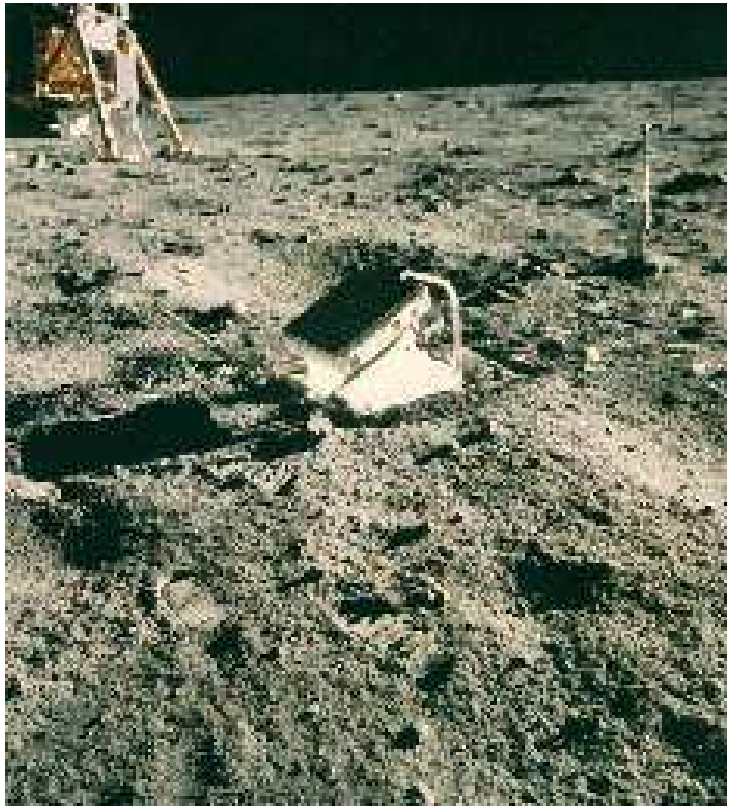
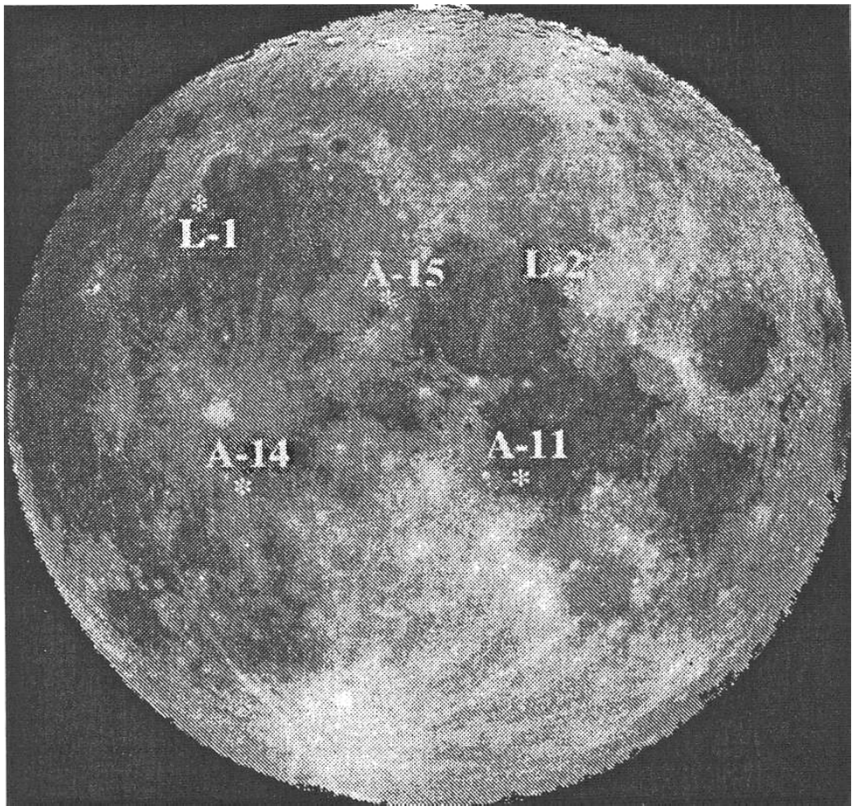
EPM-ERA2012 Lunar Ephemeris and selenodynamical parameters from LLR data(1970-2012)

