# The Next Generation Very Large Array

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With some slides contributed by
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ngvla.nrao.edu

SIW 05.21.24

National Radio Astronomy Observatory

***A transformative new facility that will replace the VLA and VLBA to tackle a broad range of science questions.***

## *ngVLA* Concept:

**10x** the sensitivity of the VLA/ALMA

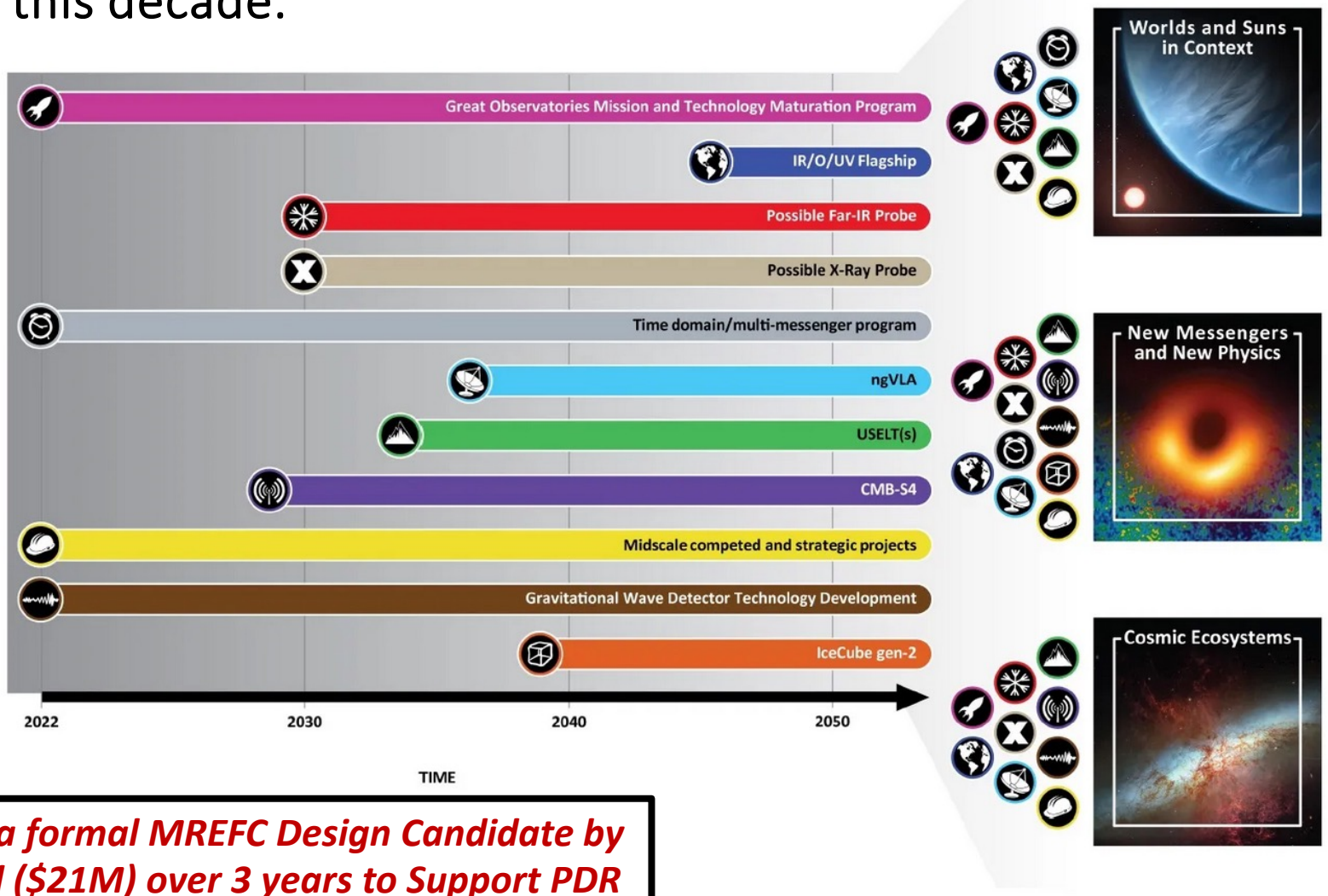
**10x** higher resolution than the VLA/ALMA

**1.2 - 116 GHz** Frequency Coverage

**244 x 18m + 19 x 6m** offset Gregorian Antennas

- Centered at VLA site, extending over USA & MX
- Fixed antenna locations; 4 TP antennas

# Astro2020 identified the ngVLA as a high-priority large, ground-based facility whose construction should begin this decade.



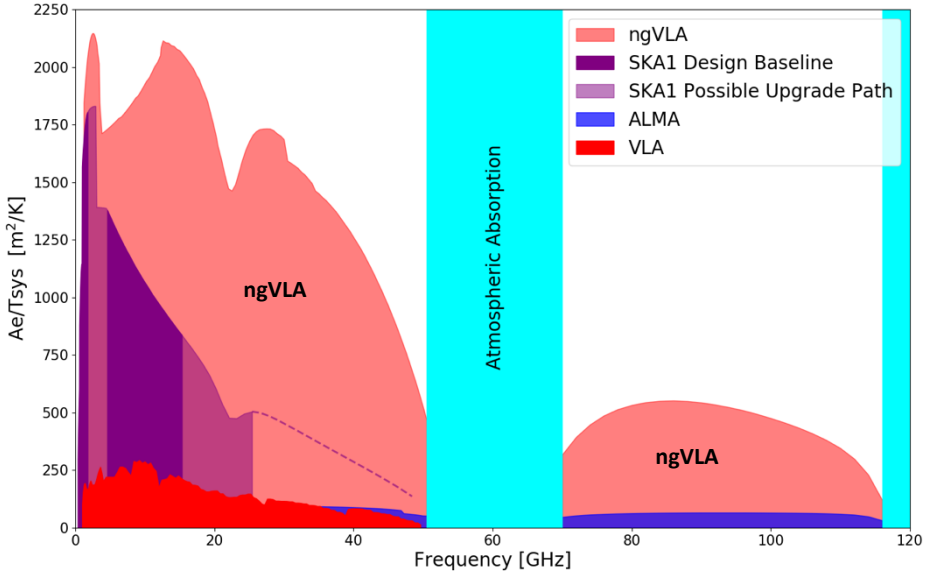

***Identified as a formal MREFC Design Candidate by NSF Awarded ($21M) over 3 years to Support PDR***

# Bridging SKA & ALMA Scientifically

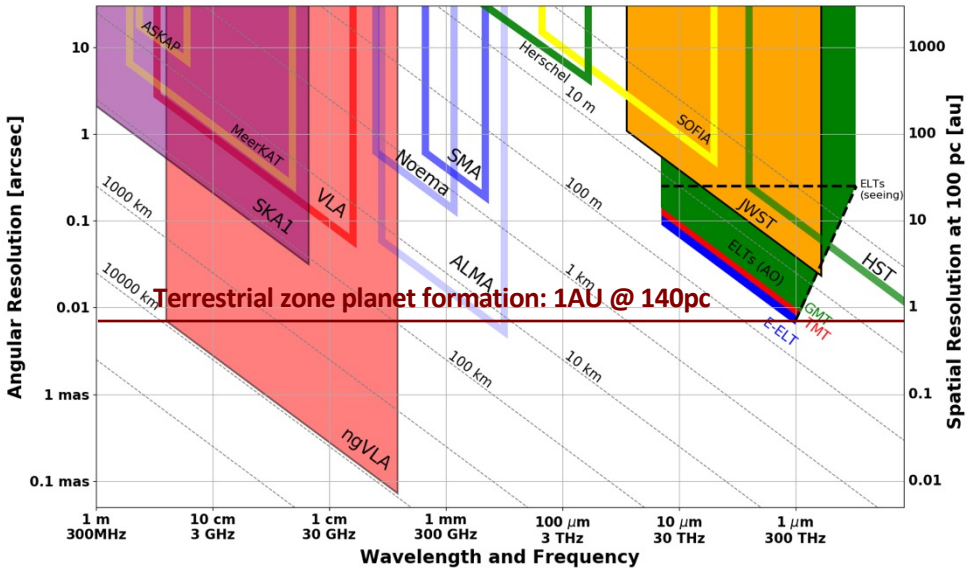
## Thermal Imaging on mas Scales at λ ~ 0.3cm to 3cm

New Parameter Space for the mid century

*Sensitivity*




*Resolution*




Complementary suite of arrays from meter to submm wavelengths

- **> 120GHz:** ALMA 2030 superb for chemistry, dust, fine structure lines
- **1.0 - 116GHz: ngVLA superb for terrestrial planet formation, dense gas history, black holes**
- **< 15 GHz:** SKA superb for pulsars, reionization, HI + continuum imaging

# ngVLA Key Science Goals (ngVLA memo #19)

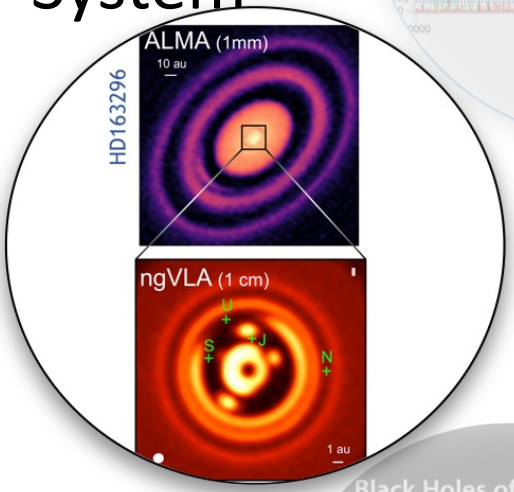
The science cases are a representation of the full range of science capabilities

