Impact of planetary ephemerides on Pulsar Timing Arrays results

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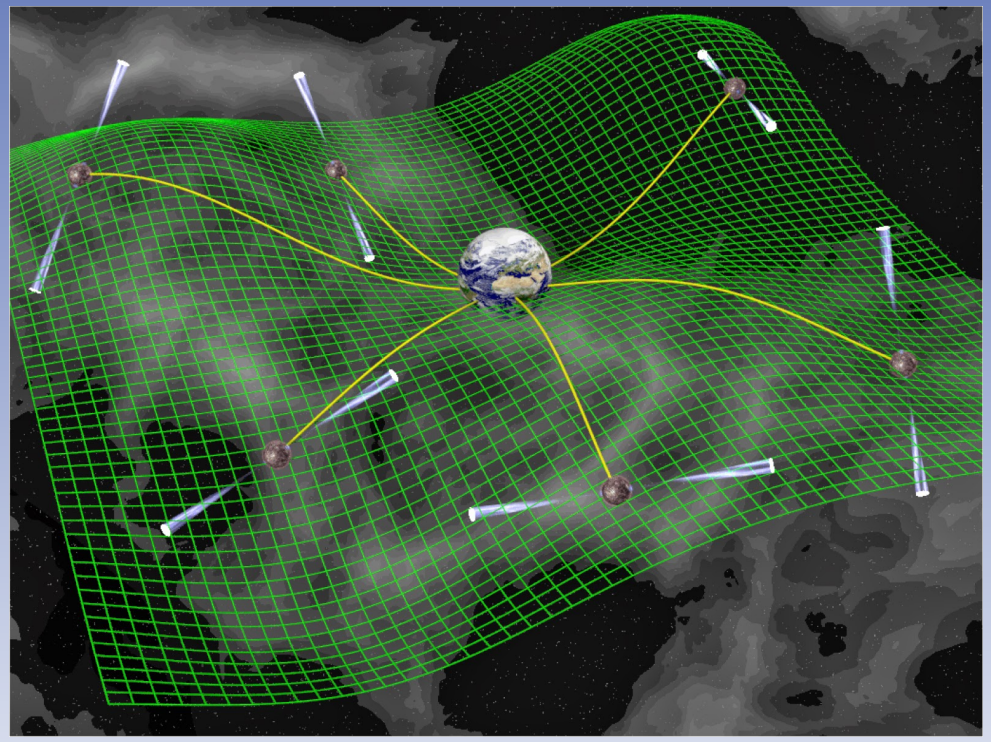
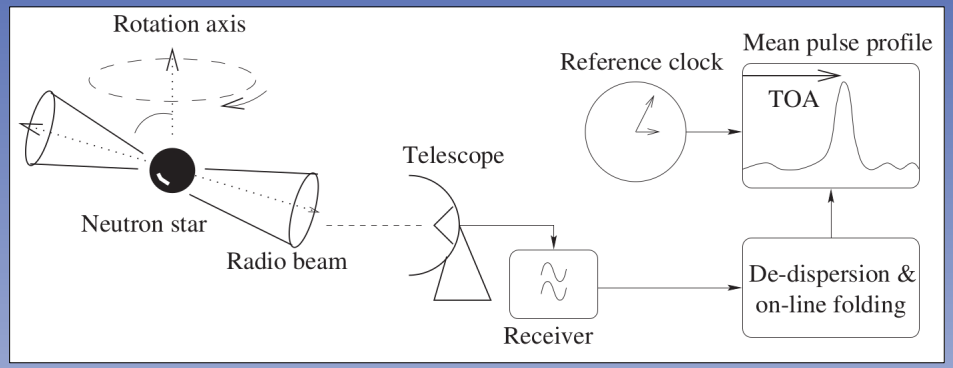


