Difference of LAGEOS satellite response from raw data analysis of the collocation experiment between the Grasse Satellite and Lunar Laser Ranging stations

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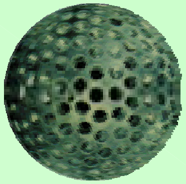
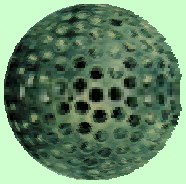
Overview



- Introduction and context of the study
- LAGEOS satellites
- Grasse SLR and LLR stations differences
- Method
- Results
- Discussion
- Conclusion and prospect

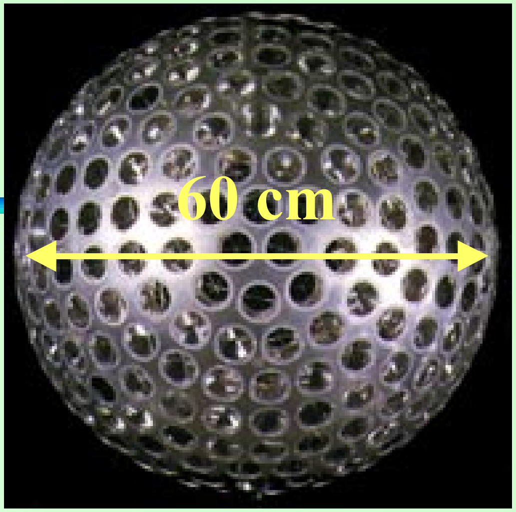
Introduction



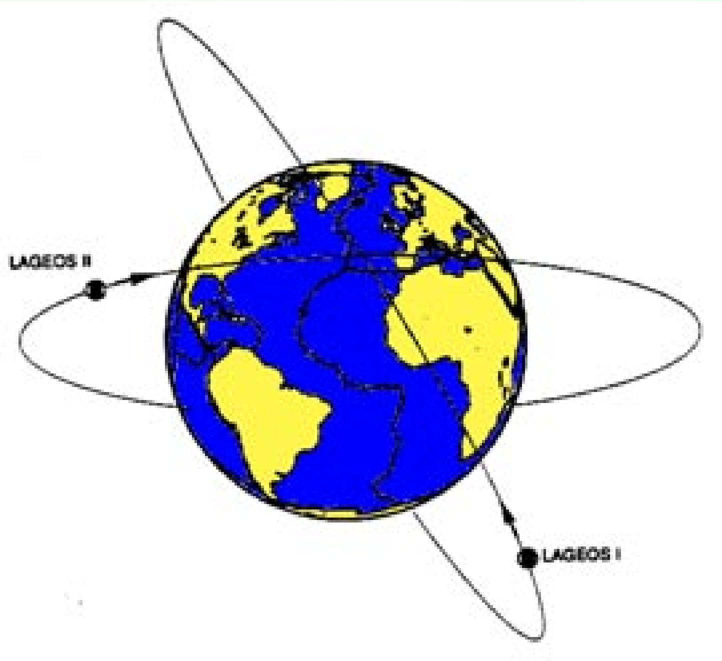
- Collocation experiment between the 3 Grasse laser stations (SLR, LLR, and FTLRS) at the end of 2001 (3 months)
- Analysis of LAGEOS common normal points
  - ⇨ *Difference of 13 mm between LLR and SLR*

- Evaluate the LAGEOS satellite response difference from:
  - – geometrical considerations
  - – station instrumental differences

LAGEOS satellites

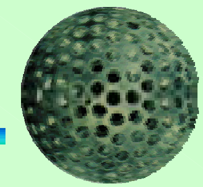


- **LA**ser **GEO**dynamics **S**atellite
- Reference for accurate station positioning
- LAGEOS-1 (1976) and LAGEOS-2 (1992)

