Publication Year	2016
Acceptance in OA@INAF	2020-07-09T10:28:00Z
Title	Design of the ERIS calibration unit
Authors	DOLCI, Mauro; VALENTINI, Angelo; DI RICO, Gianluca; ESPOSITO, Simone; FERRUZZI, Debora; et al.
DOI	10.1117/12.2233662
Handle	http://hdl.handle.net/20.500.12386/26400
Series	PROCEEDINGS OF SPIE
Number	9908

Design of the ERIS calibration unit

Dolci, Mauro, Valentini, Angelo, Di Rico, Gianluca, Esposito, Simone, Ferruzzi, Debora, et al.

Mauro Dolci, Angelo Valentini, Gianluca Di Rico, Simone Esposito, Debora Ferruzzi, Armando Riccardi, Paolo Spanò, Jacopo Antichi, "Design of the ERIS calibration unit," Proc. SPIE 9908, Ground-based and Airborne Instrumentation for Astronomy VI, 990839 (9 August 2016); doi: 10.1117/12.2233662

Event: SPIE Astronomical Telescopes + Instrumentation, 2016, Edinburgh, United Kingdom

Design of the ERIS Calibration Unit

Mauro Dolci*[a], Angelo Valentini[a], Gianluca Di Rico[b], Simone Esposito[b],
Debora Ferruzzi[b], Armando Riccardi[b], Paolo Spanò[b], Jacopo Antichi[b]
[a]INAF – Osservatorio Astronomico di Teramo, Via Maggini snc, I-64100 Teramo, Italy; [b]INAF – Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy

ABSTRACT

The Enhanced Resolution Imager and Spectrograph (ERIS) is a new-generation instrument for the Cassegrain focus of the ESO UT4/VLT, aimed at performing AO-assisted imaging and medium resolution spectroscopy in the 1-5 micron wavelength range. ERIS consists of the 1-5 micron imaging camera NIX, the 1-2.5 micron integral field spectrograph SPIFFIER (a modified version of SPIFFI, currently operating on SINFONI), the AO module and the internal Calibration Unit (ERIS CU). The purpose of this unit is to provide facilities to calibrate the scientific instruments in the 1-2.5 micron and to perform troubleshooting and periodic maintenance tests of the AO module (e.g. NGS and LGS WFS internal calibrations and functionalities, ERIS differential flexures) in the 0.5 – 1 μm range.

The ERIS CU must therefore be designed in order to provide, over the full 0.5 – 2.5 μm range, the following capabilities: 1) illumination of both the telescope focal plane and the telescope pupil with a high-degree of uniformity; 2) artificial point-like and extended sources onto the telescope focal plane, with high accuracy in both positioning and FWHM; 3) wavelength calibration; 4) high stability of these characteristics.

In this paper the design of the ERIS CU, and the solutions adopted to fulfill all these requirements, is described. The ERIS CU construction is foreseen to start at the end of 2016.

Keywords: ERIS, VLT, calibration, Visible, Neat-Infrared, Adaptive Optics

1. INTRODUCTION

ERIS (Enhanced Resolution Imager and Spectrograph) is an innovative 1 – 5 μm instrument which will be installed at the Cassegrain focus of the ESO UT4/VLT. It will use the Adaptive Optics Facility (AOF)[1] to perform AO-assisted imaging and integral-field spectroscopy. The concept of ERIS maximizes the re-use of existing sub-systems and components: the AO correction is provided by the AOF Deformable Secondary Mirror (DSM), the artificial Laser Guide Star (LGS) is generated by the 4 Laser Guide Star Facility (4LGSF)[2] at UT4, the wavefront sensor camera detectors are identical to those used for GALACSI[3] and GRAAL[4] (the two GLAO systems of the AOF) and the Real-Time Computer (RTC) is a modified version of SPARTA[5]. In addition, one of the scientific instruments (SPIFFIER) is modified version of SPIFFI[6], the 1 – 2.5 μm integral field unit used on-board SINFONI[7].

ERIS basically hosts two science instruments, an Adaptive Optical Module and an internal Calibration Unit (Figure 1):

- NIX (Near Infrared Camera System)[8] provides diffraction-limited imaging, sparse-aperture masking (SAM) and pupil plane coronagraphy capabilities in the 1 – 5 μm (J to M') bands, either in "standard" observing mode or with "pupil tracking" and "cube" readout mode. NIX is a cryogenic instrument equipped with a 2048 × 2048 detector, cooled at 40K by means of a Closed Cycle Cooler (CCC). The camera optics is able to provide a Field-of-View (FoV) of 27" × 27" in the J to Ks bands or 55" × 55" in the J to M' bands.
- SPIFFIER[9], which is a refurbished version of SPIFFI, modified in order to be integrated into ERIS. Its observing modes are identical to those of SINFONI, with the goal of adding a high-resolution (R=8000) grating.

Infrared light from the telescope to NIX and SPIFFIER is transmitted by a dichroic beamsplitter, which reflects the visible light to the AO module.

- The AO Module[10] is integrated in ERIS and uses the AOF DSM and one AOF laser to provide NGS and LGS visibile wavefront sensing with real-time computing capabilities, allowing for single-conjugate adaptive optics (SCAO) operations. It includes a Laser Guide Start (LGS) Wavefront Sensor (WFS), that allows high-order AO correction, and a Natural Guide Star (NGS) Wavefront Sensor (WFS), that provides high-order AO correction or is used as low-order sensor for the LGS mode.

