THE SPIN EVOLUTION OF YOUNG PULSARS

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PULSAR SPIN-DOWN

$$\dot{\nu} \propto \nu^n$$

n is the braking index

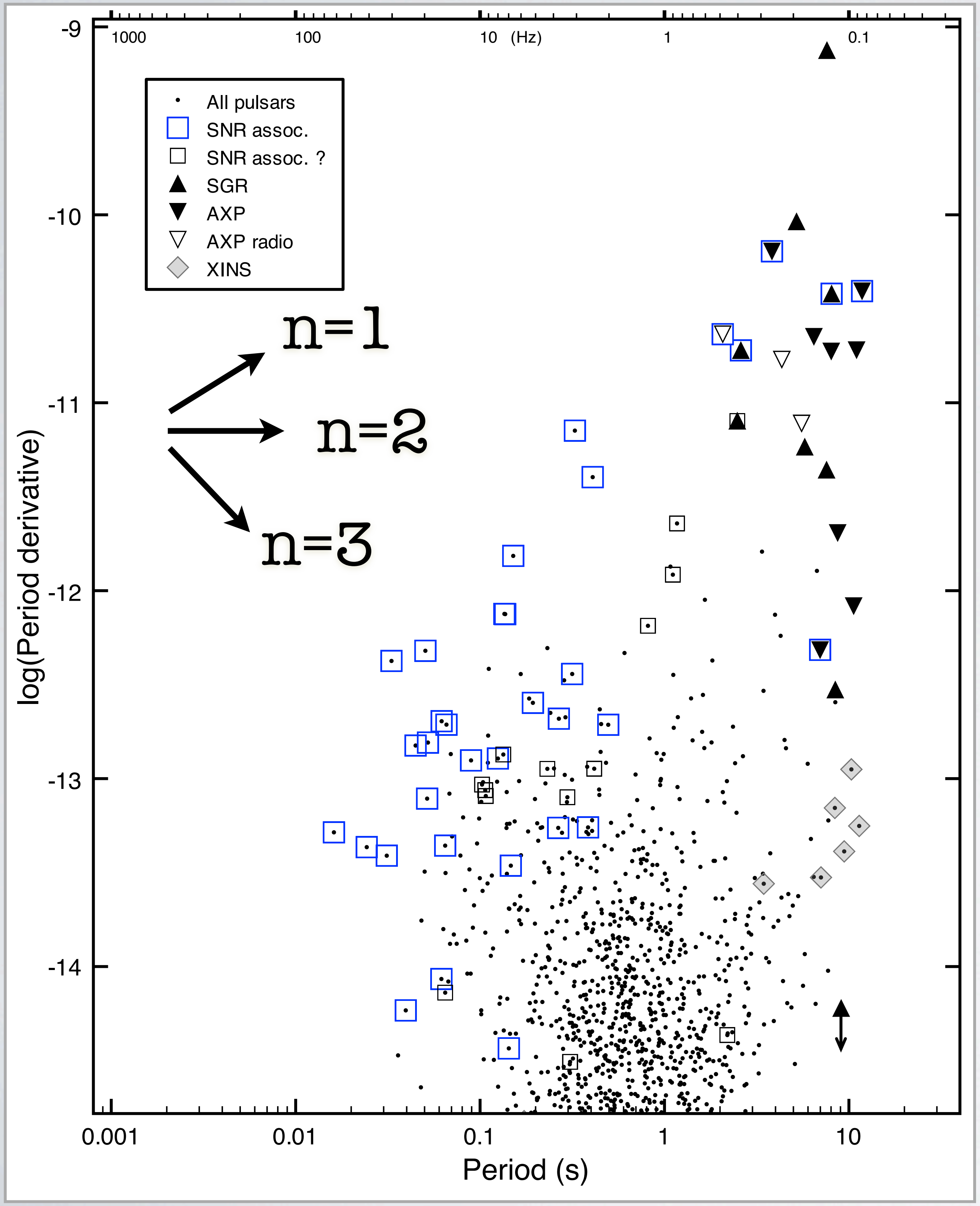
The braking index can be measured:

$$n = \frac{\nu \ddot{\nu}}{\dot{\nu}^2}$$

If pure magnetic dipole braking:

$$n = 3$$

The P-$\dot{P}$ diagram



slope on diagram = $2-n$

If pure magnetic dipole braking:

$$n = 3$$

-45 deg

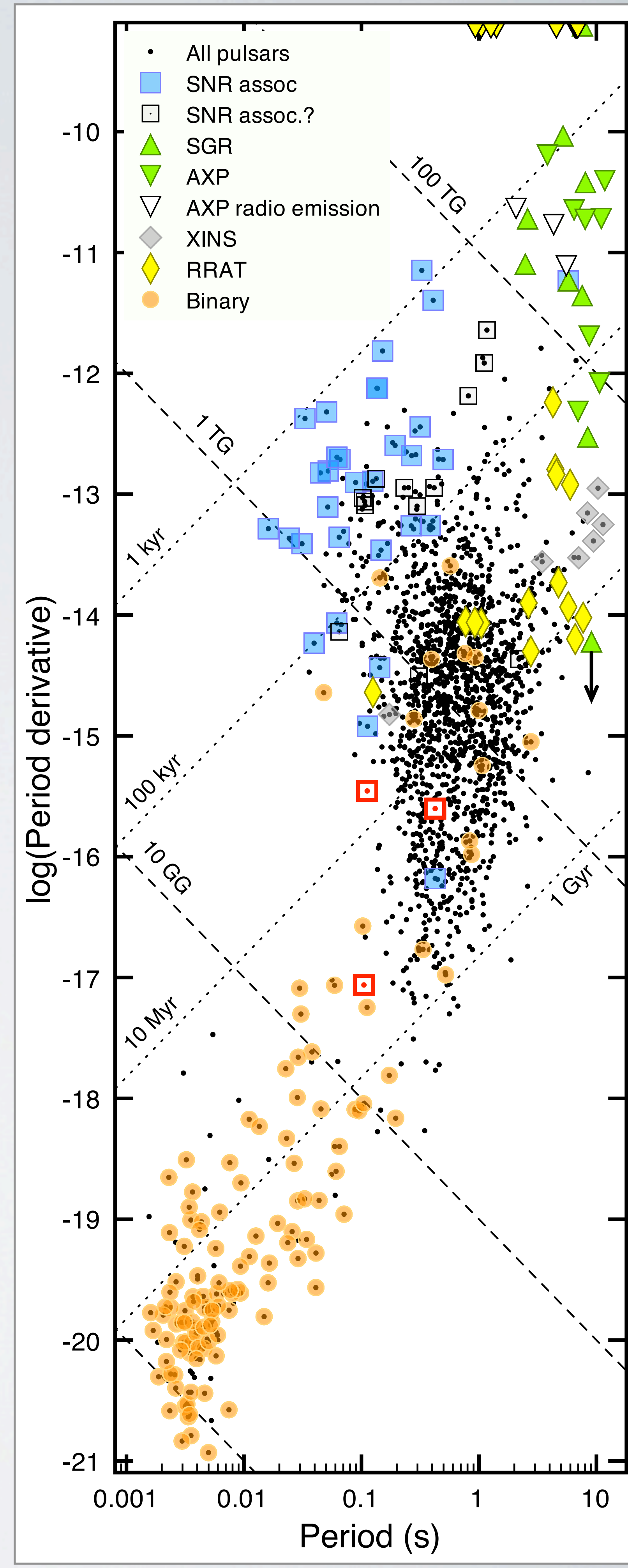
Why is n important?

