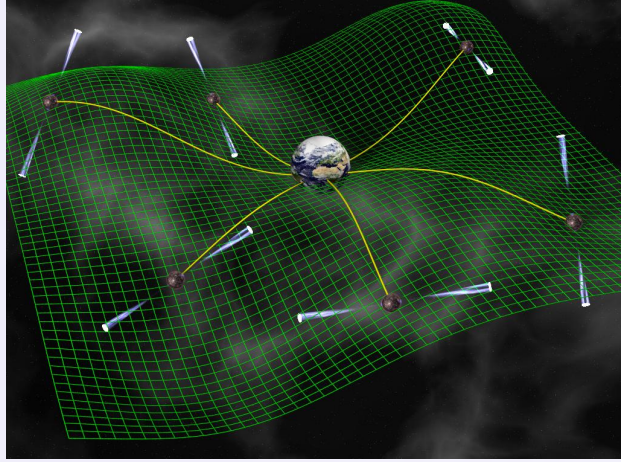


Peculiar results of long-term millisecond pulsar timing

The European Pulsar Timing Array

Gemma Janssen – ASTRON, The Netherlands

In collaboration with:

Cees Bassa, James McKee, Ben Stappers

Thomas Tauris, Lindley Lentati,

EPTA timing/observing working groups

What is required for a PTA GW detection?

- Detecting gravitational waves requires:
  - Long-term stable pulsars
  - Timing models that include “all” non-GW effects
  - Understanding of “other” red noise processes in the timing data

- What do we need for that:
  - A lot of MSPs
  - A lot of observing time
  - A lot of TOAs
  - Checks across instruments, pulsars, etc

EPTA Data Release 1: 42 millisecond pulsars

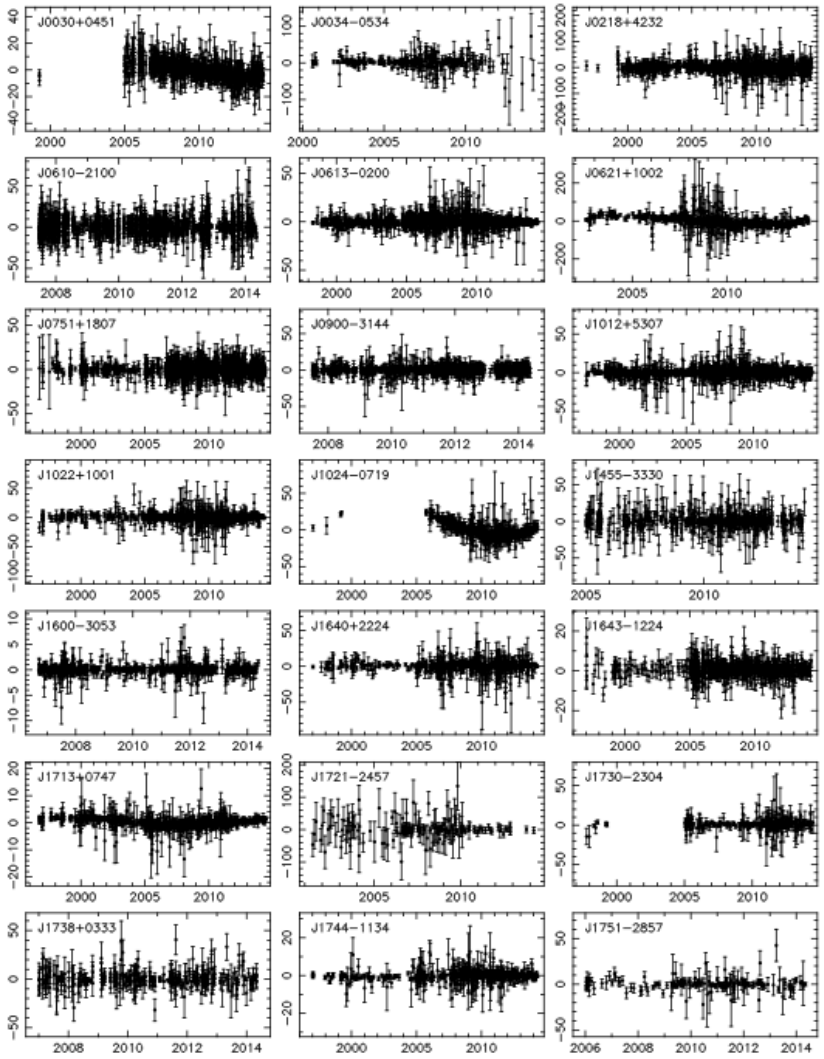


Figure A1. Timing residuals in microseconds (y-axis) for the first 21 pulsars as a function of time in years (x-axis). The plots show the multifrequency residuals after subtracting the contribution from the DM model. The red noise seen in the timing residuals of PSRs J0030+0451 and J1024−0719 will be discussed by Caballero et al. (2015).

