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SPACE DEBRIS TRACKING AT SAN FERNANDO LASER STATION

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RESUMEN

En los próximos años todo lo relacionado con la basura espacial será considerado por nuestra sociedad como un asunto de la mayor importancia. En la actualidad tiene un impacto negativo sobre las misiones satelitales activas, y lo tendrá sobre las futuras. Realizar un seguimiento sobre la basura espacial tan exacto como sea posible constituye el primer paso en la dirección correcta para poder controlar este problema, aunque este aspecto aun constituye un reto para la ciencia. La mayor limitación viene impuesta por la pequeña precisión de los procedimientos utilizados hasta el momento para el seguimiento de este tipo de objetos. Evidentemente, la mejora de las precisiones de las predicciones orbitales es un asunto crucial (evitando así realizar maniobras anti-colisión innecesarias). Recientemente hemos incorporado un nuevo campo de trabajo en nuestra estación de telemetría laser, éste es el del seguimiento de satélites artificiales inactivos equipados con retroreflectores. Hasta la fecha, trabajamos en coordinación con agencias espaciales internacionales que están prestando atención al problema. Por todo ello, nos hemos propuesto utilizar esta técnica telemétrica para proporcionar datos que permitan alcanzar un conocimiento más preciso de los elementos orbitales (precisiones de nivel métrico), manteniendo en paralelo nuestras tradicionales actividades de seguimiento sobre satélites activos. En este trabajo presentamos las acciones emprendidas hasta el momento.

ABSTRACT

For years to come space debris will be a major issue for society. It has a negative impact on active artificial satellites, having implications for future missions. Tracking space debris as accurately as possible is the first step towards controlling this problem, yet it presents a challenge for science. The main limitation is the relatively low accuracy of the methods used to date for tracking these objects. Clearly, improving the predicted orbit accuracy is crucial (avoiding unnecessary anti-collision maneuvers). A new field of research was recently instituted by our satellite laser ranging station: tracking decommissioned artificial satellites equipped with retroreflectors. To this end we work in conjunction with international space agencies which provide increasing attention to this problem. We thus proposed to share our time-schedule of use of the satellite laser ranging station for obtaining data that would make orbital element predictions far more accurate (meter accuracy), whilst maintaining our tracking routines for active satellites. This manuscript reports on the actions carried out so far.

Key Words: methods: observational — space vehicles

1. INTRODUCTION

In the beginning satellite tracking was done by means of optical methods. Photographs of large zones of the sky were taken, using telescopes, and star catalogues, were used to determine the satellite position. Those methods greatly contributed to the first standard Earth models, e.g. I, II and III of the Smithsonian Astrophysical Observatory. However, these angular methods did not achieve accuracies better than 10 m. Satellite laser ranging techniques contributed to the advance of Earth and space science knowledge from the early 70s onwards. Data from over 100 laser tracking stations (fixed and mobile) has improved the accuracy and precision of satellite orbits up to the sub-centimeter level (Degnan 1993). The idea is to measure the time of flight of very short pulses of visible light from a ground station to satellites equipped with retro-reflectors. From this value we can infer the distance traveled by light in vacuum, and measure the one-way distance from the ground station to a remote optical receiver in space. The ionosphere does not affect the propagation of the visible laser radiation, whereas the troposphere introduces an error of several meters into the range measurement. Applying a correction based on a model of the atmosphere can reduce this error. The formulation by Marini & Murray (1973) is commonly used. Further additional range corrections take into account the translation of the measurement from the laser retroreflector array phase center

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to the satellite's center of mass, accounting for local site displacements by solid earth-tide models, plus a relativistic correction, which for near Earth objects is submillimetric (McCarthy 1992). This technique has been applied not only to improve the accuracy and precision of satellite orbits, but to help define the geocenter position and its motion, that is, the terrestrial framework of reference— in conjunction with other techniques (GPS, VLBI,. . .). When we track artificial satellites such as Laser geodynamics satellite (Lageos), the stability of its orbit against the influences of non-gravitational forces (solar radiation pressure, atmospheric drag), and the small effect of earth gravity anomalies, the inverse problem can be solved: inferring the ground station coordinates in the terrestrial reference frame to monitor their variation over time, a question called geodynamics.

