Pulsars with LWA1

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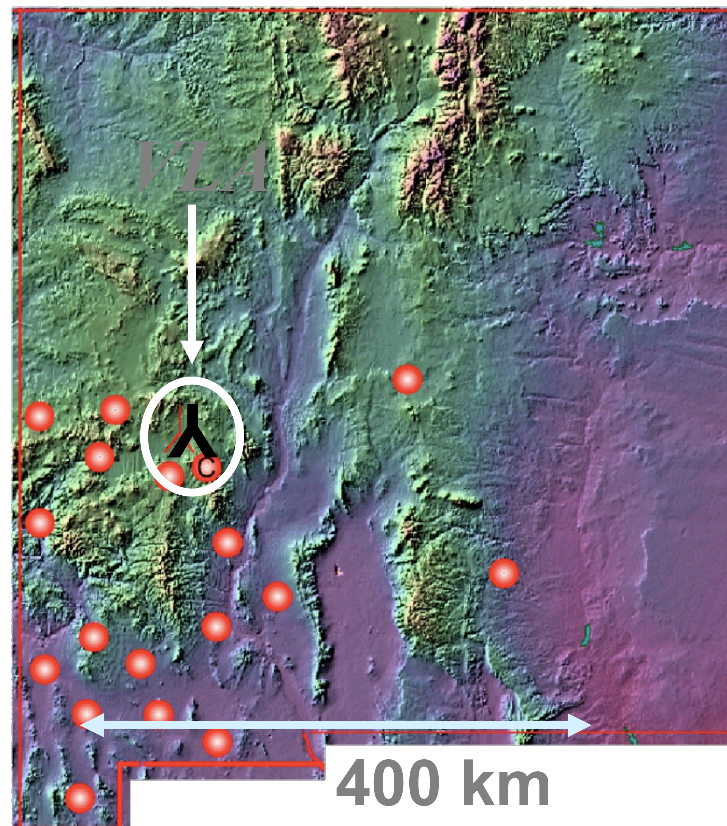
Acknowledgement
Funding for pulsar science at NRL is provided by NRL/ONR

Vision: Long Wavelength Array (20-80 MHz)
Far Larger than the VLA

1 "LWA Station" = 256 antennas

100 m

Full LWA: 50 stations spread across NM



400 km

State of New Mexico

10-88 MHz usable; Galactic noise-dominated (>4:1) 24-87 MHz

4 independent beams x 2 pol. X 2 tunings each ~16 MHz bandwidth

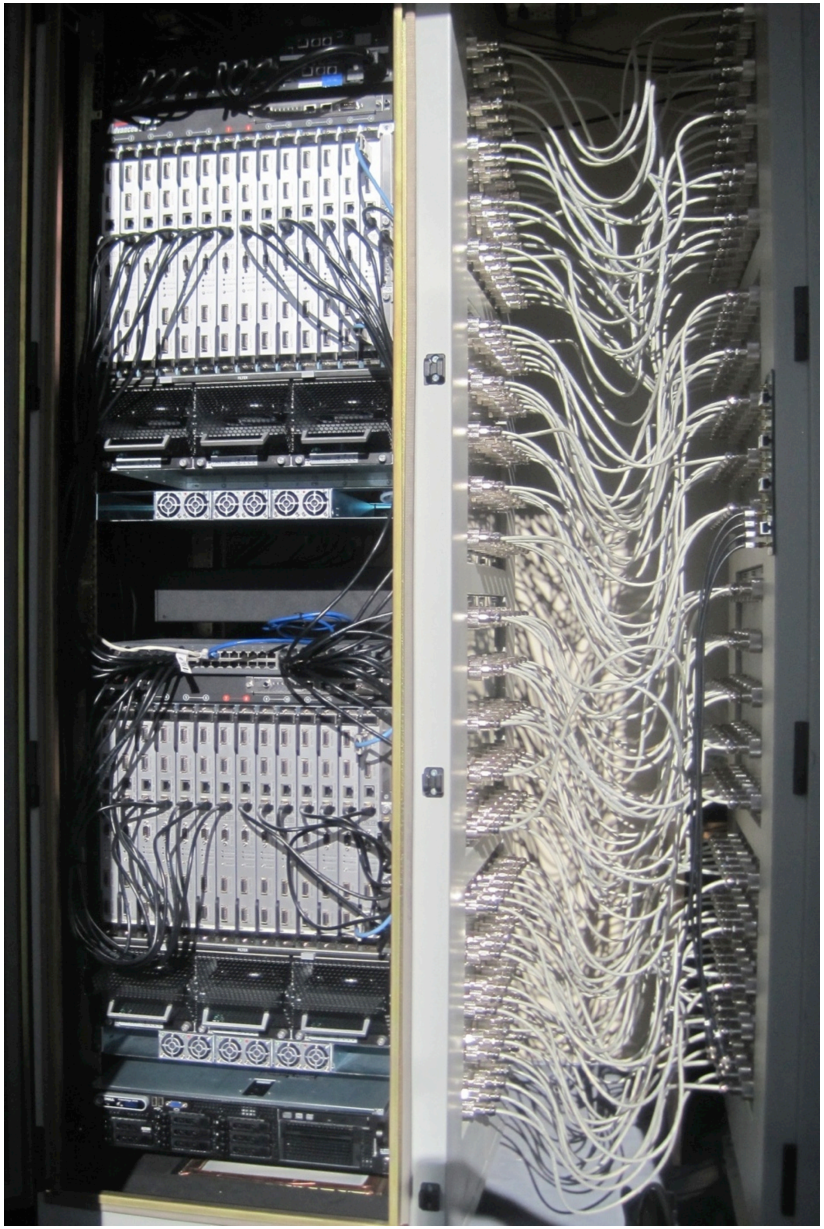
SEFD ~ 3 kJy (zenith) S_{min} ~ 5 Jy (5sigma, 1 s, 16 MHz, zenith)

All sky (all dipoles) modes: TBN (67 kHz-bandwidth; continuous)

