Karl G. Jansky Very Large Array

Amy Kimball, *NRAO Scientist*

The (Karl G Jansky) VLA interferometer

Located in New Mexico, on San Agustin Plains, 6970 ft (2120m) altitude

→ 27 antennas (+1 additional)

→ arranged in Y-shape

→ 25-meter diameter dishes

→ reconfigurable: range of surface brightness sensitivity, resolution

→ observes north of –40° decl.

NRAO/AUI/NSF

Four main VLA array configurations

Re-configuration approximately every 4 months (16-month cycle)

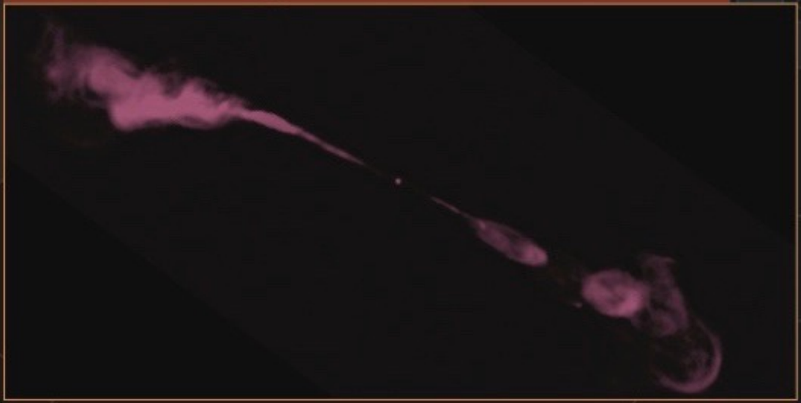
- A: largest baseline 36.4 km
- B: largest baseline 11.1 km
- C: largest baseline 3.4 km
- D: largest baseline 1.03 km

NRAO/AUI/NSF, J. Hellerman; New Mexico GDACC

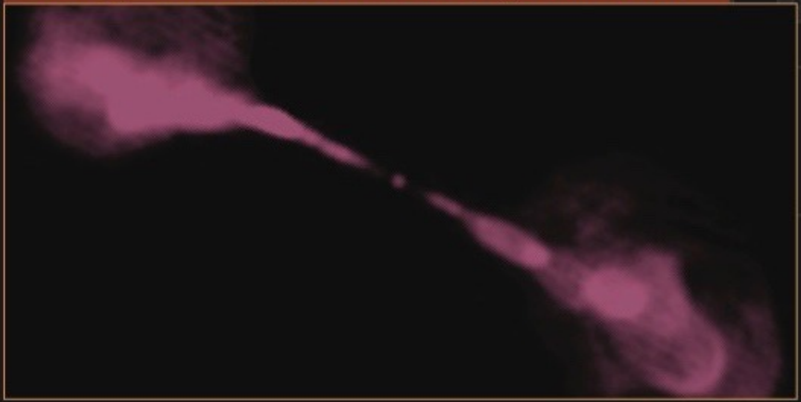
The four antenna configurations of the Karl G. Jansky Very Large Array (VLA) work together to reveal the jets emerging from galaxy Hercules A. Compact antenna spacings provide maximum sensitivity to diffuse clouds. Wide spacings provide the resolving power needed to see fine details. Combined, they yield a complete picture.

Configuration Ⓐ: 22 mile array diameter

Configuration Ⓑ: 7 mile array diameter



Configuration Ⓒ: 2 mile array diameter



Configuration Ⓓ: 0.6 mile array diameter

Image credit: NRAO/AUI/NSF

Observing frequencies

- 8 cryogenic bands (Cassegrain focus)
  - **1 – 50 GHz (L to Q-band)**
  - signal directed by subreflector
- 2 uncooled prime-focus bands:
  - **54 – 86 MHz (4-band)**
  - **200 – 500 MHz (P-band)**
  - low frequency dipoles
- Wide-band: up to 8-GHz bandwidth
  - two sets of samplers:

    8-bit (Δν = 2 GHz),   3-bit (Δν = 8 GHz)
  - full polarization:

