Introducing Young Scientists to Research Opportunities With Pulsar Surveys & Timing

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GROWTH Education Workshop
July 27, 2016

NANOGrav

PULSAR SEARCH COLLABORATORY

The Leonard E. Parker
Center for Gravitation, Cosmology & Astrophysics
at the University of Wisconsin-Milwaukee

Outline

- The Pulsar Search Collaboratory (2008-2013)
- ARCC@UWM observing and candidate rating for Green Bank North Celestial Cap survey
  - Spring 2016 UWM timing workshop + results
- PSC 2016
  - Online training and tiered mentorship

A LIVELY ELECTRONIC COMPENDIUM OF RESEARCH, NEWS, RESOURCES, AND OPINION
Astronomy Education Review
2010, AER, 9, 010106-1, 10.3847/AER2010004

The Pulsar Search Collaboratory

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Received: 02/4/10, Revised: 02/24/10, Accepted: 02/25/10, Published: 04/9/10

Abstract

The Pulsar Search Collaboratory (PSC) (NSF #0737641) is a joint project between the National Radio Astronomy Observatory and West Virginia University designed to interest high school students in science, technology, engineering, and mathematics related career paths by helping them to conduct authentic scientific research. The 3 year PSC program, which began in the summer of 2008, teaches students to analyze astronomical radio data acquired with the 100 m Robert C. Byrd Green Bank Telescope for the purpose of discovering new pulsars. We present the results of the first complete year of the PSC, which includes two astronomical discoveries.

1. FOREWORD

High school freshman Lucas Bolyard (Fig. 1) was bored one Saturday. He decided to log on to the Pulsar Search Collaboratory (PSC) database and analyze some plots. He had become adept at the work after having scored over 2000 of them in the few months since he joined his school's research team. Among the dozens of data sets he looked at that day, one single pulse plot intrigued him. Single pulse plots (one of two types of diagnostic plots used to analyze data in the database) display the properties of short, transient signals. Usually, these signals are produced by radio frequency interference.

But what caught Lucas's eye was a bright signal at a nonzero dispersion measure. This is a clue that the signal came from space, not Earth. So he reported it, and after a great deal of persistence on his part, it went on a list of candidates for astronomers to observe with the Green Bank Telescope (GBT). Disappointingly, the follow-up observations showed nothing, indicating that the object was not a normal pulsar. And still Lucas asked: "What could cause such a signal?" Eventually astronomers went back to the original raw data and confirmed that Lucas had discovered a signal that was of astronomical origin and most likely a cosmic object

The Pulsar Search Collaboratory

(2008-2013)

"…designed to interest high school students in STEM-related career paths by helping them to conduct authentic scientific research."

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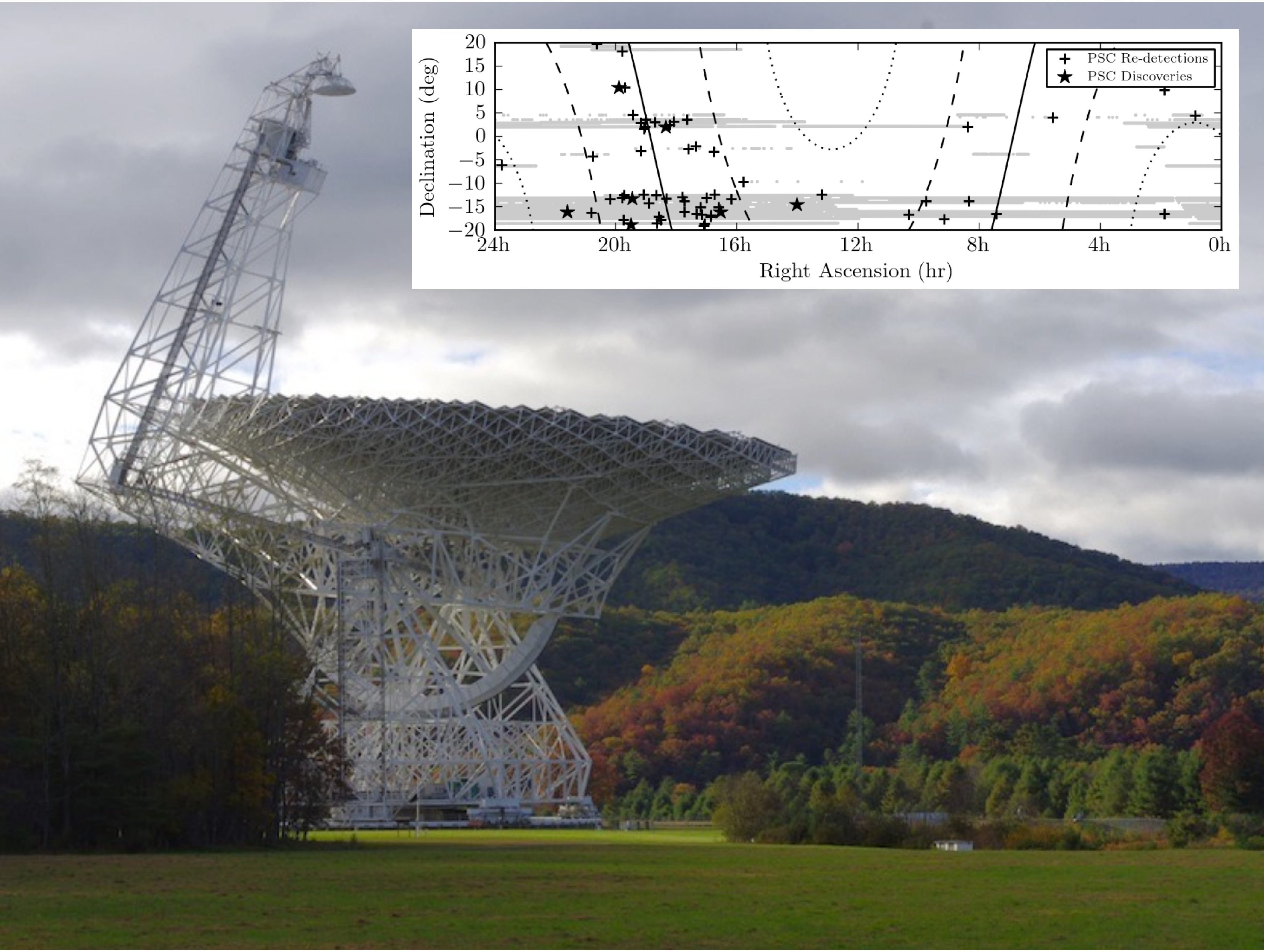
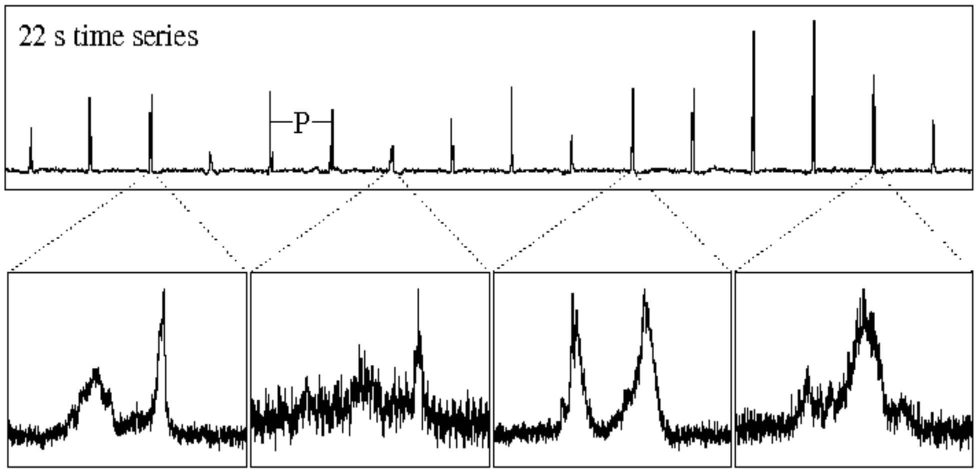


