The Radio Emission Properties of Pulsars

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Neutron Stars and Pulsars, Bad Honnef

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Current (lack of) understanding

Cyclotron lines

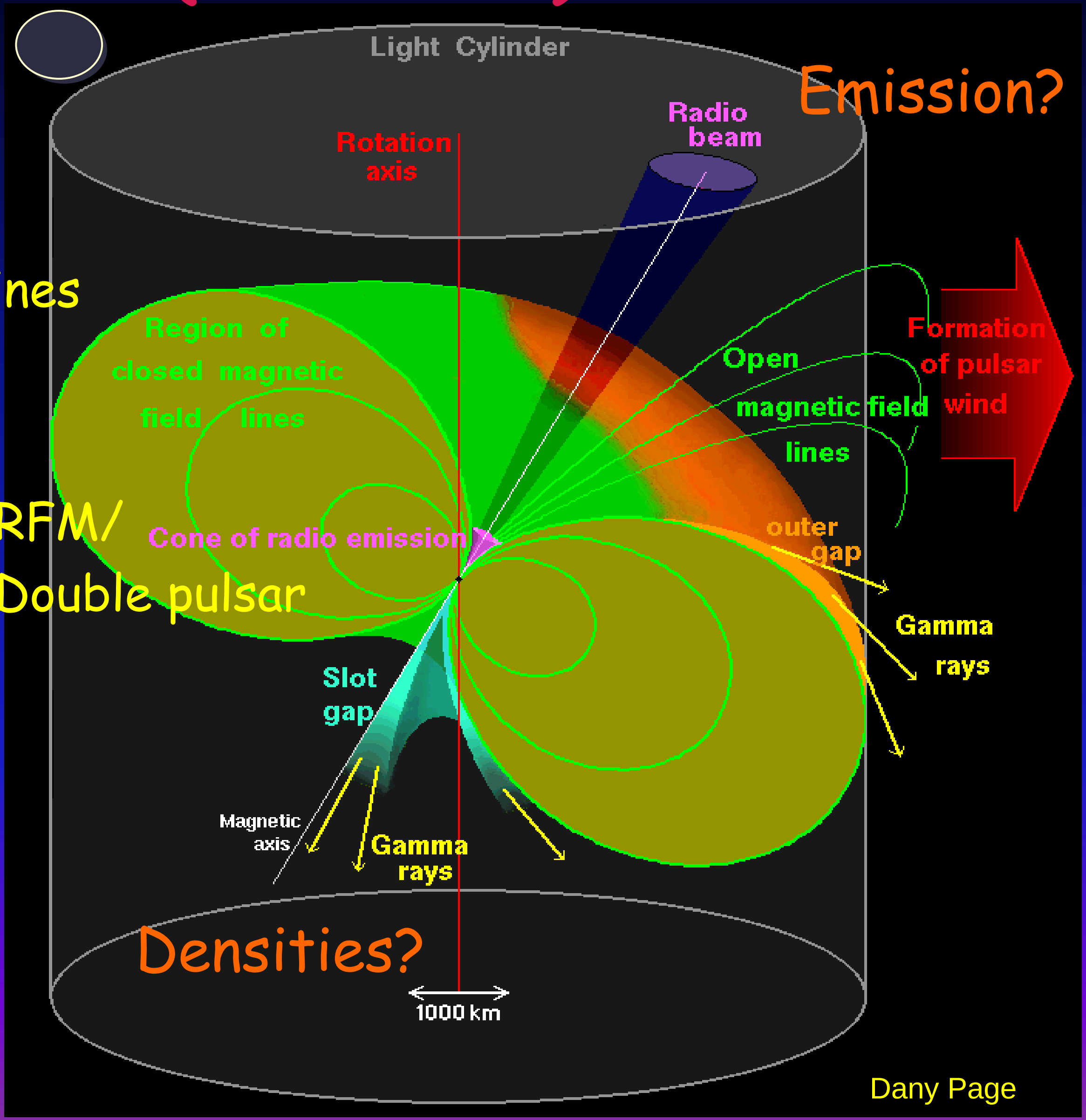
RFM/
Double pulsar

Emission?

Pulsar wind
nebulae/
Double pulsar

Torque?

Densities?



Introduction

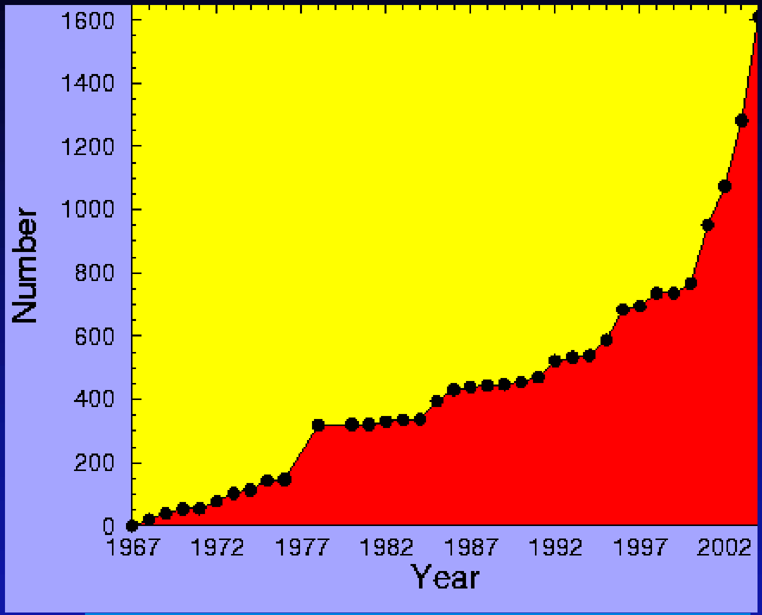
- Repeating Radio Transient sources (RRATs)
  - Discovery
  - Properties
  - Galactic population
  - Relationship to normal pulsars ?
- Sometimes a pulsar (B1931+24)
  - The quasi-periodic phenomenon
  - The changing slow-down rate
  - Implications for magnetospheric currents

Rotating Radio Transient Sources – RRATs

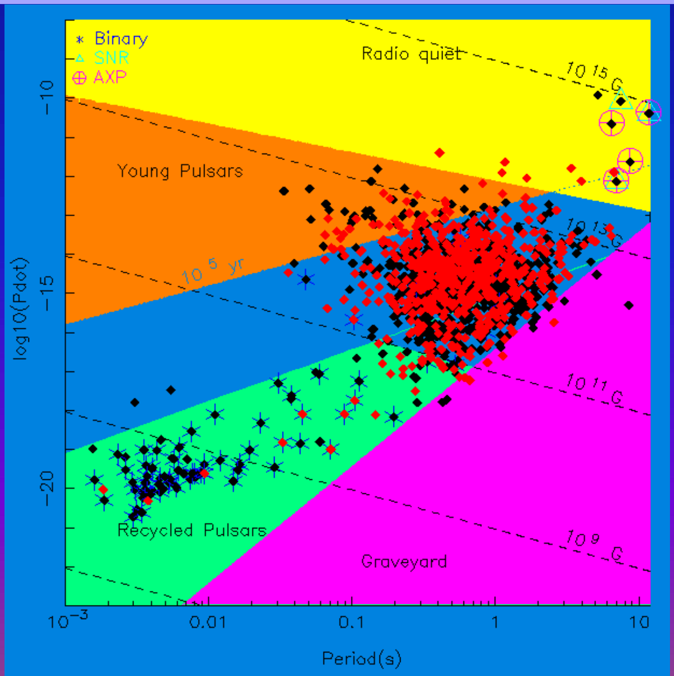
Mclaughlin et al. 2006, Nature 439, 817-820

