PSRs with LWA1 (update & thoughts on a path forward)

Namir E. Kassim (with lots of help from Paul Ray!)
Chief Scientist, LWA1 Radio Observatory
Naval Research Laboratory

Pulsars & Fast Transients with LWA1: Capabilities

Pulsars and Fast Transients are perfect "single dish" science

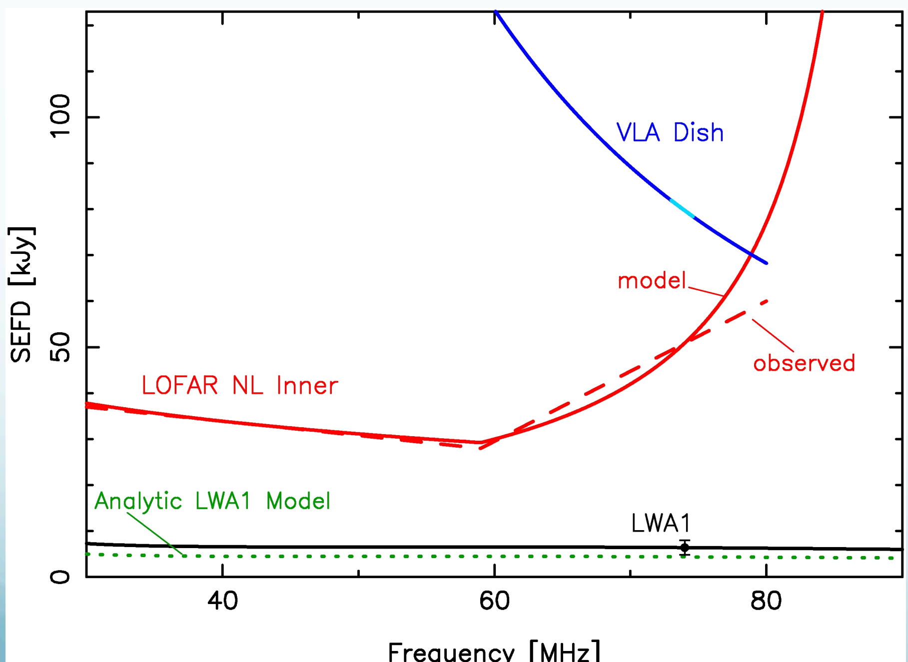
- LWA1 is comparable to a 100 m dish at 38 MHz
- Broad bandwidth observations are possible
- Wide field of view for rapid survey speed
- Raw voltage data recorded so coherent dedispersion and other techniques can be applied in post-processing
- Dispersion is a powerful discriminator against RFI
- Data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

- Similar sensitivity to LOFAR for pulsar work, but
  - Better sky coverage (site is 20° further south)
  - Larger bandwidth (78 MHz vs 48 MHz)
  - Better RFI environment
  - LWA1 records raw voltages, allowing more flexible processing

LWA Antenna-based Station Performance

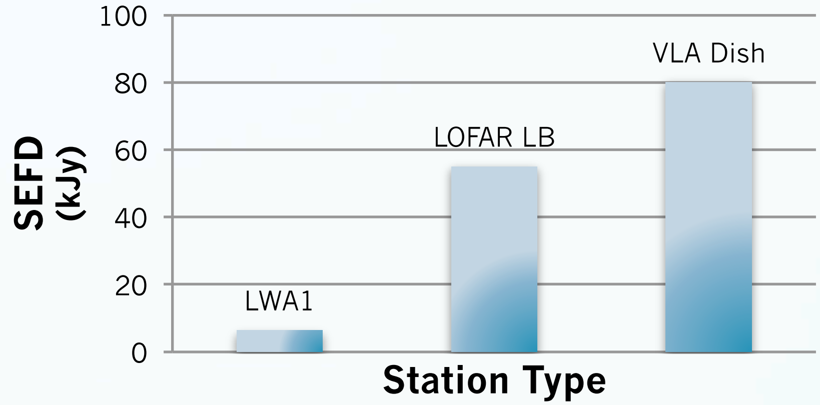
LWSC antenna stations in the SW US offer advantages over LOFAR stations and the VLA, in both performance and sky coverage.

Single Station Performance

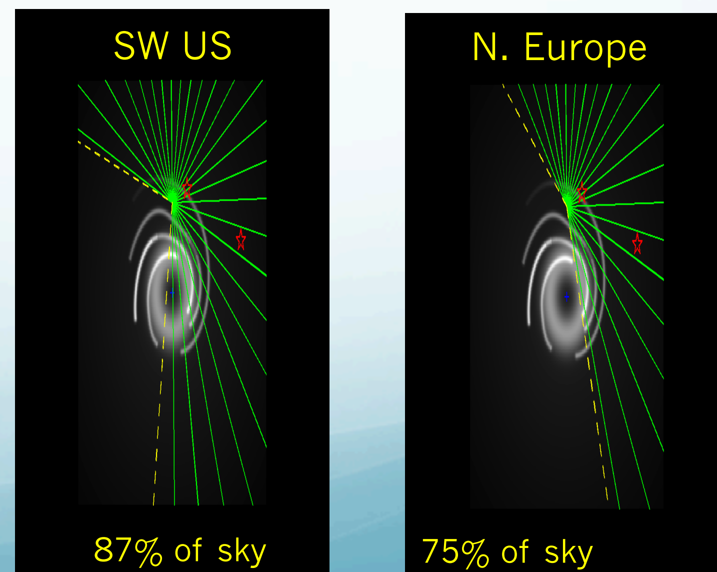


SEFD Ξ System Equivalent Flux Density $\alpha\, T_{sys}/A_e$

Station Performance
(74 MHz @zenith)



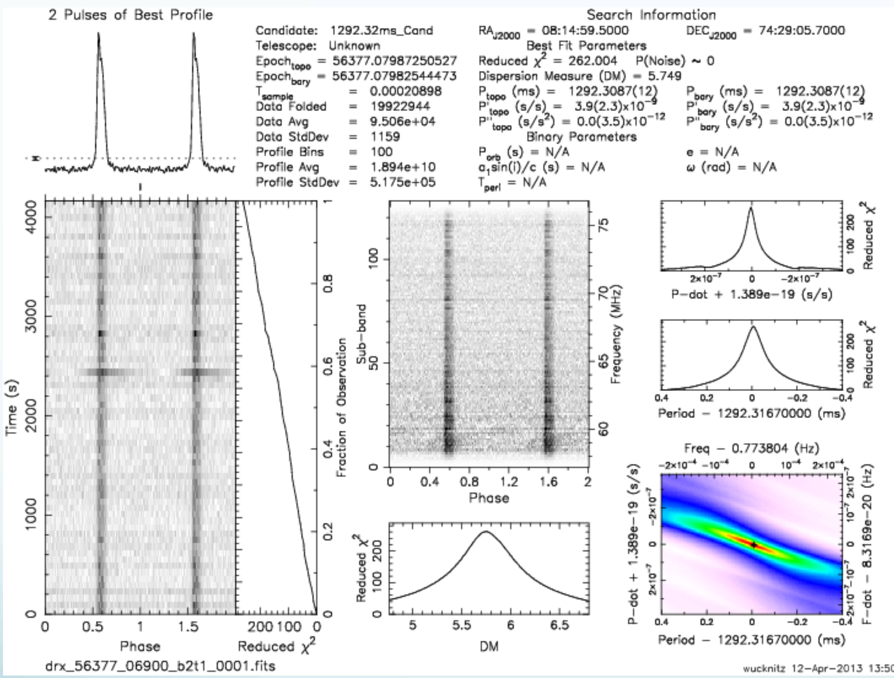
Sky Coverage



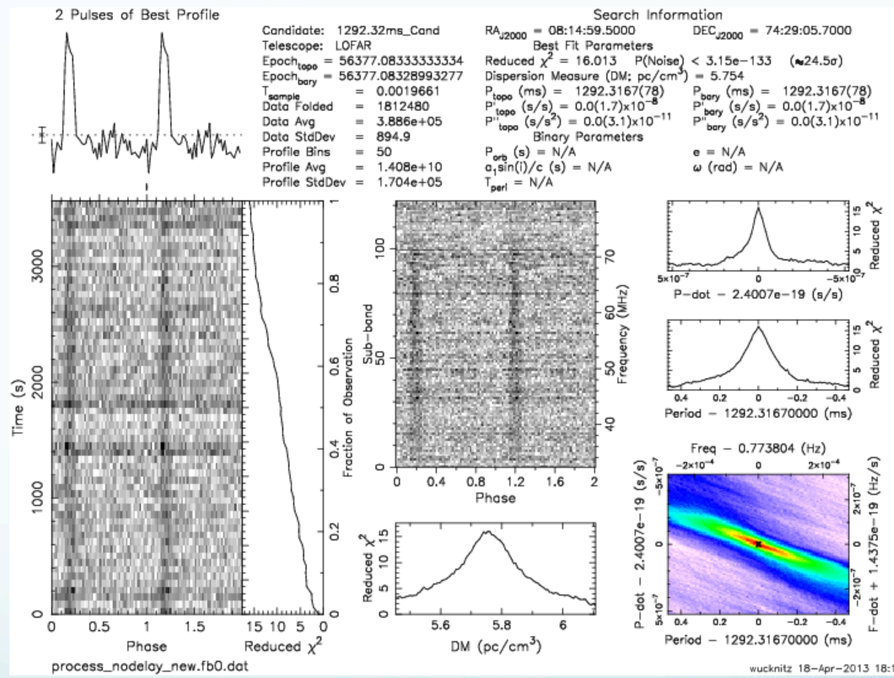
Single Station Performance

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

LWA1 Station (NM)
(58-76 MHz; $\Delta \nu \sim$ 20 MHz; 256 dual pol)



LOFAR LB Station (SW)
(30-80 MHz; $\Delta \nu$ ~50 MHz; 96 dual pol)



Prepfold plot: time domain and pulse profile.

