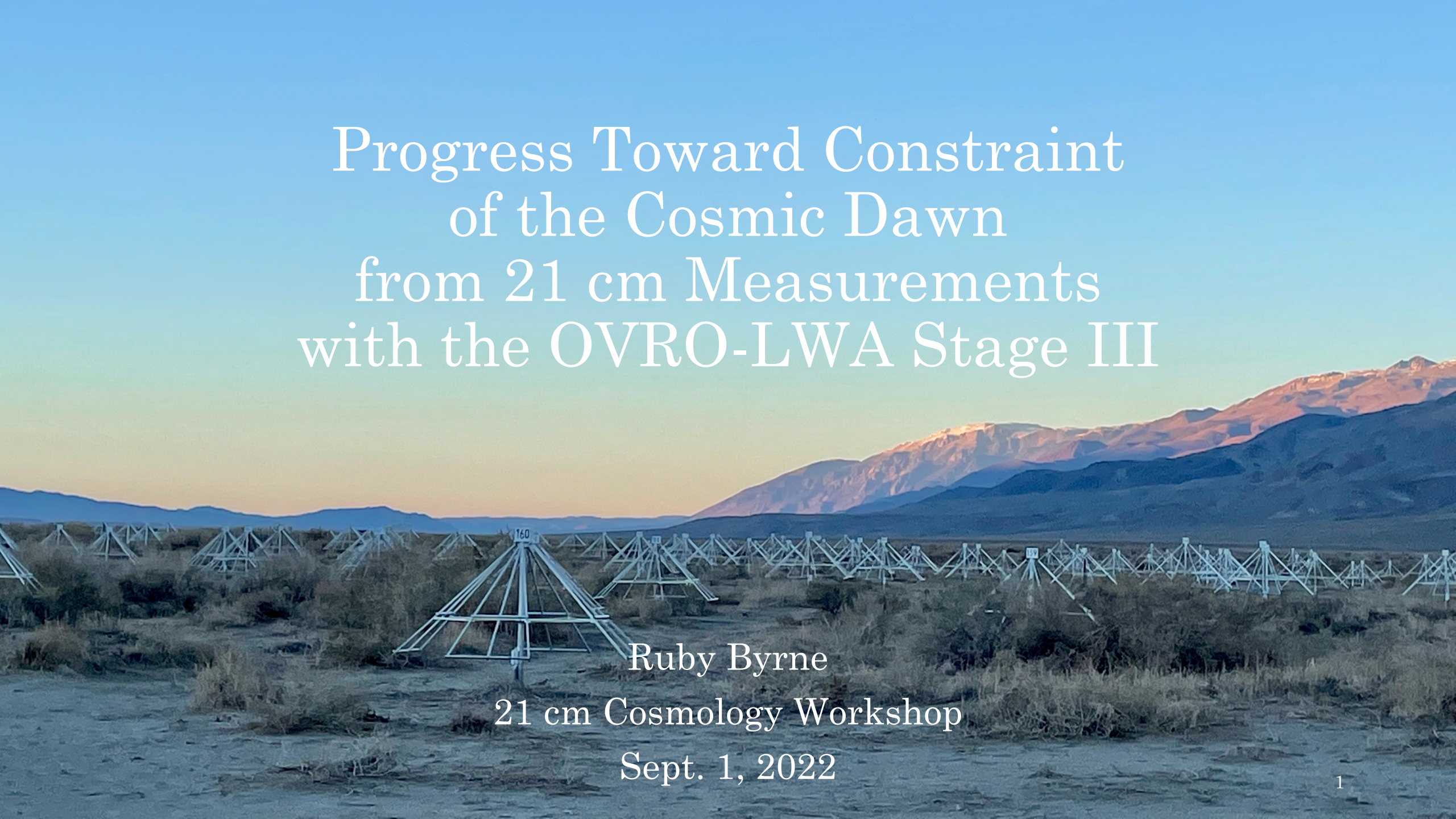
Progress Toward Constraint of the Cosmic Dawn from 21 cm Measurements with the OVRO-LWA Stage III



Ruby Byrne

21 cm Cosmology Workshop

Sept. 1, 2022

What is the OVRO-LWA?

- Owens Valley Radio Observatory (OVRO) Long Wavelength Array
- Located near Big Pine, California
- Dual-polarization dipole antennas (same antennas as the New Mexican LWA arrays and NenuFAR)
- Fully cross-correlated
- 15-85 MHz
- Currently undergoing the “Stage III” upgrade

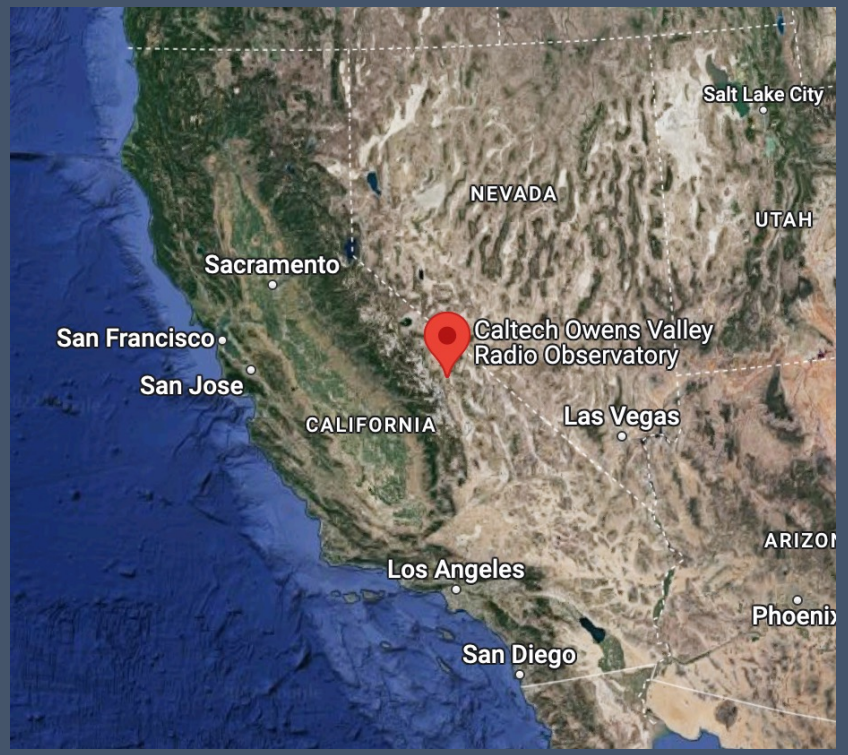


Image source: Google Maps

The OVRO-LWA Stage III Team

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21 cm Cosmology with the OVRO-LWA

