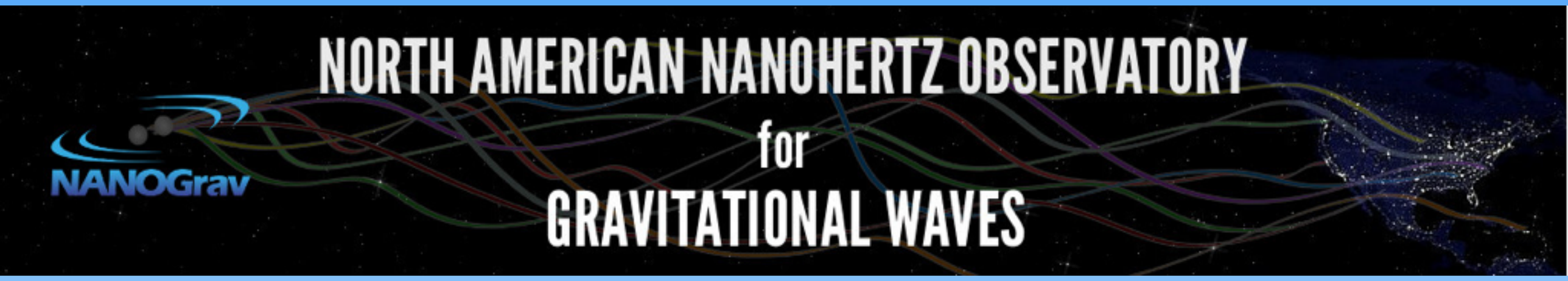
In Search of New MSPs for Pulsar Timing Arrays

Kevin Stovall, NRAO Socorro
NANOGrav Collaboration

NRAO Postdoc Symposium, March 27, 2017



- NANOGrav = US/Canada-based collaboration working to detect nHz GW via pulsar timing.
- Large and still growing collaboration: Currently over 80 members (~45 SP, ~25 PD, ~10 GS)
- Geographically distributed, ~20 different institutions.
- Strong commitment to undergrad education and involvement in research.
- Awarded $14.5M / 5 year NSF Physics Frontier Center grant

See www.nanograv.org for more info

Pulsar Timing Arrays

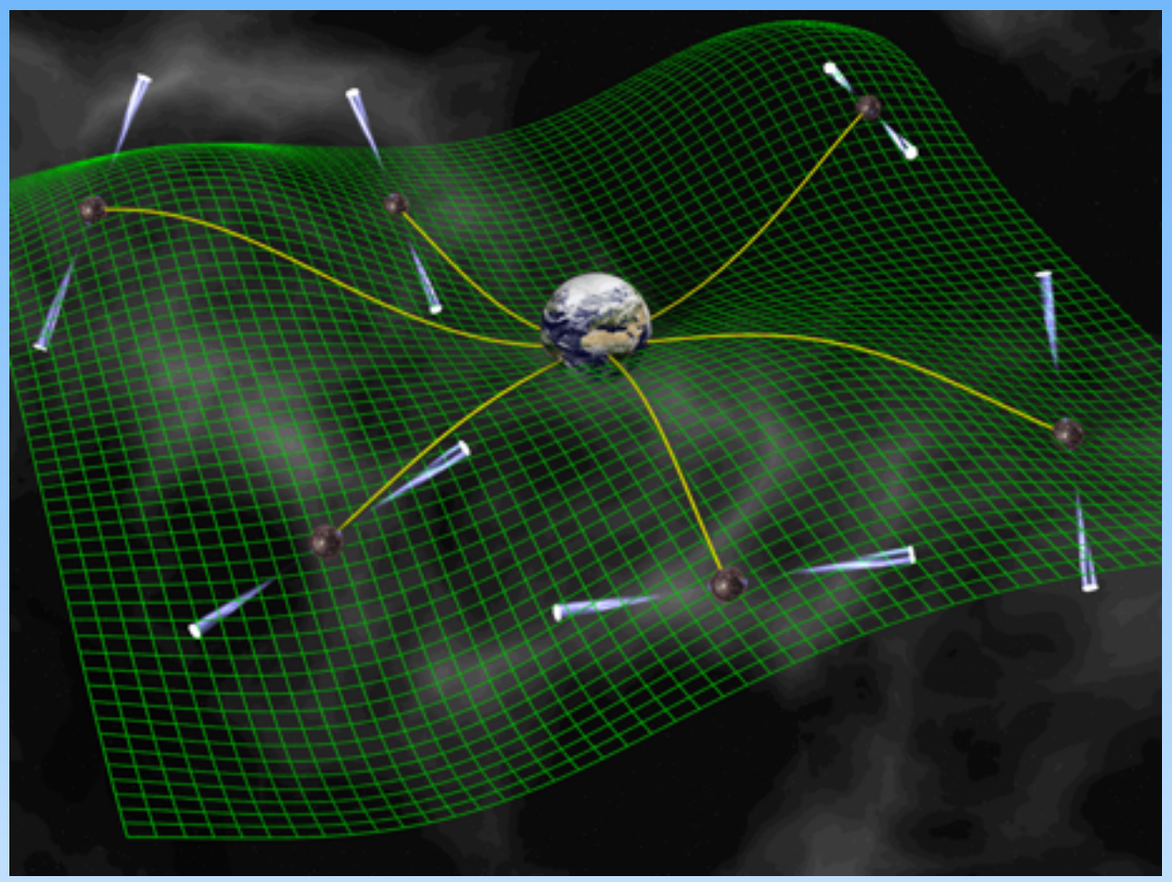


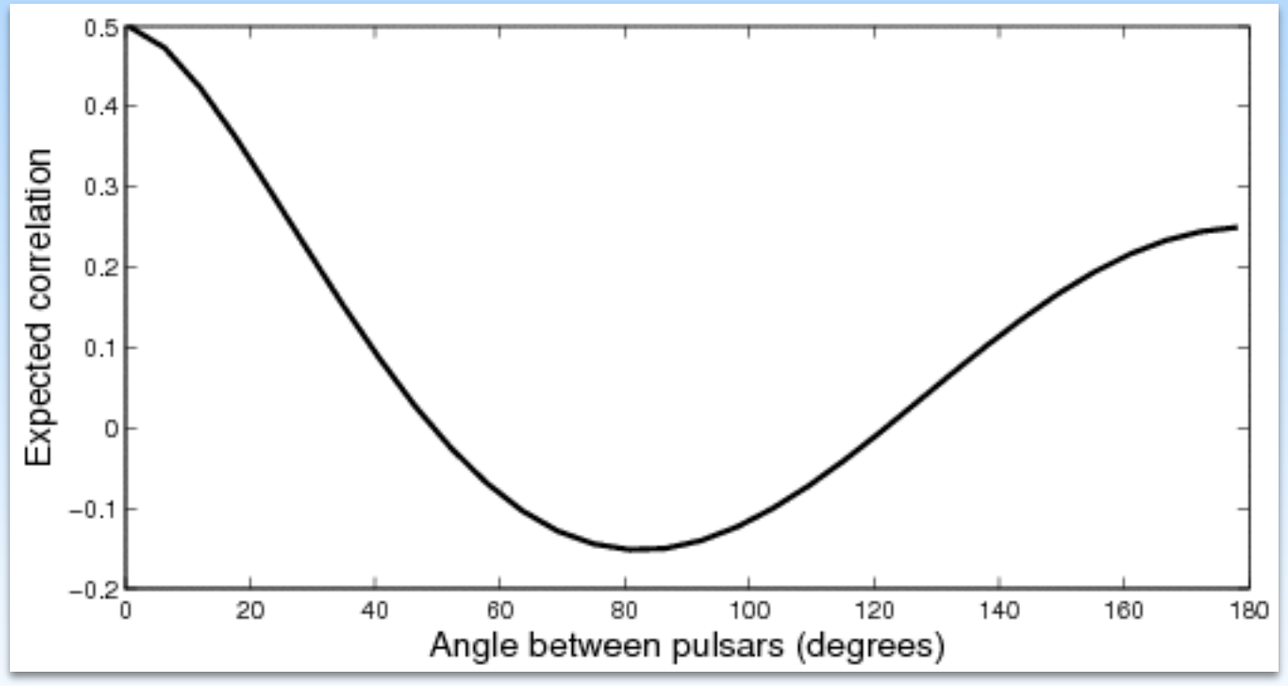
Image Credit: David Champion

NANOGrav monitors a set of very stable millisecond pulsars (MSPs) to look for GW signals. Such signals would be correlated vs. pulsar angular separation.

The NANOGrav Collaboration et al. 2015, ApJ, 813, 65

Other PTA Experiments
Parkes Pulsar Timing Array (PPTA)
European Pulsar Timing Array (EPTA)
International Pulsar Timing Array (IPTA)

Hellings & Downs Curve

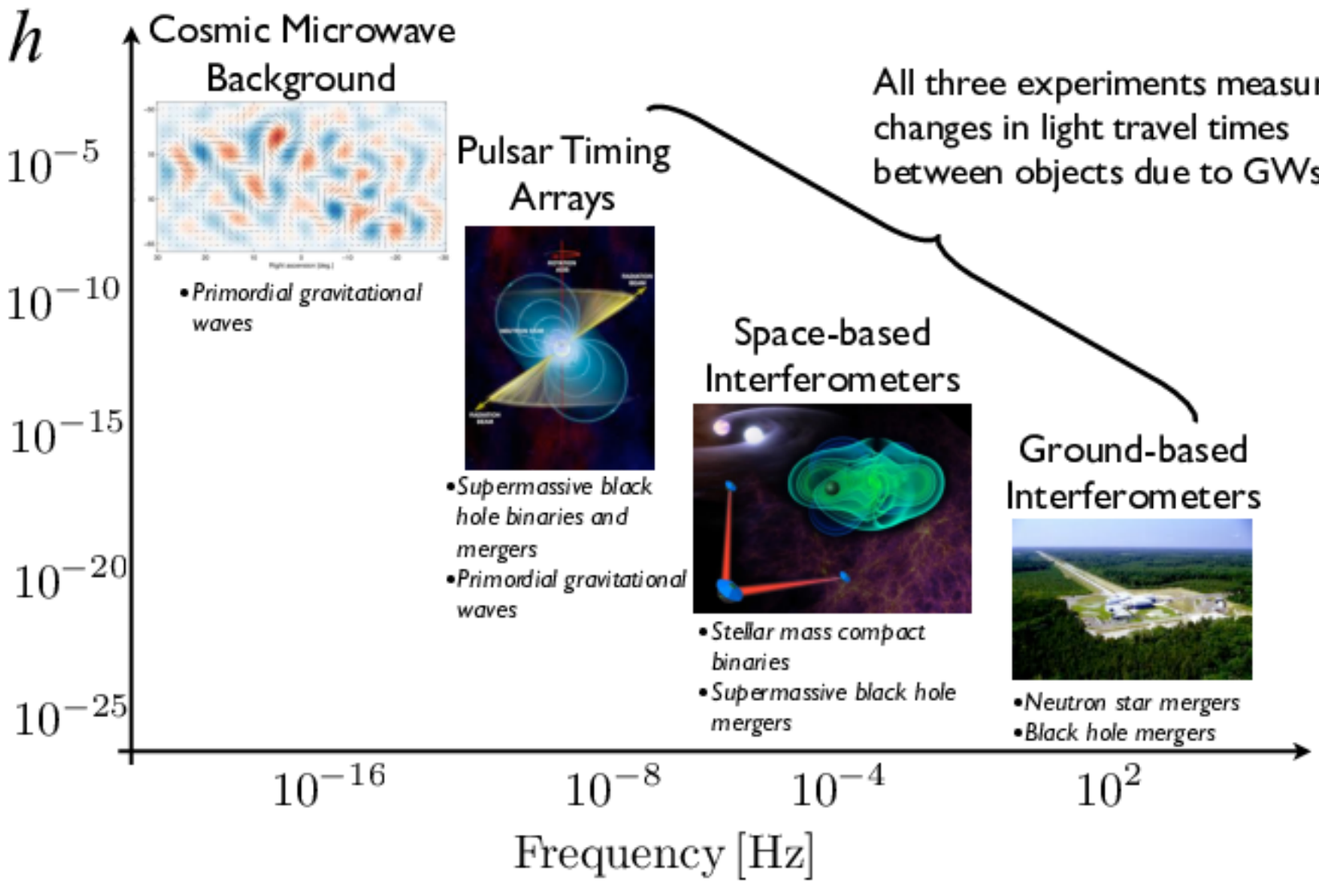


Hellings & Downs 1983, ApJ, 265, 39

Pulsar Timing Array

NANOGrav

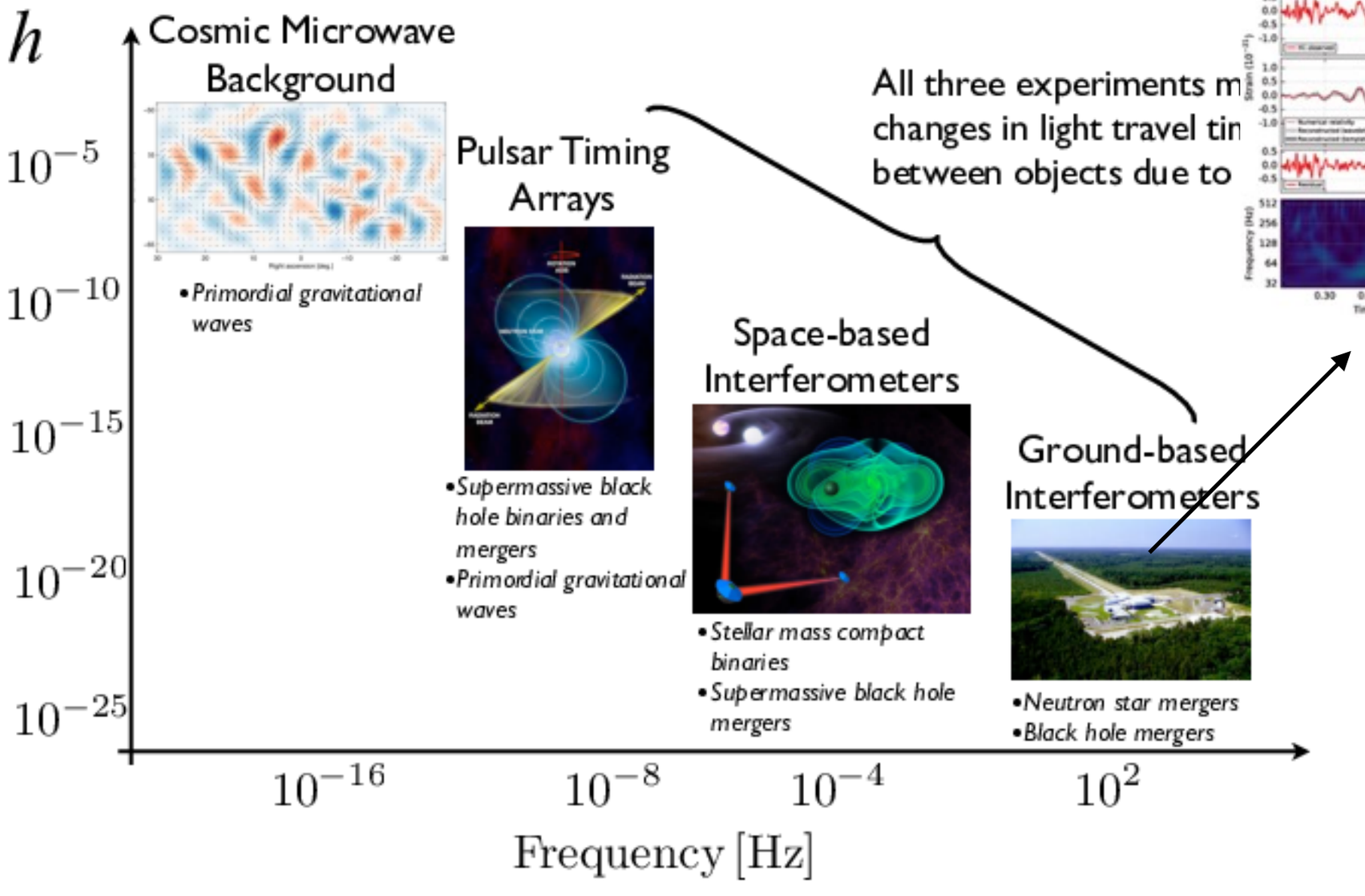
The spectrum of gravitational wave astronomy



