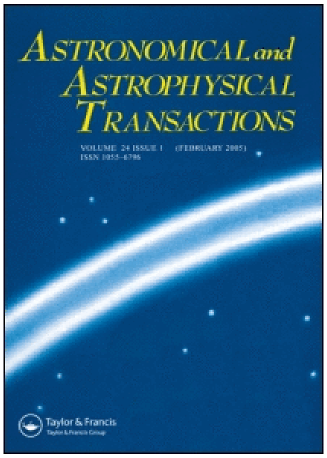

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

International low-frequency very-long-baseline interferometry network project milestones

Molotov; Kovalenko; Samodurov; Lipatov; Dementiev; Antipenko; Snegirev; Nechaeva; Reznikova; Altunin; Benz; Mantovani; Stanghellini; Tuccari; Konovalenko; Falkovich; Gridin; Ananthakrishnan; Balasubramanian; Sankararaman; Hong; Huang; Shiguang; Dougherty; D. Del Rizzo; Fink; Liu; Na; Zhang; Kus; Borkowski; Quick; Nicolson; Shmeld; Koyama; Sekido; Gorshenkov; Poperechenko; Saurin; Ozolins; Bezrukov; Zhang

Online Publication Date: 01 January 2003
To cite this Article: Molotov, Kovalenko, Samodurov, Lipatov, Dementiev, Antipenko, Snegirev, Nechaeva, Reznikova, Altunin, Benz, Mantovani, Stanghellini, Tuccari, Konovalenko, Falkovich, Gridin, Ananthakrishnan, Balasubramanian, Sankararaman, Hong, Huang, Shiguang, Dougherty, Rizzo, D. Del, Fink, Liu, Na, Zhang, Kus, Borkowski, Quick, Nicolson, Shmeld, Koyama, Sekido, Gorshenkov, Poperechenko, Saurin, Ozolins, Bezrukov and Zhang (2003) 'International low-frequency very-long-baseline interferometry network project milestones', Astronomical & Astrophysical Transactions, 22:4, 743 - 752
To link to this article: DOI: 10.1080/10556790310001609205
URL: http://dx.doi.org/10.1080/10556790310001609205

Astronomical and Astrophysical Transactions
Vol. 22, Nos. 4–5, August–October 2003, pp. 743–752

INTERNATIONAL LOW-FREQUENCY VERY-LONG-BASELINE INTERFEROMETRY NETWORK PROJECT MILESTONES

I. MOLOTOV[a], A. KOVALENKO[a], V. SAMODUROV[a], B. LIPATOV[b], A. DEMENTIEV[b], A. ANTIPENKO[b], S. SNEGIREV[b], M. NECHAEVA[b], V. REZNIKOVA[b], V. ALTUNIN[c], A. BENZ[d], F. MANTOVANI[e], C. STANGHELLINI[e], G. TUCCARI[e], A. KONOVALENKO[f], I. FALKOVICH[f], A. GRIDIN[f], S. ANANTHAKRISHNAN[g], V. BALASUBRAMANIAN[g], M. SANKARARAMAN[g], X. HONG[h], X. HUANG[h], L. SHIGUANG[h], S. DOUGHERTY[i], D. DEL RIZZO[i], A. FINK[i], X. LIU[j], W. NA[j], J. ZHANG[j], A. KUS[k], K. BORKOWSKI[k], J. QUICK[l], G. NICOLSON[l], I. SHMELD[m], Y. KOYAMA[n], M. SEKIDO[n], YU. GORSHENKOV[o], B. POPERECHENKO[o], V. SAURIN[o], G. OZOLINS[p], D. BEZRUKOV[p] and X. ZHANG[q]

