The Next Generation Very Large Array (ngVLA): "Near" Exascale Computing

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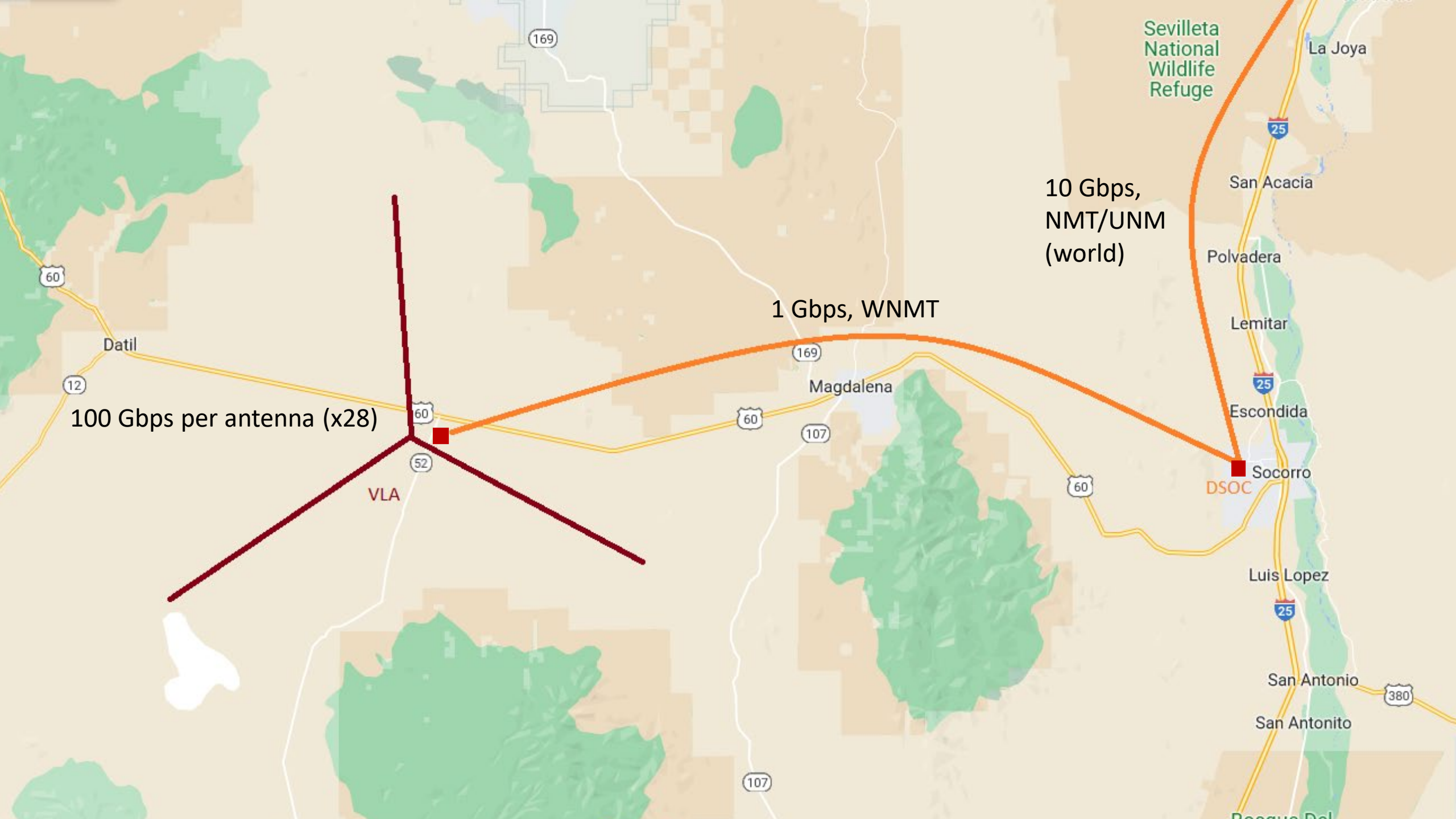
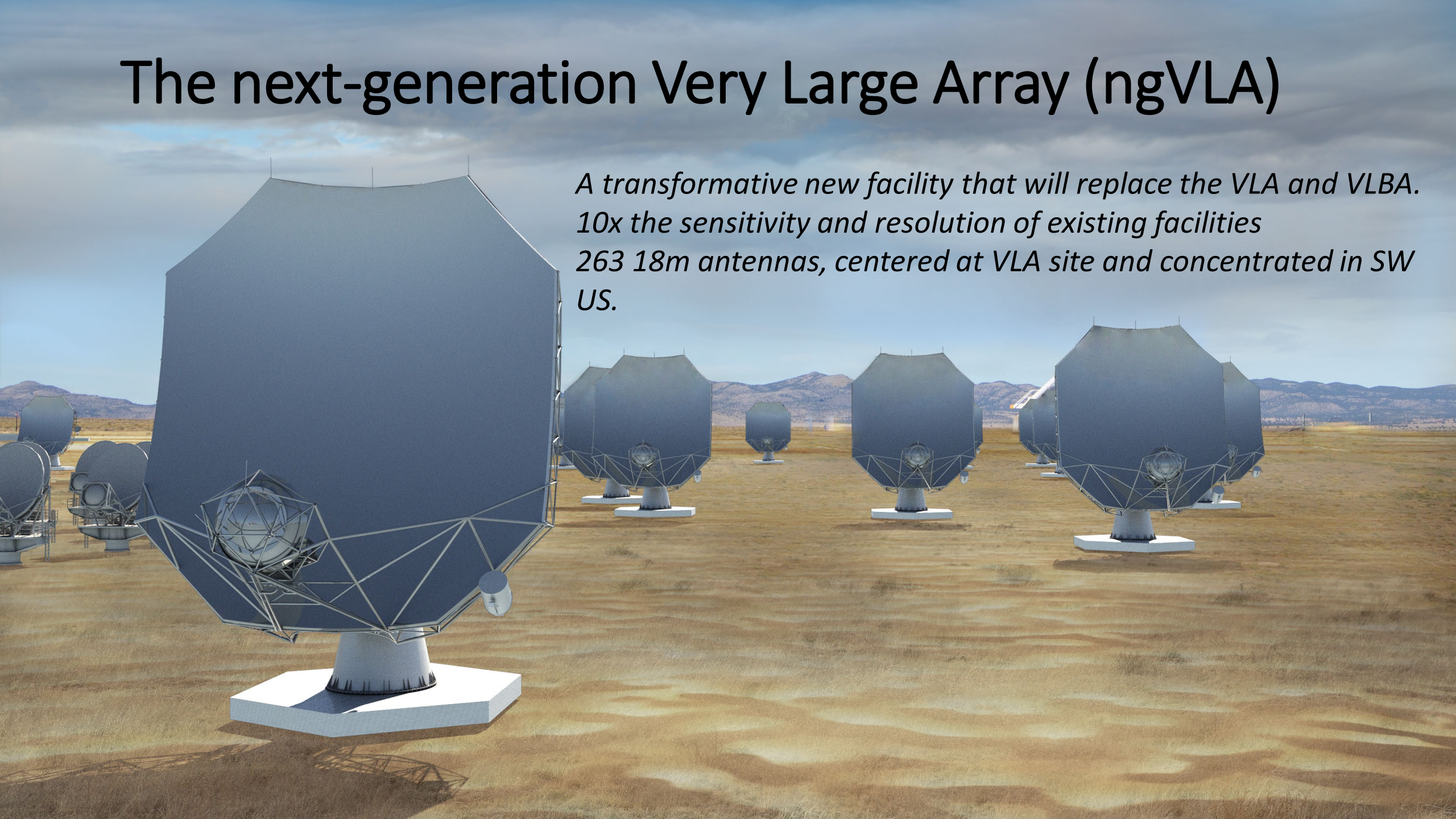
The Jansky Very Large Array

