Advances of ArianeGroup capabilities for laser optical observation of LEO objects

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ABSTRACT

With the continuous growth of space applications, the number of objects in orbit is increasing dramatically. Space Situational Awareness has become a necessity to insure safe operation of space assets. The number of conjunction data messages that need to be screened is expected to increase by a factor of three by 2030 and thus requiring more data and more accuracy to concentrate the resources on high interest events to mitigate associated risks.

Whereas Satellite Laser Ranging is used for a lot of applications like validation of GNSS constellation or scientific earth monitoring satellites orbits, metrology and geodesy; it has the potential to provide high accuracy for CDM refinement at an affordable cost.

Recent improvement in laser technologies will allow the development of "eye safe" laser ranging station with the ability to reach meter level accuracy. The objective of this station is in particular to be compliant with air traffic in order to not require huge NOTAM (Notice to Airmen) and impact the Air Traffic Management operations. This type of design will allow to deploy more easily this technology across the world in order to improve the accuracy of orbital parameters of space objects and contribute to the reduction of collision warning false alarms.

Using its experience and skills from the GEOTracker® Network development, ArianeGroup has designed an eye safe satellite ranging station with the ability to perform ranging measurements on non-cooperative target (satellite without retroreflector) in LEO orbit day and night.

Results from field tests will be presented in this paper including accuracy evaluation vs cooperative targets.

This presentation describes the concept and architecture of the station under development, the main challenges we had to address, the way-forward for laser station network deployment, the connection to the GEOTracker® system and associated data services delivery.

1. INTRODUCTION

With more than 10 000 objects expected to be launched in Low Earth Orbit by 2025 and the activation of new space surveillance systems, the LEO object catalogue is expected to grow by a factor of at least 2. The direct impact for space safety is that the number of collision risks in orbit is expected to be multiplied by 3 or 5, leading to a need for more space surveillance system and more accuracy to prevent those risks.
SLR (Satellite laser ranging) systems have been used for a long time to provide high accuracy range measurements for scientific satellite mission and GNSS orbit determination. With the evolution of laser and optronic technologies, safer laser operations are now possible to allow global operation of those systems in compatibility with Air Traffic.

This paper will present the work performed at ArianeGroup level to reach this goal:

- tests of high-power laser and demonstration achieved in the past
- new design of SLR station for operations compatible with air traffic
- results achieved with this new design which demonstrated operational process

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2. INTEREST OF SATELLITE LASER RANGING SYSTEM

The use of laser system allows to improve measurements performed with passive optical system at two different levels. First, combining this range measurements with traditional angular measurements, gives the system the observability lacking while using only angular measurement. Indeed, we obtain the 3rd dimension that allows to obtain a 3D position with only one measurement. This observability gives a better accuracy on the orbit without the need to observe the object during several passes or with several optical system at the same time. Theoretically, with only 2 measurements (including angles + range) an orbit could directly be determined. In practice, more measurements are needed to filter the measurement noise and obtain the right level of accuracy. This very high level of accuracy obtained in a short period is a good way to reduce the number of relevant conjunction alerts (see. Fig. 1)

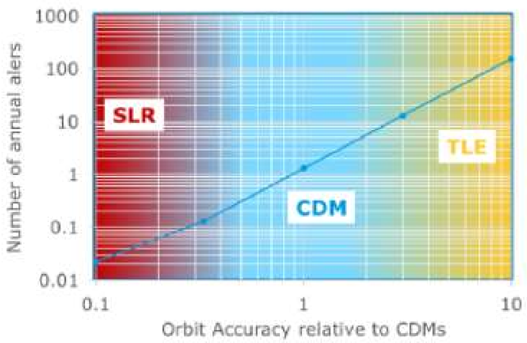

Fig. 1 : Number of alerts in a year for a LEO spacecraft (safety sphere with 4.5 radius) as a function of the orbit data quality, for a risk threshold corresponding to 90% risk reduction
(From ground-based Autonomous Passive Optical Staring Sensor for Orbital Object Detection and Position – Paul-Philip Wagner – April 2022)

The second advantage is a consequence of the first one: as shorter observation time is required to obtain a very good level of accuracy; the system can track more objects than a standard passive optical station in a similar period.
Today, no survey observations can be done using a laser system (survey means simultaneous measurements on a large part of the sky), as the laser can track only one object at a time. In other terms, there is no parallelization of the observation of several objects. The system should switch from one object to the next one to observe different objects. Such system is then well designed to refine a specific orbit of an object involved in a conjunction or in a reentry.

As more and more objects will be in orbit, conjunctions/reentry will increase dramatically in the next years. Therefore, even if such stations are used only for conjunction processes, a lot of them could be needed. The large deployment capability is a necessity and should be considered at the development/prototype phase to cope with laser operation restriction that can occur depending on the laser characteristics.

3. LASER SAFETY REGULATION

The advantage of lasers for SLR system is their high energy spatially and temporally concentrated. But this huge energy density can be dangerous for human and especially for human eyes. As SLR stations are used for pointing at the sky direction, the safety problems that can occur are linked to airplane and other air users. Authorizations are most of the time difficult to obtain as air space is nowadays very crowded and airways are almost everywhere. Therefore, we should find a way to operate laser station with very limited impact on air traffic management. This results in authorization processes to be engaged before any laser operations. It is not only a matter of administrative process that we would like to avoid, but also a matter of location where we could be deployed.