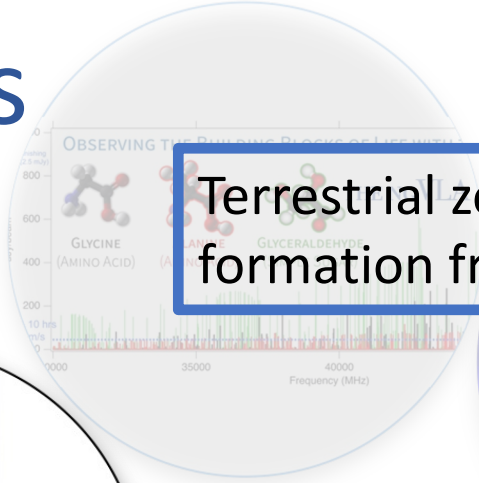
1. *Unveiling the Formation of Solar System Analogues on Terrestrial Scales*
2. *Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry*
3. *Charting the Assembly, Structure, and Evolution of Galaxies Over Cosmic Time*
4. *Using Pulsars in the Galactic Center as Fundamental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

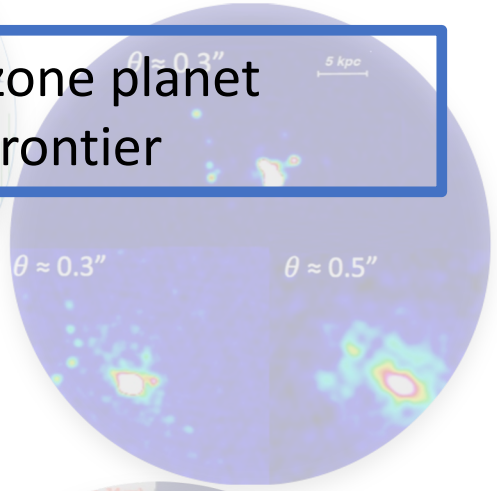
# Key Science Requirements

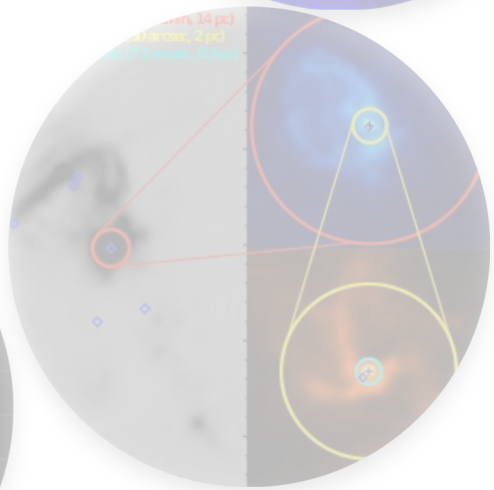
KSG1: Unveiling the Formation of Solar System Analogues

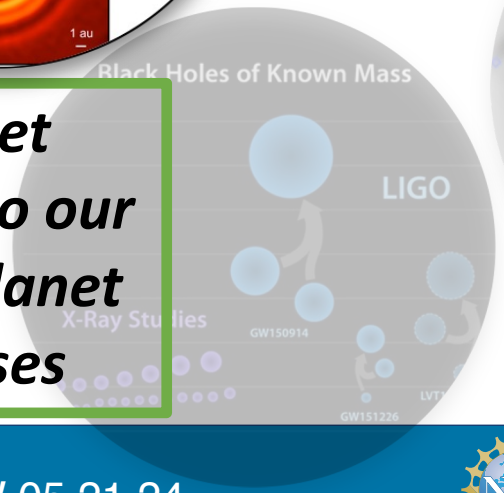
Terrestrial zone planet formation frontier



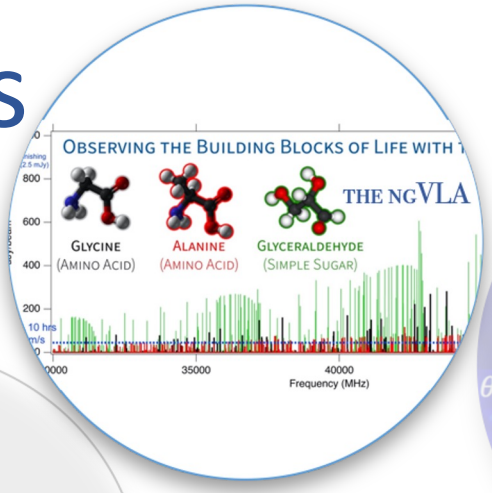


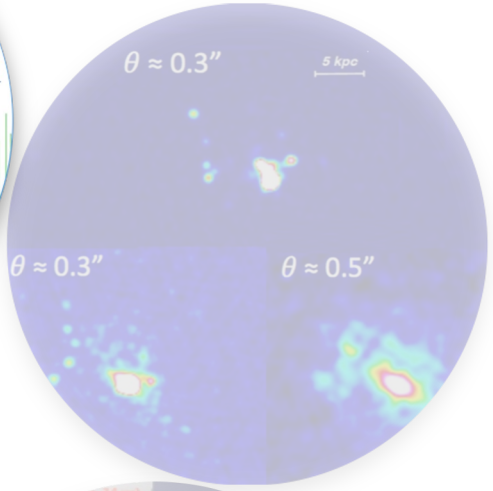

Ricci et al. 2019

***The ngVLA will image planet formation in systems similar to our own Solar System, down to planet masses of a few earth masses***

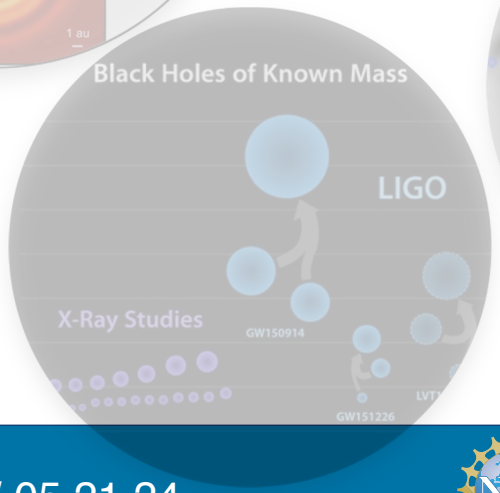
# Key Science Requirements

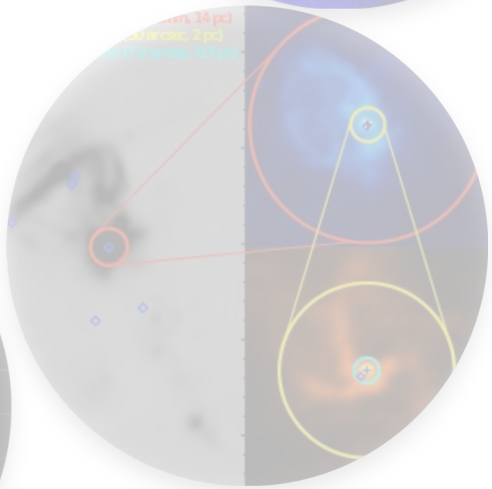
KSG2: Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry







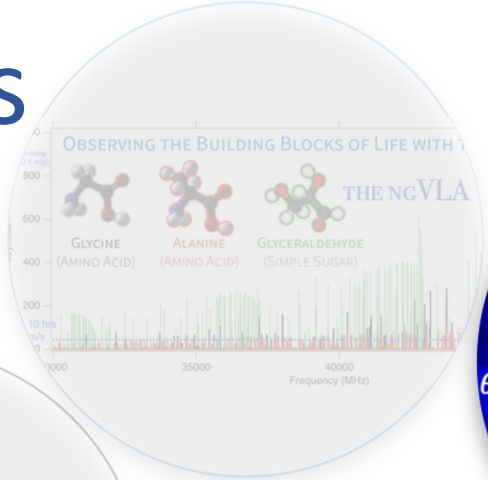



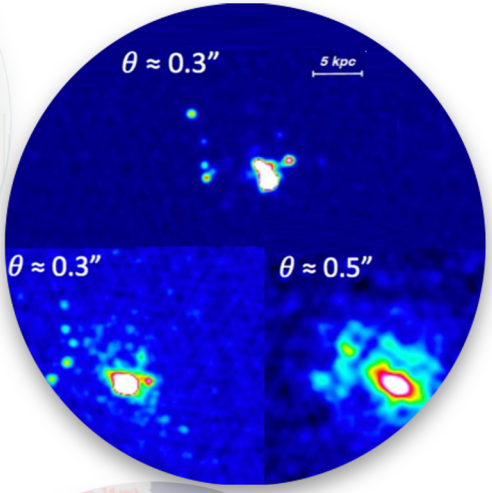
Credit: Brett McGuire

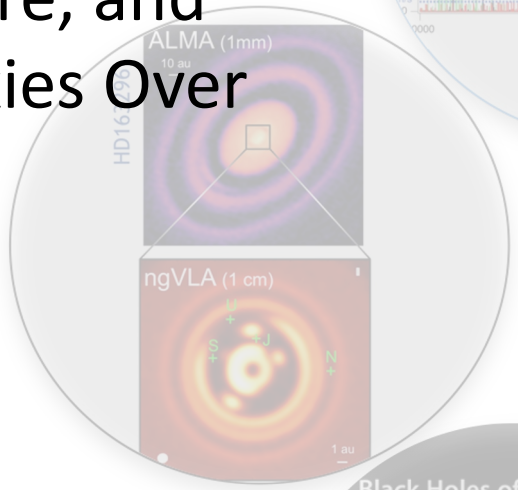
The ngVLA can detect complex pre-biotic molecules and provide the chemical initial conditions in forming solar systems and individual planets