Current data-communications system dates to 2001-2011 Electronics Upgrade:

100 Gbps generated continuously per antenna (x28).
200 Mbps (average) generated by central signal processing system.

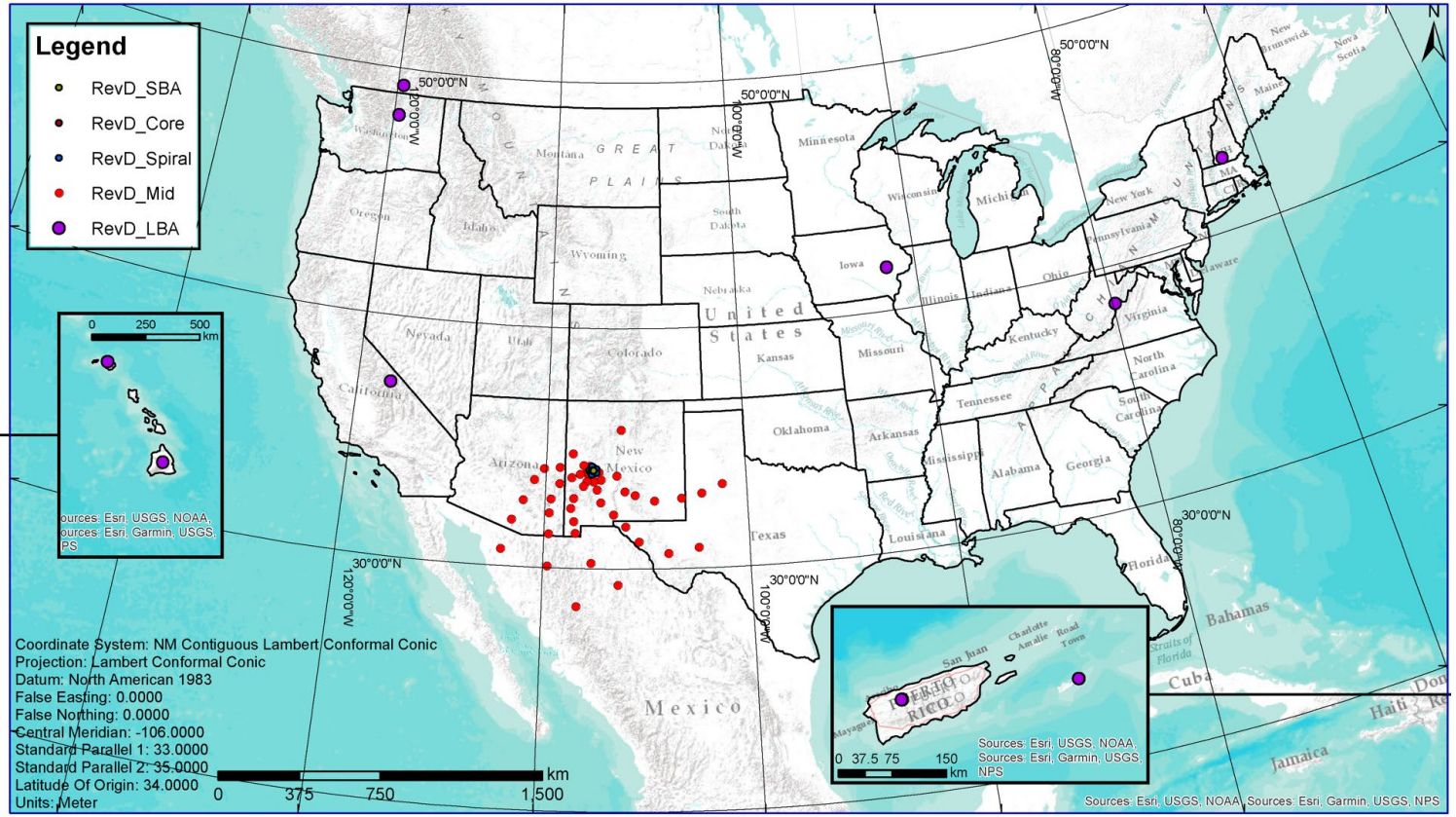

10 Gbps, NMT/UNM (world)
1 Gbps, WNMT
100 Gbps per antenna (x28)
VLA
DSOC
Socorro
Magdalena
Datil
Sevilleta National Wildlife Refuge
La Joya
San Acacia
Polvadera
Lemitar
Escondida
Luis Lopez
San Antonio
San Antonito
169
60
12
52
107
25
380