Space debris is already a major problem for society. From 1957 onward its magnitude has increased almost linearly every year with the launch of new artificial satellites and new rocket bodies. Fragments coming from satellites and/or collisions between them increase the population of debris. Nowadays, there are some 20,000 fragments larger than 10 cm, while the number of fragments having a size larger than 1 cm is estimated to be near 1,000,000. Most space debris is concentrated in the Low Earth Orbit (LEO) segment, with a greater density in the range 800-1000 km, and 1400-1500km altitude. This makes it necessary to perform maneuvers, which consume propellant and furthermore reduces the lifetime of artificial satellites. One well documented collision was that of the Iridium 33 and Cosmos 2251 in February 2009. The Cosmos 2251 was not functional and not even tracked at that time. This collision produced nearly 2,000 pieces of debris measuring at least 10 cm.

2. SAN FERNANDO SLR STATION

The Royal Observatory of the spanish navy (ROA) has worked on satellite geodesics since the early days of the space age, when the first artificial satellite tracking telescope was installed in 1958: the Baker-Nunn camera. In 1975 the French satellite laser ranging (SLR) station was installed at ROA. Since 1980, ROA has been operating this instrument, eventually upgraded to a third generation and continuously updated to attain the highest level of operability. Over the years ROA has participated in different space geodesic campaigns through the International Laser Ranging Service stations (ILRS) or its European regional organization (EUROLAS), tracking a number of artificial satellites types —ERS,

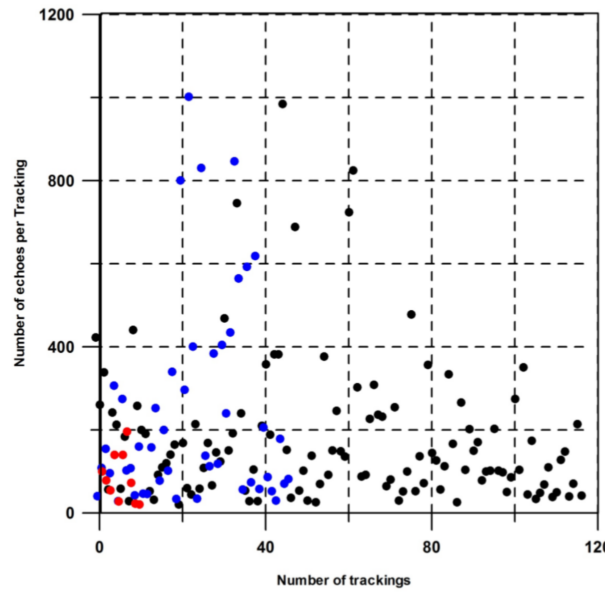

Fig. 1. Number of trackings done over Starlette (in black) and over ERS-1 (in blue), and ERS-2 (in red) from June 15th till October 15th by San Fernando SLR.

ENVISAT, LAGEOS, and TOPEX-POSEIDON, to mention just a few. Our SLR station transmits at a 10 Hz repetition rate and 0.2 W as the mean power at 532 nm wavelength. The stability of the station can be gauged from the analysis of the LAGEOS satellite residue in the past 15 years (20.76 $\pm$13.24 mm for the period 2000 to 2015, and 21.63 $\pm$7.77 mm for 2015).

3. SAN FERNANDO SLR ACTIVITIES

Other SLR stations like the one in Graz or the one in Shangai have shown to be able to track space debris (Zhang et al. 2012) (Kirchner et al. 2012) but their powers were larger: 40 W (2 J at 20 Hz) at Shanghai, or 25 W (25 mJ at 1 kHz) at Graz. Our power was far below these values (0.25 W - 25 mJ at 10 Hz) therefore it does not allow us to track ordinary space debris objects (opaque objects).

