The PULSAR-MAGNETAR Connection

Andrew Lyne
University of Manchester, UK

Isolated Neutron Stars, London,
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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: 0.4-7 sec, \(<P>\) = 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 $B \sim 0.5 \times 10^{14}$ 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
  \[ N = 4 \times 10^5 \times \left( \frac{L_{\text{min}}}{10 \text{ mJy kpc}^2} \right) \times \left( \frac{0.5}{f_{\text{on}}} \right) \times \left( \frac{0.5}{f_{\text{int}}} \right) \times \left( \frac{0.1}{f_b} \right) \]
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:

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

where \( P = 1/\nu \)

- Characteristic ages are calculated as:

\[ \tau = \frac{1}{n-1} \frac{P^{n=3}}{\dot{P}} = \frac{P}{2P} \]
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-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, $\tau = \text{constant}$
  - 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

\[ n \approx 2.4 \text{ and decreasing} \]
PSR B0540-69
Rotational Frequency Evolution

$n \approx 2.0$

See also Livingstone et al 2005
PSR B0833-45
Rotational Frequency Evolution
PSR B0833-45
Rotational Frequency Evolution

$n \sim 1.5$

Vela - B0833-45

Log(Pdot) vs. Log(P)

$n=1$
$n=2$
$n=3$
PSR B1737-30

Rotational Frequency Evolution

$n \sim -1$

$n=1$, $n=2$, $n=3$
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 $\sim 2\tau \ln(B_f/B_i)$ yr
  - $\sim 10$ kyr for Crab, $\sim 100$ 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