YEBES LASER RANGING STATION (YLARA) SPACE DEBRIS AND SATELLITE OBSERVATION CAPABILITIES

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ABSTRACT

Yebes Observatory (OY), located at Yebes (Guadalajara, Spain), worked for years on the construction of a Fundamental Geodetic Station that fulfils the requirements of the Global Geodetic Observations System (GGOS) project [1].

Previously to the Satellite Laser Ranging Station deployment, the Observatory already hosted a VGOS radio telescope in operation since 2016, GNSS receivers, a gravimetry laboratory (with absolute and relative superconducting gravimeters), time and frequency systems and a local tie network.

At the beginning of 2018, funds for the construction of a Laser Ranging station at Yebes, coming from the European Regional Development Fund (ERDF), were approved. By including this technique, OY would become a GGOS Core Site.

The main objective of the YLARA station is to perform geodetic observations contributing to the International Laser Ranging Service (ILRS) network, but a second application is under implementation. The station will be equipped with a dedicated laser-based system for space debris observations.

Regular observations started last April in order to overcome the ILRS quarantine and become part of the network as an active station, reaching the approval last October.

Related to the space debris observation capabilities, the purchased laser has pulse energy 1000 times higher than the laser used for satellites equipped with retro-reflectors. It has a repetition rate of 200 Hz, a pulse width of 5-8 ns and it will be able to perform two-color observations (532 nm and 1064 nm) as in cooperative targets.

The laser and opto-mechanical elements needed for its operation are currently being installed and integrated at both HW and SW levels, with the goal of having the system operational by summer 2025.

Keywords: SLR, SDLR, Active Optical Observations, Space Debris Tracking, cooperatives and non-cooperative objects, Two-Color Capabilities, Core site, GGOS.

1 INTRODUCTION

The following paper describes, in the first part, the main technical characteristics of the Satellite Laser Ranging (SLR) station at the Yebes Observatory (OY), as well as a summary of the first analysis carried out with the observations performed at the station.

The second part presents the current status of the project of implementing the station capability to track space debris objects, observations that have been carried out in SLR stations for more than a decade [2].

2 YEBES LASER RANGING STATION (YLARA)

The system design is based on the classic architecture of Satellite Laser Ranging (SLR) stations [3], incorporating a biaxial telescope with a Coudé focus and a conditioned room fully prepared for laser system installation.

However, the design also incorporates the state of art of the SLR technique, with satellite ranging conducted using a laser package installed in a piggy-back configuration [4]. The system utilizes a two-color laser, operating at 532 nm and 1064 nm, with a repetition rate of 1 kHz. The detector package, which includes a C-SPAD and an IR-SPAD detectors, is also mounted on the telescope and attached to the first Nasmyth focus.

Figure 1. YLARA, 532 nm observation, night view.

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2.1 System Specification Overview

The Telescope Assembly (TA), comprising the receiving telescope (Rx), the mount, and the complete Coudé optical path, was designed by the Italian company Officina Stellare.

The customized RC700 model features a primary mirror with a diameter of 700 mm and three Nasmyth foci. It provides a beam pointing accuracy of ≤3 arcseconds and an operational azimuth rotation range from -270° to +270°. Additionally, it is equipped with an Az/El mount capable of a high slew rate of 12° per second on both axes.

The Coudé focus design enables the installation of additional laser systems in a controlled environment, allowing pulses to be transmitted through the Coudé optical path.

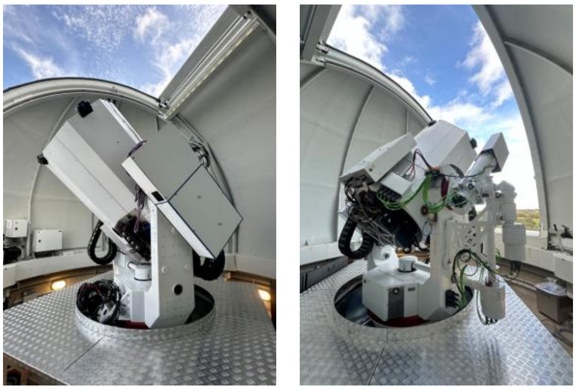

Figure 2. Telescope Assembly Overview (Officina Stellare). Laser and Detector packages (integrated by IWF-Graz).

