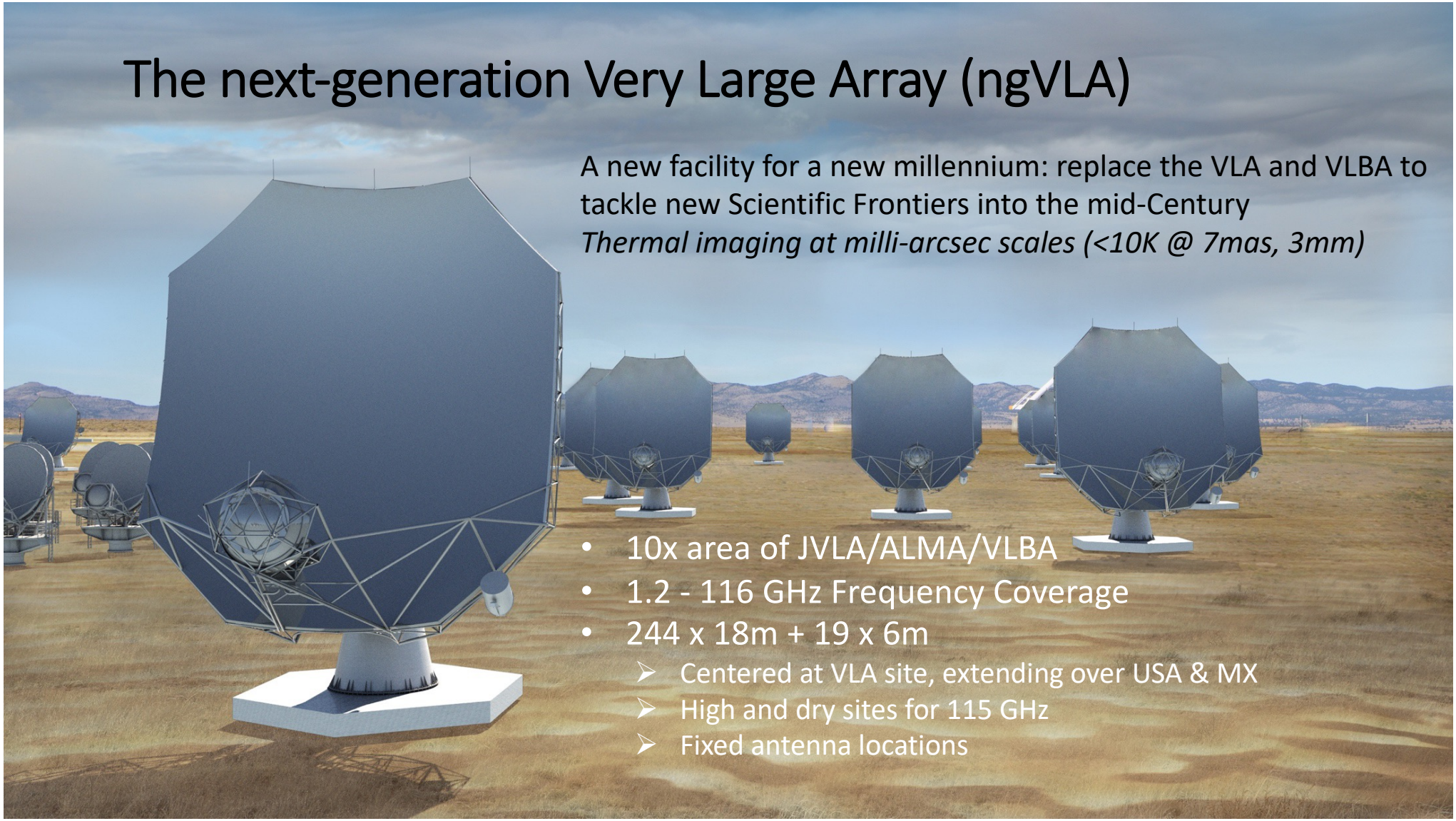
The next-generation Very Large Array (ngVLA)

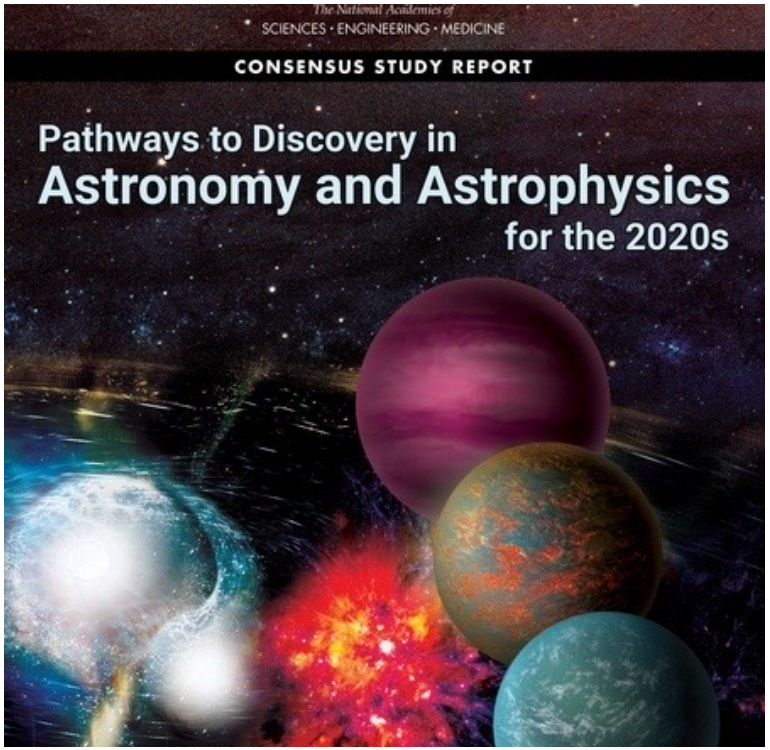


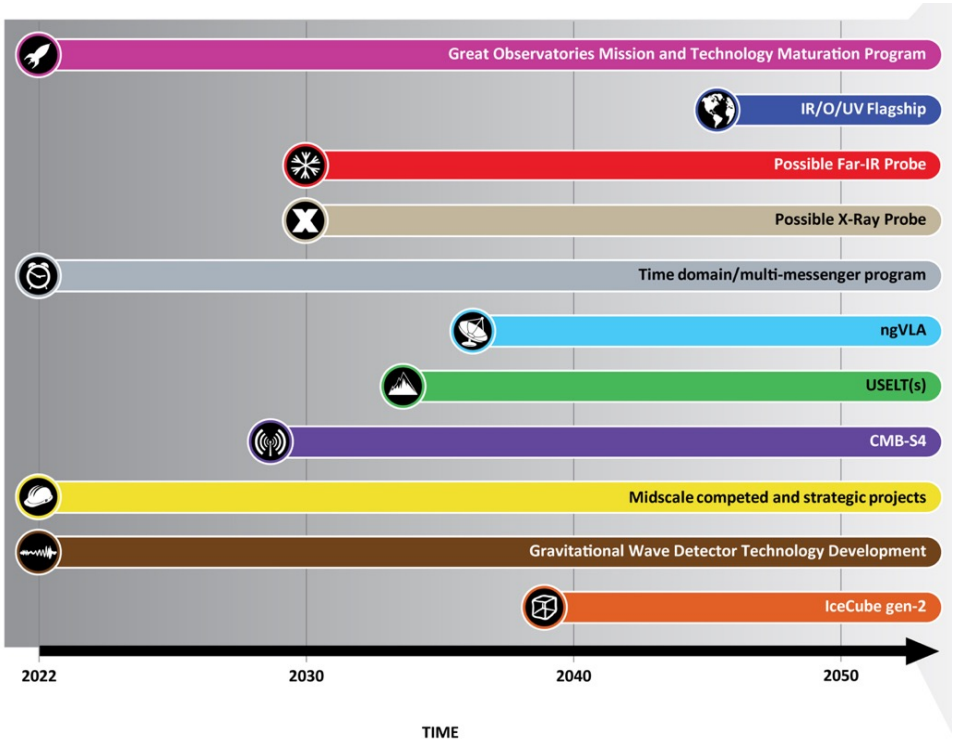
A new facility for a new millennium: replace the VLA and VLBA to tackle new Scientific Frontiers into the mid-Century

Thermal imaging at milli-arcsec scales (<10K @ 7mas, 3mm)

