The Legacy of Clark Lake

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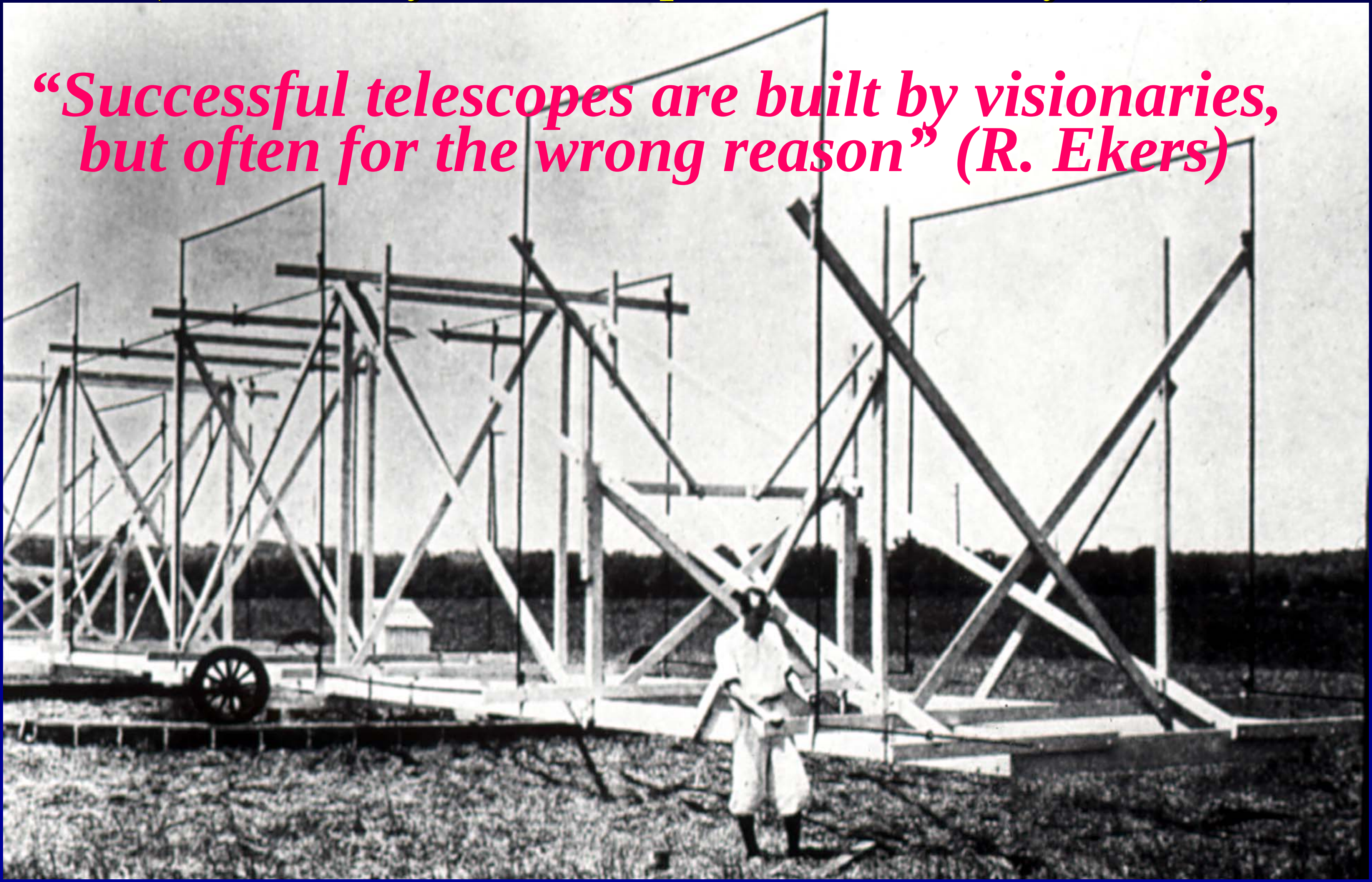
The First Low Frequency Radio Telescope

