NATIONAL RADIO ASTRONOMY OBSERVATORY

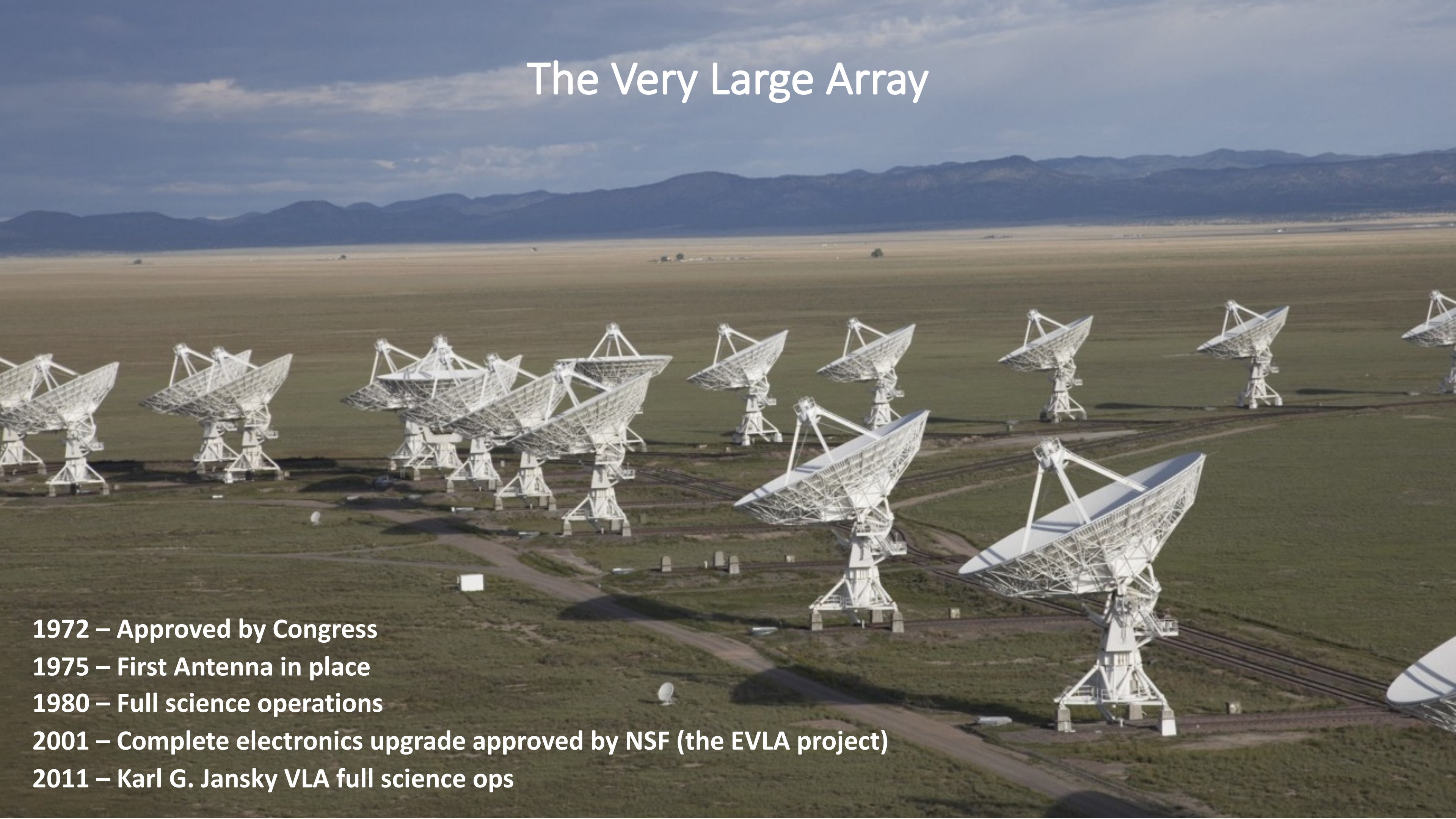
A Brief Project Overview

Emmanuel Momjian

Slides from E. Murphy and the ngVLA team

ngvla

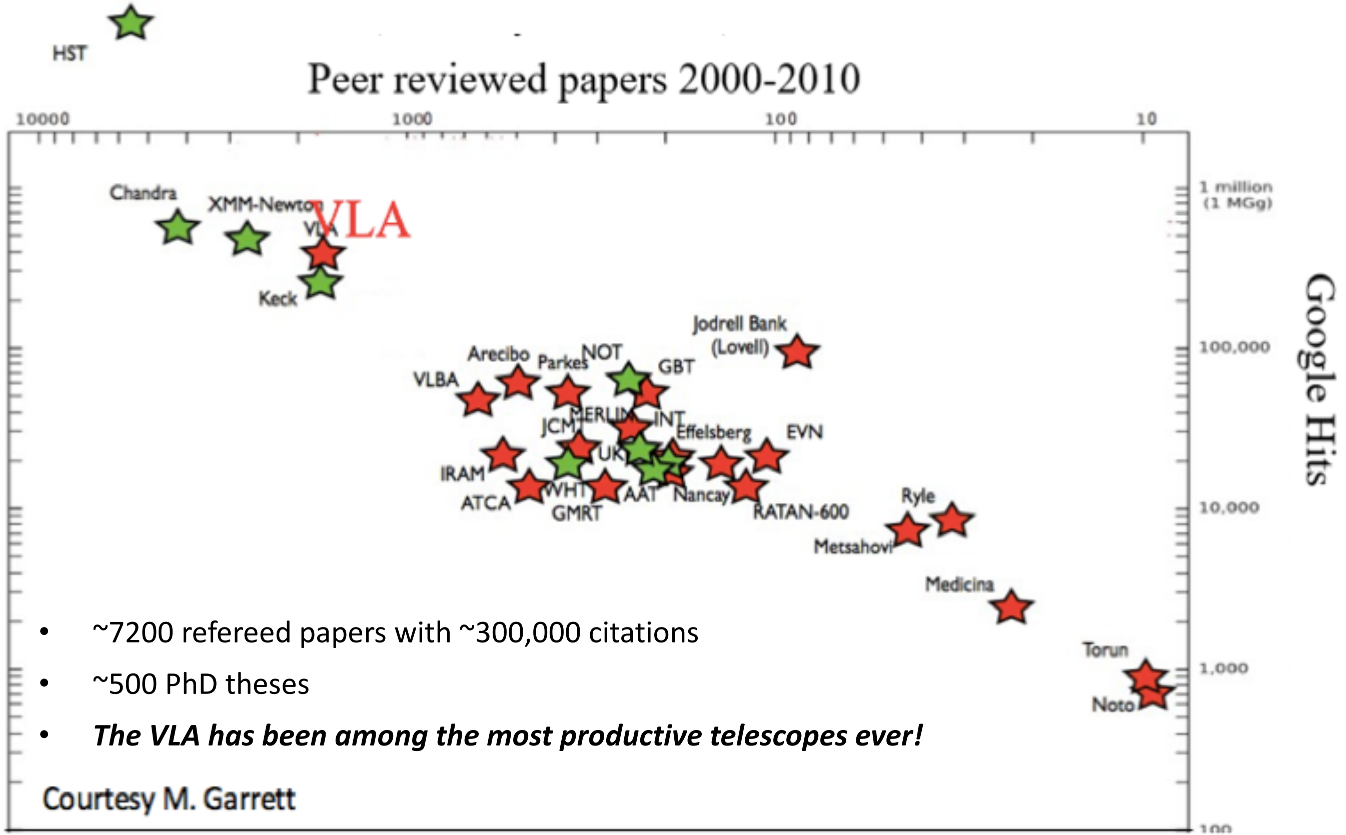
Next Generation Very Large Array



The Very Large Array

1972 – Approved by Congress
1975 – First Antenna in place
1980 – Full science operations
2001 – Complete electronics upgrade approved by NSF (the EVLA project)
2011 – Karl G. Jansky VLA full science ops

