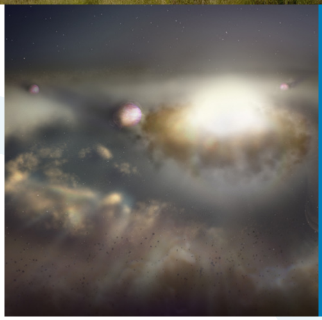


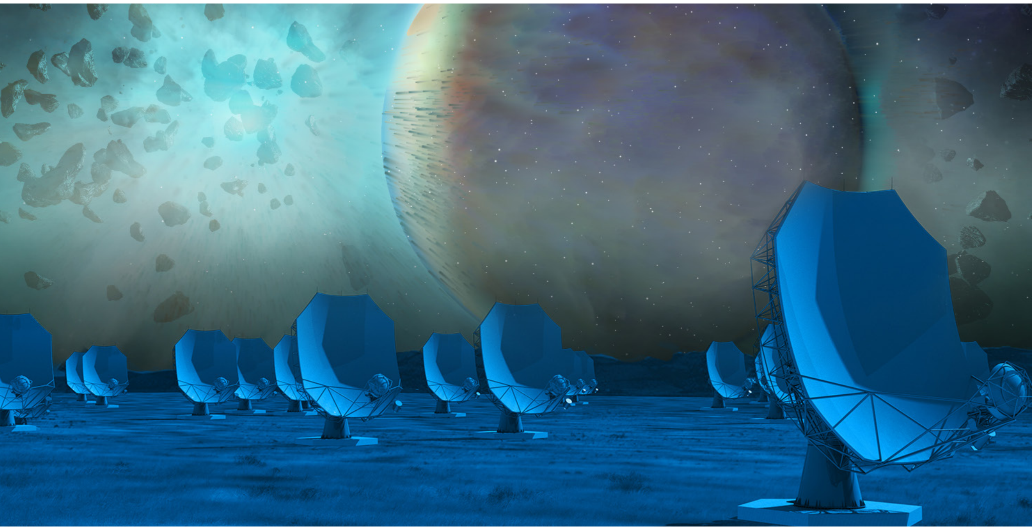
ngvla

Next Generation Very Large Array

The next-generation Very Large Array will directly image the formation of Solar system analogues and Earth-like planets, probe the initial conditions for life with astrochemistry, characterize the assembly, structure, and evolution of galaxies, test theories of gravity with Galactic center pulsars, reveal the explosive universe through multi-messenger discoveries, and more.

Technical Overview

The ngVLA is a radio telescope that will be comprised of an array of 244 antennas each 18 m in diameter, supplemented with a short baseline array of 19 antennas each 6m in diameter. Each fixed antenna is outfitted with front ends spanning 1.2-50.5 and 70-116 GHz. The array achieves high surface brightness sensitivity and high-fidelity imaging on ~1" to sub-mas angular scales by having a large fraction of the total collecting area randomly distributed in the array core with spiral arms out to ~1000 km baselines. Extended baselines reaching across North America will enable sub-mas imaging capabilities, sampling a broad range of scales for stand-alone sub array use, as well as for integrated operation with the main array.



Timeline

MID-2021	NSF Awards Funding for ngVLA Antenna Prototype
LATE-2021	ngVLA Strongly Endorsed in Astro2020 Decadal Survey Report
MID-2022	Completed Technical Conceptual Design Review
MID-2024	Prototype Antenna Installed
MID-2028	Complete NSF – MREFC Final Design Review
LATE-2028	Start ngVLA Construction
MID-2031	Initiate ngVLA Early Science
MID-2037	Achieve ngVLA Full Science Operations

ngVLA Design Parameters

Receiver Band	1	2	3	4	5	6
Frequency Range (GHz)	1.2-3.5	3.5-12.3	12.3-20.5	20.5-34	30.5-50.5	70-116
Max Bandwidth (GHz)	2.3	8.8	8.2	13.5	20	20
Sampler Resolution (bits)	8	8	8	8	8	8
Noise Figure (T_{sys}, K)	17.07	22.00	24.40	32.42	47.41	65.37
Antenna SEFD (Jy)	232.3	264.8	292.2	397.3	602.8	1136.3

