SUBMILLIMETER TELESCOPE FOR THE RUSSIAN SEGMENT OF THE ISS: SUBMILLIMETRON PROJECT

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Abstract

The Submillimetron is the international project of the space telescope for astronomical studies at the submillimeter and infrared wavelengths using facilities of the Russian segment of the International Space Station (ISS). The concept of the telescope includes a 60 cm mirror cooled to liquid helium temperature with a novel type of microbolometers arrays using effects of superconductivity. This combination gives unique possibility to realize background limited sensitivity in the spectral minimum of the extraterrestrial background near frequency 1 THz between peaks of galactic dust emission and CMB. The angular resolution about 1 arcmin, field of view about 1°, and optics are similar to IRAS satellite, but the sensitivity is better on more than order of magnitude for about $10^{-18} W/Hz^{-1/2}$. This improvement and another spectral region permits to reveal in full sky survey considerably more new astrophysical objects. The concept of free flying instrument with periodic docking to ISS gives possibility to combine low cost with reliability, refilling, repairment and maintenance.

Key words: Submillimeter – Surveys – Telescopes – Space vehicles: instruments – Instrumentation: Detectors – Cosmology: observations – early Universe – Galaxies: active – dust – circumstellar matter

1. Introduction

The initiative of the project (see Gromov, Kardashev, Kurt et al. 2000) was done in Astro Space Center of the P.N. Lebedev institute RAS after discussions with NASA and JPL. Detectors are under development in Chalmers University of Technology, Sweden (Vystavkin et al. 1999, Kuzmin et al. 1999, Gromov et al. 2000). The proposal was undertaken to feasibility study in S.P. Korolev Rocket Space Corporation Energia and approved by the Russian Space Agency for the 2-d stage of ISS realization after years 2004 – 2005.

The size and cooling of the Submillimetron telescope optics is the same as it was in previous infrared mission IRAS and ISO. Two main features differ it from these missions and new ones (SIRTF, FIRST, Planck, Astro-F):

- free flying spacecraft using facilities of the Russian segment of ISS for deployment and maintenance
- novel type microbolometers (NHEB) with cooling down to 0.1 K and reaching sensitivity limited by low extraterrestrial background

First feature permits to realize the instrument of relatively low mass and cost, second one - to surpass new missions submillimeter instruments in sensitivity for surveys of large sky regions (full sky).

2. Scientific objectives

First and most bulky goals of Submillimetron observations are:

- full sky catalog of submillimeter sources, confusion limited at 1′ resolution;
- cosmological background study, reducing errors of anisotropy measurements by means of more detailed information on foreground sources.

In the field of observational techniques the goal is testing of novel type high-sensitive bolometer, which has not been used for astronomical observation and was especially designed for conditions of low extraterrestrial background. The experiment can be also testbed for future large cryogenic telescopes, including ASC/LPI Millimetron project for Lagrange point L2 (Kardashev et al. 2000).

Other tasks:

- study in submillimeter and infrared wavelengths of the "cold" component of the matter in the Universe (dust in the Solar system, Galaxy, and in extragalactic sources)
- study of the anisotropy of the cosmic microwave background radiation and search for Lyman-alpha line in the epoch of recombination and secondary heating
- studies of the spectra of astronomical sources and their variability.

Targets of observations:

- CMB - cosmological background radiation, spectrum, mapping;
- clusters of galaxies, dust, SZ-effect;
- "mirror" galaxies, relativistic particles, dust;
- IR galaxies, dust, cosmological evolution;
- AGN - active galactic nuclei, spectrum, variability;
- interstellar dust in our galaxy, spectrum, mapping;

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- cocoons, young stars, star envelopes, protoplanets;
- cold stars, peculiar and variable stars;
- neutron stars and galactic black holes, remnants of supernovae;
- center of galaxy Sgr A*;
- interplanetary dust, belts;
- planets, asteroids and comets;
- Dyson spheres (CETI).

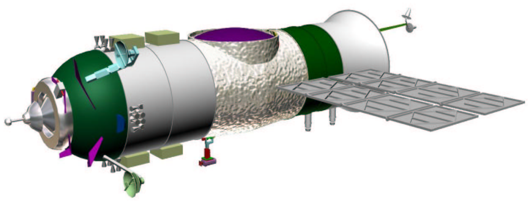

Figure 1. Free-flying spacecraft for RS/ISS. At left is docking assembly, antennas of docking system, and pressurized compartment. Center - nonpressurized compartment for telescope. At right - aggregates compartment and solar panels.

