U.S. NAVAL RESEARCH LABORATORY

LWA Path Forward:
The Journey to a Station Begins with a Single Dipole

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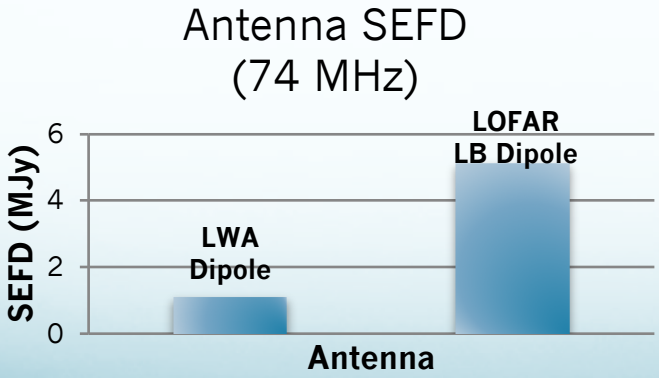
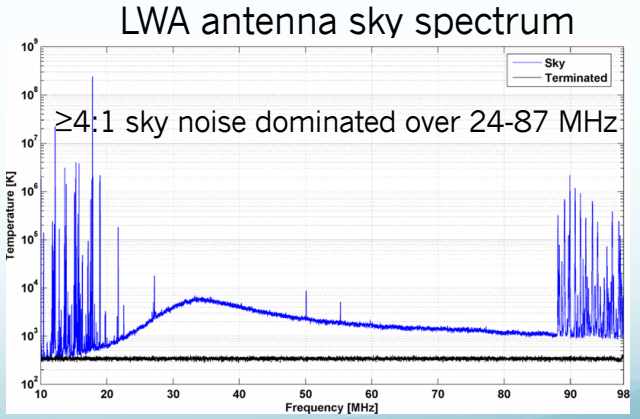
Sound Foundation: LWA Antenna & FEE Performance

- The LWA antenna & FEE are among the best, broad-band antennas deployed for radio astronomy and remote sensing below the FM bands
  - ➢ Advantages in bandwidth, sensitivity, & lifetime
  - ➢ Growing distribution across US & world (inc. e.g. Nancay, future LOFAR upgrade, etc)
  - ➢ **Characteristics continue to be refined (e.g. D. Jacobs talk this meeting).**



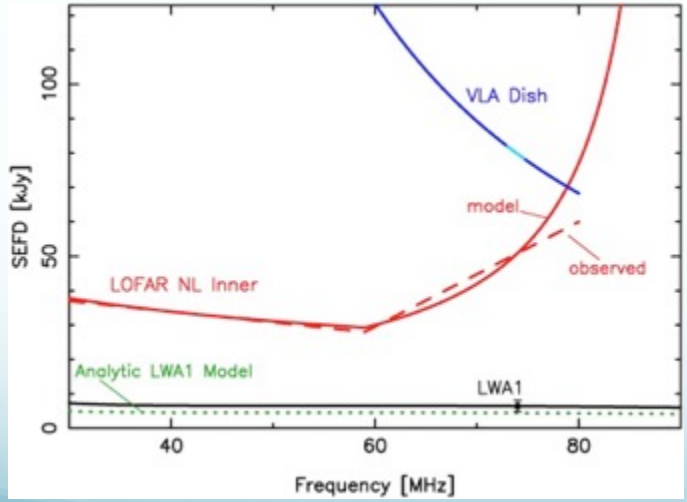


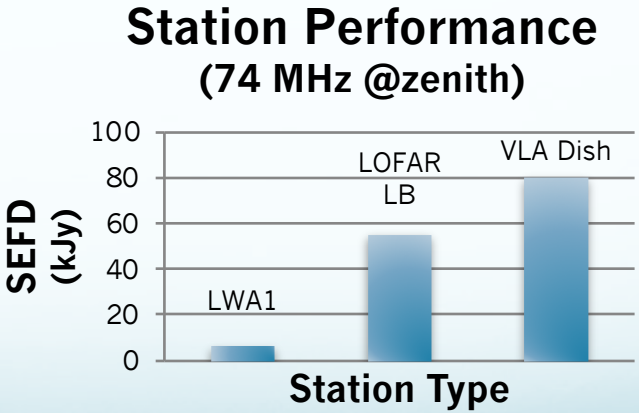
Design documented in Hicks et al. 2012, PASP, 1024, 1090.

