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THE LAM SPACE ACTIVE OPTICS FACILITY

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ABSTRACT

The next generation of large lightweight space telescopes will require the use of active optics systems to enhance the performance and increase the spatial resolution. Since almost 10 years now, LAM, CNES, THALES and ONERA conjugate their experience and efforts for the development of space active optics through the validation of key technological building blocks: correcting devices, metrology components and control strategies. This article presents the work done so far on active correcting mirrors and wave front sensing, as well as all the facilities implemented. The last part of this paper focuses on the merging of the MADRAS and RASCASSE test-set up. This unique combination will provide to the active optics community an automated, flexible and versatile facility able to feed and characterise space active optics components.

I. THE LAM SPACE ACTIVE OPTICS ACTIVITIES

Partnership. Started ten years ago, the LAM space active optics activities are undertaken in partnership with Thales Alenia Space (TAS) and ONERA, in close collaboration with the french space agency (CNES). In the frame of R&D projects, these partners conjugate their experience and efforts for the development of space active optics through the validation of well identified building blocks: correcting devices, metrology components and control strategies and algorithms.

Space active mirror. In 2012, the MADRAS project successfully resulted in the design, integration and characterization of the first active correcting mirror for space applications, able to achieve a correction performance below 3nm RMS for each low order aberration, and below 9nm RMS for random phase maps of amplitudes around 1µm PtV. The MADRAS experiment reached a TRL4 (See Sec II.B and Laslandes 2013 [1]).

Wave front sensing and control. The second step, achieved in the frame of the RASCASSE project, consisted in the design, development and characterization of wave-front sensors dedicated to extended and dynamic scenes. Two WFS were built and characterized, in pupil and focal plane. This experiment achieved exquisite performance, around 10nm RMS of precision on the measurement of specific phase maps blurring extended scenes (See Liotard et al [2], Bonnefois et al [3], this conference).

A versatile facility. The space active optics facility at LAM consists in the different building blocks of these two complementary experiments. Not only that the natural next step will be the merging of RASCASSE and MADRAS to test an entire active correction loop. The bench is also a versatile facility able to test any deformable mirror technology with a 20-200mm pupil, and to test any WFS working in pupil or focal plane.

II. DESCRIPTION OF THE FACILITIES

Both MADRAS and RASCASSE projects were dedicated to the case of 2-3m class orbiting telescopes, with a 1deg FoV and a 100mm relay pupil were the active correction occurs. The set ups are constituted of these main building blocks:

- Point and extended sources
- Telescope simulators (static and dynamic generation of calibrated WFE)
- Relay optics for beam expansion or compression and mechanical interfaces
- Active mirror
- Commercial pupil wave front sensors (Shack Hartmann)
- Customized homemade pupil and focal plane wave front sensors
- Imaging cameras

A. Sources and telescope simulator

The extended source is a 1280x1024pxs OLED screen (mono or polychrome) able to send different extended or moving sources, with a spectrum between 450nm and 700nm. Additional pinholes are also used for alignment purpose and performance characterization in the case of star pointing. A set of objectives and collimation lenses allows to transfer the beam and adapt its size to the aberrations generators.

Two different solutions are proposed to send calibrated wave front errors to the active optics system. The dynamic solution, adopted for MADRAS characterization, is based on a magnetic ALPAO DM88 [4], which performance is better than the requirements. The static solution adopted for the RASCASSE experiment consists in a rotating wheel carrying different phase screens (SILIOS technologies [5]) with calibrated WFEs from 40 to 200nm RMS. Deviation from specifications is lower than 4 nm RMS for each masks.

The different SILIOS phase screens allow sending WFE with only form content, only mid or high spatial frequency contents, polishing errors and different combinations of these WFEs. This strategy is fundamental to characterize the WFS performance on low order modes estimation with and without high order modes. The amplitude of WFE are defined by the TAS system studies and directly etched on a glass polished transmitting plate. Additional laser cut pupil masks can be added close to the pupil plane to simulate the telescope spiders and secondary mirrors obscuration.