[a]Astro Space Center, P.N. Lebedev Physical Institute, Russian Academy of Sciences, 84/32 Profsoyuznaya, 117997 Moscow, Russia; [b]Radiophysical Research Institute, B. Pecherskaya 25, 603950 North Novgorod, Russia; [c]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, California 91109, USA; [d]Institute of Astronomy, Eidgenössiche Technische Hochschule Zentrum, SEC F7, CH-8092 Zurich, Switzerland; [e]Istituto di Radioastronomia, Consiglio Nazionale delle Ricerche, Via P. Gobetti 101, 40129 Bologna, Italy; [f]Institute of Radio Astronomy, Chervonopraporna 4, 310002 Kharkiv, Ukraine; [g]National Centre for Radioastrophysics, Postbag 3, Ganeshkind, 411007 Pune, India; [h]Shanghai Astronomical Observatory, Nandan Road 80, 200030 Shanghai, PR China; [i]Dominion Radio Astrophysics Observatory, PO Box 248, V2A 6K3 Penticton, British Columbia, Canada; [j]Urumqi Astronomical Observatory, S. Beijing Road 40, 830011 Urumqi, PR China; [k]Centre for Astronomy, NCU, Gagarina 11, 87-100 Torun, Poland; [l]Hartebeesthoek Radio Astronomy Observatory, PO Box 443, 1740 Krugersdorp, South Africa; [m]University of Latvia, Astronomical Institute, Raina Boulevard 19, 1586 Riga, Latvia; [n]Communications Research Laboratory, Hirai 893-1, Kashima, 314-0012 Ibaraki, Japan; [o]Special Research Bureau, MPEI, Krasnokazarmennaya 14, 111250 Moscow, Russia; [p]Ventspils International Radio Astronomy Center, Akademijas Laukums 1, 1050 Riga, Latvia; [q]National Astronomical Observatories, A20 Datun Road, Beijing 100012, PR China

(Received August 31, 2002)

The low-frequency very-long-baseline interferometry network (LFVN) project was started in 1996, having the purpose to arrange the international very-long-baseline interferometry (VLBI) cooperation with participation of former Soviet Union radio telescopes. Currently there are three directions of LFVN development: a Mk 2 subsystem at 92 cm wavelength for solar research, an international S2 ad hoc array at 18 cm for active Galactic nuclei and OH-maser survey, and VLBI radar at 6 cm for investigation of Solar System bodies. 14 VLBI experiments were carried out using various combinations of radio telescopes in Canada, China, England, India, Italy, Japan, Latvia, Poland, Russia, South Africa, Ukraine and USA. The five sessions were processed by the Jet

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

ISSN 1055-6796 print; ISSN 1476-3540 online
DOI: 10.1080/10556790310001609205

Propulsion Laboratory (California Institute of Technology) Block II and Dominion Radio Astrophysics Laboratory Penticton correlators. The Russian Mk 2 correlator in Nizhny Novgorod is under development. The paper describes the main project milestones, results obtained so far and further plans.

Keywords: Radio telescope; Equipment; Very-long-baseline interferometry observation; Correlator; Quasar image; Radar echo

1 INTRODUCTION

The technique of very-long-baseline interferometry (VLBI) is the best for research of small-scale space phenomena and astrometry measurements, and under very active development around the world. The former Soviet Union countries have many large suitable radio telescopes, namely Evpatoria RT-70 (Crimea of Ukraine), Ussuriisk RT-70 (Far East), Bear Lakes RT-64, Kalyazin RT-64, Puschino RT-22 (near Moscow), Svetloe RT-32 (near St Petersburg), Ventspils RT-32 (Latvia), but they participated irregularly in international VLBI activity, because of lack of modern VLBI equipment. The next attempt to improve this negative situation was undertaken at the time of a meeting between representatives of the Astro Space Centre (ASC) of the P.N. Lebedev Institute, the Jet Propulsion Laboratory (JPL) (California Institute of Technology) and the National Centre for Radio astrophysics, TIFRA, in December 1996, during the Workshop for APT and APSG in Kashima, Japan. It was proposed to arrange an international radio interferometry array with the use of the accessible and most cheap VLBI apparatuses Mk 2 and 92 cm frequency band equipment. Two Russian and two Indian radio telescopes had installed 92 cm receivers. Mk 2 terminals still existed in Russia and on some world radio telescopes. In addition, a large quantity of Mk 2 equipment was released at JPL and the National Radio Astronomy Observatory (Charlottesville, Virginia, USA) to be installed at Russian and Indian radio telescopes, and other accessible antennae. As the JPL Block II correlator had much experience of work with 'Russian' Mk 2 tapes, plans were made to use it for processing future VLBI experiments. The purpose of the US–Russian activity based on the agreement of the US–Russian Astronomy and Astrophysics Joint Working Group signed in February 1996 was the VLBI training of ASC personnel to prepare for the Radioastron project. Indian–Russian joint activity was planned under the Indo-Russian Integrated Long Term Programme of Cooperation in Science and Technology (project B3.9: VLBI observation of radio source using GMRT, Ooty radio telescopes in India and Russian radio telescopes in Ussuriysk, Simeiz and Evpatoria). The INTAS proposal entitled 'Low frequency VLBI research for solar studies and as a precursor to space VLBI with 'RadioAstron' was prepared in order to obtain the necessary finance. The resulting INTAS co-operation agreement N 96-0183 allowed enlargement of the low frequency very-long-baseline interferometry network (LFVN) cooperation by joining scientists from Swiss Institute of Astronomy (Eidgenössiche Technische Hochschule Zentrum), the Italian Istituto di Radioastronomia (IRA) (Consiglio Nazionale delle Ricerche) and the Ukrainian Institute of Radio Astronomy (NASU). Furthermore the LFVN project united scientists from Poland, China, Latvia, Canada and Japan. During the project, the following documents were signed: an agreement between Urumqi Astronomical Observatory and LFVN; an agreement about scientific–technical collaboration between ASC, the Radiophysical Research Institute (RRI) (Russia) and the Ventspils International Radio Astronomy Center in 1999; minutes of a Chinese–Russia radio astronomy meeting between ASC and Shanghai Astronomical Observatory; a letter of understanding between ASC and the Dominion Radio Astrophysics Observatory (DRAO) in 2000; an agreement on scientific collaboration between National Astronomical Observatories of China and ASC in 2002.

