

INPOP06.

A New Numerical Planetary Ephemeris

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with support from CNES R&T
and discussion in the GTEP working group

Fienga et al, 2007, submitted
www.imcce.fr/inpop

First step → INPOP05

Understand the model used for DE405
Same initial conditions and parameters

Second step → INPOP06

Improvement of the dynamical model
Fitted to planetary observations
Fitted to the Earth-Moon distance of DE405

Third step → INPOP07 (work in progress)

Fitted to LLR data

INPOP05

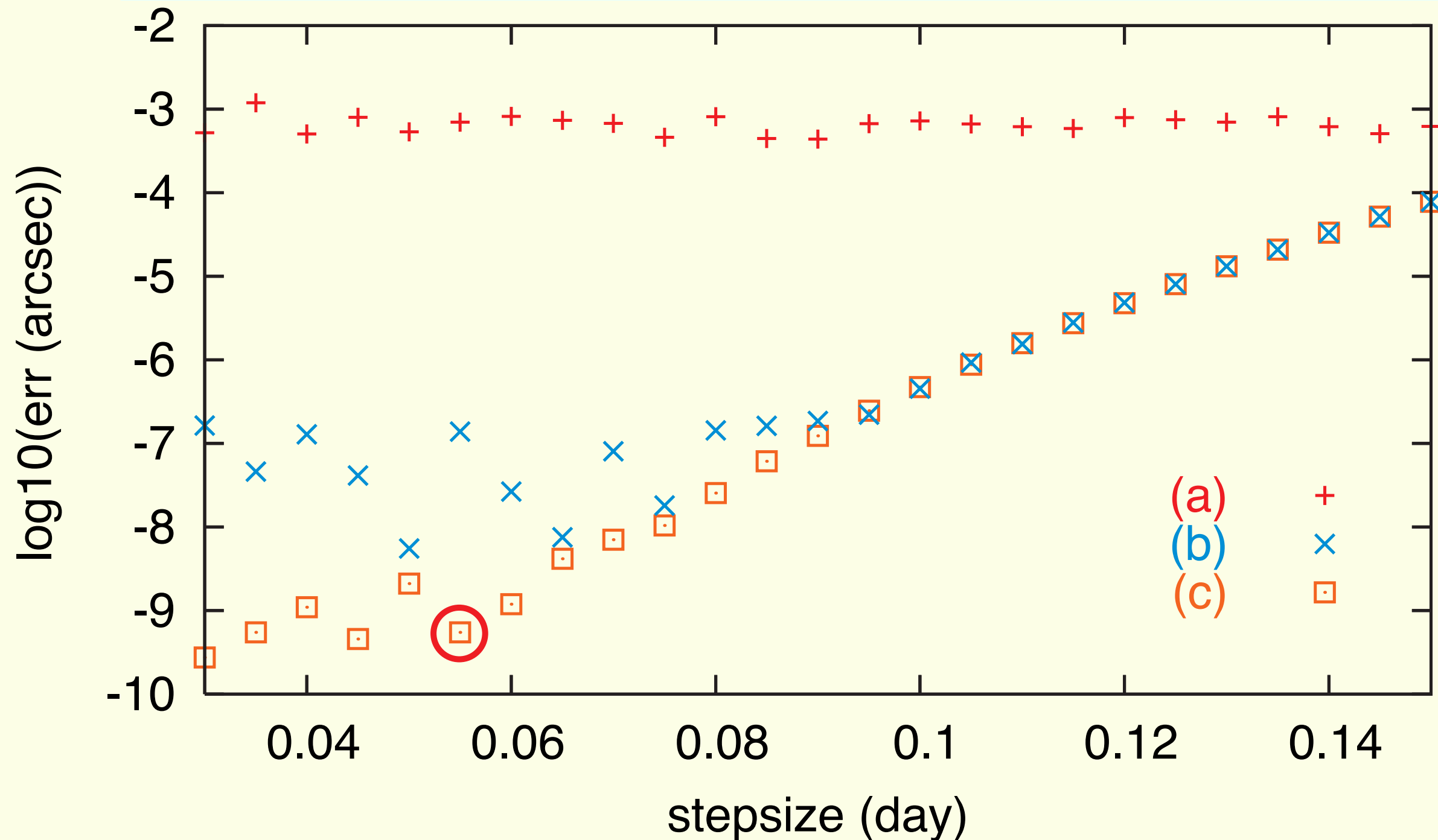
Dynamical model~ DE405

- Newtonian interactions (planets, asteroids)
- Relativistic corrections (planets)
- Interactions due to the shape of bodies
 - Earth - (Moon, Sun, Venus, Jupiter)
 - Moon - (Earth, Sun, Venus, Jupiter)
 - Sun - (Planets)
- Tidal effects → deformation of bodies
 - Earth (Moon, Sun) - (Moon, Sun, Venus, Jupiter)
 - Moon (Earth, Sun) - (Earth, Sun, Venus, Jupiter)