MODE-SNR-PWN Orléans 2019

The pulsar timing process

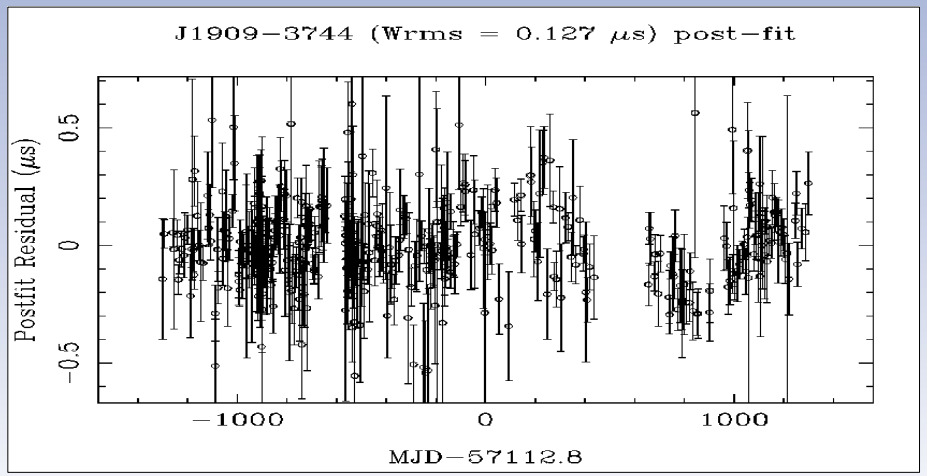
Observational TOAs



Timing model

- Rotational params
- Astrometric params
- Orbital params
- ISM effects
- Clock correction
- Transformation to the SSB
- ...

Residuals



cf. Lorimer & Kramer 2005

The pulsar timing process

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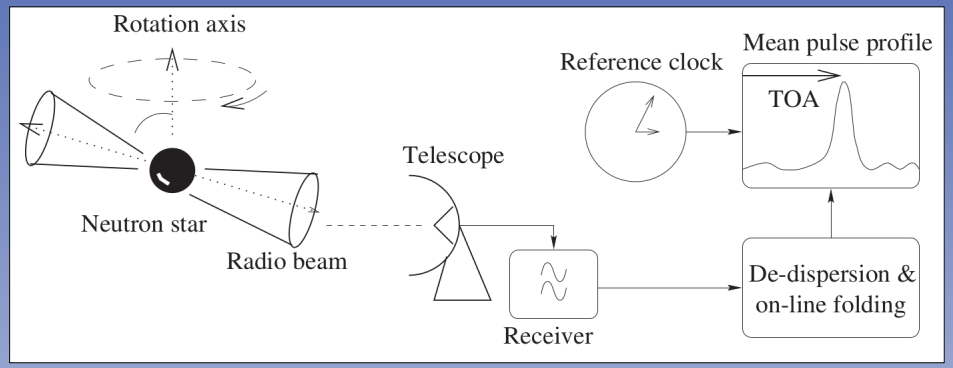

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- **Transformation to the SSB**
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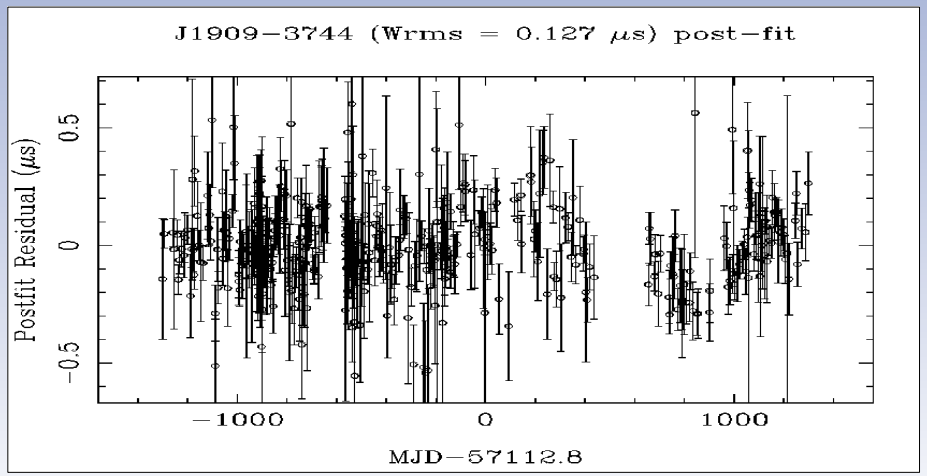
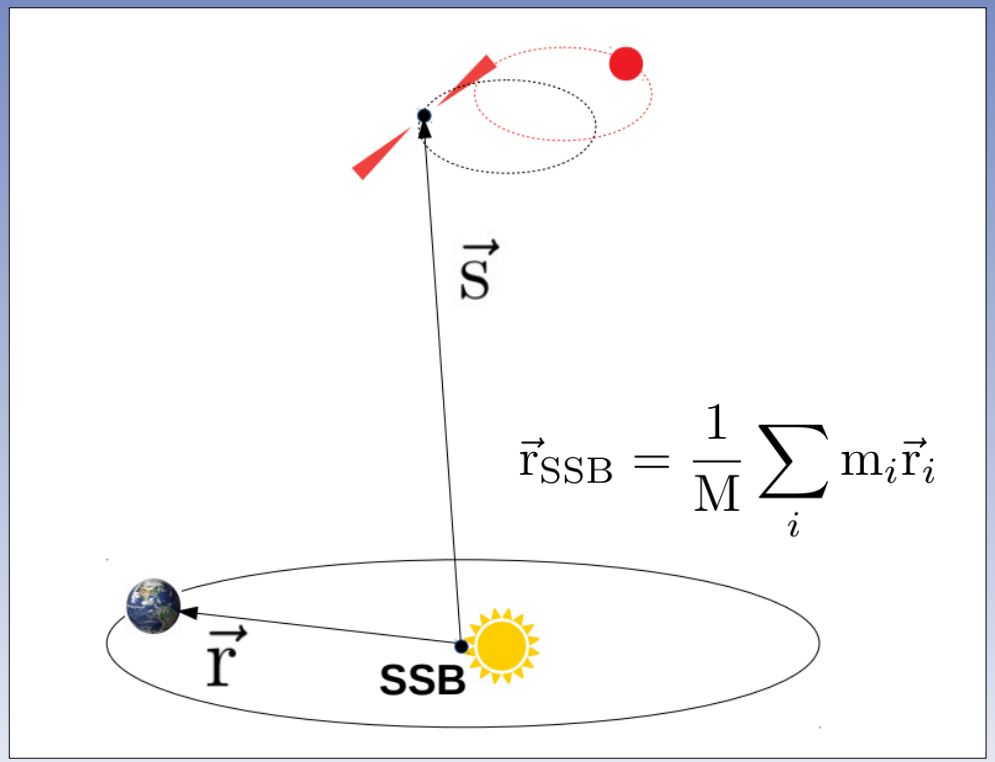


