

ngVLA: Key Science Goals Update

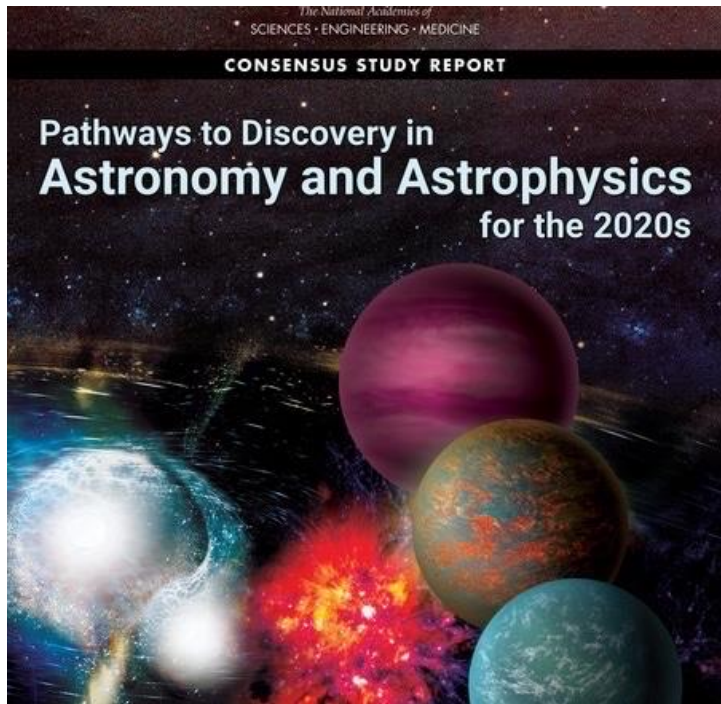
Alberto D. Bolatto – U. Maryland (ngVLA SAC)

AAS 245 Splinter Session January 2025

ngVLA.nrao.edu



Astro2020 identified the ngVLA as a high-priority large, ground-based facility whose construction should begin this decade.



Science Frontier Panel Questions / Discovery Areas	ngVLA	CMB-S4	MSO1	MSO2	MSO3	MSO4	Arecibo	GBT	ALMA	VLBA	VLA
Panel on the Interstellar Medium, Star and Planet Formation (ISM)											
1) How do star-forming structures arise from, and interact with, the diffuse ISM?	■	■						■	■	■	■
2) What regulates the structure and motions within molecular clouds?	■	■						■	■	■	■
3) How does gas flow from parsec scales down to protostars and their disks?	■	■						■	■	■	■
4) Is planet formation fast or slow?	■	■						■	■	■	■
D) Detecting and characterizing forming planets											
Panel on Exoplanets, Astrobiology and the Solar System (EAS)											
1) What is the range of planetary system architectures and is the configuration of the solar system common?	■	■							■	■	■
2) What are the properties of individual planets, and which processes lead to planetary diversity?	■	■							■	■	■
3) How do habitable environments arise and evolve within the context of their planetary systems?	■	■							■	■	■
4) How can signs of life be identified and interpreted in the context of their planetary environments?	■	■							■	■	■
D) The search for life on exoplanets											
Panel on Stars, the Sun and Stellar Populations (SSSP)											
1) What are the most extreme stars and stellar populations?	■	■	■								
2) How does multiplicity affect the way a star lives and dies?	■	■	■								
3) What would stars look like if we could view them like we do the Sun?	■	■	■								
4) How do the Sun and other stars create space weather?	■	■	■								
D) "Industrial Scale" Spectroscopy											
Panel on Compact Objects and Energetic Phenomena (COEP)											
1) What are the mass and spin distributions of neutron stars and stellar black holes?	■	■	■						■	■	■
2) What governs the diversity of explosive phenomena across the electromagnetic spectrum?	■	■	■						■	■	■
3) Why do some compact objects eject material in nearly-light-speed jets, and what is that material made of?	■	■	■						■	■	■
4) What seeds supermassive black holes and how do they grow?	■	■	■						■	■	■
D) Transforming our view of the Universe by combining new information from light, particles, and gravitational waves											
Panel on Galaxies (GAL)											
1) How did the intergalactic medium and the first sources of radiation evolve from cosmic dawn through the epoch of reionization?	■	■	■				■				
2) How do gas, metals, and dust flow into, through, and out of galaxies?	■	■	■				■				
3) How do supermassive black holes form, and how is their growth coupled to the evolution of their host galaxies?	■	■	■				■				
4) How do the histories of galaxies and their dark matter halos shape their observable properties?	■	■	■				■				
D) Mapping the circumgalactic medium and intergalactic medium in emission											
Panel on Cosmology (COS)											
1) What set the Hot Big Bang in motion?	■	■	■								
2) What are the properties of dark matter and the dark sector?	■	■	■								
3) What physics drives the cosmic expansion and the large-scale evolution of the Universe?	■	■	■								
4) How will measurements of gravitational waves reshape our cosmological view?	■	■	■								
Discovery Area: The Dark Ages as a cosmological probe											

