Very Long Baseline Array (and ngVLA)

George Moellenbrock, NRAO

(Anna Kapinska, Frank Schinzel, Walter Brisken, Eric Murphy)

VLBA Interferometer

VLBA antennas are spread across USA with the longest baseline between Hawai'i and St Croix locations.

→ 10 antennas, with longest baseline 8,611km (5,350mi)
→ each location has one antenna
→ no configurations as such, but free selection of dishes

→ frequency coverage 0.3 GHz – 96 GHz (90cm – 3mm)
→ resolution 0.17 – 22 mas

(Kapinska, Schinzel)

VLBA Interferometer

Realtime Photos for All Sites

http://www.vlba.nrao.edu/sites/SITECAM/allsites.shtml

VLBA data correlator: located in Socorro, NM

→ data from each antenna are digitalised locally, recorded and physically sent to Socorro

→ data correlation to the specifications of PI

→ supporting multiple phase centres, and correlations “per mode”

(Kapinska, Schinzel)

VLBA Frequency Bands

https://science.nrao.edu/facilities/vlba/docs/manuals/oss/bands-perf

[1] Receiver Band Designation (*)	[2] Nominal Frequency Range [GHz]	[3] Typical Zenith SEFD [Jy]	[4] Center Frequency for SEFD [GHz]	[5] Typical Peak Gain [K Jy^{-1}]	[6] Baseline Sensitivity $\Delta S^{512,1m}$ [mJy]	[7] Image Sensitivity $\Delta I_m^{4096,8h}$ [μJy $beam^{-1}$]
90 cm (a)	0.312 - 0.342	2742	0.326	0.077	111	(i) 266
50 cm (a,b)	0.596 - 0.626	2744	0.611	0.078	443	(j) 753
21 cm (c)	1.35 - 1.75	289	1.438	0.110	2.9	(k) 10
18 cm (c)	1.35 - 1.75	314	1.658	0.112	3.2	(k) 11
13 cm	2.2 - 2.4	347	2.269	0.087	3.5	(k) 12
13 cm (d)	2.2 - 2.4	359	2.269	0.085	3.6	(k) 12
6 cm (e)	3.9 - 7.9	210	4.993	0.119	2.1	5
7 ghz (e)	3.9 - 7.9	278	6.660	0.103	2.8	7
4 cm	8.0 - 8.8	327	8.419	0.118	3.3	8
4 cm (d)	8.0 - 8.8	439	8.419	0.105	4.4	11
2 cm	12.0 - 15.4	543	15.363	0.111	5.5	13
1 cm (f)	21.7 - 24.1	640	22.236	0.110	6.5	16
24 ghz (f)	21.7 - 24.1	534	23.801	0.118	5.4	13
7 mm	41.0 - 45.0	1181	43.124	0.090	12	29
3 mm (g)	80.0 - 90.0	4236	86.2	0.033	(h) 60	(l) 184

Single receiver

13/4-cm (S/X) dichroic system

C-band simultaneous tunings anywhere in 4-8GHz band

C-band → best sensitivity

(Kapinska, Schinzel)

VLBA Resolution & Data rates

Milli-acrsecond resolution

Observing band [cm]:	90	50	21	18	13	6	4	2	1	0.7	0.3
θ_{HPBW} [mas]:	22	12	5.0	4.3	3.2	1.4	0.85	0.47	0.32	0.17	0.12

22 mas in P band

120 µas at 3mm

Data rates: up to 4Gbps

→ in principle allows for broadband (frequency) observing

→ but full polarisation products will reduce the bandwidth (and max number of correlator passes)

→ some bands allow only 32 Mbps – 2Gbps (the lowest ones)

(Kapinska, Schinzel)

VLA/VLBA Proposals & Observations

Two aims & One place where to do both: https://my.nrao.edu

Regular VLA/VLBA Proposal Calls are 2x each year: 1st Feb & 1st Aug

Ad-hoc **DDT proposals** (Director Discretionary Time) can be submitted at any time (but need good reason why can't wait for regular call)

Upcoming 2024A semester:

→ deadline around 1st Aug

→ VLBA observing: 1 Feb – 1 Aug 2024

→ VLA observing dependent on configuration changes;
in 2024A: B, C configurations & observing 25 Jan – 16 Sep 2024

(Kapinska, Schinzel)

Needed: my.nrao.edu account

Provides access to various services:

– Proposal preparation

  - creating and submitting new proposals
  - access to all proposals you are associated with regardless of your role (PI, co-I, contact author, reviewer)

– Data Processing on NM computing cluster

– VLA Observation Preparation Tool (OPT)

– VLA,VLBA, GBT data archive

(Kapinska, Schinzel)

Extended VLBA: Y1/Y27, HSA, GMVA, etc

VLBA + VLA/Y1
→ can use a single VLA antenna (Y1) with standard VLBA
→ offers shortest baseline on VLA – VLBA/PT station: ~50km

HSA (High Sensitivity Array)
→ VLBA, VLA/Y27, GBT, Effelsberg combined into a single interferometer
→ can use any combination of the stations
→ note that GBT time is very limited, Effelsberg support 5GHz and above

GMVA (Global 3mm VLBI Array)
→ combines: 8 VLBA stations (HN and SAC excluded), GBT, Effelsberg, Pico Veleta, Onsala, Metsaehovi, Yebes, and Korean VLBI Network (KVN)
→ phased ALMA can be requested
→ European part of the GMVA coordinated by MPIfR, Germany

EVN (European VLBI Network) and Global cm VLBI
→ a VLBI network of stations operated by an international consortium of institutes: https://www.evlbi.org/
→ VLBA can be requested for observations

(Kapinska, Schinzel) https://science.nrao.edu/facilities/vlba/docs/manuals/oss/vlba-plus

Joint Proposals

VLBI proposals submitted via NRAO:
– pure VLBA
– VLBA+VLA
– HSA if each telescope used for VLBI only (otherwise separate proposals)
– GMVA

EVN proposals submitted via European system
(https://www.evlbi.org/call-proposals)

Joint Proposals

- **radio**
  – Joint between VLA, GBT and VLBA require separate proposals for each (with the same scientific justification), except as elements of HSA.
  – Joint Proposals with ALMA → single proposal only.
- **multi-wavelength**
  – Joint proposals with HST, Chandra, XMM-Newton, Swift, Fermi
  – Each has own Memorandum with NRAO:
  https://science.nrao.edu/observing/call-for-proposals/2023b/joint-proposals
  – can request time with either telescope in joint proposals

(await 2024A CfP for up-to-date details)

(Kapinska, Schinzel)

VLBA Resources

- NRAO Science Helpdesk: https://help.nrao.edu
- Call for Proposals: https://go.nrao.edu/cfp ← ***Coming July ~1***
  (pre-Announcement distributed yesterday!)
- VLBA Observational Status Summary (OSS):
  https://go.nrao.edu/vlba-oss
- VLBA Proposing Guide (including HSA, GMVA):
  https://go.nrao.edu/vlba-prop-doc
- VLBA Archive data:
  https:// data.nrao.edu

Proposal Deadline 2024A

Monday, 1 Aug 2023, 21:00 UTC

(Kapinska, Schinzel)

Resources

Student Observing Support (SOS) Program
→ competitive student funding in support of successful highly ranked proposals (NRAO)
https://science.nrao.edu/opportunities/student-programs/sos

Publication support
→ NRAO provides publication support for qualified papers, proportionate to the page charges of qualified authors
https://library.nrao.edu/pubsup.shtml

Observing support pages
→ one stop page for guides for process of proposing for and using NRAO observing time
https://science.nrao.edu/observing

Science helpdesk – contact us, ask questions: https://help.nrao.edu/

(Kapinska, Schinzel)

VLBA technical developments to date

- VLBA construction began in 1984
- Inaugurated Aug 20, 1993 – almost 30 years ago!
- No major upgrade project such as EVLA, but many meaningful improvements made:
  - Tape recorder → two tape recorders → Mark5A → Mark5C → Mark6
  - Hardware correlator → DiFX software correlator
  - Max data rate: 128 Mbps → 4096 Mbps
  - Addition of W-band (86 GHz) receiver
  - Sensitivity upgrade of K-band (22 GHz) receiver (MPIfR funded)
  - C-band upgrade from 4.8-5.1 GHz → 4-8 GHz based on EVLA project (MPIfR funded)

(Brisken)