cf. Lorimer & Kramer 2005

TOA transformation to the SSB

From the topocentric to the quasi-inertial solar system barycenter frame

$$t_{SSB} = t_{topo} + t_{corr} - \Delta D/f_{obs}^2 + \Delta_{R\odot} + \Delta_{\pi} + \Delta_{S\odot} + \Delta_{E\odot}$$



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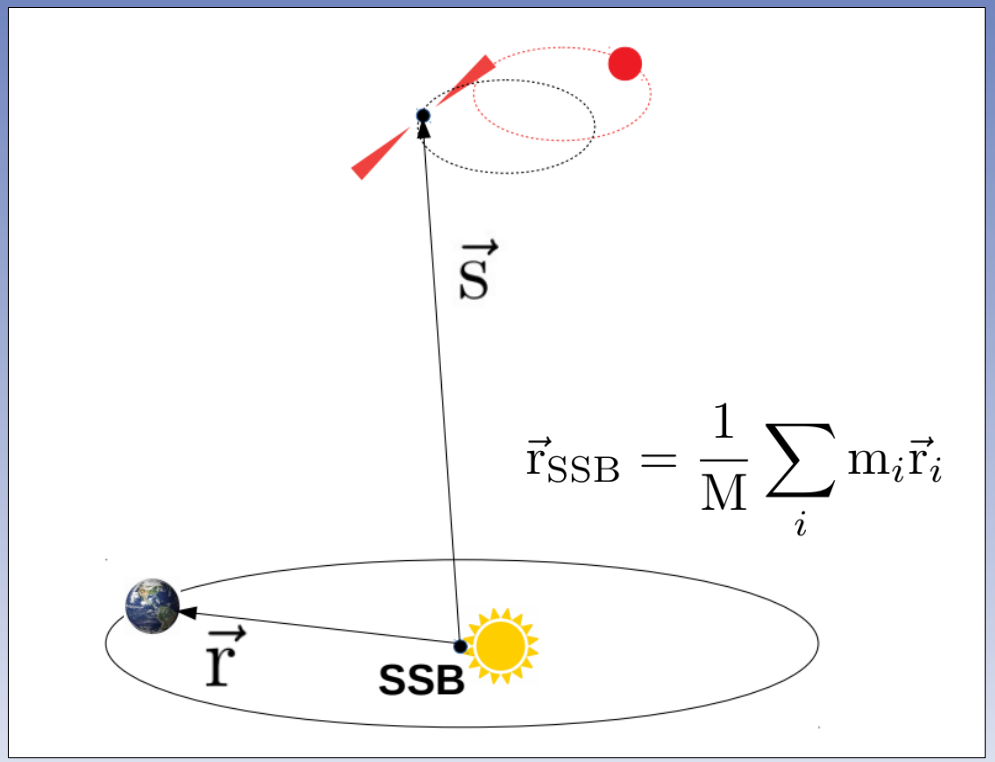


Römer delay

$$\Delta_{R\odot} = -\frac{1}{c}\,\vec{r}\cdot\hat{s}$$

Parallax

$$\Delta t_{\pi} = -\frac{1}{2cd}\,(\vec{r}\times\hat{s})^2$$

Shapiro

$$\Delta_{S\odot} = -2\sum_i \frac{GM_i}{c^3}\ln\left[\frac{\hat{s}\cdot\vec{r}_i^{\,E} + r_i^{\,E}}{\hat{s}\cdot\vec{r}_i^{\,P} + r_i^{\,P}}\right]$$

