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Space debris observational test with the Medicina-Evpatoria bistatic radar

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Abstract. In the framework of the space debris monitoring program of the Italian Space Agency (ASI), the Italian Institute of Radioastronomy (IRA), the Turin Astronomical Observatory (OATO) and the Ukrainian Institute of Radioastronomy performed a space debris observational test by using the Medicina-Evpatoria bistatic radar. Several kinds of objects orbiting in LEO, MEO, GEO and HEO were selected as target in order to validate the hardware setup and new observational techniques. Echoes coming from small space debris were detected with an extremely high signal to noise ratio as well as still unknown orbiting objects were presumably discovered during the observations.

Key words. Space debris – Observational Techniques: bistatic radar – Telescopes: Medicina-Evpatoria

1. Introduction

Space debris (inoperative spacecraft and their fragments, NaK coolant droplets, etc.) orbiting around Earth has become a growing problem in recent years. These objects represents a real threat for any human activity in space, as clearly demonstrated by the collision occurred in July 1996 between the French satellite CERISE and a fragment of the Ariane third stage (Alby et al. 1997). As a consequence, the worldwide space agencies have adopted mitigation and protection measures, as well as research programs directed to characterize the space debris environment in vicinity of the Earth. Most of the data concerning debris that are localized in the Low Earth Orbit (LEO) region (at an altitude below 2000 Km) are collected by ground-based radars, whereas electro-optical sensors are mainly used to detect objects in Geostationary Orbits (GEO). The uncertainties determined by current orbital debris models considerably increase when the object size decreases. This is due to the lack of a sufficient observational

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dataset (Mehrholz et al. 2002). In order to enlarge mesurements databases, radar observations may be used as an extremely powerful tool because of their high sensitivity in LEO and their capability to operate independently from weather, day-night conditions and illumination of the target by the sunlight. Radars that are involved in the observation of space debris may be monostatic or bistatic. A monostatic radar is composed of only one station having both receiving and transmitting functions, whereas in a bistatic radar the transmitter and the receiver antennas are separated by a distance of several hundreds of kilometers. Targets are irradiated by the transmitting microwave beam and the scattered waves are detected by the receiving antenna. Even though the most common radar configuration is monostatic, successful observations of space debris have been also performed by bistatic systems (Leushacke et al. 1997). In July and in November 2007 observations of space debris were carried out by using an innovative bistatic system composed of the Medicina VLBI radiotelescope (Italy) and the RT-70 radar antenna at Evpatoria (Ukraine). The aim of this investigation was to check the new experimental setup (in particular with regard to the antennas pointing and to the data acquisition hardware working in frequency and time domain) and to test the beam-park and piggyback observational techniques. In this paper we give preliminary results of the first Medicina-Evpatoria space debris campaign.

2. Medicina-Evpatoria radar setup

The transmitting part of the bistatic radar consisted of the Evpatoria fully steerable 70 m parabolic dish equipped with a 6-cm band transmitter. During the experiment one of the two available klystrons radiated an unmodulated, continuous wave (CW), right circularly polarized (RCP) signal with an extremely high frequency stability. The signal was characterized by a power of 20-40 KW and it was transmitted within a beam of approximately 2.6 arcmin. The receiver antenna consisted of the Medicina VLBI 32 m fully steerable dish of the Italian Institute of Radioastronomy (IRA). The signal was received by a radioastronomical frontend cryogenically cooled. Due to the extremely low noise temperature (typically 12-14 $^{\circ}K$) this device could provide a set of measurements characterized by very high sensitivity levels.

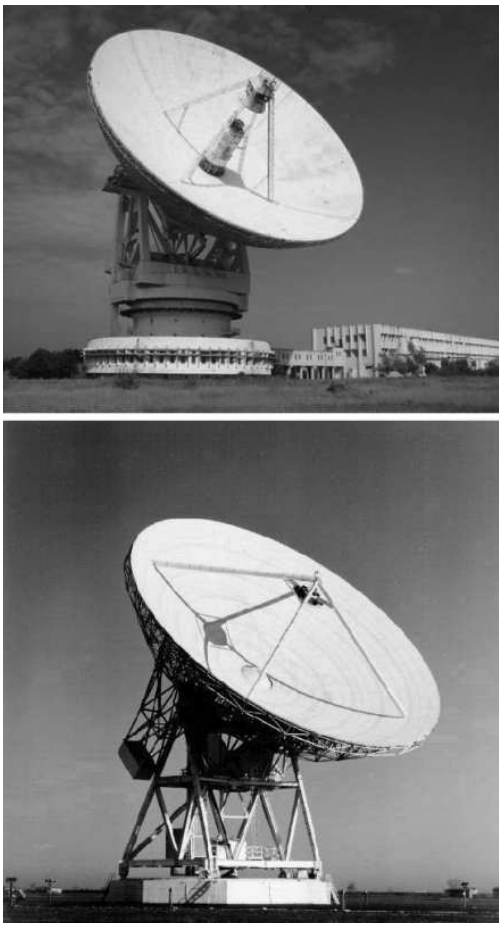

Fig. 1. Top: RT-70 transmitting antenna at Evpatoria; bottom: Medicina VLBI 32 m receiving antenna