M.V. Vasilyev, E.I.Yagudina

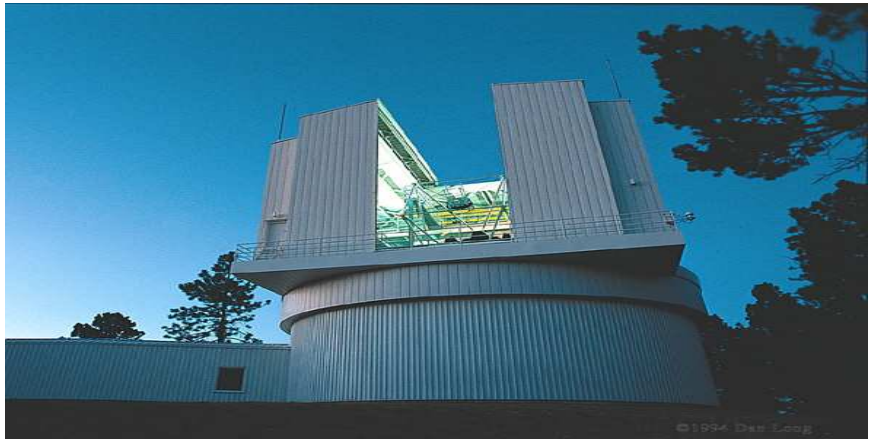
IAA RAS, St-Petersburg, Russia



Reflector at the Moon



The reflector’s positions at the Moon surface



3.5 m telescope at Apache station

INTRODUCTION

MODERN EPHEMERIDES:
1. JPL, USA: DE403, DE405, DE421;...

2. IMCCE, Observatoire de Paris
INPOP10-Integrateur Numerique Planetaire de l”Observatoire de Paris”);

3. IAA RAS, Russia-EPM-ERA2012

The present analysis of (17580) LLR observations, (time interval 1970, March - 2012, February)

Model (brief description).

The dynamical model EPM-ERA has been developed by G.A. Krasinsky.
The model is constructed by simultaneous numerical integration of the equations of orbital and rotational motion of the Moon, major planets, asteroids;
The potential of the Moon is calculated up to 5-th order of harmonics;
The potential of the Earth includes the 4-th order harmonics ;
The tidal perturbation in the lunar orbital motion (due to tidal dissipation on the Earth's body) as well as in rotational Lunar motion (due to tidal dissipation on the Moon's body) is computed by a model with a constant lag.
Method of integration : Everhart's method of the 23 order with the constant step of integration. Partials of lunar ranging respective to dynamical parameters of the orbital and rotational model of the Moon are mostly computed by integrating variational equations; in some cases, they were obtained by integration of a rigorous system of equations with slightly varied values of the parameter under study (for example, k2 Moon).
During the fitting process LLR observations are reduced with a model according to IERS Conventions.
All the calculations were made by ERA system, IAA RAS, Russia .

Station	Time interval	NumberLLR observations
McDonald	1970 March -1985 June	3440
MLRS1	1985 January- 1988 January	275
MLRS2	1988 August-2012 February	3114
HALEAKALA	1988 August-1990 August	694
CERGA	1985 Jan - 2012 February	9113
APACHE	2006 July - 2010 November	944
Total	1970 March -2012 February	17580

