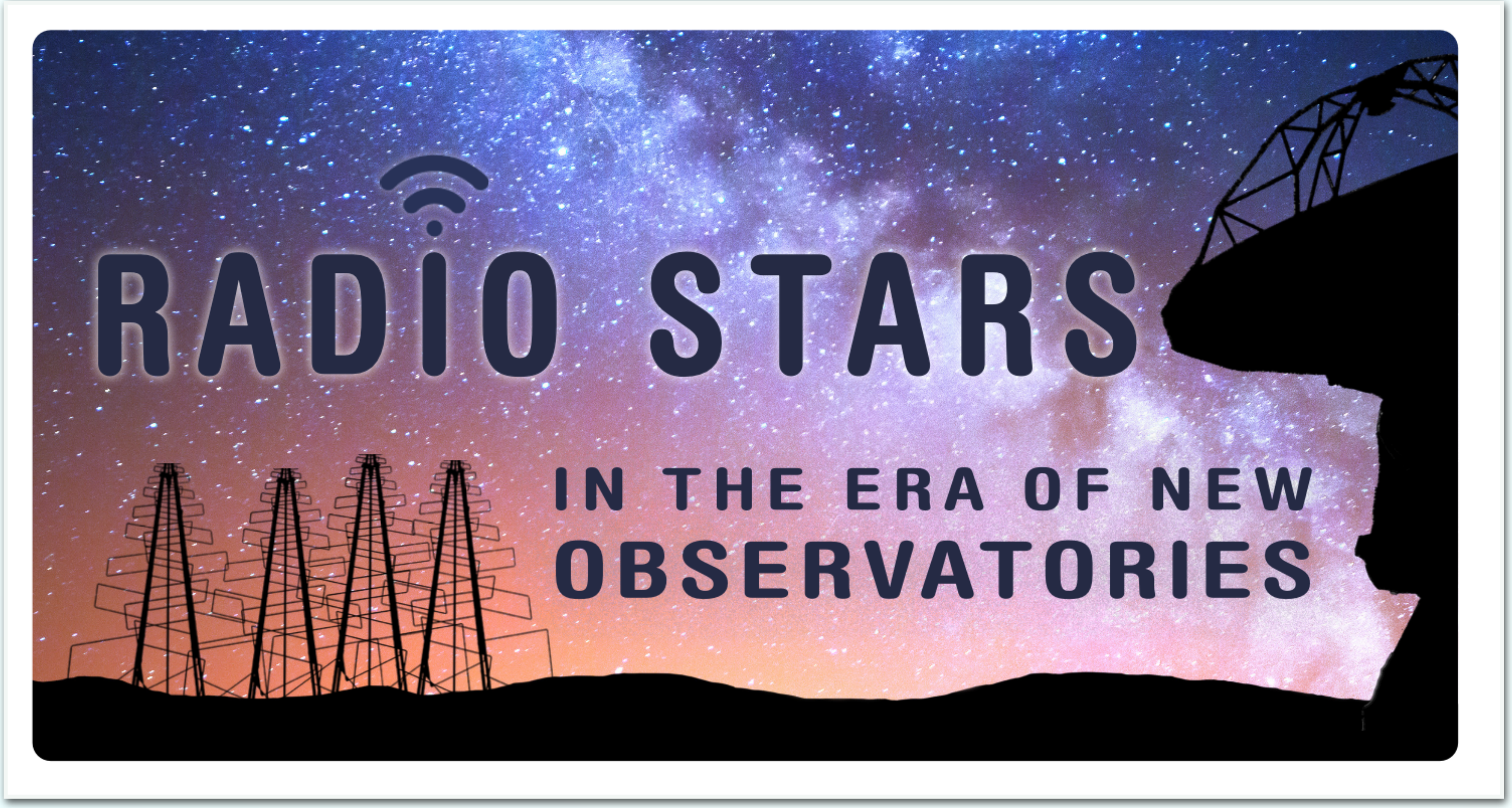
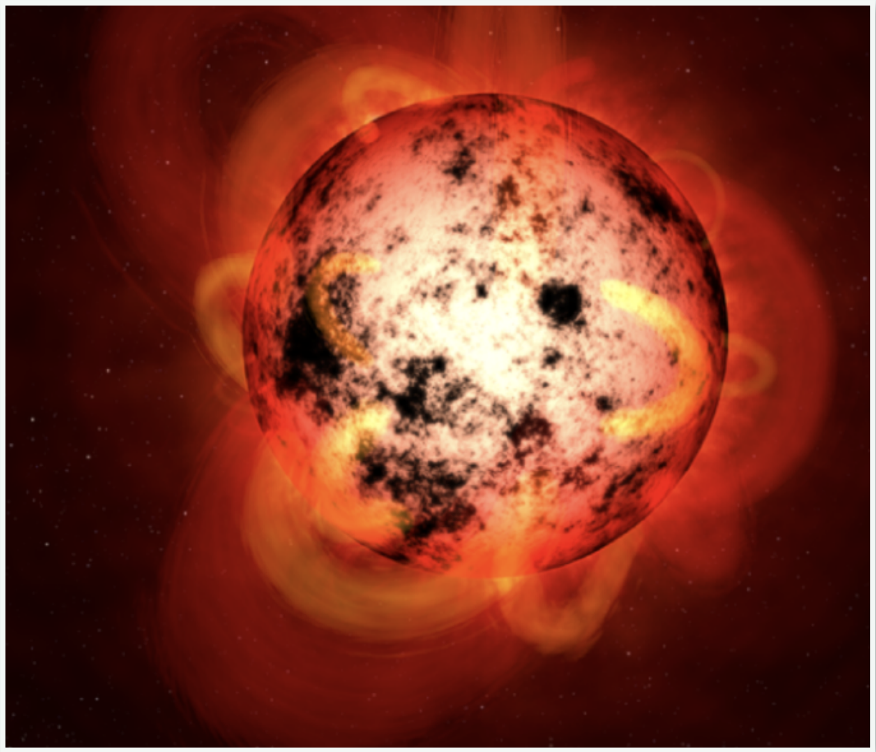