    8 main bands circular, P and 4 band linear

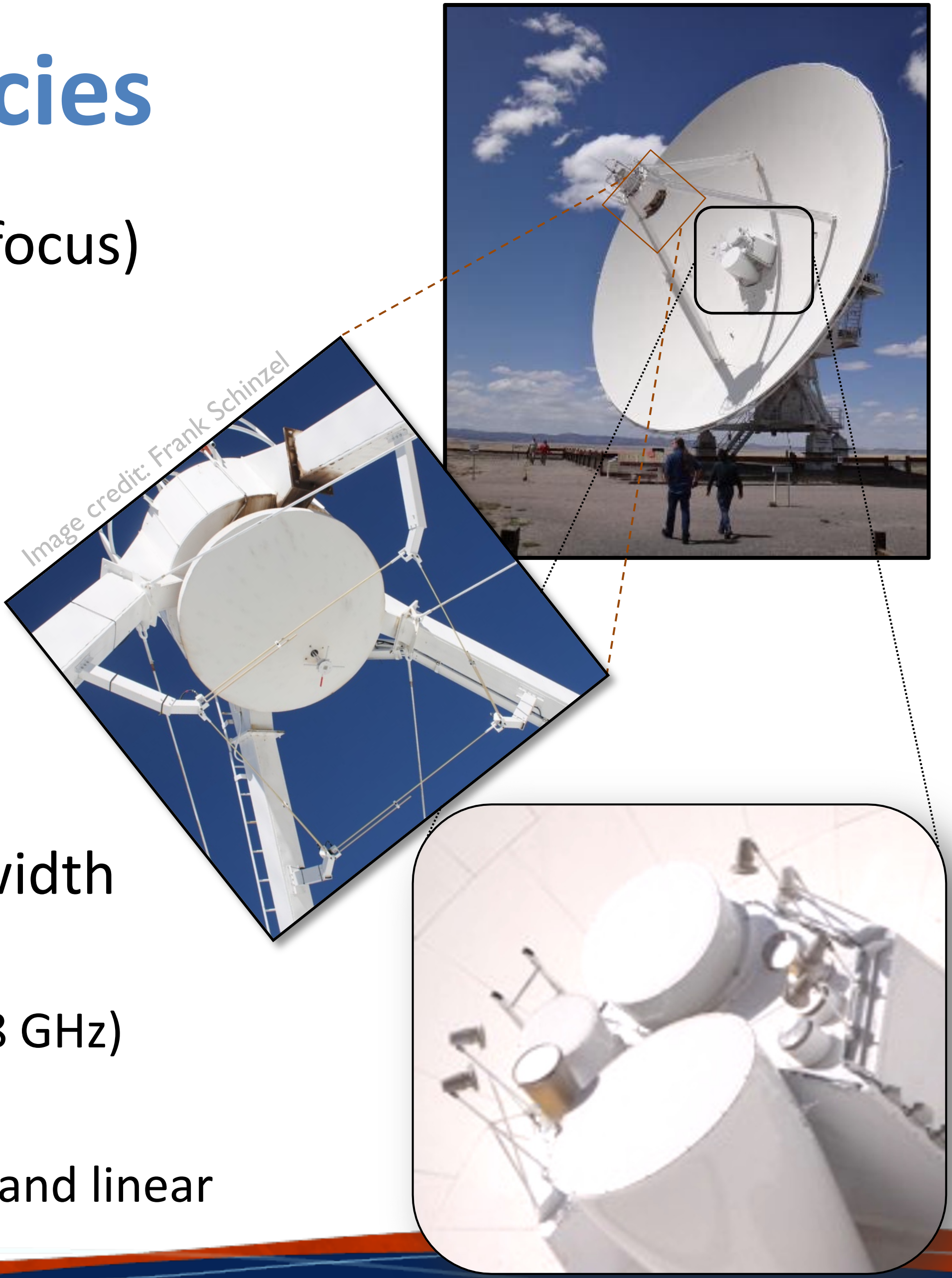
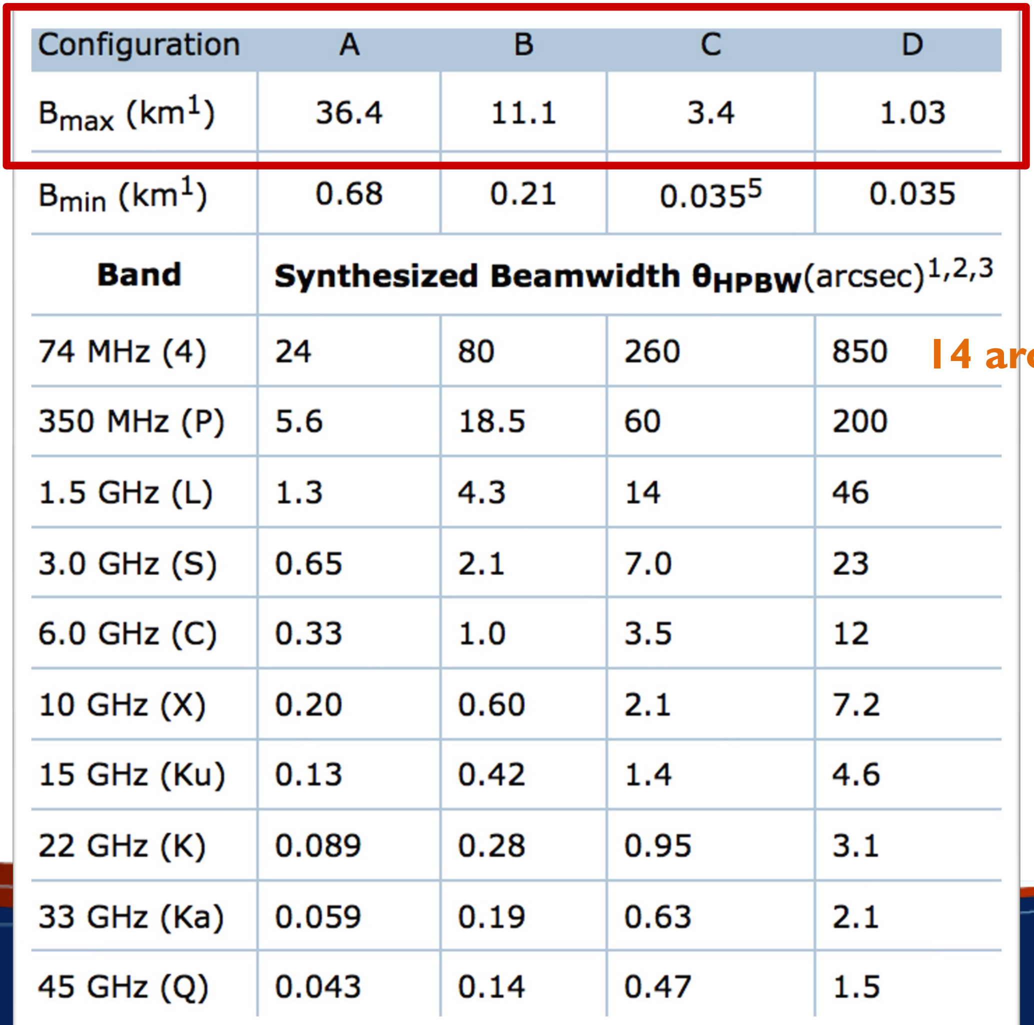


Image credit: Frank Schinzel

Angular Resolution

Depends on frequency (0.074 – 45 GHz) and VLA configuration:

A (largest) ← **B** ← **C** ← **D** (smallest)



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

14 arcmin

- Re-configure every ~4 months
- Proposal deadlines x2 per year beginning of February, August (Wednesday closest to the 1st)

Next proposal deadline:
January 31st 2024
for **A config**, semester 2024B
Oct 2024 – Feb 2025

Largest Angular Scale (LAS) & Field of View (FoV)

