ngVLA Project Overview
Rob Selina - ngVLA Project Engineer
South America Astronomy Coordination Committee, 04/2020
A next generation VLA

- Scientific Frontier: thermal imaging at milli-arcsecond resolution
- Goals
  - 10x effective collecting area of VLA: ~244x18m antennas
  - 10x better spatial resolution: up to ~1000km baselines
- Frequency range: 1.2-116GHz
- Locate in southwest US (AZ, NM, & TX) and MX, centered on present location of VLA
- Low technical risk
- NSF-Funded Development
- Under Evaluation by Astro2020 Decadal Survey
Next Generation Very Large Array (ngVLA) Project Timeline

Roadmap to the Astro 2020 Decadal Survey Submissions

<table>
<thead>
<tr>
<th>CY 2015</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
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<th>Q1</th>
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<th>CY 2018</th>
<th>Q1</th>
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<tr>
<th>CY 2019</th>
<th>Q1</th>
<th>Q2</th>
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- Engaging the Science Community / Defining the Key Science Goals / Reference Design
  - ngVLA Splinter Session at American Astronomical Society (AAS)
  - Inaugural Science and Technical Workshop

- Science Case
  - ngVLA White Papers
  - Science Advisory Council Formed
  - Second Science and Technical Workshop

- Reference Design
  - Workshop Reference Design (RDR)
  - External RDR

- Community Effort
  - Community Studies (Round 1)

- Technical Design
  - Technical Advisory Council Formed
  - Technical Concept

- Conceptual Design Development
  - Project Responses to Astro2020 DS RFIs
  - Sub-System CoDRs
  - System CoDR Complete

- Preliminary Design
  - MREFC Candidacy Proposal Submission
  - MREFC Panel Review
  - NSF Approval for Advancement to Preliminary Design

- Final Design
  - MREFC Panel Review
  - Board Approval for inclusion in MREFC Budget Request
  - System-Level FDR Complete

NSF MREFC Roadmap

- CY 2020
  - Q1
  - Q2
  - Q3
  - Q4

- CY 2021
  - Q1
  - Q2
  - Q3
  - Q4

- CY 2022
  - Q1
  - Q2
  - Q3
  - Q4

- CY 2023
  - Q1
  - Q2
  - Q3
  - Q4

- CY 2024
  - Q1
  - Q2
  - Q3
  - Q4

- CY 2025
  - Q1
  - Q2
  - Q3
  - Q4

- CY 2026
  - Q1
  - Q2
  - Q3
  - Q4

- CY 2027
  - Q1
  - Q2
  - Q3
  - Q4

- CY 2028
  - Q1
  - Q2
  - Q3
  - Q4

- CY 2029
  - Q1
  - Q2
  - Q3
  - Q4

- CY 2030
  - Q1
  - Q2
  - Q3
  - Q4

- CY 2031
  - Q1
  - Q2
  - Q3
  - Q4

- CY 2032
  - Q1
  - Q2
  - Q3
  - Q4

- CY 2033
  - Q1
  - Q2
  - Q3
  - Q4

- CY 2034
  - Q1
  - Q2
  - Q3
  - Q4

Procurement
- MREFC Panel Review
- MREFC Construction Funds Obligated
- Construction Start

Construction
- Commissioning

Commissioning and Early Science Start
- Array Transition to Full Scientific Operations
International Partnerships

• International involvement via SAC, TAC, Community Studies
  • Canada, Mexico, Japan, Germany, Netherlands, Taiwan

• Inaugural international development meeting, Socorro (May 2019)
  • Provided project overview; possible distribution of work packages

• ngVLA-SKA *Future Large Radio Telescope Alliance* meeting in Reykjavik, Iceland (Jun 2019)
  • Purpose: investigate process and possibility of a scientific alliance between SKA and ngVLA

• NAOJ-ngVLA workshop, Mitaka (Sep 2019)
Recent Highlights

• ngVLA Science Book published (Dec 2018)
• Facilitated community submission of ngVLA science white papers to Astro2020 Decadal Survey (Jan 2019)
• Submitted ngVLA facilities white paper to Astro2020 Decadal Survey (Jul 2019)
• ngVLA Reference Design Concept completed (Aug 2019)
  • https://ngvla.nrao.edu/page/refdesign
• **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. Antenna
  • 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 8860km

