ngvla
Next Generation Very Large Array

ngVLA: Key Science Goals Update

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ngVLA.nrao.edu

NSF AUI NRAO

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

ngvla
Next Generation Very Large Array

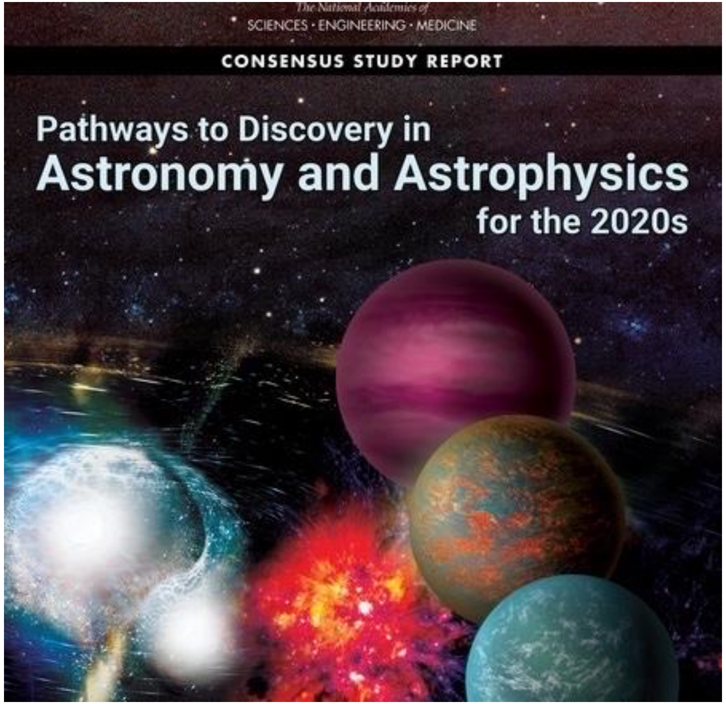


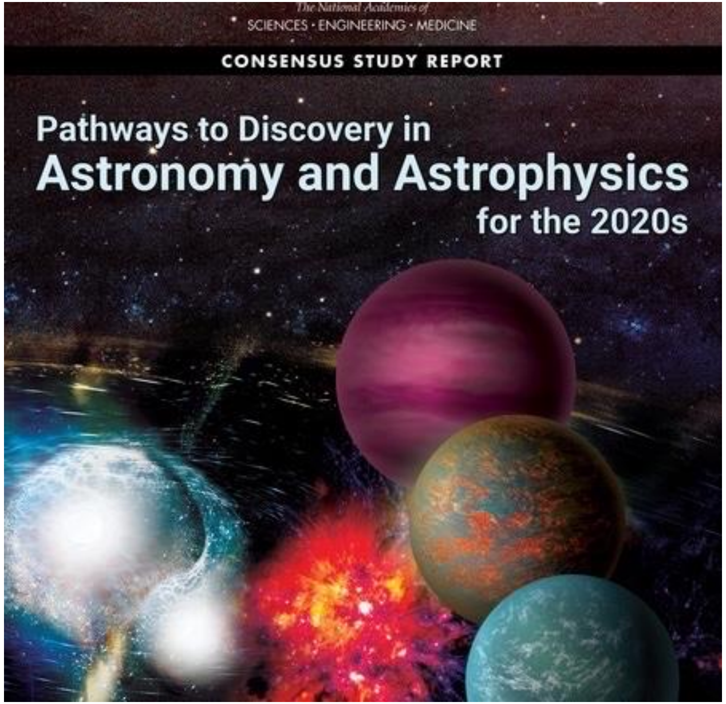
Table M.1 from RMS report

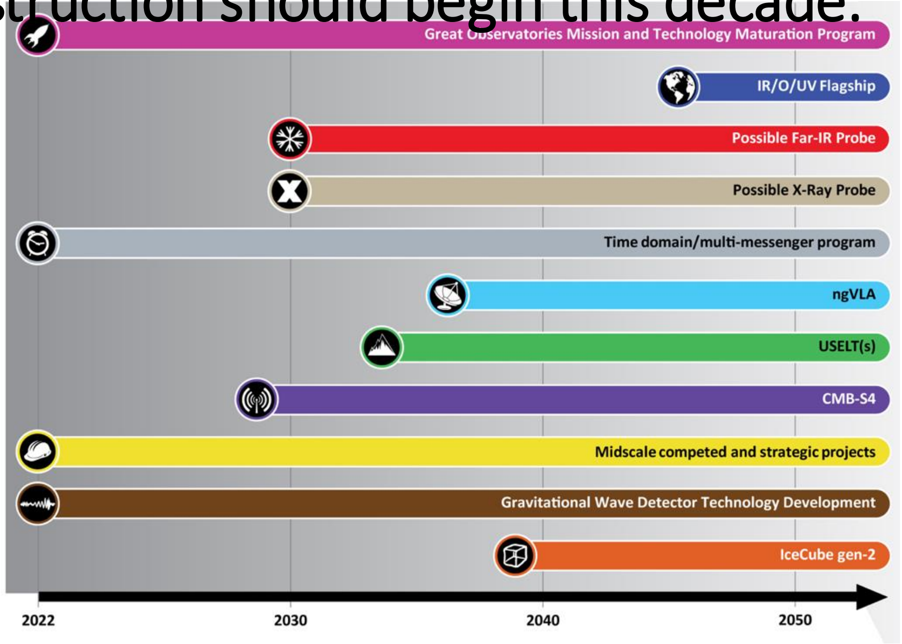
Left column: Science questions in Astro2020 by discovery area

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”*

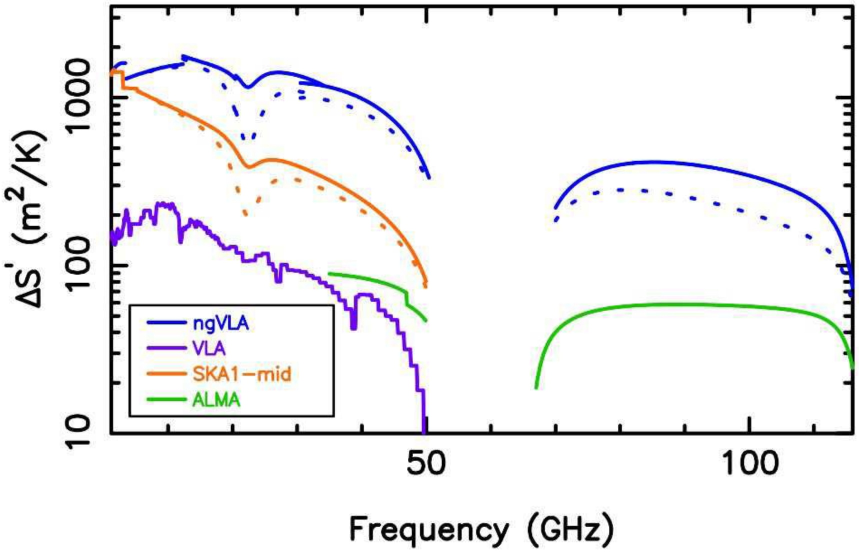
- **Frequency Range**: 1.2 - 116 GHz