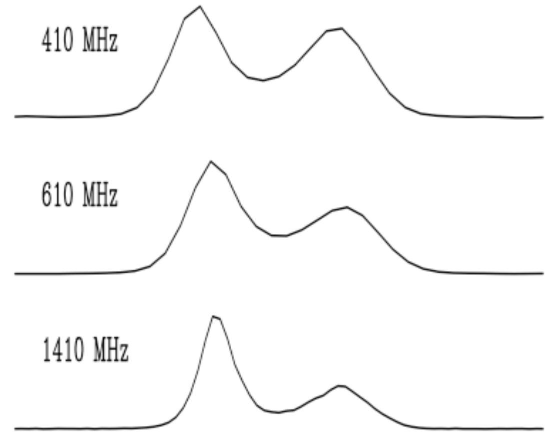
Declination (deg)
20
15
10
5
0
−5
−10
−15
−20
24h
20h
16h
12h
8h
4h
0h
Right Ascension (hr)
PSC Re-detections
PSC Discoveries

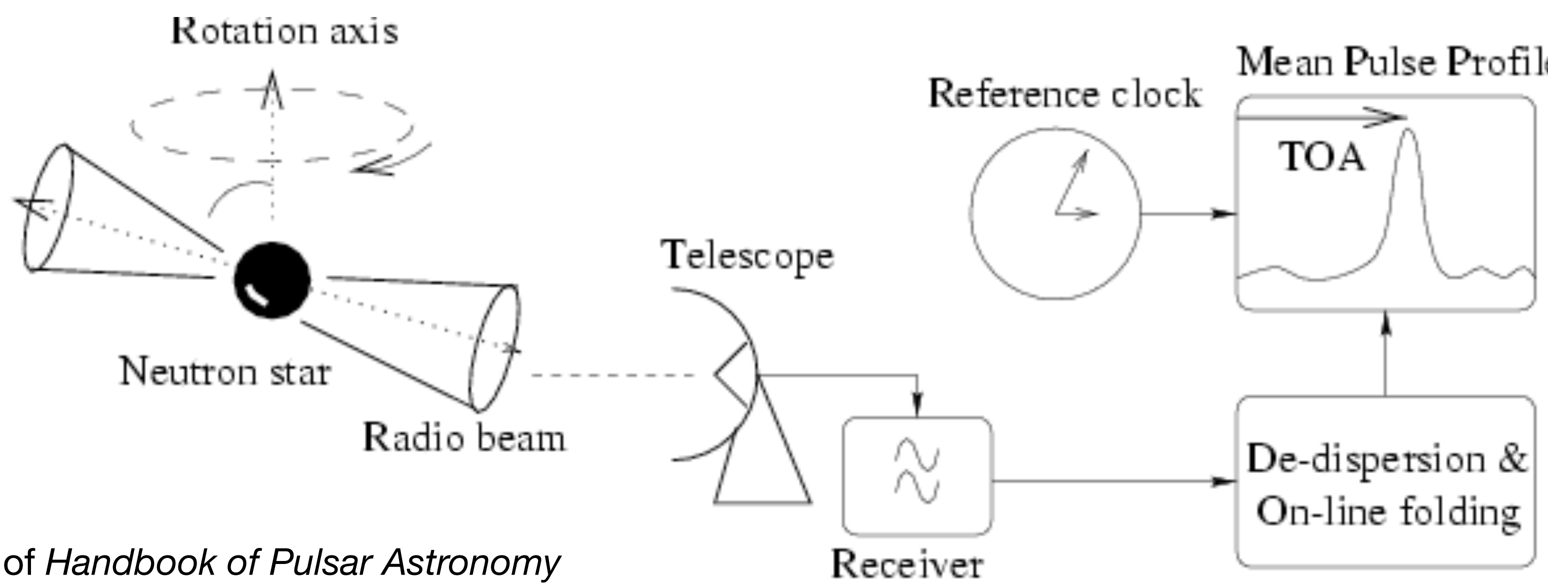
Single Pulses



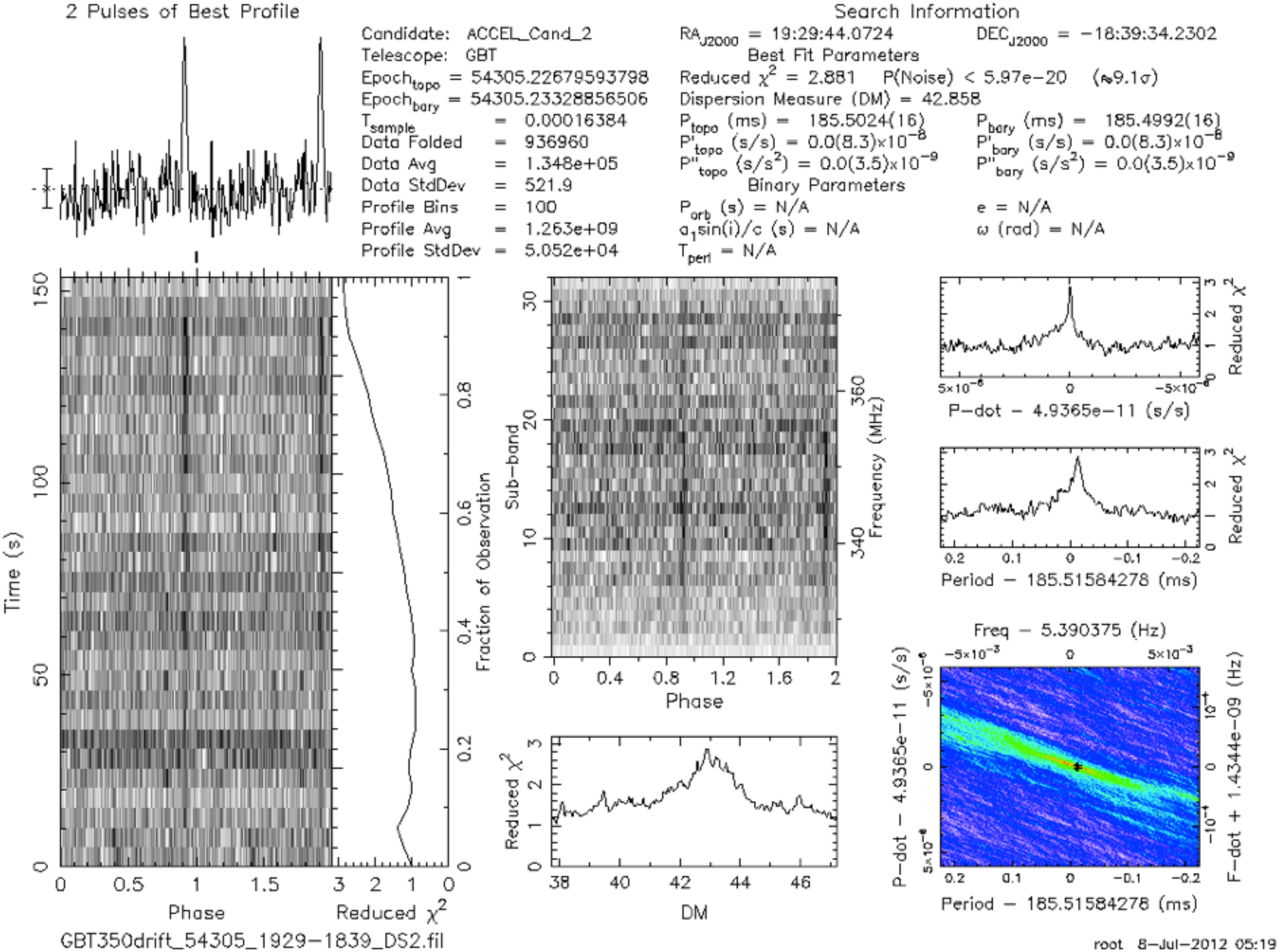
> 1000s of pulses

Mean Profile





Figures courtesy of *Handbook of Pulsar Astronomy* (Lorimer & Kramer 2004)