Einstein delay

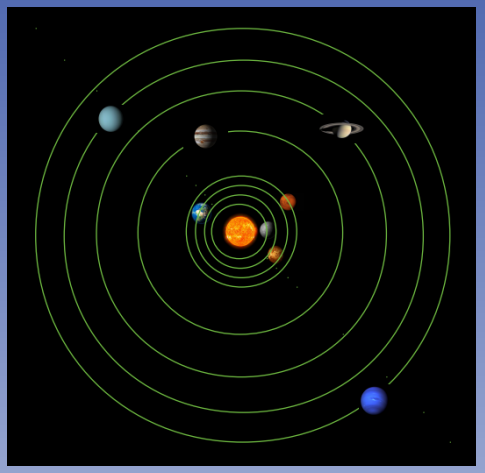
$$\frac{d\Delta_{E\odot}}{dt} = \sum_i \frac{GM_i}{c^2 r_i^E} + \frac{v_E^2}{2c^2} - \text{constant}$$

➡ **Orbits of solar system bodies needed !**

cf. Lorimer & Kramer 2005

Solar system ephemeris (SSEs)

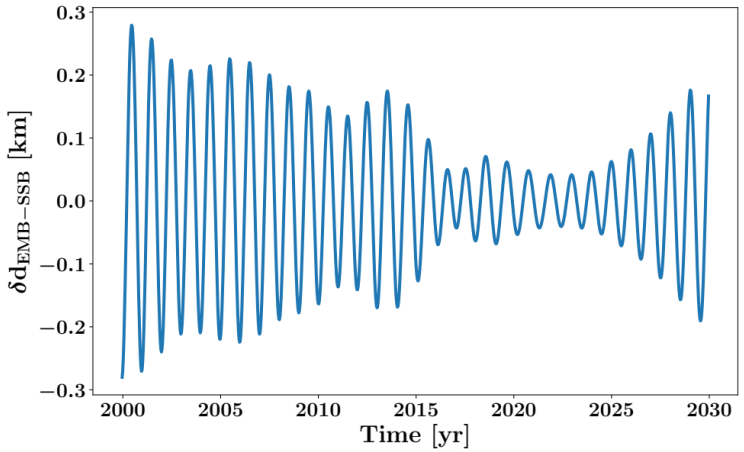
Predict positions and velocities of solar system bodies