~~*Summary*~~ ~~and~~ **Perspectives for the future**

Robert Mutel, University of Iowa

Stellar radio astronomy in one slide

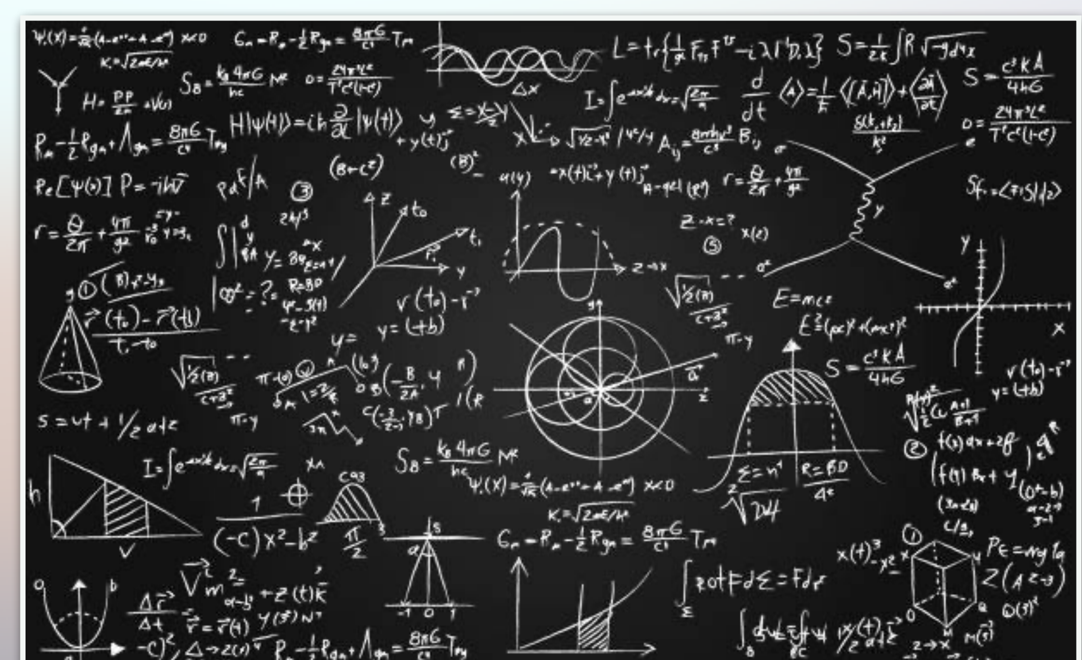


Nature's
Filter

Actual physical environment

Magnetic field, electron density, energy, temperature, spatial and temporal distribution,...

Low-energy photons ($10^{-6} < E < 10^{4}$ eV)



Stellar radio emission is ubiquitous, spanning [nearly] all stellar types

But detection is frequency-dependent, limited by sensitivity of existing survey telescope arrays

Example:

The radio Sun would be undetectable at a few pc distance with current telescopes

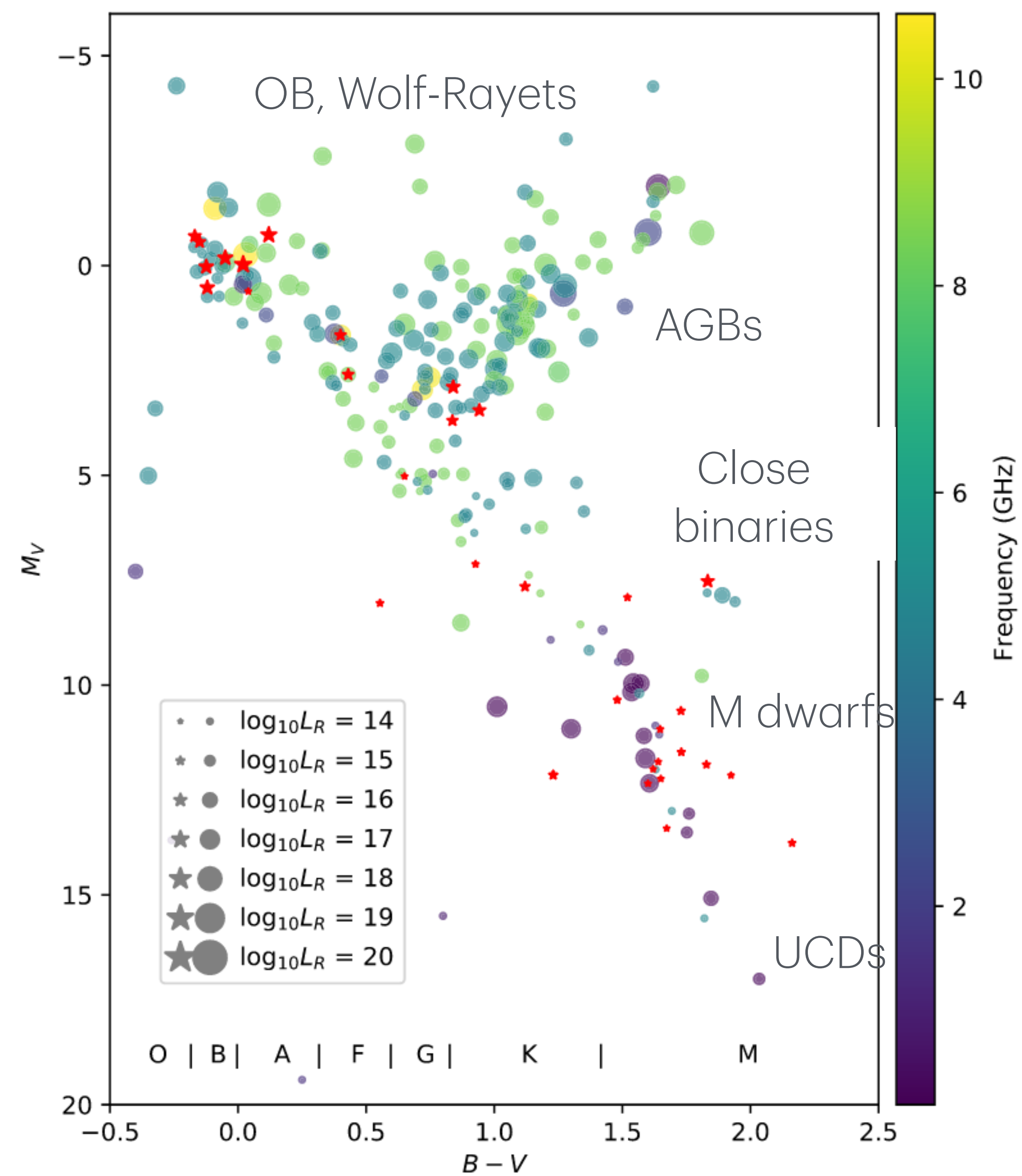


Figure 2. Radio-selected Hertzprung–Russell diagram, showing 231 previously detected radio stars (Wendker 1995) as circles with our sample overlaid as red stars. The size of each marker represents the greatest radio luminosity recorded for that star, and the colour map indicates the observing frequency. Prichard et al MNRAS 2021

After 75 years, we still have fundamental questions, all addressed in this meeting, that stellar radio astronomy is especially well-suited to contribute:

Audience: Think of your favorite question

- How is the solar (and all) stellar corona heated?
- Can we reliably predict space weather hazards? (CME characterization, other stars?)
- Exoplanets:
  - Do some/all have significant magnetic fields?(direct detection of ECMI)
  - Can we detect exoplanets using radio techniques? (astrometric VLBI)
- Star formation:
  - What is the role of the magnetoplasma (esp. in solving the angular momentum problem)?
  - Build a comprehensive picture of complex astrochemistry in SFR
- Why do fully convective stars (late-M, UCD's) have such large magnetic fields?
- Where is the energetic plasma in interacting binaries?
- Why are planetary nebulae morphologies so complex? How do they evolve from MS stars?
- What is the galactic distribution of evolved stars ?