Same initial conditions & parameters as DE405

INPOP : Adams PECE order 12

Error in the Moon longitude after 100 years



- (a) + double precision 64 bits
(b) x extended precision 80 bits
(c) □ extended precision 80 bits + 1 quad. prec. addition

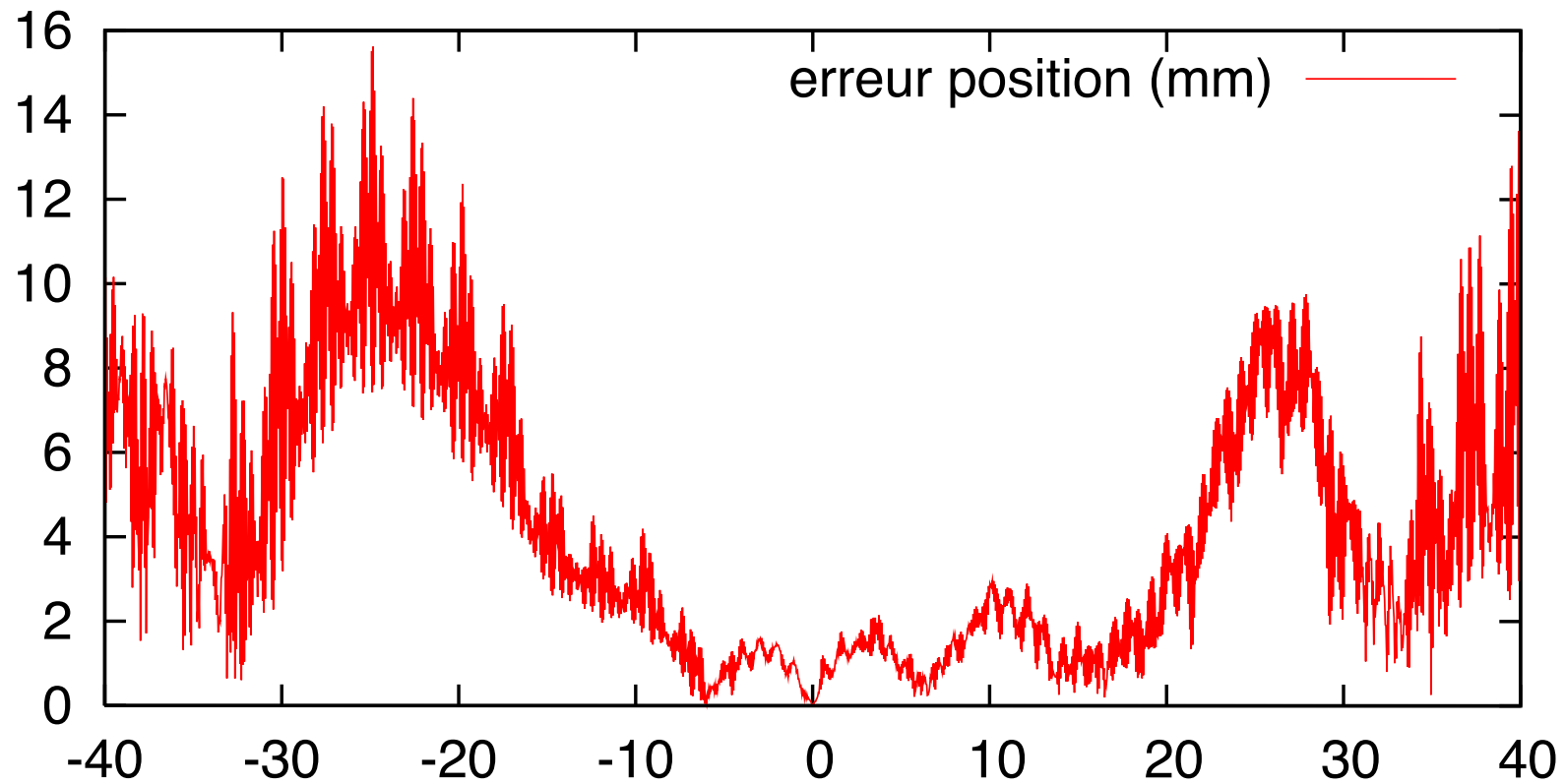
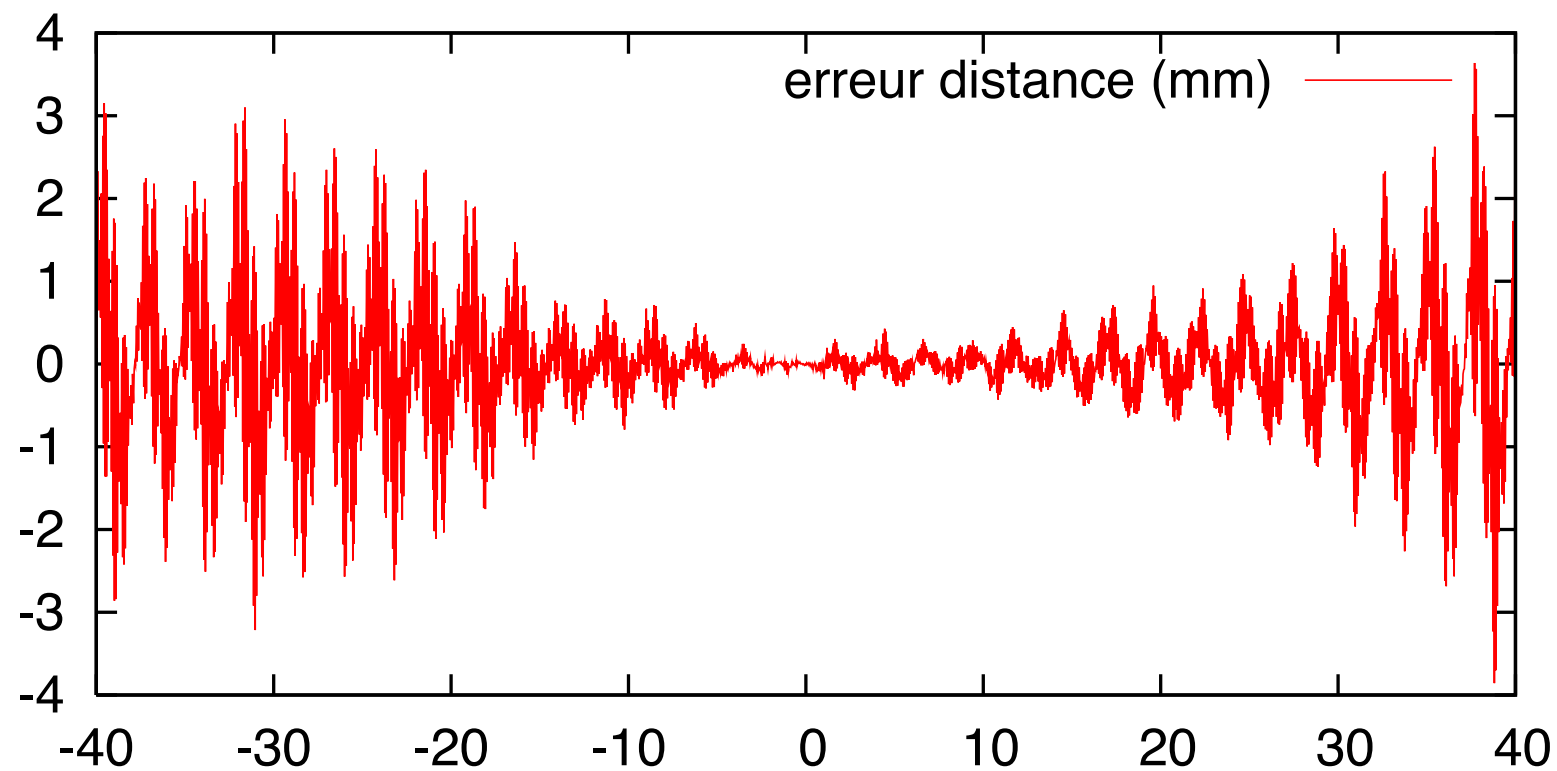
INPOP06

