# Key Science Goals for a next-generation Very Large Array

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## Summary

Inspired by dramatic discoveries from the Jansky VLA and ALMA, a plan to pursue a large collecting area radio interferometer that will open new discovery space from proto-planetary disks to distant galaxies is being developed by NRAO and the science community. Building on the superb cm observing conditions and existing infrastructure of the VLA site, the current vision of the ngVLA will be an interferometric array with more than 10 times the sensitivity and spatial resolution of the current VLA and ALMA, that will operate at frequencies spanning ~1.2. – 116 GHz.

The ngVLA will be optimized for observations at wavelengths between the exquisite performance of ALMA at submm wavelengths, and the future SKA-1 at decimeter to meter wavelengths, thus lending itself to be highly complementary with these facilities. As such, the ngVLA will open a new window on the universe through ultra-sensitive imaging of thermal line and continuum emission down to milliarcecond resolution, as well as deliver unprecedented broad band continuum polarimetric imaging of non-thermal processes.

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.

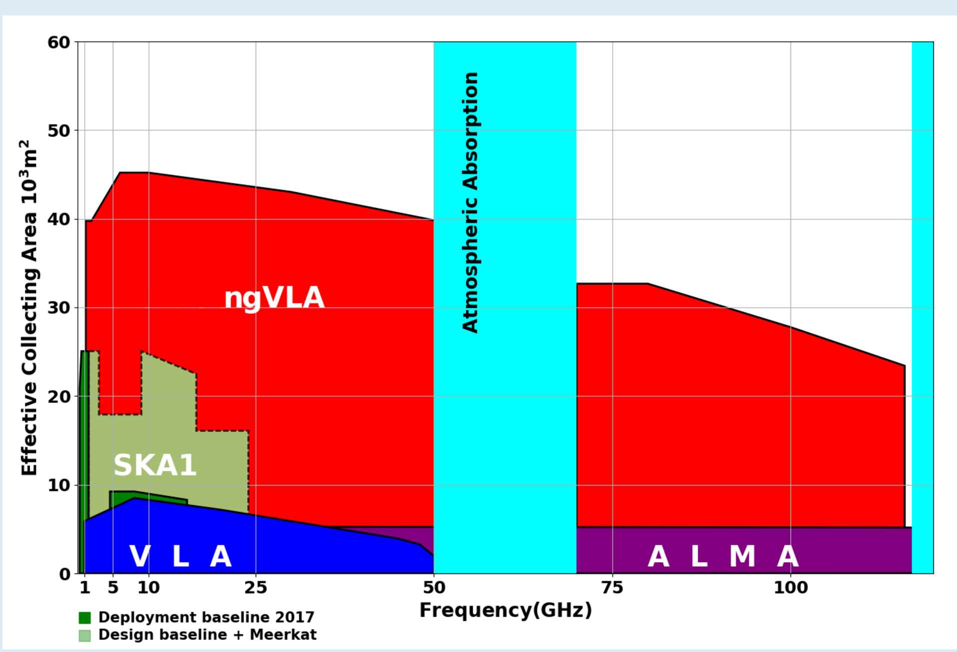



*Figure 1: A comparison of effective collecting area for a number of radio, mm, and sub-mm dish arrays expected to be operational in the 2030's. The ngVLA nicely sits between the decimetric and submm wavelengths covered by SKA1 and ALMA, respectively.*