Radio Astronomy Powerhouse from 1980 to Present

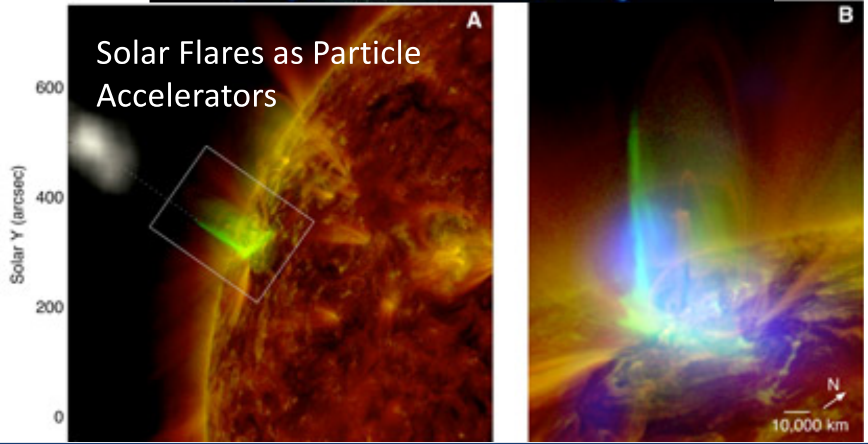


- ~7200 refereed papers with ~300,000 citations
- ~500 PhD theses
- ***The VLA has been among the most productive telescopes ever!***

Courtesy M. Garrett

ngvla NRAO Associated Universities, Inc.

Still a Radio Astronomy Powerhouse: VLA Recent Discoveries



A next generation VLA

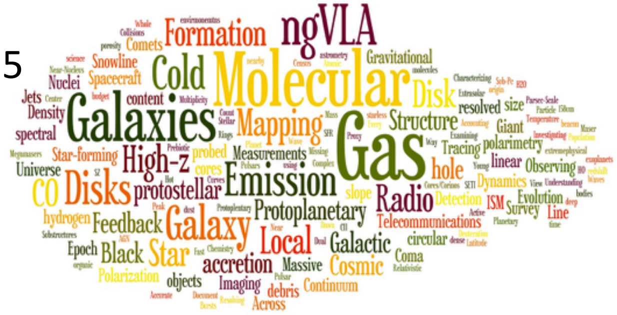
- Scientific Frontier: Thermal imaging at milli-arcsecond scale resolution
- Core Design Requirements
  - *10x effective collecting area of VLA and ALMA*
  - *10x resolution of VLA and ALMA*
  - *Frequency range: 1.2 –116 GHz*
- Located in Southwest U.S. (NM+TX) & Mexico, building from VLA site
- Baseline design remains under continuous development
- Low technical risk (reasonable step beyond current state of the art)

https://ngvla.nrao.edu

Developing the ngVLA Science Case

Community-Driven, Growing, and Evolving

- Numerous Science and Technical meetings, starting from Jan 2015 AAS
- Initial Science Working Group reports covering 4 broad areas, Nov .2015 (*http://library.nrao.edu/ngvla.shtml*)
  - ➢ ***Cradle of Life: CoL*** *(Isella et al):* Terrestrial-zone planet formation, Massive Stars, etc.
  - ➢ ***Galaxy Ecosystems: GEco*** *(Leroy et al):* wide field, high resolution/sensitive imaging
  - ➢ ***Galaxy Formation: GFor*** *(Casey et al): Dense gas history of the Universe*
  - ➢ ***Time domain, Cosmology, and Physics: TdCP*** *(Bower et al):* Plasma physics, Exo-space weather, Strong Lensing



- **Community Studies Program**: 38 studies approved over 2 Rounds, *financially supported by NRAO* (*http://ngvla.nrao.edu/page/commstudiesprogram*)
- **Community-Led Science Use Cases**: 80 submitted for 'Reqs to Specs' process (ngVLA memo # 18)

Community-Led Advisory Councils

ngVLA Science Advisory Council

- Interface between the science community & NRAO
- Recent/Current Activities:
  - Science working groups: science use cases → telescope requirements
  - SOC for science meeting in June 2017/2018
  - Winter 2018 AAS Special Session
  - Lead Science case development → 'science book' & DS2020 White Papers

Alberto Bolatto (University of Maryland: **co-Chair**)
Andrea Isella (Rice University : **co-Chair**)
Brenda Matthews (NRC-Victoria: **SWG1 Chair**)
Danny Dale (University of Wyoming: **SWG2 Chair**)
Dominik Riechers (Cornell: **SWG3 Chair**)
Joseph Lazio (JPL: **SWG4 Chair**)

ngVLA Technical Advisory Council

- Interface between the engineering & computing community and NRAO
- Membership covers a broad range of expertise in relevant technical areas including:
  - Antennas, low-noise receiver systems, cryogenics, data transmission, correlators, and data processing

James Lamb (Caltech : **co-Chair**)
Melissa Soriano (JPL : **co-Chair**)

Community Participation

Jet Propulsion Laboratory
Johns Hopkins University
University of Virginia
Ohio State
The University of New Mexico
California State University Northridge
Asia
Cornell University
NOAO
The George Washington University, Washington, DC
BYU Brigham Young University
Michigan State
University of Maryland
University of Wyoming
LSST Large Synoptic Survey Telescope
Rice
Green Bank Observatory
Texas Tech University
Harvard-Smithsonian Center for Astrophysics
Berkeley University of California
Texas The University of Texas at Austin
The University of Arizona
The University of Iowa
UC San Diego
West Virginia University
STScI Space Telescope Science Institute
Caltech

General Dynamics Mission Systems
Quantum Design
REhnu Next Generation Solar
LaserLaB Amsterdam
VU
MINEX Engineering Corp.

