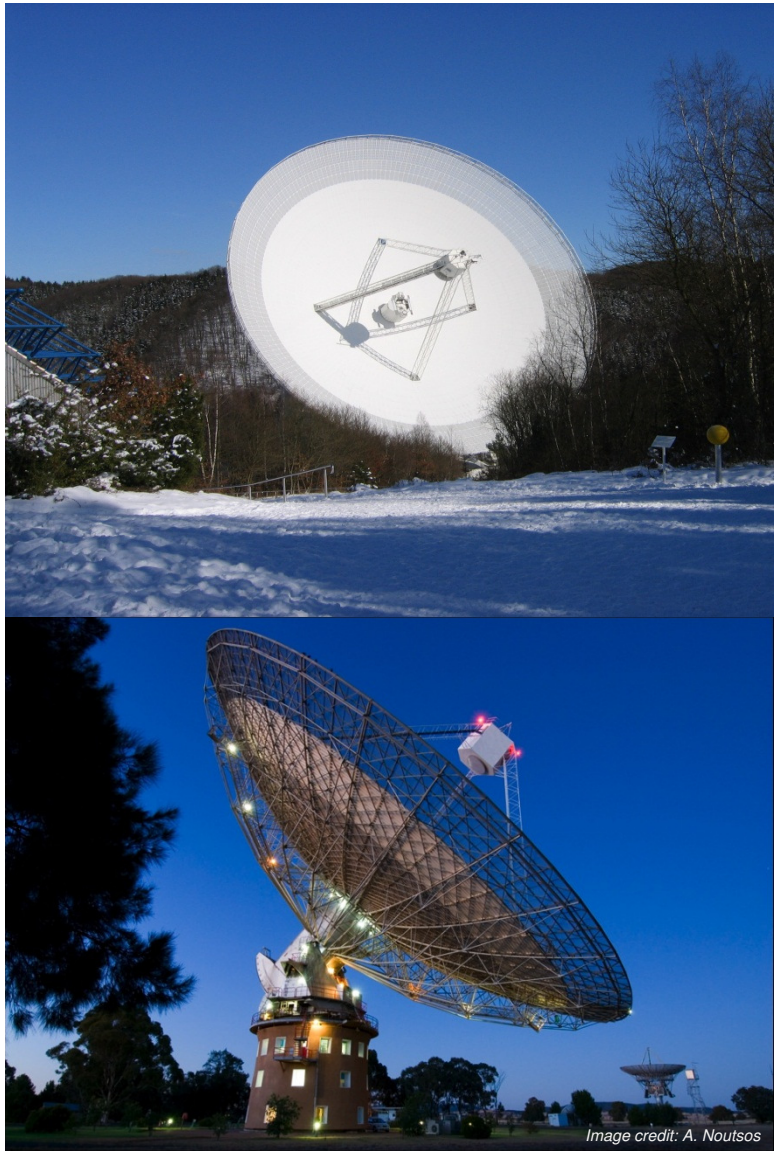
IAU 2012 – Symposium 291 Neutron Stars and Pulsars



The all-sky High Time Resolution Universe Pulsar Survey (HTRU)

Part II. More highlight discoveries & binary search

Cherry Ng
August 20th 2012

Supervisors: Michael Kramer, David Champion
Max-Planck-Institut für Radioastronomie

On behalf of the HTRU consortium (Max-Planck-Institut für Radioastronomie, Swinburne University of Technology, the University of Manchester, the INAF-Osservatorio Astronomico di Cagliari, and CSIRO

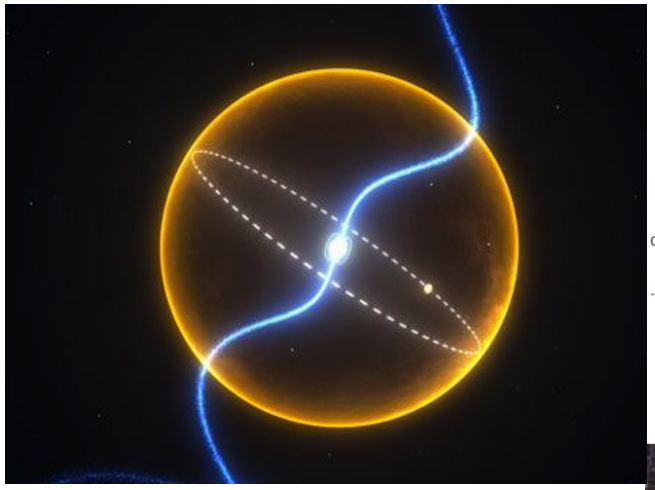
MAX-PLANCK-GESELLSCHAFT

Max-Planck-Institut für Radioastronomie

IMPRS astronomy & astrophysics Bonn and Cologne

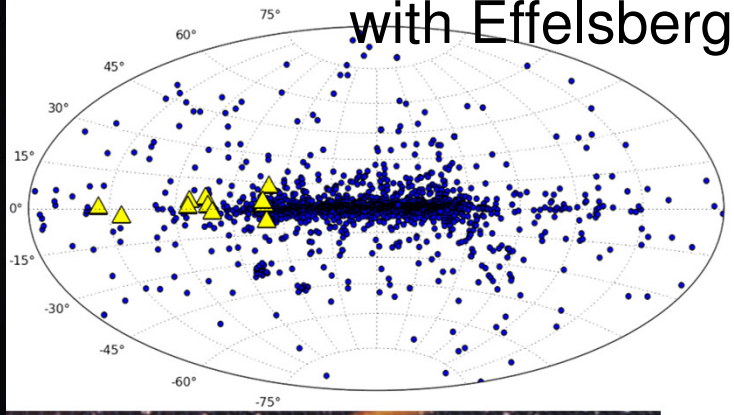
Outline

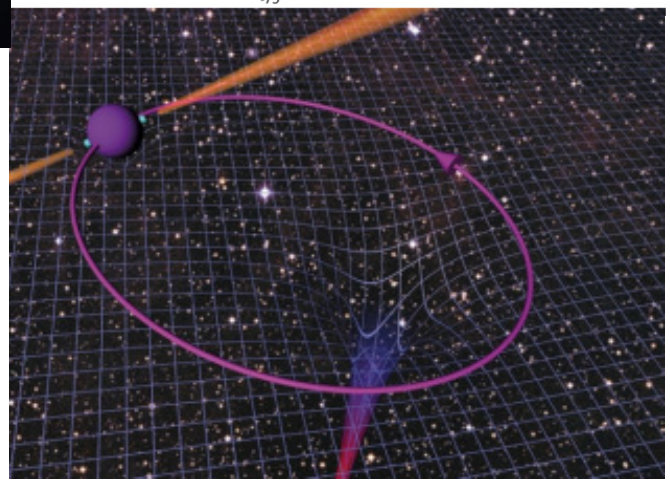
More HTRU discoveries and highlights:



"Planet-pulsar" binaries

HTRU Northern survey with Effelsberg Telescope





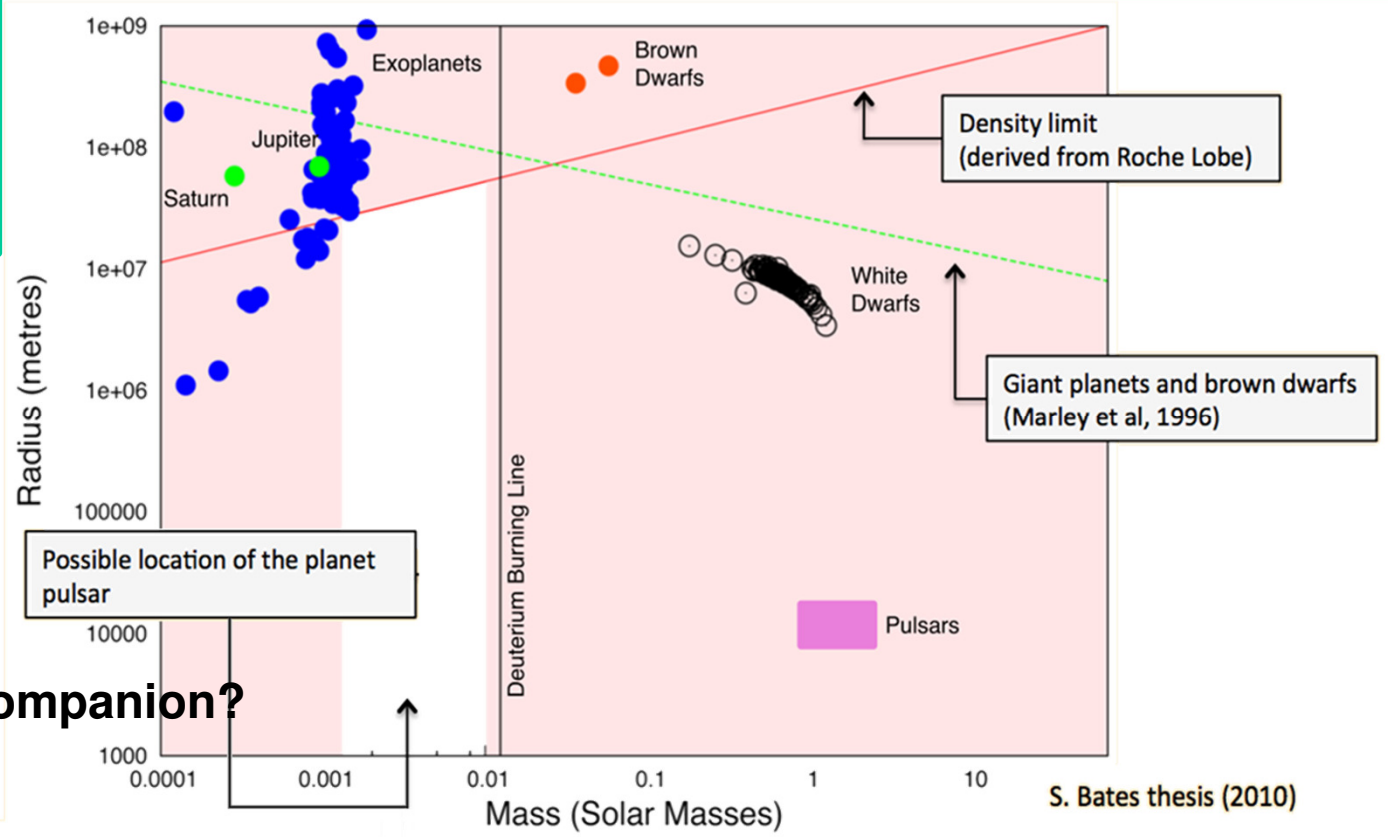
Efforts in Galactic plane binary search

HTRU highlights: Planet-pulsar J1719-1438

J1719-1438

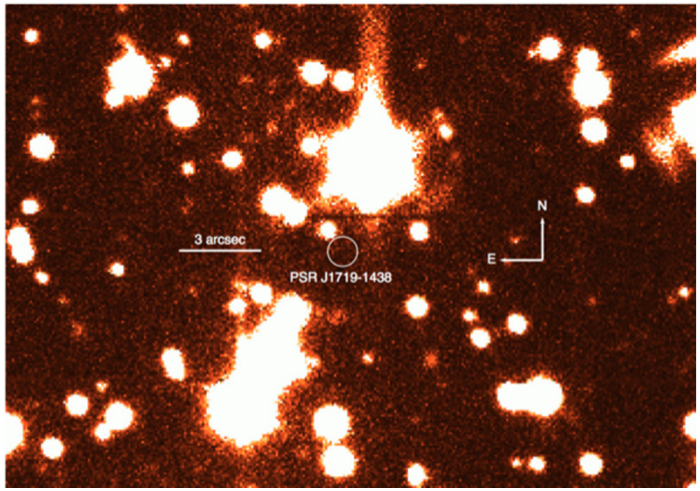
- P_{spin} = 5.7 ms
- d = 1.2(3) kpc
- P_{orb} = 0.09 days
- a sin *i* = 0.0018 lt-s
- $m_{comp} \geq 0.00115 M_{\odot}$
- $\rho_{comp} > 23$ g/cm^3

- Mass comparable to Jupiter (~ 1.2 M_J)
- Density much higher (ρ_J<2 g/cm^3) → Not a planet
- No evidence solid-body eclipses → Not "black widow" MSP



But what is it this companion?