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

The Parkes Multibeam Pulsar Survey



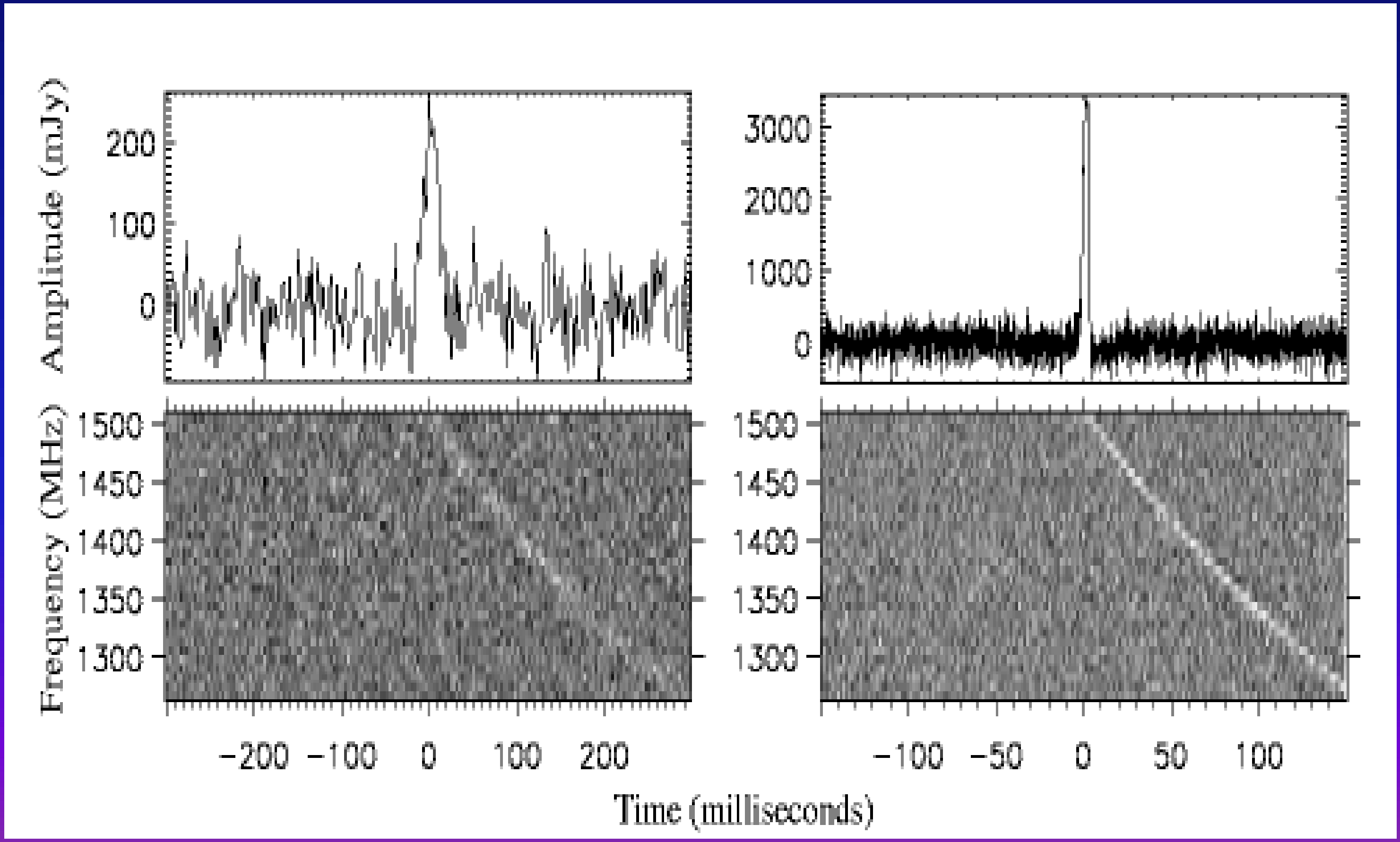
- 13-beam receiver on Parkes 64m radio telescope at 1400 MHz
- Team lead by JBO, ATNF, Cagliari
- 260<l<50, -5<b<+5
- 35-min dwell time
- Most sensitive & most successful
- More than 740 discoveries
- Lots of exciting systems…



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

Transient Event Search

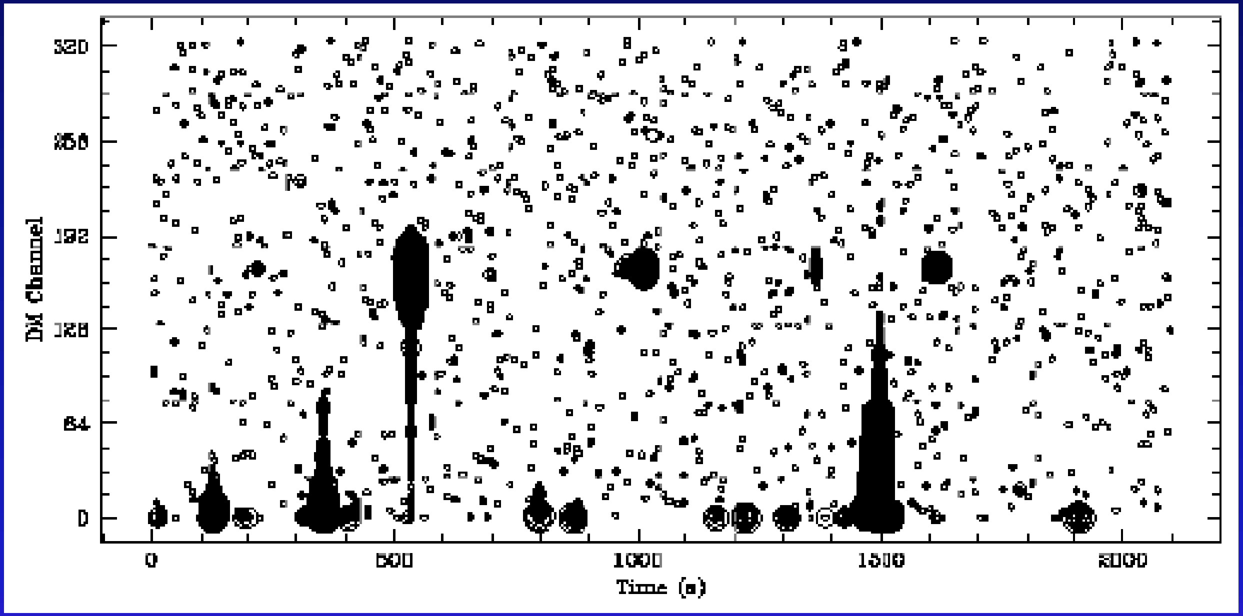
- Conducted a search for single, dispersed transient events in the Parkes Pulsar Multibeam Survey data set
- Good sensitivity to pulsars with occasional "giant" pulses



