

# The First Component of the Adaptive Optics Facility Enters Operations: The Laser Traffic Control System on Paranal

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The Laser Traffic Control System (LTCS) entered routine operations on 1 October 2015 at the Paranal Observatory as the first component of the Adaptive Optics Facility (AOF). LTCS allows the night operators to plan and execute the observations without having to worry about possible collisions between the AOF's powerful laser beams and other telescopes with laser-sensitive instruments. LTCS provides observers with real-time information about ongoing collisions, predictive information for possible collisions and priority resolution between telescope pairs, where at least one telescope is operating a laser. LTCS is now deployed and embedded in the observatory's operational environment, supporting high configurability of telescopes and instruments, right-of-way priority

rules and interfacing with ESO's observing tools for Service and Visitor Mode observations.

The Laser Traffic Control System of Paranal (LTCS-Paranal or LTCS hereafter) is the first (small) piece of the Adaptive Optics Facility to enter routine operations, on 1 October 2015. Its genesis dates back to the 2009 AOF Final Design Review, when the need for a laser beam avoidance tool was recognised as the best way to support operations of an observatory equipped with four powerful lasers (MLGSF — Multiple Laser Guide Star Facility) and a large number of non-laser telescopes and instruments sensitive to laser light. Every visible-light instrument sensitive to the wavelength of the Na lines (589 nm) can “see” laser light if it enters the optical path.

LTCS encompasses software tools, both developed by third parties and within ESO, which allow the night operators to plan and execute their observations without having to worry about possible collisions between the laser beam and other laser-sensitive equipment. As requested by Paranal Science Operations (SciOps), this is an early release, which

also supports PARLA laser (Lewis et al., 2014) operations, before the AOF comes online; moreover, the tool will be fully tested in routine operations and possibly further tuned to best serve the observatory during the AOF operations era.

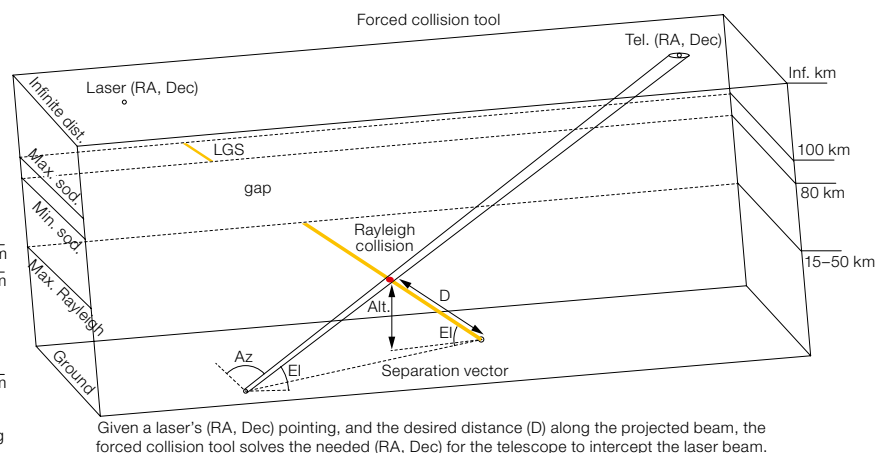
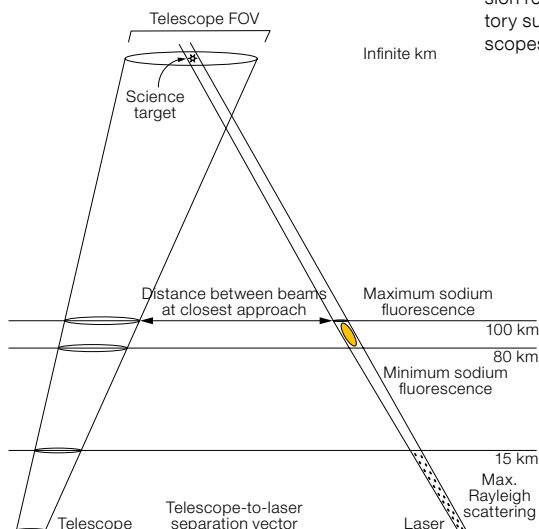
## What is a laser collision?

