The University of Manchester
Jodrell Bank Observatory

New Transient sources - RRATs and Intermittent Pulsars

MANCHESTER 1824

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PPARC

Introduction

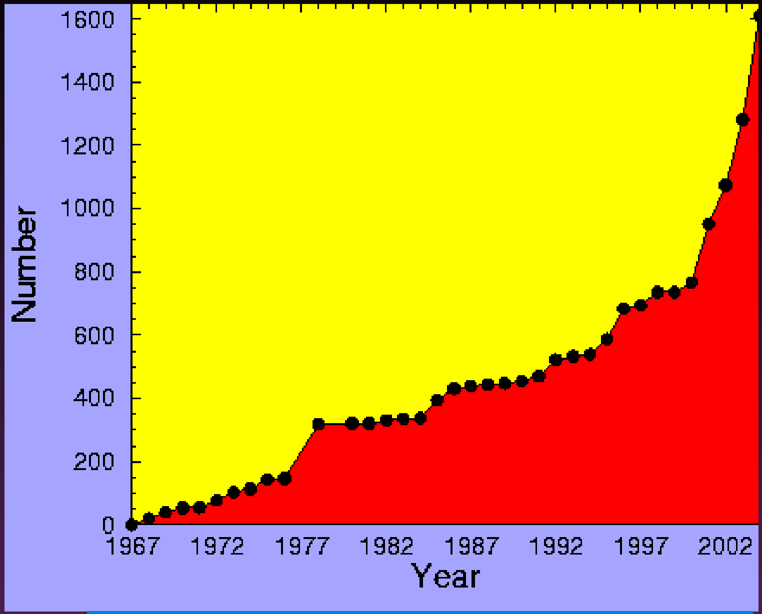
- Repeating Radio Transient sources (RRATs)
  - The phenomenon
  - Properties
  - Relationship to other pulsars ?
  - Galactic population
- PSR B1931+24 and other Intermittent Pulsars
  - The phenomenon
  - The changing slow-down rate
  - Implications for magnetospheric physics
  - Galactic population

Rotating Radio Transient Sources – RRATs

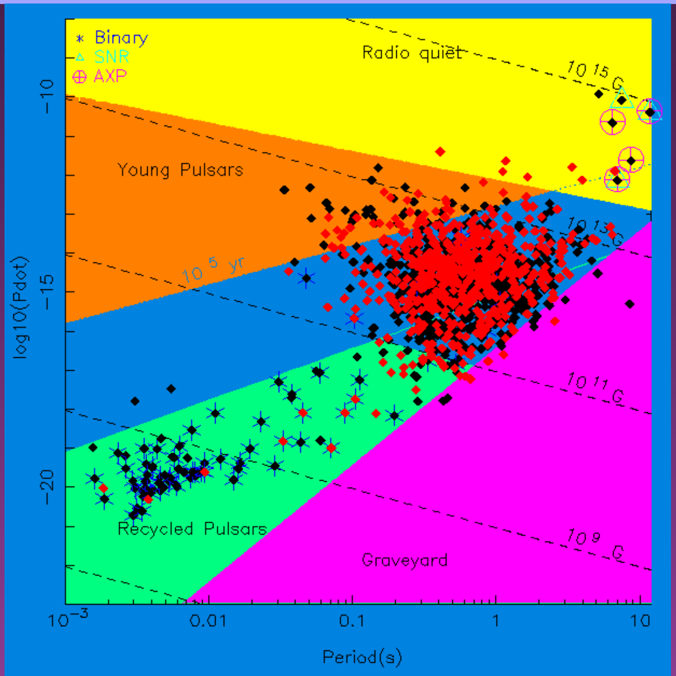
Mclaughlin et al. 2006, Nature 439, 817-820

Discovered in the the Parkes Multibeam Pulsar Survey …..

The Parkes Multibeam Pulsar Survey



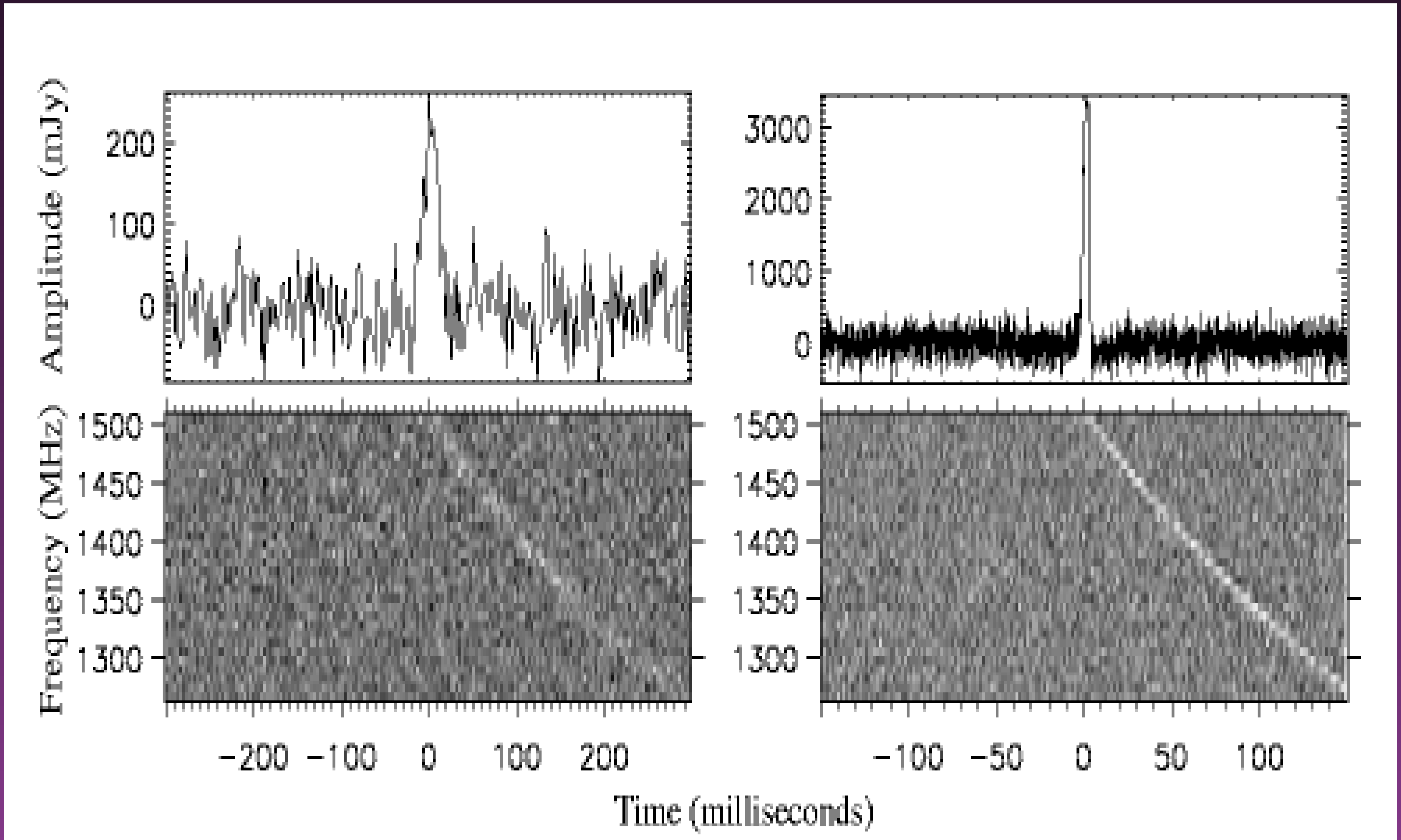
- 13-beam receiver on Parkes 64m radio telescope at 1400 MHz
- Team lead by JBO, ATNF, Cagliari
- $260<l<50$, $-5<b<+5$
- 35-min dwell time
- Most sensitive & most successful
- More than 740 discoveries
- Lots of exciting systems…



