INPOP10a

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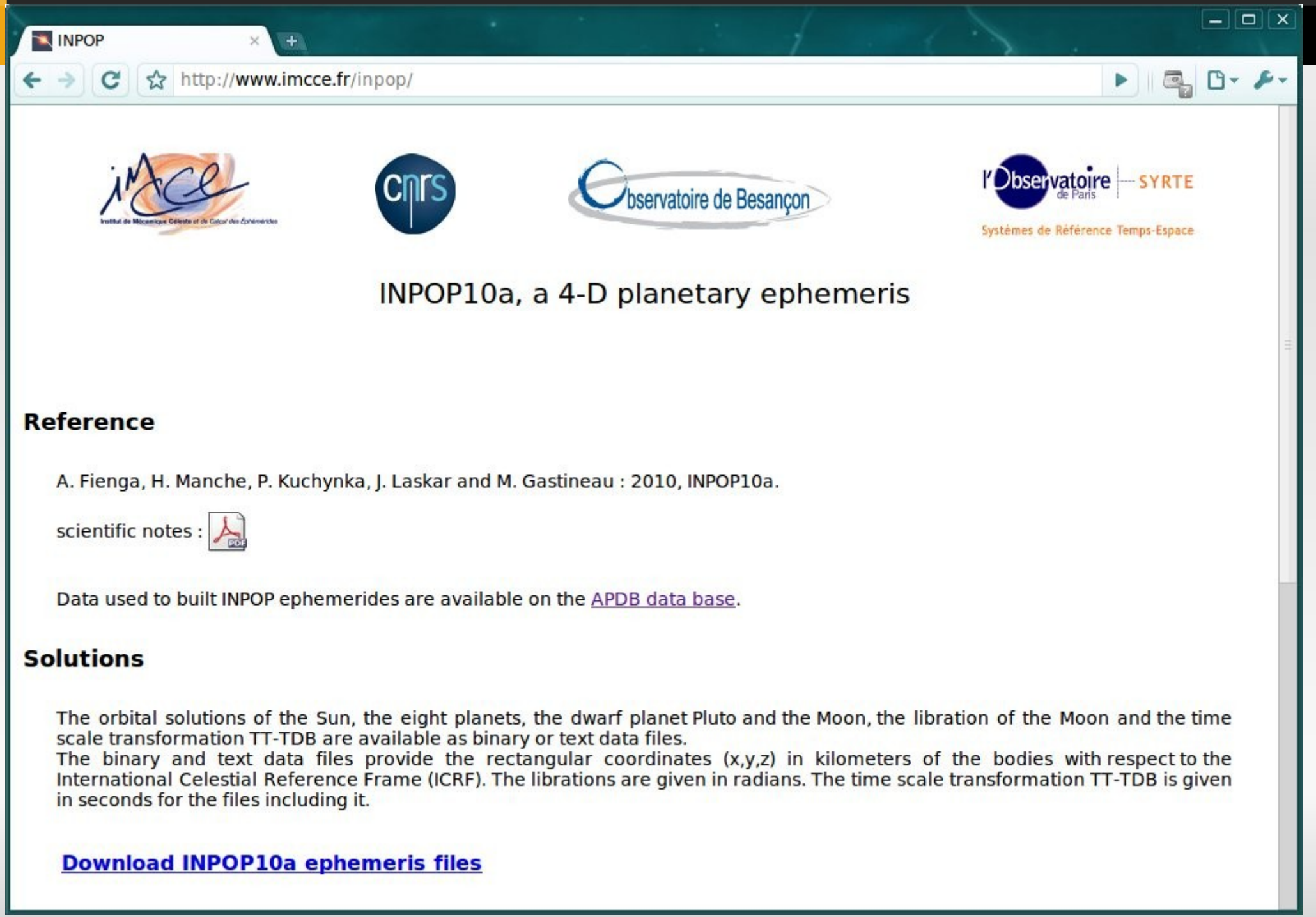
Journées “Systèmes de référence spatio-temporels”
Paris, 20-22 September, 2010

INPOP new release: INPOP10a



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

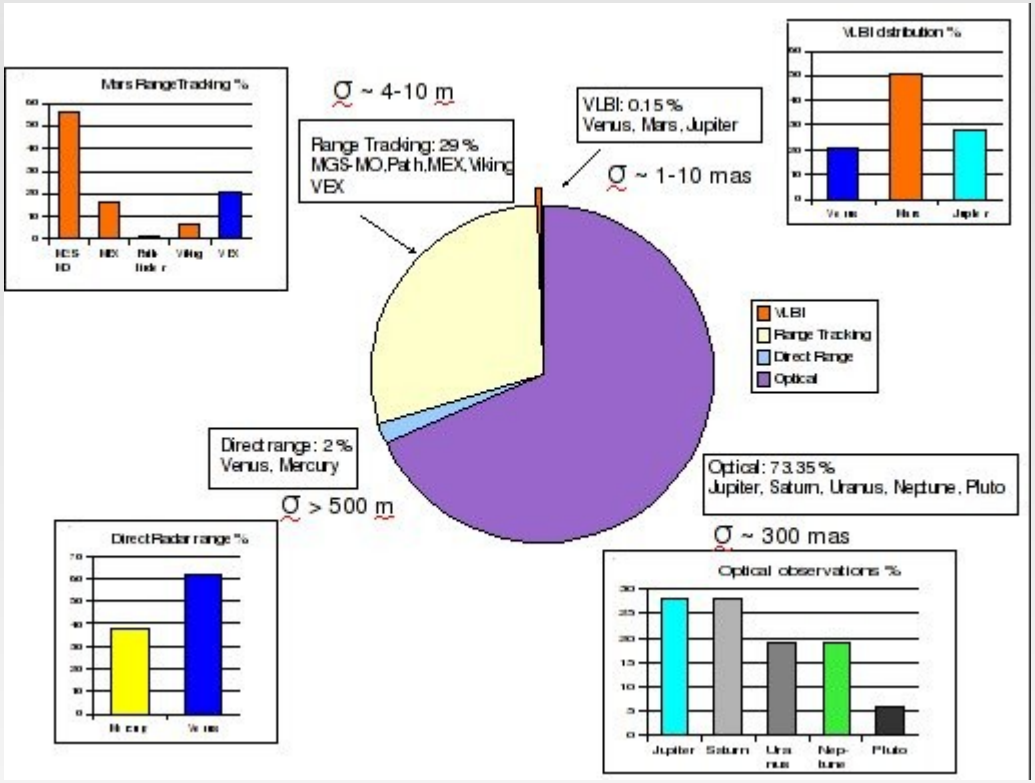
- Millisecond pulsars use for testing INPOP10a link to ICRF

With INPOP10a ...

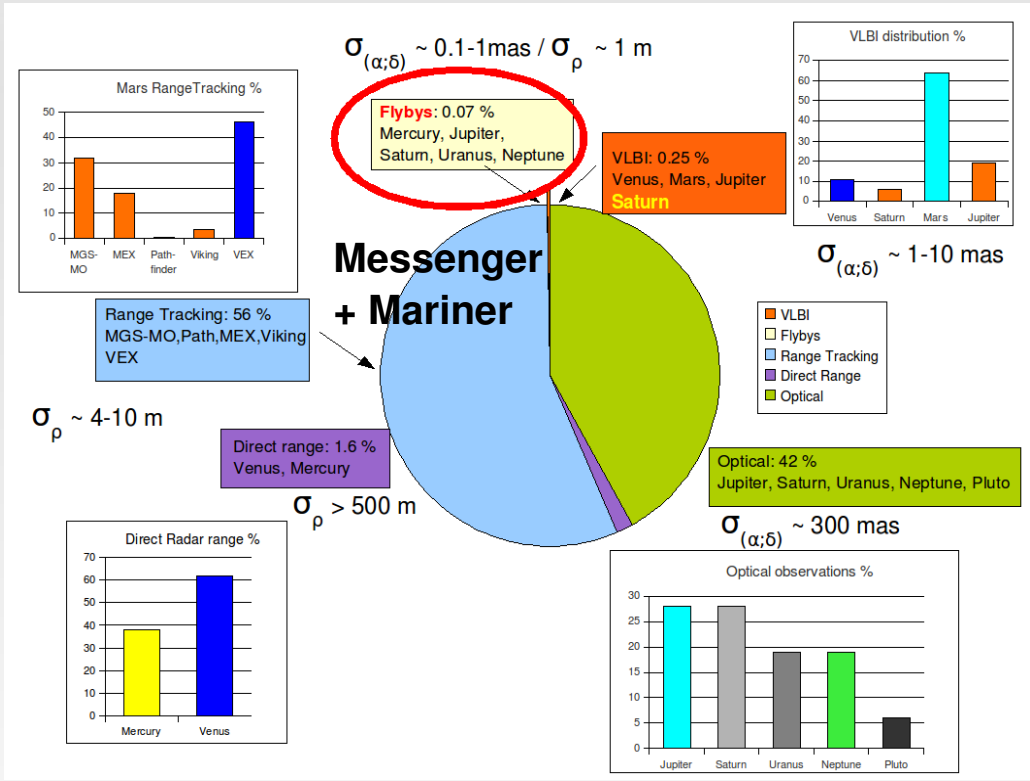
- PPN β, PPN γ separately and simultaneously, with planets and moon
- Secular advances of perihelia

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)

