Recent Radio Observations of Pulsars

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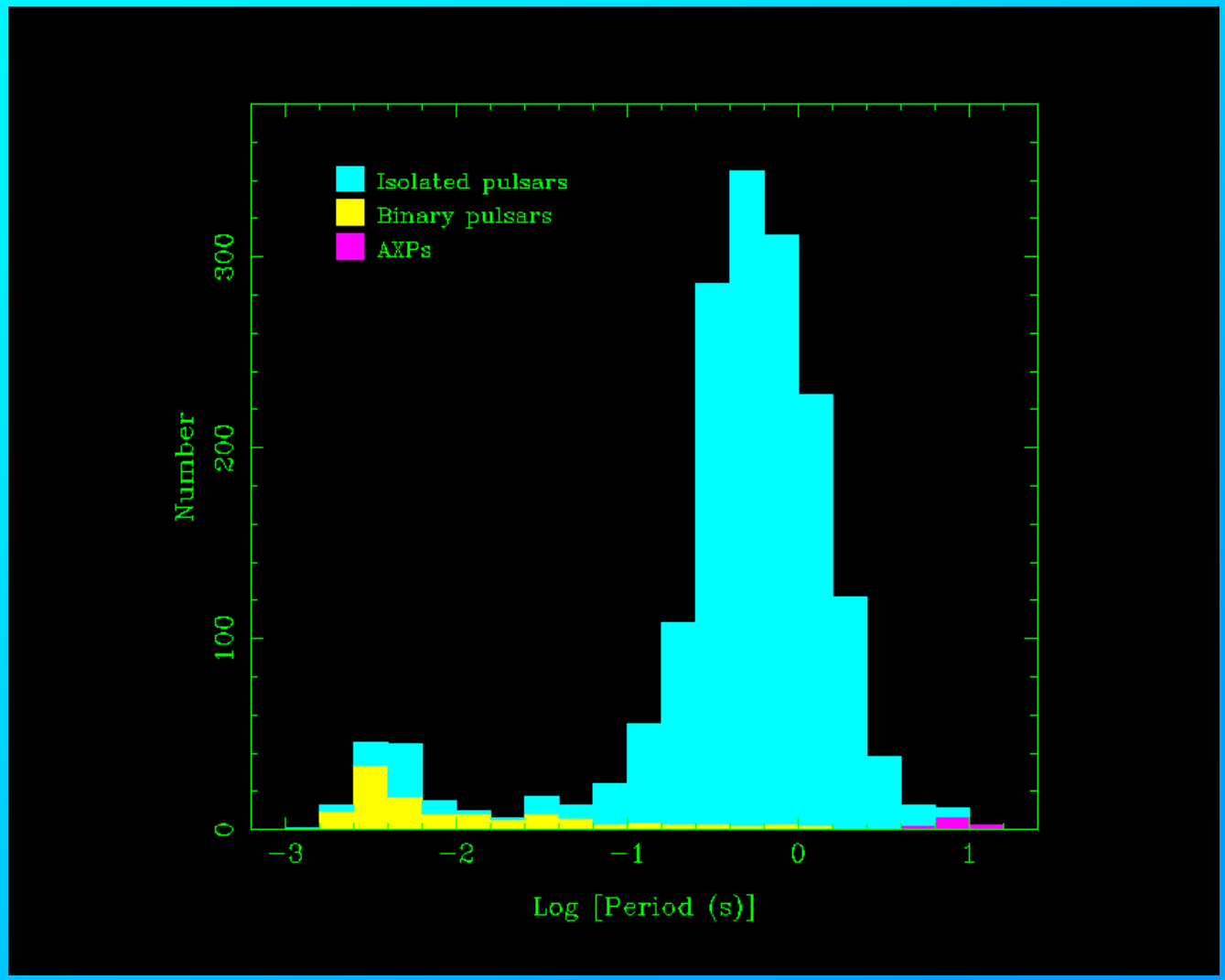
Summary

- A pulsar census
- Recent pulsar surveys
- Pulse modulation and drifting subpulses
- Giant pulses from young and old pulsars
- Radio pulses from a magnetar
- Mean pulse polarisation - kicks and velocities

Spin-Powered Pulsars: A Census

- Number of known pulsars: 1765
- Number of millisecond pulsars: 170
- Number of binary pulsars: 131
- Number of AXPs: 12
- Number of pulsars in globular clusters: 99*
- Number of extragalactic pulsars: 20

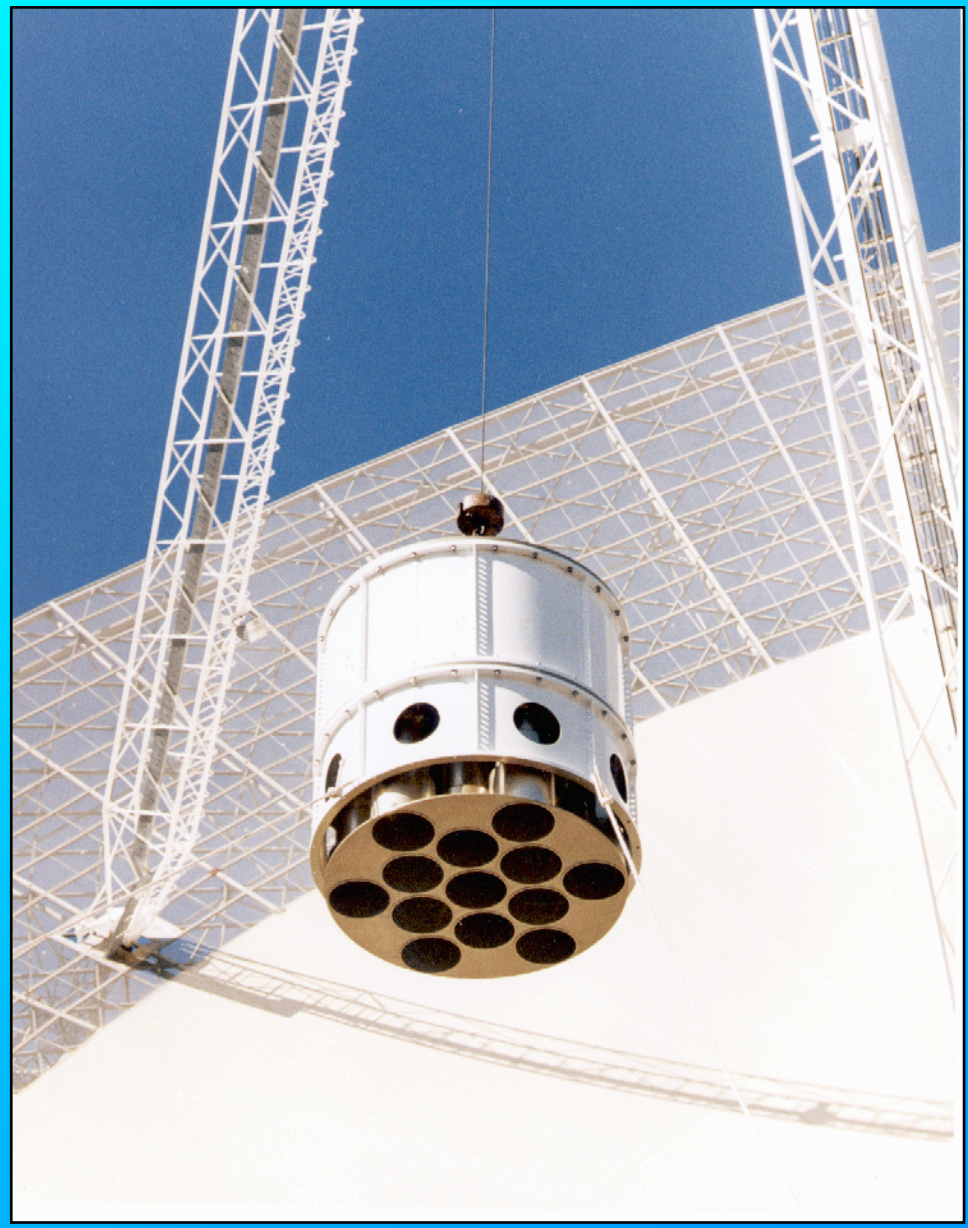


* Total known: 129 in 24 clusters (Paulo Freire's web page)

Data from ATNF Pulsar Catalogue, V1.25 (www.atnf.csiro.au/research/pulsar/psrcat; Manchester et al. 2005)

Parkes Multibeam Pulsar Surveys

- More than 880 pulsars discovered with multibeam system.
- The Parkes Multibeam Pulsar Survey (an international collaboration with UK, Italy, USA, Canada and Australia) has found ~760 of these (including RRATs).
- High-latitude surveys have found ~120 pulsars including 15 MSPs
- 14 pulsars found in Magellanic Clouds

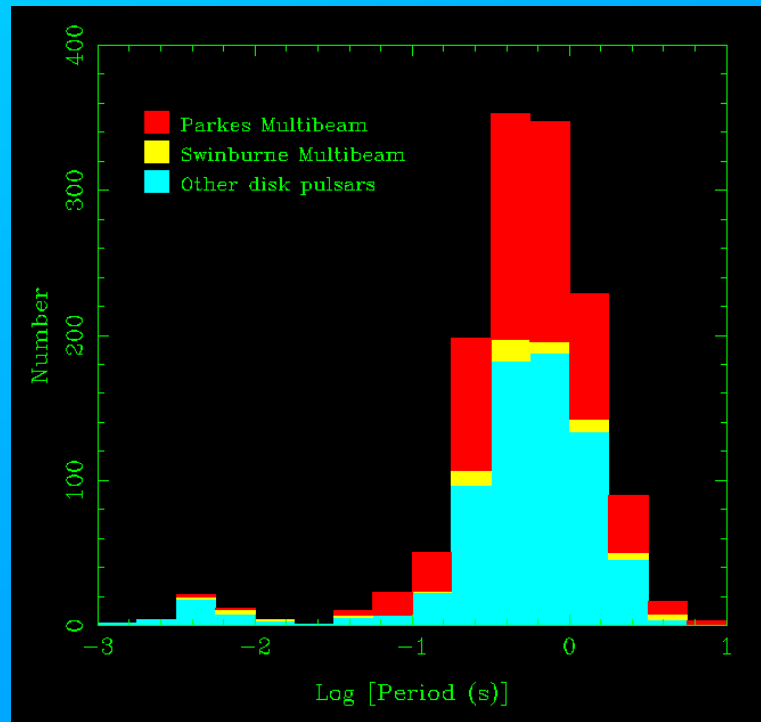


Parkes Multibeam Pulsar Survey

- Covers strip along Galactic plane, $-100^o < l < 50^o$, $|b| < 5^o$
- Central frequency 1374 MHz, bandwidth 288 MHz, 96 channels/poln/beam
- Sampling interval 250 μs, time/pointing 35 min, 3080 pointings
- Survey observations commenced 1997, completed 2003
- Processed on work-station clusters at ATNF, JBO and McGill
- 1015 pulsars detected
- At least 18 months of timing data obtained for each pulsar

Principal papers:

I: Manchester et al., MNRAS, 328, 17 (2001)
System and survey description, 100 pulsars
II: Morris et al., MNRAS, 335, 275 (2002)
120 pulsars, preliminary population statistics
III: Kramer et al., MNRAS, 342, 1299 (2003)
200 pulsars, young pulsars and γ-ray sources
IV: Hobbs et al., MNRAS, 352, 1439 (2004)
180 pulsars, 281 previously known pulsars
V: Faulkner et al., MNRAS, 355, 147 (2004)
Reprocessing methods, 17 binary/MSPs
VI: Lorimer et al., MNRAS, in press (2006a)
142 pulsars, Galactic population and evolution

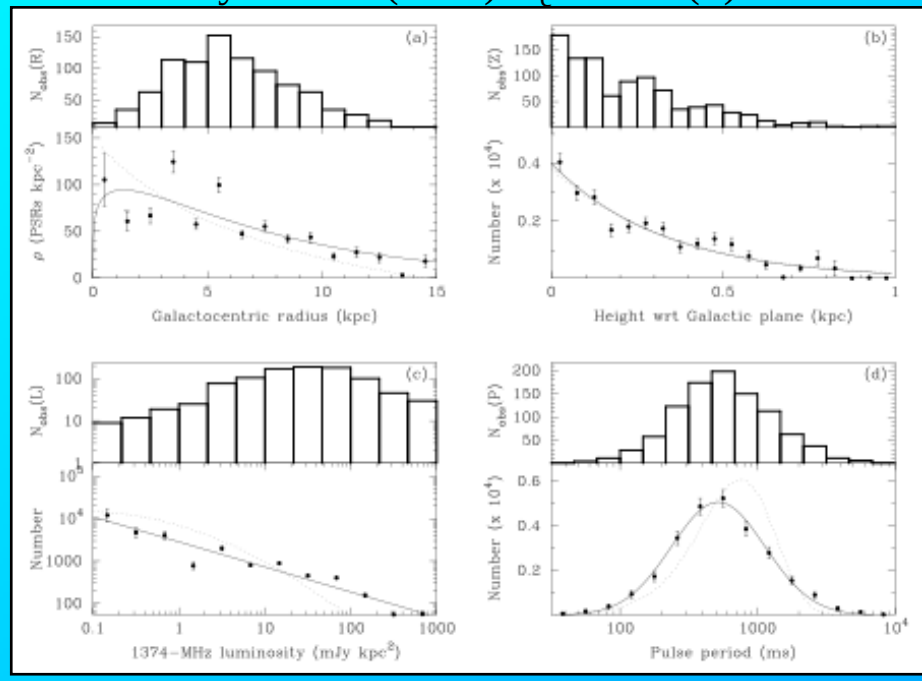


Galactic Distribution of Pulsars

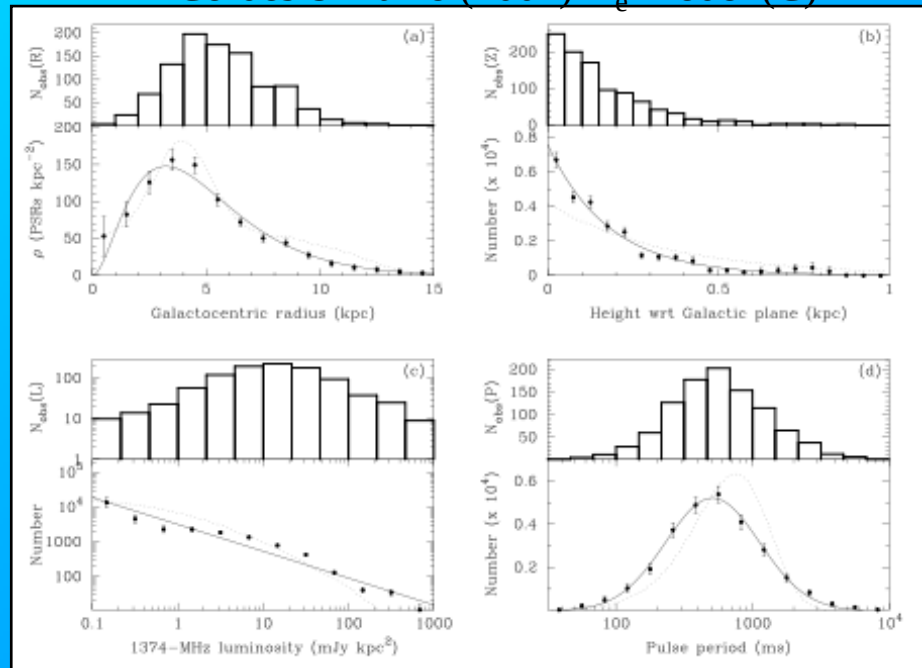
- Number of potentially detectable pulsars in Galaxy ~ 30,000 ± 1100
- With beaming correction ~ 150,000
- Derived radial distribution ***very*** dependent on Galactic electron density model
- *z* scale height ~330 pc (Model S), ~180 pc (Model C) - larger scale height more consistent with other results
- Luminosity function slope -0.6 (S) or -0.8 (C)
- Birthrate of potentially observable pulsars L > 0.1 mJy kpc2 ~ 0.34 ± 0.05 pulsars/century
- With beaming correction ~ 1.3 /century