Ongoing developments

- ngVLA is NRAO's long term vision
  – Will replace both VLA and VLBA with one new instrument
  – Need to keep VLBA operating well and competitively until this transition occurs (mid 2030s)
- Several projects are in development now
  – New digital back-end
  – High-speed fiber network and related infrastructure
  – New GNSS antennas and receivers
  – New synthesizers
- Other developments are being considered (not yet funded and not covered here)
  – 8-36 GHz ultra-wideband receiver
  – Wide-band LO/IF system
  – Updated antenna control units

(Brisken)

VLBA New Digital Architecture (VNDA)

- Replace aging RDBEs with new, extensible architecture
  - RDBEs are becoming difficult to maintain
  - They have some design deficiencies that impact science and operations
- Driving VNDA requirements:
  - Sample at > 8 bits per sample
  - Avoid sampler resets to improve delay stability
  - No user-visible tuning restrictions within bands
  - One personality supporting all PFB & DDC modes
    - To be fully backward compatible with RDBEs
  - Use of commercially available equipment to degree possible
  - Use standard interfaces wherever possible
  - Extensible: support user-provided guest equipment
    - E.g., spectrometer, pulsar backend, transient detector, …

(Brisken)

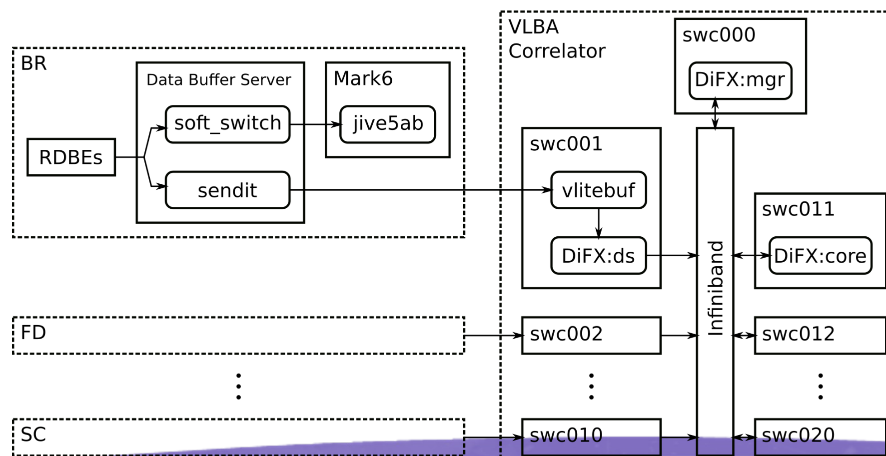
VNDA project status

- Engineering change being considered to reduce development time and project costs
  - No change of scope or capabilities is being considered
- First laboratory tests anticipated in late CY2023
- First on-the-sky tests anticipated in mid CY2024
- Project completion targeting early CY2025

(Brisken)

