The PULSAR-MAGNETAR Connection

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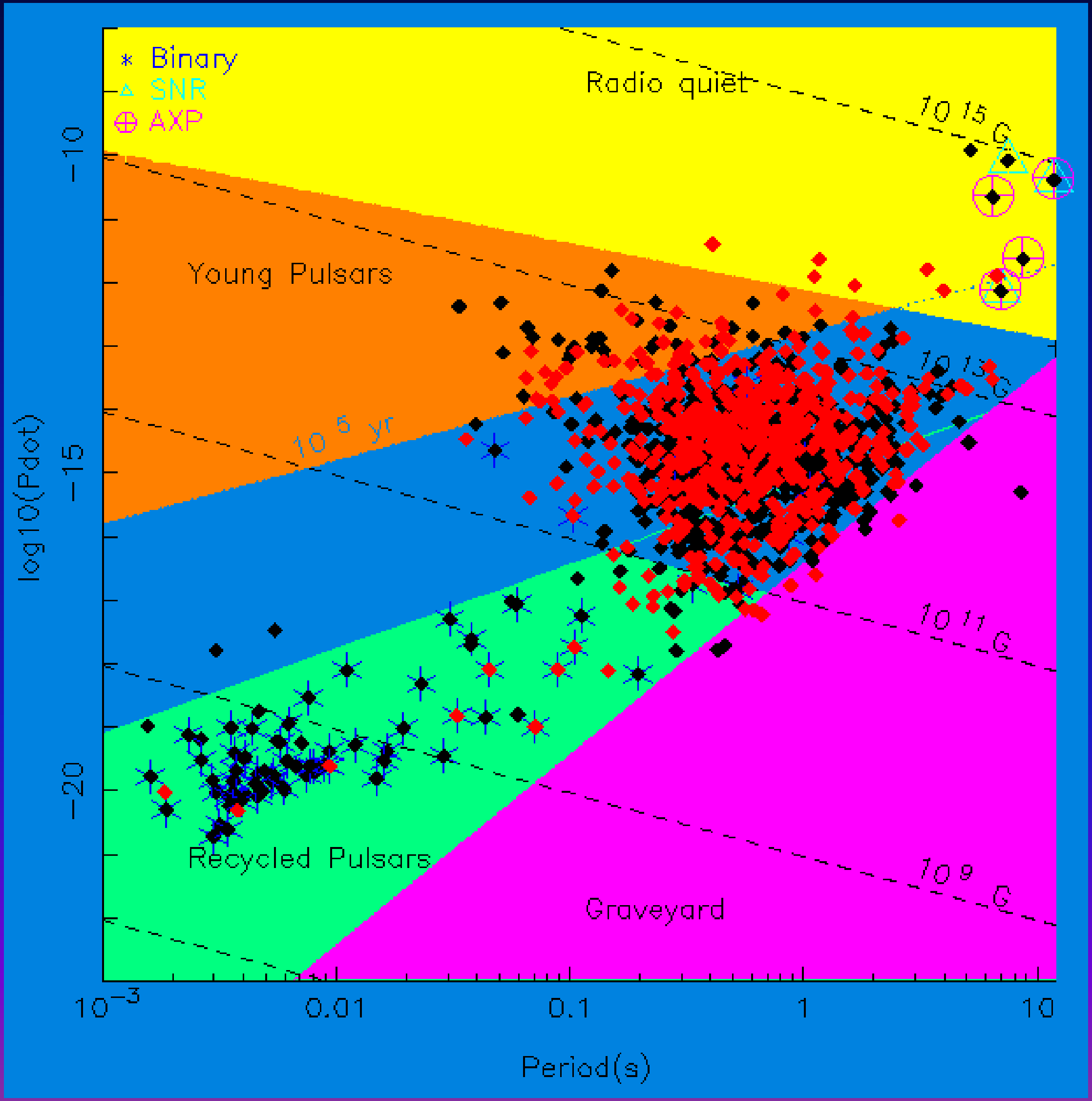
Isolated Neutron Stars, London,
24th April 2006

Introduction

- Four main manifestations of Neutron Stars
  - Radio Pulsars
  - Magnetars (SGRs and AXPs)
  - Isolated Neutron Stars (INSs)
  - Rotating Radio Transients (RRATs)
- How can we identify relationships ?
  - Different formation conditions -> different populations
  - One population evolves into another
- Positions in P/Pdot plane give some clues
- Ideally would like to measure motion in plane
- Explore possibility that young pulsars evolve into magnetars (Lyne, IAU Symposium 218, 2004)

Introduction

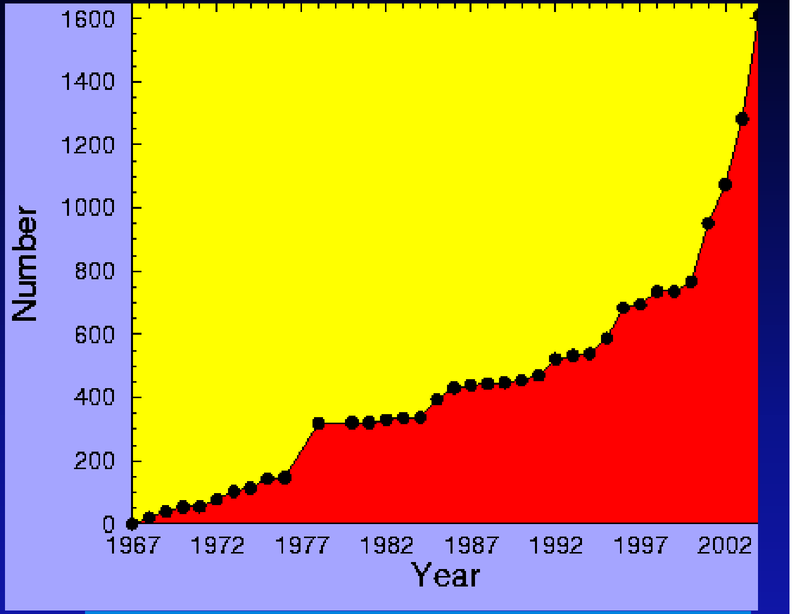


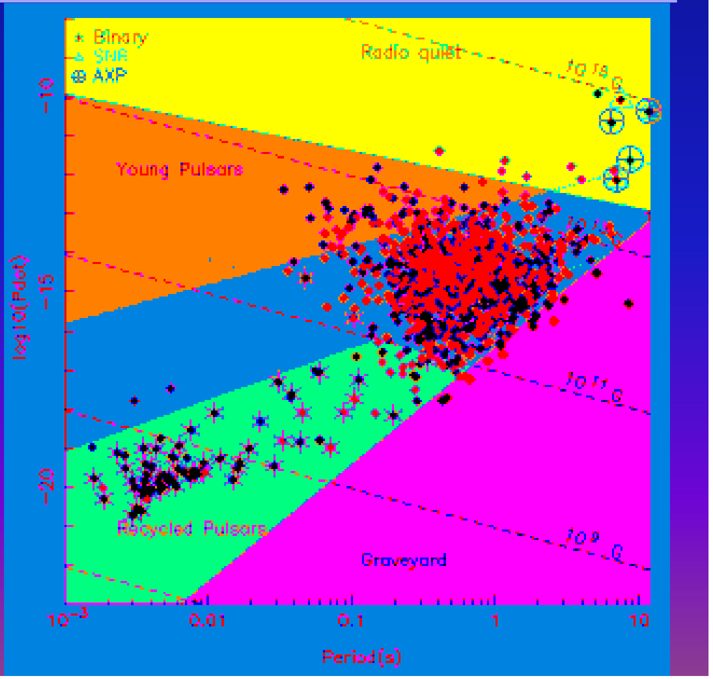
Rotating Radio Transient Sources – RRATS

Mclaughlin et al. 2006, Nature 439, 817-820

- The Parkes Multibeam Pulsar Survey
- New transient sources
- Detection of periodicity
- Galactic population