Sound Foundation: LWA Station Performance

LWA stations in the SW US offer advantages over LOFAR stations and the VLA, in performance (and sky coverage, inc. Galactic center).

Single Station Performance

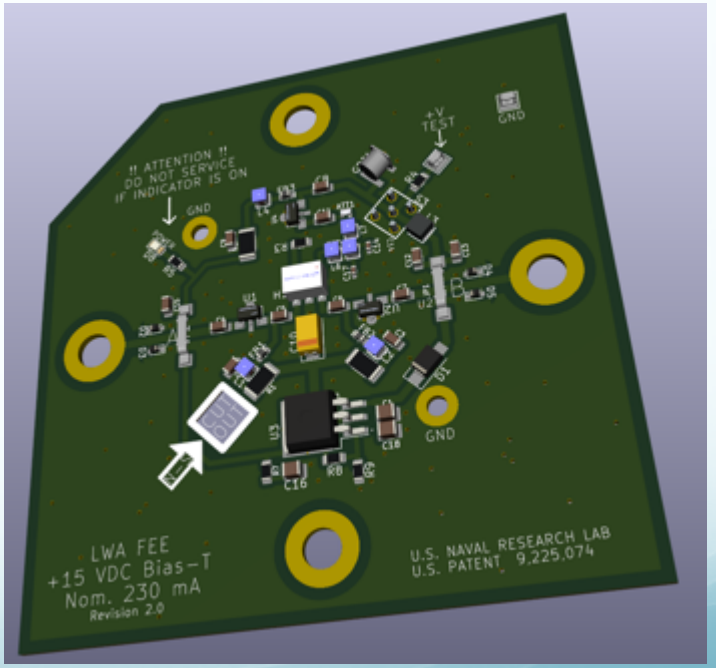




SEFD ≡ System Equivalent Flux Density $\alpha T_{sys}/A_e$

Can we make them better? Of course!
Front End Electronics

- **Transitioning Design to Open Source Tools (KiCAD > 5.x)**
- **Incorporating lessons learned in the field:**
  - Increased feedpoint connection diameter
  - **Elimination of tantalum capacitors while retaining low-dropout voltage regulator**
  - Protection of final output amplifier with new attenuator option to also increase reverse isolation
  - Improvements to increase manufacturing yield
  - Many more…
- Produce complete ‘build package’ with standard file set (Gerber Files, BOM, Pick-and-place, Netlist, Mechanical Drawings, etc.):
  - **Ensure future availability**
  - **Encourage Experimentation and Improvement – Enable students to try new amplifiers, filters and combiners without being burdened by mechanical details**
  - Design will encapsulate all relevant documentation (datasheets, etc.)



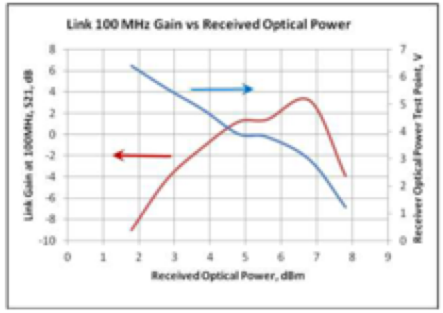
KiCAD 3D (STEP) Model

Can we make them better? Of course!
Front End Electronics (continued)

- NRL Test Array at Pomonkey, Maryland enabling renewed innovation
  - **Initial work focusing on finding an economical and more readily available alternative to the HX62A quadrature hybrid. At ~$30 USD each, this component is the primary cost and availability determinant of the FEE.**
  - Industrial Partnership with ATM Mid-Atlantic / Mini-Circuits to produce stock part to replace the HX62A at a greatly reduced cost.
  - **FEE being optimized for mass production.**
- **Steve Burns assures the project of future antenna stand availability** through his family owned company and experienced supply and manufacturing chain.

From LWA-OVRO:
Optical Fiber Option – thanks Sandy!

- **Laser link to extend the baselines of LWA-OVRO (S. Weinreb – JPL-Caltech)**
- Array operates 20-80 MHz range but link accommodates a much wider bandwidth, 10 to 2000 MHz, at no higher cost for future applications.
- **Link designed with near 0 dB insertion loss** so as to be transparent to operation and has 13dB noise figure and -10 dBm input 1dB compression point
- **Compatible with the 36 dB gain of the LWA LNA**.