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

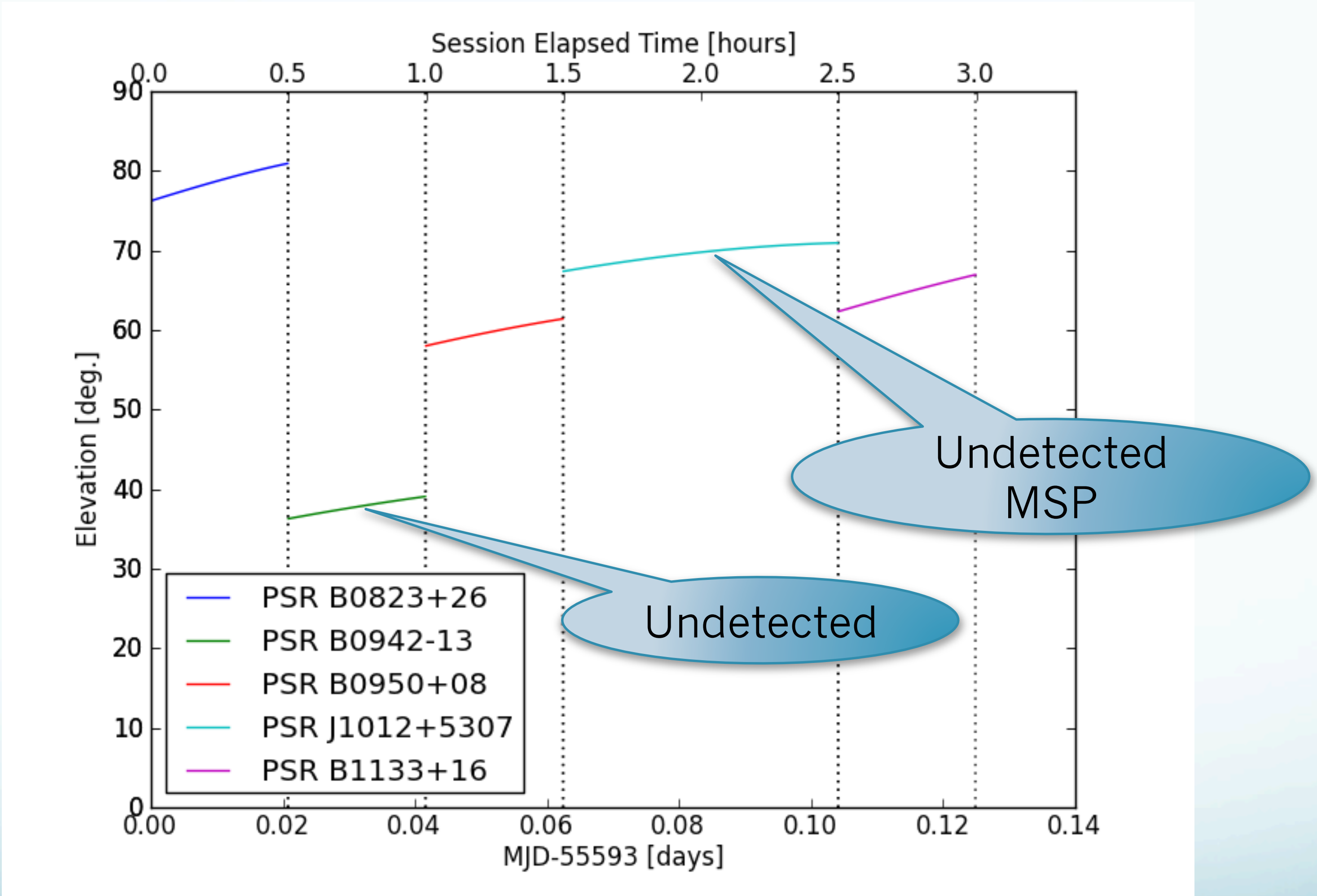
Propagation Effects

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

Transient and Exotic Sources

LWA
Long Wavelength Array

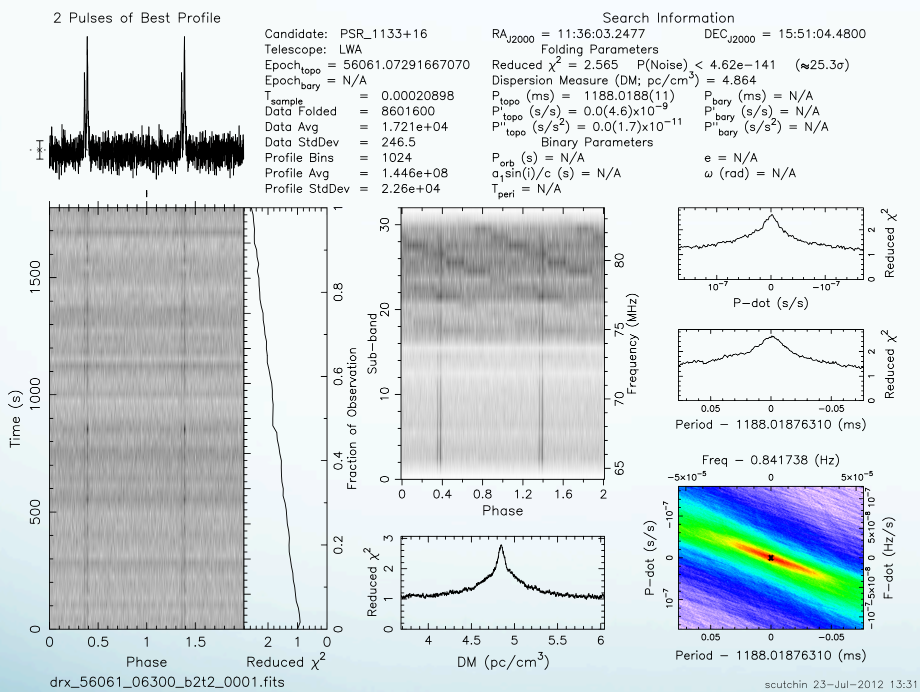
Elevation/Pointing Issues?



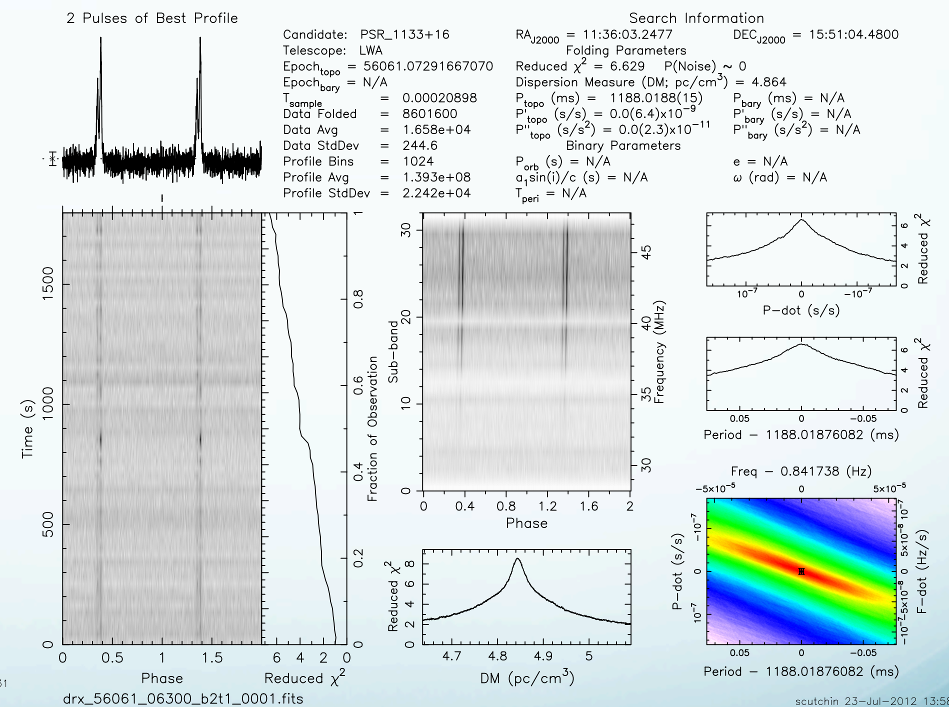
Early pointing issues that prevented some PSR detections have mainly been addressed.
1.0 second time stamp offset discovered

Example of Recently Detected Normal PSR
PSR B1133+16
(580 mJy at 74 MHz)