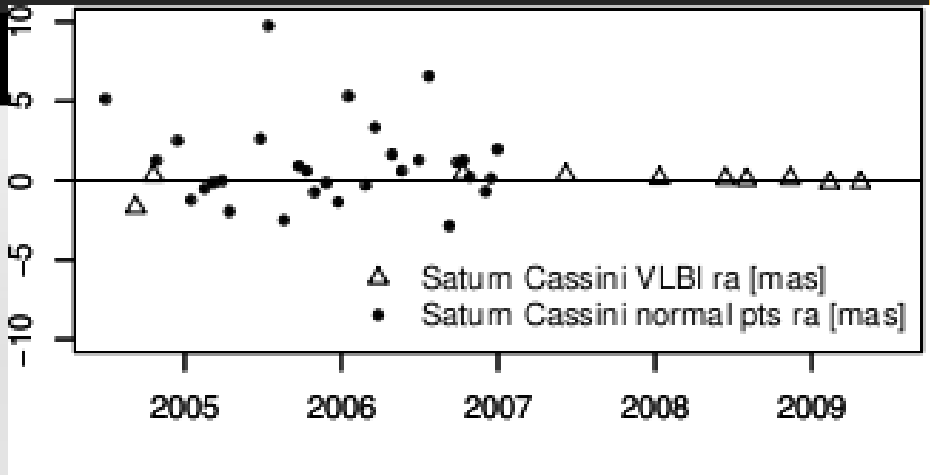
  => prolongation of data interval

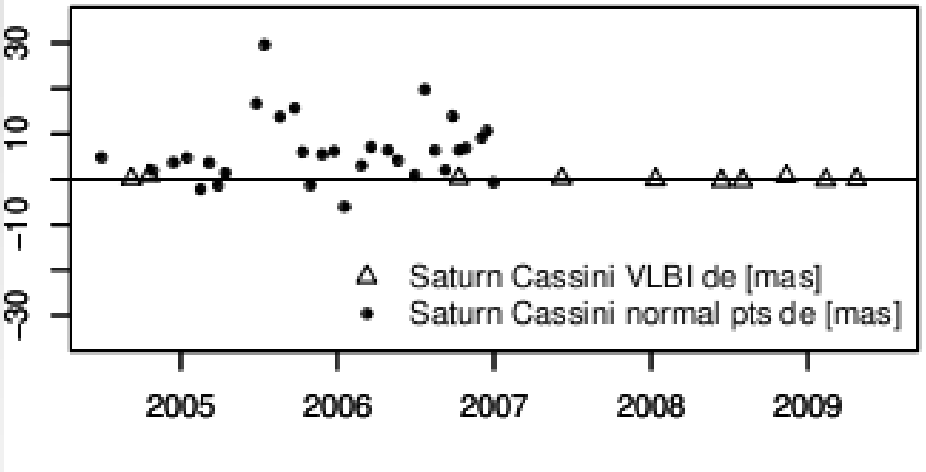
- Cassini VLBI Saturn positions

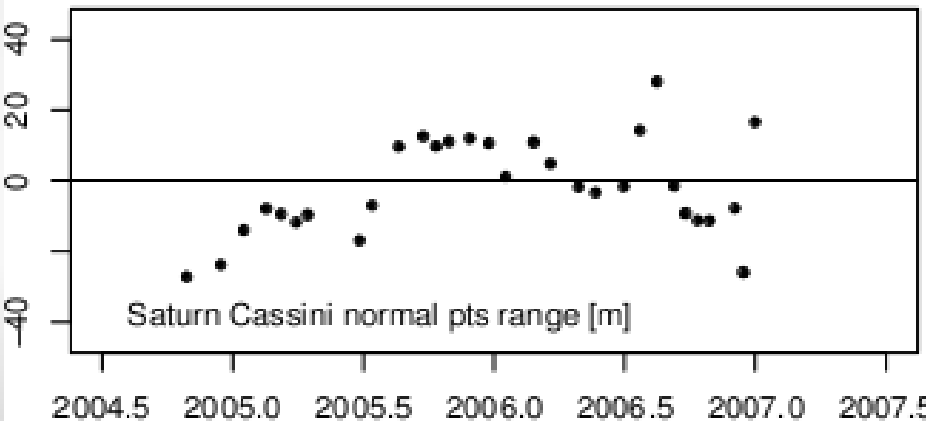
  (Jones and al. 2010)

  => 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]

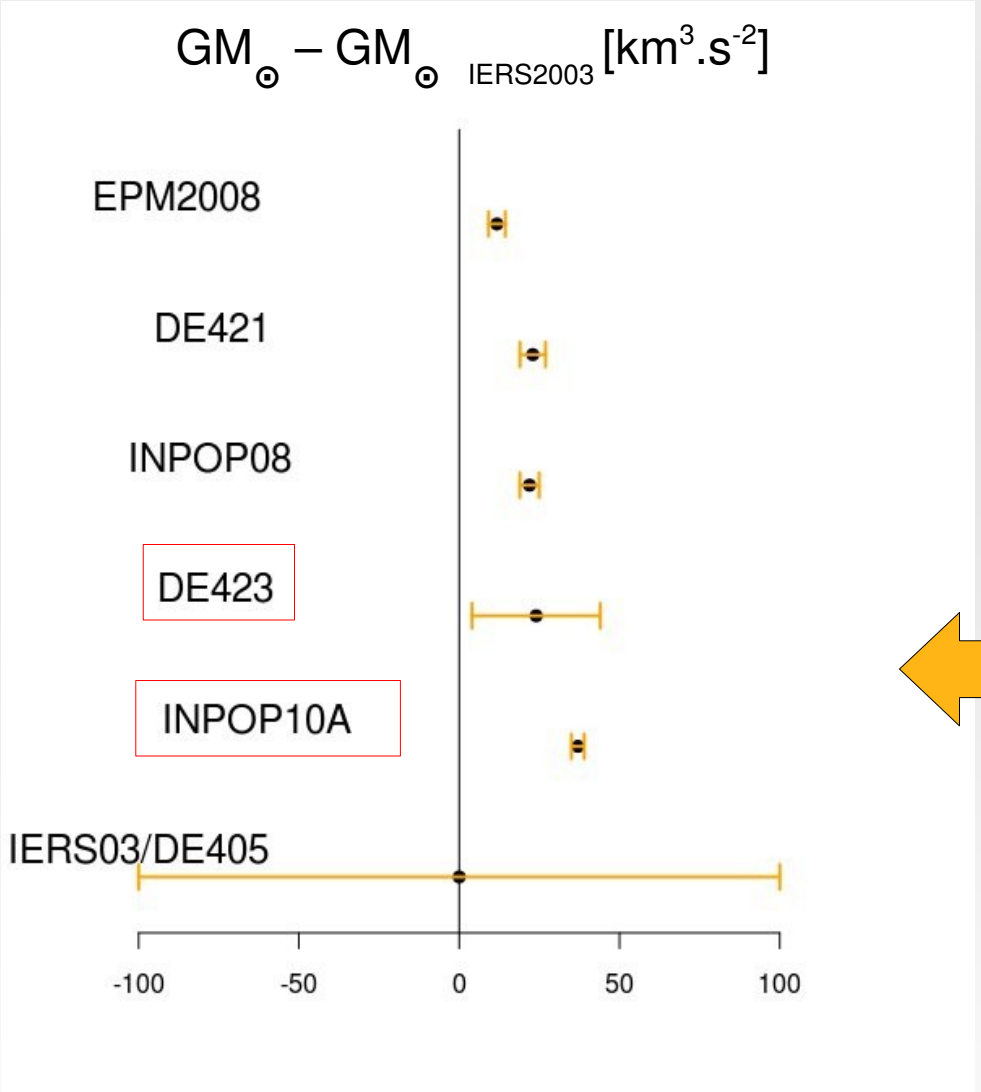
- Jupiter, Uranus, Neptune normal points
- Pluto stellar occultations (Sicardy 2009)