The Parkes Multibeam Pulsar Survey



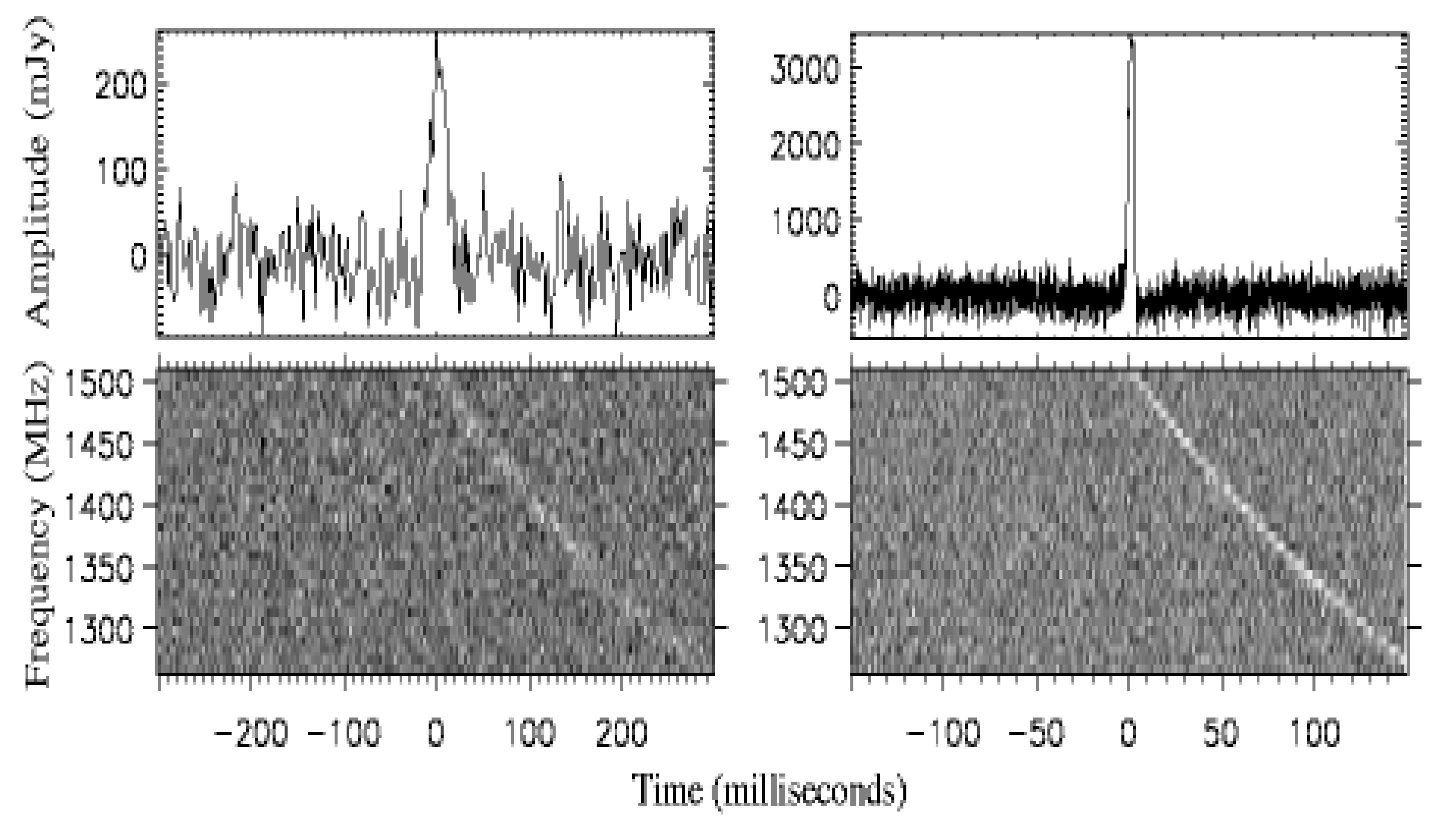


- 13-beam receiver on Parkes 64m radio telescope at 1400 MHz
- Team lead by JBO, ATNF, Cagliari
- 260<l<50, -5<b<+5
- 35-min dwell time
- Most sensitive & most successful
- More than 740 discoveries
- Lots of exciting systems…

Manchester et al. 2001, Morris et al. 2002
Kramer et al. 2003, Hobbs et al. 2004,
Faulkner et al. 2004

Transient Event Search

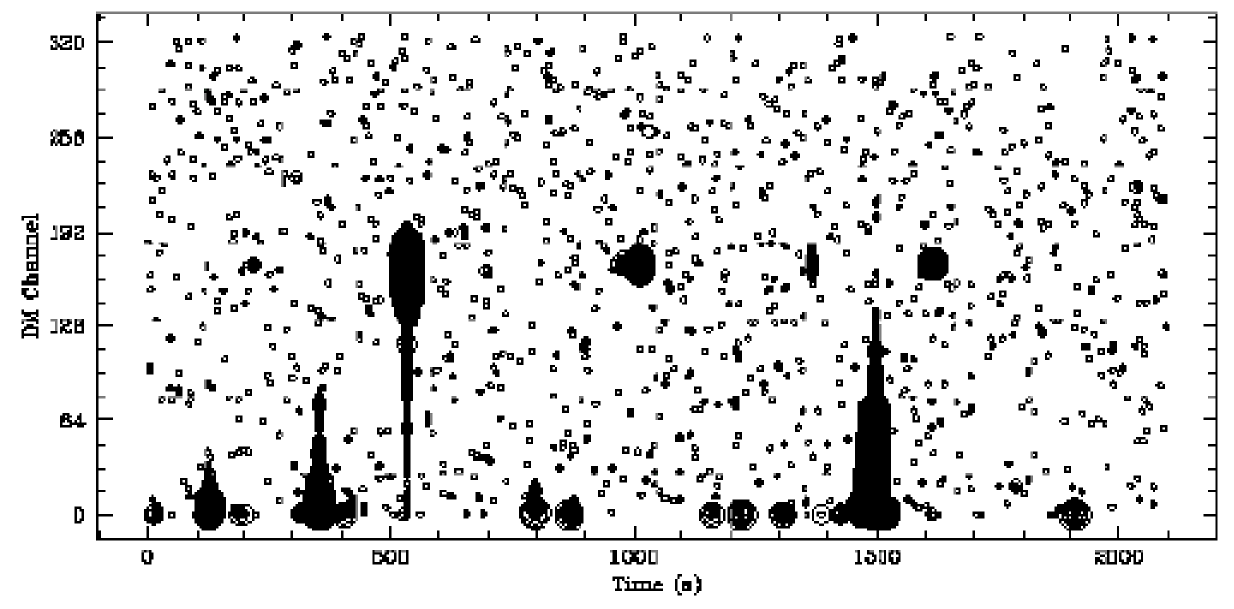
- Conducted a search for single, dispersed transient events in the Parkes Pulsar Multibeam Survey data set
- Good sensitivity to pulsars with occasional “giant” pulses



