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A potential Italian radar network for NEO and space debris observations

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Abstract. Nowadays radars provide a powerful source of information, often complementary to that obtained by other observational techniques, about physical and dynamical properties of asteroids and space debris. A number of large Italian antennas, as radiotelescopes and telecommunication facilities, could be used as elements of a radar network for the study of Near Earth Objects (NEOs) and space debris orbital environment. In this paper we briefly describe the potential capabilities of such a system and the results of some preliminary radar experiments carried out by the antennas of the Istituto Nazionale di Astrofisica.

Key words. Space Surveillance; Near Earth Objects; Space debris – Observational Techniques: bistatic and monostatic radar

1. Introduction

During the last years radars have became very important tools for planetary science and space debris investigation. Radars may be distinguished in monostatic and bistatic systems. A monostatic radar is composed of one station having both receiving and transmitting functions, whereas in a bistatic radar transmitting and receiving antennas are separated by a large distance. In comparison with optical telescopes, radar measurements benefit of some advantages since they can operate independently from weather, day-night conditions and illumination of the target by the sunlight. another advantage is given by the full control of the transmitted signal used to illuminate the target. While other astronomical techniques rely on passive measurement of reflected sunlight or naturally emitted radiation, radars are able to transmit a coherent signal of well-known characteristics. From the comparison between of the characteristics of the transmitted signal and those of the received one, it is possible to deduce some physical and dynamical properties of the target (Ostro 1993).

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Radars, however, suffer an important limitation due to the fact that the received power P_r decreases as the fourth power of the target distance, according to the monostatic radar equation (1).

$$P_r = \frac{P_T G_{ant}^2 \lambda^2 \sigma_m}{(4\pi)^3 R^4} \tag{1}$$

In eq.1 P_T is the transmitted power (W), G_{ant} is the antenna gain, λ is the transmitted wavelength (m), σ_m is the monostatic radar cross-section (RCS) of the target (m^2) and R is the range of the target from the antenna (m). A similar problem also afflicts bistatic radars, where the received power P_r (W) is given by:

$$P_r = \frac{P_T G_T G_R \lambda^2 \sigma_b}{(4\pi)^3 R_T^2 R_R^2} \tag{2}$$

In eq.2 P_T is the transmitted power (W), G_T is the transmitter antenna gain, G_R is the receiver antenna gain, λ is the transmitted wavelength (m), σ_b is the bistatic RCS of the target (m^2), R_T is the transmitter-to-target path length (m) and R_R is the receiver-to-target path length (m). The rapid decreasing of the received power with the target distance limits the use of the radar technique to the study of nearby Solar System bodies and Earth orbiting objects.

Near-Earth Objects (NEOs) are asteroids and comets on orbits having a perihelion distance $q \leq 1.3AU$. These objects are of special interest since: 1) they are the parent bodies of meteorites and meteor streams; 2) they represent the relatively unchanged remnant of the planetary accretion occurred about 4.6 billion years ago; 3) they pose a potential risk of collision with Earth. Improvements in the knowledge of NEO orbits is fundamental to assess the impact probabilities. For this purpose radar astrometry is very effective since radars can provide an extremely accurate determination of range and range-rate (Valsecchi et al. 2006). This lead to a precision in the orbit determination that is an order of magnitude better than optical astrometry. Several NEO physical and dynamical properties can be determined by radar measurements. Distribution of echo power in time delay and Doppler frequency, allows observers to obtain bi-dimensional images with a spatial resolution better than 100 meters. Furthermore the rotational properties can be derived from the frequency dispersion of the received echo as well. Finally some surface properties, as roughness or presence of metallic elements, can be inferred by the circular polarization ratio (Ostro 1993).

One of the most important applications of the radar technique is the monitoring and characterization of space debris environment around Earth. Space debris (inoperative satellite and their fragments, rocket stages, etc.) has become a growing problem in recent years since they represent a serious risk for any human activity in space. Due to the lack of sufficient observational data (Mehrholz et al. 2002) the uncertainties in orbital debris models do considerably increase when the object size decreases Radar observations may be used as a powerful tool because of the high sensitivity, especially in the Low Earth Orbit (LEO) region (at an altitude below 2000 km) that is the most populated orbital region.

