

Operations of the laser traffic control system in Paranal

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ABSTRACT

The Laser Traffic Control System (LTCS) of the Paranal Observatory is the first component of the Adaptive Optics Facility (AOF, [8]) entering routine operations: a laser beam avoidance tool to support operations of an observatory equipped with five lasers and several laser-sensitive instruments, providing real-time information about ongoing and future collisions. LTCS-Paranal interfaces with ESO's observing tools, OT and vOT. Altogether, this system allows the night operators to plan and execute their observations without worrying about possible collisions between the laser beam(s) and other laser-sensitive equipment, aiming at a more efficient planning of the night, preventing time losses and laser-contaminated observations.

Keywords: laser traffic control system, laser collisions, observing tools, Paranal Observatory, ESO

1. PARANAL OBSERVATORY

Located in the Chilean Atacama Desert, the La Silla Paranal Observatory is, today, ESO's flagship visible and infrared astronomical facility and home to the Very Large Telescope (VLT). The VLT is composed of four 8.2m Unit Telescopes (UT) and four 1.9m Auxiliary Telescopes (AT), which can be combined as the Very Large Telescope Interferometer (VLTI). The platform atop Cerro Paranal is also shared with VST, the VLT Survey Telescope, and the DIMM weather monitoring telescope while, on a neighbouring hill, the Visible and Infrared Survey Telescope for Astronomy (VISTA) surveys the skies. Altogether, these telescopes feed a large set of imaging and spectrographic instruments. In addition, the UT4 is equipped with a laser guide star facility (LGSF) for adaptive optics. Up to March 2016, this included only PARLA (PARanal Laser, [3]), a single centrally propagated laser beam, which will soon be complemented by the 4 Laser Guide Facility (4LGSF), currently being commissioned.

With such a high number of telescopes and instruments, Paranal Observatory, unsurprisingly, harbours a highly dynamic environment, with different telescopes changing pointing several times a night, many equipped with sodium laser sensitive equipment, and an eminent need of fast real-time decisions during operations is evident.

2. UPGRADE OF THE LASER GUIDE STAR FACILITY

A laser-equipped telescope sharing the same site with other telescopes has the potential of impacting instruments sensitive to the sodium laser light. This can manifest through the contamination of scientific images and spectra or negative effects on observatory equipment – what we call, in the context of this paper, laser collisions (see 3. LASER COLLISIONS3.1). With its single laser beam, Paranal Observatory already had a laser collision avoidance strategy in place, where laser operations were aided by a tool providing the projection of the laser path in the sky onto alt-az diagrams for each laser-telescope pair (Figure 1). While this already offered useful information, the night operators had to put a significant effort in evaluating the situation for each laser/telescope pointing, resulting in a highly conservative approach in an attempt to avoid as many collisions as possible. LTCS upgrades this first tool, in the sense that it covers all laser sensitive telescopes

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and equipment and geometrically calculates collisions in three dimensional space. Plus, it interfaces to the Observing Tools, eliminating the “guessing” part from nighttime operations with lasers.

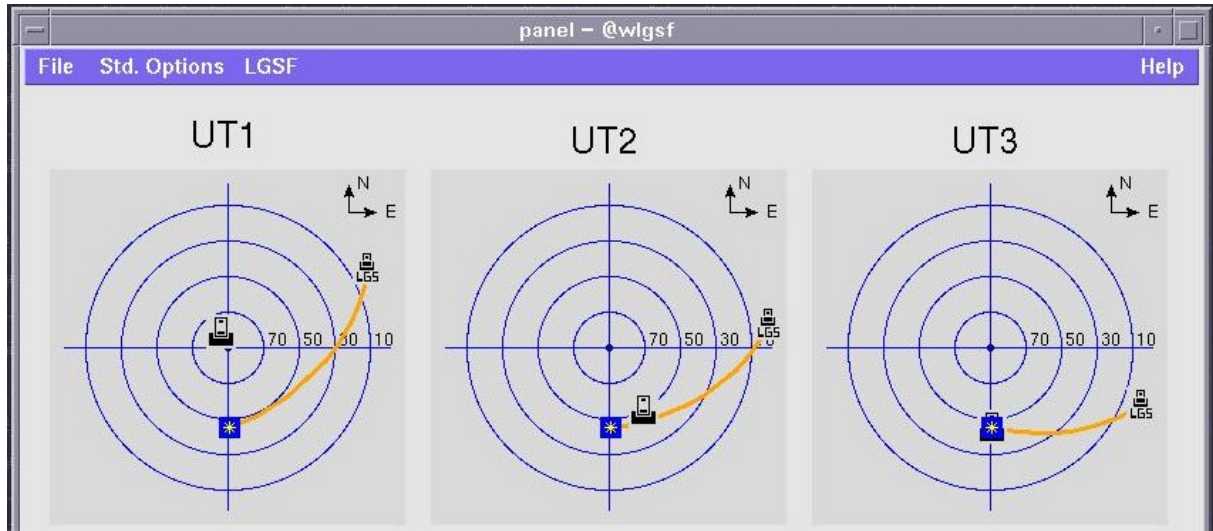


Figure 1. The laser beam projected on the alt-az diagrams for the other UTs as seen from the UT4 telescope control. The tool has been available to operators since the commissioning of the first laser in 2007 and has helped UT operators to decide whether to point or move their telescopes.

With the upgrade of the Laser Guide Star Facility, the UT4 is now additionally equipped with four new lasers: the 4LGSF – 4 Laser Guide Star Facility. Consequently, observations carried out on other telescopes while the lasers are being used might be increasingly impaired by the effects of the laser beams. In particular, with the 4LGSF, the observatory has increased the number of on-sky laser configurations from one (single centrally propagated laser) to eight (additionally, three 4-laser constellations and four single lateral laser propagations). Already a non-trivial consideration, with the addition of the 4LGSF, laser collision detection becomes increasingly complex and the need of a more automatic system, requiring a lesser degree of human interpretation, becomes clear: a laser beam avoidance tool was then recognised as the best way to support operations of an observatory equipped with four powerful lasers and a large number of instruments sensitive to the laser light.

3. LASER COLLISIONS

To address the problem of laser collisions, let's first understand its definition: “a laser beam collision occurs when any portion of the cone volume determined by the field of view of the (non-laser) telescope intersects with any portion of the laser beam cone defined within the Rayleigh scattering limits or sodium fluorescence limits, provided that the non-laser telescope instrument or other systems are sensitive to the laser wavelength” [4].

How collisions can happen between a single laser and a telescope is almost counterintuitive: the probability of a collision is proportional to the fields of view on sky of the telescope and inversely proportional to the distance on the ground between the telescope and the laser. A common misconception is that, if the laser and telescope point to the same target, there is necessarily a collision – this is not always the case (Figure 2). More importantly, collisions are possible when they are pointing to different targets (Figure 3). In order to determine whether or not a collision takes place, one has to calculate the geometry of the collision in 3D space.

In observatory operations, a collision, even if it happens “geometrically”, may not produce any negative effects, for instance, if the telescope and annexed equipment is not sensitive to the laser light centered at ~589 nanometers. The ability to differentiate correctly between collisions that may produce real contamination and those that are harmless adds complexity to any laser traffic control system but guarantees efficient observations for the observatory as a whole.

