Lunar Dynamical Modeling with Improved IR Lunar Laser Ranging data

V. Viswanathan [1], A. Fienga [1], H. Manche [2], J.Laskar [2], C.Courde[1], J.M. Torre[1], P. Exertier [1]

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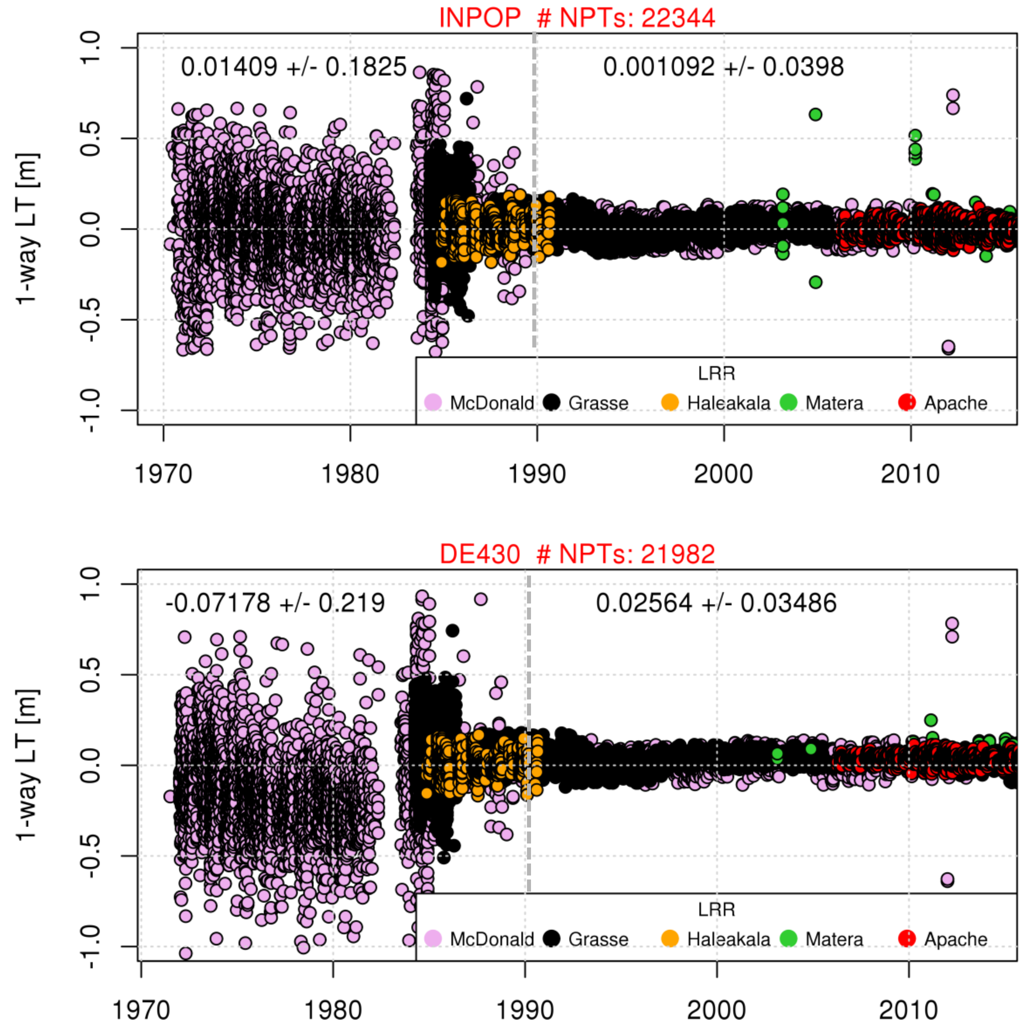
(1) Observatoire de la Côte d'Azur, CNRS-Géoaur, OCA
(2) Observatoire de Paris, CNRS-IMCCE, PSL

Data Reduction Model : GINS[6]

Géodésie par **I**ntégrations **N**umériques **S**imultanées

- Developed and maintained by **OCA-GRGS-CNES**
- Time of flight (photon) to Residuals
- Planetary and lunar ephemeris (libration angles)
- Earth orientation (IERS C04 / JPL KEOF)
- Tides and loading
- Tropospheric delay
- Crustal deformation (Love & Shida numbers)
- Relativistic effects
- Under study : Hydrology loading

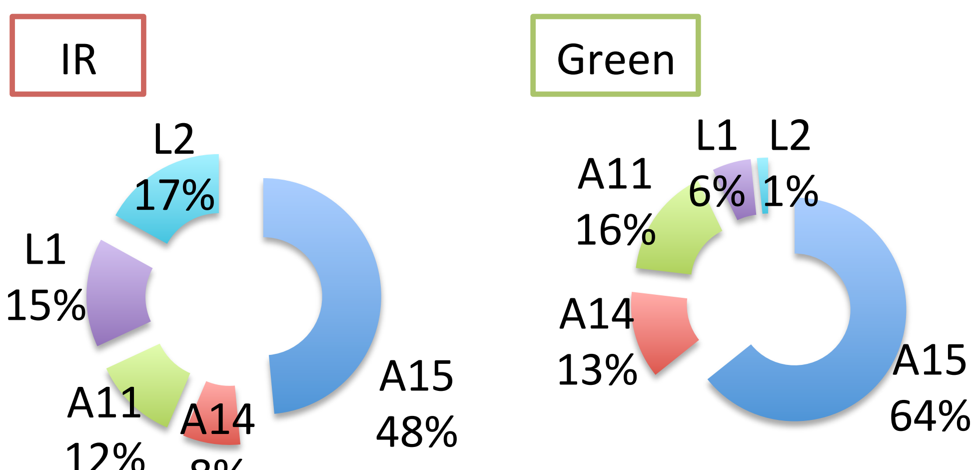


Residuals (m) vs time (year)