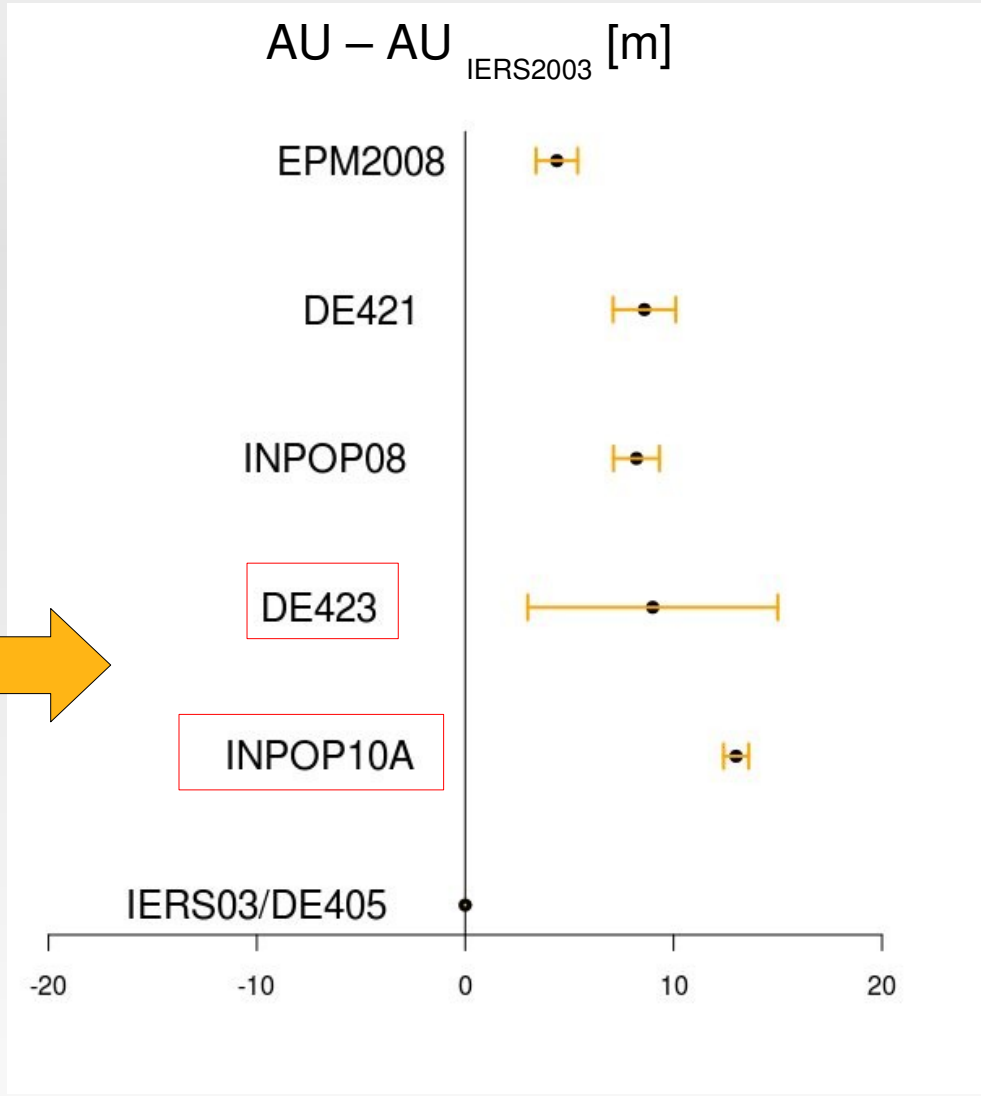
Sets of fitted parameters

First set of fitted parameters

	INPOP08	INPOP10a	DE423
	$\pm 1\sigma$	$\pm 1\sigma$	$\pm 1\sigma$
EMRAT	(81.30054 ± 0.00005)	$(81.3005700 \pm 0.0000010)$	$(81.3005694 \pm 0.0000015)$
$J2_\odot$	$(1.82 \pm 0.47) \times 10^{-7}$	$(2.40 \pm 0.25) \times 10^{-7}$	
$(\beta$ -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

Direct estimation of the mass of the sun with AU fixed





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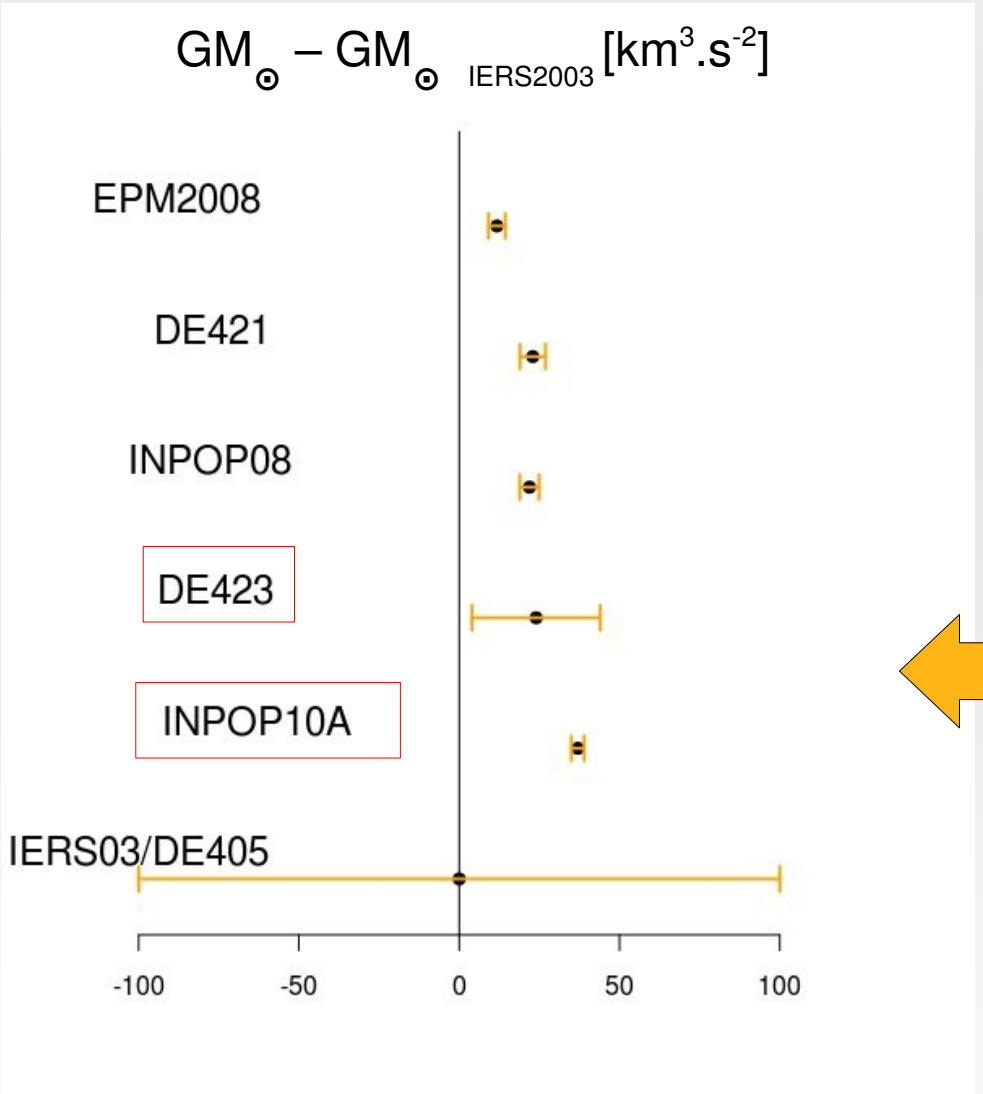
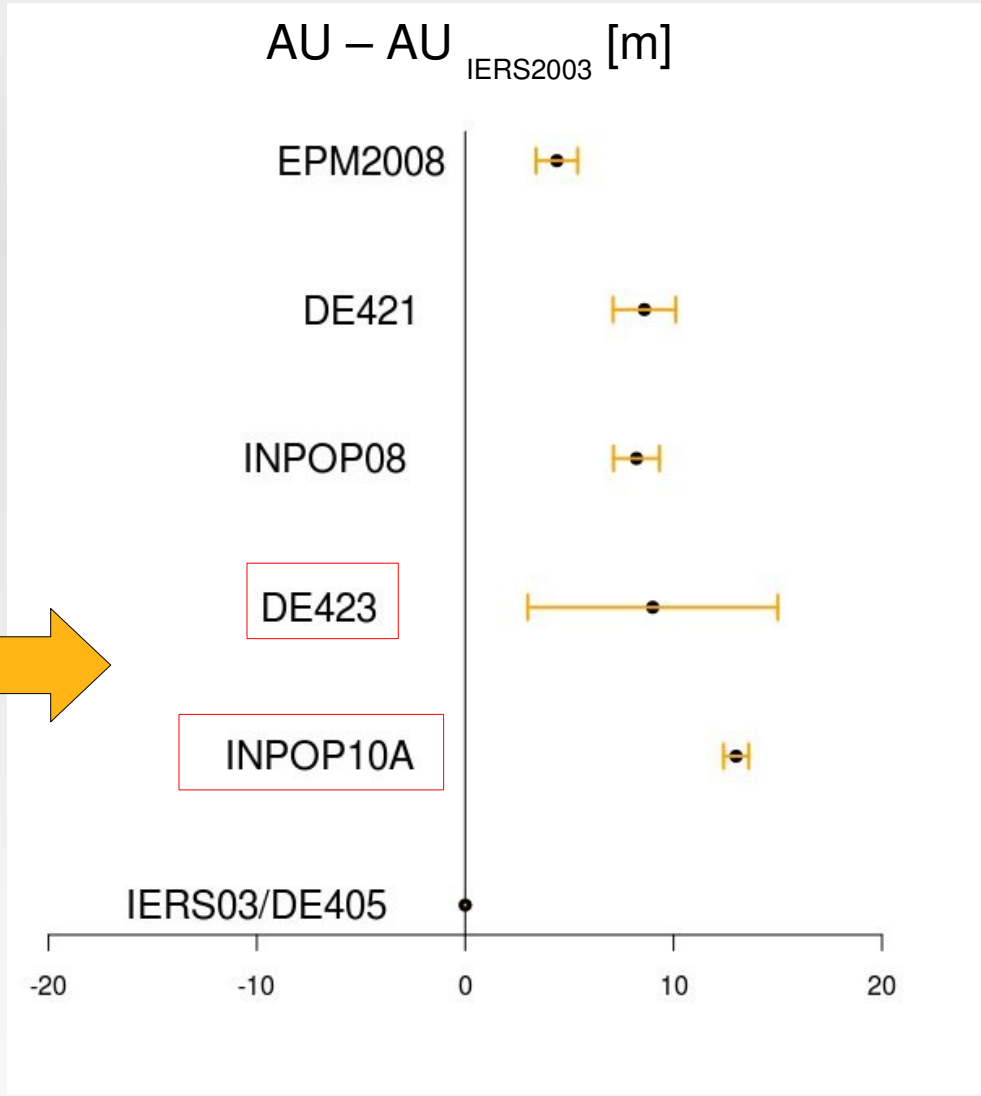




