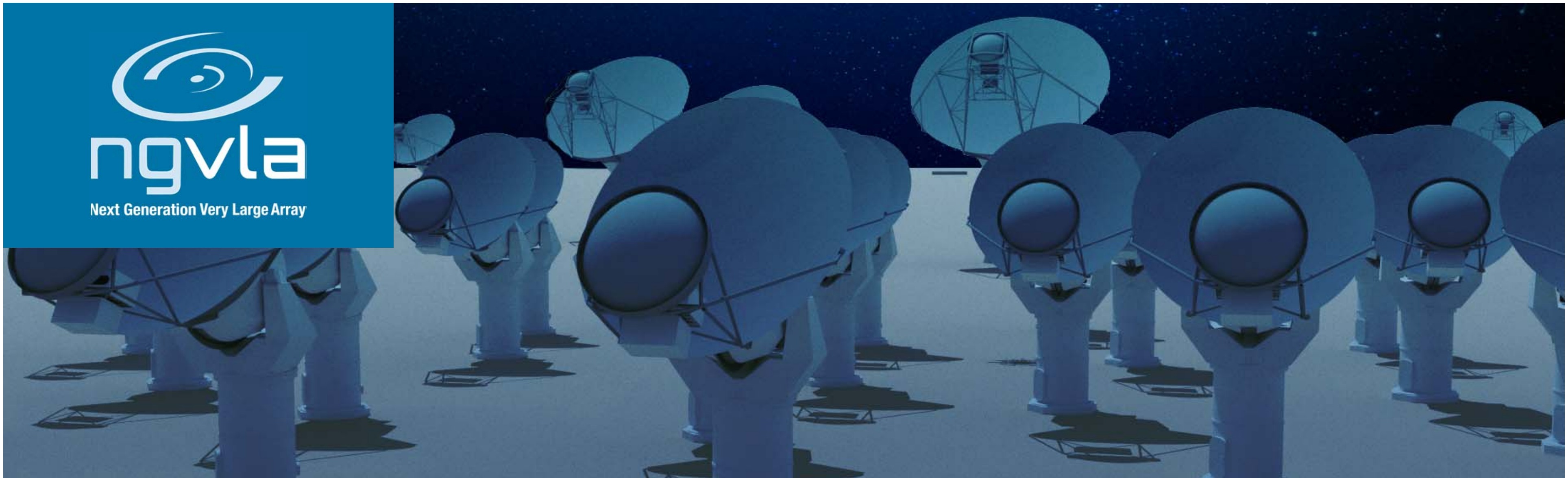


ngVLA: Project Overview

R. Selina, ngVLA Project Engineer
rselina@nrao.edu


The Jansky Very Large Array
1972 – Approved by Congress
1975 – First Antenna in Place
1980 – Full Science Operations
2001 –Electronics Upgrade Approved by NSF
2011 – Jansky VLA Full Science Operations

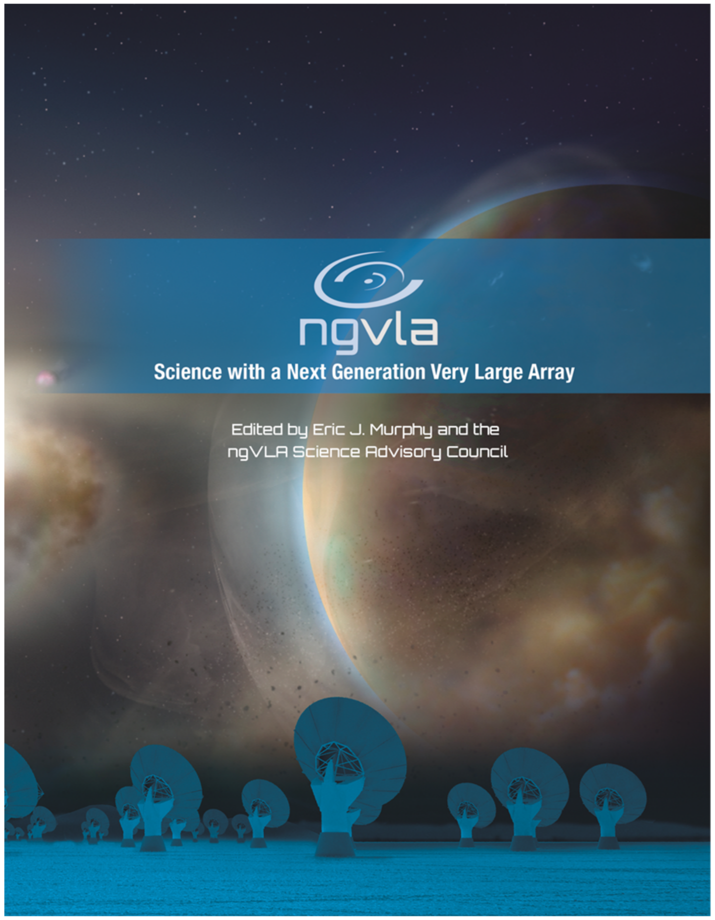

ngvla
ngvla.nrao.edu

2018 Science Meeting

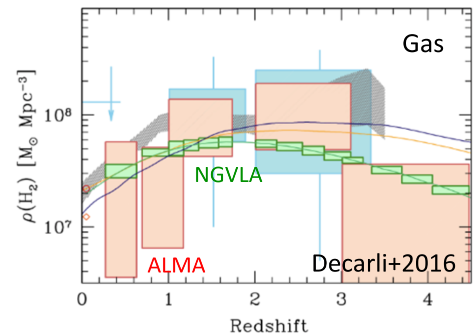
- Meeting was science-focused and wavelength agnostic
  - Brought together a broad cross—section of community
- 3 Parallel Sessions:
  - Origins of Exoplanets and Protoplanetary Disks
  - Mechanisms of Galaxy Evolution
  - Black Holes and Transient Phenomena
- 200+ registrants and *70+ students*! - We are creating our next-generation of users.

Science Book

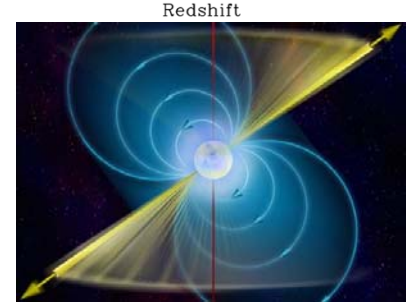
- <u>Science Book published by ASP!</u>
  - 88 peer-reviewed contributions received
  - 286 unique authors
- Volume is culmination of:
  - Numerous science/technical meetings, beginning with Jan 2015 AAS
  - Community-led Science Use Cases:
    - 80+ submitted for 'Reqs to Specs' process (ngVLA memo # 18)
  - Community Studies Program:
    - 38 studies over two rounds, financially supported by NRAO.



