NATIONAL RADIO ASTRONOMY OBSERVATORY

Intro and Science Program

Chris Carilli

https://ngvla.nrao.edu

Next Generation Very Large Array

Next Generation Very Large Array: URSI 2018 Talks

- J1-1 THE SCIENCE PROGRAM FOR THE NEXT GENERATION VERY LARGE ARRAY, Chris Carilli
- J1 -2 ANTENNA CONCEPT FOR THE NEXT GENERATION VERY LARGE ARRAY, James M. Jackson
- J1-4 BASELINE RECEIVER CONCEPT FOR A NEXT GENERATION VERY LARGE ARRAY, Wes Grammer
- J2-2 ADVANCES IN AN 8 TO 50 GHZ CRYOGENIC LOW NOISE AMPLIFIER FOR THE NEXT GENERATION VERY LARGE ARRAY, Andrew Janzen
- J4-2 THE NEXT GENERATION VERY LARGE ARRAY LONG BASELINE OPTION, Robert J. Selina
- J5-2 PERFORMANCE ESTIMATES FOR THE NEXT- GENERATION VERY LARGE ARRAY, Robert J. Selina
- J5-3 A STUDY OF THE COMPACT WATER VAPOR RADIOMETER FOR THE KARL G. JANSKY VERY LARGE ARRAY, Ajay Gill

A next generation VLA

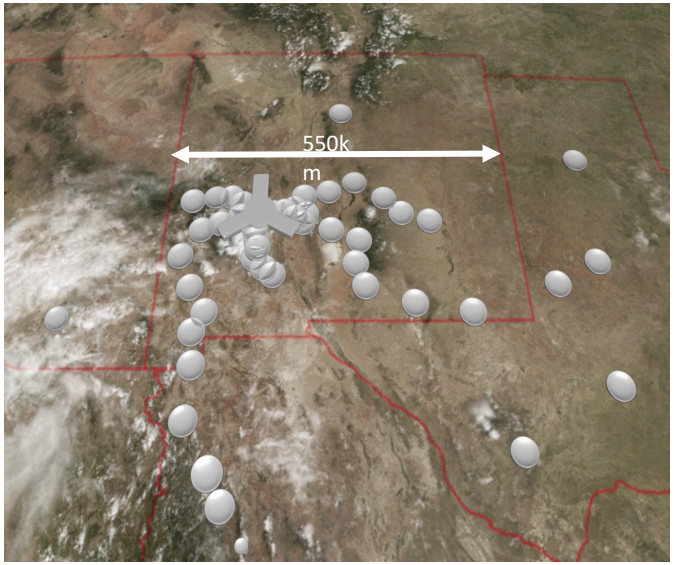
A New Array for the mid-21st Century: thermal imaging on milliarcsec scales

- Core Design Requirements
  - *10x effective collecting area of JVLA and ALMA at 30GHz*
  - *10x resolution of JVLA and ALMA*
  - *Frequency range: 1.2 –116 GHz*

- Reference design established; DS2020 Baseline design under development
  - Numerous Science and Technical meetings, starting Jan 2015 AAS
  - Initial Science Working Group reports Nov 2015
  - Community Studies Program: 38 studies approved over 2 Rounds
  - Community-Led Science Use Cases: 80 submitted for 'Reqs to Specs' process
  - SAC and TAC established
  - Socorro June 2017 Sci/Tech meeting: *Consensus Reference Design and Key Science Goals*

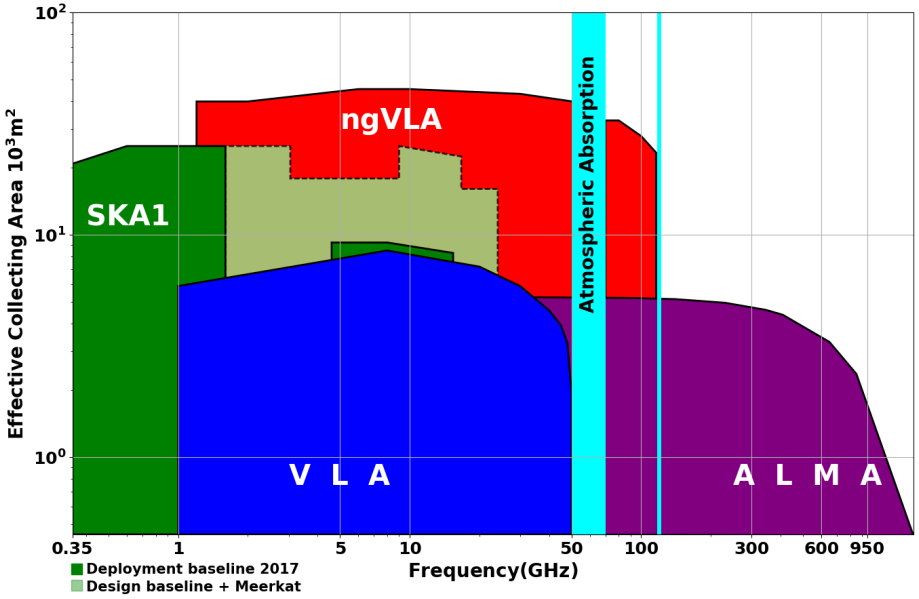
Reference Design: 'Southwest Array' (*memo 17*)

