The efficient E-field Parallel Imaging Correlator (EPIC) and first deployment on LWA-Sevilleta station

Nithyanandan Thyagarajan (NRAO)
Adam P. Beardsley (ASU)
Judd Bowman (ASU)
Kevin Shah (ASU)
Greg Taylor (UNM)
Jayce Dowell (UNM)
Miguel Morales (UW)
+
Gregg Hallinan, Aaron Parsons, Dan Werthimer,
Peter Williams, Casey Law, Ralph Wijers

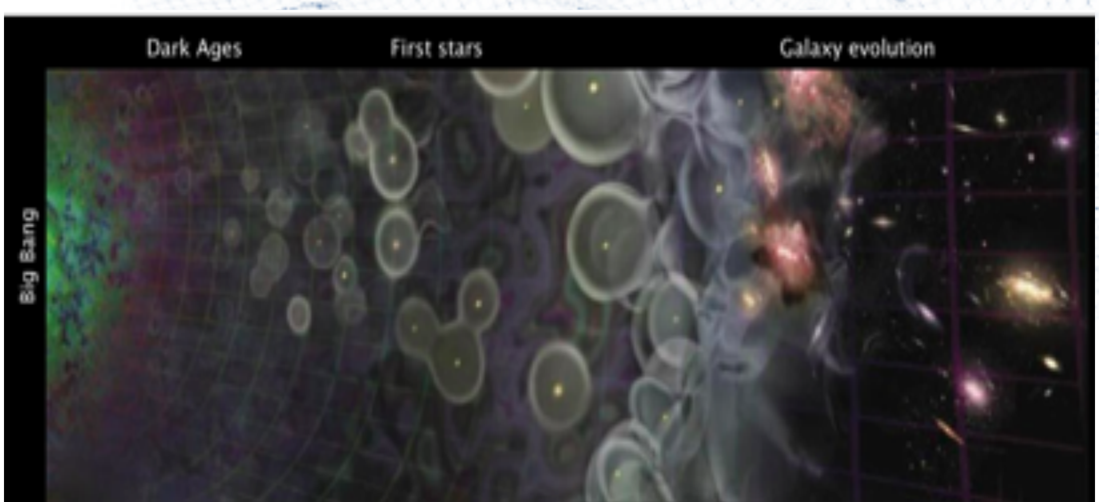
Motivations for Direct Imaging

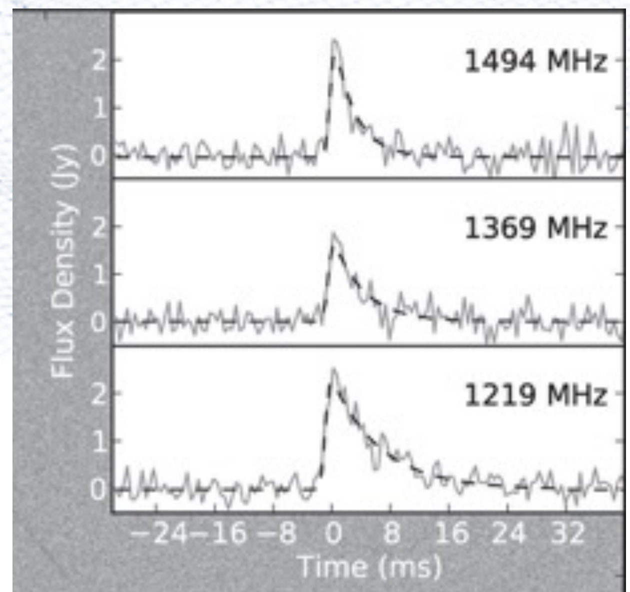
Scientific

- Cosmology / EoR studies
- Transient studies

Technological

- Large collecting areas require large-N arrays
- Cost of the correlator scales as N^2
- Require fast writeouts

