Cluster Samples with the Long Wavelength Array (LWA)

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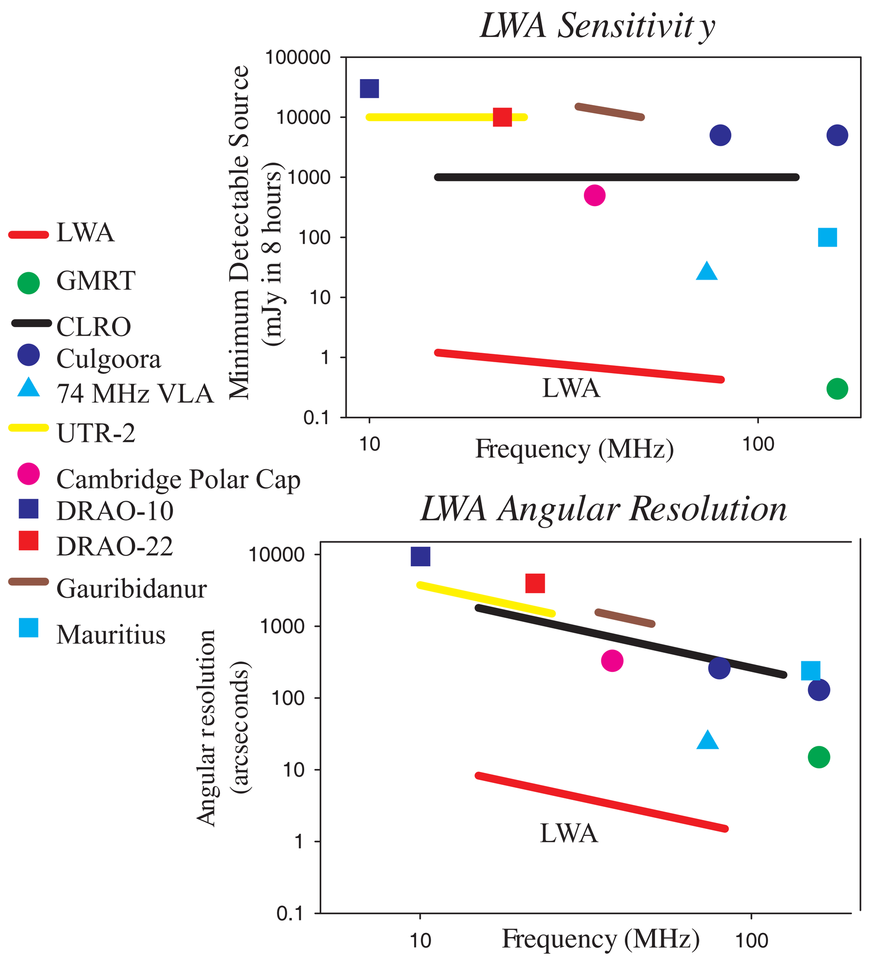
Timeline

- ***Present: Phase 0***
  -74 MHz capacity to the VLA (completed in 1998), VLA Low-frequency Sky Survey (VLSS)
- ***2005-2006: Phase 1***
  -Construction of the Long Wavelength Development Array (LWDA)
- ***2006-2008: Phase 2***
  -8 or 9 stations with baselines up to 150-200 km
- ***2008-2010: Phases 3 & 4***
  -Phase 3: compact core of ~15 stations to fill in short baselines
  -Phase 4: addition of more stations to even out UV coverage with baselines up to 500 km
  Full LWA with 52 stations and full imaging capability across the entire 23-80 MHz range

The LWA project is being developed by the Southwest Consortium (SWC) - a university-based consortium led bv UNM, & including ARL-UT, NRL, & LANL:
<URL:http://lwa.nrl.navy.mil & http://lwa.unm.edu>

