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The crucial role of the Laser Pointing Camera in the CANAPY-ALASCA project

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THE NEW ROLE OF THE LPC

The **role** played by the LPC within the CANAPY-ALASCA project is **crucial**.
CANAPY-ALASCA is an experimental LGS-AO system, achieved thanks to a synergy between INAF, ESO, ESA, Microgate, Durham University, IAC - *refer to the related posters and talks* -).

Its cruciality was expressed in a particular way during the commissioning of the CANAPY-ALASCA: the LPC is useful not only in the purely astronomical context (VLT/E-ELT) but also in the context of the use of adaptive optics for satellite communications tests.

For the CANAPY-ALASCA project, LPC is used for the first time for Satellite Communications test.

The Laser Pointing Camera is produced by ASTREL Instruments in collaboration with INAF-OAR.

LPC @ VLT SINCE 2015

- LPC[1] has been developed by Astrel Instruments and INAF-OAR (Italian National Institute of Astrophysics - Rome Observatory) for the 4LGSF of the ESO Adaptive Optics Facility, and installed on the UT4 telescope at ESO Paranal Observatory.
- LPC is currently a fully operational instrument on UT4 at VLT, since 2015.
- The LPC allows a fast pointing of single or multiple LGS on the AO wave-front sensor (WFS) during the initial acquisition phase of the telescope preset, thus reducing considerably the overheads currently experienced in most LGS-AO systems in operation.
- By recognizing via astrometric software the field stars as well as the multiple LGS, LPC is insensitive to flexures of the laser launch telescope or of the receiver telescope opto-mechanics.
- Moreover, LPC gives regularly the photometry and FWHM of the LGS, as well as the scattering of the uplink beams at the height of 10-15 km, thus monitoring the presence and evolution of cirrus clouds.
- Finally, besides eliminating the overhead of the LGS acquisition in the AO WFS during operation, the LPC is a very powerful tool during the calibration of the lasers pointing and WFS wobbling during LGS-AO systems commissioning.

LPC1 on the Maksutov

THE NEW LPC

The LPC camera has been customized for the CANAPY-ALASCA[2,3] project (see posters related) in order to extend the LGS observable wavelength range from the current 400-750 nm to the near infrared region including 1064 nm.

The software capabilities will also be improved adding a custom routine for aligning the visible and infrared lasers and for detecting automatically the signal by the satellite and applying offset to the telescope to center the satellite downlink in the field of view of the WFS, as required by the project.

NEW CHARACTERISTICS

The CANAPY-ALASCA LPC is very different from the first LPC instruments installed at VLT almost 8 years ago: almost all the aspects of the LPC where improved.

NEW SENSOR : Sony IMX492 CMOS !
Respect to the old sensor @ VLT (KAF8300 CCD):
- Readout noise lowered from ~7e- to <2e-
- Peak QE raised from ~55% to ~82%
- Resolution raised from 8Mpx to 47Mpx unbinned
- Readout time lowered from ~6s to 1/3s

NEW COMPUTING CAPABILITIES: 4 cores Intel at 1.8GHz !
Respect to the old architecture @ VLT (single core ARM926 at 456MHz, 128Mb of DDR2 memory, 128Mb flash of storage, 100Mbit Ethernet and USB 2.0 with only allowed a basic Linux OS on board):
- 4Gb DDR4 memory
- 32Gb of flash storage
- 256Gb SSD disk
- 1Gbit Ethernet and USB 3.0
- running a standard Ubuntu Linux distribution

Main result: time of the LPC LGS position calculation reduced from 20/40s to ~3/6s !

NEW FORM FACTOR: all in one !
Respect to the old form factor @ VLT (distributed in two parts: the calculation engine inside the camera body and the peripheral interface on a separate board mounted on the telescope frame):
- the peripheral interface electronics moved inside the camera body too: the camera body embeds a large number of interfaces that can directly control the motors and sensors that are eventually needed by the specific LPC implementation.

Commissioning ALASCA during May 2024: LPC brings the ALPHASAT downlink on the ALASCA IR Pyramid WFS

LPC CONCLUSIONS

- The LPC has proven and is proving crucial for the commissioning of the CANAPY/ALASCA project.
- Its technical specifications and versatility make it not only a precious but necessary and strategic tool for facilities that use laser technology for adaptive optics, both for large telescopes (VLT/E-ELT) and for medium ones.
- Furthermore, the first use in the field of satellite communication has highlighted its potential also in other research areas, not strictly astronomical.
- Nowadays the most modern telescopes use LPC to solve the problems we have faced and described so far.
- And perhaps it will also solve new unknown problems that the future will bring.