- **Main Array**: 244 x 18m offset Gregorian Antennas
  - **Core**: 114 antennas; B_{max} = 4.3 km
  - **Spiral**: 54 antennas; B_{max} = 39 km
  - **Mid**: 46 antennas in NM, AZ, TX, MX; B_{max}=1070 km
  - **Long**: 30 antennas across continent; B_{max}= 8860 km
- **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

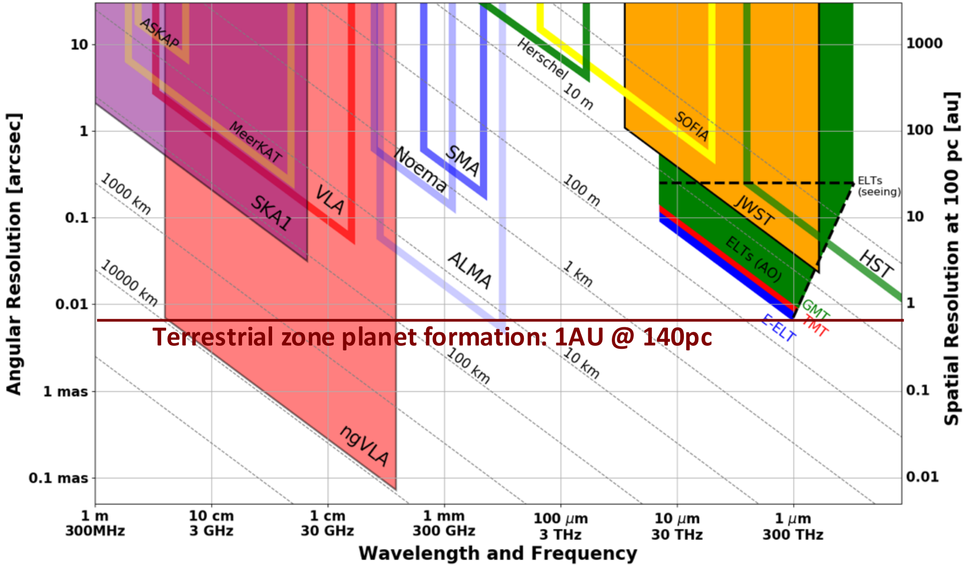
Correlator / Beamformer	Requirement (design)
digital efficiency	>95%
narrowest channel	<1 kHz
total # channels	>240,000
sub-band width	<250MHz (218.75)
total bandwidth	>14GHz/pol (20)
# formed beams	10

