The TESIS experiment on EUV imaging spectroscopy of the Sun

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Abstract

The TESIS is a set of solar imaging instruments which is developed by Lebedev Physical Institute of Russian Academy of Science to be launched aboard the Russian spacecraft CORONAS-PHOTON at the end of 2007 – early of 2008. The main goal of the TESIS is to provide complex observations of solar active phenomena through from the transition region to the inner and outer solar corona with high spatial, spectral and temporal resolution in the EUV and Soft X-ray spectral bands. The TESIS includes five unique space instruments: the MgXII Imaging Spectroheliometer (MISH) with spherical bent crystall mirror for observations of the Sun in the monochromatic MgXII 8.42 Å line; the EUV Spectoheliometer (EUSH) with grazing incidence diffraction grating for registration of full solar discs in monochromatic lines of the spectral band 280–330 Å; two Full-disk EUV Telescopes (FET) with multilayer mirrors covering the band 130-136 Å and 290-320 Å; and Solar EUV Coronagraph (SEC) based on the Ritchey-Chretien scheme to observe the inner and outer solar corona from 0.2 to 4 solar radiuses in spectral band 290-320 Å. The TESIS experiment will start at the rasing phase of the 24th cycle of solar activity. With advanced capabilities of its instruments, the TESIS will help better understand the physics of solar flares and high-energy phenomena and provide new data on parameters of solar plasma in the temperature range $10^5 - 10^7$ K. This paper gives a brief description of the experiment, its equipment and scientific objectives.

Key words: Sun; Flares; X-rays

1 Introduction

The experiment TESIS dedicated to EUV imaging spectroscopy of the Sun is scheduled to be started at the end of 2007 – early of 2008 on board the Russian spacecraft CORONAS-PHOTON with the aim to provide complex observations of solar energetic phenomena in the transition region and lower and outer corona with a set of imaging instruments. The organization responsible for the experiment TESIS and its instrumental equipment is the Laboratory of X-ray Astronomy of the Sun (Laboratory XRAS) of the P.N.Lebedev Physical Institute of Russian Academy of Science (http://tesis.lebedev.ru).

The laboratory XRAS began systematic studies of solar EUV radiation in 1957. The first experiment at a measuring of solar X-rays was carried out by Mandel'stam, Efremov and Lebedev aboard the second Soviet Earth satellite launched on 1957, November 3 (Mandel'Stam, 1965). Scientific apparatus on satellite registered many signals, but they all were not due to solar X-ray. It became clear later that these signals were due to radiation belt particles. Apparently, these measurements were the first observations of the radiation belts. Afterwards, space instruments designed by the Laboratory XRAS worked on board third Soviet satellite (May 15, 1958), spacecrafts Cosmos-166 (June 14, 1967), Intercosmos-1 (October 14, 1969), Intercosmos-4 (October 14, 1970) and on other Soviet spacecrafts dedicated to observations of the Sun.

During the last decade, the Laboratory XRAS carries out its space experiments in the frameworks of Russian programm CORONAS (Complex ORbital ObservatioNs of the Activity of the Sun) developed in cooperation with Russian Space Agency. From 1994 to 2008, this programm assumes the launch of three spacecrafts adopted for investigation of the Sun and solar-terrestrial connections.

The first satellite from the three planned, CORONAS-I, was successfully started on March 2, 1994 from the cosmodrome Plesetsk in the North of Russia. The scientific payload of spacecraft included the TEREK-K multichannel telescope and the RES-K spectroheliometer operating in the EUV band 180-304 Å (Sobelman et al., 1996). In the experiment, the first systematic observations of the Sun were performed at wavelengths 132, 175 and 304 Å with spatial resolution up to 1 arcsec per cell. Monochromatic spectrograms of the Sun in the bands 8.41-8.43 Å and 180-209 Å without overlapping were also obtained for the first time. Experiment successfully revealed new aspects of solar flares in EUV emission. Unfortunately, the scientific program of the experiment was ceased in July 5, 1994 because of the lost of the satellite orientation. Some results obtained during the experiments TEREK-K and RES-K are considered by Zhitnik et al. (1999).