Parameter	Description/Capability
Antennas	244 x 18 m, 19 x 6 m
Continuum Bandwidth	Up to 20 GHz x 2 pol
Finest Spectral Resolution @ 30 GHz	0.01 km/s (1 kHz)
Maximum Angular Resolution	0.2 mas @ 30 GHz
Maximum Baseline	8860 km
Continuum Sensitivity (60 min, max BW)	0.14 to 0.4 μJy/bm, NA weights
Spectral Line Sensitivity (60 min, 10 km/s)	19 to 35 μJy/bm, NA weights
Imaging Sensitivity Ratio (rms/rmsNA)	1.5x to 2.5x

How does the ngVLA complement and extend the VLA, the Atacama Large Millimeter/submillimeter Array (ALMA), and the Square Kilometre Array Phase 1 (SKA1)?

The VLA has enabled transformative science at radio wavelengths since the late 1970's with 27 reconfigurable, 25 m diameter antennas having 36 km maximum baselines, and continuous frequency coverage spanning 1-50 GHz since December 2012. The ngVLA markedly advances these capabilities with 244, 18 m diameter dishes extending to 8860 km baselines to support transformative science across 1.2 – 116 GHz.

ALMA is optimized for submillimeter wavelength observations via the atmospheric windows accessible from a dry site at 5000 m elevation on the northern Chilean plateau. The ngVLA (2100 m elevation) 214 antenna main array complements these capabilities by operating at and below the 3 mm band, providing ~10x more sensitivity and 60x longer baselines.

SKA1 will be the premier radio interferometer at decimetric wavelengths, with a maximum baseline of ~150 km and a frequency range spanning 350 MHz – 14 GHz. The ngVLA is being optimized for complementary frequencies beyond the highest SKA1 band and will achieve much higher angular resolution.

ngVLA PURPOSE

Inspired by the dramatic discoveries from the Jansky VLA, VLBA, and ALMA, NRAO and the international science community are currently designing a large collecting area radio telescope that will open new discovery space from protoplanetary disks to distant galaxies. Building on the superb centimeter observing conditions and existing VLA and VLBA site infrastructure, the ngVLA is an interferometric array with more than an order of magnitude improvement in sensitivity and spatial resolution of the Jansky VLA and ALMA, operating at 1.2 – 116 GHz.

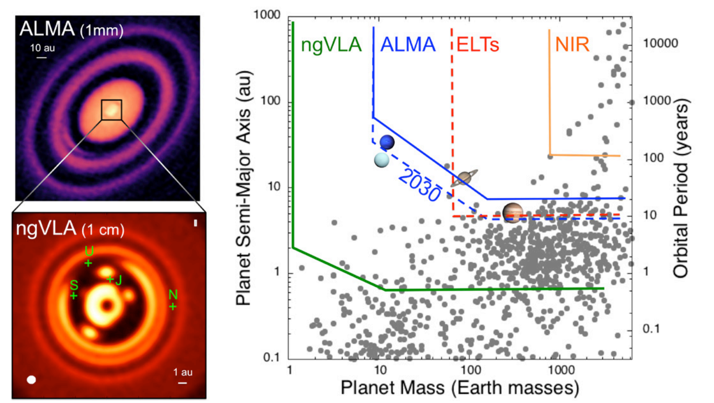
The ngVLA is optimized for observations at wavelengths between the exquisite performance of ALMA at submillimeter wavelengths, and the future SKA1 at decimeter to meter wavelengths, and will be highly complementary with these facilities. The ngVLA will open a new window on the Universe through

KEY SCIENCE GOALS

The ngVLA will have broad impact on many of the high priority goals of modern astrophysics, including the science priorities described in the **Astro2020 Decadal Survey: Pathways to Discovery in Astronomy and Astrophysics for the 2020s**. The ngVLA Science Working Groups have identified five Key Science Goals for the ngVLA through a community-driven exercise led by the ngVLA Science Advisory Council.

