

THE ROA LASER STATION: FROM ARTIFICIAL SATELLITES TO SPACE DEBRIS TRACKING

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RESUMEN

El Real Observatorio de la Armada Española (ROA) trabaja en geodesia espacial desde el comienzo de la era espacial. En 1975 quedó instalada en el recinto del ROA una estación láser en colaboración con CERGA (Centre de Recherches en Géodynamique et Astrométrie). Desde 1980 esta estación ha sido operada únicamente por el ROA, y realiza seguimientos en base de rutina de satélites artificiales equipados con retro-reflectores. En 2014 el ROA abrió una nueva línea de investigación: seguimiento de satélites artificiales inactivos equipados con retroreflectores. Esto supuso un reto dada la precisión tan pobre de las efemérides utilizadas para su búsqueda al no incorporar datos de seguimiento que proporcionen un conocimiento actualizado de su posición. Esta temática sirvió como aproximación al objetivo más ambicioso: el seguimiento de objetos catalogados como basura espacial. Ello incluye a cualquier objeto realizado por el hombre que orbite de forma no-controlada. Para implementar este objetivo, desde 2017 venimos realizando cambios significativos en la instalación. El avance más relevante lo supuso la sustitución del antiguo banco láser por dos bancos nuevos. Uno de estos emisores transmite pulsos a 500 mW, mientras que el segundo banco lo hace a 25 W. El estudio que motivó la instalación del banco más potente fue financiado por la Unión Europea a través de fondos H2020 gestionados por el Centro para el Desarrollo Tecnológico Industrial (CDTI). Aunque este sistema es capaz de realizar seguimientos sobre objetos colaborativos, es ideal para seguimientos de objetos no-colaborativos. Este tipo de actividades comenzaron en Noviembre de 2017. Desde entonces se realizan de forma rutinaria. Este trabajo muestra las modificaciones ya realizadas, y los resultados obtenidos hasta 2019.

ABSTRACT

The Royal Observatory of the Spanish Navy (ROA) is specialist in space geodesy since the beginning of the space race. In 1975 a laser station was installed at ROA in collaboration with the French CERGA (Centre de Recherches en Géodynamique et Astrométrie). Since 1980, ROA has operated that station by their own. This equipment routinely tracks artificial satellites equipped with retro-reflectors. In 2014 ROA opened a new field of research: tracking of artificial satellites currently not active and equipped with retroreflectors. This new area was a challenge given the poor orbital accuracies that are available for these objects as they were not tracked on a routine basis. This served as an approach to our final goal: to strictly monitor space debris, this is, any type of uncontrolled man-made orbiting objects. To fulfill the objective, since 2017, we made significant changes to our laser installation. The most important was the replacement of the old laser bench with two new ones. One transmitting 500 mW-pulses, and another laser bench with 25 W transmission power. The study for the installation of the later laser was financed through European Union (EU) H2020 fundings and granted by the Spanish Centre for Industrial Technological Development (CDTI). Although it allows the tracking of collaborative objects, it is ideal for tracking non-collaborative too. Tracking activities begin in November 2017. From then onward, non-collaborative objects are monitored on a regular basis. This work shows the modifications already made, and the results obtained until 2019.

Key Words: astronomical data bases: catalogues — methods: observational

1. GENERAL

The Royal Observatory of the Spanish Navy has been involved in space geodesy operations since 1958, almost since the launch of the first artificial satellite when the first network of Baker-Nunn cameras were

installed throughout the world. Regarding satellite laser ranging this technique appeared in 1975 after the first laser, a Ruby one, was installed at ROA by a french group, which released it to ROA in 1981. Since then ROA has been operating it regularly. Through the 80's and the 90's this laser station has participated in different space geodesy experiments under the International Laser Ranging

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Service (ILRS) or its European regional counterpart (EUROLAS). Since 2015 ROA has been successfully tracking collaborative objects (non-active artificial satellites with retroreflectors). This activity was carried out using our old laser bench that operated at 10 Hz, and transmitted at relatively low power (250 mW) (Catalán et al 2015). Although this achievement could be considered a big step forward, we were only able to track slightly more than 50 collaborative objects. With the aim of supporting Spanish SST activities, a study was carried out on the improvements that could be achieved by having a more powerful laser bench than the one currently installed in the ROA, taking advantage of the experience and infrastructure available at this centre. The study of the improvement due to this new instrument was financed through the European Union by the Spanish Centre for Industrial Technological Development (CDTI) within the EU SST Support Framework. This new laser bench was 100 times more powerful than the old one. Thus, it allows tracking on non-collaborative objects, that it is space debris.