Linking ngVLA, ALMA (& ELTs) Scientifically

Sensitivity



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

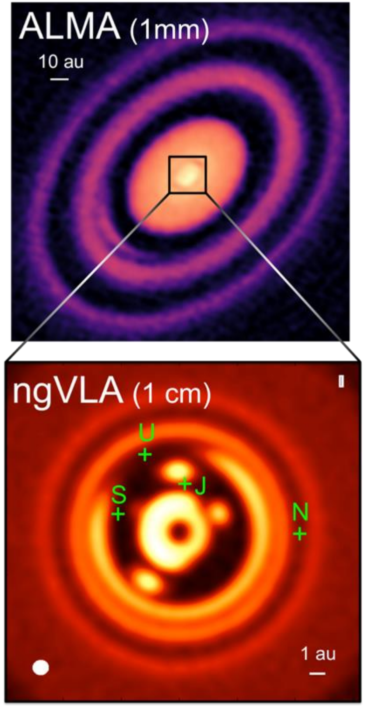
1. *Unveiling the Formation of Solar System Analogues on Terrestrial Scales*
2. *Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry*
3. *Charting the Assembly, Structure, and Evolution of Galaxies Over Cosmic Time*
4. *Using Pulsars in the Galactic Center as Fundamental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

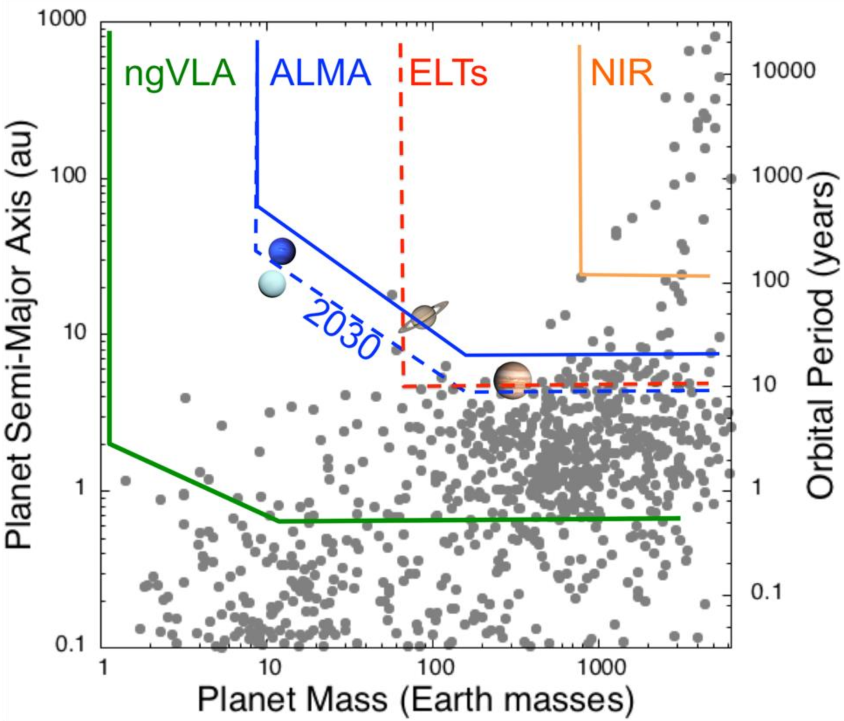
ngVLA Key Science Goals Update
(ngVLA memo #125) 2024