High-speed fiber networks

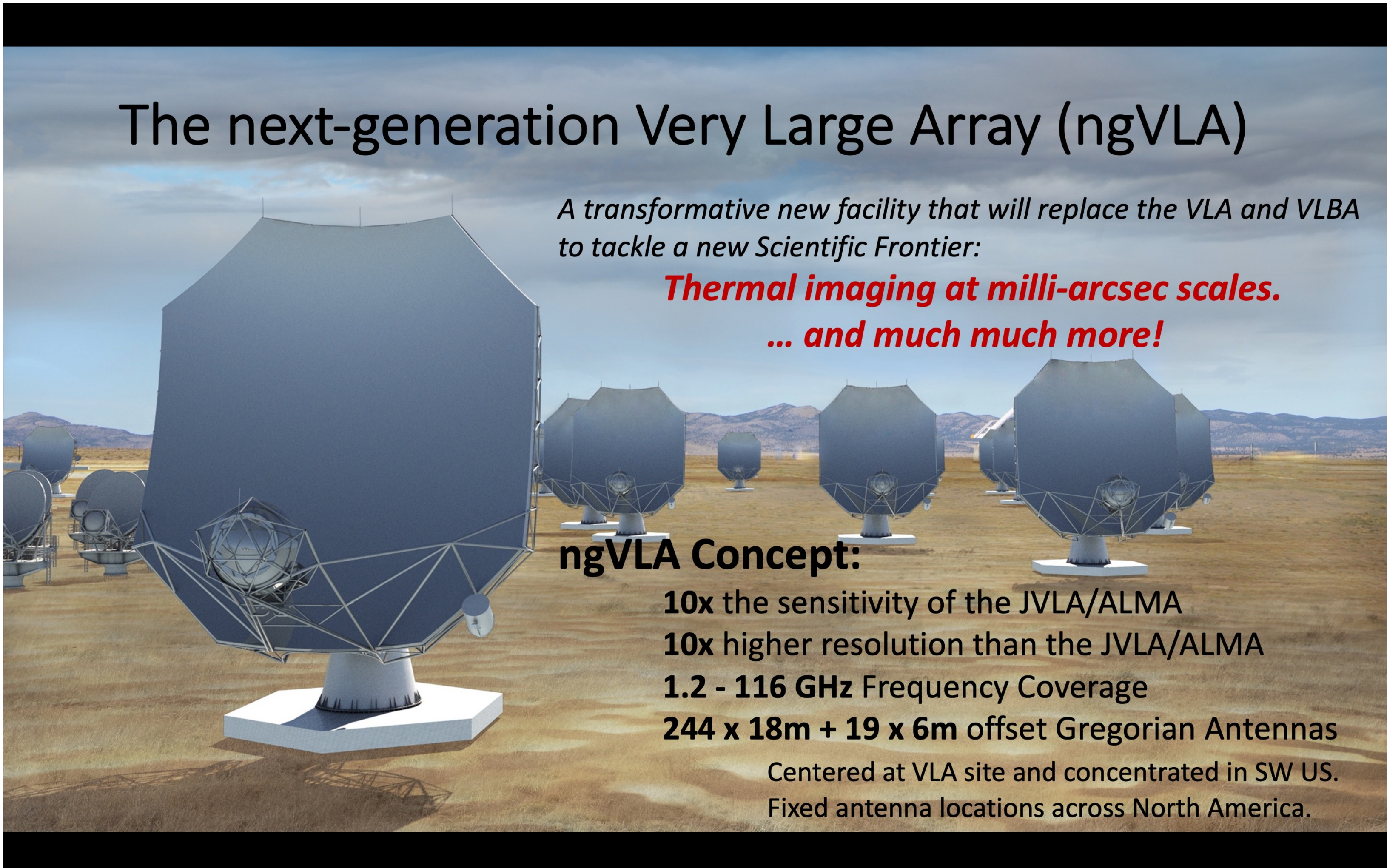
- NSF award funded deployment and initial operations Aug 2018 to Aug 2023
  - 4 sites at 200 Mbps, 2 sites at 10 Gbps and 4 somewhere in middle
  - Real-time operations at 128 Mbps can be supported
  - Real-time diagnostic testing is now routinely done
- Near-term goal: increase to support 512 Mbps observing data rates
  - Could transfer 1+ sub-bands of data for any operational configuration
  - Could lead to initial *quick-look* science data
- Program goal: support full real-time operations
  - Using current VLBA: 4.2 Gbps per site
  - Initial VNDA operations: up to 8.4 Gbps per site
  - Target 10 Gbps at all antennas



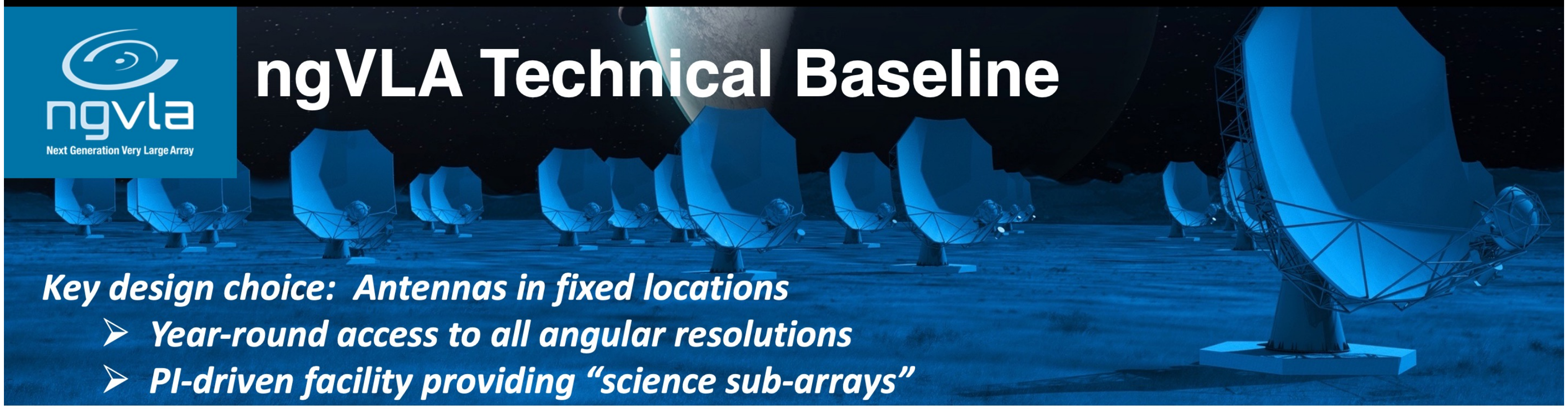
(Brisken)

