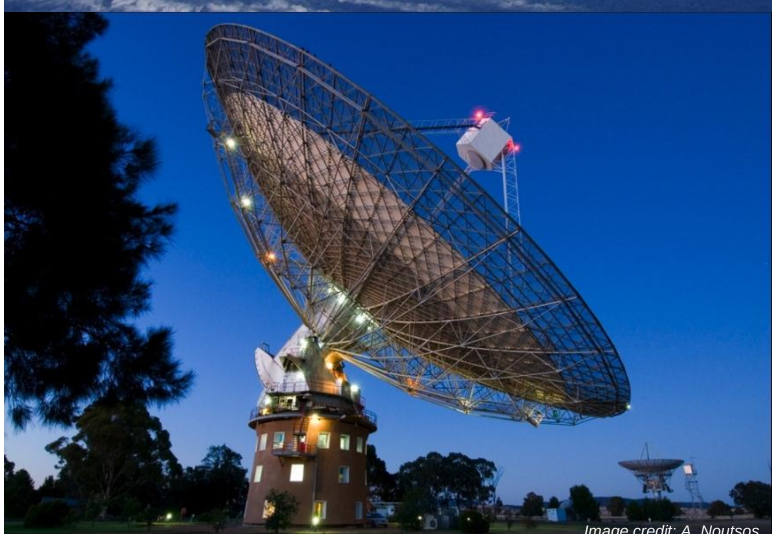


Image credit: A. Noutsos

The High Time Resolution Universe Legacy Survey (HTRU)

Cherry Ng
July 20th 2011

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

MAX-PLANCK-GESELLSCHAFT

Max-Planck-Institut
für Radioastronomie

Outline

- Motivations – What is a pulsar? Why search?
- Standard search pipeline
- Previous survey – PMPS
- Specifications of HTRU
- Survey status & data processing
- Current work - RFI mitigation

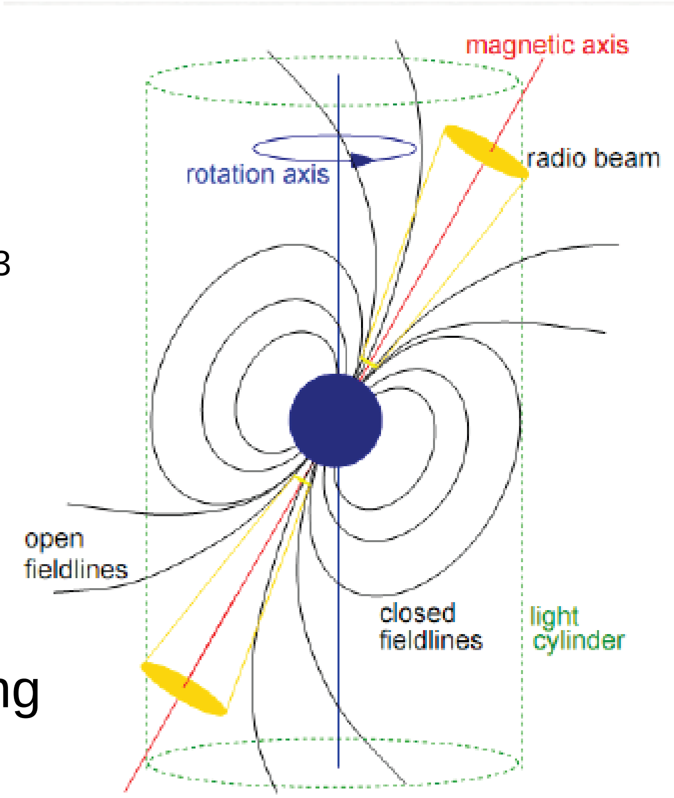
What is a Pulsar?

- Rapidly rotating Neutron Stars
- Radius ~ 10 km, mass ~ 1.4 solar mass

  → central densities: order of a billion tons / cm^3
- Highly magnetized (10^8 ~ 10^{14} Gauss)

  → emit steep spectrum radio emission aligned

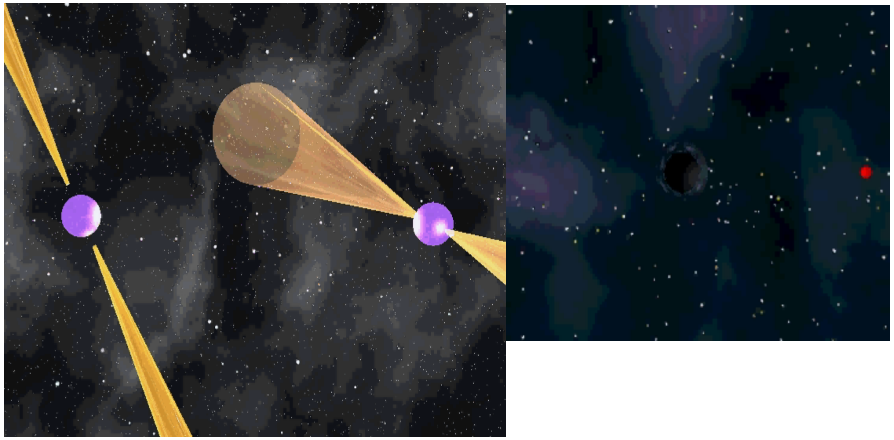
with β-field axis
- Misalignment of rotational and β-axes → pulsing



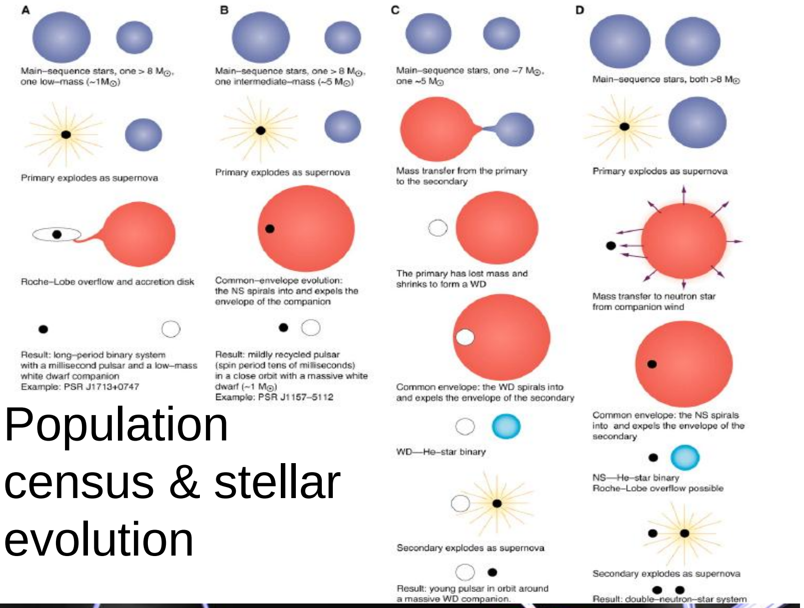
Large mass → consequent rotational stability → accurate clocks

→ many astrophysical applications!

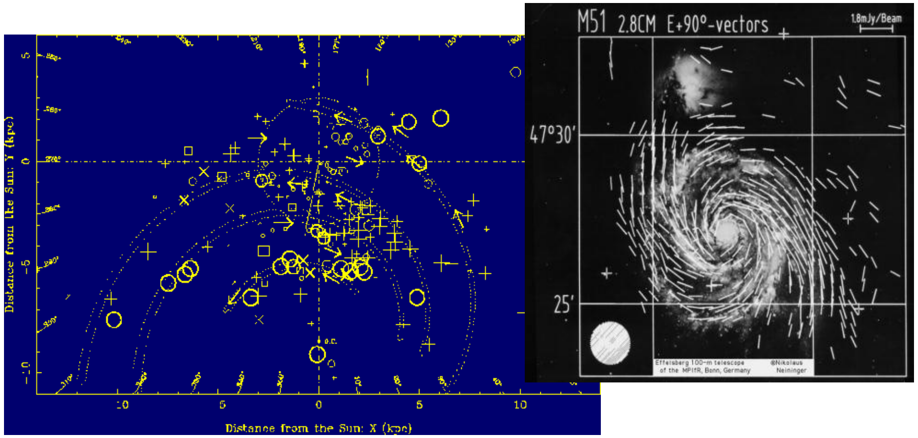
Motivations – Why search for pulsars?



