Anomalie pioneer, PPN et J2 solaire avec INPOP

A. Fienga, UTINAM/IMCCE

INPOP team:

J. Laskar, IMCCE, Obs. de Paris
H. Manche, IMCCE, Obs. de Paris
P. Kuchynka, IMCCE, Obs. de Paris
M. Gastineau, IMCCE, Obs. de Paris

Journées GRAM
Nice, 29-30 november 2010

INPOP new release: INPOP10a

INPOP

http://www.imcce.fr/inpop/

INPOP10a, a 4-D planetary ephemeris

Reference

A. Fienga, H. Manche, P. Kuchynka, J. Laskar and M. Gastineau : 2010, INPOP10a.

scientific notes :

Data used to built INPOP ephemerides are available on the APDB data base.

Solutions

The orbital solutions of the Sun, the eight planets, the dwarf planet Pluto and the Moon, the libration of the Moon and the time scale transformation TT-TDB are available as binary or text data files.
The binary and text data files provide the rectangular coordinates (x,y,z) in kilometers of the bodies with respect to the International Celestial Reference Frame (ICRF). The librations are given in radians. The time scale transformation TT-TDB is given in seconds for the files including it.

Download INPOP10a ephemeris files

INPOP10a: what's new ?

In INPOP10a ...

- Data
- CBE 2009 for planet masses
- Direct Fit of the mass of the Sun with AU fixed
- Asteroid selection and new method for mass estimation

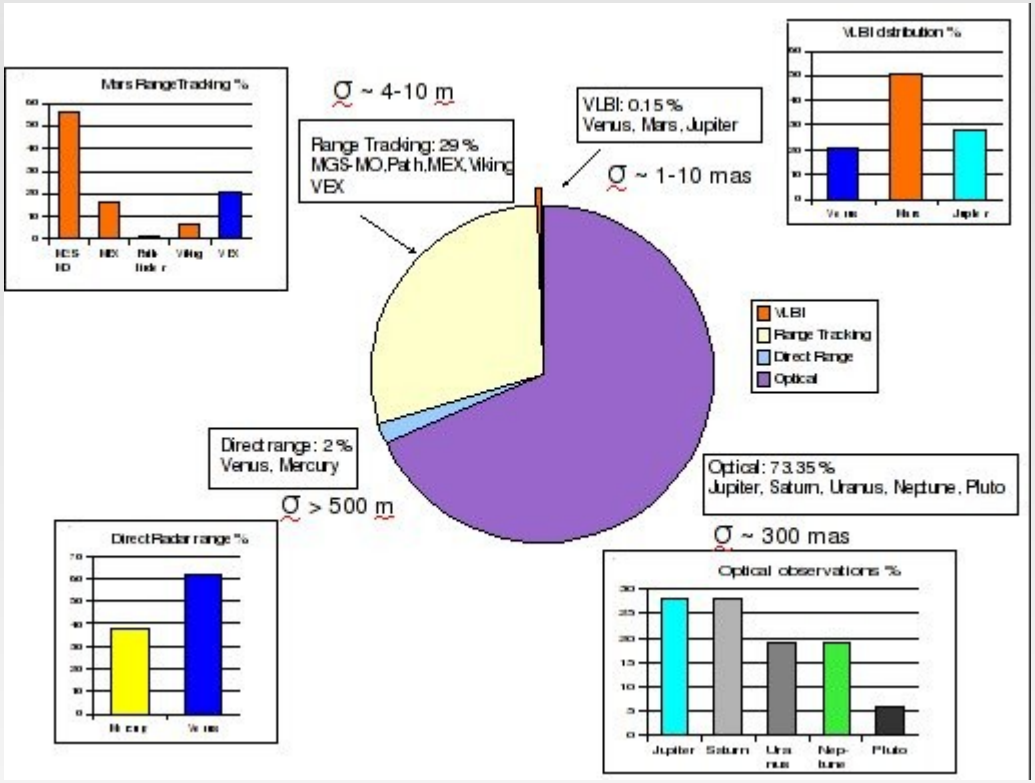
- Millisecond pulsars use for testing INPOP10a link to ICRF

With INPOP10a ...

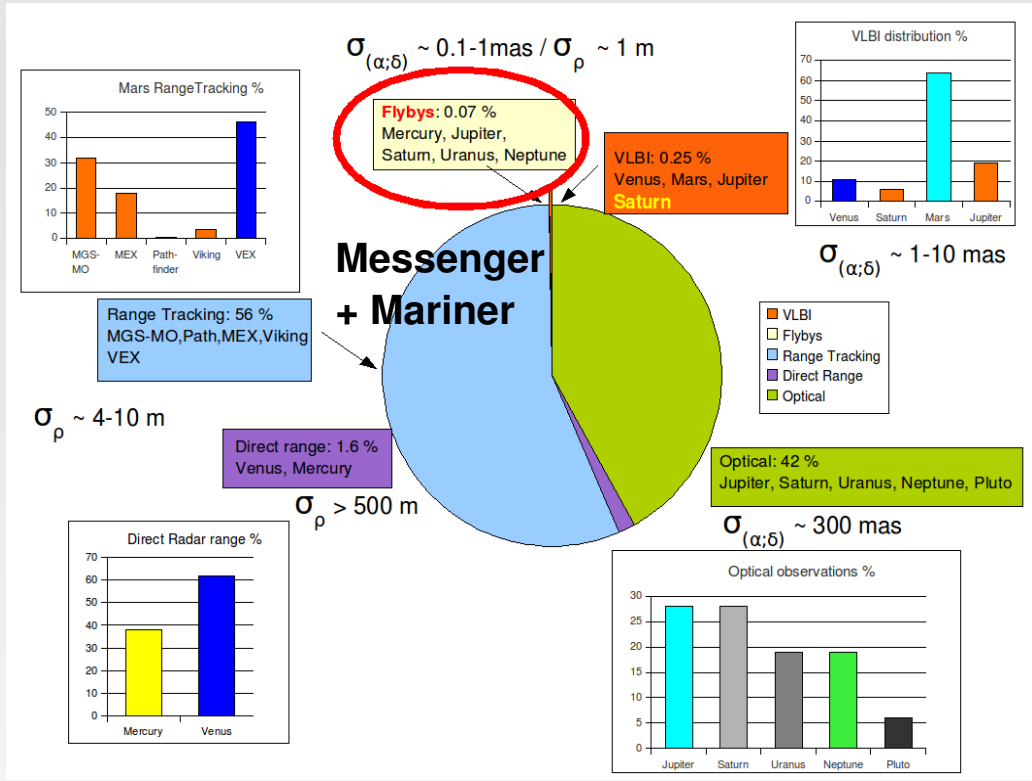
- PPN β, PPN γ separately and simultaneously, with planets and moon
- Secular advances of perihelia