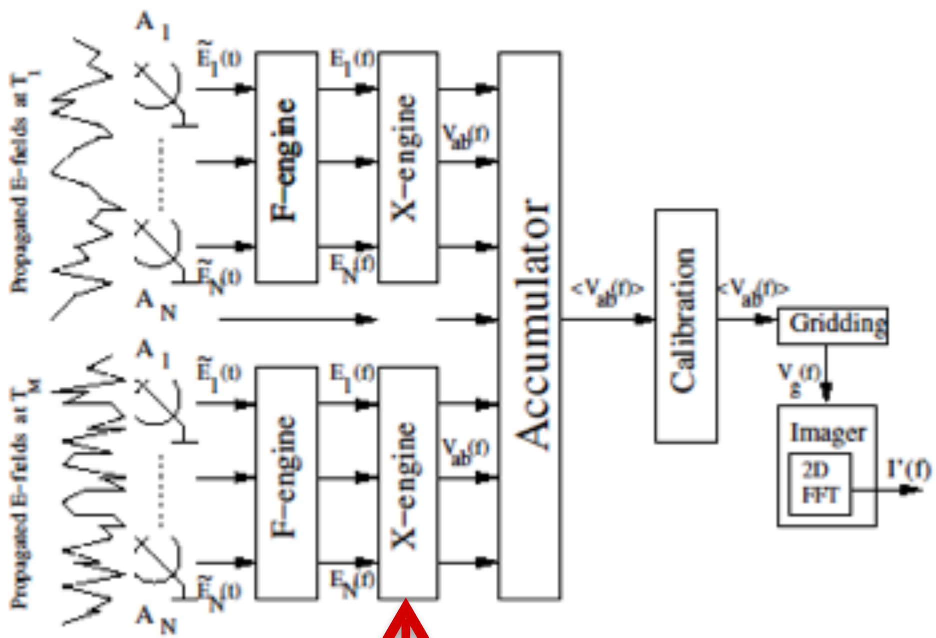




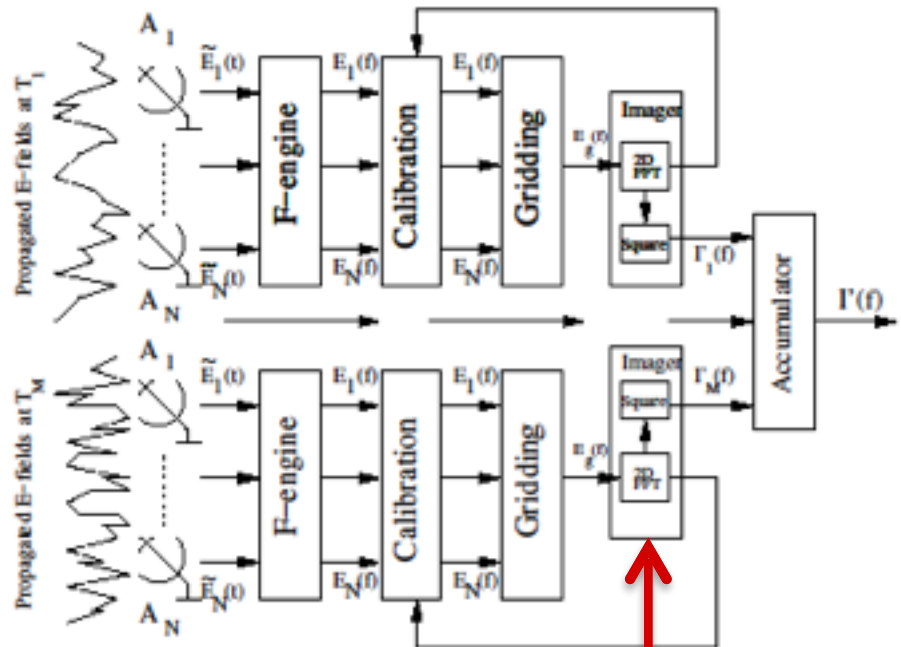
Thornton et al. (2013)