2. Previous Italian radar observations

The Italian radiotelescopes of the Istituto nazionale di Astrofisica (INAF) are involved in radar experiments for both asteroids and space debris studies. The target of the first Italian planetary radar experiment was the NEA 33342 (1998 WT24). The observation took place in December 2001 utilizing two bistatic configurations: Goldstone-Medicina and Evpatoria-Medicina. Radio signals were transmitted from the Goldstone (Mojave Desert, California) 70-m antenna at a wavelength of 3.5 cm (X-band) and from the 70-m dish in Evpatoria (Crimea, Ukraine) at a wavelength of 6 cm (C-band). The 32-m antenna of Medicina (Bologna, Italy) was utilized in both baselines as receiving part of the bistatic system. The received signal in X-band was analyzed in the frequency domain both in real time and in post-processing. For the real time analysis two fast programmable spectrometers were used, allowing a radial velocity component resolution of 21 mm/s at 8.56 GHz. Echoes in X-band were clearly detected by both devices in different time intervals. Figure 1 shows two of the recorded spectra.

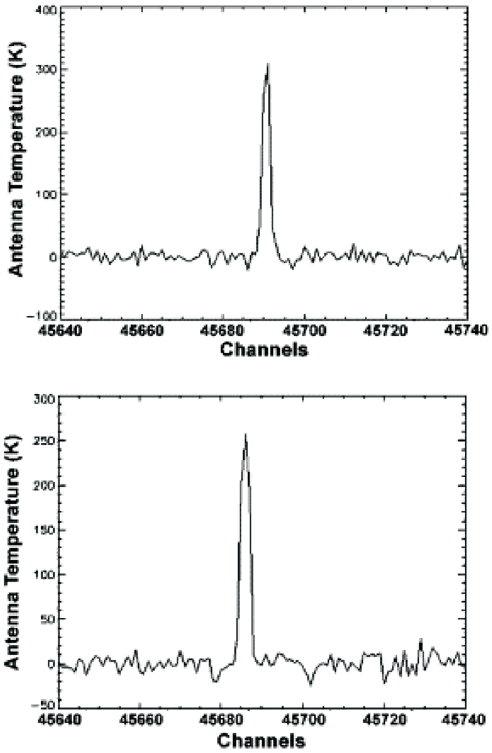

Fig. 1. Two uncalibrated spectra of the X-band echoes from asteroid 1998WT24 recorded by the Medicina 32-m antenna.

These measurements allowed an estimation of the RCP radar cross section of about 0.04 km^2. The C-band signal was recorded in the time domain and processed off-line at the Institute of Radio Engineering and Electronic at Friazino, Russia. These measures reached a frequency resolution of about 0.15 Hz (Fig. 2). The circular polarization ratio μ_c was estimated to be approximatively one, in agreement with the monostatic observations performed at Goldstone. An unexpected result was that spectra for both circular polarizations have similar parameters for the different rotation phases (Di Martino et al. 2004).

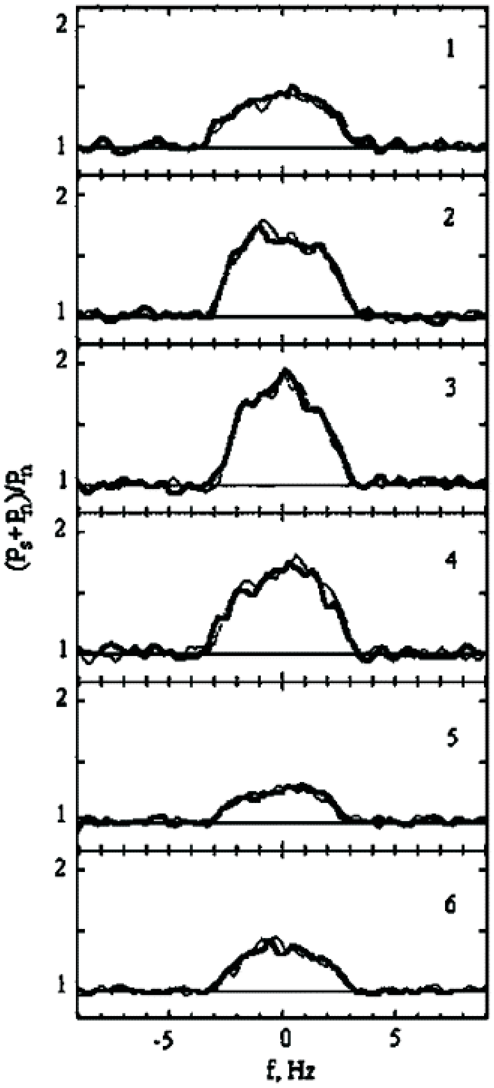

Fig. 2. Normalized C-band spectra of asteroid 1998WT24 obtained in the OC and SC polarization (thick and thin curves). Value f=0 Hz corresponds to hypothetical echoes from asteroid's center of mass.