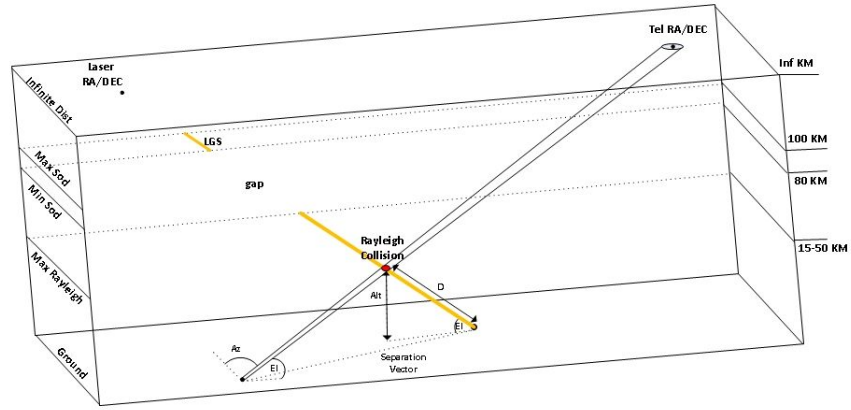


Figure 2: Schematic of the forced collision tool to calculate the Right Ascension (RA) and Declination (Dec) for a telescope to intercept the laser beam. Given the coordinates (RA, Dec) of a laser pointing and the desired distance along the projected beam (D), the tool solves the telescope (RA, Dec) that intercepts the laser beam and produces a Rayleigh collision at an altitude (Alt).

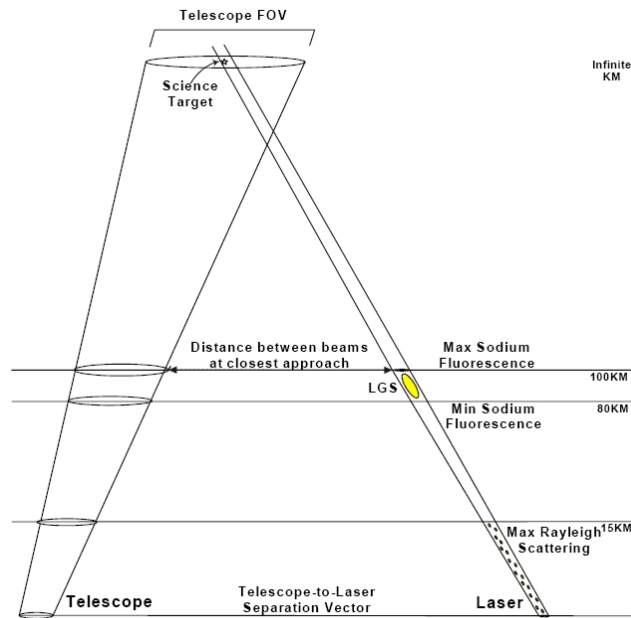


Figure 3. Schematic representation of the geometry involved in the interaction between a laser and a non-laser telescope ([4], [5]). The heights of the Rayleigh scattering and the sodium fluorescence limits are location-dependent parameters that were measured during the March 2014 commissioning run. The calculation of a collision requires an accurate knowledge of the observatory survey, the relative position in space of all telescopes with respect to the laser-equipped telescope (e.g., telescope-to-laser separation vector and relative height difference between telescopes, as in the case of the VISTA–UT4 pair).

3.1 Effects of collisions

Contamination of scientific images and spectra

The most obvious effect of a collision is the contamination of scientific images and spectra of the “offended” telescope. In the “fortunate” cases, a conspicuous pattern of illumination can be immediately identified as a contamination. The observation can then be postponed or aborted, although the observatory productivity of the night is adversely affected. On the other hand, subtler contamination of science images can go unnoticed, leaving the perceived productivity intact but

potentially damaging the derived science results. The overall damage increases in cases like ESO, where the data archive ensures that the contaminated science frames are distributed in time to a wider community.

Negative effects on observatory systems

Laser light contamination can adversely affect telescope operations [1] in other ways: guiding systems, active optics, wavefront sensors and monitoring systems are often sensitive to the laser light, which can severely affect their ability to provide real-time measurements needed for efficient telescope operations.

Figure 4 and Figure 5 show examples of contaminated images and spectra obtained in the 2014 LTCS commissioning run with the PARLA laser. In the case of UT3 and VST, at higher risk of collision due to their short distance (57 and 80 meters, respectively) from UT4, the laser telescope, but in general for all telescopes at the observatory, the light contamination can significantly affect optical imaging and spectroscopy.

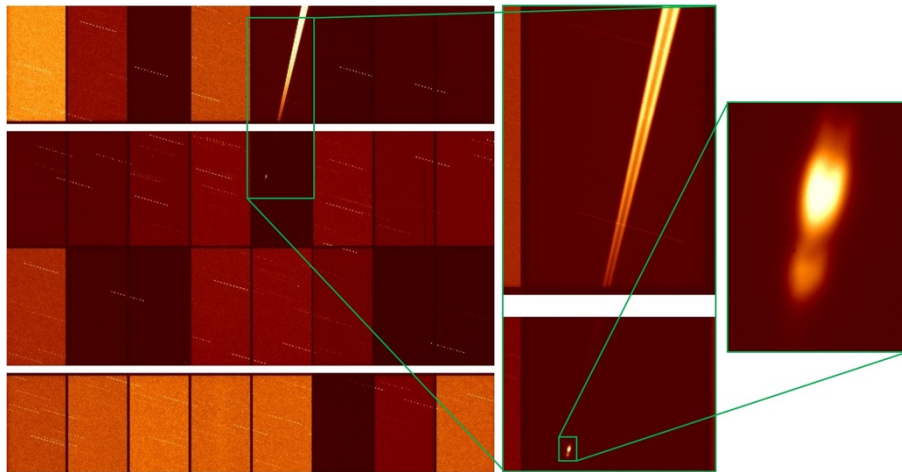


Figure 4. OmegaCAM 10s image with details of the laser beam, including the Rayleigh cone and the sodium fluorescence spot. There is an increase of ≥ 2000 counts above the sky level. Imaging a laser beam can quickly bring the detectors to saturation and other related effects such as persistence. The test was done at zenith with no telescope tracking.

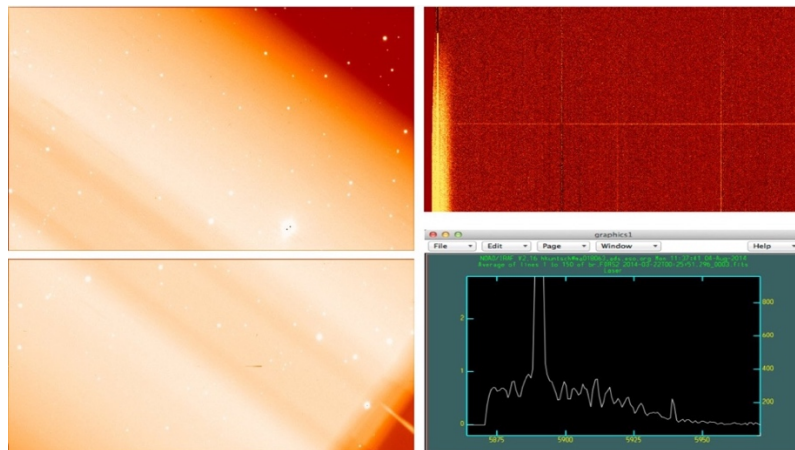


Figure 5. Left: FORS2 1s acquisition image (chip1 and chip2) of the Rayleigh beam. The beam brightness peaks at ~ 500 counts above the sky background. Upper right: 60s 1200R spectrum of the Rayleigh beam as seen by FORS2. Lower right: Plot of the line profile of the Rayleigh beam as observed with the FORS2 1200R grating. Assuming that the wings are symmetric, the total width is 12nm. The average count levels of the wings are between 0 and 0.7 counts. The laser light peaks at 430 counts and the full width at half maximum of the laser line is 0.222nm.