On December 16-17th, 2001 the same receiver was utilized by the Medicina team during a planetary radar experiment together with the Evpatoria and Goldstone antennas. On that occasion the asteroid 1998 WT24 was observed during its close approach to the Earth (Di Martino et al. 2004).

During the space debris campaign the data acquisition system was considerably improved compared to the setup utilized in the asteroid observation. For the debris observational test data were contemporary acquired and analyzed in both frequency and time domain with several backends. The programmable spectrometers MSpec0 and SPECTRA-1, developed for the ITASEL-ASI program, performed a real-time analysis of the signal in the frequency domain. The signal was also digitized and stored in time domain by the VLBI standard formatter MK-V and by the new high performance BEE-2 (Berkeley Emulation Engine 2) FPGAs cluster, suitable to an off-line processing. The scheme of the innovative multi-backend data acquisition for the Medicina VLBI antenna is shown in Figure 2.

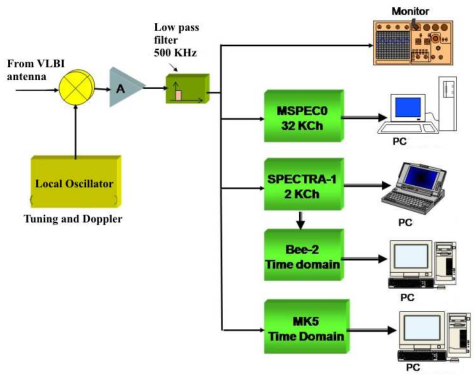

Fig. 2. Data acquisition setup scheme with programmable spectrometers, VLBI formatter and high performance BEE-2 FPGAs cluster

Tables 2 and 2 respectively provides details of the settings of the frequency-domain and time domain back-ends used during the Medicina-Evpatoria debris observational test campaign. Data recorded by MK-V and BEE-2 allow an off-line frequency analysis, where time and frequency resolution can be chosen in the post-processing phase.

3. Observations

The capability of the bistatic radar system Medicina-Evpatoria to perform space debris observations was tested during three different experiments. For this purpose, several kinds of suitable orbiting objects were selected as targets. Some inactive geostationary satellites were pointed in order to make preliminary calibration measurements and to check the overall operation of the radar setup. Further observations of known debris having different radar cross sections (RCS) and orbiting in Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) regions were carried out to test the efficiency of the data acquisition system in detecting echoes coming from fast transiting objects.

The first and the second space debris experiments were carried out on July 17-19th and on July 28-31st, 2007. The former experiment was completely planned by the Medicina and Evpatoria teams, whereas the latter was part of the international campaign VLBR07.1 of radar interferometry coordinated by the Keldysh Institute of Applied Mathematics (Russian Academy of Sciences). The main goal of the VLBR07.1 project was the investigation of faint fragments in high geocentric orbits (GEO, HEO and high near-circular non-GEO) having high area-to-mass ratio.

Table 1. Settings of the frequency-domain back-ends MSpec0 and SPECTRA-1

	MSpec0	**SPECTRA-1**
Bandwidth (MHz)	0.5	2.5
N. of channels	32000	2000
Avg spectra	20	100
A/D	10 bit	14 bit
Domain	freq.	freq.
Freq. res. (Hz)	15.6	1200
Time res. (sec)	1.2	0.08

Table 2. Settings of the time-domain back-ends MK-V and BEE-2

	MK-V	**BEE-2**
Bandwidth (MHz)	0.5	10
A/D	2 bit	8 bit
Sample-rate	1 MHz	20 MHz
Domain	time	time

During the first experiment, almost all the selected targets were successfully detected by the operative acquisition devices. In particular some of the smaller space debris catalogued by NASA/NORAD were observed with an extremely high signal to noise ratio. This result proved the instrumental high sensitivity and the capability of the system to correctly point and detect fast and small targets. Figure 3 shows the strong echo coming from the small space debris 29040 (CZ-4 debris) as recorded by the spectrometer MSpec0.