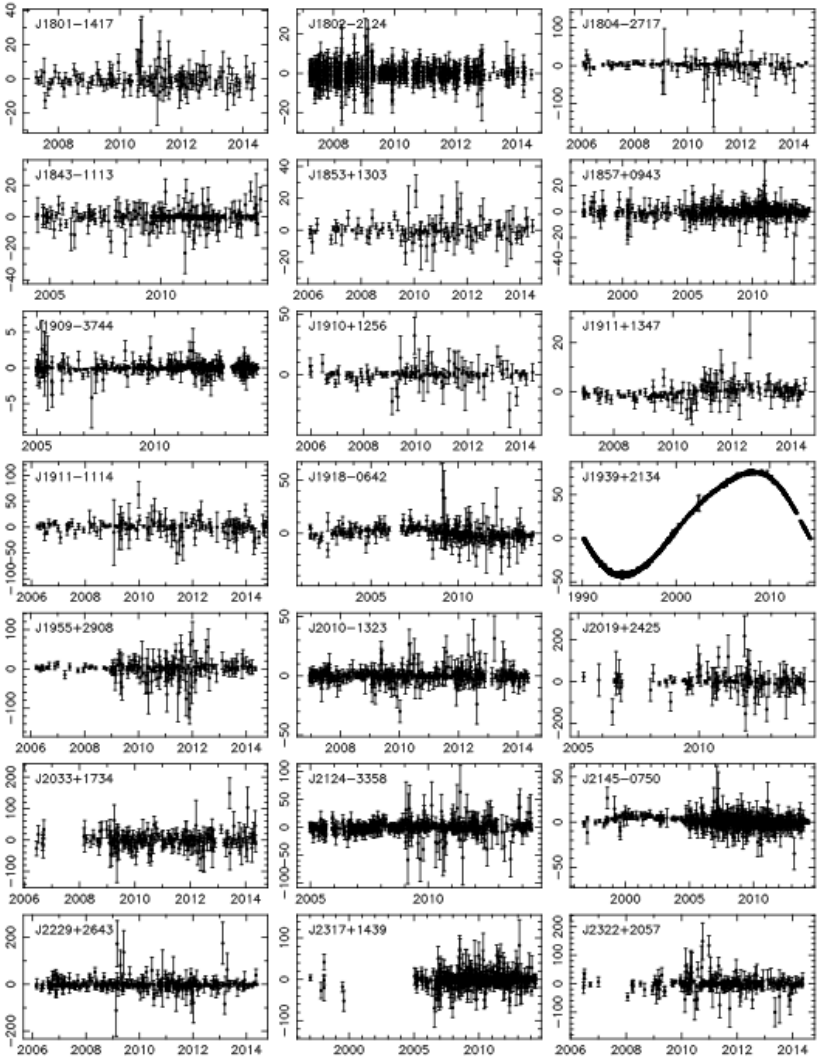
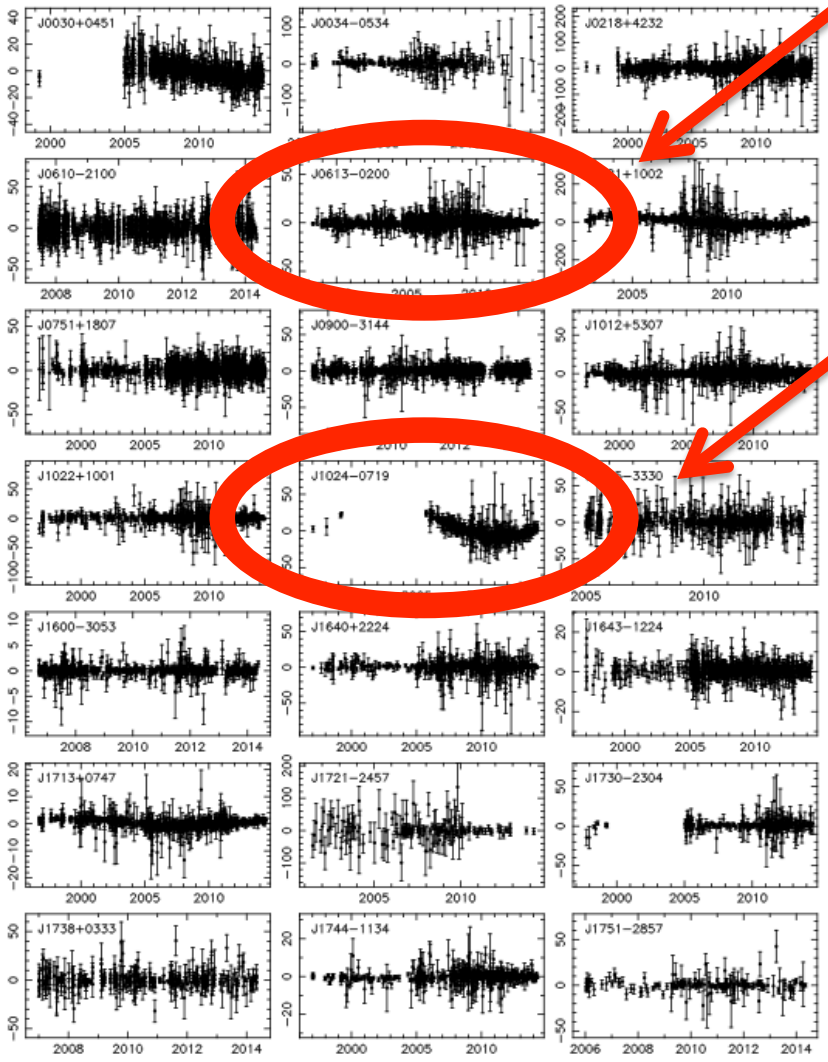


Figure A2. Same caption as Fig. A1 for the last 21 MSPs. The large amount of red noise seen in the timing residuals of PSR J1939+2134 will be discussed by Caballero et al. (2015).

Desvignes et al. 2016, MNRAS 458, 3341, EPTA data release: 42 pulsars

Two interesting cases: J0613-0200 and J1024-0719



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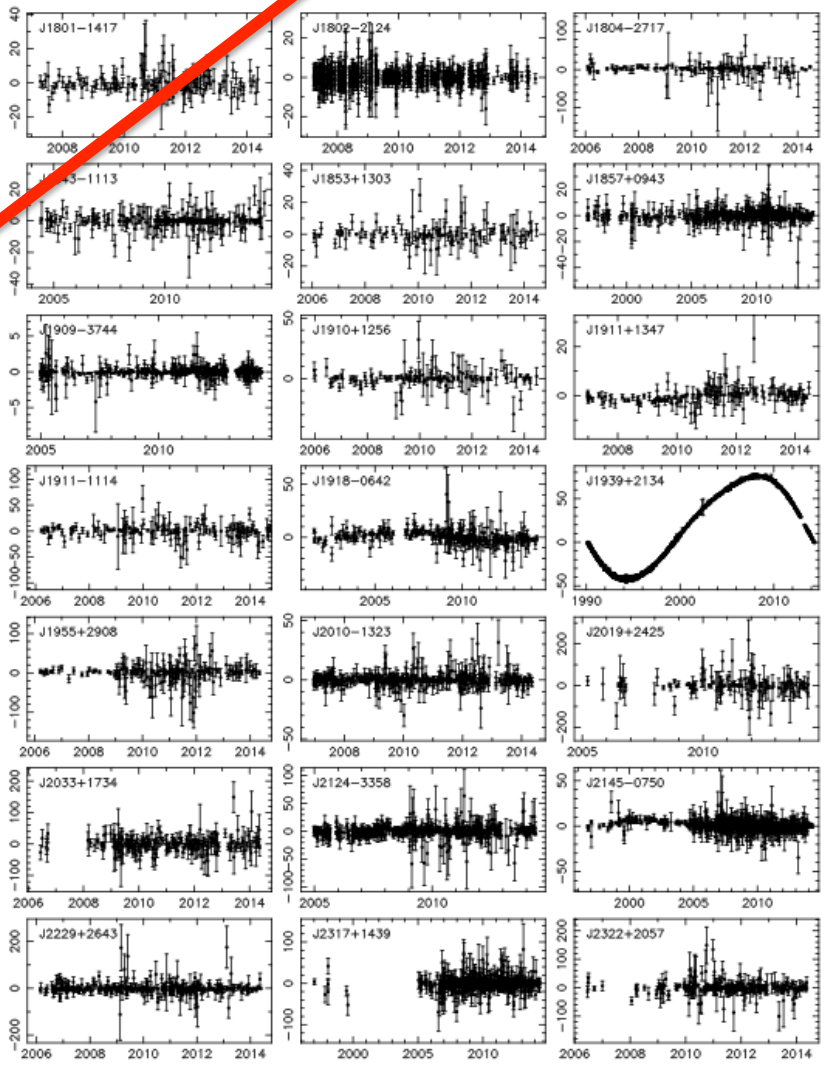