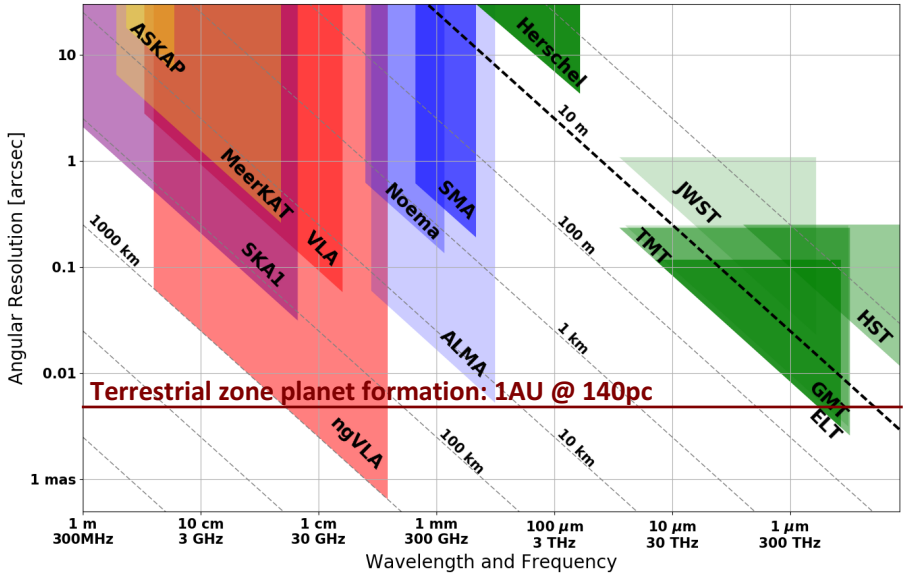
- 214 18m offset Gregorian (feed-low) antennas
- Fixed antenna locations in Southwest USA and Mexico: good 3mm site (elev ~ 2000m)
  - 50% to core: b < 3km => 1" at 30GHz
  - 80% to mid: b < 30km => 0.1"
  - 100% to long: b < 800km => 0.003"
- 1.2 – 50.5 GHz; 70 – 116 GHz
  - Single-pixel feeds
  - 6 feeds / 2 dewar package
- Continuum sens (10hr) = 0.1uJy/bm @ 1cm, 0.01" (T_B = 2K)
- Line sens = 21.5uJy/bm @ 1cm, 10 km/s, 1" (T_B = 35mK)
- Main options under consideration
  - VLBI: dedicated and/or networked?
  - Short-spacing/total power array



Bridging SKA & ALMA Scientifically

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





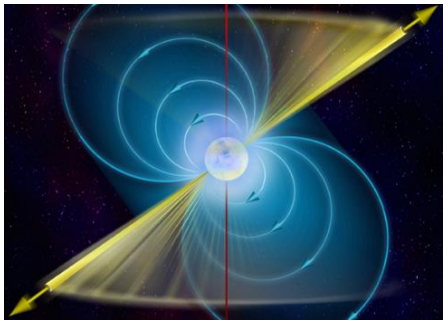
Complementary suite from cm to submm arrays for the mid-21st century

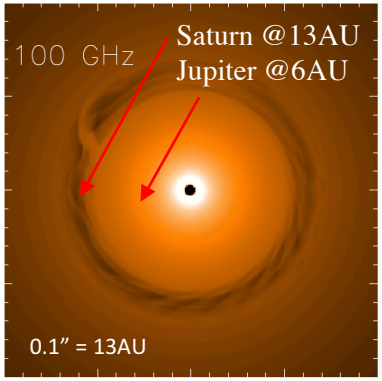
- **< 0.3cm:** ALMA 2030 superb for warm chemistry, dust, fine structure lines
- **0.3 to 3cm: ngVLA** ngVLA superb for terrestrial planet formation, dense gas history, baryon cycling
- **> 3cm:** SKA superb for pulsars, reionization, HI + continuum surveys

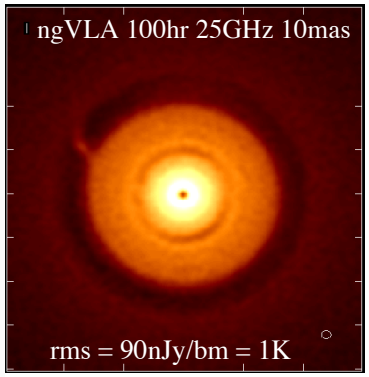
ngVLA Key Science Mission

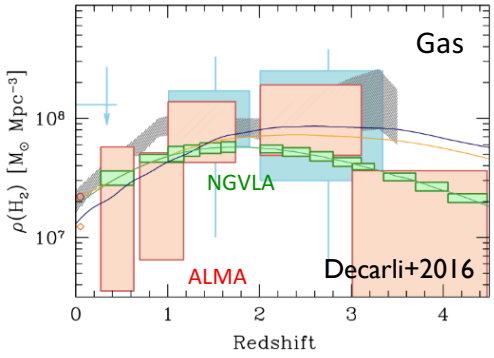
(ngVLA memo #19)

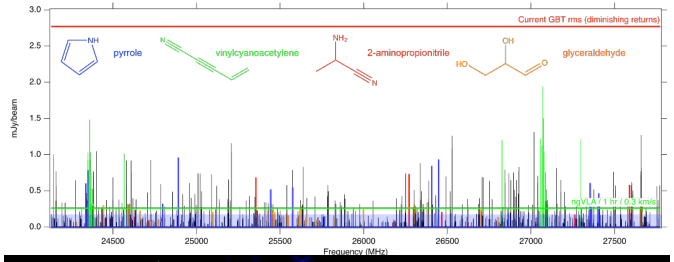
- ***Unveiling the Formation of Solar System Analogues***
- ***Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry***
- ***Charting the Assembly, Structure, and Evolution of Galaxies Over Cosmic Time***
- ***Using Pulsars in the Galactic Center as Fundamental Tests of Gravity***
- ***Black Hole formation and physics and time domain astronomy (GW, FRBs, GRBs…)***