Pulsar Timing Array

NANOGrav

The spectrum of gravitational wave astronomy



Current Telescopes

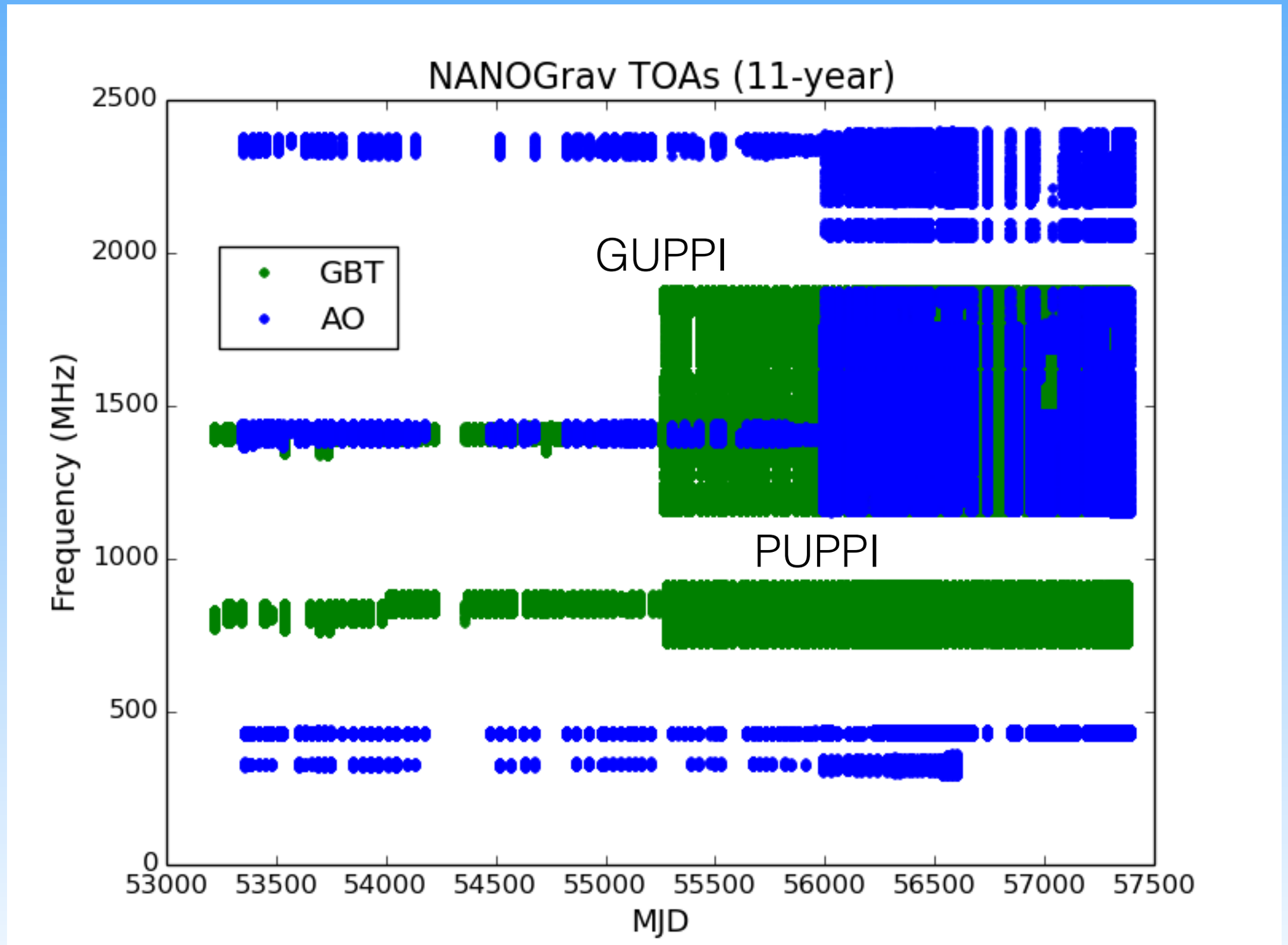
Arecibo Observatory

305 meter diameter
Dec range:-1 deg to 38 deg
Sources visible for ~2 hours
L-Band SEFD ~ 2 Jy

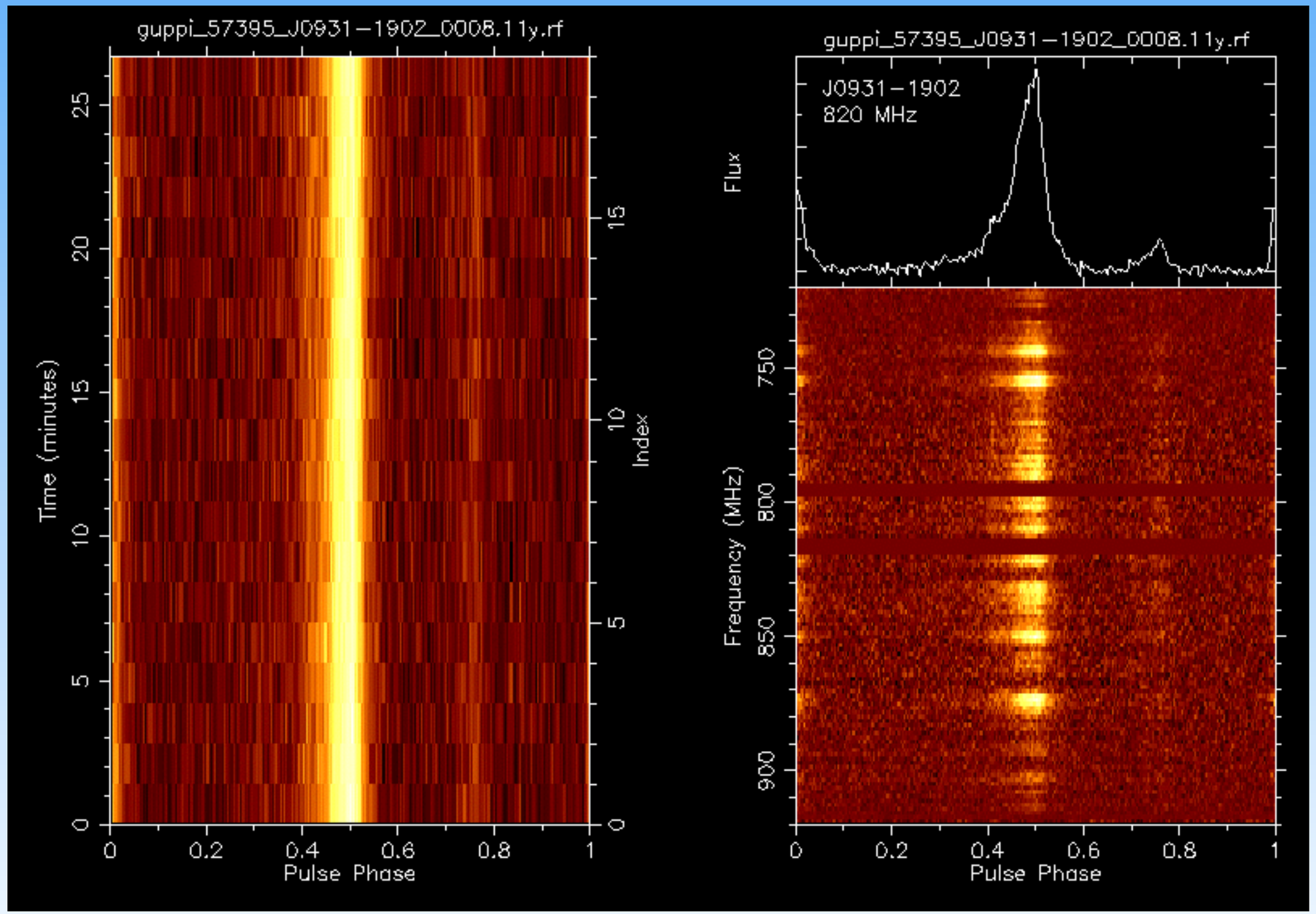
Green Bank Telescope

100 meter diameter
Dec range: > -45 deg
Sources visible for many hours
L-Band SEFD ~ 10 Jy

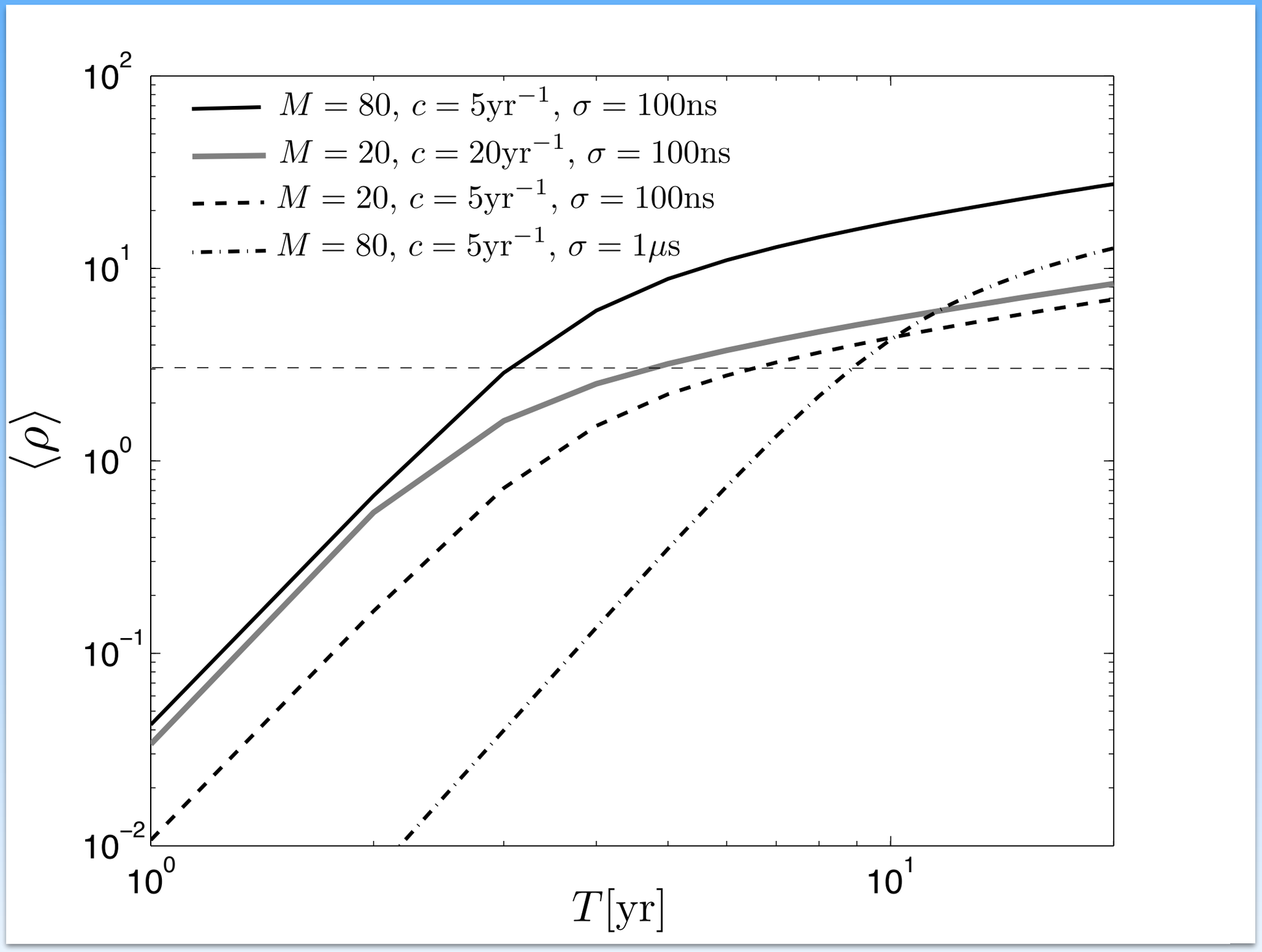
Frequency Coverage



MSPs


guppi_57395_J0931−1902_0008.11y.rf
Time (minutes)
Index
Pulse Phase
guppi_57395_J0931−1902_0008.11y.rf
J0931−1902
820 MHz
Flux
Frequency (MHz)
Pulse Phase

