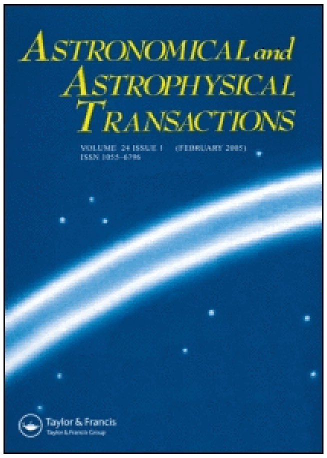

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INTERNATIONAL COOPERATION IN THE FIELD OF RADIO ASTRONOMY EXPLORATION WITH THE APPLICATION OF THE RT-70 RADIO TELESCOPES

E. P. MOLOTOV*

Federal State Unitary Enterprise (FSUE), Russian Scientific Research Institute for Space Device Engineering, ("Russian Institute of Space Device Engineering" RISDE), 53 Aviamotornaya Str., Moscow 111250, Russia

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Since the moment of creation of the RT-70 radio telescopes in Evpatoria (1979) and Ussuriisk (1985) they have been used not only for control of deep-space vehicles but also with the purpose of conducting a wide range of radio astronomy explorations.

Both radio telescopes within the international very-long-baseline interferometry (VLBI) networks (the USA network Deep Space Network (DSN), European and global VLBI networks, and Australian network Long Baseline Array (LBA)) regularly participated in the observation of compact space radio sources by the VLBI method.

The Evpatoria radio telescope RT-70 was involved in performing radar-aided explorations of the Solar System bodies. Since 1999 within the framework of Russia–Ukraine collaboration a new radio-astronomical method of VLBI location for exploration of the Earth group of planets, the Earth approaching asteroids and space debris has been under development. Observatories in China, Japan, Poland, Italy and the UK participated in these experiments. Since 1998 the Evpatoria RT-70 has been operated within the international 'low frequency VLBI network'.

For the future the radio telescope RT-70 is expected to be used in the international project 'Radioastron' for joint observations with the space-based 10 m radio telescope.

Keywords: Radio telescopes; Very-long-baseline interferometry network; International cooperation

From the moment of their creation the radio telescopes RT-70 in Evpatoria (1979) (Fig. 1) and Ussuriisk (1985) (Fig. 2), as a part of tracking stations, have been used not only for control of deep-space vehicles but also for conducting radio astronomy explorations.

The Evpatoria radio telescope has been regularly used for radio location of the planets Mars, Mercury and Venus.

These studies together with analogous investigations by American scientists allowed us to improve fivefold the accuracy of measuring the size of the Solar System, to specify more closely the value of the astronomical unit and to develop a highly precise theory of planet motion.

Within the international very-long-baseline interferometry (VLBI) network the radio telescopes participated in the aerostat experiment of the 'Vega' project that was carried out under the guidance of the Institute of Space Exploration. This experiment allowed the wind velocity and other motion parameters of the Venus atmosphere to be determined.

