

The Long Wavelength Array

Project Update and Future Outlook

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April 18, 2007

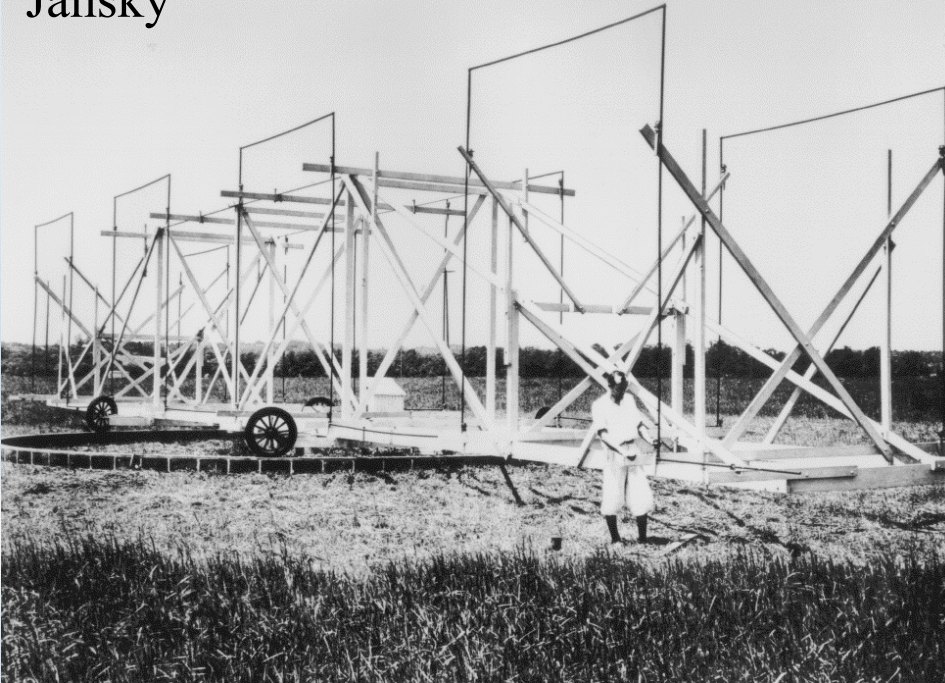
(LWA: <http://lwa.unm.edu>)

A project of the Southwest Consortium

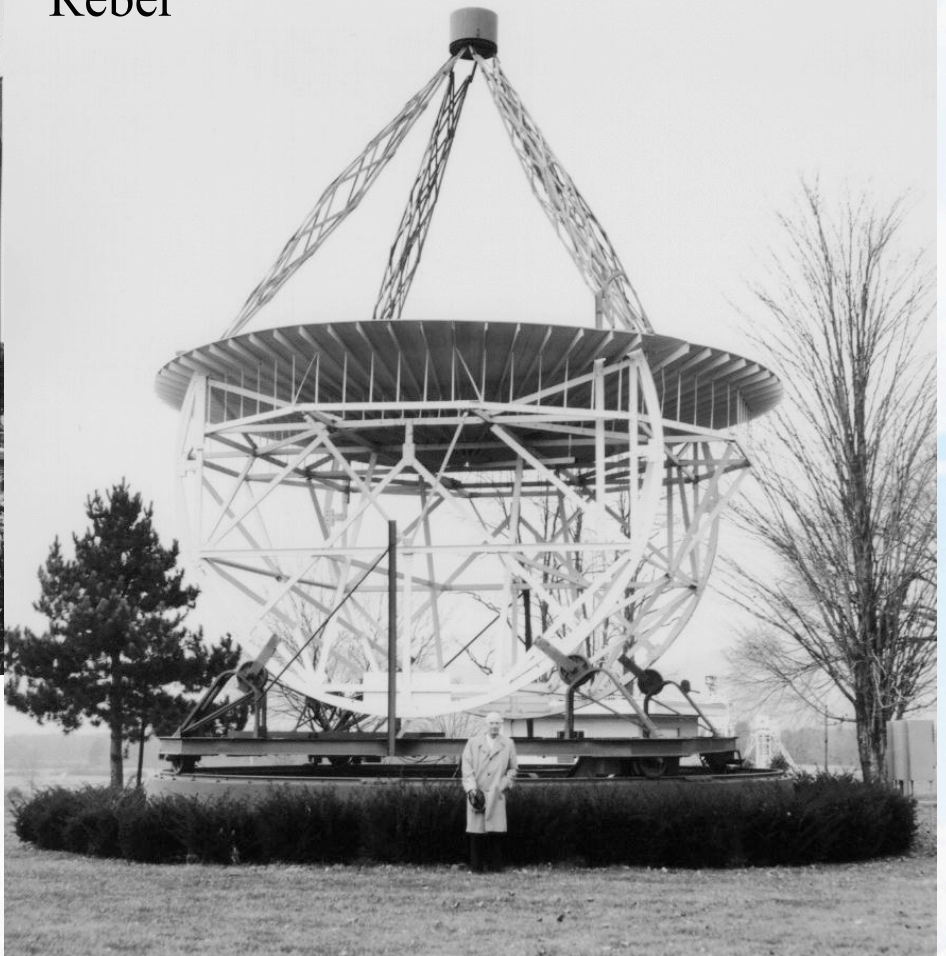


History of Radio Astronomy: Low Frequencies

Jansky



Reber



➤ Radio astronomy was born in the 1930's with Karl Jansky's work at 20.5 MHz (14.5 m) at Bell labs