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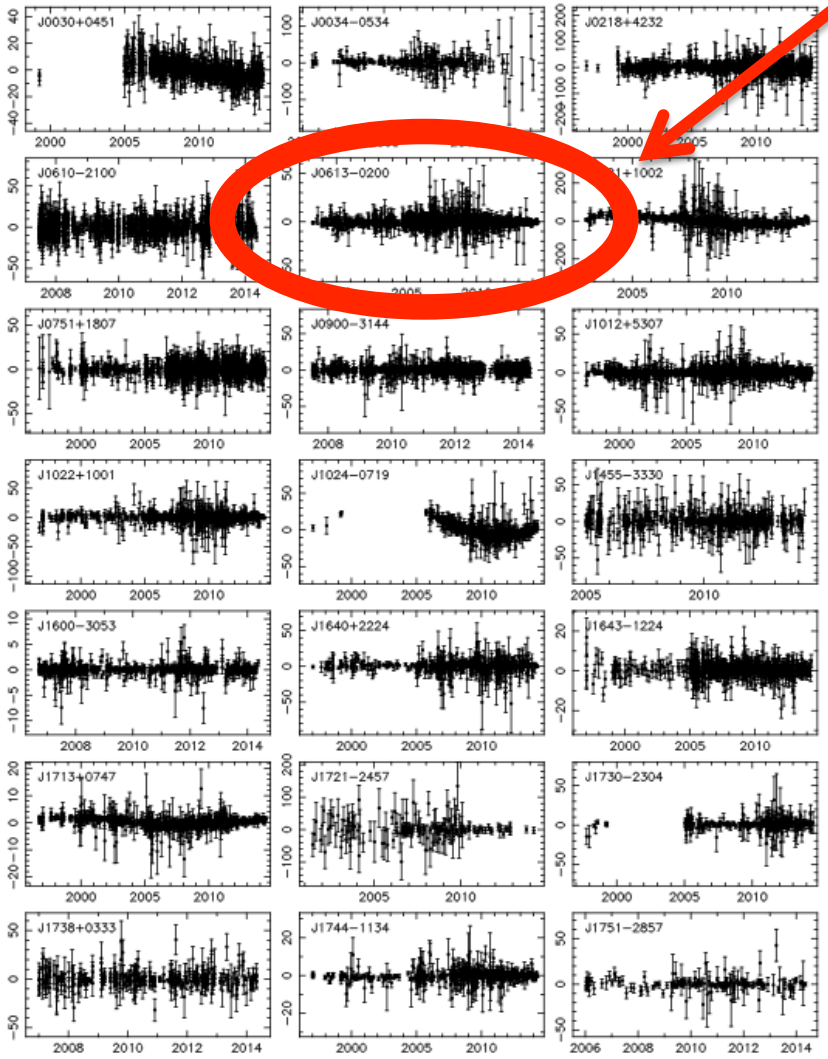

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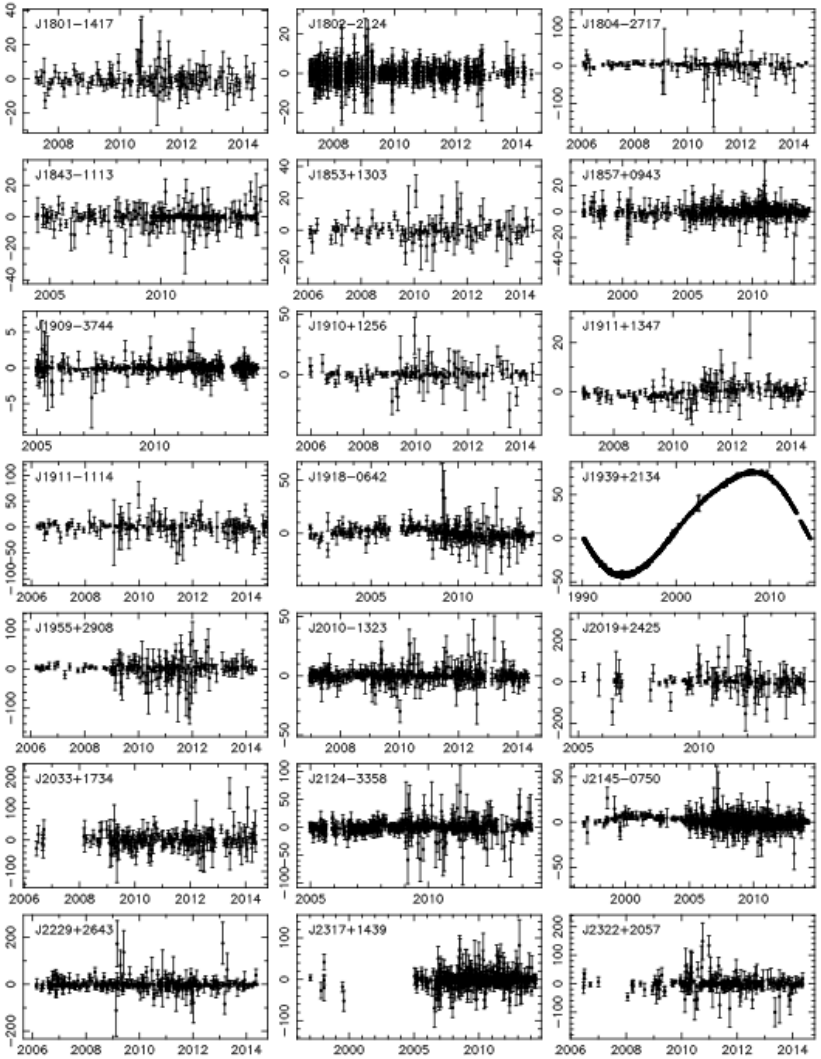