Fit of $GM_\odot$ with AU fixed ⟺ **Fit of AU with $GM_\odot$ fixed**

Compatible values

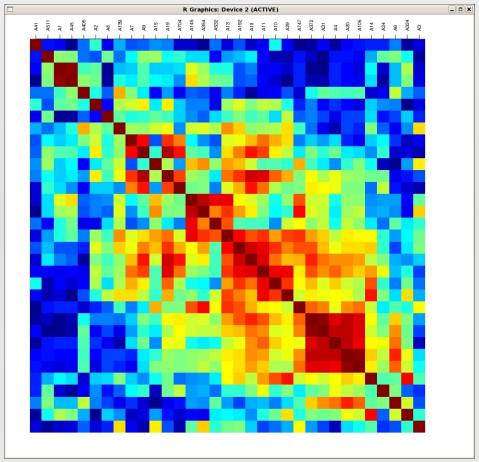
Asteroid masses and selection

- Kuchynka et al. 2010 => fixed mass of the ring +

  list of the most probable 161 perturbers

- Correlation study => 15 GMs fixed to (Baer 2010) close-encounters values

- Bounded values least squares with $0.5 < \rho < 10$



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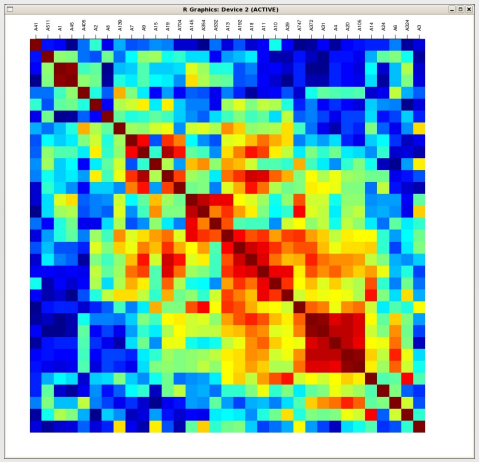
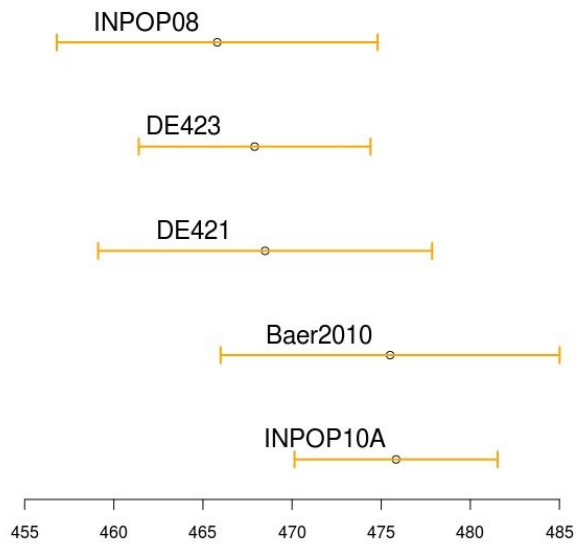
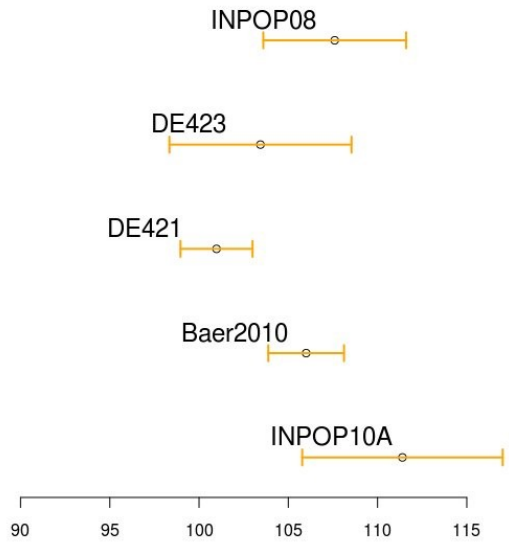


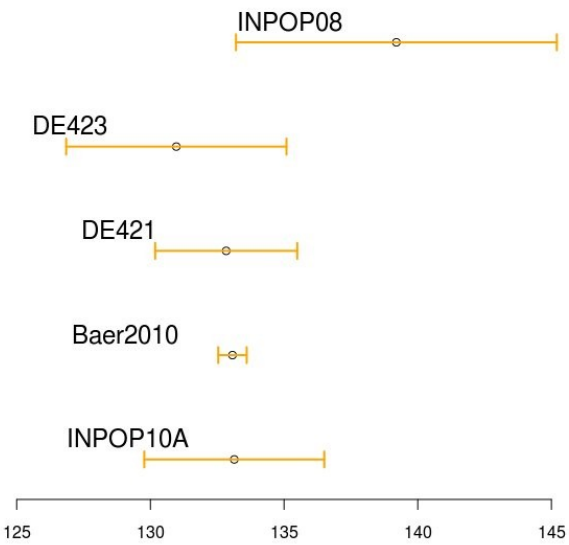
Mass of Ceres [10^{12} $M_\odot$]



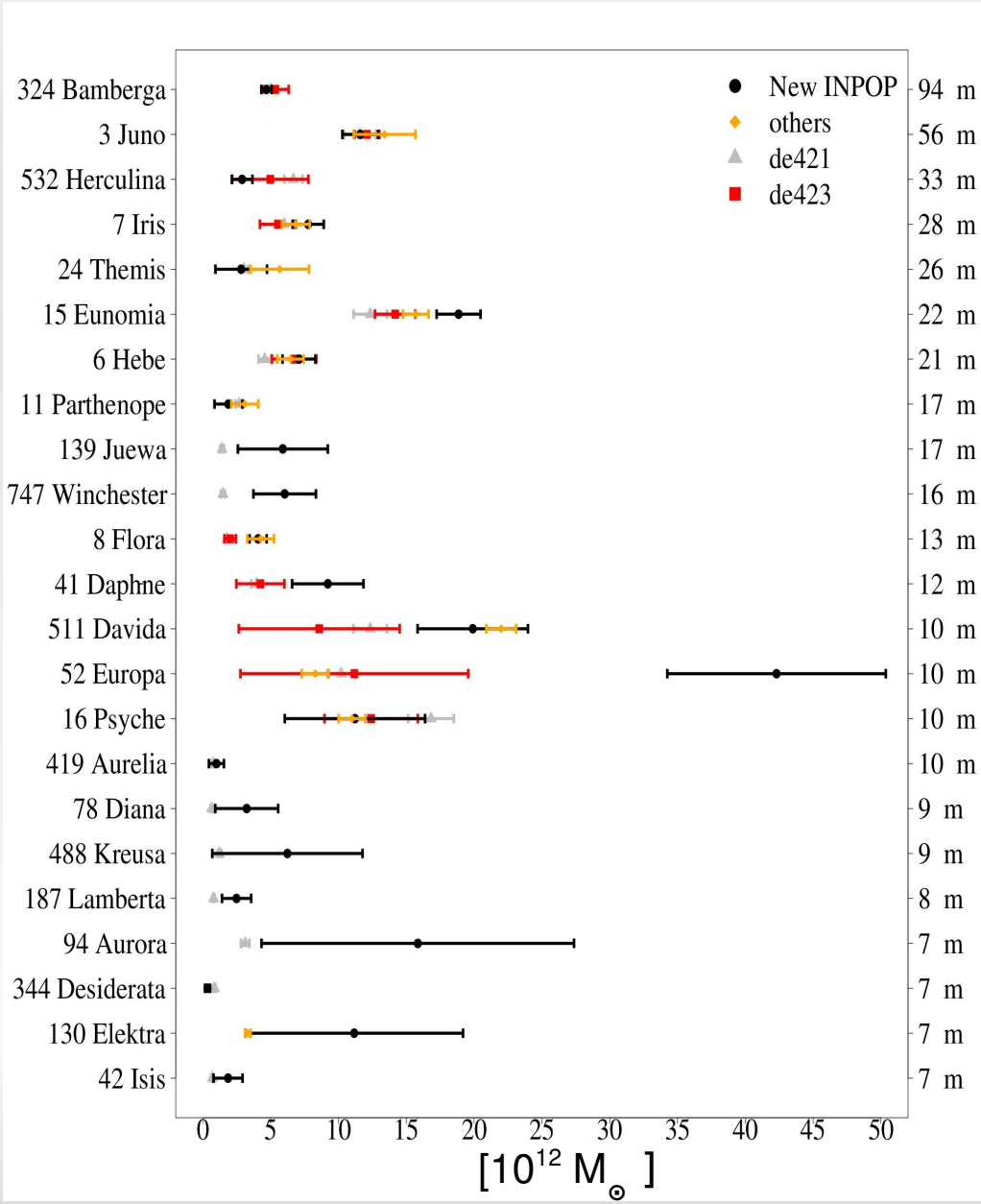
Mass of Pallas [10^{12} $M_\odot$]