(Lorimer et al. 2006a)

Lyne et al. (1985) N_e Model (S)

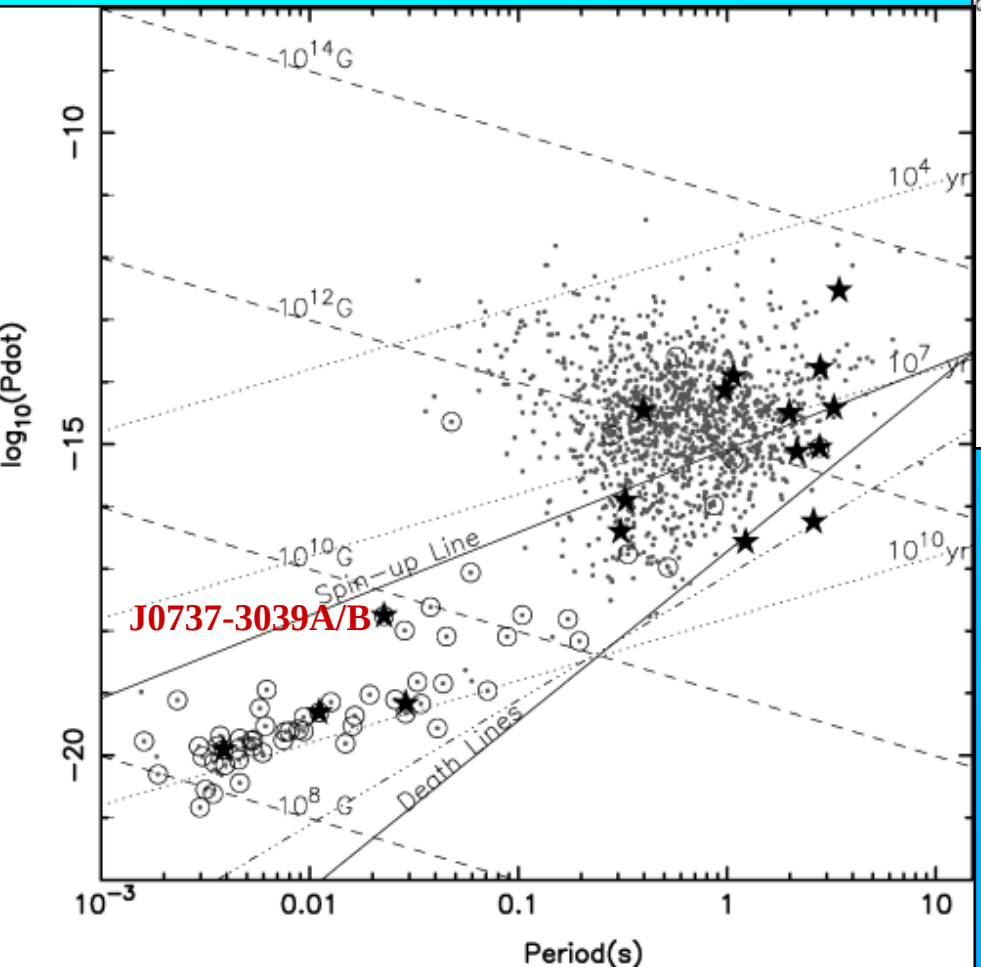


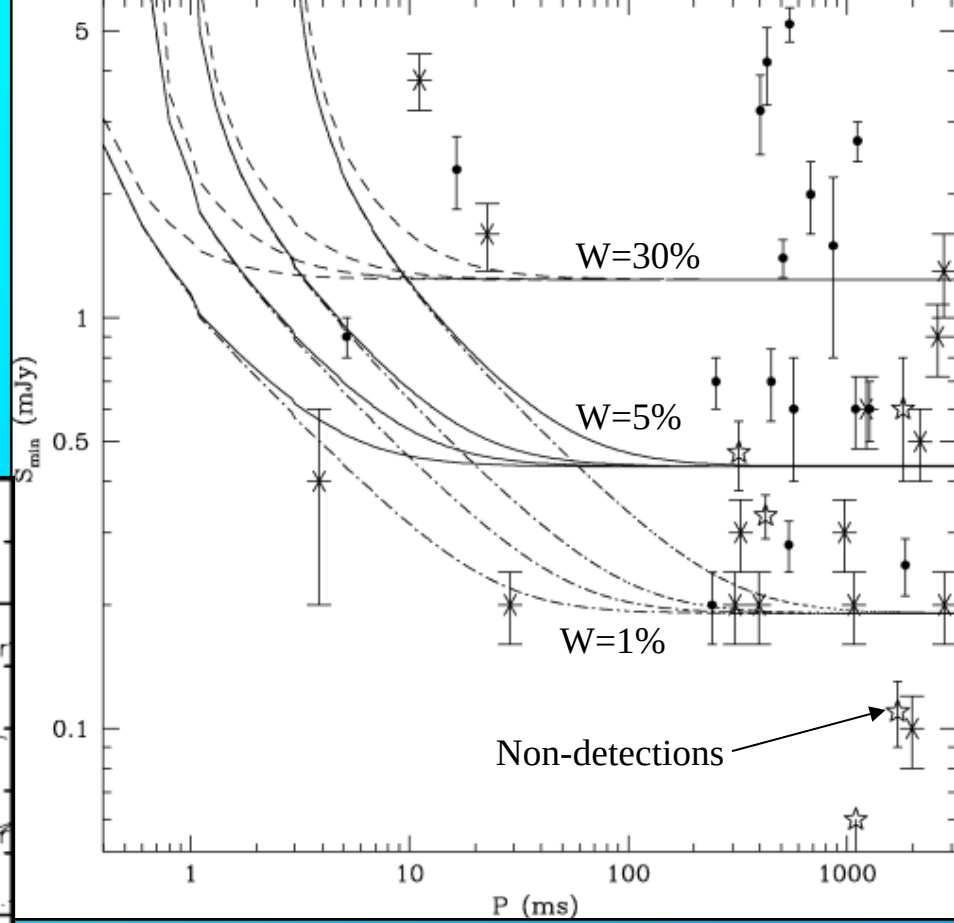
Cordes & Lazio (2002) N_e Model (C)



The Parkes High-Latitude Multibeam Survey

- $220^o < l < 260^o$, $|b| < 60^o$
- Samp. int. 125 ms, obs. time 4 min
- 6456 pointings

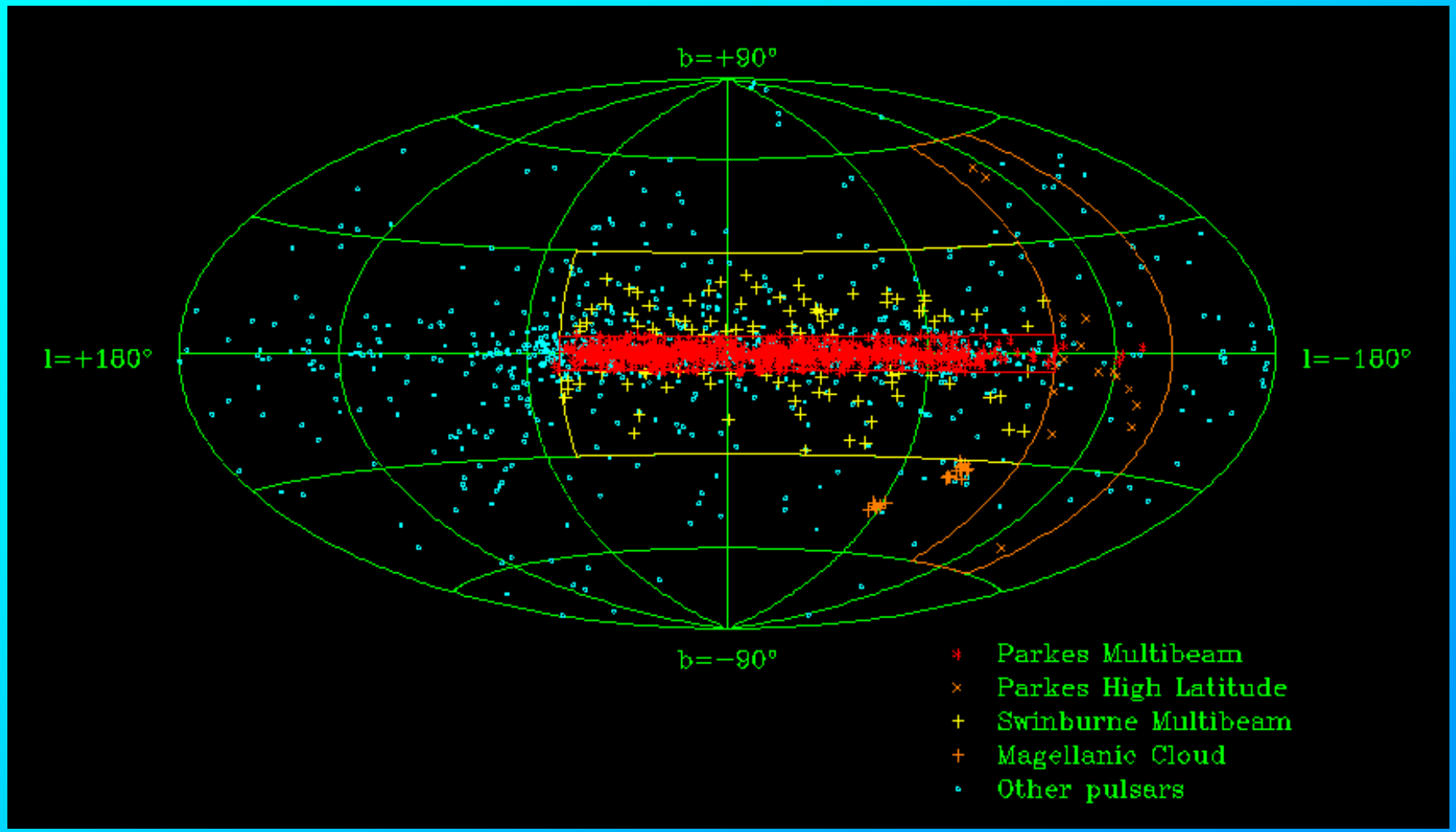




- 18 discoveries, 42 pulsars detected
- 4 MSPs, including the double pulsar!

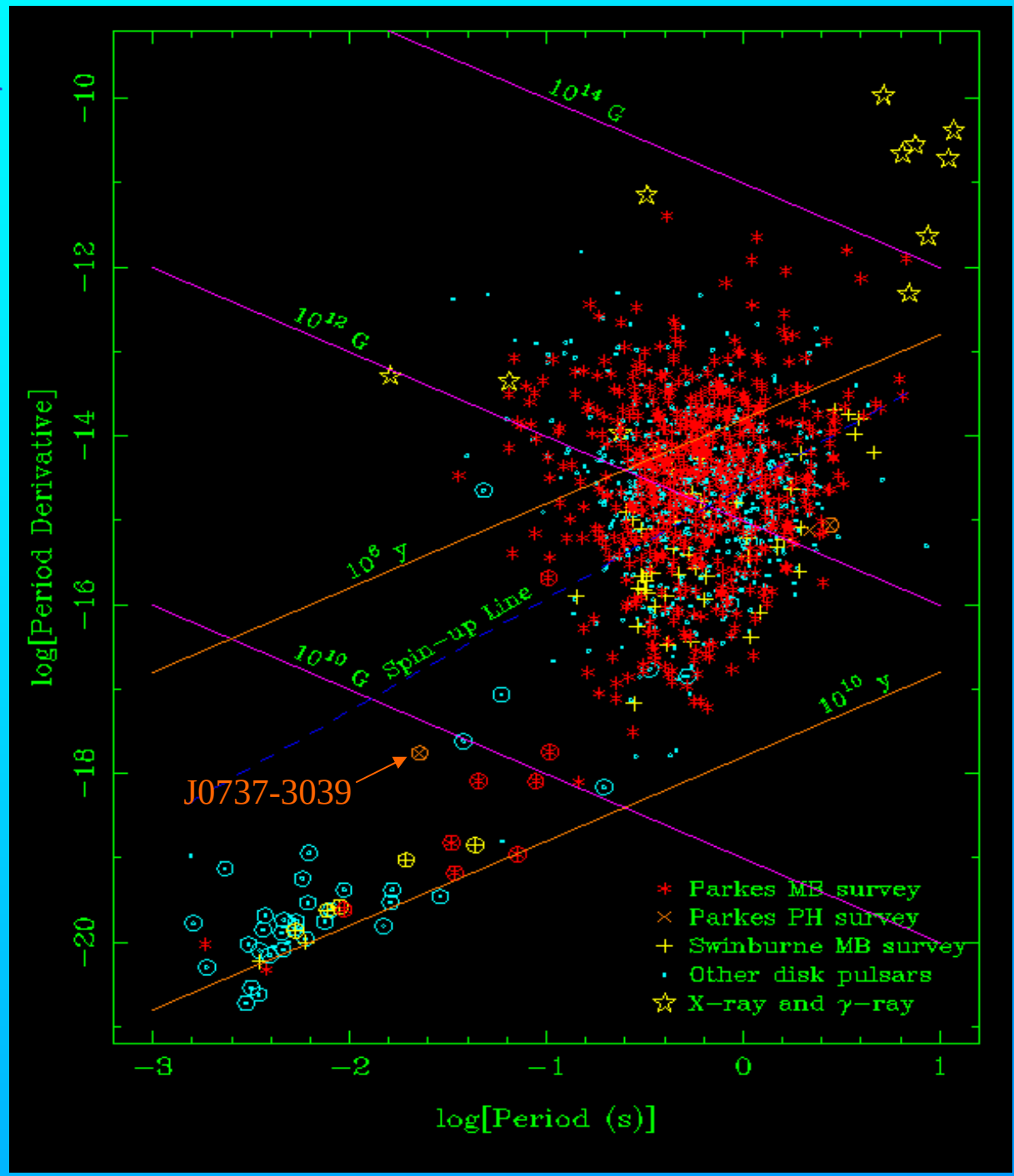
(Burgay et al. 2006)

Galactic Distribution of Pulsars



Parkes Multibeam Surveys: P vs $\dot{P}$

- New sample of young, high-B, long-period pulsars
- Large increase in sample of mildly recycled binary pulsars
- Three new double-neutron-star systems and one double pulsar!