LWA Basic Specifications

Parameter	Design Goal
Frequency Range	10-88 MHz (20-80 MHz Optimized)
Effective Collecting Area	1 km² at 20 MHz
Number of Dipoles	~13,000
Number of Stations	~52
Point-Source Sensitivity (2 pol., 1hr, 4MHz BW)	~1.1 mJy at 30 MHz ~0.7 mJy at 75 MHz
Maximum Angular Resolution	~5" at 30 MHz ~2" at 75 MHz
Mapping Capability	Full field of view
Number of Independent FOV	2-8
Maximum Observable Bandwidth	32 MHz
Spectral Resolution	< 1 kHz
Image Dynamic Range	> 10,000
Digitized Bandwidth	Full RF

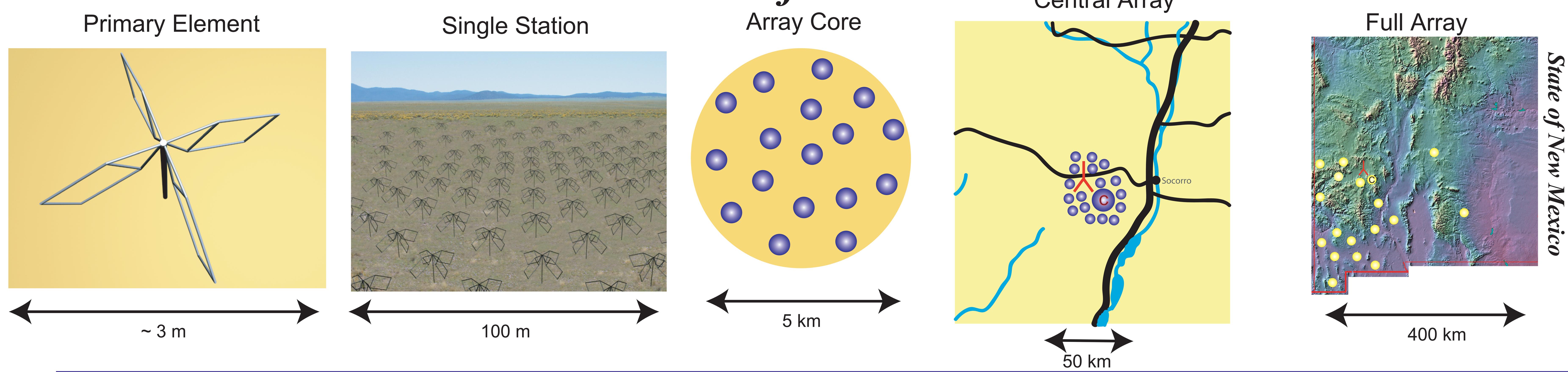


LWA Science Drivers

- ***Cosmic Evolution***
  - The High Redshift Universe
    - Detection and study of the first supermassive black holes
    - Search for localized HI absorption during the Epoch of Reionization
  - The Evolution of Large Scale Structure, Dark Matter & Dark Energy
    - Merging galaxy clusters and large scale structure filaments identified through diffuse synchrotron emission
    - Cluster emission used to study Dark Matter dominated merging systems
    - Relaxed or non-merging systems sample for study of Dark Energy
- ***Acceleration of Relativistic Particles***
  - In SNRs in normal galaxies at energies up to 10E15 ev.
    - Cosmic ray tomography to study the distribution, spectrum, and origin of Galactic cosmic rays
    - Spectral SNR studies to probe shock acceleration, SNR evolution, interactions with the surrounding environment
  - In radio galaxies & clusters at energies up to 10E19 ev.
    - Self-absorption processes, the low-γ electron population, Intra-cluster magnetic fields, and merger shocks
    - Radio galaxy lifecycles and radio jet composition
  - In ultra high energy cosmic rays at energies up to 10E21 ev and beyond.
    - Cosmic Ray air-showers; ultimate source unknown.
- ***Plasma Physics***
  - Ionospheric turbulence and structures
    - Including traveling ionospheric distrubances (TIDs)
  - Solar and Planetary Science
    - Active & quiet sun studies, measurements of Coronal Mass Ejections, IP shocks & scintillations
  - The interstellar medium (ISM) and beyond
    - Propagation, scattering, & absorption in the ISM of the MW & normal galaxies.
    - Scattering from the inter-galactic medium
    - Census of Galactic SNRs with distances.
- ***Opportunity: Discovery Science***
  - The greatest discoveries in astrophysics have coupled key technical innovations with the opening of new windows on the EM spectrum.
    - Technical breakthrough: demonstration of ionospheric calibration with 74 MHz VLA.
    - Last poorly explored spectral region: < 100 MHz.
    - New observing paradigms: multi-beaming, wide-field sky monitoring.
  - Potential new horizons: transients, extra-solar planets, coherent emission sources.