New Transient Sources

J1819–1503

DM = 194 pc cm^{-3}



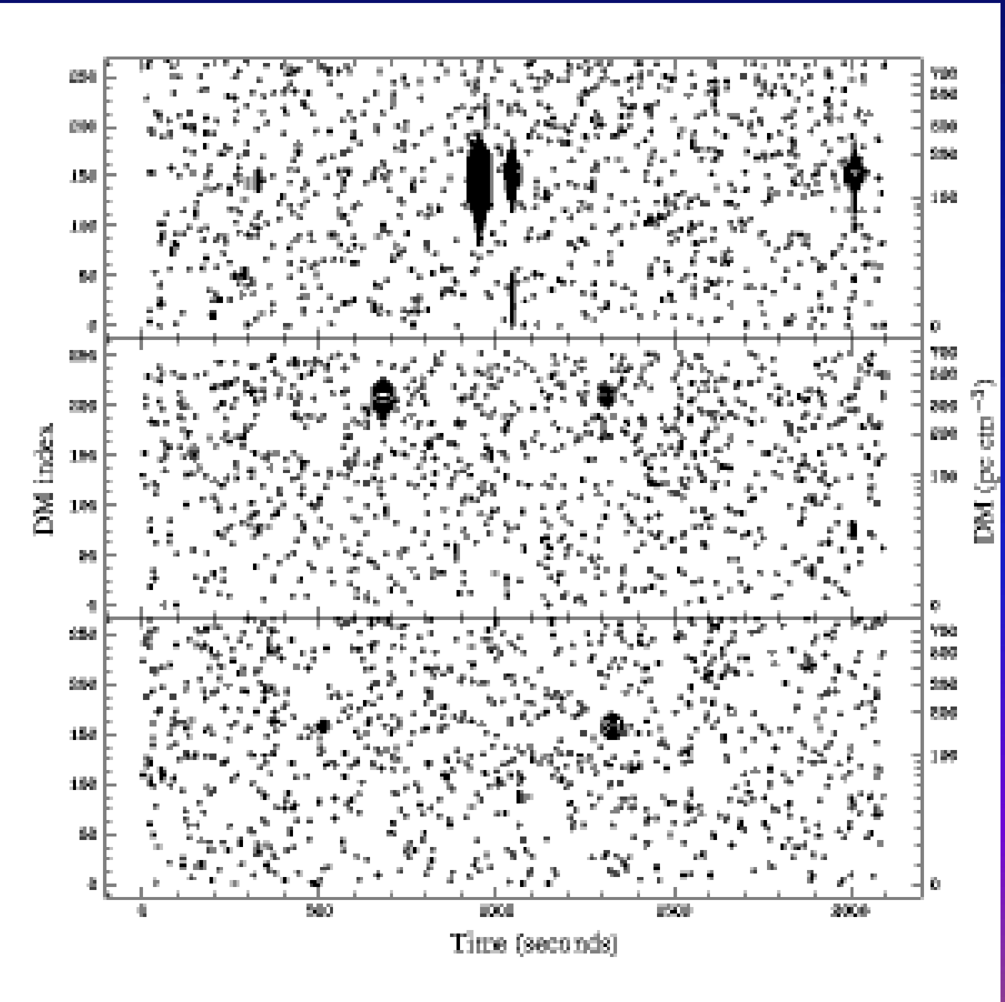
No periodicity detected, but confirmed

New Transient Sources

J1317-5759

J1443-60

J1826-1429

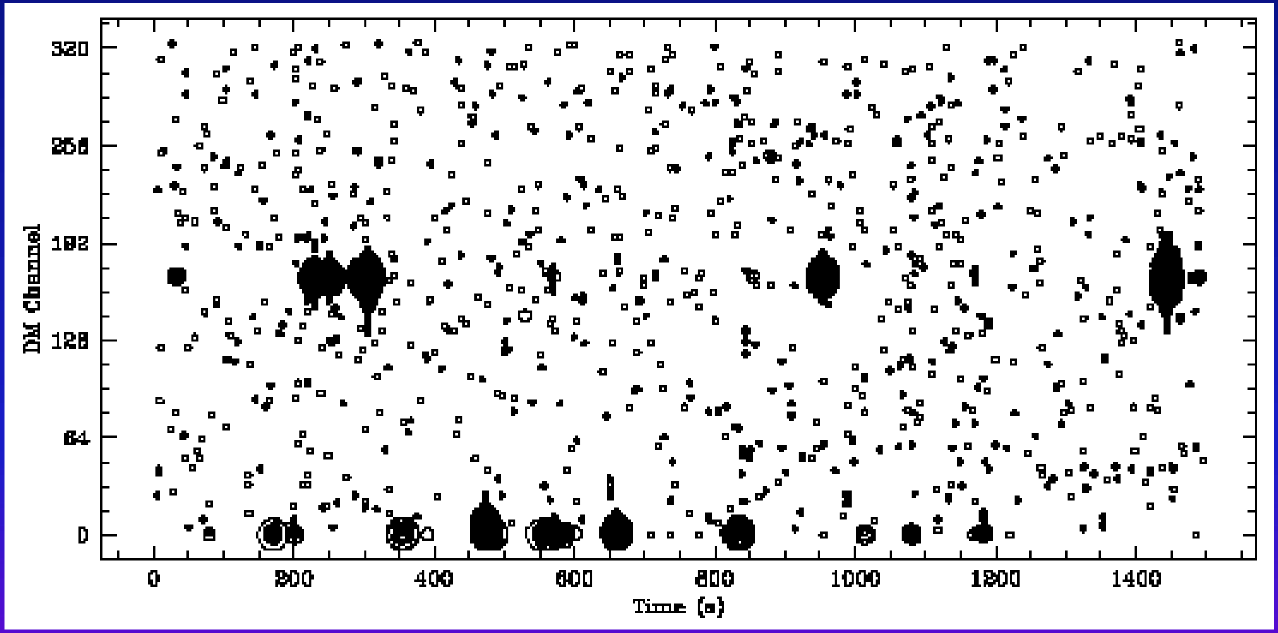


New Transient Sources

- 11 sources confirmed
- FFT searches showed no periodicity
- Time difference analysis reveals periodicity in 10 sources

J1819–1503

DM = 194 pc cm^{-3}



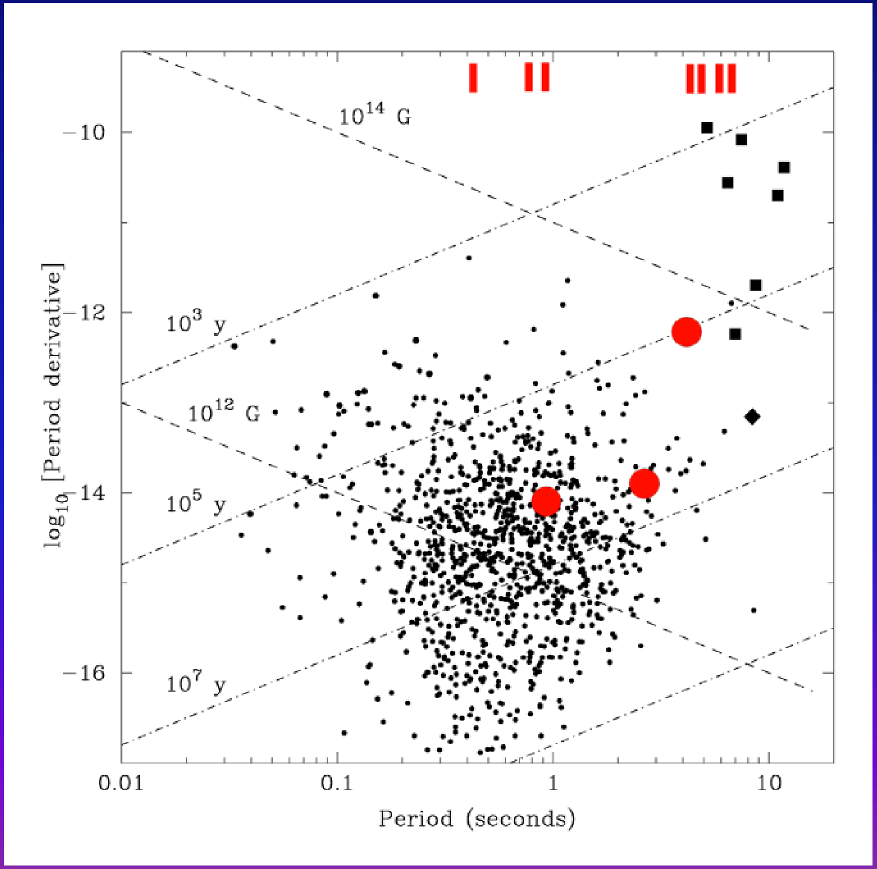
Arrival time differencing reveals period of 4.26 sec

