УДК 520.274

RESEARCH OF THE NEAR-EARTH BODIES IN LATVIA[1]

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ИССЛЕДОВАНИЕ ОКОЛОЗЕМНЫХ ТЕЛ В ЛАТВИИ

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Дается обзор проводимых в Вентспилсском международном радиоастрономическом центре и в Астрономическом институте Университета Латвии работ по исследованию астероидов и космического мусора.

Ключевые слова: РСДБ локация, космический мусор, лазерное зондирование, астероиды.

Introduction

There are two astronomical observatories in the Latvia dealing with near Earth astronomy — Ventspils International Radio Astronomy Centre (VIRAC) and Institute of Astronomy University of Latvia (IA UL)

The one of research areas of VIRAC is the radiolocation of space debris (SD) and asteroids in near-Earth (NEA) space and refinement of their trajectory. For this purpose, the method of VLBI is used. During the period 2009–2012 in VIRAC a software package for correlation of the VLBI radiolocation data was developed and series of observations of space debris and asteroids using the radio telescope RT-32 (fully steerable parabolic antenna with the mirror diameter $D = 32$ m), which is located near Ventspils in Irbene, were conducted.

Since 2008, by help of the Schmidt telescope of IA UL (80×120×240 cm) 42 new asteroids were discovered. To three asteroids Nr. 274084, Nr. 284984, Nr. 330836 were assigned names, “Baldone”, “Ikaunieks” and “Orius”. In order to develop the laser ranging atthe laser sensing station “Riga” of IA UL, efforts on the reconstruction of 1 m laser rangefinder began.

1. Receiving and data acquisition systems of RT-32

Partial upgrade of drive mechanisms and receivers of VIRAC 32 m radio telescope (RT-32) in Irbene (near Ventspils, Latvia) was implemented in 2009-2012 with the financial support

[1]This contribution was partially supported by Ventspils City Council Financed Project “Research in VIRAC using Irbene radio telescope” and by the FP7-REGPOT-CT-2011 project “Unlocking and Boosting Research Potential for Photonic in Latvia - Towards Effective Integration in the European Research Area”.

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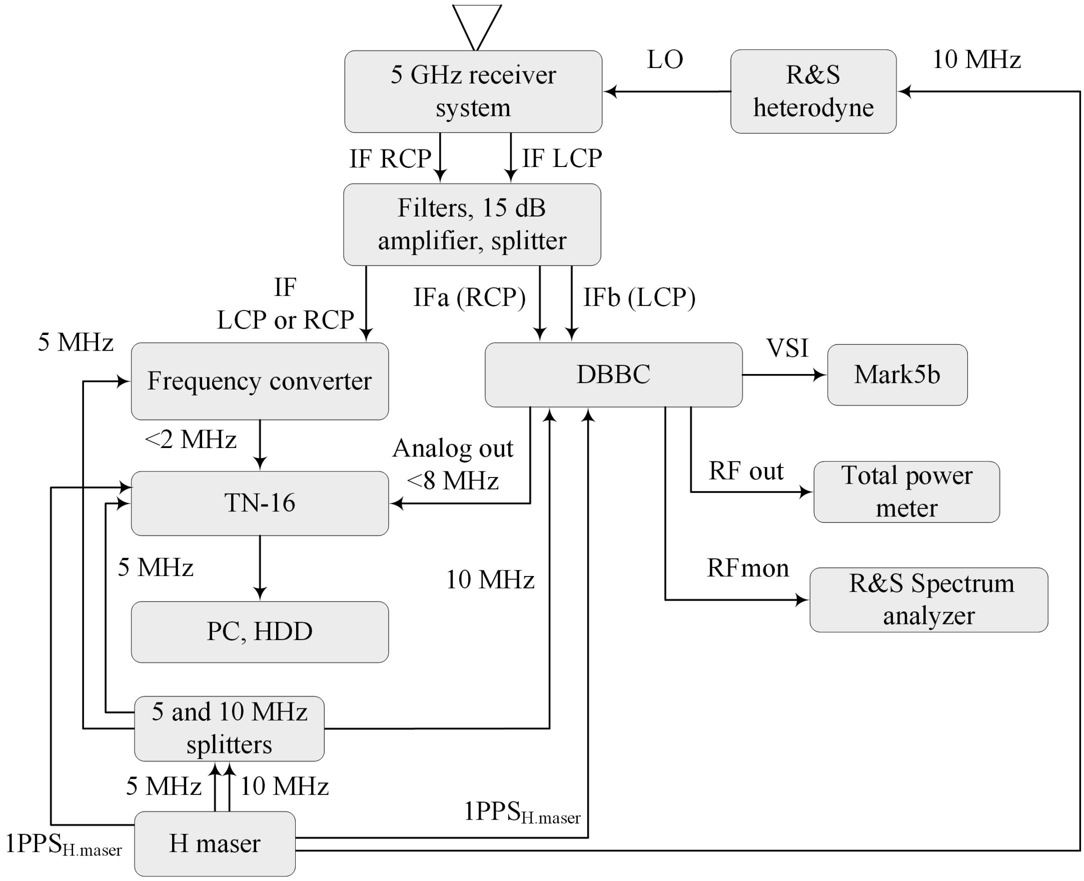