And finally, what is up with Betelgeuse??

In order to make progress on these questions, we need:

Better instruments [more sensitive, higher resolution, most $$$]

Better analysis tools* [AI, ML, HPC]

Clever ideas [hardest]

** Only 1 ML reference at conference, no AI*

Clever ideas can be found in unusual settings...

Einstein's small apartment in Bern
During his Annus Mirabilis (1905)

Personal Historical note

First maps of the mas-structure of "radio stars" were made exactly 40 yrs ago [1984]

6-telescope VLBI array including Haystack

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DUAL POLARIZATION VLBI OBSERVATIONS OF STELLAR BINARY SYSTEMS AT 5 GHz

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AND

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Haystack Observatory
Received 1984 March 26; accepted 1984 August 15

ABSTRACT

The milli-arcsecond (mas) radio structures of seven binary stellar systems (σ CrB, SZ Psc, HR 1099, UX Arietis, HR 5110, Algol, and Cyg X-1) were determined using an intercontinental VLBI array at 5 GHz. Two sources (HR 5110 Arietis) were undergoing intense radio outbursts during the observations. Four of the seven sources were fitted with single Gaussian brightness distributions with θ(FWHM) ranging from 0.5 mas to 2.0 mas, corresponding to brightness temperatures 2×10^8 K $\leq T_B \leq 2 \times 10^{10}$ K. Cygnus X-1 was unresolved, corresponding to a linear size less than 1.4 AU (assuming a distance of 2.5 kpc).

The sources UX Arietis and Algol had a core-halo structure. In each case the core size was smaller than an individual stellar diameter, and the halo was comparable in size to the binary system. The centroid of the halo and core of UX Arietis was offset by $\sim$1.8 mas. For all sources, an upper limit to the angular separation between left- and right-hand circular emission regions was $\theta \leq 0.05$ mas.

A simple expanding coronal loop model is proposed in which a flare event originates in a compact, optically thick source on the surface of the spotted star and radiates by gyrosynchrotron radiation. One or more coronal loops, whose feet are tied to the active region, expand into the outer corona, eventually becoming about as large as the binary system. The long-lasting, quiescent radio emission arises from the expanded loop or loops, which are optically thin at gigahertz frequencies. The model explains the gross features of angular sizes, brightness temperatures, polarization, spectral indices, and time scales observed in most radio observations of RS CVn systems.

Subject headings: interferometry — polarization — stars: binaries — stars: radio radiation

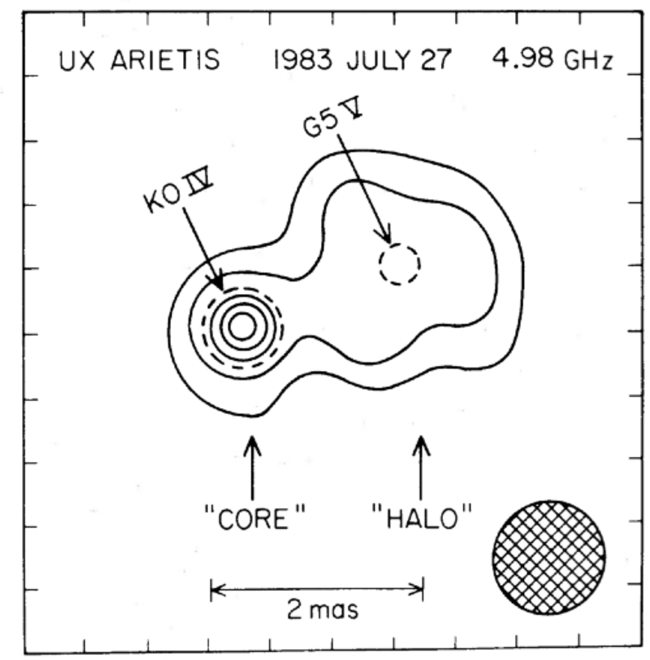


FIG. 4.—Hybrid map of UX Arietis at 4.98 GHz. The restoring beam (shown in lower right corner) is a circularly symmetric Gaussian of θ(FWHM) = 1.0 mas. (N-S structure is somewhat overresolved.) The contour levels are at 25%, 35%, 50%, 70%, and 90% of the peak brightness. The dashed circles show the stellar system at phase 0.2. Note that the alignment of the radio and optical images is conjectural (see text).

