The Green Bank North Celestial Cap Pulsar Survey

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GBNCC Collaboration

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GBNCC Collaboration

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Pulsars Have a Variety of Applications

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

Study of Medium
- Dispersion
- Scattering/Scintillation
- Faraday rotation

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

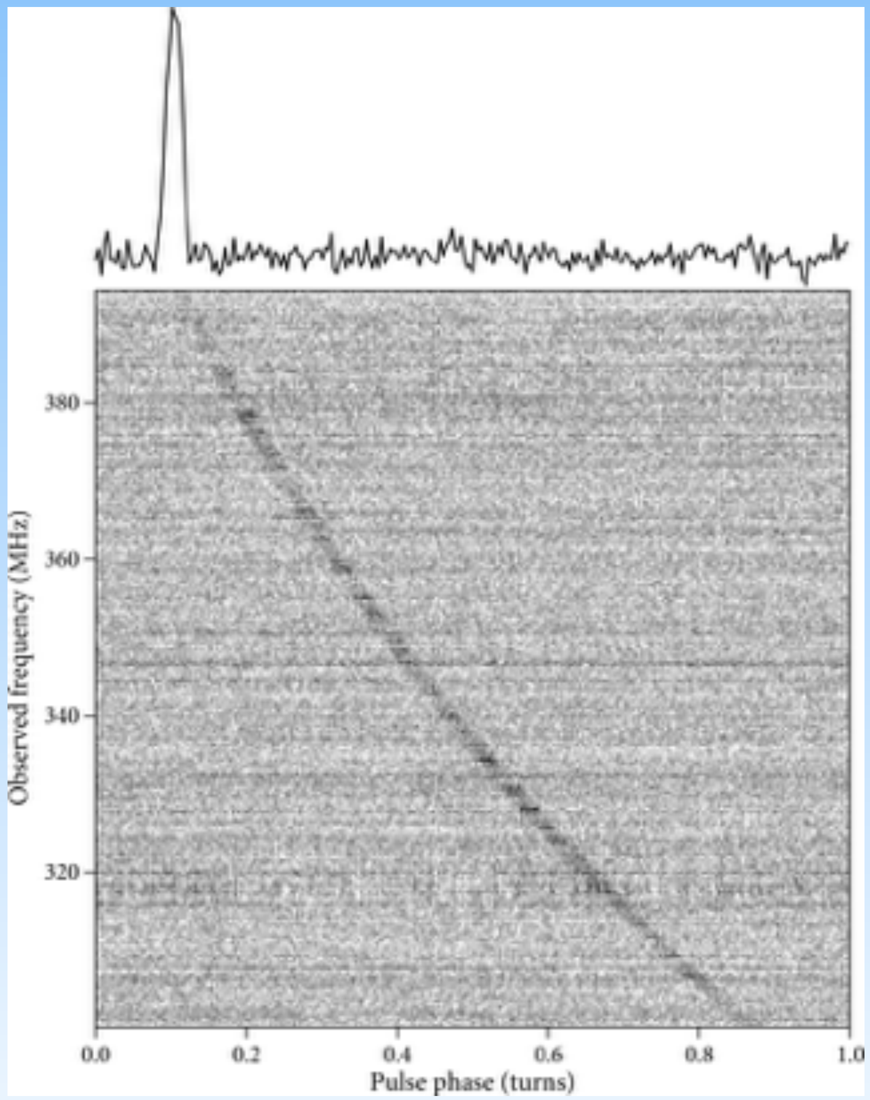
Theories of Gravity
- Tests of GR
- Tests of Alternatives
- Gravitational Waves

Interstellar Medium Effects

Dispersion

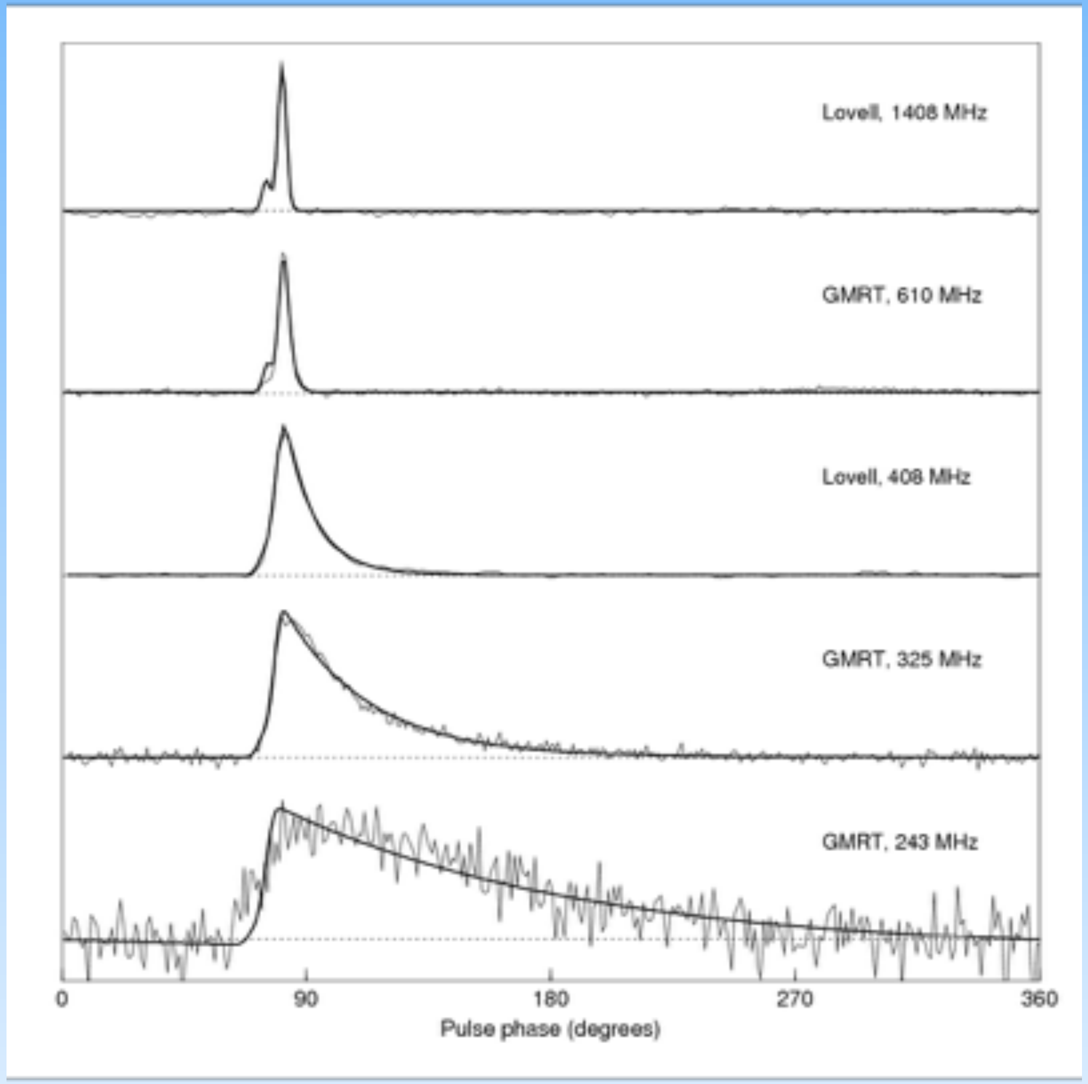
Delay $\propto$ DM ν^{-2}

DM = $\int_0^d n_e dl$



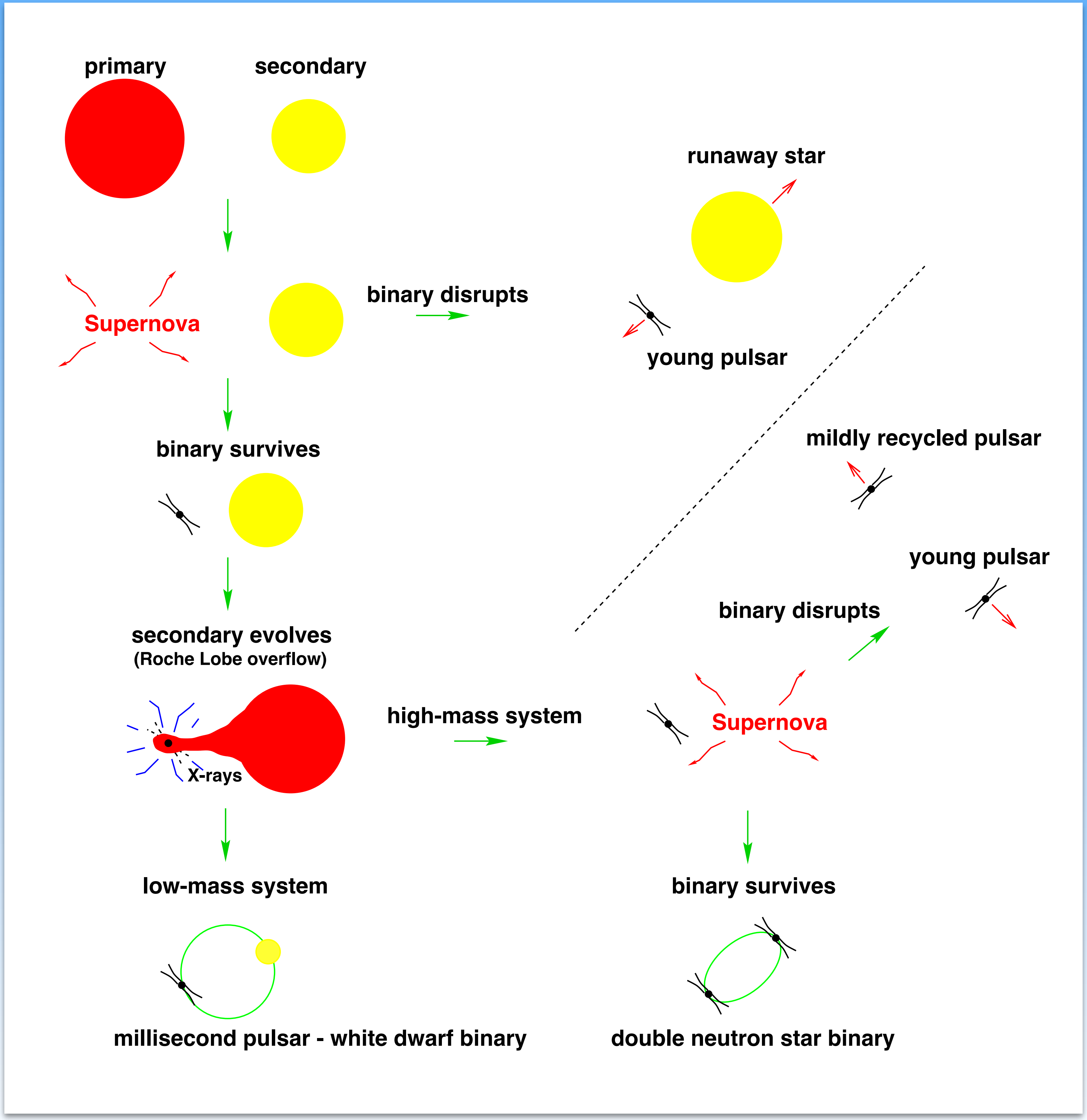
From "Essential Radio Astronomy", Condon & Ransom

