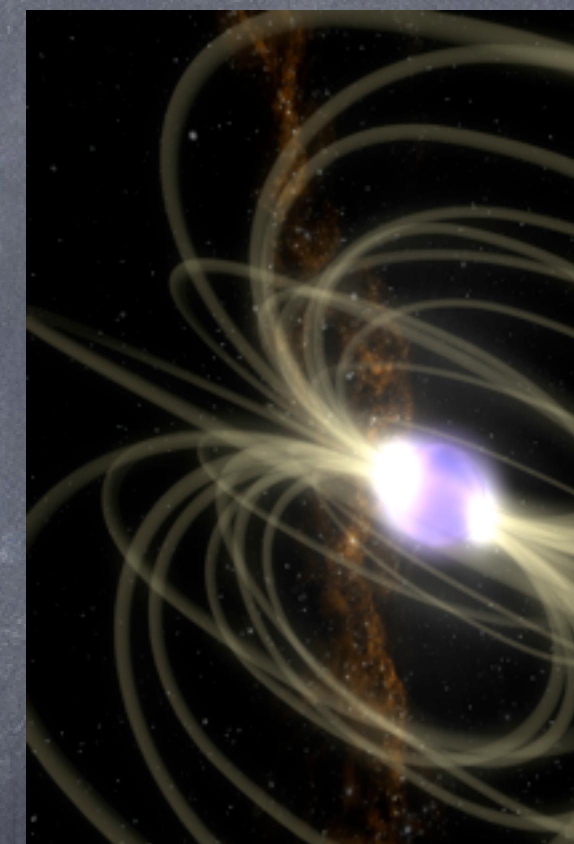
# Magnetospheric moment of inertia changes as a source of timing noise in magnetars



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1. McGill University
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Acknowledgements: Anne Archibald, Rob Archibald, Vicky Kaspi, Andrew Cumming, Jim Cordes, Ioannis Contopoulos, Maxim Lyutikov, Joanna Rankin, Chris Hirata, Peter Goldreich

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# Outline

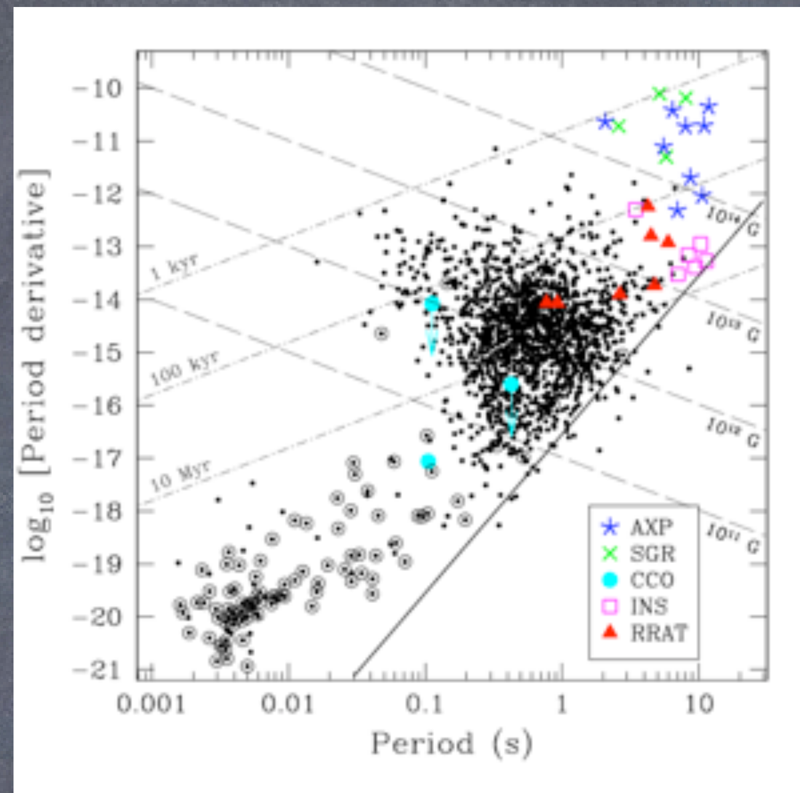
- Magnetars - High Magnetic Field pulsars
- Timing noise
- Observations
- Magnetospheric moment of inertia

Tsang & Gourgouliatos, ApJL 2013

# Pulsars

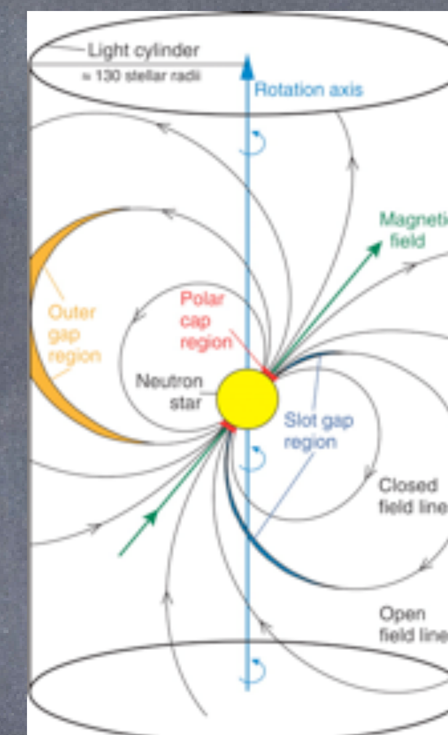
Periods ranging from ms to 10 s.

Magnetic fields from $10^8$G to $10^{15}$G.



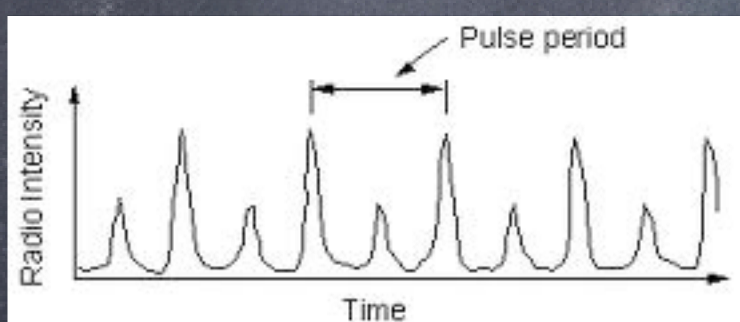

Kaspi (2010)

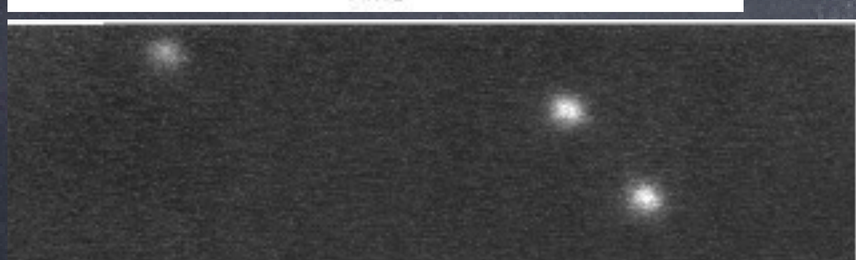
They spin-down steadily because of "dipole radiation".