<table>
<thead>
<tr>
<th>Band #</th>
<th>Dewar</th>
<th>(f_L) GHz</th>
<th>(f_M) GHz</th>
<th>(f_H) GHz</th>
<th>(f_H : f_L)</th>
<th>BW GHz</th>
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<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>1.2</td>
<td>2.35</td>
<td>3.5</td>
<td>2.91</td>
<td>2.3</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>3.5</td>
<td>7.90</td>
<td>12.3</td>
<td>3.51</td>
<td>8.8</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>12.3</td>
<td>16.4</td>
<td>20.5</td>
<td>1.67</td>
<td>8.2</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>20.5</td>
<td>27.3</td>
<td>34.0</td>
<td>1.66</td>
<td>13.5</td>
</tr>
<tr>
<td>5</td>
<td>B</td>
<td>30.5</td>
<td>40.5</td>
<td>50.5</td>
<td>1.66</td>
<td>20.0</td>
</tr>
<tr>
<td>6</td>
<td>B</td>
<td>70.0</td>
<td>93.0</td>
<td>116</td>
<td>1.66</td>
<td>46.0</td>
</tr>
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</table>
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).
Main Array (MA) Configuration

- 214 x 18m Antennas

<table>
<thead>
<tr>
<th>Radius</th>
<th>Collecting Area Fraction</th>
</tr>
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<tbody>
<tr>
<td>0 km &lt; R &lt; 1.3 km</td>
<td>44%</td>
</tr>
<tr>
<td>1.3 km &lt; R &lt; 36 km</td>
<td>35%</td>
</tr>
<tr>
<td>36 km &lt; R &lt; 1000 km</td>
<td>21%</td>
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</table>
Long Baseline Array (LBA)

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

<table>
<thead>
<tr>
<th>Qty</th>
<th>Location</th>
<th>Possible Site</th>
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</thead>
<tbody>
<tr>
<td>3</td>
<td>Puerto Rico</td>
<td>Arecibo Site</td>
</tr>
<tr>
<td>3</td>
<td>St. Croix, US VA</td>
<td>VLBA Site</td>
</tr>
<tr>
<td>3</td>
<td>Kauai, HI</td>
<td>Kokee Park Geo. Obs.</td>
</tr>
<tr>
<td>3</td>
<td>Hawaii, HI</td>
<td>New Site (off MK)</td>
</tr>
<tr>
<td>2</td>
<td>Hancock, NH</td>
<td>VLBA Site</td>
</tr>
<tr>
<td>3</td>
<td>Westford, MA</td>
<td>Haystack</td>
</tr>
<tr>
<td>2</td>
<td>Brewster, WA</td>
<td>VLBA Site</td>
</tr>
<tr>
<td>3</td>
<td>Penticton, BC, CA</td>
<td>DRAO</td>
</tr>
<tr>
<td>4</td>
<td>North Liberty, IA</td>
<td>VLBA site</td>
</tr>
<tr>
<td>4</td>
<td>Owens Valley, CA</td>
<td>OVRO</td>
</tr>
</tbody>
</table>
Antenna Data Rates

- Real-time correlation of all 244 array elements.
- Up to 20 GHz of instantaneous bandwidth per polarization.
- 8-bit digitization below 50 GHz.
- 4-bit digitization for 70-116 GHz band.
- Requantized and formatted for data transmission on packet-switched networks.

- 320 Gbps per antenna, over 4x100 Gbps links.
- ~3 antenna LBA sites = ~1 Tbps link
Main Array Fiber Optic Network

- Dedicated point-to-point fiber links for ~196 antennas in NM within ~300 km radius of core.
- ISP connected elements beyond inner stations.
- ISP connections to LBA sites.
- Leased fiber vs Leased Bandwidth (TBD)
VLB Fiber Optic Network
Facility Integration

• VLBI Recording Capabilities:
  • 3 beams, VDIF, Mark-X recorder standard

• eVLBI Integration:
  • ~260 element correlator
  • Built-in data buffers and packet re-ordering for packet switched network interfaces.
  • Real time links to GBT? LMT? ALMA? Others?
Data Processing

• **Post Processing**: storing the raw visibilities will be possible.
  • Data processing is post-facto, with system sized for average throughput.
  • Data Rates:
    • Average – 8 GB/s.
    • Peak - 128 GB/s.