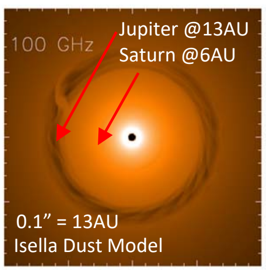
Key Science Goals

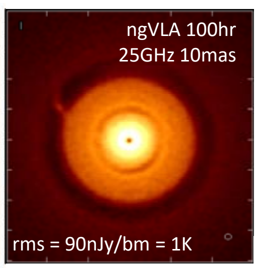


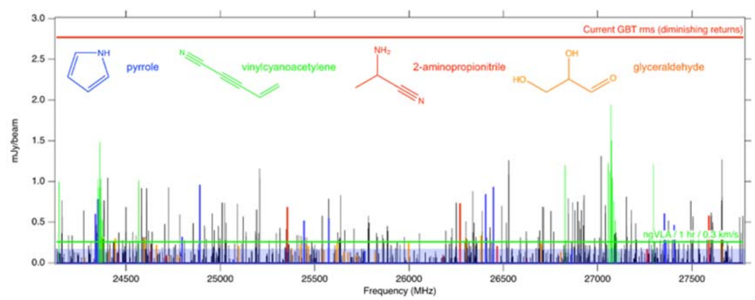
- ***Unveiling the Formation of Solar System Analogues on Terrestrial Scales***
- ***Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry***
- ***Charting the Assembly, Structure, and Evolution of Galaxies Over Cosmic Time***
- ***Using Pulsars in the Galactic Center as Fundamental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

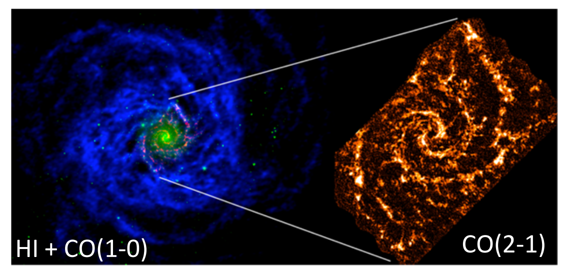


Highly synergistic with next-generation ground-based OIR and NASA missions.



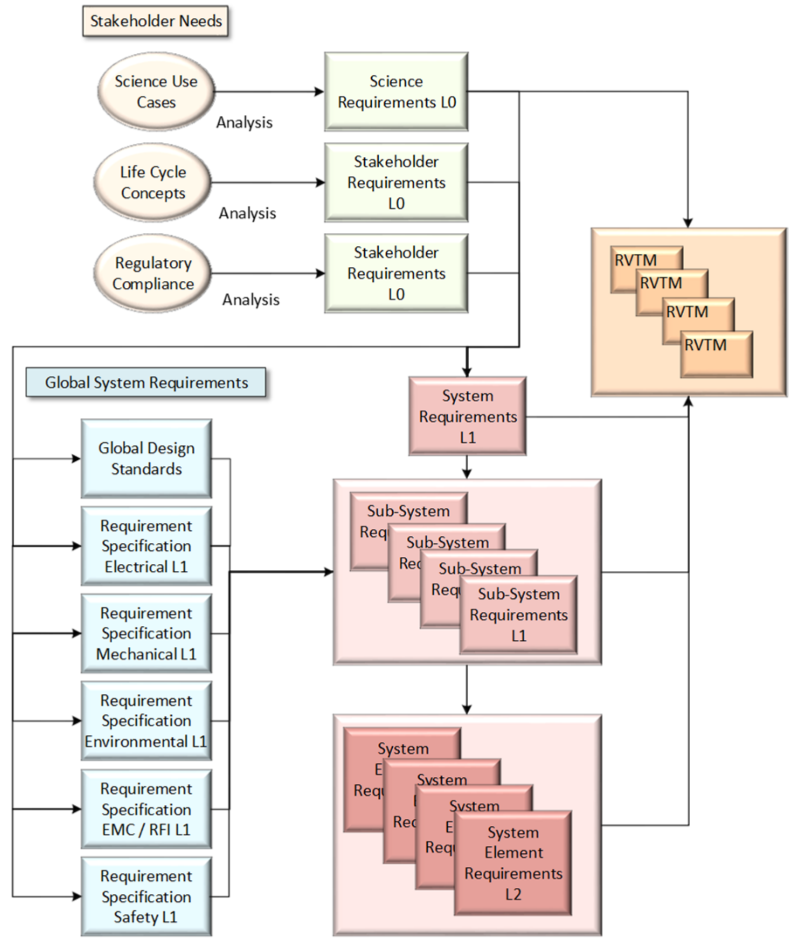






Requirements Flow-Down

- Begins with Science Use Cases (>80)
  - Distilled into ~200 unique observations
- Prioritization by SAC
  - 5 KSGs born out of various use cases
- Converted into Level 0 Science Reqs.
  - 36 Requirements to support KSGs
    - 18 Functional Reqs.
    - 18 Performance Reqs.
- Translated into Level 1 Technical Reqs.
  - 180+ System Level Reqs.

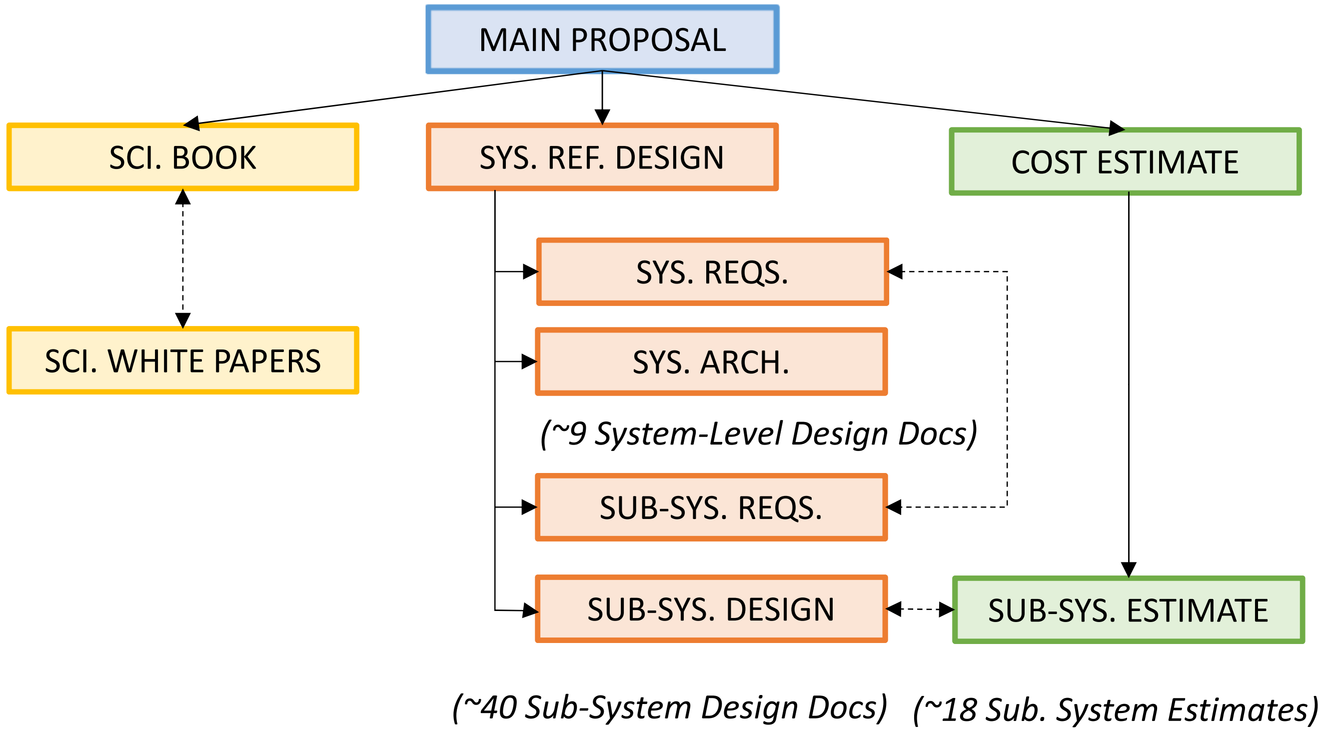


Design Drivers

- **Frequency Coverage**: 1.2 to 116 GHz, both edges drive design.
- **Sensitivity**: Area, Tsys, bandwidth, deconvolution algorithms.
- **Resolution**: 400km+ minimum extent, continental scale for multi-messenger.
- **Image Fidelity:** Even sampling of (u, v)-plane from 10s of meters to 100s of km.
- **Dynamic range**: pointing, phase cal, electronic stability.
- **Large-N**: central archive and compute. High level data product delivery pipelines.