Let’s have a focus on what is dangerous while using laser beam. Considering the visible spectrum, light goes through the cornea and is focused to create the image at the retina level. The beam energy density is then hugely increased on the retina by comparison to the energy density on the cornea due to the focus (see. Fig. 2). So, for visible beam (and all beams going through the cornea), a very small amount of energy at the entry of the eye is sufficient to be dangerous for the retina. This is true for beam whose wavelengths are from the visible part up to 1400nm.

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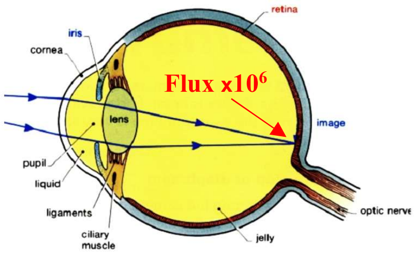

Fig. 2 : Beam entering at the cornea is focused in the retina resulting in a huge increase of the power-flux density (From pedagogie.ac-nantes.fr – Sylvie Serot, Lycée Guist'Hau, Nantes)

For wavelengths above 1400nm, the beam is stopped by the first elements of the eye (cornea, …) , which means no focus at the retina level (see Fig. 3 for transmission regarding wavelength). The energy density of a beam at these wavelengths can then be higher before presenting a danger for the cornea. The regulation is considering this effect and allow a MPE (Maximal Permissible Exposure) much higher for wavelengths above 1400nm. (see in [1] and [2])
The above explanation can be summarized as follow: with a laser with a wavelength higher than 1400nm, the energy density can be much higher than with a visible laser before being dangerous for human eye and impacting air traffic. Therefore, the wavelengths of the lasers used for ArianeGroup SLR station are superior to 1400nm to reduce the impact on air traffic. The goal is indeed to obtain the smallest distance as possible where the laser emission is dangerous for human eye. The distance obtained with ArianeGroup laser configurations are explained later in this article.

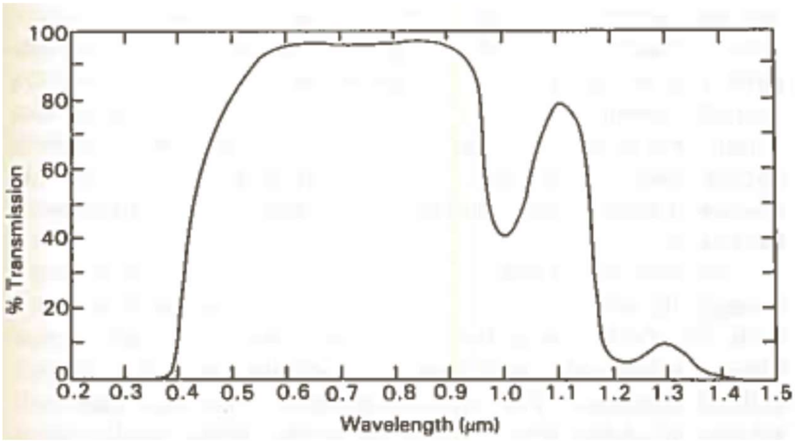

Fig. 3: Transmission of the elements of the eye prior to retina regarding wavelength (from D. Sliney and M. Wolbarst – Safety with Lasers and Other Optical Sources – 1980)

4. STATION DESCRIPTION

Since the beginning of the SLR project, several years ago, the configuration of the laser station has changed several times to take advantage of return of experience and to make the initial alignment and the operation easier. This section describes the current monostatic configuration detailing the different elements that constitute the SLR station of ArianeGroup in terms of hardware and software. The system could be separated in 4 parts:

- Pointing and autotracking subsystem
- Laser emission subsystem
- Laser reception subsystem
- Ranging software

Fig. 4: SLR station: mount, telescope, emission, and reception path – Zoom on the tip tilt platform for emission path

4.1 Pointing and auto-tracking subsystem

The pointing subsystem is composed of a mount, a telescope, a visible camera (see Fig. 4) and the associated software (see Fig. 5) in charge of controlling the mount and performing the auto-tracking of the object to be ranged.
This software has been fully internally developed and its purpose is to manage the controlling of the mount to acquire the object, to follow it and to keep it with stability at the exact position defined in the field of view.
This software is also in charge of executing sequentially the different tracking of the observation plan. This plan is computed by another software (also fully internally developed) regarding the list of targets we want to track and the visibility of the objects.

Fig. 5: Visualization of the auto-tracking software
Green cross is the position where to align the object, red dotted square is the detection area around the detection in the center

4.2 Laser emission subsystem

The laser emission subsystem is composed of the laser and a beam expander located on a tip-tilt platform as shown in Fig. 4. As it can be seen on this figure, it should be noticed that the tip-tilt platform is mounted on the same mount as the telescope used for the tracking and the laser reception.

