Karl G. Jansky Very Large Array

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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.

Four main VLA array configurations

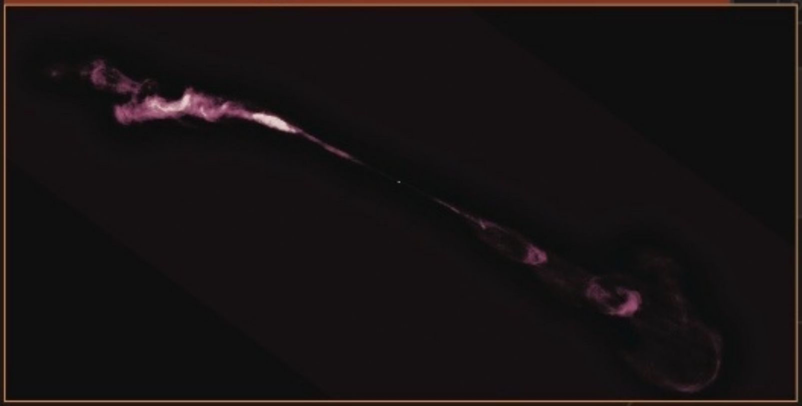
Re-configuration approximately every 4 months (16-month cycle)

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

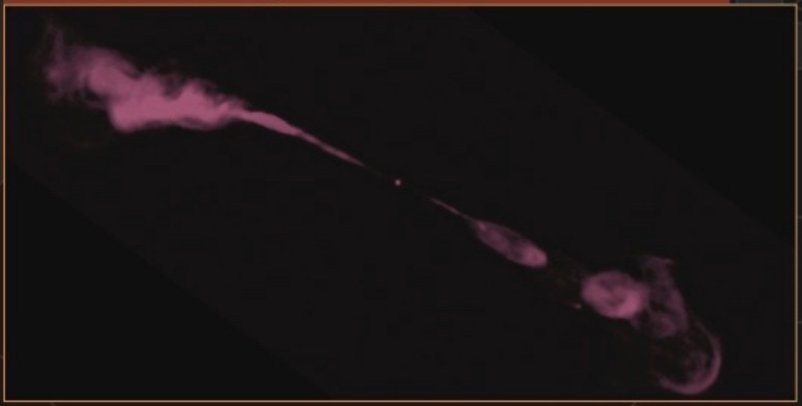
NRAO/AUI/NSF, J. Hellerman; New Mexico GDACC

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 A: 22 mile array diameter



Configuration B: 7 mile array diameter



Configuration C: 2 mile array diameter

Configuration D: 0.6 mile array diameter

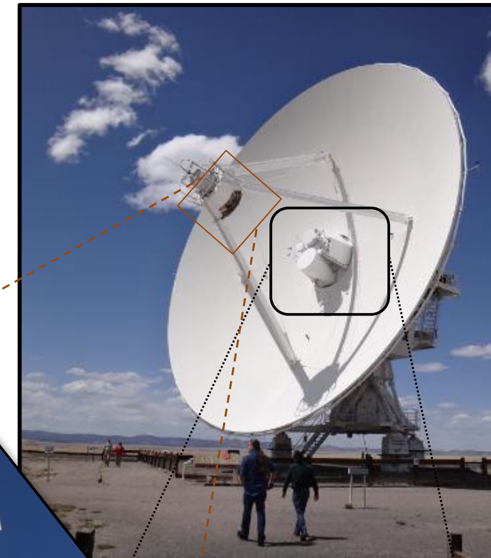
Image credit: NRAO/AUI/NSF

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



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 **14 arcmin**
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

- Re-configure every ~4 months
- Proposal deadlines: 6 months
  ~ 1st of February, August

Next proposal deadline:
February 1st 2021
for **B config** (2021B)

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)

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]			
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*] = $50 / \nu_{GHz}$

11.3 deg

2.4 deg

Configuration	A	B	C	D
B_{max} (km[1])	36.4	11.1	3.4	1.03
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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}

θ_{PB} [*arcmin*] = 42 / ν_{GHz}

11.3 deg

2.4 deg

28 arcmin

56 arcsec

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]			
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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

