NATIONAL RADIO ASTRONOMY OBSERVATORY

NRAO

ngVLA Sensitivity

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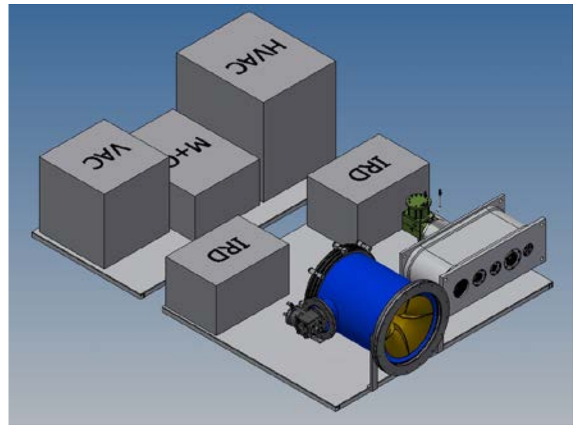
Associated Universities, Inc.

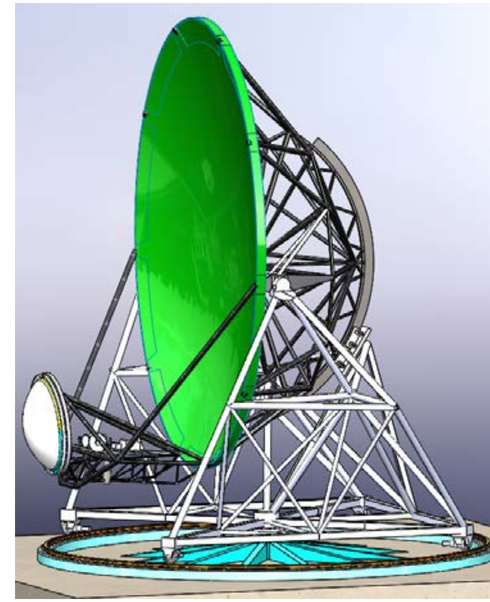
ngvla

Next Generation Very Large Array

Current Reference Design Specifications

- 214 18m offset Gregorian (feed-low) Antennas
- Fixed antenna locations across NM, TX, MX
  - ~1000 km baselines being explored
- 1.2 – 50.5 GHz; 70 – 116 GHz
  - Single-pixel feeds
  - 6 feeds / 2 dewar package
- Short-spacing/total power array under consideration





- Continuum Sensitivity: ~0.1uJy/bm @ 1cm, 10mas, 10hr => T_B ~ 1.75K
- Line sensitivity: ~21.5uJy/bm @ 1cm, 10 km/s, 1", 10hr => T_B ~ 35mK

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

Receiver Configuration

Sensitivity Metrics

- Point Source Sensitivity
  - Continuum
  - Fixed Spectral Resolution or Bandwidth

$$\Delta S(\nu) = \frac{4\sqrt{2}k}{\pi D^2 \sqrt{n_p [N(N-1)/2] \Delta\nu \Delta t}} \frac{1}{\Delta\nu} \int_{\nu_1}^{\nu_2} \frac{T_{sys}(\nu)}{\eta_a(\nu)} d\nu \qquad [\mathrm{W/m^2/Hz}]$$

- Imaging Sensitivity (as a function of resolution & beam quality)
  - Modeled as degraded from point source sensitivity by an efficiency term:

