ESA'S DEBRIS TRACKING LASER NETWORK

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ABSTRACT

The increasing number of resident space objects necessitates the development of advanced ground sensor technologies to ensure sustainable space operations. One such technology is space debris laser ranging (SDLR), an evolution of the Satellite Laser Ranging (SLR) technique. ESA has recently launched an activity within its Space Safety program to develop the Debris Laser Tracking Network (DLTN).

This network comprises a global sensor network and an online platform for user interaction. Key objectives include upgrading the Izaña (IZN) station for daylight tracking, developing a web-based platform for Space Situational Awareness (SSA) and Space Traffic Coordination, and validating the DLTN system through observation campaigns. The platform supports various use cases, such as collision risk refinement, by optimizing observation plans and tasks for laser stations.

This paper presents the DLTN's online platform capabilities, user interactions, and observation campaign results, highlighting the benefits of laser tracking technology for debris tracking and space traffic coordination.

1 INTRODUCTION

The recent increase in the number of resident space objects demands the simultaneous development of new ground sensor technologies that can provide the required coverage and accuracy to ensure the sustainability of space operations. One of the sensor technologies currently being developed for monitoring space debris is laser ranging technology.

Tracking debris with ground-based lasers is becoming a mature technology. As a result, ESA has recently launched an initiative within its Space Safety program [1] to develop the Debris Tracking Laser Network (DTLN). This network consists of two main components: a sensor network made up of participating laser stations and an online platform that allows users to interact with this sensor network for various applications.

The initiative has several key objectives: 1. To enhance the ESA's robotic optical ground station, Izaña-1 (IZN-1), enabling it to track space debris during daylight. 2. To create an online platform for end-users that supports a range of applications, including sensor calibration, object observation, catalogue maintenance, collision risk assessment, re-entry prediction refinement, and both stare and chase operations. This is supported by a thorough business case analysis. 3. To validate the DLTN system and IZN-1 capabilities through observational campaigns planned for various use cases, involving multiple SLRs in a Network. [2].

This paper will present the main results of the activity, focusing on the capabilities of the system accessible through the on-line platform developed by GMV, as well as the partial results of the observation campaign that took place during autumn 2024. The second part of the observation campaign is planned for spring 2025. In terms of the on-line platform's capabilities, we will describe the expected user interactions for various use cases, along with the required inputs and anticipated outputs of these interactions. For instance, to refine collision risk, a user can provide a Conjunction Data Message (CDM) to the system and request observations from the DLTN until the covariance of the secondary object reaches a specified reduction factor. Based on this request, the platform analyses which lasers in the network are available and have observation opportunities. It then prepares an optimized plan for observation requests to the lasers during the time interval leading up to the event deadline and tasks them to gather the necessary observations. As the lasers produce observations and submit them back to the on-line platform, an orbit determination update is carried out, along with a

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reassessment of the collision risk posed by the event. Once the specified covariance reduction factor is achieved, no further observations are requested from the network, and the user's request is considered fulfilled. A similar process applies to the re-entry use case, where the user provides a Re-entry Data Message (RDM) instead of a CDM. Additionally, the paper will provide an overview of the various sub-campaigns conducted to validate each use case of the DLTN, outlining both the objectives and outcomes of these initiatives.

2 DEBRIS TRACKING LASER NETWORK CONCEPT

DLTN is an ESA initiative designed to enhance Space Surveillance and Tracking, as well as satellite and Space Traffic Management operations, using SDLR. This technology extends the well-established SLR technique, traditionally used with cooperative satellites equipped with retroreflectors.

The DLTN system comprises two main components:

DLTN Stations Network (DLTN-SN): A network of laser stations participating in observations.

DLTN Online Platform (DLTN-OP): An online platform for near real-time requesting, scheduling, analysis, display, and provision of space safety-related data products to end users, based on observational data from the DLTN-SN.

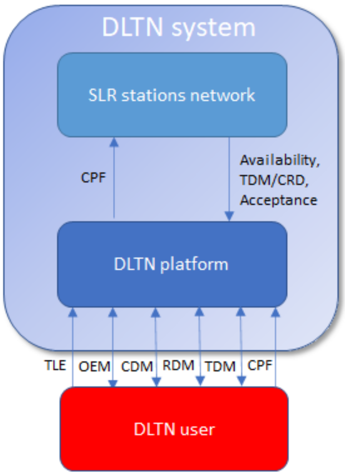

Figure 1. Data flow diagram of the DLTN system functions

The DLTN system processes requests from external users by using both user-provided data and external information to task the laser ranging sensors for the necessary observations.

Fig. 1 shows a Data Flow Diagram of the DLTN system, highlighting the information flows among its functions. Blue boxes represent the mentioned main system components, while red box correspond to the system users. The diagram shows the main information exchanges between the DLTN-OP and DLTN-SN, including observation requests based on CPF-formatted orbital information and observational data in Track Data Message (TDM) and/or Consolidated Laser Ranging Data (CRD) formats. It also depicts the information flows between the DLTN-OP and users for various supported use cases.

The DLTN system offers several key use cases to users:

Observation Request: Users provide orbital information of an object, select one or more SLR sensors, and request tracking data for the object.