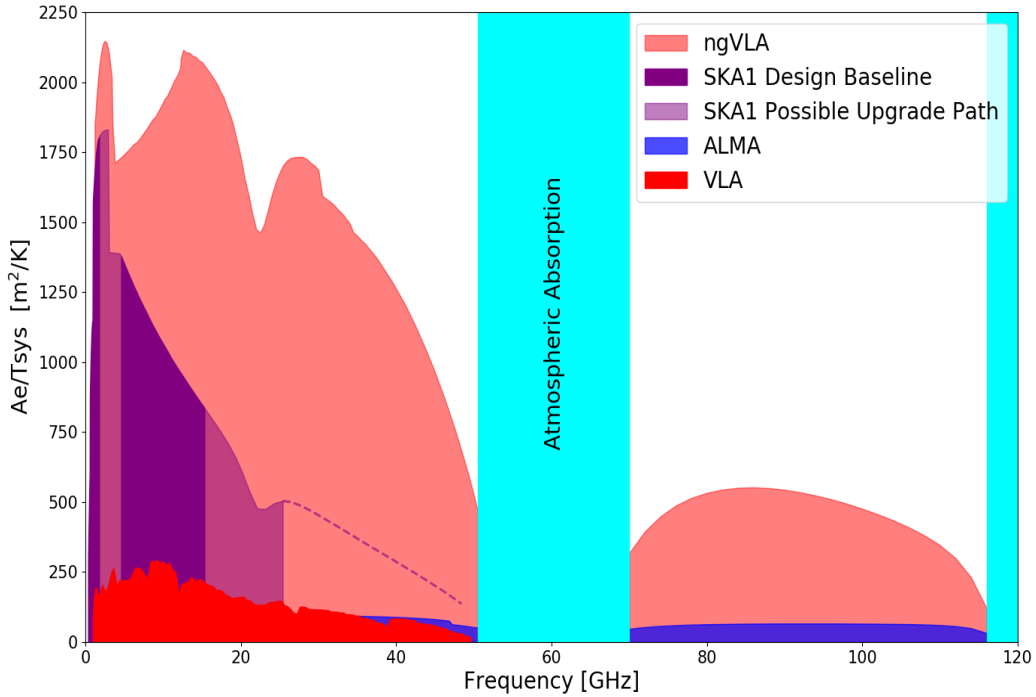
- 10x area of JVLA/ALMA/VLBA
- 1.2 - 116 GHz Frequency Coverage
- 244 x 18m + 19 x 6m
  - Centered at VLA site, extending over USA & MX
  - High and dry sites for 115 GHz
  - Fixed antenna locations

Astro2020 identified the ngVLA as a high-priority large, ground-based facility for science operations in 2030's





New Parameter ('Discovery') Space for the mid-Century

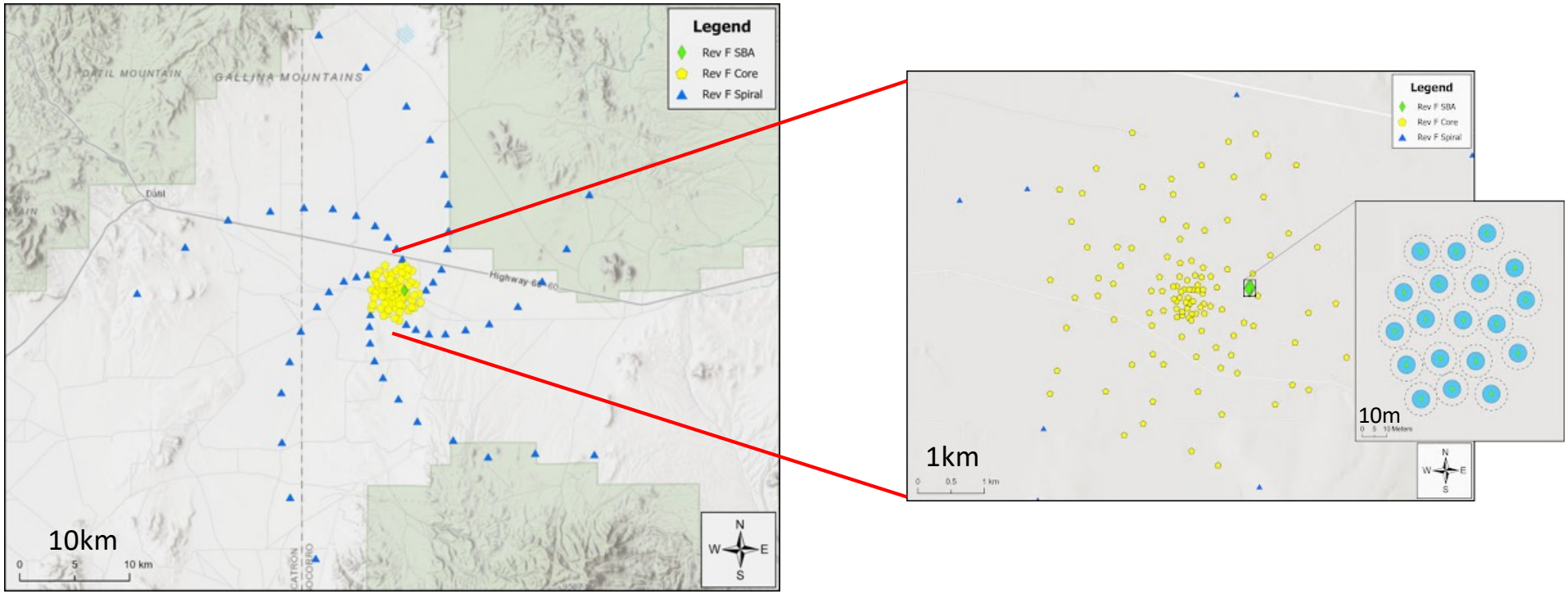


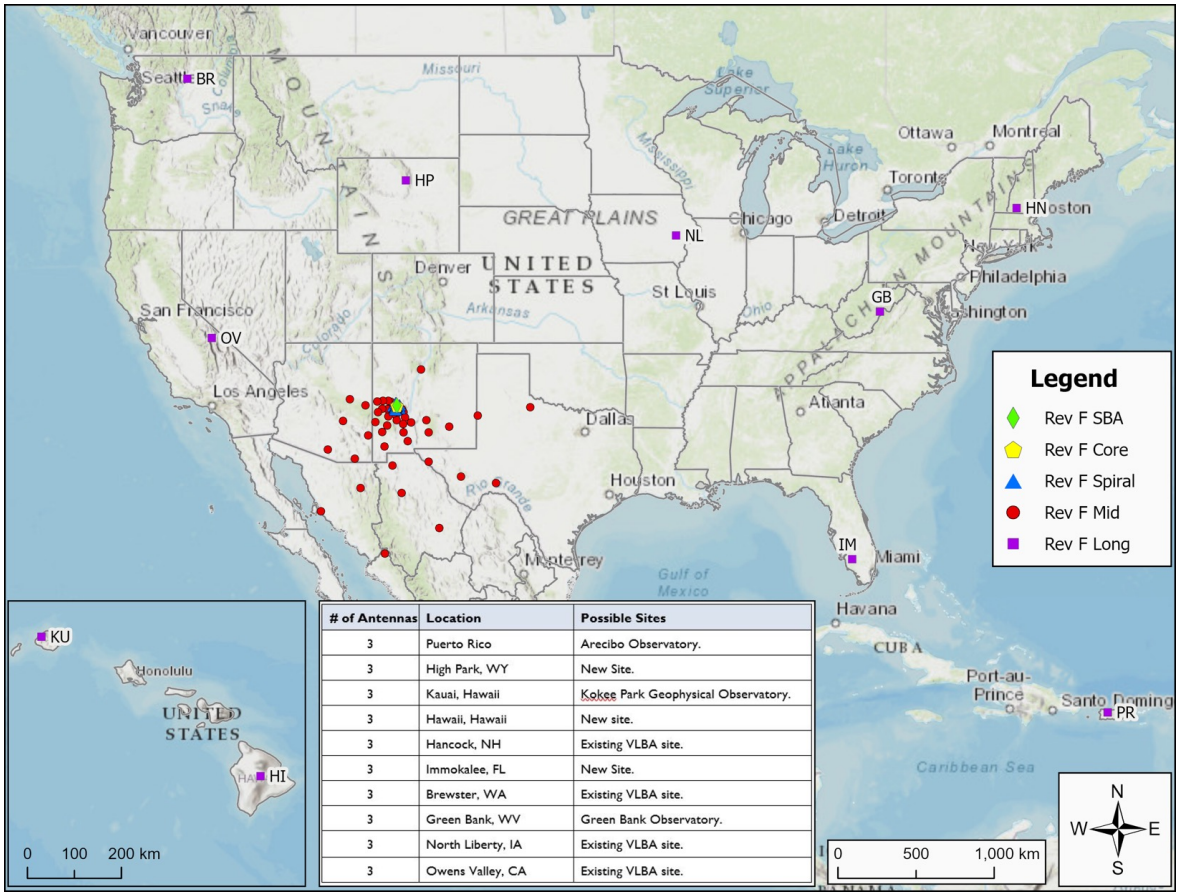
Complementary suite of arrays from meter to submm wavelengths