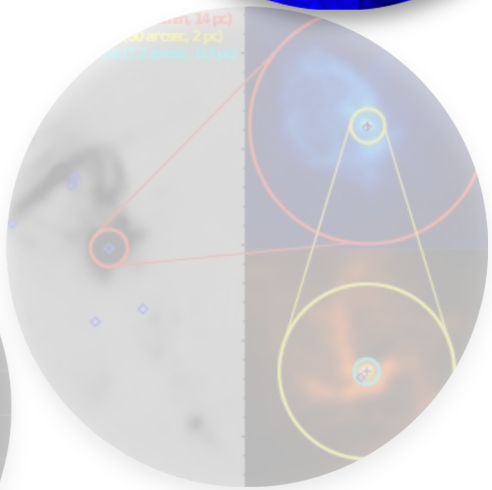
# Key Science Requirements

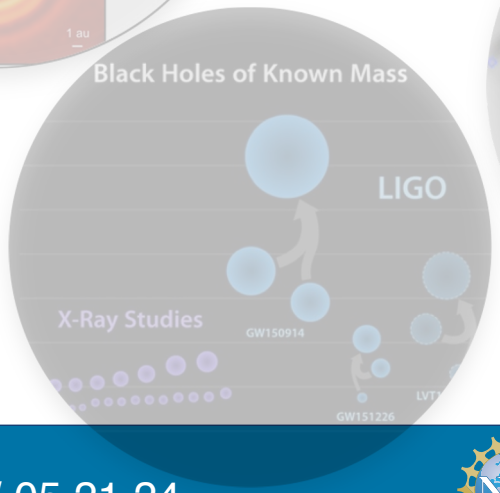
KSG3: Charting the Assembly, Structure, and Evolution of Galaxies Over Cosmic Time






Cool Gas in distant Galaxies: history of the formation of stars in the Universe

Credit: Caitlin Casey



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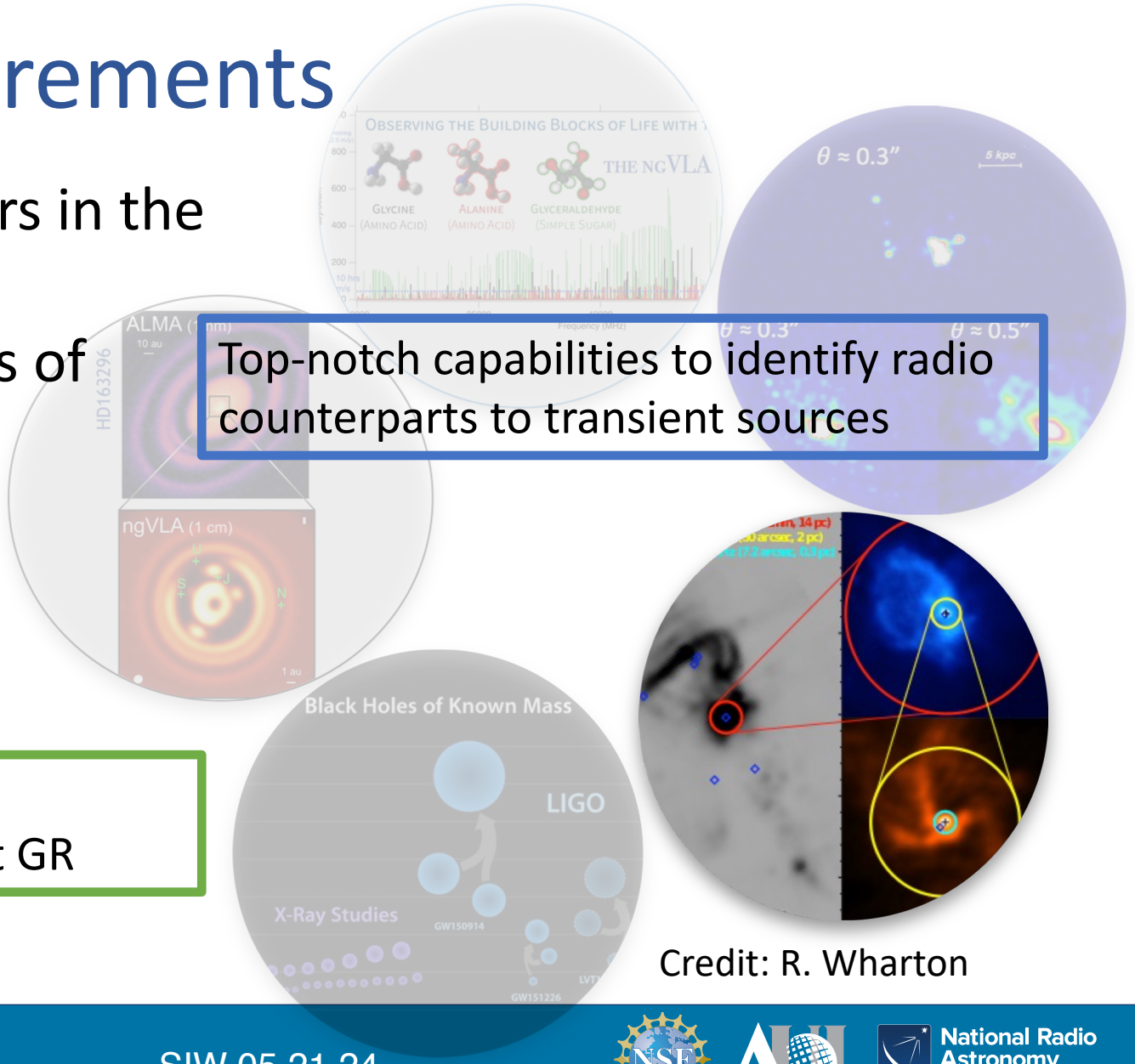
# Key Science Requirements

KSG4: Using Pulsars in the Galactic Center as Fundamental Tests of Gravity

Top-notch capabilities to identify radio counterparts to transient sources

Discovering pulsars around Sgr A* to test GR




Credit: R. Wharton



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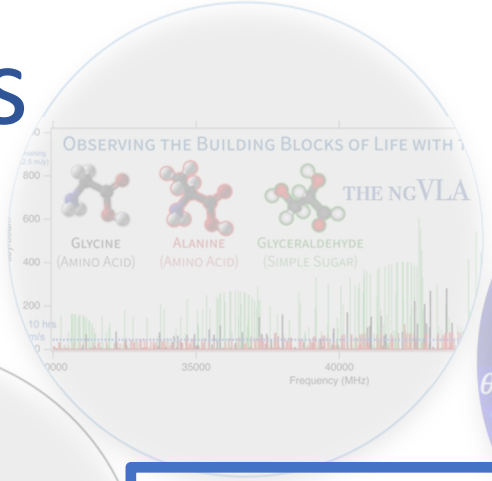
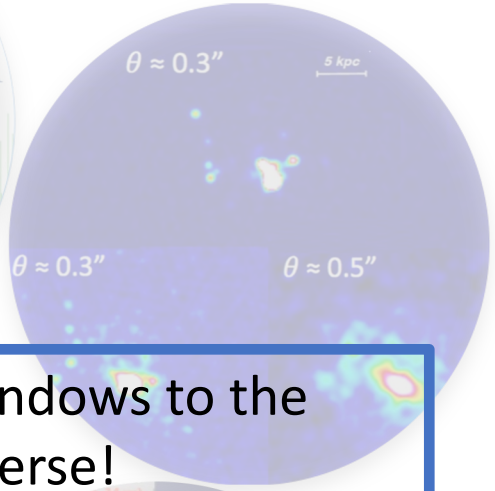
# Key Science Requirements

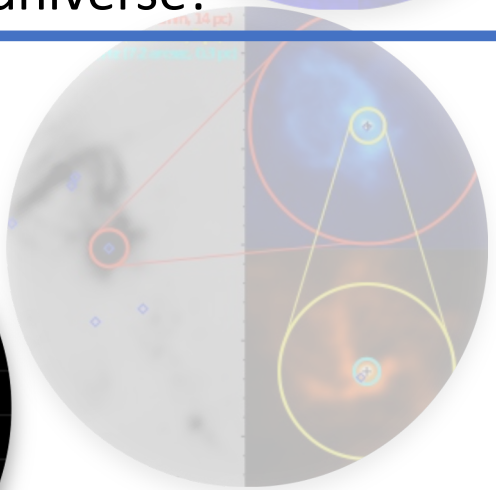
KSG5: Understanding the Formation and Evolution of Stellar and Supermassive BH's in the Era of Multi-Messenger Astronomy



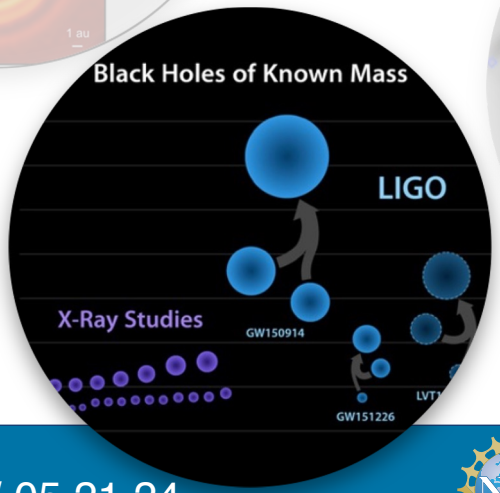





Open new windows to the dynamic universe!