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The following spacecraft of the CORONAS project was the CORONAS-F launched in July 31, 2001 (Oraevsky and Sobelman, 2002). On board the satellite, the Laboratory XRAS carried out experiment SPIRIT to study solar flares and high-energetic phenomena during the maximum of solar activity with multichannel telescope SRT-C and spectroheliograph RES-C (Zhitnik et al., 2003a). Over four years of observations, from July 31, 2001 to December 6, 2005, SPIRIT obtained about 100 000 images of the full Sun at wavelengths 175 Å and 304 Å, more than 200 000 monochromatic images of the Sun in the MgXII 8.42 Å line and about 10 000 spectroheliograms in the 177-207 Å and 285-335 Å bands. The data obtained during the experiment characterize the dynamics of solar plasmas with a temperature $10^5 - 10^7$ K on time scale from several seconds to tens of day and spatial scale from thousands to hundreds of thousands of kilometers. Main results of the experiment SPIRIT are summarized in Zhitnik et al. (2003b, 2006).

Basing upon its previous space projects, the Laboratory XRAS develops the next experiment, TESIS, which will take place on board the third spacecraft of the CORONAS programm – CORONAS-PHOTON. The experiment is directed at acquiring data on the physical parameters and spatial structure of plasma in the transition region and in the inner and outer corona with the aim to solve the following fundamental problems of solar physics: (1) the study of mechanisms of solar wind generation and coronal heating, (2) the development of methods for space weather forecasting, (3) the study of the production and evolution of high-temperature plasmas in the corona, and (4) the analysis of processes of magnetic energy accumulation and release before and during flares. Spatial, spectral and temporal characteristics of the TESIS is improved significantly compared with characteristics of its predecessor, SPIRIT. This is largely determined by the last year's progress in production of high-resolution optics based on multilayer normal-incidence mirrors.

In the present paper, we give a brief description of the TESIS experiment from the viewpoints of the spacecraft characteristics in Section 2, the scientific instruments in Section 3, and the onboard data processing and telemetry rate in Section 4. In the Section 5 we discuss the scientific objectives of the experiment.

2 The spacecraft

The CORONAS-PHOTON is to be launched at the end of 2007–early of 2008 from the cosmodrome Plesetsk (latitude 62°43', longitude 40°17'; Arkhangelsk region) into a nearly circular orbit of about 550 km altitude, 82.5° inclination and 95 min period (Kotov et al., 2001). Each three months, the orbit of the spacecraft will become completely illuminated for a period of 10-20 days, pro-

viding possibilities for continuous observations of the Sun during about a half of its period of rotation.

The satellite will carry 12 scientific instruments (X-ray and gamma-ray telescopes and spectrometers, charged particles analyzers, monitors of X-ray and ultraviolet radiation and a magnetometer) with total weights of about 540 kg (see http://www.astro.mephi.ru/english/e_photon.htm). The weight of spacecraft with two external solar panels is equal to 1900 kg. Solar sell panels have to supply about 800 W of electric power during a day.

The spacecraft will be stabilized along the axis Z which is pointed at the center of the Sun with accuracy of about 1 arc sec s^{-1}, while the plane X-Y rotates around axis Z. Stability of the angular velocity will be of the order 0.005° per sec. Note that the TESIS will include own sensors based on star trackers for absolute pointing of spacecraft with an accuracy of 10 arc sec.

Daily telemetry rate of CORONAS-PHOTON is assumed to be 8.2 Gbit. The life time of the mission will be 5 years.

3 TESIS Scientific Instruments

The experiment TESIS on board spacecraft CORONAS-PHOTON will include 5 scientific instruments: the MgXII Imaging Spectroheliometer (MISH), the EUV Spectroheliometer (EUSH), two Full-disk EUV Telescopes (FET) and the Solar EUV Coronograph (SEC). Below we briefly describe the technical details of these instruments. The summary is given in Table II.