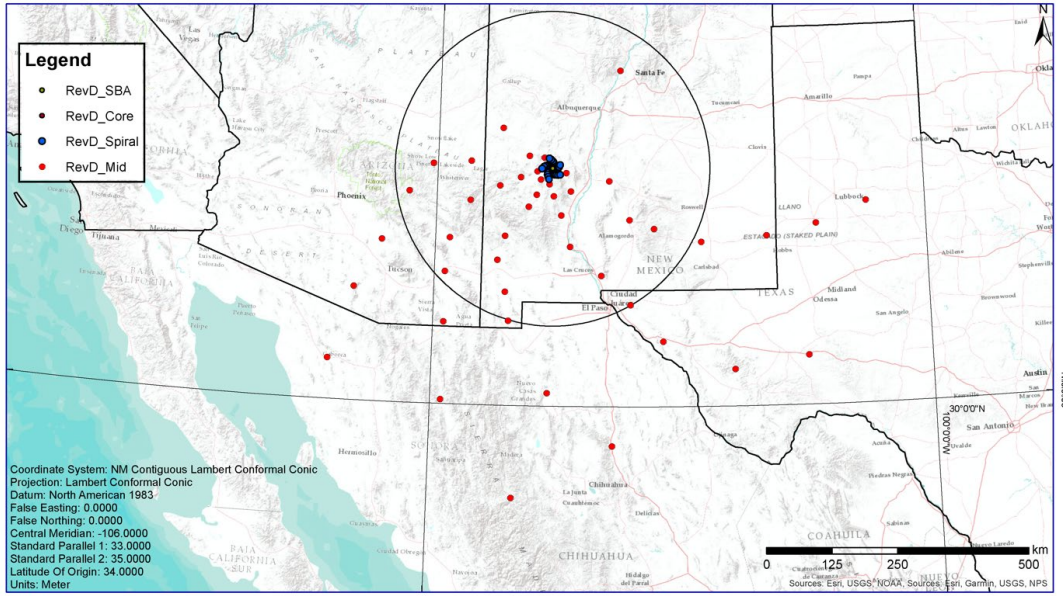
The next-generation Very Large Array (ngVLA)

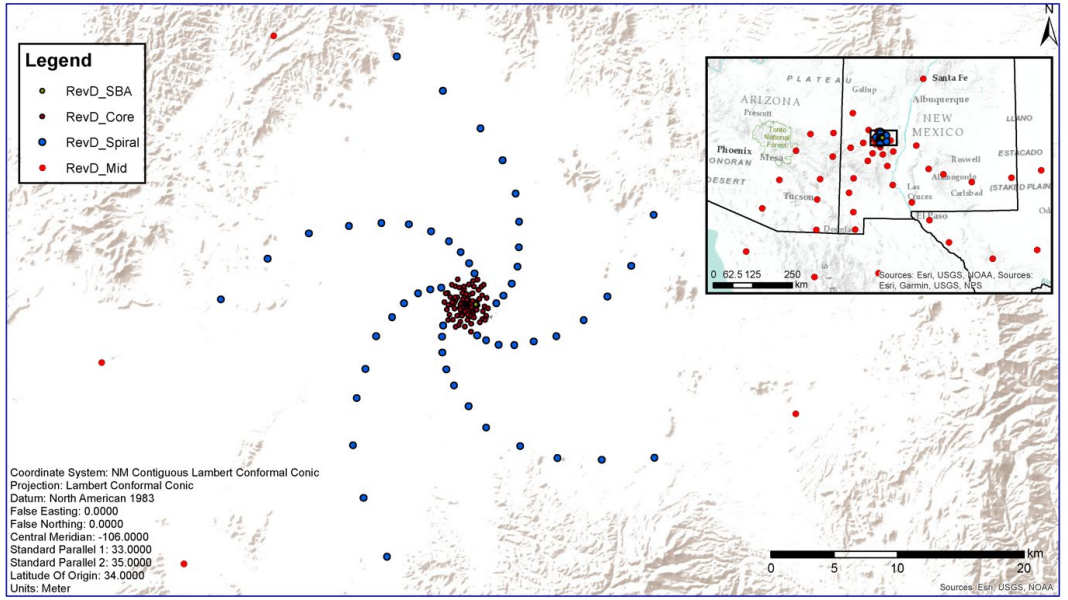


A transformative new facility that will replace the VLA and VLBA.
10x the sensitivity and resolution of existing facilities
263 18m antennas, centered at VLA site and concentrated in SW US.