- **> 120GHz:** ALMA 2030 superb for chemistry, dust, fine structure lines
- **1.0 - 116GHz:** ngVLA superb for terrestrial planet formation, dense gas history, black holes
- **< 10 GHz:** SKA superb for pulsars, reionization, HI + continuum imaging

Table 1: Rev D Configuration Components

Component	Station code	N ants	D_{ant} meters	B_{min} meters	B_{max} meters	Resolution at 32GHz
Core	cor	114	18	39	4240	0.44”
Spiral	sp[a-e]	54	18	810	38995	0.045”
Mid	mid[a-e]	46	18	17050	1068000	0.018”
Long Baseline	stations	30	18	130000 (40)	8794000	0.002”
Short Baseline	sba	19	6	10.9	59.7	34”





# of Antennas	Location	Possible Sites
3	Puerto Rico	Arecibo Observatory.
3	High Park, WY	New Site.
3	Kauai, Hawaii	Kokee Park Geophysical Observatory.
3	Hawaii, Hawaii	New site.
3	Hancock, NH	Existing VLBA site.
3	Immokalee, FL	New Site.
3	Brewster, WA	Existing VLBA site.
3	Green Bank, WV	Green Bank Observatory.
3	North Liberty, IA	Existing VLBA site.
3	Owens Valley, CA	Existing VLBA site.

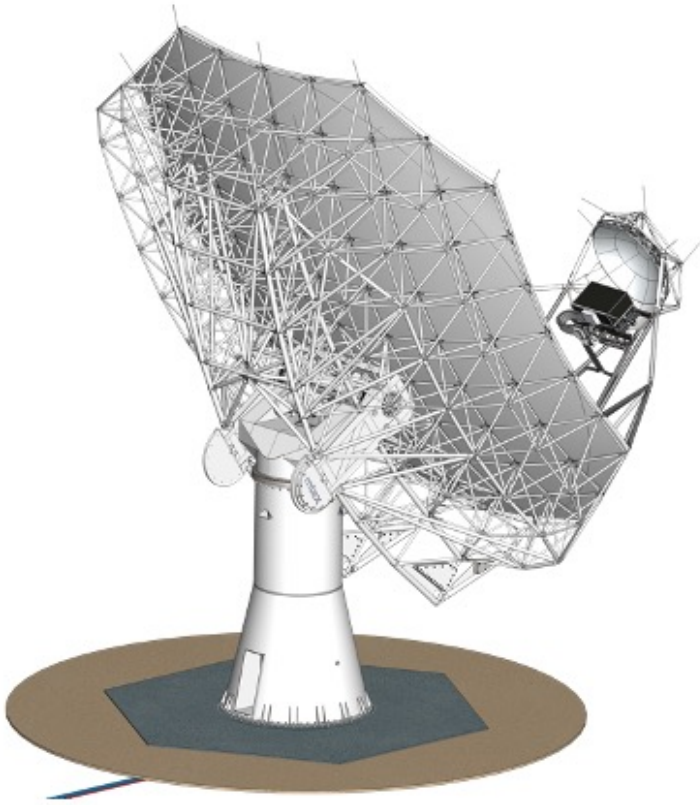
- 10m to 8000km => 200” to 0.2 mas @ 32GHz: subarrays will be key usage

18m Prototype Antenna

Key Specifications	
18m Aperture	Offset Gregorian
Shaped Optics	3° Slew & Settle in 7 sec
Surface: 160 µm rms	Reference pointing: 3” rms
Precision conditions:	Total efficiency >80% (X..Q)

Status

- Antenna proto-type contract 2022 to MTEX
- Delivered to VLA site end 2025
- Testing includes correlation with VLA

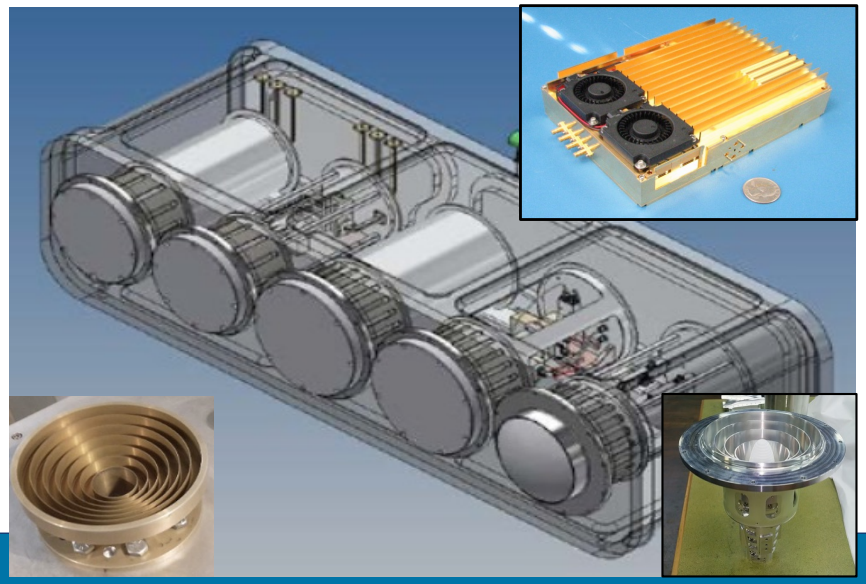


mtex | antenna technology

Technical Design: Well advanced and costed

- Reference Design: Build on ALMA, JVLA, SKA development => low-technical-risk, well costed, *optimize life-cycle cost*
- U.S. agencies (DOD, NASA): ICRF, Space Situational Awareness (radar), Spacecraft tracking/imaging, `burst-telemetry'
- International partners: Mexico, Japan, others?
- Integrated Receiver and Digitizer: RF signal -> mix to baseband; sampled and digitized (8bit) to fiber; 20 GHz BW
- All compact and field replaceable