38 MHz



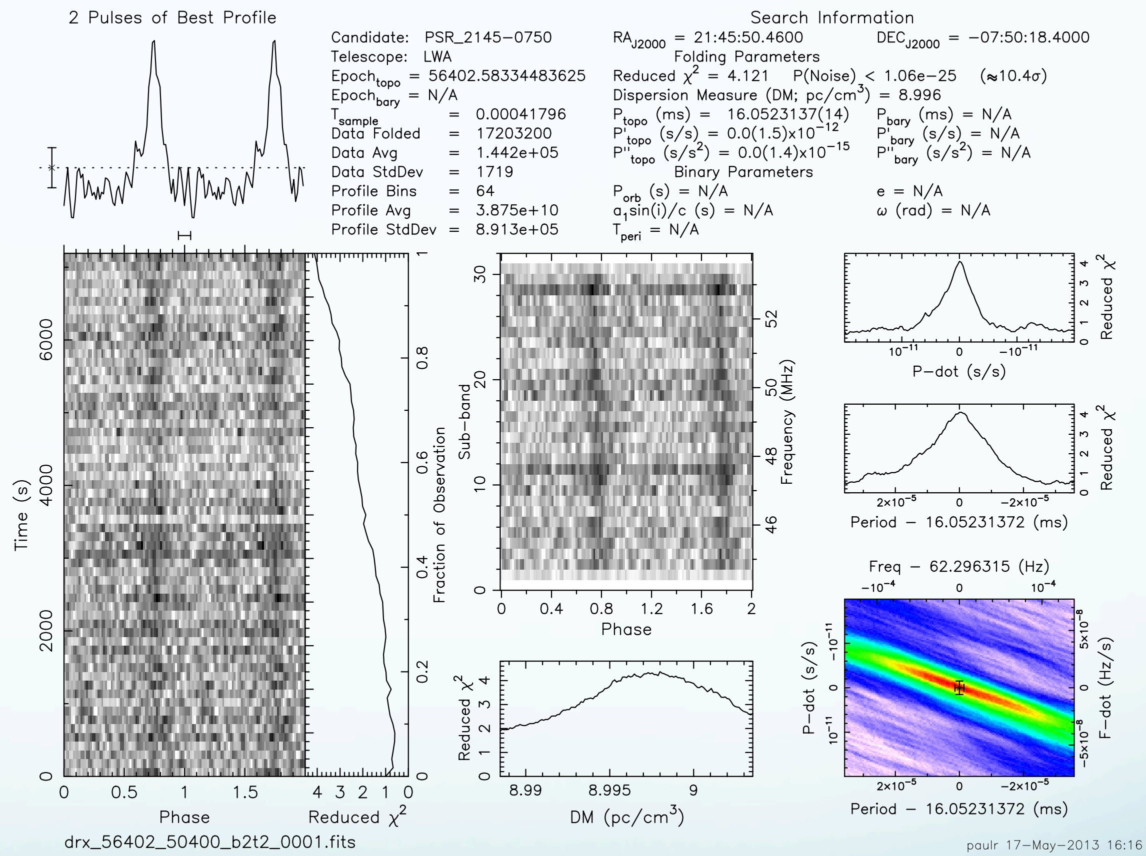
74 MHz



LWA1 Pulsar Detections

Including 1st MSP! (w/ coherent dedispersion)

B0031-07	B1508+55
B0320+39	B1540-06
B0329+54	B1541+09
B0450+55	B1604-00
B0525+21	B1612+07
B0809+74	B1706-16
B0823+26	B1822-09
B0828-13	B1839+56
B0834+06	B1842+14
B0919+06	B1845-19
B0943+10	B1919+21
B0950+08	B1929+10
B1133+16	B2110+27
B1237+25	J2145-0750
B1642-03	B2217+47

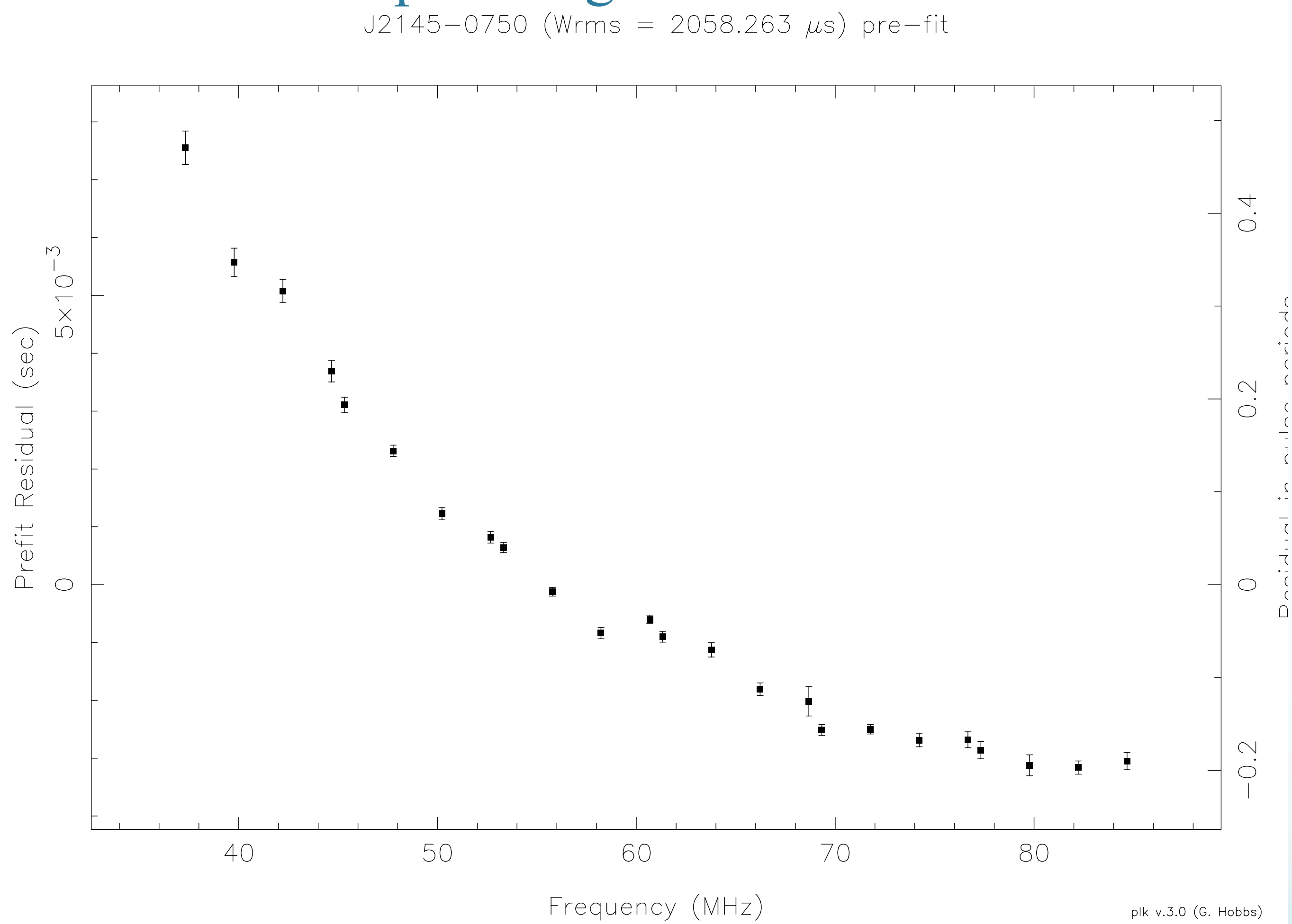


- 29 normal bright young pulsars
- 1 MSP (J2145-0750)
- Crab Pulsar Giant Pulses

Observation Summary Table:
http://goo.gl/Oj5eCD

Superb Sensitivity to Dispersion Measure

Example using MSP J2145-0750

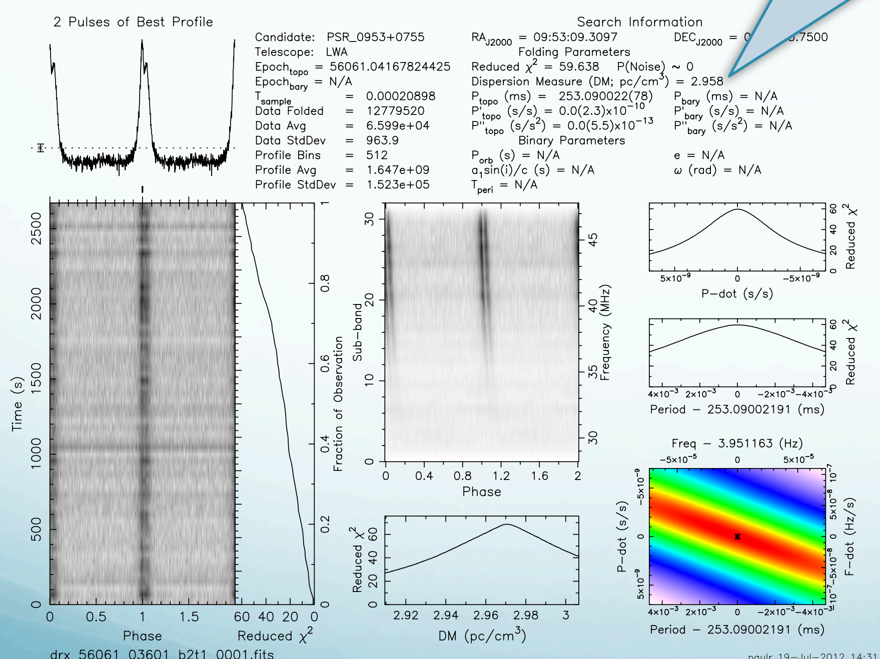


Residuals as a function of frequency using a DM of 9.000
Best fit DM is 9.0046 with uncertainty of $1\text{x}10^{-4}$ pc/cm^3