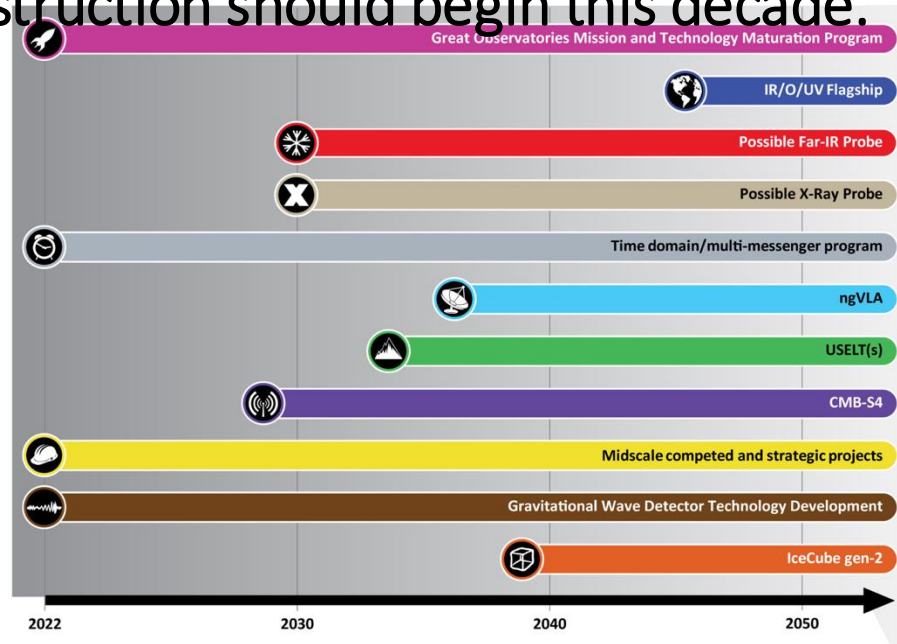
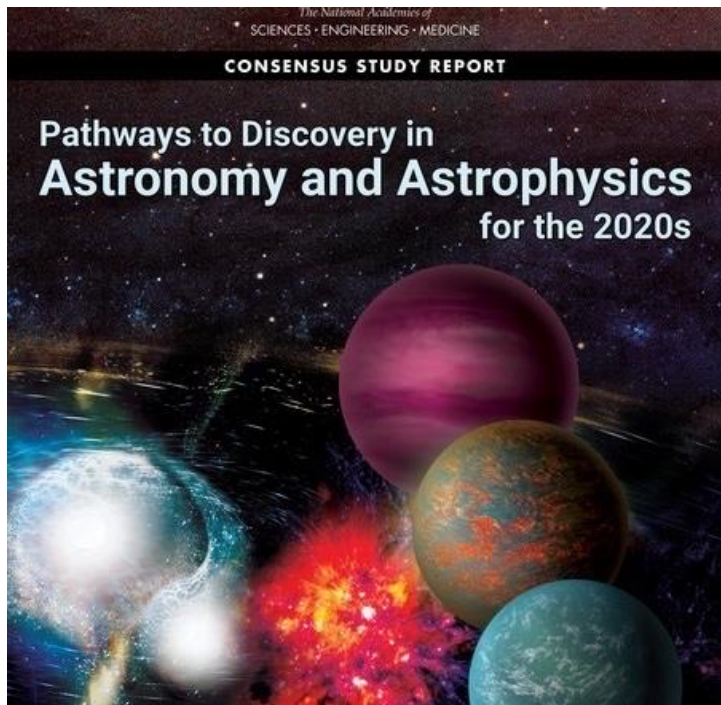
Table M.1 from RMS report

Left column: Science questions in Astro2020 by discovery area

Right columns: Facilities. Depth of green is role of the facility in addressing topic

Guess which column is ngVLA?

Astro2020 identified the ngVLA as a high-priority large, ground-based facility whose construction should begin this decade.