Astro2020: ngVLA Reference Design

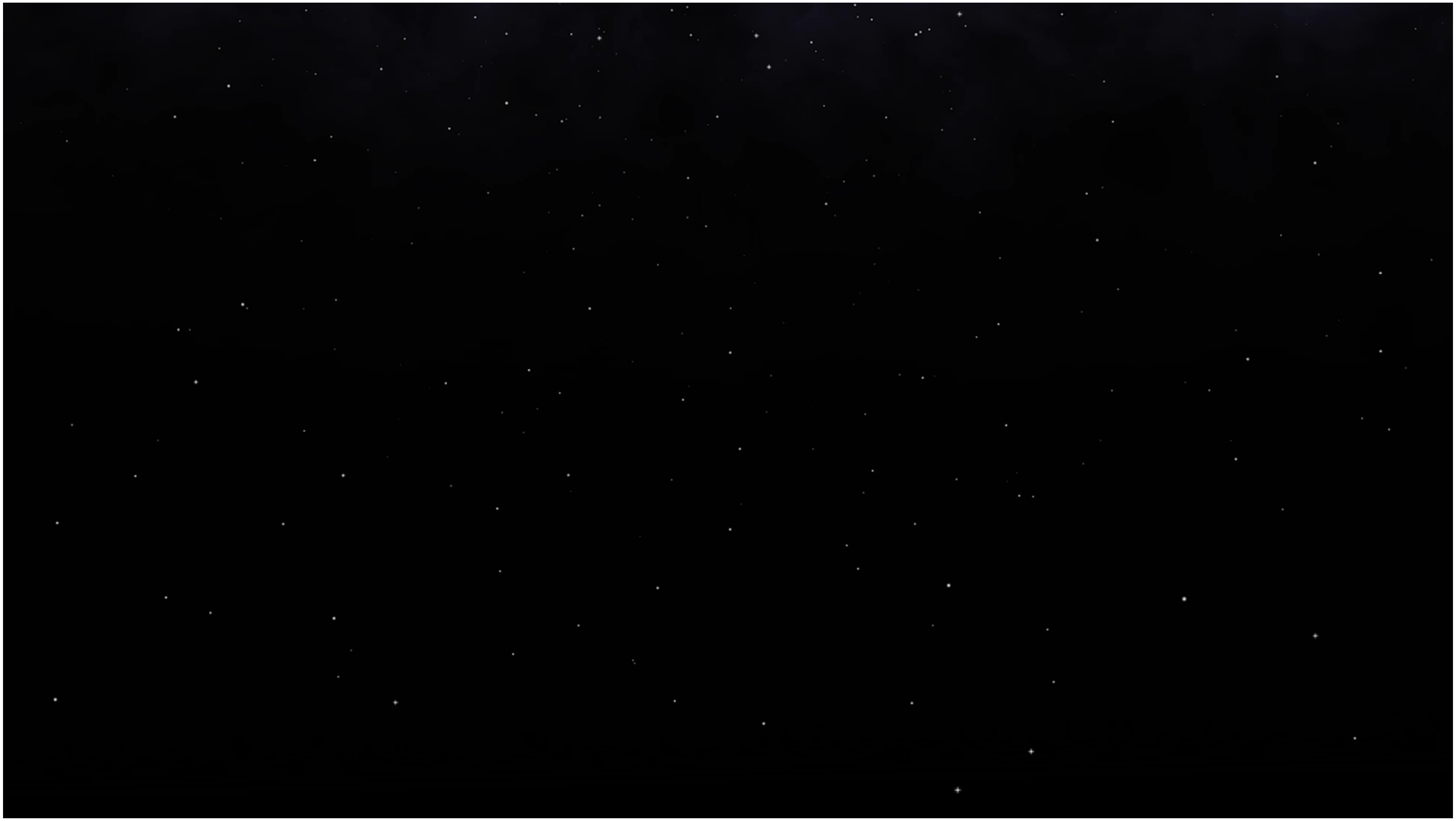
- A baseline design with known cost and low technical risk. Technical & cost basis of the Astro2020 Decadal Survey proposal.
- 1500 page, 75 document package that describes end-2-end system design.
- Bottom-up supporting cost estimate.



- **1.2 - 116 GHz** Frequency Coverage
- **Main Array**: 214 x 18m offset Gregorian Antennas.
  - Fixed antenna locations across NM, TX, AZ, MX.
- **Short Baseline Array**: 19 x 6m offset Greg. Ant.
  - Use 4 x 18m in TP mode to fill in (*u, v*) hole.

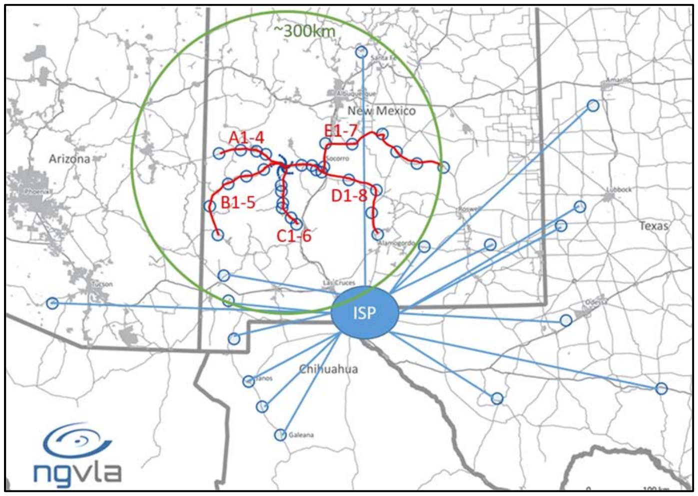
Band #	Dewar	f_L GHz	f_M GHz	f_H GHz	f_H: f_L	BW GHz
1	A	1.2	2.35	3.5	2.91	2.3
2	B	3.5	7.90	12.3	3.51	8.8
3	B	12.3	16.4	20.5	1.67	8.2
4	B	20.5	27.3	34.0	1.66	13.5
5	B	30.5	40.5	50.5	1.66	20.0
6	B	70.0	93.0	116	1.66	46.0