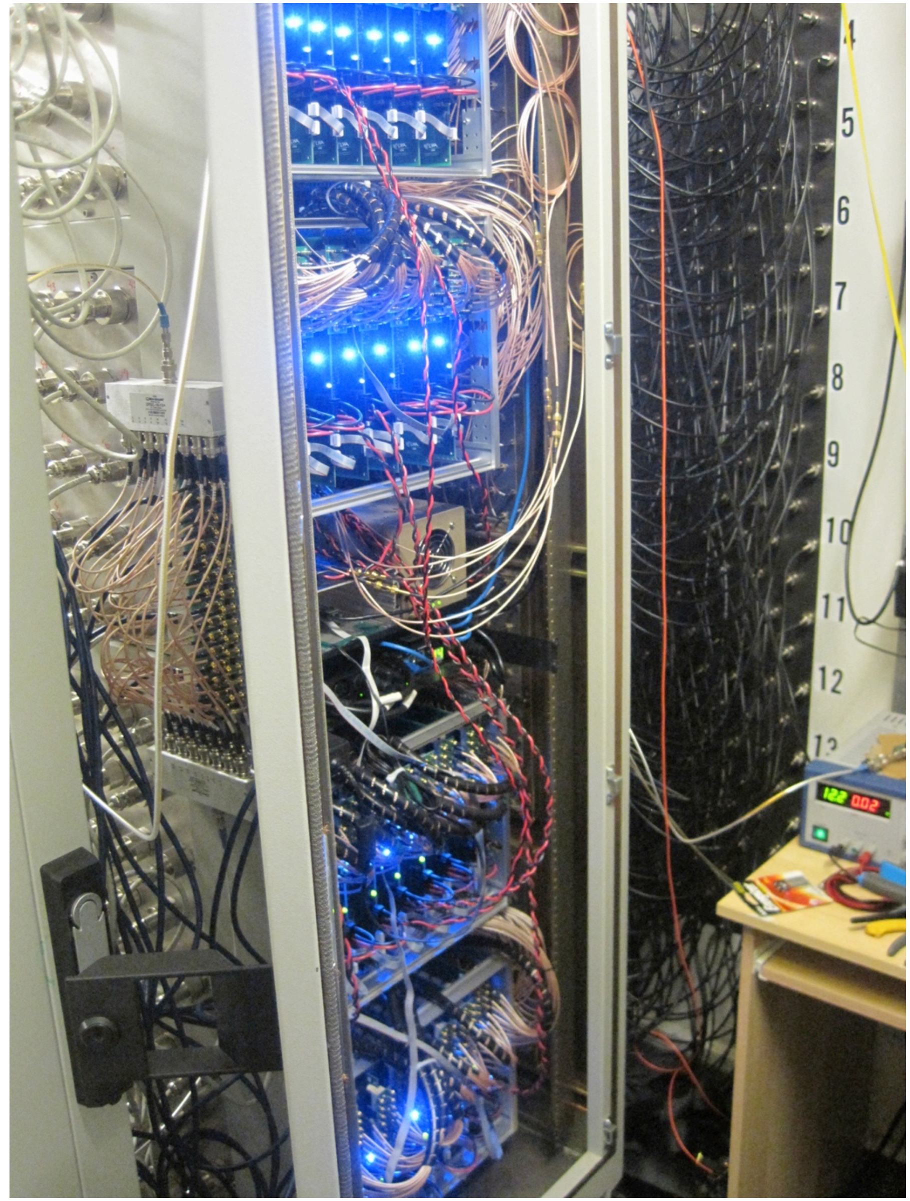
TBW (78 MHz-bandwidth, 61 ms burst)

One "outrigger" antenna pair ~300 m to the East

LWA1 science emphasis: transients, pulsars, Sun, Jupiter & Ionosphere



Digital Processor (DP)



Analog Signal Processor (ASP)