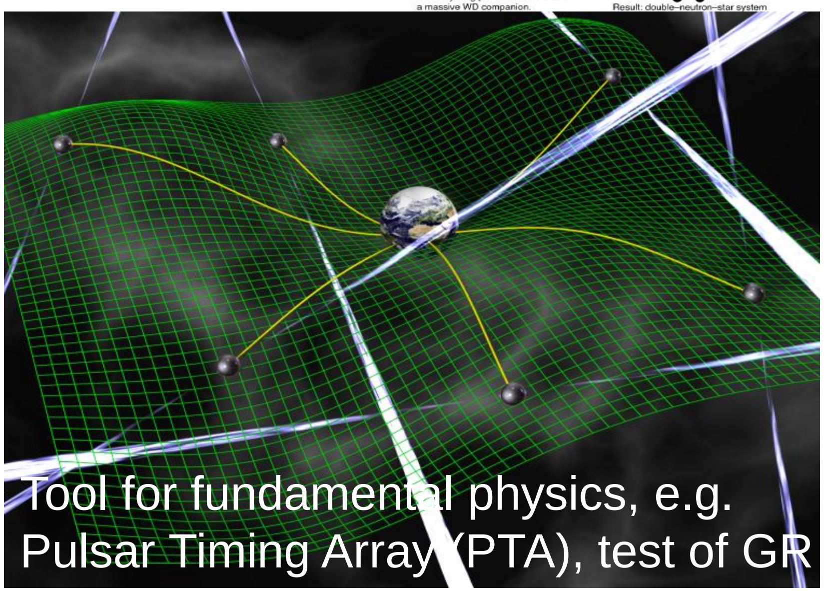
Exotic objects: NS-BH binaries, Planetary Systems, Glitches, RRATs, magnetars ...



Population census & stellar evolution



Galactic probe: ISM, Magnetic field



Tool for fundamental physics, e.g. Pulsar Timing Array (PTA), test of GR

Standard search - Sample pipeline

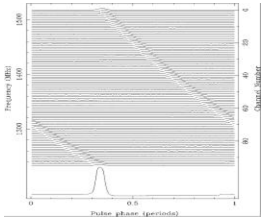
Take the data

Standard search - Sample pipeline

Take the data

RFI removal

Dedisperse



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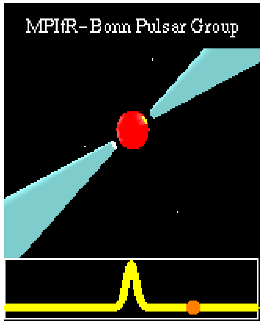
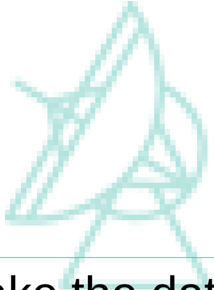
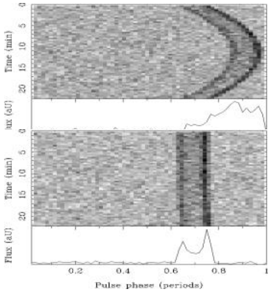




Take the data → RFI removal → Dedisperse → Remove acceleration →



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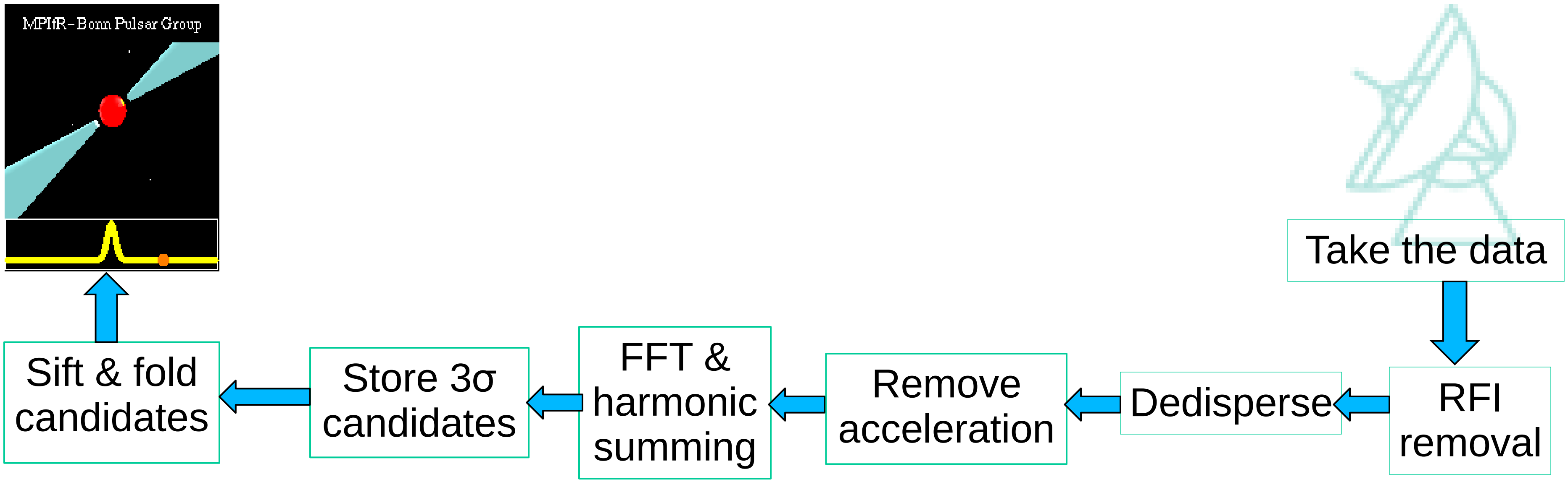

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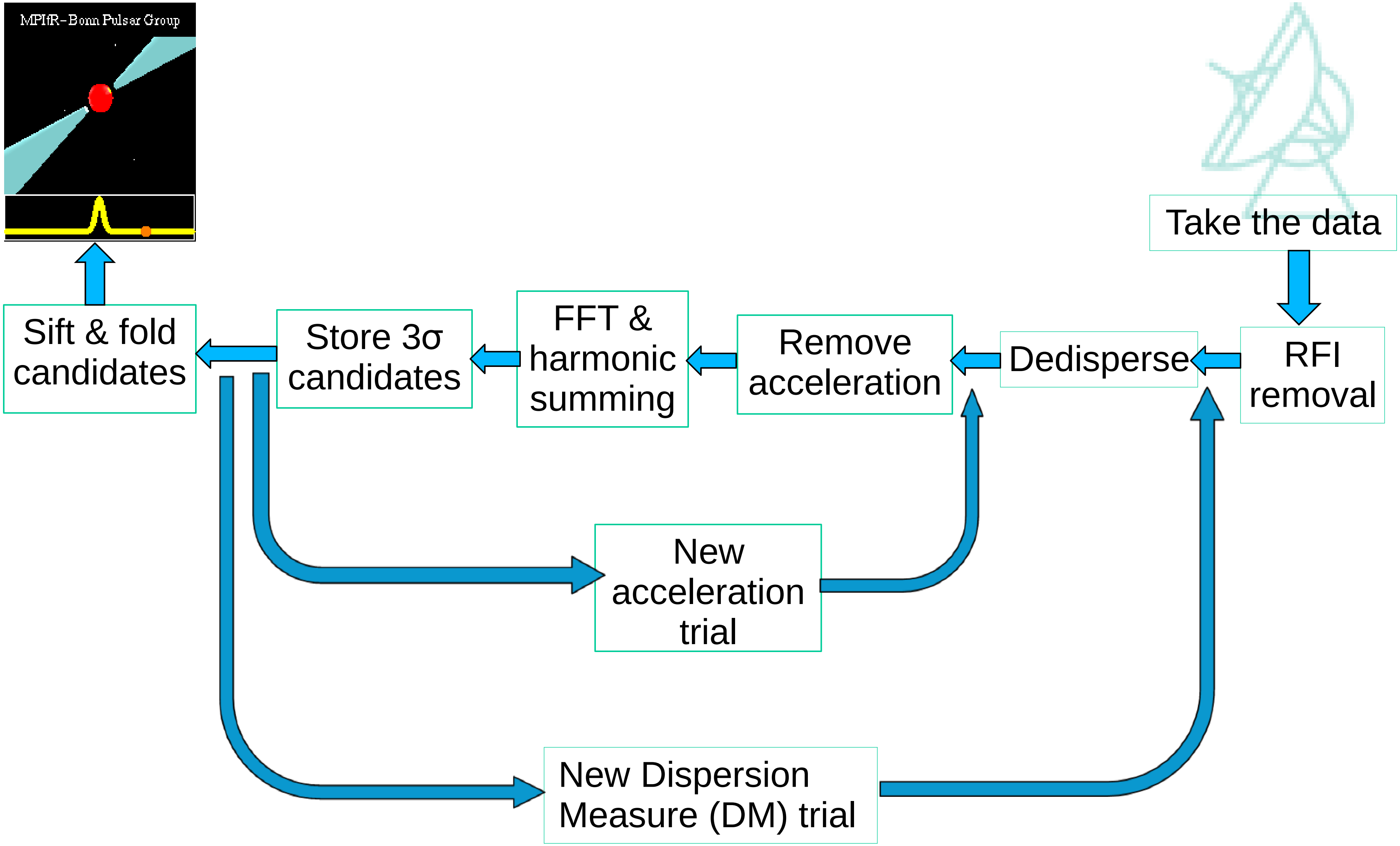
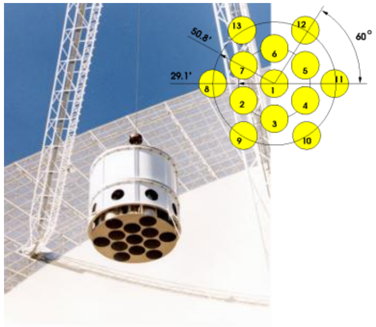