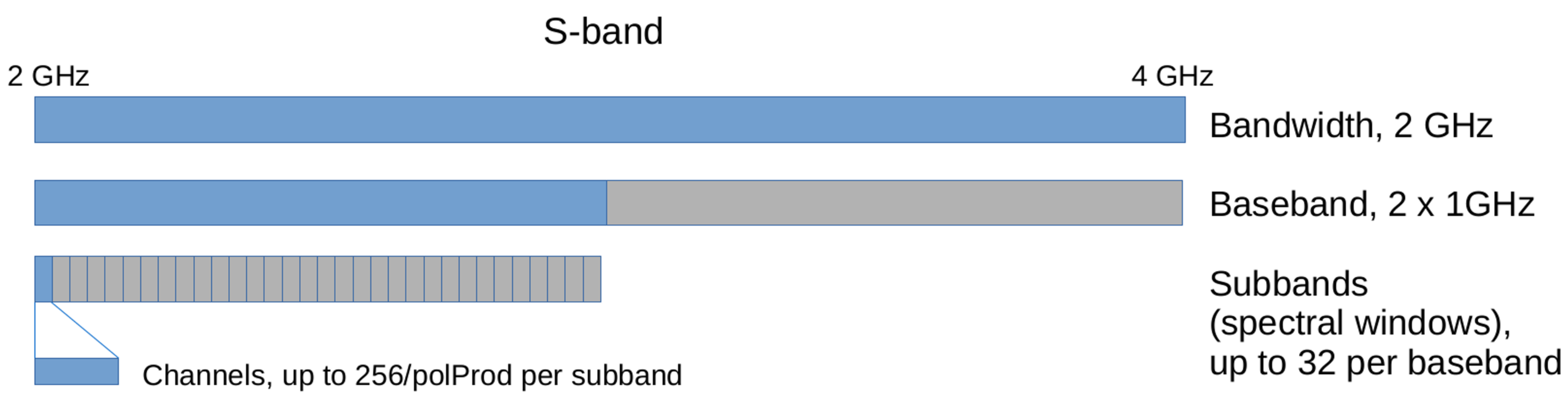
The VLA's Correlator (WIDAR)

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).

Correlator tuning example



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.

General Observing (GO)

Standard observing setups available to anyone:

- Standard bands L/S/C/X/Ku/K/Ka/Q (1-50 GHz), P-band (224-480 MHz)
- Up to 8-GHz (3-bit mode) or 2-GHz (8-bit mode) bandwidth
  - 16384 spectral channels with 2 MHz spectral resolution (full polarization)
- Independent sub-band tuning: from 31.25 kHz to 128 MHz bandwidth each
- Mix of 3-bit and 8-bit modes (e.g. 3-bit for continuum, 8-bit for line)
- Three simultaneous, fully independent subarrays (8-bit continuum only)
- Solar observing
- On-The-Fly-Mosaicking at low frequency (P, L, S, and C bands)
- Pulsar observing: phase-binned and coherent de-dispersion (except 4-band)
- Frequency averaging (to reduce data rates) up to a factor of 4

Dump times as fast as 50msec, allowed data rates up to 60 MB/s (216 GB/hr).

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

Post processing of VLA data

https://casa.nrao.edu/

- ***CASA*** is NRAO's data reduction software for the VLA:
  - Designed to handle wide-band VLA and ALMA data, plus other radio telescopes
  - Uses C++ tools under-the-hood, with iPython interface for access to easy data manipulation
  - Current versions:

    CASA 5.7 (Python 2) / CASA 6.1 (Python 3)

CASA Common Astronomy Software Applications

CASA is available as a self-contained package, *or* CASA tasks can now be imported into your own customized Python/iPython environment!
(CASA 6.0 and beyond)

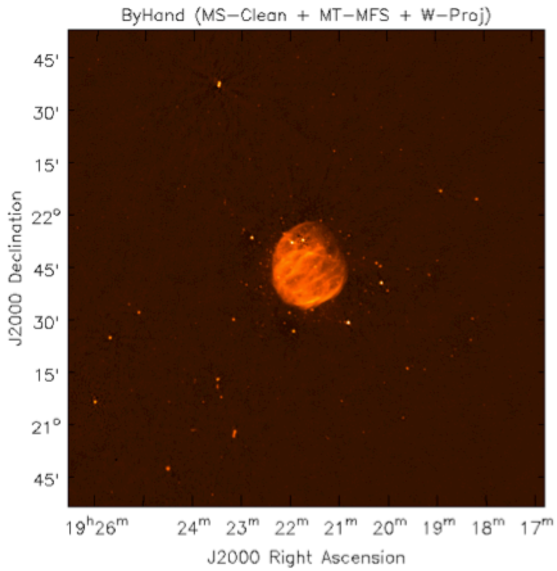
Developed by an international consortium composed of:

NRAO ESO NAOJ ASIAA ALMA CSIRO ASTRON JIVE Joint Institute for VLBI ERIC

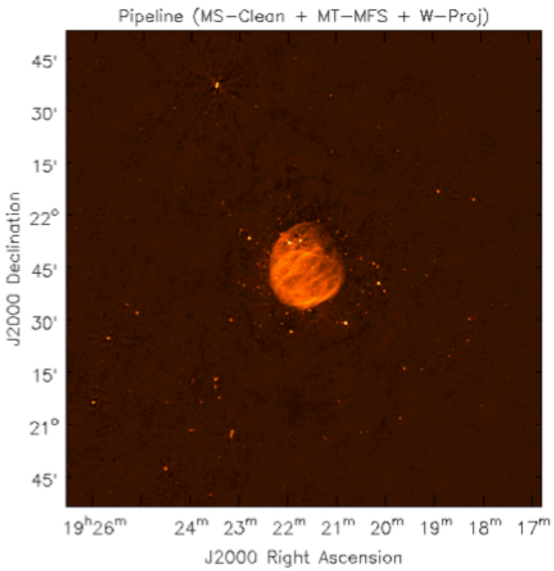
VLA Calibration Pipeline

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

Supernova remnant G55.7+3.4



hand-flagged and calibrated



pipeline-calibrated

RMS is within 10%

Science-Ready Data Products (SRDP)

Now available! (for some observing modes)

- Provide calibrated (and eventually imaged) PI observations
- Provide expertise required for radio data processing
  → users can focus on their science
- Make radio astronomy more accessible to non-radio-experts
- Intended ultimately for all NRAO instruments

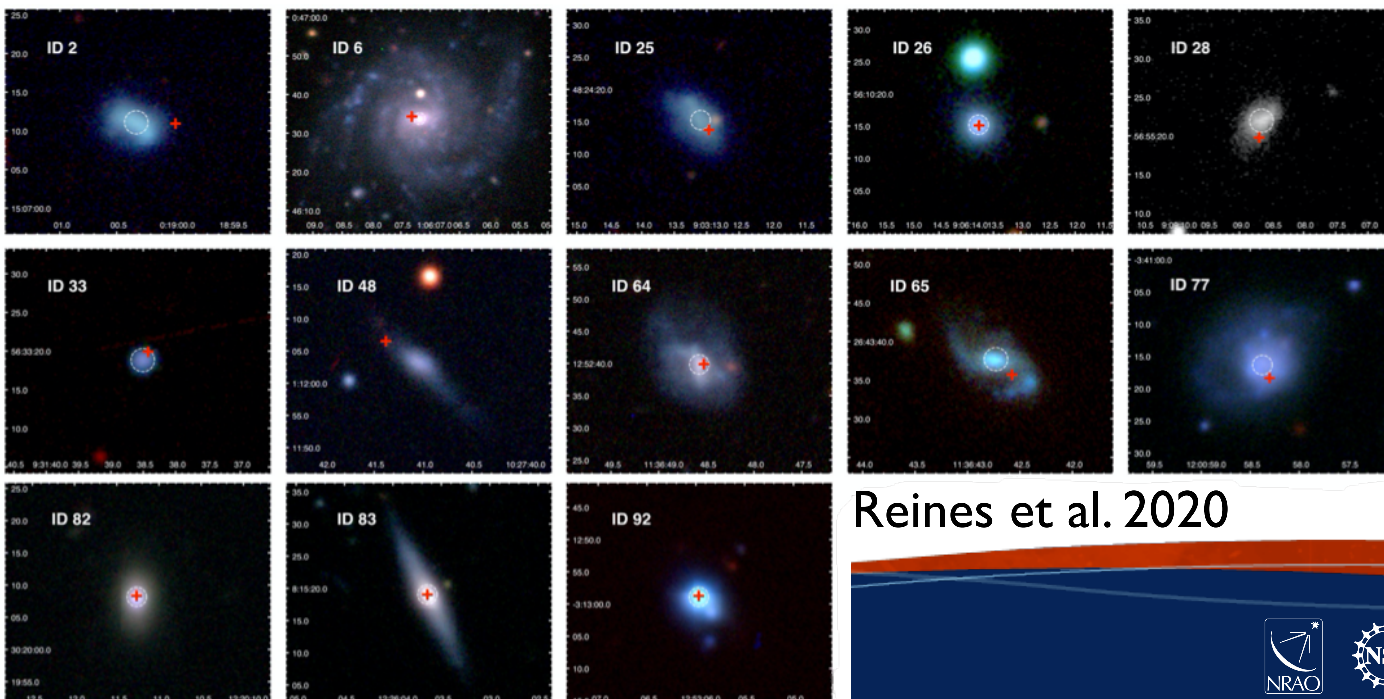
SRDP project will cover increasing functionality over the next several years.
Currently available for:

- C-band and higher frequencies (≥ 4 GHz)
- continuum science only
- pipeline-compatible data (e.g. correct scan intents, calibrator cycles)
- setups following all VLA observing guidelines

Some recent VLA Science Highlights

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

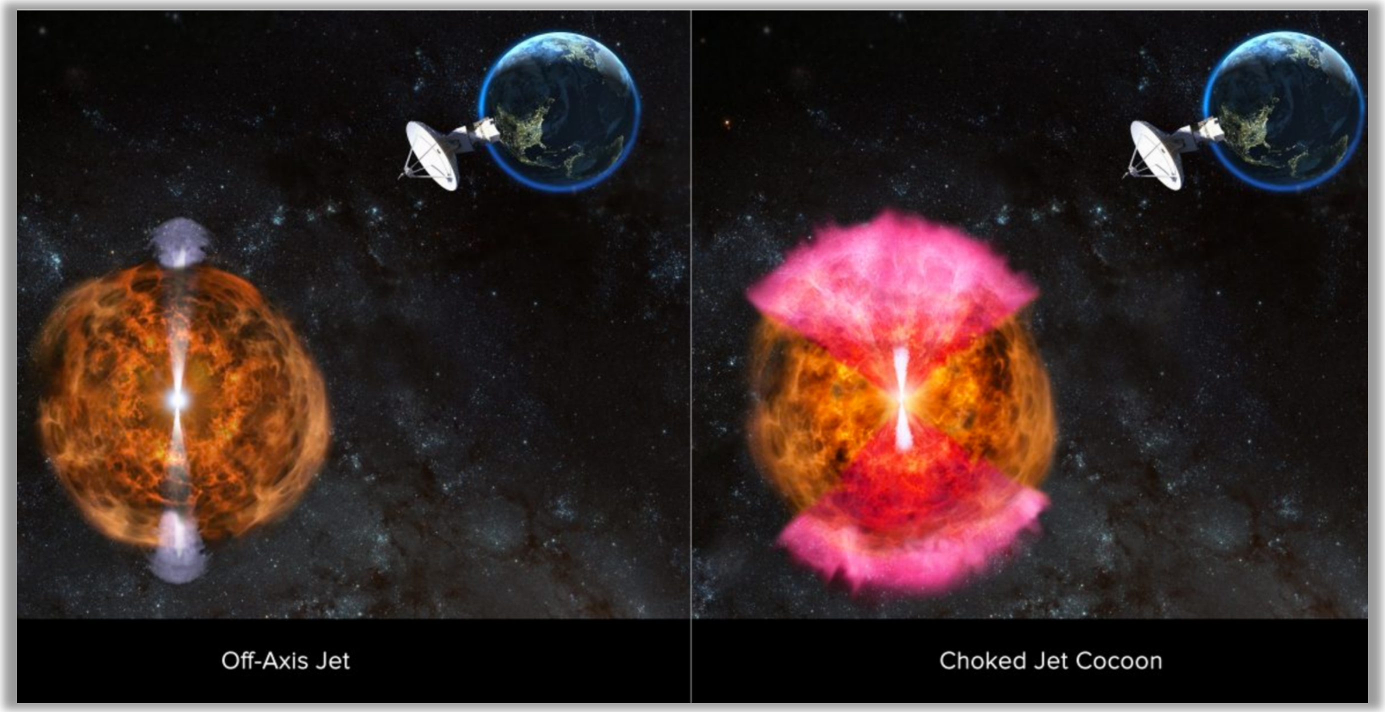


Reines et al. 2020

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)

