Einstein@Home Discoveries of Fermi-LAT Pulsars

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on behalf of the Fermi-LAT Collaboration and the AEI Hannover

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MAX-PLANCK-GESELLSCHAFT

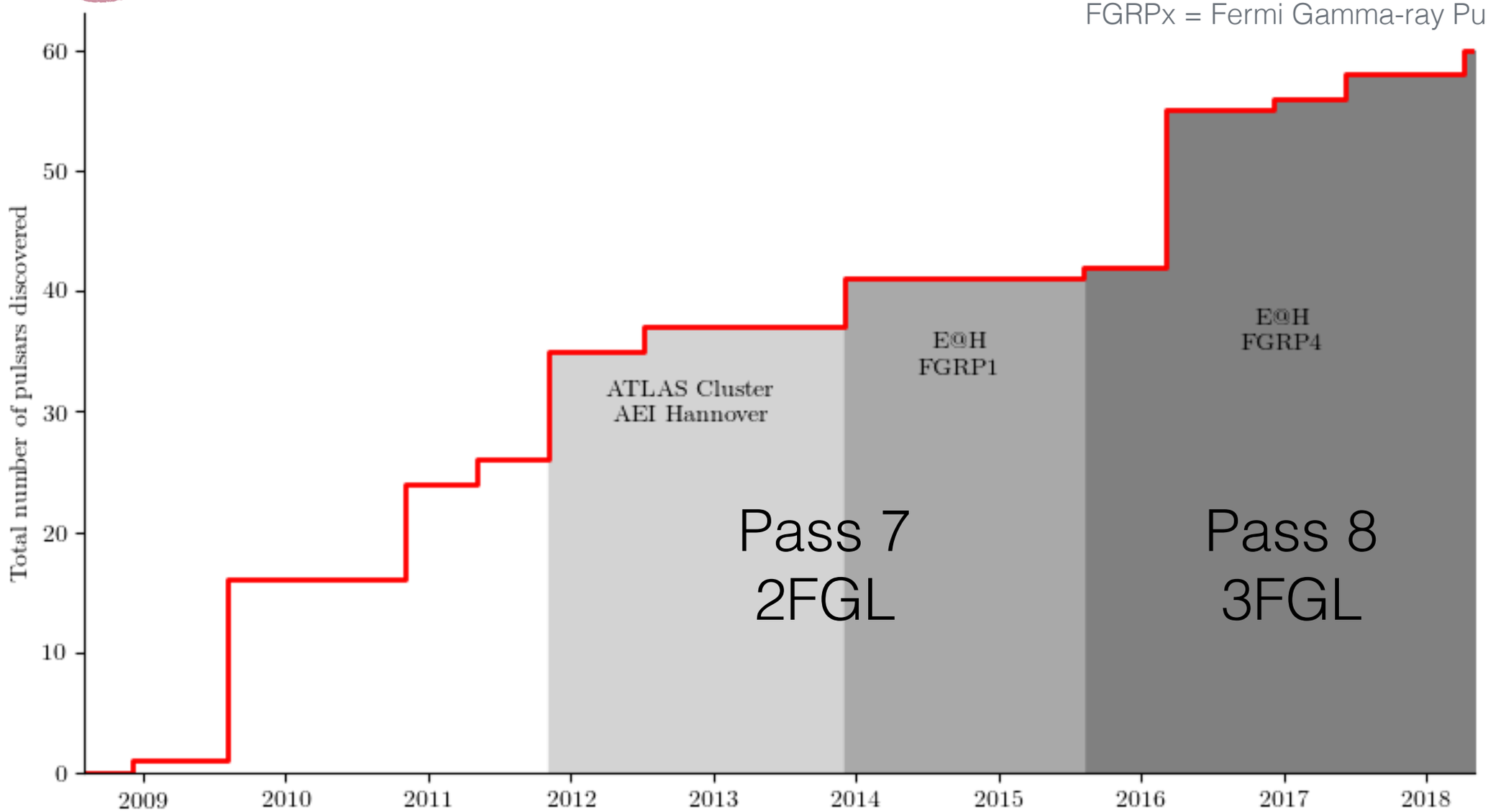
Max Planck Institute
for Gravitational Physics
(Albert Einstein Institute)

Leibniz
Universität
Hannover

Fermi
Gamma-ray
Space Telescope

Blind Searches for Gamma-ray Pulsars

https://einsteinathome.org/gammaraypulsar/FGRP1_discoveries.html
FGRPx = Fermi Gamma-ray Pulsar Survey x

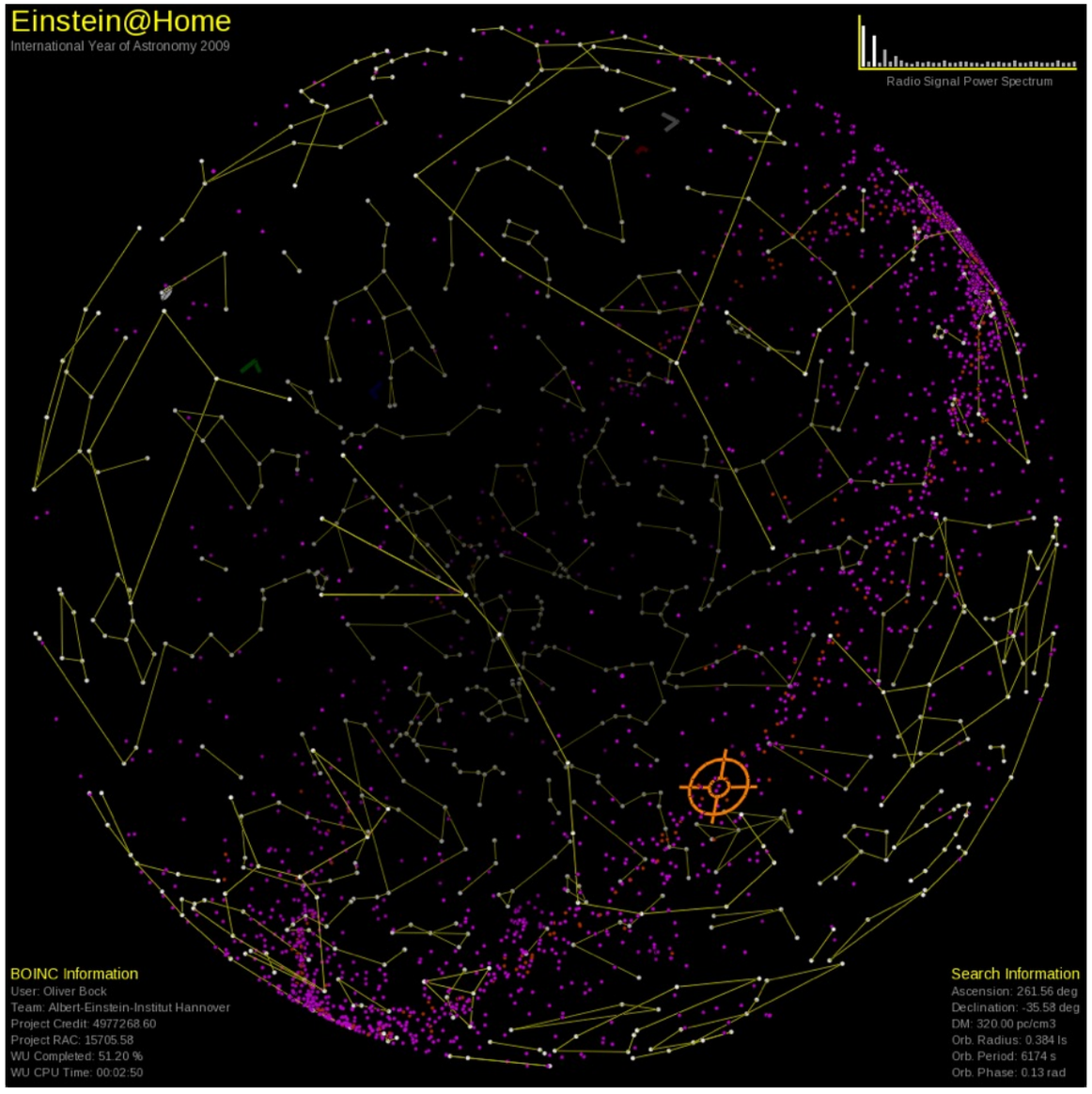


- Einstein@Home discovered 23 pulsars (surveys ongoing!)
- Most blind-search pulsars remain radio-quiet

Einstein@Home

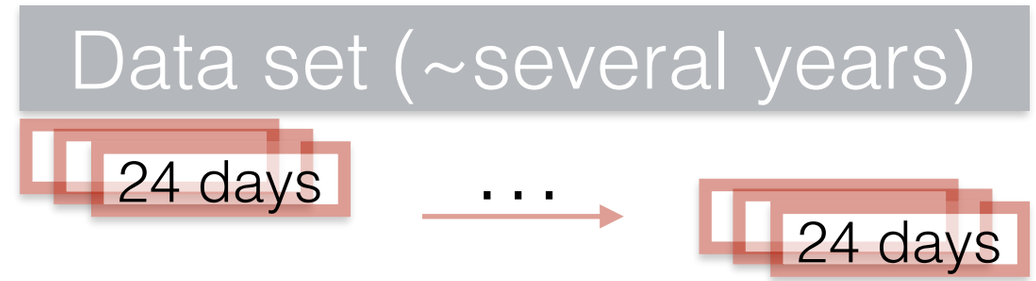
https://einsteinathome.org/server_status.php
https://einsteinathome.org