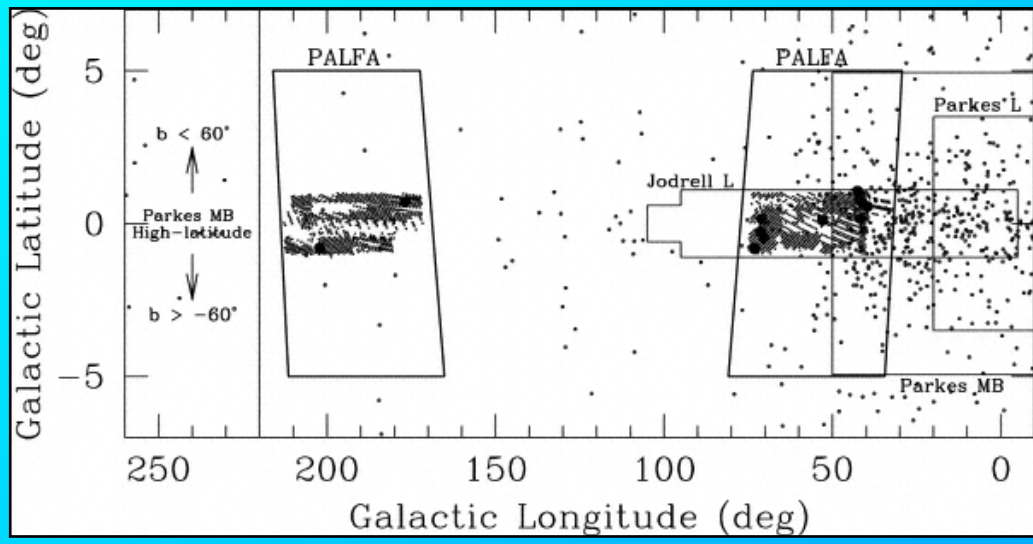


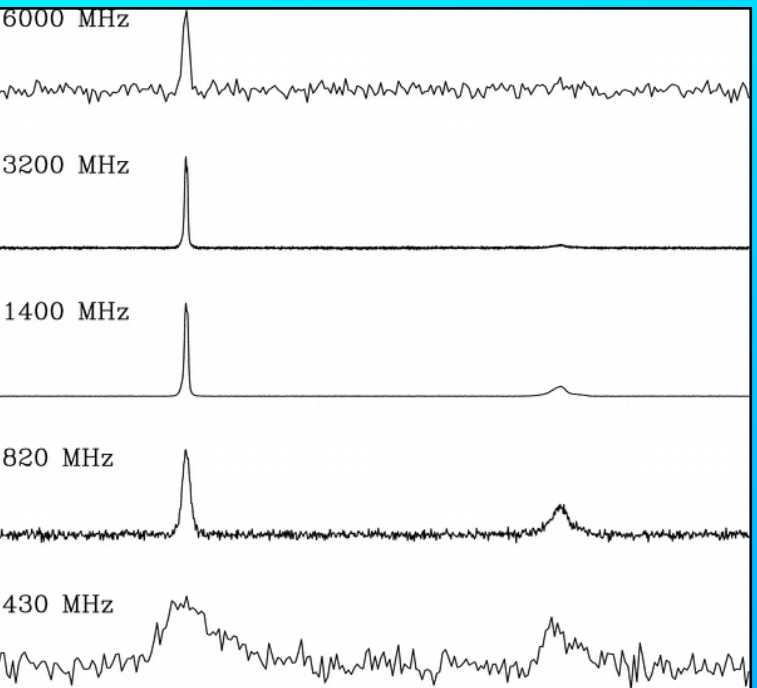
The PALFA Survey - A multibeam survey at Arecibo

- 7-beams, 1.4 GHz, 100 MHz (300 MHz later), 256 channels
- $32^o < l < 77^o$, $168^o < l < 214^o$, $|b| < 5^o$
- Samp. Int. 64 μs, obs time 134 (67) s
- Preliminary analysis: 11 discoveries, 29 redetections
- Full survey:1000 new psrs

(~375 - Lorimer et al. 2006a)

(Cordes et al. 2006)





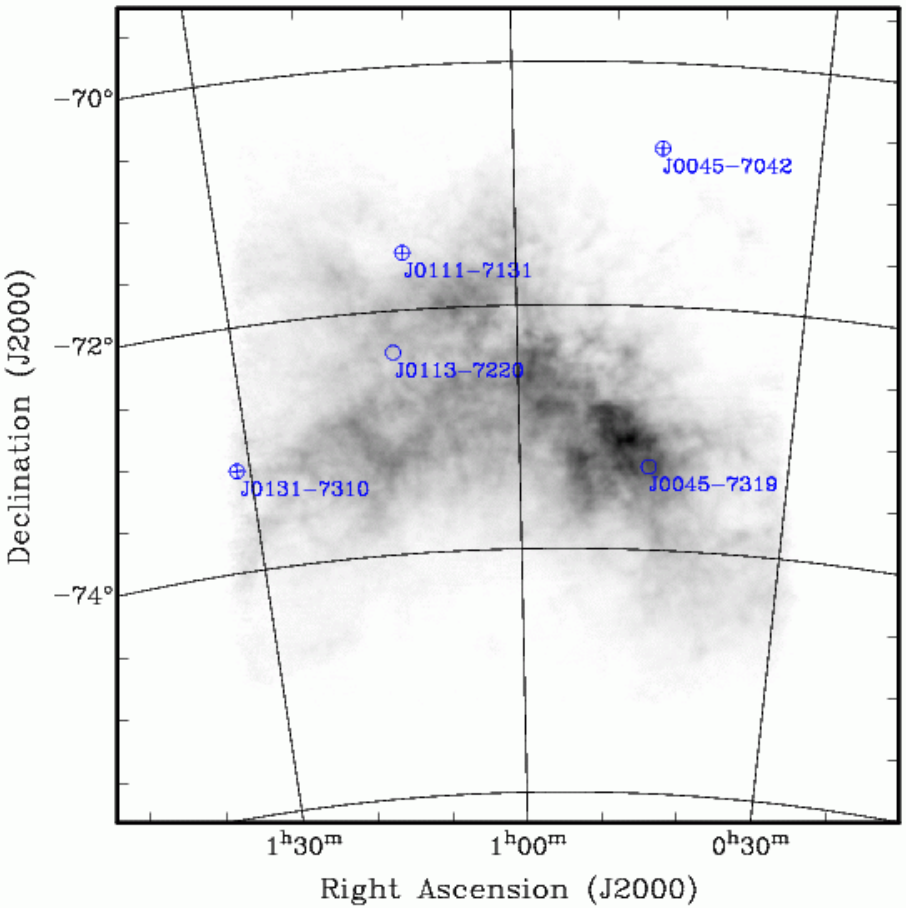
PSR J1906+0746

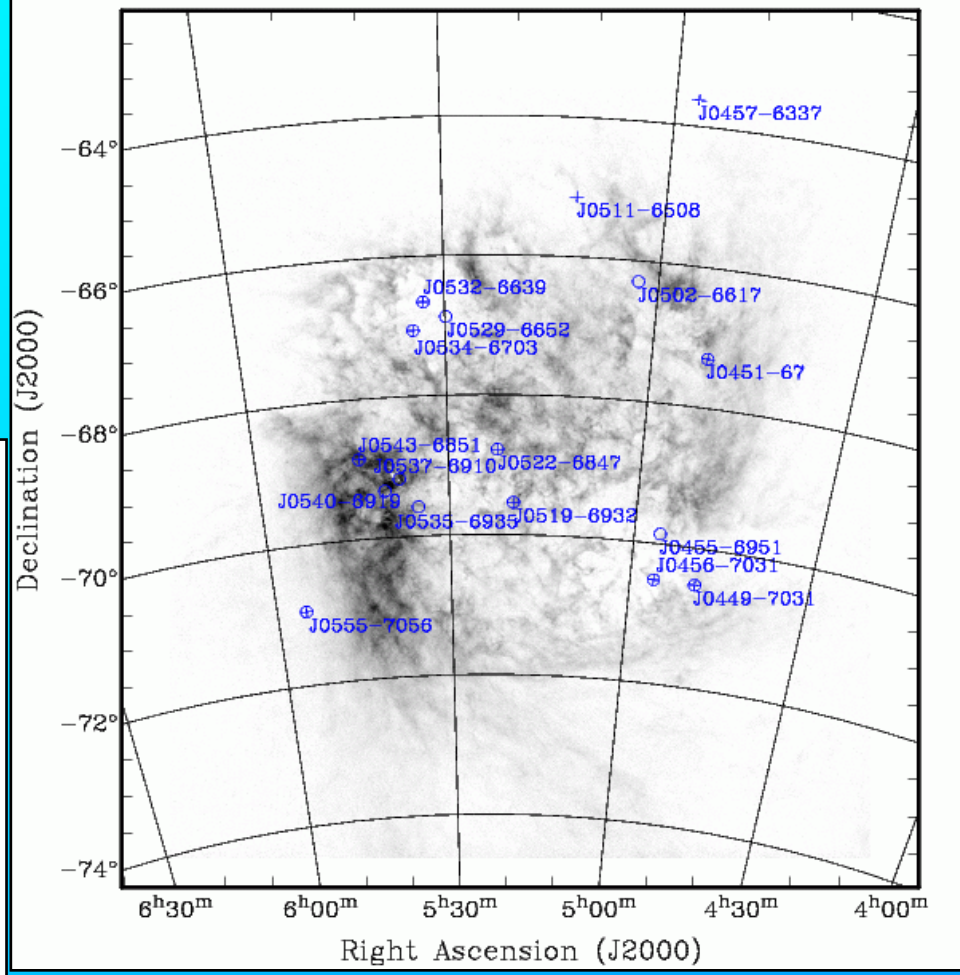
- 144-ms pulsar in 3.98-h binary orbit
- Highly relativistic, $\omega \sim 7.6^o$/yr
- $m_p + m_c = 2.61 \pm 0.02\ M_\odot$
- Pulsar is young! $\tau_c \sim 112$ kyr
- Companion either a massive white dwarf or a neutron star (observed pulsar is the second born)
- Coalescence time ~300 Myr

(Lorimer et al. 2006b)

Magellanic Cloud Survey

- Parkes multibeam system
- 73 (SMC), 136 (LMC) pointings
- Samp. int. 1 ms, Obs. time 2.3 h
- S_{min} ~ 0.12 mJy

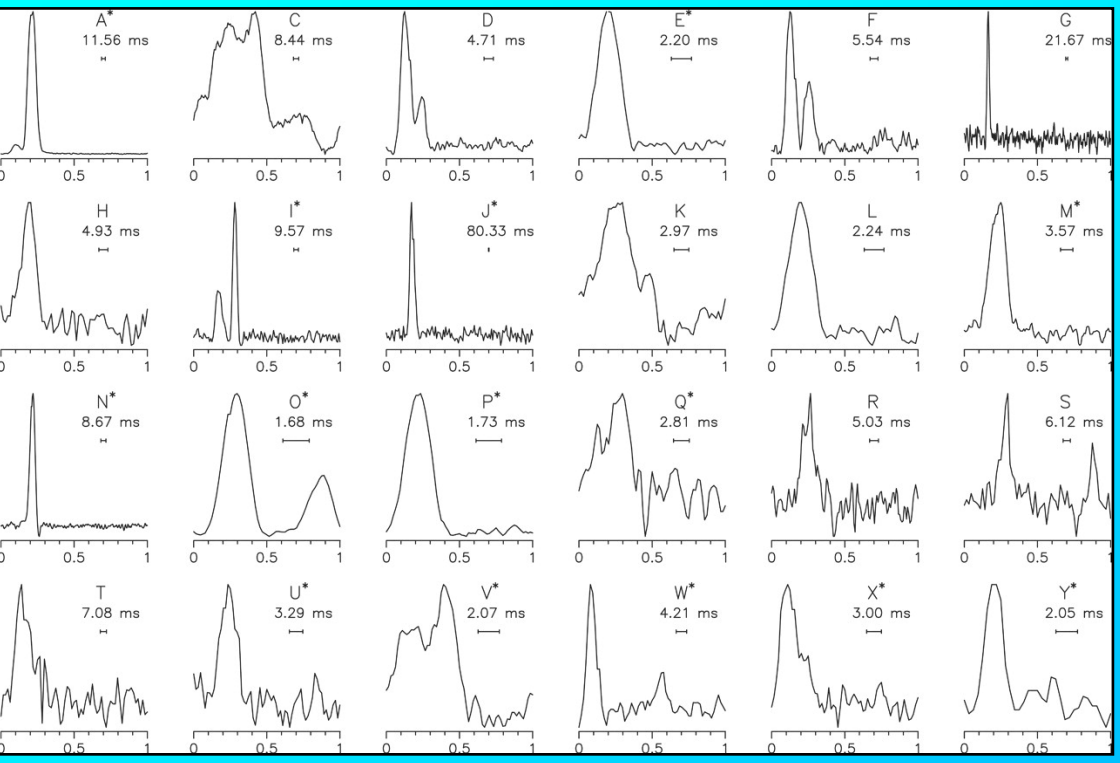




- 14 pulsars discovered, 12 in MC
- Total of 20 known pulsars in MC
- Luminosity function consistent with that for Galactic pulsars
- No significant L(P), L(τ_c)

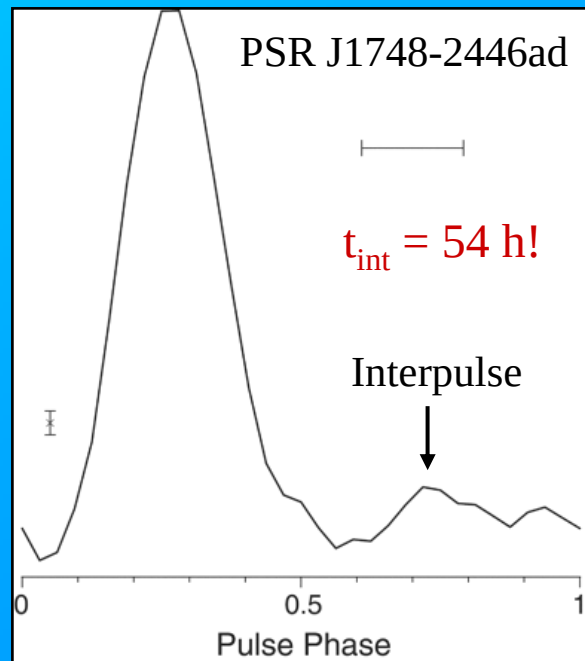
(Manchester et al. 2006)

GBT Search of Globular Cluster Terzan 5



(Ransom et al. 2005)

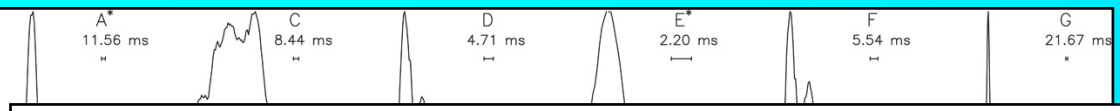
- 600 MHz bandwidth at 2 GHz
- 5.9h obs with 82 μs sampling
- S_{min} ~ 15 μJy
- 31 pulsars discovered!! 33 total in cluster (www.naic.edu/~pfreire/GCpsr.html)
- Two eccentric relativistic binaries; N-star ~ 1.7 $M_\odot$?