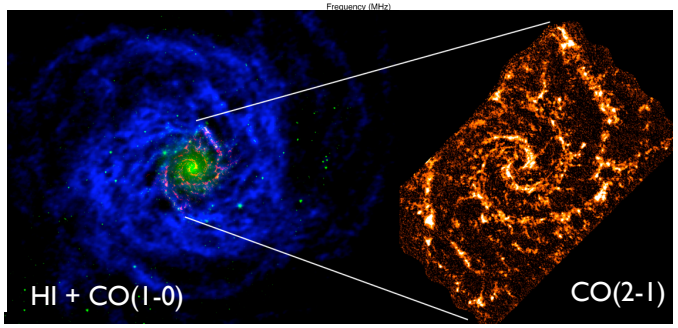












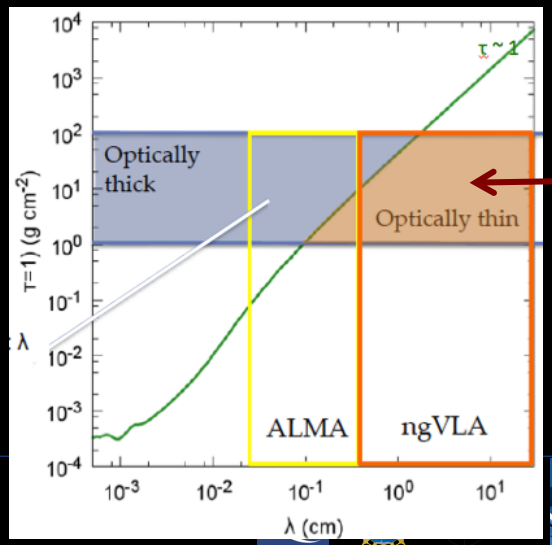
Terrestrial zone planet formation

ALMA 250GHz (Brogan ea.)

HL Tau: Rosetta Stone of planet formation around Solar-mass protostar

- Distance = 140pc
- 1Myr protostar ~ 1 M_o w. 0.1 M_o dusty disk

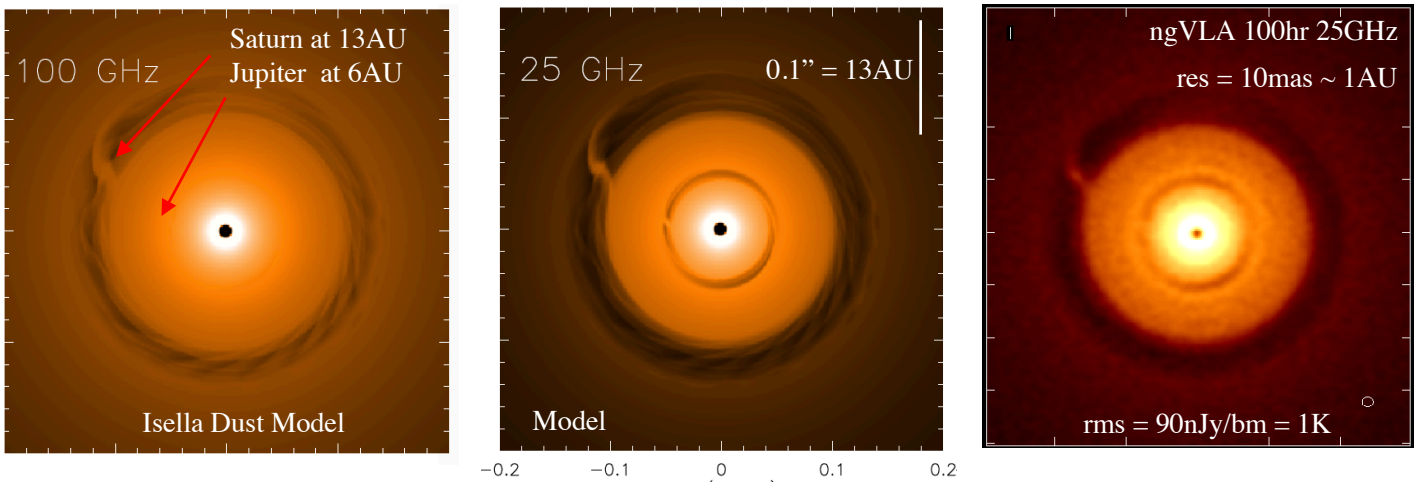
100AU = 0.7”



Inner ~ 10AU optically thick at mm wavelengths = ‘ngVLA zone’

Isella ea.

NGVLA: 1Myr Protoplanetary disk at 140pc distance



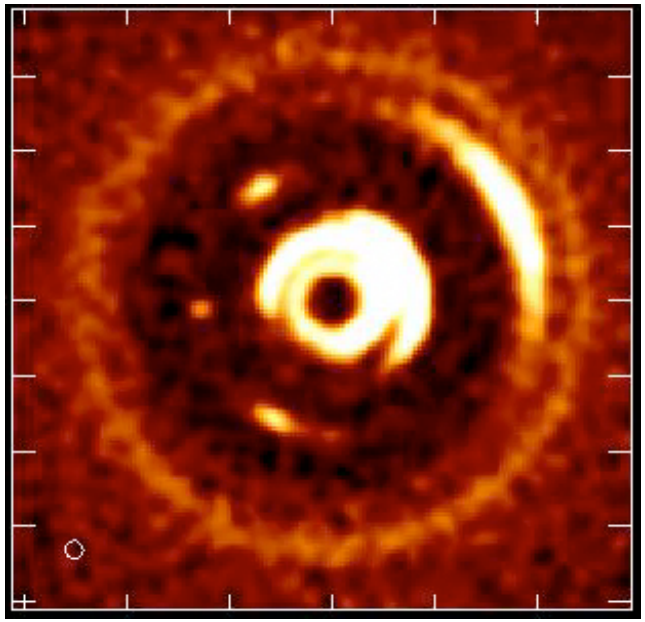
Next generation VLA and Planet formation

- Probe inner few AU-scales ('Solar-system scales')
- Measures the planet initial mass function down to 5-10 Earth masses and unveil the formation of planetary systems *similar to our own*
- Reveal circumplanetary disks and sub-structures in the distribution of mm-size particles created by close-in planets, and measure the orbital motion of these features on monthly timescales.

ngvla

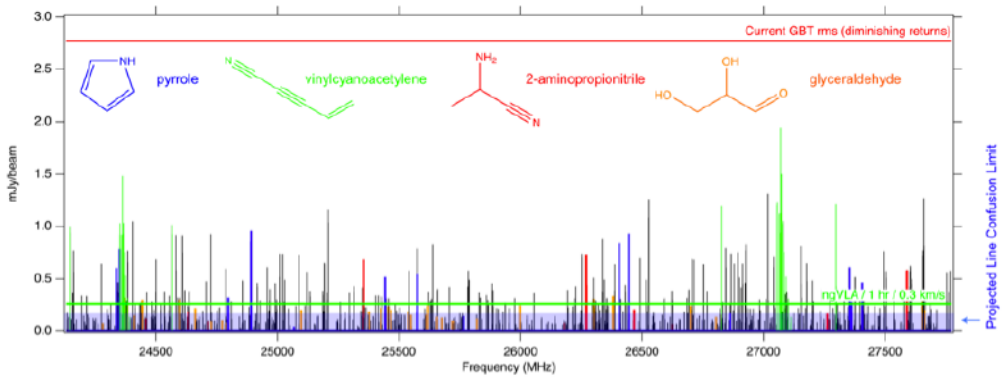
NRAO NSF Associated Universities Inc.