- Project using volunteer computer's idle time
- Searches for weak astrophysical signals
  - Data from LIGO, Parkes, Arecibo and Fermi-LAT
- Apps for CPUs and GPUs
  - More than 5.6 PFLOPS



New Search Methods

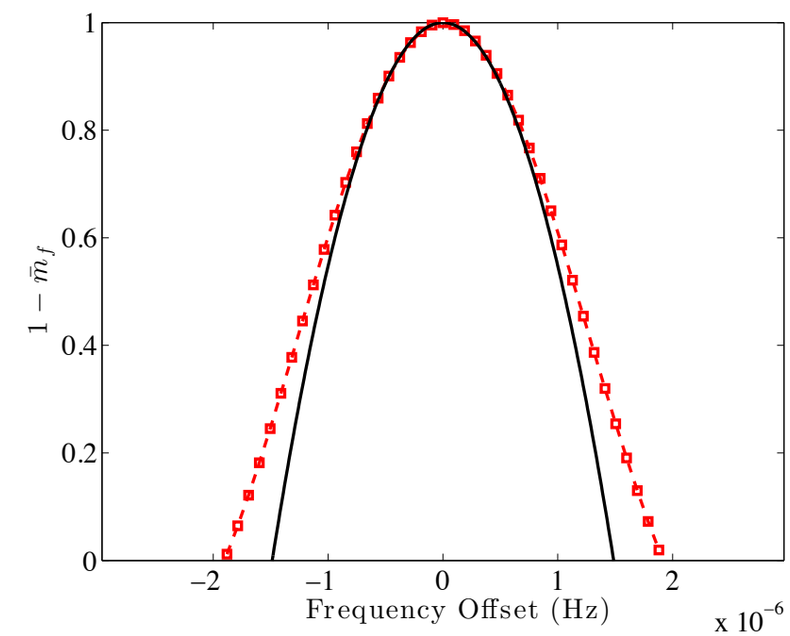
Pletsch, H. J., & Clark, C. J. 2014, ApJ, 795, 75



Hierarchical multi-stage search:

Zooming in

- Semi-coherent stages
  - Efficiently scan large parameter spaces
- Fully coherent follow-up in finer grid
- Include power in higher harmonics

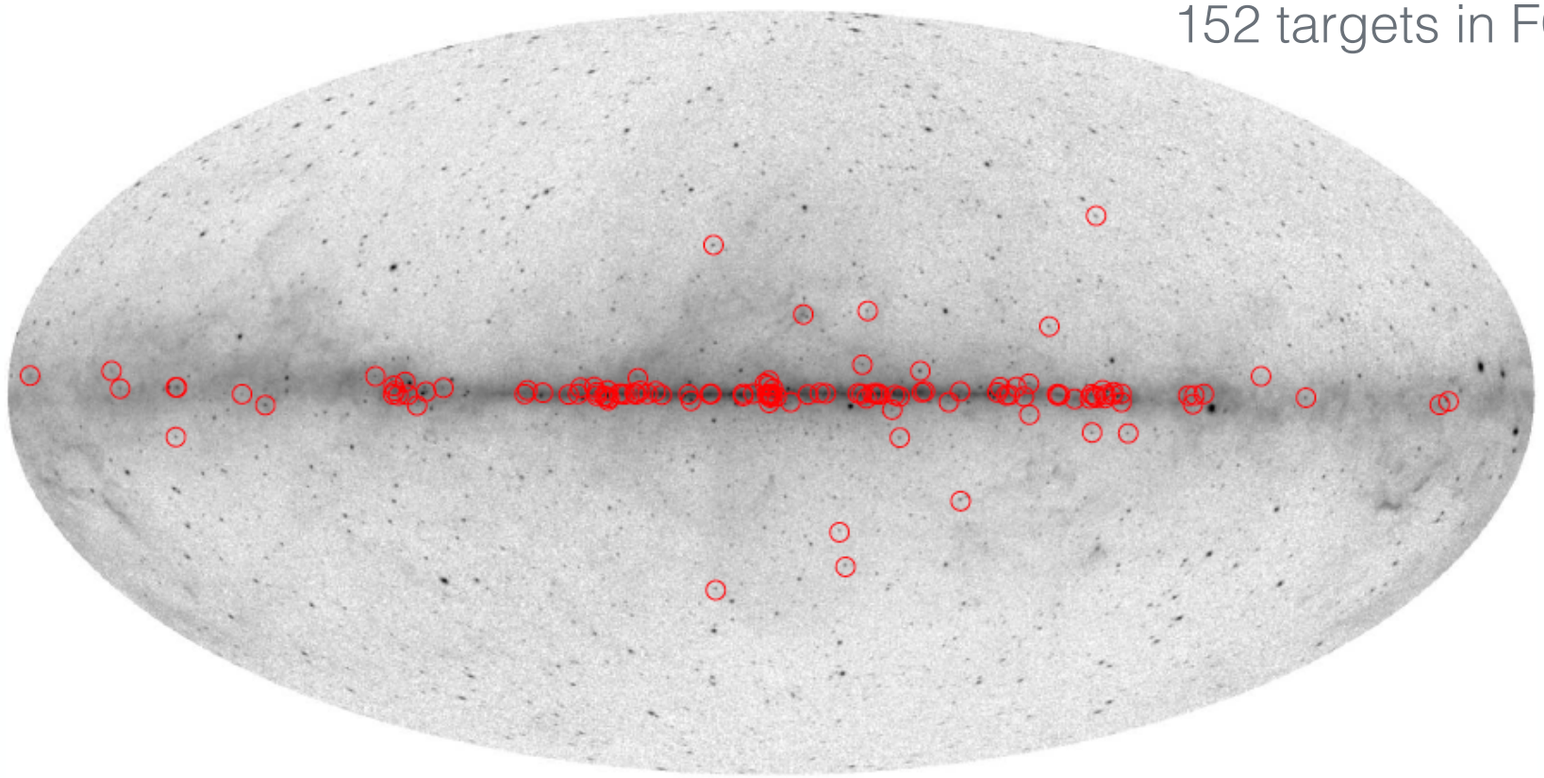


Generation of efficient grid:

- Utilization of distance metric
  - Second order approximation of expected signal-to-noise loss
- Frequency dependent grid
  - Denser grid in sky position at higher frequencies

Discovered Young Pulsars

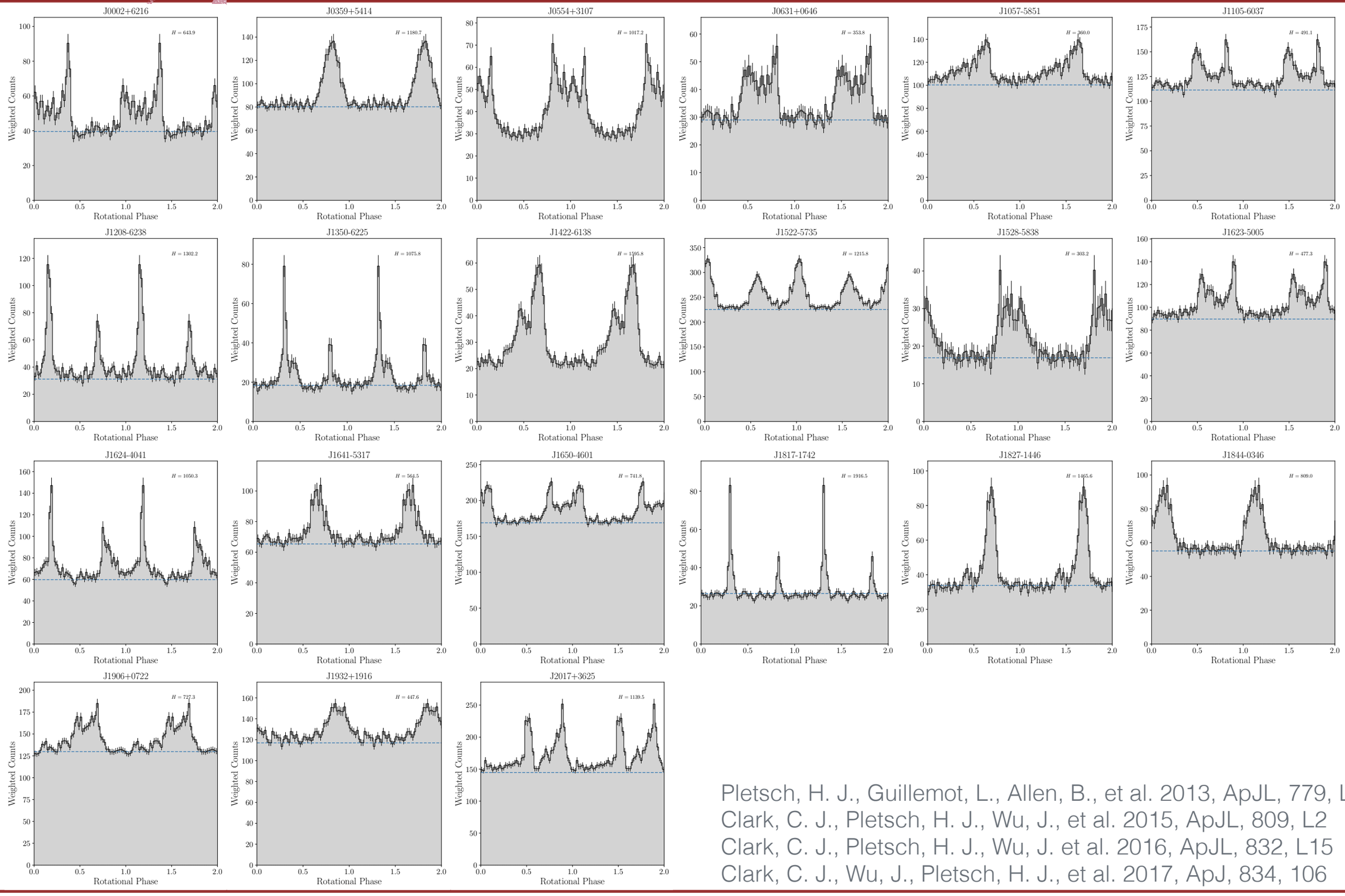
152 targets in FGRP4 survey



- Past surveys targeted 2FGL and 3FGL point sources
- 21 young pulsars have been detected
  - Age: 2.7 kyr - 2 Myr
  - Spin frequency: 1.6 - 12.6 Hz
  - Spin-down power: 1e+34 - 4e+36 erg/s
- 4 pulsars glitched throughout Fermi mission
- Many pulsars show timing noise