11 Transient Sources

J1819–1503

DM = 194 pc cm^{-3}



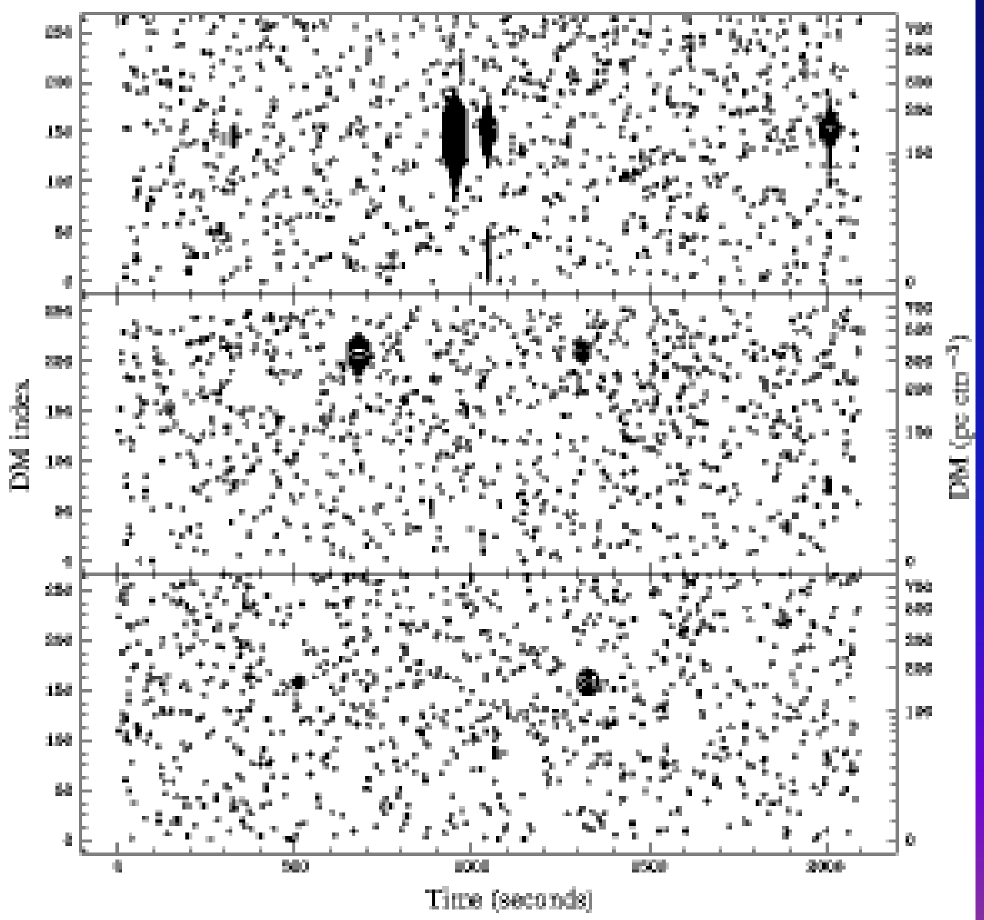
No periodicity detected, but confirmed

11 Transient Sources

J1317-5759

J1443-60

J1826-1429

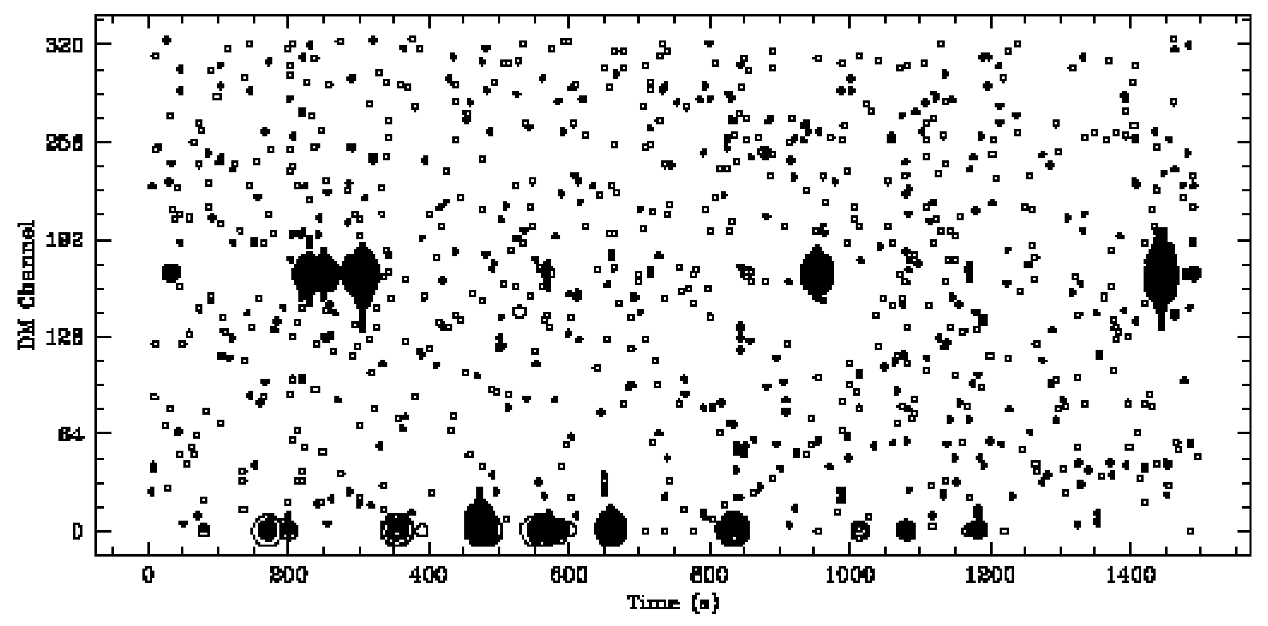


New Transient Sources

- 11 sources confirmed but no periodicities could be detected through standard FFT searches
- Time difference analysis reveals periodicity in 10 sources

J1819–1503

DM = 194 pc cm^{-3}



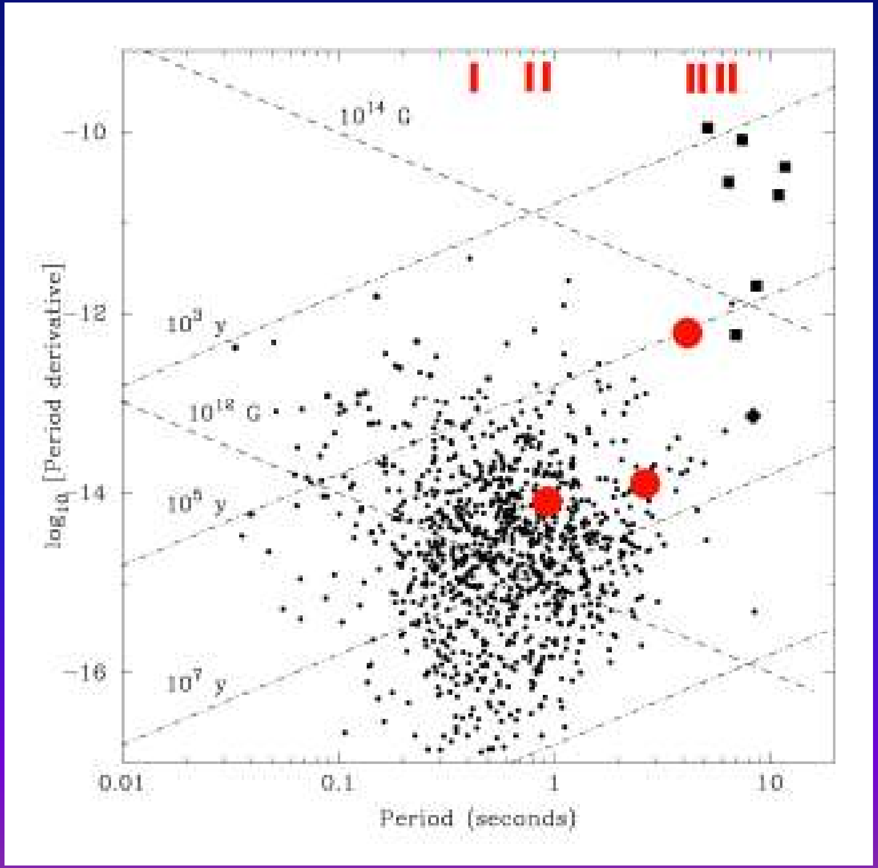
Arrival time differencing reveals period of 4.26 sec

New Transient Sources

- Characteristics of new sources:
  - Burst lengths: 2-30 msec
  - Maximum burst flux density 0.1-4 Jy
  - Mean interval between bursts: 4 min – 3 hrs
  - Periods: 0.4-7sec, <P> =3.1 sec

New Transient Sources

- For 3 of the 10 RRATs with periods, coherent timing solutions have been obtained from burst arrival times
- This gives values of Period Derivative (and position)



  - J1819-1458 has B~0.5×10^{14} Gauss, close to Magnetars
  - All youngish: Age 0.1-3 Myr

New Transient Sources

- Previously unknown Galactic population
  - Concentrated towards plane and inner Galaxy – like normal young pulsar population
  - Selection effects are considerable
  - Only long observing times can detect them
  - Terrestrial impulsive interference is severe, particularly for small DMs
- Galactic population

$$N = 4\mathrm{x}10^5$$

$$\mathrm{x}(L_{min}/10\ \mathrm{mJy\ kpc}^2)\mathrm{x}(0.5/f_{on})\mathrm{x}(0.5/f_{int})\mathrm{x}(0.1/f_b)$$

Summary

- 11 new objects which only radiate for typically 0.1-1 second/day
- Not detectable in periodicity searches or by folding
- Periods found for 10 from time differences
- Probably rotating neutron stars
- Ages 0.1–3 Myr
- Possible relationship with magnetars
- Large galactic population