Movies of planet formation: Solar System Analogues and the Initial Conditions for the Develoment of Life



Luca Ricci et al.

Simulated 100 GHz ngVLA observations of a newborn planetary system comprising a Jupiter analogue orbiting at 5 AU from a Solar type star, over ~ 10 years.



Large Molecule Astrochemistry: Observe complex pre-biotic molecules and determine the chemical initial conditions in forming solar systems and individual planets

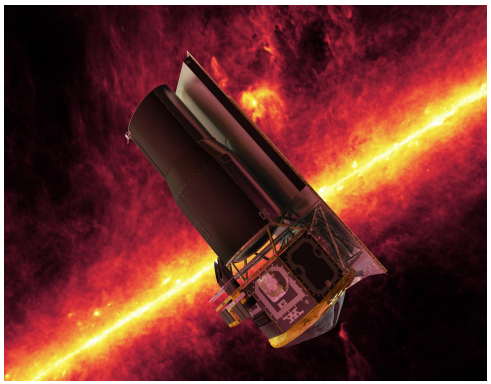
ng-Synergy: Terrestrial zone exoplanets and life

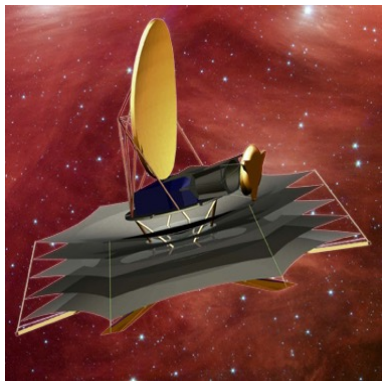
Habitable Exoplanet imaging mission

- Direct detection of earth-like planets
- Search for atmospheric bio-signatures

Origins Space Telescope

- Prevalence of water



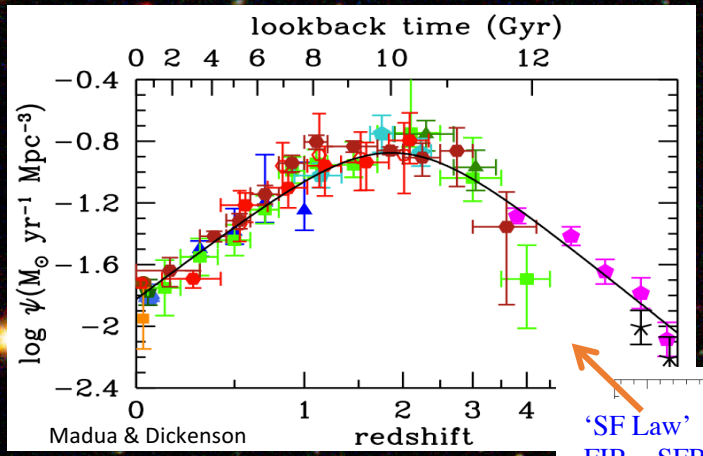


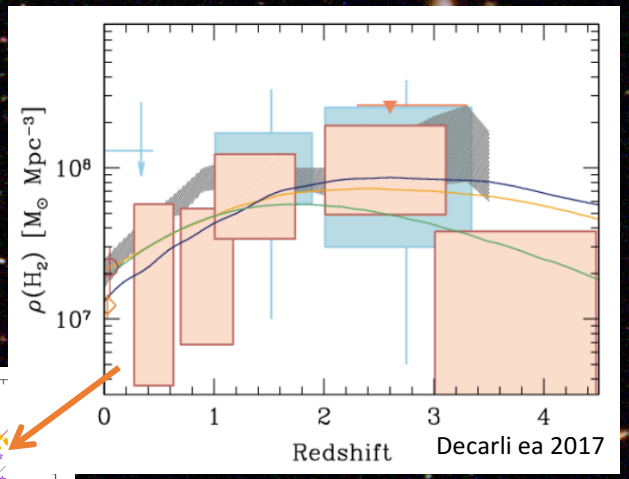
ngVLA

- Imaging *formation* of terrestrial planets
- Pre-biotic chemistry

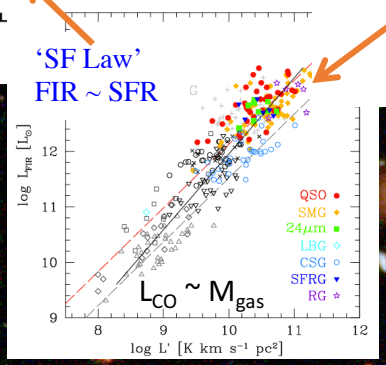
SWG3: Dense Gas History of the Universe

'Missing half of galaxy formation'