➡ Real ages

➡ Connection between different populations

- Young: SNR's
- Magnetars: AXPs, SGRs
- X-ray Isolated NSs (XINS)
- RRATs
- CCO's
- MSPs: Binaries

➡ Rate of SN explosions (Keane+2008)

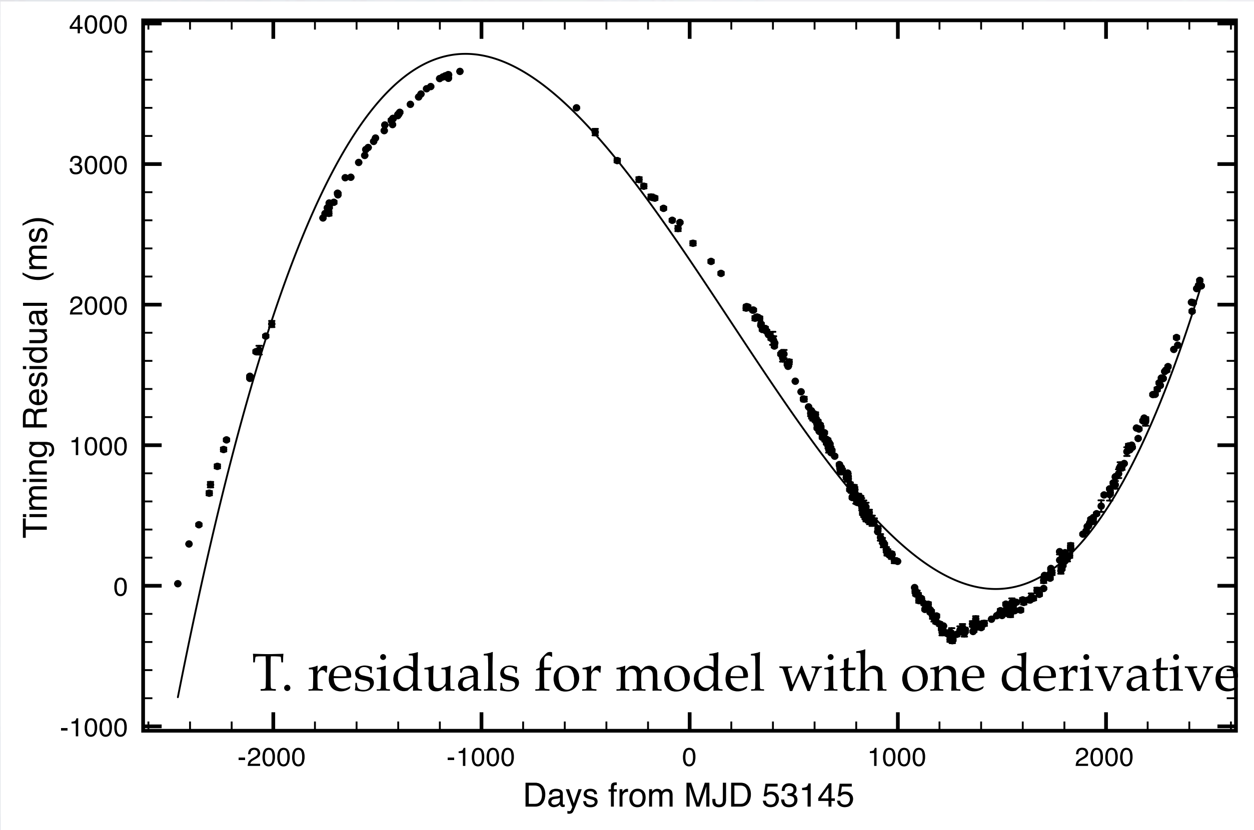


PSR J1734-3333

$$P = 1.169$$
$$\dot{P} = 2.3 \times 10^{-12}$$
$$\tau_c = 8 \text{ kyr}$$
$$B_{\rm s} = 5 \times 10^{13} \text{ G} \quad \text{(dipole)}$$

13.5 years of observations

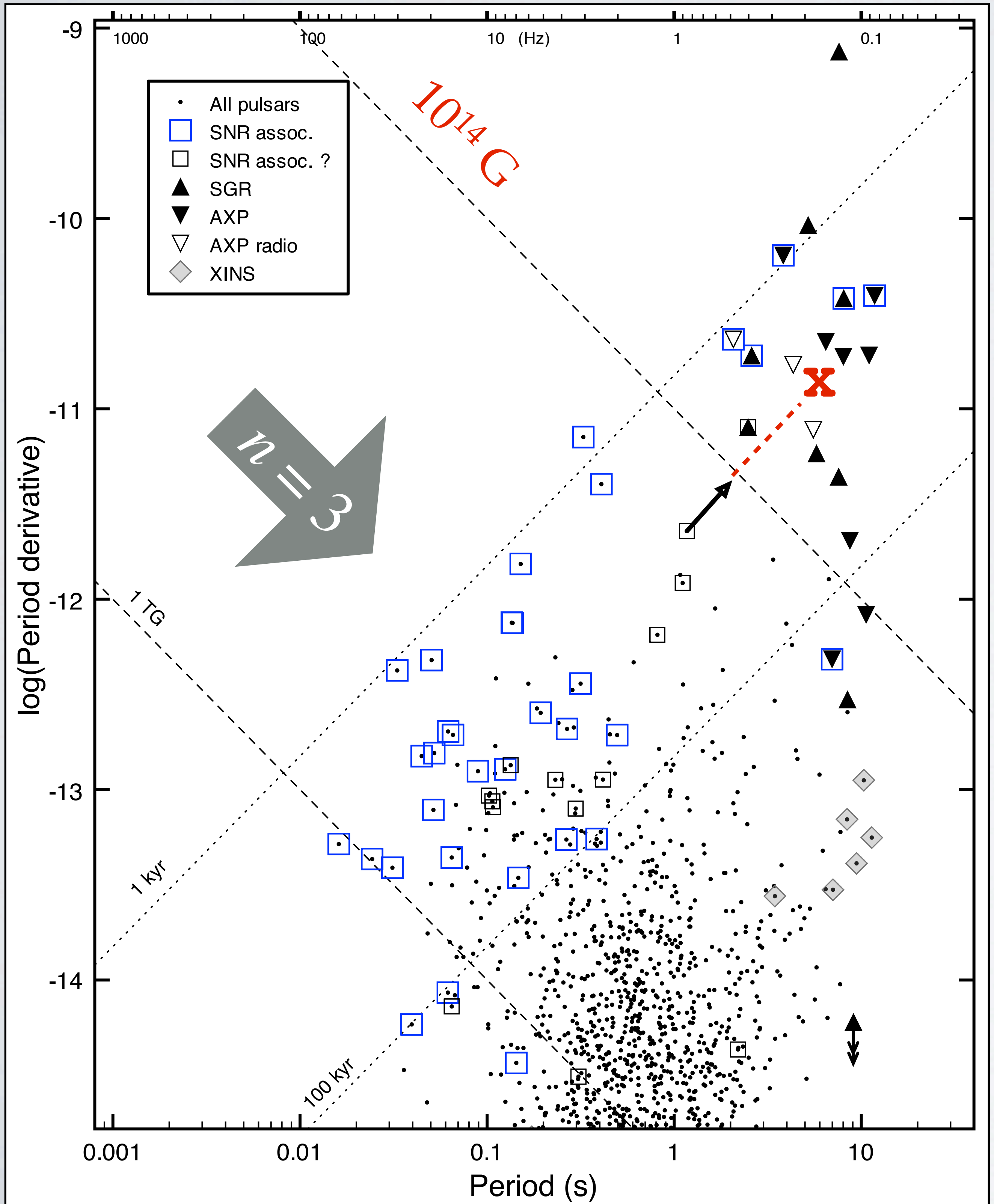
$$\ddot{\nu} = 2.8 \pm 0.6 \quad \times 10^{-24} \text{ Hzs}^{-2}$$



Espinoza+2011 (ApJL 741,L13)