NRC·CNRC Canada
The University of Western Australia
US University of Sussex
国立天文台 NAOJ National Astronomical Observatory of Japan
Universidad Nacional Autónoma de México
東京大学 The University of Tokyo
ICRAR International Centre for Radio Astronomy Research
RIKEN

ngVLA
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NSF
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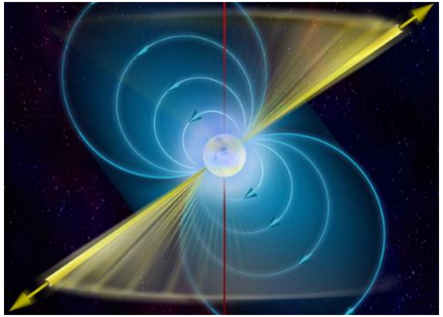
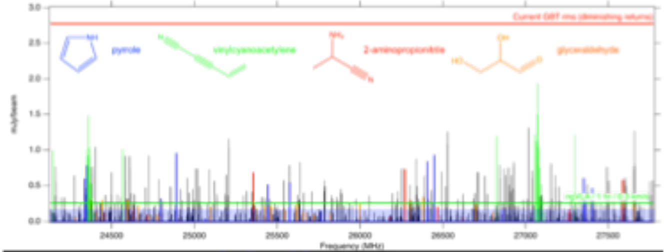
ngVLA Key Science Mission

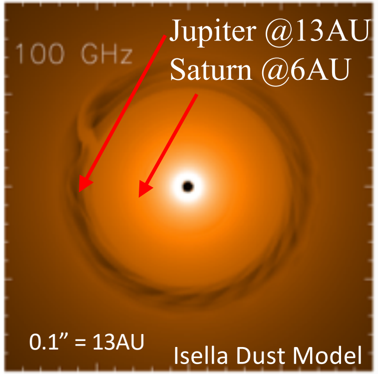
(ngVLA memo #19)

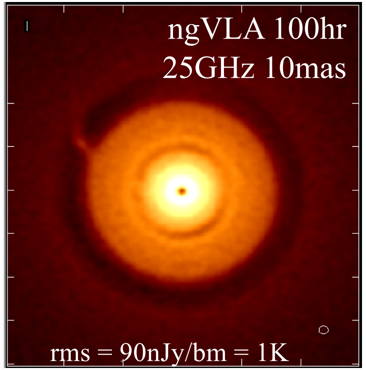


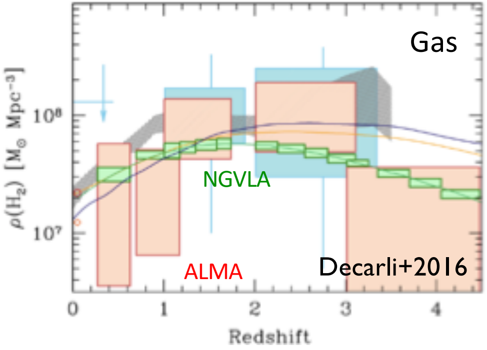
- ***Unveiling the Formation of Solar System Analogues***
- ***Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry***
- ***Charting the Assembly, Structure, and Evolution of Galaxies Over Cosmic Time***
- ***Using Pulsars in the Galactic Center as Fundamental Tests of Gravity***
- ***Understanding the Formation and Evolution of Stellar and Supermassive BH's in the Era of Multi-Messenger Astronomy***

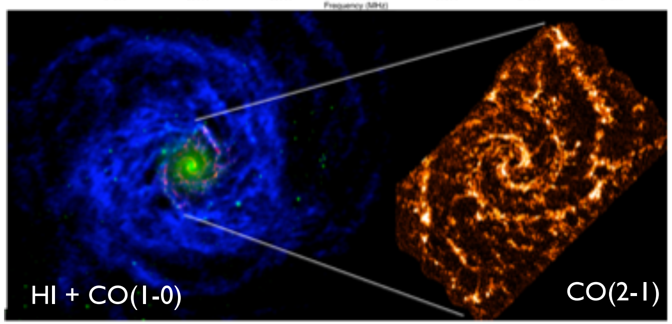


Highly synergistic with next-generation ground-based OIR and NASA missions.



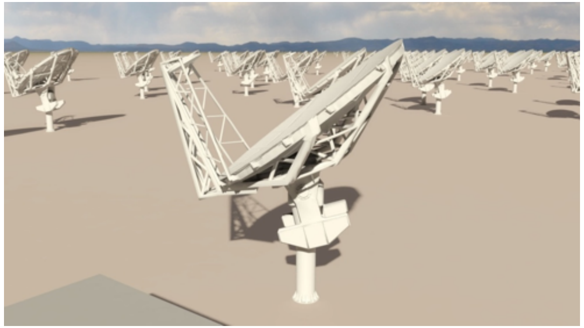






Current Reference Design Specifications

(ngVLA Memo #17)



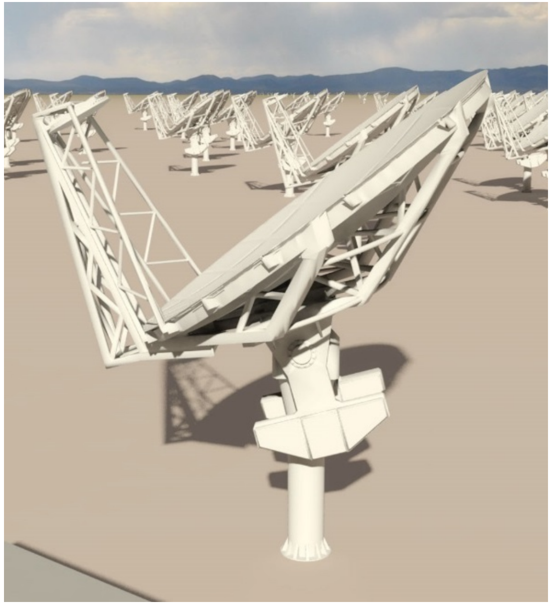
- 214 18m offset Gregorian Antennas
  - Supported by internal cost-performance analysis
- Fixed antenna locations across NM, TX, MX
  - ~1000 km baselines being explored
- 1.2 – 50.5 GHz; 70 – 116 GHz
  - Single-pixel feeds
  - 6 feeds / 2 dewar package
- 19 6m short spacing array + 4 18m in TP mode to fill in (*u, v*) hole.

- Continuum Sensitivity: ~0.1uJy/bm @ 1cm, 10mas, 10hr => T_B ~ 1.75K
- Line sensitivity: ~21.5uJy/bm @ 1cm, 10 km/s, 1", 10hr => T_B ~ 35mK