$$B^2 \sim -\dot{\nu}/\nu^3$$

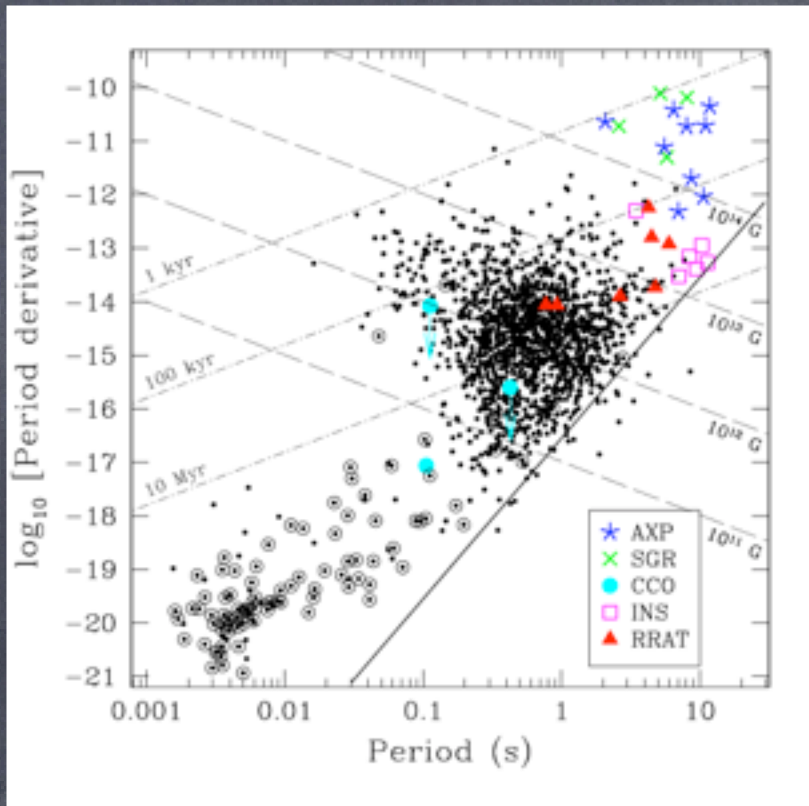
$$B^2 \sim P\dot{P}$$



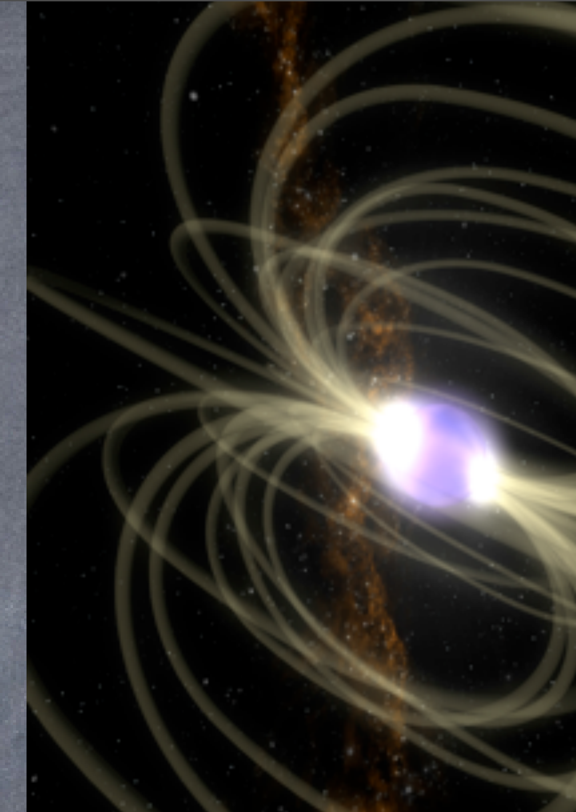



800 nm, slowed down, pulse and subpulse P=33ms of the crab pulsar; LUCKY IMAGING PROJECT

Magnetosphere:
Vacuum dipole, Force-free, MHD models.
(Deutch 1955, Goldreich & Julian 1969, Mestel 1971, Scharlemann & Wagoner 1973, Contopoulos et al. 1999, Spitkovsky 2006).




# Magnetars



- Anomalous X-ray Pulsars: slowly rotating pulsars, bright in X-rays, strong inferred dipole magnetic fields.
- Soft Gamma-ray Repeaters: detected during bursts of Gamma-rays, too faint to time during quiescence.
- Strongly magnetized pulsars

# Timing noise

- Pulsars spin-down regularly and can be fitted by a timing solution $\nu,\ \dot{\nu}$.
- Comparison of the Times of Arrival (ToA) with the timing solution has some residuals.
- The residuals can be due to some long-term effect (i.e. magnetic field evolution, crust cooling, orbital modulation), but there is an underlying irreducible component that appears as random irregularities.

Wolszczan & Frail (1992)