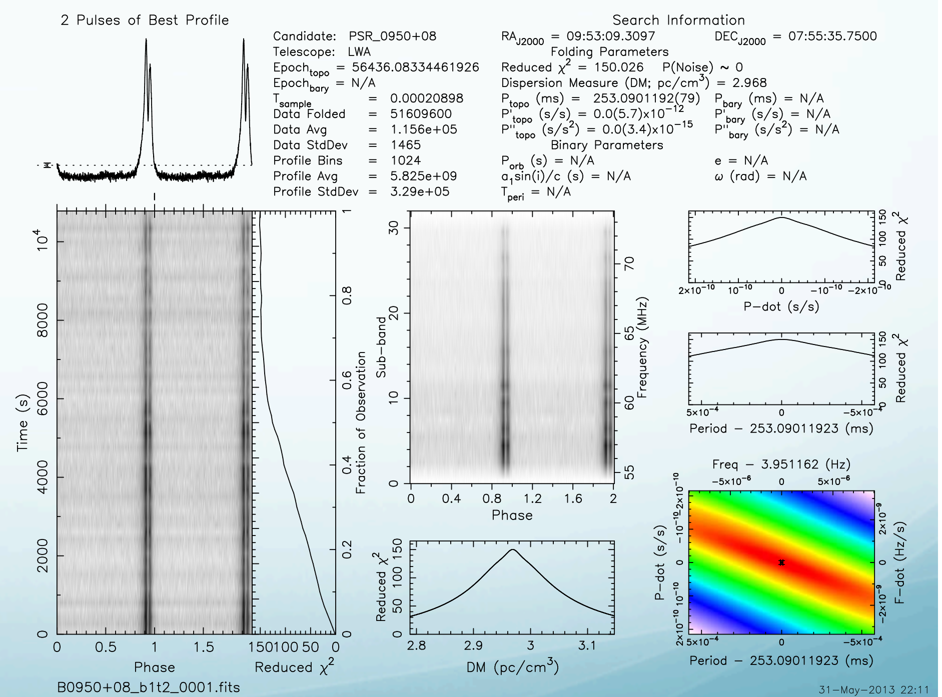
DM Accuracy:
PSR B0950+08

Note poor accuracy of initial DM. Improved with TEMPO2 & LWA1 data to accuracy of few × 10^{-4} pc/cm^3