- Good *uv* coverage and plenty of short baselines
- Widefield for horizon-to-horizon imaging
- High redshift: z ≈ 16-100
- Could probe the Dark Ages, Cosmic Dawn, X-Ray Heating
- Complementary to global 21 cm experiments

The OVRO-LWA: A Brief History

- Stage I: 2013-2014
- Stage II: 2015-2020
- Stage III: 2021-present

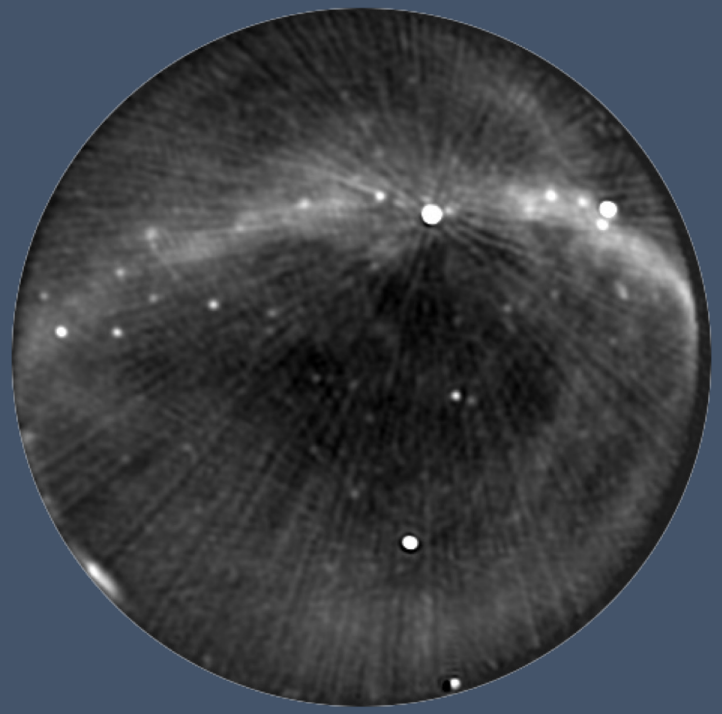
The OVRO-LWA: A Brief History

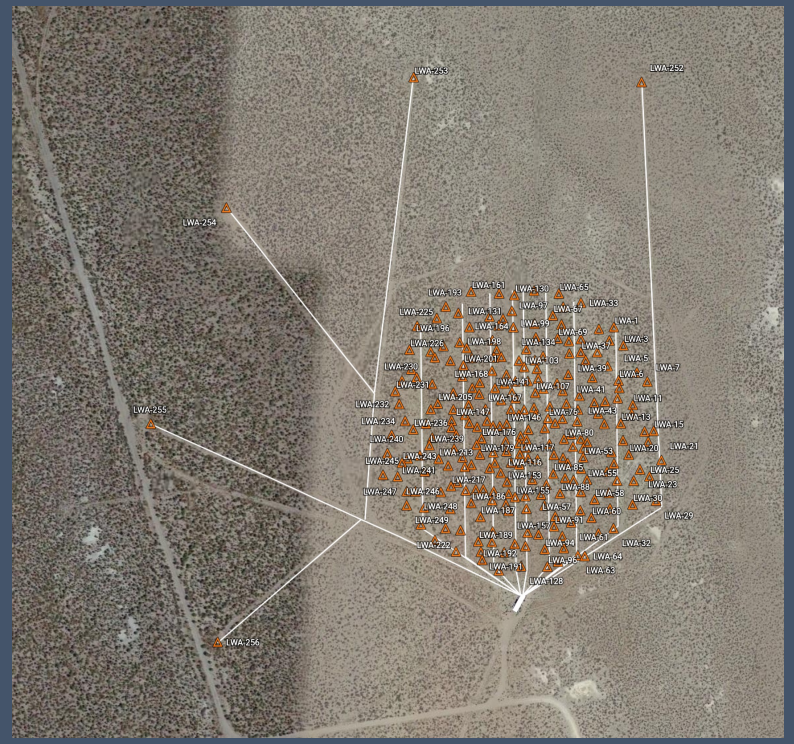
- **Stage I: 2013-2014**
- Stage II: 2015-2020
- Stage III: 2021-present

Stage I

- 2013-2014
- 251 antennas
- 5 outriggers
- LEDA correlator (Kocz et al. 2015)