Orbit Refinement Request: Users provide orbital information of an object, select one or more SLR sensors, and request orbit refinement. The DLTN delivers the tracks obtained by the stations and the refined orbital information.

CDM Refinement Request: Users provide a CDM, select one or more SLR sensors, and request CDM refinement. The DLTN provides the tracks obtained, refined orbital information, and an updated CDM.

RDM Refinement Request: Users provide an RDM, select one or more SLR sensors, and request RDM refinement. The DLTN delivers the tracks obtained, refined orbital information, and an updated RDM.

Catalogue Maintenance Request: Users provide orbital information for multiple objects, select an end date for catalogue maintenance, and request iterative orbit refinement to maintain object covariance within specific limits.

Calibration: Users request calibration of an SLR station by analyzing observational data for objects with precise orbits, typically in SP3 format.

Stare & Chase Request: Users provide a TLE file, select an optical sensor and one or more SLR sensors, and request orbit refinement using the stare & chase technique. The DLTN delivers the tracks obtained and the refined orbital information. Note that this scenario may require specific stare & chase software to estimate the object's orbit based on stare observations for subsequent tracking by the chase sensor.

The general behavior of the DLTN is illustrated in the Fig. 2 and operates as follows:

User Input: The user provides initial orbital data and configures parameters via the web interface to initiate one of the specified requests.

Observation Planning: Periodically, the software calculates observation opportunities for all objects involved in active user requests, generates an optimized

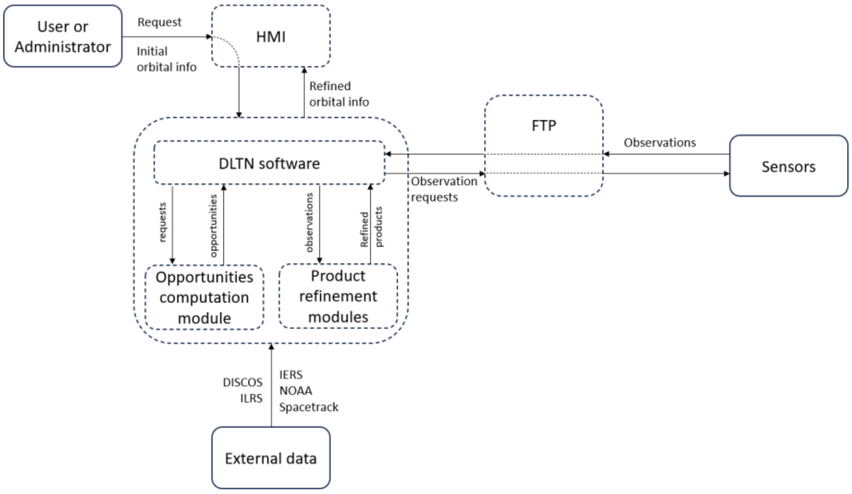

Figure 2 General software diagram

plan for all SLR sensors in the network, and sends observation requests to the sensors via File Transfer Protocol (FTP). The planning process considers station capabilities, object properties, request urgency, etc.

Data Upload: Sensors eventually upload tracks for some requested objects via FTP. The software then processes these tracks and performs necessary computations to generate the expected outputs (track files, refined ephemerides, refined CDMs, refined RDMs, etc.).

Product Delivery: The generated products are made available to the user through the web interface.

Additionally, the software utilizes external data such as Earth Orientation Parameters and leap seconds from International Earth Rotation and Reference Systems Service (IERS), solar activity parameters, object properties from ESA's DISCOS, and orbital information from space-track.org to perform these analyses.

The user interactions within the DLTN system are represented by the seven use cases mentioned earlier. Some of them are presented more in detail in the following sub-sections.

2.1 Request for Orbit Refinement of a Space Object

User Configuration: The user specifies the basic configuration for all type of requests (request type, time period) and the specific configuration for particular types (orbit improvement in terms of orbit covariance reduction factor or intended number of tracks). The user then provides the orbital information for the object in one of the following formats Two-Lines Elements (TLE), Orbit Ephemeris Message (OEM), Orbit Parameter Message (OPM) or CPF, and selects the stations to be used from the available options.

Data Storage and Processing: The DLTN system stores the user inputs and uses them to achieve the required orbit improvement. These parameters are considered in the calculation of observation opportunities for the objects from the selected stations, assigning the corresponding priorities to generate the CPF files.

Notification and Observation: The SLR stations within the DLTN system receive a notification with the new CPF. Once an SLR station accepts the request and acquires the observations, the data is uploaded to the system in the agreed format, typically CRD or TDM.

Data Utilization and Results: The DLTN system stores the acquired observations and uses them for orbit determination. The updated orbital information in OEM format is then stored in the DLTN system, and the user receives the results: observations (TDM) and updated orbital information (OEM). Fig. 4 presents the workflow for orbit refinement request.