LAS: Depends on frequency and VLA configuration

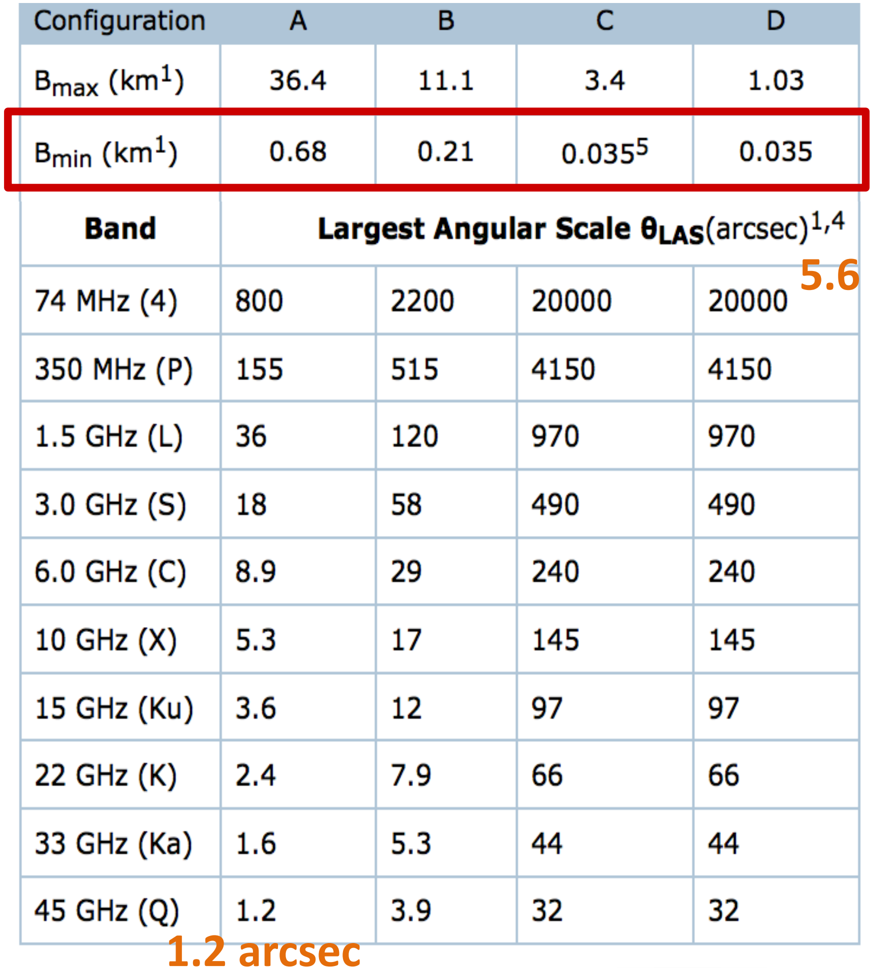
LAS is the largest angular scale the interferometer is sensitive to. Source features more extended than that will be “*resolved out*”.

FoV: Depends on frequency and individual antenna size

This will be larger than LAS. FoV is the amount of sky the antennas “see” with a single pointing (→ "primary beam")

Largest Angular Scale (LAS) & Field of View (FoV)

LAS: depends on frequency and configuration (set by shortest baseline)



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B_{min} (km^1)	0.68	0.21	0.035^5	0.035
Band	**Largest Angular Scale θ_{LAS}**(arcsec)^{1,4}			
74 MHz (4)	800	2200	20000	20000
350 MHz (P)	155	515	4150	4150
1.5 GHz (L)	36	120	970	970
3.0 GHz (S)	18	58	490	490
6.0 GHz (C)	8.9	29	240	240
10 GHz (X)	5.3	17	145	145
15 GHz (Ku)	3.6	12	97	97
22 GHz (K)	2.4	7.9	66	66
33 GHz (Ka)	1.6	5.3	44	44
45 GHz (Q)	1.2	3.9	32	32

5.6 deg

1.2 arcsec

Largest Angular Scale (LAS) & Field of View (FoV)

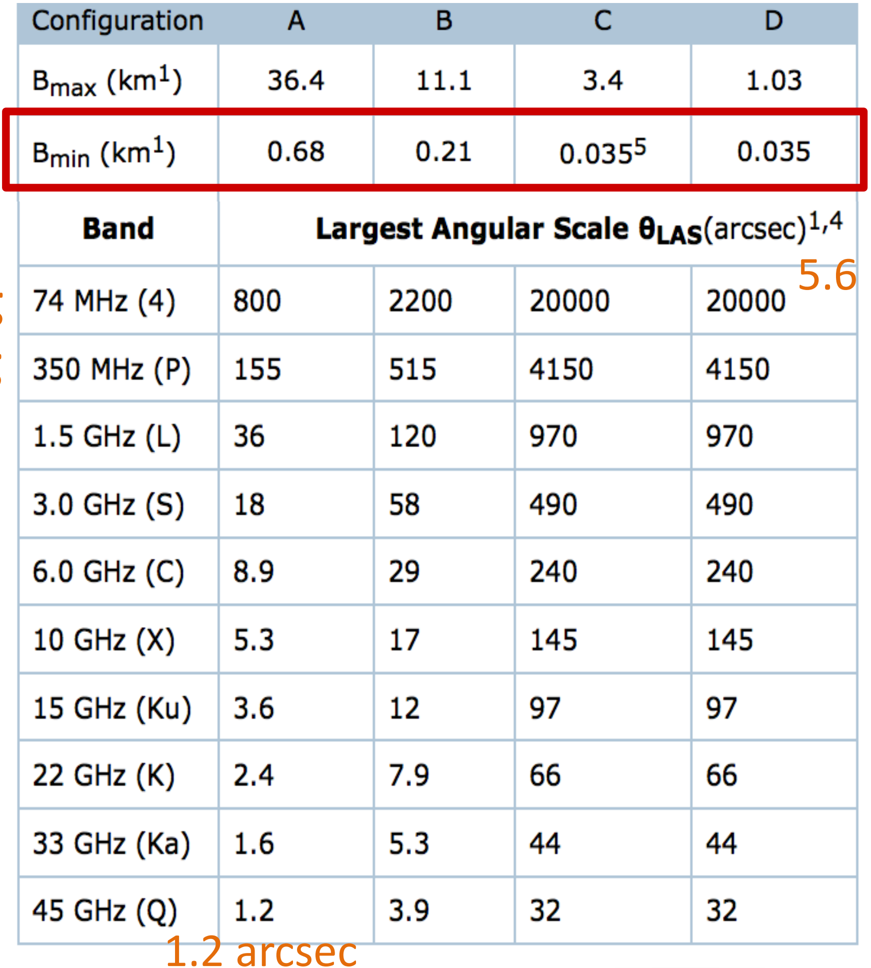
LAS: depends on frequency and configuration (set by shortest baseline)