INPOP10a Datasets

INPOP10a data sets: General comment



INPOP06



INPOP10a

Spacecraft tracking data (range, VLBI, flybys) are now the majority (56%) of INPOP data sets

INPOP10a data sets: New data

- Mercury flybys normal points

  * 2 Mariner normal points [1974-1975] (Folkner 2010)
  * 3 Messenger flyby corrections to DE405 [2008-2009]

  (SPICE NAIF, Taylor 2008, 2009)

  * High improvement of the Mercury orbit: ~800 m => few meters

			INPOP08	INPOP10a	
Direct range [m]	1965-2000	462	30 ± 842	7 ± 866	
Mariner range [m]	1974-75	2	-1000 ± 305	-28 ± 85	Folkner (2010)
Messenger Flybys	2008-2009	3			SPICE NAIF flybys Mercury positions
ra [mas]			1.1 ± 0.7	0.4 ± 1.2	
de [mas]			2.0 ± 1.9	1.9± 2.1	
range [m]			52 ± 619	-0.6 ± 1.9	

INPOP10a data sets: New data

- Mercury flybys normal points

- MEX, VEX (Morley 2009, 2010)

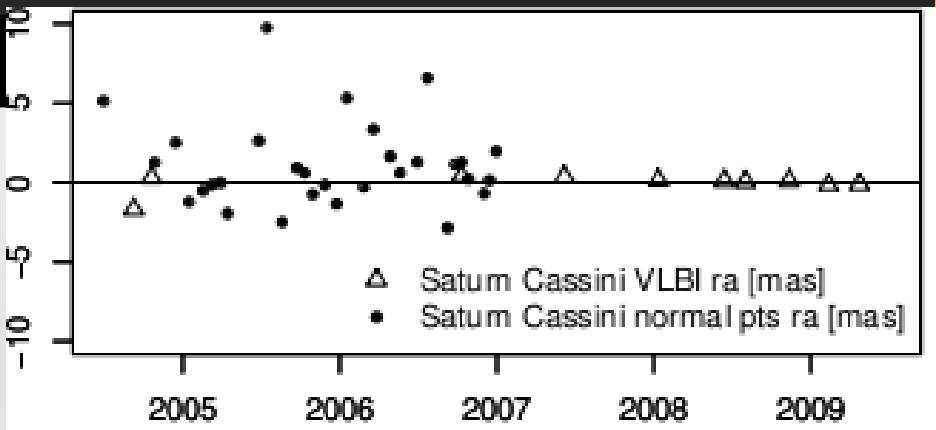
  => prolongation of data interval

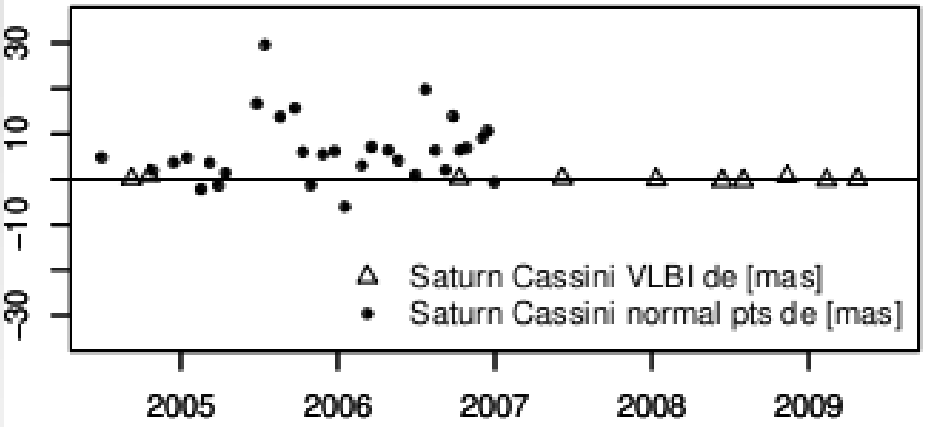
- Cassini VLBI Saturn positions

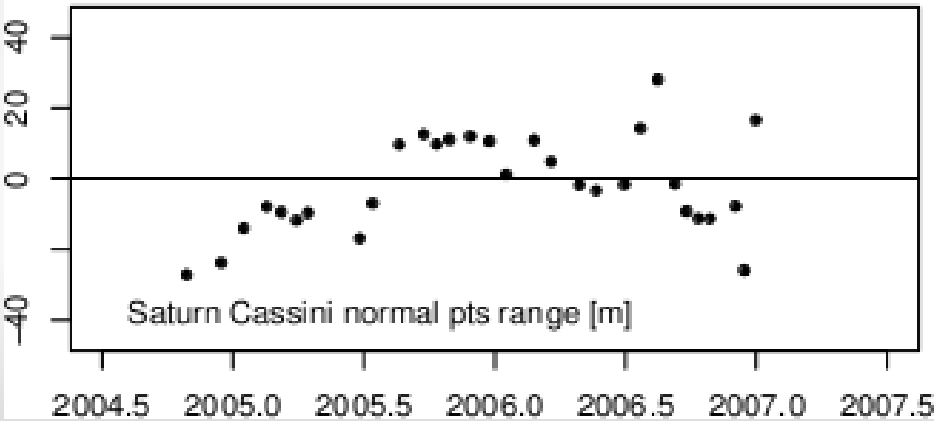
  (Jones and al. 2010)

  => complementary data sets

  [2004:2009] / INPOP08 [2005:2009]







INPOP10a data sets: New data

- Mercury flybys normal points

- MEX, VEX

  => prolongation of data interval

- Cassini Saturn positions

  => complementary data sets [2004:2009] / INPOP08 [2005:2009]

- Jupiter, Uranus, Neptune normal points
- Pluto stellar occultations (Sicardy 2009)