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The beam expander has a double advantage: it reduces the divergence, which increases the link budget (see section 5 for details), and it increases the size of the beam at the output of the emission subsystem which reduces the energy density and so the danger for short range location.
For cooperative targets, the first choice was to use COTS (Commercial On The Shelf) elements to achieve the expanding factor needed. As the factor needed was important, we used 2 different beam expanders one behind the other (see left part of Fig. 6), which was a great choice working for cooperative target using the cooperative laser.
For non-cooperative targets using a new more powerful laser, first tests were done using the same assembly of COTS elements, but we faced 2 different problems. First, the beam expander located immediately after the laser output was not supporting the energetic flux and one part has been broken after a few tracking. Second, the optical quality of the COTS beam expander was not compatible with the very low level of divergence we would like to achieve.
For these two reasons, we decided to invest in the design and build of a custom beam expander (see Fig. 6).

Fig. 6: 1st Beam expander used with cooperative laser (left) – New Beam expander for non-cooperative laser

The other important part of the emission path is the motorized tip-tilt platform in charge of aligning the laser with the reception path. Indeed, due to the very high level of accuracy we need for this alignment, this cannot be done by fixed mechanical construction. This platform is then used to initially align the laser beam with the very narrow reception area collecting photon returns. During the tracking, the platform is also used to compensate the slight mechanical slack or deformation that could result in a misalignment of the emission path with the reception path.

4.3 Laser reception subsystem

The laser reception subsystem is composed of the telescope (the same used by the auto-tracking subsystem), a system to inject the photons of a specific part of the field of view in an optical fiber, an interferential filter, a SPAD (Single Photon Avalanche Detector) and a TDC (Time Digital Converter).
The photons coming from the satellite (solar photons and laser photons) enter the telescope and are injected in an optical fiber (if emission and reception are well aligned). Then the filter is in charge of keeping only photons compatible with the laser wavelength, the SPAD performs the detection and informs the TDC each time a photon has been detected. The TDC has the role of dating the detection coming from the reception path as well as the instant of emission of each pulse of the laser. The equipment allows to obtain a very accurate (several picoseconds) relative timestamping of the different triggers it receives. Fig. 7 illustrates the above description in a schematic way.

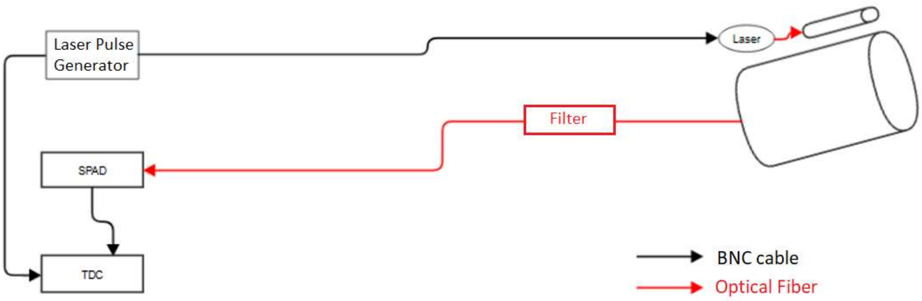

Fig. 7: Ranging process data collection scheme

4.4 Ranging software

The principle of the ranging software is to use a reference distance from which we can compute for each laser pulse, the flight duration of the photons and their precise time of return. For ArianeGroup SLR station, this reference distance is based on TLE format orbit coming from Space-Track or from the GEOTracker® catalogue. As this format is intrinsically not perfect, the software considers all detections coming from the SPAD inside a specified gate around

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the a priori time of return. This is done for every pulse emitted by the station and the difference between the estimated range using detection and the range using the reference is computed. These are called the residuals and they are commonly plotted through time.

Even if the reference orbit (the TLE file) used is not perfect, the difference with the reality stays continuous through the time. The residuals coming from detection from the satellite should then be almost aligned in the plot contrary to detection from the noise as there is no reason for the noise detection to have similar distance difference with the reference through the time. Fig. 8 shows an example of such residual graph with an obvious presence of laser returns for a tracking of several seconds.

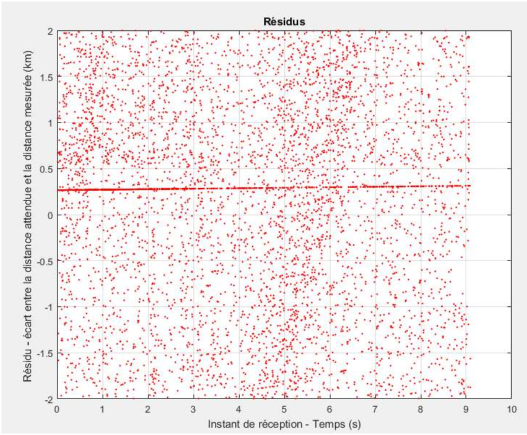

Fig. 8: Example of residuals graph with laser returns

5. LINK BUDGET AND SIMULATOR

As mentioned in section 3, using a wavelength higher than 1400nm allows to drastically increase the energy of the laser while staying below the threshold of the regulation regarding laser safety. On one hand, we need a very high energy density to maximize the link budget and on other hand we would like to keep a small NOHD (Nominal Ocular Hazard Distance), which implies to keep a limited energy density. To deal with those 2 opposite statements and find the better compromise, we developed different tools to assess the feasibility of the system regarding those 2 constraints. Amongst those tools, the main one is a simulator of the photons returns that we could have regarding the characteristics of the different elements of the system. The goal is to obtain a visual result on the level of confidence we can have on a ranging regarding a specific configuration.