A text description of these goals can be found at http://lwa.nrl.navy.mil/LWA/LWA_science_summary.html

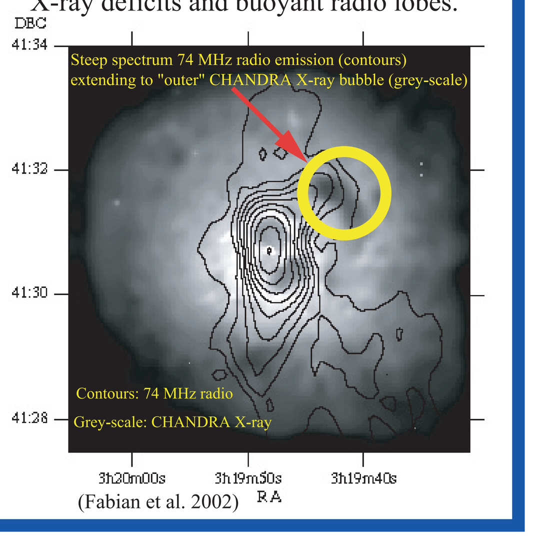
A Vision of the LWA



Constraining the Cosmological Evolution of Dark Matter & Energy with the LWA

Bubbles in Cooling Flow Clusters

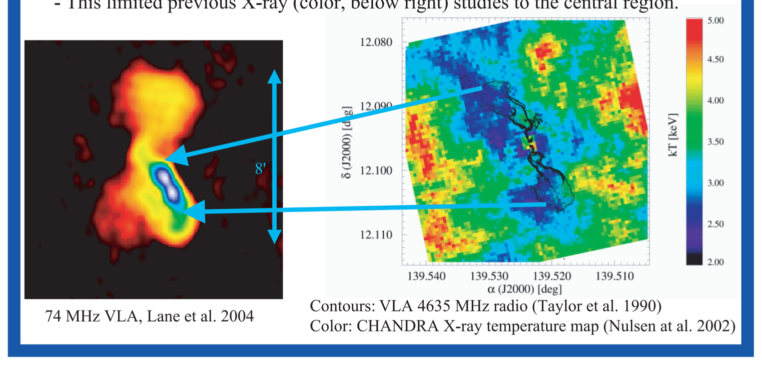
- First spatially resolved connection between X-ray deficits and buoyant radio lobes.



(Fabian et al. 2002)

What is the real size of radio galaxies?

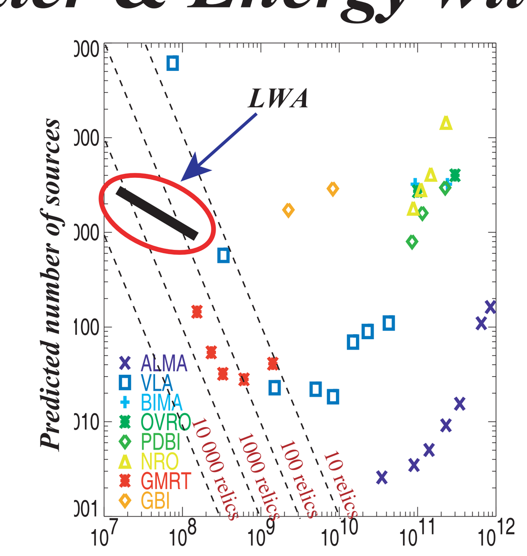
- Sensitivity of cm-λ interferometers can greatly underestimate the true size of radio galaxies.
  - 74 MHz image of Hydra A (left) shows how much larger the source is than as revealed at 4635 MHz image (contours, below right).
  - This limited previous X-ray (color, below right) studies to the central region.