2 MK 2 LOW-FREQUENCY VERY-LONG-BASELINE INTERFEROMETRY NETWORK SUBSYSTEM

The Mk 2 subsystem was created to fulfil a multifaceted programme of solar and interplanetary medium research and to learn about the processes of solar energy release, the structure of the solar wind, and the influence of space media on VLBI. Plans were made to study the spatial and temporal parameters of spike-like events (short-lived bursts of solar radio emission with a narrow-band spectrum and expected spatial scales of field of their generation about 0.1–0.001 arcsec), the parameters of solar wind irregularities and the physics of active stars with the use of solar–stellar analogy. The method of research of the solar corona and interplanetary medium is based on the analysis of radio signals characteristics after their propagation through an investigated medium. The VLBI technique is well suited to interplanetary medium turbulence studies. A radio emission of source reaches widespread radio telescopes of an interferometric array by different routes and, hence, the medium introduces different phase distortions along its passage to different telescopes. The distance between these routes determines the maximum extent scale of the irregularities. The scales and parameters of turbulence of the propagating medium are deduced through the analysis of the interferometric response spectra. The use of a VLBI array, which has baselines with different lengths and directions, provides the possibility of investigating the irregularities with sizes from a minimum to a maximum baseline, providing measurements of the anisotropy of these irregularities through providing ‘instant’ pictures (Alexeev et al., 1998).

In 1997, the US Mk 2 equipment was adjusted and installed at Puschino RT-22 near Moscow, Russia, GMRT (one 45 m antenna) at Pune and ORT (500×30 m parabolic cylinder) at Ooty, India; a new VLBI site was arranged at RT-14 in St Pustyn near Nizhny Novgorod, Russia (it was equipped with a 92 cm receiver and feed, a one-channel base band converter, a rubidium frequency standard and a Mk 2 terminal). The first LFVN experiment INTAS 1 was arranged in November 30–December 2, 1997, with participation of Noto, Puschino, St Pustyn, Ooty and GMRT (the bandwidth of recording was 325.99–327.99 MHz). The observation programme contained 37 sources and the Sun and included the following scientific goals: research on the solar spikes and irregularities of the solar corona and wind, study of the limitations of VLBI caused by the scattering effect, compilation of a source list for a space VLBI Radioastron mission, and investigation of the nearest active stars. Successful processing with the Block II correlator allowed pioneering fringes for the GMRT and St Pustyn VLBI points to be found (Chuprikov et al., 1999).