In addition to instruments listed above, the TESIS includes X-ray photometer-spectroheliometer SphinX designed by Space Research Center of Polish Academy of Science (Sylwester et al., 2006).

3.1 MgXII Imaging Spectroheliometer (MISH)

The MISH is an imaging spectroheliometer for registration of monochromatic images of the Sun in the narrow spectral region, which covers a resonance doublet of the hydrogen-like ion MgXII with wavelengths 8.418 Å and 8.423 Å. This spectral region is chosen to get information about the temperature, spatial distribution and dynamics of high-temperature plasmas in active regions and solar flares. The X-ray radiation is focused on the CCD detector of 2048 × 2048 pixels by spherical mirror made from the bent quartz $[10\bar{1}0]$ crystal. The blocking of visible light is provided with two 3.6 μ mylar filter (at the entrance window and in the front of detector), both sides of which is

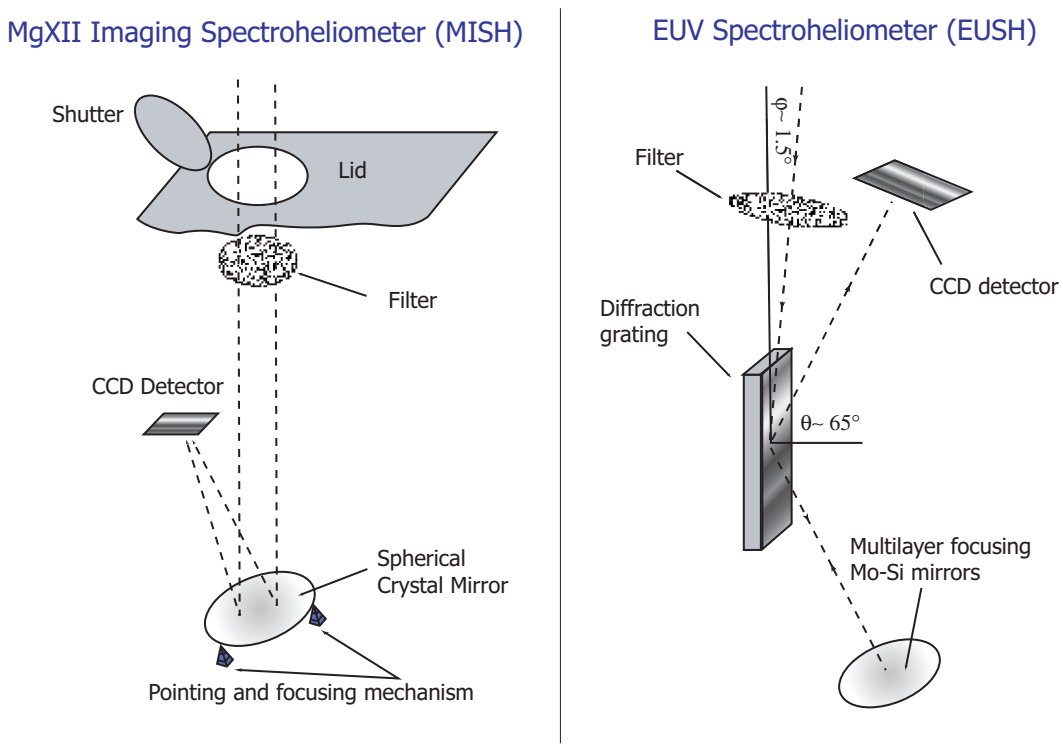

Fig. 1. The TESIS scientific instruments: MgXII Imaging Spectroheliometer (left panel) and EUV Spectroheliometer (right panel).

coated with 0.15 μ Al. The angular size of a CCD pixel is on the order of 2 arc sec. The MISH field of view is equal to 1°.15 and covers the Sun and above-limb regions with the aim to observe high altitude hot structures in the corona. The spectroheliometer is dedicated to high-cadence observations with temporal interval less than 10 seconds in the full frame mode.