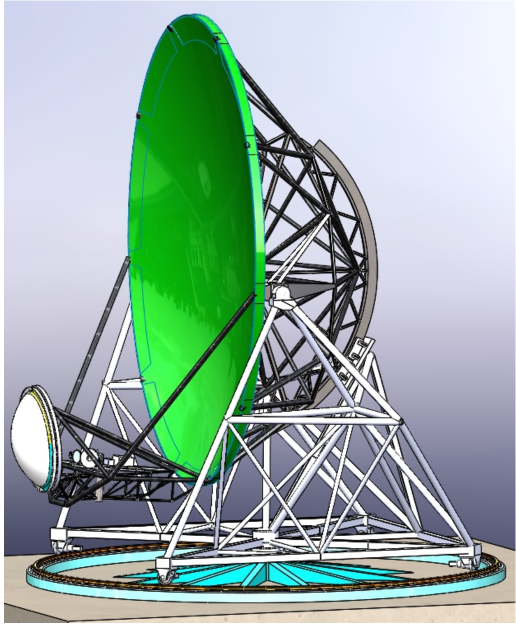
Receiver Configuration

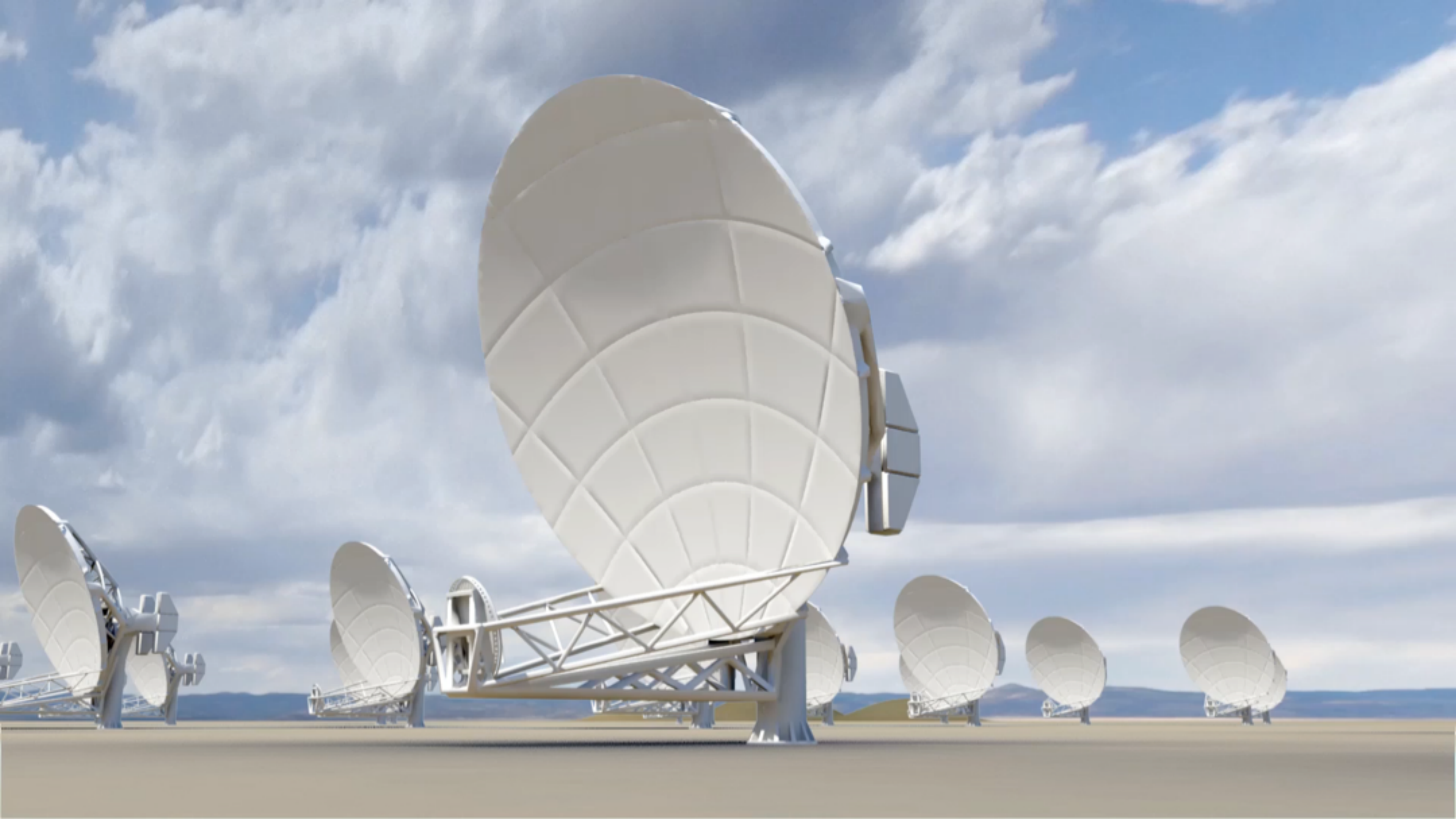
Band #	Dewar	f_L GHz	f_M GHz	f_H GHz	f_H: f_L	BW GHz
1	A	1.2	2.35	3.5	2.91	2.3
2	B	3.5	7.90	12.3	3.51	8.8
3	B	12.3	16.4	20.5	1.67	8.2
4	B	20.5	27.3	34.0	1.66	13.5
5	B	30.5	40.5	50.5	1.66	20.0
6	B	70.0	93.0	116	1.66	46.0

Antenna Concept



- **18m Aperture**: Based on cost and performance modeling.
- **Offset Gregorian**: Off-axis geometry minimizes scattering, spillover, and sidelobe pickup
- **Feed Low**: Performance and maintenance requirements favor a receiver feed arm on the low side of the reflector
- **Mount concept**: TBD.
  - Evaluating pedestal mount vs wheel and track.
  - Pointing specification is a design driver.
- <u>Pursuing antenna reference design this fall.</u>



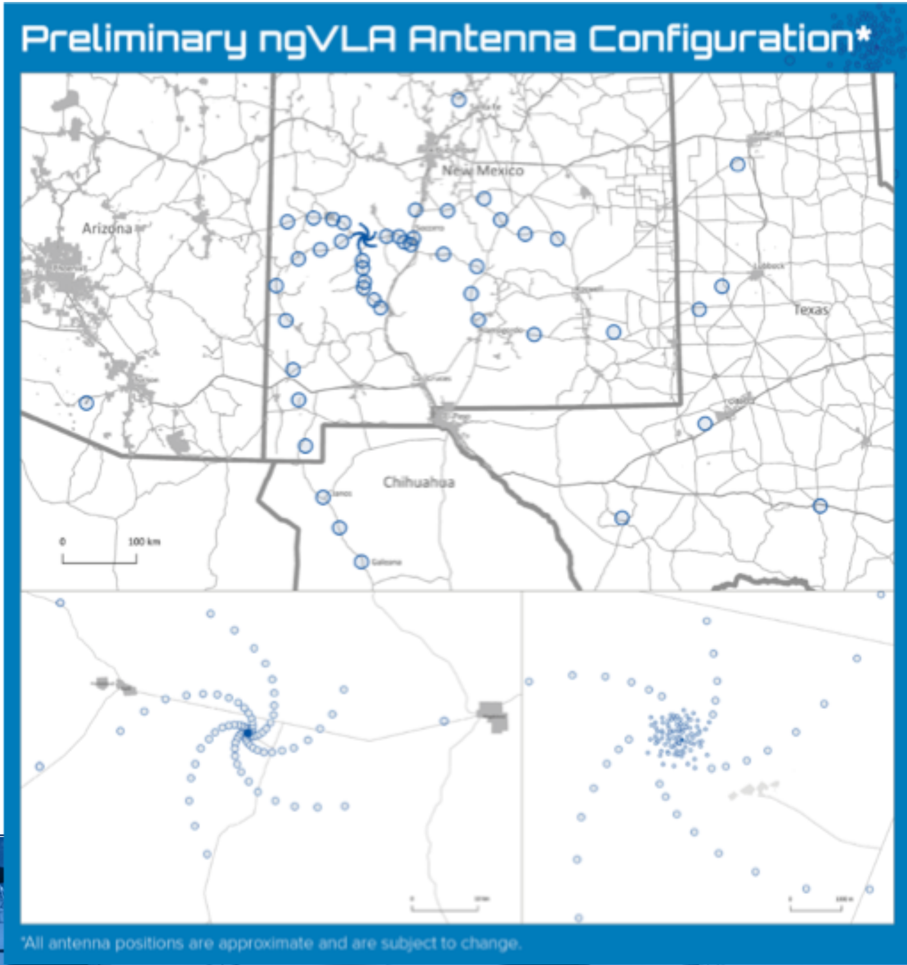


The ‘Southwest Array’

