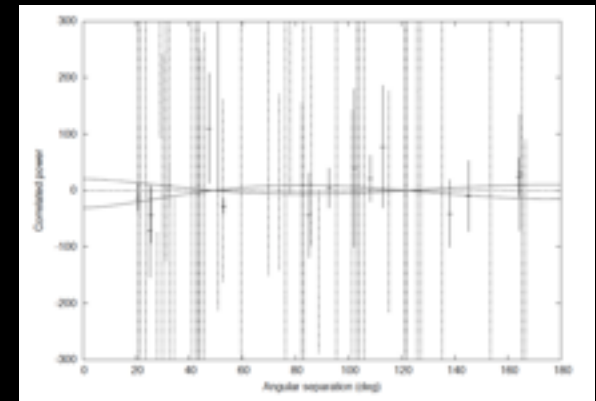
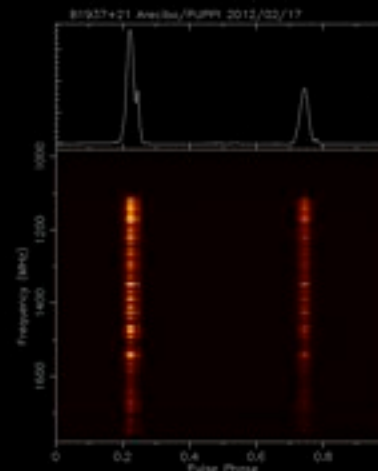




Maura McLaughlin
West Virginia University

Outline

- Who are we?
- Policies and Organization
- Science
- International Education
- Outreach
- Summary and the Future



Who are we?



A consortium of researchers using North American telescopes for pulsar timing for GW detection. Formed in 2007.

Anyone who shares this goal is welcome to apply for membership!

DRAFT membership policy defines Junior, Associate, Full, and Legacy Members.

<http://nanograv.org>

Who are we?



Current *members* include 15 SP, 2 computing staff, 10 postdocs, 10 graduate students, and 8 undergrads.

Australia Telescope National Facility – Ryan Shannon

Cornell University – Jim Cordes, Adam Brazier, Shami Chatterjee, Dusty Madison

Franklin & Marshall College – Andrea Lommen, Brian Christy, Ryan Anella, Emma Handzo, Joe Simon

Goddard Space Flight Center – Zaven Arzoumanian

Lafayette College – David Nice, Anthony Post, Joey Tumulty

McGill University – Vicky Kaspi

Oberlin College – Dan Stinebring, Tim Dolch, Sam Berney, Greg Stevens

NRAO/UVA – Scott Ransom, Paul Demorest, Tim Pennucci

Jet Propulsion Laboratory – Joe Lazio, Sarah Burke-Spoloar

Penn State University – Sam Finn, Xihao Deng, Michael Koop

University of British Columbia – Ingrid Stairs, Marjorie Gonzalez, Weiwei Zhu

University of Cagliari – Delphine Perrodin

University of Manchester – Rob Ferdman

University of Texas, Brownsville – Rick Jenet, Yan Wang, Jing Lou, Kevin Stovall

University of Wisconsin, Wilwaukee – Xavier Siemens, Justin Ellis, Sydney Chamberlin

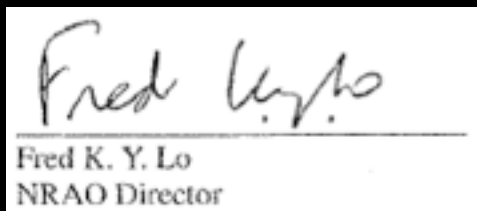
West Virginia University – Duncan Lorimer, Maura McLaughlin, Nate Garver-Daniels,

Nipuni Palliyaguru, Joe Swiggum, Gary Marchiny

Who are we?



The NRAO and the Arecibo Observatory are institutional members as of March/April 2012.



Draft Publication Policy

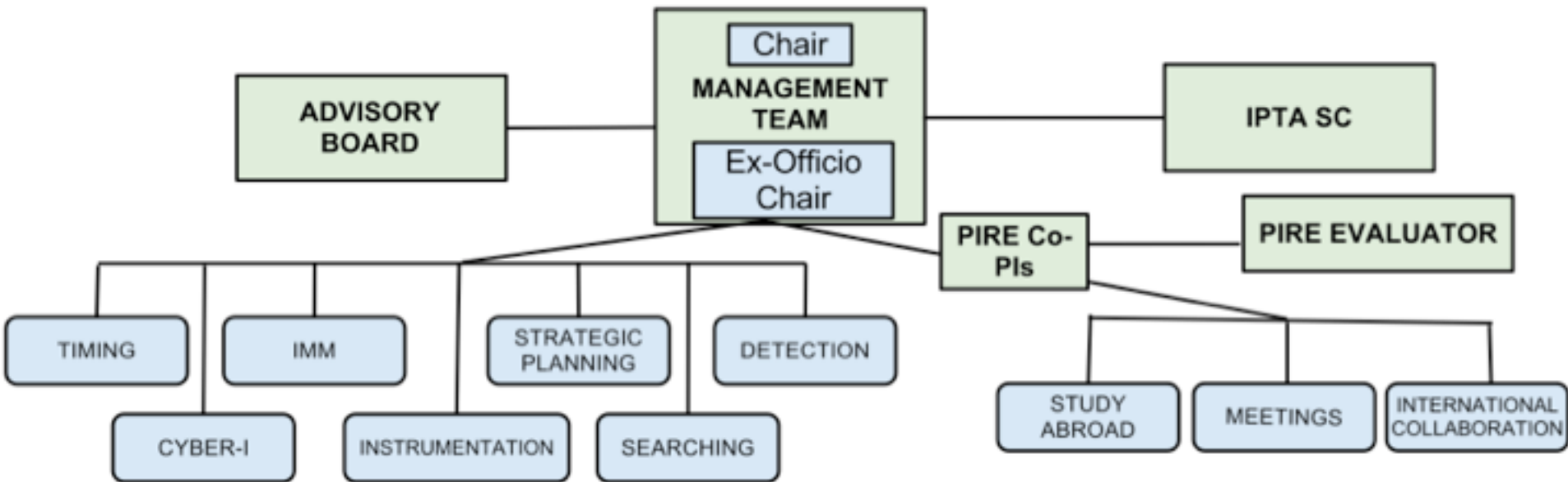


A NANOGrav paper is one which is related to NANOGrav science, or which uses data collected for the NANOGrav project, or which uses NANOGrav-developed tools, and which has one or more members of NANOGrav as authors.

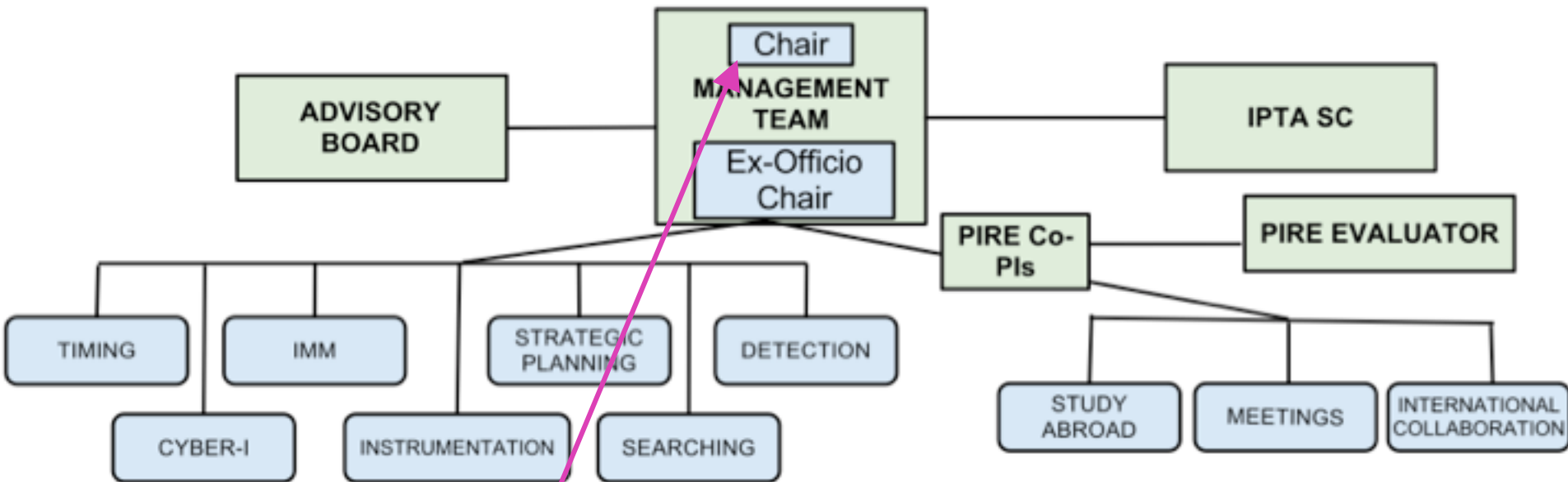
NANOGrav upper limit and detection papers will include all Full Members and have alphabetical authorship.

Other papers will be authored by all who contributed significantly, with author order determined by the authors.