The collision geometry is shown in Figure 1. To quote Summers et al. (2003): “a 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”.

A common misconception is that, if two telescopes point to the same target, there is necessarily a collision — this is not always the case. On Paranal this is only true for the Very Large Telescope (VLT) Unit Telescope 4 (UT4) and the VLT Survey Telescope (VST) operating OmegaCAM. More importantly, collisions are possible when telescopes are pointing to different targets (see Figure 1).

Figure 1. Left: Schematic representation of the geometry involved in the interaction between a laser and a non-laser telescope (Summers et al., 2003; 2006). 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). Right: 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 (RA, Dec) of a laser pointing and the desired distance along the projected beam (D), the tool solves the needed (RA, Dec) for the telescope to intercept the laser beam and produces a Rayleigh collision at an altitude (Alt).



Laser-light contamination can adversely affect telescope operations (Amico et al., 2010), such as guiding systems and active optics, monitoring systems and science frames. Examples of the latter, images and spectra, were obtained in the 2014 LTCS commissioning run with the PARLA laser. In the case of UT3 and the VST, they are at higher risk of collision due to their proximity to UT4 (57 and 80 metres respectively), but in general for all telescopes at the observatory, light contamination can significantly affect optical imaging and spectroscopy. Figure 2 shows an image of the Rayleigh beam as seen by the FOcal Reducer and Spectrograph (FORS2) and a spectrum taken with the 1200R grism. Figure 3 shows an image of the laser beam and spot as seen by OmegaCAM on the VST.

### LTCS: Laser Traffic Control System

LTCS is a system that comprises four main components, as shown in Figure 4:

- 1) LTCS Publisher: An ESO application that provides and updates files containing the Telescope and Instrument Position Information (TIPI) for each telescope, as required by the LTCS Core process for assessing the beam collision geometry when the laser is propagating. The LTCS Publisher collects the dynamic pointing data and the telescope configuration (focus in use) in real time from the telescope databases.
- 2) LTCS Core: A third-party application, originally developed for Mauna Kea (Summers et al., 2003; 2006), 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 with LAMP extension. The processes are the collector, the geometric analysis engine, the status manager and web displays and have the following functions:
  - a. The collector sends position updates only when the change in telescope positions is sufficient to warrant recalculation of prediction data;
  - b. The geometric analysis software calculates and predicts collision events for all telescopes that are sensitive