Identified as a formal MREFC Design Candidate by NSF Awarded (\$21M) over 3 years to Support PDR

ngVLA Technical Baseline

Key design choice: Antennas in fixed locations

- *Year-round access to all angular resolutions*
- *PI-driven facility providing “science sub-arrays”*

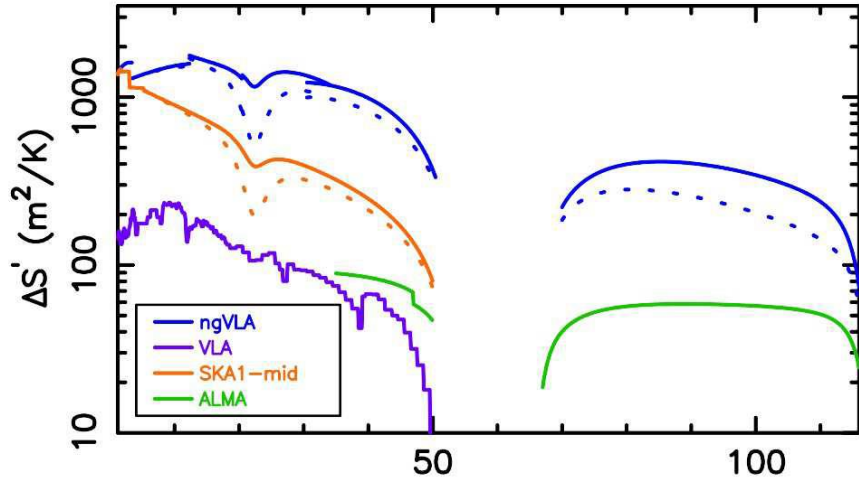
- **Frequency Range:** 1.2 - 116 GHz
- **Main Array:** 244 x 18m offset Gregorian Antennas
 - **Core:** 114 antennas; $B_{\max} = 4.3$ km
 - **Spiral:** 54 antennas; $B_{\max} = 39$ km
 - **Mid:** 46 antennas in NM, AZ, TX, MX; $B_{\max} = 1070$ km
 - **Long:** 30 antennas across continent; $B_{\max} = 8860$ km
- **Short Baseline Array:** 19 x 6m offset Greg. Antennas
 - Use 4 x 18m in **Total Power mode** to fill (u,v) hole

Band #	freq. range (GHz)
1	1.2 - 3.5
2	3.5 - 12.3
3	12.3 - 20.5
4	20.5 - 34
5	30.5 - 50.5
6	70 - 116

Correlator / Beamformer	Requirement (design)
digital efficiency	>95%
narrowest channel	<1 kHz
total # channels	>240,000
sub-band width	<250MHz (218.75)
total bandwidth	>14GHz/pol (20)
# formed beams	10

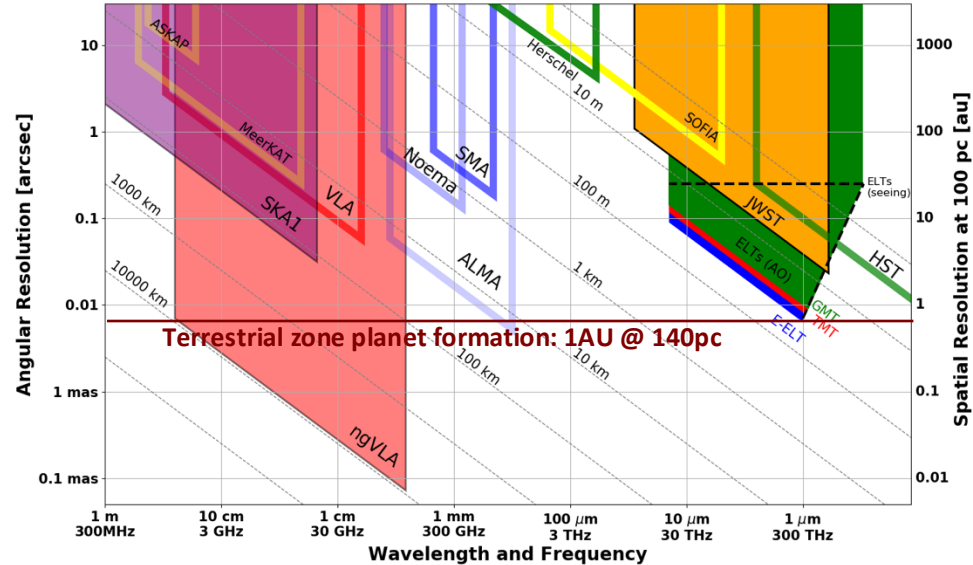
Linking ngVLA, ALMA (& ELTs) Scientifically

Sensitivity



Frequency (GHz)