2 Pulses of Best Profile
Search Information
Candidate: ACCEL_Cand_2
Telescope: GBT
$Epoch_{topo}$ = 54305.22679593798
$Epoch_{bary}$ = 54305.23328856506
T_{sample} = 0.00016384
Data Folded = 936960
Data Avg = 1.348e+05
Data StdDev = 521.9
Profile Bins = 100
Profile Avg = 1.263e+09
Profile StdDev = 5.052e+04
RA_{J2000} = 19:29:44.0724
DEC_{J2000} = −18:39:34.2302
Best Fit Parameters
Reduced χ^2 = 2.881 P(Noise) < 5.97e−20 (≈9.1σ)
Dispersion Measure (DM) = 42.858
P_{topo} (ms) = 185.5024(16)
P_{bary} (ms) = 185.4992(16)
P'_{topo} (s/s) = 0.0(8.3)×10^{-8}
P'_{bary} (s/s) = 0.0(8.3)×10^{-8}
P''_{topo} (s/s^2) = 0.0(3.5)×10^{-9}
P''_{bary} (s/s^2) = 0.0(3.5)×10^{-9}
Binary Parameters
P_{orb} (s) = N/A
e = N/A
$a_1$sin(i)/c (s) = N/A
ω (rad) = N/A
T_{peri} = N/A
Time (s)
Phase
Reduced χ^2
Fraction of Observation
Sub−band
Frequency (MHz)
Phase
Reduced χ^2
DM
P−dot − 4.9365e−11 (s/s)
Period − 185.51584278 (ms)
Freq − 5.390375 (Hz)
P−dot − 4.9365e−11 (s/s)
F−dot + 1.4344e−09 (Hz)
Period − 185.51584278 (ms)
GBT350drift_54305_1929−1839_DS2.fil
root 8−Jul−2012 05:19

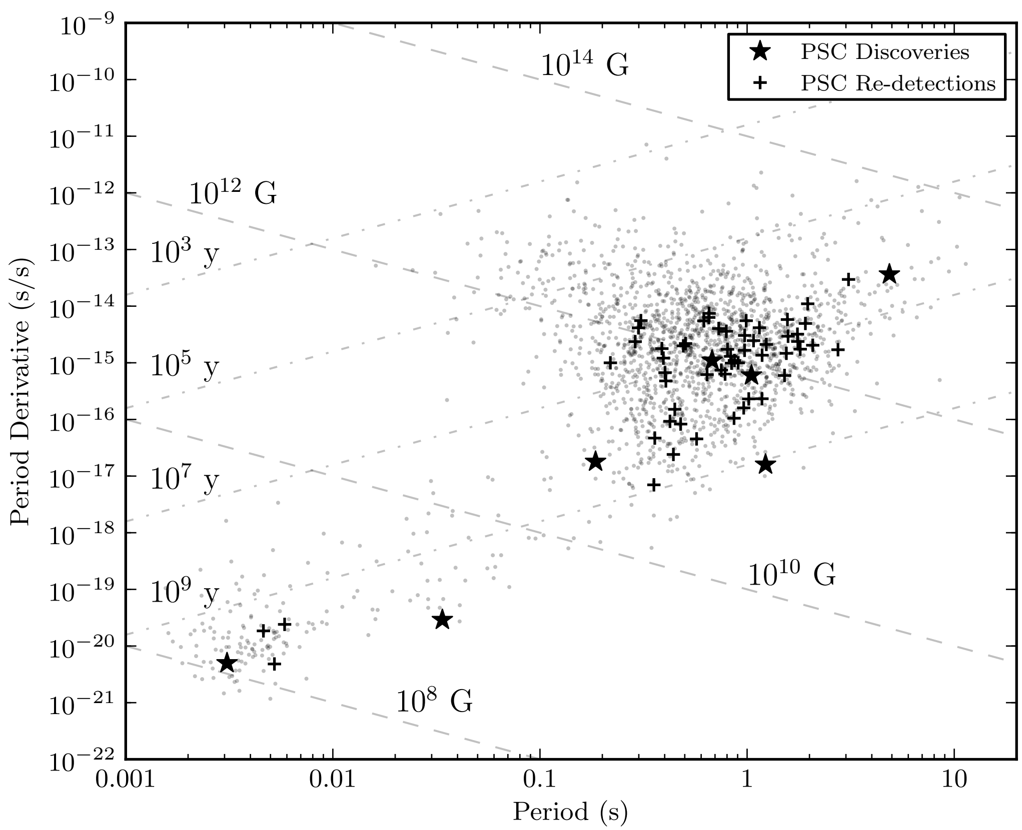
https://vimeo.com/70743540

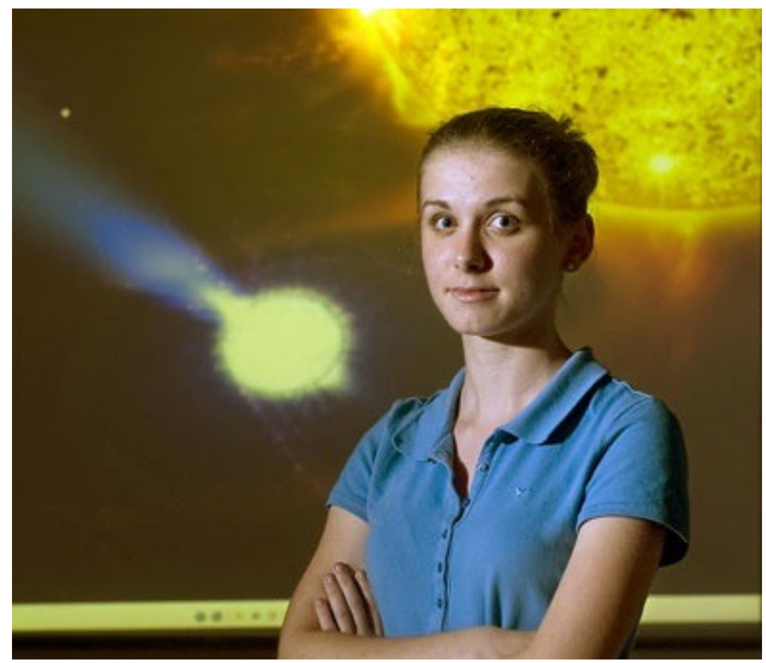
Recruitment & Training

- Intensive summer workshops in Green Bank with teachers and students
  - Attendees return, recruit, and train during school year
- School visits
- End of year “Capstone” at WVU