4. THE LASER TRAFFIC CONTROL SYSTEM

The operations concept for a laser beam avoidance system to avoid LGS and/or Rayleigh “collisions” between laser equipped telescopes and collocated non-lasing telescopes was originally envisioned by [7]. A “first generation” LTCS system was developed in 2001, and has been in continuous use on Mauna Kea since 2002. A detailed description of the initial LTCS implementation was provided by [4]. During the final design review of the Adaptive Optics Facility (AOF) and its 4LGSF in 2010 at ESO, the need for a complete laser beam avoidance system, compatible with VLT software standards and embedded in the Paranal Observatory’s operation schema was identified. The project to create a custom-made LTCS-Paranal [6] was then initiated and completed with the final commissioning on-sky in March 2015 [2].

The different components of the LTCS-Paranal system will be described in the following sections: the publisher, the core, the configuration and the query server.

4.1 LTCS Publisher

The LTCS Publisher is an ESO application that provides and updates files containing the Telescope and Instrument Position Information (TIPI) for each telescope at the summit, as required by the LTCS Core process for assessing the beam collision geometry when the laser is propagating. The LTCS Publisher collects, in real-time, the dynamic pointing data and the telescope configuration (focus in use) from the telescope databases.

4.2 LTCS Core

The LTCS Core is a third party application, originally developed for the Mauna Kea Observatory, composed of three executable UNIX processes, and HTML/PHP displays. The source code makes use of some third party software (mySql, Apache, Log4J, PHP, and SLALIB). The LTCS-Paranal version is run on ESO-standard scientific LINUX. The developed processes are the collector, the geometric analysis engine, the status manager and the web displays:

- a. The **collector** sends position updates only when telescope positions change sufficiently to warrant recalculation of prediction data.
- b. The role of the **geometric analysis software** is to calculate and predict collision events for all telescopes that are sensitive to laser emission and for all lasers that are actively propagating.
- c. The **Status Manager** and **Web displays** provide the interface to the users: the GUI is different for laser telescopes, which offer with a full overview of all other telescope status (Figure 7), and non-laser telescopes, which are only provided with information concerning their status with respect to the laser telescopes (Figure 6). The GUI provides additional tools for checking the overall health of the software, for overriding parameters (such as laser sensitivity or laser status) and for manual queries.

All these processes were developed in Java with the exception of the geometric analysis engine, which was written in Java and C. The C portion is a shared library that performs a single telescope-to-laser collision calculation using calls to SLALIB astronomy library functions. Modifications to these processes were implemented for use in Paranal but kept generic to be inserted as part of the general world-wide distribution of the package.

4.3 LTCS Configuration

LTCS is highly configurable to support modifications of static and dynamic parameters and changes on the priority policies. Configurations are stored in system files, which hold the information regarding static data for the observatory (e.g. AT positions on the platform, relative to UT4, addition of new telescopes or instruments), environmental parameters (e.g. measured height of the Rayleigh beam at Paranal), instrument sensitivity table, and priority rule settings for the night (i.e. which, amongst laser and telescope, has the right-of-way in case of a collision). The latter takes into account the SciOps policies for the operation of the LGSF. The configuration files are modified by means of VLT software compatible scripts developed at ESO on a need-to basis: at least once a day, during startup, but also during the night, if, for instance, the right-of-way changes (e.g. when a telescope switches from service to visitor mode). The reconfiguration is done automatically upon change of focus on a telescope, as well as the handling of both the PARLA & 4LGSF lasers, which will coexist and be operated alternatively, with different geometrical parameters, on UT4.

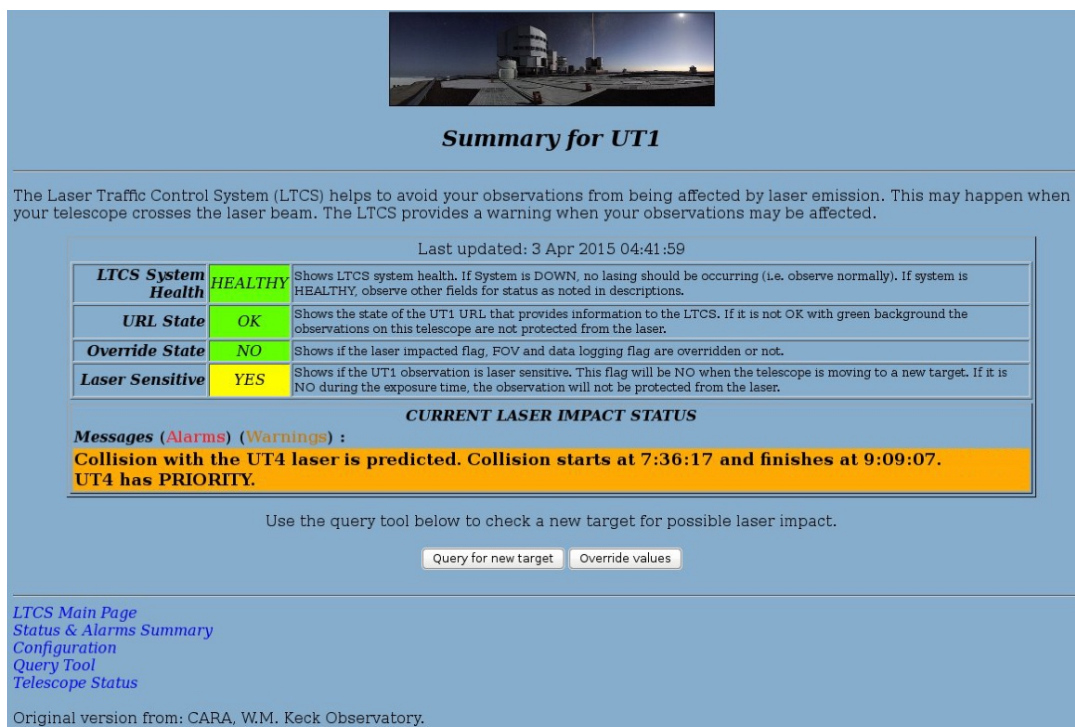


Figure 6. Non-laser telescope (UT1) panel as seen by the operators. It provides information via written and audio messages on the real-time status. In the case shown, there is a prediction of a collision where UT1 should yield to UT4.