$$\Delta S_I = \Delta S_{NA} * F(res, Q)$$

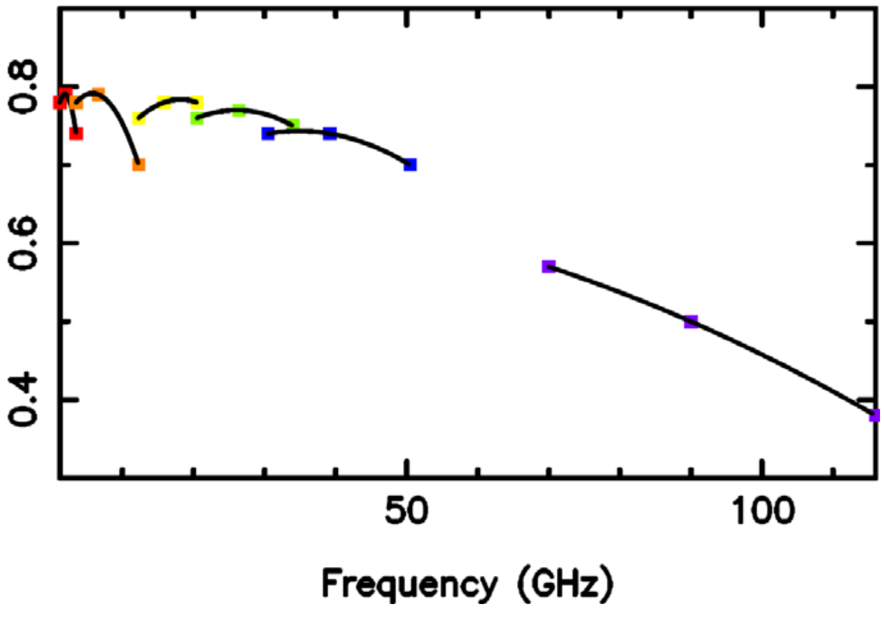
ngVLA T_{RX} Cascade Analysis

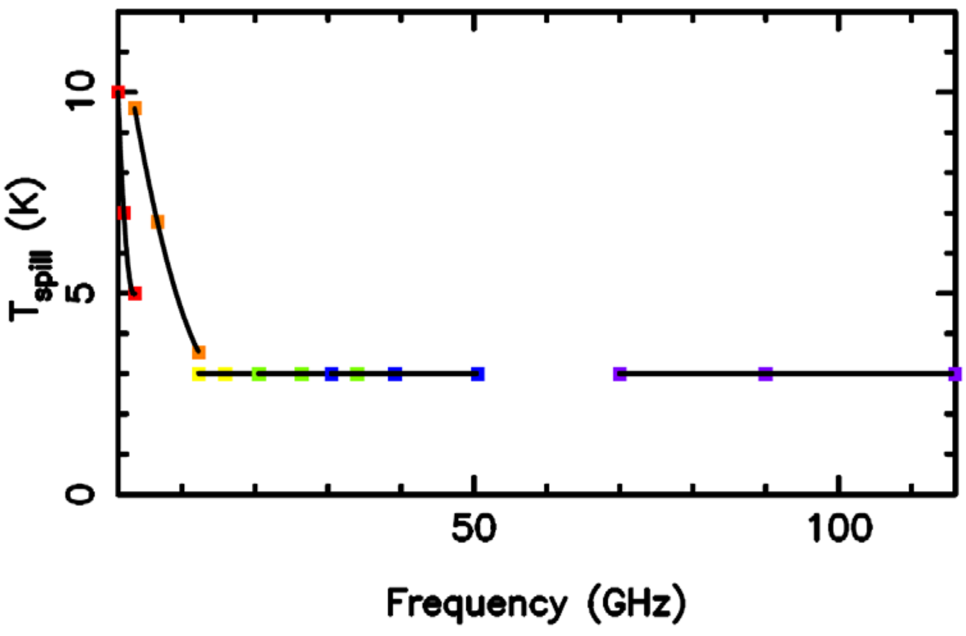
$$T_{sys}(\nu) = \alpha T'_{rx} + \alpha\eta_l T'_{atm} + \alpha T'_{spill} + T'_{bg} \qquad [\mathrm{K}]$$

Band #:	**1**			**2**			**3**			**4**			**5**			**6**		
Frequency:	**1.2**	**2**	**3.5**	**3.5**	**6.6**	**12.3**	**12.3**	**15.9**	**20.5**	**20.5**	**26.4**	**34**	**30.5**	**39.2**	**50.5**	**70**	**90**	**116**
Wx_Radome	1.38	1.38	1.38	1.38	1.38	2.08	2.08	2.08	2.78	2.78	2.78	3.47	3.47	3.47	3.47	3.47	4.17	6.99
Vacuum_Window	1.38	1.38	1.38	1.38	1.38	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	3.47
IR_Filter	0.88	0.88	0.88	0.88	0.88	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	2.20
Feed_Horn	1.86	1.86	1.86	0.70	0.70	1.43	0.23	1.43	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.28	0.47
OMT	0	0	0	0	0	0	0.94	0.94	0.94	0.94	0.94	0.94	1.68	1.68	1.53	2.44	1.93	1.68
Cal_Coupler	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.94	0.94	0.94	0.94	0.94	1.19	1.19	0.94	3.50	2.70	2.44
Coax/Waveguide	0.43	0.63	0.63	0.37	0.37	0.72	0.27	0.14	0.12	0.33	0.24	0.21	0.71	0.45	0.40	2.29	1.53	1.33
LNA (T_noise)	**3.0**	**3.0**	**3.5**	**5.0**	**5.0**	**7.5**	**5.0**	**6.0**	**7.0**	**7.0**	**8.0**	**11.0**	**10.0**	**12.0**	**14.0**	**29.0**	**26.0**	**40.0**
LNA (Gain)	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**
Overall T_{RX}:	**9.0**	**9.2**	**9.7**	**9.8**	**9.8**	**15.2**	**12.9**	**14.9**	**15.4**	**15.6**	**16.5**	**20.2**	**20.7**	**22.4**	**24.0**	**44.4**	**40.1**	**58.6**