Previous survey - PMPS

- commenced in 1997, completed in 2003
- 20-cm Multi-beam receiver



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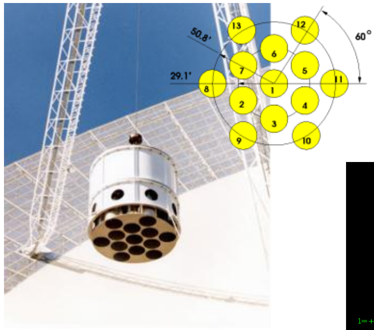

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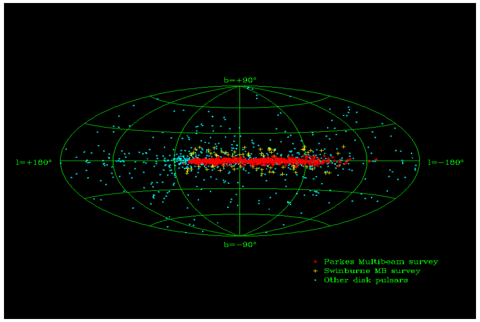
- Discoveries:

~ 60% of all PSR known, 6 DNSs, Double-PSR (from sister survey), first RRATs …



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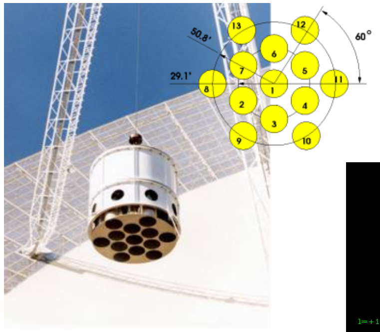
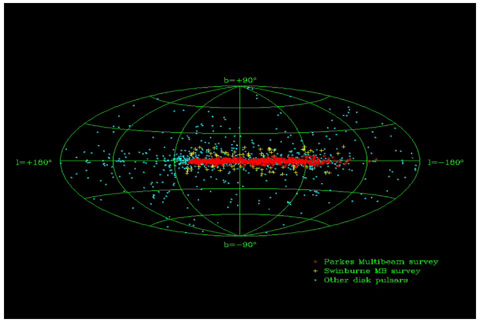




Limitations:

- Modest sampling time (250μs)
- Low freq resolution (3MHz)

→ dispersion smearing & low time resolution

→ miss high DM MSPs

- Only Southern Hemisphere

→ latitude > 38°N virtually unsearched

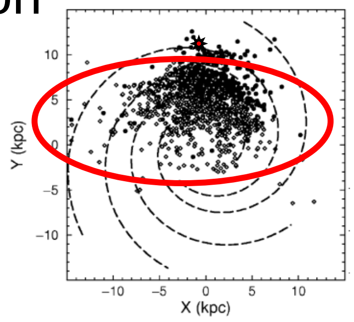
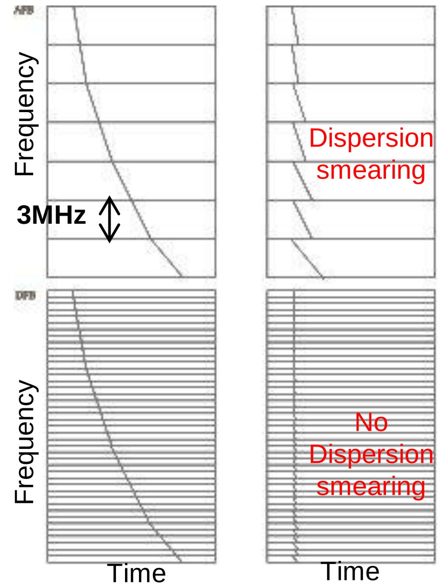


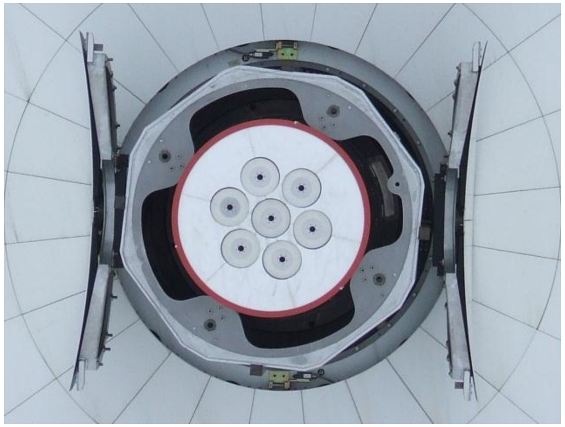
Image credit: R. Eatough



Specifications of HTRU

	Northern Survey	Southern Survey
Start date:	Summer 2010	Early 2008
Telescope:	Effelsberg-100m	Parkes-64m
Sky coverage:	$\delta > 0^\circ$	$\delta < +10^\circ$
Integration time:	Low-lat: 1500 s Mid-lat: 180 s High-lat: 90 s	Low-lat: 4300 s Mid-lat: 540 s High-lat: 270 s
Receiver:	7-beam 1.4-GHz receiver	13-beam 1.35-GHz receiver
Backend:	Pulsar Fast Fourier Transform Spectrometer (PFFTS)	Berkeley-Parkes-Swinburne Recorder (BPSR)
Bandwidth:	300MHz	340MHz
No. of channels:	512	1024
Freq resolution:	0.58MHz	0.39Mhz
Time resolution:	54 μs	64 μs
No. sky pointings:	~ 180,000	~ 43,000
Data sizes:	~ 5 petabytes	~ 1 petabyte

Pulsar Fast Fourier Transform Spectrometer (PFFTS)


New 7-beam 21-cm primary focus receiver at Effelsberg

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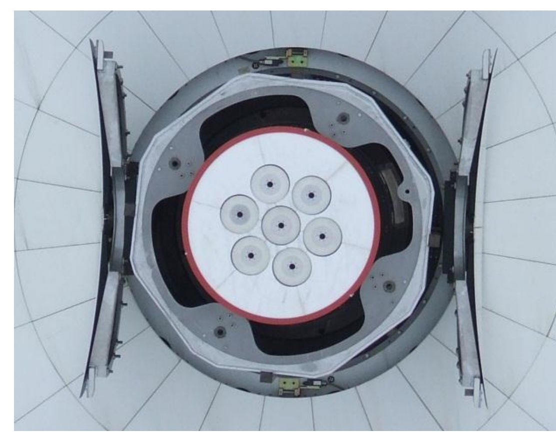
Pulsar Fast Fourier Transform Spectrometer (PFFTS)

High time & freq resolution previously unachievable

→ transient sky on timescale down to 10s of μs

→ Higher freq resolution for negation of IS dispersion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HTRU Observing Strategy

To optimise pointing times for different regions of the Galaxy, the survey will be split into 3 distinct observing regions:

- High-lat ($|b| > 15°$):

  → sub-millisecond PSRs and transients

- Mid-lat ($3.5° < |b| < 15°$):

  → Survey for MSPs as timing array sources

  → large number of MSPs separated by variety of angular distances

- Galactic plane ($|b| < 3.5°$):

  → Deep survey - longest observation per pointing

  → ultimate goal: discovery of PSR-BH binaries

Current Survey Status

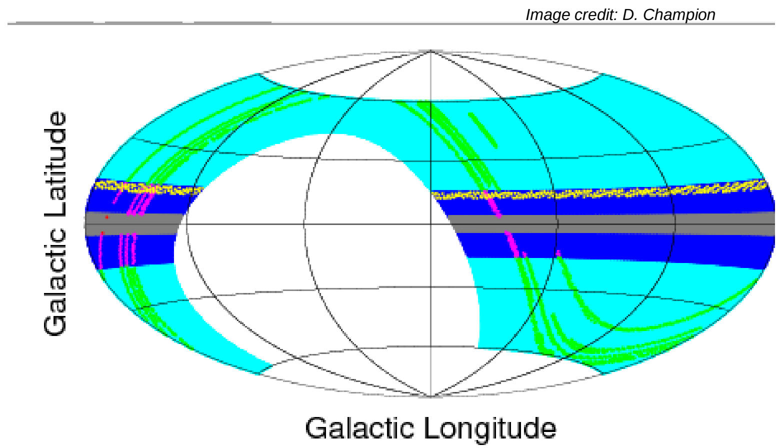
HTRU-North:

- Effelsberg pilot observations in 2009

→ System tests by observing unidentified Fermi point sources

→ Jan 2010 Effelsberg´s first ever MSP

- Survey observations underway & data processing just begun in last few months

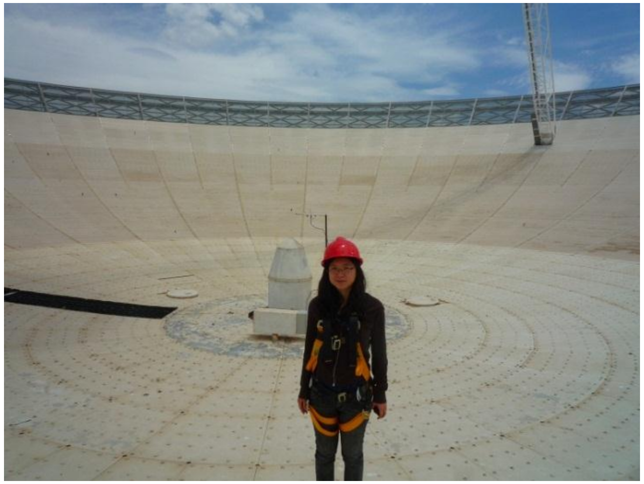


HTRU-South:

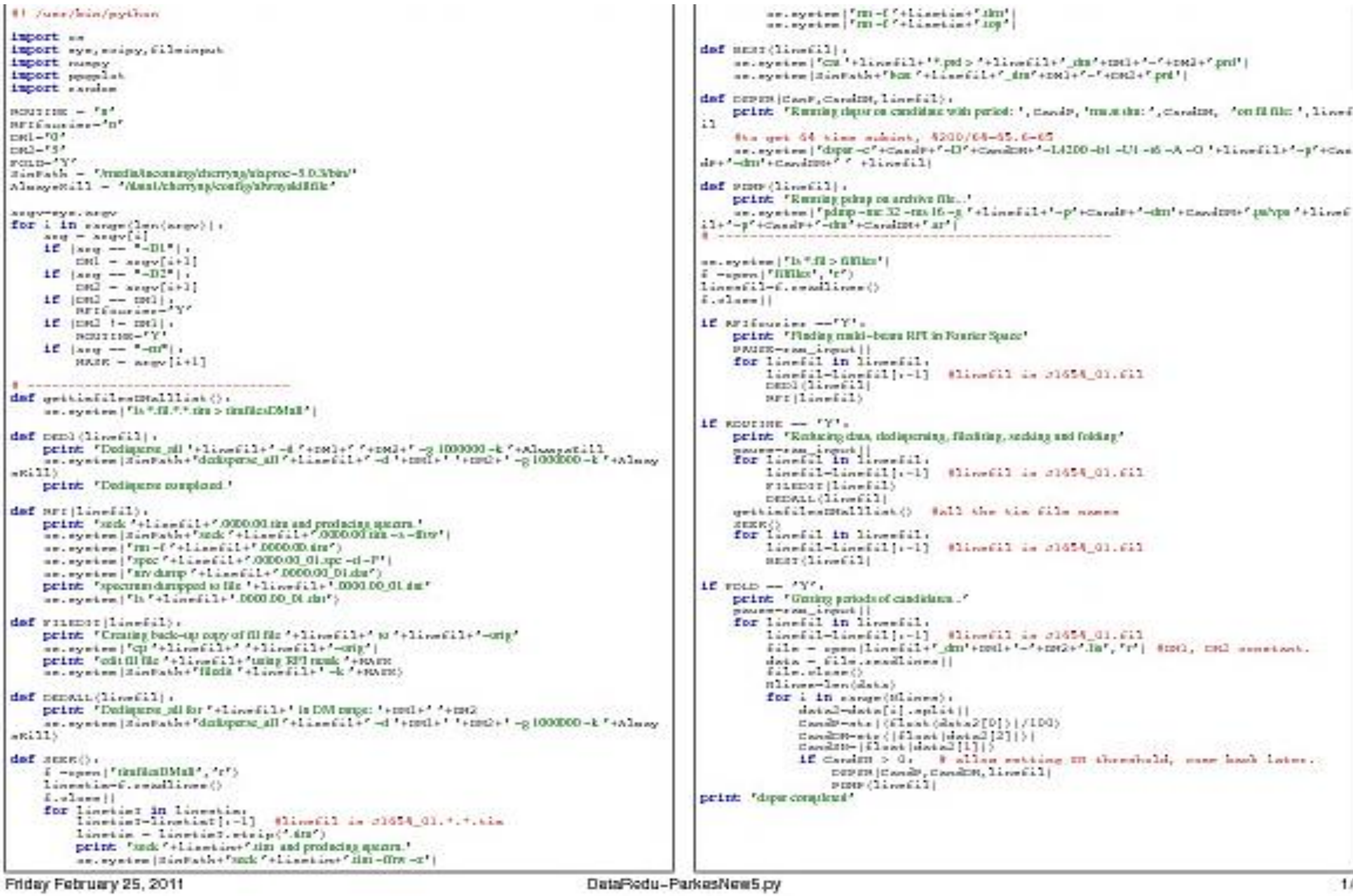
- > 95% mid-lat & >30% high-lat been observed
- Currently 88 pulsars discoveries

→ 15 new MSPs, 5 at high DMs

- First low-lat observation >12% observed



Data processing: Computational power challenges



Data processing: Computational power challenges

Parkes low-lat (70min deep pointings) observation:

- Size of 1 raw filterbank data file: 17Gb
- Number of pointings ($N_{pointings}$) = 1230
- Number of beams = 13

→ Total raw data: S_{fil} = 17Gb x N_{beam} x $N_{pointings}$ ~ 265Tb !

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- Size of 1 time series ~ 65Mb
- ~ 1350 dispersion measure (DM) trials each → 65Mb x 1350 ~ 85Gb

→ Total time series: S_{tim} = 85Gb x N_{beam} x $N_{pointings}$ >1Pb !

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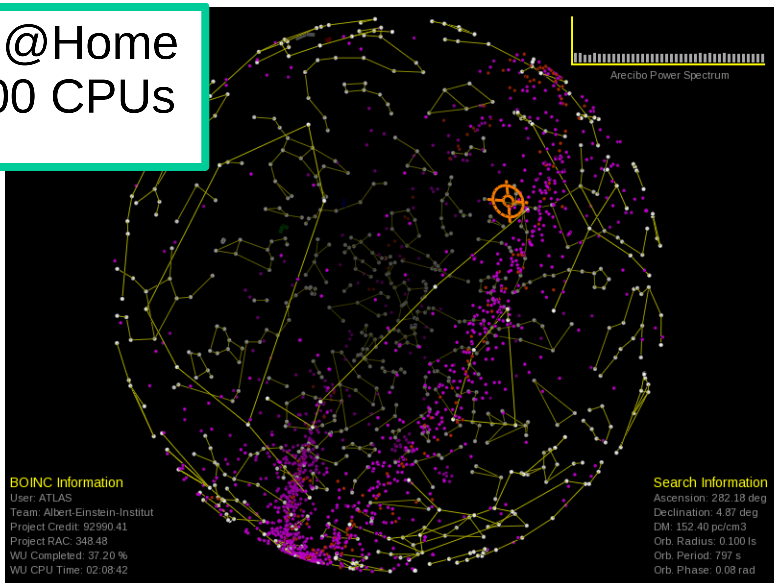
- Time needed for 1 beam standard search on 1 computer ~ 3 days

→ Total time for analyzing all data:

T_{total} = 3 days x N_{beam} x $N_{pointings}$ ~ 131 years !