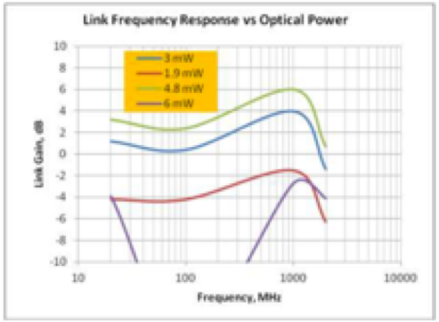
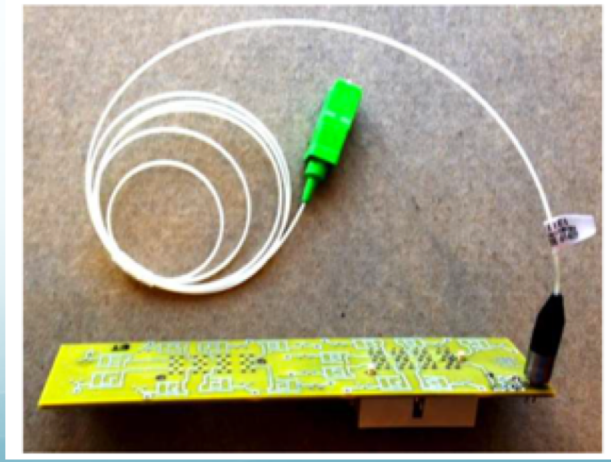


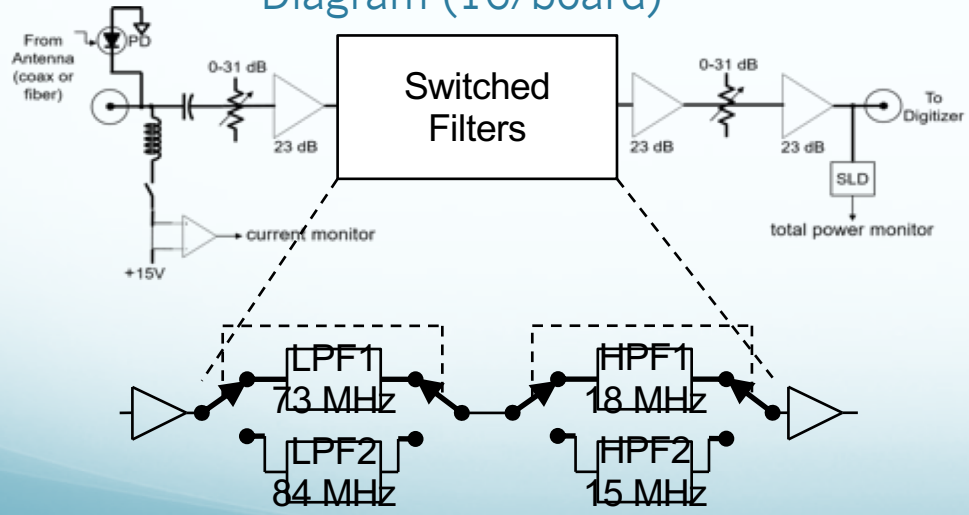
Photo Diode Receiver Board



More Innovations:
From LWA-OVRO: Improved ARX (I. D'Addario, Caltech/JPL)

- Undoubtedly benefited from tremendous field experience from LWA-OVRO
- Significant improvements over original LWA ARX (as expected)

ARX Signal Channel Block Diagram (16/board)