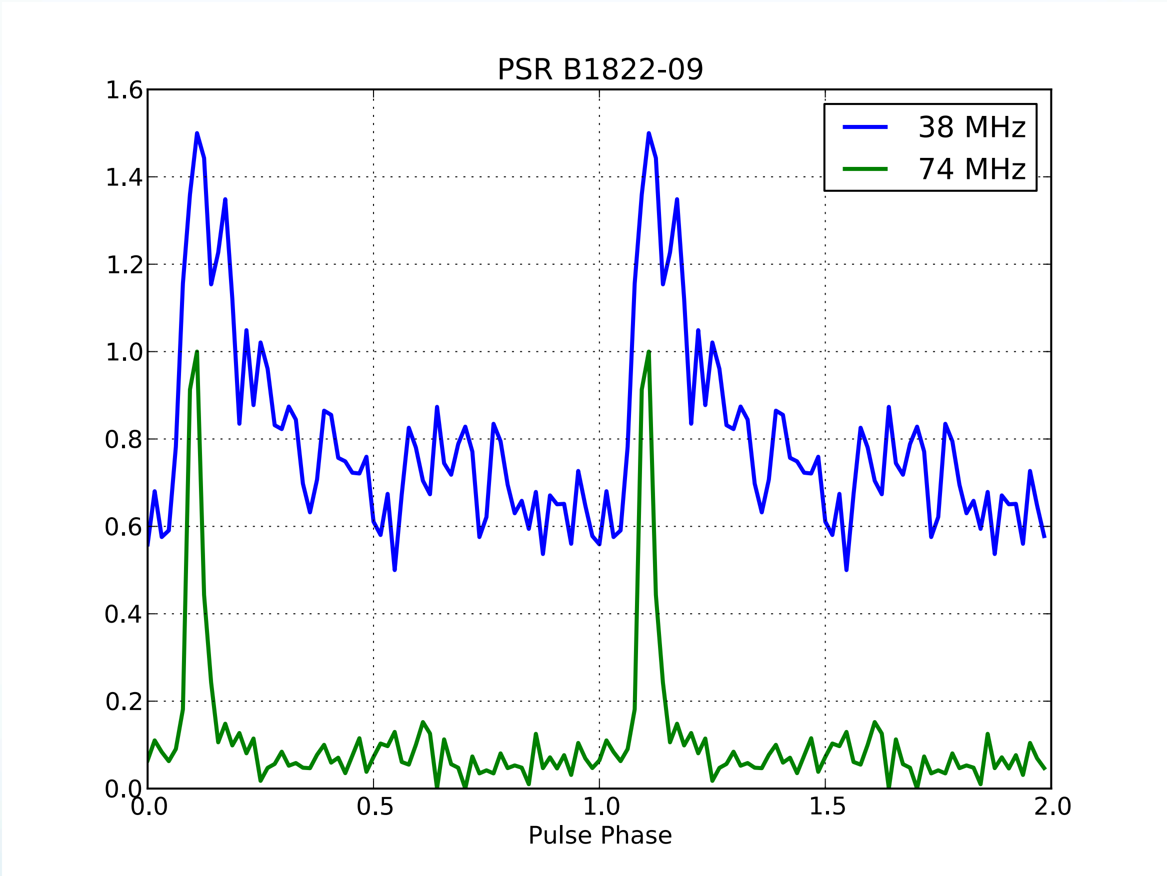
38 MHz



65 MHz



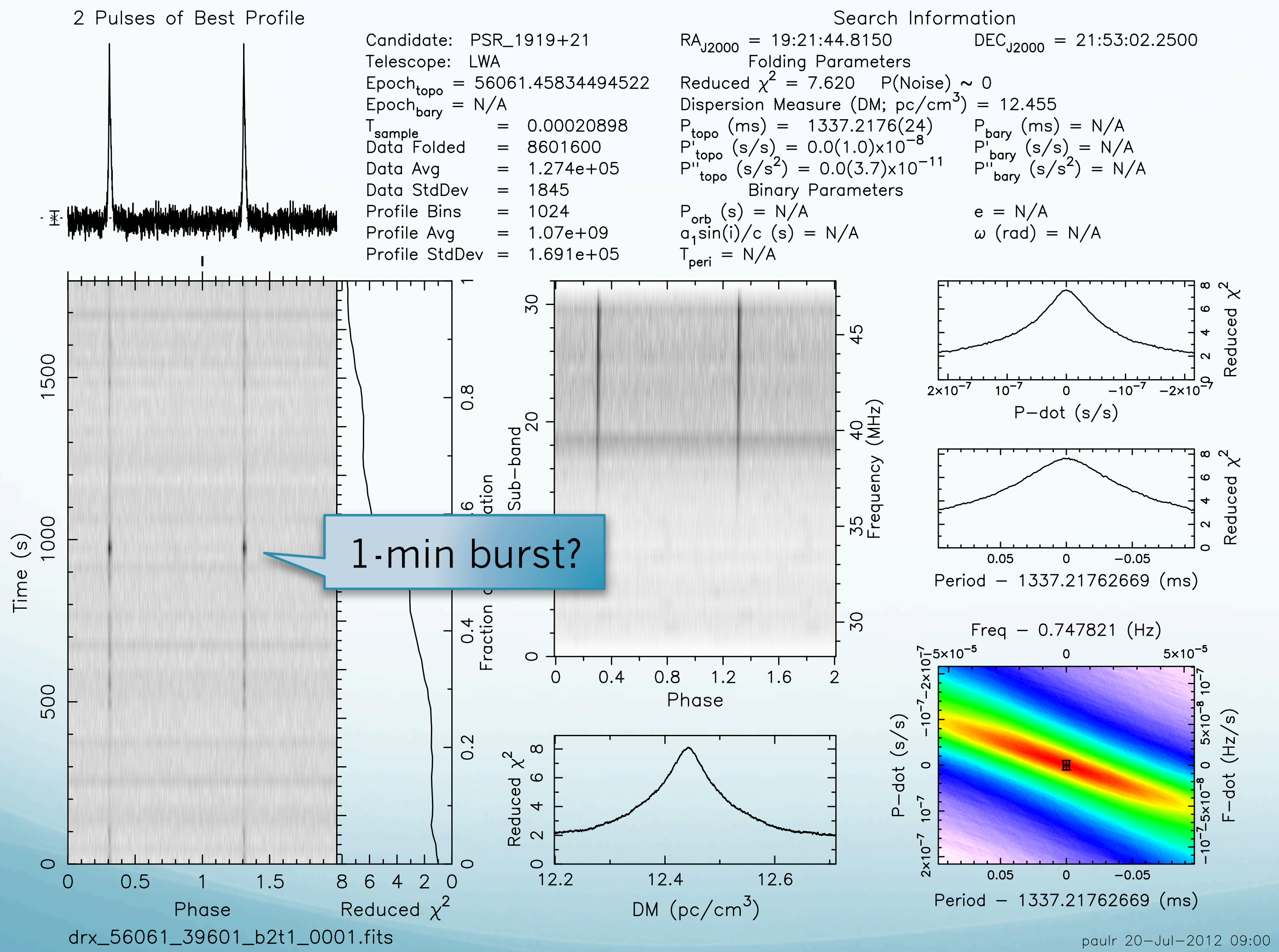
… and to Scattering Effects



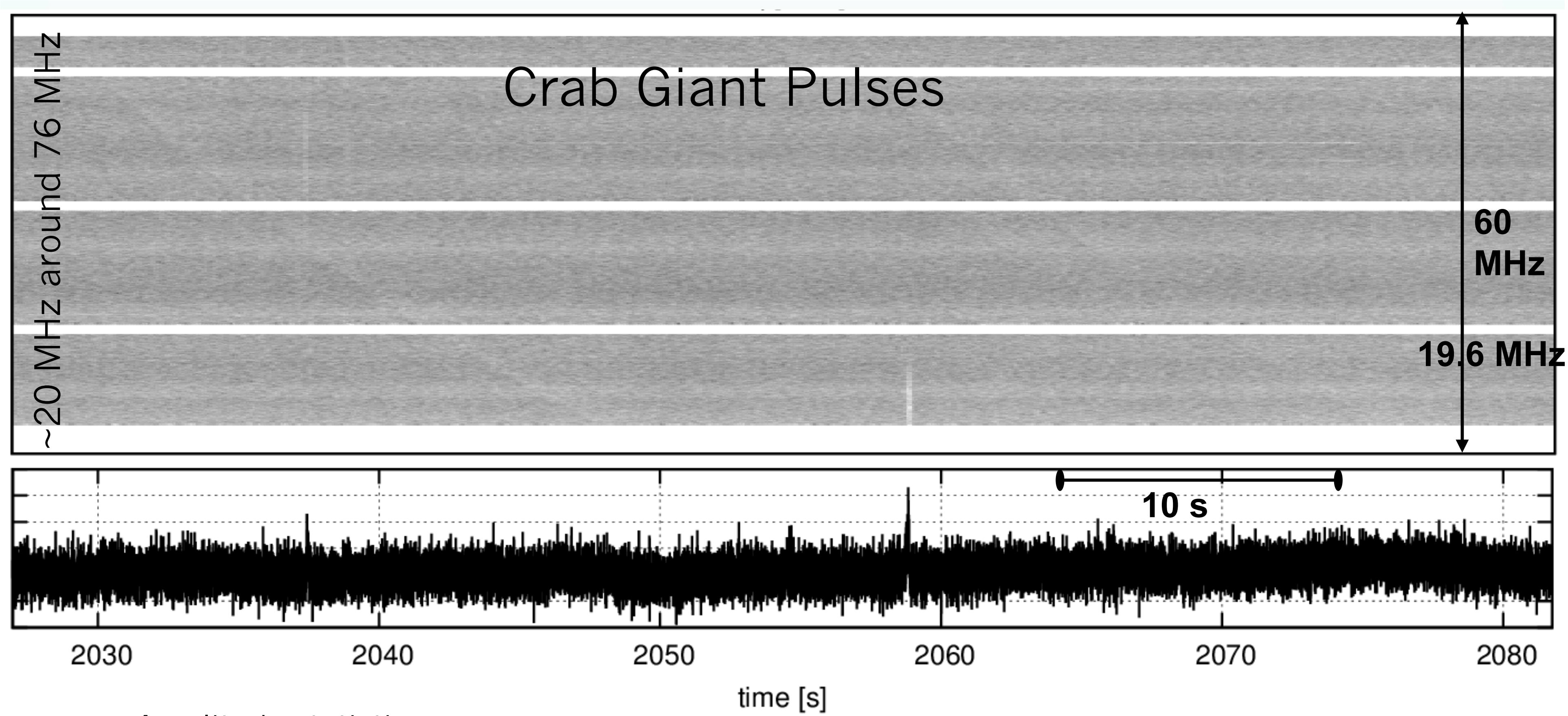
Note the sensitivity to scattering indicated by the large scattering tail at 38 MHz, relative to the narrow, symmetric tail seen at 74 MHz.

Interpulse Variations

Example: PSR B1919+21



Related to PSRs with non-aligned rotation and magnetic axis.



Amplitude statistics consistent with expectations

Pulse broadening high but not unexpectedly so

Good tutorial for using LWA1 for similar studies of other objects

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OBSERVATIONS OF CRAB GIANT PULSES IN 20–84 MHz USING LWA1

S. W. Ellingson[1], T. E. Clarke[2], J. Craig[3], B. C. Hicks[2], T. J. W. Lazio[4],
G. B. Taylor[3,5], T. L. Wilson[2], and C. N. Wolfe[1]
[1] Bradley Department of Electrical & Computer Engineering, Virginia Tech, Blacksburg, VA 24060, USA
[2] US Naval Research Laboratory, Code 7213, Washington, DC 20375, USA
[3] Department of Physics and Astronomy, University of New Mexico, Albuquerque NM 87131, USA
[4] Jet Propulsion Laboratory, California Institute of Technology, MS 138-308, 4800 Oak Grove Dr., Pasadena, CA 91109, USA
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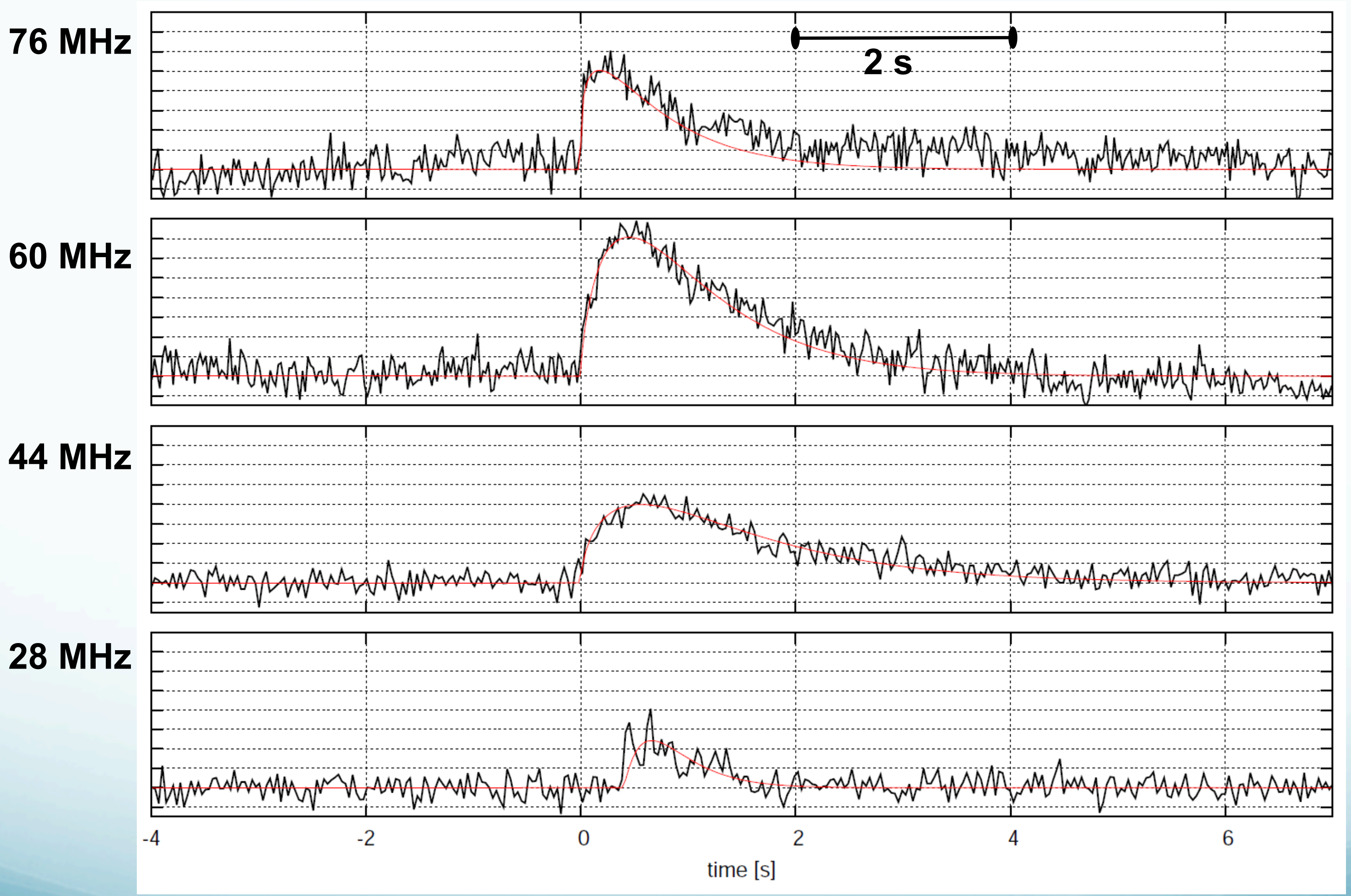
ABSTRACT