THE NEW LPC AT the OPTICAL GROUND STATION
(OGS, Teide Observatory - TENERIFE)

Two new LPCs have been installed at ESA's Optical Ground Station, Teide Observatory in Tenerife.
The LPC1 is installed on a Maksutov telescope (FL 1.8m, PS 1.1"/pix) and the LPC2 on a refractor telescope (FL 3 m, PS 0.6"/pix).
Both telescopes are attached to the OGS main telescope, as guiders.

The two LPCs are part of the CANAPY/ALASCA instruments, installed at OGS since last year and currently under commissioning.

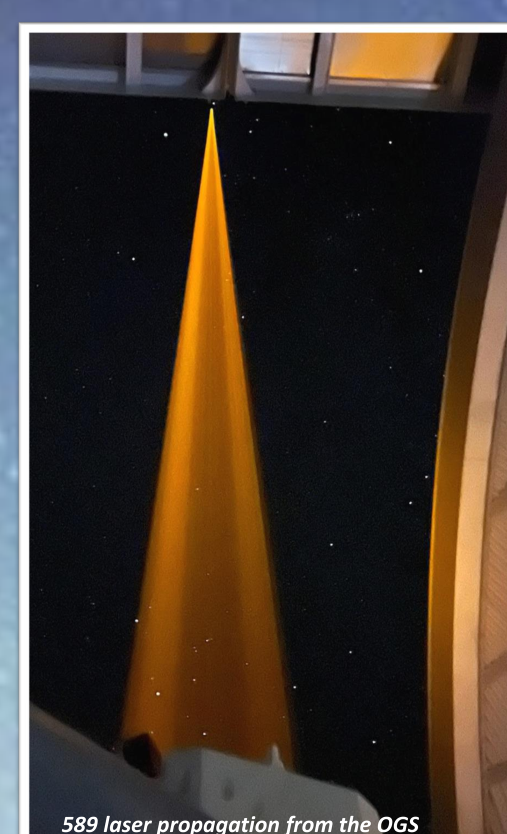
The LPC is an instrument that is included in several LGS facilities.
In particular, for the CANAPY-ALASCA projects, has multiple **roles**:

- **distinguishing** the LGS from the Rayleigh beam
- **extending the LPC use on daytime**
- **increasing the pointing precision** of the laser launch telescopes.
- **monitoring of the LGS** in terms of focus, flux and scattering levels.
- **aligning** the visible and infrared lasers.
- **detecting** automatically the signal by the satellite during the Phase1 of the link.
- **applying** offset to the telescope to move the satellite downlink exactly in the center of the FoV of the WFSs, as required by the project during the Phase 2 of the link.

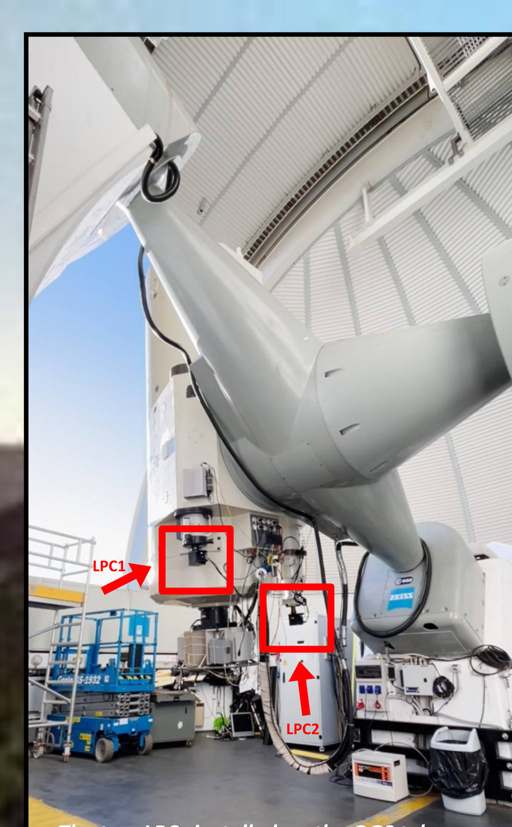
The integrated PU, being a normal PC with a Linux or Windows OS, enables **easy customization of the operations** and data that can be delivered by the LPC, meaning that it can **easily adapt to different requirements**, as it happened for the CANAPY/ALASCA project.

