NRAO
NATIONAL RADIO ASTRONOMY OBSERVATORY

Project Update

Eric J. Murphy, ngVLA Project Scientist

NSF AUI

ngvla
Next Generation Very Large Array

The Jansky Very Large Array

1972 – Approved by Congress
1975 – First Antenna in place
1980 – Full science operations
2001 – Complete electronics upgrade approved by NSF
2011 – Jansky VLA full science ops

ngvla.nrao.edu

A Next-generation Very Large Array

- Scientific Frontier: Thermal imaging at milliarcsecond-scale resolution
- Principle: Scientifically-compelling instrument for 2020s.
- Core Design Requirements
  - ***10x sensitivity of JVLA and ALMA***
  - ***10x resolution of JVLA and ALMA***
  - ***Frequency range: 1.2 –116 GHz***
- Located in Southwest U.S. (NM+TX+AZ) & Mexico, building from JVLA site
- Reference design remains under continuous development
- Low technical risk (measured step beyond current state of the art)
- Stand-alone, multi-wavelength & multi-messenger scientific roles.

https://ngvla.nrao.edu

ngvla NRAO NSF AUI

Community Participation

Jet Propulsion Laboratory (JPL)
Johns Hopkins University
University of Virginia
Ohio State
The University of New Mexico
California State University Northridge
Cornell University
NOAO
The George Washington University, Washington, DC
BYU Brigham Young University
Michigan State
University of Maryland
University of Wyoming
LSST Large Synoptic Survey Telescope
Rice
Green Bank Observatory
Texas Tech University
Harvard-Smithsonian Center for Astrophysics
Berkeley University of California
Texas The University of Texas at Austin
The University of Arizona
The University of Iowa
UC San Diego
West Virginia University
STScI Space Telescope Science Institute
Caltech

General Dynamics Mission Systems
Quantum Design
REhnu Next Generation Solar
LaserLaB Amsterdam
VU
MINEX Engineering Corp.

NRC·CNRC Canada
ASIAA
The University of Western Australia
University of Sussex
国立天文台 NAOJ National Astronomical Observatory of Japan
Universidad Nacional Autónoma de México
東京大学 The University of Tokyo
ICRAR International Centre for Radio Astronomy Research
RIKEN
Max-Planck-Institut für Astronomie Heidelberg

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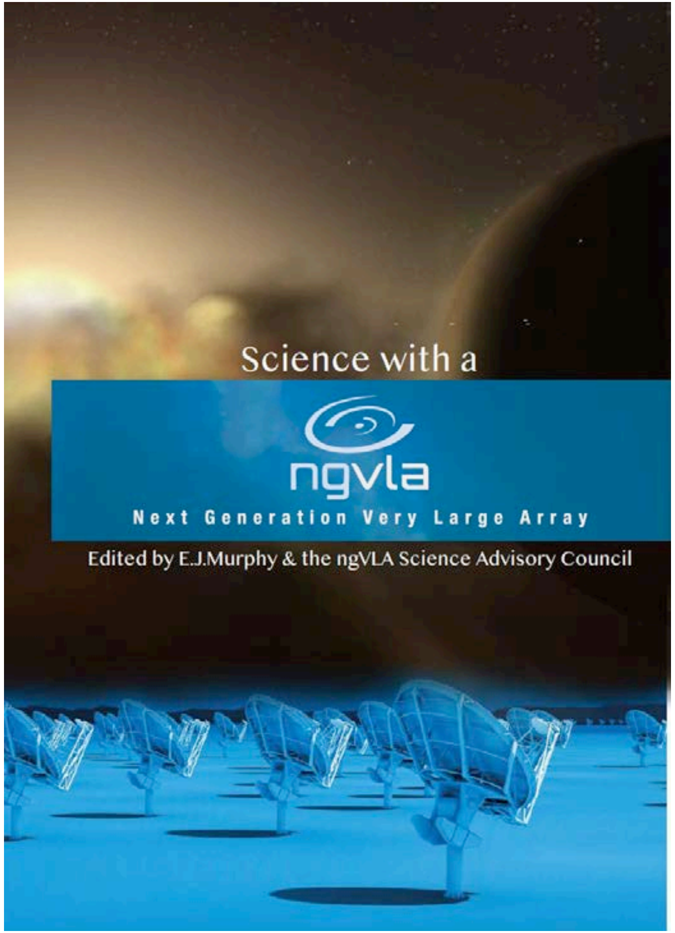
ngVLA 2018 Science Meeting

- 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

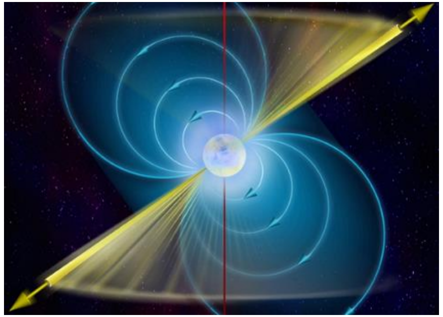
ngVLA Science Book

- First draft of Science Book released in June 2018
  - 58 (refereed) contributions received
  - ~200 unique authors
  - 10+ contributions known to be in preparation, more expected
- Volume is culmination of:
  - Numerous science/technical meetings, beginning with Jan 2015 AAS
  - Community Studies Program:
    - 38 studies over 2 rounds, financially supported by NRAO
    - Community-led Science Use Cases: 80 submitted for ‘Reqs to Specs’ process (ngVLA memo # 18)
- Related: Kavli science meeting series: 2016-2017
- Science Book to be published by ASP
  - Distribute at 2019 Winter AAS Meeting