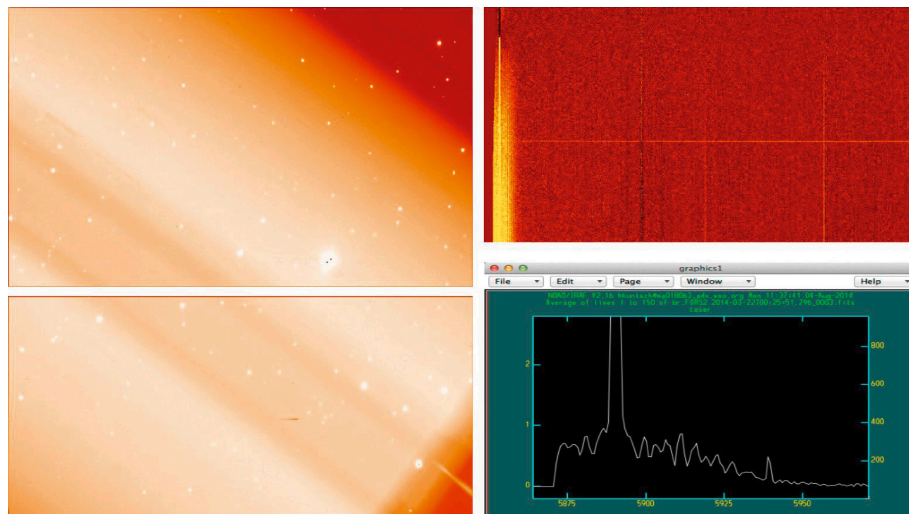


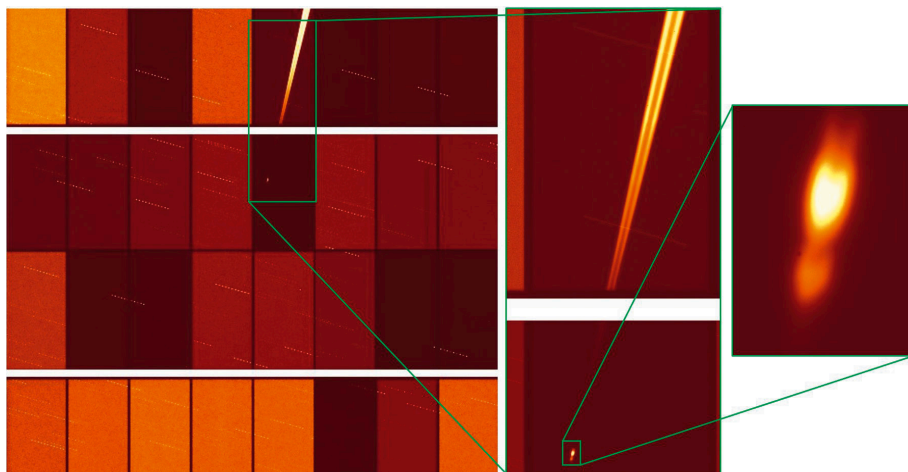
Figure 2. Left: FORS2 1-second acquisition image (chip1 and chip2) of the Rayleigh beam. The beam brightness peaks at ~ 500 counts above the sky background. Upper right: 60 s 1200R spectrum of the Rayleigh beam as seen by FORS2. Lower right: Plot of the line profile of the Rayleigh beam as observed with the FORS2 1200R grating. Assuming that the wings are symmetric, the total width is 12 nm. 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 0.222 nm.

- c. The status manager and web displays provide interface to the users. The graphical user interface (GUI) is different for laser telescopes, which are provided with a full overview of the status of all other telescopes, and non-laser telescopes, which only receive information concerning their status with respect to the laser telescope(s) (see Figure 5). 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 which performs a single

telescope-to-laser collision calculation using calls to the SLALIB astronomy library functions. Modifications to these processes were implemented for use at Paranal, but kept generic so that they

Figure 3. OmegaCAM 20 s image with details of the laser beam, including the Rayleigh cone and the sodium fluorescence spot. There is an increase of  $\geq 2000$  counts above the sky level. The test was done at zenith with no telescope tracking.



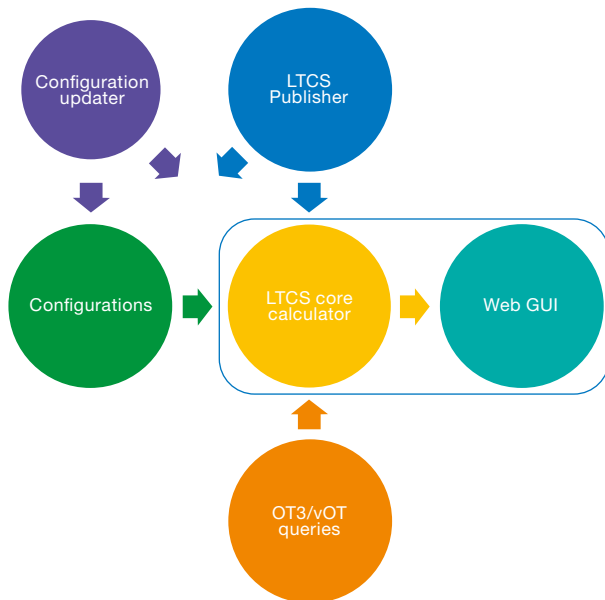


Figure 4. Schematic representation of LTCS-Paranal. Its four main components are included (see text). In addition, the configuration updater allows the user to re-configure the system and restarts the appropriate process of LTCS-Core once a configuration change is committed.