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~0.5x10^{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

$$N = 4\times10^{5}$$

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

Summary

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

Summary

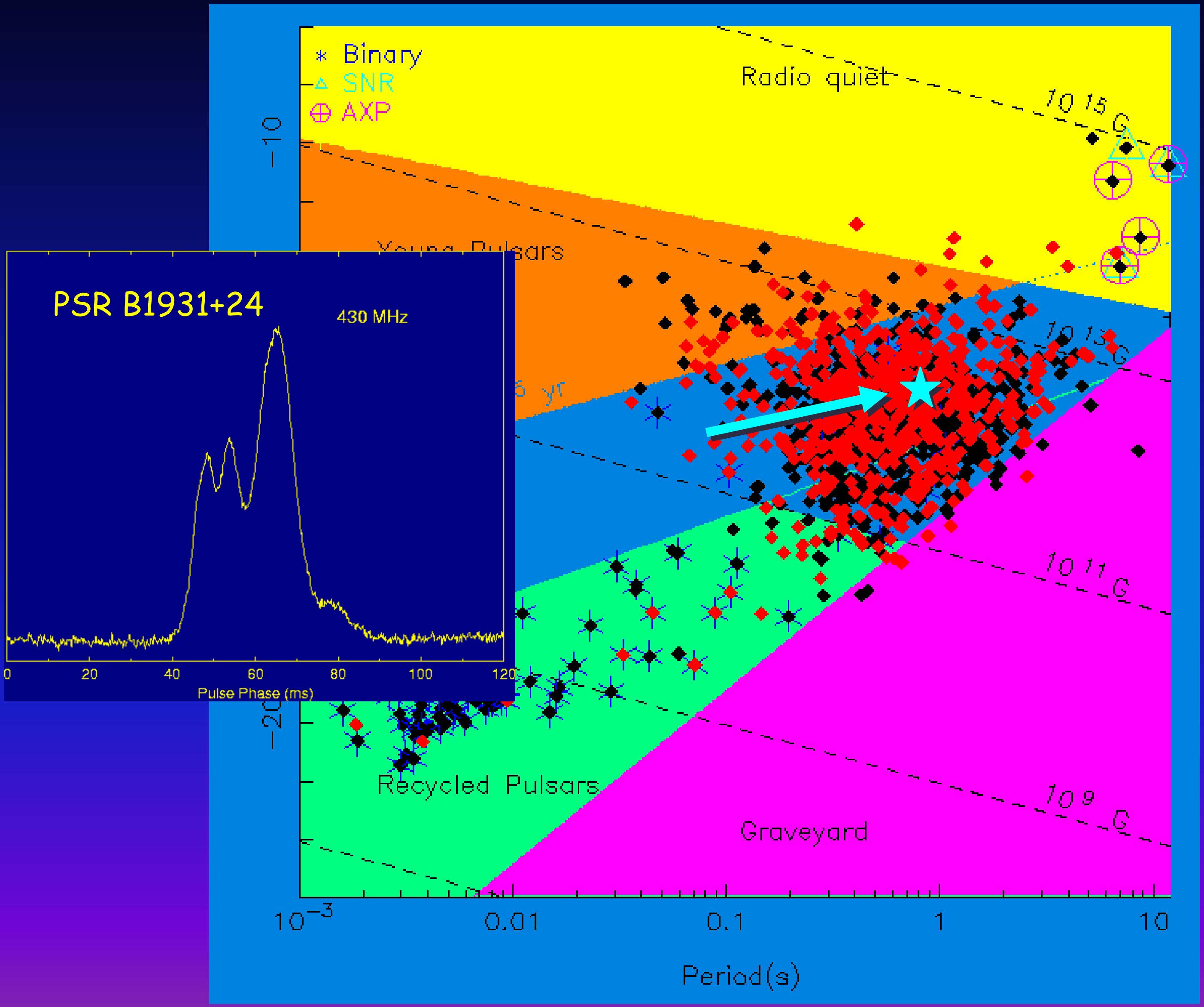
- But why do they only radiate so rarely ?

Sometimes a Pulsar – PSR B1931+24

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

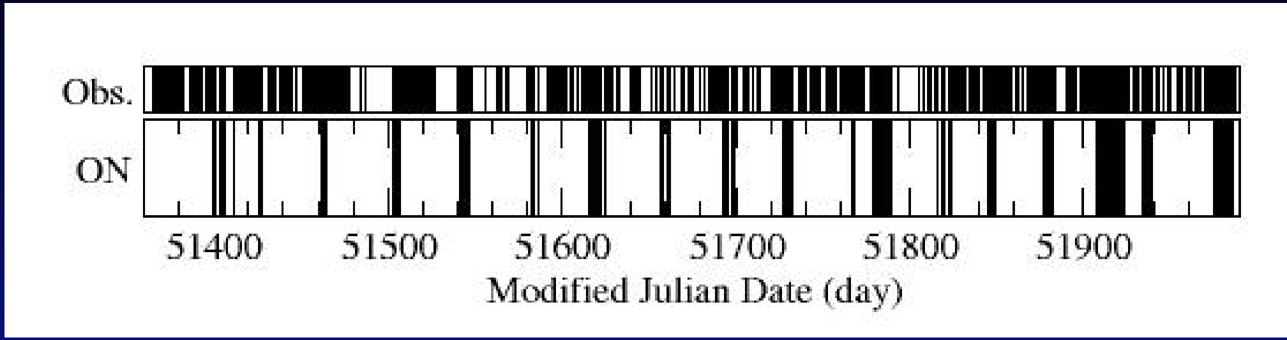
- Introduction
- Seemingly 'normal' pulsar
- Long time-scale, quasi-periodic switching
- Are there any others ?
- Conclusions

Some unexpected help…!