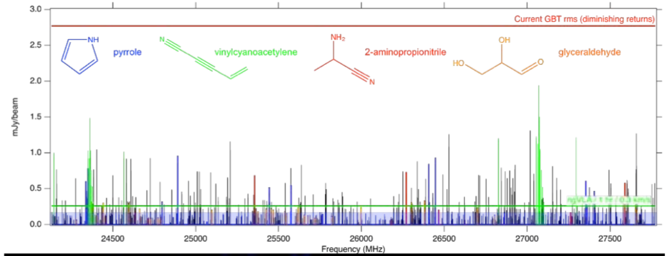


ngVLA Key Science Missions

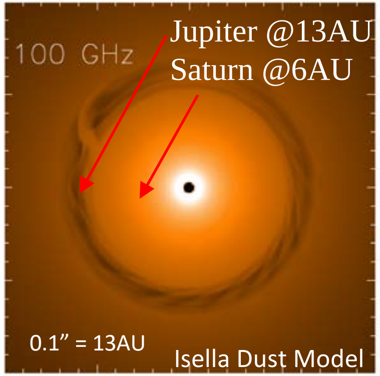
(ngVLA memo #19)

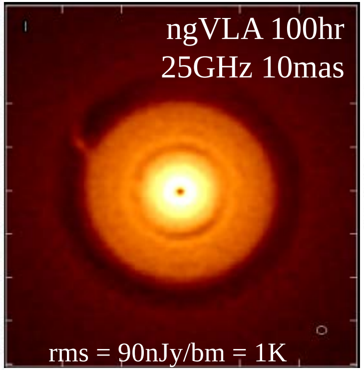


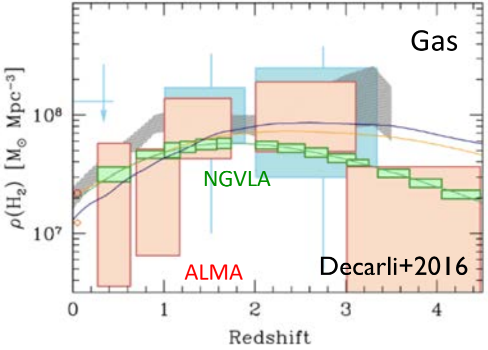
- ***Unveiling the Formation of Solar System Analogues on Terretrial Scales***
- ***Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry***
- ***Charting the Assembly, Structure, and Evolution of Galaxies Over Cosmic Time***
- ***Using Pulsars in the Galactic Center as Fundamental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

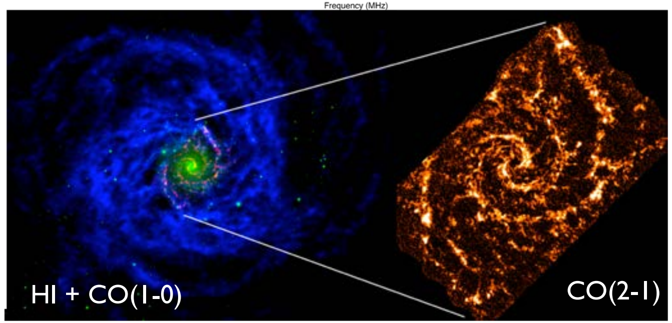


Highly synergistic with next-generation ground-based OIR and NASA missions.

