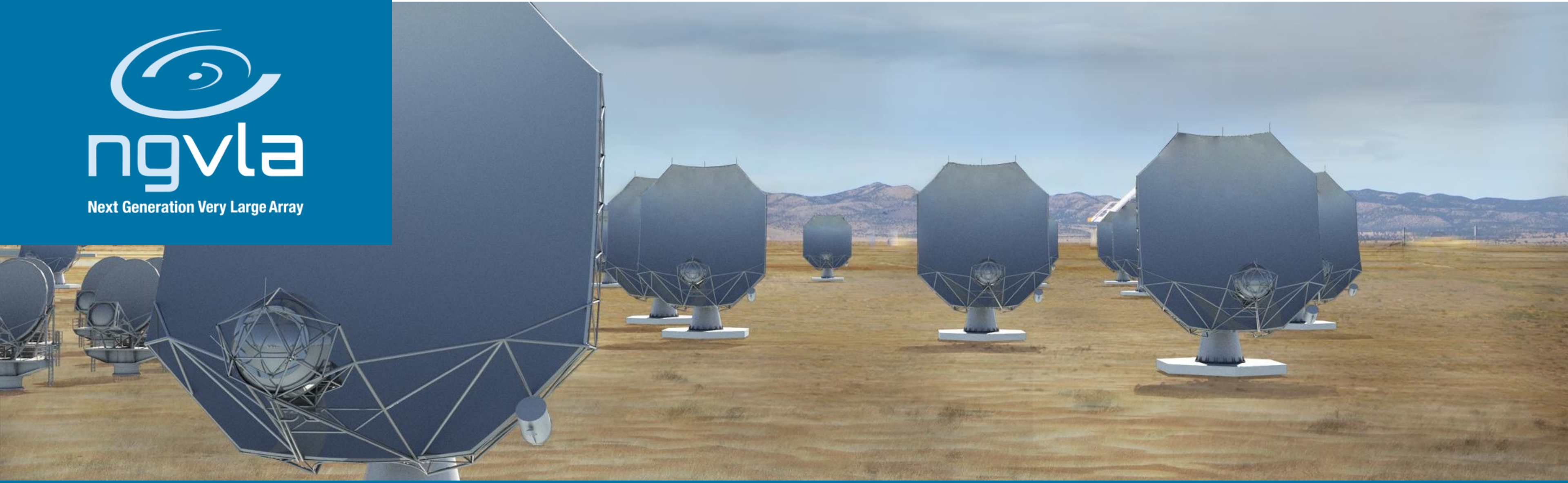


Next Generation Very Large Array

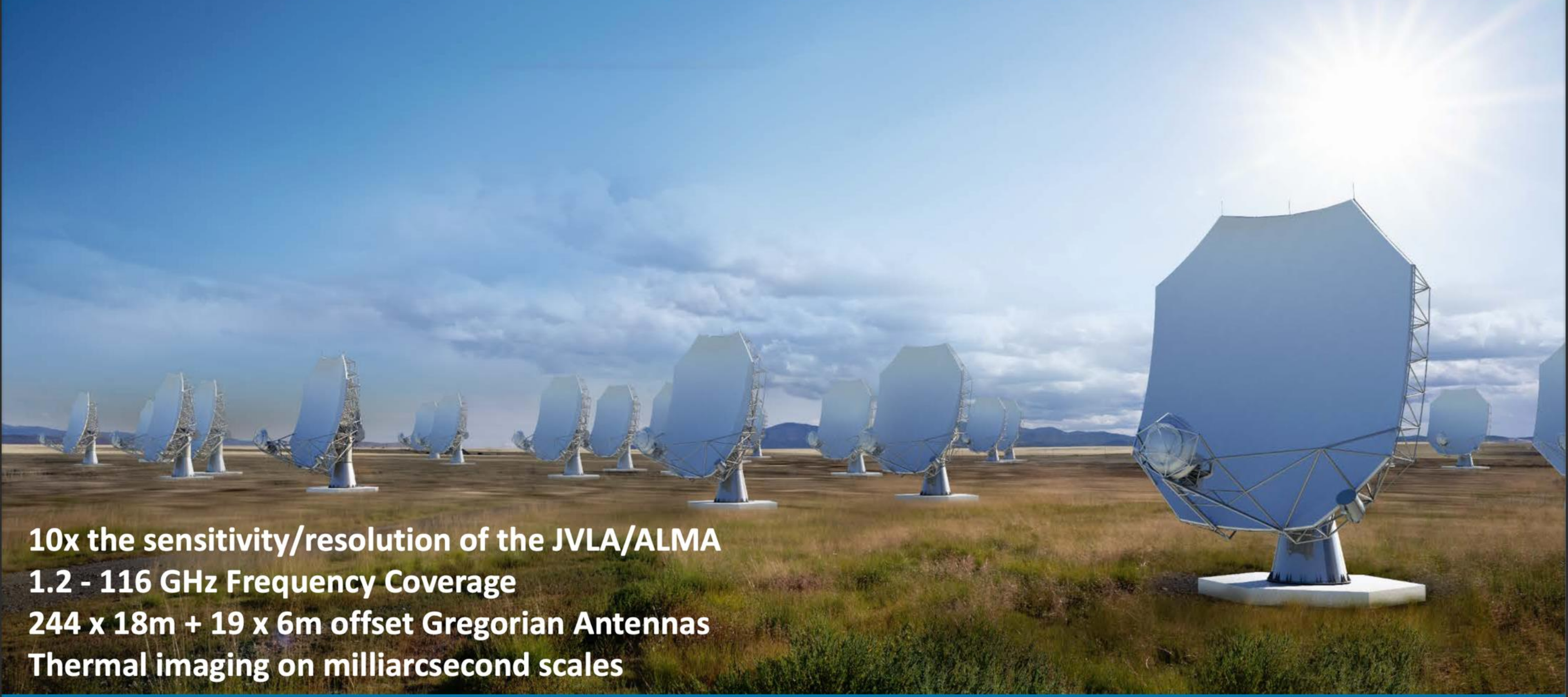
Precise Astrometry with ngVLA

ngVLA Project Team

Lucas Hunt

National Radio Astronomy Observatory

The next-generation Very Large Array (ngVLA)



10x the sensitivity/resolution of the JVLA/ALMA
1.2 - 116 GHz Frequency Coverage
244 x 18m + 19 x 6m offset Gregorian Antennas
Thermal imaging on milliarcsecond scales