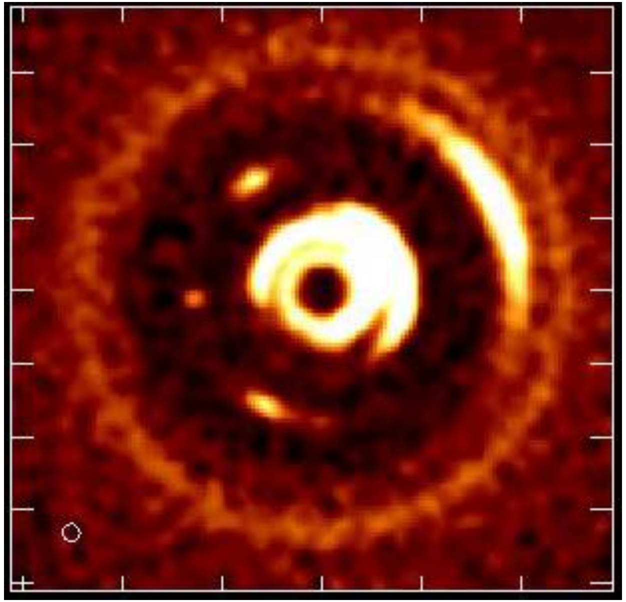
1. *Unveiling the Formation of Solar System Analogues on Terrestrial Scales*
2. *Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry*
3. *Charting the Assembly, Structure, and Evolution of Galaxies Over Cosmic Time*
4. *Science at the Extremes: Pulsars as Laboratories for 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.





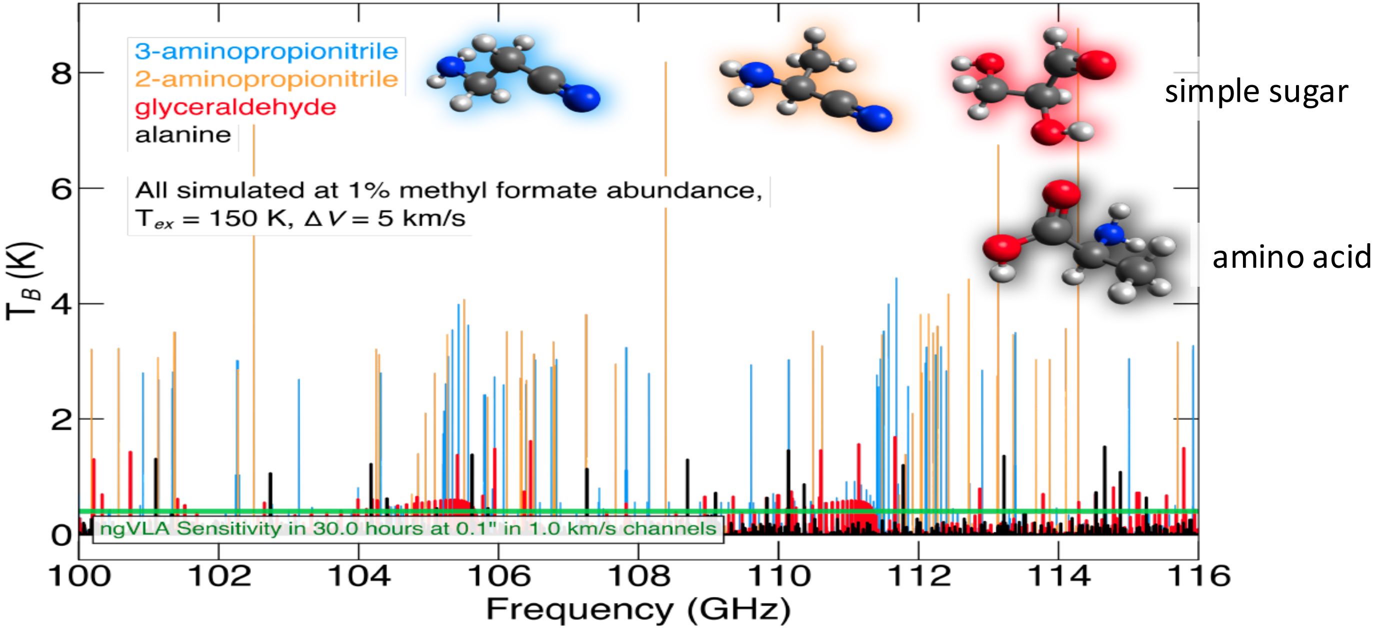


See Ricci et al. (2018), Harter et al. (2020)