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

Transient Event Search

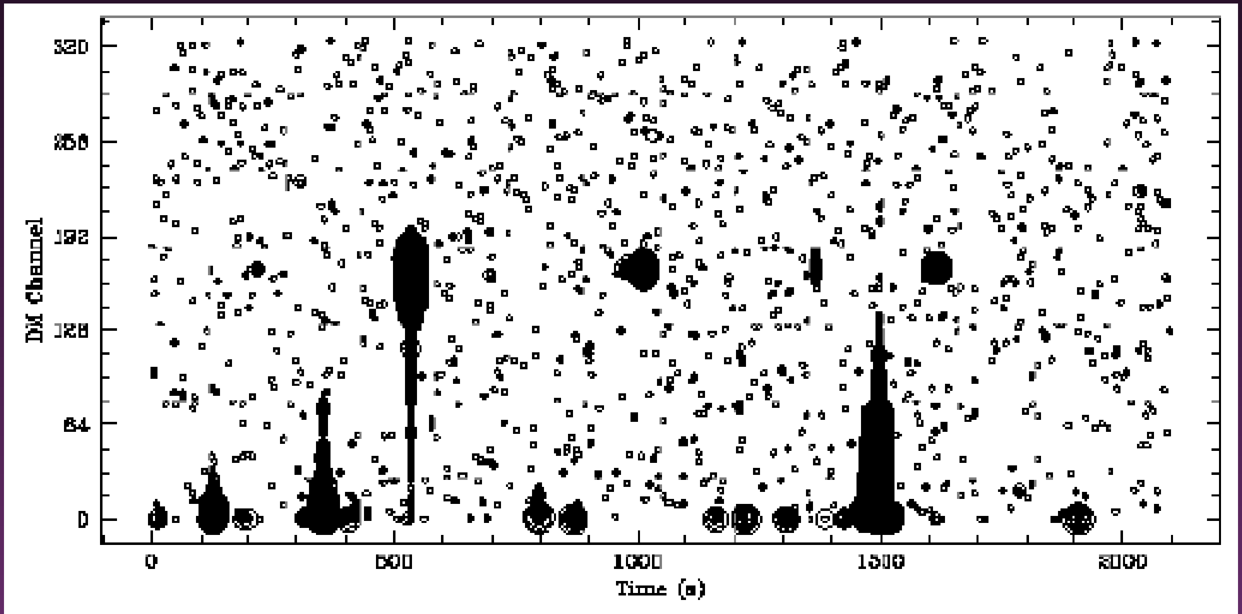
- Conducted a search for single, dispersed transient events in the Parkes Pulsar Multibeam Survey data set
- Good sensitivity to pulsars with occasional “giant” pulses



New Transient Sources

J1819–1503

DM = 194 pc cm^{-3}



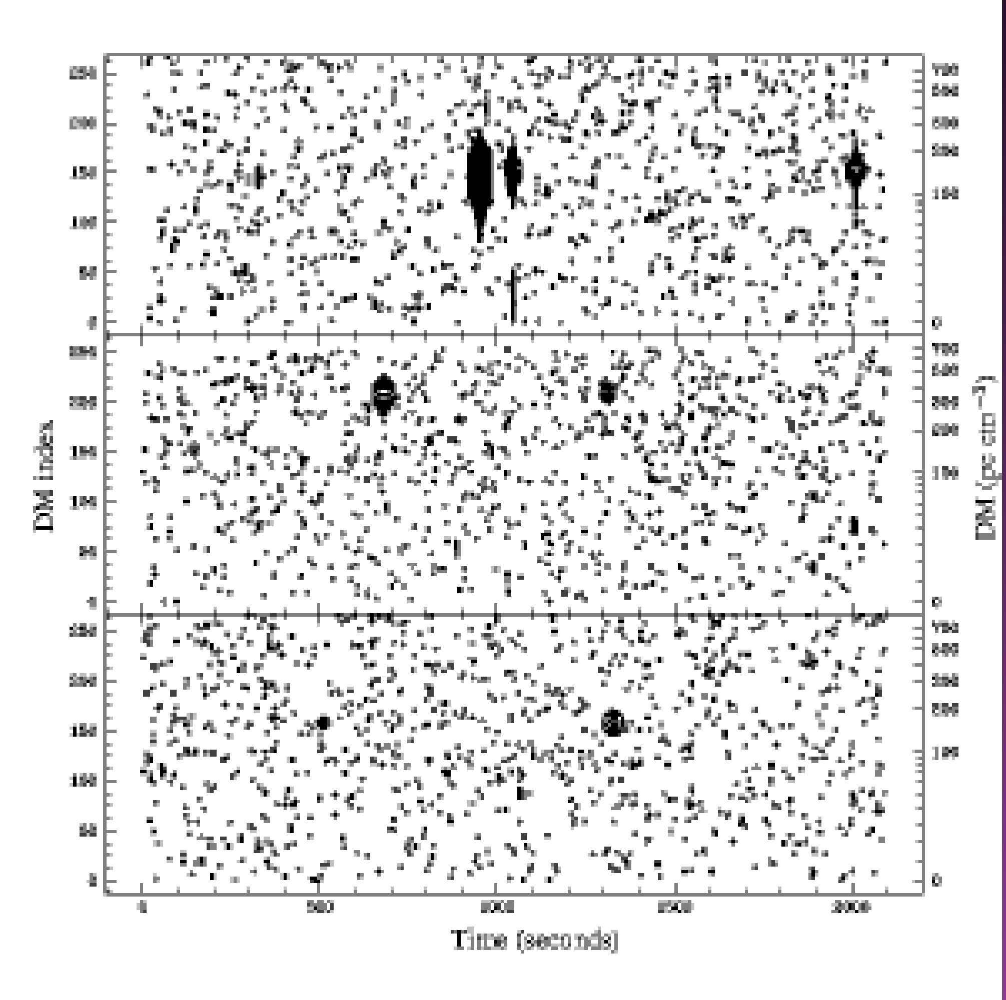
No periodicity detected, but confirmed as source of pulses