Resolution



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 21cm: ngVLA superb for terrestrial planet formation, gas history, baryon cycling, pulsars
- > 3cm: SKA (Southern Hemisphere) superb for pulsars, reionization, HI + continuum surveys



~~ngVLA Key Science Goals (ngVLA memo #19)~~

2017

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



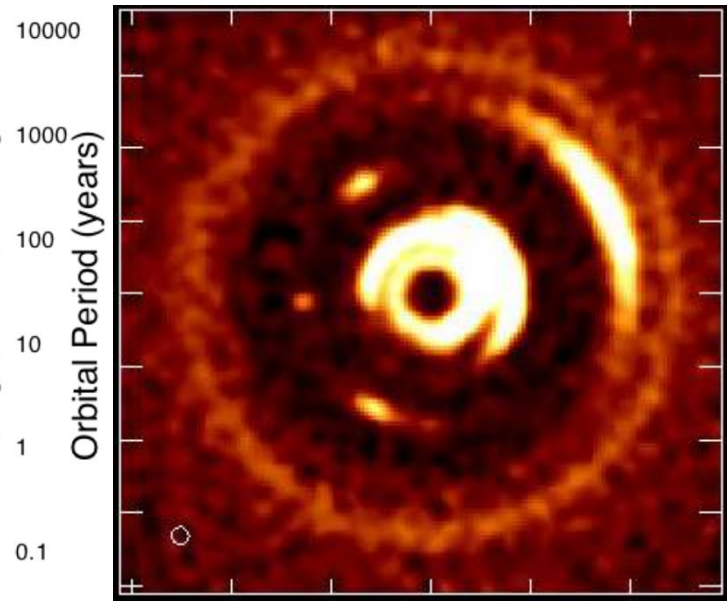
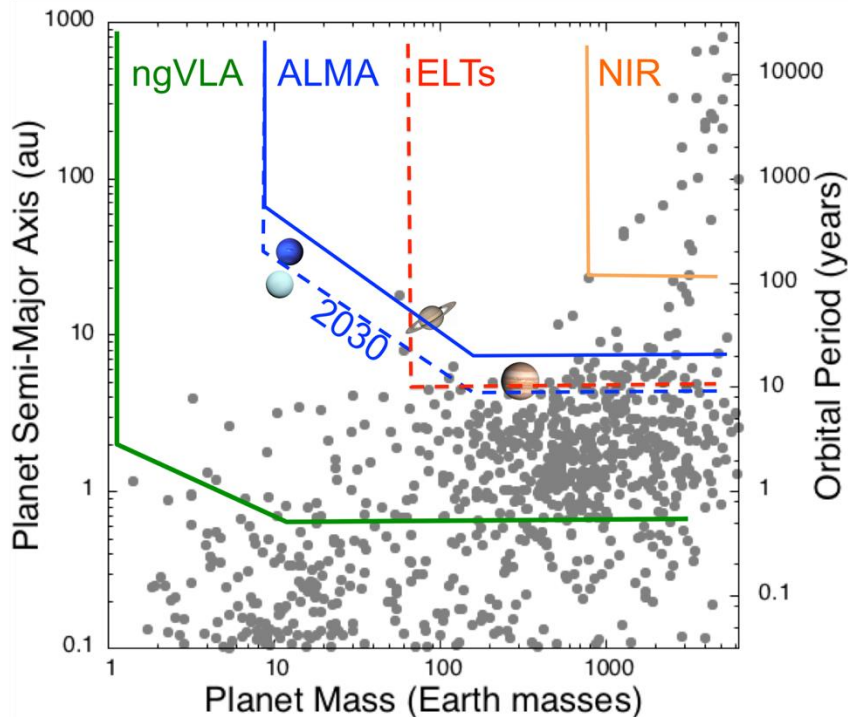
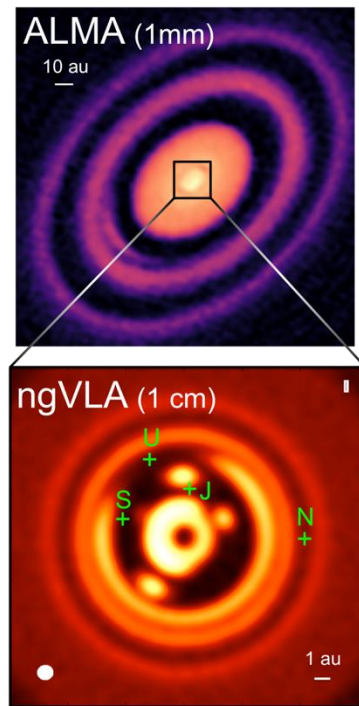
ngVLA Key Science Goals Update (ngVLA memo #125)

2024

1. *Unveiling the Formation of Solar System Analogues on Terrestrial Scales*
2. *Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry*
3. *Charting the Assembly, Structure, and Evolution of Galaxies Over Cosmic Time*
4. *Science at the Extremes: Pulsars as Laboratories for Fundamental Physics*
5. *Understanding the Formation and Evolution of Stellar and Supermassive BH's in the Era of Multi-Messenger Astronomy*

KSG1: Solar System Analogues on Terrestrial Scales

The ngVLA will measure the planet IMF down to ~5-10 Earth masses and unveil the formation of planetary systems similar to our own Solar System.

