crystal Characteristics

Section	A	A	B	B
Crystal No.	1	2	3	4
Material	Si	Quartz	Si	Quartz
Plane	111	$10\bar{1}0$	111	$10\bar{1}0$
Bent radius [mm]	1110	1450	1000	525
2d [Å]	6.27122	8.510558	6.27122	8.510558
Wavelength range				
1st order [Å]	3.369 – 3.879	4.307 – 4.890	3.821 – 4.326	4.960 – 6.086
Average reflecting properties[a]				
1st order λ[Å]	3.579	4.599	4.073	5.523
R_c [μrad]	51	20	50	17
FWHM [$\mu rad/arcsec$]	84/17	62/13	113/23	94/19
Peak reflectivity [%]	51	24	36	13

[a] – from Cowan & Brennans Code (Brennan S. and Cowan P.L.: 1992, *Rev. Sci. Instr.*, **63**, 850), assuming perfect crystals. Thanks to Charlie Brown

of silicon as well as 1s-3p, and 1s-4p lines of Helium-like aluminum and 1s-4p, 1s-5p lines of H-like magnesium (cf. review by Dubau and Volonte, 1980). The photometer consists of a system of two simple proportional detectors with apertures of 0.3 cm^2 and 0.01 cm^2. However, we noticed that the photometer signal has unfortunately gone after initial 5 hours of the instrument operation. Diogeness covers two of the four wavelength ranges being now measured by *Yohkoh* BCS. Cross comparison of the spectra between these instruments will allow to better understand the linearity of the BCS wavelength scale and help to calibrate other instrumental problems related to bent crystal devices, (both RESIK and BCS). As the possibility exists to change the on-board program of Diogeness operation, we will exercise this in order to try to revitalize the collimator detector and the BF photometer after we check the ground-to-satellite telemetry link.

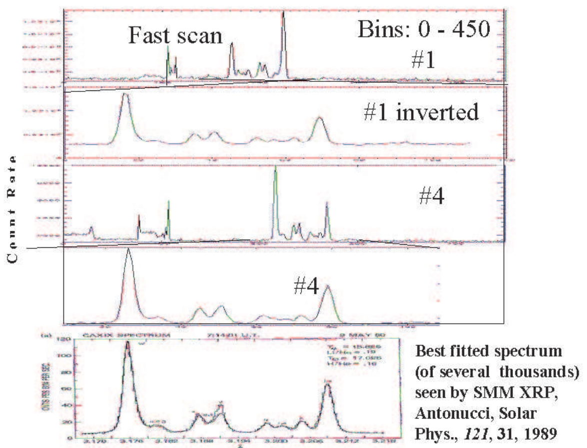

Figure 4. High resolution Ca XIX triplet spectra taken during early decay of the X5 flare. The upper two panels cover the entire range scanned (one scan only shown), including the "fast scans". The lower two panels present the actual resolution of the spectrometer. The spectra measured appear to be the best available astrophysical observations in this spectral region, superior in spectral resolution to the SMM BCS results (see bottom panel).

3. RESIK

RESIK is the bent crystal spectrometer designed to cover the spectral range below 6 Å with the aim to measure line and continuum fluxes for many lines belonging to ions with atomic numbers $30 > z > 14$. The crystals used as dispersive elements are thin wafers (0.5 mm and 1 mm) of silicon and quartz monocrystals of large area (Table 2). The wavelength channels of RESIK spread over ten different spectral bands (including higher order reflections) covering almost entirely 1.1 Å - 6.1 Å range. The crystals are bent to a convex cylindrical profiles since this geometry allows to reduce the overall size of the crystal-detector assembly. As a consequence of the wavelength coverage selected, the widths of most of the lines to be measured are defined (in the first order of reflection) by the detector bin widths which means

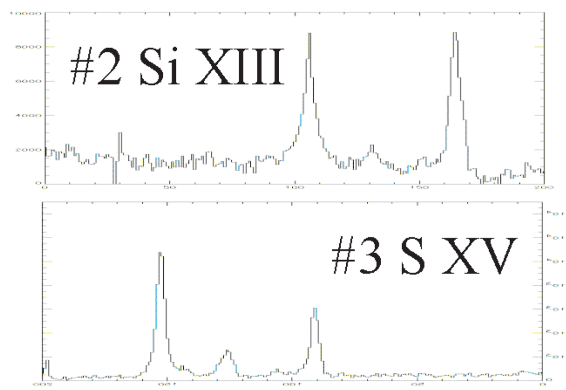

Figure 5. Average decay phase spectra in the other two spectral bands seen by Diogeness. The spectral averaging has been made over the decay period of the X5 flare.