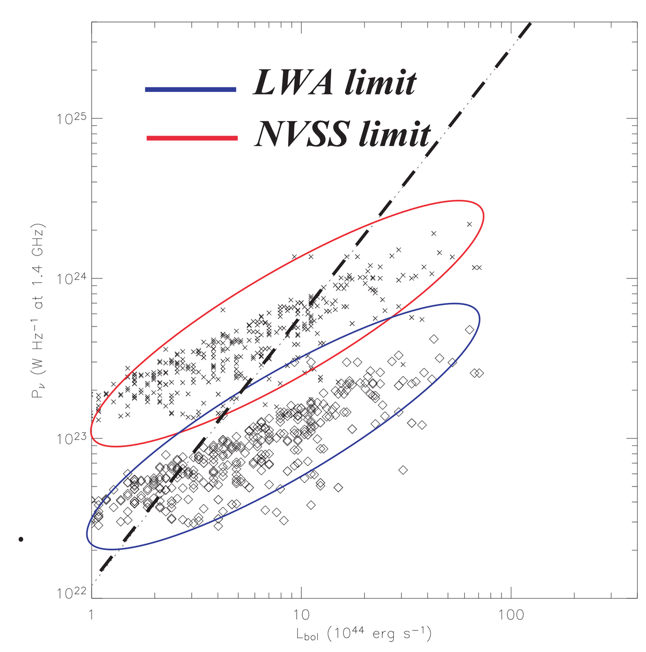
74 MHz VLA, Lane et al. 2004

Contours: VLA 4635 MHz radio (Taylor et al. 1990)
Color: CHANDRA X-ray temperature map (Nulsen at al. 2002)

- **Current studies:** the panels to the left show two examples of how current observations below 100 MHz provide the sensitivity to steep-spectrum emission important for understanding the physical processes in individual clusters.
  - Current observations with the 74 MHz VLA can only detect emission from the brighest, relatively nearby clusters.
  - Cosmology requires studies of much larger, and more distant samples - ***not currently possible.***
- **Future studies:** the panels to the right show that sensitivities of an emerging generation of much more sensitive low frequency instruments such as the LWA and LOFAR, will increase the census of diffuse radio emission from clusters by *2-3 orders of magnitude*.
  - The current census of diffuse cluster radio emission is very incomplete.
    - Only a few dozen currently known.
  - The LWA and LOFAR will detect thousands of cluster radio halos & relics.
- Cosmology with LWA Cluster Samples ***(see also poster by T. Clarke)***
  - Diffuse cluster radio emission can differentiate between clusters in hydrostatic equilibrium and those having undergone recent merger activity.
  - A complete census of diffuse emission in merging clusters would make it possible to trace the dark matter potentials which govern mergers.
  - They would also define a non-merging cluster sample that would provide the undisturbed systems necessary to study the dark energy equation of state through determination of the baryonic mass fraction in massive clusters.



The panel to the left shows that the LWA may detect over 1000 new cluster radio relics (T. Ensslin private communication.).



The lower left panel shows the observed Lx-P1.4 relation for cluster radio halos & relics (diagonal line). Crosses show 3-sigma NVSS radio detection limits for 1 Mpc halos. Diamonds show 3-sigma LWA radio detection limits - it is easily able to detect sources ~10-100 times weaker than currently possible with the NVSS. LWA surveys, with their larger FOVs, will be much more efficient at finding new steep-spectrum diffuse cluster emission. (See poster by T. Clarke at this meeting.)

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