

Lastest news from the pulsar in a triple system J0337+1755 as seen from Nançay

Guillaume Voisin, LUTh, Observatoire de Paris

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With Ismaël Cognard and Lucas Guillemot (LPC2E / OSUC
Orléans), Paulo Freire and Norbert Wex (MPIfR Bonn)



Introduction

Publication of the discovery of J0337+1755 by Ransom et al. (2014)

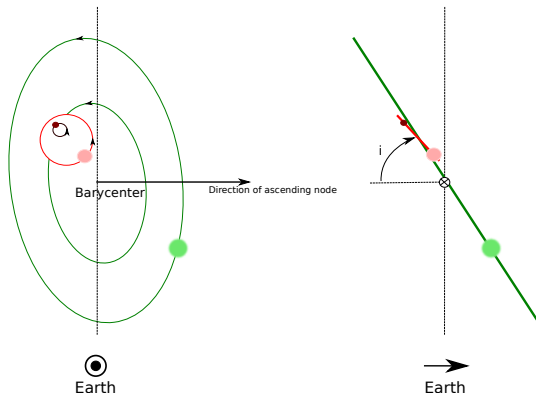


Figure : Sketch of the orbits. The neutron star is the smallest of the bodies but the heaviest so has a smaller amplitude of motion. Together with the closest (red) white dwarf they form the inner system. To a good approximation this one can be considered as a body orbiting the outer (green) white dwarf to form the outer system.

Some characteristics (from Ransom et al. (2014)) :

- ▶ Spin period : 2.7 ms; Magnetic field : 10^8 Gauss
- ▶ Masses : $1.43 M_{\odot}$ (pulsar), $0.2 M_{\odot}$ (inner WD), and $0.4 M_{\odot}$ (outer WD).
- ▶ Periods : 1.6 days (inner system), 327 days (outer system)
- ▶ Eccentricities : $7 \cdot 10^{-4}$ (inner), $3 \cdot 10^{-2}$ (outer)
- ▶ Semi-major axes for the pulsar : 1.9 ls (inner), 118 ls (outer)
- ▶ Inclination on the sky : 39°

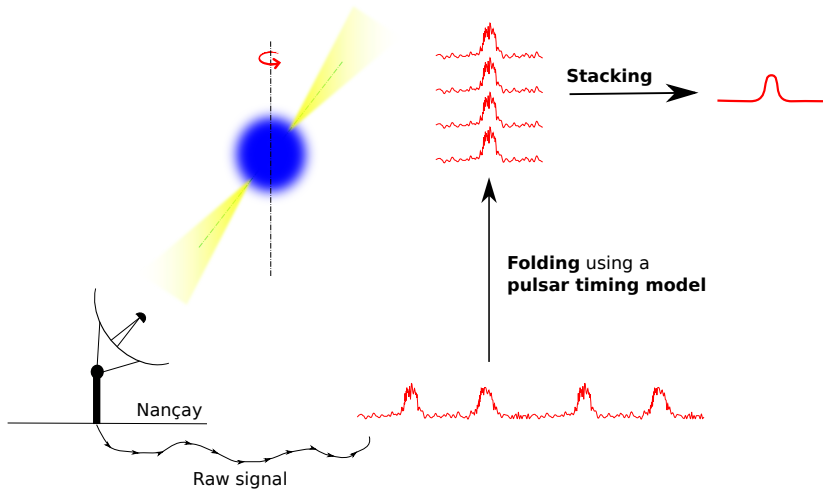


Figure : Principle of pulsar timing

PSR J0337+1715 est un système triple. Par conséquent, **il est impossible d'obtenir une description à long terme de la rotation du pulsar avec des méthodes "classiques"** (cf. exemple d'observation contenant une **dérive temporelle, page suivante**).

Besoin d'échantillonner la rotation du pulsar avec une grande résolution temporelle. À Nançay : un TOA (temps d'arrivée d'impulsion radio) toutes les 10 minutes.

