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ODISSEE, a promising tool for Lunar Laser Ranging.

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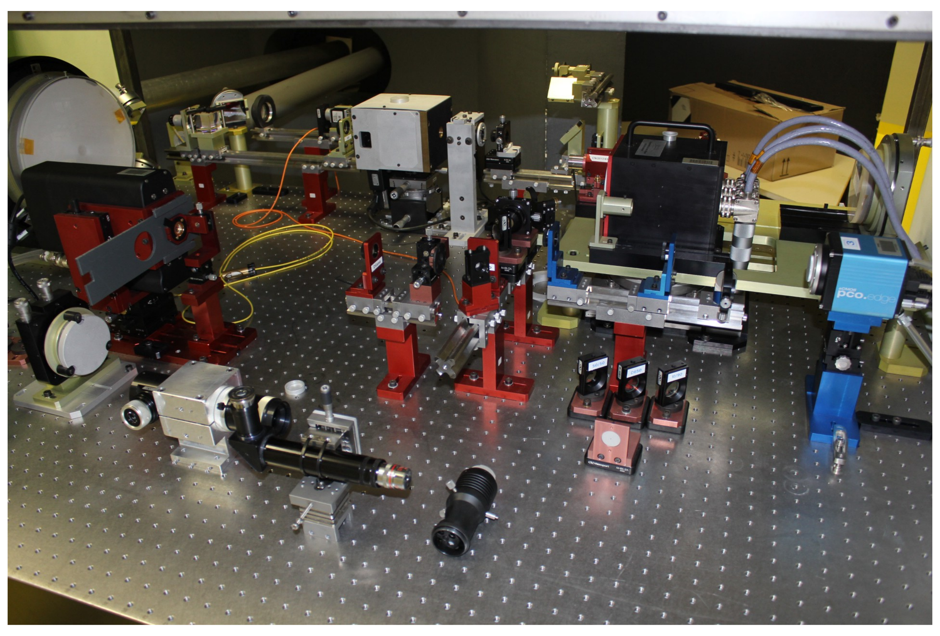


a) bench ODISSEE ;

Introduction :

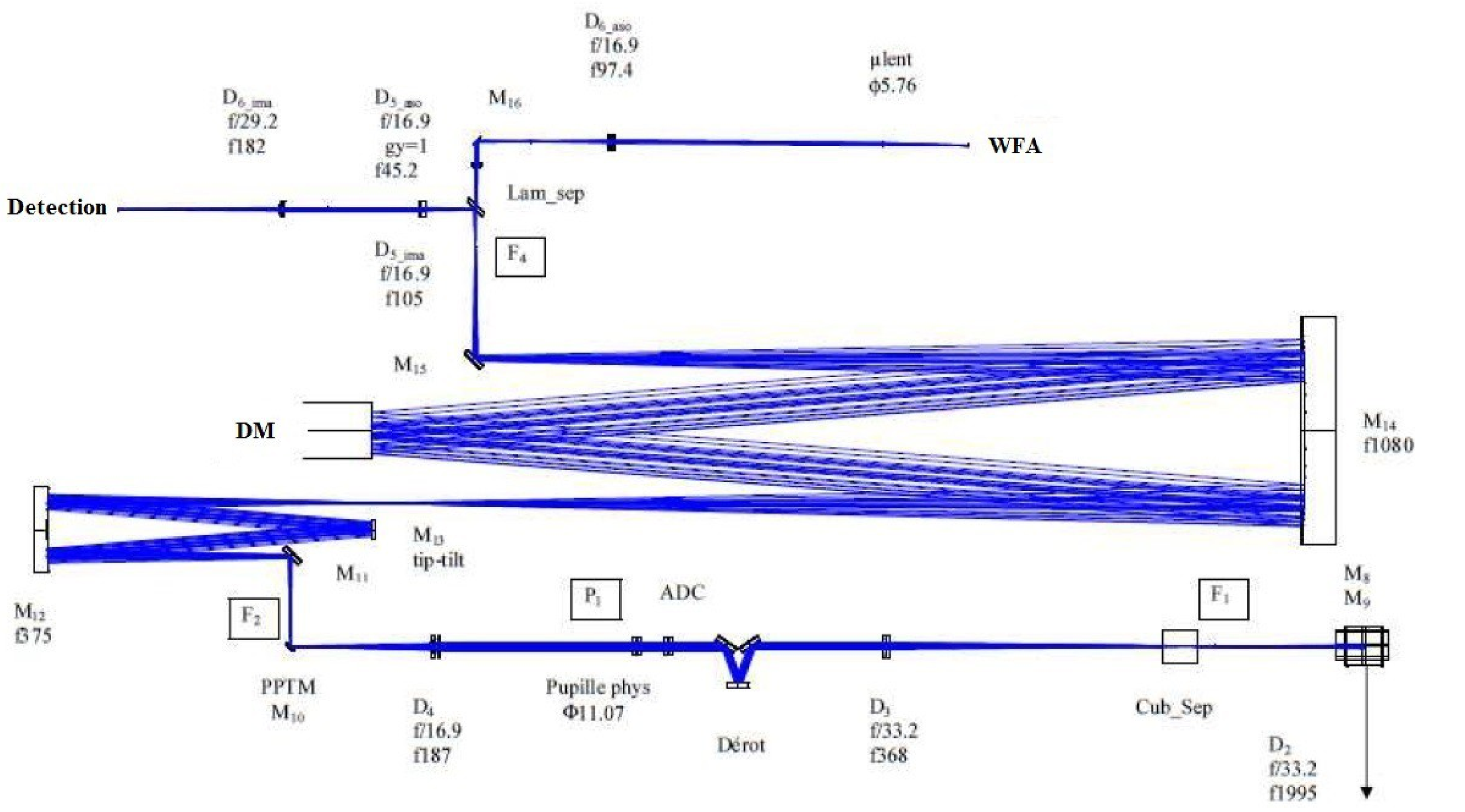
Today, laser ranging to the moon is very difficult. The signal to noise ratio is very low, and the link budget is extremely weak. In partnership with Onera, we have developed an adaptive optics bench (ODISSEE) to correct the atmospheric turbulence. Used in association with the MeO station, it allows 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 turbulence atmospheric. 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) ; a **Deformable Mirror** (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 (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 ;

