Perspective from the Technical Advisory Council

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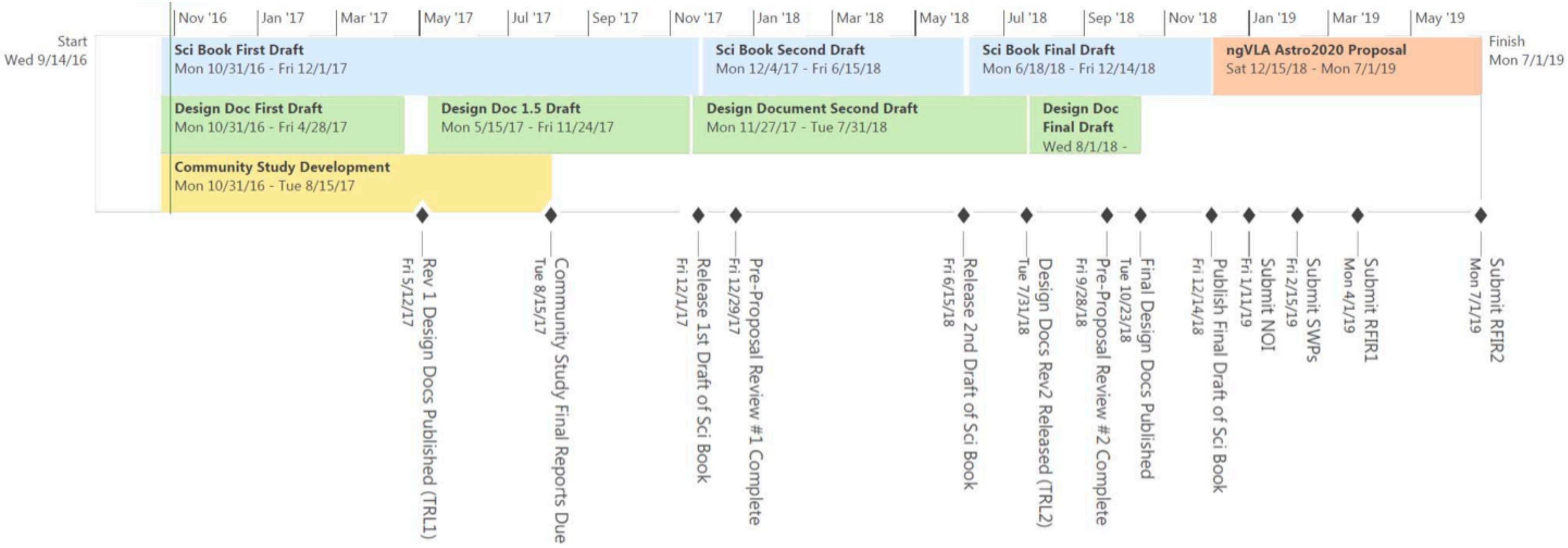
ngVLA
The Next Generation Very Large Array

Disclaimers

- The cost information contained in this document is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and/or Caltech.

ngVLA high-level project schedule



Nov '16 | Jan '17 | Mar '17 | May '17 | Jul '17 | Sep '17 | Nov '17 | Jan '18 | Mar '18 | May '18 | Jul '18 | Sep '18 | Nov '18 | Jan '19 | Mar '19 | May '19