LWA Long Wavelength Array

Currently operated by NSF as a University Radio Observatory

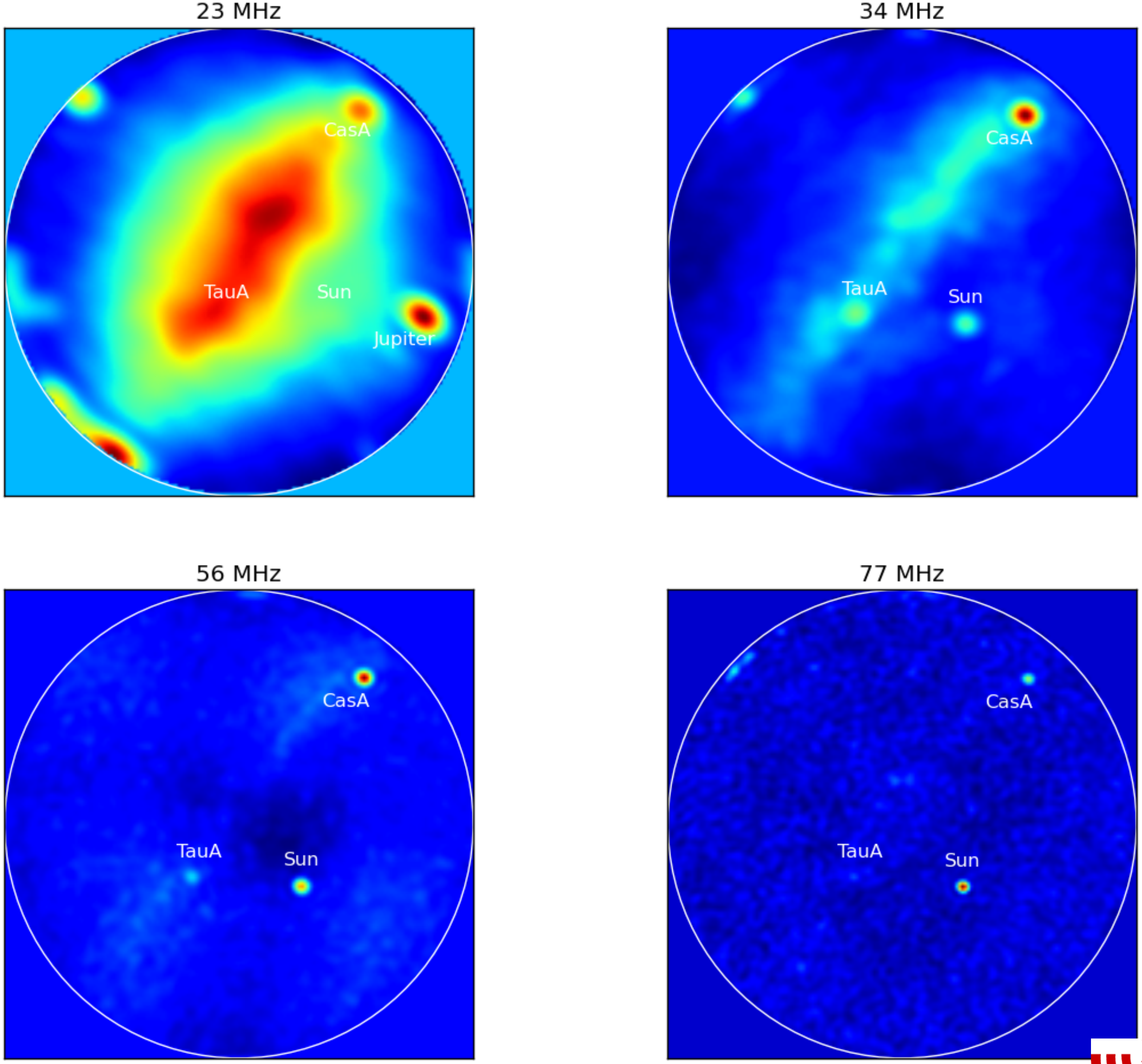
URO Partners

LWA Collaborators

Sponsors

Images

10 sec
50 kHz
210
dipoles

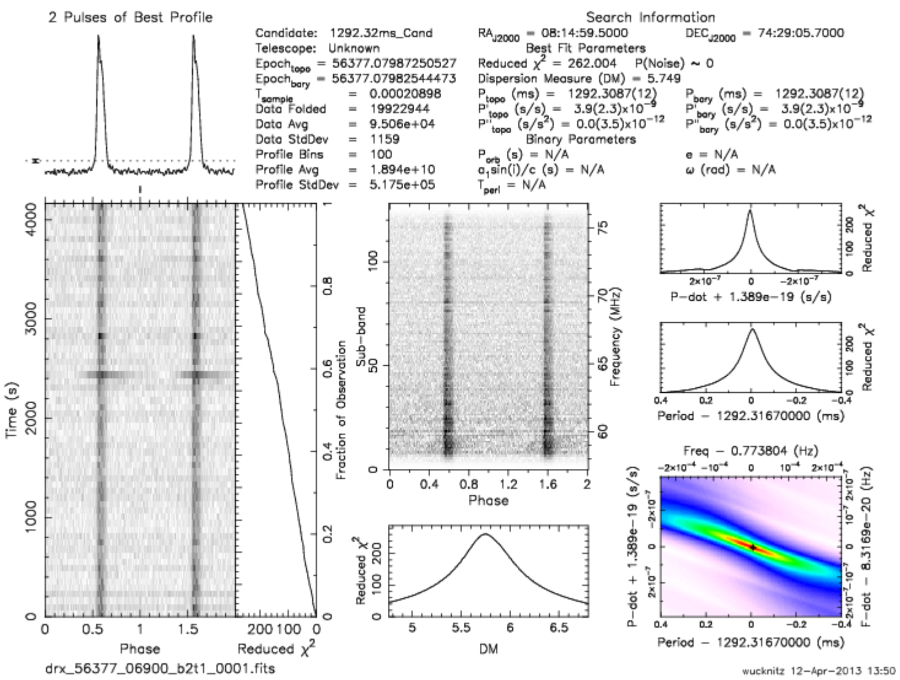


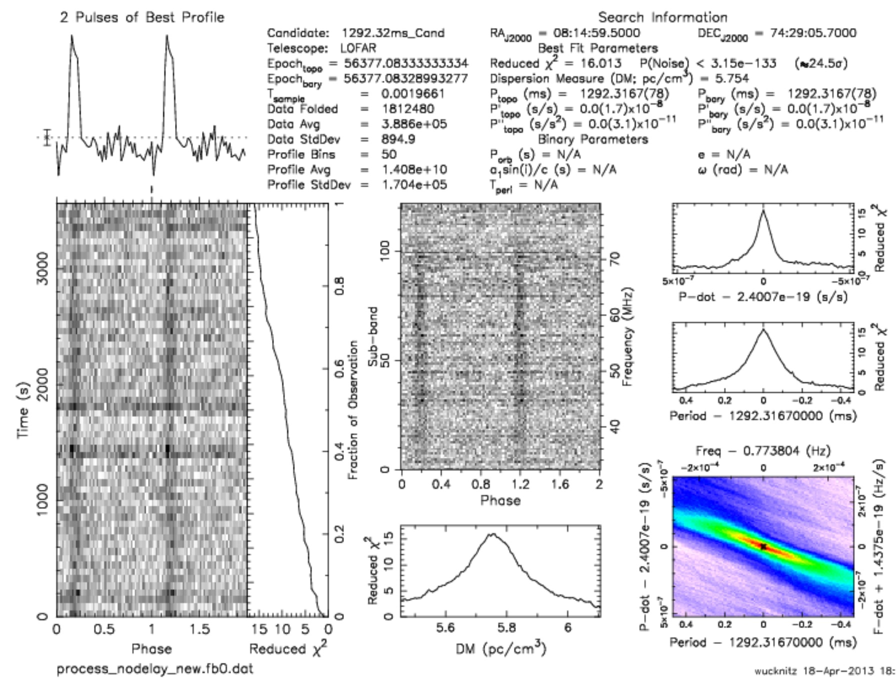
Long Wavelength Array

Single Station Performance

(Frank Schinzel and Olaf Wucknitz)

LWA1 Station (NM)	LOFAR LB Station (SW)
(58-76 MHz; Δν~ 20 MHz; 256 dual pol)	(30-80 MHz; Δν~50 MHz; 96 dual pol)





Simultaneous observations of PSR B0809+74 from LWA1 & LOFAR LB station (Onsala)

(This, and simultaneous observation of PSR B1133+16 with GBT, revealed 1.0 second offset in LWA1 time stamps!)

Pulsars and Fast Transients With LWA1: Capabilities

Pulsars and Fast Transients are perfect "single dish" science

- LWA1 is comparable to a 100 m dish at 38 MHz
- Broad bandwidth observations are possible
- Wide field of view for rapid survey speed
- Raw voltage data recorded so coherent dedispersion and other techniques can be applied in post-processing
- Dispersion is a powerful discriminator against RFI
- Data time tagged to GPS for precise timing

- Similar sensitivity to LOFAR Low Band for pulsar work with
  - Better sky coverage (site is 20° further south)
  - Wide bandwidth (24–88 MHz)
  - Benign RFI environment
  - LWA1 records raw voltages, allowing flexible processing

LWA1 Can Address A Wide Range of Pulsar Science Topics

- Profile evolution (at high time resolution) vs. frequency
- Polarization studies
- Subpulse structure (nulling and drifting subpulses)
- Spectral turnovers

Emission Mechanisms

- Searches for steep-spectrum pulsars

New Sources

- ISM, Solar Corona, and Ionosphere effects
  - Scattering (including variable scattering)
  - "Super"-dispersion
  - Faraday rotation

Propagation Effects

- Single pulse studies
  - Crab Giant Pulses, Anomalously Intense Pulses
  - RRATs
  - Single dispersed pulses (FRBs, PBHs and other exotica)

Transient and Exotic Sources

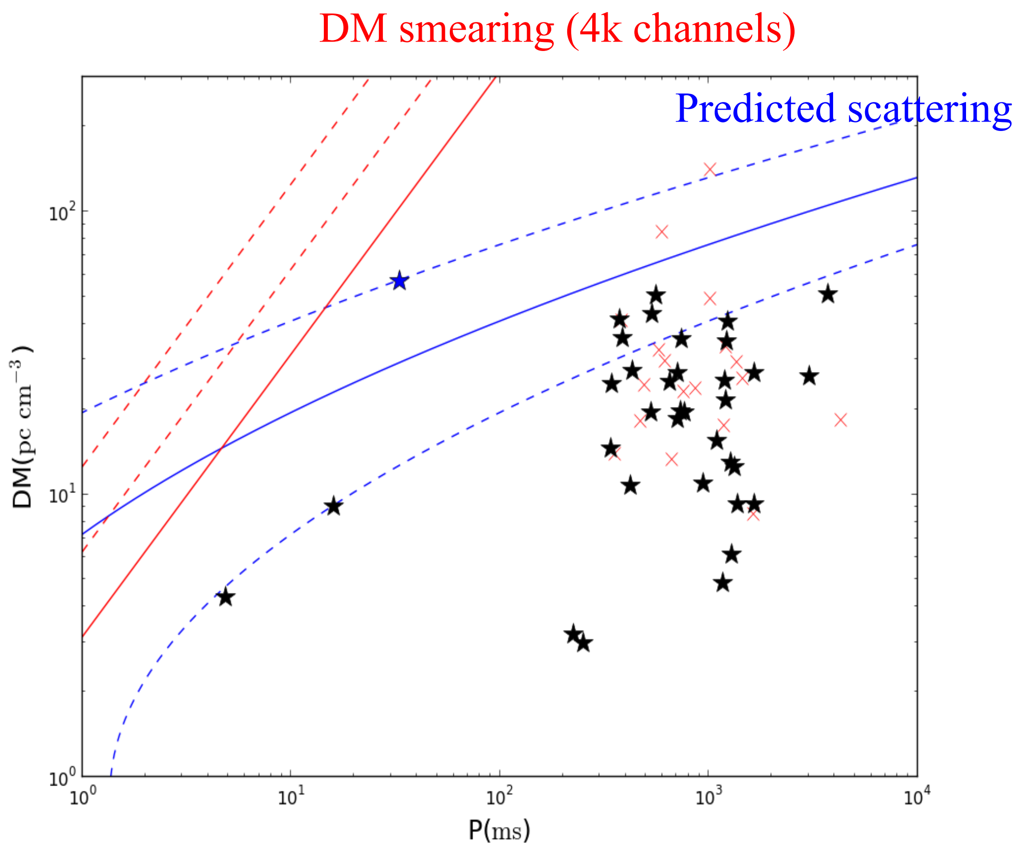
LWA Long Wavelength Array

LWA1 Pulsar Detections

J0030+0451
B0031-07
B0138+59
B0320+39
B0329+54
B0450+55
B0525+21
B0531+21*
B0809+74
B0818-13
B0823+26
B0834+06
B0919+06
B0943+10
B0950+08
B1112+50
B1133+16
B1237+25