Scattering



From "Handbook of Pulsar Astronomy", Lorimer & Kramer

Pulsar Binary Evolution



Lorimer, 2008, LRR, 11

Pulsar Timing Arrays

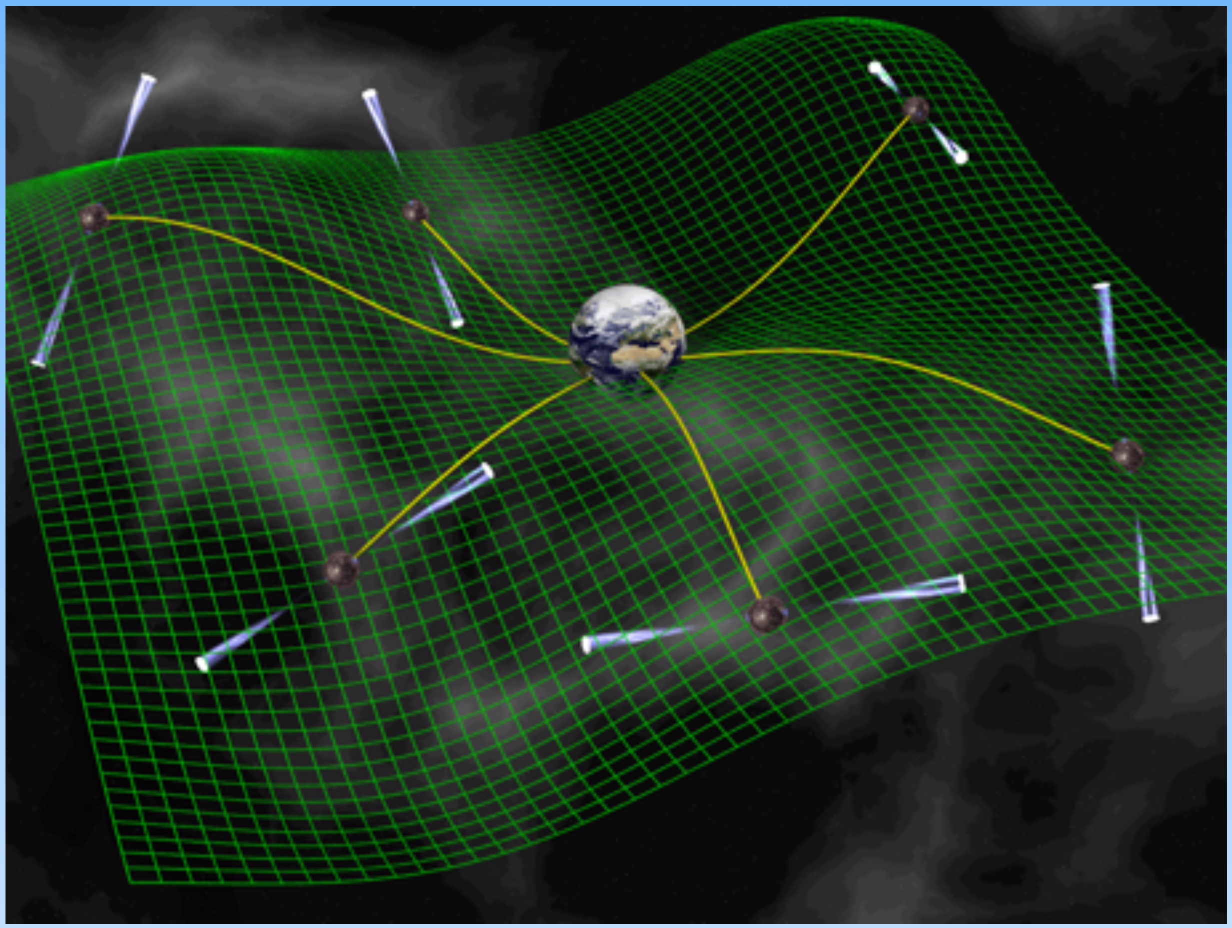
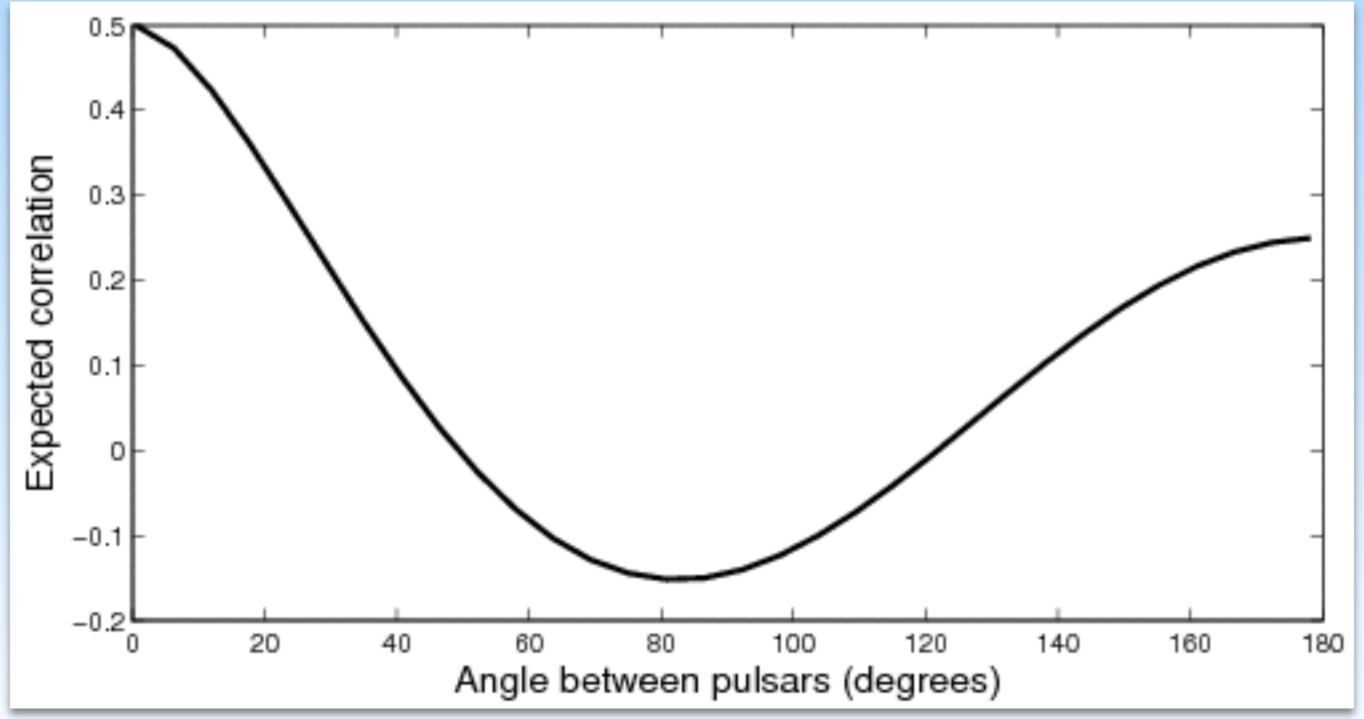


Image Credit: David Champion

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

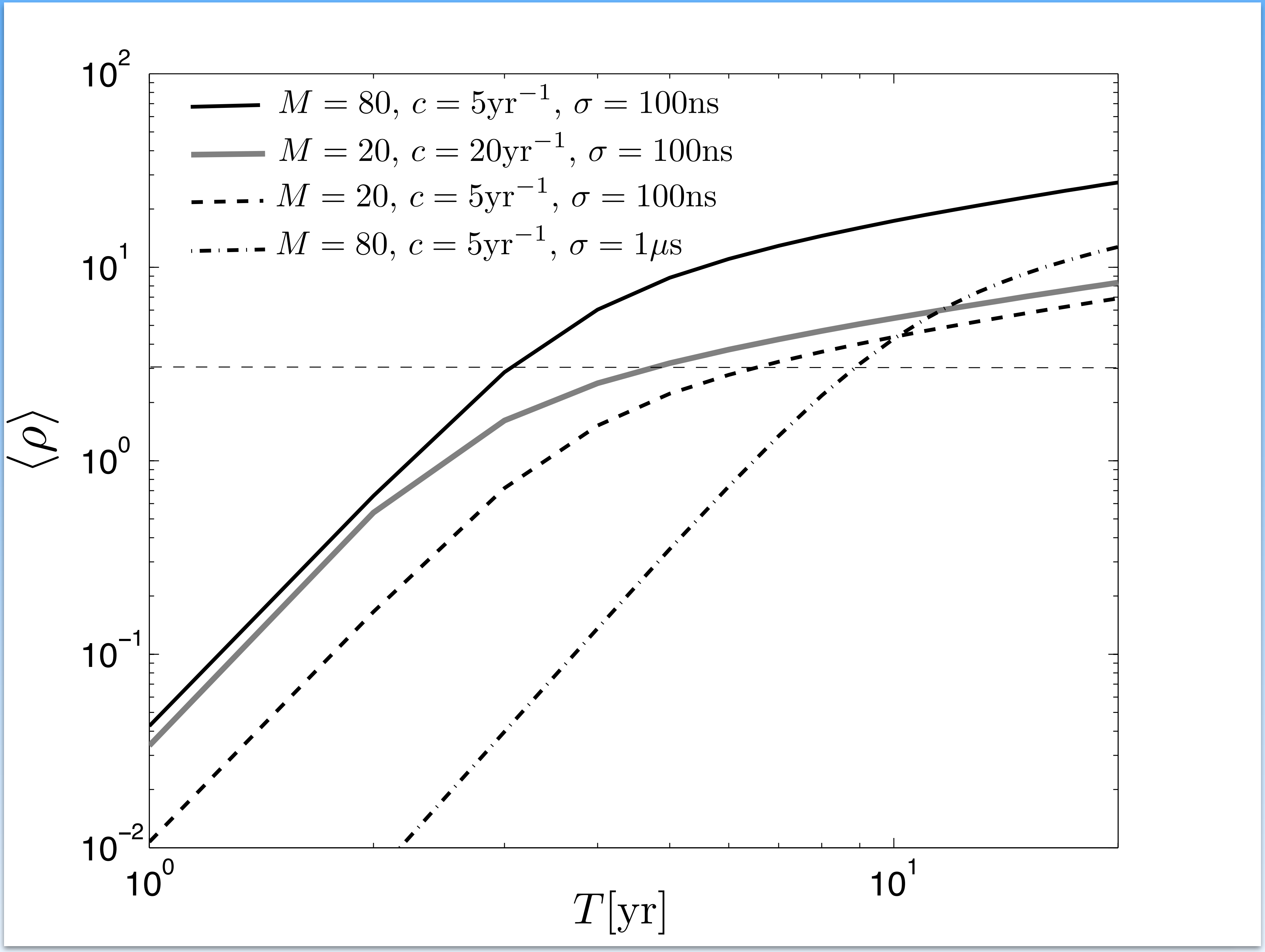
Pulsar Timing Arrays (PTAs) monitor a set of very stable millisecond pulsars (MSPs) to look for GW signals. Such signals would be correlated vs. pulsar angular separation.