(Karl Jansky Bell Telephone Laboratory 1933)



History of Low Frequency Astronomy

- *1931-35: Discovery of cosmic radio waves,* ***birth of radio astronomy*** *(Jansky)*
- 1935-40: ***Discovery of nonthermal emission*** *(Reber, Heneye, Keenan)*
- *1942: Discovery of solar radio emisson (Hey)*
- *1946:* ***First 2 element interferometer*** *(Ryle)*
- *1946-50:* ***Discovery of discrete cosmic radio sources*** *(Ryle)*
- *1946-51: Discovery of radio galaxies & SNRs (Ryle et al.)*
- *1955: First all-sky surveys (Kraus, Mills, Baldwin, others)*
- *1955:* ***First detection of planetary radio emission*** *(Burke, Franklin, Shain)*
- *1962-63: First widely used radio catalogue (Bennett – 3C)*
- *1963:* ***Discovery of quasars*** *(Hazard, Schmidt, Sandage, Greenstein, others)*
- *1967: First VLBI fringes*
- *1968:* ***Discovery of pulsars***

The History of Clark Lake: I

- Convair Scientific Research Lab (CSRL)
  - In the late 1950s, Convair creates the CSRL in San Diego
  - Mantra – do anything creative – keep costs low
- Director Critchfield draws upon prior contacts in academia and attracts a strong group of young scientists and engineers
  - Erickson, his former student at UMN, is hired to begin work at Clark Lake
  - By the early 1960s, Convair transfers the CSRL to the University of Maryland.
- Science at Clark Lake
  - Over the course of the next 3 decades a series of pioneering instruments are built by Erickson, his colleagues, and their collective students at Clark Lake
  - Other groups also exploit the site and develop unique instruments
    - Including NASA, UCSD, U. Iowa

Clark Lake Instruments

- Decametric Array (Convair & UMd: Erickson & students)
  - Still the highest resolution sky survey below 30 MHz (26.3 MHz)
- IPS Array (UCSD: Coles, Rickett, Jackson, & students)
  - Clear demonstration of the solar cycle effect on the solar wind velocity.
- Log Periodic Array (UMCP: Erickson, Hubbard, Kundu & students; GSFC: Stone, Alexander, Fainberg)
  - 1D brightness distribution and position of solar emission regions.
  - Time resolution of solar bursts in angular and frequency coordinates.
- Jupiter Antennas (UMd: Erickson; GSFC: Stone, Alexander, Kaiser, Fainberg)
  - Determination of the rotation period of Jupiter.
- CoCoa Cross (U. Iowa: Cronyn & Shawhan, & students)
  - Observed IPS of QSOs to locate, map, and track solar wind features.
- CLRO TPT (UMd: Erickson, Kundu, & their students)
  - Galactic survey; Predicted fast PSR 4C21.53 (found to be first msec PSR by Backer & Kulkarni), Predicted 1st globular cluster PSR in M28 - now hundreds known; first radio detection of CMEs

The Clark Lake TPT

- Broad-band (10-123 MHz)
- Reasonable collecting area ($A_e \sim 250\lambda^2$)
- Fully electronic - fast and versatile