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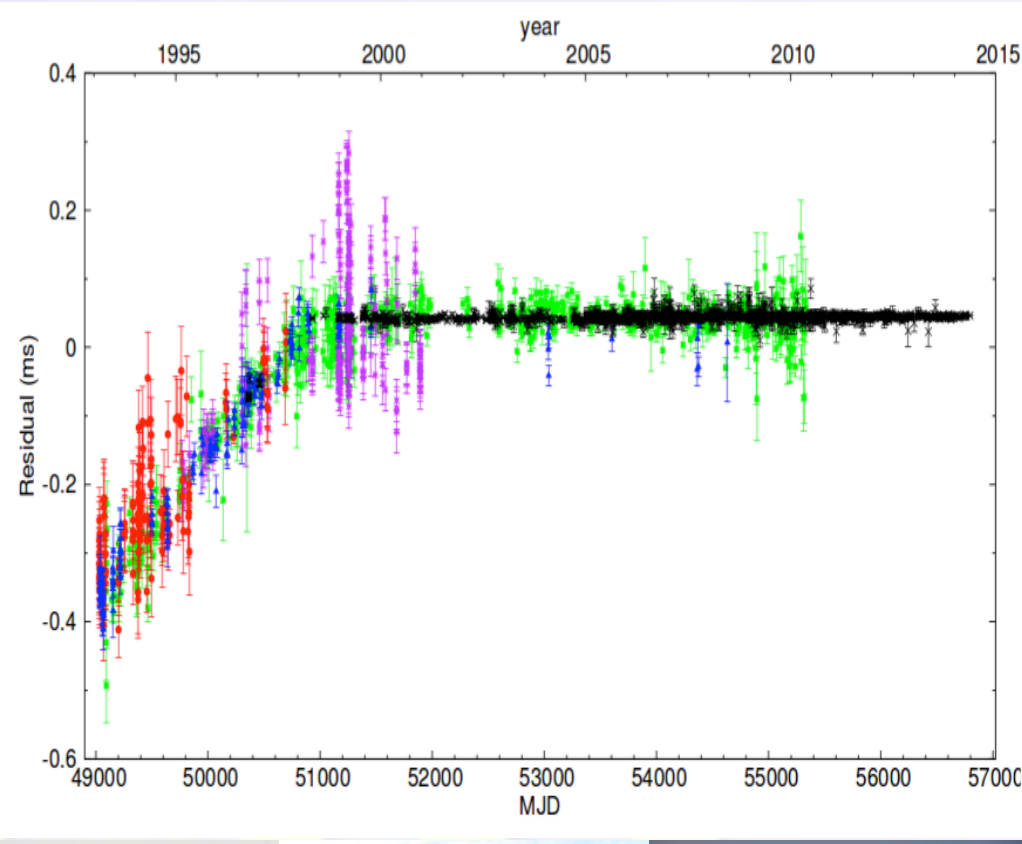
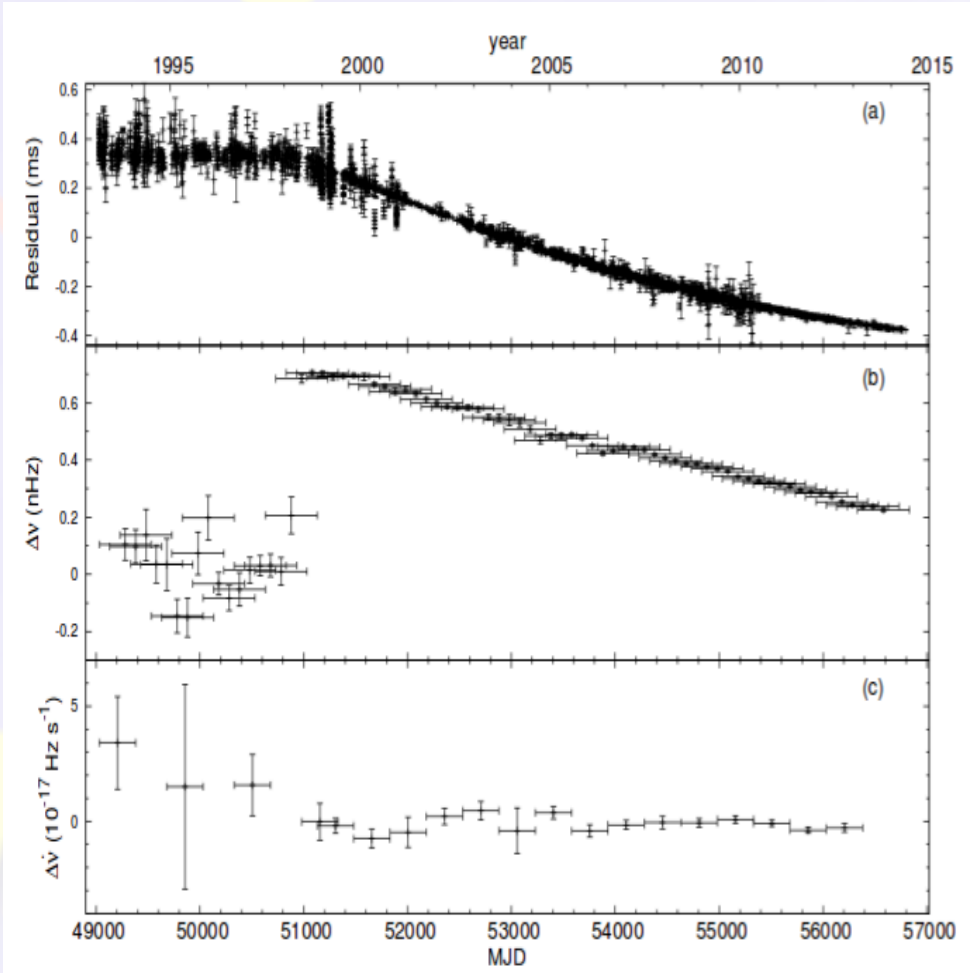
PSR J0613-0200: a very stable MSP

- One of our most stable pulsars
- Included in all PTAs
- DR1 ephemeris did not accurately model pre-DR1 TOAs
- TOAs at frequencies of 400-1410 MHz affected identically -> not ISM
- Multiple backends affected identically -> not instrumentation/clock
- Must be caused by a process intrinsic to the pulsar
- Conclusion: a small glitch



