The Green Bank North Celestial Cap Pulsar Survey

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GBNCC Collaboration

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GBNCC Collaboration

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Reasons for Searching for New Pulsars

Populations

- Neutron Stars
- Supernovae / Massive Stars
- Binaries
- Millisecond Pulsars (MSPs)

Exotic Systems

- Triple Systems
- Double Pulsar
- Pulsar-BH
- Double Neutron Stars (DNSs)

Clocks

- Time Standard

Transients

- FRBs
- RRATs

Study of Medium

- Dispersion
- Scattering/Scintillation
- Faraday rotation

Extreme Environments

- Large B-field
- Neutron Star Interior
- Tight Binary systems
- Fast Spinning

Physics

- Tests of GR
- Tests of Alternatives
- Gravitational Waves
- Pulsar Masses (EOSs)

Pulsar Timing Arrays

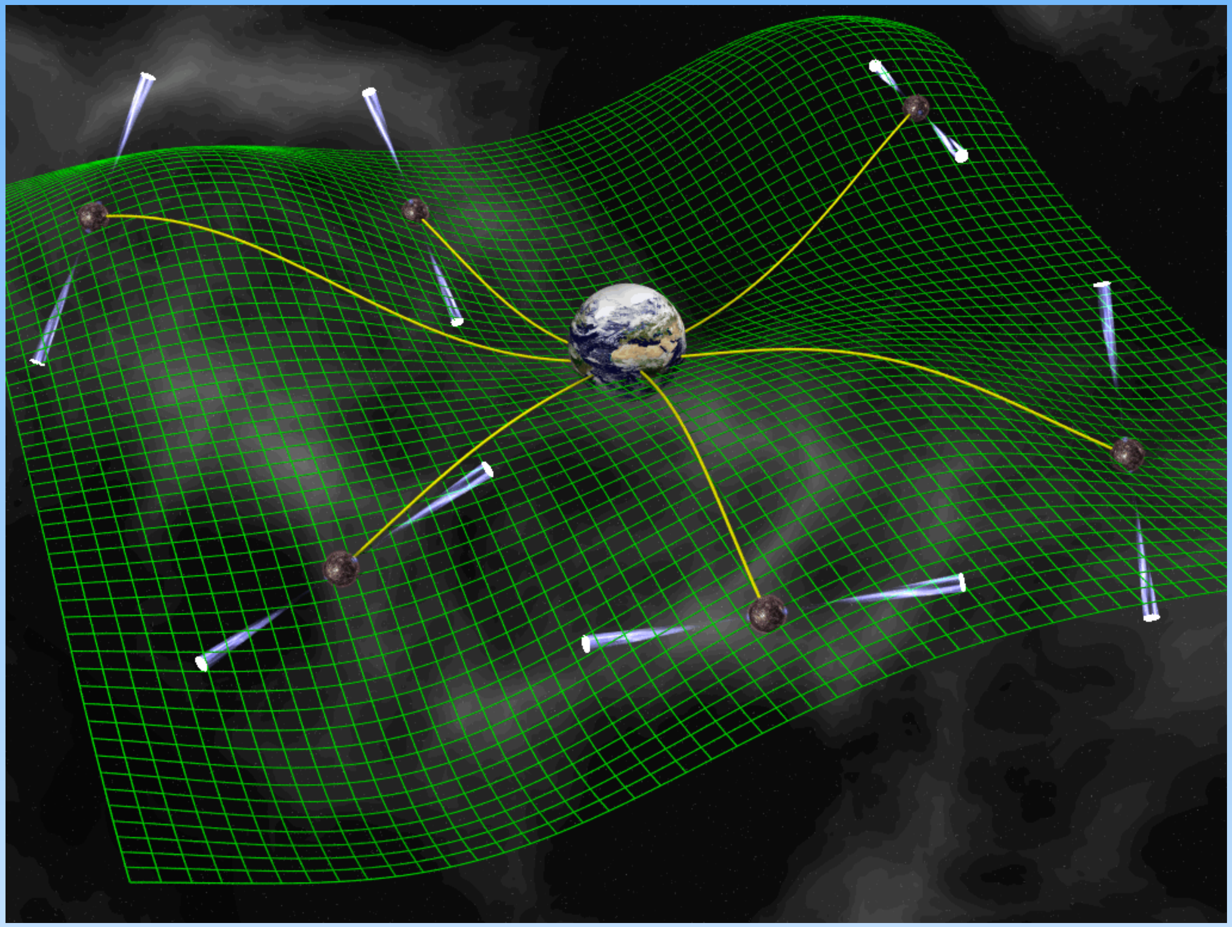
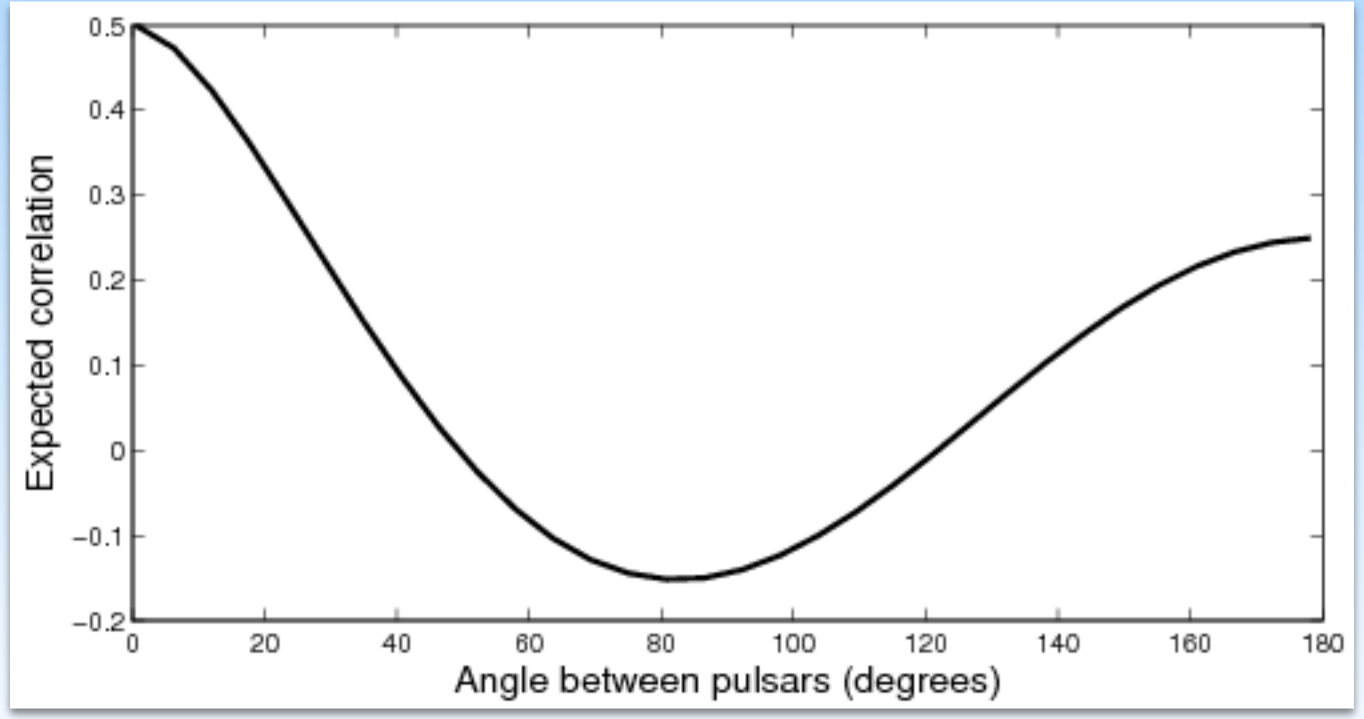


Image Credit: David Champion

Pulsar Timing Arrays (PTAs) monitor a set of very stable millisecond pulsars (MSPs) to look for GW signals. Such signals would be correlated vs. pulsar angular separation.

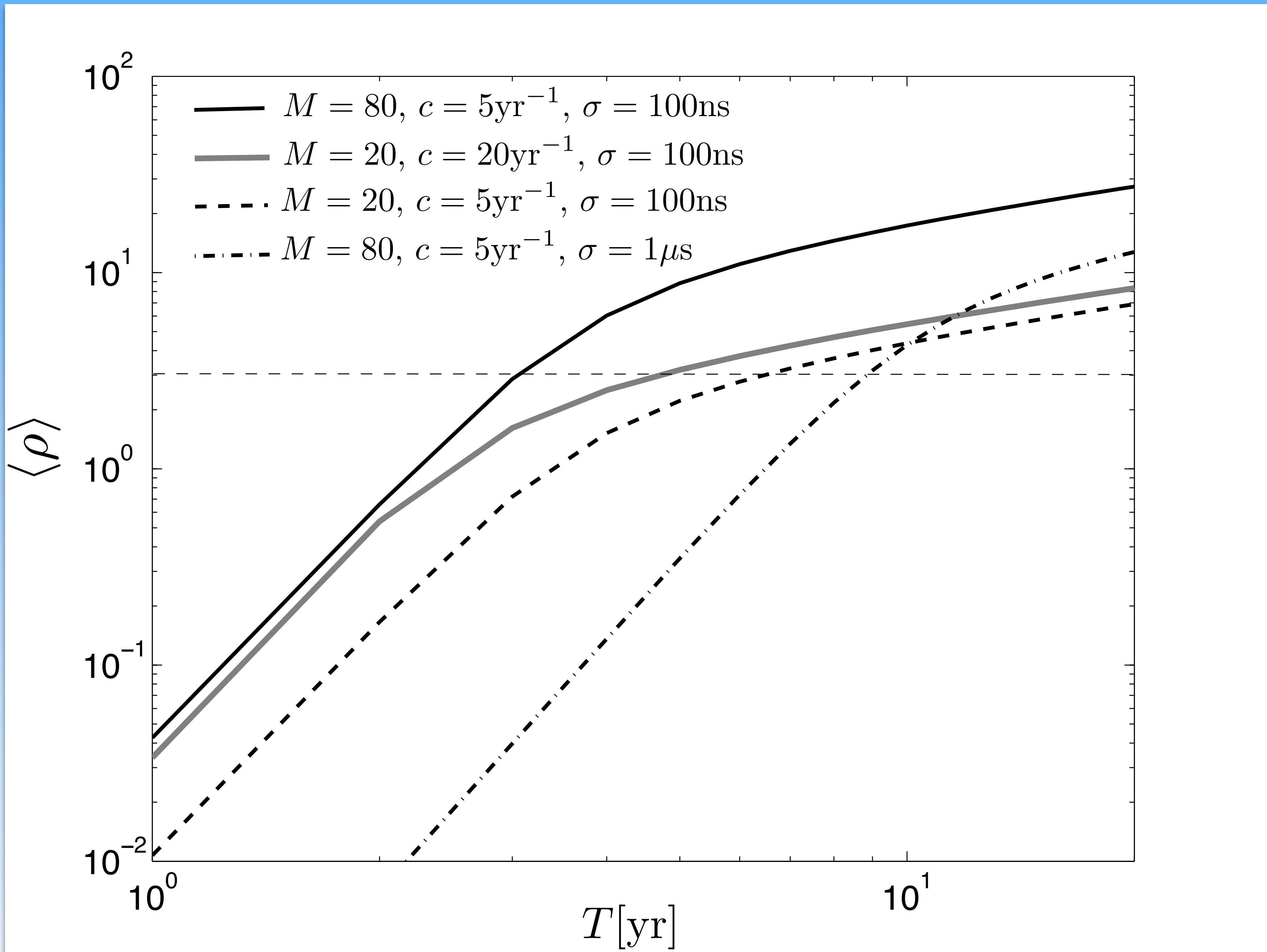
Hellings & Downs Curve



Hellings & Downs 1983, ApJ, 265, 39

- North American Nanohertz Observatory for Gravitational Waves (NANOGrav)
- European Pulsar Timing Array (EPTA)
- Parkes Pulsar Timing Array (PPTA)
- International Pulsar Timing Array (IPTA)