Ground-based and Airborne Instrumentation for Astronomy VI, edited by Christopher J. Evans, Luc Simard, Hideki Takami
Proc. of SPIE Vol. 9908, 990839 · © 2016 SPIE · CCC code: 0277-786X/16/$18 · doi: 10.1117/12.2233662

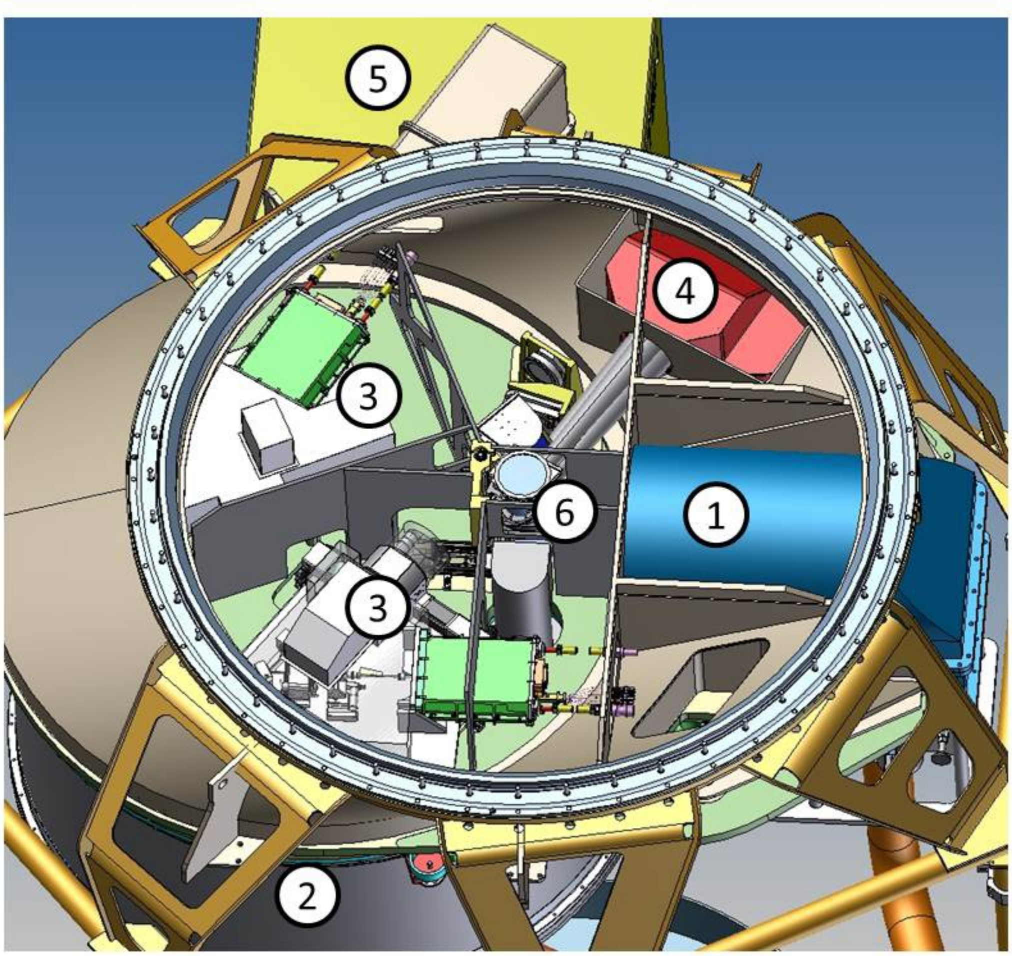

Figure 1 - A global view of the ERIS system. (1) NIX; (2) SPIFFIER; (3) AO Module; (4) Calibration Unit Main Bench (CUMB); (5) Cabinet hosting (in addition to other devices) the Calibration Unit Fiber Switchyard (CUFS); (6) Calibration Unit Selector Mirror (CUSM).

The operations all these modules are supported by the internal Calibration Unit.

- The Calibration Unit (CU) is integrated in ERIS and provides calibration and technical testing (including periodic maintenance) capabilities for both the science instruments (e.g. flat fielding, wavelength calibration and detector linearity tests) and the AO modules (e.g. calibration of Non-Common Path (NCP) aberrations and flexure pointing models).

This paper describes the required functionalities of the ERIS CU, as arising from the higher level requirements, and the development of its design in order to fulfill them, up to the Preliminary Design Review of the project.

2. CU OPERATION SCENARIOS AND CONFIGURATIONS

The Calibration Unit (CU) is a subsystem of ERIS aimed to provide calibration capabilities for the ERIS instruments (NIX, SPIFFIER and AO WFS). In detail, it has to provide:

- photometric flat fields for NIX, in broad- (J, H, K) and narrow-bands;
- spectroscopic flat fields for SPIFFIER over its full wavelength range (1 – 2.5 μm);
- wavelength calibration for SPIFFIER, in the same range as above;

- point-like (DL and 0.5”) and extended (1.0 and 1.5”) sources for AO LGS and NGS WFS calibration (e.g. Non-Common Path Aberrations, Differential Flexures between science instruments and AO systems), at optical wavelengths (R-band);
- point-like sources for SPIFFIER technical checks (e.g. slits orientation), at its working wavelengths.

As a basic consequence of these general requirements, the CU design must include an optical system, a stiff mechanical structure, positioning stages and artificial light sources.
The CU is therefore a complex system composed by several subunits. Each subunit can be characterized by several states, such as OFF, ON, STANDBY, READY, FAULT, UNKNOWN, and can be undergoing specific actions like <init>, <move> and <wait for positioning completion> (for the positioning stages) or <power> and <wait for warm-up completion> (for the lamps).
Some assumptions must be made on the start-up sequence, in order to make it as simple as possible the definition of a set of internal “global” states for the CU. We can a typical start-up sequence as follows:

1) all the controllers (positioning stages and lamps) are switched ON at startup and for each of them a transition from OFF to ON state occurs;
2) all the controllers for the positioning stages are then initialized, i.e. set to zero reference position, and for them a transition from ON to INITIALIZING and finally to STANDBY state occurs.