In 1998, sets of a 92 cm receiver and feed, a base-band converter and a videocassette recorder were installed at Bear Lakes RT-64 near Moscow and Evpatoria RT-70, Crimea of Ukraine; a new VLBI site was arranged at RT-15 in Zimenki near Nizhny Novgorod, Russia (a 92 cm receiver and feed, a base-band converter, a rubidium frequency standard and a Mk 2 terminal). This allowed the test VLBI experiments INTAS 98.3 to be carried out on August 28–29, 1998, with the participation of Bear Lakes, Puschino, St Pustyn, Zimenki and Evpatoria and INTAS 98.4 on October 28–31, 1998, with the participation of Bear Lakes, Puschino, St Pustyn, Evpatoria, Ooty and Urumqi RT-25, China (Belousov et al., 2000).

In 1999, a new VLBI site was arranged at Ventspils RT-32 in Latvia (a 92 cm receiver and feed, a base-band converter, a rubidium frequency standard and a Mk 2 terminal) and the Polish team repaired their 92 cm receiver and Mk 2 terminal at Torun RT-15; the test experiment INTAS 99.3 was carried out with the participation of Puschino, St Pustyn, Urumqi, Torun and Ventspils on November 10–14, 1999 (Shmeld et al., 2000).

The last experiments were not processed because the Block II correlator was stopped. The results of the first LFVN observations were added to data from our previous VLBI