Data processing: Computational power challenges

Einstein@Home
~ 200000 CPUs



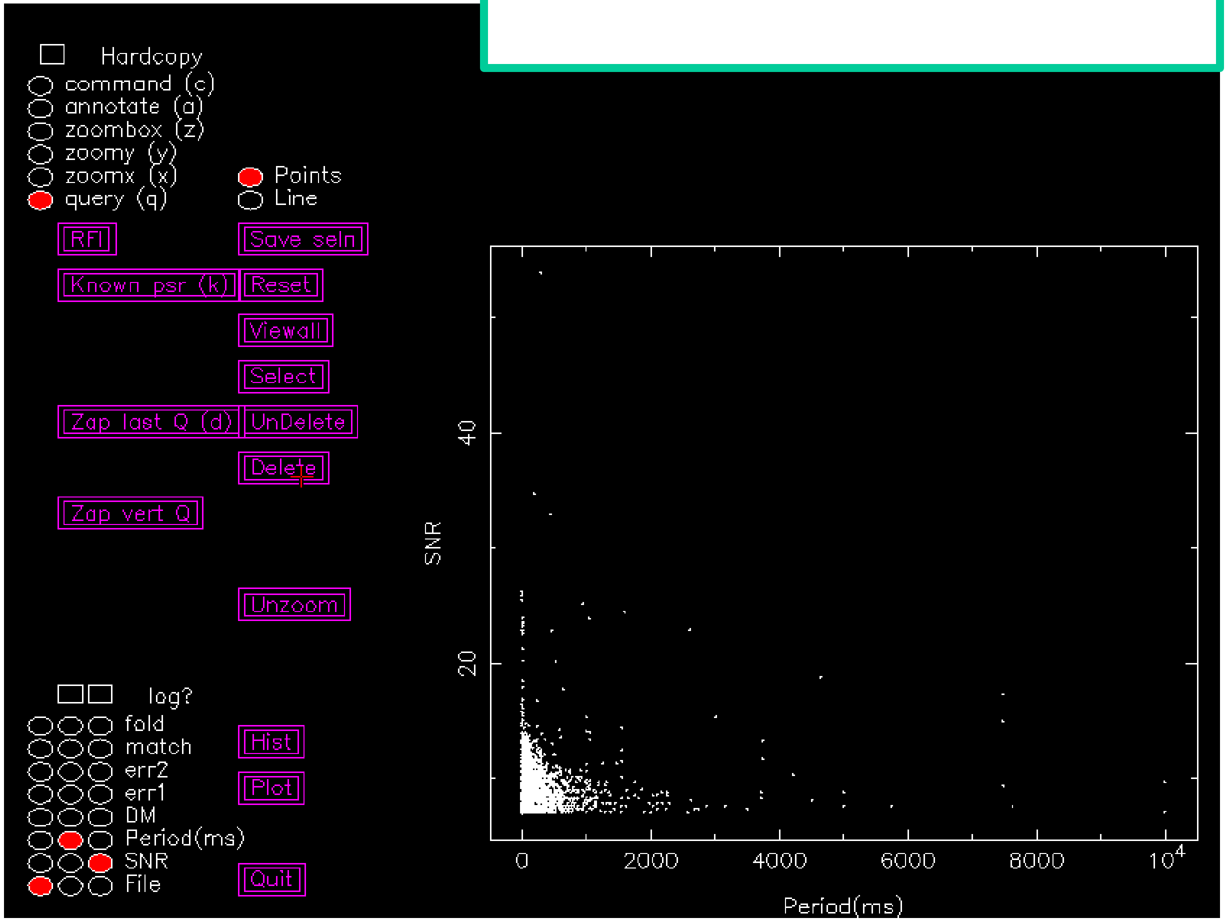
Jordell Bank –
HYDRA Pulsar Searching Cluster
~ 1200 CPUs

Image credit: The University of Manchester

Hannover ATLAS computer cluster
~ 8000 CPU

Data processing: Candidates viewing

- 122 processed beams
- 16085 candidates
- Plot here: SNR vs Period



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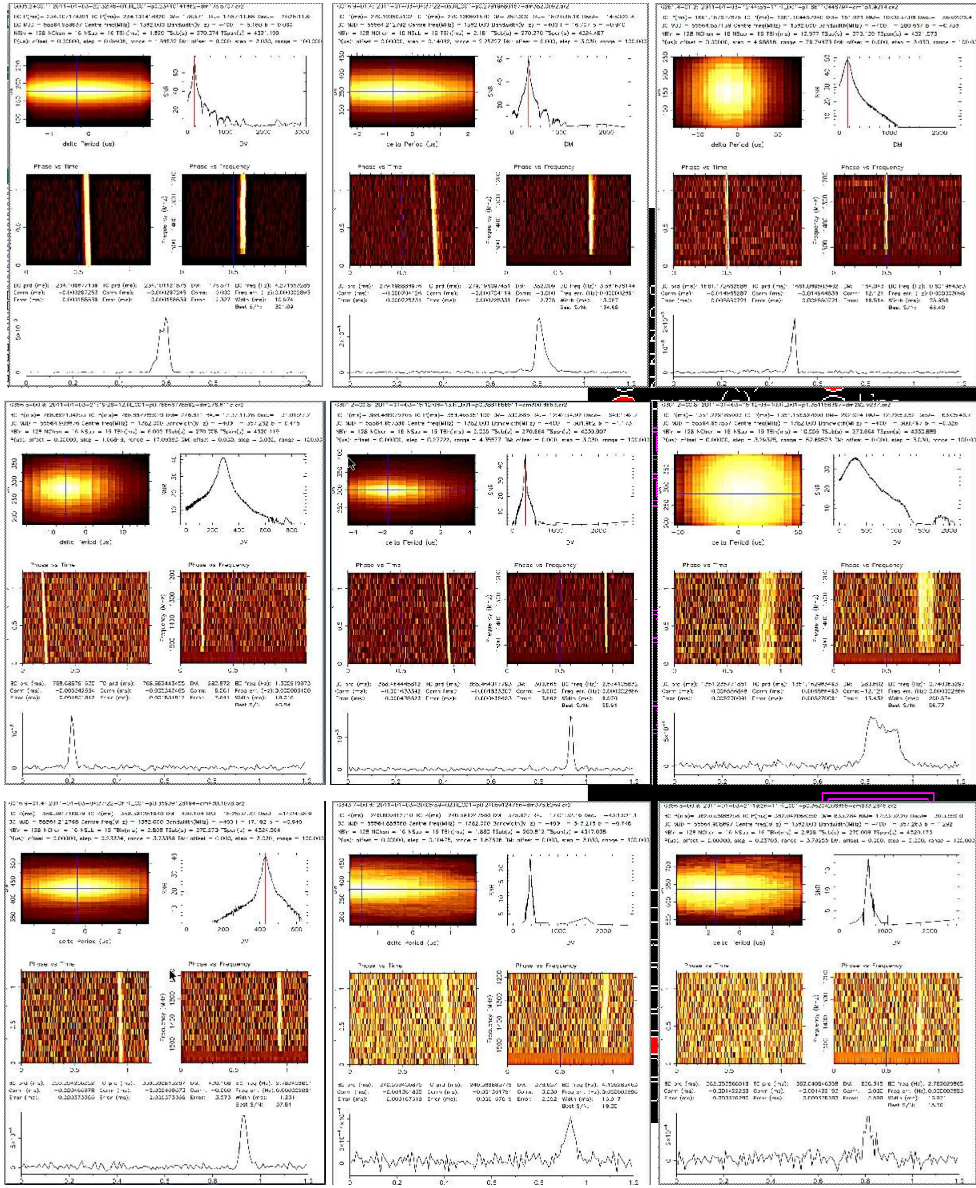
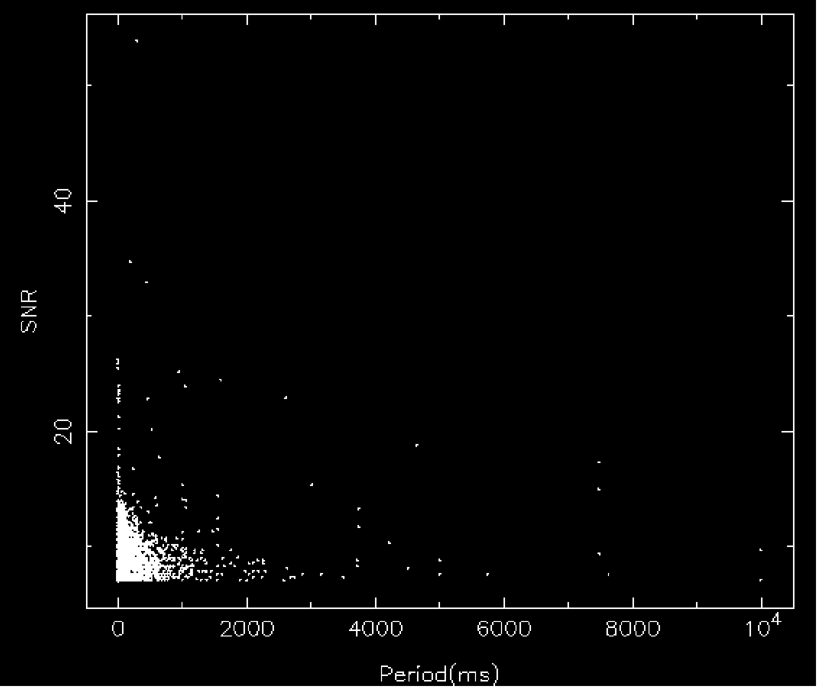
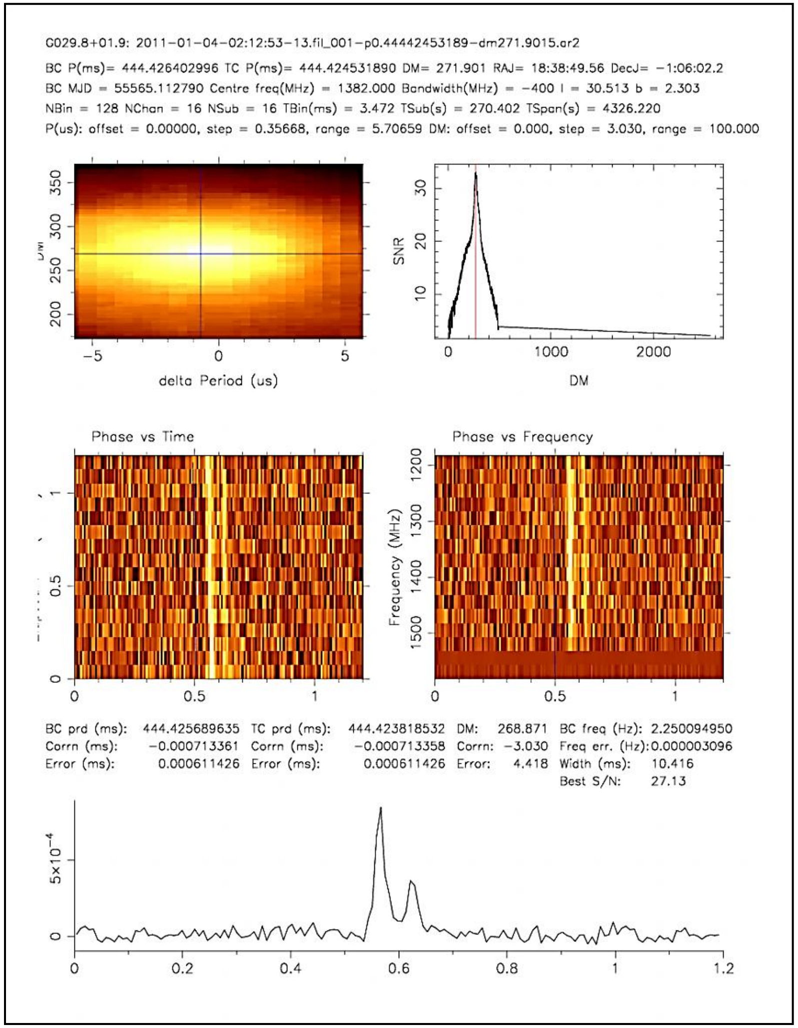