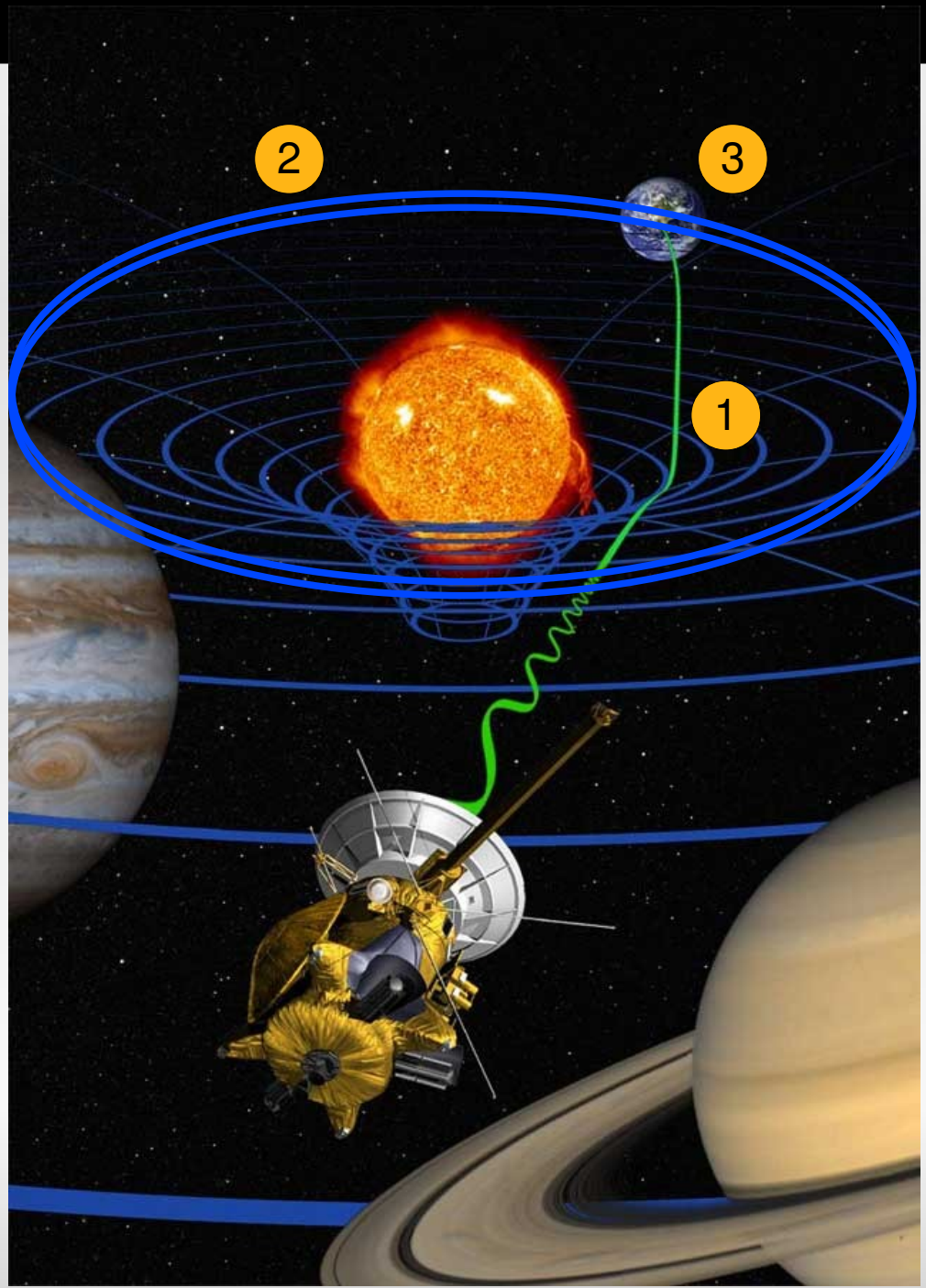
Sets of fitted parameters

First set of fitted parameters

	INPOP08	INPOP10a	DE423
	$\pm 1\sigma$	$\pm 1\sigma$	$\pm 1\sigma$
EMRAT	(81.30054 ± 0.00005)	(81.3005700 ± 0.0000010)	(81.3005694 ± 0.0000015)
$J2_\odot$	$(1.82 \pm 0.47) \times 10^{-7}$	$(2.40 \pm 0.25) \times 10^{-7}$	
$(\beta$ -1) $\times 10^{-4}$	(0.75 ± 1.25)	(0.25 ± 0.75)	(0.4 ± 2.4)
	$\pm 5\sigma$	$\pm 5\sigma$	$\pm 1\sigma$
$GM_\odot$ [$km^3 . s^{-2}$]	132712440017.98700 (F)	132712440055 ± 1	132712440042 ± 10
AU [m]	149597870699.2 ± 0.55	149597870691.0 (F)	
AU [m] from $GM_\odot$		149597870704.9 ± 0.3	149597870700.0 ± 3
	$\pm 1\sigma$	$\pm 1\sigma$	$\pm 1\sigma$
Ceres $[10^{12} \times M_\odot]$	465.8 ± 4.5	475.836 ± 2.849	467.900 ± 3.250
Pallas $[10^{12} \times M_\odot]$	107.6 ± 10.0	111.394 ± 2.808	103.440 ± 2.550
Vesta $[10^{12} \times M_\odot]$	139.2 ± 15.0	133.137 ± 1.683	130.970 ± 2.060