5.1 SIMULATOR PRESENTATION

This simulator is based on the link budget equation expressed below in 2 different ways: giving the reception power and the number of photons received regarding the parameters of the system, the environment and the target.

$$P_r = P_{laser} \times T_e \times \frac{G_{laser}}{4\pi r^2} \times OCS \times \frac{1}{4\pi r^2} \times S_r \times T_{atm}^2 \times T_r$$

$$n_{ph_r} = \frac{E_{laser}}{h} \times \frac{\lambda}{c} \times T_e \times \frac{G_{laser}}{4\pi r^2} \times OCS \times \frac{1}{4\pi r^2} \times S_r \times T_{atm}^2 \times T_r$$

Where:

- P_r, optical power received [W];
- $n_{ph\,r}$, number of photons received;
- P_{laser}, optical energy emitted by the laser [W];
- E_{laser}, laser energy by pulse [W];
- h, Plank constant ($6{,}626.10^{-34}$ J.s);
- λ, laser wavelength [m];

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- c, light celerity (m/s);
- G_{laser}, emitting laser gain (defined below);
- r, emitting laser / receiver to target distance [m];
- OCS, optical cross section [m²];
- S_r, reception collecting surface of the telescope [m²];
- T_{atm}, atmospheric transmission;
- T_r et T_e, reception and emission transmission factor

The laser gain considers the divergence of the laser and the potential pointing error. Its expression is given below:

$$G_{laser} = \frac{8}{\theta_{1/2}^2} \exp\left(\frac{-2\theta^2}{\theta_{1/2}^2}\right)$$ in general cases

$$G_{laser} = \frac{8}{\theta_{1/2}^2}$$ for perfect pointing

Where:

θ, pointing error [rad];
$\theta_{1/2}$, half divergence of the emitting system [rad]

The simulator considers the characteristics of:

- the laser itself: power, wavelength, frequency, divergence,
- the emission system: transmission, beam expander factor
- the target: OCS (Optical Cross Section), distance
- the pointing system: pointing error
- the environment: transmission of the atmosphere at the specific wavelength of the laser, solar noise
- the reception system: collection diameter, transmission of the filter and other reception elements, SPAD efficiency, noise and deadtime

The distance is considered as a constant by the simulator, which is of course not the case in reality as the satellite is moving during the tracking. However, this shows the result we can have for an object at that specific distance. Besides, the simulation being performed on periods around 10s, the distance of the objects is not modified so much in reality (max around 70km) and the link budget is quite similar with a distance of +/- 70km.

The solar noise corresponds to the photons at the wavelength of the laser (so they are not filtered by the interferential filter) and coming from the reflection of the sun on the satellite. The level of solar noise has been estimated regarding different pass of satellites for which we aligned the satellite with the fiber going to the SPAD to assess the increase of the SPAD detection by comparison with the satellite not being aligned with the fiber. Rigorously this value should depend on the object (its size and reflectiveness at least), but the current version of the simulator does not consider this phenomenon and a constant value around 5kHz has been considered.

Based on the link budget equation, the simulator computes the probability for each pulse that a laser photon is reflected by the satellite and is detected by the SPAD.
At each time, the probability that the SPAD detects a noise photon (solar noise or SPAD noise) is also computed. Regarding those 2 probabilities and the dead-time of the SPAD, residuals can be generated and plotted.

5.2 SIMULATOR RESULTS

In the simulations presented below, the assumption is made with residuals of 100m. This has no impact on the analysis. This is just a matter of displaying the laser returns at a specific value of residuals. Indeed, the simulator is not considering the difference between a reference orbit and the reality, its role is to assess the detectability of laser photons returns and it does not need a reference orbit for that. The table below provides the characteristics of the cooperative configuration

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Table 1 : Characteristics of the cooperative configuration of the SLR station

Characteristics	Values
Energy / Pulse	150µJ
Wavelength	1550nm
Frequency	10kHz
Total divergence (after beam expander)	300 µrad
NOHD for this configuration	106m

The figures below show the results obtained with the simulator for our laser station for different cooperative configurations of the pointing and the target.

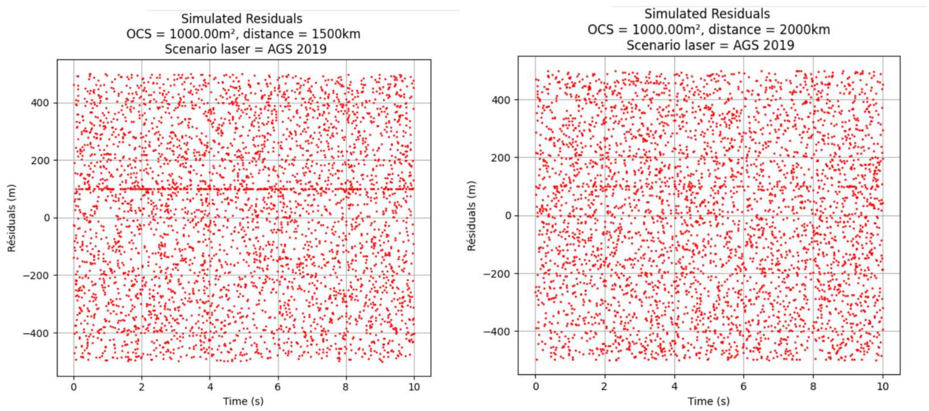

Fig. 9 : Simulated residuals for cooperative target OCS = 1000m² and distance = 1500km or 2000km with perfect pointing