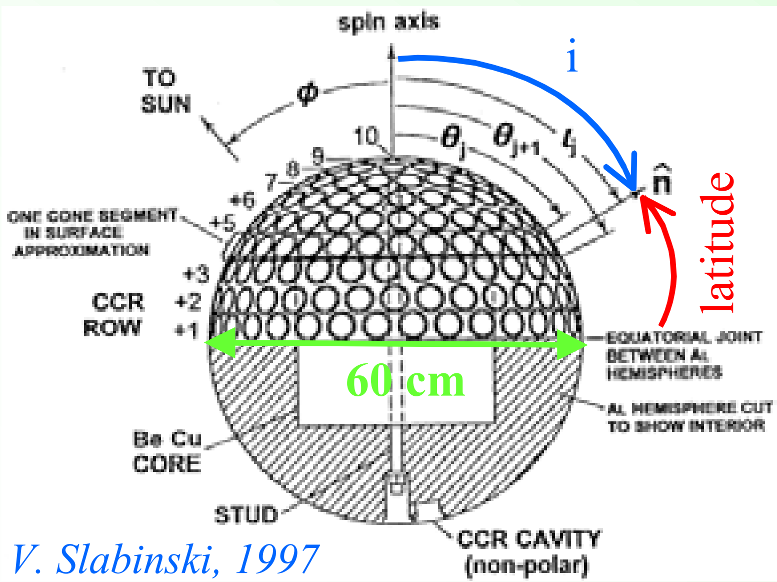


- ~ 6000 km altitude (circular orbits)
- inclination LA1: 110°, LA2: 53°
- 2 identical satellites:
  - 60 cm diameter sphere
  - ~ 400 kg
  - area/mass = 0.00069 m_/kg

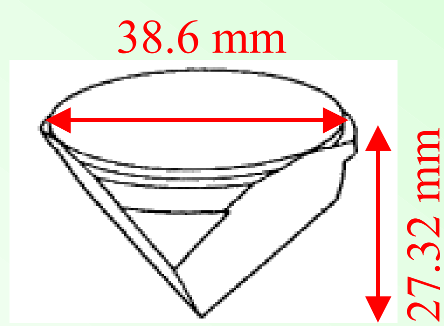
LAGEOS CCRs



- 426 Cube Corner Reflectors (CCRs)
  - ➪ *422 Silica + 4 Germanium **
  - ➪ *2x10 rows*



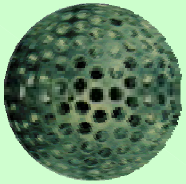
V. Slabinski, 1997



row number	CCR number	Latitude (°)
1	1 *	90.00
2	6	79.88
3	12	70.15
4	18	60.42
5	23	50.69
6	27	40.96
7	31	31.23
8	31	22.98
9	32	13.25
10	32	4.86
11	32	- 4.87
12	32	-13.25
13	31 *	-22.98
14	31	-31.23
15	27	-40.96
16	23	-50.69
17	18	-60.42
18	12	-70.15
19	6	-79.88
20	1	-90.00

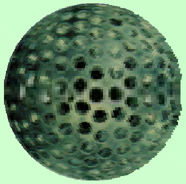
P. Avizonis, 1997

Grasse SLR and LLR station characteristic differences



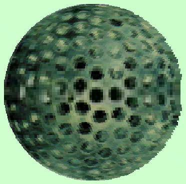
	SLR	LLR
telescope diameter	1.00 m	1.54 m
laser	Nd:YAG	Nd:YAG
	532 nm	532 nm
	40 ps	20 ps
	10 Hz	10 Hz
	divergent	parallel beam
calibration	semi-internal	internal
	post-pass	real time
return photodetector	C-SPAD	APD
return level	multi-photon	single photon

Method of computation



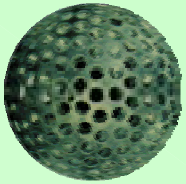
- Computation of the contribution of each CCRs row in the reflected signal for a given incident angle and a given pulse width
- Computation of the corresponding delay for each CCRs row
- Computation of a satellite response histogram (summation of each CCRs row contribution)
- Adjustment of this response amplitude to the real satellite response (raw data)
- Deduction of the corresponding bias for each station and the difference of the range bias between LLR and SLR