Courtesy of W. Grammer

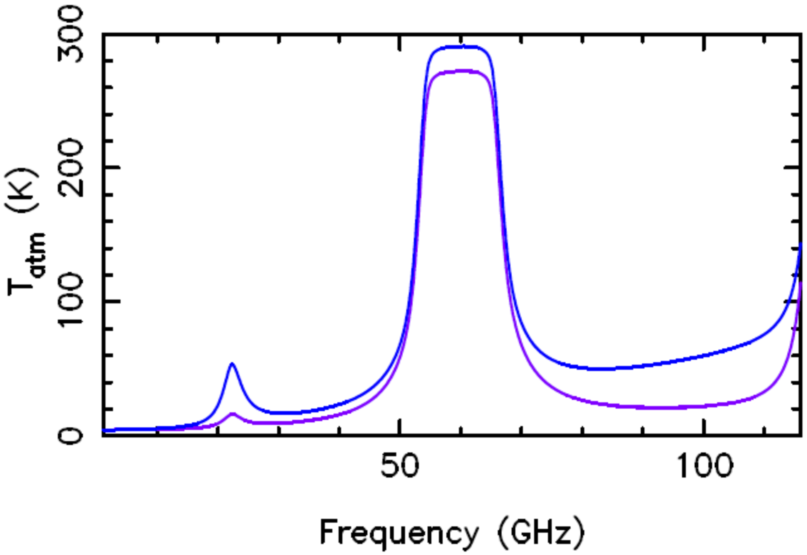
Antenna Efficiency & Spillover

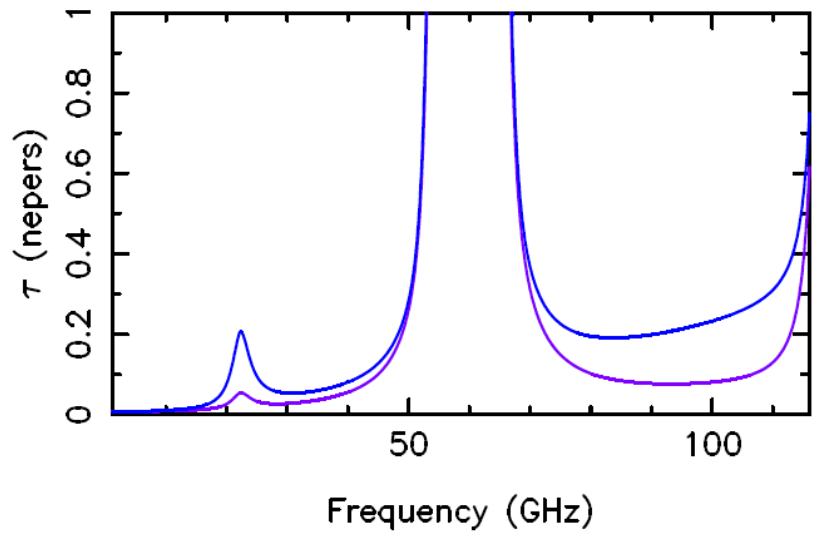


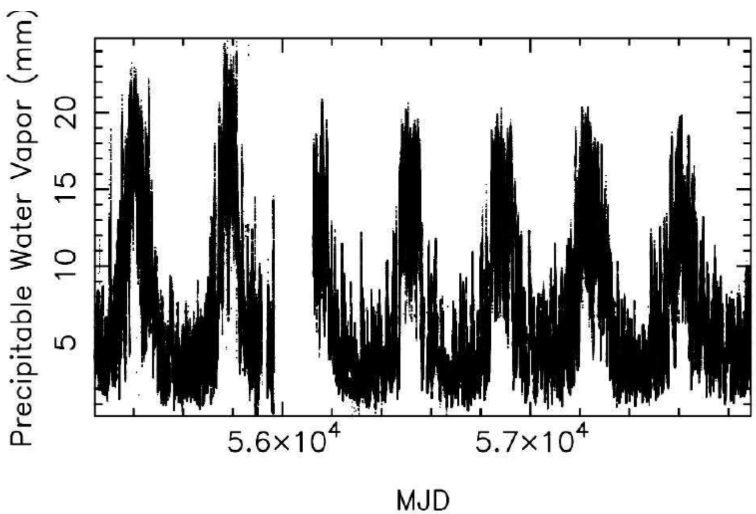


$$\eta_{surf} = e^{-\left(\frac{4\pi\sigma}{\lambda}\right)^2}$$

Refined T_{ATM} Model



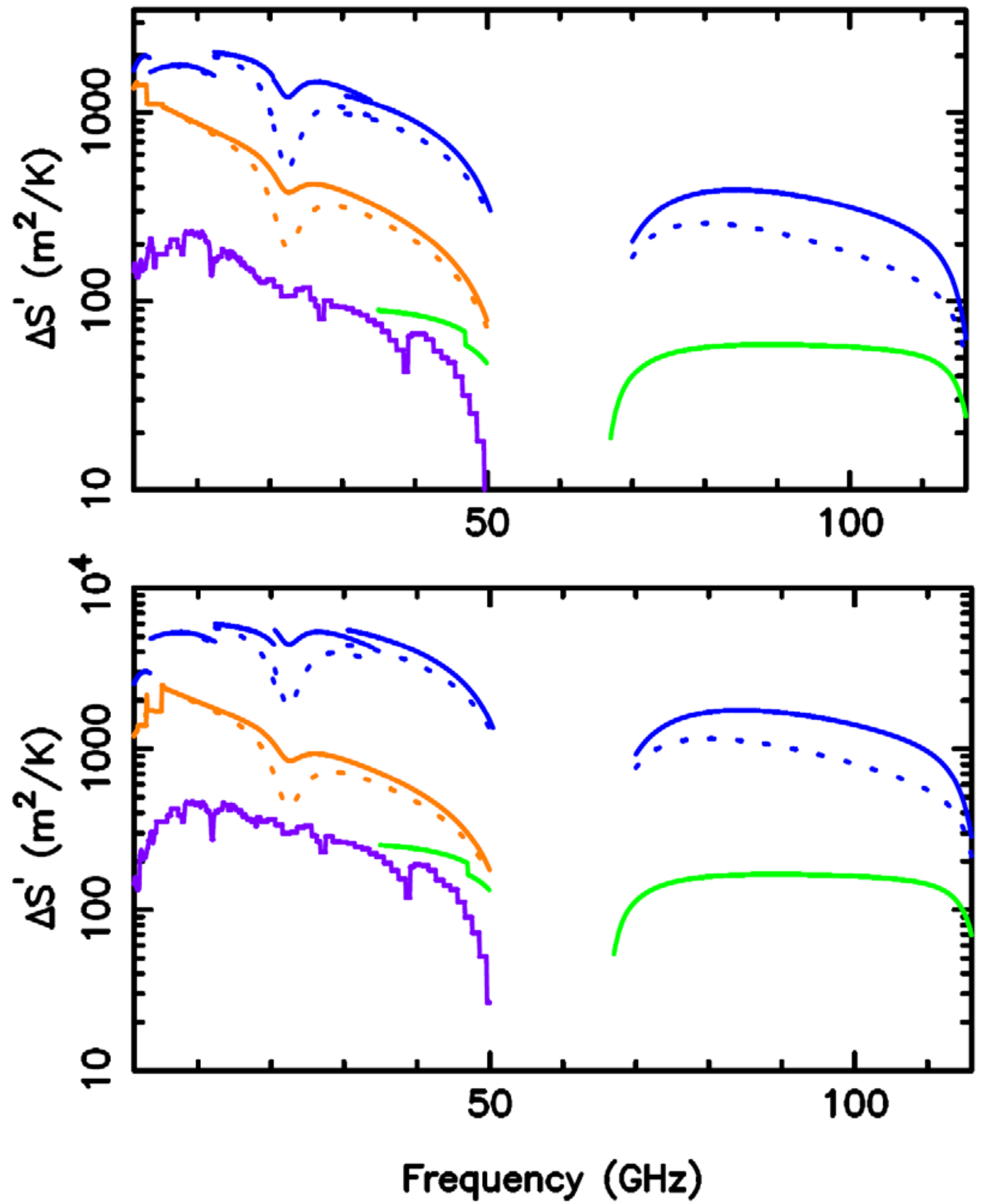




Point Source Sensitivity (Continuum)

frequency range (GHz)	precision dry sensitivity (μJy)	precision wet sensitivity (μJy)	non-precision dry sensitivity (μJy)	non-precision wet sensitivity (μJy)