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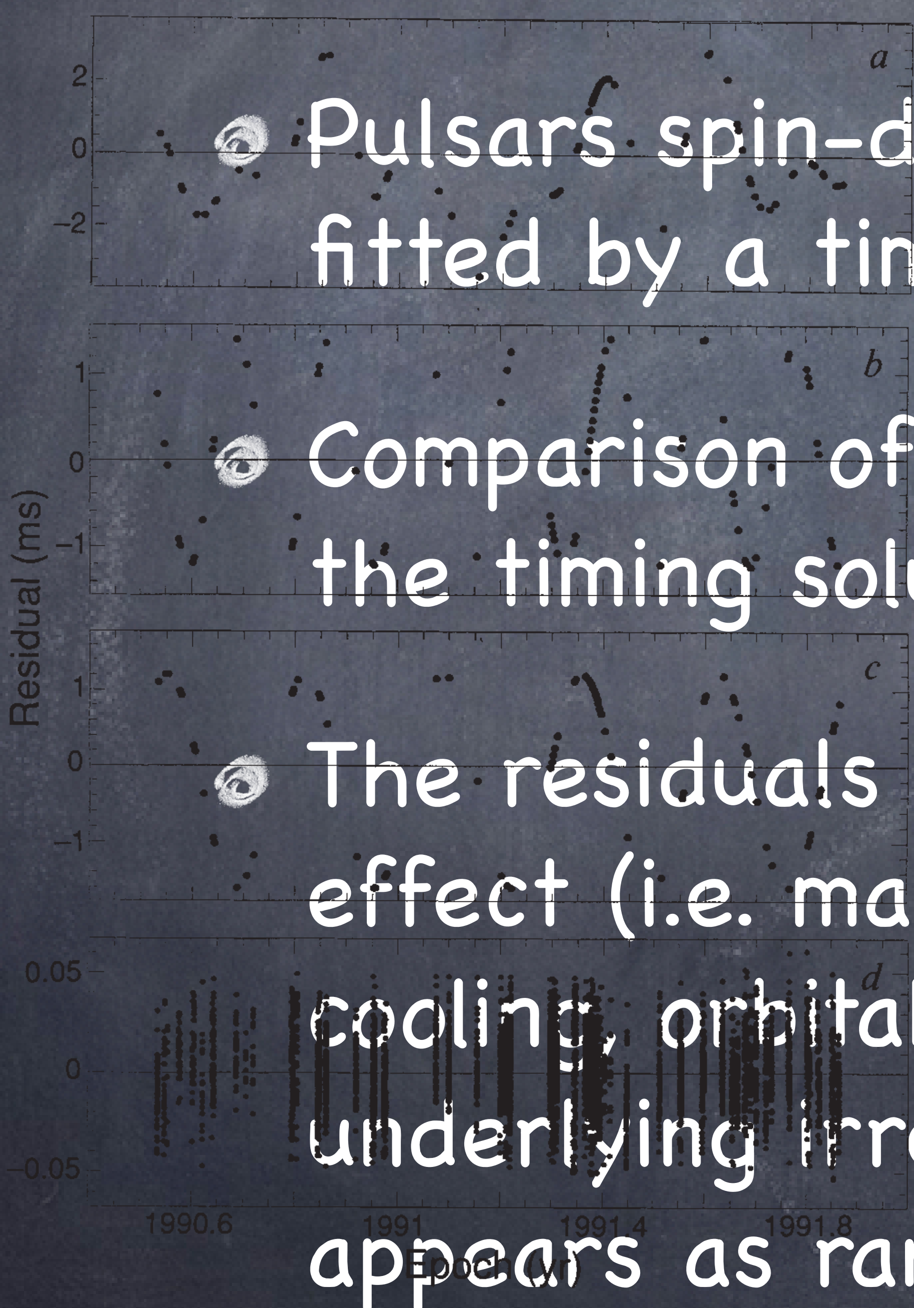


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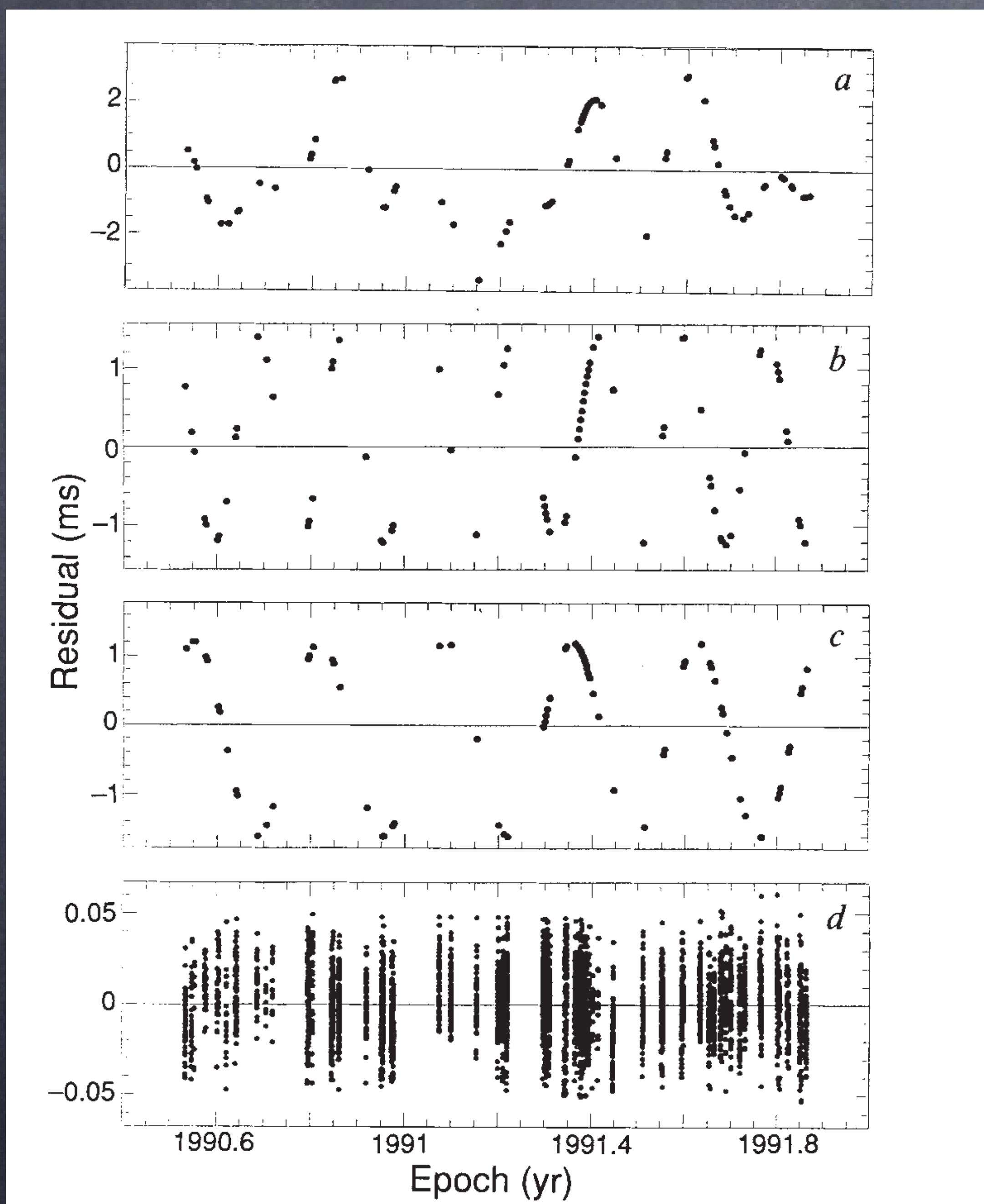


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- The physical cause is poorly understood (Hobbs et al. 2010)
  - Slow glitches (Shabanova 2010).
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- Phenomenological description (Cordes 1980)
  - Fitting of higher frequency derivatives
  - White noise - Random Walk

# Random Walks

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Regardless of the origin of the noise it can be approximated by a random walk in phase, frequency or torque. The random walk strengths have different dependence on the timing residuals.