Organization

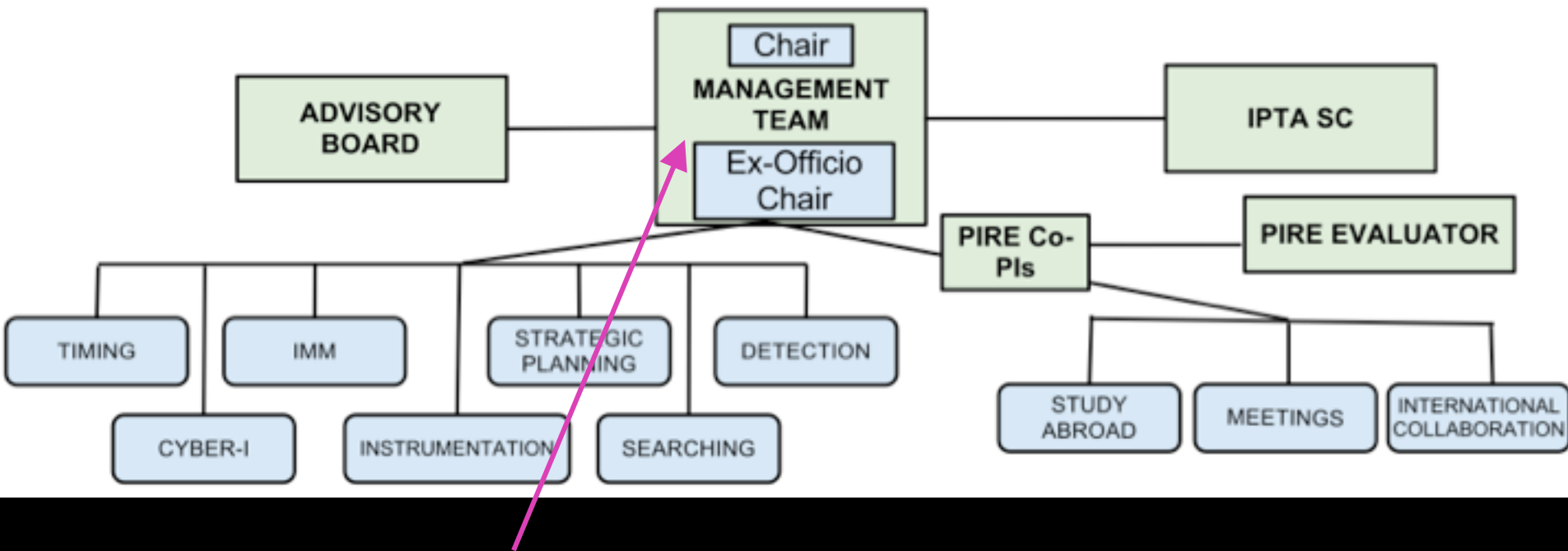


Organization



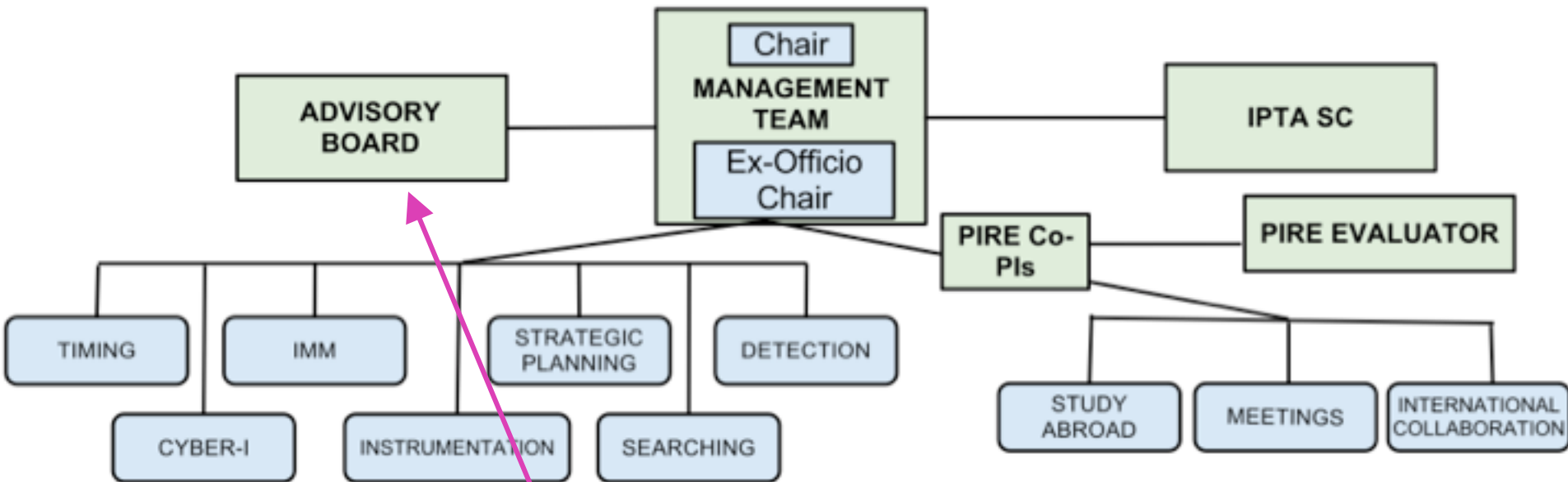
Election for Chair will be held every two years.

Organization



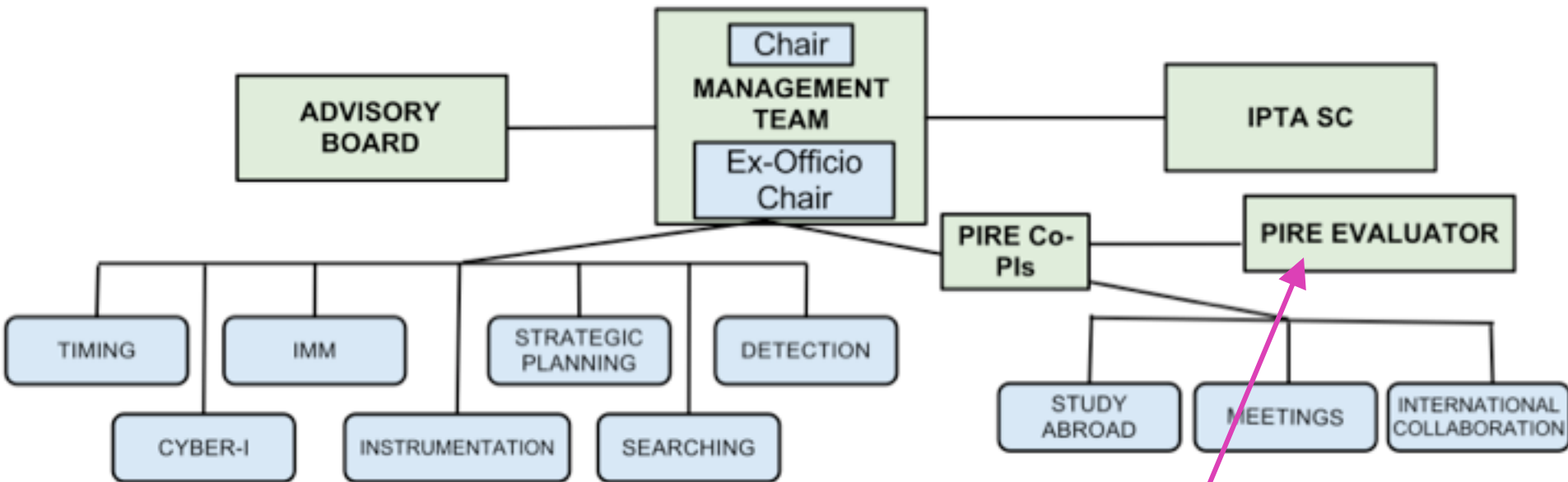
Management Team consists of four or five other members.