EPIC implementation of MOFF imaging

FX



EPIC / MOFF

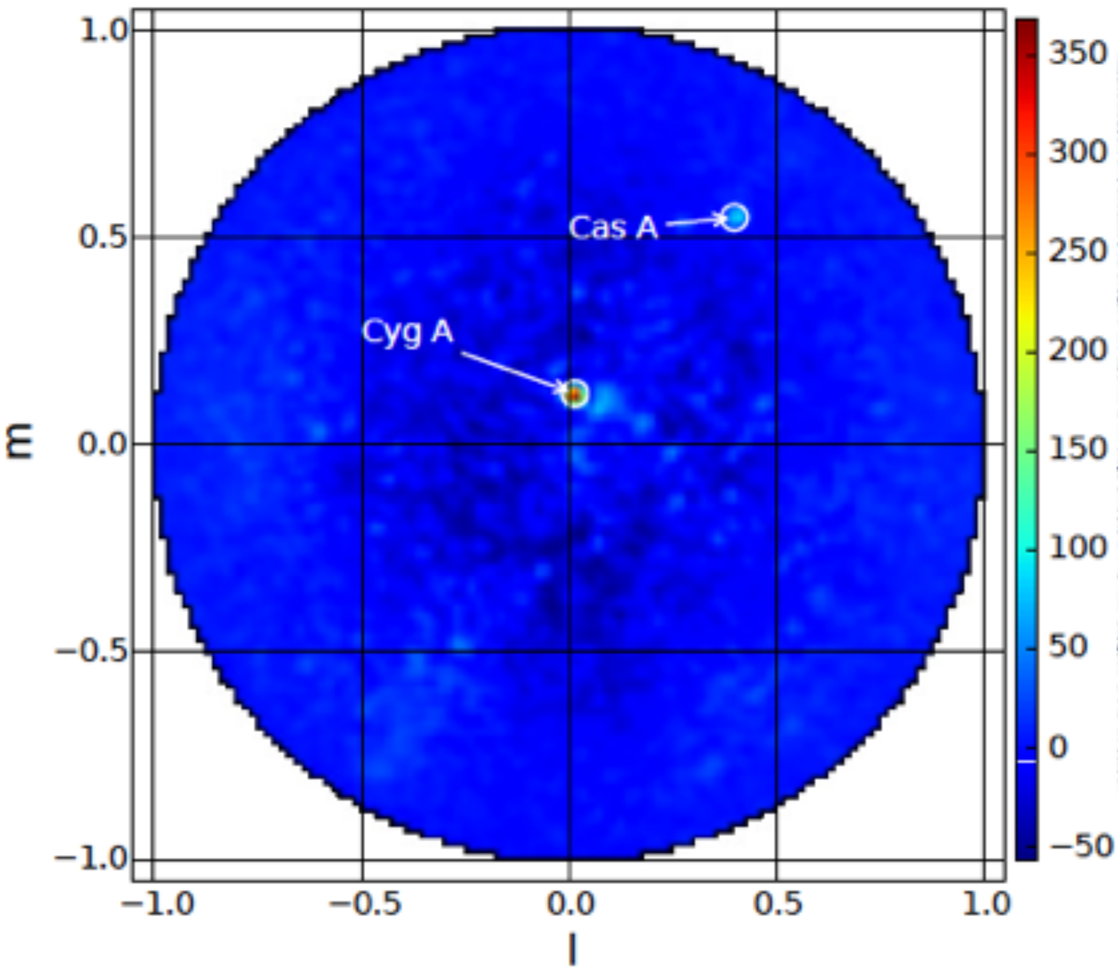


$O(N_a^2)$

Thyagarajan et al. (2017)