HTRU highlights: Planet-pulsar J1719-1438



- Keck 10-m telescope (g, R, I bands)
- No optical detection

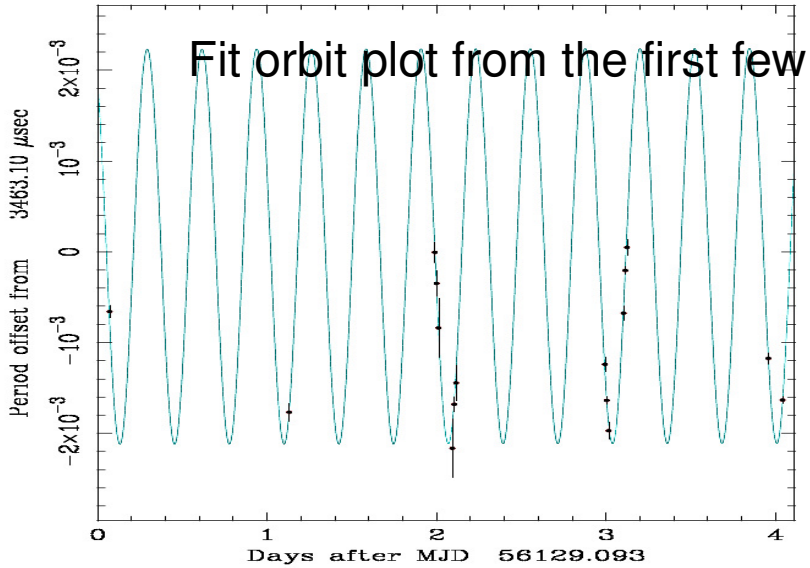
→ Diamond planet !

- Companion likely to be Carbon WD that has lost 99+% mass
- Remains of degenerate core
- Ultracompact (UC) LMXB potential progenitor?
- Bailes et al. (Science Express 25 Aug 2011 *science.1208890)*

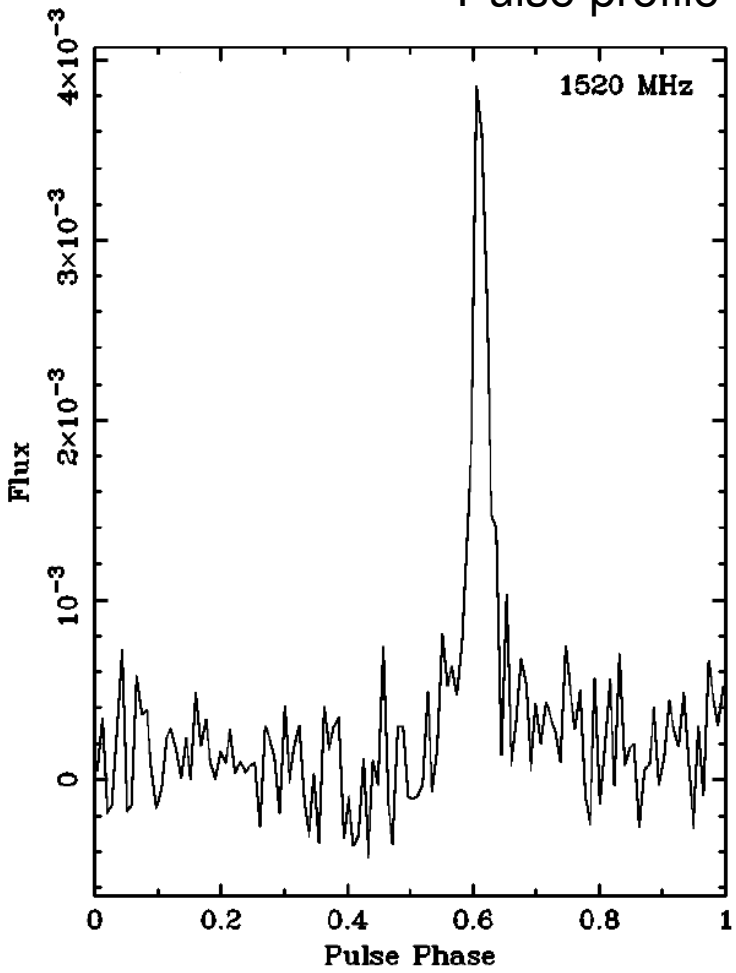
HTRU highlights: Planet-pulsar (Another one!)

J1719-1438	**"Planet-pulsar" nº 2**
• P_{spin} = 5.7 ms	→ P_{spin} = 3.46 ms
• d = 1.2(3) kpc	→ d = 0.313 kpc
• P_{orb} = 0.09 days	→ P_{orb} = 0.32 days
• a sin *i* = 0.0018 lt-s	→ a sin *i* = 0.002 lt-s
• $m_{comp} \geq 0.00115 M_{\odot}$	→ $m_{comp} \geq 0.00076\ M_{\odot}$
• ~ 1.2 M_{Jovian}	→ ~ 0.8 M_{Jovian}

Fit orbit plot from the first few days



Pulse profile

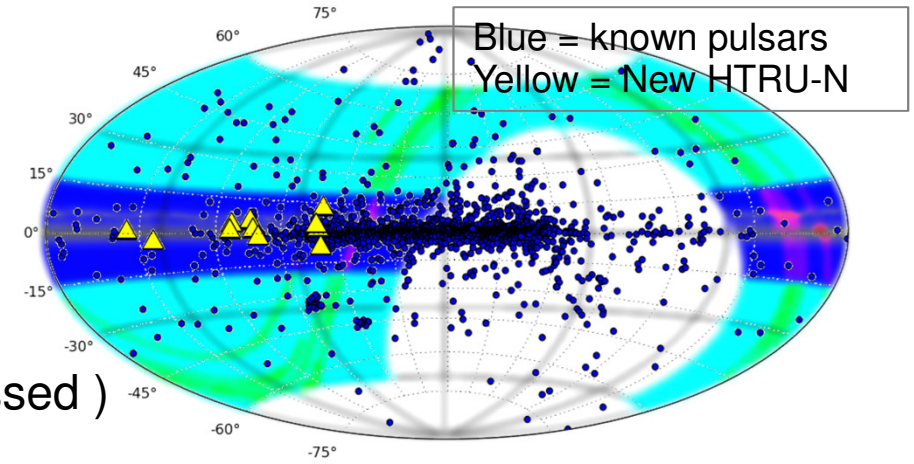


D. Thornton et al (in prep 2012)

HTRU Northern Survey

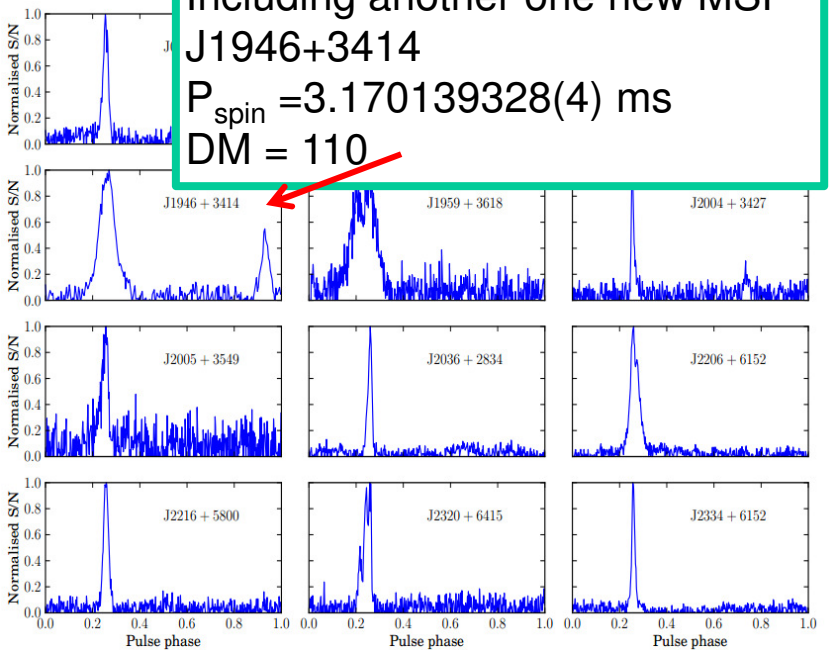
HTRU-North:

- Effelsberg pilot observations in 2009
- Jan 2010 Effelsberg´s first ever MSP
- Known pulsar re-detections: 93
- Up-to-date: 12 new Pulsars (~10% processed)



PSR	R.A. (hh:mm:ss.ss)	Decl. (° ′ ″)	Period (ms)	Period derivative (s/s)	Dispersion measure (pc cm^{-3})
J0325+5239	03:24:55	+52:39:37	336.62		119
J0425+4936	04:26:06.82(1)	+49:33:38.3(1)	922.47389507(2)	$3.934(4)(1) \times 10^{-14}$	89
J1913+3733*	19:13:27	+37:32:12	815.07		70
J1946+3414*	19:46:24	+34:14:16	3.170139328(4)		110
J1959+3618*	19:59:38	+36:20:26	406.08117(1)		273
J2004+3427*	20:04:34	+34:27:36	240.95		351
J2005+3549*	20:05:26	35:49:04	307.95		445
J2036+2834*	20:36:46	+28:35:10	1358.72672(1)	$2.0(1) \times 10^{-15}$	99
J2206+6152	22:06:23	+61:51:55	322.67		167
J2216+5800	22:16:05.92(5)	+57:59:54(1)	419.100708(3)	$6.900(3) \times 10^{-14}$	176
J2320+6415	23:18:58	+64:15:28	216.01828(3)		247
J2334+6152	23:33:19.46(2)	+61:45:30.0(4)	756.899355(2)	$1.17(2) \times 10^{-15}$	98

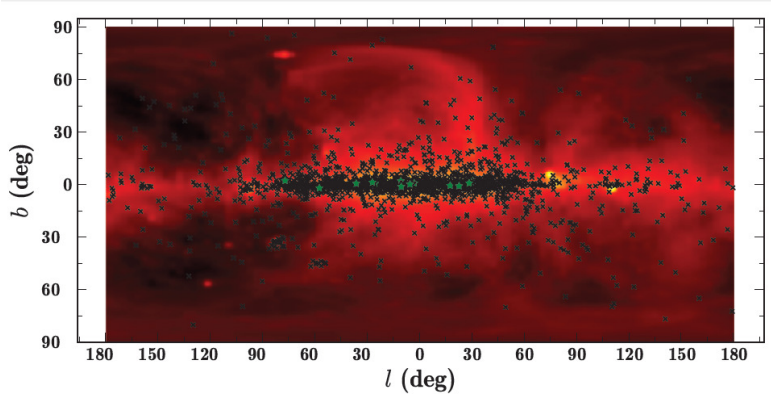
Including another one new MSP
J1946+3414
P_{spin} =3.170139328(4) ms
DM = 110



