Research Article

ALR_Sim_tracks - trajectory simulator software to assist the search for favourable trajectories for the exploration of the triple Asteroid 2001-SN263 from the Laser Altimeter point of view

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***ALR_Sim_tracks* is a trajectory simulator/analyser software for space missions involving the exploration of the surface of celestial bodies using optical instrumentation. The software was created to carry out an analysis that would allow the identification of favourable trajectories for carrying out the intended exploration of the triple asteroid 2001-SN263 during Brazil's first deep space mission (ASTER mission) [1][2] from the point of view of the Laser Altimeter, called ALR, which is one of the optical instruments designed to fly in this mission [3][4]. With its use, trajectories of interest for the intended exploration were simulated and evaluated to identify the most promising ones, which were then presented [5][6]. This article contains a presentation and description of this software, and everything involved in its operation. Because it was first created to represent the view of a laser altimeter, the descriptions involve this instrument. However, Other optical instruments of similar operation are also considered for analysis once a proper modelling is available.**

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1. Introduction

ALR_Sim_tracks is a trajectory simulator/analyzer software for space missions involving the exploration of the surface of celestial bodies using optical instrumentation and was created to help in the analysis of space mission ASTER from the point of view of the Laser Altimeter designed for this mission, called ALR.

More specifically, the simulator was created to: **i)** generate 3D trajectories for the spacecraft based on geometric considerations of the target-spacecraft movement within the period considered and analyze their effectiveness in exploring the surface of the celestial body targeted by the mission; **ii)** receive as input 3D trajectories of the spacecraft generated externally to the program and then analyze their effectiveness in exploring the surface of the celestial body targeted by the mission. In this case, the input trajectories are generally generated taking into account the dynamics relevant to the spacecraft's movement within the considered system during the period of interest.

The modeling and simulation of the trajectories generated by the software based on purely geometric considerations are described, and the details of the analysis undertaken to evaluate the test trajectories in the exploration of the surface of the celestial body targeted by the mission, based on parameters created for this purpose, are also presented and explained. The advantages of this approach are its simplicity and speed in obtaining preliminary results. For validation purposes, a comparison of the results obtained using this approach with the traditional one, which uses trajectories generated by integrating the relevant dynamics involved, was carried out and is discussed in reference [5].

The results expected from the analysis make it possible to qualitatively and quantitatively predict the type of surface coverage that the instrument will be able to obtain using the parameters employed in the simulation.

Because it was created to simulate the ALR point of view within the period considered for the ASTER mission, the examples given in this article are related to this mission.

The program has been used twice to analyze trajectories favorable to the ASTER mission, from the point of view of the Laser Altimeter. In the first [5], it was used to generate and analyze encounter trajectory arcs that would allow the main target of the mission to be explored; in the second [6], it was used to help analyze specific orbits around the main target, called 'terminator orbits', with the aim of complementing the exploration carried out in the first part of the exploration. The modular nature of the software, however, allows other optical equipment to be modeled to have their specific points of view simulated and analyzed in any period of interest.

2. What the software does and how it works

The ALR_Sim_Tracks is a software created using the MATLAB platform. The main program works as a script, where the sequence of activities carried out in the simulation is called. Designed to be modular,

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each task performed in the simulation is carried out using specific functions called within the main program, but which are programs outside of it. The same applies to data input, which is read from specific 'txt' files produced for this purpose. Figure 1 shows the sequence of operations carried out by the simulator in its first use, dedicated to the simulation and analysis of encounter trajectories for the ASTER mission [5].

In the second simulation carried out using it [6], terminator orbits were analyzed to allow the poles of the main asteroid to be explored, while at the same time allowing the interior of the triple system to be observed and evaluated. Figure 2 shows the sequence of operations carried out by the program in this second case.

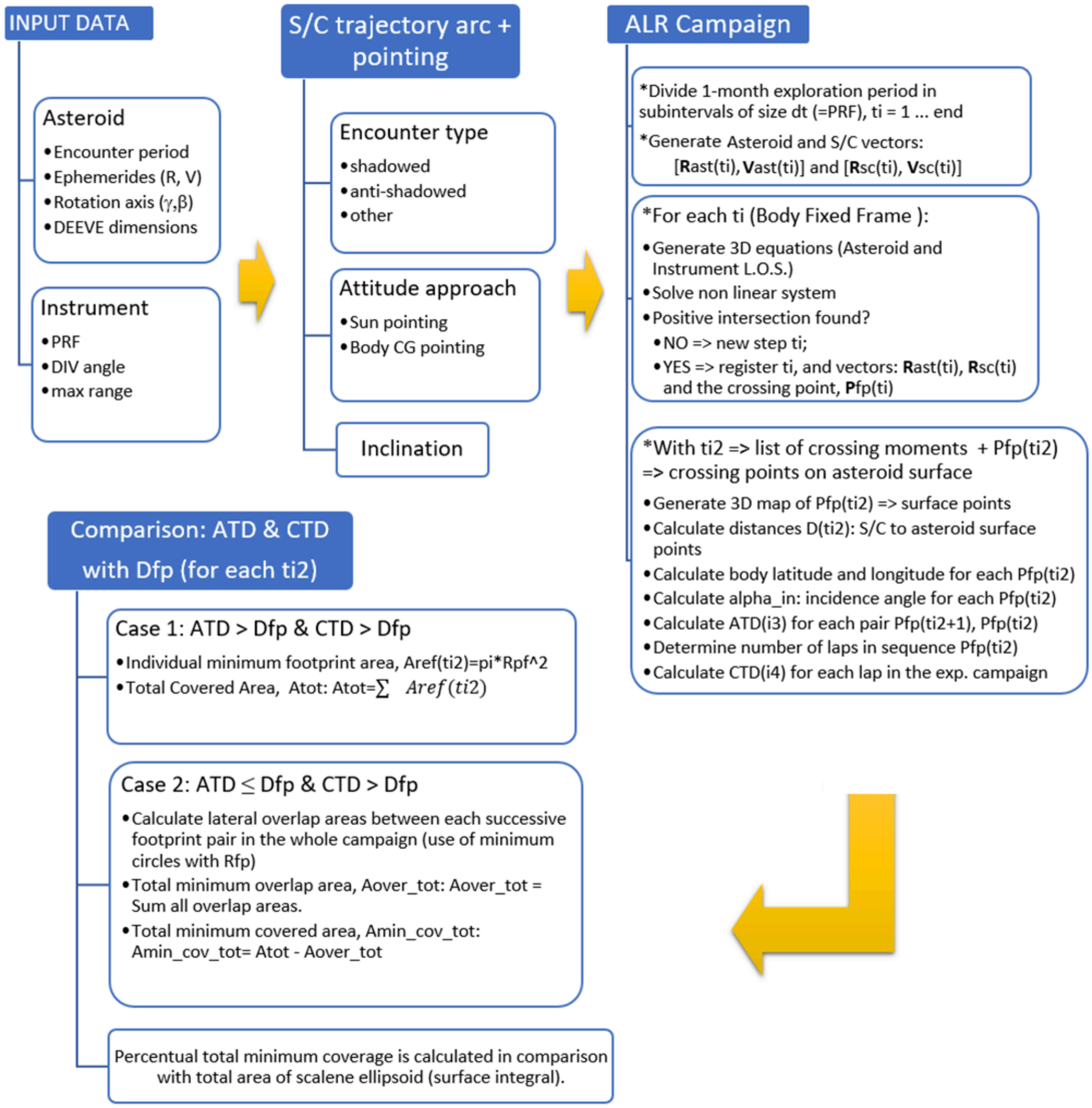

Fig. 1. Flow diagram of the sequence of operations carried out to simulate encounter trajectories favorable to the exploration intended by the ASTER mission in the view of the laser altimeter. **SOURCE:**[5]

