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The Main Results and the Perspectives in the Researches at SSRT*

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Abstract In this report briefly presented the contemporary state of the experimental base of Radio Astrophysical Observatory (RAO) of the Institute of Solar-Terrestrial Physics (ISTP), the methodology of radioheliographic monitoring of the solar corona, the SSRT database, the RAO Web-pages, factors limiting the effective use of SSRT. Here are formulated the original results of the basic directions of the solar activity researches and the problems solutions on SSRT: (1) active regions at various development stages, morphology, modeling, signs of energy accumulation and flares buildup, forecast of powerful flares; (2) scenario, topology and the fine temporal picture of flares development, signs of primary energy release, radio emission mechanisms, scatter effects of radio emission in turbulent corona, energetic particles fluxes; (3) filaments; (4) CME with the localization of their initiation at the solar disk background, development scenario of filament activation + CME + flare; (5) coronal holes, and (6) bright coronal points.

Key words Monitoring, Diagnostic, Space weather, Solar factors, Microwave emission

1 Introduction

Use of data obtained almost in all the ranges of Sun emission spectrum and also the necessity of the more deep processes diagnostics in its corona (where they are appeared more effectively) orient us on the clearing out and taking into account the effects of radio emission transference, the quantity description of its turbulence, definition of the radio emission nature in the interesting sources, modeling of radio emission of active regions, singling out of the enough precursors of flares build-up, modeling of flare processes, research of energy accumulation processes and its primary release, accompanying fluxes of energetic particles, shock waves and others; CME modeling, their initiation signs singling out, research of possibility of CME development prediction; analysis of space weather solar factors in solar-terrestrial connections. Researches have been performed formerly and will be further in the frames of quasi virtual solar observatory on the basis of SSRT + NoRH + China NAO Radiospectrograph + Yohkoh, SOHO, TRACE and other orbital observatories.

All this are caused the SSRT transformation in to the multiwavelength radioheliograph with the realization of the Russian program "Space Weather", the completion of radiospectrograph creation of CM-diapason, development of the software, the improvement of collaboration with other observatories (also with the projects of solar radio telescopes of the new generation), the collaborates qualification improvement, preparation of future generation of RAO. Now is working out and coordinated with the units creators the variant of creation on the SSRT basis the radioheliograph of the wave-length range of 3—9 GHz. The basic project parameters: number of used in the T-scheme antennas 192, angular resolution 13″, operating bandwidth 10^2 MHz, sensitivity 100 K, temporal resolution 1 s.

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2 SSRT Nowadays[1],[2]

2.1 Goals (from the initial one up to the present time)

(1) Research of corona structure of active regions with the spatial resolution of more than the resolution of before working radioheliographs.

(2) Systematic research of active regions and dynamic processes in the corona on the background of solar disk and beyond its limb, and after SSRT modernization in 1990-all the appearances of solar activity (simultaneously of all the spatial, temporal and power scales) at the chosen wavelength.

(3) To distinguish of the build-up signs and the improvement of scientific basics of forecast of geoeffective events-initial factors of space weather.

2.2 Principle of Operation

(1) Direct receiving of the radio images by the multichannel digital registration of the radio brightness distribution of the Sun according to the altitude with its scanning by the fan diagram of directivity in interference maximums and the diurnal rotation of the Earth along azimuth.

(2) Use of two 128 element equidistant antenna arrays, oriented to the lines E-W and N-S, wideband waveguide system of the signals sampling from the antennas, multifrequency (180 and 500 channels) receiving systems.

(3) Synchronous accompanying of the Sun by the antennas during the day.

(4) Automatization of all the systems of SSRT complex.

(5) The openness of all the systems for the development and modernization.

2.3 Basic Parameters

(1) Working wavelength of 5.2 cm at range of maximal contrast of active regions.

(2) 1D and 2D-resolutions up to 15″ and 21″, correspondently.

(3) Sensitivity. 1500 K for the one passing (time of initial countdowns integration 0.336 s).

(4) Time resolution in 1D-mode: 0.336 s (initial averaging), 56 ms (1992—1995), 14 ms (1993 up to now), in 2D-mode during the day from 2 to 10 min.

(5) Stocks parameters: I, V.