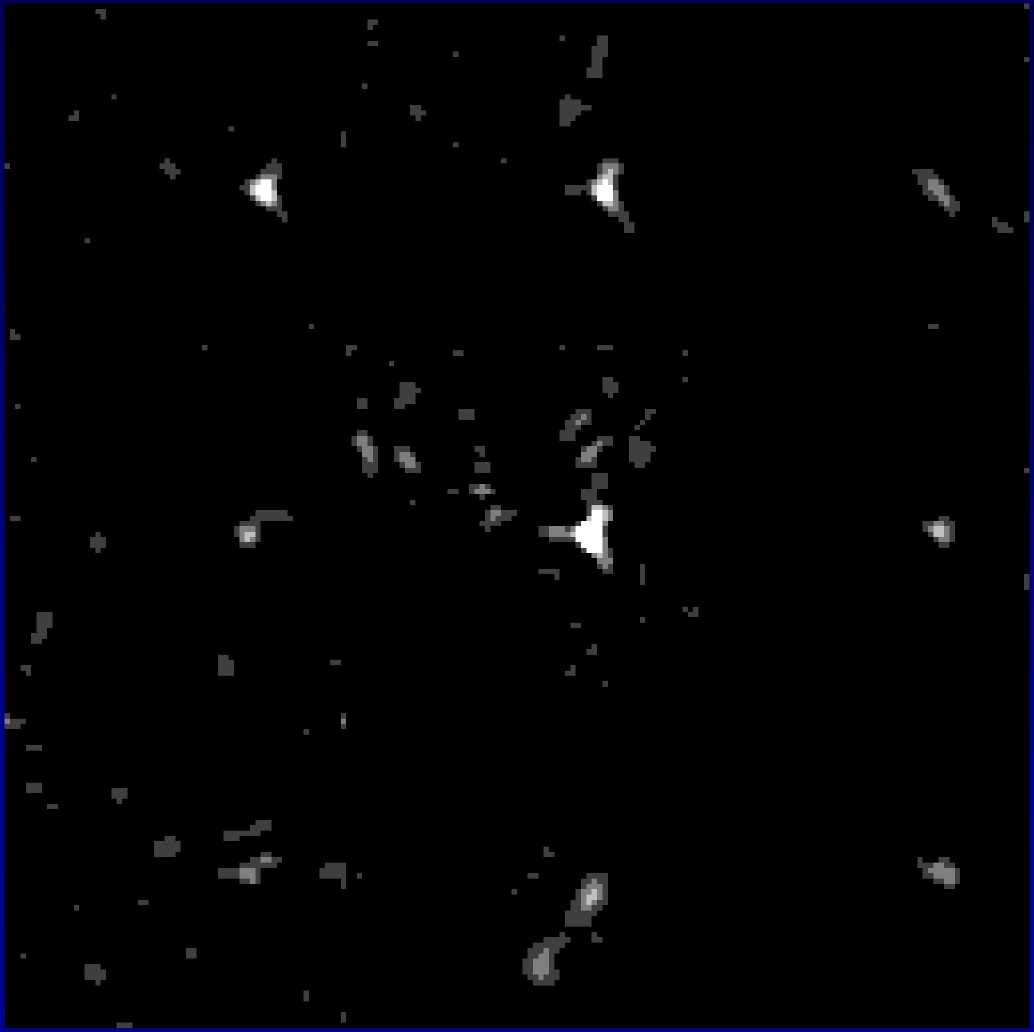
Will be surpassed in sophistication & size only by the LWA and LOFAR

Clark Lake History: II

- In the late 1990s the CLRO closed.
- Clark Lake was successful in many ways, but if low frequency radio astronomy is really worthwhile, why didn't the CLRO have a longer life?
  - The most important reason: λ/D (angular resolution)
  - CLRO TPT
    - » D ~3 km baselines
    - » ~900" resolution at 30 MHz
    - » ~1000 mJy rms with infinite integration (confusion limited)
  - VLA
    - » D ~35 km baselines
    - » ~2" resolution at 1400 MHz
    - » ~0.5 mJy in 1 minute

Astronomy is difficult when you are nearly blind.