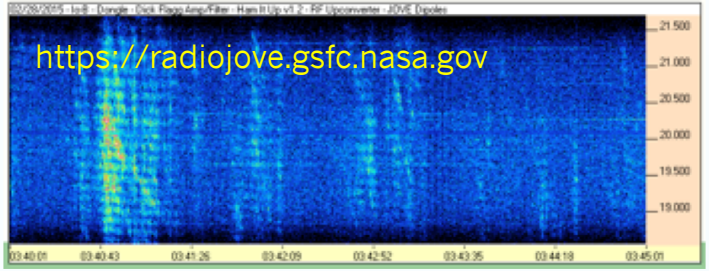


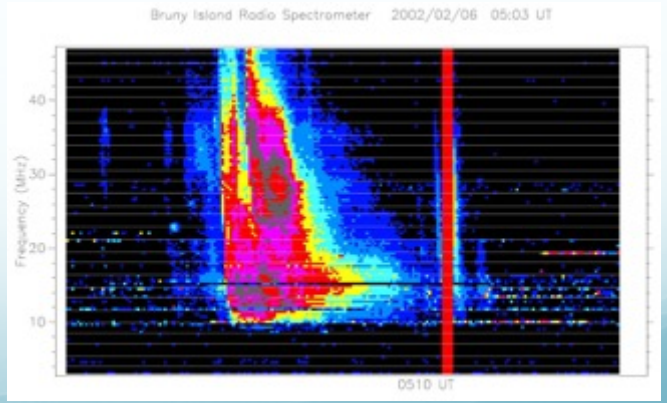
Ideal -3dB frequencies shown

Test board designed and fabricated, testing in progress

Following our Nose!
Step 1: Single Dipole

- Single dipole
  - Excellent means of developing basic experience in LWA antenna and front-end technology.
  - Well matched for students to develop and deploy
  - Inexpensive
  - Science
    - Jupiter – Radio Jove (right top)
      - Extensive LWA work by Clarke, Imai(s), Higgins, etc
    - Solar bursts – BIRS Type V (right bottom)
      - Work by S. White (AFRL)





Following our Nose!
Step 2: DLITE 4 elements

- DLITE Station
  - 4 element interferometer - ≥ 300 m to resolve out Galactic background
  - Footprint can encompass expansion to future SWARM or LWA station.
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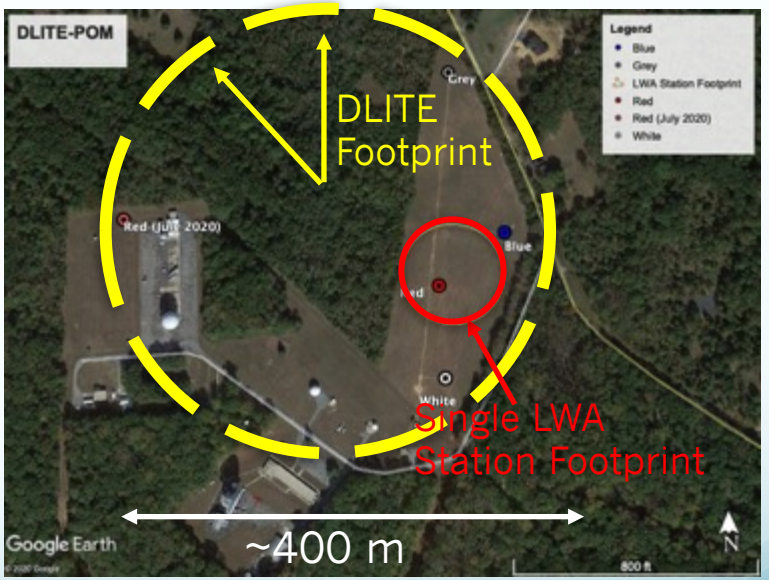
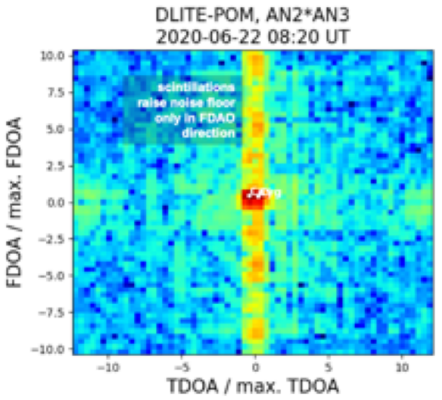
  - With infrastructure in place, straightforward to populate footprint with more antennas
  - DLITE digital backend offers guidelines for sub-SWARM level LWA deployments
  - See UTGRV's 12 element LoFASM stations as a possible intermediate step to a SWARM station (Jenet, Creighton et al.)

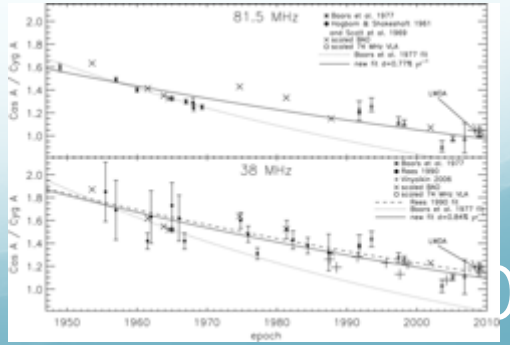


Following our Nose!
Step 2: DLITE 4 elements (continued)