Neutron Star Spin-down

- NS magnetic fields are calculated as:

$$B = \sqrt{\frac{3c^3}{8\pi^2}\frac{I}{R^6 \sin^2\alpha} P \dot{P}} = 3.2 \cdot 10^{19} \sqrt{P \dot{P}} \text{ Gauss}$$

where P=1/ν

- Characteristic ages are calculated as:

$$\tau = \frac{1}{n-1}\frac{P}{\dot{P}} \overset{n=3}{=} \frac{P}{2\dot{P}}$$

Neutron Star Spin-down

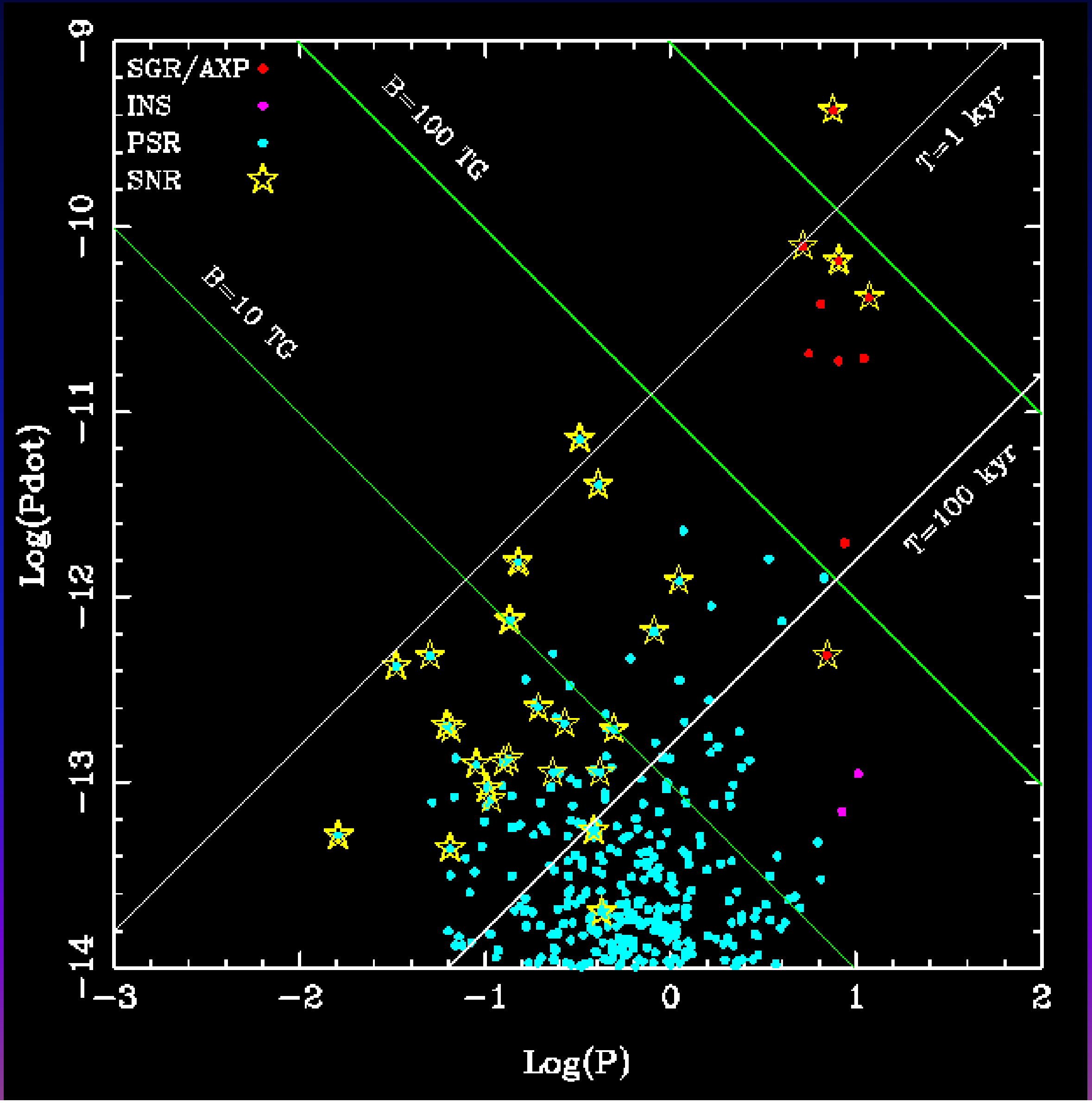
- Neutron star rotation is usually modelled as a power-law slowdown:

$$\dot{\nu} = k\nu^{n}$$

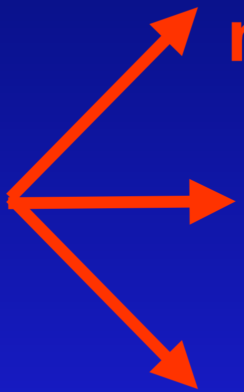
where n is the braking index (3 for dipole)

- Differentiation gives $n=\nu\ddot{\nu}/\dot{\nu}^2$
- Difficult to determine for young pulsars:
  - Perturbations due to gitches
  - Timing noise irregularities
- Long time-baselines required

The P-$\dot{P}$ Diagram



Slope of motion =2-n



n=1

n=2

n=3

Neutron Star Spin-down

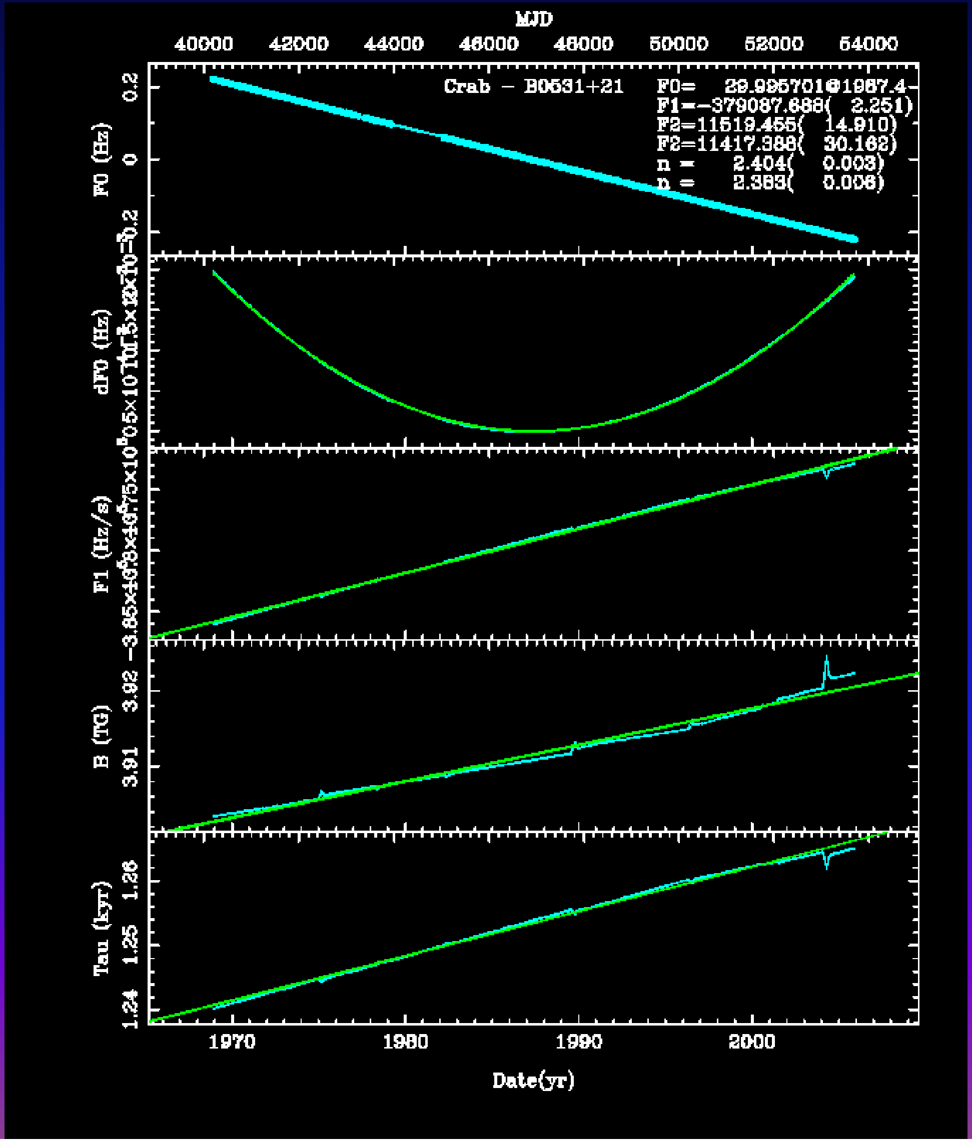
- Slope of motion across P-$\dot{P}$ diagram = 2-n
  - If $n>3$, B decreasing, $d\tau/dt > 1$
  - If $n=3$, B constant, $d\tau/dt = 1$
  - If $n=2$, B increasing, $d\tau/dt = 0.5$
  - If $n=1$, B increasing, τ = constant
  - If $n<1$, B increasing, $d\tau/dt < 0$

Neutron Star Spin-down

- Usually, $n \neq 3$
- For a few pulsars, $n<3$. These
  - have increasing magnetic field
  - are ageing more slowly than the passage of time
- Some examples:

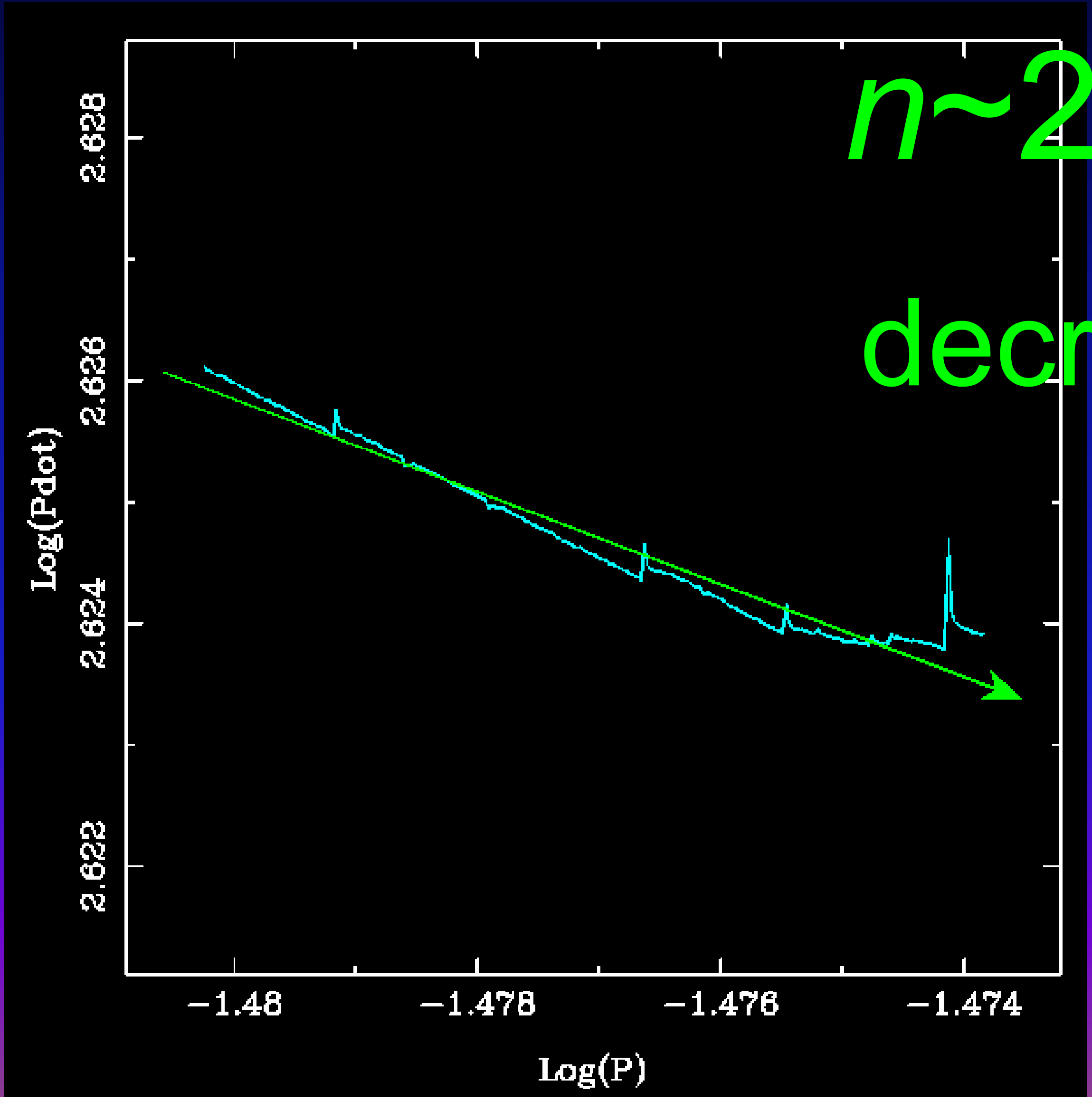
PSR B0531+21

Rotational Frequency Evolution

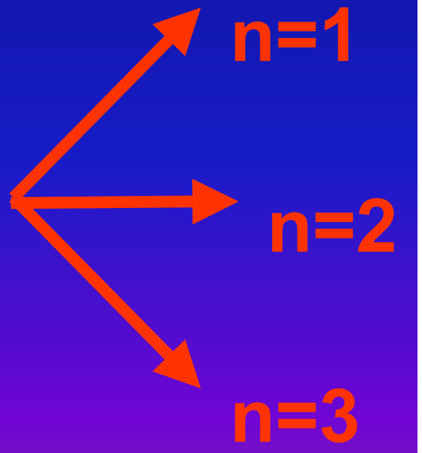


PSR B0531+21

Rotational Frequency Evolution



n~2.4 and decreasing


n=1

n=2

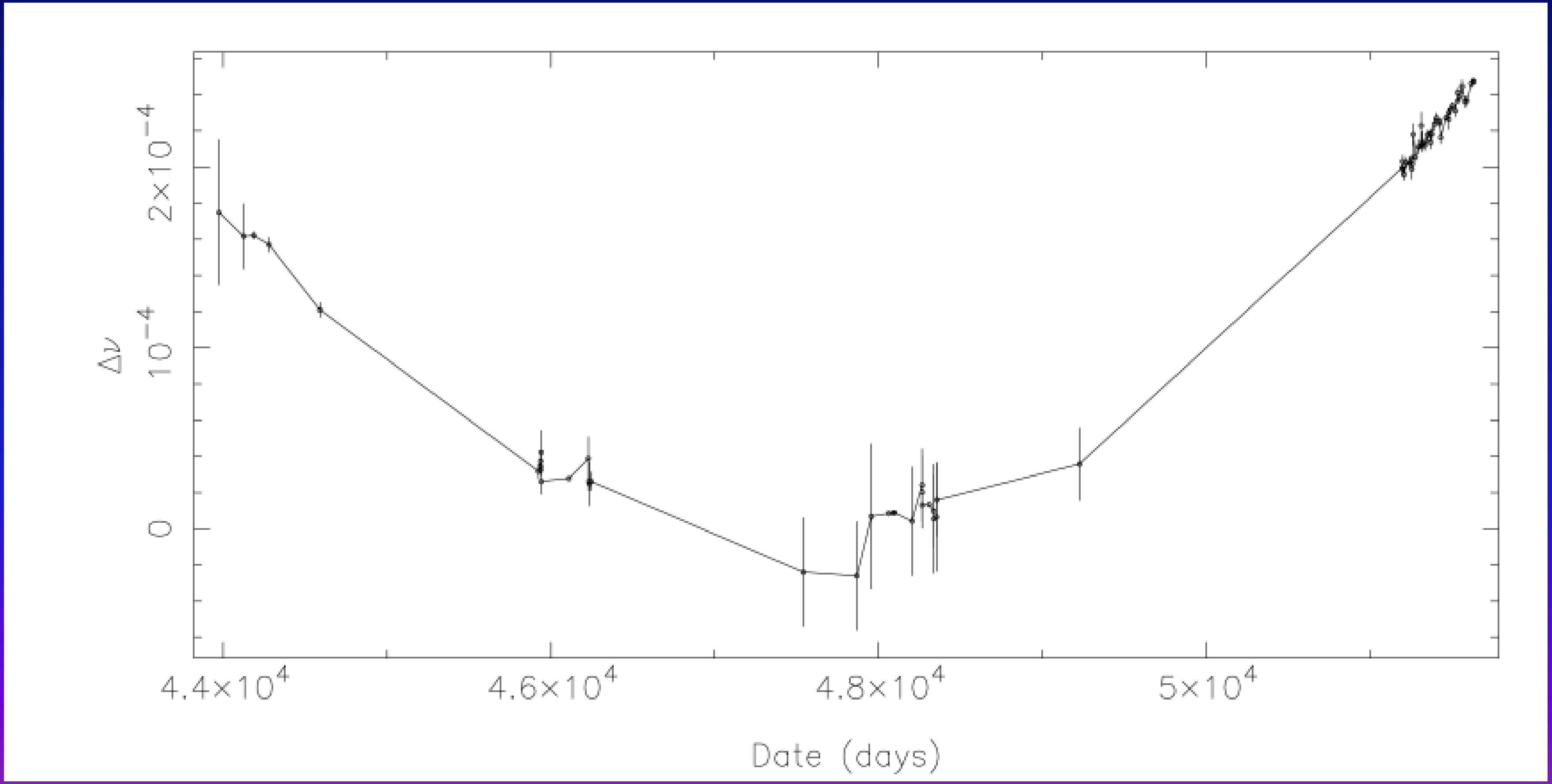
n=3

PSR B0540-69

Rotational Frequency Evolution

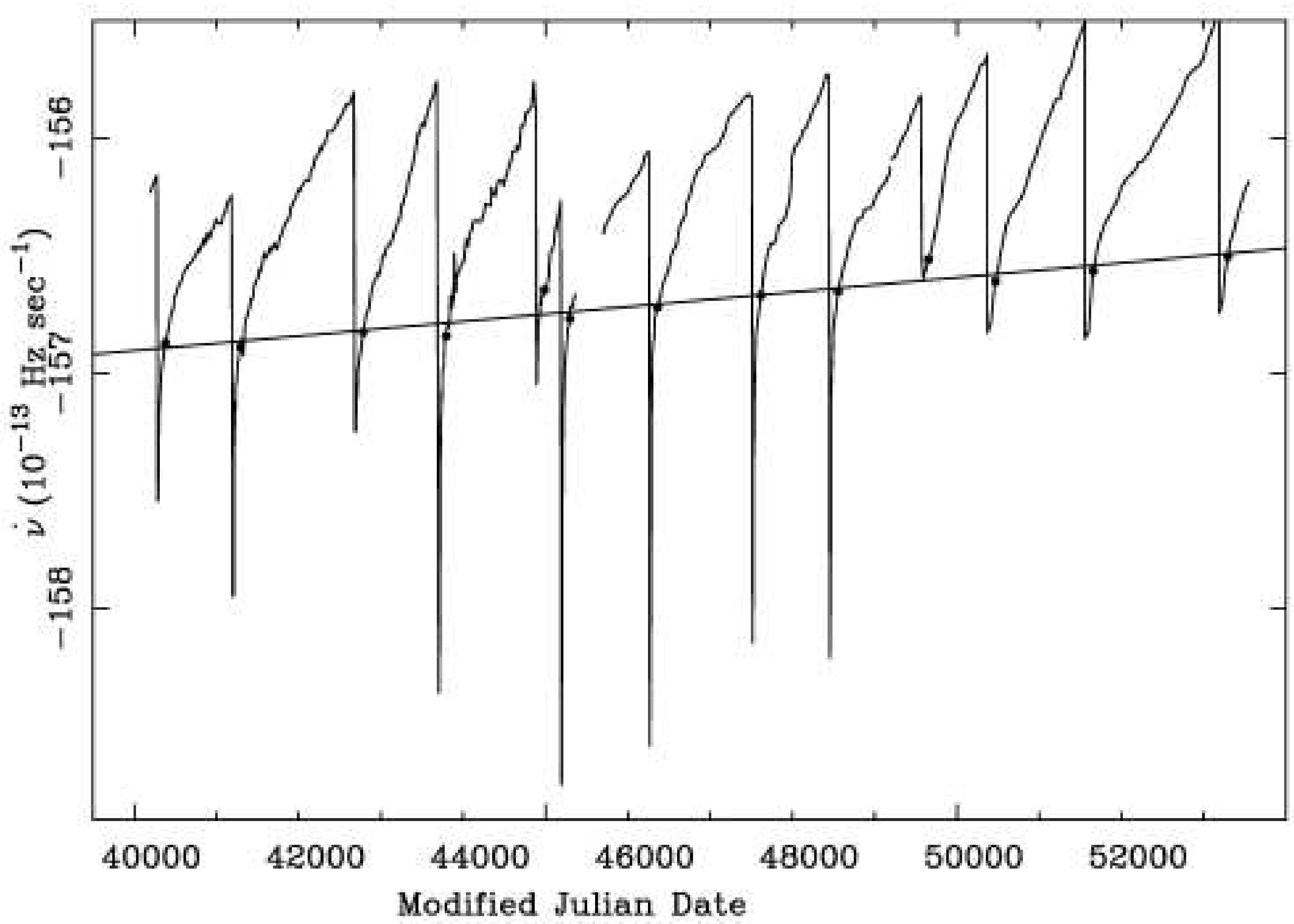
$n \sim 2.0$

See also Livingstone et al 2005



PSR B0833-45

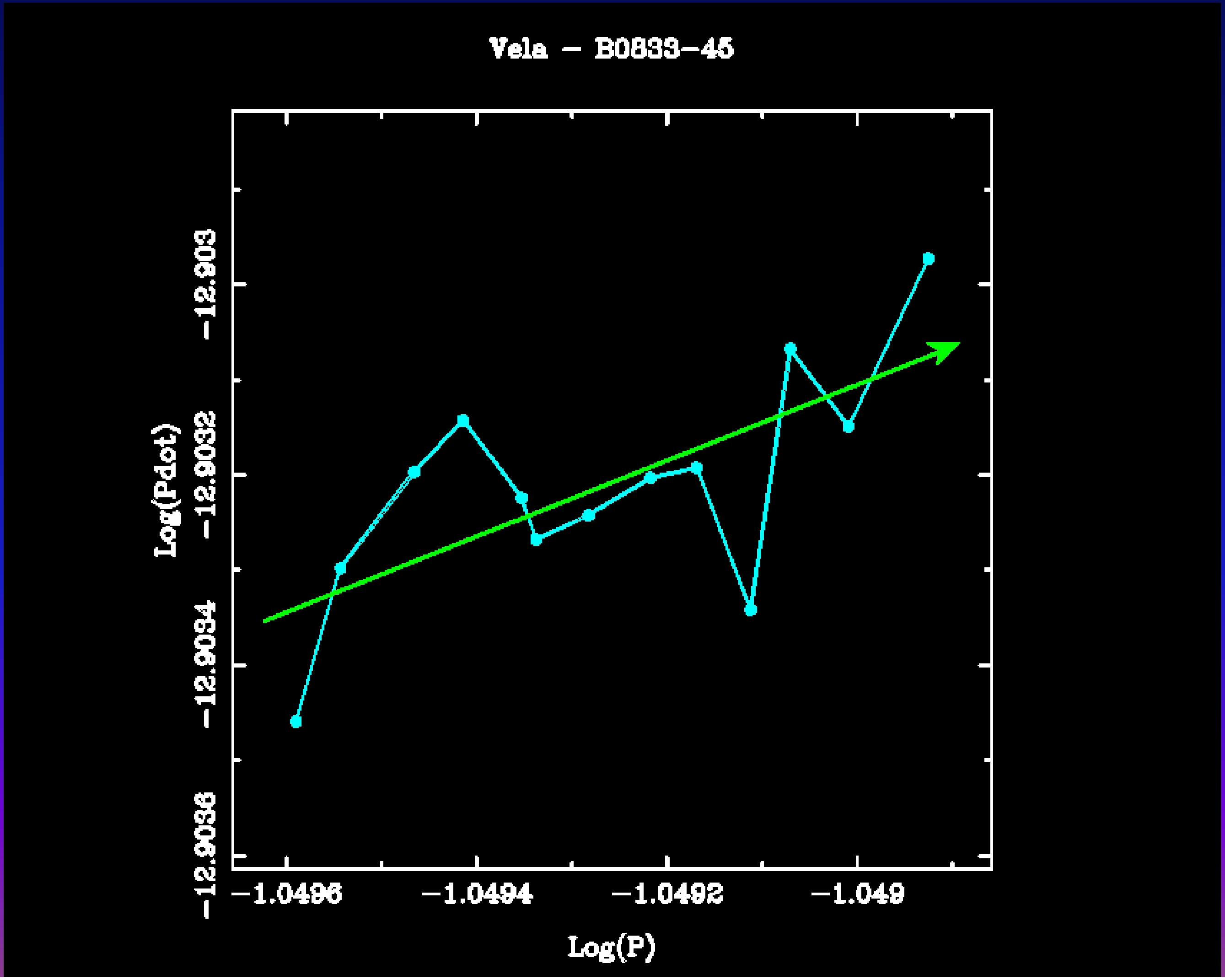