Fig. 1. Connection scheme of receiving and recording equipment for radar VLBI experiments at RT-32

of European Social Funds. Currently, there are following receiving systems available on this radio telescope:

– 327 MHz (92 cm, P band) — primary focus;

– 1.6 GHz (18 cm, L band) — secondary focus;

– 5 GHz (6 cm, C band) — secondary focus;

– 6.9–9.3 GHz (3.7–4.2 cm) — secondary focus;

– 12 GHz (2.3 cm, X band) — secondary focus.

The 5 GHz receiver is engaged for the studies of SD and NEA. For digital representation of received signal, two independent systems are used: TN-16 — the terminal for signal record with a sampling frequency up to 16 MHz developed at the Radiophysical Research Institute, Nizhniy Novgorod, Russia (RRI) and The Digital Base Band Converter developed at the Institute of Radio astronomy, Noto [1] (DBBC2) in conjunction with Mark5b recorder [2]. The latest system allows simultaneous registration of of two intermediate frequencies (IF) with left and right circular polarizations (LCP and RCP) each split into eight channels with the maximum bandwidth up to 16 MHz, with 2-bit quantization. The maximum write speed available in the existing configuration is 1 Gbps. As the frequency and time standard an active hydrogen maser Quartz CH1-75A, generating a reference frequencies of 5 and 10 MHz, and a 1PPS signal is used. The connection scheme assembled in the RT-32 for the radar VLBI observations including the receiving and recording systems described above is shown in Fig. 1 [3].

2. Radar VLBI observations

The radar VLBI method has been experimentally used for refinement of the orbit parameters of space debris fragments, near-Earth asteroids and evaluation of planets rotation parameters [4, 5]. It combines the radar sounding of the space objects by the transmitter and the receiving of radar echos by an array of radiotelescopes. During 1999–2008 the Low Frequency VLBI Network (LFVN) carried out a large number of radar VLBI observation sessions of SD [6,7]. VIRAC radio telescope RT-32 joined the radar VLBI activities in 2007.

Table 1. Radar VLBI observations conducted in the RT-32

Experiment, date	Participating VLBI-stations	Objects	Data processing	References
VLBR 07.2 Nov. 10–14, 2007	Simeiz, Noto, Medicina, Kalyazin, Ventspils	Space debris	Vympel, RRI	6, 7
VLBR 08.1 Sep. 3–12, 2008	Simeiz, Ventspils, Noto, Medicina, Kalyazin, Urumqi	Space debris	Vympel, RRI	
VLBR10.1 June 30, 2010.	Medicina, Ventspils	Iridium-Cosmos and Fengyun-1C collision fragments in LEO, searching in the several LEO regions for not yet catalogued debris, high area/mass debris in GEO	RRI	8, 9
Debris 2012 Apr. 17–20, 2012.	Simeiz, Medicina, Urumqi, Ventspils	3 rocket stages of launch vehicle “Molnia” (SL-6); 1 rocket stage of launch vehicle ,,Proton” (SL-12), 5 inactive satellites	RRI, VIRAC	5
2012 DA14 Feb. 15–16, 2013.	Medicina, Ventspils	Asteroid 2012 DA14	RRI, VIRAC	10

