TESIS experiment on EUV imaging spectroscopy of the Sun


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Received 16 April 2007; received in revised form 25 September 2008; accepted 20 October 2008

Abstract

TESIS is a set of solar imaging instruments in development by the Lebedev Physical Institute of the Russian Academy of Science, to be launched aboard the Russian spacecraft CORONAS-PHOTON in December 2008. The main goal of TESIS is to provide complex observations of solar active phenomena 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. TESIS includes five unique space instruments: the MgXII Imaging Spectroheliometer (MISH) with spherical bent crystal mirror, for observations of the Sun in the monochromatic MgXII 8.42 Å line; the EUV Spectroheliometer (EUSH) with grazing incidence diffraction grating, for the registration of the full solar disc in monochromatic lines of the spectral band 280–330 Å; two Full-disk EUV Telescopes (FET) with multilayer mirrors covering the band 130–136 and 290–320 Å; and the Solar EUV Coronagraph (SEC), based on the Ritchey–Chretien scheme, to observe the inner and outer solar corona from 0.2 to 4 solar radii in spectral band 290–320 Å. TESIS experiment will start at the rising phase of the 24th cycle of solar activity. With the advanced capabilities of its instruments, 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 10⁵ – 10⁷ K. This paper gives a brief description of the experiment, its equipment, and its scientific objectives.

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Keywords: Sun; Flares; X-rays

1. Introduction

The experiment TESIS, dedicated to EUV imaging spectroscopy of the Sun, is scheduled to start on December 15, 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. The organization responsible for TESIS and its instrumental equipment is the Laboratory of X-ray Astronomy of the Sun (XRAS) of the P.N. Lebedev Physical Institute of the Russian Academy of Science (http://tesis.lebedev.ru).

XRAS began systematic studies of solar EUV radiation in 1957. The first experiment attempting to measure solar X-rays was carried out by Mandel'stam, Efremov and Lebedev aboard the second Soviet Earth satellite launched on November 3, 1957 (Mandel'Stam, 1965). Scientific apparatus on the satellite registered many signals, but none were due to solar X-rays. It became clear later that these signals were due to radiation belt particles. Apparently, these measurements were the first observations of the radiation belts. Afterward, space instruments designed by XRAS worked on board the third Soviet satellite (May 15, 1958), Cosmos-166 (June 14, 1967), Intercosmos-1 (October 14, 1969), Intercosmos-4 (October 14, 1970) and
on other Soviet spacecrafts dedicated to the observation of the Sun.

During the last decade, XRAS carried out its space experiments in the framework of the Russian program CORONAS (Complex ORbital ObservatioNs of the Activity of the Sun) developed in cooperation with the Russian Space Agency. From 1994 to 2008, this program assumed the launch of three spacecrafts adapted for investigation of the Sun and solar-terrestrial connections.

The first satellite of the three, CORONAS-I, was successfully launched on March 2, 1994 from the cosmodrome Plesetsk in northern Russia. Scientific payload of the 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 this 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 and 180–209 Å, without overlapping, were also obtained for the first time. This experiment successfully revealed new aspects of solar flares in EUV emission. Unfortunately, the scientific program of the experiment ceased in July 5, 1994 because of the loss of the satellite orientation. Some of the results obtained during TEREK-K and RES-K are considered by (Zhitnik et al., 1999).

The following spacecraft of CORONAS project was CORONAS-F, launched in July 31, 2001 Oraevsky and Sobelman, 2002. On board the satellite, XRAS carried out the SPIRIT experiment 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 4 years of observations, from July 31, 2001 to December 6, 2005, SPIRIT obtained about 100,000 images of the full Sun at wavelengths 175 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 and 285–335 Å bands. The data obtained by the experiment characterize the dynamics of solar plasmas with temperature of $10^5 - 10^7$K on a time scale from several seconds to tens of days and a spatial scale from thousands to hundreds of thousands of kilometers. Main results of the SPIRIT experiment are summarized in Zhitnik et al. (2003b, 2006).

Based on its previous space projects, XRAS has developed the current experiment, TESIS, which will take place on board the third spacecraft of CORONAS program: 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 following aims: (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. The spatial, spectral and temporal characteristics of TESIS are improved significantly compared with those of its predecessor, SPIRIT. These improvements are mostly due to last year’s progress in the production of high-resolution optics based on multilayer normal-incidence mirrors.

In the present paper, we give a brief description of TESIS experiment regarding the spacecraft characteristics.

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

CORONAS-PHOTON should be launched on December 15, 2008, from the cosmodrome Plesetsk (latitude 62°43', longitude 40°17'; Arkhangelsk region). The satellite will enter a nearly circular orbit of about 550 km altitude, 82.5° inclination and 95 min period (Kotov et al., 2001). Each 3 months, the spacecraft will become completely illuminated for a period of 10–20 days, providing continuous observations of the Sun.