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

Fiber: real time VLBI

- Dedicated lines < 300 km
- ISP leased bandwidth > 300 km

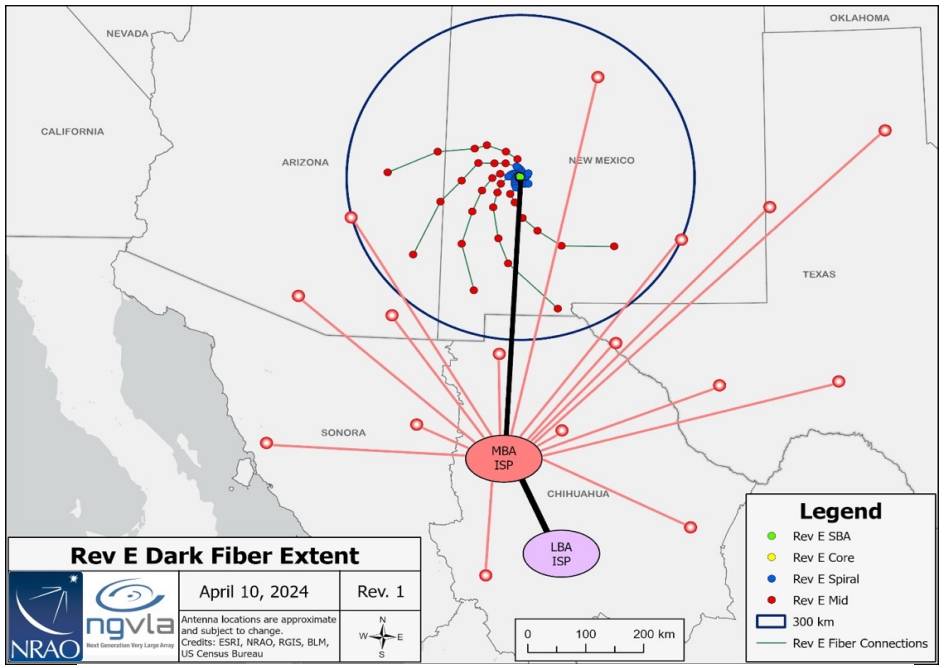
Data Rates

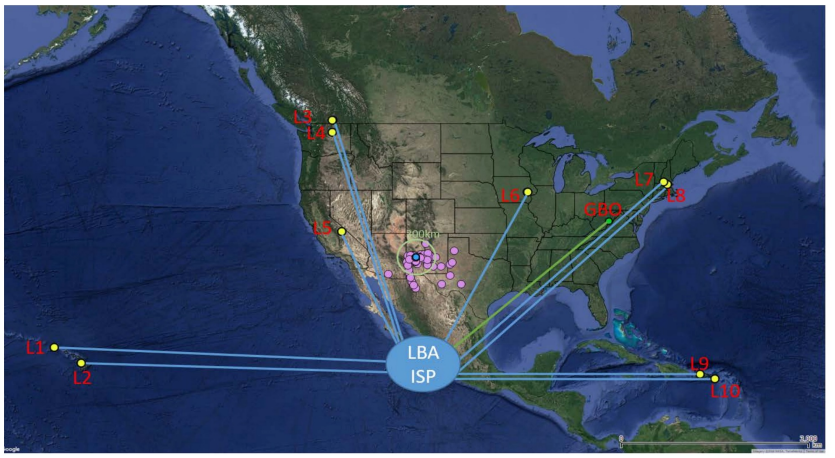
- Data rate into correlator ~ 800 Gbps per antenna => 210 Tbps total
- Archive: 240 PB/yr

Power

- Correlator ~ 1 MW, Antennas ~ 3.6MW
- Exploring power purchasing agreement: on-site photovoltaic system

Long Haul Fiber Workgroup Preliminary Report
020.60.00.00.00-0002-REP-A-LONG_HAUL_FIBER_WORKGROUP_REPORT



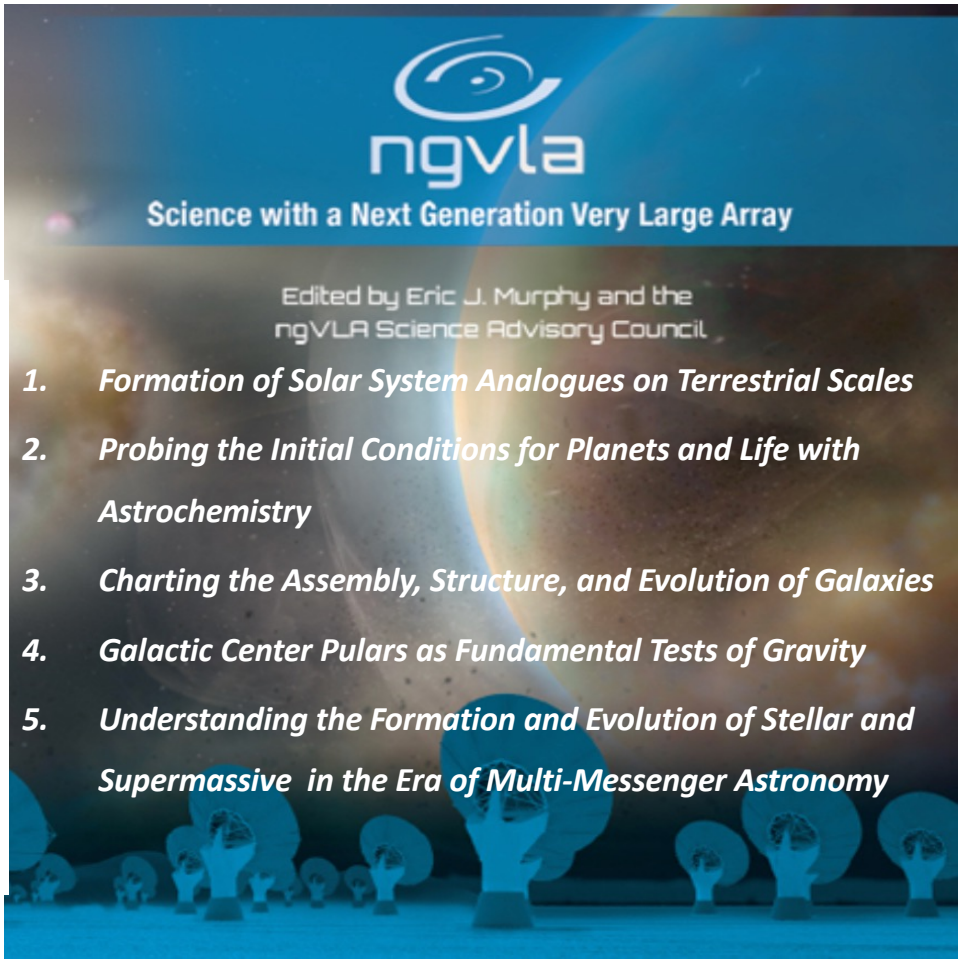


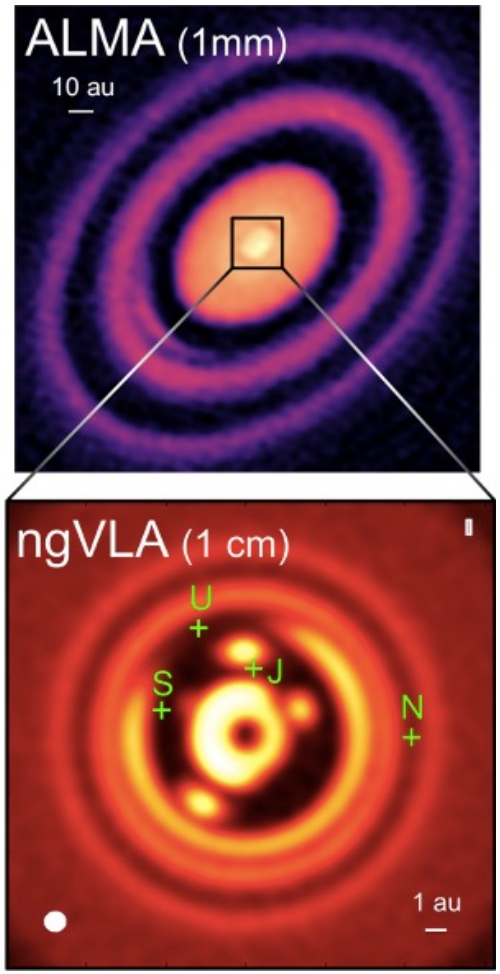
ngVLA Science

Strength in Versatility
Planets to Cosmology

Science Advisor Committee and Working Groups

- Chairs: D. Wilner and B. Matthews
  - SWG1: Stars, Planetary Systems, and their Origins
  - SWG2: Astrochemistry and the Emergence of Life
  - SWG3: Galaxies and Galaxy Evolution
  - SWG4: Pulsars, Cosmology, and Fundamental Physics
  - SWG5: Exploring the Dynamic Universe
- 2019 Science Book: 90 chapters, 300 authors
- Key Science: SAC ngVLA Memo 125