+ 146 asteroid masses estimated

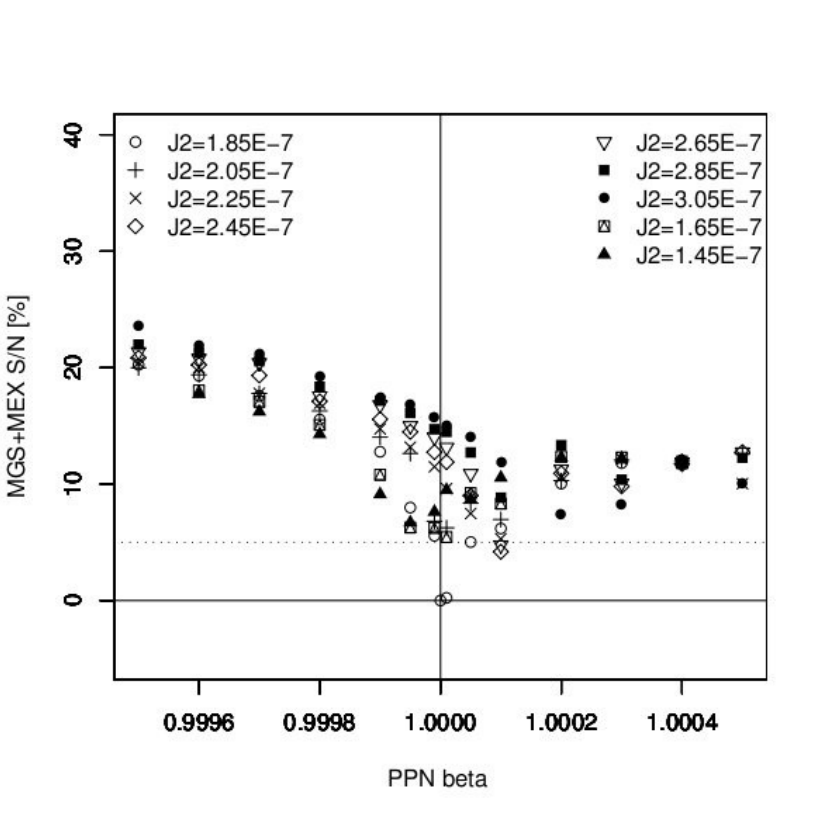
General relativity tests



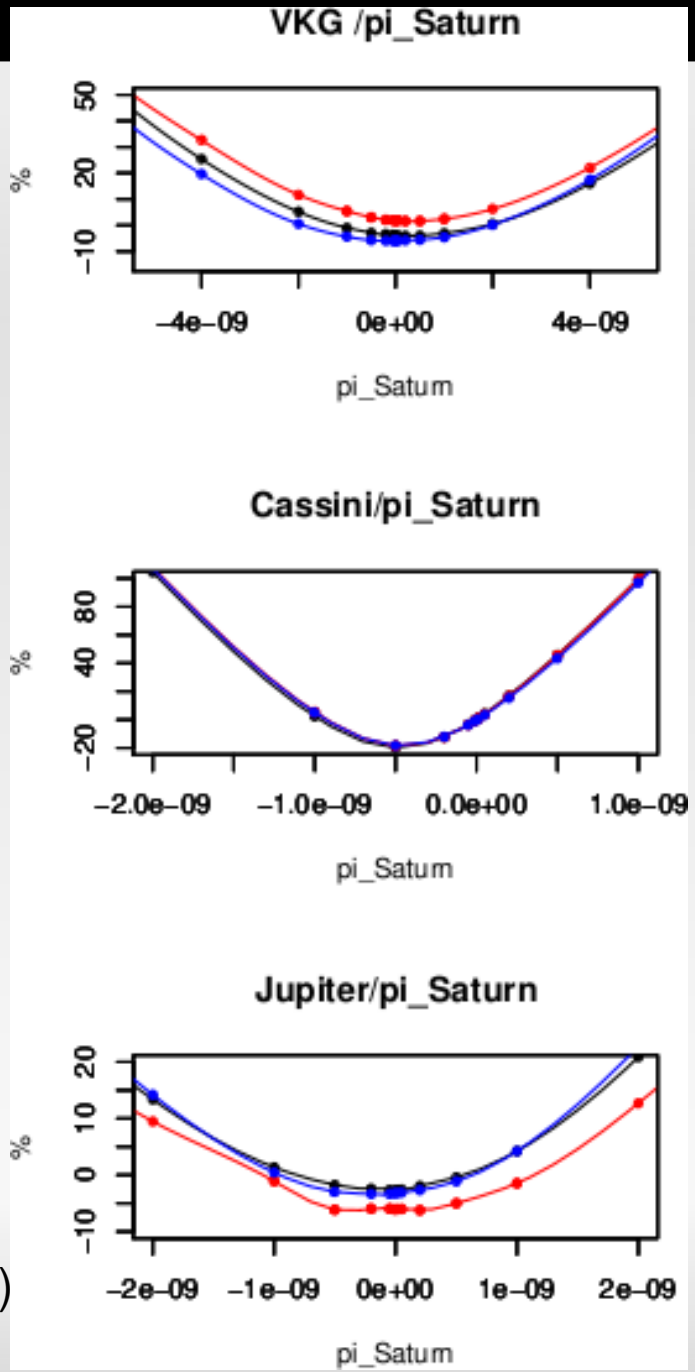
1. Deflection of light, γ
2. Non-linearity of gravity, β
3. Supplementary advances of perihelia
4. Supplementary accelerations for outer planets

Supplementary advances in solar system orbits

Maps of observation sensitivity
to supplementary rotations in perihelia or
nodes and in variations of γ and β



(Fienga et al. 2010)



Supplementary advances in solar system orbits

In the uncertainty of the present observations, does a room exist for unexplained advances in node or perihelia of orbits ?

For perihelia,

	d ϖ Mer	d ϖ Sat	d ϖ Earth
	mas/cy	mas/cy	mas/cy
Fienga et al. 10	-10 ± 30	-10 ± 8	0 ± 0.016
Pitjeva 2009	-3.6 ± 5	**-6 ± 2**	-0.2 ± 0.4
Pitjeva 2010	-4 ± 5	-10 ± 15	6 ± 7
INPOP10a	**0.2 ± 3**	**0 ± 2**	

No supplementary advances with the new data of INPOP10a

Supplementary advances in solar system orbits

In the uncertainty of the present observations, does a room exist for unexplained advances in node or perihelia of orbits ?