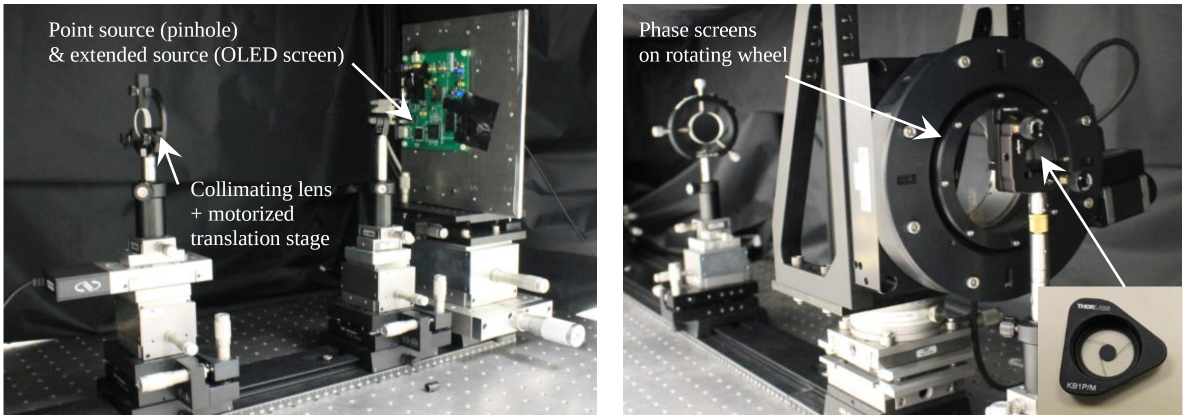

Fig. 1 Left: Illumination unit, Right: telescope simulator and zoom on the spider pupil

B. The MADRAS active mirror: closed loop performance.

The design and performance of the space active mirror are extensively described by Laslandes et al in [1]. The active mirror is based on boundary actuation, ie the actuators influence is transmitted through the edges of the mirror in order to avoid any actuator print through effect (see Fig. 2).

The Zerodur mirror is hold by an Invar warping harness and actuated with classical PZT. With a useful diameter of 90mm, a total volume of 80x200x200mm^3 and a mass of 4.0kg, the system is able to generate 24 modes with a correction performance of 5nm RMS per mode and less than 10nm RMS on random phase maps.

Fig. 3 right shows the **closed loop performance** of the active mirror on each mode, while the specifications and FEA results are presented on the left. Opto-mechanical interfaces can be adapted to receive and characterize any active mirror from 20mm to 200mm in diameter.