Hellings & Downs Curve



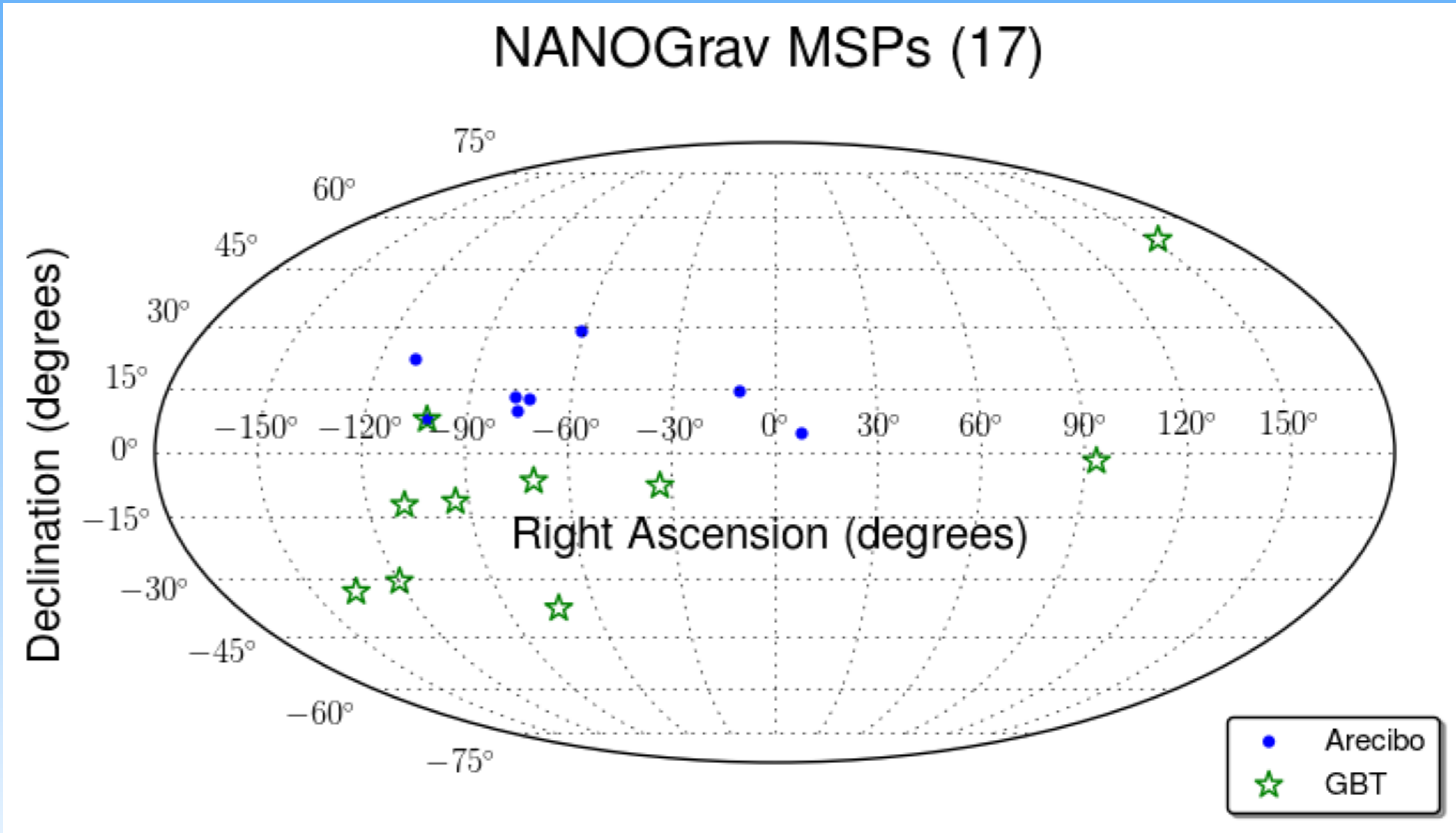
Hellings & Downs 1983, ApJ, 265, 39

Improving PTA Sensitivity



Siemens et al. 2013, CQG, 30, 4015

NANOGrav MSPs in 2009



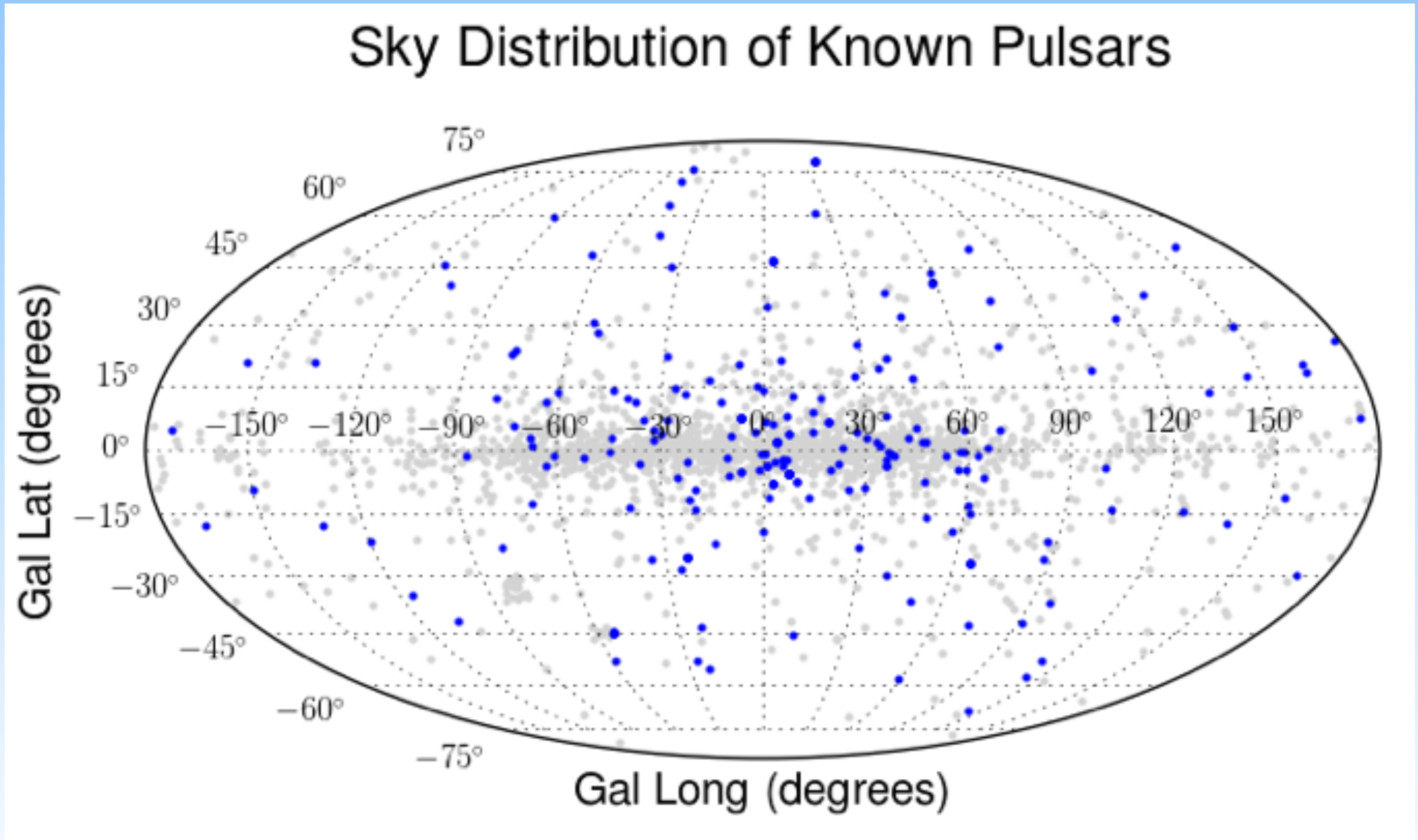
Where to Search for MSPs?

Nearby MSPs are expected to be essentially isotropic.

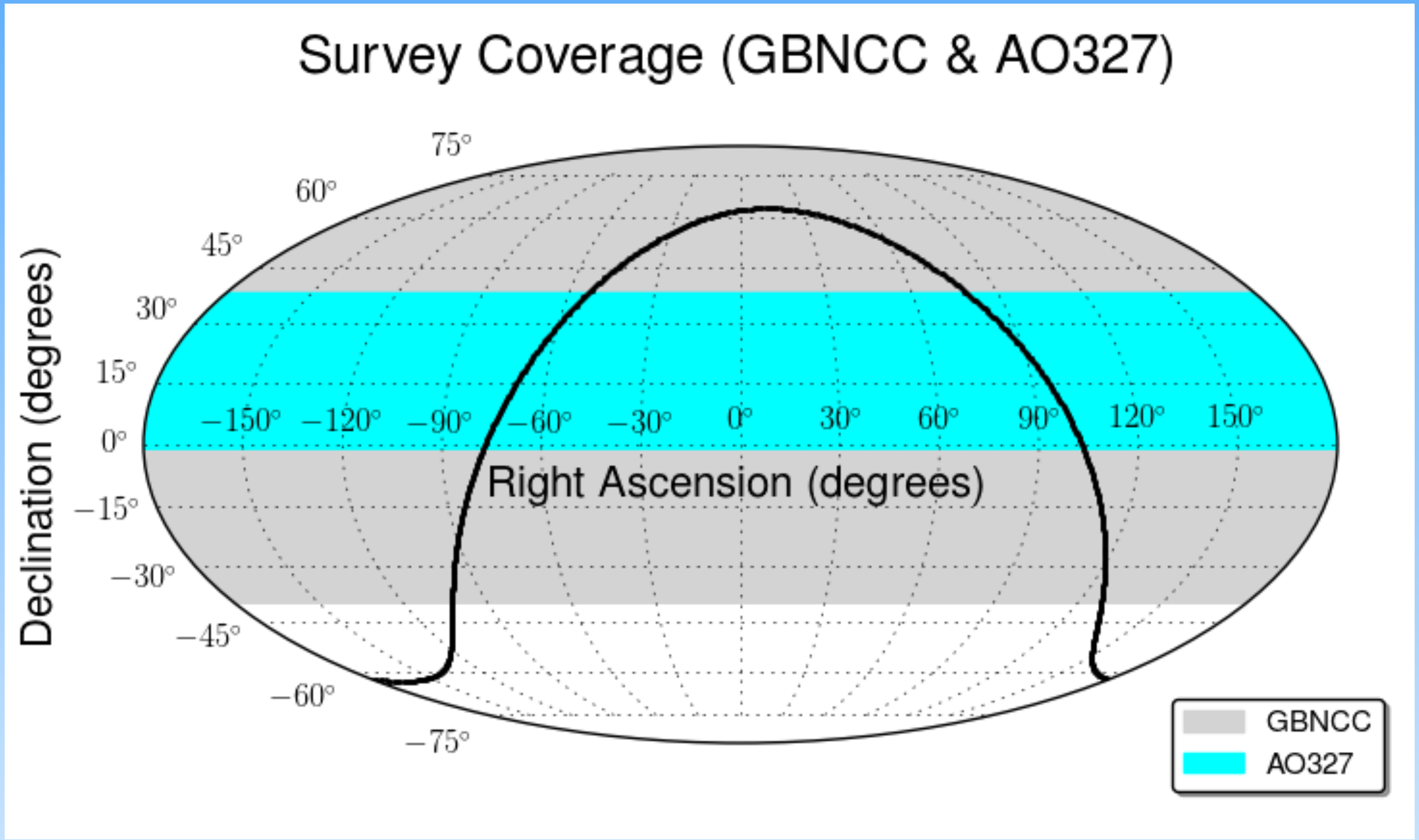
Searches in 1990s found many MSPs at a wide range of Galactic latitudes.