- DLITE Ionospheric Science - **Scintillometry**
  - By monitoring “A-Team” sources DLITE can detect intensity & phase fluctuations from irregularities with strength parameters ≥ $C_K L \sim 10^{27}$.
  - Our goal: making software to extract these measurements available for distribution.
- Additional Science
  - Ionospheric remote sensing: Travelling Ionospheric Disturbances
  - Cas/Cyg ratio for monitoring temporal variation in Cas A (Helmboldt & Kassim 2009)

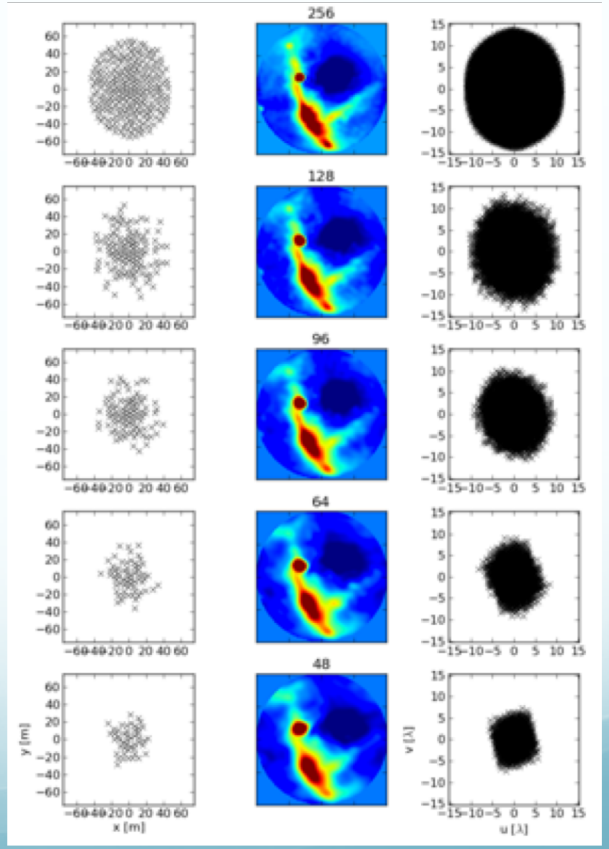


Scintillations (above) show diurnal variation matching established model predictions. Light curve (below) shows secular decease of Cas A including short term variations.

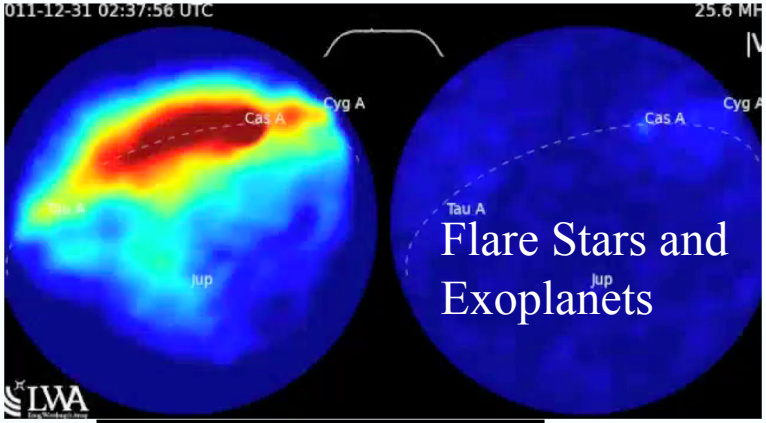


Following our Nose!
Step 3: SWARM Station 64 elements

- SWARM concept developed as stepping stone to full-up LWA station
  - 64 elements operated as phased array (beamforming).
  - PSF optimized based on decimation experiments with LWA1.
  - Modest investment for those who cannot afford LWA station
    - Look to UNM for technical guidance, follow their footsteps
  - Additional Science
    - Interferometry with other LWA Stations!!
    - Meteors
    - Recombination lines? Someone please try!