Results

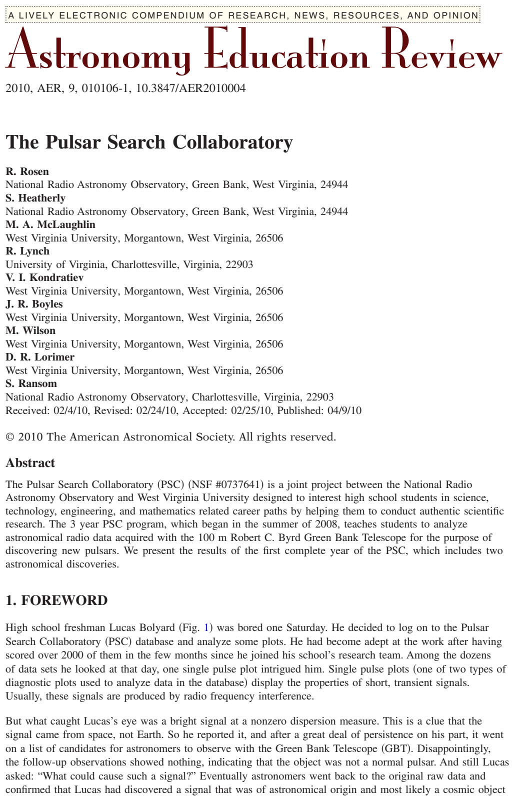
- > 2,500 students involved from 18 states (and >100 teachers)
- 7 pulsars discovered…





PSC Publications

2010



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2013

The Astrophysical Journal, 768:85 (10pp), 2013 May 1 doi:10.1088/0004-637X/768/1/85

THE PULSAR SEARCH COLLABORATORY: DISCOVERY AND TIMING OF FIVE NEW PULSARS

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Received 2012 September 16; accepted 2013 February 13; published 2013 April 17

ABSTRACT

We present the discovery and timing solutions of five new pulsars by students involved in the Pulsar Search Collaboratory, a NSF-funded joint program between the National Radio Astronomy Observatory and West Virginia University designed to excite and engage high-school students in Science, Technology, Engineering, and Mathematics (STEM) and related fields. We encourage students to pursue STEM fields by apprenticing them within a professional scientific community doing cutting edge research, specifically by teaching them to search for pulsars. The students are analyzing 300 hr of drift-scan survey data taken with the Green Bank Telescope at 350 MHz. These data cover 2876 $\deg^2$ of the sky. Over the course of five years, more than 700 students have inspected diagnostic plots through a web-based graphical interface designed for this project. The five pulsars discovered in the data have spin periods ranging from 3.1 ms to 4.8 s. Among the new discoveries are PSR J1926−1314, a long period, nulling pulsar; PSR J1821+0155, an isolated, partially recycled 33 ms pulsar; and PSR J1400−1438, a millisecond pulsar in a 9.5 day orbit whose companion is likely a white dwarf star.

Key words: pulsars: general – pulsars: individual (PSR J1400−1438, PSR J1631−1612, PSR J1821+0155, PSR J1926−1314, PSR J2136−1606

Online-only material: color figures

1. INTRODUCTION

Pulsars, rapidly rotating highly magnetized neutron stars, are most commonly studied at radio wavelengths. The first pulsar was discovered in 1967 (Hewish et al. 1968) and currently over 2000 of these objects have been cataloged[33] (Manchester et al. 2005). Over 30,000 normal pulsars are potentially detectable in

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[33] For an up-to-date catalog of pulsars, see http://www.atnf.csiro.au/research/pulsar/psrcat.

62 HS co-authors

2015

The Astrophysical Journal, 805:156 (7pp), 2015 June 1 doi:10.1088/0004-637X/805/2/156

PSR J1930–1852: A PULSAR IN THE WIDEST KNOWN ORBIT AROUND ANOTHER NEUTRON STAR

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Received 2014 August 22; accepted 2015 April 2; published 2015 May 28

ABSTRACT

In the summer of 2012, during a Pulsar Search Collaboratory workshop, two high-school students discovered J1930–1852, a pulsar in a double neutron star (DNS) system. Most DNS systems are characterized by short orbital periods, rapid spin periods, and eccentric orbits. However, J1930–1852 has the longest spin period ($P_{\rm spin} \sim$ 185 ms) and orbital period ($P_b \sim$ 45 days) yet measured among known, recycled pulsars in DNS systems, implying a shorter than average and/or inefficient recycling period before its companion went supernova. We measure the relativistic advance of periastron for J1930–1852, $\dot{\omega} = 0.00078\,(4)\ \deg\,{\rm yr}^{-1}$, which implies a total mass ($M_{\rm tot} = 2.59\,(4)\,M_\odot$) consistent with other DNS systems. The 2σ constraints on $M_{\rm tot}$ place limits on the pulsar and companion masses ($m_p < 1.32\,M_\odot$ and $m_c > 1.30\,M_\odot$ respectively). J1930–1852's spin and orbital parameters challenge current DNS population models and make J1930–1852 an important system for further investigation.

Key words: pulsars: general – pulsars: individual (J1930–1852) – stars: evolution – stars: neutron

1. INTRODUCTION

To date, ~2300 pulsars are known (Manchester et al. 2005) and ~10% of them are in binary systems, orbiting white dwarf (WD), neutron star (NS) or main sequence star (MS) companions. The vast majority of these binaries are NS-WD systems; many of these systems emerge from scenarios where the pulsar forms first, followed by its companion, which overflows its Roche Lobe; accretion transfers angular momentum to the pulsar, decreasing the spin period and resulting in a millisecond pulsar orbiting a WD (Alpar et al. 1982). This process of accretion and spin-up is commonly referred to as *recycling* and the period derivative of a recycled pulsar tends to be significantly lower than that of an unrecycled pulsar with the same spin period. There are four observed examples of pulsars orbiting stars that have yet to evolve off the main sequence (Johnston et al. 1992; Kaspi et al. 1994; Stairs et al. 2001; Lorimer et al. 2006a); an additional four have been found with planet-sized companions (Thorsett et al. 1993; Wolszczan 1994; Bailes et al. 2011; Stovall et al. 2014). More massive companions end their evolution off the main sequence in supernovae, resulting in double neutron star (DNS) systems. DNS systems are far less likely to remain bound than NS-WD systems, since the former must survive two supernova explosions during formation. Only about 10% of these binary systems remain bound after one supernova explosion (Bailes 1989). The probability of remaining bound after two supernovae is much lower (~1%) and only nine such systems have been found and studied previously (see references in Table 2).

