New Transient sources - RRATs and Intermittent Pulsars

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Introduction

- Repeating Radio Transient sources (RRATs)
  - The phenomenon
  - Properties
  - Relationship to other pulsars?
  - Galactic population

- PSR B1931+24 and other Intermittent Pulsars
  - The phenomenon
  - The changing slow-down rate
  - Implications for magnetospheric physics
  - Galactic population
Rotating Radio Transient Sources – RRATs

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

Discovered in the the Parkes Multibeam Pulsar Survey .....
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
New Transient Sources

J1819–1503

DM = 194 pc cm$^{-3}$

No periodicity detected, but confirmed as source of pulses
New Transient Sources

J1317-5759

J1443-60

J1826-1429
New Transient Sources

- 11 sources confirmed
- FFT searches showed no periodicity
- Time difference analysis shows periodicity in all 11 sources

J1819–1503

DM = 194 pc cm$^{-3}$

Arrival time differencing reveals period of 4.26 sec
New Transient Sources

- Characteristics of new sources:
  - Single bursts of length 2-30 msec
  - Maximum burst flux density 0.1-4 Jy
  - Mean interval between bursts: 4 min – 3 hrs
  - Periods: 0.4-7 sec, $<P> = 3.6$ sec
- Periodicities suggest rotating NS
- Can time like normal pulsars, but using single pulses
New Transient Sources

- For 4 of the 11 RRATs, coherent timing solutions have been obtained from burst arrival times.
- This gives values of Period Derivative (and position).

- J1819-1458 has $B \approx 0.5 \times 10^{14}$ Gauss, close to Magnetars and XDINS.
- All youngish: Age 0.1-3 Myr.
New Transient Sources

- Serendipitous detection of J1819-1458 in 30ks Chandra observation of field (Reynolds et al 2006)
- New detection in 40ks XMM Epic PN observation

\[ \sim \text{BB, } T=0.14 \text{ keV} \]
\[ \sim 30\% \text{ modulation} \]

McLaughlin et al 2007, in preparation
New Transient Sources

- Spectral lines at 0.5 and 1 keV – likely to be proton cyclotron absorption
- If so, implies $B \sim 0.7 \times 10^{14}$ G. Consistent with $B_{\text{surf}} = 0.5 \times 10^{14}$ G from spin-down
- *Possibly* atmospheric in origin

McLaughlin et al 2007, in preparation
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
  \[ N = 2 \times 10^5 \times \left( \frac{L_{\text{min}}}{100 \text{ mJy kpc}^2} \right) \times \left( \frac{0.5}{f_{\text{on}}} \right) \times \left( \frac{0.5}{f_{\text{int}}} \right) \times \left( \frac{0.1}{f_{\text{b}}} \right) \]
Summary

- 11 ephemeral objects which only radiate for typically 0.1-1 second/day
- Not detectable in periodicity searches or by folding
- Periods found from time differences
- Probably rotating neutron stars
- Ages 0.1–3 Myr
- Young cooling NSs?
- Large galactic population
PSR B1931+24 and other Intermittent Pulsars

(Kramer, Lyne, O’Brien, Jordan and Lorimer 2006 Science, 312, 549)

- Seemingly ‘normal’ pulsar, discovered at Green Bank
- Monitored in Jodrell Bank timing programme
PSR B1931+24

It looks like an ordinary pulsar... when you see it!
Sometimes a pulsar...

- 'ON' for 1 week, 'OFF' for 1 month
- Only visible for ~20% of time
- Relatively strong when 'ON'
- Deep observations do not show any emission when 'OFF'
- Broadband phenomenon
- Complete radio emission is shut off in <10 sec to remain off for ~month
Sometimes a pulsar...

... and the whole process is (quasi-) periodic!
What causes phenomenon?

- **Is this related to “Nulling”?**
  - Emission $\ll$ mean pulse power
  - Durations of typically a few pulse periods
  - No nulls in B1931+24 during ‘ON’ phase

- **Is the periodicity due to Free Precession?**
  - Expect slow periodic wobble
  - But switches ‘OFF’ in $<10$ seconds
  - No profile changes
  - Therefore probably not precession
  - Probably some relaxation oscillation of unknown origin, internal to NS
More surprises...