Although the design includes a Coudé path, the primary configuration for SLR is with the laser package installed in a piggy-back setup, mounted on top of the main mirror cell, in line with the latest developments implemented in other SLR stations [5][6].

A similar approach was adopted for the detector package, which is attached to one of the telescope's Nasmyth foci. This package includes a C-SPAD detector for the green wavelength and an IR-SPAD detector for the infrared wavelength.

Both the laser and detector packages were designed and integrated by the IWF-Graz team in Austria.

The following tables present the main specification parameters of the currently installed laser and detectors.

Model	Compiler Compact Passat
Wavelength	532 nm, 1064nm (2 exits)
Pulse Repetition rate	1000 Hz (adjustable)
Energy per pulse	355 µJ avg @ 532 nm 543 µJ avg @ 1064 nm
Pulse width	7 ps @ 532 nm 8.5 ps @ 1064 nm

Table 1. Passat Laser specifications.

Detector	λ	Diameter	QE @ λ
C-SPAD	532 nm	200 µm	> 40 %
IR-SPAD	1064 nm	80 µm	max 30 %

Table 2. Detectors specifications.

The YLARA station is equipped with a classical slit-type dome from Baader, featuring a 5.3-meter diameter. This new design, including a solar shield, ensures maximum protection for the system both during observations and downtimes.

In the Coudé room, two racks house all essential hardware required for controlling and securing the station's operation. This includes the Lantime M3000 with a Timing Antenna, the Riga Event Timer A033-ET/USB model, and the Range Gate Generator (RGG).

Meteorological parameter monitoring is achieved through sensors measuring temperature, humidity, pressure, rain detection (on/off), cloud cover, and wind speed. Although the observatory already had a complete meteorological station, a new dedicated system was acquired specifically for SLR operations. This new station is located near the SLR building, with sensors positioned at the same height as the station invariant point (telescope Az/El axes intersection).

For aircraft safety, the system is equipped with ADS-B and FLARM receivers, along with an all-sky camera. Additionally, the station is equipped with a set of cameras serving various purposes, including station and sky monitoring, as well as a dedicated satellite camera that enables operators to observe satellites during night-time operations. This set up is particularly useful when operating the station remotely.

The entire station is managed using the SCOPE software, developed by DiGOS, which provides a centralized solution for station operation, control, monitoring, data analysis and processing.

All components are integrated through a modular platform with intuitive and modern interfaces, including SCOPE GUI, Motion, and Grafana.

Regular calibration is performed via an optical fiber system; however, a secondary system is available for verifying fiber calibration, utilizing external targets that can be temporarily mounted.

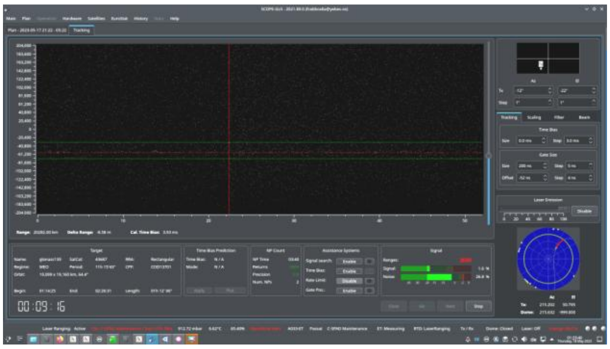

Figure 3. May 18th, 2023 → First SLR Observation at *532 nm to GLO139 2023-05-18, 00:24 UTC.*

2.2 Preliminary analysis results and quarantine process

After completing the installation and integration of all subsystems and performing the initial observations (spring 2023), a series of observations was carried out during the commissioning phase to evaluate the station's performance.

Data processing, both automatic and manual, is performed using the NPgo software.

NPgo reports include relevant information for analyzing the quality of satellite passes before uploading the data to the designated data centers.