The radar VLBI experiment consists in irradiation of the objects with the signal of the transmitter of planetary radar RT-70 in Evpatoria ($D = 70$ m, National Space Facilities Control and Test Centre, Ukraine). Typical carrier frequency for planetary radar is 5010.024 MHz. During the VLBI observations reflected signal is received in the VLBI mode by set of radio telescopes. During the history of observations the following VLBI stations took part: Ventspils, RT-32 ($D = 32$ m), Latvia; Medicina ($D = 32$ m), Noto ($D = 32$ m), Italy; Urumqi ($D = 25$ m), China; Simeiz RT-22 ($D = 22$ m), Ukraine; Kalyazin RT-64 ($D = 64$ m), Russia. Data processing was mainly implemented in NIRFI (Nizhnij Novgorod) and partially in JSC “Vimpel” International Corporation. Since 2010 data processing is also carried out in VIRAC.

The objectives of the international multipurpose radar VLBI sessions included the following:

– measurement of the Doppler frequency shifts and signal delays between radio telescopes for orbit refining of the space debris objects and near Earth asteroids;

– reception of the reflected signals in the single dish mode to determine rotation period and size of the objects;

– searching for not catalogued debris at the Low Earth Orbits.

List of most successful radar VLBI observation sessions conducted with participation of the radio telescope RT-32 shown in the table 1.

The last radar experiment, carried out of our group in February of 2013, was aimed on observation of asteroid 2012 DA14. The large size of the asteroid, together with its close distance from Earth at the time of observation, allowed to clearly detect the reflected echoes with a high level of details. The first results of the data processing revealed the detection of a powerful echo in the first three radar sessions, at the asteroid’s closest approach (33000 km) to the Earth. A weaker signal was also detected when the distance of 2012 DA14 from the Earth was increased to 10 times. The measurement of Doppler shift frequency were successfully carried out for the whole duration of the radar experiment [10].

3. Data proceeding of the radar VLBI observations in VIRAC

Several years VIRAC team are working by the research of a mathematical apparatus for a near-Earth VLBI signal processing. The typical radar VLBI (and VLBI) data processing is performed in at least a two major steps. The first, correlation step with high computational complexity acts on the raw sampled signals from the pairs of VLBI stations, yielding signal interference functions, in further — ”fringe functions” and basic parameters (delays), optimal for their construction. The spectral characteristics of the fringe functions with the corresponding delays are used in the second step of data processing, which ultimately leads to the measured physical parameters of observed object, such as angular positions, velocities, etc.

Let’s consider the correlation. Due to the SD closeness to the Earth and its fast motion on the sky, implementations of the wave front path corrections in the data processor

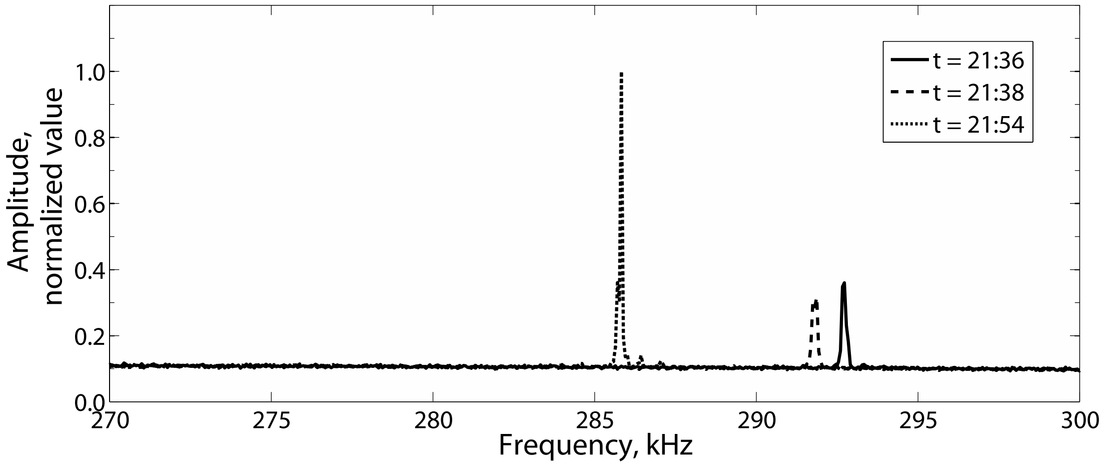

Fig. 2. The spectra of auto-correlation calculated at 21:36 UT (solid line), 21:38 UT(dash line) and 21:54 UT (dotted line), object: asteroid 2014 DA14,Irbene, 15 February, 2013 [10]