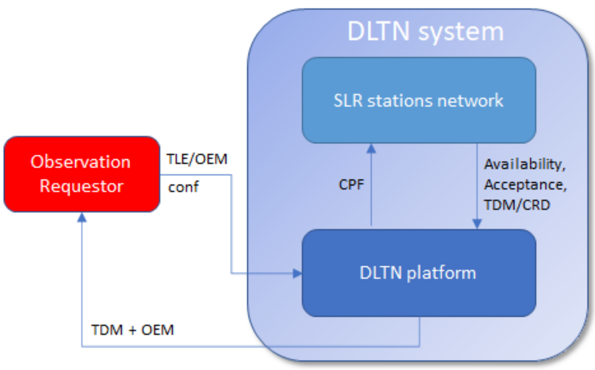

Figure 3. Request for orbit refinement of a space object

2.2 Request to Refine a Conjunction Data Message

User Configuration: The user configuration, in addition to the basic settings, includes request-specific details (objects to be re-evaluated - only secondary or both - and orbit improvement in terms of orbit covariance reduction factor or intended number of tracks). The user then provides the CDM and selects the stations to be used from the available options.

Data Storage and Processing: The DLTN system propagates the state vector of the objects included in the CDM and calculates observation opportunities based on the provided parameters, assigning priorities to generate the CPF files.

Notification and Observation: This step works similarly for all request types, eliminating the need for additional actions from SLR stations, simplifying the task and ensuring a repetitive process.

Data Utilization and Results: The DLTN system uses the acquired observations for orbit determination. The updated orbital information (OEM) is stored in the DLTN and used to generate an updated CDM. The orbital information is updated as soon as new tracks are available, and the newly generated OEM is shared with the stations as updated predictions for further observations. The results of the CDM are continuously refined and presented on the B-plane plot within the DLTN platform. Fig. 5 presents the workflow for conjunction refinement request.

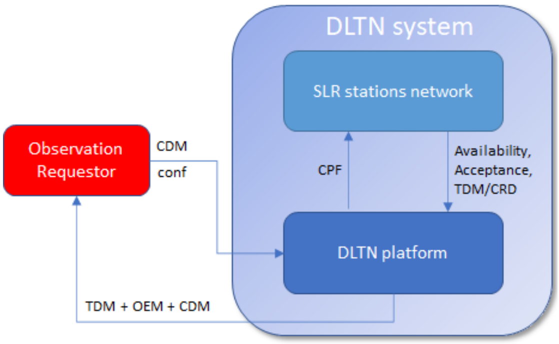

Figure 4. Request to refine a Conjunction Data Message

2.3 Perform Stare and Chase Operations

Stare and chase operations in the DLTN system are typically conducted on known objects with coarse a-priori orbital information.

User Configuration: The user configuration, in addition to the basic settings, provides approximate orbital information for the object, and selects the supporting passive optical sensor for stare observations and the chasing SLR sensor.

Observation Planning: The DLTN system stores the user inputs and calculates observation opportunities for the object using the selected passive optical sensor.

Notification and Observation: The supporting passive optical sensor receives a notification with the rough orbital information to follow. Once the optical observations are acquired, they are uploaded to the system in TDM format. If a co-located SLR sensor is selected, internal communication within the site ensures the SLR sensor follows the object based on the improved orbital information from the passive optical observations. The laser observations are then uploaded to the DLTN.

Data Utilization and Results: The DLTN system stores the acquired observations and performs orbit improvement. This refined orbit is used to calculate observation opportunities from additional chasing SLR stations, if any, and the generated CPF file is sent to them. The SLR station receives a notification with the new CPF, and once the observations are acquired, they are uploaded to the system.

The primary goal of this use case is to perform stare and chase operations at a site with co-located sensors. However, the proposed solution can also be applied to non-colocated sensors, although the accuracy of the refined orbit from stare observations degrades rapidly, making it challenging to schedule chasing operations at a different site. Fig. 6 presents the workflow for stare and chase request.

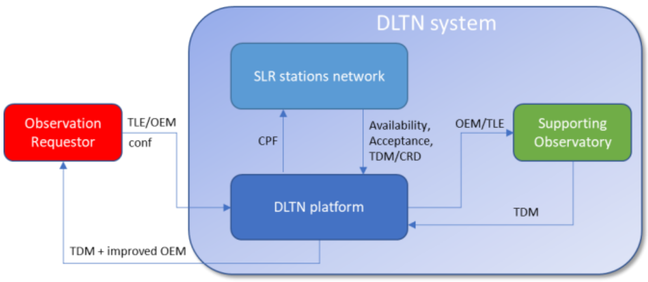

Figure 5. Request for stare and chase operations

3 DLTN OPERATIONAL PLATFORM

Fig. 6 illustrates the key components of the DLTN operational platform. Two crucial components can be highlighted: the frontend, which is a web application that provides a user interface for two types of users (end users and administrators), and the backend, which delivers the necessary business logic through a well-defined REST API. The backend also relies on a relational database to store various types of data related to the functionality implemented, such as user requests, observation data from the SLR stations, and the orbits generated from this data.

The SLR stations upload their observation data files to an FTP store managed by the DTLN-OP. This store is continuously monitored by the system to ingest observations as soon as they are available. The same interface is used to send tasking requests calculated by the system to the stations, which are expected to retrieve these requests from the FTP store.