Why we need more MSPs



Siemens et al. 2013, CQG, 30, 4015

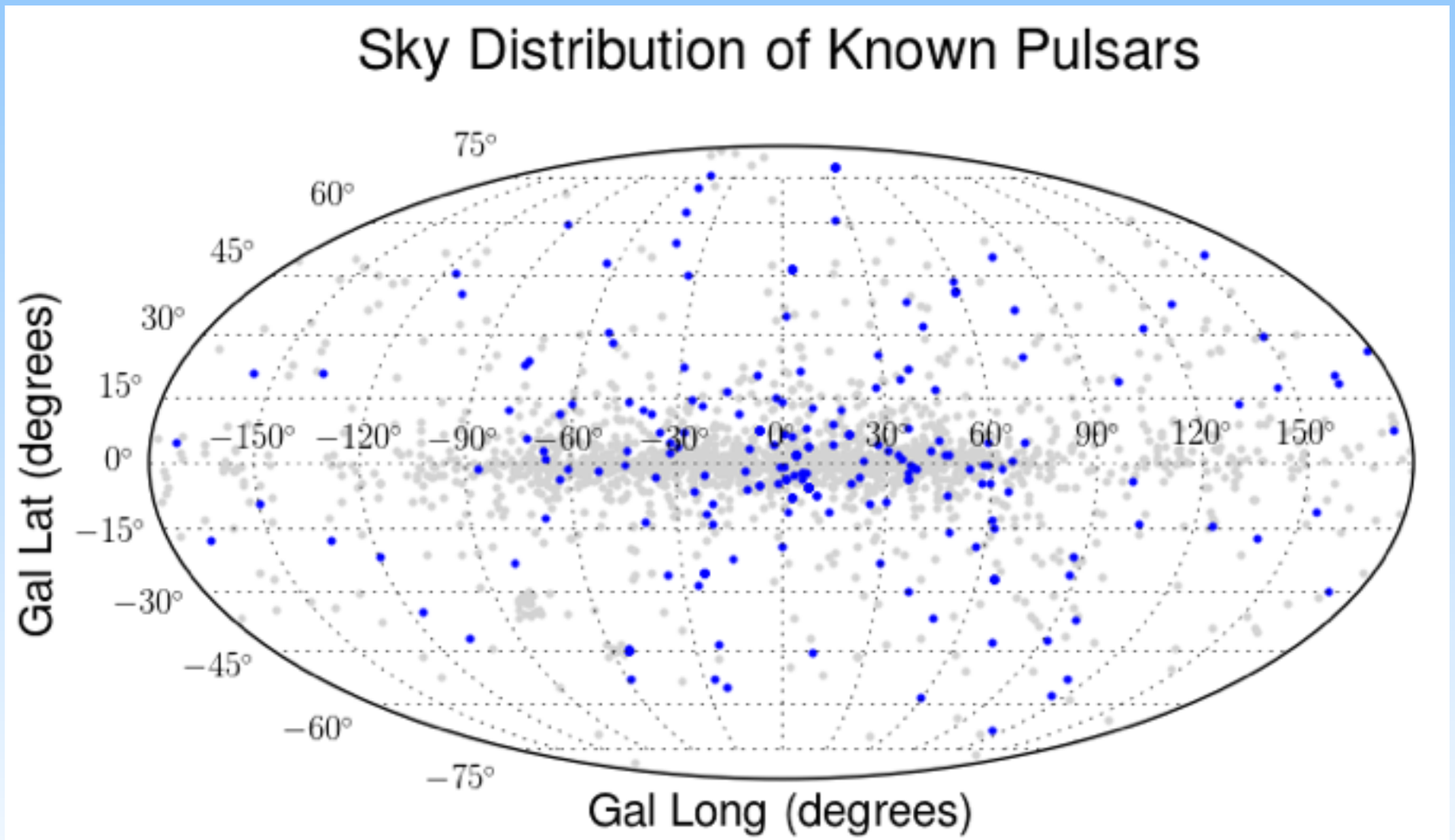
Where to Search for MSPs?

Nearby MSPs are expected to be essentially isotropic.

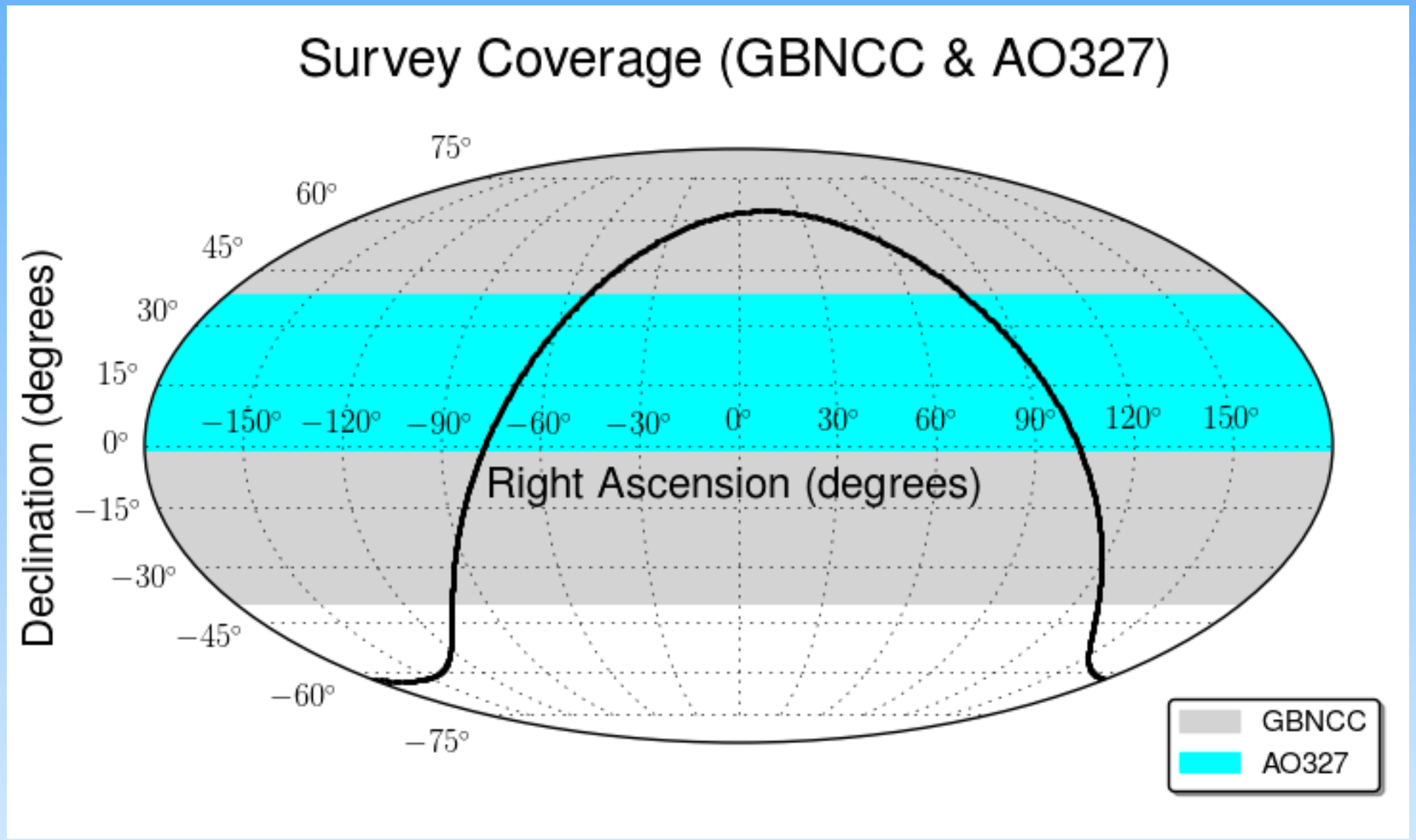
Searches in 1990s found many MSPs at a wide range of Galactic latitudes.

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



Large Area Pulsar Surveys



Green Bank North Celestial Cap (GBNCC)
Arecibo 327 MHz Drift Scan (AO327)

Survey Parameter Comparison

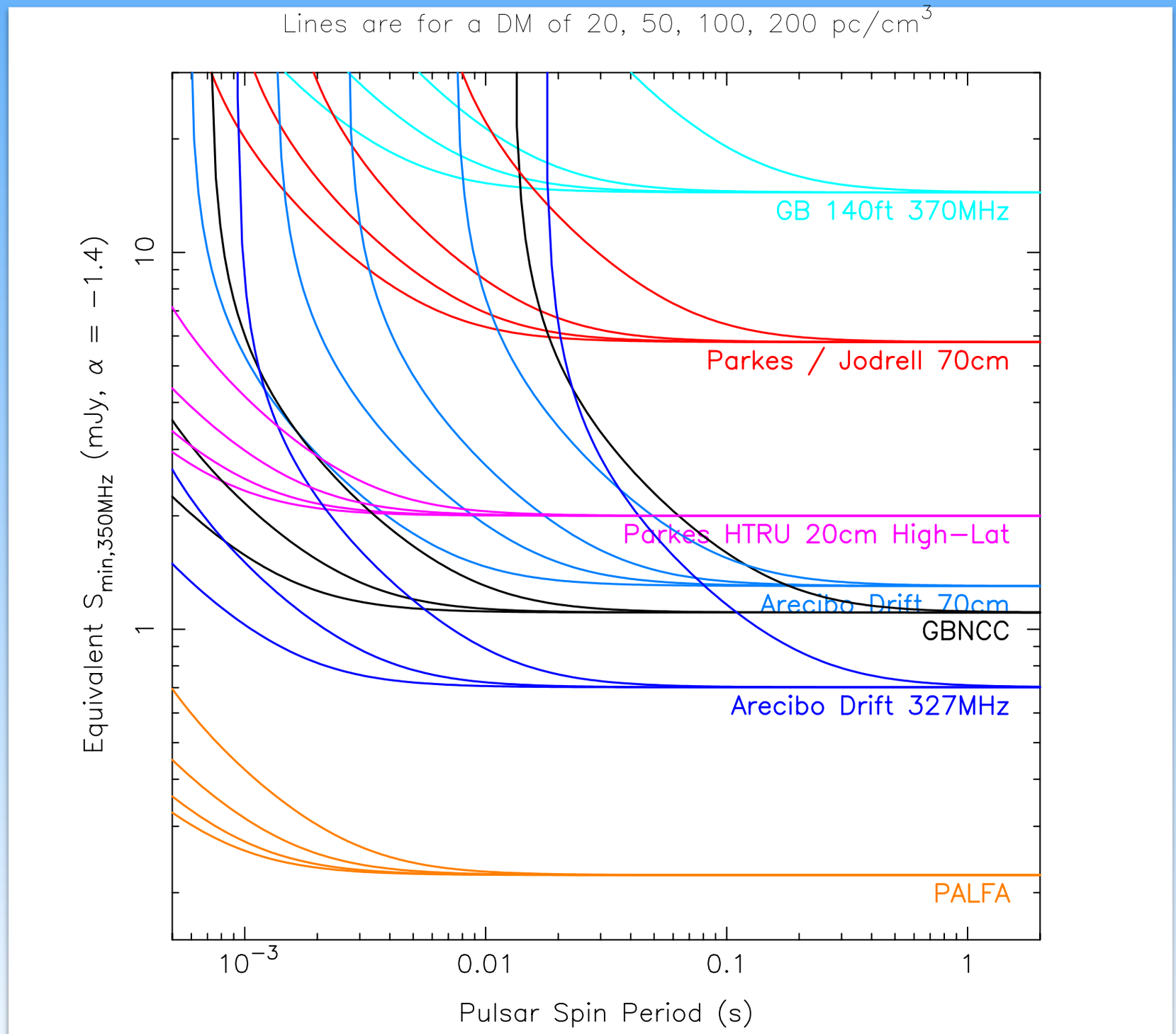
Survey	Center Frequency (MHz)	Bandwidth (MHz)	Frequency Resolution (kHz)	Sample Time (us)	Integration Time (s)	Style
AO327	327	57/69	56/24	125/82	64	Drift
GBNCC	350	100	24	82	120	Pointed

AO327 - Deneva et al. 2013, ApJ, 775, 51
GBNCC - Stovall et al. 2014, ApJ, 791, 67

AO327 Collaborators: J. Deneva, M. Bagchi, P. Freire, F. Jenet, J. Martinez, M. McLaughlin

GBNCC Collaborators: S. Ransom, M. Decesar, R. Lynch, J. Swiggum, H. Al Ali, P. Chawla, T. Cromartie, J. Hessels, F. Jenet, D. Kaplan, V. Kaspi, V. Kondratiev, J. van Leeuwen, M. McLaughlin, M. Roberts, X. Siemens, R. Spiewak, I. Stairs

