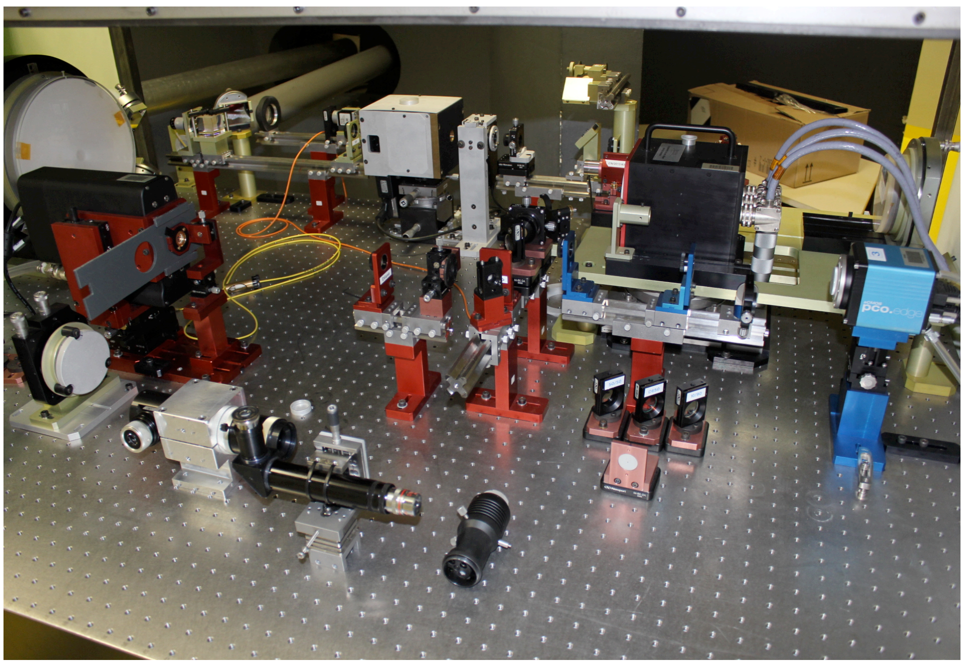
ODISSEE, a promising tool for Lunar Laser

M. Aimar, H. Mariey, D. Albanese, E. Samain, G. Martinot-Lagarde : Université de Nice Sophia-Antipolis, CNRS, IRD, Observatoire de la Côte d'Azur, Géoazur UMR 7329, 2130 route de l'observatoire, 06460 Caussols, France (mourad.aimar@oca.eu)



a) bench ODISSEE ;

Introduction

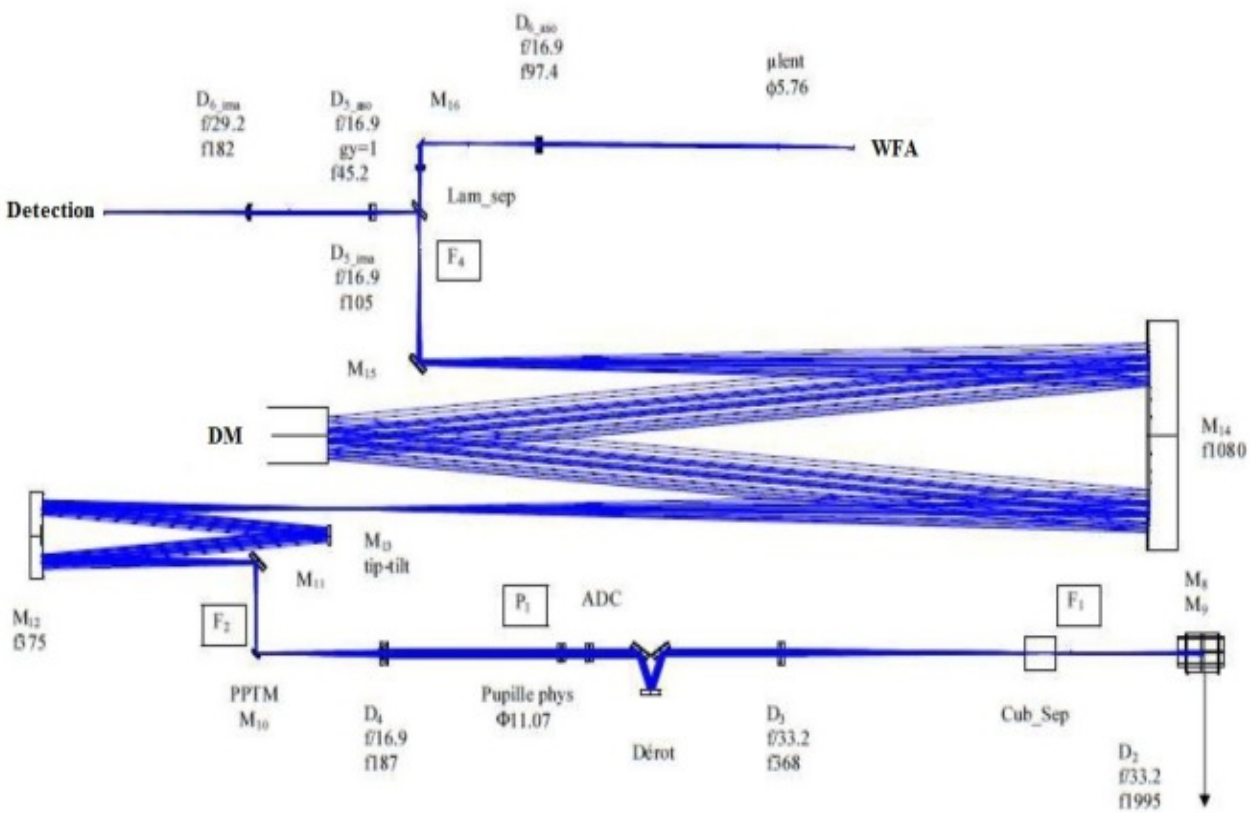
Today, laser ranging to the moon is very difficult. The signal to noise ratio is very low, and the link budget is extremely weak. In partnership with Onera (France), we have developed an adaptive optics bench (ODISSEE) to correct the atmospheric turbulence. Used in association with the MeO station, it allows to significantly improve both the S/N and the link budget.