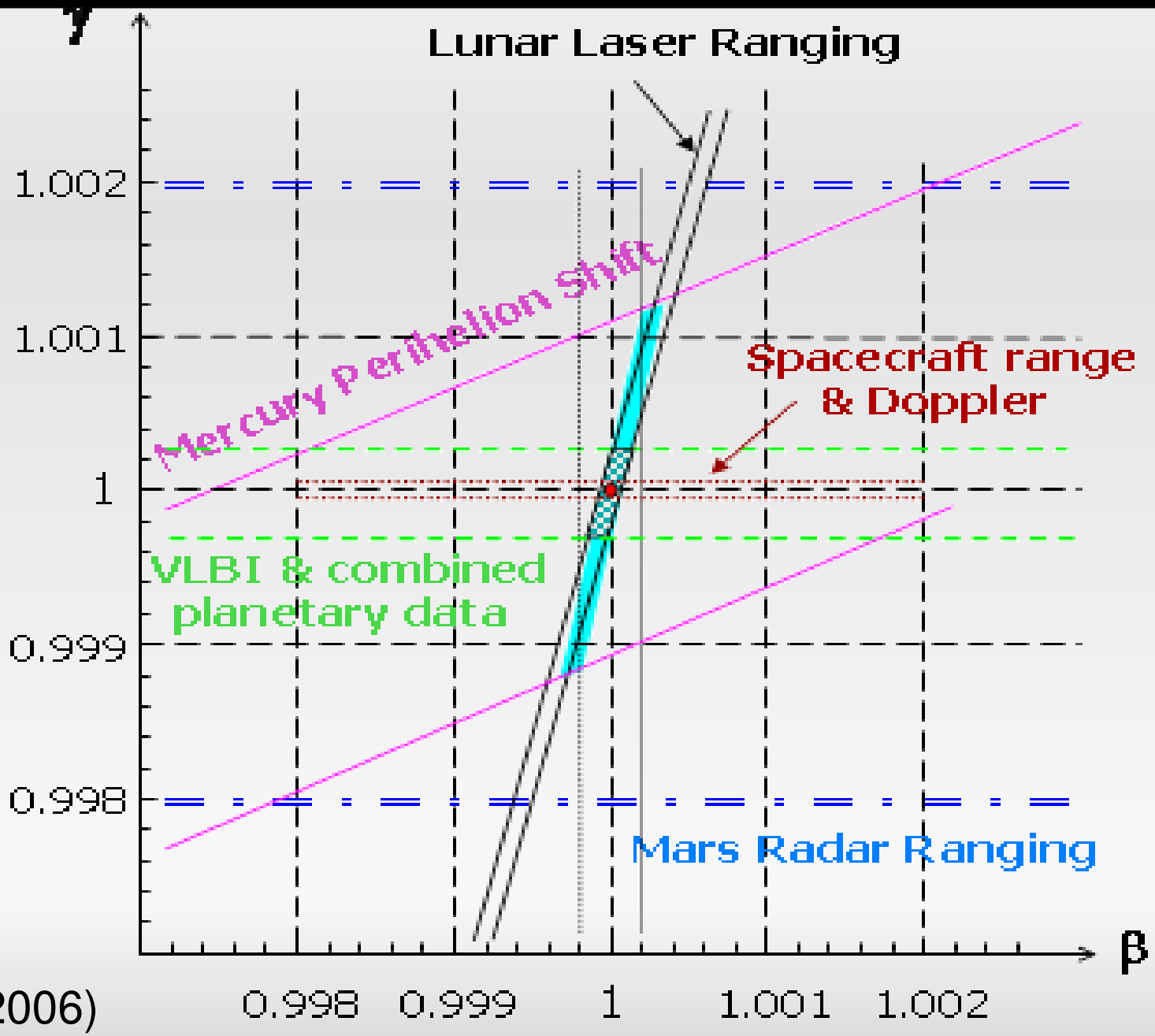
For perihelia,

	d ϖ Mer	d ϖ Sat	d ϖ Earth
	mas/cy	mas/cy	mas/cy
Fienga et al. 10	-10 ± 30	-10 ± 8	0 ± 0.016
Pitjeva 2009	-3.6 ± 5	**-6 ± 2**	-0.2 ± 0.4
Pitjeva 2010	-4 ± 5	-10 ± 15	6 ± 7
INPOP10a	**0.2 ± 3**	**0 ± 2**	

<u>No supplementary advances with the new data of INPOP10a</u>

What happen if we reprocess the computation of the Cassini data + planetary ephemerides fitting ?

(γ, β)

