RESIK – A High-sensitivity Soft X-ray Spectrometer for the Study of Solar Flare Plasmas

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1 Introduction

Flares are the impulsive release of energy that occur in solar active regions. The play an important role in the overall energy balance of the Sun, particularly during times of maximum solar activity. In order to understand what phenomena that produce flares, it is important to measure the physical paramaters of the flare plasma (temperature, emission measure and compostion) as the flare evolves.

RESIK (REntgenovsky Spektrometr s Izognutymi Kristalami) is a Bragg crystal spectrometer designed to observe active region and solar flare plasmas and has been selected for the payload of the KORONAS-F (FIAN coordinated) satellite. This mission is one of a series of observatories devoted to solar physics that will be launched by Russia (???) during the decay of the current solar cycle and into the rise of the next.

The primary objective of the experiments aboard the KORONAS-F satellite is to study global solar oscillations, solar constant variation, physics of flares and active regions. Besides RESIK, KORONAS-F will carry a number of instruments with complementary science objectives - important ones are DIOGENESS, a flat crystal spectrometer, and RES-K, a spectropolarimeter. KORONAS-F also carries instruments that will make high resolution measurements of the gamma-ray flare spectra, in situ charged particles composition, solar neutron, UV and radio fluxes. The satellite is to be put in a circular orbit around the Earth with an altitude of 500 km and its orbital plane inclined at 82^{o} to the equator - this results in periods of several days of uninterrupted observations of the Sun (the longest satellite night will last for 35 minutes). The operational lifetime of the satellite is expected to be not less than 2 years.

2 Scientific Objectives

One of the primary objective of the RESIK spectrometer will be the study of active region and flare plasma elemental composition, coupled with the determination of differential emission measure distributions.

The determination of elemental composition of solar plasma has recently become one of the central problems of solar UV and X-ray spectroscopy. Various independent observations support the idea that the solar plasma composition is not uniform between individual flares, between active region or between regions with open or closed magnetic structures. Some investigators believe that a First Ionization Potential (FIP) dependent mechanism operates in the lower temperature region of the "transition layer", causing enrichment of the low-FIP elements in the corona. Detailed analysis of time variations of abundance pattern in various coronal structures will certainly help to reveal physical mechanisms responsible for enrichment of coronal plasma abundance. Systematic measurements of (soft X-ray) spectral range where the resonance lines of both high and low-FIP element ions are present may show any patterns in elemental enrichment.

The determination of differential emission measure (DEM) distribution, characterizing the spread of the source plasma temperature, is a basic step in derivation of the elemental composition. Knowledge of the DEM evolution will allow for studies of the energy balance of the solar active region and flare plasmas. Investigations of the energy balance are important for better understanding of the heating mechanisms and processes leading to the energy dissipation, transport and redistribution between its various forms.

Relative spectral line intensities are essentially related to the distribution of temperature within the source plasma, while the absolute line intensities are proportional to the plasma emission measure, ϵ, and the elemental composition. The high sensitivity of RESIK and its broad spectral coverage will allow the study of a composition of flare and active region plasmas for a range of elements including S, (Ca, Fe, possibly in the 2nd and 3rd order), Ar, Mg and Si (DIOGENESS spectra will contain additional information on K). Of special interests will be measurements of the continuum radiation since the line-to-continuum ratio will allow to fix derived abundances in "absolute" scale i.e. relative to hydrogen.

By measuring the line fluxes formed in a wide temperature interval it would be possible to perform a differential emission measure analysis in the 5-20 MK range. It has been observed for the Mg XII Lα line, that for components of the Lα doublet, the intensity ratio often departs from the theoretically predicted value 0.5 . It has been suggested [?] that opacity effects may be responsible for the observed deviations. RESIK spectra would allow the study of such doublet for S XVI and Si XIV resonance and subordinate lines. It would be interesting to analyse relative intensities of the lines of higher members of the series, with excitation energies close to the ionization and thermal limit. The intensity of such lines might help to study influence of the excited state populating processes like charge exchange, recombination etc. and a possible role of non-Maxwellian "tails" in electron energy distribution of colliding electrons.

To fulfil such a broad scientific objectives we have to combine possibility to observe flares and active regions at the period of low expected solar activity, taking into account several stringent construction limitations. Four relatively wide bands were selected for differential emission measure and abundance studies in flares and non-flaring active regions. By selecting widebands, the coverage of many lines important for the described study has been traded against the possibility of detailed line profile analysis.

3 Instrument Concept

The basic concept of the RESIK is similar to that spectrometers flown of several previous missions - a diffracting crystal is used to select a limited wavelength range that covers spectral emission lines of interest.

The instrument consists of the two separate modules: the spectrometers and main electronics box. The main electronics box (including the microprocessor) will be located inside the pressurized section of the KORONAS spacecraft. The spectrometers and front-end electronics are mounted in a box open to space.

The RESIK instrument employs four bent crystals (in two seperate spectrometers) to diffract in incident X-rays. The use of bent crystals allows the entire wavelength range to be integrated simultaneously, whereas a flat crystal spectrometer must scan to cover its wavelength range. The channels of RESIK cover four different spectral bands: 3.37– 3.79 Å, 4.31 – 4.89 Å, 3.82 – 4.33 Å, and 4.96 – 6.09 Å.

The crystals are bent to a concave cylindrical profiles - since this geometry allows to reduce the overall size of the crystal-detector assembly. The crystals of the two spectrometers are deployed with their dispersion axes opposed. As a consequence of the wavelength coverage selected, the widths of most of the lines to be measured by RESIK will be defined by the instrumental effects (i.e. will be larger than actual physical widths).

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The crystals selected for the spectrometers were chosen because they were not subject to fluorescence. Previous spectrometers have had problems with a background flux caused by photons emitted from the diffracting crystal when the crystal is illuminated with energetic photons (11.2 KeV in the case of Germanium). The elimination of this background is of particular importance when abundance measurements, involving the ratio of the line to continuum fluxes, are being made.

In each spectrometer a double position-sensitive proportional counters is used to record the diffracted photons. The detectors used will be spare units from Yohkoh [**?**]. Spare analogue electronics processing cards are also being used.

There will be no moving parts (except for the stepper motors used with the Fe^{55} calibration sources) and no collimator will be used.

The RESIK instrument is to be constructed by a consortium of four groups, namely, the Mullard Space Science Laboratory (Univerity College London) and the Rutherford Appleton Laboratory in the UK, the US Naval Research Laboratory, and the Space Research Centre of Polish Academy of Sciences. The RESIK consortium interfaces with IZMIRAN (??????) in all matters relating to the spacecraft interface.

All the parties involved share the same rights to access, use and interpretation of the data from the RESIK instrument. The data will be jointly analysed and general public access will be allowed immediately after reformatting. The arrangements for data distribution will be defined at a later date.