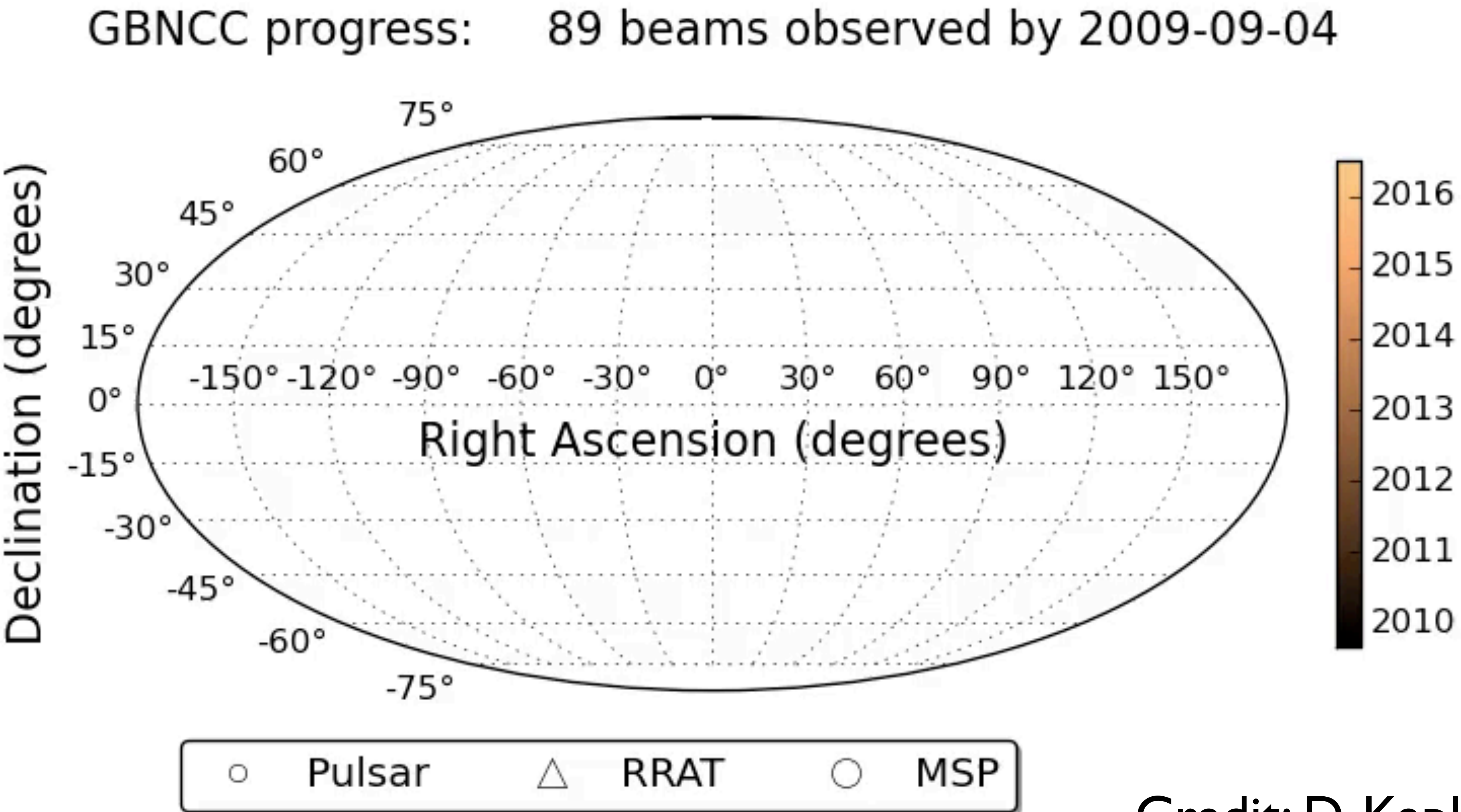
DNS systems have tantalizing applications—for example, testing theories of gravity by measuring relativistic effects (Kramer et al. 2006; Weisberg et al. 2010; Fonseca et al. 2014) and predicting DNS merger rates relevant to ground-based gravitational wave detectors like LIGO (Kim et al. 2010, 2013). DNS systems have also provided some of the most precise NS mass measurements, allowing for a statistical investigation of the underlying mass distribution (Thorsett & Chakrabarty 1999; Schwab et al. 2010; Özel et al. 2012).

Thorsett & Chakrabarty (1999) used a sample of 26 NSs (21 MSPs and five binary companion NSs) with measured masses to determine a mean NS mass, $\langle m \rangle = 1.35 \pm 0.04\,M_\odot$. More recently, Schwab et al. (2010) argue that the underlying NS mass distribution for objects in DNS systems is bimodal, with narrow peaks at $1.246\,M_\odot$ and $1.345\,M_\odot$. They also suggest that these peaks indicate unique formation scenarios, where the lower mass component represents NSs that formed via electron capture (Nomoto 1984; Podsiadlowski et al. 2004) and the higher mass component is indicative of iron core-collapse (Woosley & Weaver 1986). Özel et al. (2012) use a Bayesian statistical approach to infer mass distributions for NSs with distinct evolutionary histories; they agree that NS masses