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



GBNCC Pulsar Survey



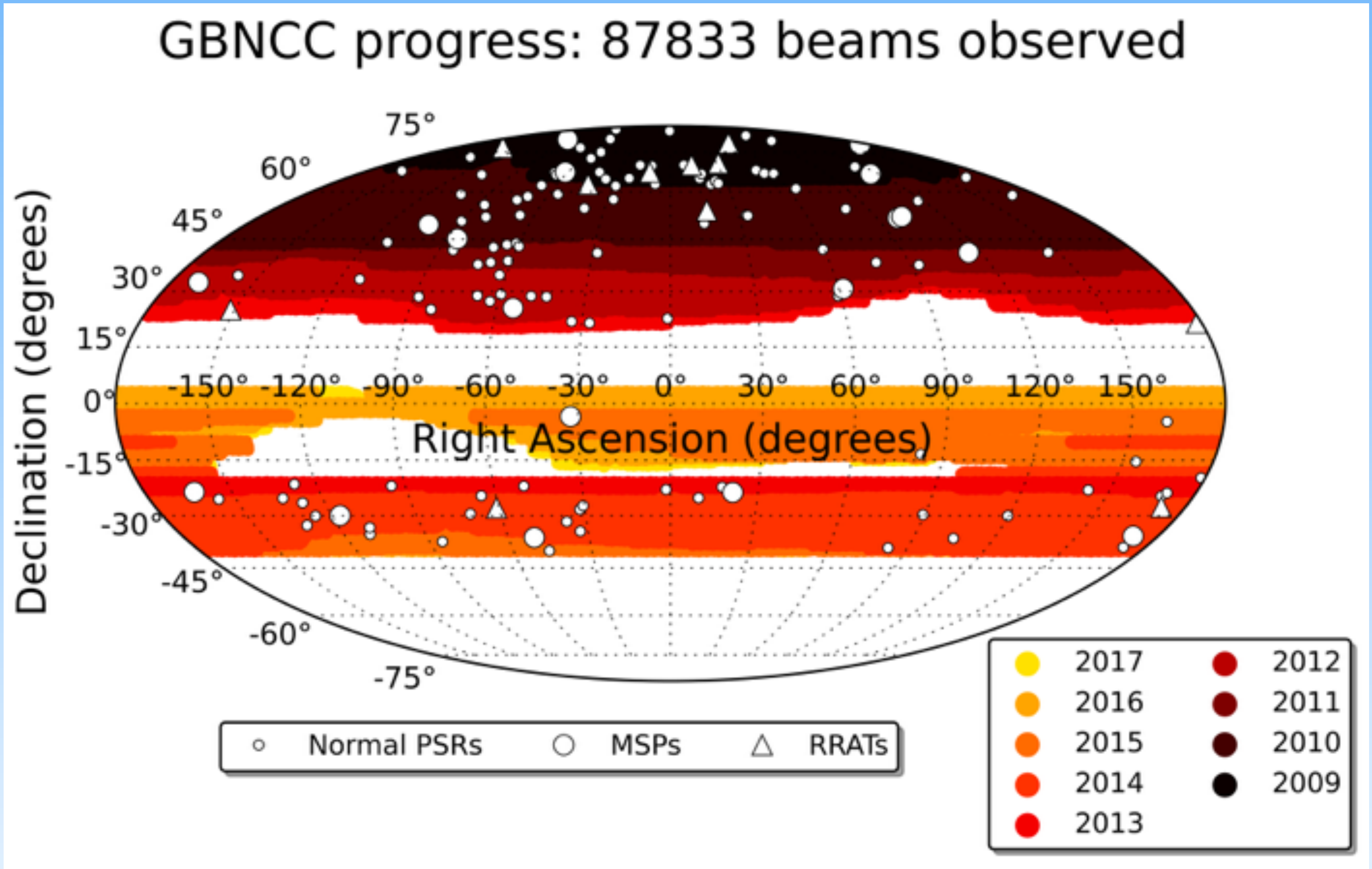
Survey	Center Frequency (MHz)	Bandwidth (MHz)	Frequency Resolution (kHz)	Sample Time (us)	Integration Time (s)	Style
GBNCC	350	100	24	81.92	120	Pointed

GBNCC

156 Pulsars
20 MSPs
11 RRATs
1 DNS
2 wide binaries
2 low-B pulsars

~75% complete

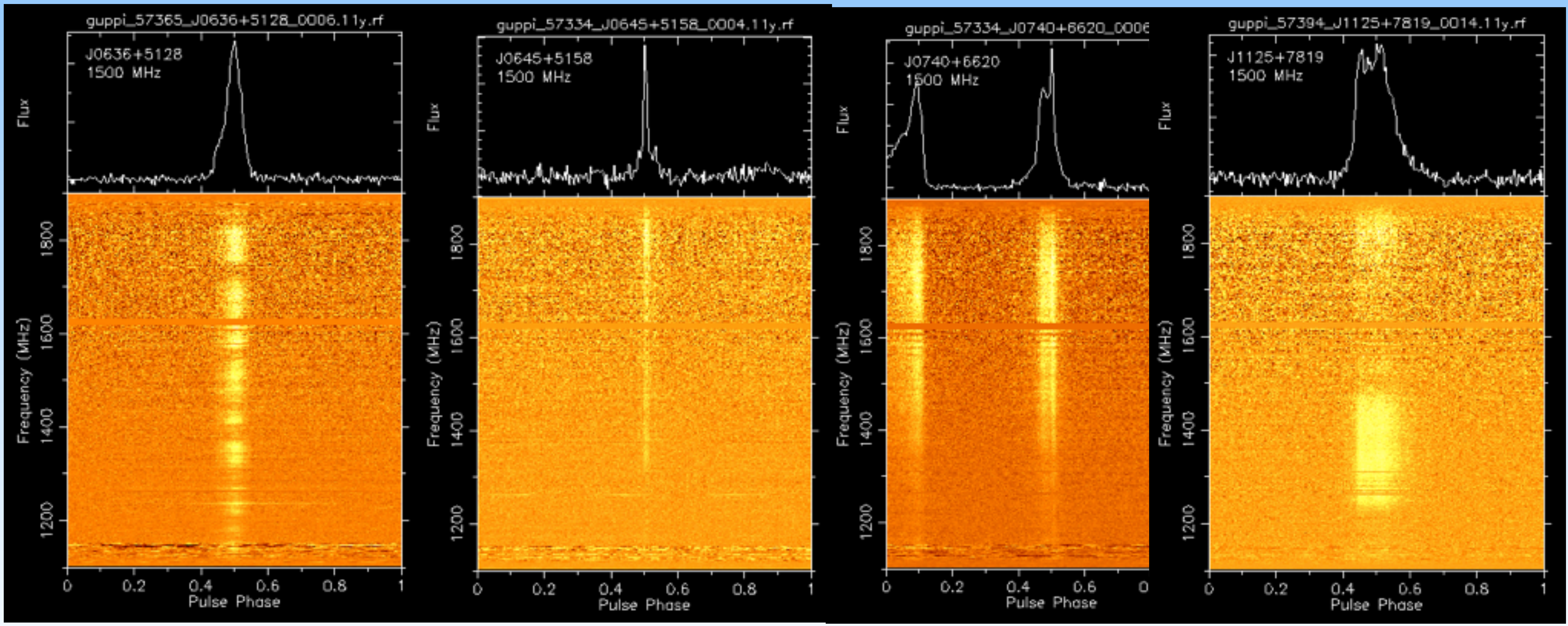
we plan to make data available, ~500 TB, we are converting from 8-bit to 2-bit