- PSR J1748-2446ad - fastest known pulsar!
- P = 1.3959 ms, f_0 = 716.3 Hz, S_{2000} ~ 80 μJy
- Binary, circular orbit, P_b = 1.09 d
- Eclipsed for ~40% of orbit
- $m_c > 0.14\ M_\odot$

(Hessels et al. 2006)

GBT Search of Globular Cluster Terzan 5



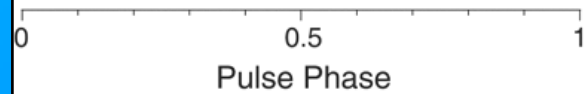
- 600 MHz bandwidth at 2 GHz

Table 2. The 10 fastest spinning known radio pulsars. Data compiled from the Australia Telescope National Facility pulsar database (*33*).

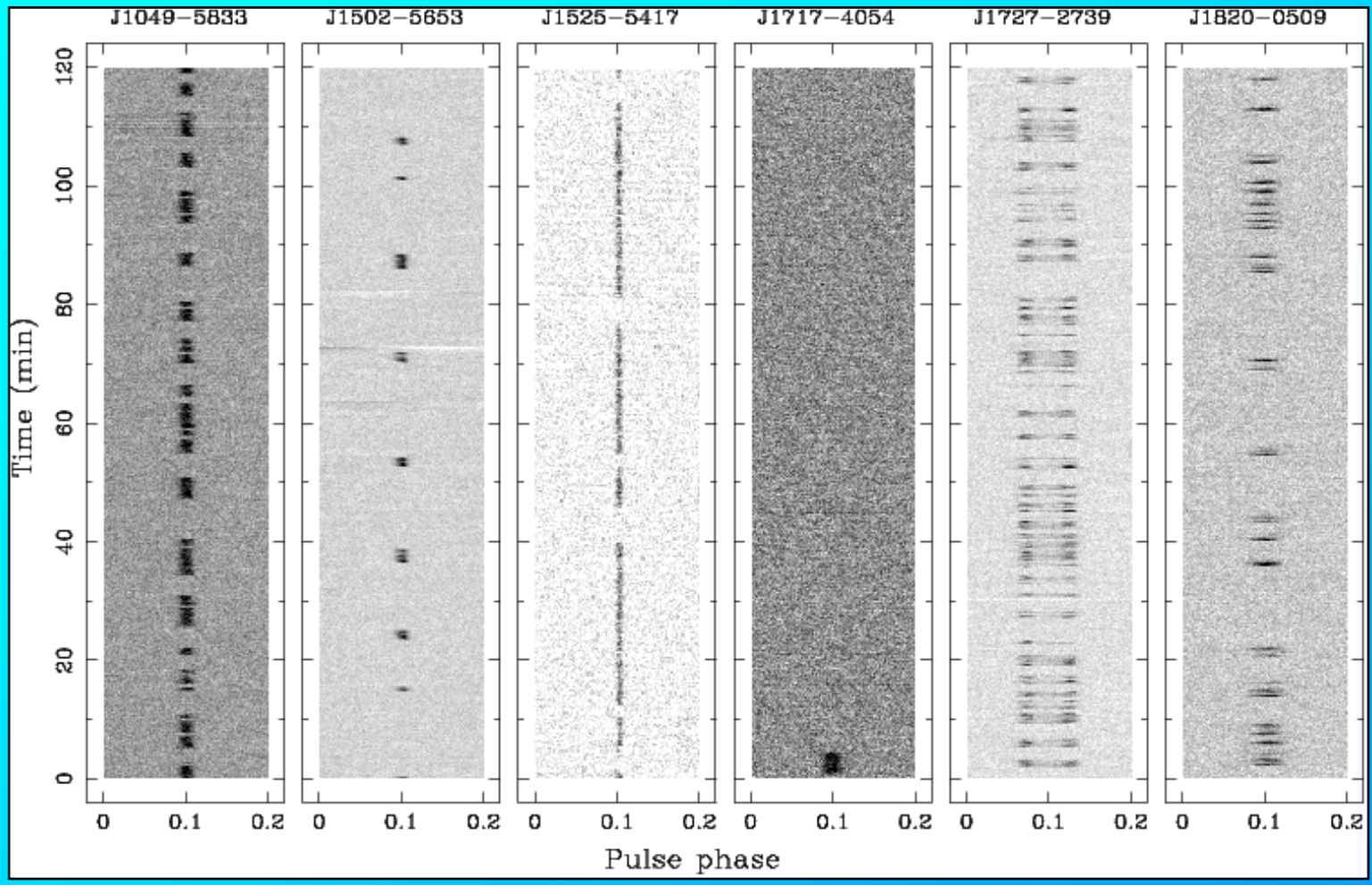
Pulsar	Spin frequency (Hz)	P_b (days)	$M_{2,min}$ ($M_\odot$)	Eclipse fraction	Location
J1748–2446ad	716.358	1.0944	0.14	0.4	Terzan 5
B1937+21	641.931	isolated			Galaxy
B1957+20	622.123	0.3819	0.021	0.1	Galaxy
J1748–2446O	596.435	0.2595	0.035	0.05	Terzan 5
J1748–2446P	578.496	0.3626	0.37	0.4	Terzan 5
J1843–1113	541.812	isolated			Galaxy
J0034–0534	532.714	1.5892	0.14	0	Galaxy
J1748–2446Y	488.243	1.17	0.14	0	Terzan 5
J1748–2446V	482.507	0.5036	0.12	0	Terzan 5
B0021–72J	476.048	0.1206	0.020	0.1*	47 Tucanae

$m_c > 0.14\ M_\odot$

(Hessels et al. 2006)



Pulsar Nulling

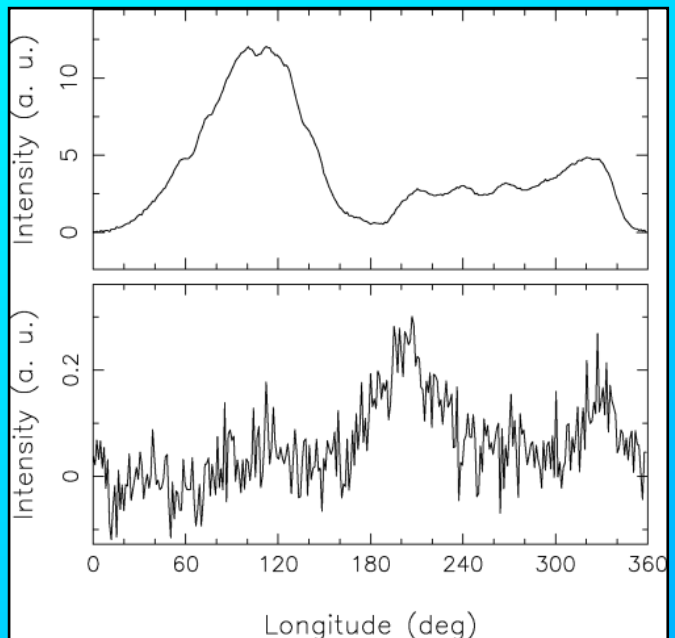


- Parkes observations of 23 pulsars, mostly from PM survey
- Large null fractions (up to 96%) - mostly long-period pulsars
- Nulls often associated with mode changing (Wang et al. 2006)

PSR B0826-34

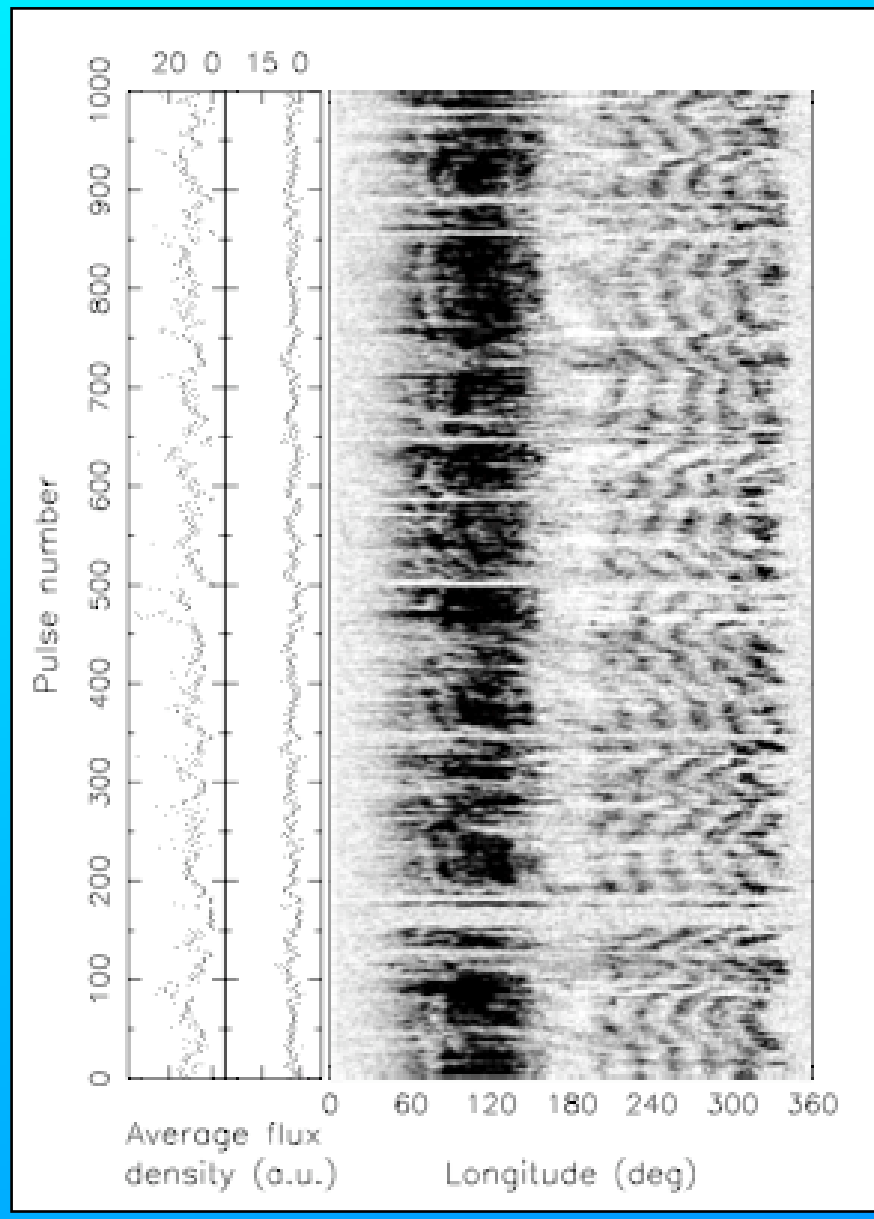
- P = 1.848 s, pulsed emission across whole of pulse period
- In “null” state ~80% of time
- 5-6 drift bands across profile, variable drift rate with reversals
- Weak emission in “null” phase, ~2% of “on” flux density
- Different pulse profile in “null” phase

Null is really a mode change!



On

“Null”



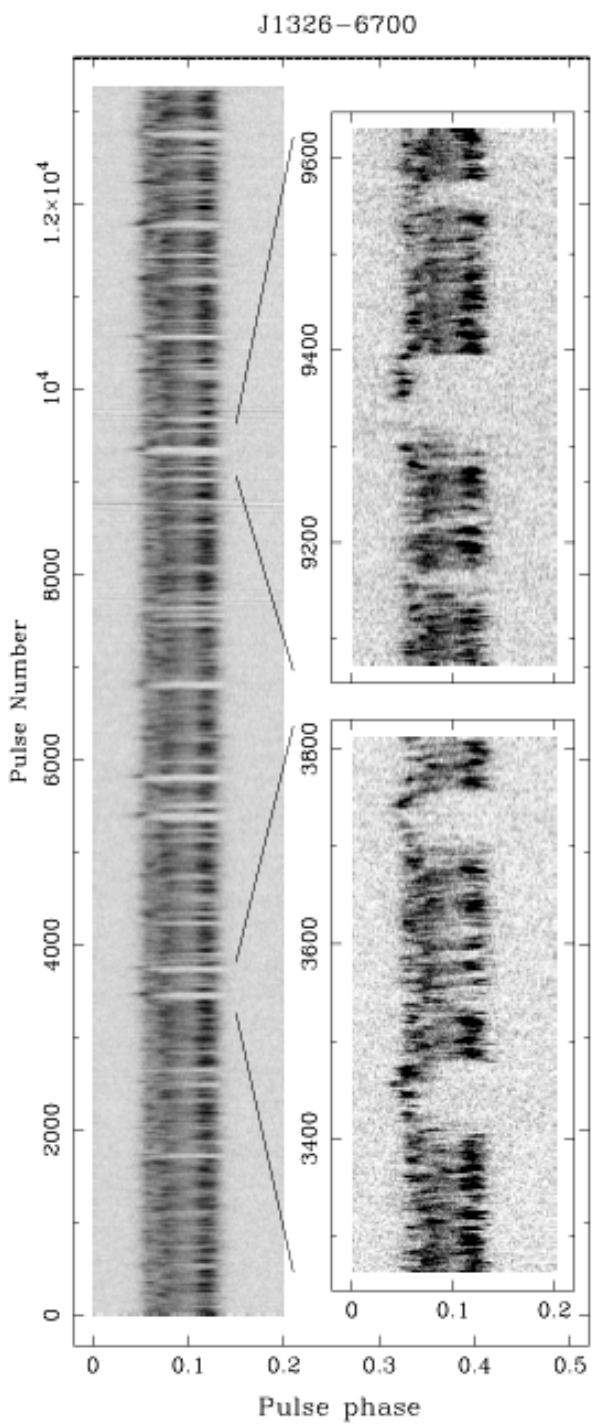
(Esamdin et al. 2005)