can be inserted as part of the general worldwide distribution of the package, since LTCS has been deployed to various observatories in the world after Mauna Kea (Summers et al., 2012).

- 3) Configurations: Files with the information regarding static data for the observatory (e.g., Auxiliary Telescope [AT] positions on the platform), environmental parameters (e.g., measured height of the Rayleigh beam at Paranal), instrument sensitivity table, and priority rules for the night (e.g., which, between laser and telescope, has the right of way in case of a collision). The latter take into account the SciOps policies for laser operations. The configuration files are modified on a need-to basis by means of VLT-software compatible scripts developed at ESO: 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 Mode [SM] to Visitor Mode [VM]). The reconfiguration is done automatically upon change of focus on a telescope, as well as the handling of both the PARLA and MLGSF lasers, which will coexist and be operated alternately on UT4.

- 4) Query Server + Observing Tools: External clients, such as the Observing Tool (OT) and visitor OT (vOT), can interface directly to the external query server. The query server deals with the calculation of external queries itself, instead of the core calculator; however, it accesses the LTCS database for information on dynamic pointing data.

The LTCS implementation is meant to be operated stand-alone: all processes are running in background, and no manual operation is required to update the configurations, except for setting the night-time priorities between telescope pairs (UT4 vs. non-laser telescope). The only interface to the users is through a web browser and PHP queries from OT/vOT.