Clark, C. J., Wu, J., Pletsch, H. J., et al. 2017, ApJ, 834, 106
Wu, J., Clark, C. J., Pletsch, H. J., et al. 2018, ApJ, 854, 99

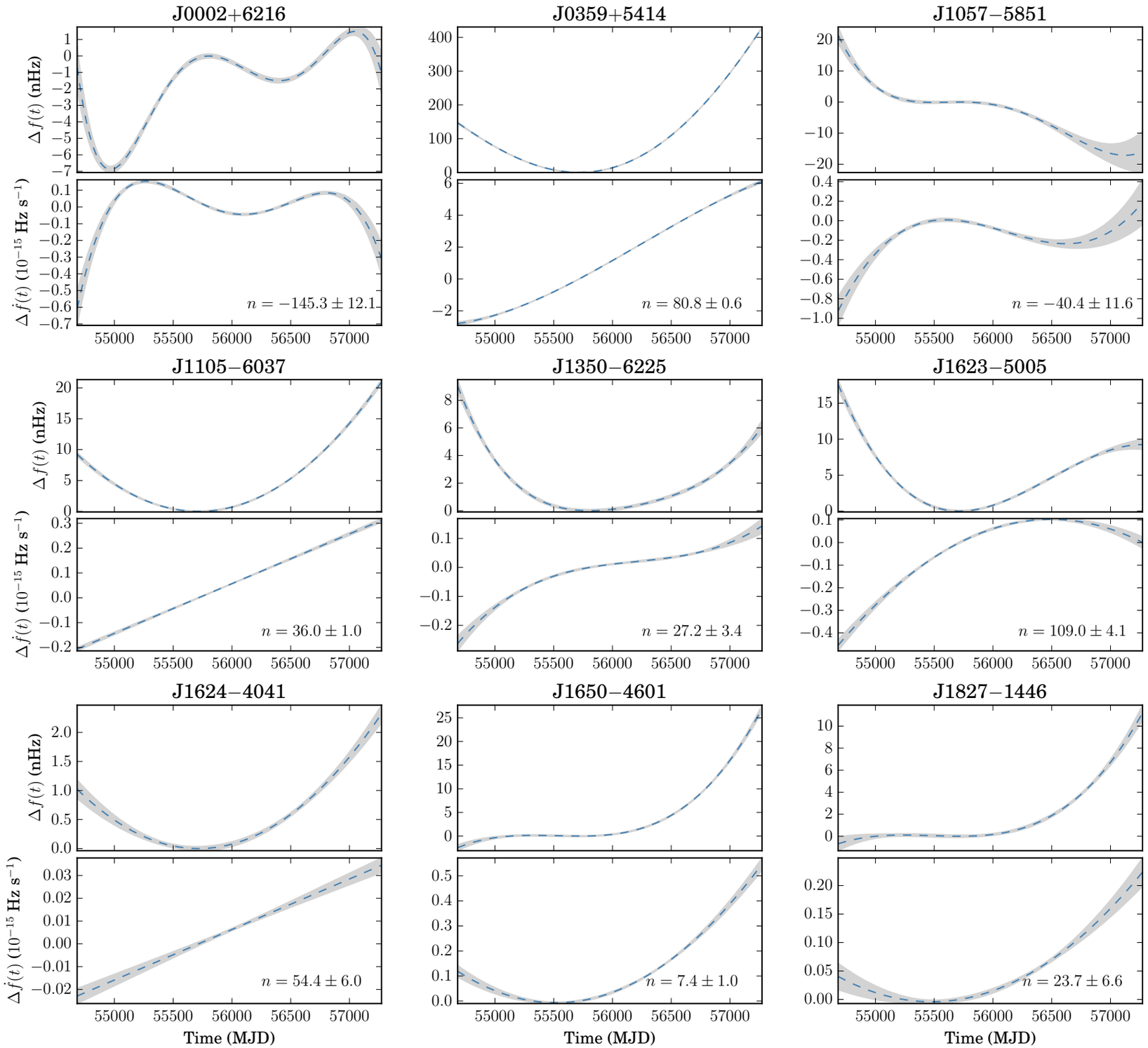
Young Pulsars: Pulse Profiles

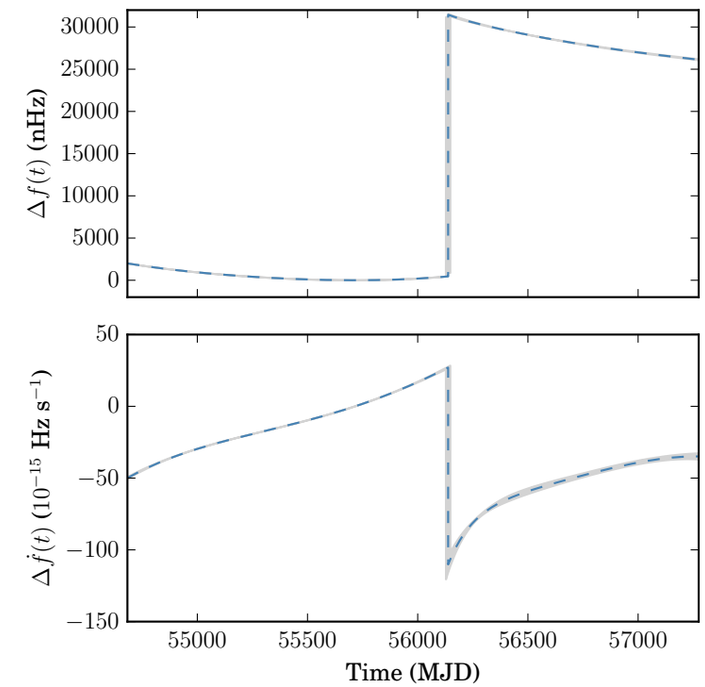


Pletsch, H. J., Guillemot, L., Allen, B., et al. 2013, ApJL, 779, L11
Clark, C. J., Pletsch, H. J., Wu, J., et al. 2015, ApJL, 809, L2
Clark, C. J., Pletsch, H. J., Wu, J. et al. 2016, ApJL, 832, L15
Clark, C. J., Wu, J., Pletsch, H. J., et al. 2017, ApJ, 834, 106

Timing Young Pulsars

Clark, C. J., Wu, J., Pletsch, H. J., et al. 2017, ApJ, 834, 106





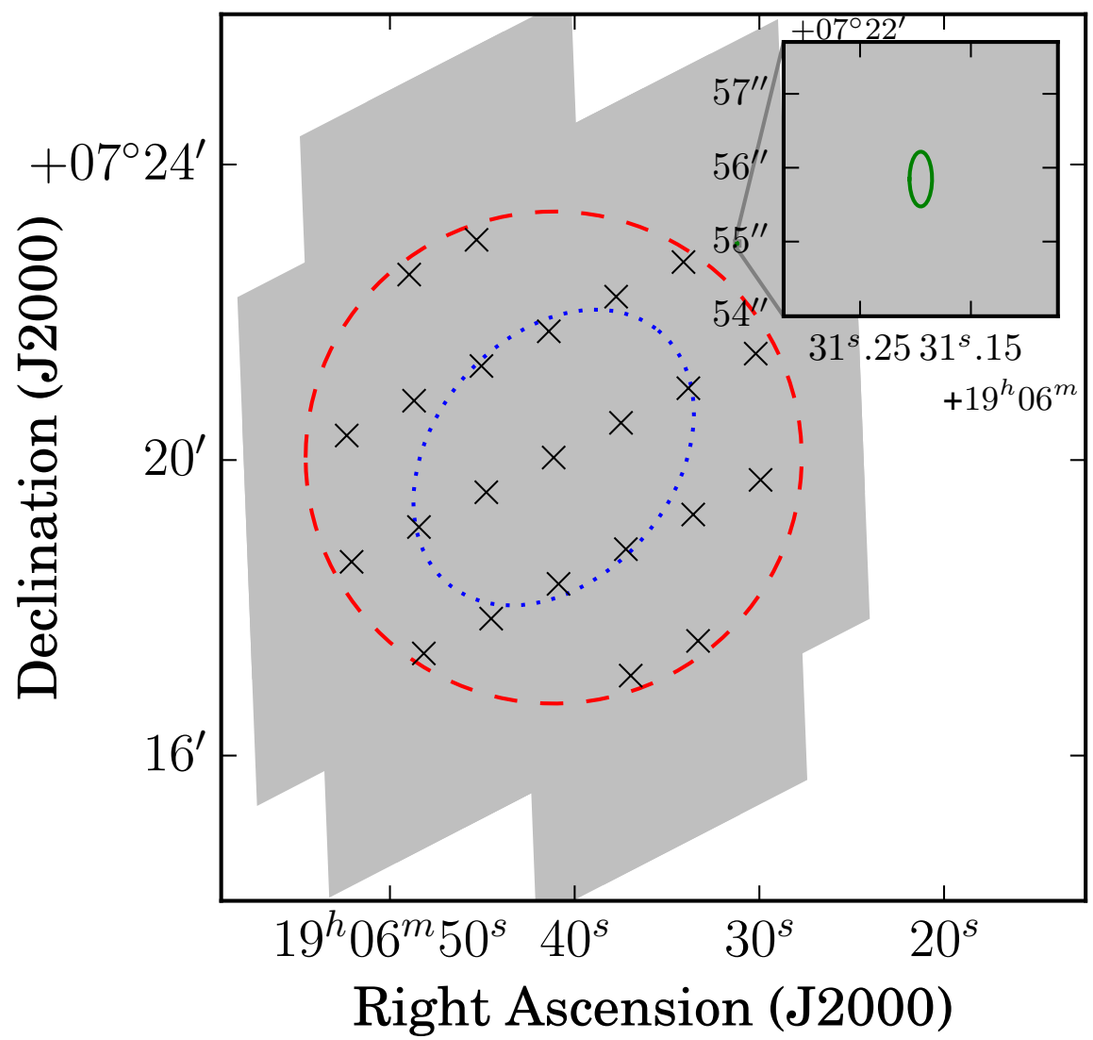
- Glitches and timing noise in most young pulsars
- Continuous all-sky survey helpful for long timing solutions