Kitt Peak fire, June 17, 2022

- Downtime of 232 days; back online early Feb, 2023
- Network restoration in progress; currently relying on ViaSat


The next-generation Very Large Array (ngVLA)
A transformative new facility that will replace the VLA and VLBA to tackle a new Scientific Frontier:
Thermal imaging at milli-arcsec scales.
… and much much more!
ngVLA Concept:
10x the sensitivity of the JVLA/ALMA
10x higher resolution than the JVLA/ALMA
1.2 - 116 GHz Frequency Coverage
244 x 18m + 19 x 6m offset Gregorian Antennas
Centered at VLA site and concentrated in SW US.
Fixed antenna locations across North America.

(Murphy)



ngVLA Technical Baseline

Key design choice: Antennas in fixed locations

- *Year-round access to all angular resolutions*
- *PI-driven facility providing "science sub-arrays"*

- **Frequency Range**: 1.2 - 116 GHz
- **Main Array**: 244 x 18m offset Gregorian Antennas
  - **Core**: 114 antennas; B_{max} = 4.3 km
  - **Spiral**: 54 antennas; B_{max} = 39 km
  - **Mid**: 46 antennas in NM, AZ, TX, MX; B_{max}=1070 km
  - **Long**: 30 antennas across continent; B_{max}= 8860 km
- **Short Baseline Array**: 19 x 6m offset Greg. Antennas
  - Use 4 x 18m in **Total Power mode** to fill (*u*,*v*) hole

Band #	freq. range (GHz)
1	1.2 - 3.5
2	3.5 - 12.3
3	12.3 - 20.5
4	20.5 - 34
5	30.5 - 50.5
6	70 - 116

Correlator / Beamformer	Requirement (design)
digital efficiency	>95%
narrowest channel	<1 kHz
total # channels	>240,000
sub-band width	<250MHz (218.75)
total bandwidth	>14GHz/pol (20)
# formed beams	10

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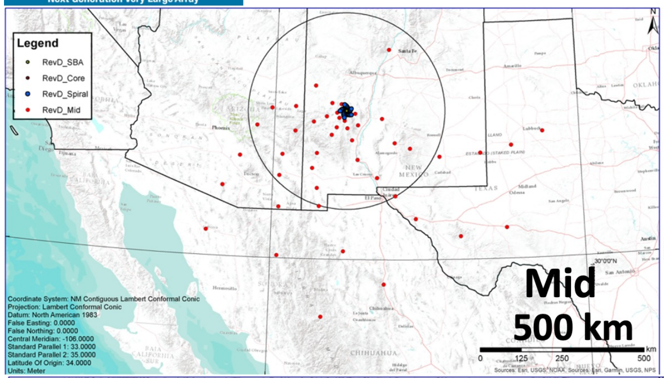
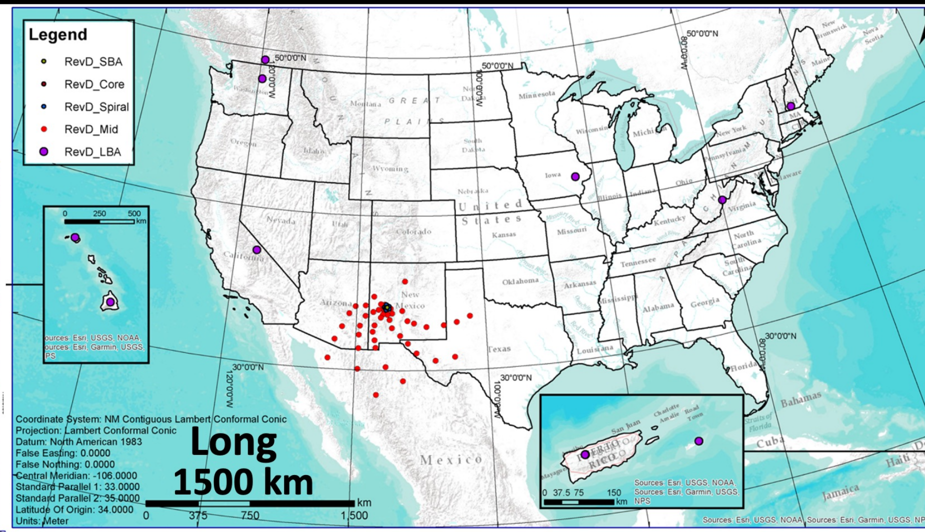
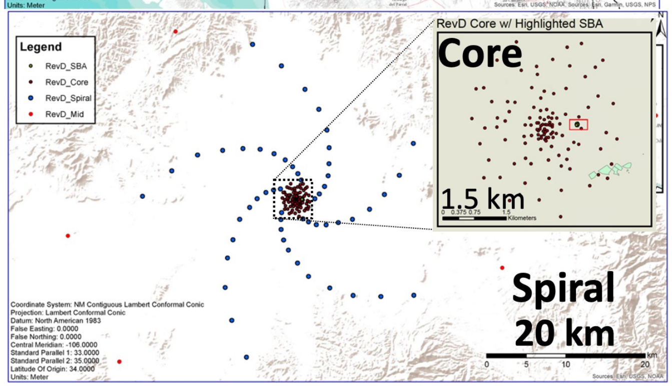
(Murphy)