New Transient Sources

J1317-5759

J1443-60

J1826-1429

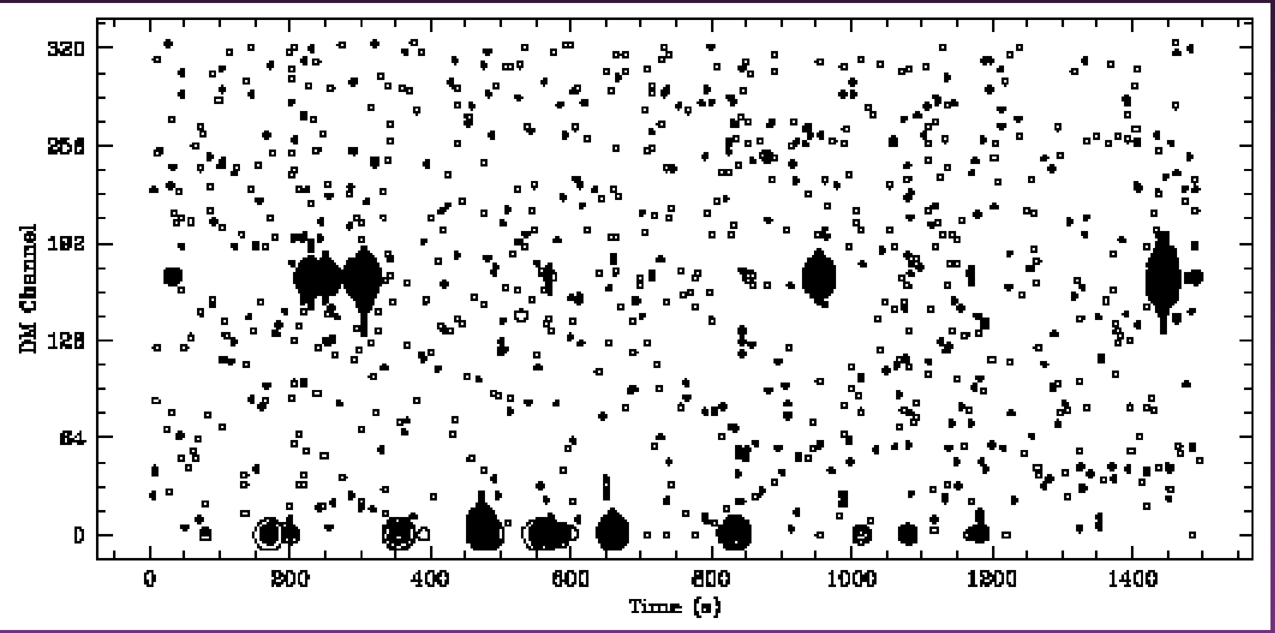


New Transient Sources

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

J1819–1503

DM = 194 pc cm^{-3}



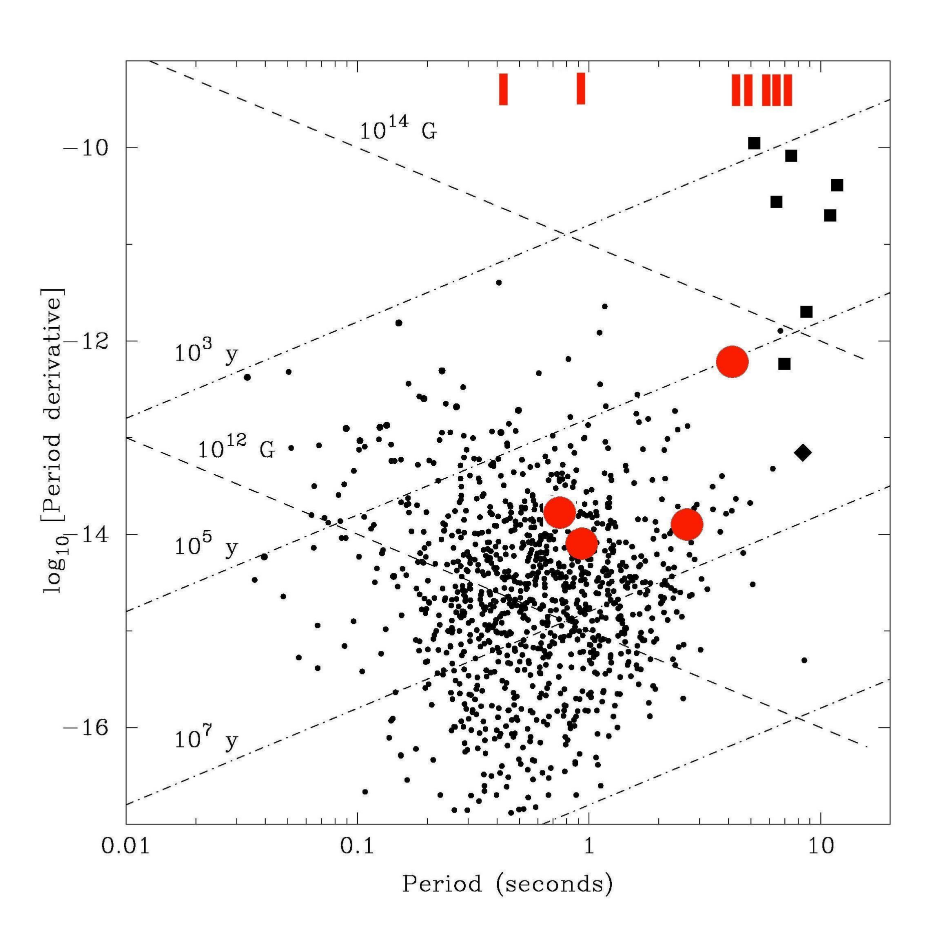
Arrival time differencing reveals period of 4.26 sec

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: 0.4-7sec, <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)