• **Computing**: Challenging, but feasible with current technology.
  • Sized by time resolution, spectral resolution, and multi-faceting in imaging.
  • ~60 PFLOPS/s (inc. efficiency factors) matches average data throughput.
Serving Data to Users

• “Science Ready Data Products” Operations Model
• Process-in-place for data to most PIs.
• Data products requested in proposal; Pipeline interaction possible.
• Low-level data products (visibilities, flagging tables)
• High-level data products for Standard Observing Modes (e.g., calibrated image cubes)
• Archive reprocessing interface for users.
• Data Reduction S/W; Data Analysis S/W
Summary

- ngVLA is being designed to tap into the astronomy community’s intellectual curiosity and to enable a broad range of scientific discovery.
- Key Science Goals, science use cases, and Science Book are complete.
- The ngVLA Reference Design, a credibly-costed and low-technical risk concept, is complete and ready for Astro2020 Decadal Survey.
- System-level design (requirements, architecture) will be baselined in 2020 to enable sub-system conceptual design down-selects.
- Major Challenges: No major technological blockers. Challenges are in cost-performance optimizations, manufacturability and reliability.
Key Science Goals

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

• Science meetings sponsored
  • *Developing the ngVLA Science Program*, Socorro, NM (Jun 2017)
  • *The VLA Today and Tomorrow: First Molecules to Life on Exoplanets*, National Harbor, MD (Jan 2018)
  • *Astrophysical Frontiers in the Next Decade*, Portland, OR (Jun 2018)
  • *Theoretical Advances Guided by RMS Arrays*, Seattle, WA (Jan 2019)
  • *Radio/Millimeter Astrophysical Frontiers in the Next Decade*, Charlottesville, VA (Jun 2019)
Performance Comparison

Sensitivity

Angular resolution
Project Organization

- 10 Integrate Product Teams (IPTs)
- MREFC-style project definition
- Actively-engaged science and technical advisory councils
18m Antenna Optics

- **Offset Gregorian**: Wide subtended angle of the subreflector for small feeds. Likely lowest cost for required A/T. (Ant. Memo #1)
- **18m Aperture**: Based on cost and performance modeling (Ant. Memo #2)
- **Shaped**: Aperture efficiency optimized for single pixel feeds.

- 3.5m Subreflector
- 55° Half Angle
- 95% Illum. Eff.
- -16dB Edge Taper
- -19dB First Side Lobe
- -27dB Second Side Lobe
Antenna Concept

- **Feed Low**: Maintenance requirements favor a receiver feed arm on the low side of the reflector.

- **Mount concept**: Leaning towards pedestal concepts for life-cycle cost. W/T under evaluation.

- **Drives**: All motor-gearbox; gearbox and linear drives; all direct drive, etc.

- **Materials**: Traditional Al panels & steel BUS; composite reflector and mix of steel and carbon BUS.

**Key Specifications**

<table>
<thead>
<tr>
<th>18m Aperture</th>
<th>Offset Gregorian</th>
</tr>
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<tbody>
<tr>
<td>Shaped Optics</td>
<td>4° Slew &amp; Settle in 10 sec</td>
</tr>
<tr>
<td>Surface: 160 µm rms</td>
<td>Referenced Pointing: 3” rms</td>
</tr>
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</table>
Front End Concept

- 6 Bands in 2 Cryogenic Dewars
- 1.2-3.5 GHz and 3.5-12.3 GHz Quad-Ridge Horns, 3.5:1 bandwidth, coaxial LNAs.
- 12.3-50.5 GHz using three 1.67:1 BW corrugated horns and waveguide LNAs.
- 70-116 GHz 1.67:1 BW corrugated horn and waveguide LNAs.
- Single stage down-conversion to baseband for 5 bands. Direct SSB or IQ sampling using modular devices @ FE.
- Two-stage Gifford-McMahon cryogenic system with variable-speed cryocoolers and compressors for reference design.
ASU/Caltech Band 1 Prototype Cryostat

(Credit: Sander Weinreb, Caltech & Hamdi Mani, ASU)
Feed Development

(courtesy S. Srikanth, NRAO CDL)

(courtesy R. Lehmensiek, EMSS)
Orthomode Transducer (OMT)

- Developed by NAOJ for ALMA Band 2+3 (67 – 116 GHz)
- Modified Boifot double-ridged waveguide junction
- Highly compact
- Very low loss, excellent port match
- Readily manufactured with conventional CNC mills
- Directly applicable on Band 6
- Design will scale for Bands 3 – 5