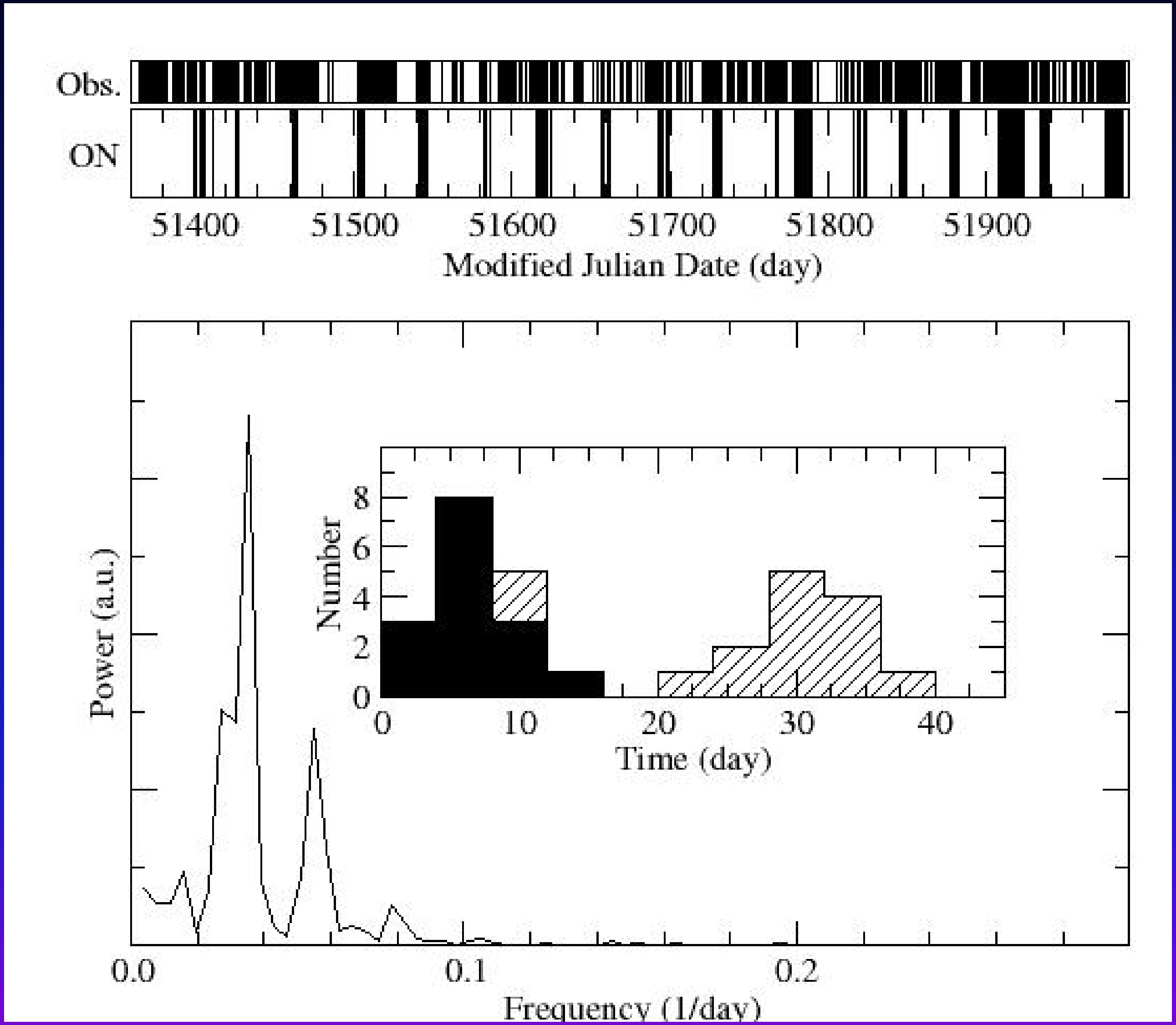
It looks like an ordinary pulsar… when you see it!

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…

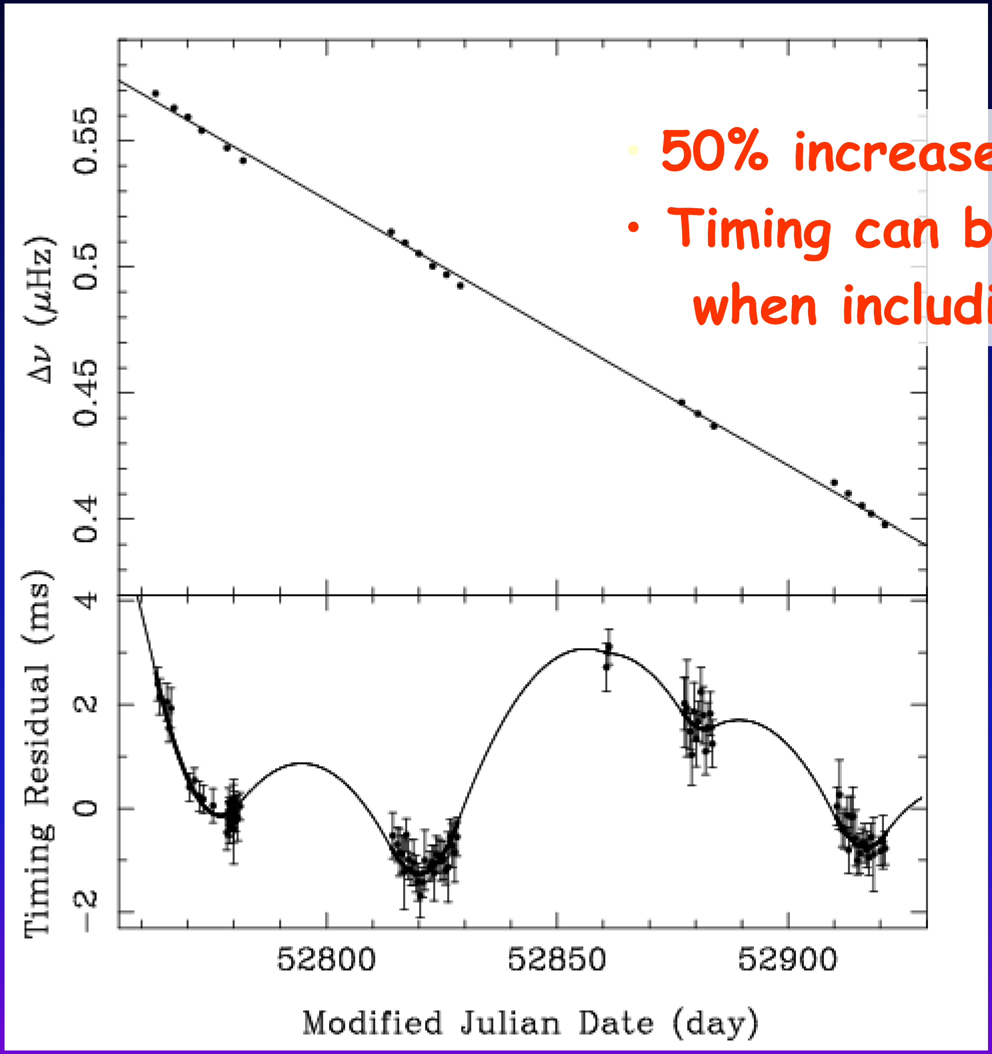


… and the whole process is (quasi-) periodic!

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 ?
  - 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 dP/dt!
- Timing can be well modelled when including this effect

…the spin-down is faster when on!