A - The adaptive optics bench ODISSEE

A-1- The bench ODISSEE:

The bench ODISSEE corrects, in real time, the wavefront distortions caused by atmospheric turbulence. It mainly consists of:

- **adaptive optics system** : a **tip-tilt** mirror that can correct modes related tilting of the wave (87% in the dynamics of corrections, low order) ; a **Deformable Mirror** (DM), with 88 actuators, that can correct the majority of the remaining modes (13% in the dynamics of corrections) ;
- **Wave Front Analyzer** : composed of a microlenses array (8x8) and a high-speed camera (up to 1500Hz) with a CCD of 240x240 pixels (pixel size = 24µm) ; It analyses the deformations of the wave front, and sends the corrections to the DM to compensate ;
- **Detection** : comprises a field iris diaphragm of 1", and a single photon photodetector ;



b) optical path in bench ODISSEE ;

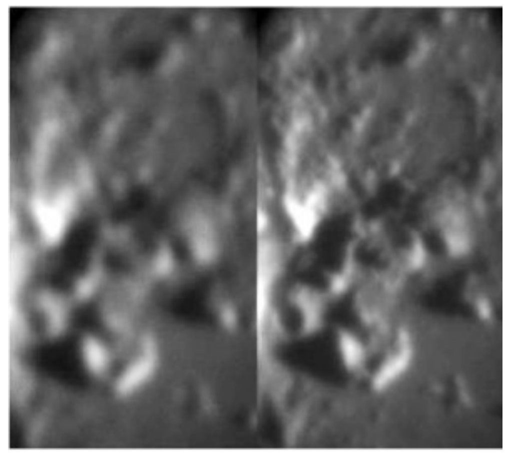
A-2- Performances of the bench:

Before to close the loop on a star or on an extended source, the bench has to be prepared for the acquisition. The loop is closed on an artificial source placed at different location in the bench. Some slope references and an interaction matrix (to compute the control matrix) are acquired.

Different acquisitions on a artificial source, in different time (several months), show that the stability of the bench is very good (80% of strehl).

During a qualifying campaign of the ODISSEE bench, in April 2014, we demonstrated its capacity to correct wave fronts distorted by the atmosphere on different targets.

We can see on figure c (left) the uncorrected image (open loop) of the lunar region of the Apollo XV retro-reflector, and the corrected image (right) of the same region (closed loop) ;



c) OL and CL of the moon surface

Figure d is a capture of the " Seginus " star, (Gamma Bootis), in the Boötes constellation. On the left, we have the uncorrected image (open loop) and on the right the corrected (closed loop).