(courtesy Alvaro Gonzalez and Shinichiro Asayama, NAOJ)
Compressor Development by Sumitomo

• **Phase 1:**
  • Build FA40 prototype with VFD (completed)
  • Measure the performance: flow vs power (completed)
  • Measure RFI and design shielded enclosure for electronics (pending)

• **Phase 2:**
  • Integrate FA40 capsule into a FA70 outdoor enclosure
  • Relocate control/power electronics to an outdoor-rated RFI enclosure (ngVLA prototype)
Integrated Receiver Digitizers (IRD)

- Small integrated modules mounted at secondary focus near the front ends
- Direct sampling for 1.2 – 3.5 GHz
- Downconverted sideband separating sampling for 3.5 – 116 GHz
- Custom digitizer IC in development:
  - 8 bit, 7 Gsps for bands 1-5
  - 4 bit, 14 Gsps for band 6
- Output on multiple 56 Gbps unformatted optical data streams
Integrated Receiver Digitizers (IRD)

- Side-Band Separating Sampling for Bands 2-6.
- All Local Oscillator (LO) Signals are harmonics of 2.9 GHz.
- 3.5 GHz Sampler Clocks provide overlapping side-bands.
Antenna Electronics Development

- Digitizer-Serializer ASIC Prototype.
- Custom MMIC chips for Band 5, 6 (Post Amps).
- IRD Deserialization Code.
- WVR Test Platform Using Integrated MMIC Modules.
FE:

1.5 m × 1.0 m × 0.6 m
Time & Frequency References

- **187 Antennas on Plains of San Agustin:**
  - Central clock and LO generation. Within 40 km point-to-point.
  - Fiber optic links to Front End.

- **30 Mid-baseline Antennas:**
  - Synchronous Time & Frequency Reference Distribution to ~300 km.
  - Repeaters and EDFAs.

- **16 Mid-Baseline Antennas + LBA:**
  - Local clocks and LO generation.
  - Fallback: Local primary references (e.g., Active Hydrogen Maser & GPS)
Based on SKA1-MID Implementation, uses image reject receiver principle first developed by [Hitoshi Kiuchi, 2011]

- Dual optical carrier transmission of reference & timing to antennas
  - $L_1$: Laser source
  - $L_2$: $L_1$ offset by 5.8 GHz + DDS
  - DDS offset is per antenna
- MS: microwave shift frequency = 5.8 GHz (RF)
- 1 PPS embedded timing signal
- Provides for round trip phase stabilization

Central Signal Processor

IRD
ADCs
IF digitized
signal/s

Digital data
from antenna/s

Antenna site
CSP site

DBE

CBF
Beamformed
signals

PE
Pulse profiles

M&C

CSP
Visibilities
Pulse profiles
Beamformed signals

CBE

TRIDENT
ngVLA CBF
National Research
council Canada
Conseil national
d’e recherches Canada

Canada
• **Post Processing**: storing the raw visibilities will be possible.
  - Data processing is post-facto, with system sized for average throughput.
  - Data Rates
    - Average – 8 GB/s.
    - Peak - 128 GB/s.
  - Based on CASA.

• **Computing**: Challenging, but feasible with current technology.
  - Sized by time resolution, spectral resolution, and multi-faceting in imaging.
  - ~60 PFLOPS/s (inc. efficiency factors) matches average data throughput.
S/W Architecture

- First decomposition:
  - 5 subsystems
  - 4 datastores
- Integrates with external on-going projects: TTA, SRDP, ngCASA, HTC, etc.
- Proposal Mgt. and Offline subsystems expected to be substantially inherited (ngCASA based).
Technical Risks

• Moore’s Law
  • Don’t need transistor density to continue to increase, but do need Oper./$ trends to continue.
  • Parallelization efficiency is a concern.

• 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

![Graph showing global satellite launches, cumulative, '000](The Economist)
Summary

• The project has developed a coherent technical concept to achieve the identified science.

• The project and international partners are developing novel technologies to a suitable level of technical readiness prior to conceptual design down-selects.

• Technical risks are understood. Project should exploit technical opportunities to improve cost and/or technical performance.
RFI Mitigation:
- Scheduler
- RFI-DB
- DBE
- CBE
- Post Proc.