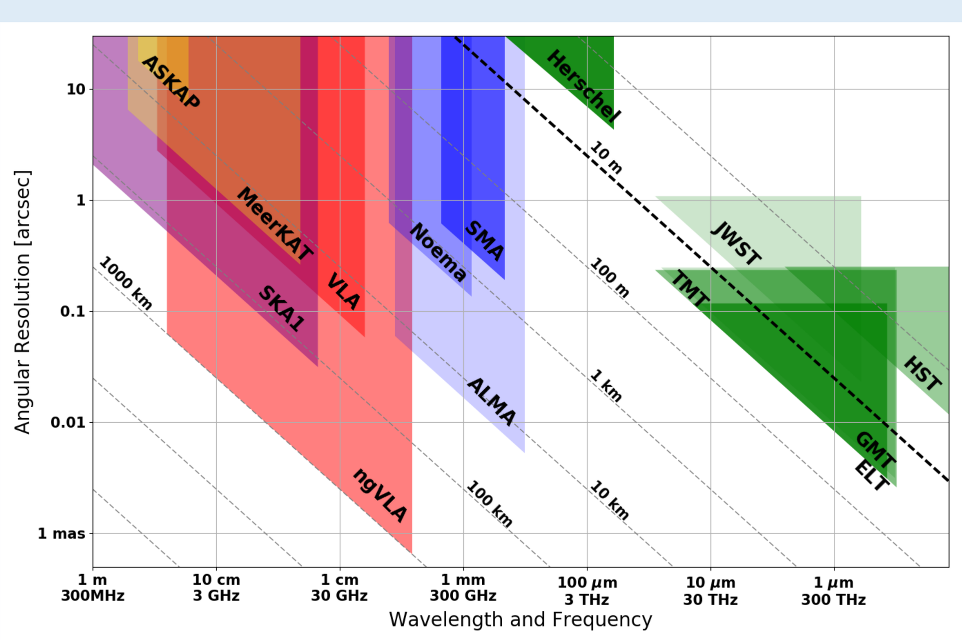
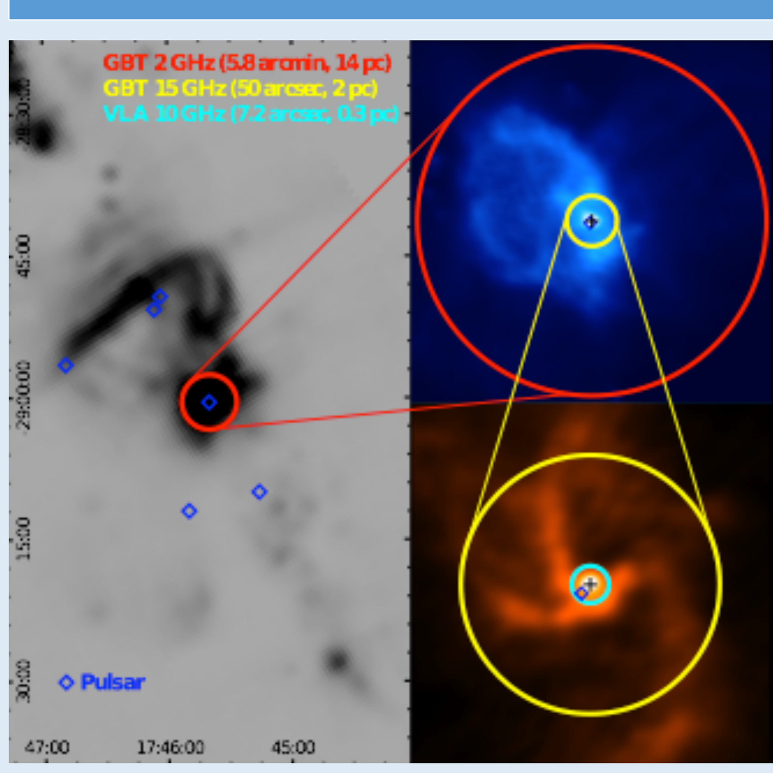



*Figure 2: A comparison of achievable angular resolutions for a number of existing and expected facilities spanning the electromagnetic spectrum. The ngVLA will achieve AU-scale resolution for the nearest star-forming regions to study the formation of rocky planets.*

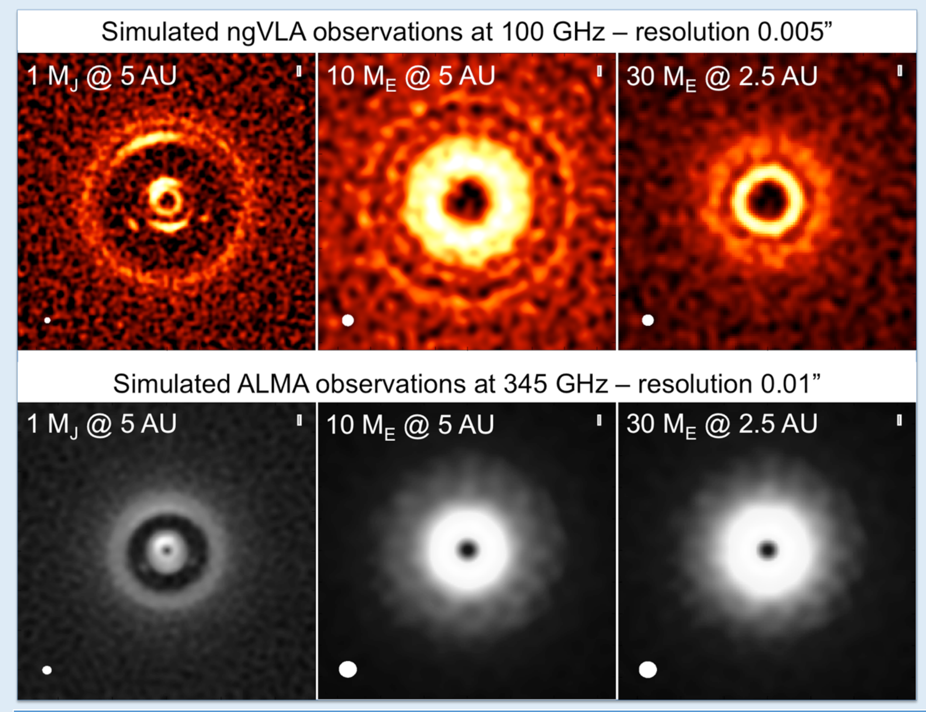
## Using Galactic Center Pulsars to Make a Fundamental Test of Gravity