Organization



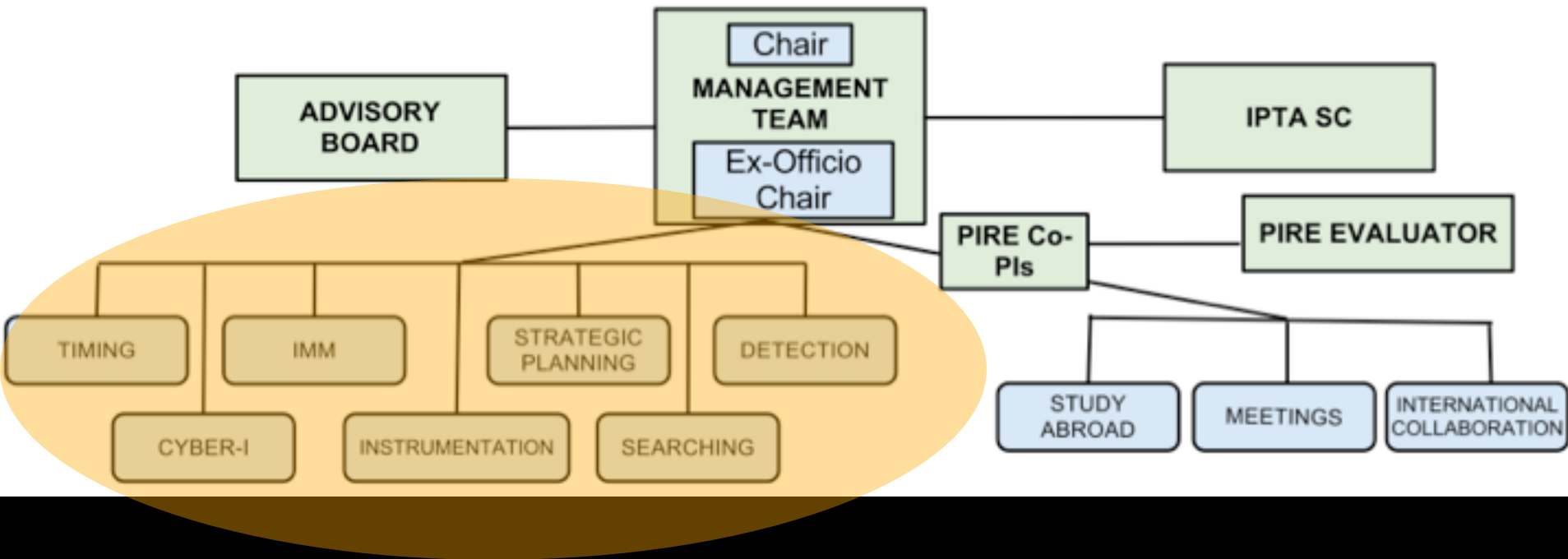
Advisory Board consists of six eternal experts.

Organization



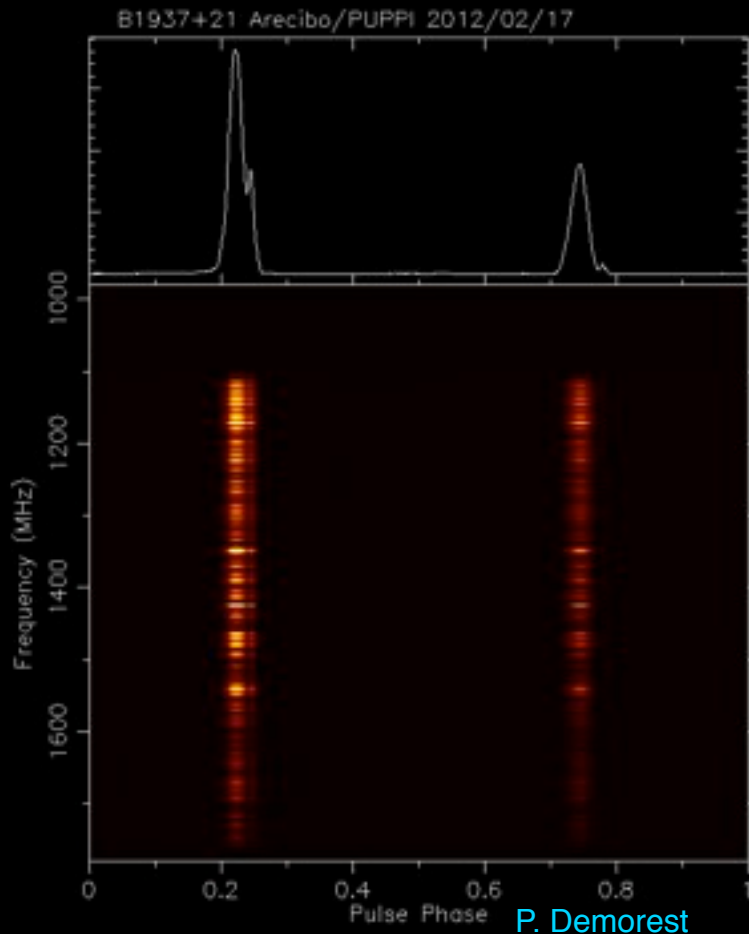
Lisa Kohne evaluates our organization, milestones, and meetings.

Science Working Groups



Timing

Instrumentation:



- Mark4 & ABPP (1998 – 2005)
- ASP (2004 – 2012)
- WAPP (2004 – 2012)
- PUPPI (2012 – present)

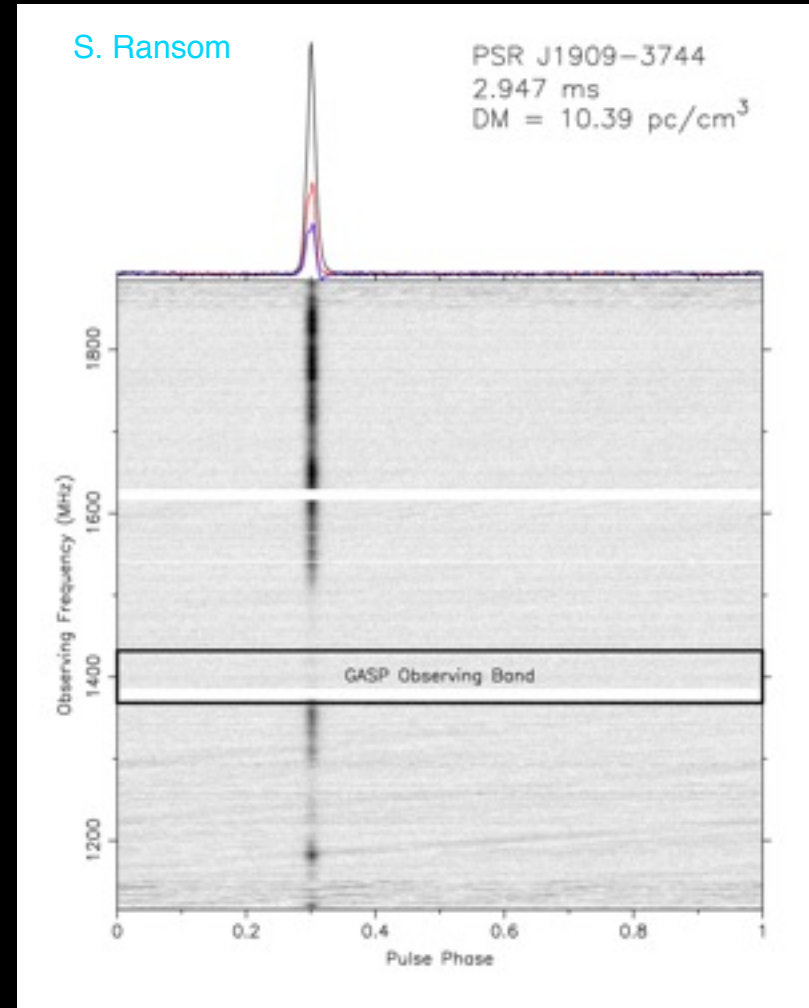
Timing



Instrumentation:



- GASP (2004 – 2011)
- GUPPI (2011 – present)
- factor of 2-3 improvement in timing precision!



Current Observations:

- Observing 35 pulsars (19 with AO and 18 with GBT)

- GBT every 20 days at 800/1400 MHz

- AO monthly at two of 327/430/1400/2350 MHz

- At 18 hr/epoch on each telescope, total of 540 hours per year (plus more hours for additional pulsars!)

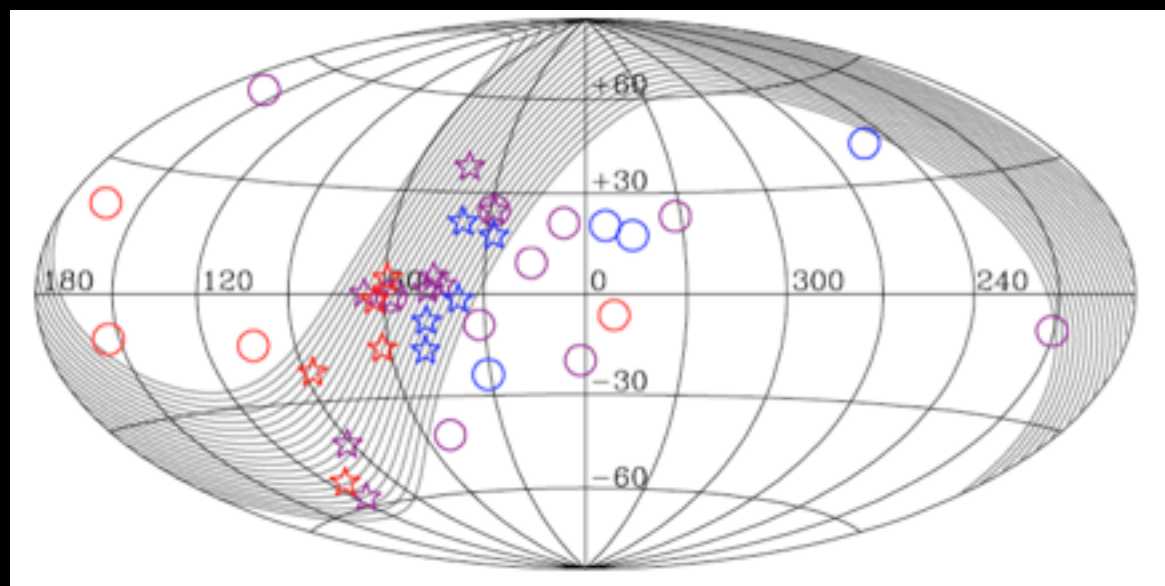
Observed since 2005
Pulsars added ~2009
Pulsars added ~2011