- Location: U.S. Southwest, Mexico
- Homogeneous array 214 x 18m, off-axis antennas
- 50% to core: b < 3 km => 1” at 30GHz
- 80% to mid: b < 30 km => 0.1”
- 100% to long: b < 1000 km => 0.003”

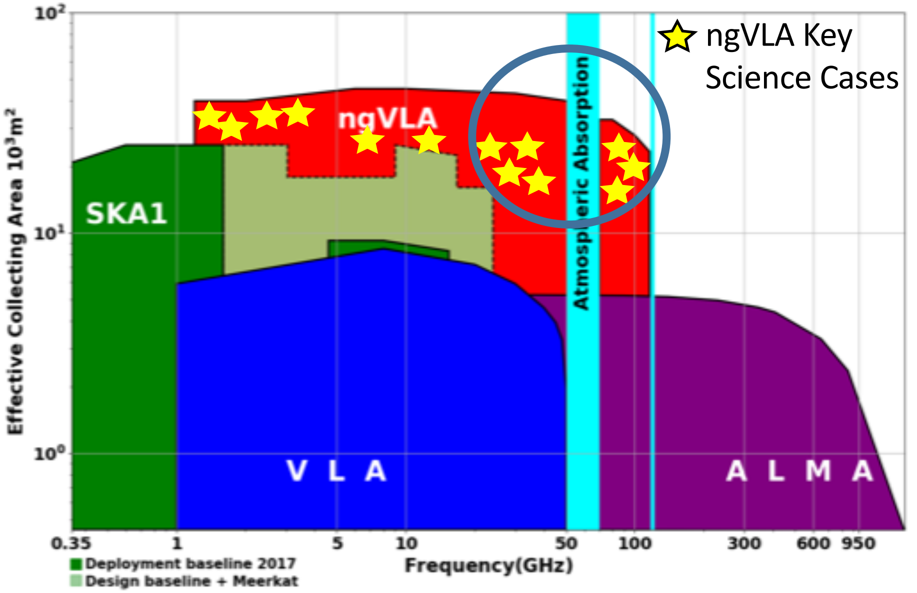
Nominal 18m homogeneous array
- Consensus design
- Challenge of tri-scale-array: Sensitivity vs. resolution

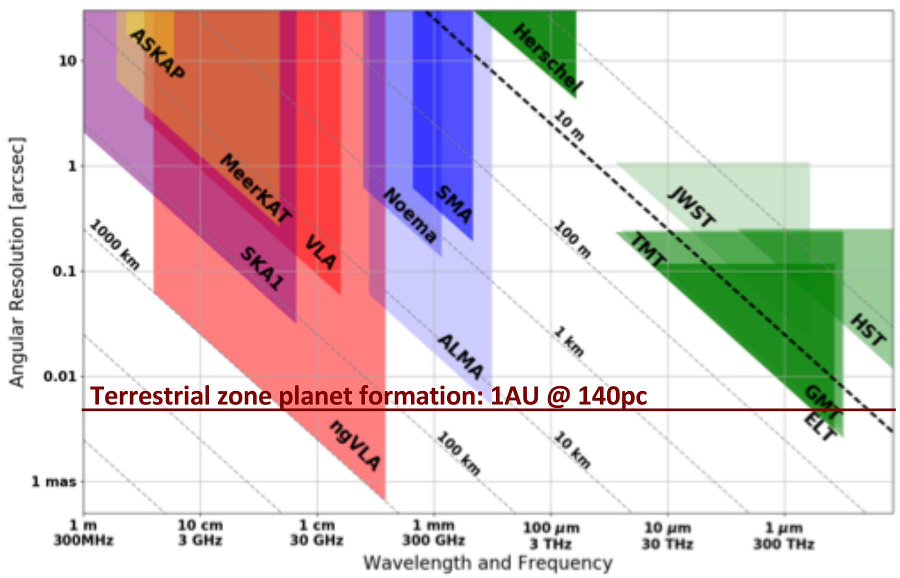
Options
- Long baselines: continental VLBI
- Short baselines: 16 x 6m array + 18m total power



Bridging SKA & ALMA Scientifically

Thermal Imaging on mas Scales at λ ~ 0.3cm to 3cm





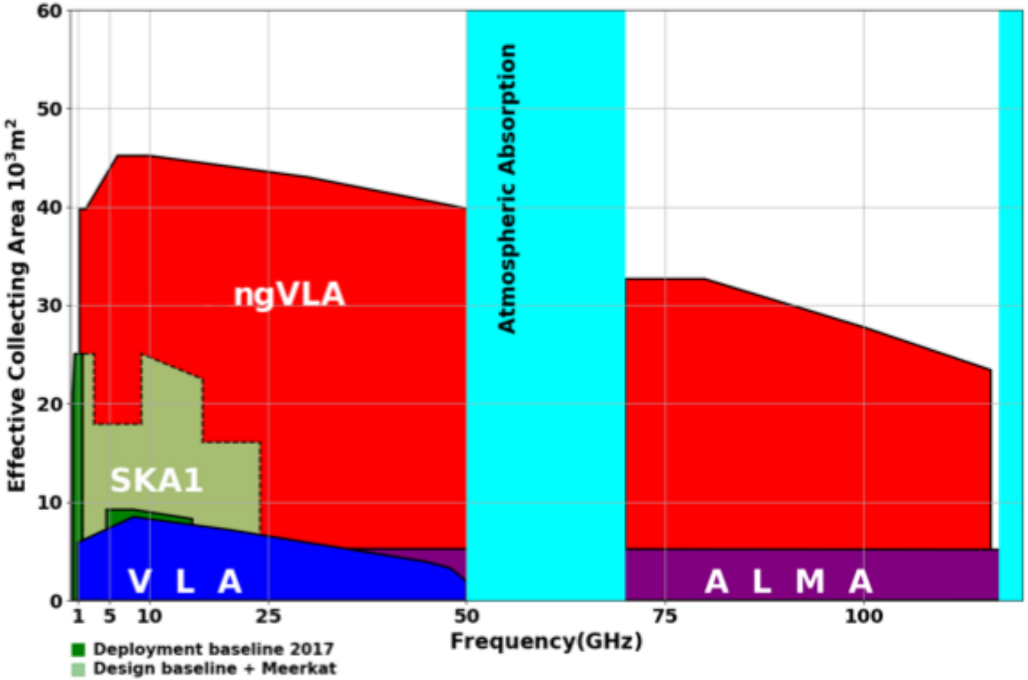
Complementary suite from cm to submm arrays for the mid-21st century

