French LLR Station and New Project

C. Courde(1), P. Exertier(1), A. Fienga(1,2), E. Samain(1), J.M. Torre(1), H. Manche(2)
M. Aimar(1), D. Albanese(1), A. Belli(1), D. Feraudy(1), H. Mariey(1), G. Martinot-Lagarde(1), J. Paris(1), H. Viot(1)

1) *Geoazur UMR 7329, Universite de Nice Sophia Antipolis, Observatoire de la Côte d'Azur, CNRS 2130 Route de l'Observatoire 06460 Caussols, France*
2) *) IMCCE-Observatoire de Paris, 77 av. Denfert-Rochereau, 75014 Paris, France*

1. French LLR station

a) Presentation:

The LLR experiment uses the Me0 telescope of the Geoazur laboratory, located in Caussols, near Grasse (France) at an altitude of 1,270 m. A 1.54m telescope is coupled to a Cr^{4+}:YAG (firing frequency: 10Hertz, pulse width: 70ps, energy: 200mJ in green) for LLR and SLR tracking. The detector is an APD in single photon mode.

b) History

2003: Three stations were operating on the plateau:

- The Lunar Laser Ranging station (LLR) with the 1.54m telescope, used for MEO to the Moon.
- The Satellite Laser Ranging station (SLR) with the 1m telescope (now installed in South Africa), used from LEO to HEO.
- The French Transportable Laser Ranging System (FTLRS) with 13cm telescope, used during campaigns for radar altimeters calibrations (Topex-Poseidon, Jason 1-2) and time transfer (T2L2).

2008: Since 2004 a new organization has been set up to initiate, in addition to the actual program on the Moon and satellites, a Research and Development activity. The SLR station was dismounted and sent to South Africa. The speed of the MeO (ex LLR) telescope was increased to be able to track LEO (400 km).

2013: The FTLRS station was stopped. The accuracy of the station was not sufficient to continue to calibrate the altimeters and the laser was difficult to maintain. Only the MeO station is operating on the plateau. A new station is under consideration (C. Courde, Advanced technologies II, 3091).

c) New considerations

After four years of tracking with MeO it appears that the tracking of targets from LEO to the Moon is very difficult. From LEO to HEO satellites, short pulses (10ps) and high firing frequency (kHz), is the best configuration. For the Moon, a high energy laser (200mJ) is necessary. In this case the pulse width is larger (70ps to 100ps).

The high number of satellites and tracking nights does not allow enough time to maintain a good optical alignment on the Moon.

Other projects, such as adaptive optics, time transfer by laser link, and telecommunication by laser link also time share on the MeO station.

d) New priorities

As we can see in table 1 (Satellite data), Grasse (MeO) station is one of the least productive stations. Additionally, due to the wild pulse width of the laser, the accuracy is bad.

Location	LEO pass	LAGEOS pass	High pass	Total passes	LEO NP Total	LAGEOS NP Total	High NP Total	Total NP	Min. of Data	Cal RMS	LAG RMS
Baseline	1000	400	100	1500							
Zim	6874	1375	4549	12798	111578	19974	18612	150164	116511	5.2	11.0
Wettzell	5404	851	4140	10395	54789	6073	14957	75819	50269	6.8	13.4
Graz	4310	697	3171	8178	78445	5651	18606	102702	58017	2.0	5.0
Herst	3294	740	2189	6223	41520	7134	6647	55301	41768	7.2	15.3
Matera	2802	1080	1167	5049	33966	9379	5208	48553	48106	1.2	3.9
Potsdam	2679	298	269	3246	47611	3147	2102	52860	31236	7.3	12.9
Grasse	895	559	877	2331	34406	6624	3343	44373	32069	9.0	16.2

Table 1: SLR Global Performance Report Card July 1, 2013 through June 30, 2014

In table 2 (Moon data), we see that the Grasse_MeO station is one of the best stations in the world (The APOLLO station is not included because they do not furnish their data to the IRLS in real time or in a useful format).

Site Information		Data Information			
Column L1	L2	L3	L4	L5	L6
Location	Station Number	num nights tracking last 12 mon	num npt last 12 mon	num npts last 3 mon	ave npt rms last 3 mon
Grasse_MEO	7845	94	362	50	37.1
McDonald	7080	7	15		
Matera_MLRO	7941	6	10		

Table 2: LLR Data Report Card

In these circumstances, new priorities have been adopted. The first priority is Moon tracking. Geodetic satellites like Lageos and Etalon will be continue to be tracked to maintain a good reference point of the station. Time transfer on Jason 2 (T2L2) will continue. LRO tracking will also continue. Short campaigns on HEO satellites will be undertaken on a case by case basis. Other experiments like telecommunications will be developed.

e) Infrared detection

To increase the number of echoes on the Moon reflectors, we will develop a new infrared detection system. This detection was used in 1994 with a high number of echoes, but at that time the accuracy of the detector was bad, rendering the data useless. Today with the new detectors, it is possible to increase the number of echoes with a good accuracy. As you can see on tables 3 and 4, the transparency of the sky and the external noise are less problematic for red infrared (1064nm) than for green (532nm).