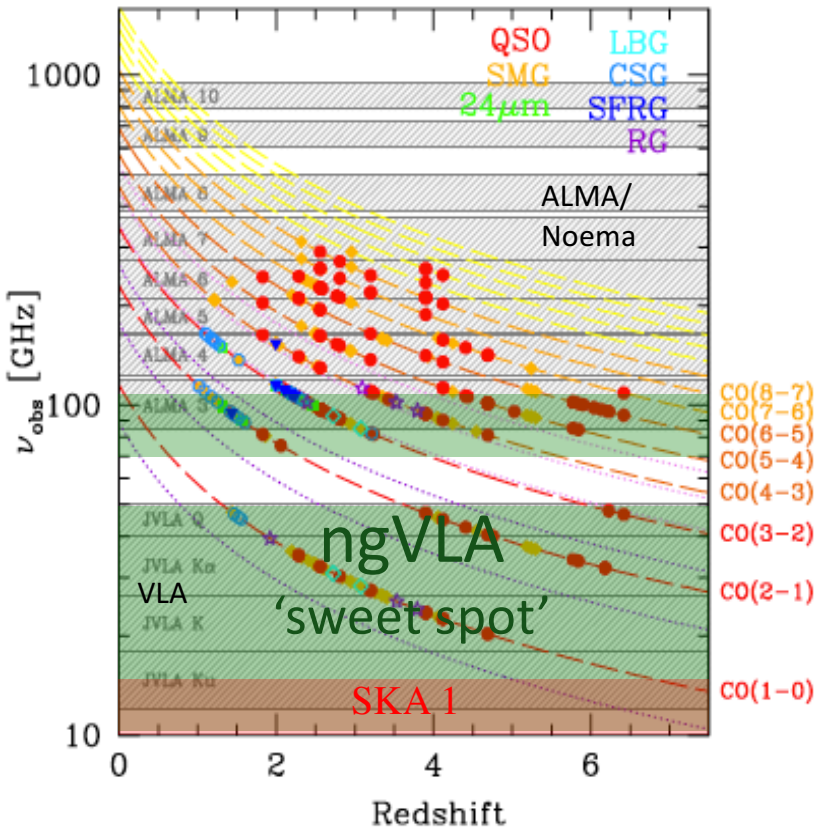


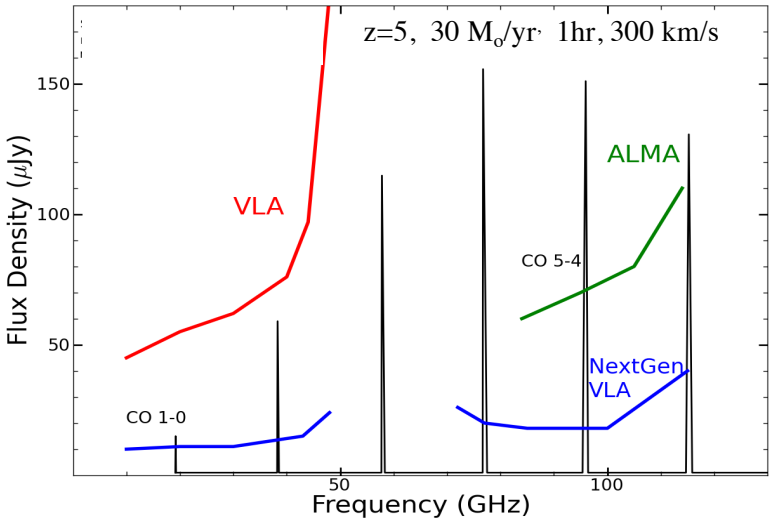


'SF Law'
FIR ~ SFR

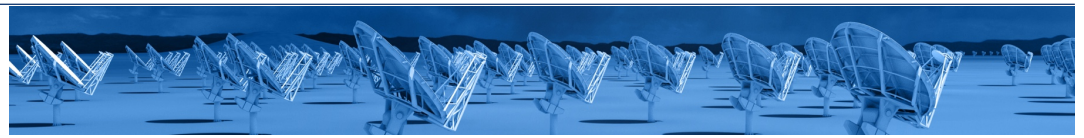


- SFHU has been delineated in remarkable detail back to reionization
- SF laws => SFHU must result from evolution of dense gas in galaxies
- ALMA, JVLA, Noema: first attempts at the DGHU w. 100's hours





- Frequency range: ideal to study dominant molecular gas tracers
- 10x Sensitivity: detect star forming disk ('main sequence') galaxies in ~ 1hr



ngVLA revolution!

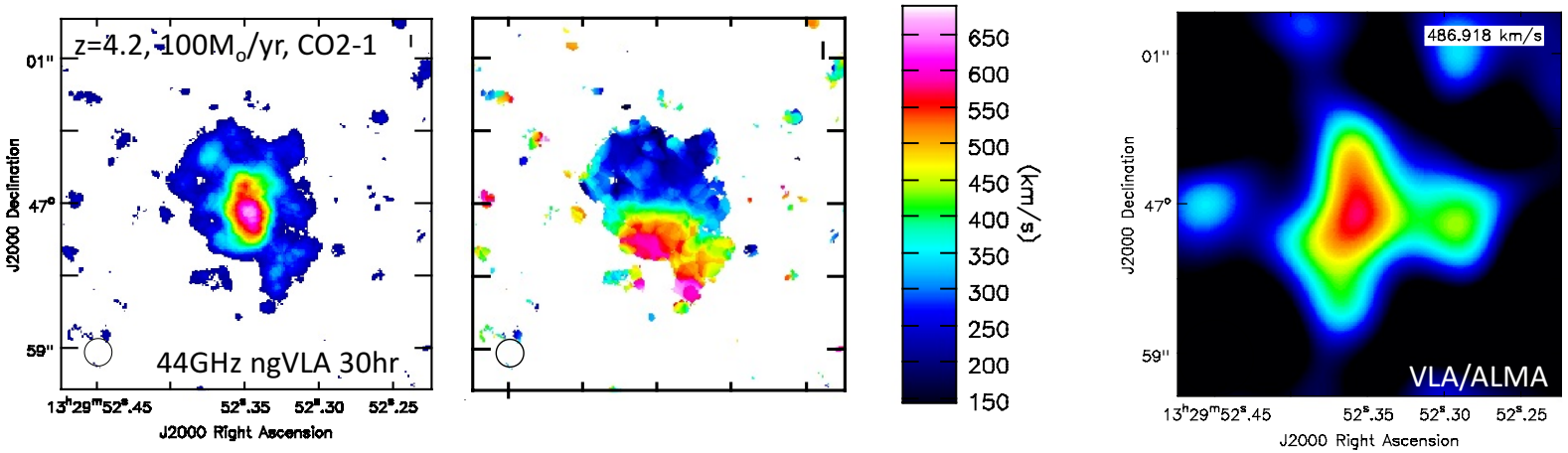
10x sensitivity + 2:1 band ratio => 50 to 100-fold increase in CO-discovered galaxies per hour:

- JVLA ~ 1/hr, $M_{gas} > 10^{10} M_o$
- ngVLA ~ 100/hr, $M_{gas} > 2x10^9 M_o$

Galaxy counts in CO ~ deepest optical fields, with redshifts (3D)!

ngvla NRAO NSF Associated Universities, Inc

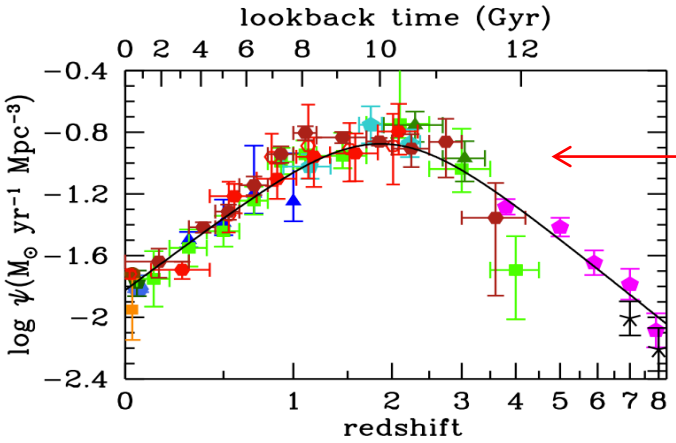
Imaging the fuel for star formation during epoch of galaxy assembly: massive disk galaxy

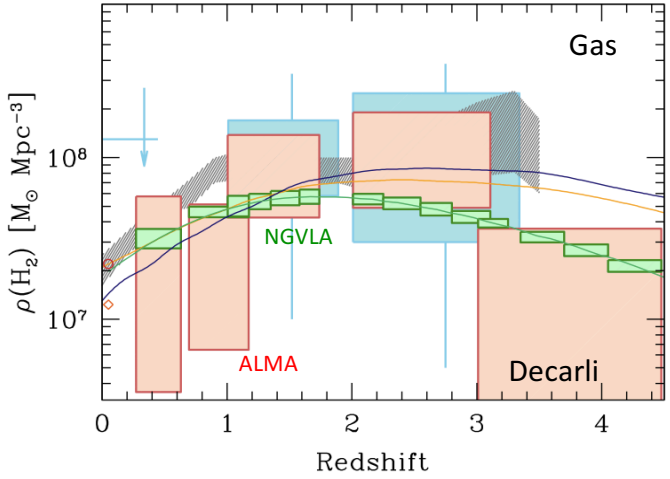


- Resolution = 0.15” => 1kpc
- Sensitivity 30hrs ~ few 10^8 M_o at z ~ 2 to 4
- Imaging gas dynamics

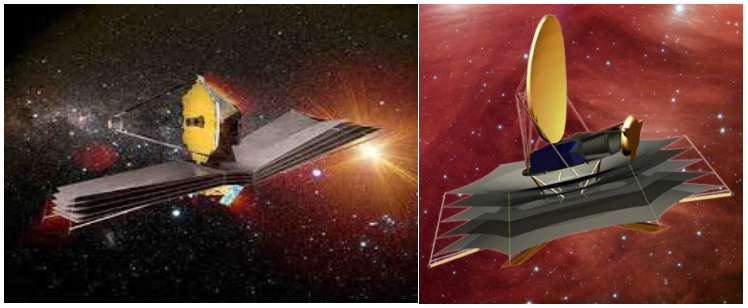
Next-Gen Synergy: Cosmic Conversion of Gas to Stars

'Precision galaxy formation'





JWST/ELT/OST: stars, star formation, dust



ngVLA: cold gas fueling cosmic star formation

Versatility: Remarkable breadth of Science Enabled by the ngVLA

Time Domain

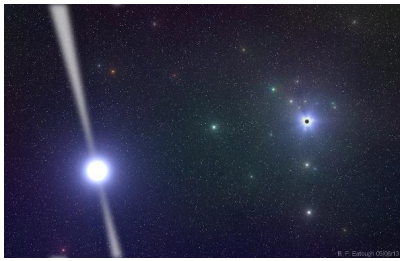
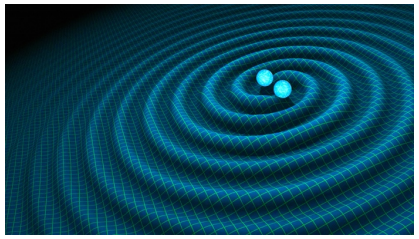
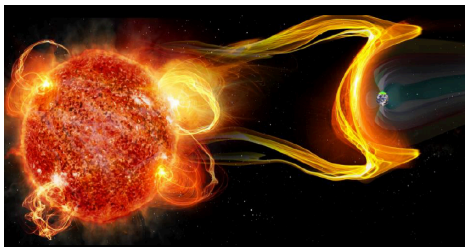
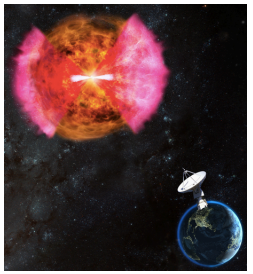
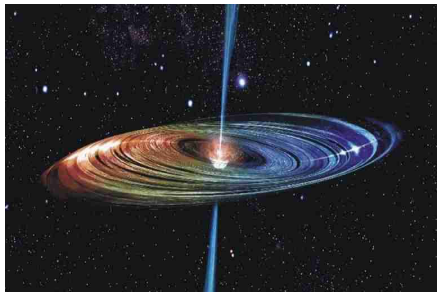
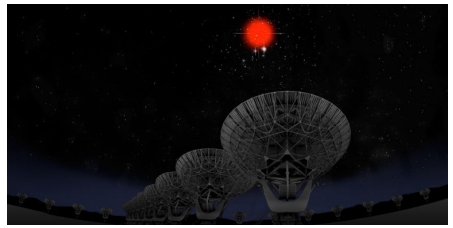
- Galactic Center pulsars: *testing GR*
- Gravitational Wave EM Follow-up
- Extrasolar Space Weather: impact on formation of life!
- Bursting universe (FRB, GRB, TDE…)