1.2-3.9	0.356	0.355	0.356	0.355
3.9-12.6	0.202	0.205	0.203	0.206
12.6-21.0	0.190	0.234	0.196	0.242
21.0-35.0	0.210	0.334	0.229	0.362
30.5-50.5	0.315	0.372	0.389	0.459
70.0-90.0	0.675	0.964	–	–
95.0-115.0	0.965	1.641	–	–

Relative Sensitivity

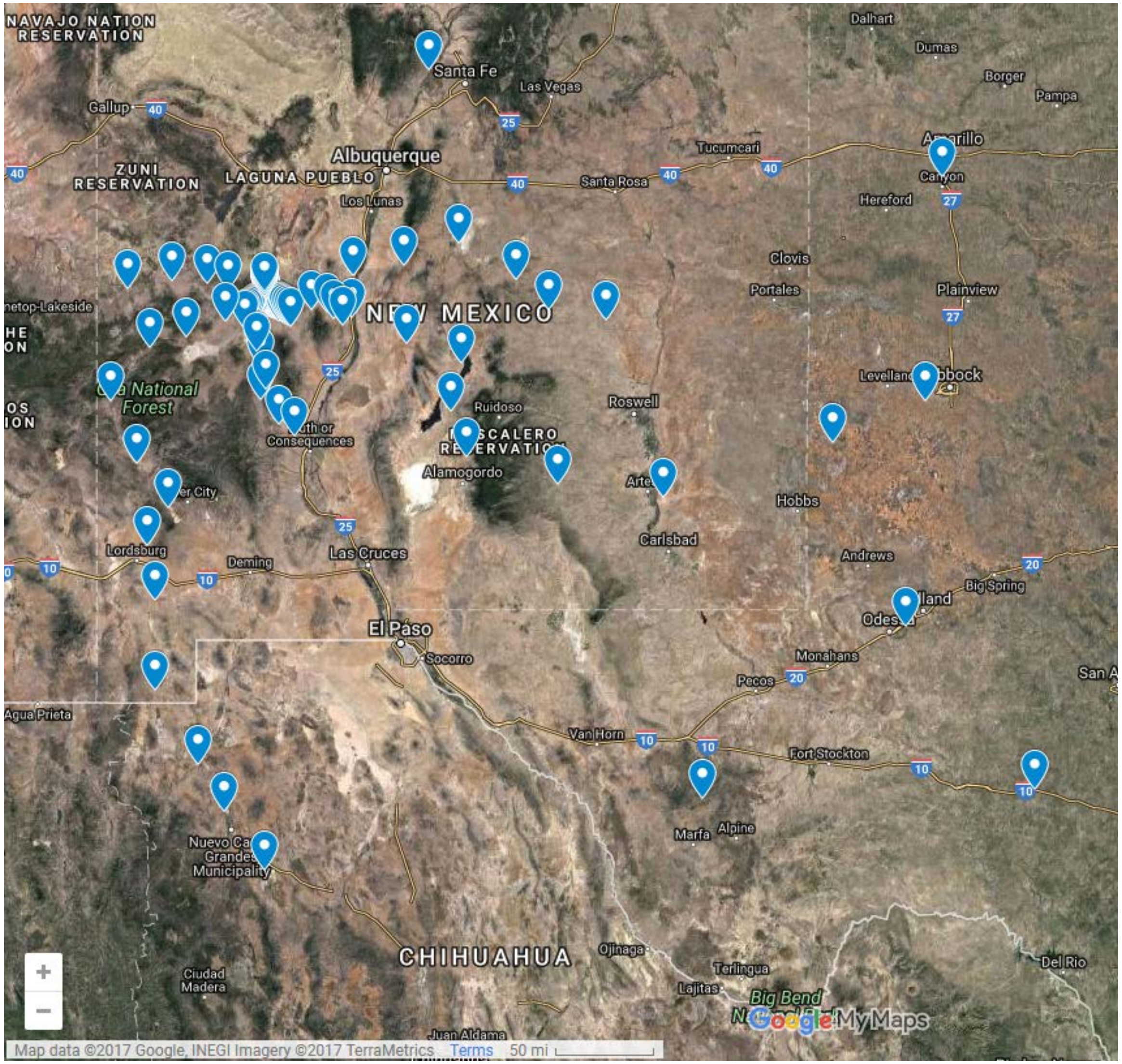


Spectral Line (top) & Continuum (bottom) sensitivity as a function of frequency for ngVLA, VLA, ALMA, and SKA1-mid.