Fig 4. and Fig 5. show processed passes for Lares-2 ang Galileo 208. Full Rate RMS are 5.09 mm and 6.51 mm, and Normal Points (NP) RMS, 0.14 mm and 0.53 mm, respectively. Values that meet the requirements established by the ILRS.

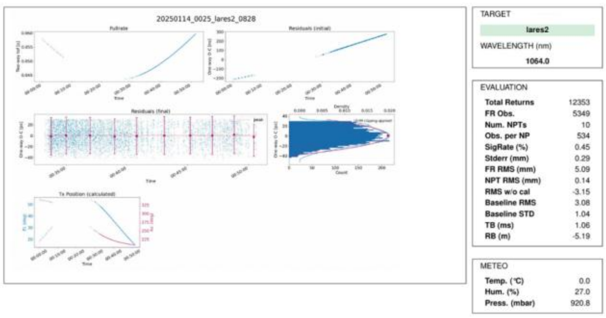

Figure 4. LARES-2 Observed at 1064 nm, 14-01-25. NPs formed with automatic DiGOS NPgo module.

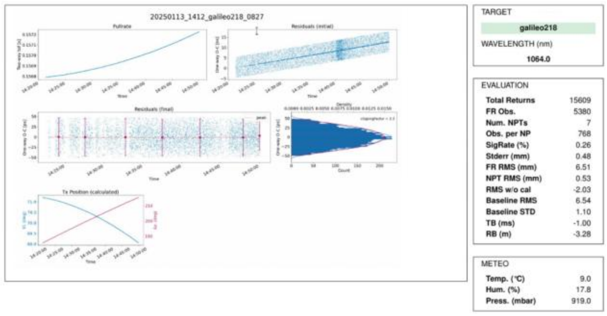

Figure 5. Galileo 208 Observed at 1064 nm, 13-01-25.

To join the ILRS network, it is required to undergo a quarantine period, during which a minimum number of observations of four selected satellites must be achieved, meeting specific quality standards (https://ilrs.gsfc.nasa.gov/network/site_procedures/quarantine_procedure.html).

In order to fulfill these quarantine requirements, observation schedules were established, focusing on hours when the four priority satellites were available.

Regular observations for the quarantine process began in April 2024, with approval from the ILRS Analysis Standing Committee (ASC) granted last October. Since then, the station has continued regular operations.

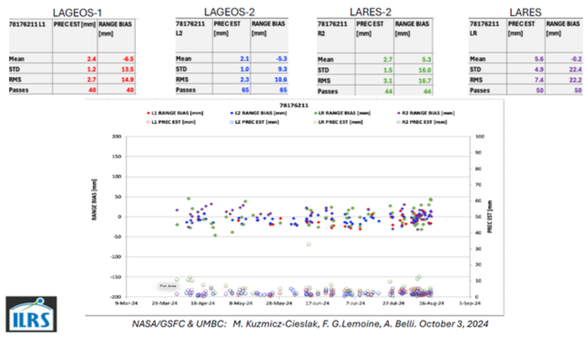

Figure 6. Acceptable passes from April to August. Quarantine Release October 2025 (Analysis by ILRS ASC).

The National Geographic Institute of Spain (IGN), through its Associated Analysis Centre (AAC), is capable of analyzing the data from observations accomplished at the station, as well as comparing them with data from other SLR stations. Fig. 7 presents the residuals calculated at Yebes in comparison with those from other stations in the network.

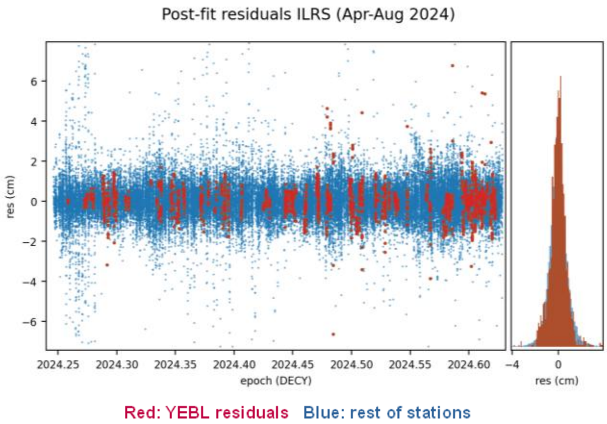

Figure 7. Residuals obtained at Yebes compared to other stations in the network (Analysis by the AAC IGN-Yebes).

