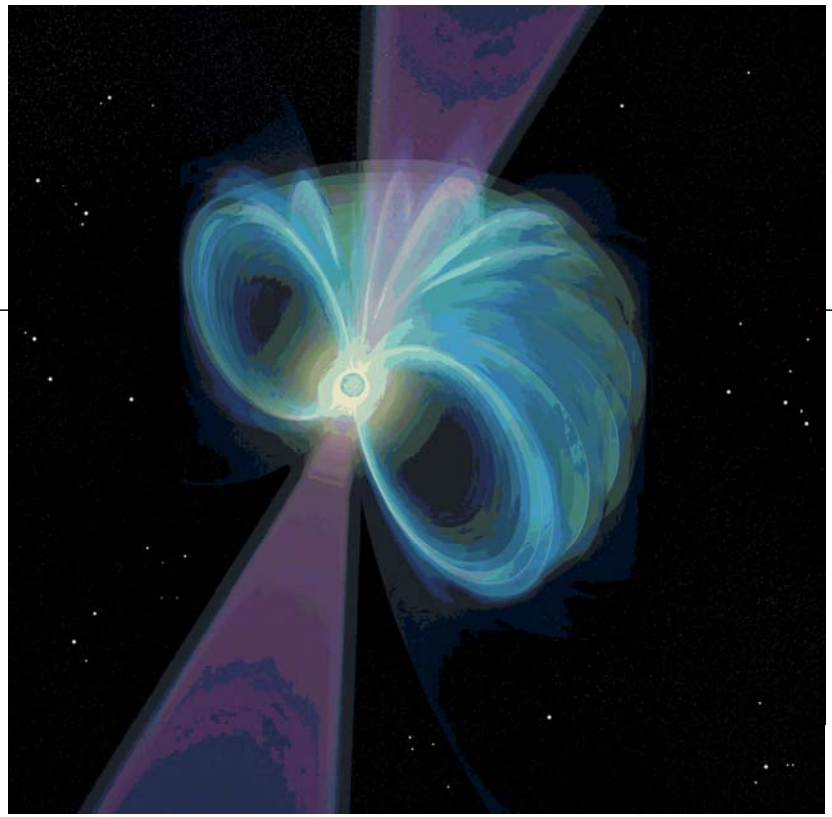
A RRAT Infestation

New Results on Rotating Radio Transients



Russell Kightley Media

Maura McLaughlin
West Virginia University
16 August 2006

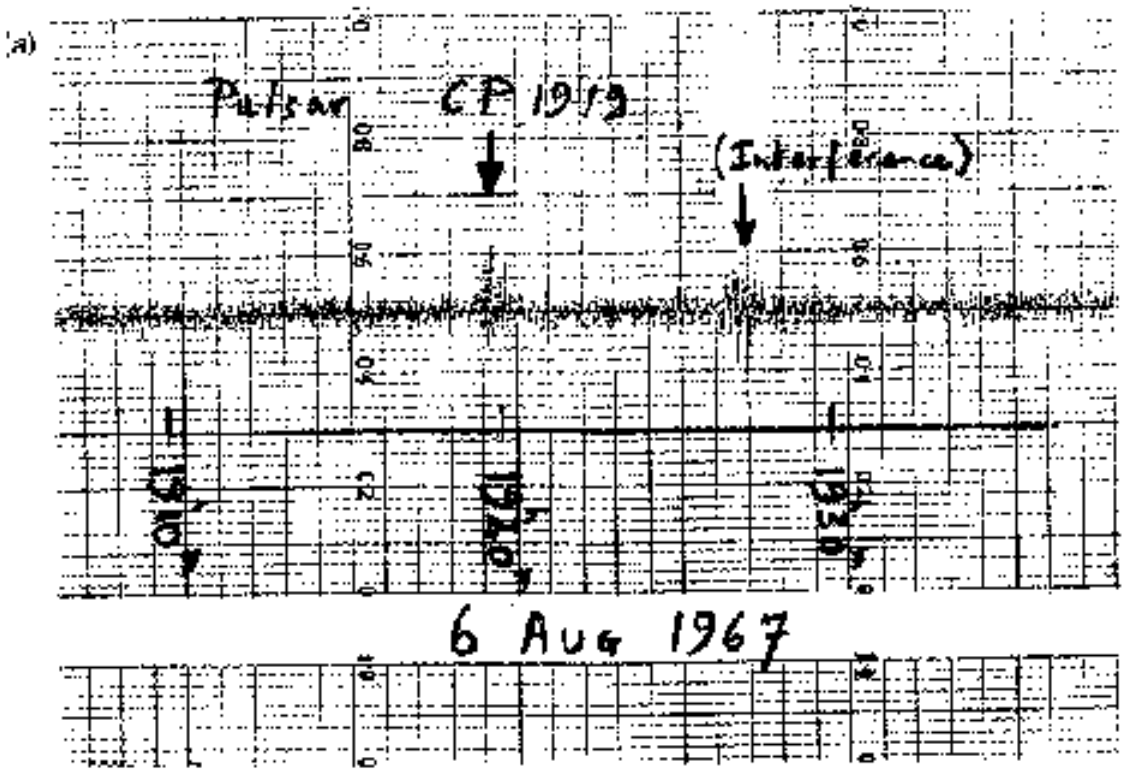
In collaboration with Andrew Lyne, Jim Cordes, Duncan Lorimer, Michael Kramer, Dick Manchester, Andrea Possenti, Marta Burgay, Ingrid Stairs, Nichi D'Amico, Fernando Camilo, Andrew Faulkner, Georg Hobbs, Jennifer O'Brien, Stephen Reynold Bryan Gaensler, Shami Chatterjee, Nanda Rea, Kazimierz Borkowski and Gianluca Israel

Outline

- A bit of single-pulse search history
- Parkes Multibeam single-pulse search
- Properties of RRATs
- X-ray observations
- What are they?
- Population estimates
- Summary and future work

A bit of SP search history

- Hewish et al. (1968) – first pulsar discovery



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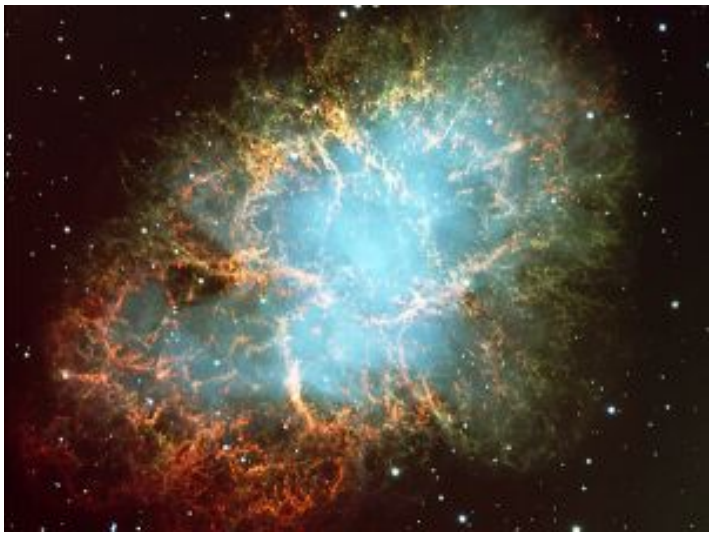
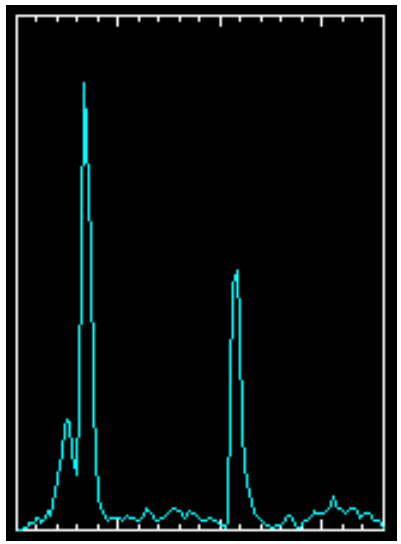


Crab nebula (VLT)



Crab radio profile

A bit of SP search history

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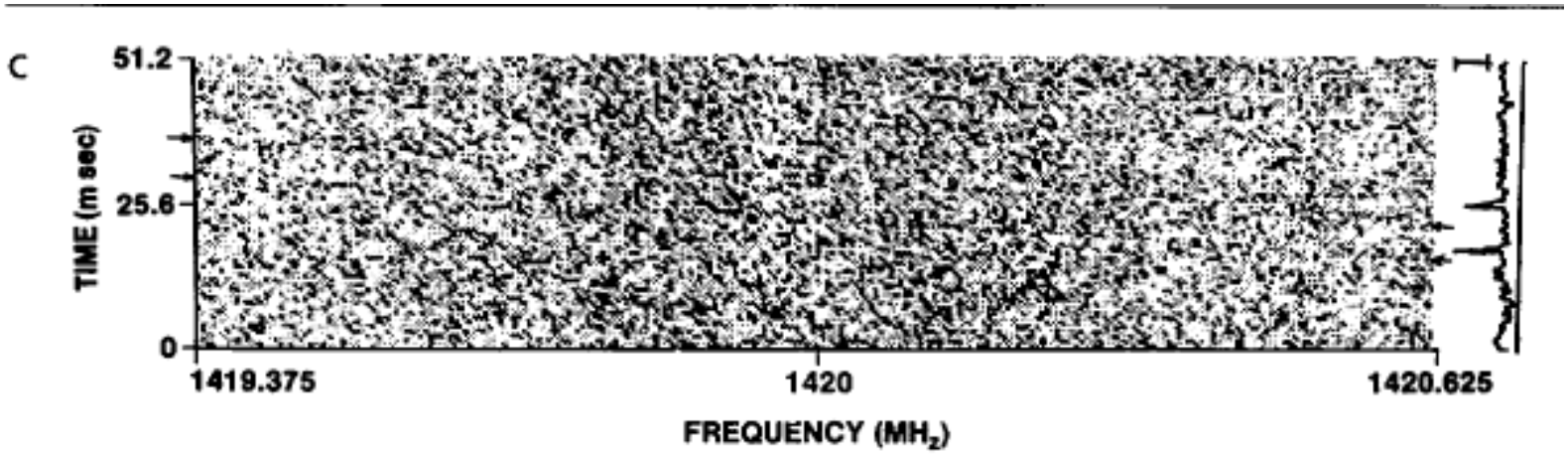

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- Nice (1999) detect PSR J1918+08 in single-pulse search
- McLaughlin & Cordes (2003) report possible detection of bursts from M33….but not confirmed yet

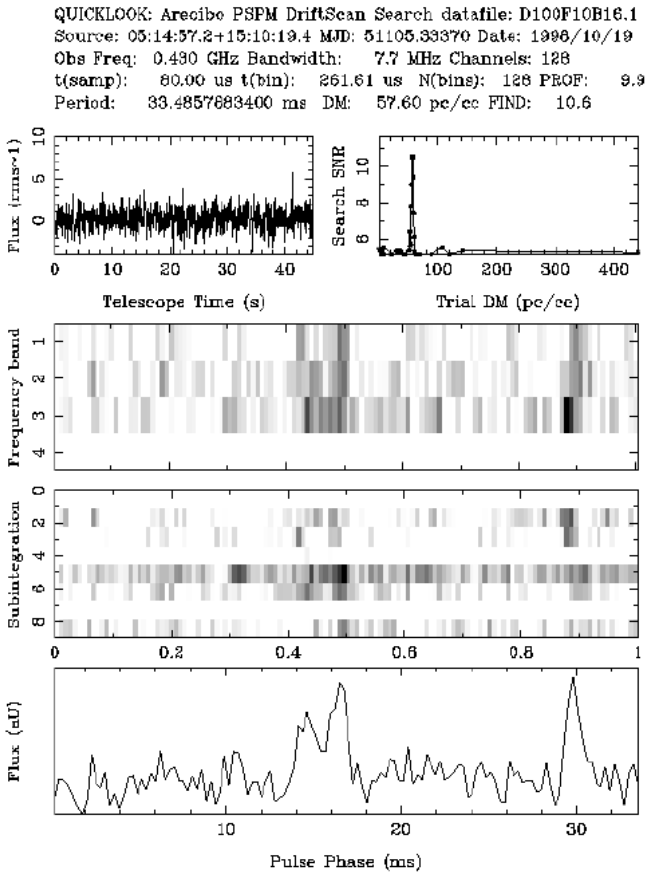
A bit of SP search history

- Low immunity to Radio Frequency Interference (RFI)
- Difficult to gauge reality of signals without multiple beams/telescopes
- LOTS of output can be tedious to sift through
- Most pulsars are detected with much higher signal-to-noise in periodicity searches

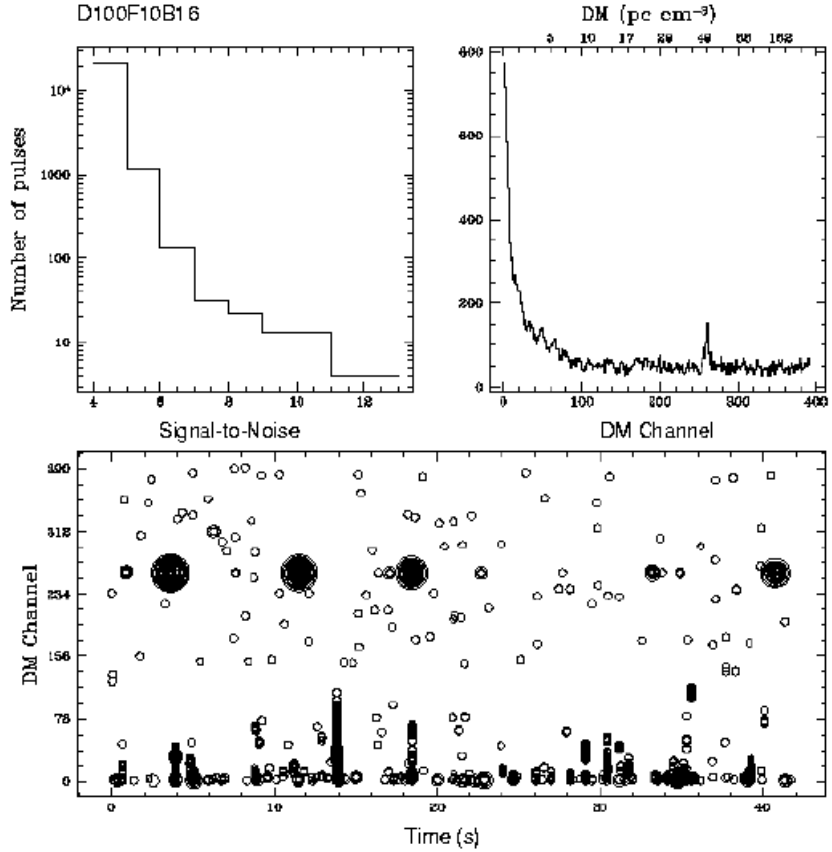
→ Most pulsar searches have used only Fourier techniques

So why bother?

- Increased sensitivity to ‘giant’ pulsing pulsars



FFT search results for Crab



SP search results for same pointing

Arecibo data at 430 MHz

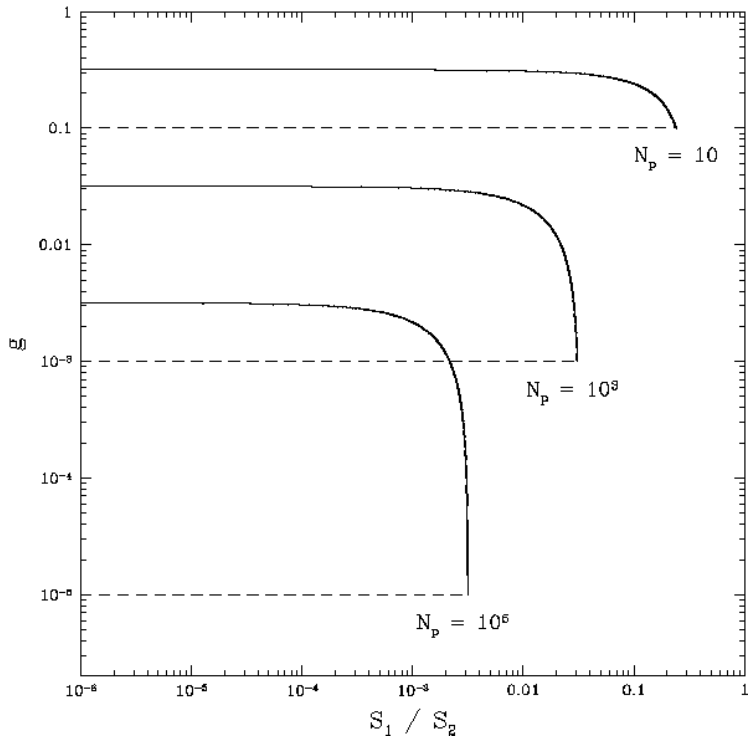
So why bother?

- Increased sensitivity to ‘giant’ pulsing pulsars
  and to smeared pulses (W > P) and long period pulsars

g = % giant pulses

S_1 = flux of normal pulse

S_2 = flux of giant pulse



McLaughlin & Cordes (2003)

So why bother?

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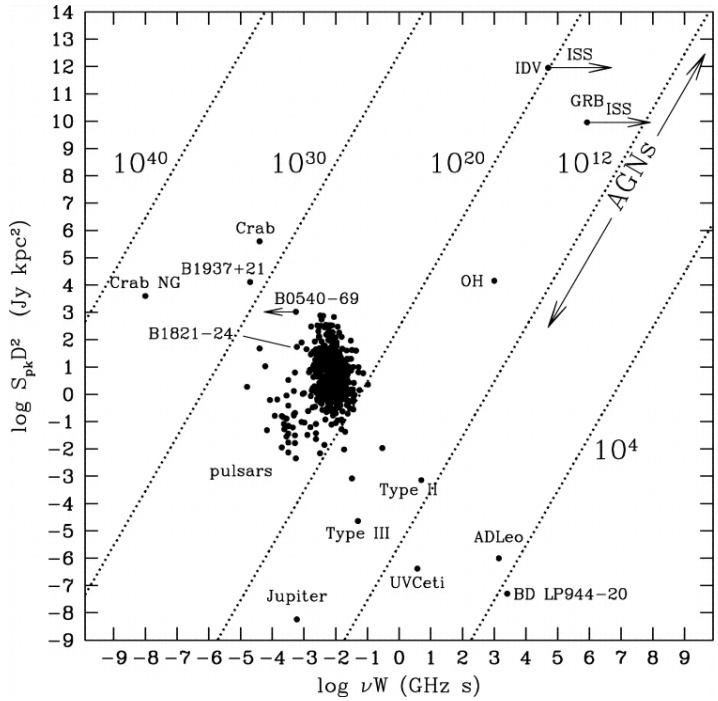
- Other sources?



Cordes & McLaughlin (2003)

So why bother?

- Increased sensitivity to ‘giant’ pulsing pulsars
  and to smeared pulses (W > P) and long period pulsars
- Other sources!

- GCRT

  Hyman et al. (2005)

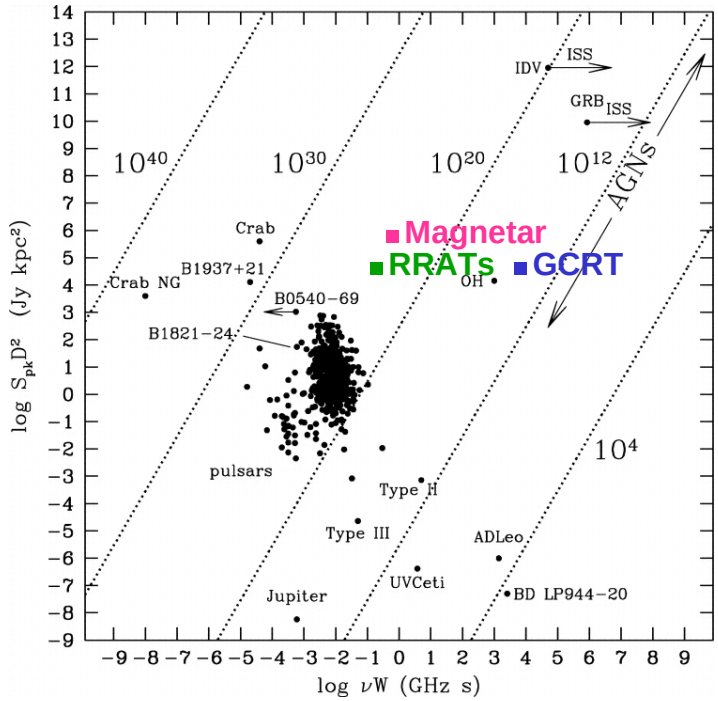
- Magnetar radio bursts

  Camilo et al. (2006)

- RRATs

  McLaughlin et al. (2006)

Lots and lots of activity…..