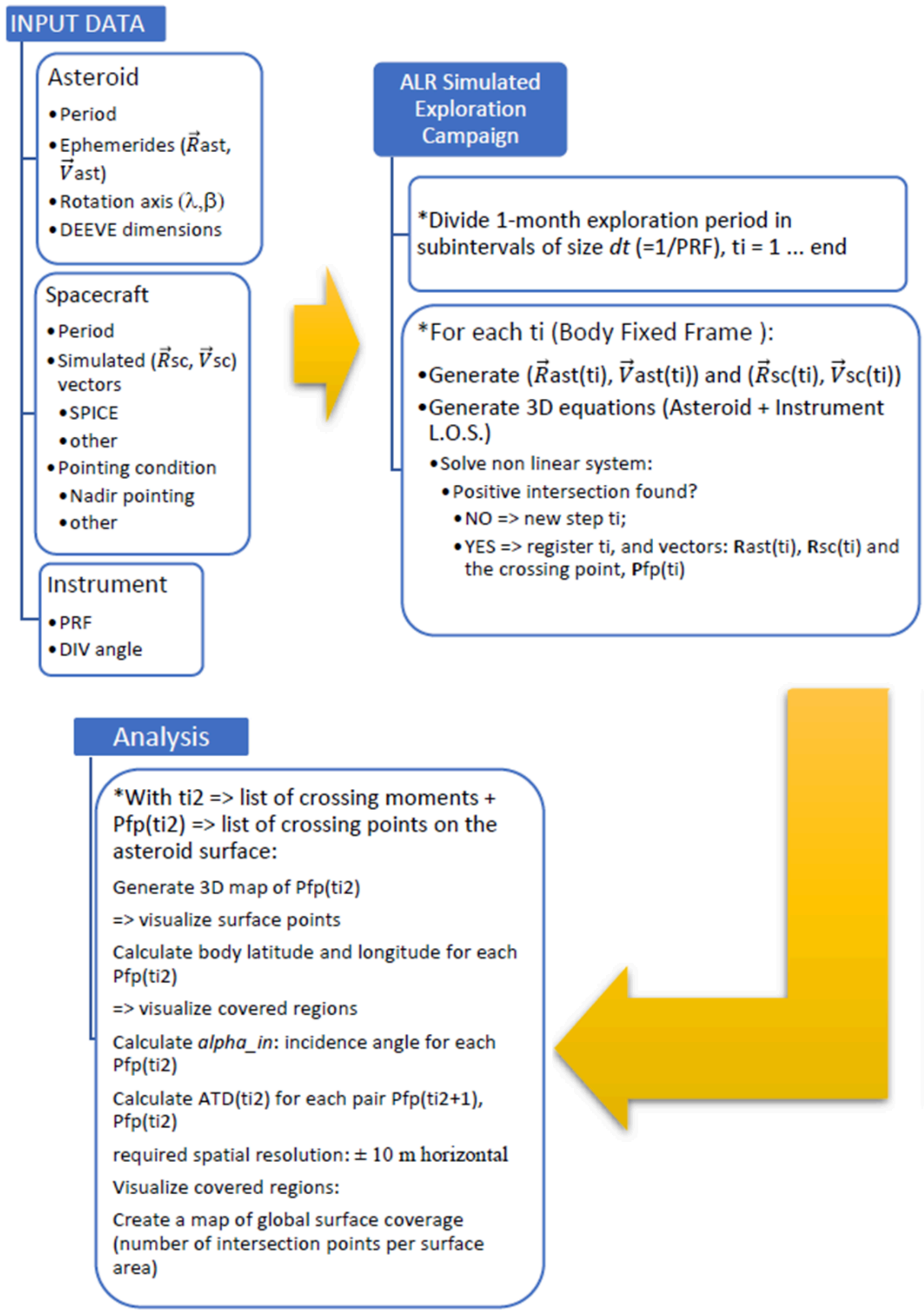

Fig. 2. Flow diagram with the steps followed in the 2nd simulation process with use of the simulator

ALR_Sim_Tracks. **SOURCE:**[6].

Obs.: In these Figures, *DEEVE* means ‘dynamically equivalent, equal volume ellipsoid’, *PRF* is the pulse repetition frequency of the laser source, and DIV is the divergence angle (half cone) of the laser emitter, 'max range' is the maximum range of the instrument, *dt* relates to the time subdivisions within a simulated trajectory; *ti* are the time instants within a trajectory; ***R***ast and ***V***ast are the position and velocity vectors of the main asteroid (Alpha), ***R***sc and ***V***sc are the position and velocity vectors of the ASTER spacecraft; *Pfp* and *ti2* are, respectively, the crossing points identified as intersections of the instrument's line of sight (l. o.s.) with the surface of the asteroid and the instants at which these intersections occur; ATD (Along Track Distance) and CTD (Cross Track Distance) are distance parameters that characterize the spacing of the exploration carried out on the surface. They were created to make it possible to preview the quality of the surface exploration that would be carried out using some inserted set of parameters (they are better explained below); *Dfp* is the diameter of the footprint, i.e. of each circular area illuminated by the laser pulse during its operation.

A more detailed explanation of the program's operation is given below, starting with a description of the input parameters used, simulations carried out, analysis parameters created, visualizations offered (graphs) and results displayed by the program.

2.1. Input parameters

The input parameters for the simulator are described. Each different target and/or optical instrument should have its own module, usually a specific function, where the respective characterizing parameters are listed and described, along with the values assigned to them, which will be accessed by the program at the start of each simulation. The parameters that model a target or instrument are usually more or less accurate models of them. The simulator can even be used to test different models and parameters in order to refine them.

2.1.1. Target parameters

i. Position and velocity: composed by vectors generated externally to the simulator, within the desired period and in the desired frame. For example, in the case of the ASTER mission, where the target is the triple asteroid 2001-SN263, the period of investigation simulated and analysed was between Dec/2024 and Feb/2025. Cartesian coordinates and velocities of the target in the heliocentric ecliptic inertial frame were generated with help of the HORIZONS[1] tool, at time intervals of hours to 1 day. Smaller intervals are obtained by interpolation.

ii. Shape, dimensions and rotation: a solid that models the target and its rotational parameters (axis and rotation speed) are required. For example, in the case of the ASTER mission, Asteroid Alpha is modelled, according to [7], as a 3D scalene ellipsoid with diameter dimensions equal to the minimum values of its DEEVE (dynamically equivalent, equal volume ellipsoid; radii: (rx, ry, rz) = (2. 5, 2.4, 2.1)/2 km), with rotation period of 3.4 hours, and pole direction (ecliptic longitude and latitude): (γ, β) = (309°, -80°) + 15°. It is important to note that the uncertainty in these parameters constitutes also an important input data for the analysis enabled by the simulations.

2.1.2. Instrument parameters

Here the parameters that describe the instrument under analysis, with greater or lesser specificity, are entered. These parameters can be tested to refine their design values. In the case of the Laser Altimeter for the ASTER mission, the laser divergence angle (DIV; equivalent to the Field of View of an optical instrument), the pulse repetition frequency (PRF) and the maximum range of the instrument were used. Other characteristics of the instrument, which are important for analysing the expected return signal and include features of the signal generated and/or received, along with its processing and analysis, have been the subject of previous studies aimed at defining the instrument's design parameters [8][9].

2.1.3. Spacecraft parameters[2]

i. Selected trajectory: the type of trajectory the spacecraft is to follow is entered here. In the case of mission ASTER, encounter trajectories for the 1st phase of the mission were initially tested; then, with a view to exploring the poles of the main asteroid, terminator orbits were tested. Reference [10] explains what a terminator orbit is and provides useful parameters for its modelling. Other trajectories and orbits can be tested by simply modelling them (internally) or inserting them (from an external source).

ii. Attitude: taking into account the trajectory to be followed, the pointing condition of the spacecraft must be selected so that the scan is carried out accordingly. In the simulations carried out, the attitude chosen is directly associated with the pointing of the device. The attitude conditions modelled and already used are:

- * *Sun pointing attitude* – This attitude approach was inserted to comply with the encounter test trajectories of the types 'shadowed' and 'anti-shadowed' proposed in [5]. The Sun pointing attitude is not a steady inertial pointing condition, but a special Sun pointing condition, which requires attitude control to keep the instrument line of sight (l.o.s.) aligned with the Sun-to-spacecraft (s/c) line (positive or negative) during the exploration period. For the anti-shadowed trajectory (means the s/c is positioned in between the Sun-Asteroid line, in front of the Asteroid), the instrument l.o.s. is pointing to the direction from the Sun to the Asteroid C.G. Similarly, the negative Sun-s/c direction was used together with shadowed test trajectories (when the s/c is simulated in a position along the Sun-Asteroid line, behind the Asteroid).
- * *Nadir pointing attitude* – In this condition, the s/c (and also the instrument l.o.s.) is always pointing to the Asteroid C.G. no matter the s/c position. In reference [6], this pointing condition was used together with terminator orbits to allow the exploration of the poles of Asteroid Alpha. An important issue, in that paper, the analysis demonstrated the mission need for 'off axis' capability to assure the coverage of both poles.