- 50% increase in $d\nu/dt$!
- Timing can be well modelled when including this effect

...the spin-down is faster when on!
The facts and their explanation...

- Pulsar is active in periodic fashion
- When the pulsar emits radio emission, the braking is greatest
- When the radio emission is shut off, the braking is less

Simplest explanation:
- both radio emission and increased braking arise from magnetospheric plasma currents
- the plasma creating the radio emission provides the extra torque
- no currents, no radio, only magnetic braking
• First observational evidence for pulsar wind torque
• First ever chance to test basic magnetospheric theories
• Confirmation of Pacini & Goldreich-Julian models 39/37 years after they have been proposed

... in a rather unexpected fashion!

M. Kramer
We can do more...!

We observe different losses in rotational energy:

\[ \dot{E}_{ON} = 4\pi^2 I \nu \dot{\nu}_{ON} \quad \dot{E}_{OFF} = 4\pi^2 I \nu \dot{\nu}_{OFF} \]

In our simple model:

\[ \dot{E}_{ON} = \dot{E}_{OFF} + \dot{E}_{Wind} \]

The wind contributions contains information about the torque and hence charge density in the current associated with radio emission:

\[ \dot{E}_{Wind} = \dot{E}_{ON} - \dot{E}_{OFF} = \Omega T \]

\[ T = \frac{2}{3c} j B_0 R_{pc}^2 \quad j = c \pi R_{pc}^2 \rho \]
The charge density

We find:

\[ \rho = \frac{3I(v_{ON} - v_{OFF})}{R_{pc}^4 B_0} \]

Based on observations, canonical values for size and moment of inertia, and computing magnetic field from OFF-period spin-down:

\[ \rho = 0.034 \frac{C}{m^3} \]

Goldreich & Julian predict:

\[ \rho_{GJ} = \frac{B_0}{Pc} = 0.033 \frac{C}{m^3} \]
Any more like this?

- Many more should exist
- Inspected Parkes Multibeam Pulsar Survey
- Any amongst 750 new pulsars found?
Yes! 4 more!!
Properties: J1107-5907

- Exhibits 3 different emission states
- Period = 253 ms
- Unusually small period derivative = $1.13(6) \times 10^{-17}$
- Large characteristic age = 354 Myr

=> Interesting region – normal / recycled pulsars
Properties: J1717-4054

- Observations show ‘on’ < 20% time
- No periodicity yet
Properties: J1634-5107

- Strong ‘ON’ state
- Completely ‘OFF’ state
- Quasi-periodicity ~ 10 days
Properties: J1832+0029

- Discovered in PMPS
- ‘ON’ state >300 days
- ‘OFF’ state ~600 days

- Increase in slow-down rate during ‘ON’ state

\[
\frac{(dv/dt)_{ON}}{(dv/dt)_{OFF}} = 1.8 \pm 0.1
\]
Conclusions

- Some pulsars cease emitting for long periods
- PSR B1931+24 showed new bursty behaviour on a quasi-periodic timescale
- Found 4 other similar pulsars
- From simple calculations, they represent a significant fraction of Galactic population
- Provide evidence that particles play large role in slow-down – a handle on particle densities
Conclusions

- What is the origin of the periodicity?
- Why does the particle flow fail?
- Are there ANY particles during ‘OFF’ phase?
- What happens in other wavebands?
- Need to expand observational base of phenomenon (more pulsars)
- Maybe ALL nulling is associated with failure of particle flow – only testable in pulsars with switch timescales >> days
RRATs and Intermittent Pulsars require large amounts of conventional telescope time to find and study.

Instruments like LOFAR and other wide FoV telescopes should open up such new fields and reveal:

- major new populations
- unforseen new insights into NS physics
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 \( P = 1/\nu \)

- Characteristic ages are calculated as:
  \[
  \tau = \frac{1}{n - 1} \frac{P}{P} = \frac{P}{2P}
  \]