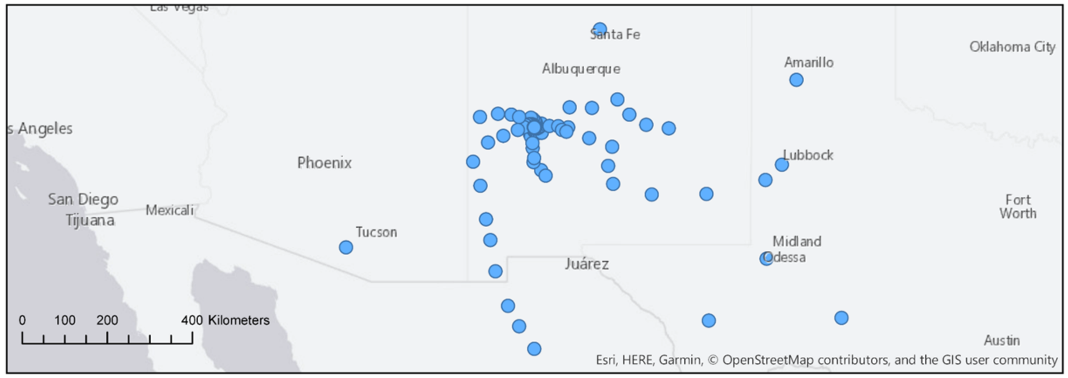
- **Long Baseline Array**: 30 x 18m antennas located across continent for baselines up to 8860km.

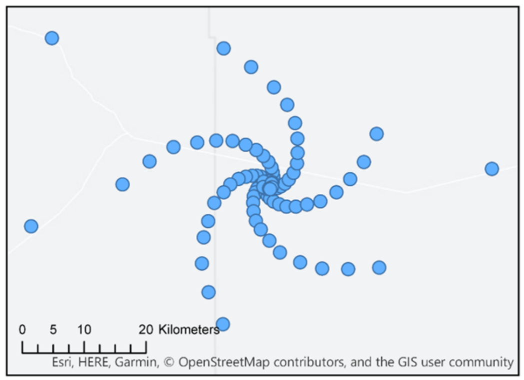


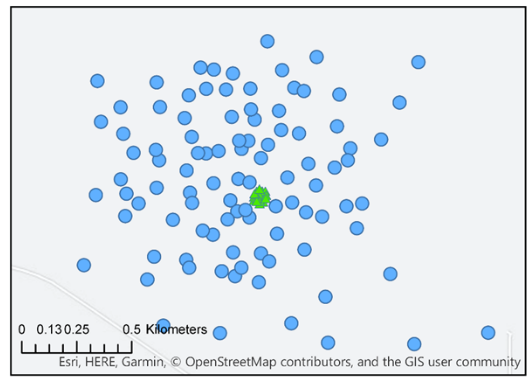
The Main Array (MA) Configuration

Radius	Collecting Area Fraction
0 km < R < 1.3 km	44%
1.3 km < R < 36 km	35%
36 km < R < 1000 km	21%



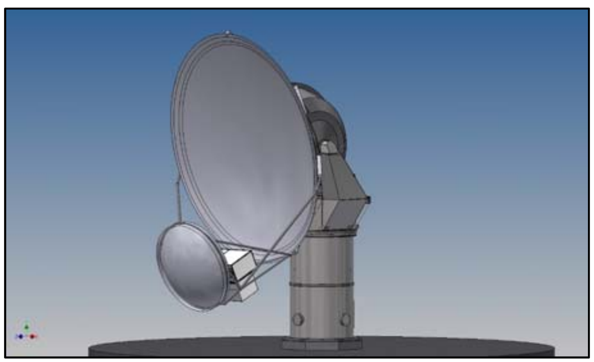


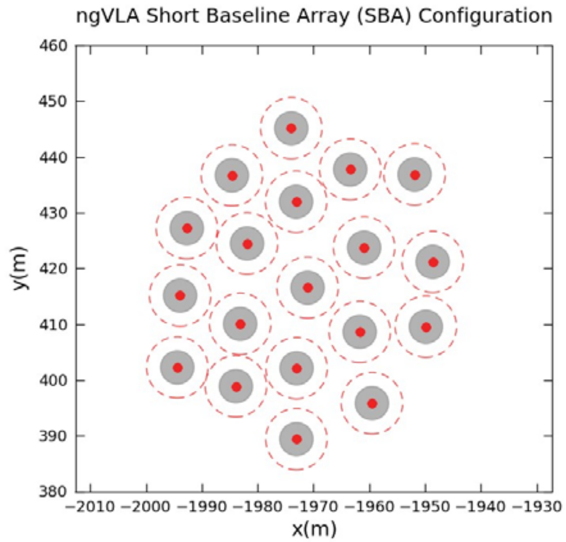


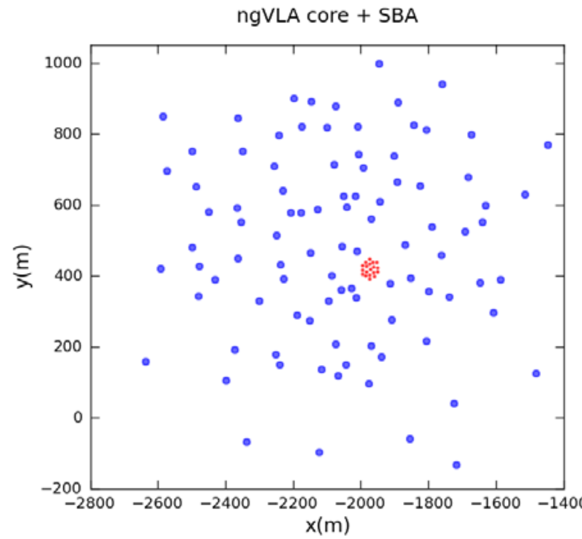


Short Baseline Array (SBA)

- Short Baseline Array of 19 x 6 m
- Total Power Array of 4 x 18 m (included as part of the 214 main array).