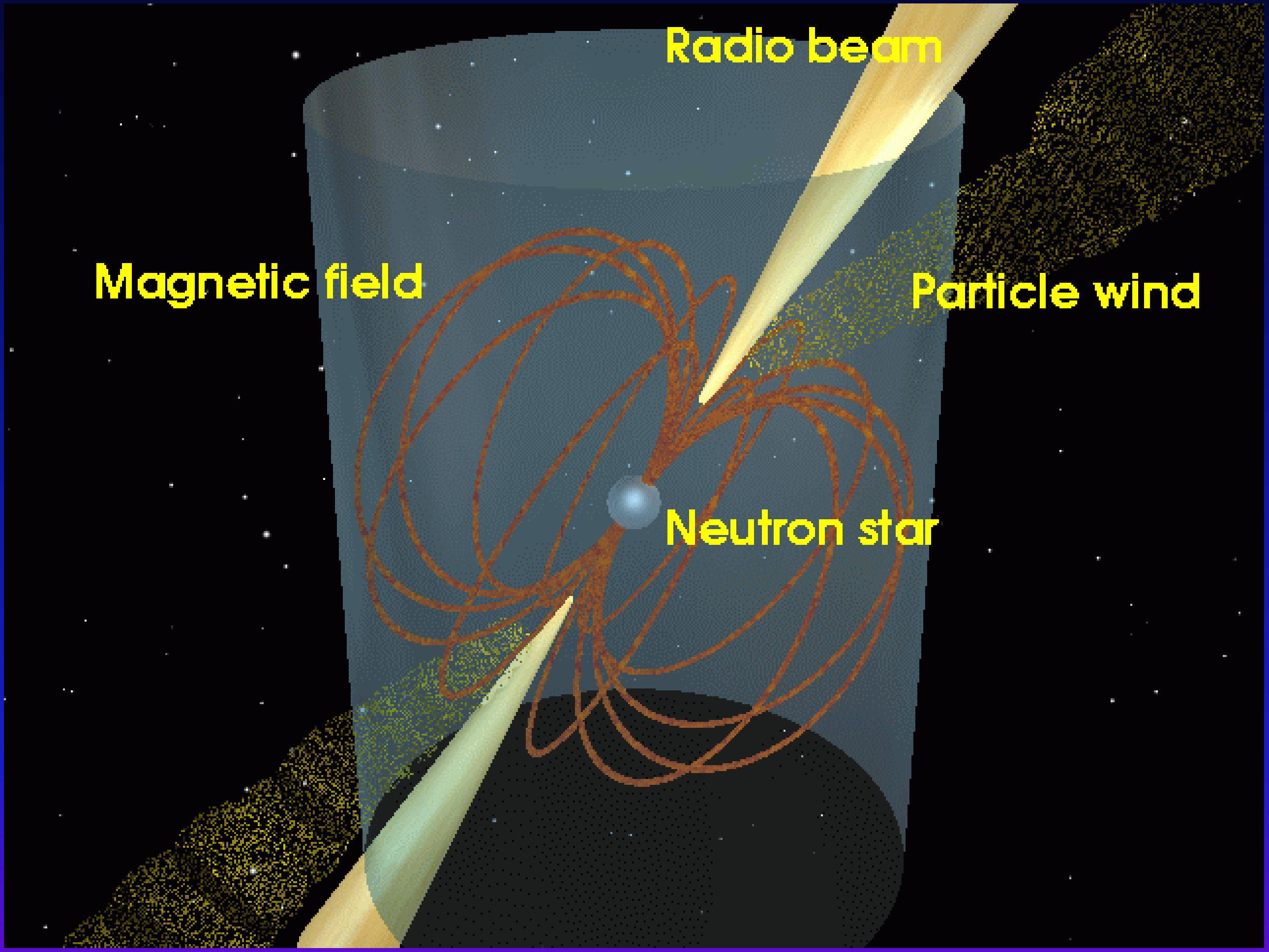
The facts and their explanation…

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

Simplest explanation:

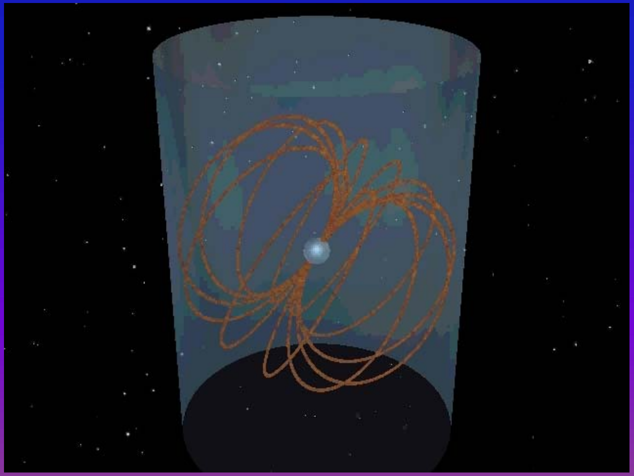
- the braking is related to radio emission
- the plasma creating the radio emission provides the expected extra torque
- when the plasma is absent, braking is less

→ First observational evidence for pulsar wind torque


Radio beam
Magnetic field
Particle wind
Neutron star

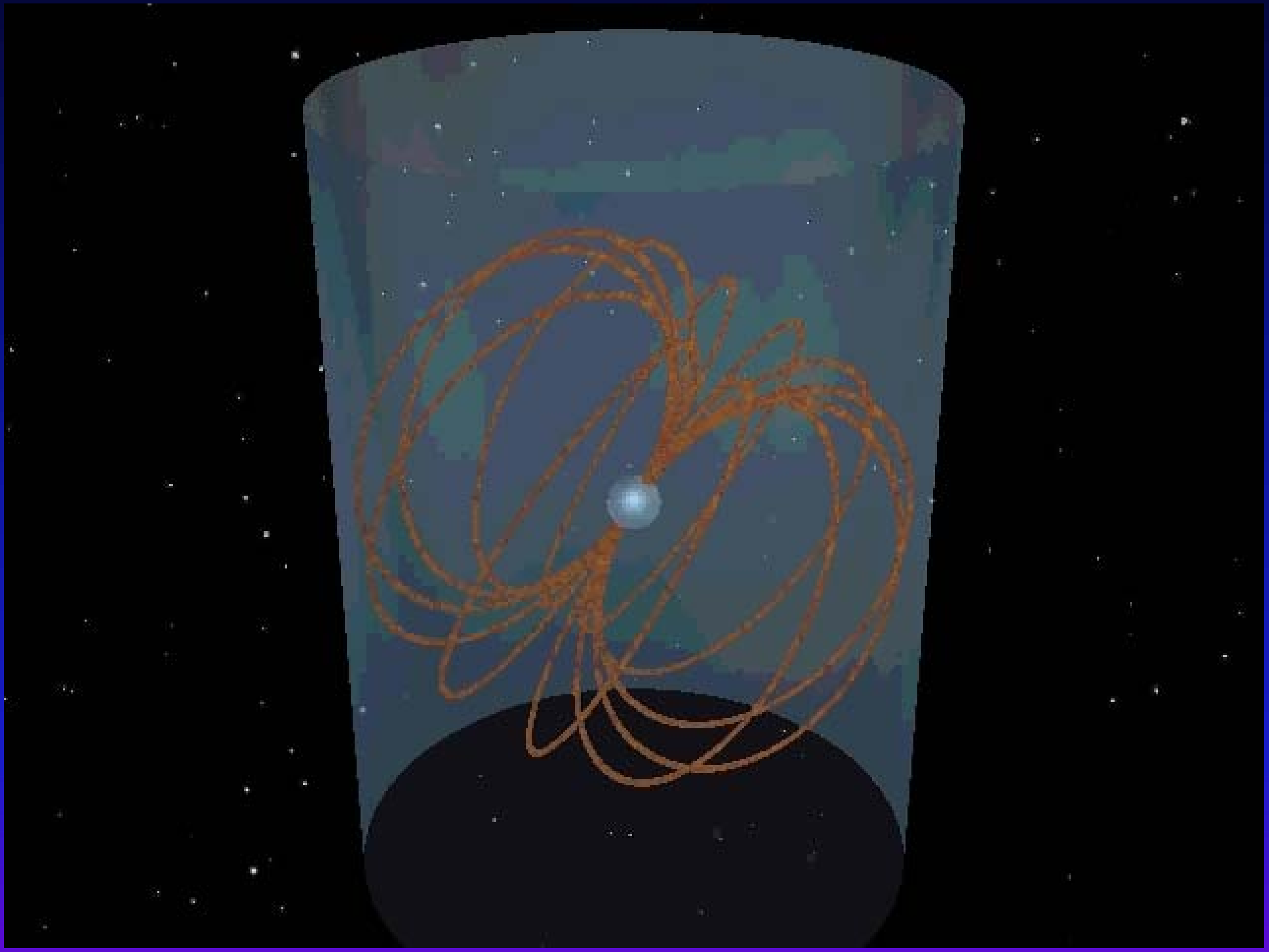
Summary

- We found a new pulsar phenomenon
- Unexpectedly, it has consequences for spin-down
- First observational evidence for pulsar wind torque
- First ever chance to test basic magnetospheric theories
- Confirmation of Pacini & Goldreich-Julian model 39/37 years after they have been proposed



… in a rather unexpected fashion!

