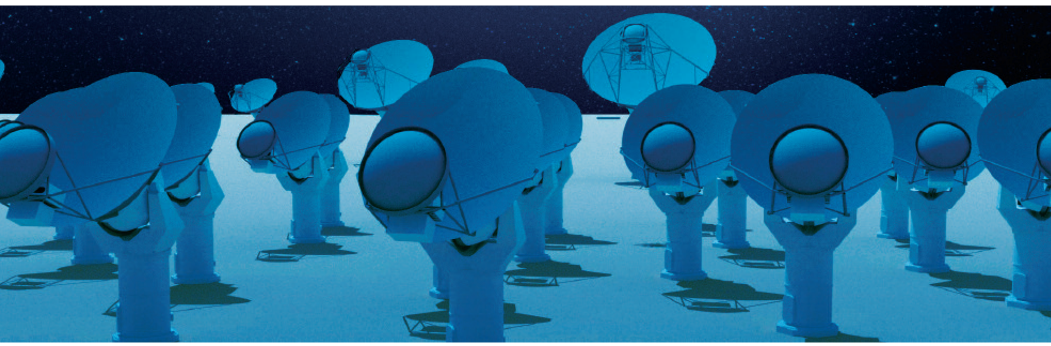
ngvla

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 will be a radio telescope comprised of an array of 244 antennas each 18m 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.



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 1970s with 27 reconfigurable, 25m diameter antennas and 30 km maximum baselines, and continuous frequency coverage spanning 1 – 50 GHz since December 2012. The ngVLA markedly advances these capabilities with 244, 18m 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 5000m elevation on the northern Chilean plateau. The ngVLA (2100m elevation) 214 antenna main array complements these capabilities by operating at and below the 3mm band, providing ~10x more sensitivity and 60x longer baselines.

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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.

TIMELINE

mid-2019	ngVLA Submissions to Astro2020 Decadal Survey
early 2021	National Academies Astro2020 Recommendation Report Published
mid-2021	Submit ngVLA Proposal to NSF – MREFC
mid-2024	Complete NSF – MREFC Final Design Review
mid-2025	Start ngVLA Construction
mid-2028	Initiate ngVLA Early Science
mid-2034	Achieve ngVLA Full Science Operations

ngVLA Reference Design Parameters

RECEIVER BANDS

Band Name	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	4
Noise Figure (T_{sys}, K)	25	27	28	35	56	103
Antenna SEFD (Jy)	372	419	372	485	809	2081

Parameter	Description/Capability
Antennas	244 x 18m, 19 x 6m
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	8860km
Continuum Sensitivity (60 min, max BW)	0.2 to 0.7 µJy/bm, NA weights
Spectral Line Sensitivity (60 min, 10 km/s)	24 to 65 µJy/bm, NA weights
Imaging Sensitivity Ratio (rms/rms_{NA})	1.5x to 2.5x

ngVLA PURPOSE

Inspired by the dramatic discoveries from the Janksy VLA, VLBA, and ALMA, a plan to pursue a large collecting area radio telescope that will open new discovery space from protoplanetary disks to distant galaxies is being developed by NRAO and the international science community. Building on the superb centimeter observing conditions and existing VLA site infrastructure, the ngVLA vision 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.

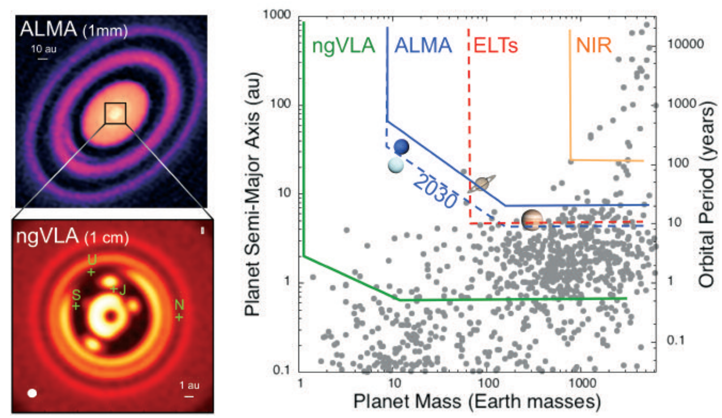
The ngVLA will be optimized for observations at wavelengths between the exquisite performance of ALMA at submillimeter wavelengths, and the future SKA1 at decimeter to meter wavelengths, and will be highly complementary

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 *New Worlds, New Horizons* Astro2010 Decadal Survey. 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