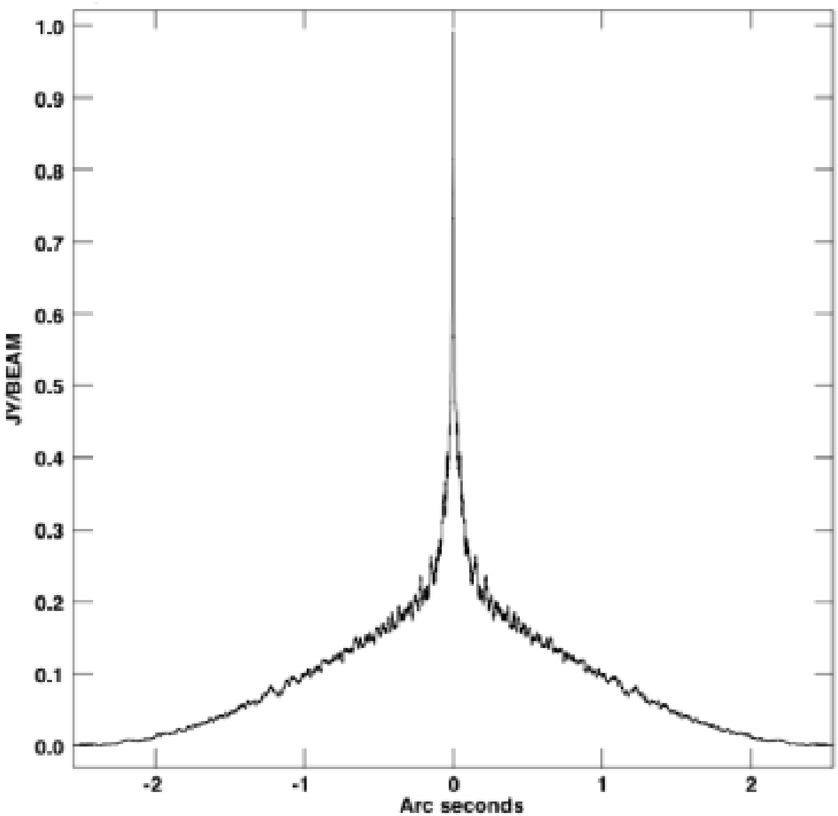
Values are plotted for winter (solid line) and summer (dashed line).

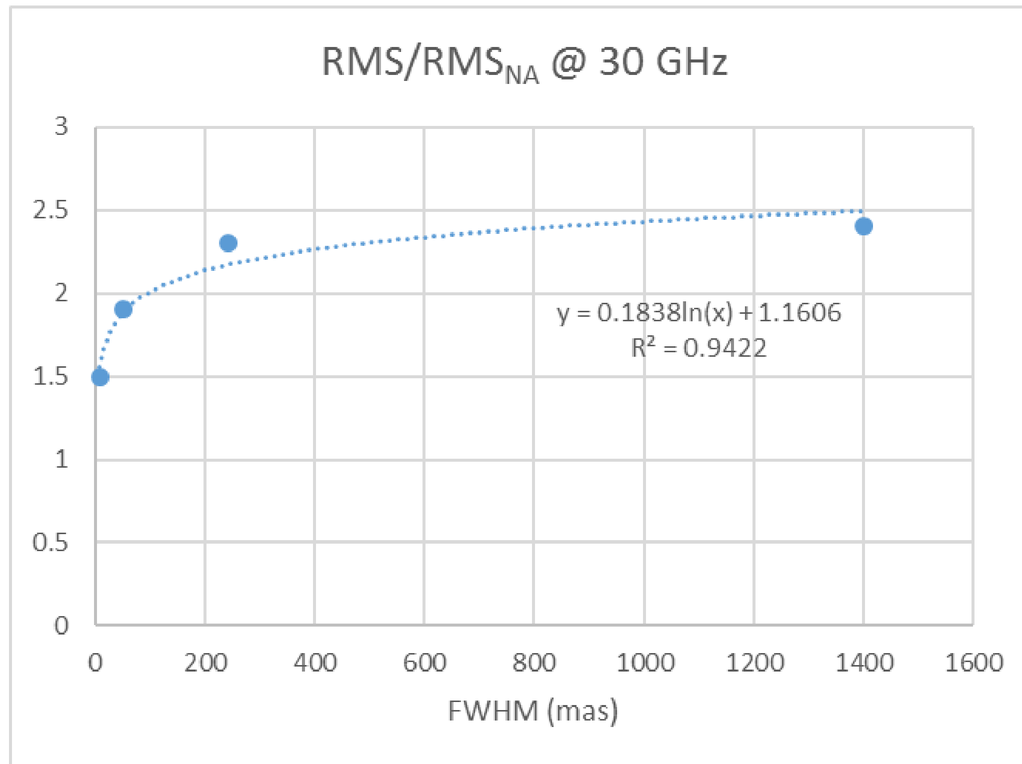
ngVLA = blue
VLA = purple
ALMA = green
SKA1-mid design baseline = orange

ngVLA Configuration



Imaging Sensitivity





Courtesy of C. Carilli, Memo #16

Conclusions

- ngVLA will offer unprecedented point source and imaging sensitivity over it's operating frequency range.
- Both continuum and spectral line sensitivity metrics should be considered equally when comparing capabilities.
- The noise increase in imaging with sculpted beams should be a key design metric in the configuration design and gridding/deconvolution algorithmic development.