The LPC is designed to operate stand-alone, that is it doesn't rely on an external PC to elaborate the data it collects: it is able to deliver to the telescope system ready-to-use data using a simple protocol through Ethernet connection.

In this sense, the LPC is a full subsystem, not only a camera.



589 laser propagation from the OGS



The two LPCs installed on the OGS telescope

THE LPC FOR CANAPY

NEW CHALLENGES :

The CANAPY project introduces several challenges respect to the classical LPC systems already working on other telescopes.

1. LGS-BEAM SEPARATION

First of all, usually LGS facilities are installed on 8mt or bigger class telescopes, while the CaNaPy project, working on a much smaller OGS telescope, impose a very different system geometry: the LPC telescope is much closer to the main telescope optical axis, which is also the laser launch telescope. This geometry implies that the LGS is not well separated from the laser plume, as it happens with bigger telescopes where the LPC is much more offset respect to the launch telescopes and it looks at the LGS more sideways. The light from the plume scattering is very strong, stronger than the LGS itself, so it is difficult to isolate the LGS in this much brighter background.
The main approach to solve the problem is based on the capacity of the system to "detune" the laser frequency slightly, a condition where the LGS disappears while the plume stays almost the same. This means that we can subtract a detuned image from the LGS image and this way remove a large part of the plume light. Unfortunately the plume intensity and shape change in time, so the detuned image subtraction leaves large plume residuals, too large to cleanly reveal the LGS, especially at low elevation angles: some post processing background subtraction algorithms are needed to reduce these residuals to a manageable level.

2. DAYLIGHT USE

The CaNaPy project has to work also in daylight[4], so the LPC has to be able to reveal the 2 lasers during both day and night. This requirement can't be satisfied using only the standard LPC clear and green filter: 2 narrowband filters centered on each laser's frequency has been added in the LPC filter wheel in order to increase the contrast between the background and the laser. This is especially true for the 589nm laser, which has a frequency where the daylight is very strong, so a very narrow band filter has to be used for it (the use of the MOF filter is under evaluation).

TYPICAL PURPOSES :

3. LGS POSITION DETERMINATION

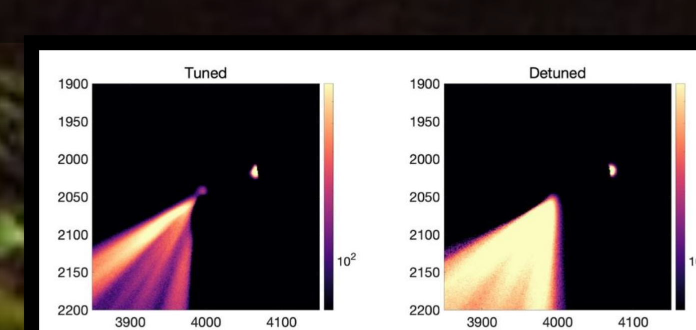
An usual task running on the LPC for CANAPY is to give to the telescope system **very precise indication of the LGS position** respect to the position in the Wave Front Sensors.

The typical pointing model accuracy on most telescopes is not enough to guarantee that the LGS is positioned in the very small field of view of the WFS, because of flexures, mechanical hysteresis, calibration errors, and so on.

The LPC looks to the LGS position in a wide field (some tenths of arc minutes) and finds out its absolute RADEC position by plate solving the stars in the field, then it converts this position to offsets respect to the expected position (the WFS field of view) and send them to the telescope system that can apply the needed corrections to the launch telescope actuators.

4. LGS PARAMETERS MONITORING

Another usual task performed by the LPC is monitoring the main LGS parameters: FWHM, flux and plume scattering levels. This is most important, not only but especially, during LGS systems commissioning.



The LGS tuned/detuned method to solve the LGS identification (LPC1)

THE LPC FOR ALASCA

NEW CHALLENGES :

In addition to the previous tasks due to the CANAPY and the usual purposes, for the ALASCA project there are these additional challenges:

1. MULTIPLE LASERS SENSITIVITY

The CaNaPy project needs an LPC able to operate on 2 different lasers: a 589nm Sodium laser and a 1050nm infrared laser, so the CMOS sensor of the LPC camera has a spectral sensitivity extending to the infrared laser frequency, even if with a reduced sensitivity.