Table1: Distribution of LLR observations

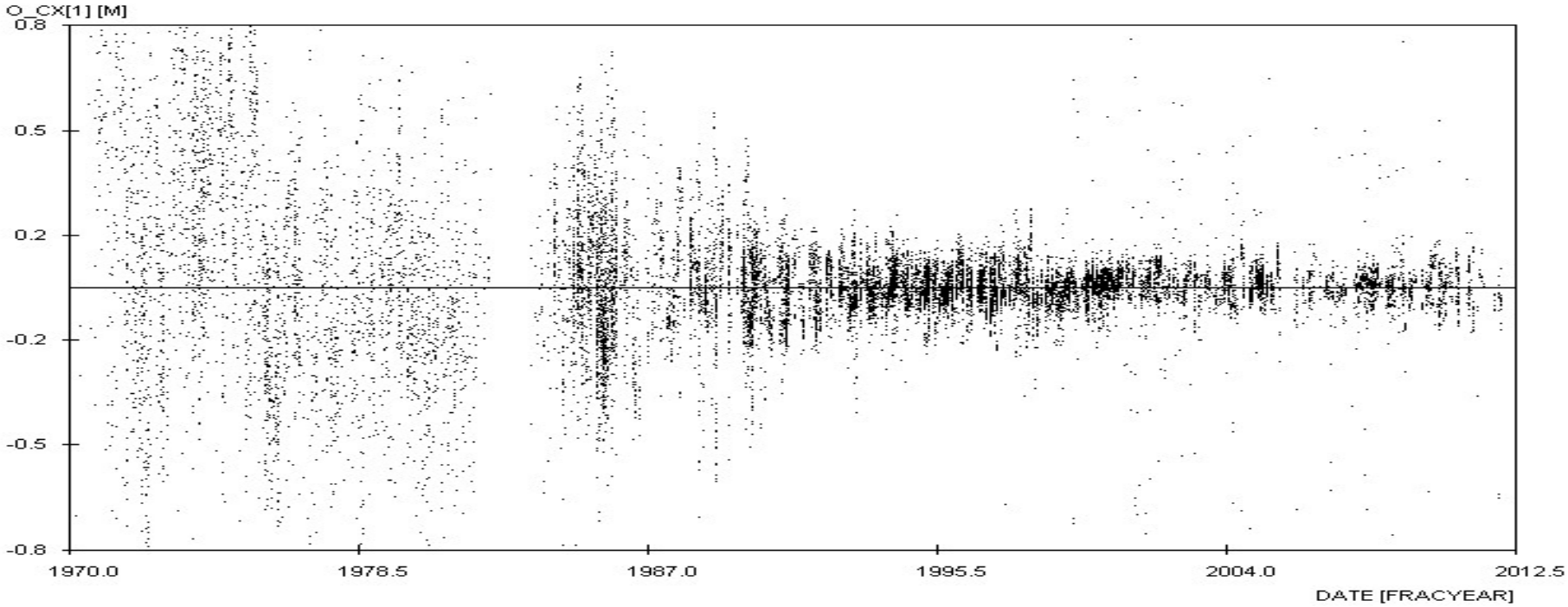
Reflectors:	number of ranging:
1. Apollo-11	1788;
2. Apollo-14	1769;
3. Apollo-15	13492;
4. Lunochod2	504;
5. Lunokhod1	29.

Observations obtained using FTP servers:
ccdisa.gcfc.nasa.gov/pub /slr,
Oca.eu/gemini/donnes/las_lune,
(Partly from private correspondence , thank to Dominique Feraudy)

N	Parameters estimated
1-6	Lunar orbital state vector for the epoch JD 2446000.5
7-12	Euler's angles and their time derivatives for the same epoch
13-18, 22-24 45-47	Coordinates of reflectors A11, A14, L2, L1
20	X coordinate for reflector Apollo 15 (A15)
25-42	Coordinates of 6 observational stations
44	Lag of the Earth's body tides
48-51	Secular trends in siderial angles of the Earth and Moon
55	Lag of the Moon's body tides
52-54, 59-63	Harmonics of lunar potential from C_{20} to S_{33}
56-58	Lunar Love numbers k_2, h_2, l_2
64-65	Secular trends of the corrections to the parameters of Earth's equator ε, Φ

wrms (cm) O-C	wrms (cm) postfit residuals	Number of observations	Observational stations	Interval of observations
27.7	27.9	3143	McDonald	19700415.0 - 19850630.0
13.3	13.0	253	MLRS1	19850301.0 - 19880127.1
18.8	18.7	1135	CERGA	19840407.2- 19860612.2
7.5	7.4	2969	CERGA	19871012.2-19941213.2
4.6	4.5	4870	CERGA	19950107.2-20120202.2
11.3	11.3	538	Haleakala	19841113.1 - 19900830.1
6.4	6.3	1002	MLRS2	19880229.0 – 19951228.0
6.5	6.4	2203	MLRS2	19950113.0 -20120201.0
4.4	4.4	944	Apache	20060407.1 - 20101030.1
5.9	5.8	16658	(All stations)	19700415.0 -20120202.2