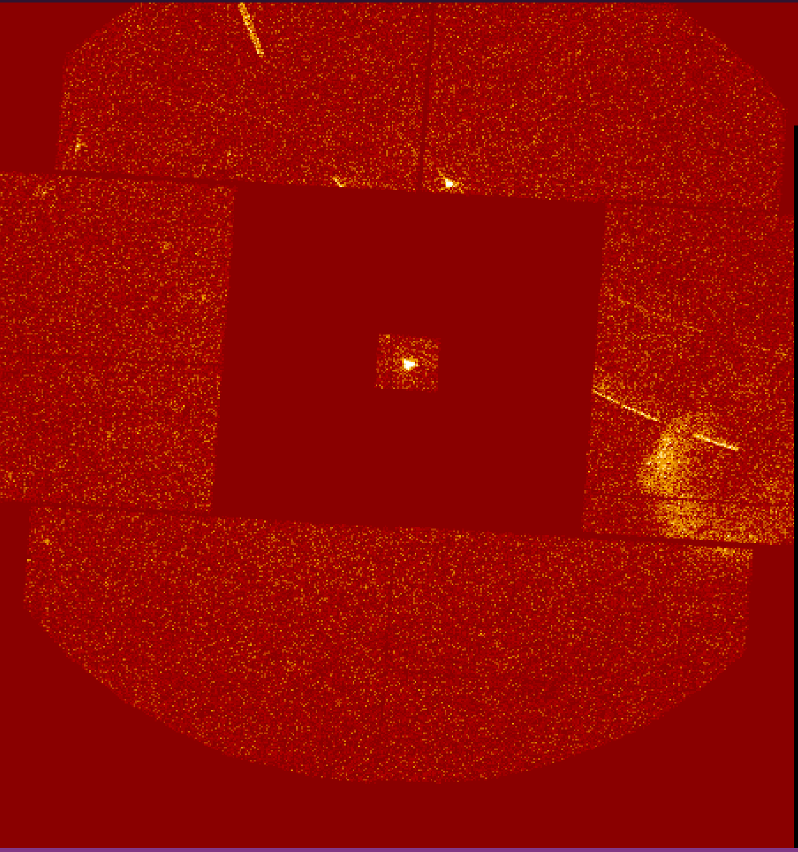


– J1819-1458 has B~0.5×10^{14} Gauss, close to Magnetars and XDINS

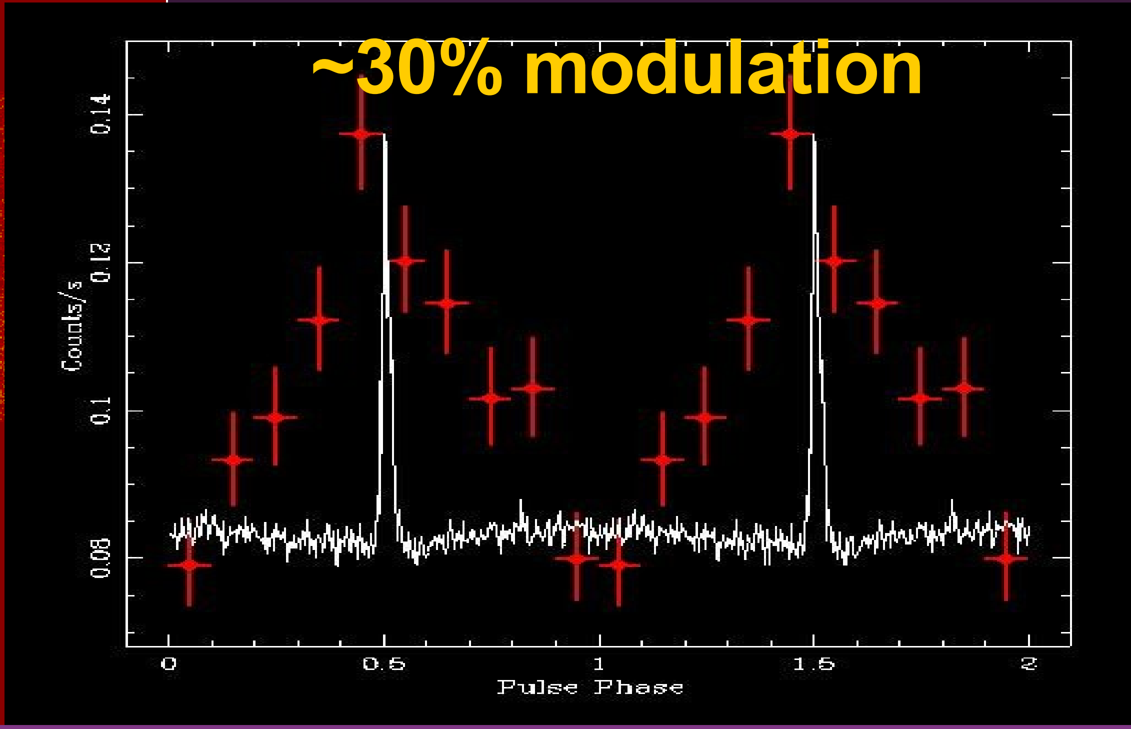
– All youngish: Age 0.1-3 Myr

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



~BB, T=0.14 keV



~30% 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 ~ 0.7×10^{14} G. Consistent with $B_{surf} = 0.5 \times 10^{14}$ 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

$$N = 2\times10^5$$

$$\times(L_{min}/100\ \mathrm{mJy\ kpc^2})\times(0.5/f_{on})\times(0.5/f_{int})\times(0.1/f_b)$$

Summary

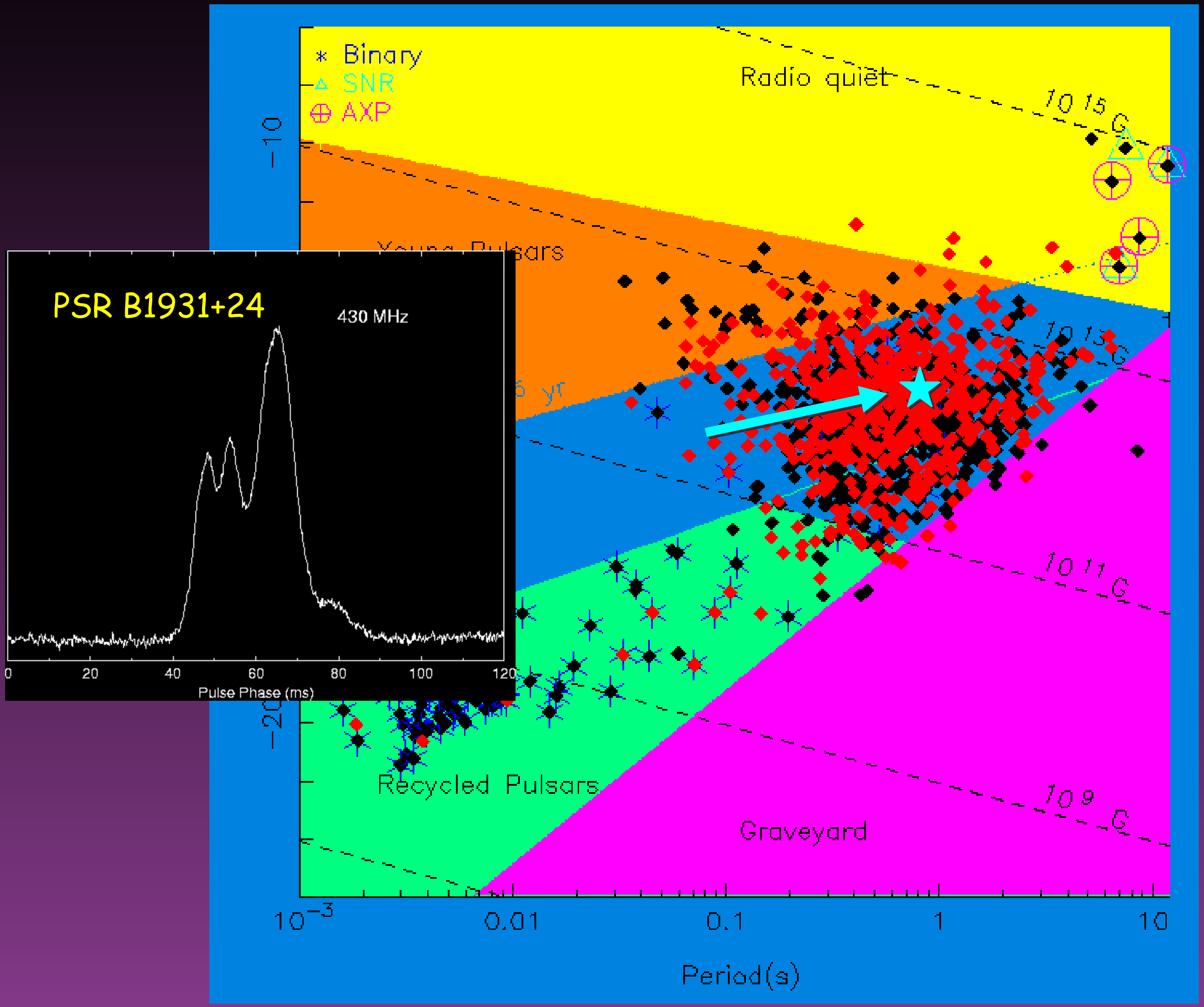
- 11 ephemeral objects which only radiate for typically 0.1-1 second/day
- Not detectable in periodicity searches or by folding
- Periods found from time differences
- Probably rotating neutron stars
- Ages 0.1–3 Myr
- Young cooling NSs ?
- Large galactic population