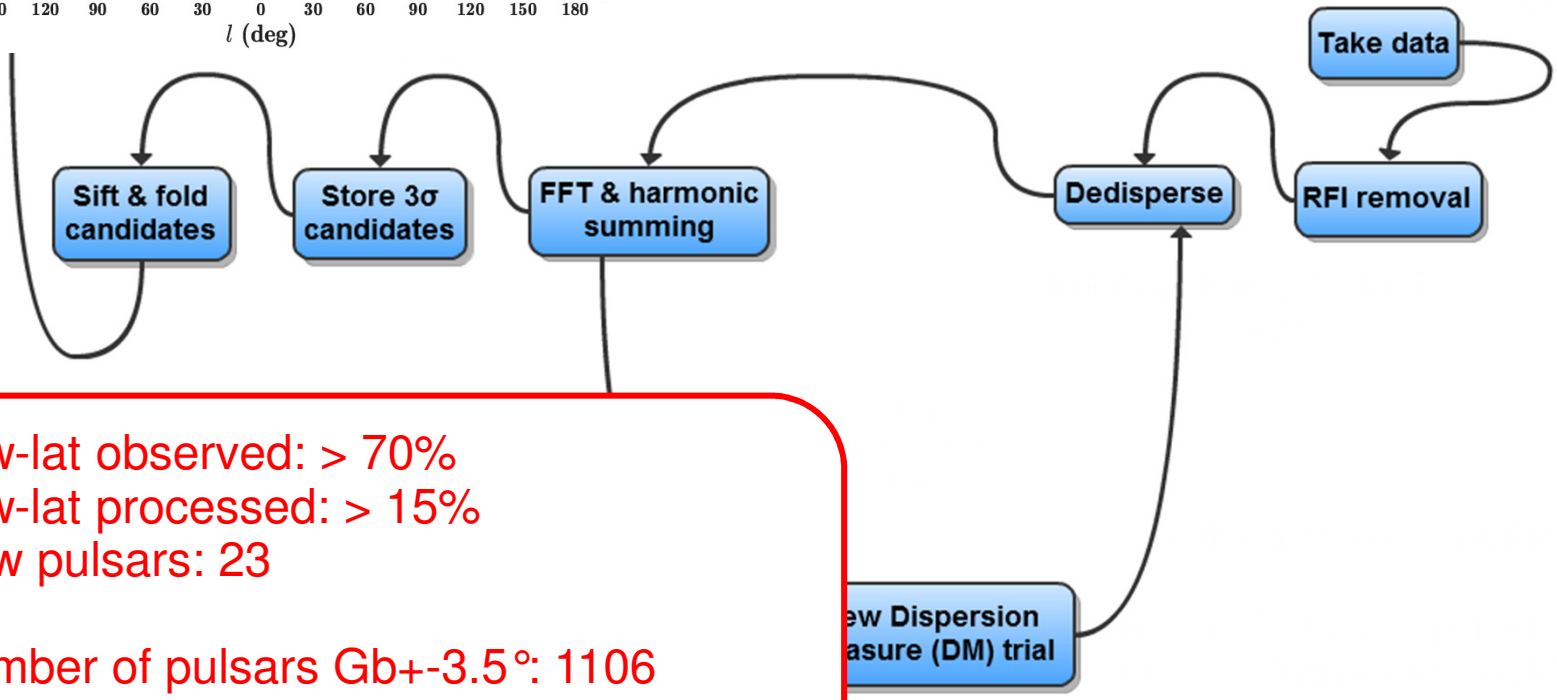
- Extrapolated new pulsars ~100 (med-lat)
- Population simulation for full HTRU-N:
  - ~ 500 new normal pulsars
  - ~ 40 new MSPs

E. Barr et al (in prep 2012)

Standard search - Discoveries



72-min integration, deepest search ever in the Galactic Plane



Low-lat observed: > 70%
Low-lat processed: > 15%
New pulsars: 23

Number of pulsars Gb+-3.5°: 1106
Pulsars re-detected: 171 (256 detection)
Expected new pulsars from low-lat: 130!

Galactic Plane Search for Binary Pulsars

Complications in binaries search:

- Pulsar in binary orbit, accelerated:

  → Periods:1.6 hr – several days

- Periodic changes in pulse frequency

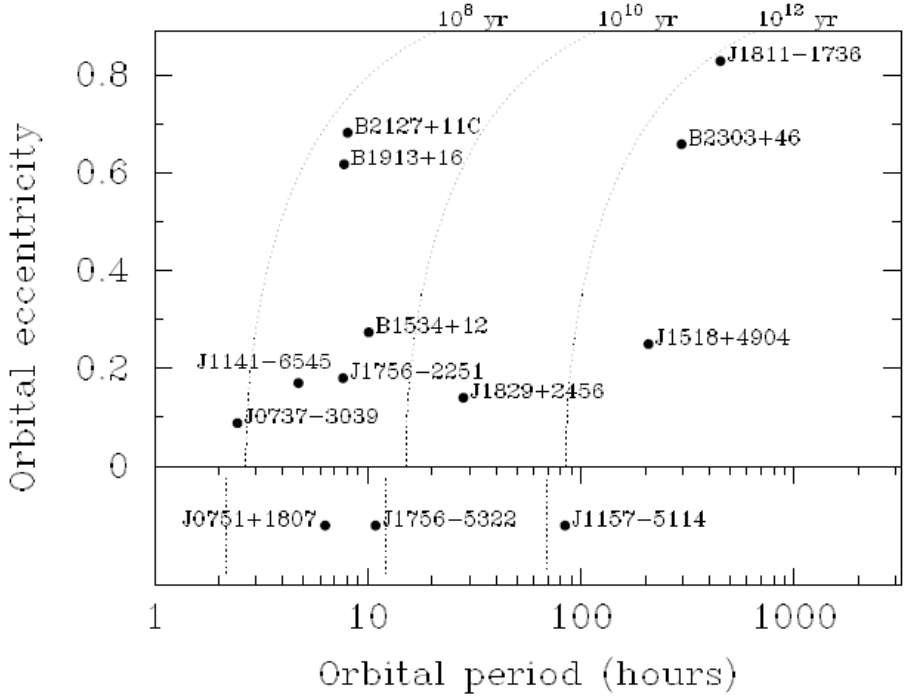
  → Doppler Effect

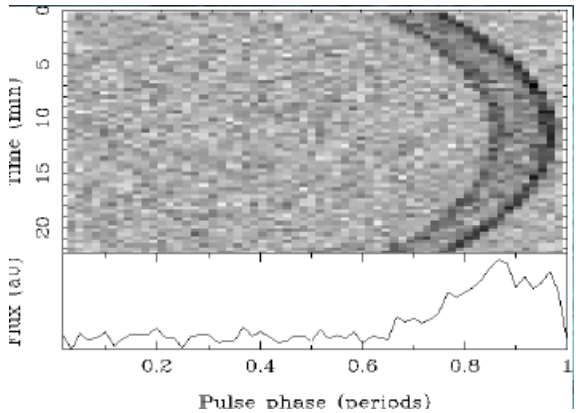
$$v_{app\ freq}(t) = v_{int\ freq}\left(1 - \frac{V(t)}{c}\right)$$

$$V(t) = V_0 + a_o t + \ldots..$$

- Fourier space search not sensitive to changing period

- Power smeared over no. of Fourier spectral bins → PSR less detectable





Galactic Plane Search for Binary Pulsars

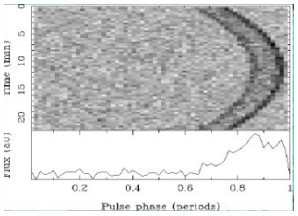
Solution: Acceleration Search

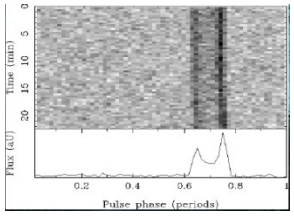
- Search in acc space to recover power
- If $T_{obs} \leq \frac{P_{orb}}{10}$ constant acc approx OK

$$v_{app\ freq}(t) = v_{int\ freq}\left(1 - \frac{V(t)}{c}\right)$$

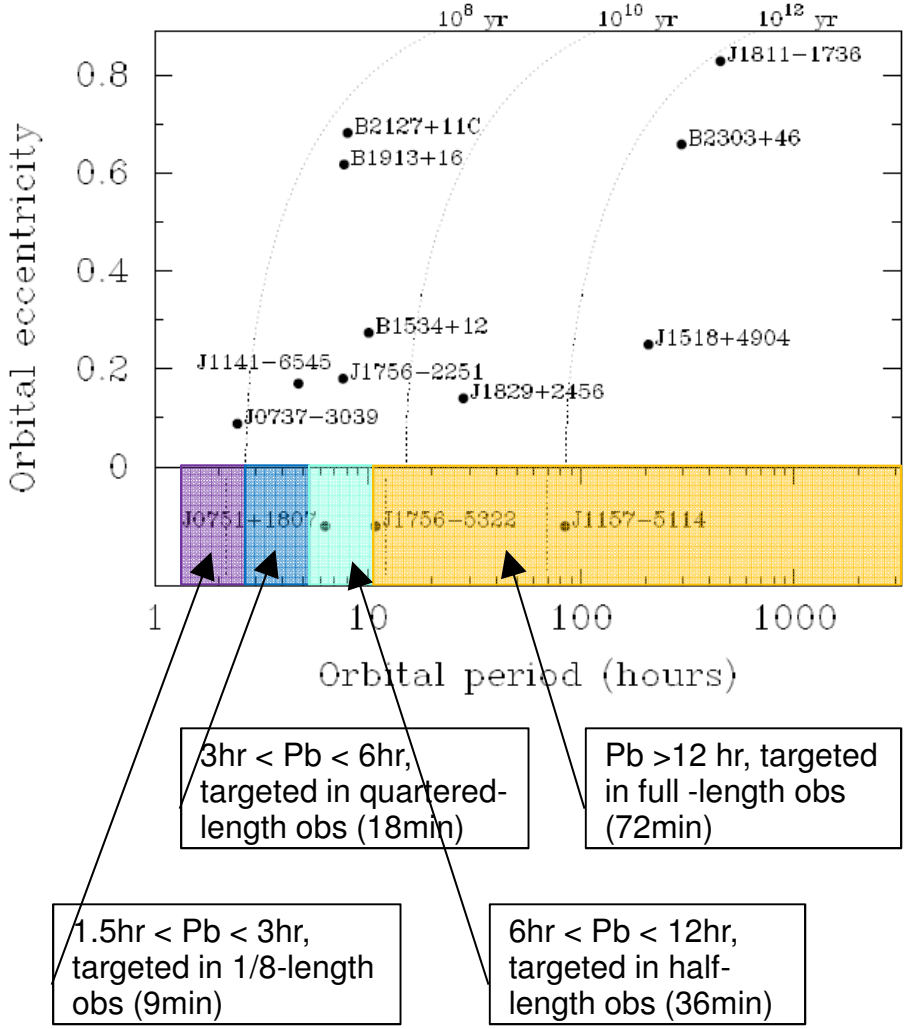
$$V(t) = V_0 + a_o t + \ldots..$$

- → Resample time series (Stretching and squashing time domain)

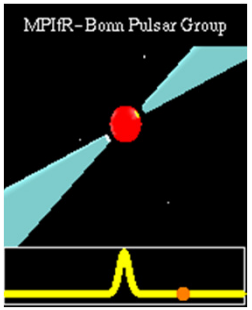




- Divide data into segments according to ranges of targeted orbital periods



Binary search - Sample pipeline



n-beams per pointing = 13
n-pointings total = 1230

Output: 6GB

Raw data: 17GB

Take data

Sift & fold candidates

Store 3σ candidates

FFT & harmonic summing

Remove acceleration

Dedisperse

RFI removal

Intermediate products: 12GB

New acceleration trial

New Dispersion Measure (DM) trial

Challenges in file sizes:

Raw data: 17x13x1230 = 265 TB
Intermediate product: 12x13x1230 = 187TB
Output storage: 6x13x1230 = 94TB

Challenges in computing time:

n-FFT: 1584134 operations
Processing per beam:140hr CPU
Total: 140x13x1230 = 255.5 years

Binary search - Computing resources

CAASTRO
ARC **C**entre of Excellence for **A**ll-sky **Astro**physics
Awarded 0.5 million CPU hours