Antenna Sites



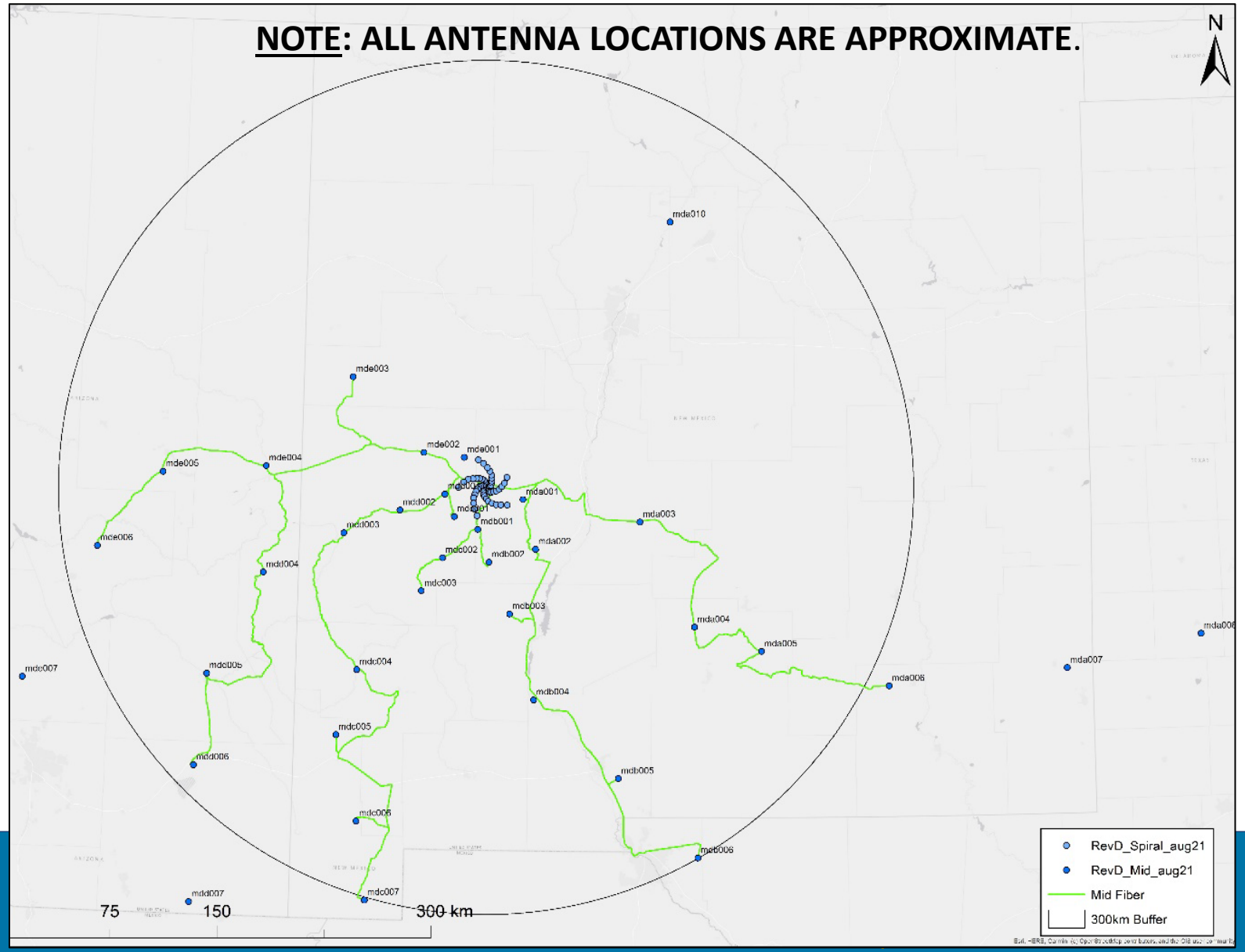




NOTE: ALL ANTENNA LOCATIONS ARE APPROXIMATE.