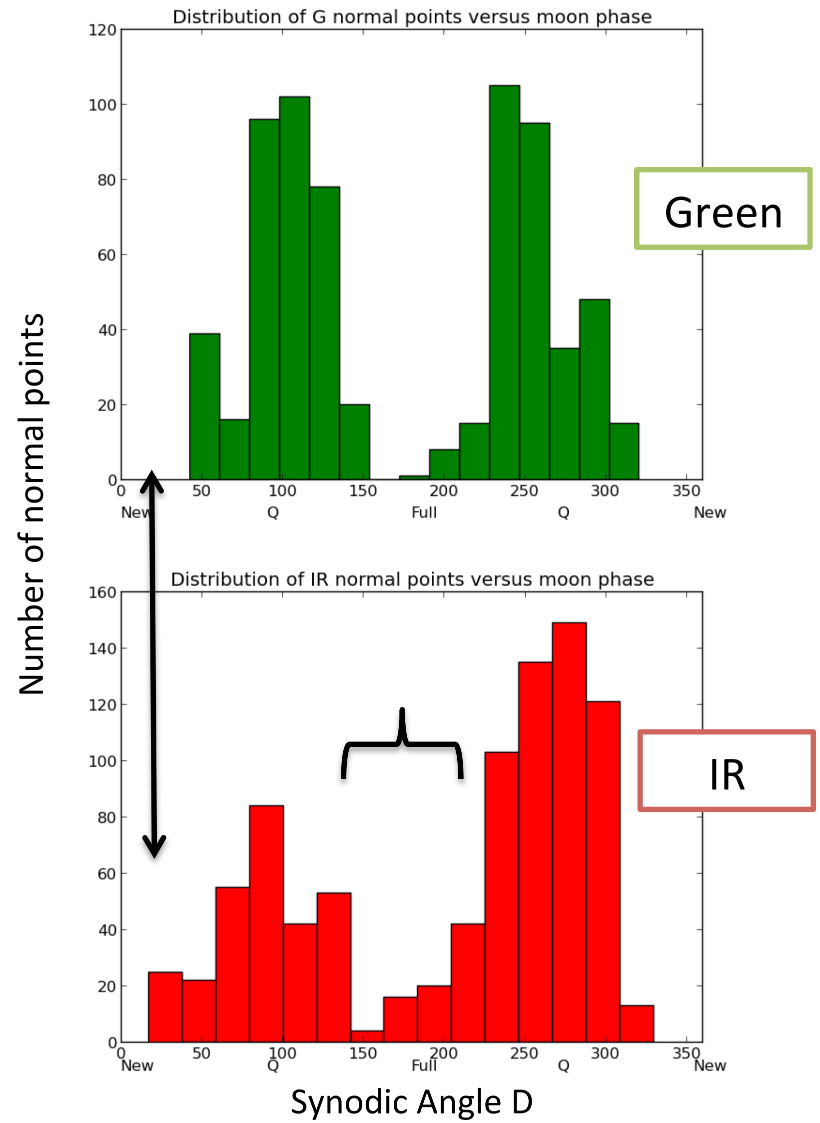
Improved IR LLR data

- LASER : Infrared wavelength (1064nm)
- **Advantages**[7]:
  - ✓ Better atmospheric transmission
  - ✓ Observations round the clock (high SNR)
  - ✓ Diversification of observed reflectors
  - ✓ **Observations during new and full moon**