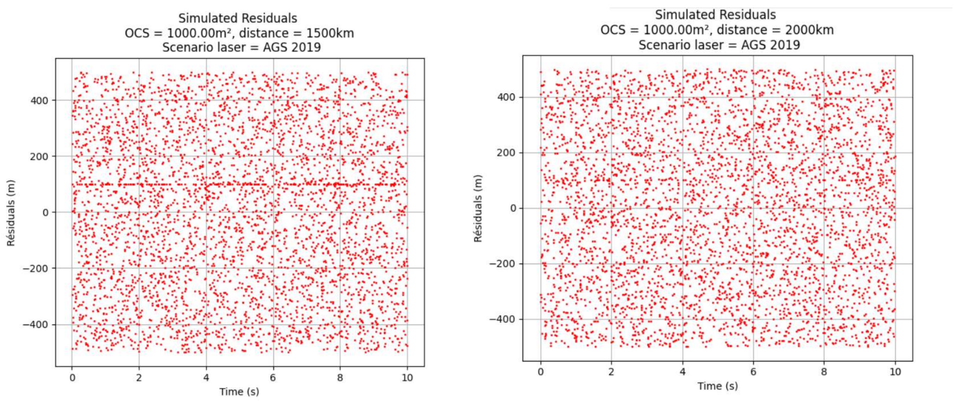

Fig. 10 : Simulated residuals for cooperative target OCS = 1000m² and distance = 1500km or 2000km with pointing error = 10 arcsec

Fig. 9 shows the residuals graphs that we could obtain with the cooperative configuration for an object at 1500km and 2000km distance with an OCS of 1000m² and without any pointing error. In this configuration, there is no problem to identify visually the line of residuals indicating there are laser returns. It is obvious for 1500km (left graph) and can be seen for 2000km distance even if the line is less visible due to the noise.
Regarding the automatic process of auto-tracking for the reception and the semi-automatic laser alignment for the emission, we can consider that at that stage of the station development, the pointing could have an error of a few arcsec. So, this could be considered to assess the impact it can have on the link budget and the residuals graph.

Fig. 10 shows the same configuration as the previous figure except for the pointing error which has been set to 10 arcsec. It is difficult to assess precisely the pointing error that we made (otherwise, we would have compensated it…), but this value of 10 arcsec is an overestimated value to be sure to be conservative on the results obtained with the

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simulator. The graph at 2000km shows that for an OCS of 1000m² (which is very low for cooperative targets), a pointing error of 10 arcsec is too large to be able to detect laser returns.

The results shows that there is no problem with this configuration to perform cooperative target ranging.
Indeed, there is a comfortable margin for such objects for the 2 following reasons:

- Depending on the number of corner cube onboard, the OCS of the cooperative target is said to be between 10^4 m² and 10^7 m². The simulations above have been performed for an OCS of 1000m² to show the limit for this configuration.
- Even with an important pointing error (10 arcsec), the laser returns could be detected easily on the residuals graphs

The table below provides the characteristics of the non-cooperative configuration

Characteristics	Values
Energy / Pulse	28mJ
Wavelength	1617nm
Frequency	200Hz
Total divergence (after Beam Expander)	50 µrad
NOHD for this configuration	1264m

The first thing to be noticed is the NOHD which is around 1km. This value is most of the time compatible with the air traffic because it is below the minimum altitude that is regulated for airways. However, an authorization should be requested, but is easier to obtain. For comparison, a laser working in visible spectral band with similar characteristics would have a NOHD of several hundreds of km.
Those characteristics and the equipment to obtain them, especially the divergence, have been selected regarding the results of the simulation. Indeed, the design of the beam expander presented in section 4.2 and Fig. 6 has been chosen to reach the expansion factor needed to obtain the right divergence for which the simulator indicates we could have laser returns detection.
To increase the link budget, we could also have increased the power of the laser, but to be able to quickly perform the demonstration, it was easier to use a laser on the shelf and to work on the laser beam after it exits the laser than to develop the perfect laser with directly the right power and the right divergence. This would be done in the near future.

Fig. 11 shows the result for the configuration of the non-cooperative laser for an object with an OCS of 5m².