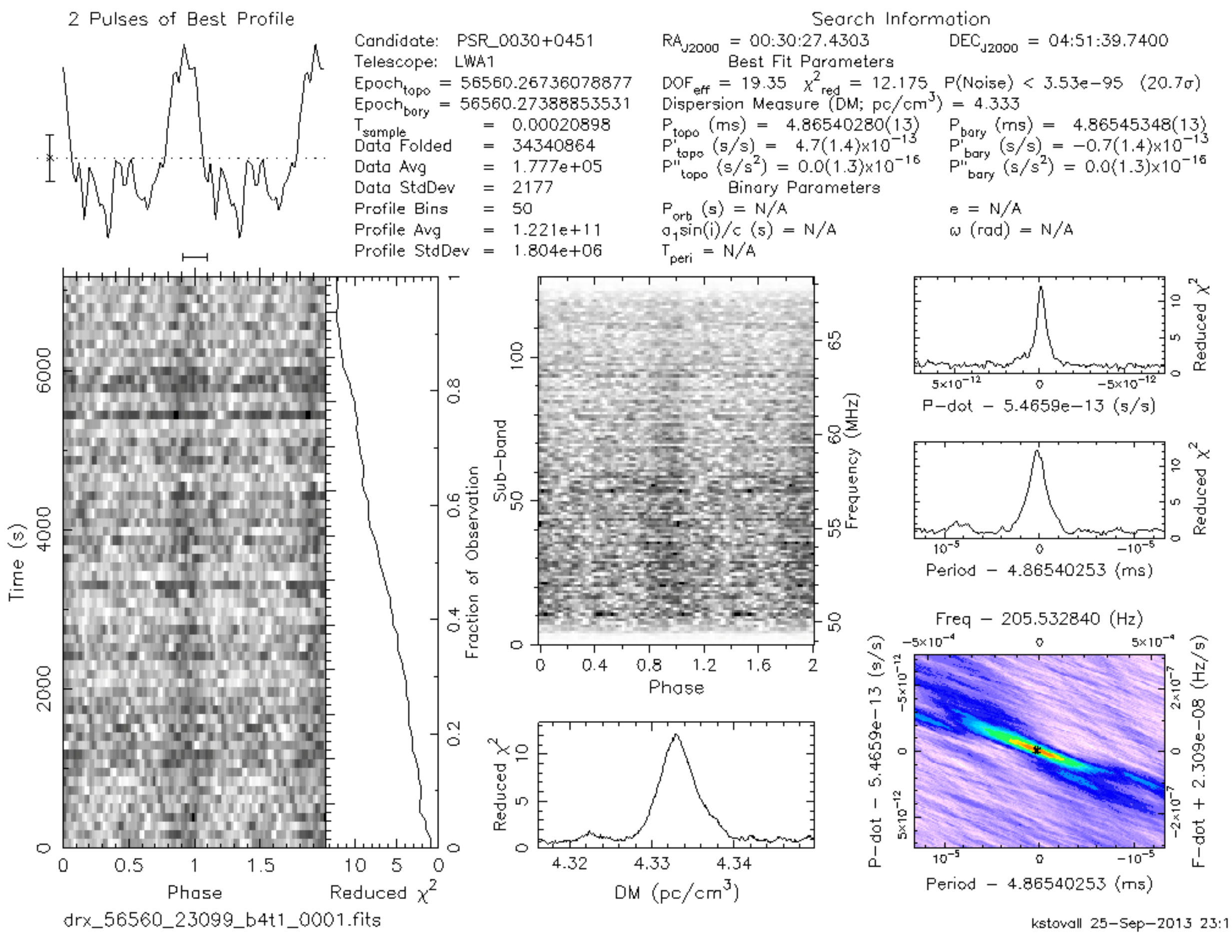
B1508+55
B1540-06
B1541+09
B1604-00
B1612+07
B1642-03
B1706-16
B1749-28
B1822-09
B1839+56
B1842+14
B1919+21
B1929+10
B2020+28
B2110+27
J2145-0750
B2217+47

- 35 Pulsars detected (34 through pulsations, 1 through giant pulses)
- 2 MSPs detected
- Periods from 4.9 ms to 4.3 s



PSR J0030+0451

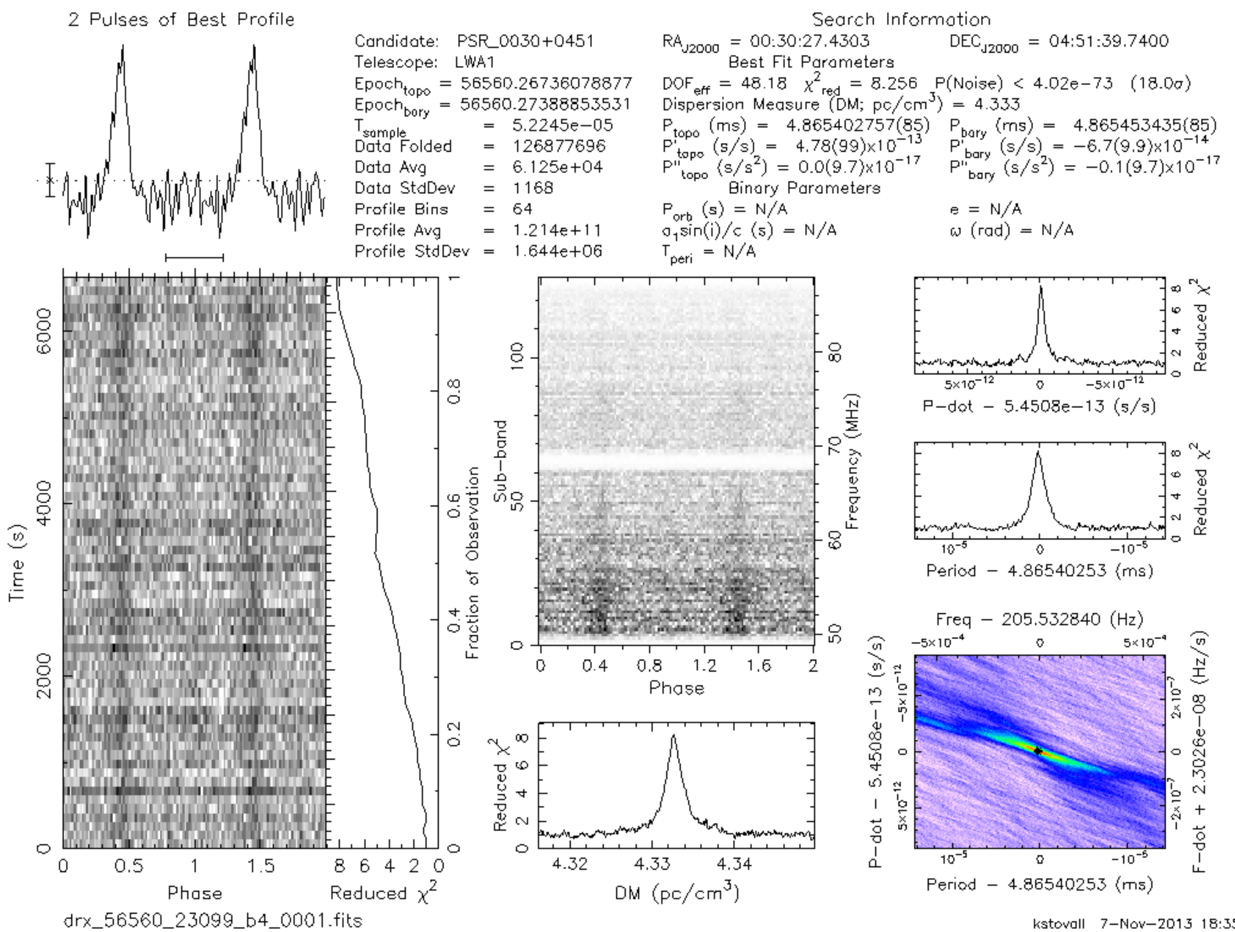
(Thanks to Kevin Stovall and Jayce Dowell)