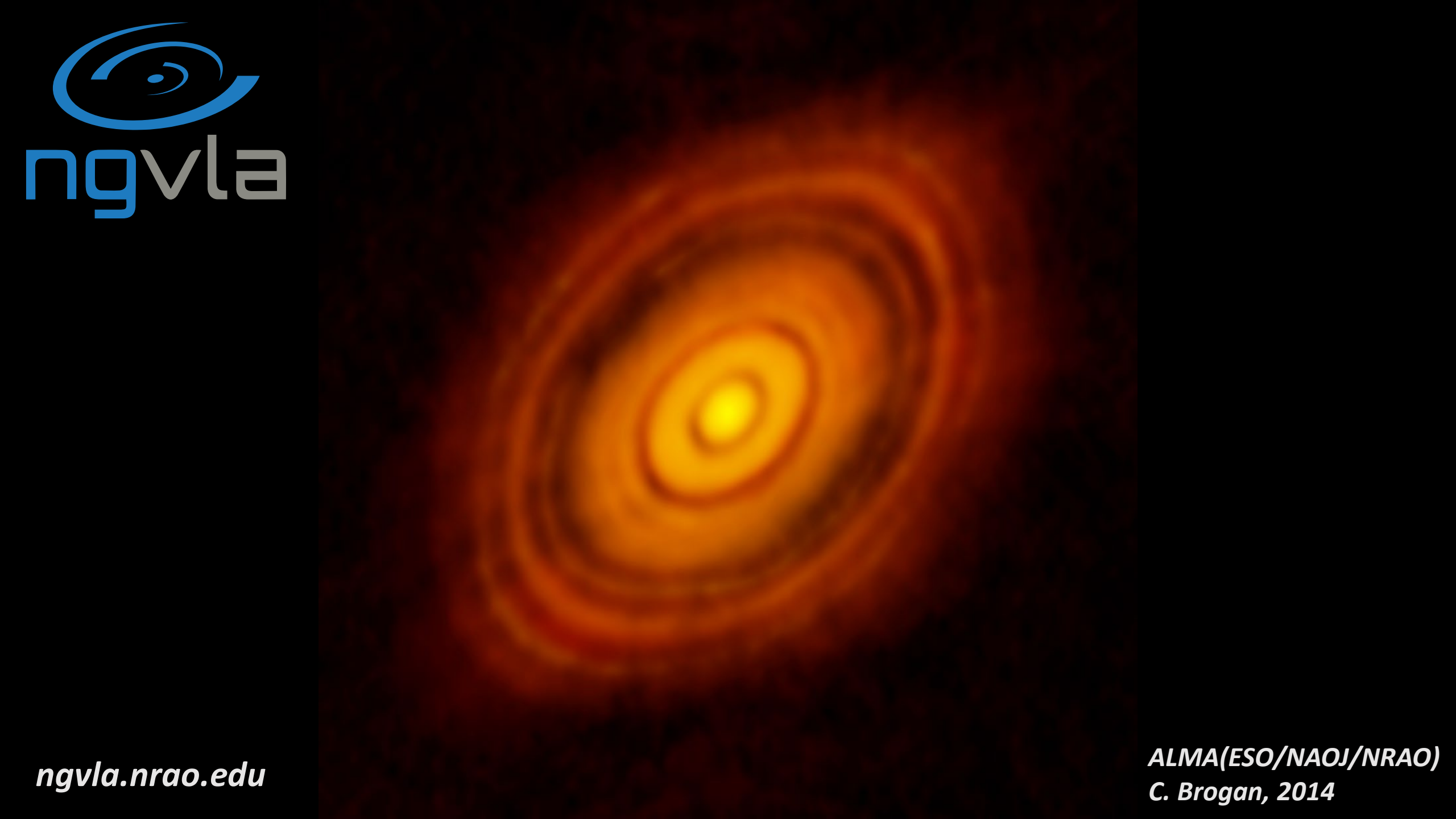
Main Array Fiber Optic Network

- **400 - 800 Gbps** per antenna
- **200 Gbps** link to world
- Dedicated point-to-point fiber links for ~187 antennas near VLA Site
- ~31 antennas connected over dedicated fiber network (see figure)
- ~25 sites connected via ISPs (packet switched, TCP/IP)
- **60 PFLOP/s** Computing Center (site TBD)



ngVLA Key Science Goals

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



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ALMA(ESO/NAOJ/NRAO)
C. Brogan, 2014

ngvla

Demonstrating the power of the Atacama Large Millimeter/submillimeter Array, this image reveals a spectacular planet-forming disk of dust and gas around the young Sun-like star HL Tauri, located 450 light-years from Earth. The superposed ellipses indicate, for comparison, the orbits of the planets in our Solar System.

Credit: ALMA (NRAO/ESO/NAOJ); NRAO/AUI/NSF; C. Brogan, B. Saxton, J. Hellerman

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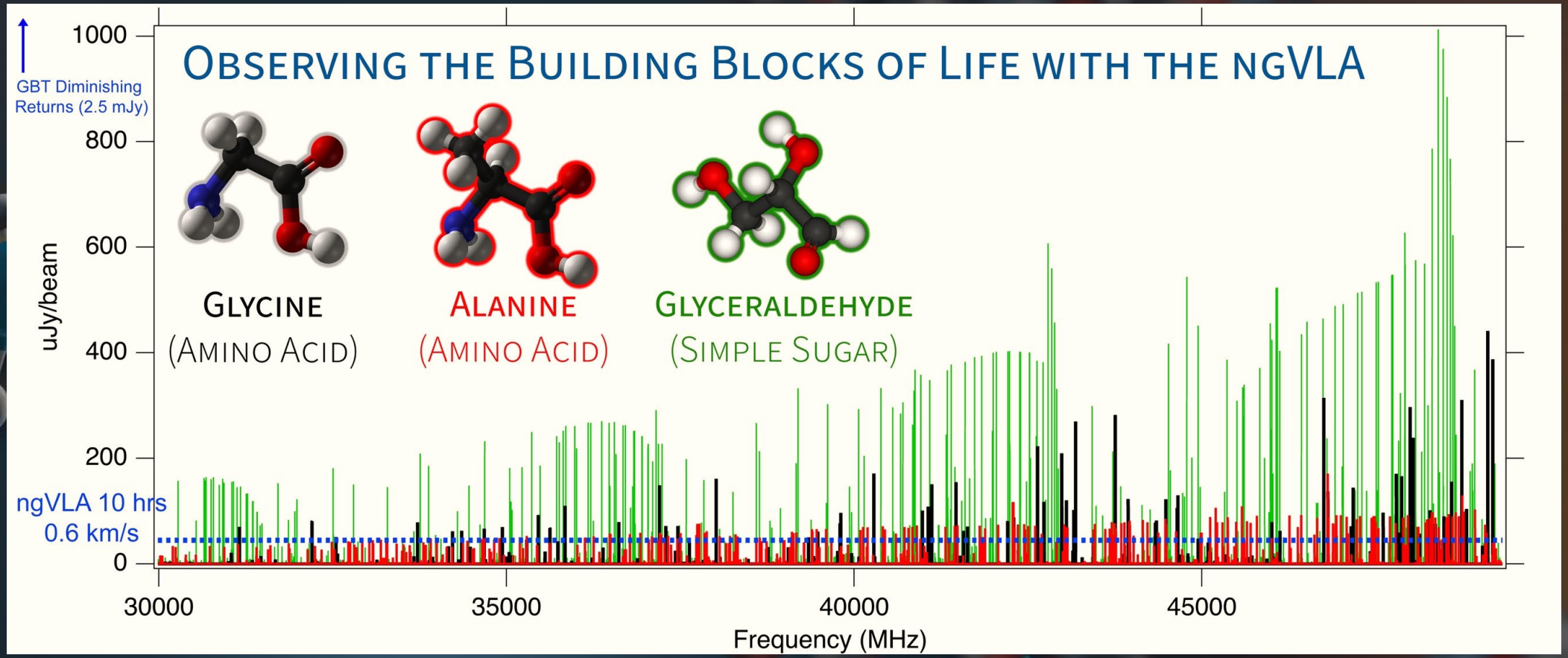
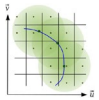