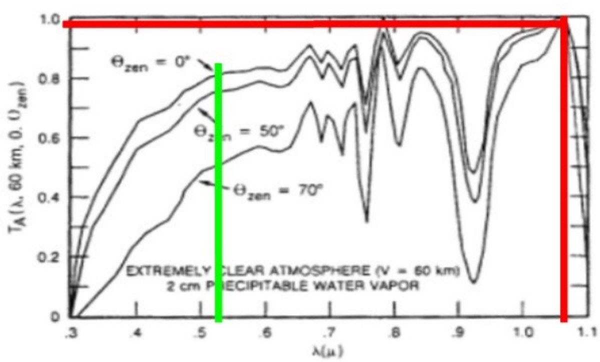


Table 3

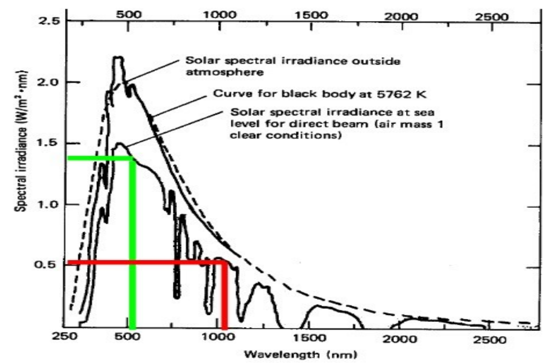
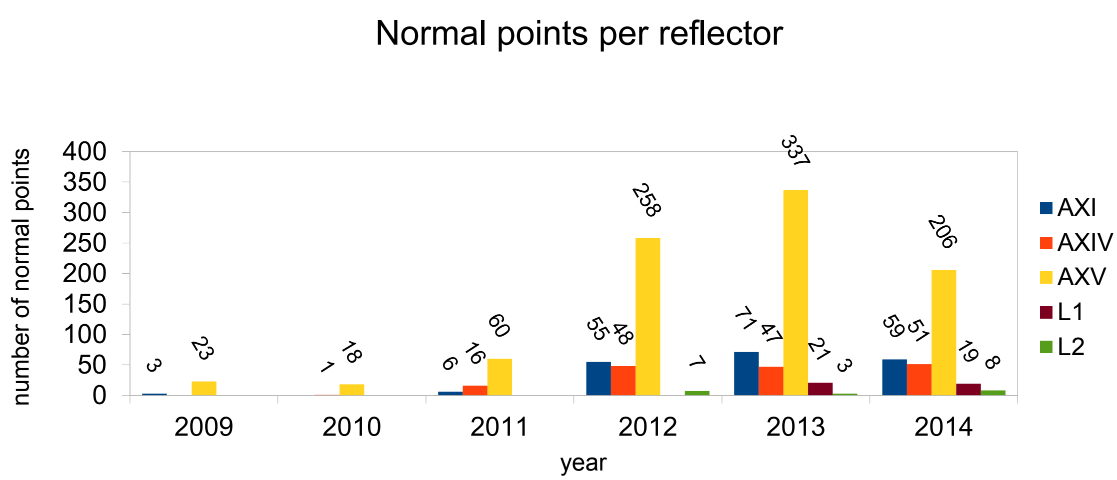


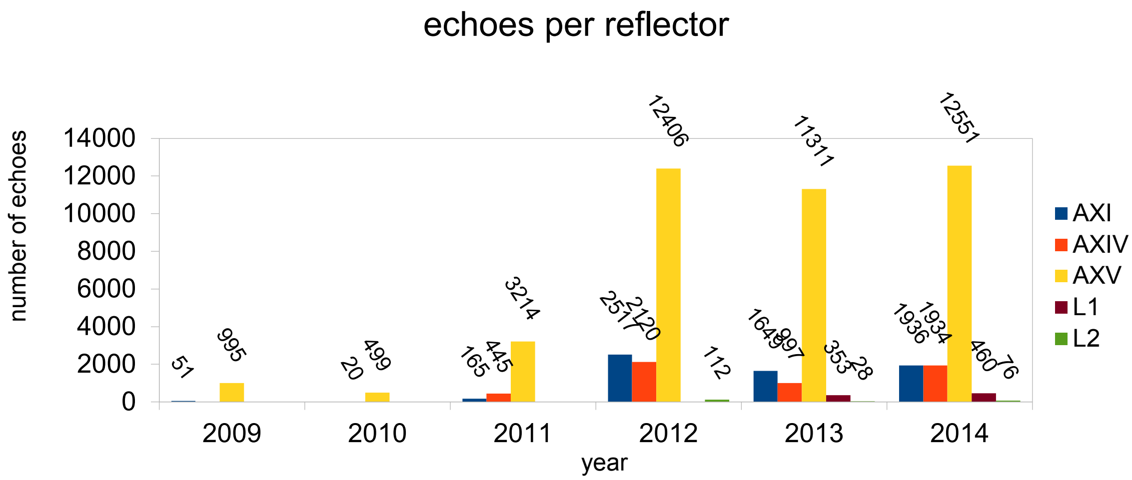
Table 4

The more important dark noise generated by the infrared detectors is not a problem because the accuracy of the predictions is so good that gates are very short. Prediction error is always less than +- 2ns.