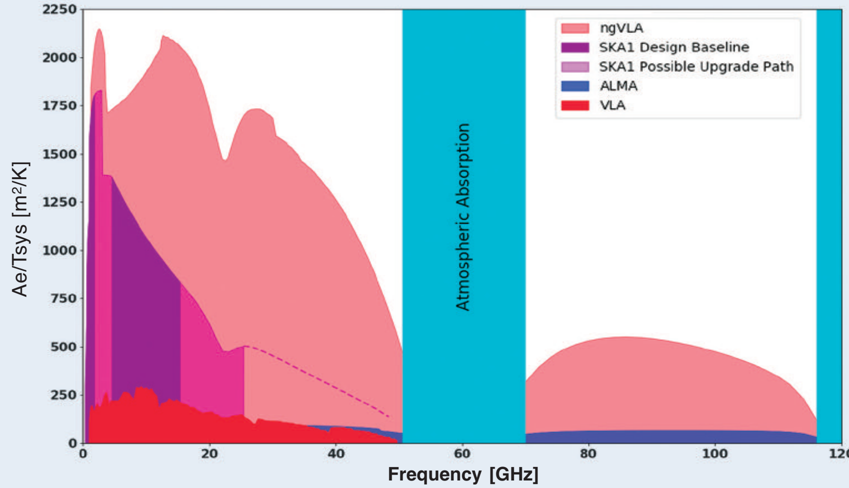
The ngVLA will measure the planet initial mass function to 5 – 10 Earth masses and unveil the formation of planetary systems similar to our Solar System by probing the presence of planets on orbital radii as small as 0.5 AU at a distance of 140 pc. The ngVLA will also reveal circum-planetary disks and 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 1mm observations of HD163296 with a resolution of 0.04" (4 au 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" (1 au) resolution, assuming the presence of (J)upiter-, (S)aturn-, (U)ranus-, and (N)eptune-like planets. Right – The 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.

with these facilities. The ngVLA will open a new window on the Universe through ultra-sensitive imaging of thermal line and continuum emission down to milliarcsecond resolution, and deliver unprecedented broadband continuum polarimetric imaging of non-thermal processes.

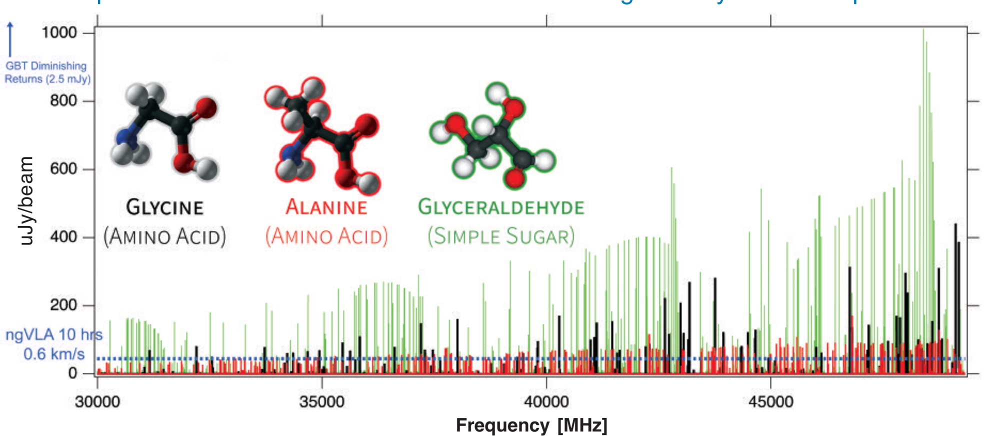
The ngVLA will be the only astronomical research facility that can simultaneously deliver the capability to: unveil the formation of Solar System analogues on terrestrial scales; probe the initial conditions for planetary systems and life with astrochemistry; characterize the assembly, structure, and 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 2030s.

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

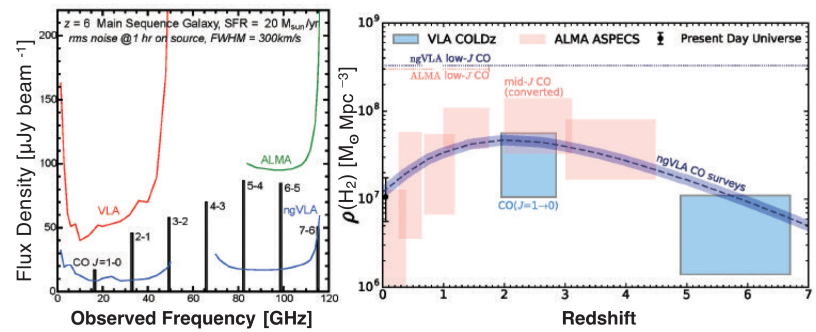
The ngVLA will detect predicted, but as yet unobserved, complex prebiotic species that are the basis of our understanding of chemical evolution toward amino acids and other biogenic molecules. The ngVLA will enable the detection and study of chiral molecules, testing ideas on the origins of homochirality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