Figure 2. Submillimetron module docked to Russian Segment of the ISS for service and instruments replacement. Observational phase begins after screens deployment and detachment from ISS

3. The mission

Design of the free-flying spacecraft (Figure 1) for Submillimetron is based on Progress cargo ship and Soyuz rocket. Their reliability was proved in numerous space flights. Main scientific payload of the spacecraft is cryogenic telescope for submillimeter photometry in sky survey. A call for proposal on additional scientific instruments for heterodyne spectrometry and interferometry is now in stage of preparation. The launch is approved for the 2-d stage of ISS realization, when finished its assembling. After docking to ISS, deployment of the telescope and screens there will begin a period of free-flying observation with duration of 1-2 year. In this period docking for repair and replacement of instruments parts are permitted. After the end of this observation period and docking to Russian segment of ISS (Figure 2) an upgrade of instrument is planned with attachment of larger telescope mirror with diameter 3.5 m or more.

4. The Instrument

Cryogenic telescope of the Submillimetron project consists of Cassegrain optical system entirely cooled with several stages of refrigeration: radiation cooling, active cooling machine, and passive cooling with storage of liquid helium. Additional stage of refrigeration included for cooling of bolometers for subhelium temperatures. Main focal instrument - submillimeter photometers includes bolometers arrays and dichroic mirrors. A whole design of the telescope and bolometers is optimized for achievement of sensitivity close to fundamental limit of fluctuations of extraterrestrial background in its spectral minimum, which takes place in submillimeter region between spectral peak of galactic dust emission and CMB. Additional focal instruments are infrared photometer and/or submillimeter superheterodyne focal instrument. Schematical view of the cryogenic telescope is shown in Figure 3, main parameters of the instrument - in Table 1.

Table 1. Submillimetron telescope parameters

Telescope diameter:	D=0.6 m
Field of view	1°
Angular resolution:	$1'$-$10'$.
Cooling:	telescope 5K,
	detectors 0.1K .
Wavelengths:	
submillimeter bands:	0.3, 0.4, 0.5, 0.6,
	0.8, 1, 1.5 mm ;
infrared bands:	3, 10, 30, 100, 200 μm.
Detectors:	
in submm bands	bolometer arrays,
one-pixel NEP	$10^{-18} W/Hz^{1/2}$,
in IR bands	photoconductor arrays ,
one-pixel NEP	$10^{-17} - 3 \times 10^{-16} W/Hz^{1/2}$.
Sensitivity of the telescope (for integration time 1 s)	
Submm bands:	3-12 mJy,
Infrared bands:	6-40 mJy.

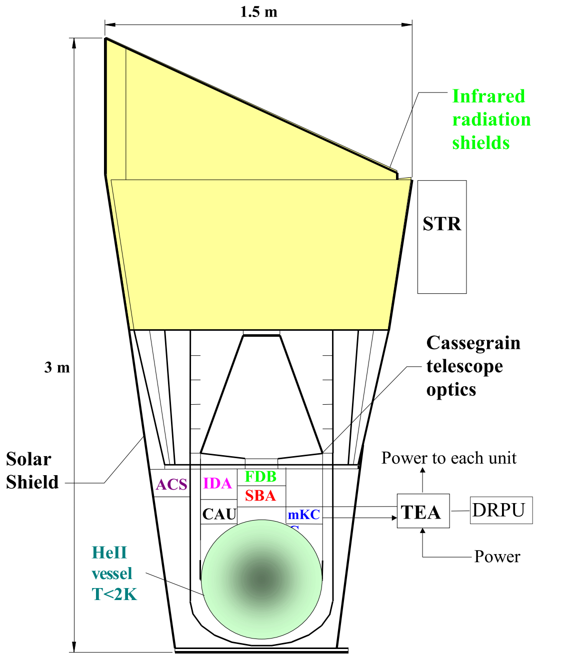

Figure 3. Schematical view of the cryogenic telescope.
ACS - Active Cooling System, T=20K;
STR - Star Tracker, defines pointing of the telescope;
HeII - superfluid helium vessel T=2K for cooling of focal instruments, primary and secondary mirrors on orbit (warm start);
FDB - Focal Dichroic Beam-splitters assembly;
IDA- Infrared Detector Array;
SBA - Submillimeter Bolometer Arrays assembly;
CAU - Cool Amplifiers Unit;
mKC - milli-Kelvin Cooler (T=100 mK);
TEA - Telescope Electronics Assembly;
DRPU - Data Registration and Processing Unit.