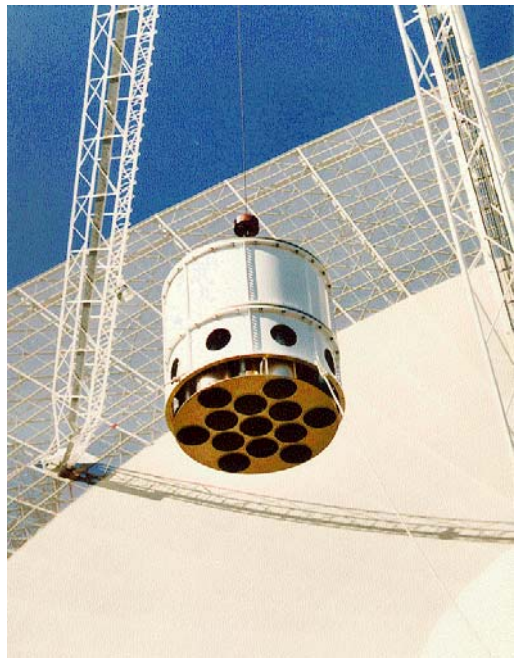


Cordes & McLaughlin (2003)

Single-pulse searches are cool again!

PMB Single Pulse Search

- As part of PMPS reprocessing
- Includes dedispersion and thresholding with various smoothing filters
- Have applied search to all 13 beams times 2670 pointings
- Covering Galactic plane at $b < 5^{O}$ and between $260^{O} < l < 50^{O}$
- Largest scale search for ms-s radio transients ever



Parkes Multibeam 1400-MHz receiver

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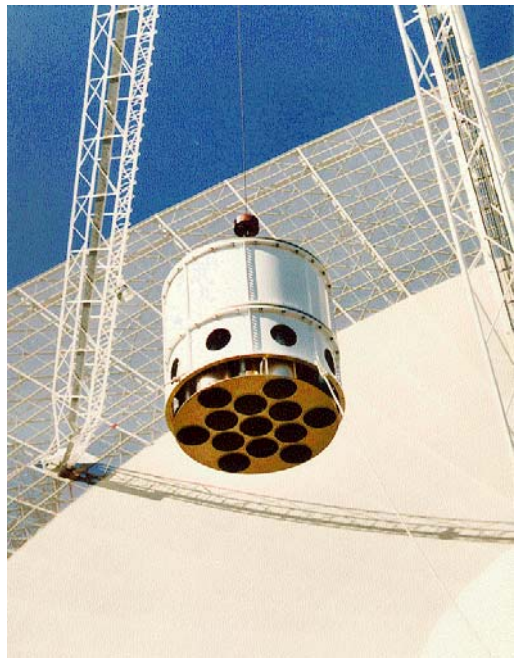
Multiple beams!



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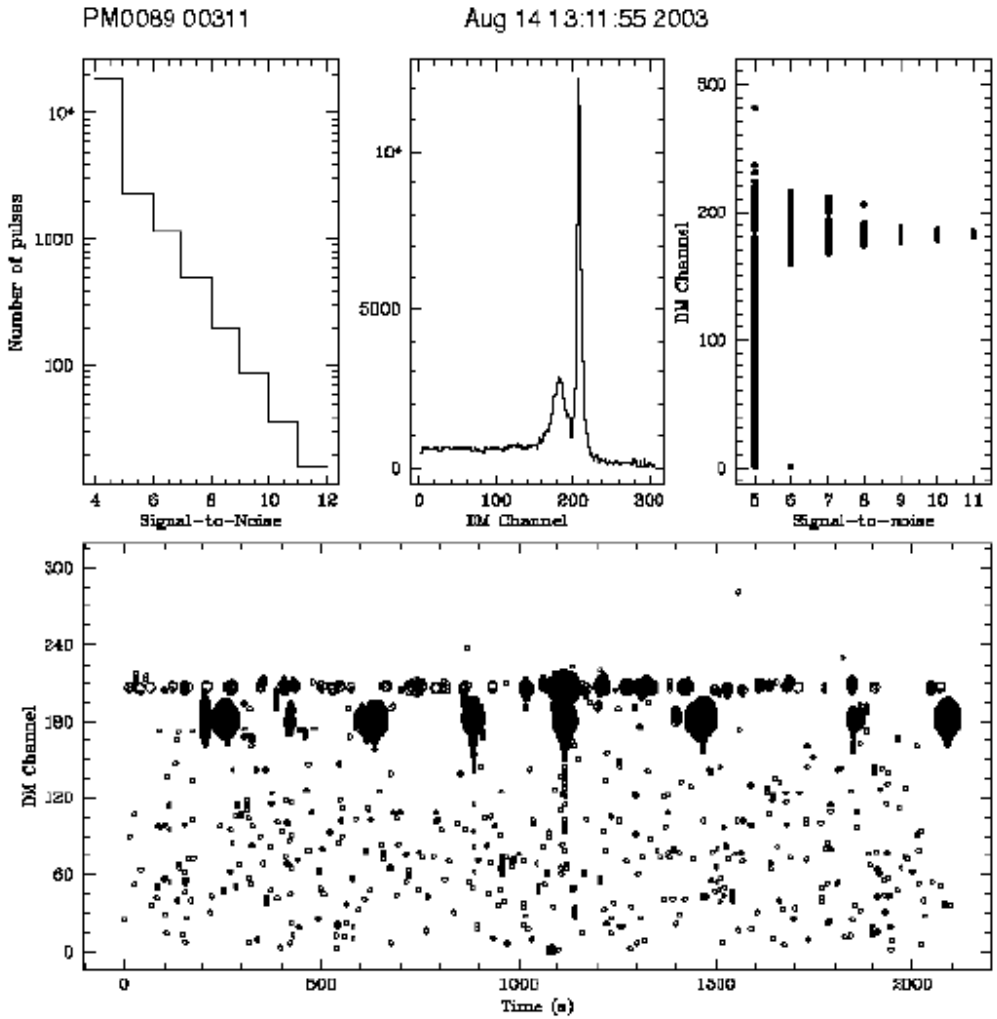
PMB Single Pulse Search

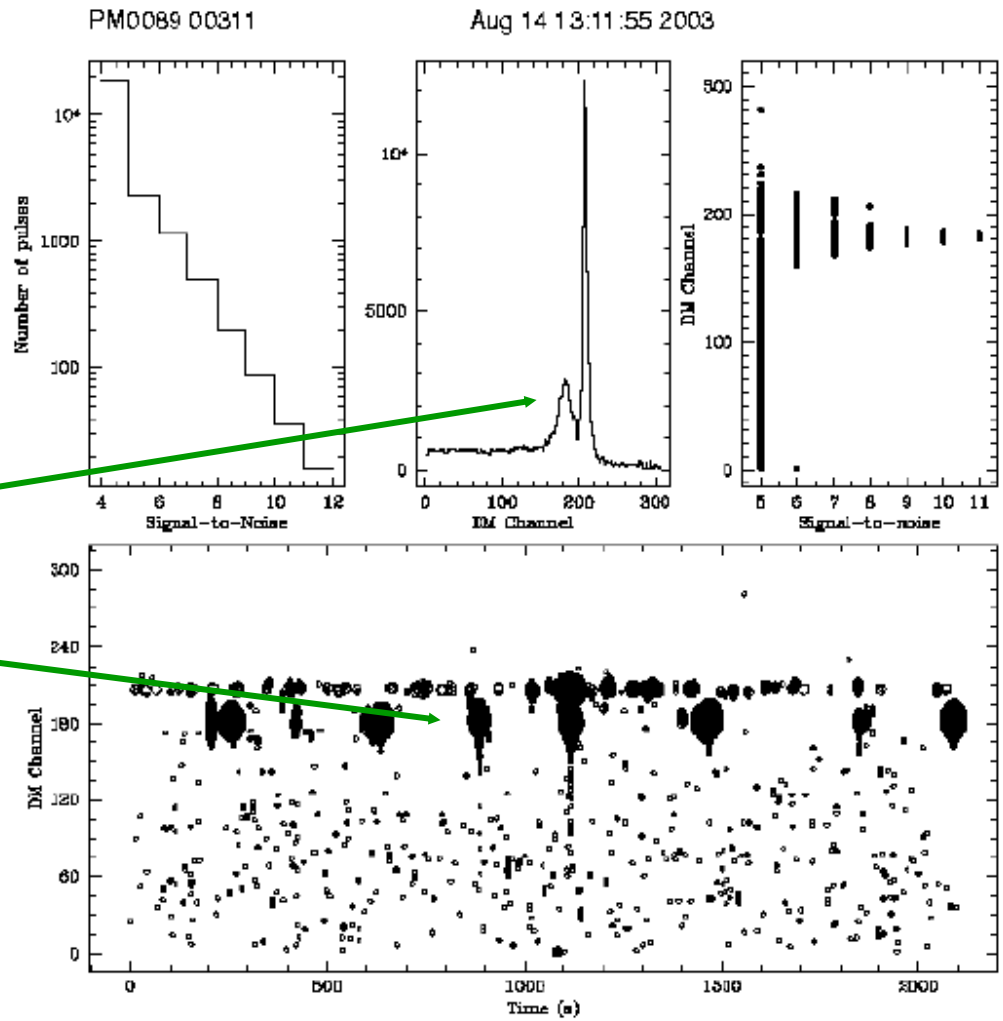
- Roughly 1/3 of all psrs detected with FFT also detected in SP search



PMB Single Pulse Search

- Roughly 1/3 of all psrs detected with FFT also detected in SP search
- Wide range of properties

J1840–0815
P = 1.1 s
DM = 225 pc cm^{-3}

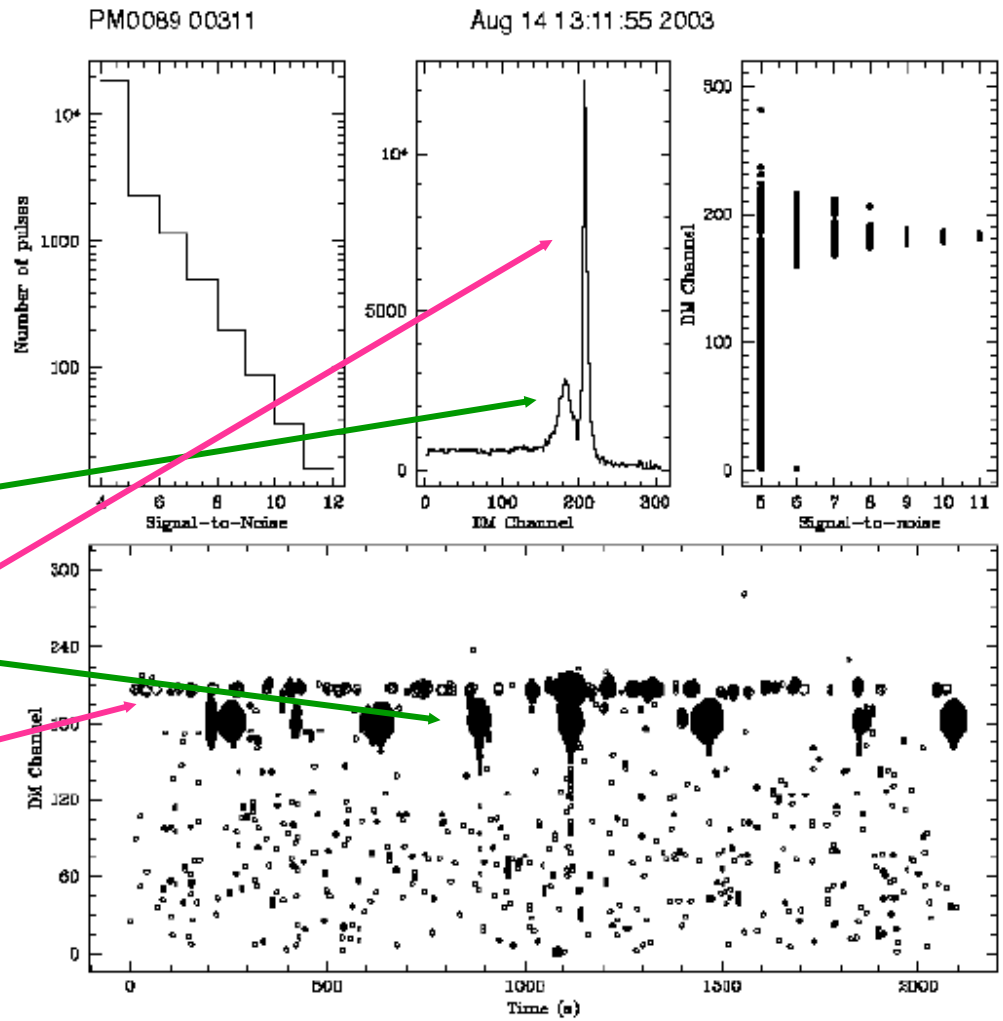


PMB Single Pulse Search

- Roughly 1/3 of all psrs detected with FFT also detected in SP search
- Wide range of properties

J1840–0815
P = 1.1 s
DM = 225 pc cm^{-3}

J1840–0809
P = 0.96 s
DM = 353 pc cm^{-3}



PMB Single Pulse Search

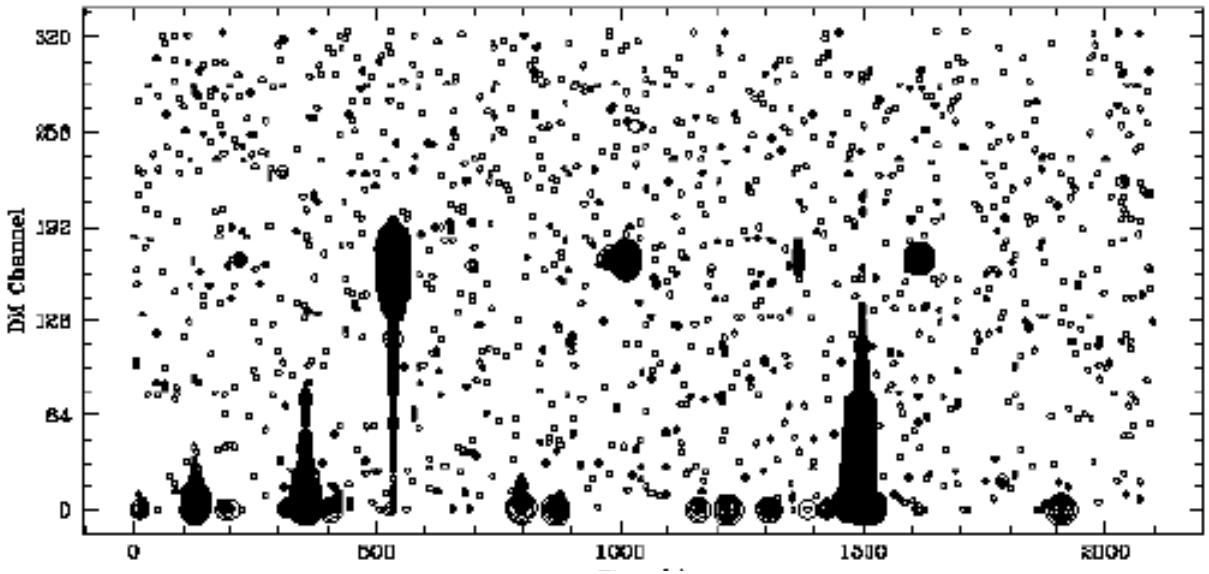
- About 20 sources discovered just in SP search
  - a few `bursty' pulsars and a few objects missed in original search

PMB Single Pulse Search

- About 20 sources discovered just in SP search
  - 11 mysterious sources!

J1819–1458

DM = 194 pc cm^{-3}



Original observation – no periodicity detected in FFT/FFA

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Single pulses reveal periodicity of 4.26 s.

J1819–1458

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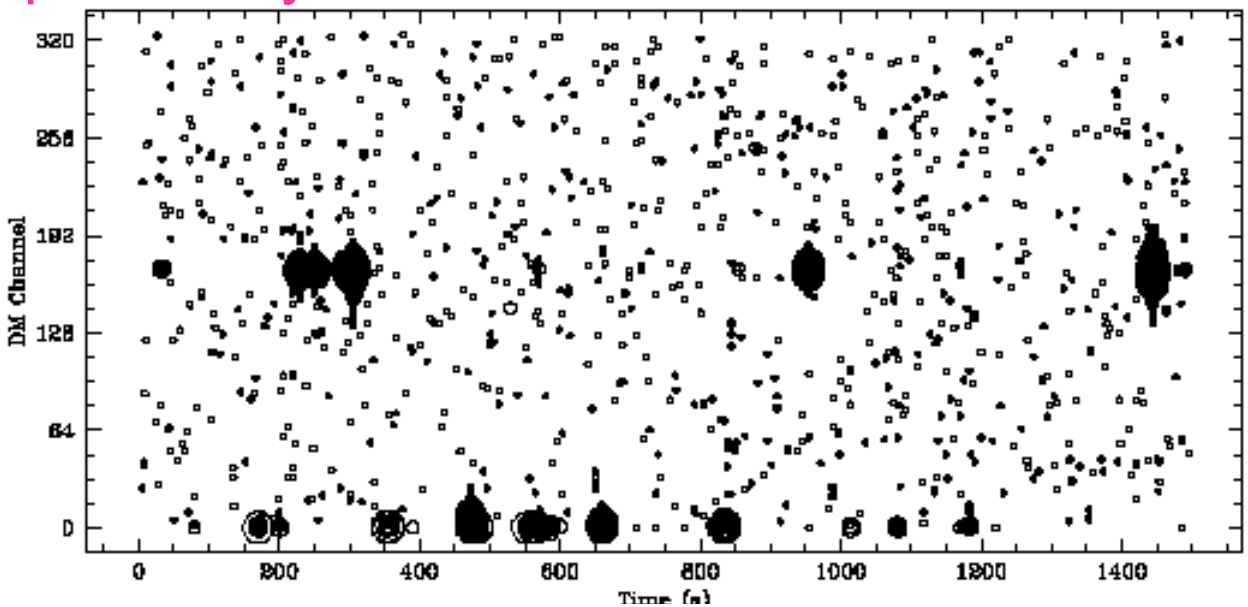