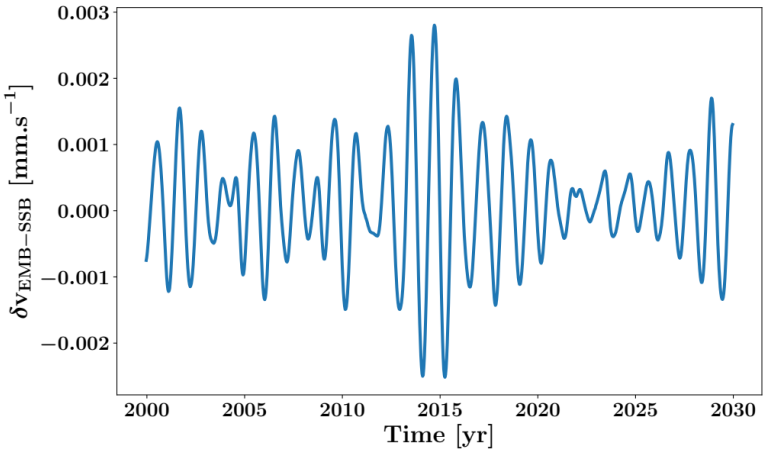


➡ Numerical integration of planetary motion fitted to the observational data

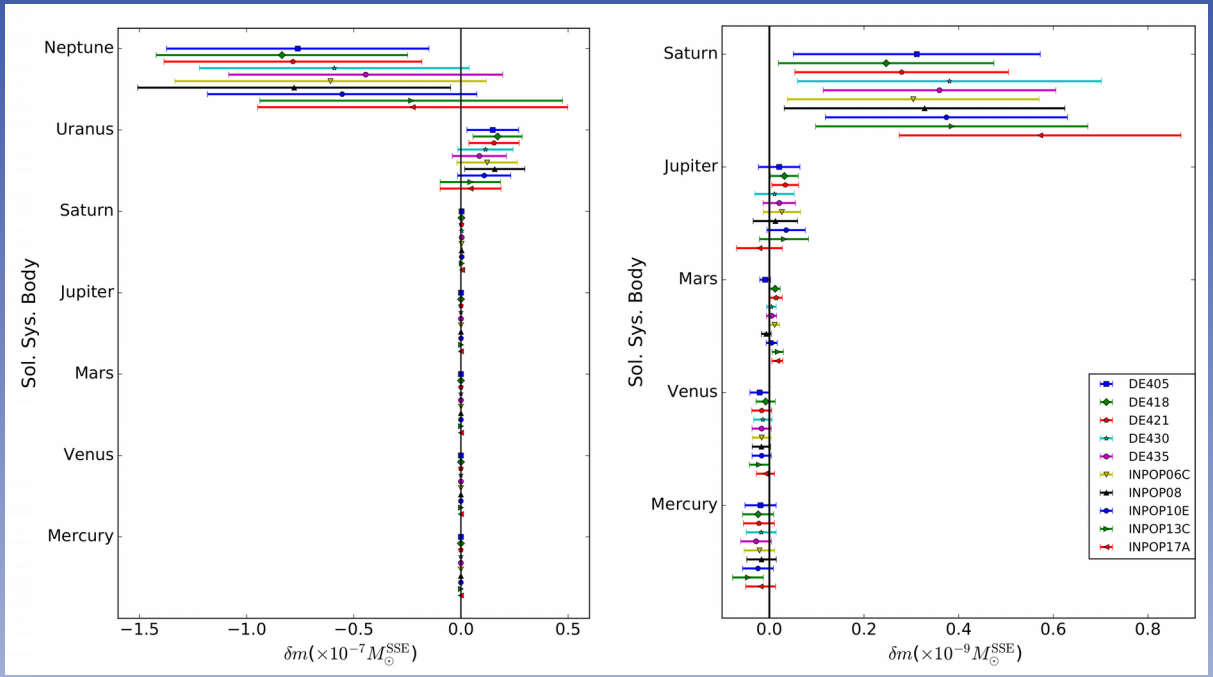
➡ SSE produced by JPL, IMCCE, ….