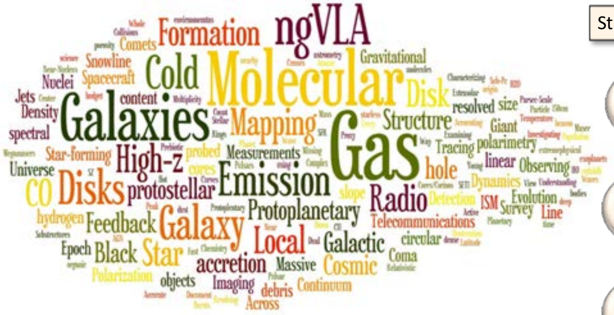




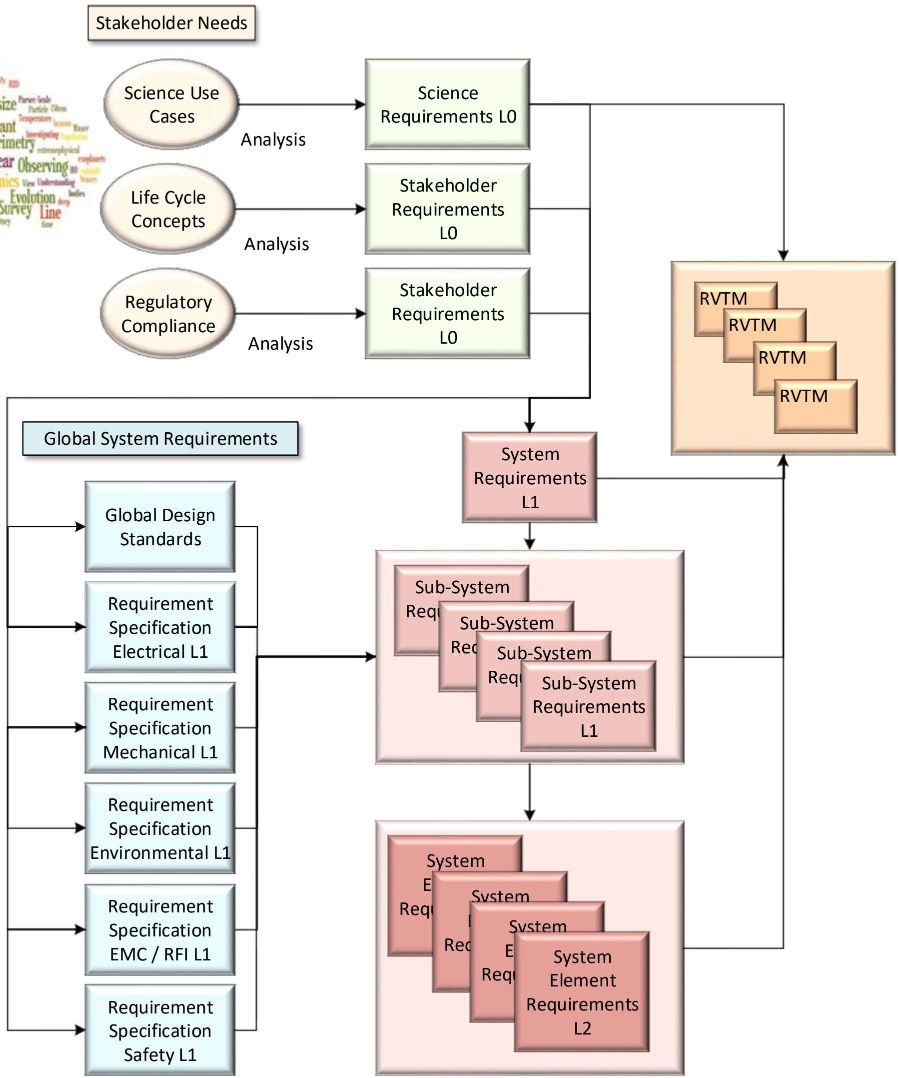




System Flow-Down

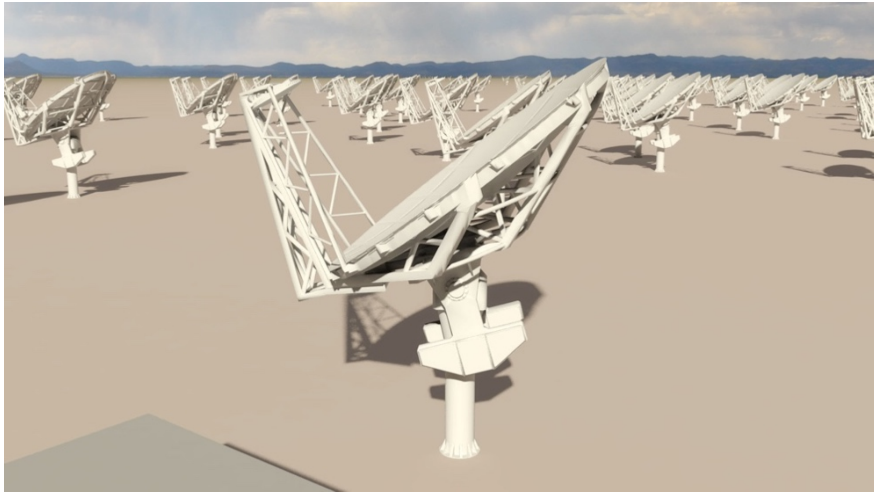


- Begins with Science Use Cases (>80)
  - Distilled into ~200 unique observations
- Prioritization by SAC
  - 5 KSGs born out of various use cases
- Converted into Level 0 Science Requirements
  - 36 Requirements to support KSGs
    - 18 Telescope Reqs.
    - 18 Performance Reqs.
- Translated into Level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