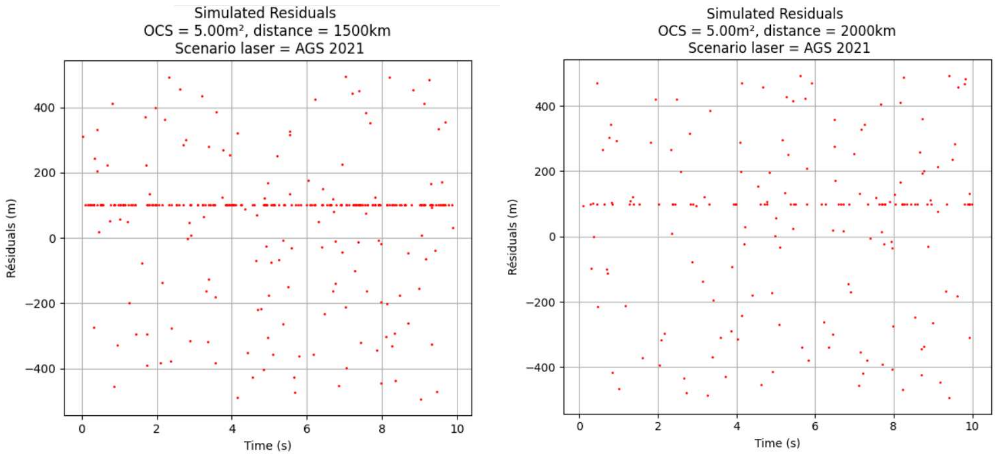

Fig. 11: Simulated residuals for cooperative target OCS = 5m² and distance = 1500km or 2000km with perfect pointing

As the repetition rate of the laser is lower than with the cooperative configuration (200Hz vs 10kHz), less gates are opened (200 per second vs 10^4 per second for the cooperative configuration), which explains the different aspects of the graphs with apparently much less noise, but there are also much less opportunities to receive laser returns as less laser pulses are sent per seconds.

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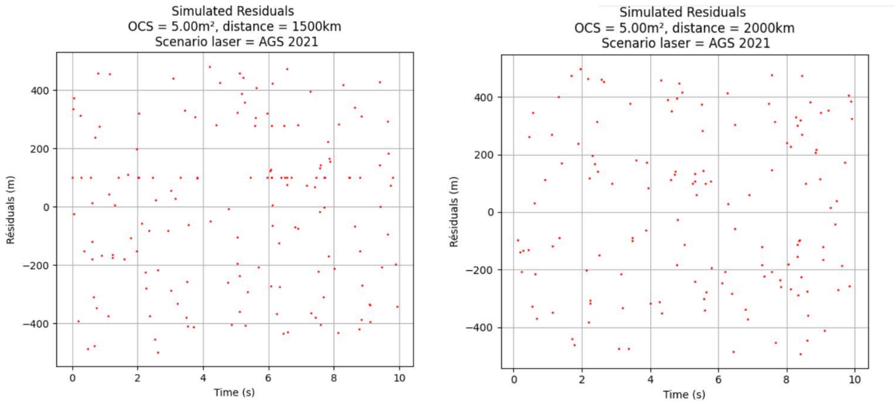

Fig. 12: Simulated residuals for cooperative target OCS = 5m² and distance = 1500km or 2000km with pointing error = 5 arcsec

Fig. 11 shows that the laser returns can be easily detected at least until 2000km distance without any pointing error for an object with an OCS of 5m².
Fig. 12 shows the impact of the pointing error when we have a very small divergence. Indeed, with such a divergence and a small error, the main powerful part of the beam does not impact the tracked object. We see that a pointing error of 5 arcsec is allowed for 1500km but is too large for 2000km.
Although this configuration is not the final one for an operational system, the result obtained with the simulator gave us confidence for a first demonstration of non-cooperative target ranging.

6. RESULTS

6.1 COOPERATIVE RESULTS

Since the first laser photons received at the end of 2019 from cooperative satellites, further tests have been performed to improve the station in terms of easiness of initialization, calibration, and operation.
Fig. 13 shows results from 2019 using the cooperative configuration of the station (the only one we had at that time).

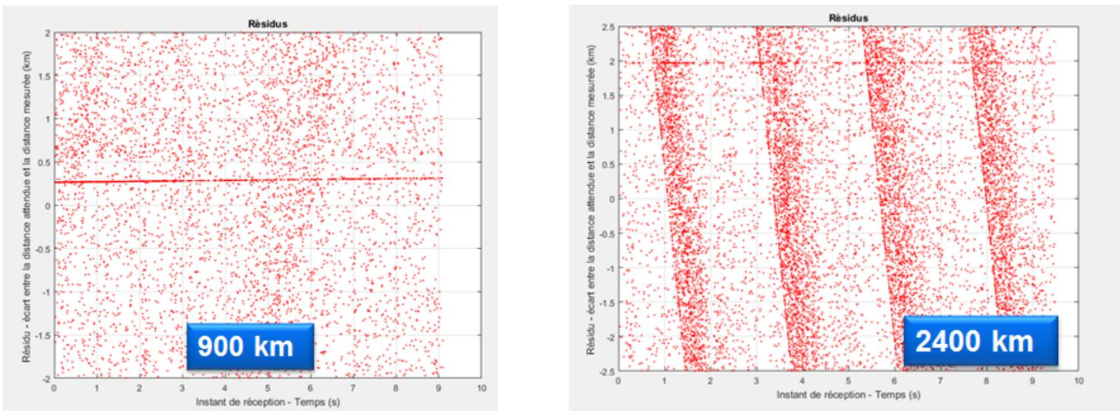

Fig. 13: Residual on GEOS 3 (cooperative target) at the minimal and the maximal distance obtained (with cooperative configuration)

For this tracking, the reference orbit was the public TLE from Space-Track. This explains the important value of the laser residuals (from 200m to 2km) and their non-horizontality. The fact that the line is not perfectly horizontal is mainly due to a time bias in the TLE. This phenomenon is highlighted later in this section.
The very inclined lines of detection seen on the 2400km figure are not to be considered: there are due to the very low elevation resulting in some photons from the laser impacting the wall of the shelter and going back to the reception path. It corresponds to a ranging at a constant distance being the distance between the system and this wall. As the

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residuals are compared with a reference orbit, we observe the difference between a constant distance and the distance of the orbit through the time.