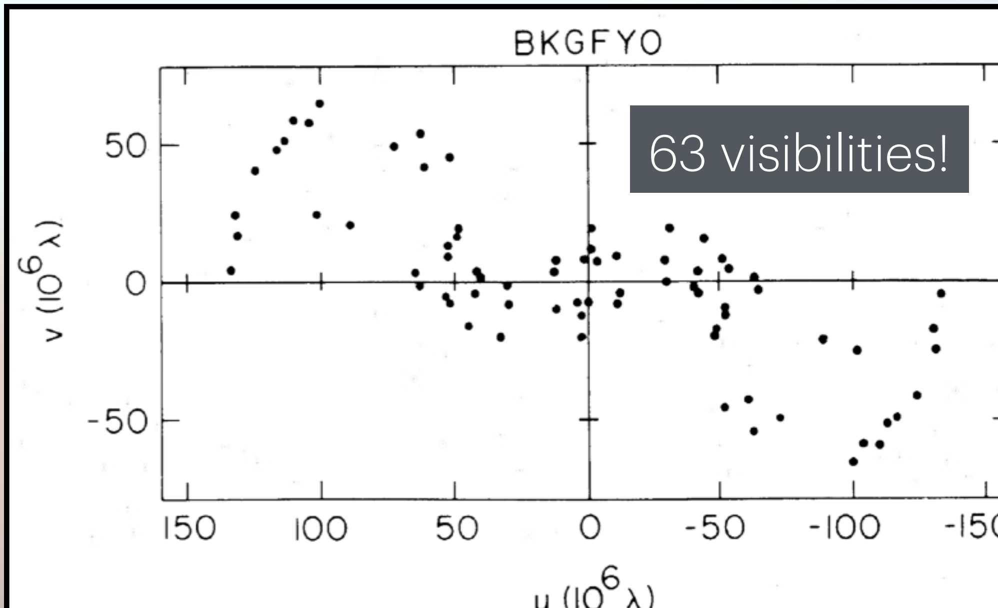
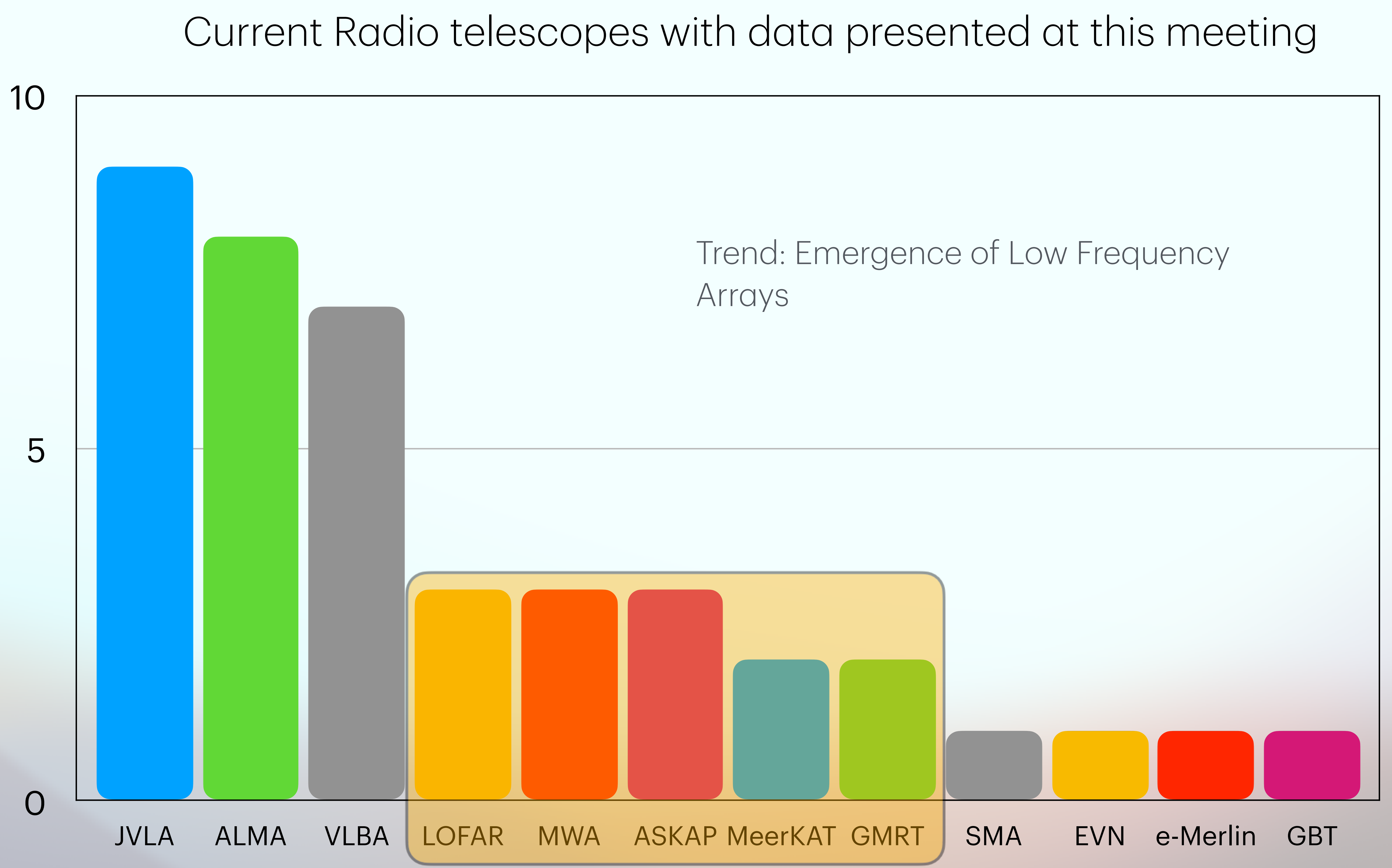


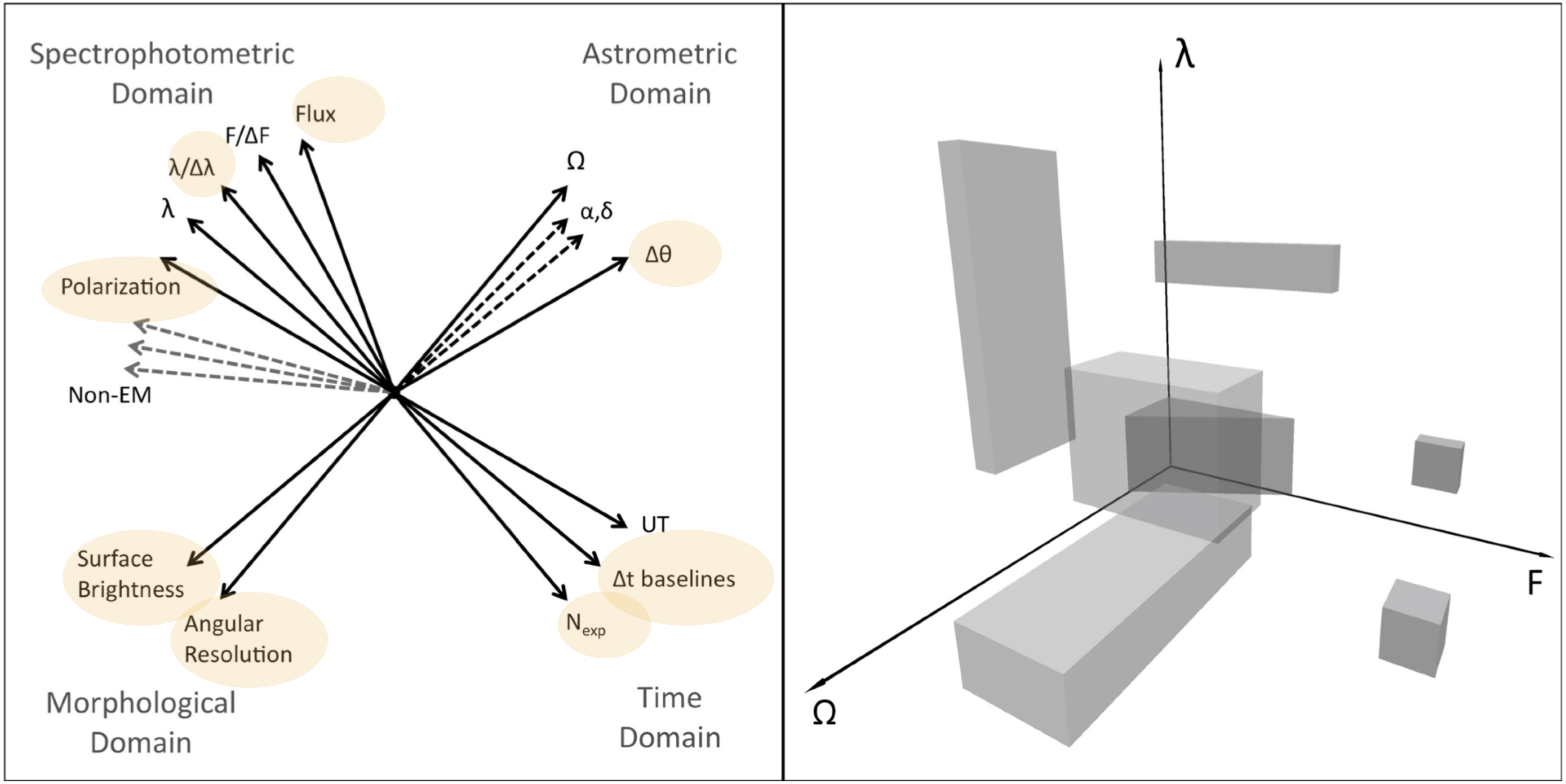
FIG. 2.—Transfer function for UX Arietis observations


Current Radio telescopes with data presented at this meeting
10
5
0
Trend: Emergence of Low Frequency Arrays
JVLA
ALMA
VLBA
LOFAR
MWA
ASKAP
MeerKAT
GMRT
SMA
EVN
e-Merlin
GBT

Why build bigger, more complex (and $$$) radio telescopes?