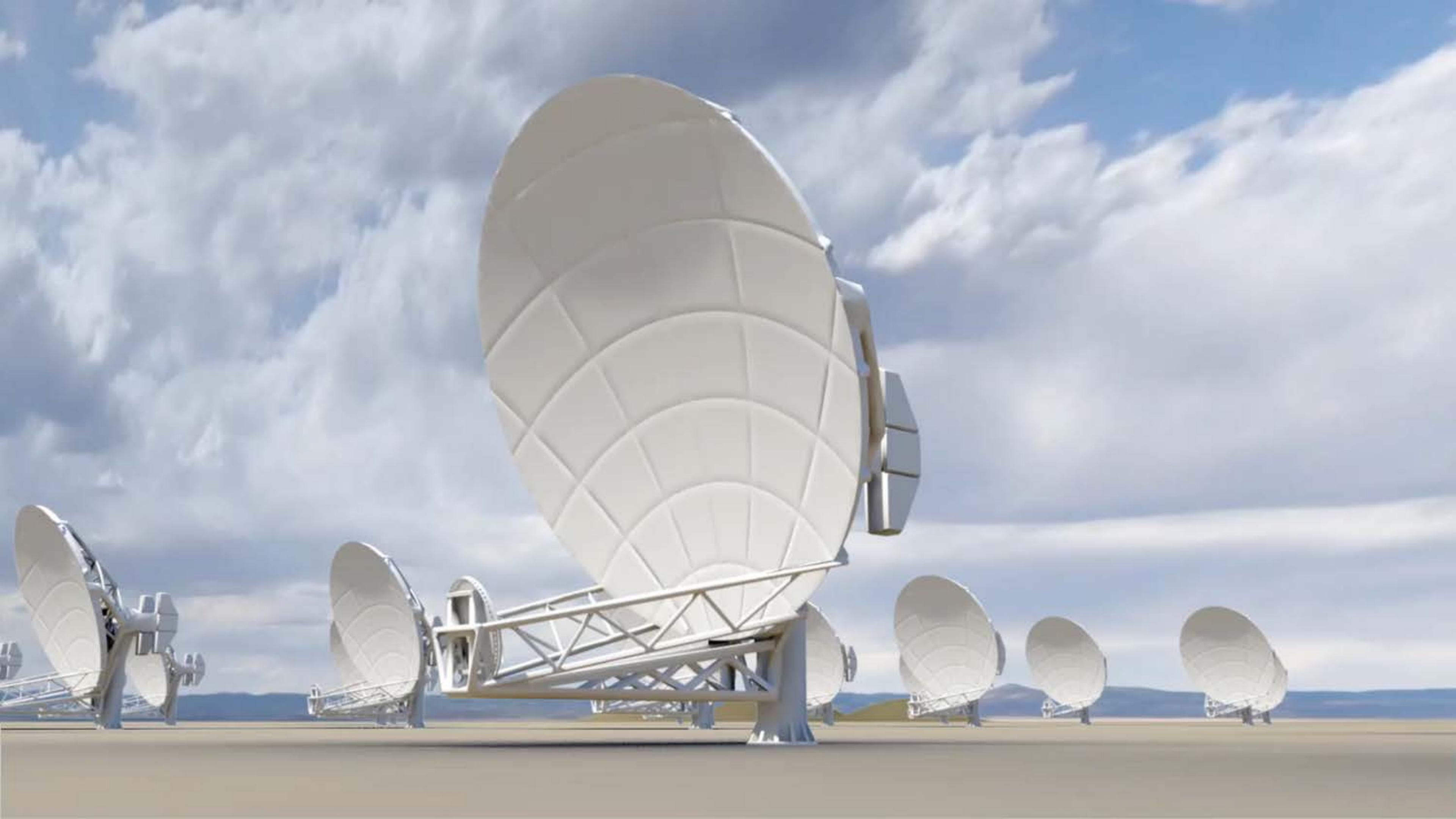


ngVLA Reference Design

- A baseline design with known cost and low technical risk. Technical & cost basis of the Decadal proposal.
- 1.2 - 116 GHz Frequency Coverage
- **Main Array**: 214 18m offset Gregorian Antennas.
  - Fixed antenna locations across NM, TX, AZ, MX.
- **Short Baseline Array**: 19 6m offset Gregorian antennas
  - Use 4 x 18m in TP mode to fill in (*u, v*) hole.
- **Long Baseline Array**: 30 x 18m antennas located across continent for baselines up to 8000km.
  - Designed for both integrated and subarray use.