Confirmation observation – still no periodicity detected in FFT/FFA

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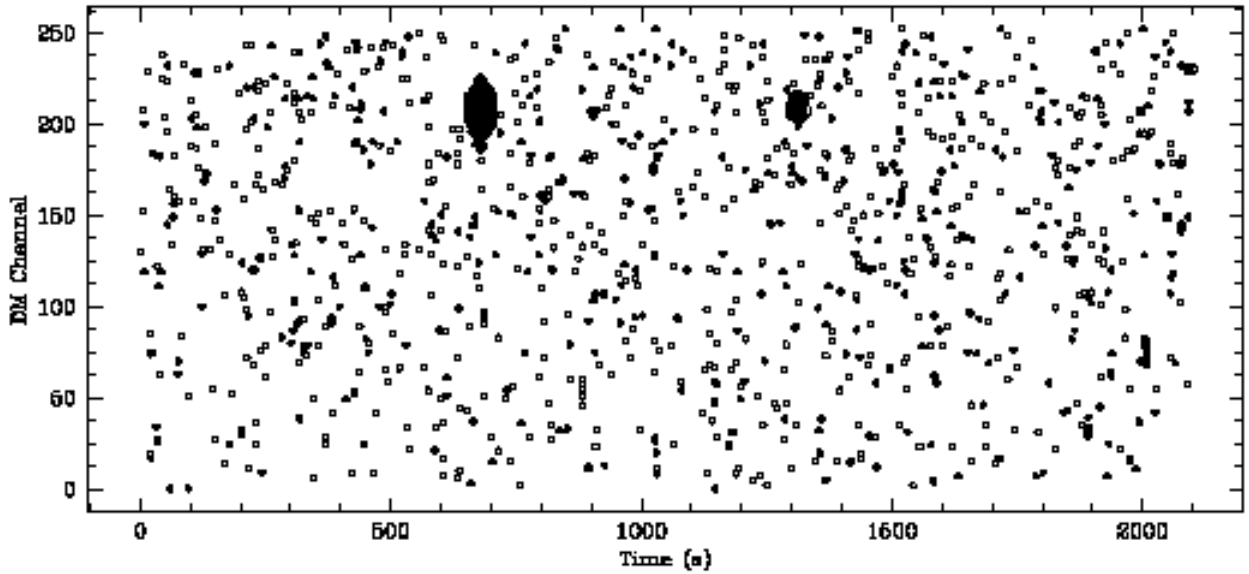
J1443–60

DM = 374.2 pc cm^{-3}



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PMB Single Pulse Search

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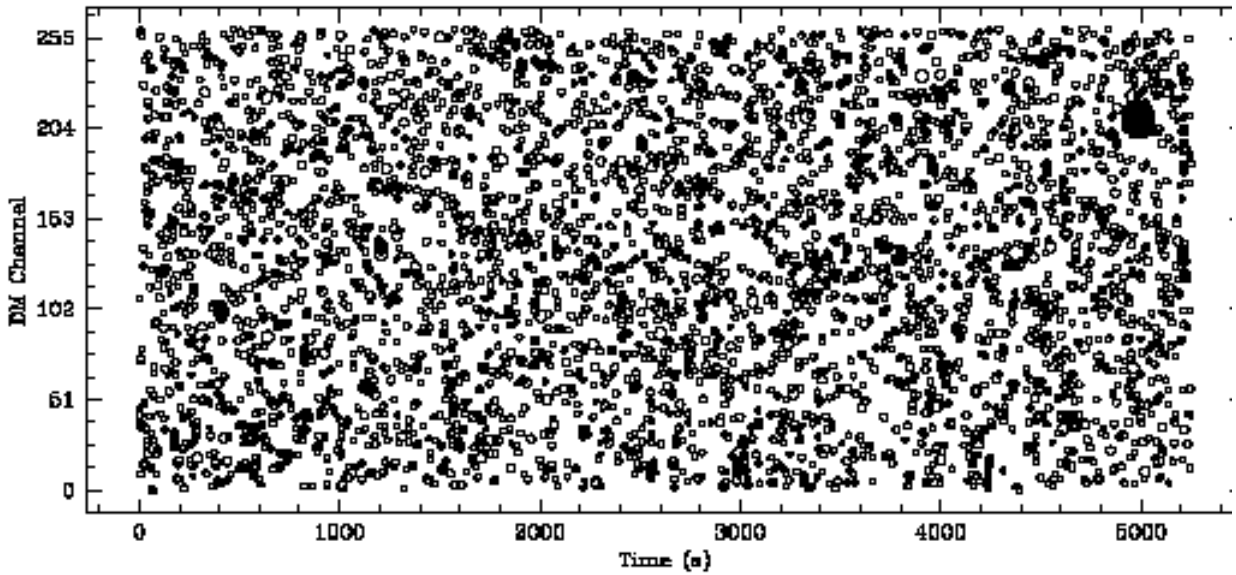
  - 11 mysterious sources!

Single pulses reveal period of 4.75 s (eventually!)

J1443–60

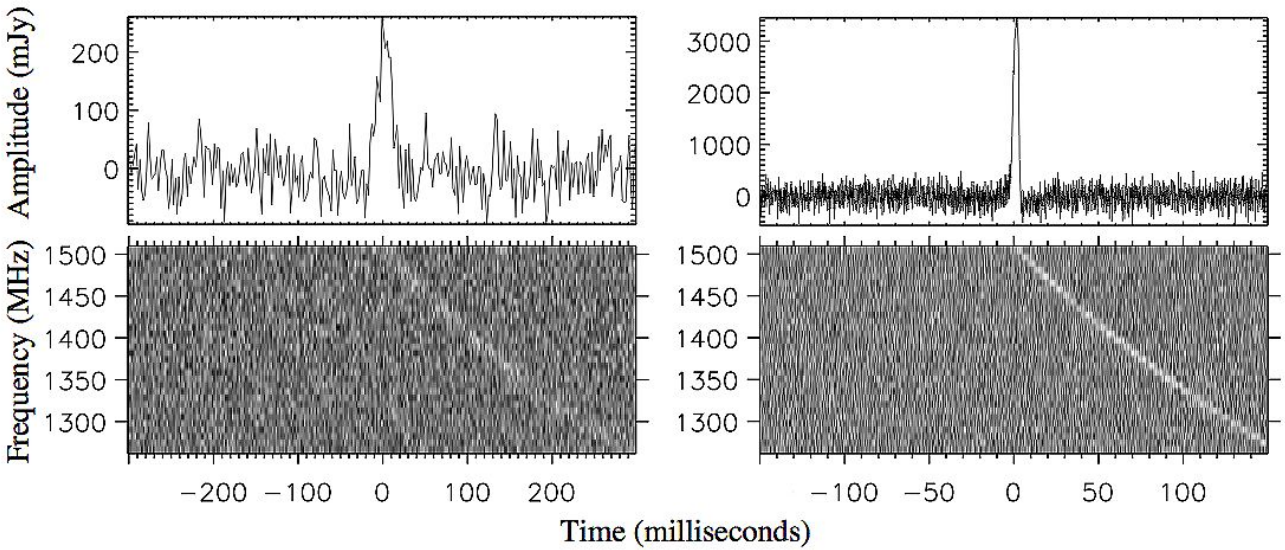
DM = 374.2 pc cm^{-3}



Confirmation observation – still no periodicity detected

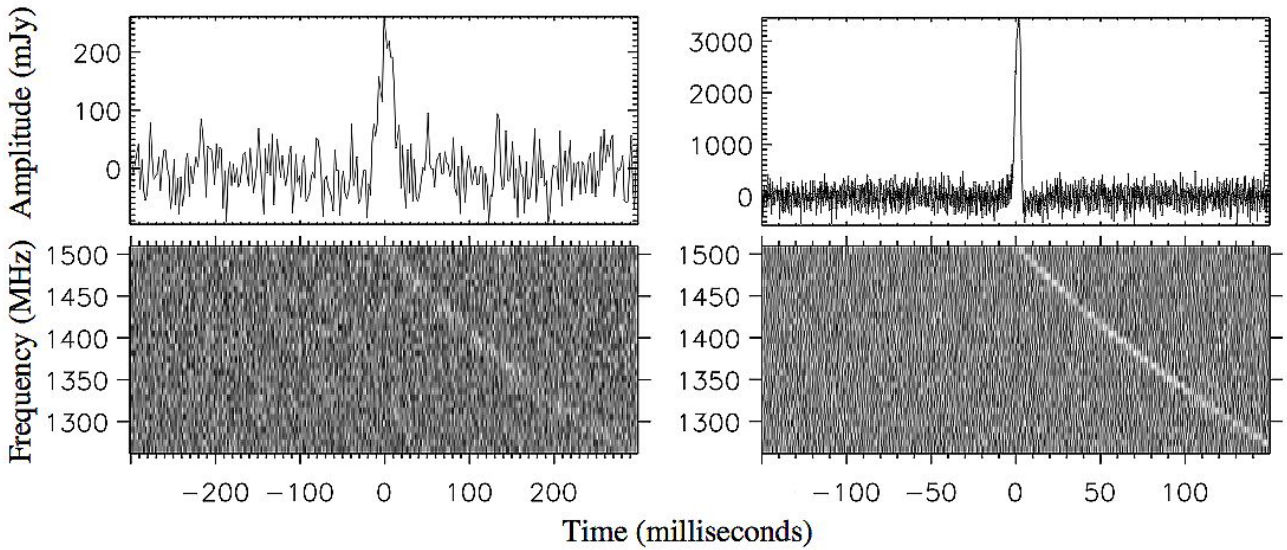
RRATs are born…..

- Dispersed single pulses
  - Repeating Radio Transients



RRATs are born…..

- Dispersed single pulses
  - Repeating Radio Transients
- Not detectable in FFT/FFA or by folding
- BUT periods in the 1-7 second range from single pulses indicate they are almost certainly rotating NSs
  - Rotating Radio Transients

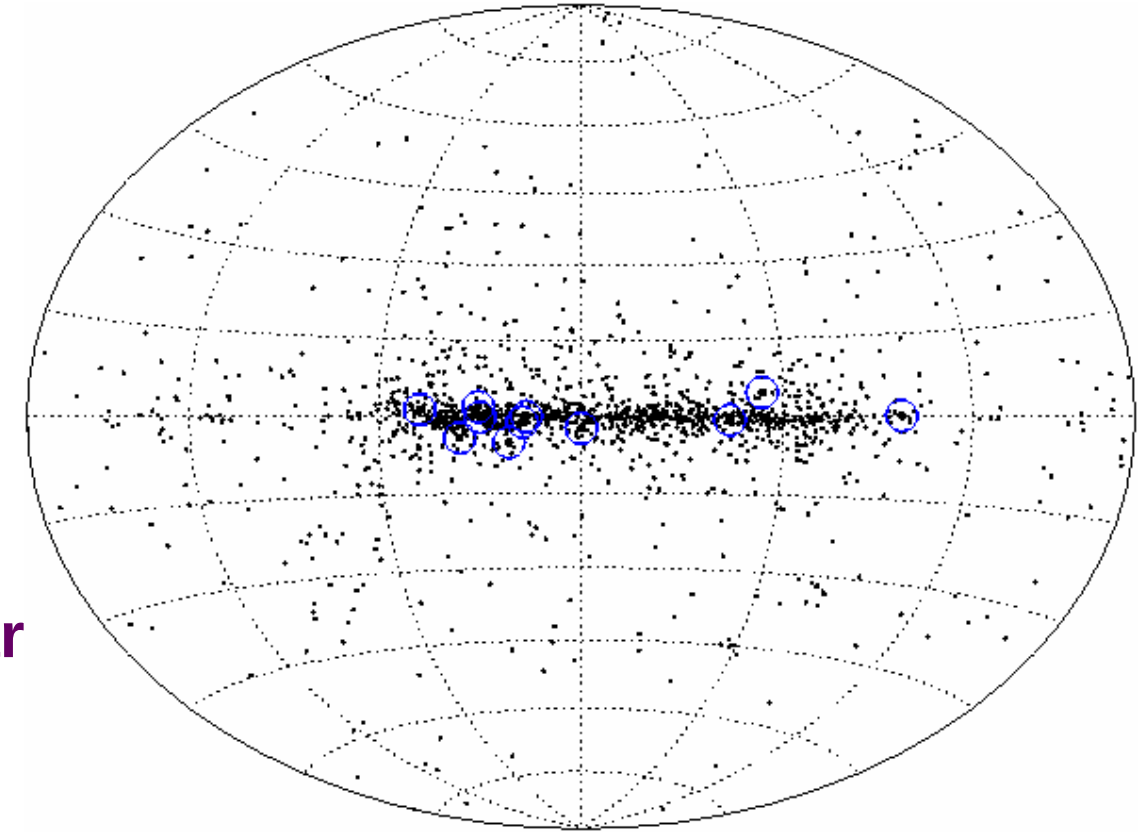


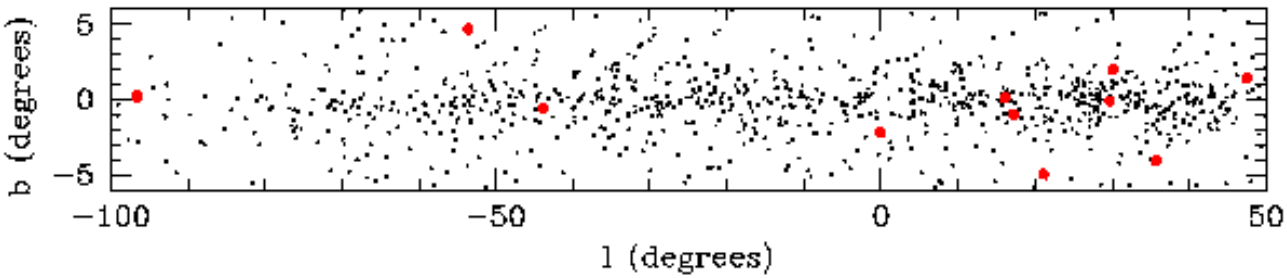
RRAT properties - locations

Name	l (deg)	b (deg)	DM (pc cm^{-3})	D (kpc)
J0848-43	263.4	0.2	293	5.5
J1317-5759	306.4	4.7	145	3.2
J1443-60	316.2	-0.6	369	5.5
J1754-30	359.9	-2.2	98	2.2
J1819-1458	16.0	0.1	196	3.6
J1826-14	17.2	-1.0	159	3.3
J1839-01	30.1	2.0	307	6.5
J1846-02	29.7	-0.1	239	5.2
J1848-12	21.1	-5.0	88	2.4
J1911+00	35.7	-4.1	100	3.3
J1913+1333	47.5	1.4	176	5.7

RRAT properties - locations

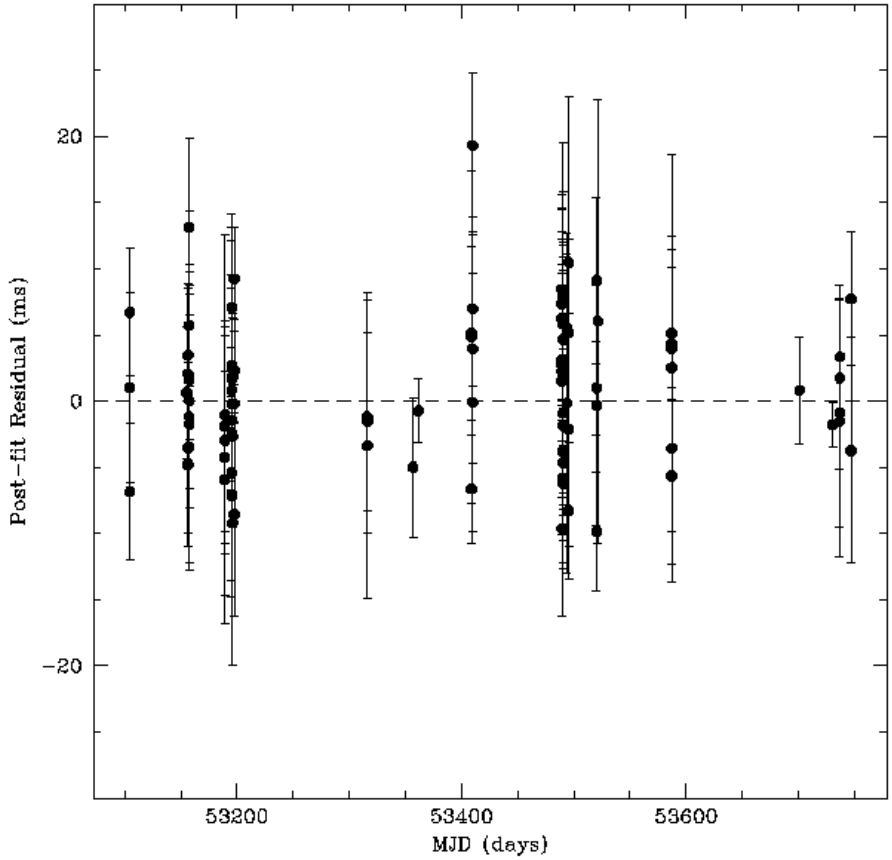
- Slight concentration towards Galactic plane (but small number stats!)
- Consistent with pulsar distribution





RRAT properties - timing

- For RRATs with highest bursting rates, can time just like normal pulsars (but from single pulses!)



Timing residuals for J1317-5759

RRAT properties - timing

Name	P (s)	$\dot{P}$ (10^{-15})	B (10^{12} G)	T_{char} (kyr)	$\dot{E}$ (10^{31} ergs s^{-1})
J0848-43	5.98				
J1317- 5759	2.64	12.5	5.8	3337	2.7
J1443-60	4.76				
J1754-30	1.32				
J1819-1458	4.26	575	50	117	25
J1826-14	0.77				
J1839-01	0.93				
J1846-02	4.47				
J1848-12	6.79				
J1911+00	6.94				
J1913+1333	0.92	7.8	2.7	1860	3.9

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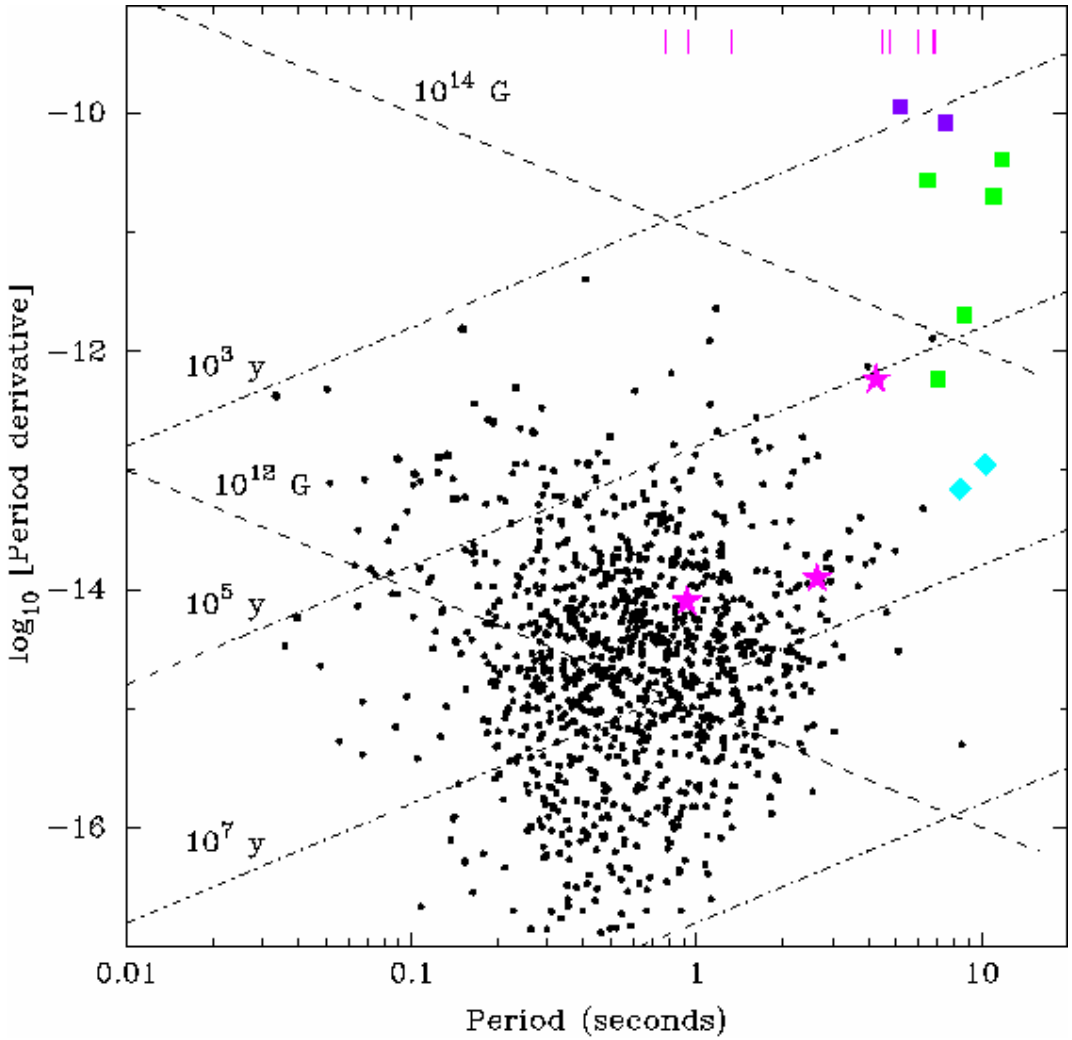
RRAT properties - timing

- 6/11 RRATs have P > 4 s (compared to 1/200 of radio psr population!)