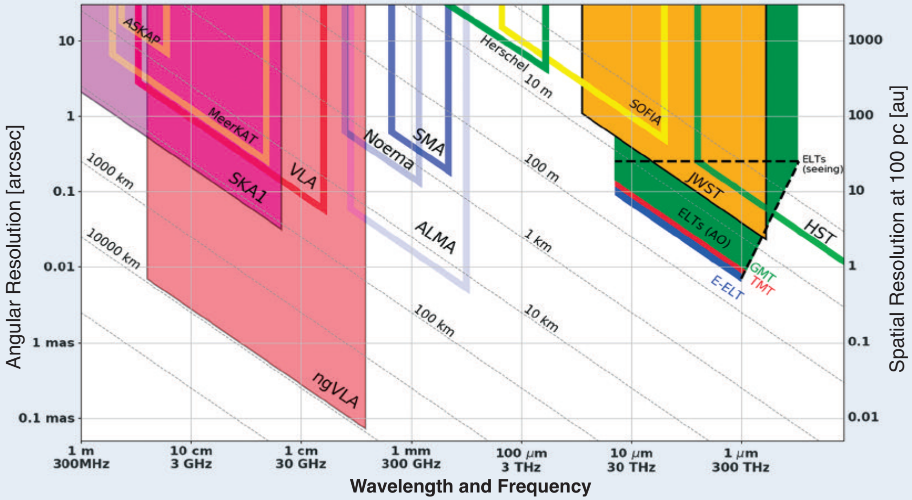
Simulations of three biogenic molecules in a typical hot core source, based on existing upper limits, assuming T = 80 K, dV = 3 km/s, and a 5" source. The ngVLA's sensitivity to detect these lines for the first time in a 10 hr integration is shown as a dashed blue line. For comparison, diminishing returns with GBT integrations 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 the Assembly, Structure, and Evolution of Galaxies from the First Billion Years to the Present

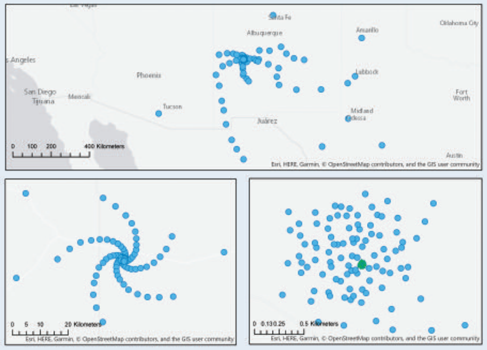
The ngVLA will provide a 10x improvement in depth and area for cold gas surveys in galaxies to early cosmic epochs, and will enable routine sub-kiloparsec scale resolution imaging of the gas reservoirs. The ngVLA will afford a unique view into how galaxies accrete and expel gas and how this gas is transformed 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.



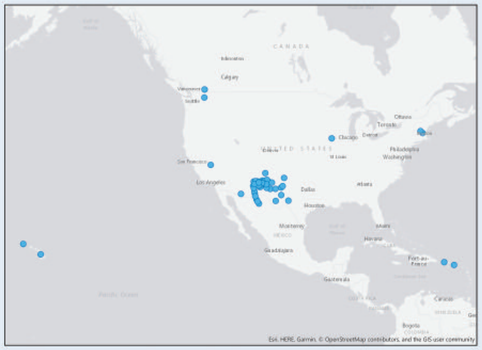
Left – With its unparalleled sensitivity, the ngVLA will routinely detect molecular gas in "normal" star-forming galaxies at z=6, including the critical low-J transitions that remain inaccessible to ALMA. Right – The ngVLA will provide more than an order of magnitude improvement in our knowledge of the 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 into the Epoch of Reionization.