These first two steps complete the “basic initialization” of the CU. After these steps, every action is somewhat related to the specific calibration case. Generally speaking:

3) each requested lamp is powered on, and for it a transition from ON to STANDBY state occurs. In STANDBY state the lamp is simply warming up to the final operating temperature/brightness;
4) each requested positioning stage is moved to the requested position, and for it a transition from STANDBY to SETTING and finally to READY state occurs when the final position is reached;
5) for each lamp, finally, upon completion of its warm-up, a transition from STANDBY to READY state occurs.

Basing on this scheme, the CU internal “global” states OFF, ON, INITIALIZING, STANDBY, SETTING, READY, FAULT, UNKNOWN are defined, which refer every time to the specific calibration case of interest (the CU is not to be used as a stand-alone system).

Each of the above-mentioned states can be internally assumed by the CU in a set of different “CU Configurations”. Three general configurations are able to cover all the calibration cases:

A) PPL (Pupil Plane). In this configuration the telescope pupil is simulated (through the exit hole of a Integration Sphere, IS) and used to illuminate the exit pupil into the scientific instruments (for special calibration purposes) or the focal plane (mainly for flat field purposes);
B) FPN (Focal Plane, NGS). In this configuration a set of artificial sources, positioned at the telescope Cassegrain focal plane (i.e. at infinite distance), are used (for special calibrations of SPIFFIER plus the calibration of the NGS WFS);
C) FPL (Focal Plane, LGS). In this configuration the same set of artificial sources is used, but positioned at the telescope focal plane corresponding to a finite distance (85 km, TBC). This configuration is used for the calibration of the LGS WFS.

Setting the CU for each of these three configurations requires a set of steps. Figure 2 shows a full operational life-cycle for the CU:

1) the system is initially in OFF state;
2) the start-up sequence puts it to the ON state (first blue arrow) and then in the STANDBY state (second blue arrow);
3) additional specific functions (e.g. moving the ISSM; moving the Focus Z stage and waiting for LDLS warm-up) allow it to reach one of the three operating modes (third blue arrow);
4) the system can move from each operating mode to each other (green arrows), or
5) it can move back to OFF state with a shut-down TBD procedure (red arrow).

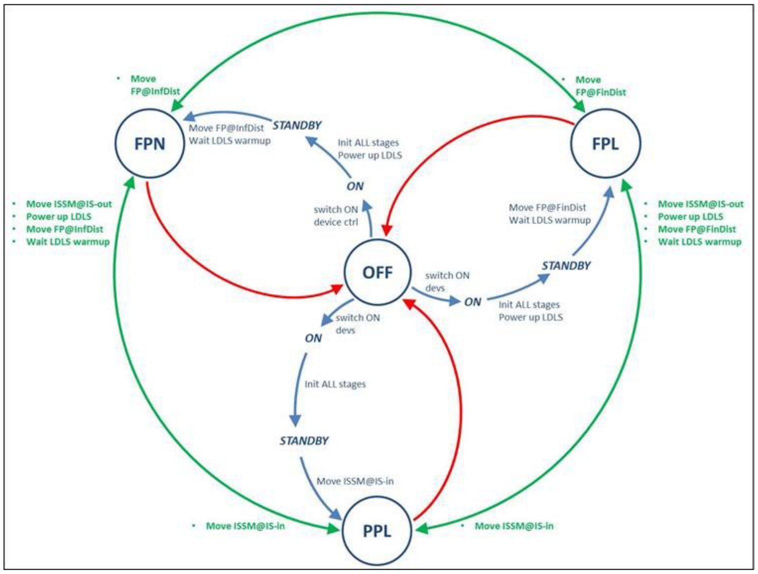

Figure 2 - Complete calibration lifecycle

3. CALIBRATION UNIT DESIGN

The CU is composed by three separate units. The first two units, called Calibration Unit Main Bench (CUMB) and Calibration Unit Selector Mirror (CUSM) respectively, are optically and mechanically interfaced with the ERIS optical plate; the third unit, called Calibration Unit Fiber Switchyard (CUFS), is hosted inside one of the ERIS cabinets and electrically and optically interfaced with the CUMB only. The choice to having separate units derives from the need to reduce at maximum the volume occupied by the CU onto the ERIS plate, as well as it weight.

3.1 Main Bench

The CUMB (Figure 3) is mounted across the ERIS optical plate, with the main axis parallel to the telescope axis and the entrance beam tilted by 103° with respect to it (13° with respect to the ERIS optical plate). It is equipped with an objective transmitting from 0.5 to 2.5 μm that operates with a magnification of 1 : 1.296 in order to project point sources of various sizes onto the Cassegrain focal plane and to deliver a projected virtual position of the pupil that coincides with the telescope secondary mirror.

A pattern of artificial point-like and extended sources (*pinhole mask*, PHM) is placed onto the back focal plane of the objective. Two orthogonal linear stages allow to position it at any point over the focal plane with high precision (0.2 μm over a 25mm range). The plane, in turn, can be placed at different distances from the objective in order to reproduce either celestial sources and natural guide stars or laser guide stars (variable height between 80 km and 200 km), as well as for focus fine adjustment. A linear stage ensures such a positioning with a resolution of 1 μm over a 102 mm range.

Flat field capabilities are obtained by inserting a plane mirror (called IS selector mirror or ISSM) across the optical path, in order to project onto the telescope focal plane the light coming from an IS whose output port is placed at the position of the pupil. The insertion of the mirror is performed by rotating it by at least 90°, through a rotation stage able to provide a proper positioning accuracy (15 arcmin) over a range of 270°.

A fixed pupil stop in the PHM optical path (needed to ensure correct AO calibration operations) and a folding mirror (that allows to make the CU compact) are also part of the complete CU opto-mechanical assembly.