Example Snapshot Image





Source: Marin Anderson and Morgan Catha

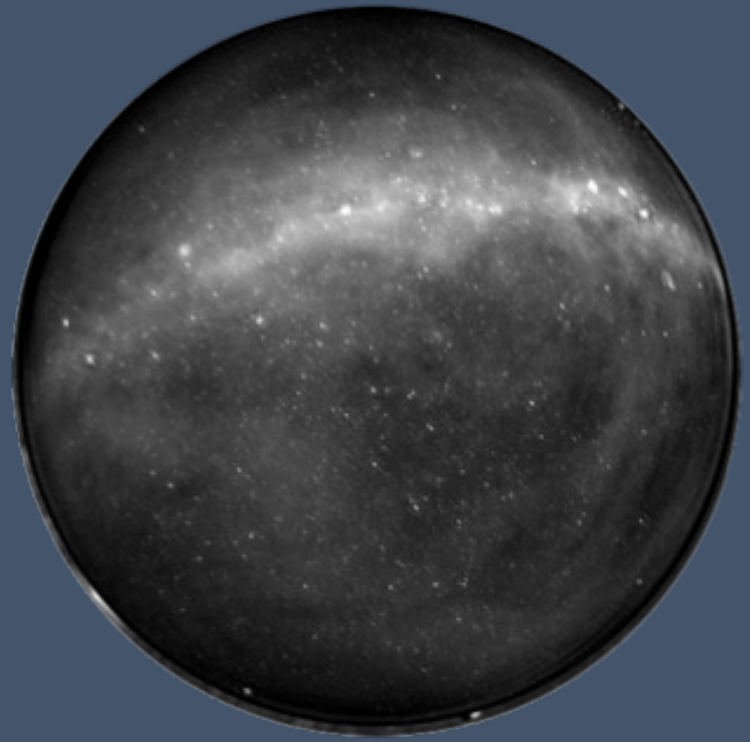
The OVRO-LWA: A Brief History

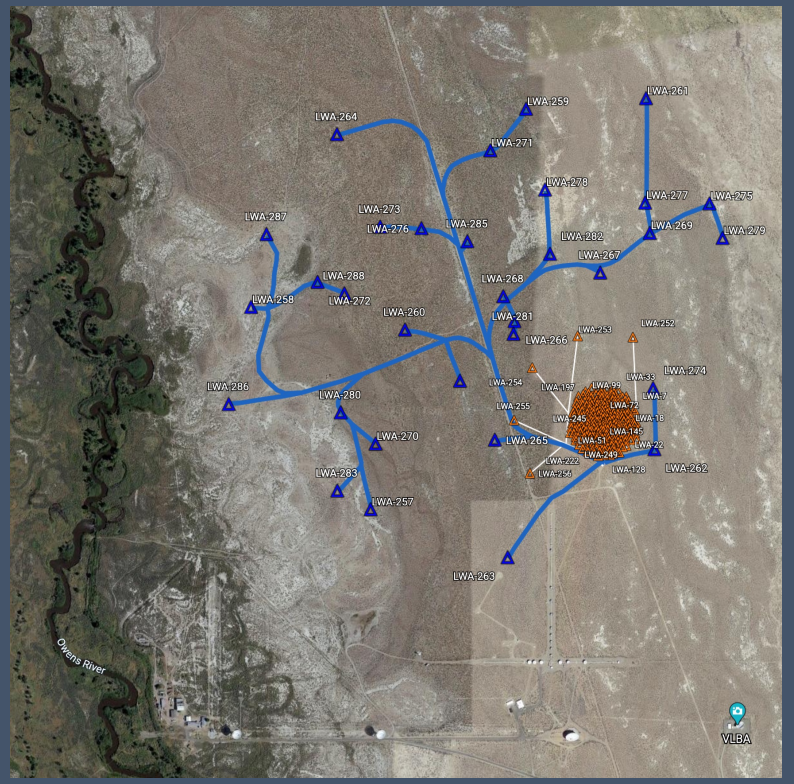
- Stage I: 2013-2014
- **Stage II: 2015-2020**
- Stage III: 2021-present

Stage II

- 2015-2020
- 283 antennas
- Addition of 32 fiber-fed outrigger antennas
- Longest baseline extended to 1.5 km
- Custom fiber-link board