AO GBT
★ ○
★ ○
★ ○

Timing



J0023+0923	AO	J1713+0747	AO,GBT	B1937+21	AO,GBT
J0030+0451	AO	J1738+0333	AO	J1944+0907	AO
J0340+4130	GBT	J1741+1351	AO	B1953+29	AO
J0613-0200	GBT	J1744-1134	GBT	J1949+3106	AO
J0645+5158	GBT	J1747-4036	GBT	J2010-1323	GBT
J1012+5307	GBT	J1853+1303	AO	J2017+0603	AO
J1024-0719	GBT	B1855+09	AO	J2043+1711	AO
J1455-3330	GBT	J1903+0327	AO	J2145-0750	GBT
J1600-3053	GBT	J1909-3744	GBT	J2214+3000	AO
J1614-2230	GBT	J1910+1256	AO	J2302+4442	GBT
J1640+2224	AO	J1918-0642	GBT	J2317+1439	AO
J1643-1224	GBT	J1923+2515	AO		



Timing



Demorest et al. (2012) on > 5 years of ASP and GASP data for 17 pulsars.

http://www.cv.nrao.edu/~pdemores/nanograv_data/

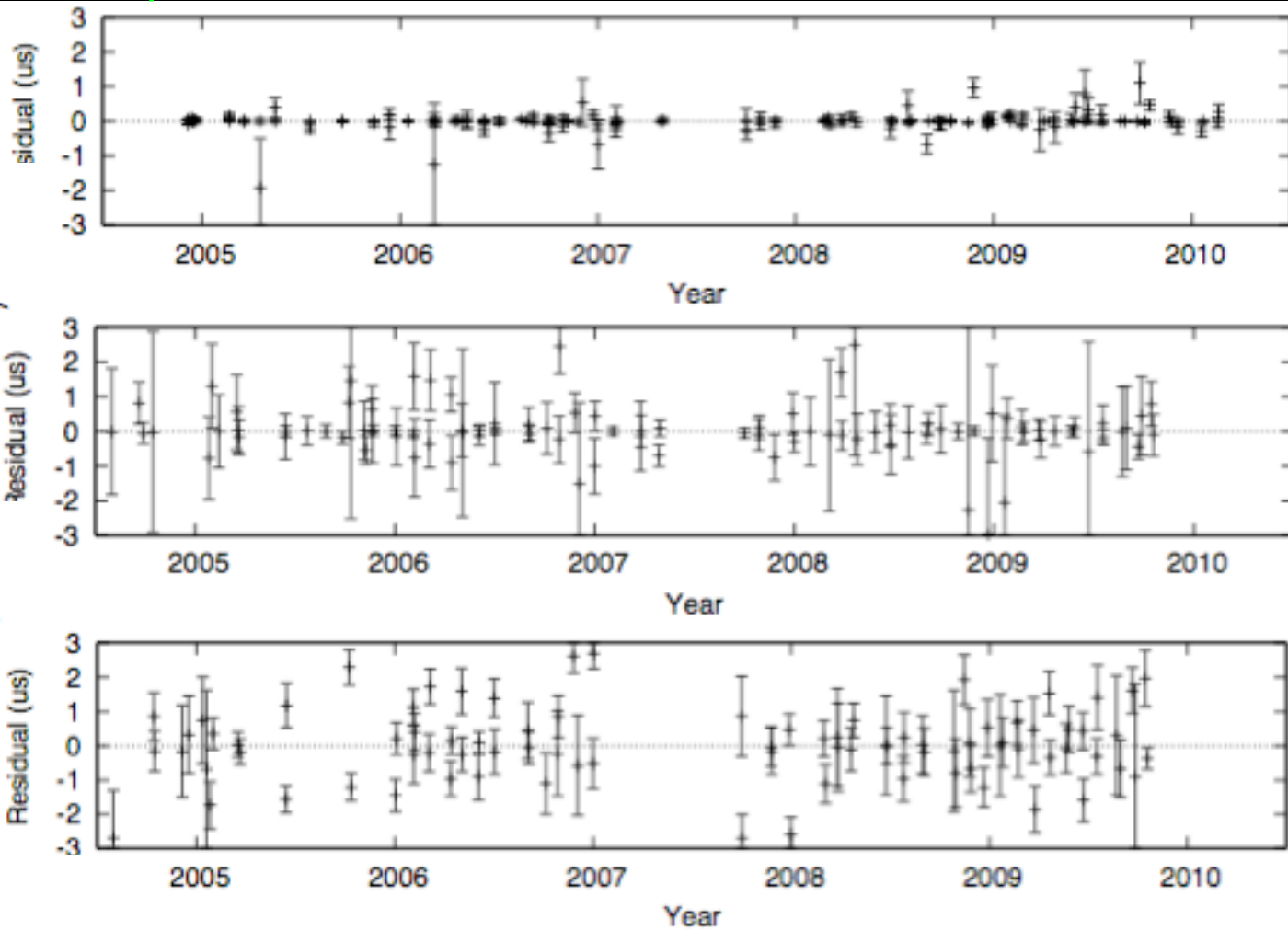
OVERVIEW AND RESULTS FROM TIMING MODEL FITS.

Source	# of TOAs ^a	# of parameters			RMS (μ s)	Fit χ^2	Epoch-averaged RMS (μ s) ^c		
		DM	Profile	Other ^b			Low-band ^d	High-band	Combined
J0030+0451	545	20	26	7	0.604	1.44	0.019	0.328	0.148
J0613-0200	1113	34	45	12	0.781	1.21	0.021	0.519	0.178
J1012+5307	1678	52	53	14	1.327	1.40	0.192	0.345	0.276
J1455-3330	1100	37	53	12	4.010	1.01	0.363	1.080	0.787
J1600-3053	625	21	31	14	1.293	1.45	0.233	0.141	0.163
J1640+2224	631	23	26	12	0.562	4.36	0.057	0.601	0.409
J1643-1224	1266	40	48	13	2.892	2.78	0.589	1.880	1.467
J1713+0747	2368	50	111	15	0.106	1.48	0.092	0.025	0.030
J1744-1134	1617	54	49	7	0.617	3.58	0.139	0.229	0.198
J1853+1308	497	0	34	12	1.028	1.16	0.271	0.096	0.255
B1855+09	702	29	21	14	0.395	2.19	0.277	0.101	0.111
J1909-3744	1001	31	37	14	0.181	1.95	0.011	0.047	0.038
J1910+1256	525	0	34	14	1.394	2.09	0.712	0.684	0.708
J1918-0642	1306	49	37	12	1.271	1.21	0.129	0.211	0.203
B1953+29	208	0	27	12	3.981	0.98	1.879	0.543	1.437
J2145-0750	675	20	37	12	1.252	1.97	0.068	0.494	0.202
J2317+1439	458	30	12	15	0.496	3.03	0.373	0.150	0.251

Timing



Demorest et al. (2012) on > 5 years of ASP and GASP data for 17 pulsars.



J1713+0747
30 ns RMS

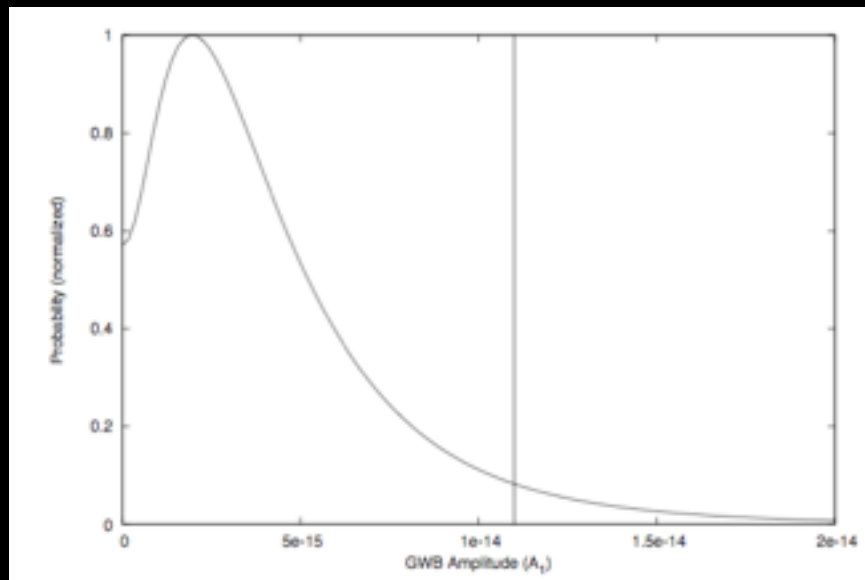
J1012+5307
280 ns RMS

J1643-1224
1.5 μ s RMS

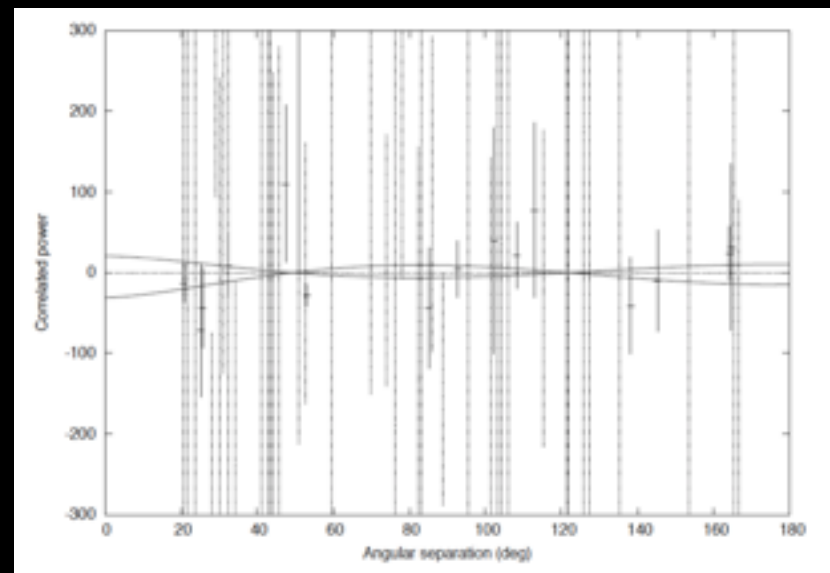
Timing



Demorest et al. (2012) on > 5 years of ASP and GASP data for 17 pulsars.