2.2. Computations and evaluation parameters created

The parameters for evaluating the scanning carried out by the optical instrument during its operation are created according to the instrument and the specifications of the planned exploration. Their purpose is to make it possible to qualitatively and quantitatively evaluate the type of surface coverage expected for the device's operation during simulations using a set of parameters. In this way, the parameters that characterize the simulated device can be refined. When considering a laser altimeter, the footprint diameter (FTD) is a very important item to consider in the evaluation of instrument results. It influences not only the amount of coverage, but also its quality (horizontal resolution). It depends on the laser-surface distance, and on the divergence angle of the instrument. In the case of a narrow FOV camera, this parameter would be related to the surface area imaged by each shutter release.

Another important evaluation parameter that has an impact on the quality of the coverage is the angle of incidence (*Alpha_in*), defined between the line connecting the instrument and the normal to the target's surface. This angle must be small enough so that the deformation (elongation) of the area covered by each image taken, in the case of a camera, or illuminated by the laser in each pulse (the footprint shape, in the case of a laser altimeter) is also small. So, favorable incidence angles are important for a good surface coverage. As an example, in the evaluation of encounter trajectories favorable to the ASTER mission, FTD (footprint diameter), ATD (along track distance) and CTD (cross track distance) parameters were created to allow the quality of the coverage provided by the laser altimeter to be assessed in each simulation of the device's continuous operation in an exploration campaign.

These parameters are used to assess: **i)** FTD - the area covered by each laser pulse on the surface and its (geometric) shape, which is a function of the apparatus (optics) and the relative instrument-surface position (*Alpha_in*); **ii)** ATD - the distance between successive pulses and/or images taken along the imaged line, which is a function of the frequency of image-taking or emitted pulses (PRF) and the rotation dynamics of the target body; **iii)** CTD - the distance between successive lines (profiles) in an exploration campaign, which is a function of the instrument-surface distance and of the trajectory under test (inclination between the simulated spacecraft trajectory arc and the target orbit). Figure 3 illustrates ATD and CTD in the case of the instrument ALR, the laser altimeter for mission ASTER.

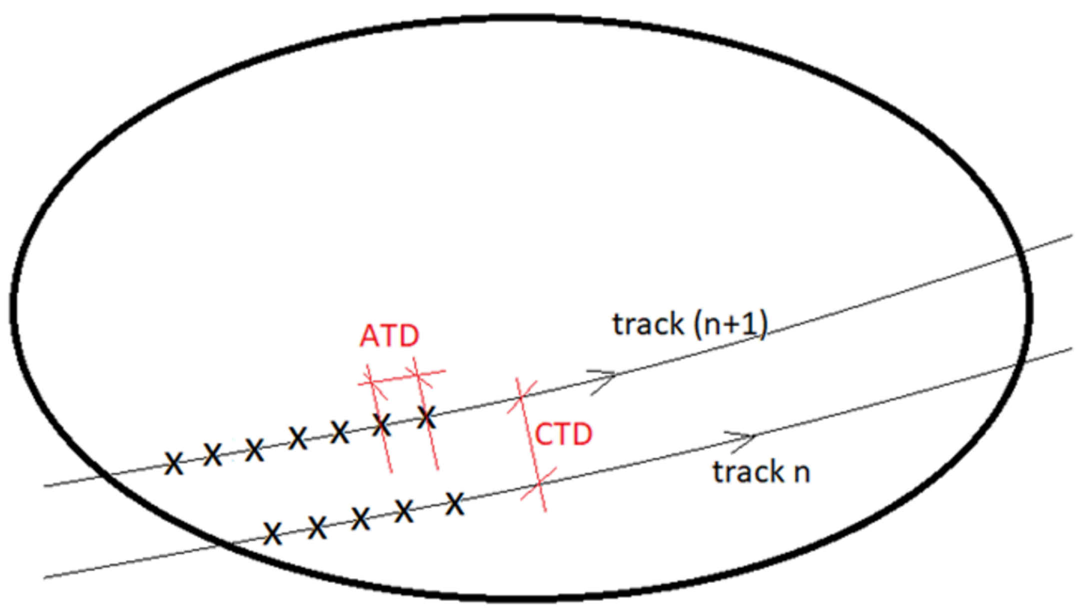

Fig. 3. Definitions of ATD, and CTD, on the target surface, during a simulated exploration campaign. The side-by-side points in a track represent the successive footprint centre points obtained through successive emission of laser pulses and are related to the instrument PRF. CTD is represented by the distance between track *n* and track *(n+1)*. SOURCE: [5].

It is important to emphasise that, depending on the selected trajectory type, some of the mentioned parameters may become meaningless, and other parameters or approaches will be used to assess coverage. For example, in the case of the simulation of the complementary part of the exploration to be carried out with the laser altimeter during the ASTER mission, described in [6], which aimed to identify trajectories favourable to exploring the poles of the main asteroid, terminator-type orbits were identified and simulated. In this case, because of the geometry involved and the relative target-spacecraft dynamics, the CTD parameter became less important, and coverage was assessed using the more usual approach of the number of images taken per sector of surface area.

2.3. Main results produced by the simulations

Once the simulation has been carried out, the simulator offers graphs and tables that allow visualisation of the details of the exploration that would be conducted using the set of parameters entered in the simulation. Although the software also allows the insertion of externally generated trajectories, as is the case with trajectories and orbits generated from the integration of the dynamics relevant to the movement of the spacecraft [6], which is the most common case, special attention is paid here to the results obtained using geometrically simulated trajectories. This possibility makes it simple, easy and quick to obtain a preliminary view of the results expected for the exploration to be conducted using a set of parameters and is useful in defining and refining them. Some results regarding the use of the simulator to study the intended exploration in the ASTER mission with the laser altimeter have been presented previously [5][6].

2.3.1. Main graphical results produced

i. **Visualisation of simulated or inserted trajectories or orbits:** in the preferred system, inertial or body, this graph makes it possible to visualise the trajectories in use in the current simulation over an exploration period. Encounter trajectories (side by side with the target) and orbits around the target have been simulated. Other trajectories can also be modelled and inserted. Figure 4 shows 'terminator' orbits around the main asteroid, with a reference distance of 8 km from it. This orbit was identified as promising for the mission [6]. It has been widely studied, and was called the 'reference orbit'. The analysis carried out in the aforementioned work used orbits obtained externally, from the integration of the dynamics relevant to the spacecraft's movement within the triple system. However, internally simulated orbits (Fig. 4c, 4d), using characterisation parameters obtained in [10], were also studied and produced similar results.