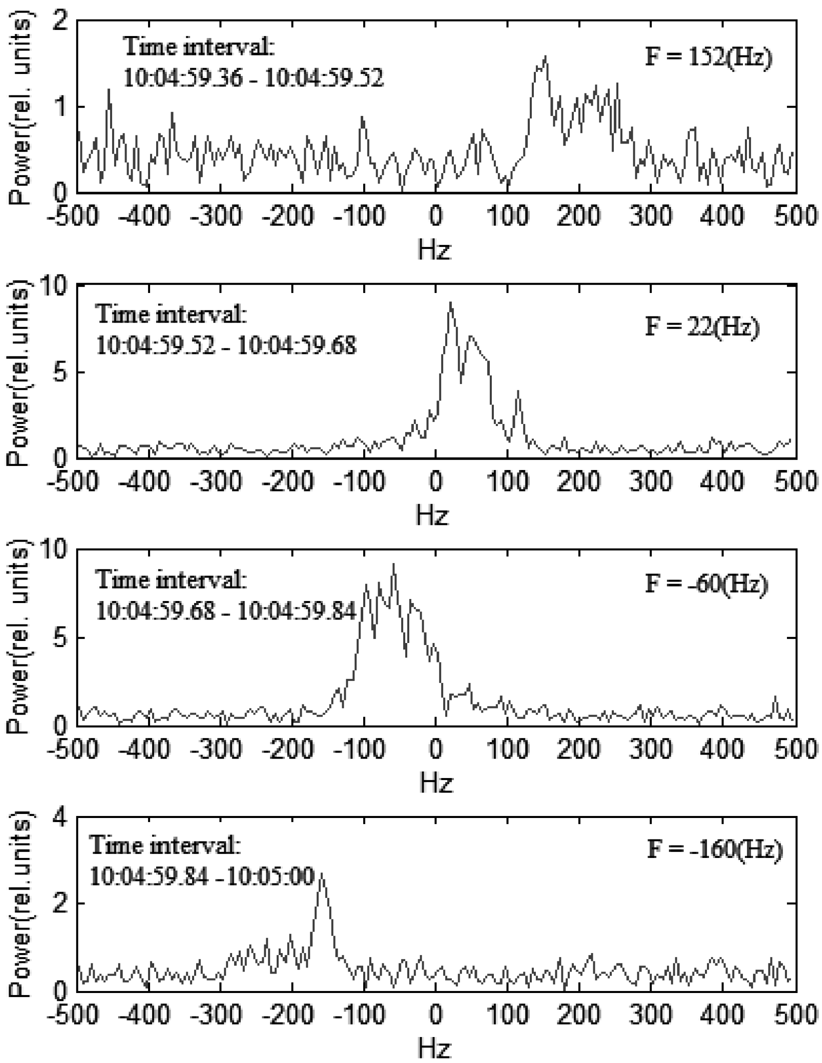

Fig. 3. Spectra of correlation between transmitted signal and received signal from SD object 35303, experiment VLBR 10.1 The peak in spectra represents the frequency shift. Frequency shift is shown for four sequential periods of time [11]

Table 2. The named asteroids were discovered in Baldone observatory

Number	Designation	Name	Date of discovering	Discoverer(s)
24984	2010 GC158	Ikaunieks	2010.04.12	Eglitis, I., Cernis, K.
274084	2008 AU101	Baldone	2008.01.03	Eglitis, I., Cernis, K.
294664	2008 AL86	Trakai	2008.01.03	Eglitis, I., Cernis, K.
321324	2009 HJ68	Vytautas	2009.04.25	Eglitis, I., Cernis, K.
330836	2009 HW77	Orius	2009.04.25	Eglitis, I., Cernis, K.
332530	2008 OS18	—	2008.07.29	Eglitis, I., Cernis, K.
343157	2009 HH68	Mindaugas	2009.04.25	Eglitis, I., Cernis, K.
352646	2008 OZ1	—	2008.07.25	Eglitis, I., Cernis, K.