Future Work

- Refine Tspill & Illumination Efficiency to incorporate updated optical design (by Lynn Baker + NRCC)
- Quantify the Beam Quality required for key science cases, and update the rms/rms_{NA} ratio.
- As the calibration strategy is developed, estimate typical calibration overheads and total observing time.
- Build a reference observing program, and estimate the time required to execute the key science cases.

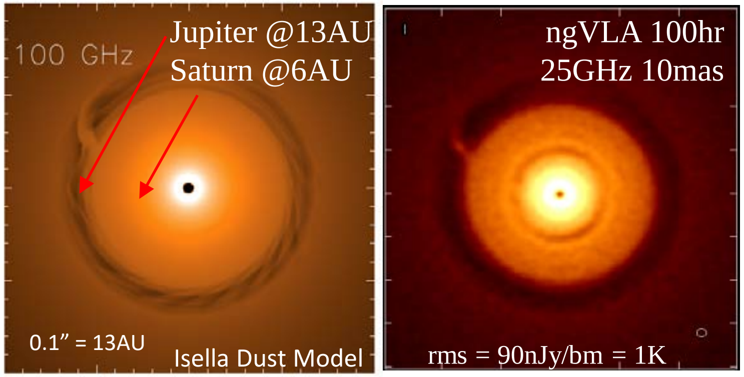
Next Generation Very Large Array

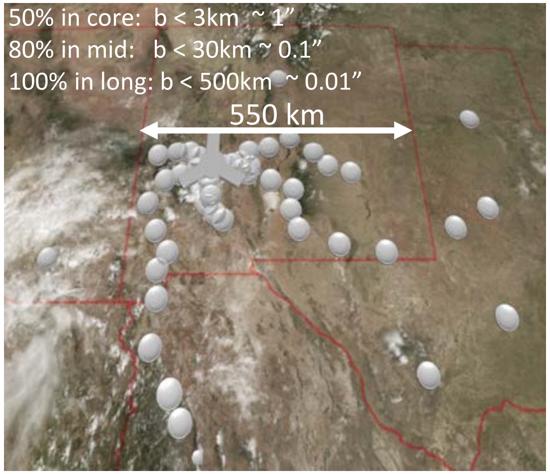
ngvla.nrao.edu

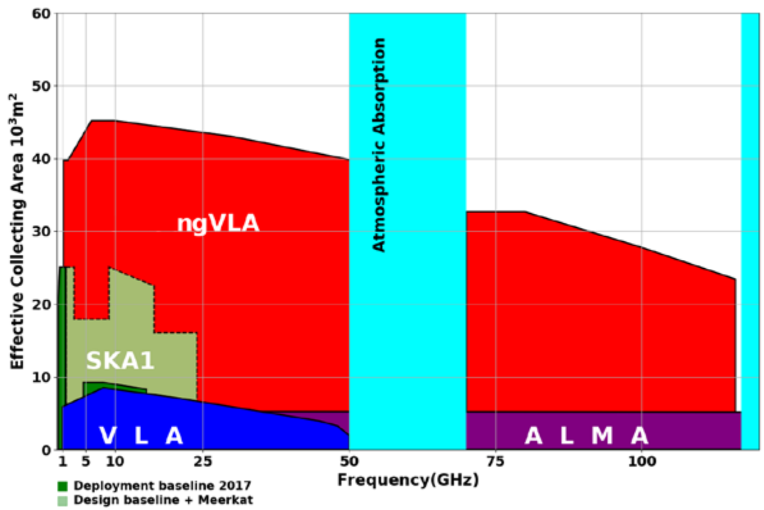
The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

A next-generation Very Large Array (ngVLA)

- Scientific Frontier: ***Thermal imaging at milli-arcsec resolution***
- Sensitivity/Resolution Goal:
    - ***10x sensitivity & resolution of JVLA/ALMA***
- Frequency range: ***1.2 –116 GHz***
- Located in Southwest U.S. (NM+TX) & MX, centered on VLA
- Baseline design under active development
- Low technical risk (reasonable step beyond state of the art)





