Impact on lunar dynamics from recent developments at OCA Station

V. Viswanathan (1), A. Fienga (1), J.Laskar (2), H. Manche (2), P. Exertier (1)

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

OCA LLR Station

OCA LLR Station

- French station dedicated for Earth-Moon measurements since 1984
- **Lunar Laser Ranging**
- Time of flight measurements
- Millimetric precision
- Target => Passive retroreflectors on the Moon placed by:

➢ Apollo astronauts : A11,A14,A15
➢ Russian rovers : L1, L2

- 11,146 observations and counting..

Recent developments

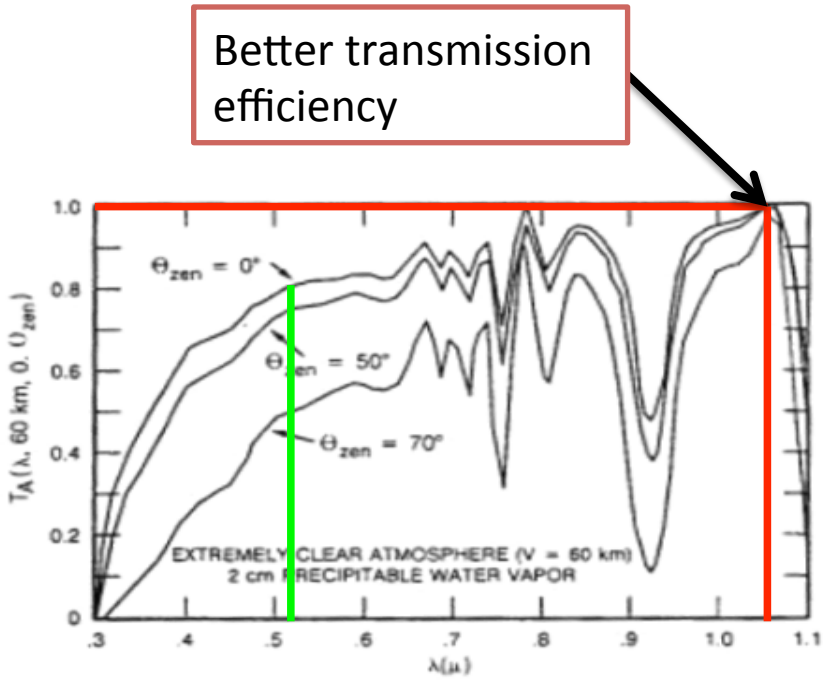
- **LASER: Green to Infrared wavelength**
- **differential / direct calibration**

Recent developments

- LASER: Green to Infrared wavelength
- differential / direct calibration

- **Advantages**:

  ✓ **Better atmospheric transmission**



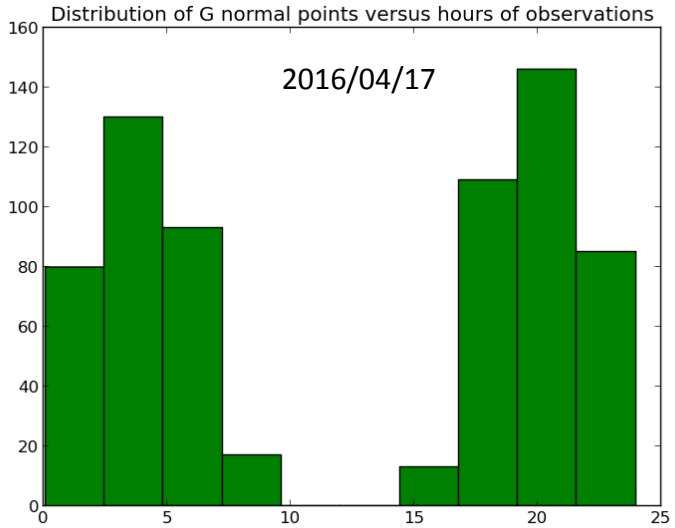
Recent developments

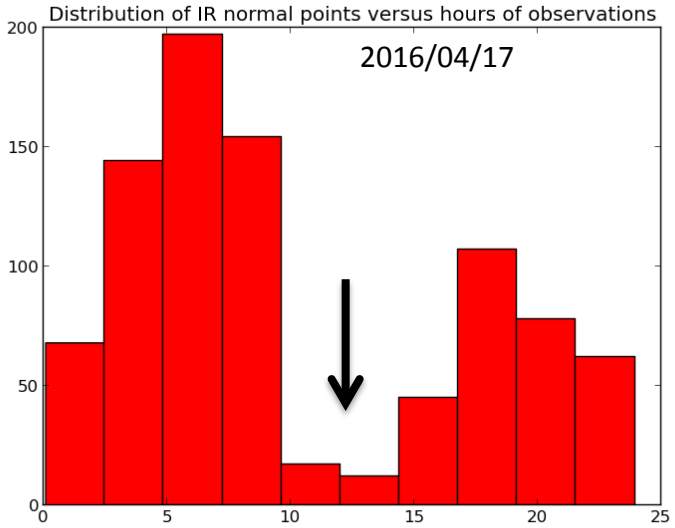
- LASER: Green to Infrared wavelength
- differential / direct calibration