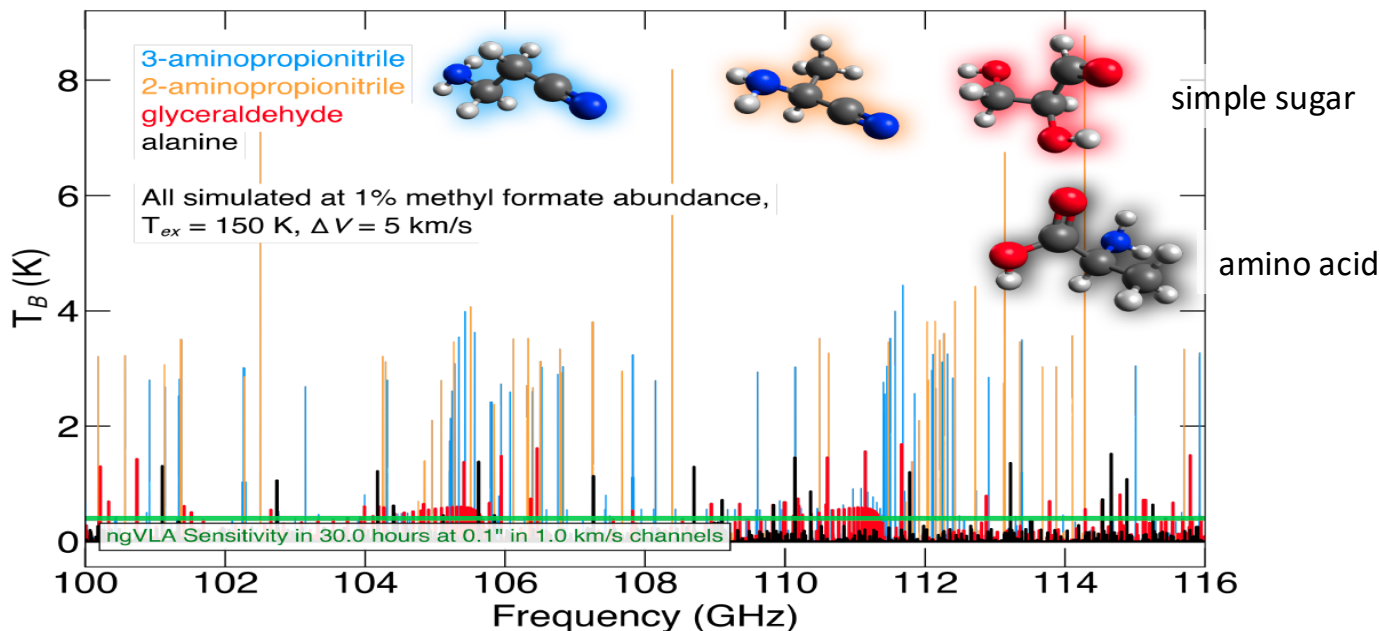


See Ricci et al. (2018), Harter et al. (2020)