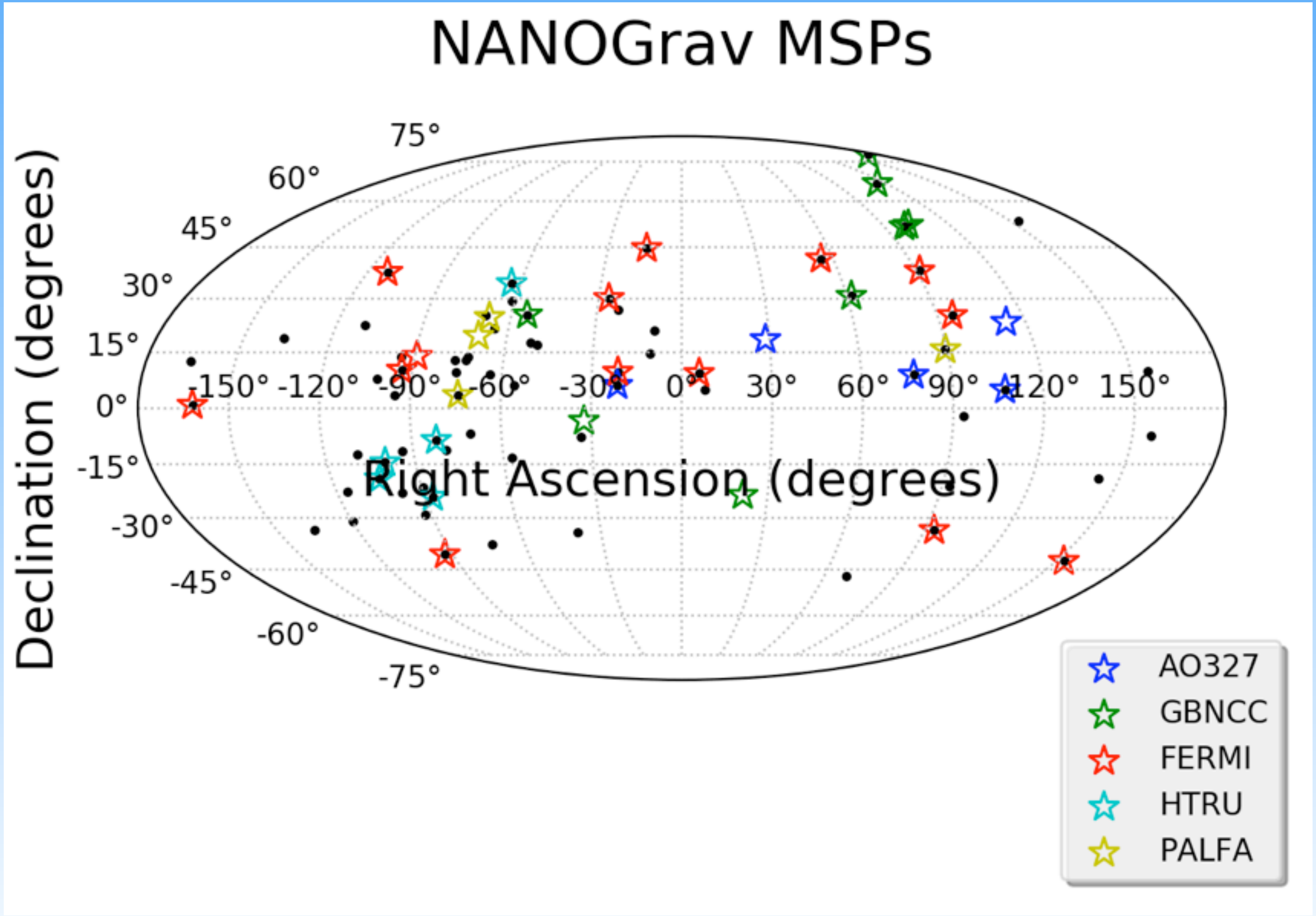
http://astro.phys.wvu.edu/GBNCC/

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



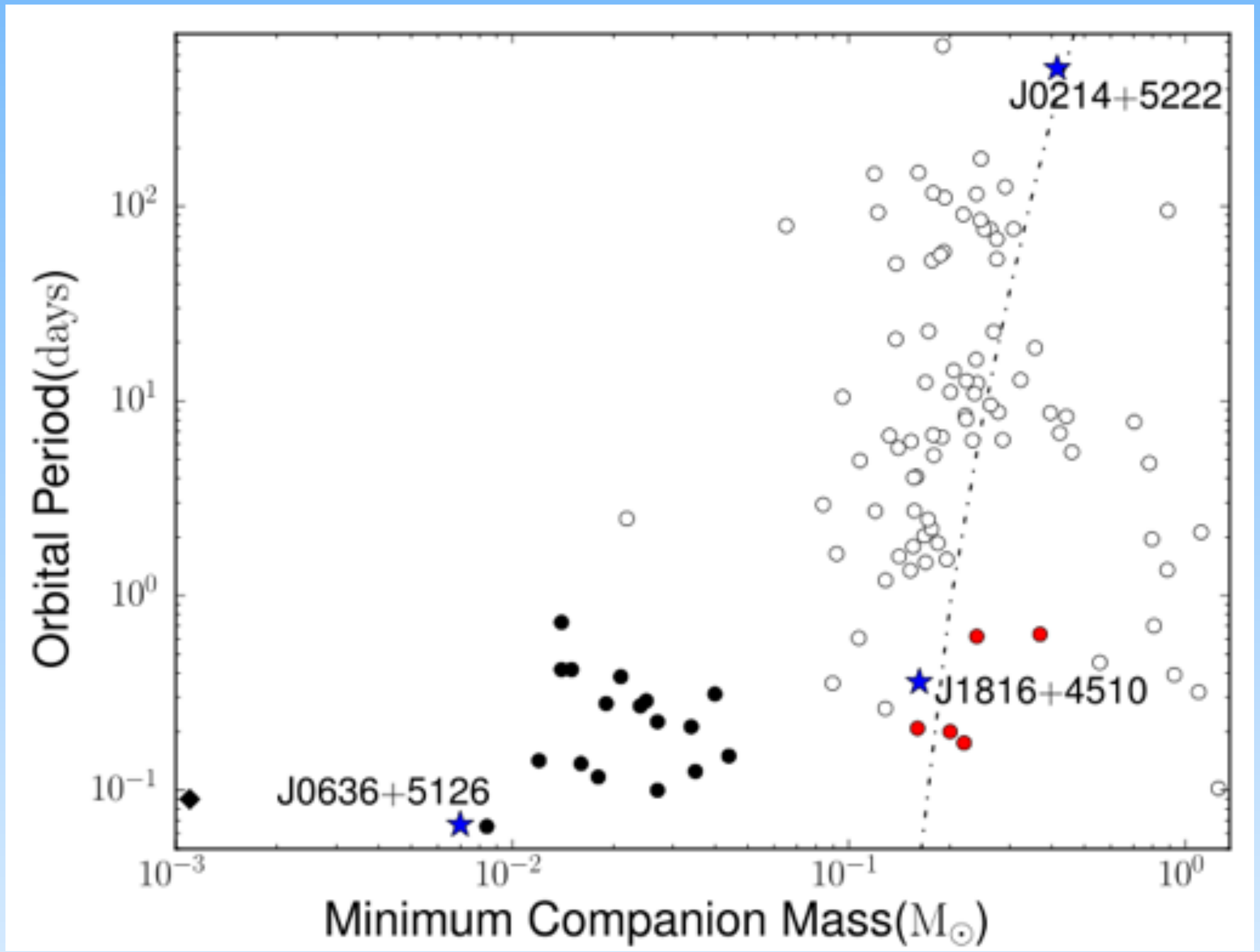
GBNCC Discoveries

J0636+5129

- 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

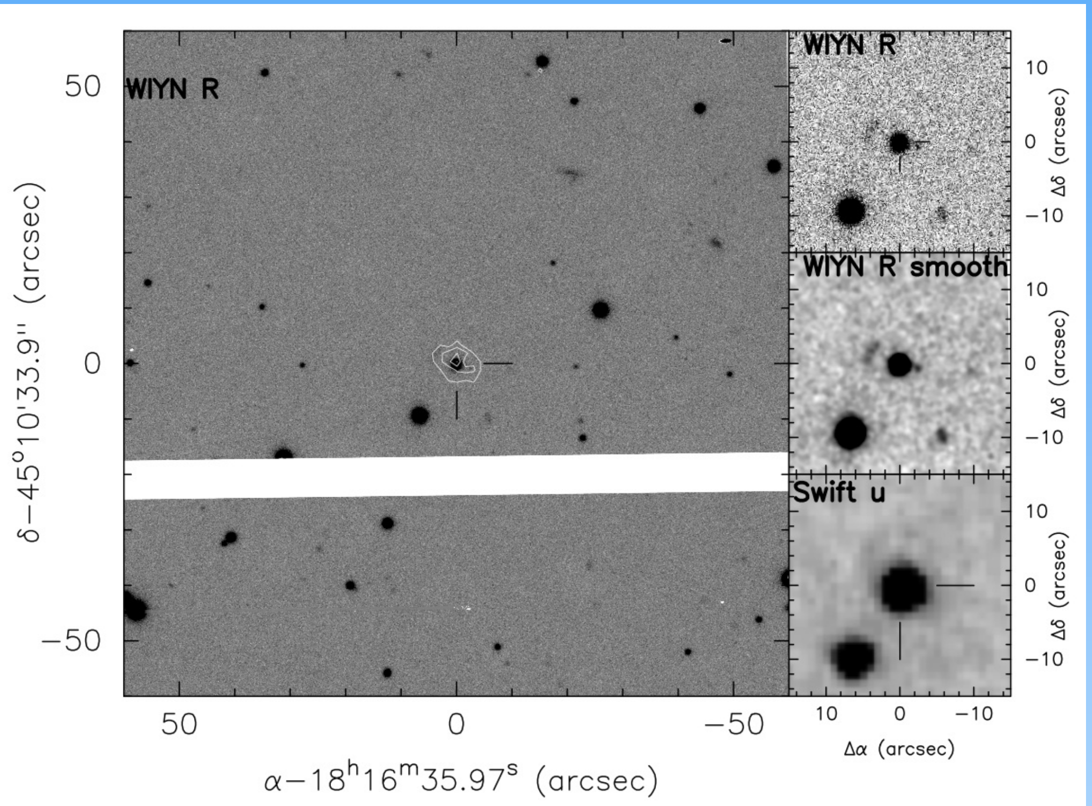
- Appears to be a black widow system, but no radio eclipses