- **Advantages**:

  ✓ Better atmospheric transmission

  ✓ **Observations round the clock**





Recent developments

- LASER: Green to Infrared wavelength
- differential / direct calibration

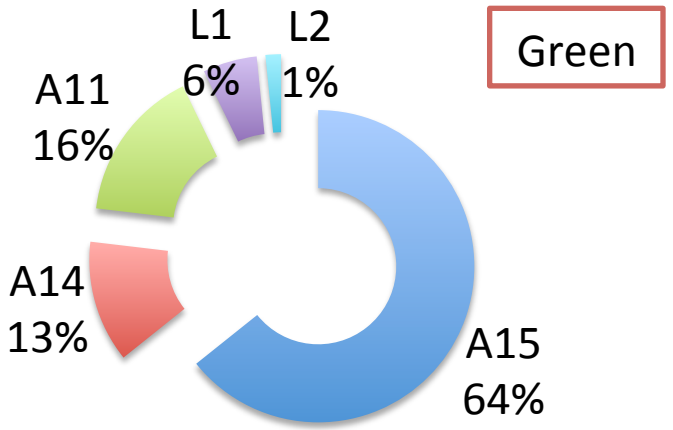
- **Advantages over Green**:

  ✓ Better atmospheric transmission

  ✓ Observations round the clock

  ✓ **Diversification of observed reflectors**

2016/04/17



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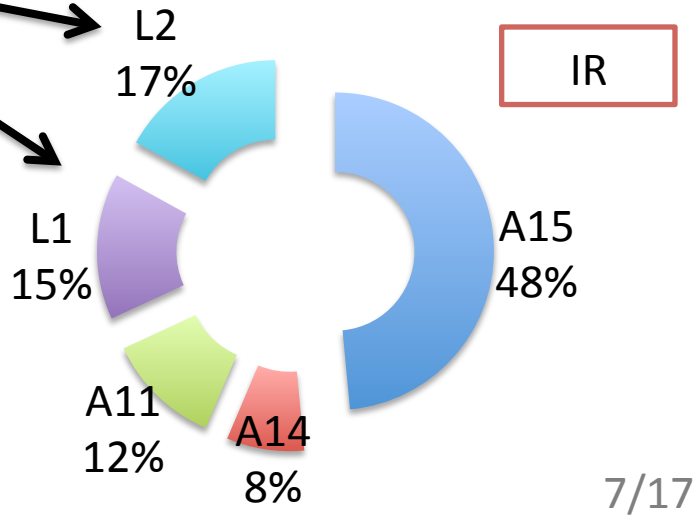


Recent developments

- LASER: Green to Infrared wavelength
- differential / direct calibration

- **Advantages**:

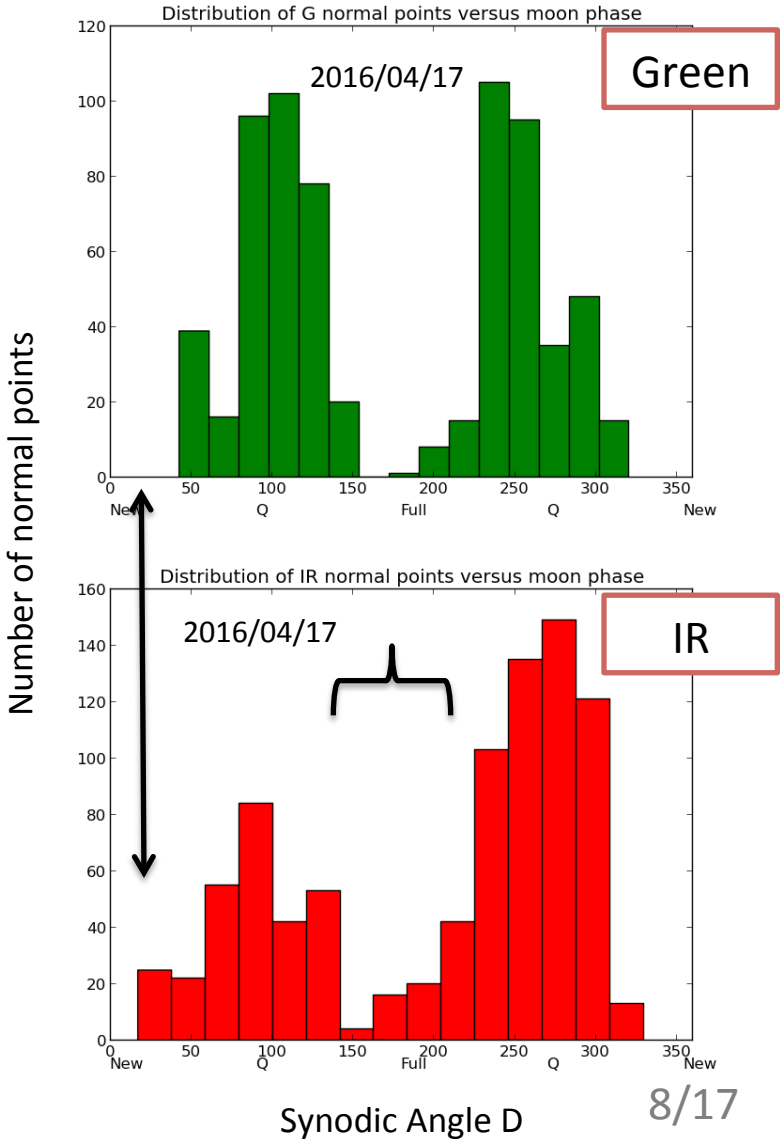
  ✓ Better atmospheric transmission

  ✓ Observations round the clock

  ✓ Diversification of observed reflectors

  ✓ **Observations during new and full moon**

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



Data Reduction Model : GINS

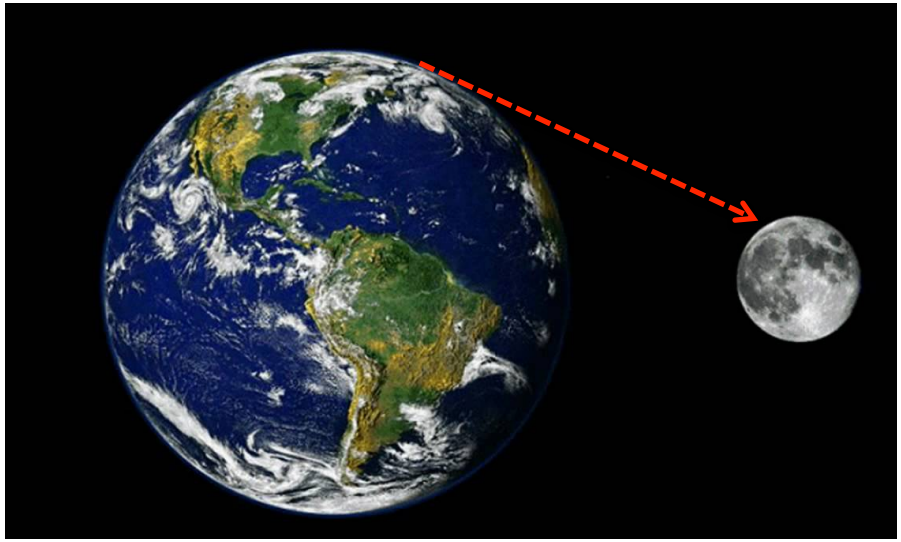
Géodésie par Intégrations Numériques Simultanées | OCA,GRGS,CNES

Time of flight => **Reduction model**

- Planetary ephemeris
- Earth orientation
- ITRF Station:
  - Coordinates
  - Plate motion
- Tides and loading
- Atmospheric delay