Single-pulsar limit of
 $h_c < 1.1 \times 10^{-14}$ ($f=1 \text{ yr}^{-1}$)



Hellings and Downs limit
 $h_c < 7 \times 10^{-15}$ ($f=1 \text{ yr}^{-1}$)

See Paul's talks for details of analysis and astrophysical implications.

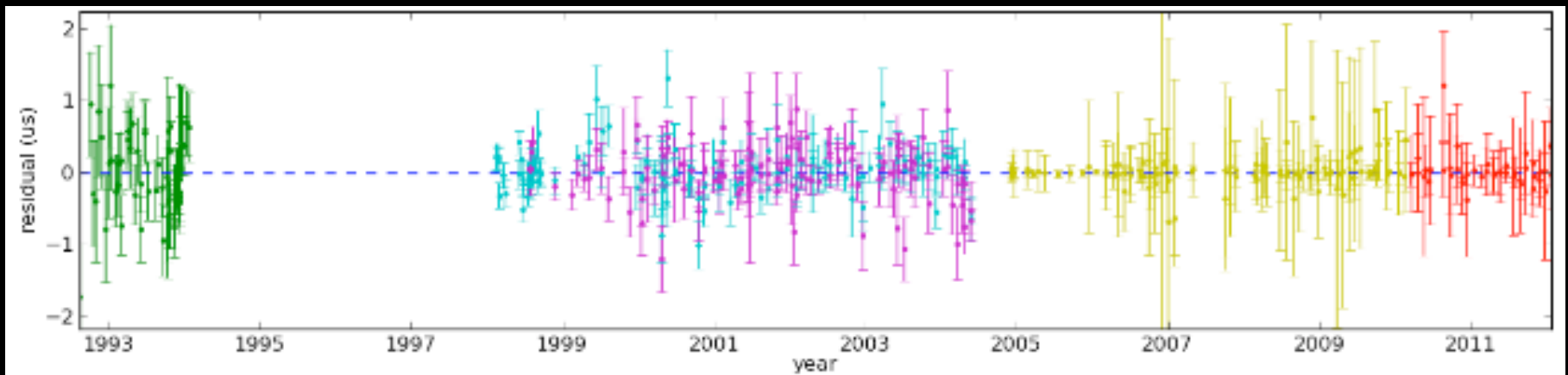
Timing



Current projects:

- "final reduction" of historic data

19 years of J1713+0747



Zhu et al. in preparation

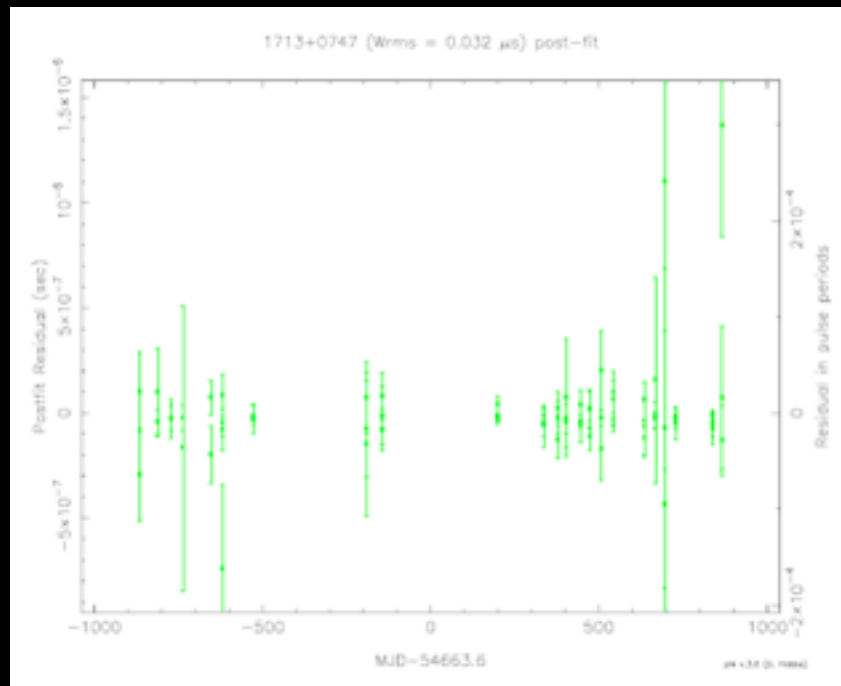


Timing



Current projects:

- "final reduction" of historic data
- reduction of WAPP data (non-coherent but wider band)
(See Joe Swiggum! Results look promising so far).



Timing



Current projects:

- "final reduction" of historic data
- reduction of WAPP data (non-coherent but wider band)
- full calibration of ASP/GASP data (Mueller matrices)
- polarization calibration of PUPPI/GUPPI data
- accounting for profile evolution with frequency
- measuring "local" DM as part of fit (UVA student Tim Pennucci!)
- measuring Shapiro delay for circular binaries



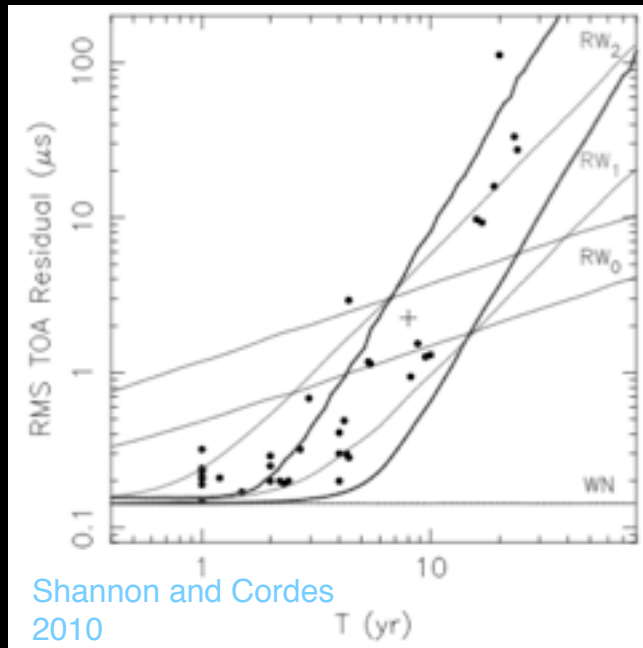
Noise Budgets

- Identify components of variance and then associate them with astrophysical and instrumental causes.