3 SPACE DEBRIS LASER RANGING (SDLR)

As mentioned above, the station will extend its capabilities to improve knowledge of the position of space debris objects from positions previously determined by other techniques with lower resolution [7].

3.1 SDLR System Description

The system to be implemented, hereafter SDLR system, is similar in concept to the one implemented for SLR and consists, from a functional point of view, of three subsystems: transmission, reception and calibration.

In terms of design and architecture, while the signal reception subsystem is common to both techniques Receiving Telescope (Rx) and Detector Package, the transmission and calibration subsystems are different.

3.2 SDLR System Transmission Path (TP)

Following the path of the photons, the elements that make up the TP are briefly described below (the first two will be described in more detail later).

- Space Debris Laser (SDL). It is the source of the SDLR system consisting in a Nd:YAG DPSS laser emitting both at 532 nm and 1064 nm with a pulse repetition rate of 200 Hz. It has been provided by InnoLas Laser.
- SD Optical Package (SDOP). It is a set of electro-opto-mechanical components that modify both emitted laser beams expanding, attenuating and/or blocking them before being delivered to the next element. It is being designed for the Yebes Observatory (opto-mechanics) jointly with DiGOS (calibration, safety and integration in the station control system, SCOPE).
- Laser Transmission Path (LTP). It is a set of five flat folding mirrors, three of them remotely controlled (tip & tilt), which delivers the receipt beam from the SDOP to the next element by modifying only its direction of propagation. Design, manufactured and tested by Officina Stellare.

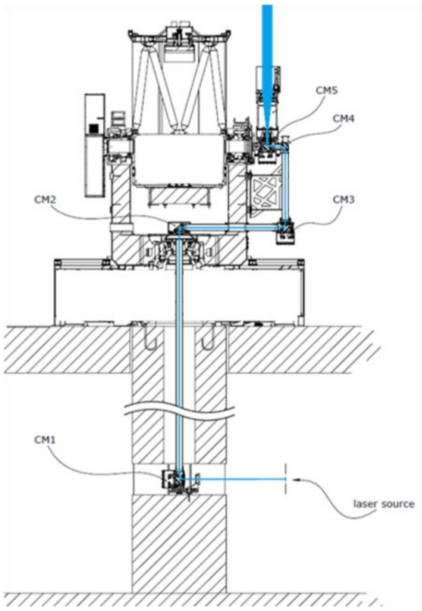

Figure 8. Laser Transmission Path (LTP) & Tx.

- Transmission Telescope (Tx). It is a Galilean beam expander (60 mm output aperture) which expands the size of the received beam by a factor of x3 before to be launched to the targeted space debris piece. In addition, it allows to modify the emitted beam divergence to help in the target acquisition and tracking. Design, manufactured and tested by Officina Stellare.

Both the SDL and SDOP are located on a dedicated optical bench at the station Coudé room being the SDL located at the station Coudé focus (Coudé Focus configuration). The whole setup will be covered with a dedicated cover with two hinging doors for assuring the maximum safety level when operating the SDLR system, and to keep the optical elements as clean as possible.

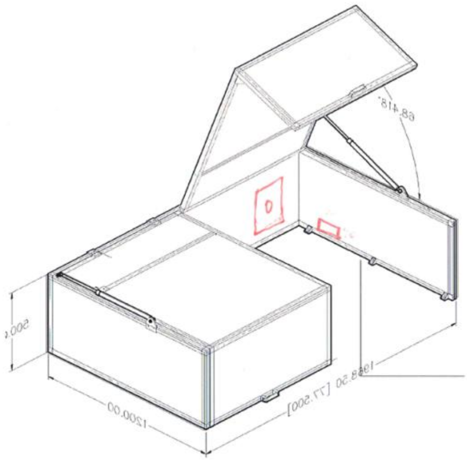

Figure 9. Optical Bench Cover concept.