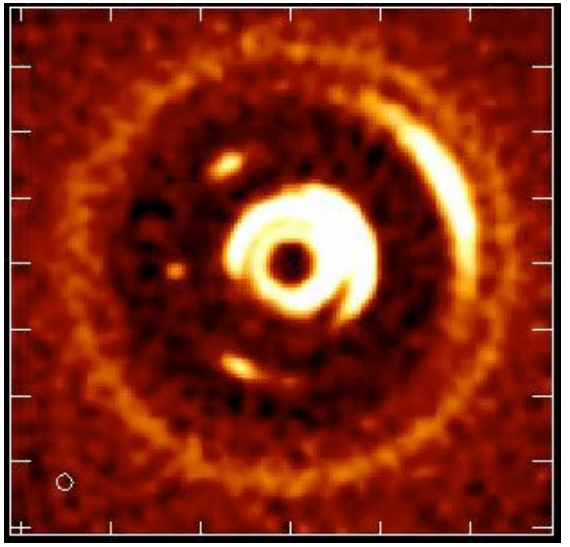


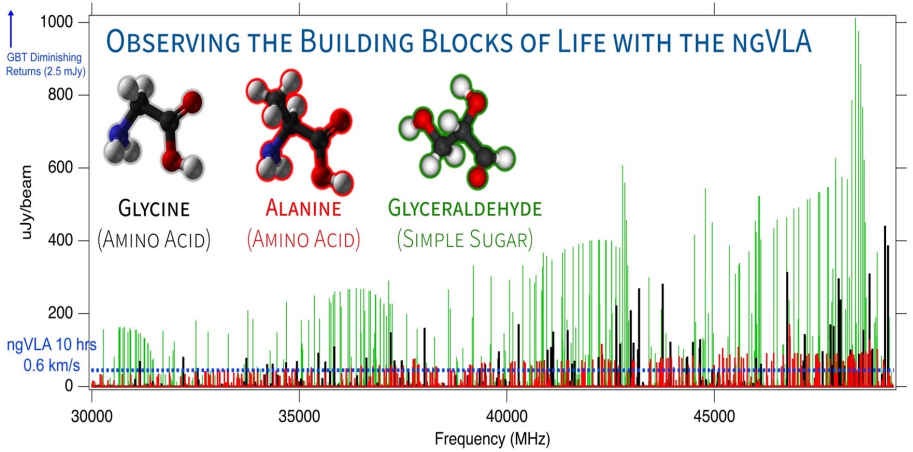


KSG1&2: Unveiling the Formation of Solar System Analogues and Life

Image Earth-mass planets in proto-Solar Systems

- Resolution needed: 7mas = 1 AU at 140pc
- ngVLA at 30 to 100 GHz resolves the inner few AU; optically thick to ALMA
- Ideal freq range for pre-biotic molecules



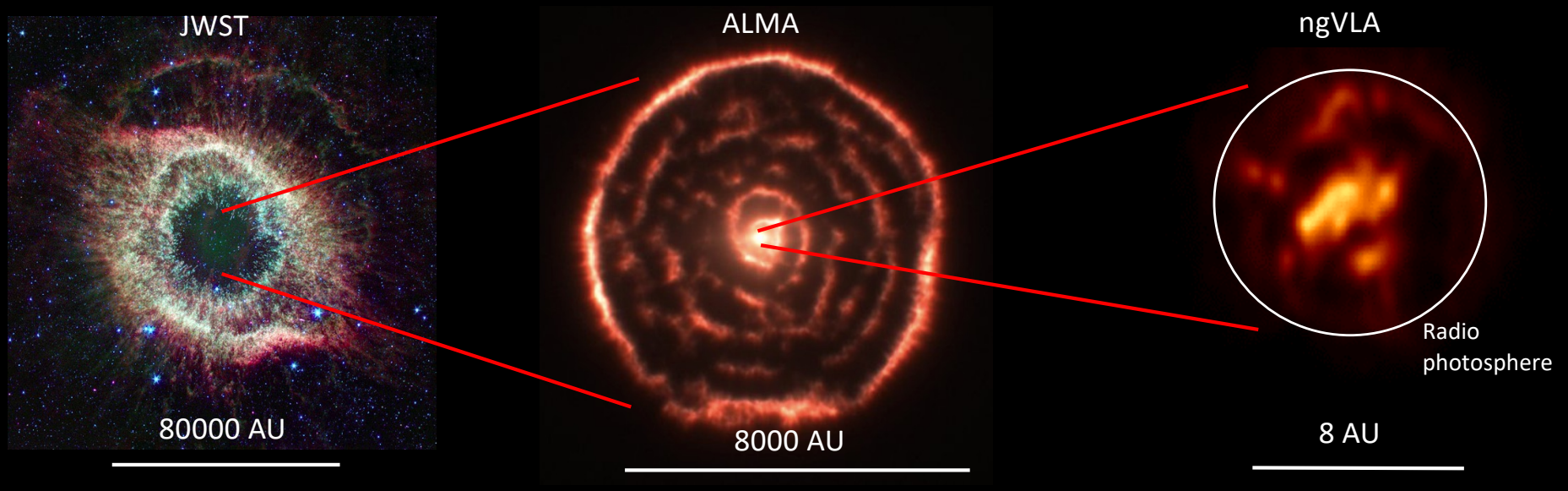


Movies of planet formation

- Forming Jupiter in 1Myr, $1M_o$ protostar and disk at 140 pc
- Monthly obs over few years at 100 GHz, 7mas resolution
- Image dust gaps and traps, and potentially the circumplanetary disk = accretion onto planet!

Stellar end-of-life: movies of stars

- Movies of extreme mass-loss in evolved (AGB) stars
- Primary enrichment mechanism of ISM



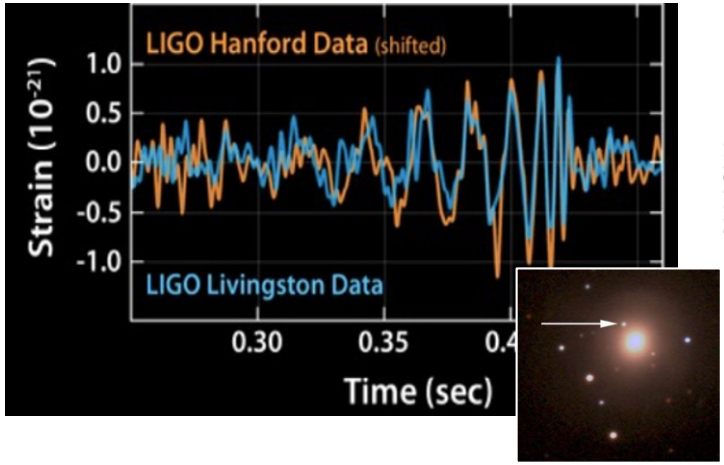
Petretti, Akiyama & Mathews 2021

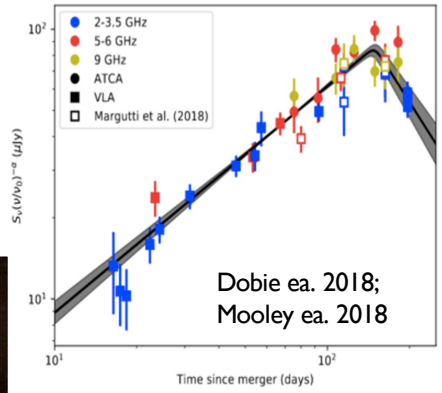
➢ ngVLA imaging of 'boiling' AGB star atmosphere

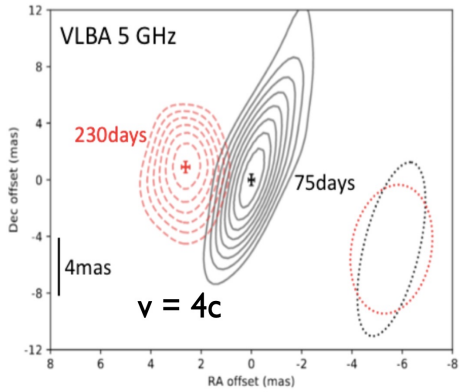
- ngVLA @ 46 GHz; 1.5 mas ~ 0.04 stellar radii at d=150pc
- 1.3 year pulse period observed every 2-3 weeks

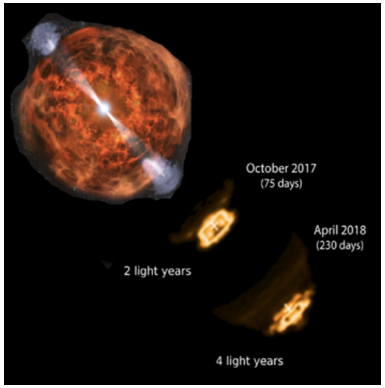
KSG 5: New Windows on the Dynamic Universe

Multi-messenger, time-domain astronomy (LIGO, neutrino sources, LSST, Euclid surveys, GRBs, TDEs…): radio provides unique tools to unlock physics of the 'explosive universe'