Improving PTA Sensitivity



Siemens et al. 2013, CQG, 30, 4015

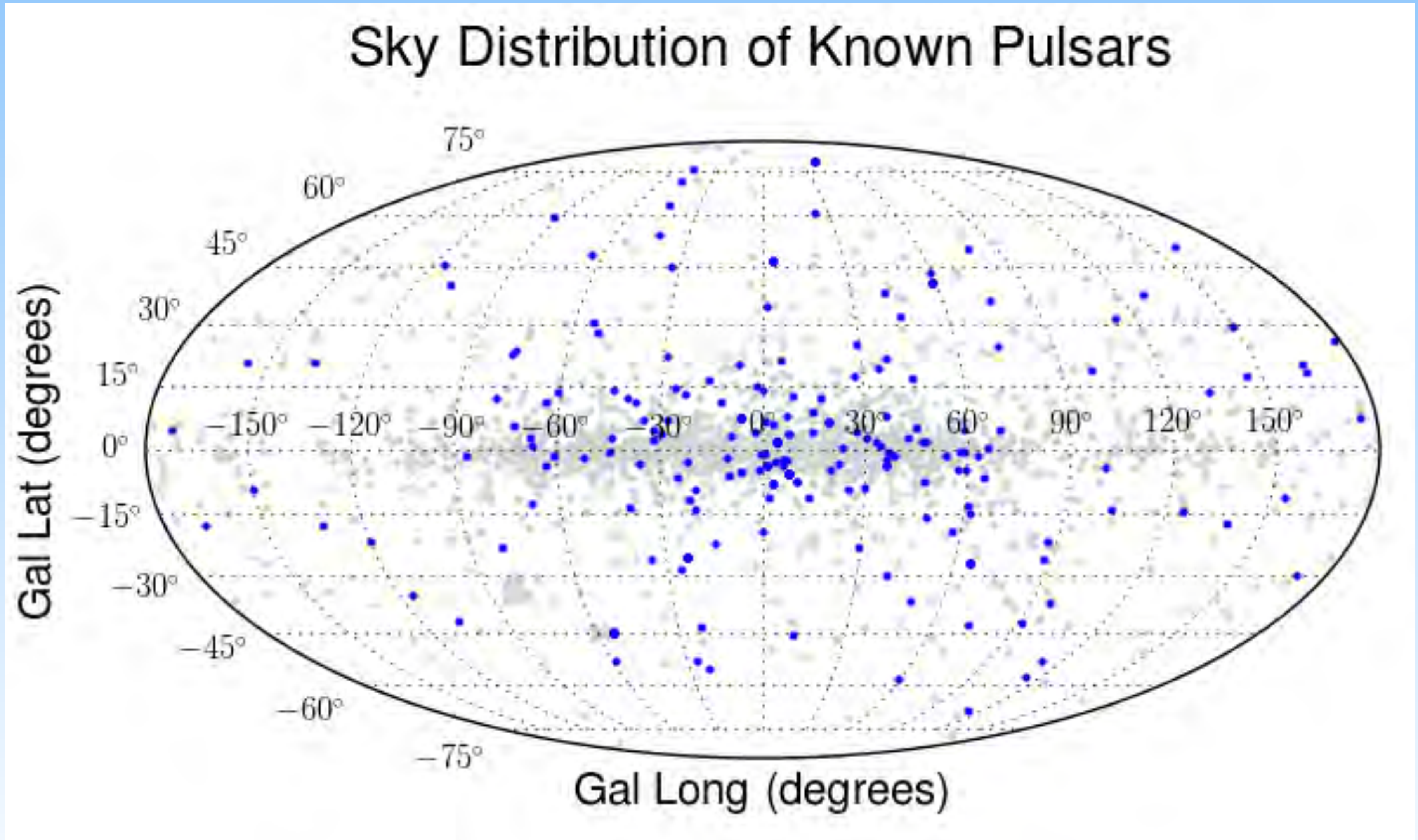
Where to Search for MSPs?

Nearby MSPs are expected to be essentially isotropic.

Searches in 1990s found many MSPs at a wide range of Galactic latitudes.

Low frequencies are optimal:

- Dispersion/Scattering are less of a problem out of Galactic plane, so we can take advantage of steep spectrum
- Larger beam size -> faster survey speed