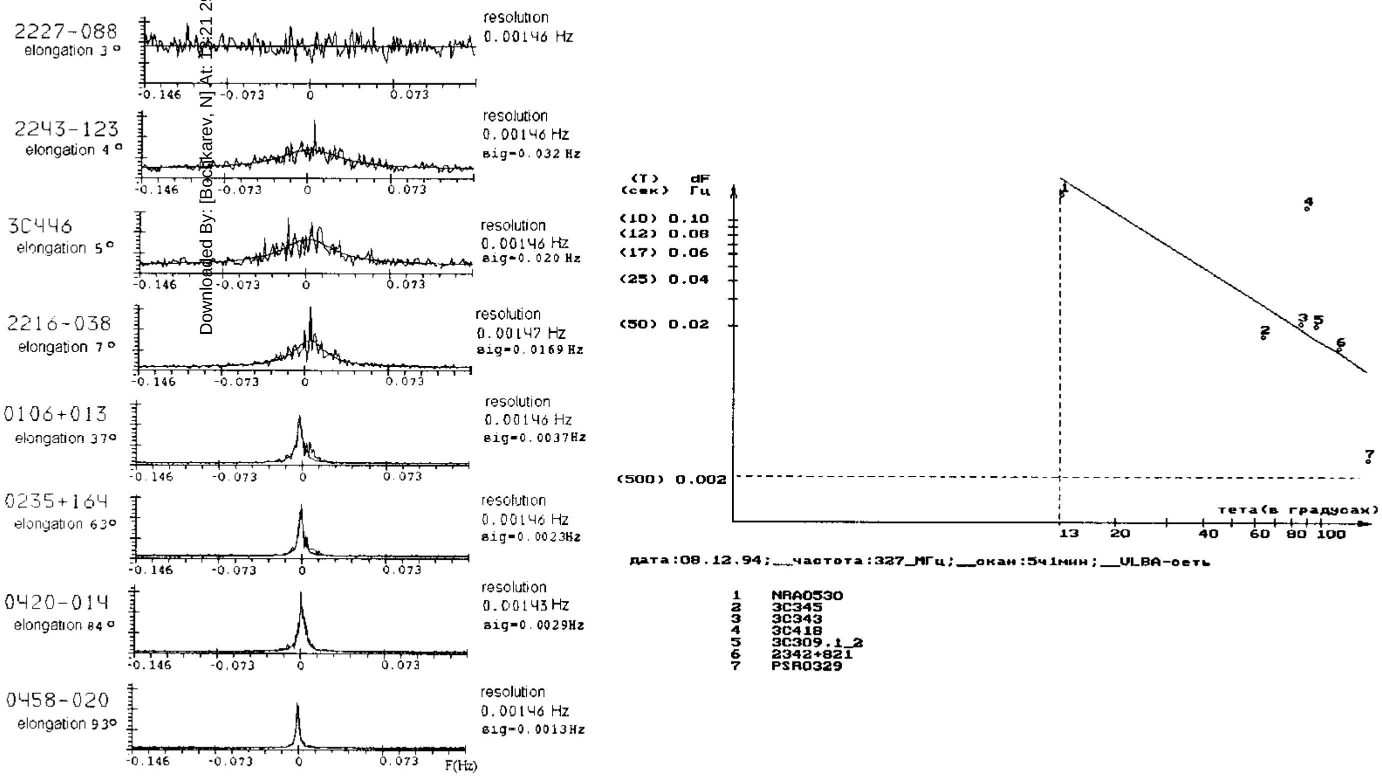

FIGURE 1 Results of the Mk 2 experiments, demonstrating the influence of solar wind irregularities on the interferometric spectrum: (a) the spectra of interferometric responses for different elongation angles from the Sun at 1665 MHz; (b) the dependence of the interferometric spectrum width and corresponding maximum coherent integration time of signal energy on elongation angles at 325 MHz.

experiments and allowed us to suppose the existence of medium-scale structure of solar wind irregularities in the form of 'stream filaments' (Altunin et al., 2000). Their directions coincide with the direction of the solar wind; the cross dimension of such streams is estimated to be about 1500–2000 km and their longitudinal scale is no less than a few hundred thousand kilometres. Also, the limits that the interplanetary medium places on the operation of the VLBI systems in the decimetre wavelength range were determined; the influence of the solar plasma irregularities is essential for source elongations from the Sun of up to 30° at 1665 MHz and of up to 80° at 327 MHz; it is still appreciable up to 90° and 140° respectively and for elongations of the sources from the Sun of less than 3° (1665 MHz) and of less than 13° (327 MHz); the phase coherence is disturbed completely (Fig. 1) (Guirin et al., 1999). 17 sources displayed unresolved components on the maximal baseline Noto-GMRT (about 5800 km) and were selected for future observations. Only two spike-like solar microbursts have been detected at 18 cm on the shortest baseline (118 km (Bear Lakes and Puschino)) with a time resolution of 2 s and a maximum interference amplitude of more 3σ that allowed us to estimate their upper limit of angular size (400 marcsec) and lower limit of the brightness temperature (a Sun brightness temperature of 50,000). This may be explained by the low time resolution of the Block II correlator. The first direct evidence of spatial fragmentation of a radio emission source with very small time intervals of 100 ms was obtained recently (Alexeev et al., 1997). Thus the interferometer response may be close to zero if the time resolution of the correlator does not permit resolution of the separate subsecond components, even if its spatial resolution is high enough to resolve multicomponent sources in space. Therefore development of the Russian Mk 2 correlator NRFI-3 was started at RRI, Nizhny Novgorod, in 1999. The unique feature of this correlator is the very high time resolution (up to 64 μs). It is planned that high-temporal-resolution VLBI will open up new perspectives in investigations of spatial dynamics of solar sources of radio bursts with a fine temporal structure and will allow the fragmentation of flare energy release to be studied.

The last 92 cm LFVN experiment was arranged on July 15–17, 2000, with participation of Puschino, St. Pustyn, Zimenki, Urumqi, Torun and Ventspils. The processing of this experiment was carried out with the NIRFI-3 correlator. Fringes were not found on any baseline. This may be explained by the negative influence of the Earth's ionosphere owing to a very high level of solar activity. Since 2000, the 92 cm observations were temporarily interrupted because of lack of finance. During 2001–2002, the Mk 2 subsystem was fruitfully used in another LFVN project 'VLBI radar'. The LFVN operations at low frequencies will be continued in 2003 under INTAS Grant IA-2001-02, RFBR-02-02-39023 and National Science Foundation of China Grant 10173015. Currently the Mk 2 LFVN subsystem includes the Bear Lakes RT-64, Puschino RT-22, St Pustyn RT-14, Zimenki RT-15, Evpatoria RT-70, Noto RT-32, Torun RT-15, Ventspils RT-32, Ooty 500×30 m and Urumqi RT-25. Future plans are to arrange a VLBI site at RT-15 in Beijing, and to start equipping LFVN antennae with a 49 cm receiver (first three existing receivers will be installed at St Pustyn, Zimenki and Bear Lakes). A more long-term plan foresees the renewal of Ussurisk RT-70 operations in the Far East.