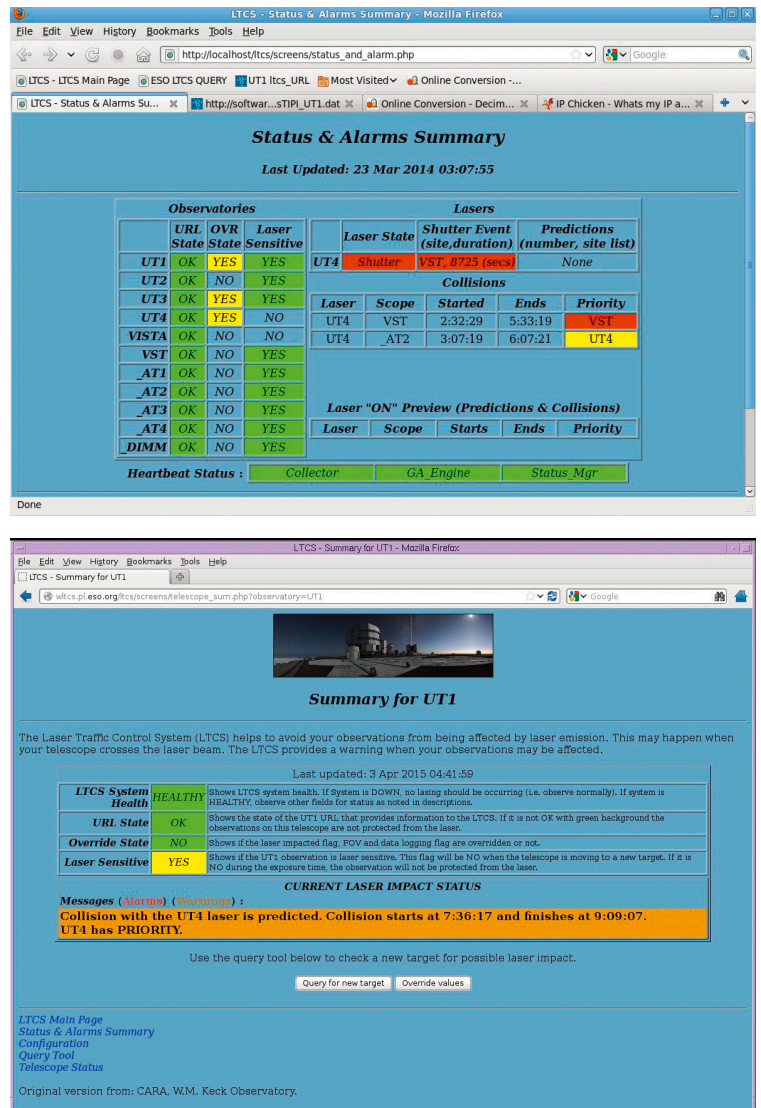


Figure 5. Upper: LTCS Main Summary panel, as seen by the laser telescope. This panel informs the operator of the status of all telescopes at the observatory and of all collisions and predictions, including priority information and all details concerning the collision, such as start time, end time, duration, plus relevant geometric parameters. Lower: Non-laser telescope (UT1) panel, as seen by the operators, 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 has to yield to UT4.

## OT/vOT interface to LTCS

The Observing Tool and the visitor Observing Tool are Java desktop applications used on Paranal to perform Service and Visitor Mode observations, respectively. With the OT, the operators can browse through the Observing



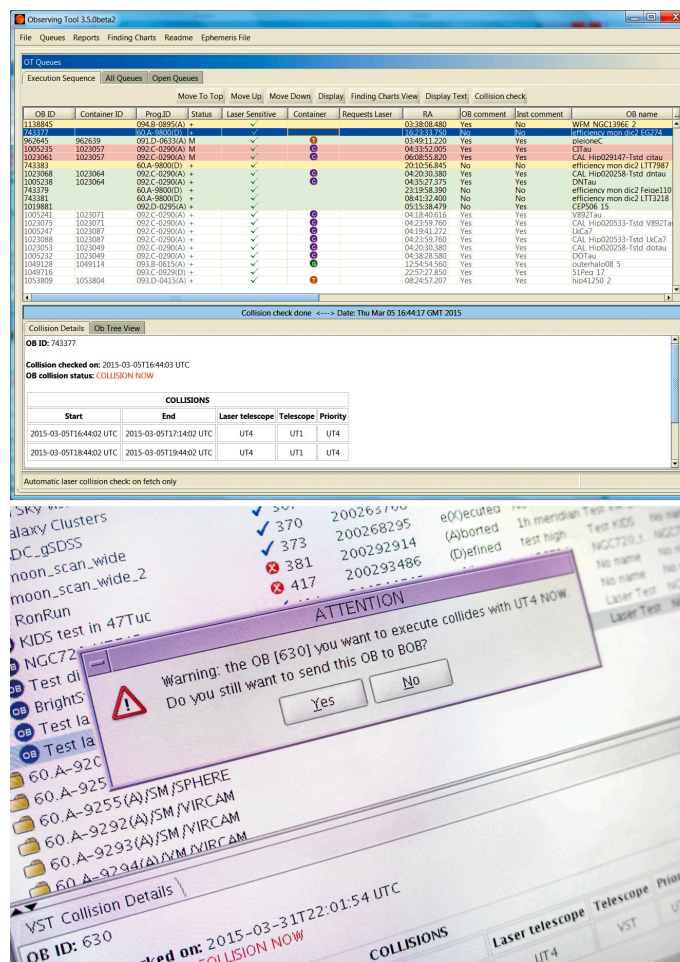
Blocks (OBs) in the queues and, through OT's ranking engine (ORANG), filter and sort (rank) them according to the current conditions. The OBs to be executed next are then put into an execution sequence from where they can be fetched with BOB (Broker of Observing Blocks) for observation. vOT, with very similar features to P2PP, the service mode Phase 2 Proposal Preparation tool, also interfaces with BOB and is mainly used by the visiting astronomers to create and execute their OBs.