2. SLR SET UP FOR SPACE DEBRIS TRACKING

The number of objects classified as space debris is increasing very rapidly. It could reach a point of no return in the region between 160 km and 2000 km in a few years, as the probability of collision increases to such a level that more space debris is generated than is extracted as a result of atmospheric friction.

This carries a risk for manned and unmanned space missions, with devastating consequences in some cases. We could cite as incidents those suffered by the *Jason-1* satellite in March 2002, or the collision of the *Iridium 33* with the *Cosmos 2251* in 2009 with catastrophic results.

The estimated population of objects (space junk) with an approximate size of 1 cm is thought to be larger than 600,000, with approximately 16,000 objects being larger than 10 cm according to the North American Space Command catalog³.

While objects with a size less than 1 cm can be adequately handled by an appropriate design that protects aircraft, collision with objects larger than a few cm can have catastrophic results due to their high kinetic energy (velocities over 6 km/s). They must be avoided by performing maneuvers, always expensive from the point of view of the fuel of the space vehicle itself. Specifically, and as the end of 2013, space debris involved 16 evasive maneuvers in the *International Space Station (ISS)* since October

1999 (Orbital Debris Quarterly News, Jan. 2014). At present, tracking of these objects is mainly focused on large ones (about 22,000 objects larger than about 10 cm), using radar stations on low orbits, or by optical tracking for more remote regions (geostationary ring). Tracking accuracy using radars is over hundreds of meters. In some cases, it can reach errors of 1 km. Laser ranging is an inherently accurate technique whose accuracy is 10 times better than current radar technology. The use of laser stations to track these objects was first proposed in October 2002 by an Australian group at the 13th International Laser Ranging Workshop (Greene 2002). In this work he showed laser echoes obtained on objects up to 15 cm in size at 1250 km. This meant increasing the accuracy on tracking these objects to values below 1 m. This idea has been successfully implemented by the Laser station of Graz (Austria) (Kirchner et al. 2012) and by a Laser station of the Shanghai Observatory (China) (Zhang et al. 2012). In both cases they showed that the return signals were clear, and that it was possible to track objects located in the Low Earth Orbit (LEO) segment (between 600 km to 2,000 km range). In 2015, the ROA requested a research project in which, among other objectives, it was proposed a goal which consisted on monitoring a special type of space debris, that is, inactive satellites equipped with retro-reflectors. This meant we have to accomplish a series of modifications to the original configuration. Results were satisfactory. We tracked many of these objects at low orbits, getting tens of thousands of echoes, which helped to know their position with an accuracy of the order of the meter (Catalán et al 2015). Throughout 2017 modifications continued. Specifically, a study was carried out to test the effect that a more powerful laser bench could have on this SST activity. For this, significant modifications were done in the installation. The main ones were:

- Installation of a nanosecond laser pulse generator bench able to transmit 2.5 J pulses.
- Timing of the output pulse of light.
- Modifications aimed to receive an external 10 Hz synchronization signal.
- Installation of a new cooling unit.
- Modifications in the optical system to increase the efficiency of the transmission/reception path.

2.1. Non-collaborative objects

After being able to shoot in automatic mode and once the laser device was fully operative we have set along 2018 and 2019 a daily observational schedule every night. We must emphasize that these type