KSG2: Initial Conditions for Planetary Systems and Life with Astrochemistry

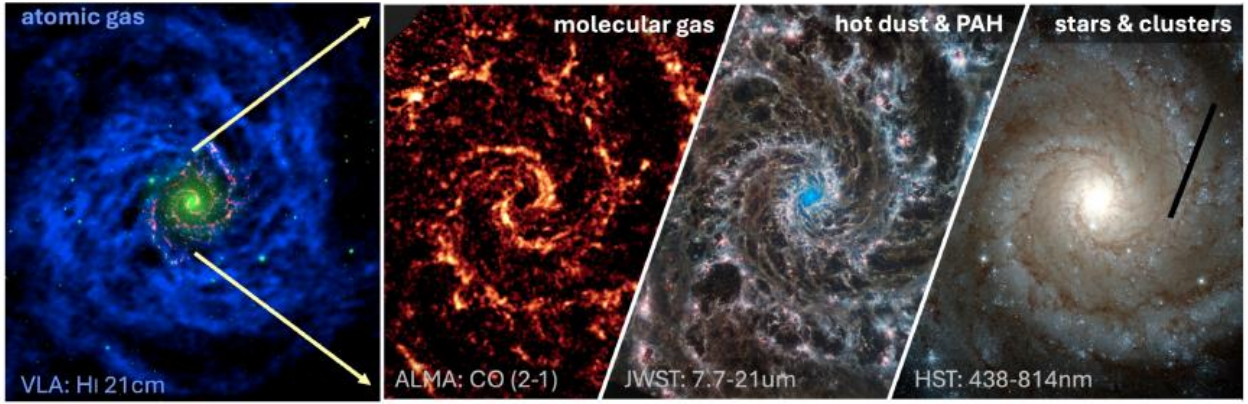
The ngVLA will detect complex pre-biotic molecules and provide the chemical initial conditions in forming solar systems and individual planets

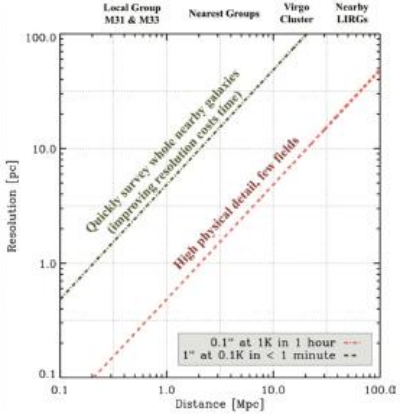
- Cm-wave spectral coverage mitigates dust opacity, line confusion. High angular resolution disentangles different components.
- Disks, astrobiology, comets, chirality, molecules with biogenic heavier atoms (S, P, Na, Cl, K)



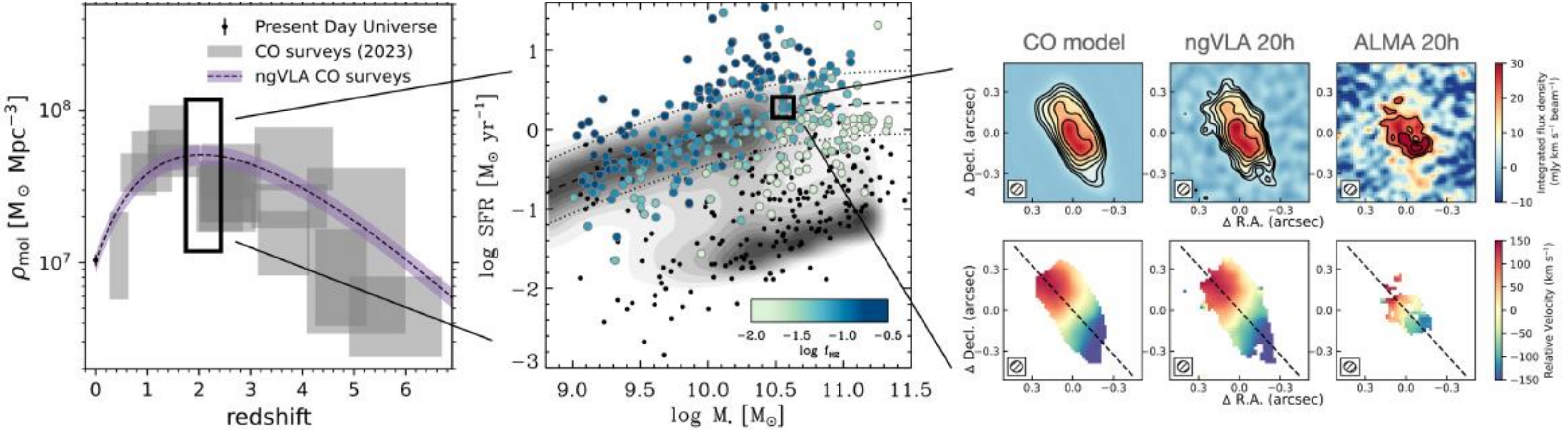
KSG3: Assembly, Structure, and Evolution of Galaxies

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.