Jordell Bank –
HYDRA Pulsar Searching
Cluster ~ 1200 CPUs

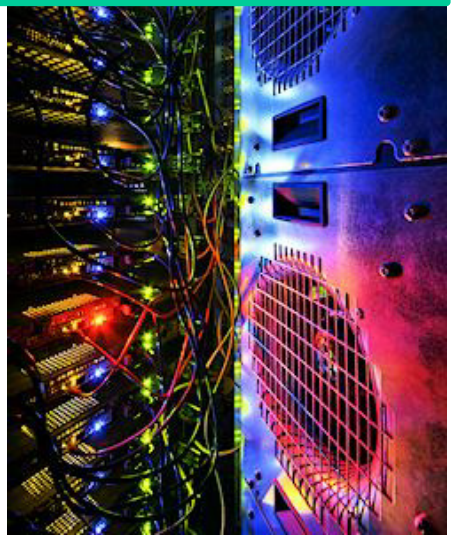


Image credit: The University of Manchester

Miraculix at mpifr
64 CPUs

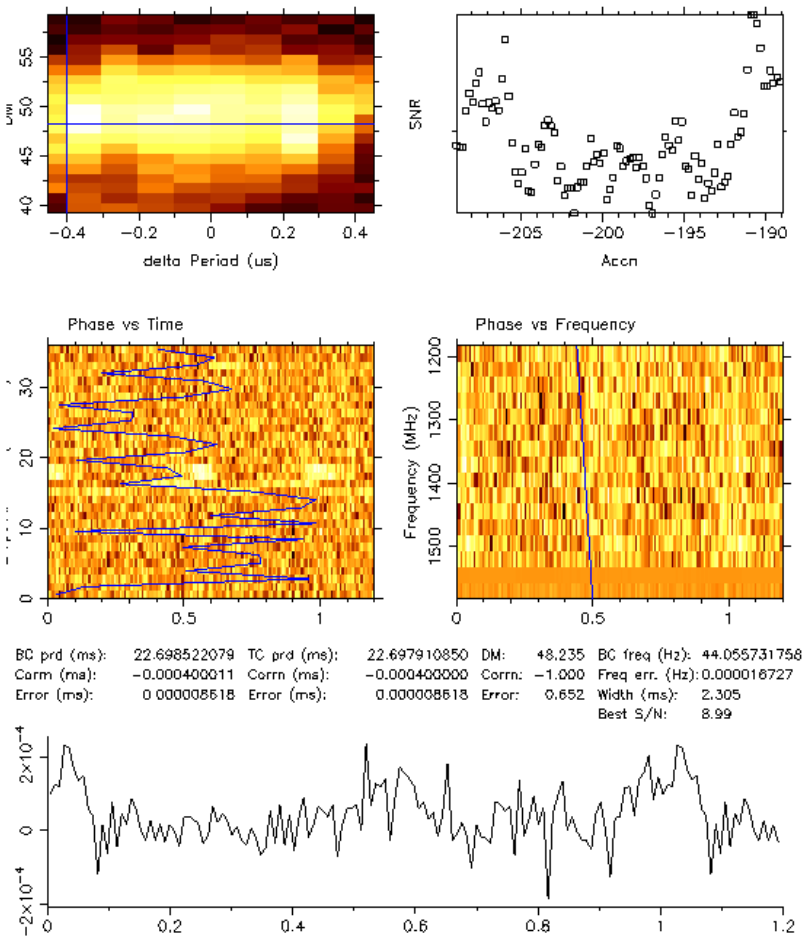
Green Machine, Swinburne
145 nodes, 2 quad-core CPUs

Hannover ATLAS computer
cluster ~ 8000 CPU

Forschungszentrum
Jülich, Germany

Binary search – Test results with J0737-3039A

Blind search pipeline:
Segment 1/2 (T_{obs} = 2150s)



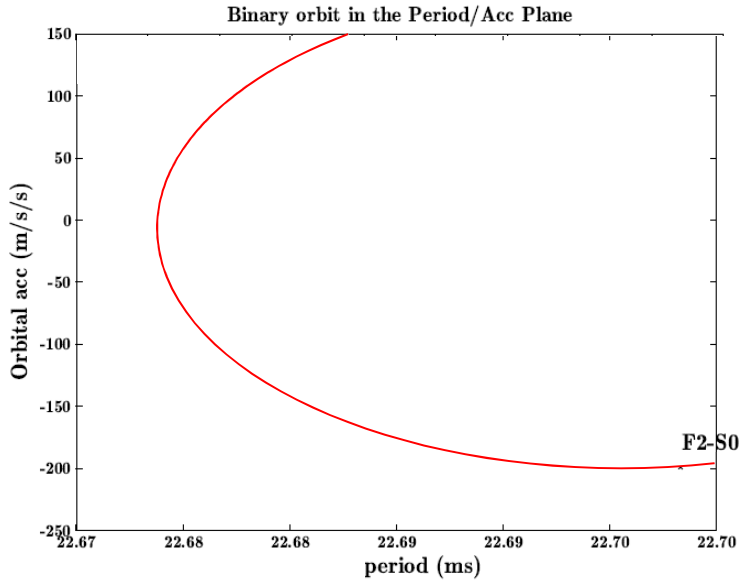
Double pulsar J0737-3039A

Spin period: 22.6993786 ms

Eccentricity: 0.0877775 (approx circular)

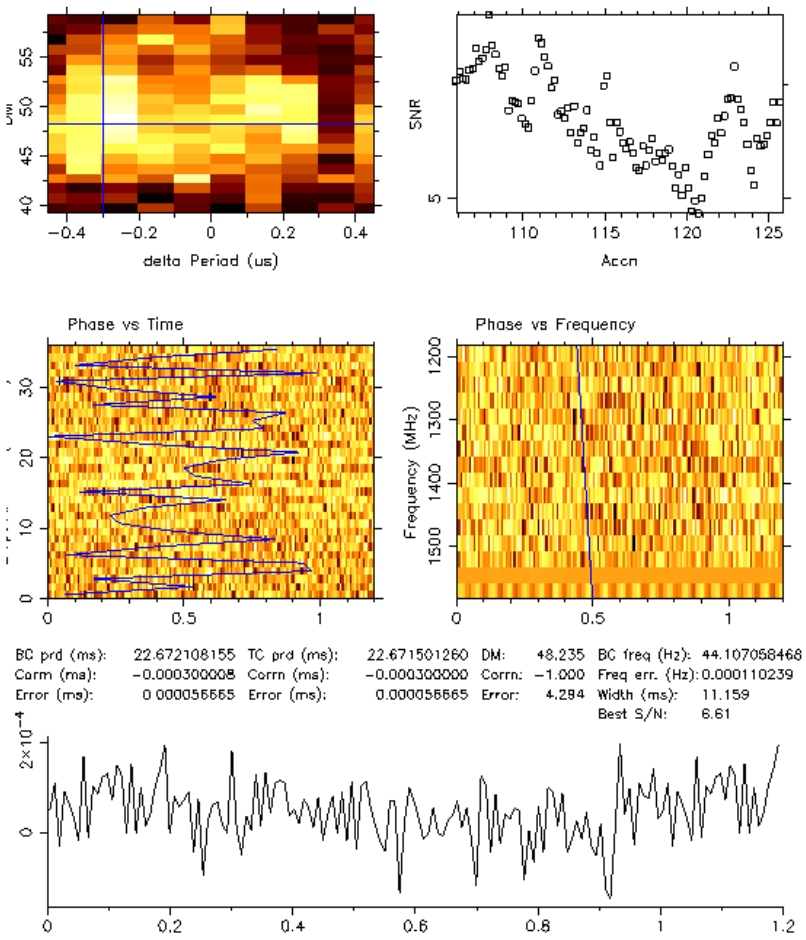
Orbital period (P_{orb}) = 2.4hr

Const. acc OK if: $T_{obs} \leq \frac{2.4hr}{10} \leq 864s$



Binary search – Test results with J0737-3039A

Blind search pipeline:
Segment 2/2 (T_{obs} = 2150s)



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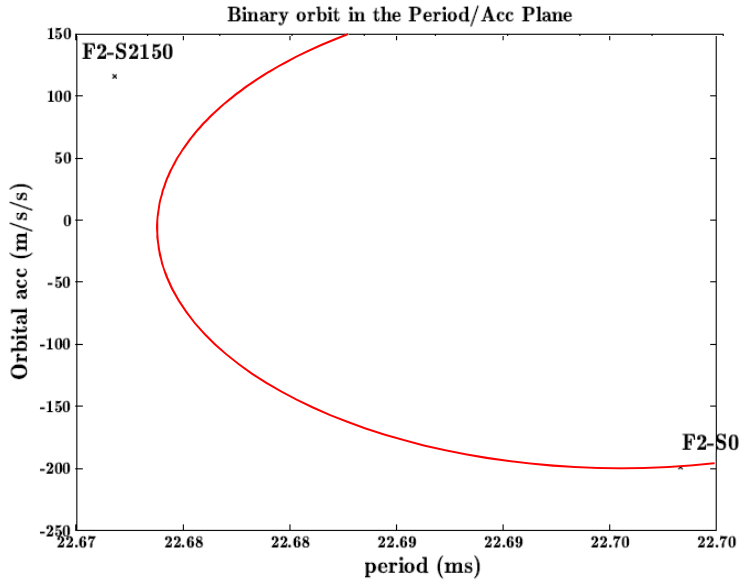
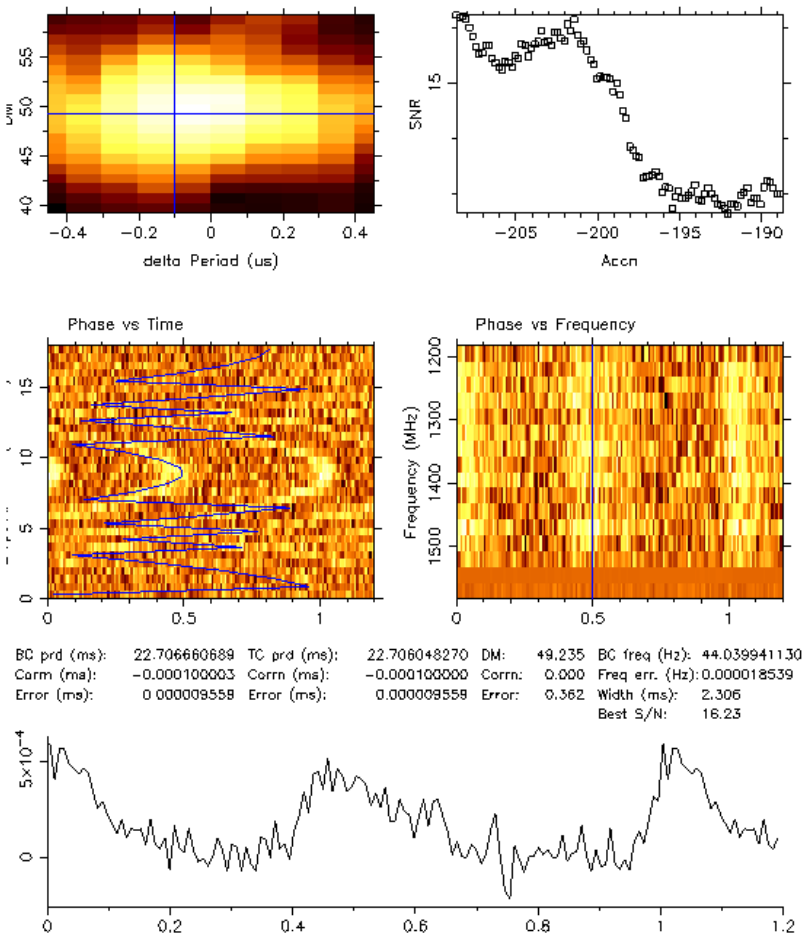


Binary search – Test results with J0737-3039A

Blind search pipeline:
Segment 1/4 (T_{obs} = 1075s)