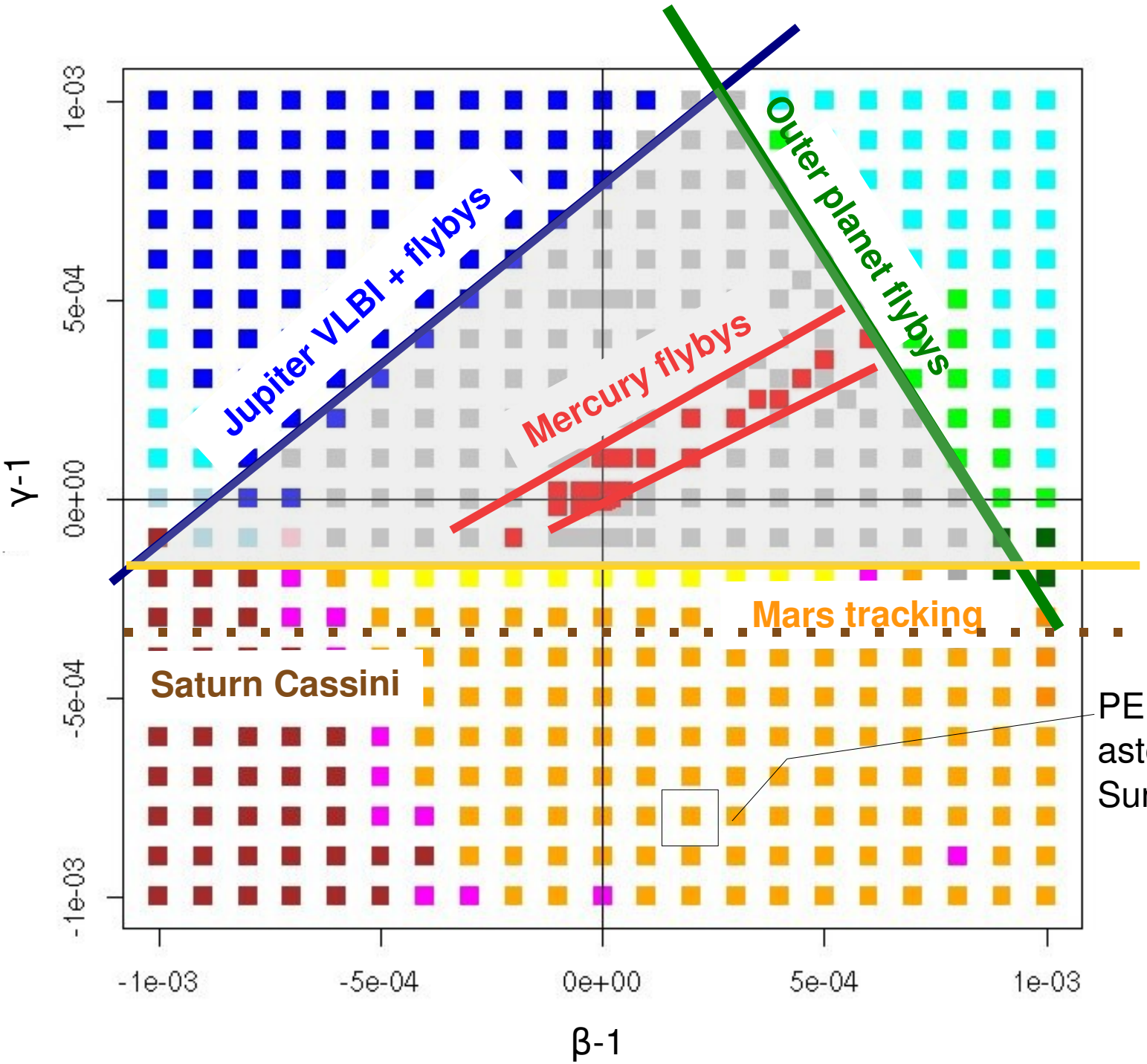


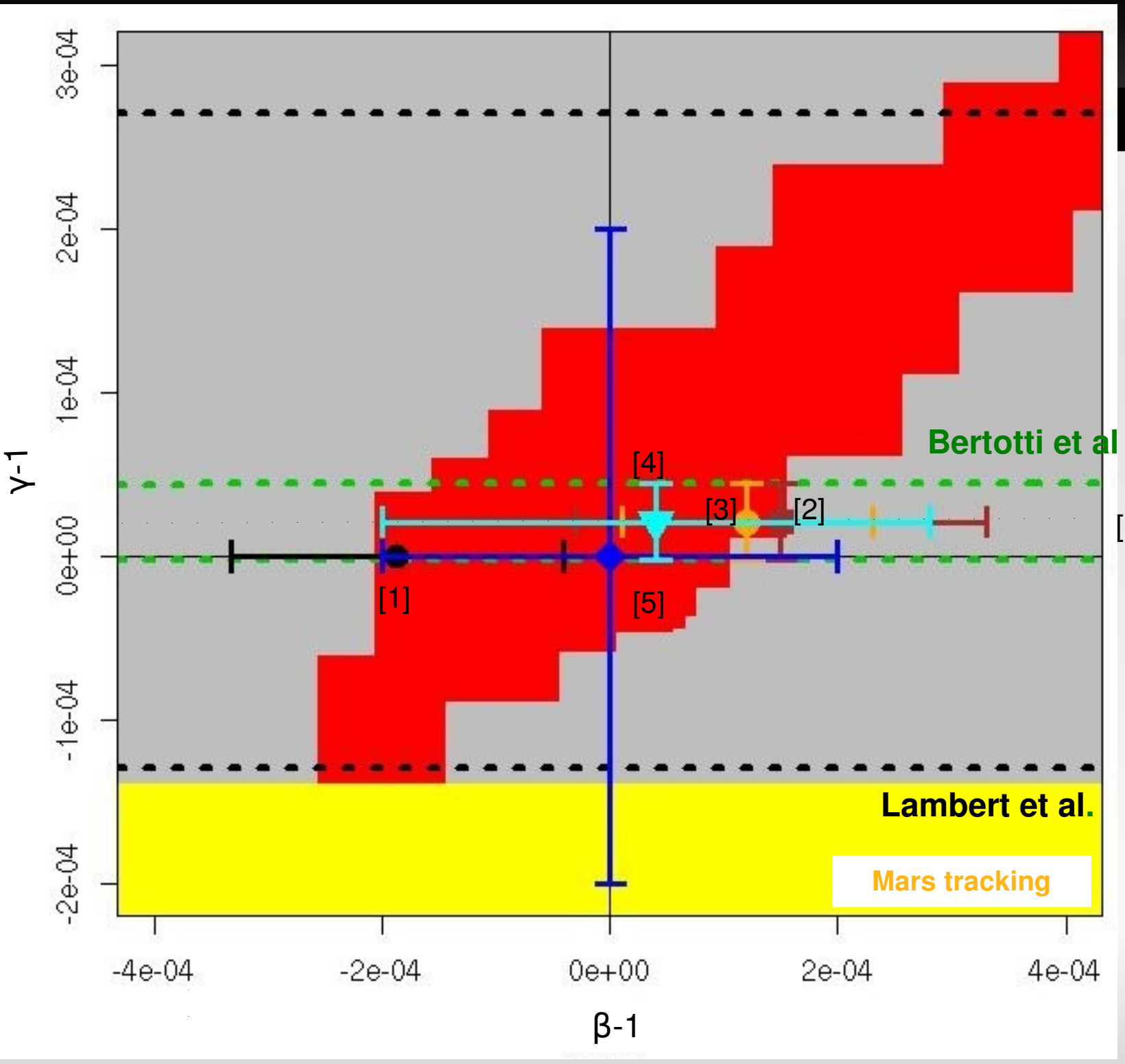
(Murphy 2006)

(γ, β)

- Sensitivity map of observations to changes in (γ and β)
- ~ 500 PE with fit of IC, asteroid GMs, Sun J2, $GM_{\odot}$
- Differences in data residuals induced by (γ,β)
- Limit of sensitivity is 5 %

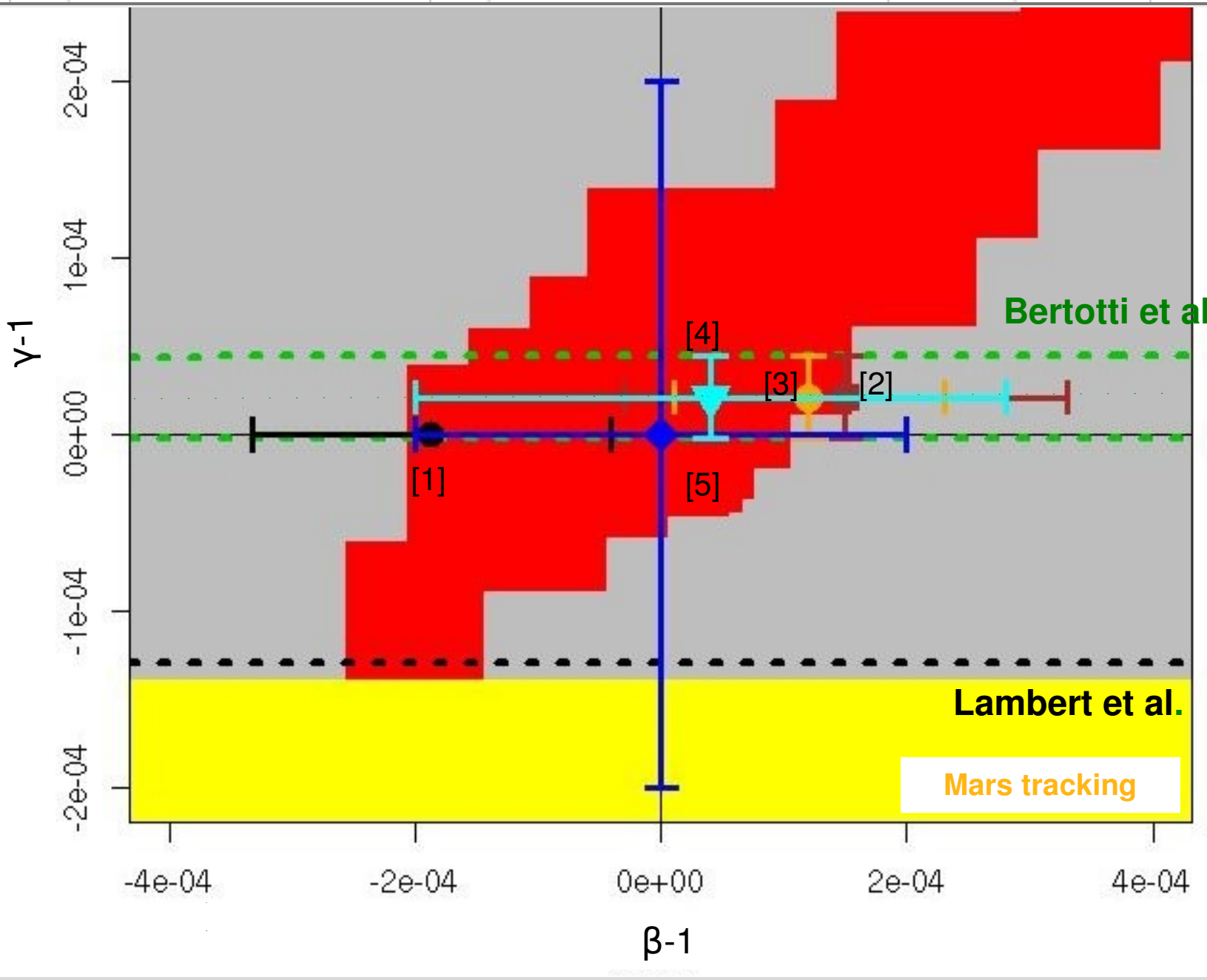
→ Big impact of mercury new metadata


Jupiter VLBI + flybys
Outer planet flybys
Mercury flybys
Mars tracking
Saturn Cassini
PE with IC,
asteroid GMs,
Sun J2, GM sun fit
γ-1
β-1
1e-03
5e-04
0e+00
-5e-04
-1e-03
-1e-03
-5e-04
0e+00
5e-04
1e-03



