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VLBI — A Vital Player in Global Observing Systems

Astrometry of the Solar System Bodies with VLBI Radar

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Abstract. Three VLBI sessions of Low Frequency VLBI Network (LFVN) were carried out in 2006–2007 (VLBR06.1, VLBR07.1, VLBR07.2) having the main goal to adjust the application of the VLBI radar method for astrometry of the solar system bodies. The transmitter of Evpatoria RT-70 provided the radio sounding of planets, asteroids and space debris objects at 6-cm wavelengths. Also LFVN joined to the radar experiments of Goldstone RT-70 at 3.6 wavelengths for NEA during VLBR06.1 and VLBR07.1 sessions. The echo-signals were recorded by array of the radio telescopes in Russia, Ukraine, Italy, China and Latvia using NRTV, Mk5 and Mk2 terminals. The number of experimental results is presented in the paper.

1. Introduction

The project of the Low Frequency VLBI Network (LFVN) was started in 1996 in order to arrange the international VLBI cooperation with participation of former USSR radio telescopes [1]. One of the LFVN goals is developments of the VLBI radar (VLBR) for the investigations of the Solar system bodies. LFVN arranges VLBR experiments since 1999 with the help of the C-band transmitter of Evpatoria RT-70. The VLBR combines the radar sounding of space objects with a powerful transmitter and the receiving of radar echoes by an array of radio telescopes in VLBI mode. VLBR is a scientific instrument for 3-D measurements: the radar has the high resolution for range and radial velocity, and the VLBI provides the angle and angular rate. VLBR allows to measure the variations of proper rotation of the Earth group planets and determine the trajectories of planets and asteroids in the Radio Reference Frame. VLBR program of research of new promising space debris problem was started in 2001 [2]. The main tasks were the VLBI measurements of the Doppler shifts and fringe rates of echoes from the space debris objects and determination of the object rotation period and orientation of rotation axis, as well as the estimation of the objects size and their basic constructions [3].

The efforts of three LFVN sessions during 2006-2007 were concentrated on the adjustment of the VLBR method for the planets, asteroids, and small fragments of space debris in geostationary orbit. Also complimentary work was carried out, which included the development of an e–VLBI technique with dedicated Near-Real-Time-VLBI (NRTV) terminal, improvement of the correlation center of the Radiophysical Research Institute (RRI) in Nizhnij Novgorod, elaboration of the new data processing center of the International Vimpel Corporation in Moscow (for Mk5 format VLBI data) and testing of the Ventspils RT-32 in Latvia with new equipment (a new C-band receiver, feed-horn and digital BBC).

2. Observations and Results

VLBR06.1 (Jul. 3–9, 2006), VLBR07.1 (Jul. 28 – Aug. 3, 2007) and VLBR07.2 (Nov. 10–14, 2007) experiments were carried out with participations of Evpatoria RT-70 and Simeiz RT-22 in Ukraine, Kalyazin RT-64 and Zelenchuckskaya RT-32 (06.1) in Russia, Noto RT-32 and Medicina RT-32 (07.1 & 07.2) in Italy, Urumqi RT-25 (06.1 & 07.1) in China, and Ventspils RT-32 (07.2) in Latvia. Twice (06.1 & 07.1) JPL joined the asteroid radar experiments LFVN with the Goldstone RT-70 in USA at X-band. The recorded VLBI data was partially received on videocassettes and partially downloaded through Internet, converted into uniform format and processed at the RRI correlation center. Vimpel processing center was used for the primary autocorrelation of VLBR data and for Mk5 data extraction. In the course of the data processing the correlation of the transmitter signal model and the echo signal, obtained at each receiving point, was performed. Then a spectral analysis of the correlation signal was done for further calculation of frequencies. The measurement of the frequency of the maximum spectral response allows to evaluate the Doppler frequency shift, conditioned by the object radial velocity.