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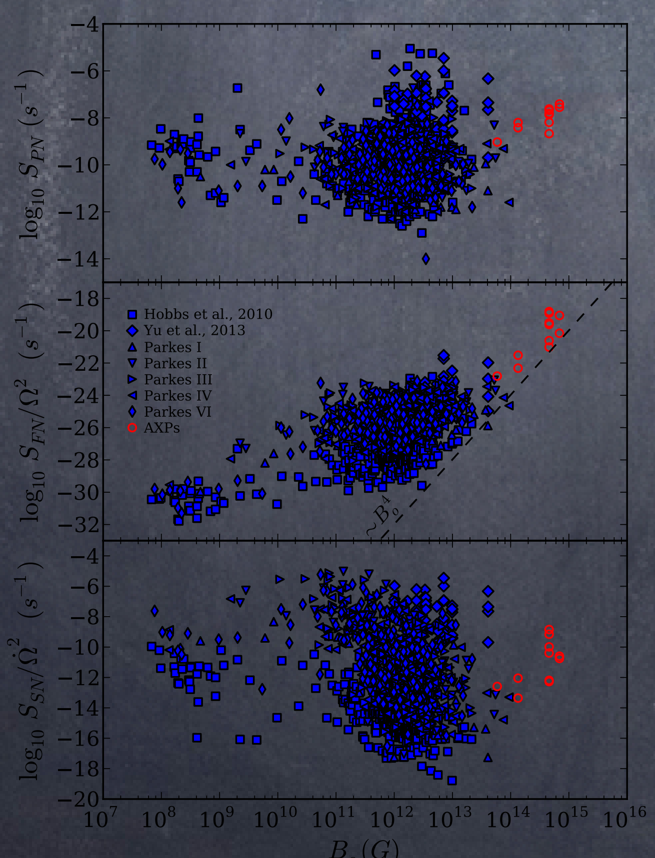

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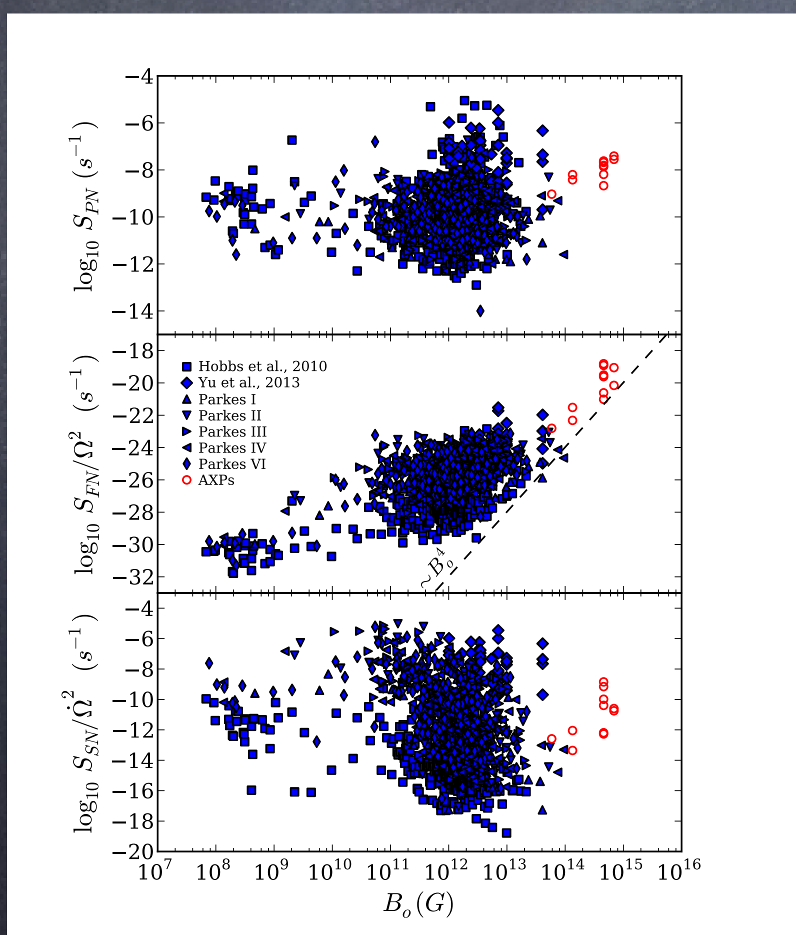

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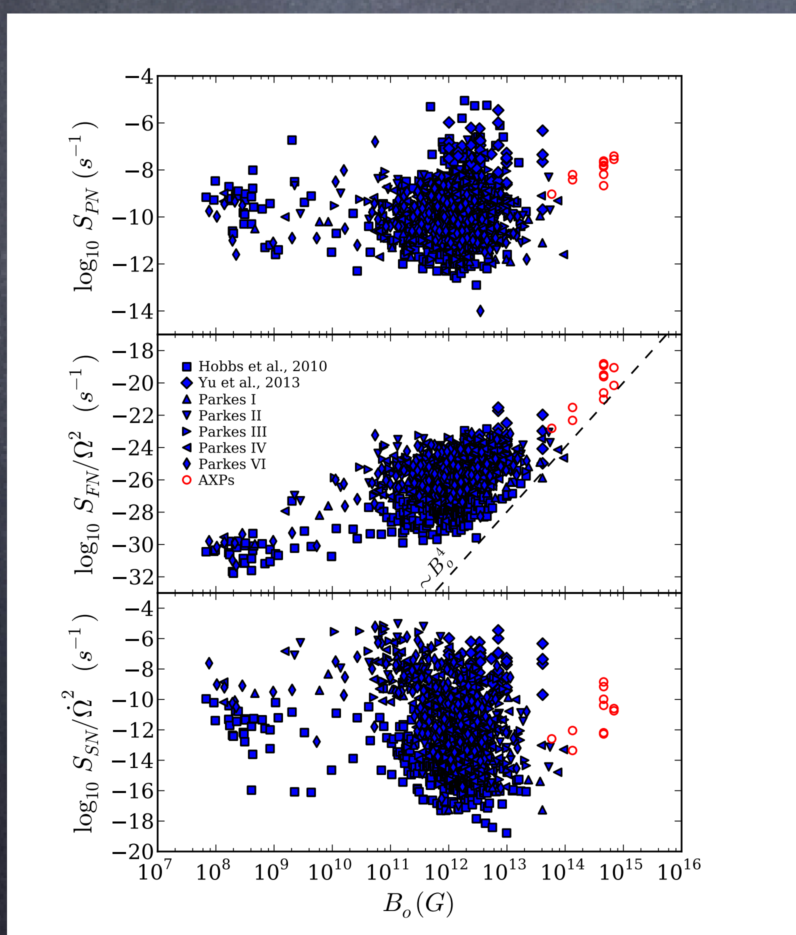


Plotting random walk strengths we find a trend with $S_{FN}/\Omega^2 \sim B^4$, for $B > 10^{12.5}$G. (1183 Pulsars, 8 AXPs: Hobbs et al. 2010, Yu et al. 2013, Parkes I, II, III, IV, VI; AXPs: Gavrill & Kaspi 2002, Dib et al. 2007, 2008, did not include SGRs because they are only timed during outbursts).