- Coefficients of lunar potential
- Crustal deformation
- Libration angles

- J2 Sun
- Relativistic effects



Data Reduction Model : GINS

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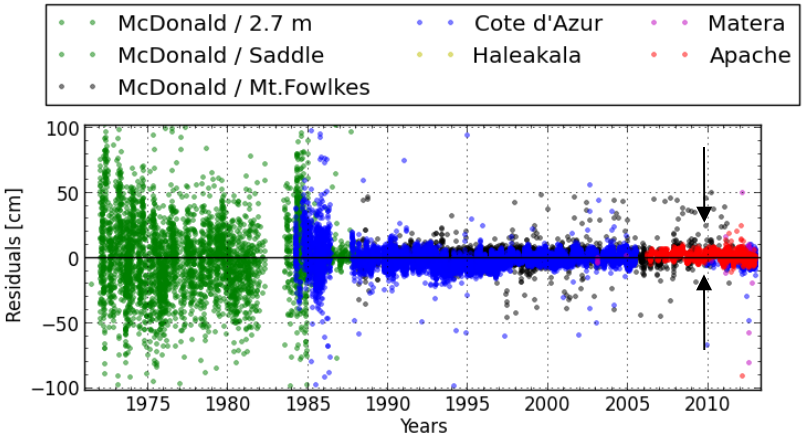
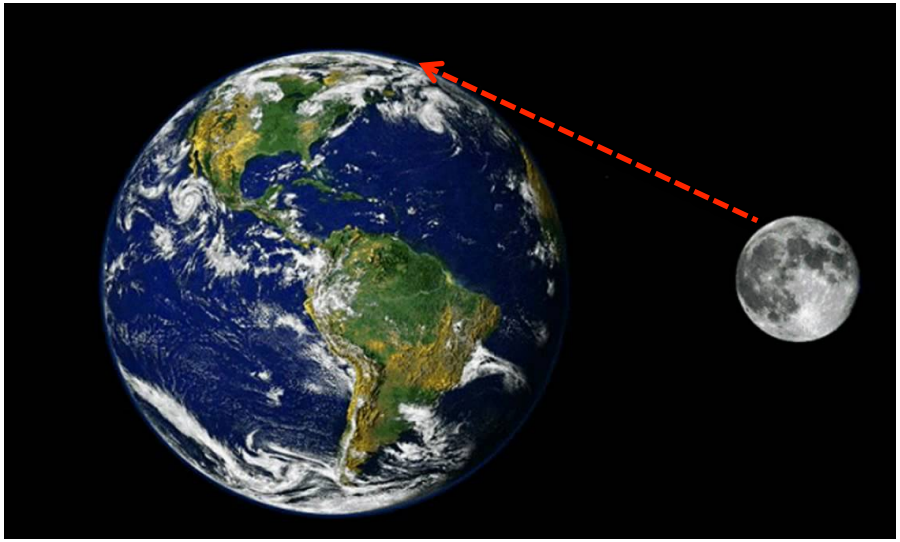
Time of flight => Reduction model => **Residuals**



Residuals < 5 cm

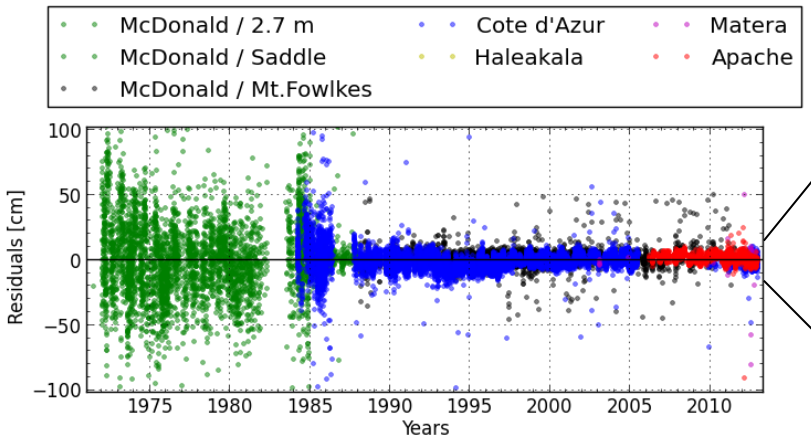


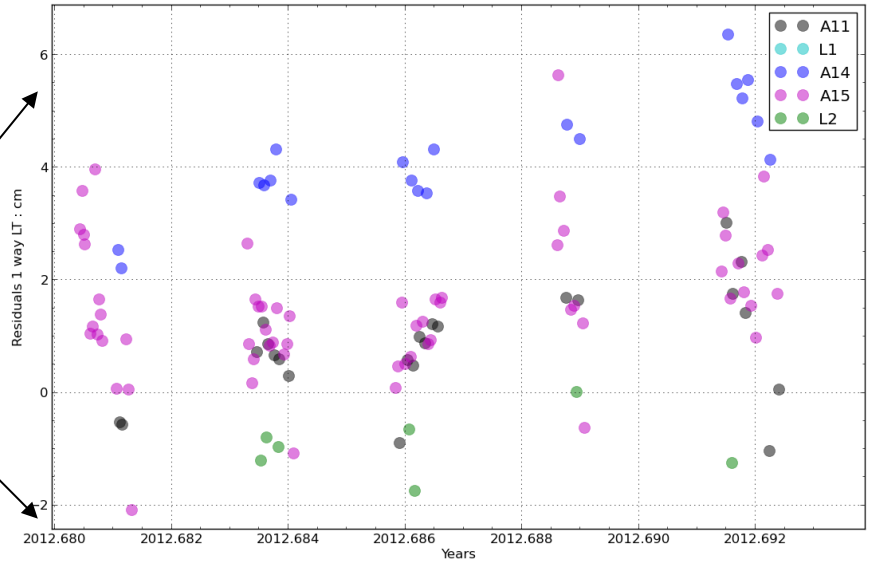
T_R-T_e ~ 2.5s

Data Reduction Model : GINS

Géodésie par Intégrations Numériques Simultanées | OCA,GRGS,CNES

Time of flight => Reduction model => Residuals => **Regression**





Dynamical modeling inaccuracies:

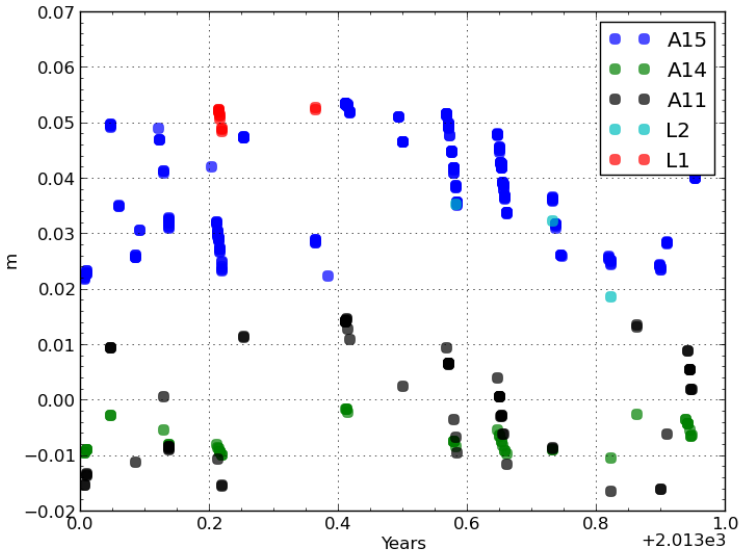
- Insufficient **libration** sensitive data
- Lack of **uniform sampling** (time and space)
- Unmodelled effects