PSR B1931+24 and other Intermittent Pulsars

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

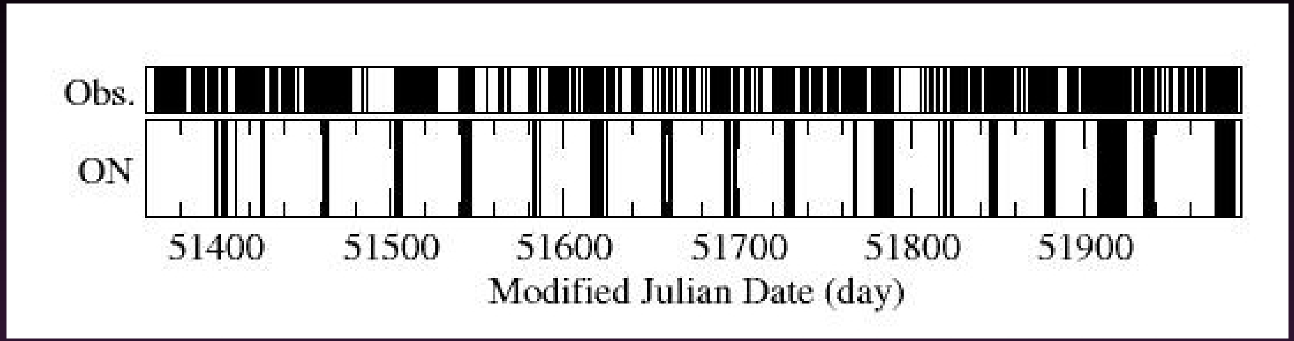
- Seemingly 'normal' pulsar, discovered at Green Bank
- Monitored in Jodrell Bank timing programme

PSR B1931+24



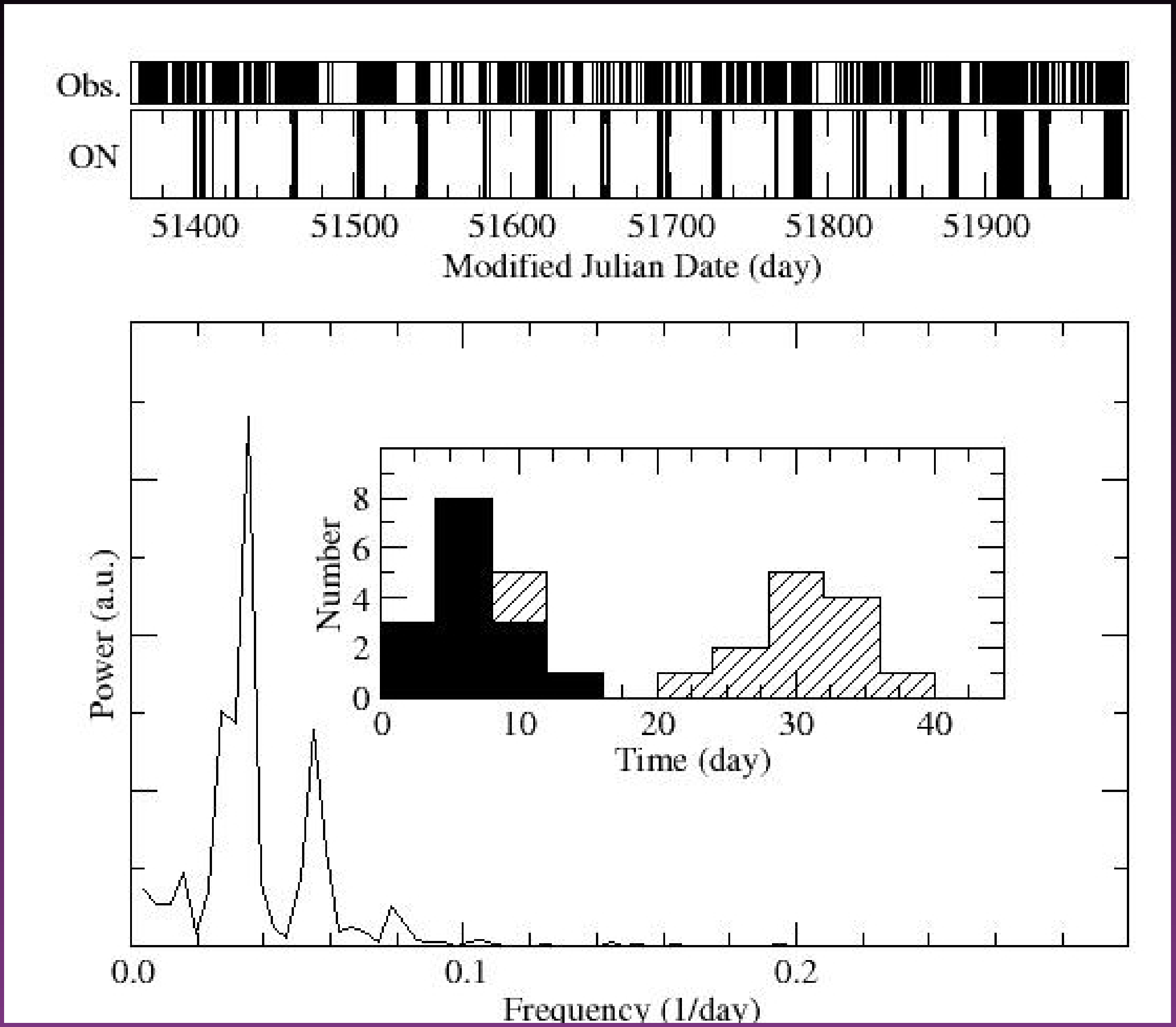
It looks like an ordinary pulsar… when you see it!