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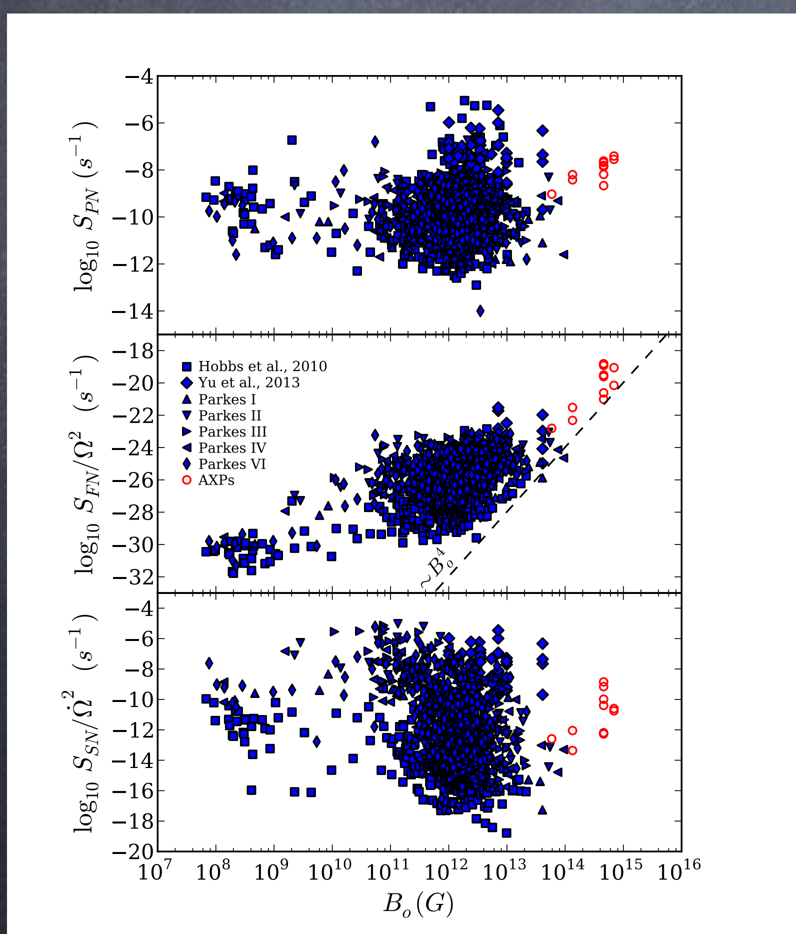


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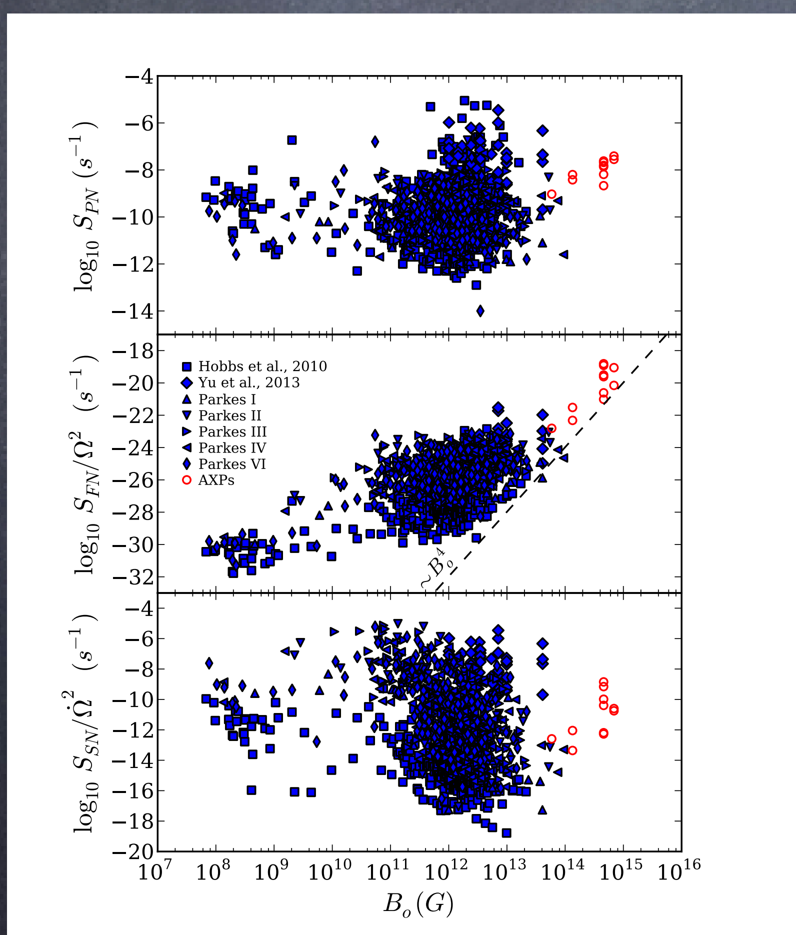


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Changes in the moment of inertial will cause the immediate response of the frequency.

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This moment of inertia is about $10^{-6}$ of the NS moment of inertia for $B_0$ $10^{15}$G.