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

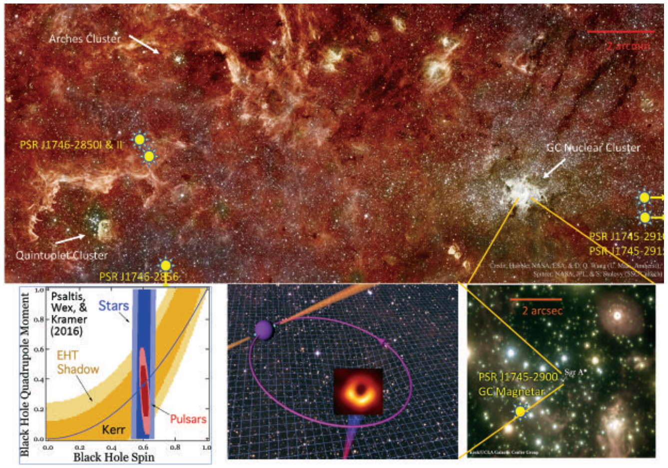


Main interferometric array composed of a compact core (bottom right; short baseline array antennas are shown in green), a five arm spiral spanning the Plains of San Agustin (bottom left) and a nearly 3-armed spiral that extends into TX, northern Mexico and AZ (top).



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 Baseline Array.

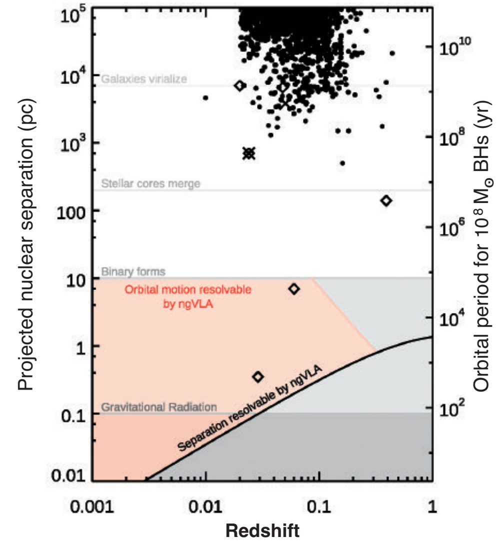
Key Science Goal 4 – Using Galactic Center Pulsars for a Fundamental Test of Gravity



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 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 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 pulsar distribution near the Galactic Center. Despite being the highest density in the Galaxy and multiple searches at sensitivities comparable to the VLA, only a few pulsars are known 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.*

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. Its high-resolution, 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 10^8 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 are collaboratively engaging 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.

Both the ngVLA science book and recently published ngVLA reference design are major project deliverables that represent the work of hundreds of scientists and engineers from the U.S. and international astronomy communities. Containing nearly 90 contributions by more than 285 unique authors, the ngVLA science book summarizes the ngVLA Key Science Goals for the Astro2020 Decadal Survey, and demonstrates the Project's commitment to achievable technology and rigorous cost definition. The reference design is a low-technical-risk, costed concept that supports the Key Science Goals for the facility, and forms the technical and cost basis of the ngVLA Astro2020 Decadal Survey proposal. The compendium includes 56 technical documents (1400+ pages) and represents the work of more than 54 engineers and scientists contributing to the project.

We thank all community members who contributed to both of these volumes and helped demonstrate a highly compelling science case for the ngVLA that is achievable within a realizable facility concept.

The Next Generation Very Large Array is a design and development project of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc. Learn more...

Contact the Project Director with general ngVLA project queries and partnership interests; **Mark McKinnon,** *Project Director* • mmckinno@nrao.edu

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Learn about ngVLA career opportunities at https://careers.nrao.edu
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UPCOMING EVENTS:

The Scientific Quest for High Angular Resolution

Tuesday, 7 January, 2020
Poster Session: 9:00 am – 6:30 pm HST
Oral Session: 2:00 – 3:30 pm HST
235th American Astronomical Society Meeting
Hawaii Convention Center
Honolulu, Hawaii, USA

This Special Session includes invited oral presentations and an associated poster session with contributed presentations.

Compact Objects and Energetic Phenomena in the Multi-Messenger Era

14 - 16 July, 2020
Intercontinental Hotel
Saint Paul, Minnesota, USA

Now, at the dawn of the multi-messenger era, electromagnetic waves, high-energy particles, and gravitational waves are jointly revealing previously-hidden clues into the workings of compact objects. These clues are guiding observers, theorists, and computational researchers to new and deep insights about compact objects. This meeting will emphasize the current state of research on compact objects that leverages on multi-messenger information. The meeting will also be forward-looking to help planners define an interoperable suite of multi-messenger facilities for the 2030s and beyond. An example suite might include SKA, ngVLA, ELTs, LSST, Cosmic Explorer/Einstein Telescope, LISA, and IceCube, as well as future X-ray missions.

Learn more and register: https://go.nrao.edu/ngvla20