- **< 0.3cm:** ALMA 2030 superb for chemistry, dust, fine structure lines
- **0.3 to 3cm: ngVLA** ngVLA superb for terrestrial planet formation, dense gas history, baryon cycling
- **> 3cm:** SKA superb for pulsars, reionization, HI + continuum surveys

Bridging SKA & ALMA Scientifically

Thermal Imaging on mas Scales at $\lambda \sim 0.3$cm to 3cm

A linear Scaling more clearly illustrates the large slice of frequency space opened up by ngVLA



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Five Key Science Goals for the ngVLA

http://library.nrao.edu/public/memos/ngvla/NGVLA_19.pdf

Unveiling the Formation of Solar System Analogues

Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry

Charting the Assembly, Structure, and Evolution of Galaxies from the First Billions Years to the Present

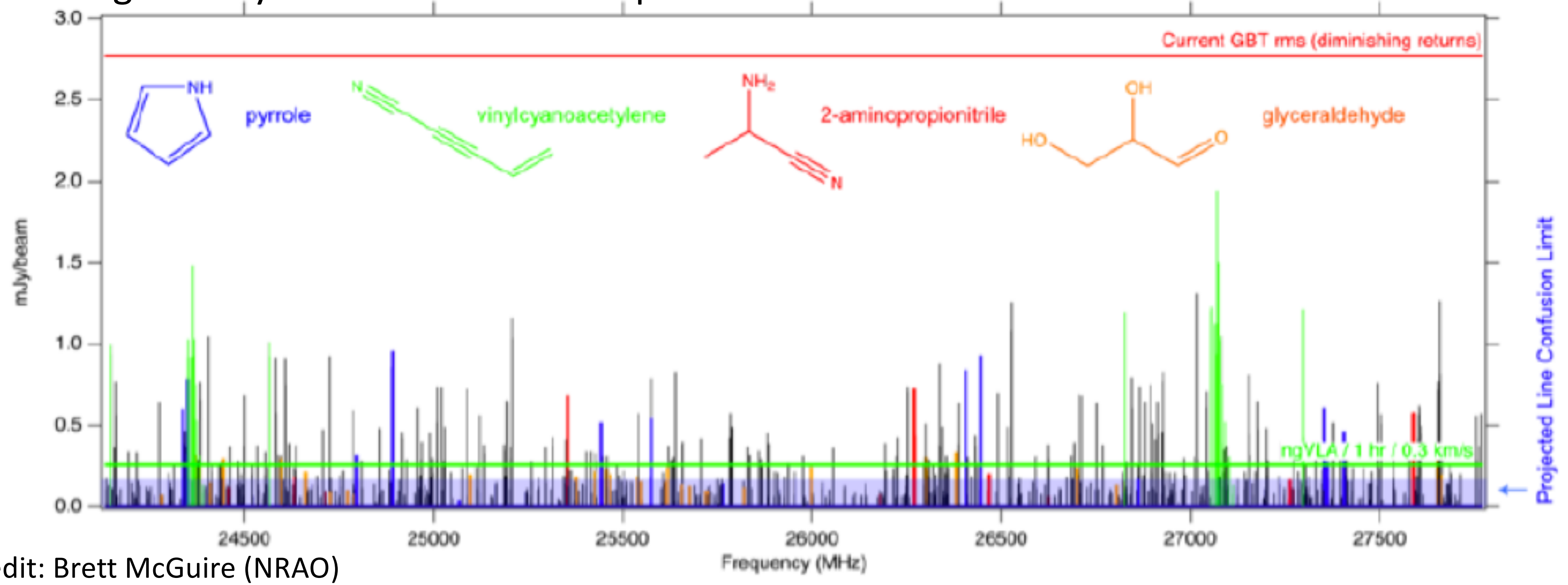
Using Pulsars in the Galactic Center as Fundamental Tests of Gravity

Understanding the Formation and Evolution of Stellar and Supermassive Black Holes in the Era of Multi-Messenger Astronomy

Unveiling the Formation of Solar System Analogues

Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry

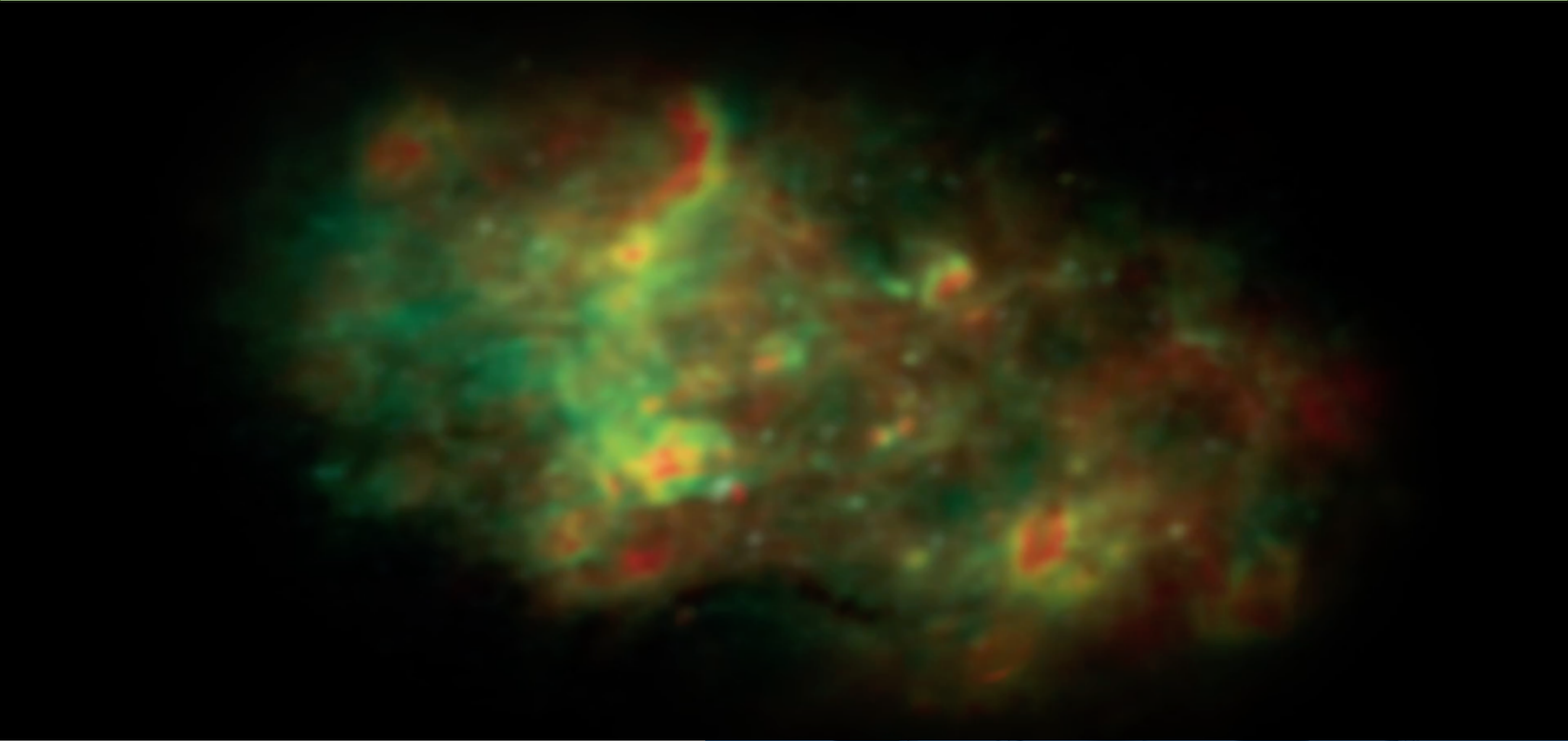
The ngVLA can detect complex pre-biotic molecules and provide the chemical initial conditions in forming solar systems and individual planets