Survey Sensitivities

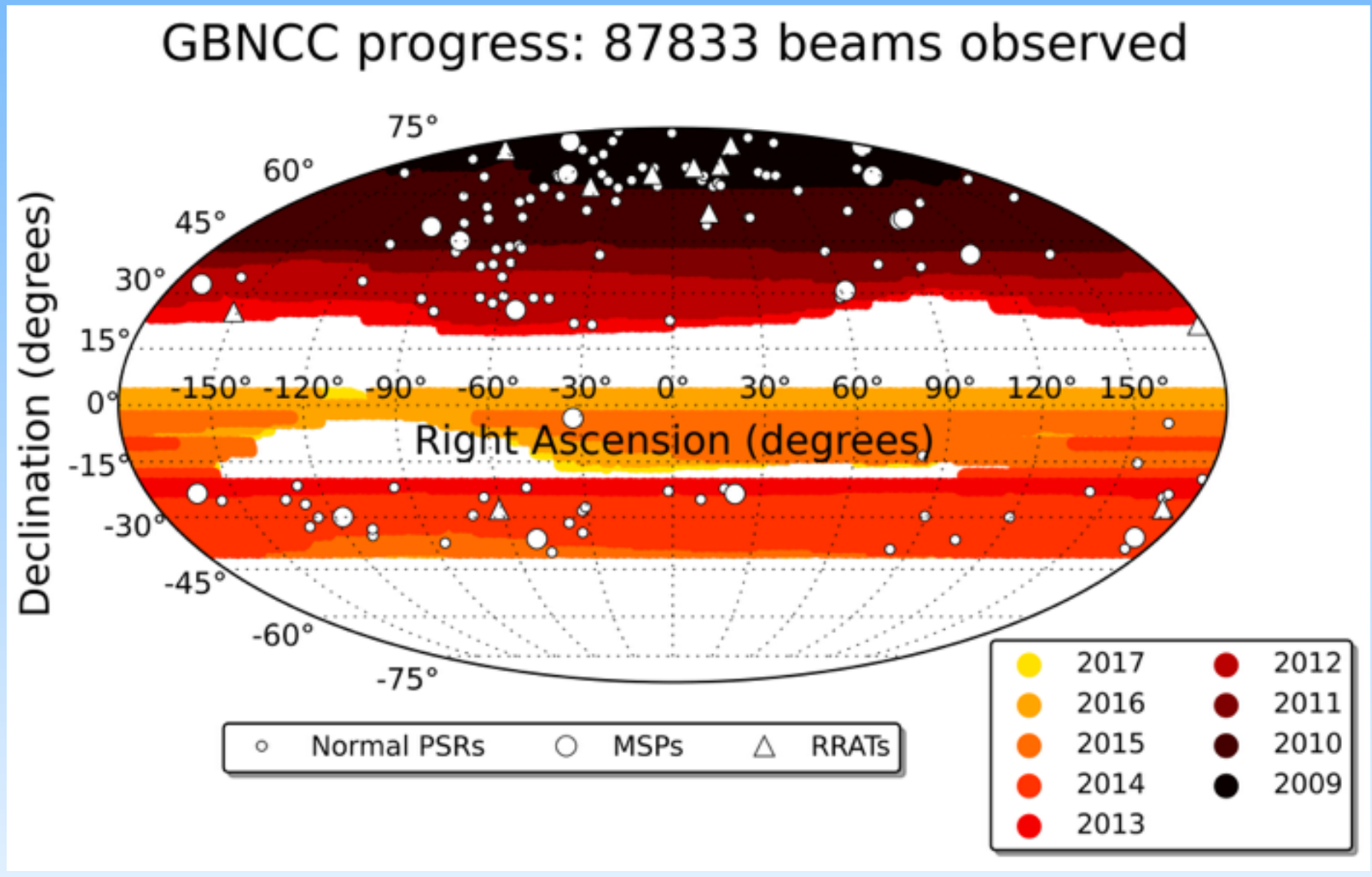


GBNCC

145 Pulsars
18 MSPs
11 RRATs
1 DNS (2 more?)
2 wide binaries

~75% complete

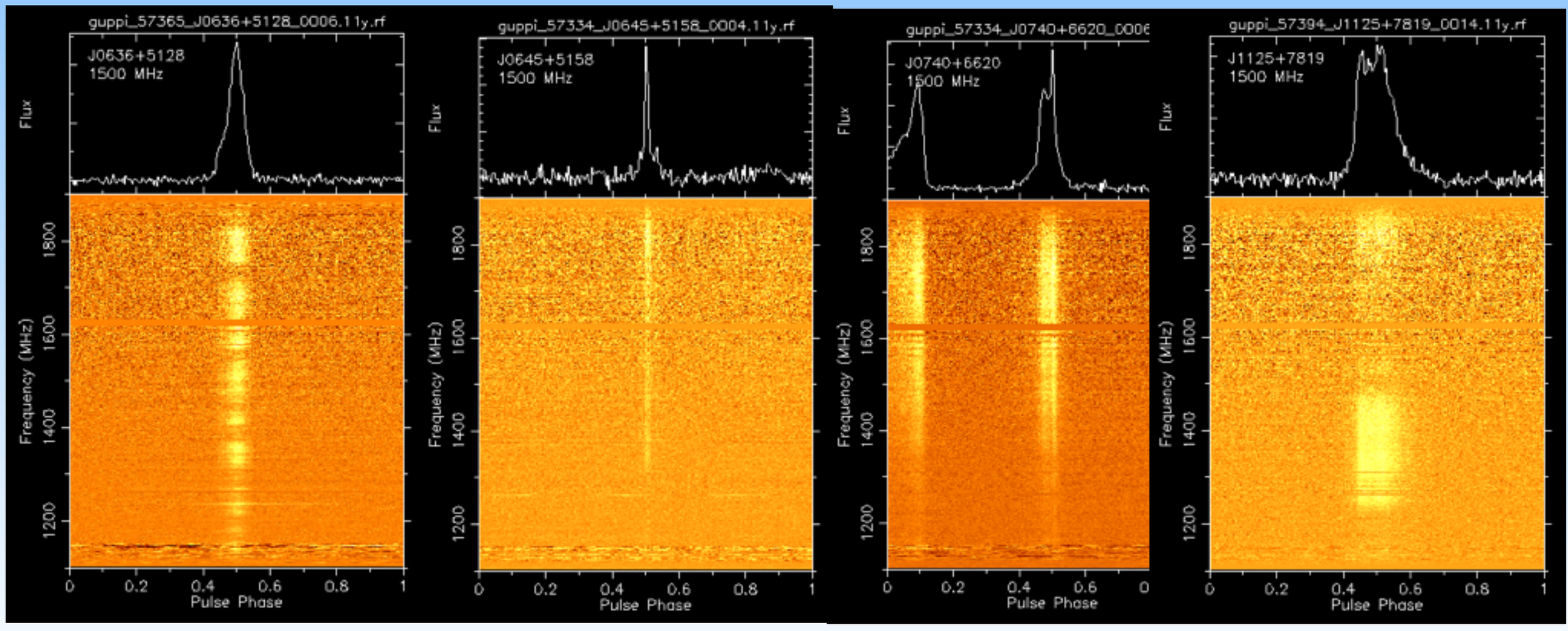
We plan to make data available, ~500 TB, we are converting from 8-bit to 2-bit



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

GBNCC Discoveries

5 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



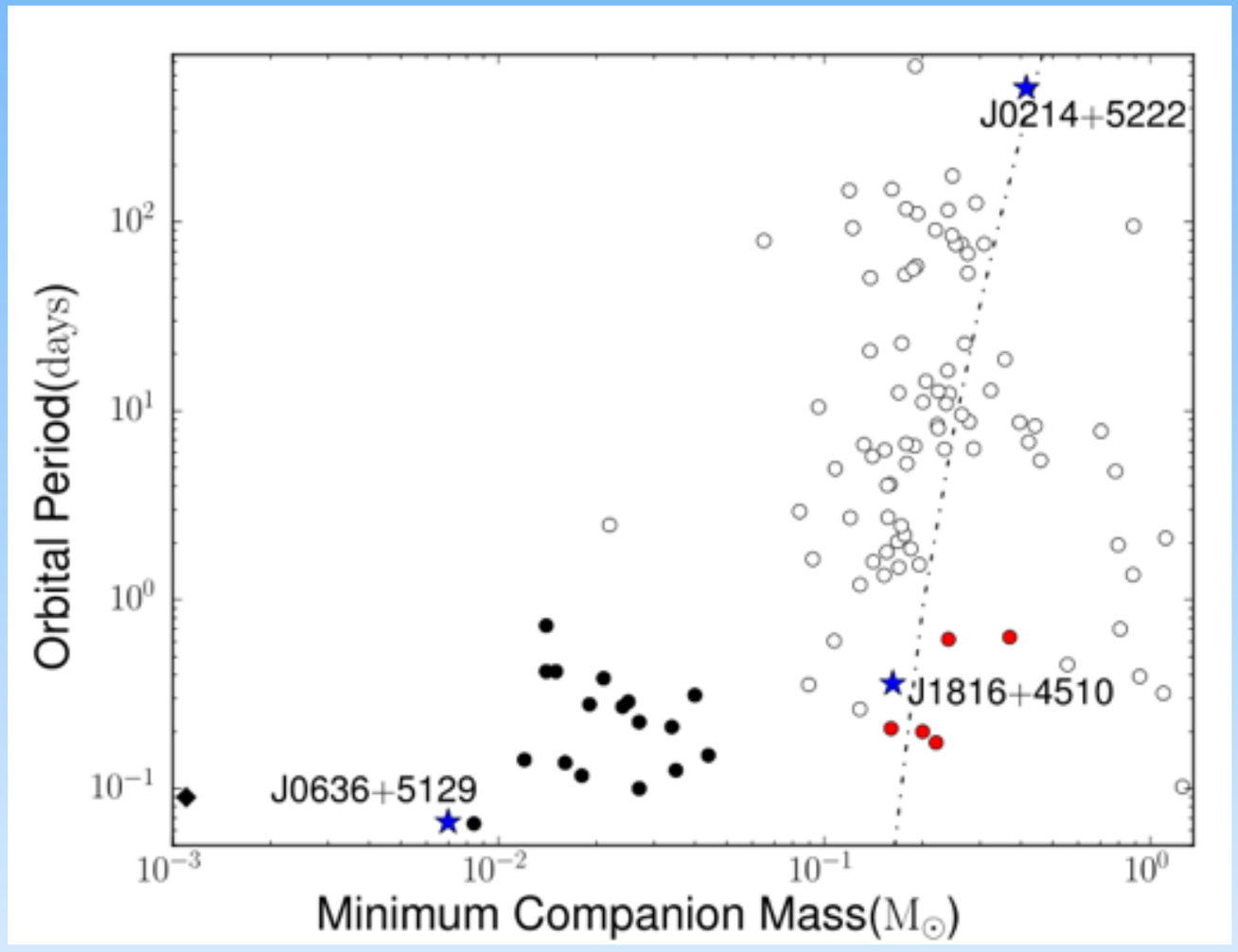
GBNCC Discoveries

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

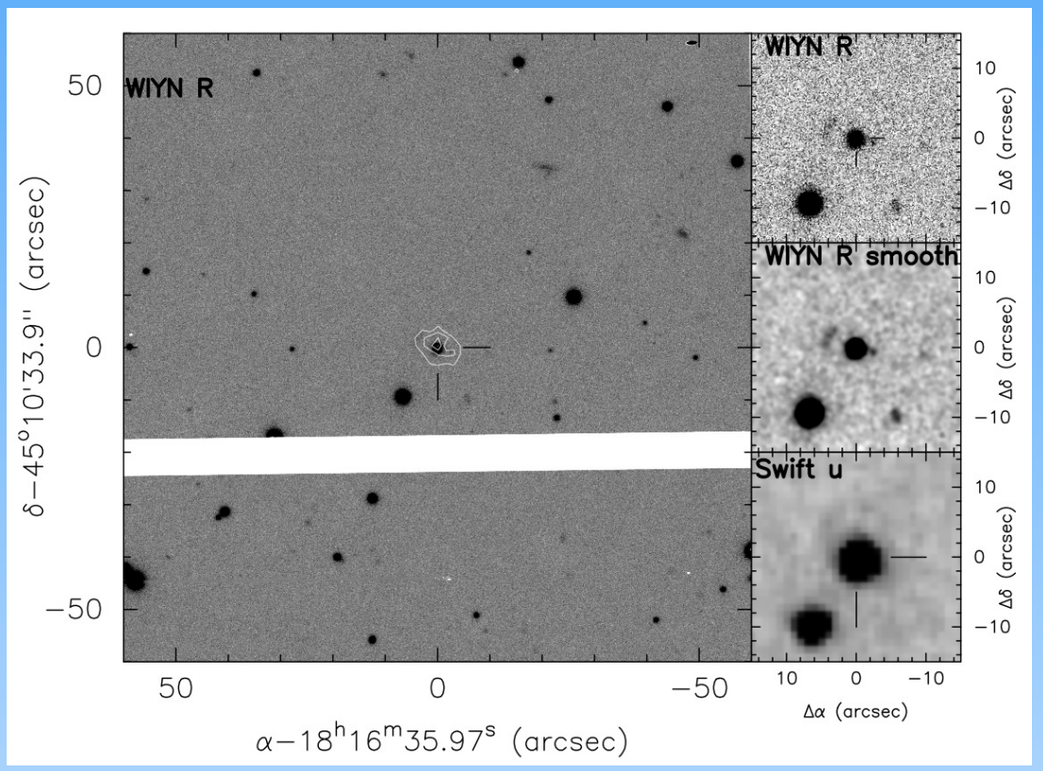
- Appears to be a black widow system, but no radio eclipses