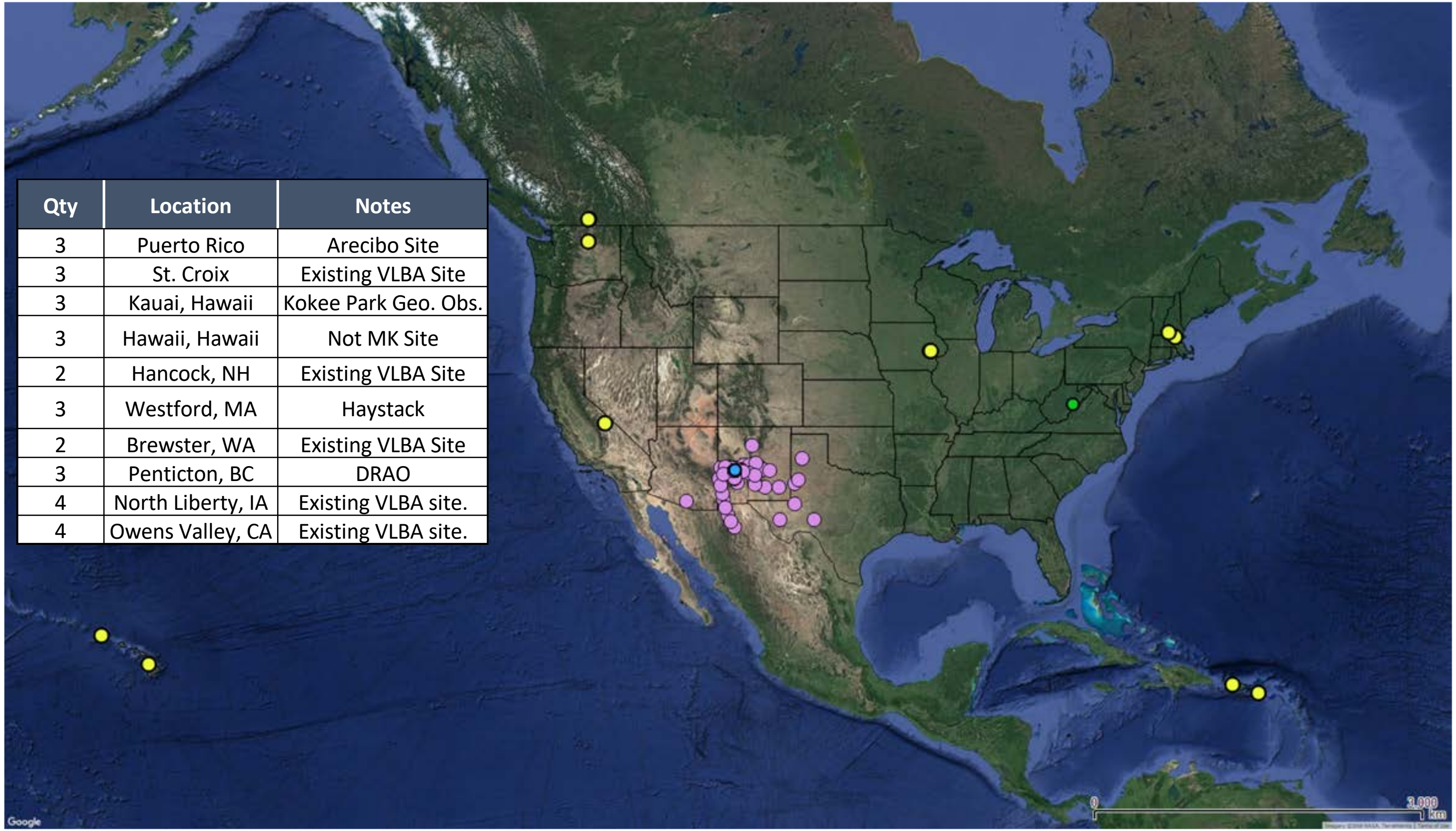


Band #	Dewar	f_L GHz	f_M GHz	f_H GHz	f_H: f_L	BW GHz
1	A	1.2	2.35	3.5	2.91	2.3
2	B	3.5	7.90	12.3	3.51	8.8
3	B	12.3	16.4	20.5	1.67	8.2
4	B	20.5	27.3	34.0	1.66	13.5
5	B	30.5	40.5	50.5	1.66	20.0
6	B	70.0	93.0	116	1.66	46.0



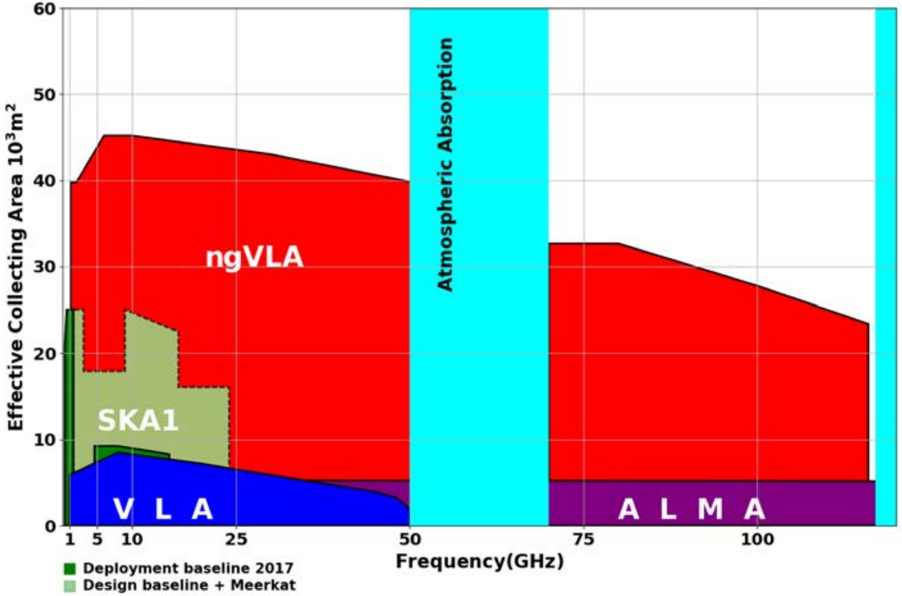
Long Baseline Array

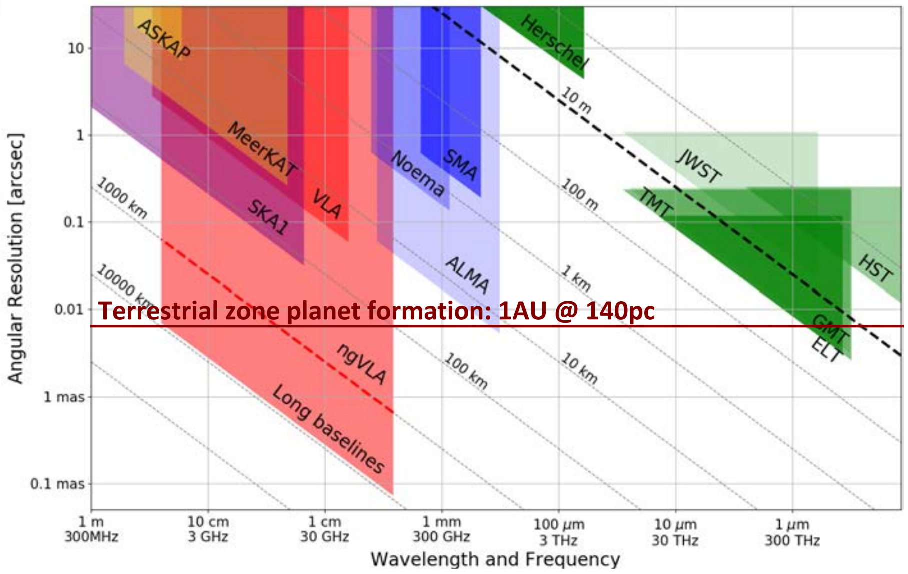
Qty	Location	Notes
3	Puerto Rico	Arecibo Site
3	St. Croix	Existing VLBA Site
3	Kauai, Hawaii	Kokee Park Geo. Obs.
3	Hawaii, Hawaii	Not MK Site
2	Hancock, NH	Existing VLBA Site
3	Westford, MA	Haystack
2	Brewster, WA	Existing VLBA Site
3	Penticton, BC	DRAO
4	North Liberty, IA	Existing VLBA site.
4	Owens Valley, CA	Existing VLBA site.