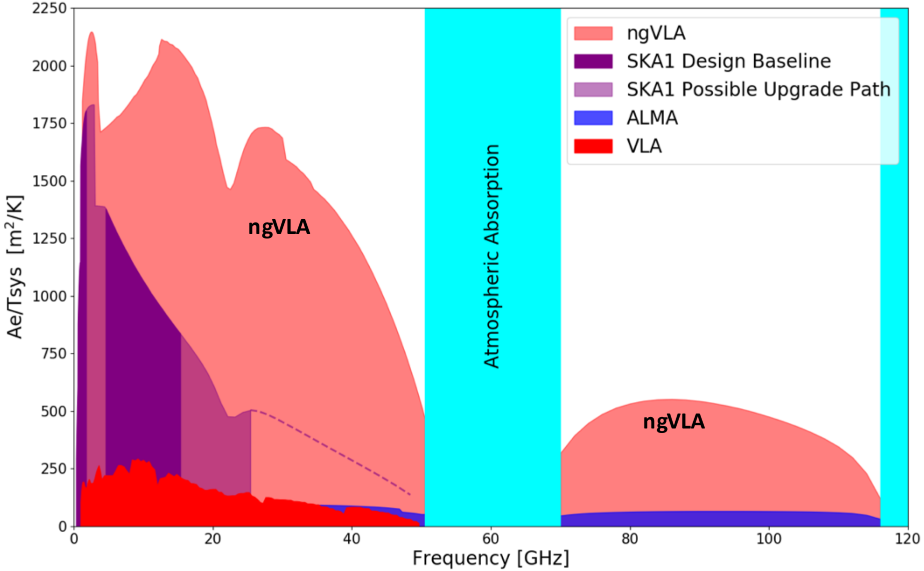
ngVLA Key Science Goals
(ngVLA Science Book, memo #19)

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*

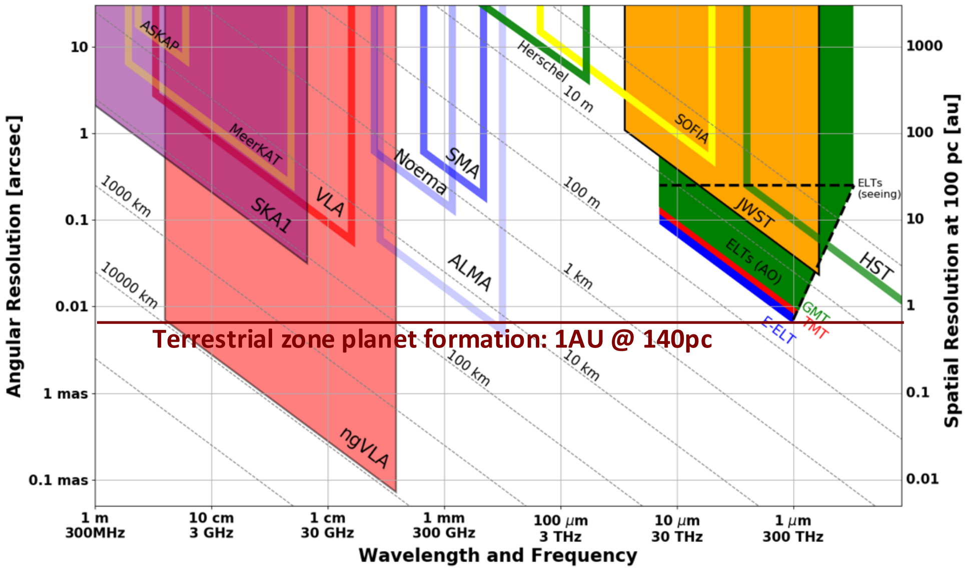
ngvla
Next Generation Very Large Array

Linking SKA & ALMA Scientifically

Sensitivity



Resolution



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

- **< 0.3cm:** ALMA 2030 superb for chemistry, dust, fine structure lines
- **0.3 to 3cm: ngVLA superb for terrestrial planet formation, dense gas history, baryon cycling**
- **> 3cm:** SKA superb for pulsars, reionization, HI + continuum surveys

Receivers

	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6
Frequency Range (GHz)	1.2 – 3.5	3.5 – 12	12.3 – 20.5	20.5 – 34	30.5 – 50.5	70 – 116
Field of View FWHM (arcmin)	24.8	7.4	3.6	2.1	1.4	0.6
Antenna SEFD (Jy)	232	265	292	397	602	1136
Instantaneous Bandwidth (GHz)	2.3	8.8	8.2	13.5	>14.0	>14.0

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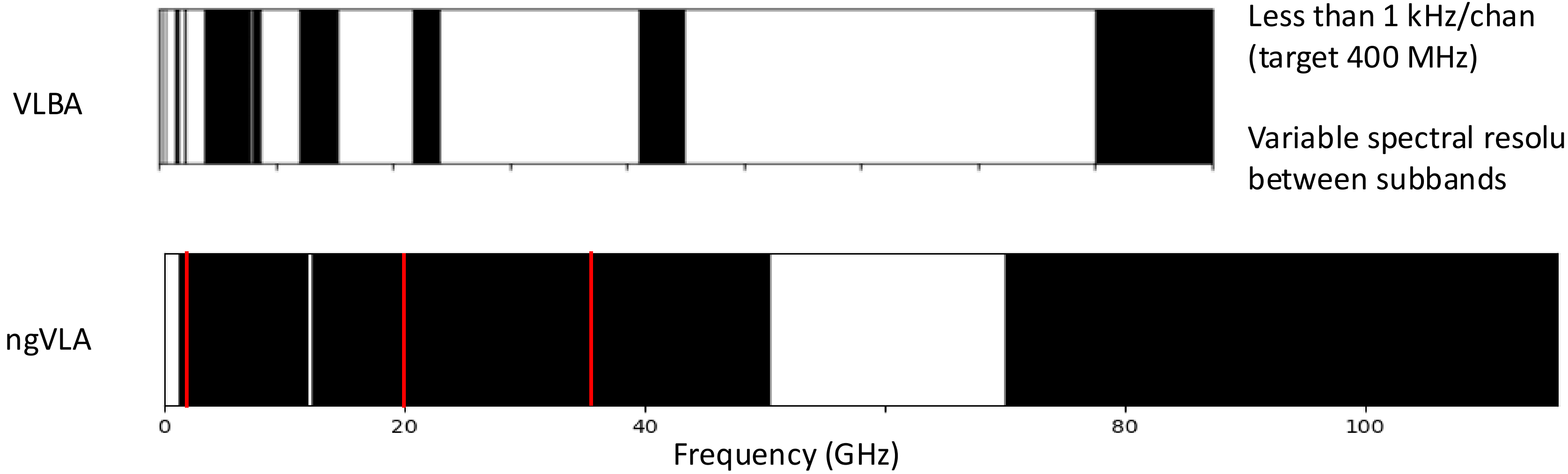
Frequency Coverage



Spectral Resolution:
Less than 1 kHz/chan
(target 400 MHz)