The SATCAT and TLE catalogues are routinely downloaded from Space-Track (https://www.space-

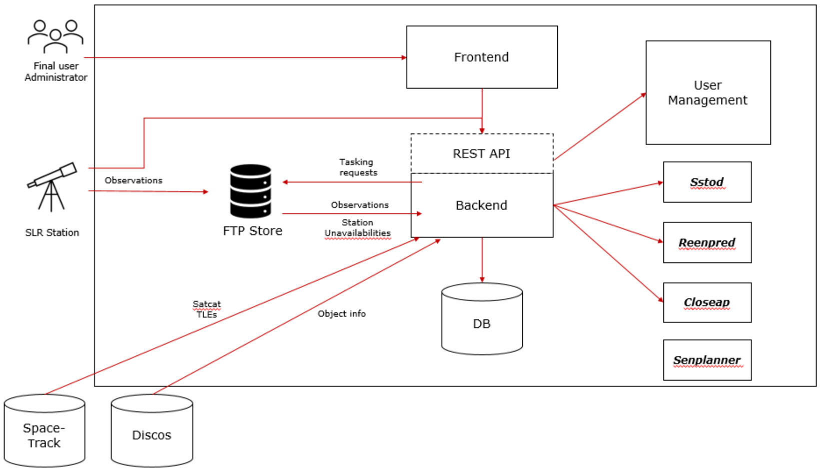

Figure 6. Overall architecture of the DLTN-OP

track.org) to maintain an updated catalogue of objects. This data is supplemented with information from ESA's DISCOS database (https://discosweb.esoc.esa.int/) to obtain accurate details about the mass, area, and other properties of objects. Additionally, solar activity, Earth orientation parameters, and leap seconds are regularly downloaded from external sources.

User Management is responsible for maintaining the user database and ensuring that access to the REST API is authenticated and authorized based on user roles. This module is implemented using the open-source solution Keycloak.

GMV COTS software components - ***Sstod***, ***Reenpred***, ***Closeap*** and ***Senplanner*** handle the computational tasks for each use case. ***Closeap*** is used for conjunction analysis and CDM refinement, ***Reenpred*** for re-entry refinement and ***Senplanner*** for initial visibility calculations and sensor network task planning. ***Sstod*** is used for orbit determination and sensor calibration.

Each component is deployed in a separate container. ***Sstod***, ***Reenpred***, ***Closeap*** and ***Senplanner*** are volatile containers, meaning they run when called and are disposed of after the task is completed, with results returned via the corresponding outputs. The other containers run continuously as services.

Fig. 7 illustrates the homepage of the DLTN operational platform, featuring a world map with configured stations that participate the observation campaign and a left menu displaying all the functionalities available on the platform.

The left menu of the home page includes the following links:

Home: Displays a map with all available sensors.

Sensors: Provides detailed information about the sensors.

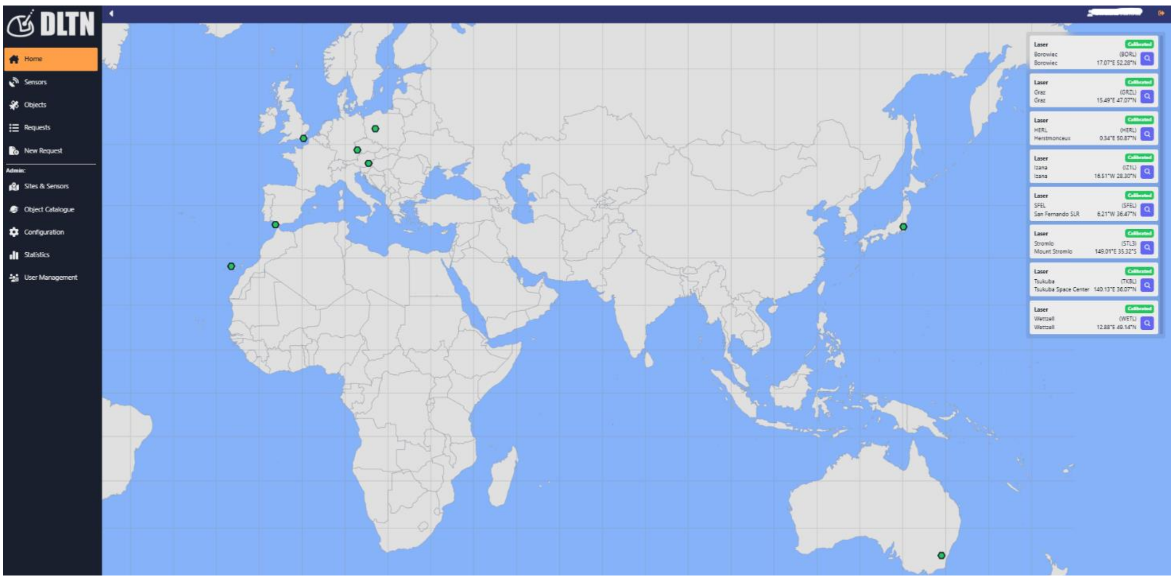

Figure 7. Home page of the DLTN operational platform

Objects: Contains detailed information about the objects and allows users to create catalogue maintenance requests (see figure below).