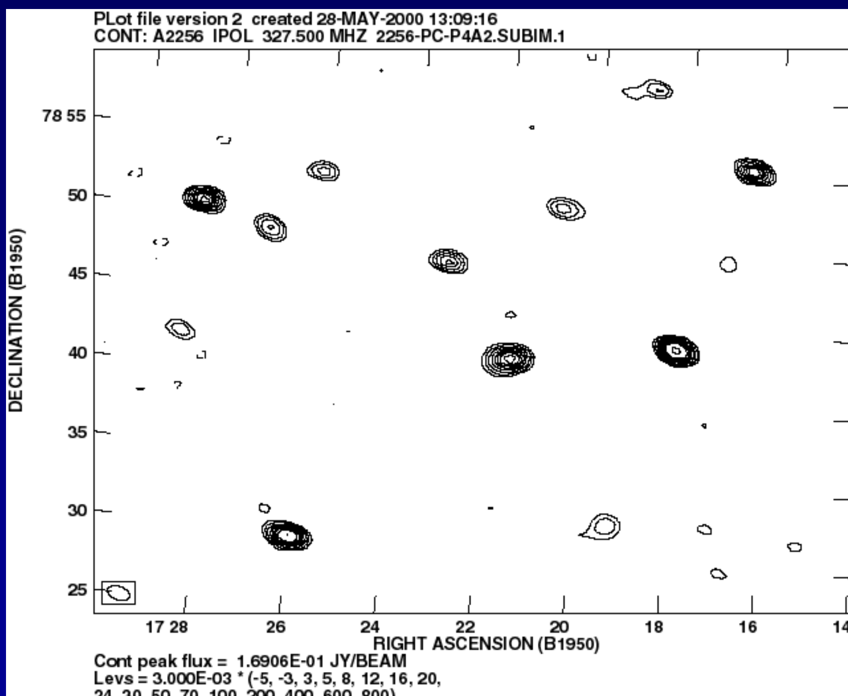
Differential Ionospheric Refraction



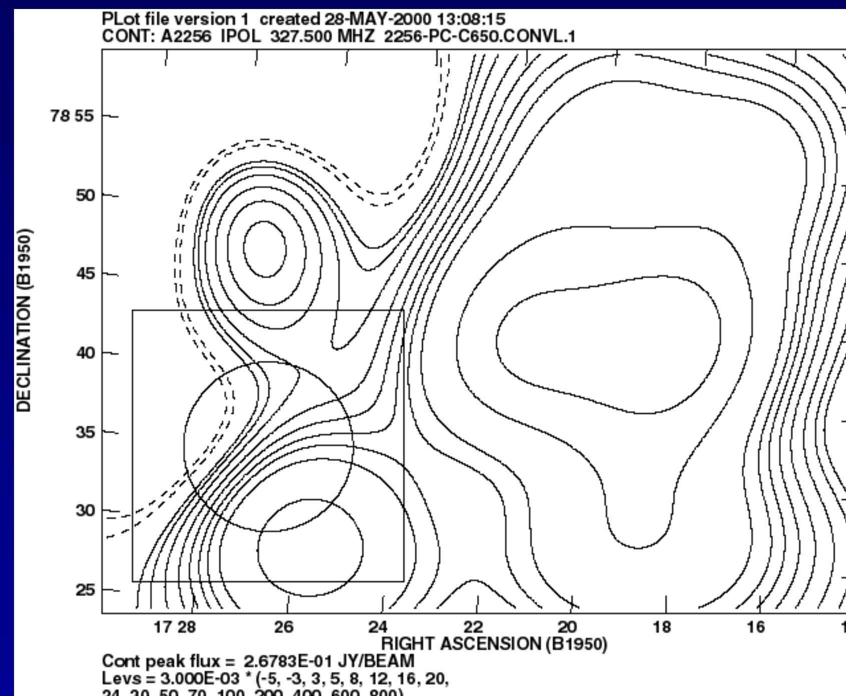
- The ionosphere limited the maximum baseline of interferometers below 100 MHz to ~5 km.
- As the rest of radio astronomy went to high resolution and sensitivity with the development of instruments like the VLA, low frequency radio astronomy was left behind.