Key Science Goal 1: Unveiling the Formation of Solar System Analogues on Terrestrial Scales

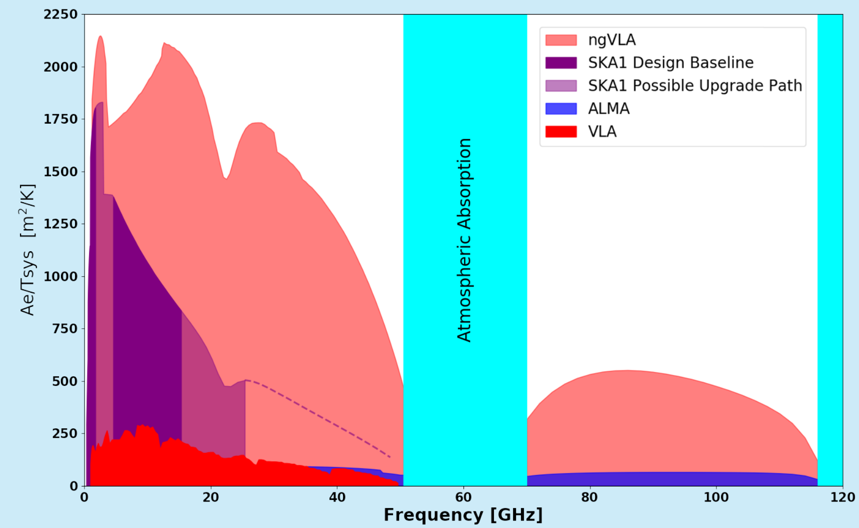
The ngVLA will measure the planetary initial mass function to 5–10 Earth masses and unveil the formation of planetary systems similar to our Solar System by probing the presence of planets on orbital radii as small as 0.5 AU at a distance of 140 pc. The ngVLA will also reveal circum-planetary disks and sub-structures in the distribution of millimeter-size dust particles created by close-in planets and will measure the orbital motion of these features on monthly timescales.



Top left: ALMA 1 mm observations of HD163296 with a resolution of 0.04" (4au at d=101 pc) revealing gaps and rings indicative of the presence of Saturn-like planets (Liu et al. 2018: Zhang et al. 2018). **Bottom left**: Simulated 1 cm ngVLA observations of the innermost 24 au region at 0.01" (1au) resolution, assuming the presence of (J)upiter-, (S)aturn-, (U)ranus-, and (N)eptune- like planets. **Right:** Distribution of exoplanets around mature stars and young planets embedded in circumstellar disks probed by current NIR telescopes (orange box), future ELTs (red box), ALMA & ALMA2030 (blue boxes), and the ngVLA (green box). The ngVLA will discover many hundreds of planets with orbital periods <10 yr, allowing for temporal monitoring and characterization of their orbital motions.

ultra-sensitive imaging of thermal line and continuum emission down to milliarcsecond resolution, and deliver unprecedented broadband continuum polarimetric imaging of non-thermal processes.

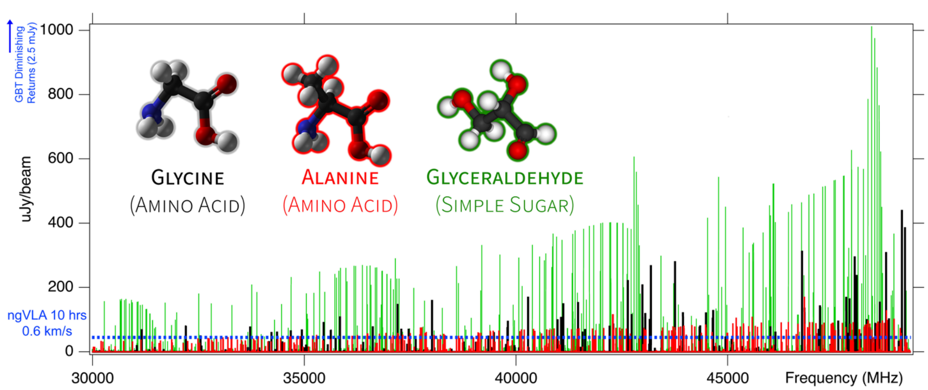
The ngVLA will be the only astronomical research facility that can simultaneously deliver the capability to: unveil the formation of Solar System analogues on terrestrial scales; probe the initial conditions for planetary systems and life with astrochemistry; characterize the assembly, structure, and evolution of galaxies from the first billion years to the present; use pulsars in the Galactic Center as fundamental tests of gravity; and understand the formation and evolution of stellar and supermassive black holes in the era of multi-messenger astronomy.



A sensitivity comparison of radio, mm, and sub-mm dish arrays expected to be operational in the 2030's.