(correlator) are more complex as in the case of distant deep space sources of radio astronomy. Several years VIRAC team are working by the research of a mathematical apparatus for a near-Earth VLBI signal processing. Three processing regimes — auto-correlation, correlation of received and transmitted signal and correlation between received signals of station pairs — are implemented in VIRAC software correlator written in C programming language, uses FFTW for computing of the Fast discrete Fourier Transform (FFT) and is working in quasi-real-time. Three regimes are used depending on result needed.

The auto-correlation (Mode 1): the purpose of auto-correlation spectra is to detect presence of the signal reflected from object at the particular frequency f, calculated before observation from already known orbital elements. Additionally, auto-correlation spectra can be useful for system noise and parasitic signal monitoring. However, it appears that accuracy of peek position in the frequency domain is far too low for Doppler shift measuring purpose in our case. Additionally, auto-correlation spectra can be useful for system noise and parasitic signal monitoring. The first step is to define auto-correlation function $V(\tau)$ which is depend on time lag τ. The second step is to do the Fourier transform of auto-correlation function, which results gives the spectra of auto-correlation. The third step is to find the local maximum in spectra of auto-correlation, which corresponds to the presence of the received signal at frequency f. The examples of auto-correlation spectra, obtained in VLBI experiment on radar of asteroid 2012 DA14 in 2013, are given on Figure 2.

The correlation of received and transmitted signal (Mode 2): the purpose in this case is sensitive Doppler shift detection on the signal path transmitter-object-receiver. The Doppler shift than can be used to obtain the radial velocity of the object. The first step is to generate transmitted signal which can be monochromatic or linear frequency modulated (LFM) — depends on purposes of the observation goal. The next step is to do time and frequency compensation for received signal and get corrected received signal. After that the correlation between corrected received signal and transmitted signal is made. Applying Fourier transform to vector which is get from the correlation result (the result is depend on delay values) the correlation spectra can be found. Its maximum usually is located in low frequency region and corresponds to the measured correction of the Doppler shift. Figure 3 demonstrates a number of cross-correlated spectra for several time interval, obtained at radar of SD in radar experiment in 2010. Combing Doppler shift measurements on different antennas baselines the information about an object velocity can be obtained.

The correlation between received signals of station pairs (Mode 3): the correlation between VLBI stations is made for each baseline on VLBI network. In general, the correlation on Mode3 gives opportunity to calculate the angular coordinates of object, if the irradiation is performed by wide-band or LFM signals. Using the spectral analyses, it is possible to extract information of velocity in the plane of object. The steps of processing is the same as in Mode 2. At least three VLBI stations are needed, in order to acquire angular coordinates and velocities of the object in a single observation. Efforts for the Mode 3 development will be continued [11].

4. Optical observations of asteroids

The studies of asteroids in Baldone with Schmidt telescope (80×120×240 cm) installed by SBIG CCD ST-10XME (2184×1472 pixels; 6.8×6.8 μ size of pixel) was initiated in January 2008. Asteroids orbit calculation were made in cooperation with Moletai observatory of In-