Low Angular Resolution: Limits Sensitivity due to Confusion

θ ~ 1’, rms ~ 3 mJy/beam



θ ~ 10’, rms ~ 30 mJy/beam



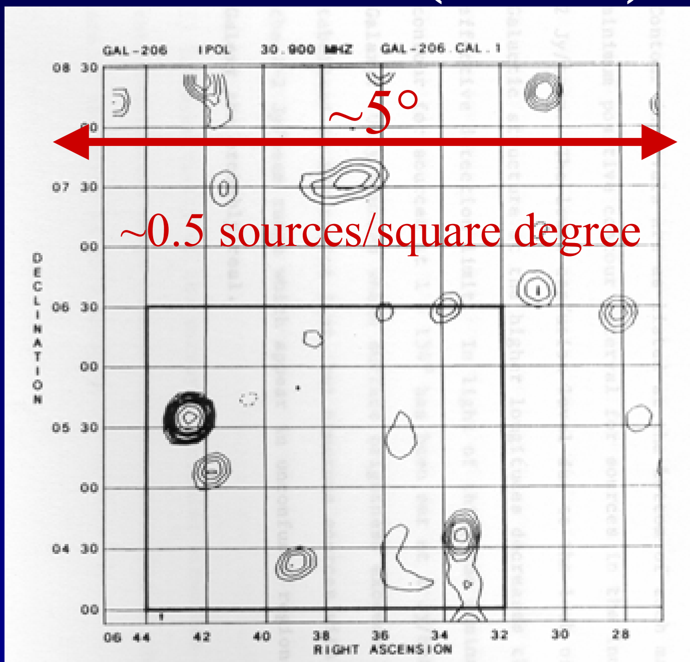
After Clark Lake: Persistence

- After self-calibration was developed (1980s), Erickson and others recognized that it might be able to remove ionospheric effects from low frequency data
  - Came too late for Clark Lake, but not too late for low frequency radio astronomy.
- In 1990, Erickson designs the 74 MHz system at the VLA
  - Resourceful implementation of inexpensive, dipole-based system that leverages off of the most powerful interferometer in the world.
  - Demonstrates that self-calibration can remove ionospheric effects.
    - » Simple demonstrator system becomes the most powerful low frequency interferometer.

Initiates quiet renaissance in LF radio astronomy.
(and getting louder)

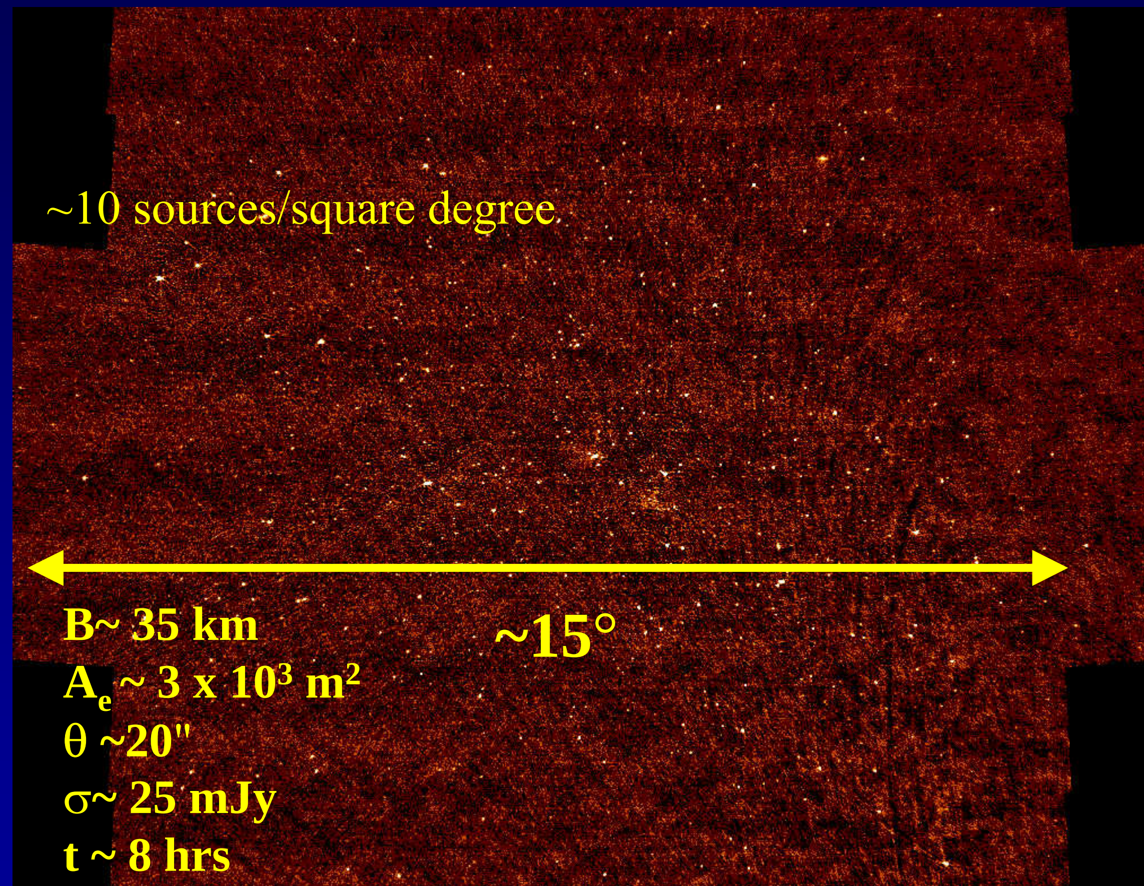
Comparison of the Clark Lake TPT to the 74 MHz VLA

