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Radar VLBI activity with participation of Noto

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Abstract. The radar VLBI method represents potentially a powerful tool for investigating radio-silent space objects. The combination of both techniques - radar for good range and radial velocity resolution and VLBI for angle and angular rate information - results in three dimensional measurements. Possible applications cover the fields of research of near Earth asteroids, investigation of short periodic variations of Earth group planet rotations and investigation of space debris. The special nature of such observations, involving narrow bandwidths because of the monochromatic emission of the transmitter, permits the implementation of a link between VLBI stations using a standard Internet connection. A dedicated, fully-digital acquisition terminal is being developed for such applications and includes: a narrow-band digital baseband converter whose output is recorded on disk, observation and correlation software. Such hardware includes the entire acquisition chain fed by the receiver output, and produces files for transfer through the network and correlation at a single point. A description of the activities involving the Noto station is presented. Further plans are connected with INTAS-01-0669 project.

1. Background

Studies of the Solar System have resulted in the discovery of a population of asteroids crossing the Earth orbit (Near Earth Asteroid, NEA) and identified the problem termed Asteroid Impact Hazard. Cosmic impacts represent an extreme example of a class of hazards with low probability but high damage. Asteroid Impact Hazard is the only known natural danger that can destroy civilisation as a whole. Impacts from large bodies could cause local, regional or global catastrophes. The present great uncertainty in risk analysis arises from the current incomplete knowledge of the NEA population. The initial step in any scheme for prevention or mitigation of impacts must involve a comprehensive NEA search and detailed analysis of their orbits. Analysis of NEA discovery statistics and the cratering record on the Moon shows that there are probably 1 to 2 thousand NEA larger than 1 km, 4 to 8 thousand larger than 500 m, and 0.5 to 1.5 million larger than 50 m. Therefore the goal of searching, cataloguing and tracking this dangerous population seems to be of primary importance. There are many optical telescopes which are searching for new NEA as an activity of Space Guard organisations in different countries and NASA. The Minor Planet Center is compiling a list of NEA. The activity to track and discover new NEA and to improve their orbits represents a very important goal. Moreover, NEA are usually discovered at a short distance from the Earth and there is little time for orbital measurement. A NEA position can often not be predicted with the accuracy necessary to find it again a few years later. Moreover, some asteroids can significantly change their orbit due to tiny gravitational kicks produced by nearby planets. Therefore, in addition the periodic survey of known NEA is of great interest. A careful cataloguing of the data obtained could prevent confusion between newly detected and known NEA. The work could also be directed to the estimation of the mass and size of asteroids, which is necessary for evaluation of impact consequences.

"Technogenic" pollution of the near-Earth environment, termed Space Debris (SD), is a direct consequence of human activity in space. In nearly 44 years the use of space flights has brought many benefits to science and its applications. On the other hand, the quantity of SD fragments in near-Earth space has already reached a huge size, representing a serious danger, not only for manned orbital stations, rockets and operational satellites, but even for the life of people and the ecology of the Earth (and the quantity is permanently growing). SD consists of uncontrolled payloads, upper rocket stages, fragments of exploded objects, operational fragments (i.e. fastening, lens caps), dispersion and dust (i.e. solid-fuel particles, inner atmosphere of payloads). The investigating activity of different scientific organisations and space agency committees is directed towards SD measurement, elaboration of SD distribution models, development of a database and software for prediction of dangerous approaches to operational satellites, study and implementation of mitigation methods and elaboration of spacecraft protection. Currently, about 8700 identified and 2500 unidentified objects from 26900 officially catalogued objects are tracked (only about 6% of the identified orbiting objects are operational satellites). The total number of catalogued geostationary (GEO) objects is about 900 and among these about 300 are controlled satellites. There are many obvious gaps in current SD knowledge caused by the lack of experimental data. The current capabilities of SD sensors are limited to 10-cm size fragments in low-elliptic-orbit (LEO) and 80-cm size objects in GEO. Trial radar observations have detected a large number of small-sized SD particles (from 2 mm to 5 cm) with altitudes between 150 and 2000 km and optical observations have discovered a significant population of uncatalogued GEO objects with diameters about 10 cm. A motion analysis of 350 uncontrolled GEO objects during the period 1993 - 2000 showed occasional changes in rates of drift (0.0002-0.05 deg/day) for more than 100 objects, due to collisions of these objects with undetected SD fragments. Explosions of satellites could explain the origin of such fragments (each explosion produces an orbital cloud of debris which is extremely dangerous for operational satellites). The current status of the pollution of high-elliptic orbits is unclear.