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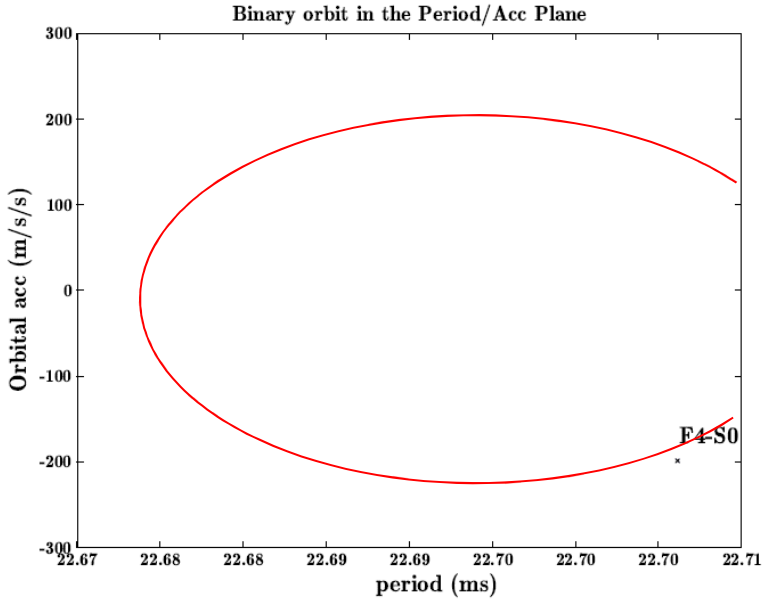
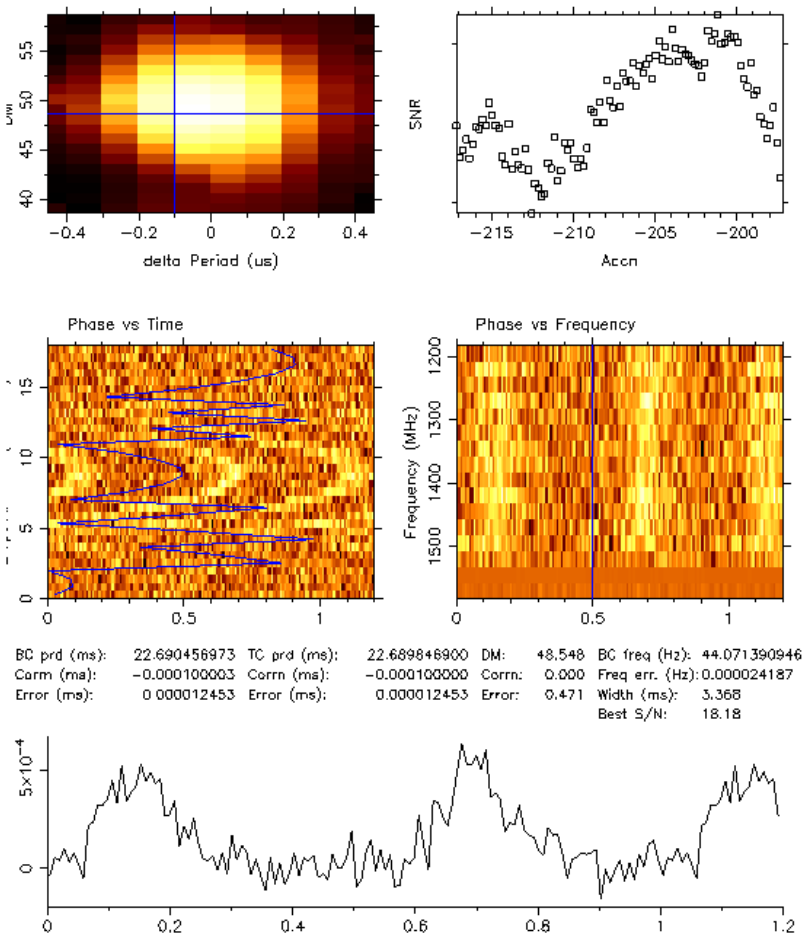


Binary search – Test results with J0737-3039A

Blind search pipeline:
Segment 2/4 (T_{obs} = 1075s)



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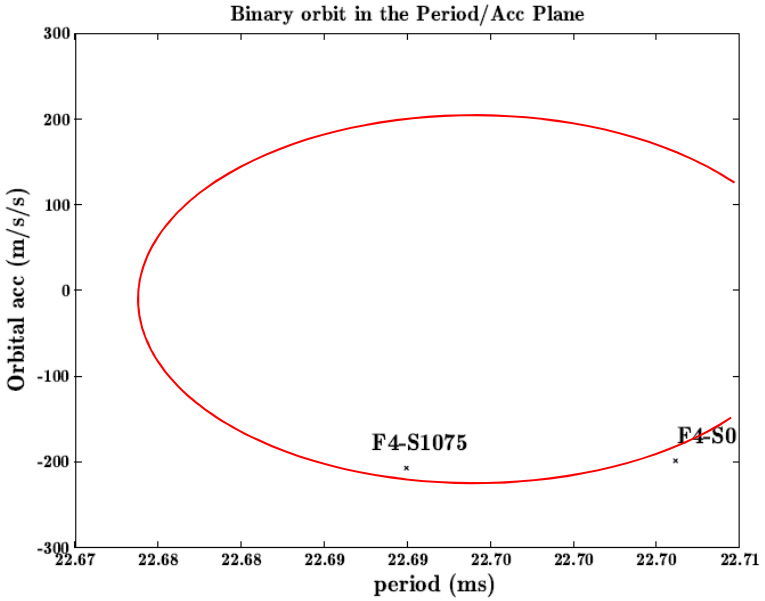
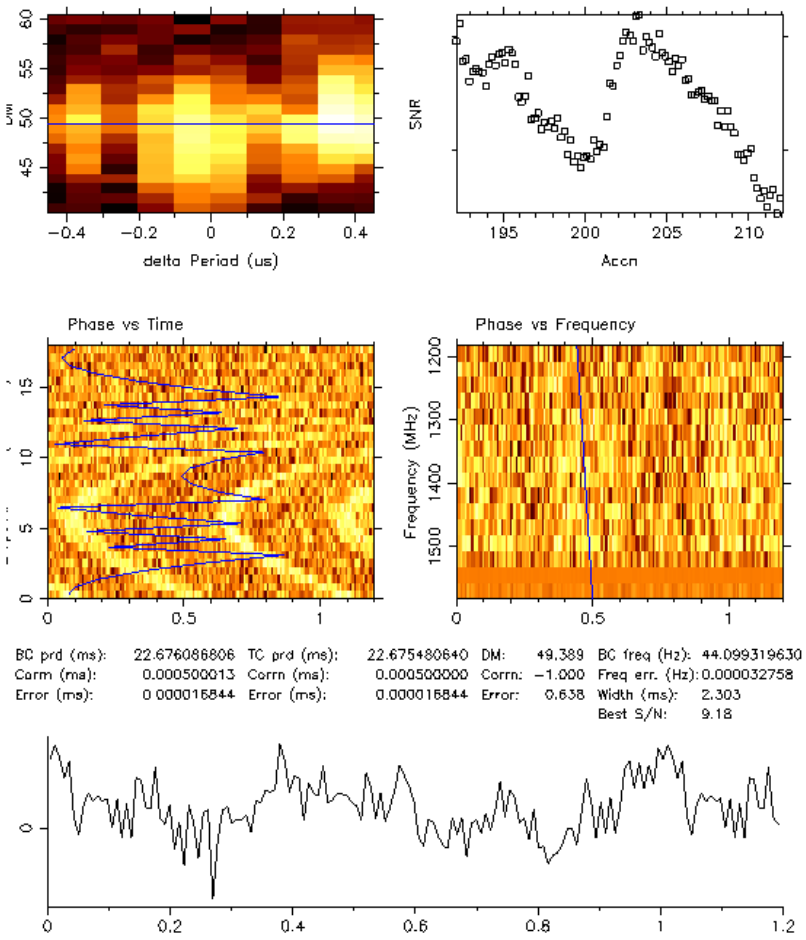


Binary search – Test results with J0737-3039A

Blind search pipeline:
Segment 4/4 (T_{obs} = 1075s)



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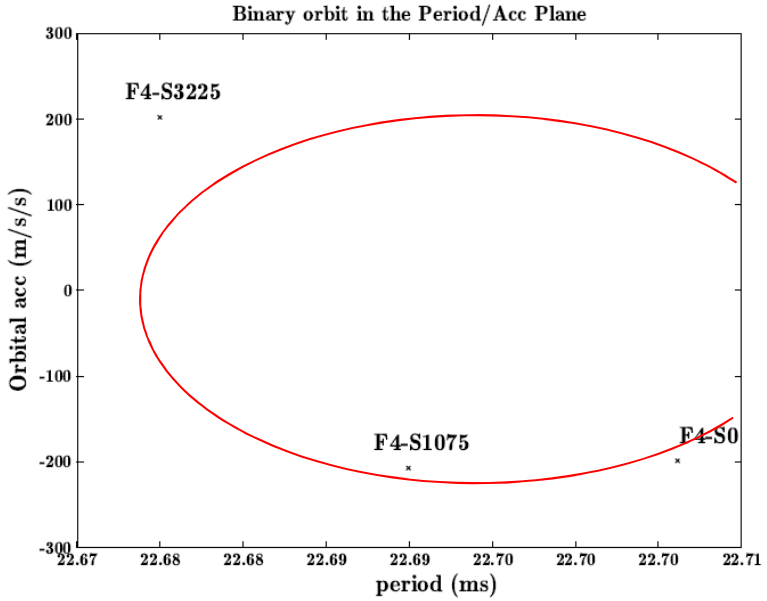
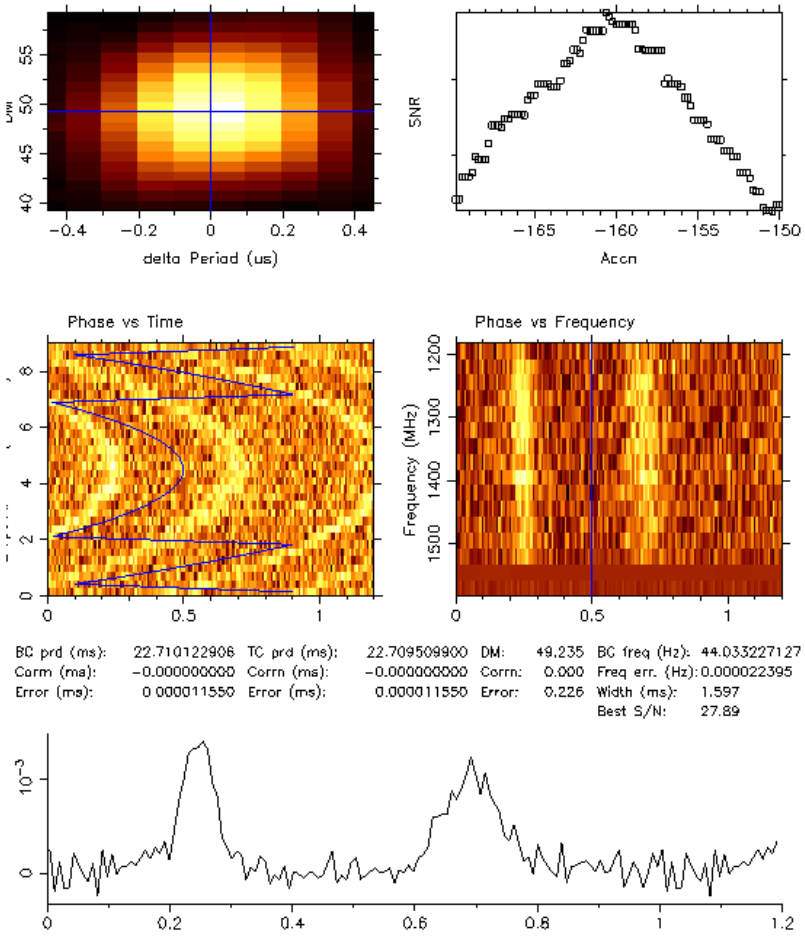
Const. acc OK if: $T_{obs} \leq \frac{2.4hr}{10} \leq 864s$



Binary search – Test results with J0737-3039A

Blind search pipeline:
Segment 1/8 (T_{obs} = 537s)



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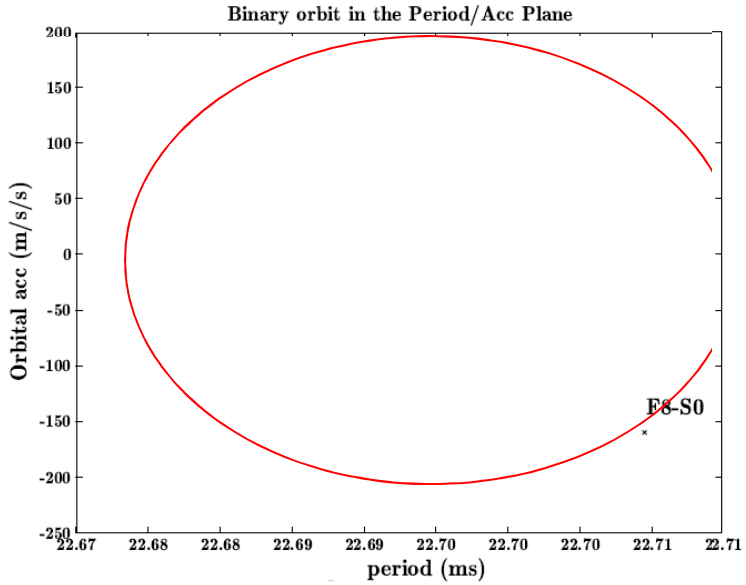
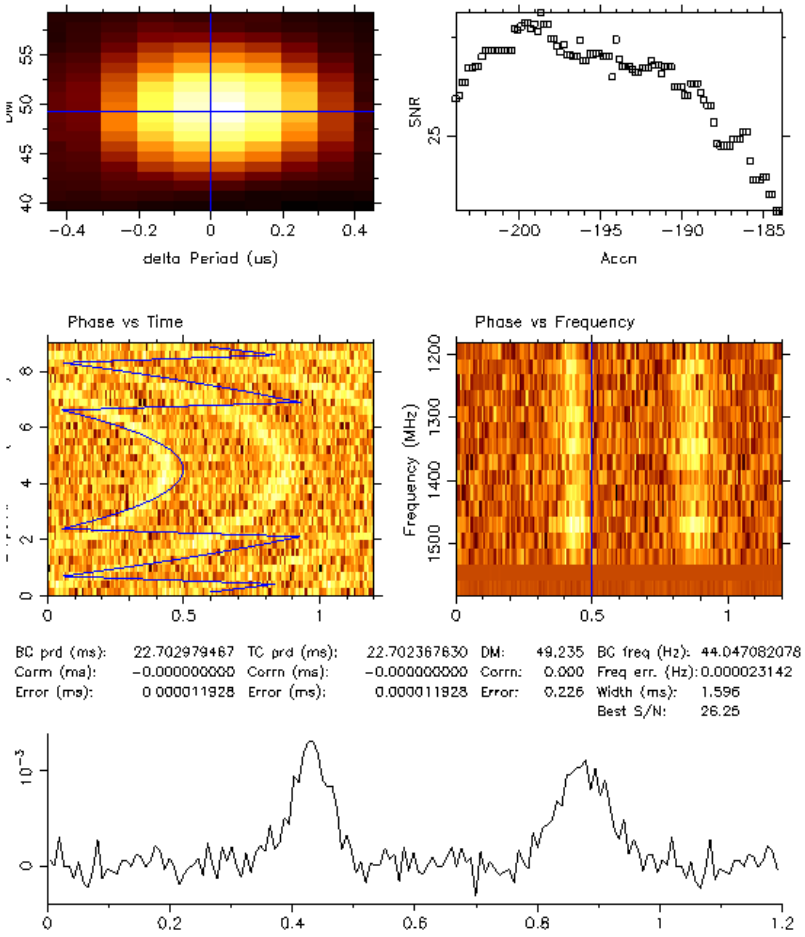