➤ Reber continued radio astronomy at 160 MHz

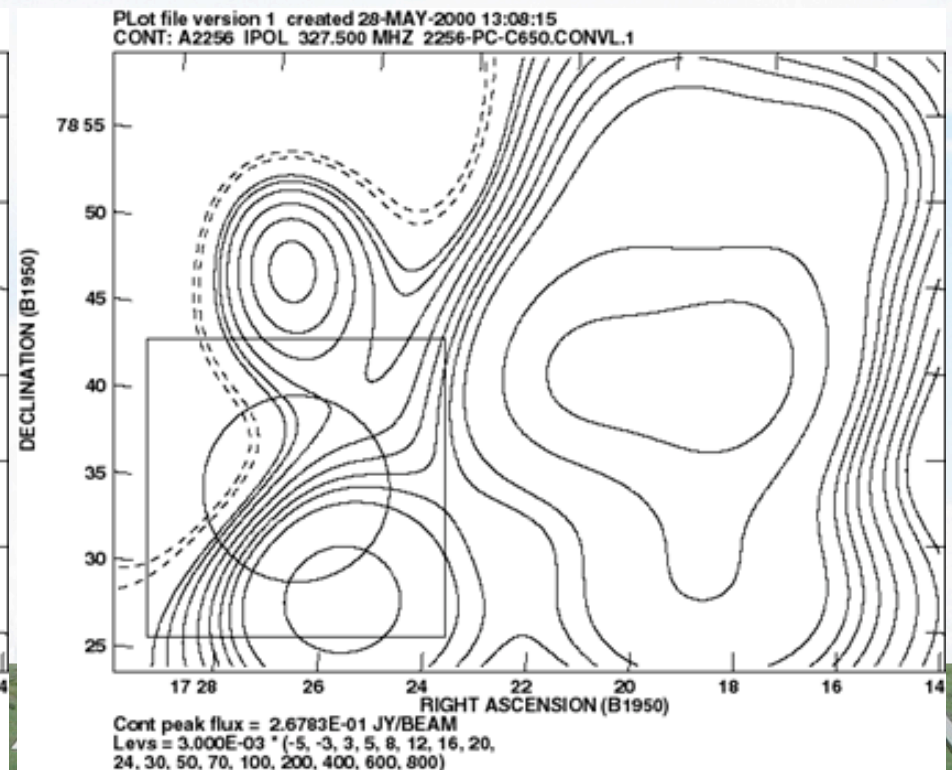
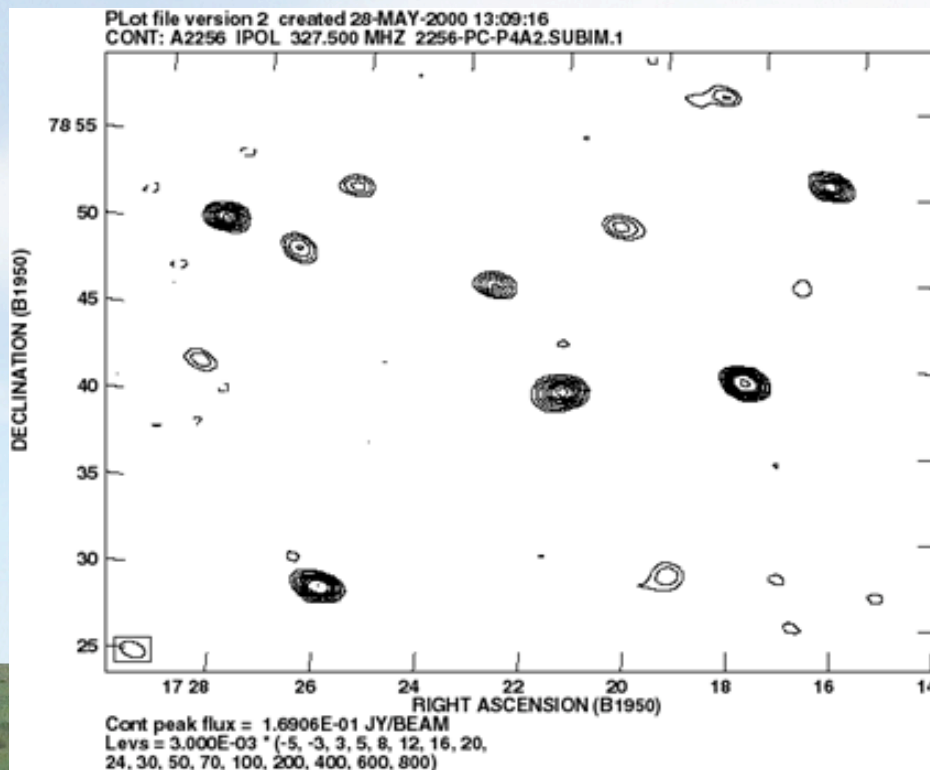


Resolution and Sensitivity Challenges

- First radio telescopes operated at long wavelengths with low spatial resolution and very high system temperatures
- Radio astronomy quickly moved to higher frequencies with better spatial resolution and lower system temperatures