Key Science Goal 2: Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry

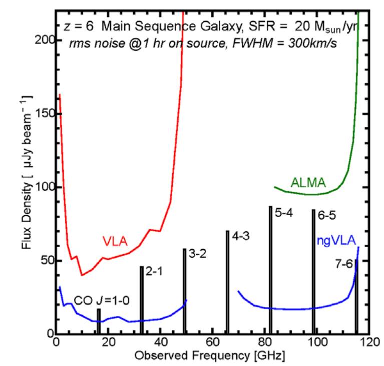
The ngVLA will detect predicted, but as yet unobserved, complex prebiotic species that are the basis of our understanding of chemical evolution toward amino acids and other biogenic molecules. The ngVLA will enable the detection and study of chiral molecules, testing ideas on the origins of homochirality in biological systems. The detection of such complex organic molecules will provide the chemical initial conditions of forming solar systems and planets.

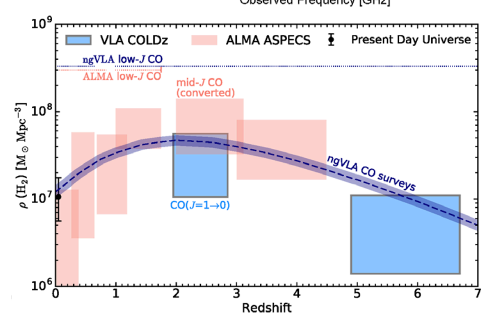


Simulations of three biogenic molecules in a typical hot core source, based on existing upper limits, assuming T= 80 K, dV = 3 km/s, and a 5" source. The ngVLA's sensitivity to detect these lines for the first time in a 10hr integration is shown as a dashed blue line. For comparison, diminishing returns with GBT integration's start around 2.5 mJy; to detect any new molecules below that limit would require 100s to 1000s of hours.

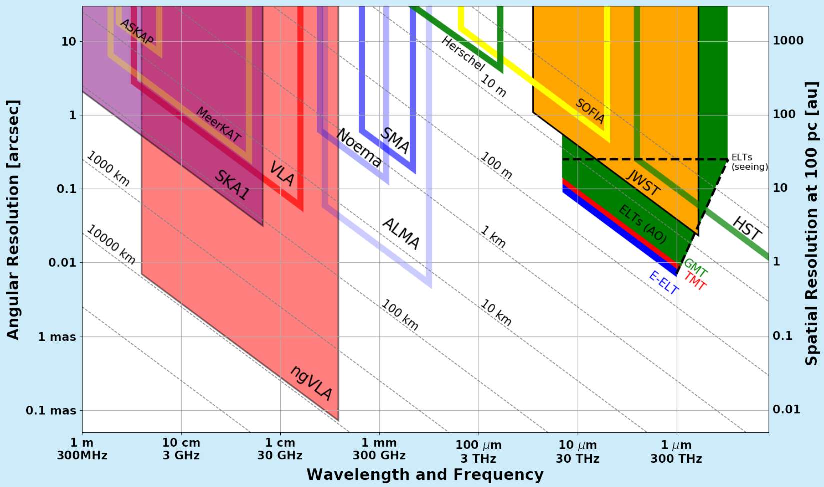
Key Science Goal 3: Charting Assembly, Structure, and Evolution of Galaxies – First Billion Years to the Present

The ngVLA will provide a 10x improvement in depth and area for cold gas surveys in galaxies to early cosmic epochs, and will enable routine sub-kiloparsec scale resolution imaging of the gas reservoirs. The ngVLA will afford a unique view into how galaxies accrete and expel gas and how this gas is transformed inside galaxies by imaging their extended atomic reservoirs and circum-galactic regions, and by surveying the physical and chemical properties of molecular gas over the local galaxy population. These studies will reveal the detailed physical conditions for galaxy assembly and evolution throughout the history of the Universe.