Incoherent dedispersion

PSR J0030+0451

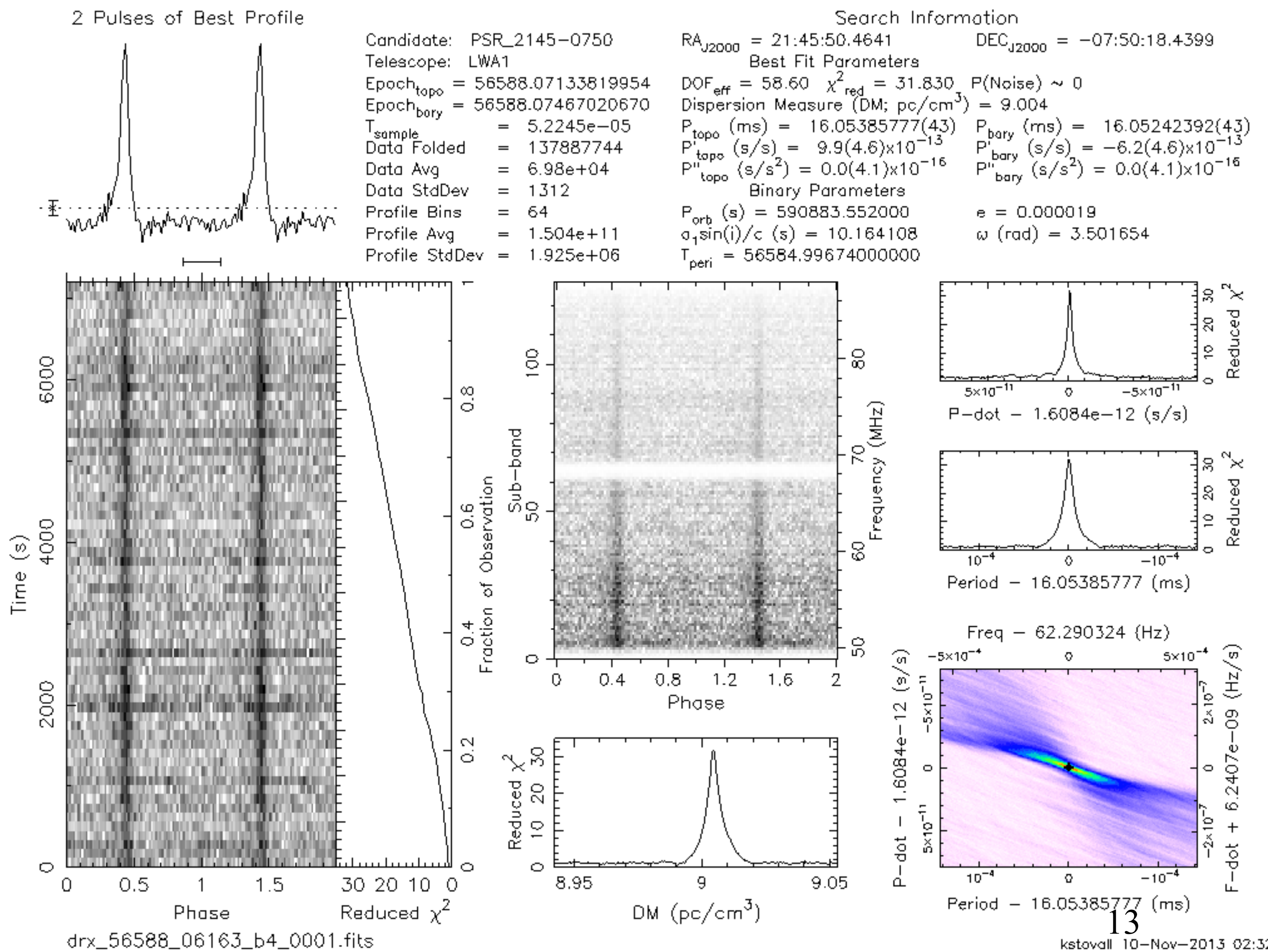
(Thanks to Kevin Stovall and Jayce Dowell)



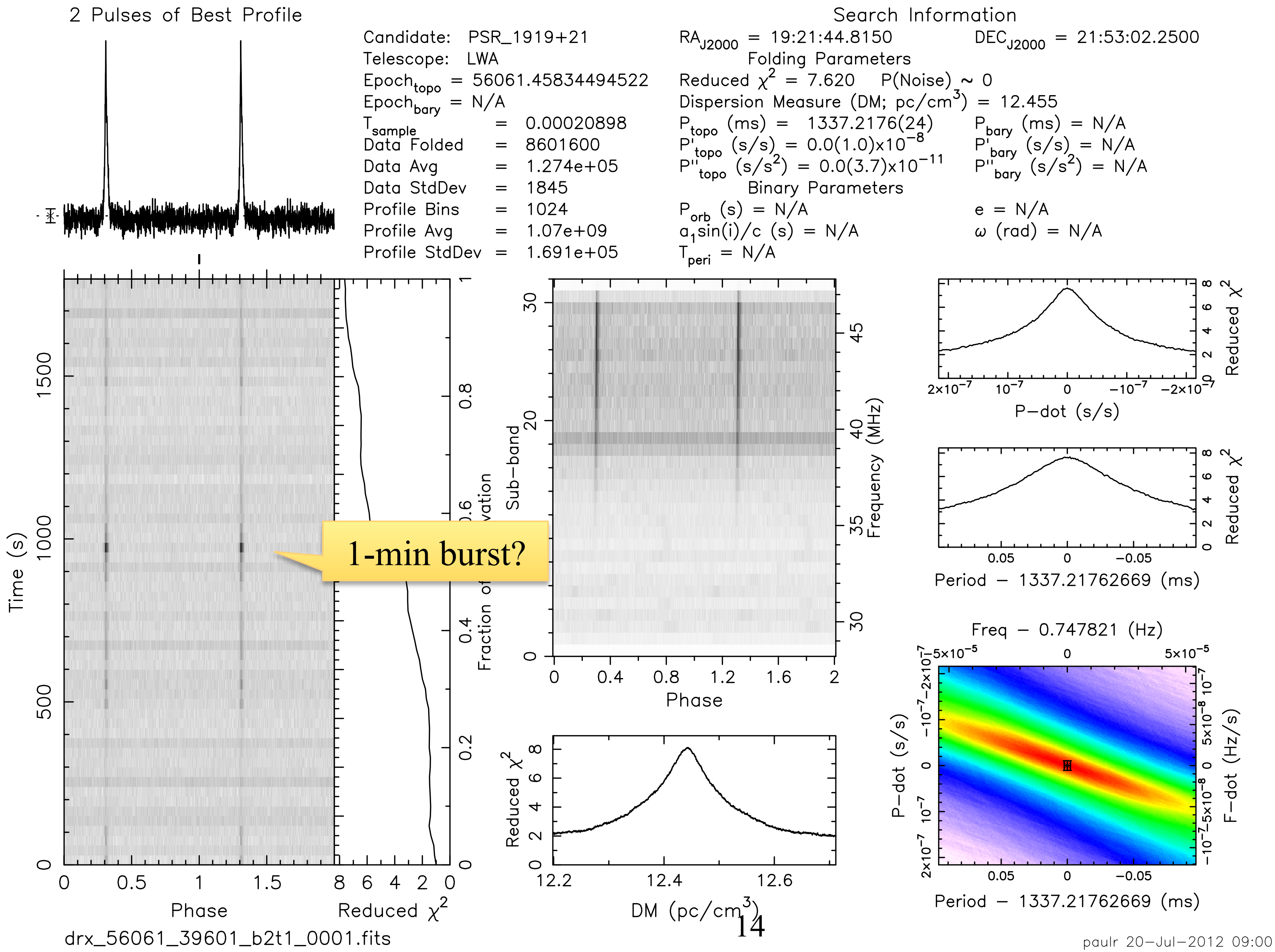
Coherent dedispersion

PSR J2145-0750

(Thanks to Kevin Stovall and Jayce Dowell)