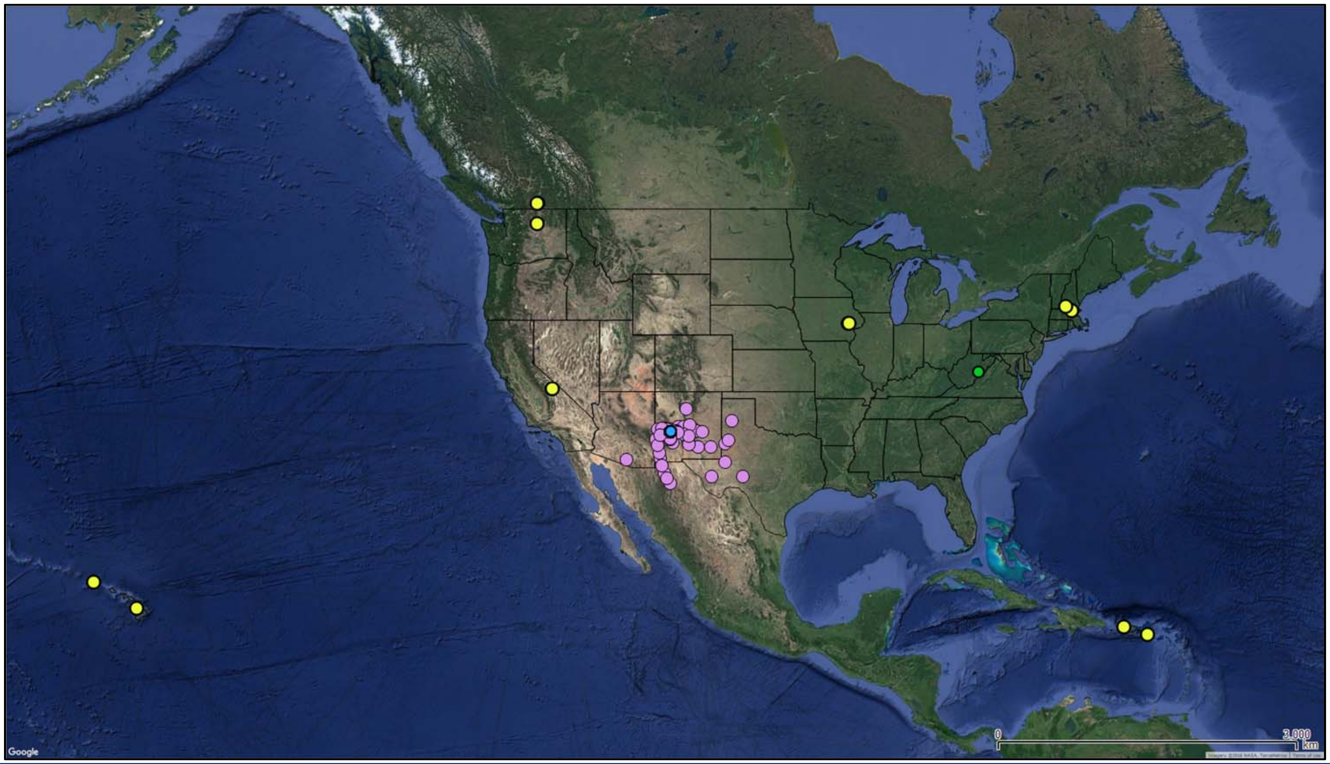




Long Baseline Array (LBA)

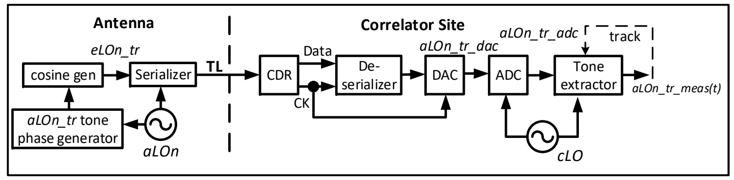
- 30 x 18m Antennas at 10 sites.
- Balance between Astrometry & Imaging Use Cases.

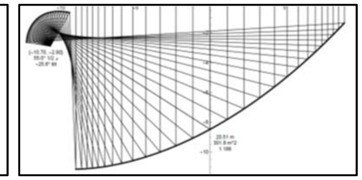
Qty	Location	*Possible* Site
3	Puerto Rico	Arecibo Site
3	St. Croix, US VA	VLBA Site
3	Kauai, HI	Kokee Park Geo. Obs.
3	Hawaii, HI	New Site (off MK)
2	Hancock, NH	VLBA Site
3	Westford, MA	Haystack
2	Brewster, WA	VLBA Site
3	Penticton, BC, CA	DRAO
4	North Liberty, IA	VLBA site
4	Owens Valley, CA	OVRO

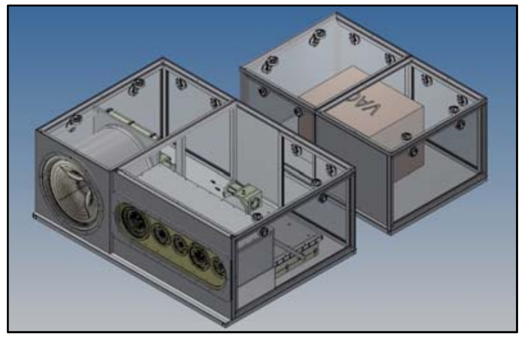


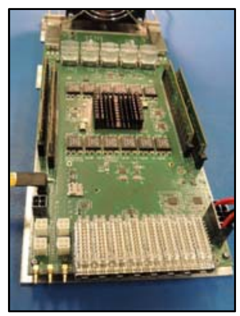
Session Talks

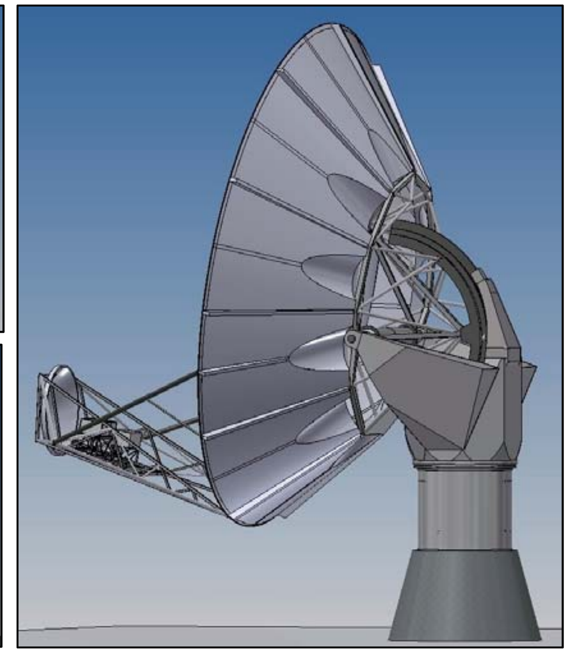
- LBA – T. Maccarone
- Optics – L. Baker
- Antennas – D. Chalmers
- Antenna Electronics – J. Jackson
- Front End – D. Urbain, H. Mani
- Digitizer – M. Morgan
- Correlator – M. Pleasance
- RFI Mitigation – B. Jeffs
- Incoherent Clocking – B. Carlson









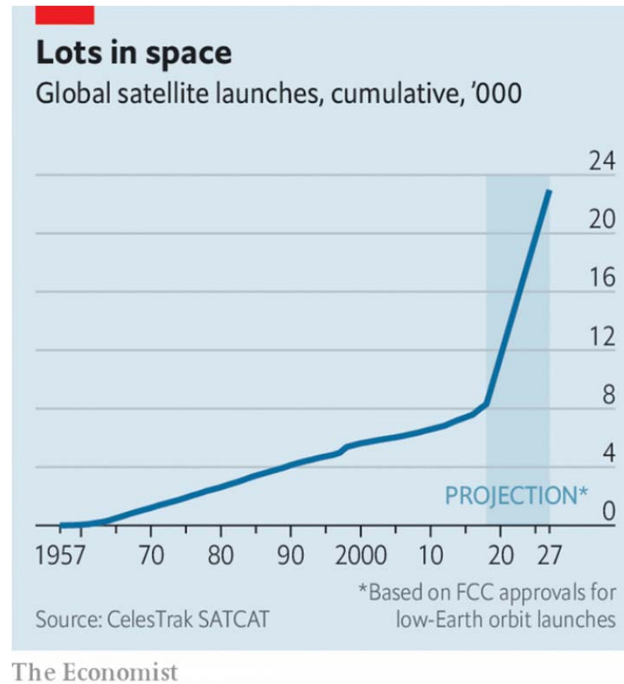


S/W and Computing Considerations

- **Operations Concept**: SRDP (Science Ready Data Products) Telescope
  - Both for 1st Observations and Archive projects.
- **Post Processing**: Analysis shows that storing the raw visibilities will be tractable when ngVLA goes into operations.
  - Data processing is post-facto, with system sized for average throughput.
  - Average Data Rate – 25.8 GB/s. Designed for 128 GB/s peak.
  - 4 hr. observation – 372 TB. Requires ~1000 cores to process in a few days.
- **Computing:** Needs can be met with a COTS cluster.
  - Set by time resolution, spectral resolution, and multi-faceting in imaging
  - Some low-frequency, full-beam, w-projection cases restricted in early operations.
  - Plan is a 2000 core cluster. (~30x VLA/ALMA)