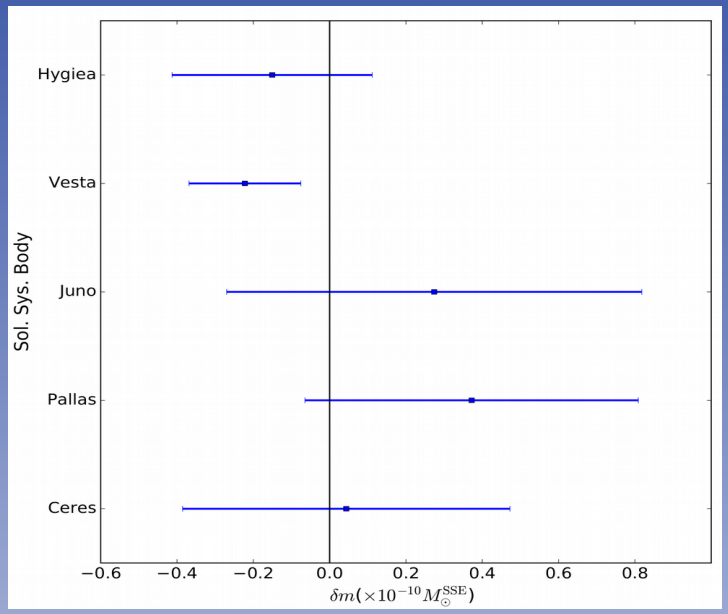
INPOP17a vs. DE436

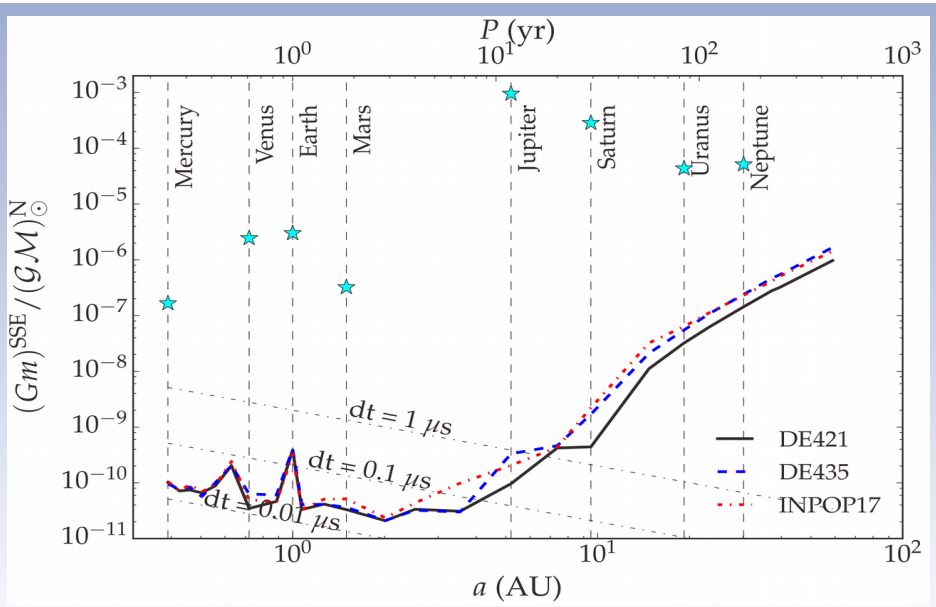




A possible study : use PTA to constraint SSEs







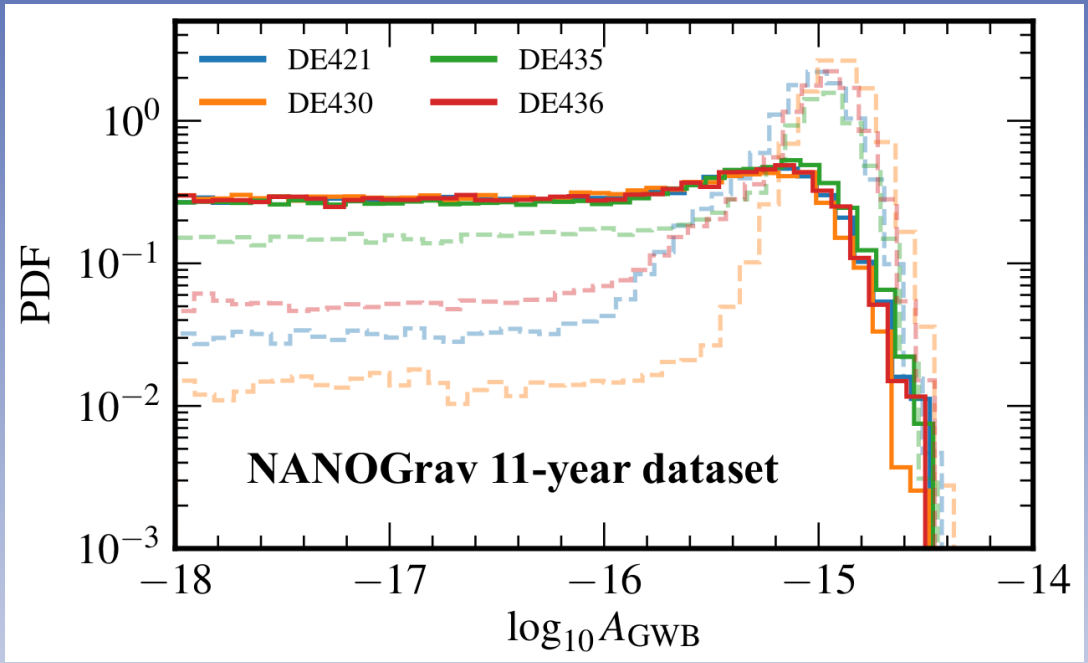
- Mass constraints :
  - Planetary systems
  - Asteroid-belt objects
- Limits on unmodelled object masses
- ULs on putative exotic object mass

cf. Caballero et al. 2018

Impact of SSEs on PTA results

Systematic biases larger than the statistical uncertainty of the limits

SSE errors can mimic a GWB signal !



➡ **BAYESEPHEM** model (11 parameters) to marginalize A_{GWB} over ephemeris uncertainties