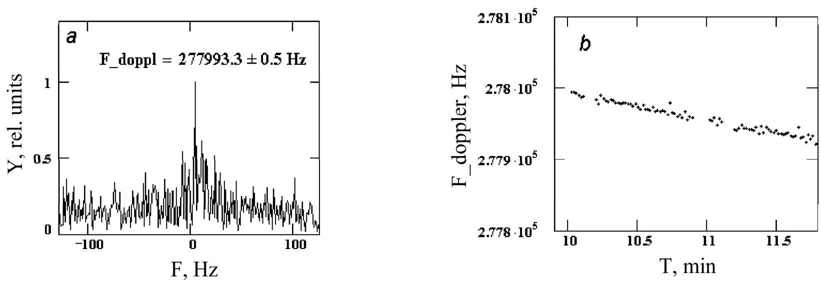


Figure 1. The cross-spectra of echo from Venus, received in Kalyazin RT-64 in 08:11:25 UT and the time dependence of Doppler shift frequency (Experiment VLBR07.1, Jul. 31, 2007, 08:10:00 UT)

One of the tasks of the VLBR sessions was research of the orbital parameters of Earth's group planets. During July 2007 Venus was at a comparatively small distance from the Earth (about 0.3 AU), that allowed to successfully implement the cross-correlation of transmitted signal of Evpatoria radar and received signal at station Evpatoria (the radio telescope in Evpatoria was switched to receive mode in the period $\sim$ 5 minute before the end of each scan) and Kalyazin. The signal spectrum, obtained as a result of the correlation between Evpatoria transmitter signal and echo from Venus, obtained at Kalyazin is presented in Fig. 1a. The estimation of Doppler shift frequencies F_doppl was made in result of spectral analyses according to the frequency of main maximum of the spectrum. Fig. 1b shows the Doppler shift frequencies as a function time.

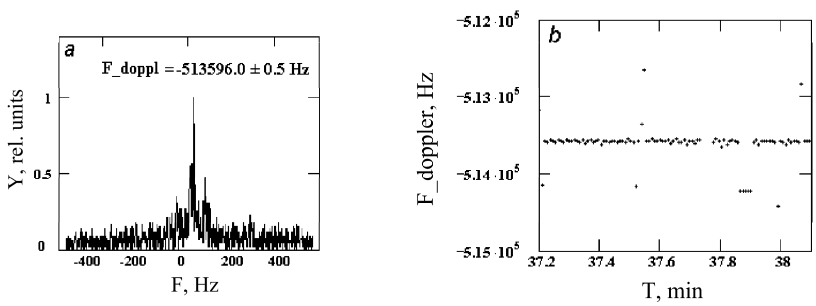


Figure 2. The cross-spectrum of echo from asteroid 2004XP14, received in Evpatoria RT-70 in 08:39:00 UT and the time dependence of Doppler shift frequency. The radar sounding provided with Goldstone RT-70 at X-band. (Experiment VLBR06.1, Jul. 3, 2007, 08:37 UT)

The successful radar detection of asteroid 2004 XP14 was carried out on Jul. 3, 2006, when the asteroid reached minimal distance to Earth (near 400000 km). The assumed diameter of the asteroid is 430 m. The radar of such large asteroid on small distance did not carried out before. In session VLBR06.1 the radar sounding was provided in two frequency range: at 5010.024 MHz by Evpatoria RT-70 transmitter and at 8560.0 MHz by Goldstone RT-70 transmitter. The correlation and spectral analysis of data allowed to obtain the response from asteroids in both frequency ranges. The cross-correlation of model of transmitter signal and signal, reflected from asteroid, has been performed. The spectral response of Evpatoria on echo from asteroid at radar of Goldstone emission is on Fig. 2a. Evaluations of Doppler shift frequencies are carried out according main spectral maximum (Fig. 2b).