f) Statistics

As you can see in these 2014 statistics, the increased emphasis on satellite tracking and time spent on other experiments is problematic because it allows less time to conduct LLR.





2. New project: S.HE.L.L.I.

Project to install a Southern Hemisphere Lunar Laser Instrument at La Silla, ESO, Chile

a) S.HE.L.L.I.

SHELLI is a Lunar Laser instrument to be installed at the Nasmith of NTT. This instrumentation is very important, and the scientific communities of fundamental physics and solar system formation will benefit highly from a LLR station in the Southern Hemisphere. The quality of the NTT 3.6 meter telescope will greatly complement the LLR 3.6 meter APOLLO instrument in the Northern Hemisphere (USA). Finally, about 50% of the observations will be operated during the day and during small sessions of one or two hours.

b) Impact of a Southern station

Improvements in the geometric coverage on the Earth will have a direct impact on the science gained through LLR. Studies of the structure and composition of the interior require measurements of the lunar librations, while tests of GR require the position of the lunar center of mass. The addition of one ranging station in the Earth's Southern Hemisphere would strengthen the geometric coverage and increase the sensitivity to lunar motion by as much as a factor of 4 in some degrees of freedom at the same level of ranging precision (Merkovitz et al. 2007, Hofmann et al. 2014). We operated computations considering simulated observations obtained by a LLR station located at La Silla. In using the INPOP planetary and Moon ephemerides (Fienga et al. 2010), we have simulated the construction of new orbital and rotational ephemerides of the Moon including 50% of Northern Hemisphere observations and 50% of simulated Southern Hemisphere data. This percentage is realistic as it corresponds to the percentage of data obtained by the APOLLO instrument during the past 6 years. Based on the weather conditions at La Silla, one can expect to reach this level of sampling after 4 years of SHELLI exploitation. In considering an uncertainty for the Southern Hemisphere data equivalent to classic (OCA) LLR observations (with an accuracy of about 2cm), we have obtained improvements in the determination of dynamical parameters (reflector positions, geocentric Moon positions and velocities) but also internal parameters as presented in Table 5. These results demonstrate the interest of developing a Southern Hemisphere LLR station, especially for dynamical parameters crucial for testing gravity and fundamental physics but also for a better knowledge of the size and density of the inner core.

Parameter	Southern station	3.6 m Southern station	What for ?
Geocentric position and velocity of the Moon	10 to 30%	25 to 40%	Dynamics, Tests of GR
Gravity Field coefficients	2 to 30%	15 to 30%	Dynamics, Libration
C/MR^2 ratio	15%	25%	Inner core size and density
Love Numbers	10%	25%	Elastic properties of the Moon
τ parameters	5%	25%	Q of dissipation
Mass of the Moon-Earth system	10%	30%	Dynamics, Tests of Gravity
Positions of the reflectors at the Moon surface	5%	20%	Dynamics, Libration, Tests of GR

Table 5: Improvements in Moon dynamical and internal parameter estimations obtained by including simulated Southern Hemisphere observations (with a simulated accuracy of 2 cm) and 3.6m Southern Hemisphere observations (with a simulated accuracy of 0.5 cm).

c) Impact of a 3.6m Southern station

The first LLR measurements had a precision of about 20 cm. Over the past 35 years, the precision has increased by a factor of 10. The APOLLO instrument has gained another factor of improvement, achieving the sub-centimeter level precision. Poor detection rates are a major limiting factor in past LLR. The large collecting area of the NTT (3.6 m) comparable to the Apache Point telescope, will reach thousands of detections leading to a potential statistical uncertainty of about 1 mm. The simulations presented in Table 5 illustrate the important improvement brought by a 3.6m technology in the Southern Hemisphere in considering a mean accuracy in the simulated observations of about 0.5 cm (to be compared to the 2 cm of the previous simulation).

d) New project, conclusion

Unfortunately, this project has not been accepted by ESO, because the science case of SHELLI is quite remote from that of the ESO community, and SHELLI requires using the telescope during day time, which may be problematic for subsequent night observing.

We take this opportunity to thank all the people of the community who have helped us develop the proposal for this experiment. Your assistance has been greatly appreciated.