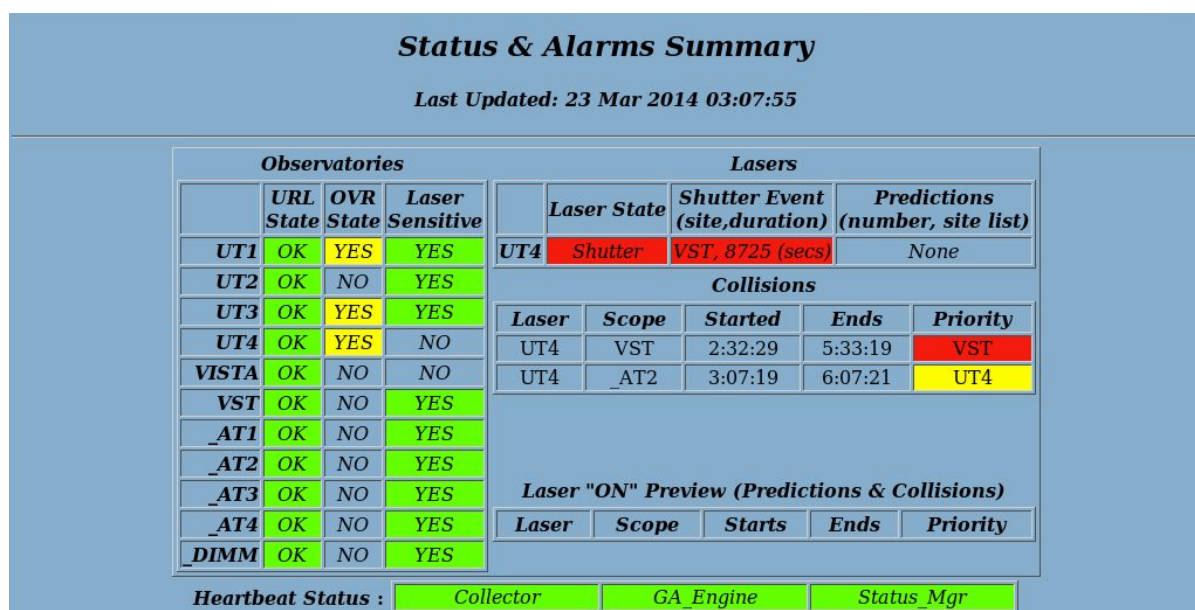


Figure 7. LTCS main summary panel as seen by the laser telescope. This panel informs the operator of the status of all telescopes at the observatory and of all collisions and predictions, including priority information and all details concerning the collision, such as start time, end time, duration, plus relevant geometric parameters.

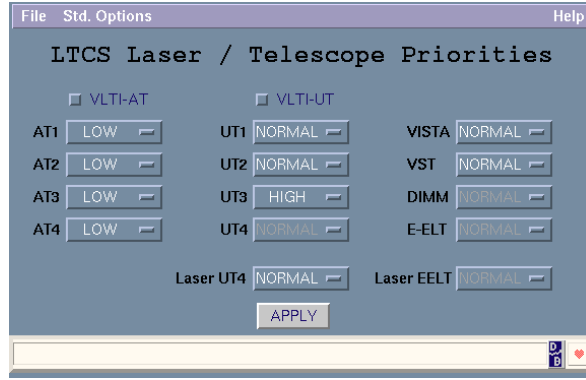


Figure 8. Configuration panel priority schemas: different priority scenarios are supported by LTCS-Paranal and dynamically configurable also during the night. Note that the panel is already planning ahead for the E-ELT!

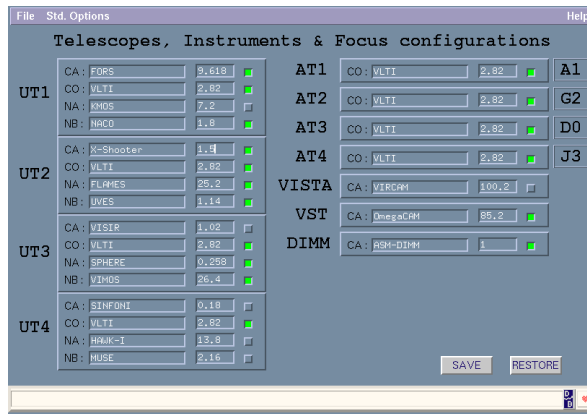


Figure 9. Configuration panel for instrument and telescope data: instruments are linked to a telescope focus and their field of view on-sky can be modified according to need. AT positions on the platform are configured daily.

4.4 LTCS Query Server

The laser collision calculation features implemented by LTCS-Paranal are made available to external clients, such as OT and vOT, through the LTCS Query Server, which can be accessed through an HTTP interface. The clients send a GET request with the target's coordinates, the field of view, the laser state and the querying telescope. The required parameters are described in Table 1.

Table 1. Query parameters

Parameter	Description
telescope	Querying telescope name
ra	Target's right ascension
dec	Target's declination
equinox	Equinox of the coordinates
fov	Field of view of the laser constellation (for laser propagators) or of the instrument (for laser impacted)
laser_state	ON-SKY if propagating the laser, OFF otherwise

As a reply, the LTCS Query Server will return one of:

- **NONE**: collision geometry calculated, no collisions detected.
- **<laser> <telescope> <start_time> <end_time> <priority>**: in case a collision has been detected, LTCS returns a space separated string with the laser propagating telescope, the laser impacted, the start and end times of the collision and the telescope with priority. The reply will contain as many of these strings (also space separated) as collisions have been detected. The collision start time might correspond to the current moment or to some time in the future. The first case means there is an ongoing collision, while the second is a prediction of a collision.
- **LTCS SYSTEM PROCESSES DOWN**: LTCS server not running.
- **WRONG INPUT**: the input parameter values are not valid according to the specification.

Example request:

`http://ltcs/query.php? telescope=UT4&ra=5.045&dec=27.5243&equinox=2008.12345&fov=0.022&laser_state=OFF`

Example reply:

UT4 UT3 21:00:00 21:20:31 UT3 UT4 UT3 20:30 22:45 UT4

The Query Server deals with the calculations pertaining to external queries itself instead of the core. It does access the core, however, to retrieve the dynamic pointing data of the telescopes and to access the configuration.

The duration of the observation is not taken into account. Whatever LTCS reports is the collision status for the current moment and assuming the telescopes keep the exact same pointing for a configured amount of time (e.g. 12h). Given the start/end timestamps of the collisions are clearly indicated, the operator must evaluate the risk and understand whether or not reported collisions may actually affect the observation. For instance, if a collision is predicted to start 1.5h from the current moment but the observation only takes 30 minutes, it would be safe to proceed.

5. THE OBSERVING TOOLS INTERFACE WITH LTCS

At each telescope, observatory staff and visitors have at their disposal two dataflow observing tools to facilitate operations: OT – the Observing Tool – used for Service Mode observations (i.e. “Q mode” observations submitted to ESO beforehand and executed by the observatory without the presence of the investigator), and vOT – the visitor Observing Tool – used by the visiting astronomers to create and execute their own Visitor Mode (“classical mode”) observations at the observatory or by the staff to create and execute technical observations. Both are Java Desktop applications accessing a Sybase database where all the Observing Blocks (OBs) – observation definitions – are contained. They connect with BOB – the Broker of Observing Blocks – a tcl/tk tool which interfaces the dataflow tools with the instrument software. To execute an observation, the operators typically fetch an OB with BOB, either from OT or vOT. Along this paper, OT and vOT shall be collectively designated as the Observing Tools or (v)OT, for short.