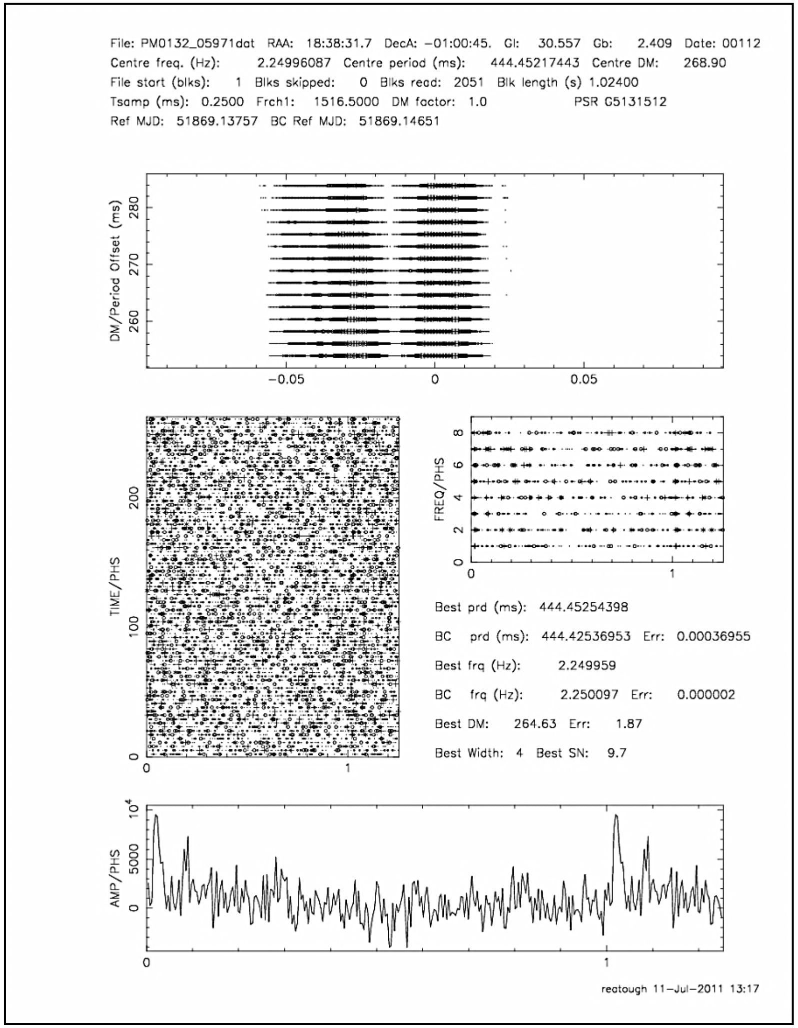
- 122 processed beams
- 16085 candidates
- Plot here: SNR vs Period
- Re-detection of known pulsars



Data processing: 2 New Pulsars!

New Pulsar 1: J1838-0106

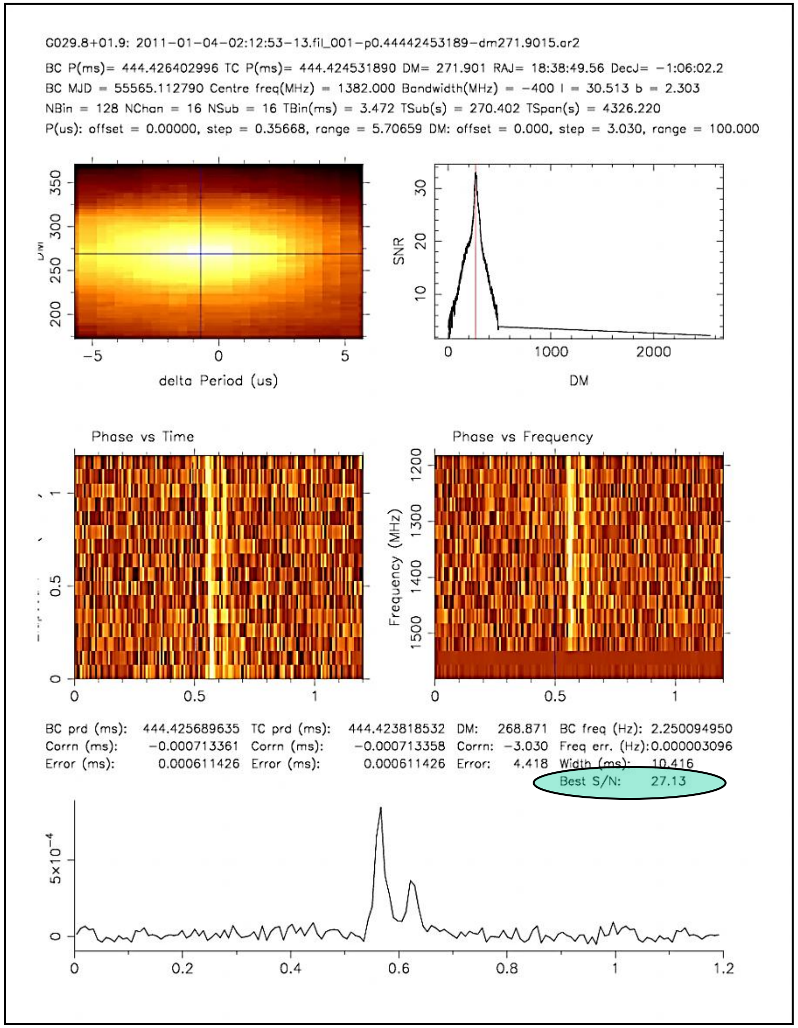


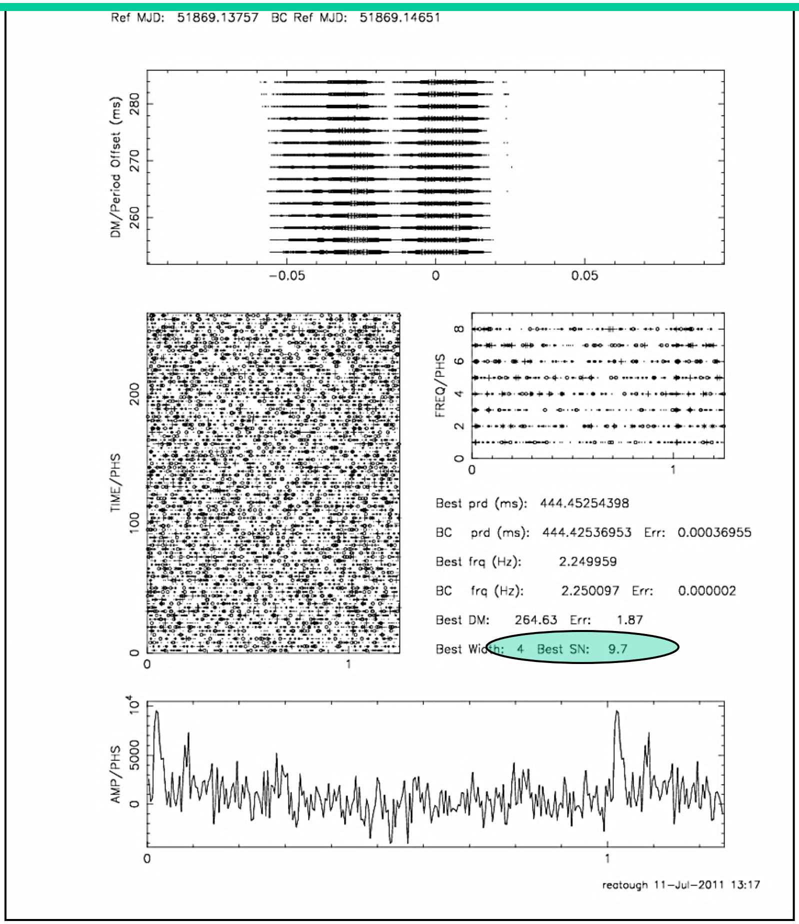


Data processing: 2 New Pulsars!