Bridging SKA & ALMA Scientifically

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





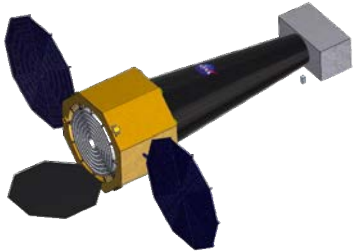
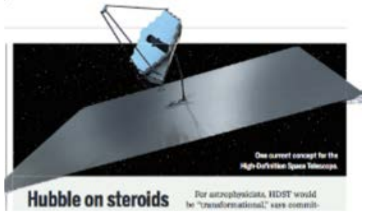
Complementary suite from cm to submm arrays for the mid-21st century

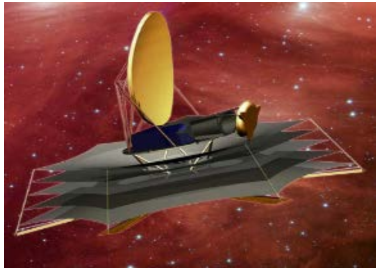
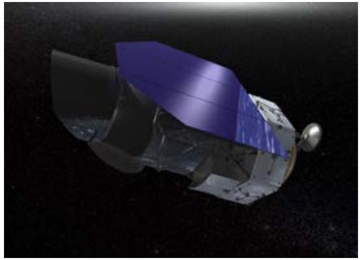
- **< 0.3cm:** ALMA 2030 superb for chemistry, dust, fine structure lines
- **0.3 to 3cm: ngVLA** ngVLA superb for terrestrial planet formation, dense gas history, baryon cycling
- **> 3cm:** SKA superb for pulsars, reionization, HI + continuum surveys

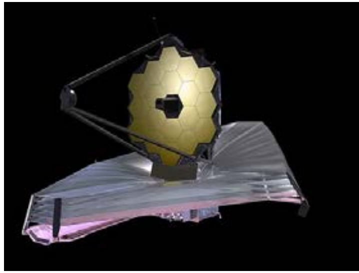
Highly Synergistic with Other Facilities on Similar Timescales

- SKA/Lynx
  - Atomic/non-thermal
  - *Molecular/thermal*
- ALMA
  - Warm/star-forming
  - *Cold/dense fuel for SF*
- LUVOIR/HabEx
  - Image earth-like planets
  - *Image terrestrial-zone planets forming*
- OST (FIR surveyor)
  - C/WNM & WIM
  - *Cold Molecular Medium*
- TMT/GMT
  - *Stellar Mass and Unobscured SF*
  - *Dense Gas and Obscured SF*
- JWST/WFIRST
  - *Continuing its legacy in many areas of astrophysics*



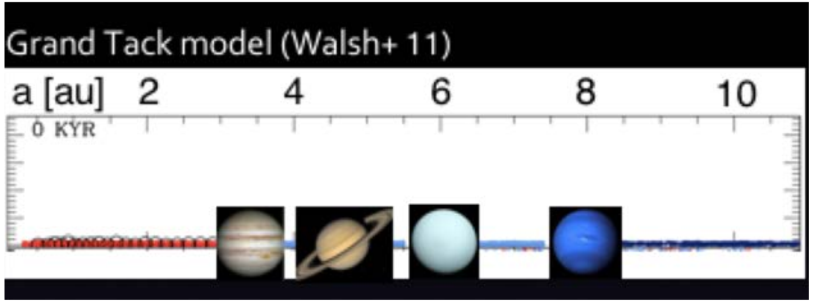



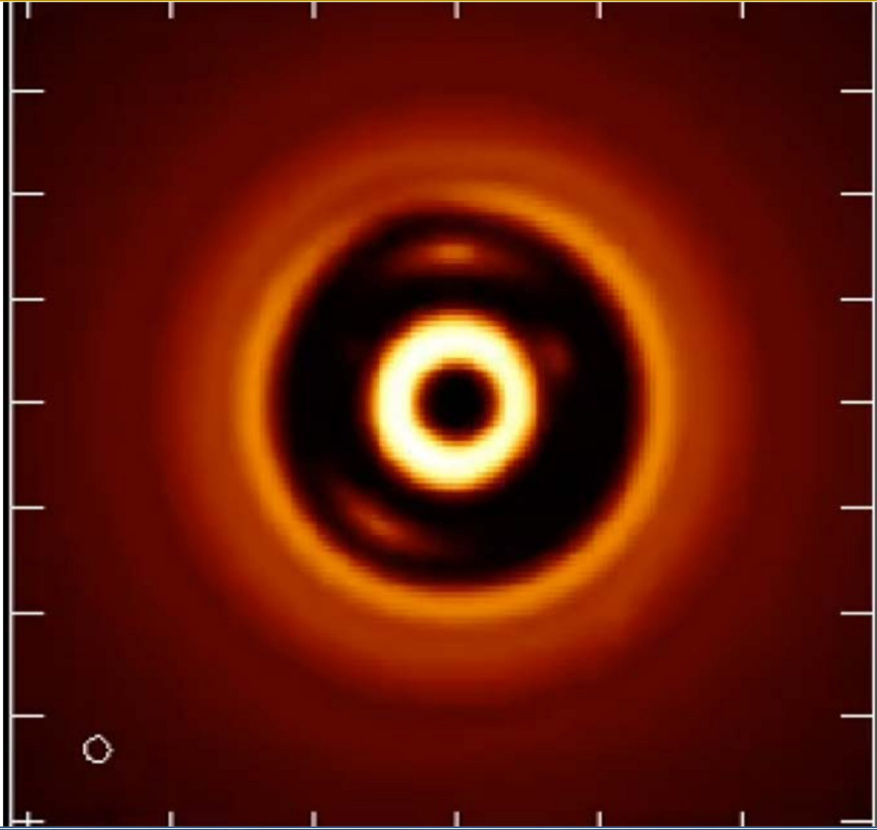
Unveiling the Formation of Solar System Analogues