The plans to upgrade the LGSF brought new requirements to the Observing Tools: add laser collision detection features to facilitate the observation planning for the night, informing the users of any laser collisions before starting an observation. For this purpose, an interface between the Observing Tools and the LTCS Query Server has been implemented, following the same procedure as described in section 4.4 LTCS Query Server: whenever checking a given OB for a laser collision, (v)OT sends an HTTP GET request to the LTCS Query Server. While the target’s coordinates are taken from the OB, the instrument’s field of view is read from the respective Instrument Package: a set of instrument-specific text files where the field of view and instrument setup laser sensitivity information are available (see 5.1 Laser sensitivity). For the laser state on sky, the tools simply assume “ON-SKY” for queries performed at the UT4, currently the only laser telescope (subject to whether or not the OB effectively requests the usage of the laser guide star, in which case no query is even issued), and “OFF” for the remaining.

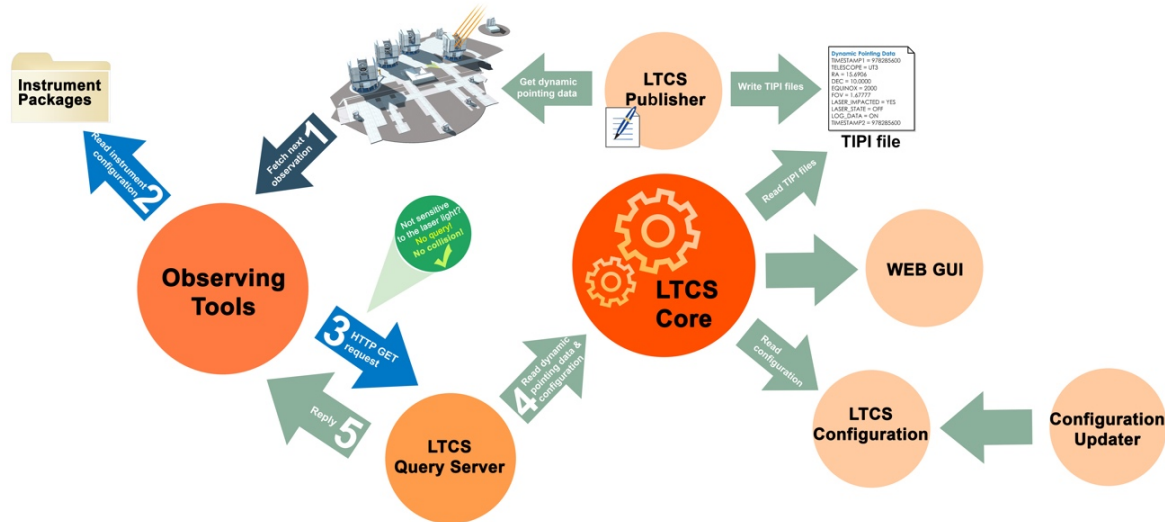


Figure 10. System diagram, highlighting the main components and their interactions. When the next observation to be executed at the telescope is fetched from (v)OT, a laser collision check is triggered. The observing tools read the field of view and the laser sensitive setups from the respective instrument package and query LTCS for the given target, if sensitive to the laser light or using the laser. The LTCS Query Server gets the dynamic pointing data and configuration through the Core. The Core, on its turn, reads the LTCS Configuration and the TIPI files produced by the Publisher with the dynamic pointing data retrieved from the telescope. The Query Server then replies with the result of the collision computation. This process allows external tools to access the laser collision computation features without the need of implementing this logic. In parallel, the LTCS Core continuously verifies the real-time telescope ‘pointings’, and through its web displays and alarms provides full information on collision events. A configuration updater makes sure that, whenever the users change a configuration during operations (e.g. priorities, AT telescope stations) this is automatically refreshed in LTCS as well, without the need of restarting the service.

5.1 Laser sensitivity

As previously mentioned, LTCS knows which instruments are sensitive to the laser light and, therefore, for which instruments observations would be impaired in case of a laser collision. For those not sensitive to the laser light, LTCS can immediately report no collision, skipping any calculations. On the other hand, the Observing Tools have access, not only to the instrument, but to the full setup to be used for an observation (e.g. which filters, grisms). Combined with the laser sensitivity setup information provided by the Instrument Packages, the Observing Tools can already perform a laser sensitivity check and to a deeper level than LTCS can achieve. This means avoiding queries for non-laser sensitive setups, simply reporting no collision. However, this can lead to discrepancies between the results presented by (v)OT and those presented by the LTCS real-time displays. For example: using OT, an operator checks a non laser sensitive OB to be executed by an instrument identified as laser sensitive by LTCS (which means at least some setups will be sensitive); OT marks the OB as collision-free and the operator sends it for execution; yet, because there is an ongoing geometrical collision with the laser beam, LTCS alarms the operator for a laser collision once execution starts. The operators have been instructed about such events, in which case they can safely ignore LTCS’ alarm and proceed with the observation. The laser-sensitivity of a given OB is always displayed in (v)OT.

In the same fashion, when checking an OB to be executed at the laser telescope for collisions, querying LTCS can also be skipped if the OB doesn’t request to use the laser – because, currently, there’s only a single laser-equipped telescope in Paranal. Table 2 summarises the query actions and returned results by the Observing Tools according to the OB’s setup. Some cases already foresee the possibility of adding further laser-equipped telescopes to the observatory, which could then act as both laser propagators and laser impacted. If the OB is not requesting the laser but it’s laser sensitive, then it must query. If the OB is both requesting the laser and laser sensitive, then two queries will have to be executed: one with the field of view of the instrument and laser status “OFF” and another one with the field of view of the laser constellation (0 for single lasers) and laser status “ON-SKY”. This feature is, however, not yet implemented in the current versions of the Observing Tools.

Table 2. Query actions executed by the observing tools

Query actions			
OB Setup		(v)OT action	(v)OT result
No laser required / non laser telescope	Non laser sensitive	No query	No collision
No laser required / non laser telescope	Laser sensitive	Query	Returned by LTCS
Laser required	Non laser sensitive	Query	Returned by LTCS
Laser required	Laser sensitive	Query as propagator and as impacted (as impacted only if there are multiple laser-equipped telescopes in the same site)	Returned by LTCS

5.2 Laser collision status

If a query is required, the Observing Tools will derive an observation's laser collision status based on the OB setup or the reply from LTCS, as follows:

- Ongoing collision:** LTCS was queried and it reported one or more collisions (more than one collision only possible for laser-equipped telescopes), and, at least for one of those collisions, start time of collision \leq current time + threshold (30s). This means that if a collision starts, at most, 30 seconds ahead of the current time, it will be reported as an ongoing collision.
- Collision prediction:** LTCS was queried and reported one or more collisions, and the earliest collision start time is more than 30 seconds (the threshold for reporting an ongoing collision) ahead of current time.
- No collision:** there are currently no laser collisions for this OB. This can happen if 1) LTCS was queried and reported no collisions; 2) The OB is on the UT4 and does not request the laser guide star (and there are no further laser-equipped telescopes); or 3) The OB is on a laser impacted telescope but it is not sensitive to the laser light (see 5.1 Laser sensitivity).
- Unknown:** it was not possible to perform a collision check for this OB (e.g. LTCS server is unreachable), or LTCS returned "WRONG INPUT" or "LTCS SYSTEM PROCESSES DOWN".
- Unchecked:** no collision check has been performed for this OB.