Error in position after 100 or 10000 years

	100 yr (micro m)	10000 yr (mm)
Mercury	93.3	41.29
Venus	7.5	4.90
EMB	14.0	5.34
Mars	3.4	0.46
Jupiter	0.6	0.04
Saturn	0.2	0.04
Uranus	5.5	0.02
Neptune	3.1	0.03
Pluto	2.2	0.04
Moon	1.0	2.51

INPOP05

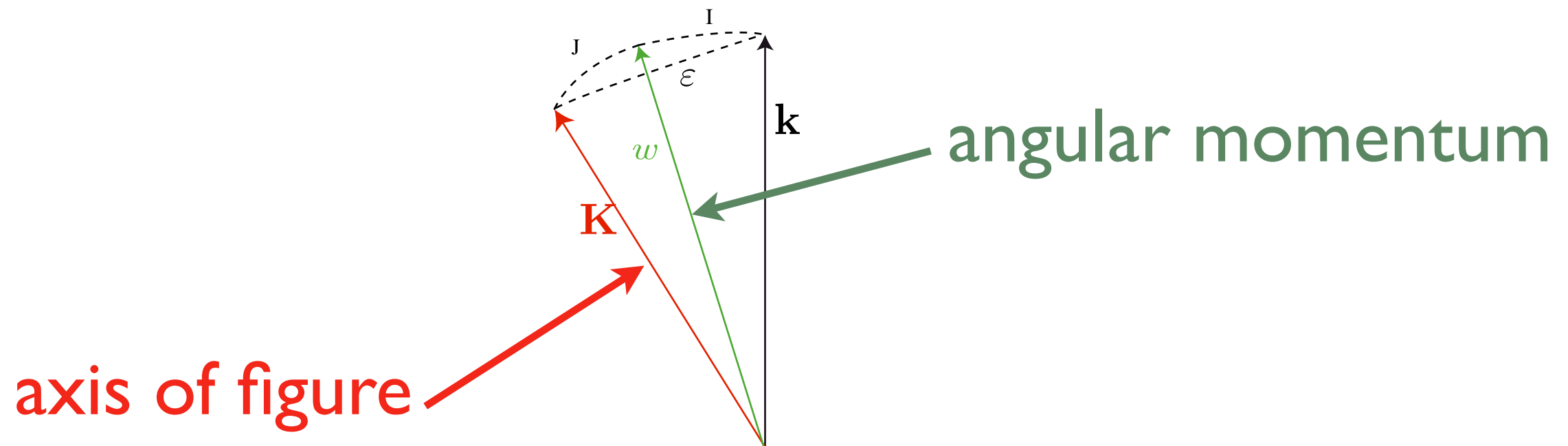
Moon : INPOP - DE405



numerical error over 40 years : < 0.001 mm

- Asteroids
 - 5 Bigs considered as planets (newtonian interactions, GR, solar J2)
 - 295 (Newtonian interactions with all planets and 5 Bigs)
 - Ring (Krasinsky et al., 2002)
- Integration of the Earth 's orientation
- Secular variation of the terrestrial J2 (post-glacial rebound)
- Initial conditions and parameters fitted to planetary observations
- TDB and TCB versions