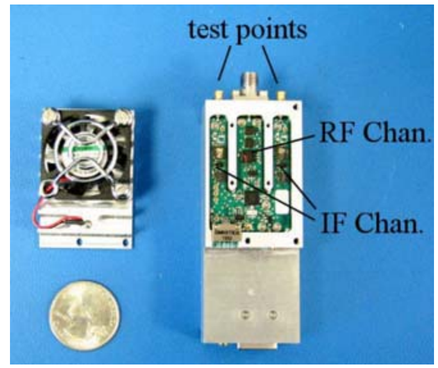
Technical Risks

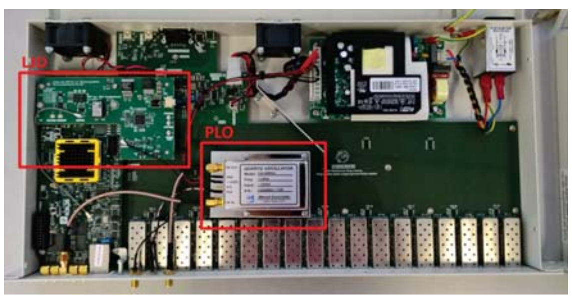
- Moore's Law
  - Don't need transistor density to continue to increase, but do need Oper./$ trends to continue.
- The new RFI environment
  - LEO satellite revolution will impact all ground based facilities.
- Cost vs. Risk Curve - Choices
  - E.g., integrated receiver ASIC, composite reflectors

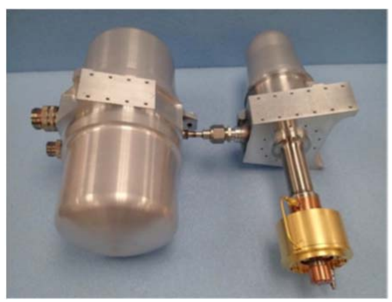


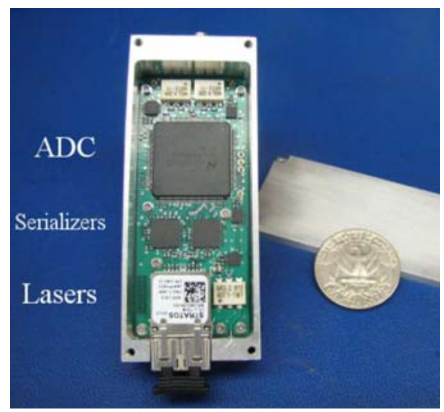
Tech. Development

- Prototype Band 1 Feed, Caltech
- Prototype Band 5 Feed, NRC
- Integrated receiver / digitizer prototype, NRAO CDL
- Two-stage hybrid sterling refrigerator, Raytheon LT-RSP2









Cost Estimates

- Most recent cost estimate for construction:
  - **$1.9B** in 2018 base-year dollars.
- Target operations budget of **$80M/yr.** (3x current VLA + VLBA Ops)
- Scope changes and cost data refinement have adjusted the initial estimate:
  - Short Baseline Array (19 six-meter antennas)
  - Long Baseline Array (30 eighteen-meter antennas)
- All ngVLA components will be reviewed as part of Astro2020 process.
- **<u>Next Steps</u>**: Continue at $6-8M/yr. design through 2021. Ramp up to complete design in 2024. (2 + 3 yr. model)

Summary

- The ngVLA Reference Design, a credibly-costed and low-technical risk concept, is near complete and will be ready for Astro2020.
- System-level design (requirements, architecture) will be baselined in 2019 to enable sub-system conceptual design down-selects.
- The project is developing novel technologies to a suitable level of technical readiness prior to conceptual design down-selects.
- Major Challenges: No major technological blockers. Challenges are cost-performance optimizations, manufacturability and reliability.
- Next Steps: Submit to Astro2020; Continue Design/Development; Baseline requirements to sub-system level; System-level CoDR by end of 2020.