Caption: CSIRO's Parkes radio telescope. Credit: David McClenaghan, CSIRO

PSR J1734-3333



$$n = 0.9 \pm 0.2$$

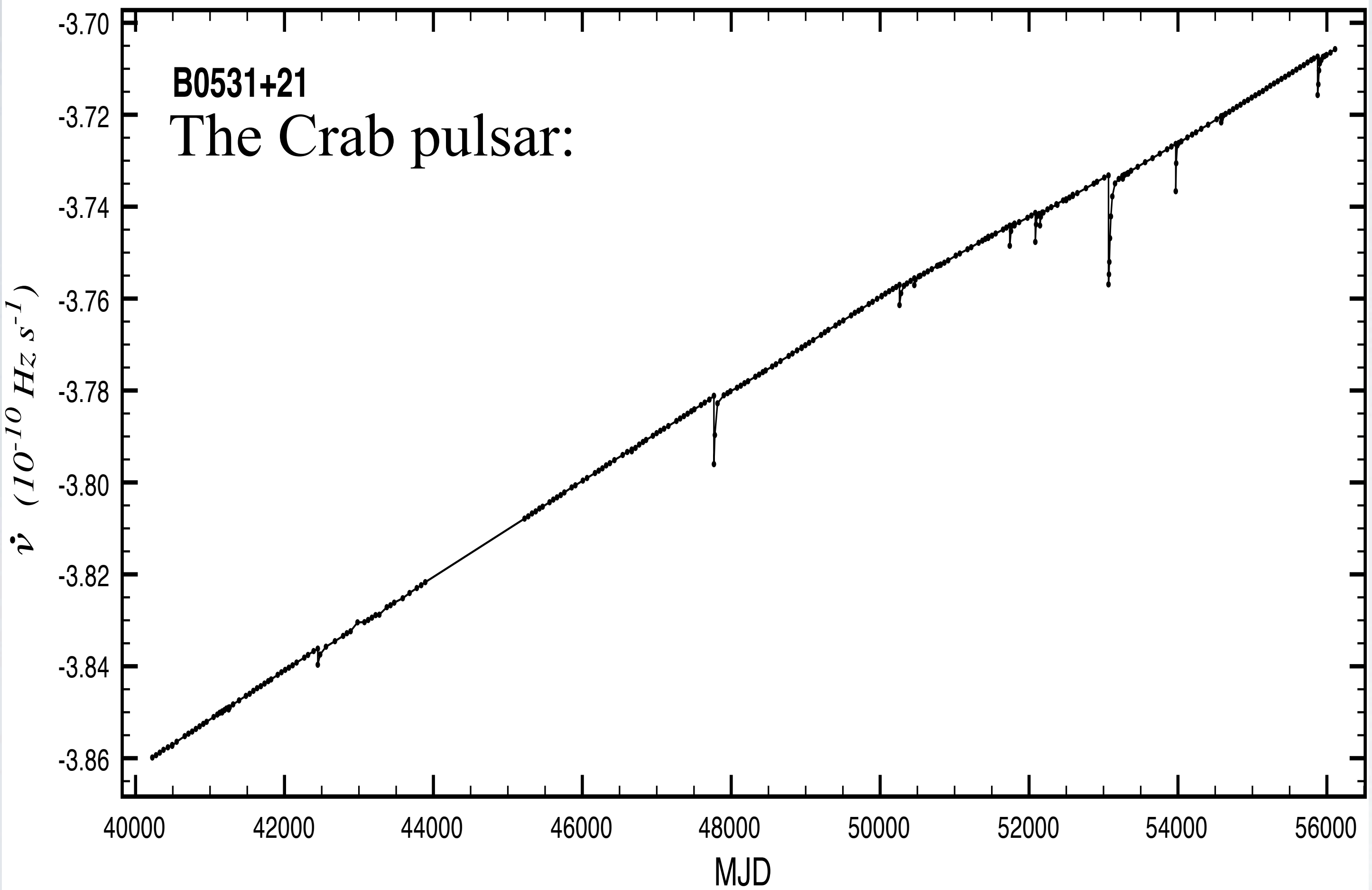
Slope > 0.9 on diagram

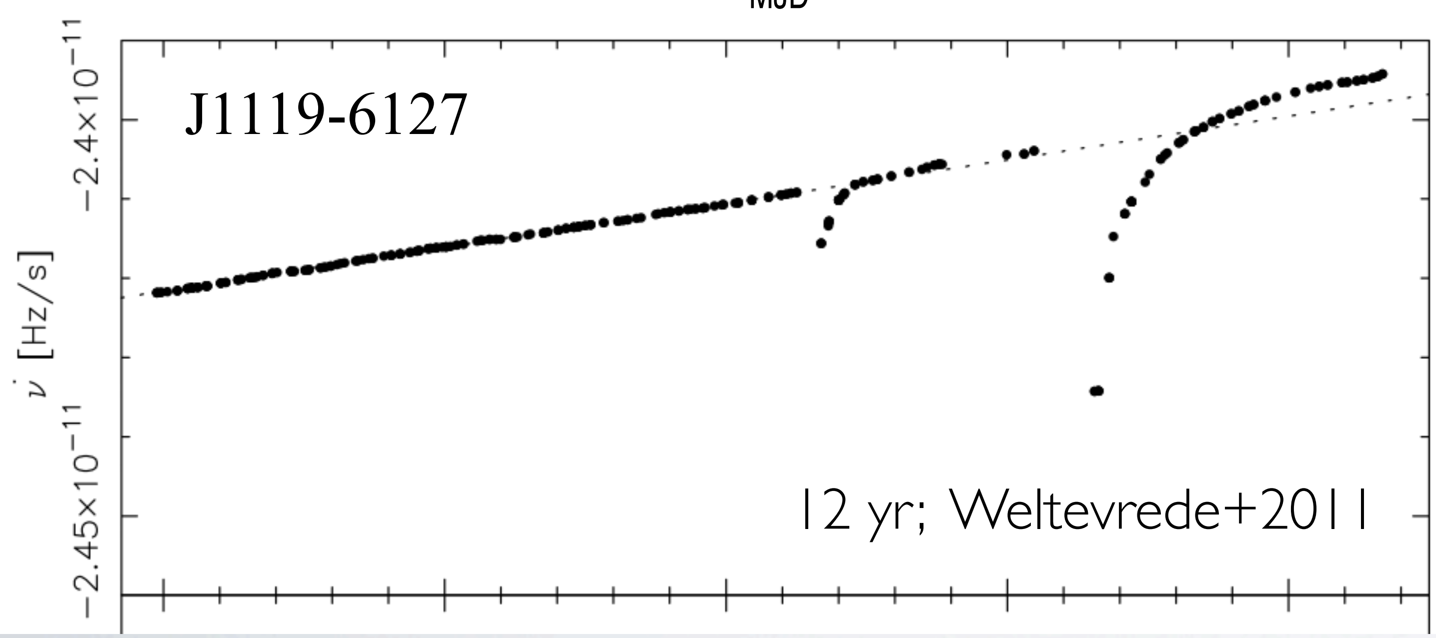
Slowdwon is not pure dipolar

If underlying physics remains the same, it will be among the magnetars (P = 8 s) in 29 kyr.