Example Snapshot Image

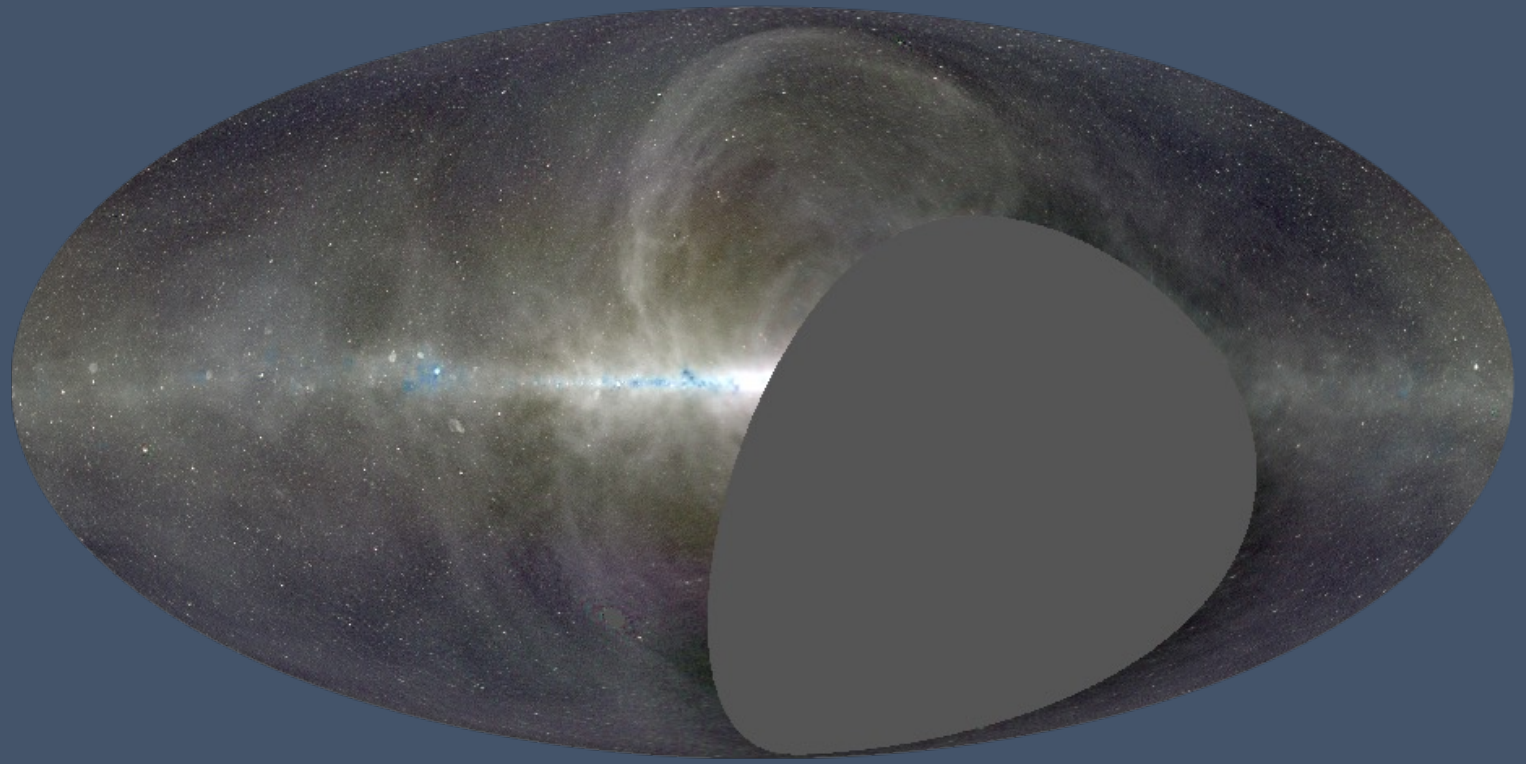




Source: Marin Anderson and Morgan Catha

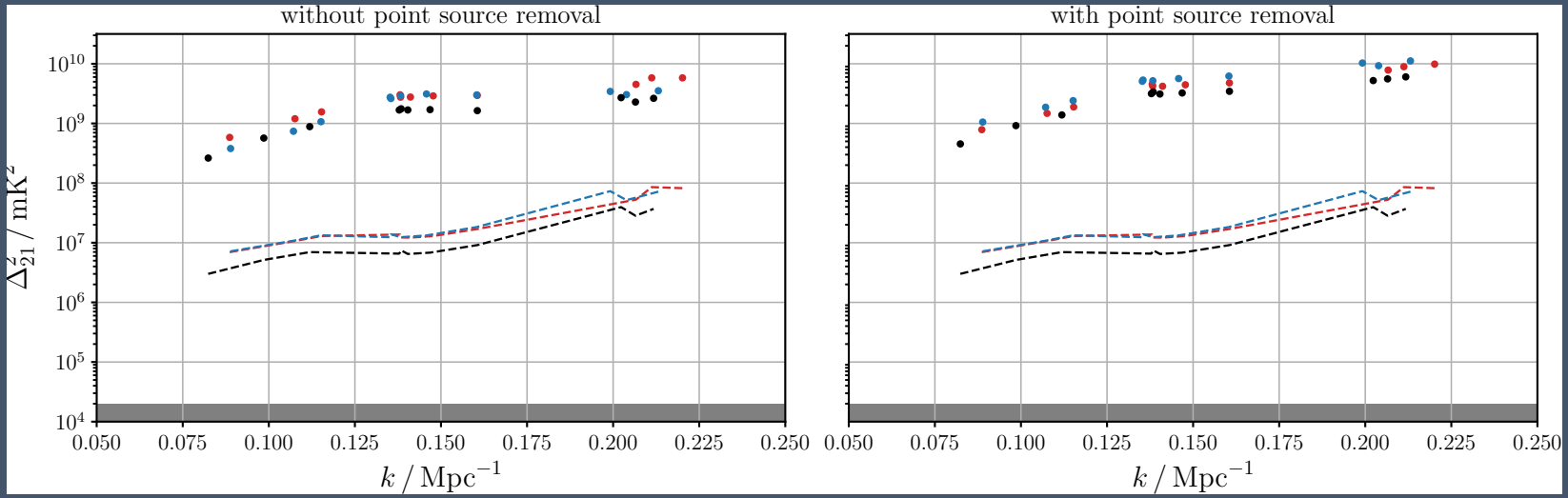
Stage II Results: M-Mode Mapping

- Eastwood et al. 2018
- All-sky mapping
- Custom analysis pipeline written in Julia
- Based on the formalism developed in Shaw et al. 2014, 2015



Stage II Results: 21 cm Limit

- Eastwood et al. 2019
- PS estimation pipeline based on m-mode analysis
- Non-constraining limit on the 21 cm PS of $\Delta_{21} < 10^4$ mK at $z \approx 18.4$