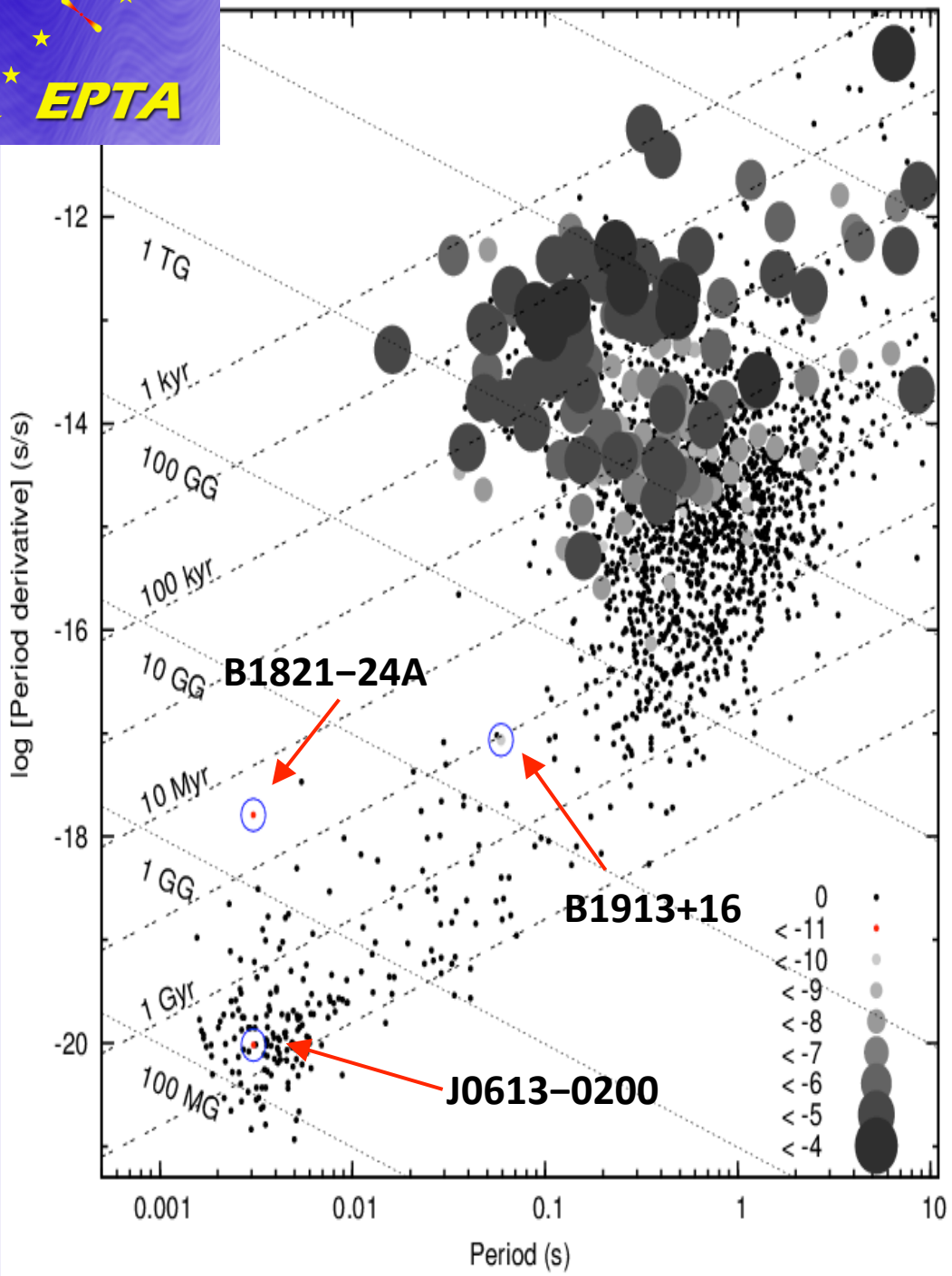
PSR J0613-0200: a very small glitch

- $\Delta\, \nu/\nu = 2.5(1) \times 10^{-12}$
- $\Delta\, \dot{\nu} = -1.6(39) \times 10^{-19}$ Hz s^{-1}
- Epoch = MJD 50888(30)
- Glitch = spin-up of NS
- Mostly in young pulsars, only 2 in recycled pulsars
- Unique tool to probe NS interior
- Potential GW source



Compare with other glitches

$$\text{cumulative frequency change} = \log\left(\sum \frac{\Delta\nu}{\nu}\right)$$



- Recycled pulsar glitches immediately stand out
- Glitch in J0613-0200 the smallest ever detected
- The only one in a PTA pulsar

Glitch: Relevance for PTAs

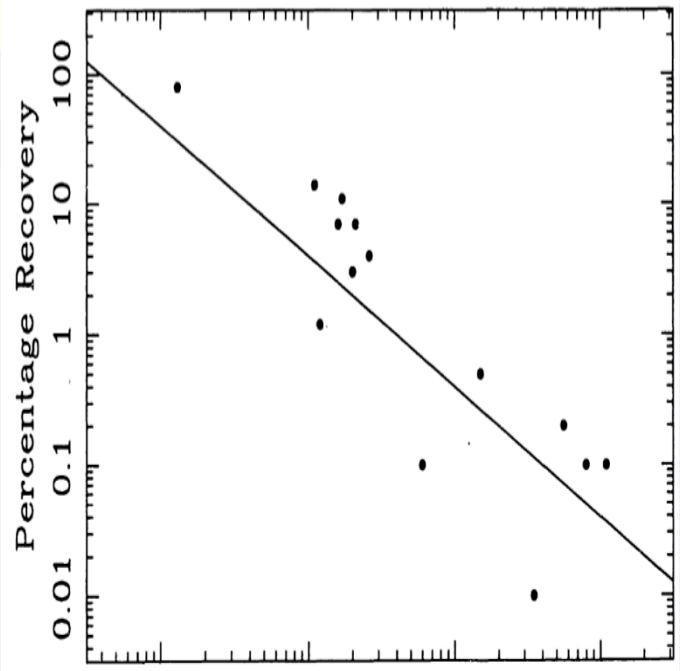
- GW detection prospects
  - Pulsars in a PTA must have extremely stable rotations and accurate timing models -> Reason for caution?

- Caballero et al. (2016) J0613−0200 timing noise
  - TOAs from the post-glitch epoch
  - Glitch is small
  - Red noise in the pulsar is not well-defined
    - Glitch probably not the source of timing noise
    - Any glitches smaller than this should also have been detectable

- Future glitches
  - Pre-glitch data would still be useable
  - Glitch can be modelled after a while

Glitch: Alternative explanations

- Proposed explanations:
  - Evidence for strange star
    - Small glitch
    - Indistinguishable from normal glitch
  - Gravitational wave memory burst
    - Affects pulsar term
    - Looks like a glitch, with no recovery
    - No F1 step
- Credible?
  - Strange star: not easy to confirm, but possibility
  - Memory burst: requires ~10^{10} $M_\odot$ edge-on SMBHB merger
    - Unrealistic (ruled out by e.g. Babak et al. 2016)



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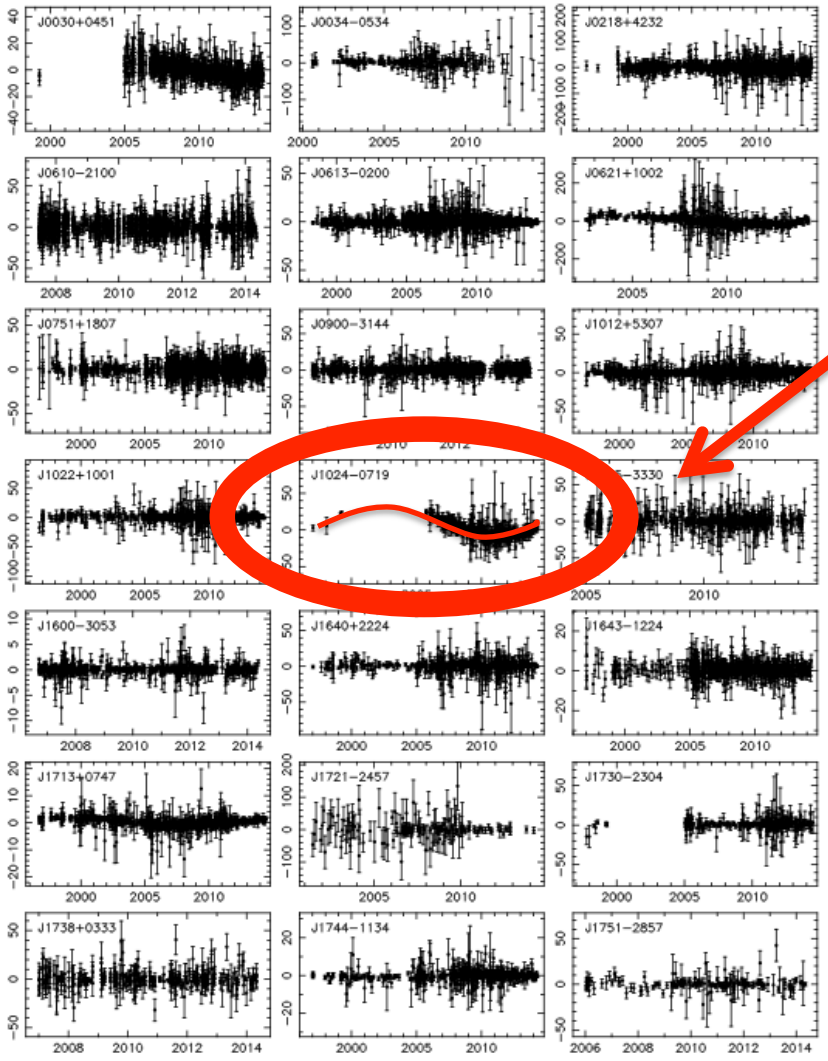