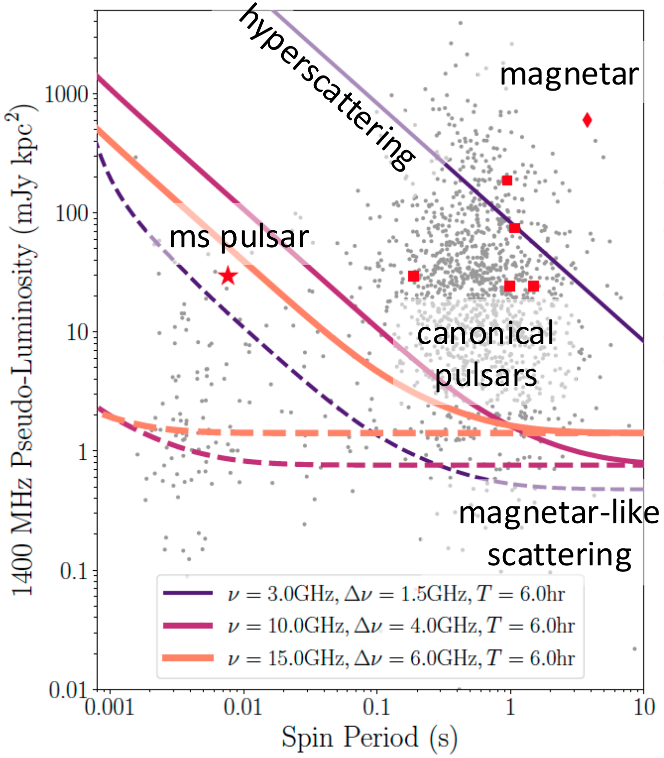
Cosmic dense gas history and distribution and kinematics of a normal SF galaxy at z=1.7 (20 hrs, comparing ngVLA and ALMA, Carilli & Neeleman 2022)

KSG4: Pulsars as Laboratories for Fundamental Physics

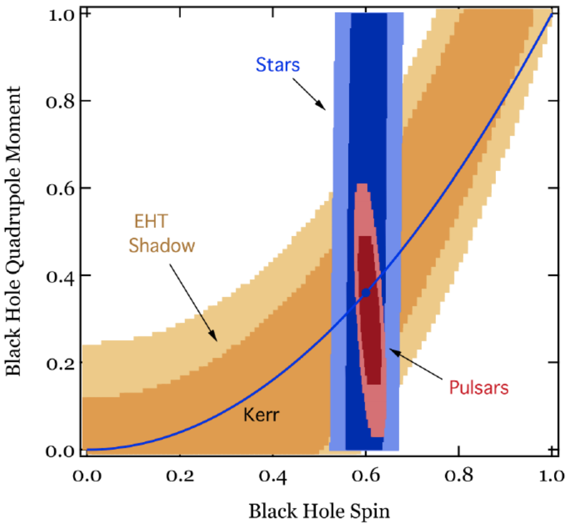
The ngVLA will test gravity by measuring clocks in the space-time of Sgr A*