Variable spectral resolution between subbands

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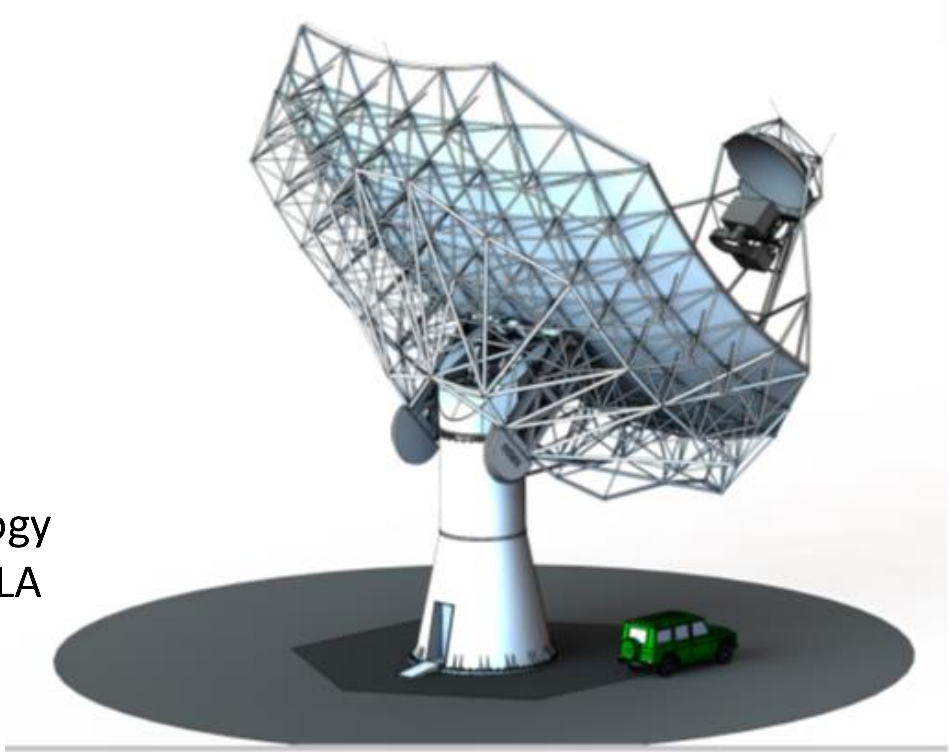
Antenna Development

Some Specs

- 18m Aperture
- Offset Gregorian
- 3˚ slew and settle in 7 seconds

Current Status

- Prototype construction underway at VLA site
  - Developed by mtex antenna technology
- Plans to test including correlation with VLA antennas
- Design for LONG low elevation antenna underway



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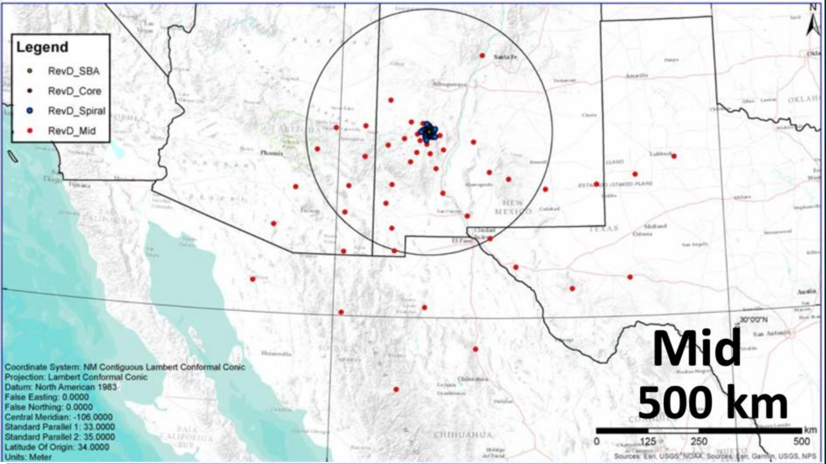
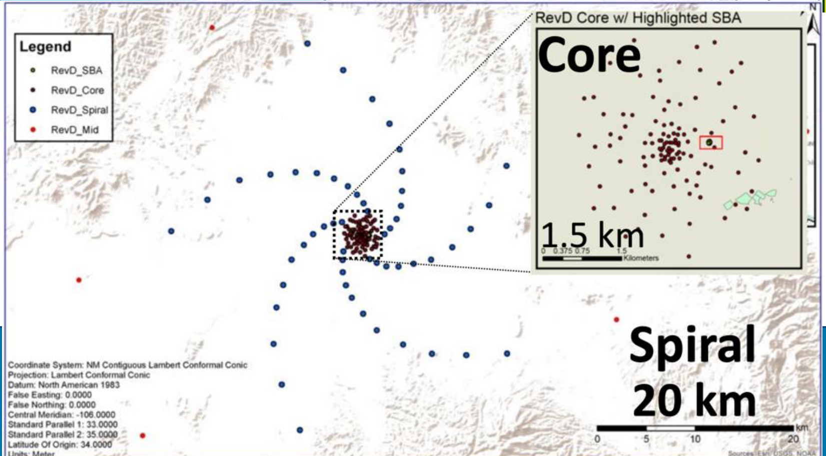
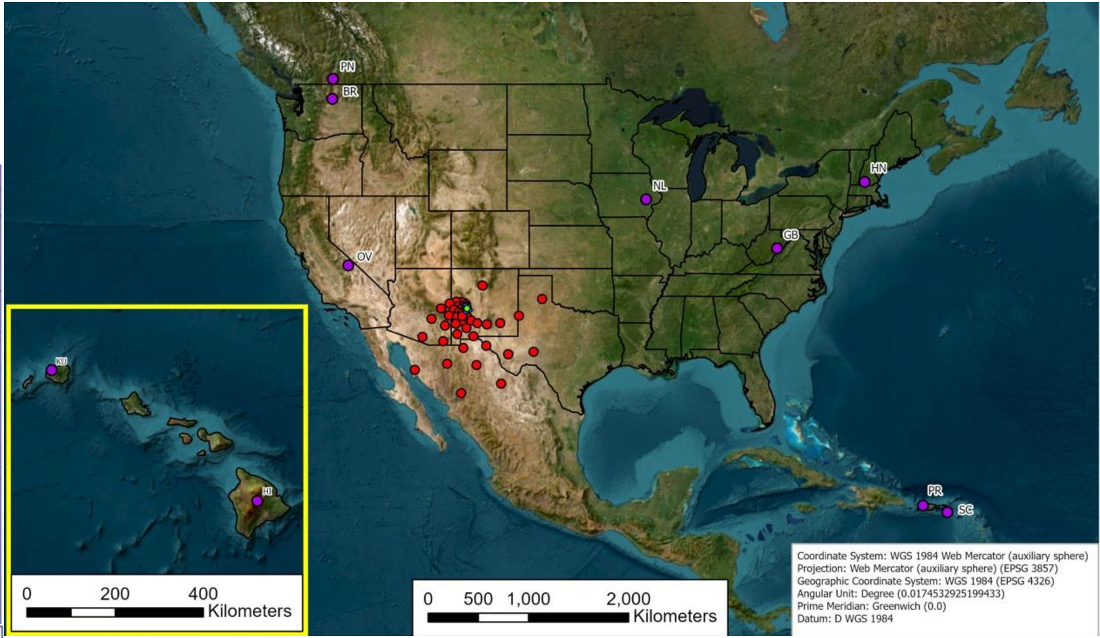
Configuration







Main Array: 244 x 18m Antennas

- Core: 114 Antennas; B_{max} = 4.3 km
- Spiral: 54 Antennas; B_{max} = 39 km
- Mid: 46 Antennas; B_{max} = 1070 km
- Long: 30 Antennas; B_{max} = 8860 km