OTHER MEASUREMENTS (1): The case of Very young pulsars

$\dot{\nu}(t)$ – plots : slope = $\ddot{\nu}$



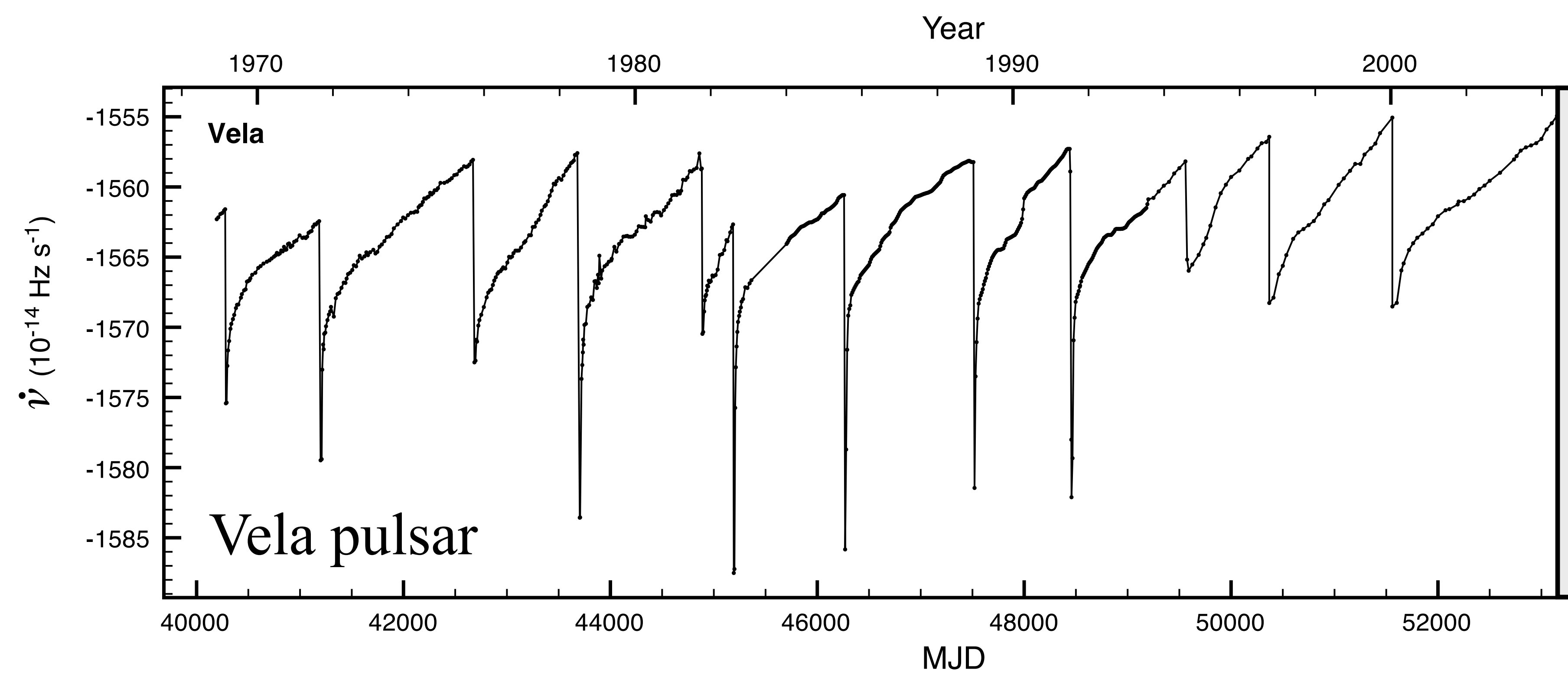


- Their $\dot{\nu}$-evolution is clean and very much linear.
- Long-term $\ddot{\nu}$ is easy to detect via coherent timing
- Glitches are not a problem

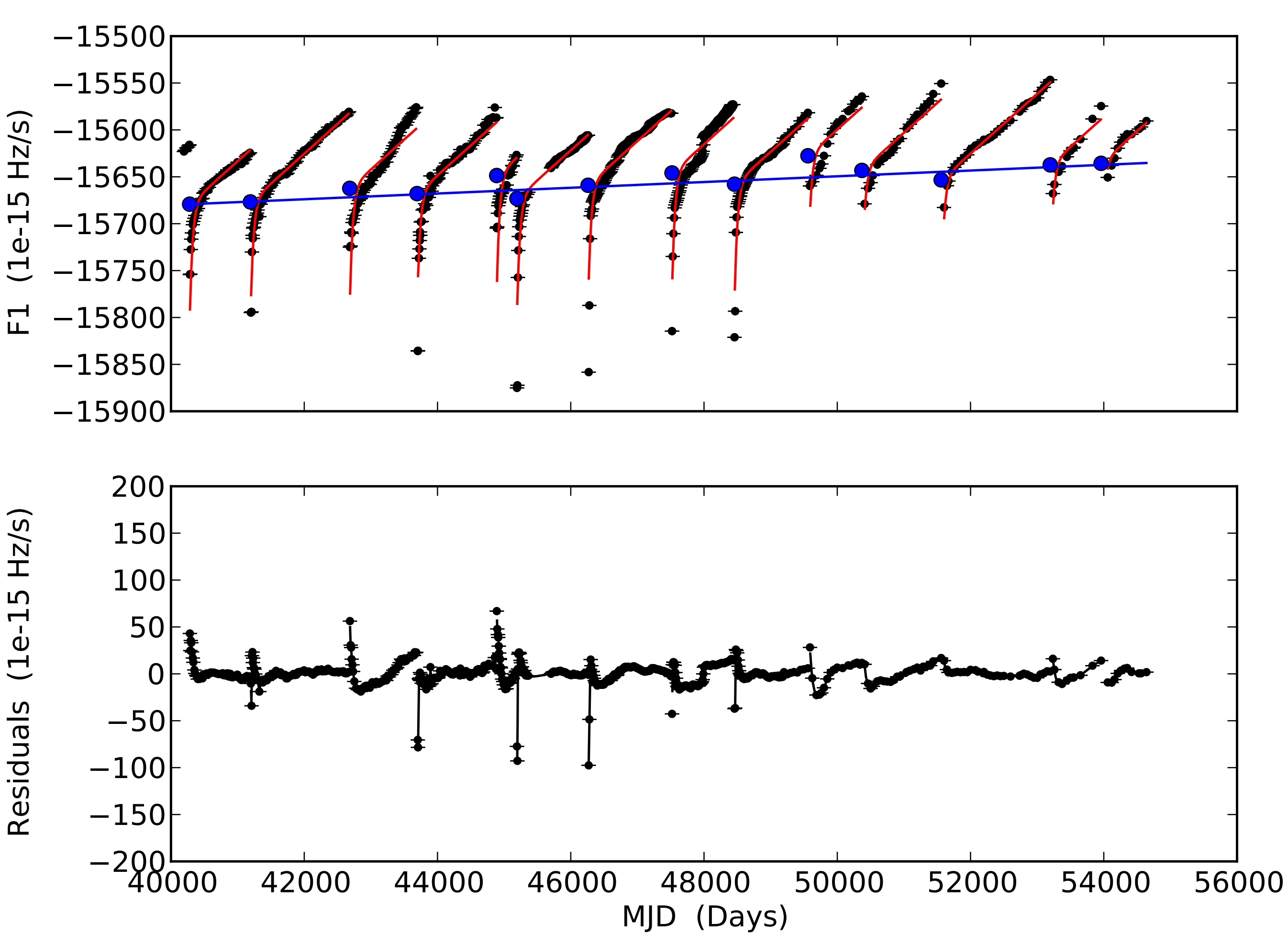
Pulsar	n	Reference
B0531+21	2.51(1)	Lyne et al. (1993)
B0540-69	2.14(1)	Livingstone et al. (2007)
J1119-6127	2.91(5)	Weltevrede et al. (2011)
B1509-58	2.839(1)	Livingstone et al. (2007)
J1846-0258	2.65(1)	Livingstone et al. (2007)
1833-1034	1.857	Roy et al. (2012)

OTHER MEASUREMENTS (2):