★ RRATs ■ SGRs

■ AXPs ◆ INSs

RRAT properties - bursts

Name	w_{50} (ms)	S_{1400} (mJy)	N_p/T_{obs} (hr^{-1})	N_{det}/N_{obs} (%)	N_p
J0848-43	30	100	4.2	32	58
J1317-5759	10	1100	4.5	93	144
J1443-60	20	280	0.8	68	42
J1754-30	16	160	0.6	55	25
J1819-1458	3	3800	18.0	100	363
J1826-14	2	600	1.0	62	18
J1839-01	15	100	0.4	7	8
J1846-02	16	250	0.8	50	13
J1848-12	2	450	0.7	57	11
J1911+00	5	250	0.3	45	5
J1913+1333	2	650	4.7	60	93

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J1754-30	16	160	0.6	55	25
J1[illegible]					
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J1848-12	2	450	0.7	57	11
J1911+00	5	250	0.3	45	5
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No obvious correlations between parameters!

RRAT properties - bursts

loosely!

RRATs seem to belong to one of three classes.

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loosely!

RRATs seem to belong to one of three classes.

1) Burpers

Sporadic but predictable.

RRAT properties - bursts

loosely!

RRATs seem to belong to one of three classes.

1) Burpers

Sporadic but predictable.

2) Nullers

“On”/”Off” states.

RRAT properties - bursts

loosely!

RRATs seem to belong to one of three classes.

1) Burpers

Sporadic but predictable.

2) Nullers

“On”/”Off” states.

3) Pulsars

Continuous distribution of amplitudes

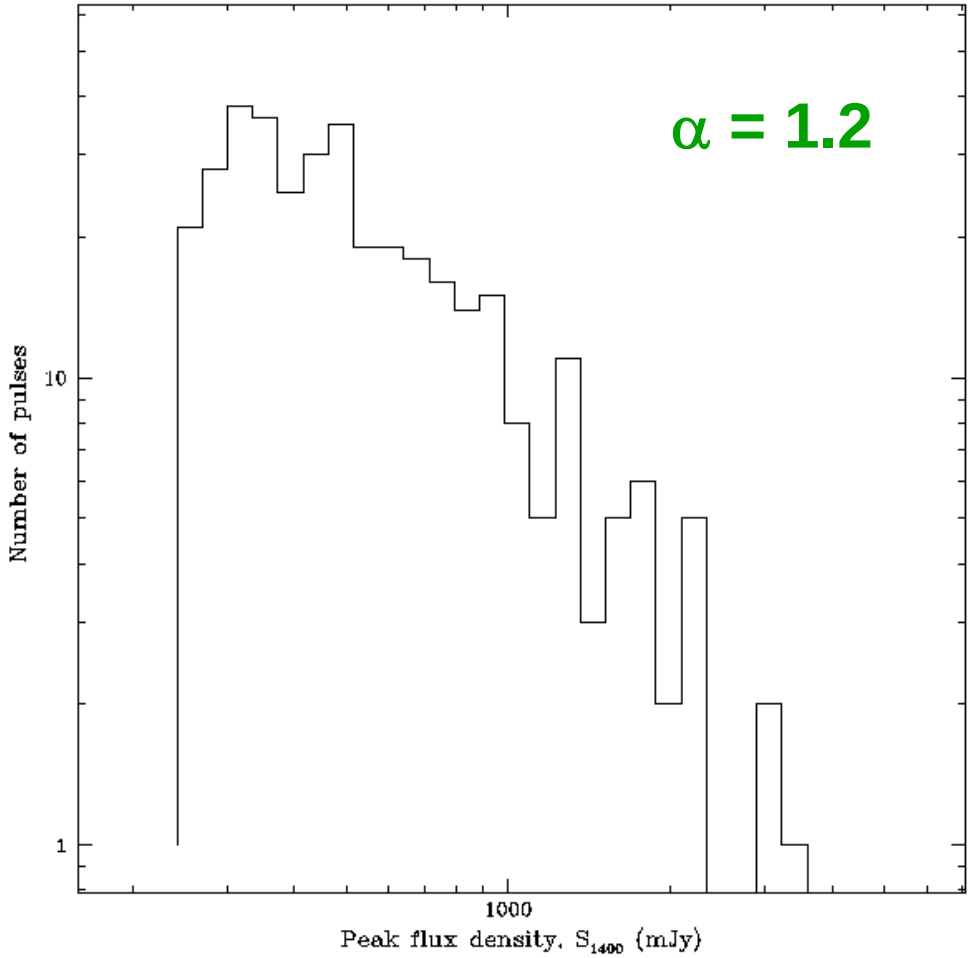
RRAT properties - bursts

Individual source properties…

Naptime!

RRAT properties - J1819-1458

burpers



P=4.26 s

B=5x10^{13} G

R=18 pulses/hr

N_{det}/N_{obs}=100%

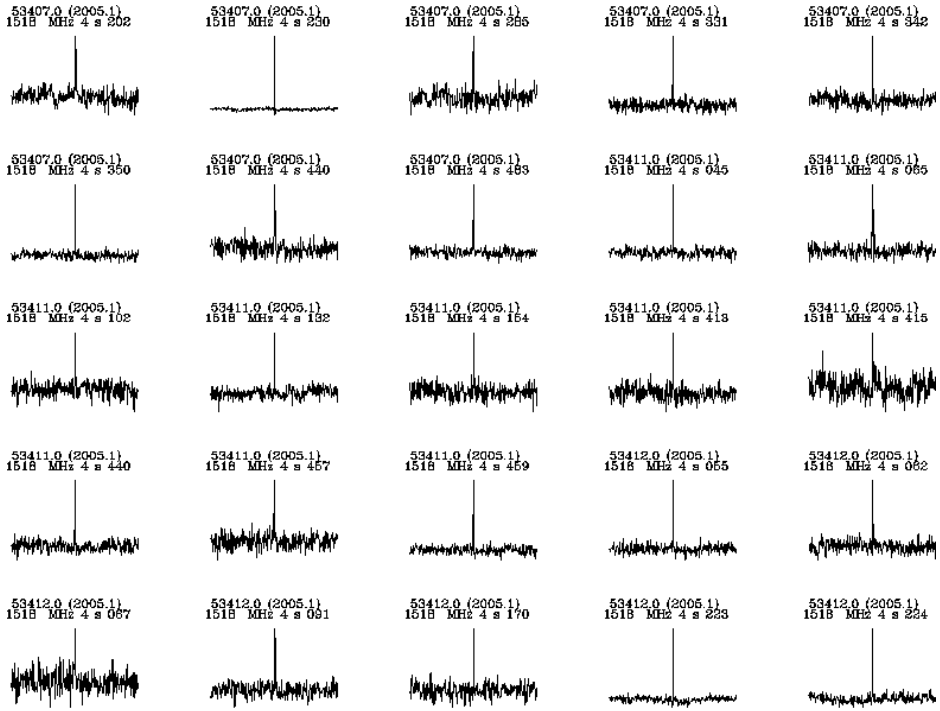
S_{1400}=3600 mJy

N_p=363

Pulse amplitudes seem to follow power-law distribution

RRAT properties - J1819-1458

burpers



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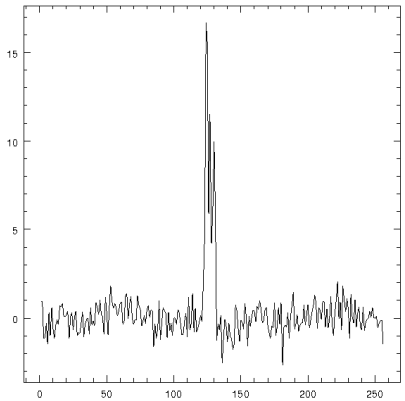
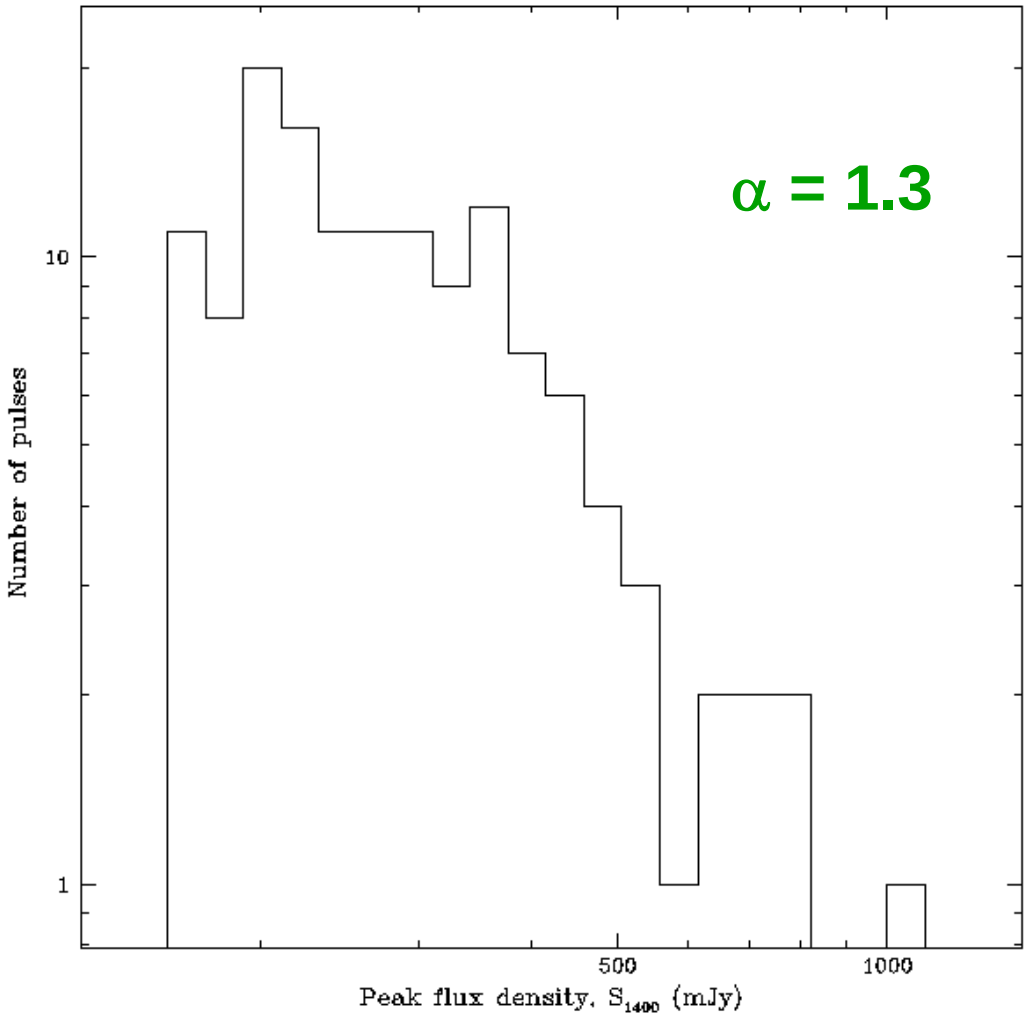


Composite profile from single pulses

RRAT properties - J1317-5759

burpers



P=2.64 s

B=6x10^{12} G

R=4.5 pulses/hr

N_{det}/N_{obs}=93%

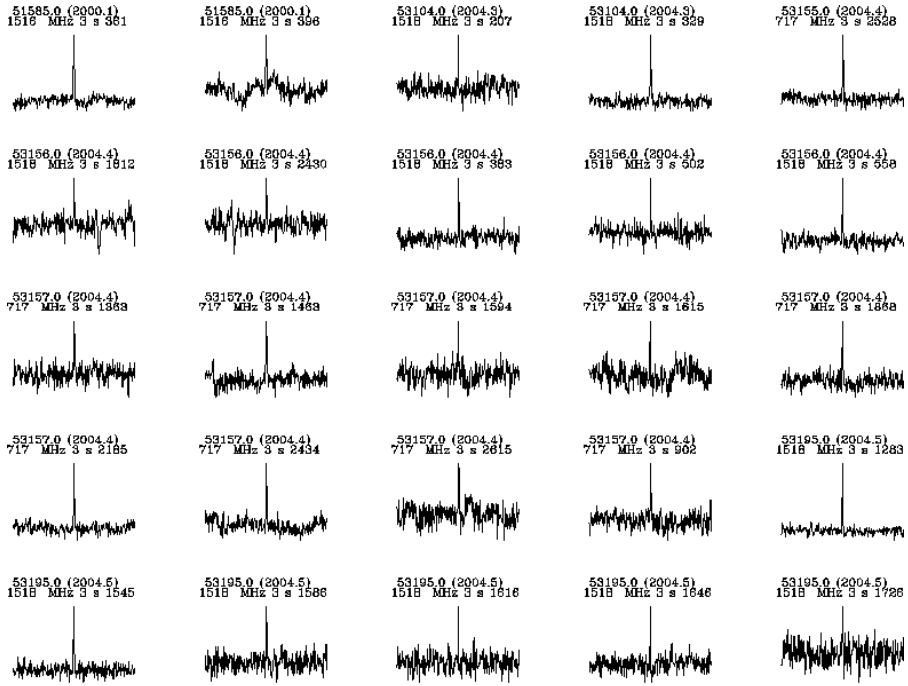
S_{1400}=1100 mJy

N_p=144

Again, power-law distribution seems to work

RRAT properties - J1317-5759

burpers



Single pulses

P=2.64 s

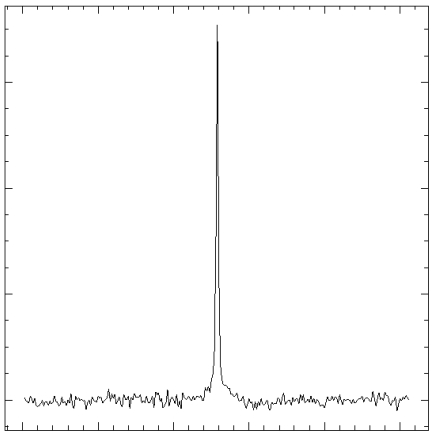
B=6x10^{12} G

R=4.5 pulses/hr

N_{det}/N_{obs}=93%

S_{1400}=1100 mJy

N_p=144

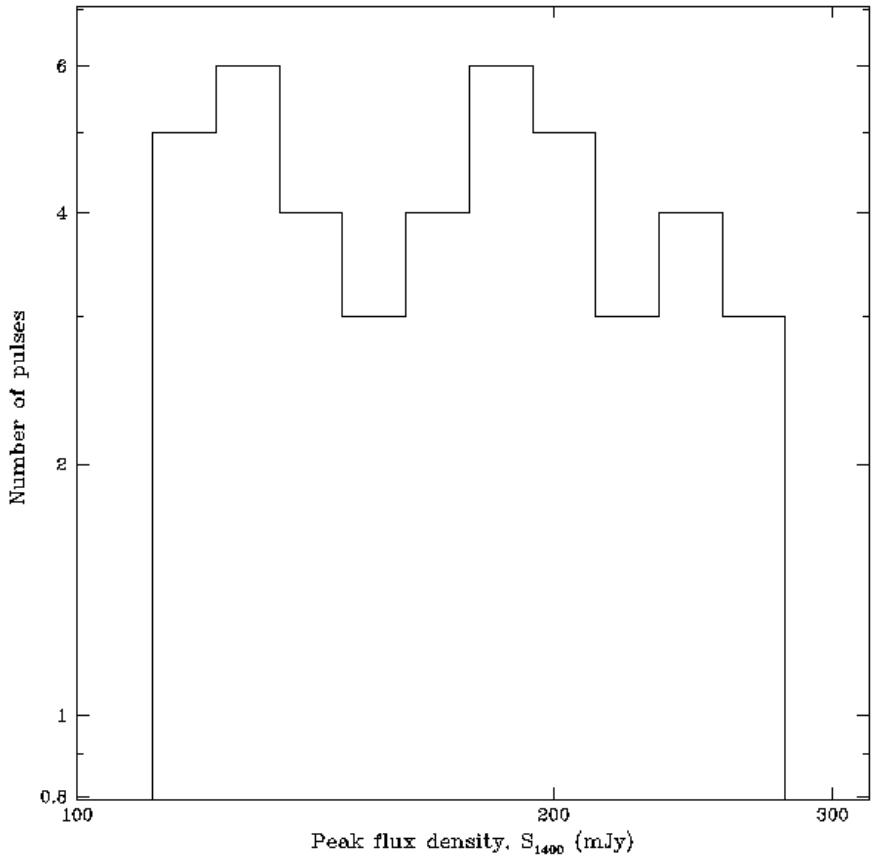


Composite pulse profile from single pulses

Duty cycle=3%

RRAT properties - J1443-60

burpers

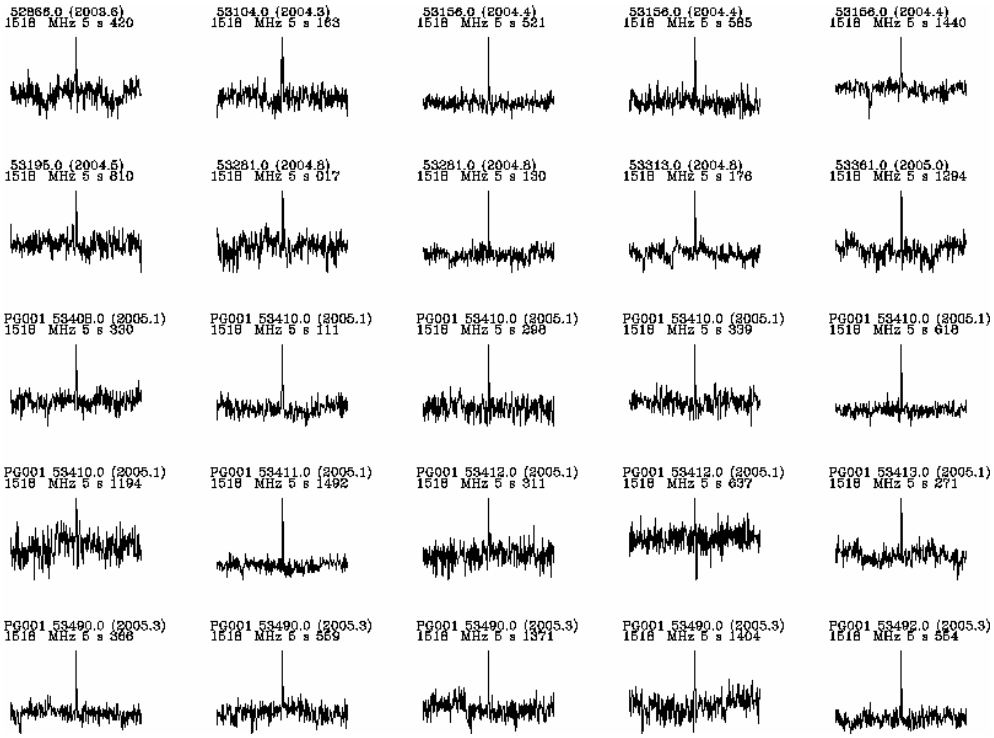


Pulse amplitude distribution

P=4.75 s
No Pdot
R=0.8 pulses/hr
N_{det}/N_{obs}=68%
S_{1400}=280 mJy
N_p=42

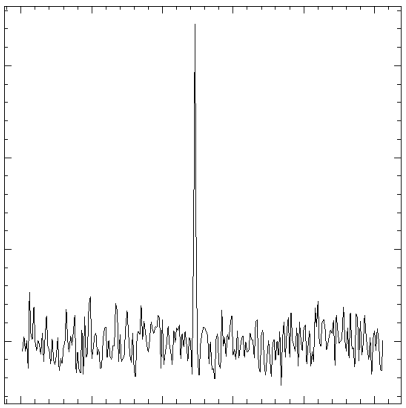
RRAT properties - J1443-60

burpers



Single pulses

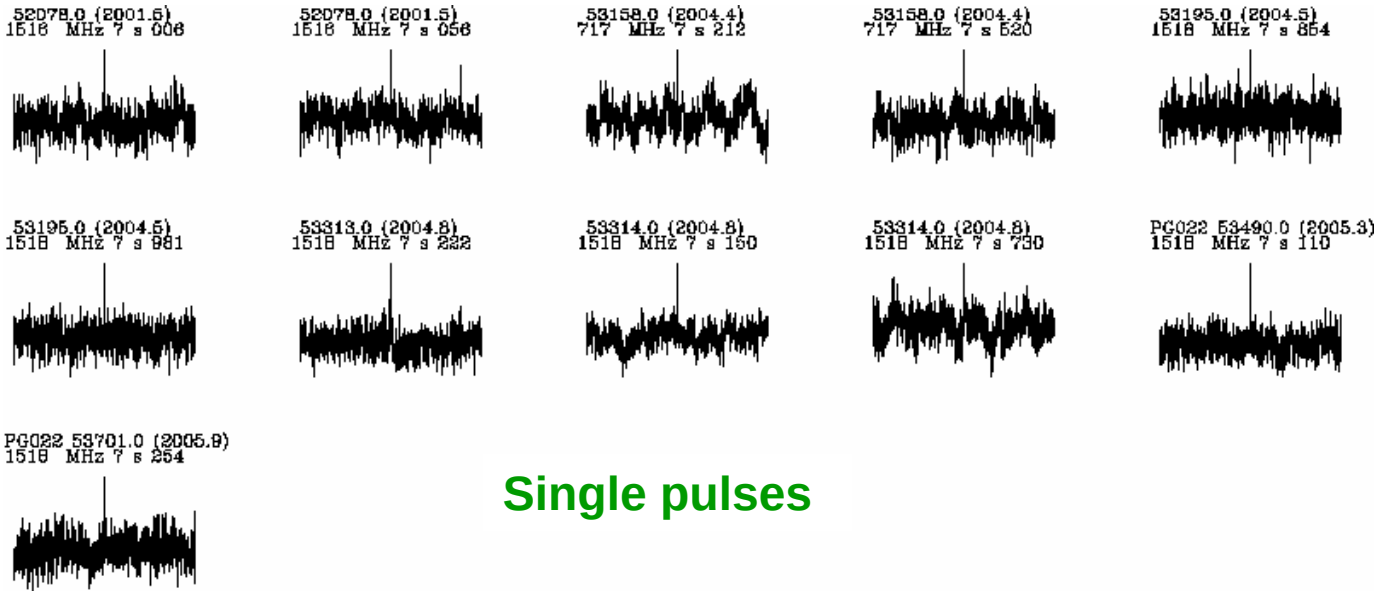
P=4.75 s
No Pdot
R=0.8 pulses/hr
N_{det}/N_{obs}=68%
S_{1400}=280 mJy
N_p=42