5. Bolometers

High sensitive submillimeter detectors were specially developed for Submillimetron project. The NHEB use submicron-size sensors cooled to extremely low temperature about 0.1 K to reduce thermal fluctuations to level less than background emission fluctuations. The initial version of this detector has been proposed by Nahum & Martinis (1993), Nahum et al. (1993). Figure 4 shows schematics of the bolometer version (Golubev & Kuzmin 2001) adapted for array application and low-noise readout with SQUID. Electromagnetic radiation induces current in planar antenna. This current heats electron gas in a metal strip. SIN junction is used as temperature sensor. The example of the bolometer made in the Microelectronics Center of Chalmers University is shown in Figure 5. Measured parameters of this detector are given in Table 2.

6. Discussion

Other type of bolometer with sensitivity comparable with NHEB is TES (Transition Edge Superconductive) bolometer, which technology uses experience of TES detectors for X-ray astronomy. Its drawback is a narrow temperature region of superconductive transition, which exclude functioning of the device overheated by enhanced background emission possible in sufficient part of submillimeter-wave survey. On the contrary the NHEB has wider diapason of working temperatures, and uses effect of electronic cooling improving its characteristics (Golubev & Kuzmin 2001).

The orbit of ISS is entirely different from that of most astronomical satellites. Low, non solar-synchronous orbit put severe restrictions on telescope pointing, which are

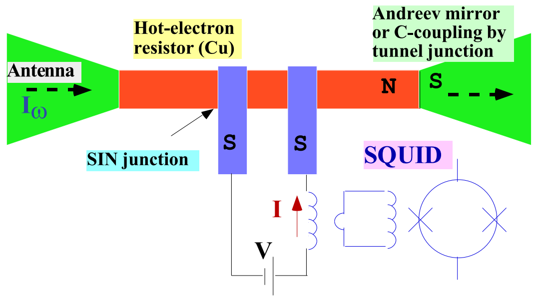

Figure 4. Schematics of the NHEB bolometer with SQUID readout.
NHEB - Normal-metal Hot Electron Bolometer,
SQUID - Superconductive Quantum Interferometer Device,
SIN - Superconductor - Insulator - Normal metal

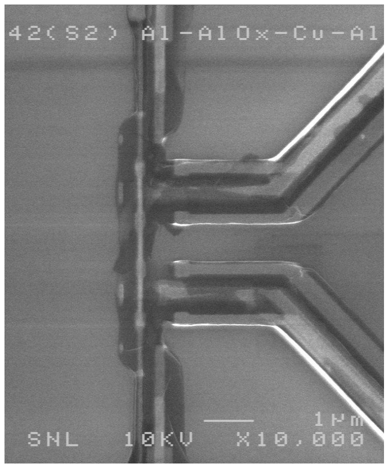

Figure 5. Sensor element of the NHEB bolometer (electron microscope picture)

Table 2. Measured parameters of the NHEB bolometer at temperature 0.1 K

Absorber dimensions	$5 \times 0.25 \times 0.07 \mu m^3$
Thermal conductance, G= dP/dT	$7 \times 10^{-14} W/K$
Time constant	$\tau = 5 \mu s$
NEP_a (experiment, amplifier limited)	$5 \times 10^{-18} W/Hz^{1/2}$
NEP_T (thermal fluctuation noise)	$2 \times 10^{-19} W/Hz^{1/2}$

nevertheless not so important for sky survey from free flying spacecraft, where are no problem with shadowing by space station elements. Protection of cooled optics from strong infrared radiation of Earth and from contamination (cryocondensation) guaranteed by large reflective cooled screens shown in Figure 3. The merits of the ISS-related experiment are: it's low cost, reliability and flexibility due to use of ISS means for deployment, maintenance and instruments change.

New IR/submm projects following on IRAS, COBE and ISO use large mirrors (more than meter), which cannot be cooled to temperatures lower than tens of K. A development of the Submillimetron project has shown that progress in observational technique is possible not only by refuse of proven technology of space optics and cryogenics, but also by progress in detector technology. Full sky data of high sensitive submillimeter observations with resolution about $1'$ are important complementary to FIRST and Plank missions.

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