Black Holes

- Obscured Black Hole Growth and AGN Physics
- Quasar-Mode Feedback and the SZ Effect
- Black hole masses and H_o with Mega-Masers

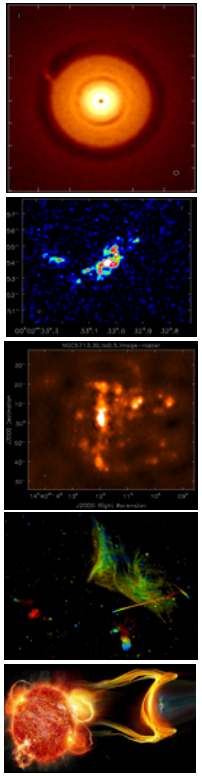
Solar System and non-RA applications

- µas Astrometry: ICRF, Galactic structure…
- Solar system remote sensing: passive and active radar
- Spacecraft telemetry, tracking: *movies from Pluto!*

Next step: Fine-tune Science Requirements and Map to Telescope Specifications (80 use-cases to date)

Goal	Science Requirement	Array Specification
Terrestrial-Zone Planet Formation	Optically thin	Freq ~ 15 to 50GHz
	1AU at 130pc @ 30GHz	B < 300-500km
	1K in 10hrs @ 10mas, 30GHz	A_{full} ~ 300 x 18m; BW ~ 20GHz
Dense gas History of the Universe	CO 1-0 to z=8	Freq = 15 to 115GHz
	$M_{gas} = 10^9 M_o$ at z = 3 in 1hr	A_{mid} ~ 70% to B ~ 30km
	500pc resolution at z = 3 (60mas)	30km
	Large volume surveys	Octave Band Ratio
Baryon Cycling	T_B < 0.2K (1hr, 10 km/s, 80GHz, 1")	A_{core} >30% to B ~ 2km
	Continuum science	Octave BR; Linear pol to 0.1%
Time Domain, Cosmology, Physics	Explosive follow-up (GRBs, GW/EM…)	Minute trigger response time
	Blind discoveries (e.g.. FRBs)	millisecond searches
	Exo-space weather: 1uJy in 1min	Freq ~ 1 to 20GHz A_{full} ~ 10x JVLA Circular pol to few %



Estimated Price Tag

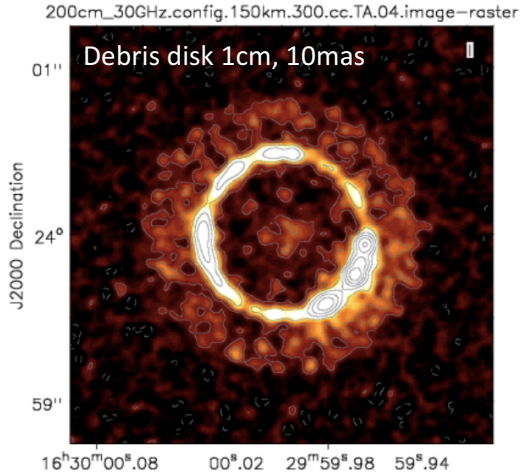
(Internal Preliminary Costing Exercise)

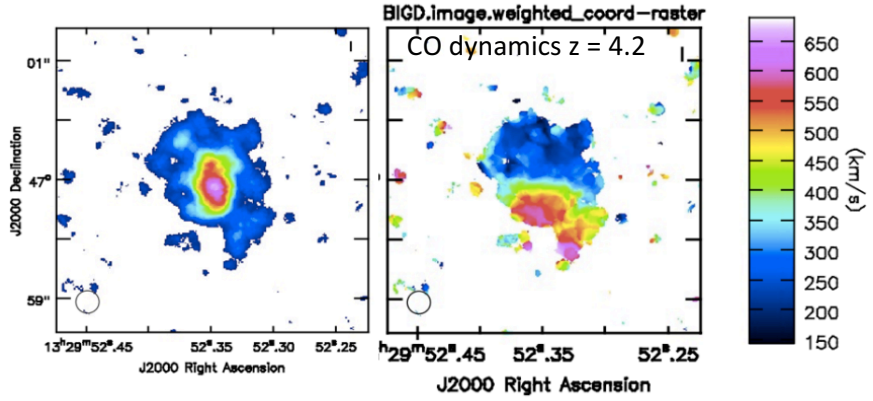
- Target construction baseline budget **~ (2016) $1.5B**
- Target operations budget of **< (2016) $75M** (< 3x current VLA)
  - Operations, maintenance, computing, archiving, etc.: *optimize as part of design*
- **Partnerships:**
  - Possible U.S. Multiagency Interest [including VLBI option]
    - ICRF – DOD/Navy, Air Force
    - Spacecraft tracking/imaging, `burst-telemetry' (mission-critical events) – NASA, DOD
    - Space situational awareness – DOD
  - ***Strong International Partnership critical for success:***
    - Current International Involvement in SAC/TAC/Community Studies:
      - Canada, Mexico, Japan, Germany, Netherlands, Taiwan
  - Current Industrial Involvement through Community Studies:
    - REhnu Inc., Minex Engineering Corp, LaserLaB, Quantum Design

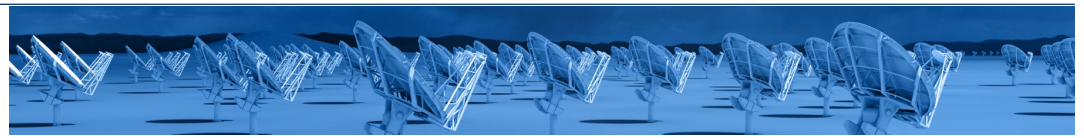
Array Simulation Tools: working and improving