Start
Wed 9/14/16

Finish
Mon 7/1/19

Sci Book First Draft
Mon 10/31/16 - Fri 12/1/17

Sci Book Second Draft
Mon 12/4/17 - Fri 6/15/18

Sci Book Final Draft
Mon 6/18/18 - Fri 12/14/18

ngVLA Astro2020 Proposal
Sat 12/15/18 - Mon 7/1/19

Design Doc First Draft
Mon 10/31/16 - Fri 4/28/17

Design Doc 1.5 Draft
Mon 5/15/17 - Fri 11/24/17

Design Document Second Draft
Mon 11/27/17 - Tue 7/31/18

Design Doc Final Draft
Wed 8/1/18 -

Community Study Development
Mon 10/31/16 - Tue 8/15/17

Rev 1 Design Docs Published (TRL1)
Fri 5/12/17

Community Study Final Reports Due
Tue 8/15/17

Release 1st Draft of Sci Book
Fri 12/1/17

Pre-Proposal Review #1 Complete
Fri 12/29/17

Release 2nd Draft of Sci Book
Fri 6/15/18

Design Docs Rev2 Released (TRL2)
Tue 7/31/18

Pre-Proposal Review #2 Complete
Fri 9/28/18

Final Design Docs Published
Tue 10/23/18

Publish Final Draft of Sci Book
Fri 12/14/18

Submit NOI
Fri 1/11/19

Submit SWPs
Fri 2/15/19

Submit RFIR1
Mon 4/1/19

Submit RFIR2
Mon 7/1/19

Introduction to Technical Advisory Council

- Technical Advisory Council (TAC) formed in February, 2017
- Monthly telecons
- Activities
    - Review of cost model
    - Discussion of ngVLA technical concept have identified areas in need of additional study
    - This talk will summarize key community studies
- Plans
    - List of needed ngVLA memos
    - Review of science use cases
    - Development phase proposal input
    - Review of ngVLA requirements

TAC members

- Larry D’Addario (JPL)
- Sean Dougherty (NRC)
- Mark Gurwell (CfA)
- Andy Harris (Maryland)
- Tetsuo Hasegawa (NAOJ)
- Jeff Kantor (LSST)
- James Lamb (Caltech)
- Michael Rupen (NRC)
- Melissa Soriano (JPL)
- Sandy Weinreb (Caltech)

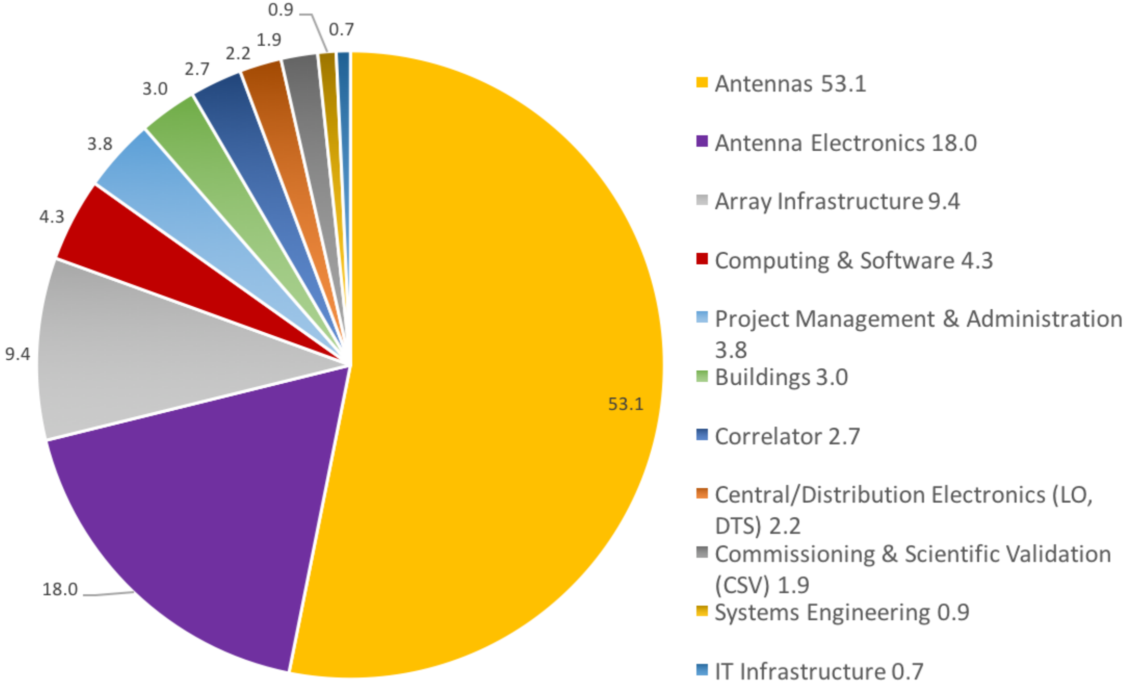
ngVLA cost model

- Developed by Rob Selina (ngVLA systems engineer) and Jeff Kern
- 3.07 version of model shown in this talk
- 214 x 18-m offset Gregorian antennas, 6-band receiver configuration, 20 GHz instantaneous bandwidth, 320 km max baseline, 7.65 x effective area of VLA @ 30 GHz
- Cost cap of $1.5B for construction and $75M for operations
- **TAC consensus: The TAC has not reviewed the entire cost model, but rather only those portions that are discussed here. We have concentrated on construction costs, and we have not yet paid close attention to operating costs. The TAC is still actively working on analysis of the cost model. We plan to study all parts of the model in more depth before delivering a final report.**