Composite pulse profile from several single pulses

RRAT properties - J1848-12

burpers



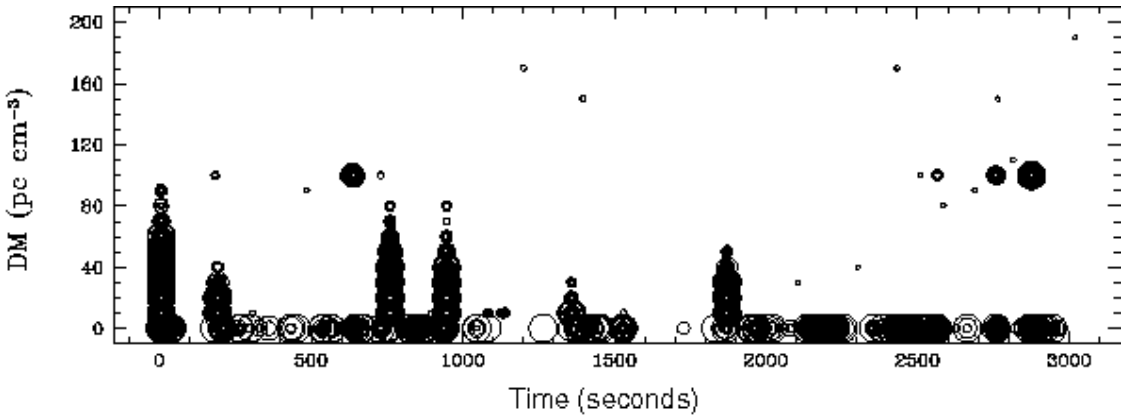
Single pulses

P=6.79 s
No Pdot
R=0.7 pulses/hr
N_{det}/N_{obs}=57%
S_{1400}=450 mJy
N_p=11

- Sporadic - no detection in 2-hr GBT obs at 327 MHz.

RRAT properties - J1911+00

burpers



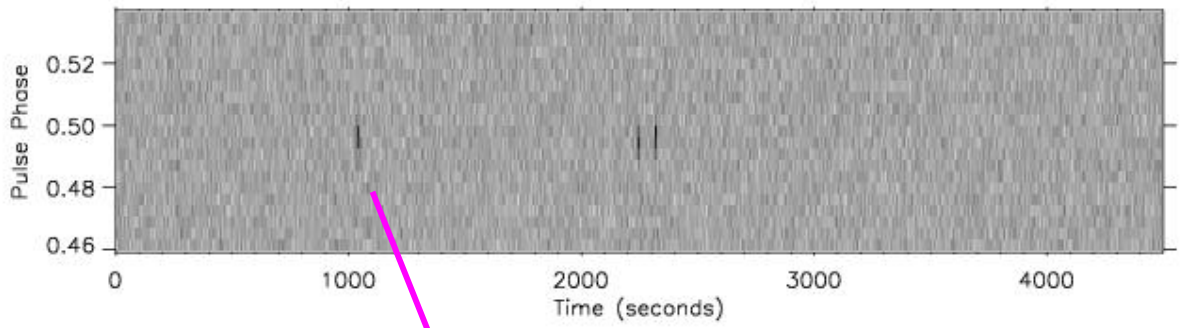
Recent observation with AO at 327 MHz

P=6.90 s
No Pdot
R=0.3 pulses/hr
N_{det}/N_{obs}=45%
S_{1400}=250 mJy
N_p=11

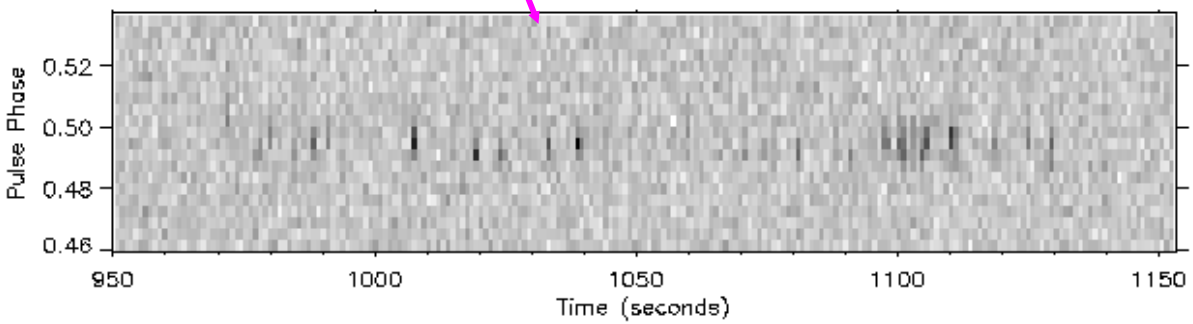
- No period measurable with Parkes obs.
- Recent 327-MHz AO obs reveal more pulses and a period of 6.9 seconds.

RRAT properties - J1913+1333

nullers



Arecibo observations at 327 MHz



Several minutes in “on” state

P=0.923 s

Pdot=8x10^{-15}

R=4.7 pulses/hr

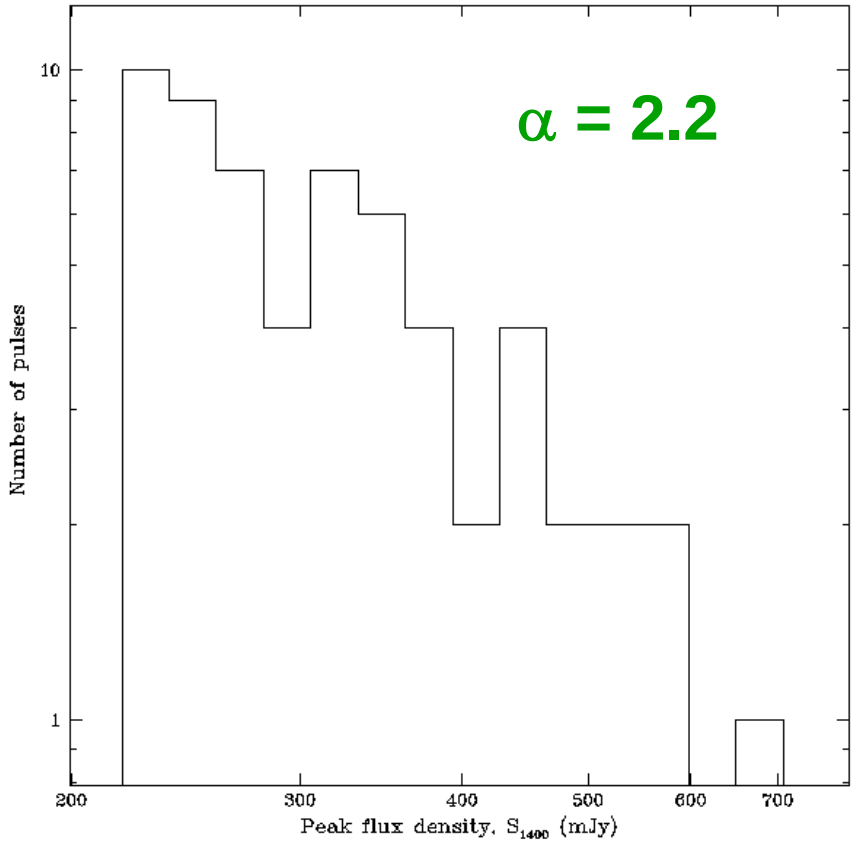
N_{det}/N_{obs}=60%

S_{1400}=650 mJy

N_p=93

RRAT properties - J1913+1333

nullers



P=0.923 s

Pdot=8x10^{-15}

R=4.7 pulses/hr

N_{det}/N_{obs}=60%

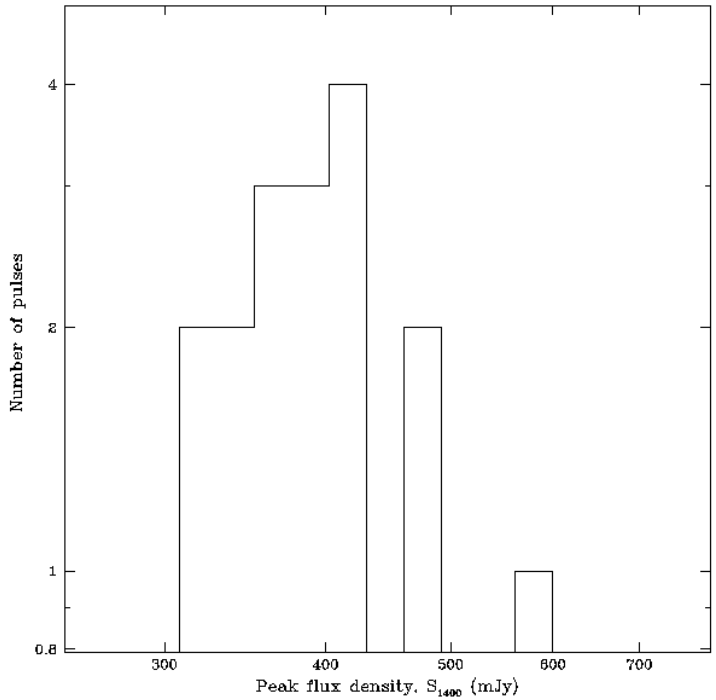
S_{1400}=650 mJy

N_p=93

Pulse amplitudes seem to follow power-law distribution

RRAT properties - J1826-14

nullers



Pulse amplitude distribution

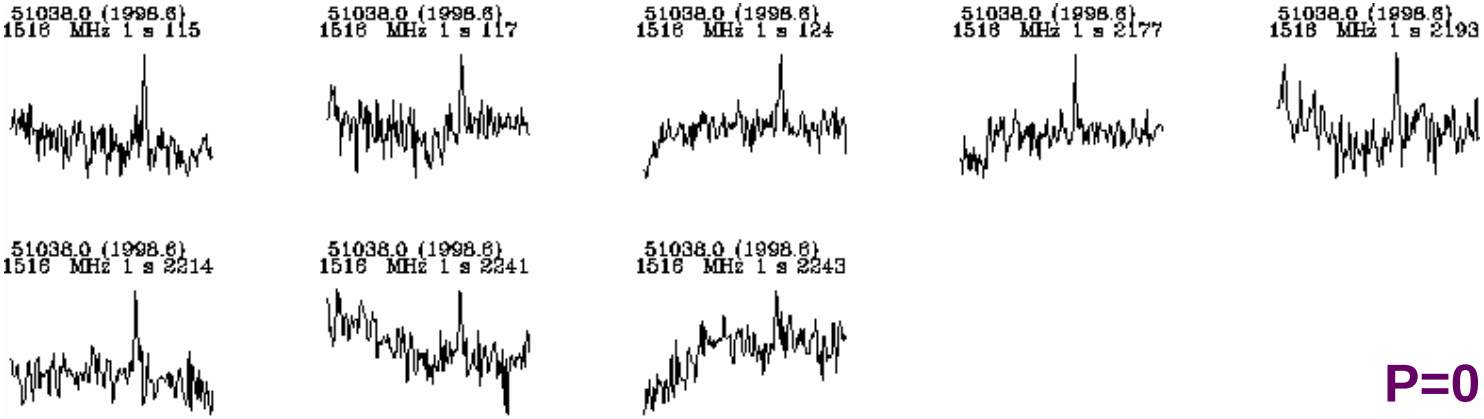
P=0.770 s
No Pdot
R=1.0 pulses/hr
N_{det}/N_{obs}=62%
S_{1400}=600 mJy
N_p=18

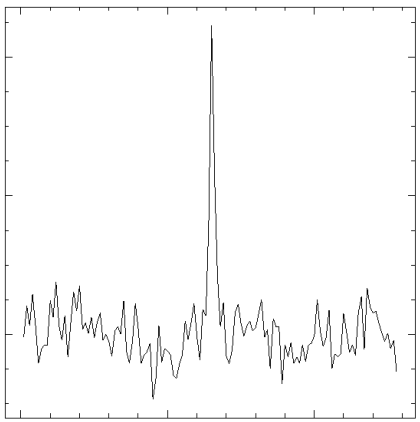
- **No detection in 2-hr GBT obs at 327 MHz in July 2006.**
- **No detection with Parkes since May 2005.**

Long timescale nuller!

RRAT properties - J1839-01

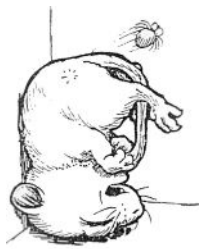
nullers





Composite pulse profile from single pulses

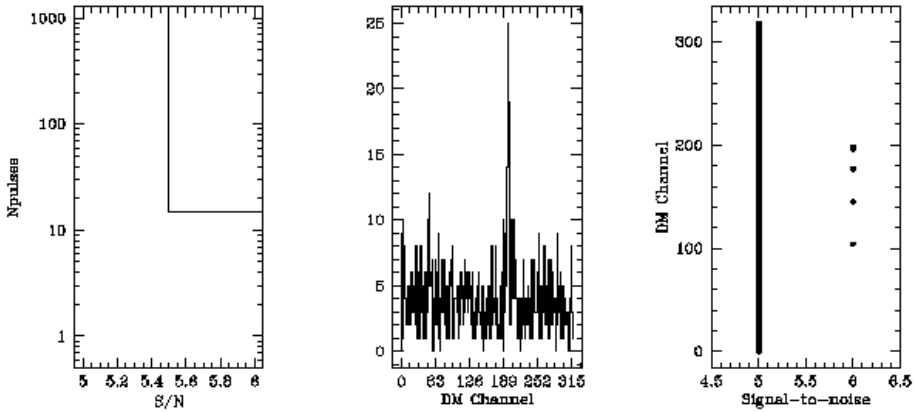
P=0.932 s
No Pdot
R=0.4 pulses/hr
N_{det}/N_{obs}=7%
S_{1400}=100 mJy
N_p=8

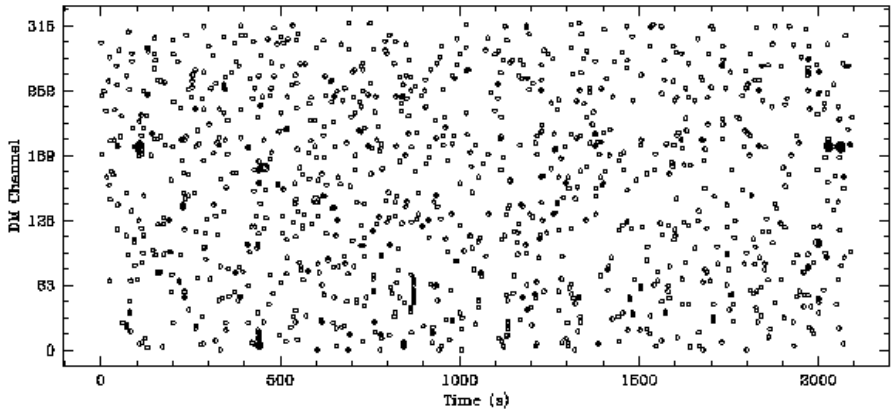


a dead rrat?

- Only 8 pulses in total - all from one day seven years ago!

RRAT properties - J1839-01



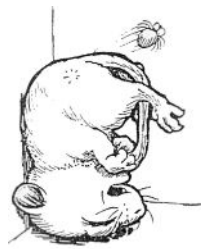


Original detection in PMPS

Long AND short timescale nuller!

nullers

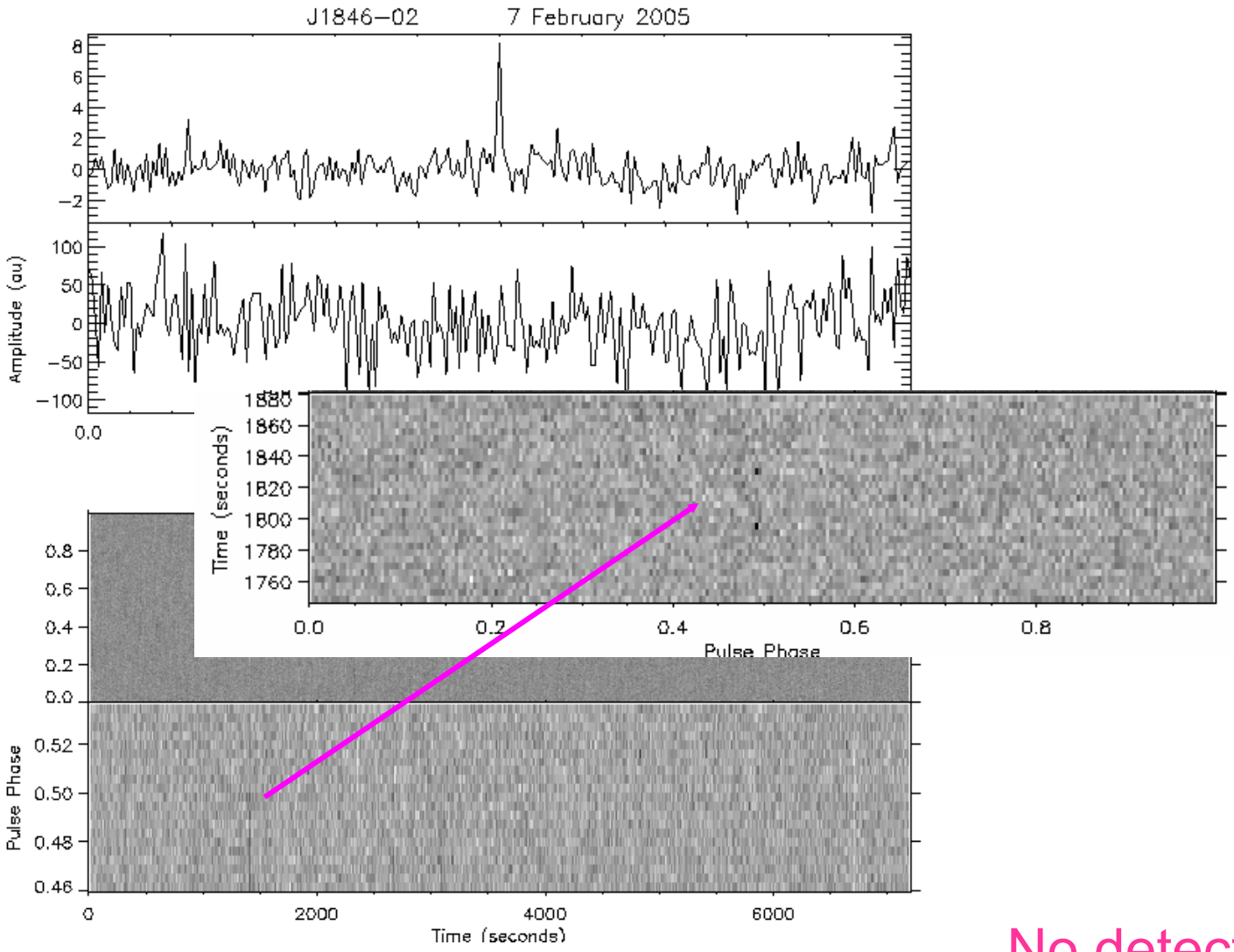
P=0.932 s
No Pdot
R=0.4 pulses/hr
N_{det}/N_{obs}=7%
S_{1400}=100 mJy
N_p=8



a dead rrat?