NRAO/AUI/NSF
B. Saxton, J. Hellerman

Imaging Compute Costs

Gridding : Convolutional resampling
MPI based CPU implementation
Multi-threaded GPU
accelerated approach

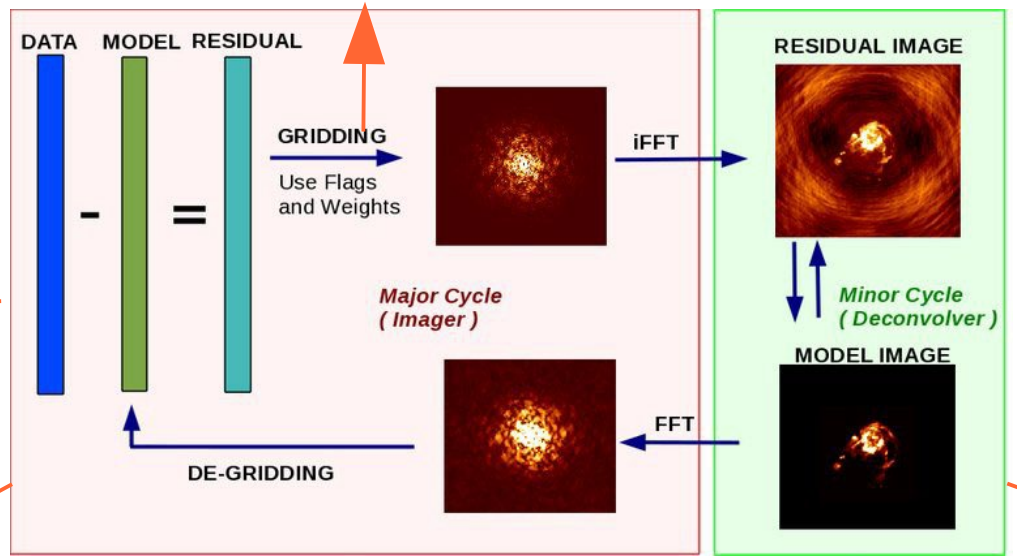


→ Adjust data ordering/access

Data I/O

Mostly Reads
Write once at the end.

Partition in chunks by
“row” / “chan” / “time”



Images : 4D cubes

FFTs, Math operations,
Fitting algorithms

Image reads/writes

Multi-threading

Partitioning on “chan”
or “pixels”

Number of iterations : 5 – 10 major cycle loops
100 to 10k minor cycle steps

Runtime varies by 1-2 orders of magnitude. Depends on data.