Requests: Shows detailed information about the past and present requests of a given user.

New Request: Enables users to generate a new request of any type.

Sites & Sensors: Allows administrators to visualize and manage all sites and sensors in the database.

Object Catalogue: Enables administrators to visualize and manage all objects in the database.

Configuration: Allows administrators to configure various parameters related to automatic processes and the internal behavior of the platform.

Statistics: Provides administrators with statistics about user requests and the sensors integrating the network.

User Management: Allows administrators to manage user accounts and permissions.

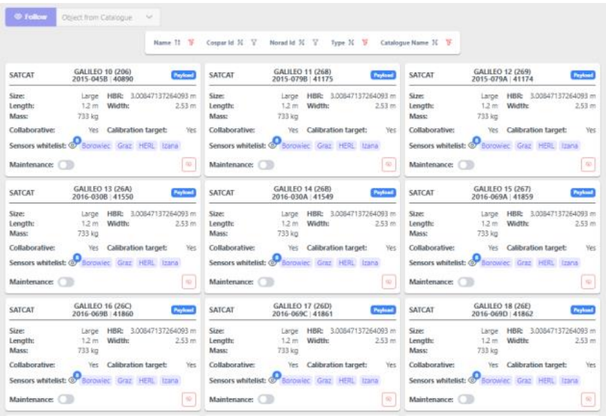

Figure 8. DLTN-OP object panel – example objects whitelisted for stations during observation campaign

4 DLTN OBSERVATION CAMPAIGNS DESCRIPTION

An observation campaign has been designed to validate the developed DLTN system. The observation campaign was divided into 6 sub-campaigns intended to fulfil different requirements and a preceding calibration campaign to test the DLTN interfaces and established functionalities of the platform.

The first 4 sub-campaigns focused on collision avoidance scenarios (CDM refinement requests), LEO space debris catalogue (object refinement requests) and re-entry (RDM refinement requests) were combined to improve the efficiency of observed targets, as the daily number of collision and re-entry opportunities is insufficient to meet the observation scenario's defined success criteria. Furthermore, the sub-campaigns were divided into two phases: Phase 1 and Phase 2. Phase 1 took place during Autumn 2024 and involved seven stations. Phase 2 is scheduled for Spring 2025 including the same stations from Phase 1 that can track non-collaborative objects, along with Izaña Station, upgraded during this activity. During Phase 2, the sub-campaigns focused on daytime and nighttime non-cooperative laser tracking and stare and chase scenario shall be conducted, being the dedicated scenarios for Izaña Station, supported by the other stations.

The list of SLR sensors that have been participating in the Observation Campaign is provided by name, country and ILRS code:

- Graz, Austria (GRZL)
- Borowiec, Poland (BORL)
- San Fernando, Spain (SFEL)
- Mt Stromlo, Australia (STL3)
- Tsukuba, Japan (TKBL)
- Herstmonceux, United Kingdom (HERL)
- Wetzell, Germany (WETL)
- Izaña, Spain (IZ1L)

It is important to note that each sub-campaign has specific objectives, which are detailed in the following paragraphs.

4.1 DLTN-OC-01 (DLTN - Contingence or Collision Avoidance scenario)

DLTN-OP CDM refinement requests are generated in response to identified collision avoidance scenarios. The selection of CDMs is based on sources authorized by ESA, with primary objects designated specifically for ESA-affiliated satellites. Secondary objects are considered for collision avoidance requests only if they meet the criteria of being catalogued as large (greater than 1 m²) and situated within the LEO regime. This includes non-operational payloads launched prior to the year 2000, as well as objects for which clear decommissioning information is available, in addition to space debris and rocket bodies. All selected objects are intended for observation by stations capable of observing them with either low or high power. The size and regime limitations are determined by network capabilities, while safety considerations dictate the criteria for selecting objects.

Objects with a Time of Closest Approach (TCA) that is at least one week away are prioritized to meet the requirement of refining the CDM by a factor of 10, seven days in advance of the event, with a refined CDM produced 24 hours prior. Most CDMs can be accessed with TCA availability of 6-7 days in advance; therefore, requests may be initiated 5-6 days before the event to enhance the possibility of successfully processing the request in DLTN-OP. Furthermore, a refined CDM may be generated within a window of a few hours to 24 hours before the event, considering both the visibility of the objects by the network and the availability of each observation station.

The second sub-campaign, called DLTN-OC-02 (DLTN – Real Contingency or Collision Avoidance Scenario), is based on selected collision events derived from the CDMs proposed by ESA. This represents the primary distinction from DLTN-OC-01. Consequently, the overall processes for both sub-campaigns remain consistent.

4.2 DLTN-OC-03 (DLTN - High Accuracy LEO debris catalogue)

DLTN-OP orbit refinement requests are generated in response to the catalogue scenarios. The list of targets is specified based on various categories, including all ILRS targets, collaborative objects (non-operational payloads with retroreflectors), non-collaborative objects (non-operational payloads), space debris, and rocket bodies. Each station from the network was asked to provide a list of space debris and rocket bodies they had successfully tracked in the past. Using this feedback, additional objects were included on the list. Targeted objects were selected according to the capabilities of each station. An additional review was conducted to identify opportunities for all objects and stations, ensuring that objects not visible from certain locations were excluded.