White noise: Radiometer, Scintillation, Jitter

Red noise: Spin/torque, Orbital, Scattering

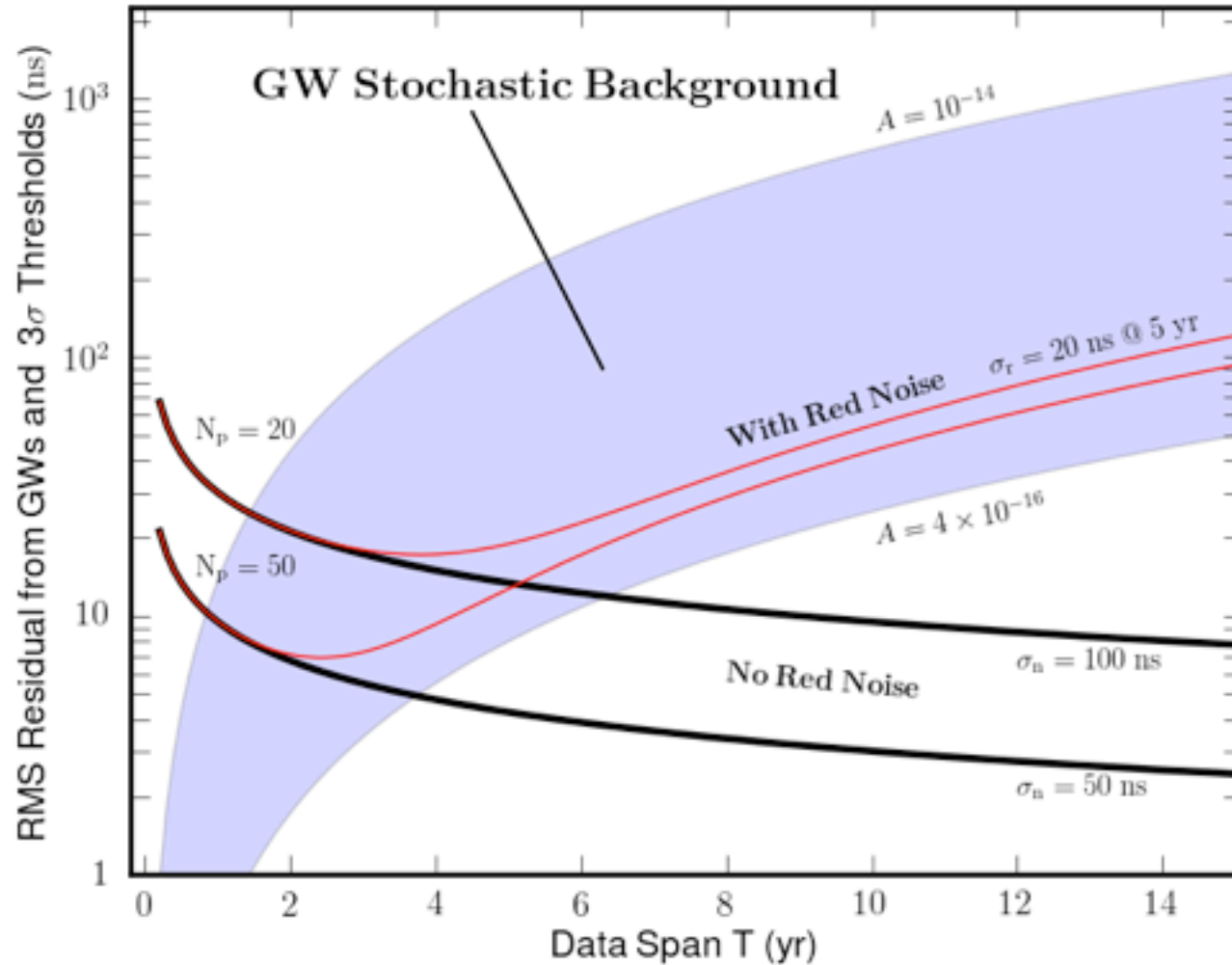
Non-white, non-red: Ephemerides, Instrumental polarization



See Jim Cordes' talk and
Delphine Perrodin's talk!



Noise Budgets

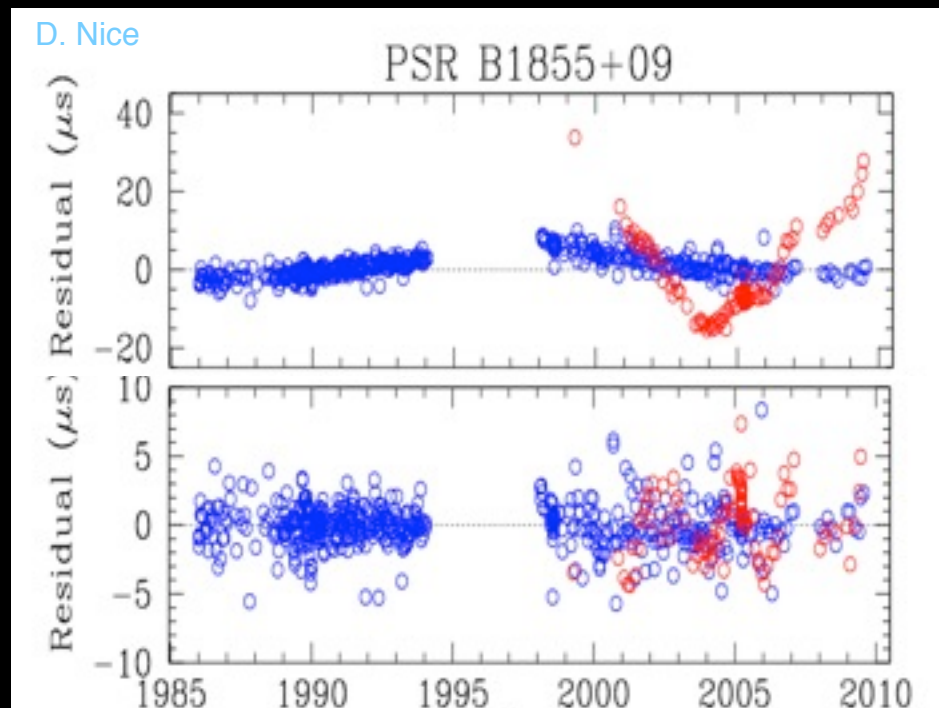


See Jim Cordes

Interstellar Medium Mitigation



- David Nice will discuss DM correction scheme for Demorest et al. 2012.
- Exploring covariance between DM determination method and timing params. See Tim Dolch's talk!