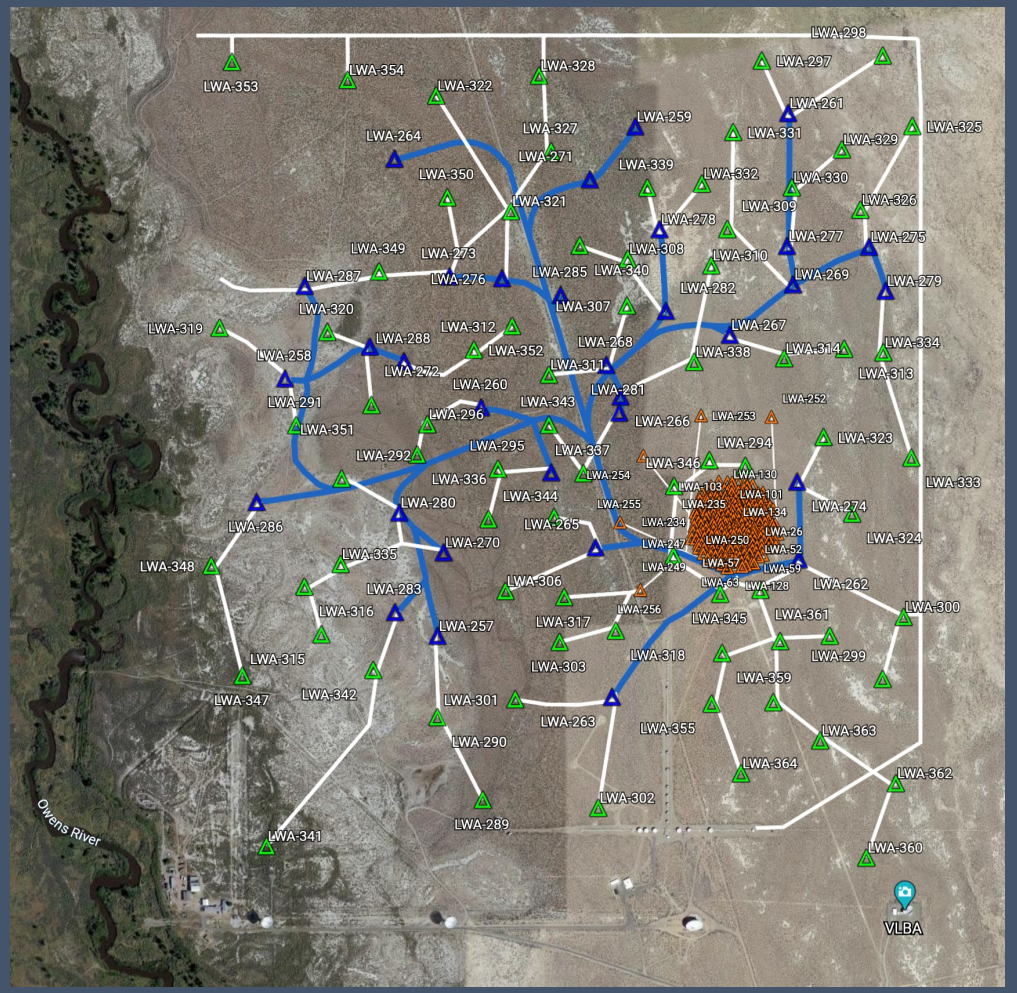


The OVRO-LWA: A Brief History

- Stage I: 2013-2014
- Stage II: 2015-2020
- **Stage III: 2021-present**

Stage III

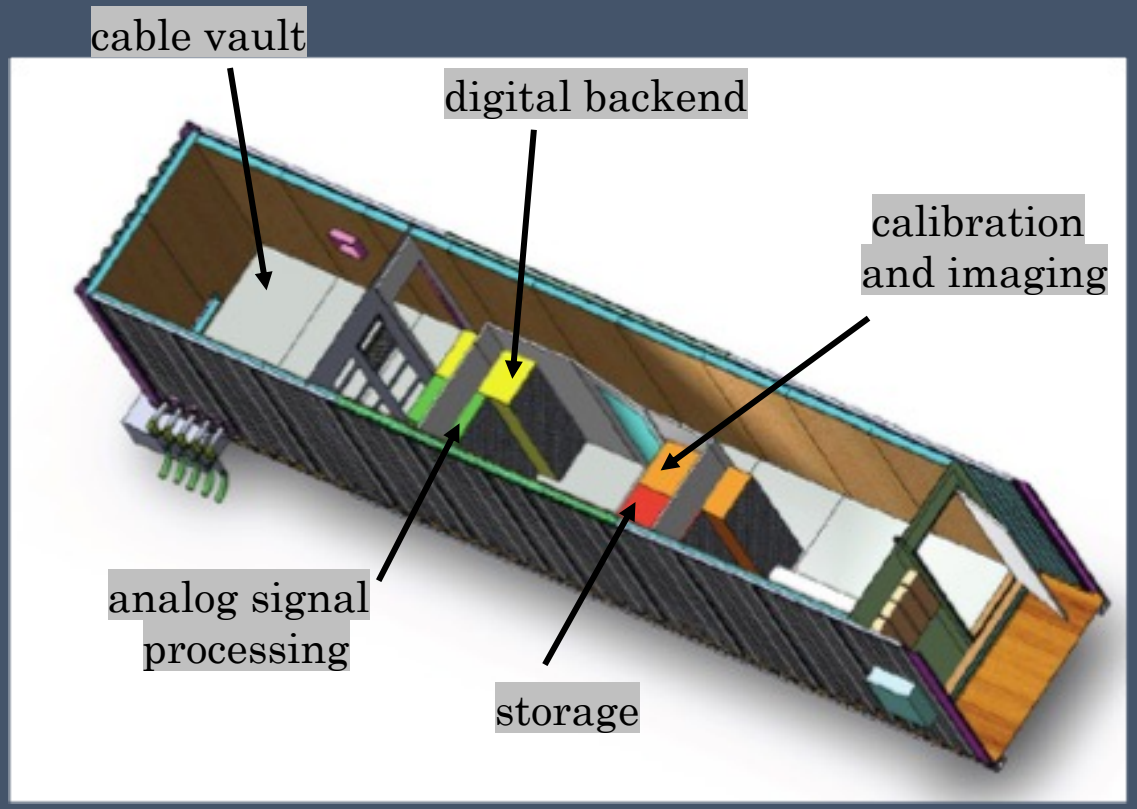
- 352 antennas
- 109 outriggers: 69 additional
- Longest baseline extended to 2.4 km
- Complete overhaul of the analog and digital backend