Distribution of Antennas







Long Baseline Antenna Locations

Qty	Location	Notes
3	Puerto Rico	Arecibo Site
3	St. Croix	VLBA Site
3	Kauai, HI	Kokee Park Obs.
3	Hawaii, HI	not Mauna Kea Site
3	Hancock, NH	VLBA Site

Qty	Location	Notes
3	Green Bank, WV	GBO
3	Brewster, WA	VLBA Site
3	Penticton, BC	DRAO
3	North Liberty, IA	VLBA site
3	Owens Valley, CA	VLBA site

(Murphy)

S/W and Computing Considerations

- **Operations Concept**: HLDP (High-Level Data Product) Telescope
  - Both for 1st Observations and Archive projects.
- **Post Processing**: Analysis shows that storing the raw visibilities will be tractable when ngVLA goes into operations.
  - Data processing is post-facto, with system sized for average throughput.
  - Average Data Rate – 7.6 GB/s. Designed for 320 GB/s peak.
  - 4 hr. observation – 109 TB. Requires ~1000 cores to process in a few days.
- **Computing:** 2B Core-hr: Challenging, but can be met w/ COTS cluster.
  - Set by time resolution, spectral resolution, and multi-faceting in imaging
  - Some low-frequency, full-beam, AW-projection cases restricted in early operations.

(Murphy)

Project Timeline

ngvla
Next Generation Very Large Array

Astro 2020
Decadal Survey on Astronomy and Astrophysics

2019 · 2021 · 2024 · 2027 · 2031 · 2038

- 2019: ngVLA Submission to Astro2020
- 2021: Astro2020 Recommendation Published
- Submit ngVLA Proposal to NSF/MREFC
- 2024: Prototype Delivered to VLA Site
- 2027: Complete NSF/MREFC FDR
- ngVLA Construction →
- 2031: Initiate ngVLA Early Science (> VLA capabilities)
- 2038: Achieve Full Science Operations

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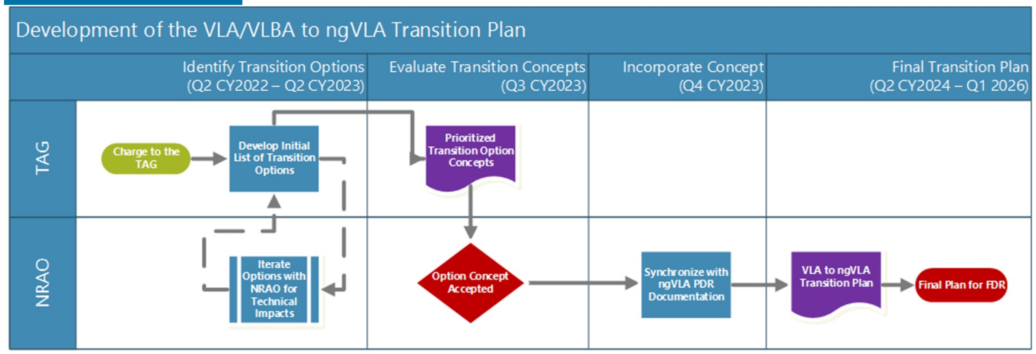
VLA/VLBA → ngVLA Transition Plan Development