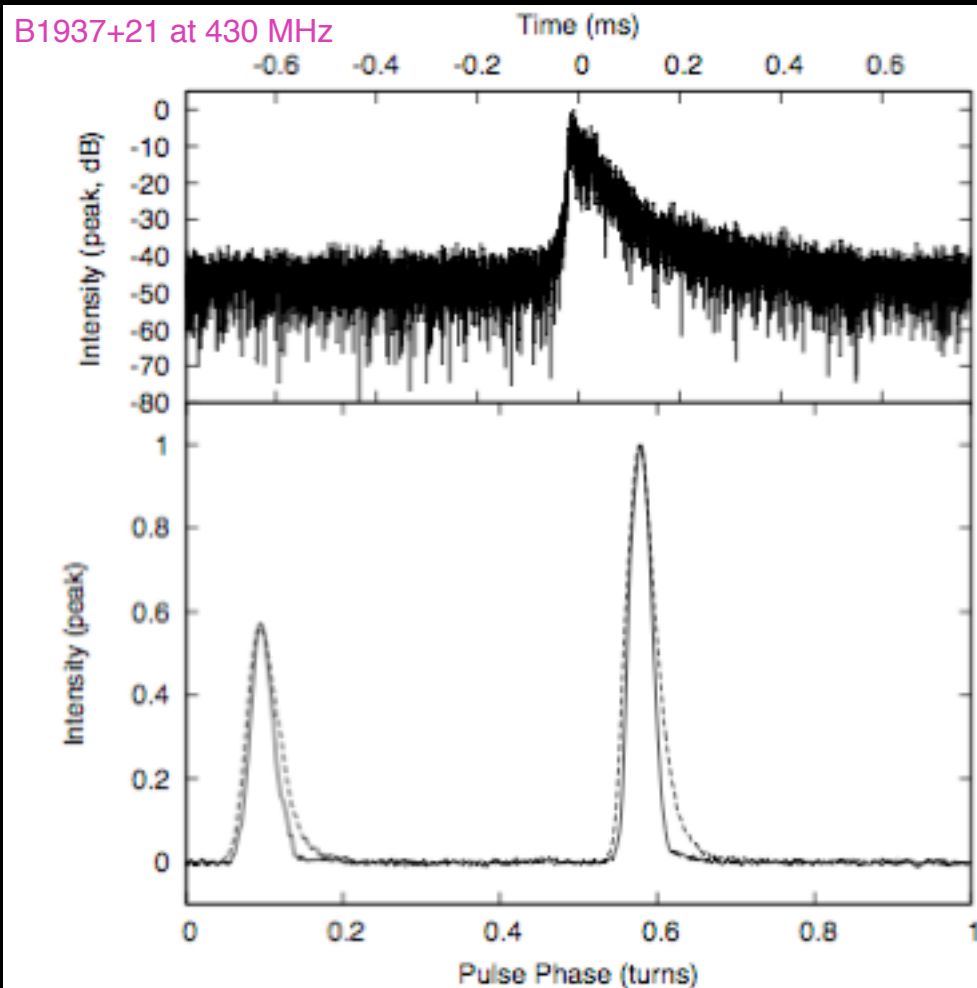


○ 1410 MHz
○ 430 MHz

Interstellar Medium Mitigation



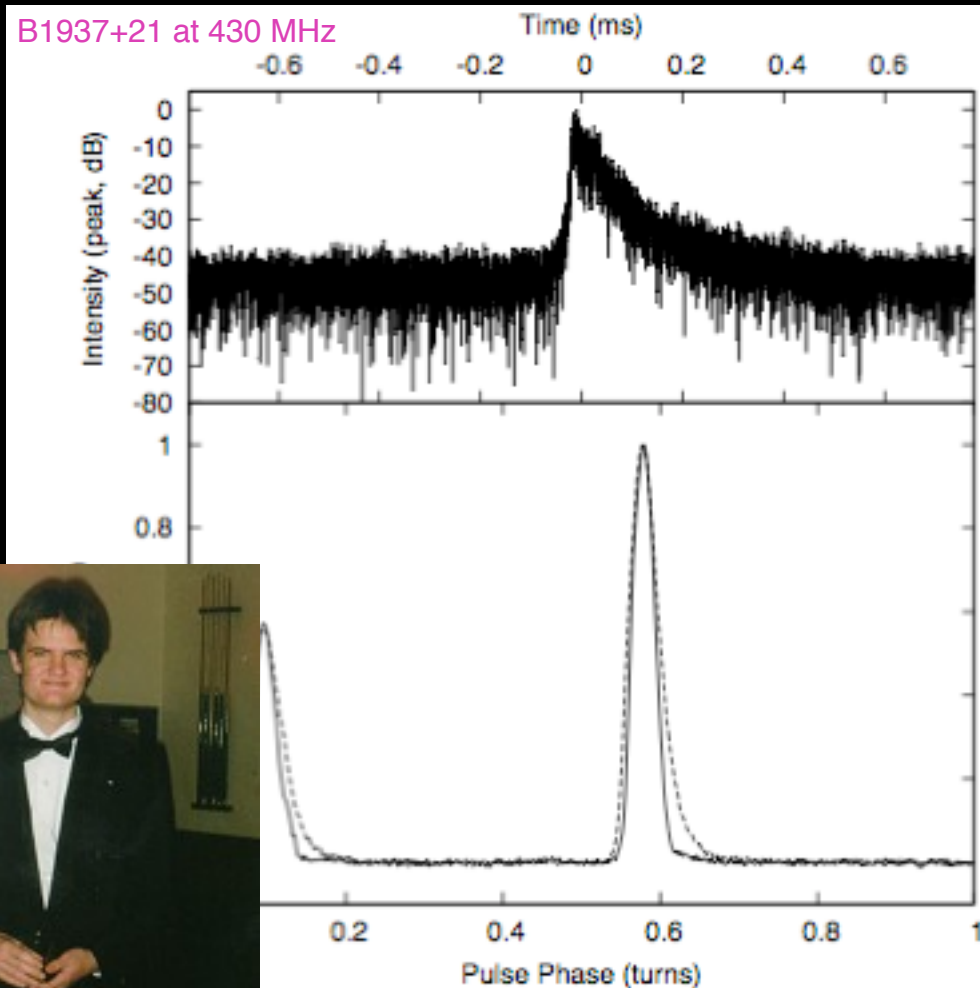
- Experimenting with de-convolution methods to remove scattering delays.
- Successful application of cyclic spectroscopy (CS) to B1937+21 data (Demorest et al. 2011).
- J1713 observed at AO to test CS delay correction. See Nipuni Palliyaguru's talk!



Interstellar Medium Mitigation



- Experimenting with de-convolution methods to remove scattering delays.
- Successful application of cyclic spectroscopy (CS) to B1937+21 data (Demorest et al. 2011).
- J1713 observed at AO to test CS delay correction.
- GPU-based CS!
See Glenn Jones' talk!

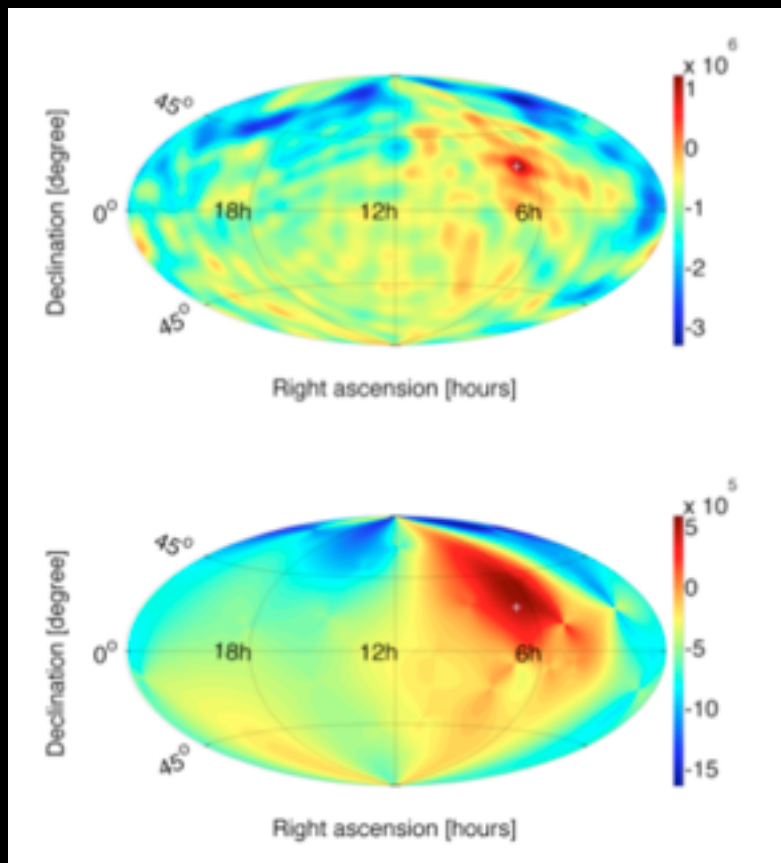


Detection



Recent Papers:

- "Practical Methods for Continuous Gravitational Wave Detection," Ellis, Jenet, McLaughlin, accepted by ApJ.



Detection



Recent Papers:

- "Practical Methods for Continuous Gravitational Wave Detection," Ellis, Jenet, McLaughlin, accepted by ApJ.
- "Optimal Strategies for Continuous Gravitational Wave Detection," Ellis, Siemens, Creighton, submitted to ApJ. See Justin's talk!
- "Maximum Likelihood estimation of timing noise parameters for NANOGrav pulsars," Ellis et al. in preparation.
- "Searching for Periodic Gravitational Wave Sources with Pulsar Timing Arrays," Deng and Finn, in preparation.

Detection



Pipeline status:

- Three independent continuous wave pipelines (time and frequency domain) currently under development. One already deployed on IPTA and EPTA data.
See Justin Ellis's talk and Yan Wang!



- Developing New Stochastic Gravitational Wave Search Pipelines
See talk by Xavi Siemens!
- Developing Burst Gravitational Wave Search Pipelines
Talk to Sam Finn and Andrea Lommen!
- Running the first IPTA data challenge in collaboration with PPTA and EPTA.

NANOSoft repository located at:

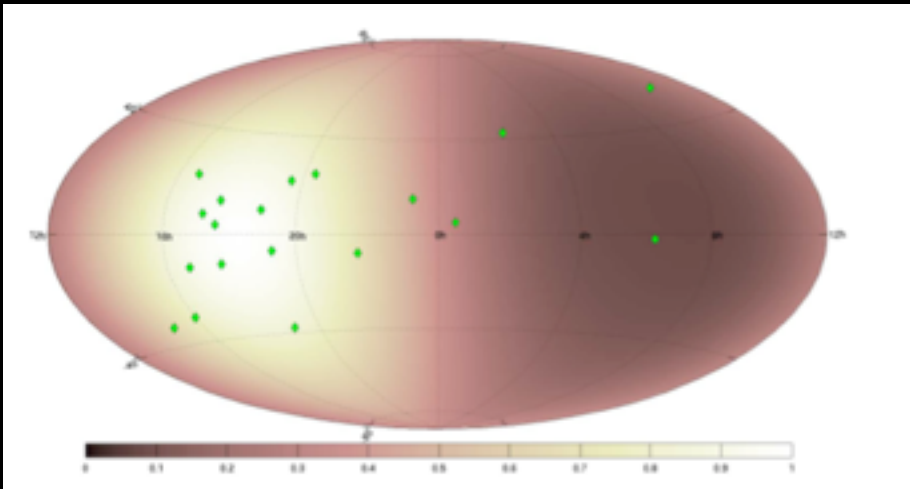
<https://sourceforge.net/projects/nanosoft/>

Observing Optimization



- Optimize observing frequencies, cadences, and MSP locations.

See talks by Andrea Lommen, Joe Simon, and Sam Finn!



Burt, Lommen, and Finn 2011

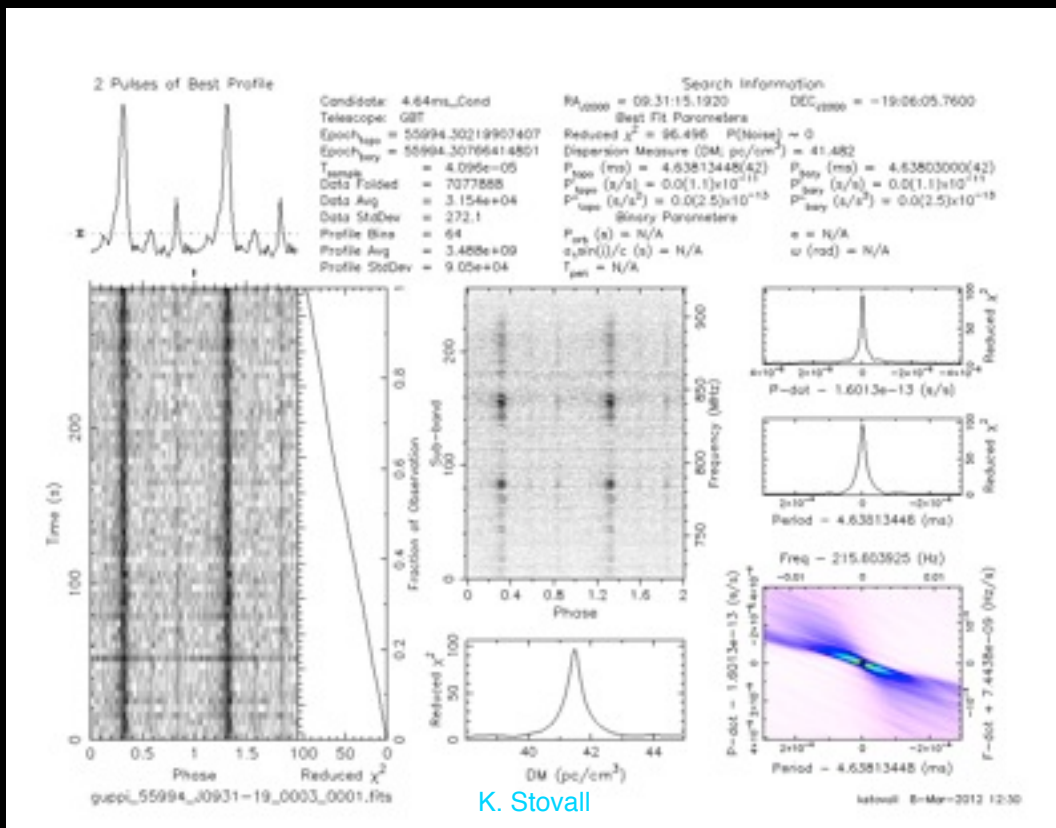
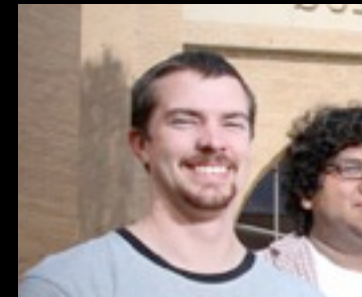