Source: Marin Anderson and Morgan Catha

Stage III: Signal Backend

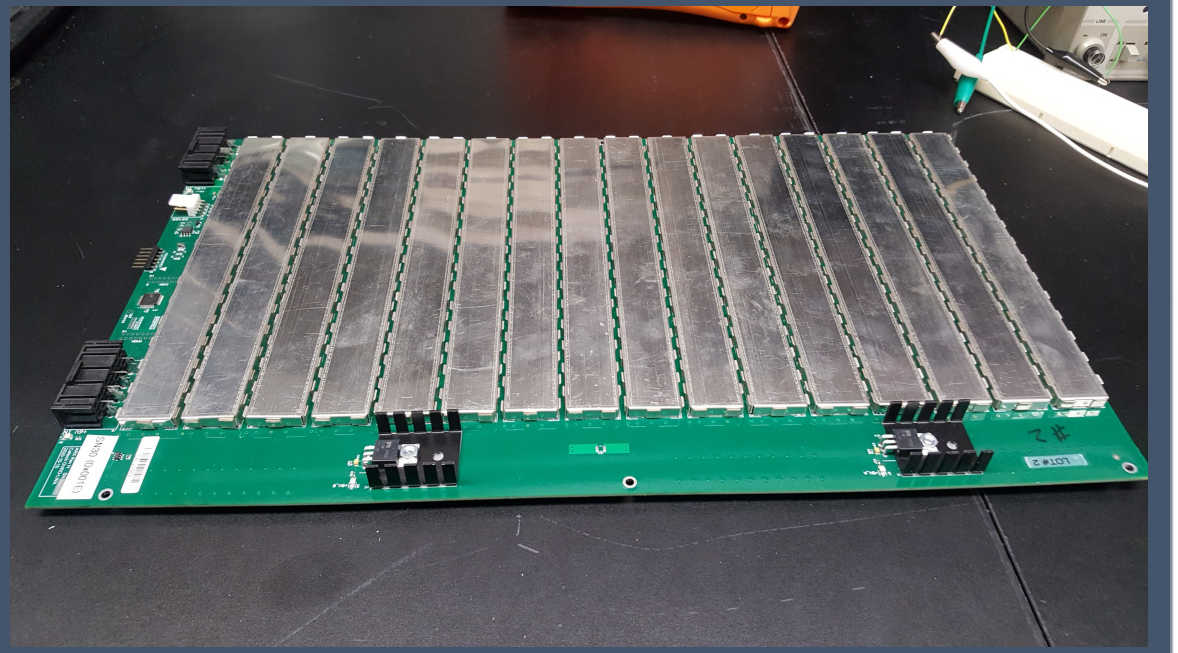
- All data processing is on-site



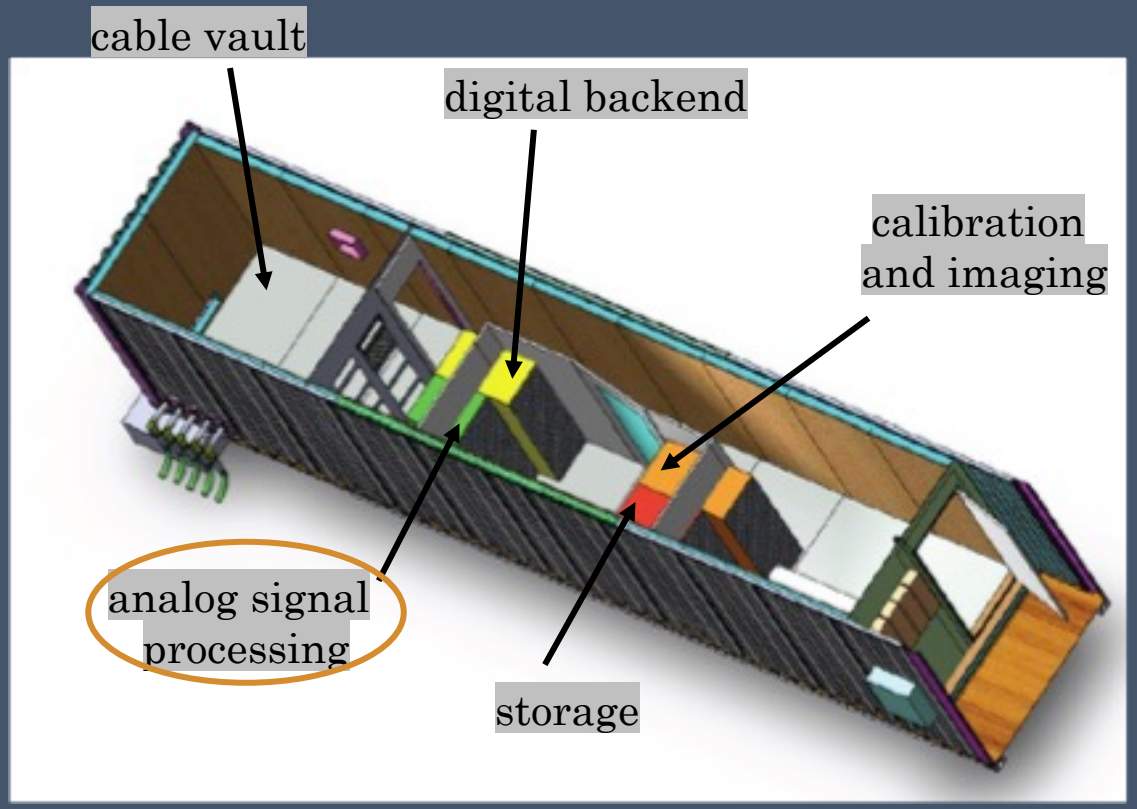
Source: Gregg Hallinan

Stage III: Signal Backend

- Custom redesigned analog receiver boards developed by Larry D'Addario



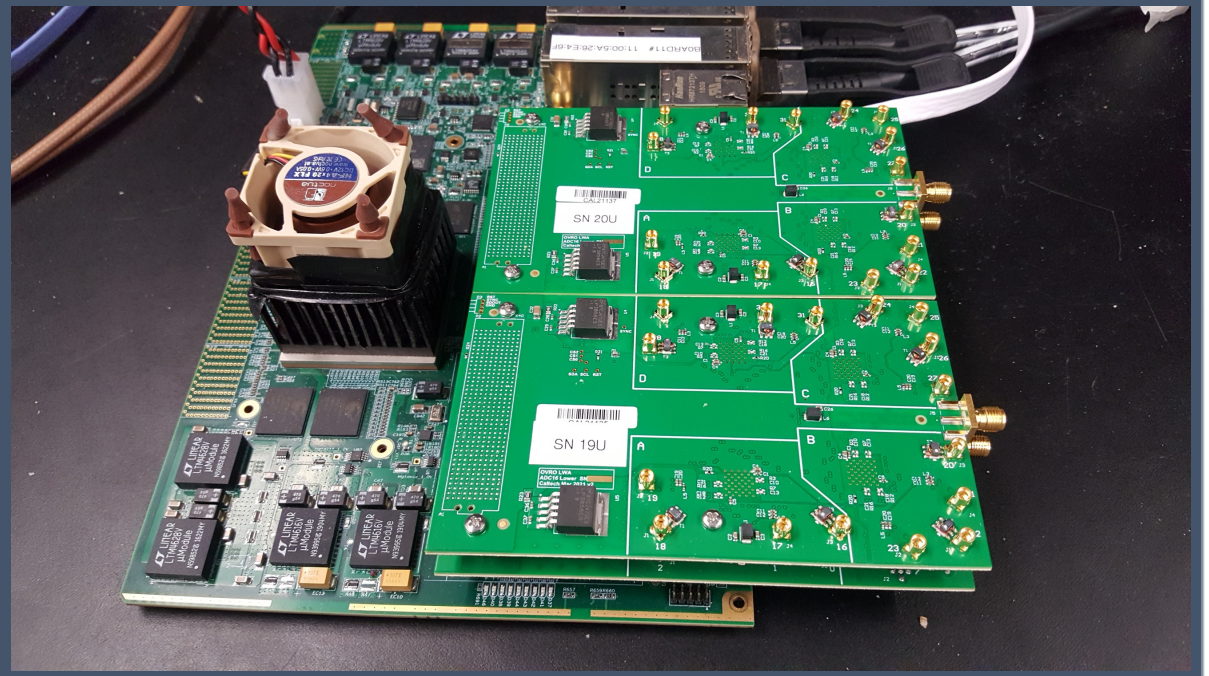
Source: Larry D'Addario



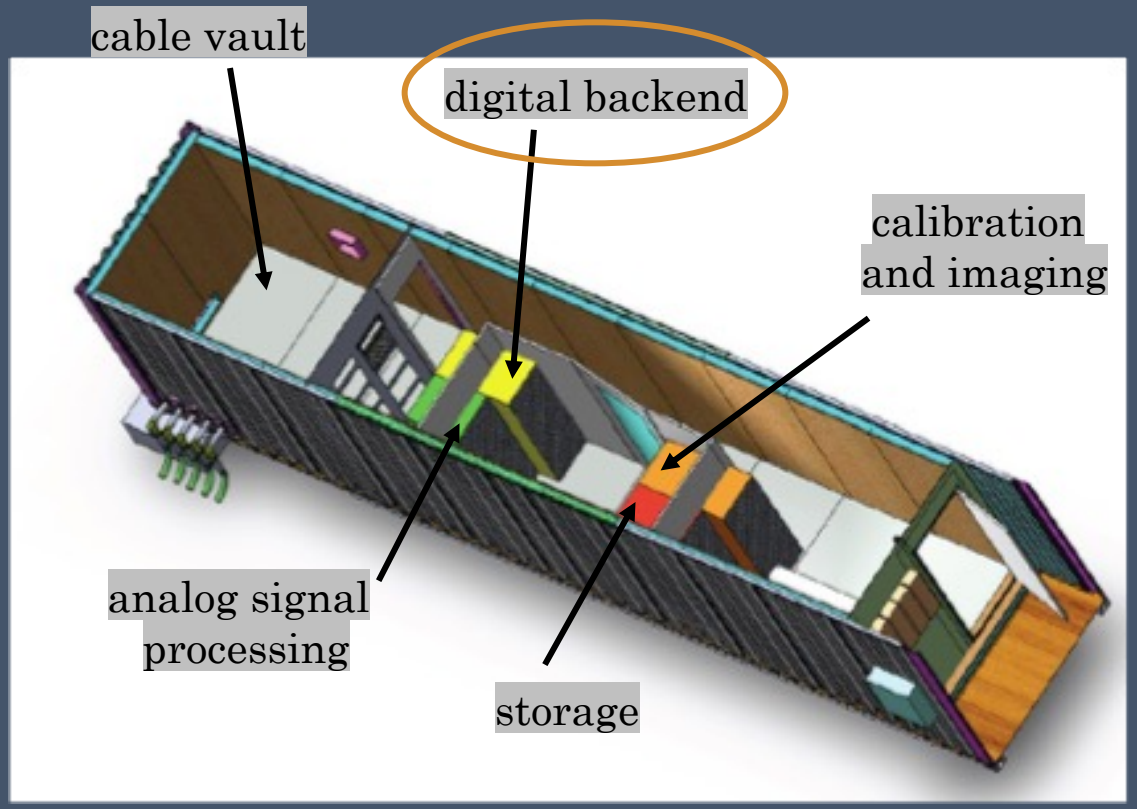
Source: Gregg Hallinan

Stage III: Signal Backend

- Custom ADCs (Jack Hickish)
- 4 ADC boards mounted on SNAP2 boards



Source: Larry D'Addario



Source: Gregg Hallinan

Stage III Upgrade: Current Status

- Core upgrade is complete and undergoing commissioning