Remarks on our computation

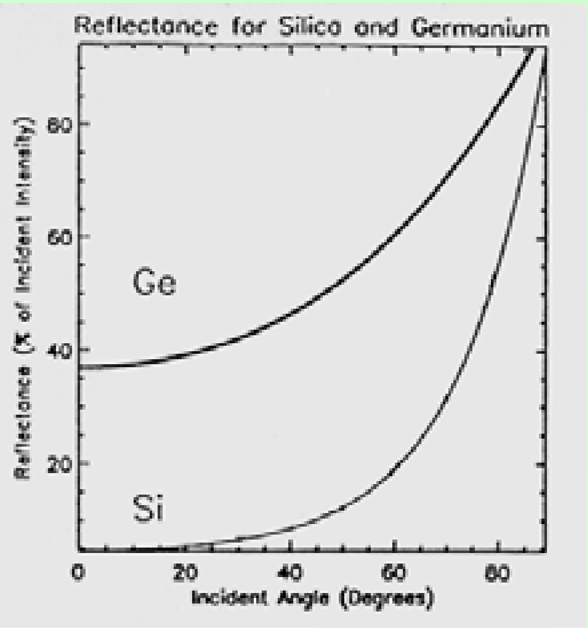


- Computations performed for:
  - the single photon electron case
  - LAGEOS -2 raw data
- Treatment of the 426 CCRs as made of fused silica even if 4 are made of germanium
- Hypothesis of an homogeneous repartition of the CCRs on the satellite
- We ignore:
  - the CCRs recess of 1 mm behind the satellite surface and treat the CCRs as coplanar with the satellite surface
  - the satellite spin (a pass => several satellite rotations around itself)
  - the differences of the optical path inside the CCRs depending on the incident angle

Contribution of each CCR row



- Contribution $P = N_{CCR} \times R_{CCR} \times \cos i$ with:
  - N_{CCR} = CCR number
  - R_{CCR} = CCR reflectance
  - i = incident angle
- CCR of row 1 = arbitrary reference unit

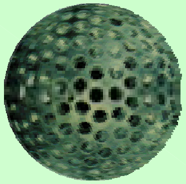


Avizonis, 1997

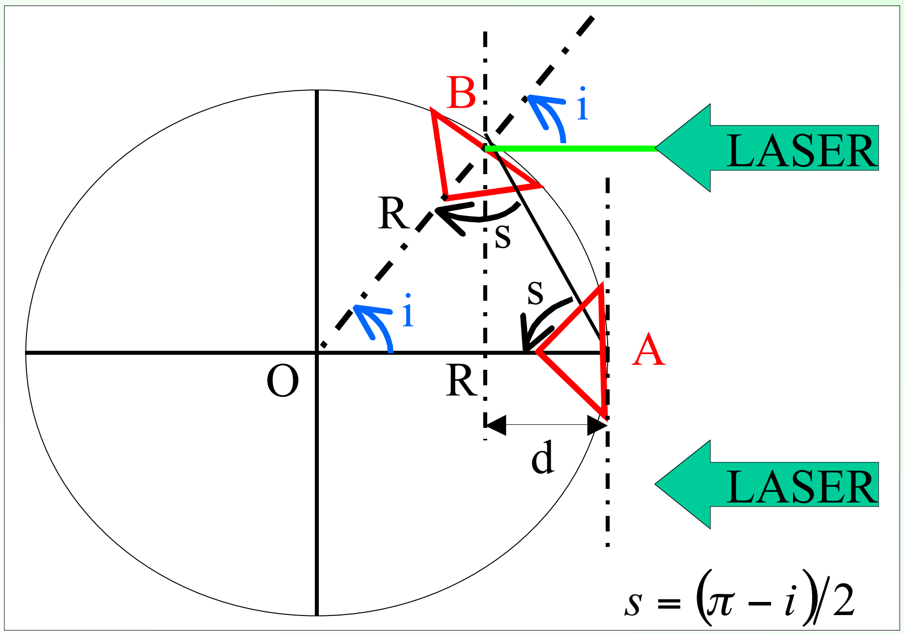
Row	N_{CCR}	R_{CCR}	cos i	P
1	1	1	1	1
2	6	0.5	0.984	2.953
3	12	0.3	0.940	3.386
4	18	0.2	0.870	3.131
5	23	0.1	0.770	1.780
6	27	0.05	0.510	0.885
7	31	0.02	0.656	0.406
8	31	0.01	0.390	0.121

- Rows 8 and 9 are negligible
- The other rows are invisible

Delay of each CCRs row

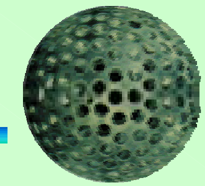


- Delay $$d = \frac{R \sin i}{\tan[(\pi - i)/2]}$$ with:
  - R = satellite radius
  - i = incident angle