³<https://www.space-track.org/>

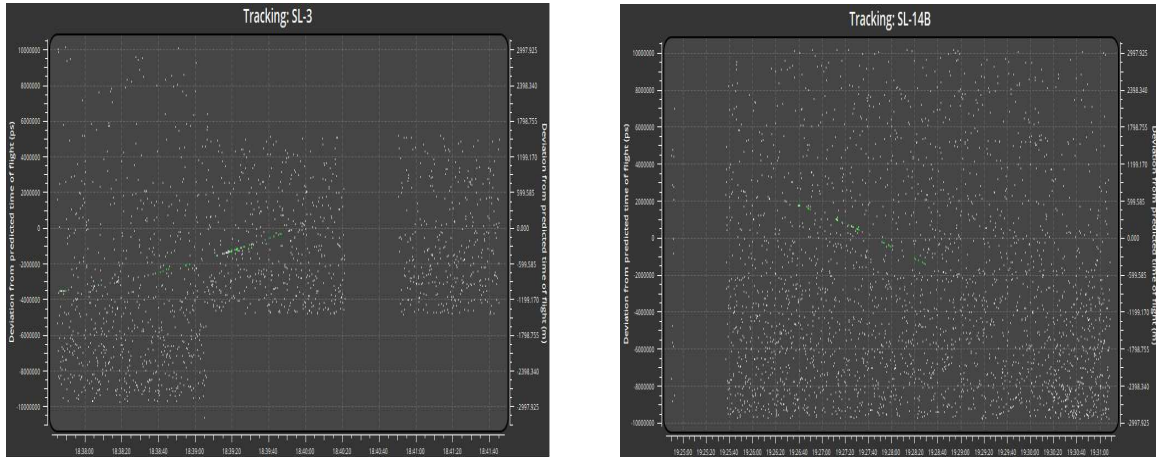


Fig. 1. Laser returns from two space debris objects. Horizontal axis in time in HH:MM:SS format. Vertical axis in ps the deviation from the expected time of flight. Green highlights the clusters showing the diffusely reflected photons. Note the low signal-to-noise ratio which makes it difficult to distinguish when we are shooting the target.

of measurements are carried out in a poor signal-to-noise ratio environment. Additionally, the ephemeris used to search for the object have poor precision, so these tracking must currently be carried out under visual contact of the target. It obliges to perform them in twilight periods. According to that our daily schedule reserves about 1.5 h during early evening to opaque objects (rockets, launch stages). These orbiting objects were still in sunlight, but with San Fernando in darkness. This allowed us to visualize the objects with cameras in the main receiver telescope, to correct the telescope pointing taking into account the relatively large time and range biases, and to adapt range gate positions and offsets accordingly. Along our first tests, we checked different divergences and range gates always taking into account the peculiarities of such targets. We checked divergences of 20, 30 and even 50 arcseconds in order to maximize our chances (of getting echoes), and different range gates: 500 ns, 5, 10, 15, 30 and even 50 microseconds to take into account an unknown and expected too large bias in range. After several tests and trackings we found that the best choice to get echoes on non-collaborative objects would be to use a minimum divergence and a range gate equal to 10 microseconds. These tests also served to highlight aspects that were not critical so far and that, with non-collaborative tracking, they already were: a) clearances in the telescope's horizontal and vertical gears, and b) a divergence of 20 arc seconds is excessively large. In spite of that since November 2017 non-collaborative objects tracking have been included in our day-to-day schedules.

2.2. Pico seconds laser bench

Throughout the year 2019, we installed a new laser bench able to track artificial satellites with retroreflectors. This new laser shots at 10 Hz (50 mJ per pulse). Its pulse duration is 30 ps. With this last component, the ROA laser station has been renewed and enhanced, being able to track both collaborative and non-collaborative objects.

2.3. Station performance

The activities carried out throughout 2018 and 2019 are resumed in Figure 2. It shows under which conditions the station performance is optimal, as well as those situations where its performance is limited. Figure 2 represents the distance and elevation at which the laser echoes were obtained along a track. Echoes from collaborative objects are plotted in black, and in color (according to its size) when they were got on a non-collaborative object tracking. It shows that although our station has been able to track up to distances of 3500 km, the area where the station shows a better behavior is concentrated between 2000 km and 900 km distance, regardless of the elevation. If the object is closer than 700 km (approx.) its relative speed is too high for the laser station, hence the decrease and interruption of returning echoes. Regarding its size, the station has proven to be able to track an $4.6 m^2$ object of section at distances of 2500 km.

2.4. Results

Throughout 2018 the laser station has participated in various tracking campaigns as one of the

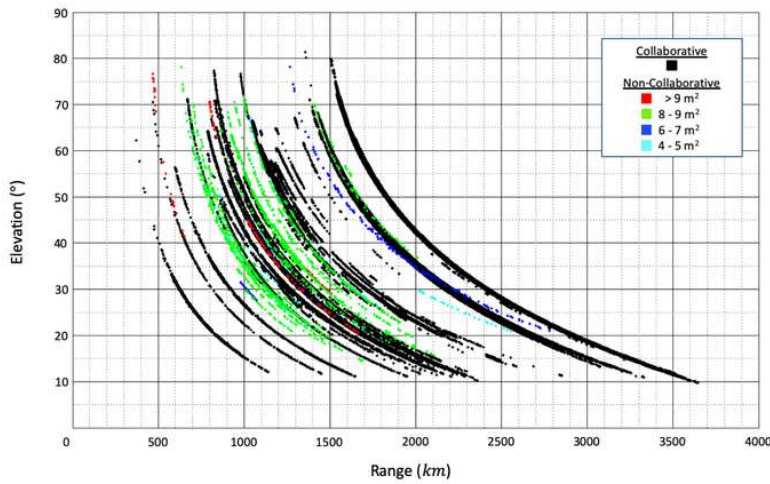


Fig. 2. Range vs. elevation. Passes correspond to tracking sessions performed along 2018 and 2019.