$O(N_g \log N_g)$

EPIC on LWA1 Data

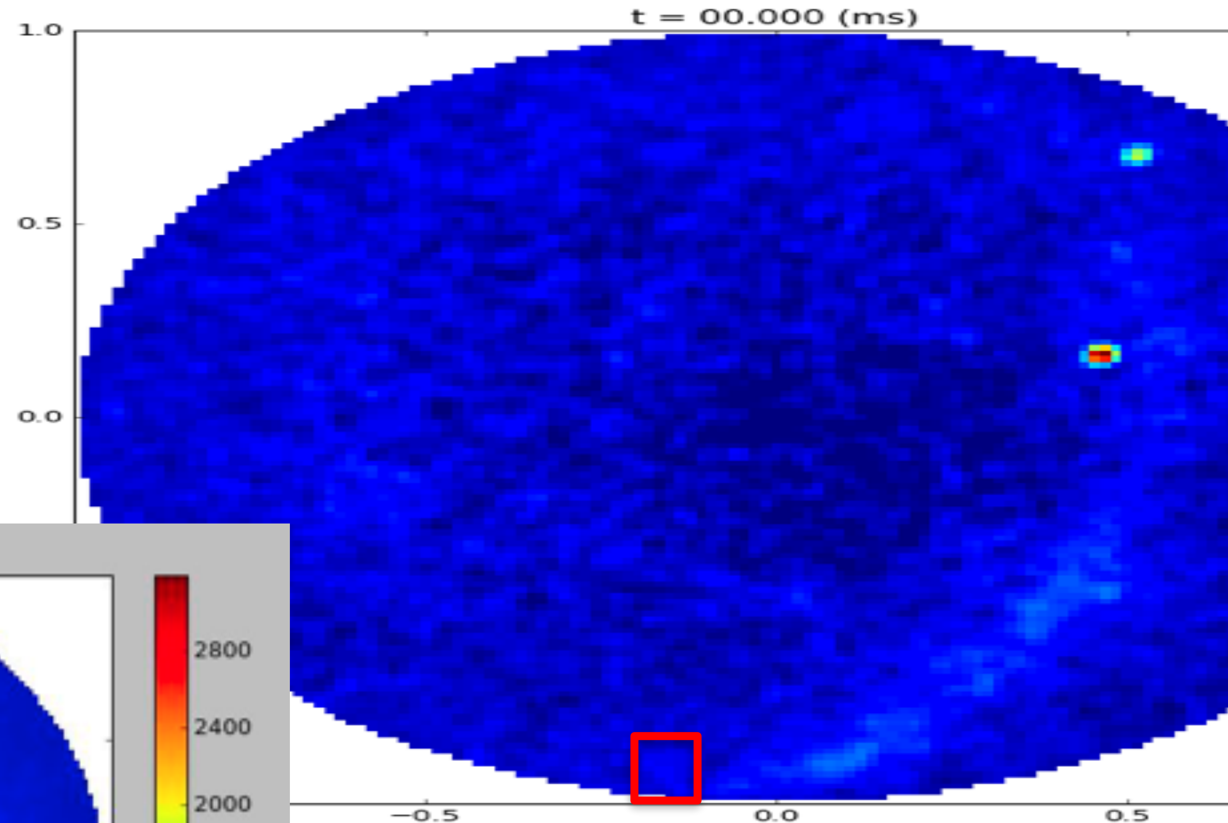


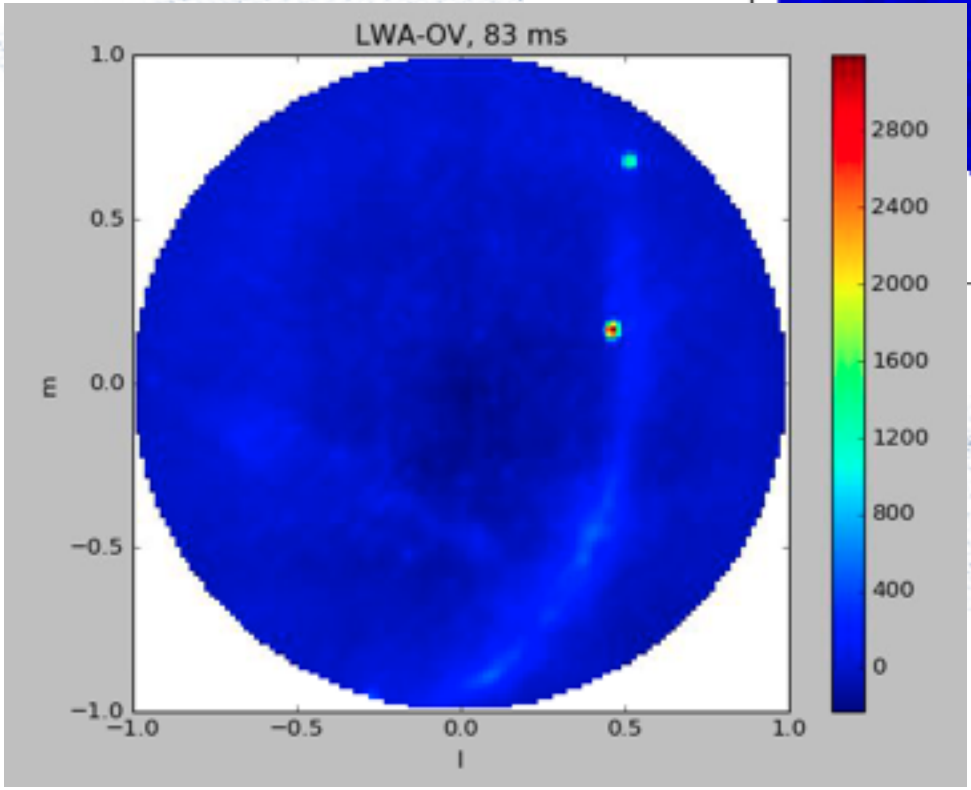
- TBN data with a total of 2s and 100 kHz
- Image obtained with 20 ms, 80 kHz
- Cyg A and Cas A prominently visible

