The Next-Generation Very Large Array (ngVLA)

Joan Wrobel, National Radio Astronomy Observatory
Outline

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• Summary
Summary

- The ngVLA is a versatile interferometric array at radio frequencies, envisaged to operate as a flagship NSF facility starting in the 2030s.
- Successful proposers will use its transformative capabilities to:
  - Probe the terrestrial zones of circumstellar disks for forming planets;
  - Search for signals from telltale prebiotic molecules;
  - Trace the evolution of gas in galaxies across cosmic time;
  - Scour the Galactic Center for pulsars to test General Relativity;
  - Pinpoint black holes in and beyond our Galaxy in the era of multi-messenger astronomy; and much more.
- Its science will be synergistic with other facilities on similar timescales.
- It will complementarily bridge radio frequencies between those observable with ALMA and the planned Square Kilometer Array (Phase 1).
Community Engagement

• 2015 – NRAO launched community discussions on future of radio astronomy
  • Formed science working groups, held science and technical conferences
  • Led to a vision for a facility 10x more capable than the Very Large Array (VLA)
  • Formed a Project Office for such a next-generation VLA (ngVLA)

• 2016 – Formed a Science Advisory Council
  • Offer expertise, guidance and feedback on science topics
  • Help prepare for Astro2020 Decadal Survey

• 2017 – Formed a Technical Advisory Council
  • Offer expertise, guidance and feedback on engineering and computing topics
  • Help prepare for Astro2020 Decadal Survey
Community Highlights 2015 – 2019

- Participated in science and technical conferences
  - CA, CO, DC, FL, MD, NM, OR, TX, VA, WA, Japan
- Documented their ideas
  - 67+ memos, 38 studies, 80+ science use cases
  - 88 Science Book chapters, 285 unique authors
  - 83 Science White Papers for Astro2020 Decadal Survey
  - 460+ contributions in the Astrophysics Data System
- Guided a Reference Design
- Identified Key Science Goals
  - Must have synergies and complementarity with other facilities on similar timescales
ngVLA Key Science Goals  
(ngVLA memo #19)

KSG1: Unveiling the formation of Solar System analogs on terrestrial scales

KSG2: Probing the initial conditions for planetary systems and life with astrochemistry

KSG3: Charting the assembly, structure, and evolution of galaxies over cosmic time

KSG4: Using pulsars in the Galactic Center as fundamental tests of gravity

KSG5: Understanding the formation and evolution of stellar and supermassive black holes in the era of multi-messenger astronomy
KSG1: Unveiling the Formation of Solar System Analogs on Terrestrial Scales

- Measure the planet initial mass function to $5 - 10$ Earth masses
- Probe the presence of planets on orbital radii as small as $0.5$ AU at a distance of $140$ pc
- Reveal circumplanetary disks and other dust substructures carved by close-in planets
- Measure the orbital motions of features on monthly timescales

ALMA image at 300 GHz and 4 au resolution, revealing gaps and rings that suggest the presence of planets. Simulated ngVLA image of the inner region at 30 GHz and 1 au resolution, assuming the presence of (J)upiter-, (S)aturn-, (U)ranus- and (N)ptune-like planets.

Exoplanets around mature stars and young planets in circumstellar disks as probed by various telescopes. The ngVLA will discover many 100s of young planets with orbital periods < 10 yr.

Credit: Andrea Isella, Rice U
KSG2: Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry

- Detect the complex, as-yet-unobserved prebiotic species to understand the chemical paths to biogenic molecules
- Detect chiral molecules to test ideas about the origins of homochirality in biological systems
- Such complex organic molecules will provide the initial chemical conditions for forming solar systems and planets

Credit: Brett McGuire, NRAO
KSG3: Charting the Assembly, Structure, and Evolution of Galaxies Over Cosmic Time

- Improve by 10x the depth and area of cold gas surveys to early cosmic epochs
- Routinely image that cold gas at sub-kiloparsec resolution
- For nearby galaxies, show how they accrete, expel and transform their atomic and molecular gas

With its unparalleled sensitivity, the ngVLA will (left) routinely detect molecular gas in normal star-forming galaxies at z=6, including the critical low-J transitions that remain inaccessible to ALMA; and (right) provide over 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 and ALMA.