New Pulsar 1: J1838-0106

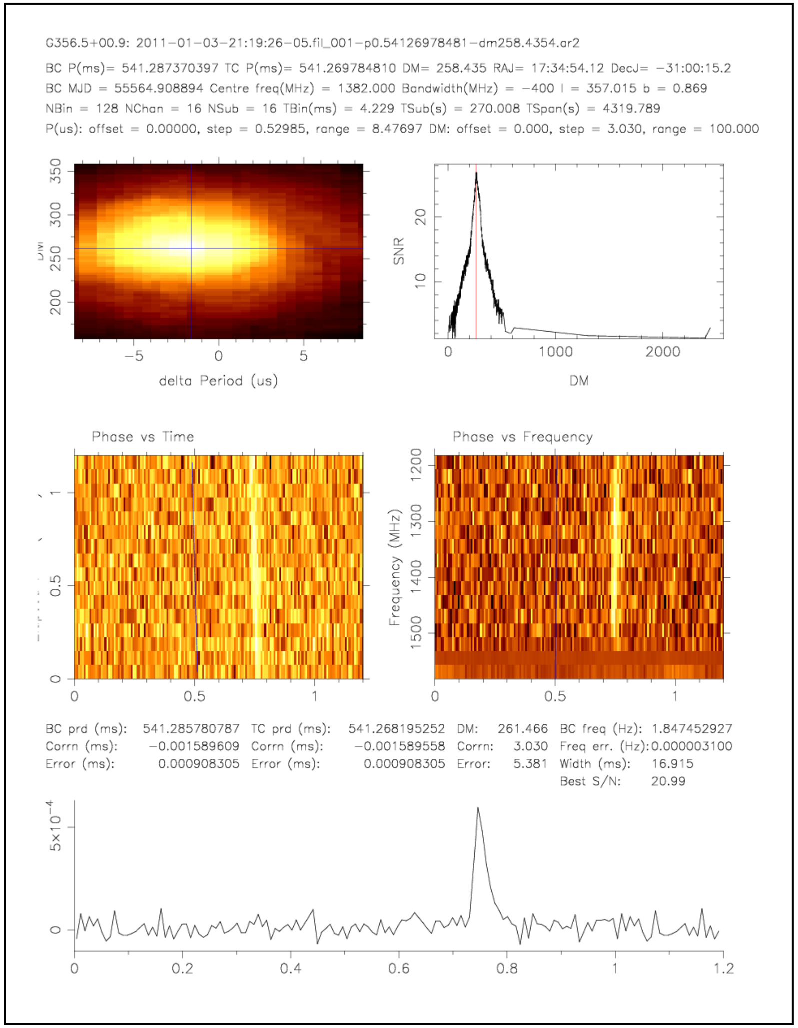
- Tobs(HTRU) ~ 70 min ~ 2 x Tobs(PM)
- Expected SN(HTRU) -> at least √2 x SN(PM)

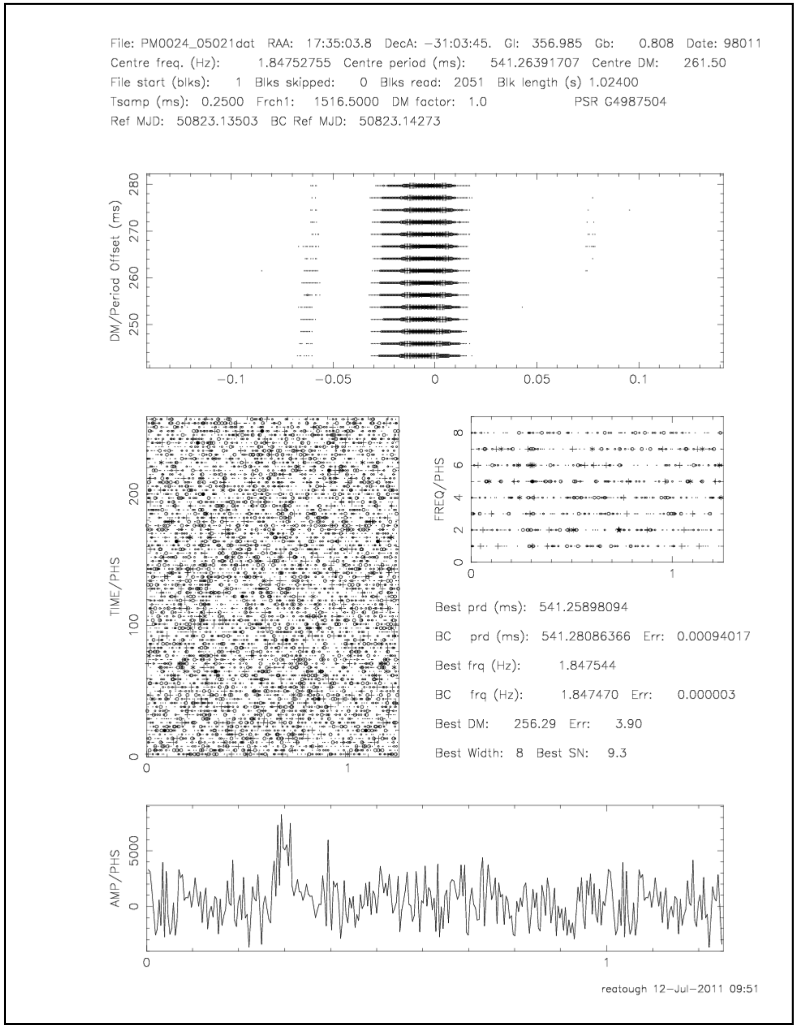




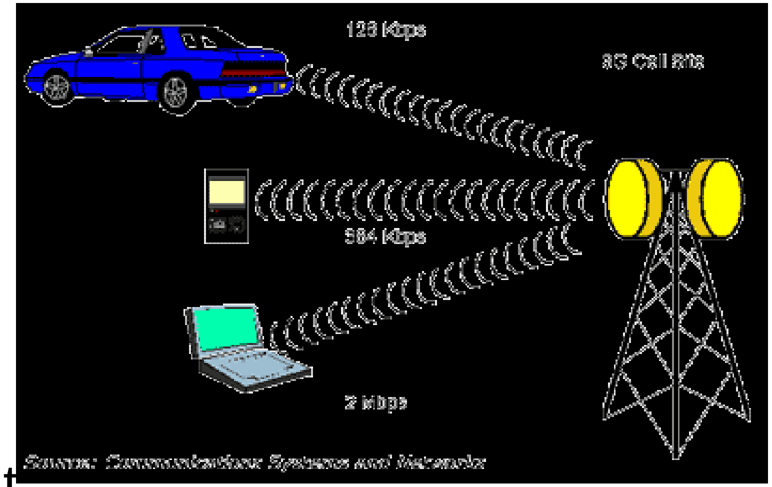
Data processing: 2 New Pulsars!