Precession model : Integration of the angular momentum



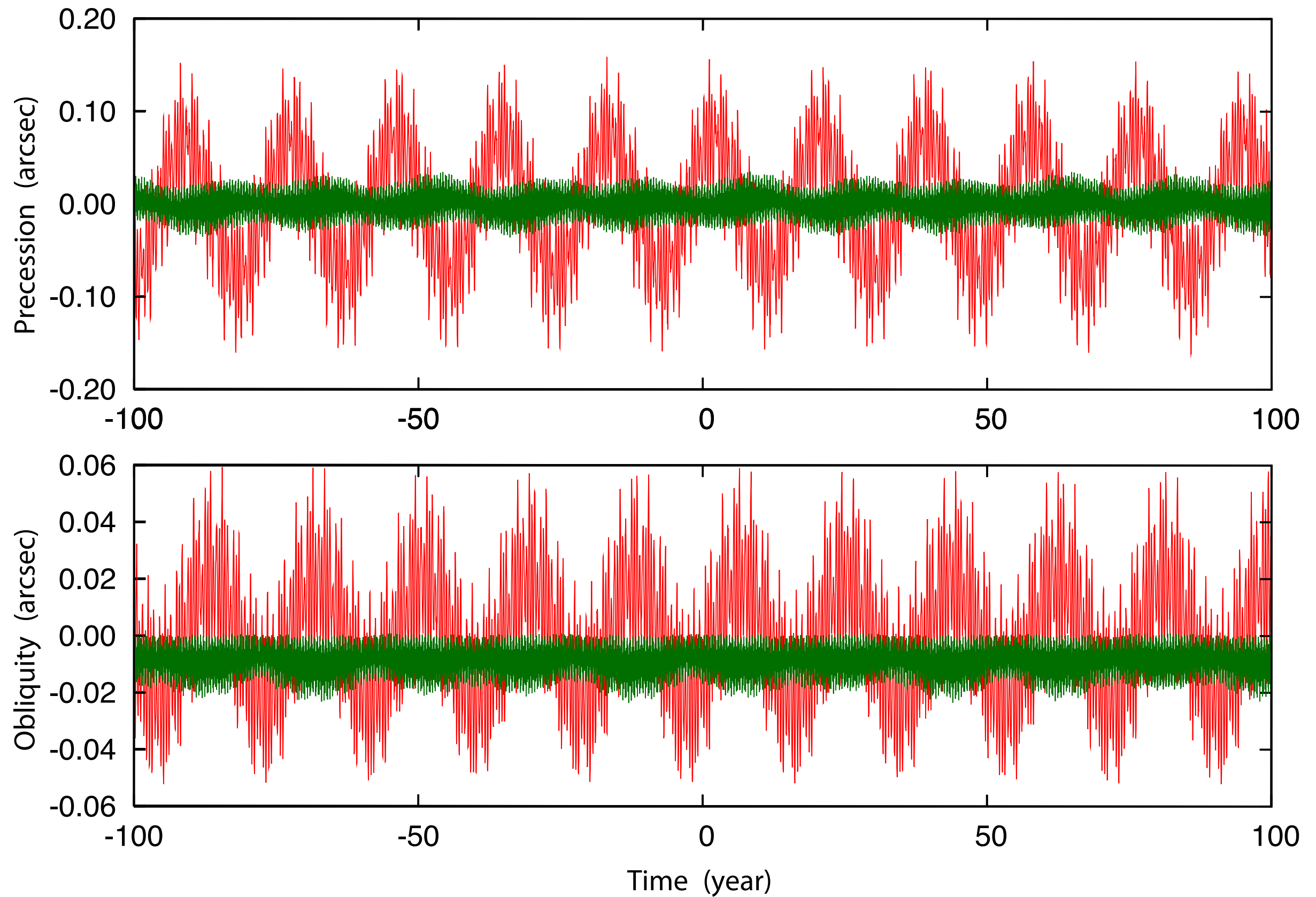
nearly diurnal motion around w

$$\langle K \rangle = \cos J \, w = w + O(J^2) \quad J < 0.2''$$

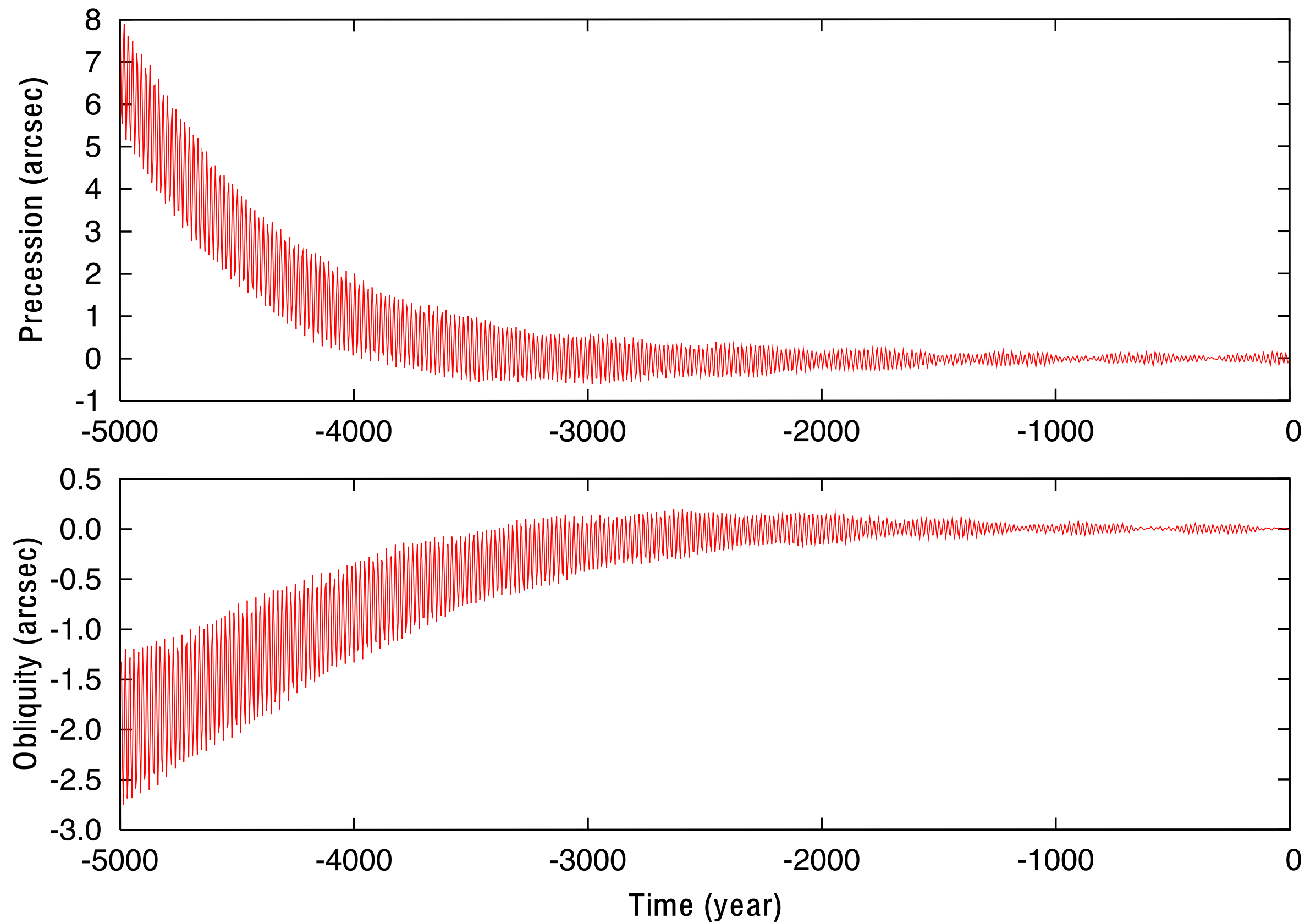
In INPOP we integrate the angular momentum without averaging over the orbital periods.