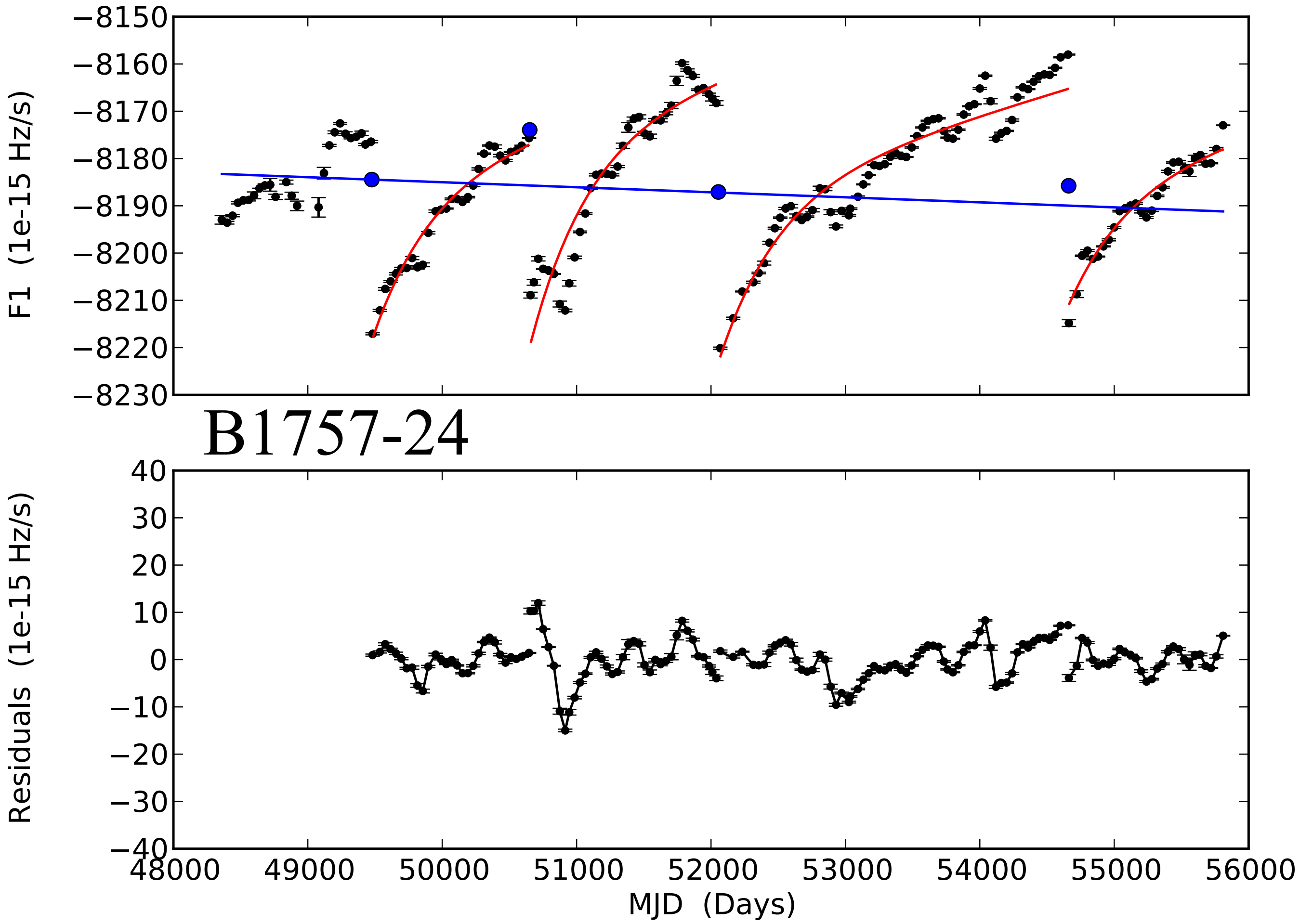
The case of Vela-like pulsars

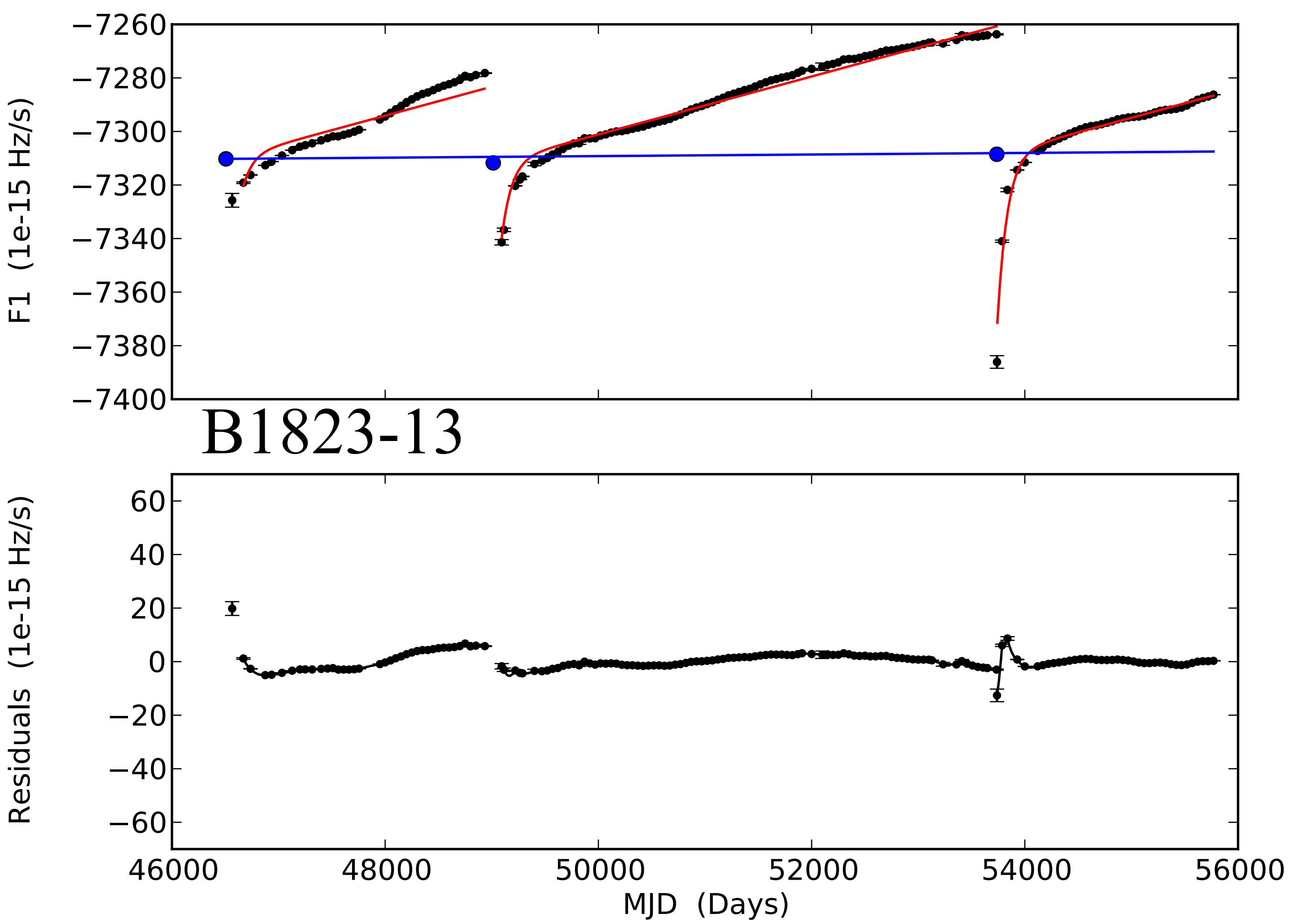


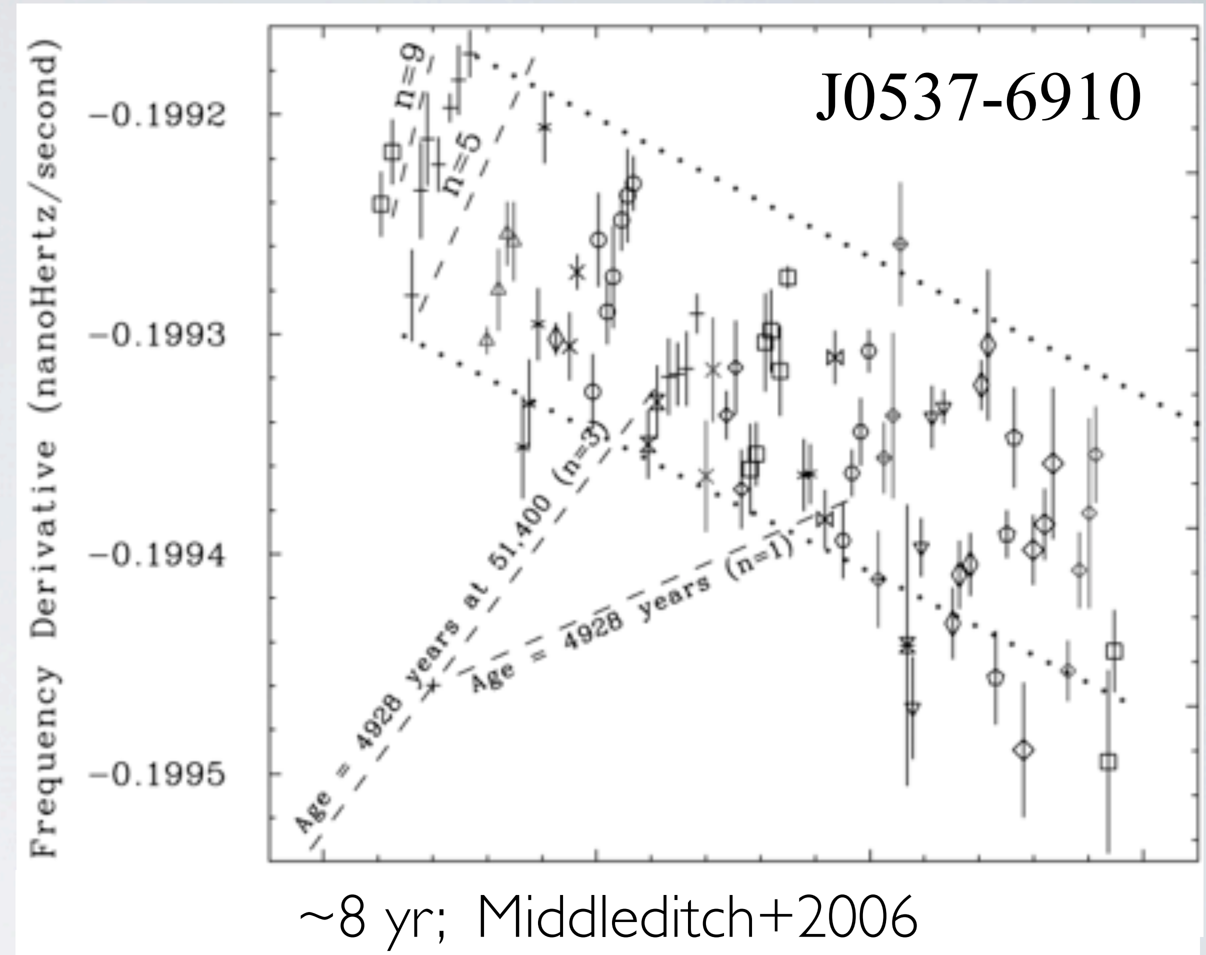
Long-term $\ddot{\nu}$ obscured by larger glitch activity