Nulls as Mode Changes

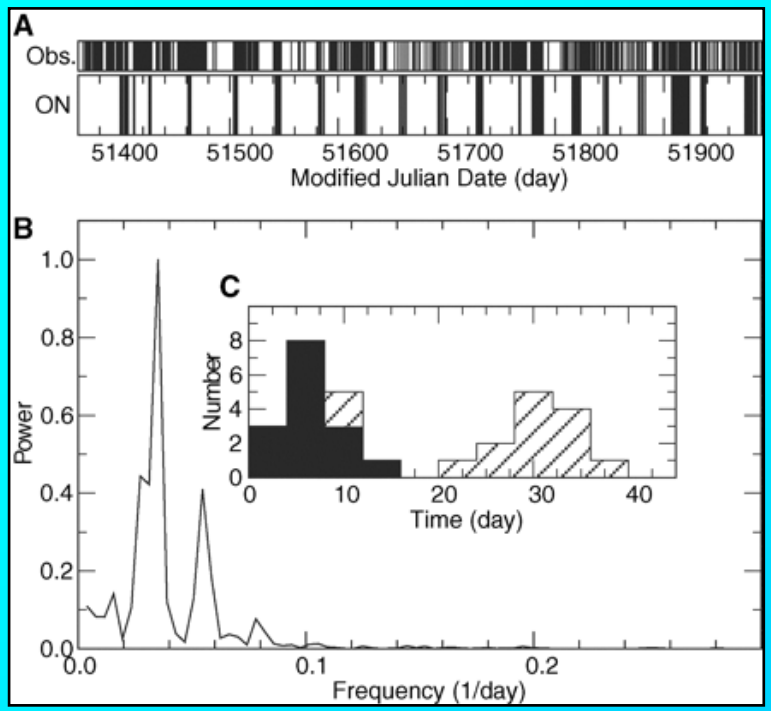
- Parkes observation of PSR B1322-66 (J1326-6700)
- 2 hours at 1.4 GHz
- Individual pulses recorded
- Frequent short “nulls” observed
- During “null”, new component appears at leading edge of pulse
- Highly variable in both phase and amplitude

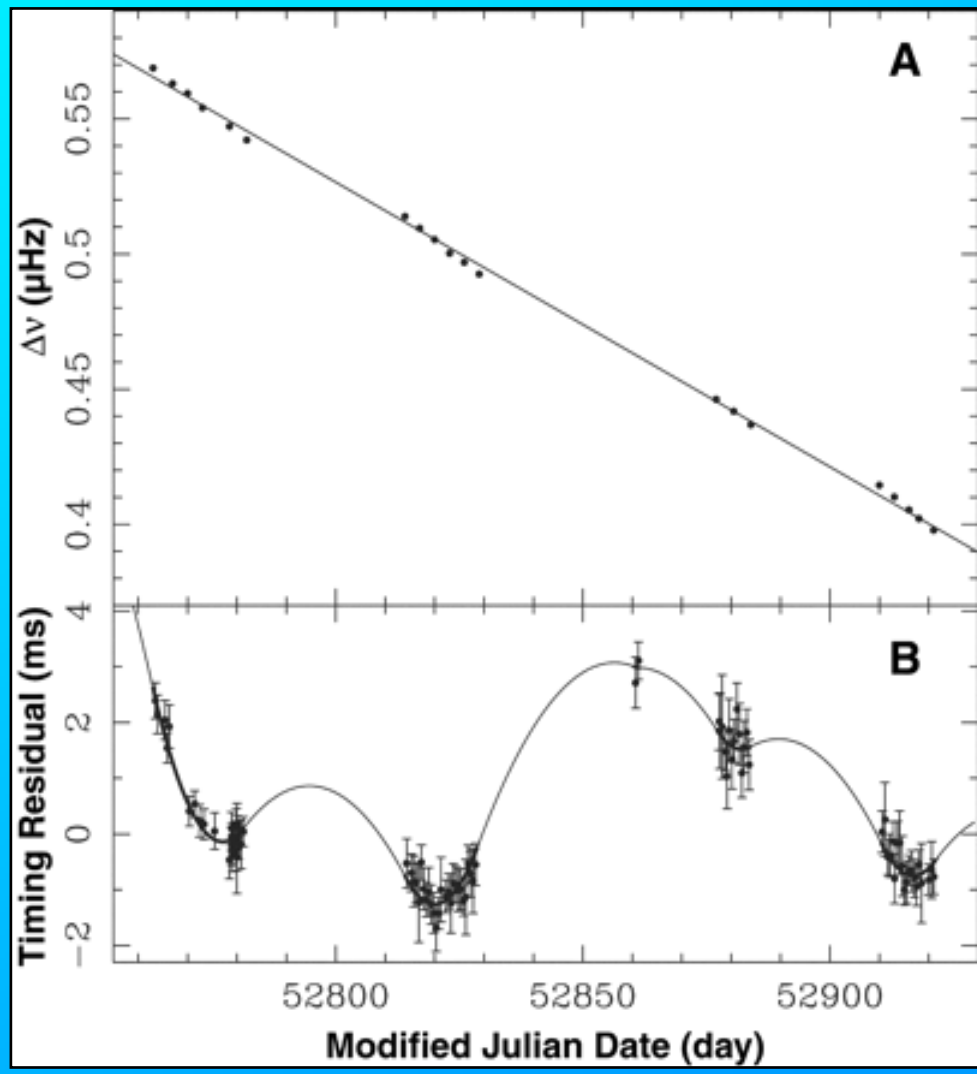
Nulls and mode changes represent a sudden transistion between two (occasionally more) quasi-stable states of current flow in the magnetosphere

(Wang et al. 2006)



PSR B1931+24 - An extreme nuller



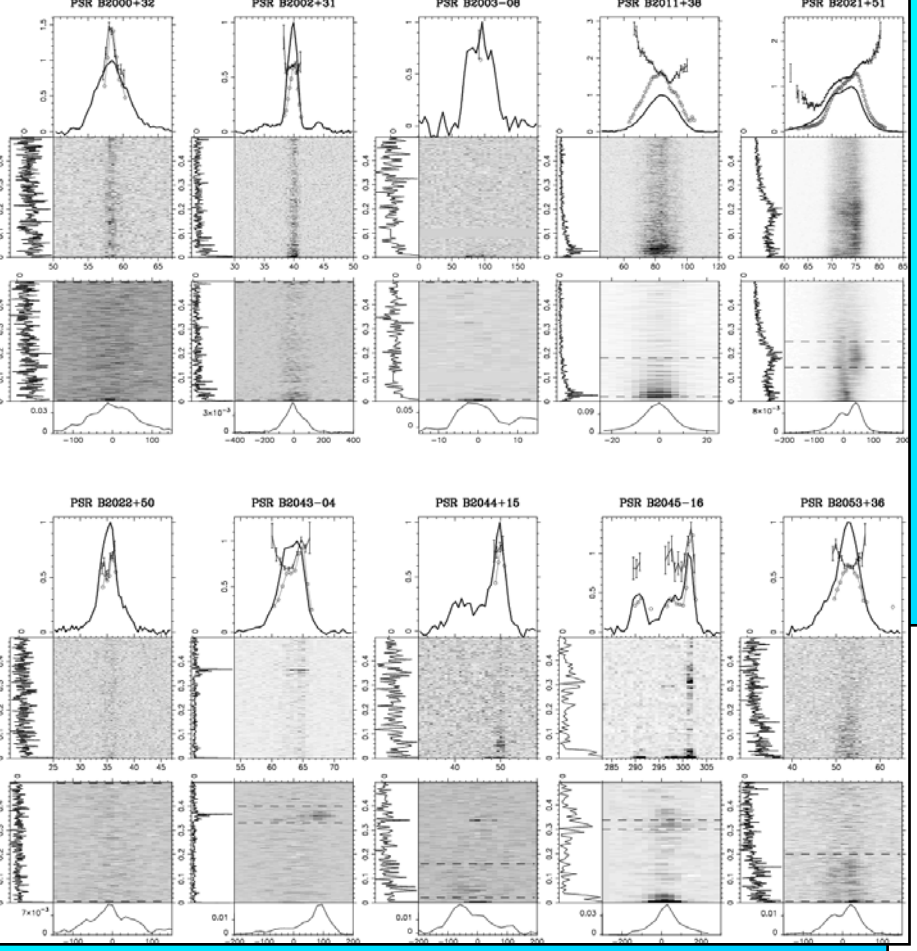


- Quasi-periodic nulls: on for 5-10 d, off for 25-35 d
- **Period derivative is ~35% smaller when in null state!**
- Implies cessation of braking by current with G-J density
- Direct observation of current responsible for observed pulses

(Kramer et al. 2006)

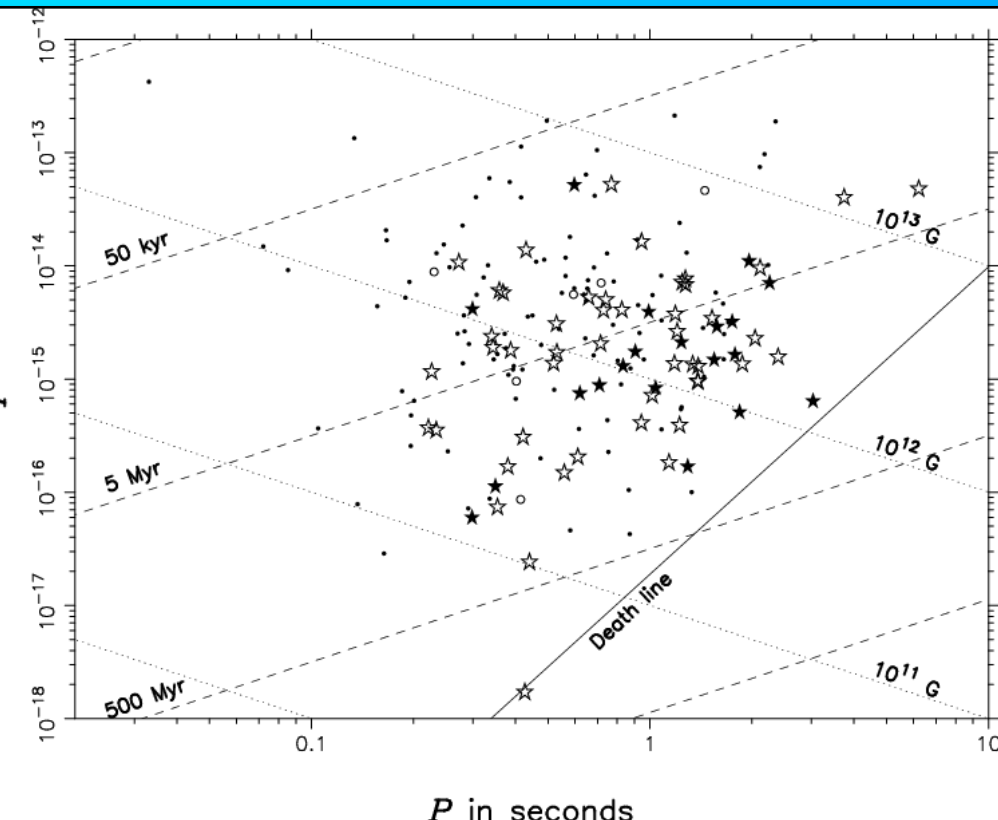
Pulse Modulation

- Extensive survey of pulse modulation properties at Westerbork - 187 pulsars
- Observations at 1.4 GHz, 80 MHz bw
- Modulation indices, longitude-resolved and 2D fluctuation spectra computed
- 42 new cases of drifting subpulses



- At least 60% of all pulsars show evidence for drifting behaviour
- "Coherent" drifters have large characteristic age, but drifting seen over most of P - Ṗ diagram

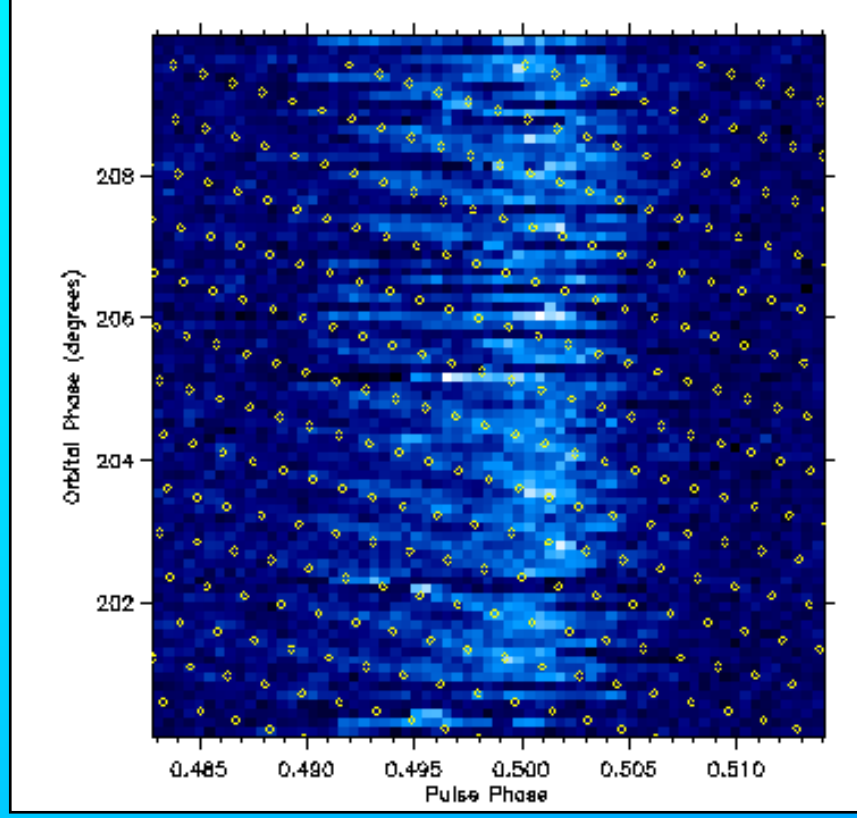
(Weltevrede et al. 2006a)

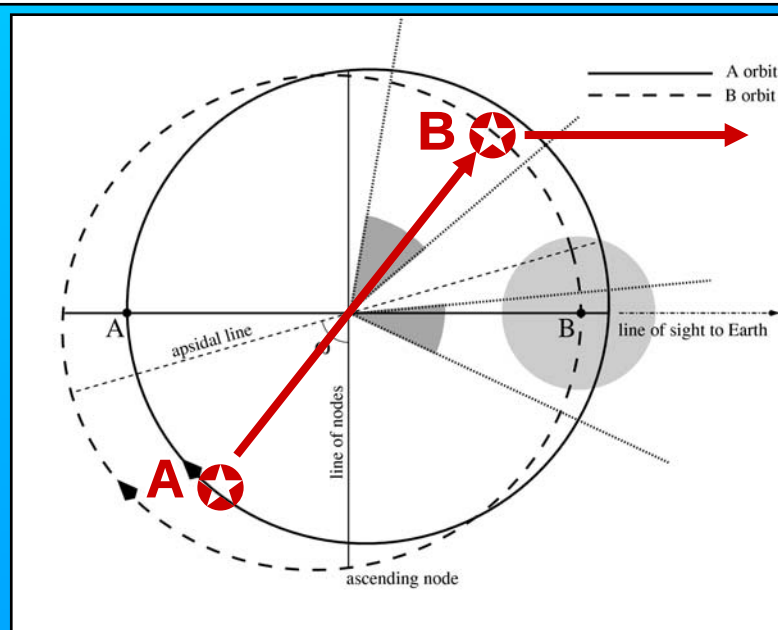


PSR J0737-3039A/B
Modulation of B pulses by A

- "Drifting subpulses" observed in B pulse emission in leading bright phase, $P_2 \sim P_A$
- Drift rate of 0.196 cycles/period
- Ratio of pulsar barycentric periods: $P_B/P_A = 122.182$
- Doppler shift from varying separation of A & B - at orbital longitude 205°, predicted beat frequency ~ 0.196 cycles/period, exactly as observed!
- Suggests that modulation is due to impact of A's **magnetic-dipole radiation field** on B's magnetosphere, rather than A pulses or wind
- Mechanism not clear - modulation of beam direction or emission intensity?