Maximum sensitivity for tests of **EP : cos(D)**

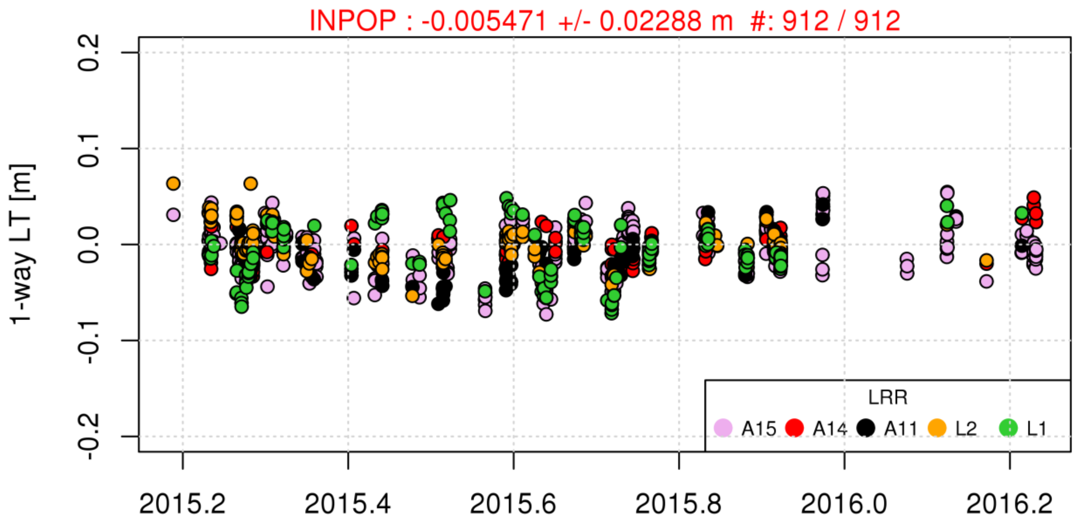


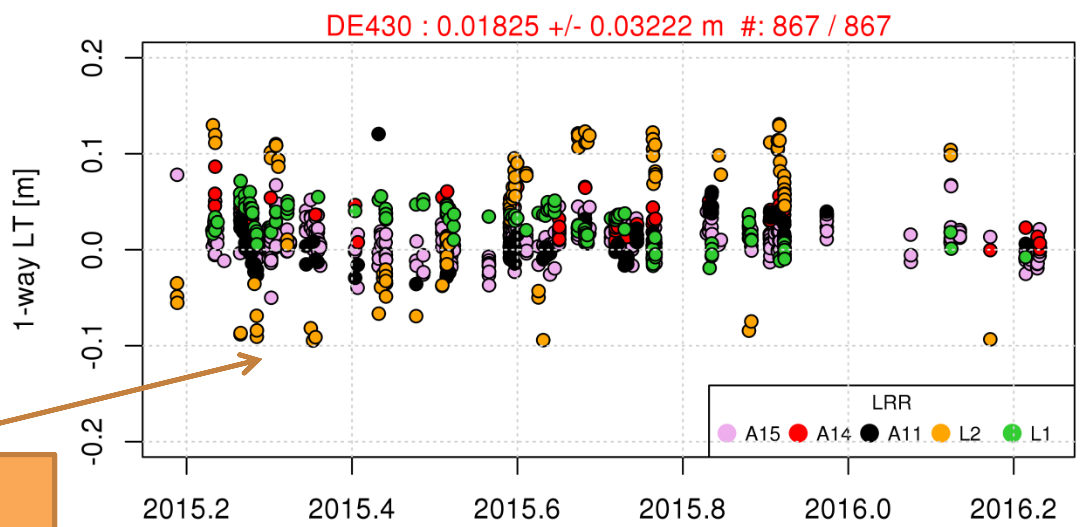
Distribution of observation



OCA IR Residuals

Reflector-wise σ(m) after 5σ filter		
Reflector	**INPOP15b***	**DE430**
A15	0.022	0.016
A14	0.018	0.018
A11	0.024	0.025
L1	0.030	0.020
L2	0.019	0.070





DE430
L2 signature

Preliminary estimates with formal uncertainties from INPOP15b WLS fit

Parameter	INPOP15b	DE430[1][2]
Radius Moon km	**1.738E+03**	**1.738E+03**
EMRAT	**81.3005718**	**81.3005691±0.0000024**
GM_EMB	8.99701159E-10	8.99701139E-10
k2 Moon	2.295E-02 ± 2E-05	**2.4059E-02**
h2 Moon	1.503E-02 ± 9.9E-05	4.76E-02 ± 6.4E-03
l2 Moon	**1.070E-02**	**1.070E-02**
CMR2 Moon	3.928E-01 ± 1.331E-06	3.93142E-01
Gravity field coefficients	GRAIL 660b (BVLS 2 x sig)	GRAIL 660b
C(2,0) Core	-8.501E-08 ± 3.052E-10	**-6.78E-08 (computed)**
CMR2 Core	6.006E-04 ± 2.771E-06	**2.75E-04 (computed)**
K CMB	5.560E-09 ± 1.167E-11	6.43E-09
Angular velocities	6.255E-03 ± 2.544E-06	**–2.4199E–03**
	-4.147E-04 ± 1.232E-06	**4.110195E-01**
	-8.040E-04 ± 5.090E-06	**–4.630947E-01**
Cf/C ratio	1.5E-03 ± 7.060E-06 (computed)	**7E-04**

***bold : fixed parameters**

Future work

Current assumptions

- Axial symmetry of liquid core
- Non-differential rotation
- Shape constrained by CMB
- Only viscous drag at CMB
- No topography at CMB

Discussions

- Introduction of inner solid core[8]
- Electromagnetic coupling[8]
- Interaction at ICB[8]

References :

[1] Folkner,W. M. et al (2014)
[2] Williams, J. G. et al (2014)
[3] Fienga, A. et al (2014)
[4] Konopliv, A. et al (2001)
[5] Konopliv, A. et al (2013)
[6] Viswanathan, V. et al (2016)
[7] Courde, C. et al (2016)*
[8] Wieczorek, M. et al (2016)