Credit: Brett McGuire (NRAO)

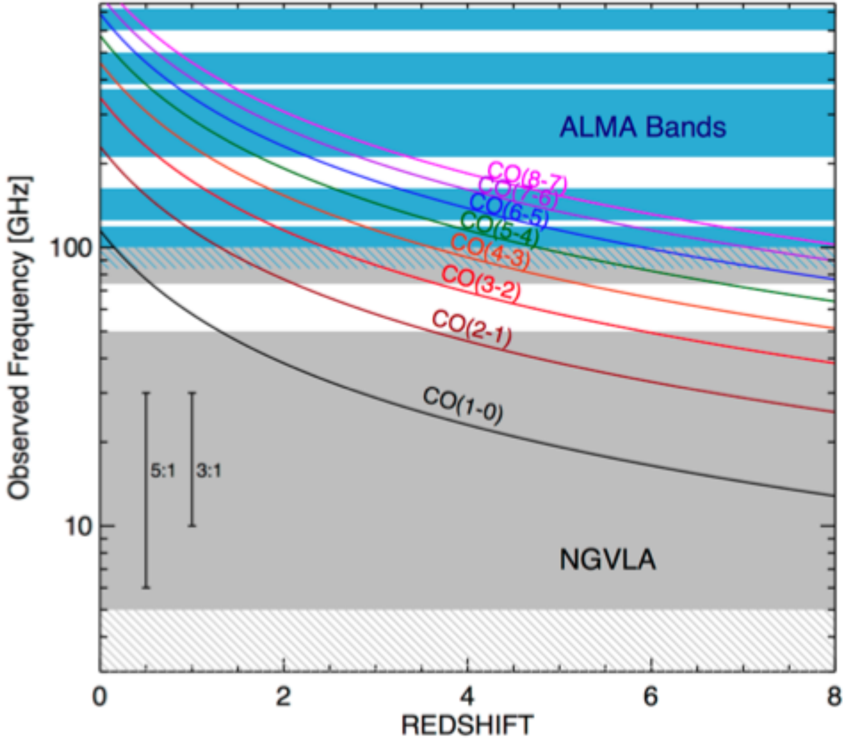
ngvla NRAO NSF Associated Universities, Inc.

Charting the Assembly, Structure, and Evolution of Galaxies from the First Billions Years to the Present



Charting the Assembly, Structure, and Evolution of Galaxies from the First Billions Years to the Present

- Order-of-magnitude improvement in depth and area for surveys of cold gas in high-z galaxies
- Routine sub-kpc imaging of the structure of protogalactic disks at any redshift where CO exists



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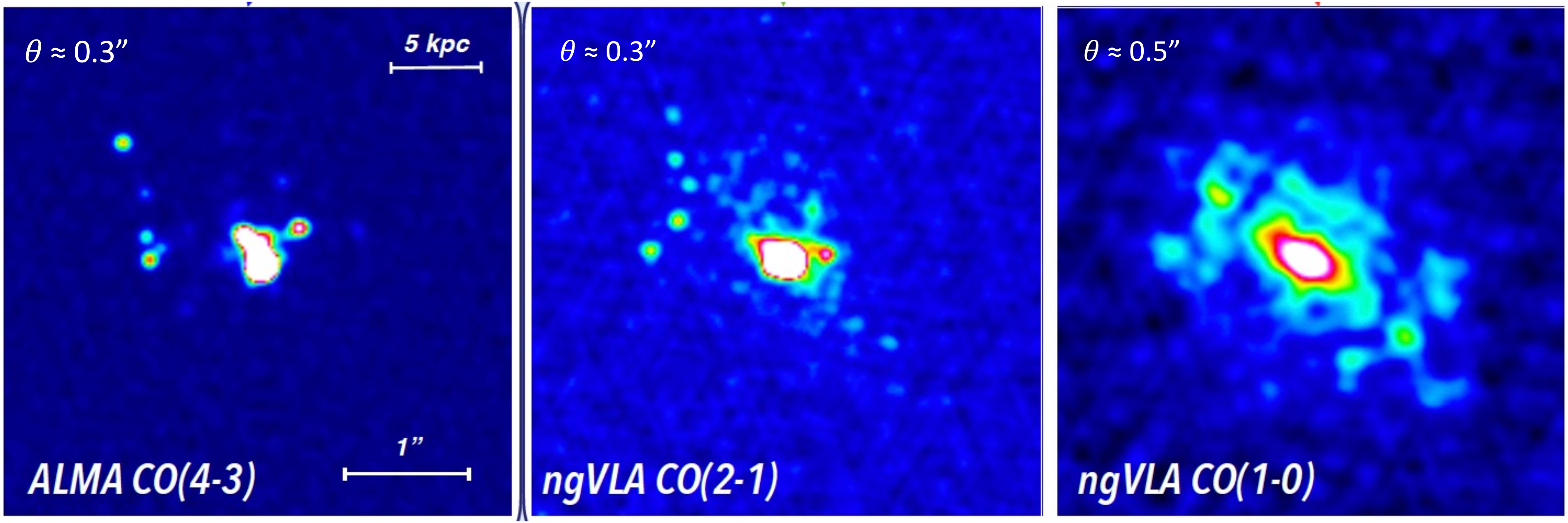