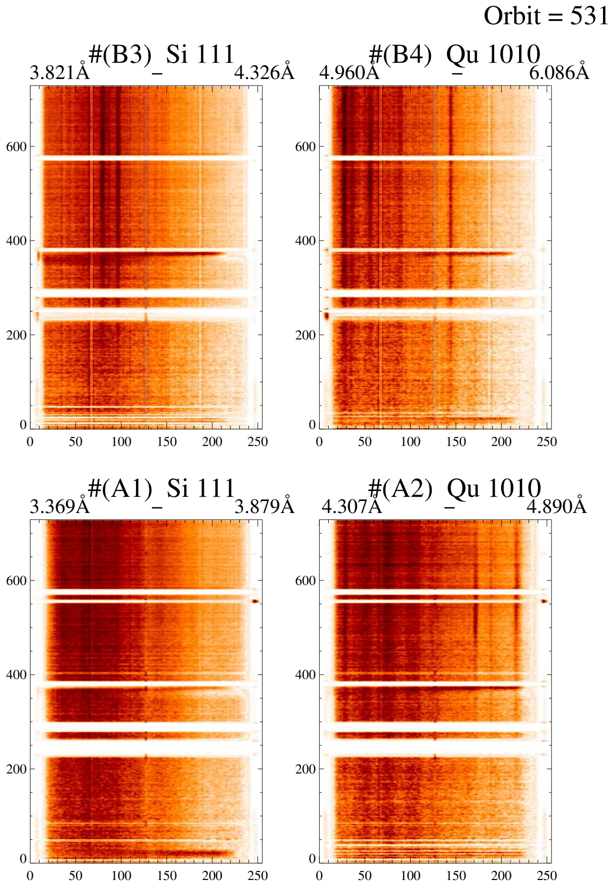

Figure 6. Examples of spectral time evolution from RESIK records (grey-scale representation). The four panels represent the four spectral ranges covered in the first order reflection. The time runs vertically and wavelength horizontally (spectral bin No.) in each panel. Individual spectra are recorded each 10 s. Vertical strips represent spectral lines. Spectra has not been corrected for instrumental effects.

that the observed line widths are larger than respective physical widths. The crystals selected for the spectrometers were chosen because they were not expected to be a subject to fluorescence. Previous spectrometers have had problems with background flux caused by photons emitted from diffracting crystals when they were illuminated with energetic photons (E >11.2 keV in case of germanium crystals). The elimination of this fluorescence contamination was of particular importance during the flare impulsive phase. The absence of fluorescence contamination is essential when abundance measurements involving the ratio of the line to continuum fluxes are to be made. However, in the initial spectra recorded by RESIK we see substantial background signal, similar in appearance to that related with the fluorescence. We are investigating means to decrease this very unwanted interference (reloading amplitude discrimination levels in the electronics of the instrument from the ground). In each of the two RESIK spectrometer units (A & B) a double position-sensitive proportional counter is used in order to record the crystal-diffracted photons. The detectors used are upgraded spares from Solar-A (*Yohkoh*) BCS (Culhane et al, 1991). There are no moving parts (except for the stepper motors used for calibration purposes (Fe^{55}) and no collimator is used, so the X-ray radiation of the entire solar corona contributes to the spectra. In Figure 6 we present the example spectral records in the four main wavelength bands (first order reflection) measured by RESIK during a flare on 4 September 2001. The time runs vertically (covering 2 hours during a flare rise phase) and the wavelength runs horizontally (as indicated). Spectral lines are pronounces as dark vertical patches. The identification of lines seen is in progress.

Scientific Rationale

Here we list a number of parameters and problems which will be determined or addressed based on the analysis of incoming Diogeness (D) and RESIK (R) spectra:

1. Spectra "formation" temperature for each range covered obtained from fitting of the synthetic spectra (R&D).
2. Turbulent line widths (D).
3. Differential emission measure distribution for hot coronal structures: $5 < T < 60$ MK, (R&D).
4. "Absolute" flaring plasma Doppler motions of the hotter component (Ca XIX w, T > 10 MK) using dopplerometer concept (shifts of few km/s can be reliably measured), (D).
5. Ionization state of the plasma (i.e. the analysis of "equivalent" ionization temperature) as derived from respective hydrogen (Ly_α) to helium-like resonance lines ratios of Si and Ca ions (R&D).
6. Verification of atomic theory for ionization balance, (R&D).
7. Search for possible local non-Maxwellian velocity distribution of collisional exciters, (R&D).
8. Determination of plasma composition for elements with low (4.34 eV for K) and high (15.79 eV for Ar) FIP, (R&D).
9. Studies of coronal composition variability in time and between different coronal structures, investigation of possible active region ageing and/or solar cycle effects (R).

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