Of course, the non-cooperative configuration can also be used to track and range cooperative targets and this has been performed to test different things. As much more power is available with this configuration, the margin on the link budget is very important for cooperative target and we can, for example, voluntarily create a pointing error to see the impact on the residual graphs. Such tests are not detailed in this paper.

Fig. 14 and Fig. 15 shows residual for 2 other cooperative satellites using the non-cooperative configuration.

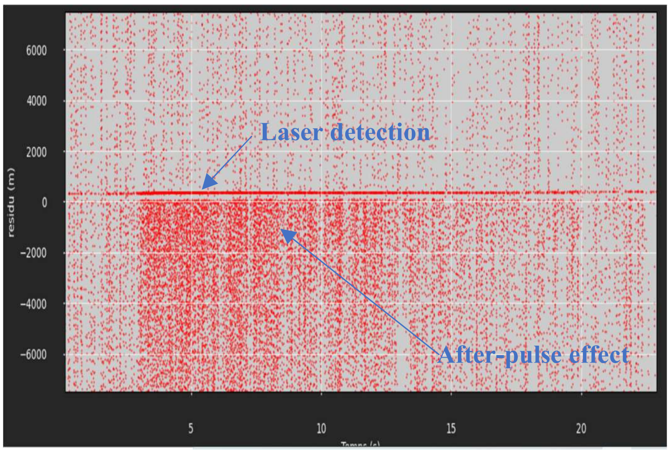

Fig. 14 : Residual using non cooperative configuration for CARTOSAT (cooperative target)

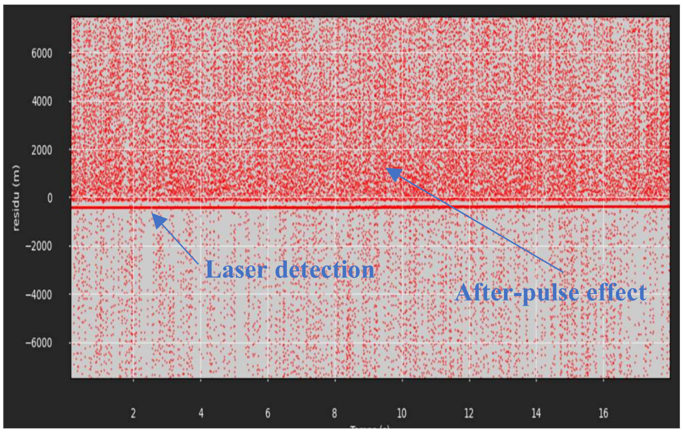

Fig. 15: Residual using non cooperative configuration for STARLETTE (cooperative target)

We immediately noticed that the link budget is much more important. This cannot be seen on the graphs, but more than 70% of the laser pulses are returning. To complement this statement, the graphs shows well the after-pulse effect, which is an evidence that a lot of photons are returning. This is a property of the SPAD that has more chance to perform a false detection after a detection has been made. This effect explains the increase of noise after the effective laser detection. As the graph shows only the detections performed in a gate around the time the laser photon should return, if a lot of laser photons come back, the residual graph highlights the phenomenon with this second line of detection and an increased level of noise after the detection.

6.2 ILRS COMPARISON

To assess the level of accuracy and to calibrate our station, comparison of the measurements obtained with ILRS orbits has been performed. This section shows the result obtained on STARLETTE. First, let's have a look at the comparison with the reference orbit used for the tracking: the public TLE. Fig. 16 shows the residual around the laser photons returns using this TLE as a reference.

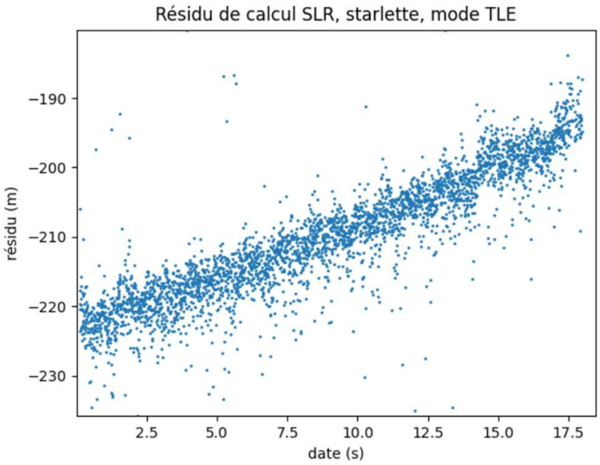

Fig. 16: Residual based on TLE for one pass of STARLETTE (cooperative target)

With no surprise, we see the TLE has time bias (inclined line of laser returns) and a lack of accuracy.
Fig. 17 shows the residuals around the laser photons returns using the ILRS orbit (CPF format) as a reference.