Furthermore, there are a few special cases for which additional rules apply, such as VLTI OBs and those grouped in scheduling containers (see 5.5 Special cases for details).

5.3 The service mode Observing Tool

With the service mode Observing Tool the operators can browse through the scheduling queues and sort and filter observations according to the current conditions with the tool's ranking engine, ORANG. Observable OBs are shown in an ordered list, ranked according to certain priority rules. From this list, the operators select a set of OBs (from the top) and send them to the execution sequence. The execution sequence is essentially a dynamic prioritised list of OBs to be executed during the night, usually composed of about 10-20 OBs at a time. The first on the list is the one to be executed next. In OT, the execution sequence is where the laser collision check takes place.

OBs in OT's execution sequence can be checked for collisions:

- Manually** on-demand by pushing a dedicated collision check button.
- Automatically** at a **given periodicity** specified in OT's configuration file (currently set to 60 seconds). This frequency doesn't need to be in the order of seconds, but it's recommended to be of less than five minutes to ensure a proper refresh of the collision status according to the current conditions.
- When **fetching** an OB from BOB for execution at the telescope.

The automatic collision check mode is configurable in the user interface. OT allows setting it to “off”, “on fetch only” and “on fetch and periodically”. Currently, it’s mandatory to have a minimal check on fetch active.

When a check is triggered through any of the above actions, OT performs a laser collision check for the first N (currently five) OBs in the execution sequence. Although the number of OBs put into the execution sequence is not that high, indeed we must consider that each telescope (each of the four UTs, the two surveys and VLTI) will be issuing several queries to LTCS. To avoid overloading the LTCS Query Server, and because the operator is, in reality, only interested in laser collisions for the OBs to be executed immediately next, we chose to limit the number of OBs for which a check is done.

For each of the first N OBs, OT first verifies if the OB is sensitive to the laser light (for laser impacted telescopes) or if the OB requests a laser guide star (for laser equipped telescopes). If it is not laser sensitive or does not request a laser guide star, then OT can simply report no collision, skipping the query to LTCS, and move on to the next OB in the sequence.

Whether or not OT should query LTCS for each and every OB – including those not sensitive to the laser light – is a configurable option. Users might still want to effectively verify if there is a collision, for instance, when using a setup other than the one originally defined in the OB (e.g. visitor filters, manual OB editing in BOB).

If a query is needed, OT sends an HTTP GET request to the LTCS Query Server and parses the reply (see 4.4 LTCS Query Server). Each row of the execution sequence is then highlighted in a different colour corresponding to its collision status (see 5.2 Laser collision status): green for no collision, orange for predicted collision, red for ongoing collision, grey for unknown collision status and uncoloured/white for unchecked OBs. Colours can also be customised upon user needs (e.g. colour blind people) in OT’s configuration file (see Table 3). In addition to the colour code, further information about the laser collision status of each OB is also provided by OT. When selecting a given row, a collision details panel displayed below the execution sequence table presents detailed information about the collision check, including whether or not a query has been performed, a table with the summary of collisions and predictions (start/end times, colliding telescopes, telescope with priority), the full query string and the raw LTCS reply (see Figure 12).

If the check was triggered when fetching an OB to the telescope and collisions, predictions or an unknown collision status has been detected, OT will request the user’s confirmation to proceed with the fetch. As in any other case, the ultimate decision is the operator’s responsibility (see Figure 11).

Further collision check parameters can be configured through OT’s configuration file, accessible only by the system manager (see Table 3 for details).

Table 3. Configuration parameters available in the observing tools

Parameter	Description
Laser collision check support	Allows to completely enable/hide the laser collision check features
Laser telescopes	List of the laser-equipped telescope names
VLTI UT baseline telescopes	List of all telescopes that can be part of UT baseline configurations
VLTI AT baseline telescopes	List of all telescopes that can be part of AT baseline configurations
LTCS server URL	LTCS server URL
Default collision check mode	Collision check mode set by default when the tool starts: on fetch, on fetch and periodically (OT only) and off
Top N OBs	Top number of OBs to check for collisions in the execution sequence (OT only)
Collision check frequency	If periodic check is active, defines the frequency in seconds (OT only)

Query timeout	LTCS query timeout in seconds
Time buffer	Buffer to define when is "now" in seconds (collision now if "collision time" + "buffer" <= "now")
Lookback time tolerance	When translating a time (from LTCS's reply) into a timestamp, the considered date is always in the future from "now", where now = machine time - lookback time tolerance (in seconds)
Highlight/font colours	Background and font colour codes for the different collisions statuses

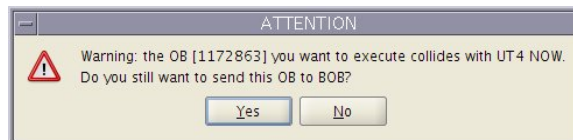


Figure 11. Fetching an OB for execution triggers a laser collision check. In this case, an ongoing collision was detected and the tool asks the user for confirmation to proceed with the operation.

Observing Tool 3.5.2

File Queues Reports Finding Charts Readme Ephemeris File

OT Queues

Execution Sequence All Queues Open Queues

Move To Top Move Up Move Down Display Finding Charts View Display Text Collision check

OB ID	OB name	Container ID	Prog.ID	Status	Laser Sensitive	Requests Laser	OB comment	Inst comment	Cont...
200347844	LaserTest		60.A-9253(H)	+	✓	✓	No	No	
1135284	J0901_LGSnot...		094.A-0568(A)	A	✓	✓	Yes	Yes	
1215080	WFM_Standard...	1215075	095.C-0149(A)	+	✓		Yes	No	
1215076	MOV_WFM_Jup...	1215075	095.C-0149(A)	+	✓		No	No	
1218634	V777Mon_3	1218633	095.D-0390(A)	+	✓		Yes	Yes	
1218637	PSF_V777Mon_3	1218633	095.D-0390(A)	+	✓		Yes	Yes	
1080856	11097084	1080841	093.C-0213(A)	+	✓		Yes	Yes	
1115741	WFM_QSO_B05...		094.B-0304(A)	A	✓		Yes	No	
200322022	LTT3218-E-std		60.A-9900(T)	M	✓		Yes	No	

Collision check done <---> Date: Thu Apr 02 05:44:05 GMT 2015

Collision Details Ob Tree View

OB ID: 200347844

Collision checked on: 2015-04-02T05:44:05 UTC

OB collision status: COLLISION NOW

COLLISIONS				
Start	End	Laser telescope	Telescope	Priority
2015-04-02T05:44:04 UTC	2015-04-02T07:16:14 UTC	UT4	UT2	UT2
2015-04-02T05:54:50 UTC	2015-04-02T07:27:04 UTC	UT4	UT3	UT3

DETAILED INFO

Reply:
UT4 UT2 5:44:04 7:16:14 UT2 UT4 UT3 5:54:50 7:27:04 UT3

Request:
http://wltcs.pl.eso.org/lts/screens/query.php?telescope=UT4&ra=14&dec=-65&equinox=2000&fov=0.003&laser_state=ON-SKY&ob_id=200347844

Automatic laser collision check: on fetch and periodically every 60 seconds

Figure 12. OT's main view showing the execution sequence after a laser collision check. The selected OB, created for test purposes, has one ongoing collision and a collision prediction, as reported on the bottom collision details panel. This was running on the laser telescope, the UT4, hence the possibility to have multiple collisions/predictions.

