Karl G. Jansky Very Large Array

Emmanuel Momjian

The (Jansky) VLA

- 27x25m antennas (Y-shape) reconfigurable on baselines 35m to 36km
- located in New Mexico at 2100m altitude
- Construction from 1973-1980, upgrade 2003-2012 to Jansky VLA

Spatial Resolution

- With reconfiguration of the antennas, the array can vary its spatial resolution by a factor of ~40.
- Configuration sequence: D (B_{max}~ 1 km) → C → B → A (B_{max}~ 36 km).
- Reconfiguration about every 4 months.
- The August 1, 2018, proposal deadline is for both the A and B configurations.

Configuration	A	B	C	D
B_{max} (km[1])	36.4	11.1	3.4	1.03
B_{min} (km[1])	0.68	0.21	0.035[5]	0.035
Band	**Synthesized Beamwidth θ_{HPBW}**(arcsec)[1,2,3]			
74 MHz (4)	24	80	260	850
350 MHz (P)	5.6	18.5	60	200
1.5 GHz (L)	1.3	4.3	14	46
3.0 GHz (S)	0.65	2.1	7.0	23
6.0 GHz (C)	0.33	1.0	3.5	12
10 GHz (X)	0.20	0.60	2.1	7.2
15 GHz (Ku)	0.13	0.42	1.4	4.6
22 GHz (K)	0.089	0.28	0.95	3.1
33 GHz (Ka)	0.059	0.19	0.63	2.1
45 GHz (Q)	0.043	0.14	0.47	1.5

Largest Angular Scale

- The *shortest* baseline sets the largest angular scale that an interferometer is sensitive to.
- Compact configurations have less spatial resolution but cover larger angular scales and increase surface brightness sensitivity.

Field of view (depends on diameter of a single antenna)

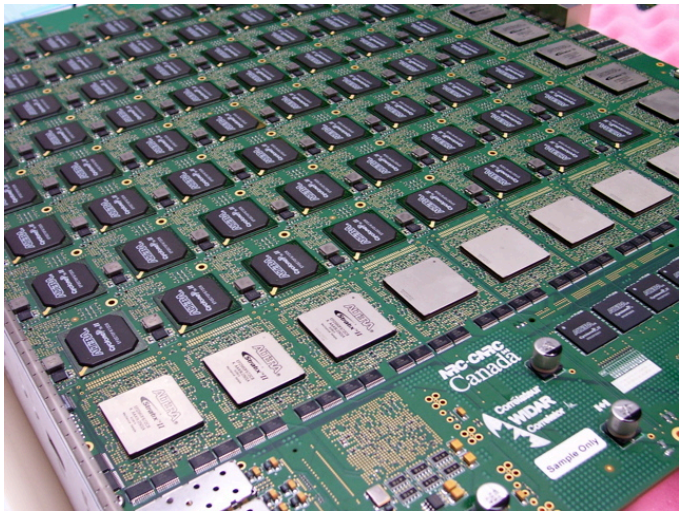
Configuration	A	B	C	D
B_{max} (km[1])	36.4	11.1	3.4	1.03
B_{min} (km[1])	0.68	0.21	0.035[5]	0.035
Band	**Largest Angular Scale θ_{LAS}(arcsec)[1,4]**			
608' 74 MHz (4)	800	2200	20000	20000
129' 350 MHz (P)	155	515	4150	4150
30' 1.5 GHz (L)	36	120	970	970
15' 3.0 GHz (S)	18	58	490	490
7.5' 6.0 GHz (C)	8.9	29	240	240
5.3' 10 GHz (X)	5.3	17	145	145
3' 15 GHz (Ku)	3.6	12	97	97
2' 22 GHz (K)	2.4	7.9	66	66
1.4' 33 GHz (Ka)	1.6	5.3	44	44
1' 45 GHz (Q)	1.2	3.9	32	32