KSG2: Initial Conditions for Planetary Systems and Life with Astrochemistry

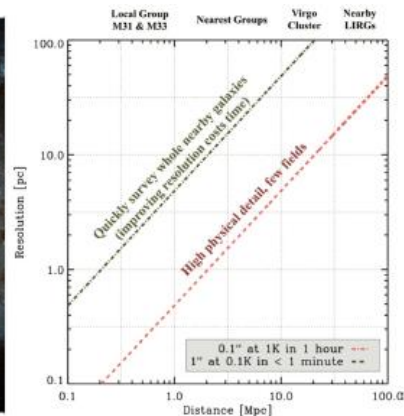
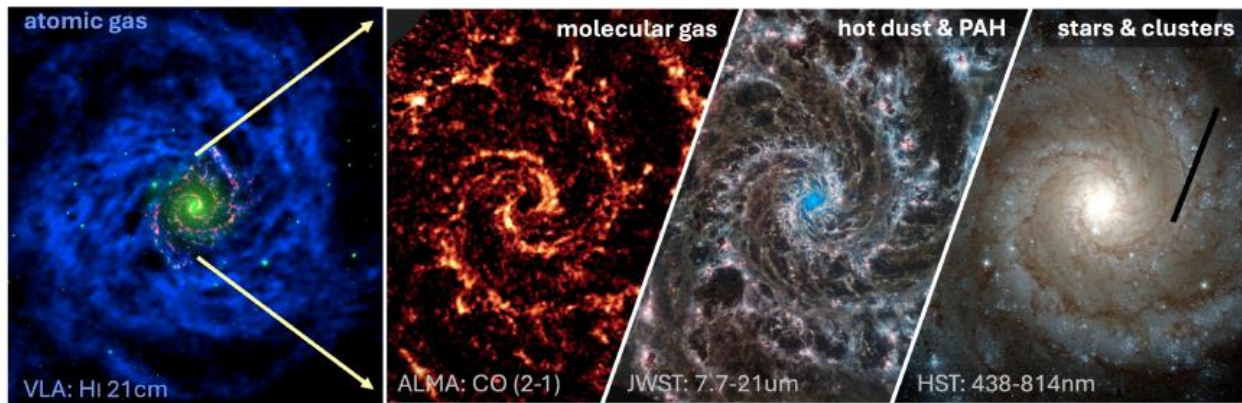
The ngVLA will detect complex pre-biotic molecules and provide the chemical initial conditions in forming solar systems and individual planets

- Cm-wave spectral coverage mitigates dust opacity, line confusion. High angular resolution disentangles different components.
- Disks, astrobiology, comets, chirality, molecules with biogenic heavier atoms (S, P, Na, Cl, K)

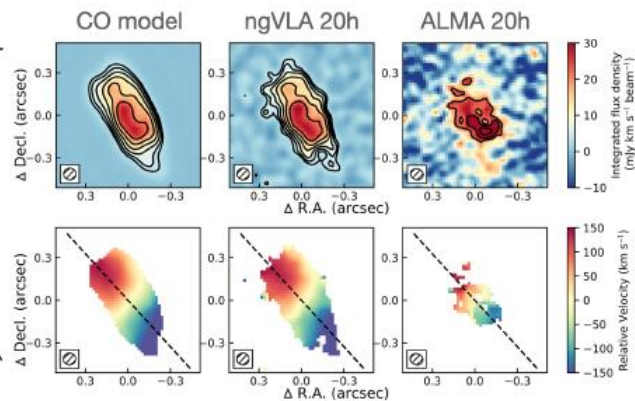
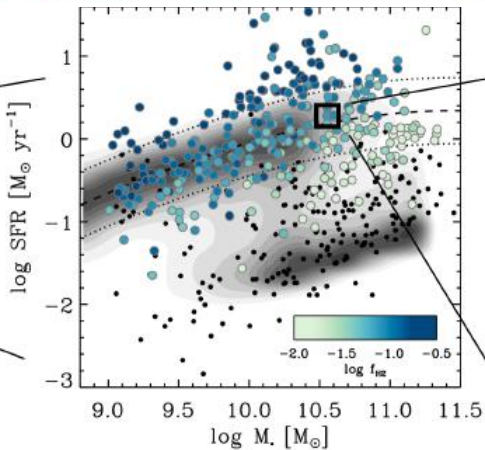
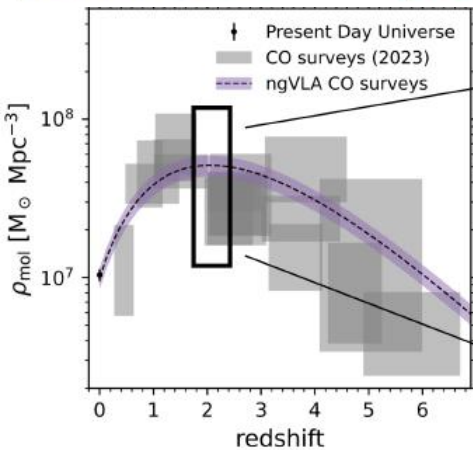


KSG3: Assembly, Structure, and Evolution of Galaxies

The ngVLA will routinely detect molecular gas in “normal” galaxies at $z=6$ via low- J transitions inaccessible to ALMA.



Extended HI disks, GMC-scale CO data on local LIRGs, and opening up fainter molecules.