Short Baseline Array

- 19 x 6m Antennas

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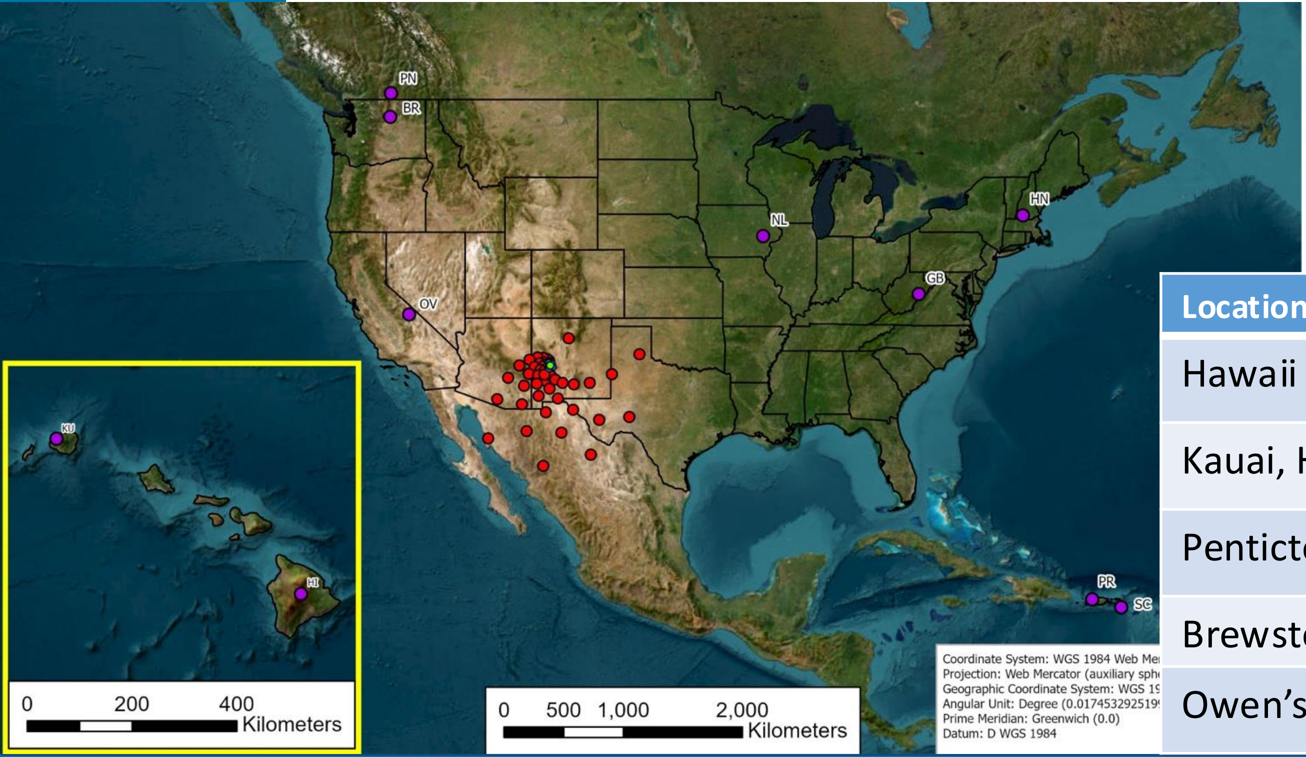
ngVLA Long



- 10 sites with 3 antennas each

Locations	
Hawaii	North Liberty, IA
Kauai, HI	Green Bank, WV
Penticton, BC (CA)	Hancock, NH
Brewster, WA	Puerto Rico
Owen's Valley, CA	St. Croix

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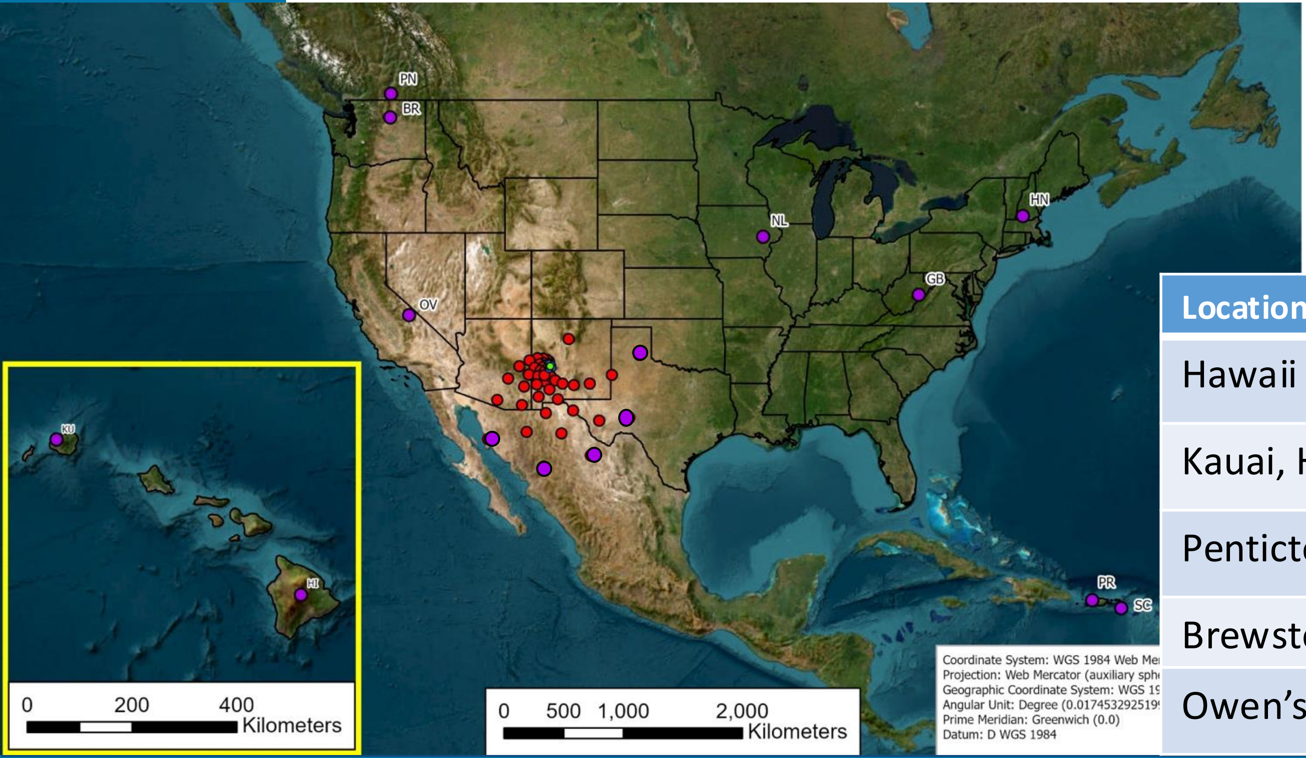
ngVLA Long



- 10 sites with 3 antennas each
- Add the antennas at the end of Mid

Locations	
Hawaii	North Liberty, IA
Kauai, HI	Green Bank, WV
Penticton, BC (CA)	Hancock, NH
Brewster, WA	Puerto Rico
Owen's Valley, CA	St. Croix