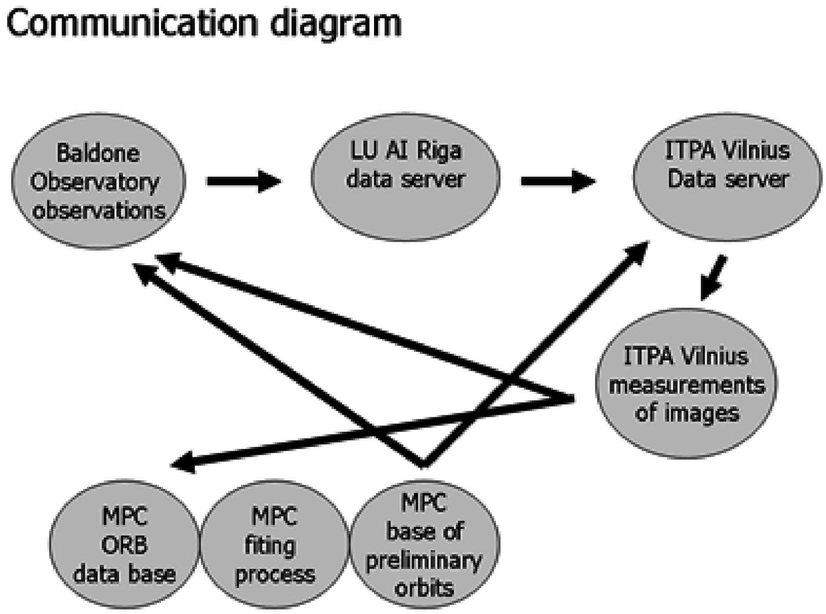

Fig. 4. Observation data and results communication diagram between Baldone observatory, ITPA and Minor Planet Center (MPC)

stitute of Theoretical Physics and Astronomy of Vilnius University (ITPA). In the following five years has managed to reveal 42 new asteroids and to identify more precisely about 3000 known asteroids orbit parameters. Eight of asteroids are numbered and six of them designated by names. More famous from these — 2009 OS9 belongs to the Apollo type [12]. Its absolute magnitude is 19.4. On the base of collection of 830 astrometric positions (during 7 nights) obtained in Baldone and Moletai the orbit of this asteroid was determined. The accuracy of astrometric observations was roughly $0.4''$. From the brightness variation with the 0.27 mag amplitude, a rotation period of 8.430 ± 0.005 h was determined.

The first orbit calculations were made by help of the OrbFit v. 4.0 software[9]. Next step, by help of the method of multiple solution [13] was detecting the orbits of clones. 3σ uncertainty for them around the first orbit was taken. Then close approaches of the first orbit with the terrestrial planets up to $JD = 2492000$ were calculated. Clones orbital evolution showed that the closest approach to Earth will be on 2085-08-13 at 0.0722 AU ($\sim$1695 R_{Earth}). In order to obtain more precise orbital calculations taking into account the Yarkovsky and YORP effects is necessary.

The effective diameter D of 2008 OS9 was estimated by the relation from [14]

$$D = \frac{1.329 \cdot 10^{6-0.2H}}{p^{0.5}}$$

where H is absolute magnitude and p is geometric albedo ($p = 0.4$ for C-type and $= 0.2$ for S-type bodies) of asteroid. Then the diameter of 2008 OS9 would be 837 and 388 m respectively. Observation data and results communication diagram between Baldone observatory, ITPA and Minor Planet Center (MPC)is shown on Figure 4.

The second more famous asteroid discovered in Baldone observatory was a transsaturn Centaur 2009 HW77="Orius" [15]. The absolute magnitude of asteroid was 9.7 (the approximate size is 30–60 km).

Orbit of asteroid also was calculated in two steps as described above. The perihelion distance was determined as 12.5 AU, and aphelion as 30.5 AU. Therefore, Orius belongs to the group UN, such that the perihelia are controlled by Uranus and the aphelia by Neptune. The calculations reveal that in the next 200 years the asteroid won't approach to large planets closer than 4.7 AU therefore orbit will be stable during this time. More complicated further calculation in time span 10^6 years of evolution of orbit using Swift[10] and Mercury [16] soft-

[9]http://adams.dm.unipi.it/~orbmaint/orb_t.
[10]http://www.boulder.swri.edu/?hal/swift.html.

ware packages (for details see paper [15]) led to the result that asteroid will become the short period comet of Jupiter with a Tisserand parameter smaller than 3. The half-life of Orius is about 5 Gyr.

Baldone observatory of IA UL took part in the INASAN coordinated observations of NEO 2010 CF19. Eight observations for them in integral light were obtained at 29.10.2013.

It was agreed with the Space Situational Awareness of Near Earth Object Coordination Centre at ESRIN, that Baldone observatory of IA UL will participate in coordinated observations of NEO.

In order to detect the reflected light from the space debris at the laser sensing station "Riga", owned by the Astronomical Institute, efforts on the reconstruction of 1 m laser rangefinder began.