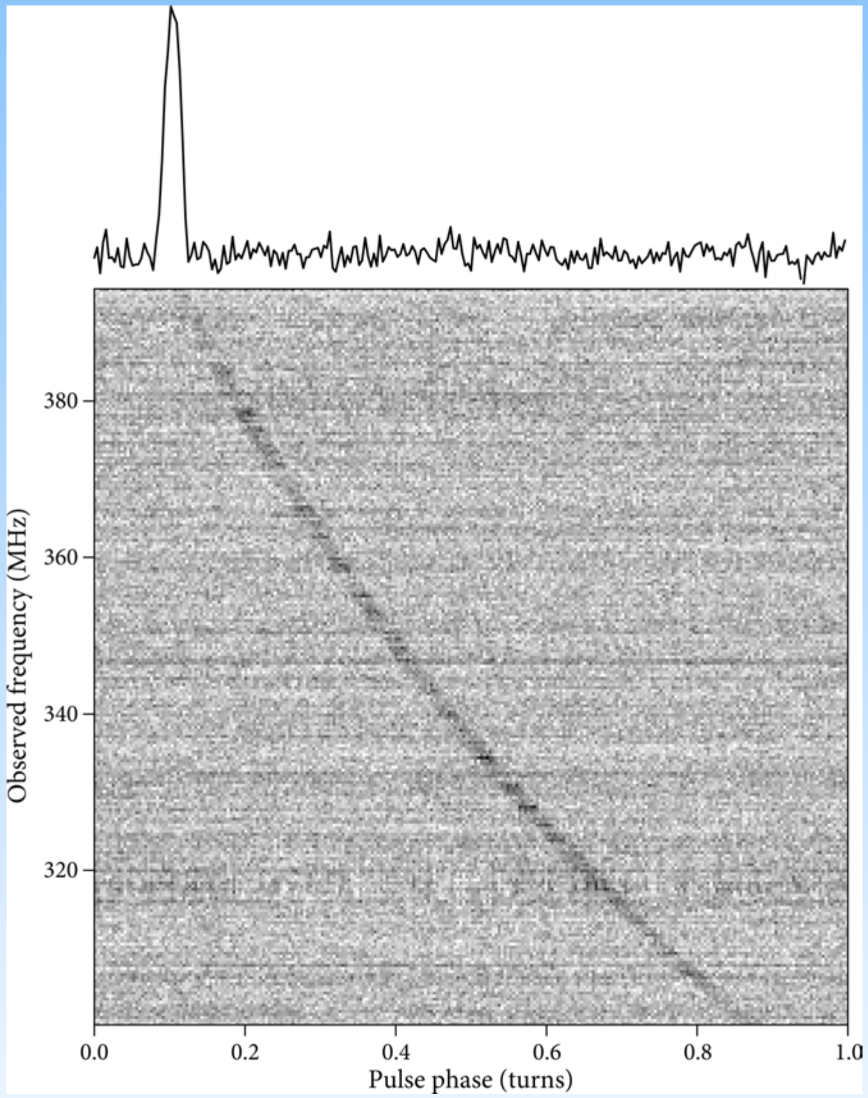


Interstellar Medium Effects

Dispersion

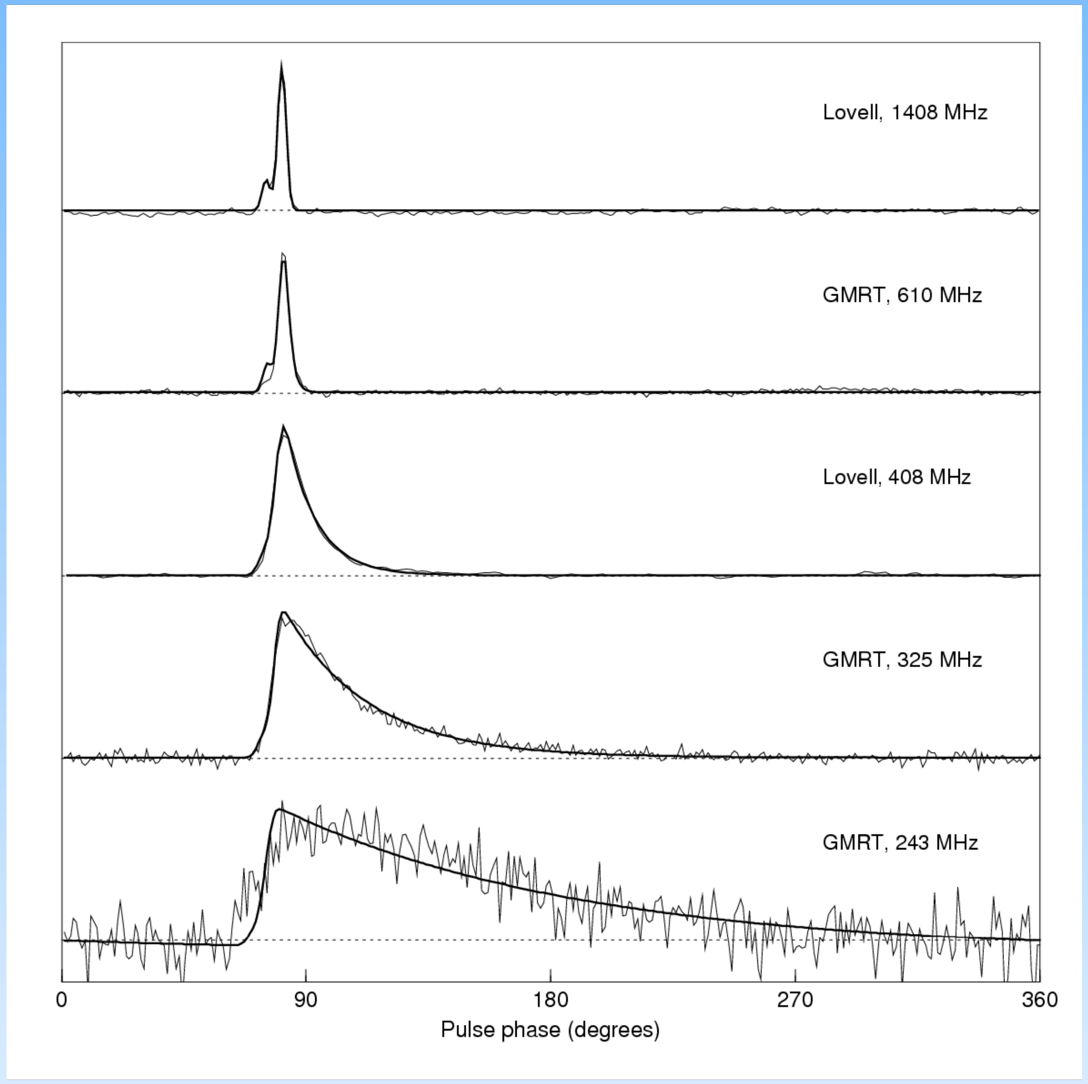
Delay $\propto$ DM ν^{-2}

DM = $\int_0^d n_e \, dl$



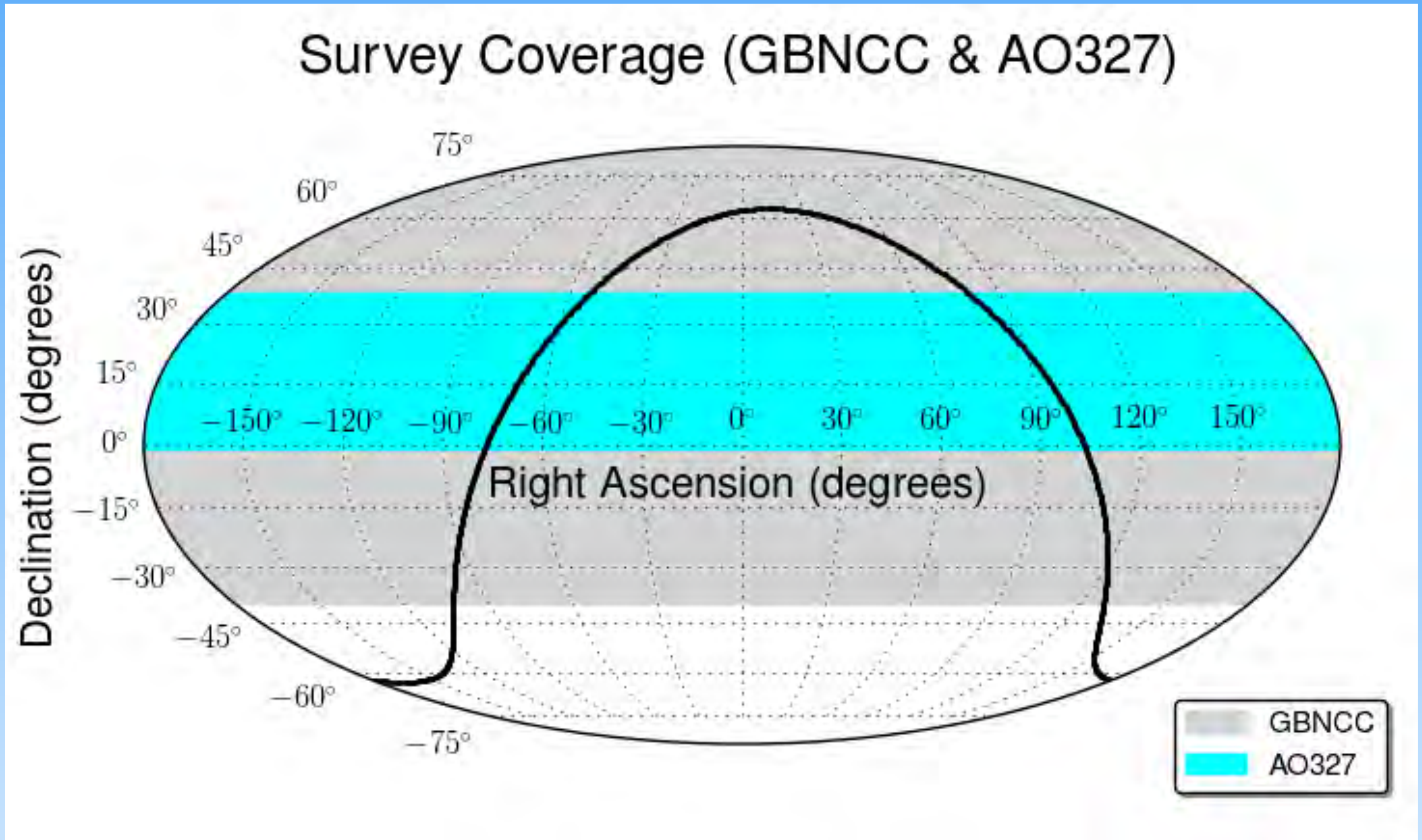
From "Essential Radio Astronomy", Condon & Ransom

Scattering



From "Handbook of Pulsar Astronomy", Lorimer & Kramer

GBNCC Pulsar Survey

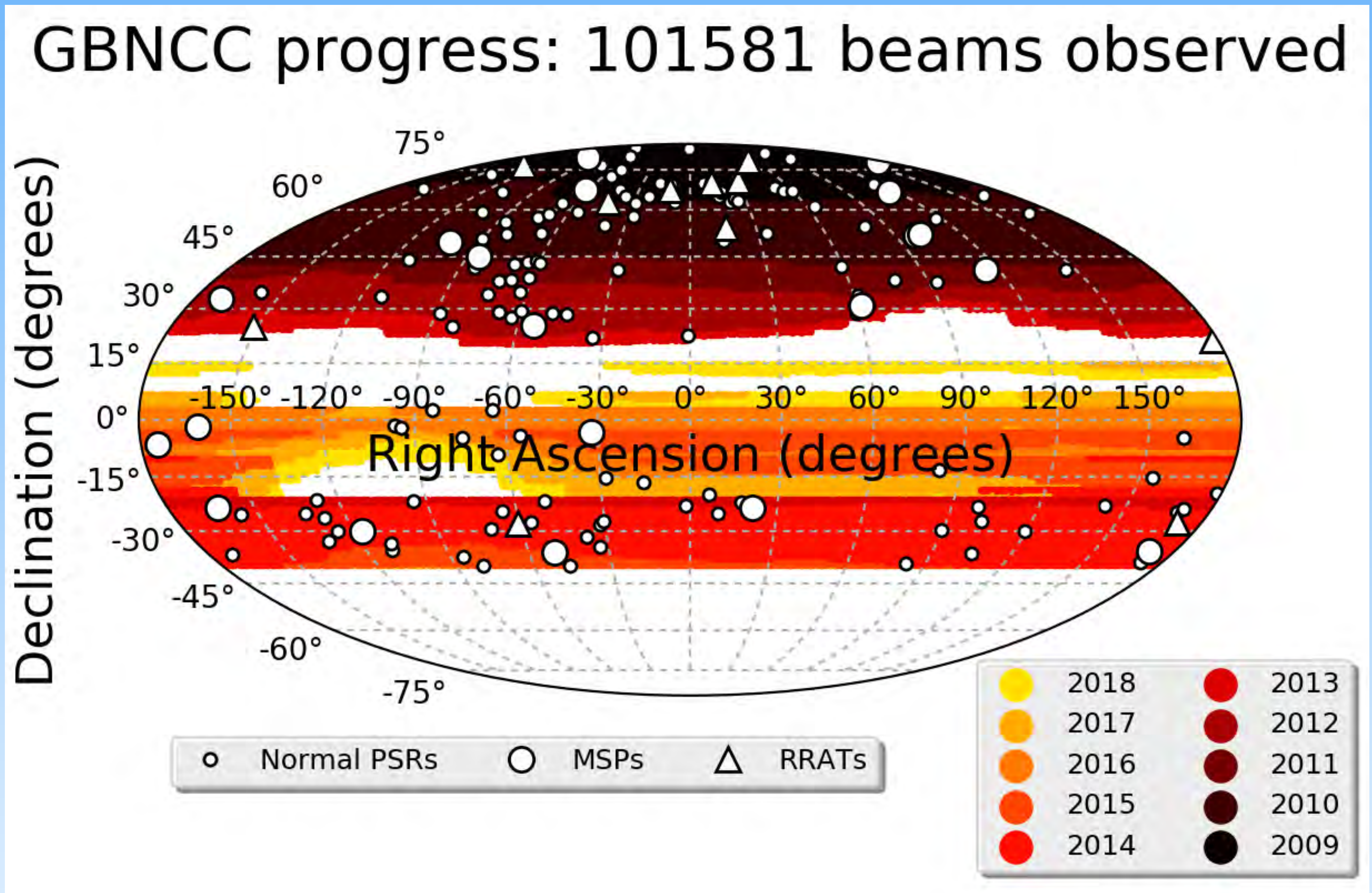


Survey	Center Frequency (MHz)	Bandwidth (MHz)	Frequency Resolution (kHz)	Sample Time (us)	Integration Time (s)	Style
GBNCC	350	100	24	81.92	120	Pointed