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…

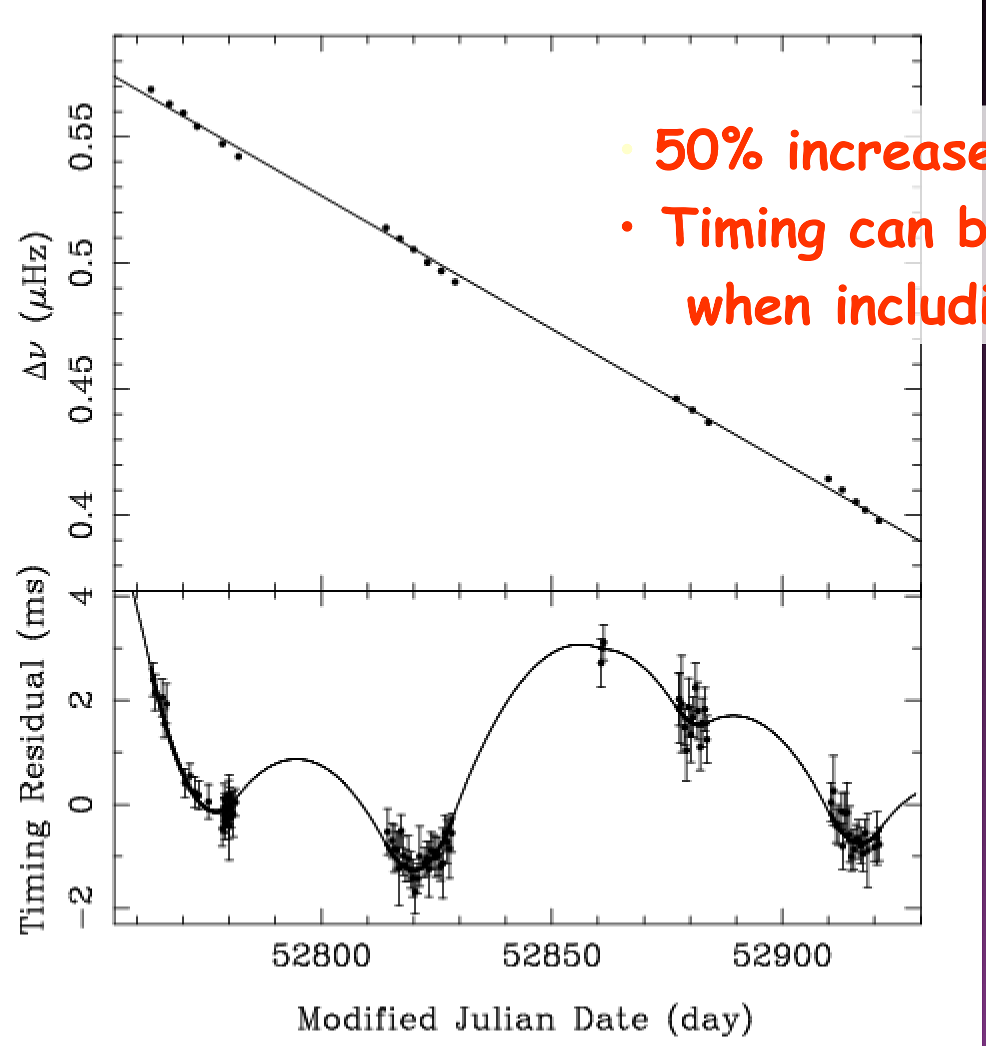


… and the whole process is (quasi-) periodic!

What causes phenomenon ?

- Is this related to “Nulling” ?
  - Emission << 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 dν/dt!
- Timing can be well modelled when including this effect

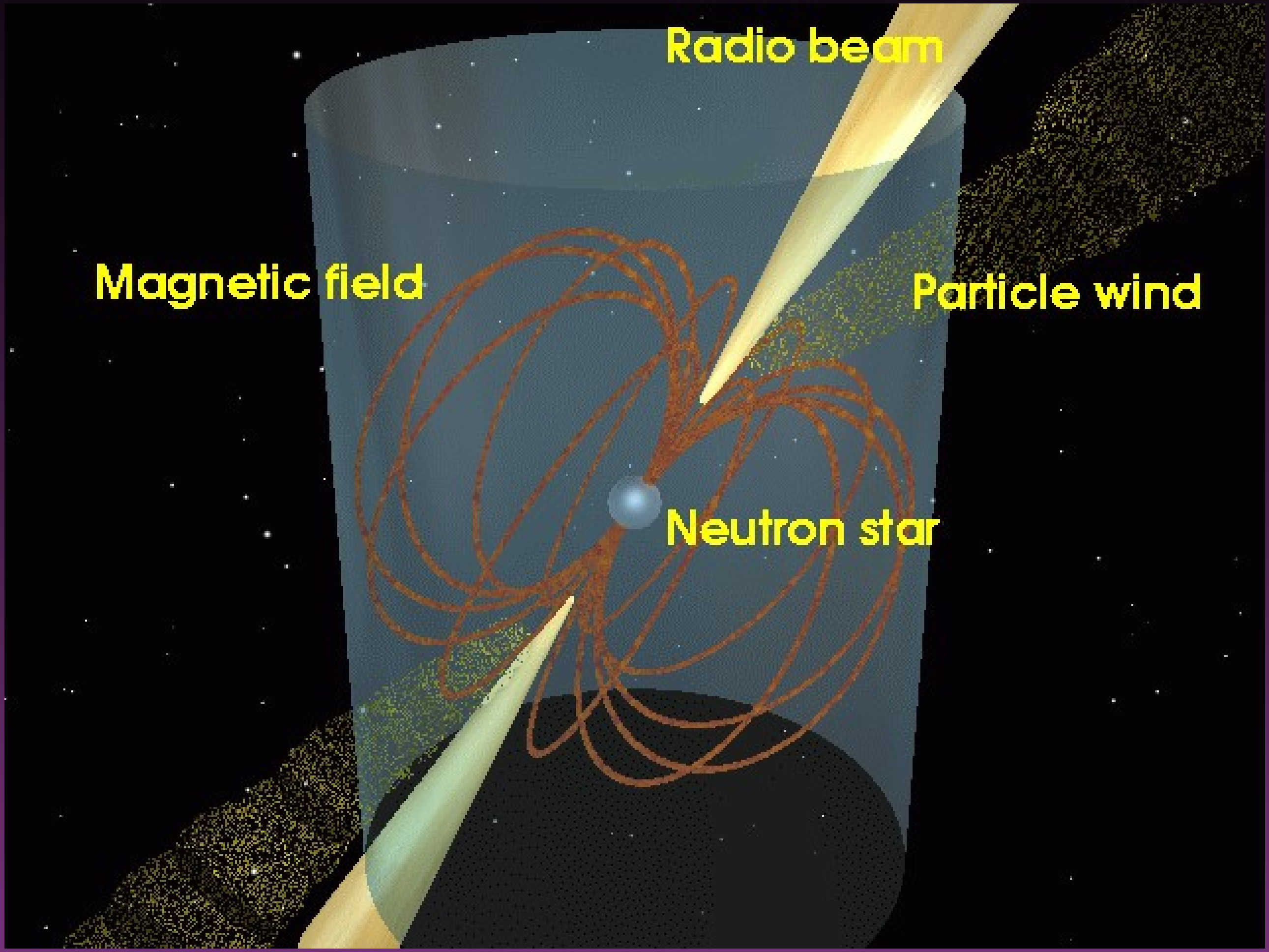
…the spin-down is faster when on!

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



M. Kramer

- 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

Theory works!

We can do more...!

We observe different losses in rotational energy:

$$\dot{E}_{ON} = 4\pi^2 I\nu\dot{\nu}_{ON} \qquad \dot{E}_{OFF} = 4\pi^2 I\nu\dot{\nu}_{OFF}$$

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:

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

$$T = \frac{2}{3c} j B_0 R_{pc}^2 \qquad j = c\pi R_{pc}^2 \rho$$

The charge density

We find: $$\rho = \frac{3I(\dot{\nu}_{ON} - \dot{\nu}_{OFF})}{R_{pc}^4 B_0}$$

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

$$\rho = 0.034 \frac{C}{m^3}$$

Agreement within 2%!