Observable Parameter Space for Astronomical Discovery

Harwit 1975, Djorgovski 2012



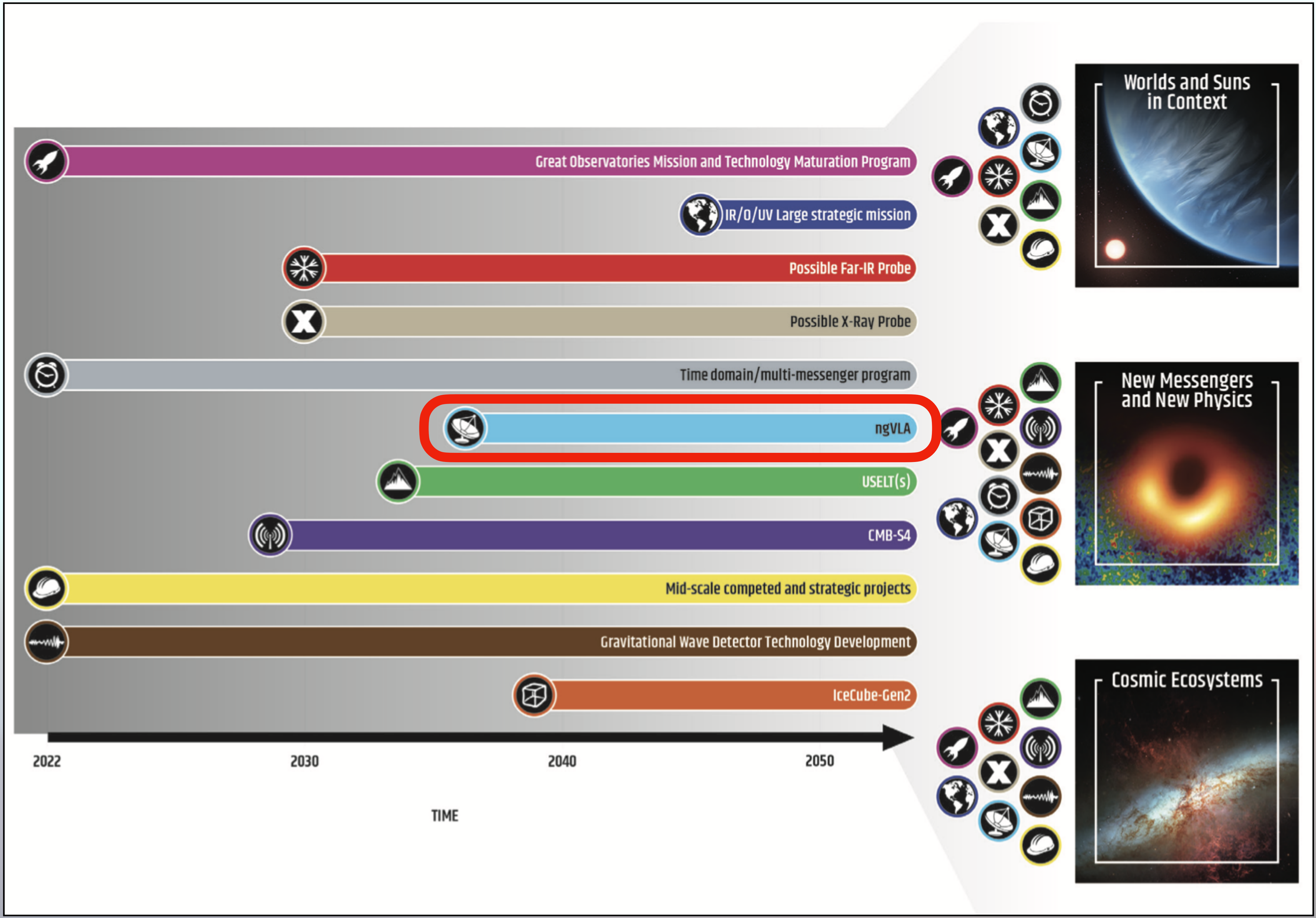
Recent radio astronomy discoveries resulting from exploring observable parameter space: FRBs, UCDs, EHT BH images

A Golden Age for Radio Astronomy is dawning in the next 10 years

This omits many smaller, more targeted telescopes (Solar, HI, etc) and ALMA upgrades

In US, the only major new radio facility in next decade is ngVLA (first light ~2035)