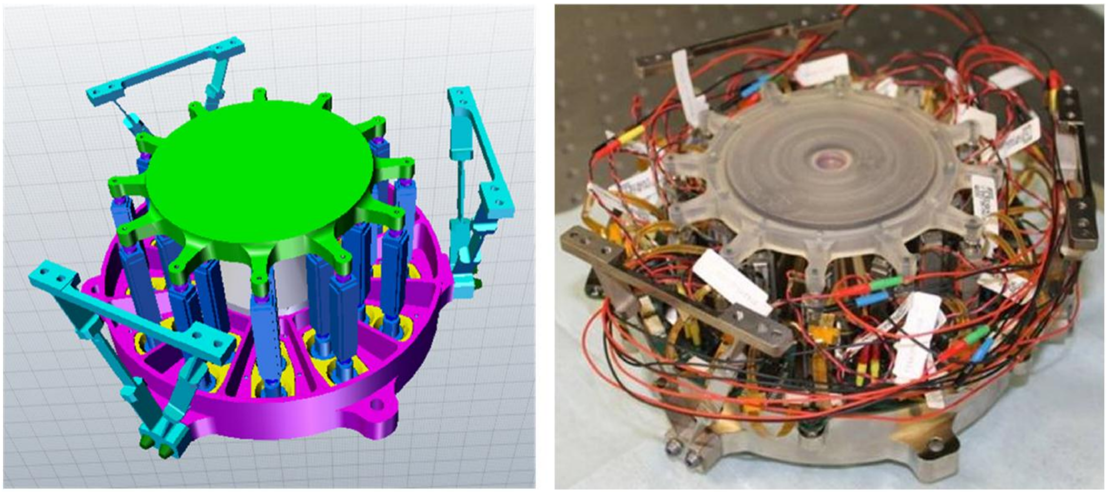

Fig. 2. The MADRAS CAD and equipped prototype

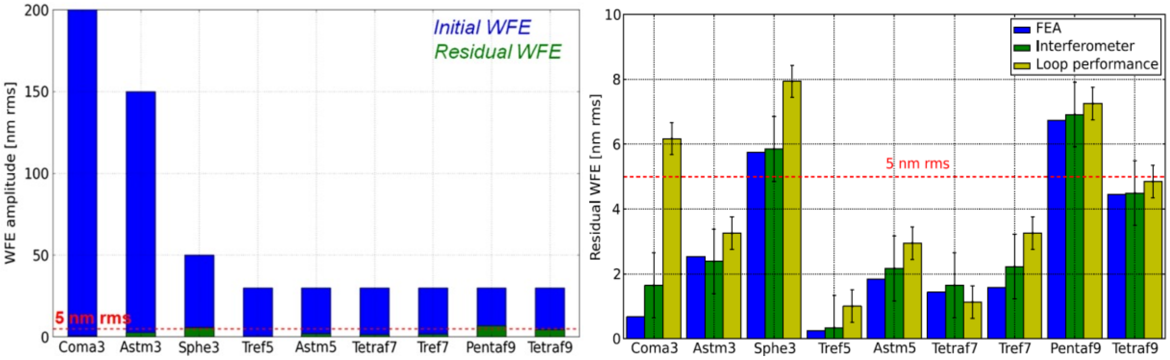

Fig. 3. Left: RMS of modes to be generated and performance obtained after FEA optimization. Right: Closed loop performance.

C. The RASCASSE wave front sensors

RASCASSE aimed to design, realise and integrate two types of wavefront sensors, and compare their performance in the case of extended moving scenes for different scenarios. The scenarios are defined by the luminosity parameters, the contrast in the scene, and the content and amplitude of the WFE to be measured. The bench was designed to provide a 1x1deg² FoV with an optical quality of 60nm RMS and a WFE variation lower than λ /100 over the entire field. Each optical component have been characterized using Fizeau interferometer (accuracy<1nm RMS, repeatability<1 nm RMS). The static wavefront error induced by all lenses is less than 10 nm RMS.

The pupil WFS is a customized Shack Hartmann WFS, designed for the specific scenarios. It is made of a field stop, a pupil relay and a 10x10 µlenses matrix. (Fig. 4 Right)

The focal plane WFS is based on the phase diversity method, and uses a lateral shift splitter to feed the camera with two twin images, with a focus difference of 1.2λ. The Phase diversity channel is telecentric to provide a constant magnification on the two images (Fig. 4 Left).

Both WFS use an ORCA2 camera with a water cooling system. Fig. 5 shows the images obtained with an entrance grid of 7x7 point sources for the phase diversity, and a point source for the SH channel. Initial performances were characterized using an extended scene: grid of 7x7 points covering all the field of view. Initial aberrations are less than 60 nm RMS as specified. Variations on the field of view are around λ/25 with a major contribution coming from filed curvature.