FoV: depends on frequency and antenna size

θ_{PB} [*arcmin*] = 50 / ν_{GHz}

11.3 deg

2.4 deg



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5.6 deg

1.2 arcsec

Largest Angular Scale (LAS) & Field of View (FoV)

LAS: depends on frequency and configuration (set by shortest baseline)

FoV: depends on frequency
and antenna size

θ_{PB} [*arcmin*] = $50 / \nu_{GHz}$

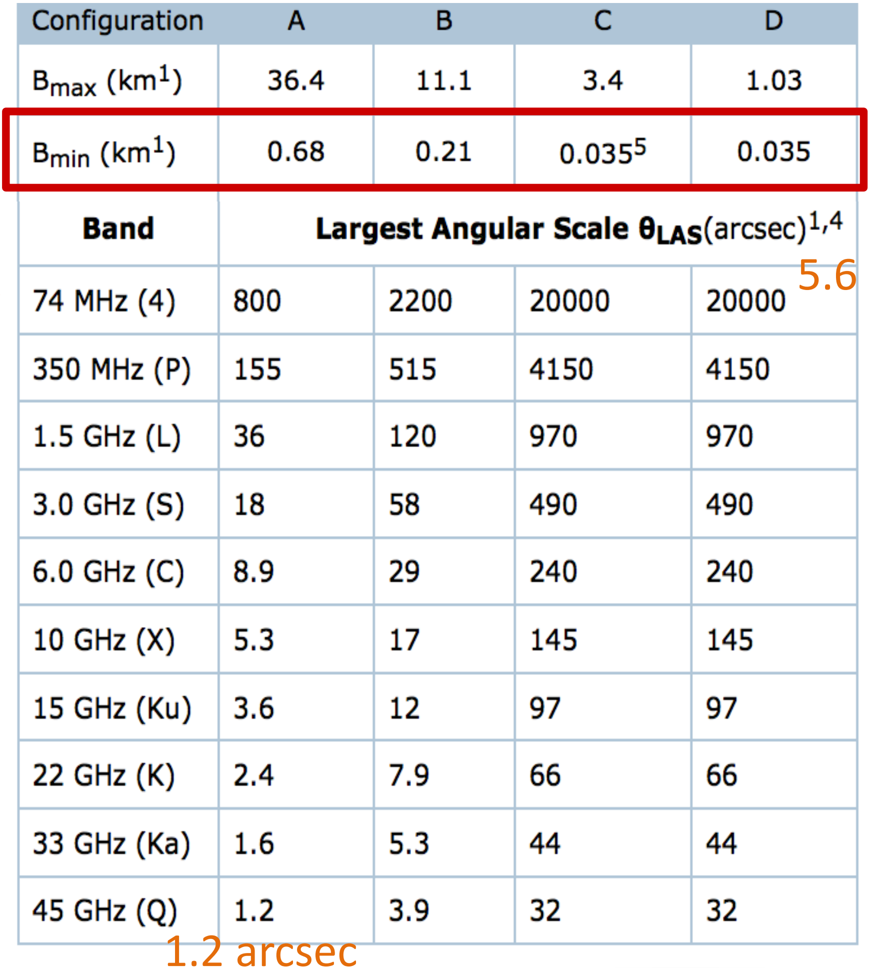
11.3 deg

2.4 deg

28 arcmin

θ_{PB} [*arcmin*] = $42 / \nu_{GHz}$

56 arcsec



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5.6 deg

1.2 arcsec

VLA observing modes

- Continuum (Stokes I)
- Polarimetry (Stokes Q,U,V)
- Spectral lines
- Sub-arrays [simultaneous independent observing by groups of antennas]
- Mosaicking [multiple pointings and phase centers]
- On-the-fly mapping (OTF) [“scanning” mode]
- Solar system objects
- Use VLA as a VLBA station
- Pulsar observing

The VLA's Correlator (WIDAR)

WIDAR = **W**ideband **I**nterferometric **D**igital **AR**chitecture

Basic features (not all implemented yet):

- **64 independent full-polarization subbands.** Can be tuned to their own frequency, own bandwidth (128 MHz to 31.25 kHz), own spectral resolution (2 MHz to 0.5 kHz)
- **50 msec dump times** with 16,384 channels, full polarization
  (faster if spectral resolution, bandwidth, or number of antennas is decreased)
- **Up to 8 sub-arrays.** (maximum to date is 3)
- **Phased array** with full bandwidth (pulsar and VLBI)
- **Special pulsar modes**: 2 banks of 1000 time bins, and 200 μsec time resolution (all spectral channels), or 15 μsec (64 channels/spw).