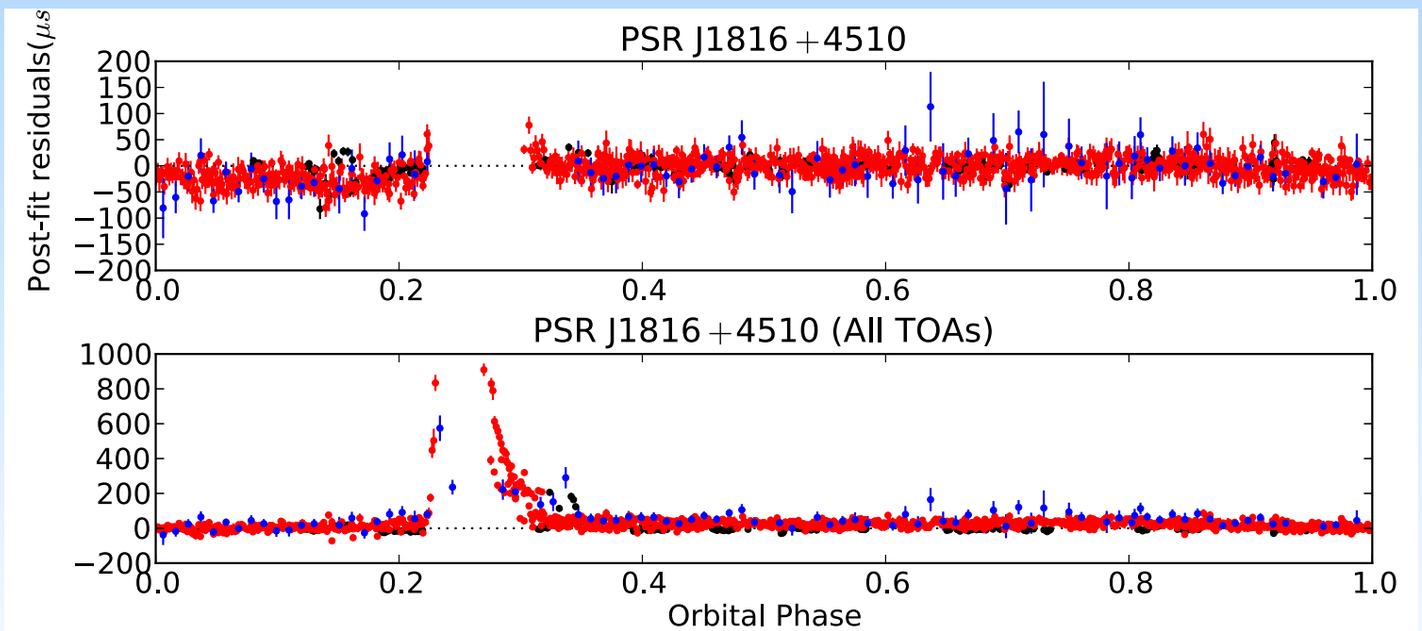


GBNCC Discoveries

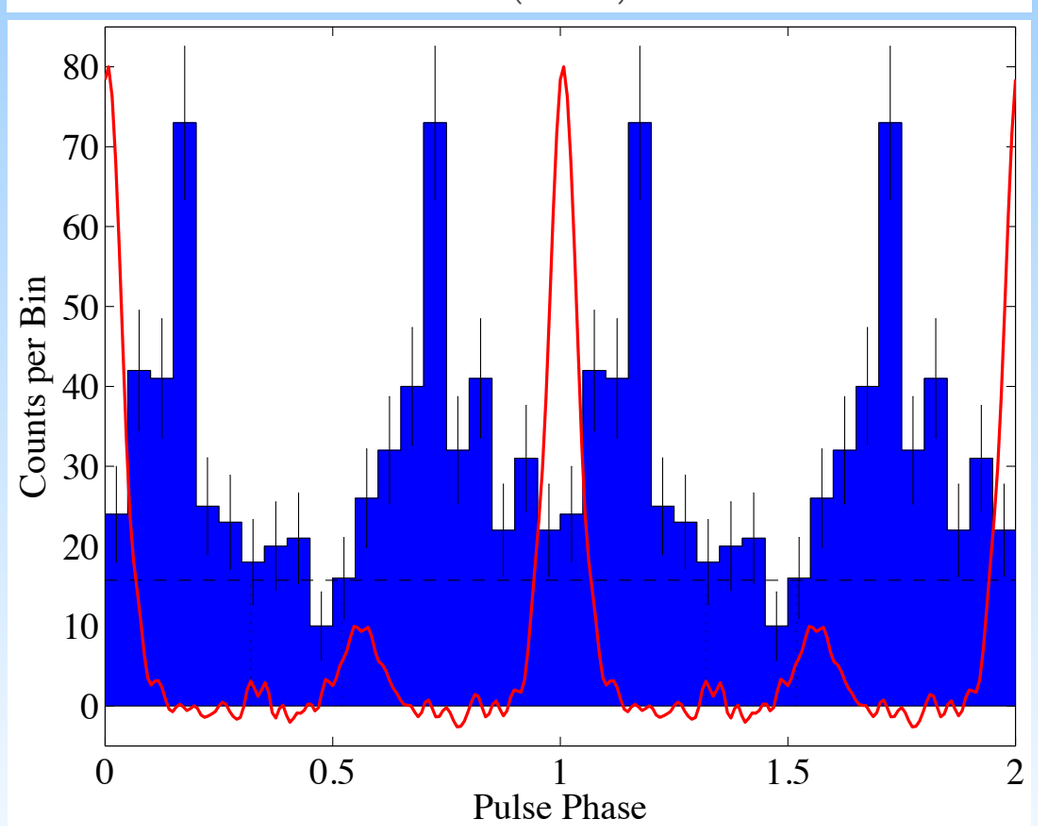
J1816+4510

- 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



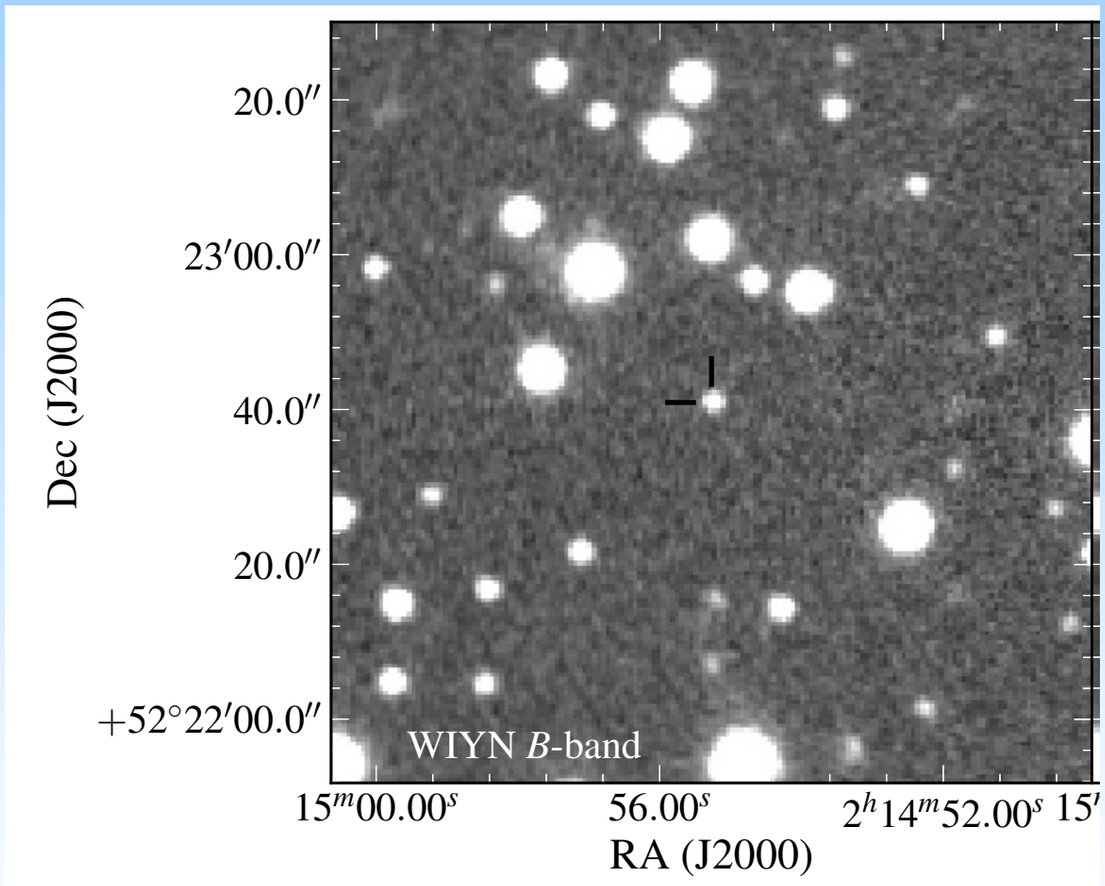
Kaplan et al. 2012, ApJ, 753, 174

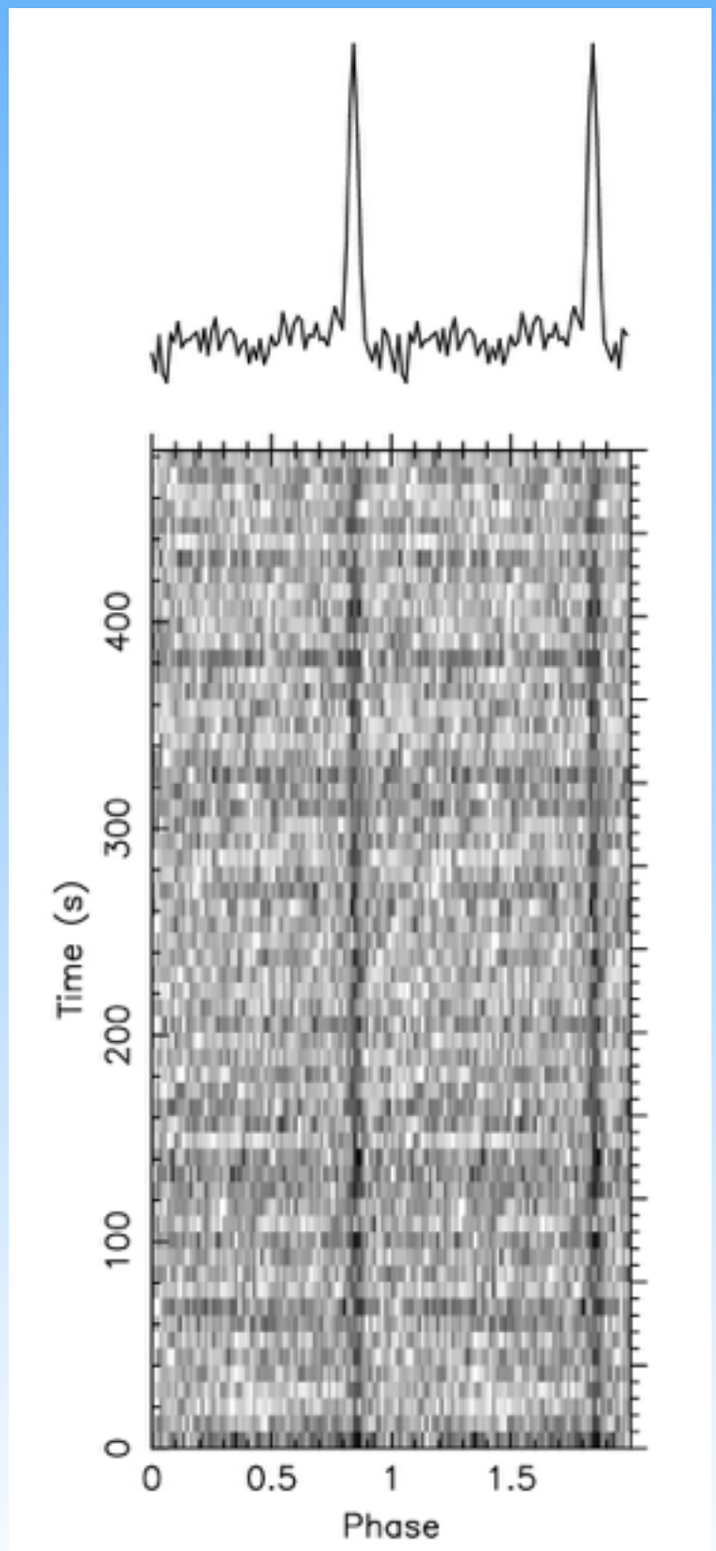
GBNCC Discoveries

J0214+5222

- 24.5 ms pulsar with a DM of 22 pc/cm^3 (D~1 kpc).

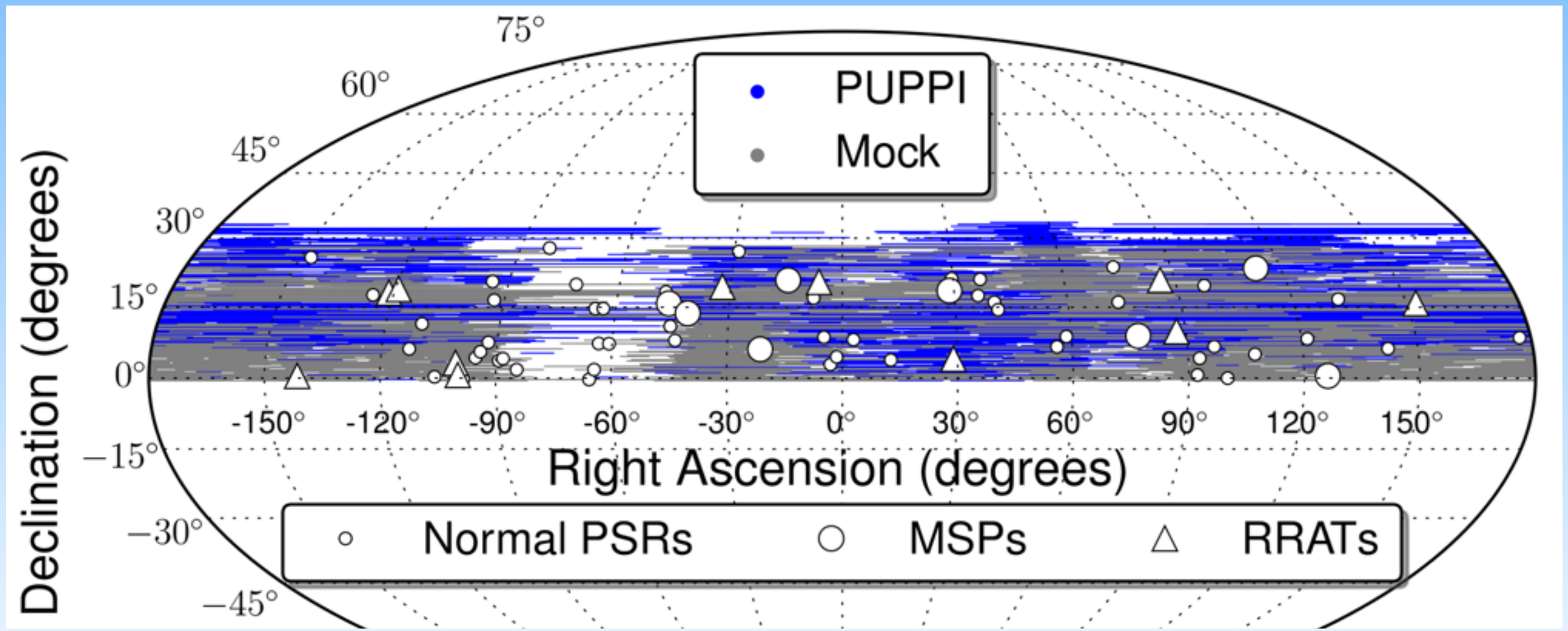
- In a 512 day orbit with a ~0.4 solar mass companion.





AO327

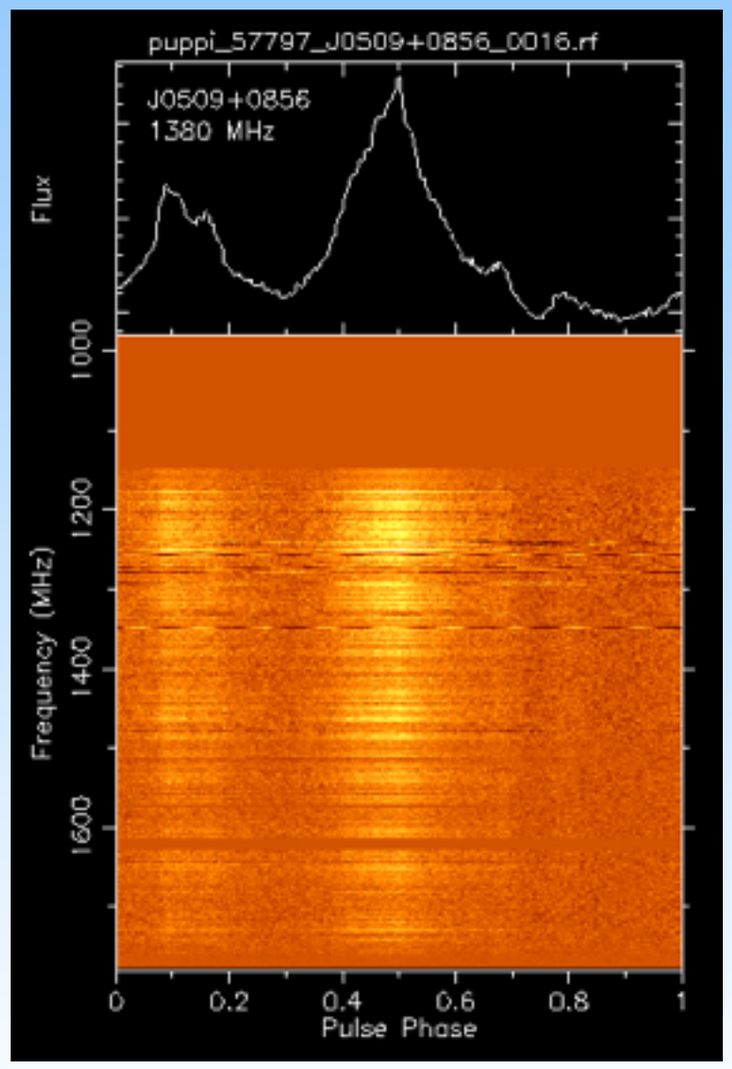
Discoveries to date:
72 Pulsars, 8 MSPs,13 RRATs, 2 DNSs, 1 wide binary