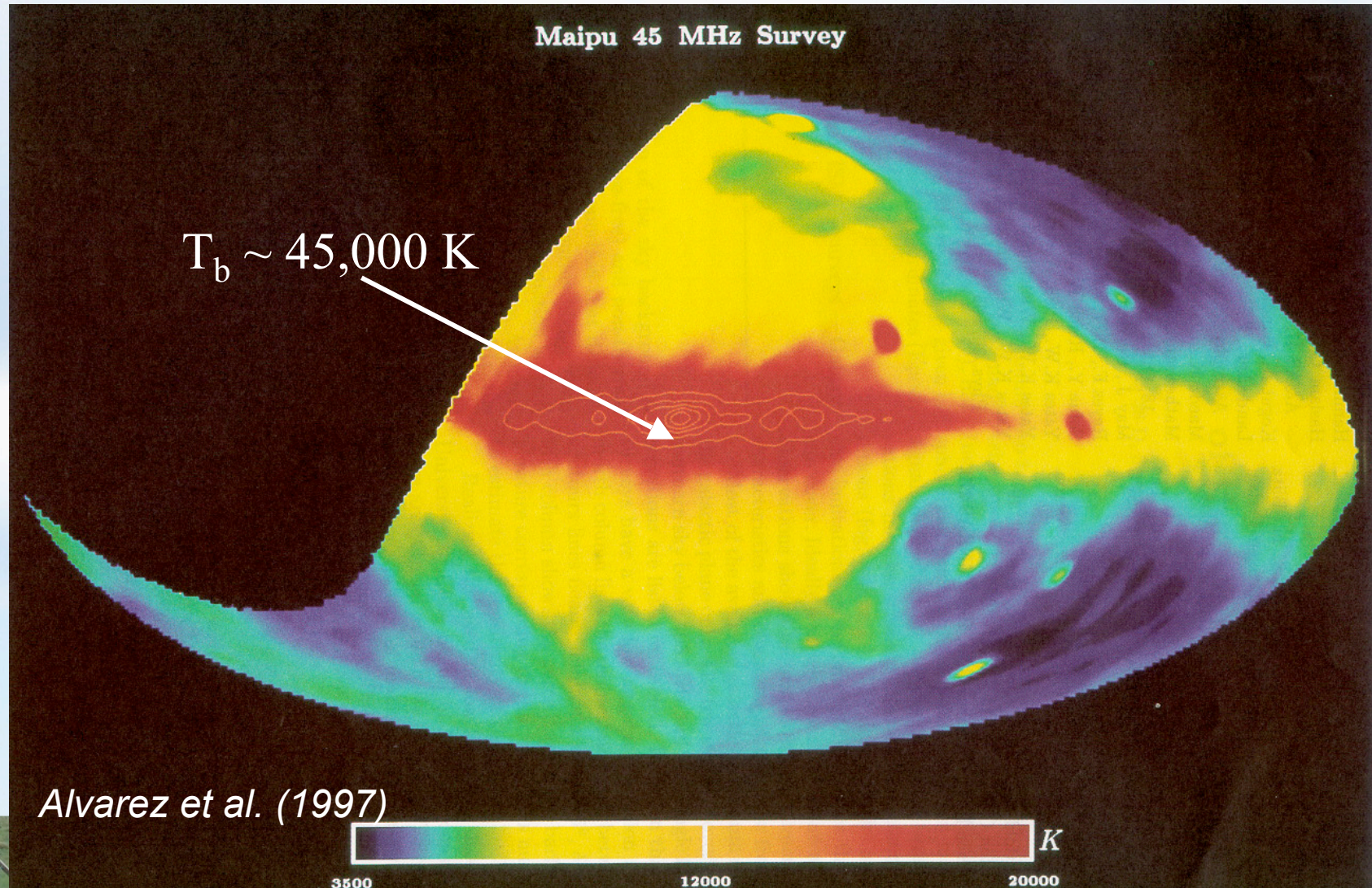
$\theta \sim 1'$, rms ~ 3 mJy/beam

$\theta \sim 10'$, rms ~ 30 mJy/beam

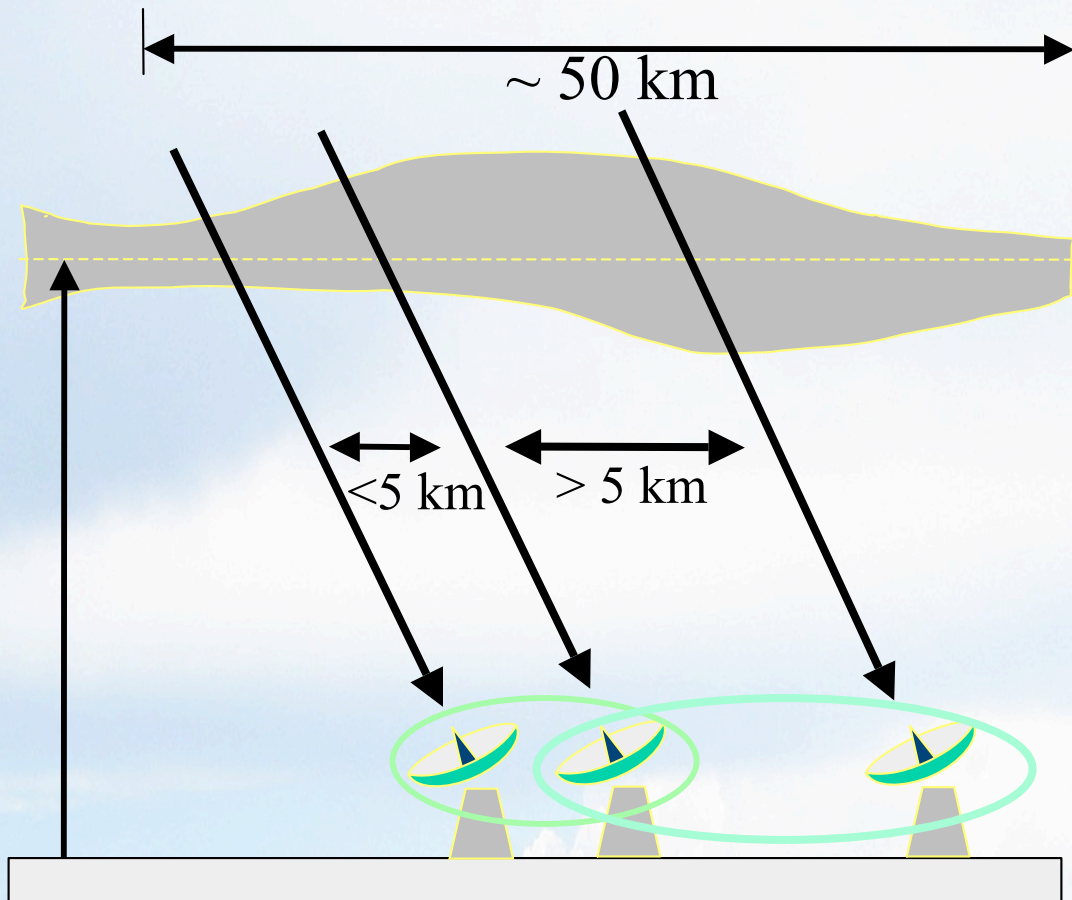


All-sky map, 45 MHz

Best $T_{\text{sys}} > 3000$ K
resolution ~ 4 degrees



Ionospheric Structure:



- Waves in the ionosphere introduce rapid phase variations ($\sim 1^\circ/\text{s}$ on 35 km baselines)