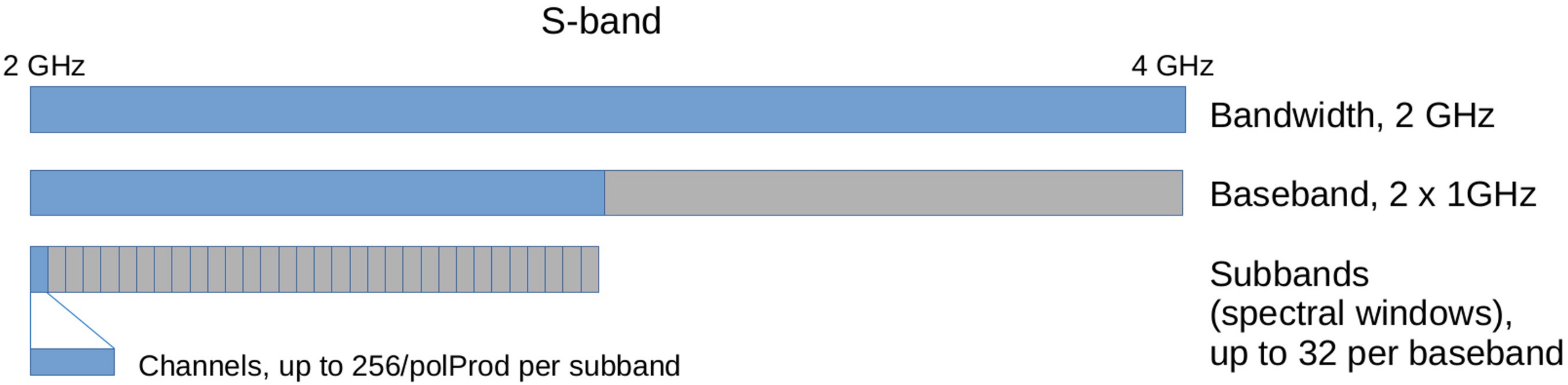
General Observing (GO)

Observing modes: continuum, polarization, spectroscopy, solar observing, OTF mosaicking (P,L,S,C bands)

Standard observing setups available to anyone:

- up to 8-GHz (depending on band)
- 3-bit and 8-bit modes, or mixed mode (e.g. 3-bit for continuum, 8-bit for line)
- up to 3 simultaneous, independent subarrays in 8-bit mode
- spectral setup:
  - 1- or 2-GHz basebands (can have independent setups)
  - 1 baseband can be made of up to 32 independently tunable spectral windows
  - spectral window widths: max 128 MHz, min 31.25 kHz
  - for a single baseline board pair (BlBP; one per spectral window is the default):
    - 256 spectral channels in a single polarization
    - 128 spectral channels in dual polarization mode
    - 64 spectral channels in full polarization mode

Correlator tuning example



S-band

2 GHz

4 GHz

Bandwidth, 2 GHz

Baseband, 2 x 1GHz

Subbands
(spectral windows),
up to 32 per baseband

Channels, up to 256/polProd per subband

This setup provides 16,384 spectral channels.

If more are needed, there are options: (1) recirculation, (2) baseline board stacking, or using (1) and (2) simultaneously

Up to 1,048,576 channels, with recirculation.

Shared Risk Observing (SRO)

Allows access to extra capabilities that have not been as well tested as GO capabilities. Currently these are:

- On-The-Fly-Mosaicking at high frequency (X through Q-bands)
- 4-band (54-86 MHz) Stokes I continuum
- Dual 4-band/P-band Stokes I continuum
- Data rates up to 100 MB/s (360 GB/hr)

Resident Shared Risk Observing (RSRO)

Access to more extended capabilities that still require testing

- Requires a period of residence at NRAO to help with the testing/commissioning

- Correlator dump times < 50 msec (as short as 5 msec for transients)
- Data rates > 100 MB/s
- Recirculation factor > 64
- 4-band polarization
- 4-band coherent-dedispersion pulsar observing
- More than 3 subarrays, or subarrays with the 3-bit samplers
- Complex phased-array observations (e.g. pulsars or complex VLBI observing)
- Frequency averaging by a factor > 4

Joint proposals

https://science.nrao.edu/observing/call-for-proposals/2024a/joint-proposals

- Joint between VLA, VLBA, GBT (shared proposal deadline):
  - submit a proposal for each; they will be considered jointly by the TAC

- With "external" facilities:
  - ALMA, NICER, XMM-Newton, Chandra, HST, Swift, Fermi
  - reciprocal agreements to award time to proposers at other observatory
  - submit proposal to the observatory with the higher time request
  - science review by the "primary" facility where proposal was submitted; technical review by the "partner" facility

Post processing of VLA data

- NRAO data reduction software: ***CASA***
  - Designed for wide-band VLA and ALMA data (can work for other radio telescopes)
  - Based on C++ tools under-the-hood, with iPython interface for easy data manipulation
  - Latest versions *(Python 3 from CASA 6.0+)* :

    CASA 6.5.6 for general use

    CASA 6.4.1 with ALMA/VLA pipelines

- "monolithic CASA": a self-contained package
- "modular CASA": import CASA modules into your own Python/iPython environment *(CASA 6.0+).* Use *pip* to install.

https://casa.nrao.edu/

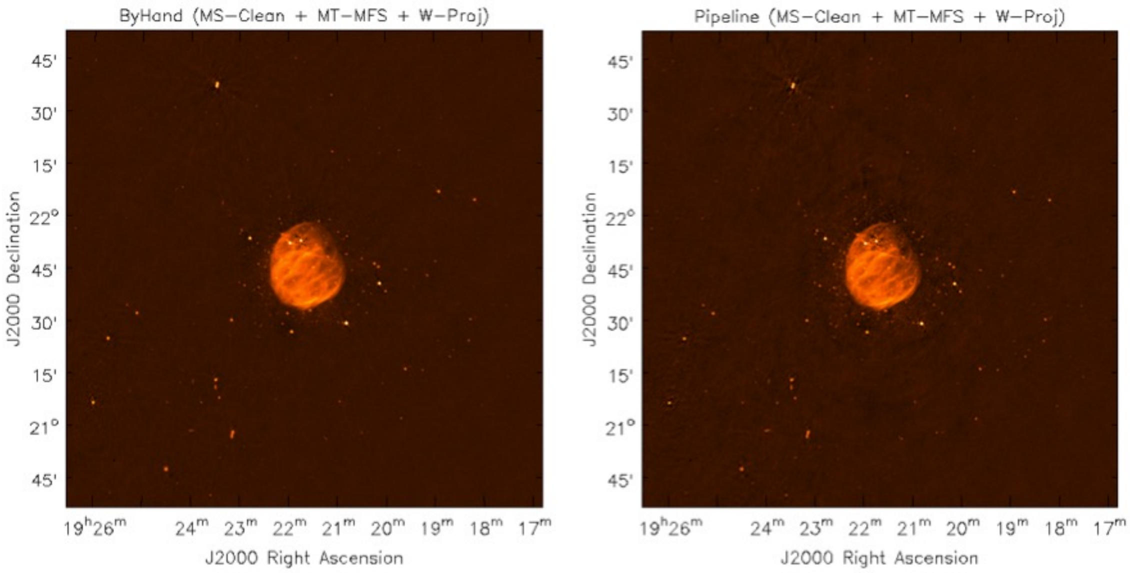
CASA
Common Astronomy Software Applications