The AOF project brought new requirements to OT and vOT: adding laser collision detection features to facilitate the short-term observation planning; and informing the users of any laser collisions before starting an observation in a what-if scenario (e.g., what if I started this observation now, would there be any laser collisions?).

To fulfil this requirement, these tools now interface with LTCS, asking this question through an HTTP get request that includes the telescope, the target's coordinates and equinox, the instrument field of view and the laser state on sky. As a reply, LTCS sends a list of ongoing/future collisions, including the colliding telescope pair, the start/end of collision and the telescope with priority — or “none” if there are no collisions.

In OT, this check is done on the OBs in the execution sequence, either on demand, by pressing a collision check button, or automatically at a specified frequency. Most importantly, given the dynamic nature of the Observatory, a check is automatically performed whenever the user fetches an OB for execution. If collisions or predictions are detected, the OT requests confirmation to proceed. In the execution sequence, the OBs are highlighted according to their collision status: green (no collision), orange (predicted collision), red (collision now), grey (unknown) and white (unchecked). Collision details are displayed upon selection of the OB (Figure 6).

In the vOT, the user can also check for collisions on demand, by selecting the OBs and pressing the collision check button. Once the check is done, vOT displays a report with basic collision infor-



**Figure 6.** Upper: Snapshot of OT execution sequence as tested in March 2015. The colour-coding informs the operators of the possibility of collision if the OBs were executed right away. The semaphore logic applies in all cases: green means no collision; yellow means prediction of a collision; red means collision; grey means the collision status is unknown; and white means no checks were performed. The tool deals with all possible aspects of operations, including flagging equally OBs in a concatenation, dealing with multiple telescope queries for VLTI, etc. Lower: Photo of a monitor in the Paranal Control Room showing vOT after an OB was fetched for execution. A dialogue is presented to the user, informing that a collision will happen if the selected OB is started and requesting confirmation before proceeding.

mation — further collision details are displayed once the report is closed. Again, an automatic collision check is triggered on fetching an OB.

For the VLTI, both tools include an option to select the baseline: all ATs, all UTs or all UTs + ATs. The collision check is performed for all telescopes included in that baseline, and it is the operator's task to analyse the result and understand if the reported collisions present an impediment, depending on which telescopes are effectively being used for each VLTI observation.

Since the observing tools have access to the full OB setup, they can evaluate whether or not an OB is laser sensitive. Information on which setups are sensitive is read from the instrument configuration files in the Instrument Packages. If an OB is not laser sensitive, no checks need to be done with respect to UT4 (laser tele-

scope) — these OBs are therefore shown as green. Nevertheless, there is an option to force the collision check, which is useful when using a different setup other than that specified in the OB (e.g., visitor filters), or manually edit it in BOB. In the same fashion, when starting an OB from UT4, a check for possible collisions with observations on other telescopes is only done if UT4 uses the laser guide star.

The first versions to include these features were OT3.5.0 and vOT3.4.0, deployed and tested at the Observatory in integration with LTCS during the March 2015 mission to Paranal. These versions have been in use since 1 October 2015.

## Operations

LTCS+OT/vOT form together a user-friendly system that supports nighttime operations with the laser. Both the real-

time operations and the what-if scenarios are supported by the LTCS GUIs (Figure 5) and the OT/vOT interfaces (Figure 6). In real time, LTCS calculates whether the geometry of the pointing of each telescope pair formed by UT4 + laser-sensitive telescope + instrument generates a collision or a prediction. Contamination from indirect laser stray light cannot be taken into account. In the what-if scenarios, LTCS is used as a predictive tool.