GBNCC

161 Pulsars
20 MSPs
11 RRATs
2 DNSs
2 wide binaries
2 low-B pulsars

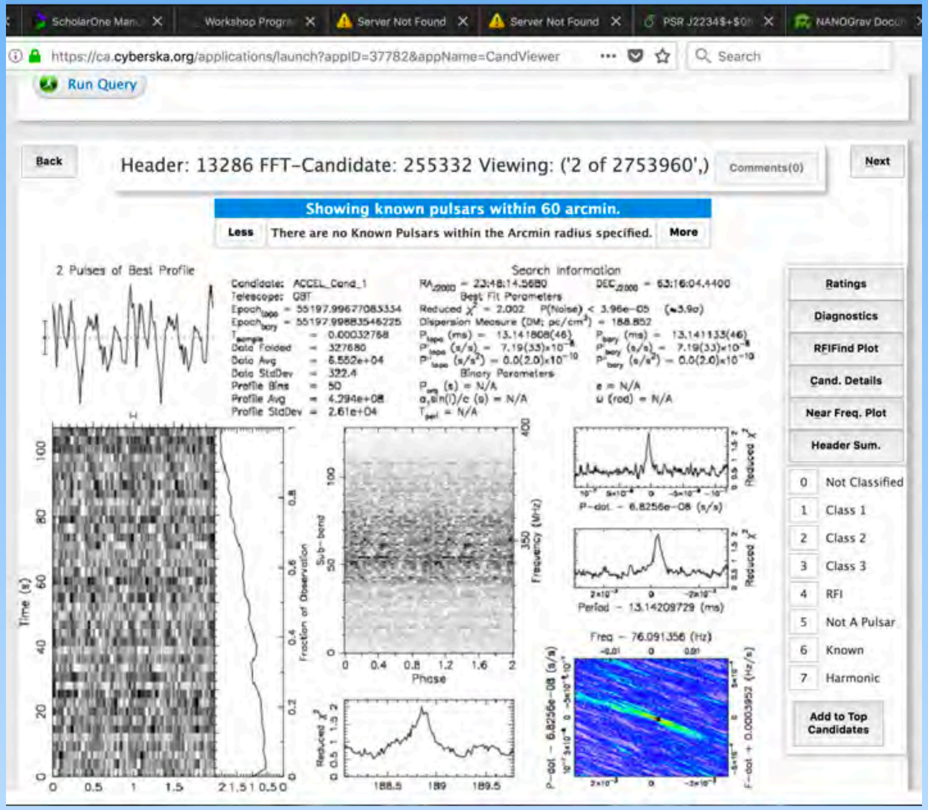
~81% complete

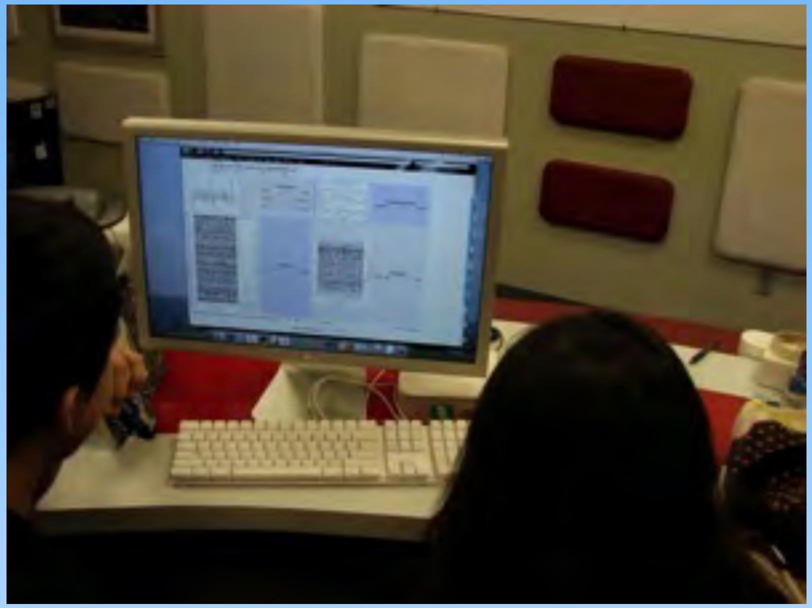


http://astro.phys.wvu.edu/GBNCC/

Student Involvement

Observing, Identifying New Pulsars, and Projects.





Communication

Mailing List (hosted by NRAO)

Monthly telecons (using an NRAO line)

Slack

Trello (for tracking pulsar progress)

Data Storage

Data is moved to storage in Charlottesville soon after observation has ended. It is stored on the lustre filesystem there (many lustre nodes have been purchased by GBNCC personnel).

Size of raw data for current raw data ~700 TB (~850 TB total), we are converting from 8-bit to 2-bit (after it has been searched), so the current usage is ~200TB.

We plan to make data publicly available, but currently only available through request.

Pulsar Search Computing

1) Excise RFI. (Note: We have to remove 360-380 MHz before doing anything else.)
2) De-disperse into “trial DMs” (about 25,000 of them).
3) For each trial DM, perform FFT search (with and without acceleration), single-pulse search, fast folding algorithm (FFA) search.
4) Identify best candidates and make diagnostic plots.

Takes ~45 hours of CPU time per beam. So, pulsar searching is done on HPC systems. GBNCC has mostly been processed using the Guillimin HPC machine from Compute Canada.

Identification of New Pulsars

Each search of a beam produces ~50 candidates => 5 million diagnostic plots.

We run the candidate plots and their associated information through some rating algorithms to help identify the real pulsars.

The highest rated candidates are then looked at by a person using a "candidate viewer" that reads data from a database. In addition postdocs and grad students working on these surveys, we have taught high school and undergraduate students from many institutions to identify new pulsars.

Follow-up of New Pulsars

- Confirm through observing it again.

- Propose to “time” the new pulsars. This entails some observations close together, ranging from back-to-back days to a few days. Then monthly observations over a year. (Note: We have had issues getting the time needed for this on the GBT.)

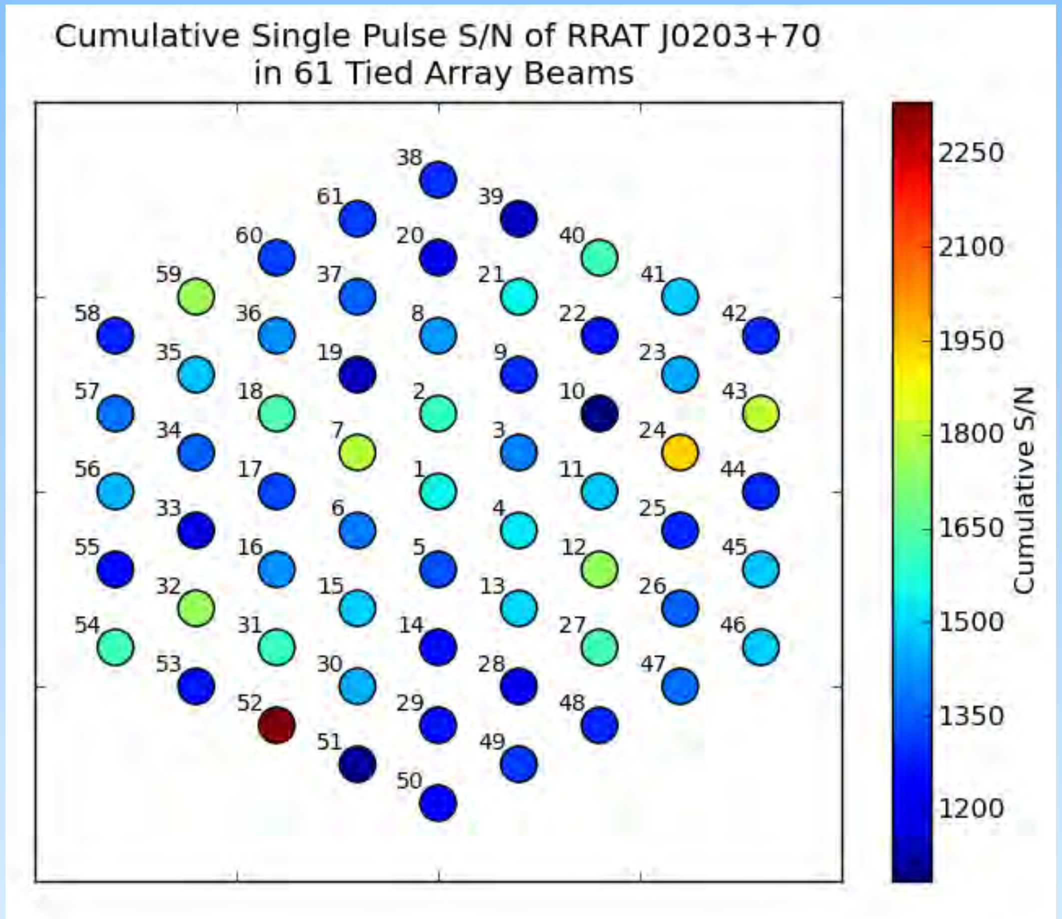
- Binary systems require more close together observations.

- We follow-up in other wavelengths as needed.