CIP (P03) - INPOP (w)

INPOP K - w



CIP (P03) - INPOP06 (same $\dot{J}_2$)



Planets	Types of Observations		INPOP06
Mercury	Radar [m]	444	-239 ± 855
Venus	Radar [m]	737	-1727 ± 4051
	Radar [m] (after 1965)	488	-583 ± 1385
	Spacecraft VLBI [mas]	18	1.7 ± 2
Mars	Vkg radar [m]	1256	-23 ± 18
	MGS Radar [m]	10474	4.0 ± 5.5
	Spacecraft Doppler Vkg [mm/s]	1501	-0.26 ± 4.4
	Spacecraft Doppl MGS [mm/s]	1519	-0.34 ± 0.97
	Spacecraft VLBI [mas]	44	0.4 ± 0.5
Jupiter	Spacecraft VLBI [mas]	24	-9 ± 12
	CCD or transit (α,δ) [mas]	5536	(17 ± 341, -24 ± 331)
Saturne	CCD or transit (α,δ) [mas]	5573	(-6 ± 347, -13 ± 311)
Uranus	CCD or transit (α,δ) [mas]	3848	(12 ± 357, 10 ± 366)
Neptune	CCD or transit (α,δ) [mas]	3898	(-11 ± 368, 12 ± 356)
Pluto	CCD or transit (α,δ) [mas]	1024	(11 ± 260, -8 ± 190)

1 mas = 725 m at 1 AU

INPOP06 adjusted physical parameters

With $\beta=1$, $\gamma=1$

	Unit	DE405 (Standish, 98)	EMP04 (Pitjeva 05)	DE414 (Standish, 05)	INPOP06
Mass of Ceres	$10^{-10} M_{\oplus}$	4.64	4.753 ± 0.007	4.699 ± 0.006	4.756 ± 0.006
Mass of Vesta	$10^{-10} M_{\oplus}$	1.34	1.344 ± 0.001	1.358 ± 0.004	1.348 ± 0.002
Mass of Pallas	$10^{-10} M_{\oplus}$	1.05	1.027 ± 0.003	1.026 ± 0.006	1.025 ± 0.003
Mass of Iris	$10^{-10} M_{\oplus}$		0.063 ± 0.001	0.060 ± 0.002	0.058 ± 0.002
Mass of Bamberga			0.055 ± 0.001	0.047 ± 0.002	0.046 ± 0.002
Density of C class		1.8	1.5 ± 0.03	1.62 ± 0.07	1.56 ± 0.02
Density of S class		2.4	2.2 ± 0.04	2.08 ± 0.19	2.18 ± 0.04
Density of M class		5.0	3.84 ± 0.12	4.32 ± 0.37	4.26 ± 0.12
Mass of asteroid ring	$10^{-10} M_{\oplus}$		3.55 ± 0.35	0.31 ± 0.27	0.34 ± 0.15
Distance of ring	UA		3.13 ± 0.05	2.8	2.8
Sun J2	$\times 10^{-7}$	2	1.9 ± 0.3	2.34 ± 0.49	2.46 ± 0.40