The orbit refinement requests typically lasted one week, with the output orbit end date set for 10-12 days for LEO objects. After successfully closing the orbit refinement request, refined output data was generated, prompting the opening of catalogue maintenance requests based on the produced OEMs. The goal was to maintain orbit accuracy for two weeks. Consequently, the maintenance end date was defined to be 2-3 weeks from the request's opening. The covariance thresholds applied were adjusted to strive for the requested accuracy of 10 meters. However, it was recognized that maintaining such accuracy for non-collaborative objects was too challenging.

4.3 DLTN-OC-04 (DLTN - Re-entry)

DLTN-OP re-entry refinement requests are generated in response to identified re-entry scenarios. The selection of RDMs is based on sources authorized by the Agency, which are accessed through ESA's re-entry predictions panel. Each RDM has been enhanced by including the required covariance matrix fields. Additionally, some RDMs needed orbit fitting by GMV COTS solutions to improve the state vector and compute covariance matrix, along with other fields necessary for the DLTN-OP computation of RDM opportunities and the nominal re-entry epoch.

Objects selected for re-entry requests were based on the same criteria as those used for the collision avoidance scenarios. Specifically, they are catalogued as large objects (greater than 1 m^2) in LEO regime and include operational payloads, debris, or rocket bodies. In addition to the criteria for selecting appropriate objects and re-entry events, visibility of these objects by the network and the availability of each observation station are also considered. The start and end times for observations were aligned with the nominal re-entry epoch and its associated uncertainty. This meant that the request's end time was set to be a few days earlier than the nominal re-entry epoch.

4.4 DLTN-OC-05 (IZN & DLTN - Day and nigh-time non-cooperative laser tracking)

The main objective of this scenario is to acquire observations of objects during daylight. Requests for DLTN-OP orbit refinement will be initiated. This scenario is designed to verify and test the new capabilities of the Izaña SDLR. The campaign will be supported by DLTN-SN, which can track non-cooperative targets during nighttime.

Daytime observations are defined for smaller targets when the Sun's elevation above the horizon is up to 20 degrees. For larger targets, such as rocket bodies, the Sun's elevation must be more than 20 degrees above the horizon. The observation campaign aims to generate range, angular, and photometric measurements for non-cooperative targets.

The selection of non-cooperative objects will be consistent with the list identified in DLTN-OC-03. The specific objects for daylight tracking have been coordinated and agreed upon with both the Izaña Operator and ESA. It is important to note that this scenario was not executed during Phase 1 of the observation campaign and is scheduled for execution in Phase 2.

4.5 DLTN-OC-06 (IZN & DLTN - Stare and Chase)

The main objective is to conduct stare and chase observations on selected targets to demonstrate the active and passive optical capabilities of the Izaña SLR (IZN-1) and SDLR (IZN-2) station, where IZN-1 has the receiver capacity and IZN-2 transmitter.

5 OBSERVATION CAMPAIGN RESULTS

Many user requests were opened during the 9-week observation campaign - Phase 1 during Autumn 2025. Each request specified one or more selected space objects, along with several assigned sensors that were

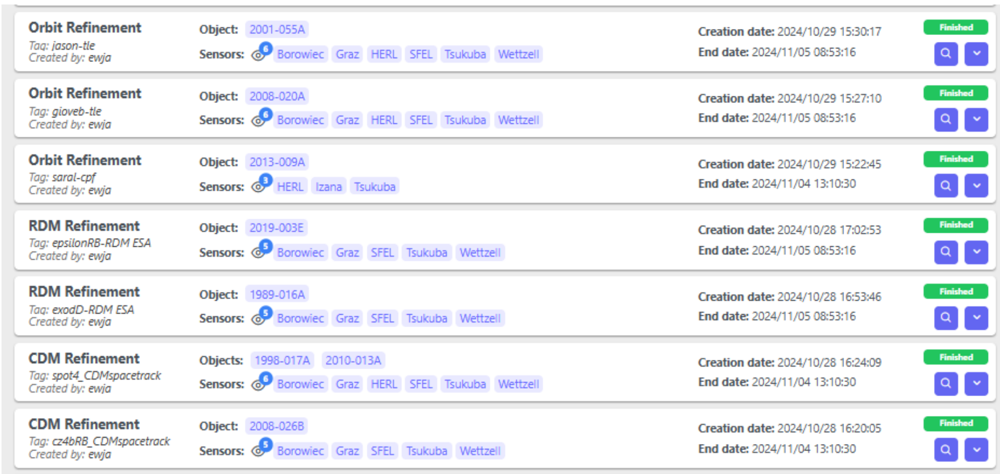

Figure 9. DLTN-OP requests panel – example requests opened during observation campaign

authorized to observe the identified objects. The requests included details such as the observation start and end dates, the output orbit end date (OEM), the target number of tracks, or the target covariance reduction factor. Additionally, input files were required, which either contained the orbits of the selected objects or included a checked box to directly download the Spacetrack TLE data.