- Phase coherence is preserved on baselines $< 5 \text{ km}$

- baselines $> 5 \text{ km}$ have limited coherence times

- Historically limited capabilities of low frequency instruments



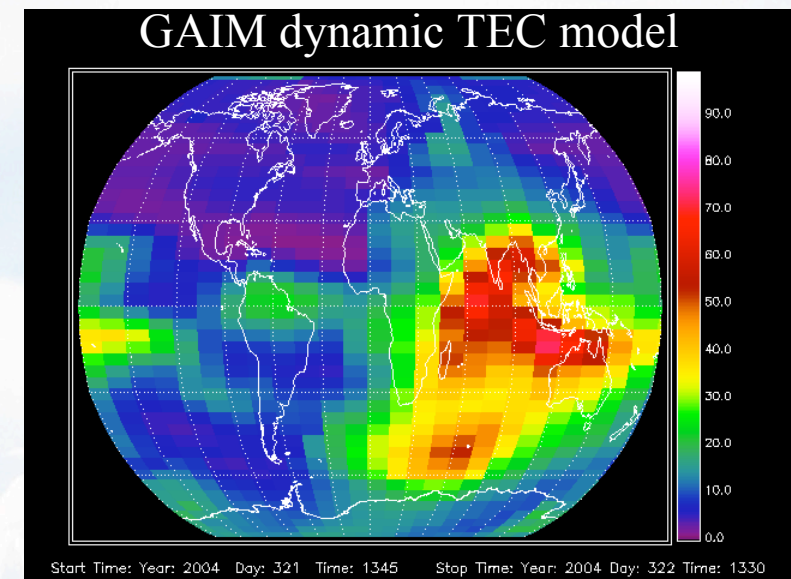
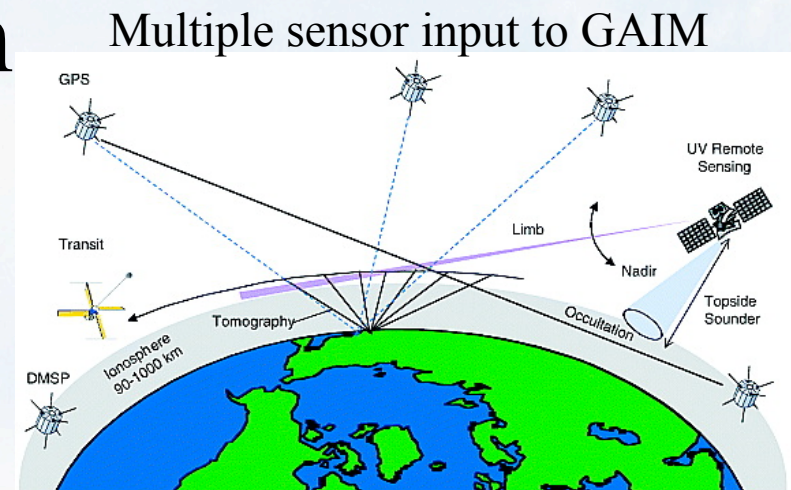
Motivation

- The LWA will provide the high spatial and temporal resolution needed to understand the ionosphere
 - Multi-beam provides multiple pierce lines
- The LWA will open one of the last and most poorly explored regions of the EM spectrum below 100 MHz
 - Multi-beam, multi-frequency electronic array will herald revolutionary new approach to astronomical observations
 - Key science drivers include Cosmology, Acceleration physics, Plasma Astrophysics, & Solar and Space Weather Physics
- Exploration of the Transient Universe
 - *Possible new classes of sources*
 - *Magnetar Giant Flares*
 - *Extra-solar planets*
 - *Prompt emission from GRBs*

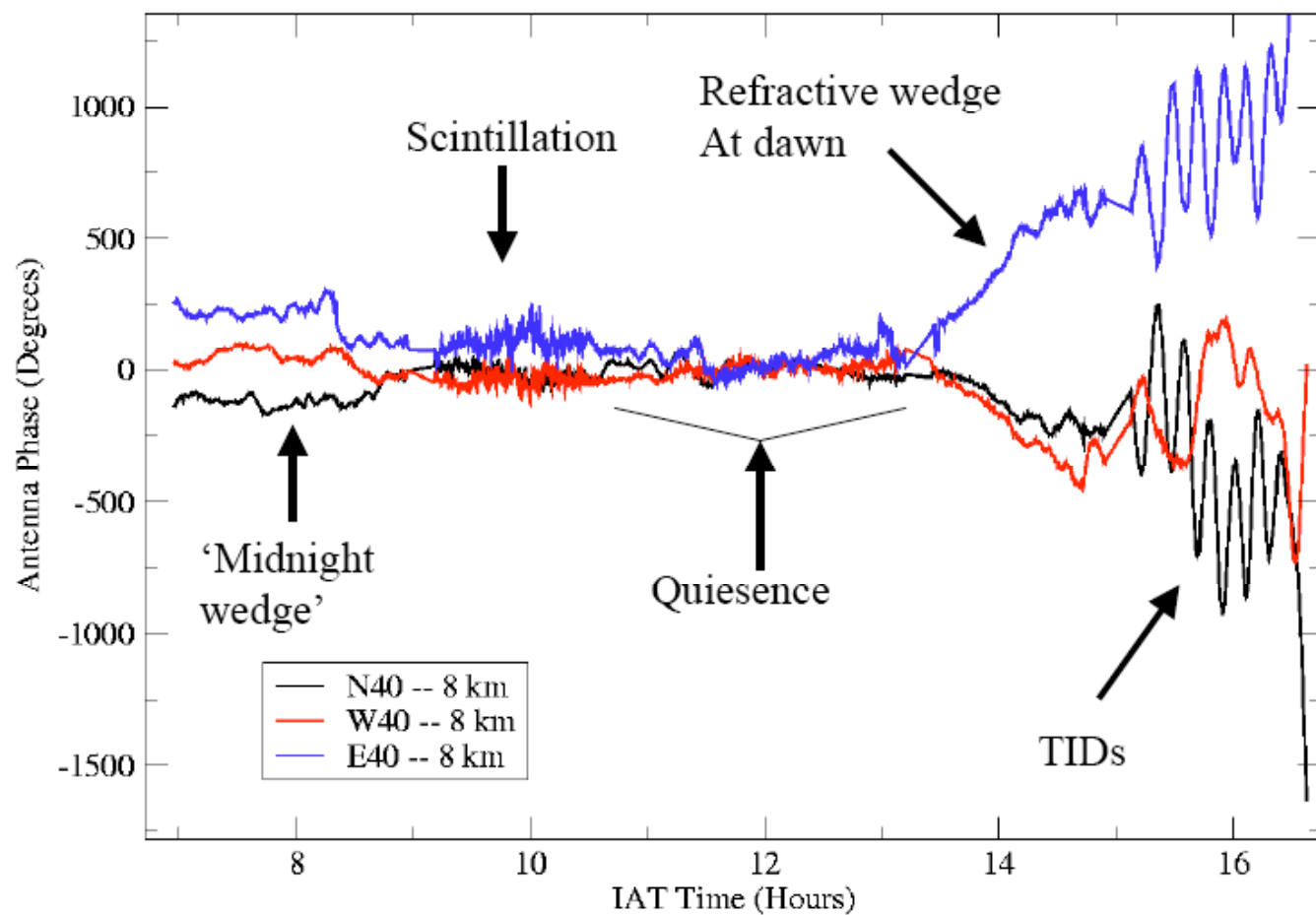


Scientific Payoff: Ionospheric Research

- LW data provides unprecedented spatial & temporal ionospheric imaging
 - Radio provides continuous monitoring (day & night).
 - High resolution probes fundamental physical understanding
 - LWDA/LWA can be used to gather return signals from HAARP
- Potential to test and improve global ionospheric models.