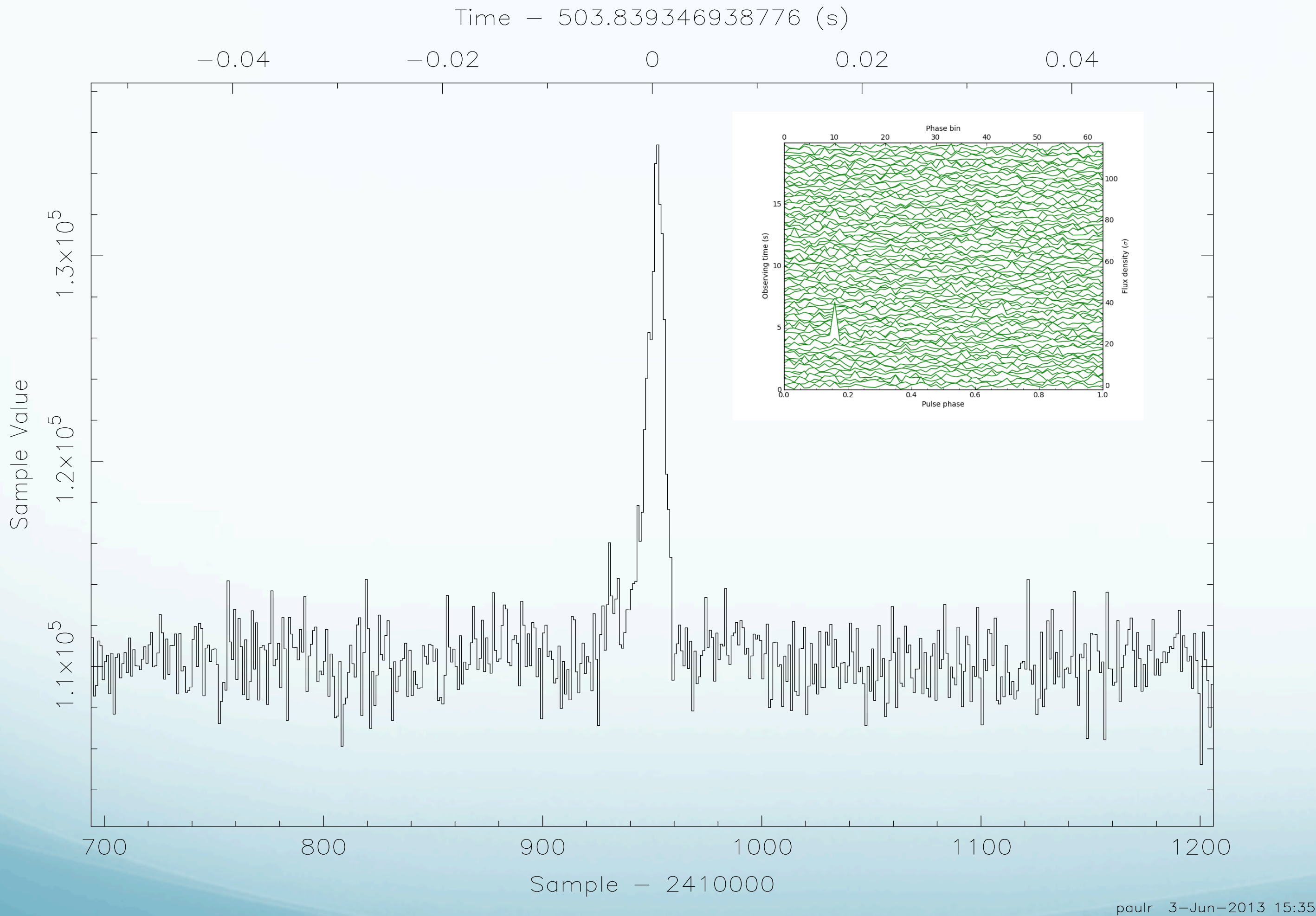
We report the detection and observed characteristics of giant pulses from the Crab Nebula pulsar (B0531+21) in four frequency bands covering 20–84 MHz using the recently completed Long Wavelength Array Station 1 (LWA1) radio telescope. In 10 hr of observations distributed over a 72 day period in fall of 2012, 33 giant pulses having peak flux densities between 400 Jy and 2000 Jy were detected. Twenty-two of these pulses were detected simultaneously in channels of 16 MHz bandwidth centered at 44 MHz, 60 MHz, and 76 MHz, including one pulse which was also detected in a channel centered at 28 MHz. We quantify statistics of pulse amplitude and pulse shape characteristics, including pulse broadening. Amplitude statistics are consistent with expectations based on extrapolations from previous work at higher and lower frequencies. Pulse broadening is found to be relatively high, but not significantly greater than expected. We present procedures that have been found to be effective for observing giant pulses in this frequency range.

A Crab GP Observed Simultaneously in 20-84 MHz



astro-ph/1304.0812 (2013 *ApJ,* 768, 136)

Anomolously Intense Pulses
Example: Largest AIP -- B0950+08



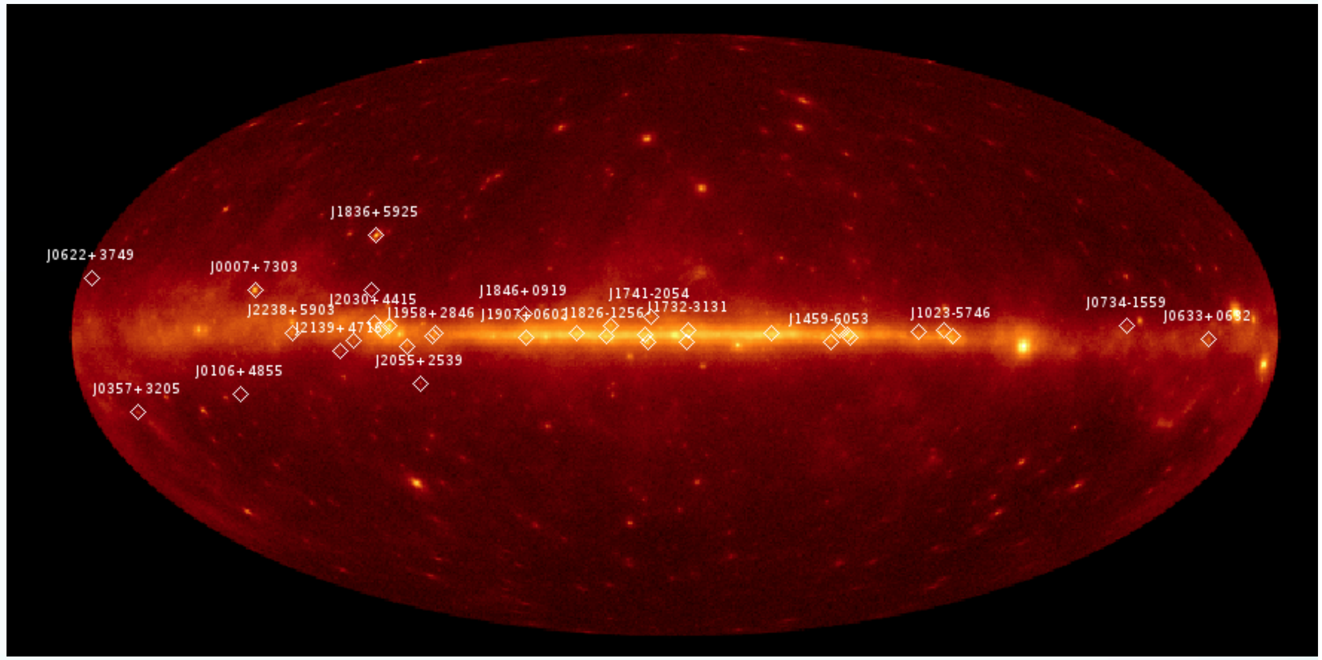
Analogues of CGPs?

Classic giant pulses are related to PSRs with strong magnetic fields – AIPs seen in low magnetic field PSRs.

Motivates LF monitoring by LWA1

Steep Spectrum Pulsars & Fermi

- Before 2008, Geminga was the only known radio-quiet gamma-ray pulsar
- Blind searches of Fermi LAT data have discovered over 36 pulsars in the gamma-ray band
- So far, only 4 have been found to pulse in radio, despite very deep searches



Is this a beaming effect or some other physical mechanism?