- 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



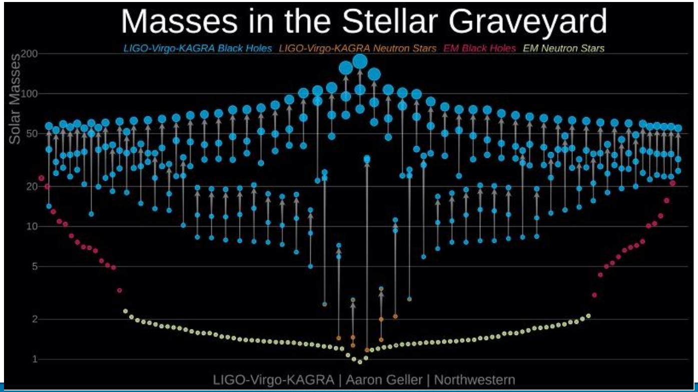
Credit: R. Wharton

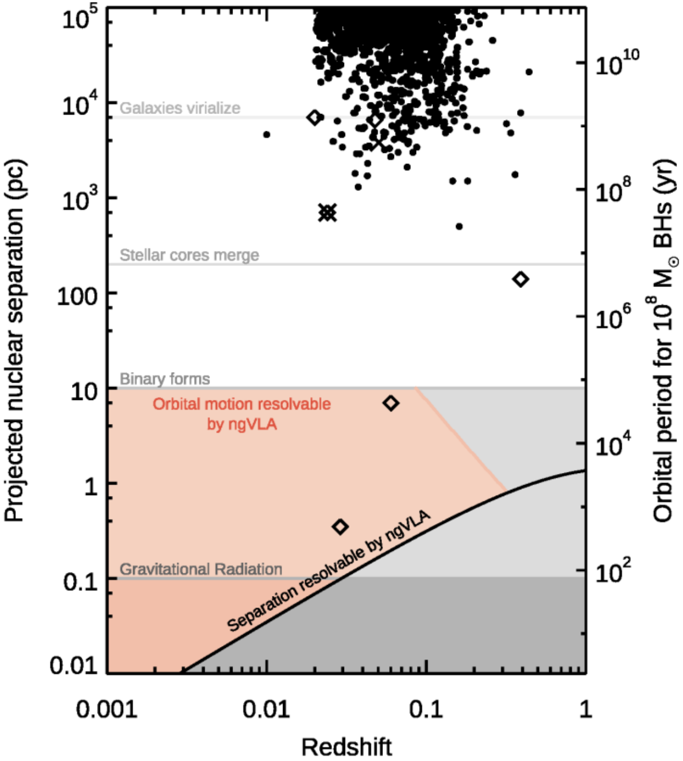


Posteriors testing the Kerr metric with data from EHT, 2 orbiting stars, or one pulsar (Psaltis et al. 2016).

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

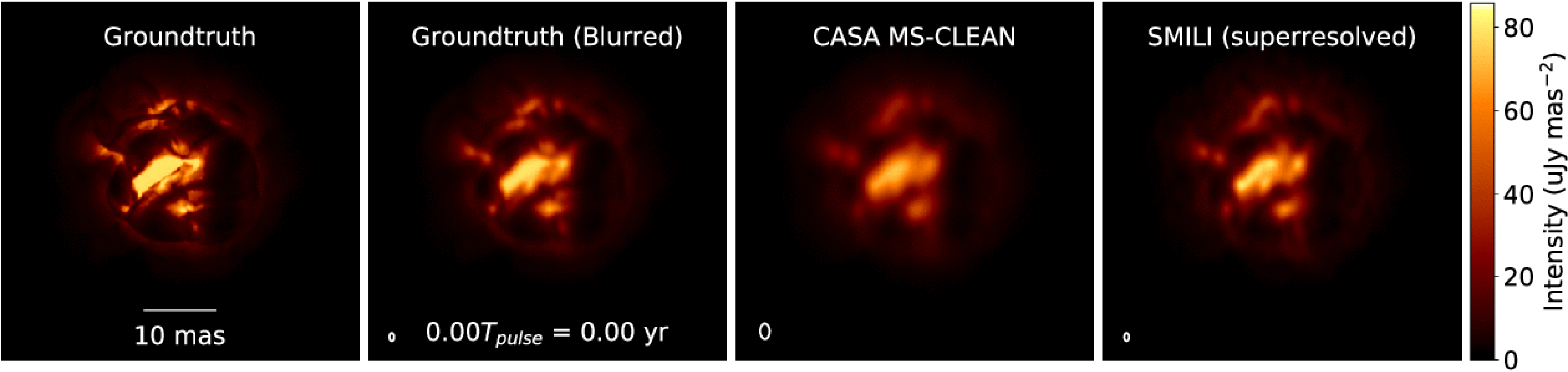
- The ngVLA's sensitivity & angular resolution will be able to:
  - Localize & Resolve dual AGN and BH binaries directly in the Radio.
    - Detect GW170817 source at Adv LIGO horizon dist. of 200 Mpc.
  - Measure proper motion expansion over 5 year periods (orange shaded region), including GW sources
- Search for BHs across all masses
  - e.g., weakly accreting MW BHs & SMBHs in nearby dwarfs via *proper motions*
  - Increase sample by ~x10