SMG at z = 4.4; SFR ≈ 400 $M_{\odot}$ /yr

Total molecular gas content largely missed by high-J lines

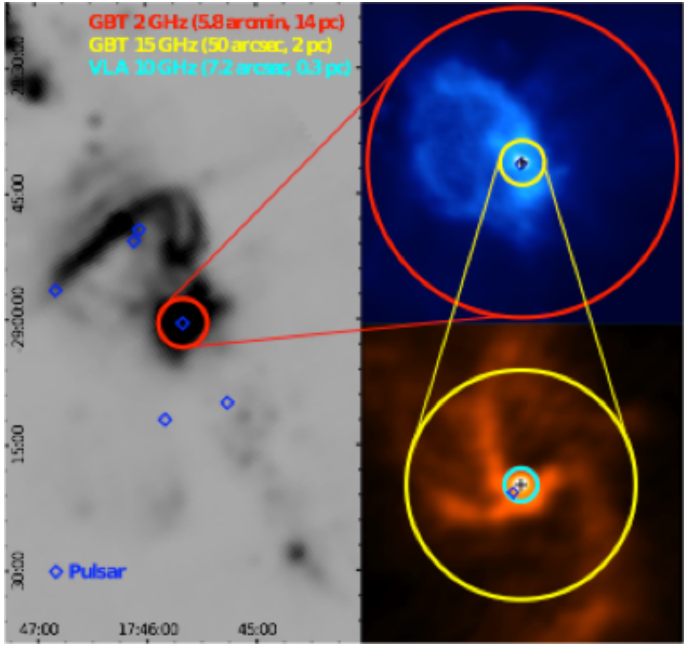
Credit: Caitlin Casey (UT Austin)

Using Pulsars in the Galactic Center as Fundamental Tests of Gravity

- The ngVLA sensitivity and frequency coverage will probe deeper than currently possible into the GC area looking for pulsars, which are moving clocks in the space-time potential of Sgr A*

- New tests of theories of gravity, constraints on exotic binaries, SF history, stellar dynamics and evolution, and ISM at the GC

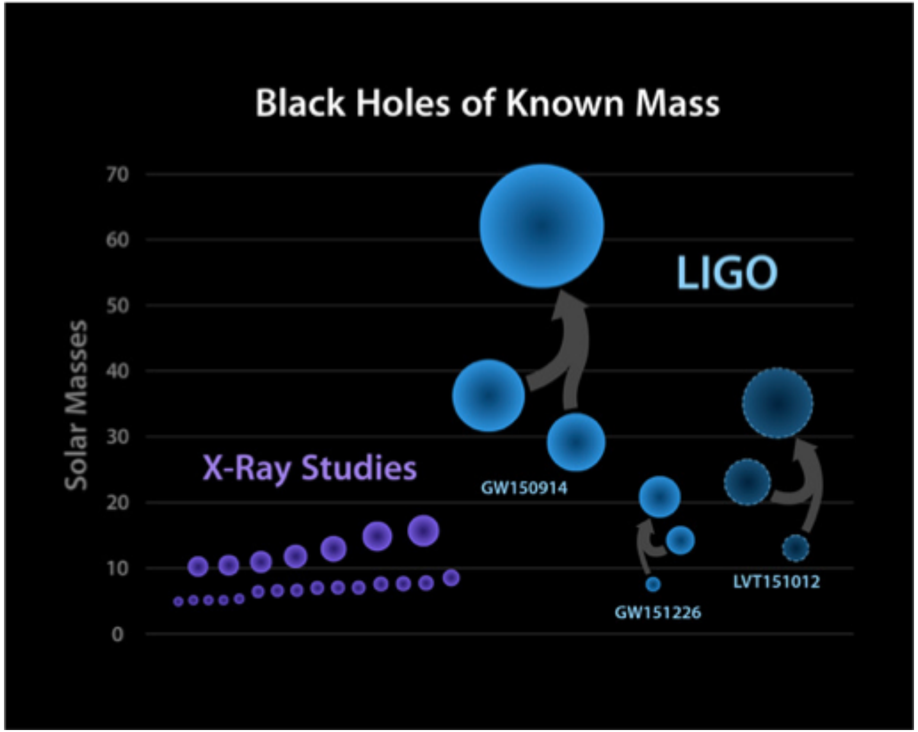
- Estimates are as high as 1,000 PSRs. Only known example is PSR J1745-2900 magnetar, which are extremely rare (<1%)



Credit: R.Wharton

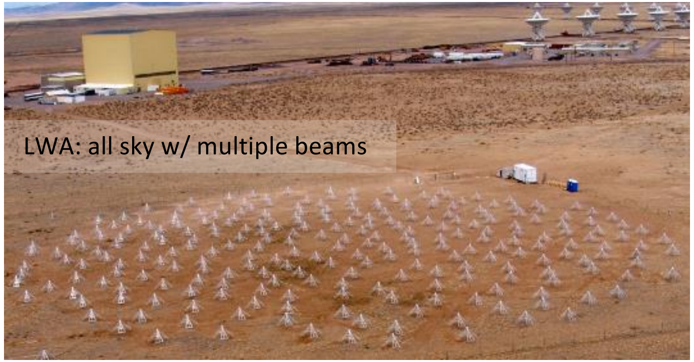
Understanding the Formation and Evolution of Stellar and Supermassive Black Holes in the Era of Multi-Messenger Astronomy

- Unaffected by dust obscuration and with the angular resolution to separate Galactic sources from background objects using proper motions, the ngVLA will enable a search for accreting black holes across the entire Galaxy.
- The ngVLA, with its deep high resolution imaging capabilities, will enable discovery of many binary supermassive black holes.
- Key to understanding GW discoveries.

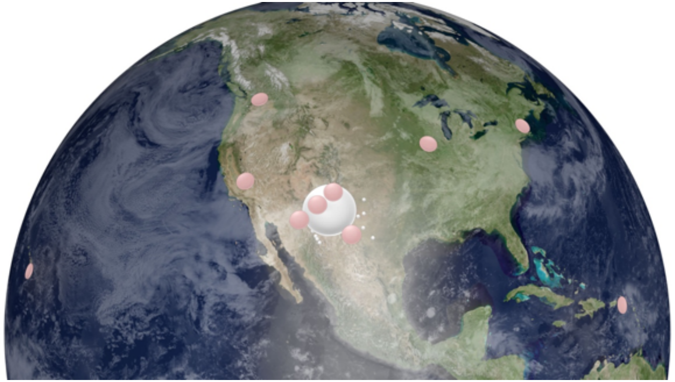


Science Options

- Commensal Low Frequency Science
  - Leverage ngVLA infrastructure (land/fiber/power) for commensal LF capabilities (ngLOBO)
    - 5 – 150 MHz: multi-beam dipole arrays alongside ngVLA long-baseline stations (e.g., LWA style).
    - 150 – 800 MHz commensal prime focus feeds on ngVLA antennas (e.g., VLITE style)



- U.S. VLBI Expansion of Capabilities
  - Replace existing VLBA antennas/infrastructure with ngVLA technology
  - Introduce new >~1000 km baseline stations to bridge gap between ngVLA & existing VLBA baselines
  - Cross correlate VLBI antennas with phased ngVLA core



Summary

- The ngVLA is being designed to tap into the astronomical community's intellectual curiosity and enable a broad range of scientific discovery (e.g., planet formation, signatures of pre-biotic molecules, cosmic cycling of cool gas in galaxies, massive star formation in the Galaxy etc.)

- Based on community input to date, the ngVLA is the obvious next step to build on the VLA's legacy and continue the U.S.'s place as a world leader in radio astronomy.

- Major Challenges: No major technological risks identified, but continually looking to take advantage of major engineering advancements seeking performance and operations optimizations.

- Next Steps: Continue to refine the ngVLA science mission and instrument specifications/performance through detailed science book and reference design study.

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