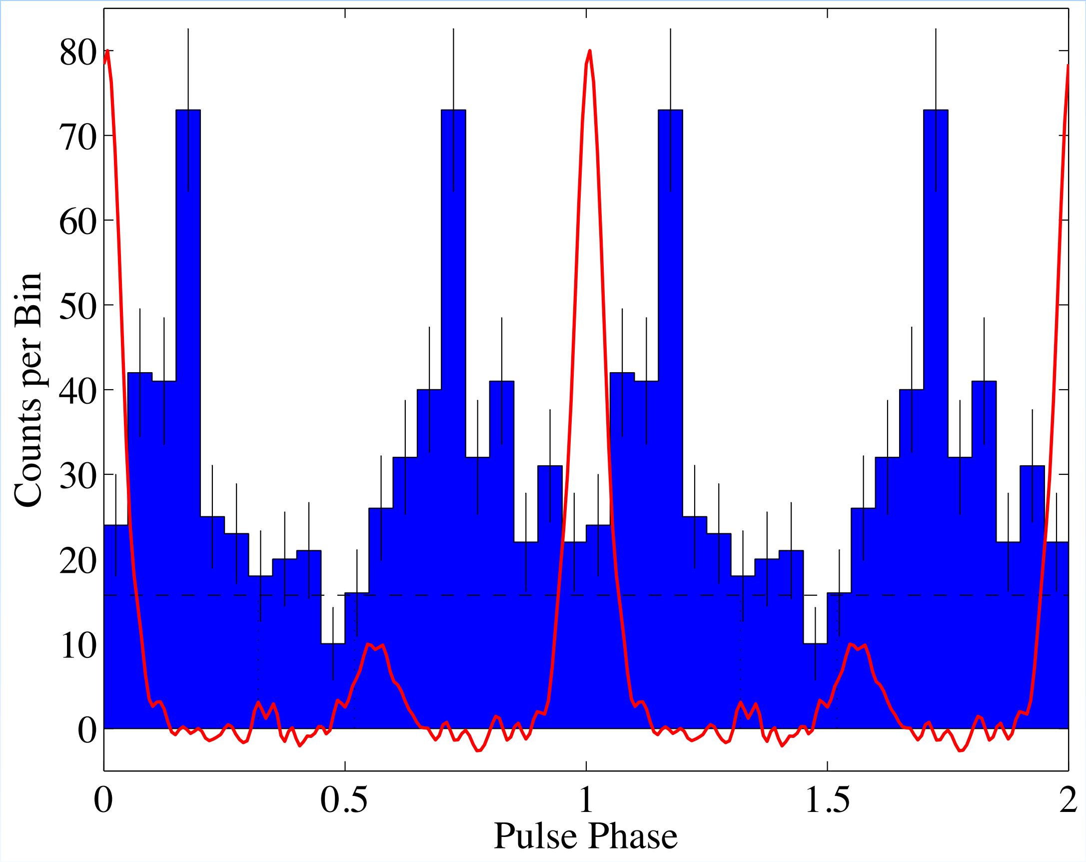


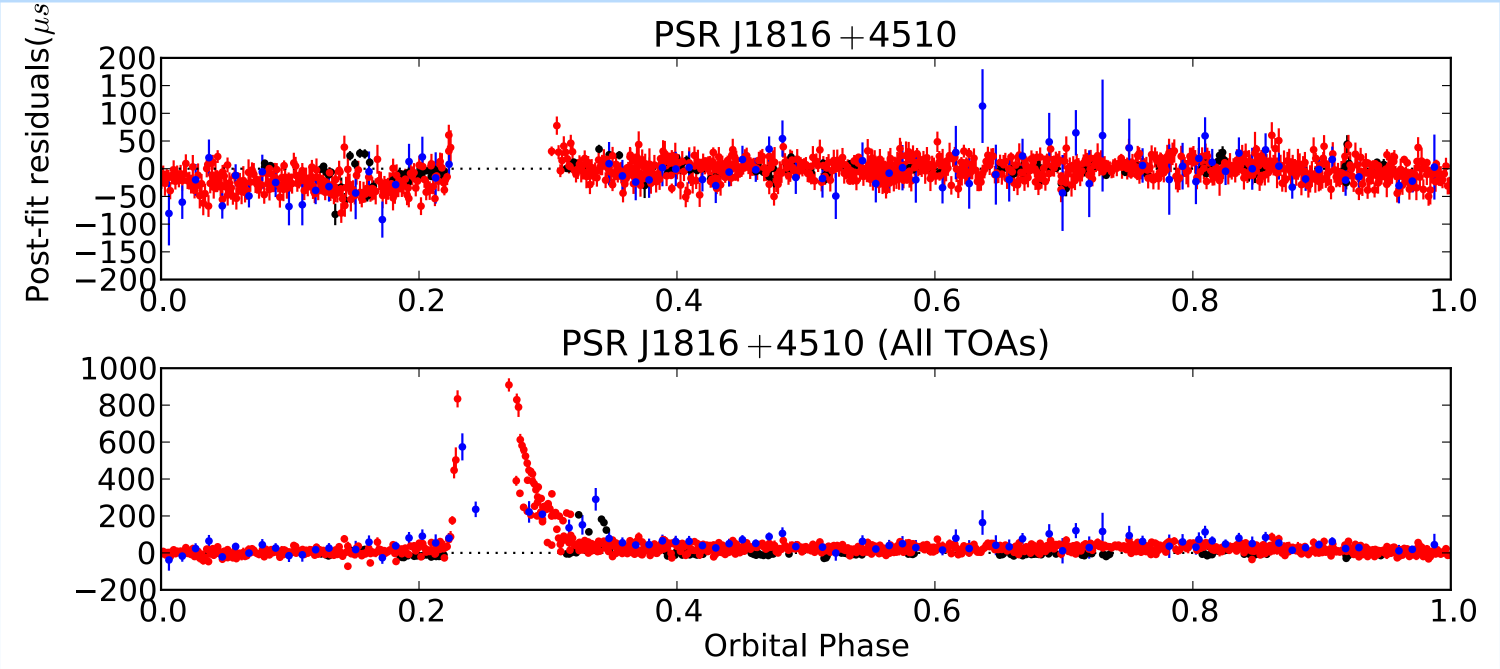
GBNCC Discoveries

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.







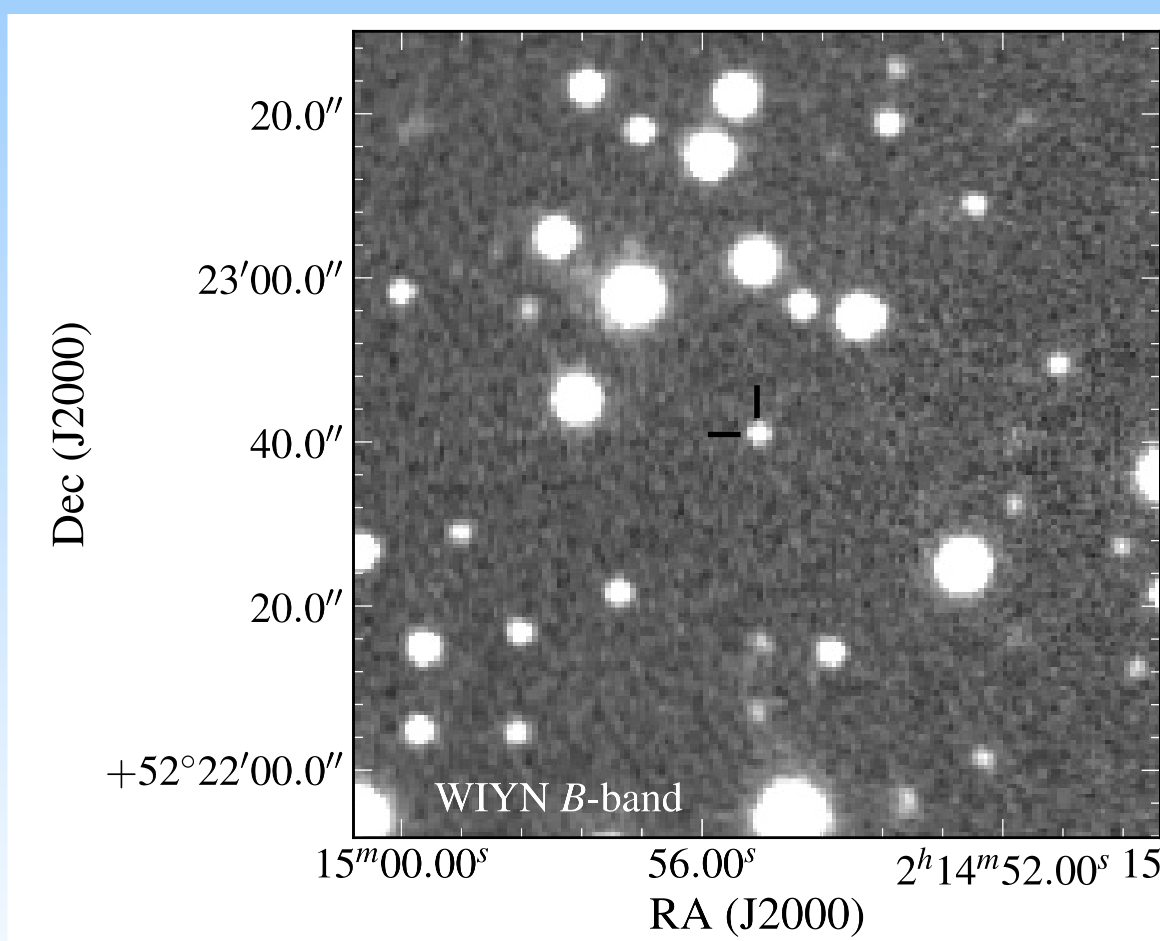
Stovall et al. 2014, ApJ, 791, 67

Kaplan et al. 2012, ApJ, 753, 174

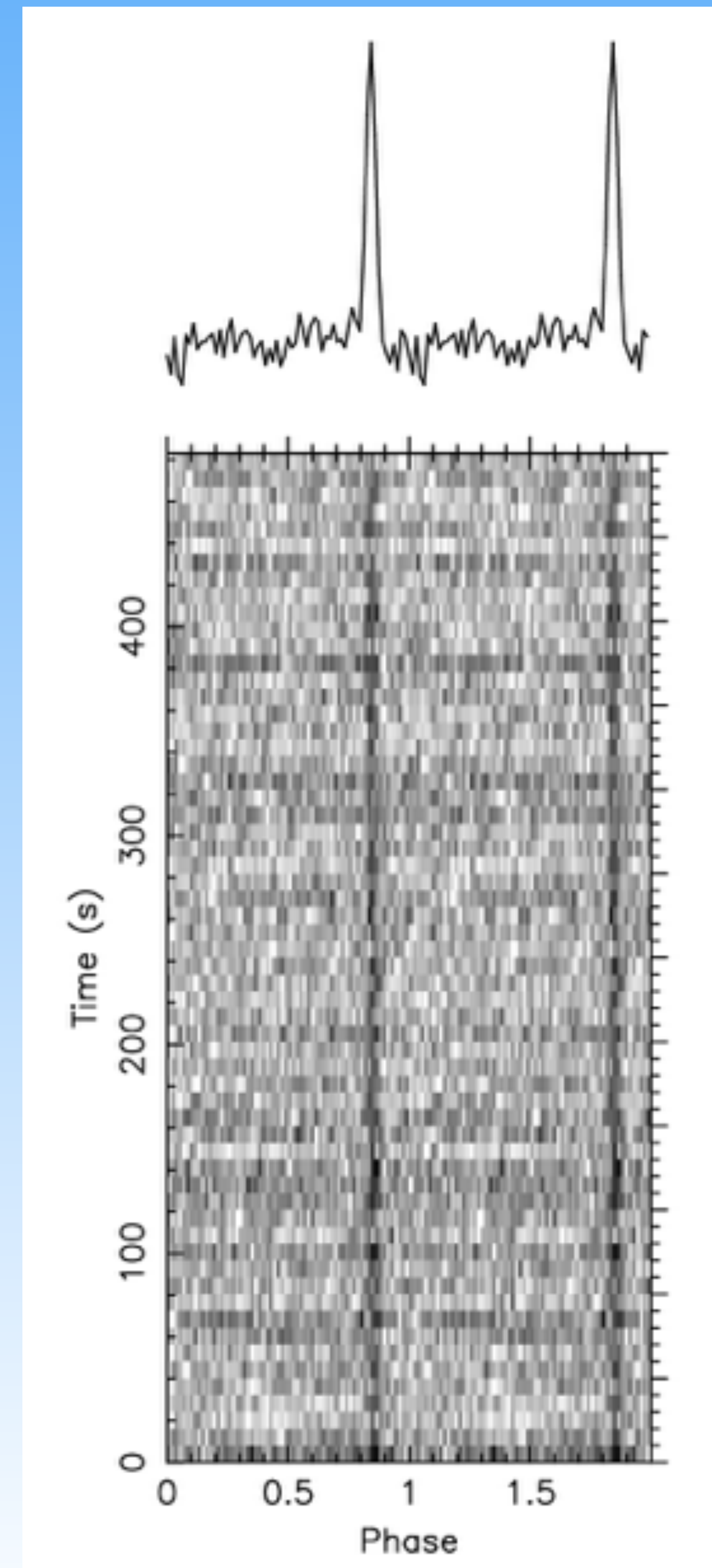
GBNCC Discoveries

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.