➡ GWB constraint gets robust against SSE errors

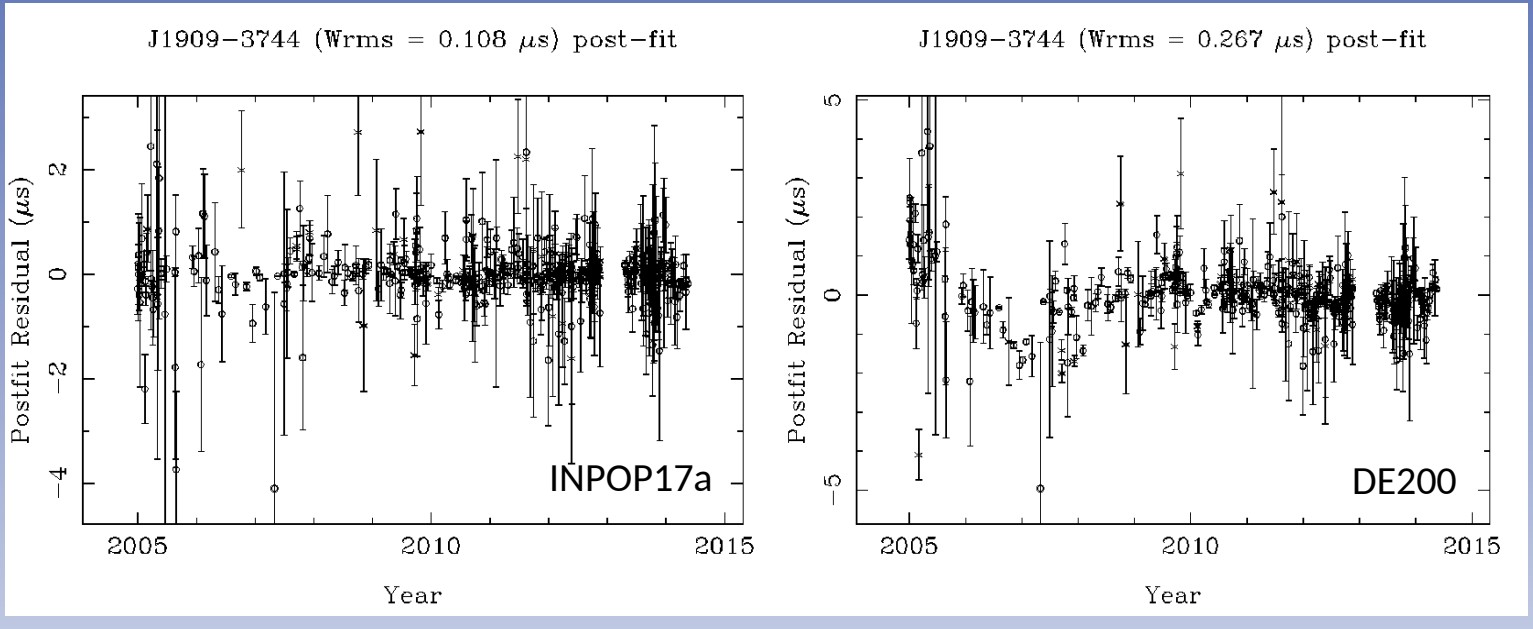
➡ **Problem : Modelling SSE errors can absorb some of the GWB signal**

cf. Arzoumanian et al. 2018

Impact of SSEs on PTA results

Characterization of the impact of SSE errors

Using **INPOP** data with a direct expert support (cf. **A. Fienga** (Géoazur))



- Production of perturbated SSEs
- Input perturbated SSEs in timing process
- Same for the full GWB search process

Impact of SSEs on PTA results

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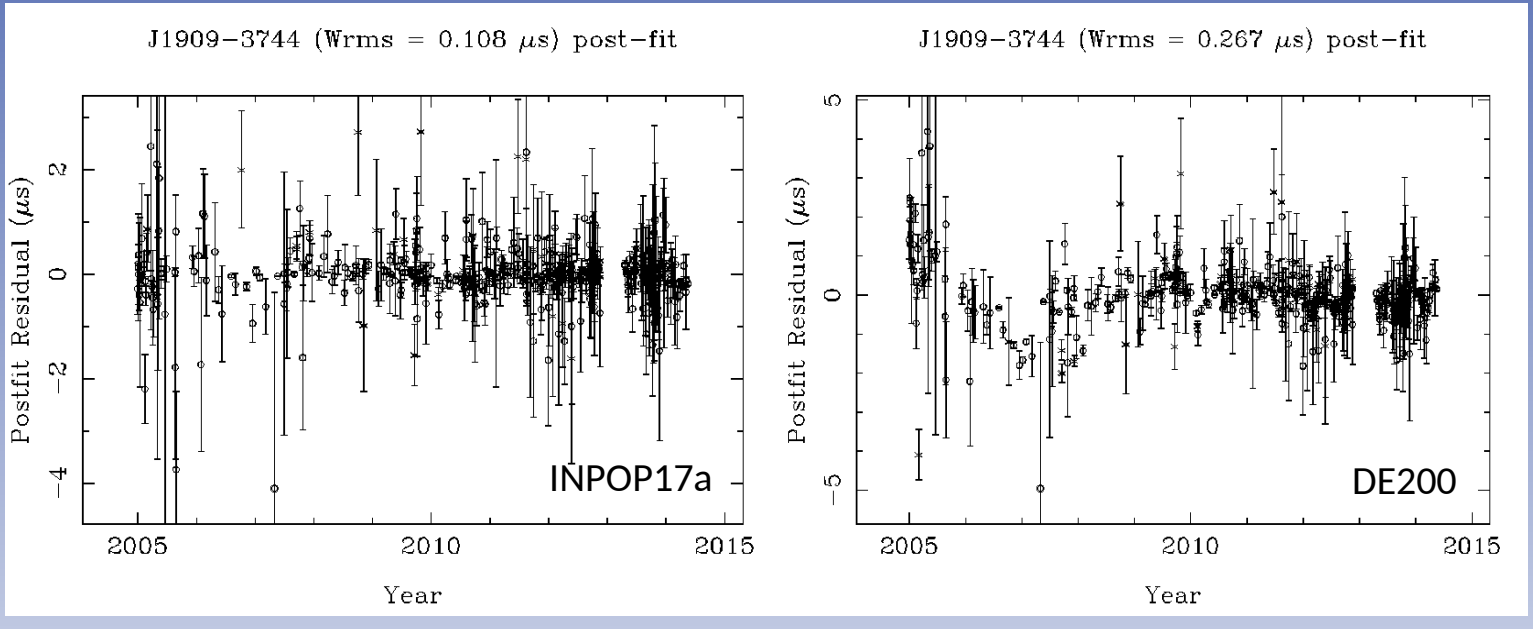