Follow-up beyond GBT

LOFAR

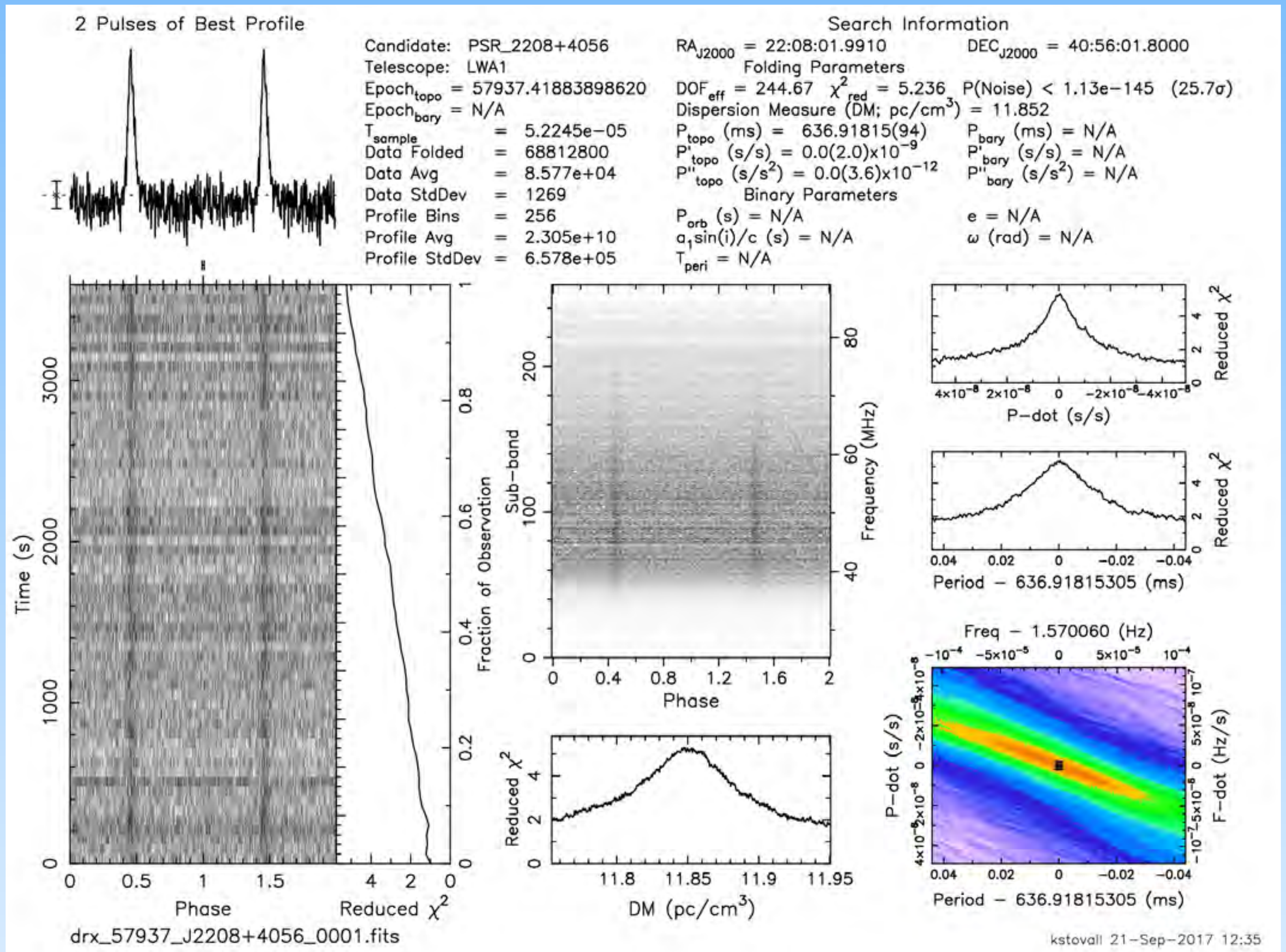
Localization and timing of ~40 pulsars



Karako-Argaman et al. 2015, ApJ, 809, 67

LWA1

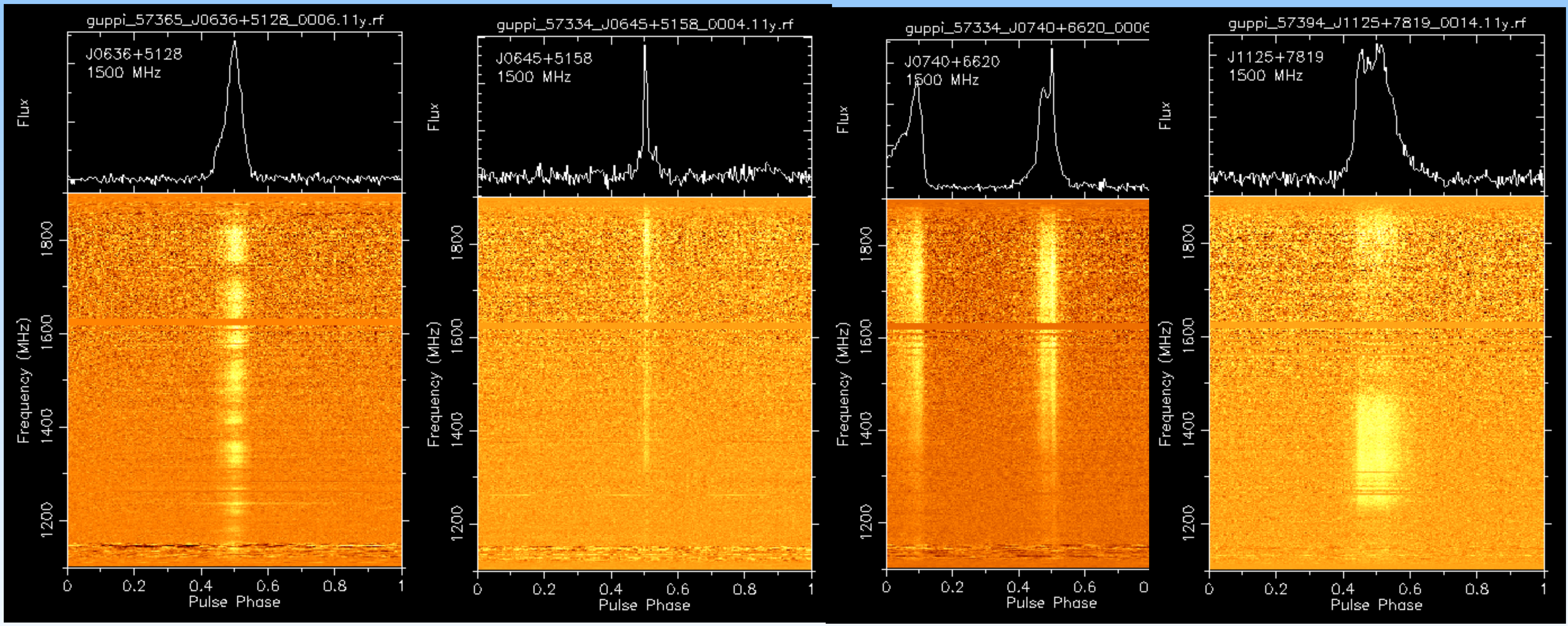
Timing of 2 pulsars



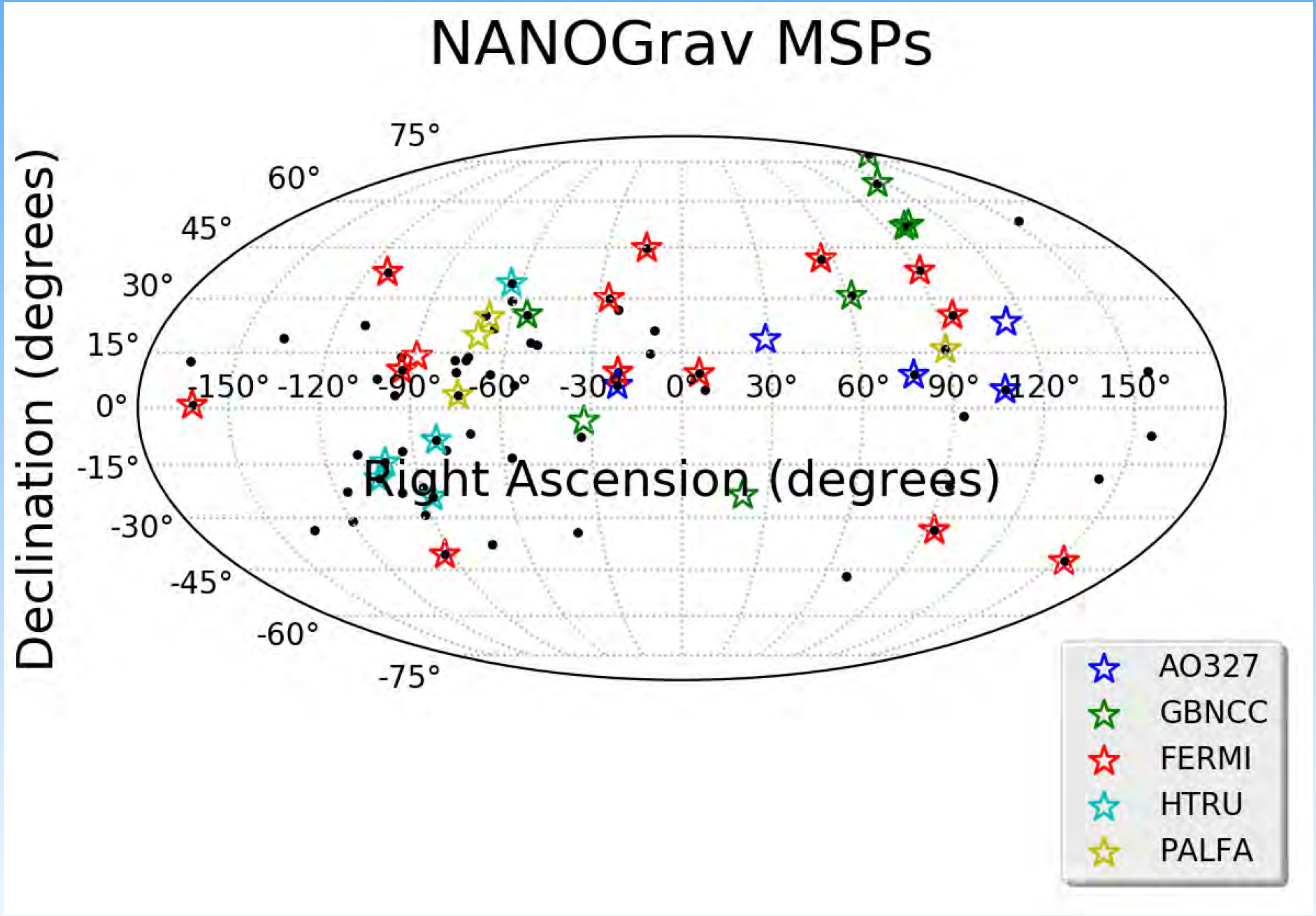
We have also begun to observe some pulsars with GMRT.

GBNCC Discoveries

6 MSPs added to NANOGrav so far, 2 more currently being tested for potential inclusion and ~5 others currently being follow-ed up that may be included in the future



Survey Contributions to NANOGrav



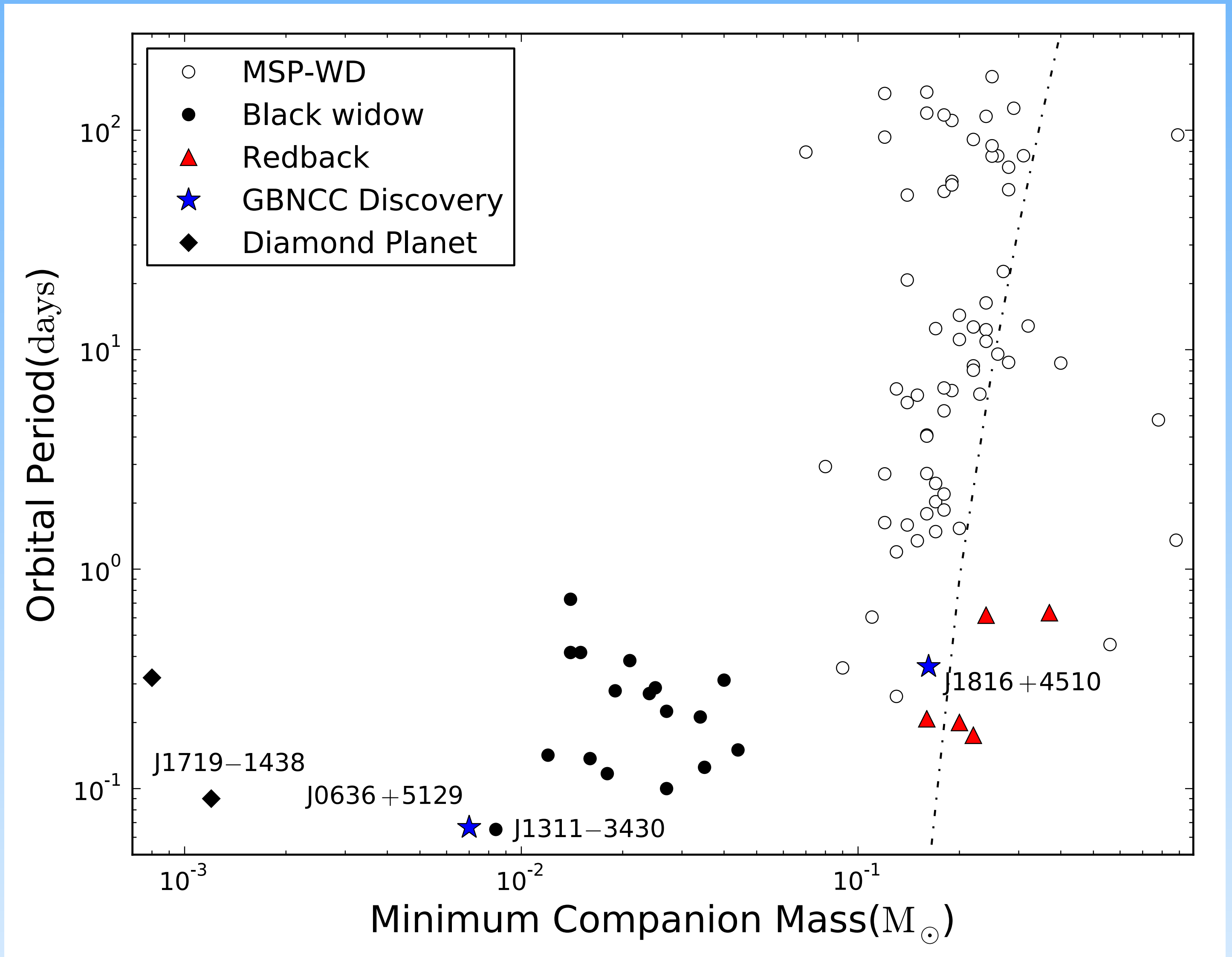
GBNCC Discoveries

J0636+5128

- Is a 2.87-ms pulsar in a 96-minute orbit with a 0.008 solar mass (9 M_J) companion.