À cause des dérives temporelles intra-observations, il est difficile d'intégrer les observations pour produire des impulsions de référence ("templates"). La précision des TOAs est dégradée, jusqu'à ce qu'un intégrateur numérique fonctionne pleinement.

Exemples de TOAs de Nançay à 1,4 GHz, enregistrés toutes les 10 minutes :

```
nuppi_57409_0337+1715 1484.000 57409.788070830108979 0.825 f -i NUPPI -r ROACH -bw 512
nuppi_57409_0337+1715 1484.000 57409.794758191890002 0.741 f -i NUPPI -r ROACH -bw 512
nuppi_57409_0337+1715 1484.000 57409.801452034988739 0.754 f -i NUPPI -r ROACH -bw 512
nuppi_57409_0337+1715 1484.000 57409.808158084487653 0.805 f -i NUPPI -r ROACH -bw 512
```

0337+1715 /NEWnuppi/archives-calibrated/nuppi_57409_0337+1715_211398.calibP.zap
Freq: 1484.000 MHz BW: 512.000 Length: 4038.817 S/N: 147.070

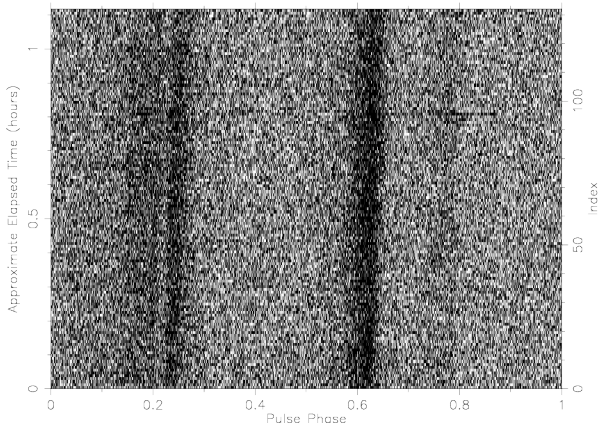


Figure : Exemple d'observation de J0337+1715 à Nançay, présentant une dérive temporelle.

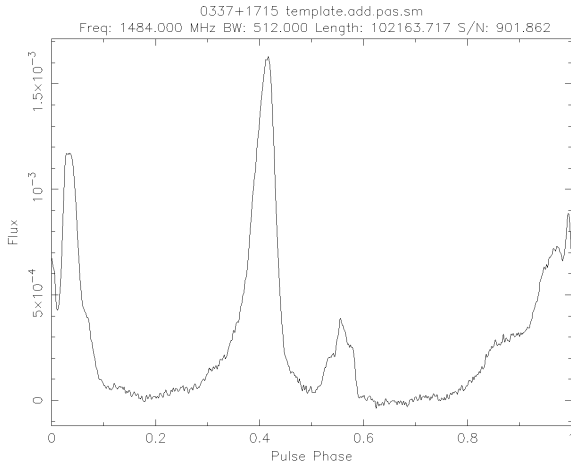


Figure : Impulsion moyenne de référence obtenue par addition d'environ 28h de données, utilisée pour déterminer les temps d'arrivée de J0337+1715.

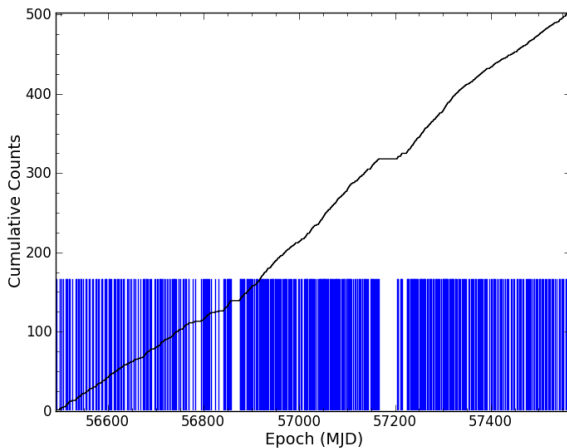


Figure : Observations de J0337+1755 à Nançay en fonction du temps. Depuis juillet 2013, le pulsar a été observé 500 fois environ, avec une cadence moyenne de 14 observations par mois !