Parameter sensitivity

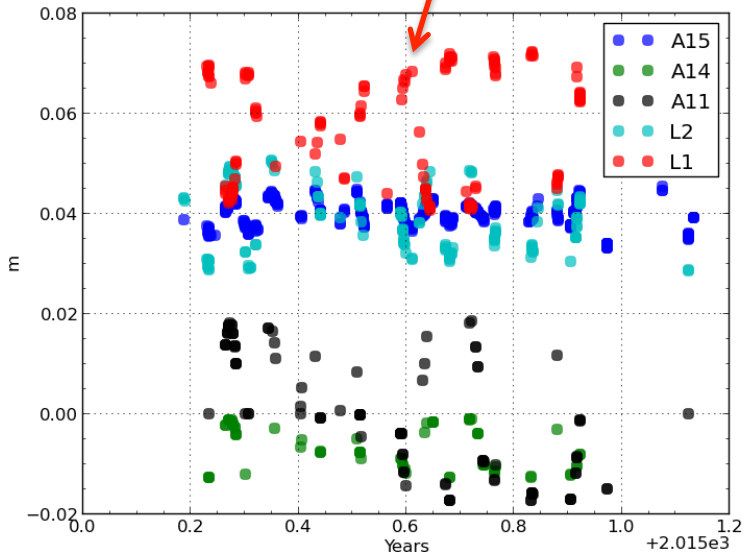
- Eg: 1. C_{20} of Moon's core

Most sensitive

Time of flight => Reduction model => Residuals => **Regression**



Green



IR

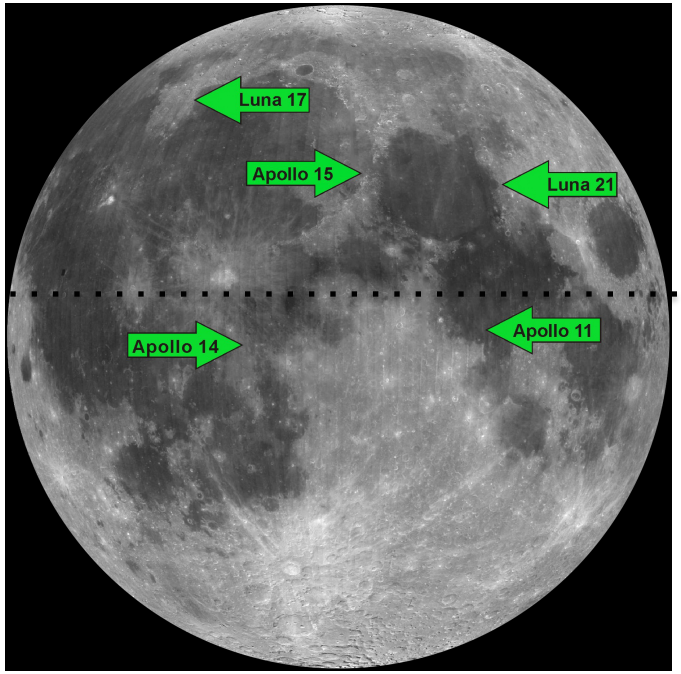
Parameter sensitivity

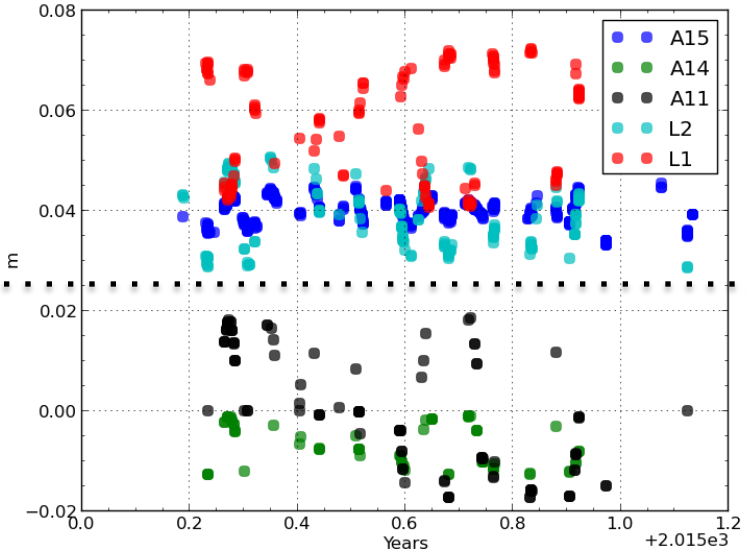
- Eg: 1. C_{20} of Moon's core

Time of flight => Reduction model => Residuals => **Regression**

N

S





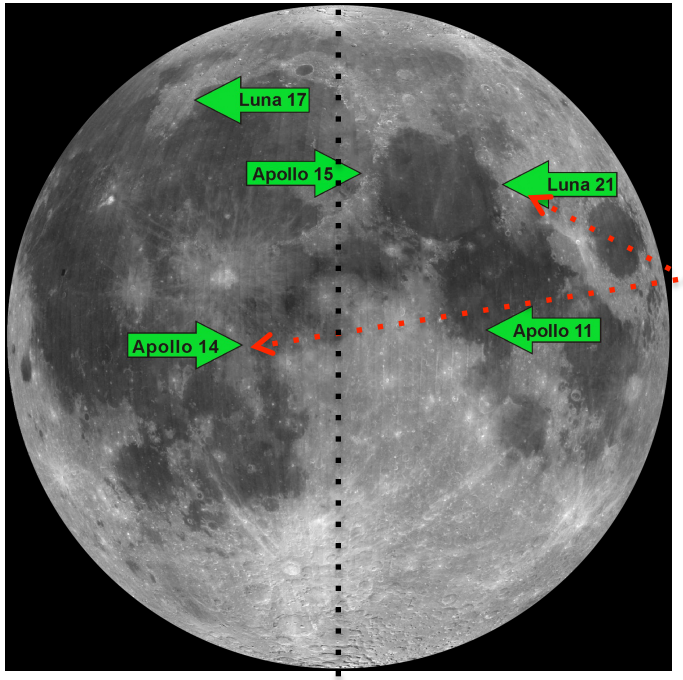
IR

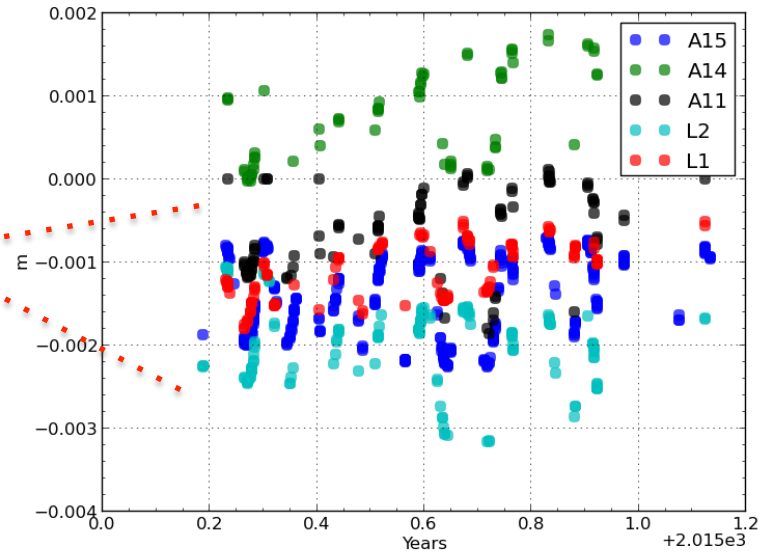
- Latitudinal sensitivity : **L1**
- factor 2 improvement in estimate with IR over Green