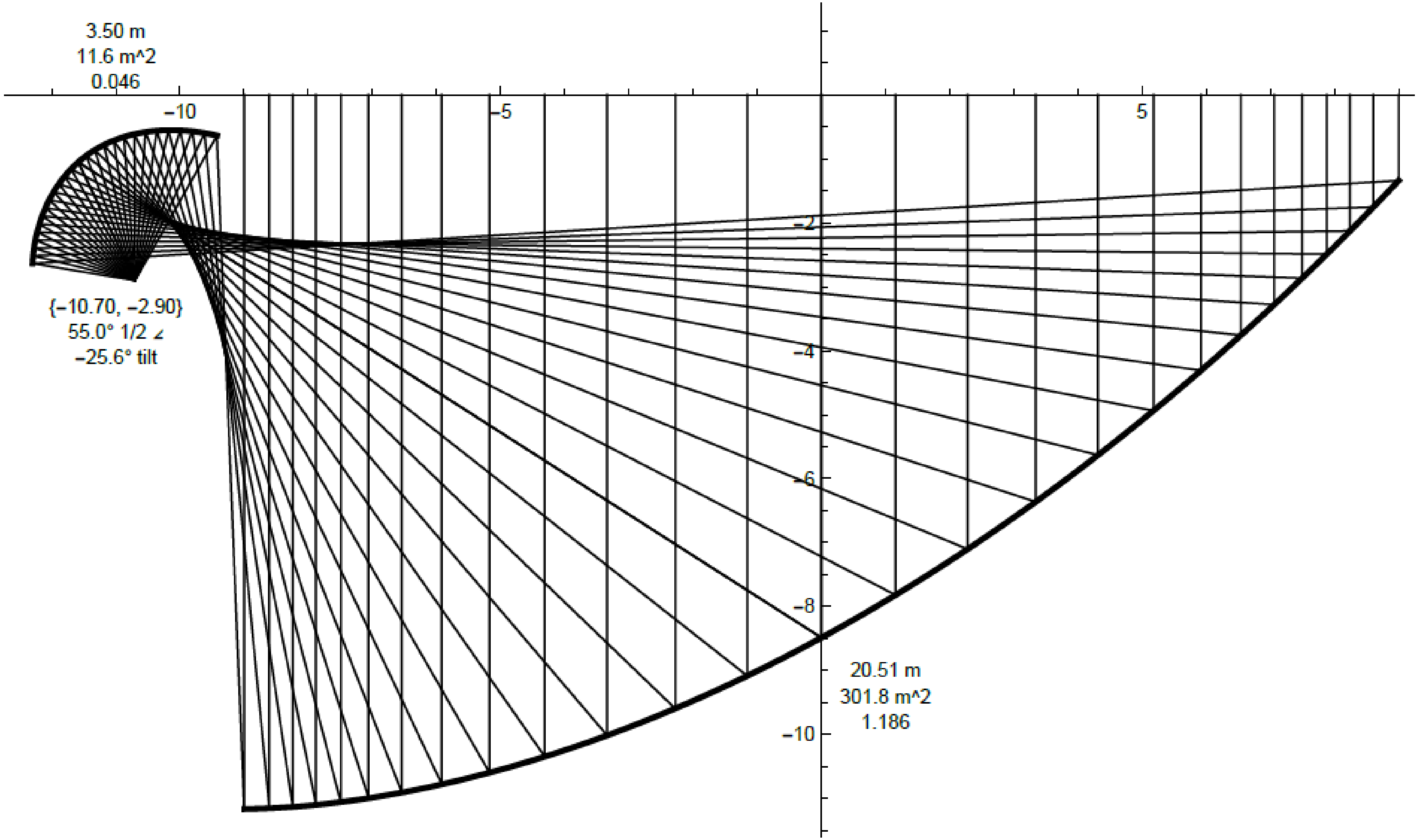


Complementary suite from meter to submm arrays for the mid-21st century

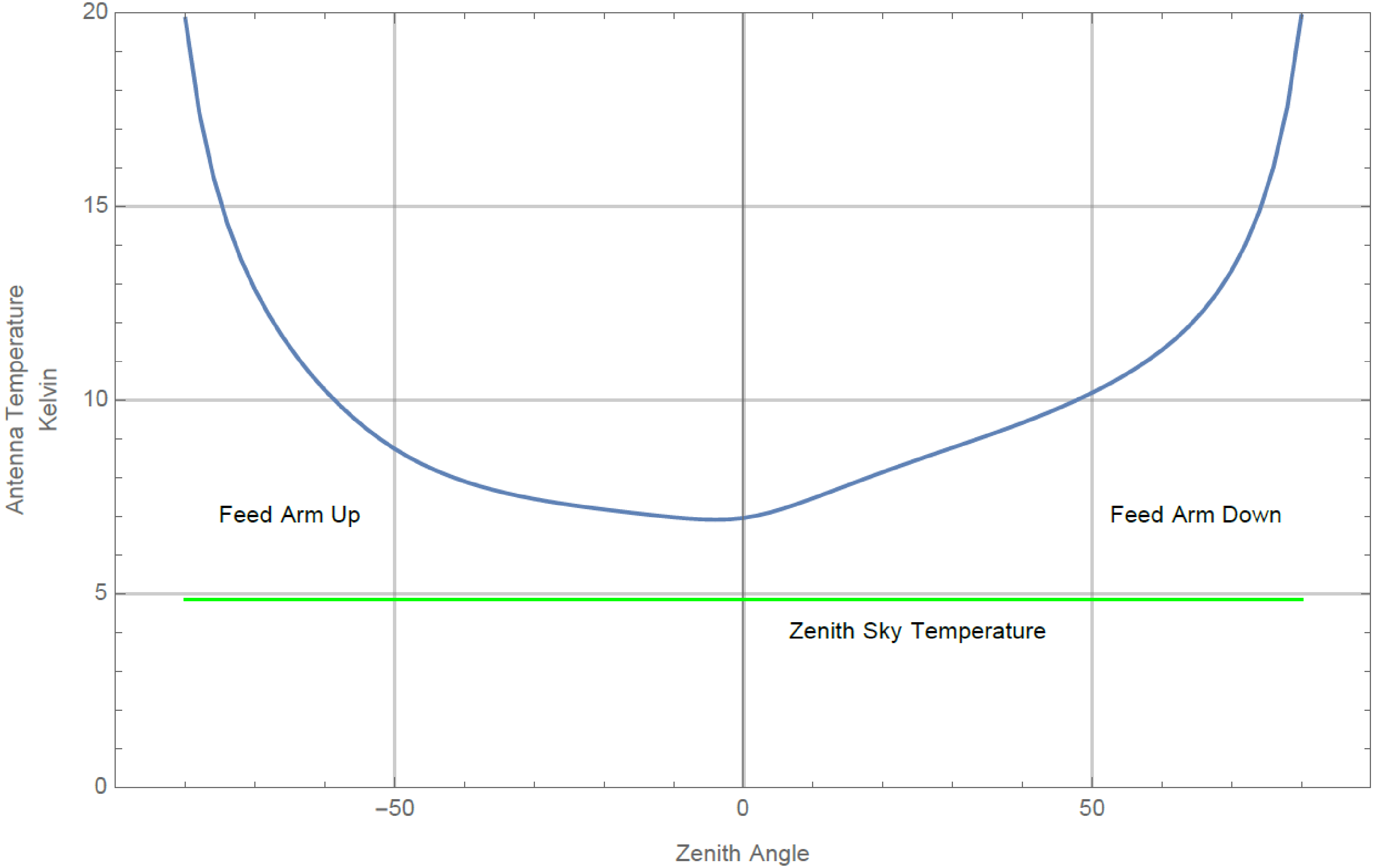
- **< 0.3cm:** ALMA 2030
- **0.3 to 3cm: ngVLA**
- **> 3cm:** SKA