* E-mail: molotov@kiam1.rssi.ru

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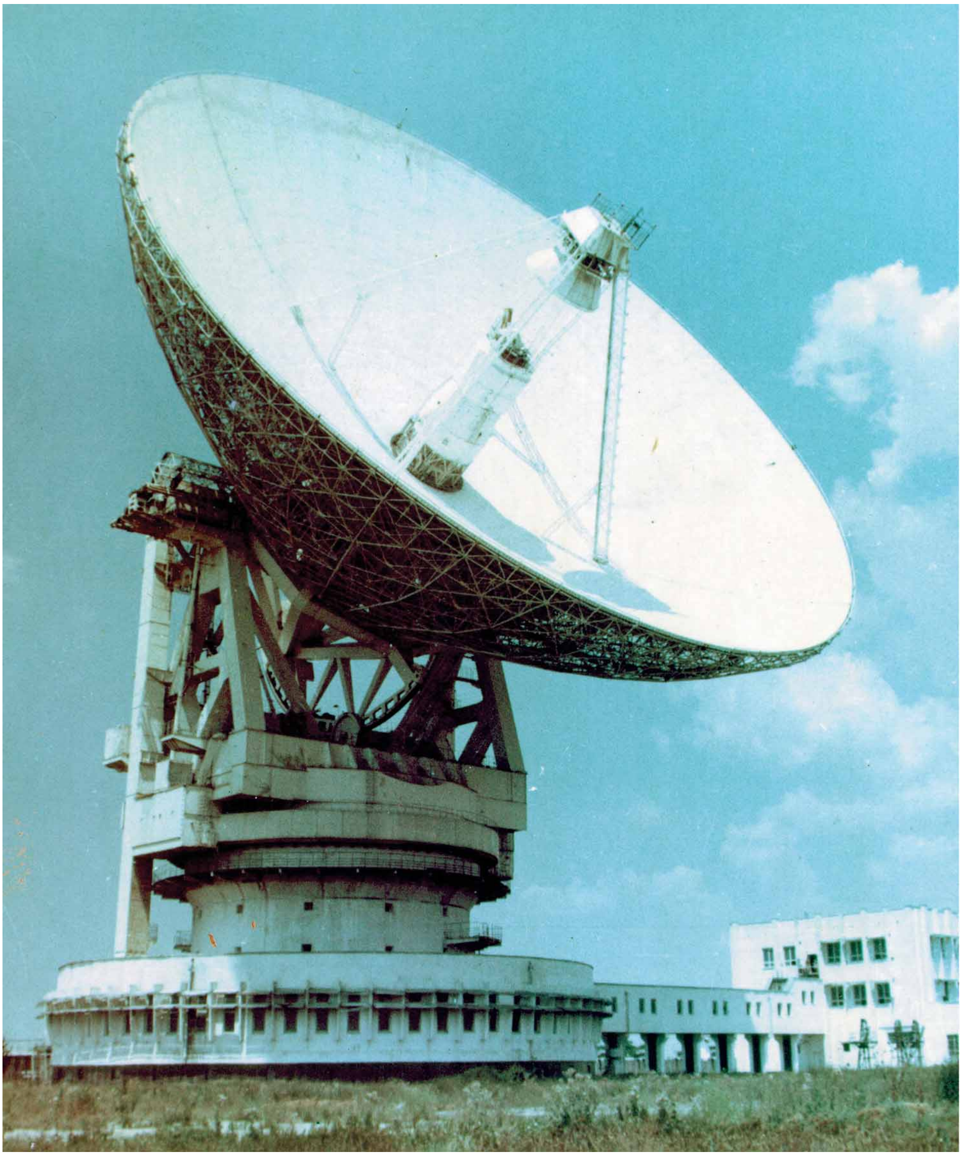

FIGURE 1 Antenna system RT-70 in Evpatoria.

Both radio telescopes as a part of the American and European VLBI networks have been used for explorations in the period 1991–1995 (including the experiment ‘crustal dynamics’ conducted by the USA). The radio telescopes in Hobart, Parks, Canberra (Australia), Madrid (Spain), Fairbanks, Kauai (USA), European VLBI Network – EVN (Europe), Noto (Italy) and others were operated concurrently with RT-70. The work was carried out at a wavelength of 18 cm.

The recorded interferometry information was processed at the Radio Physical Research Institute in Nizhny Novgorod (Russia), California Technological Institute (USA), Australian Telescope National Facility – ATNF (Australia), National Radio Astronomy Observatory – NRAO (USA), Haystack (USA), correlator EVN (Germany) and other places.