Online simulators available at http://arcc.phys.utb.edu/nano_sandbox/
and <http://gwastro.psu.edu>.

Searching



- Still finding MSPs in PMPS (3! Mickaliger et al. in preparation)
- 12 MSPs in 350-MHz GBT surveys (Boyles et al., Lynch et al., and Stovall et al. in preparation)



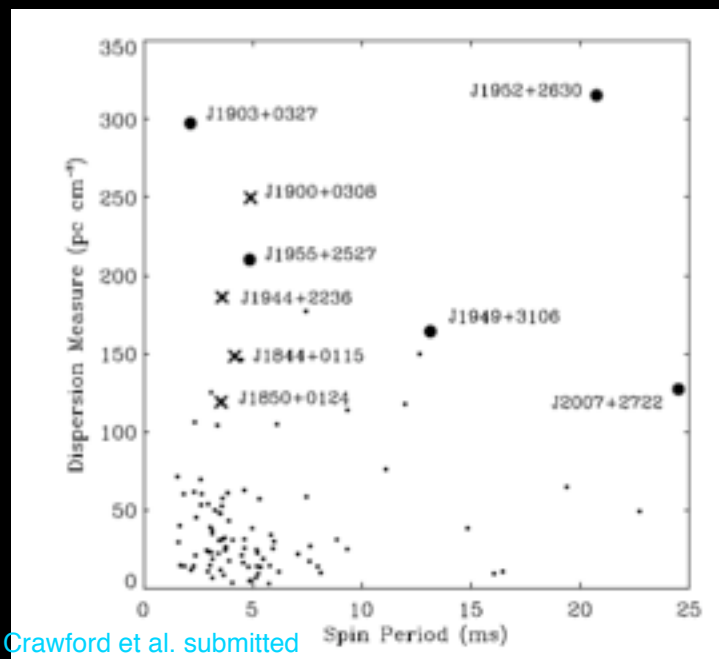
Expect 50 MSPs by completion of all GBT sky survey!

See Ryan Lynch's and Joe Swiggum's talks!

Searching



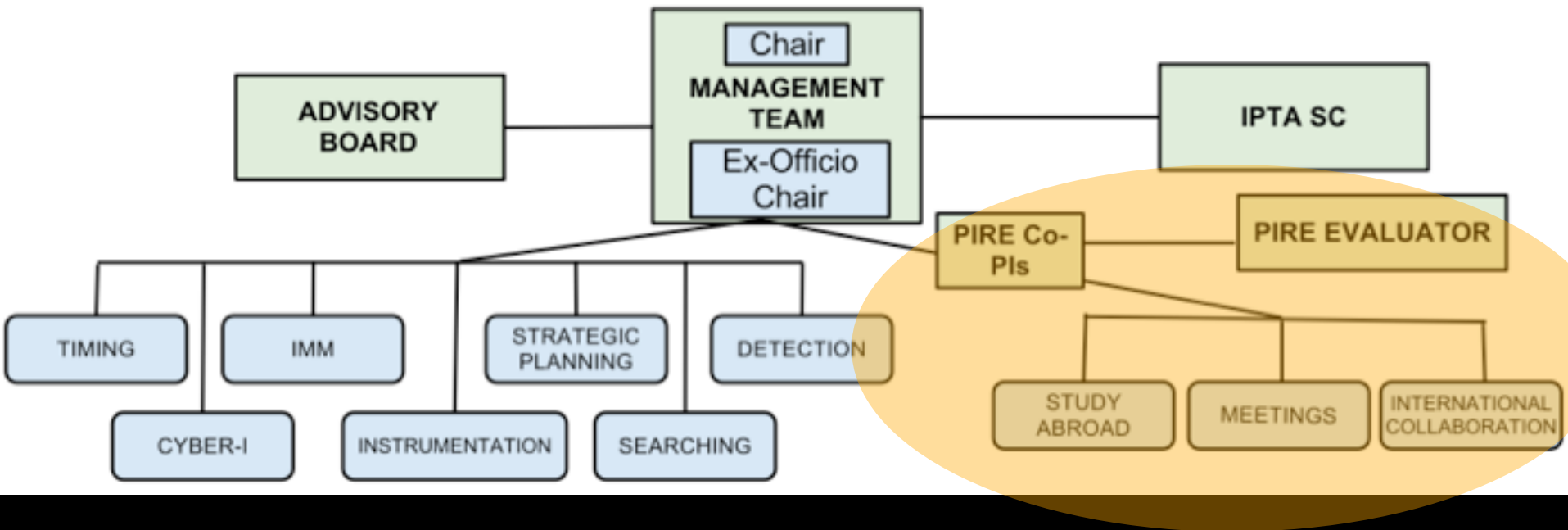
- Still finding MSPs in PMPS (3! Mickaliger et al. in preparation)
- 12 MSPs in 350-MHz GBT surveys (Boyles et al., Lynch et al., and Stovall et al. in preparation)
- 15 MSPs in 1400-MHz PALFA Survey (Deneva et al. submitted, Crawford et al. submitted).



Expect 50 MSPs by completion of PALFA!

See Duncan Lorimer's talk!

International Education



International Education



PIRE is a \$6.5M NSF grant to 9 U.S. institutions. The project has 5 goals:

International Education



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● Goal 1 Knowledge – Advance new knowledge and discoveries at the frontiers of science?

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International Education



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- Goal 4 **Institutional Capacity** - Strengthen the capacity of institutions and networks to engage in and benefit from international research and education collaborations ?



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- Goal 4 **Institutional Capacity** - Strengthen the capacity of institutions and networks to engage in and benefit from international research and education collaborations ?
- Goal 5 **Workforce Development** - Develop a diverse, globally-engaged science workforce by catalyzing a higher level of international engagement by the U.S. science community?

International Education



PIRE award supports workshops and meetings (like this one!) and also funds students to travel abroad for research and study.

Willie Kunert (Oberlin) @ ATNF In 2010
and Bonn in 2011.

Emma Handzo and Abi Polin (F&M) @ Manchester
in summer of 2011.



Mikaela Larkin (Oberlin) @ Tasmania now.

Joey Martinez (UTB) @ Bonn now.

David Day (UWM) @ Manchester now.

Gary Marchiny (WVU) @ Manchester for 2012-2013.



We also welcome foreign students visiting our institutions!



Outreach



MARIE (Mid-Atlantic Relativistic Initiative in Education) @ F&M - undergraduates teach in high schools (including remote observations), and host open houses at F&M.



ARCC @ UTB and ARCC @ UWM involve high-school and undergraduate students in pulsar searching – 25 new pulsars in last 1.5 years!

PSC (NRAO and WVU) involves > 600 high-school students throughout US in pulsar searching – 5 new pulsars found, including one MSP.



See Joe Swiggum's talk!



Summary of Successes



We have developed an infrastructure which will foster exchange of ideas, recognition of contributions of all members, student nurturing, and creativity.

We are forming partnerships with observatories.

Our first “NANOGrav” paper has been published and we have several other pipelines in the pipeline.

We are receiving more observing time than ever and hope to continue to see that increase even further.

We’ve received our first multi-institutional grant and aim for more such funding opportunities.

We are training many students for the international research climate.

The Future



Funding for Arecibo and the GBT is not guaranteed and the NSF Portfolio Review may dramatically affect the operation of these telescopes.

We are advocating for new L+S-band receivers on both GBT and Arecibo.

We are working to determine the optimal observing plans for each telescope.

What are the ultimate limits of our sensitivity?

What do our source classes really look like?

How much data should we store and how much storage capacity do we need?

How can we work with other institutions to connect our outreach and education efforts?

How can we work with other telescopes such as FAST and MeerKAT and eventually SKA (See Scott's Talk!)? Coordinated IPTA effort!!