RRAT properties - J1846-02

nullers

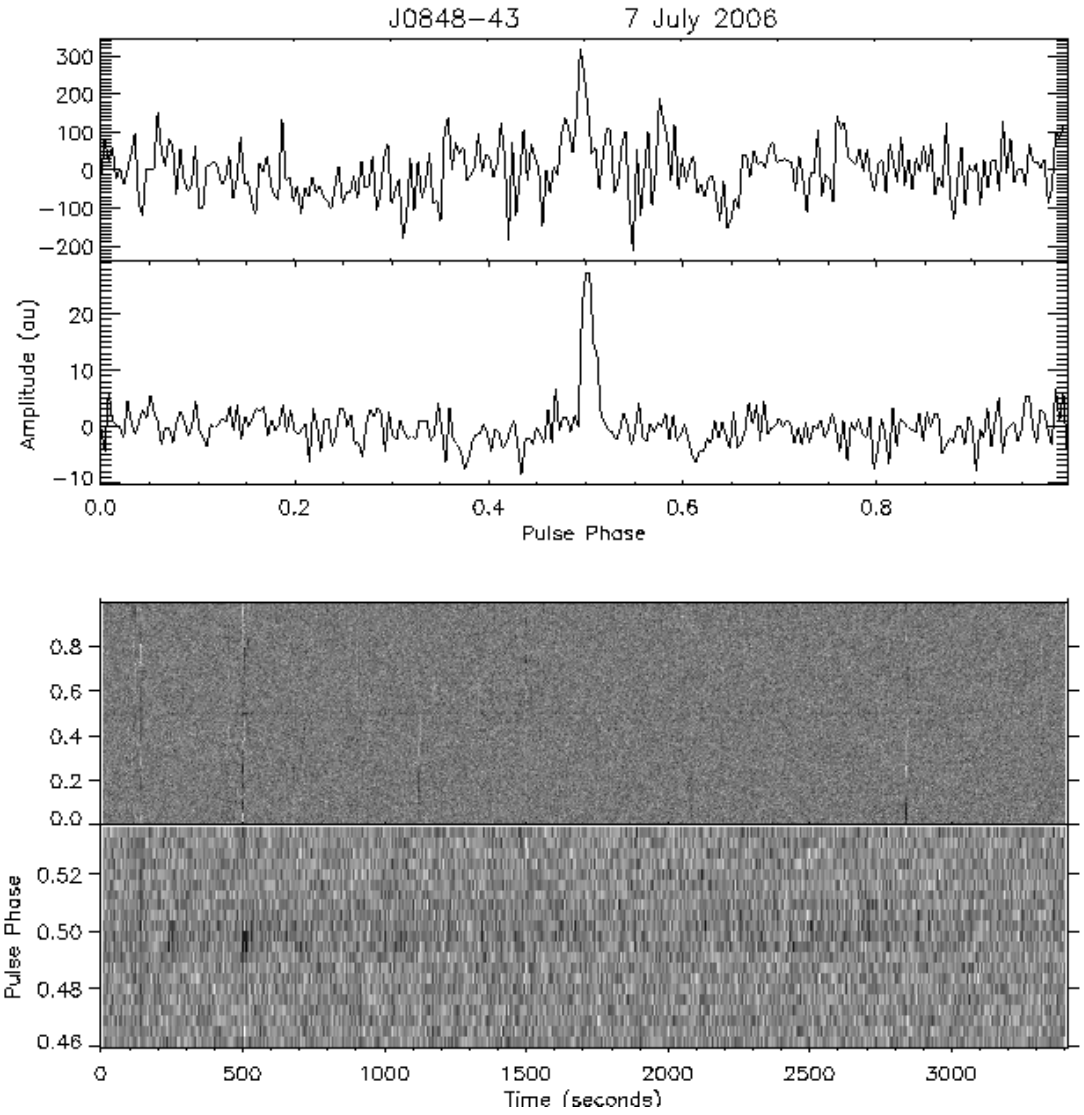


Recent reobservation

P=4.47 s
No Pdot
R=0.8 pulses/hr
N_{det}/N_{obs}=50%
S_{1400}=250 mJy
N_p=13

No detection in GBT data at 327 MHz.

RRAT properties - J0848-43



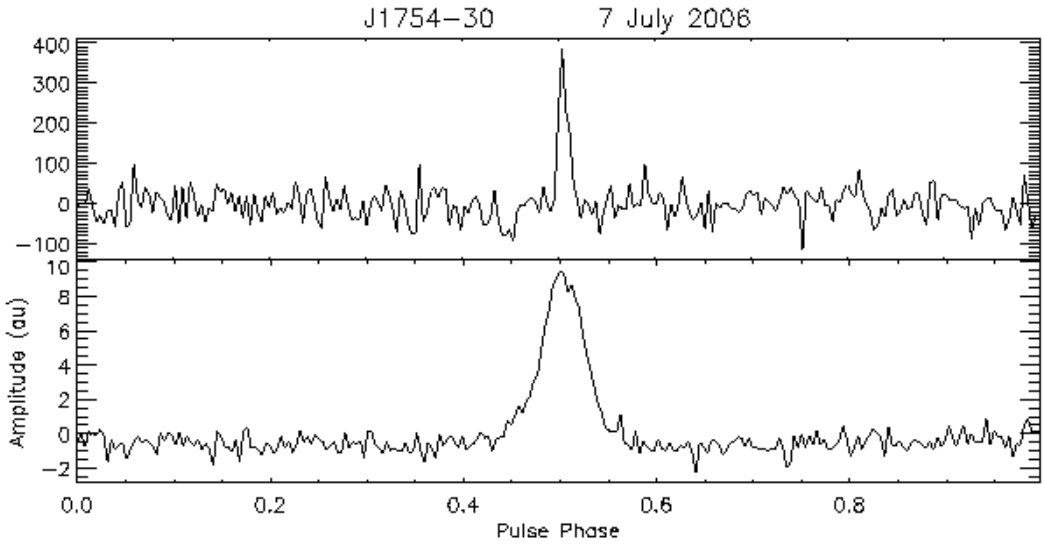
GBT observation at 327 MHz

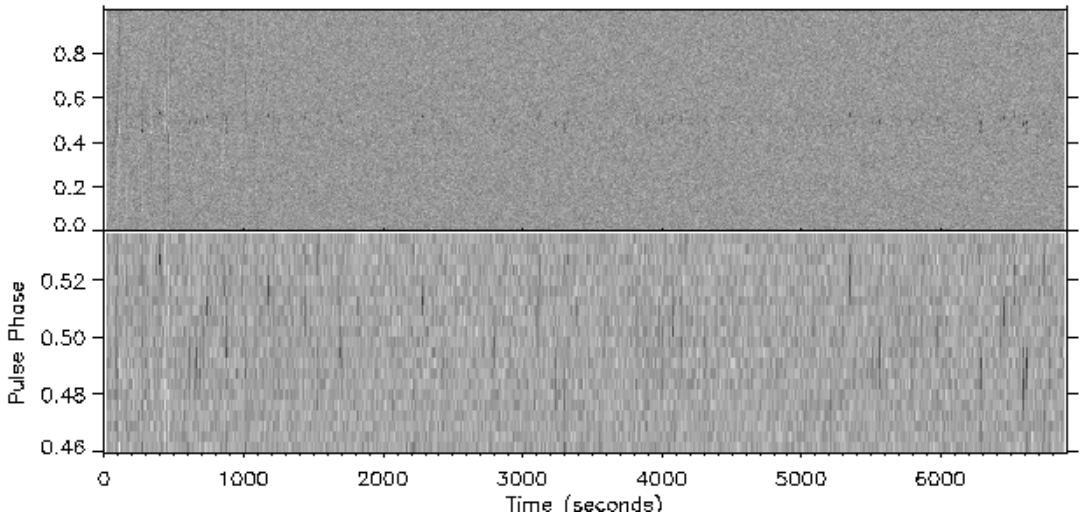
pulsars

P=5.98 s
No Pdot
R=4.2 pulses/hr
N_{det}/N_{obs}=32%
S_{1400}=100 mJy
N_p=58

RRAT properties - J1754-30

pulsars





GBT observation at 327 MHz

P=1.32 s
No Pdot
R=0.6 pulses/hr
N_{det}/N_{obs}=55%
S_{1400}=160 mJy
N_p=25

RRAT properties - timing

burpers
nullers
pulsars

Name	P (s)	$\dot{P}$ (10^{-15})	B (10^{12} G)	T_{char} (kyr)	$\dot{E}$ (10^{31} ergs s^{-1})
J0848□-43	5.98				
J1317-	2.64	12.5	5.8	3337	2.7
J1443-60	4.76				
J1754-30	1.32				
J1819-	4.26	575	5.0	117	25
J1826-14	0.77				
J1839-01	0.93				
J1846-02	4.47				
J1848-12	6.79				
J1911+00	6.94				
J1913+133	0.92	7.8	2.7	1.86	39.4

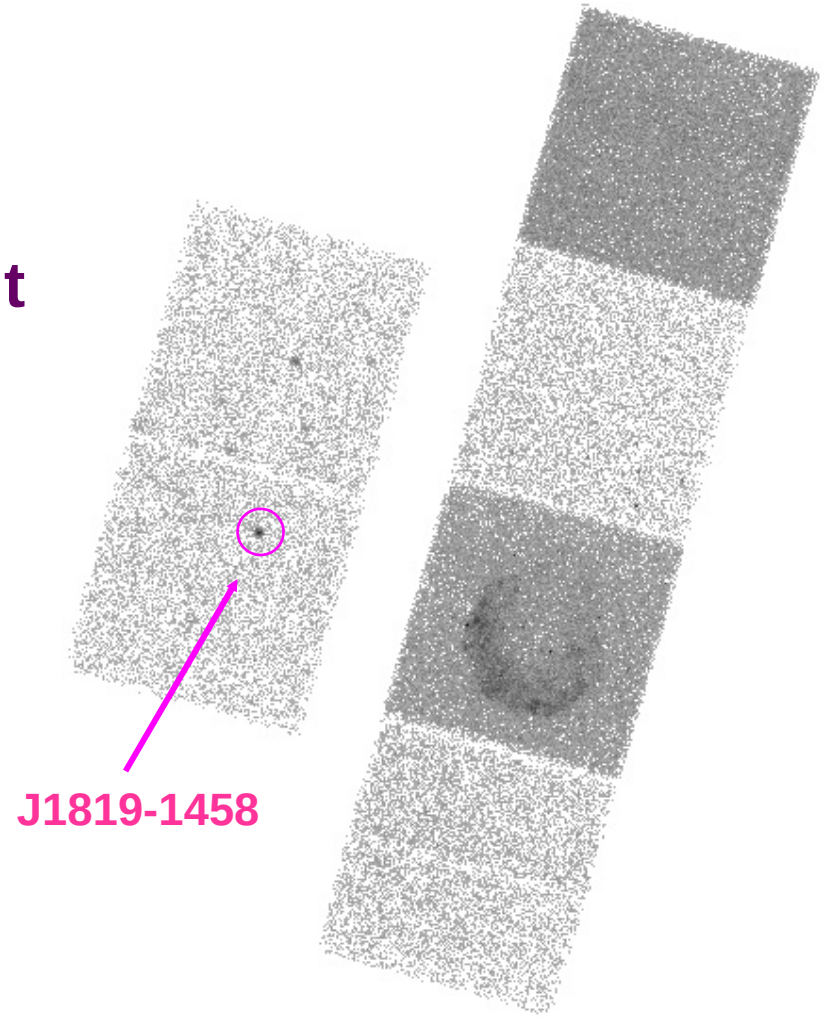
RRAT properties - bursts

burpers
nullers
pulsars

Name	w_{50} (ms)	L_{1400} (Jy kpc^2)	N_p/T_{obs} (hr^{-1})	N_{det}/N_{obs} (%)	N_p
J0848-43	30	3	4.2	32	58
J1317-5759	10	11	4.5	93	144
J1443-60	20	8	0.8	68	42
J1754-30	16	0.7	0.6	55	25
J1819-1458	3	49	18.0	100	363
J1826-14	2	7	1.0	62	18
J1839-01	15	4	0.4	7	8
J1846-02	16	7	0.8	50	13
J1848-12	2	3	0.7	57	11
J1911+00	5	3	0.3	45	5
J1913+1333	2	21	4.7	60	93

X-ray observations of J1819-1458

- 30 ks ACIS obs in May 05
- J1819-1458 11’ from aimpoint
- Clear detection ($P < 10^{-4}$)
- J1819-1458 and SNR likely not related

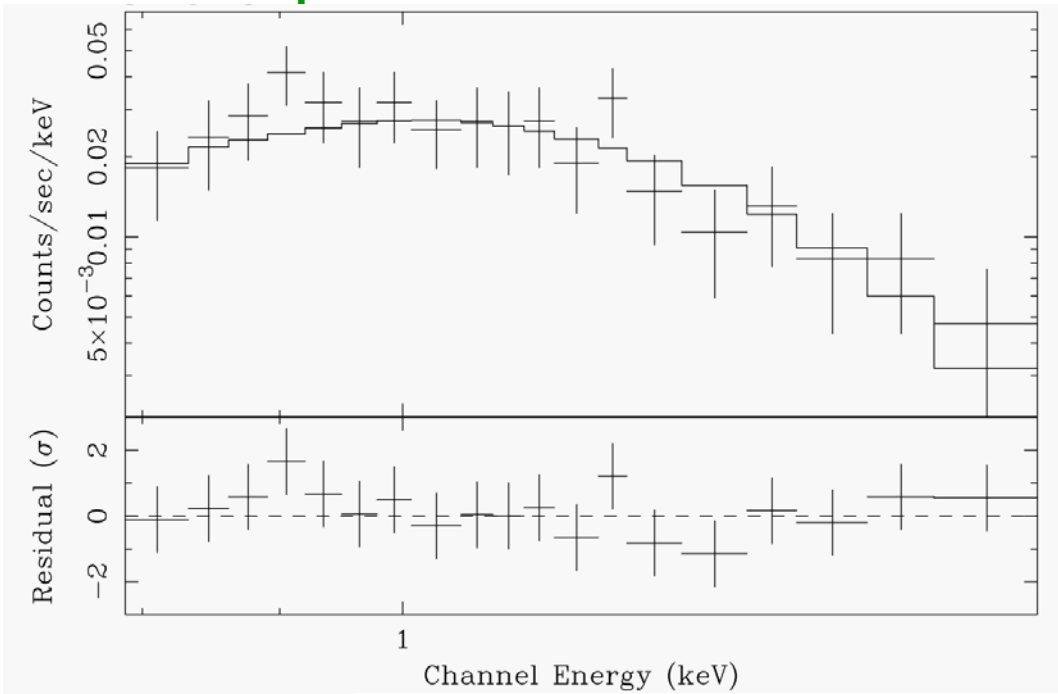


Chandra image of SNR G15.9+0.2

X-ray observations of J1819-1458

- 524 +/- 24 counts
- No x-ray bursts
  $E_{burst} < 10^{36} \times d^2_{3.6}$ ergs
- No variability on scales of 3.5 s to 5 days
- No pulsations
  $f < 70\%$ for sinusoid
- Poor fit to power-law
- Good fit to BB
  $R_{BB,\infty} \approx 20 d_{3.6}$ km

Spectrum of J1819-1458



Reynolds et al. 2006

$N_H = 7\ (+7,-4) \times 10^{21}$ cm^{-2}
$kT_\infty = 120 \pm 40$ eV
$f_{X,unabs} \approx 2\times10^{-12}$ ergs/cm^{-2}/s
$L_X \approx 3.6 d^2_{3.6} \times 10^{33}$ ergs/s (0.5-8 keV)

What are they?

X-ray populations:

- Magnetars kT, L_x too low But maybe transient?
- INSs kT, L_x a bit high But birthrate works! (Popov et al. 2006)
- CCOs kT too low and no SNRs

- Radio pulsars

RRAT J1819-1458 : kT_∞ = 120 ± 40 eV (117 kyr)
PSR B0656+14 : kT_∞ = 70 eV (110 kyr)
PSR J0538+2817 : kT_∞ = 160 eV (30 kyr)

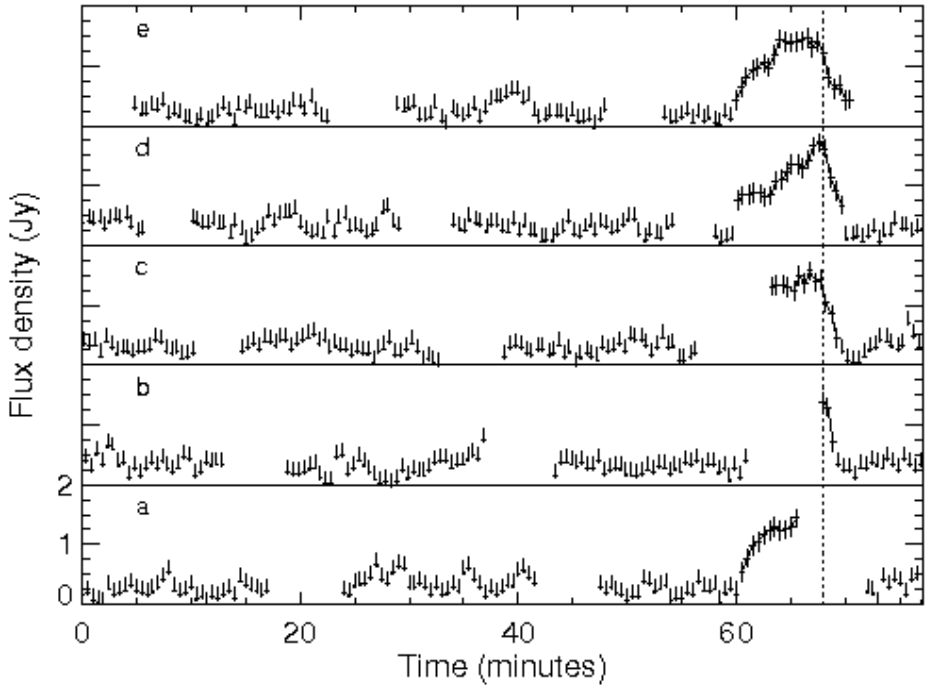
Good agreement though slightly hotter than predicted.
(Maybe due to high B field? See Shibanov & Yakovlev 1996)

What are they?