Pulsar	n	Reference
B0833-45	1.7(3)	**Preliminary**
B1757-24	-1(2)	**Preliminary**
B1800-21	2(1)	**Preliminary**
B1823-13	2(1)	**Preliminary**
J0537-6910	-1.5	Middleditch et al. (2006)
J1747-2958	<1.3	Hales et al. (2009)







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Constrain via p. motion/age

All together...

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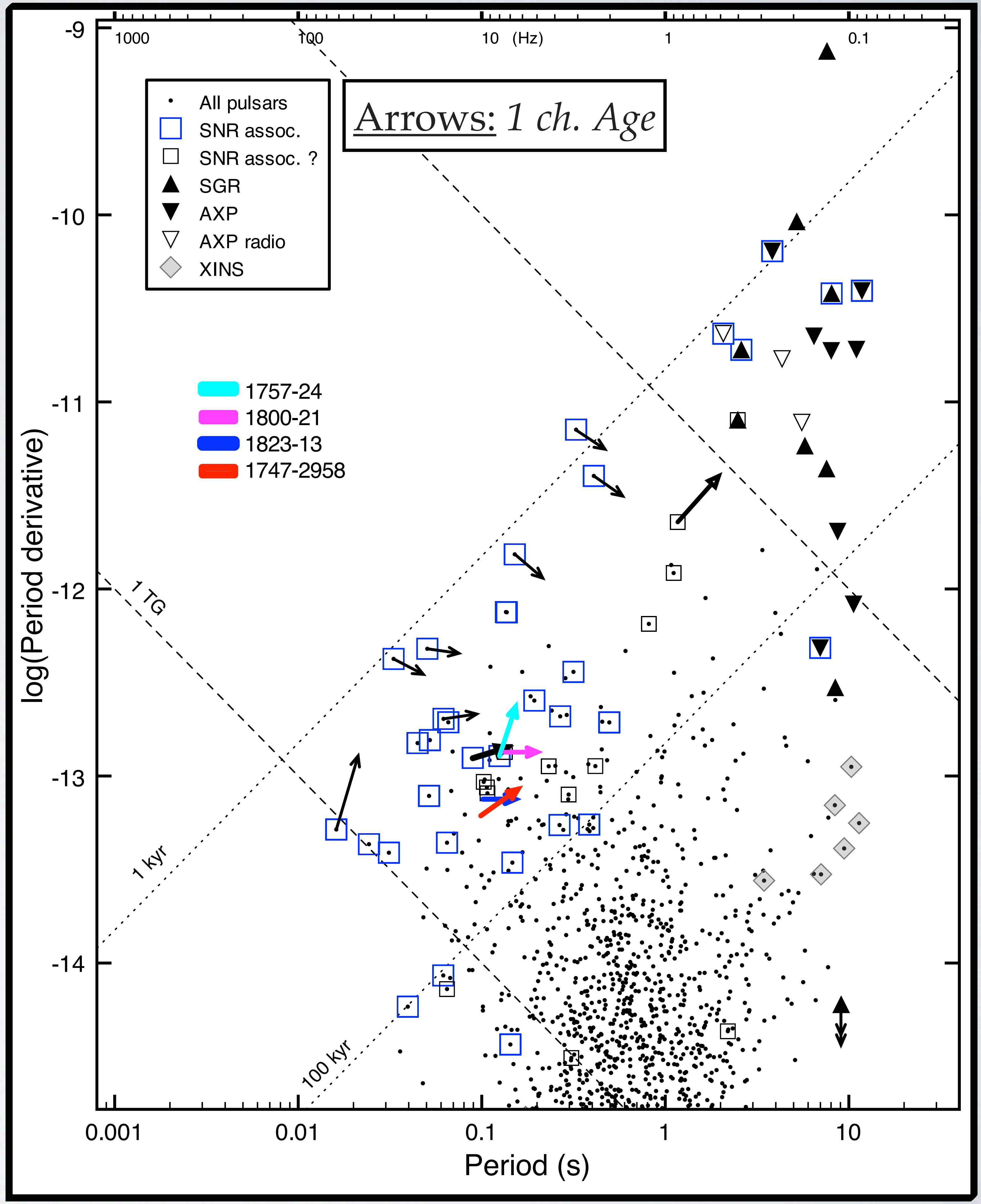
Very young PSRs move with negative slopes

Vela-like PSRs and 1734 are moving upward



$$n < 3$$

SO WHAT'S THE EXPLANATION?

- Magnetic field variations
  - Magnitude
  - Inclination
- Moment of inertia
  - shape
  - Decoupling of internal SF (Ho+2012)
- Wind
- Others: QVF, multipolar B, etc.

The only evidence points to alignment in $10^{6\text{-}8}$ yr

Tauris+1998; Weltevrede+2008; Young+2010

Unlikely to be sustained for long periods of time

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No evidence in X-ray observations

Olausen+2012

Gavriil+2008; Livingstone+2011

PSR J1846-0258: Magnetar-like episode. No evidence for wind braking.