VLA Ionospheric studies at 74 MHz



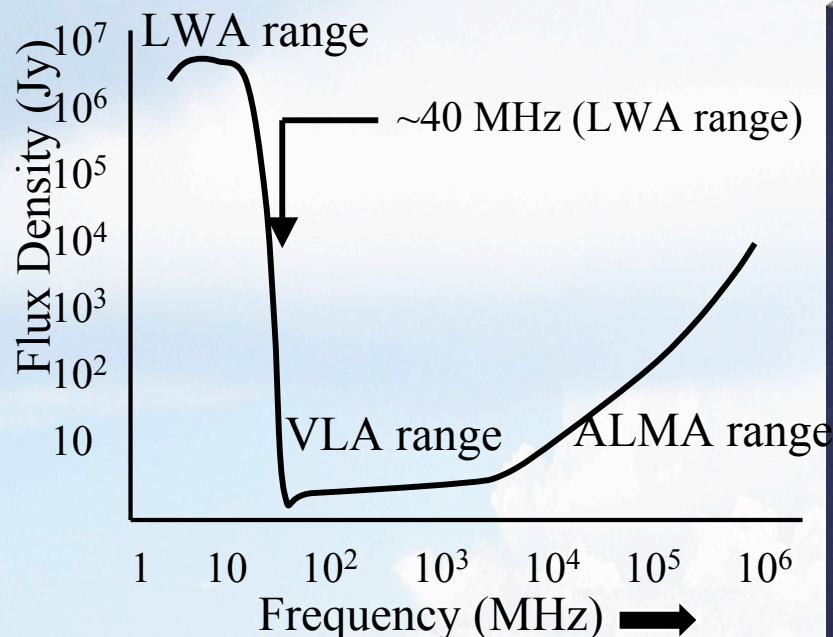
Galactic Science Examples

- Galactic:
 - Galactic center black hole Sgr A*
 - non-thermal filaments: magnetic field orientation
 - transients (including Jovian-type planets)
 - supernova remnant census
 - SNR acceleration
 - HII regions
 - pulsars



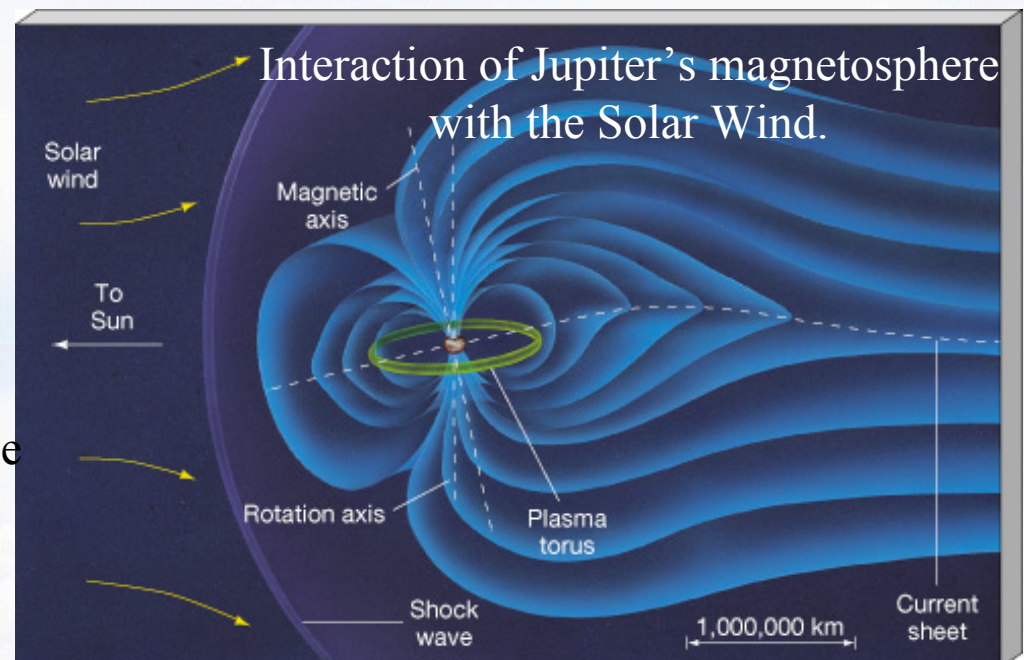
Potential Discovery Science: LWA Detection of Exo-Planets

- Below 40 MHz, Jupiter is the brightest object in the solar system.
- The LWA has a good chance of detecting emission from extra-solar “Jupiters”.
 - Would provide independent verification of planetary systems.
 - Would confirm presence of magnetic field – pre-requisite for life as shield against cosmic rays.



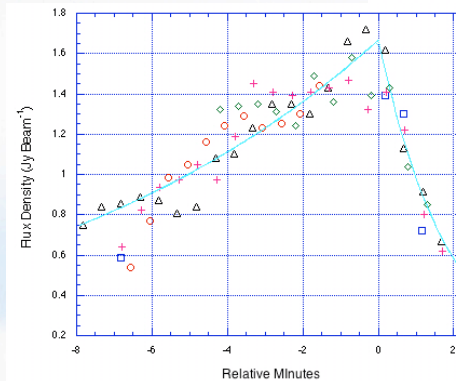
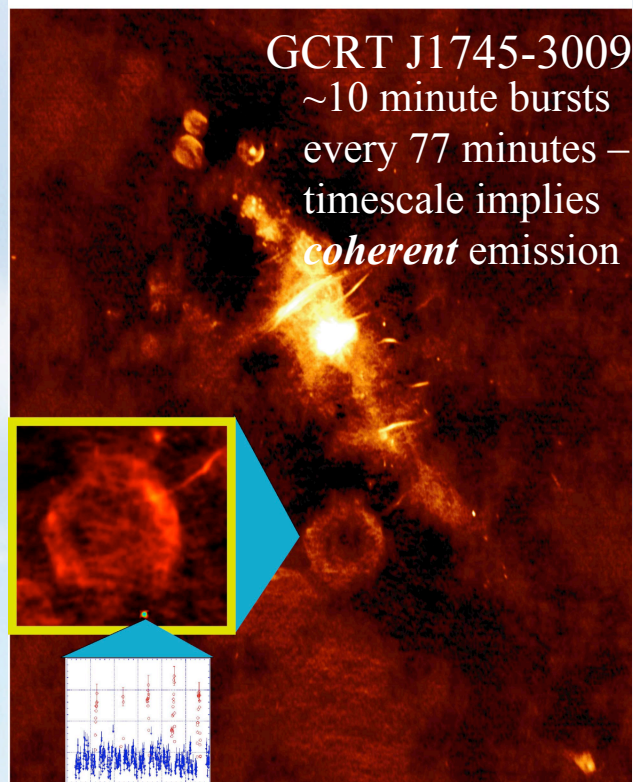
S-bursts