Search for BHs across all masses including binary systems



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# Capture Technical Specifications

Technical requirements are based on science goals

- Frequency range: antenna accuracy, receivers, site
- Field of view: antenna size
- Sensitivity: total collecting area (antenna size and number), receiver quality, bandwidth
- Resolution: maximum baseline length, frequency
- Dynamic range: number of antennas, calibration style
- Polarization: feeds, receiver, antenna
- Spectral resolution: correlator capabilities

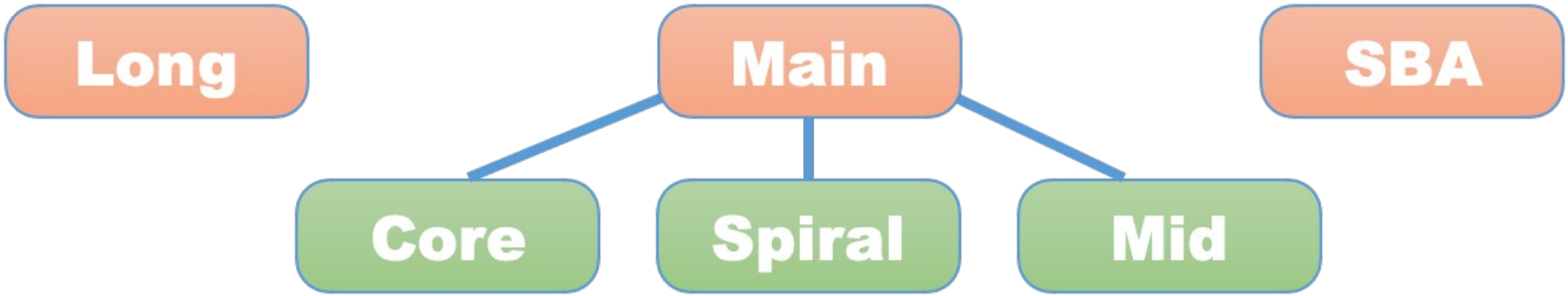
# ngVLA Configuration

Subsets

Subarrays

**Compromise to deliver good brightness temperature sensitivity and high angular resolution imaging**

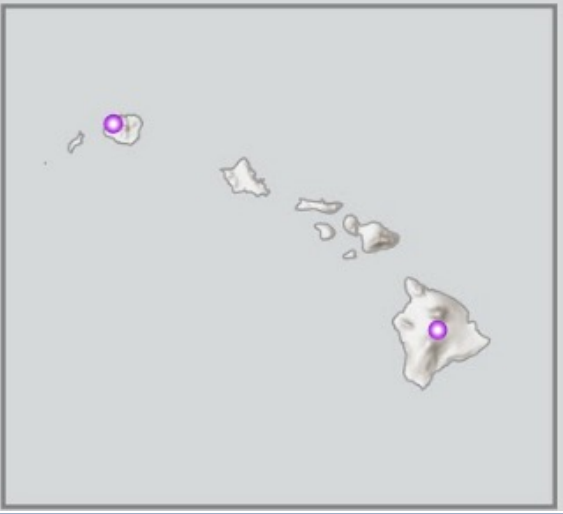
Non-reconfigurable array designed to deliver high sensitivity over a range of resolutions



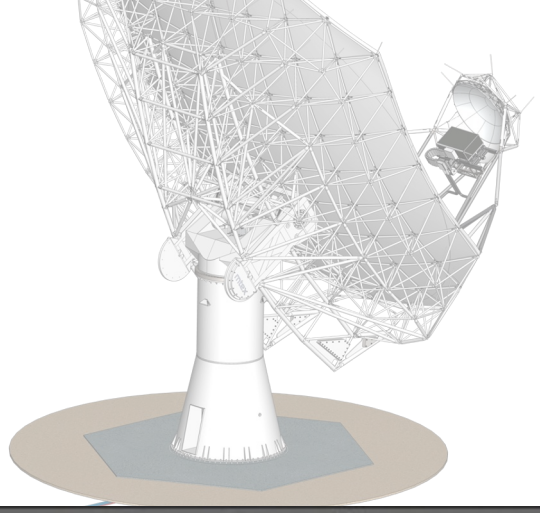

**263 antennas total!**

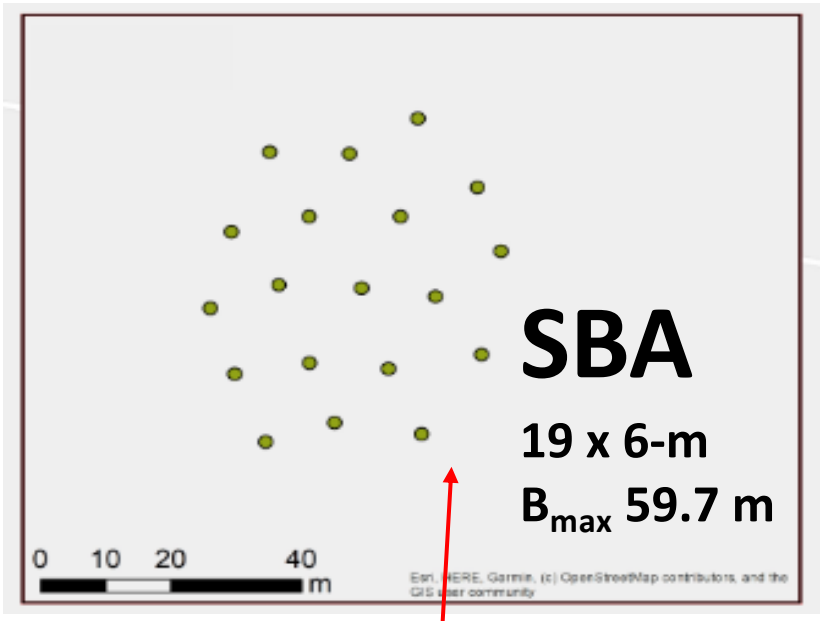
# Configuration (Rev. D)

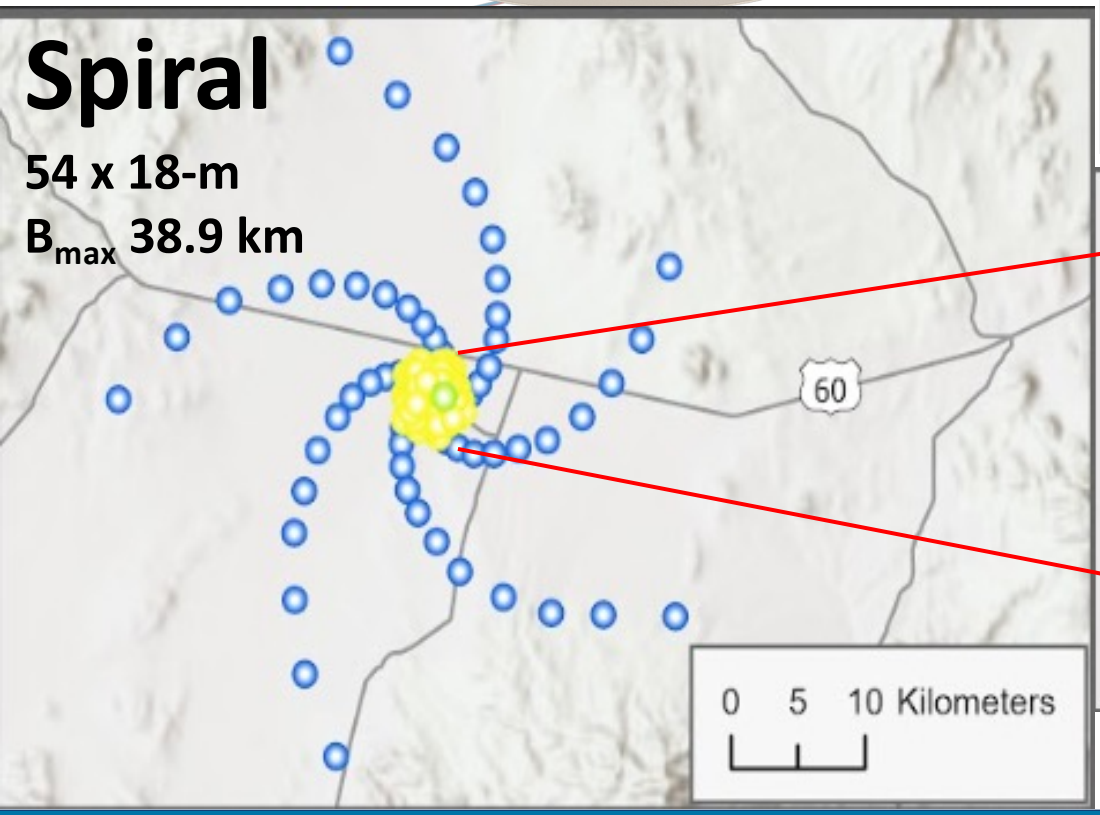
| Long Antenna Sites | | |
|---|---|---|
| Qty | Location | Notes |
| 3 | Puerto Rico | Arecibo Site |
| 3 | Immokalee, FL | UF IFAS Site |
| 3 | Kauai, HI | Kokee Park Obs. |
| 3 | Hawaii, HI | Not MK Site |
| 3 | Hancock, NH | VLBA Site |
| 3 | Green Bank, WV | GBO |
| 3 | Brewster, WA | VLBA Site |
| 3 | High Park, WY | New Site |
| 3 | North Liberty, IA | VLBA site |
| 3 | Owens Valley, CA | VLBA site |