2. Detection of Space Debris with the VLBI Radar Technique

The VLBI radar technique may represent a useful tool to investigate NEA and SD, due to the possibility, in principle, of applying a combination of both techniques to such non-emitting objects; radar has the resolution in range and radial velocity, VLBI provides the angle and angular rate. VLBI radar may be a tool for 3D-measurements; a combination of radar maps and VLBI images can result in a “radio holography” picture of the object investigated.

The possibility of using the Evpatoria RT-70 planetary radar for space debris research was tested in two trial experiments on targets in geostationary (GEO) and high-elliptic (HEO) orbits in 2001. The RT-70 has a 200 kW continuous-power transmitter at 6-cm wavelength, which was used for radio location of planets. The receiving antennas (Bear Lakes RT-64, Svetloe RT-32, Noto RT-32, Torun RT-32, Shanghai RT-25, Kashima RT-34 and Urumqi RT-25) used VLBI equipment (S2 and MkII) for recording the echo-signals because they do not have specialised radar apparatus. Such multi-antenna configurations allow combining classic radar data with VLBI measurements. Seven GEO objects were detected in the May session and four GEO + two HEO objects in the December session.

It was proposed to study the asteroid 1999KW4, which approached Earth at a distance of 0.03 AU on May 25, using the VLBI Radar (VLBR) method. The Evpatoria RT-70 planetary radar was used to “illuminate” the space body and produce its visibility at radio frequencies. This allowed the organisation of a differential VLBI observation, between the reflected echo-signals and signals from a nearby extragalactic reference source, in order to improve our knowledge of the orbit of the asteroid. In addition, it was planned to investigate the possibility of VLBR measurements of short, periodic variations of the rotation of the planets Venus and Mercury and definition of their orbital trajectories in the Radio Reference Frame.

Detection spectra of the echo signals are shown in the figures for some participating stations, along with the

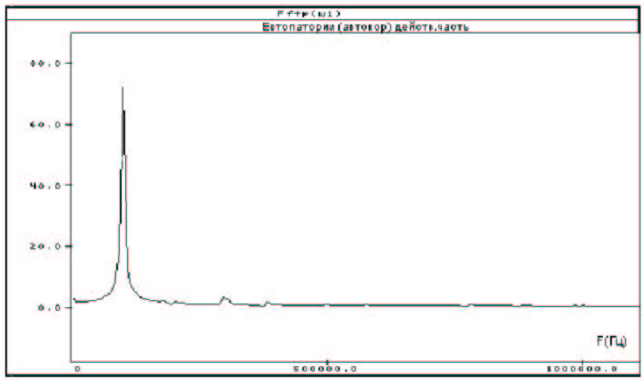

Fig. 1. Power Spectrum of sounding signals in Evpatoria. Sky frequency 5010.024

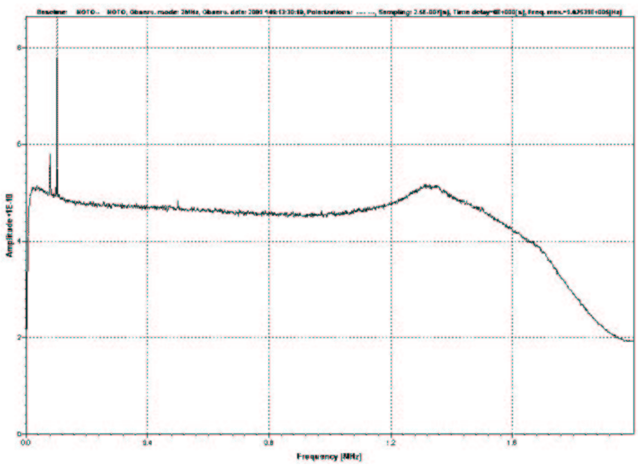

Fig. 2. Spectrum of echo-signals received at Noto (second peak from the left), May 29 2001, 13:30 UT, Geo object 13177

transmitted signal spectrum, demonstrating the possibility to receive the reflected signals using standard VLBI observing modes. The data processing for these observations is still in progress and the cross correlation in particular is hampered by the fact that the VLBI correlator software models far field signals, while in most cases the near field must be taken into account. Development of appropriate software is thus a critical point for correlating radar VLBI experiments.