- Production of perturbated SSEs ✓
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Impact of SSEs on PTA results

Production of perturbated SSEs

$$\vec{x}_{new}(\vec{\theta}) = \vec{x}_{ref}(\vec{\theta}) + \frac{\partial \vec{x}_{ref}(\vec{\theta})}{\partial \vec{\theta}} \delta\vec{\theta}$$

Reference (P,V)

$\vec{x}_{ref}(\vec{\theta})$

Partial matrices

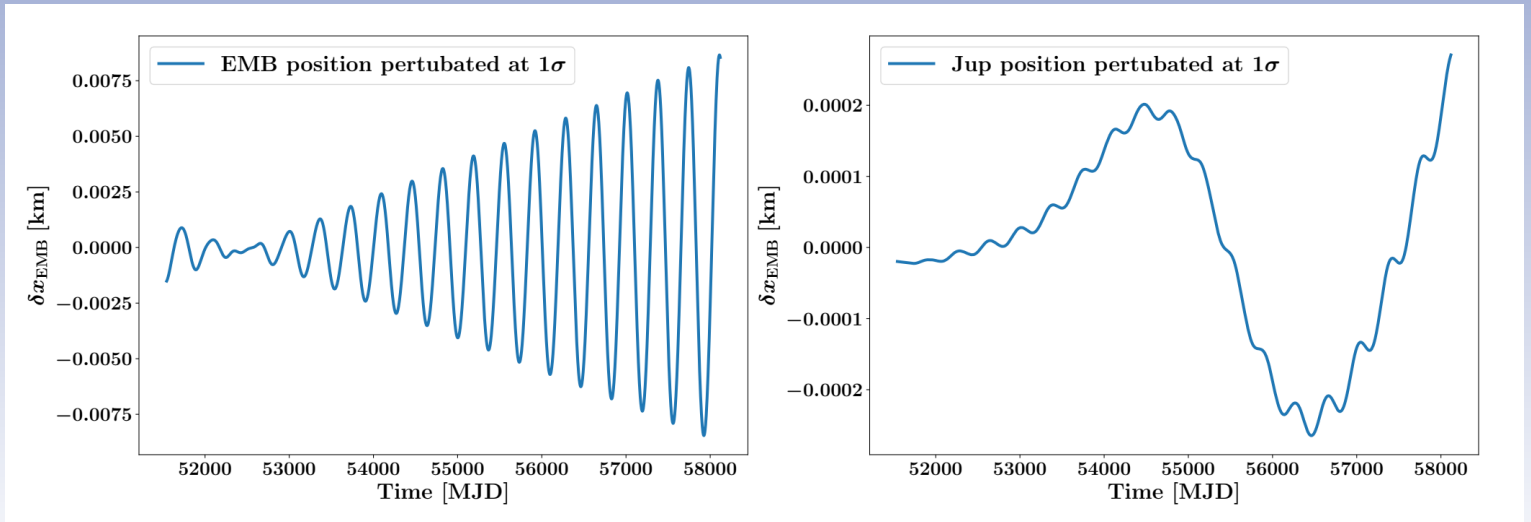
$\frac{\partial \vec{x}_{ref}(\vec{\theta})}{\partial \vec{\theta}}$

Covariance matrix

$\delta\vec{\theta}$

Orbital elements

$$\vec{\theta} = \begin{pmatrix} a \\ l \\ k(e,\pi) \\ h(e,\pi) \\ q(I,\Omega) \\ p(I,\Omega) \end{pmatrix}$$



Conclusion

- PTA sensitivity limited by SSE imperfections
- **BAYESEPHEM** corrects SSE systematics but could subtract the sensitivity
  - ➔ Essential to characterize properly the impact on PTA results
- Perturbated SSE produced thanks to A. Fienga – PTA-France group collaboration
- Next steps :
  - ➔ Study the effects on timing residuals and pulsar parameters
  - ➔ Characterize properly the effects on GW search results