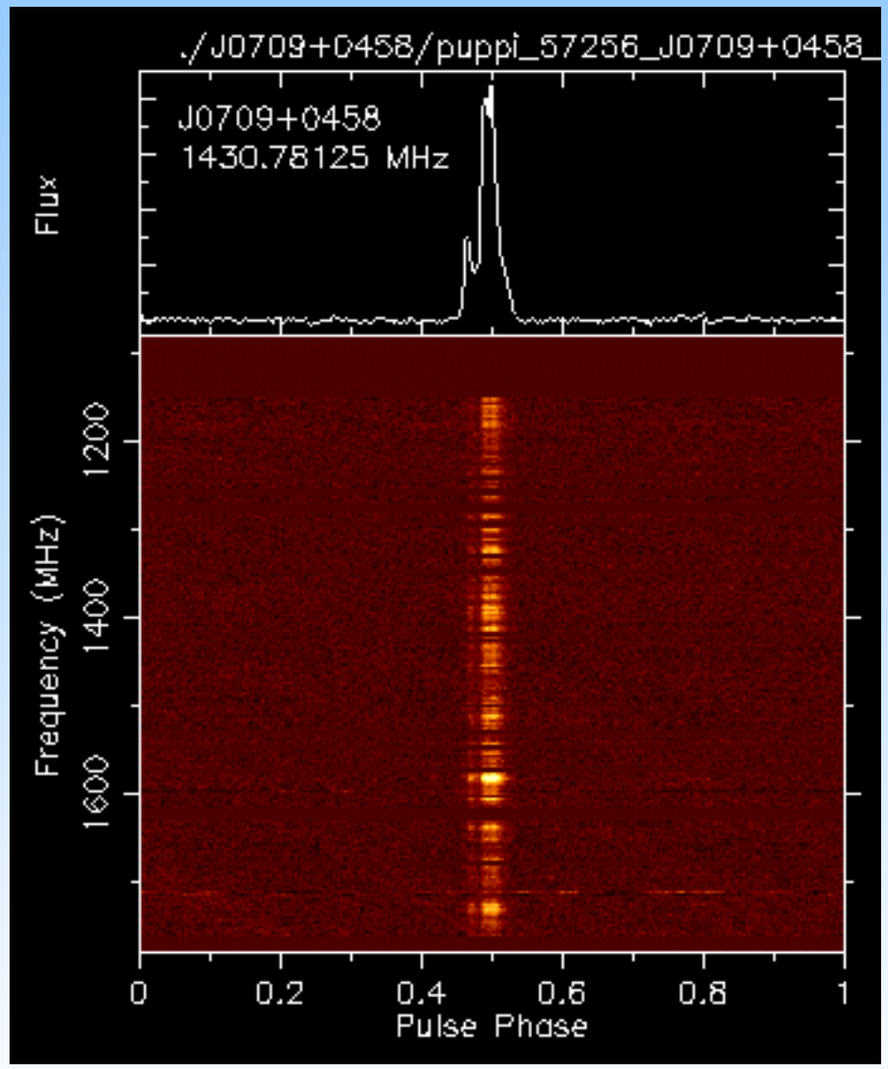


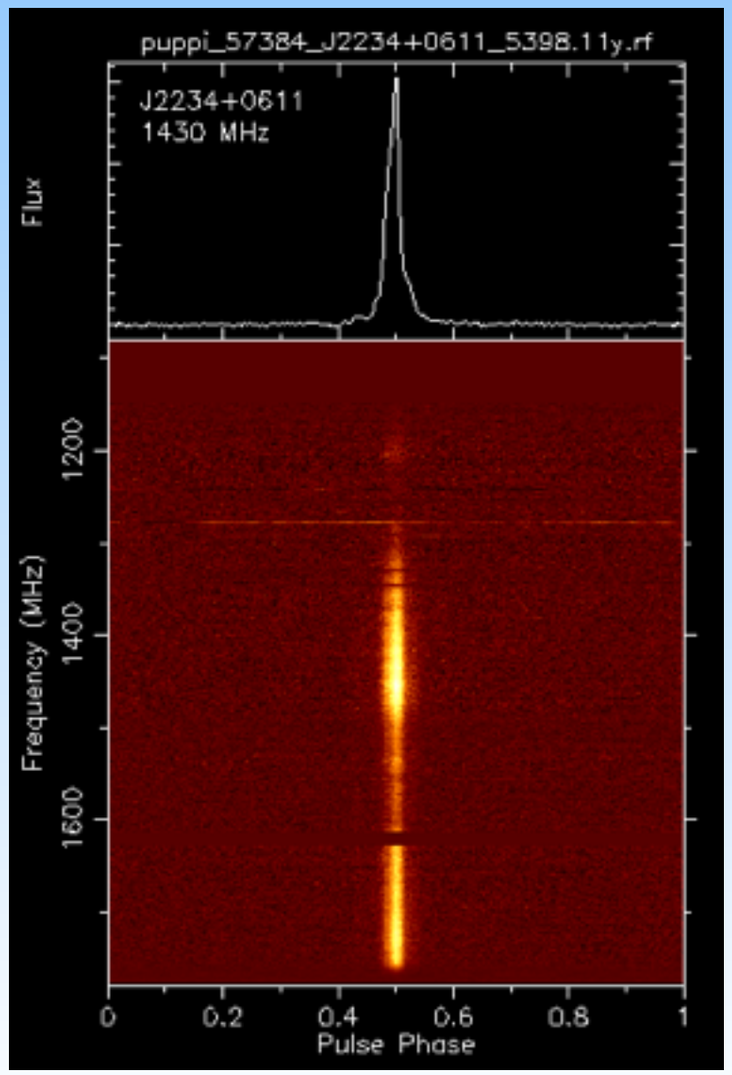
http://www.naic.edu/~deneva/drift-search/

AO327 Discoveries

3 MSPs added to NANOGrav so far, ~3 others currently being followed up that may be included in the future

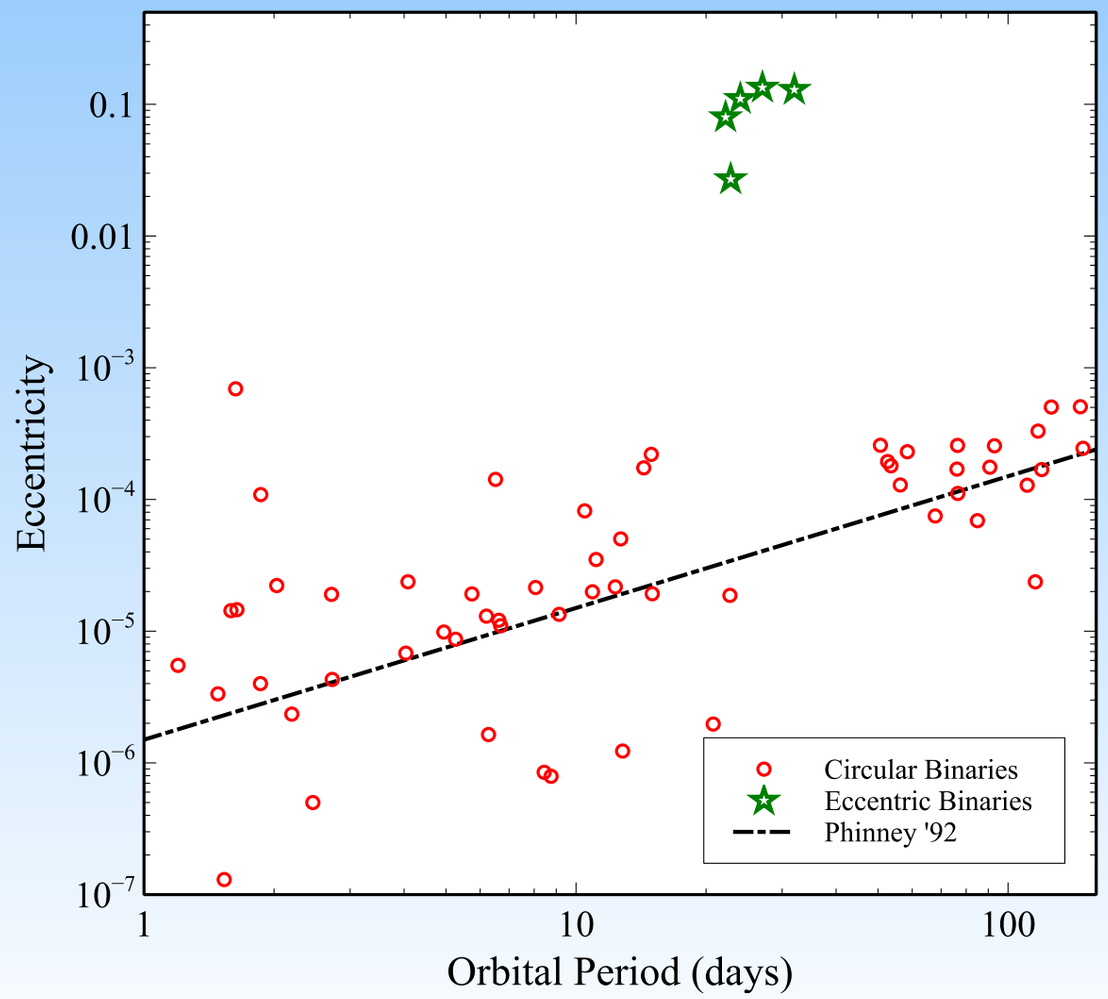




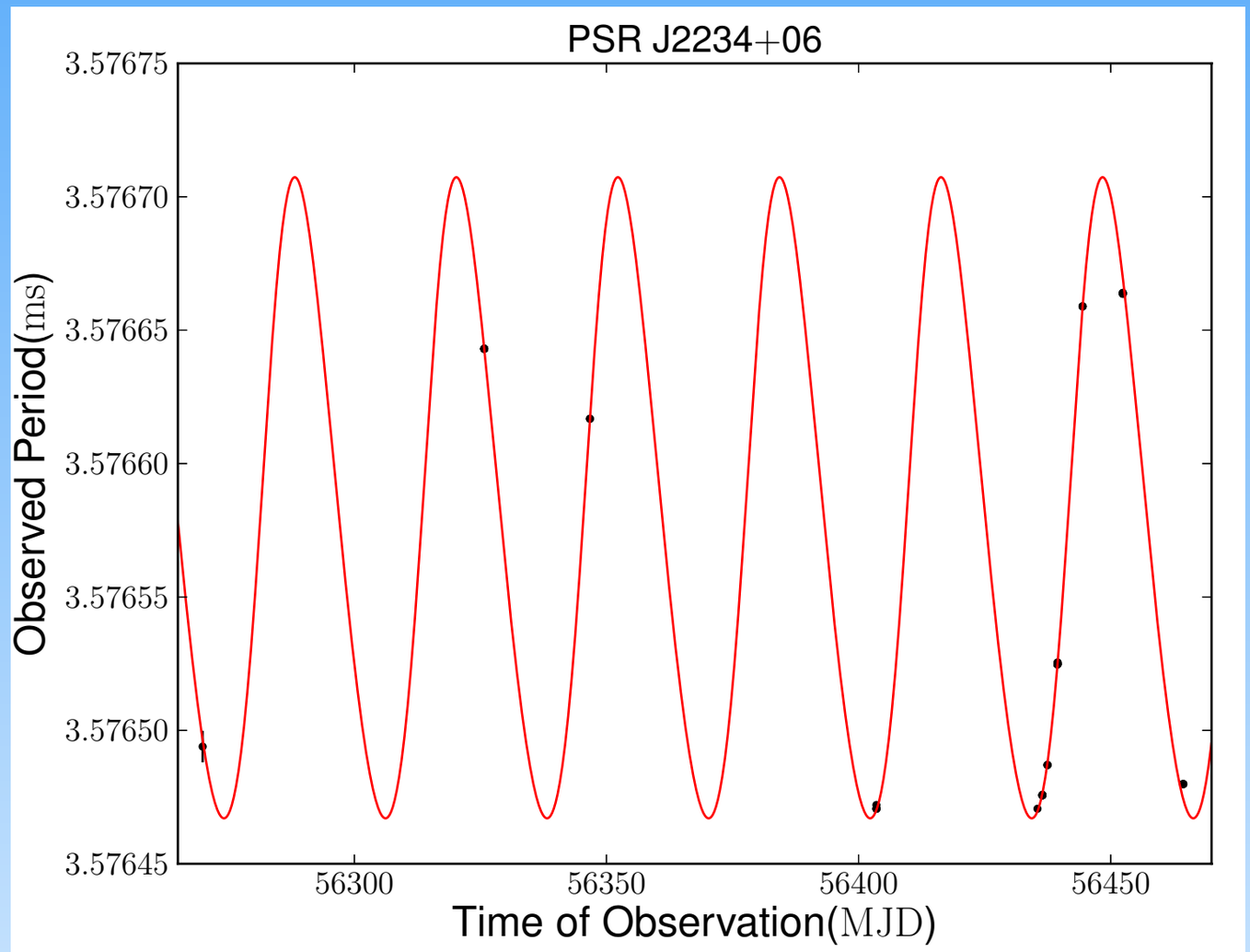


AO327 Discoveries

PSR J2234+0611
3.58 ms pulsar with DM of 10.8 pc/cm^3 in a 32 day orbit with a 0.2 solar mass companion, but eccentricity ~0.13.