- Trenching for outriggers is ~90% complete

Photo credit: Marin Anderson

Cosmology with the OVRO-LWA Stage III

How can we improve upon the Eastwood et al. 2019 limit?

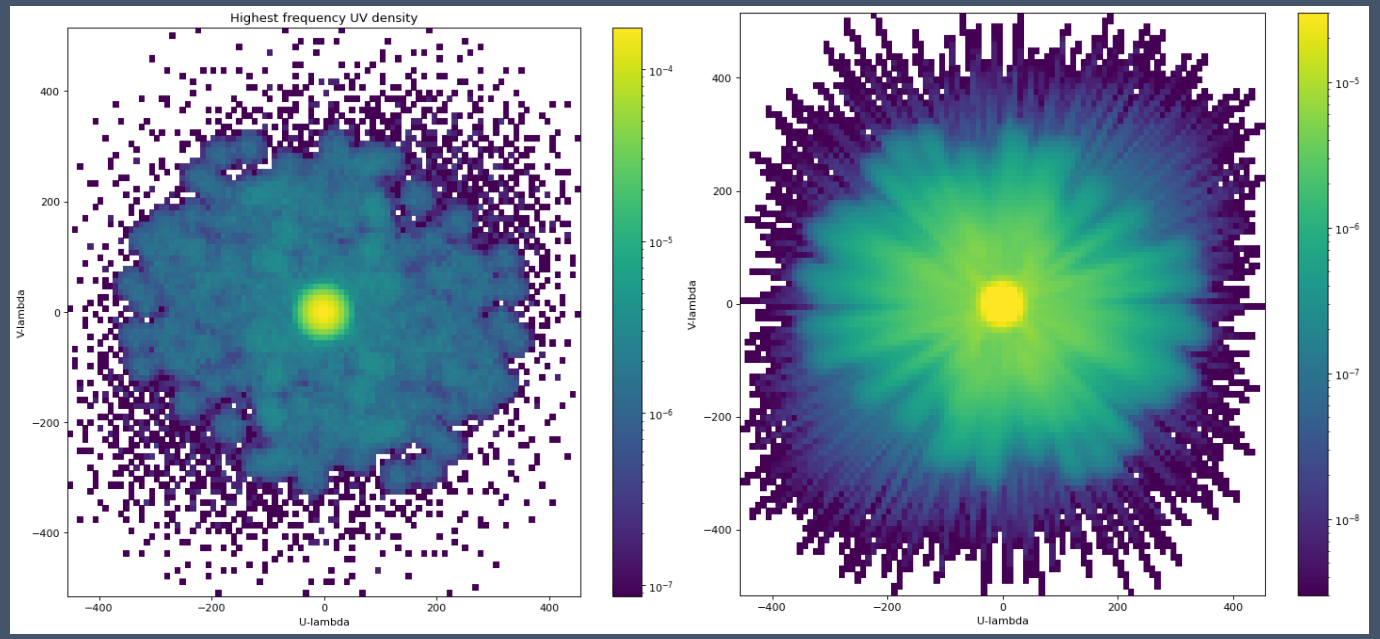
Cosmology with the OVRO-LWA Stage III

How can we improve upon the Eastwood et al. 2019 limit?

1. More antennas

Improved *uv* coverage and resolution

- Increased sensitivity to the 21 cm signal
- Reduced calibration error from improved *uv* coverage
- Long baselines help calibrate and deconvolve compact sources



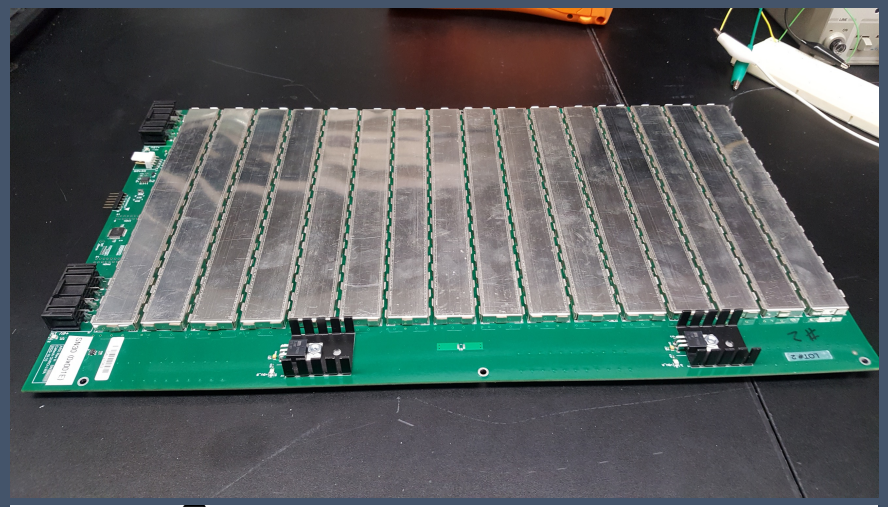
Source: Yuping Huang

Cosmology with the OVRO-LWA Stage III

How can we improve upon the Eastwood et al. 2019 limit?