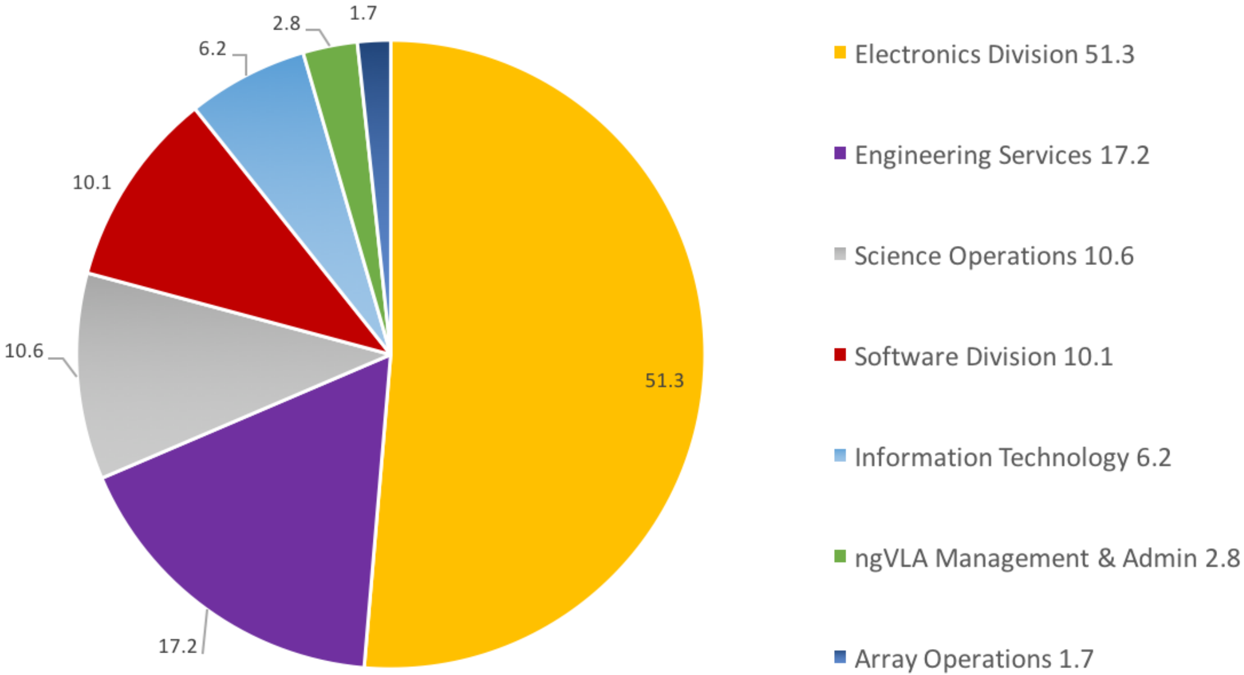
ngVLA Subsystems

- **Antenna-** includes optical configuration, surface accuracy, pointing accuracy of antennas
- **Array Infrastructure-** antenna pads, electrical distribution system, fiber optic distribution system, service roads, relocation system
- **Antenna Electronics-** analog and digital electronics in each antenna
- **Central Electronics-** generation and distribution of local oscillator and reception and deformatting of digital transmission signal from each antenna
- **Correlator-** FX correlator based on FPGA technology
- **Computing-** storage and processing costs

ngVLA Construction cost distribution



ngVLA Operations cost distribution



Antenna subsystem

- In current cost model, antenna subsystem is a cost driver.
- **TAC consensus: To the extent that the basic antenna requirements are known (size ~12m to ~25m, maximum frequency ≤ 120 GHz), it is clear that constructing them is technically feasible. Larger and more precise antennas have already been built. The main question is cost.**
- Cost uncertainty is high for antenna subsystem
  - We don’t have good data on costs of existing antennas
  - Cost premium for offset vs symmetrical is unknown
  - Cost premium for elevated bearing vs wheel and track is unknown, hopefully answered by Matt Fleming community study.
  - This area is a risk to a credible costed proposal. Need to reduce uncertainty in cost to make cost model useful for system trade studies.