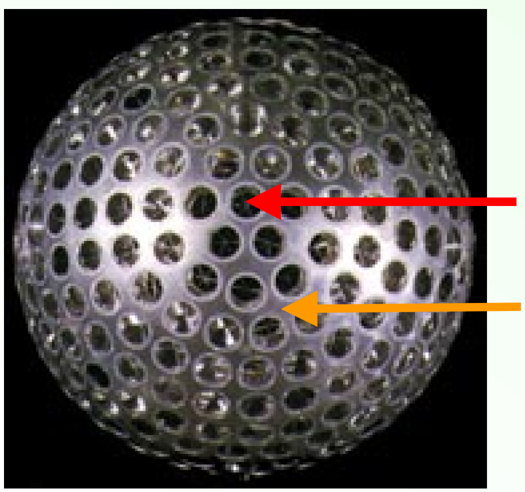


Row	d (mm)
1	0
2	4.7
3	17.8
4	39.1
5	67.9
6	103.3
7	144.5
8	182.9

Laser beam orientation on the CCRs



- To take into account the spin of the satellite, we consider 2 extreme cases:
  - **Case 1** : laser beam direction perpendicular to a CCR face
  - **Case 2** : laser beam in the center of 3 CCRs
- All the previous computations are in the case 1



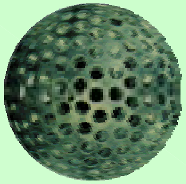
Case 1

Case 2

- Supplement delay between case 1 and case 2

  ➩ *Statistical widening of 22 ps of the CCRs row response*

Satellite response



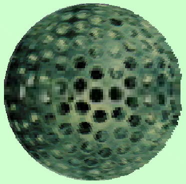
- The satellite response is computed as the convolution of gaussian curves with:
  - a shift given by the delay of each CCRs row
  - the widening of 22 ps computed previously (satellite spin)
  - a width corresponding to each station response (laser, photo-detector, atmosphere ...)

⇨ *Realistic values*

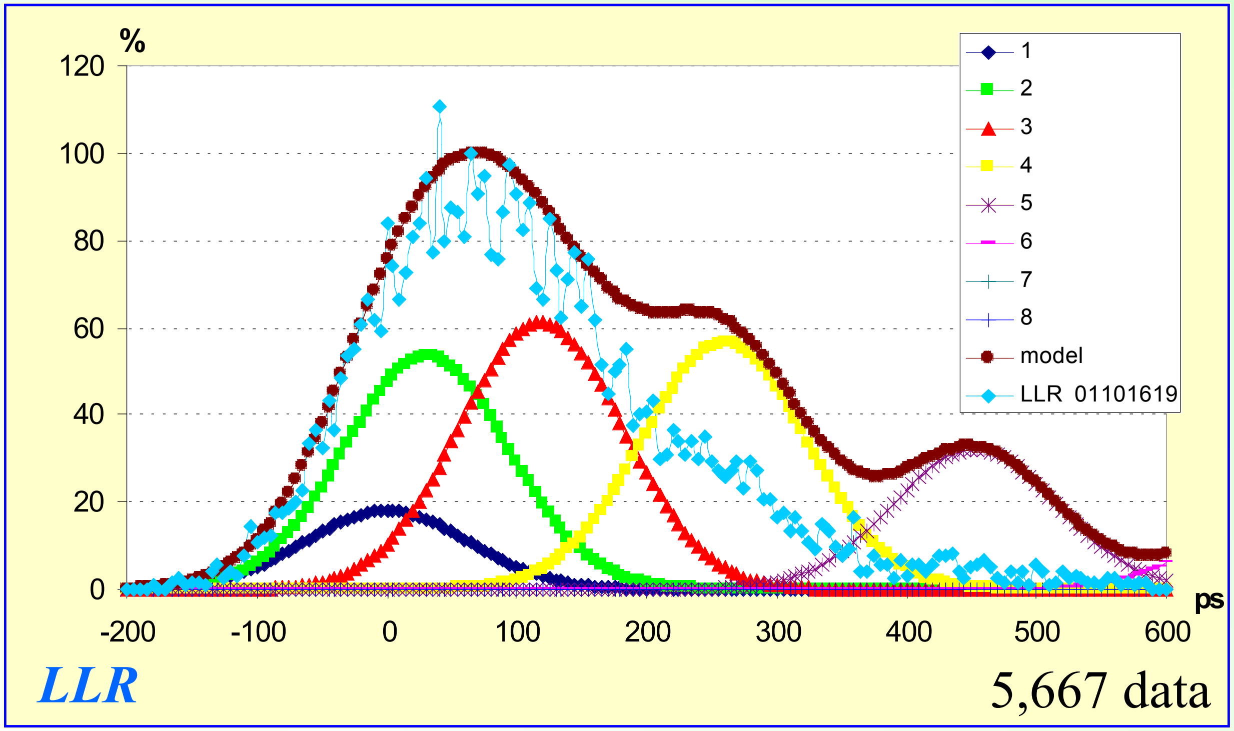
  - ☆ 63 ps for the LLR (50 ps from the station)
  - ☆ 48 ps for the SLR (40 ps from the station)