(McLaughlin et al. 2004)





Giant Pulses

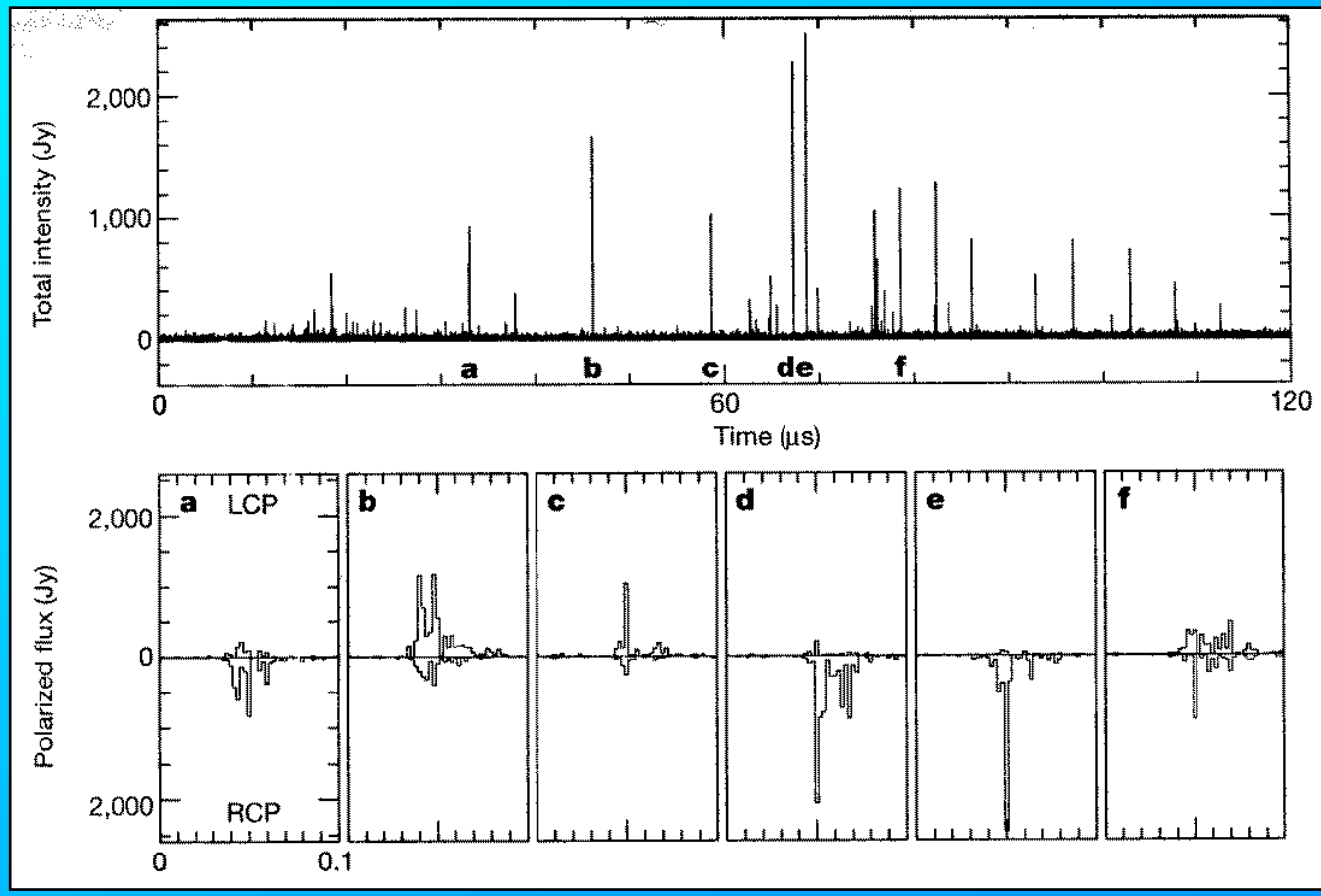
Intense narrow pulses with a pulse energy many times that of an average pulse - characterised by a power-law distribution of pulse energies.

First observed in the Crab pulsar - discovered through its giant pulses!

- Arecibo observations at 5.5 GHz
- Bandwidth 0.5 GHz gives 2 ns resolution
- Flux density > 1000 Jy implies $T_b > 10^{37}$ K!
- Highly variable polarisation
- Suggests emission from plasma turbulence on scales ~ 1 m

(Hankins et al. 2003)

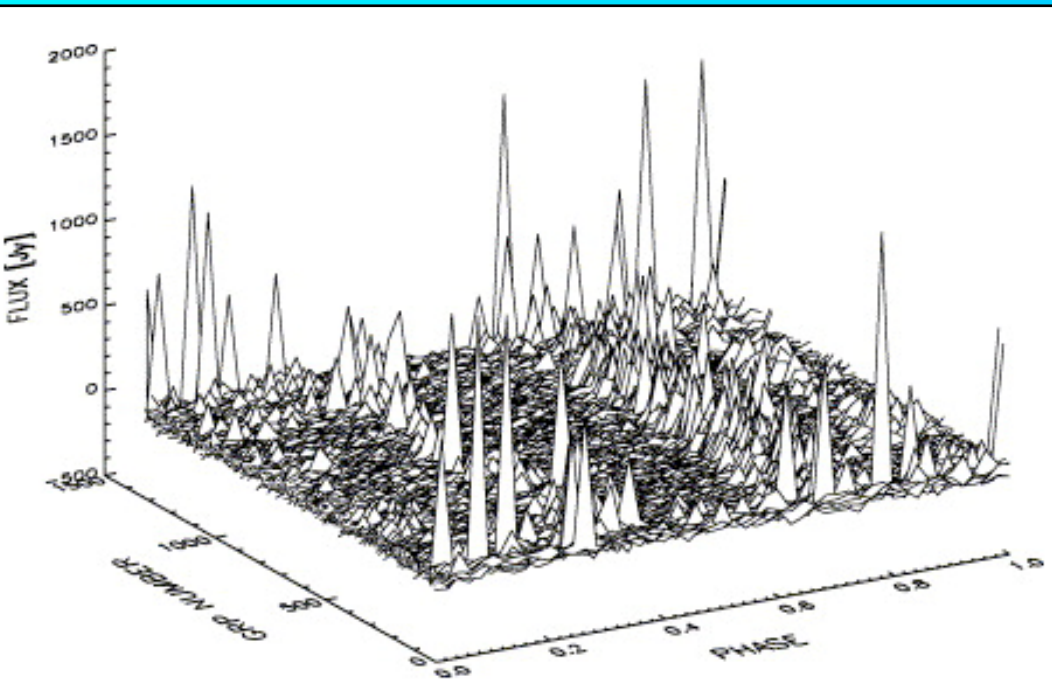
Crab Giant Pulses

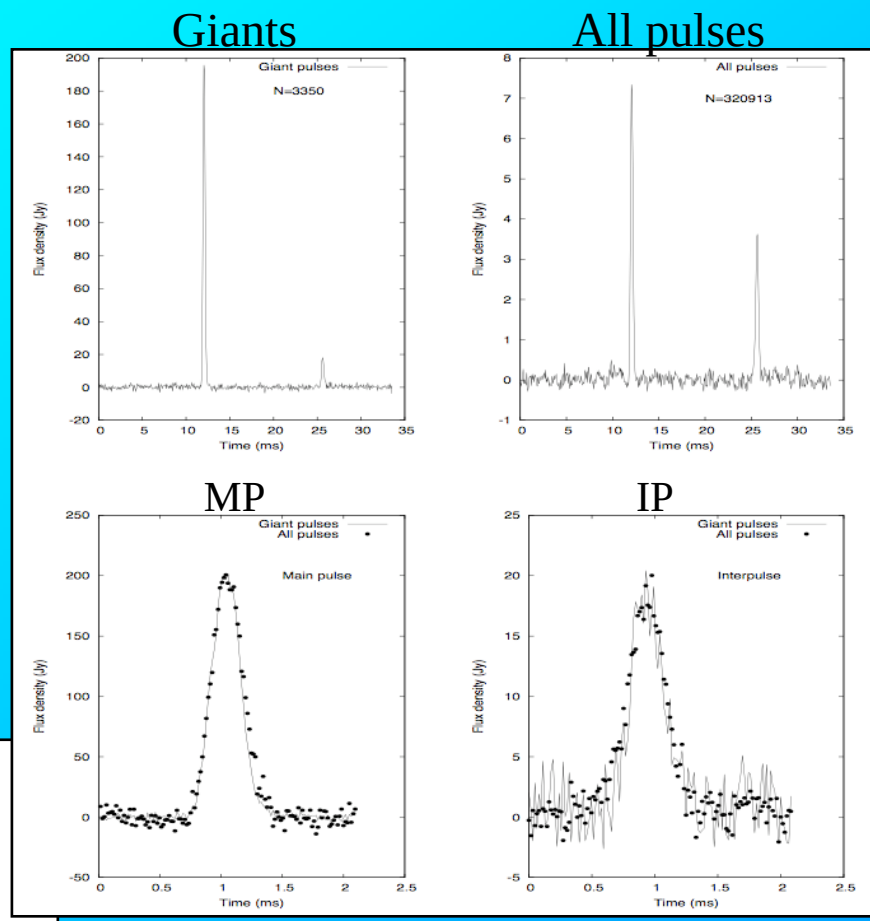


Crab Giant Pulses

- 600 MHz observations, Kalyazin 64m
- All pulses from the main pulse and interpulse are giant
- Precursor has no giant pulses
- Giants have high circular polarisation, typically > 40%

(Popov et al. 2006)





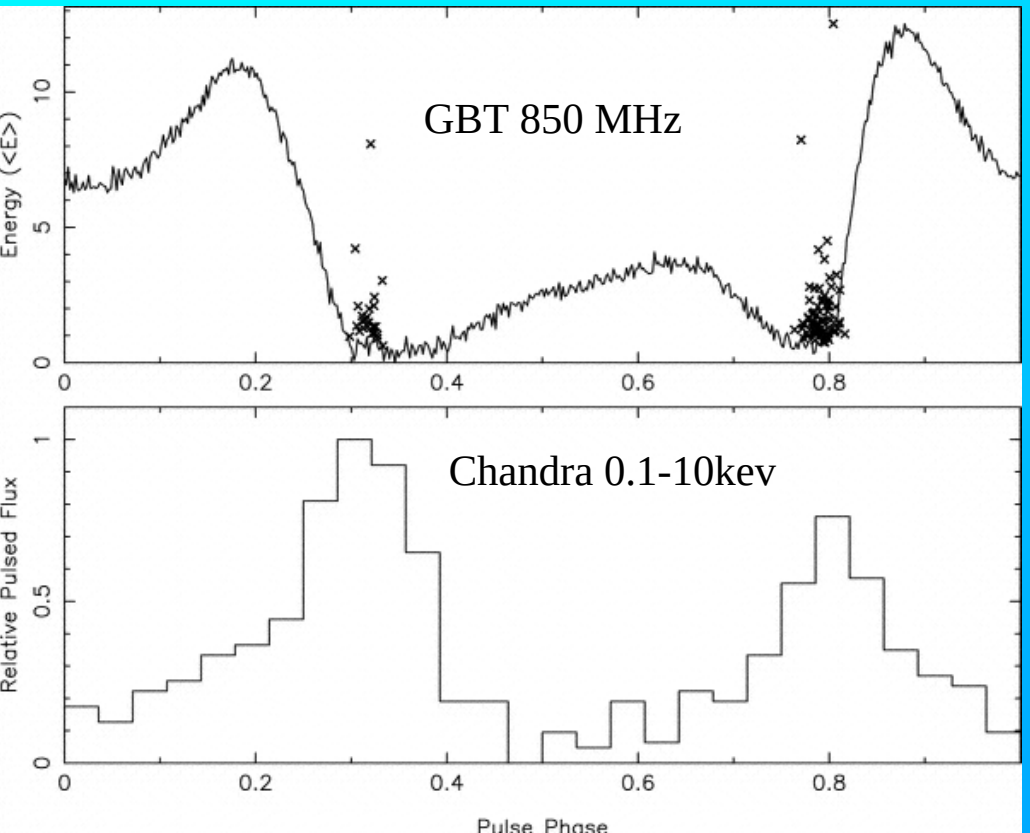
- Effelsberg, 8.3 GHz, 6.7 hours
- Giant pulses from HF components (Moffet & Hankins 1996) as well as MP and IP

(Jessner et al. 2005)

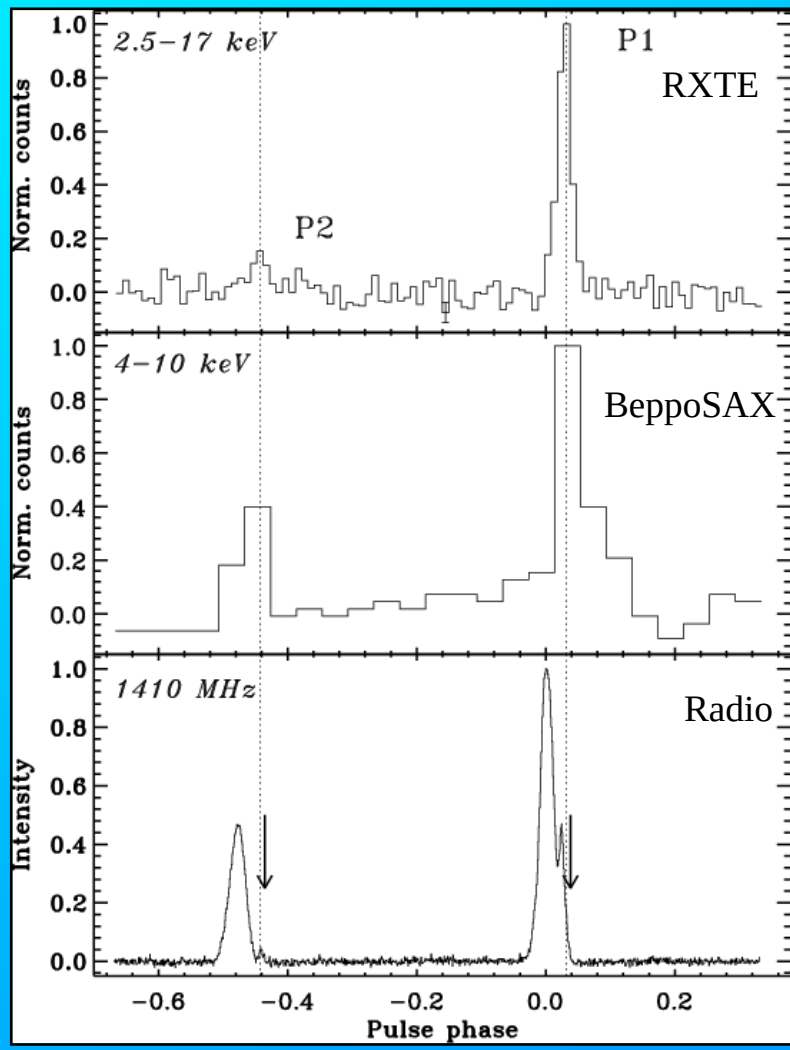
Giant Pulses from Millisecond Pulsars

- Giant pulses seen from several MSPs with high B_{LC}
- Most also have pulsed non-thermal emission at X-ray energies
- Giant pulses occur at phase of X-ray emission