A Young Solar Nebula

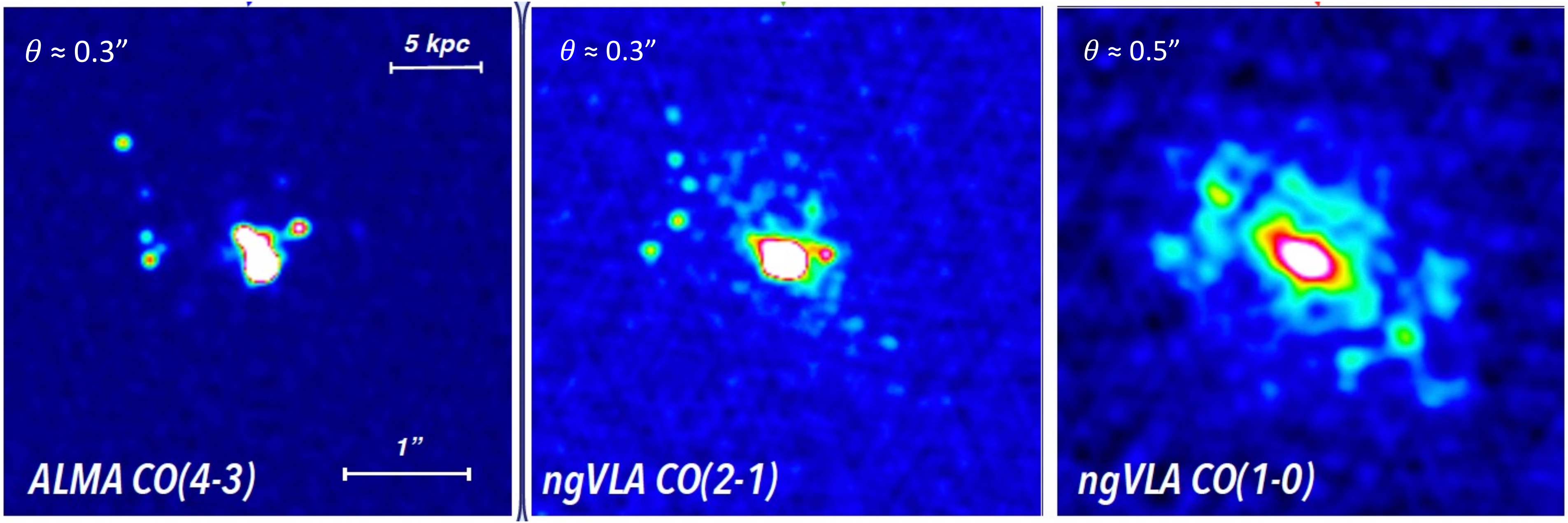
- M_{disk} = 0.08 M_{sun}
- d = 140 pc
- ngVLA @ 3mm
- rms 0.3uJy/bm; 5mas bm ~ 0.7 au (~8hr observation)



Jupiter, Saturn, Uranus, Neptune



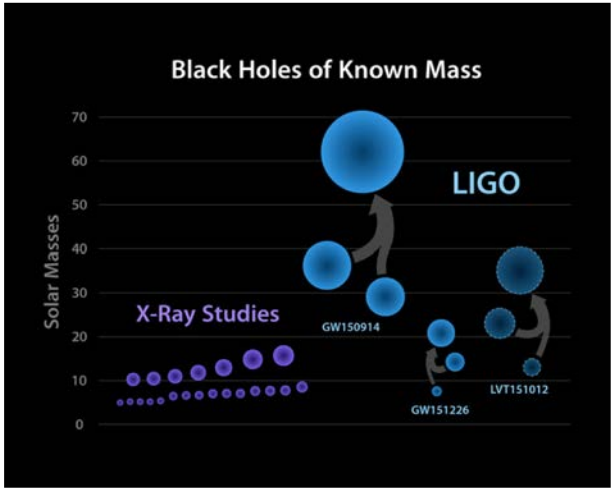
Charting the Assembly, Structure, and Evolution of Galaxies from the First Billions Years to the Present



SMG at z = 4.4; SFR ≈ 400 $M_{\odot}$ /yr
Total molecular gas content largely missed by high-J lines

Credit: Caitlin Casey (UT Austin)

Understanding the Formation and Evolution of Stellar and Supermassive Black Holes in the Era of Multi-Messenger Astronomy

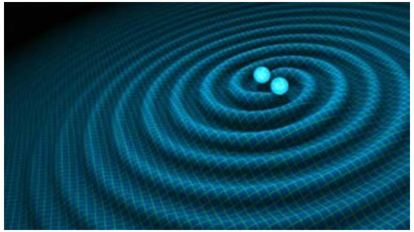


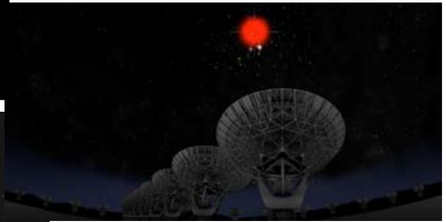
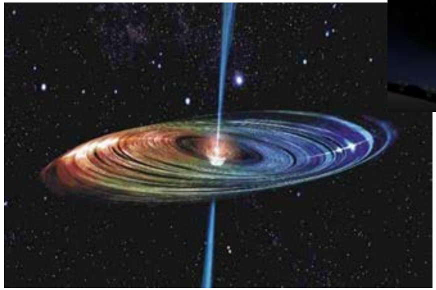
- Unaffected by dust obscuration and with the angular resolution to separate Galactic sources from background objects using proper motions, the ngVLA will enable a search for accreting black holes across the entire Galaxy.