L-bursts

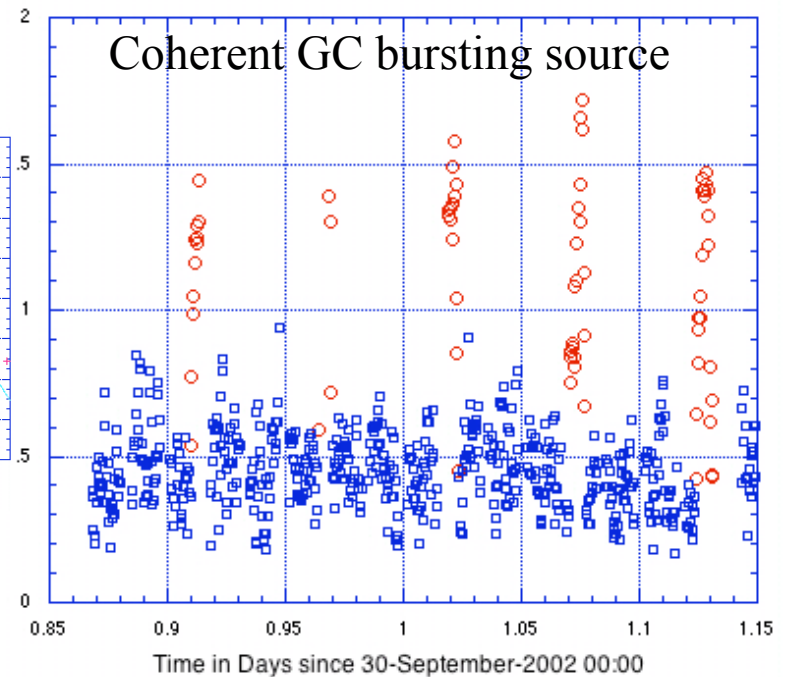


Transients

- Transients: sensitive, wide fields at low frequencies provide powerful opportunity to search for new transient sources
- candidate coherent emission transient recently discovered near Galactic center



(Hyman, et al. 2005, Nature)



Pulsars

- Detecting fast (steep-spectrum) pulsars
 - highly dispersed, distant PSRs
 - tight binaries
 - sub msec periods?
- Probe PSR emission mechanism
 - explore faint end of luminosity function
 - spectral turnovers near 100 MHz
- New SNR/pulsars associations
- Deep, high surface brightness imaging of young pulsars

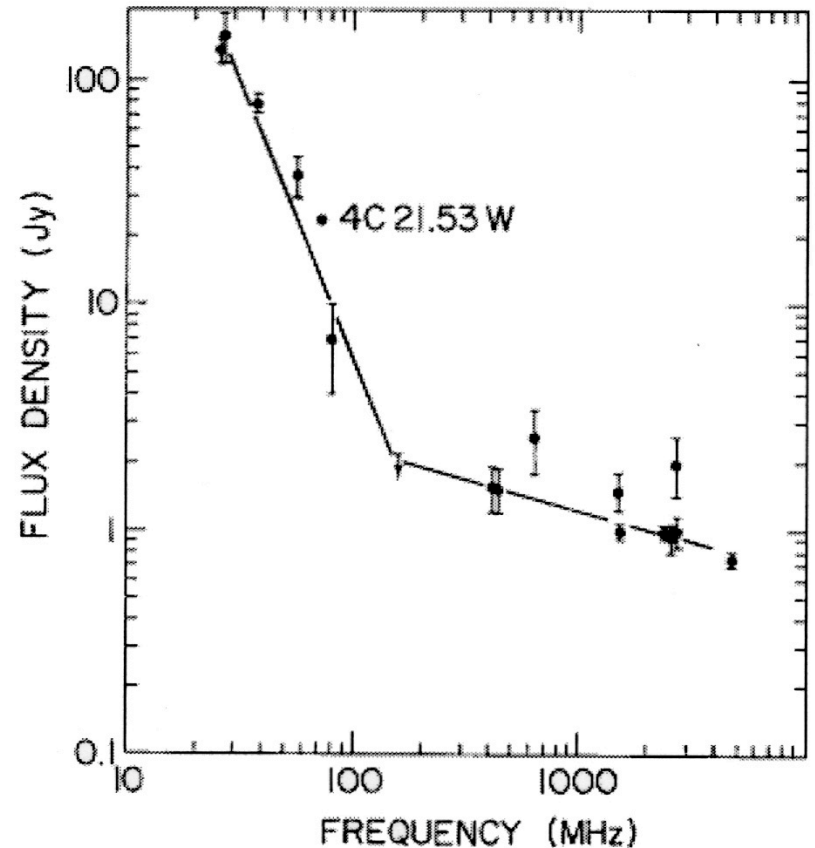


FIG. 2.—The radio spectrum of 4C 21.53W. Data are listed in Table 2. The solid lines correspond to spectral indices of -0.26 ($\nu > 150$ MHz) and -2.44 ($\nu < 150$ MHz).