References

1. *Tuccari G., Alef W., Bertarini A., Buttaccio S., Comoretto G., Graham D., Meidhart A., Platania P., Russo A., Roy A., Wunderlich M., Zeitoefler R., Xiang Y.* DBBC2 backend: Status and development plan // IVS General Meeting Proceedings. 2010. P. 392–395.
2. *Whitney A. R.* Mark 5 Disk-Based Gbps VLBI Data System // New Technologies in VLBI. Astronomy Society of the Pacific Conf. Series, 2003. Vol. 306. Pp. 123–134.
3. *Bezrukovs V., Shmeld I., Nechaeva N., Trokss J., Bezrukovs D., Klapers M., Berzins A., Lesins A.* Receiving and data acquisition systems of RT-32 for VLBI observations. // Latvian Journal of Physics and Technical Sciences. 2012. Vol. 6. No. 2. Pp. 30–42.
4. *Molotov I. E., Nechaeva M. B., Konovalenko A. A, et al.* VLBI radar method development under LFVN project // Journal of the Central Astronomical Observatory in Pulkovo. 2006. Vol. 218. Pp. 402–414.
5. *Nechaeva M., Antipenko A., Bezrukovs V., Bezrukov D. et al.* An Experiment on Radio Location of Objects in the Near-Earth Space with VLBI in 2012 // Baltic Astronomy. 2013. Vol. 22. No. 1. P. 35–41.
6. *Nechaeva M. B., Antipenko A. A., Dement'ev A. F., Dugin N. A., Snegirev S. D., and Tikhomirov Yu. V.* VLBI Studies at the Radiophysical Research Institute // Radiophysics and Quantum Electronics. 2007. Vol. 50. No. 7. Pp. 527–541.
7. *Molotov I., Nechaeva M., Falkovich I., Konovalenko A., et al.* Astrometry of the Solar System Bodies with VLBI Radar // "Measuring the Future": Proc. of the Fifth IVS General Meeting. A. Finkelstein, D. Behrend (Eds.). StPb: Nauka, 2008. Pp. 30–36.
8. *Pupillo G., Salerno E., Bartolini M., et al.* The INAF contribution to the ASI Space Debris program: observational activities // Memorie della Societa Astronomica Italiana Supplement. 2012. Vol. 20. Pp. 43–49.
9. *Шмелд И., Нечаева М. Б.* Технологии обработки информации при интерферометрическом приёме сигналов искусственных космических объектов // Тезисы докладов на Всероссийской астрономической конференции «От эпохи Галилея до наших дней», Нижний Архыз, 12–19 сентября 2010. Геленджик: «Кадо». С. 37.
10. *Nechaeva M., Antipenko A., Bezrukov D., Bezrukovs V., et al.* First results of the VLBI-experiment on radar of asteroid 2012 DA14 // Baltic astronomy. 2013. Vol. 22. Pp. 341–346.
11. *Jekabsons N., Kotlere D., Nechaeva M., Smeld I.* Mathematical and algorithmic description of software correlator for space debris data processing in VIRAC // European Space Surveillance Conference, 7–9 June 2011, INTA HQ, Madrid, Spain. Proceedings WPP-321. [URL] http://www.congrex.nl/11c01proceedings/ (7 pages).
12. *Černis K., Eglitis I., Wlodarczyk I., Zdanavièius J., Zdanavièius K.* The Apollo Group Asteroid 2008 OS9: Discovery, Orbit, Rotation and the Yarkovsky/YORP Effects // Baltic Astronomy. 2010. Vol. 19. Pp. 235–263.
13. *Milani A., Sansaturio M. E., Tommei G., et al.* Multiple solutions for asteroid orbits: Computational procedure and applications // A&A. 2005. Vol. 431. Pp. 729–746.
14. *Fowler J. W., Chillemi J. R.* IRAS asteroid data processing / The IRAS Minor Planet Survey. E. F. Tedesco (Ed.) 1992. Phillips Laboratory, Hanscom AFB, Technical Report PL-TR-92-2049. P. 17–44.
15. *Wlodarczyk I., Cernis K., Eglitis I.* Analysis of the orbit of the Centaur asteroid 2009 HW77 // MNRS. 2011. Vol. 418. Pp. 2330–2335.
16. *Chambers J. E.* A hybrid symplectic integrator that permits close encounters between massive bodies // MNRS. 1999. Vol. 304. Pp. 793–799.

Keywords: radar VLBI, space debris, laser ranging, asteroids.

Статья поступила 28 ноября 2013 г.

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