EPM-ERA2012 ephemeris, statistics of residuals

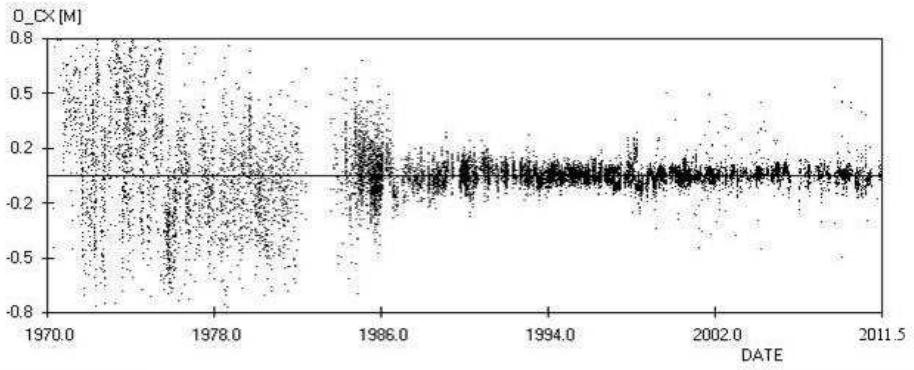


EPM-ERA2012 ephemeris, residuals (laser ranging)

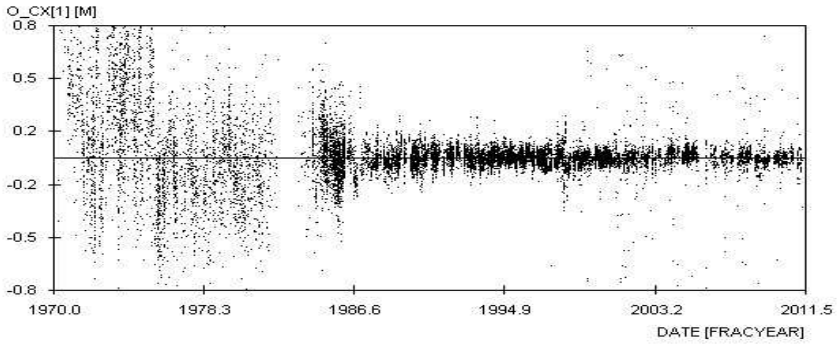
Residuals for DE and INPOP10 ephemerides compared with EPM-ERA2011

Ephemeris	Residuals Wrms (cm)	Number of observations	Number of deleted observations
DE403	5.1	17134	579
DE405	5.3	17134	543
DE421	5.2	17134	500
INPOP10	5.1	17134	578
EPM-ERA 2012	5.8	17580	890

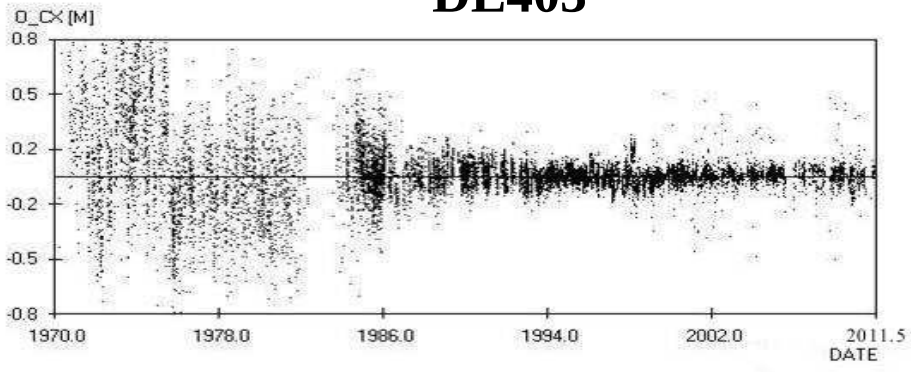
	EPM-ERA2010	EPM-RA2012
Interval of observations	19700315.0-20100404.1	19700315.0-20120202.0
Number of observations	17134	17580
Wmrs (cm) Postfit res.	6.8	5.8