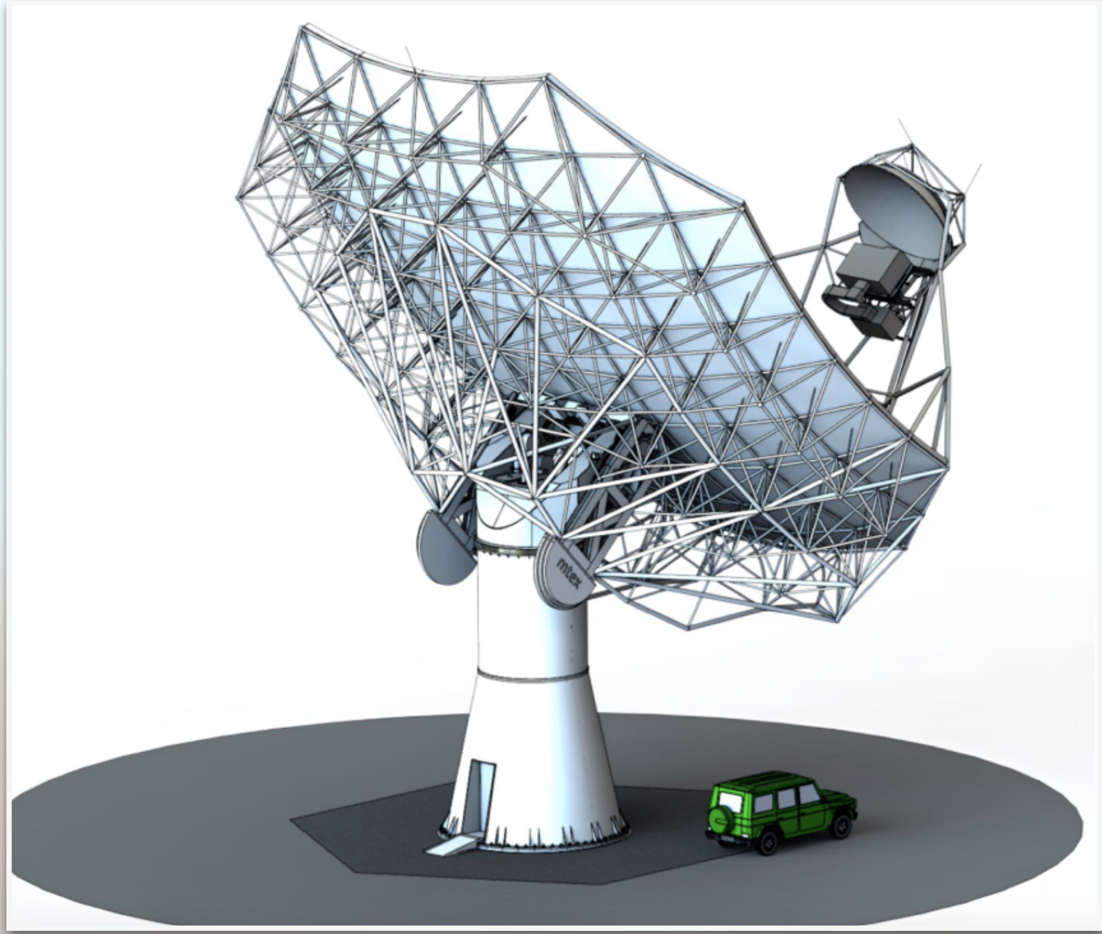
2020 [U.S.] Decadal Survey



New Generation VLA
ngVLA*

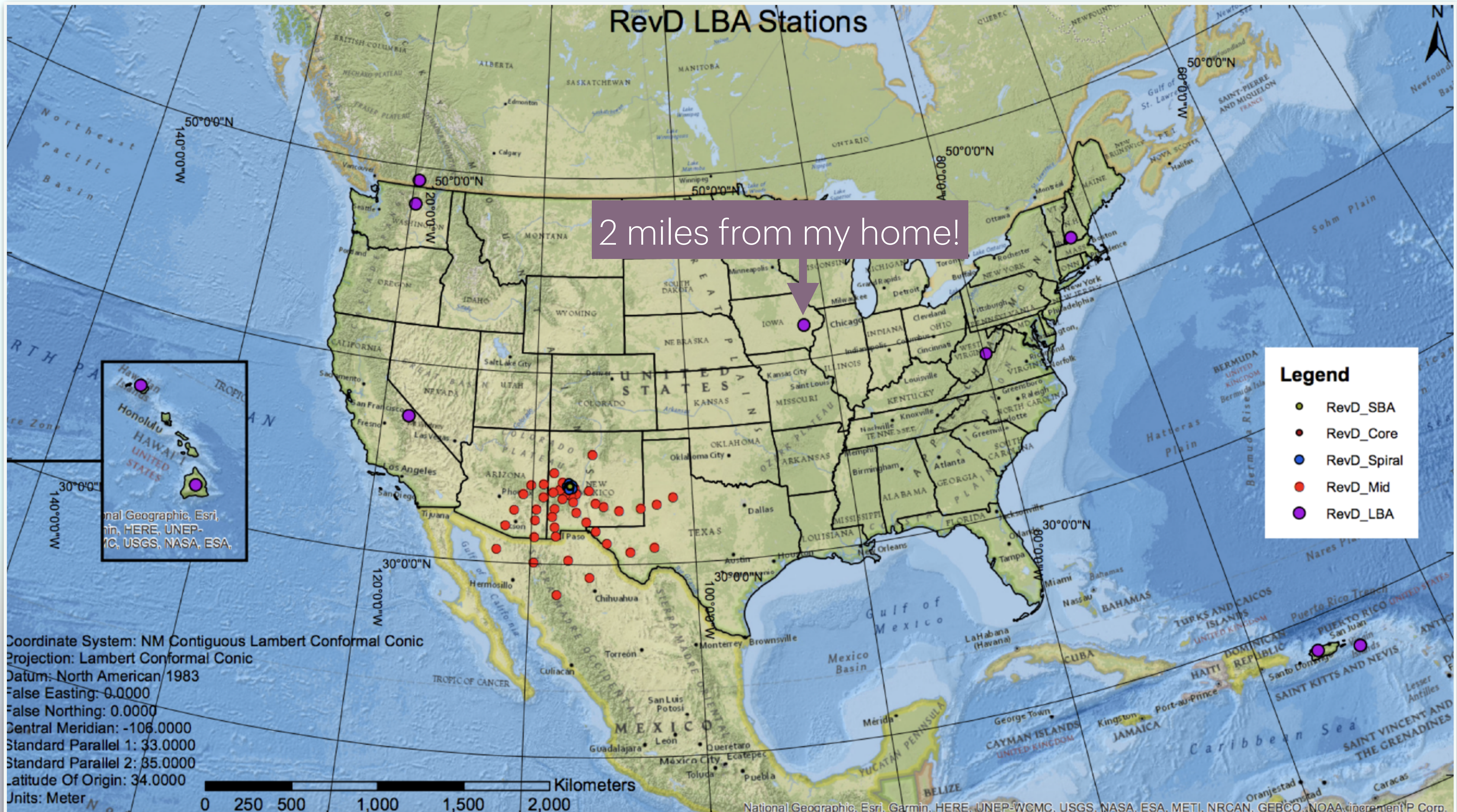
- Main Array: 214 x 18 m reflector antennas
- Short Baseline Array (SBA): 19 x 6 m reflector antennas
- Long Baseline Array (LBA): 30 x 18 m reflector antennas

- 10x sensitivity of JVLA, ALMA
- Sub-mas angular resolution [will replace VLBA]
- Frequency range 2 - 100 GHz