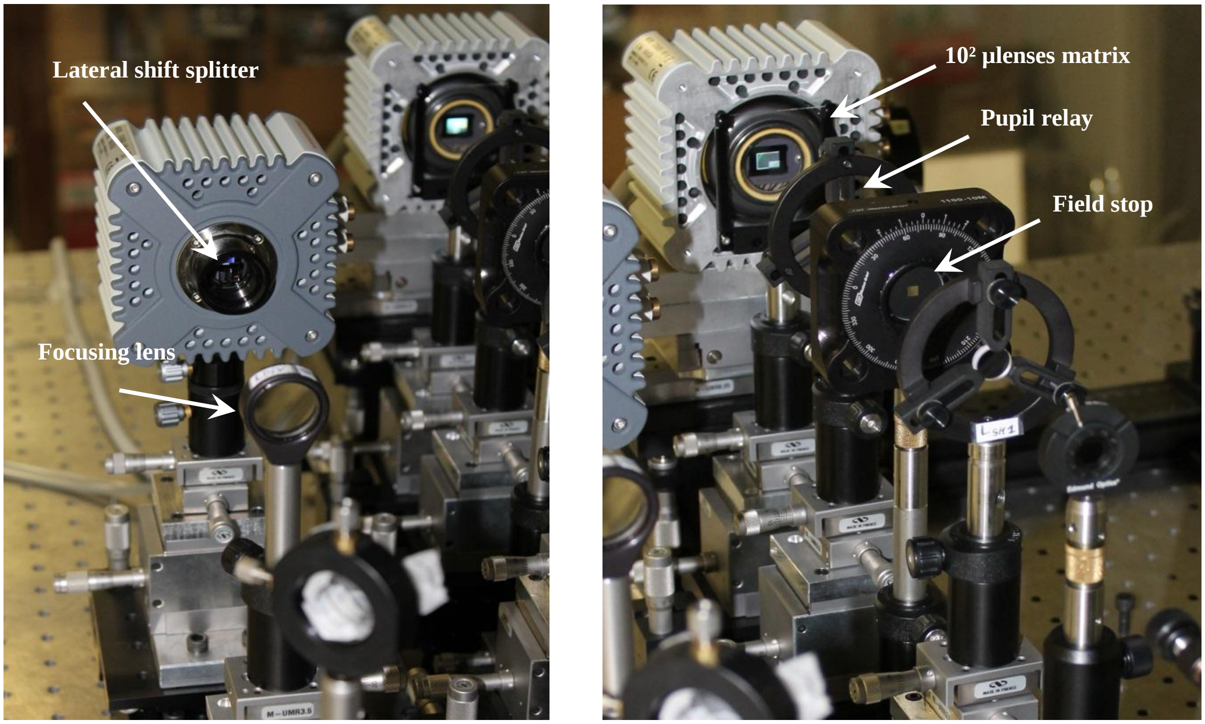

Fig. 4 Left: The phase diversity channel. Right: The Shack Hartmann channel

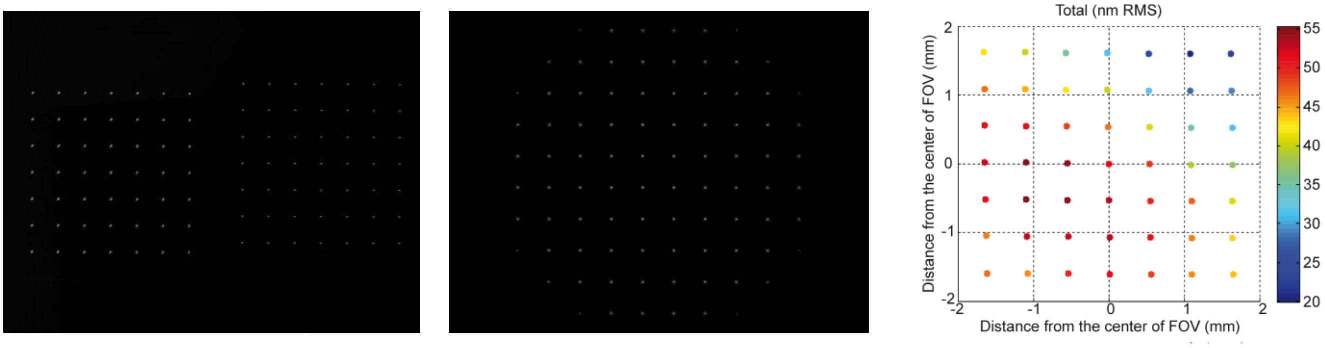

Fig. 5 Left: Phase diversity image obtained with a grid of 7x7 point sources; Middle: Shack-Hartmann image obtained with a point source; Right: Total WFE over the field.