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

The spacecraft will be stabilized along the axis Z which is pointed at the center of the Sun with an accuracy of about 1 arcsec 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 TESIS will include its own sensors based on star trackers for absolute pointing of the spacecraft with an accuracy of 10 arcsec. The daily telemetry rate of CORONAS-PHOTON is assumed to be 8.2 Gbit. The lifetime of the mission will be 5 years.

3. TESIS scientific instruments

TESIS, on board the CORONAS-PHOTON satellite, will include five 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 1. In addition to the instruments listed above, TESIS includes an X-ray photometer-spectroheliometer SphinX, designed by the Space Research Center of the Polish Academy of Science Sylwester et al. (2008).

3.1. MgXII Imaging Spectroheliometer (MISH)

The MISH is an imaging spectroheliometer for the 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 and 8.423 Å (Fig. 1). 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 a spherical mirror made from bent quartz [1010] crystal. The blocking of vis-
isible light is provided with two 3.6 μm mylar filters (at the entrance window and in the front of detector), both sides of which are coated with 0.15 μm Al. The angular size of a CCD pixel is of the order of 2 arcsec. 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 a temporal interval of less than 10 s in 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 $5 \times 10^4$ to $1.2 \times 10^7$ K (Fig. 1).

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

The EUSH is aimed at multi-wavelength spectral diagnostics of coronal plasma. In contrast to slit spectrometers, which register only a small area of the Sun, the EUSH enables us to carry out detailed diagnostics of isolated phenomena in the whole solar atmosphere. The angular resolution of the spectroheliometer depends on the direction.
Perpendicular to dispersion (Y-axis of the image), the resolution is about 4.4 arcsec. Along the dispersion (X-axis), the images will be compressed by a factor of ~20. This compression allows separation of the images of the Sun obtained in different spectral lines. Angular resolution along this direction will be ~1.5 arcmin.

3.3. Full-disk EUV Telescopes (FET)

The FET includes two normal-incidence Herschelian telescopes with multilayer mirrors (Fig. 2). The first telescope operates in the 130–136 Å spectral region with FeXX 132.8 Å and FeXXIII 132.91 Å lines. The second one covers the 290–320 Å spectral region centered at the HeII 303.8 Å line. The images obtained by the first telescope will provide data on spatial distribution and dynamics of the 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 on the operating mode.

In both instruments, the Sun’s image is formed by parabolic mirrors with multi-layered coatings. Visible light is blocked by thin-film pre-filters placed after the front panel of the instrument and by similar filters coated on the CCDs. The entrance windows of the HeII-telescope are equipped with an artificial moon.

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

3.4. Solar EUV Coronograph (SEC)

The SEC is a solar coronograph based on the Ritchey–Chretien optical scheme (Fig. 2). The SEC operates in the spectral band 290–320 Å, centered at the lines covered by SiXI 303.3 Å and HeII 303.8 Å. Its field of view is 2°.5, covering the inner and outer corona from the solar limb at 0.7 solar radius to 4 solar radii.

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

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, 1 MB read-only memory (ROM) for storage of unchangeable prior-to-flight instruction, and 128 MB RAM for data storage. 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. The number of images equals several days of TESIS work. This avoids losses of data if ground-stations are not available for a long period of time. The control on the data to record, read, and overwrite is executed by the onboard software which may operate in automatic mode. TESIS has a flexible system of the instructions which may be reprogrammed in flight from commands from Earth.

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

5. Scientific tasks

TESIS is a unique space experiment based on the methods of imaging spectroscopy of the full Sun. The instruments of TESIS are combined 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 a wide temperature range from 10^5 to 2×10^7 K. This breadth guarantees simultaneous observations for most solar phenomena at different heights in the solar atmosphere. Thanks to high sensitivity, wide dynamic range and a flexible command system, TESIS will provide high-quality observations not only of flares but also of faint pre-flare and post-flare objects. Non-flare data provides critically important information about mechanisms of magnetic energy accumulation and storage in solar active regions. The non-flare data are an interesting objective to be examined in detail.
All instruments of TESIS have field of view more than 1°. This wide angle 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 gather the most significant data from 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 ~ 10 MK) and FET in the spectral range 130–136 Å (T ~ 12 MK) should help locate isolated hot and super-hot regions in the solar corona and to measure temperature of plasma in the flaring loop structures, above-loop-top sources and cusp-like regions. These observations will give much-improved physical interpretation of the energy released in solar flares.

We expect that TESIS will become an important part of the international program of collaborative observations of the Sun with ground-based and near-earth telescopes during the rising phase and the maximum of the 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. TESIS will make an important contribution to this cooperation as it increases our knowledge about the Sun and the mechanisms of solar activity.

Acknowledgements

This work was supported by the Russian Foundation for Basic Research (projects 08-02-01301-a and 08-02-13633-ofi-c) and Fundamental Research Program #16 of the Presidium of Russian Academy of Sciences.