**Detection**
- Median / MAD / MoM / Kurtosis etc... w/wo FFT.

**Action**
- Add to RFI monitoring database but don't edit data
- Remove/replace samples containing RFI (and adjust weight)

**Detection**
- Matrix decomposition (PCA)
- Imaging (RealFast) / Peeling
- Any post-processing algo (if useful at this timescale)
  - RFI source location

**Action**
- Subtraction (subspace projection / PCA methods)
- Remove samples that go into the next integration step and adjust weight
Operations Drivers

• SRDP (Science Ready Data Products) Telescope
  • Data must be processable with a standard pipeline.
  • Data calibration can/should drive the design.
  • Repeatability & stability in analog system, finite tuning choices.
  • Flexible sub-array management, but fixed sub-array definitions.
  • Service calibrations, impact on data model.

• “Large N” Array & Life-cycle Cost
  • Manufacturability & maintainability.
  • Automation of routine calibrations, data validations.
  • Expert system for maintenance prediction & issue resolution.
  • Reduced parts count, parts integration.
  • Power consumption.
Science Drivers

• **Frequency Coverage**: 1.2 to 116 GHz, both edges drive design.

• **Sensitivity**: Area, Tsys, bandwidth, deconvolution algorithms.

• **Resolution**: 400km+ minimum extent, 8000km+ 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.
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.
<table>
<thead>
<tr>
<th>Module</th>
<th>ALMA (SLOC)</th>
<th>EVLA (SLOC)</th>
<th>Estimation (MSLOC)</th>
<th>Estimated reuse (%)</th>
<th>Effort Size (MSLOC)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Online Subsystem</strong></td>
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<td>Calibration</td>
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<td>9,857</td>
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<td>40%</td>
<td>0.060</td>
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<td>16,863</td>
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<td>Control</td>
<td>222,233</td>
<td>439,876</td>
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<td>Correlator</td>
<td>710,860</td>
<td>846,112</td>
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<tr>
<td>Diagnostic and Engineering Tools</td>
<td>18,721</td>
<td>66,833</td>
<td>1.400</td>
<td>30%</td>
<td>0.980</td>
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<td>Metadata Capturer</td>
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<td>8,998</td>
<td>0.050</td>
<td>0%</td>
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<td>Monitoring</td>
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<td>24,365</td>
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<td>50%</td>
<td>0.025</td>
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<td>Operation</td>
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<td>49,285</td>
<td>0.100</td>
<td>20%</td>
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<td>Observation</td>
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<td>0.200</td>
<td>0%</td>
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<tr>
<td>Quick-Look</td>
<td>31,547</td>
<td>-</td>
<td>0.050</td>
<td>0%</td>
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<td>3,127</td>
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<td>30%</td>
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<td>0.100</td>
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<td><strong>Offline Subsystem</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Archive &amp; Observatory Interfaces</td>
<td>504,545</td>
<td>303,035</td>
<td>1.000</td>
<td>80%</td>
<td>0.200</td>
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<td>2.000</td>
<td>70%</td>
<td>0.600</td>
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<td></td>
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</tr>
<tr>
<td>Proposal Management</td>
<td>279,728</td>
<td>444,527</td>
<td>0.500</td>
<td>80%</td>
<td>0.100</td>
</tr>
<tr>
<td><strong>Maintenance, Support &amp; Development</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMMS Integration</td>
<td>-</td>
<td>-</td>
<td>0.100</td>
<td>0%</td>
<td>0.100</td>
</tr>
<tr>
<td>Simulation</td>
<td>-</td>
<td>-</td>
<td>0.050</td>
<td>0%</td>
<td>0.050</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>4,773,579</td>
<td>4,346,076</td>
<td>5.750</td>
<td>54%</td>
<td>2.630</td>
</tr>
</tbody>
</table>
Mid-Scale Baseline Optimization: the Walker Configuration
### In Support of Astro 2020 Decadal Survey

- **PEP Finalized**
- **FY20/FY21 Mid-Scale D&D Preliminary Proposal to NSF**
- **FY20/FY21 Mid-Scale D&D Full/Final Proposal to NSF**

### In Support of Concept Development/MREFC

- **Solicitation of Project Funding**
- **Completed Effort (as 4/20/2019)**

### ngVLA Submission to Astro 2020

### Ref. Designs Incorporated in Cost Model

- **Prepare Risk-adjusted, Fully Costed and Documented Estimate for the Ref. Design**
- **Respond to Any Requests Regarding the Ref. Design Cost Estimate**