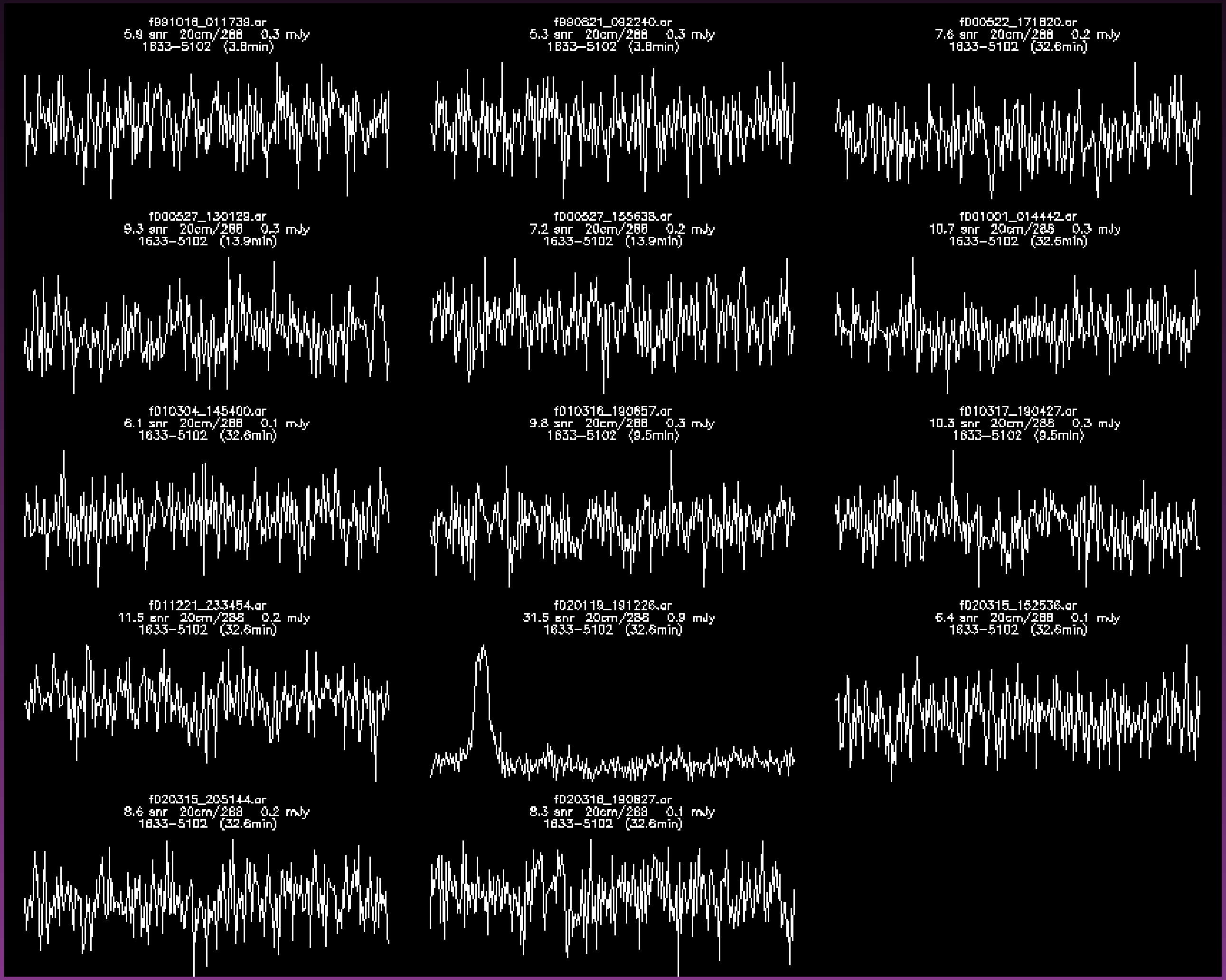
Goldreich & Julian predict:

$$\rho_{GJ} = \frac{B_0}{Pc} = 0.033 \frac{C}{m^3}$$

Any more like this?

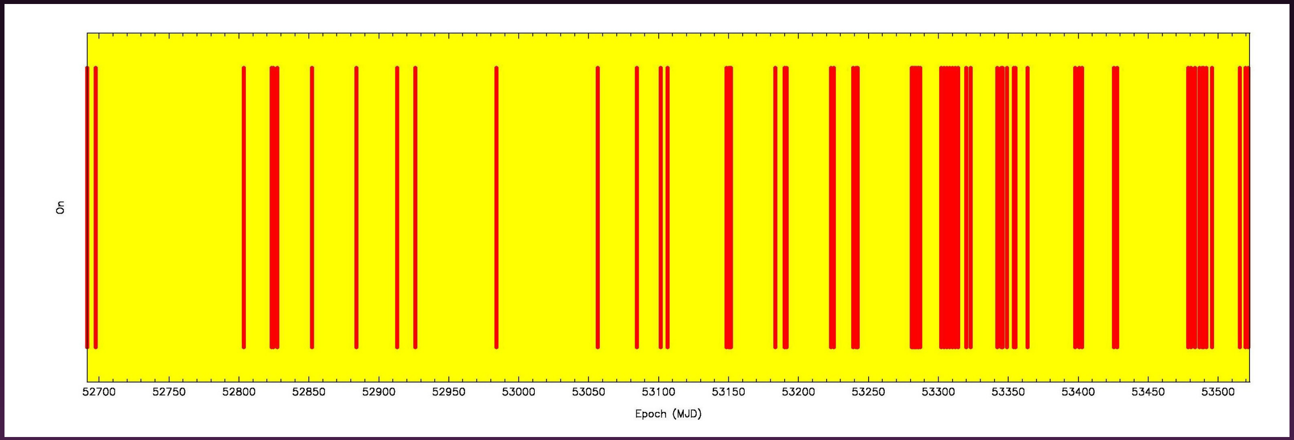
- Many more should exist
- Inspected Parkes Multibeam Pulsar Survey
- Any amongst 750 new pulsars found ?

Yes! 4 more!!



f991016_011739.ar
5.9 snr 20cm/288 0.3 mJy
1633-5102 (3.8min)
f990821_092240.ar
5.3 snr 20cm/288 0.3 mJy
1633-5102 (3.8min)
f000522_171820.ar
7.6 snr 20cm/288 0.2 mJy
1633-5102 (32.6min)
f000527_130129.ar
9.3 snr 20cm/288 0.3 mJy
1633-5102 (13.9min)
f000527_155638.ar
7.2 snr 20cm/288 0.2 mJy
1633-5102 (13.9min)
f001001_014442.ar
10.7 snr 20cm/288 0.3 mJy
1633-5102 (32.6min)
f010304_145400.ar
6.1 snr 20cm/288 0.1 mJy
1633-5102 (32.6min)
f010316_190657.ar
9.8 snr 20cm/288 0.3 mJy
1633-5102 (9.5min)
f010317_190427.ar
10.3 snr 20cm/288 0.3 mJy
1633-5102 (9.5min)
f011221_233454.ar
11.5 snr 20cm/288 0.2 mJy
1633-5102 (32.6min)
f020119_191226.ar
31.5 snr 20cm/288 0.9 mJy
1633-5102 (32.6min)
f020315_152536.ar
6.4 snr 20cm/288 0.1 mJy
1633-5102 (32.6min)
f020315_205144.ar
8.6 snr 20cm/288 0.2 mJy
1633-5102 (32.6min)
f020318_190827.ar
8.3 snr 20cm/288 0.1 mJy
1633-5102 (32.6min)