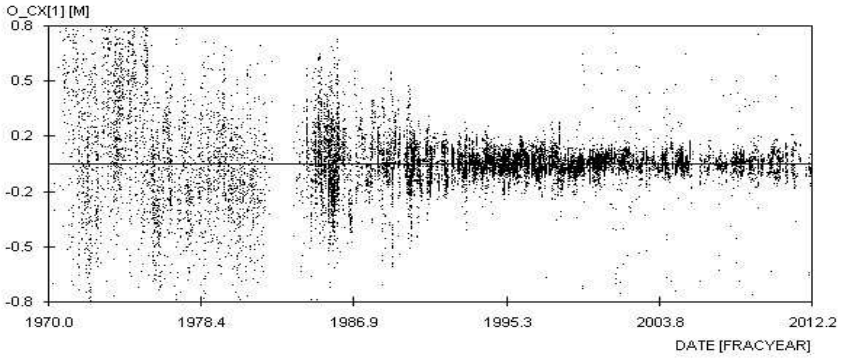
DE403



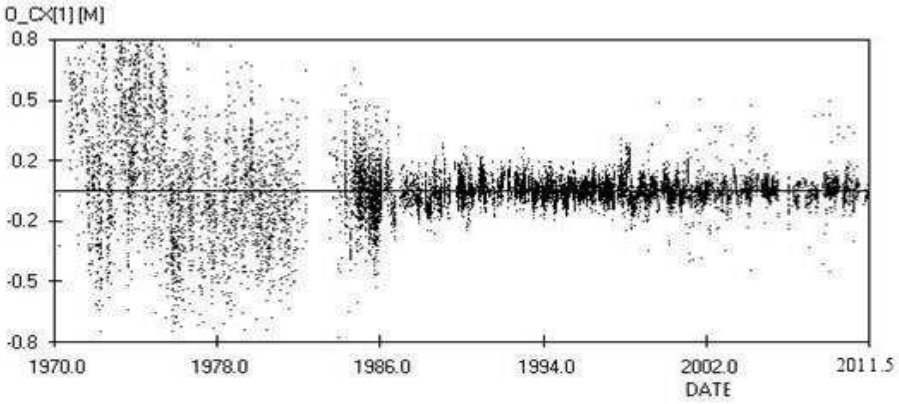
INPOP10



DE405



EPM-ERA 2012



DE421

Residuals (laser ranging) for DE, INPOP10 и EPM-ERA 2012ephemerides

Conclusion

- **The investigation has shown that the inner accuracy of DE ephemerides (5.1-5.3cm) and INPOP10 French one (5.1 cm) (in the case the derivatives from EPM-ERA are used) is slightly better than that of EPM-ERA2012 (5.8 cm).**
- **The re-weighting LLR observations was a main factor for result improvement.**
- **It is shown that the inner accuracy of EPM-ERA model does not practically depend on the use of either 19 or 15 significant decimal digits in floating point calculations.**
- **The processing of LLR observations of Haleakala station was modified.**
- **The improvement of dynamical model (tidal perturbations in Moon's rotation) is still required.**

Future work:

- **The model of tidal perturbations in Moon's rotation will be adjusted and tested.**
- **The observations of Matera station will be added in common solution.**
- **To put at site IAA RAS the value of selenodynamical parameters from EPM-ERA 2012 version.**

- **Thank you very much for your attention!**

REFERENSES

- 1)Krasimsky G.A., Vasiliev M.V. ERA: knowledge base for Ephemeris and dynamical astronomy // Proceedings of IAU Colloquium 165, 1996, Poznan, Poland, P.239-244.
- 2)Aleshkina E.Yu., Krasinsky G.A., Vasiliev M.V . Analysis of LLR data by the program ERA // Proceedings of IAU Colloquium 165, 1996, Poznan, Poland, P.228-232.
- 3)Krasinsky G. A. Selenodynamical parameters from analysis of LLR observations of 1970-2001.// Comminications of the IAA RAS, 2002, N 148. P 1-27.
- 4)Yagudina E.I. Numerical Lunar Theory EPM2008 from Analysis of LLR data.// Book of abstracts Journees2008, Dresden, 22-24 September 2008. P 11.
- **Referenses at Krasinsky' papers on orbital and rotational model of the Moon.**
- "Tidal Effects in the Earth-Moon System and Earth's Rotation." , Celestial Mechanics 75/1, 39-66,1999.
- "Dynamical history of the Earth-Moon system. " Celestial mechanics 84, 27-55,2002