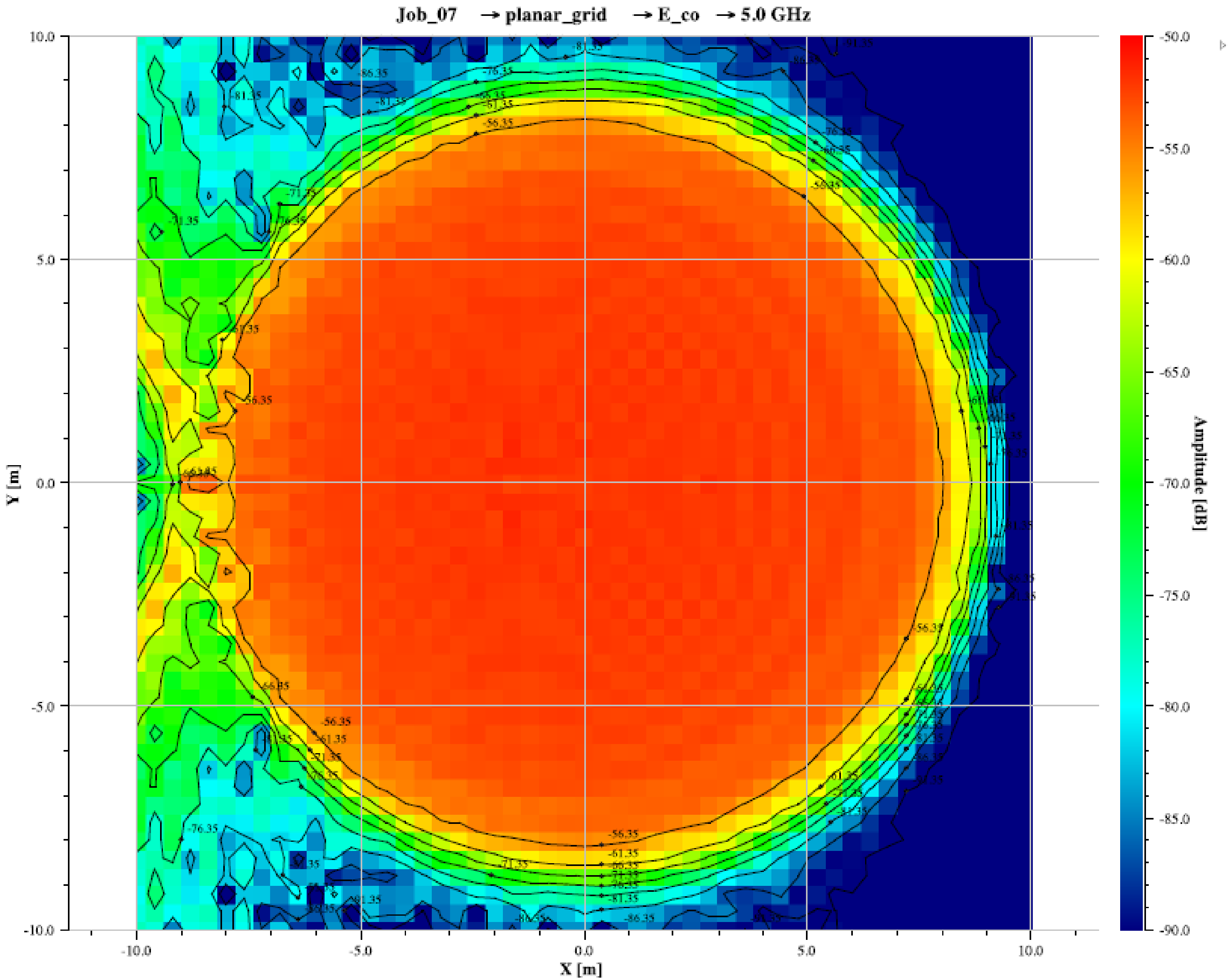
NEW WEBSITE:
https://ngvla.nrao.edu

ngVLA 18 meter reflector system, Ver. 6
Cross section in the symmetry plane



ngVLA Design #6, Tipping Curve @ 5 GHz. With LB Horn Feed
SKA Noise Model





Job_07 → planar_grid → E_co → 5.0 GHz
X [m]
Y [m]
Amplitude [dB]
10.0
5.0
0.0
-5.0
-10.0
-50.0
-55.0
-60.0
-65.0
-70.0
-75.0
-80.0
-85.0
-90.0