Binary search – Test results with J0737-3039A

Blind search pipeline:
Segment 2/8 (T_{obs} = 537s)



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Eccentricity: 0.0877775 (approx circular)

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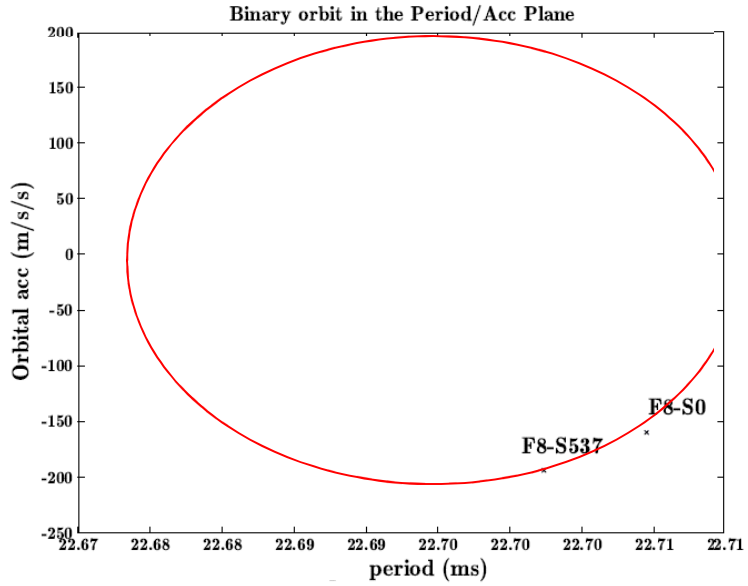
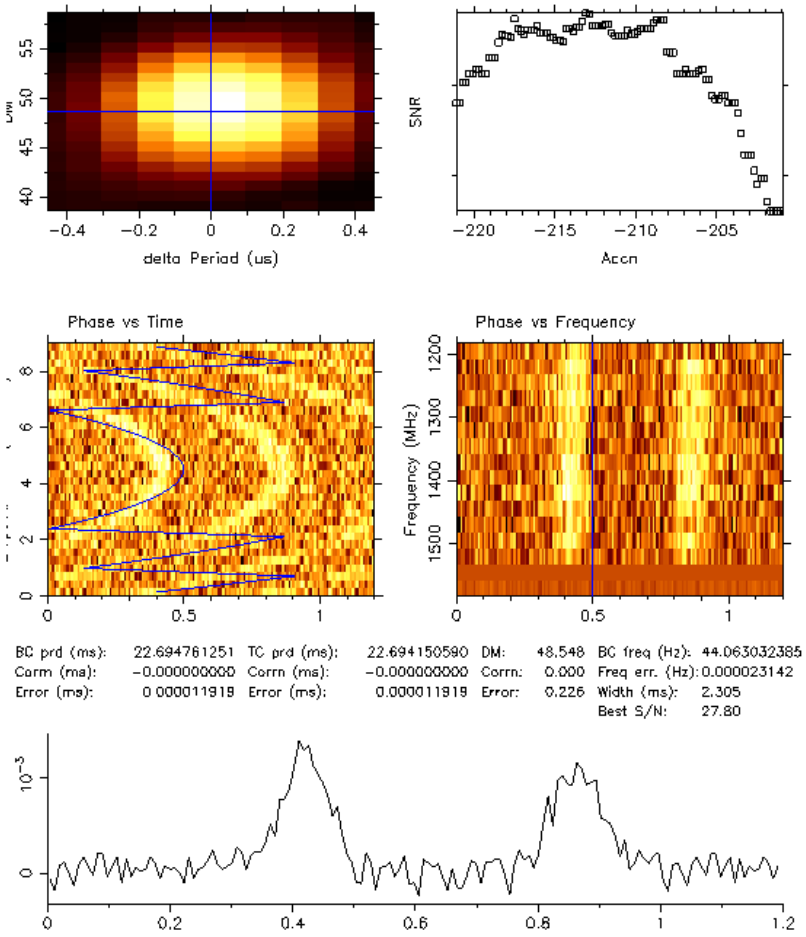
Const. acc OK if: $T_{obs} \leq \frac{2.4hr}{10} \leq 864s$



Binary search – Test results with J0737-3039A

Blind search pipeline:
Segment 3/8 (T_{obs} = 537s)



Double pulsar J0737-3039A

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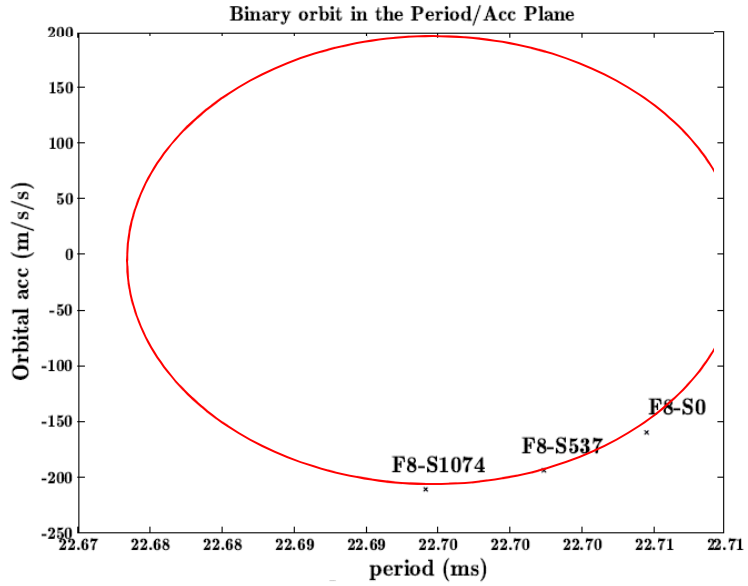
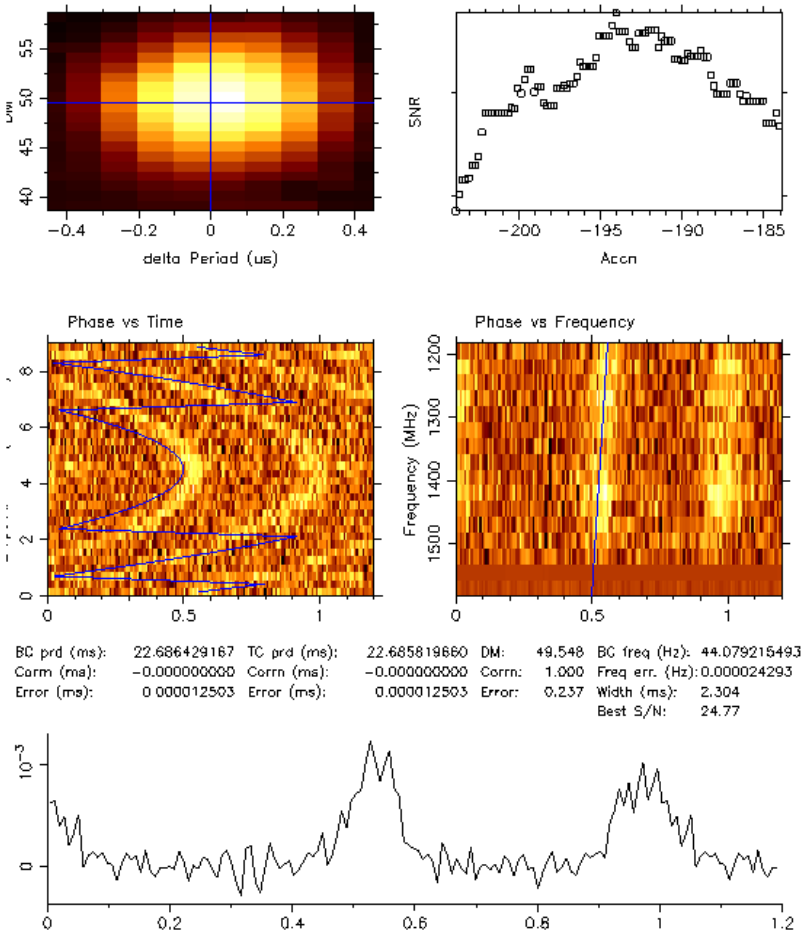
Const. acc OK if: $T_{obs} \leq \frac{2.4hr}{10} \leq 864s$



Binary search – Test results with J0737-3039A

Blind search pipeline:
Segment 4/8 (T_{obs} = 537s)



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Eccentricity: 0.0877775 (approx circular)

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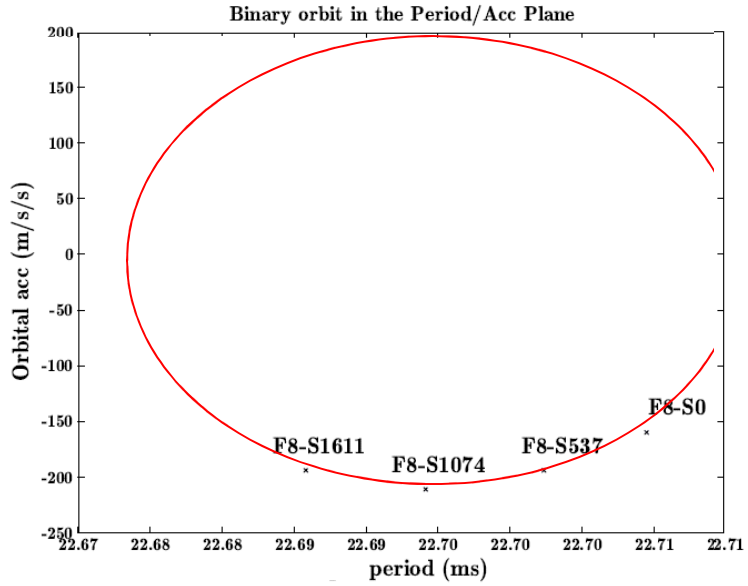
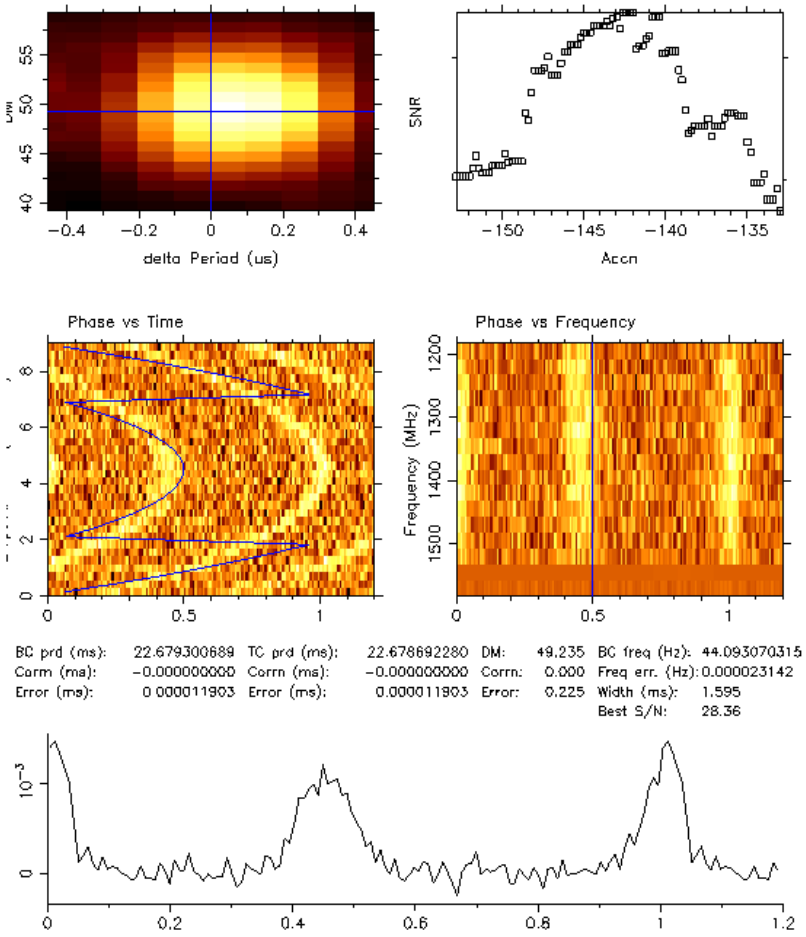
Const. acc OK if: $T_{obs} \leq \frac{2.4hr}{10} \leq 864s$