Radio populations:

- Almost-dead pulsars, brought back to life temporarily (Zhang et al. 2006)

Proposed mechanism fo
GCRT (Zhang & Gil 2005)



GCRT (Hyman et al. 2005)

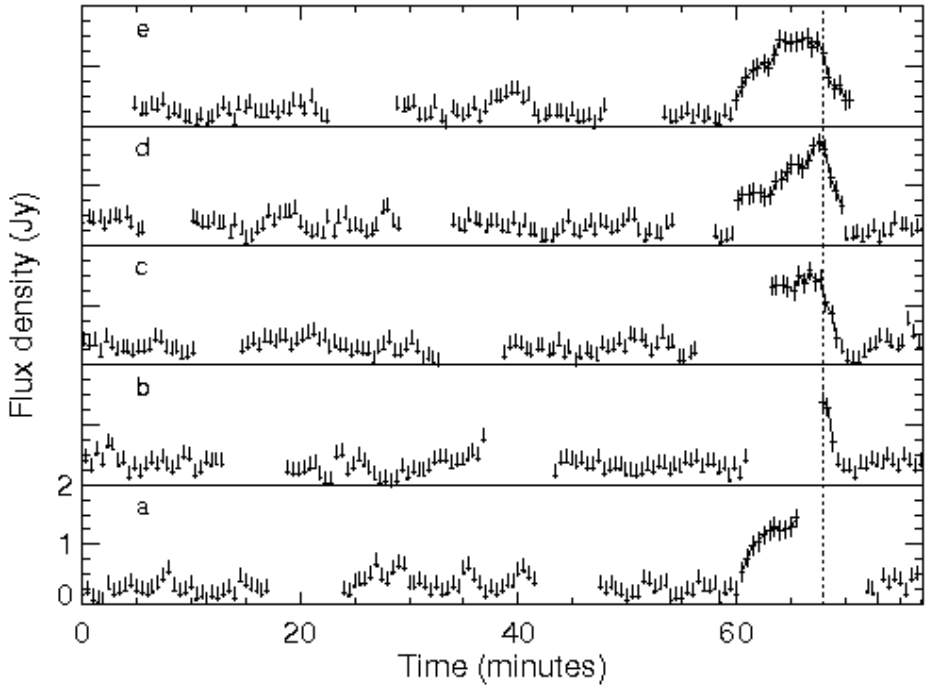
What are they?

Radio populations:

- Almost-dead pulsars, brought back to life temporarily (Zhang et al. 2006)

Proposed mechanism fo
GCRT (Zhang & Gil 2005)

But RRATs are not near death line and J1819's X-ray emission suggests youthfulness.



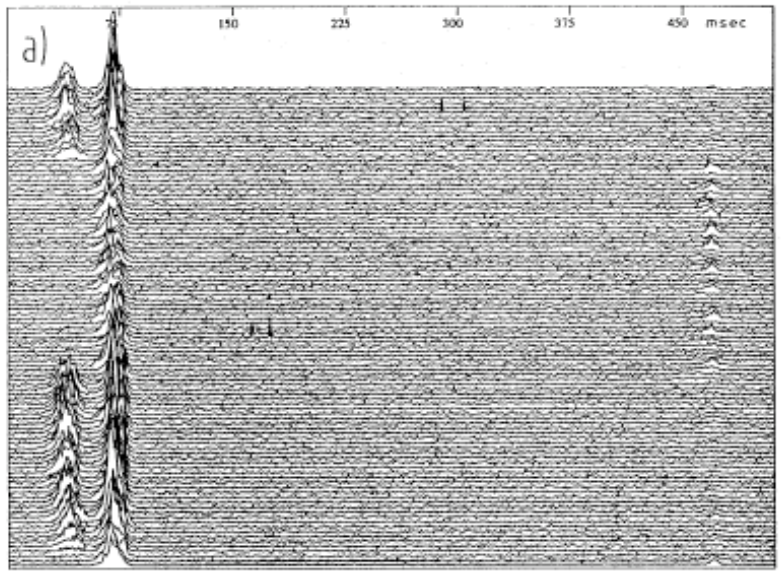
GCRT (Hyman et al. 2005)

What are they?

Radio populations:

- Almost-dead pulsars, brought back to life temporarily
- Pulsars with temporary reversal of radio emission direction (Dyks et al. 2005 and Zhang et al. 2006)

Proposed to explain strange mode-changing of B1822-09.



B1822-09 (Gil et al. 1994)

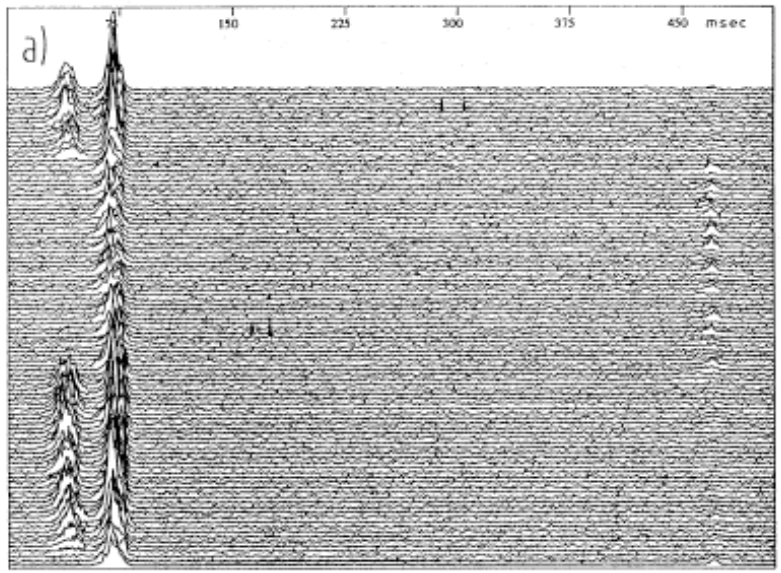
What are they?

Radio populations:

- Almost-dead pulsars, brought back to life temporarily
- Pulsars with temporary reversal of radio emission direction (Dyks et al. 2005 and Zhang et al. 2006)

Proposed to explain strange mode-changing of B1822-09.

But we don't often see multiple successive bursts from the RRATs!



B1822-09 (Gil et al. 1994)

What are they?

Radio populations:

- Almost-dead pulsars, brought back to life temporarily
- Pulsars with temporary reversal of radio emission direction
- Pulsars with asteroid belts (Cordes & Shannon 2006 and Li 2006) See poster!!

Can also explain sometimes-pulsars like B1931+24 and nullir and mode-changing pulsars.

B1931+24 (Kramer et al. 2006)

What are they?

Radio populations:

- Almost-dead pulsars, brought back to life temporarily
- Pulsars with temporary reversal of radio emission direction
- Pulsars with asteroid belts (Cordes & Shannon 2006 and Li 2006) See poster!!

Can also explain sometimes-pulsars like B1931+24 and nullir and mode-changing pulsars.

Need sensitive radio or IR obs to detect disk!

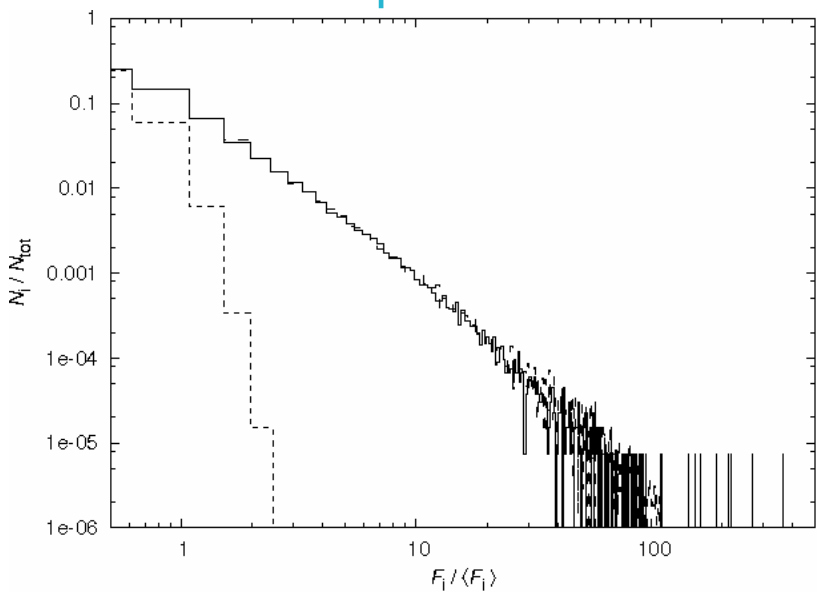
B1931+24 (Kramer et al. 2006) **Changing Pdot?**

What are they?

Radio populations:

- Almost-dead pulsars, brought back to life temporarily
- Pulsars with temporary reversal of radio emission direction
- Pulsars with asteroid belts
- Pulsars like B0656+14 (Weltevrede et al. 2006)

See poster!!



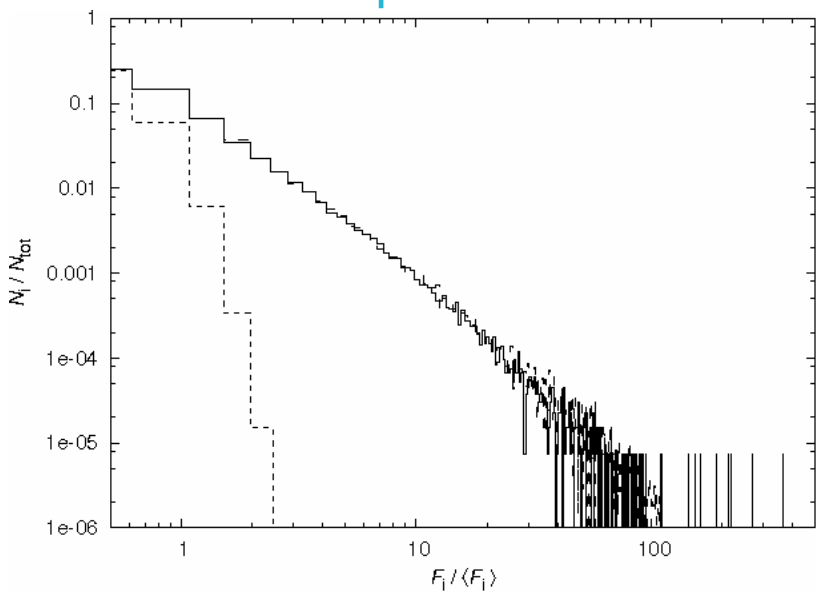
Weltevrede et al. 2006

What are they?

Radio populations:

- Almost-dead pulsars, brought back to life temporarily
- Pulsars with temporary reversal of radio emission direction
- Pulsars with asteroid belts
- Pulsars like B0656+14 (Weltevrede et al. 2006)

See poster!!



Consistent with GBT obs of J0848-43 and J1754-30 and with X-ray obs.

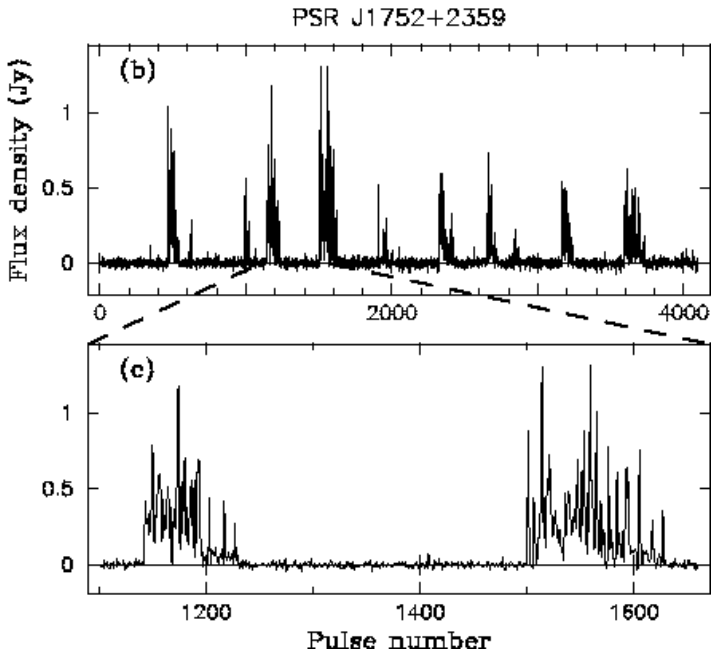
But not consistent with obs of other RRATs (though more sensitive obs needed).

Weltevrede et al. 2006

What are they?

Radio populations:

- Almost-dead pulsars, brought back to life temporarily
- Pulsars with temporary reversal of radio emission direction
- Pulsars with asteroid belts
- Pulsars like B0656+14
- Sometimes-pulsars like B1931+24 (Kramer et al. 2006) or J1752+2359 (Lewandowski et al. 2004)



Lewandowski et al. 2004

What are they?

Radio populations:

- Almost-dead pulsars, brought back to life temporarily
- Pulsars with temporary reversal of radio emission direction
- Pulsars with asteroid belts
- Pulsars like B0656+14
- Sometimes-pulsars like B1931+24 or J1752+2359
- Extreme cases of nulling and/or giant pulsing pulsars
- All of the above and/or none of the above?!

What a mess!!!

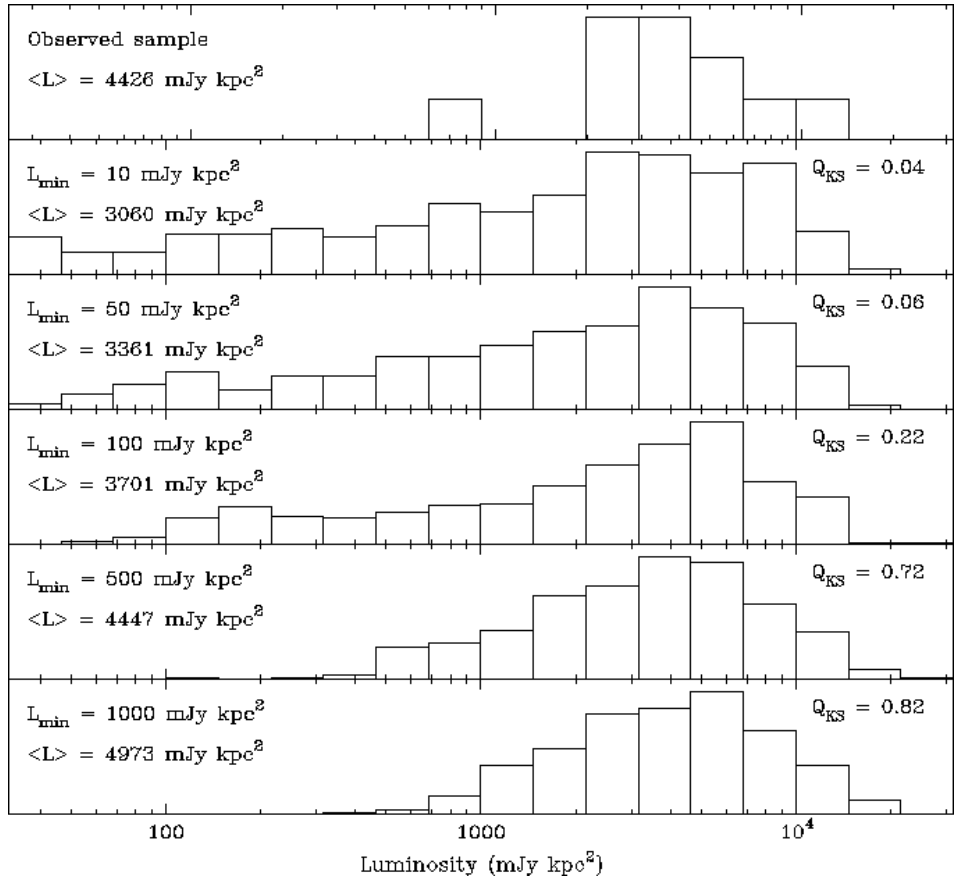
How do we define a RRAT/pulsar/sometimes pulsar????

Where do we go from here???

Population Estimates

- Revised population analysis favors
  L_{min} > 100 mJy kpc^2
- PALFA surveys -> 5 RRATs
- 10 RRATs in Parkes high-B surveys

All estimates depend highly on assumed L_{min}!



Lorimer et al. in preparation

$$N_{RRATS} \approx 2\times10^{5}\left(L_{min}/100\ \mathrm{mJy\ kpc^2}\right)^{-1}\times(0.5/f_{on})\times(0.5/f_{rfi})\times(0.1/f_{beam})$$

Population Estimates

- Revised population analysis favors
  $L_{min} > 100$ mJy kpc^2
- PALFA surveys -> 5 RRATs
- 10 RRATs in Parkes high-B surveys

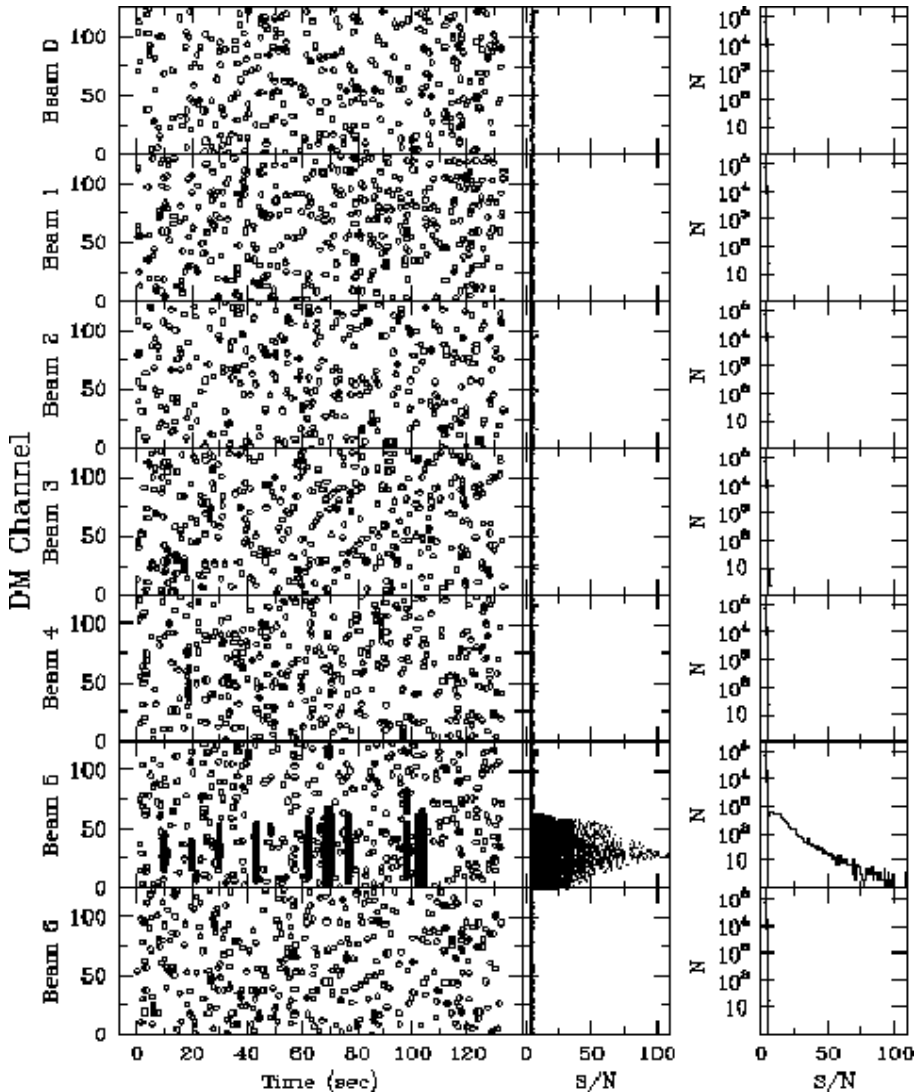
All estimates depend highly on assumed L_{min}!

Expect 20,000 RRATs detectable by SKA!