2. TWO LASERS ALIGNMENT

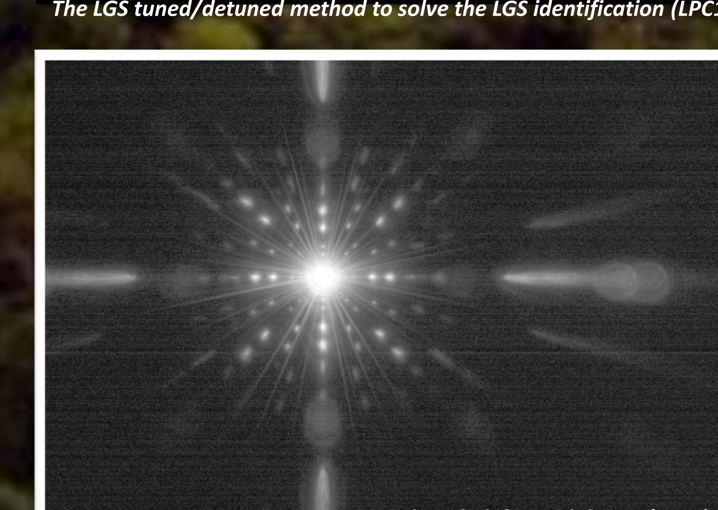
The software capabilities will also be improved adding a custom routine for aligning the visible and infrared lasers

3. SATELLITE BLIP AUTOMATIC DETECTION (PHASE 1)

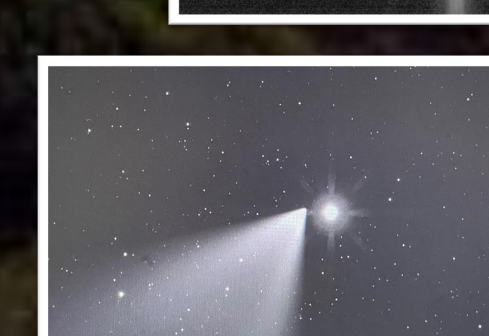
The LPC is able to **detect automatically** (in few seconds) the IR signal pulsing from the satellite (BLIP) and to **determine its position** respect to the center of the FoV of the WFS.

4. APPLYING OFFSET TO THE TELESCOPE from the SAT. DOWN LINK (PHASE 2)

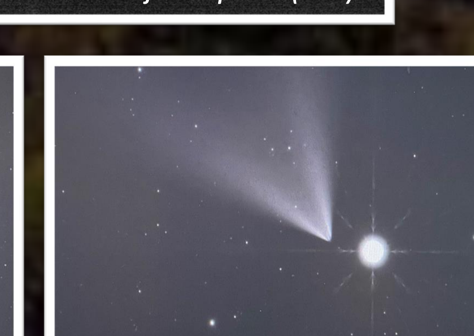
The LPC is able to apply automatically the offset to the telescope to move the satellite downlink IR signal exactly in the center of the FoV of the WFSs, as required by the project during the Phase 2 of the link.



IR downlink from Alphasat (LPC2)



IR uplink and signal from Alphasat (LPC1)



IR uplink and signal from Alphasat (LPC2)

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[1] M. Centrone, D. Bonaccini Calia, F. Pedichini, A. Cerruto, A. Ricciardi, and F. Ambrosino "Laser pointing camera: a valuable tool for the LGS-AO operations", Proc. SPIE 9909, Adaptive Optics Systems V, 99095L (27 July 2016); doi.org/10.1117/12.2233399

[2] Petr Janout, Noelia Martinez Rey, Domenico Bonaccini Calia, Renate Hinterschuster, Ralf Dieter Conzelmann, Enrico Pinna, Marco Bonaglia, Marcos Reyes Garcia Talavera, Matthew Townson, James Osborn, Marco Faccini, and Mauro Centrone "CaNaPy facility: opto-mechanical design and requirements for optimal visible systems LGS-AO", Proc. SPIE 12182, Ground-based and Airborne Telescopes IX, 1218226 (29 August 2022); doi.org/10.1117/12.2629266

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[4] Jacques M. Beckers "Laser guide stars for daytime thermal IR observations", Proc. SPIE 6986, Extremely Large Telescopes: Which Wavelengths? Retirement Symposium for Arne Ardeberg, 69860G (22 April 2008); doi.org/10.1117/12.801270

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