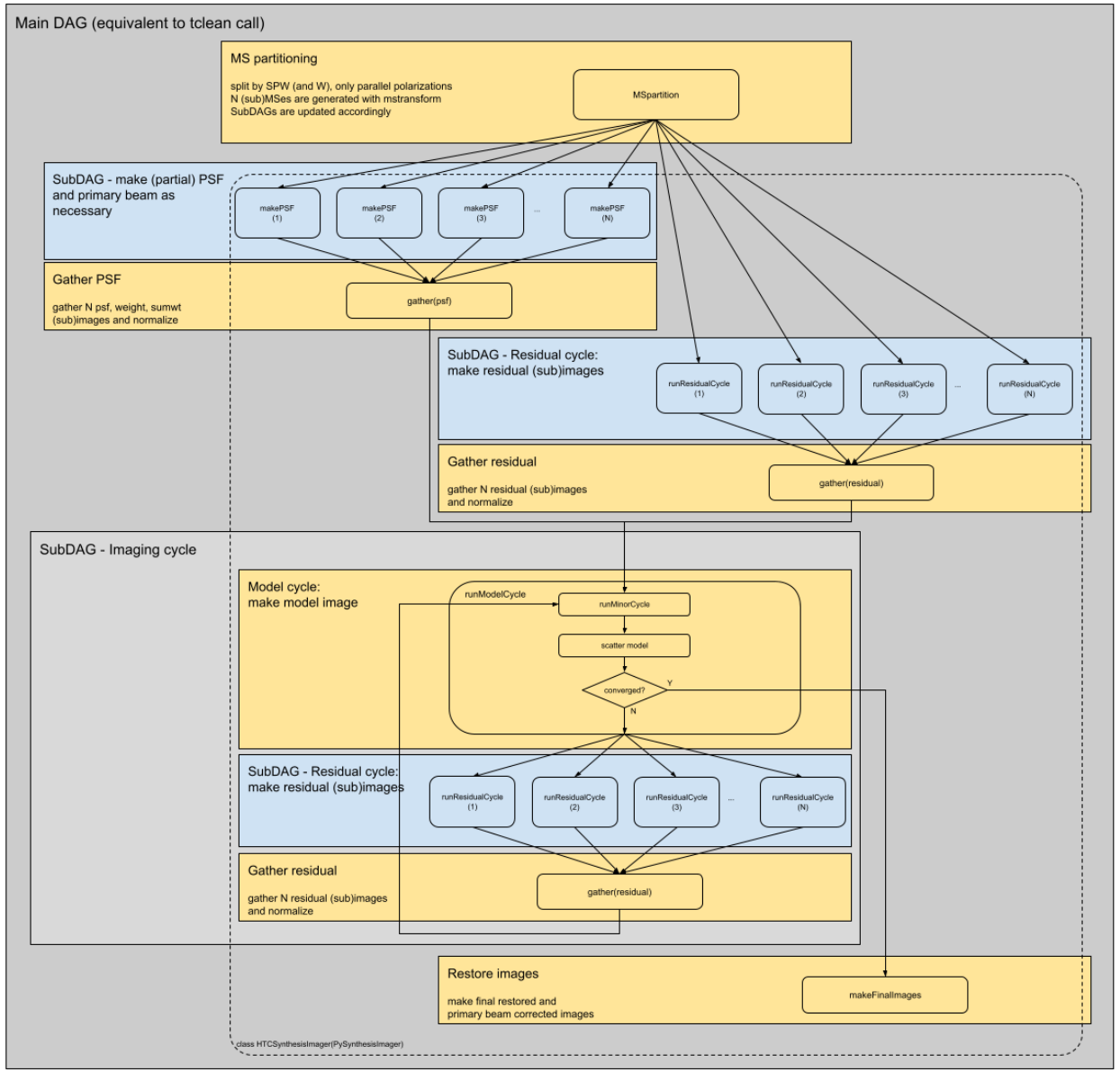
S/W and Computing Considerations

- **Post Processing**: Analysis shows that storing the raw visibilities will be tractable when ngVLA goes into operations.
  - Data processing is post-facto, with system sized for average throughput.
  - Average Data Rate – 7.6 GB/s, capable of a 320 GB/s peak.
  - 4 hr. observation – 109 TB. Requires ~1000 cores to process in a few days.
  - Peak planned data rate – 190 GB/s. Will require ~750PFlops/s (Key science goal 2)
- **Operations Concept**: SRDP (Science Ready Data Products) Telescope
  - Both for 1st Observations and Archive projects.
- **Computing:** 2B Core-hr: Challenging, but can be met w/ COTS cluster.
  - Set by time resolution, spectral resolution, and multi-faceting in imaging
  - Some low-frequency, full-beam, AW-projection cases restricted in early operations.

NRAO collaborations with CHTC

- Early work: Prototyped distributed imaging algorithm (HTClean) with help of CHTC staff
- Support for Very Large Array Sky Survey (VLASS)
  - 34,000 square degree deep survey of sky visible from northern hemisphere
  - Processed validation imaging utilizing HTClean and CHTC resources
- All NRAO Operational pipelines for JVLA are or will soon be running via HTCondor
  - VLASS calibration and imaging pipelines
  - Calibration and imaging pipelines for PI defined observations

tclean decomposition with HTCondor




```
HTCSynthesisImager.makePSF()
    initializeImagers()
    initializeNormalizers()
    setWeighting()

    makePSFCore()
```

```
HTCSynthesisImager.runResidualCycle()
    initializeImagers()
    setWeighting()

    runMajorCycleCore()
```

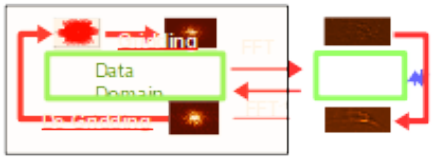
```
HTCSynthesisImager.runModelCycle()
    initializeDeconvolvers()
    initializeIterationControl()

    hasConverged()
    updateMask()

    runMinorCycle()
    _scatter()

    if hasConvered():
        touch stopIMCycles
```

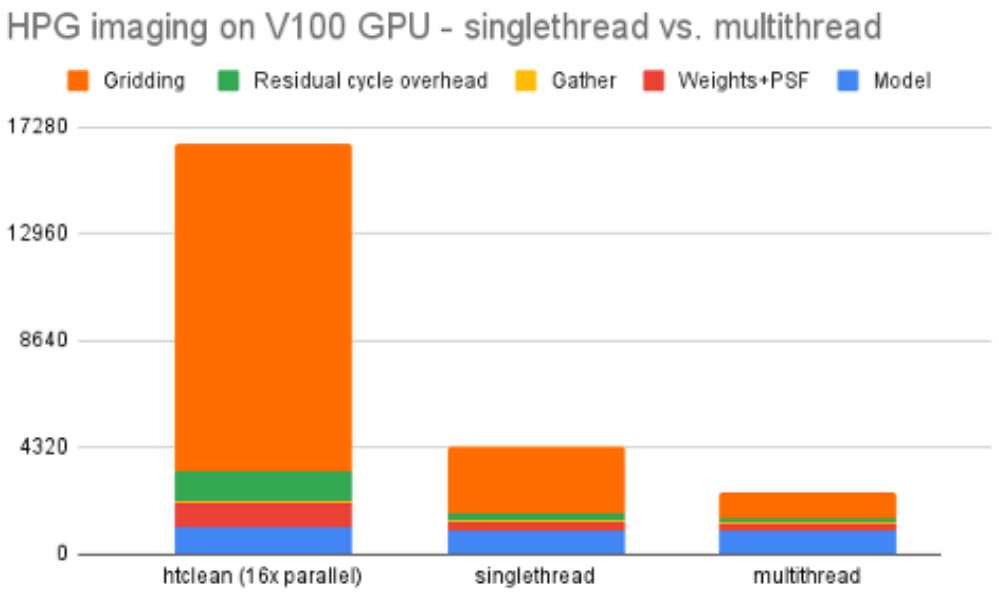
```
HTCSynthesisImager.gather()
    initializeDeconvolvers()
    initializeIterationControl()

    append(synthesisnormalizer())

    for immod in range(self.NF):
        PStools[immod].setupnormalizer()

        If imtype == 'psf':
            PStools[immod].gatherpsfweight()
            PStools[immod].dividepsfbyweight()

        If imtype == 'residual':
            PStools[immod].gatherresidual()
            PStools[immod].divideresidualbyweight()
            PStools[immod].multiplymodelbyweight()
```