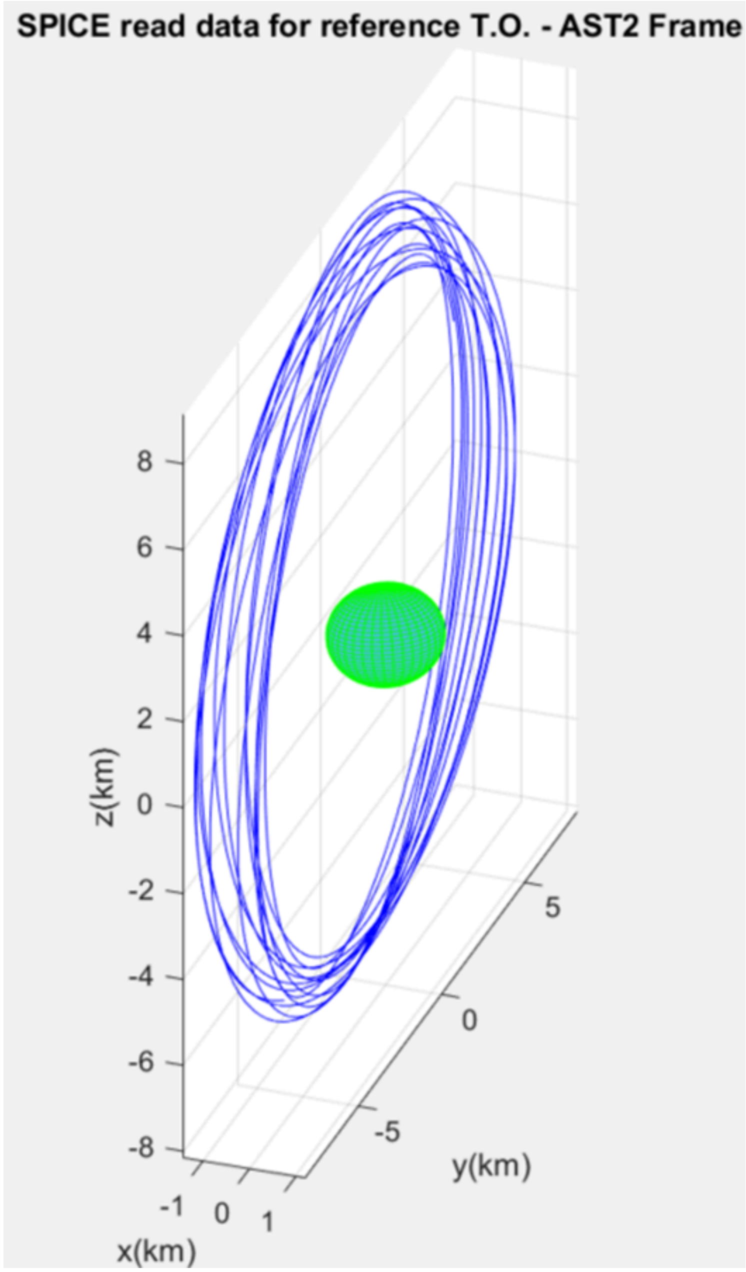

Fig. 4(a). Terminator orbits obtained externally, inserted into the main program for analysis. Here views of the AST2 frame (centred on the asteroid with X to Sun, y to the Asteroid's Velocity vector).

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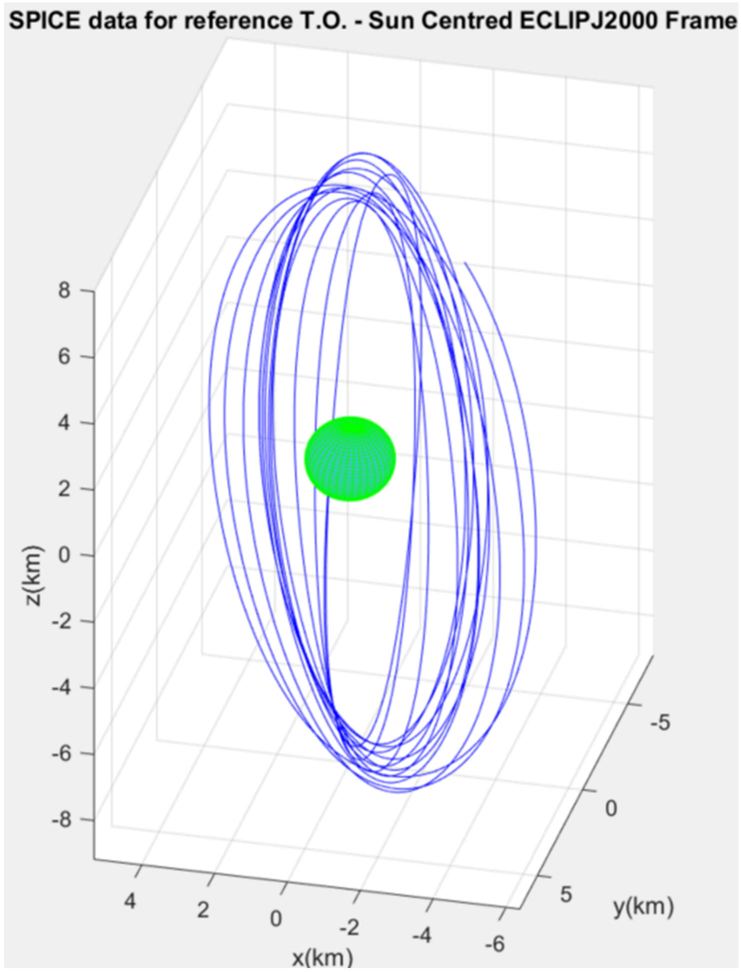

Fig. 4(b). The same Terminator orbits obtained externally are seen here from the ECLIP J2000 frame, which is heliocentric, ecliptic and inertial.

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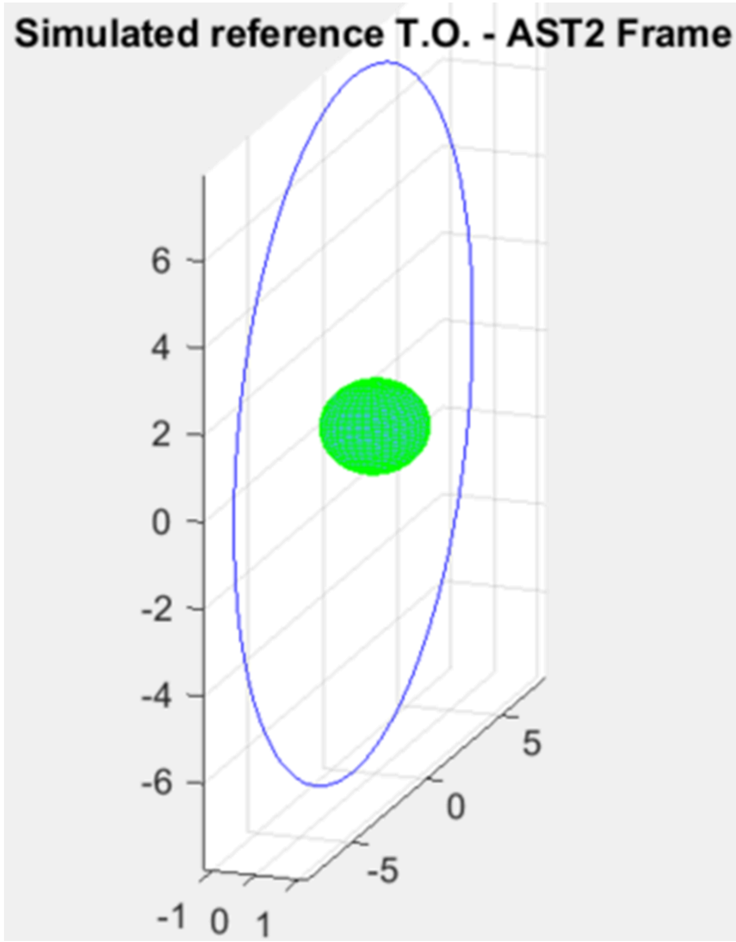

Fig. 4(c). Terminator orbits simulated from the expected geometry within the simulator software are seen here in the AST2 system. Because of the idealisation, the 11 orbits simulated in the period coincide in this frame.

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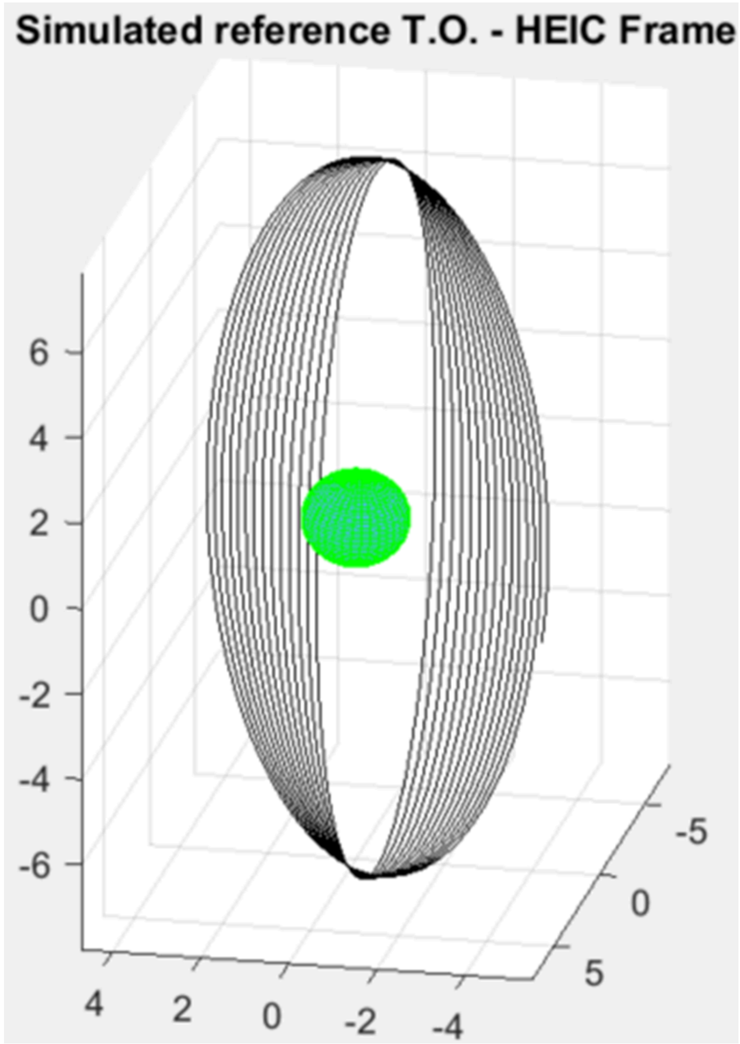