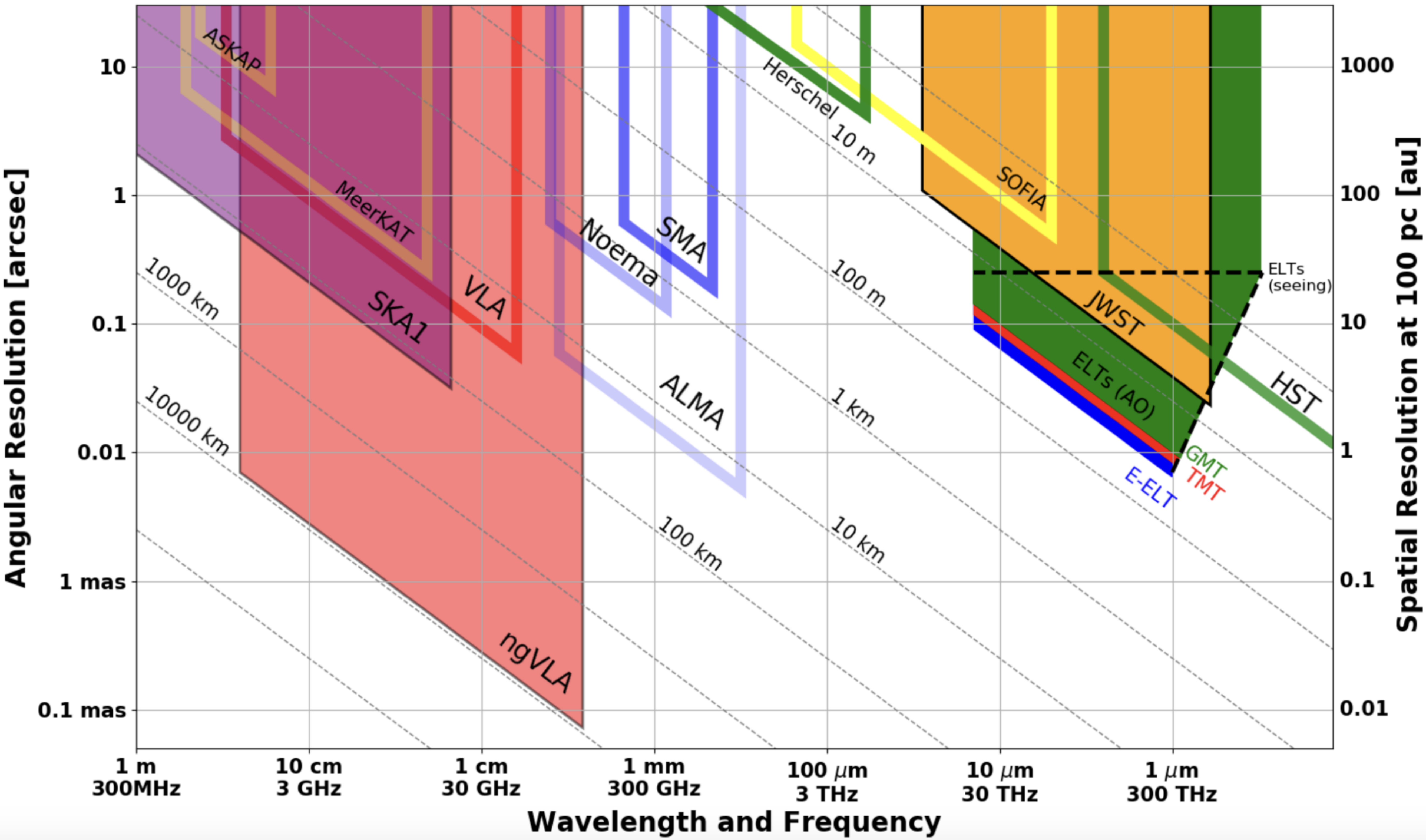


* Can someone create a more appealing name?