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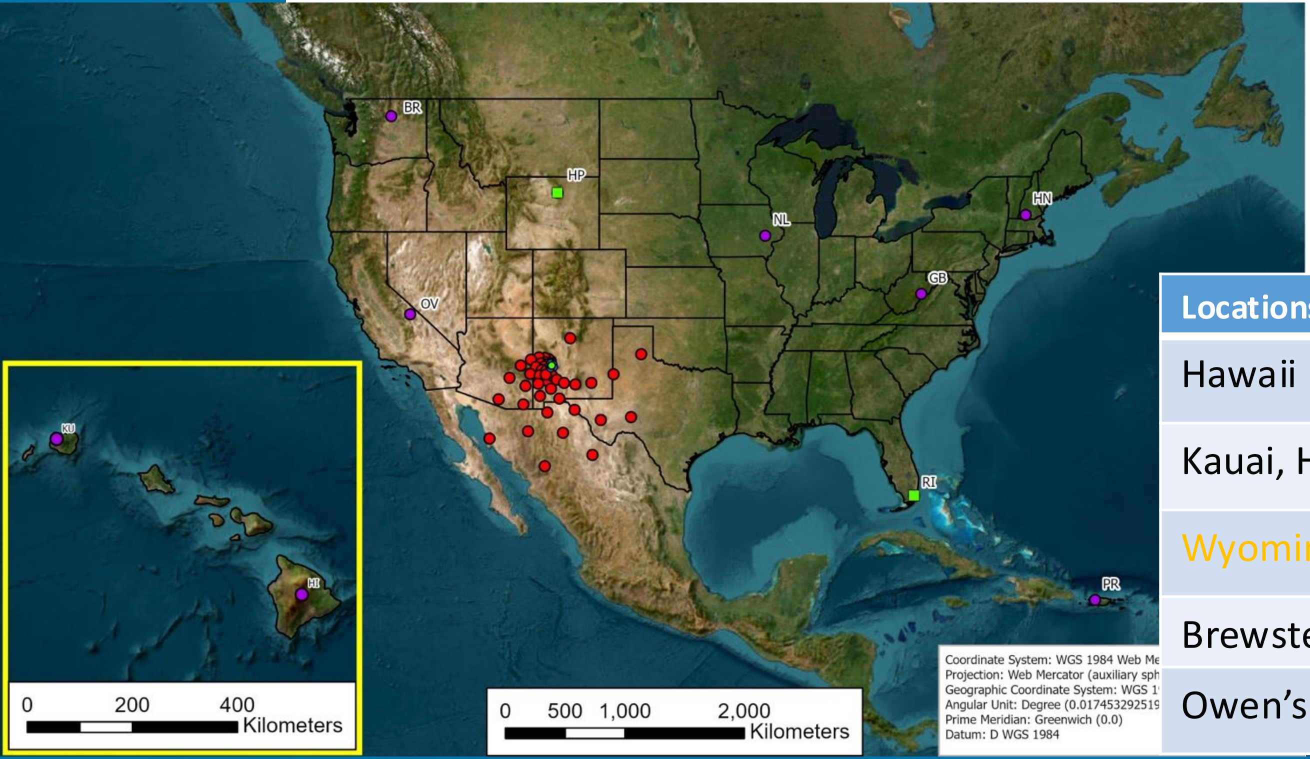
ngvla
Next Generation Very Large Array

ngVLA Long



- Proposed changing two sites, Penticton moves to Wyoming and St. Croix moves to Florida

Locations	
Hawaii	North Liberty, IA
Kauai, HI	Green Bank, WV
Wyoming	Hancock, NH
Brewster, WA	Puerto Rico
Owen's Valley, CA	Florida

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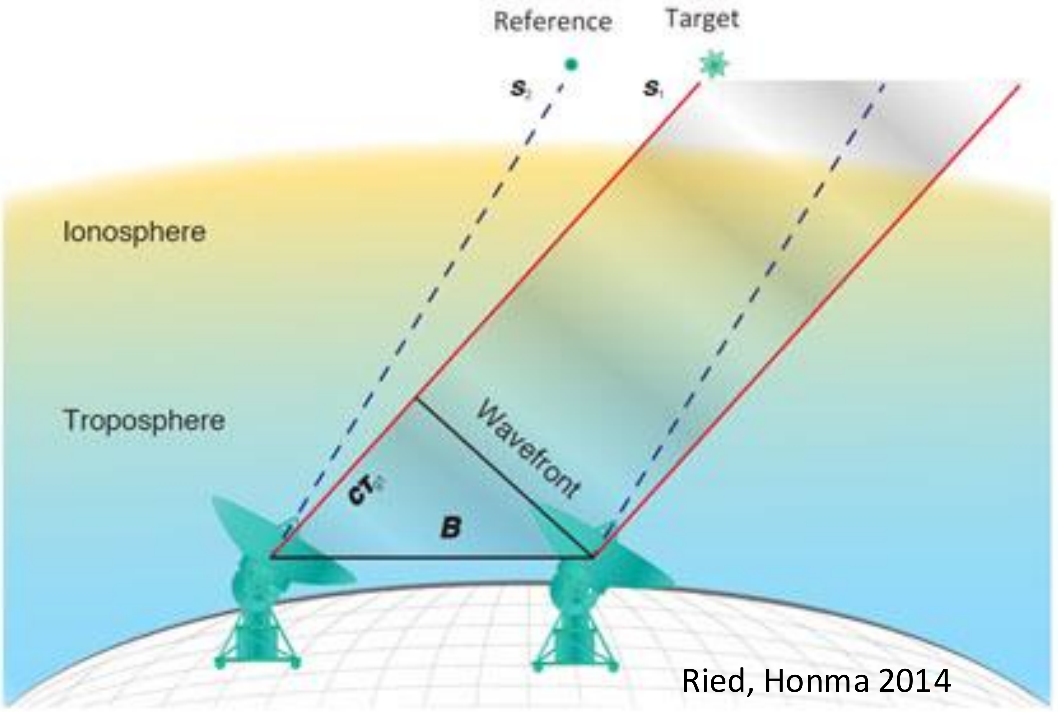
Interferometry Primer

- Improve resolution with longer baselines
- Measurements of delay tell us about source position
  - Errors can be caused by atmosphere, instrumentation/electronics, antenna position.



Ried, Honma 2014

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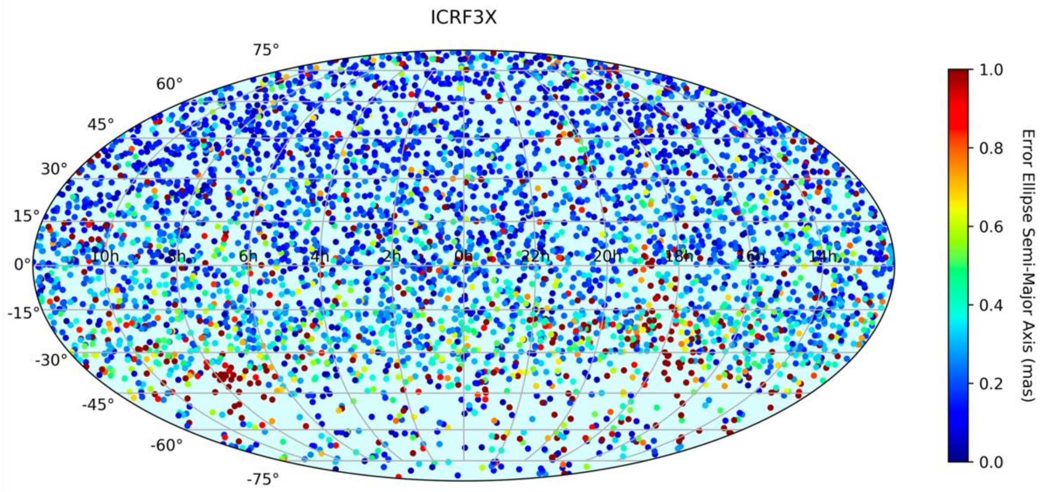
Types of Radio Astrometry