For several months we have been performing an experiment that consists of testing our ability to track decommissioned satellites equipped with retroreflectors. This particular type of tracking entails some added difficulties to this space geodesy technique. First, there is uncertainty in the satellite position due to unaccurate ephemerids, and an additional challenge is related to the satellite attitude, which is not controlled anymore. It spins, meaning the retroreflector array is not always aiming at the ground station. To illustrate these drawbacks we selected three artificial satellites with similar altitudes,

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two decommissioned (ERS-1 and ERS-2) and another still in operation (Starlette). Satellites ERS-1 and ERS-2 were launched in 1991 and 1995, respectively. The ERS mission was governed by the European Space Agency, to gather information about the Earth: land, water, ice and atmosphere. ERS-1 was decommissioned in 2000, and ERS-2 in 2011. In turn, Starlette was launched in 1975 by the Centre National d'Etudes Spatiales (CNES) to measure variations in the Earth's gravity field. All these missions share similar orbital parameters: 800 km above the Earth, and an inclination 98.5°. Figure 1 shows the number of successful trackings done over Starlette (in black), ERS-1 (in blue) and ERS-2 (in red) from June 15th to October 15th by the San Fernando SLR. The ERS-1, ERS-2 and Starlette were tracked 10, 47 and 119 times, respectively. This serves as an evidence of how difficult it is to track decommissioned satellites, owing to a lack of precision of their ephemerids, and the fact that attitude is no longer maintained and the retroreflector array does not necessarily point to the ground station.

The lack of accuracy on ephemerids can be visualized by checking the laser distance residua in three cases: a) on Ajisai, as an example of a satellite which is being tracked by ground stations and has all its positioning systems in operation (Figure 2(a)); b) on ERS-1 as a decommissioned satellite no longer tracked by ground stations (Figure 2(b)); c) on Envisat as an example of a decommissioned satellite that is nonetheless still routinely tracked by ground stations (Figure 2(c)). All SLR residuals were derived using the most up-to-date ephemerids available. The laser ranges were corrected by atmospheric refraction using the Marini and Murray model (Marini & Murray 1973). The center-of-mass correction was applied only on Ajisai. It was not introduced for Envisat and ERS-1 data, as their attitude control systems are no longer in operation and so it is impossible to refer our measurements to the satellite center of mass. In most cases the ephemerids available for ERS-1 (decommissioned) satellite-like objects are based on two-line element (TLE), meaning quite poor accuracy, as neither sophisticated gravity models nor observations are included. Range residuals based on these kinds of ephemerids, in light of our experience, could be in the km range. These decommissioned satellites are large objects, and largely intact. For instance, Envisat is an 8211 kg platform, 25 m in length, and almost 10 m wide. It is crucial to track all such objects as they might generate clouds of smaller debris due to a hypothetical collision with other objects.

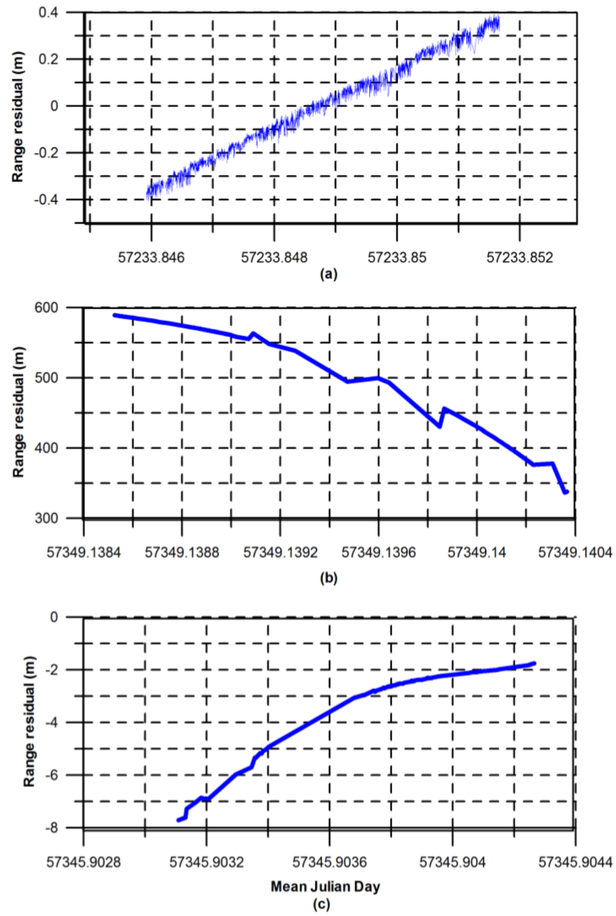

Fig. 2. Laser range residua obtained: a) on Ajisai, b) on ERS-1 and c) on Envisat.