+ 40 other GMs determinations

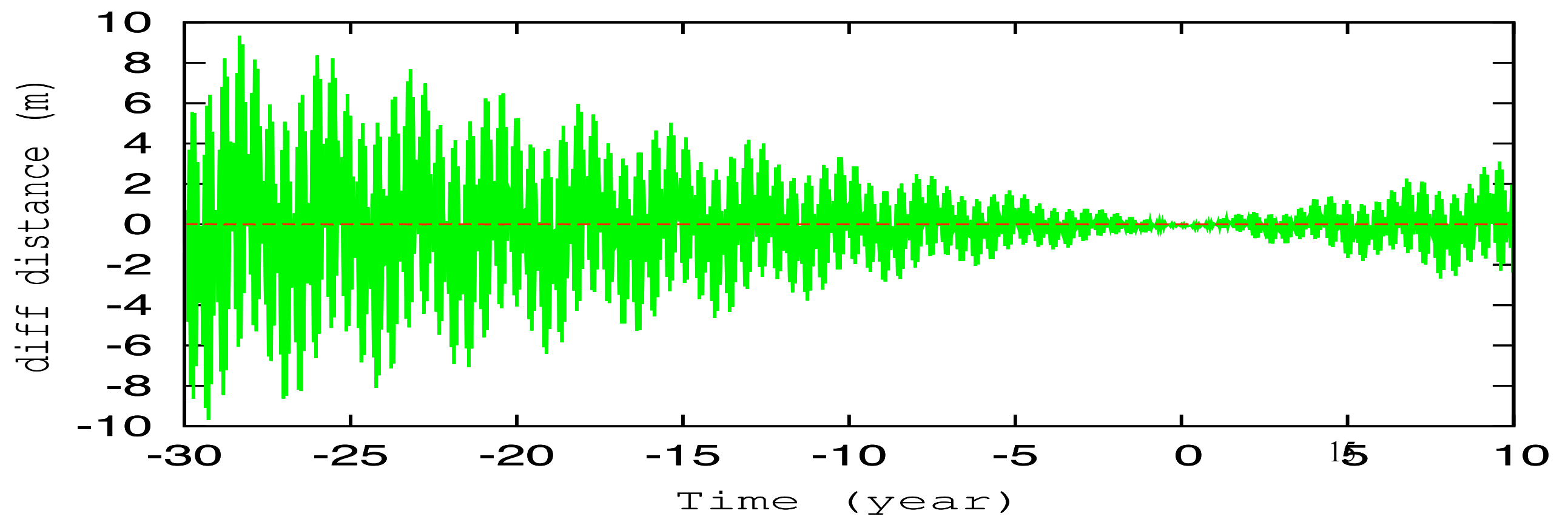
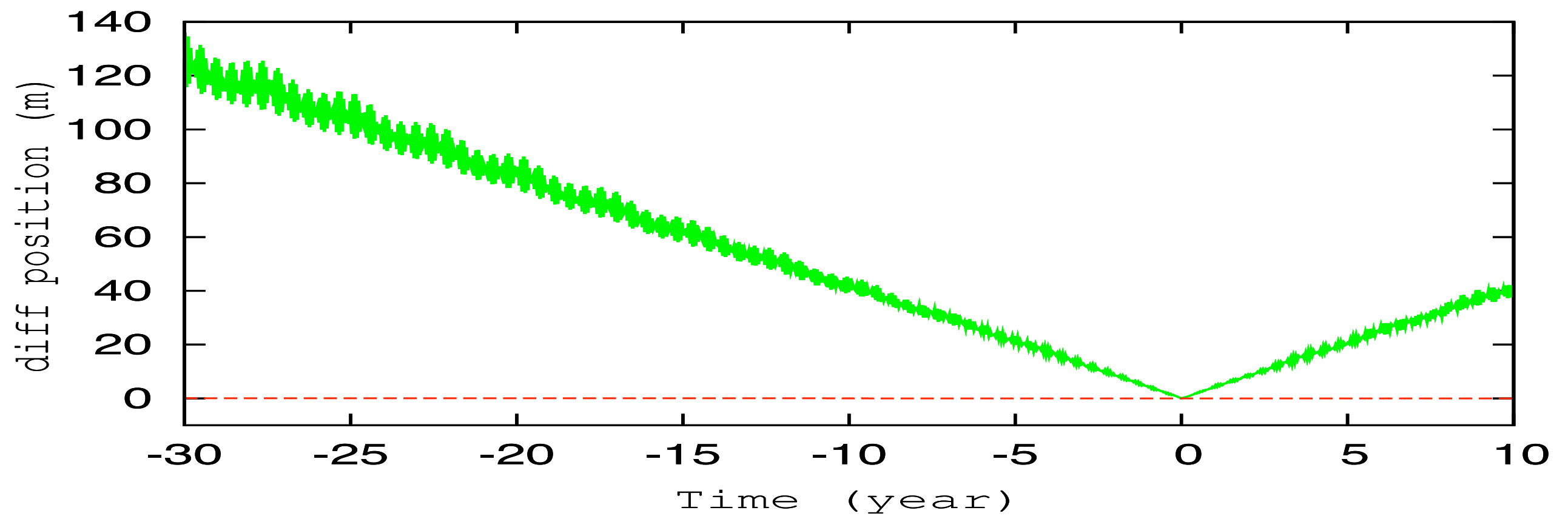
- Initial conditions and parameters fitted to planetary observations