Pulsars in the Galactic Center represent clocks moving in the space-time potential of a super-massive 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'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.

**Figure 6:** *(Credit: R. Wharton) The distribution of known pulsars near the Galactic center. Despite being the region of highest density in the Galaxy and despite having been searched multiple times at a range of frequencies with sensitivities comparable to that of the VLA, only a small number of pulsars are known while up to ~1000 are predicted.*

## Unveiling the Formation of Solar System Analogs




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.

**Figure 3: Ricci et al. (2018, submitted) – ngVLA- (top row) and ALMA- (bottom row) simulated observations of protoplanetary disk continuum emission perturbed by a Jupiter mass planet orbiting at 5 AU (left column), a 10 Earth mass planet orbiting at 5 AU (center column), and a 30 Earth mass planet orbiting at 2.5 AU (right column). The ngVLA observations at 100 GHz were simulated with 5 mas angular resolution and an rms noise level of 0.5 μJy/bm. ALMA observations at 345 GHz where simulated assuming the most extended array configuration comprising baselines up to 16 km and a rms noise level of 8 μJy/bm.**

## 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.

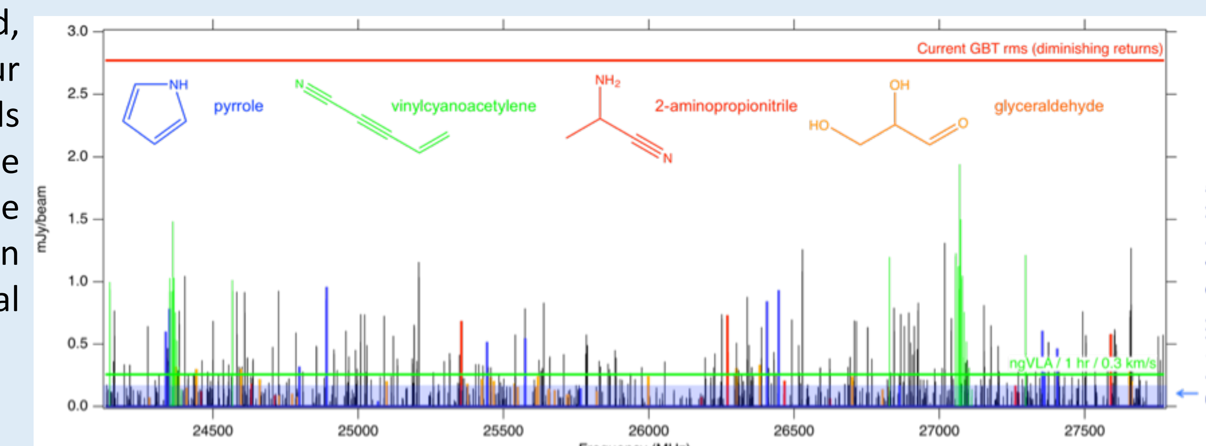
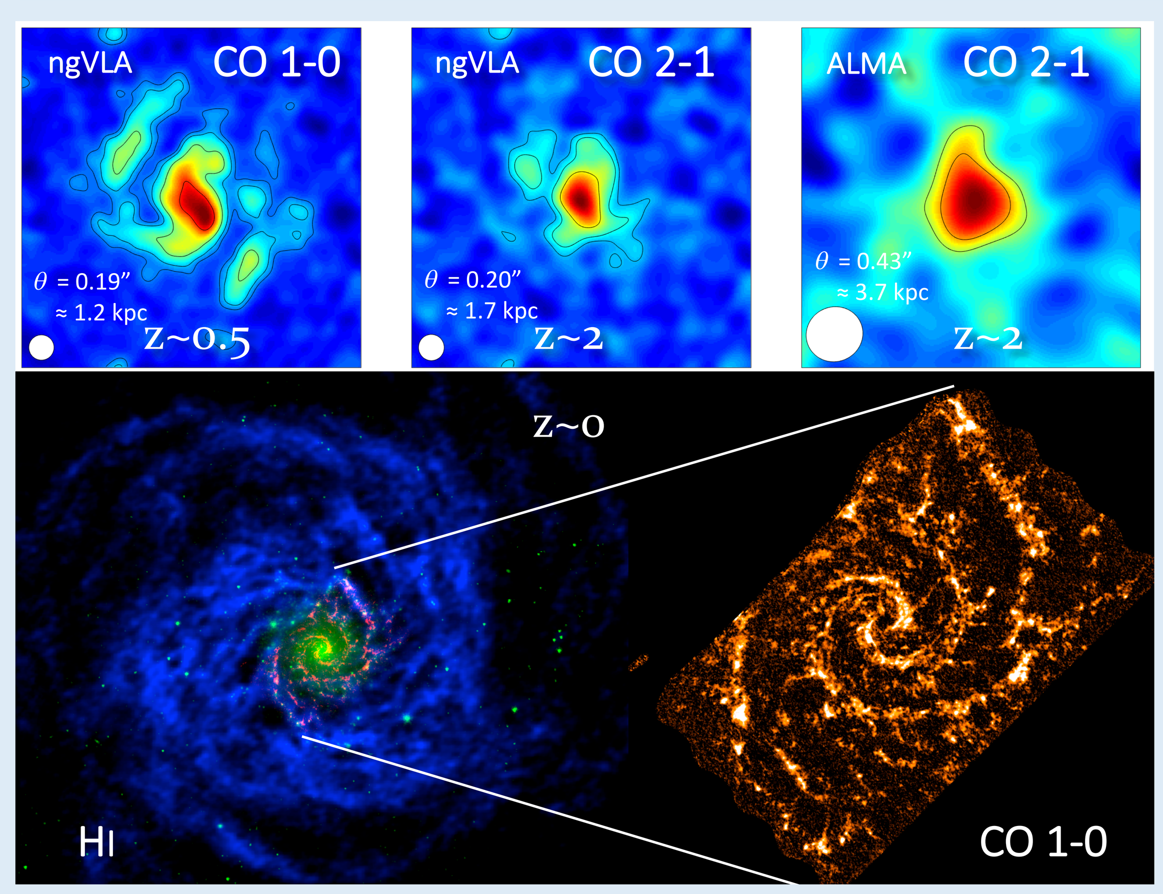