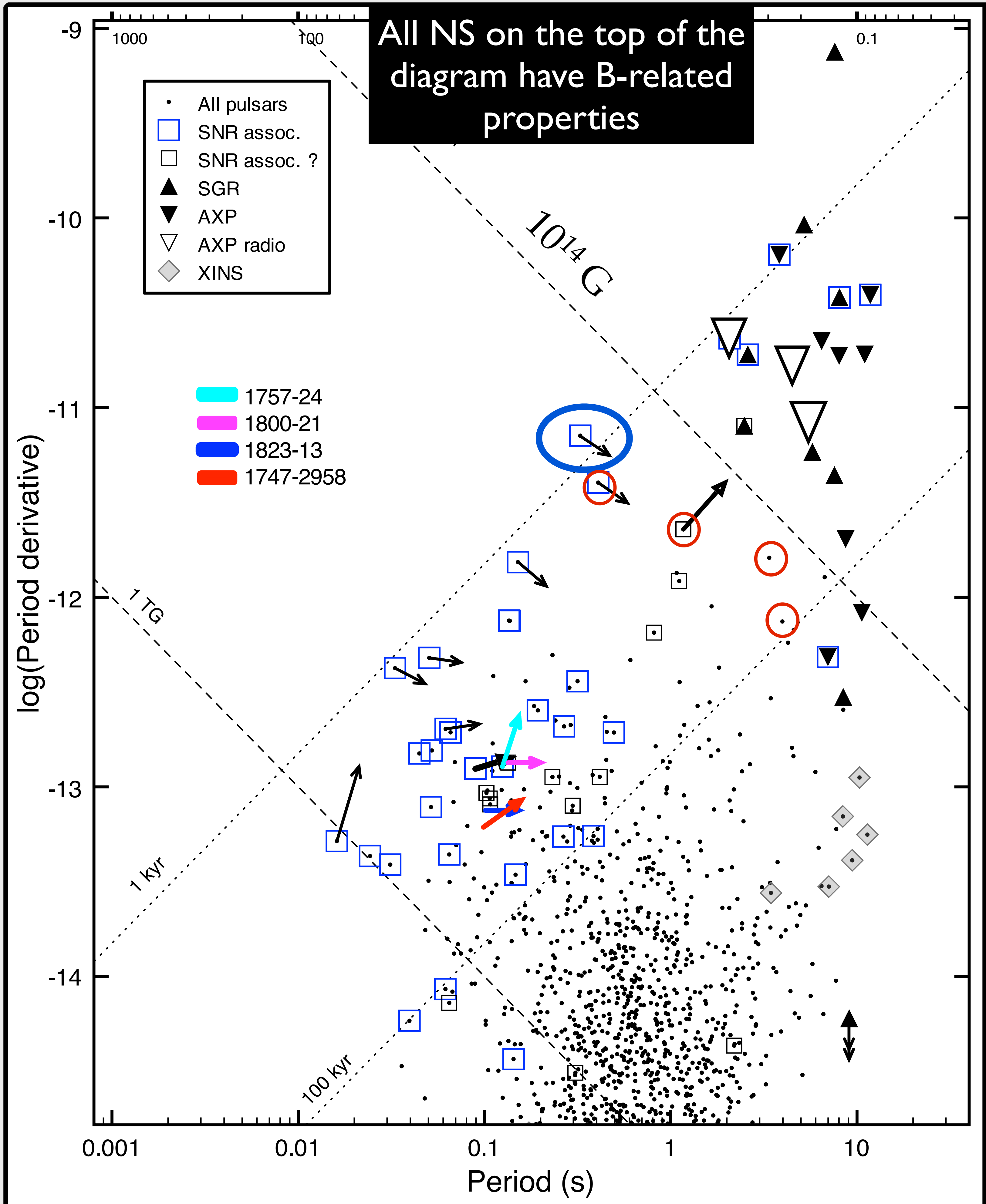
Kramer+2007; Camilo+2008; Levin+2010

Radio Magnetars: peculiar radio properties

Olausen+2010,2012; Zhu+2011

1734 and other High-B pulsars are hotter than other radio pulsars of similar ch. age.

All these props. have been associated with strong magnetic fields



Given that magnetars and high-$\dot{P}$ PSRs have all very strong dipole magnetic fields,
the most natural interpretation for the movement of J1734-3333 on the diagram is that its surface dipole magnetic field is increasing.

will it become a magnetar?

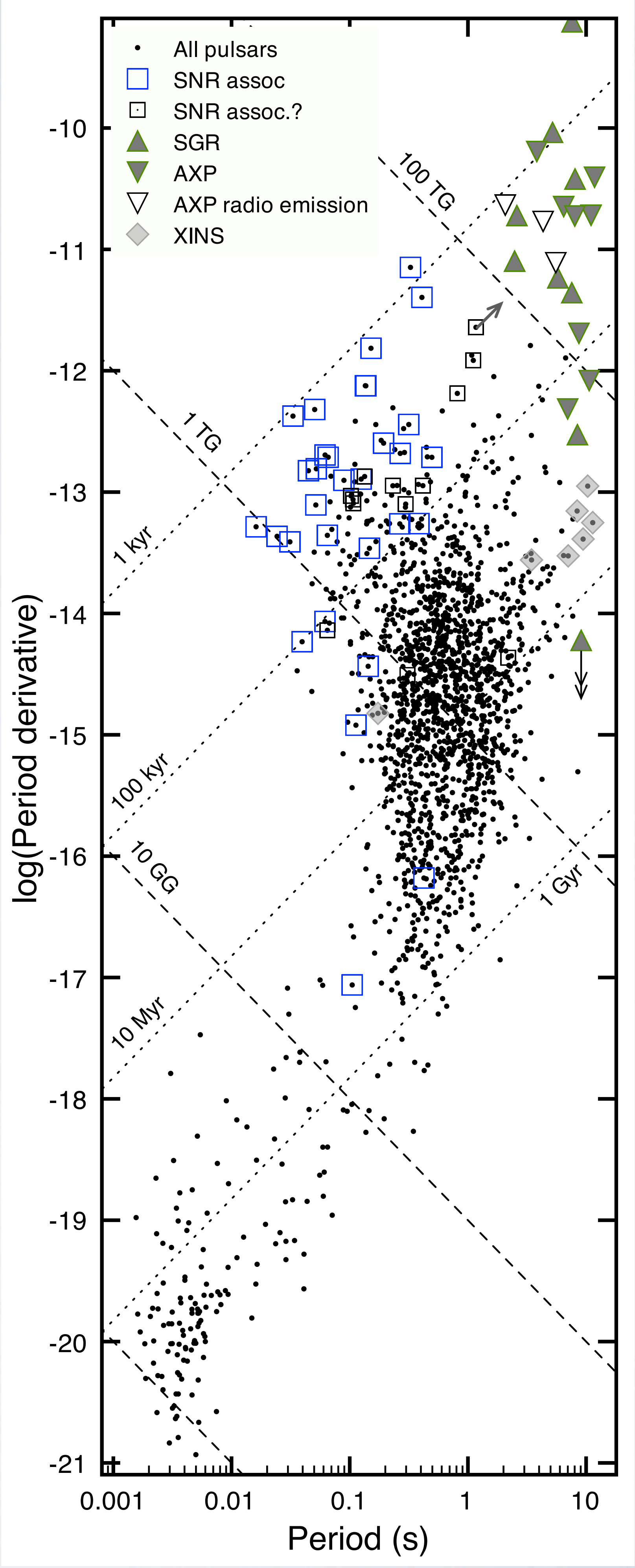
This could be driven by emergence of a stronger field buried underneath the NS surface, with timescales depending on submersion depth.

(Muslimov & Page 1996; Geppert+1999; Ho2011, Viganò+2012).

this could be common among the PSR population.

CONCLUSIONS

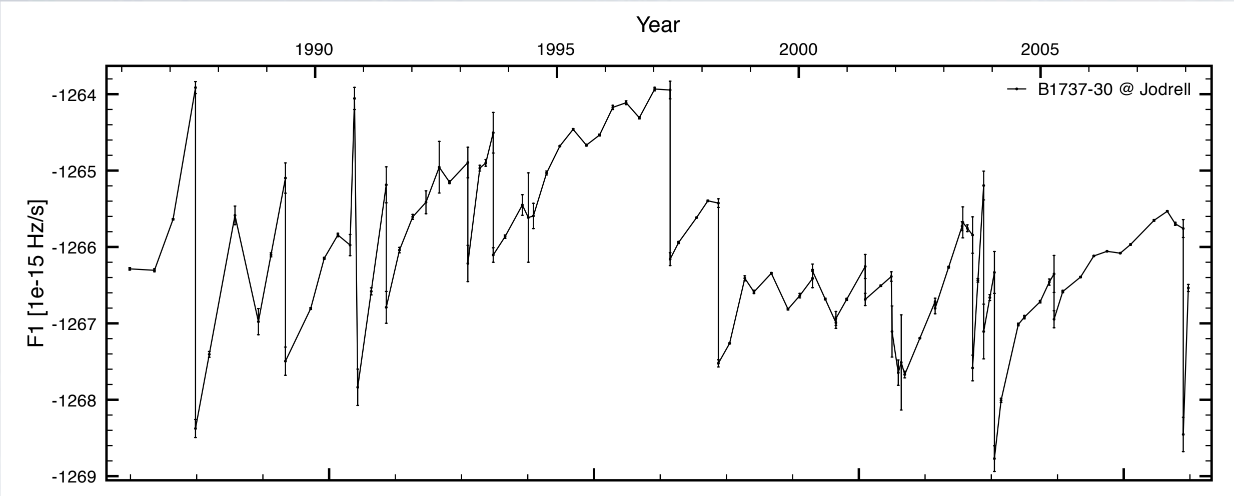
- The spin evolution of young pulsars is not dominated by a electromagnetic torque caused by a constant magnetic dipole.
- The low braking index of J1734-3333 could be caused by the increase of the dipolar component of its magnetic field.
- It may be that all NSs have a strong internal magnetic field buried underneath the surface, in particular, young PSRs and CCOs. Some of them could become magnetars.