- Comparison with the raw data to adjust the computation
- Remarks
  - Computation of a gaussian curve even if non gaussian shape of the photodiode response (especially for the C-SPAD)
  - Uniform laser energy distribution on the satellite

Model and LLR raw data comparison



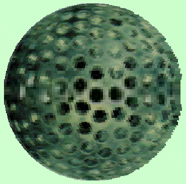
LAGEOS -2 (October, 16 - 2001)



- Rows ≥ 4 are over-estimated
- Very low contribution of the rows > 5

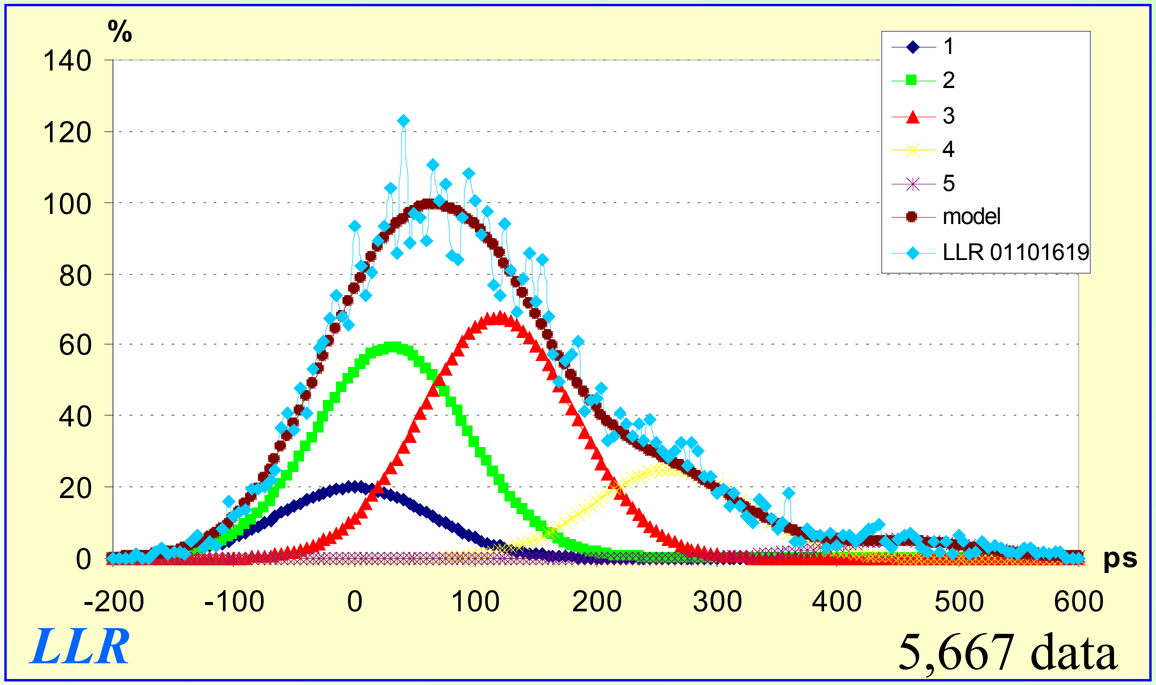
- Over-estimation linked to the CCR limit incident angle (35°)
- Attenuation coefficient adjustment from the raw data comparison

Results

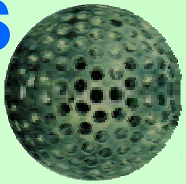


- Example based on the LAGEOS-2 LLR pass of the 16th October 2002
- Adjusted empirical attenuation coefficients