1. More antennas
2. Improved analog receiver board

Upgraded analog receiver boards



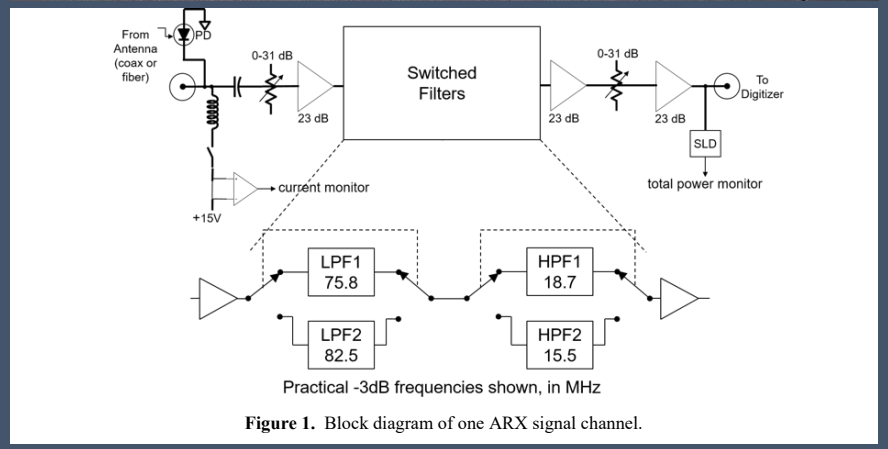


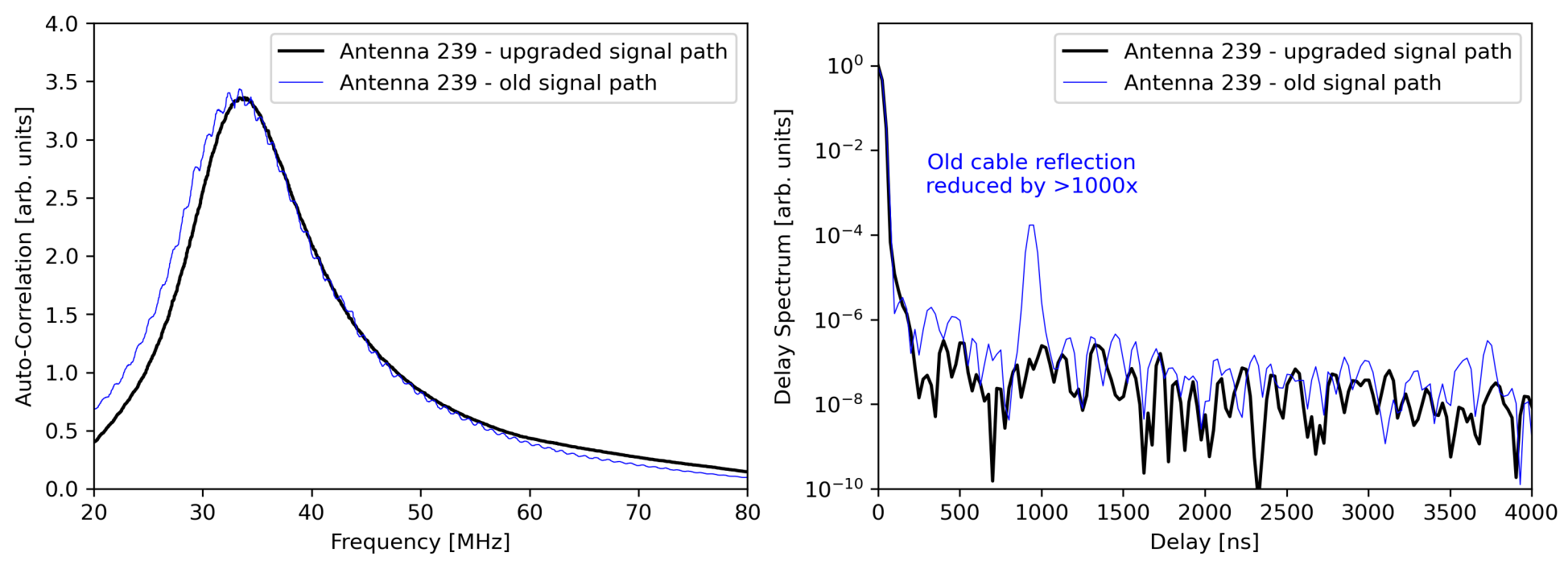
Figure 1. Block diagram of one ARX signal channel.

- Signal isolation for preventing cross-talk
  - RFI-tight enclosure for each signal channel
  - Individual power and ground for each channel
- Impedance matching to reduce signal reflections

Source: Larry D'Addario

Upgraded analog receiver boards

Signal reflection analysis: preliminary results



Source: Judd Bowman

Cosmology with the OVRO-LWA Stage III

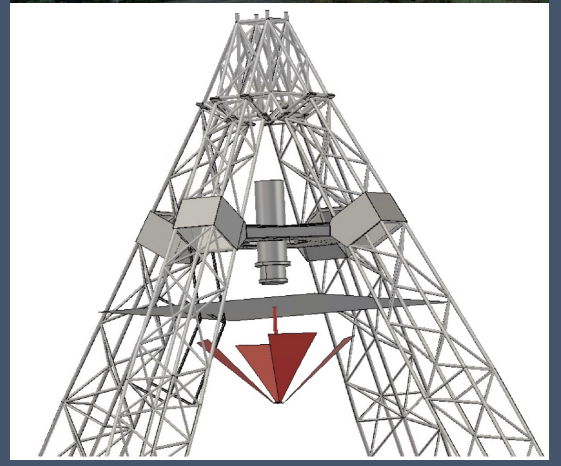
How can we improve upon the Eastwood et al. 2019 limit?

1. More antennas
2. Improved analog receiver board
3. Updated data analysis methods

21 cm analysis pipeline with Stage III

New analysis pipeline will adopt best practices developed by the 21 cm community

- Improved RFI flagging (Greg Hellbourg)
- Improved beam modeling with holography measurements
- Foreground mapping with m-mode analysis (Xander Hall)
- Calibration with DWCal
- Power spectrum estimation with FHD/eppsilon
  - Snapshot processing – NOT all-sky
  - Modified gridding kernel (Barry et al. 2019)
  - Foreground avoidance



Beam holography with the 40 m telescope
Source: Gregg Hallinan

21 cm analysis challenges

- OVRO's RFI environment
- Mutual coupling: beams are per-antenna
- Ionosphere

Conclusions

- 21 cm measurements with the OVRO-LWA could probe pre-Reionization cosmology
- Eastwood et al. 2019 developed a first limit on the signal
- Stage III upgrade is overhauling the instrument and will enable deeper 21 cm limits
  - Improved uv coverage and long baselines
  - Systematic-resistant signal backend
  - State-of-the-art data analysis