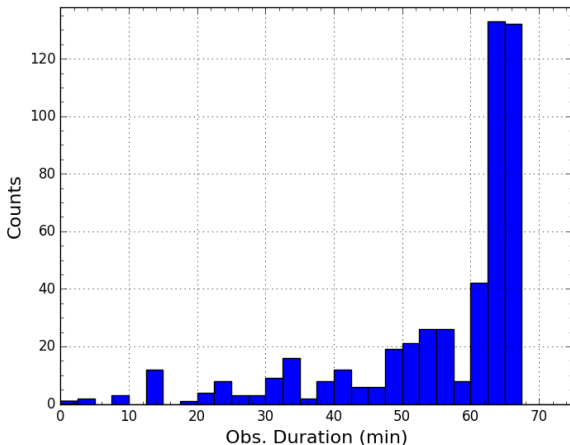


Figure : Histogramme des durées d'observation de J0337+1715 à Nançay. Le pic entre 60 et 70 minutes correspond à la durée maximale réalisable au grand radiotélescope de Nançay, télescope méridien.

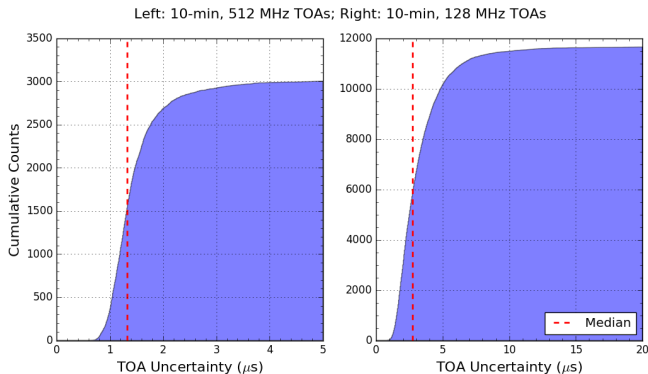


Figure : Histogrammes cumulatifs des incertitudes sur les TOAs individuels, pour les observations de J0337+1755 à Nançay à 1,4 GHz. A gauche, un TOA est enregistré toutes les 10 minutes, pour la totalité de la bande de 512 MHz. A droite, la bande est divisée en quatre sous-bandes de 128 MHz (ce qui permet de contraindre la mesure de dispersion DM).

A timing model for J0337+1755

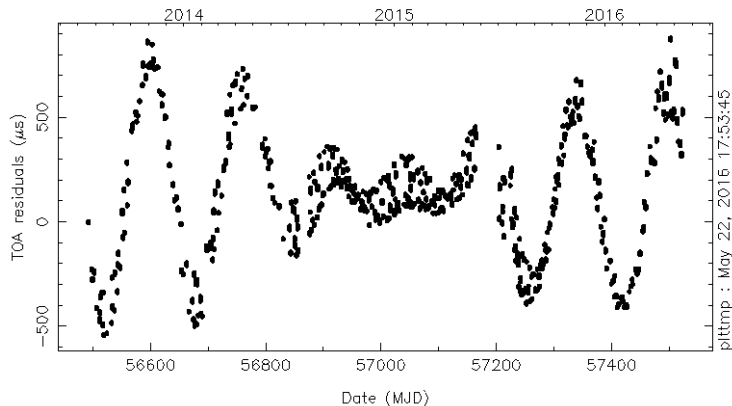


Figure : Residuals of the BTX model applied to the last-to-date Nançay data, that is the difference between the time of arrivals (TOAs) predicted by the model and the measured times.

