NATIONAL RADIO ASTRONOMY OBSERVATORY

# Strawman System Specification

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ngVLA

The Next Generation Very Large Array

# Outline

- System Specifications
  - Key Technical Parameters
  - Key Open Questions
- Sub-System Specifications
  - Antennas
  - Front-End
  - Cryogenics
  - M&C System
- Additional Information
  - Technical Advisory Council Nominations

# Significant Requirements & Constraints

- Ops cost as a driver – 2x VLA Ops design cap.
- 10x the sensitivity of the VLA @ 30GHz.
- US driven project, North American emphasis.
- PI driven / pointed operations model.
- Bridge ALMA / SKA gap. (1-120 GHz, with emphasis on 10-50GHz & 70-120GHz windows)

- ➢ *In the age of diminishing facility budgets, could this be a “killer app”?*
- ➢ *Main performance requirement.*
- ➢ *Northern hemisphere location (i.e., VLA site)*
- ➢ *General purpose instrument. Drives the entire scientific operations concept.*
- ➢ *The end goal is to build the most flexible and capable system, within the programmatic constraints of cost and schedule.*

# Operating Modes / Functional Capabilities

- Spectral Line & Continuum Modes
  - *Goal to maximize flexibility of both modes.*
- Phased Array Capability
  - *Operate as both an interferometer and phased array.*
- Time Domain Capabilities
  - *Time domain search capabilities on msec scales.*
- Solar Observation Capabilities
  - *Possible to observe the sun at all available frequencies.*
- VLBI Capabilities
  - *Goal to perform VLBI within a phased sub-array.*
- Sub-Array Capabilities
  - *Divisible into multiple sub-arrays for operation, calibration, and maint.*



# Key Technical Parameters

- Frequency Range – **1-120Ghz**
- Imaging Sensitivity – **0.1uJy/10 Hrs; 1000m$^2$/K @ 30GHz**
- Surface Brightness Sensitivity – **6K/hr @ 30GHz**
- Angular Resolution – **9mas @ 30GHz**
- Dynamic Range – **$10^4$ - $10^5$**

➢ *Reduced performance 1-10GHz*

➢ *Effective Collecting Area*
➢ *Tsys*
➢ *Instantaneous Bandwidth (20GHz/ pol.)*
➢ *Aperture fill ratio*

➢ *300km+ baselines*
➢ *Pointing, phase cal, stability…*



# Data Products & Archive

- Raw visibilities shall be stored as the fundamental data product.
  - ➢ *Raw visibilities can be archived in a cost-effective manner based on projected data volumes.*
- Will produce "Science Ready Data Products" (SRDP) using automated pipelines.
  - ➢ *Definition of SRDP is still lacking.*
- May store a generic SRDPs in the archive, if they are reusable.
  - ➢ *E.g., should the entire primary beam be imaged and stored, regardless of the needs of the 1st user?*



# Key Open Questions – Spec. Decisions

- Reconfiguration Capability
  - *Trade off between array efficiency & reconfiguration overhead.*
- Short Spacings
  - *Is twice the antenna diameter good enough?*
  - *Desirable to stick to a single aperture size given the cost impact.*
- Total Power
  - *Is there a science case for accurately measuring source spectral flux density?*



# Architecture Design Decisions

- Array Configuration / Distribution
- Reconfiguration Capability
- Phase Calibration Strategy

- Aperture Size
- Optical Configuration
- Band Configuration



# Sub System Specs - Antennas

- Aperture Size (**12-25m**)
- Shaped Optics
- Optical Configuration – (TBD)
- Effective Aperture / Surface Accuracy (**180um**)
- Pointing Accuracy (**FWHM/10**)
- Beam Stability
- Polarization - Mizuguchi-Dragone condition
- Low $T_{SPILL}$ at all elevations
- Relocatable (TBC)

➢ *Likely **18-25m** range given cost analysis.*
➢ *Optimized for single-pixel feeds.*
➢ *Likely an **unblocked aperture**.*
➢ *Impact on dynamic range*
➢ *No cross-pol power @ center of FOV*
➢ *Impact on system sensitivity. Favors **dual-offset Cassegrain**.*
➢ *Conflict between pointing accuracy and reconfiguration capability?*



# Sub System Specs – Front End

- 1-120GHz, emphasis on 10GHz+
- $T_{SYS}$ – **40K @ 30GHz**
- Bandwidth –2:1+ LF; 1.6:1+ HF
- Max Total Heat Load on Cryo – TBD W @ 15K, TBD W @ 50K
- Max # of Dewars – $N_{DEWAR} \leq$ **3**
- Illumination Efficiency – $\eta_{FEED} \geq$ **75%**
- Gain Curve Flatness – **6db over 18GHz** or RF bandwidth
- Gain Stability - Noise Diode Gain Calibration (TBC)

- *Need minimum $T_{REC}$ to meet sensitivity goals with a minimum # of apertures.*
- $SNR \propto \eta A \sqrt{\Delta\nu\, t} / T_{SYS}$
- *Heat load / Cooling capacity dictates the electrical load for Cryo. After that, $N_{DEWAR}$ has more impact on Ops \$ than $N_{REC}$.*
- *Impact on effective aperture.*
- *Need a flatter gain curve for wide bandwidth, low bit-depth samplers.*
- *Need to consider gain calibration strategy*
- *Can various feed designs accommodate a common illumination angle?*