D. Automation of optical configurations, acquisitions and data storage

Specific GUIs were developed for both benches. The MADRAS GUI allows calibration of the system and closed loop control as well as a display of actuators commands, WFS signal and imaging cameras.

All operations on the RASCASSE test bench have been automated for remote control:

- change of optical configurations: rotation of the phase wheel, translation of the collimation lens to move the focal plane,
- control of the extended source: flux adjustment and change of picture,
- modification of the camera’s integration time,
- data storage, with automatic naming and recording of acquisition parameters (date, configuration, phase mask, etc…)

E. Long term stability

The uncertainties on long term were determined using representative sequences, including rotation of the phase wheel and translation of the collimation lens. Several sequences of more than 24 hours with more than one hundred changes of optical configurations were done.

For this long term characterization, an extended scene was used: grid of 7x7 points covering all the field of view. Using these acquisitions, the uncertainty at 3σ was estimated for astigmatism, coma and focus.

In addition, stability of the image position was checked by controlling the distance from the field of view center. Concerning aberrations, the uncertainty meet the requirement of λ/100 (Tab.1) Variations of distance from the center of field of view is less than a pixel, so that the image deformation can be neglected.

Tab. 1 Synthesis of uncertainties

Parameter	*Uncertainty at 3σ*
Astigmatism	±2.5 nm RMS
Coma	±1 nm RMS
Focus	±3,5 nm RMS
Distance from center of FOV	±5.5 µm

III. **RAPACE:** BREADBOARDS MERGING AND IMPROVEMENT

RAPACE stands for **R**eal-time **A**utomated **P**latform for **A**ctive **C**orrection of **E**arth orbiting imagers. This facility aims at merging the MADRAS and RASCASSE test beds in order to propose an integrated facility to the community able to test and characterize any type of active mirror or WFS (see a view of the facilities on Fig.6). Work is ongoing to upgrade the existing hardware and software to tend to a versatile and flexible operating system. The RAPACE preliminary requirements are listed in Tab. 2. The following building blocks are addressed in priority:

Telescope simulator. The block corresponding to the telescope simulator must now merge both proven technologies, namely ALPAO DM88 and SILIOS phase screens, to provide either static or dynamic calibrated WFEs. An effort on the optical design is ongoing and will use the existing characterized pupil relays.

Active mirror and WFS. The LAM space active optics facilities is now an automated platform able to hold and characterize any active mirror and wavefront sensor, for point or extended sources, with minor modifications on the beam expanders and compressor if necessary.

Closed loop. The natural next step is the merging of the two benches in order to demonstrate a closed loop performance using the RASCASSE customized WFS instead of commercial ones used on MADRAS.

Automation. A general effort is put on the harmonization of the control panels and software, in order to provide a versatile bench able to test any component.

Tab. 2 RAPACE preliminary requirements

System requirements	
FOV	1°×1°
Number of pupil relays	>5
Active optics pupil relay size	[20mm – 200mm]
Temperature control	+/-1K
Vibrations control and local turbulence	Image stability <1pix
Bench specifications	
Static WFE	<60 nm RMS
WFE variation vs FOV	$<\lambda/100$
WFE stability	$<\lambda/100$
Stray light	<1%
SNR	30 to 150
WFE generation specifications	
Focus	>20µm
Low order modes	>1µm PV for each of the first 36 Zernikes
WFE generation accuracy	<5 nm RMS per mode
Wave front sensing specifications	
WFS type	Pupil and image WFS
WFS accuracy	<10nm RMS on random phase maps
Correction specifications	
WFE correction accuracy	<5 nm RMS per mode on the first 17 Zernikes
	< 10nm RMS on random phase maps
Bandwidth	1-10Hz