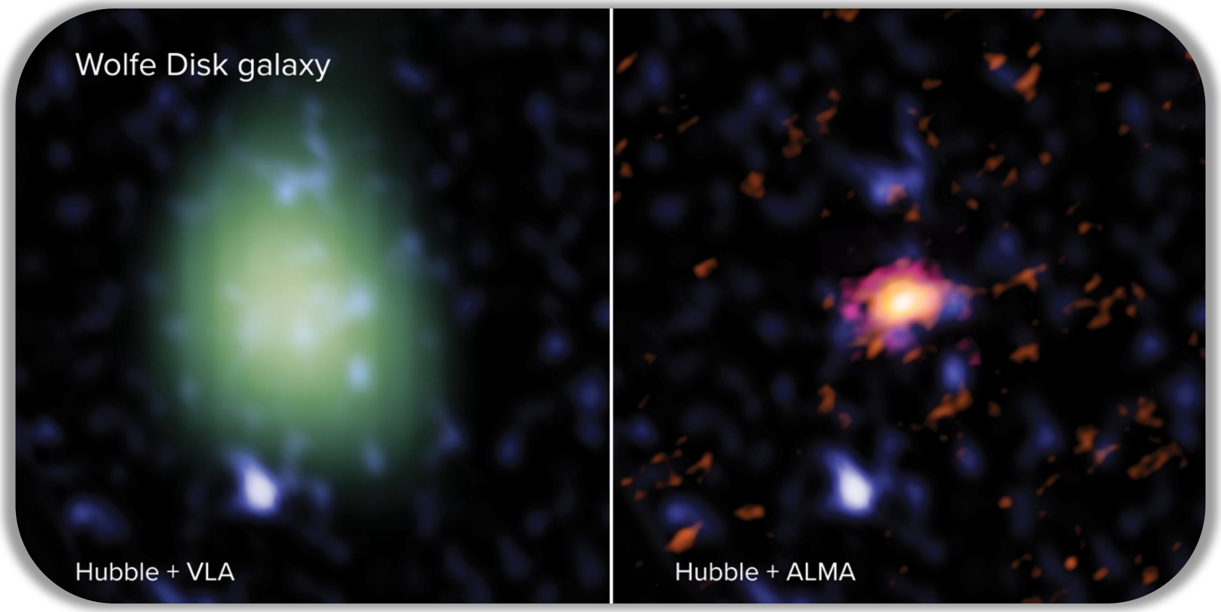


NRAO/AUI/NSF: D. Berry

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

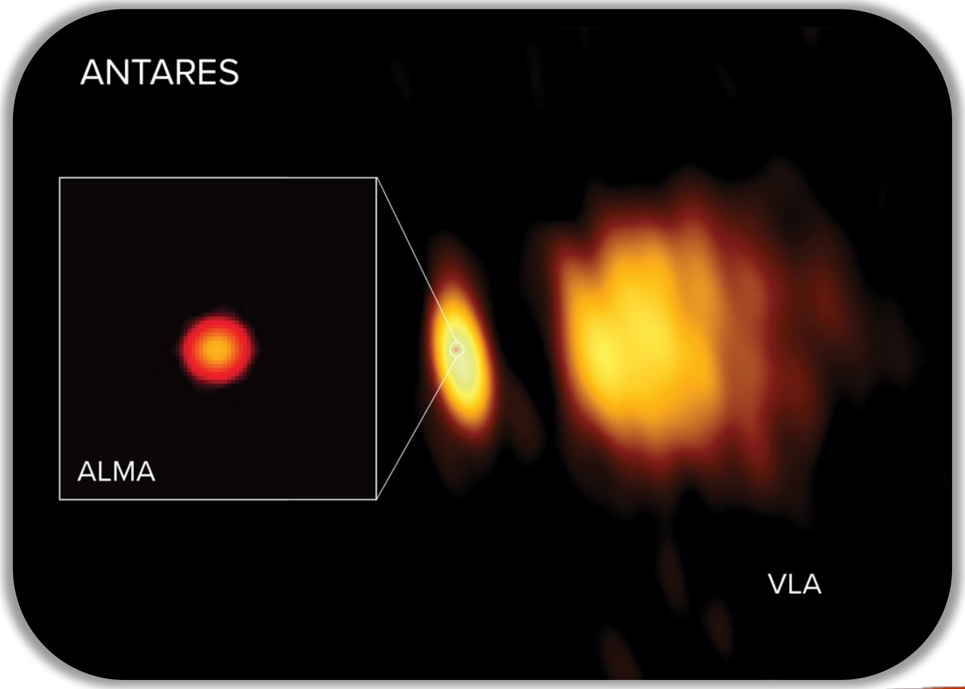


ALMA (ESO/NAOJ/NRAO), M. Neeleman; NRAO/AUI/NSF, S. Dagnello; NASA/ESA Hubble

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