Theory works!



We can do more…!

We observe different losses in rotational energy:

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

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

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:

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

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

$$j = c\pi R_{pc}^2 \rho$$

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%!

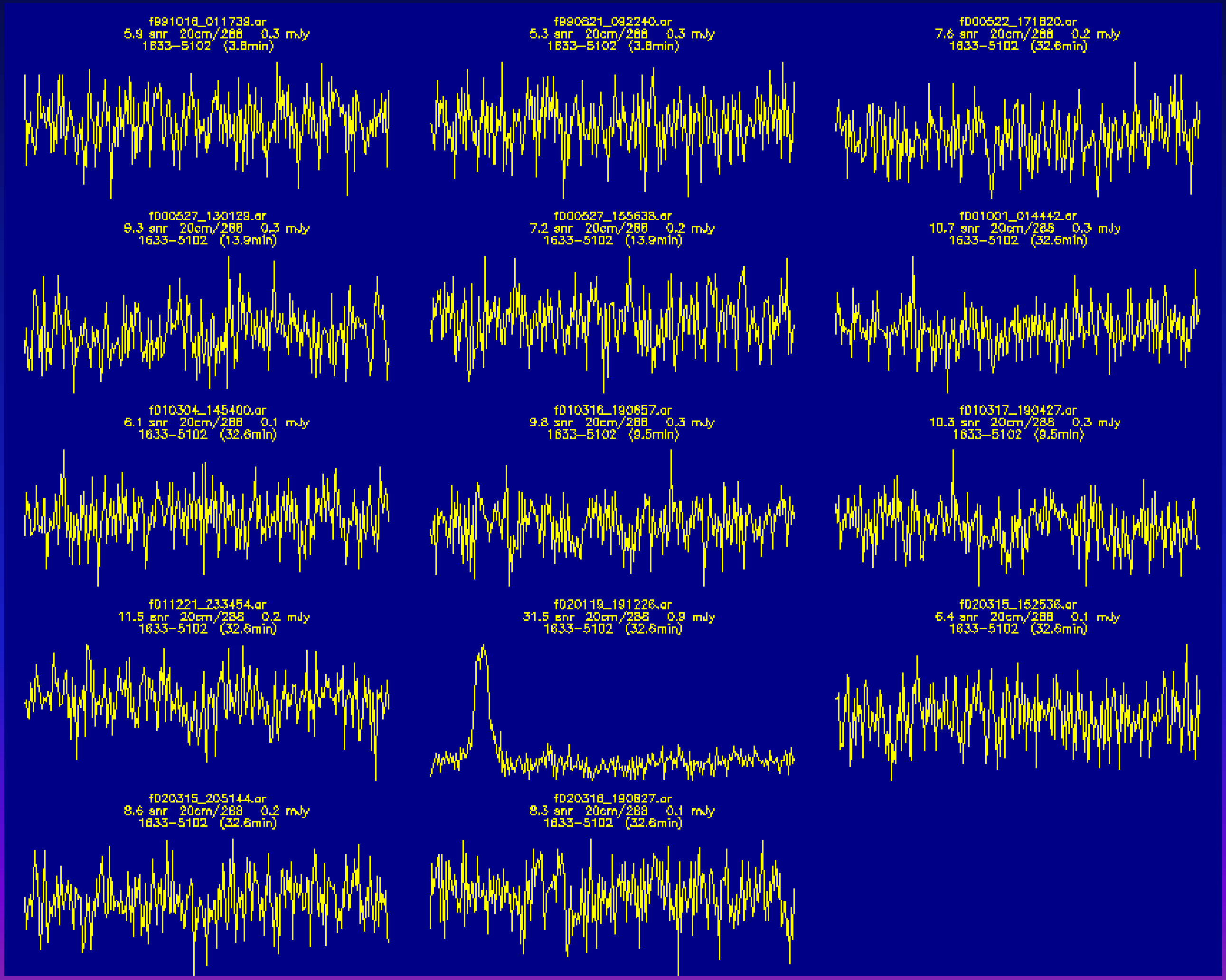
Goldreich & Julian predict:

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

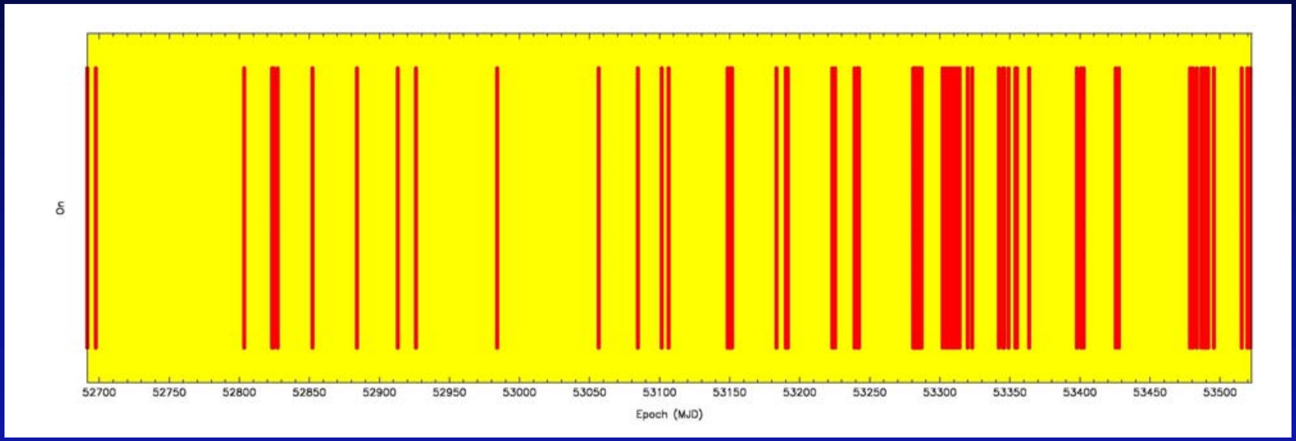
Any more like this?