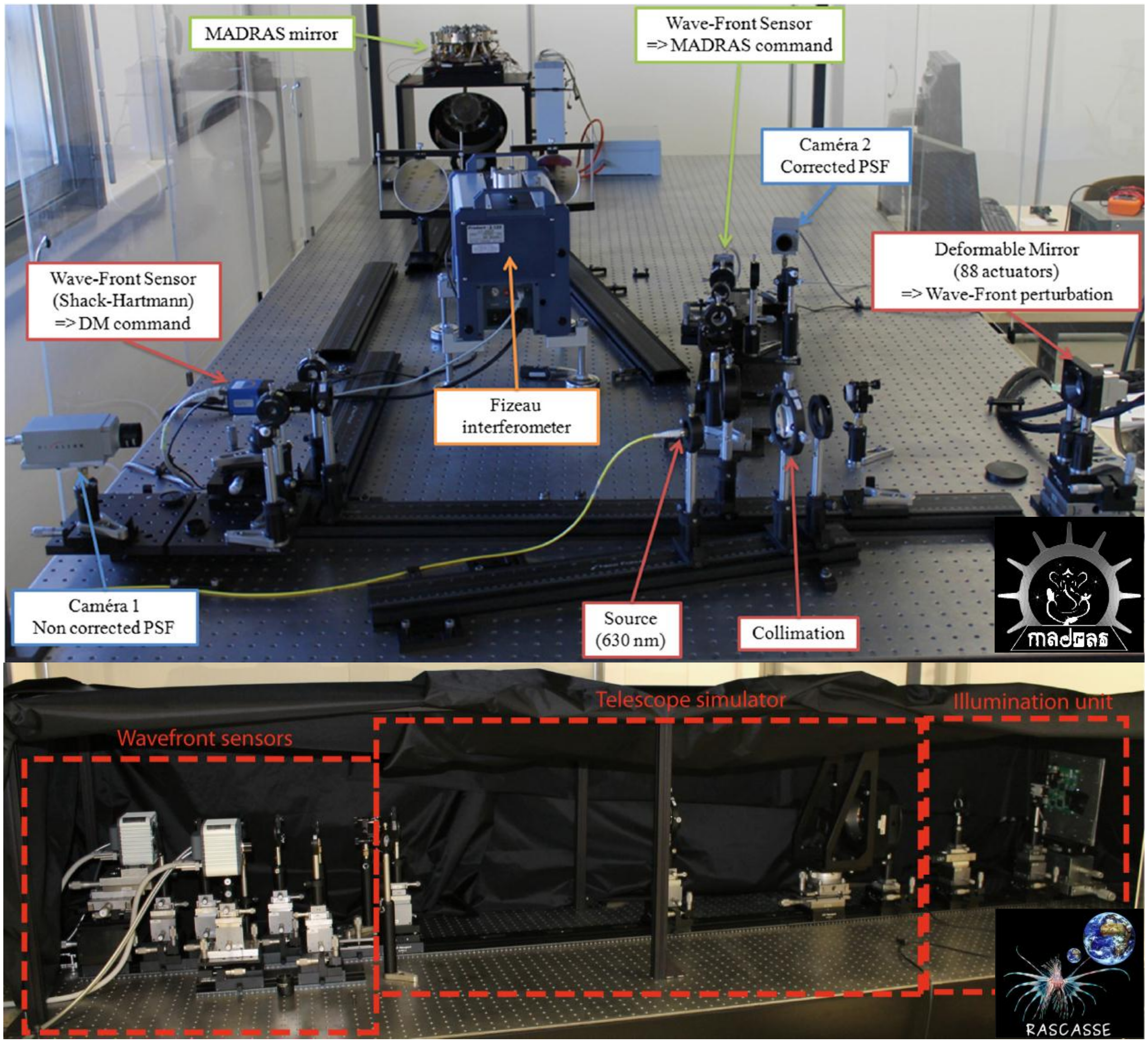

Fig. 6. Up: The MADRAS bench with point source and dynamic telescope simulator, beam expanders and pupil relays, interferometer, commercial SH WFS and imaging cameras.
Down: The RASCASSE bench with static telescope simulator, beam expanders and pupil relays, extended illumination unit, and two parallel optical paths for WFS simultaneous comparison.

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