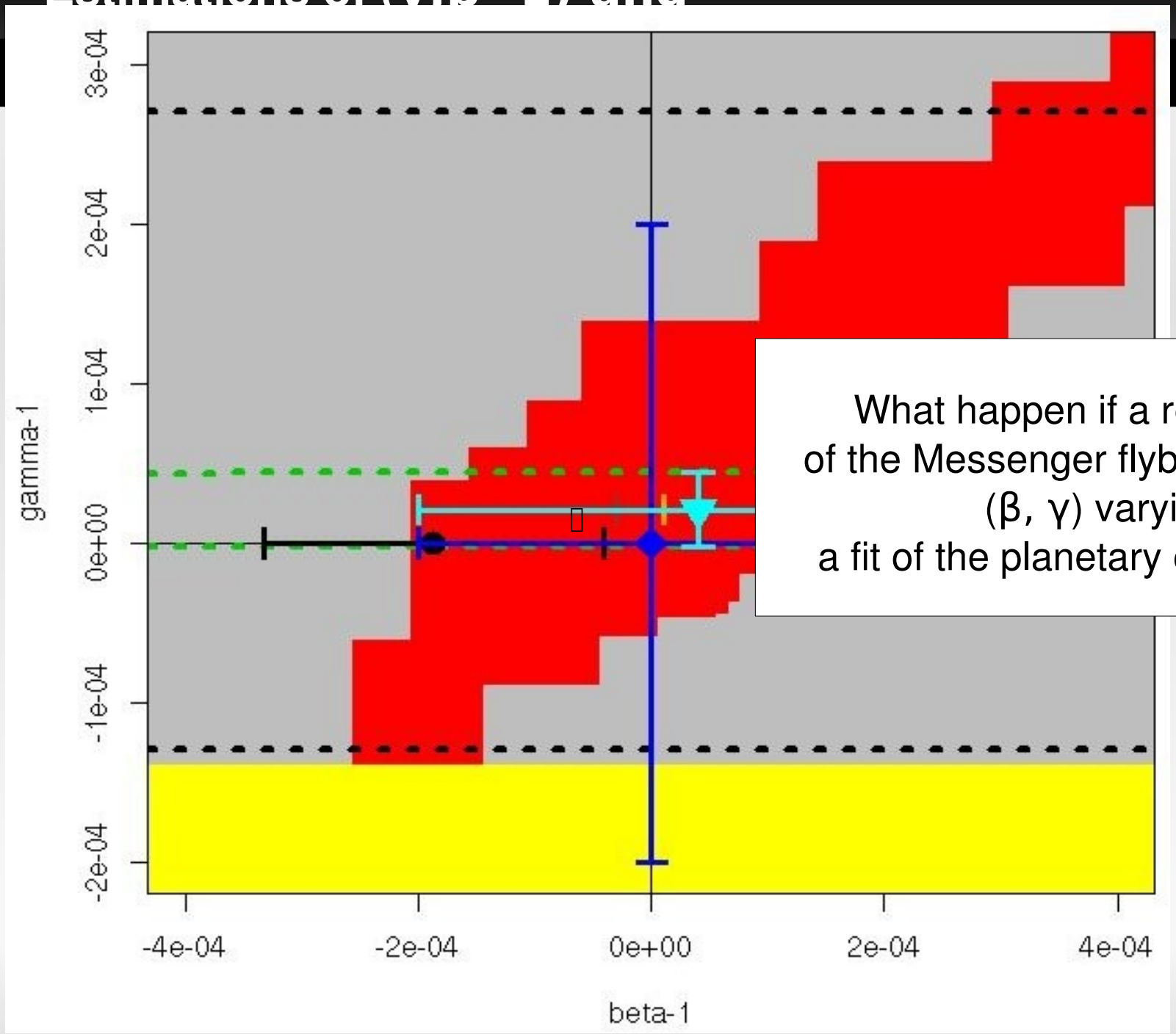
[1] INPOP10a LLR
[2] Williams et al. 2010
[3] Mueller et al. 2008
[4] Konopliv et al .2010
[5] Pitjeva 2010

PPN parameter fixed	PPN estimated	INPOP08	INPOP10a	(Konopliv et al. 2010)
$(\gamma - 1) = 0$	$(\beta - 1) \times 10^{-4}$	(0.75 ± 1.25)	(-0.5 ± 1.5)	
$(\gamma - 1) = (0.21 \pm 0.23) \times 10^{-4}$	$(\beta - 1) \times 10^{-4}$		(-0.1 ± 1.9)	(0.4 ± 2.4)
$(\beta - 1) = 0$	$(\gamma - 1) \times 10^{-4}$		(0.6 ± 1.0)	(1.8 ± 2.6)



[1] INPOP10a LLR
[2] Williams et al. 2010
[3] Mueller et al. 2008
[4] Konopliv et al .2010
[5] Pitjeva 2010