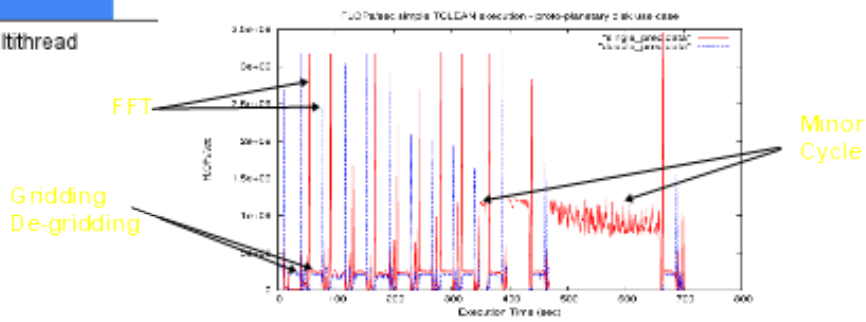
```
HTCSynthesisImager._scatter()
    _mkImagePartList()*

    append(synthesisnormalizer())

    for immod in range(self.NF):
        PStools[immod].setupnormalizer()
        PStools[immod].dividemodelbyweight()
        PStools[immod].scattermodel()
```

* implemented for the context of HTC

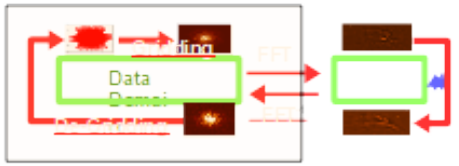
High Performance Gridder (HPG)

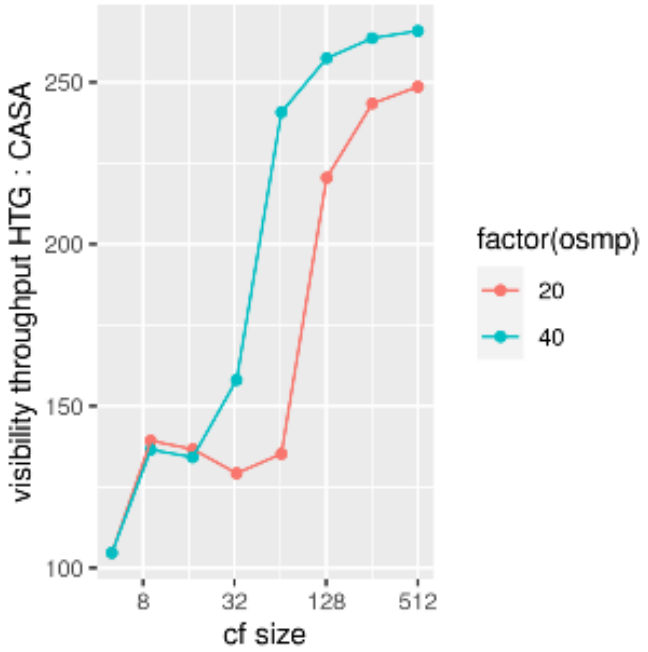


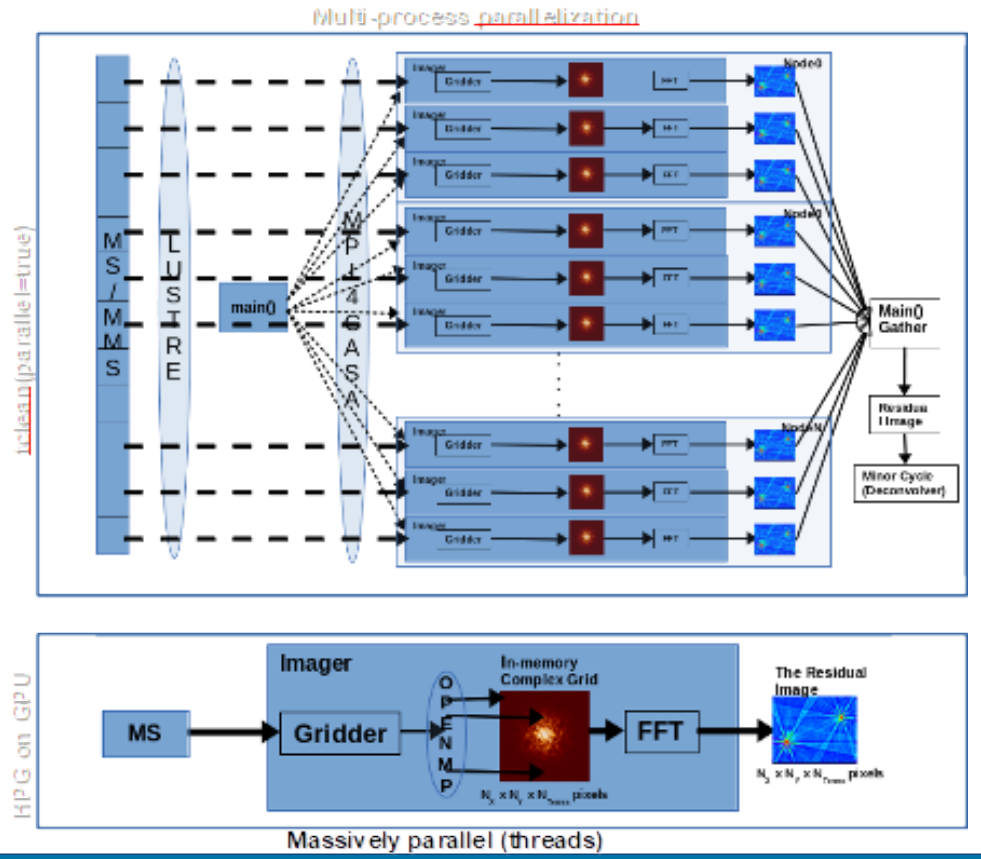




High Performance Gridder (HPG)







Future of ngVLA with HTC

- ngVLA will be an LHC scale computing problem (~2B core hours/year)
- Planning for a tiered distributed processing model
  - E.g. Specific science cases distributed to specific data processing centers
  - Elements of imaging algorithms distributed to tailored systems within a processing center
- ngVLA in early development stage:
  - prototype antenna 2024
  - early science 2029
  - full operations 2035
- We're hiring: http://jobs.jobvite.com/nrao/jobs
- Other links: https://ngvla.nrao.edu/page/science