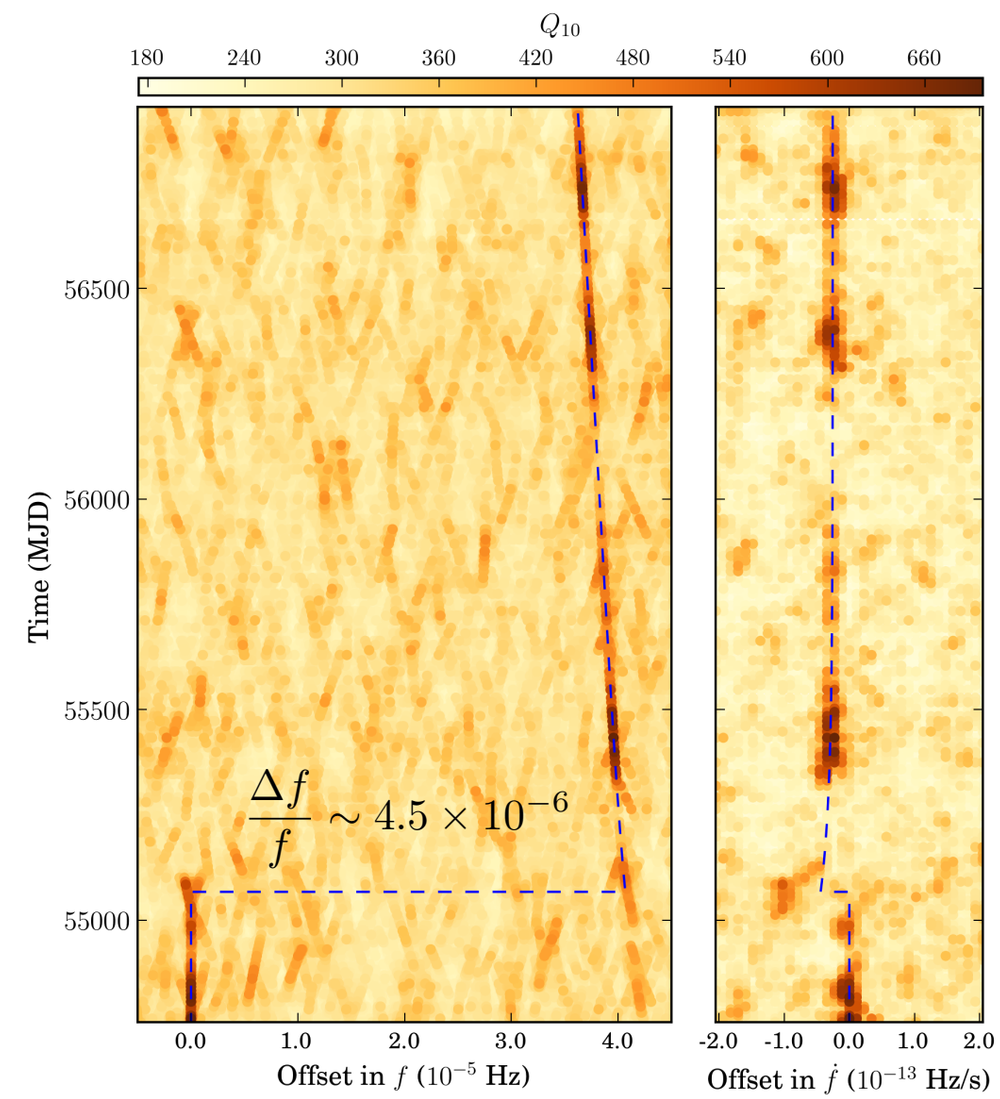
An Elusive Gamma-ray Pulsar

Clark, C. J., Pletsch, H. J., Wu, J., et al. 2015, ApJL, 809, L2

PSR J1906+0722

- Large offset from 3FGL position
- One of the largest glitches from a gamma-ray pulsar
- Off-pulse data revealed additional nearby source





The Youngest Radio-Quiet Pulsar

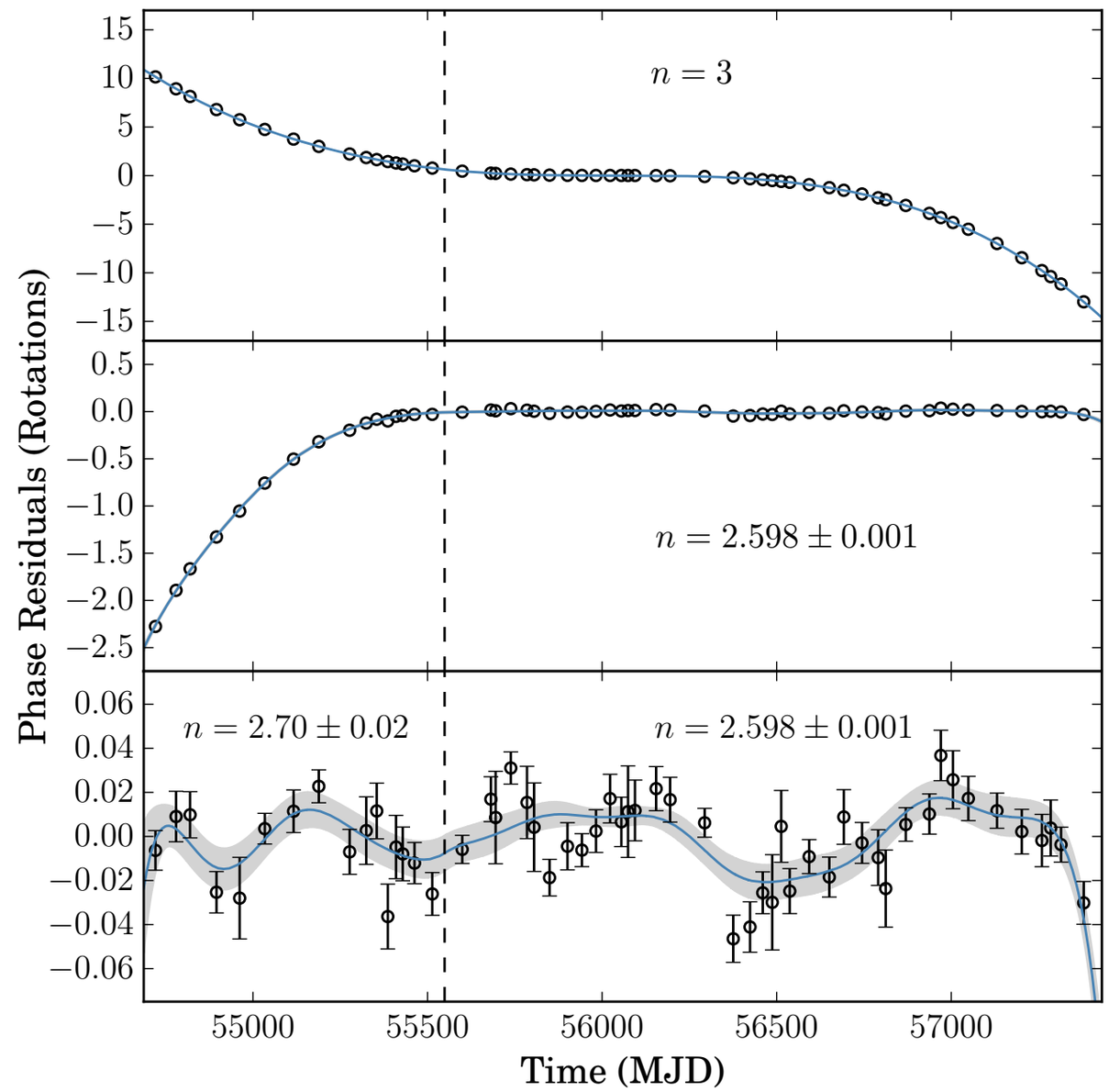
Clark, C. J., Pletsch, H. J., Wu, J. et al. 2016, ApJL, 832, L15