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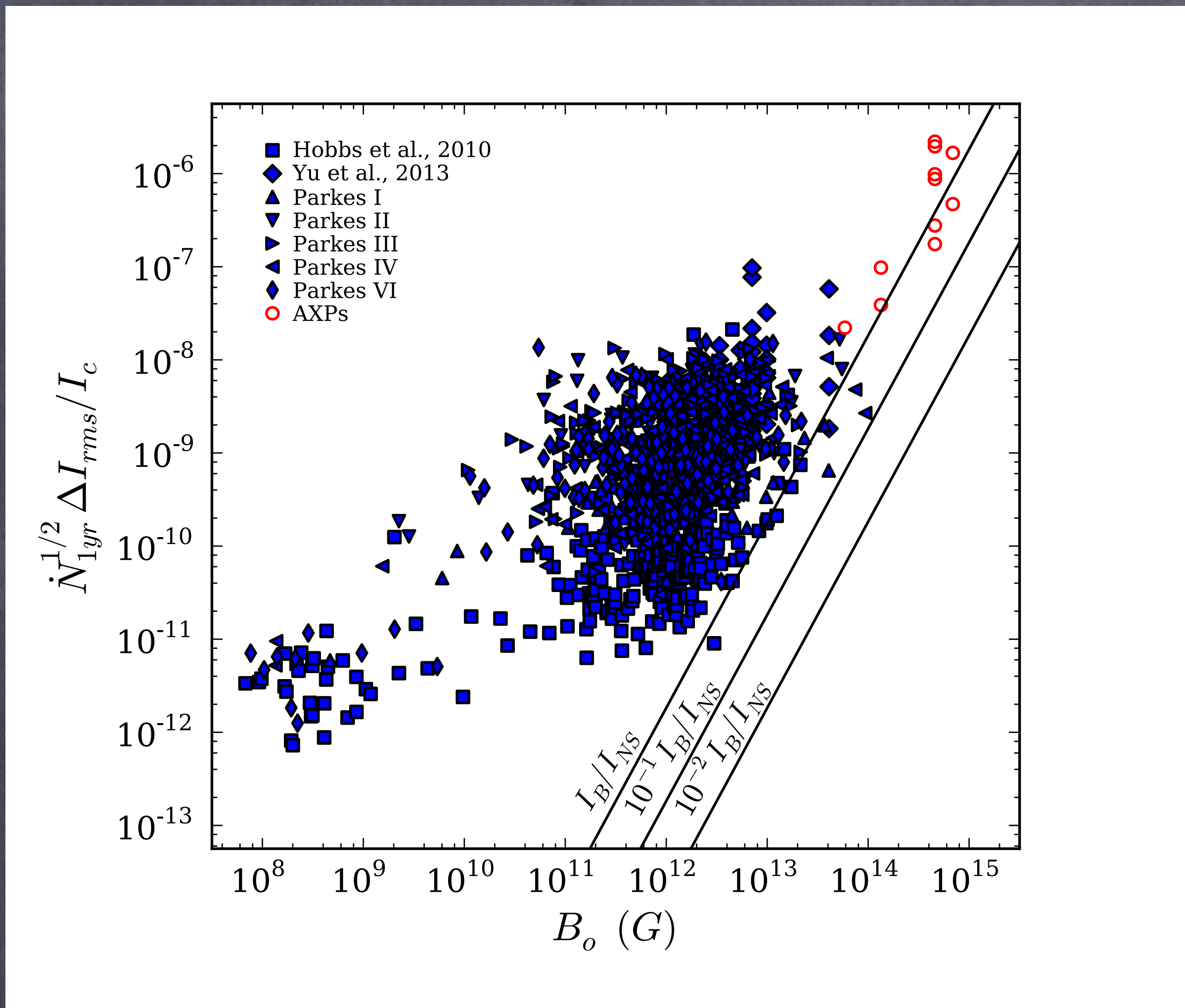


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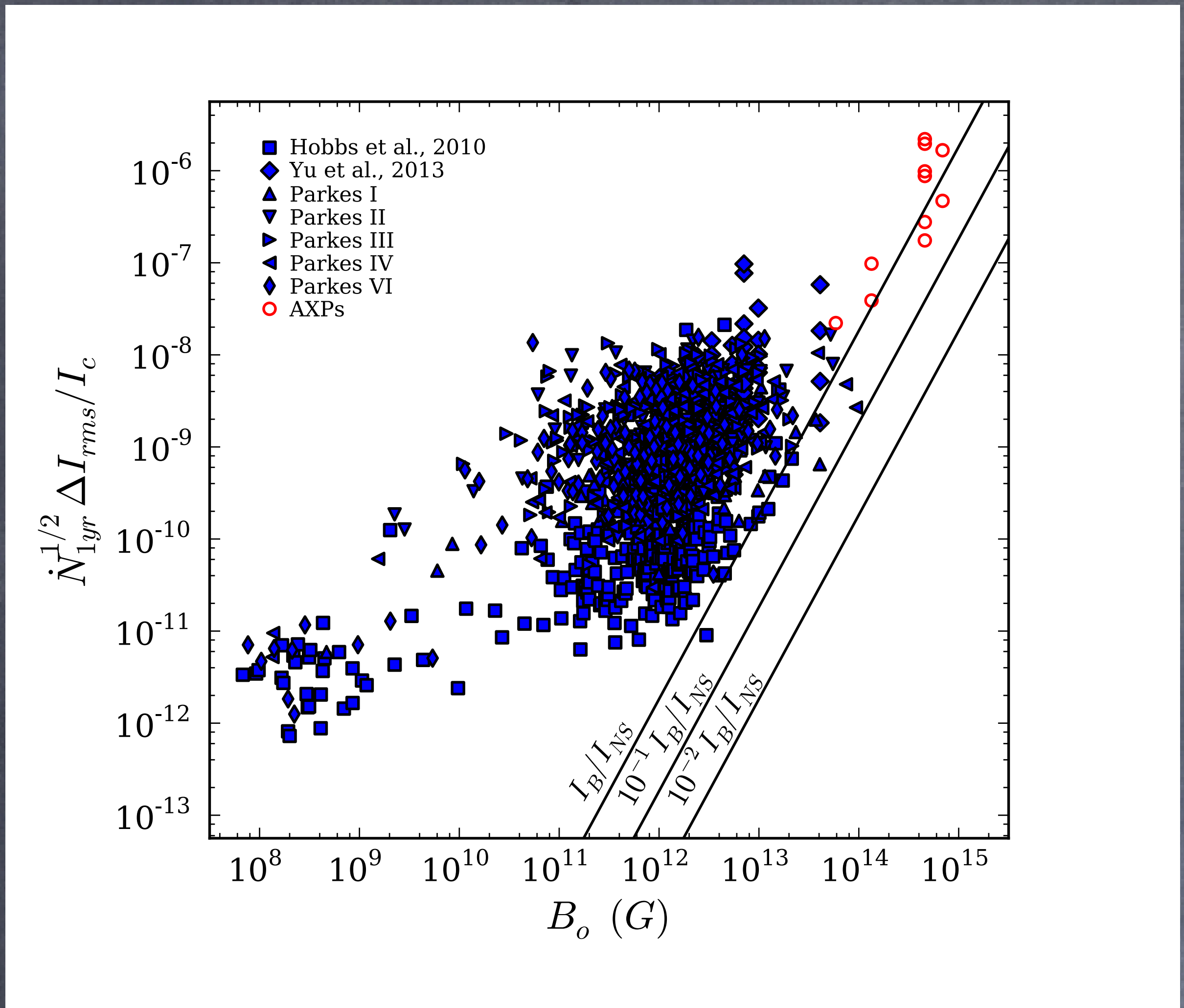