3.2 EUV Spectroheliometer (EUSH)

The EUSH is an imaging spectroheliometer operating in the band 285-335 Å. This band covers HeII, SiIX, SiXI, FeXIV-FeXVI, MgVIII, NiXVIII, CaXVII, AlIX, FeXXII and other spectral lines formed at temperatures through from 5×10^4 to 1.2×10^7 K.

The optical layout of EUSH includes objective grazing incidence diffraction grating and normal incidence multilayer parabolic mirror. The visible light is blocked by thin-film filters installed in entrance of the instrument and coated on the 1024×2048 backside CCD.

The EUSH is aimed at multi-wavelength spectral diagnostic of coronal plasma. In contrast to slit spectrometers which register only the small area of the Sun, the EUSH enables to carry out detailed diagnostic of isolated phenomena in

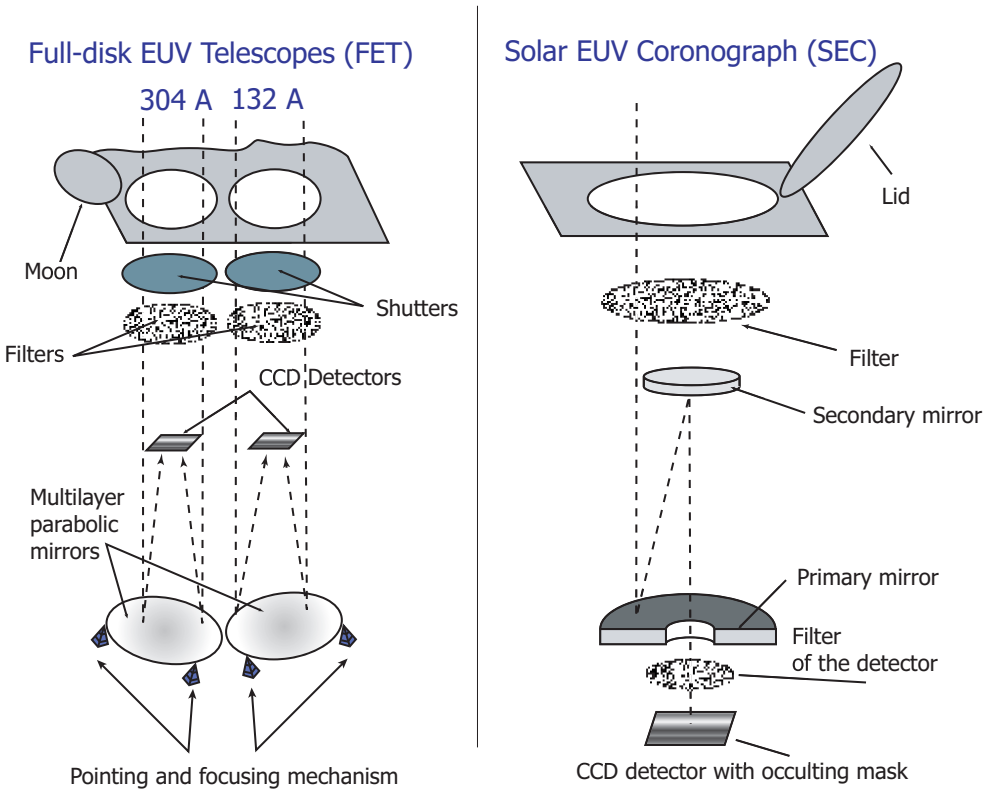

Fig. 2. The TESIS scientific instruments: Full-disk EUV Telescopes (left panel) and Solar EUV Coronograph (right panel).

the whole solar atmosphere. The angular resolution of the spectroheliometer depends on the direction. In perpendicular to dispersion (Y-axis of the image), the resolution is about 4.4 arc sec. Along the dispersion (X-axis), the images will be compressed by a factor of ~ 20. This allows to separate the images of the Sun obtained in different spectral lines. Angular resolution along this direction will be ~ 1.5 arc min.