Definition of braking index: $\dot{f} \propto -f^n$

Fixed dipole braking index

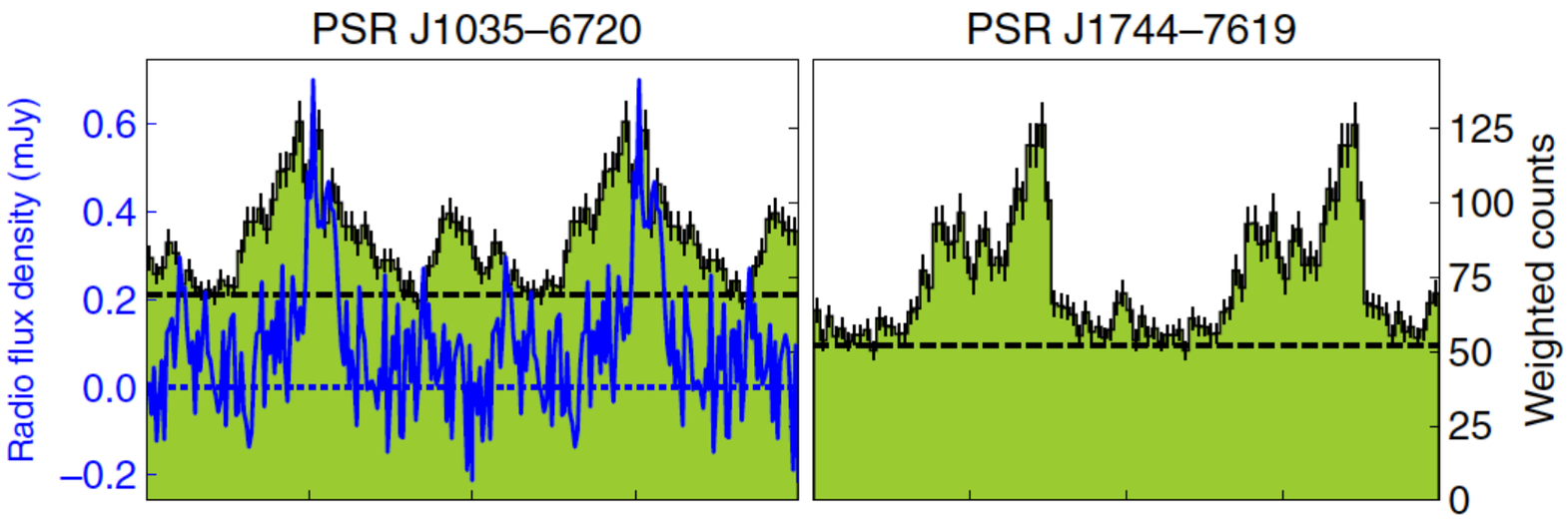
Bestfit constant braking index

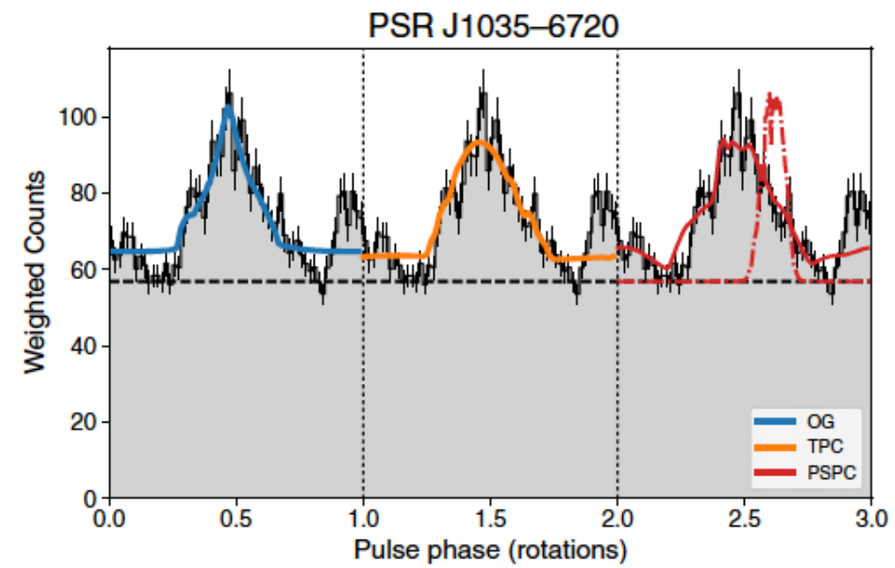
Change in braking index and spin-down rate

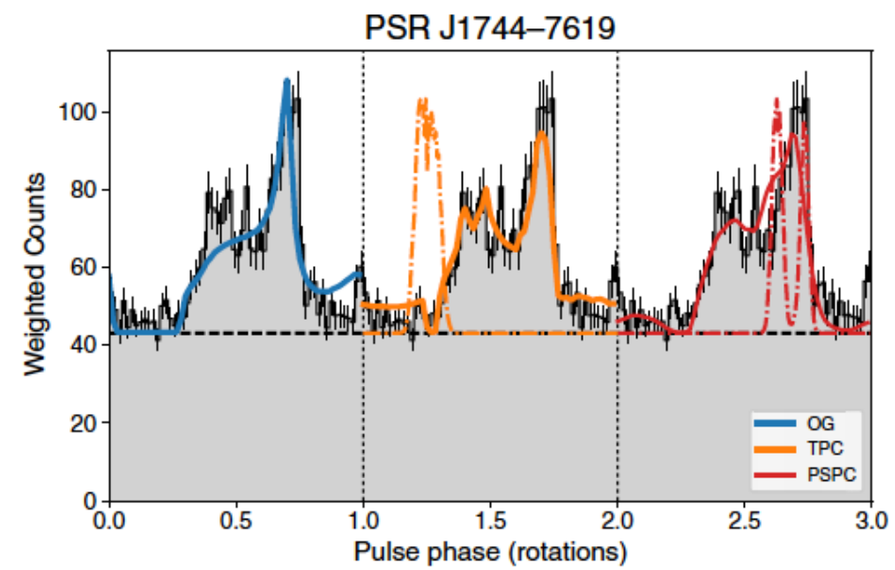


Hunt for Millisecond Pulsars

Clark, C. J., Pletsch, H. J., Wu, J., et al. 2018, Science Advances, 4, 937 eaao7228





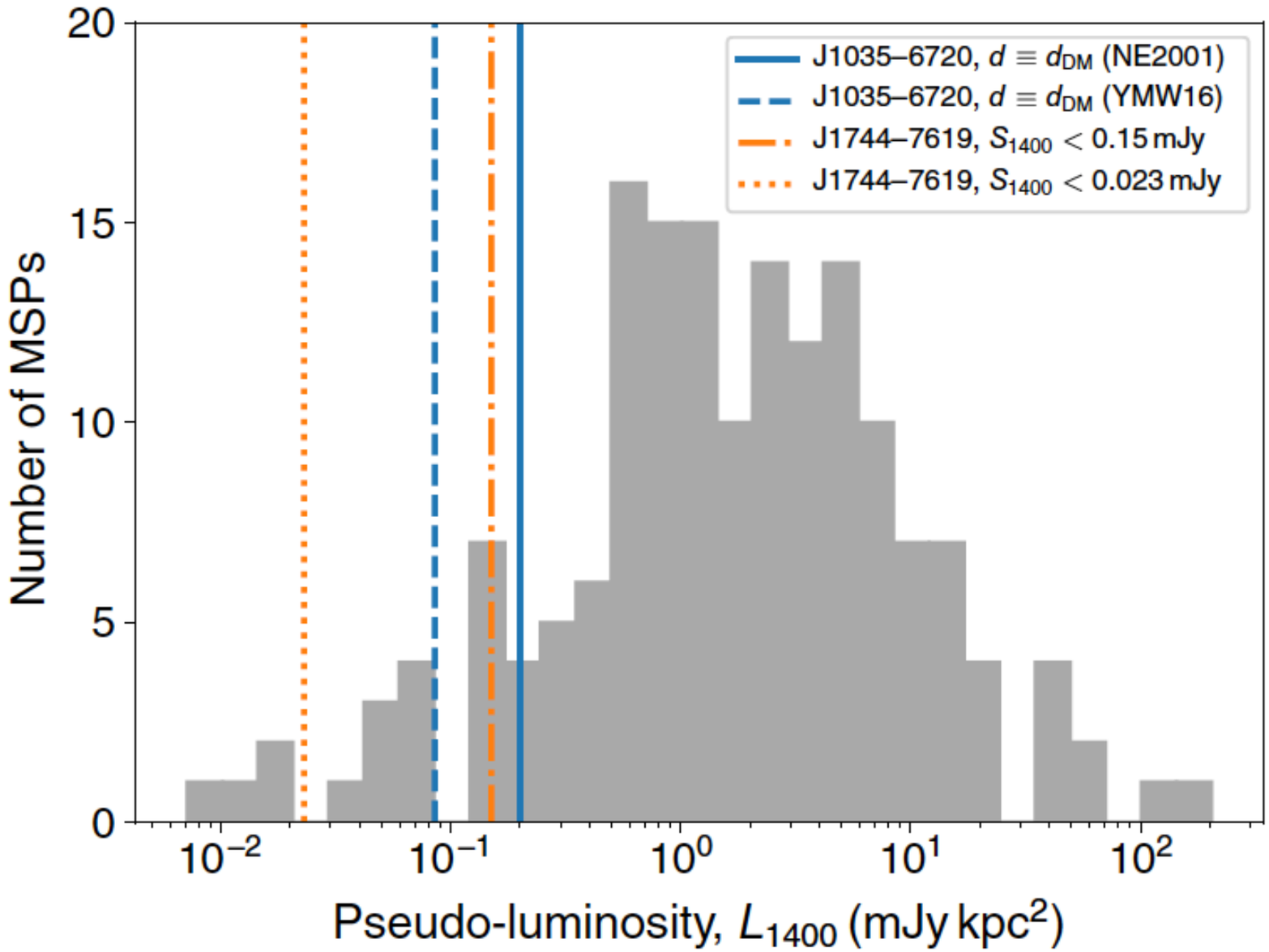


- Search up to 1.4 kHz
- First MSPs solely found in gamma-ray blind search
- Good test for pulsar emission models