The most successful requests were those for orbit refinement, which were conducted at the beginning of the campaign. However, achieving successful outcomes for collision avoidance and re-entry scenarios proved to be more challenging. This difficulty arose because requests for special events were opened only shortly before the events themselves. Moreover, poor weather conditions significantly impacted the results of the observations.

Each opened request generated multiple requests, resulting in a total of approximately 1,899 individual requests that were sent to the stations via FTP. The stations could either accept or reject the sensor requests, though it was not mandatory. Of these, 881 requests were rejected, with various justifications. Notably, 720 rejections—accounting for about 82% of the total rejections—were attributed to "bad weather." The other justification for rejected requests were the station issues and mostly for non-collaborative objects, the reasons were such as too low elevation of the requested passes, too small RCS, object found and ranged but no laser return signal detected, object not found. In response to identified issues, the DLTN-OP operator has been actively adjusting the settings for stations and selection of the objects. These proactive adaptations helped minimize rejections and optimize request handling.

Of the total requests, some were initially accepted but failed to contribute within 24 hours, leading to their classification as rejected. Meanwhile, a portion of the requests successfully contributed, meaning the required observational tracks were received. A significant number of requests remained open without any contributions or responses from the sensors. These unresolved requests are effectively considered rejected for reasons that were not explicitly specified. However, when queried, the sensors attributed the lack of response primarily to adverse weather conditions. This limitation underscores the challenges associated with tracking, which are significantly influenced by external factors such as the availability of observation stations and prevailing weather conditions. Furthermore, collaboration among the various stations in the DLTN-SN initiative presents an additional challenge, as each station operates under slightly different processes. Consequently, this leads to variations in how requests are managed, data is submitted, and other on-site issues are addressed.

A well-known and notable trend observed, particularly for non-collaborative objects, is the strong correlation between the number of measurements received from multiple stations and the quality of the resulting data. Each submitted observation triggers an orbit refinement, and the improved orbit is then sent back to the stations for further observations. Generally, objects tracked by a greater number of stations yield better results in terms of orbital refinement and accuracy. This highlights the importance of collaboration among stations to increase the chances of successful observations.

A successfully completed request contains the generated output set including all tracks used in the refinement process (TDM/CRD) and, if the orbit determination quality is sufficient, refined orbital data files (OEM, CDM, RDM). These files are generated based on internal thresholds for the observation residuals and the percentage of observations rejected. Residuals and orbit comparison plots are created during the orbit determination process.

Fig. 10 represents the example of the plots generated during orbit refinement. The results are obtained for the ILRS object Cryosat 2 (2010-013A), collected from 5 stations (GRZL, WETL, BORL, TKBL, SFEL), and 11 tracks received (CPF) with average number of 20 measurements each.

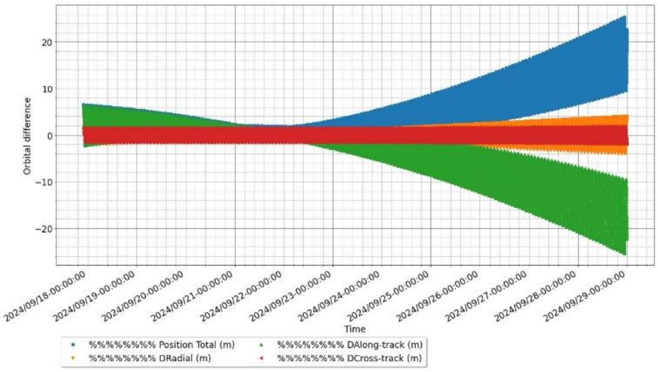

Figure 10. Orbit comparison plot between the two last refined OEMs, Cryosat2 (2010-013A), ILRS object

Fig. 11 represents the example of the plots generated during orbit refinement. The results are obtained for the non-operative payload equipped with retroreflectors, collaborative object that can be ranged with high power SLR, Seasat 1 (1978-064A), collected from 3 stations (GRZL, BORL, HERL), 8 tracks received (CPF) with average number of 16 measurements each.

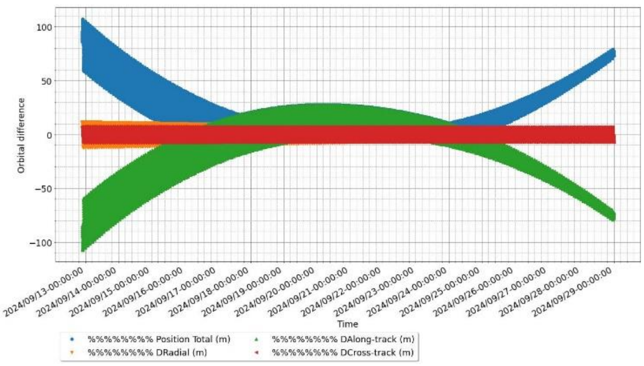

Figure 11. Orbit comparison plot between the two last refined OEMs, Seasat1 (1978-064A)

Fig. 12 represents the example of the plots generated during orbit refinement. The results are obtained for the non-operative payload equipped with retroreflectors, collaborative object that can be ranged with high power SLR, Geos 3 (1975-027A), collected from 2 stations (GRZL, BORL), 10 tracks received (CPF) with average number of 20 measurements each.