The VLA

- Nine Frequency Bands
  - Eight cryogenic bands, covering 1 – 50 GHz. Utilizes cassegrain subreflector.
  - One uncooled, prime-focus band, covering 50 – 450 MHz.
- Up to 8 GHz instantaneous bandwidth
  - All digital design to maximize instrumental stability and repeatability.
- Full polarization correlator with 8 GHz instantaneous BW
  - Provides 64 independent 'sub-correlators', and 16384 spectral channels.
  - Many specialized operations modes (burst, pulsar binning, phased arrays …)

The ‘WIDAR’ Correlator

- The VLA’s correlator was built to NRAO’s requirements by the DRAO correlator group, located at the HIA facility near Penticton, BC.
- This ‘WIDAR=**W**ideband **I**nterferometric **D**igital **AR**chitecture’ correlator was paid for by the Canadian government, as part of a cooperative agreement between NRC and NSF.



Basic Features of the 'WIDAR' Correlator

The correlator's basic features (not all implemented yet):

- **64 independent full-polarization subbands** Each can be tuned to its own frequency, with its own bandwidth (128 MHz to 31.25 kHz) and spectral resolution (from 2 MHz to .12 Hz)
- **100 msec dump times with 16384 channels and full polarization**
  - Faster if spectral resolution, BW, or number of antennas is decreased.
- **Up to 8 sub-arrays**. Maximum to date is three.
- **Phased array capability** with full bandwidth – for pulsar and VLBI applications.
- **Special pulsar modes**: 2 banks of 1000 time bins, and 200 μsec time resolution (all spectral channels), or 15 μsec (64 channels/sp.window). Undergoing testing; See RSRO.

General Observing (GO)

- Up to 8 GHz bandwidth with 16384 spectral channels – 2 MHz spectral resolution (full pol).
- All 64 subband pairs can be separately tuned, and set to any of 128, 64, 32, 16, … ,0.03125 MHz widths.
- Up to 16384 spectral channels (no recirculation), or up to 1048576 (with recirculation).
- Three simultaneous, fully independent subarrays.
- Mix 3-bit and 8-bit modes.
- Phased Array (for VLBI).

Shared Risk Observing (SRO)

Access to extra capabilities that have not been as well tested as GO capabilities. These currently are:

- On-the Fly mosaicking
- Up to 32 subbands per baseband with the 8-bit samplers
- Solar observing
- P-band (224–480 MHz) spectroscopy
- Frequency averaging in the correlator (up to a factor of 4): C through Q bands for 3-bit wide-band continuum science projects

Resident Shared Risk Observing (RSRO)

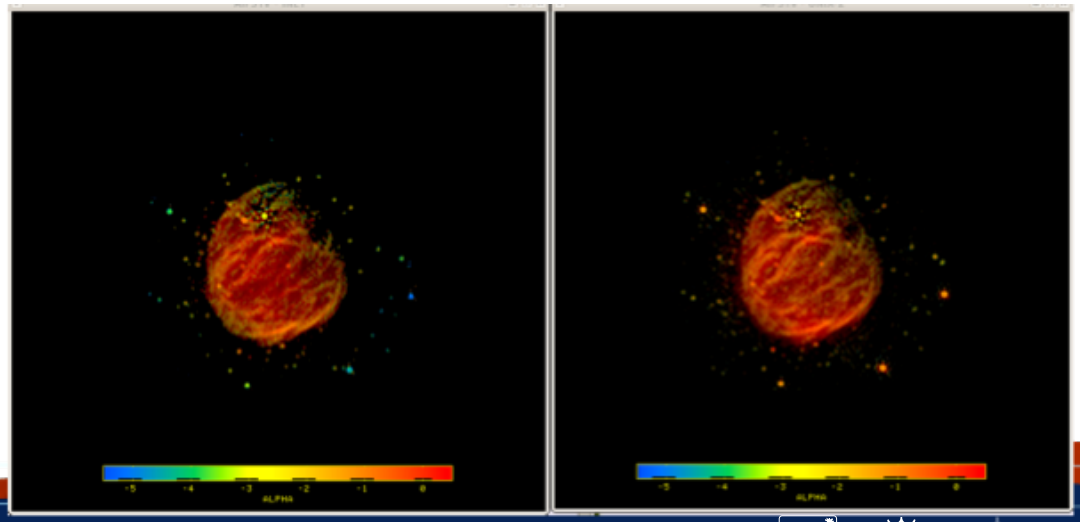
- Access to extended capabilities that require more testing
  - In exchange for a period of residence