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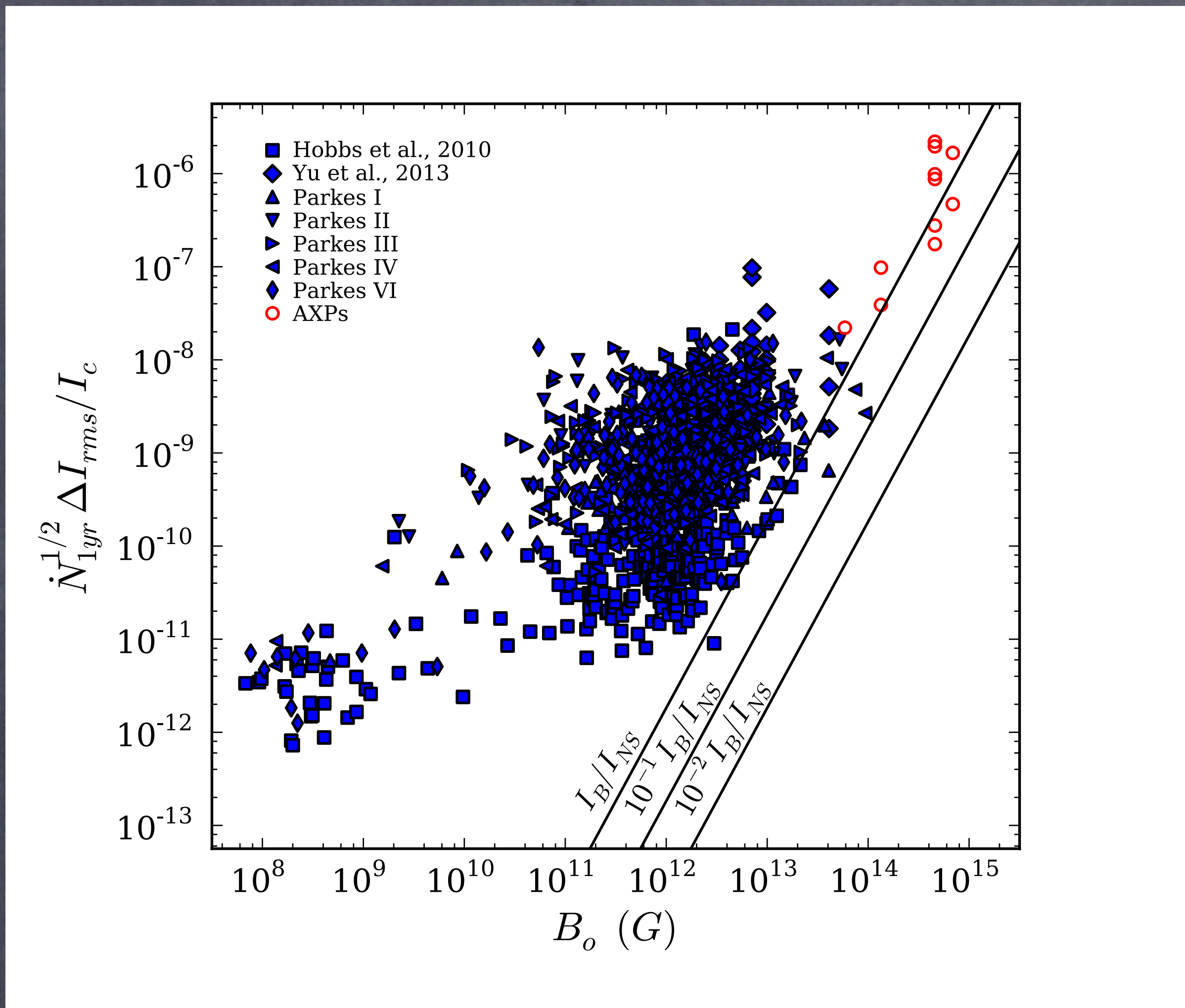


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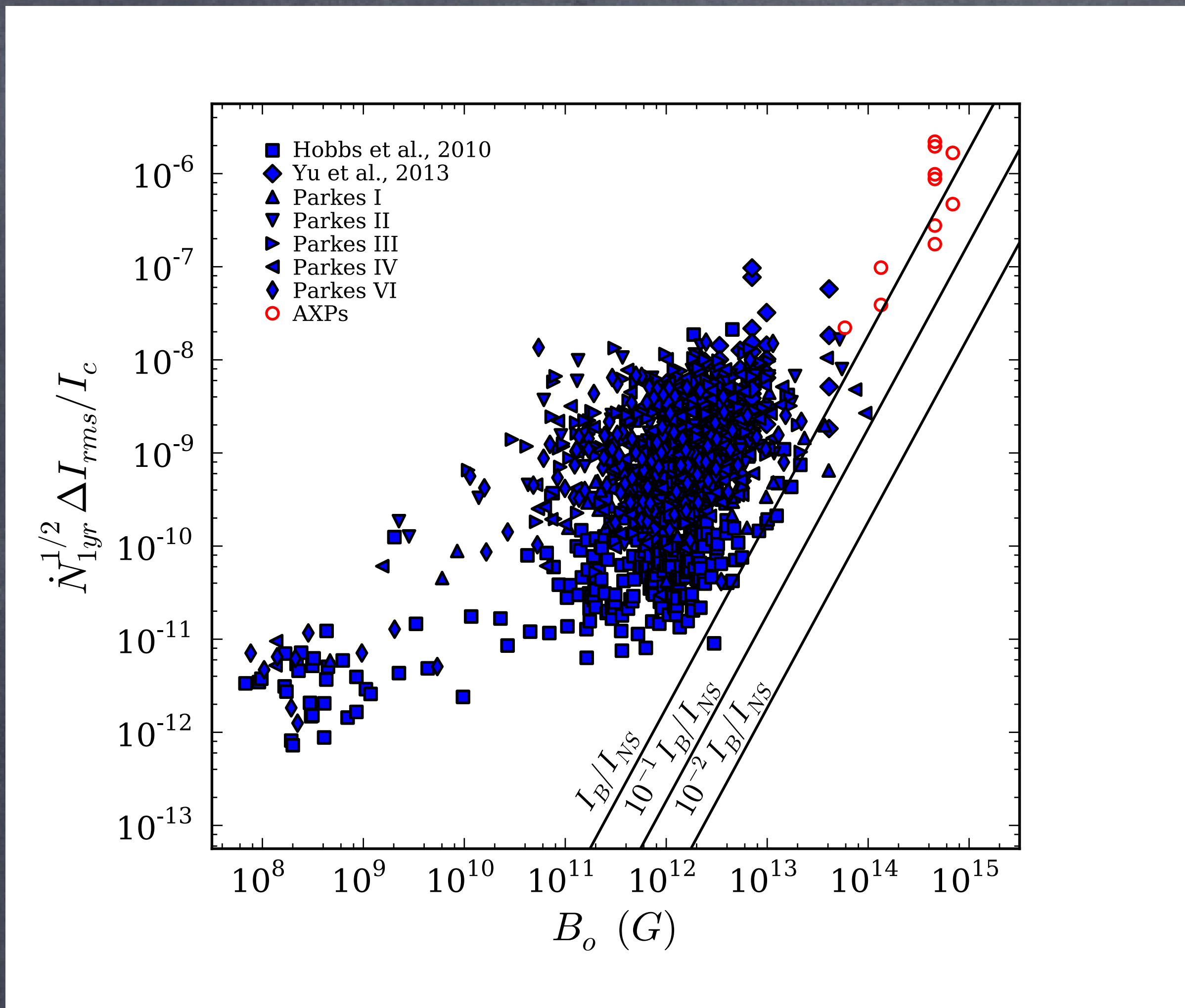