One important application of radar technique is the monitoring of space debris. The number of orbital debris fragments between 1 and 10 cm in diameter has been estimated at several hundred thousands (Rossi 2005) whereas the population of particles smaller than 1 cm probably exceeds hundreds of millions. This number is steadily growing, therefore the characterization and the monitoring of the orbital debris environment has became one of the most important activities carried out by worldwide space agencies.

Since 2006 INAF radiotelescopes are involved in the ”Space Debris” program of the Italian Space Agency (ASI). In 2007-2008 radar sessions were performed by a radar bistatic configuration composed of the Medicina VLBI antenna (Rx) and the RT-70 at Evpatoria (Tx). The main aim of these observational campaigns was to check the performances of the radar setup as well as to test the efficiency of different observational techniques. During the experiments RT-70 radiated 20-40 kW unmodulated signal (CW) at 6-cm wavelength (C-band). Catalogued fragments characterized by few square centimeters RCS were detected with a very high signal to noise ratio. An example of a centimetric debris detection is shown in Figure 3. The echo came from the debris catalogued as 29040 (CZ4-DEB) that, according to the public US Strategic Command (USSTRATCOM) orbital objects catalog (updated on July 2007), has a RCS of 0.0004 m^2.

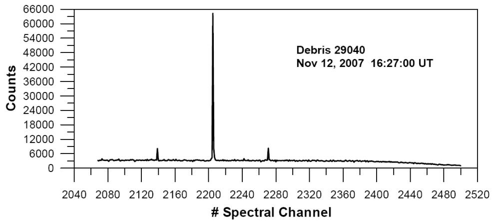

Fig. 3. Spectrum of the echo from the debris 29040 detected by the Medicina-Evpatoria bistatic radar on November 12, 2007.

During these campaigns several uncatalogued debris were recorded by Medicina-Evpatoria radar system. Figure 4 shows the spectrum of one of these objects. The echo was acquired in time domain by the MK-V backend and off-line analyzed in the frequency domain. These results have confirmed the extremely high sensitivity of the bistatic radar Medicina-Evpatoria (Pupillo et al. 2008).

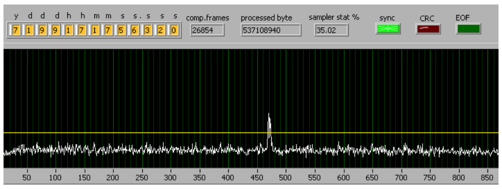

Fig. 4. Echo from an uncorrelated debris orbiting at a geodetic height of 871.7 km. The signal was recorded during a Medicina-Evpatoria radar session performed in beam-parking mode.

After the collision between Iridium 33 and Cosmos 2251 satellites occurred in February 2009, a radar experiment was performed in order to identify some objects contained in the clouds generated by the collision event. All the selected objects were detected with a very high signal to noise ratio.

The last observational radar campaign was carried out in October 2009. During this session the new multistatic radar configuration Evpatoria-Medicina-Noto was successful utilized. The main advantages of using two receiving spaced antennas, instead of one, are: 1) the capability to measure two different topocentric bistatic doppler-shifts that improves the orbital constraints of the observed target, when both antennas observe the same common volume; 2) increasing of the explored space volume when the two receiver beams cross the transmitter’s one at different heights. The common volume exploration observational mode was performed mainly for calibrators and catalogued debris, whereas the differential height technique was adopted for the search of not yet catalogued fragments.

3. Potential Italian radar network

The use of the existing Medicina radiotelescopes (the 32-m antenna and the ”Northern Cross” UHF interferometer) as a possible integrated radar system for space debris detection and tracking has been already extensively discussed in (Montebugnoli et al. 2010). However in Italy there are a number of antennas having a diameter $\geq 20m$ that could be utilized as part of a national network for space debris and NEO monitoring (Tab.1). All the

Table 1. Italian antennas with a diameter ≥ 20*m*. The frequency ranges are referred to the installed Tx or Rx. * Sardinia Radio Telescope (SRT) is currently under completion.