Illumination of point-like and extended sources on the PHM is obtained by rear-feeding the mask with a mono-mode optical fiber (for the DL source) and a multi-mode optical fiber (for all other sources). Another multi-mode optical fiber feeds the IS for flat fielding capability. All the fibers are connected to proper light sources inside the CUFS (see section 3.3) and provide very low attenuation over the full wavelength range of operation. Wavelength calibration is provided by four spectral calibration lamps (Ne, Xe, Ar, Kr), directly connected to the IS.

The CUMB is provided with temperature sensors to monitor lamps and sensitive components (such as the pupil stop). Finally, manual adjustment are foreseen for internal alignment purposes: tip/tilt adjustment for the folding mirror, the pupil stop and the ISSM, triplet lens position along the optical axis and position and orientation of the IS.

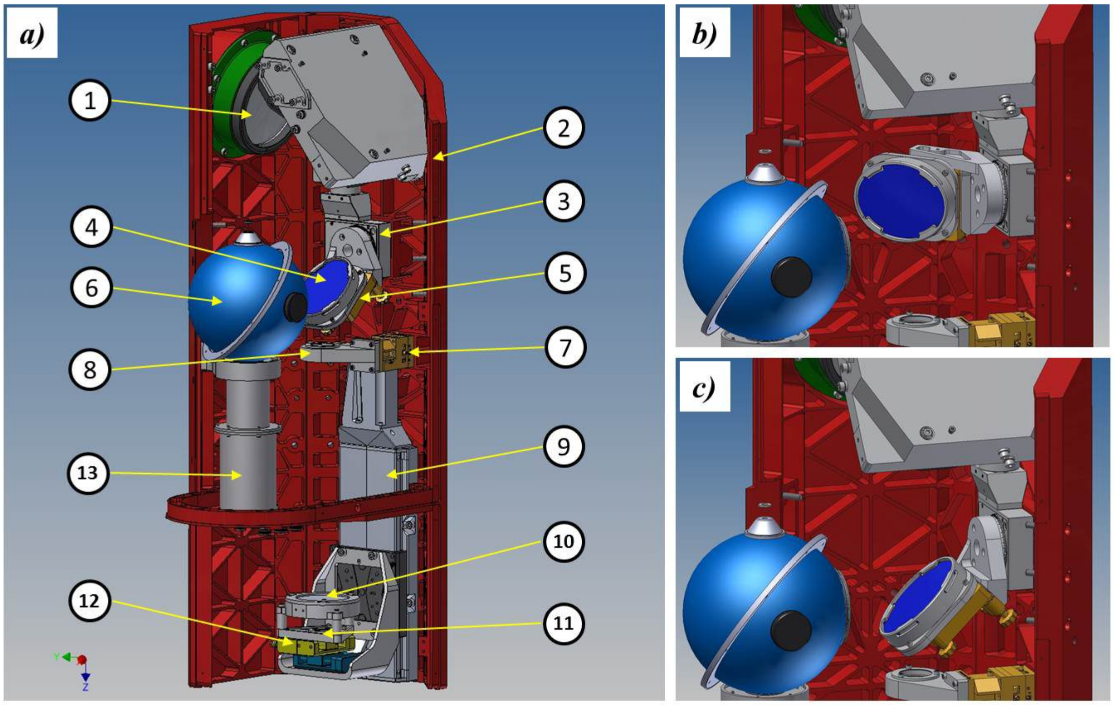

Figure 3 – **a)** CUMB and its internal components: (1) triplet lens assembly; (2) folding plane mirror; (3) ISSM rotary stage; (4) ISSM (plane mirror); (5) ISSM mount with manual adjustment device; (6) IS (6-inch outer diameter); (7) Pupil Stop mount with adjustment mechanism; (8) Pupil Stop; (9) Focussing stage; (10) PHM ; (11) PHM mount; (12) PHM positioning stages; (13) IS light-pipe, hosting the spectral calibration lamps. **b)** ISSM position (removed from the focal plane path) for FPN and FPL configurations. **c)** ISSM position (inserted into the focal plane path) for PPL configuration.

3.2 Selector Mirror

The CUSM (shown in Figure 1) is a plane mirror devoted to redirect the output beam from the CU towards the telescope focal plane and, at the same time, to stop the light from the telescope when the system is under calibration. It is provided with a manual tip-tilt adjustment mechanism (for the procedures of optical alignment between the CU and the other ERIS subsystems) and integrated in a larger ERIS mechanical system provided with a motorized insertion mechanism whose control is external to the CU.

3.3 Fiber Switchyard

The CUFS (Figure 4) hosts the light sources for feeding both the IS and the PHM into the CUMB. A white-light, broad-spectrum lamp (a Laser Driven Light Source, LDLS, from Energetiq Inc.[11]) provides an almost flat spectral output over the 0.4 – 2.4 μm wavelength range, delivering a power of 50 μW/nm at optical wavelengths and up to 10 μW/nm at 2.5 μm. In addition, a Quartz-Tungsten Halogen (QTH) lamp, able to provide up to 6 W/nm at optical wavelengths, is foreseen as additional source for NIX narrow band and SPIFFIER spectroscopic flat fielding, where the photon rate from the LDLS alone is not sufficient.

The lamps output is sent to a fiber selection mechanism placed inside the CUFS. This is composed by a fixed structure supporting the output fiber (from the lamps) plus an output collimator, and a movable structure supporting three input fibers (a mono-mode fiber and a multi-mode fiber to feed the PHM, plus a multi-mode fiber to feed the IS), each fiber being provided with its own input/output collimator. It allows to feed a fiber at a time.

In order to adjust the light levels according to the different calibrations to be made (e.g. broad-band vs narrow-band flat field), a variable neutral density (ND) filter is placed at different positions between the output and the input collimators.