Binary search – Test results with J0737-3039A

Blind search pipeline:
Segment 5/8 (T_{obs} = 537s)



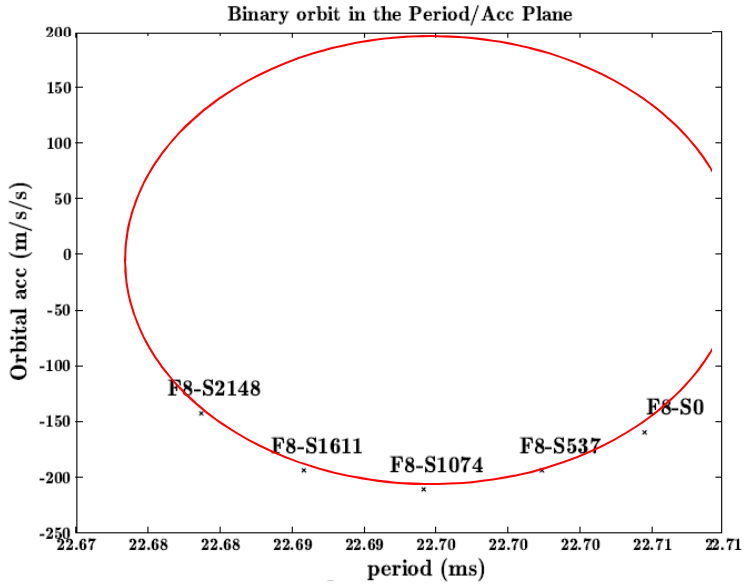
Double pulsar J0737-3039A

Spin period: 22.6993786 ms

Eccentricity: 0.0877775 (approx circular)

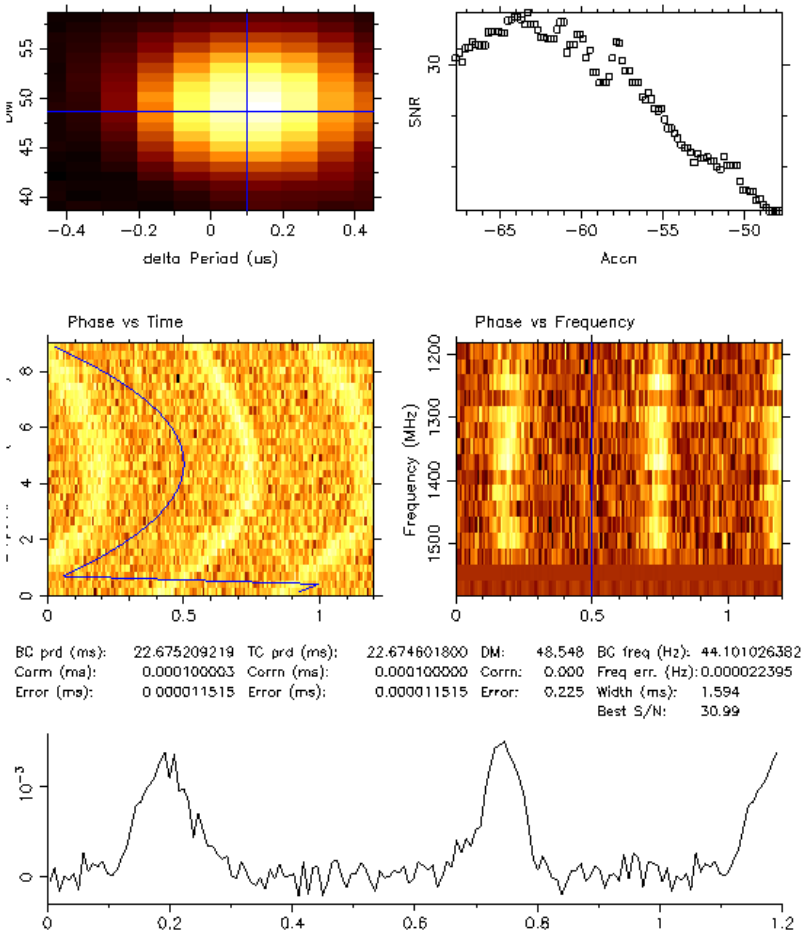
Orbital period (P_{orb}) = 2.4hr

Const. acc OK if: $T_{obs} \leq \frac{2.4hr}{10} \leq 864s$



Binary search – Test results with J0737-3039A

Blind search pipeline:
Segment 6/8 (T_{obs} = 537s)



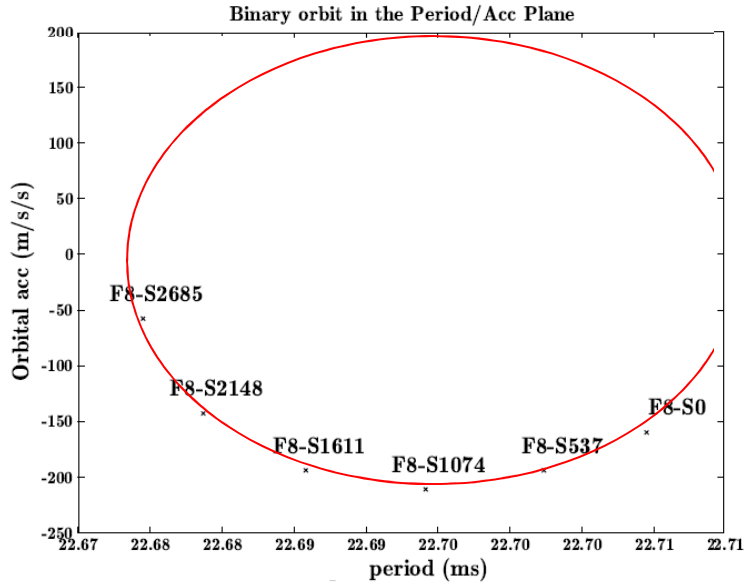
Double pulsar J0737-3039A

Spin period: 22.6993786 ms

Eccentricity: 0.0877775 (approx circular)

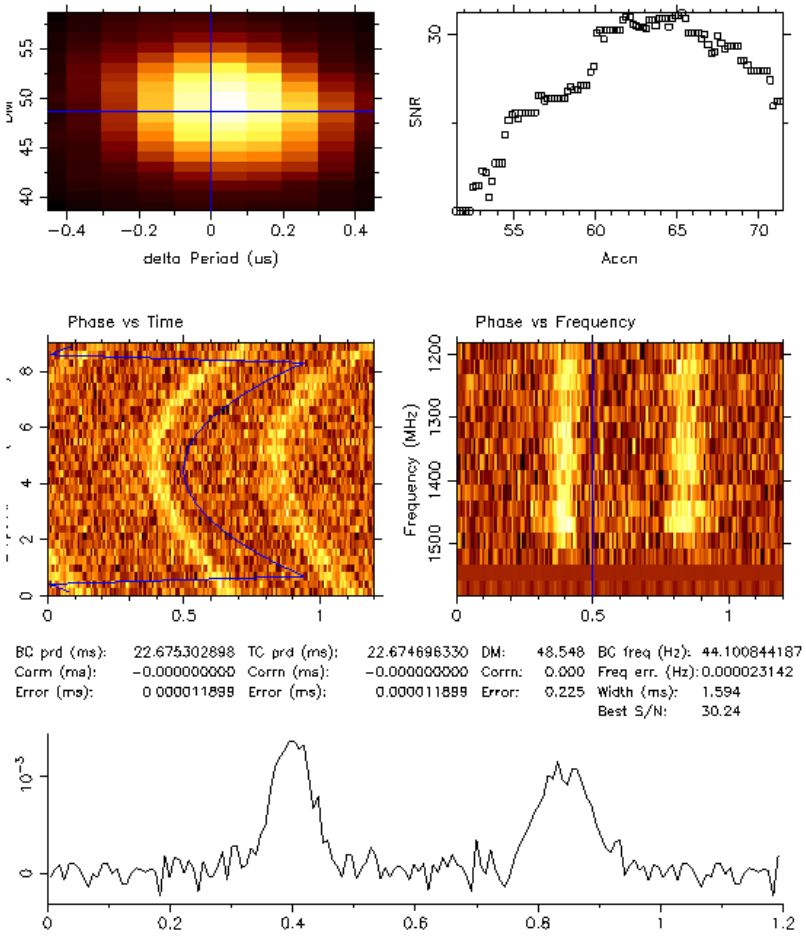
Orbital period (P_{orb}) = 2.4hr

Const. acc OK if: $T_{obs} \leq \frac{2.4hr}{10} \leq 864s$



Binary search – Test results with J0737-3039A

Blind search pipeline:
Segment 7/8 (T_{obs} = 537s)



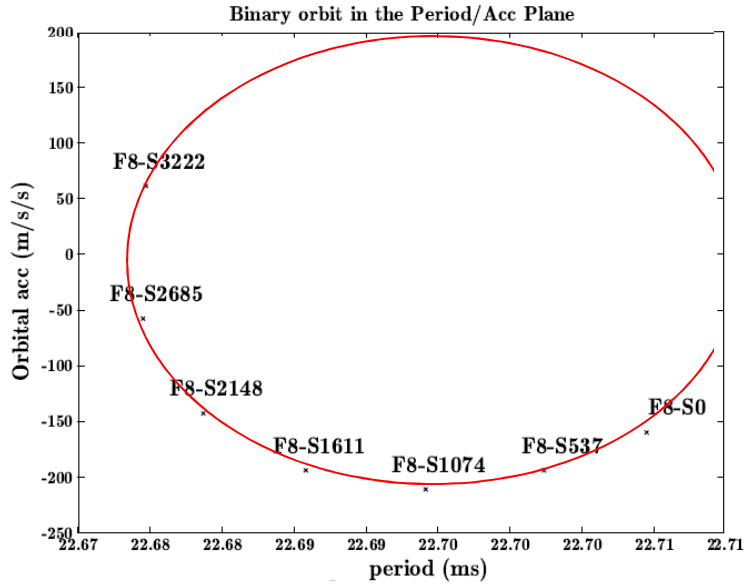
Double pulsar J0737-3039A

Spin period: 22.6993786 ms

Eccentricity: 0.0877775 (approx circular)