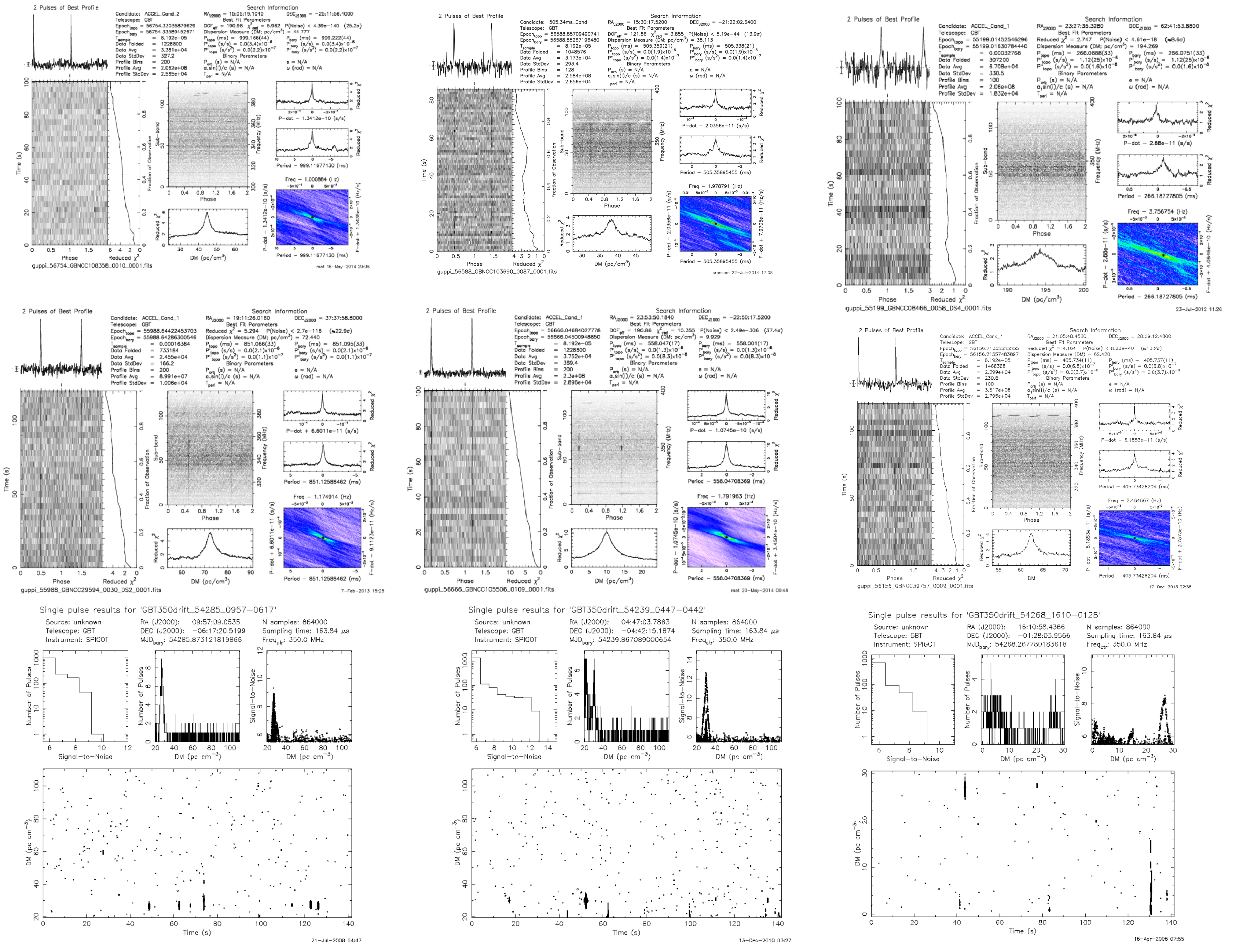
25 HS co-authors

UWM Arecibo Remote Command Center (ARCC) students

Green Bank North Celestial Cap Survey Coverage



Credit: D. Kaplan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DEC (J2000): -06:17:20.5199
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Sampling time: 163.84 μs
Freq_ctr: 350.0 MHz
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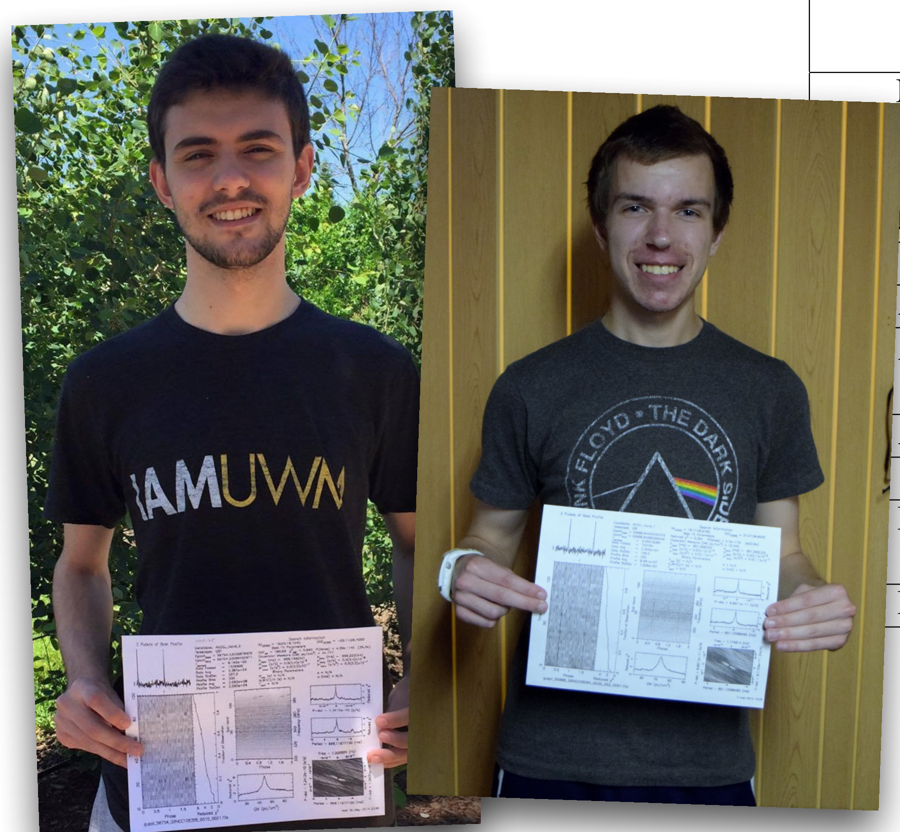
Telescope: GBT
Instrument: SPIGOT
RA (J2000): 04:47:03.7863
DEC (J2000): -04:42:15.1874
N samples: 864000
Sampling time: 163.84 μs
Freq_ctr: 350.0 MHz
Single pulse results for 'GBT350drift_54268_1610-0128'
Source: unknown
Telescope: GBT
Instrument: SPIGOT
RA (J2000): 16:10:58.4366
DEC (J2000): -01:28:03.9566
N samples: 864000
Sampling time: 163.84 μs
Freq_ctr: 350.0 MHz
Signal-to-Noise
Number of Pulses
DM (pc cm^-3)
Time (s)

UWM Timing Workshop



Date	#	Goals
Jan. 29 & Feb. 11	1	*Brief Lecture: Pulsar timing techniques and challenges.* Download VM and Tempo2 demonstration.
Feb. 16	2	Set up VM and Dropbox account. Learn to use Tempo2 (exercises 1-5).
Feb. 23	3	*Brief lecture: I smell a RRAT.* Continue Tempo2 exercises and identify solved pulsars (`psrcat`). Find P0 for a RRAT using single pulse TOAs.
Mar. 1	4	Assign ARCC curators for available pulsars; copy TOAs, generate initial par files and run Tempo2.
Mar. 8	5	Assess data quality; additional processing required (e.g. RFI excision)? If so, get NRAO accounts for ARCC timers. Work on solutions!
Mar. 15	–	*Spring Break*
Mar. 22	6	*Brief lecture: Measuring TOAs and timing sanity checks.* Distribute NRAO accounts. Work on solutions.
Mar. 29	7	*Brief lecture: Introduction to LaTeX.* Work on solutions.
Apr. 5	–	*No scheduled activities; JKS away.*
Apr. 12	–	*No scheduled activities; JKS away.*
Apr. 19	8	Use `psrcat` to make $P - \dot{P}$ diagrams and plot assigned pulsar if solved. Begin write-up. (Work on solutions?)
Apr. 26	9	Work on write-ups and identify interesting sources.
May 3	10	Work on write-ups.
May 10	11	Present/compile results, send to GBNCC collaborators and gather to discuss during a telecon.
May 17	12	Wrap-up and party!