The three input fibers are mounted onto a linear stage, able to position them with 1 μm resolution over 155 mm range. A second, identical stage is used for the variable ND filter positioning, meeting the same requirements on terms of travel range and positioning accuracy. All the fiber mounts are provided with manual adjustment mechanisms for initial alignment purposes.

Given the broad wavelength range of operation (0.4 – 2.45 μm), fibers having low attenuation at infrared wavelengths have been selected (InF_3 / $InZr_4$, hollow-core fibers). For the same reason fiber reflective collimators are used.

In order to fully comply with maintenance operations, the connections between the CUFS and CUMB (power and signal cable, plus optical fibers) are segmented by means of intermediate connectors. The number of segments for the optical fibers is reduced as much as possible, however, in order to minimize light losses at every connection,

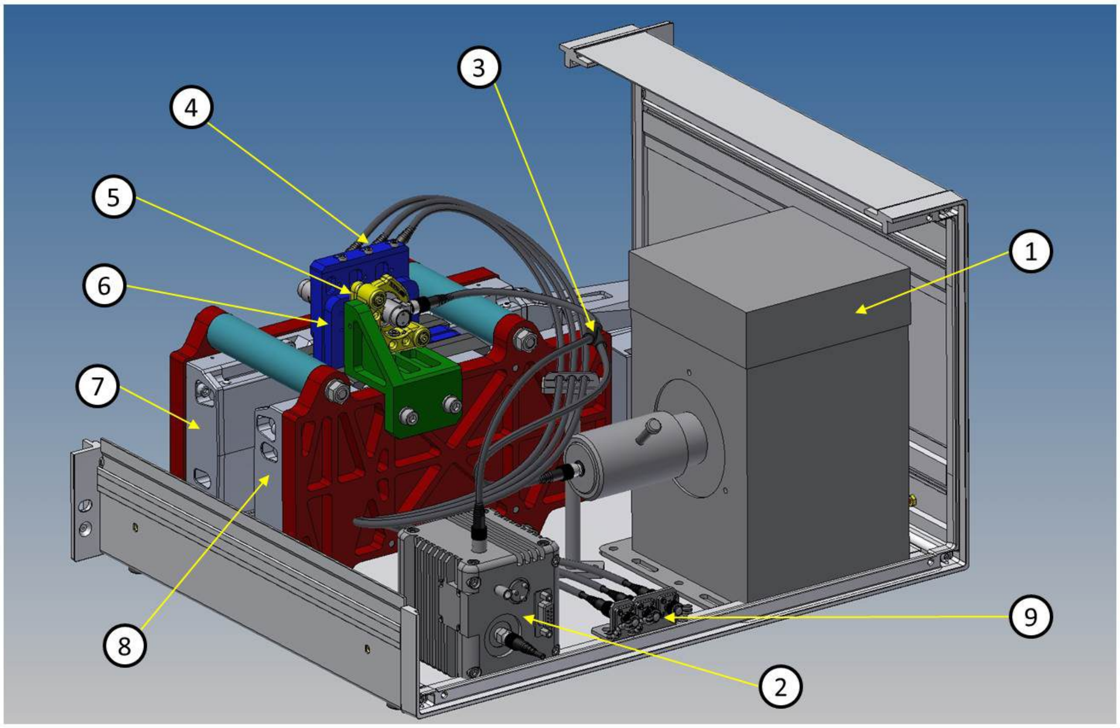

Figure 4 – CUFS and its internal components: (1) QTH lamp and housing; (2) LDLS lamp and housing; (3) bifurcated optical fiber; (4) output fiber collimators; (5) input fiber collimator; (6) Neutral Density filter; (7) fiber selector; (8) Neutral Density filter positioner.

3.4 Optical design

The CU optical system is shown in Figure 5. It is based on a lens triplet to: illuminate the VLT focal plane with a uniform “flat field” (pupil mode) and to create point sources at the VLT focal plane at different altitudes (focus mode).

In pupil mode, a diaphragm just in front of the IS simulates the VLT telescope pupil. The triplet places the image of this diaphragm at the same location of the telescope exit pupil, i.e. at 15.2 m before of the focal plane. The diaphragm diameter will define the proper focal ratio of the beams at the VLT focal plane.

In focus mode, point sources generated by a PHM are placed at the conjugate image plane of the VLT focus as seen by the triplet. These point sources can be moved axially to simulate sources at infinity, when simulating NGS sources, and at shorter distances, ranging from 80 to 200 km, for LGS sources.

The triplet is based on common glasses and one asphere is placed on one surface. Its focal length is 408 mm, and it works in a asymmetric relay system, where the PHM is at a F/10.5 and the reimaged plane is at F/13.6, with a

magnification factor of 1.296. The stop diameter is 31.1 mm. In pupil mode, the full NIX FoV is evenly illuminated. In focus mode, the corrected field of view is 12 × 12 arcsec^2.
Sensitivity to misalignments is low: in every telescope position, the image quality is required to be very high, in order to simulate AO-corrected sources. Refocusing between different bands is allowed.