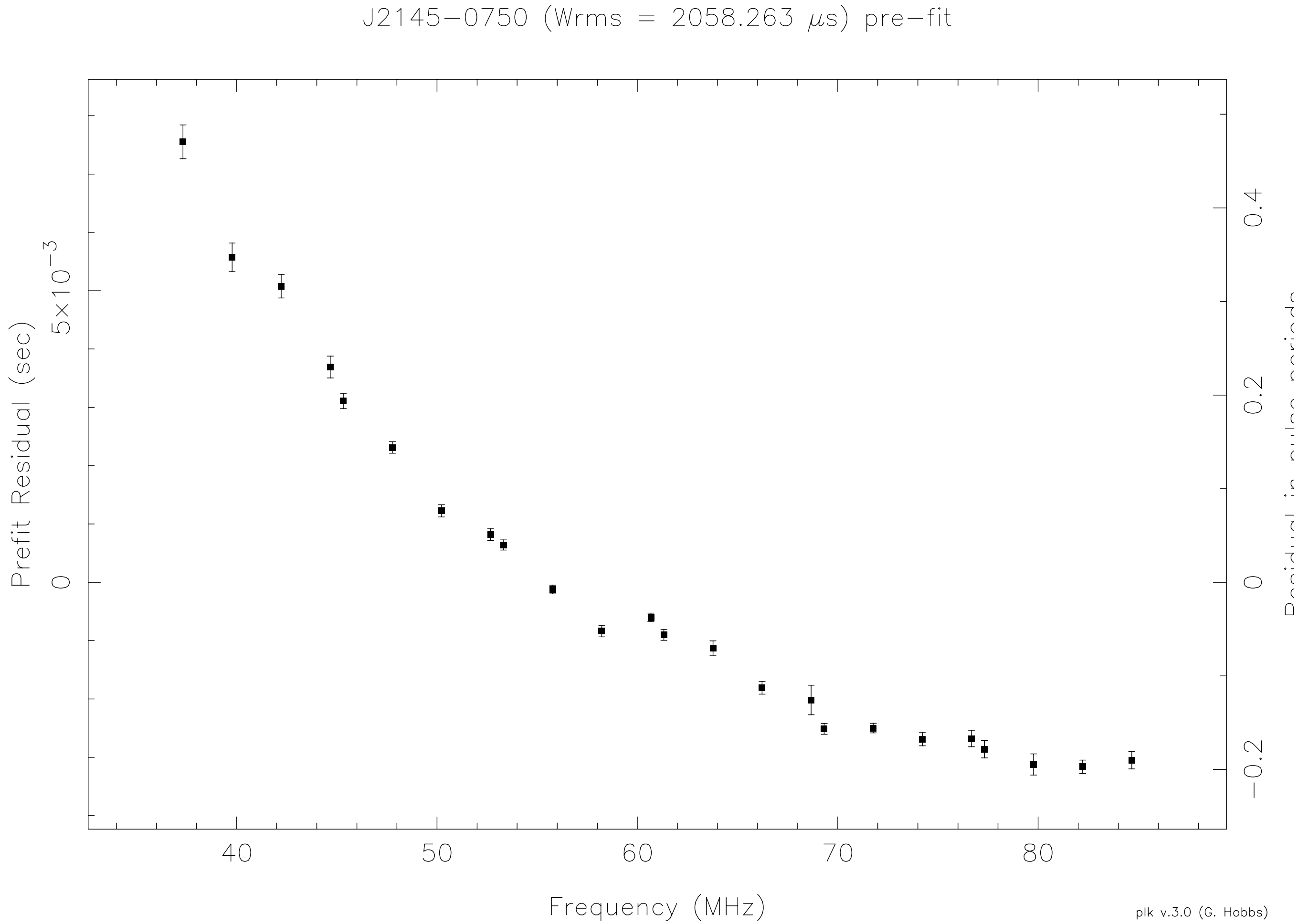


PSR B1919+21



2 Pulses of Best Profile
Search Information
Candidate: PSR_1919+21
Telescope: LWA
Epoch_topo = 56061.45834494522
Epoch_bary = N/A
T_sample = 0.00020898
Data Folded = 8601600
Data Avg = 1.274e+05
Data StdDev = 1845
Profile Bins = 1024
Profile Avg = 1.07e+09
Profile StdDev = 1.691e+05
RA_J2000 = 19:21:44.8150
DEC_J2000 = 21:53:02.2500
Folding Parameters
Reduced χ2 = 7.620 P(Noise) ~ 0
Dispersion Measure (DM; pc/cm3) = 12.455
P_topo (ms) = 1337.2176(24)
P_bary (ms) = N/A
P'_topo (s/s) = 0.0(1.0)x10^-8
P'_bary (s/s) = N/A
P''_topo (s/s2) = 0.0(3.7)x10^-11
P''_bary (s/s2) = N/A
Binary Parameters
P_orb (s) = N/A
e = N/A
a1sin(i)/c (s) = N/A
ω (rad) = N/A
T_peri = N/A
Time (s)
Phase
Reduced χ2
Fraction of Observation
1-min burst?
Sub-band
Frequency (MHz)
DM (pc/cm3)
P-dot (s/s)
Period − 1337.21762669 (ms)
Freq − 0.747821 (Hz)
F-dot (Hz/s)
drx_56061_39601_b2t1_0001.fits
paulr 20-Jul-2012 09:00

Superb Sensitivity to Dispersion Measure



Residuals as a function of frequency using a DM of 9.000

Best fit DM is 9.0046 with uncertainty of $1\text{x}10^{-4}$ pc/cm^3

So sensitive, it required improving PRESTO's handling of frequency channel assignments in PSRFITS files!