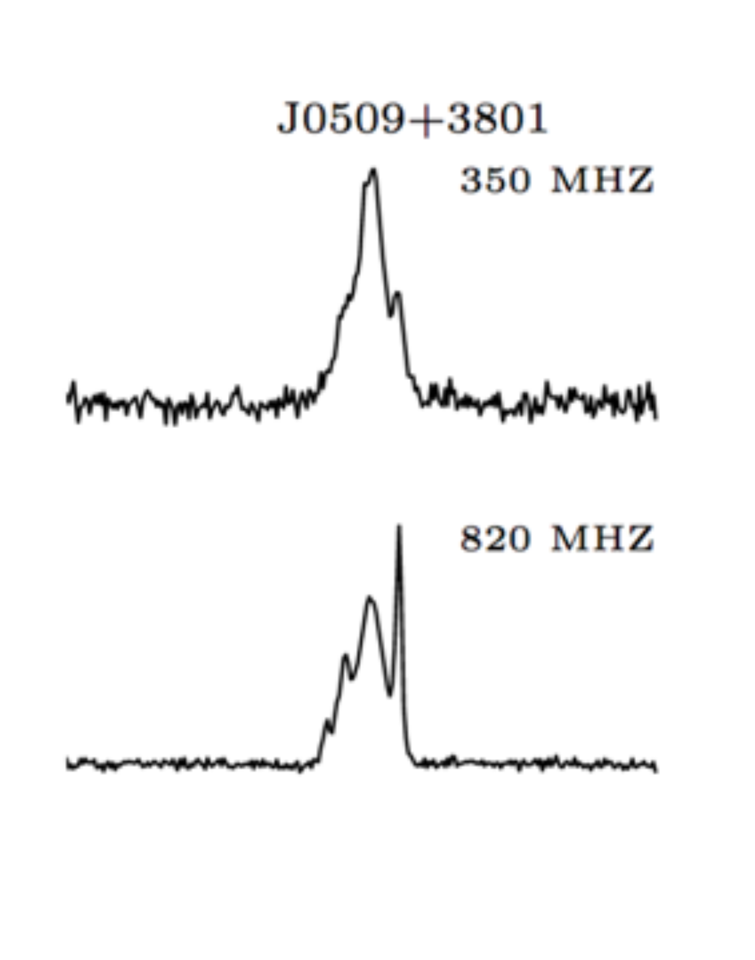
Stovall et al. 2014, ApJ, 791, 67



GBNCC Discoveries

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)

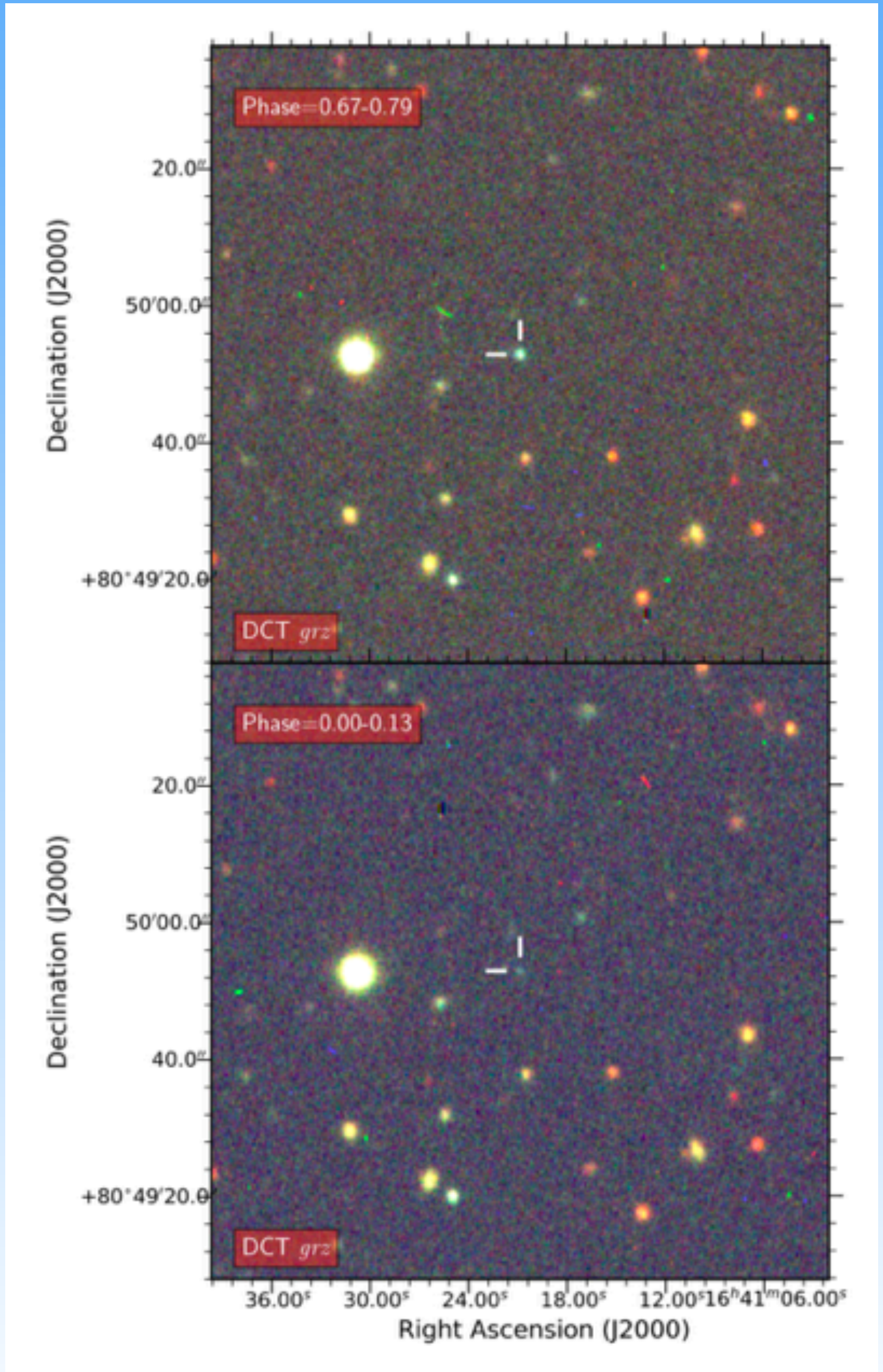
M_c=1.45(8)

Lynch et al., in prep, timing solutions for 44 pulsars

GBNCC Discoveries

J1641+8049

- 2.02 ms pulsar with a DM of 31 pc/cm^3 (D~1.6 kpc).
- In a 2.2-hour, circular orbit with a 0.04 solar mass companion.
- Eclipsing
- Optically detected companion that exhibits variability vs orbit.