➢ Correlator dump times < 50 msec (Including as short as 5 msec for transients)
➢ Pulsar observations
➢ Data rates above 60 MB/s
➢ Recirculation beyond a factor of 64
➢ P-band (230-470 MHz) polarimetry
➢ 4-band (58-84 MHz) commissioning and testing
➢ More than 3 subarrays with the 8-bit samplers
➢ Subarrays with the 3-bit samplers
➢ Complex phased array observations

Post processing

- Data reduction software: CASA
  - Handles complex observing set-ups
  - Task interface to suite of C++-based reduction tools
  - Python interface provides access to data for manipulation
  - Effective platform for algorithm development (e.g., handling effect of wide fractional bandwidths, $\Delta\nu/\nu$)

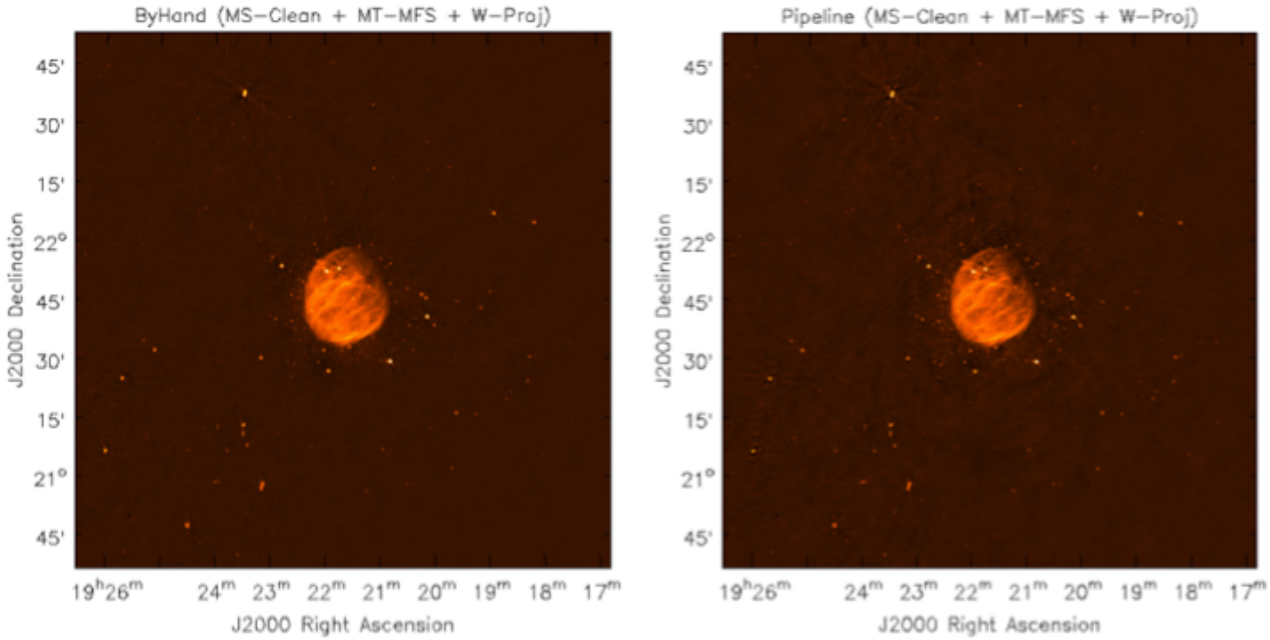
Spectral index of 1–2 GHz emission from SNR G55.7+3.4, before correction for the frequency-dependence of the primary beam (left), and after correction (right)



VLA Calibration Pipeline

- Designed for Stokes I continuum.
- Work is in progress to support spectral line and polarization.