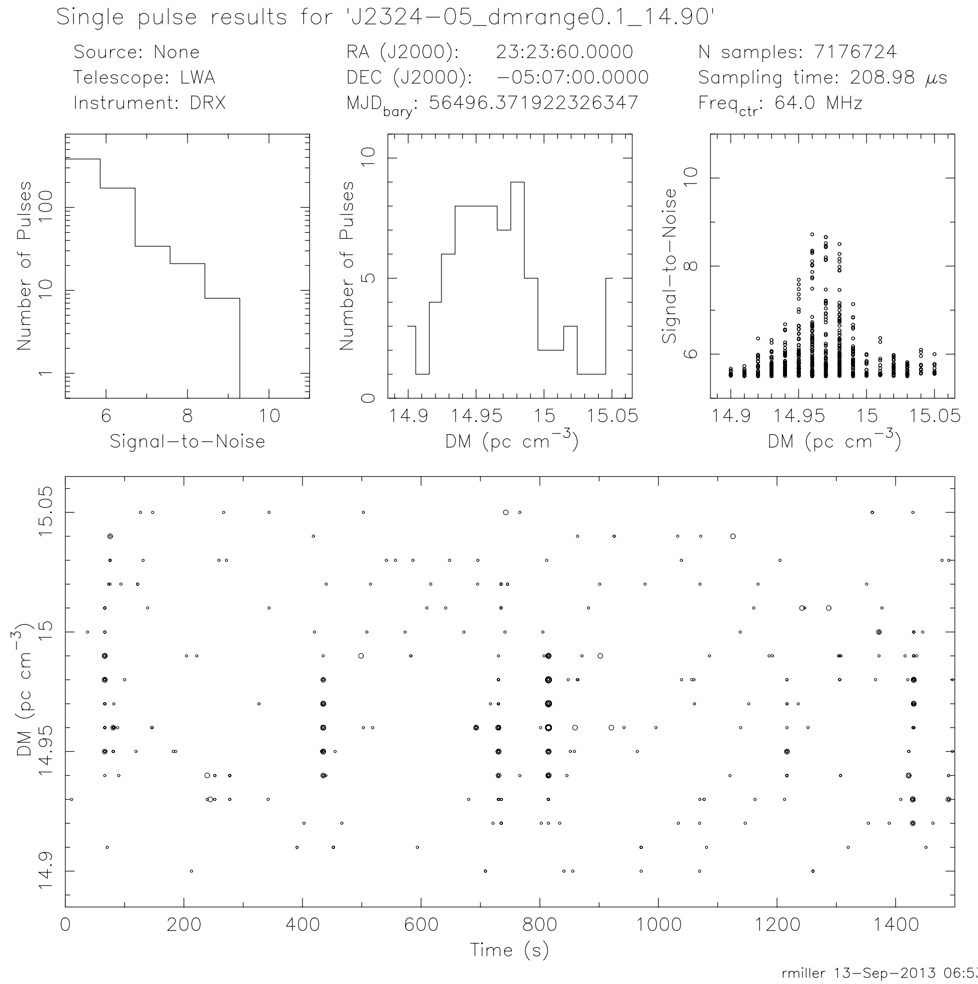
LWA1 Pulsar Projects Underway

- Search for Radio Pulsations from Gamma-Ray Pulsars Discovered with Fermi (PI: Ray)
- LWA North Celestial Cap Pulsar Survey (PI: Stovall)
- A Search for Radio Pulsars in Unidentified Gamma-ray Sources (PI: DeCesar)
- Observations of RRATS (PI: McLaughlin)
- Millisecond Pulsars: Spectra, Timing and the ISM (PI: Demorest)
- Crab Giant Pulses (PI: Majid/Ellingson)
- LWA Follow-up of GBNCC Pulsars (PI: Garcia)
- A Search for Dispersed Short Transients with the LWA1 (PI: Obenberger)
- Low Frequency Studies of Radio Pulsars (PI: Ray/Stovall)

RRAT Detection with LWA1

(Rossina Miller, Chen Karako, Maura McLaughlin)

- Plan to observe 10 RRATs
- First detection is J2324-05, which was discovered in GBT drift survey
- Observations ongoing…



Summary

- LWA1 is operating well and doing pulsar observations routinely
  - Both normal pulsars and MSPs are detected
- Papers have been published on
  - Crab giant pulses (Ellingson et al. 2013, ApJ 768, 136)
  - Detection of MSP J2145-0750 (Dowell et al. 2013, ApJ 775, 28)
  - More to come!
- Data processing pipelines employ standard tools (data written in PSRFITS format)
  - Improved coherent dedispersion in work
- Cycle 4 Call for Proposals were due on 1 November
  - But, if you have anything you want to do collaboratively, talk to me

Low Frequency Commensal Observing with the VLA

Paul S. Ray

Naval Research Laboratory

2013 November 14

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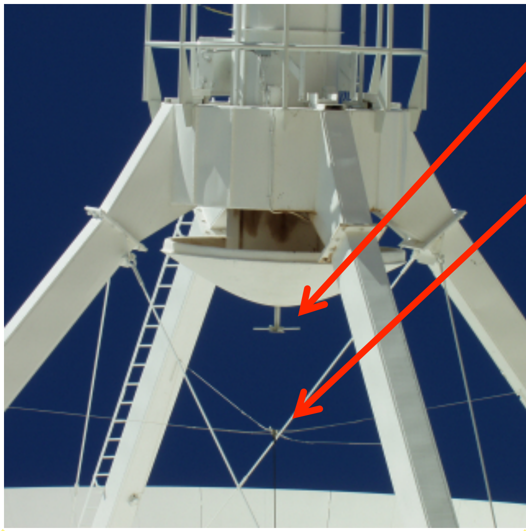
VLA Below 1 GHz



- 330 MHz (λ=90 cm) installed on VLA in 1990, and in regular use until 2009
- 74 MHz (λ=400 cm) dipoles installed in early 1990s, complete system in use from 1998 to 2009
- Systems developed by NRAO & NRL
  - Widely utilized by community
  - Both systems state-of-the art over much of their lifetime
- ***Narrow-band legacy receivers decommissioned by VLA upgrade***

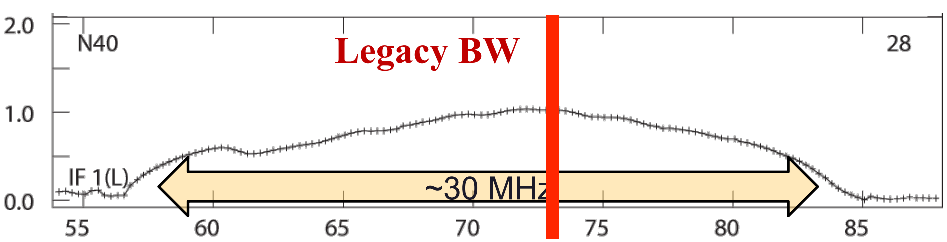
VLA *Low Band* Upgrade

- New NRL-NRAO system replaces legacy 74 & 330 MHz receivers with broadband receivers covering ~50-470 MHz

  Lower system temp, broader bandwidth, improved spectral line & RFI mitigation with WIDAR

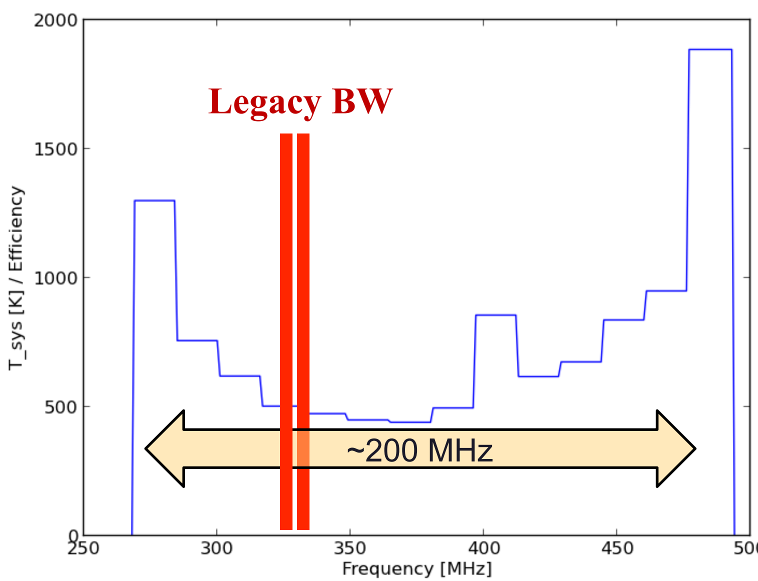
  First light in January 2012, deployment & commissioning nearing completion
- Initial operation with existing 74 & 330 MHz feeds - *motivation for migration to broadband feeds*
- *Current feeds: 58-84 MHz (~20x increased bandwidth); 230-470 MHz (~16x increased bandwidth)*