Estimations of (γ,β=1) and

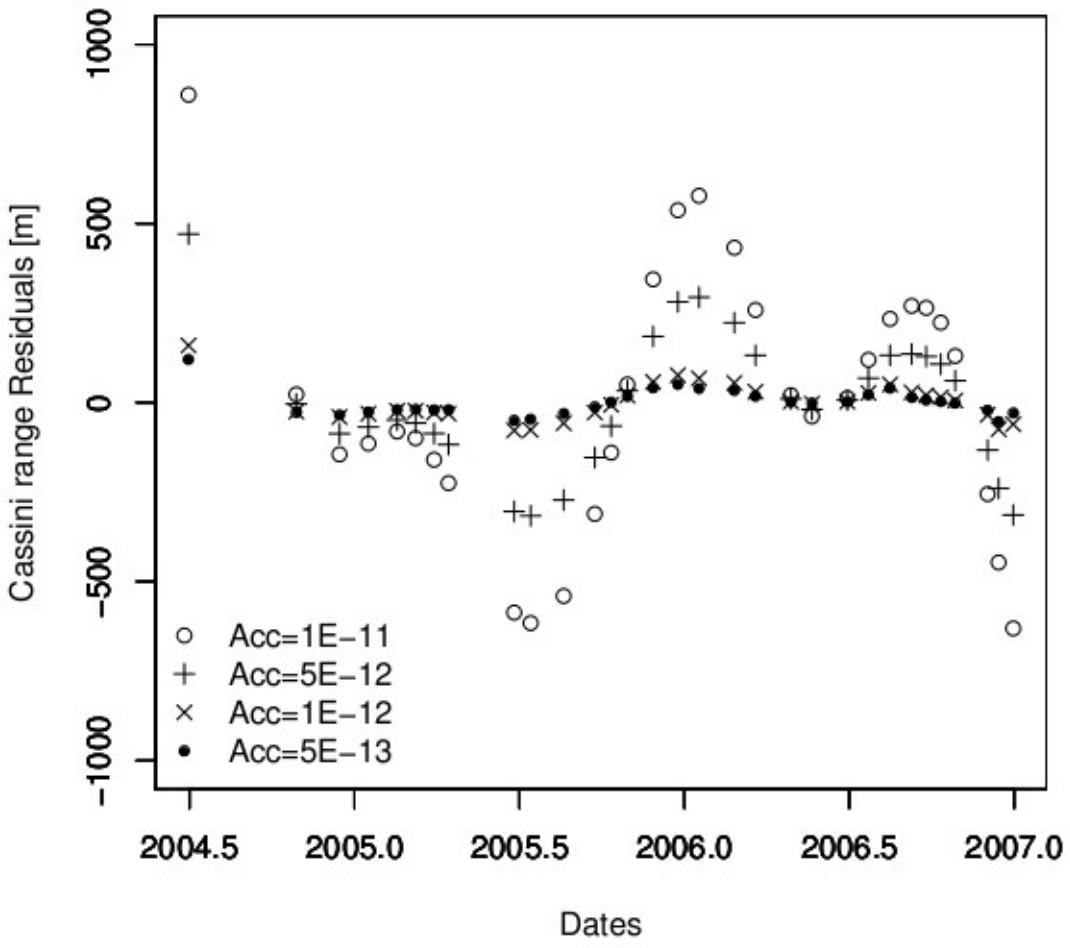


What happen if a reprocessing of the Messenger flybys is done with (β, γ) varying + a fit of the planetary ephemerides?

Supplementary accelerations for outer planets ?

Question closed since 2008
with (Standish 2009), (Folkner et al. 2010) and (Fienga et al. 2010)...

Saturn Cassini metadata

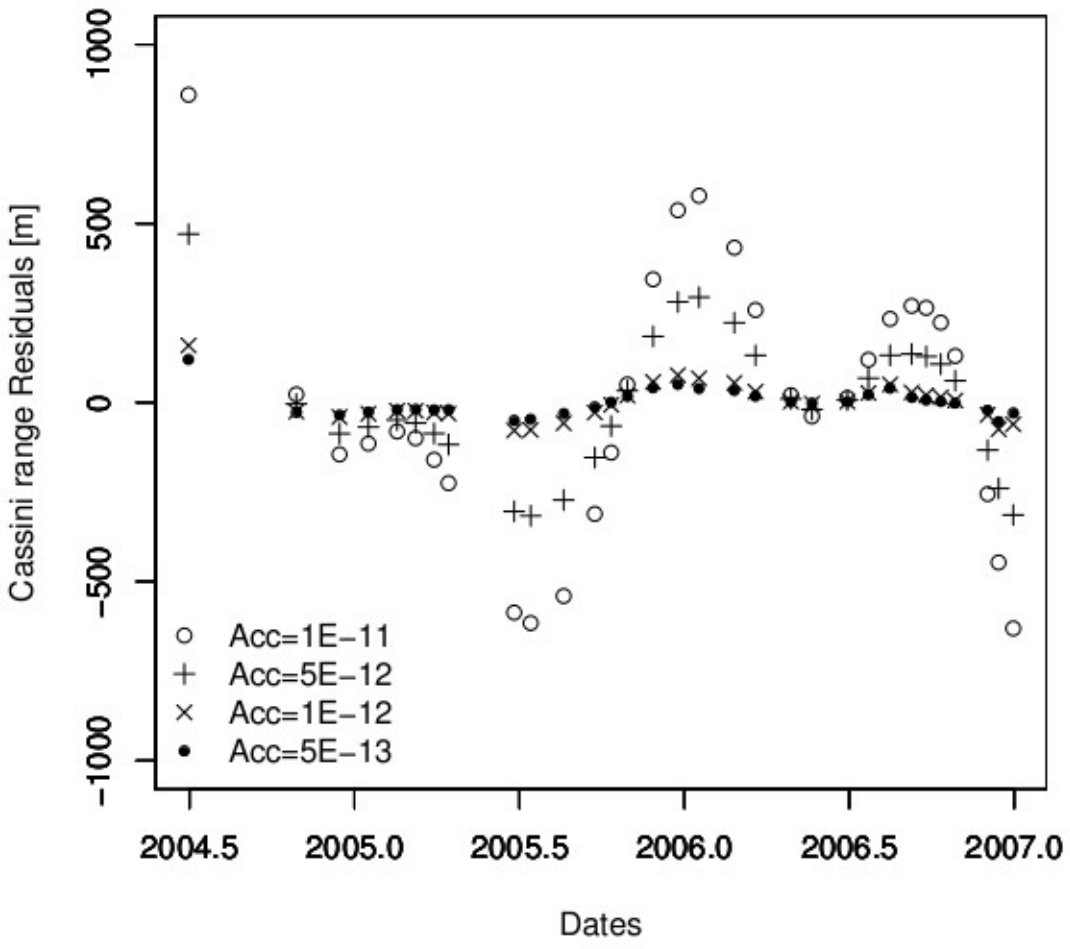


If one just add an acceleration in the planet equations of motion, then,
Tolerance for a supplementary acceleration $< 5.10^{-13}$ $m^2.s^{-3}$

Supplementary accelerations for outer planets ?

Question closed since 2008
with (Standish 2009), (Folkner et al. 2010) and (Fienga et al. 2010)...

Saturn Cassini metadata



If one just add an acceleration in the planet equations of motion, then,
Tolerance for a supplementary acceleration $< 5.10^{-13}$ $m^2.s^{-3}$

What happen if a reprocessing of the Cassini orbit is done with this supplementary acceleration + a fit of the planetary ephemerides?

Conclusions

In INPOP10a ...

- Data: Mercury + Saturn
- Direct fit of the mass of the Sun with AU fixed
- Asteroid selection and new method for mass estimation

With INPOP10a ...

- PPN β, PPN γ separately and simultaneously, with planets and moon
- No supplementary secular advances of perihelia

With INPOP10a next ...

- Reprocessing of tracking raw data to be consistent with PE
- Orbit, flyby, interplanetary phase

Conclusions

Merci