Developed by an international consortium composed of:

VLA Calibration Pipeline

- Designed for continuum (Stokes I)
- Work is in progress to support spectral line, polarimetry, improved RFI flagging
- Imaging pipeline now available!

Supernova remnant G55.7+3.4



hand-flagged and calibrated

pipeline-calibrated

RMS is within 10%

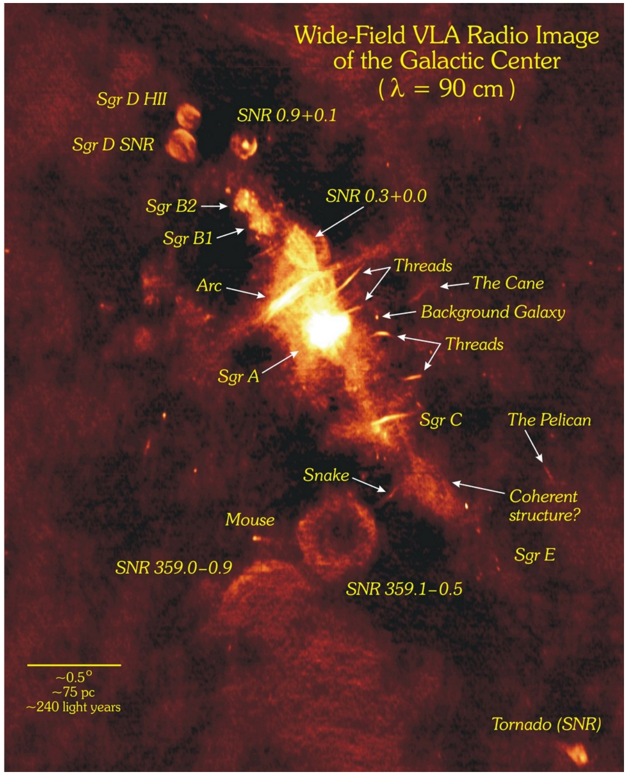
A few VLA science highlights

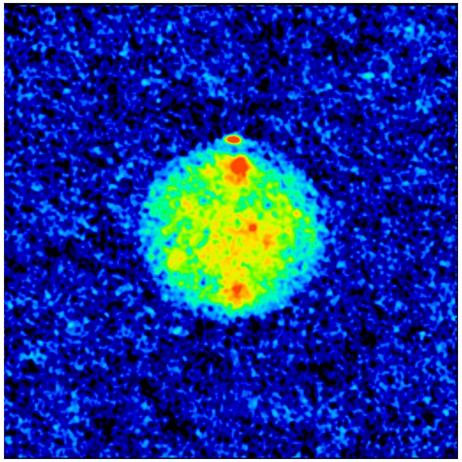
(slide courtesy of Anna Kapinska)

VLA Science

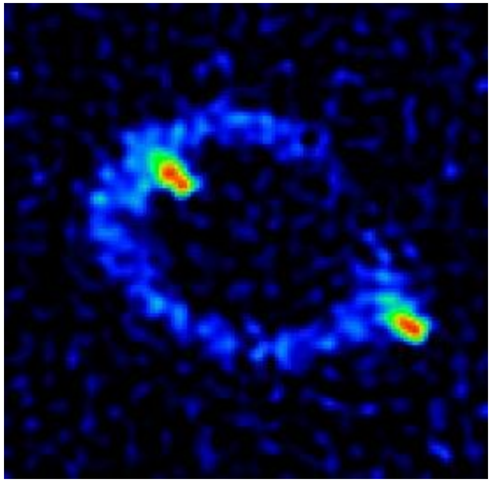
VLA is the most versatile, widely-used radio telescope in the world. It can map large-scale structure of gas and molecular clouds, pinpoint ejections of plasma from supermassive black holes, and find ice on solar system planets.

Galactic Center, Kassim+, 1986.