74 MHz Bandpass Spectrum
(amplitude vs. frequency)

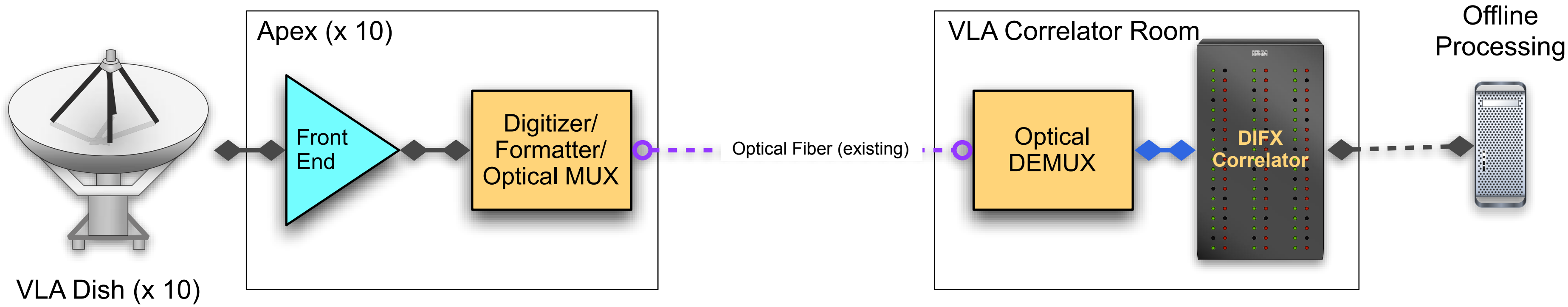


Frequency (MHz)

330 MHz Available Spectrum
(T_{sys}/efficiency vs. frequency)



LOBO: LOw Band Observatory



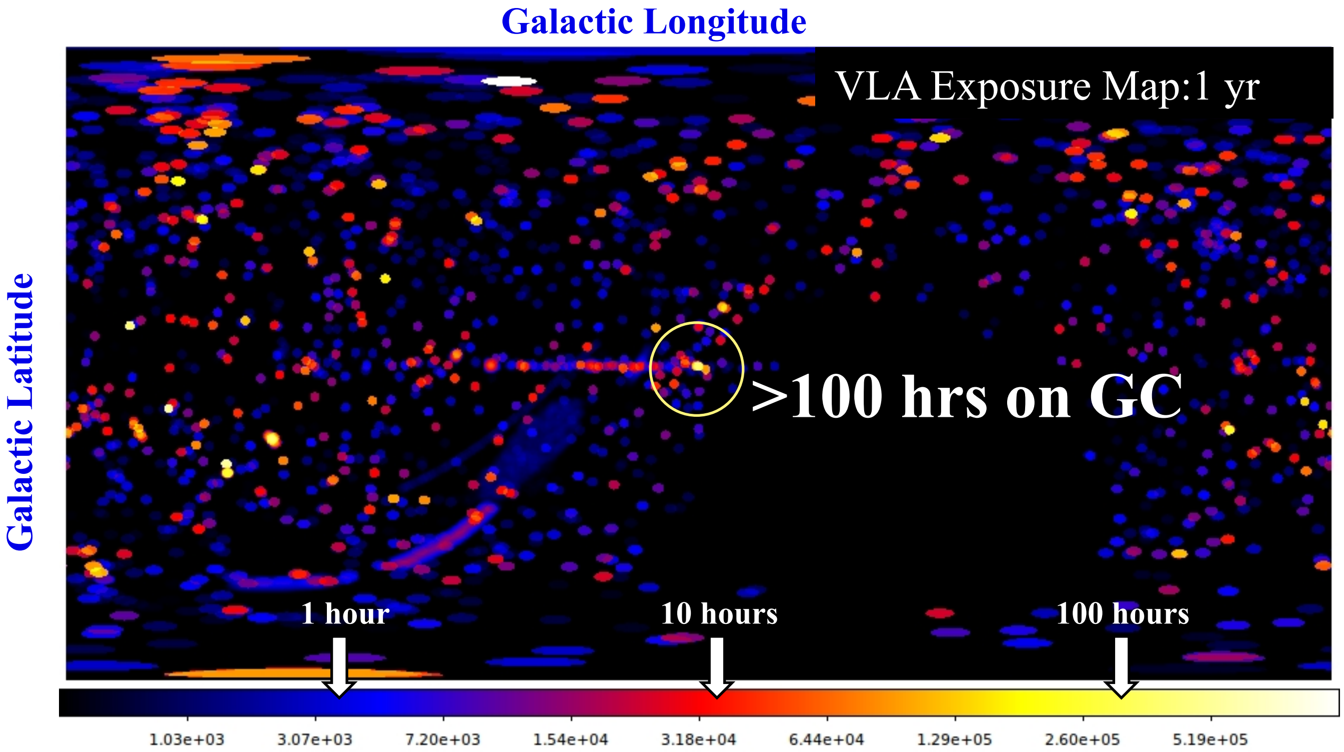
- Commensal observing with prime focus dipole feeds whenever VLA is observing a source with the Cassegrain (>1 GHz) feeds.
- Sample the dipole output and process independently of WIDAR correlator
  - Dedicated sampling, fiber transmission, & backend
- NRL got funding to implement a 10-antenna demonstration, dubbed **VLITE**
  - Contract with NRAO was recently funded, completion by October 2014
  - Data go to NRL for processing and archiving
- **Namir Kassim** is PI, Tracy Clarke is Astronomy Project Scientist
- NRAO work led by Steve Durand

VLITE Parameters

Parameter	VLITE
Feed	Crossed Dipoles at Primary Focus (existing)
Center Frequency	352 MHz
Processed Bandwidth	64 MHz
Availability	>= 50% of VLA on-sky time
Tsys	150 K
Field of View	5 deg^2
Number of Antennas	10
Polarization	Dual Linear
Receiver Location	Apex
A/D Sample Clock	1024 MHz, 8 bit sampler
Processed Bandwidth	64 MHz
Correlator Products	>=2 Stokes Parameters
Correlator Dump Time	>= 2 seconds
Spectral Resolution	>= 100 kHz
Nominal Correlator Output Data Rate	300 kB/s

VLITE/LOBO Observations

- Dedicated VLA transient & high-z spectroscopy capability.
- FoV ≥ 5 deg^2 at low frequences, naturally search for:
  - Non-thermal transients, including coherent emission from extra-solar planets & mystery sources like GCRT J1745-3009, etc
  - Spectral lines from high-z galaxies (e.g., 64 Mpc x 64 Mpc at z ~ 4).



Serendipitous, wide-field images of all targeted VLA fields – continuous on-sky transient monitoring.

Telescopes sharing the VLA sky, e.g. LWA1 (Long Wavelength Array Station 1) or LoFASM (Low Frequency All Sky Monitor) could track the LOBO FoV.

VLITE/LOBO Key Science

- **Transients**: Requires maximizing Ω (field-of-view) * *t* (observing time). Dish-based, cm-wave telescopes are inefficient because transient observing time is scarce and Ω is small. LOBO naturally inflates Ω & *t*, offering monitoring with tremendous advantages over GHz searches. The statistics of slow, radio-selected, low frequency transients alone indicate LOBO should detect thousands of transients annually. Moreover, for an isotropic distribution of "fast transients", the search is independent of pointing direction.
- **Spectroscopy**: LOBO will sweep through large swaths of the Universe. For 21 cm: $1.9 < z < 5$ (for 236 MHz < ν 492 MHz), and 64 Mpc^2 per pointing (z~4 at 330 MHz). Red-shifted HI and OH Gigamasers are two examples.
- **Radio LSST**: The simplest LOBO pipeline will deliver calibrated images & source catalogs. With time, these images will spread to cover the sky, generating a LOBO Global Sky Model. With the cadence afforded by revisiting popular Cassegrain targets (e.g. M31, Galactic center, etc), many fields will be revisited. The LSST analogy follows naturally, with LOBO providing a synoptic vision of the radio sky – slow transients are a natural byproduct.
- **Ionospheric waves**: Continuous monitoring of ionospheric disturbances at far greater sensitivity than GPS.

VLITE Summary

- Commensal observing at P-band using the 10 VLA antennas will be running in about a year
- Hope to add a fast transient search mode as well with a separate GPU data processing pipeline
- If successful, system could be expanded to full 27-antenna LOBO system