Antenna Subsystem

- **TAC consensus: The antenna cost is very poorly understood, and therefore the total project cost is poorly understood. It follows that the best antenna size (for minimizing total cost) is poorly known. This is the most fundamental problem with the current cost model. We cannot draw meaningful conclusions from the model until this is substantially improved. To do that, we recommend that significant design work be carried out as soon as possible.**
- Antenna design work is needed
  - Detailed reference design with bottom-up cost (parts list, estimated labor cost)
  - Antenna geometry fully defined

Antenna subsystem key requirements

Requirement	Drives	Cost model value
Antenna geometry (optical configuration)	Performance, cost	Offset Gregorian 18-m, shaped
Surface accuracy	Performance, cost	160 microns, 300 microns
Pointing accuracy	Performance, cost	2.7 arcsec, 4.2 arsec
Secondary angle of illumination	Interface with feed	110 degrees
Transportability	Configuration, cost	No

Antenna subsystem trade space

Offset Gregorian antennas

- Unblocked aperture results in **higher antenna efficiency**
- More available space at the secondary focus for receivers

Symmetric Cassegrain antennas

- Simpler optical design, more well-known mechanical design and cost.
- Cheaper/easier to build support structure
- Spacing can be closer

Antenna subsystem trade space

Feed-Up/Feed-high

- Lower elevation limits because less structure required to support reflector and feed arm (for pedestal mount)

Feed-down/Feed-low

- **Better performance** due to less spillover
- Easier to reach low elevation angles
- Offers easy access to the focus for maintenance
- Snow load is easier to deal with

TAC consensus: The project should adopt offset Gregorian optics with the feed at the bottom, primarily for performance reasons. It is clear that this is feasible at any size up to at least 100m diameter. This avoids the need to explore too many dimensions of parameter space.

ngVLA Antenna preliminary requirements and comparison with other projects

	Primary Aperture Diameter (meters)	Secondary angle of illumination angle (degrees)	f/D	shaped/ unshaped	surface accuracy (microns) Precision conditions	surface accuracy (microns) Standard conditions	pointing accuracy rms (arcsec) Precision conditions	pointing accuracy rms (arcsec) Standard conditions
MeerKAT	13.5	100	0.55	unshaped	600	600	5	25
DVA-2	15	110	0.8	shaped	335	?	10	180
ALMA	12	7.16	0.4	unshaped	25	25	2	2
SKA	15	110	0.36	shaped	500	500	5	10
ngVLA	20?			shaped?	160	300	2.7	4.2

Antenna requirements are reasonable when compared to other radio telescope projects in development

Note: Data shown for constructed antennas is requirements, not actual performance. Nighttime/no wind (precision) conditions and daytime (normal) conditions differ for each system.

Antenna subsystem community studies

- <u>Antenna Mount Study - Matt Fleming, Roger Schultz, Dave Enterline (MINEX)</u>
  - Analyzed three options:
    - Offset high, pedestal Azimuth Elevation Mount (DVA-1)
    - Offset low, Wheel and Track Mount, 3 points of rail
    - Offset Low, Wheel and Track Mount, 4 points of rail
  - Designs for each option including primary surface design, structure design
  - Identified the “Referenced Pointing Requirement” as the most difficult criteria
    - 3 arc-sec rms during a 4 deg movement over a 15 min period with 7m/s winds & gusts.
  - Preliminary pointing/cost comparison:
    - 4 point wheel and track performs better than 3 point
    - 3 point and 4 point wheel and track mount are not that different in cost
    - Pedestal mount is cheaper but needs more work to meet pointing requirements
- How does reconfigurability affect the antenna design? Does it limit the design to a particular mount type above a certain diameter?

Antenna subsystem community studies

- Offset Gregorian Antenna Design- David Loop, Dean Chalmers (NRC)
  - Concept design of 15m feed-down offset Gregorian antenna
  - Incorporates Minex wheel and track mount.
  - Single-piece rim-supported reflector is well suited to wheel and track feed-down configuration.
  - Single-piece rim-supported reflector is feasible for ≤ ~18 m diameter.
  - Further development required for operation to 120GHz but no show stoppers identified.
  - Optical design lessons learned from SKA work can be applied to ngVLA.