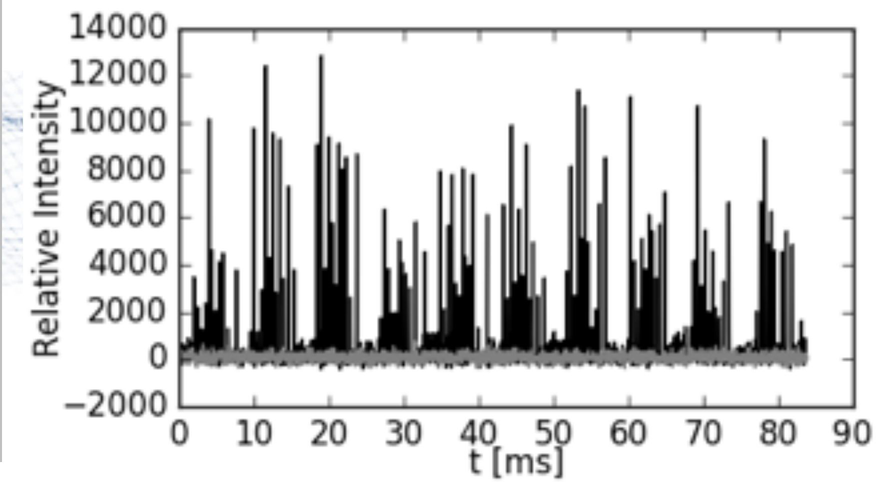
Thyagarajan et al. (2017)