3 INTERNATIONAL S2 AD HOC ARRAY

The obtaining of S2 systems that were received from ISTC, Canada, under a grant from the Russian Ministry of Science and Industry in 1998 allowed us to start a new LFVN project at 18 cm wavelength. The Canadian S2 system is used in 12 countries for VSOP mission support and it was proposed to arrange the international S2 VLBI observations in order to carry out the survey of active Galactic nuclei (AGNs) and OH masers. The first LFVN S2

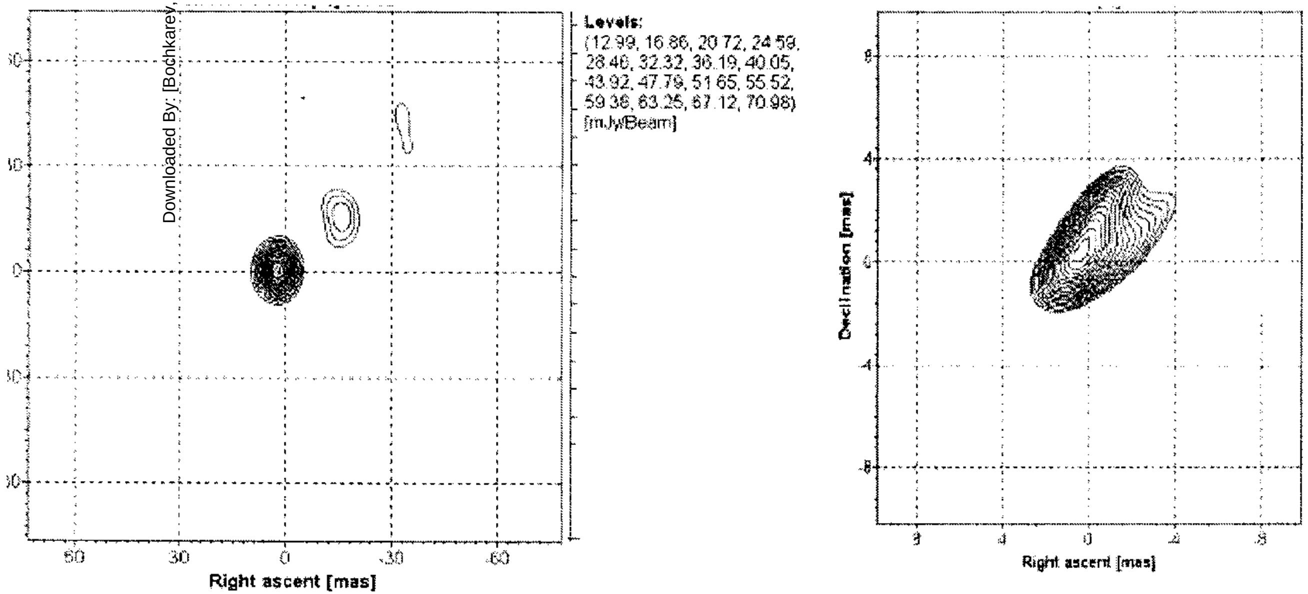

FIGURE 2 INTAS 99.4 showing the images of sources (a) $1011 + 496$ and (b) $0642 + 449$.

experiments confirmed the feasibility of this initiative. Two Canadian S2 recording terminals (frequency bandwidth of up to 64 MHz) were installed at Bear Lakes RT-64 and Puschino RT-22 in 1998 with the use of more highly developed base-band converters and S2 interfaces. The first large S2 experiment INTAS 98.5 was carried out with participation of Bear Lakes, Puschino, Svetloe RT-32 (new Russian antenna near St Petersburg), Greeb Bank RT-43, Arecibo RT-300 (USA) and Hartebeesthoek RT-26 (South Africa) in November 30–December 3, 1998. The INTAS 98.5 experiment had both test and scientific goals; the observation programme included quasars, OH masers, pulsars, Search for Extraterrestrial Intelligence (SETI) sources and compact sources with different elongation angles from the Sun. This experiment was successfully processed with the DRAO S2 correlator in Penticton, Canada. Pioneering S2 fringes were obtained at the Svetloe and Puschino ratio telescopes; moreover, the first source images of LFVN project were reconstructed on the basis of obtained data (Molotov et al., 2001).