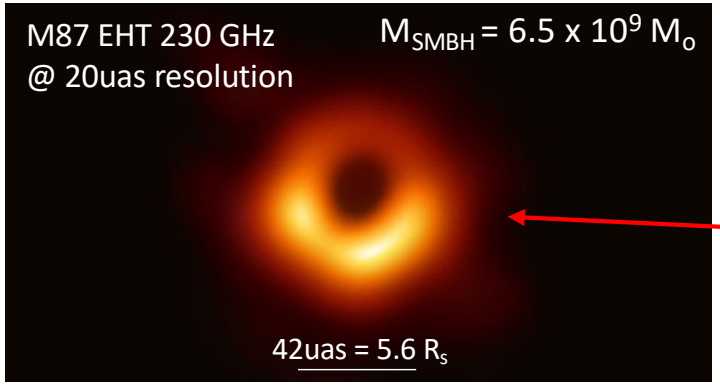


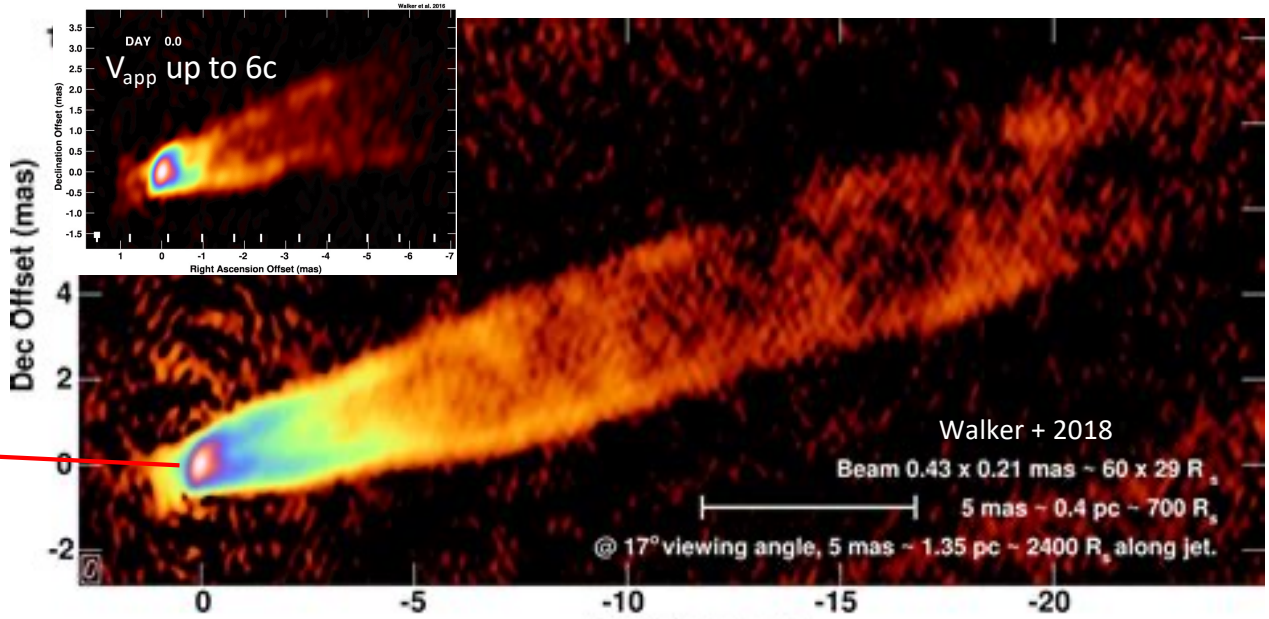




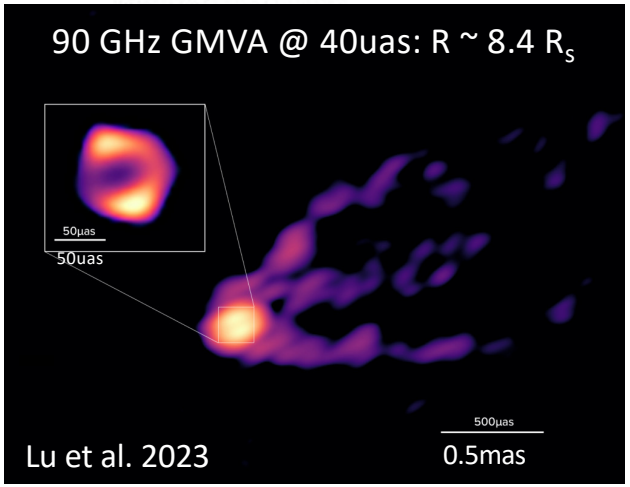
- 1st GW source: multi-wavelength campaign discovered the EM counter-part to merging binary ~ 30 M_o black-holes, identified with a galaxy at 430 Mpc
- Radio light curve and VLBA imaging => emerging relativistic jet from merging binary black holes: a wide-angle jet which is trapped by the explosion debris
- ngVLA 30x search volume => Expect 10 to 20 searchable LIGO events/year
- sub-mas resolution => ONLY method to determine EM source sizes and shapes on scales < 0.6 pc

Imaging the Black Hole Disk – Jet connection



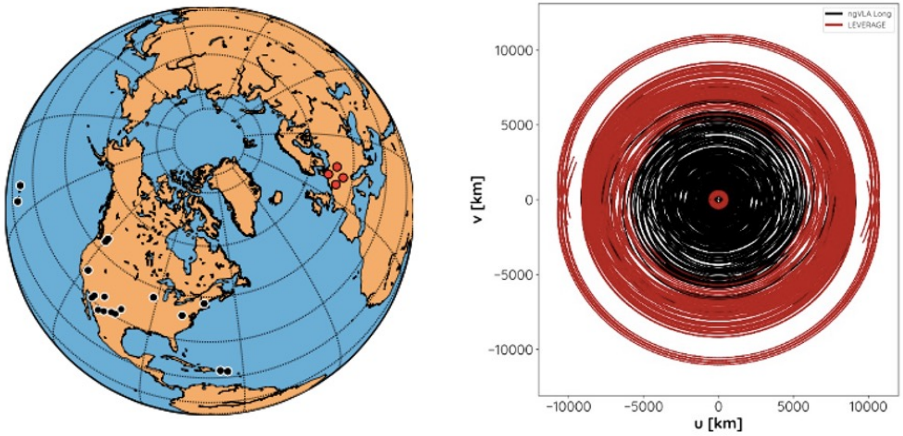


- Event Horizon Telescope imaging of the general relativistic shadow of the SMBH in M87 and Sgr A* has reinvigorated interest in radio AGN and their accretion disks and relativistic jets.
- GMVA 90 GHz imaging also shows 'ring' but 1.5x larger, plus jet on scales ~ 0.1 pc
- M87 90 GHz results open a new ngVLA key science program: imaging the accretion disk – jet connection on scales ~ 10 R_s

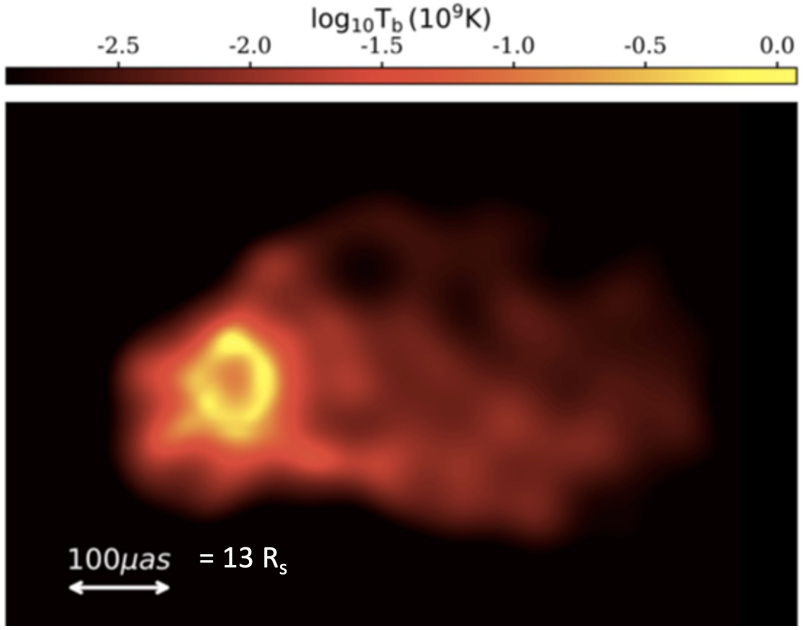


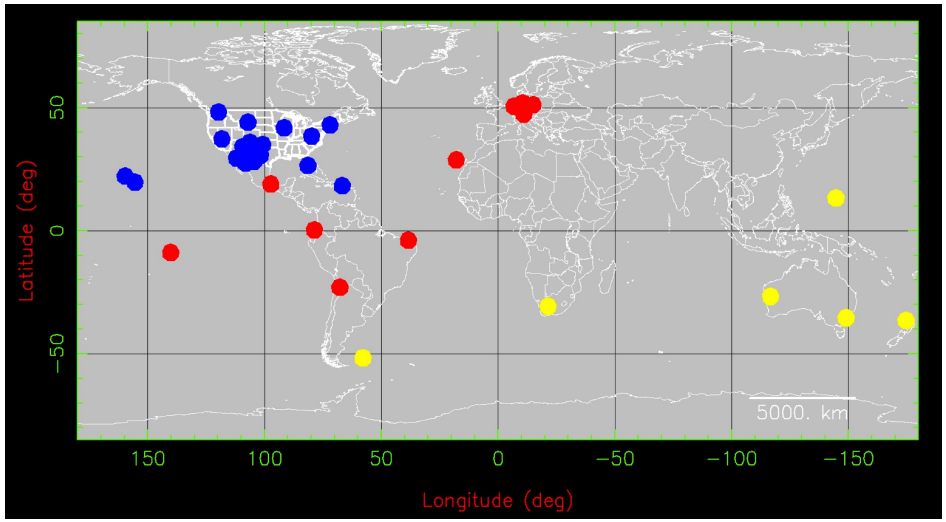
LEVERAGE: 4 ngVLA stations in Germany

Kadler et al.