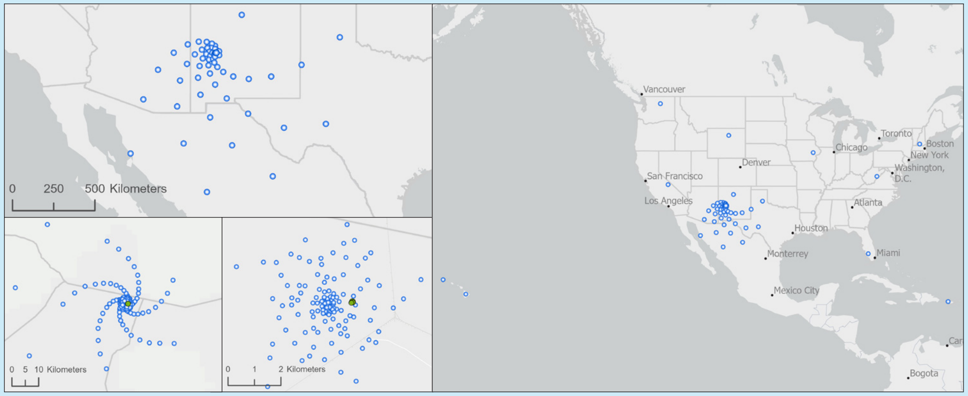




Top right: With its unparalleled sensitivity, the ngVLA will routinely detect molecular gas in "normal" star-forming galaxies at z=6, including the critical low-J transitions that remain inaccessible to ALMA. **Above:** The ngVLA will provide more than an order of magnitude improvement in our knowledge of the cold molecular gas density throughout cosmic time compared to the best efforts possible with the VLA (Riechers, D. et al. 2019) and ALMA (Decarli, R. et al. 2019) by providing direct access to low-J CO in the Epoch of Reionization.

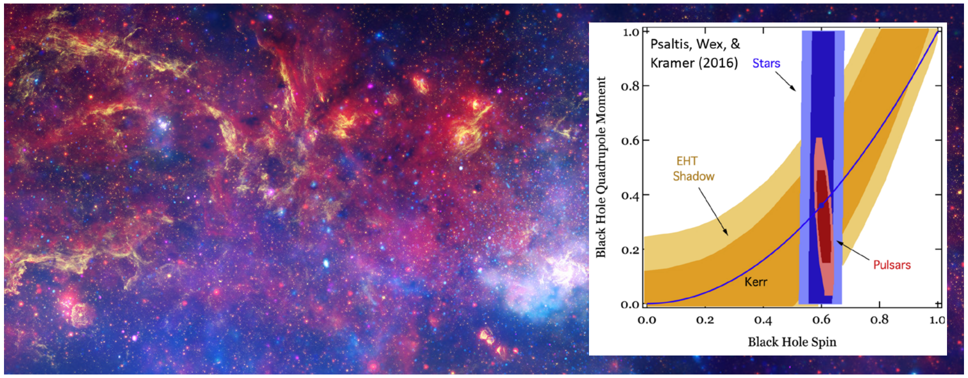


A comparison of achievable angular resolutions for a number of existing and expected facilities spanning the electromagnetic spectrum.



Left: Main interferometric array composed of a compact core (bottom center: short baseline array antennas are shown in green), a five arm spiral spanning the Plains of San Agustin (bottom left) that extends into Texas, northern Mexico and Arizona (top). **Right:** View of the main array and extended baselines (244 18 m antennas total). Multiple antennas are located in each of the 10 stations of the ngVLA's long baselines. All locations notional.

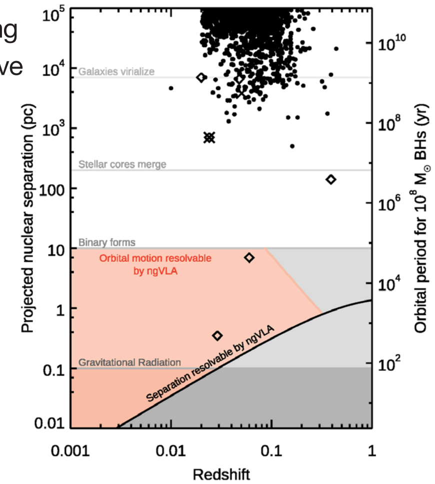
Key Science Goal 4: Using Galactic Center Pulsars for a Fundamental Test of Gravity



Pulsars in the Galactic Center are clocks moving in the space-time potential of a supermassive black hole and would enable qualitatively new tests of theories of gravity. They additionally offer the opportunity to constrain the history of star formation, stellar dynamics, stellar evolution, and the magneto-ionic medium in the Galactic Center. The ngVLA's combination of sensitivity and frequency range will probe much deeper into the likely Galactic Center pulsar population to address fundamental questions in relativity and stellar evolution.