3 Main Results of the Last Years

Initial data of every day observations (0200—0800 UT in winter and 0000—1000 UT in summer, up to 300 MB/day in summer) for the two solar activity cycles on CD-ROM with some FITS-files of radio maps in I and V. Midday I and V-images of the Sun (in digital mode in format FITS are anonymously available at ftp://iszf.irk.ru/pub/ssrt_data/fits/), and also the temporal profiles of bursts with the resolution of 14 ms on sites

http://ssrt.iszf.irk.ru/ssrt, http://www.eastsib.ru/~ssrt,

http://www.eastsib.ru/ftevents.html[2].

New methods of observation and analysis of great amounts of experimental data[3]. Here is created a new library of the programs on IDL oriented on the processing of the solar data widely used in russian observatories that made it possible to research in details the development of flare processes and CME. Observations of drifting microwave bursts of millisecond duration with angular resolution allowed to research the fine temporal structure of flare processes with the coming to the initial energy release, firstly determinate independent velocity of source emission movement on the flare loop and also the gradient of plasma density on its way of moving. The special value has the common analysis of dynamic spectra obtained in Beijing observatory at range around the receiving frequency of SSRT and spatial-temporal characteristics of such bursts[4].

Research of the dependence of apparent sizes of subsecond bursts sources from their location relatively to the center of solar disk has a very important value. It is shown that microwave radiation of flare sources at frequency of 5.7 GHz is scattered in low corona. Thus, apparent sizes of compact sources increase from 5″ in the disk center up to 40″—50″ at limb[5].

At first is researched the dynamics of microwave sources of solar flare. It is showed that in the flare process the magnetic configuration is tended towards the potential. Flare development was determined by the formation history of active region. Radiation im-

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pulses generation is preconditioned by plasma and girosynchrotron mechanisms. Efficiency of electron fixing in the flare loops was not so high and that determined the temperate power of the flare and the great duration of the interval with the fine temporal structures[6].

Localization and dynamics of eruptive processes in microwave radiation were firstly observed at SSRT[7],[8]. Here is researched in details the successive process of filament activation development of coronal mass ejection flare in corona at the background of solar disk, and supposed the model[9]. Collaboratively with Izmiran and Fian is shown that the CME process touches not only various layers of magnetosphere over the eruption center, but the large-scale and even global structures that significantly exceed according to their scales the sizes of active region[10],[11].

Collaboratively with Fian is developed the methodology and software of primary data processing of Spirit/Coronac, their common analysis with the data of Soho/Eit, Yohkoh and SSRT that allowed to find out the dimmings formed as a result of posteruptive events in solar corona, and also the delay of their development in the transitive region. According to the common data are estimated the physical parameters and magnetic fields in coronal holes and posteruptive arcades[12].

In collaboration with GAO and SAO were firstly observed and researched the spatial oscillations of magnetic structures in corona with the amplitude up to $5''$[13].

Here are singled out the new signs of major flares build-up and worked out the method of their prediction that significantly supplement the methods based on the optical observations[14].

Here are determined the conditions in the frames of which the electron bundles can propagate in the solar corona without the significant energy losses on the plasma turbulence exciting[15].

Here is worked out the new technology of magnetic field restoration in corona with high spatial and temporal resolutions[16]. On its basis is performed the original continuous monitoring of the magnetic field extrapolation in Sun corona according to the magnetograms of high spatial resolution with temporal resolution up to the magnetograms exposition (www.bdm.iszf.irk.ru).

This researches are extremely needed for the understanding of the solar events nature, degree and the character of their geoefficiency, for the space weather problems solutions and for the further development of space plasma physics.

In the time elaborating of the project, building, using and developing of the SSRT on its basis was formed the scientific school of radioastrophysical researches of the plasma and magnetohydrodynamic processes in natural conditions (solar atmosphere and heliosphere) (SciSch-00-15-96710/SciSch-477.2003.2).

4 SSRT Shortages

(1) Temporal resolution is not enough for the obtaining of 2D-images of dynamic processes in solar corona (needed $\leqslant 1$ s).

(2) Definition of diagram of directivity is complicated by its variability with the observations in various directions, phasing errors up to 5°—7° (opportunities of further certainty improvement reached its limit) and others.

(3) It is impossible to make the full diagnostics of the researched events in corona without knowing the spectrum character of microwave radiation with high spatial resolution and the magnetic field intensity with the great optical width, not having the 3D-resolution.