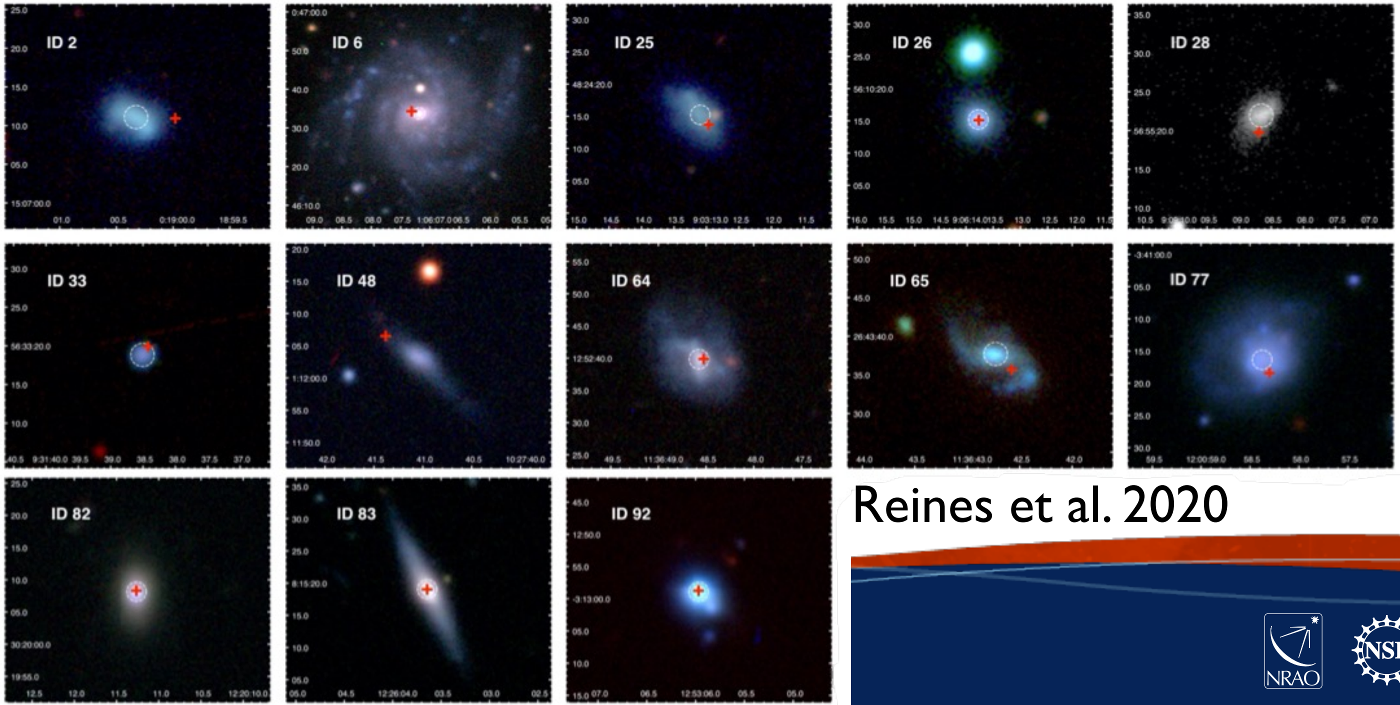
Discovery of ice on Mercury through a radar experiment in 1991 using NASA JPL/DSN 70-m antenna in Goldstone, CA, as the transmitter, and VLA as the receiver.



First Einstein ring discovered with VLA (by Hewitt+, in 1987): lensed quasar MG1131+0456.

Wandering Black Holes in Dwarf Galaxies

- Observed 111 dwarf galaxies with VLA in A-config at X-band to localize radio emission: 39 with compact radio emission, 13 AGN
- Most AGN are offset from host galaxy center. Larger offsets in more extended/disturbed galaxies.
- Consistent with interpretation of wandering BHs arising from galaxy interactions/mergers

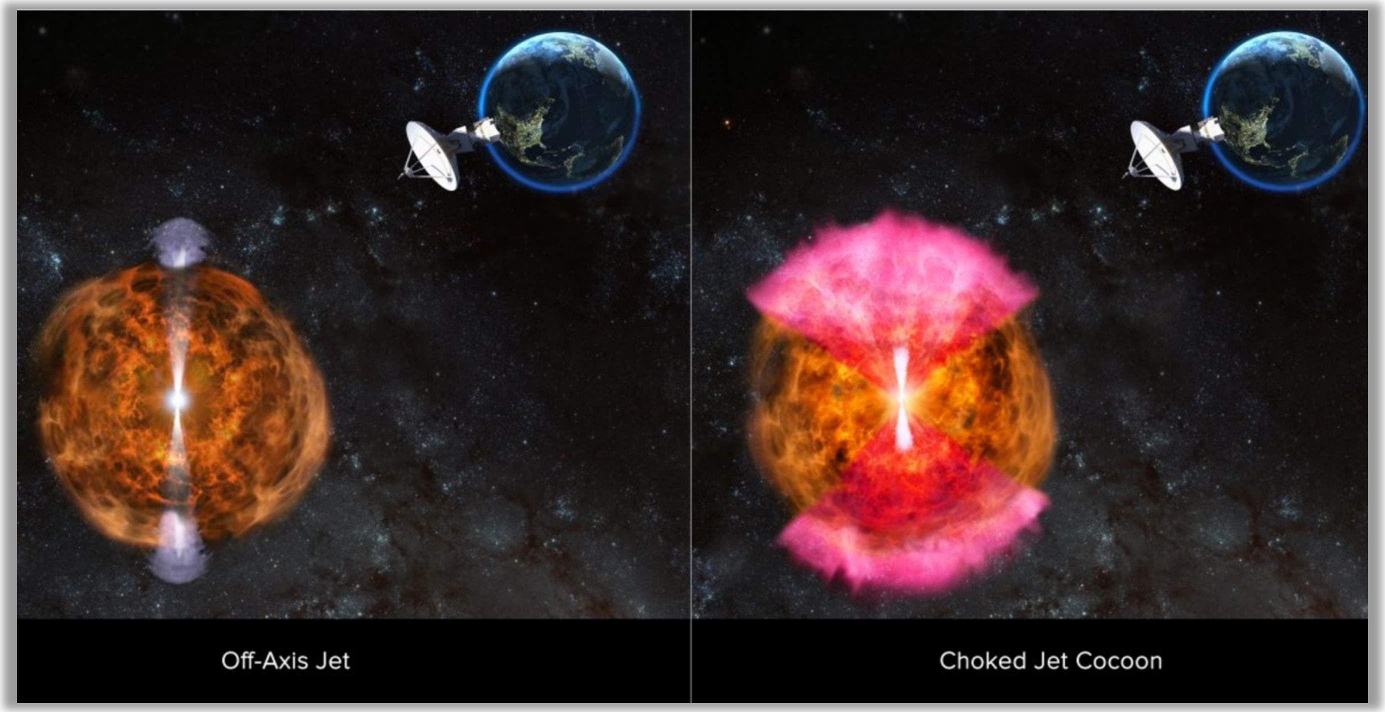


Reines et al. 2020

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.