The Galactic Center is the highest density region in the Galaxy, but multiple searches at sensitivities comparable to the VLA have revealed few pulsars though ~1000 are predicted. By discovering pulsars around Sgr A*, the ngVLA will provide new opportunities to test theories of gravity to a previously impossible precision. Image: X-ray: NASA/CXC/UMass/D. Wang et al.; Optical: NASA/ESA/STScI/D.Wang et al.; IR: NASA/JPL-Caltech/SSC/S.Stolovy

Key Science Goal 5: Understanding the Formation and Evolution of Stellar and Supermassive Black Holes in the Era of Multi-Messenger Astronomy



The ngVLA will be the ultimate black hole hunting machine, surveying from the remnants of massive stars to the supermassive black holes that lurk in the centers of galaxies. High-resolution imaging will separate low-luminosity black holes in our local Universe from background sources, providing critical constraints on their formation and growth for all sizes and mergers of black hole-black hole binaries. The ngVLA will also identify the radio counterparts to transient sources discovered by gravitational wave, neutrino, and optical observatories. It's high-resolution, and fast-mapping capabilities will make it the preferred instrument to pinpoint transients associated with violent phenomena such as supermassive black hole mergers and blast waves.

Dual AGN and black hole binaries, with optical/NIR selected sources as dots, X-ray selected sources as X's, and radio selected sources as diamonds. The region above the solid black line would be resolvable by the ngVLA, while the region shaded in orange would have measurable proper motions over 5 years if detected at signal-to-noise of 100 (which for Eddington-limited AGN should be achievable in minutes with the ngVLA), at 40 GHZ, for solar mass black holes. (from Burke-Spolaor et al. 2018)

Community Engagement

The ngVLA **Science Advisory Council** and **Science Working Groups** have established a broad and compelling science case for 1.2 – 116 GHz observations that demand sensitivity, angular resolution, and mapping capabilities far beyond the VLA, VLBA, ALMA, and SKA1. This science case strives to innovate and extend modern astrophysics to address key questions in planetary science, Galactic and extragalactic astronomy, and fundamental physics. The ngVLA **Technical Advisory Council** is working to achieve these science goals by identifying novel engineering and emerging technologies. These advisory councils collaboratively engaged the astronomical, computing, and radio engineering communities to develop the ngVLA project to the requisite level of cost fidelity and sophistication for submission to the Astro2020 Decadal Survey. The result was a strong endorsement of the ngVLA in the Astro2020 Decadal Survey Report, recommending that its construction should begin by the end of this decade.

We would like to thank the hundreds of scientists and engineers from the U.S. and international astronomy communities that have both helped with the development of the project and now continue to support the completion of the facility design so it will be ready to be approved as an National Science Foundation Major Research Equipment and Facilities Construction project.

The Next Generation Very Large Array is a design project of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc. **Learn more at ngvla.nrao.edu or contact:**

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Questions regarding the ngVLA technical concept and technical collaboration:
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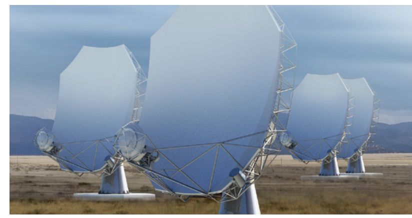
Antenna Development

In May of 2021, AUI/NRAO selected the 18m antenna concept from Mtex Antenna Technology (mtex) for the conceptual design of the telescope. Soon after, in August of 2021, the National Science Foundation (NSF) awarded the National Radio Astronomy Observatory (NRAO) $23 million for the final design and prototype of the selected 18 m antenna design.

The design was a result of years of NRAO/AUI/NSF investment with several contractors to advance multiple concepts to reduce risks and increase confidence in the feasibility of the design. The selected design by mtex was one of four submitted concepts that qualified for the final proposal.



Key Specifications	
18 m 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)

The prototype antenna development completed a major milestone, Preliminary Design Review (PDR), in December of 2022. An external panel of experts (in astronomy and ground based antenna systems) that conducted the PDR recommended that the design proceed to the prototype manufacturing phase. As a result, much of 2023 has been dedicated to the refining of the manufacturing design details and the manufacturing of parts for assembly. This prototype will lead to the final design of a high-performance antenna capable of achieving ngVLA science, and thereby the platform from which ngVLA can grow.

The teams are on schedule to have the fully erected prototype antenna at the NRAO VLA site in summer of 2024.

Milestone	Date
Antenna Delivery to NRAO (Start)	Feb. 2024
mtex Testing (Start)	Jun. 2024
Antenna Acceptance Review	Dec. 2024
Interferometric Testing (Start)	Jan. 2025