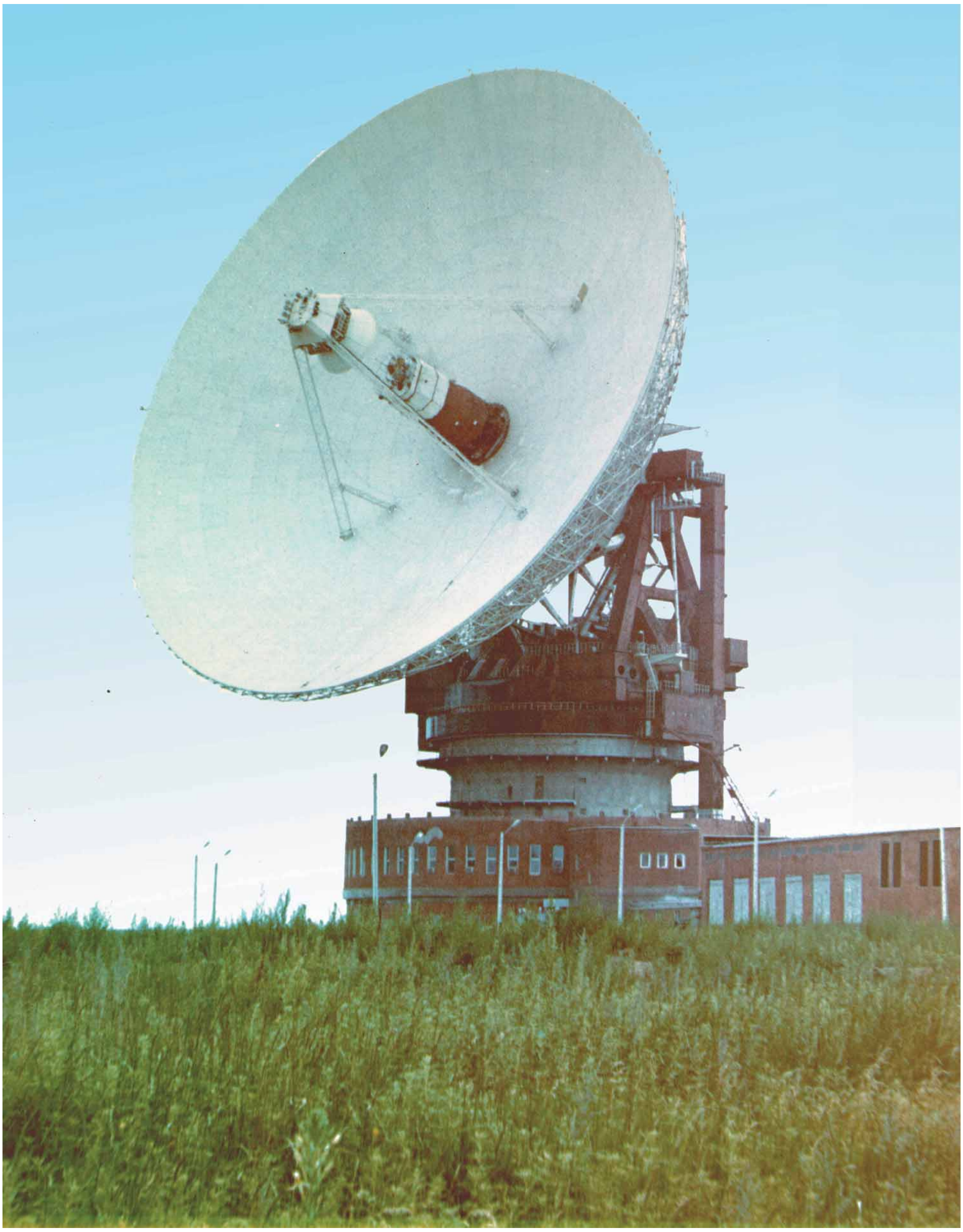

FIGURE 2 Antenna system RT-70 in Ussuriisk.

At the Ussuriisk radio telescope the equipment for recording the Very Long Baseline Array (VLBA) and S2 data was upgraded. US, Australian and Canadian scientists took part in this work.

In the course of VLBI explorations the geocentric coordinates of RT-70 radio telescopes were measured with high accuracy.

At the radio telescope RT-70 in Ussuriisk and also in Evpatoria a new band length of 92 cm was introduced. The feeds and receivers of this band were installed on antennae.

In further experiments in the period 1994–1995, explorations were conducted with the following aims:

(i) to select source candidates for the future observations with the help of ground- and space-based interferometers;
(ii) to determine the influence of the dissipation in the interstellar medium on the visible angular sizes of radio sources;
(iii) to study the structure of near-solar plasma and its influence on wave propagation;
(iv) to carry out astrometry observation of pulsars;
(v) to detect compact Sun flashes of millisecond length (‘spikes’) and to determine their parameters.