Parameter sensitivity

- Eg: 2. Coefficient of friction: Core Mantle Boundary (Moon)

Time of flight => Reduction model => Residuals => **Regression**





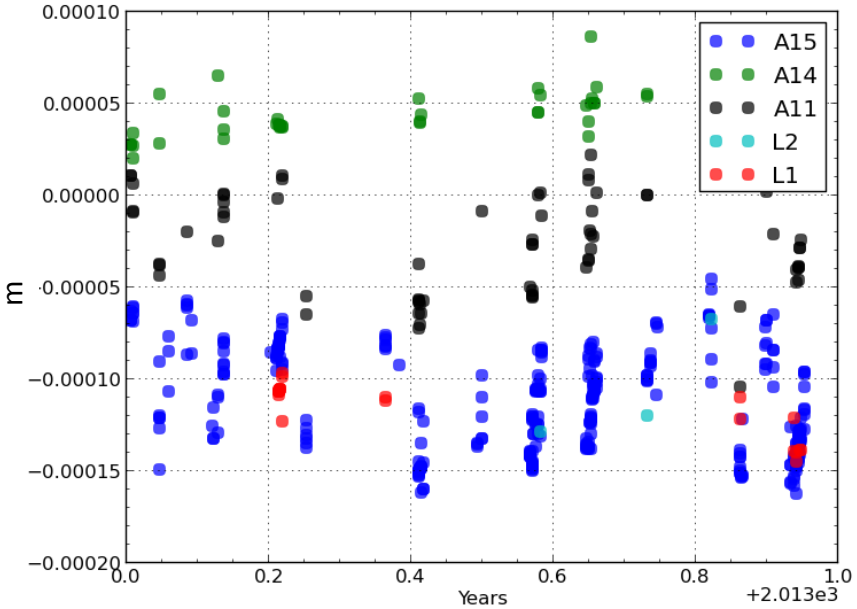
IR

- Longitudinal sensitivity : **L2**
- Improvement of 0.7% in estimate with IR over Green