The supernova remnant G55.7+3.4



hand-flagged and calibrated

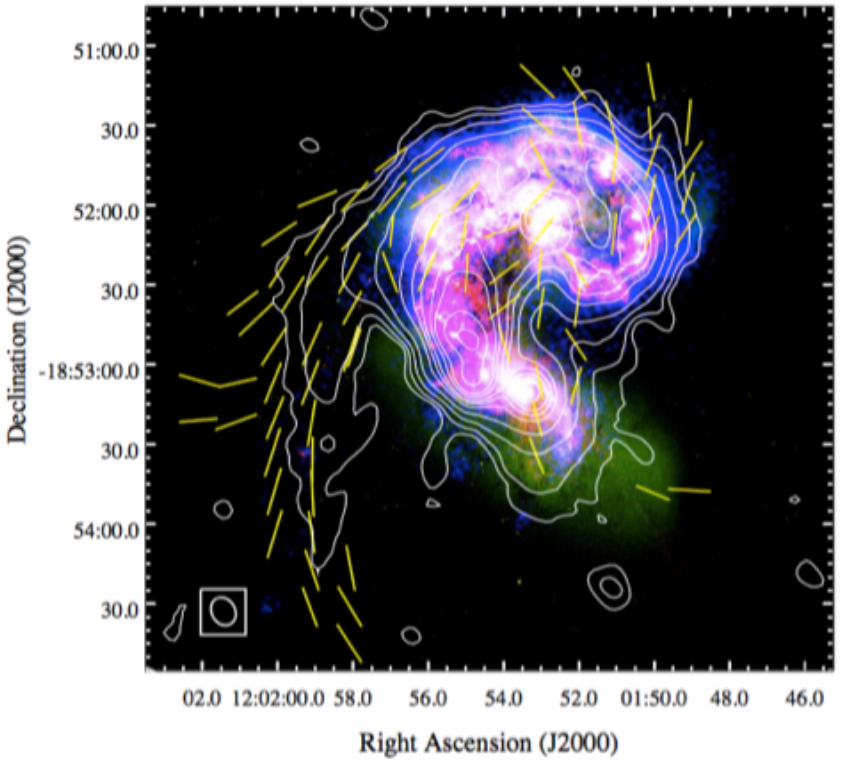
pipeline-calibrated

RMS is within 10%

Some recent VLA Science Highlights

The VLA images the large scale magnetic field in the Antennae

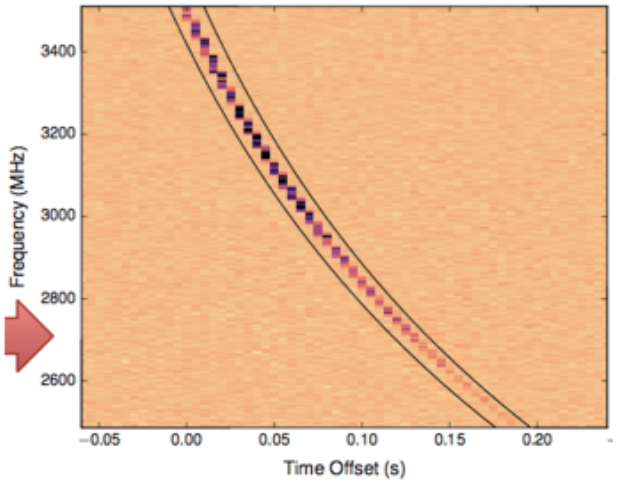
- The VLA has imaged at 1kpc res, the magnetic field in the 'Antennae' merging galaxies.
- The tail is 62% polarized, with B fields aligned along the tidal tail on a scale of 20 kpc – the largest detected regular field structure on galactic scales.
- The regular field in the tail is ~ 8.5 μG, which is stronger than the turbulent field. This field must be generated in a few 100 Myr, likely by stretching of the galactic disc field.
- Although the magnetic fields within merging bodies are dominated by strong turbulent fields, this study shows that tidal effects can produce large-scale regular field structure in the outskirts.