Row	Coef.
1	1
2	1
3	1
4	0.4
5	0.14



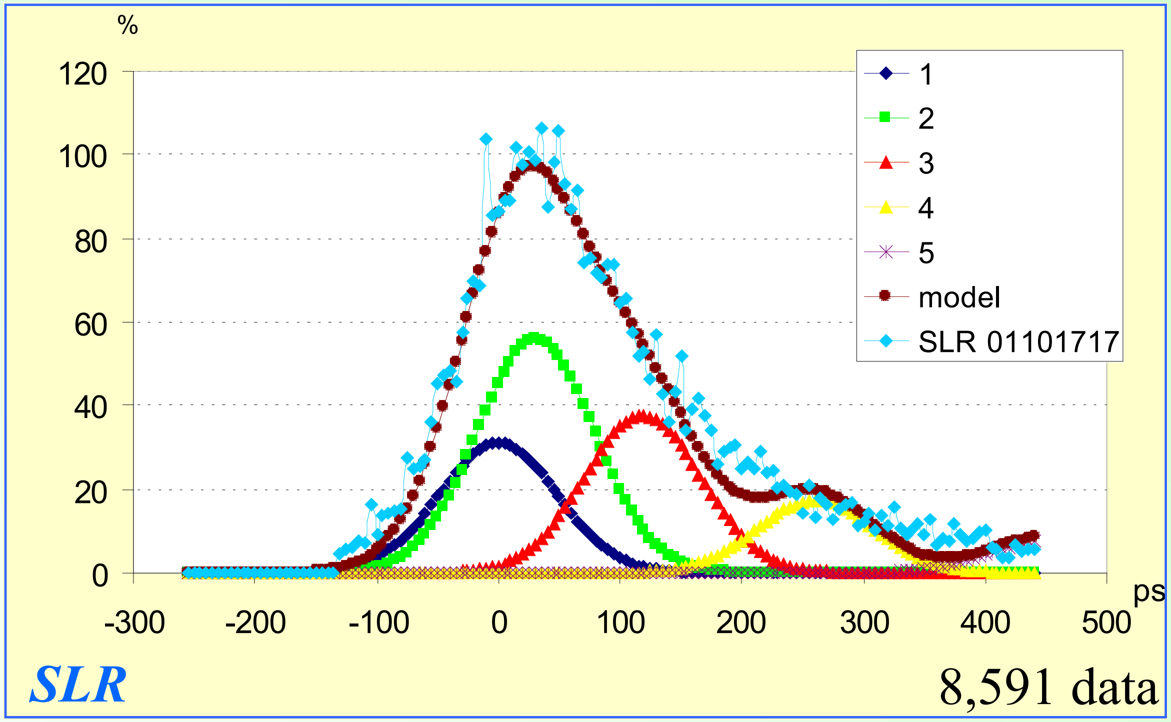
Comparison with SLR measurements



- Attenuation coefficients differ from the LLR case

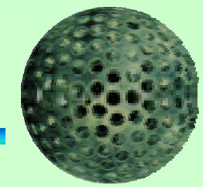
Row	Coef.
1	1.4
2	0.85
3	0.5
4	0.25
5	0.2

LAGEOS -2 (October, 17 - 2001)



- Differences linked to:
  - non gaussian curve for the C-SPAD
  - multi photon electron

Bias computation



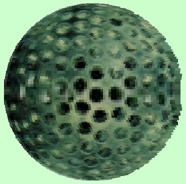
- Bias from a unique CCR at the satellite surface
- Bias: $$B = \frac{\sum_i d_i \times P_i \times coeff_i}{\sum_i P_i}$$

➩ *LLR bias: (14.8 ± 2) mm*
➩ *SLR bias: (11.8 ± 2) mm*

- **BUT** need to add a bias of 9 mm for the LLR (center-edge effect and velocity aberration)
  - ➩ *Bias difference between LLR and SLR: 12 mm*
- Collocation analysis result: 13 mm
  - ➩ *Explanation at the level of 1 mm !!!*

with realistic empirical evaluations

Center of Mass Correction



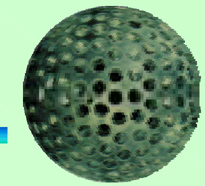
- Reference point of this virtual unique CCR $r_{sat} - l_{CCR} * n_{CCR}$ with:
  - r_{sat} = satellite radius
  - l_{CCR} = CCR length
  - n_{CCR} = CCR refraction index

⇨ *LLR center of mass correction: 244.2 mm*

⇨ *SLR center of mass correction: 247.2 mm*

- **BUT** COM standard value: 251 mm
- COM standard value non consistent with the value found from OCA laser station observations

Conclusion



- Explanation of the difference observed between the OCA SLR and LLR stations at the level of 1 mm by geometrical considerations
- Satellite signature and center of mass correction depend on the laser station characteristics !
- Necessity to use the raw data (these computations can't be performed from the normal points)

- Suggestions to the ILRS to reach the millimeter accuracy
  - ➪ *Compute tables of COM for each satellite and each station as for T/P*
  - ➪ *For T/P: update needed*