Antenna	Diameter (m)	Freq. range (*GHz*)
SRT*	64	0.3 ÷ 100
Medicina	32	1.35 ÷ 24.1
Noto	32	0.3 ÷ 86
Lario1	32	3.62 ÷ 6.425
Lario2	32	3.62 ÷ 6.425
Matera	20	2.21 ÷ 8.58

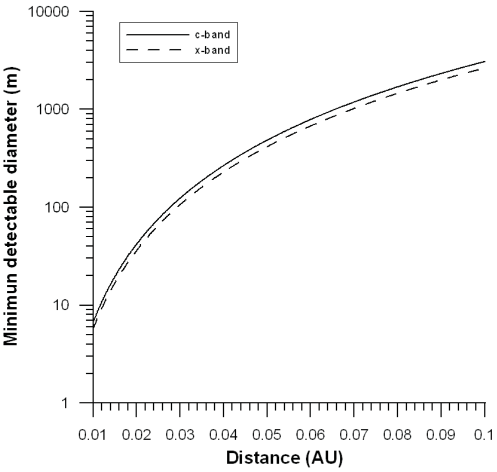

Fig. 5. Estimation of the minimum detectable diameter (m) of a NEO as a function of the object distance R (AU). It is assumed $R = R_T = R_R$.

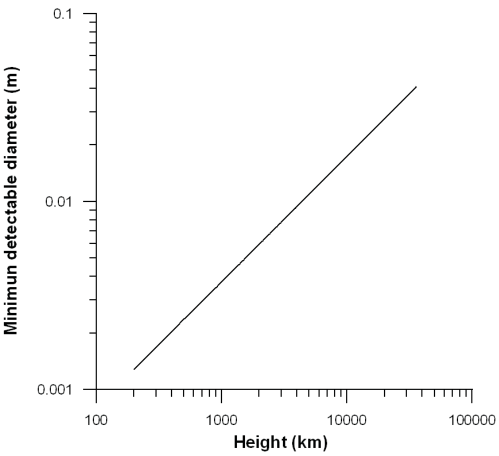

Fig. 6. Estimation of the minimum detectable diameter (m) of a space debris as a function of the object height (km).

listed antennas are fully steerable parabolic dishes with double circular polarization receivers.
A possible radar network optimized for NEO observations could be composed by a powerful transmitter (in C- or X-band) installed on the Sardinia Radio Telescope (SRT) and the remaining Italian antennas as receivers, arranged in a multistatic configuration. Numerical simulations have been performed in order to calculate the minimum detectable diameter of a NEA by a multistatic radar configuration with SRT as transmitter and Medicina, Noto, Lario1, Lario2 and Matera facilities as receivers (Figure 5) (Pupillo et al., in preparation). This diameter defines a threshold for the NEO detection only. For a more accurate physical and dynamical analysis of the target a greater SNR value is required.

For the space debris observations we propose a hybrid multistatic configuration in which the 32-m antennas (either Medicina or Noto) could be used as a monostatic radar and its transmission could be received by the other antennas of the network. In this case the minimum detectable radar cross section $\sigma_{\min}$ was estimated and results are plotted in Figure 6.

4. Conclusions

The possibility to set an Italian multistatic radar network dedicated to the NEOs and space debris monitoring has been proposed. We only consider the suitable Italian existing facilities, with the exception of the SRT that is currently under completion. An appropriate transmitter should be installed on SRT (for NEO studies) and on a 32-m class antenna, as the Medicina or Noto facilities (for space debris monitoring). Even though further investigations are necessary, observational tests and preliminary simulations confirmed the high sensitivity of such setups. High SNR echoes from NEOs, suitable for highly accurate measurements of physical and dynamical properties, could be received during their close approaches. Moreover the proposed radar network could be also able to detect sub-centimetric space debris in LEO up to centimetric fragments in GEO orbital regions.

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References

Di Martino, M., et al. 2004, Planet. Space Sci., 52, 325

Mehrholz, D., et al. 2002, ESA Bulletin, 109, 128

Montebugnoli, S., et al. 2010, Adv. Space Res., 45, 676

Ostro, S. 1993, Rev.Modern Phys., 65, 1235

Pupillo, G., et al. 2008, Mem. S.A.It, 12, 44

Rossi, A. 2005, Proc. of IAU Colloquium, 197, 427

Valsecchi, G., Milani, A., Rossi, A., Tommei, G. 2006, Mem. S.A.It, 10, 186

Zaitsev, A.L., et al. 2001, Proc. 3rd European Conference on Space Debris , ESOC, Darmstadt, Germany, 19-21 March 2001, SP-473, 79