Fig. 4(d). Terminator orbits simulated internally within the simulator software are seen here in the Heliocentric Inertial System (HEIC).

ii. **Visualisation of the pattern imprinted by the scan on the target surface:** in the coordinate system fixed on the target (body system), this visualisation shows the centre points of the images taken or areas illuminated by the optical instrument on the target surface, obtained from the intersection of the optical instrument's line-of-sight with the ellipsoid or other solid model representing the target. In the case of laser altimeter pulses, these are the centre points of the areas illuminated by each pulse according to the simulated scan. This graph shows the pattern imprinted on the target's surface by the simulated scan and, together with the accompanying data, makes it possible to assess the surface resolution of the scan that would be achieved (along track and cross track), including the visualisation of regions with greater or lesser coverage. Fig. 5(a) exemplifies a case and shows this pattern for an exploration carried out on a selected area of the target (latitude range, in this case from -40 to +40 deg). Fig. 5(b) shows a detail of the minimum areas illuminated by each pulse for a test of a set of simulation parameters.

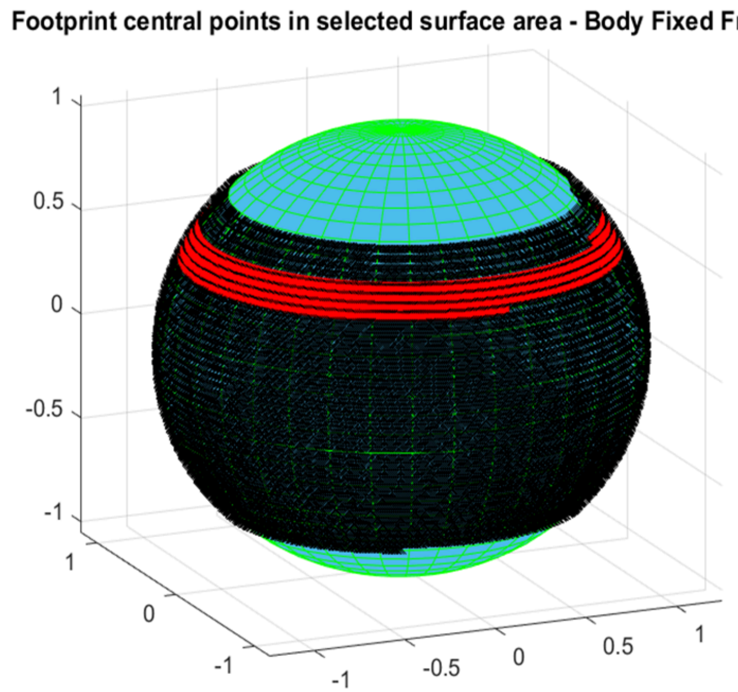

Fig. 5(a). Graph illustrating the points of intersection of the instrument's l.o.s. with the target surface (footprint central points, in black) on the asteroid surface. It is possible to zoom in the figure. In red, the footprint areas are represented.

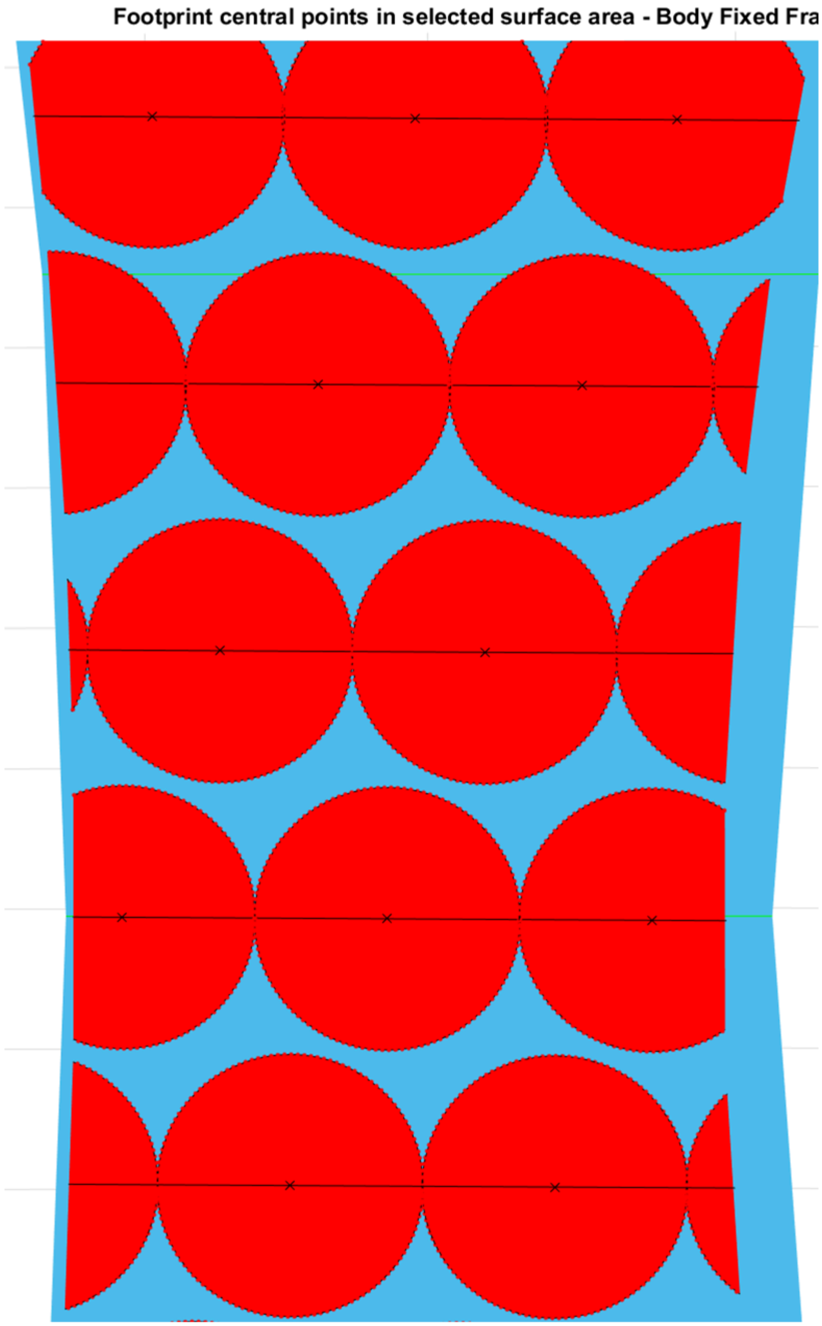

Fig 5(b). Detail of a group of footprint minimum coverage areas. Here in the limit of no overlap areas for CTD. This is a close up of a central area of the asteroid.

iii. **Incidence angle distribution along the latitudes of the target body:** in the body system and as a function of its latitudes, this graph shows the distribution of the incidence angles of each l.o.s. of the optical instrument (taken with respect to the normal to the target surface). This information is important because the intensity of the light signal that reaches the detector (to be recorded by the instrument), coming from the surface and carrying information about it, depends on this angle being sufficiently small. It is common, for example, at high latitudes and also due to the geometry (model) of the target, to have large angles of incidence. This condition makes it difficult for reflected light to return from those regions (impacting the signal-to-noise ratio).

iv. **Distribution of footprint diameters:** in the body system and as a function of body latitudes, this graph shows the variation in the footprint size (total area illuminated by each pulse over the surface) throughout the simulated exploration. In the case of an optical instrument, this information is related to the portion of terrain that will be covered by each image or illuminated by each pulse (in the case of a laser altimeter). It is clear that this parameter affects the resolution of the image and must be kept within values that comply with the mission requirements for the instrument. These values must also be controlled because, in this case, the intensity of the signal which returns for detection and recording also depends on it.