Array Configuration

- Reconfiguration capability is an open question
  - Should any antennas be reconfigurable?
  - How many, will they be in a Y configuration like the VLA?
- **TAC consensus: Reconfigurability is not cheap, and building a re-configurable array means significantly less money spent on sensitivity. Such a trade-off must be rigorously justified by compelling science.**
- Would you trade raw sensitivity for better u-v coverage over multiple configurations?
- Need to analyze array efficiency for key science use cases assuming nominal ngVLA configuration and incremental improvement provided by reconfigurability

Antenna Electronics subsystem

- Key requirements for antenna electronics subsystem
  - Frequency coverage
  - Efficiency/Tsys
  - Reliability
- Cost model by default uses 6-band receiver configuration, 3 dewars, 2 cryo compressors
- Options included for 8-band, 4-band, and 3-band receiver configurations
- Operational cost is driven by number of cryo compressors and their power usage

6-band configuration

Band	Dewar	f_L GHz	f_H GHz	BW ratio
1	A	**1.2**	**3.6**	**3.0**
2	B	**3.6**	**10.8**	**3.0**
3	C	**11**	**18**	**1.6**
4	C	**18**	**30**	**1.7**
5	C	**30**	**50**	**1.7**
6	C	**70**	**116**	**1.7**

4-band configuration

Band	Dewar	f_L GHz	f_H GHz	BW ratio
1	A	**1.2**	**4.2**	**3.5**
2	A	**4.2**	**15**	**3.6**
3	A	**15**	**50**	**3.3**
4	A	**70**	**116**	**1.7**

Antenna Electronics subsystem community studies and contributed talks

- Broadband prototype systems in development by Caltech and JPL groups
- 8-48 GHz, 6:1 receiver package- Jose Velazco (JPL)
  - LNA development and test results- Andrew Janzen
  - Wideband Feed horn and cryogenic receiver system- Ezra Long
- 1.2-116 GHz demonstration receiver- Sandy Weinreb (Caltech)
  - 4 receivers to cover ngVLA frequency range, all fit in a single dewar
- NRC Receiver Development for the NGVLA- Lewis Knee (NRC)
  - W-band 70-116 GHz receiver that builds on ALMA band 3
  - Phased Array Feed for 2.8-5.18 GHz
  - Q-band 35-50 GHz receiver optimized for DVA optics

Cryocooler community studies

- Advanced Cryocooling Techniques- Larry D'Addario (Caltech)
  - Don't try to achieve very low temperatures, especially at 1.2-3 GHz
  - Engage with the aerospace industry
  - Allocate funds for NRE, Develop hardware matched to our specific needs
  - Hire an in-house expert
  - Consider spending more on construction and NRE to save on operations
    - Pay-back time for power savings is easy to calculate
    - Maintenance saving is likely to be significant too

Cryocooler community studies

- <u>Smart Energy Cryocooler Technology- Jeff Gardiner (Quantum)</u>
  - Initial feasibility studies have shown promising results for QD cryo-refrigerator technology with the ngVLA
  - Variable speed technology offers significant power savings over older technology
  - Compressor is ruggedized for extreme operating conditions
  - Further effort needed to better shield the control and drive electronics to meet emissions requirements

Correlator subsystem

- Not a driver for construction cost, 2.7% of construction cost
- ngVLA correlator cost is scaled from SKA correlator cost
  - F-part scales with N * BW
  - X-part scales with N^2 * BW
- In current ngVLA cost model, N=214 and BW=20 GHz
  - SKA correlator supports 5 GHz instantaneous bandwidth
  - Is 20 GHz instantaneous bandwidth really needed?
    - This requirement seems driven by desire to be competitive with planned ALMA upgrades (2 x 8 GHz per sideband) for W-band
- Additional requirements (for example blind pulsar searches) have the potential to dramatically increase cost and complexity of correlator
- Cost of NRE may be more than cost of building correlator

Computing subsystem

- Cost model assumes computing cost decreases by a factor of 2 every 48 months until the time of construction start
- Adequacy of cost estimate (and archiving/processing required) depends on telescope usage.
- 10 processing use cases considered →
    - "2GHz, Full Band, Full Beam” is almost 3 orders of magnitude more demanding than the next largest one "18-30 GHz Full Band”
    - Default usage in current model: “2GHz, Full Band, Full Beam” use case is turned off. All other 9 use cases set to 11%.
- Computing subsystem is not a cost driver (4.3% of construction cost, 6.3% of operations cost) if:
    - “2 GHz, Full Band, Full Beam” case is left out
    - Computing systems costs decrease as predicted by model