AO objects

There are RRATs in the tropics too!

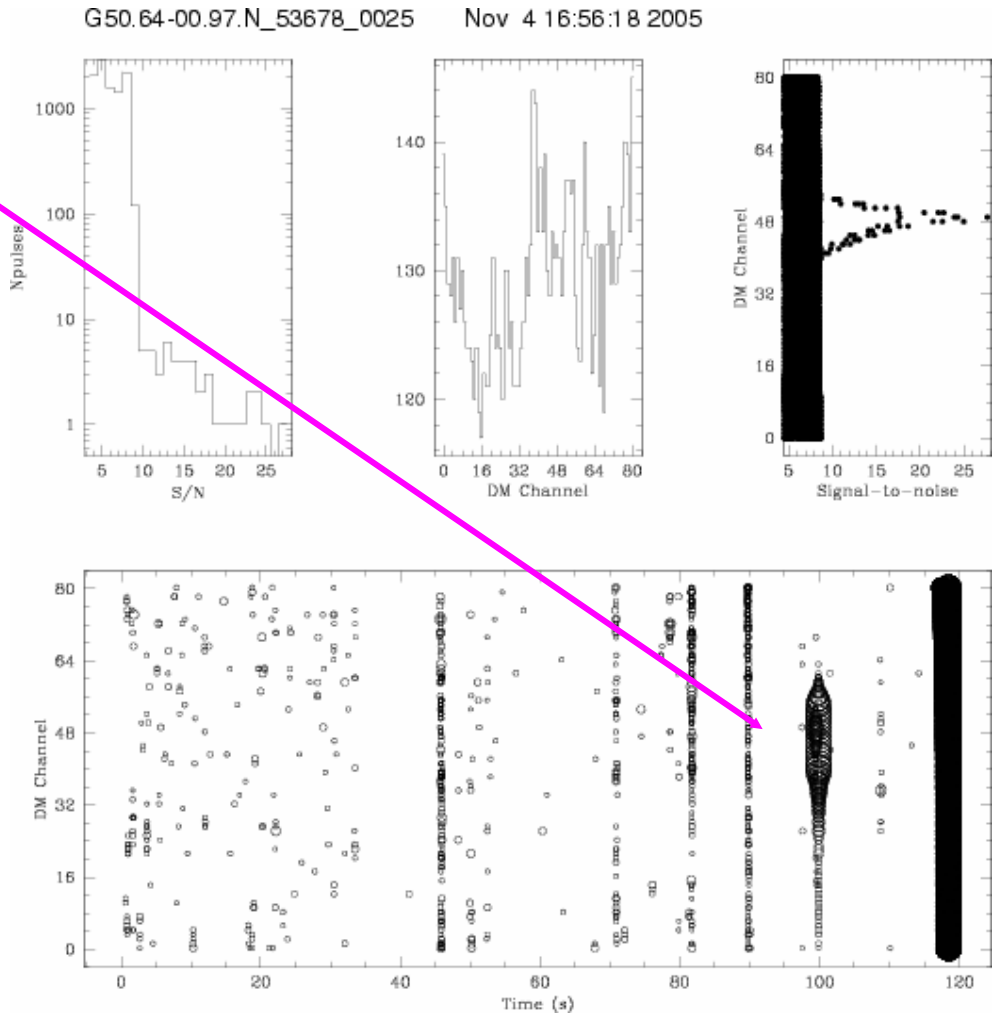
- **J0628+09 - PALFA discovery with P = 1.24 s and DM = 88 pc cm^{-3}**



AO objects

There are RRATs in the tropics too!

- **J1928+15 - PALFA RRAT candidate**
- **Two bursts separated by 405 ms at DM = 240 pc cm^{-3}**
- **An extreme nuller?**



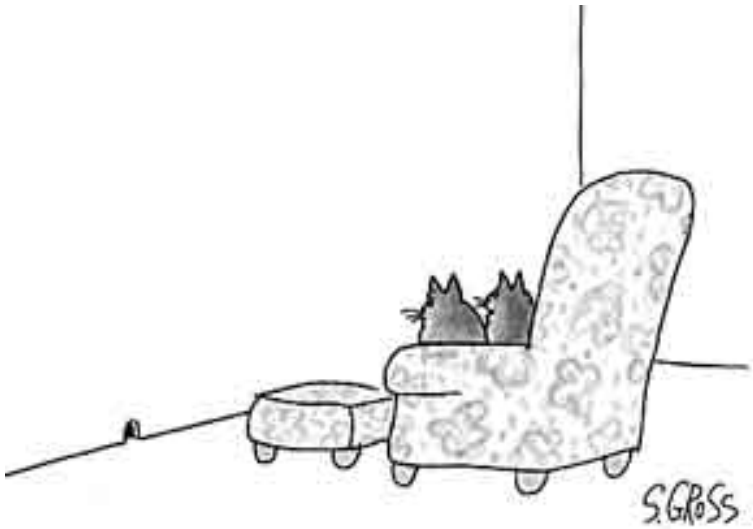
Summary

- The 11 Parkes RRATs appear to fall into three LOOSE classes: burpers, nullers and pulsars.
- Radio timing for three RRATs reveals properties consistent with those of normal pulsars (though J1819-1458 has high *B*).
- Radio observations show that their properties are very varied even within the same class of object.
- X-ray observations are consistent with them being cooling NSs.
- Regardless of origin, we expect there to be a large population of these objects, most likely more than the population of normal pulsars.

Future Work

- More sensitive obs with the GBT and Arecibo and more frequent Parkes obs will enable P/Pdot measurements for other RRATs. Timing positions will allow multiwavelength obs.
- These obs will also enable us to better determine burst burst flux distributions and how the RRATs are related to other NSs like 0656, giant and nulling pulsars.
- Radio searches for pulsations from magnetars and INSs may lead to links between these classes of NSs.
- J1819-1458 and J1317-5759 recently observed with XMM - analysis in progress. Chandra and IR (VLT-NACO) obs of other RRATs approved. X-ray obs yielding more sensitive spectra and pulsed fracs will allow discrimination between scenarios.
- More RRATs to be found by PALFA, other future surveys

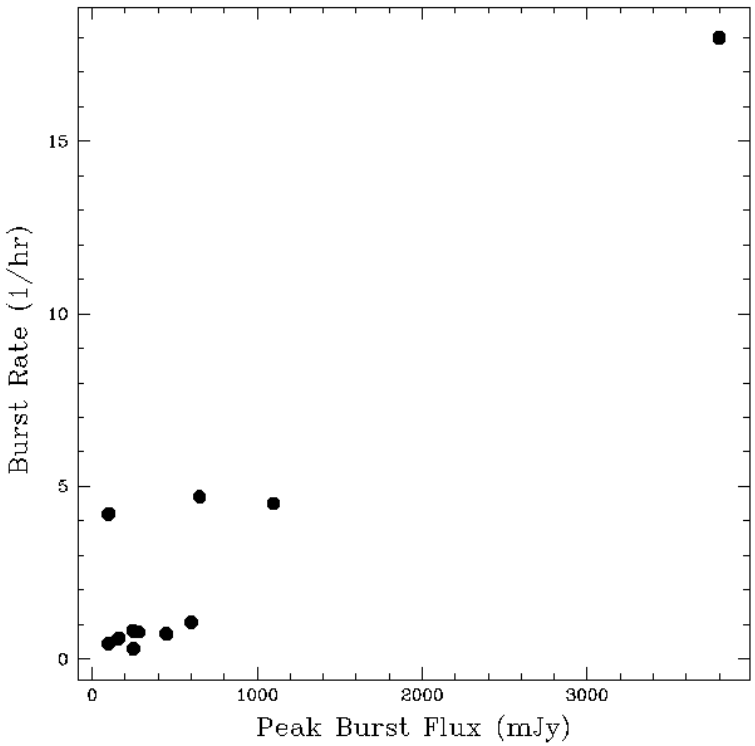
Stay tuned!

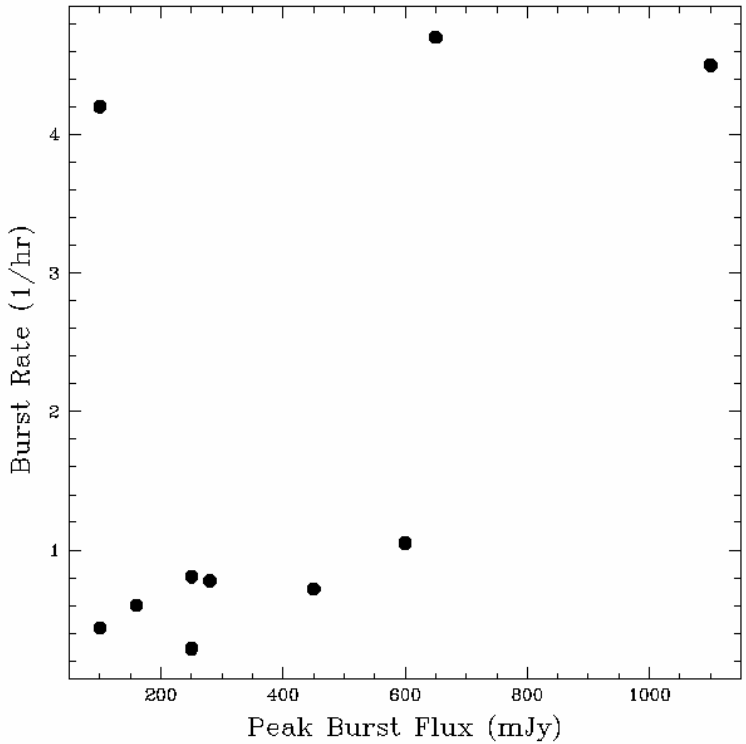


"Now, isn't this more fun than spending money on dinner and a movie?"

Thank you!

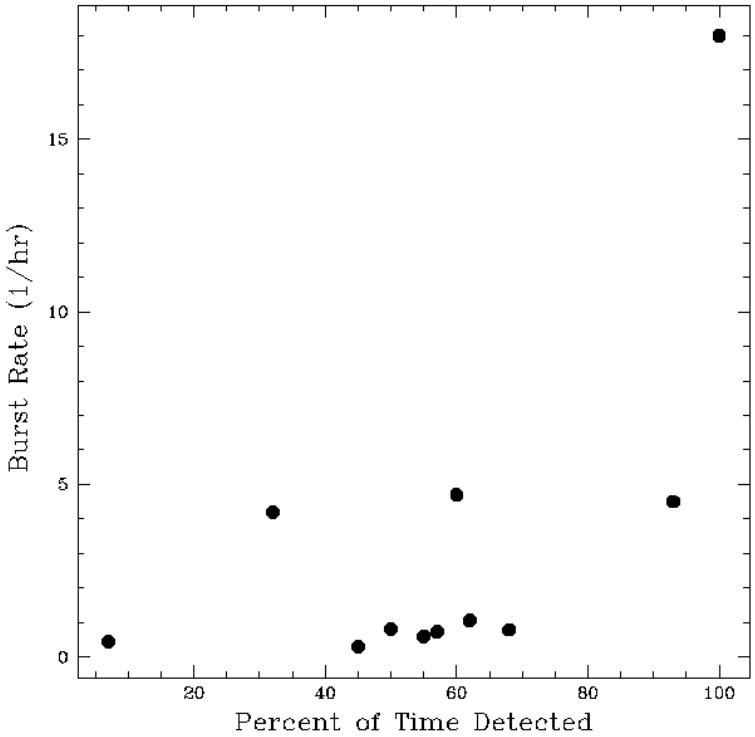
RRAT properties - bursts

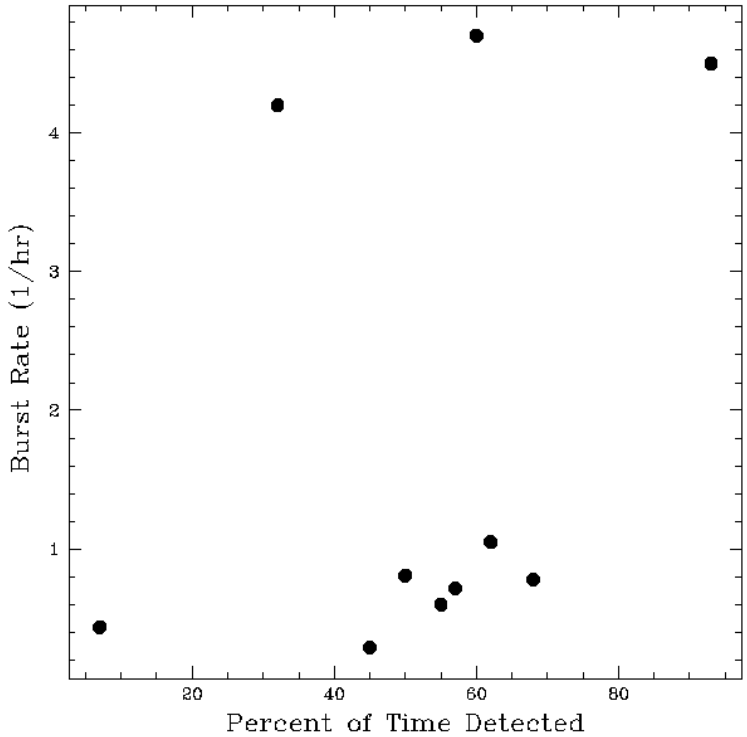




with J1819-1458 removed

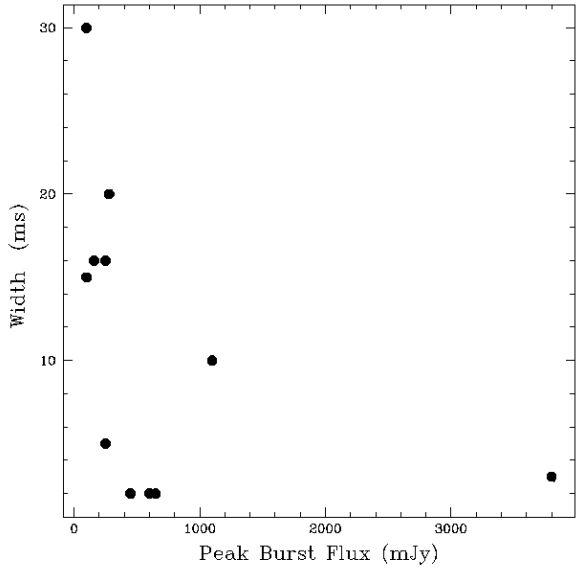
RRAT properties - bursts

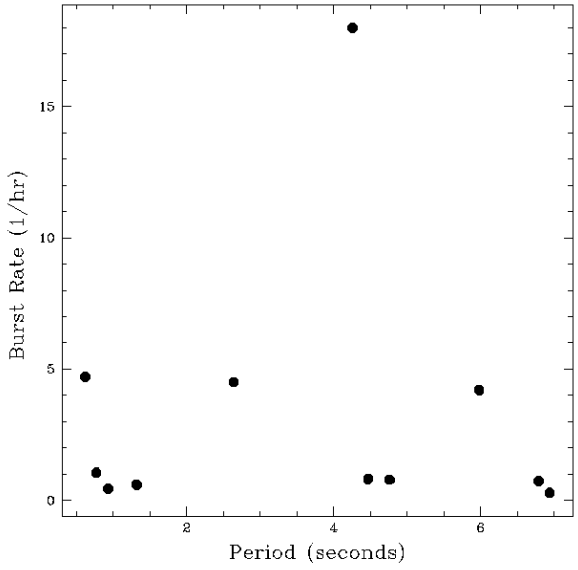


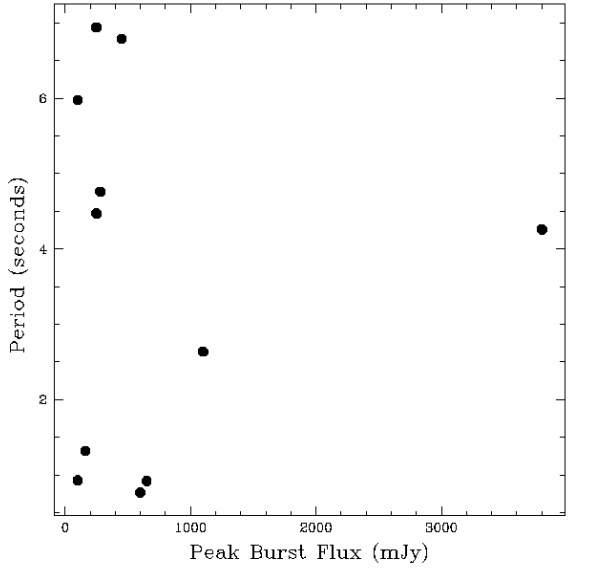


with J1819-1458 removed

RRAT properties - bursts







No obvious correlations between parameters…

Other observations of J1819-1458

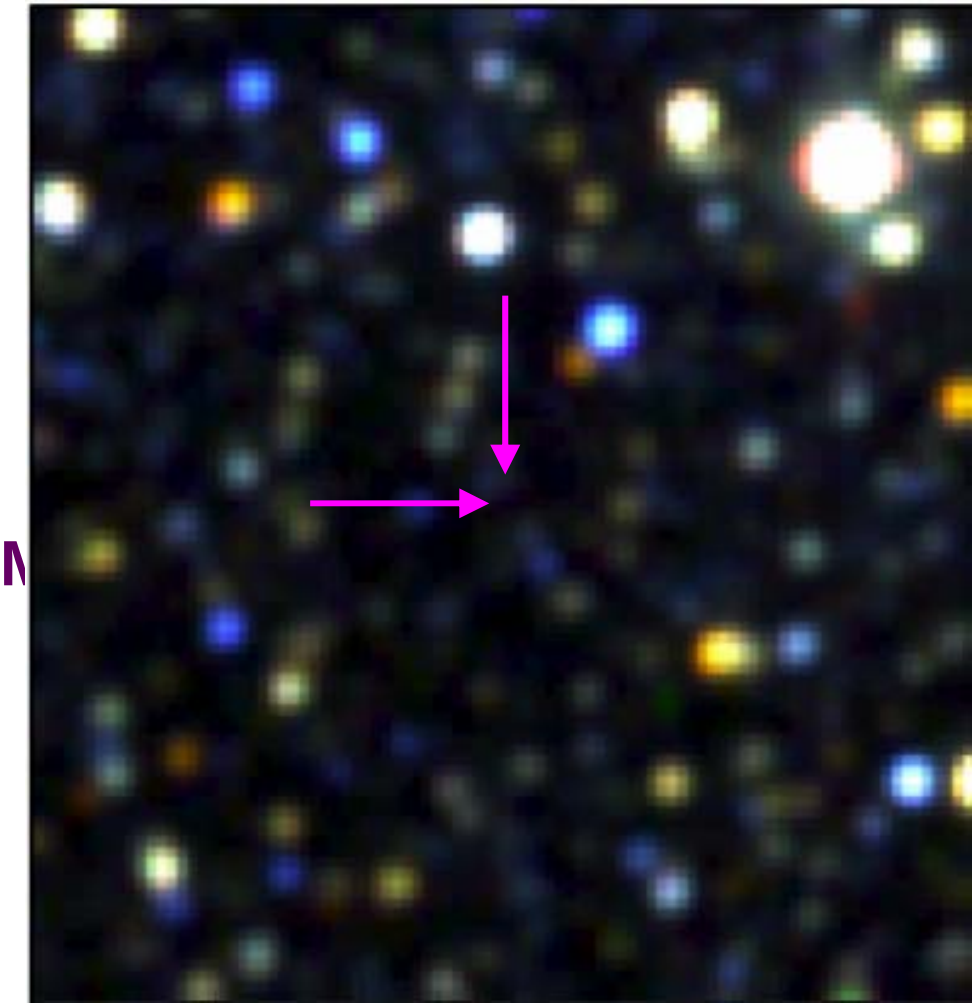
- **Not seen with VLA or 2MASS**

→ **Not a star**

- **No detection of optical pulsations with ULTRACAM (Dhillon et al. 2006)**

α < -0.7 (α = -0.2 for Crab)

→ **not `giant' pulses?**



2MASS *Image*