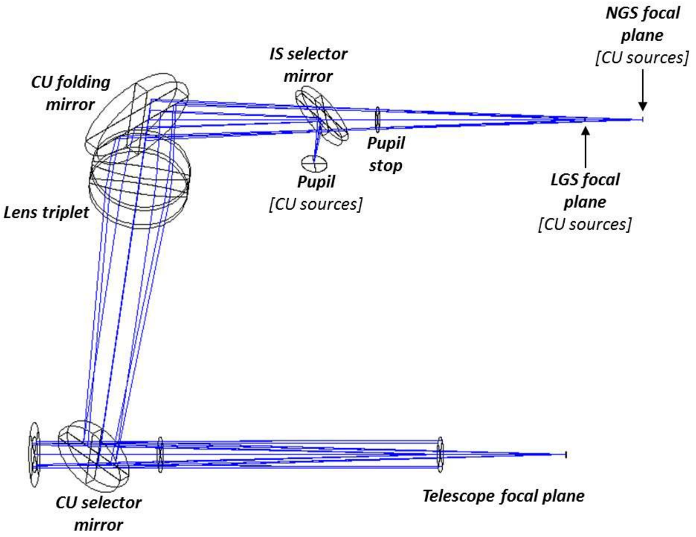

Figure 5 - CU optical layout and components

3.5 Mechanical interface with ERIS

The mechanical interface between the CU and the ERIS optical plate allow easy mounting and dismounting operations, as well as adjustments of the CU position for optical alignment purposes, from the bottom side (directly accessible by external operators).
The adjustment occurs through two movements involving the CU as a whole:

1. a rotation (current range: ±1°) around an axis perpendicular to the ERIS optical plate and passing close to the triplet lens (which lies therefore on the pivot point);
2. a translation (current range: ±1 cm) along the same axis.

The interface is composed by two parts: a structure locked to the CUMB, and a ring that remains fixed to the ERIS optical plate. In case of dismounting the CU, high-precision machined pivots are foreseen on the ring to allow its re-positioning with high accuracy.

3.6 Control system

The CU control electronics is based on a Beckhoff PCU/PLC unit, communicating through the EtherCAT/Bus with the other components and forming part of the Instrument Control Electronics (ICE). The CU electronics can be switched ON/OFF using Relays-Terminals (ES2602) by the ICE. Each assembly in the CU is provided with an EtherCAT-Coupler for Data-Communication with the PLC, a number of specific analog and digital I/O, servo-controller, etc.
The electronics architecture is shown.in Figure 6. For each unit belonging to the subsystem (left part of the figure) the main components are shown, together with the corresponding I/O and control electronics communicating through the EtherCAT bus (right part of the figure).

The CU Control Software is part of the ERIS Instrument Software (INS) which includes in a single package the control software for the AO module and CU.

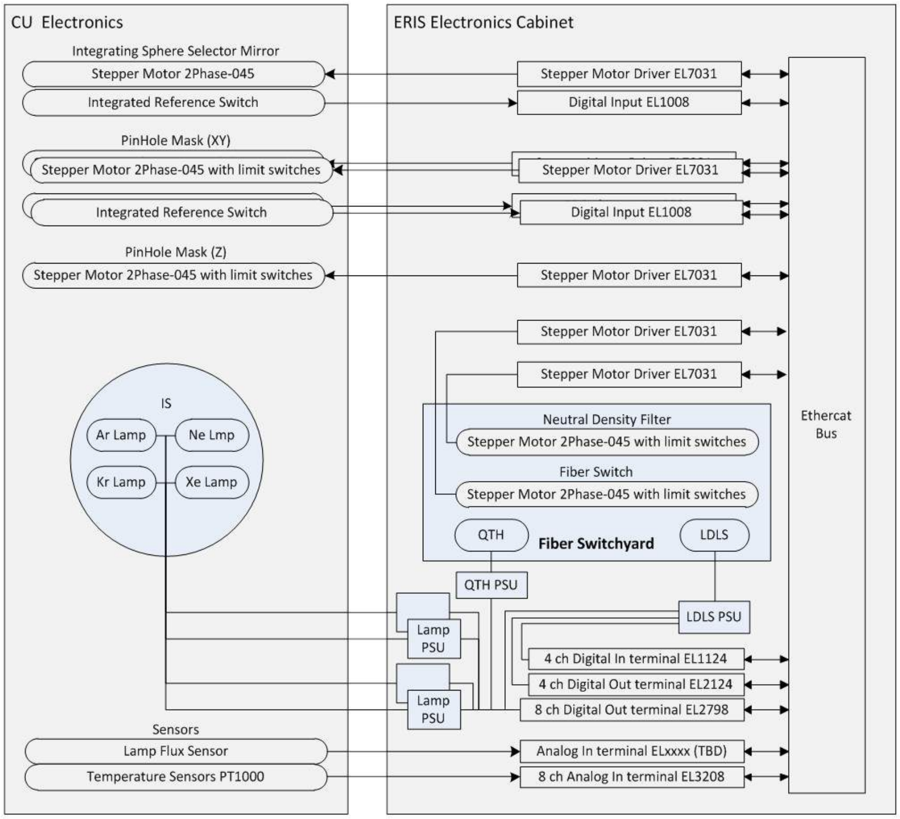

Figure 6 - CU control electronics block diagram

4. EXPECTED PERFORMANCE

4.1 Stiffness

A preliminary static finite-element analysis carried on both the CUSM and the CUMB for different positions of the telescope shows no significant deformation on both the triplet lens and the mirrors, so as to affect the optical performance of the system. The pupil stop, which is the most sensitive component in the subsystem, is also the least affected one, with X-, Y- and Z-displacements always below 1 μm.

4.2 Photon rates

Photon fluxes expected at the telescope focal plane have been computed for the different CU configurations. The scheme for the computation is shown in Figure 7.

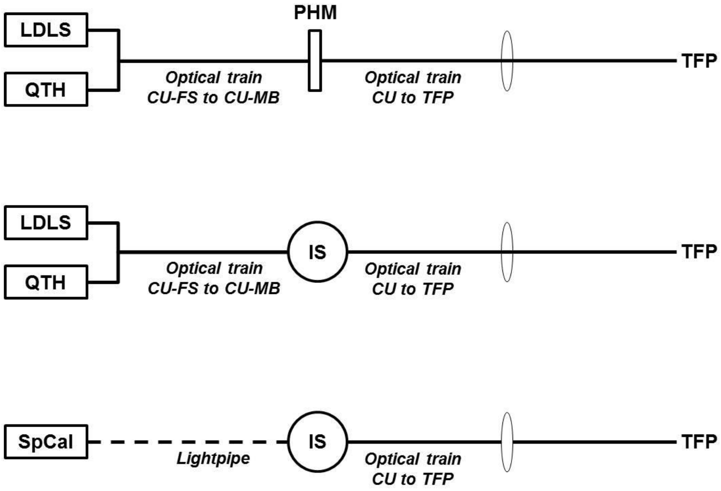

Figure 7 - Model for expected photon rates computation

The two sources into the CUFS feed both the IS and the PHM into the CUMB, with the nearly same optical train. This is composed by low-attenuation optical fibers, optical fibers connectors (used for cable sectioning and connection to both the PHM and the IS) and fiber reflecting collimators (used in the fiber selection mechanism).