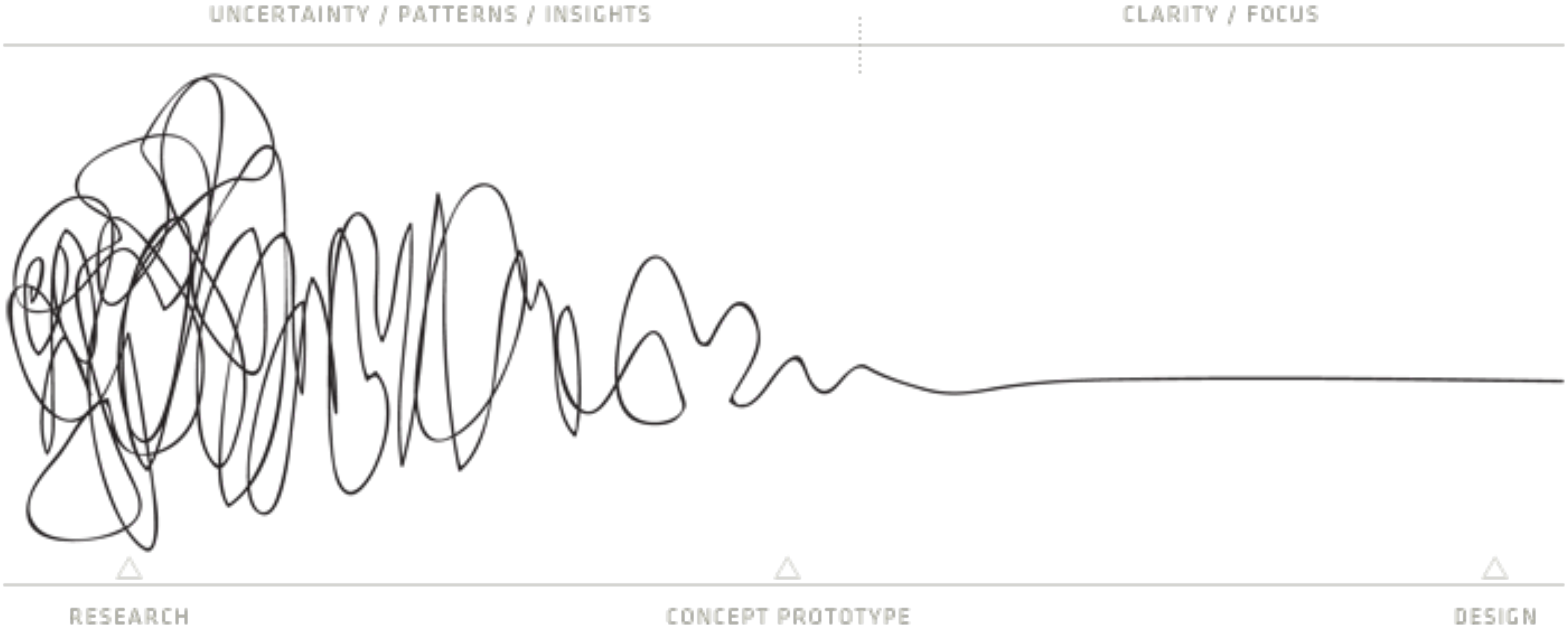
Processing Use Cases

100 GHz, Full Band, Full Beam
30-50 GHz Full Band, Full Beam
18-30 GHz Full Band (PPDisk Imaging)
11-18 GHz Full Band, Full Beam
3.6-10.8 GHz full Band
HI, Full Beam
low-z CO, Full Beam
High Z CO Imaging
Galactic Line (e.g., NH3), Full Beam
2GHz, Full Band, Full Beam (weak lensing)

Conclusions

- Excellent work has been done by ngVLA project team in analyzing trade space and design options.
- Primary task of TAC has been review of the cost model
- Antenna design work is needed as soon as possible to reduce uncertainty in antenna cost and improve the cost model.

Big picture



UNCERTAINTY / PATTERNS / INSIGHTS

CLARITY / FOCUS

RESEARCH

CONCEPT PROTOTYPE

DESIGN