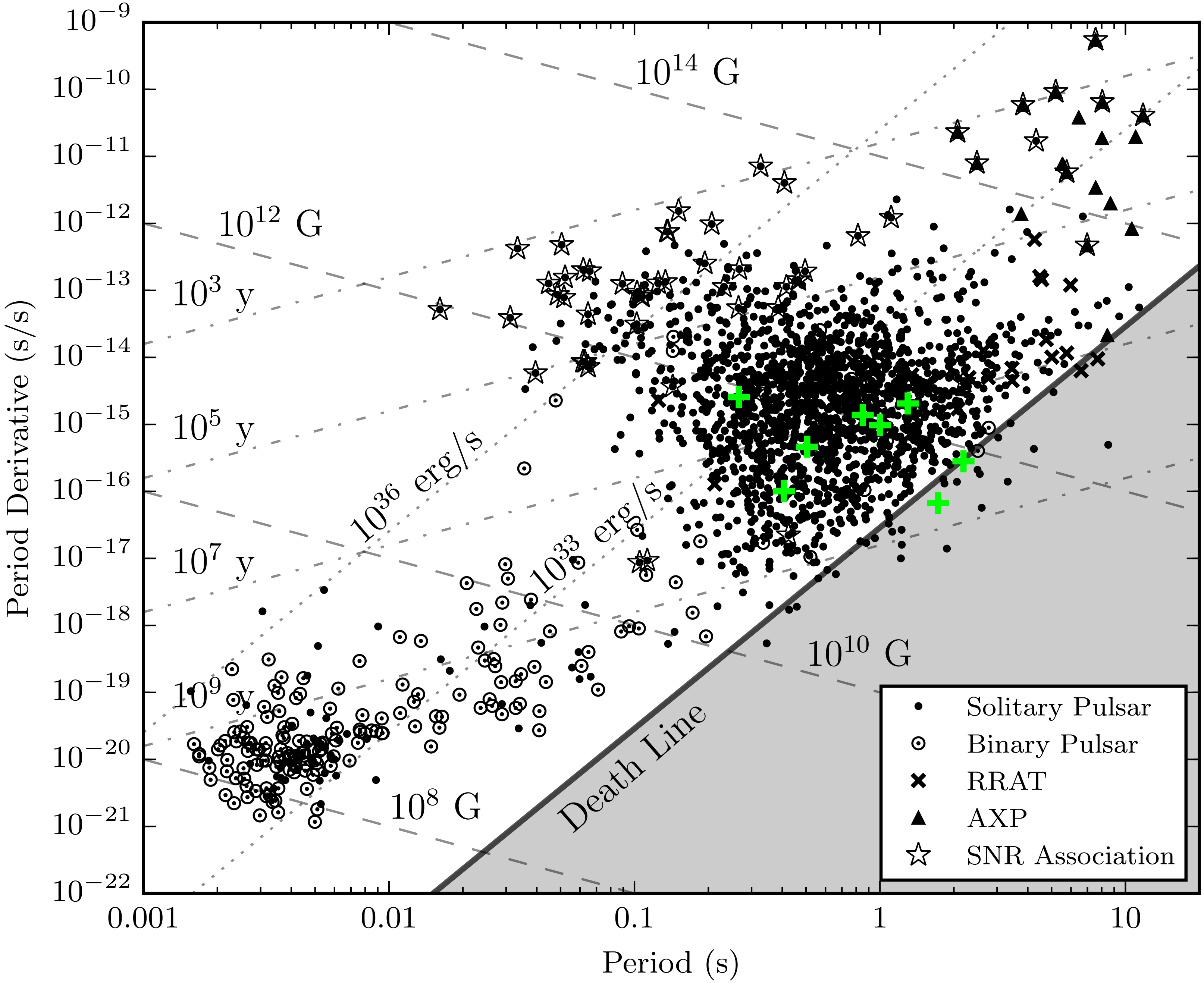
Exposure

- Pulsar processing tools
  - PSRCHIVE, Tempo, psrcat
- Python/command line exercises
- Results written up in LaTeX and presented on a GBNCC telecon
- National Council on Undergraduate Research conference proceedings + Green Bank DDT proposal for follow-up time

Problems/Solutions

- Pulsar software is difficult to install and maintain
  - Virtual Box
- Students need GB accounts to access data
  - Positive: lowers the bar for being trained as remote observers
- Students have varying levels of experience
  - Positive: more advance students can help lead, gain mentorship experience

Publication in prep. (Sep. 2016?)



Center for Gravitation, Cosmology & Astrophysics
at the University of Wisconsin–Milwaukee

The Pulsar Search Collaboratory

2016 Summer Workshop

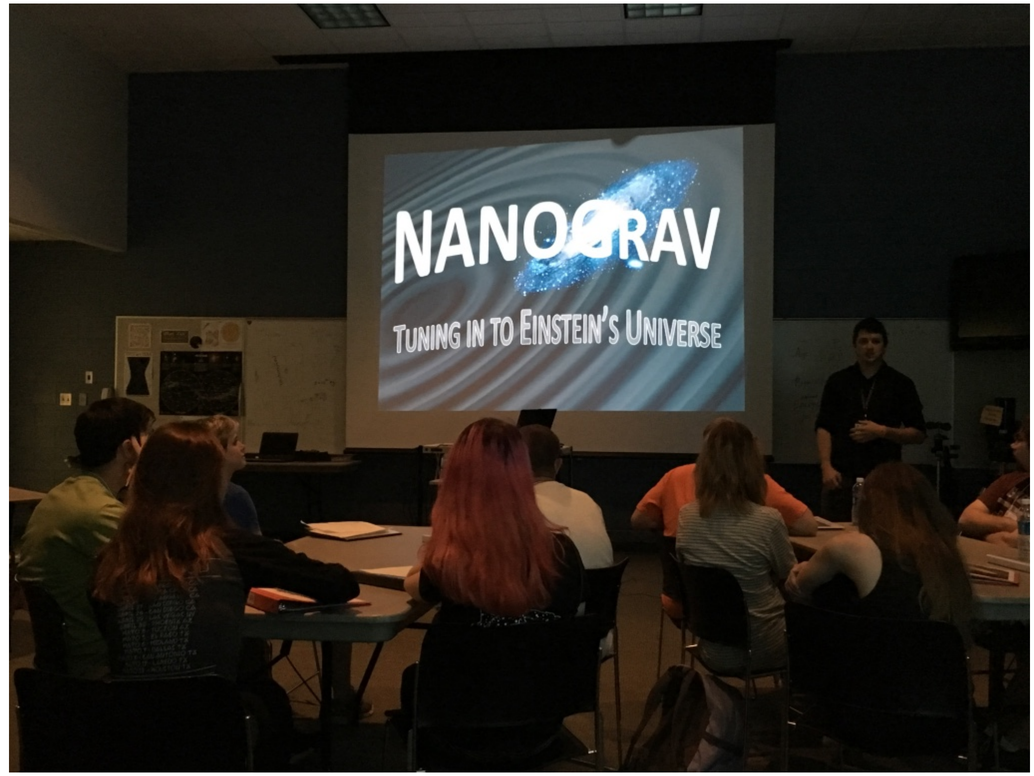
10 Faculty/Staff
11 Undergrad Mentors
15 High School Teachers
35 High School Students

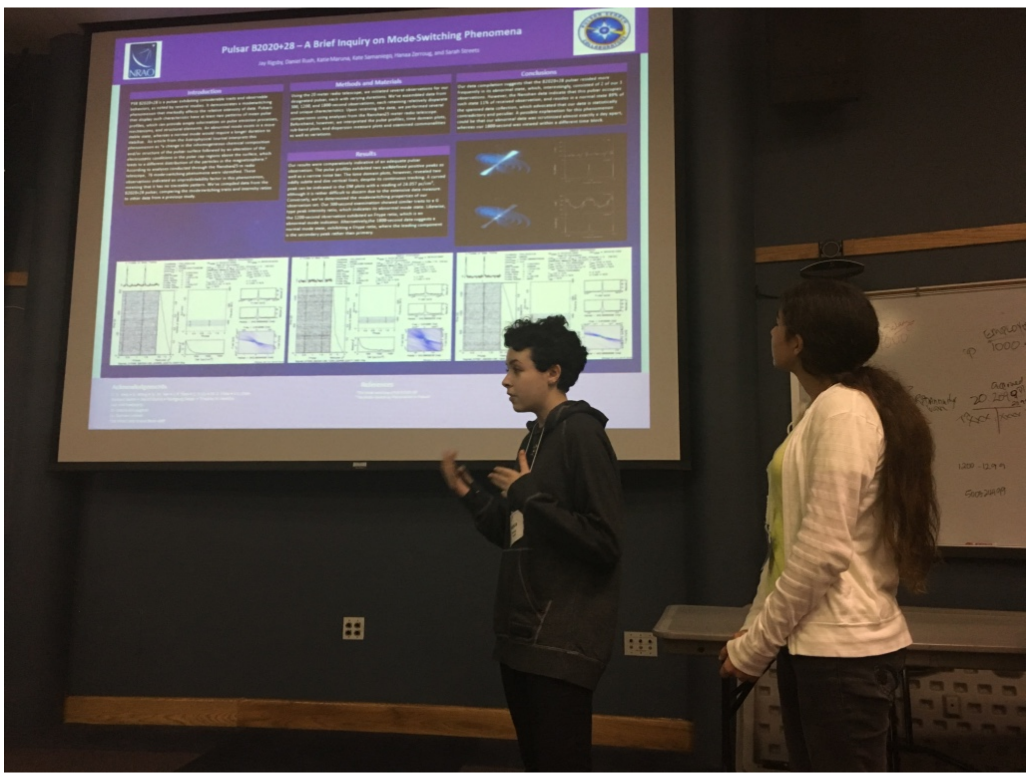
= 71 attendees!