Clark Lake (30 MHz)



- **B ~ 3 km**
- **A_e ~ 3 x 10^3 m^2**
- **θ ~ 900"**
- **σ ~ 1000 mJy**
- **t ~ ∞**

VLA (74 MHz)



Impact of the 74 MHz VLA

- Erickson's designed 74 MHz VLA system is providing a sufficient leap forward to scratch away and validate many of the key science drivers of the LWA and LOFAR
  - Limited system is enough to intimate what might be achieved by a significantly larger, broad-band system.
- LWA Key Science Drivers
  - Cosmic Evolution
  - Transient Universe
  - The ISM of the Milky Way and galaxies
  - Solar and Extra-Solar Planets
  - Ionospheric, solar, & Space Weather Science

Transients & the EOR are the only key science areas we have not been able to sample with the 74 MHz VLA.

Thinking Outside the Box: The Full Potential of LF Radio Astronomy
(inspired by R. Ekers)

- Thinking beyond key science drivers:
  - Most major discoveries in science are not predicted
    - Serendipity
  - The greatest discoveries in science have often followed technical breakthroughs.
    - De Solla Price: *most scientific advances follow laboratory experiments.*
    - Martin Harwit: *most important discoveries result from technical innovation.*
  - The greatest discoveries in astronomy have accompanied the opening of new, or poorly explored, regions of the spectrum.
    - Many examples from radio astronomy
      - Quasars, Pulsars, CMB….

The 74 MHz VLA demonstrated the technological breakthrough to open the last poorly explored window on the spectrum.

Galileo Galilei - 1609

- Galileo builds his first telescope and he sees the moons of Jupiter.

“Four planets, never seen since the beginning of the World right up to our day”

Discovery Space – what is left?

√ ■ New wavelengths - just about finished
  – *The region below 100 MHz is the last, poorly explored one.*