Rotational Frequency Evolution

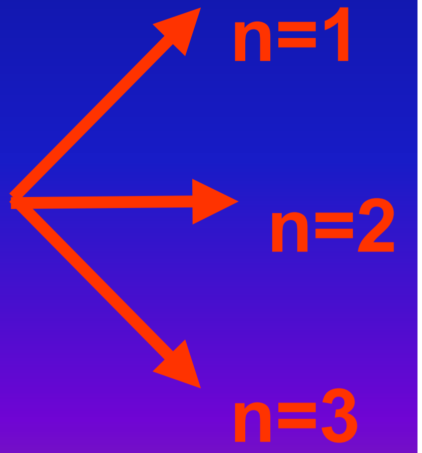


PSR B0833-45

Rotational Frequency Evolution

$n \sim 1.5$



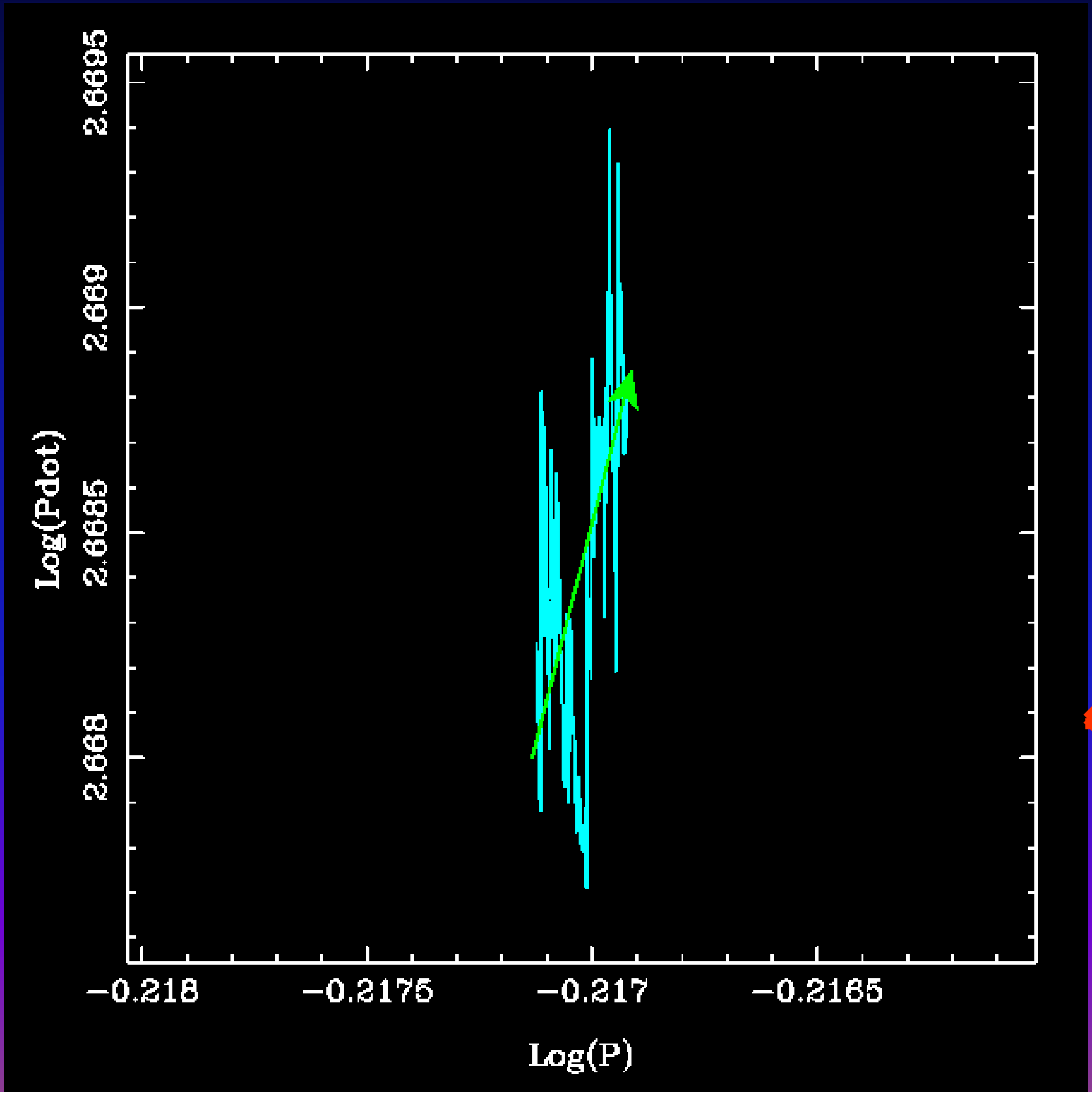

n=1

n=2

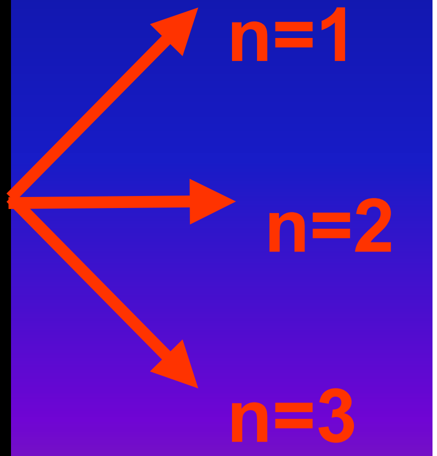
n=3

PSR B1737-30

Rotational Frequency Evolution

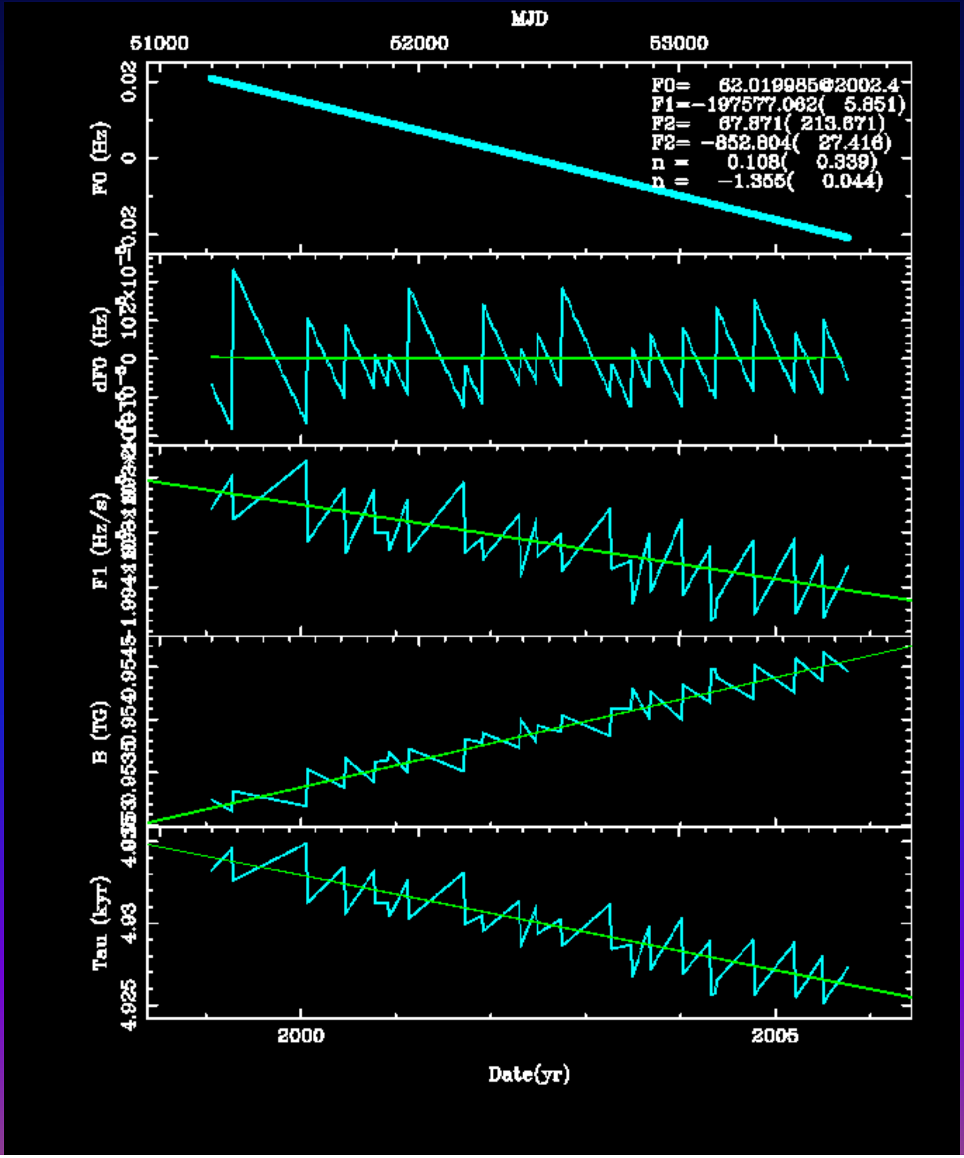


$n \sim -1$



PSR J0537-6910

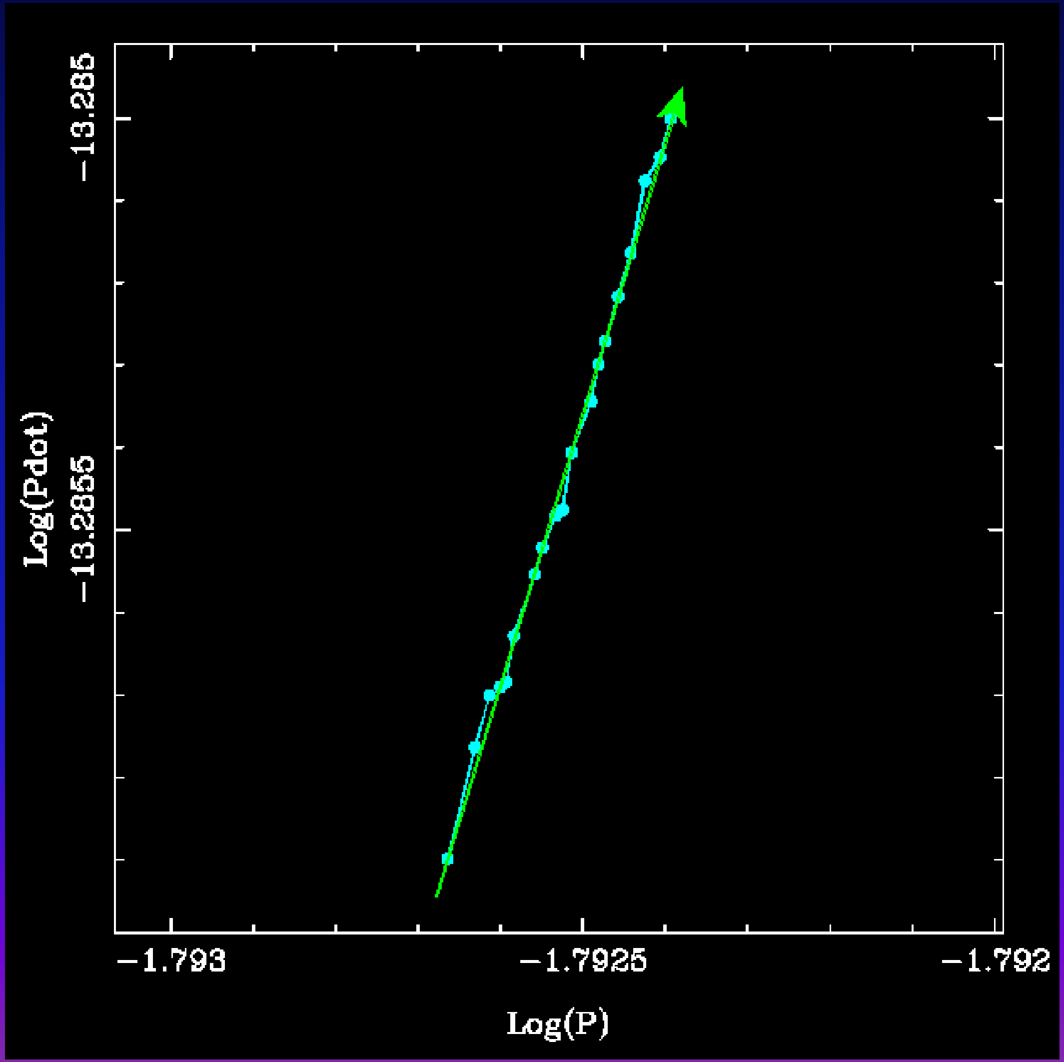
Rotational Frequency Evolution