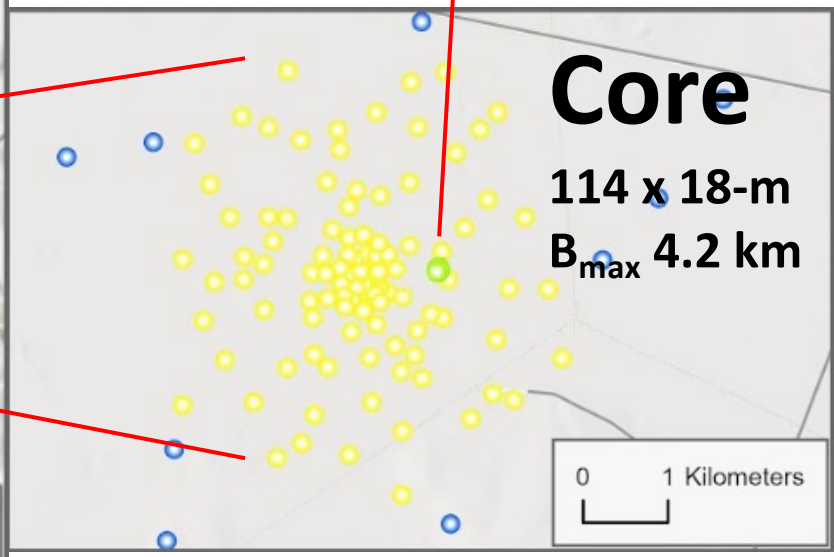


ngvla
Next Generation Very Large Array

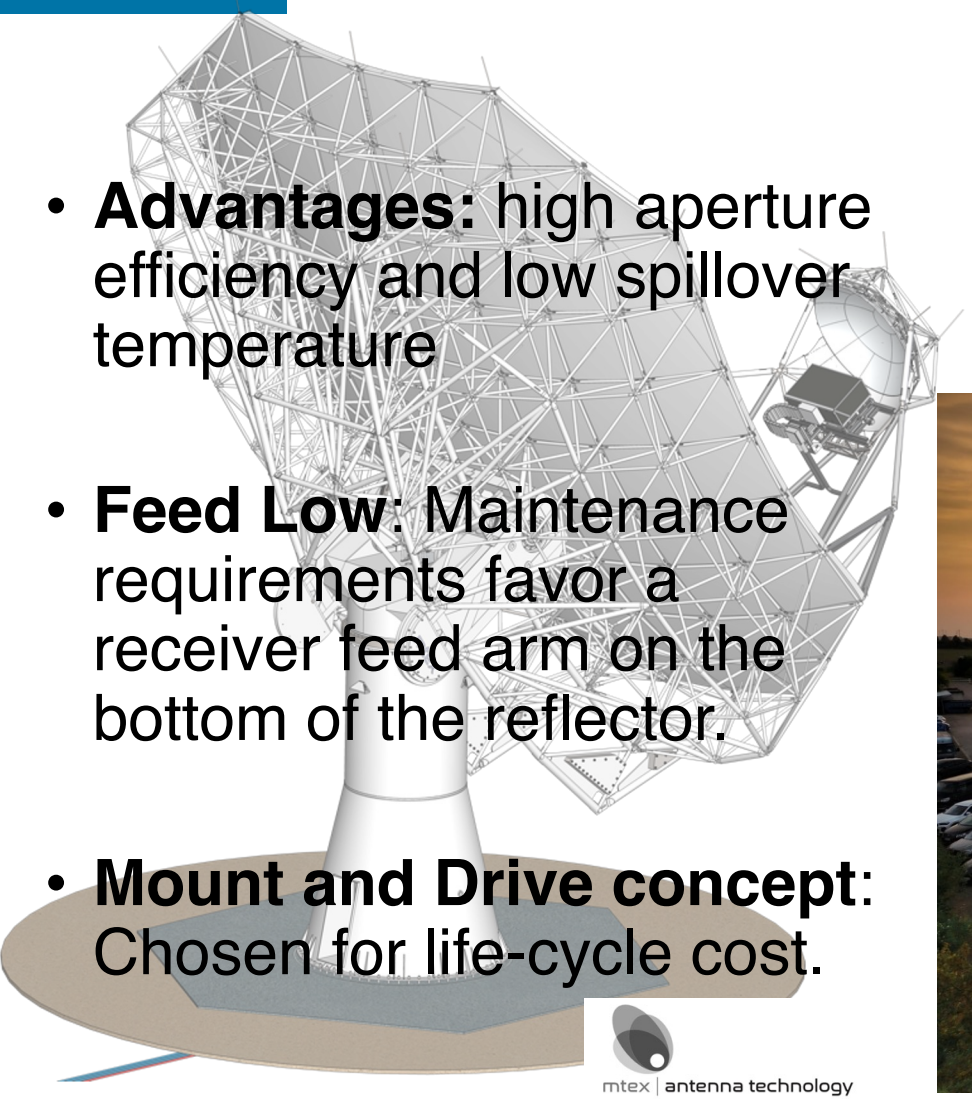




# Main Antenna Development




- **Advantages:** high aperture efficiency and low spillover temperature
- **Feed Low**: Maintenance requirements favor a receiver feed arm on the bottom of the reflector.
- **Mount and Drive concept**: Chosen for life-cycle cost.

| Key Specifications | |
|---|---|
| 18m Aperture | Offset Gregorian |
| Shaped Optics | 3° Slew & Settle in 7 sec |
| Surface: 160 µm rms | Reference pointing: 3” rms |

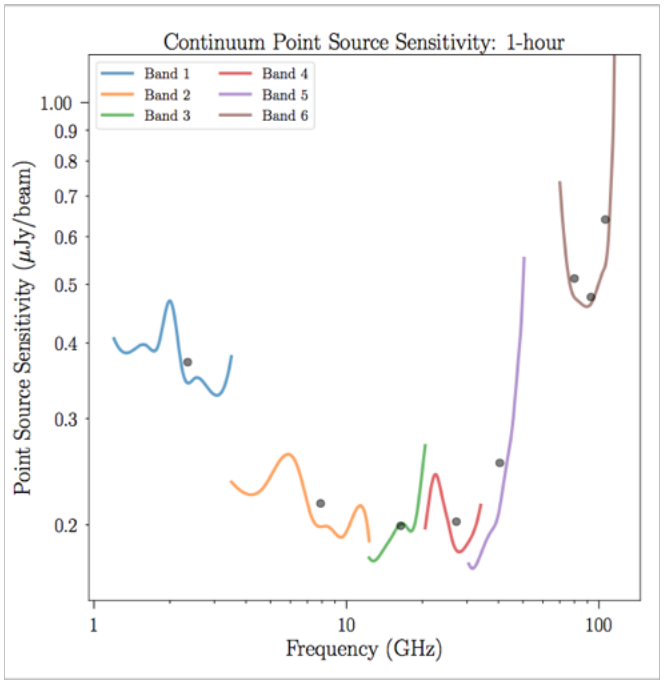

# *Performance Estimates and Metrics*

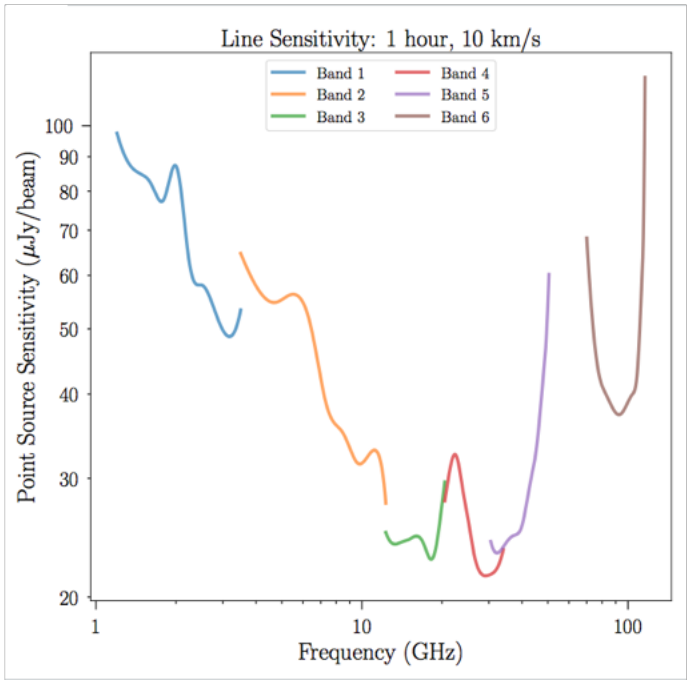
ngvla
Next Generation Very Large Array

| Band # | $f_L$ GHz | $f_M$ GHz | $f_H$ GHz | $f_H$: $f_L$ | Max BW GHz | rms 1hr uJy | Resolution mas |
|---|---|---|---|---|---|---|---|
| 1 | 1.2 | 2.35 | 3.5 | 2.91 | 2.7 | 0.24 | 11.96 |
| 2 | 3.5 | 7.90 | 12.3 | 3.51 | 8 | 0.14 | 3.58 |
| 3 | 12.3 | 16.4 | 20.5 | 1.67 | 8 | 0.16 | 1.71 |
| 4 | 20.5 | 27.3 | 34.0 | 1.66 | 14 | 0.17 | 1.03 |
| 5 | 30.5 | 40.5 | 50.5 | 1.66 | 20 | 0.21 | 0.69 |
| 6 | 70.0 | 93.0 | 116 | 1.66 | 20 | 0.40 | 0.30 |

# Performance: Estimated Sensitivity vs Frequency

ngVLA Main+Long




***For naturally weighted images.***
***Takes into account maximum continuum bandwidth, receiver temperature, aperture efficiency, atmospheric conditions and spillover.***