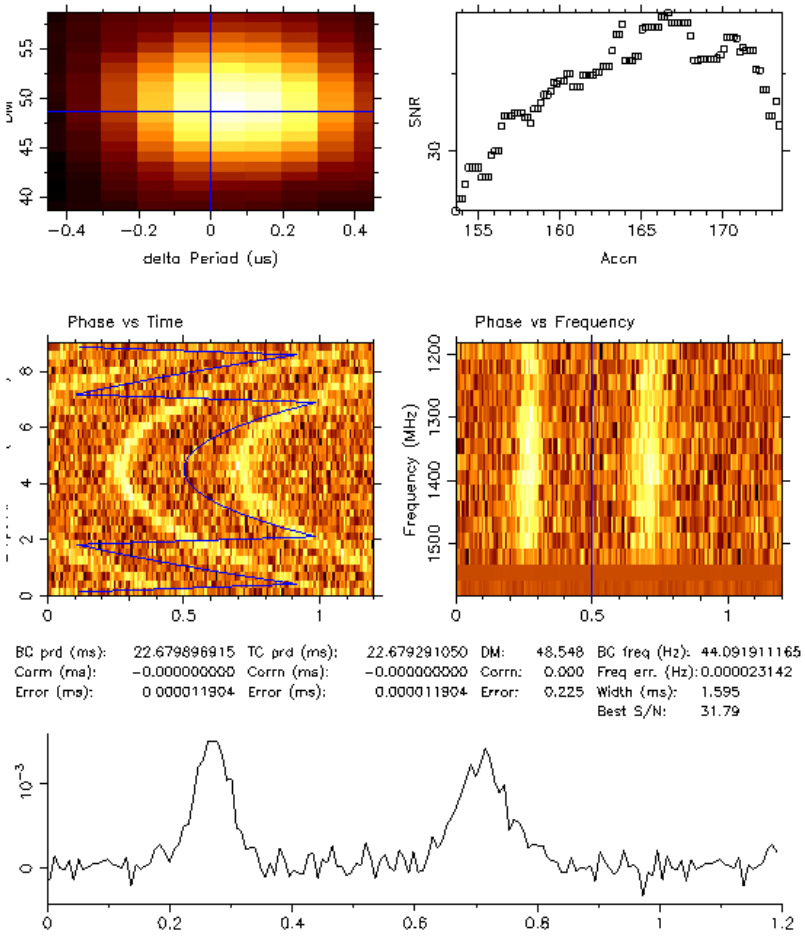
Orbital period (P_{orb}) = 2.4hr

Const. acc OK if: $T_{obs} \leq \frac{2.4hr}{10} \leq 864s$



Binary search – Test results with J0737-3039A

Blind search pipeline:
Segment 8/8 (T_{obs} = 537s)



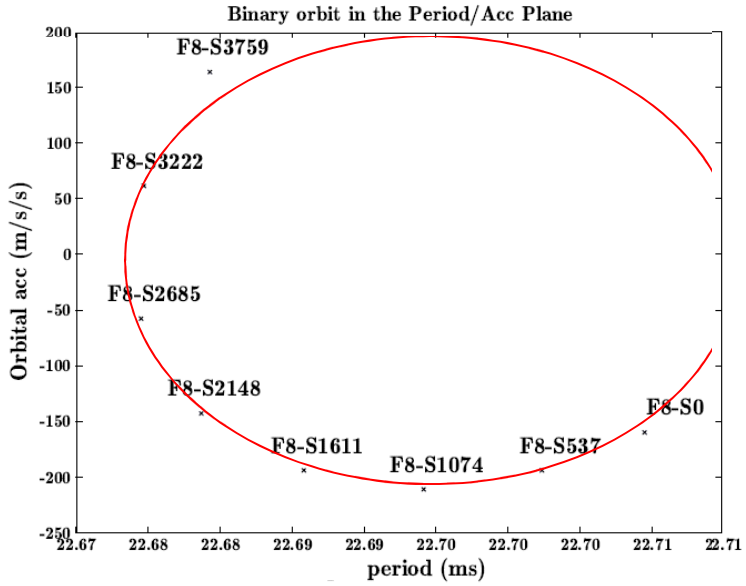
Double pulsar J0737-3039A

Spin period: 22.6993786 ms

Eccentricity: 0.0877775 (approx circular)

Orbital period (P_{orb}) = 2.4hr

Const. acc OK if: $T_{obs} \leq \frac{2.4hr}{10} \leq 864s$

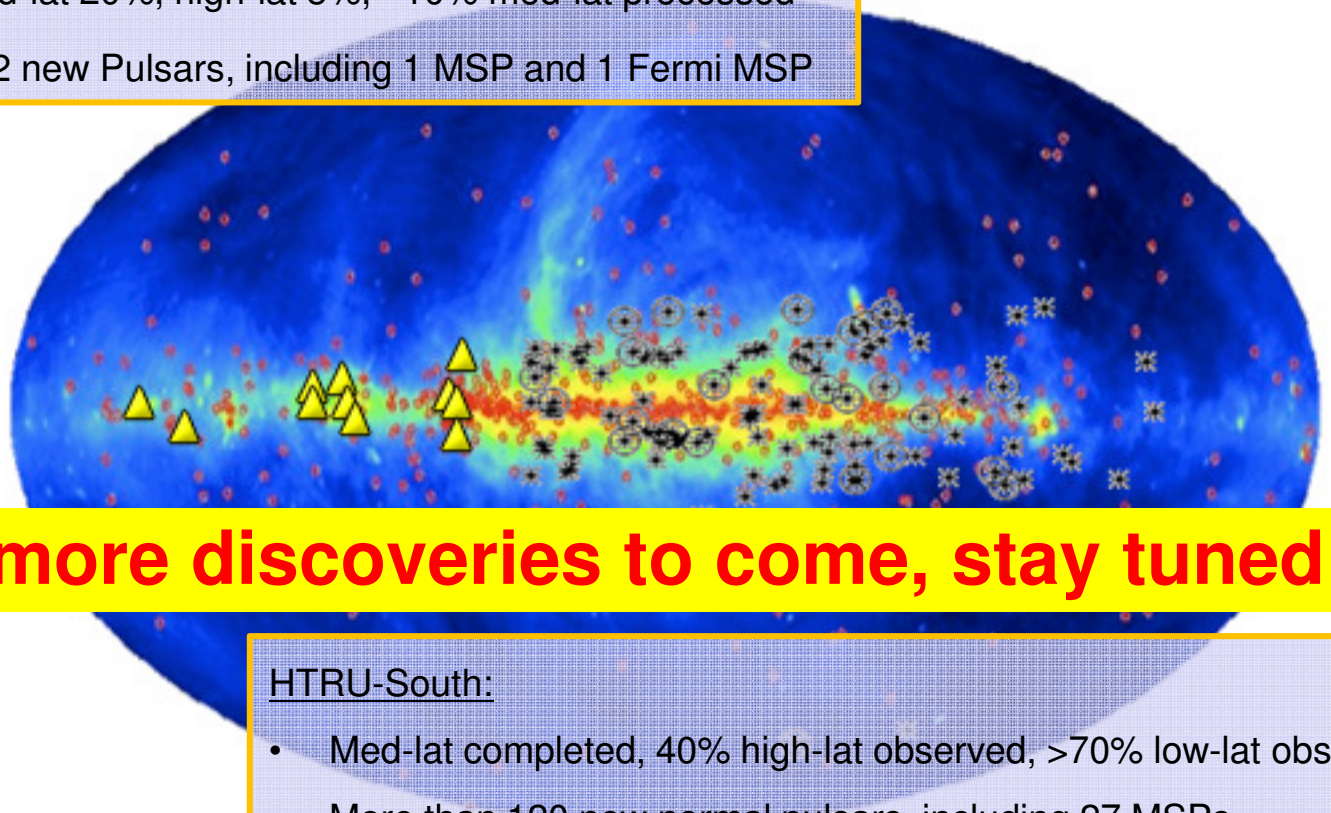


Current Survey Status updates

HTRU-North:

- Effelsberg pilot observations in 2009
- Observed med-lat 20%, high-lat 5%, ~10% med-lat processed
- Up-to-date: 12 new Pulsars, including 1 MSP and 1 Fermi MSP

*** = New HTRU-South pulsars**
o = New HTRU-South MSPs
∆ = New HTRU-North pulsars
Red = known pulsars

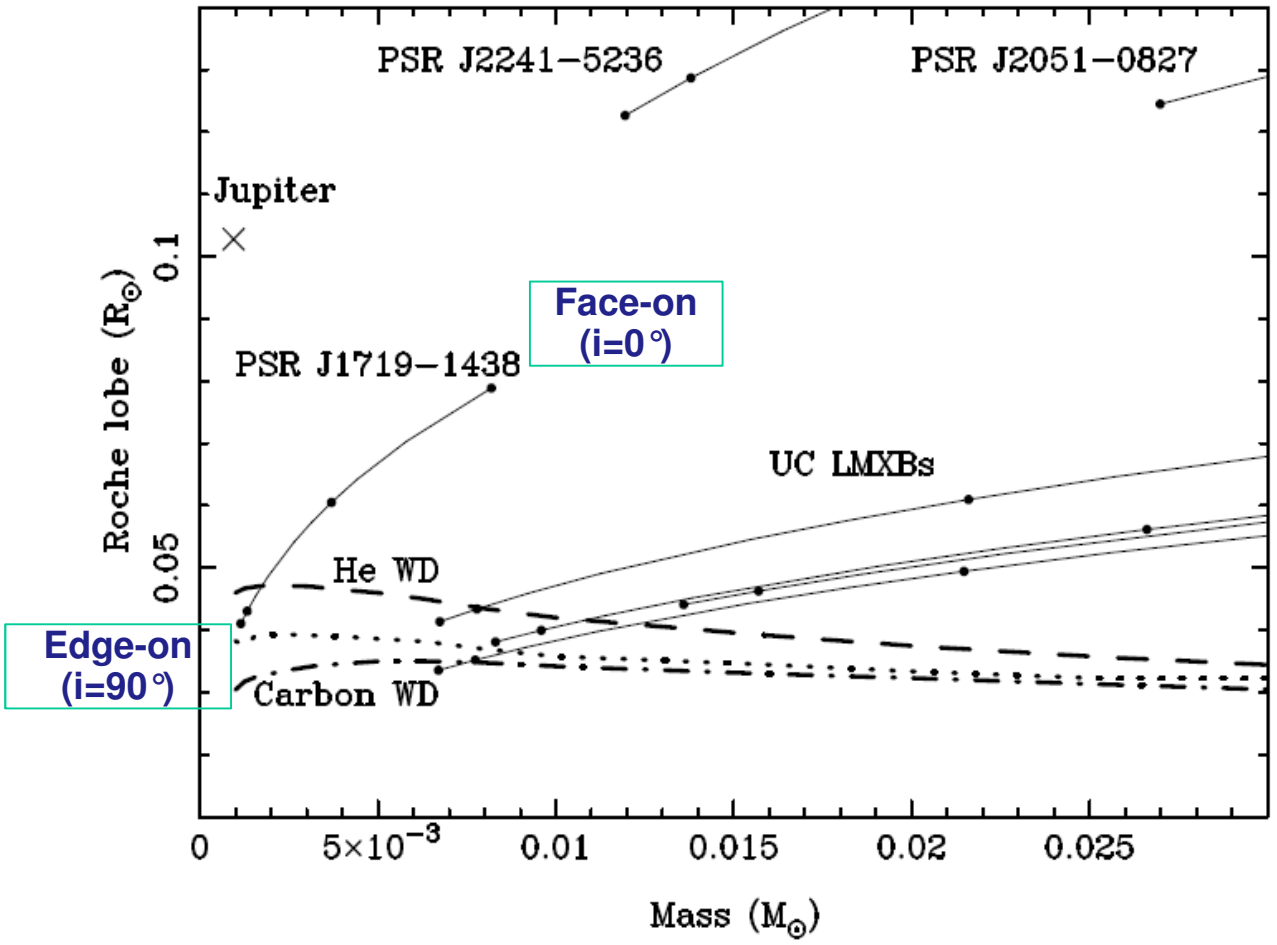


Many more discoveries to come, stay tuned!

HTRU-South:

- Med-lat completed, 40% high-lat observed, >70% low-lat observed
- More than 120 new normal pulsars, including 27 MSPs
- Magnetars, “planet”-pulsar binary, transients…
- 15% low-lat processed, already 23 new PSRs, more with binary search

BACK UP: Planet-pulsar J1719-1438



- Locus of m_{comp} and Roche lobe for different assumed inclination angle
- Dotted line: mass-radius relation (Lai+ 1991)