The tools do not replace human intervention, since the final decision to act (e.g., shutter the laser) on a collision or a prediction event is in the UT4 operator's hands. It is expected that nighttime operators will negotiate in all those cases where the collision cannot be avoided and the application of the rules, as indicated by the tools, is not efficient: for instance, in all those cases when the yielding telescope has little time left to observe and it is expected to move soon from that patch in the sky.

The tools are designed to support both SM and VM operations. The visitors, who typically have higher priority observations than SM, will be able to plan their night following the real-time recommendations of the tool. This is especially useful when more than one visitor, one on UT4 and another on a laser-sensitive instrument elsewhere, are on the mountain together.

### Future developments

LTCS has been designed with the future in mind: not only the onset of AOF operations with MLGSF, but also the case of multiple laser-telescopes, e.g., when the E-ELT comes to the observatory. LTCS can be easily configured to add or remove telescopes from the observatory survey and to redefine laser sensitivity.

Additional upgrades have been discussed with SciOps colleagues, the main users of the tools, and include:

- A first upgrade already planned for April next year, when a new version of LTCS will offer automatic nighttime reload of configuration changes, such as an OB priority change or laser constellation changes.
- LTCS configuration scripts will be modified to support all the different AOF constellation setups, to provide better collision calculations in all specific cases, including that of ERIS, the new AOF instrument foreseen for the Cassegrain focus of UT4, which has the option to use one out of the four available lasers.
- Third-party software will be fully integrated within the VLT software release (VLTSW2015) with 64-bit support, so that LTCS becomes a fully VLTSW-compliant subsystem.
- New versions of the OT and vOT also aim to support further laser-equipped telescopes on site. In such a scenario, UT4 would not only act as a laser propagator, but also as a laser-impacted telescope. After the tests carried out at Paranal, we realised that some minor

changes are still required to fully cover this scenario.

- To support the AOF, the OT and vOT will have to be modified to allow queries for all the different laser constellations.
- Lastly, the significantly different laser setup of ERIS may present some restrictions to our current assumptions and will be a topic for future discussion.

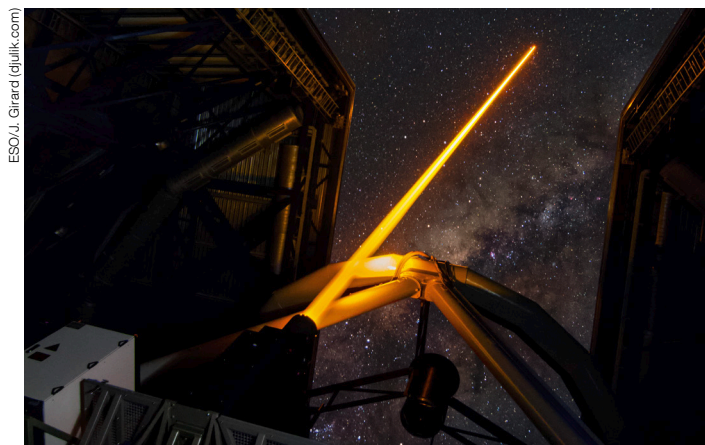
As of today, the observing tools can fully support laser collision detection with PARLA, providing a good trial period for users to become acquainted with the changes in the workflow and an opportunity to provide feedback. New versions of LTCS, to be deployed in the near future before the MLGSF starts operations, will include support for the missing functionalities mentioned above.

### Acknowledgements

LTCS-Paranal, including the update of the observing tools, was developed and commissioned thanks to the help of many contributors: the original LTCS-Mauna Kea software was courteously made available to us by the Keck Observatory; the SciOps staff, in particular S. Brilliant, A. Smette, S. Cerda, and all the operators who worked with us during the commissioning runs; M. Pasquato, who led general OT testing and support; and last but not least, the ESO Laser and Photonics group, without whose "annoying" lasers this project would not exist.

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First light of the 4 Laser Guide Star Facility (4LGSF) on Unit Telescope 4 occurred in April 2015. See Announcement eso15034 for more details.