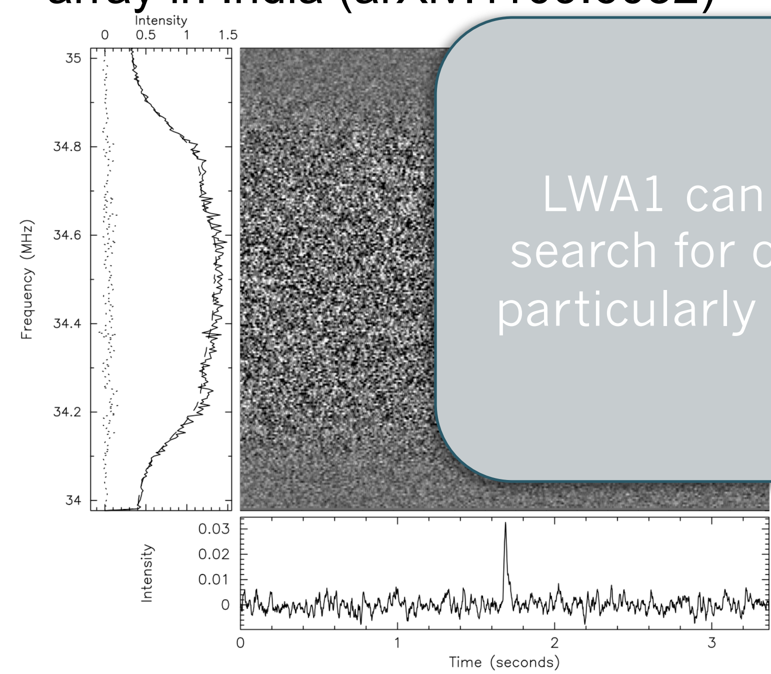
- Low frequency searches are promising because beaming fractions appear to increase
- Some pulsars appear to be very steep spectrum ($S \sim \nu^{-4}$)

LWA Long Wavelength Array

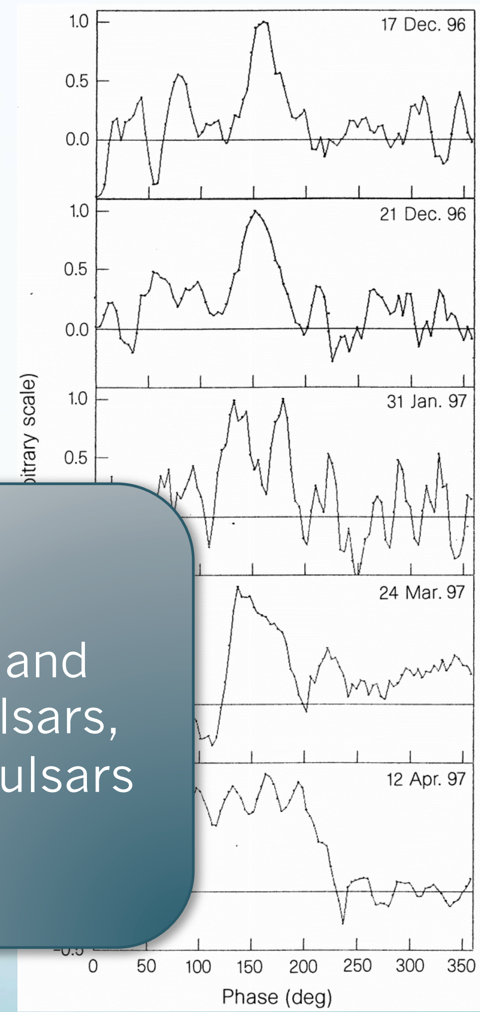
Radio Quiet or Not?
Two Enticing Examples

Geminga (Pushchino)

- Geminga radio pulsations reported at 102.5 MHz (Malofeev & Malov, Nature, 389, 697, 1997)
  - Detection remains controversial
- Very new report of radio pulsations from Fermi LAT blind search pulsar J1732-3131 at 34.5 MHz using Gauribidanur array in India (arXiv:1109.6032)



PSR J1732-3131 (Gauribidanur)



LWA1 can confirm or refute these and search for other steep spectrum pulsars, particularly low-luminosity nearby pulsars

LWA Long Wavelength Array

Ongoing CFP2 Programs
Including Fermi Radio Quiet PSRs & UNiDs

- Search Geminga and the 30 radio-quiet Fermi blind search pulsars with Decl > –33 and any new discoveries (Ray)
  - 4 hour DRX observation each with 2 tunings at 38 and 74 MHz
  - Pulsars are timed with Fermi LAT so analysis only requires folding and a search over DM
- Fermi Unidentified (UNiD Searches (DeCesar)
  - 15 LAT UnID sources already searched by PSC at higher frequencies
  - Two 3-hour observations of each at 38 and 74 MHz with LWA1
- Ongoing Large Pulsar Survey – (Stovall)
  - 320 beam-hour survey of northern celestial cap region (Decl. > 56) in the 30–62 MHz band
  - 1 hour per pointing
  - Pilot for 3400 beam-hour survey of full visible sky

Next Steps

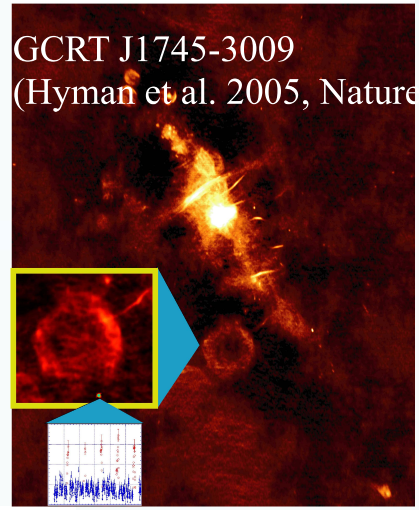
- Studies of profile evolution and scattering
- Precision DM measurements and monitoring
- Improve coherent dedispersion analysis software (incorporate into writePsrfits.py)
- Improve flux density calibration to make spectra and comparison with other observations easier
- B0950+08 is nice and bright. Analyze for AIPs, and do other single pulse studies
- Demonstrate phase connected timing across many days, after correcting for 1.0 second offset
- Start looking at polarization, especially B1929+10
- Discover our first new pulsar or RRAT!

Summary

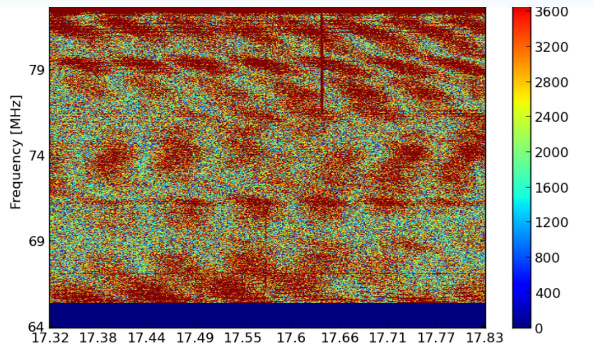
- Lots of good pulsar science to be done with LWA1 and good connections to Fermi-LAT science
- CFP3 Proposals were just evaluated, observations beginning:
  - Cheung follow up of LAT transients
  - McLaughlin observations of RRATS
  - Demorest observations of MSPs
  - Continuing pulsar survey

GC Transient Monitoring

Hyman (PI), Cutchin, Ray, Lazio et al.