Antoniadis et al. 2016, ApJ, 830, 36



Disrupted Triple System? Unlikely

RD-AIC? Maybe

Freire & Tauris 2014, MNRAS, 438, L86

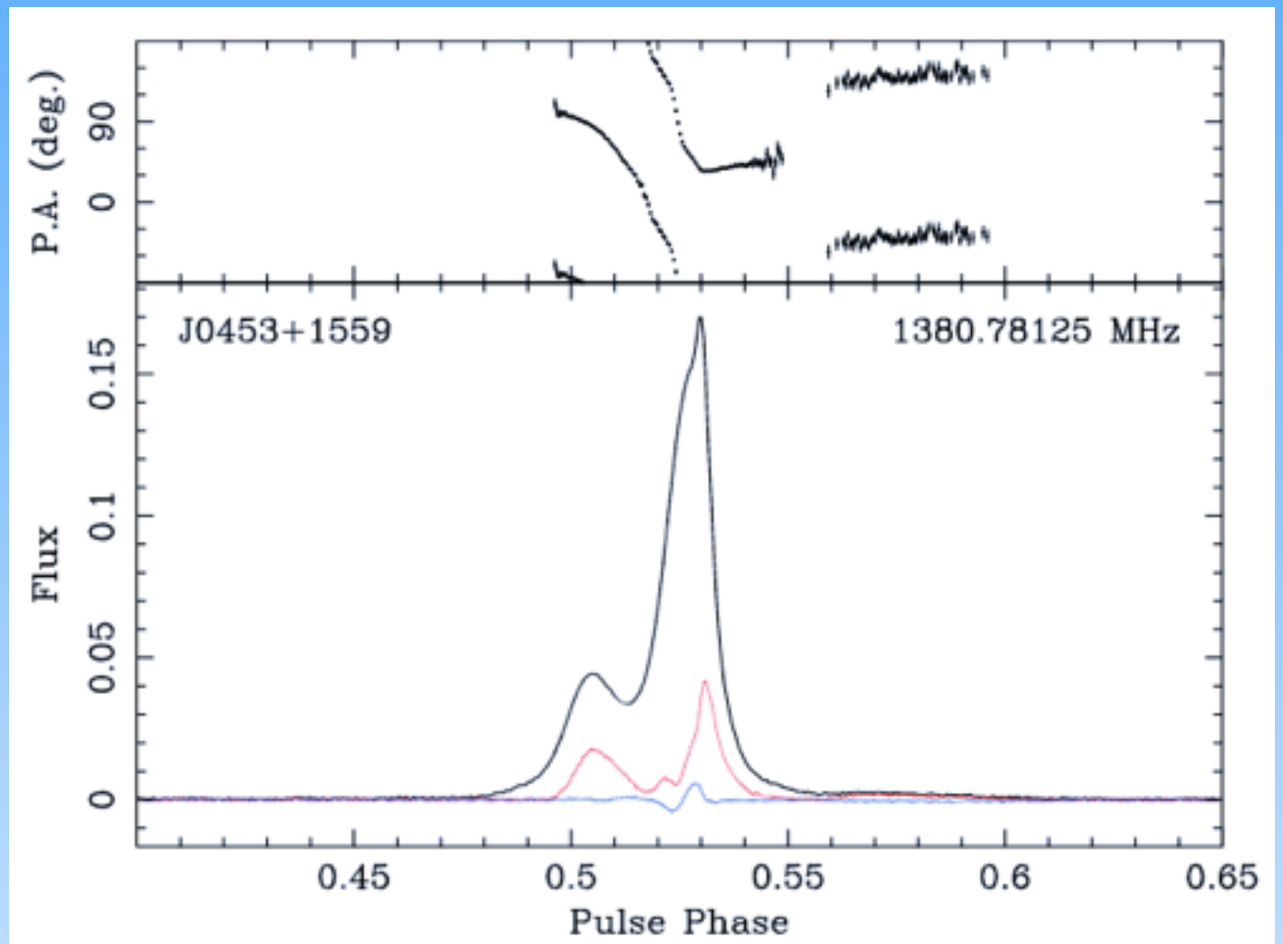
Circumbinary disk? Maybe

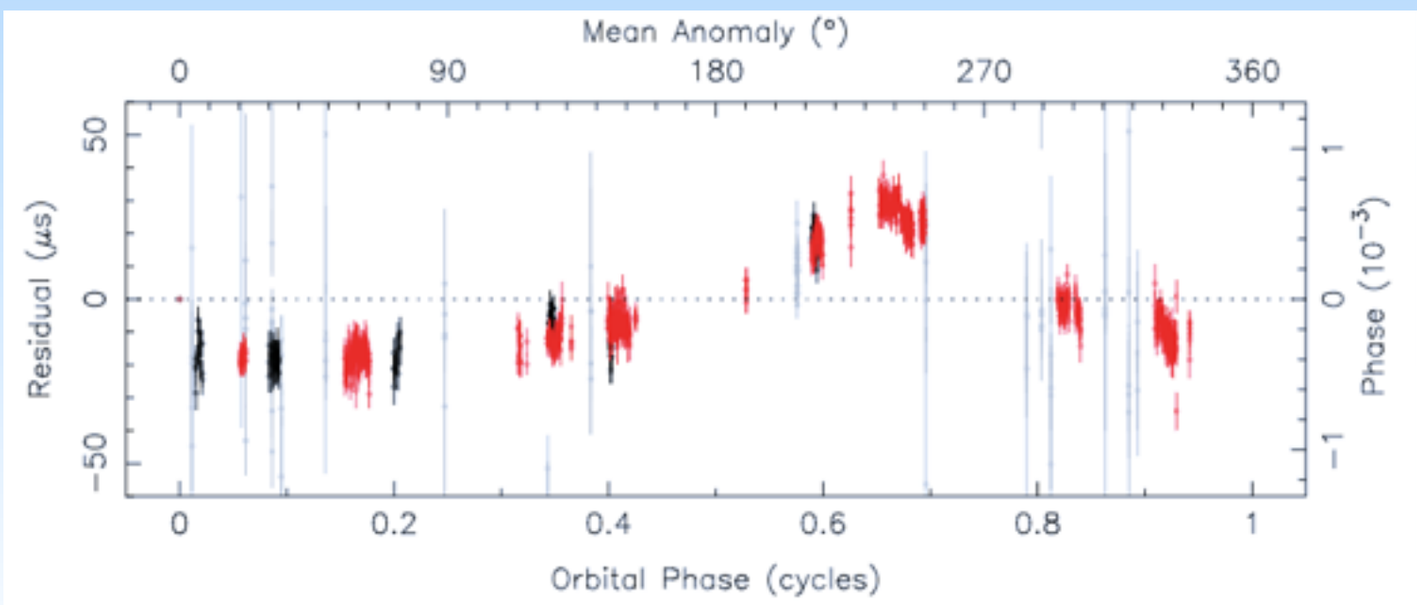
Antoniadis 2014, ApJ, 797, 24

AO327 Discoveries

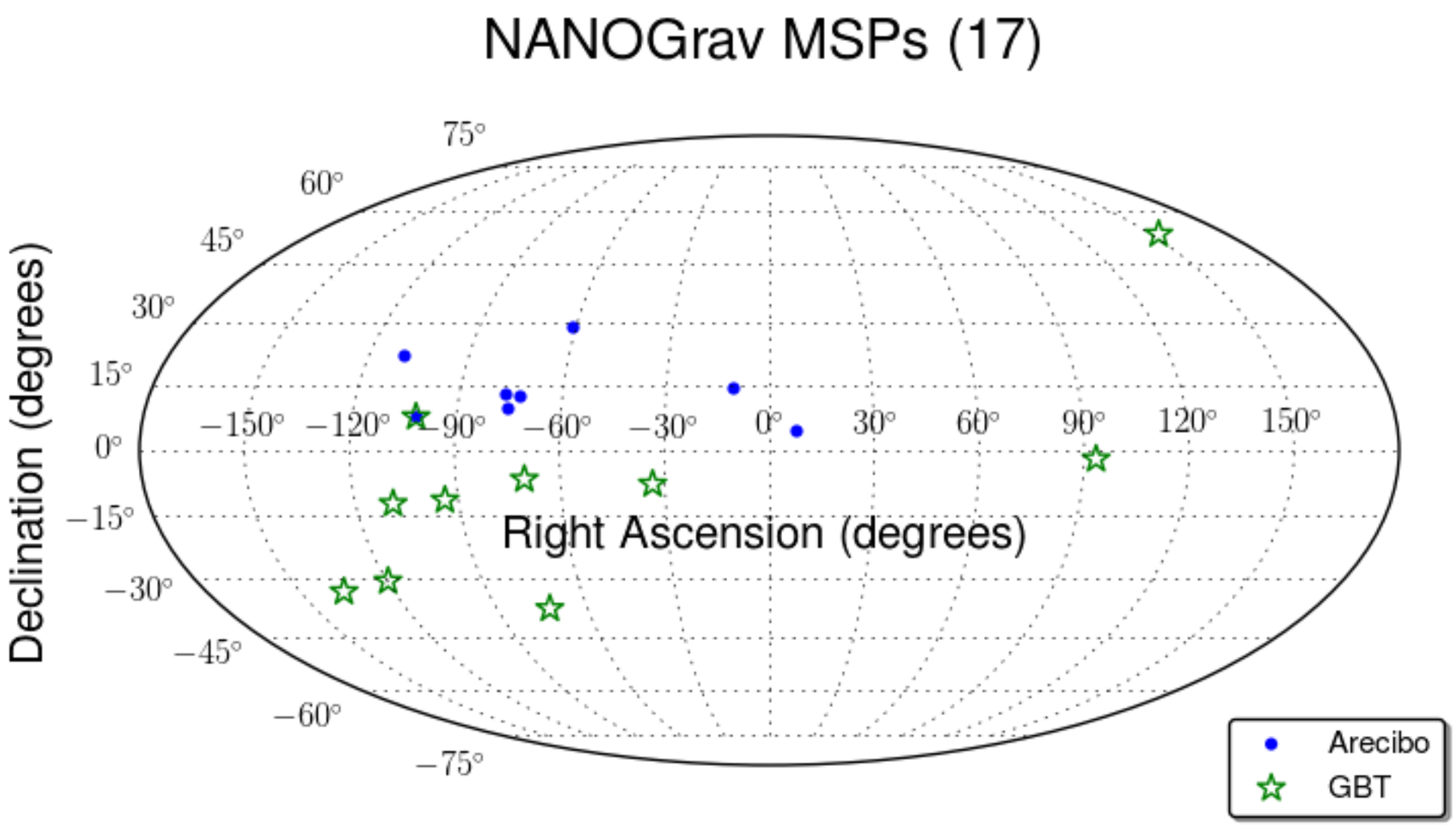
PSR J0453+1559

- 46 ms pulsar with a DM of 30.3 pc/cm^3 in an eccentric orbit (0.112) with a ~1.2 solar mass companion.
- Shapiro Delay measurement combined with rate of advance of periastron gives M_P=1.559(5) solar masses and M_C=1.174(4) solar masses.
- Largest pulsar mass for DNS system and companion has lowest neutron star mass.