- 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)

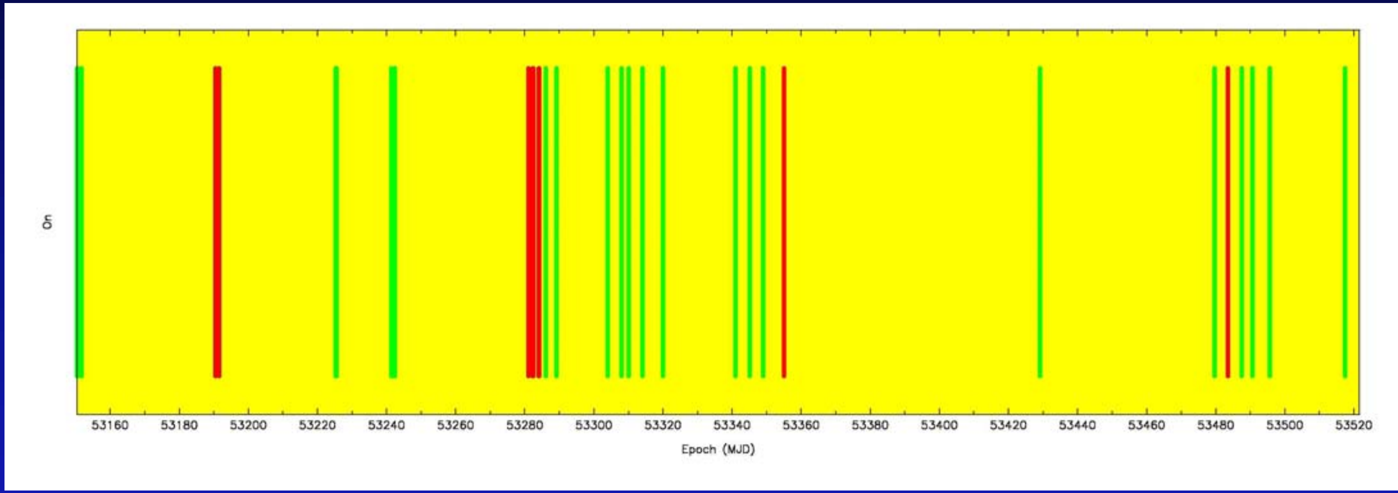
Properties: J1107-5907



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

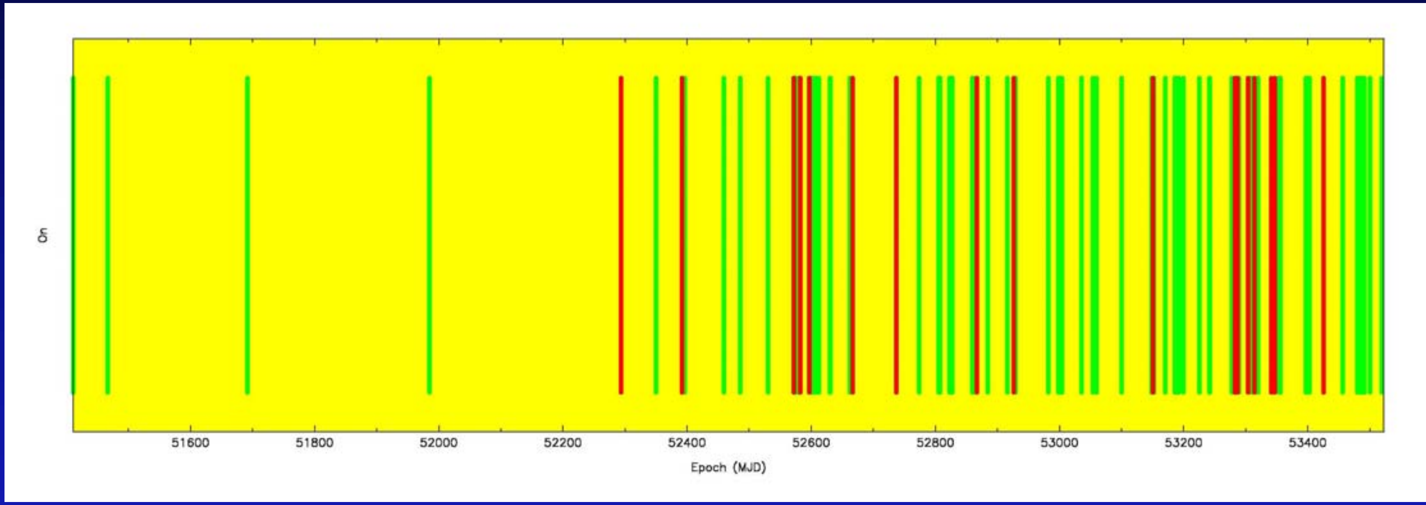
=> Interesting region – normal / recycled pulsars

Properties: J1717-4054



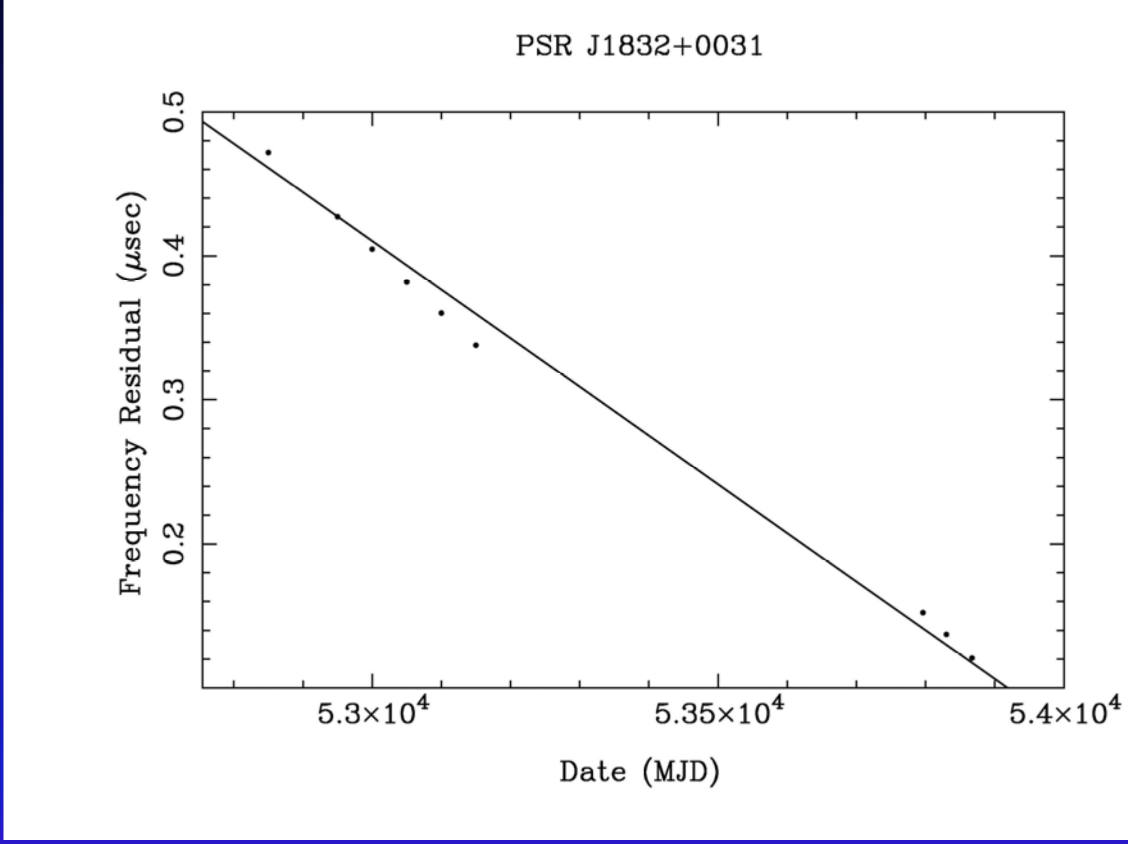
- Observations show ‘on’ < 20% time
- No periodicity yet

Properties: J1634-5107



- Strong ‘on’ state
- Completely ‘off’ state
- Quasi-periodicity ~ 10 days

Properties: J1832+0031



- ‘on’ state >300 days
- ‘off’ state ~700 days
- Quasi-periodicity ?
- Increase in slow-down rate during ‘on’ state similar to B1931+24

Conclusions

- Pulsars do not always emit
- 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)

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:

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