Spectrum of 4C21.53: 1st msec pulsar

Crab Nebula &
pulsar @ 74 MHz



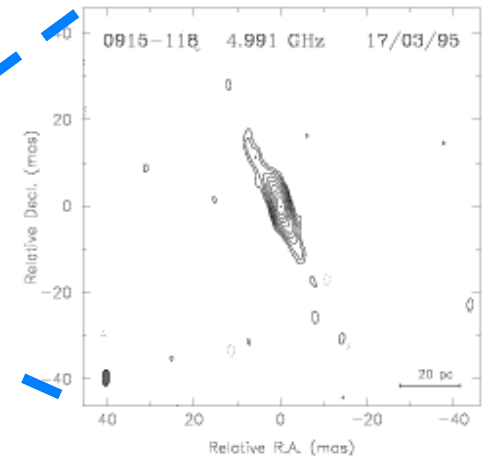
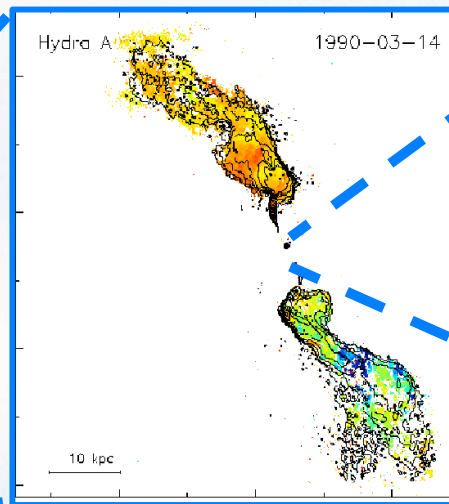
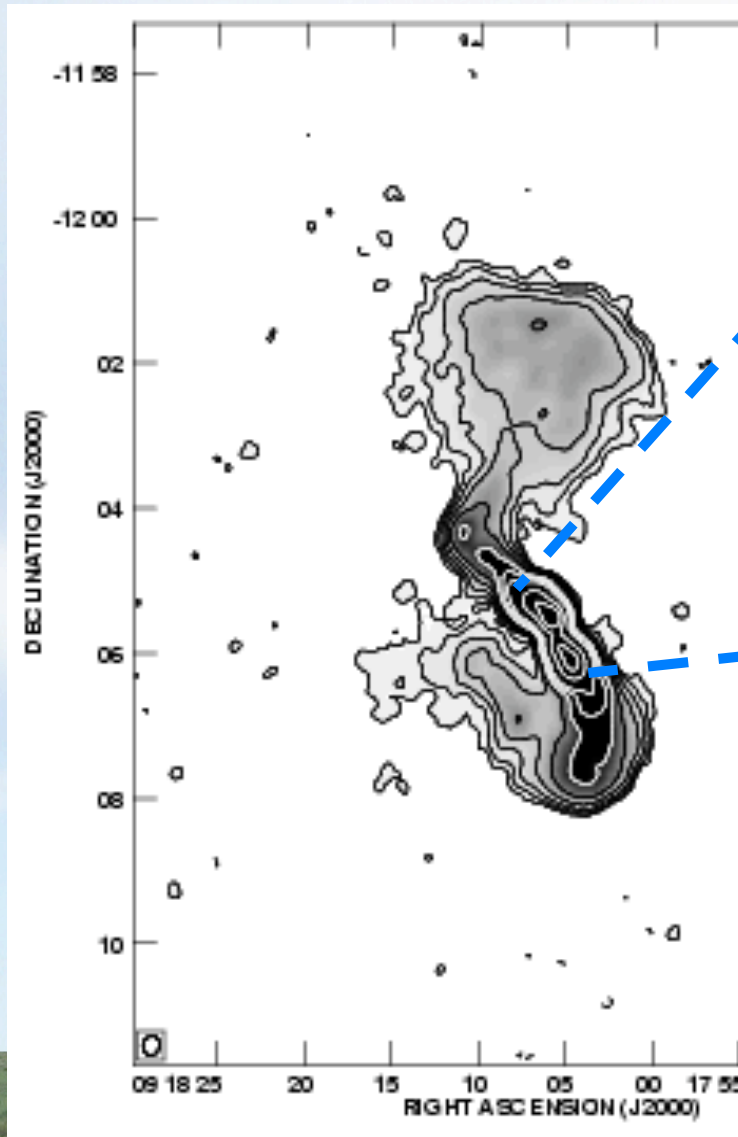
Extragalactic Science Examples

- Extragalactic:
 - radio galaxy lifecycle
 - particle acceleration in radio galaxies
 - radio lobe particle content
 - energy feedback into the intracluster medium
 - particle acceleration in merger/accretions shocks
 - tracing Dark Matter
 - sample selection for Dark Energy studies
 - detection of high redshift radio galaxies
 - study of epoch of reionization



Radio Galaxies: Outburst Lifecycle

- Hydra A at 4500 MHz (inset) shows an FR-I morphology on scales of $< 1.5'$ (100 kpc)