  Tried OG, TPC, PSPC models

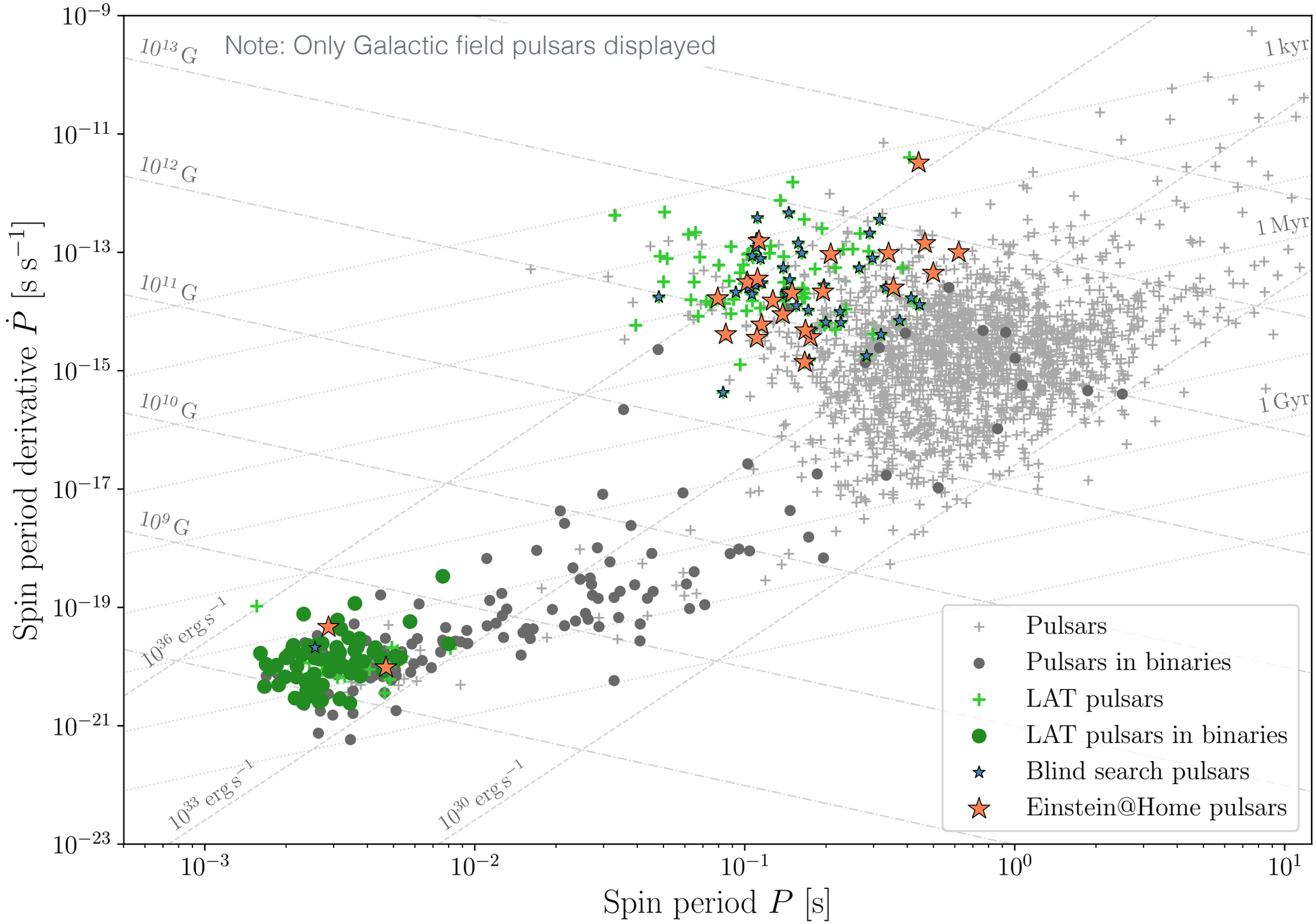
A Radio-Quiet Millisecond Pulsar

Clark, C. J., Pletsch, H. J., Wu, J., et al. 2018, Science Advances, 4, 937 eaao7228



- PSR J1035-6720 is very faint in radio
- No detection in radio for PSR J1744-7619

Einstein@Home Discoveries



http://www.atnf.csiro.au/research/pulsar/psrcat
https://tinyurl.com/fermipulsars

Current Surveys

Search for Isolated Pulsars towards the Galactic Center

- Targets from region close to the Galactic Center
  - Putative Galactic bulge population might explain inner-Galaxy GeV excess
- High background

Search for "Spider Pulsars"

- MSPs evaporating their companions
- Classified by companion mass:
  - Black widow ($M_c < 0.05\ M_\odot$)
  - Redback ($M_c \sim 0.1 - 0.4\ M_\odot$)
- Difficult to detect in radio due to large eclipses
- 3 more search dimensions

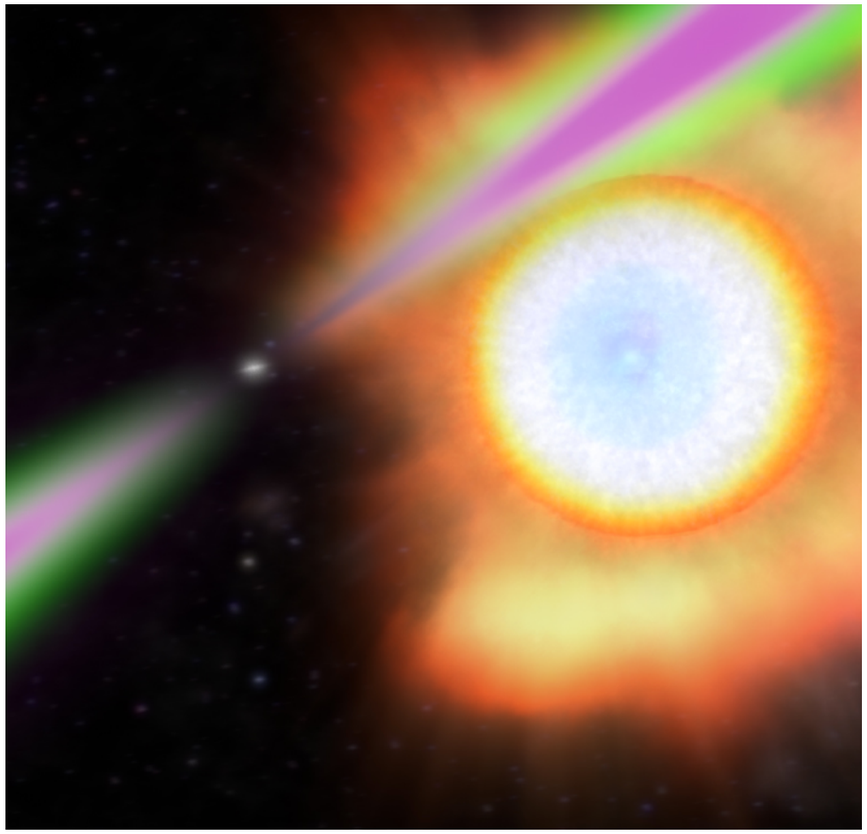


Image credit: https://www.nasa.gov

Searches for Binary Pulsars

Nieder, L., et al., in prep.