3.3 SDLR System Product Tree

The SDLR system is composed of 5 subsystems:

- SD Laser & Optics (SDLO). SDL and SDOP.
- Calibration System: composed by a permanent optical fiber and temporary external target.
- Laser Safety Subsystem. Different elements (interlocks, dumps, traps, ...) to stop or block the laser emission when it turns no safe.
- Signal Distribution. The electrical harnesses to power and control the different opto-mechanical components.
- Command and Control. I/F with the station control system.

3.4 Space Debris Laser (SDL)

The SDL is the main module of the SDLR system as it drives the design and architecture of the elements in the transmission path, especially the ones at the SDOP. Tab. 3 lists its main parameters.

Model	Innolas SpitLight EVO II
Repetition rate	200 Hz
Pulse Energy	> 350 mJ @ 1064 nm > 200 mJ @ 532 nm
Mean power	74.8 W @ 1064 nm 50.2 W @ 532 nm
Beat diameter	7 mm
Divergence	< 0.5 mrad full angle
Pulse duration	5 - 8 nm

Table 3. Innolas SpitLight EVO II Data Sheet.

Physically it consists of three elements:

- Head (SDL_H). It contains the optics and electronic to produce the two laser signals. It is a Nd:YAG DPSS laser (532 nm / 1064 nm).
- Cooler (SDL_C). It water-cools the SDL_H to assure that its internal elements operate at its nominal temperature range. In addition, it will be used to cool some dumps in the SDOP. It is manufactured by HYDAC and has a colling capacity of 2300 tu.
- Power Supply (SDL_PS). Its primary function is to generate the driving current for the diodes pumping the Nd:YAG crystal. Moreover, it feeds additional components in the SDL_H (Pockels cell, safety interlocks, etc.). The controller circuit board handles all laser control commands as well as safety related control of the laser state.

3.4.1 SDL emission configurations

The SDL emits in both wavelengths simultaneously. The ratio of their signals can be altered by changing two parameters:

- The Second Harmonic Generator (SHG) temperature. At a temperature of 48.4 ºC the pulse energy at 1064 nm is maximised (351 mJ @1064 nm vs 1.9 mJ @ 532 nm) and at 28.0ºC the emission at 532 nm maximises (95.0 mJ @1064 nm vs 245.0 mJ @ 532 nm).
- The Amplifier Delay. Its value can range from 0 (maximum emission at both wavelengths) to 250 µs (minimum emission at both) which produces a reduction of the emitted signal of ~x2.5.

It is noted that no pure emission is obtained when selecting an emission wavelength. If nothing is done, both emissions exit the head through the same port (Fig. 10 Conf. 1). Both emissions can be spatially separated by using two dichroic mirrors (DM) in the Harmonic Separation Module (HSM) located at its exit. The first DM (DM1) splits both; a second DM (DM2) redirects the 532 nm emission to exit port 2 (Fig. 10 Conf. 2).

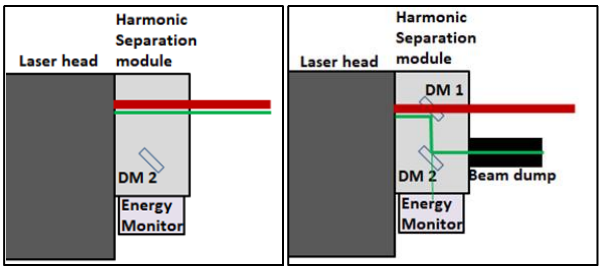

Figure 10. Conf. 1 (left). Both emissions at exit port 1. Conf. 2 (right). 1064 nm emission at exit port 1 and 532 nm emission at exit port 2.

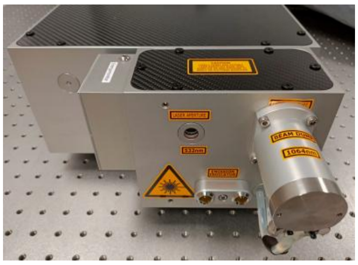

Figure 11. SDL_H emission ports, 532 nm (left) /1064 nm (right).