Fast Transient Ca
OVRO-LWA Data

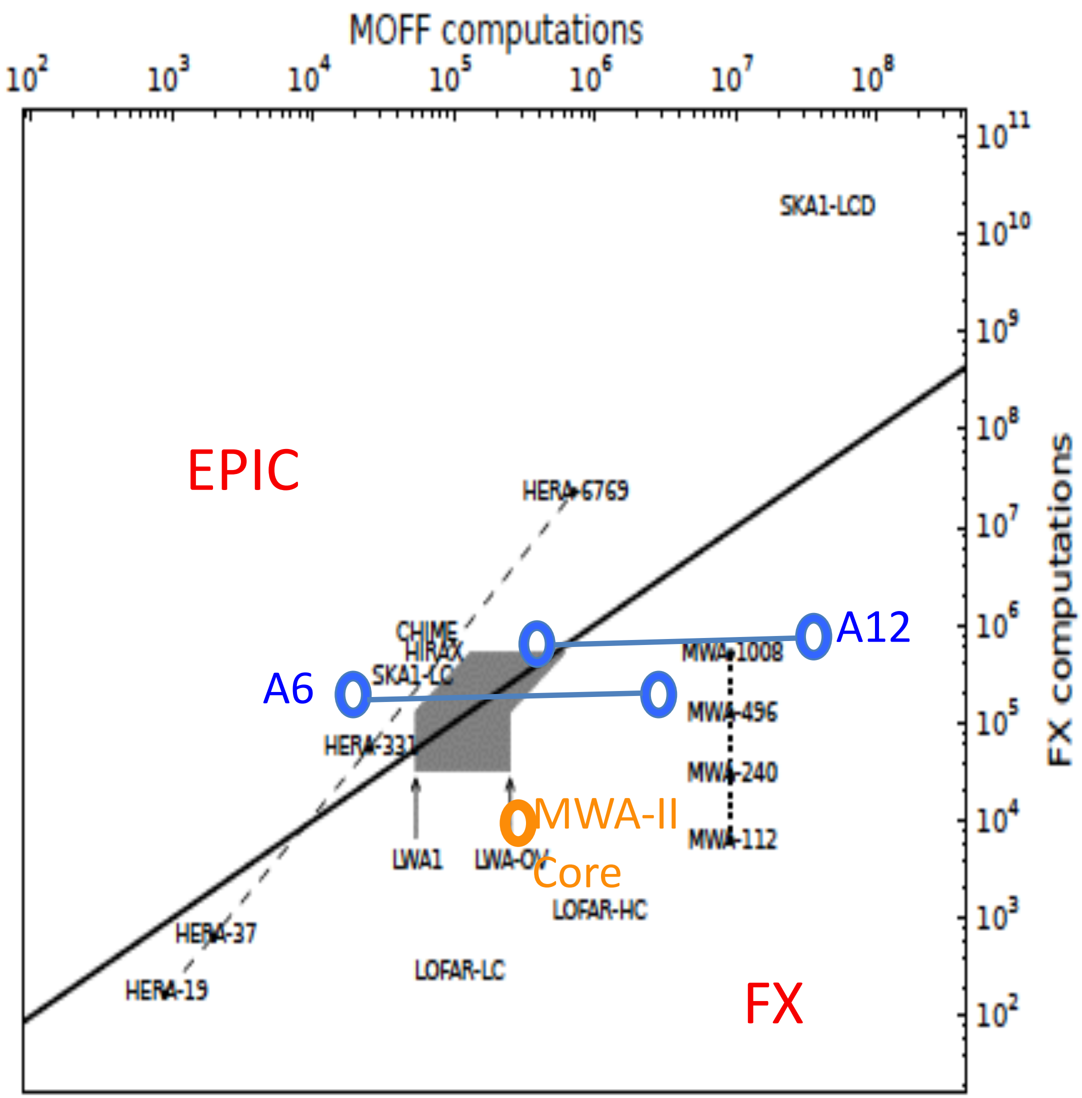
188 core antennas (2(
47 MHz, 2.6 MHz ban
Cadence 0.04 ms







Current and future telescopes in MOFF-FX parameter space



- Top left is where MOFF is more efficient than FX
- Dashed line shows where expanded HERA will be
- Shaded area is where LWA will evolve to be
- Large-N dense layouts favor EPIC
- EPIC will benefit most of future instruments

A6: 0.1 TFLOPS (10 MHz)
13 TFLOPS (90 MHz)
A12: 2.4 TFLOPS (10 MHz)
272 TFLOPS (90 MHz)

LWA-SV station

- 257 dual polarization LWA dipoles
- 20 MHz bandwidth
- New Digital Processor using Roach 2 boards and Bifrost architecture (top level access to underlying routines) (Cranmer et al. 2017)

Image Credit: Greg Taylor

EPIC deployment on LWA-Sevilleta

- $600k funded by NSF (2017-2020)
- Dense layout ideal for testing real-time GPU-based EPIC
- Instantaneous all-sky field of view also ideal for radio sky monitoring of FRBs, pulsars, and EM counterparts to GW
- Array construction has been completed and voltage capture data acquisition has commenced
- Hardware resources available on-site – 14 NVIDIA GeForce GTX 980 GPUs, each capable of 4.6 TFLOPS in single precision
- Kevin Shah (ASU student) working on GPU implementation

Deployment Plans/Objectives of EPIC on LWA-Sevilleta

Task 1

- Process real data through "software EPIC" – verify it can handle real-world data and artifacts
  - ✔LWA1
  - ✔OVRO-LWA
  - – LWA-SV (in progress)
  - – MWA-II Core VCS