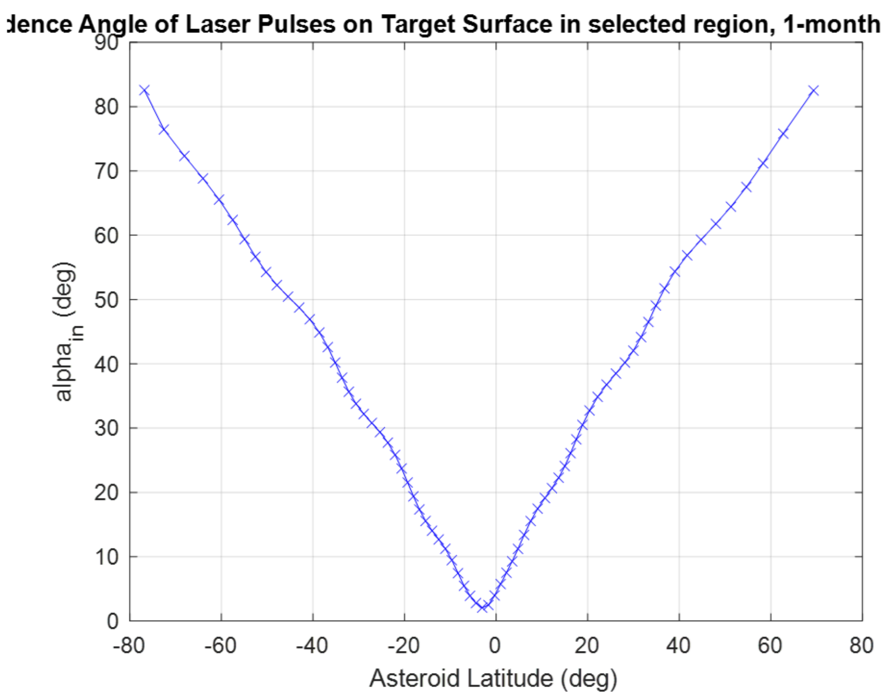

Fig. 6(a). This graph shows, for the ASTER mission study, the distribution of the incidence angles of each pulse hitting the surface as a function of the latitudes of the target body. It can be seen that at high latitudes, large incidence angles are expected, which affects the quality of the investigation.

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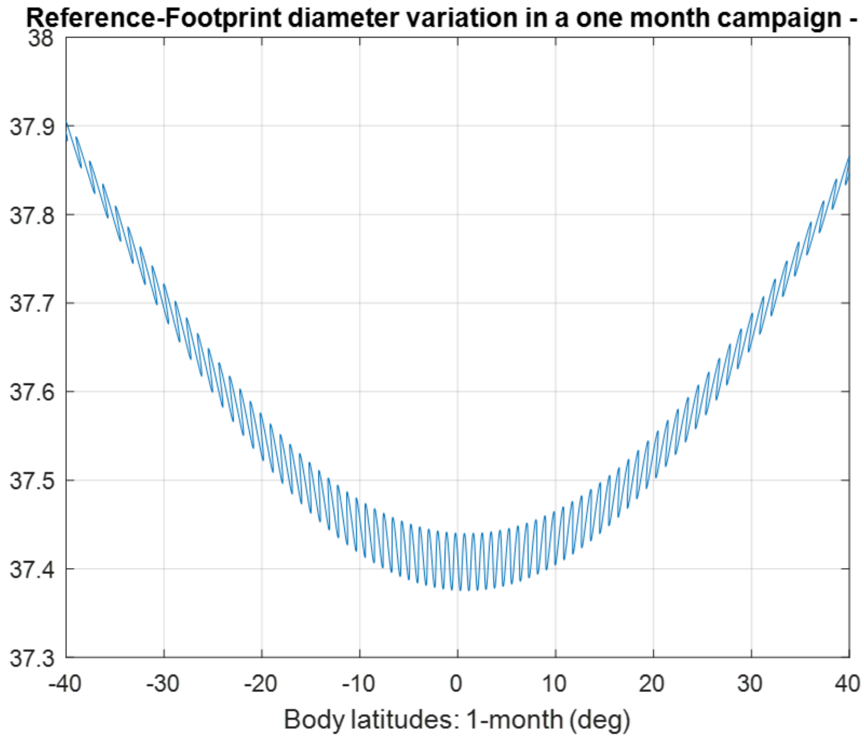

Fig. 6(b). For the study of the ASTER mission, from the point of view of the Laser Altimeter, the graph shows how the diameters of each footprint vary within a complete exploration, for a test case and within the surface area/region of interest.

v. **ATD - Along Track Distances:** in the body system and as a function of the latitudes along its surface, this graph shows the variations in the distance parameter between successively images taken (or incident pulses, in the case of the laser) over the course of a complete simulated exploration. Fig. 3 illustrates the concept of ATD and Fig. 7(a) shows the variation of this parameter in the simulated exploration in the ASTER mission. More specifically, the distances are calculated between the centers of the areas successively illuminated by each pulse or covered by each image (in the case of a photographic camera). This parameter is important if the to spatial resolution requirement imposed on the instrument in the mission is to be met.

vi. **CTD - Cross Track Distances:** similar to ATD, this graph shows the variations in the parameter which monitors the distance between successive profiles (lines imaged/scanned) during a complete exploration campaign. This is very useful when the exploration is done with use of an encounter trajectory, as in this case the target is imaged systematically and sequentially, like the peeling of an orange, but it loses (or changes) its importance when the simulated trajectory is an orbit around a rotating target. Fig. 3 illustrates the CTD concept and Fig. 7(b) shows the calculated variation of this parameter during the simulated exploration for the ASTER mission. This parameter is important for fulfilling the spatial resolution requirement of the mission in relation to the instrument operation.

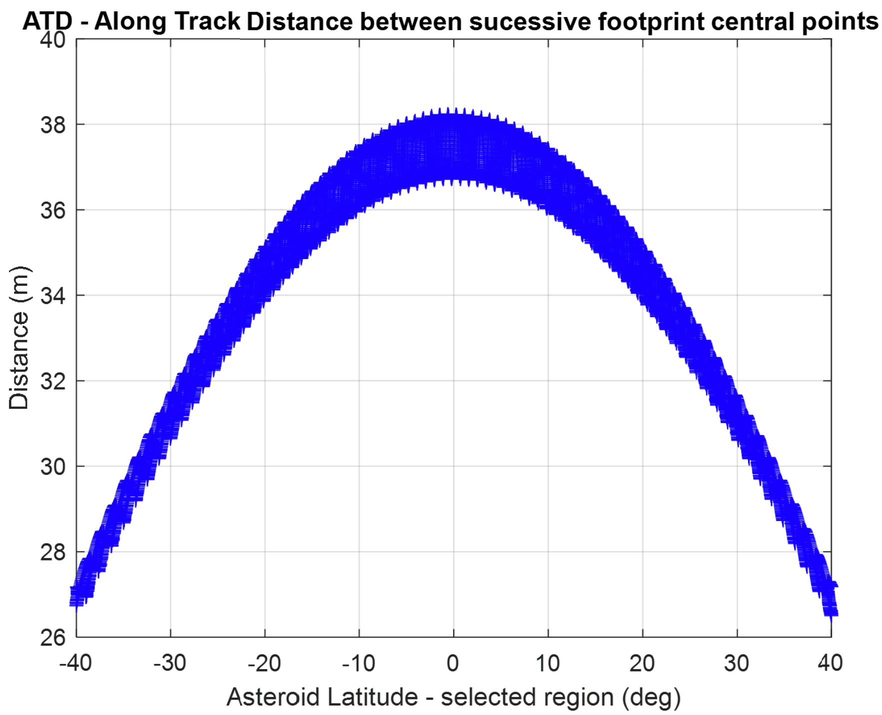

Fig. 7(a). Distribution of distances between successive pulses hitting the surface (ATD - Along Track Distances) for a test case.