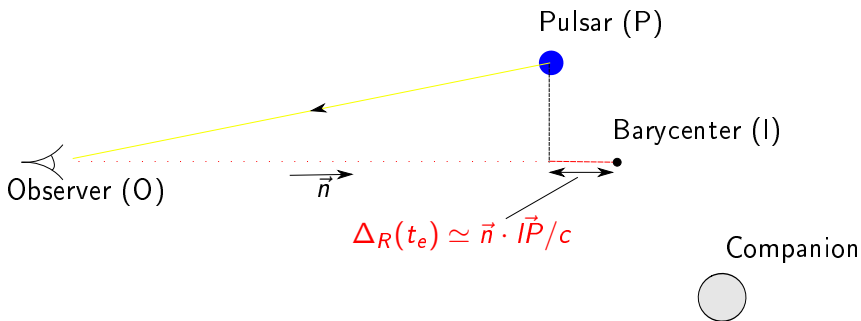
Timing model

▶ Solve for 3-body motion

There are numerous delays :

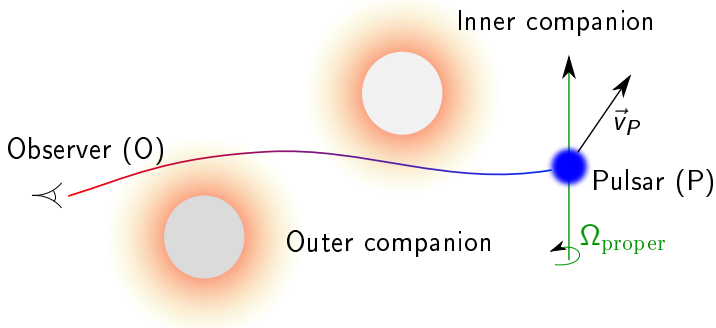
- ▶ **Rømer delay** : geometrical delay due to the propagation of light
- ▶ **Einstein delay** : time dilation due to speed and/or gravitational fields.
- ▶ **Shapiro delay** : light bending and slowing down due to companions.
- ▶ ~~Tidal delays~~ : ~~due to tidal interactions~~
- ▶ **Position and proper motion effects** : Kopeikin terms (Kopeikin (1995), Kopeikin (1996)), Schklovskii effect...

The **Rømer delay** is the variation of distance between the observer and the pulsar when it orbits one or several companions



t_e : time of emission in the frame of the observer

The Einstein delay is variation of time dilation due to speed and companion gravitational potential variations.



The Shapiro delay is due to the gravitational potential along the light path.

Result of the model

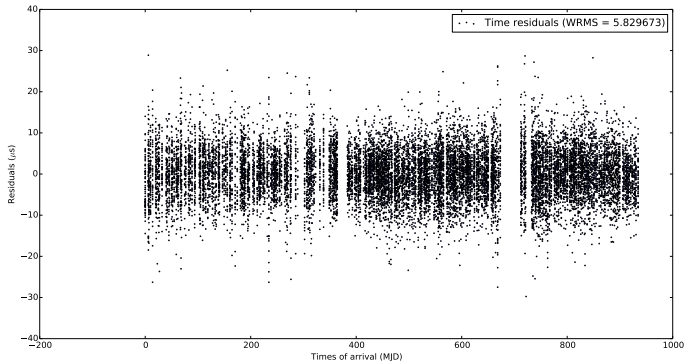


Figure : Best timing residuals obtained so far including Rømer, Einstein and Shapiro delays, position and proper motion effects. It includes ~ 16600 TOAs from Nançay spanning over ~ 900 days.

Conclusion

Conclusion

- ▶ Although there was no good timing model, **Nançay was able to time J0337+1755 for the past 1000 days with great accuracy : a few microseconds!**
- ▶ **A specific timing model has been developed**, solving for three body motion.
- ▶ Currently, the last refinements are being implemented to carry out a test of the strong equivalent principle. Preliminary results are promising!

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