- Key to understanding GW discoveries

Versatility: Remarkable breadth of Science Enabled by the ngVLA

- Galactic Center pulsars: *testing GR*
- Gravitational Wave EM Follow-up
- Extrasolar Space Weather
- Bursting universe (FRB, GRB, TDE…)
- Low surface brightness HI, CO
- Obscured Black Hole Growth and AGN Physics
- Quasar-Mode Feedback and the SZ Effect
- Black hole masses and H_o with Mega-Masers
- µas Astrometry: ICRF, Galactic structure…
- Solar system remote sensing: passive and active radar
- Spacecraft telemetry, tracking: *movies from Mars*

Cost Estimates

- Most recent cost estimate for construction
  - ~$1.6 – 2.0B in 2018 base-year dollars
- Target operations budget of **(3x current VLA) + Long Baseline Ops** (approx. $60 – 80M/yr)
  - Operations, maintenance, computing, archiving, etc.: optimize as part of design.
  - Expect changes to Observatory-wide operations model.
- Scope changes and cost data refinement have adjusted the initial estimate, examples of scope adjustments include:
  - Short Baseline Array (19 six-meter antennas)
  - Long Baseline Array (30 eighteen-meter antennas)
- All ngVLA components/data will be reviewed as part of ASTRO2020 process.

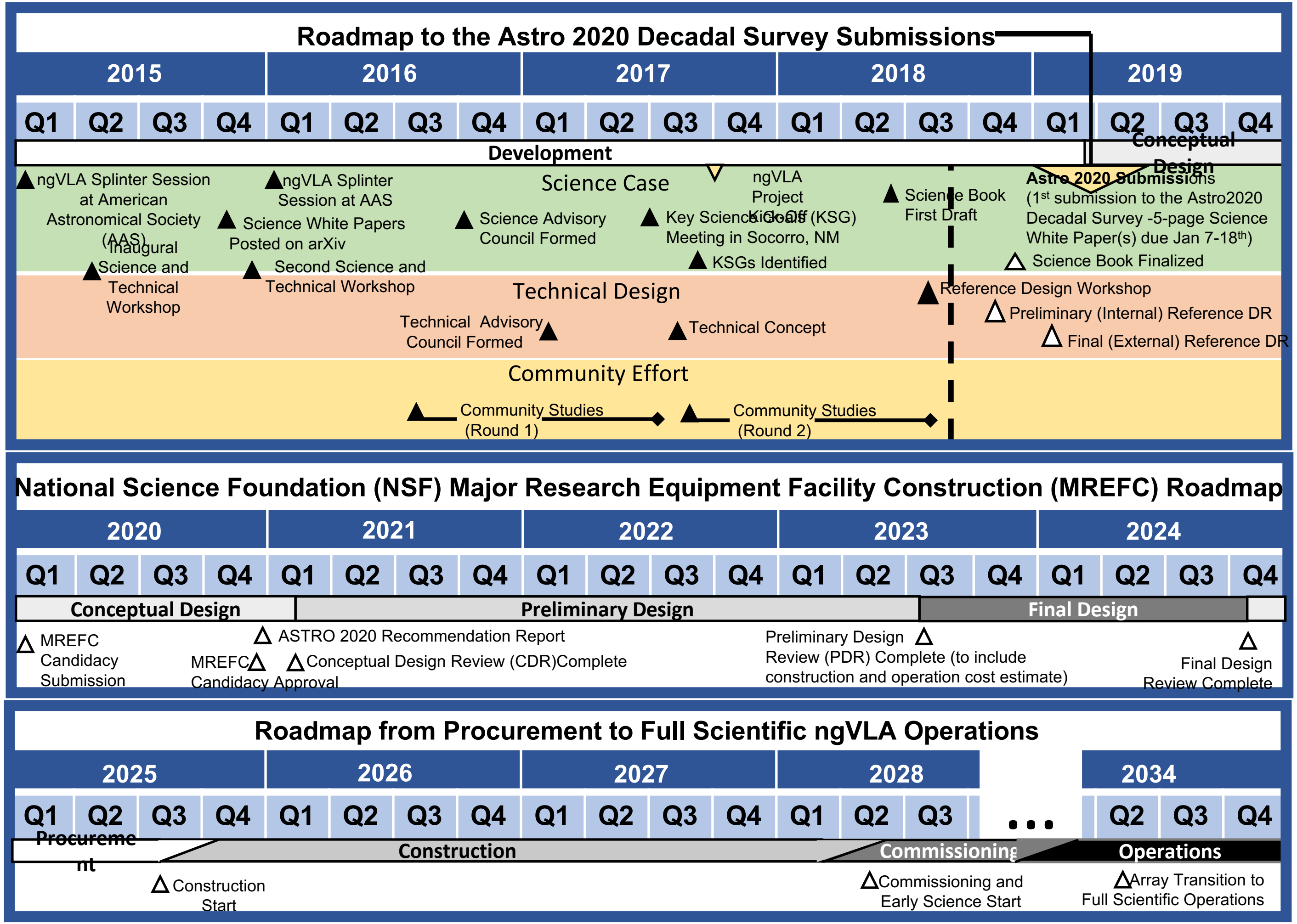
Partnerships (Science, Technical, Manufacturing)

- Possible U.S. Multiagency Interest (including long baseline 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:
  - General Dynamics, REhnu Inc., Minex Engineering Corp, LaserLaB, Quantum Design

Next Generation Very Large Array (ngVLA) Project Timeline

NAS DS2020 Roadmap

NSF MREFC Roadmap



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