- Assuming inclination angle of 60 degrees: separation between the two stars is about 0.5 solar radii

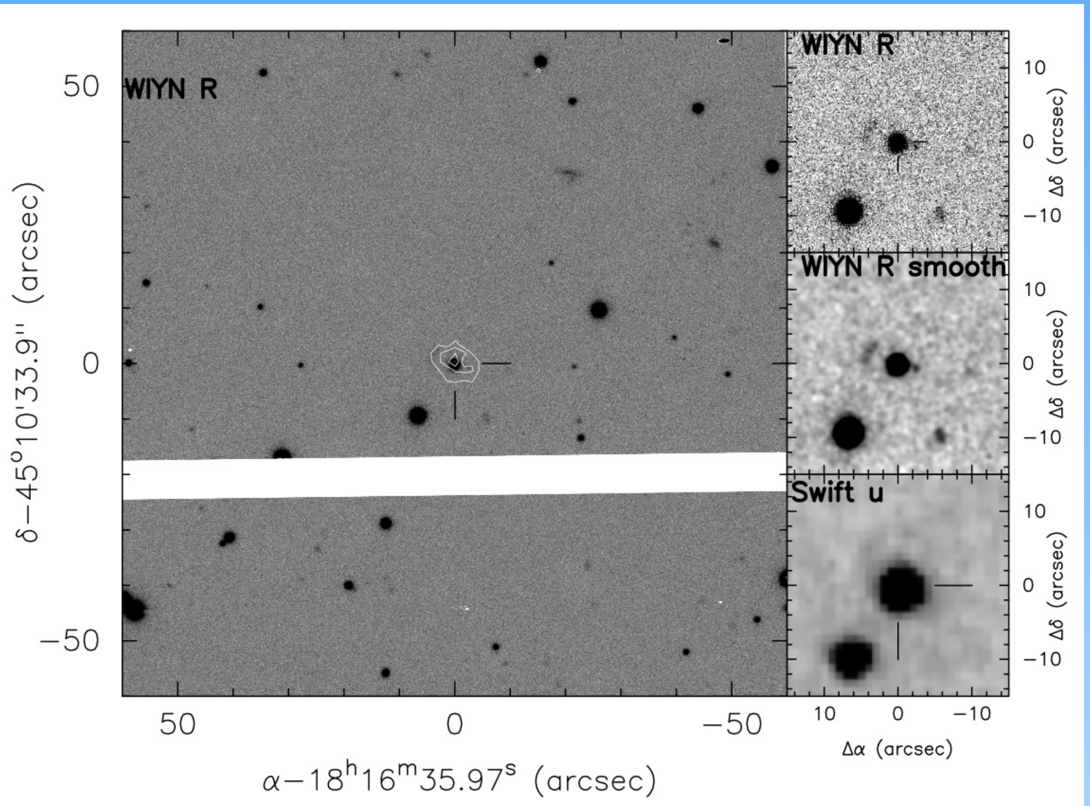
- Appears to be a black widow system, but no radio eclipses

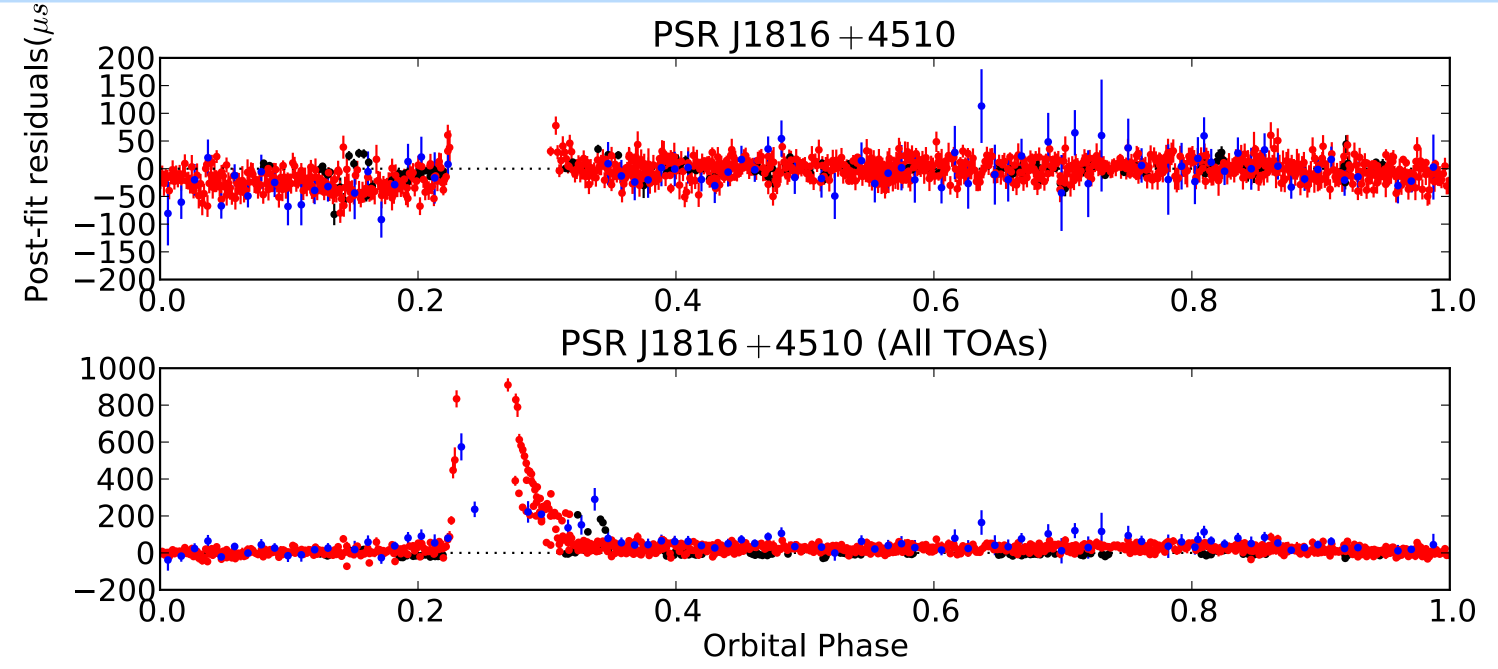


GBNCC Discoveries

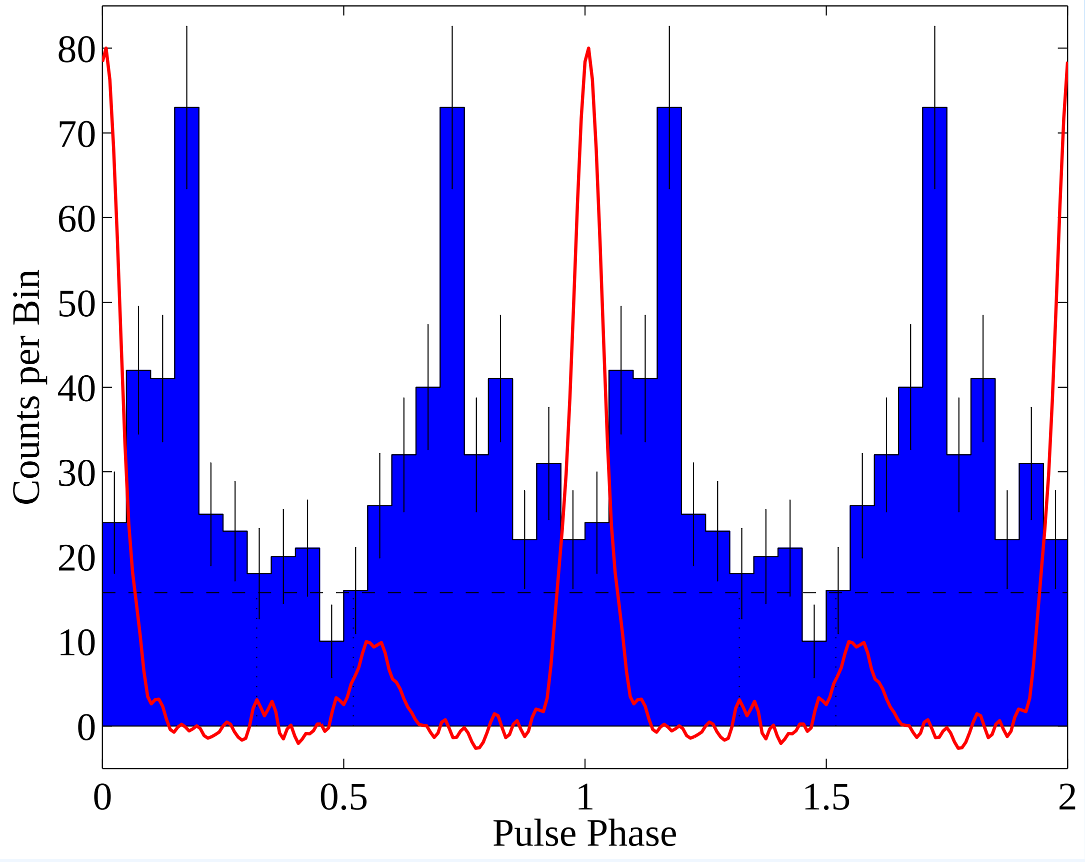
J1816+4510

- Eclipsing system with an optically detected companion.
- Spectrum is most similar to a white dwarf, but has high metallicity.
- Pulsar mass is ~1.84(11) solar masses.