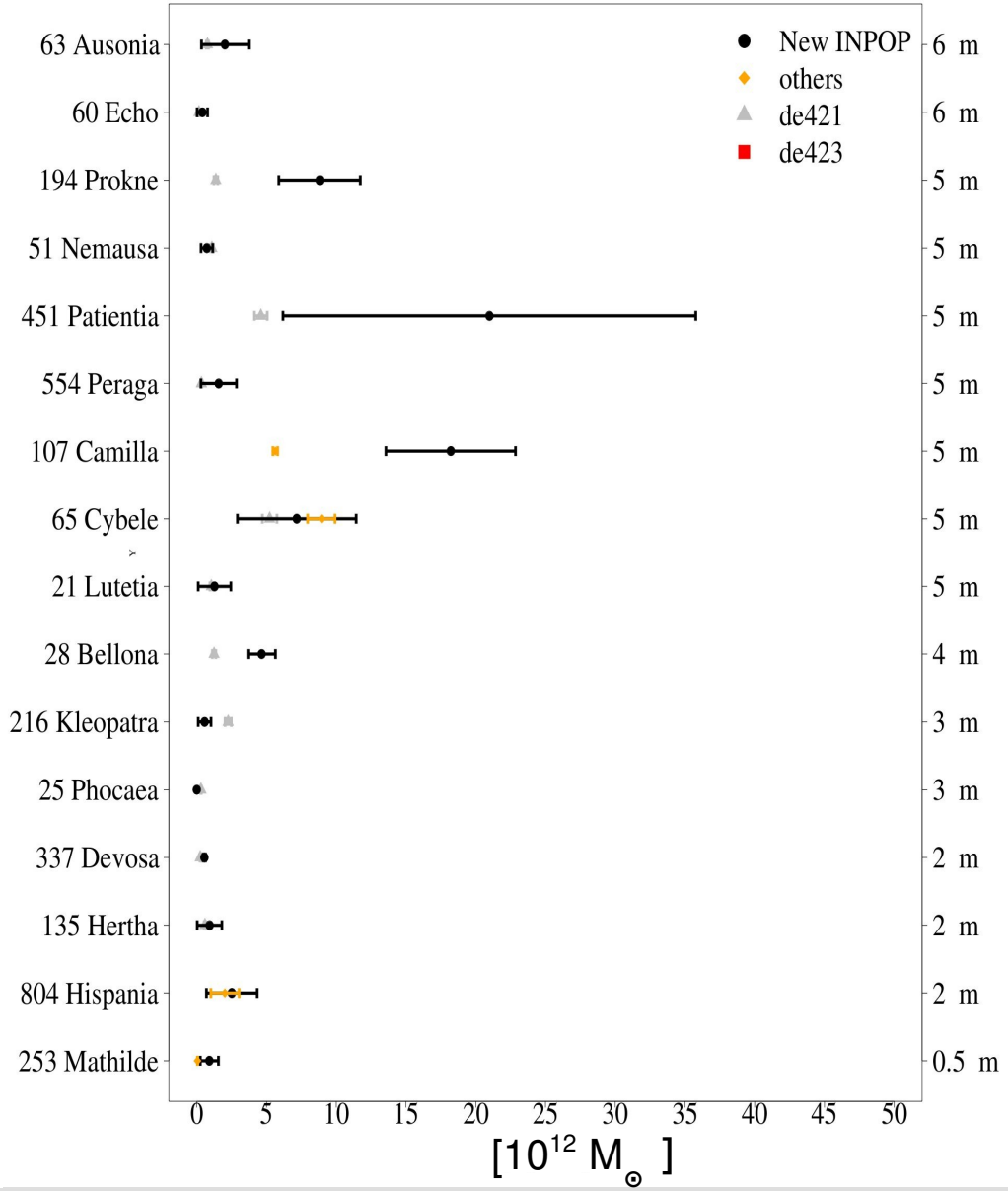


Mass of Vesta [10^{12} $M_\odot$]



Asteroid masses and selection





Frame ties and Millisecond Pulsars (poster)

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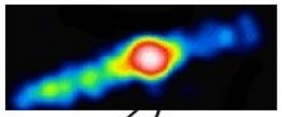
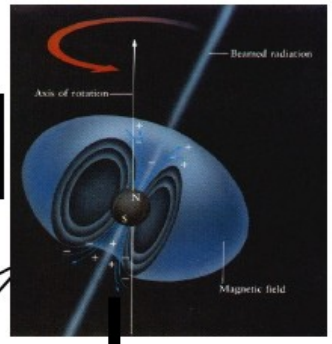
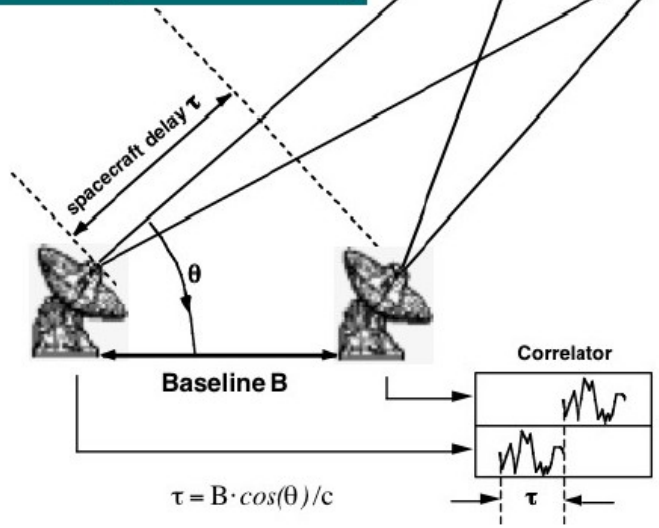
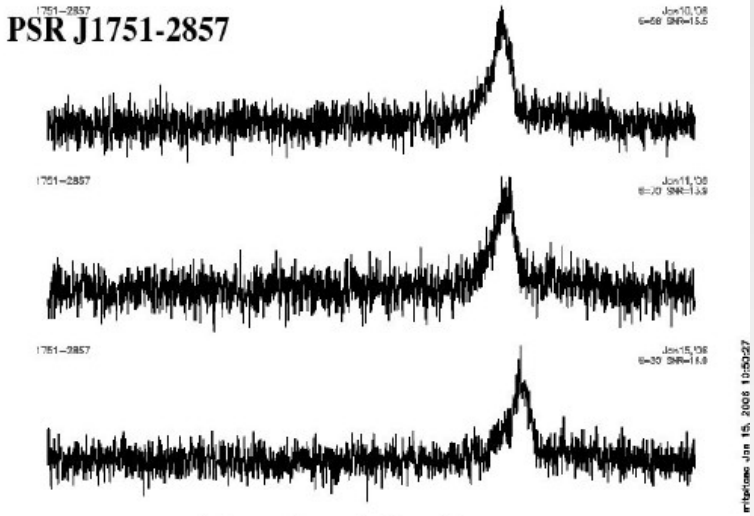






VLBI

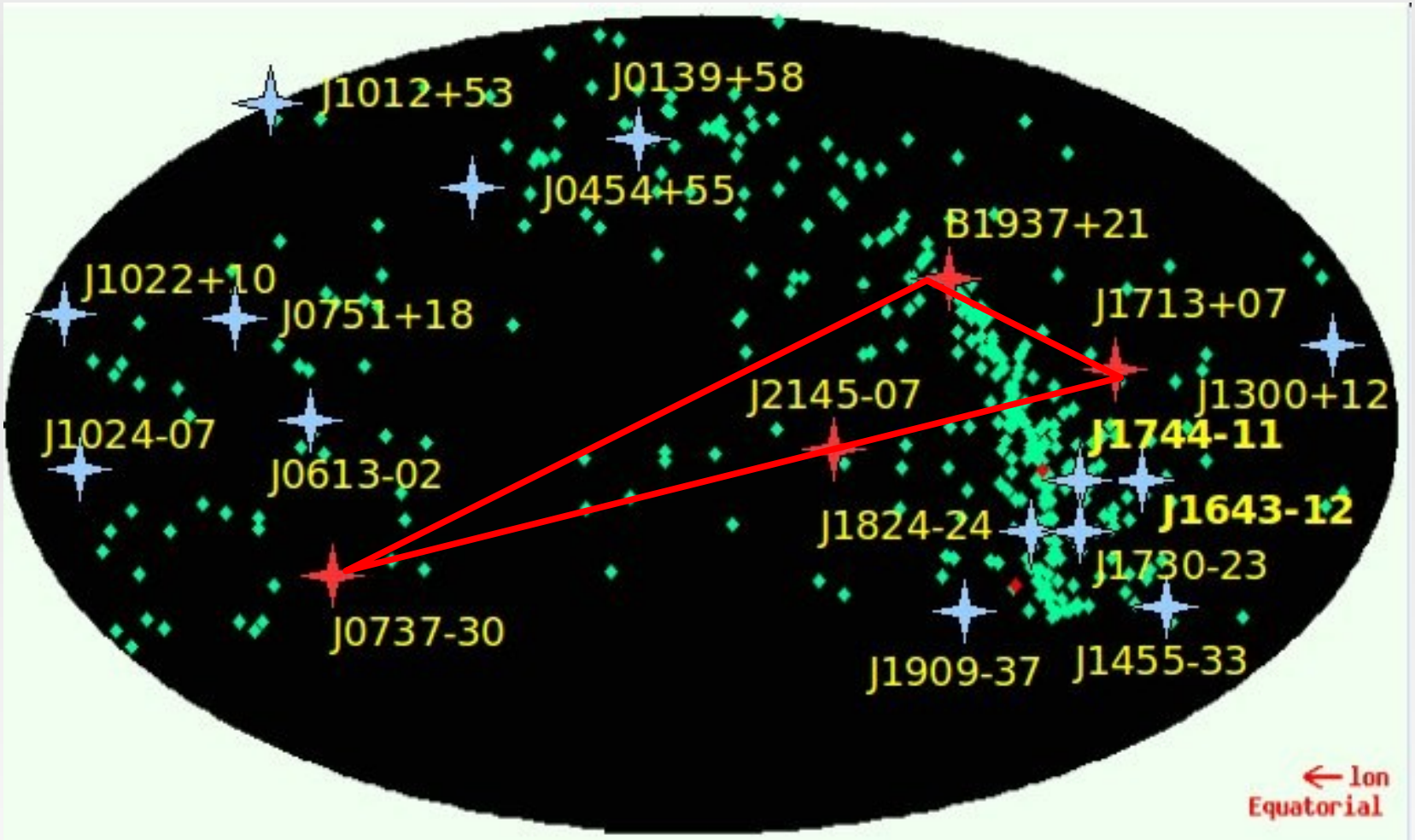
- Phase delay PSR / Calibrators
- Astrometric Accuracy below 1 mas
- Reference frame: ICRF



Radio Timing

- Measure of the Time of Arrival (TOA) of each PSR impulse at 1.4 Ghz
- Astrometric Accuracy can reach 1 mas
- Reference frame: Earth

Frame ties and Millisecond Pulsars (poster)



- 18 Radio timing at NRT (Desvignes et al.)
- 4 VLBI by Chatterjee et al. and Deller et al.