In experiments in 1995 the radio telescopes at Jodral Bank, Noto, Westerbork and Simeiz in combination with the Ussuriisk radio telescope took part. The information was processed at the Jet Propulsion Laboratory. The experience gained from these explorations can be used when implementing the ‘Radioastron’ program.

Since 1996 after unsuccessful termination of the ‘Mars-96’ program the Ussuriisk radio telescope has been preserved and is not involved in the work.

In 1998 the alignment sessions at the band length of 92 cm were carried out with the Evpatoria radio telescope within the low-frequency very-long-baseline interferometry network (LFVN).

Scientists at the Institute of Radio Electronics, Russian Academy of Sciences, Russian Institute of Space Device Engineering, National Center for Control and Test of Space Means (Ukraine) and Radio Astronomy Institute, National Academy of Sciences of Ukraine, conducted in 1992 radar-aided location of the Tautatis asteroid, and the 100 m Bonn radio telescope was used as the receiving antenna.

In 1995 the radio location of the asteroid 6489 was successfully conducted. The planet radar at Goldstone and the radio telescopes in Evpatoria and Kashima (Japan) were involved in this experiment. After implementing these studies the asteroid 6489 was called by the name Golevka (an abbreviation from Goldstone–Evpatoria–Kashima).

In the last few years a new method of investigating bodies of the Solar System, namely VLBI location, has been theoretically developed. In this method the classic (‘usual’) radio location, obtained by measuring the velocity of the object under study and consequently the range, is complemented by the fact that the reflected echo signals are received by the network of radio telescopes operating in the VLBI mode.

The ‘illumination’ of the object to be examined with signals from a powerful radio transmitter makes it ‘visible’ in a particular radio band and this allows the effective method of differential astrometry VLBI measurements to be used to determine the motion parameters of space bodies. This method has a wide application in the world for precise determination of spacecraft position in the celestial sphere relative to reference quasars fixing the coordinate system.

The theoretical development of the method of VLBI location shows that the measurement of the motion parameters of the mass centre of celestial bodies in the quasi-inertial coordinate system can be assured with an accuracy of $0.01''$ for a single measurement and with an accuracy of $0.001''$ for a set of measurements.

The importance of realizing this new method was emphasized by an international group of scientists, consisting of specialists of the Astro-Space Centre of the P.N. Lebedev Physical Institute, the Russian Institute Space Device Engineering (RISDE), National Centre for Control and Test of Space Means (Ukraine), and the Radio Astronomy Institute, National Academy of Sciences of Ukraine, played the leading part.

The first experimental session of the VLBI location of planets has been organized within the framework of Russian–Ukrainian cooperation in the field of VLBI explorations in June 1999 with the use of the Evpatoria planet radar and the network of receiving radio telescopes in Svetloe, Shanghai and Urumqi (PR China), Torun (Poland) and Kashima (Japan). The signals were recorded in the MK-2 and S2 formats.

During the experiment the radio locations of Mars and Venus were obtained. The processing of received data carried out at the Institute of Applied Astronomy (Russia) and the Radio-Physics Research Institute (Russia) has shown that the main purpose of the experiment was attained, namely obtaining the correlation fringes of echo signals reflected by planets on baselines.

In implementing the experiment the following organizations took part: Institute of Applied Mathematics (Russia), Central Institute of Machine Building (Russia) and foreign scientific centres, such as the National Astronomy Observatory, Chinese Academy of Sciences, Space Exploration Centre, Research Laboratory for Communications, Kashima (Japan), Astronomy Centre, Nicolaus Copernicus University, Torun (Poland).

The work on VLBI location was continued. In August 2000 the repeated location of Venus and the location of Mercury were obtained, and the exploration of two Earth-approaching asteroids Mitra (diameter, 2.5 km) and 2000 CE59 (diameter, about 0.5 km) was firstly performed. The asteroids were located at distances of 12×10^6 km and 7×10^6 km respectively. The same organizations that were involved in 1999 (excluding Japan) also participated in the