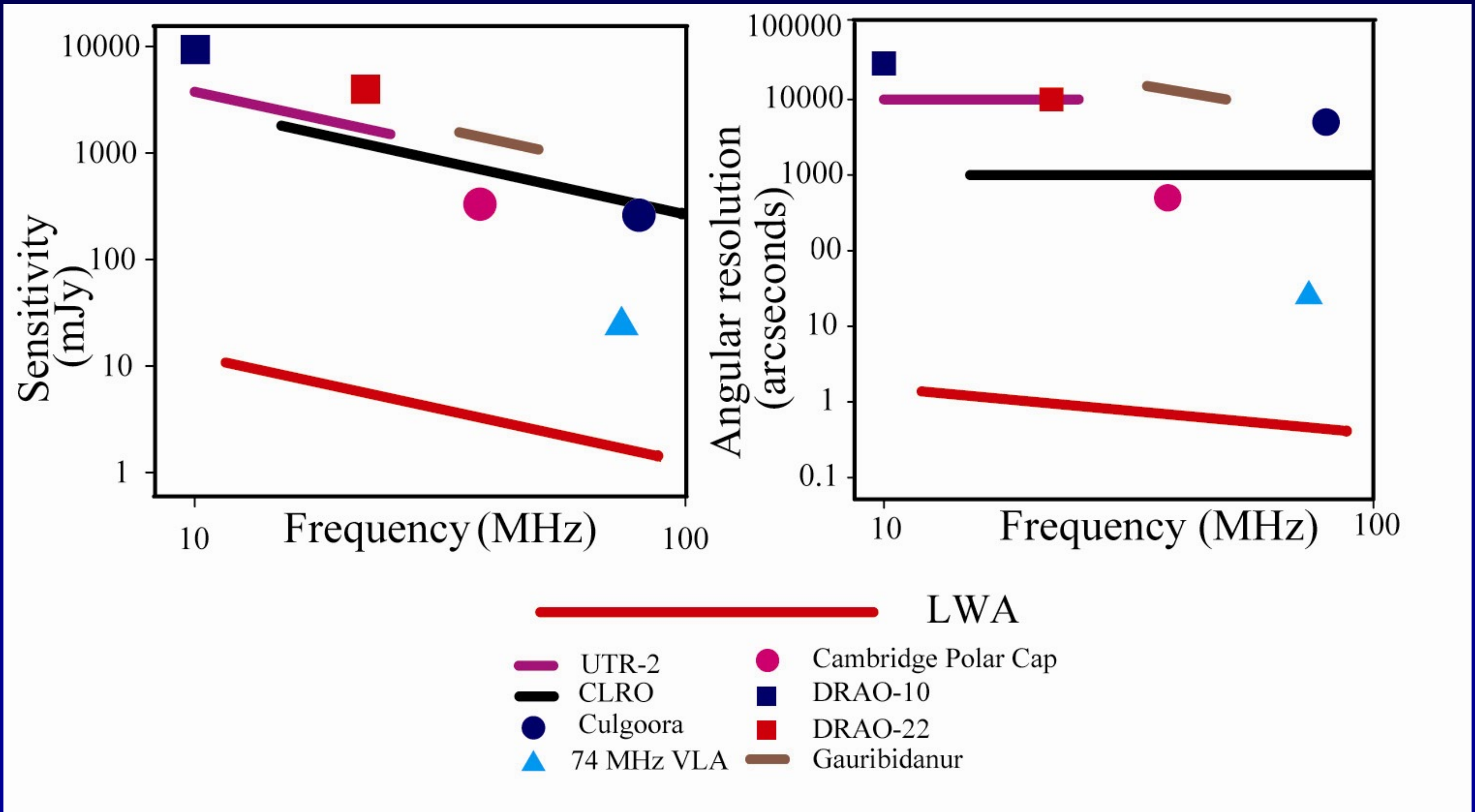
√ ■ Angular resolution & sensitivity
  – *Instruments like the LWA and LOFAR will increase both the angular resolution and sensitivity by more than two orders of magnitude compared to Clark Lake – Chandra analogy.*

√ ■ Volume of space sampled
  – *An area where low frequency instruments, with their intrinsically large fields of view, will naturally thrive.*

√ ■ New observing paradigms: multi-beaming
  – *Another natural capability of an electronic low frequency array*

The LWA & LOFAR efficiently exploit the last remaining areas of discovery space for radio astronomy.

A significantly improved view of the spectrum below 100 MHz



Summary

- The legacy of Clark Lake
  - Lies in a pioneering spirit and persistence in the face of challenge.
  - Lies in its students.
  - Lies in the ongoing renaissance in low frequency radio astronomy.
- The full potential of low frequency radio astronomy is now within our grasp
  - Erickson's last instrumental innovation has served as a pathfinder to explore the scientific and technical case for an emerging suite of new low frequency instruments.
  - The future holds the promise of unexpected discoveries that lie from unlocking this last, poorly explored spectral window.
    - » The historical record of astrophysical discoveries supports this.

The greatest legacies of Clark Lake and Bill Erickson may yet lie ahead of us.