Frame ties between ICRF and DE/INPOP with MSP (poster)

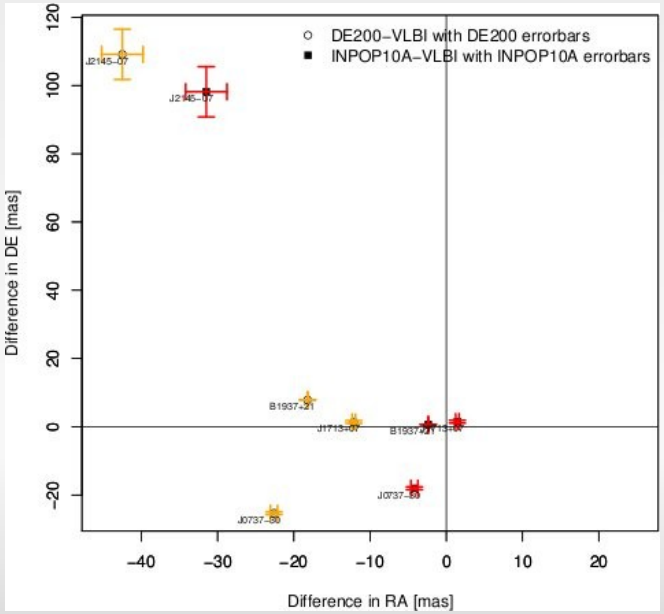
	θ mas	η mas	ζ mas
18 MSPs with TOA $(\sigma_\alpha,\sigma_\delta) < 10$ mas			
DE405 → DE200	-0.4 ± 0.3	-13 ± 0.4	-13 ± 0.3
DE405 → DE200 [22]	-1 ± 2	-14 ± 3	-10 ± 3
DE414 → DE405	1.5 ± 0.3	-1.0 ± 0.4	-0.9 ± 0.3
INPOP08 → DE405	1.3 ± 0.3	-0.3 ± 0.4	-1.1 ± 0.3
INPOP10A → DE405	1.6 ± 0.3	-0.7 ± 0.4	-0.7 ± 0.3
Only 4 MSPs with TOA $(\sigma_\alpha,\sigma_\delta) < 10$ mas			
DE405 → DE200	-0.5 ± 0.2	-12 ± 0.3	-13 ± 0.18
INPOP08 → DE405	1.4 ± 0.03	-0.03 ± 0.05	-1.4 ± 0.03
INPOP10A → DE405	1.7 ± 0.01	-0.03 ± 0.02	-1.0 ± 0.01

	θ mas	η mas	ζ mas
Only 4 MSPs with TOA + VLBI $(\sigma_\alpha,\sigma_\delta) < 10$ mas			
DE405 → ICRF	6 ± 5	15 ± 11	-4 ± 6
INPOP08 → ICRF	4 ± 5	15 ± 11	-2.5 ± 6
INPOP10A → ICRF	4 ± 5	15 ± 11	-3.0 ± 6
DE200 → ICRF	6 ± 5	28 ± 11	9 ± 6
DE200 → ICRF [1]	2 ± 2	12 ± 3	6 ± 3
DE200 → ICRF [25]	-1 ± 3	10 ± 3	4 ± 5

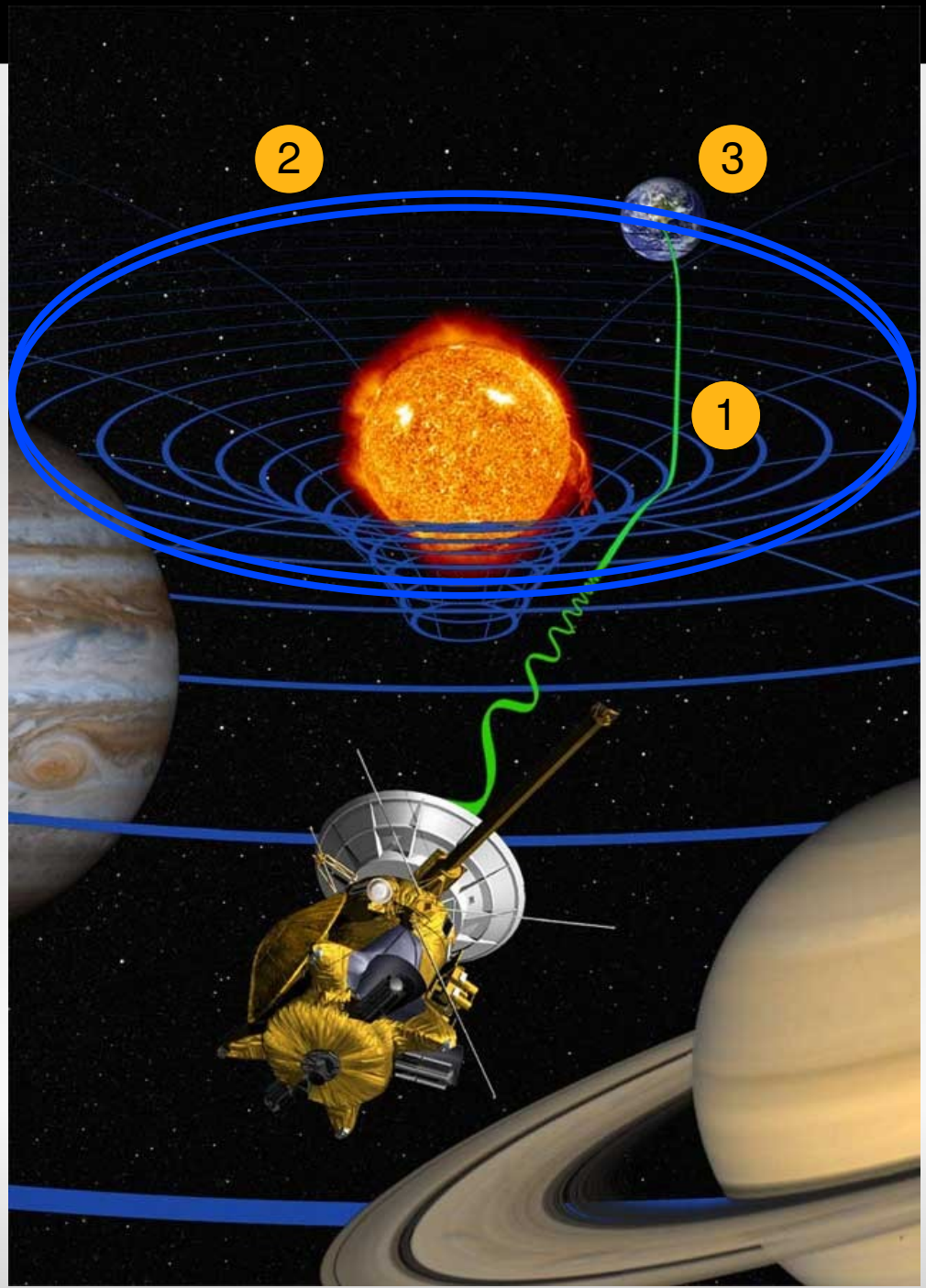
1) Confirmation of the mas-level internal accuracy of planetary ephemerides

2) Need to increase the sample of MSP observed in radio timing + VLBI with a mas-level accuracy