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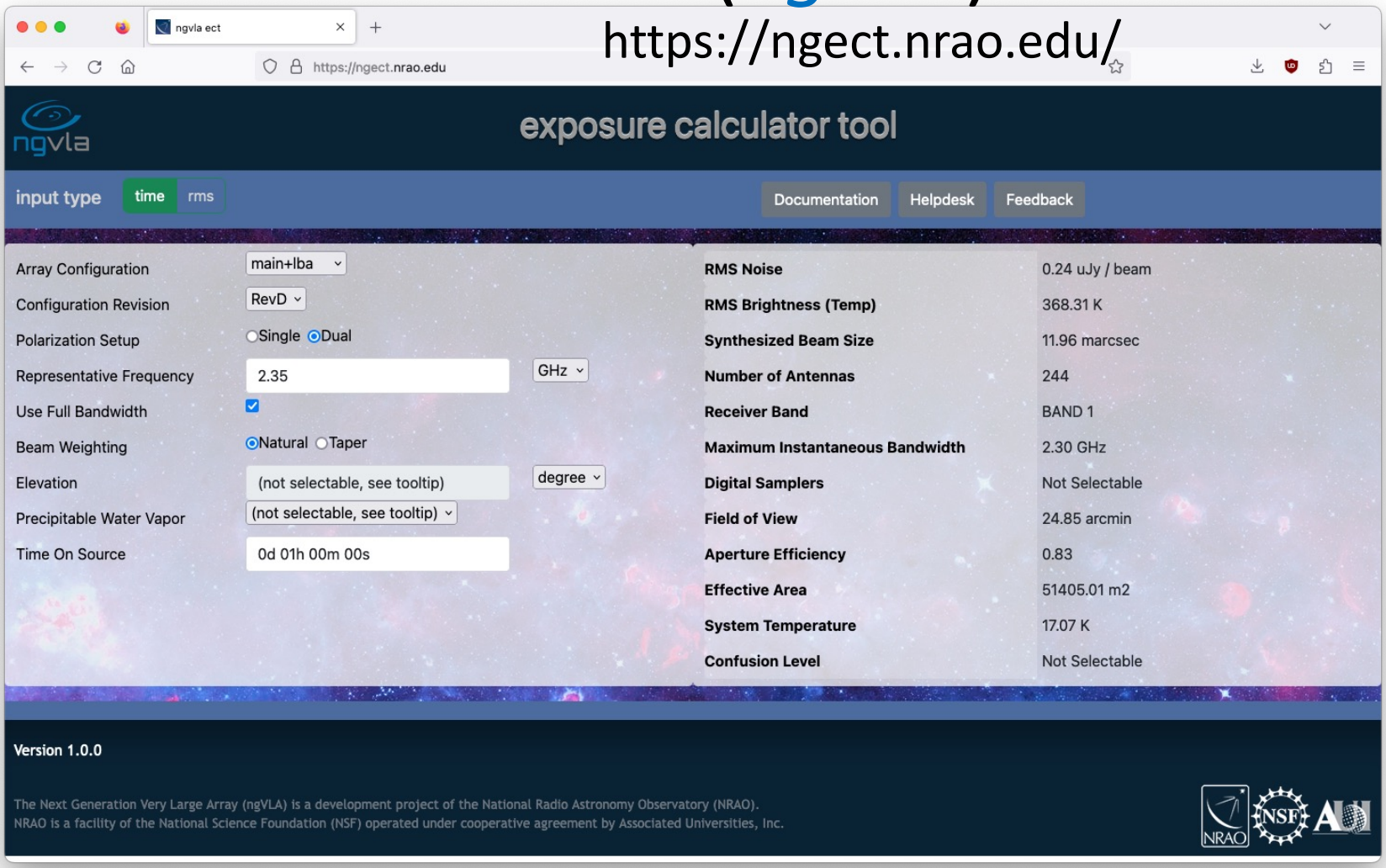
# next generation Exposure Calculator Tool (*ngECT*)

https://ngect.nrao.edu/



# Simulations

Predict how your source will look with different interferometer options

- The set up: array configuration, frequency, timing
- The source model: e.g., a real or theoretical image
- Add desired amount of noise: real vs scaled
- Account for calibration effects: amplitude, phase, pointing errors

https://casaguides.nrao.edu/index.php/Simulating_ngVLA_Data-CASA5.4.1

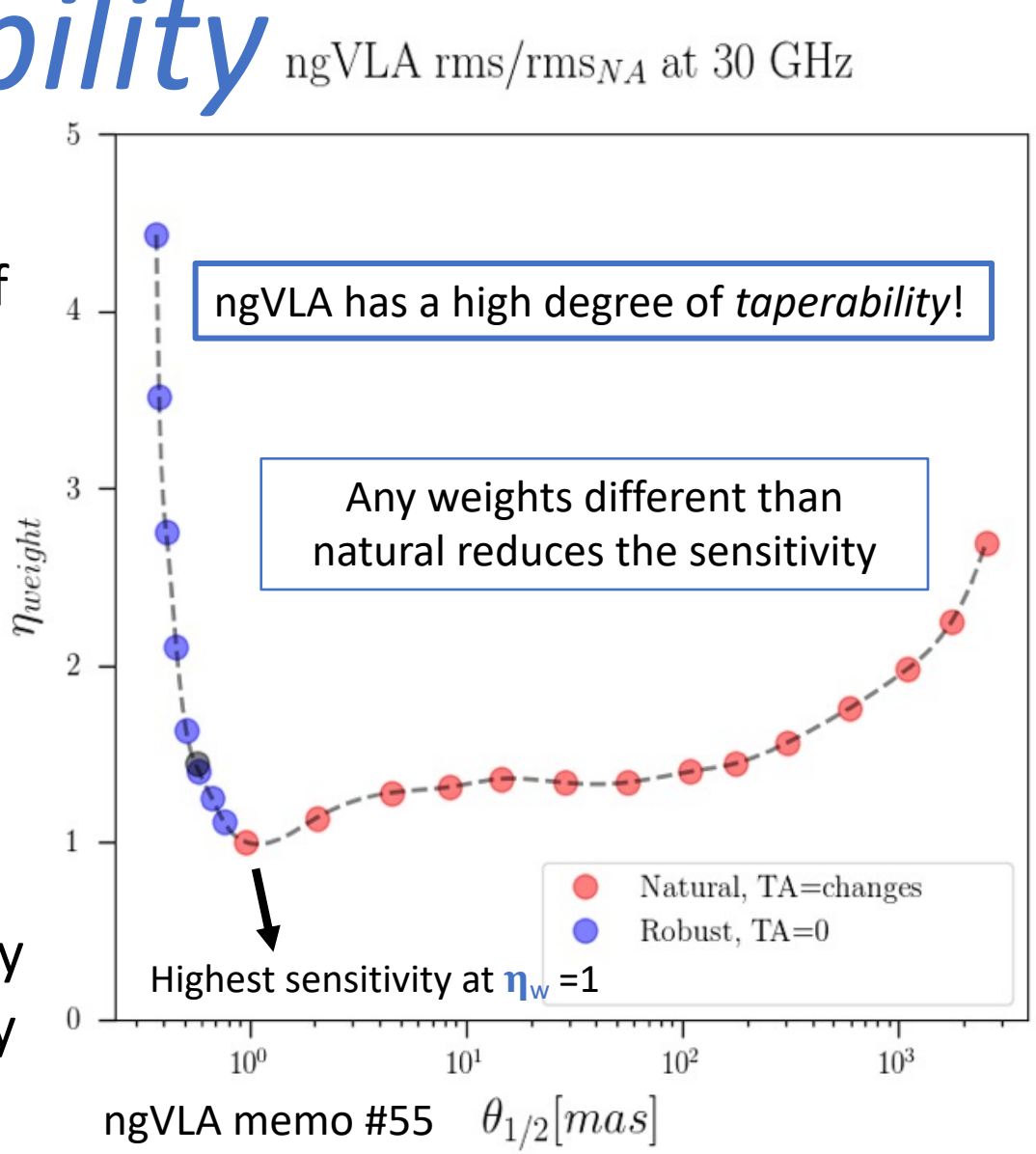
# Simulations

Study the expected performance of the ngVLA

- Change in sensitivity as a function of spatial scale
- Response of the array for specific subarrays
- Image fidelity

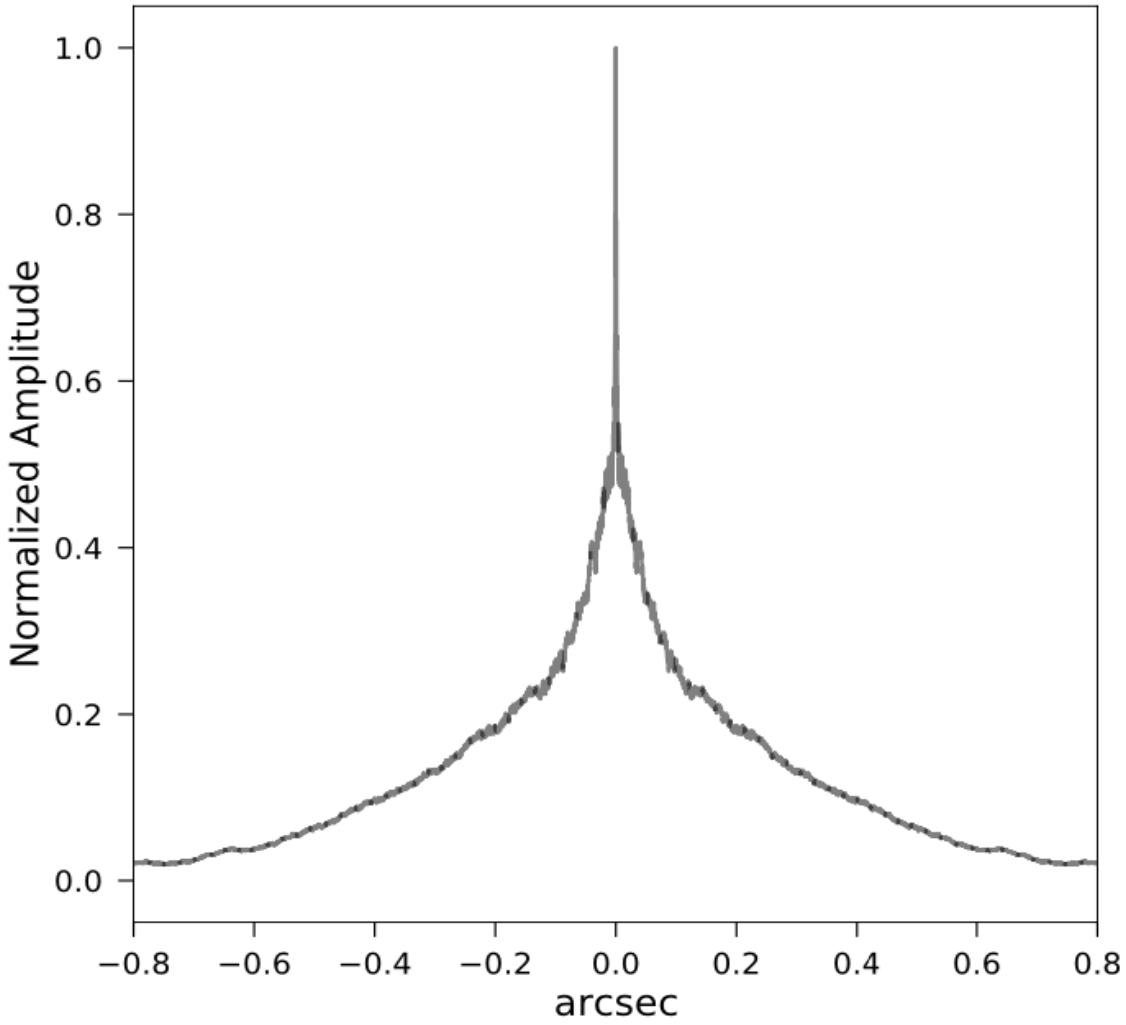
# Taperability

- Predicting change in sensitivity as a function of spatial scale
- $\eta_w$ inefficiency factor to account for change in sensitivity due to the use of image weights
- Allow to achieve desired resolution with a relatively small penalty in sensitivity