Mooley et al. (2018) Hallinan et al. (2017)

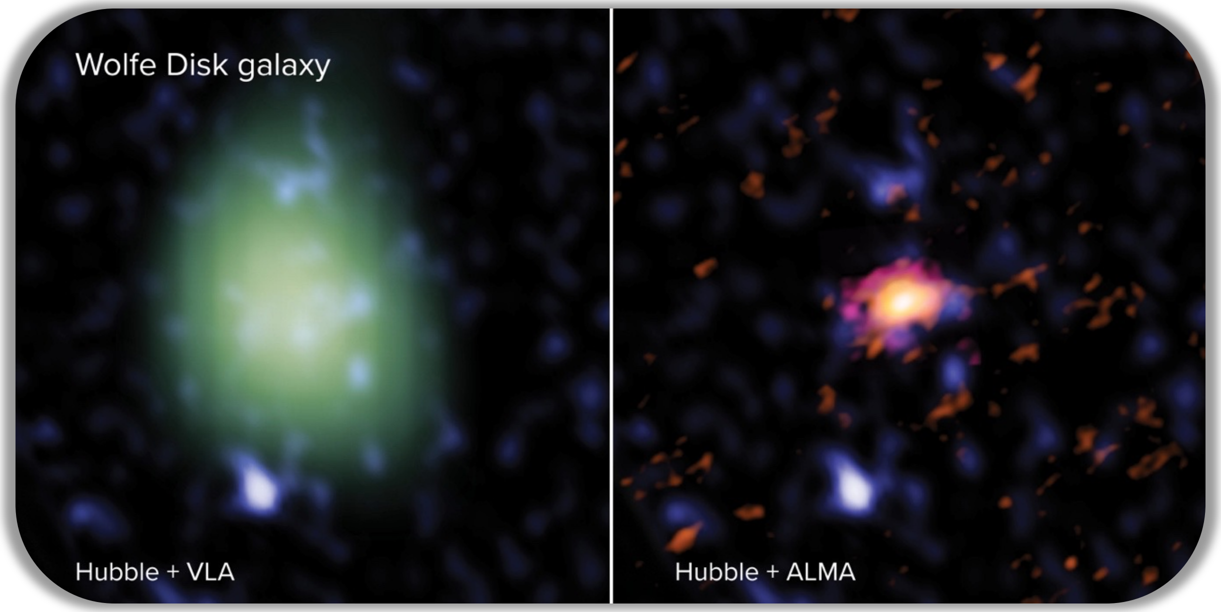


NRAO/AUI/NSF: D. Berry

VLA + ALMA synergy (lines)

- Wolfe Disk: most distant rotating disk galaxy known (z=4.26)
- CO(2-1) line observed by VLA yields total molecular gas content
- [CII] line observed by ALMA yields rotational velocity map

Neeleman et al. 2020

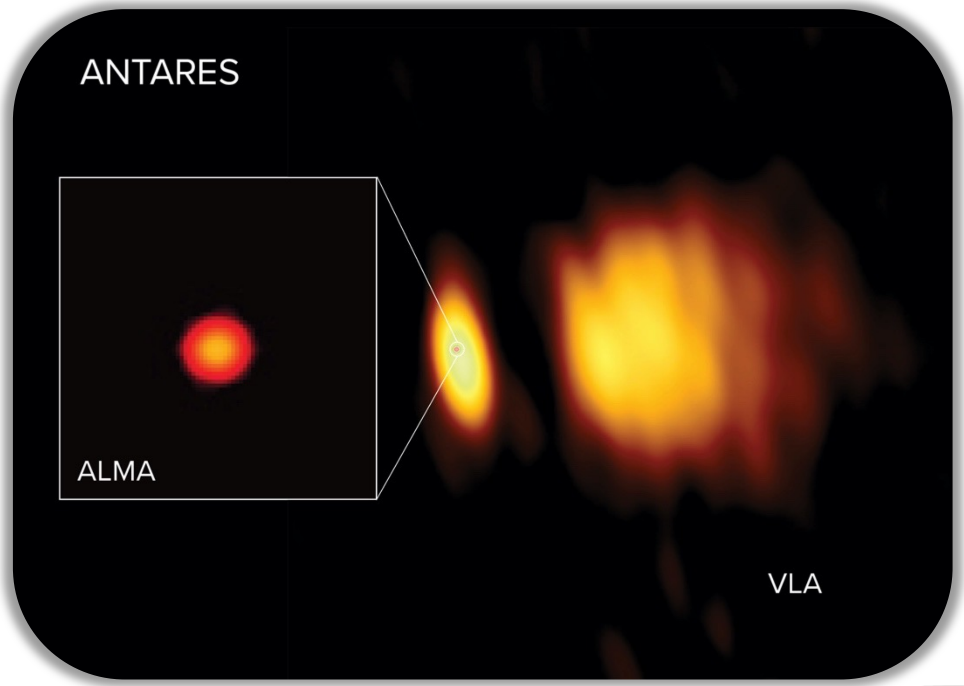


ALMA (ESO/NAOJ/NRAO), M. Neeleman; NRAO/AUI/NSF, S. Dagnello; NASA/ESA Hubble

VLA + ALMA synergy (continuum)

- VLA resolves Antares' atmosphere
- ALMA short wavelengths probe close to surface
- Reveal size of supergiant's chromosphere, and cool temperature

O'Gorman et al. 2020



ALMA (ESO/NAOJ/NRAO), E. O'Gorman; NRAO/AUI/NSF, S. Dagnello

Useful Links

- NRAO Help Desk
  go.nrao.edu/obshelp
- VLA Observational Status Summary
  go.nrao.edu/vla-oss
- VLA Proposing Guide
  go.nrao.edu/vla-prop
- VLA Observing Guide
  go.nrao.edu/vla-obs

- Proposal Submission Tool
  my.nrao.edu
- VLA Exposure Calculator
  go.nrao.edu/ect
- CASA: data reduction software
  http://casa.nrao.edu/
- VLA Calibration Pipeline
  go.nrao.edu/vla-pipe