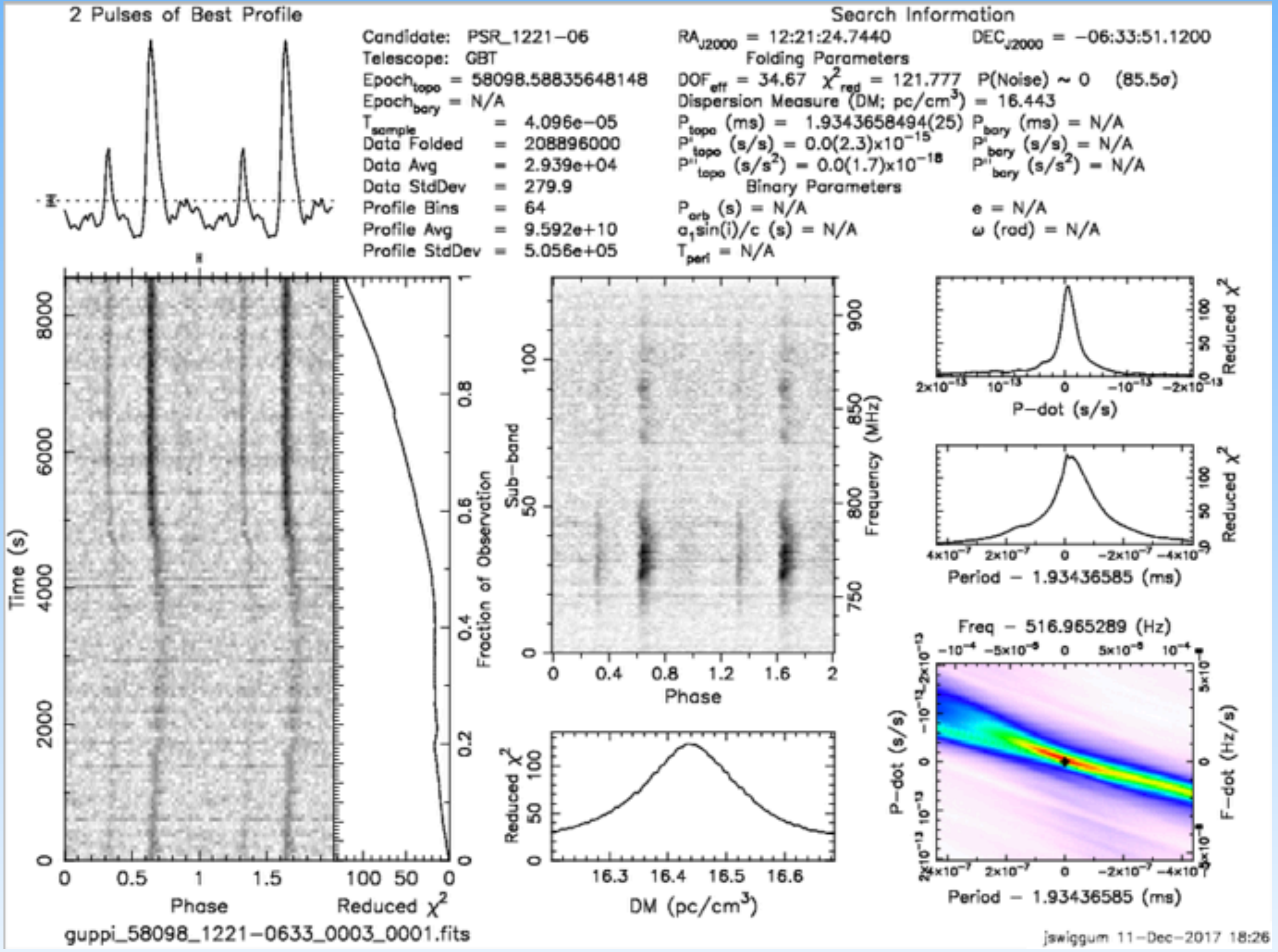


Lynch et al., in prep

GBNCC Discoveries

J1221-0633

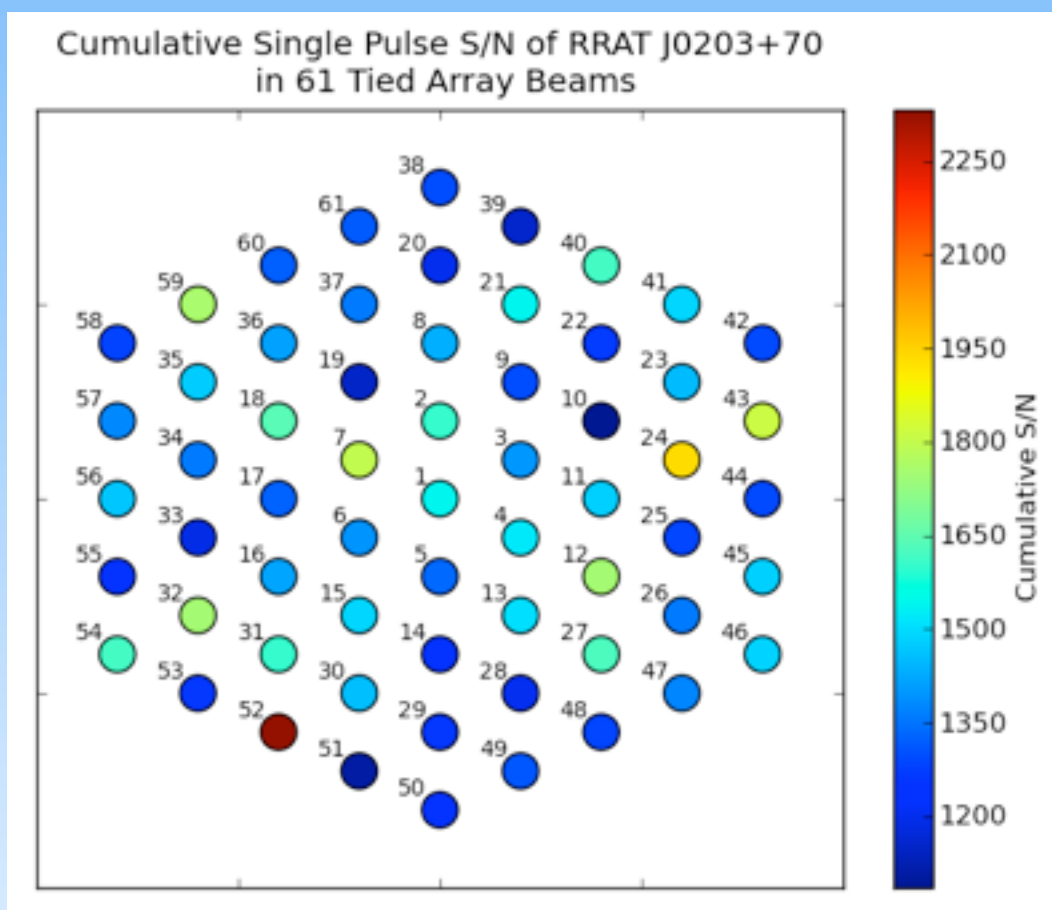
- 1.93 ms and DM of 16 pc/cm^3 (D~0.7 kpc)
- 9.3-hour orbit with ~0.015 solar mass companion



Follow-up beyond GBT

LOFAR

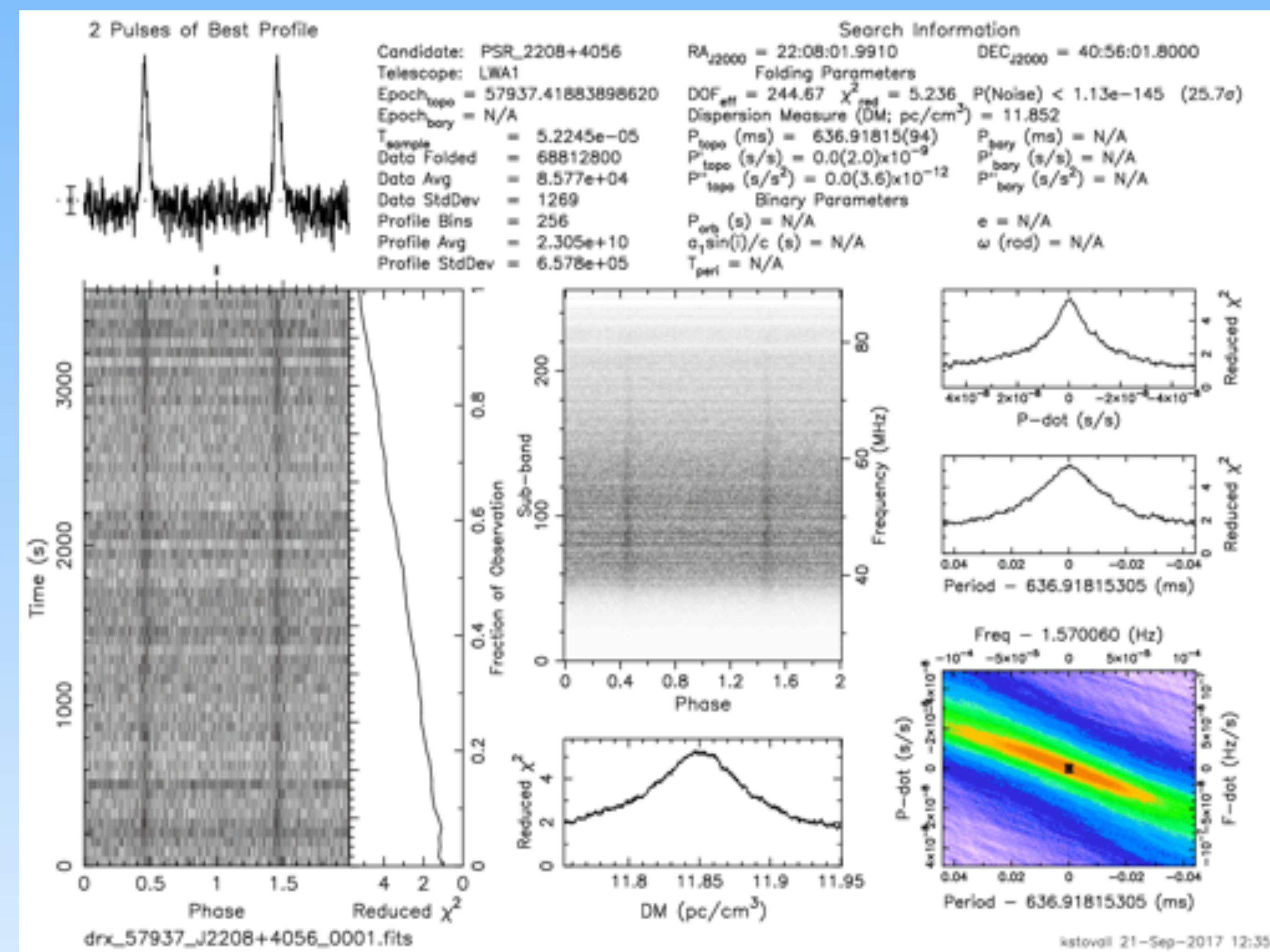
Localization and timing of ~40 pulsars



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

LWA1

Timing of 2 pulsars



More recently, we have observed with GMRT are using the ORT to localize and time about 15 and 12 pulsars, respectively.

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.

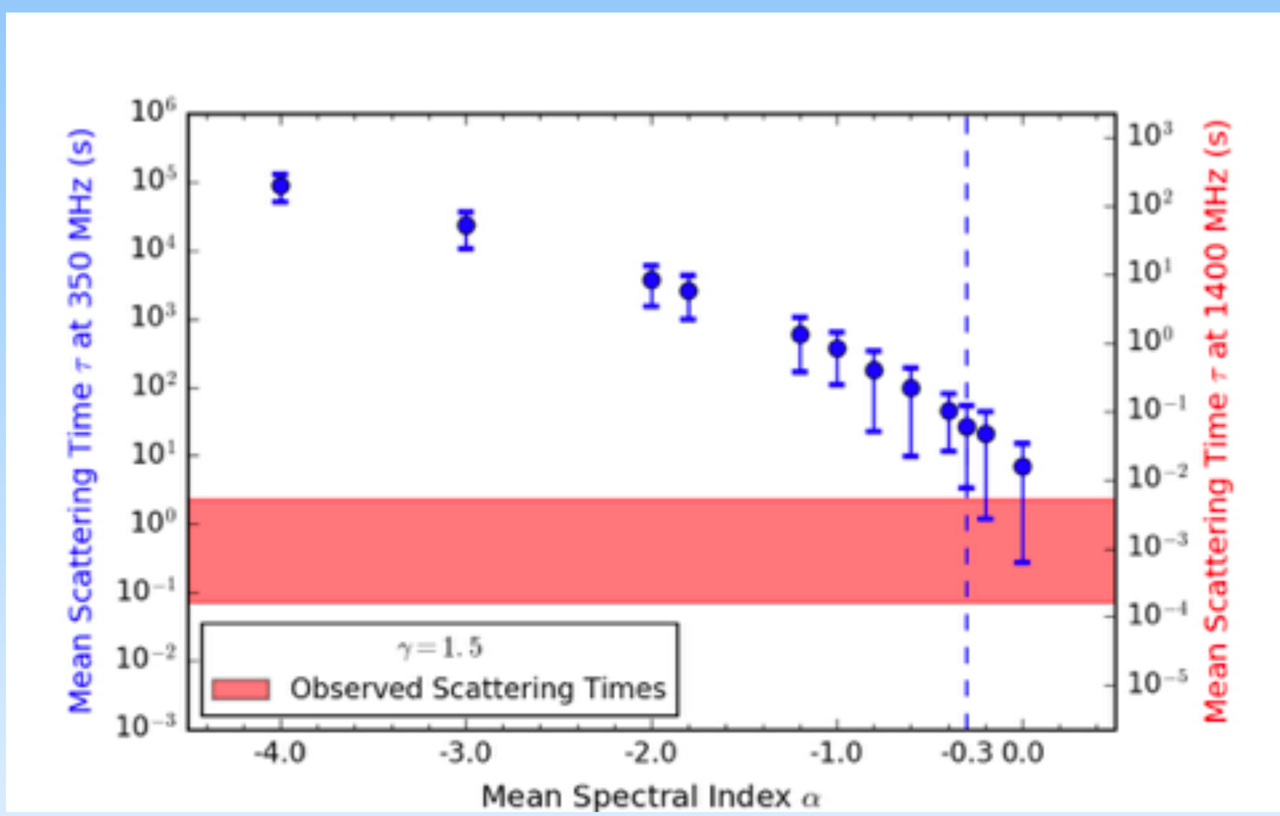


Table 2. Spectral Index Constraints

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

Summary

- The GBNCC pulsar survey was designed to try and uncover a large number of PTA-worthy MSPs distributed across the sky, covering 82% of the sky. We are currently about 75% complete.
- It has been the most productive low frequency (< 1 GHz) pulsar survey to date. We have found over 150 new pulsars, 20 of which are MSPs. Six have been added to PTAs, more being followed up that are likely to be added to PTAs in the future.
- Also among our discoveries are 1 DNS system, multiple wide binaries, nulling pulsars, etc.
- We have 4 publications to date, 2 more close to submission, 3 others that are in preparation.