- Absolute Astrometry
  - Reference frames, like ICRF
  - Observations managed by IVS
  - Compares model parameters with observations (Atmosphere, source structure, tides, clocks)



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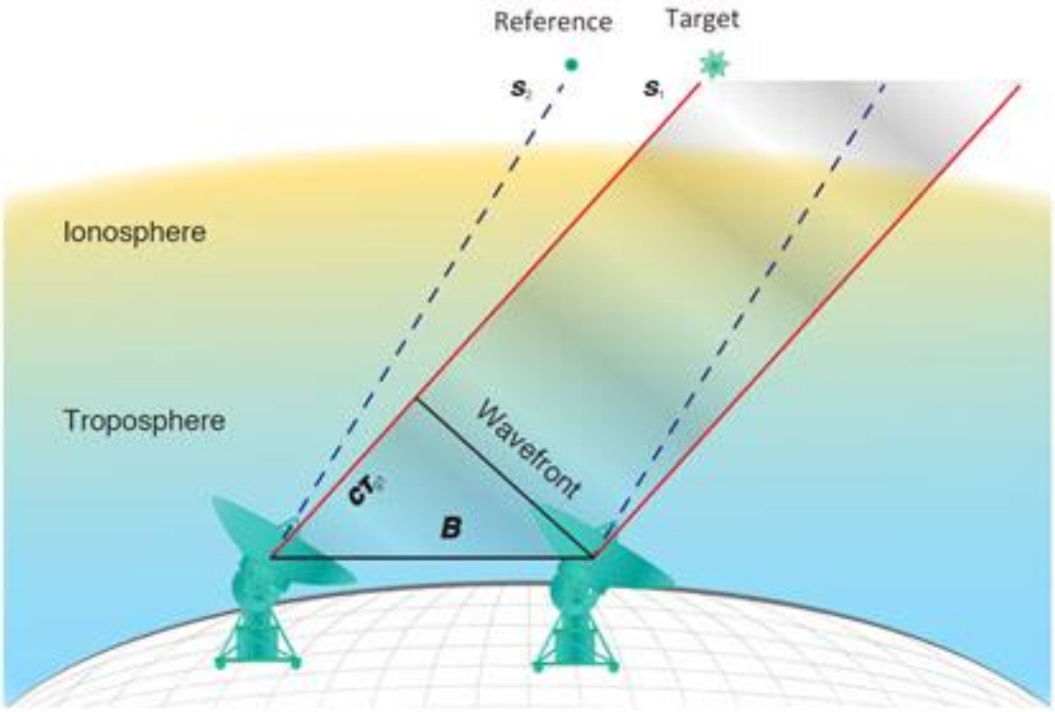
Types of Radio Astrometry

- Absolute Astrometry
  - Reference frames, like ICRF
  - Observations managed by IVS
  - Compares model parameters with observations (Atmosphere, source structure, tides, clocks)
- Relative Astrometry
  - Measuring source positions relative to a known source
  - Use observations of one to calibrate other



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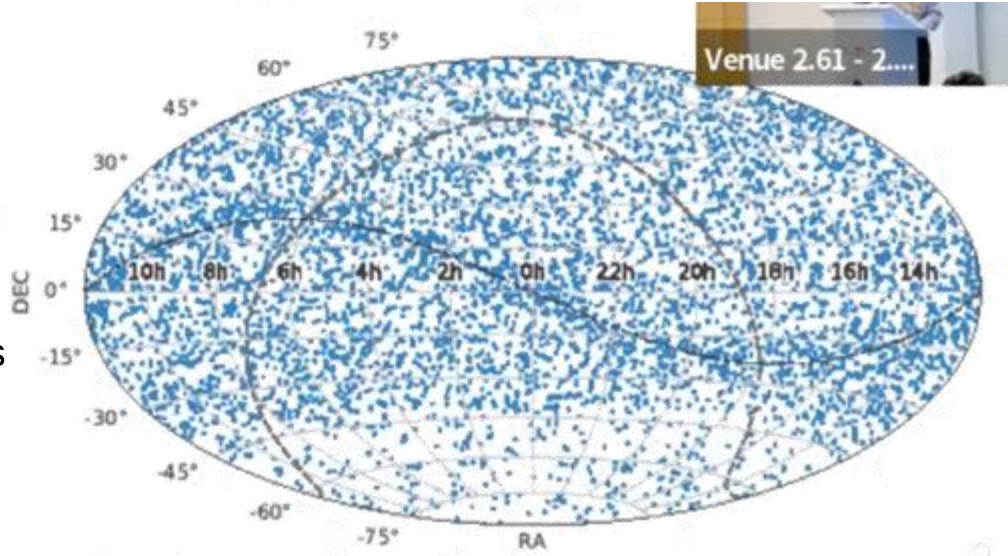
Absolute Astrometry

- Current status of ICRF
  - Most observations at 8.6/2.3 GHz
    - 18.8 million obs.; 5770 sources
    - 107/189 µasec RA/Dec median error
  - Two other frequencies currently included
    - Higher frequencies typically have less source structure
    - Likely the direction ICRF will look in the future
- Tying Gaia CRF to ICRF
  - Optical-Radio offsets still not completely reconciled



Credit: David Gordon

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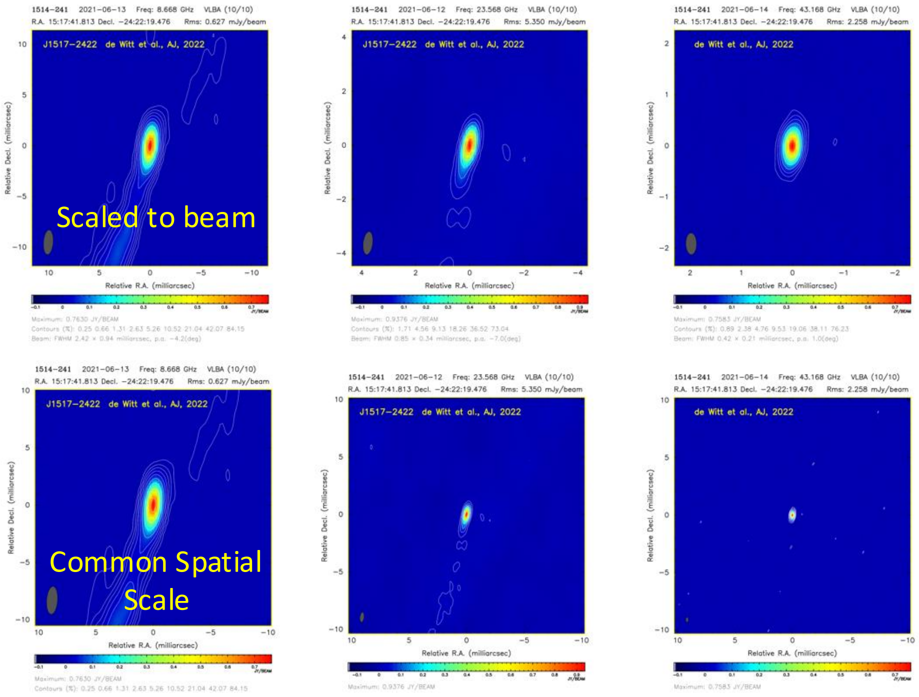
Absolute Astrometry with ngVLA