Stovall et al. 2014, ApJ, 791, 67

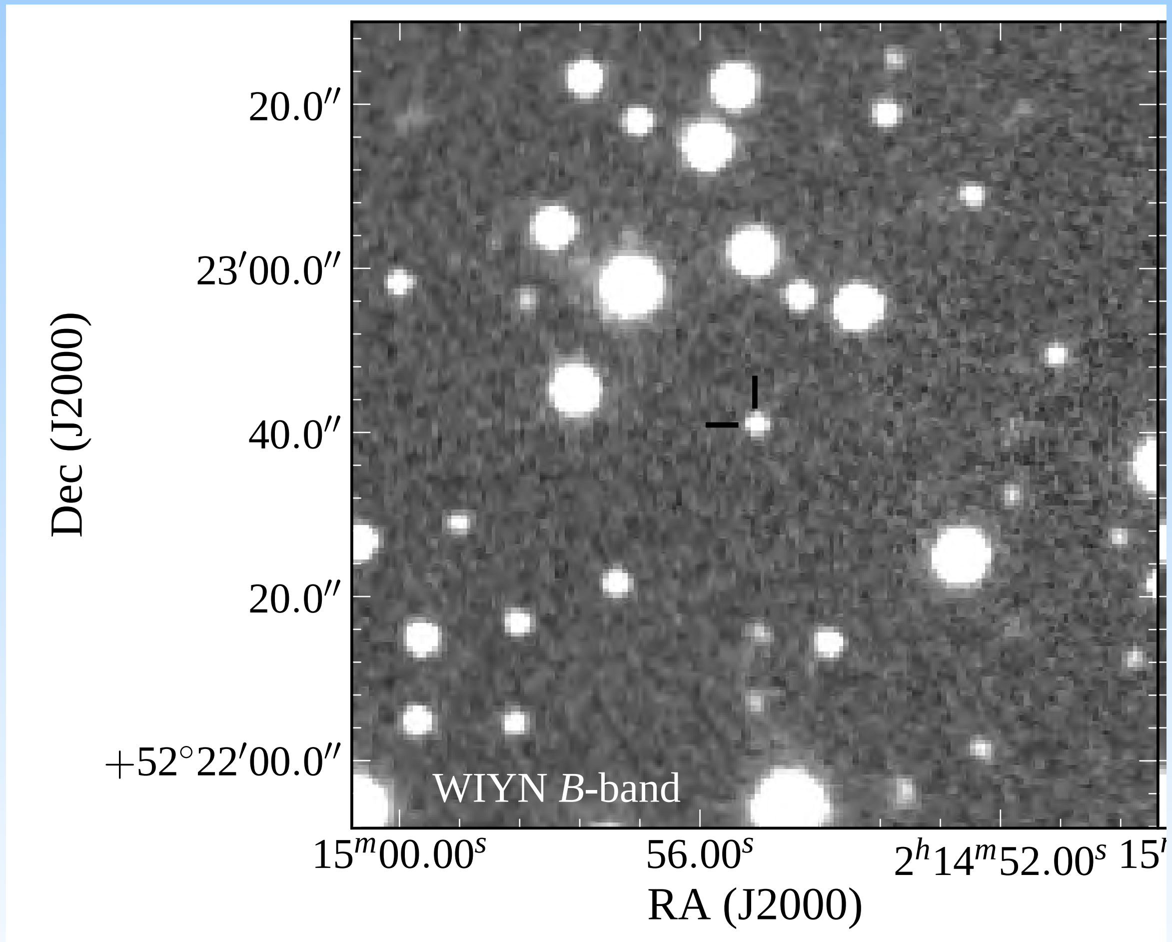


Kaplan et al. 2012, ApJ, 753, 174

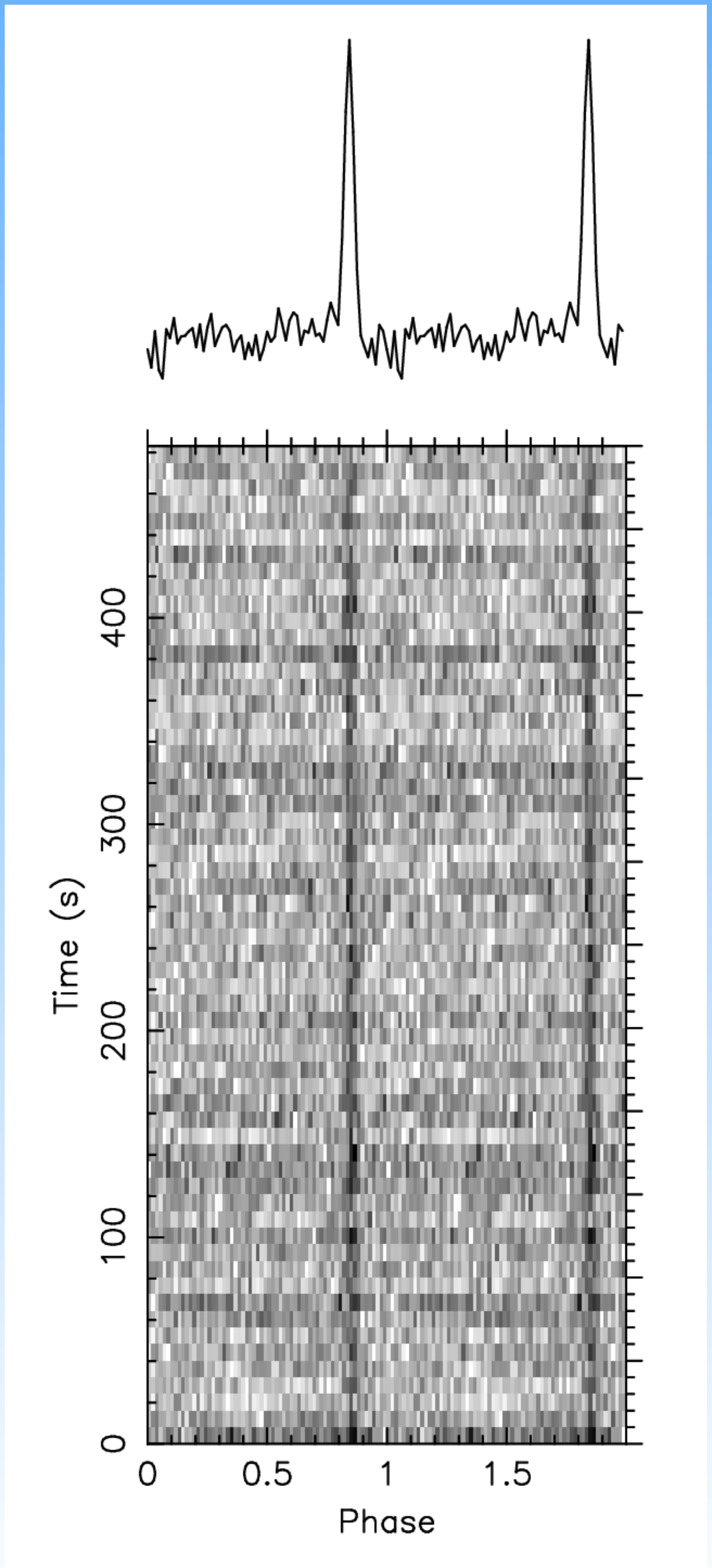
GBNCC Discoveries

J0214+5222

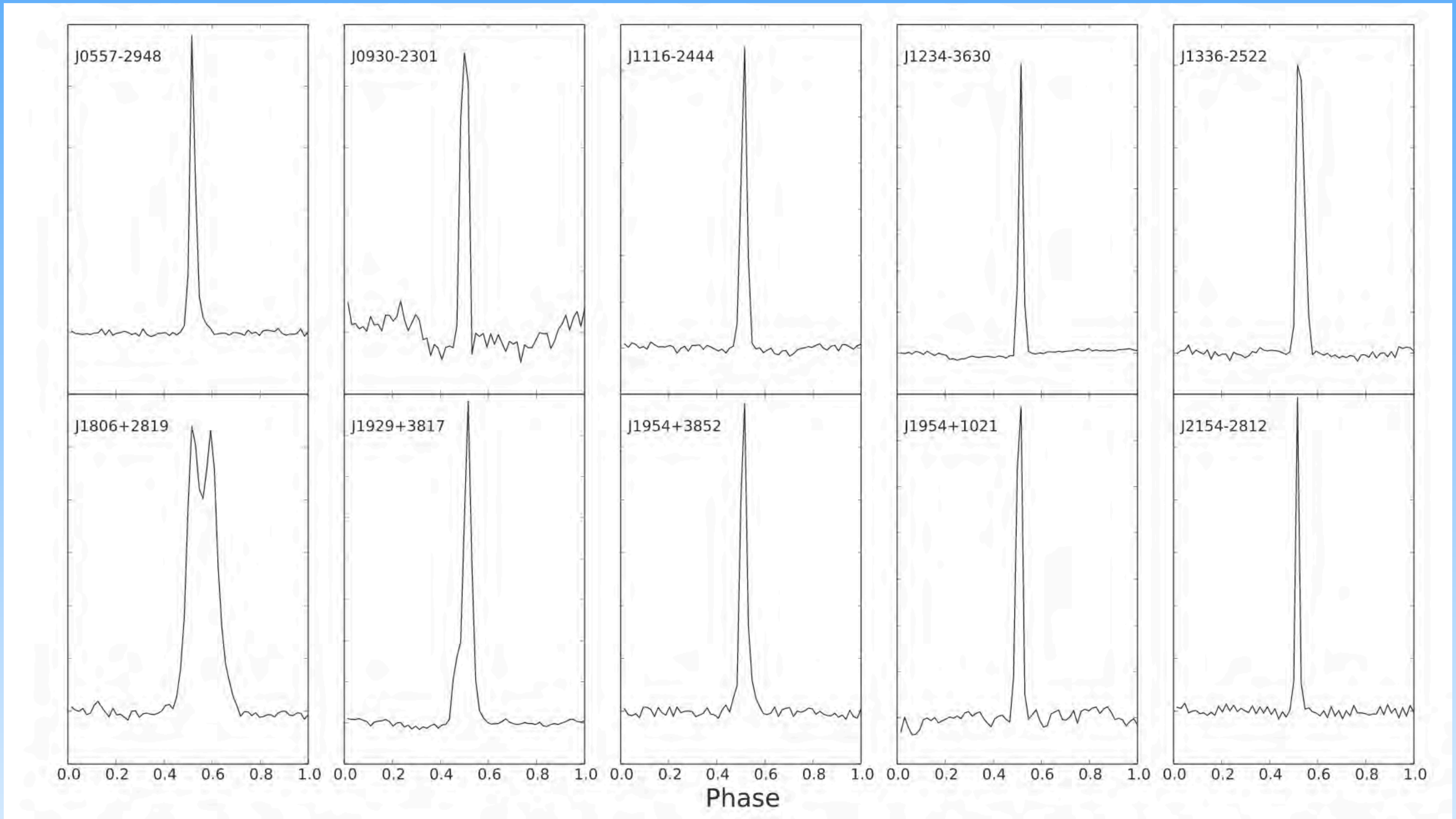
- 24.5 ms pulsar with a DM of 22 pc/cm^3 (D~1 kpc).
- In a 512 day orbit with a ~0.4 solar mass companion.