5.4 The visitor Observing Tool

vOT offers a user interface very similar to P2PP, the Phase2 Proposal Preparation Tool used to prepare and submit observations to ESO outside of the control room. The main view displays the logged-in user's observing runs, under which new observation or calibration blocks can be created. Although under implementation at the time of writing, the current version of vOT in operations does not include an execution sequence like OT. Once preparation is done, the observation to be executed next must be selected from the main view and can then be fetched with BOB. When fetching an OB from vOT, the same rule applies: a collision check is performed before sending the OB to BOB and, in case a collision or a prediction of a collision are detected, the operator is requested to confirm the operation.

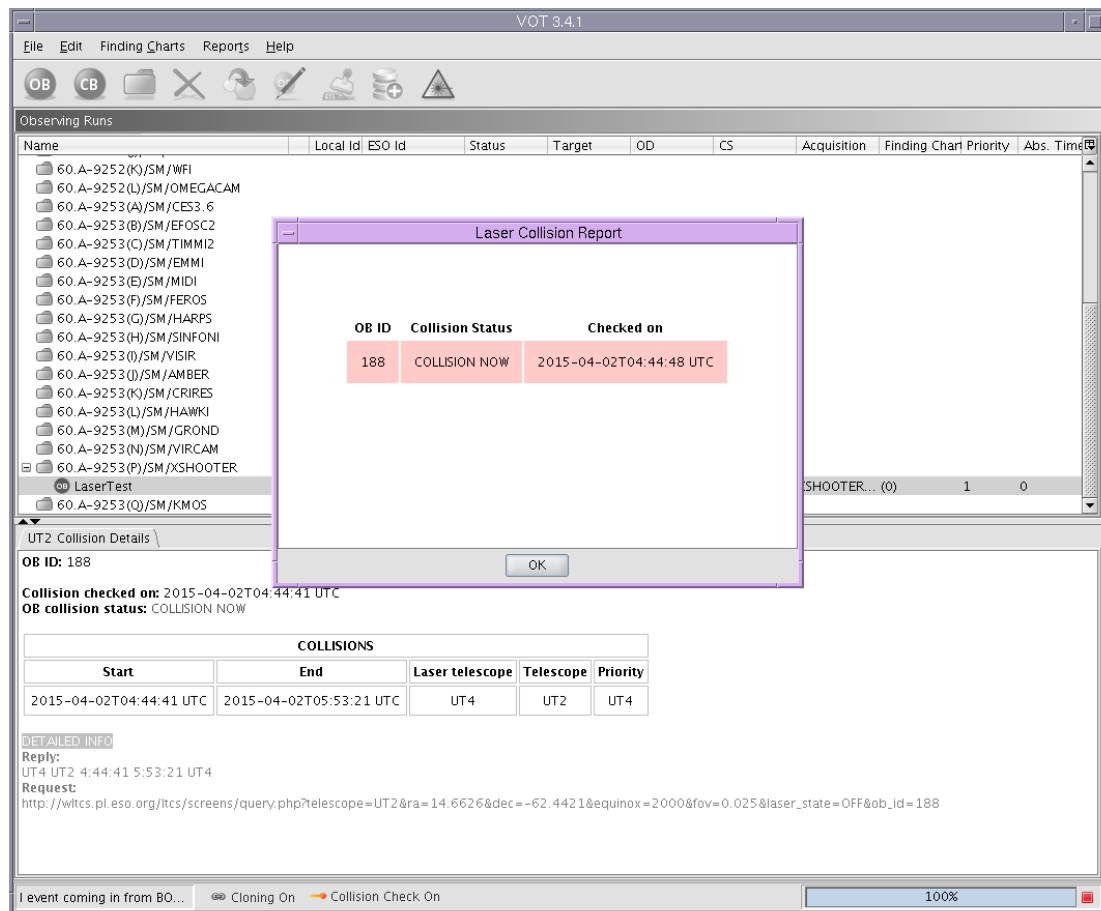


Figure 13. vOT showing the summarised report after a laser collision check on the selected OB.

The users can also manually check on-demand one or several OBs for laser collisions by selecting them in the main view and pressing the collision check button. For simplicity, given this is a visitor tool, a dialog is displayed with a very summarised collision report, highlighting each OB in the respective collision status colour (Figure 13). After dismissing the report, the users can still access the detailed information OT provides in a similar collision details panel.

5.5 Special cases

The Very Large Telescope Interferometer

When defining an observation for the Very Large Telescope Interferometer, users must specify the preferred telescope configuration, that is, the set of telescopes or base stations to use. For UT baselines, this simply corresponds to a list of UT

telescopes (e.g. UT1-UT2-UT4), while for the movable ATs, the concrete positions on the platform (base stations) are selected (e.g. K0-D2-G0). Currently, AT/UT mixed baselines are not supported.

Even though the user does specify a preferred baseline at observation preparation, this does not warrant it will be effectively used at observation execution. There is the possibility that an alternate baseline, which equally fulfills the observation's requirements, will be used instead due to operational/technical reasons. This decision is done in real-time at the telescope and, therefore, the Observing Tools do not have access to this information.

In a simplified approach, the agreed solution was to leave baseline selection to the operator. The Observing Tools for VLTI include a telescope configuration selector with three options: ATs, UTs and ATs + UTs (envisioning future support of mixed baselines). Before a given observation, the operator must choose what kind of configuration will be used. The tools then query LTCS for each telescope included in the selected set: for ATs, AT1-AT4; for UTs, UT1-UT3; and for ATs + UTs, all of the previous. There is obviously no need to query UT4 against itself, and the fact that VLTI does not use the laser when operating on the UT4 simplifies the logic. The telescopes each set is composed of is configurable and, therefore, if Paranal includes further laser-equipped telescopes, this can be easily addressed.

For laser-sensitive VLTI OBs, the overall collision status will match the worst result of all queries: collision, if there is at least one collision report; unknown, if it was not possible to determine the collision status for at least one telescope (and it might be a collision); prediction of collision, if all collision statuses are known, there are no ongoing collisions and there's at least one prediction; and no collision, if all telescopes are non-colliding.

The screenshot shows the 'Observing Tool 3.5.2' window. The top panel, 'OT Queues', displays a table of observation queues. Several rows are highlighted in red, indicating collisions. The bottom panel, 'Collision Details', shows the results of a collision check for observation 1156106. It indicates a 'PREDICTED COLLISION' and provides a table of collisions.

Start	End	Laser telescope	Telescope	Priority
2015-04-02T00:55:43 UTC	2015-04-02T01:47:45 UTC	UT4	AT3	UT4

The 'Collision Details' panel also shows the 'OB collision status' as 'PREDICTED COLLISION' and the 'Container collision status' as 'COLLISION NOW'. It includes a 'Request' section with a list of URLs for querying the LTCS.