- Improvements allow for more observations
  - Better precision on source positions
- Updated instrumentation for calibration
  - WVR, GPS, Ionosphere
- Better constrained ICRF, covering multiple frequencies



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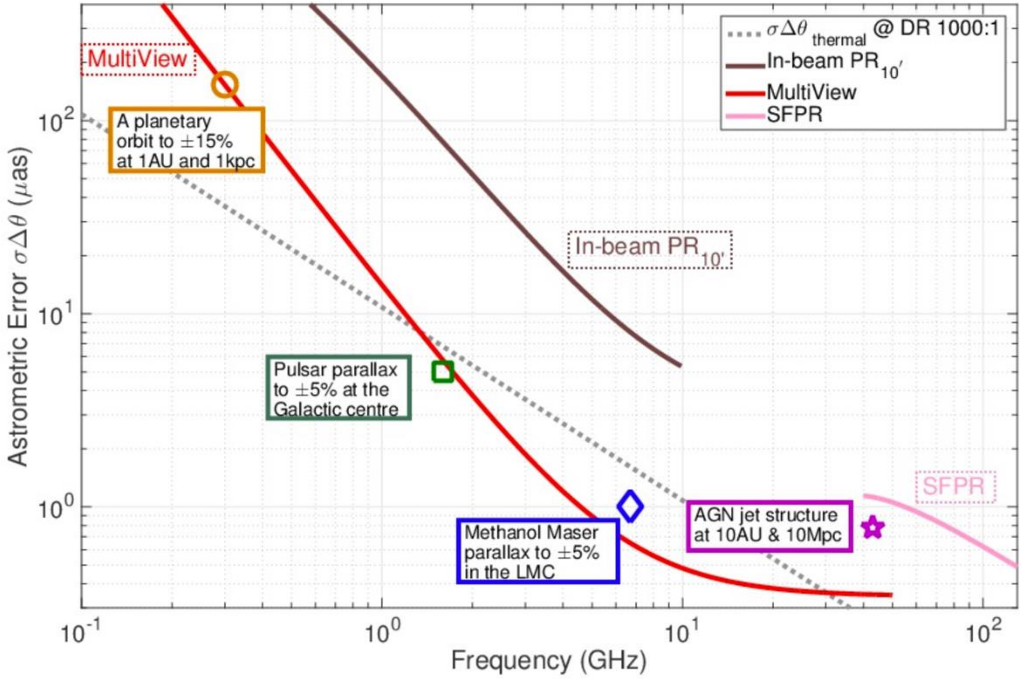
Relative Astrometry with ngVLA

- New techniques for better calibration at high frequency
  - With 3 antennas, 2 can stare at calibrators while one observes target (Multiview)
  - Can rapidly switch between two frequencies and use phase for lower frequency to calibrate higher frequency (Frequency Phase Transfer)



Credit: Rioja and Dodson 2020

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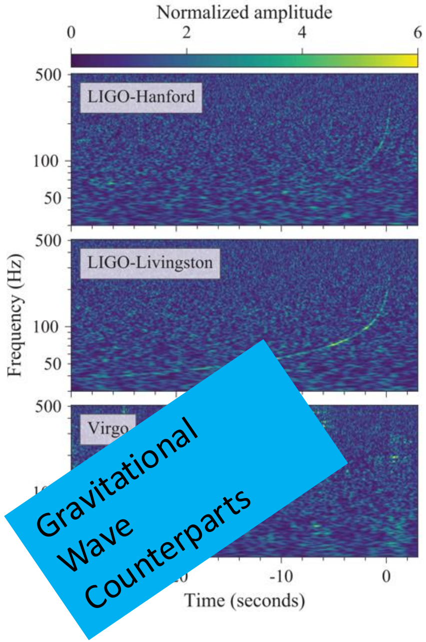
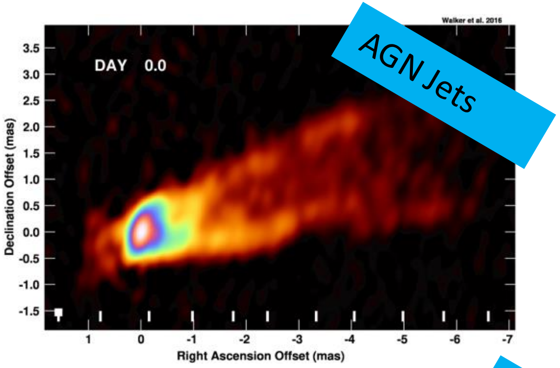
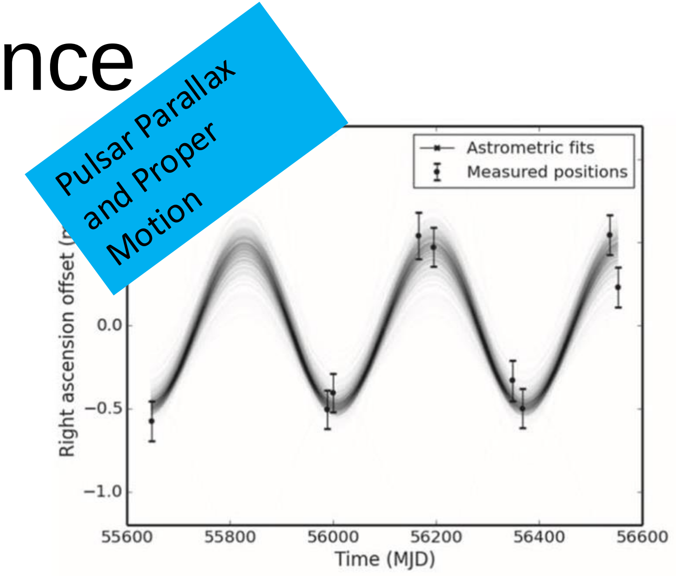
ngVLA Astrometric Science



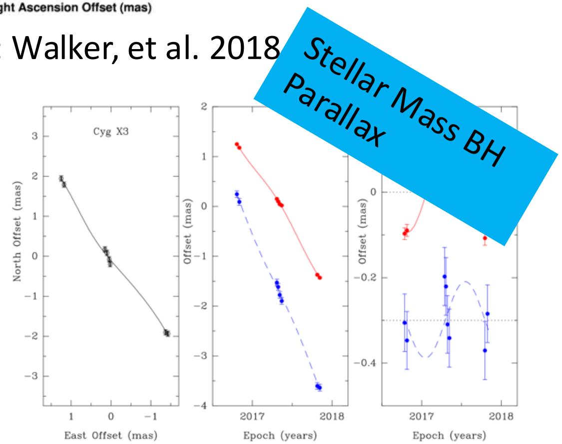
Credit: LIGO and VIRGO collaborations, 2018