### Project Office Review of the Cost Model

- **Prepare MREFC Lifecycle Cost Estimate**

### Publication of Findings from 2nd Round of Community Studies

- **Pub. ngVLA Science Book (ASP)**

### Prelim. Release of Ref. Observing Program

- **AAS & URSI**
- **AAAS**

### Reference Observing Program Released for Review

- **Science White Papers to Astro 2020**

### Science Workshop

- **ScienceWhite Workshop**

### Concept Development

- **Trade Studies**

### Technical

- **AV, CSV Concepts Released for Review**
- **Systems Requirements Released for Review**
- **LO (Sci, Stk.) Requirements Review**
- **Architecture Model Released**
- **Preliminary L2 Sub-System Requirements Released**
- **L1 System Requirements and Architecture Review**

---

**End of Document**
Electronics Design Philosophies

• Digitize as close as possible to the receiver.
  • Short, stable signal path. Minimize frequency conversion steps.

• Utilize highly integrated, manufacturable sub-assemblies.
  • Reduced parts count, mechanical connectors.
  • Limited number of Line Replaceable Units (LRUs).

• Emphasize low power, high reliability designs.

• Provide advanced remote diagnostic & fault prediction capability
  • Know which LRU has failed before visiting an antenna: swap & return.
  • Predict what’s about to fail to better schedule maintenance visits.
Front Ends / Dewars

- 6 receivers in 2 dewars
  - Covering 1.2 – 116 GHz
  - Compact, cooled feeds
  - Linear polarization
  - Total mass ~120 Kg
  - RF output at sky frequency
Local Oscillator & Clocks

- **Secondary Focus Enclosure:**
  - Reference generator:
    - Recovered signal locks 7 GHz reference oscillator
    - An offset reference is generated by dividing reference by 2, 4, or 8
    - 156.25 MHz digitizer clock reference
  - LO Modules:
    - Co-located with each 2SB IRD
    - Use 7GHz & offset reference to generated coarse tunable LO’s for the mixers in the IRD modules
Reference & Timing Distribution

- Reference signals from array center are sent to two locations for timing recovery & local oscillator (LO) / sample clock generation
  
  **Pedestal rack:** PPS timing signal is recovered and used along with NTP in an FPGA to generate:
  
  - Timecode for Digital Back End (DBE)
  - Timing signal(s) for local M&C
  - Switching signal for front end noise diodes
  - Timing signal may also be regenerated for transmission to next station

L503 - ReferenceRecv, Generator and Distribution
The Main Array (MA) Configuration

<table>
<thead>
<tr>
<th>Radius</th>
<th>Collecting Area Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 km &lt; R &lt; 1.3 km</td>
<td>44%</td>
</tr>
<tr>
<td>1.3 km &lt; R &lt; 36 km</td>
<td>35%</td>
</tr>
<tr>
<td>36 km &lt; R &lt; 1000 km</td>
<td>21%</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Qty</th>
<th>Location</th>
<th>Possible Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Puerto Rico</td>
<td>Arecibo Site</td>
</tr>
<tr>
<td>3</td>
<td>St. Croix, US VA</td>
<td>VLBA Site</td>
</tr>
<tr>
<td>3</td>
<td>Kauai, HI</td>
<td>Kokee Park Geo. Obs.</td>
</tr>
<tr>
<td>3</td>
<td>Hawaii, HI</td>
<td>New Site (off MK)</td>
</tr>
<tr>
<td>2</td>
<td>Hancock, NH</td>
<td>VLBA Site</td>
</tr>
<tr>
<td>3</td>
<td>Westford, MA</td>
<td>Haystack</td>
</tr>
<tr>
<td>2</td>
<td>Brewster, WA</td>
<td>VLBA Site</td>
</tr>
<tr>
<td>3</td>
<td>Penticton, BC, CA</td>
<td>DRAO</td>
</tr>
<tr>
<td>4</td>
<td>North Liberty, IA</td>
<td>VLBA site</td>
</tr>
<tr>
<td>4</td>
<td>Owens Valley, CA</td>
<td>OVRO</td>
</tr>
</tbody>
</table>
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.
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-to-end system design.

• Bottom-up supporting cost estimate.