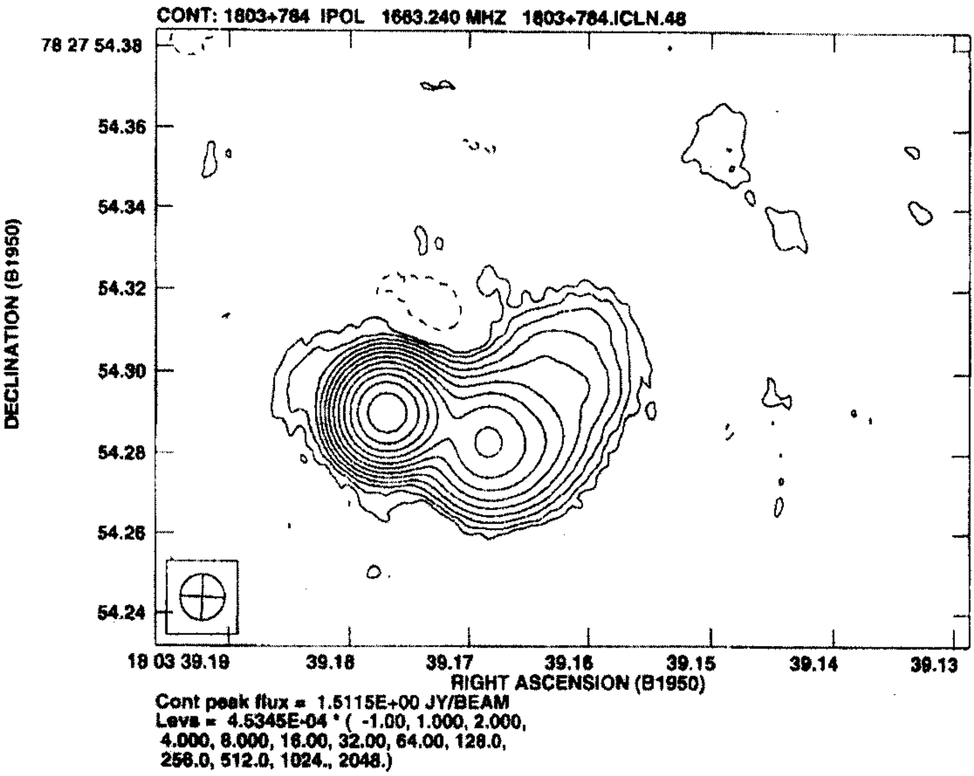

FIGURE 3 Image of the radio source BL Lac 1803 + 784 (z = 0.68) obtained on results of observations with usage of Evpatoria radio telescope RT-70 operated within the international global VLBI network at a wavelength of 18 cm (May 1993). The radio telescope of such a large diameter contributes a high sensitivity to the VLBI network.

experiment. Additionally the echo signals were received at the TNA-1500 antenna at Bear Lakes, near Moscow.

VLBI location experiments were also carried out in 2001. In May 2001 the VLBI locations of Venus, Mercury and asteroid 1999 KWU were determined; firstly an experiment was carried out to upgrade the technology and methods for determination of dynamic characteristics of space debris in geostationary orbits using the VLBI location technique. Reliable ‘replies’ from a number of chosen ‘targets’ were received (satellites with exhausted resource of the series ‘Raduga’ and ‘Kosmos’, and upper stages of missile carriers). The axial rotations of these objects with periods from 5 to 20 s were detected.

The potential capabilities of the Evpatoria radar allowed us to discover fragments of space debris with sizes of about 1 cm or less in geostationary orbits. The radio telescopes at Svetloe, Shanghai, Urumqi, Torun, Kashima, Noto and Bear Lakes were used for the experiment. The data processing was carried out on recording materials in the S-2 format at Penticton (Canada) and in the MK-2 format in Nizhny Novgorod.

The VLBI locations of the asteroid 1998 WT2U and exploration of five ‘targets’ in geostationary orbits and four in highly elliptical orbits, as well as the location of fragments of small space debris, were determined in December 2001.

The radio telescopes at Svetloe, Shanghai, Urumqi, Torun, Bear Lakes, Kalyazin, Zelenchukskaya and Medicine (Italy) participated in the experiment. The data processing was performed at Penticton and Nizhny Novgorod.