Stovall et al. 2014, ApJ, 791, 67



Recent GBNCC Publications

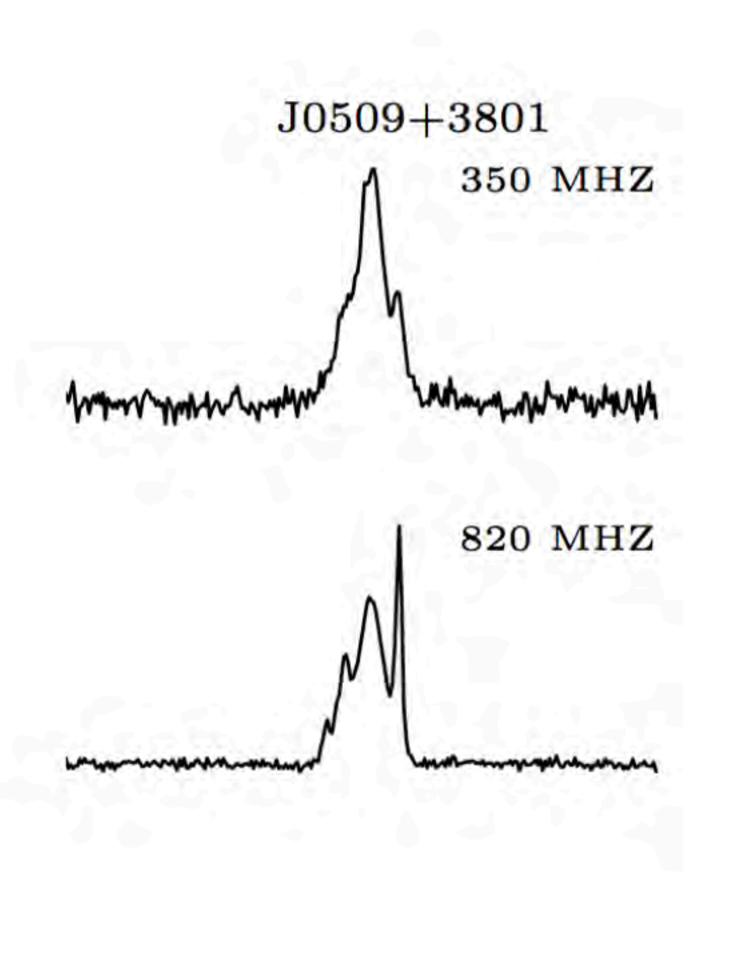


Kawash et al. 2018, ApJ, 857, 131: Timing for 10 new pulsars including a 15-ms pulsar in orbit with a ~0.25 M_sol companion, a partially recycled pulsar, and a nulling and possibly mode changing pulsar.

Recent GBNCC Publications

J0509+3801

- 76.5 ms pulsar with a DM of 69 pc/cm^3 (D~2 kpc).
- In a 9-hour eccentric (e=0.59) orbit.
- Advance in periastron passage is 3.031(2) deg/yr, M_tot=2.805(3).
- Gravitational redshift and time dilation=0.0046(3) s.



M_p=1.36(8)

M_c=1.45(8)

Lynch et al. 2018, ApJ, 859, 93: Timing solutions for 44 pulsars, including a DNS, an intermediate mass binary, a mode switching pulsar, a 138-ms pulsar with a low magnetic field, and multiple nulling pulsars.

FRB Limits

No FRBs detected in GBNCC data despite 61 days on sky searched up to a DM of 3,000 pc/cm^3 plus 23 days searched up to 500 pc/cm^3.

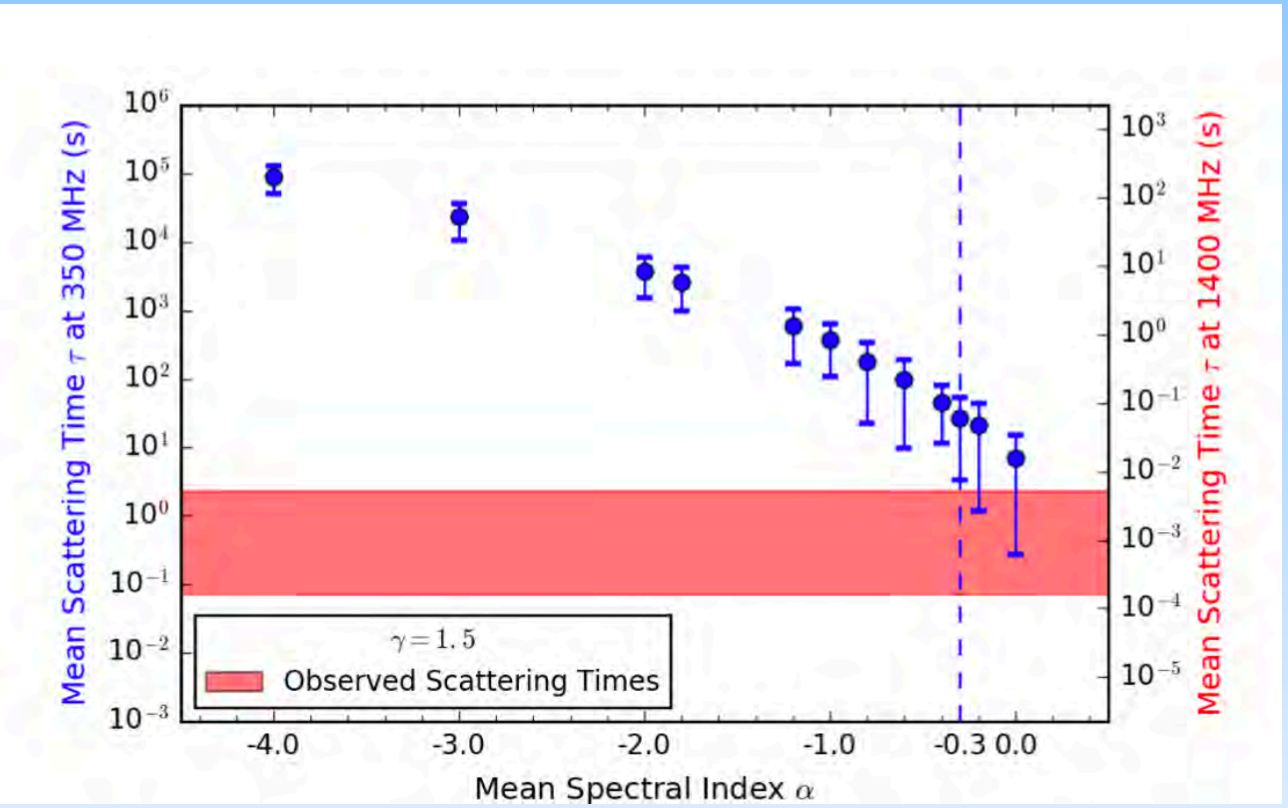


Table 2. Spectral Index Constraints

γ	No Scattering/FF[a]	Scattering[b] Crawford et al.	Scattering[b] Champion et al.
0.8	> 0.19	> -0.9	> -1.5
1.2	> 0.28	> -0.6	> -1.2
1.5	> 0.35	> -0.3	> -0.9

Chawla et al. 2017, ApJ, 844, 140

Items for GBO relevant for GBNCC and future pulsar surveys:

Webpage

Follow-up time

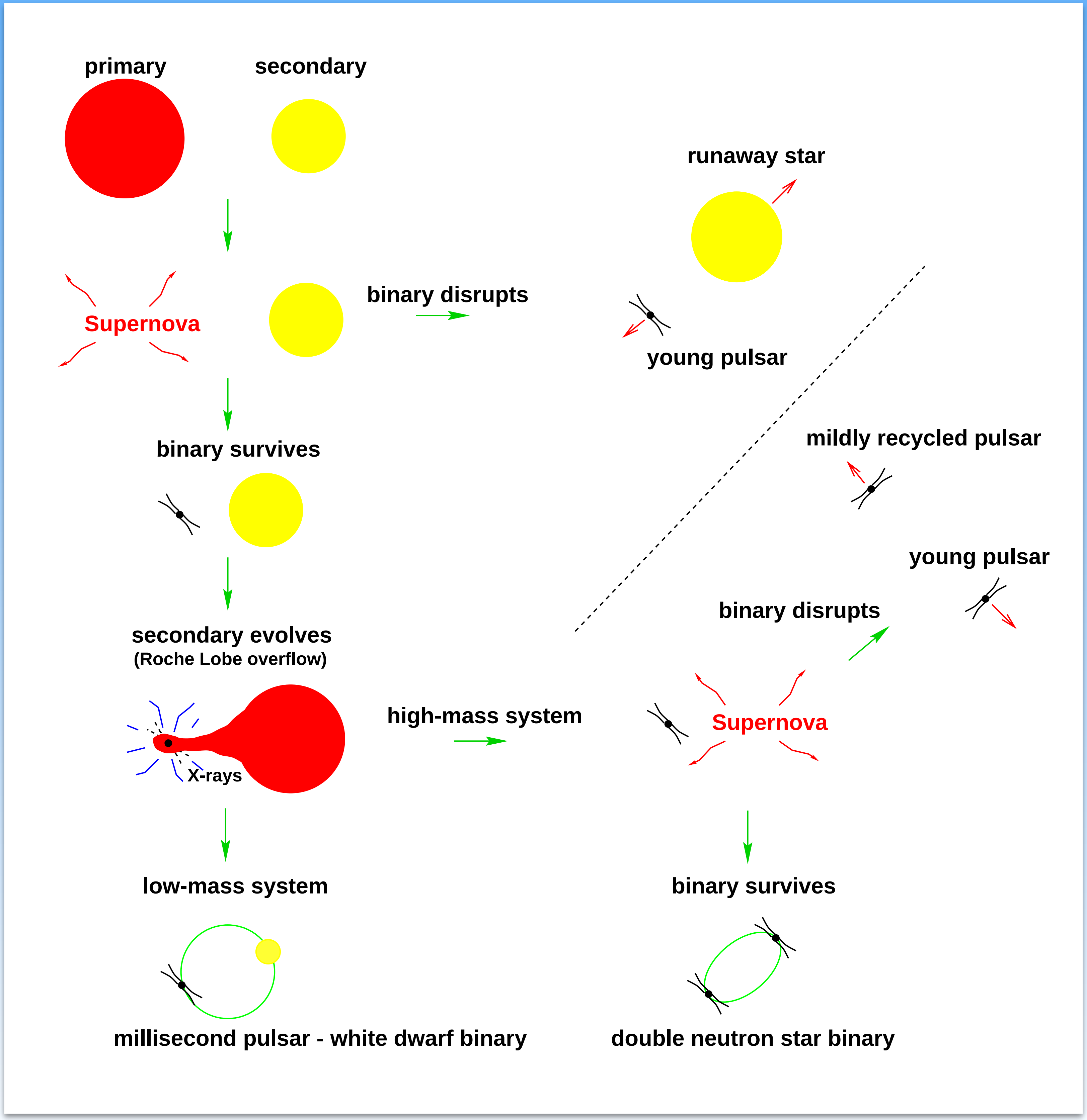
RFI (especially 360-380 MHz)

Data archiving

New receivers (FLAG and ultra wideband).

Observer training sessions have been very beneficial.

Pulsar Binary Evolution



Lorimer, 2008, LRR, 11