Figure 14. OT running on the VLTI, displaying the execution sequence after a laser collision check. The execution sequence shows several OBs with ongoing collisions (highlighted in red), some of which belong to concatenations. That's the case of the selected OB. As can be seen in the collision details in the bottom panel, the OB does indeed have a predicted collision but, because it's part of a concatenation where other OBs have ongoing collisions, the reported status is "COLLISION NOW". Since this is on the VLTI, a dedicated radio button allows the user to select the telescope configuration to query for. In this example, a query was performed for all the ATs and all the UTs.

Since we query for the full set of telescopes of each baseline type, the colliding telescope(s) may, in the end, not be used for that observation. In conclusion, for VLTI, operators have some added responsibility: it is their task to properly assess if the reported collisions are actually affecting the observation or not. The tools clearly provide the result of each individual query in the details panel, and through the collision summary table one can easily identify the colliding telescopes – if those are not to be used, the collisions can be ignored. Once the observation starts, LTCS will not report a false collision or prediction because it knows exactly which telescopes VLTI is using in real-time.

Scheduling containers: concatenations

To support different observation strategies, mainly motivated by the survey telescopes, ESO's tools offer the possibility to define so-called "scheduling containers" for service mode observations. Scheduling containers are sets of OBs to be executed according to certain rules. One of these containers are concatenations, which can be seen as a "super OB": OBs belonging to a same concatenation must be observed consecutively.

OT must, therefore, have special rules to handle concatenation OBs and this includes the laser collision check. Once selected for execution, all OBs belonging to the same concatenation are put into OT's execution sequence in a consecutive order. Since they are to be treated as a single "super OB" and must be consecutively executed without interruption, if one of the OBs in the concatenation reports an ongoing/predicted collision or has unknown collision status, this can pose a problem for the entire concatenation.

As such, for concatenation OBs:

- 1) OT first checks all individual OBs for laser collisions, exceptionally including OBs that may already be outside of the configured top N OBs in the execution sequence.
- 2) For each OB in the concatenation, the indicated laser collision status shall match the worst of all the collision reports for each of the individual OBs in the same concatenation: collision, if there is at least one OB in the concatenation with an ongoing collision; unknown, if it was not possible to determine the collision status for at least one OB (and it might be a collision); prediction of collision, if all collision statuses are known, there are no ongoing collisions and at there is at least one OB with a collision prediction; and no collision, if all OBs are non-colliding.

The collision details panel provides extra information, such as the specific collision status of each OB.

Because the observatory's nights are highly dynamic, it's not granted the collision status will be maintained for too long. One cannot know whether or not new collisions will arise later during the concatenation's observation. Once again, such a collision case requires human judgement on which has higher priority/lower negative impact: finishing the concatenation or executing the competing colliding observation. Conversely, and because it is possible to know exactly which OB(s) in the concatenation effectively have an ongoing collision, the operator may decide to go ahead if the colliding OB is only to be observed hours ahead.

Moving targets

Another special case to take into consideration are moving targets. Any OB not used for calibration must define its target coordinates. In addition, an OB can include:

- 1) Proper motion in right ascension or declination
- 2) An attached ephemeris file

In these two cases, from the Observation Tools' perspective, they are considered moving targets.

At observation time, the original target coordinates must be adequately transformed into the current ones. The first case is handled at the telescope – the observing tools simply pass on the information. In the second case, the current coordinates must be derived from the attached ephemeris by the tools before-hand.

Thus, for determining laser collisions, the “real” target coordinates must be calculated for both cases. Because LTCS only expects the current right ascension, declination and epoch, the tools must properly handle both moving target cases and query LTCS with the current coordinates – where current means at the time of the collision check. For targets with proper motion, it is important to follow the same calculations done by the telescope at execution time to ensure accurate results.

Observations bypassing the observing tools

Not all observations must be originated in OT or vOT. BOB can load observation definitions and send them directly to the telescope. In this case, users either resort to the LTCS manual query interface to check for laser collisions before observing, or they execute and wait for the alarms to ring. Furthermore, even if an observation is fetched by BOB from the Observing Tools, we’ve seen that it’s still possible to manually edit them. If any critical parameter is changed, such as a filter or coordinates, it’s possible the collision result reported by the tools before fetching does not correspond to the reality anymore. Once again, LTCS’ real-time capabilities shall alert the user of the eventual collision risks in such situations.

6. CURRENT STATUS

The Observing Tools have been tested in integration with LTCS during a mission to Paranal by the end of March 2015. After a trial period, the laser collision avoidance system has been in operations since April 2016. Being a new system and introducing a few changes to the way of operating, some further training and experience is still required till the users get fully acquainted with it. Nevertheless, feedback has been positive and the observatory staff is progressively recognising the usefulness of the laser collision traffic control system. Without it, and especially after the installation of the four lasers, resorting to the old way of evaluating laser collisions would be difficult, unpractical, and cause an overly conservative number of observations to be aborted or postponed – while others might have gone undetected.

While already foreseen, support for further laser telescopes must still be implemented in the Observing Tools. More importantly, in the near future, the Instrument Packages must be updated to include the field of view of the laser constellations, required for each instrument using the 4LGSF. Currently the tools only support PARLA (i.e. send 0 for the field of view for any laser telescope query).

7. THE FUTURE: CHALLENGES AND OPPORTUNITIES

For an astronomical observatory, the future is expected to bring more telescopes and more instruments, which means more challenges. The La Silla Paranal Observatory is of no exception. In a near future, ERIS, at the Cassegrain focus of UT4, may bring some challenges, as it will be able to use any single one of the four lasers – and this decision might be taken in real-time, therefore the configuration is not known beforehand when querying. The Query Server only knows configuration in use: if querying for a different one, results are sometimes not reliable.

Given the dynamic nature of the observatory, the validity of the query is limited, being less and less significant the further away an OB is from being executed. In practical terms, the only significant query is the one sent just before an OB is fetched – this particular check is compulsory. Even if the Observing Tools at each telescope console have a number of OBs to be executed in their execution sequences, given there are so many variables, it’s not granted they will indeed be executed next: weather conditions can change, a target of opportunity may take over priority, visiting astronomers may point to whatever target within their proposal, at any time. The interface between Observing Tools and LTCS offers an auxiliary planning tool but does not replace human judgment. This is especially true for VLTI, as the baseline is decided at observation time. In any case, LTCS and its web displays and alarms are there to support the real-time scenario.

Observation priority, in case of collision, is another item requiring human assessment. While the system’s highly configurable rules cover many different scenarios, the reported priority is still only a recommendation. In particular, no automated laser shuttering is foreseen. The operators should take the appropriate action in a case-by-case basis. For instance, the scientific priorities are not defined at observatory level, and therefore the right-of-way between laser and telescope cannot be decided based on scientific merit.

The fact that the laser sensitivity information is deeper for the Observing Tools than for LTCS raises some false alarms and discrepancies in the results. If this is shown to be an issue, one must consider extending LTCS to access the same sensitivity calculation logic of the Observing Tools.

Further ahead, the European Extremely Large Telescope, the E-ELT, will populate the top of the nearby Cerro Armazones propagating even more lasers into the sky. When this happens, if not before, the E-ELT and the UT4 will both be acting as laser propagators and, potentially, laser impacted. This will create more complex scenarios, even though the system has already been designed taking into consideration the possibility of adding further laser telescopes to the observatory.

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