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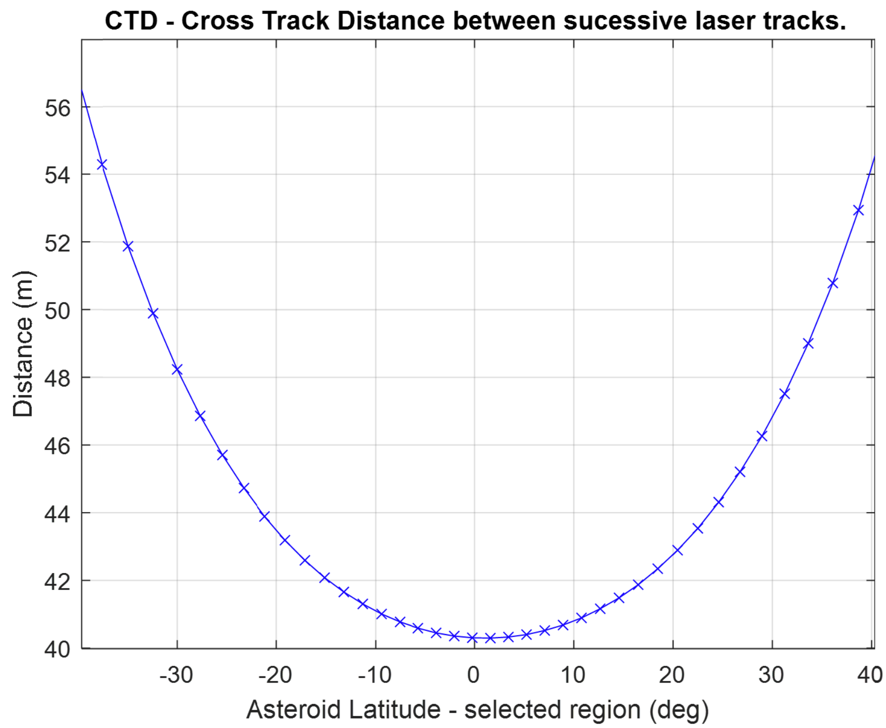

Fig. 7(b). Distribution of distances between successive lines within a complete exploration simulation (CTD - Cross Track Distances) for a test case.

vii. **Total coverage:** in the body system, this visualisation of the target shows the surface area of the target that is expected to be covered by the scan when some specific set of parameters is entered. The details of these graphs show the quality of the scan, in terms of the spatial resolution that is expected to be obtained. Fig. 5(a) illustrates the partial coverage of the target's surface in an area of interest (latitudes between +40 and -40 degrees, in this case). To visualise the details of the coverage, Fig. 5(b) shows the minimum areas covered by each pulse hitting the surface. Total coverage is calculated from the sum of all partial coverages, excluding the intersections between them, if any.

viii. **Coverage in number of hits per surface area:** this is a 'Mercator' or 'world map' type graph, which shows a flat projection of the target's surface (latitude vs longitude), where a count of the number of laser pulses or images that hit each rectangle of the target body's surface area is displayed. The latitude and longitude subdivisions are adjusted as desired, for example 2 x 2 degrees, 1 x 1 degrees, etc. Figures 8(a) and 8(b) are examples of this type of graph. In addition to the graphs, the software also calculates the value of the total minimum coverage area, based on the sum of the minimum areas covered by each footprint, excluding the areas where they intersect, within a complete exploration. In the case of the Laser Altimeter for the ASTER mission, these calculations were used to demonstrate that the minimum coverage desired for the main exploration campaign could be achieved if the conditions raised in the survey were followed.

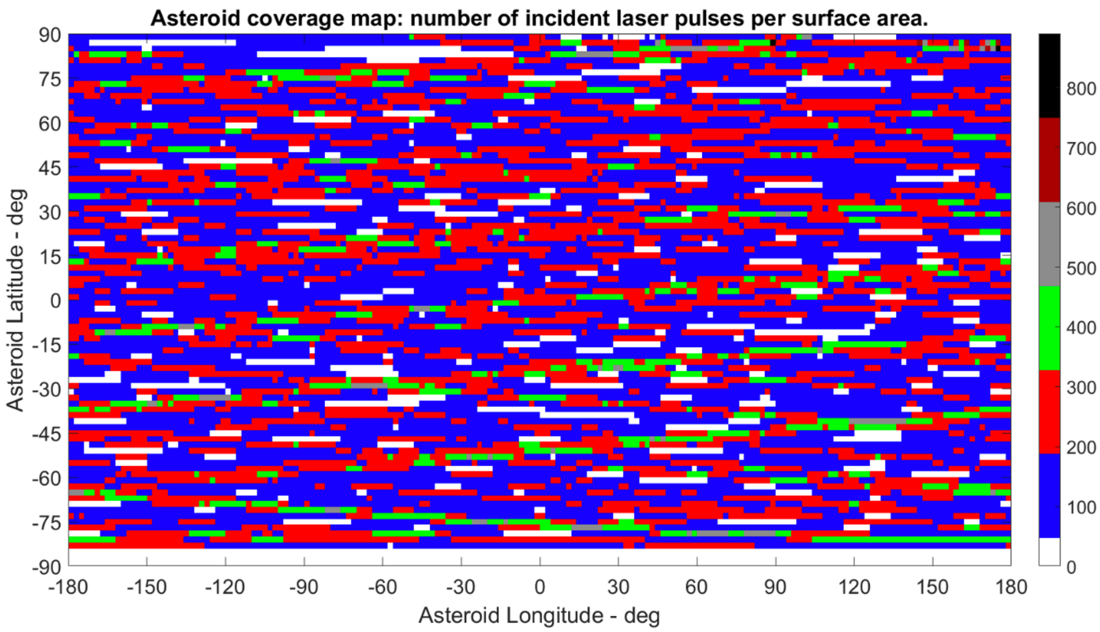

Fig. 8(a). The flat map of points per area indicates the number of times the instrument, identified by its l.o.s., hits each sector of the body's surface area, divided into latitude x longitude elements. The width of the areas is selectable (2 x 2 degrees with PRF of 1Hz, in this example).

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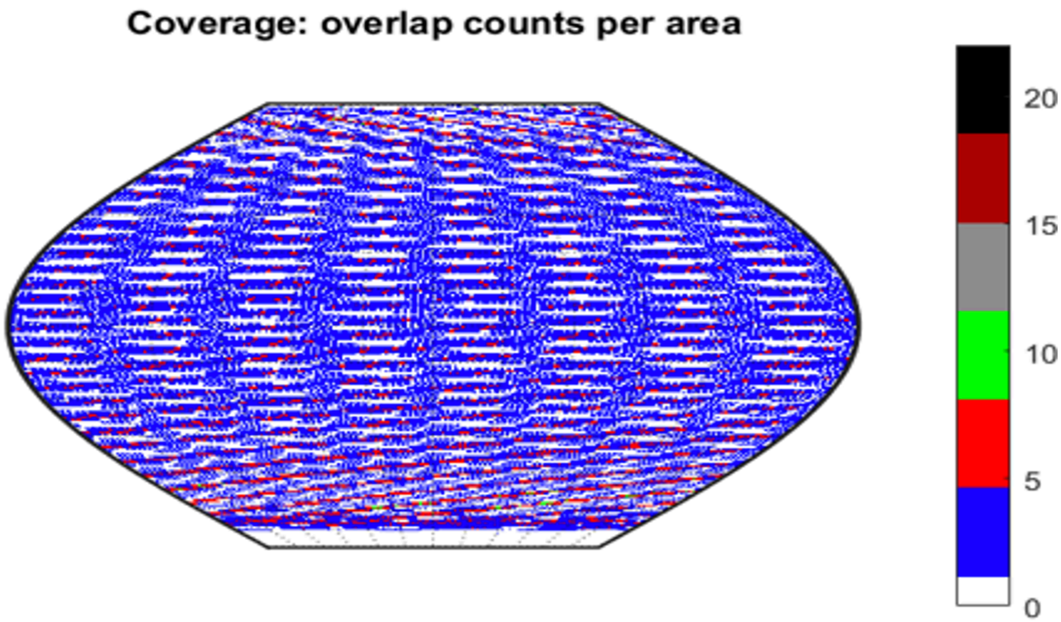

Fig. 8(b). Another presentation of the count of pulses hitting each surface area element is shown (1 x 1 deg). In this example, the *Terminator* orbit is used for a simulated 1-month exploration campaign (1 month). This figure highlights the low coverage of the target's south pole under the simulation conditions.

2.4. Functions that comprise the software

In the MATLAB environment, the simulator software was created to: i) generate 3D trajectories for the spacecraft based on geometric considerations of the target's movement over the period considered and analyse their effectiveness in exploring the surface of the celestial body targeted by the mission; ii) receive as input 3D trajectories of the spacecraft generated externally to the program and analyse their effectiveness in exploring the surface of the celestial body targeted by the mission. In this case, the input trajectories are generated taking into account the dynamics relevant to the spacecraft's movement within the considered system during the period of interest. The simulator was used twice to analyse trajectories favourable to the ASTER mission, from the point of view of the Laser Altimeter. In the first [5], it was used to generate and analyse encounter trajectory arcs that would allow the main target of the mission to be explored as intended; in the second [6], it was used to help analyse specific orbits around the main target, called 'terminators', with the aim of complementing the exploration carried out in the first part of the exploration. The modules that make up the software are listed below and the function of each is described. In the MATLAB environment, subroutines are functions called within the main program.