Credit: Dominik Riechers, Cornell U
KSG4: Using Pulsars in the Galactic Center as Fundamental Tests of Gravity

• Search for the predicted but not-yet-observed population of pulsars in the Galactic Center

• Use pulsars (clocks) moving in the spacetime potential of Sgr A*, a supermassive black hole, to make precise tests of theories of gravity

• Use the population of pulsars in the Galactic Center to constrain its
  • Star formation history
  • Stellar dynamics
  • Stellar evolution
  • Magnetoionic medium

By discovering pulsars around Sgr A*, the ngVLA will provide new opportunities to test theories of gravity.
KSG5: Understanding the Formation and Evolution of Stellar and Supermassive Black Holes in the Era of Multi-Messenger Astronomy

- Make movies to learn how black holes accrete fuel and launch jets
- Study how black holes interact with their environments and drive galaxy evolution
- Separate nearby black holes from background sources, to constrain the mass function, formation, and growth of black holes
- Pinpoint the radio counterparts to transient events discovered by electromagnetic, gravitational wave, or neutrino facilities

As the jet from the neutron-star merger event GW170817 evolves, radio images in this artist's conception (not to scale) illustrate its swift motion. In the 155 days between two observations, the jet appeared to move two light-years, requiring it to travel at about 4c. Such superluminal motion is an illusion, caused by the jet pointing nearly toward the Earth and actually travelling at about 0.97c.

See plenary talk by Alessandra Corsi, Texas Tech U
Synergies with Other Facilities on Similar Timescales

- Square Kilometer Array (SKA) / Lynx
  - Atomic/non-thermal
  - Molecular/thermal

- ALMA
  - Warm/star-forming
  - Cold/dense fuel for SF

- LUVOIR/HabEx
  - Image earth-like planets
  - Image terrestrial-zone planets forming

- OST (FIR surveyor)
  - C/WNM & WIM
  - Cold molecular medium

- TMT/GMT
  - Stellar Mass and unobscured SF
  - Dense gas and obscured SF

- JWST/WFIRST
  - Continuing its legacy in many areas of astrophysics
SKA and ngVLA Key Science Drivers

- Cosmic Dawn/EoR
- Extragalactic Continuum Studies
- Extragalactic Molecular Gas
- Prebiotics
- Stellar-Mass Black Holes
- LIGO/LISA Follow-Up

- Planet Formation
- Cradle of Life
- Transient / FRB Searches
- Cosmic Magnetism
- Low & High-z HI
- Extragalactic Molecular Gas
- Cosmology
- GC Pulsars
- LIGO/LISA Follow-Up
- GC Pulsars
- Local Group HI
- Pulsars Searches & Timing
- (3cm)
- (3, 7, 10mm)
Design Highlights 2017 – 2018

• Set Reference Design requirements
• 10x sensitivity of VLA and ALMA
• 10x angular resolution of VLA and ALMA
• Frequency range 1.2 – 116 GHz
• 263 antennas
  • Concentrated in high NM desert
  • Extend into AZ, TX, Mexico, Canada
  • Span USA territory
Design Sensitivity Complements SKA1 and ALMA

ngVLA North America
ALMA South America
SKA1 Africa, Australia
Design Angular Resolution Complements SKA1 and ALMA

← 1 au KSG1 synergy
Status

• Submitted APC White Paper for Astro2020 Decadal Survey

<table>
<thead>
<tr>
<th>ngVLA LIFECYCLE PHASE</th>
<th>TOTAL (BY2018$)</th>
<th>FUNDING SOURCES</th>
<th>SCHEDULE</th>
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Lifecycle cost estimate by project phase and funding source, showing the maximum anticipated USA investment. Risk-adjusted costs are reported at the 70% confidence level in base year 2018 dollars.
** Annual operations estimate is BY2018 $92.9 M/yr.

• Released Reference Design, a low-technical-risk and costed concept
• Received FY20 design funds via new NSF Cooperative Agreement
Compact Objects and Energetic Phenomena in the Multi-Messenger Era

2020 July 14 – 16   Saint Paul, Minnesota, USA

Meeting Themes

Discuss the current state of compact-object research that leverages on multi-messenger information.

Help planners define an interoperable suite of multi-messenger facilities for the 2030s and beyond. An example suite might include SKA, ngVLA, ELTs, LSST, CE/ET, LISA, and IceCube, as well as future X-ray missions.

SOC

Nicole Lloyd-Ronning (co-chair)
Tom Maccarone (co-chair)
Geoff Bower
Shami Chatterjee
Gregg Hallinan
Jim Hinton
Kelly Holley-Bockelmann
Joe Lazio
William Lee
Jess McIver
Masayuki Nakahata
Marcos Santander
Amanda Weinstein
Joan Wrobel

The ngVLA is a design and development project of the NSF operated under cooperative agreement by AUI.

https://go.nrao.edu/ngVLA20
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