Science Highlight: Star Formation and Stellar Evolution

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



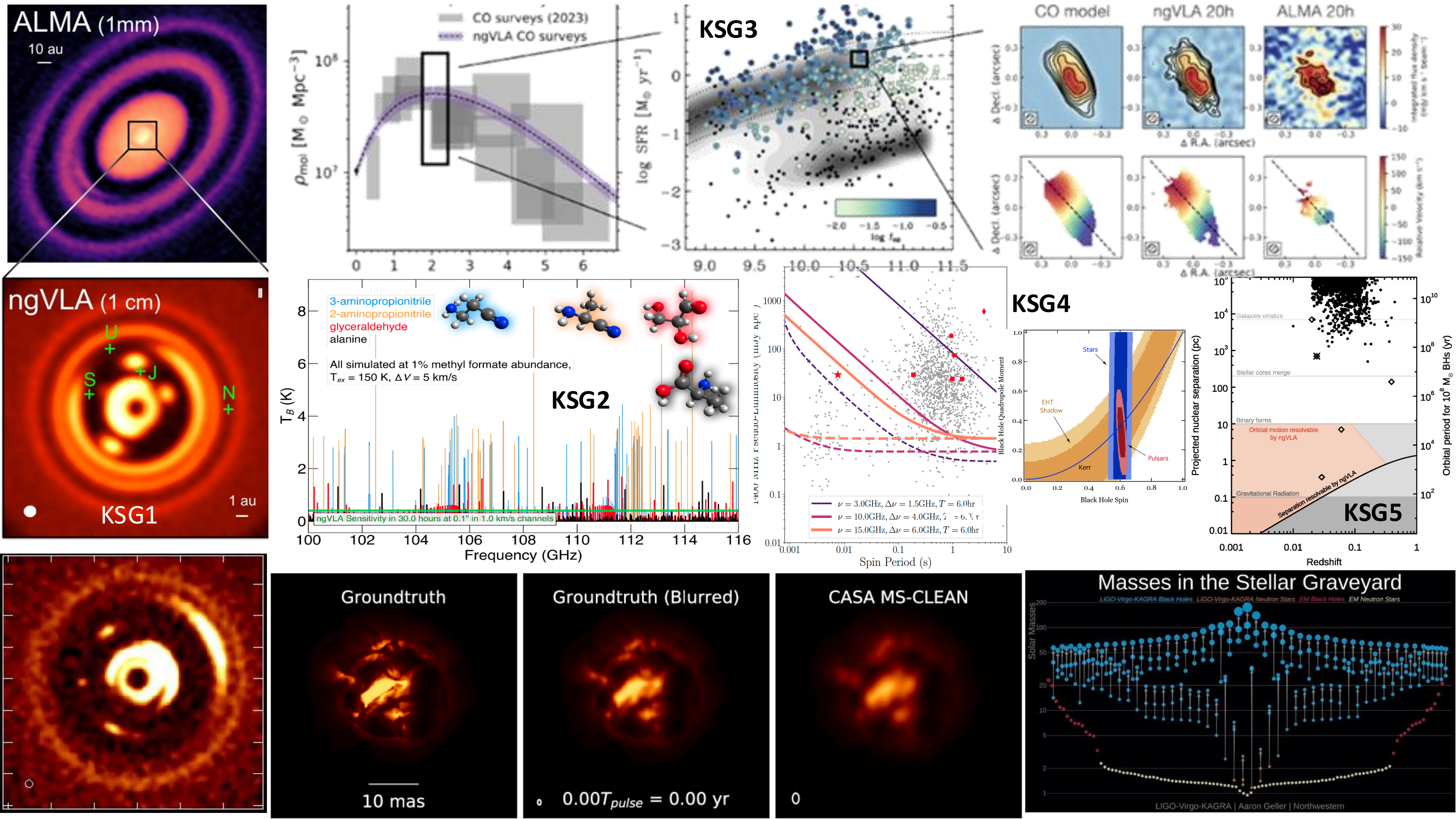
Simulation based on 3D hydrodynamic model of AGB star Atmosphere from Freytag et al. (2017):

- ngVLA Main Array at 46 GHz
- 1.5 mas ~ 0.04 stellar radii at d=150pc
- 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



ALMA (1mm)
10 au
ngVLA (1 cm)
U
J
S
N
1 au
KSG1
CO surveys (2023)
ngVLA CO surveys
ρmol [M⊙ Mpc−3]
KSG3
log SFR [M⊙ yr−1]
CO model
ngVLA 20h
ALMA 20h
Δ Decl. (arcsec)
Δ R.A. (arcsec)
3-aminopropionitrile
2-aminopropionitrile
glyceraldehyde
alanine
All simulated at 1% methyl formate abundance,
Tex = 150 K, ΔV = 5 km/s
KSG2
TB (K)
ngVLA Sensitivity in 30.0 hours at 0.1" in 1.0 km/s channels
Frequency (GHz)
KSG4
ν = 3.0GHz, Δν = 1.5GHz, T = 6.0hr
ν = 10.0GHz, Δν = 4.0GHz
ν = 15.0GHz, Δν = 6.0GHz, T = 6.0hr
Spin Period (s)
Black Hole Quadrupole Moment
Stars
EHT Shadow
Kerr
Pulsars
Black Hole Spin
Projected nuclear separation (pc)
Galaxies virialize
Stellar cores merge
Binary forms
Orbital motion resolvable by ngVLA
Gravitational Radiation
Separation resolvable by ngVLA
KSG5
Redshift
Orbital period for 10^8 M⊙ BHs (yr)
Groundtruth
10 mas
Groundtruth (Blurred)
0.00Tpulse = 0.00 yr
CASA MS-CLEAN
0
Masses in the Stellar Graveyard
LIGO-Virgo-KAGRA Black Holes
LIGO-Virgo-KAGRA Neutron Stars
EM Black Holes
EM Neutron Stars
Solar Masses
LIGO-Virgo-KAGRA | Aaron Geller | Northwestern

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