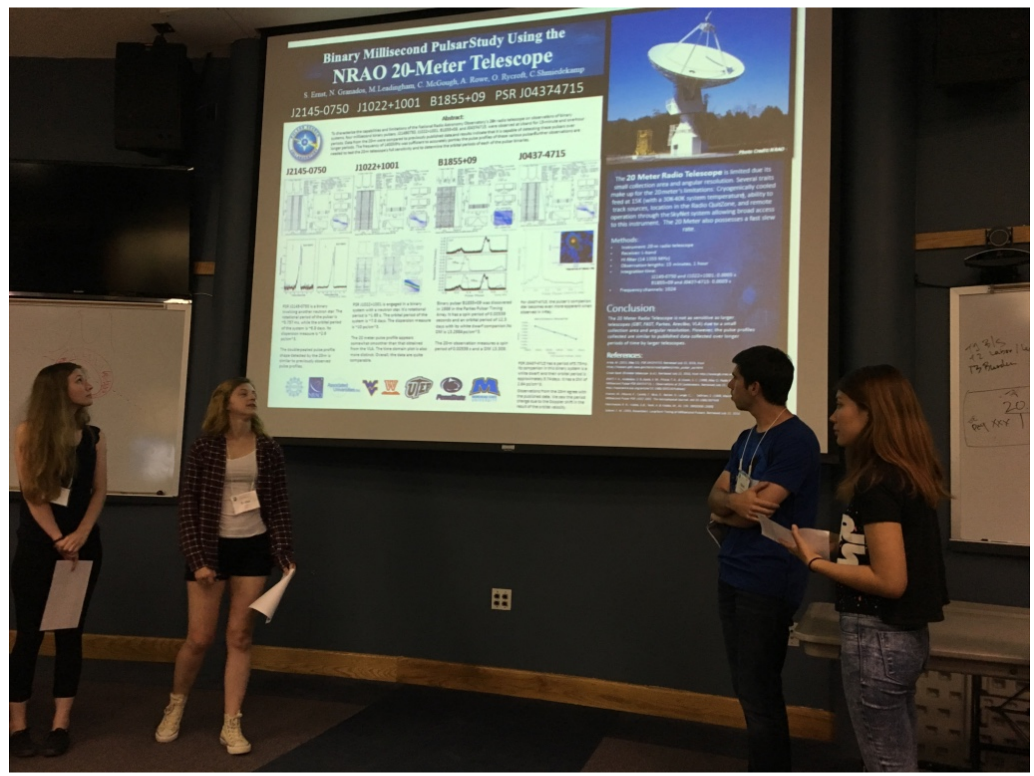
A Distributed Model

- 10 hub institutions across the US
- New students trained with online webinars
- Near-peer mentorship network (undergrad mentors from local institutions)
- NRAO 20-m radio telescope can be used remotely.

The Leonard E. Parker
Center for Gravitation, Cosmology & Astrophysics
at the University of Wisconsin–Milwaukee

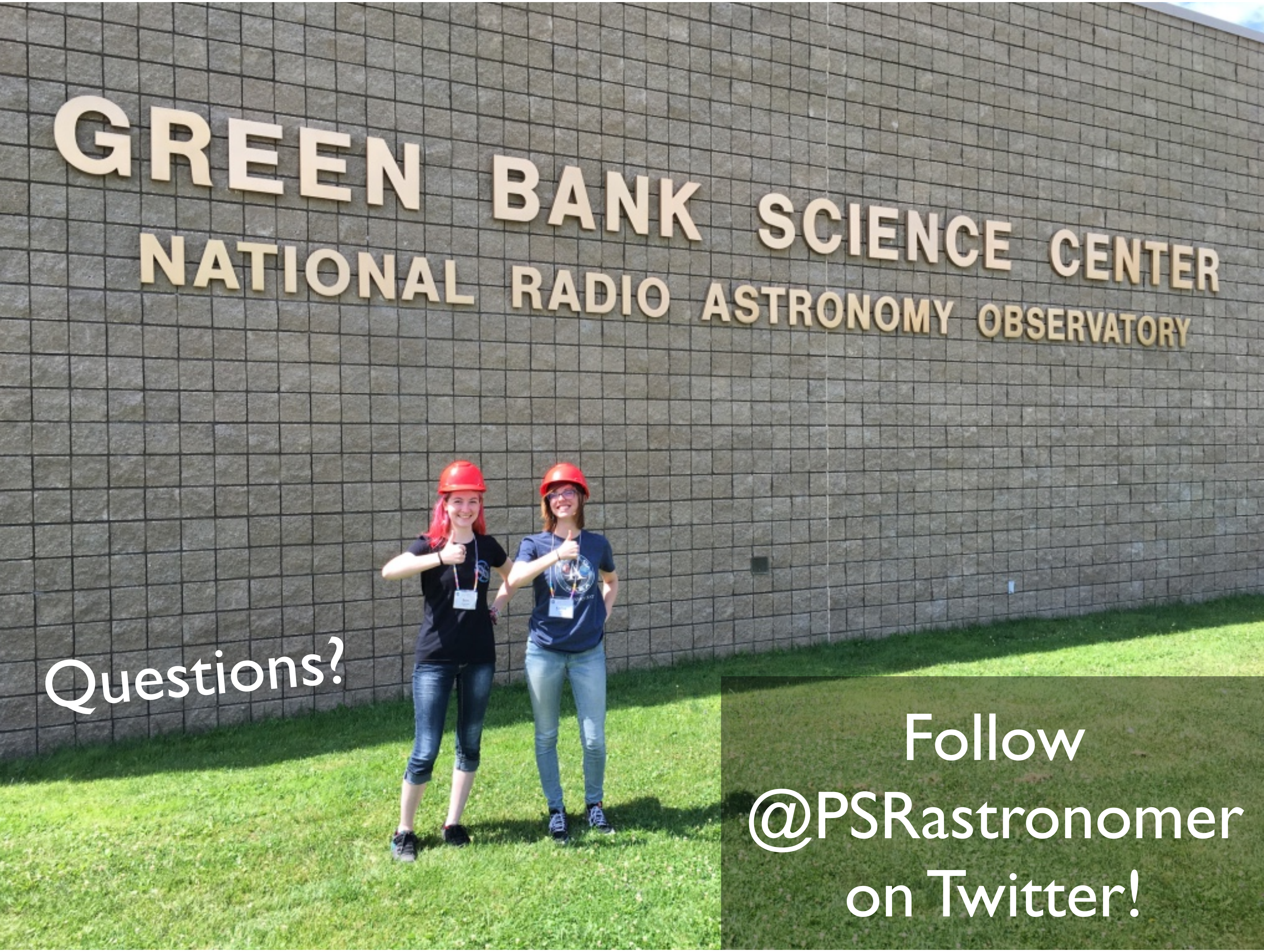

NANOGRAV
TUNING IN TO EINSTEIN'S UNIVERSE


Pulsar B2020+28 – A Brief Inquiry on Mode-Switching Phenomena
Introduction
Methods and Materials
Conclusions
Results


Binary Millisecond PulsarStudy Using the
NRAO 20-Meter Telescope
J2145-0750 J1022+1001 B1855+09 PSR J04374715
J2145-0750
J1022+1001
B1855+09
J0437-4715
Conclusion

Conclusions & Future Work

- Symbiosis between programs promotes HS/UG research and collaboration between "near peers"
  - Building a network helps students at all levels prepare for the next step
- Condense Timing WS material into a 3-4 hour activity, implement NANOGrav iPython notebooks
- Develop NRAO 20-m projects suitable for publication



Questions?

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