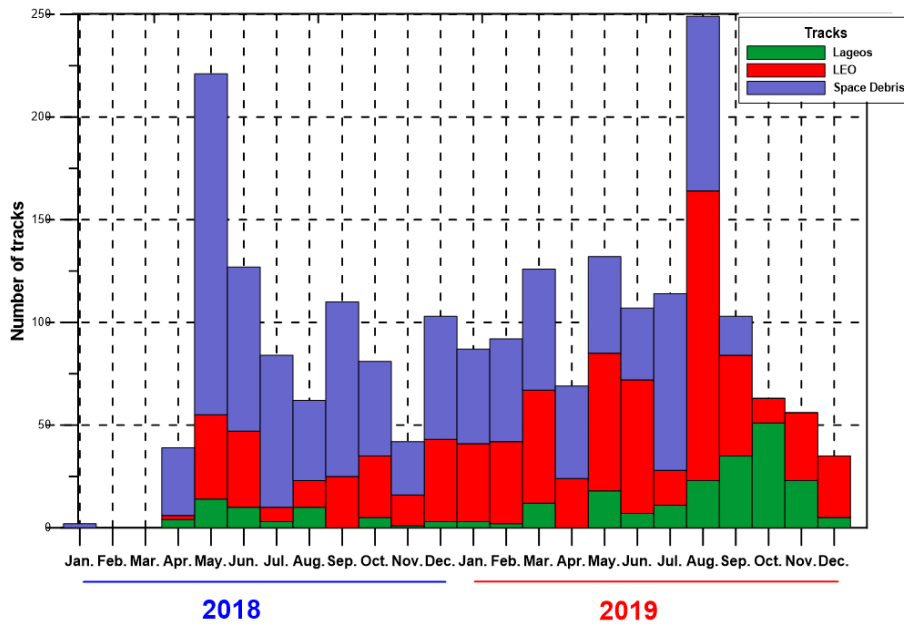


Fig. 3. Statistics of tracks for years 2018 and 2019. In green are the tracks of *Lageos I* and *Lageos II* satellites. In red are the Low-Earth-Orbits (LEO) tracks. In blue are Space Debris tracks.

Spanish contribution to the EUSST Support Framework (ref. Decision No 541/2014/EU of the European Parliament and of the Council). Apart from that, since the beginning of January 2019 San Fernando laser station has resumed its traditional role that it is to track collaborative objects. Figure 3 shows the statistics corresponding to year 2018 and 2019. Our next goal was to join again the International Laser Ranging Service (ILRS). This is an im-

portant objective as it implies the recognition that the station fulfills a high-demanding goal: to meet the standard of quality required to help defining the International Terrestrial Reference Frame. After analyzing our results on *LAGEOS-1*, *LAGEOS-2* and *LARES*. On November 27th we finally were accepted as ILRS members. The next objective will be to modify the pointing system of the station. This goal once reached will help to overcome our major

limitations: clearances in the pointing system and a large divergence. If we succeed on that we expect to improve our angular resolution in one order.

3. CONCLUSIONS

Since 2015 the ROA laser station has undergone a profound transformation related to the laser pulses benches, optics and other auxiliary elements involving both hardware and software. All these modifications make it possible to track both collaborative and non-collaborative objects since the end of 2017. These achievements make San Fernando laser station to be one of the few laser stations able to track such demanding targets (non-collaborative objects).

Acknowledgments: This study has been partially funded by the following projects: ESP2014-56577-P and RIOA 15-CE-3109 and it has received funding from the European Union's Horizon 2020 research and innovation program under the grant agreement No 713762 (CDTI's contract ref. EXPTE 10/2016 NEG LOT 3 (DPI / DPA)).

REFERENCES

- Catalán, M., Quijano, M., Pazos, A., Martín Davila, J., & Cortina, L. M. 2015, *RMxAC*, 48, 103
- Greene, B. 2002, *Proceedings of 13th Laser Ranging & Workshop*, 1-7
- Kirchner, G., Koidl, F., Friederich, F., et al. 2012, *AdSpR*, 51, 1, 21
- Zhang, Z.-P., Yang, F.-M., Zhang, H.-F., et al. 2012, *RAA*, 2, 212