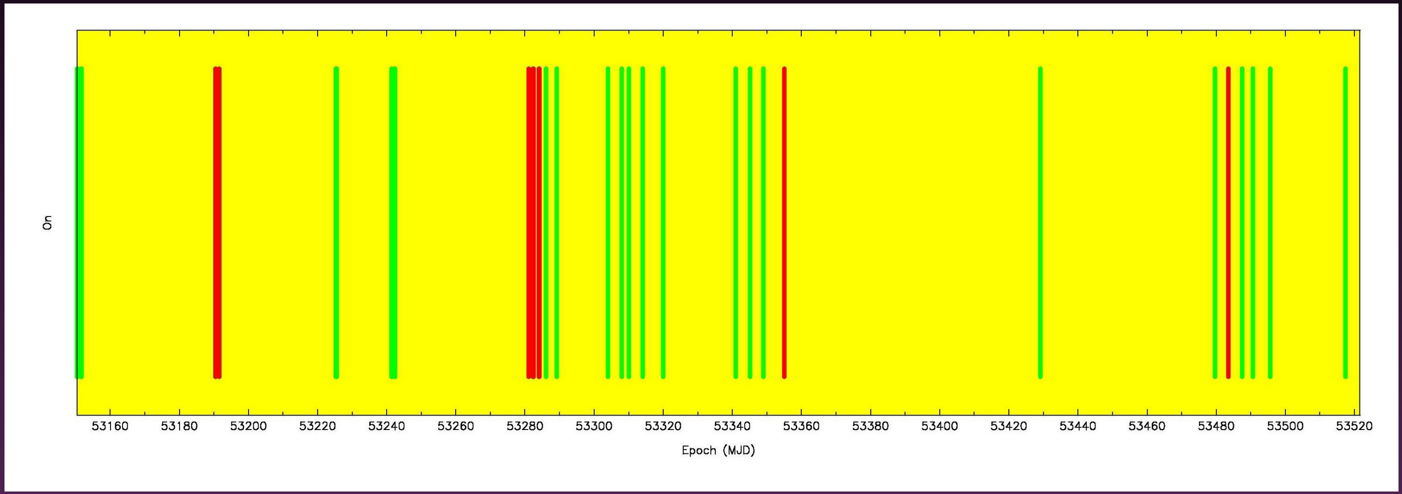
Properties: J1107-5907



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

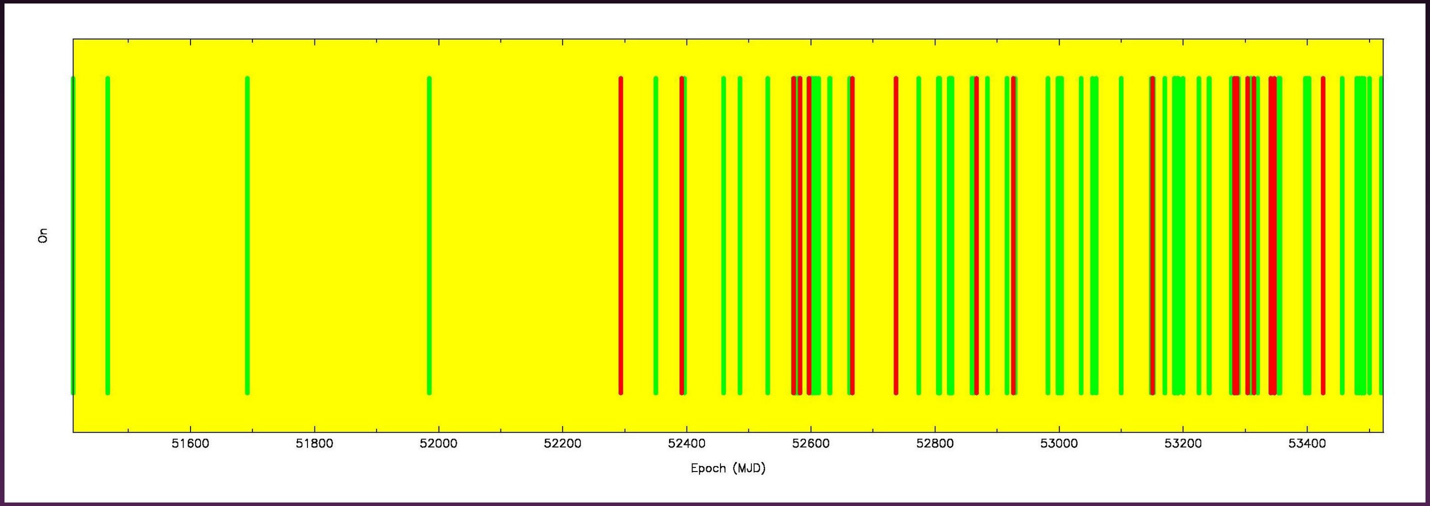
=> Interesting region – normal / recycled pulsars

Properties: J1717-4054



- Observations show ‘on’ < 20% time
- No periodicity yet

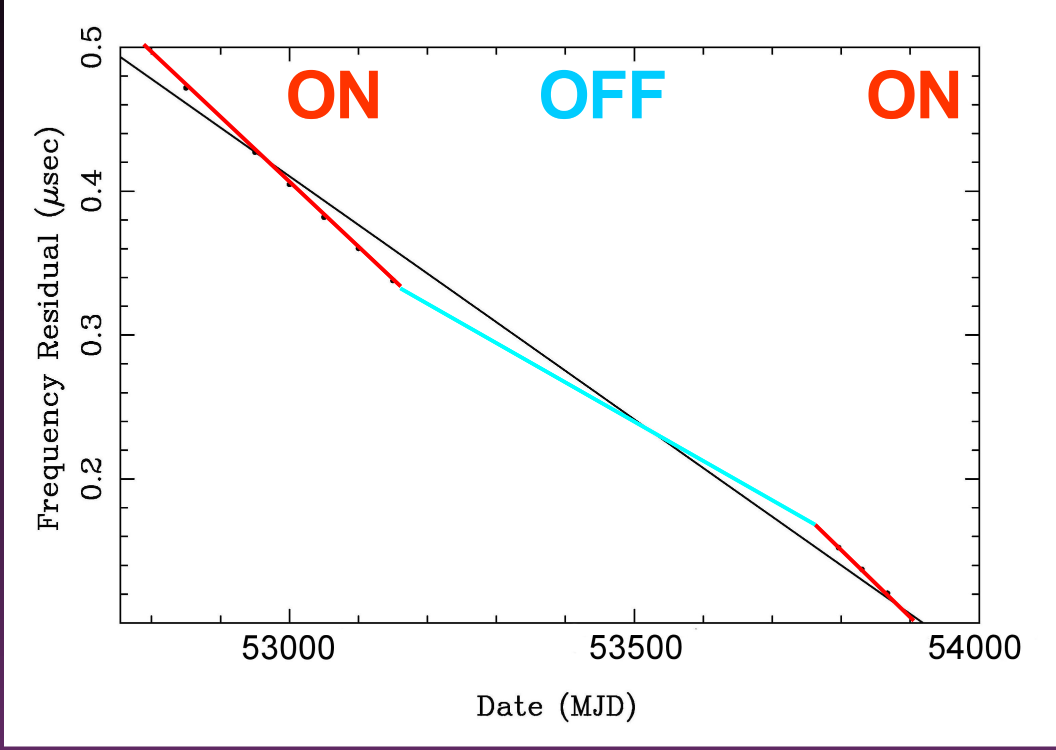
Properties: J1634-5107



- 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

$$(d\nu/dt)_{ON}/(d\nu/dt)_{OFF}=1.8\pm0.1$$

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**

Finally ……..

- 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/*ν*

- Characteristic ages are calculated as:

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