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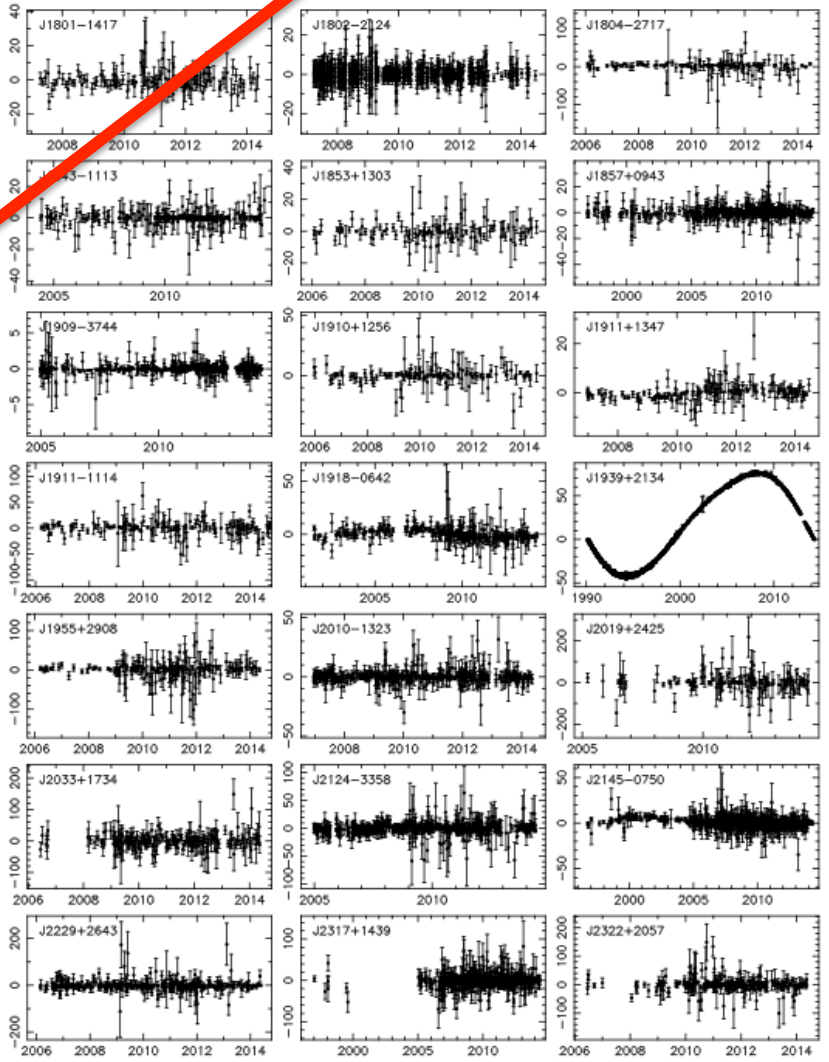

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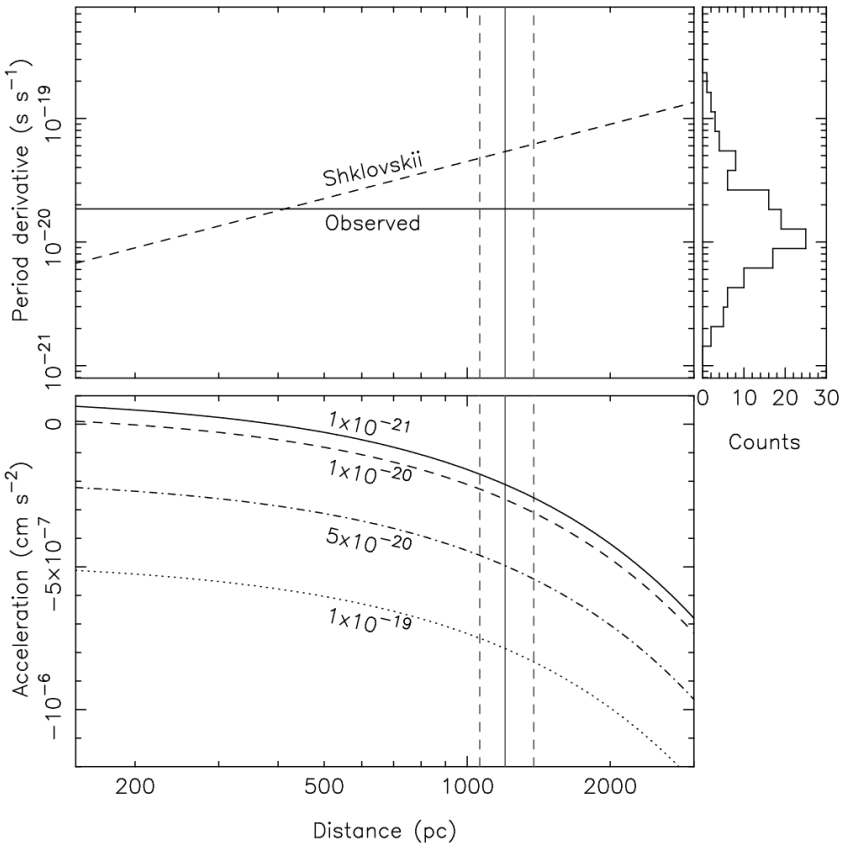
PSR J1024-0719: a MSP with large red noise

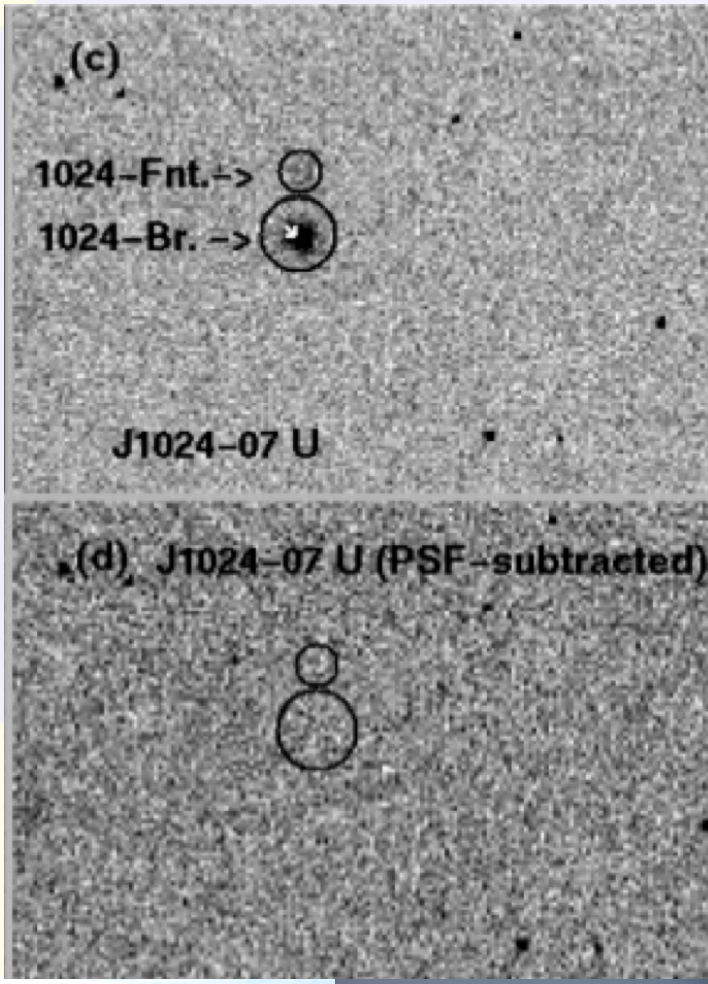
- Isolated MSP
- Red noise seen in timing residuals: Second spin derivative way too high for a normal braking index: extrinsic variable acceleration
- Desvignes et al., Matthews et al. PM and distance are incompatible with spindown: extra spindown is required



$$\dot{P}_{obs} = \dot{P}_{int} + \dot{P}_{shk} \qquad \dot{P}_{shk} = P\mu^2 d/c$$