2.4.1. ASTER_ALR_Sim_Tracks_v1.m

This is the main program. It is a script in which the entire flow of calculations involved in the simulation process is inserted. All the functions that make up the package are triggered inside this main program. A brief description of these functions and all the files called inside this main program is given.

i. **importfile_target_ephemeris_data.m** - Initially, the target's orbit data for the desired period, collected or produced externally, is read by the program using this function which points to the text file with the target's time, position (X, Y, Z) and velocity (Vx, Vy, Vz) coordinates in the coordinate system of interest and for the desired period.

Note: in the case of the study carried out for the ASTER mission, this file was used to read the Cartesian ecliptic heliocentric inertial coordinates (ICRF/J2000) of asteroid 2001-SN263, throughout the month of January 2025, every hour, collected using the HORIZONS platform (JPL/NASA).

The input parameters are then read and/or set:

ii. **read_ target_features.m** - this function loads all the parameters that define and characterise the Target, such as its dimensions (depending on the model used), spin axis pointing direction, and rate.

iii. **read_instrument parameters.m** - this function loads all the parameters that define and characterise the instrument, such as, in the case of the laser altimeter for the ASTER mission, the divergence angle of the emitter (DIV), the pulse emission frequency (PRF), etc.

iv. **read_test_track_ parameters.m** - this function loads all the parameters that define and characterise the spacecaft's test trajectory, such as the desired target-spacecraft distance and relative position (in the case of an encounter trajectory), time subdivisions of the trajectory (*dt*: in days, hours, min or sec), parameters for the relation between the trajectories (such as the slight inclination inserted between the trajectories of the spacecraft and the target, studied in the case of the ASTER mission), and any others.

v. **read_other_ parmeters.m** - This function is used to read additional parameters that are useful and/or necessary for the simulation. For example, here the scan can be focussed on the target's region of greatest interest (in the coordinate system fixed to the body of the target). This is useful for concentrating the scan with the instrument in the most favourable region. For example, in the case of the exploration of asteroid 2001-SN263 with the laser altimeter, this region is the central one (equatorial, between -40 and +40 degrees), because the simulations showed large angles of

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incidence of the laser beam in the regions near the poles, which compromises the detection of the return signal of the laser pulse emitted by the instrument.

vi. **simulate_trajectory.m** - based on the Target's trajectory, the sort of spacecraft trajectory to be tested is selected and generated at previously defined time intervals (*dt*). Initially, in the same coordinate system as the target. There are many possible variations, from various types of encounter trajectories to different types of orbits around the target.

vii. **Eclip_to_IBC.m** – this function transforms the spacecraft's trajectory coordinates from Inertial Heliocentric Ecliptic to the IBC (inertial body coordinates) system, which is a system centred on the asteroid's body, but is inertial. It has the Z_ibc axis aligned with the z_body axis.

viii. **IBC_to_ast.m** – this function transforms the spacecraft's coordinates from the IBC system to the system fixed on the target's body. It is in this system that most of the computations are carried out.

ix. **Attitude_select.m** - This function selects the attitude mode to be used in the simulation, which is supposed to coincide with the pointing of the instrument. The attitude modes used so far were Sun pointing and Nadir pointing (target CG pointing). The first is used to test encounter trajectories, where the pointing is given by the line joining the Sun and the spacecraft (direction Sun=>spacecraft or spacecraft =>Sun); the latter was used to test interesting orbits (obtained by other means) around the target body.

x. **bf3d_nonlinear_solver.m** – this function was created for the purpose of calculating intersection points of the laser l.o.s. with the surface of the modelled ellipsoid. In the case of the laser altimeter, the set of points identified represent the center of the areas iluminated by the laser pulses in all shots. This set of points depends on the attitude mode selected.

xi. **Ast_3D_ellipsoid_rotated.m** – this function generates 3D model ellipsoid already considered the rotation given by its spin axis. This graph is important for the visualizations related to the exploration done on the target surface, for instance those showing the pattern impressed by the exploration on the surface, grid of points, individual areas (footprints), overlap areas among footprints, coverage, etc.

xii. **ellipsoid_sector_area.m** – this function is dedicated to calculate properly the Target Surface Coverage and the Total Overlap Area.

xiii. **ATD_calcs.m** - In a scanning simulation, successive incident laser beams or images taken in succession have their centre points and areas calculated. This function uses the successive points of intersection of the instrument's l.o.s. with the surface of the target, the centres of the footprints, to calculate the distances between them. In the case of encounter trajectories tests, these distances depend on the latitude of the target body. The graph produced by this function shows the distribution of distances (ATD) in relation to the latitude of the body.

xiv. **CTD_calcs.m** - this function uses the sequential exploration profiles (lines) demarcated by the centres of the footprints on the target surface to calculate the distance between successive lines, referred to here as cross track distances. These distances also vary with the latitude of the body and the graph produced with this data is a function of this parameter.

xv. **Incidence_angles.m** – This function is dedicated to the calculation and analysis of the incidence angles of each instrument l.o.s. hitting the target surface. A graph with the distribution of these angles related to the body latitude is produced.

xvi. **Area_calcs.m** – this function is dedicated to the calculations related to the instrument coverage of the target surface. The whole surface area is calculated, the area of the considered sector (lat1 to lat2), the total reference area inside selected sector, total overlaps area, and the total covered area.

xvii. **Lat_Long_plainMap.m** – This function creates the Asteroid coverage map by dividing the surface area of the target in rectangular subareas of controllable size (latitude vs longitude, in degrees), then it counts the number of incident laser pulses in each area element.

3. Which optical instruments can be simulated?

The simulator has been created to represent the point of view of a laser altimeter. However, it can be adapted to the point of view of other optical instruments that operate in a similar way, which take luminous information from small areas of the target's surface to obtain from the sum of these the total coverage related to their activity. Instruments like this generally have a Field of View (FOV) with a central line of sight (l.o.s.). In general, they are used for close exploration, as is the case with a laser altimeter or a proximity imaging camera (narrow FOV). Other optical instruments will need to be adapted for use.

4. Conclusions and comments

The *ALR_Sim_tracks* simulator was created to allow early visualisation of the results that should be expected when exploring the surface of a specific target (represented by the set of parameters that characterise the target) over a specific period of time using a modelled optical instrument (represented by the set of parameters that characterise the instrument), in case the exploration is carried out when the spacecraft follows the simulated and/or inserted (read as input) trajectory. For this reason, a wide variety of trajectories can be tested with its use. The generation of trajectories geometrically, based on what is known and expected of them, is a novelty and offers an opportunity for quick preliminary analysis to reject conditions and/or first define the set of values tested in the simulation. This was done previously in the analysis carried out for the ASTER mission [5][6]. For example, the study presented in [5] aimed to verify whether there were favorable encounter trajectories for the exploration intended for the ASTER mission. In fact, the simulations and analyses carried out made it possible to answer this question by determining what values the exploration parameters (trajectory and instrument) should assume for the exploration to be as successful as intended. This simulation also showed that the coverage that would be obtained along these encounter trajectories would most likely be focused in the central regions of the asteroid, leaving the pole regions uncovered, unexplored. In reference [6], the aim was to complement the coverage obtained in the main campaign. In this way, the study indicated that some Terminator orbits would be effective in guaranteeing the coverage of the target asteroid poles. In the mentioned work, the set of conditions necessary for this complementary coverage to be achieved is outlined.

In this way, this author believes that the simulator *ALR_Sim_tracks* can be successfully used in the analysis of missions with exploration carried out by optical instruments such as laser altimeters or even proximity imaging cameras, which have a central line of sight and operate sufficiently close to the target, aiming to cover its entire surface area using sequential individual images or pulse shots.

The simulator is in its final phase of development and will be registered shortly. Some improvements to it are planned, such as replacing simplified models of the target (in the case of 2001-SN263, a scalene ellipsoid was used, according to [7]), with ones that are more faithful to its actual geometry. More elaborate geometric models of targets that are very far away, as well as information about their rotation (spin axis and speed) are not always available. However, as soon as more detailed information on the geometry and dynamics of the target is obtained, new simulations should allow better predictions of the exploration to be carried out with use of the modeled instruments.

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Footnotes

[1] JPL/NASA; http://ssd.jpl.nasa.gov

[2] Many other parameters comprise the design of an optical instrument. Not all of them, however, matter for evaluating the expected coverage of the target's surface from the type of optical scan that is carried out in the simulation.

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Declarations

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