ngVLA memo #55

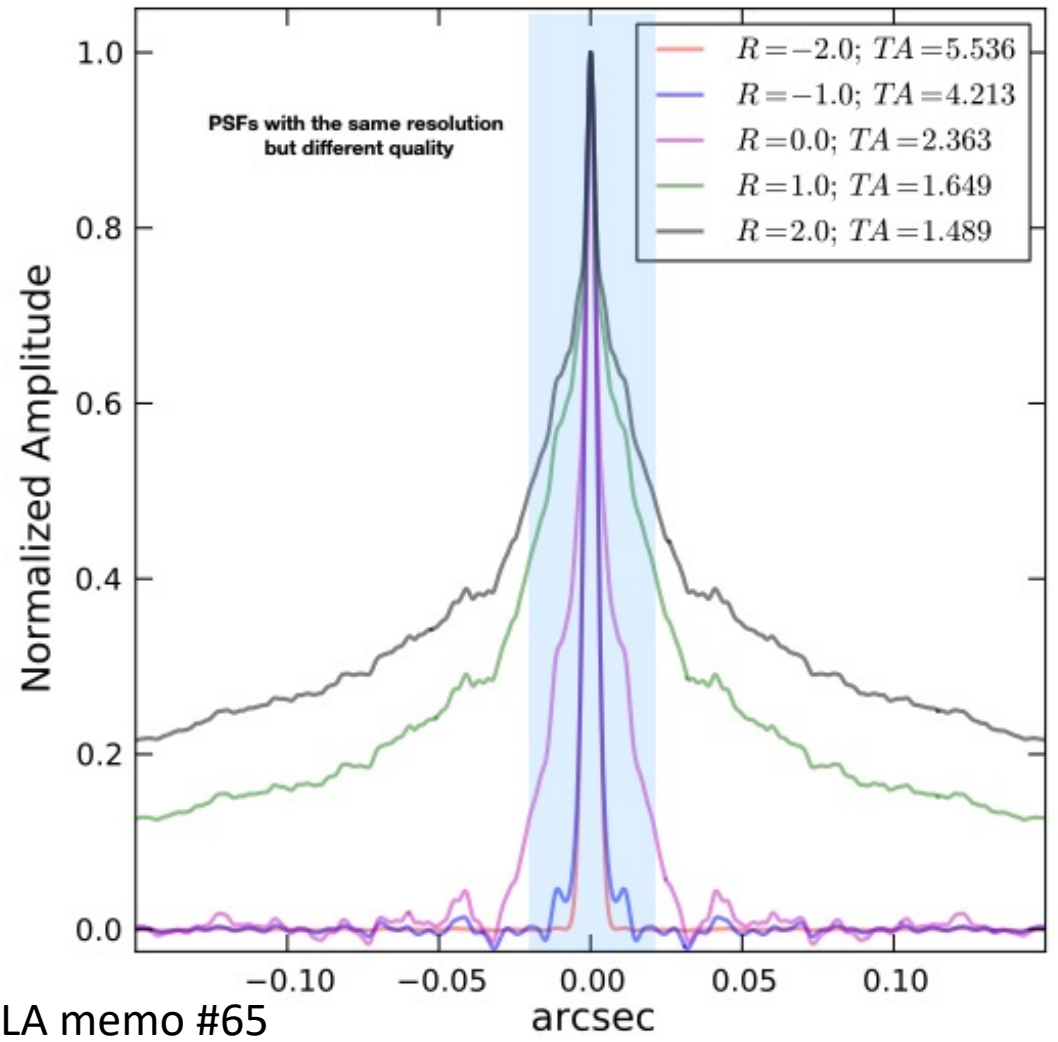
# ngVLA Natural PSF



# *Sculptability*: Simulated Resolution and PSF

- Scientific cases may need beam '*sculpting*'
- Combinations of robust and taper allow for more 'Gaussian' beam at the expense of sensitivity

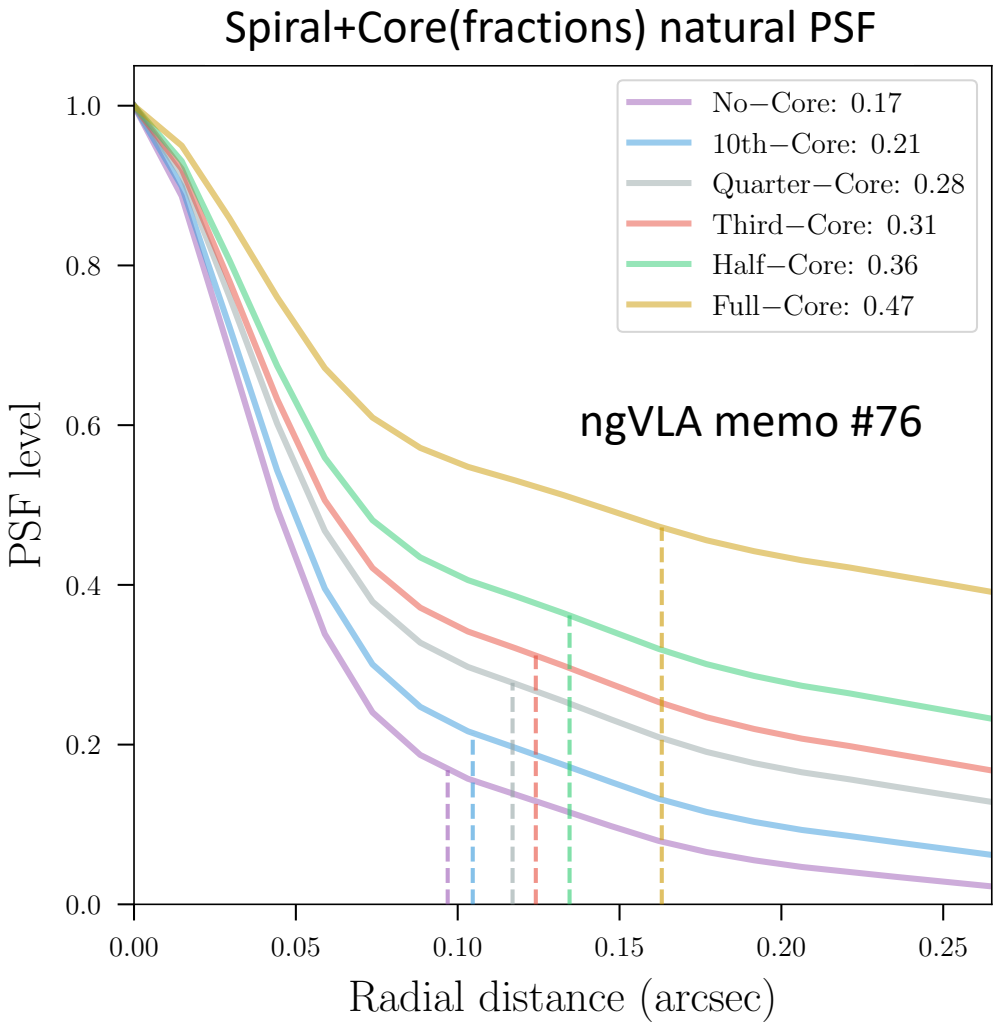
Finding an optimum compromise between sensitivity and PSF quality