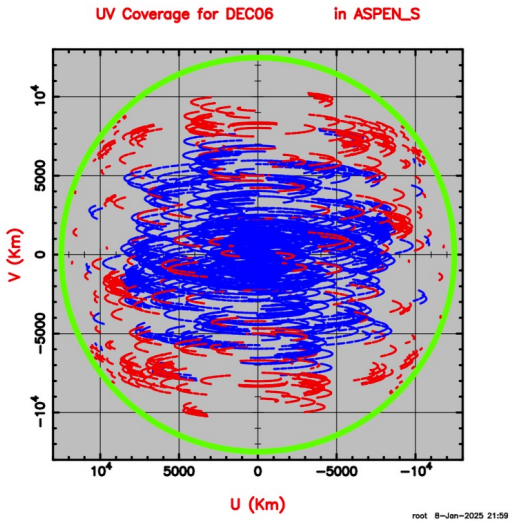
- Increase uv-coverage to baselines ~ 10000 km
- Improve resolution to ~ 60 uas @ 90GHz
- Image GR shadow on scales of 60 uas ~ 8 R_s
- Image Jet – accretion disk transition out to 1mas ~ 0.07pc

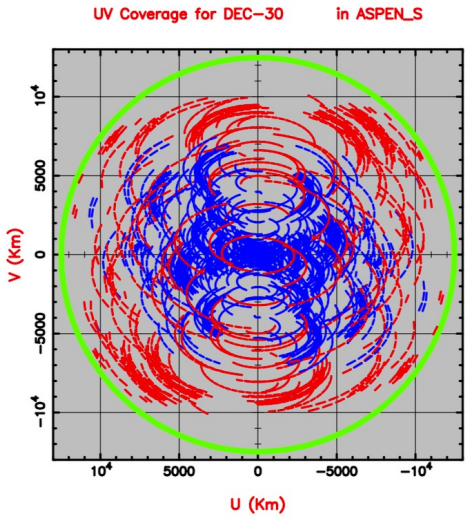


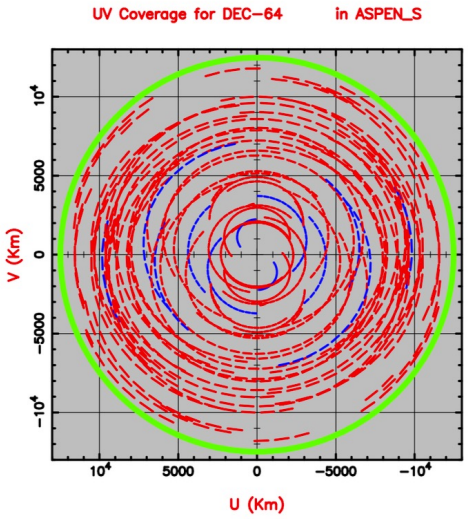


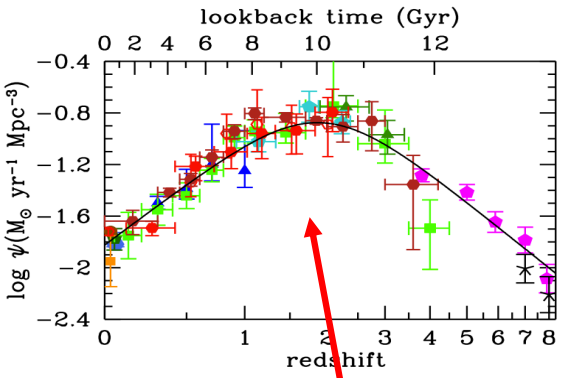
Walker ngVLA memo 128

- ngVLA + GMVA + LEVERAGE + ‘Southern Stations’
- Greatly improved u,v coverage for southern sources



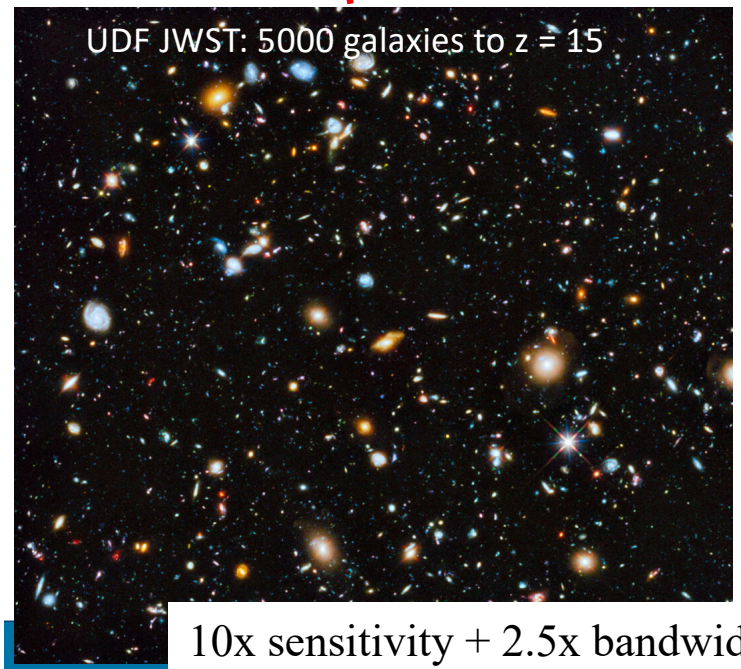


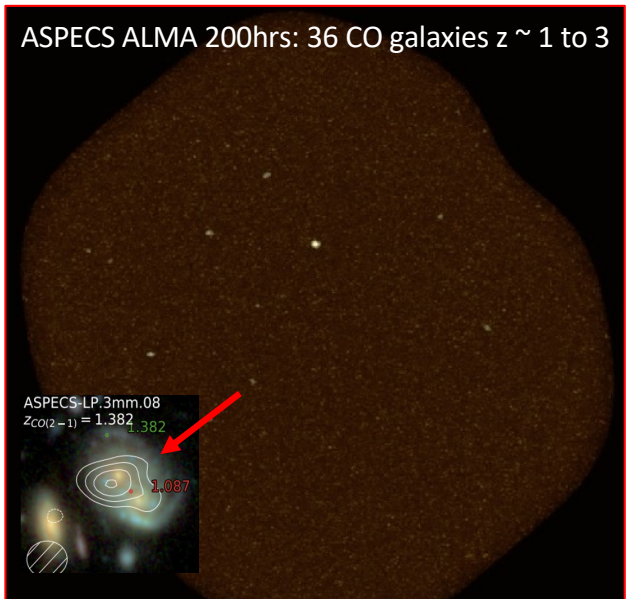




KSG3: *Molecular Deep Fields in three dimensions*

Revealing the 'missing half' of galaxy formation:
the molecular gas = fuel for star formation