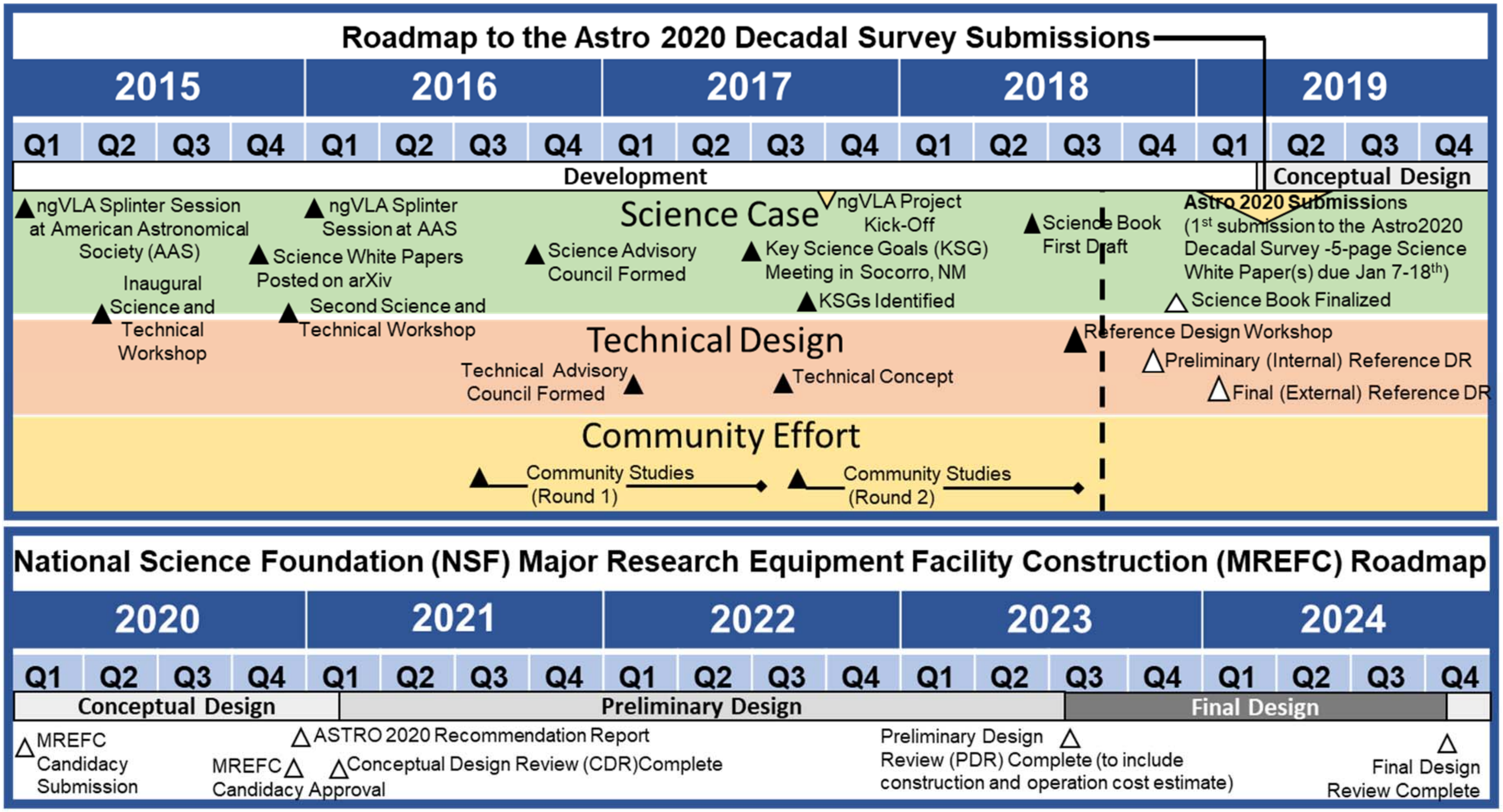
ngvla

Next Generation Very Large Array

Next Generation Very Large Array (ngVLA) Project Timeline

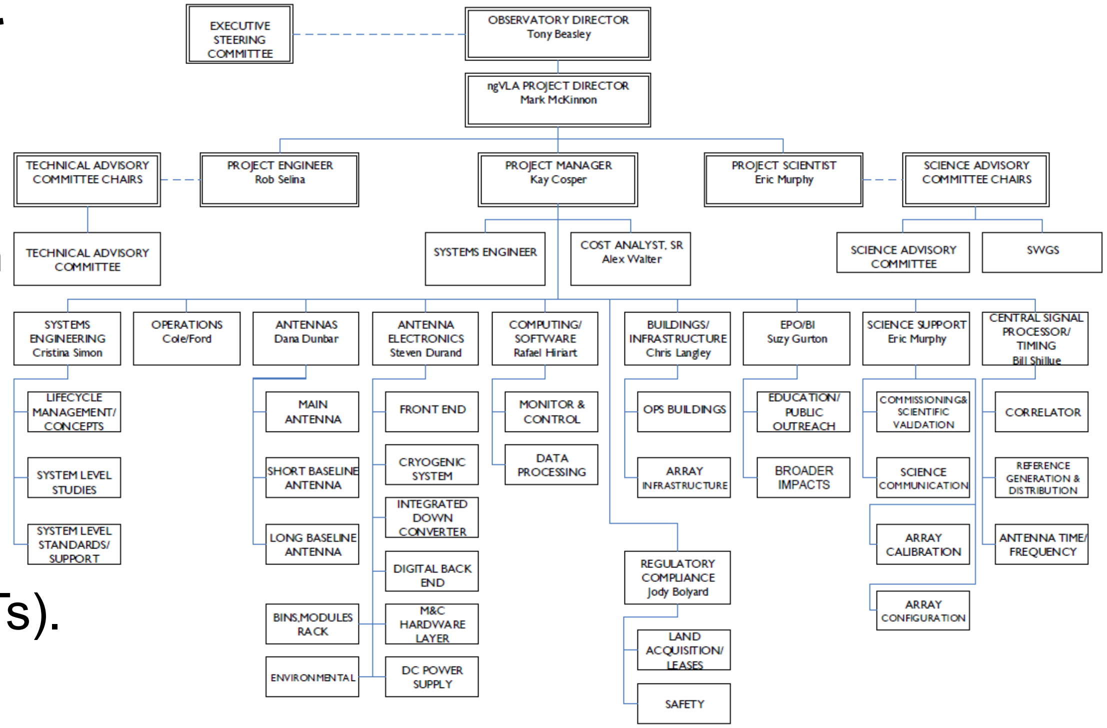
NAS DS2020 Roadmap

NSF MREFC Roadmap



ngVLA Project

- Project Office leadership team:
  - Project Director: Dr. Mark McKinnon
  - Project Manager: Kay Cosper
  - Project Scientist: Dr. Eric Murphy
  - Project Engineer: Rob Selina
  - Cost Analyst – Alex Walter



- 10 Integrated Product Teams (IPTs).
- MREFC-style project definition.
- Actively engaged science and technical advisory councils.

Community-Led Advisory Councils

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**)