(Chatterjee et al. 2010) program = VLBI astrometry of FERMI pulsars



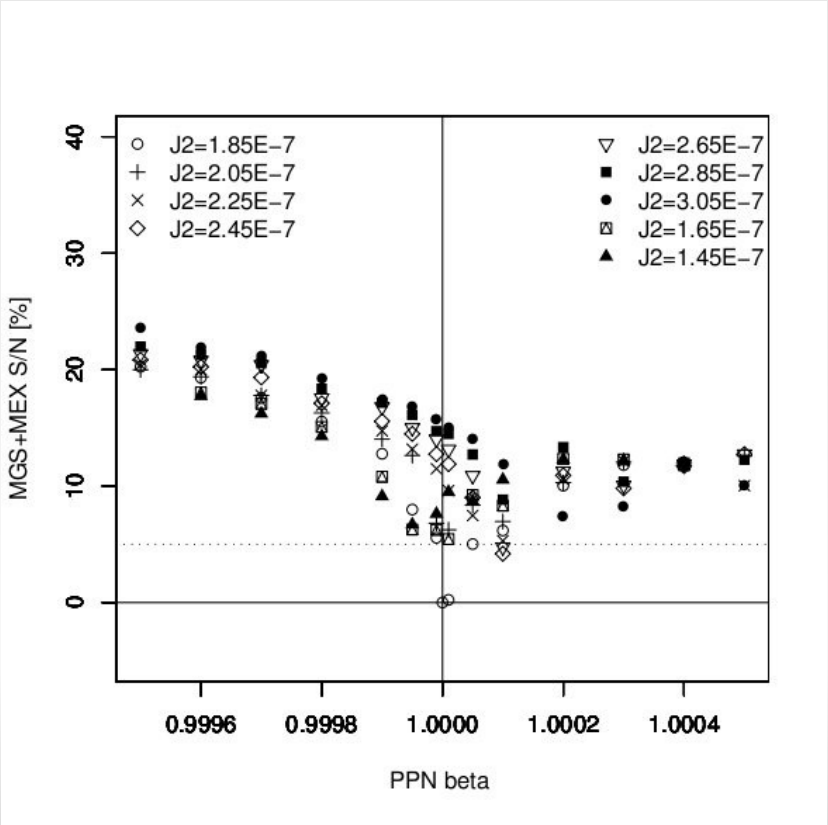
General relativity tests



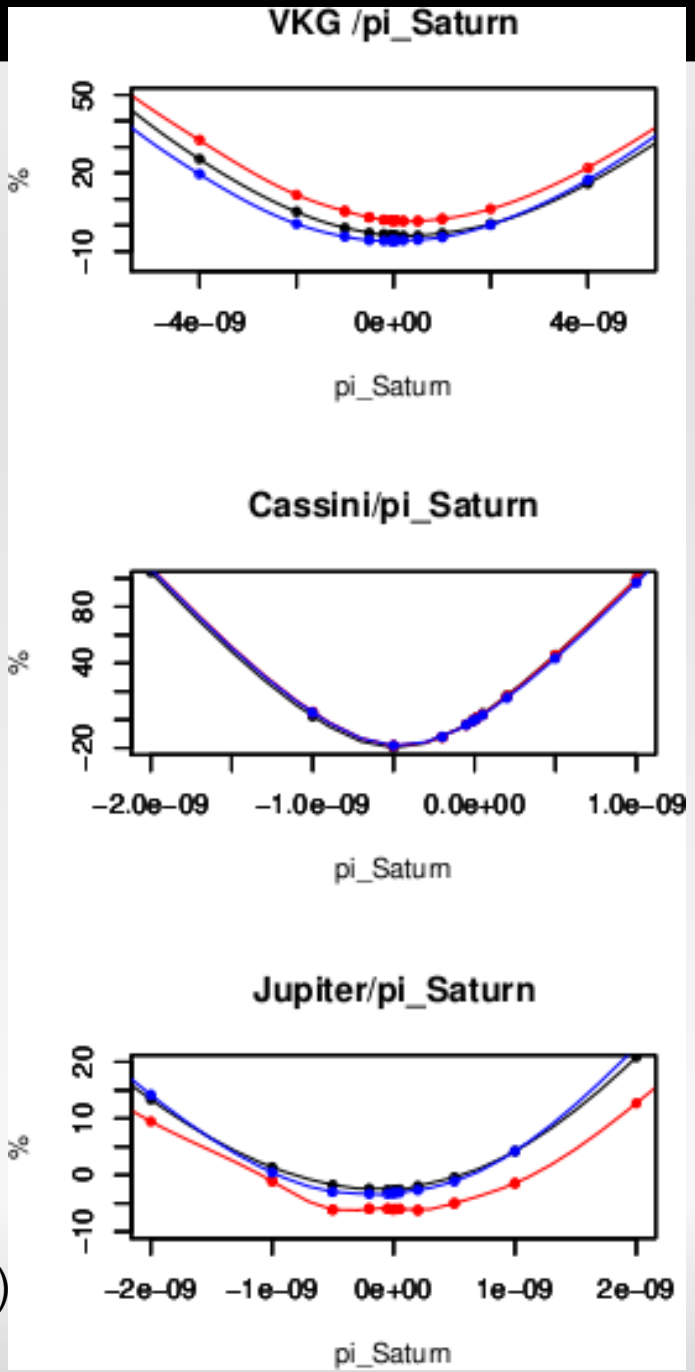
1. Deflection of light, γ
2. Non-linearity of gravity, β
3. Supplementary advances of perihelia

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

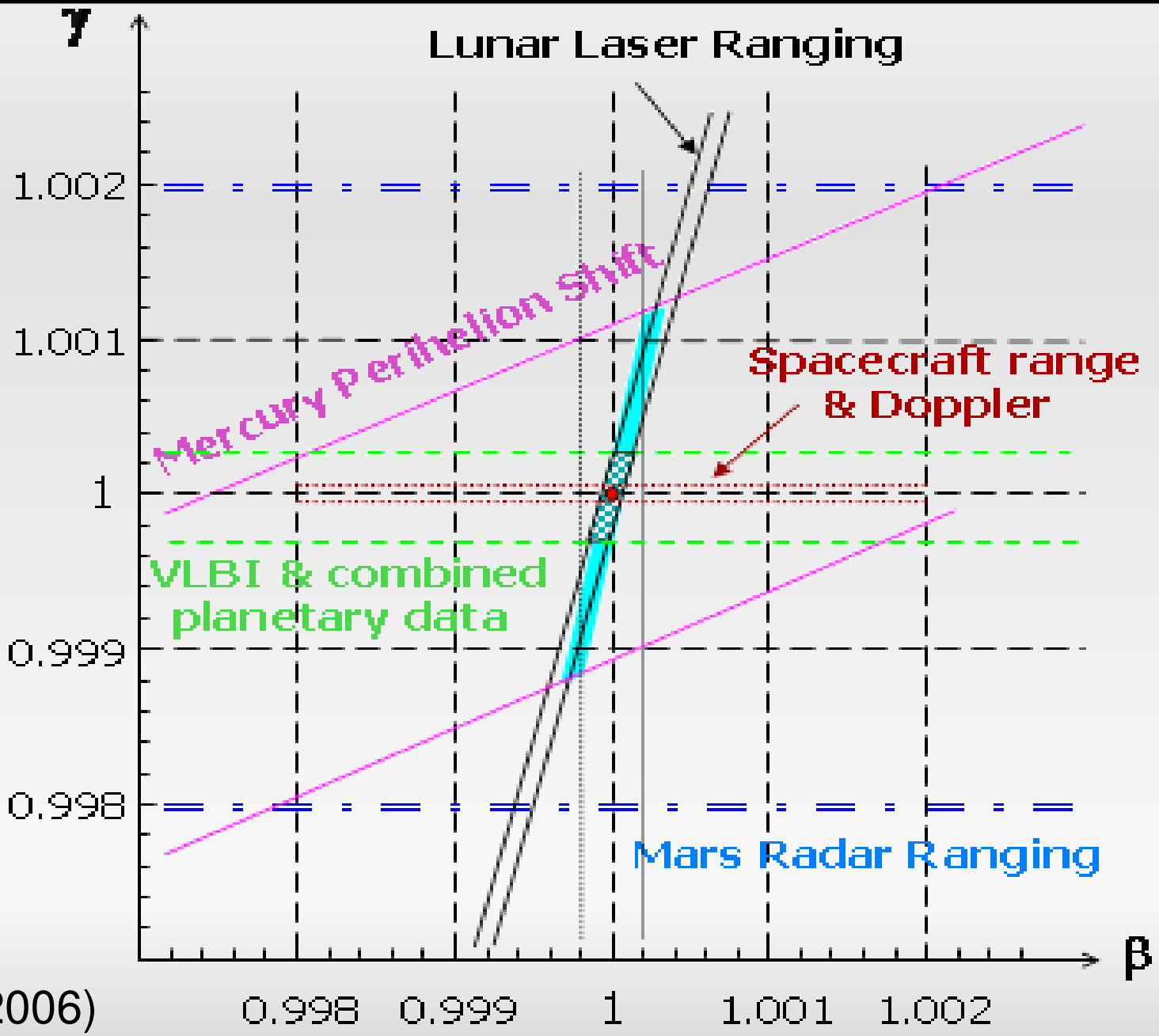
In the uncertainty of the present observations, does a room exist for unexplained advances in node or perihelia of orbits ?

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**	

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

(γ, β)