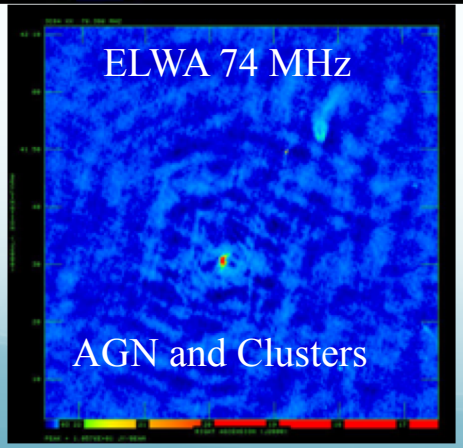


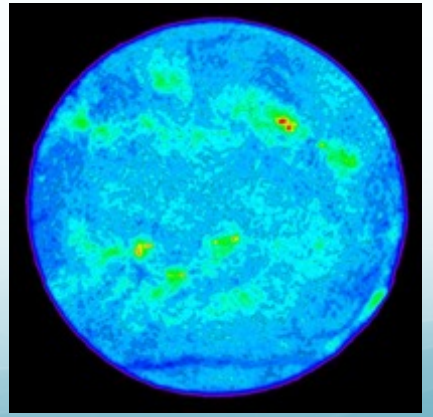
Following our Nose!
LWA SWARM Science



Flare Stars and Exoplanets

Resolving Pulsar Scattering





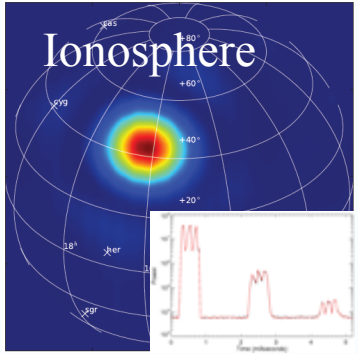
Imaging Solar Bursts (S. White)

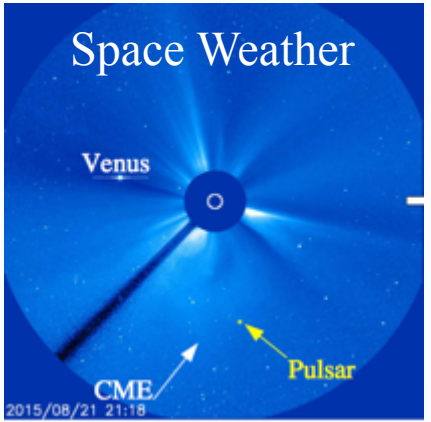
An LWA component would fit nicely into the FASR concept (Bastian 2020 WP)

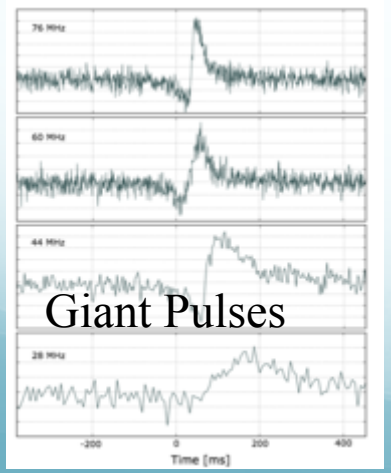
Following our Nose!
Step 4

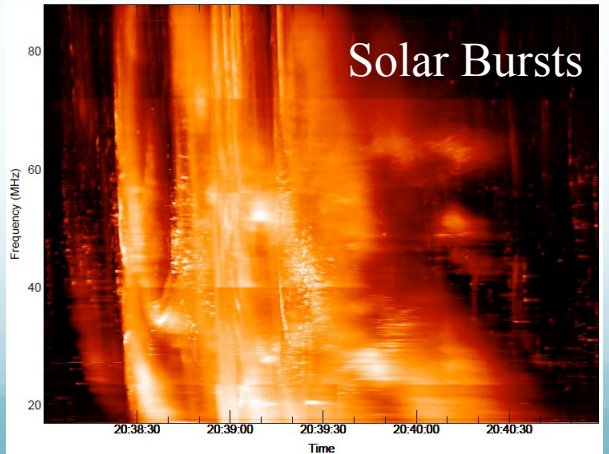
- LWA Station
  - Original design intended as a LOFAR Low Band station
  - 256 element and 100 meter design drawn from a lifetime's experience and intuition drawn from Bill Erickson's career
  - First station realized by collaboration of scientists and engineers across UNM, NRL, VT, and UT-ARL and led by project engineer Steve Ellingson (Ellingson et al. 2013)
  - Extensive software library now developed for data reduction and analysis (J. Dowell, UNM)
  - Additional Science
    - As demonstrated by LWA1, LWA-SV, and LWA-OVRO copious astronomical science if you use your imagination!
    - Meteors for sure, lots of ionospheric remote sensing, space weather science, etc
    - See LWA bibliography: **http://www.phys.unm.edu/~lwa/publ.html**