3. Near Real Time Radar VLBI

The VLBI radar technique will be able to produce measurements in quasi-real time. Indeed, the development of a real-time software correlator and ad hoc data acquisition terminals is in progress. The correlation process for radar experiments in quasi real-time, with the transfer of the received signals from antennas to a correlator through Internet, is indeed possible without a high speed connection. In this particular case, a monochromatic signal sent from a transmitter is received as a narrow-band spectral

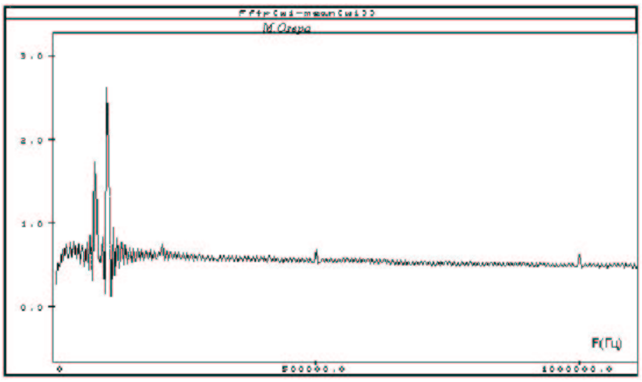

Fig. 3. Spectrum of echo-signals received at Bear Lakes (second peak from the left), May 27 2001, 23:35 UT, GEO object 20696

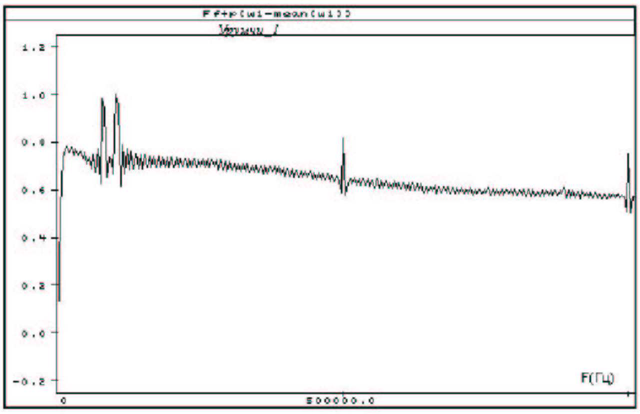

Fig. 4. Spectrum of echo-signals received at Urumqi (second peak from the left), May 27 2001, 23:35 UT, GEO object 20696

distribution. The frequency spread and the relative percent in LHC and RHC circular polarisations represents a unique probe of the material surfaces and is characteristic of the body's rotational velocity. Indeed, a CW signal transmitted in a single circular polarisation returns with a broadened and double polarised spectrum, with a Doppler frequency shift due to the relative velocity.

Starting with a minimum requirement of a standard 2×64 kbit/s bandwidth, even a telephone line connection is able to transfer near real time data for correlation, while a faster data rate can enlarge the band, with the consequent need to have an accurate Doppler shift model; a slower transfer speed expands the transmission time, contributing the "near" to the name of the method. A near real time system allows the results of radar observations to be obtained on a very rapid basis (this is an urgent requirement for real-time tracking of known space debris objects).

The system under development takes care of the fact that the ex-Soviet radio astronomy stations very often don't have a VLBI terminal. In this situation there is a need to be able to record with a limited bandwidth, starting from the receiver output and going straight to the creation of files to be sent over the network to the final correlation point.

The project development has been divided into two sub-projects: The first part includes an interface placed between the output of two baseband converters and a personal computer. Its simple function is to record time-flagged data on disk. Blocks of 1-2-4-8-16 seconds files are possible, coming from data sampled at 1-2-3-4 bits. The more accurate the representation, the more data is to be transferred.

The second, more complex, part includes a fully-digital baseband converter. This module is able to sample 4-bit data, to perform SSB baseband frequency translation, to filter with appropriate bandwidth and to format data to be inserted in the described interface. The input receiver bandwidth must be limited to about 500 MHz, and the output bandwidth consist of two channels with a maximum bandwidth of 2 MSample/s, even though for the actual slower network speed, 62.5 kSample/s will be used.

It is worth noting that, while this interface should not be compared with other projects in development (Haystack MkV, JIVE/Metsahovi) able to record high data-rates on disk, for the small band recorded the digital baseband converter could represent an interesting starting point to fully process VLBI data in the digital domain.

Correlation software is under development and some experiments have been conducted with variable baselines using geostationary emitted signals and transportable acquisition systems. The near and far field delay models are taken into account in the correlation process.

4. Conclusions

The radar VLBI activity between international stations is in development and this activity could grow, producing interesting scientific information. An efficient coordination is necessary to ensure a reliable performance, which can produce wide benefits for the ex-Soviet stations and for the entire world-wide VLBI community. It is planned to adjust the VLBI radar method and to start regular observations under the international program of optical and radar monitoring of the near-Earth space environment, which will be partially supported by INTAS-01-0669 and RFBR-02-02-17568.

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