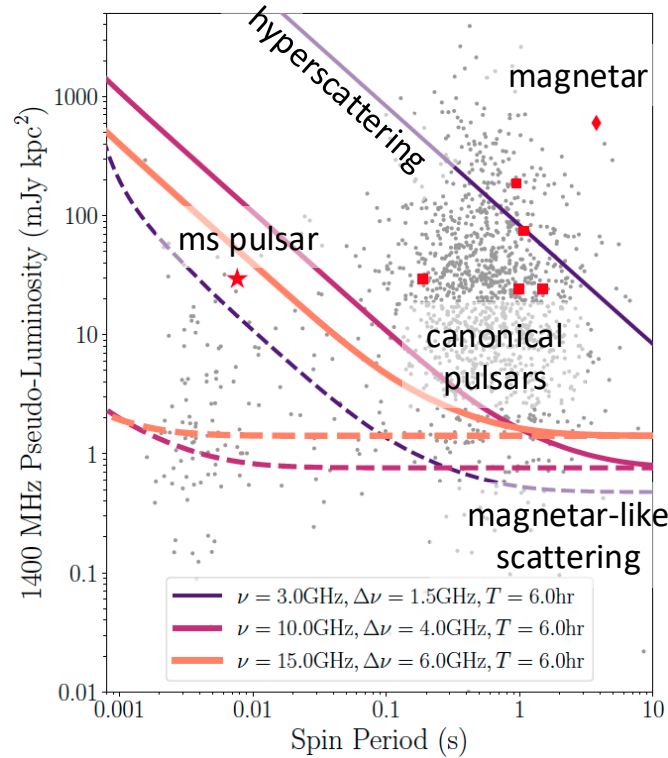


Cosmic dense gas history and distribution and kinematics of a normal SF galaxy at $z=1.7$ (20 hrs, comparing ngVLA and ALMA, Carilli & Neeleman 2022)

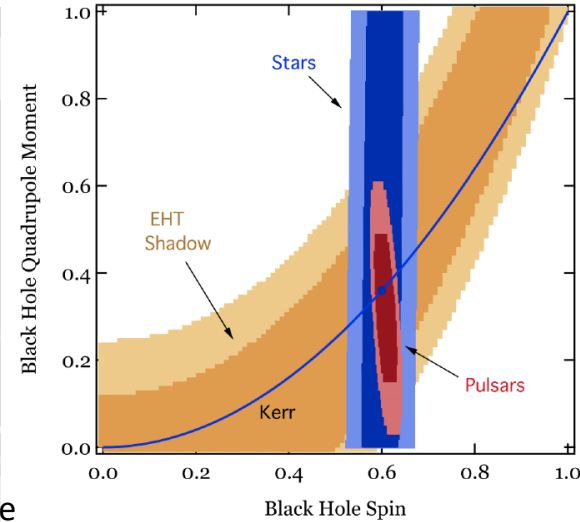
KSG4: Pulsars as Laboratories for Fundamental Physics

*The ngVLA will test gravity by measuring clocks in the space-time of Sgr A**

- The ngVLA sensitivity and frequency coverage will probe deeper than currently possible into the GC area. Estimates are as high as 1,000 PSRs. Only known example is PSR J1745-2900 magnetar, which are extremely rare (<1%)
- New tests of theories of gravity, cosmological gravitational waves with pulsar timing, constraints on exotic binaries, nuclear matter equation of state, origin of Fermi GeV excess



Credit: R. Wharton

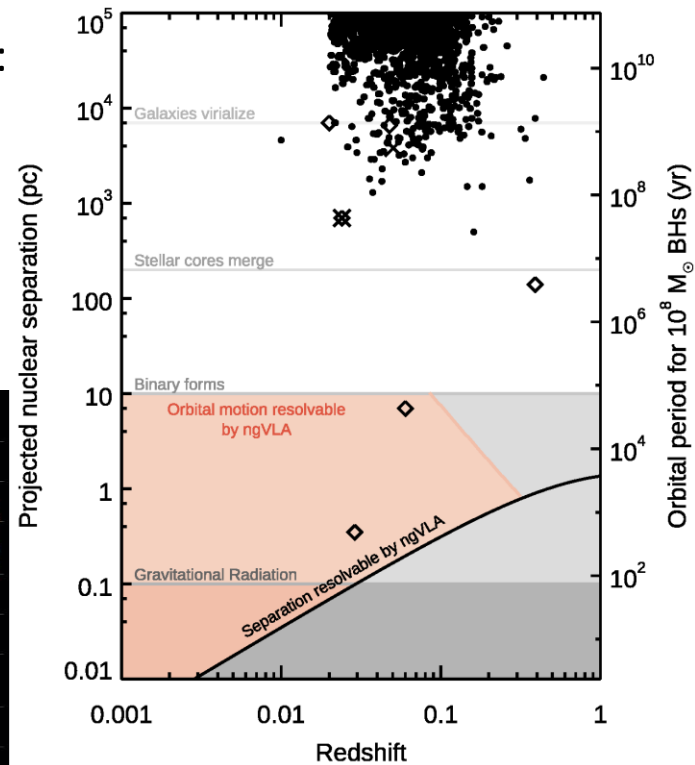
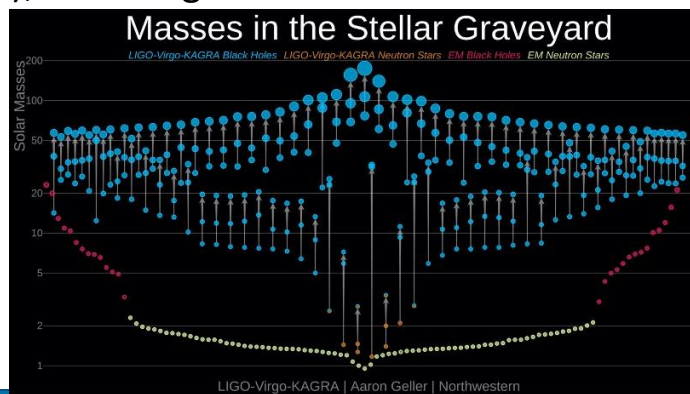