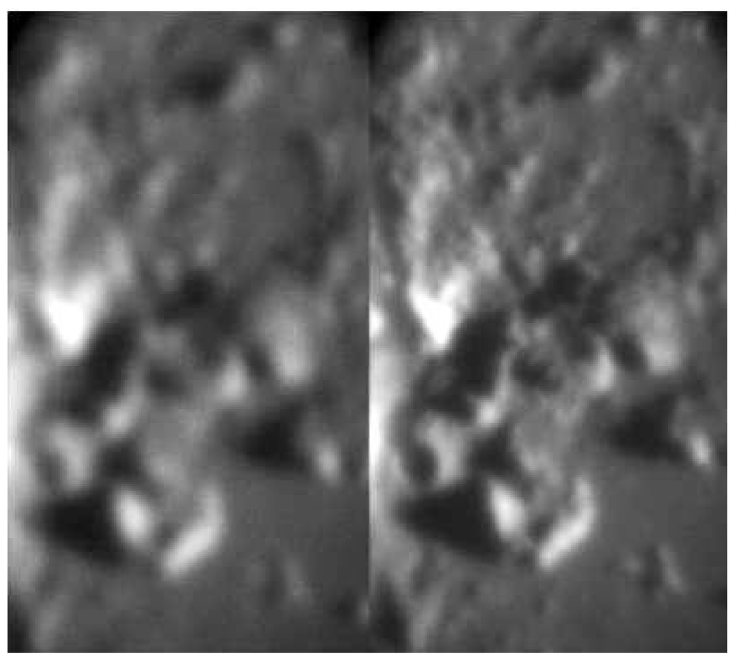


b) optical path in bench ODISSEE ;

A-2- Performances of the bench :

During a qualifying campaign of the ODISSEE bench, in April 2014, we demonstrated its capacity to correct wavefronts distorted by the atmosphere.

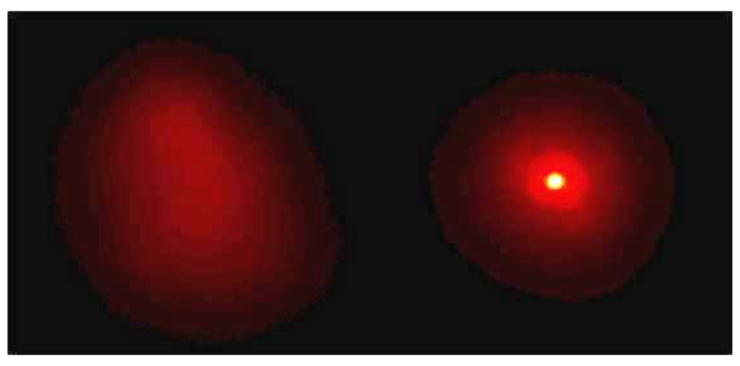
In the picture c), the uncorrected image (left) and corrected (right) of a lunar terrain ;



c) OL and CL of the moon surface ;

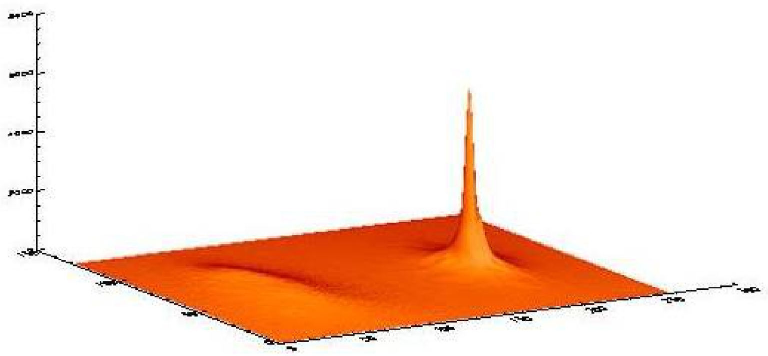
In the picture d), the uncorrected image (left) and corrected (right) of " Seginus " star.

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), the PSF of the uncorrected image (left) and corrected (right) of " Seginus " star.



e) PSF of " Seginus " star ;

B - Advantage of the adaptive optics for LLR

B-1- Improvement of the signal to noise ratio :

Laser ranging 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- Improvement of the accuracy and the standard deviation in the distance measurement :

The center/periphery effect of photo-detectors, has the result of making an error on the measurement that can reach the centimeter (20 ps). Thus by correcting the wave front on the return path, and use of a field diaphragm (1 "), will focus the laser photons at the center of the photo-detector, and thereby improve measurement accuracy. This correction on the return path, allow also to improve the standard deviation by using a photo-detector more smaller (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, will 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, it will take a number of challenges in order to make the couple " LLR – AO " fonctional.

C-1- At the laser reception :

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

- the lunar surface used to analyze has to be close to the position of the target (isoplanarity area) ;
- the analysis of the wavefront has to be done on bright 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 fwhm at 100 ps). Therefor we need to make some changes not so easy :

- high energy Deformable Mirror ;
- protect the wavefront analyzer against the diffusions of laser pulses ;
- also, the path at the emission is not the path at the reception (speed aberration) ;

Conclusions :

The use of an adaptive optics bench will 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 imagine others like space debris.