The common trend for the presented plots is that cross-track orbital difference – the deviation perpendicular to the orbital plane is negligible, indicating that the orbit remains stable in this direction. The sensors and tracking methods are performing well in maintaining the cross-track accuracy. The radial difference, which measures deviation along the radial vector is also well-controlled.

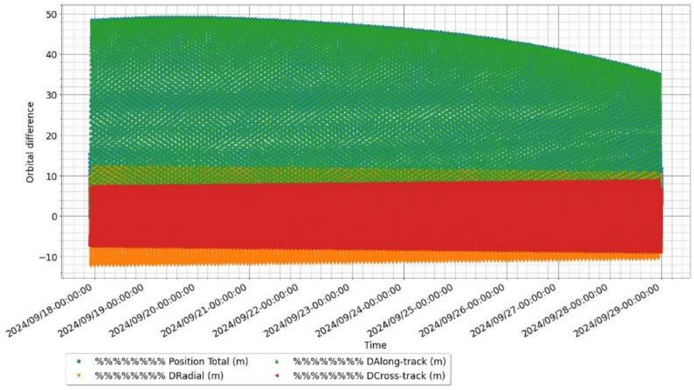

Figure 12. Orbit comparison plot between the two last refined OEMs, Geos 3 (1975-027A)

This suggests high precision in determining the satellite's altitude.

The along-track difference, representing deviation along the satellite's orbital trajectory, shows significant initial variation. The rapid increase suggests large initial discrepancies in the estimated along-track position, likely due to insufficient data or inaccurate initial conditions. However, as more data are integrated, the deviation stabilizes.

The total position error represents the combined impact of all deviations (cross-track, radial, and along-track) over time. Initially, there is a large difference (possibly due to initial estimation errors or lack of data), but as tracking measurements accumulate and orbit refinement processes take place, the error reduces and stabilizes. This demonstrates the effectiveness of the tracking system in refining the satellite's orbit over time.

Fig. 13 represents the example of collision avoidance scenario results from the event between non-collaborative object CZ-4B Rocket Body (2008-026B) and ILRS object Cryosat 2 (2010-013A) with TCA dated for 03-11-2024 09:47:31. The most meaningful information for CDM refinement requests in the B-plane plot are presented. CDM from Spacetrack Conjunctions, ESA source was provided as a reference orbit converted to CPF file to the stations. In total 6 opportunities were found and 6 CDM refinement requests were generated to 3 stations (WETL, GRZL, BORL), 3 tracks received for secondary object with average number of 40 measurements each.

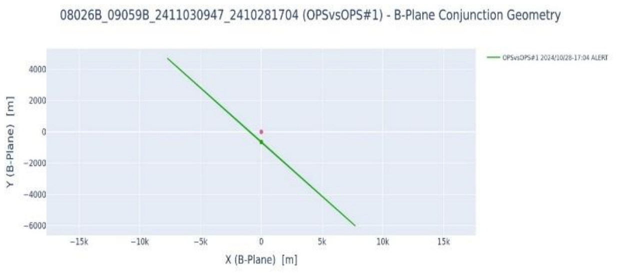

Figure 13. B-plane plot of the refined CDM for conjunction between CZ-4B Rocket Body (2008-026B) and Cryosat 2 (2010-013A)

The B-plane conjunction geometry plot provides a visual representation of a close approach event where the trajectory of an object is analysed relative to a reference point. The reference point is the theoretical closest approach between two objects, whereas the closer the trajectory remains to the central point, the smaller the miss distance, implying a higher risk of collision. If the object's actual position, considering uncertainties, deviates from the central point in the b-plane, it indicates the offset or miss distance at closest approach.

6 CONCLUSIONS

The Debris Tracking Laser Network (DTLN) initiative, implemented by ESA, seeks to enhance space surveillance and tracking through advanced laser ranging technology. The DLTN system comprises a comprehensive network of laser stations, supported by an online platform, which facilitates various applications including collision risk assessment, re-entry prediction, and orbit refinement.

During the observation campaign conducted over nine weeks in Autumn 2024, numerous user requests were processed, with a substantial focus on orbit refinement. Realizing successful outcomes for collision avoidance and re-entry scenarios presented challenges, primarily due to adverse weather conditions and the timing of requests. A significant portion of the requests was ultimately rejected due to these unfavourable weather circumstances.

A notable insight from the campaign is the strong correlation observed between the quantity of measurements obtained from multiple stations and the overall quality of the results. Collaborative efforts among stations are vital for enhancing the accuracy of orbital data. The campaign successfully demonstrated the effectiveness of the tracking system in refining satellite orbits over time, despite initial discrepancies in along-track positions.

In summary, the results demonstrate the potential of the observation network to precisely refine orbits. They also emphasize the critical role of environmental factors and the need for collaboration among stations. By optimizing observation strategies, improving coordination between stations, and developing techniques to mitigate the effects of adverse weather, it is possible to significantly enhance the overall success rate and accuracy of tracking campaigns.

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