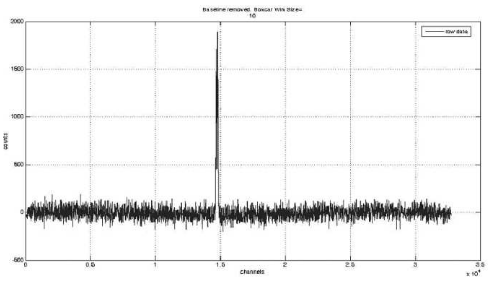

Fig. 3. Signal coming from the space debris 29040 as recorded by MSpec0 on July 18th, 2007 at 16:32:00 UT

Besides the detection of catalogued objects, a further goal of the experiment consisted of the search for space debris not yet known. For this purpose the beam park observational technique was experimented for the first time by the Medicina-Evpatoria system. With this technique both antennas are kept fixed at a given position (determined by definite elevation and azimuth coordinates) while debris randomly pass through the intersection of the common fields of view. The geodetic position (see Table 3) of the selected region was calculated according to the PROOF-2005 space debris population model (Anselmo 2007) in order to increase the probability of detection.

During the observation in beam park mode, several faint echoes were detected. Most of them were probably due to small and still unknown space debris. Figure 4 shows the spectrum of a relatively strong echo coming from a not yet catalogued object as recorded by the MK-V backend.

Table 3. Geodetic coordinates of the centroid and topocentric slant ranges (Tx and Rx) of the region observed in beam park mode.

Height (km)	871.70
Latitude (deg)	47.800
Longitude (deg)	21.172
Range Tx (km)	1348.336
Range Rx (km)	1234.270

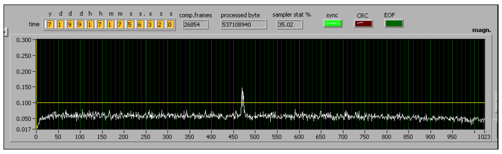

Fig. 4. Echo from a not yet catalogued debris orbiting at a geodetic height of 871.7 km detected during the beam parking session. The echo was recorded on July 18th, 2007 at 17:17:56 UT.

On this occasion the signal was post-processed applying a Fast Fourier Transform (FFT) with a size of 1024 points. If requested, the spectral resolution can be improved by increasing the size of the FFT (2048, 4096, 8192, etc.), up to the limit imposed by sample-rate and transit time of the debris trough the beam.

The last test campaign, performed on November 10-14th, 2007, was divided in two main phases. The first one (VLBR07.2) was a prosecution of the international Very Long Baseline interferometry Radar experiment dedicated to the observation of debris in GEO ad HEO. The second part of the radar session was used to validate the results obtained during the previous sessions and to optimize the backends settings. On this occasion a number of objects orbiting in LEO and MEO were selected and pointed. Some of them were already observed in the previous radar session allowing us to make a comparison between the two measurements and to evaluate possible variations of the system efficiency due to the setting changes in the backend parameters. In this session 100% of the pointed targets were detected, confirming the excellent performance of this radar system.

Fig. 5 shows the spectrogram of the echo coming from the debris 8791 (DELTA 1 deb) acquired by the BEE-2 cluster in time domain.

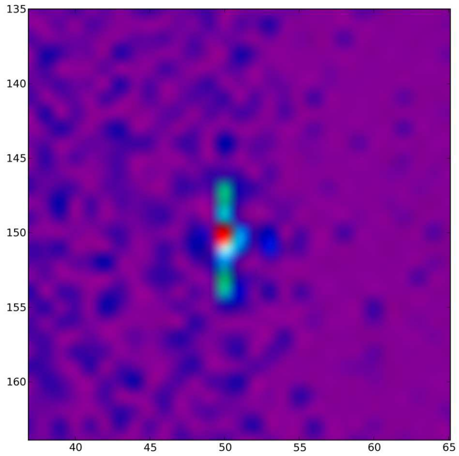

Fig. 5. Spectrogram of the echo from debris 8791 recorded by the BEE-2 FPGAs cluster. x-axis: spectral channel; y-axis: time in units of acquired spectra. The intensity of the echo signal is represented in color scale with blue being the lowest and red being the highest intensity.

4. Conclusions

In this paper we have presented some preliminary results of the space debris observational tests carried out by the Medicina-Evpatoria bistatic radar. Very small catalogued space debris were observed with a very high signal to noise ratio showing the high sensitivity and the capability of the system in detecting fast and small sized targets. A number of echoes from objets not yet catalogued were also detected by using the beam parking technique. Although further work is necessary to calibrate and improve the system, these preliminary results clearly proved that the Medicina-Evpatoria bistatic radar could represent one of the few worldwide system able to detect centimetric and presumably sub-centimetric debris.

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