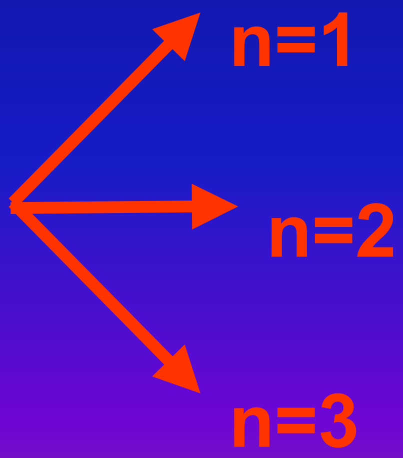
Marshall et al 2004
Middleditch et al 2005

PSR J0537-6910

Rotational Frequency Evolution



$n=-1.3$

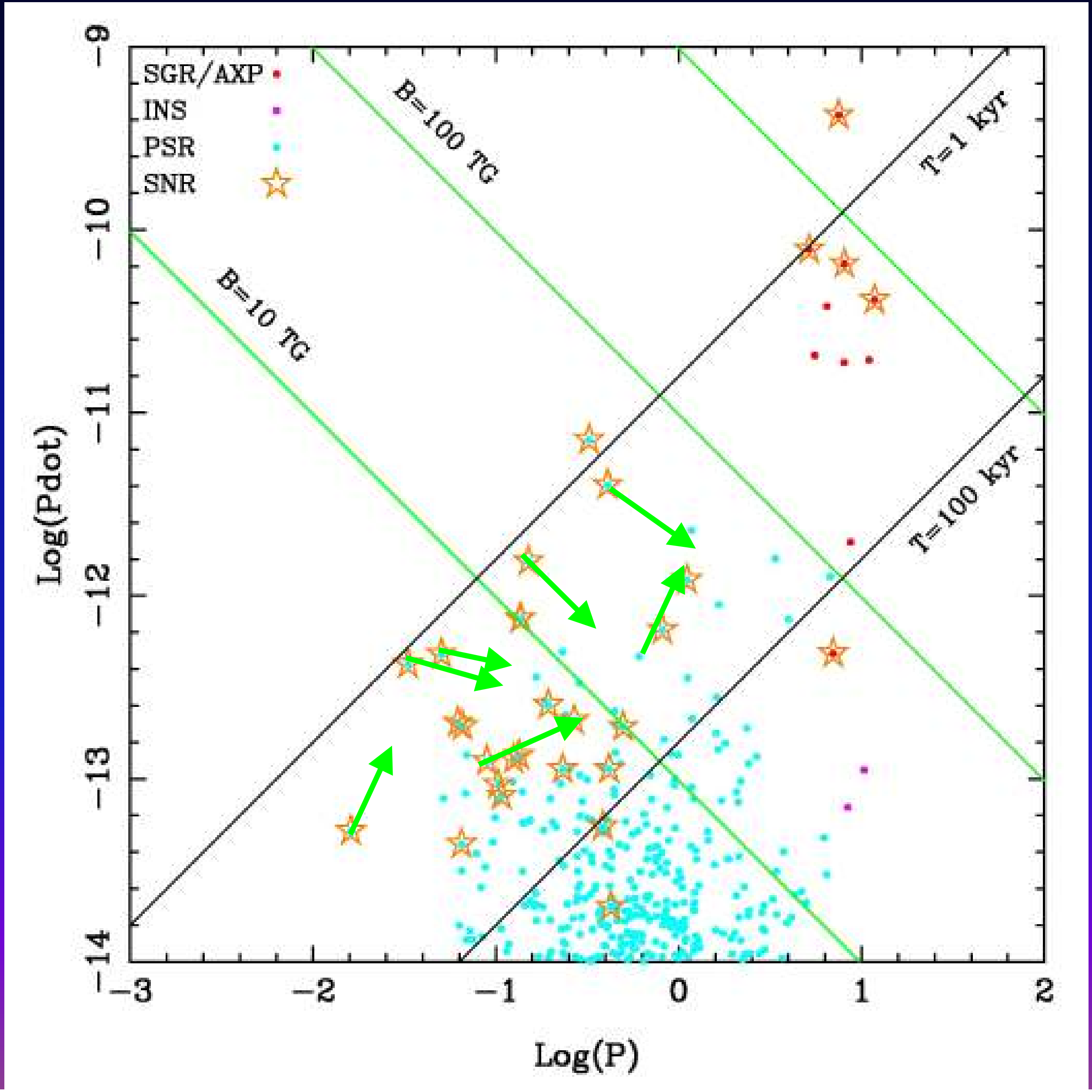


n=1

n=2

n=3

Motion in the P-$\dot{P}$ Diagram



Conclusions

- Most PSR glitches are associated with increase in B
- Prolific glitchers have rapidly increasing B
- Characteristic ages increase only slowly with time or even decrease
- Motion of some pulsars on P-Pdot diagram is consistent with travel from Crab to magnetars
  - Continuum of pulsars along track
  - Are RRATs an intermediate phase ?
- For n=1, time for travel ~ $2\tau.\ln(B_f/B_i)$ yr
  - ~10kyr for Crab, ~100 kyr for Vela
- Implies Magnetars are much older than Char Ages
  - Explains paucity of SGR/AXP SNR assocns
  - Explains large offset of SGR from SNR centres, without invoking massive velocities