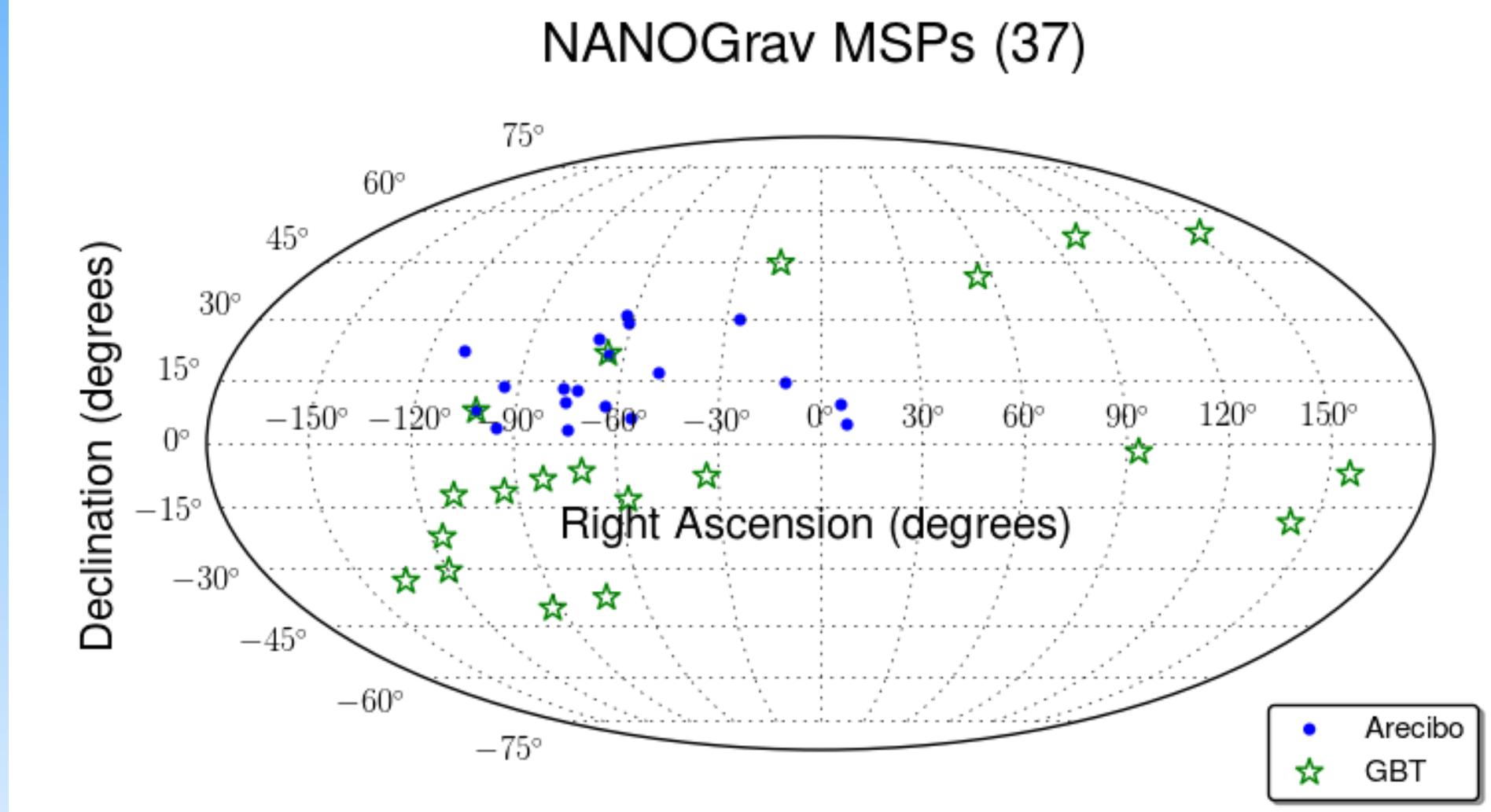




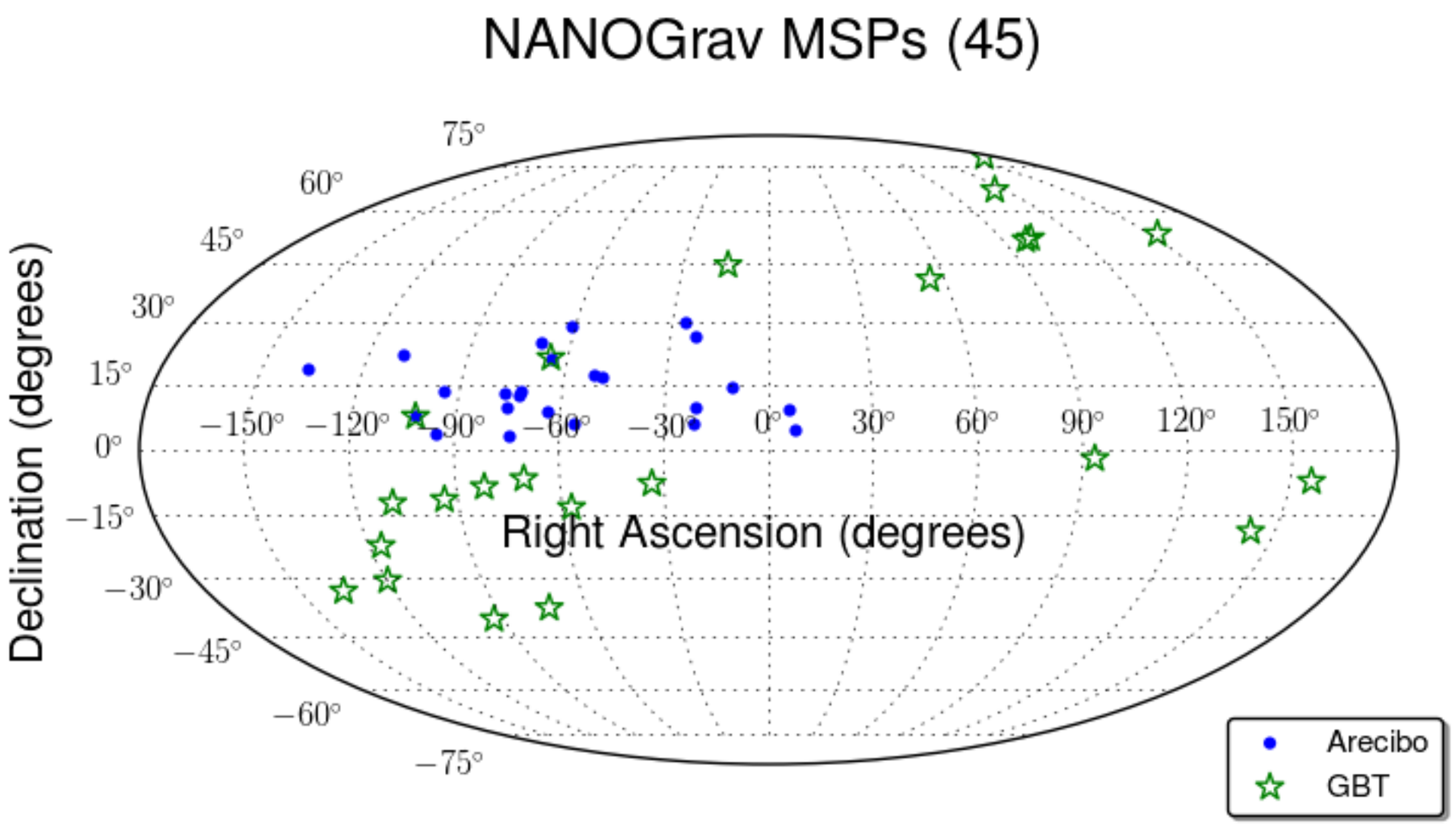
5 Year MSPs


NANOGrav MSPs (17)
Declination (degrees)
Right Ascension (degrees)
75°
60°
45°
30°
15°
0°
−15°
−30°
−45°
−60°
−75°
−150°
−120°
−90°
−60°
−30°
0°
30°
60°
90°
120°
150°
Arecibo
GBT

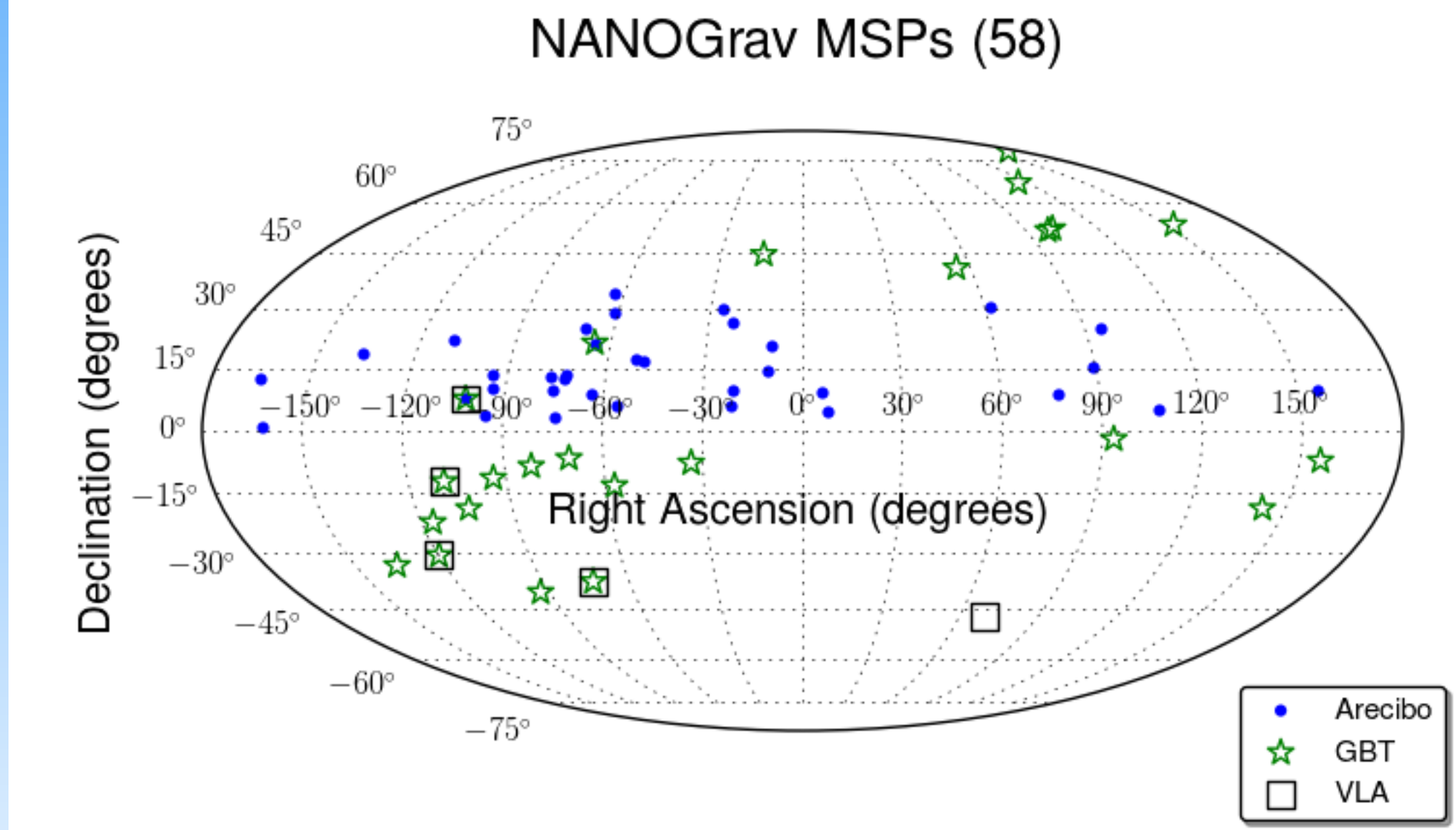
9 Year MSPs


NANOGrav MSPs (37)
Declination (degrees)
Right Ascension (degrees)
75°
60°
45°
30°
15°
0°
−15°
−30°
−45°
−60°
−75°
−150°
−120°
−90°
−60°
−30°
0°
30°
60°
90°
120°
150°
Arecibo
GBT

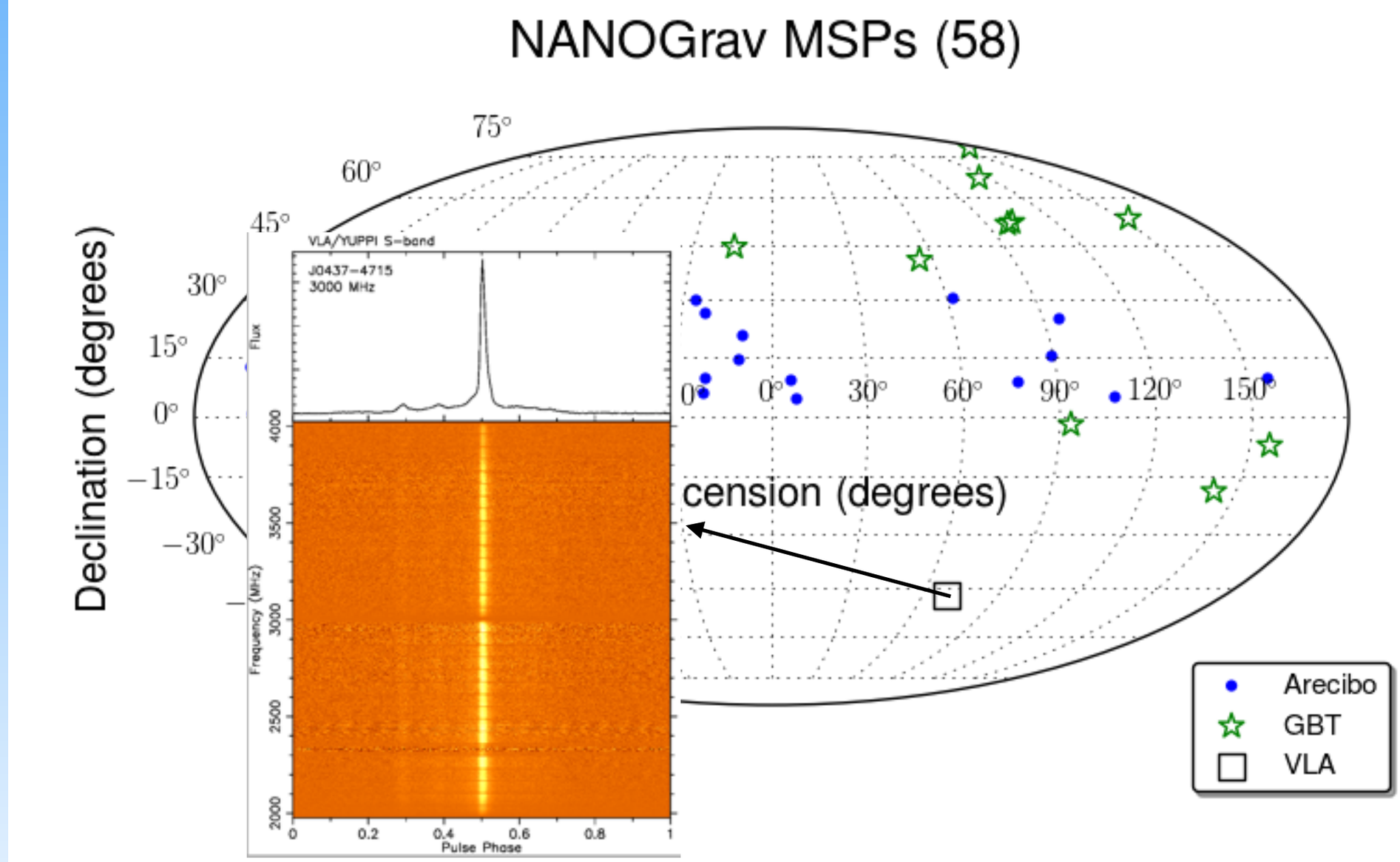
11 Year MSPs


NANOGrav MSPs (45)
Declination (degrees)
Right Ascension (degrees)
75°
60°
45°
30°
15°
0°
−15°
−30°
−45°
−60°
−75°
−150°
−120°
−90°
−60°
−30°
0°
30°
60°
90°
120°
150°
Arecibo
GBT

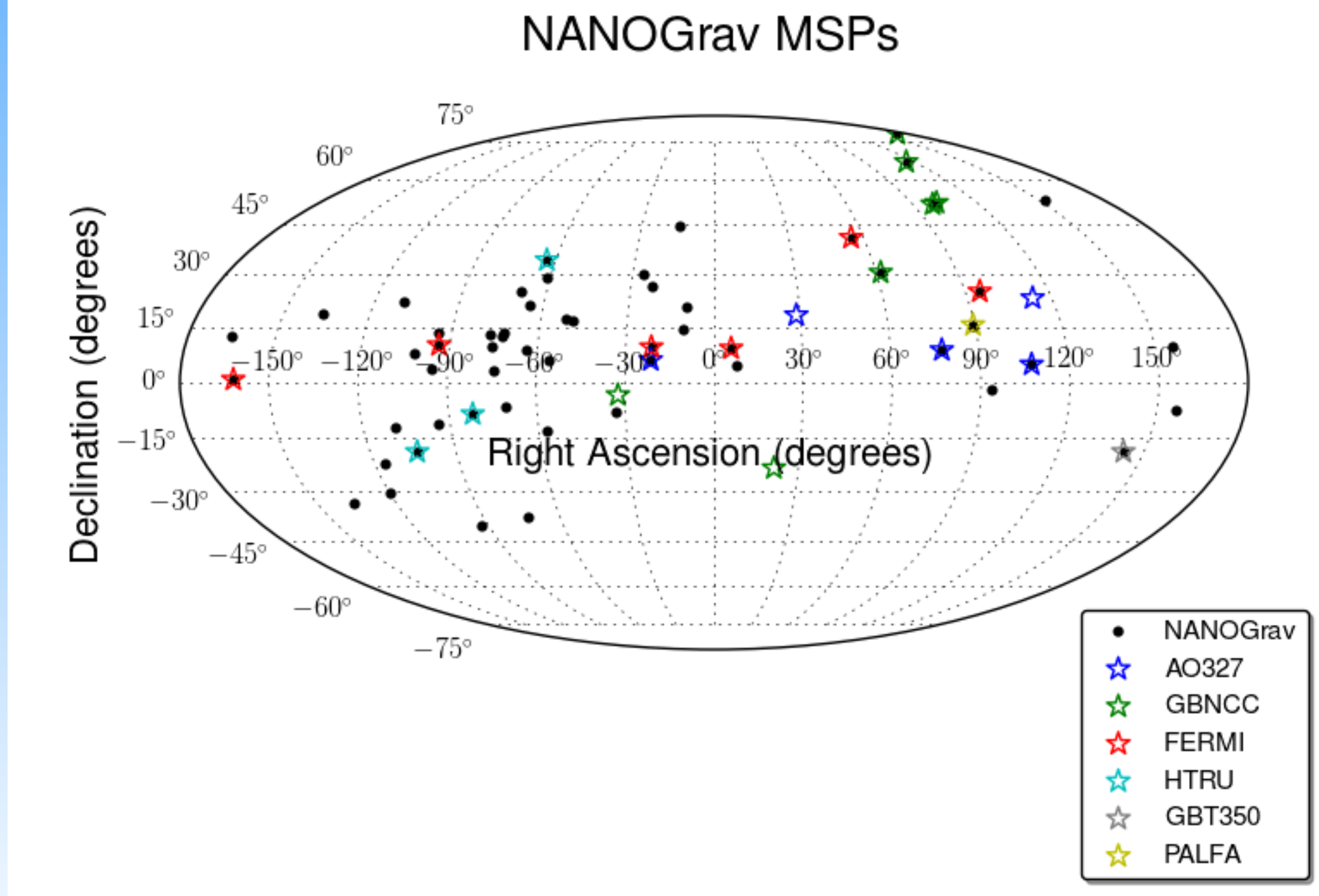
Current MSPs



Current MSPs



NANOGrav MSPs



Conclusion

- NANOGrav is using pulsars as a galactic scale gravitational wave detector.
- We gain sensitivity by finding additional MSPs and we have reason to believe not all good MSPs have been found.
- There are multiple large-scale search efforts ongoing to find suitable MSPs and they have added many new MSPs to the array.
- Eight out of the ~60 MSPs being timed were found in the 2 surveys mentioned here (within the past 5 years) and more are currently being tested for future inclusion.