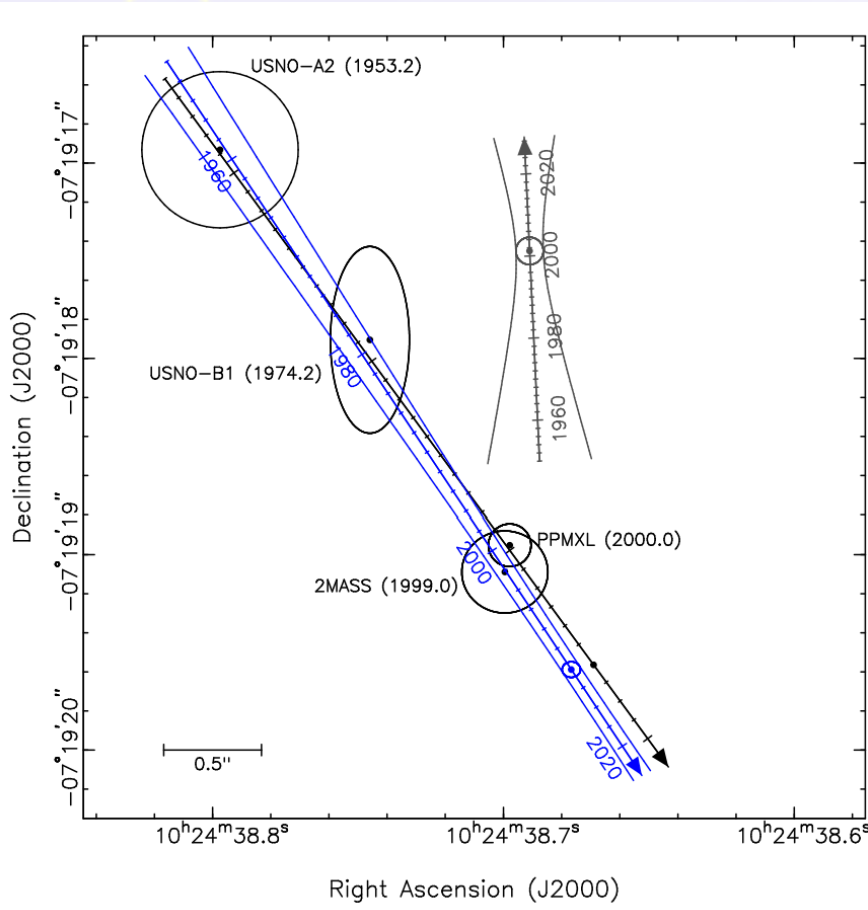
PSR J1024-0719: a MSP with large red noise

- Optical observations (Sutaria et al. 2003) show two stars near position of PSR J1024-0719:
- ‘B’ – bright; ‘F’ – Faint
- inconclusive for association



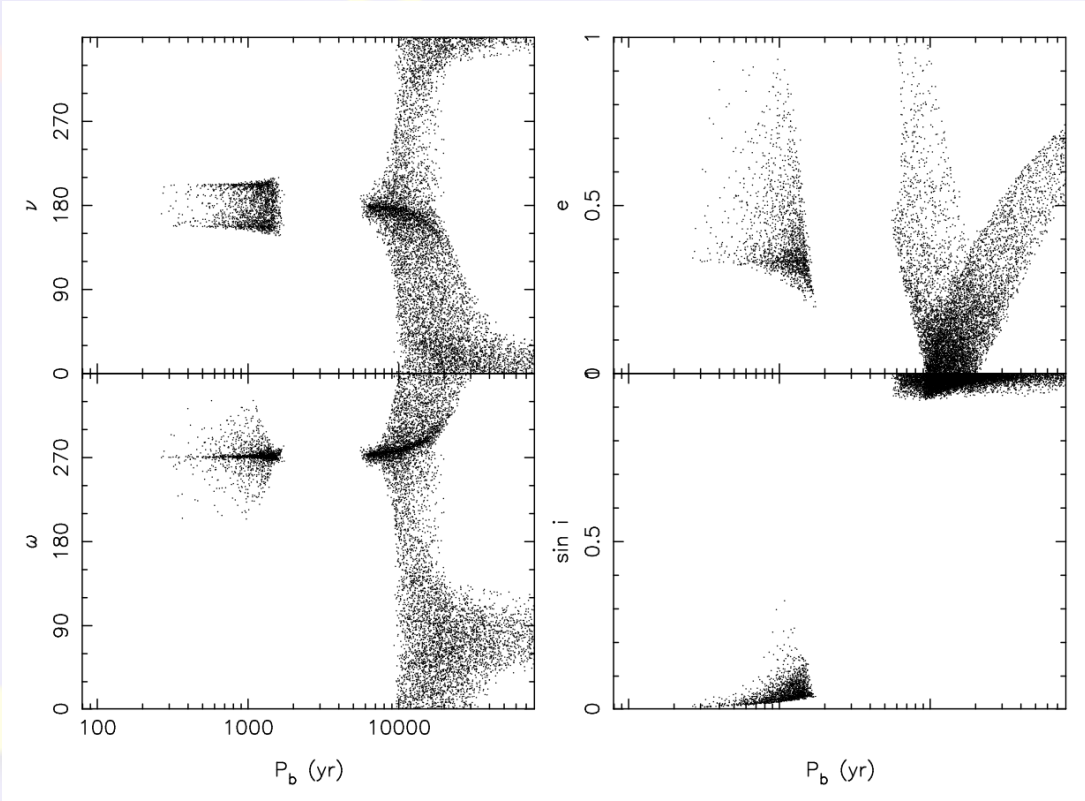
PSR J1024-0719: a MSP with large red noise

- New optical observations combined with archival data shows that star ‘B’
  - Has same position
  - Has same proper motion
- PSR J1024-0719 and Star ‘B’ form common proper motion pair – they are in a long-term binary
- Spectroscopy shows Star ‘B’ is a K5V star
- Problem for standard evolutionary scenarios