ngvla
Next Generation Very Large Array



Transition Advisory Group

- **Alessandra Corsi (Texas Tech) – Co-Chair**
- **Joe Lazio (Caltech/JPL) – Co-Chair**
- Stefi Baum (Manitoba)
- Simona Giacintucci (NRL)
- George Heald (CSIRO)
- Ian Heywood (Oxford)
- Daisuke Iono (NAOJ)
- Megan Johnson (USNO)
- Michael Lam (RIT)
- Adam Leroy (OSU)
- Laurent Loinard (UNAM)
- Leslie Looney (Illinois)
- Lynn Matthews (MIT/Haystack)
- Ned Molter (UC Berkeley)
- Eva Schinnerer (MPIA)
- Alex Tetarenko (Texas Tech)
- Grazia Umana (INAF)
- Alexander van der Horst (GWU)
- Eric Murphy (ex-officio)
- Trish Henning (ex-officio)

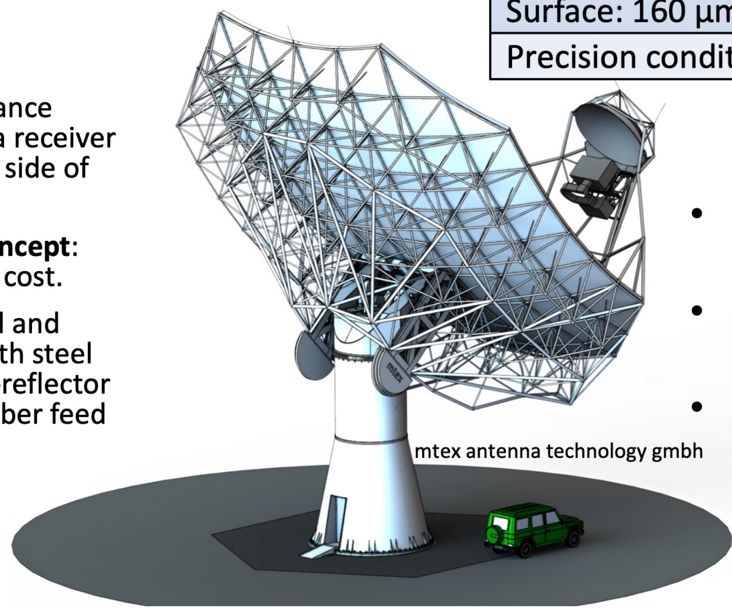
Date	Milestone
Q1 CY2022	The NRAO Internal Technical Analysis Team is formed and charged.
Q2 CY2022	Initial transition options documented for distribution to the TAG by the NRAO Internal Technical Analysis Team.
Q2 CY2022	Transition Advisory Group (TAG) formed and charged.
Q2 CY2023	Transition Option Concepts document delivered to the NRAO from TAG.
Q3 CY2023	Selected Transition Concept synchronized with ngVLA PDR documentation.
Q4 CY2025	Final Transition Plan completed and included as part of FDR documentation.

(Murphy)

Main Antenna Development

Key Specifications	
18m Aperture	Offset Gregorian
Shaped Optics	3° Slew & Settle in 7 sec
Surface: 160 μm rms	Reference pointing: 3” rms
Precision conditions:	Total efficiency >80% (X..Q)

- **Feed Low**: Maintenance requirements favor a receiver feed arm on the low side of the reflector.
- **Mount and Drive concept**: Chosen for life-cycle cost.
- **Materials:** machined and bonded Al panels with steel BUS, composite sub-reflector and mostly carbon fiber feed arm.



mtex antenna technology gmbh

Status

- Prototype under construction in Germany & Spain
- Delivery to VLA site expected in mid 2024
- Testing at 3 cm and 7 mm, including correlation with VLA antennas

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(Murphy)

- *"This event has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004719"*

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