New Pulsar 2: J1734-3100





RFI mitigation



- RFI is terrestrial in origin (DM=0 cm^{-3} pc)

  → not travelled through ISM

  → signals not dispersed across bandwidth

  → power peak at DM=0 cm^{-3} pc

- Increasingly deteriorating RFI environment

  → RFI mitigation crucial

- RFI shows up in many beams (say >3)

  Celestial sources only appear in 1 beam (or if strong, up to say 2 beams)

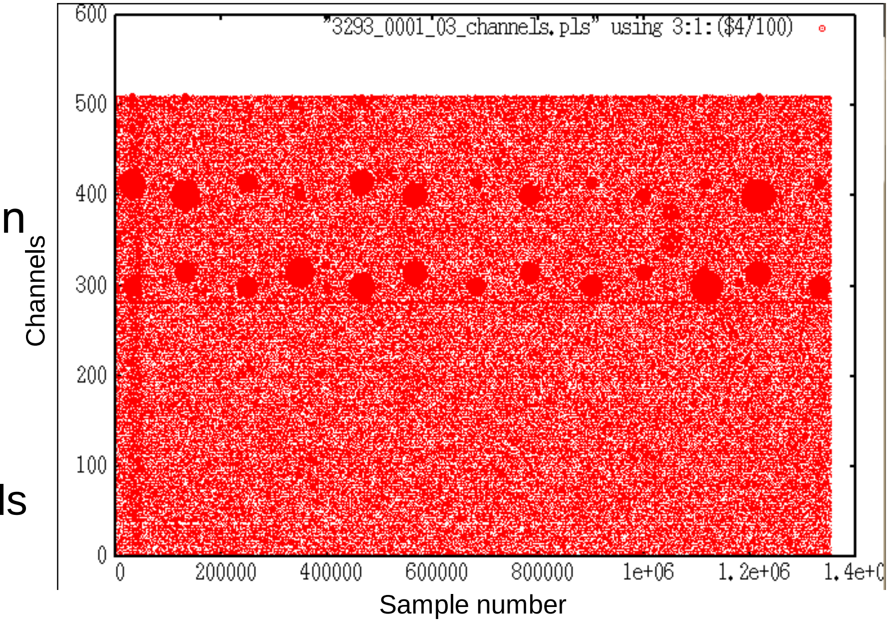
=> RFI mitigation algorithm:

```
if ((DM==0) && (no_beam >3))
```

HTRU Challenges: RFI mitigation (Time and freq channel)

- Step 1: time-domain RFI

→ remove impulsive RFI
→ apply zap mask generated during observation
→ replace with noise



- Step 2: frequency-domain RFI

→ Remove "static" (always bad) filterbank channels
→ excise channels with excess power

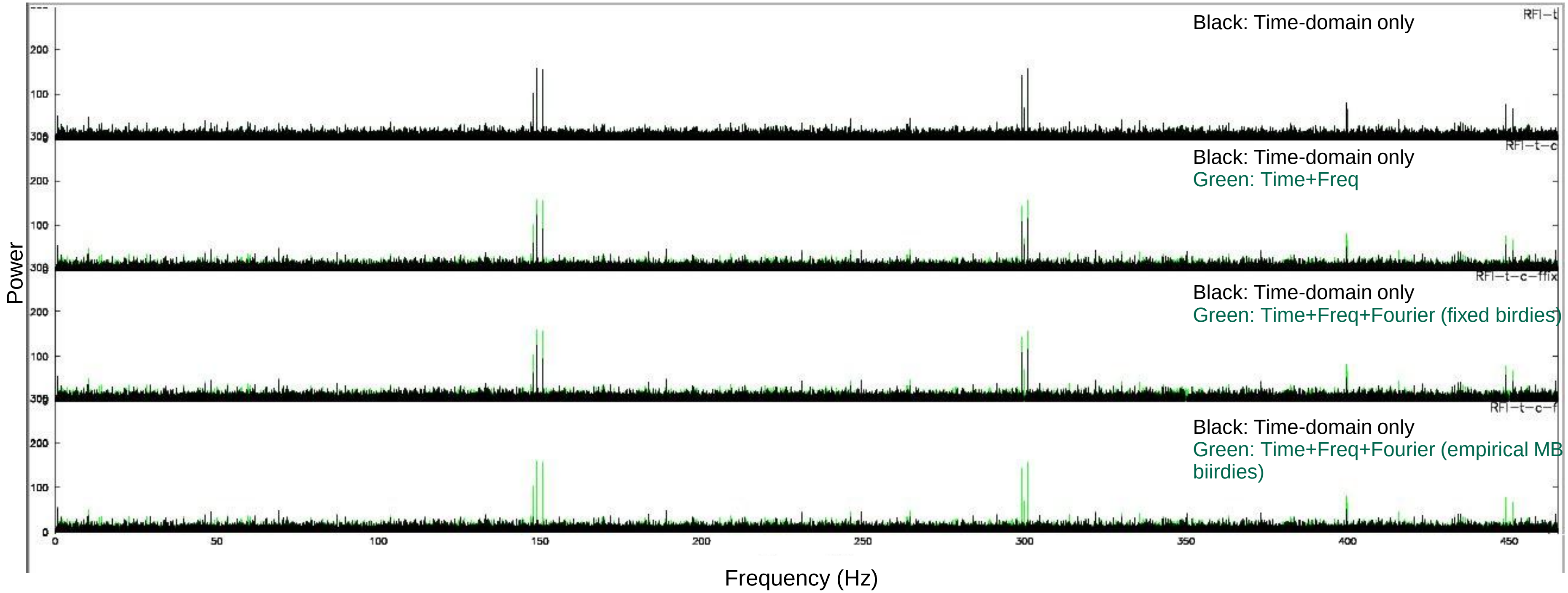
→ search each channel for excess power
→ remove contaminated channels

- Step 3: fourier-domain RFI

→ look into Fourier space
→ remove periodic, RFI with multi-beam occurrence ("birdies")

HTRU Challenges: RFI mitigation (Fourier space)

Parkes deep pointing (Tobs=4300 sec)
- Central beam (beam 01)
- Dispersion measure (DM) = 0
- Harmonic fold = 1
- Zoomed in fourier freq range 0 – 465 Hz



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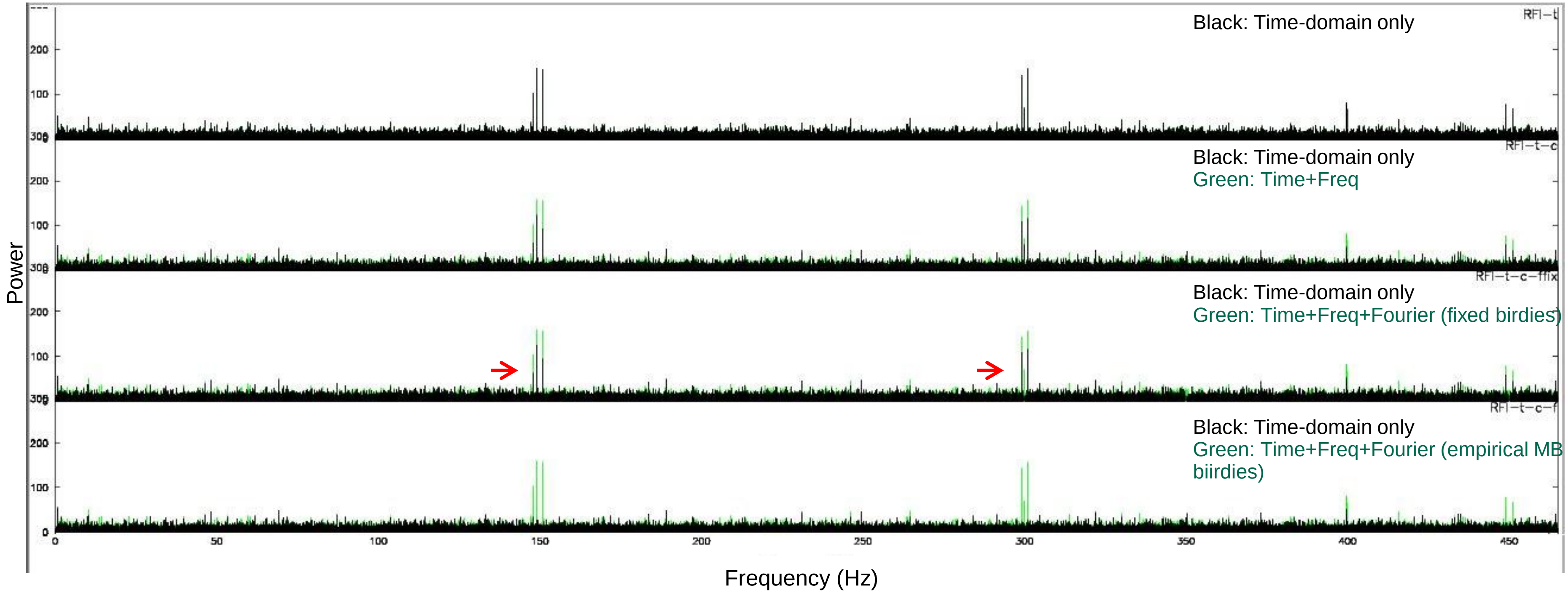

- Changing RFI environment.
- Fixed birdies list inadequate.

Conclusion

- HTRU-South galactic plane (low-lat) deep-pointings processing commenced with Hydra computer cluster since June 2011
- ~ 150 beams processed (~ 1% of all low-lat beams)
- 2 New Pulsars discovered
- Current work: better RFI mitigation
- Next stage: develop new algorithms for binary search

Thank you