**Figure 4:** *A conservative simulation of 30 as-yet-undetected complex interstellar molecules (black) likely to be observed by the ngVLA above the confusion limit around hot cores with typical sizes of ~1" – 4". Key molecules are highlighted in color.*

## 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.

**Figure 5:** ***(Top Panels) Simulations based on M51 with molecular mass scaled by 1.4x (z = 0.5) and 3.5x (z = 2) to match the lowest molecular mass galaxies observable by ALMA and NOEMA (ngVLA Memo #13). Integration times are 30 hours. (Bottom Panels) The spiral galaxy M74 illustrating the CO molecular disk imaged by ALMA (red; Schinnerer in prep.), the stellar disk at 4.5mm imaged by Spitzer (green; Kennicutt et al. 2003), and the atomic disk imaged in HI by the VLA (blue; Walter et al. 2008), showing the gas phases to which the ngVLA will be sensitive. [Right Panel] The CO J = 2 → 1 map at 1" resolution.***

## 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 (SMBHs) 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.

**Figure 7:** ***Two tiny, but very dense neutron stars merge and explode as a kilonova. Such a very rare event produces gravitational waves and electromagnetic radiation, as observed on 17 August 2017. The ngVLA will play a pivotal role in characterizing the physics of such events in the era of multi-messenger astronomy. (Artist's impression, Credit: ESO/L. Calçada/M. Kornmesser).***

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