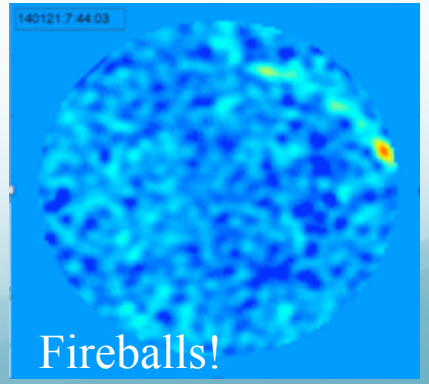
Following our Nose!
Step 4: LWA Single Station Science



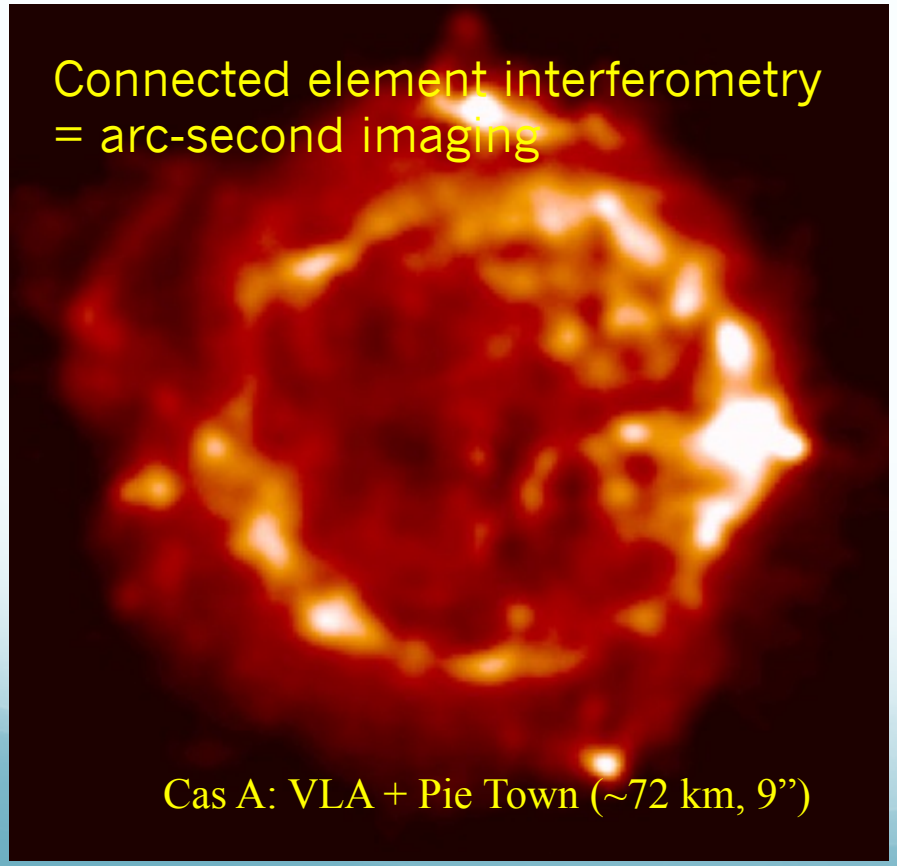








Following our Nose!
Step 5: LWA Multi-Station Science



Ultimate goal for a large LWA instrument – arcsecond resolution imaging of normal radio sources.

The image of Cas A at the left (Delaney et al. 2014) was the best we ever did at the VLA – but only because it was so bright and we didn't image a large field.

Need stations across the SW-US, e.g. around NM and AZ, and perhaps with a core at LWA-OVRO.

Tapping into the ngVLA infrastructure would be a no-brainer.

Summary: LWA = Discovery Science & STEM

- Original LWA concept had two goals
  - 1) Discovery science with large LWA spread across SW US
  - 2) Hands on S&T training for US students
- Second goal **independent of first and achievable now**
  - **Proven by succession of UNM, Caltech, UTRGV, & many other students!!**
  - From single dipole to a full station, training and science await your students
- Everything needed took hard work to develop, but is now available for everyone.
  - We are not just nice: in our interest to grow LWA infrastructure towards an ngVLA-scale instrument AND to hire your students after you train them!

LWA is a proven discovery instrument and STEM platform:
Come Join us for an adventure in science and education!!