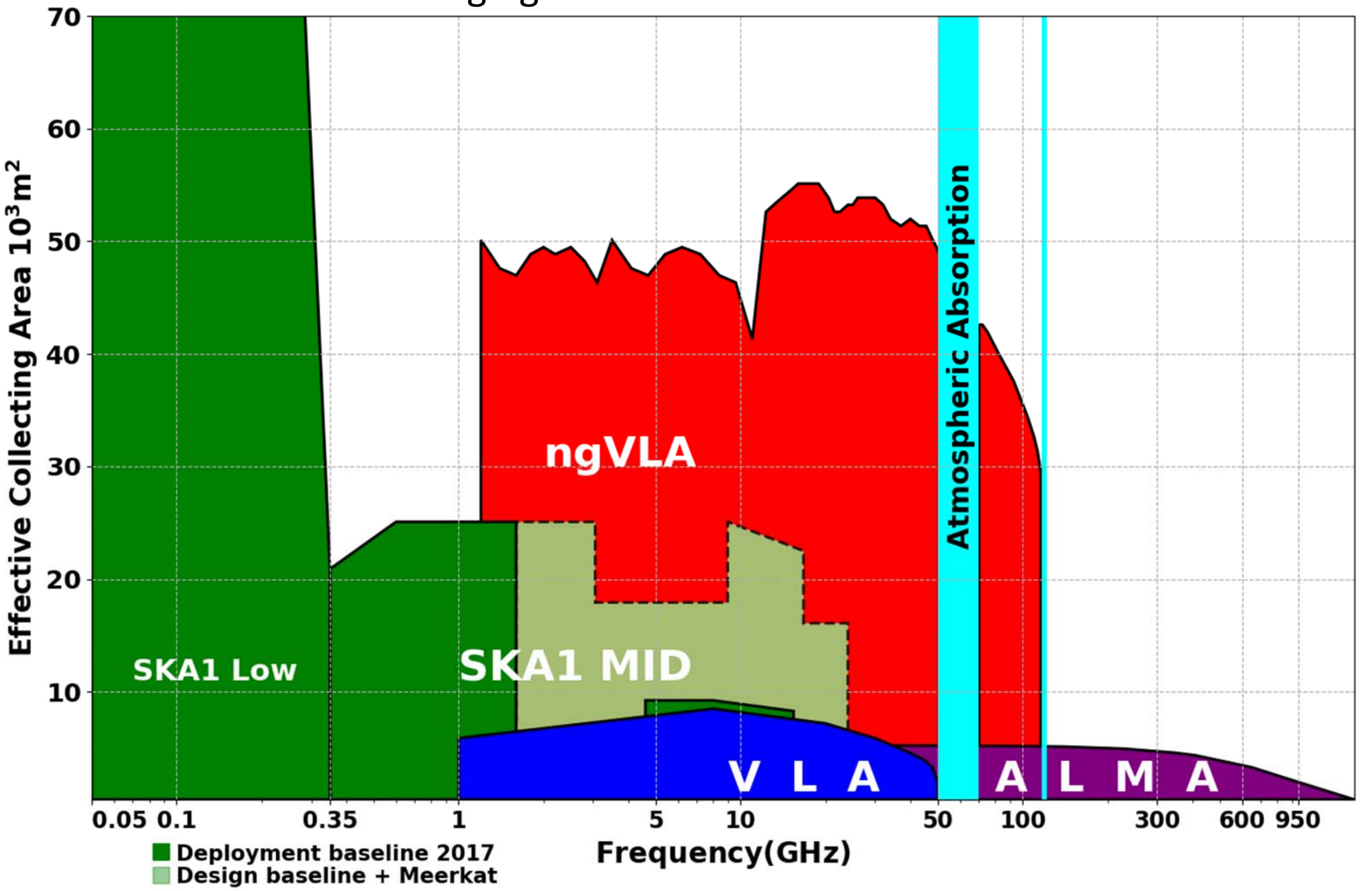
ngVLA Science Advisory Council

- Interface between the science community & NRAO
- Recent/Current Activities:
  - Science working groups: science use cases → telescope requirements
  - 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**)

Bridging SKA & ALMA Scientifically

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



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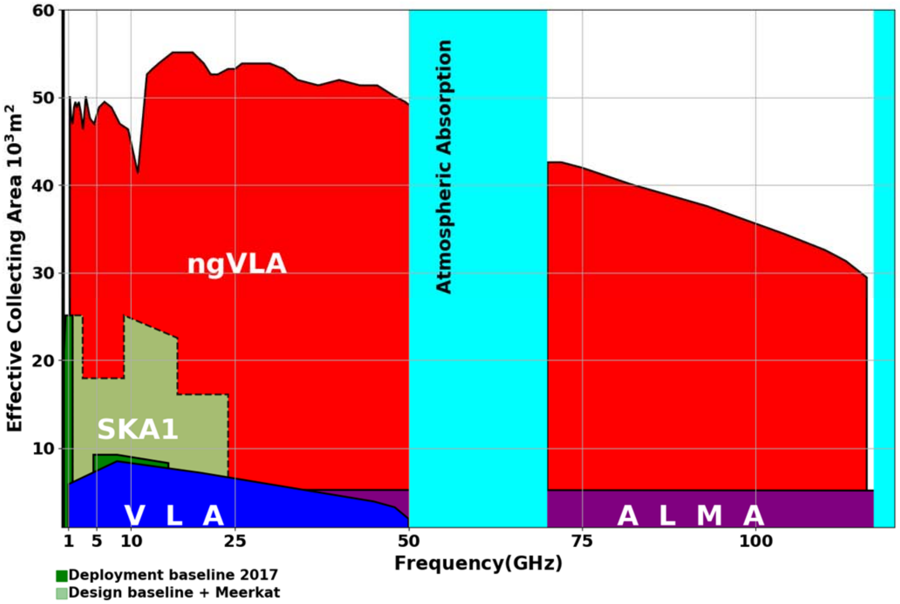

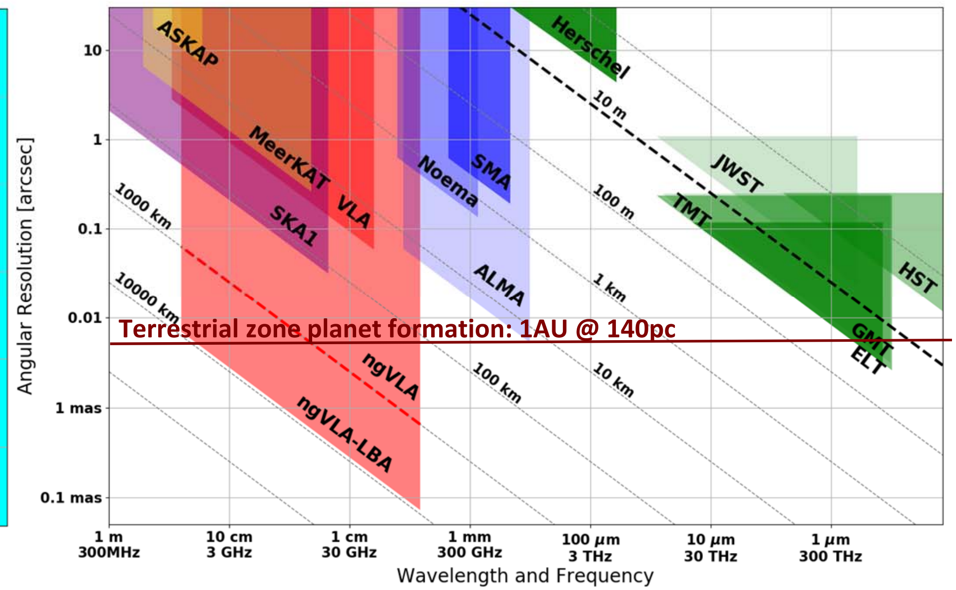

Complementary suite from cm to submm arrays for the mid-21st century

- **< 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

S/W and Computing Considerations

- **Code Development**: Approx. 2.6M new lines of code expected.
  - ALMA / VLA SLOC – 4.77M / 4.35M (Actual)
  - ngVLA SLOC – 5.75M (Projected).
  - Reuse estimated on each element of logical architecture.
  - 54% Average Reuse Projected – 2.63M new SLOC.
- **Risks**:
  - Depends upon continuation of the historic trend in cost of storage and compute capacity.
  - Uncertainty in time spent on cases (4 of 25 use cases) that need w-projection.
  - Uncertainty in algorithmic compute scaling for specific use cases.

	ALMA (SLOC)	EVLA (SLOC)	Estimation (MSLOC)	Estimated reuse (%)	Effort Size (MSLOC)
Online Subsystem					
Calibration	109,798	9,857	0.100	40%	0.060
Common	431,125	16,863			
Control	222,233	439,876			
Correlator	710,860	846,112			
Diagnostic and Engineering Tools	18,721	66,833	1.400	30%	0.980
Metadata Capturer	46,135	8,998	0.050	0%	0.050
Monitoring	15,517	24,365	0.050	50%	0.025
Observation	114,279	49,285	0.100	20%	0.080
Operation	88,177	52,934	0.200	0%	0.200
Quick-Look	31,547	-	0.050		0.050
Scheduling	37,085	3,127	0.050	30%	0.035
Telescope Configuration	85,584	2,019	0.100	0%	0.100
Offline Subsystem					
Archive & Observatory Interfaces	504,545	303,035	1.000	80%	0.200
Data Processing	2,078,245	2,078,245	2.000	70%	0.600
Proposal Management Subsystem					
Proposal Management	279,728	444,527	0.500	80%	0.100
Maintenance, Support & Development					
CMMS Integration	-	-	0.100	0%	0.100
Simulation	-	-	0.050	0%	0.050
Total	**4,773,579**	**4,346,076**	**5.750**	**54%**	**2.630**

Mid-Scale Baseline Optimization – the Walker Configuration