Star name : Seginus ;

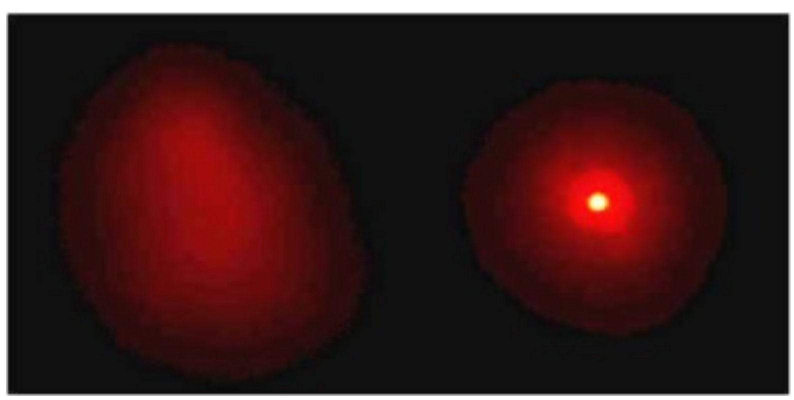
Date : 2014/04/07, 01:51 TU

Elevation : 80°

Magnitude : 3

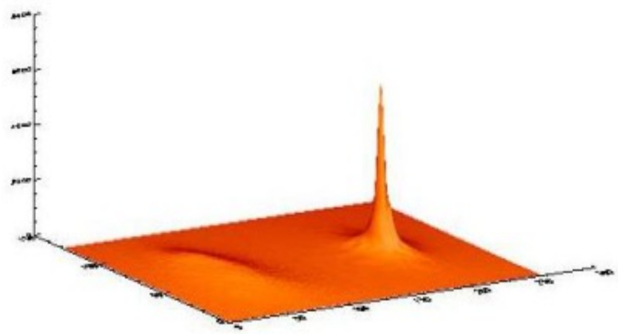
r0 (500nm) : 6,4 cm

Seeing : 1,6"



d) OL and CL of " Seginus " star ;

In the picture e, we have the point spread function (PSF) of the " Seginus " star. On the left we can see the PSF of the uncorrected image (open loop) and on the right the PSF of the corrected image (closed loop).



e) PSF of “ Seginus “ star ;

B - Advantage of the adaptive optics for LLR

B-1- <u>Improvement of the signal to noise ratio S/N</u>:

Laser ranging acquisition to the moon is closely linked to the phases of the moon. The more sunlight reflected by the moon, the larger the signal to noise ratio deteriorates. This is induced by two distinct phenomena : excess noise coming from the sunlight back scattered by the moon surface ; deterioration (reversible) of the corner cubes due to the excessive temperature. One could significantly improve the S/N by decreasing the field of view of the telescope. Thus by correcting the wavefront on the return path of the laser, it will be possible to eliminate the solar flux from the interested zone with a field iris diaphragm (1”). The signal to noise ratio would be improved by 10.

B-2- <u>Improvement of the accuracy and the standard deviation in the distance measurement</u>:

The center/periphery effect of photo-detectors, has the result of making an error on the measurement that can reach one centimeter (20 ps). Thus by correcting the wave front on the return path, and use of a field diaphragm (1 "), we will focus the laser photons at the center of the photo-detector, and thereby improve the measurement accuracy. This correction on the return path, allow also to improve the standard deviation by using a smaller photo-detector (less noisy and less repeatability error).

B-3- Improvement of the link budget:

Depending on atmospheric conditions, the size of the laser spot on the lunar surface is between 2 km and 10 km. Use an adaptive optics system at the laser emission should permits to reach the diffraction limit of a 1.54m telescope, i.e. a spot in the range of 200 m. This correction of the wave front at the laser emission, could improve the link budget by a factor of 100. But before to reach this capacity, some studies and developments are needed.

C - The challenges of adaptive optics for the LLR

Before to use an adaptive optics system for the LLR, and significantly improve both the S/N and the link budget, numerous challenges have to be done in order to make the couple " LLR – AO " functional.

C-1- At the laser reception:

At the laser reception, we need to take into account the area where the correction is made (20" of correction field, so 38 km at 400000 km):

- the lunar surface used to analyze has to be close to the position of the target (isoplanarity area ~ few arcseconds) ;
- the analysis of the wave front has to be done on contrasted details of the lunar surface ;

C-2- At the laser emission:

At the laser emission, the adaptive optics bench has to resist to a high laser flux (200 mJ with a FWHM = 100 ps). Therefore we need to make some modifications:

- high energy Deformable Mirror ;
- protect the wave front analyzer against the diffusions of laser pulses ;
- take into account the difference between the emission path and the reception path (speed aberration) ;

Conclusions

The use of an adaptive optics bench should allow to improve significantly the performances of LLR (S/N, link budget, measurement accuracy), especially allowing the observations during the day, full moon, and increased the observation arc.

Furthermore, the opportunity to correct the wavefront allowed us to invest ourselves in other projects directly related to the atmospheric turbulence like communication, satellite imagery, and space debris detection.