Search Methods

- Analytic phase model
- Multi-stage search
  - Same structure as isolated searches
- Efficient search grid
  - Stochastic 3D-grid generation on ATLAS cluster
  - Frequency dependent grid

Einstein@Home

- Code moved to GPUs
  - FFTs and barycentering
- ~13k GPUs from volunteers

Constraints from Optical

- Reduce the search space by constraints from optical
- Discovery of PSR J1311-3430
  - Companion detected
    - Romani, R. W., 2011, ApJL, 752, L25
  - Black widow in 93-min orbit
    - Pletsch, H. J., et al. 2012, Sci, 338, 1314

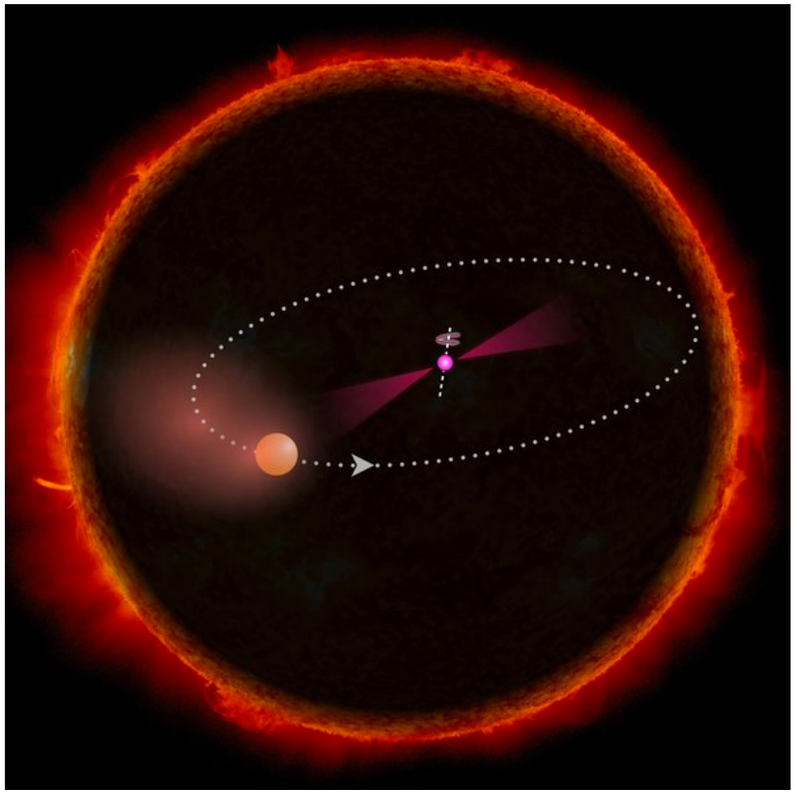
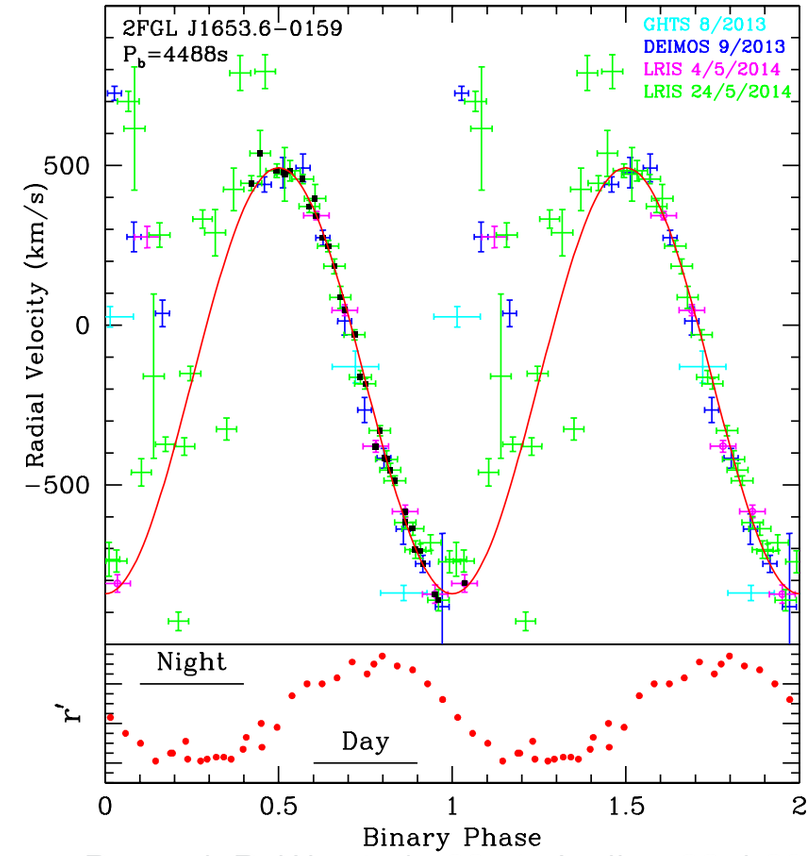


Image credit: SDO/AIA (Sun), AEI

Spider Pulsar Candidates

Multiple promising candidates:

- Likely companions detected in optical
  - E.g. 3FGL J0212.1+5320, 3FGL J0523.3–2528, 3FGL J1653.6-0158, 3FGL J2039.6–5618, …
- Collaboration with optical astronomers for even tighter constraints
- Most of them are redback candidates
  - Companions of RBs are brighter
  - More GPU expensive due to wider orbits



Romani, R. W., et al., 2014, ApJL, 793, L20

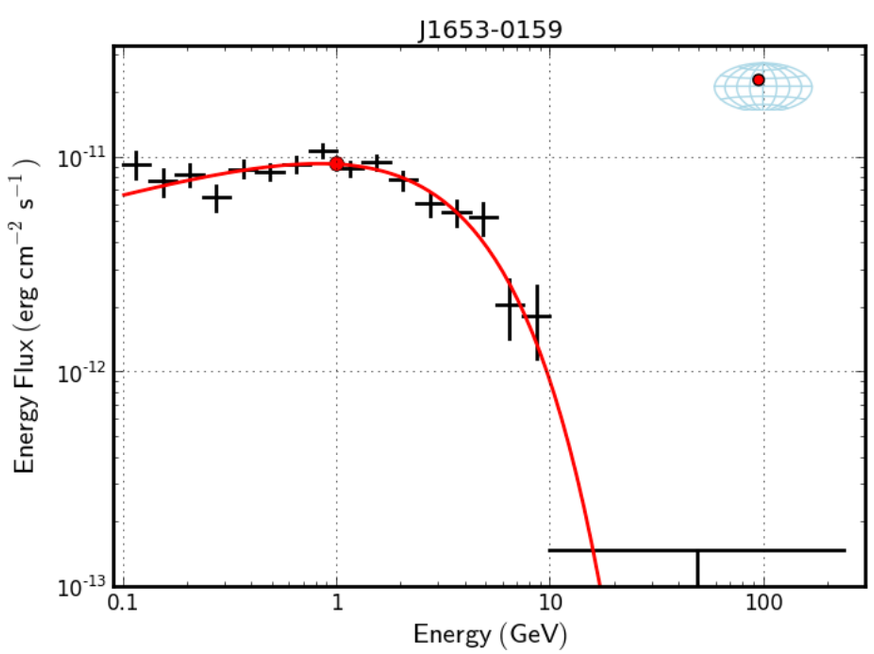
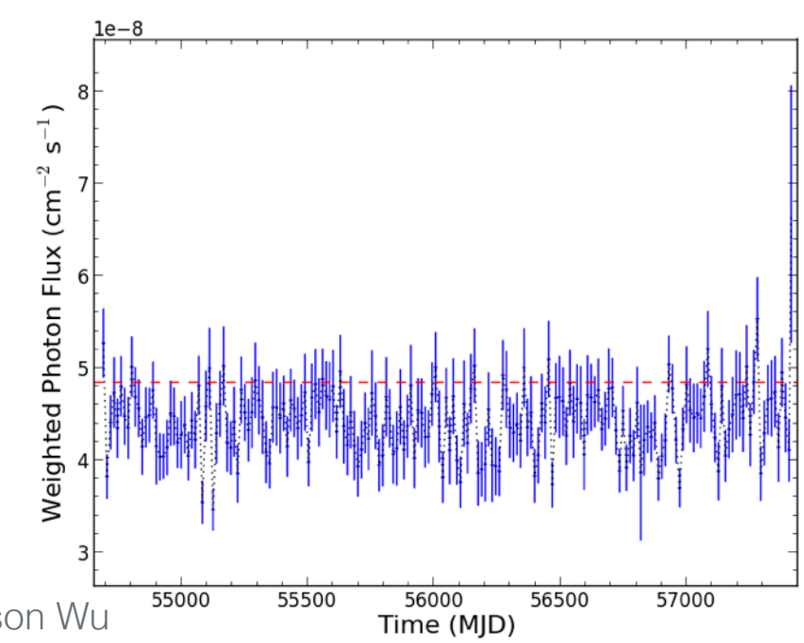