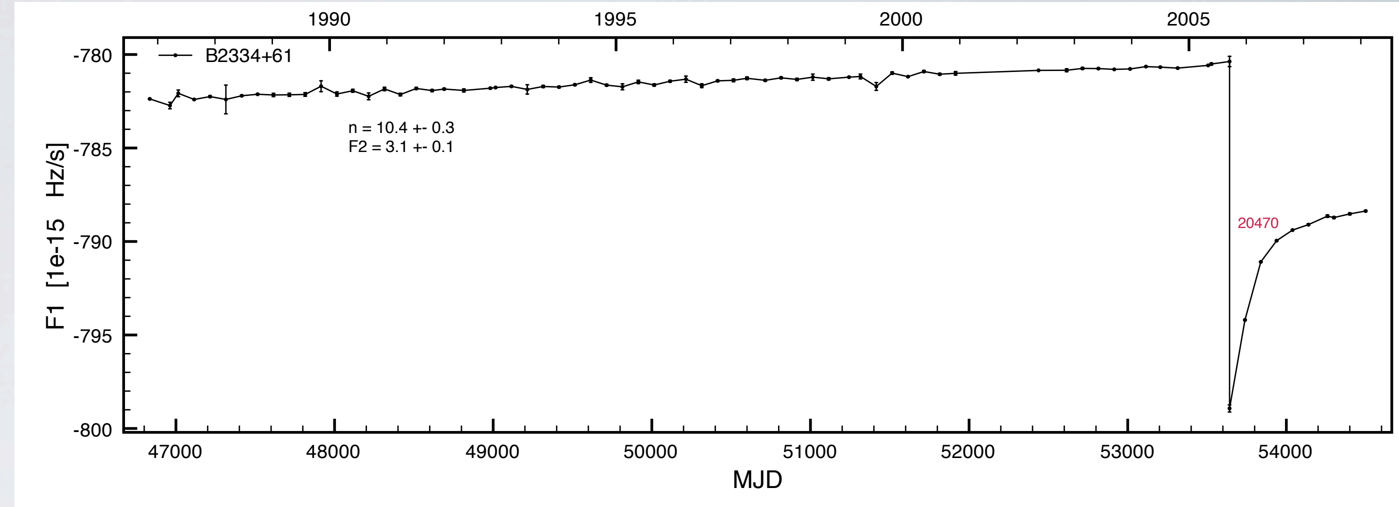


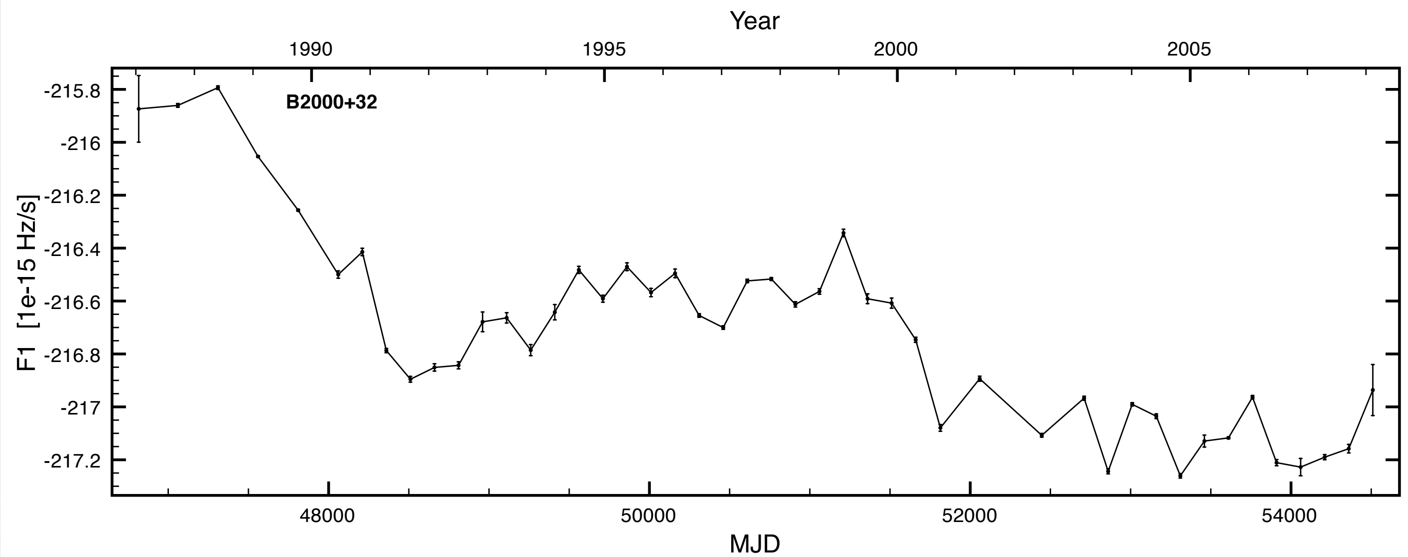
Questions for the future:

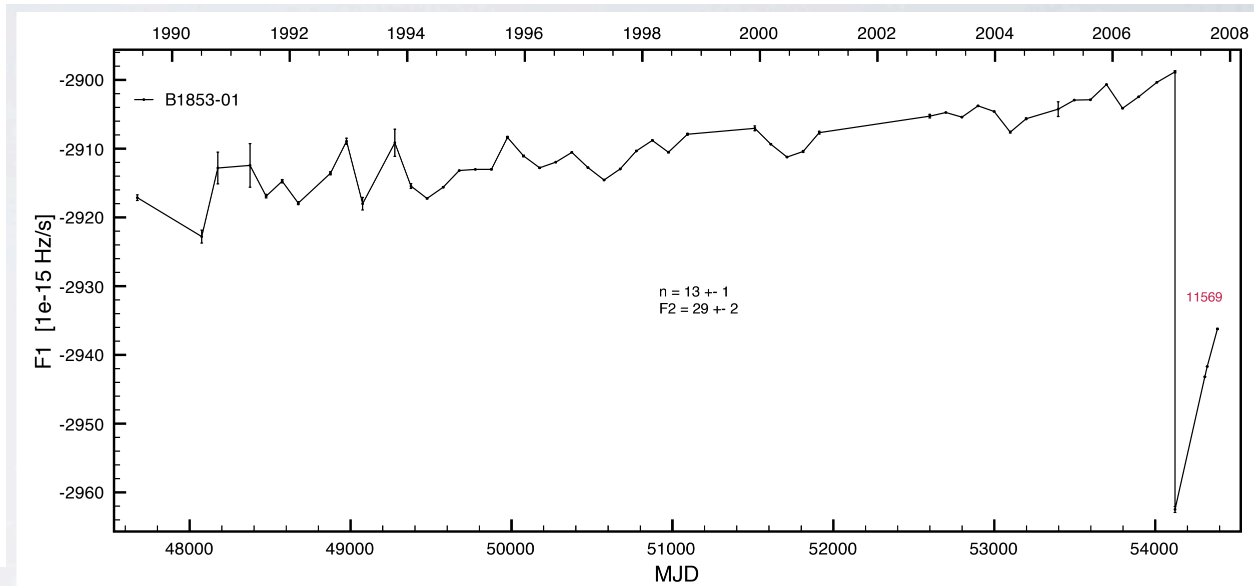
- How do the efficiencies of the different possible slowdown mechanisms compare? Can we decide which one is in action (dB/dt>0, dI/dt, winds, others)?
- Do all PSRs evolve under the same dominant process?
- Will very young pulsars turn into low-n pulsars, like Vela?
- What is the time-scale the braking index remains constant?

Fin









The case for other pulsars. *Not easy F2 detection, four possible cases:*

- Large, irregular glitch activity
- Regular glitch activity on very long timescales; normally present linear F1, corresponding to glitch recovery.
- Timing noise dominated