PSR J0218+4232



PSR B1937+21



(Cusumano et al. 2003)

(Knight et al. 2006, Kuiper et al. 2004, Rutledge et al. 2004)

“Giant” Pulses from Other Pulsars

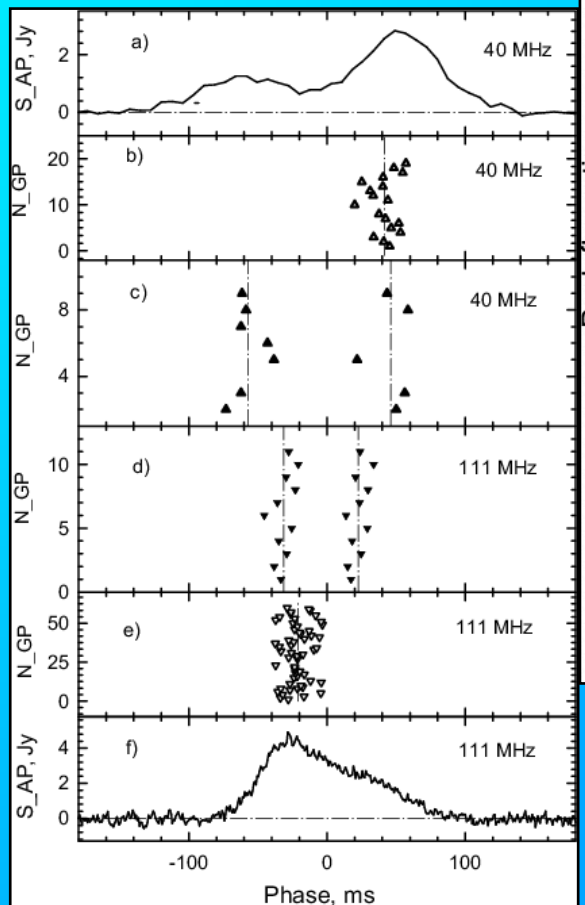
- Some pulsars occasionally emit very strong pulses - few 100x mean flux density
- Emitted at different phases across pulse profile, pulse widths ~ ms
- Not power-law distribution of pulse energies
- Not associated with non-thermal X-ray emission
- These pulsars do not have high B_{LC}

Not the same phenomenon as the giant pulses observed in the Crab and MSPs

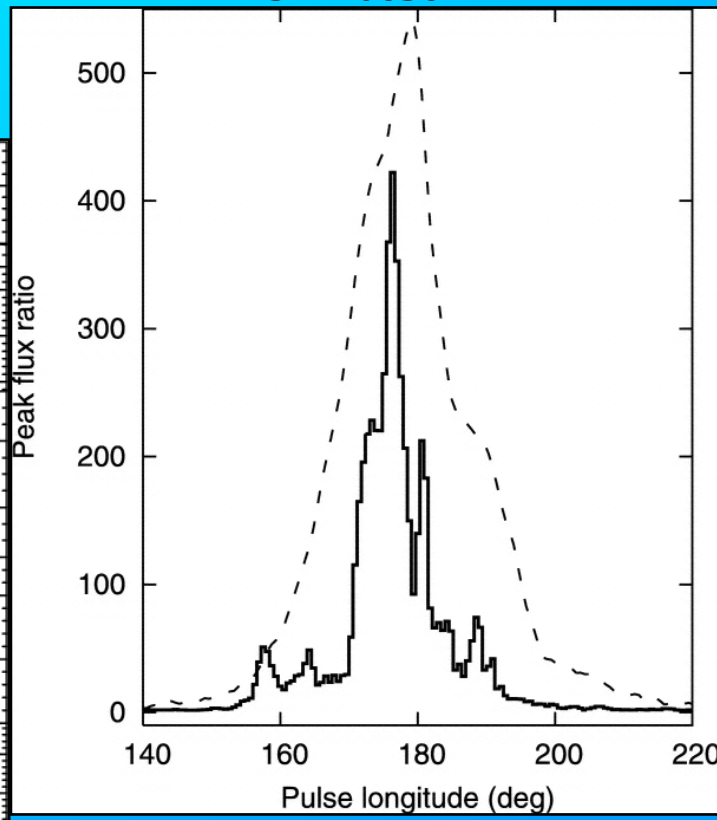
➢ Extreme examples of normal subpulse modulation

➢ Likely to be same population as RRATs

PSR B0031-07



PSR B0656+14



(Weltevrede et al. 2006b)

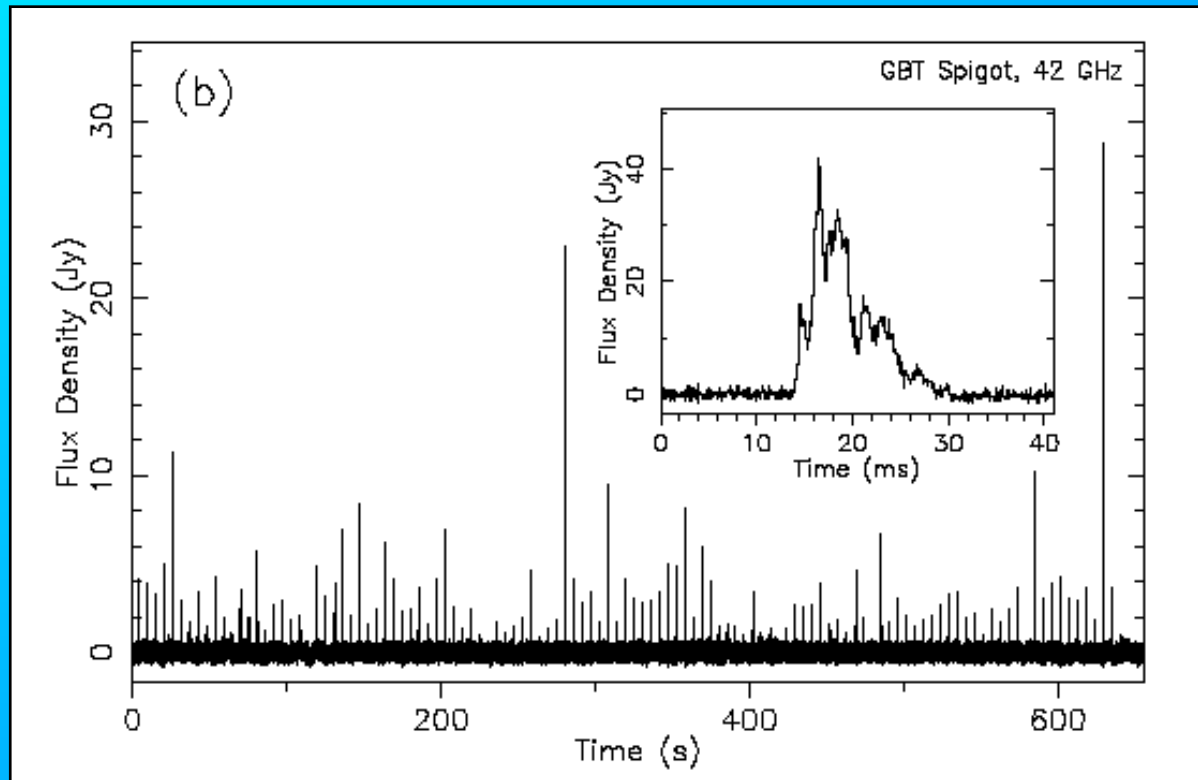
(Kuzmin & Ershov 2004)

Transient Pulsed Radio Emission from a Magnetar

- AXP XTE J1810-197 - 2003 outburst in which X-ray luminosity increased by ~100
- X-ray pulsations with P = 5.54 s observed
- Detected as a radio source at VLA, increasing and variable flux density: 5 - 10 mJy at 1.4 GHz (Halpern et al. 2005)
- Within PM survey area, not detected in two obs. in 1997, 1998, $S_{1.4} < 0.4$ mJy
- Observed in March 2006 at Parkes (Camilo et al. 2006)

- ***Pulsar detected!***
- $S_{1.4} \sim 6$ mJy
- Very unusual flat spectrum - individual pulses detected in GBT observations at 42 GHz!

Earlier unconfirmed detections (e.g. Malofeev et al 2005) accounted for by transient and highly variable nature of pulsed emission?



Rotation Axis - Velocity Correlation

• X-ray observations of Vela pulsar revealed toroidal structures which defined direction of rotation axis - within 10^{o} of proper motion direction (Helfand et al. 2001)

• Similar X-ray tori observed in several other young pulsars with similar alignment (Ng & Romani 2004)

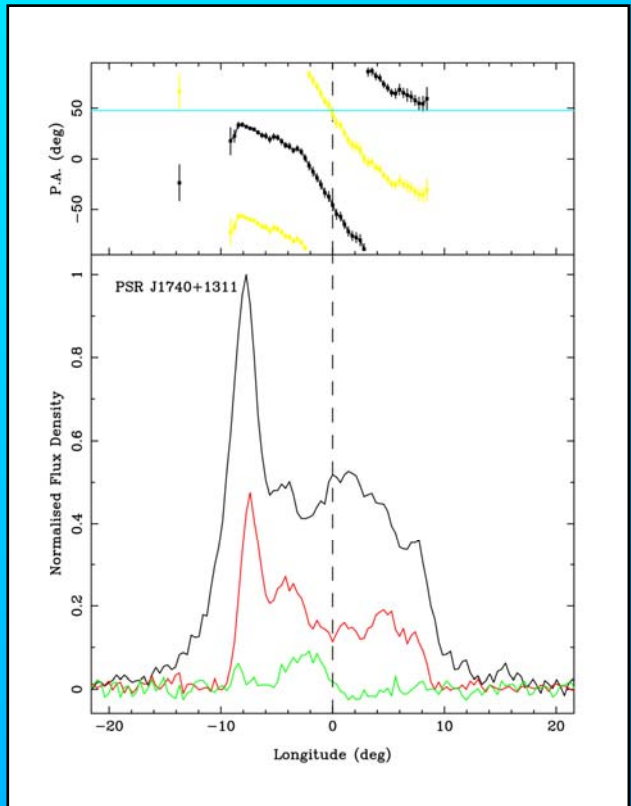
• In principle can use observed linear position angle (PA) of pulsar radio emission with rotating-vector model (RVM) to define direction of rotation axis on sky

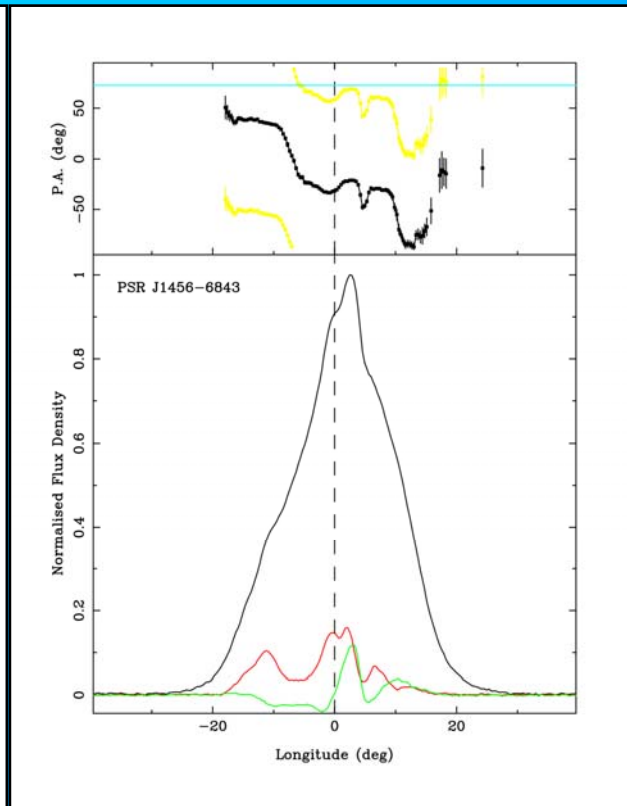
• Complicated by presence of orthogonal modes and non-RVM PA curves

• Parkes observations of 25 pulsars at 1.4 GHz

• Carefully calibrated and corrected for interstellar Faraday rotation

(Johnston et al. 2005)