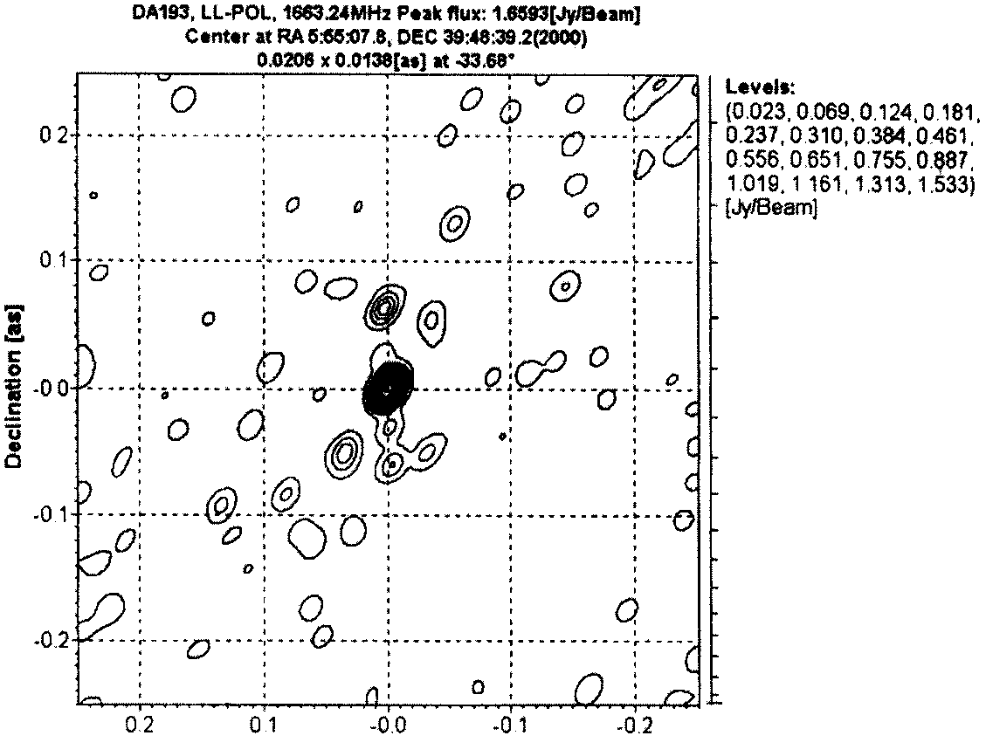

FIGURE 4 Image of the radio source DA193 obtained with the results of joint observations by the Ussuriisk radio telescope RT-70 and the European VLBI network at a wavelength of 18 cm (November 1993). The radio telescope RT-70 has provided a large increase in the EVN resolution and sensitivity and allowed the structure of this calibration source to be detected.

In the near future it is hoped to continue the explorations of the Earth-approaching asteroids by the method of VLBI location on the basis of Russia–Ukraine scientific cooperation. In this experiment all the potential capabilities of the method will be fully realized (asteroid impact hazard).

Additionally, plans are in place to measure the short-period variations in the self-rotation parameters of terrestrial group planets; the planet trajectories should also be determined within the coordinate system of the radio reference frame with high precision. This will help to solve the fundamental problem of astrometry: determination of coupling between the dynamic and quasi-inertial coordinate systems.

Explorations in the field of ‘space debris’ at high orbits are expected to be extended; this becomes particularly necessary owing to the absence of a natural self-purification mechanism at these orbits. Apart from Russian and Ukrainian scientific institutions, organizations in European countries, China and Japan are to be involved into these studies. To perform the