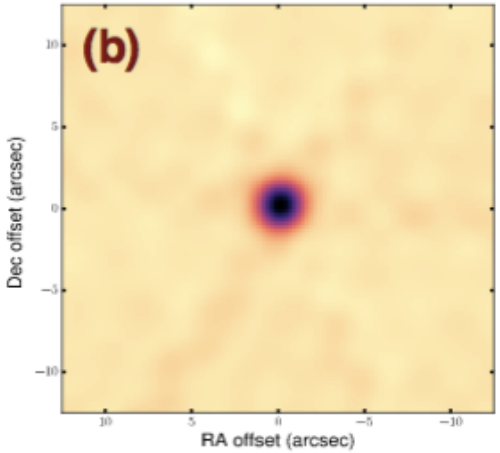


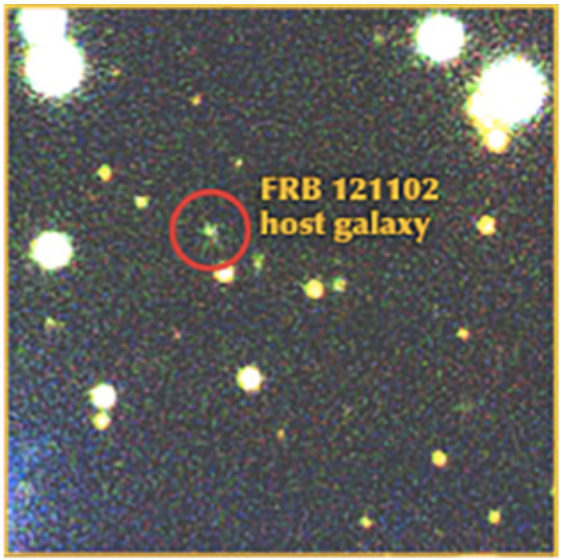
Antennae with GALEX, HST, JVLA (3GHz Contours), plus the Faraday rotation-corrected magnetic field orientations. (Basu ea. 2016).

VLA Solves the FRB Puzzle

- The VLA has localized, for the first time, a fast (milli-sec) radio burst. The repeating FRB 121102 is localized to 0.1” accuracy, and is situated at the center of a dwarf galaxy at z ~ 0.1. The galaxy shows a compact (1.7mas) persistent radio source.
- Models for the system include: a neutron star or magnetar enveloped by supernova ejecta, or a new AGN-jet related phenomenon.
- The discovery that FRBs are indeed at cosmological distances raises the potential to use FRBs as unique probes of cosmology and physics. The current result has already inspired numerous theoretical papers on the physics of the IGM and degenerate stars.