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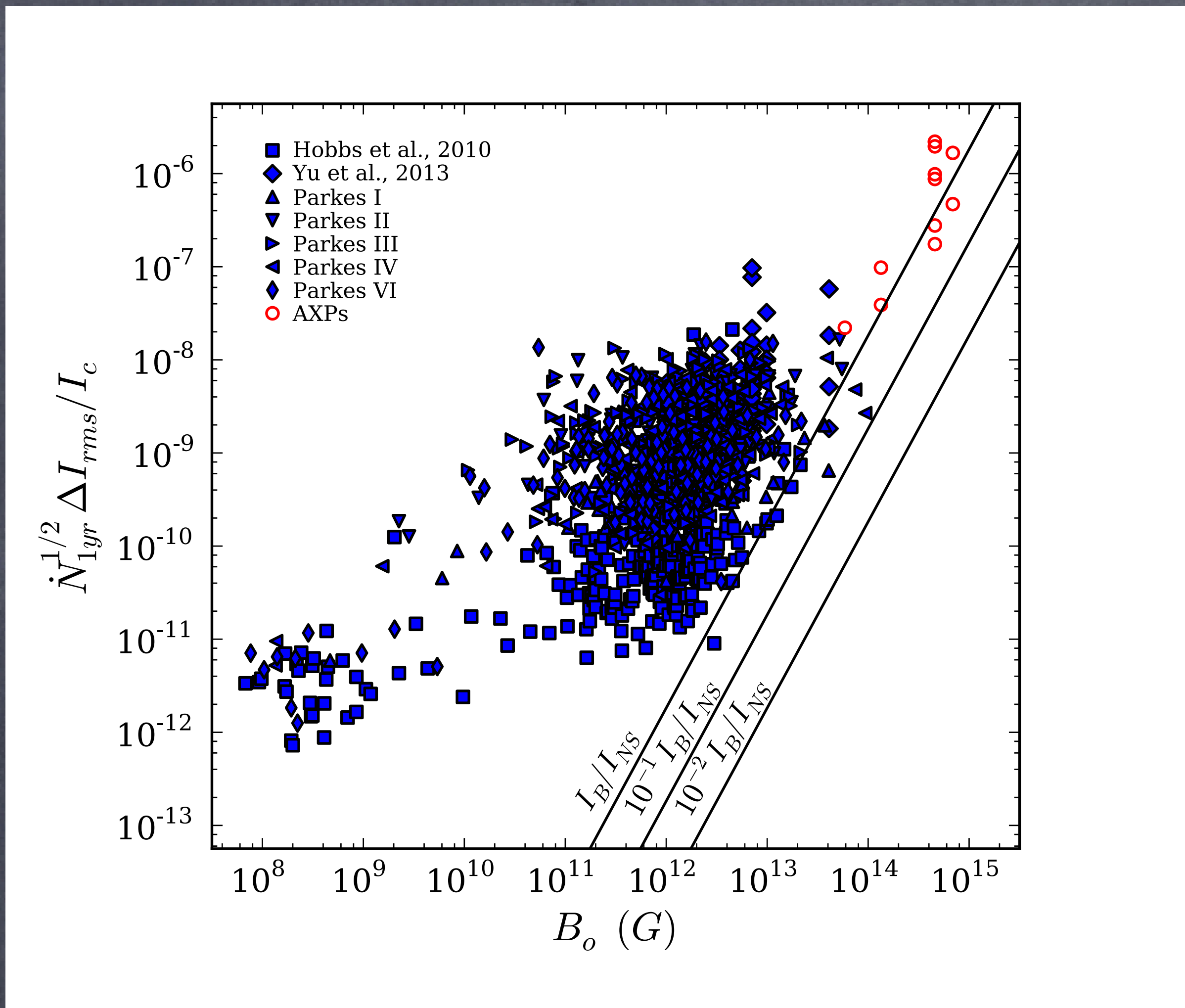


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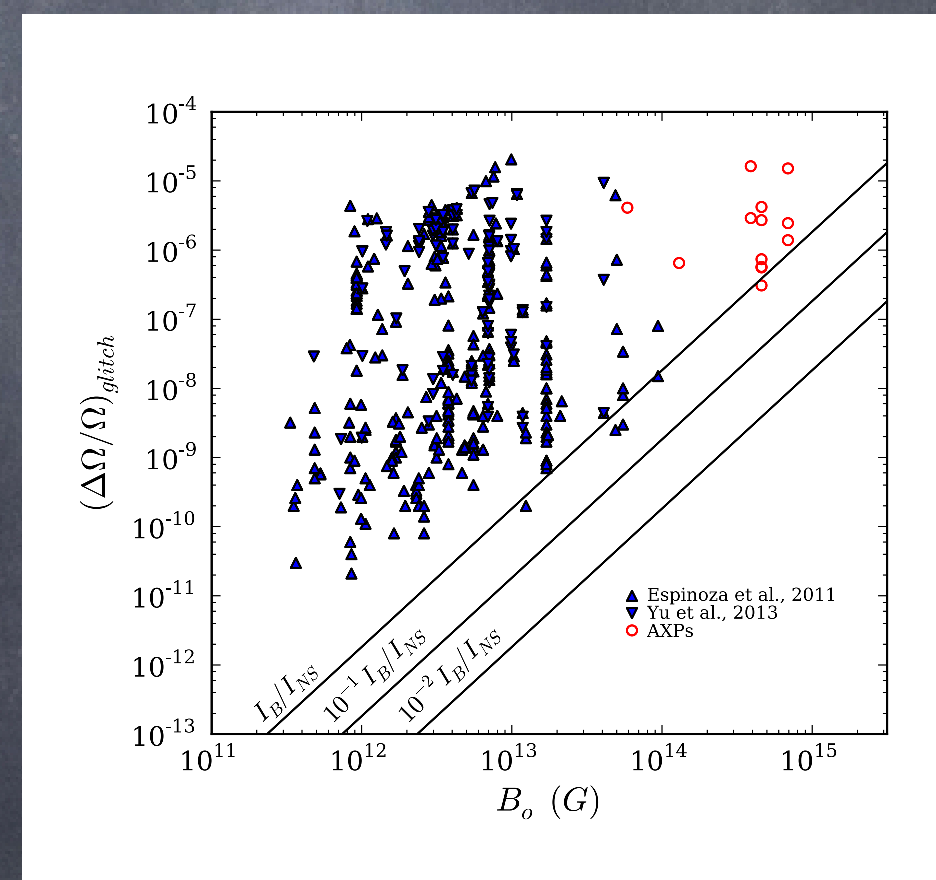

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- A random walk in frequency gives the tightest correlation.
- Assuming that the magnetosphere suffers random variations we expect random steps in frequency.
- We know that the magnetosphere is active (moding - nulling events).
- Such activity shall be seen as timing noise or in extreme cases as glitches.

Thank you!