For obtaining a monochromatic emission, the unwanted wavelength must be blocked anywhere externally to the SDL_H.

Configuration 2 has been the one selected to operate the laser for SDLR.

Figure 12. SDL emission radiometric characterization.

3.5 Space Debris Optical Package (SDOP)

This is the next element in the optical train after the SDL. It is composed by several electro-opto-mechanical elements sharing both optical paths, the 532 nm and the 1064 nm, the same structure.

For any of the two wavelengths, the main components are:

- Dual Beam Shutter (BS). It is an air-cooled dual shutter which can block independently any of the two emitted beams. By blocking one, the wavelength exiting the other port is selected while by blocking both the laser emission is fully blocked for safety reasons. Its maximum dissipation power handling is 300 W with the chiller plate properly mounted on a heat sink thermally connected to the optical table.
- Automatic Beam Attenuator (BA). It controls the amount of transmitted signal in the range. It is based in a λ/2 ZO Waveplate + High contrast Brewster type thin film polarizer. Its power attenuation range is 0.1 - 98% and has a quick close to open time < 200 ms. The non transmitted light is reflected and killed by a water-cooled dedicated beam dump allocated at its reflected port.
- Beam Expander (BEX). They are 1-4x diffraction limited variable zoom beam expanders, with a high Laser Induced Damage Threshold (LIDT) coating at 532 nm and 1064 nm. Its zoom range allows to expand the emitted laser beam (∅~7 mm) till the required 20 mm at the entrance and all along the LTP.
- Beam Combiner (BC). It combines both laser beam exiting the BEX and redirect any or both into the LTP common optical path.

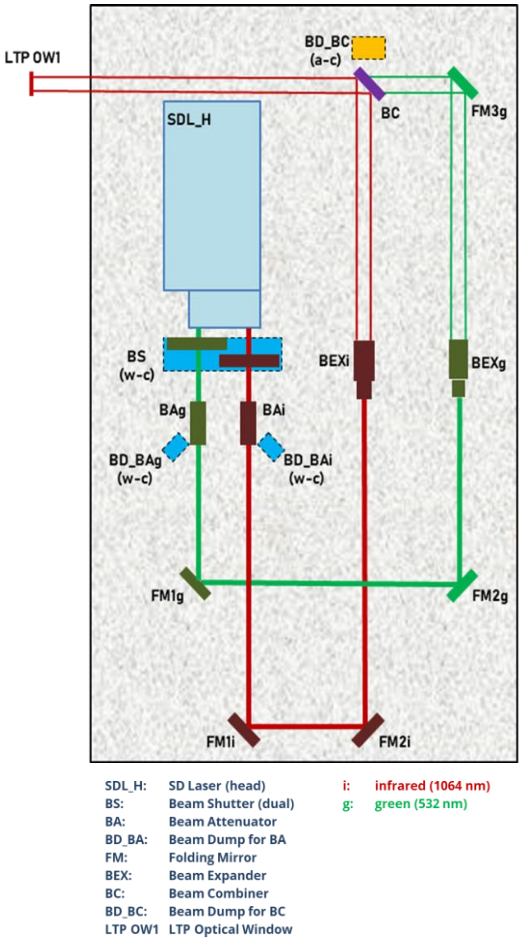

Figure 13. SDOP schematic

To save space, both wavelengths optical paths have been folded by means of high LIDT Folding Mirrors (FM).

Finally, some Beam Dumps (BD), water and air-cooled, have been placed to deal with the unwanted beams both at the Beam Attenuators and Beam Combiner.

4 CONCLUSION

After years of work developing the YLARA station project and nearly a year of system operation—during which it has demonstrated excellent observational capability, delivered positive results, and become part of the ILRS network—the Yebes Observatory is now focused on expanding the system to enhance its capacity for tracking space debris.

At the time of this paper and poster presentation, the acquisition of the main components is in its final stage, with assembly, integration, and verification set to begin shortly.

The system is expected to be fully integrated and operational by the summer of 2025, enabling collaboration in space debris observation campaigns with other stations as soon as possible.

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