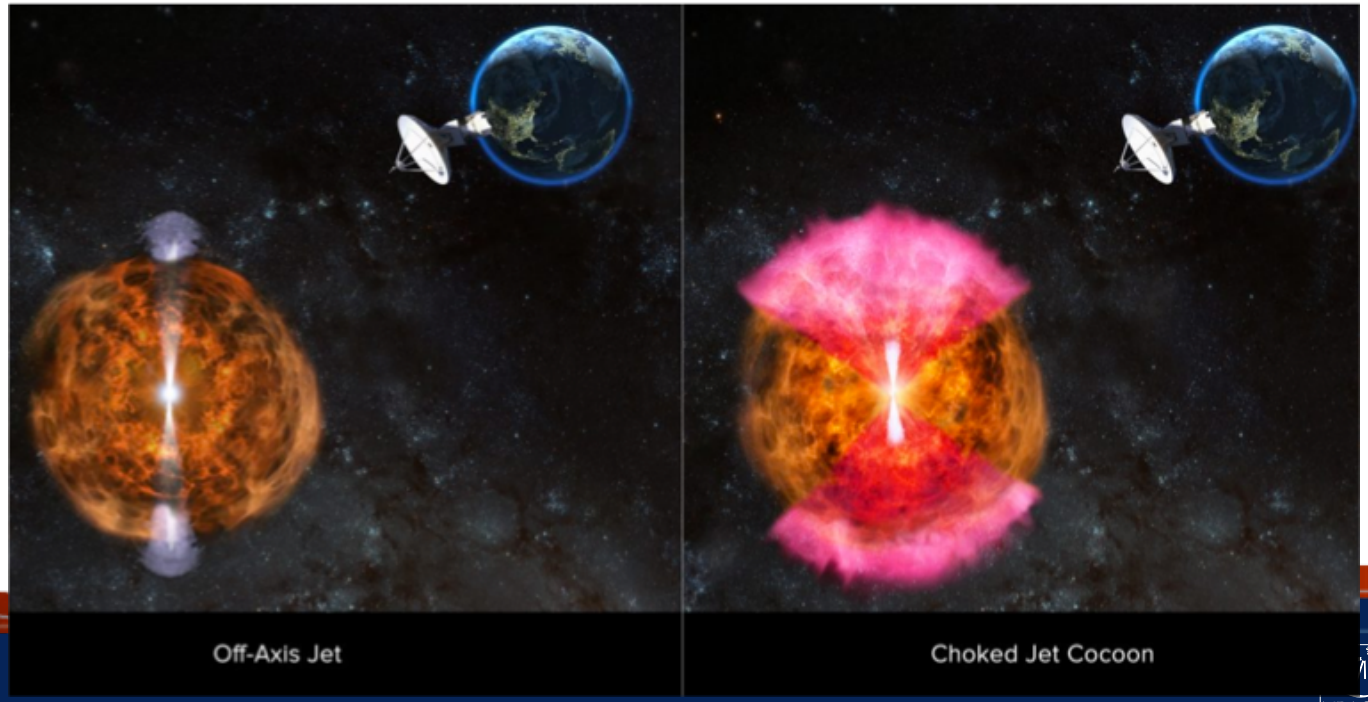




VLA 3GHz observations of the FRB 121102, plus the near-IR image of the host dwarf galaxy (Chatterjee et al. 2017, Nature)

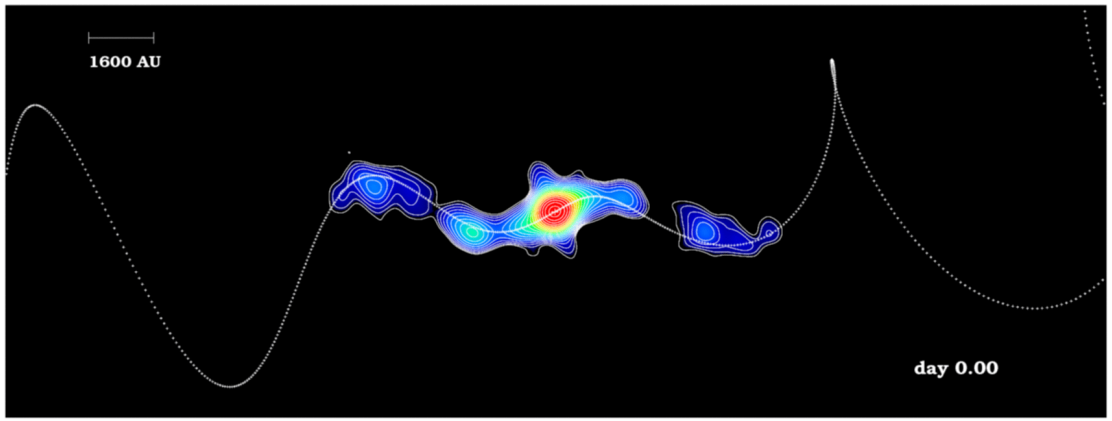
Radio Observations Point to Likely Explanation for Neutron-Star Merger Phenomena

- Three months of monitoring observations with the VLA.
- VLA, ATCA, GMRT observations showed gradual brightening of the radio signal indicative of a wide-angle outflow of material from the neutron star merger.
- The X-ray emission, measured with Chandra, had also brightened as predicted by the 'cocoon' model.



Important Links

- NRAO Help Desk
  go.nrao.edu/obshelp
- VLA Observational Status Summary
  go.nrao.edu/vla-oss
- VLA Exposure Calculator
  go.nrao.edu/ect
- Proposal Submission Tool
  my.nrao.edu
- CASA– data reduction software
  http://casa.nrao.edu/
- VLA Calibration Pipeline
  go.nrao.edu/vla-pipe



The X-ray binary SS433 at 26 GHz (0.095”; 520 AU resolution)
Credit: Miodusweski & Miller-Jones, EVLA demo science