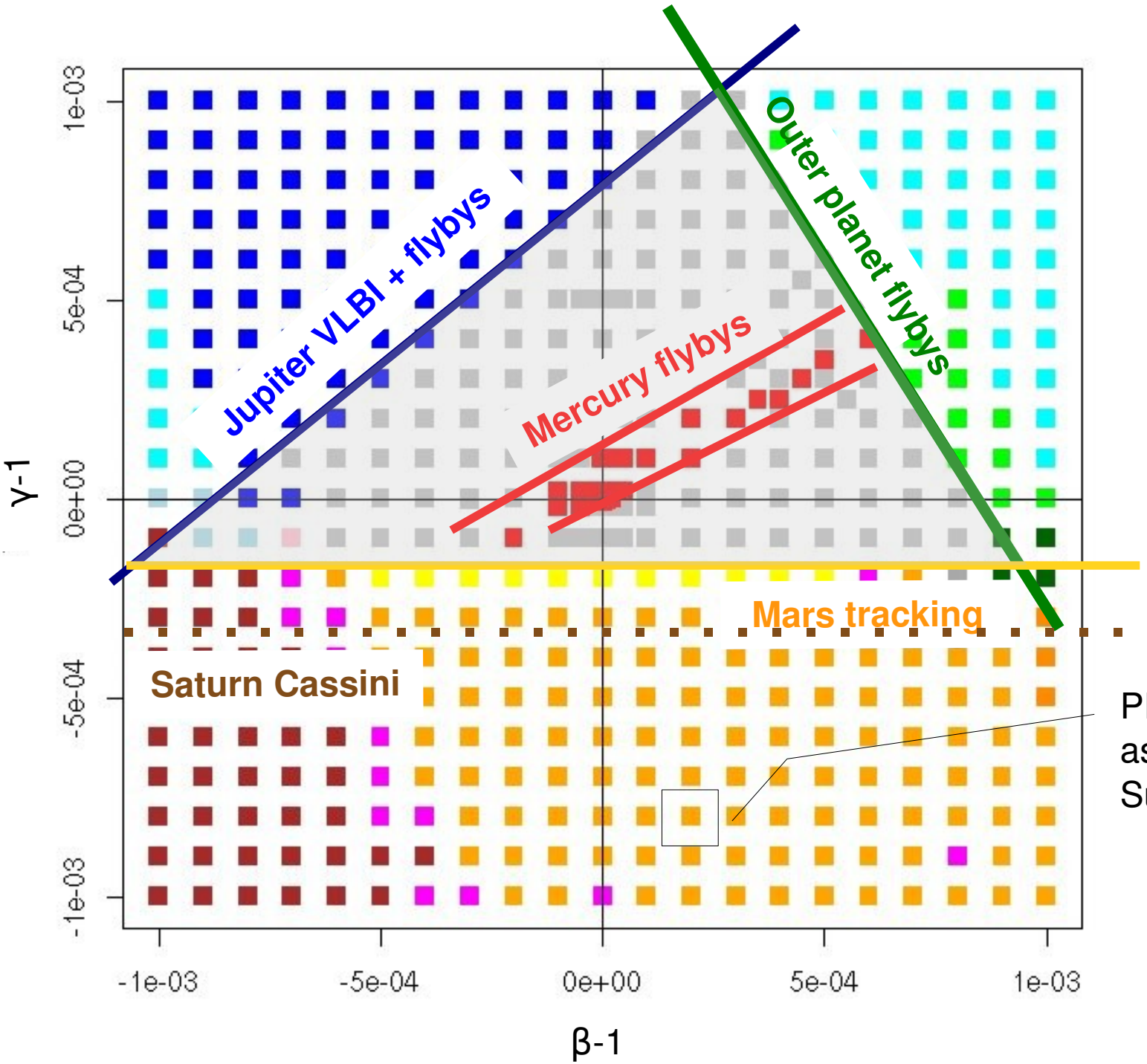


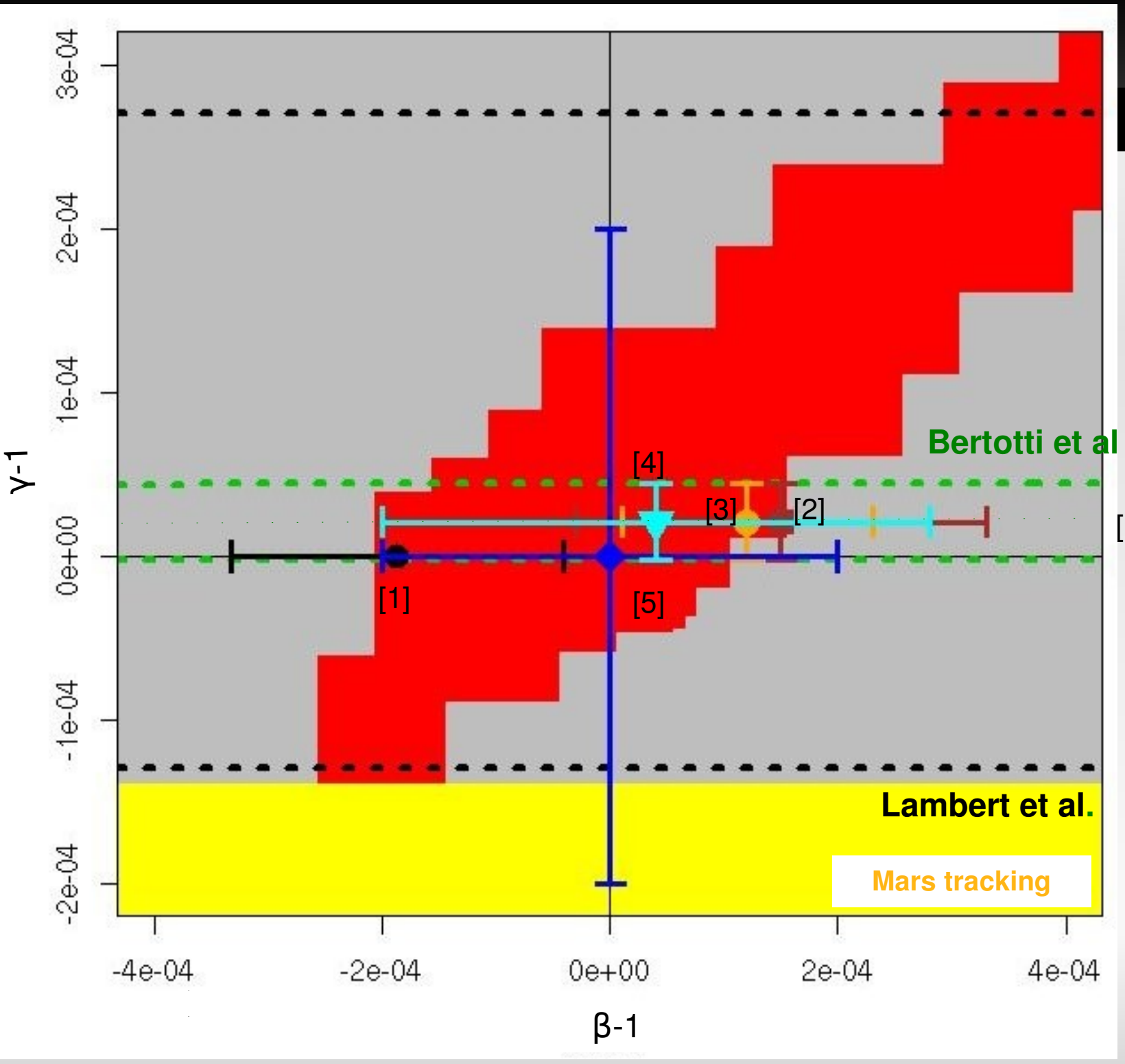
(Murphy 2006)

(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 data


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

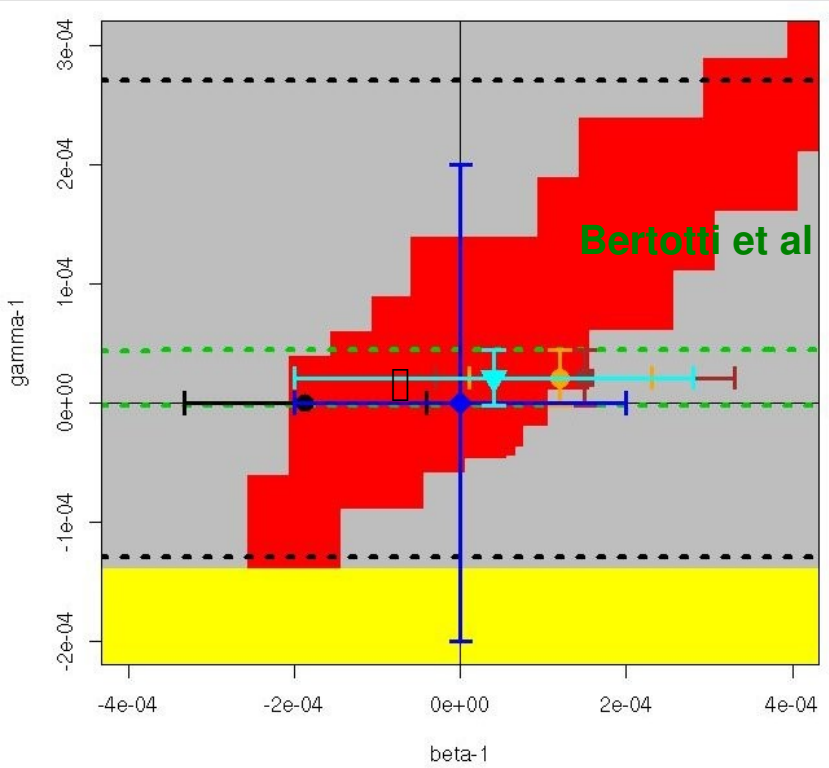


[1] INPOP10a LLR
[2] Williams et al. 2010
[3] Mueller et al. 2008
[4] Konopliv et al .2010
[5] Pitjeva 2010

Estimations of (γ,β=1) and (γ=γ_{cass},β)

(γ)		γ-1 x 10^4
INPOP10a (red)	β=1	0.6 ± 1.0
Konopliv et al. 2010	Mars SC	1.8 ± 2.6
Bertotti et al. 2003	Cassini	γ_{cass} = 0.21 ± 0.23
Lambert et al. 2008	VLBI	0.7 ± 2.0

(γ=γ_{cass},β)		β-1 x 10^4
INPOP10a	All data	-0.25 ± 0.75
INPOP08	MGS/MEX	0.75 ± 1.25
Williams et al 10	LLR/SEP	1.2 ± 1.1
Muller et al 08	LLR direct	-2 ± 4
	LLR/SEP	1.5 ± 1.8
Konopliv et al 10	Mars	0.4 ± 2.4



Conclusions

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- Data: Mercury + Saturn
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- Asteroid selection and new method for mass estimation

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