In 1999, an informal agreement about establishing an International S2 ad hoc array was obtained with Noto RT-32 (Italy) and Shanghai RT-25 (China), where an S2 system was installed recently and a Penticton S2 correlator. The observation programmes are formed on the basis of the requests of participating observatories. The first official project session INTAS 99.4 was arranged in November 29–December 2, 1999, with the participation of Bear Lakes, Puschino, Noto, Shanghai, Hartebeesthoek and Svetloe. The scientific programme included the following goals: pre-launch ‘Radioastron’ survey, searching for CSO in the sample of GPSs, research on BL Lac object properties, study of OH masers in evolved stars and attempt at stellar VLBI (λ And). The experiment was successfully processed with the Penticton correlator and partially post-processed at ASC, Moscow, with the use of ASL imaging software (Molotov et al., 2002). The first results of INTAS 99.4 are presented in Figure 2.

In 2000, the Indian GMRT joined the S2 array. The installation of a 18 cm receiver at one of the 45 m antennae and the production of a S2 sampler allowed GMRT to participate in the INTAS 00.3 experiment (GMRT, Bear Lakes, Puschino, Noto, Shanghai and Hartebeesthoek) on November 28–December 1, 2000. The scientific goals were the same as for INTAS 99.4. The processing of the first two observation days has already been finished at Penticton. Fringes were found for all participating antennae (pioneering 18 cm fringes of GMRT).

Currently the International S2 ad hoc array includes the Bear Lakes RT-64, Puschino RT-22, Noto RT-32, Shanghai RT-25, and GMRT-45. The next 18 cm experiment LFVN02.2 is arranged for January 22–25, 2003. Negotiations have been carried out about co-observing with Madrid RT-70, Green Bank RT-100 and Penticton RT-26, and about correlation processing of LFVN experiments with the National Astronomical Observatory correlator at Mitaka, Japan (it is able to cross-process the tapes of S2, VLBA and K-4 formats). There is a plan to install an S2 system at Evpatoria RT-70.

4 VERY-LONG-BASELINE INTERFEROMETRY RADAR PROJECT

The third LFVN project was started in 1999 after installation of cooling 6 cm receivers at Evpatoria RT-70 and Bear Lakes RT-64. It was planned to develop the new radio astronomy method for research of the near-Earth environments. The Evpatoria RT-70 in Crimea, Ukraine, has the unique planetary radar complex with a 200 kW transmitter of continuous power at 5010 MHz that may be used for research on Solar System bodies. This frequency is compatible with that from a typical radio astronomy band and most world radio telescopes are equipped with a suitable receiver. This circumstance provides the interesting possibility of receiving reflected echo signals with an array of antennae spaced at large distances. Such a

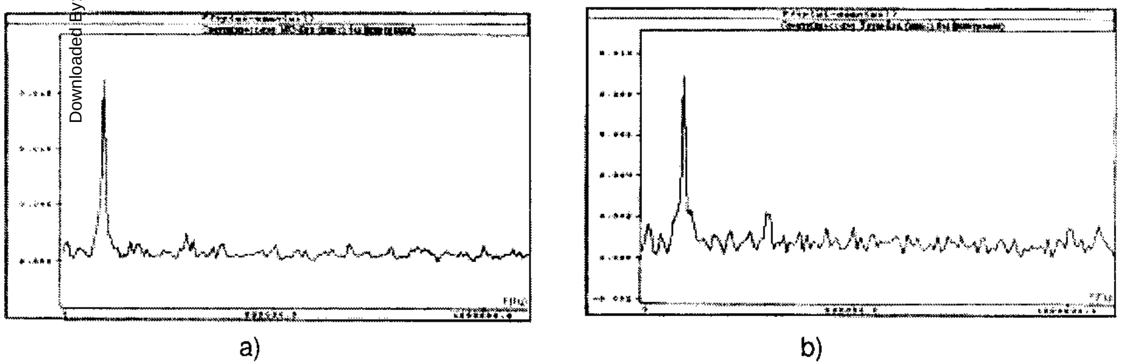

FIGURE 3 Result of the VLBR 01.1 experiment: (a) cross-correlation spectrum of the transmitted–received signal for the Evpatoria–Bear Lakes baseline; (b) cross-correlation spectrum of the transmitted–received signal for the Evpatoria–Urumqi baseline. GEO object 20696.