They are all removable by the way of SSRT transformation in an instrument complex of aperture synthesis-multiwavelenght radioheliograph (new generation instrument) using the antennas abundance, contemporary element base and computer techniques.

5 Perspectives

5.1 New Goals

(1) Diagnostics of physical conditions in corona on the background of solar disk with high temporal and spatial resolution and also with the determination of the character of microwave radiation spectrum.

(2) Research of the 3D-structure and magnetic

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fields dynamics of active regions of solar corona, development of coronal magnetography.

(3) Improvement of scientific bases of cosmic weather prediction.

5.2 New Problems

(1) Significant increase of the instrument time resolution and the quality of radio images with the use of the techniques of aperture synthesis.

(2) Use of the number of working frequencies for the spectrum character determination of microwave radiation of events in solar corona, research of their 3D-topology, realization of 3D-coronal magnetography.

5.3 Ways of Problems Solutions

(1) Use of the number of working frequencies in the interval of 3—9 GHz. Data of two more (17 and 34 GHz) will be taken from NoRH.

(2) Use of SSRT antennas abundance for 5 integrated antennal arrays with the goal of simultaneous obtaining of 2D-images at a number of frequencies by the method of aperture synthesis.

5.4 Project Solutions[17],[18]

Use of the 192 antennas of 3 baselines of SSRT radiointerferometer, i.e. antenna array of T-like configuration that has 5 integrated radioheliographs of aperture synthesis on the 5 various wavelengths.

Total number of complex correlations in them is 18 336. For the obtaining of 2D-images it is necessary to use 8192 correlations. Other correlations can be used for the decrease of instrumental phase errors.

Wideband of signals sampling systems can be provided by the use of wideband optic-fiber cable and the set of tuned heterodynes.

There are forseen two modes of observations:

(1) Routine. Consequent receiving of radio images of all the Sun with the use of the whole antenna array at the number wavelengths;

(2) Flares observation. Simultaneous obtaining of images of flare region with the use of integrated arrays at 5 frequencies.

5.5 Instrumentation

1. Antenna and front-end

There is using of the existing antennas at SSRT. The best angular resolution $-14''$ will be reached at 9 GHz. However, at this frequency appears the strong dependence of fundamental spacing from the observation time. Every antenna will be equipped by the wideband dual polarization feed, by the attenuator and amplifier. Here are considered 2 types of feeds. Or the crossed linear feeds, the hybrid sum has to be used. A multiplexer has to be used in the case of the wideband horn feed. The wideband signal would be transmitted to the apparatus hall by a one-mode optic-fiber cable.

2. Fiber-optic cable and sampler

A single-mode optic-fiber cable would be used to transmit signals from the antennas at range of 3—9 GHz to the apparatus hall. The maximal cable length is not less than 400 m. One-bit sampling at the frequency of 20 MHz would be used. The accuracy of the time delays should be of 0.25 ns in the interval of 1—2000 ns. Fine delays tuning (0.5—60 ns) would be provided by a dedicated time-delay chip, with a coarse delay realized by a shift register.

3. Correlator

For the calculation of complex functions of the visibility it is planned to use the complex of usual one bite correlators. It is more convenient to use the programmable logic matrix technologies, but the use of dedicated correlator chipset is also considered. Because the number of visibilities is 18 336, the major problem of the multichannel correlator is a cross-interference of the channels.

4. Data flow

Full number of complex correlations of 192-element antenna array is equal to 18 336. The sampling frequency is taken of 20 MHz. The size of each sample (data portion) is 24 bits. Thus the data flow is of about 20 MBps with the time of integration of 0.02 s. As the observations intervals are of 6—10 h, maximal data flow reaches of about 14 GB/d, including the data of flare events.

5.6 Expected Results

Project realization will allow to perform the fundamental and application researches with the impos-

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sible nowadays completeness and depth of processes diagnostics in solar atmosphere and the events topology.

5.7 Model Checking of the Project Decisions

Here is found the maker of 66 correlators for the modeling at the 12 antennas, and discussed the opportunity of optic-fiber technology use and the creation of range feeds at the logoperiodic elements. Heterodynes complex of the necessary calculation equipment and also the program software are under stage of study.

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