Image credits: Jason Wu



Future Surveys

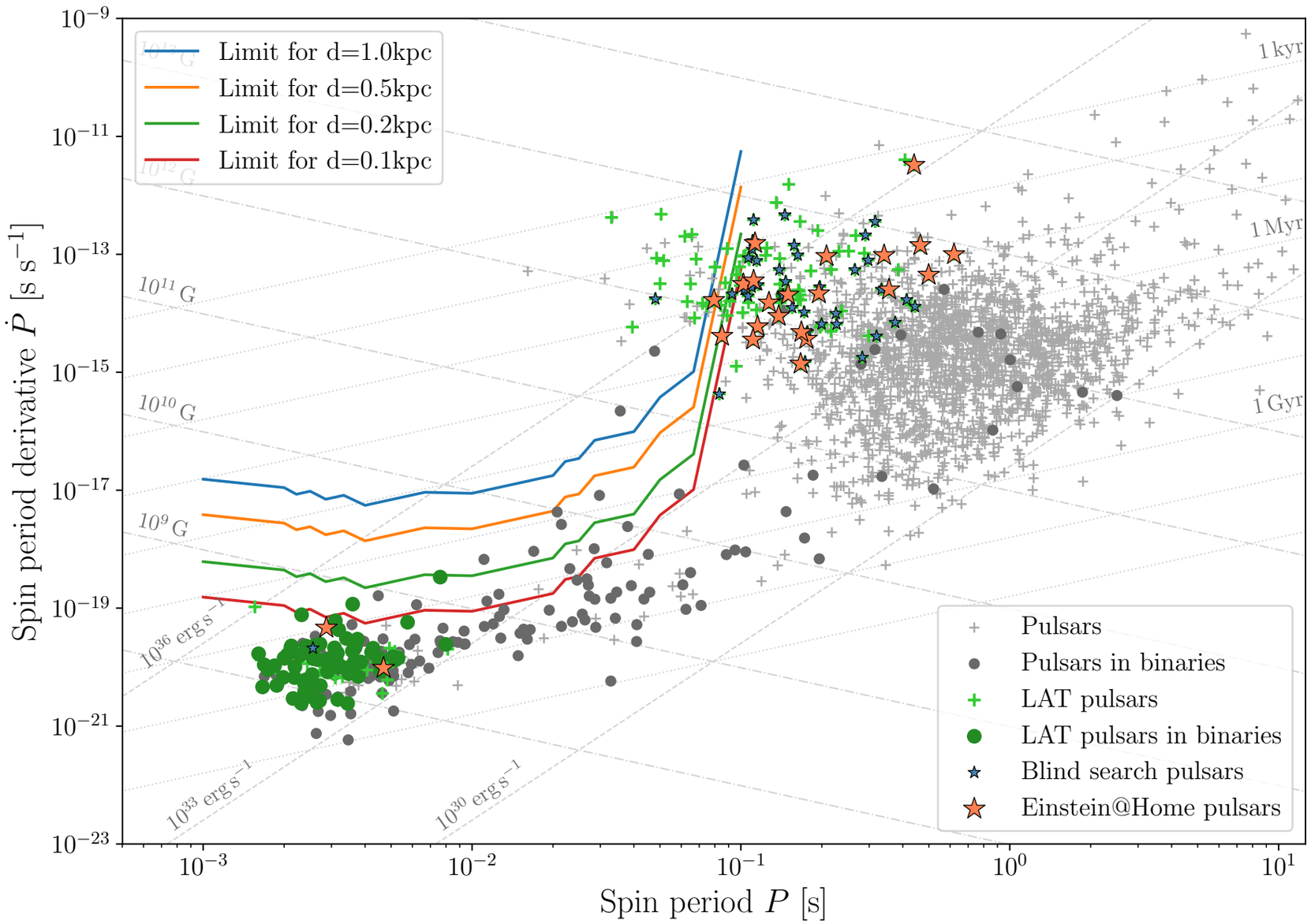
Search for Isolated Pulsars in 4FGL sources

- Higher sensitivity even for targets in past surveys
  - Longer photon dataset, but more expensive
- Hopefully many new targets

Search for Young Pulsars in Eccentric Gamma-ray Binaries

- Pulsar detection needed to explain these sources
  - E.g. LS 5039, LS I+61 303, …
- Large search ranges in 5 orbital dimensions
- Stochastic 5D-grid generation code ready

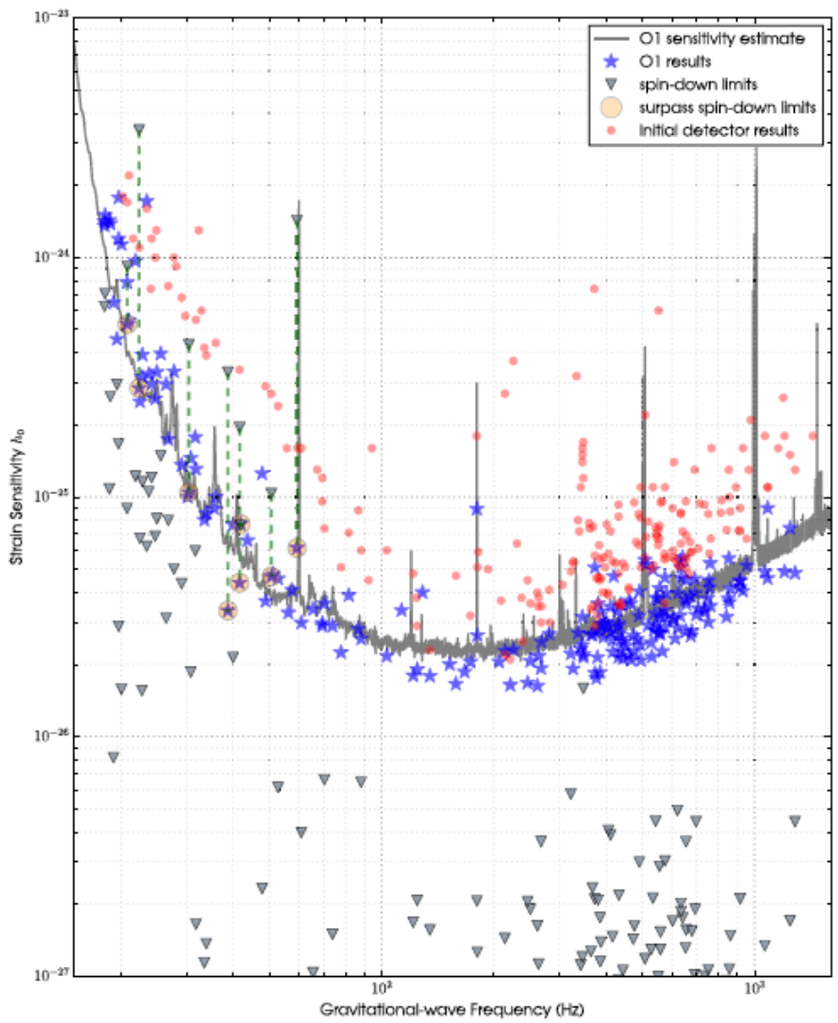
Continuous GW Follow-up

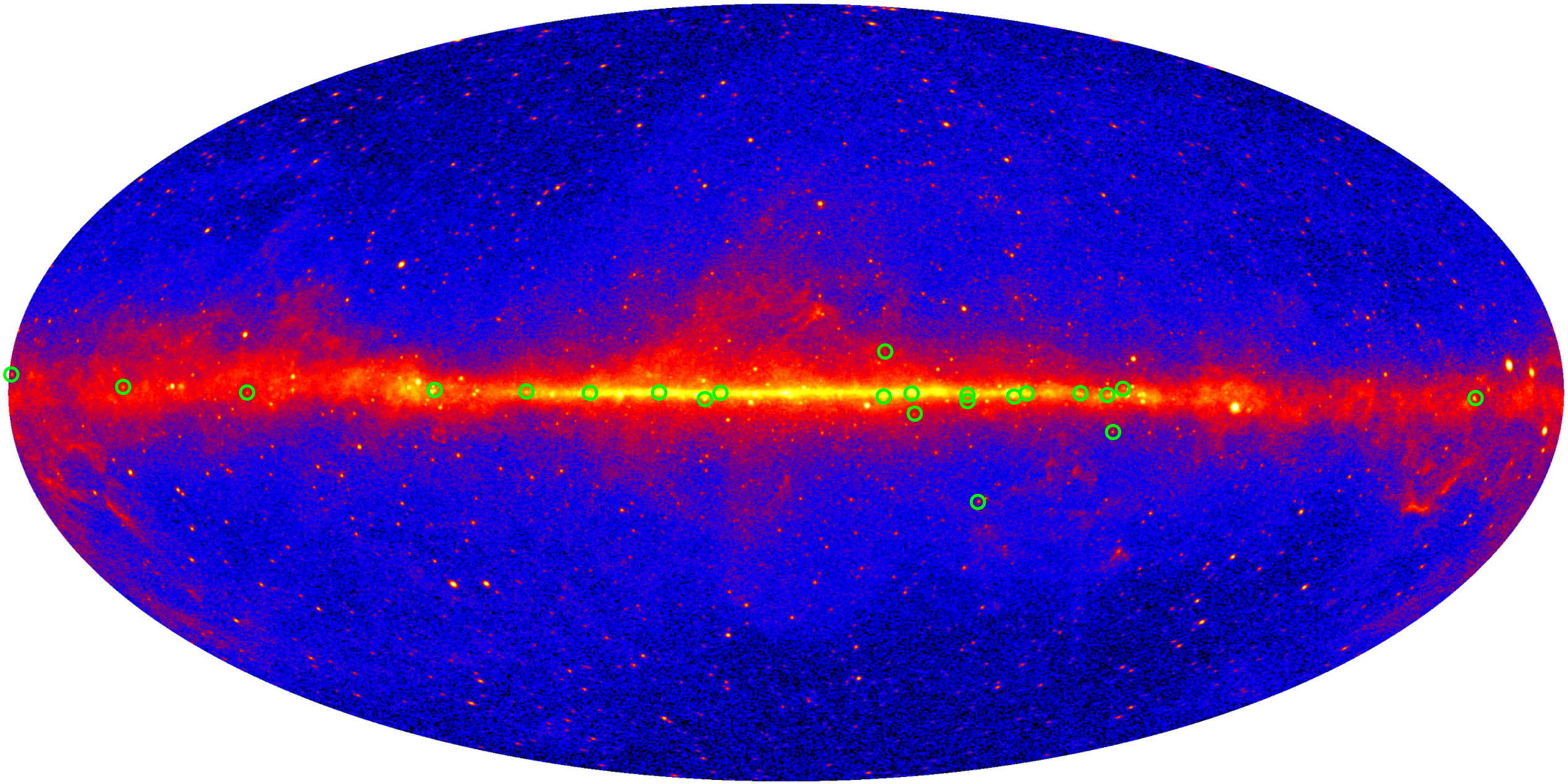


Spin-down limit:

$$h_0^{\mathrm{sd}} = \sqrt{\frac{5}{2}\frac{G I_{zz} |\dot{f}_{\mathrm{rot}}|}{c^3 d^2 f_{\mathrm{rot}}}}$$

$$I_{zz} = 10^{38}\,\mathrm{kg\,m^2}$$



Abbott, B. P., et al., 2017, ApJ, 839, 12

Summary