# Sub System Specs – Cryogenics

- Maintenance Interval – **3yrs+**
- Electrical Efficiency – (**TBD)**
- $T_{DEWAR}$ - **15K, 50K**
- Temperature Stability **~0.1K/Hr. (TBC)**
- Cooling Capacity / Heat Lift – (**TBD)**

- *Drives maintenance cost*
- *Drives Operations cost.*
- *Need to minimize $T_{REC}$ for 10GHz+ receivers.*
- *Minimize gain fluctuations to achieve dynamic range.*
- *Determine after FE design matures.*



# Sub System Specs – Antenna LO/IF & Digitizer

- Sample Full Receiver Bandwidth
- Tunable quantization vs bandwidth
- Phase Stability
- Gain Stability
- Ripple Level
- Internal Birdies
- Cost
- Reliability
- Maintainability

➢ *Desirable for RFI immunity.*

➢ *Sensitivity impact.*

➢ *Dynamic range impact.*

➢ *Sensitivity impact.*

➢ *Architectural Simplicity.*

➢ *Packaging / Modularization.*

➢ *M&C Sophistication.*



# Sub System Specs – M&C Features

- Interactive Diagnostics Tools
  - ➢ *Remote diagnostics by engineers/ technicians.*
- Automated Diagnostics
- Antenna Level Automation
  - ➢ *Reduced operational burden*
- Fault Tree Analysis, Fuzzy Sets, Heuristic Rules…
  - ➢ *Need to improve O&M productivity.*

# Concluding Remarks

- While the science requirements are still being refined, we have made progress at understanding which system requirements drive the conceptual design of the array.
- The project is starting in-depth investigations to explore the trade-space available as we refine our system requirements and architecture.
- The project expects to present a set of preliminary requirements and a corresponding conceptual design at the US Radio Futures III meeting (August 2017, Berkeley, CA)



# Additional Information

- ngVLA webpage
  - https://science.nrao.edu/futures/ngvla
- ngVLA memo series
  - http://library.nrao.edu/ngvla.shtml
- ngVLA science working groups
  - https://science.nrao.edu/futures/ngvla/science-working-groups

- ngVLA Technical Advisory Committee (**TAC**) Call for Nominations:
  - https://science.nrao.edu/enews/9.11/index.shtml#ngvla_council
  - https://science.nrao.edu/futures/ngvla/tac-application
  - Nominations due by **Monday, 16 January 2017**



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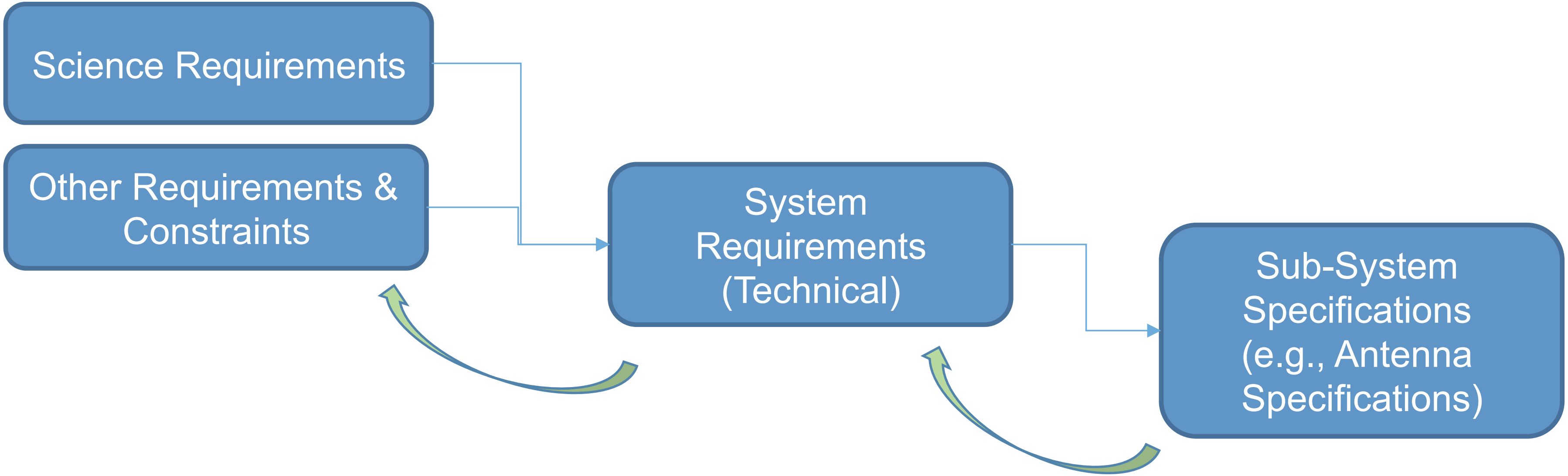
# Requirements Flow Down & Traceability




- *System Requirements Document*
- *Requirements Verification / Traceability Matrix*
- *Explanatory / Derivation Memos*



# More on Process…

- Treat the process as <u>**iterative**</u> from the start – build tools that allow for trade-offs and changes.
  - Spreadsheets and scripts with parameterized inputs.
  - Memos accompany the scripts/spreadsheets to explain their derivations, assumptions, etc.
    - Both memo & tool grow iteratively as they are used.
  - **Cost model & sensitivity analysis** – shows which parameters might significantly affect system cost.
- End result is a requirements matrix & memo.
  - Until it's integrated and committed to paper, it's hard to see all the gaps and contradictions.
- Lets not get into the weeds yet - lets focus on design drivers.
  - <u>Relative importance and scale are more meaningful right now than precise numbers.</u>