The three satellites show clear trends for their laser range residua (Figure 2). They are seen to be almost linear in Figure 2(a), yet somewhat parabolic in Figures 2(b) and 2(c). These findings evidence systematic issues in all cases, most probably owing to orbital error. The difference resides in the amplitudes. Figure 2(a) ranges from -40 cm to +40 cm. With no doubt an 'a posteriori' ephemerids, which combines all the information derived from ground tracking stations, would subtract this linear trend, thus achieving a subcentimetric laser range residual. Figure 2(b) shows the opposite, laser range residua of several hundreds of meters. In fact, our experience with other decommissioned satellites, suggests that the figure could be larger than 1 km. Figure 2(c) illustrates the benefit of keeping this sort of object tracked. Laser range residua were one order larger than at Ajisai, but they indicate that this object is still under control, as its position is still known with reasonable accuracy. Accordingly, the space agencies will have clear indications regarding any need to

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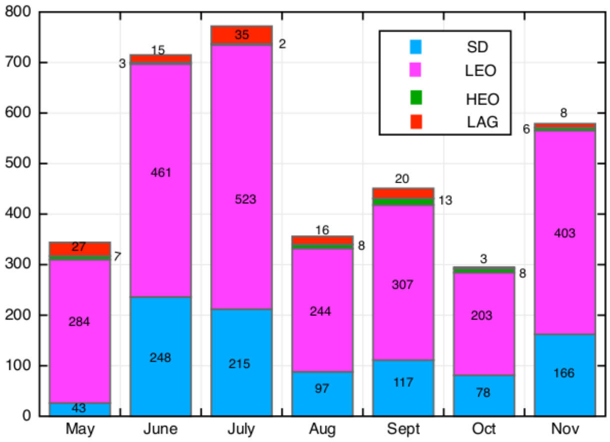

Fig. 3. Overall results obtained from May 1st 2015 to December 1st on San Fernando SLR station. SD: Space Debris; LEO: Low earth orbits active satellites; HEO: High earth orbits active satellites; LAG: Lageos satellites.The number of tracking for every kind is included.

perform an anti-collision maneuver.

On May 2015 we started tracking this kind of space debris to the extent possible with our current technical limitations. In our case this means tracking decommissioned artificial satellites equipped with retro-reflectors. Moreover, our power and beam divergence only allowed for tracking these objects at low earth orbit altitudes. The list of satellites tracked is given in Table 1. Besides this new activity, our schedule includes other tasks, such as active artificial satellite tracking (Low and High Earth Orbit -LEO and HEO), and on Lageos 1 & 2, crucial to help defining the international terrestrial reference frame. Figure 3 sums up the results of our tracking activities overall.

It is important to bear in mind that on June and July 2015 the space debris figures were larger than in the rest of the year, as we prioritized this kind of tracking (artificial satellites, Lageos) during these two months.

4. CONCLUSIONS

At the San Fernando SLR station (southern Spain) tracking of decommissioned artificial satellites equipped with retroreflectors has been performed on a regular basis since May 2015. The results thus far appear promising. This kind of activities will be an increasing demand on society. Knowing the position of these non-operational objects is the only way to keep them under control, and fulfills a need for society as large. By including this activity at every laser station we might contribute to avoid non-necessary maneuvers, or collisions. Our intention is to continue performing this activity, eventually incorporating a new laser bench with higher power, which could allow us to track not only this particular type of object but space debris in a broad sense.

TABLE 1

LIST OF DECOMMISSIONED SATELLITES TRACKED BY SAN FERNANDO SLR STATION FROM MAY TO DECEMBER 2015[a]

Satellite Name	Number of trackings
ADEOS-1	15
ADEOS-2	16
ALOS	67
DIADEME-1C	100
DIADEME-1D	103
ENVISAT	91
ERS-1	59
ERS-2	16
GEOS-3	113
JASON-1	44
METEOR-2	31
METEOR-2/Prare	36
METEOR-3M/Fizeau	2
OICETS	34
PROBA-2	18
RESURS-01	36
REFLECTOR	21
SEASAT	9
SOHLA1	3
SUNSAT	28
TOPEX/Poseidon	102
WESTPAC	1

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