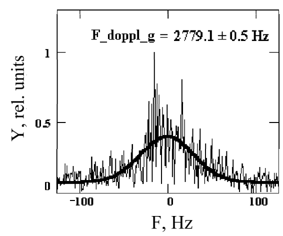


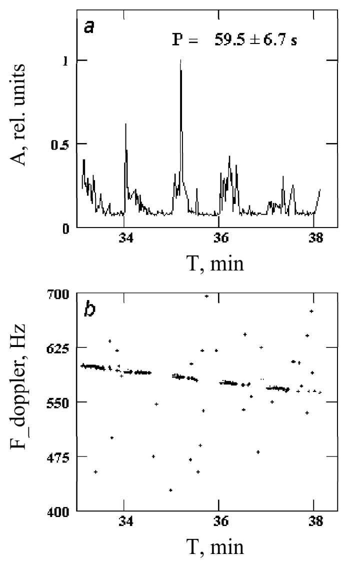
Figure 3. The cross-spectrum of echo from GEO object 95120, received in Noto (thin) and its approximation (solid). Experiment VLBR06, Jul. 6, 2006, 01:20:05.3 UT

Other goal of the sessions was improving of the measurement precision for the cases, when the spectra of space debris objects are widening up to hundreds of kilohertz. This effect is become especially apparent at large sizes and irregular shape of investigated objects and at radar of revolving objects. Besides, the main maximum may be essentially shifted from central frequency of spectrum (Fig. 3). To exclude the error in frequency Doppler shift determination, the procedure of spectrum approximation by Gauss function is applied. The solid line on Fig. 3 presents the Gaussian, which makes best fit the wide spectrum. The Doppler shift F_doppl_g, measured by frequency of Gaussian maximum, carries information about average radial velocity of space debris object.

Fig. 4 presents the time dependence of spectral maximum amplitude (Fig. 4a) and Doppler shift frequency (Fig. 4b) at radar of GEO debris fragment 95034 with size about 1 m. Analysis of temporal dynamics (Fig. 4a) of the frequency spectrum gives an additional possibility to obtain information on the general state of a spacecraft, including its rotation velocity, the presence of separate reflecting fragments on the object body, etc. Rotation period P for fragment 95034 is about 60 seconds. The Doppler shift frequency is linear dependence on Fig. 4b. The time intervals, where scattered signal is missed, may be excluded or changed by interpolated values. Fig. 5 demonstrates the results for GEO debris fragment 90032 with size about 50-cm that were discovered by International Scientific Optical Network (ISON) [3] in 2007.

3. Conclusions

The LFVN experiments of 2006-2007 provided a next step in the VLBR method development. The first VLBR results were obtained for the asteroid, Venus and the small space debris fragments. Also the procedure of spectrum approximation by Gauss function was proposed that allowed to improve the precision of Doppler shift and fringe rate frequency measurements. The pre-



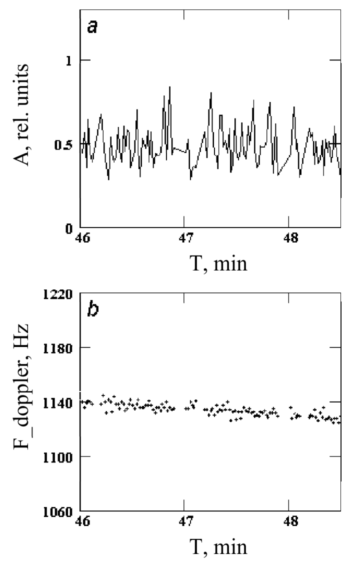


Figure 4. The time dependences of spectral maximum amplitude (a) and Doppler shift frequency (b), obtained from analysis of echo from fragment 95034, received in Urumqy. Experiment VLBR07.1, Aug. 4, 2007, 06:33 UT

Figure 5. The time dependences of spectral maximum amplitude (a) and Doppler shift frequency (b), obtained from analysis of echo from object 90032, received in Kalyazin. Experiment VLBR07.1, Aug. 4, 2007, 02:46 UT

cise measurements of ephemeris of space debris fragments are important for the prognosis of the dangerous approaches with operational satellites. During VLBR08.1 (Sep. 3–12, 2008) it is planned to arrange the VLBR observations of the objects with high AMR recently discovered into international optical observing campaigns [3].

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