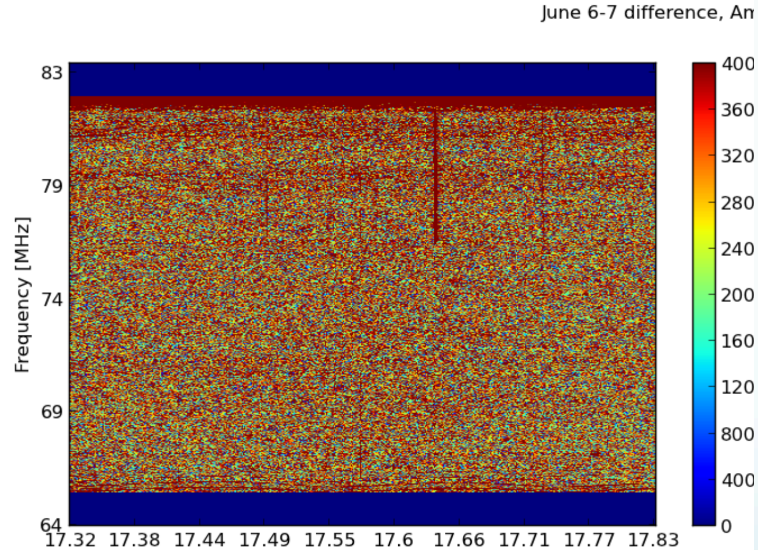
19 MHz BW, 30 minute scan



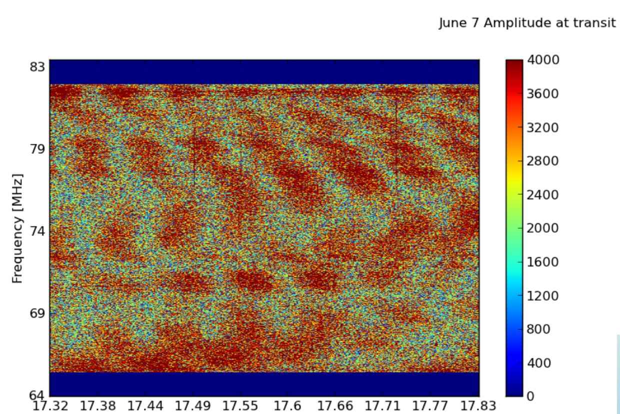
June 6

Resolution: 4 second, 4.7 KHz pixels

June 6-7



rms ~300 Jy

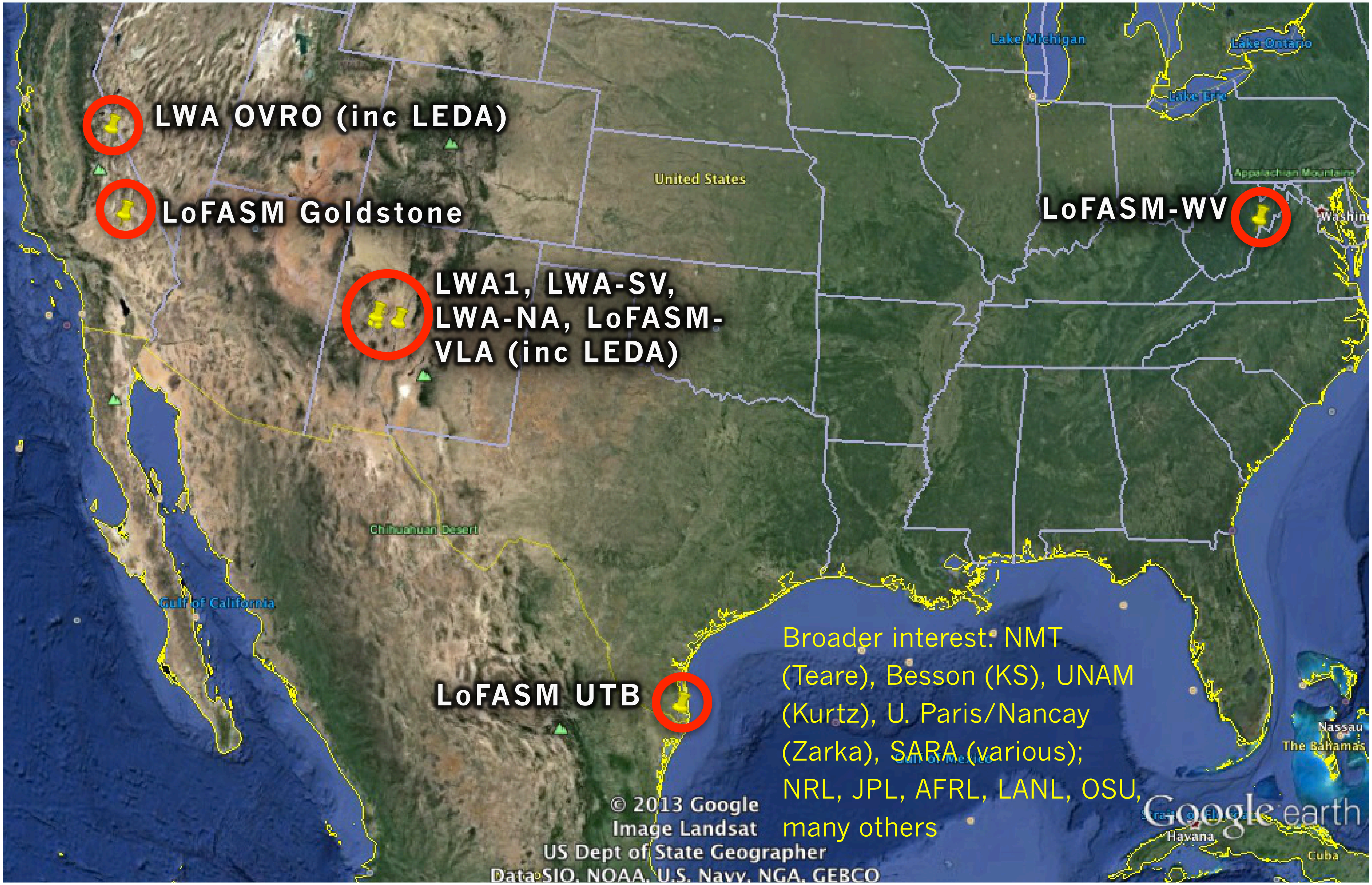


June 7

Can realize ~50X and 15X improvements in sensitivity by averaging in BW and time, respectively: **approach 1 Jy!**

Expansion of LW Radio Astronomy in the US

LWA Magna Americana (VLBI planned)



Longer Term Vision:
The need for High Angular Resolution with the LWA

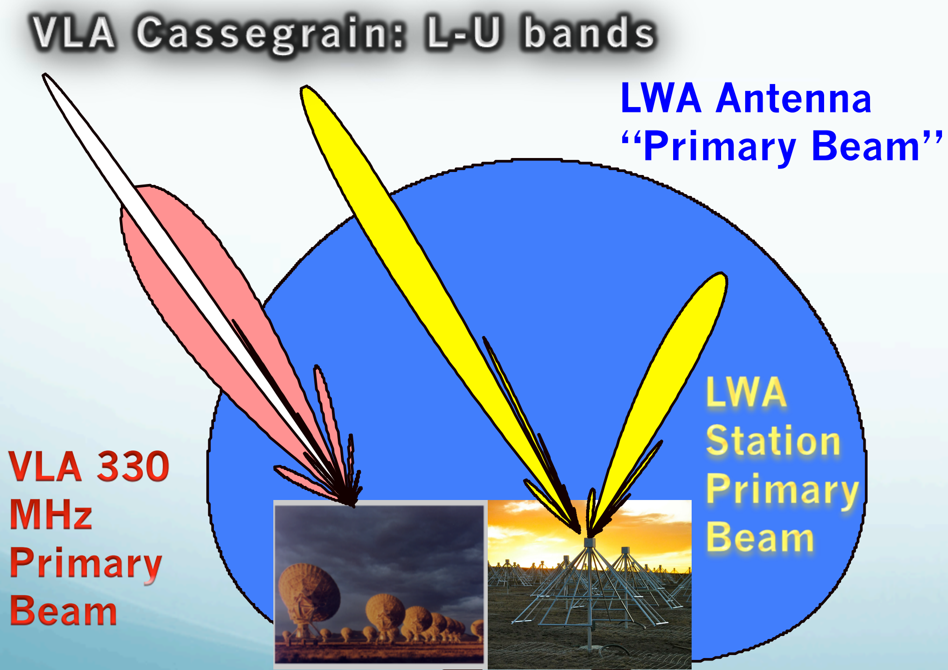
- LWSC "explorer class" instruments are taking an aggressive approach to science well worth the investment and risk
  - *However, without much longer baselines (> 400 km) they remain relatively blind and insensitive for imaging*

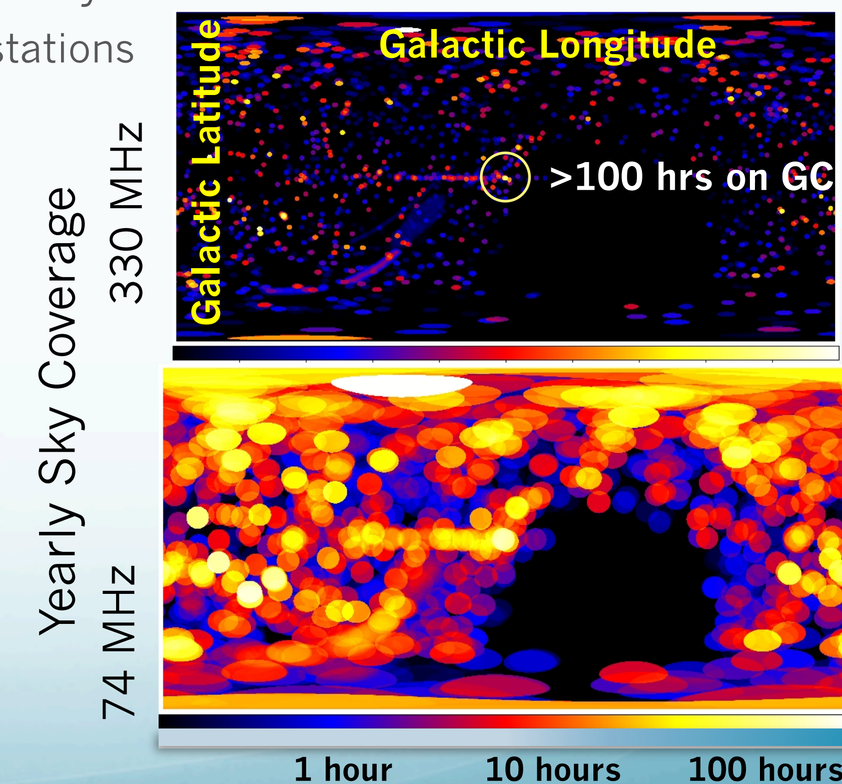
- Explorer class discoveries will demand, sensitive, high resolution follow-ups to place the observations in context
  - Astronomy has always called out for higher angular resolution – legacy of the VLA & NASA's great observatories
    - A radio transient with a poor position remains a mystery!
  - Arc-second imaging enriches most LW science & might be a prerequisite for some
    - Constraining foreground populations for Cosmic Dawn.
    - Mapping cluster emission - *sans point sources* - for D. Matter & D. Energy Studies

- Open question: how large should the LWA be?
  - Large enough so that it is not confusion limited for plausible integration times
  - Not so large that it is limited by scattering & brightness temperature limits
  - We plan a VLBI survey (LWA1, LWA-OVRO, LoFASM) to constrain the size of LWA.
  - Once footprint defined, station distribution follows to balance thermal noise, confusion w/ availability of existing infrastructure.

LWSC Explorer Class Instruments & the VLA

- The VLA is back on the sky at low frequencies, aka “Low Band”
  - Broad-band receivers 50-500 MHz initially targeting 240-470 MHz & 55-80 MHz bands
- A VLA commensal concept (LOBO) can deliver 6000 hours of VLA time per year
  - A 10 antenna system called VLITE will test the concept for ionospheric science & transients (PI: Kassim)
- LWSC instruments can target the VLA P band FoV (~5 sq. deg.) & continuously monitor phenomena across 20 octaves of spectrum – possibly more
  - VLA 74 MHz a surrogate core for early LWA stations





VLA P band: incoherent processes; LWSC instruments & VLA 74 MHz – coherent processes.