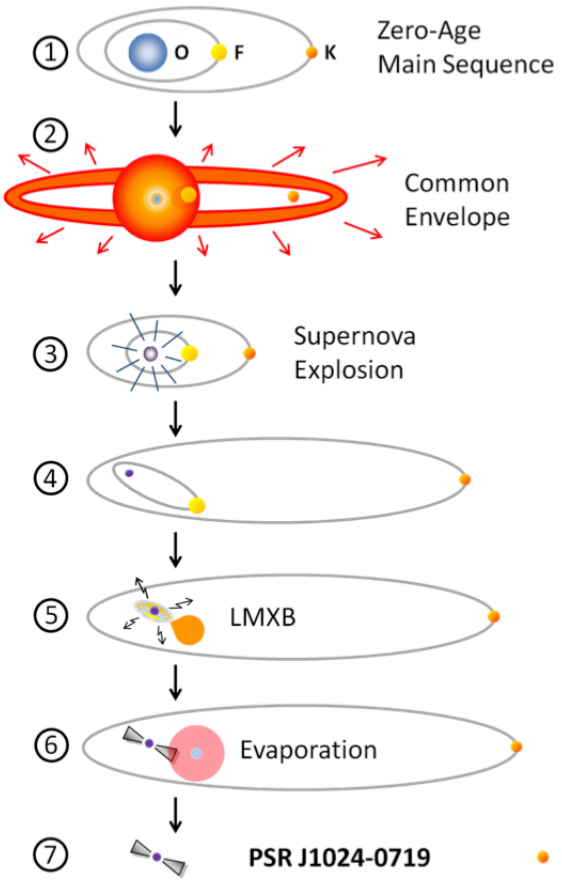
PSR J1024-0719: a MSP in a long-orbit binary

- Timing observations constrain the orbit
- F2 measured, limits on F3 -> reparametrize orbital parameters
- The orbital period is 100s to 1000s of years!



PSR J1024-0719: a MSP in a long-orbit binary

- MSP+ main sequence cannot have formed through standard evolutionary channels
- A) Triple; inner binary forms MSP, evaporates first companion, leaves MSP + K-star (Bassa et al. 2016)
- B) Globular Cluster origin; ejection from cluster through dynamical encounter (Kaplan et al. 2016)



Conclusions

- Several observational papers in last year following EPTA DR1.0
- We need to find out which pulsars are the most stable for a PTA
- Multi-telescope, multi-frequency, multi-wavelength observations are required to get the full picture
- Be prepared to find surprises: non-GW pulsar science is interesting

Thank you!

http://www.epta.eu.org -- http://www.leap.eu.org – http://www.ipta4gw.org

EPTA

Neutron Star Structure

Glitch energy budget:

$$\Delta E \sim \delta(I\nu^2) \sim I\nu^2 \left(\frac{\delta\nu}{\nu}\right) \sim E_{\rm rot}\left(\frac{\delta\nu}{\nu}\right)$$

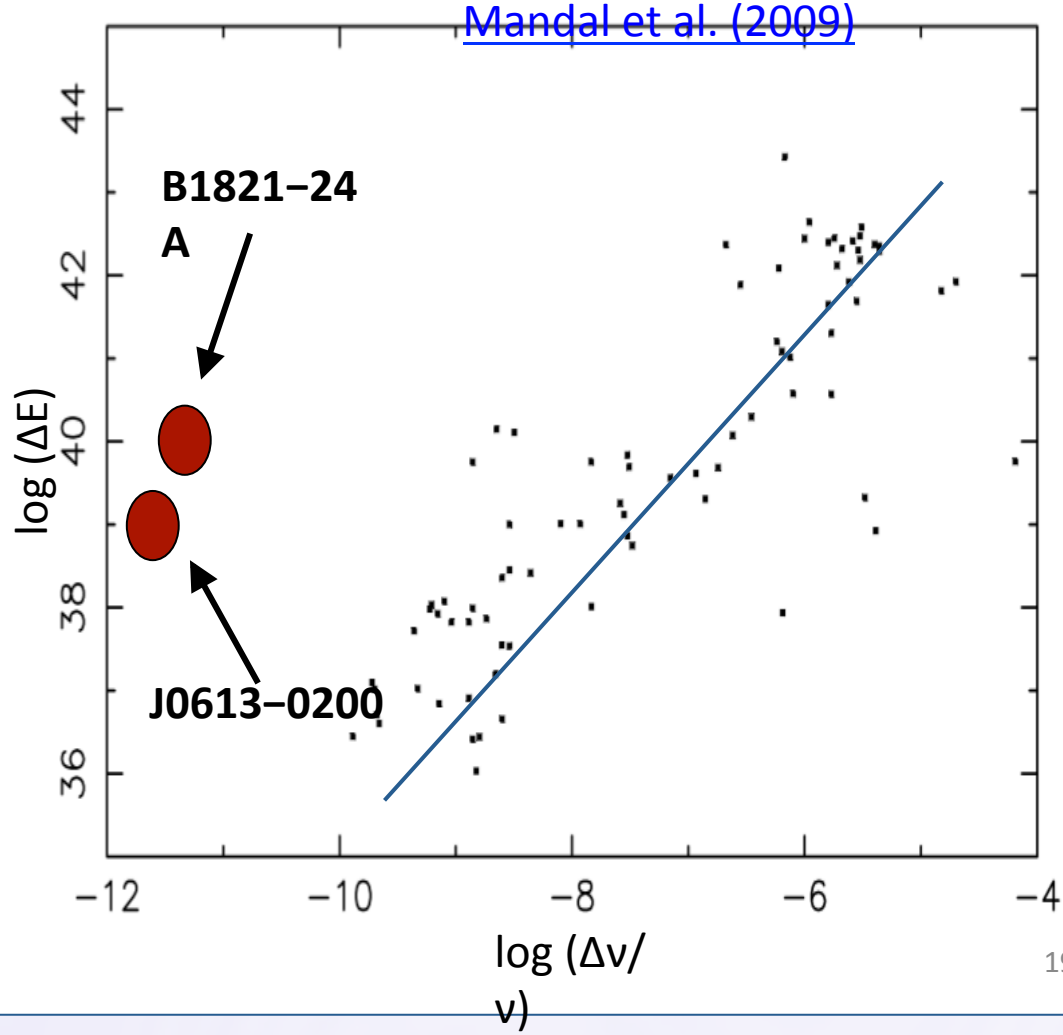
J0613−0200 **B1821−24A**

$\Delta E \sim 2 \times 10^{39}\,{\rm erg}$ $\Delta E \sim 10^{40}\,{\rm erg}$

Assuming $I = 10^{45}$ g cm^{-2} for <u>all</u> pulsars

Under this assumption, the two glitching MSPs do not follow the same trend as the general population

Figure from Mandal et al. (2009)



IPTA Glitch Probability

- What can we say about the probability of a glitch in a timing array pulsar in 10 years?
- Return rate *r* = years per glitch
- B1821−24A can be said to be untypical of the other IPTA pulsars (significant red noise, acceleration due to position in globular cluster)
- Probability of a glitch occurring in the next 10 years is not low

$$P(t) = 1 - \left(1 - r^{-1}\right)^{nt}$$

with B1821−24A	**without B1821−24A**
$r = 443\,\text{years}$	$r = 858\,\text{years}$
$P(10) \sim 70\%$	$P(10) \sim 50\%$