- ⇒ Induces a different orbit for the Moon

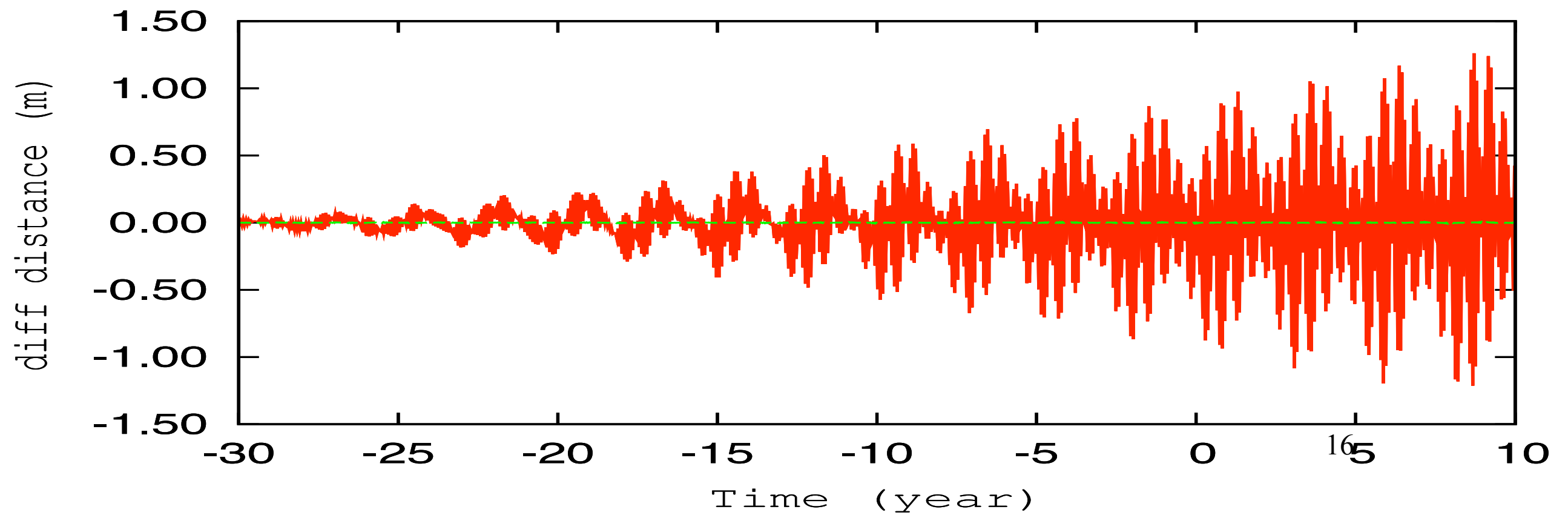
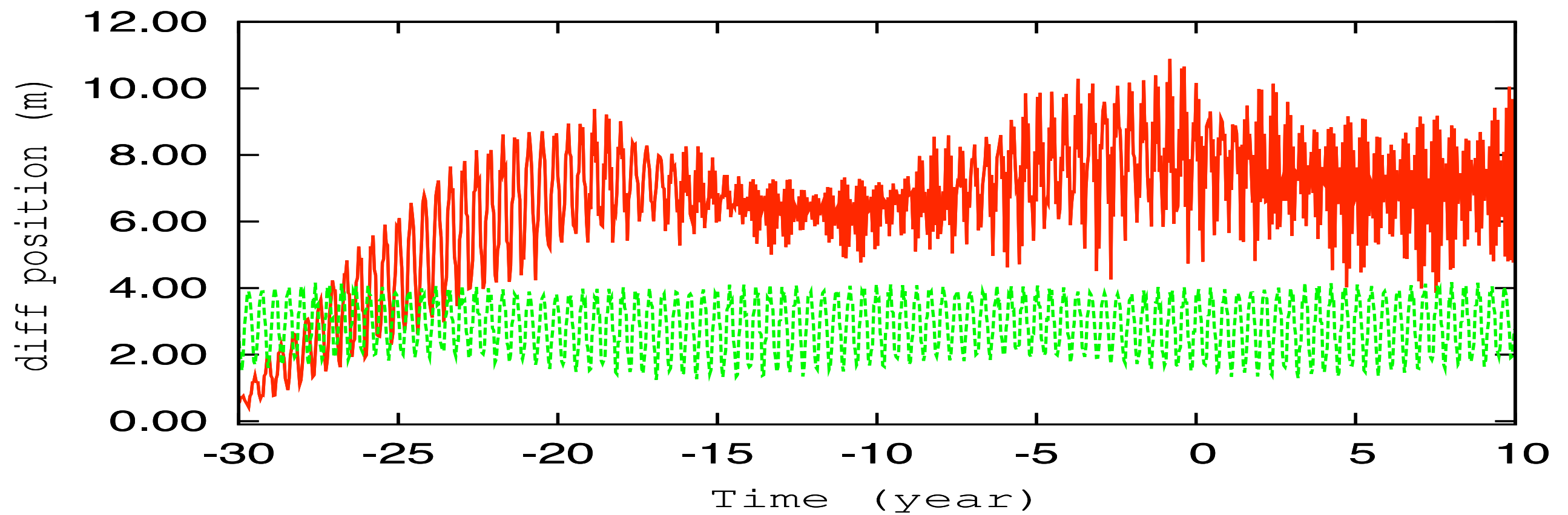
- ⇒ "degradation" of the Moon/LLR

- ⇒ fitting to Earth-Moon distance of DE405

INPOP05 / INPOP06x / DE405



DE414 / INPOP06 / DE405



For the Next INPOP 07

- Global Fit (planetary and LLR data)
- MEX and VEX tracking data
- New TDB

And Then

- Cassini Tracking data ?
- Solution in km, km/s with fitted Solar mass
- Improvement of the model of the Earth-Moon system
- Improvement of asteroid perturbations