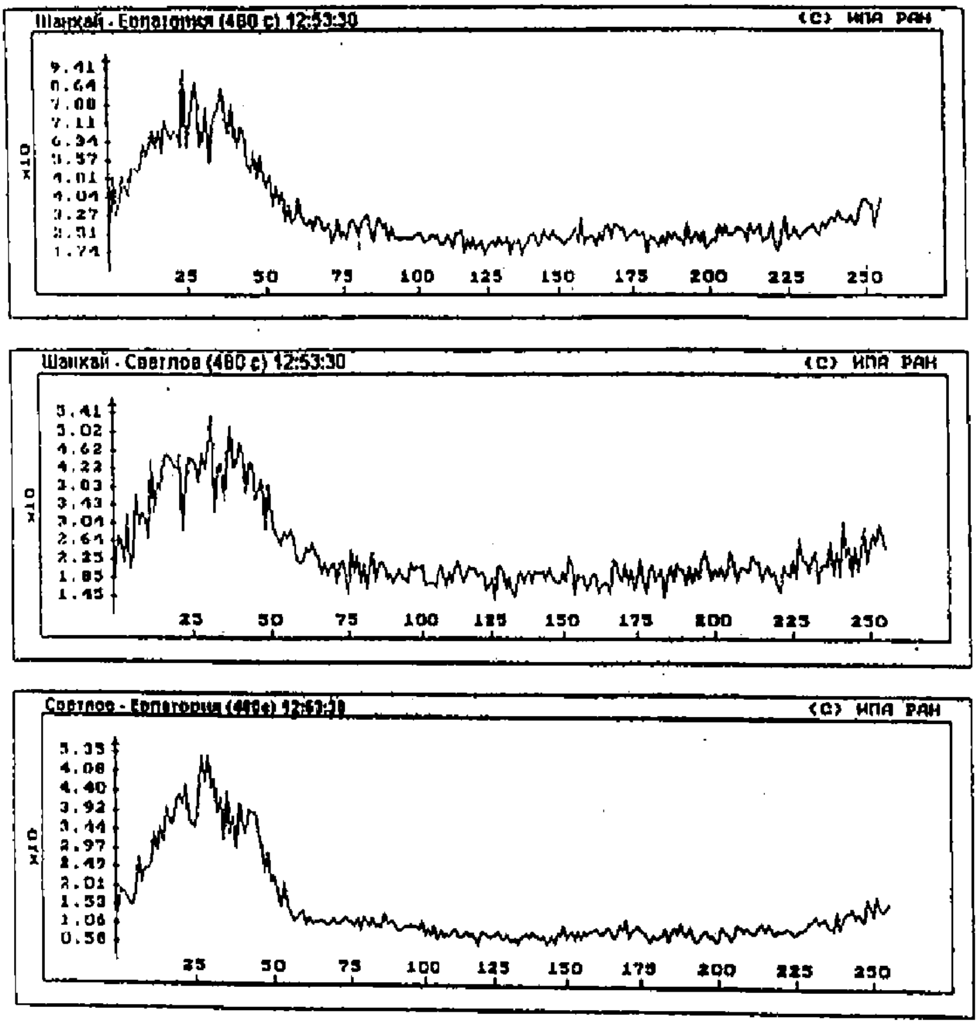

FIGURE 5 Power cross-spectra for an interference response to an echo signal reflected by the planet Venus for Shanghai–Evpatoria, Shanghai–Svetloe and Svetloe–Evpatoria baselines (June 1999; wavelength, 6 cm).

data processing the facilities of the Astro-Space Centre, P.N. Lebedev Physical Institute, developed earlier for the 'Radioastron' project will be more widely employed.

There are intentions to modernize the receiving facilities of the RT-70 in Evpatoria with the aim of expanding its capabilities in conducting radio astronomy explorations. Polarization observations should be carried out, which can serve to obtain maps of the galaxy's background, radio-spectrographic explorations of the interstellar medium in recombination lines of hydrogen at a frequency of 325 MHz and a study of the radio brightness distribution of extended Galaxy objects at a frequency of 4.8 GHz.

The RT-70 radio interferometers are also expected to be used in exploration of compact Sun flashes of millisecond length, 'spikes'.

In 2001, work on rebuilding the Ussuriisk radio telescope RT-70 was started; this will continue for 2–3 years. After that this radio telescope can be used for radio astronomy observations planned by the Astro Space Centre, P.N. Lebedev Institute, with possible participation of scientists from the Chinese Academy of Sciences.

The following tasks are waiting to be solved:

(i) exploration of the fine structure of active Galaxy cores at different wavelengths;
(ii) exploration of Solar micro flashes ('spikes') with high spatial and time division;
(iii) study of Galaxy sources of maser radio emission and pulsars;
(iv) VLBI observations of reference extra-Galaxy sources in the interests of geodynamics and astrometry.

Figures 3–5 illustrate some results of the investigations conducted with use of radio telescopes RT-70.