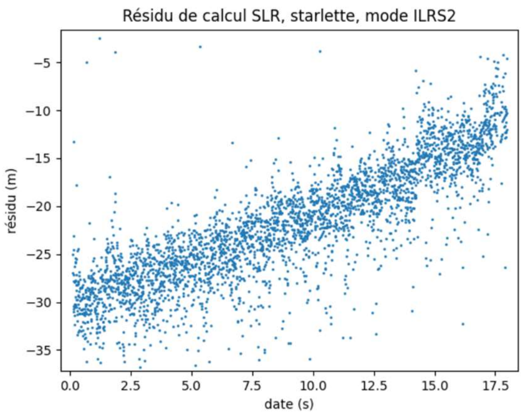

Fig. 17: Residual based on ILRS orbit for one pass of STARLETTE (cooperative target)

With this new more accurate reference, we obtained a smaller error (around 20m to 30m), but we also have a time bias. By considering the ILRS orbit do not have any bias, we correct our measurements from the bias to obtain a perfect horizontal line. This is what is shown on Fig. 18.

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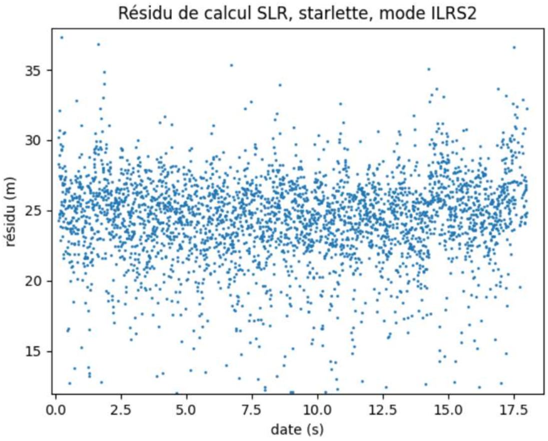

Fig. 18: Residual based on ILRS orbit with time bias correction for one pass of STARLETTE (cooperative target)

We observe resulting residuals around 25m. The difference has 2 identified origins:

- The accuracy of the CPF file used as reference: we compare the accuracy of several CPF file for this object and depending on the position on the orbit, the difference between 2 different ILRS orbits could be more than 10m.
- We did not use a precise model of atmosphere: we considered that the light way is not curved by the atmosphere. The order of magnitude of such correction could also reach more than 10m. This correction is planned to be implemented in our software pipeline in the near future.

6.3 NON-COOPERATIVE RESULTS

Beside the tests perform on cooperative targets, the non-cooperative configuration has of course been used for ranging of non-cooperative targets. Fig. 19 shows the result for one non-cooperative object. The reference orbit used was a public TLE from Space-Track but not a very fresh one. This explains the drift we observed for the laser returns residuals, that is due to an important time bias.

Obtaining an OCS of an object is difficult and is depending on the orientation of the object when we observe it. However, using the simulator presented previously, we assessed that the OCS of this object was around 10m² at the time we observed it. This is of course not a very accurate estimation.

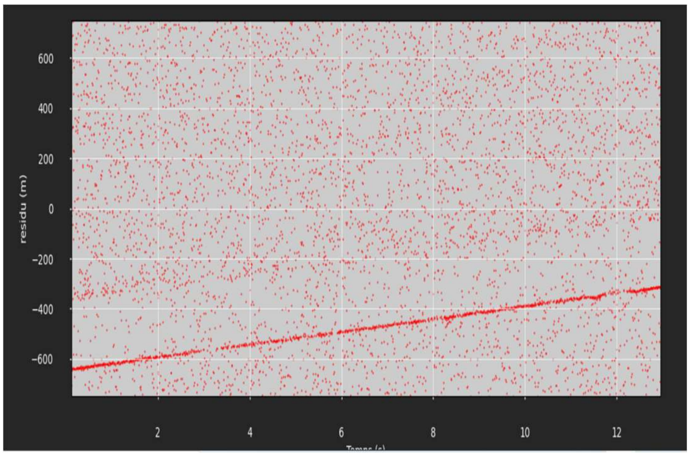

Fig. 19: Residual for a non-cooperative satellite with high OCS (around 10m²)

More tests are planned on non-cooperative targets to improve even more the station for easier operation and accuracy on the range measurements and orbits obtained.

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7. CONCLUSION

ArianeGroup has demonstrated a first step to industrialized laser ranging capabilities compatible with air and space traffic safety. This in-house development will be incrementally updated to perform fully automated and operational ranging demonstrations with non-cooperative targets and allow us to have a first operational capability.
Global network deployment will then follow to be able to deliver services with high accuracy for LEO orbit safety and security.

8. ACKNOWLEDGMENT

We warmly thank the astronomic center of Saint-Michel l'Observatoire (France - 04) for their availability, their kindness, and their help in the setup of the ArianeGroup SLR station in terms of technical tasks as well as administrative tasks. We also thank all the GEOTracker® team working directly or not on laser activities, because a lot of knowledge used for the development of this ArianeGroup SLR station have a narrow link with the operational GEOTracker® network. The creativity and competencies of the team are making such project successful.

9. REFERENCES

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