Spectral calibration lamps are mounted into a light-pipe directly connected to the IS, so the optical train is essentially composed by this internally reflecting walls. Finally, both PHM and IS feed the telescope focal plane (TFP) through an additional optical train composed by the lens triplet and the mirrors (ISSM and folding mirror) inside the CUMB, and finally the CUSM.

For the current design (and computation) a 6-inch outer diameter IS, model 819C-IS-5.3 from Newport catalogue[12], has been adopted. This IS has an inner diameter of 5.3 inch, is internally provided with a PTFE Spectralon coating and has three 1-inch ports plus one 2.5-inch port (port fraction 0.0734).

The evaluation of the efficiency for the PHM takes into account two different mounting configurations. In the first one, the mono-mode fiber end is directly connected to the mask and therefore it directly injects light into the optical path with 0.22 NA. In the second configuration the multi-mode fiber illuminates a light diffuser which, in turn, sends light into the output beam. An efficiency of 0.01 has been conservatively adopted for the diffuser.

The expected photon rates have been computed for point-like and extended sources onto the PHM, as well as for broad-band, narrow-band and spectroscopic flat fielding of NIX and SPIFFIER and, finally, for wavelength calibration of SPIFFIER. For completeness, the computation has been made taking into account the two plate scales foreseen for NIX and all the three ones for SPIFFIER:

- NIX ps#1: 13 mas/pix
- NIX ps#2: 27 mas/pix
- SPIFFIER ps#1: 250×125 mas/spax
- SPIFFIER ps#2: 100×50 mas/spax
- SPIFFIER ps#3: 25×12.5 mas/spax.

Since the line width of the spectral calibration lines is much narrower than the spectral resolution bin (not smaller than 0.55 nm), it has been assumed that light coming from a line falls onto a single detector column.

The results for NIX and SPIFFIER flat fielding, with light coming simultaneously from both the LDLS and the QTH lamps, are reported in Table 1 and Table 2, respectively. Table 3 summarizes the results from the computation for the PHM point-like and extended sources, assuming a AO module entrance filter bandwidth of 20 nm, a reference wavelength of 750 nm and illumination provided by the LDLS only. Minimum magnitude (at reference wavelength) corresponds to the reported photon flux thru pupil. Maximum magnitude is related to the insertion of the Neutral Density Filter at its highest Optical Depth (OD=4).

NIX		**J-band**		**H-band**		**K-band**	
	Plate scale	***210 nm***	***10 nm***	***300 nm***	***15 nm***	***390 nm***	***20 nm***
	13 mas/pix	3.4e5	1.6e4	4.3e5	2.2e4	1.2e5	6e3
	27 mas/pix	1.5e6	7.0e4	1.9e6	9.4e4	5.3e5	2.7e4

Table 1 - NIX flat fielding expected photon rates (photons / sec / pixel). Computation is performed by taking into account the two different NIX plate scales and typical widths of broad-band and narrow-band filters.

SPIFFIER	*Plate scale*	**J-band**	**H-band**	**K-band**
	250×125 mas/spax	1.9e5	1.5e5	3.2e4
	100×50 mas/spax	2.6e4	2.1e4	5e3
	25×12.5 mas/spax	1.9e3	1.5e3	3e2

Table 2 - SPIFFIER spectroscopic flat fielding expected photon rates (photons / sec / spaxel). Computation is performed by taking into account the three different SPIFFIER plate scales. Spectral resolution is R=2000, 3000 and 4000 in the J, H and K band, respectively.

	Source type and angular diameter			
	DL	**0.5”**	**1.0”**	**1.5”**
Min mag	3.8	12.4	10.9	10.0
Max mag	13.8	22.4	20.9	20.0

Table 3 - Pinhole mask artificial sources expected magnitude range. DL is the diffraction-limited source obtained with a monomode optical fiber.

5. CONCLUSIONS AND FUTURE WORK

In this paper the preliminary design of the ERIS Calibration Unit has been described, together with the solutions currently adopted to provide the expected calibration functionalities to NIX, SPIFFIER and the ERIS AO Module. The preliminary design did not show particular problems with the feasibility of this subsystem. The detailed design is currently still ongoing, however, and evolution and refinements can be expected to some extent. These could be aimed at simplifying as much as possible the design, reducing the number of devices – and therefore of single- or common-points of failure, and making easy mounting, management and maintenance operations. On the other hand, some of the results presented here are related to basic considerations, in particular stiffness results coming from FEA are obtained in a static configuration, without considering thermal distortion effects or dynamical behaviors (eigenfrequencis and the like). The foreseen activities until the Critical Design Review (expected on early 2017) will therefore be aimed to finally optimize the design and performance of the ERIS CU, by taking into account all the operational situations, in order to reliably start its construction.

Acknowledgements. The authors thank the Italian Ministero dell’Istruzione, dell’Università e della Ricerca (MIUR) for the financial support to this work.