Posteriors testing the Kerr metric with data from EHT, 2 orbiting stars, or one pulsar (Psaltis et al. 2016).

KSG5: Understanding the Formation and Evolution of Black Holes in the Era of *Multi-Messenger Astronomy*

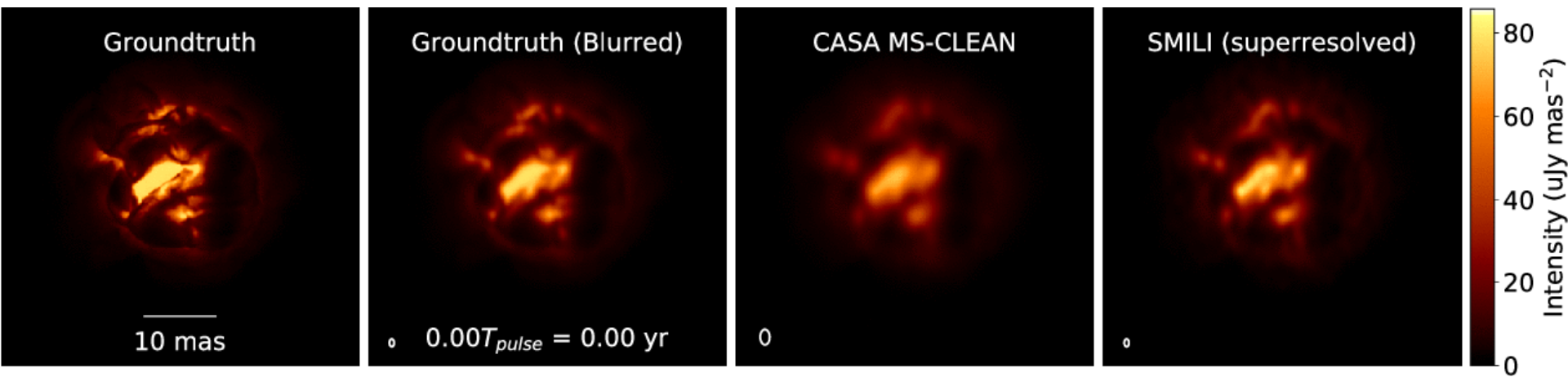
- The ngVLA's sensitivity & angular resolution will be able to:
 - Localize & Resolve dual AGN and BH binaries directly in the Radio.
 - Detect GW170817 source at Adv LIGO horizon dist. of 200 Mpc.
 - Measure proper motion expansion over 5 year periods (orange shaded region), including GW sources

- Search for BHs across all masses
 - e.g., weakly accreting MW BHs & SMBHs in nearby dwarfs via *proper motions*
 - Increase sample by $\sim x10$



Science Highlight: Star Formation and Stellar Evolution

The ngVLA will measure the in-situ gas motions from material shed around AGB stars.



Simulation based on 3D hydrodynamic model of AGB star Atmosphere from Freytag et al. (2017):

- ngVLA Main Array at 46 GHz
- 1.5 mas \sim 0.04 stellar radii at $d=150\text{pc}$
- 1.3 year pulse period
- Observed every 2-3 weeks

ngVLA Memo #66

Credit: K. Akiyama & L. Matthews
based on models from B. Freytag

Supported by ngVLA Comm Study Program