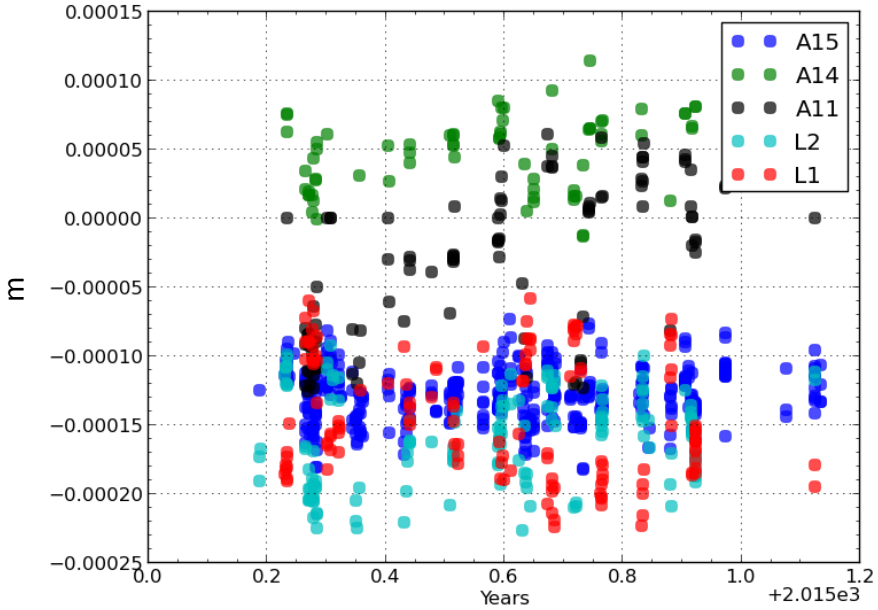
Parameter sensitivity

- Eg: 3. C/MR^2 principal moment of inertia of Core

Time of flight => Reduction model => Residuals => **Regression**



Green



IR

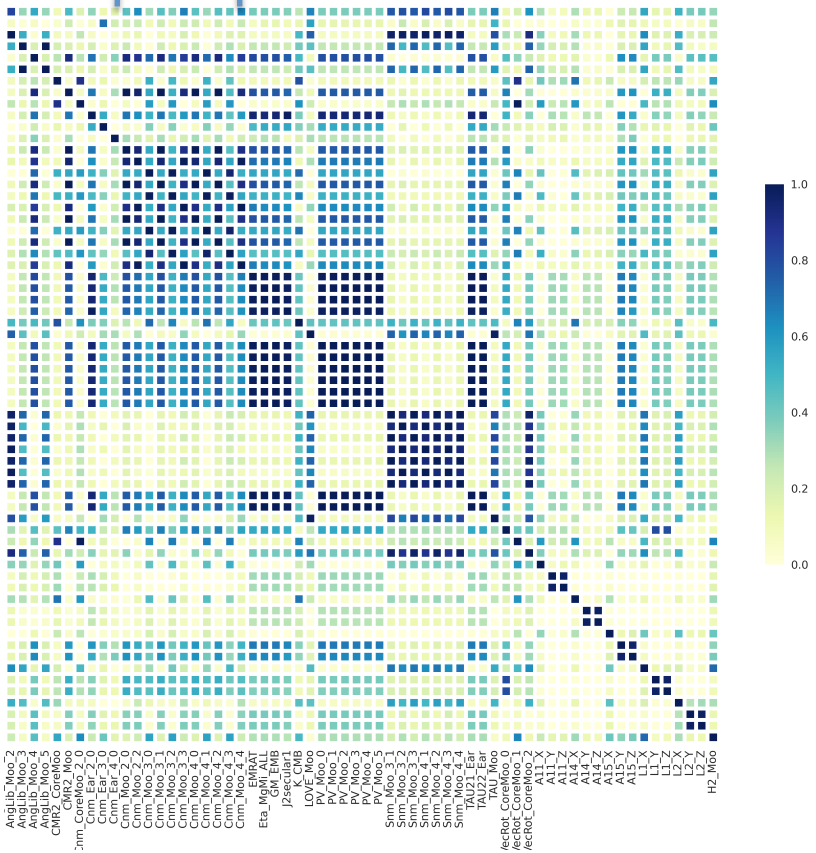
- Dense points with IR => factor 4 improvement in estimate

Correlation matrix comparison

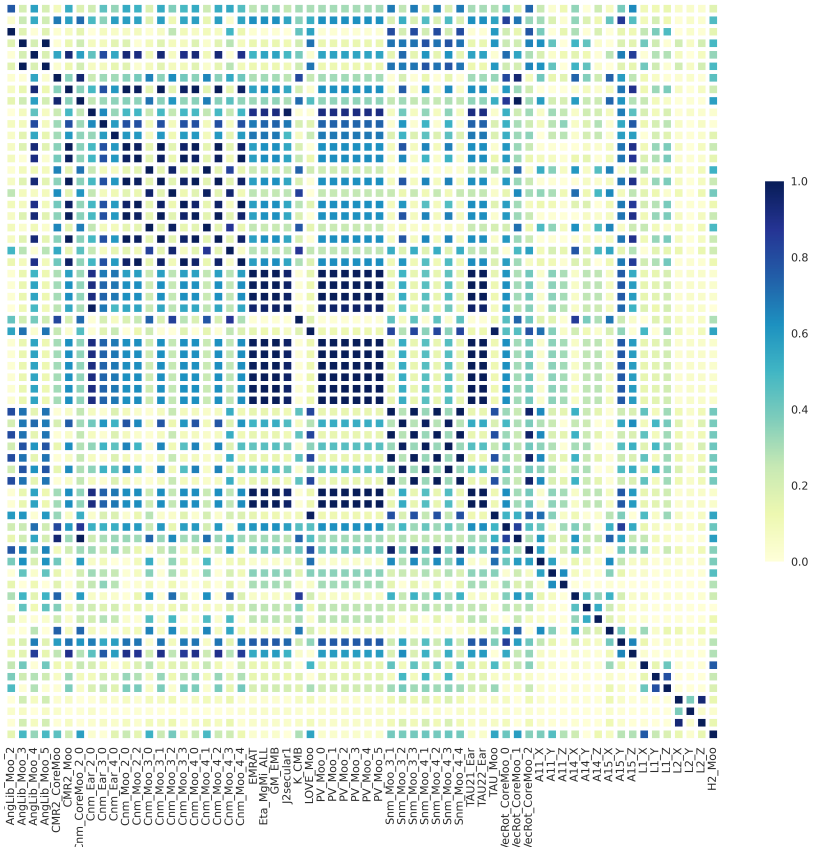
Gravity field coefficients

Reflector coordinares

IR



Green



SUMMARY

- IR LLR ranging provides **better resolution** (time+space)
- Ranging is now possible at **New and Full Moon**
  - Maximum sensitivity to tests of EP.
- IR data **more sensitive** to core parameters

PERSPECTIVES

- Combined use of **GRAIL** estimates
- **Disentangling** libration angles using IR data
- Tests of EP violation