multiantennae configuration allows one to add classic radar data to VLBI measurements; radar has the resolution for range and radial velocity, and VLBI provides the angle and angular rate. Moreover the VLBI radar may be a tool for three-dimensional measurements; the combination of a radar map and a VLBI image can result in a 'radio holography' picture of the investigated object. The five trial experiments were arranged with large international cooperation to clarify the possibility of VLBI radar method: VLBR 99.1 in June 1999, VLBR 00.2 in August 2000, VLBR 01.1 in May 2001, VLBR 01.2 in December 2001, and VLBR 02.1 in July 2002 (Molotov et al., 2002). The scientific goals of these experiments are as follows: follow-up investigation of near-Earth asteroids; study of space debris population at geosynchronous and high-elliptic orbits; measurements of the short periodic variations in the proper rotation for planets of the Earth group; establishment of linkage between two celestial reference systems (quasar and dynamic systems, based on the positions of radio sources and ephemerides of planets). Since 2002, this project has been supported by INTAS Grants 01-0669 (optical and radar ecological monitoring of near-Earth space environment for the control of technogenic pollution and natural hazard assessment due to asteroids), Grant RFBR-02-02-17568 and Grant RFBR-02-02-3108. The VLBI array for receiving echo signals consists of Bear Lakes RT-64, Kalyazin RT-64 (new Russian antenna near Moscow), Noto RT-32, Torun RT-32, Kashima RT-34, Urumqi RT-25 and Shanghai RT-25. Currently, the main efforts are concentrated on adjusting the correlation procedure of near-field echo signals. It is planned to improve the frequency resolution of the Mk 2 correlator NIRFI-3, Nizhny Novgorod, Russia, to upgrade the software of the Penticton S2 correlator, DRAO, Canada, and to develop the real-time correlator in Noto, IRA, Italy for the processing of echo signals via the Internet (Noto, Shanghai and Bear Lakes must be equipped with a digital base-band converter and a special interface system). Some of first results obtained with the NIRFI-3 correlator are presented in Figure 3.

5 CONCLUSION

The LFVN began regular VLBI activities and the first scientific results were obtained. This project allowed us to equip with radio astronomy apparatus and to keep in operation the large antennae of the former Soviet Union countries. The personnel at the newly arranged VLBI points have accumulated the necessary observational experience. Three new scientific instruments were developed under the LFVN project: a Mk 2 network at 92 cm wavelength for research on solar spikes and irregularities of the solar corona and wind; an international S2 ad hoc array at 18 cm wavelength for a survey of AGNs and OH masers, and stellar VLBI; a VLBI radar at 6 cm wavelength for investigations of the planets of the Earth group, near-Earth asteroids and space debris at geostationary and high elliptic orbits. The post-processing of all the above-mentioned experiments will be continued by the LFVN post-processing group that has just been organized at the Central Astronomical Observatory in Pulkovo. There are other objectives for further LFVN development under INTAS Grant IA-2002-02 (Bear Lakes RT-64: VLBI site for astronomy, astrometry and geodynamics). This project foresees the establishment of a group for planning LFVN operations as a subdivision of Bear Lakes Radio Astronomy Station.

References

Alexeev, V. A., Altunin, V. I., Dementiev, A. F., et al. (1998). Transactions of the Conference on Achievements and Problems of the Solar Radio Astronomy, p. 7.

Alexeev, V. A., Dugin, N. A., Lipatov, B. N., et al. (1997). Radiophysics, 40, 1063.
Altunin, V. I., Dementiev, A. F., et al. (2000). Radiophysics, 43, 197.
Belousov, K. G., Guirin, I. A., Dementiev, A. F., et al. (2000). Trans. P.N. Lebedev Phys. Inst., 229, 76.
Chuprikov, A. A., Girin, I. A., et al. (1999). New Astron. Rev., 43, 747.
Guirin, I. A., Dementiev, A. F., Lipatov, B. N., Likhachev, S. F., et al. (1999). Radiophysics, 42, 1127.
Molotov, I., Likhachev, S., Chuprikov, A., Lipatov, B., et al. (2001). IAU Symposium, Vol. 205, p. 420.
Molotov, I., Likhachev, S., Chuprikov, A., Liptov, B., et al. (2002). Proceedings of the 6th European VLBI Network Symposium, p. 19.
Shmeld, I., Benz, A., Dementjev, A., Lipatov, B., Molotov, I., et al. (2000). Proceedings of the 5th European VLBI Network Symposium, p. 247.