- Configurations
  - Southwest Configuration (214 x 18m; 1000km)
  - Add VLBA (4000km)
  - To come: short baseline array
- CASA simulator
  - Simobserve: generate mock.ms from FITS image cubes
  - Add thermal noise
  - Explore imaging capabilities (uv weights, subarrays..)
  - Explore wide field mosaic

http://ngvla.nrao.edu/page/tools



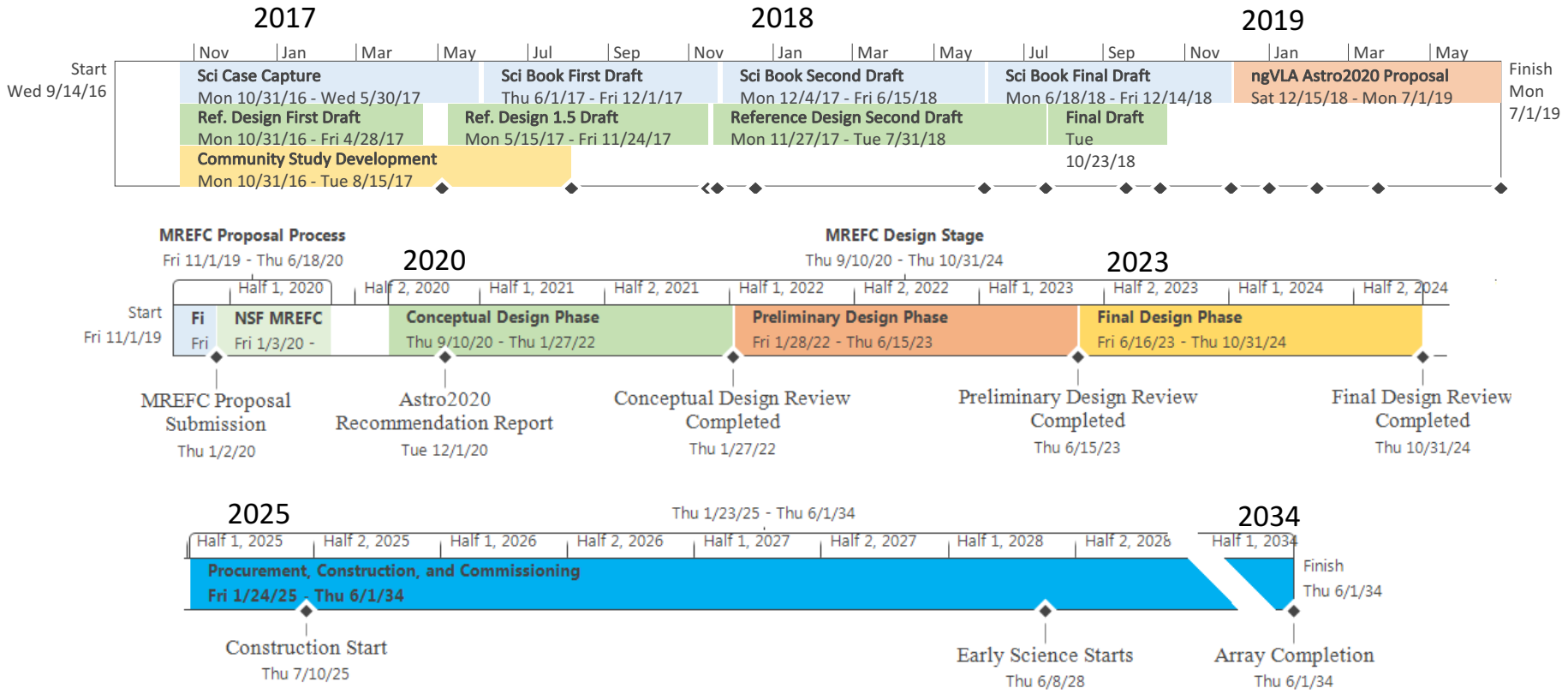




The Road to Astro 2020

Near-term Goal: CoDR-level 'proposal' to 2020 Decade Survey

Science Book and Reference Design by 2019



Astrophysical Frontiers in the Next Decade:

Planets, Galaxies, Black Holes, & the Transient Universe

Portland, OR USA June 26-29, 2018

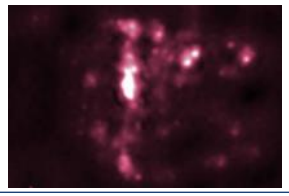
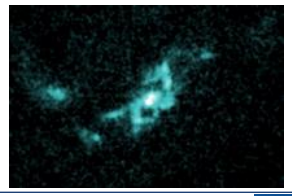
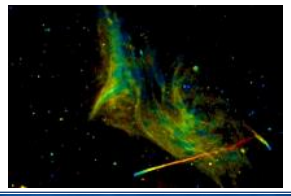
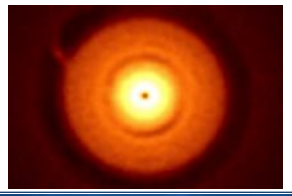
Registration open: http://go.nrao.edu/ngVLA18

New research facilities and the scientific vision outlined by New Worlds, New Horizons have motivated the exploration of vast new discovery space, and astrophysics has seen extraordinary progress in the past decade, opening new frontiers across many fields. Sponsored by the National Radio Astronomy Observatory, this conference will bring together a substantial cross-section of the astronomical community to discuss how to effectively address the highest priority astrophysical questions of our time. Plenary sessions will feature invited speakers, and three parallel sessions of contributed presentations will address (1) Exoplanet and Protoplanetary Disk Origins, (2) Galaxy Evolution Mechanisms, and (3) Black Holes & Transient Phenomena. Each session will canvas recent observational and theoretical progress, address key unanswered questions, and motivate future research directions in the context of next-generation facilities that would span the electromagnetic spectrum, including a Next Generation Very Large Array, the Large Synoptic Survey Telescope, 30m-class optical-infrared telescopes, the Advanced Laser Interferometer Gravitational-Wave Observatory, and the Square Kilometre Array.

SOC co-Chairs

Brenda Matthews (NRC – Cradle of Life)
Caitlin Casey (UT – Galaxy Evolution)
Laura Chomiuk (MSU – BHs and Transients)

ngvla

ngvla NRAO NSF Associated Universities, Inc.

Many Thanks to

- The ngVLA Science and Technical Advisory committees
- All ngVLA Science Working Group Participants
- Initial ngVLA Science White Paper Authors
- ngVLA Community Studies Participants

www.nrao.edu
science.nrao.edu
public.nrao.edu

The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.