ngVLA memo #65

# Selecting Subarrays: alternative for beam sculpting

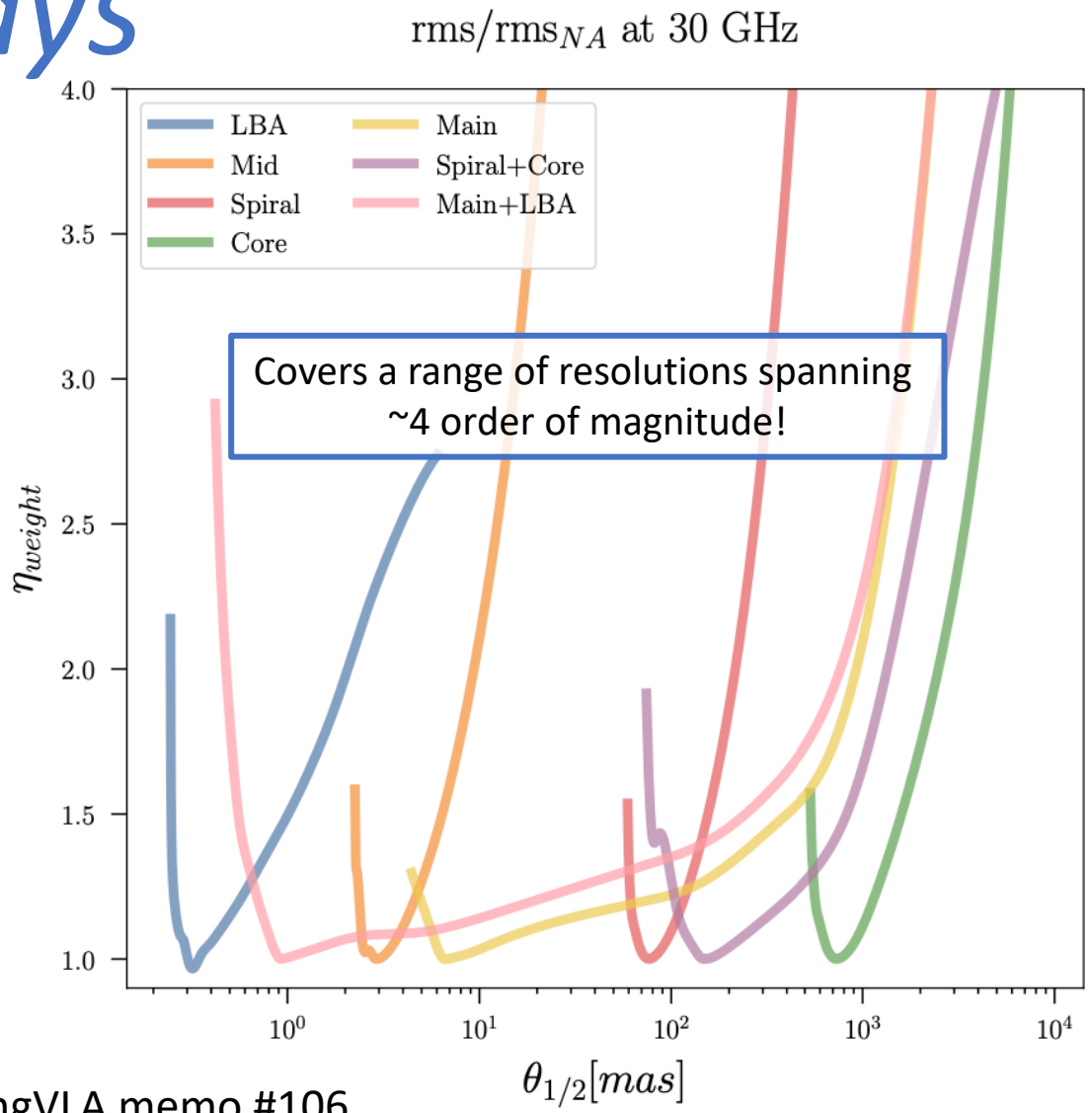
Subarrays that ‘naturally’ produce a more Gaussian PSF will require less extreme imaging weights and therefore will incur a less severe sensitivity penalty.



# Subarrays

ngVLA memo #121

- Each subarray is efficient over a narrow resolution range
- For some ‘low resolution’ projects: observation time is about the same if we include all antennas using uv-taper vs a subarray




ngVLA memo #106

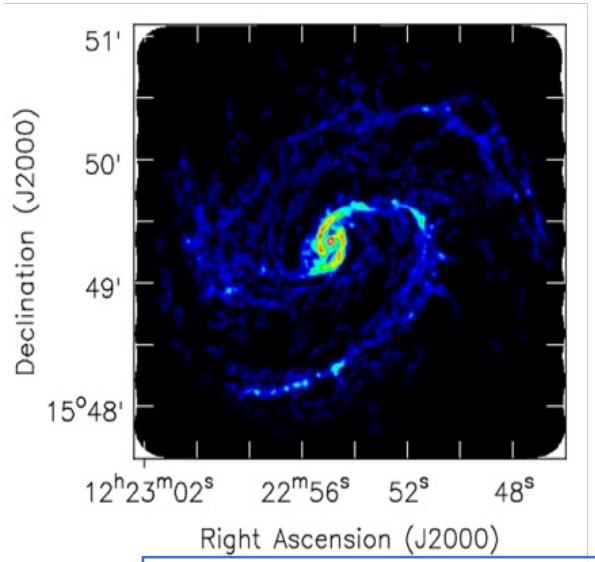
# Image Fidelity

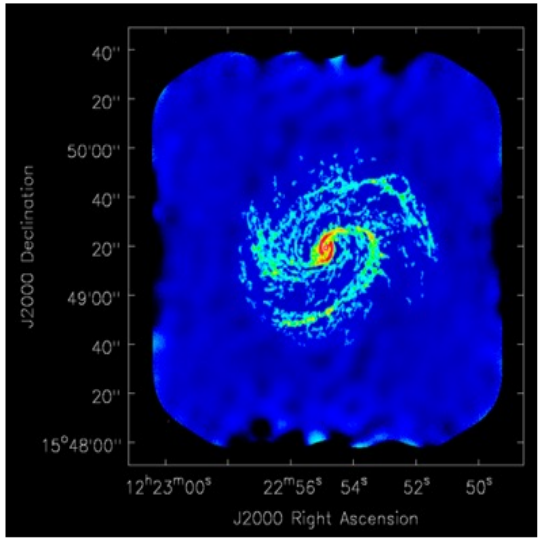
**Correctness of the reconstruction for ngVLA > 98%**

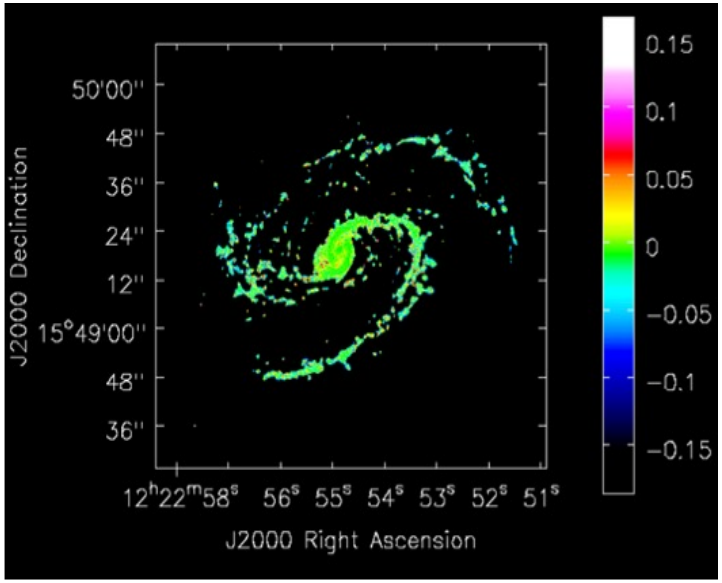
Recovery of larger scales; fill more of the central uv-plane

Measure integrated flux

Model: PHANGS NGC 4321 Image: 18m+ SBA+TP Fidelity = (Image-Model)/Model




Complex sources require spatial dynamic range: large scales and small details

ngVLA memo #89

# Successful Community Activities and International Engagement

*Broad Participation Largely Dominated by Early Career Astronomers*

http://go.nrao.edu/ngVLA18

http://go.nrao.edu/ngVLA19

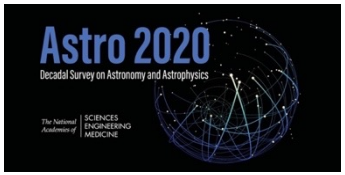
http://go.nrao.edu/ngVLA22

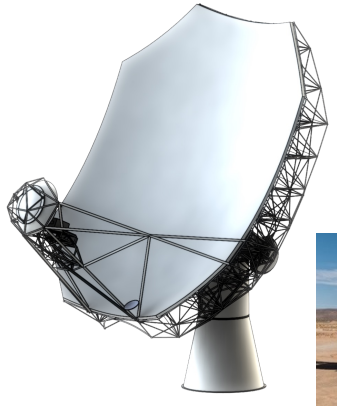
ngVLA Short Talk Series

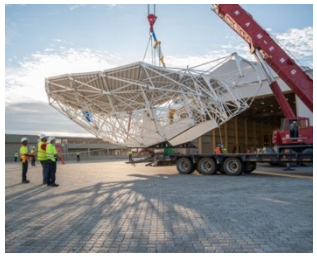
- Annual Science Meetings
- Short Talk Series
- Community Studies
- AAS Special Sessions

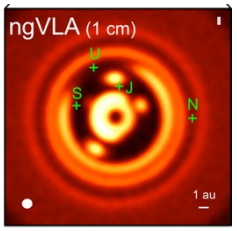

http://go.nrao.edu/ngVLASKA

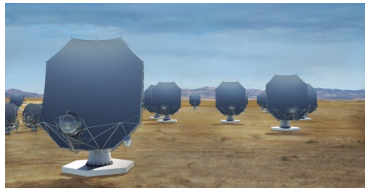
# Project Timeline

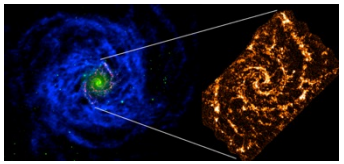


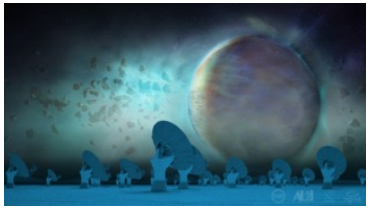











2019 — 2021 — 2024 — 2028 — 2031 — 2037

- 2019: ngVLA Submission to Astro2020
- 2021: Astro2020 Recommendation Published
- 2024: Submit ngVLA Proposal to NSF/MREFC
- 2028: Prototype Delivered to VLA Site
- 2028: Complete NSF/MREFC FDR
- 2028: ngVLA Construction →
- 2031: Initiate ngVLA Early Science (> VLA capabilities)
- 2037: Achieve Full Science Operations

# Summary

The ngVLA will be a powerful and versatile instrument for the next generation of radio astronomers

It is designed to meet the needs of many different key science goals across Galactic and extragalactic astronomy

# Summary

- Community engagement continues (e.g., through science meetings, community studies, and science and technical advisory councils).
- Project management and systems engineering execution on-going.
- Development of ngVLA conceptual design packet well underway
- International and industrial partnerships on-going.
- We will have an Antenna on the plains of San Agustin late 2024!
- ***All made possible by strong community and NSF support!***


Next Generation Very Large Array