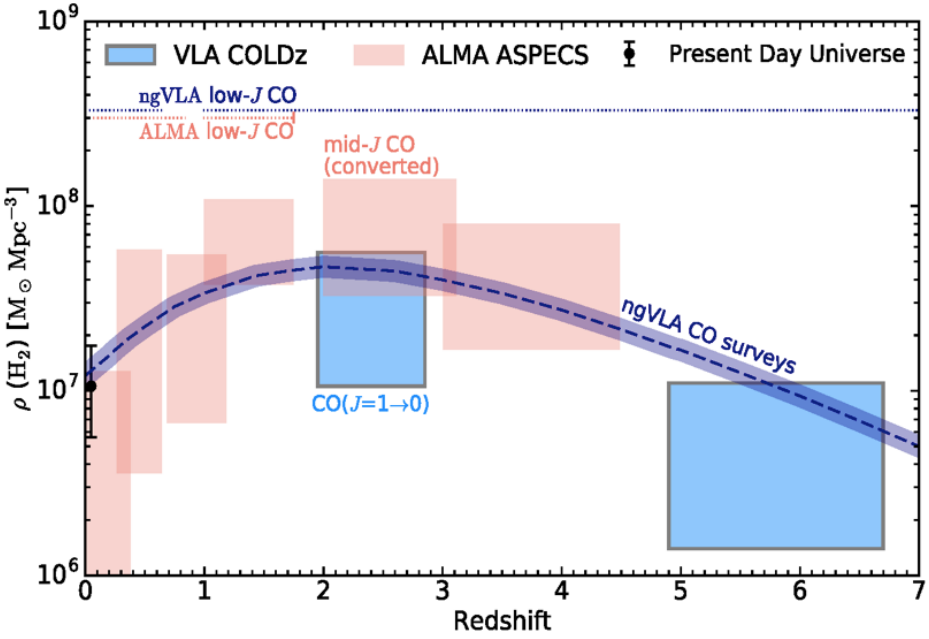


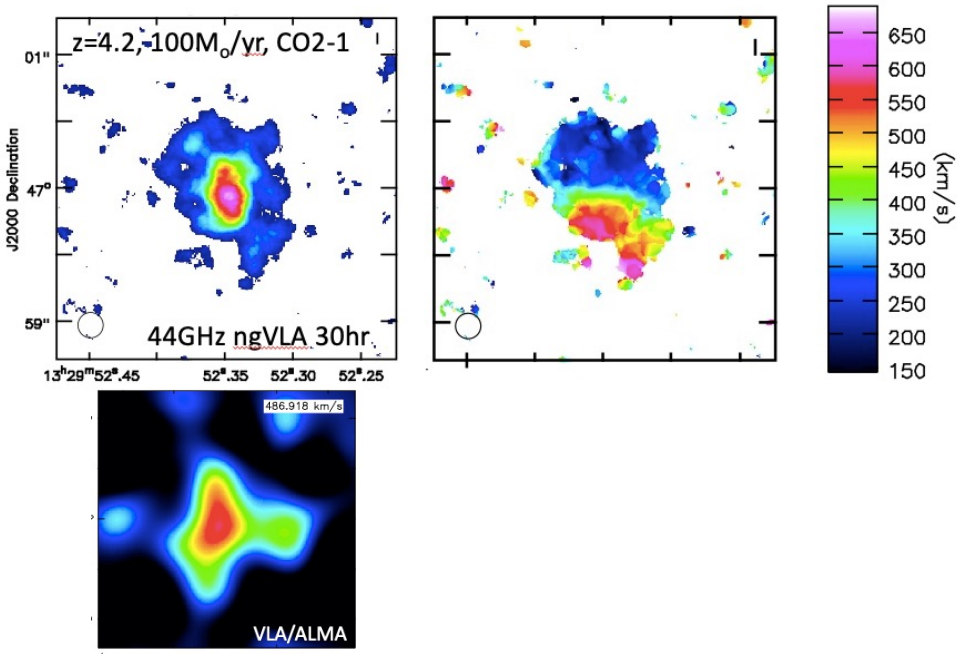


10x sensitivity + 2.5x bandwidth => 100-fold increase in CO detection rate over VLA, ALMA => *Galaxy counts in CO ~ deepest optical fields, with redshifts!*

NRAO

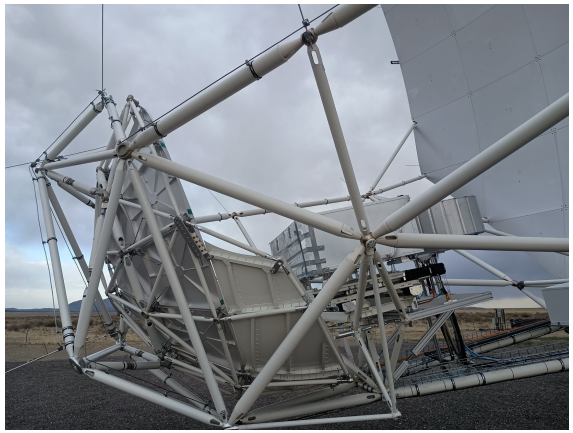
KSG3: *Measuring the Dense Gas History of the Universe*

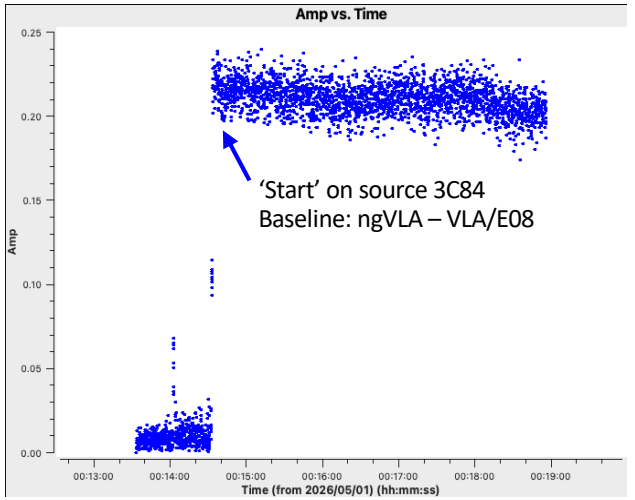


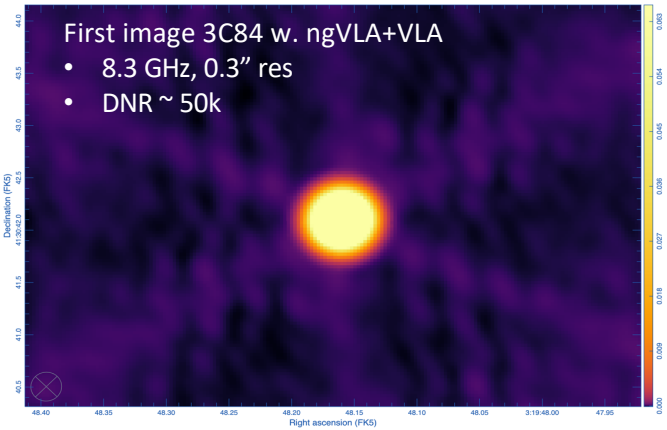


- Precise measurement of Dense Gas History of Universe
- kpc-scale imaging of gas dynamics: Dark matter?

Prototype: First Fringes and Images May 1 2026

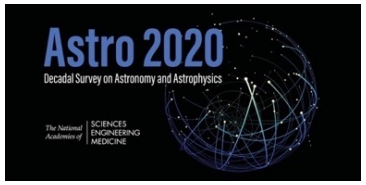


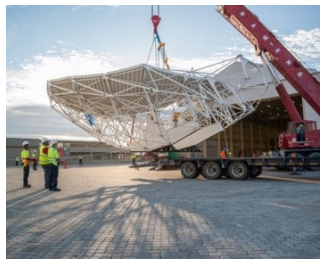


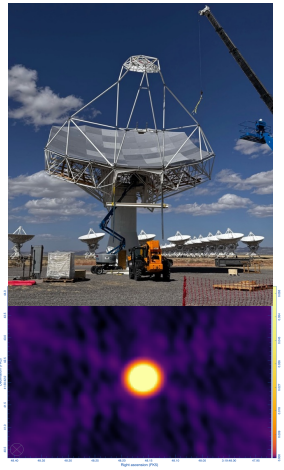


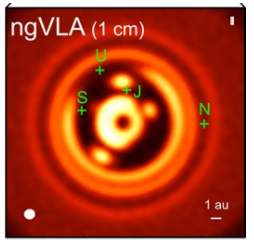
System works from Rx through IF to correlator to CASA!

Project Timeline









2018 2019 2021 2023 2026 2029 2030 2033 2038

Science Book
Ref. Design

Astro2020
submission

Astro2020 Report

NSF development
funds

NSF/MREFC CoDR

Prototype at VLA

1st fringes

NSF/MREFC FDR

Construction

Early Science

Full Science
Operations

ngVLA Science Meetings

- 2026: Multidisciplinary, Tohoku U., Japan
- 2027: Long Baseline Science in DC Area