REFERENCES

[1] Ströbele S., Arsenault R., Bacon R., Biasi R., Bonaccini-Calia D. ,Downing M., Conzelmann R. D., Delabre B., Donaldson R., Duchateau M., Esposito S., Fedrigo E., Gallieni D., Hackenberg W. K. P., Hubin N., Kasper M., Kissler-Patig M., Le Louarn M., McDermid R., Oberti S., Paufique J., Riccardi A., Stuik R., Vernet E. 2006: The ESO Adaptive Optics Facility, *Proc. of the SPIE*, 6272, id. 62720B (2006)

[2] Hackenberg W., Bonaccini Calia D., Lewis S., Holzlohner R., Buzzoni B., Comin M., Dupuy C., Guidolin I. M., Kern L., Quattri M., Quentin J., Ridings R., Argomedo J., Arsenault R., Conzelmann R., Delabre B., Donaldson R., Downing M., Duchateau M., Hubin N., Igl G., Jochum L., Jolley P., Jost A., Kiekebusch M., Kolb J., Kuntschner H., Lizon J.-L., Le Louarn M., Madec P.-Y., Manescau A., Paufique J., Pirard J.-F., Reyes J., Silber A., Soenke C., Stroebele S., Stuik R., Tordo S., Vernet E., Collazos R. Guzman 2011: The Four-Laser Guide Star Facility (4LGSF) for the ESO VLT Adaptive Optics Facility (AOF), *Second International Conference on Adaptive Optics for Extremely Large Telescopes.*

[3] Ströbele S., La Penna P., Arsenault R., Conzelmann, R. D., Delabre B., Duchateau M., Dorn R., Fedrigo E., Hubin N., Quentin J., Jolley P., Kiekebusch M., Kirchbauer J. P., Klein B., Kolb J., Kuntschner H., Le Louarn M., Lizon J. L., Madec P.-Y., Pettazzi L., Soenke C., Tordo S., Vernet J., Muradore R. 2012: GALACSI system design and analysis, *Proc. of the SPIE*, 8447, article id. 844737, (2012).

[4] Arsenault R., Paufique J., Kolb J., Madec, P.-Y., Kiekebusch M., Argomedo J., Jost A., Tordo S., Donaldson R., Suarez M., Conzelmann R., Kuntschner H., Siebenmorgen R., Kirchbauer J.-P., Rissmann A.-G., Schimpelsberger J. 2014: The Adaptive Optics Facility Module GRAAL on its Way to Final Validation, *The Messenger*, 156, p. 2 (2014)

[5] Marcos Suárez Valles, Enrico Fedrigo, Robert H. Donaldson, Christian Soenke, Stefano Zampieri, Reynald Bourtembourg, Helmut Tischer 2012: SPARTA for the VLT: status and plans, *Proc. of the SPIE*, 8447, article id. 84472Q (2012)

[6] Christof Iserlohe, Matthias Tecza, Frank Eisenhauer, Reinhard Genzel, Niranjan A.Thatte, Roberto Abuter, Matthew J. Horrobin, Alexander Schegerer, Juergen Schreiber, Henri Bonnet 2004: On-sky performance of SPIFFI: the integral field spectrometer for SINFONI at the VLT, *Proc. of the SPIE*, 5492, p. 1123 (2004)

[7] Henri Bonnet, Ralf Conzelmann, Bernhard Delabre, Robert Donaldson, Enrico Fedrigo, Norbert N. Hubin, Markus Kissler-Patig, Jean-Louis Lizon, Jerome Paufique, Silvio Rossi, Stefan Stroebele, Sebastien Tordo 2004: First light of SINFONI AO-module at VLT, *Proc. of the SPIE*, 5490, p. 130 (2004)

[8] David Pearson, William D. Taylor, Richard Davies, Beth A. Biller, Walter Bachmann, Helmut Feuchtgruber, Elizabeth M. George, Xiaofeng Gao, Adrian M. Glauser, David Henry, Sasha Hinckley, John F. Lightfoot, David W. Lunney, Michael J. MacIntosh, Stephen D. March, Michael R. Meyer, Sascha P. Quanz, Eckhard Sturm, Chris Waring 2016: NIX, the imager for ERIS: the AO instrument for the VLT**,** *Proc. of the SPIE Astronomical Telescopes and Instrumentation 2016, paper no. 9908-129 (this conference)*

[9] Elizabeth M. George, Helmut Feuchtgruber, Michael Hartl, Dominik Gräff, Frank Eisenhauer, Richard Davies, Alexander Buron, Heinrich Huber, Christian Rau, Markus Plattner, Erich Wiezorrek, Harald Weisz, Paola Amico, Andreas Glindemann, George Hau, Harald Kuntschner 2016: Making SPIFFI SPIFFIER: upgrade of the SPIFFI instrument for use in ERIS and performance analysis from re-commissioning**,** *Proc. of the SPIE Astronomical Telescopes and Instrumentation 2016, paper no. 9908-15 (this conference)*

[10] Armando Riccardi, Simone Esposito, Guido Agapito, Jacopo Antichi, Valdemaro Biliotti, Célia Blain, Runa Briguglio, Lorenzo Busoni, Luca Carbonaro, Gianluca Di Rico, Christophe Giordano, Enrico Pinna, Alfio T. Puglisi, Paolo Spanò, Marco Xompero, Andrea Baruffolo, Markus E. Kasper, Marcos Suárez Valles, Christian Soenke, Mark Downing, Javier Reyes-Moreno, Sebastian E. Egner 2016: The ERIS adaptive optics system, *Proc. of the SPIE Astronomical Telescopes and Instrumentation 2016, paper no. 9909-49 (this conference)*

[11] EQ-99XFC Laser-Driven Light Source (LDLS) data sheet and information, http://www.energetiq.com/fiber-coupled-laser-driven-light-source-long-life-compact.php

[12] Integration Sphere Newport 819C-IS-5.3 data sheet: https://www.newport.com/p/819C-IS-5.3