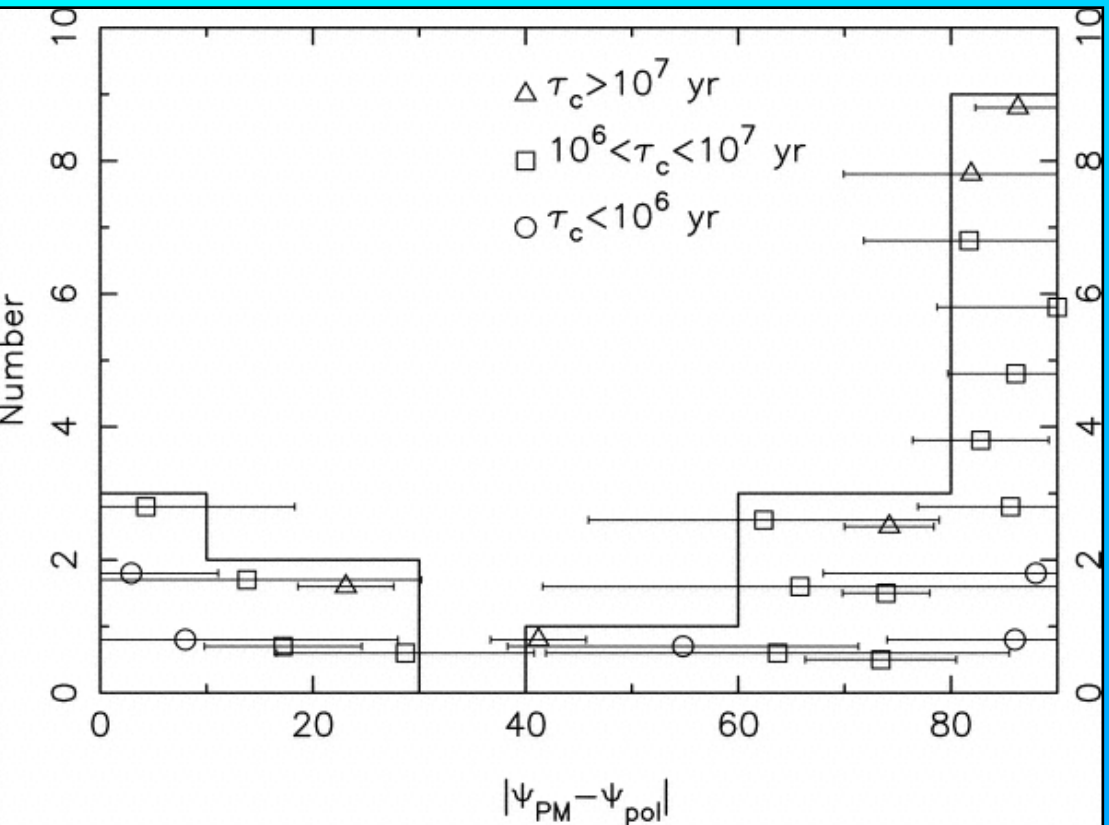


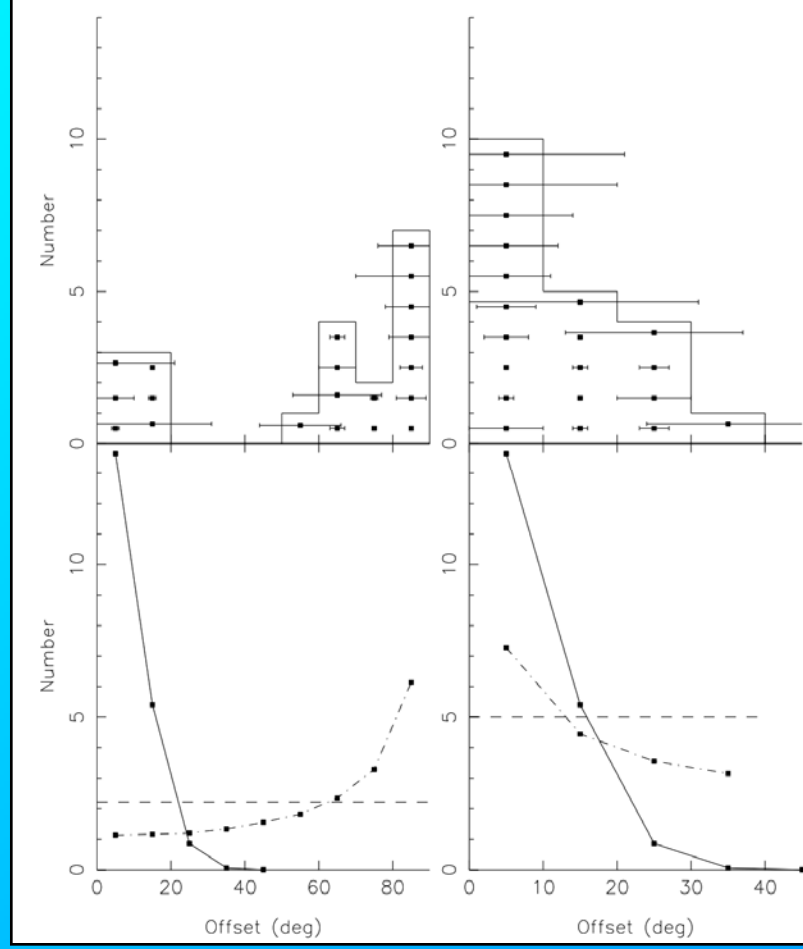


Rotation Axis - Velocity Correlation (ctd)

- Of 25 observed pulsars, 10 have offset between velocity vector and symmetry point of PA variation of $< 10^o$ or $> 80^o$
- Simulations with parallel or perpendicular PA agree well with observed distribution

(Johnston et al. 2005)





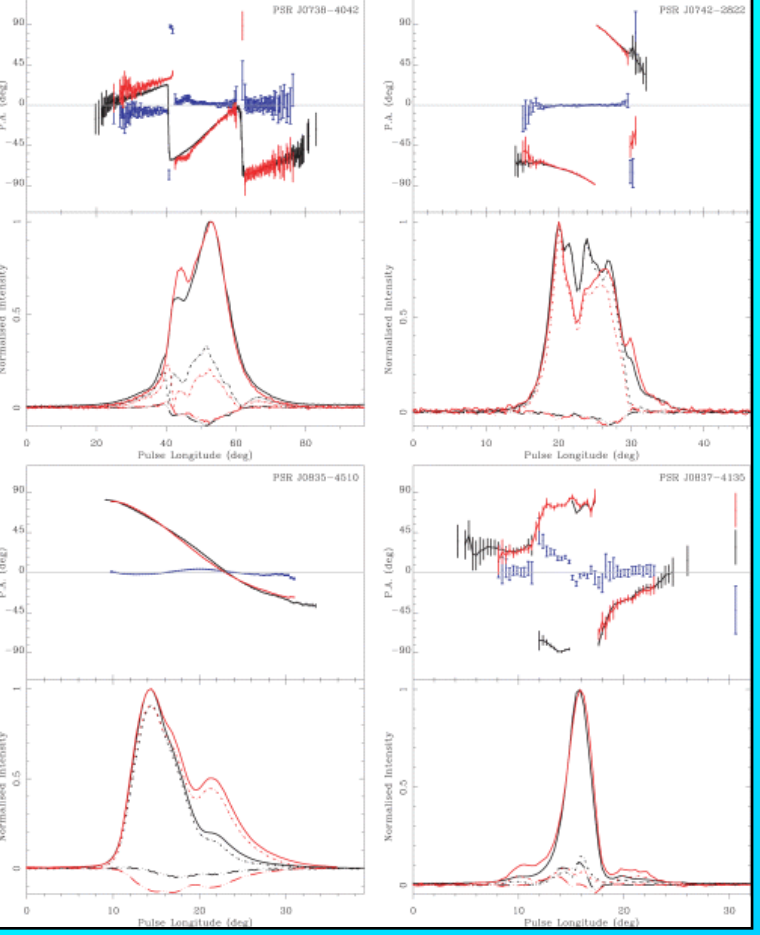
- Similar results from archival polarisation data (Wang et al. 2006)

Supports notion of alignment between rotation axis and velocity: kick-induced spin?

(e.g., Spruit & Phinney 1998)

Mean Pulse Polarisation

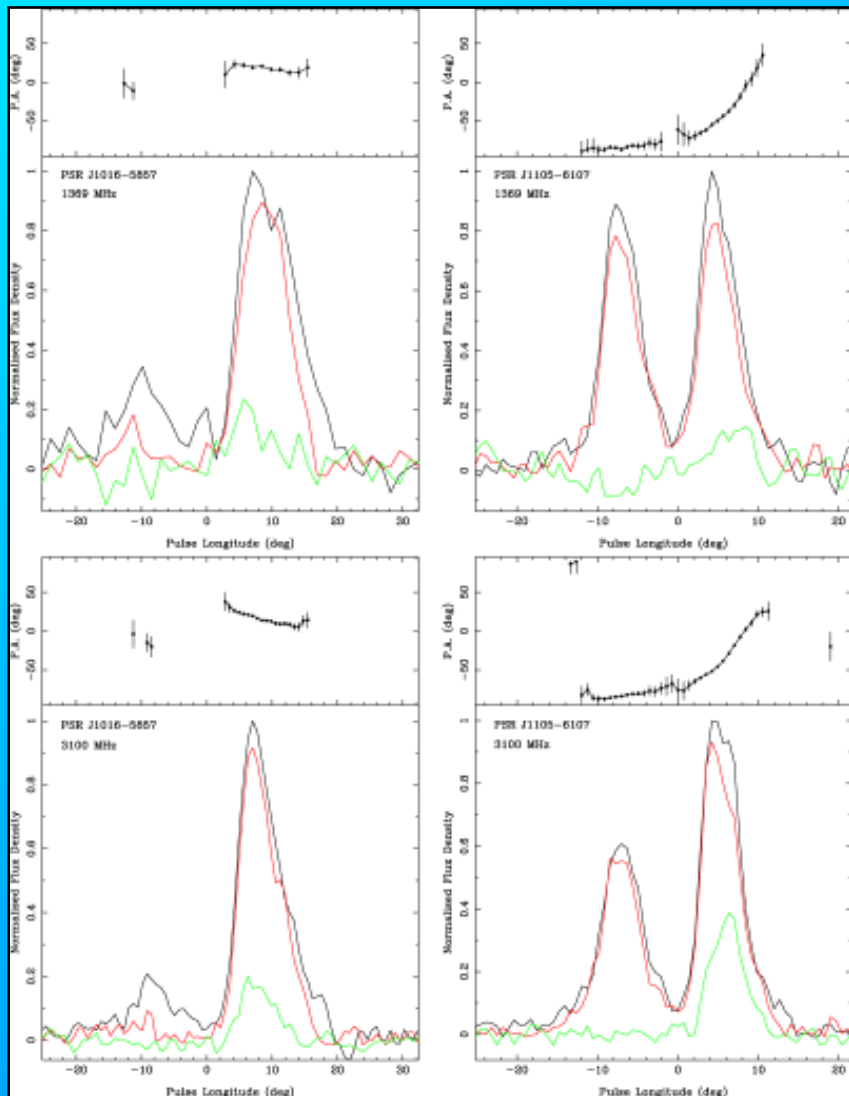
- Parkes observations at 1.4 and 3.1GHz
- Dual frequency obs of 17 pulsars, 14 young pulsars (τ_c < 75 kyr)



(Karastergiou & Johnston 2006)

- Linear polarisation very high for young pulsars, generally > 75%
- PA variations generally the same at the two frequencies - no rotation in magnetosphere
- Patchy cones - wide beams!

(Johnston & Weisberg 2006)

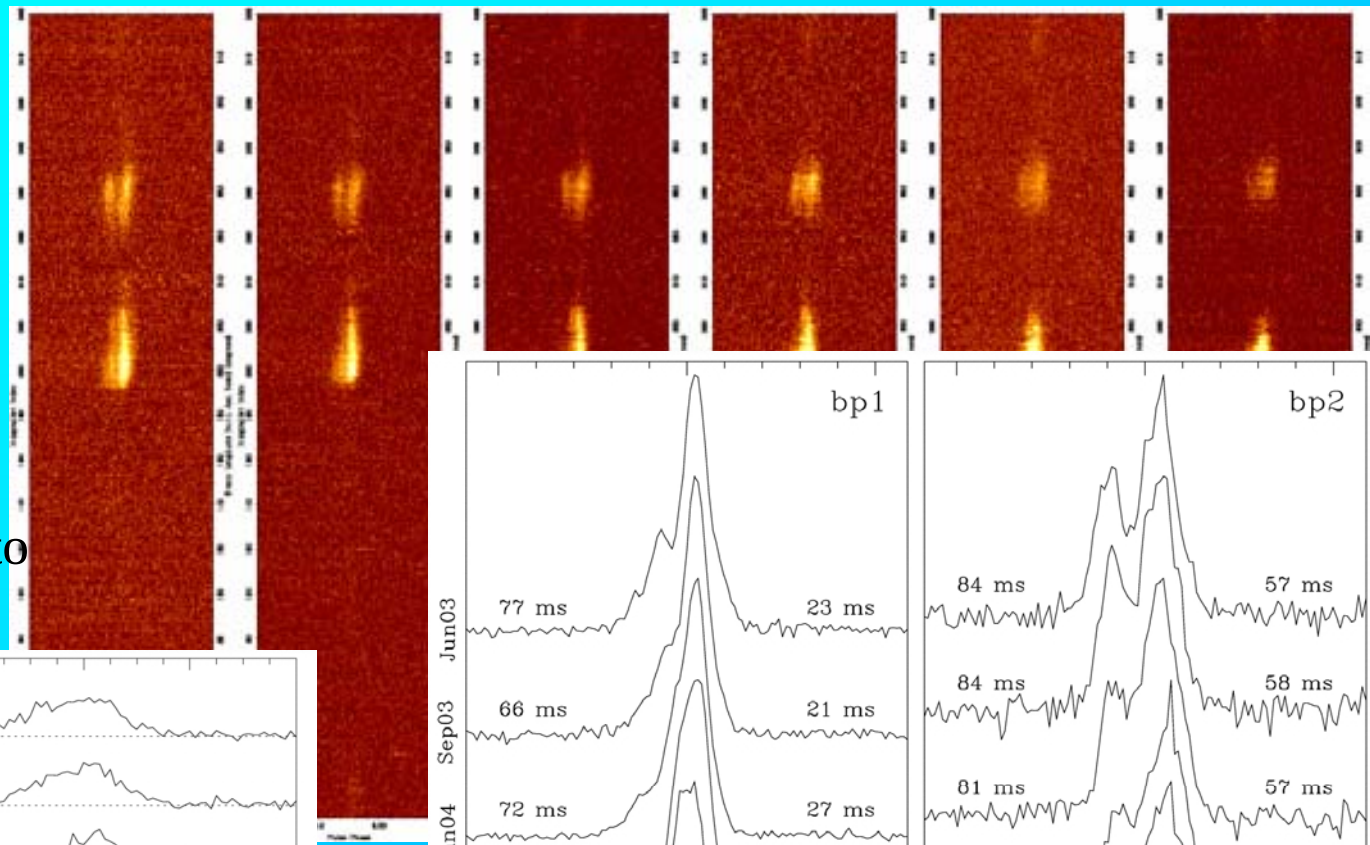


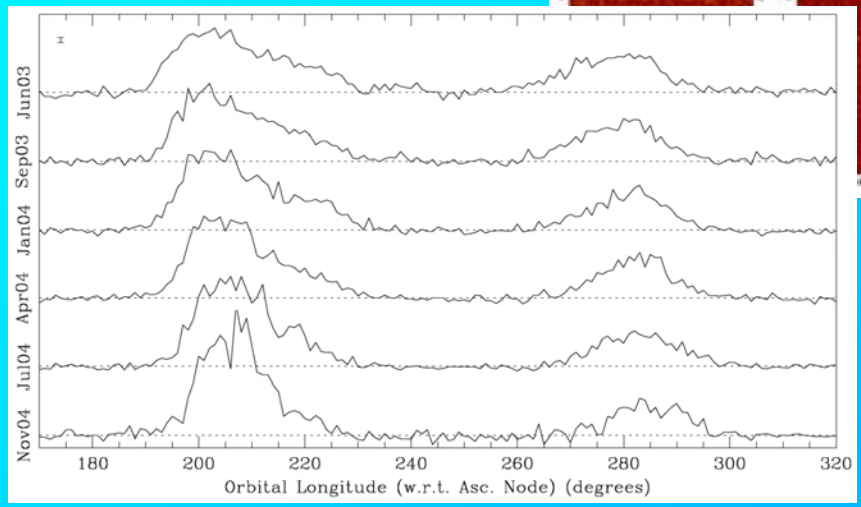
Thank you for your attention!

Orbital Modulation of PSR J0737-3039B

Secular changes are observed!

- Bright phases are becoming shorter and more widely separated
- Pulse profile is changing from double to single





(Burgay et al. 2005)