3.3 Full-disk EUV Telescopes (FET)

The FET includes two normal-incidence Herschelian telescopes with multilayer mirrors. The first telescope operates in 130-136 Å spectral region with FeXX 132.84 Å and FeXXIII 132.91 Å lines. The second one covers 290-320 Å spectral region centered at the HeII 303.8 Å line. The images obtained by first telescope will provide data on spatial distribution and dynamics of very hot coronal plasma with a temperature higher than 10^7 K. Intense emission in the line HeII 303.8 Å is mainly produced in the transition layer with a temperature lower than 10^5 K. The telescopes may operate simultaneously or in a sequence depending of operating mode.

The Sun's image if both instruments are formed by parabolic mirrors with

multilayered coatings. The visible light is blocked by thin-film prefilters placed after the front panel of the instrument and ones coated on the CCDs. The entrance windows of the HeII-telescope is equipped with an artificial moon. This allows to observe the corona from 0.2 to 4 solar radii by inclining the mirror with pointing and focusing mechanism.

The image detectors of FET are backside CCDs of 2048 × 2048 pixels. The fields of view cover the whole Sun. The angular resolution of both telescopes is on the order of 1.7 arc sec/pixel. The temporal resolution depends on the operating mode: for full frame images it equals to 10 second, while partial-frame images may be registered with up to 1 sec time resolution.

3.4 Solar EUV Coronograph (SEC)

The SEC is a solar coronograph based on the Ritchey-Chretien scheme. The SEC operates in the spectral band 290-320 Å centered at the lines SiXI 303.3 Å and HeII 303.8 Å. Its field of view is equal to 2°.5 which covers the inner and outer corona through from the solar limb from 0.7 to 4 solar radiuses.

Optical system of the SEC includes two mirrors, primary and secondary ones, which reflect and focus EUV emission on the image detector – backside CCD of 2048 × 2048 pixels. The optical radiation of the Sun is suppressed by Aluminium thin-film prefilter in the entrance window of Ritchey-Chretien objective. The second filter to choose energy band is placed in front of CCD detector. The intense light from solar disk is reduced with an occulting mask coated on the surface of CCD.

Table 1
TESIS scientific instruments

MgXII Imaging Spectroheliometer (MISH)	
Instrument	Soft X-ray full-disk Bragg spectroheliometer with spherical bent crystal $[10\bar{1}0]$ mirror
Bragg angle	$82^\circ.08$
Wavelength band	MgXII 8.418 Å and 8.423 Å doublet
Focal length	1376 mm
Mirror Aperture	71×103 mm
Field of view	$1^\circ.15$ (Full solar disk)
Angular resolution	$\sim$ 2 arc sec/ pixel
Cadence	up to 1 s (partial frame) – 10 sec (full frame)
Image detector	backside CCD of 2048×2048 pixels
CCD pixel size	13.5×13.5 μm
EUV Spectroheliometer (EUSH)	
Instrument	EUV full-disk spectroheliometer with grazing incidence diffraction grating and focusing multilayer parabolic mirror
Wavelength band	280-330 Å
Focal length	600 mm
Entrance Aperture	5×80 mm
Spectral lines	HeII, SiIX, SiXI, FeXIV-FeXVI, MgVIII, NiXVIII, CaXVII, AlIX, FeXXII and others
Field of view	$1^\circ.24$ (Full solar disk compressed along dispersion)
Angular resolution	$\sim$ 4.4 arc sec (perpendicular to dispersion) $\sim$ 1.5 arc min (along dispersion)
Cadence	30-600 s
Image detector	backside CCD of 1024×2048 pixels
CCD pixel size	13×13 μm