Credit: Walker, et al. 2018



Credit: Deller et al., 2018



Credit: Reid and Miller-Jones, 2023

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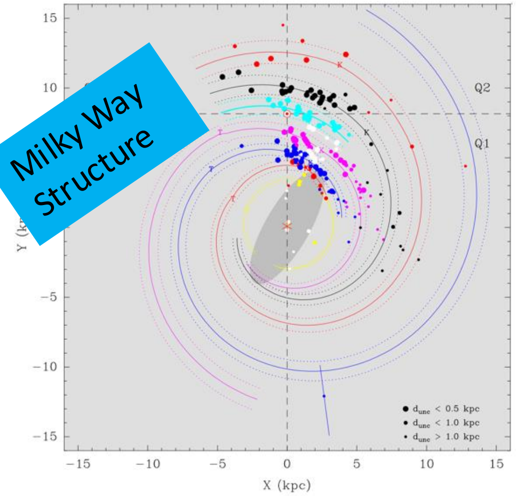
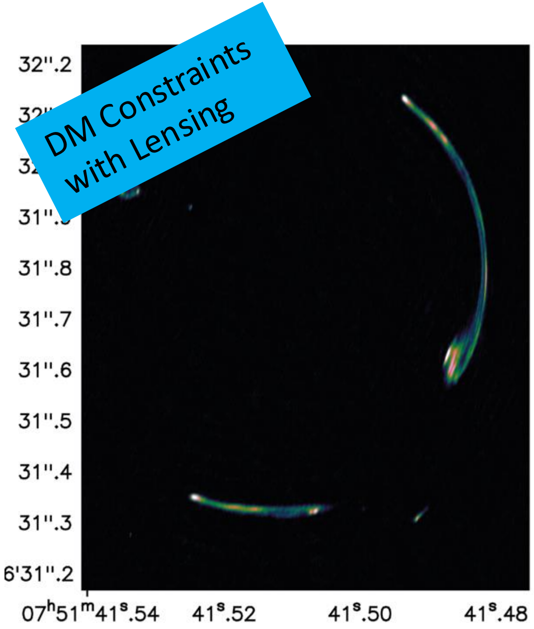
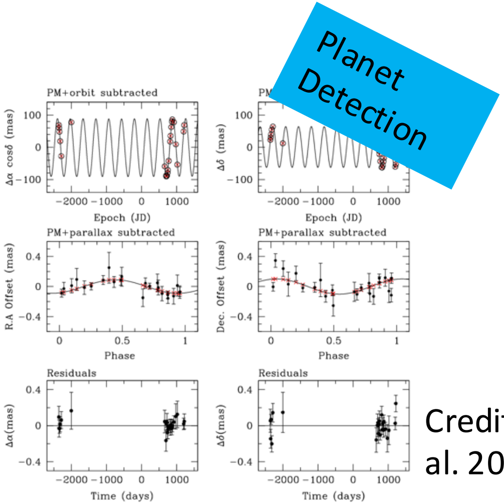
ngVLA Astrometric Science



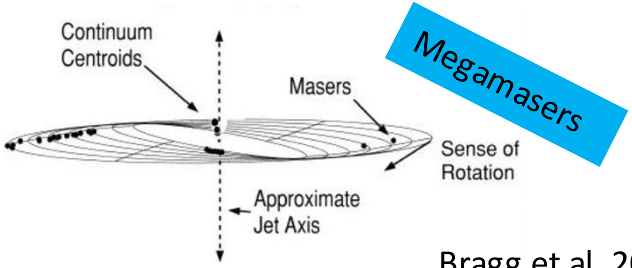
Credit: Reid et al, 2019



Credit: Spignola et al. 2019



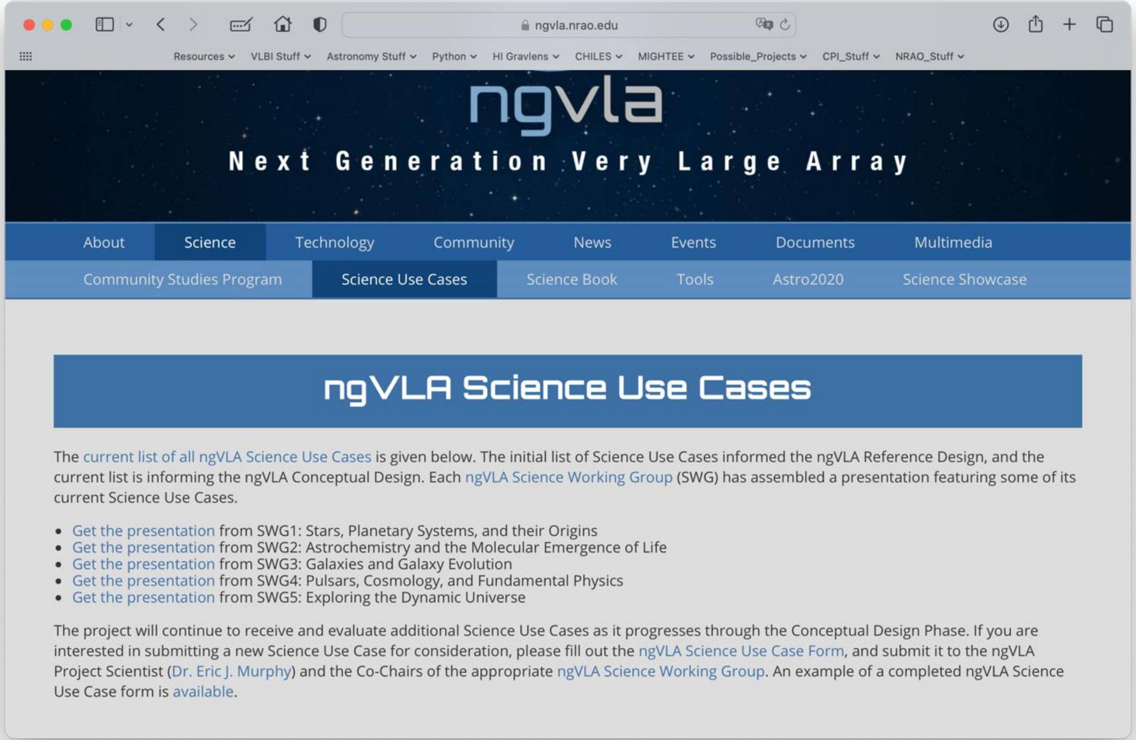
Credit: Curiel et al. 2020



Bragg et al. 2000

Science Use Cases

- ngvla.nrao.edu
  - Form
  - Example
- Talk to Me!
  - Coffee Break?
  - Email: lhunt@nrao.edu
- Open skies instrument
  - Good way to get started on your proposals now!



Conclusion

- ngVLA will be a fantastic new VLBI instrument
  - Frequency coverage from 1.2-116 GHz
  - Configuration provide good UV coverage for imaging
  - Multiple antennas per station
  - Flexible subarraying to fit science cases
- Answer targeted astrometric questions across fields
- We're happy to take science use cases

Thank You!

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