    (in progress)

    120 Antennas inside

    250m x 250m core

MWA phase 2: core region

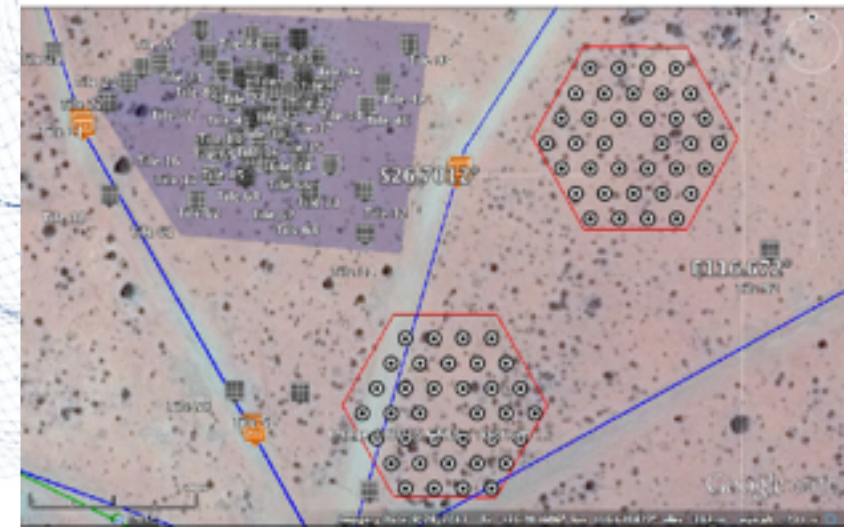


Image Credit: Randall Wayth

Deployment Plans/Objectives of EPIC on LWA-Sevilleta

Task 2

- Implement GPU-based EPIC on LWA-SV hardware (NVIDIA CUDA)
- Implementation performance
- Optimize to LWA-SV system parameters

Deployment Plans/Objectives of EPIC on LWA-Sevilleta

Task 3

- EPIC image quality verification with FX approach
- Compare to known sky models

Deployment Plans/Objectives of EPIC on LWA-Sevilleta

Task 4

- Implement a blind search for transients
- Start with low DM De-dispersion (local FRBs, Galactic pulsars)
- Monitor 6 known millisecond pulsars with the LWA, search for more

Deployment Plans/Objectives of EPIC on LWA-Sevilleta

Task 5

- Evaluate performance, potential and scalability for HERA-III, MWA-III
- Inputs to Astro2020 decadal survey
- Prepare for SKA-scale implementation

Timetable of EPIC on LWA-Sevilleta

Milestone	**Dates**
Process MWA Voltage Capture data through software EPIC	June 2017 - Oct 2017
Process LWA1 TBW and LWA-OV data through software EPIC	Sept 2017 - Dec 2017
Port EPIC code to GPUs, parallelize and optimize	Nov 2017 - March 2018
Develop polarized imager for transient searches	June 2018 - Nov 2018
Deploy GPU implementation onto existing hardware at LWA-SV	Sept 2018 - Feb 2019
Evaluate scalability of GPU correlator, and verify data products	March 2019 - May 2019
Develop image-based, efficient and sensitive transient search mode	June 2019 - Dec 2019
Conduct transient search campaign	Jan 2020 - March 2020
Analyze results from transient search Prepare white paper to outline future applications	March 2020 - May 2020 2019

EPIC Summary

- EPIC is promising for most modern/future telescopes (SKA1-low, HERA, LWA, CHIME, MWA II/III core, etc.)
  - Cosmology studies
    - Large-N dense arrays for sensitivity to large scales
  - Radio Transients
    - Fast writeouts
    - Economic data rates
    - Calibrated images at no additional cost
- NSF funded deployment on LWA-Sevilleta underway
- EPIC paper - Thyagarajan et al. 2017, MNRAS, 467, 715
- Calibration paper (EPICal) - Beardsley et al. 2017, MNRAS, 470, 4720
- Highly parallelized EPIC implementation in Python publicly available - https://github.com/nithyanandan/EPIC/