Table 2
TESIS scientific instruments - continue

Full-disk EUV Telescopes (FET)	
Instrument	Herschelian telescopes
	with multilayer parabolic mirrors
Wavelength band (telescope I)	130-136 Å
Wavelength band (telescope II)	290-320 Å
Focal length	1600 mm
Mirror Aperture	100 mm diameter
Field of view	$1^\circ.0$ (Full solar disk)
Angular resolution	$\sim$ 1.7 arc sec
Cadence	up to 1 s (partial frame) – 1 min (full frame)
Image detector	backside CCD of 2048×2048 pixels
CCD pixel size	13.5×13.5 μm
Solar EUV Coronograph (SEC)	
Instrument	coronograph based on the Ritchey-Chretien scheme
Wavelength band	290-320 Å
Focal length	600 mm
Aperture	ring aperture (25 and 85 mm diameters)
Field of view	$2^\circ.5$ (inner and outer corona from 0.7 to 4 solar radii)
Angular resolution	$\sim$ 5 arc sec
Temporal resolution	up to 600 s
Image detector	backside CCD of 2048×2048 pixels
CCD pixel size	13.5×13.5 μm

4 Onboard data processing and telemetry rate

Processing of information and control on the instruments are achieved by TESIS onboard microcomputer, which includes a CPU with 66 MHz tact frequency, a 1 Mbyte read-only memory (ROM) for storage of unchangeable prior-to-flight instruction, and a 128 Mbyte RAM for data storage.

The TESIS microcomputer is responsible for the following functions:

(1) Control on devices for mechanical units, CCD units, and power supplies.
(2) Data gathering from the instruments.
(3) Data processing and formatting into the telemetry stream.
(4) Data recording to and data dump from the RAM.
(5) The choice of a working cyclogram for a given observing mode.

The data storage system of the CORONAS-PHOTON spacecraft allows accumulation of up to 1000 compressed full-frame images before their outputting to the telemetric system. This number of images corresponds to several days of the TESIS work. This avoid loss of the data when the ground-stations are not available during long time. The control on the data record, read and overwrite is executed by the onboard software which may operate in automatical mode. The TESIS has a flexible system of the instructions which may be reprogrammed in flight on command from Earth.

Data acquired with the TESIS instruments will be telemetered to Earth with daily rate of 0.5 Gbyte. This is 50 % of summary daily telemetry from the spacecraft CORONAS-PHOTON. For archiving and scientific analysis, all the data will be finally stored in a database system of Lebedev Physical Institute in Moscow.

5 Scientific Tasks

The TESIS is a unique space experiment based on the methods of imaging spectroscopy of the full Sun. The instruments of TESIS are combined together with the aim to simultaneously obtain images and spectra of the Sun with high angular and spectral resolution in narrow EUV bands characterizing the various temperature layers of the solar atmosphere.

TESIS observations cover the whole Sun and inner and outer corona up to the distance of 4 solar radii at wide temperature range from 10^5 to 2×10^7 K. This guarantees simultaneous observations for most solar phenomena at different heights in the solar atmosphere. Thanks to high sensitivity, wide dynamic

range and flexible command system, the TESIS will provide high-quality observations of not only flares but also faint pre-flare and post-flare objects. The non-flare data provides critically important information about mechanisms of magnetic energy accumulation and storage in solar active regions. It is an interesting objective to be examined in detail.

All the TESIS instruments have field of view more than 1°. This gives significant possibilities to observe morphology and dynamics of large-scale coronal loops with the aim to reveal the magnetic structure of the outer solar corona. In this respect, we expect to obtain the most important information with the wide-field coronograph SEC and the spectroheliometer EUSH.

Comparison of flare images taken simultaneously with MISH in the line MgXII 8.42 Å (T$\sim$ 10 MK) and FET in the spectral range 130-136 Å (T$\sim$ 12 MK) will be of importance to locate isolated hot and super-hot regions in the solar corona and measure temperature of plasma in the flaring loop structures, above-lop-top sources and cusp-like regions. This will give much-improved physical interpretation of the energy release in solar flares.

We expect that TESIS will become an important part of the international programm of collaborative observations of the Sun with ground-based and near-earth telescopes during the rasing phase and the maximum of current cycle of solar activity. Solar flares have many aspects, which may be completely clarified only with cooperation of optical, radio and X-ray observations. the TESIS will make important contribution, to this cooperation, which will increase our knowledge about the Sun and the mechanisms of solar activity.

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