Locations of ngVLA telescopes

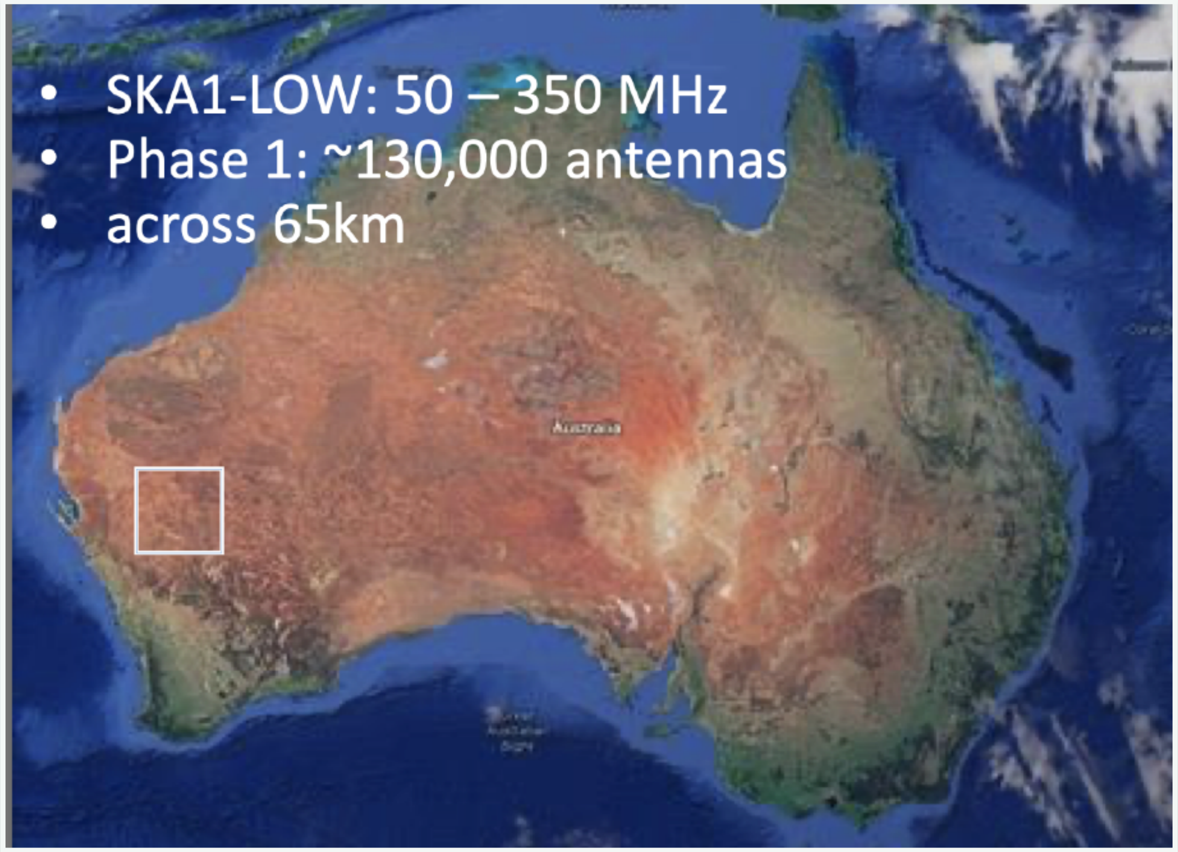


ngVLA: Best angular resolution



SKA-1

Low frequency, Midfrequency arrays in Australia, South Africa

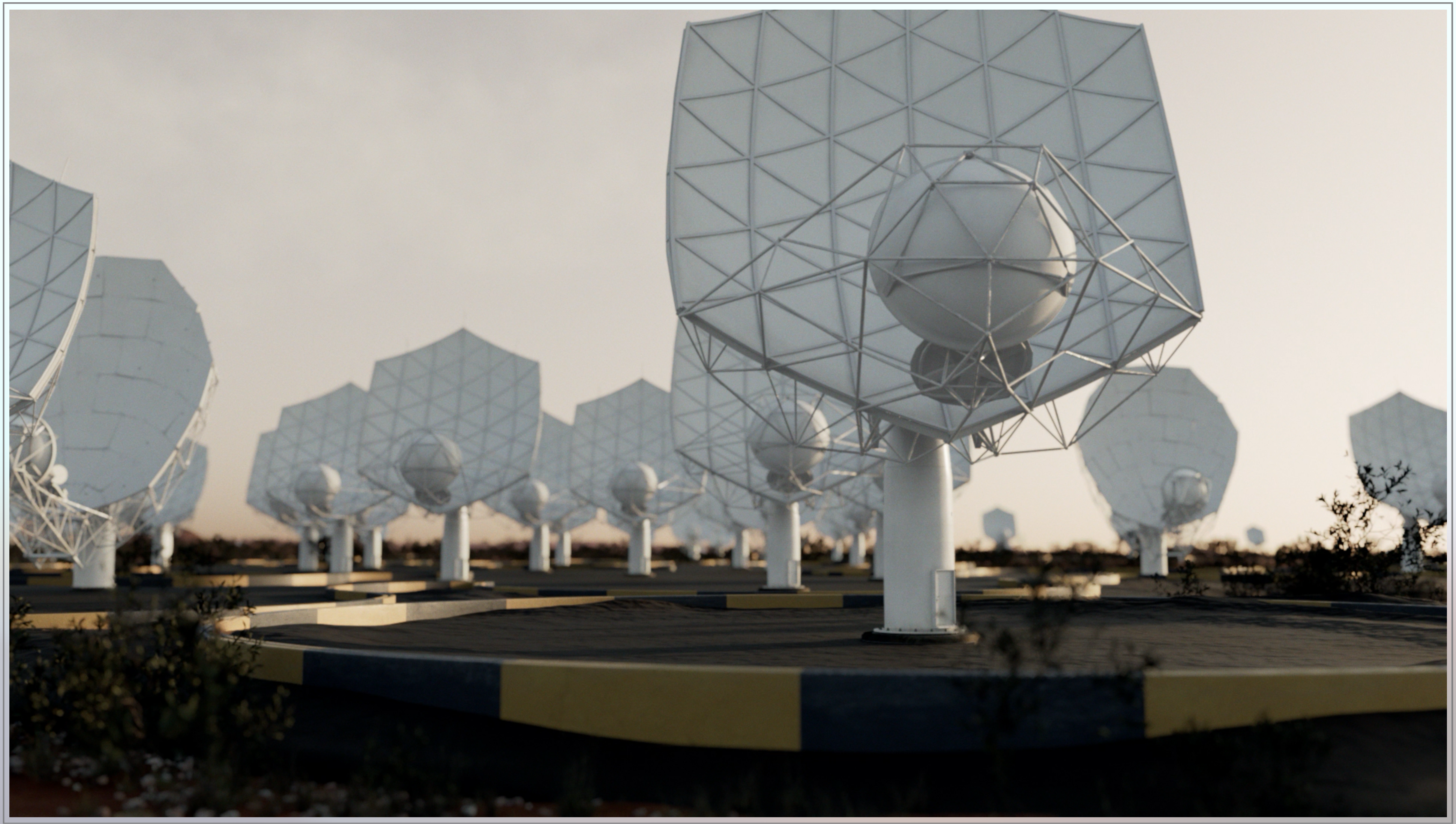


SKA low frequency array

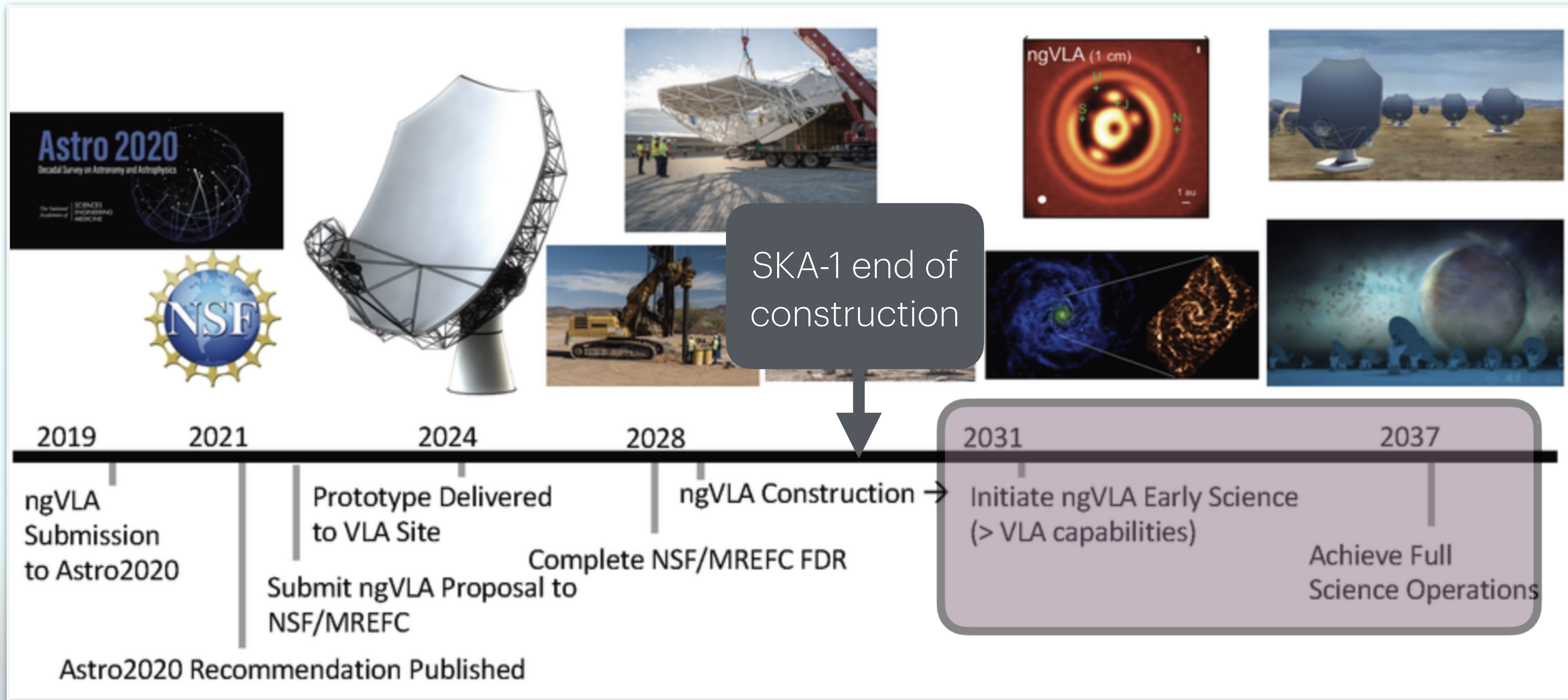
(256 ant x 512 sites = ~ 130,000 Christmas trees)

SKA mid frequency telescopes

(Southern Africa, 191x15m, including the 64 dish MeerKAT array)



ngVLA, SKA1 timelines



Radio Stars 3

Radio Stars 5

Radio Stars 6/7

ngVLA, SKAdata rates: A looming problem

• 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.

But: about user-level analysis tools?

Current AIPS/CASA architecture will completely inadequate

Will AI/ML be able to solve the massive impedance mismatch between the data streams of these instruments and the human astronomer?

Take-home memo

ngVLA and SKA 1 are expensive ($2B+), and are <u>not fully funded</u>

1. Write great science papers
2. Publicize results in many media (not just ApJ etc)
3. Mention that your research would be dramatically improved with ngVLA, SKA [+]