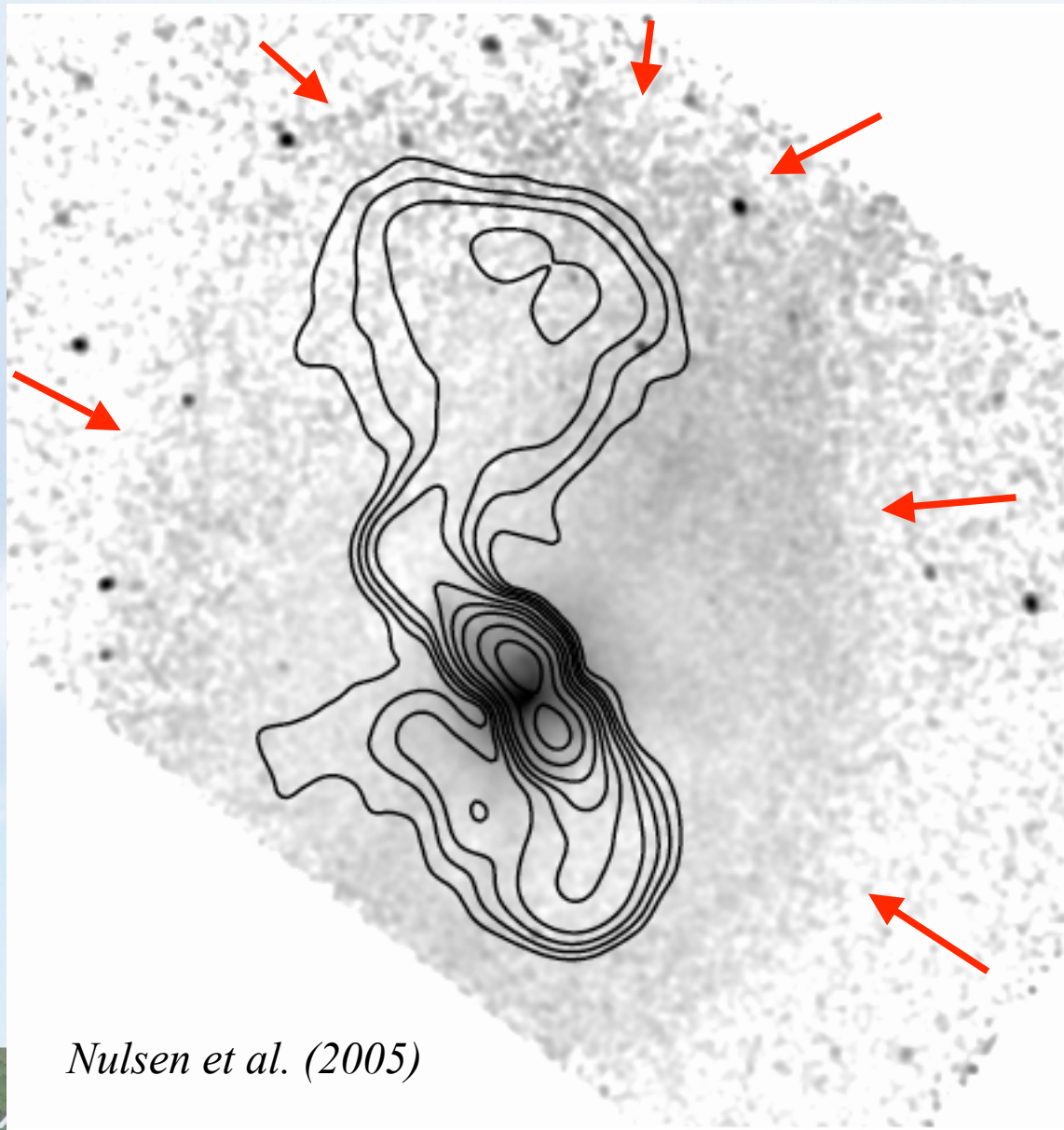
- New 74 and 330 MHz data show Hydra A is $> 8'$ (530 kpc) in extent with large outer lobes surrounding the high frequency source

Outer lobes have important implications for the radio source lifecycle and energy budget

Lane et al. (2004)



Driving Shocks into the ICM



Nulsen et al. (2005)

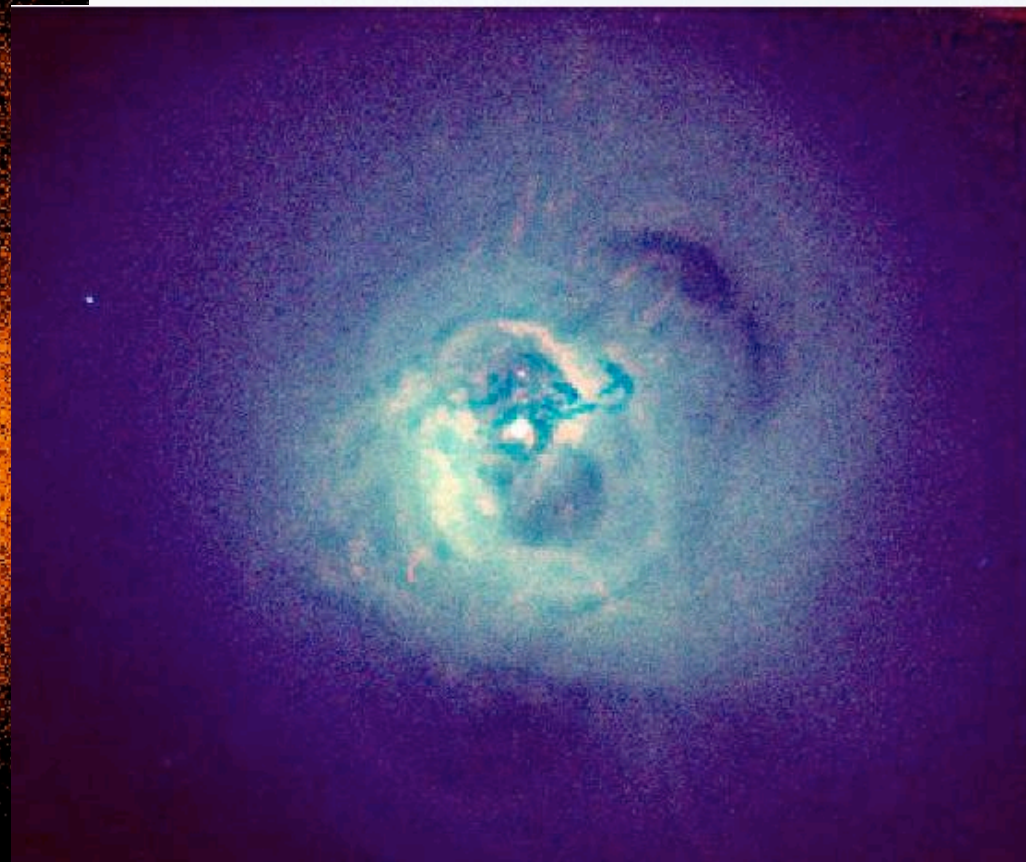
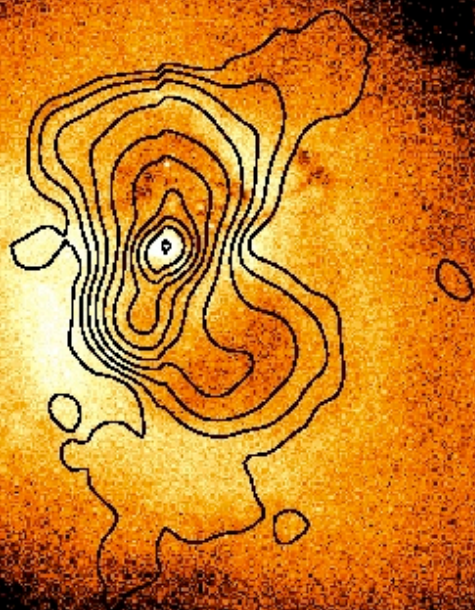
- Chandra X-ray emission detects shock front surrounding low frequency radio contours
- Expanding radio lobes drive the shock over last $\sim 1.4 \times 10^8$ yr
- Total energy input significantly exceeds requirements to offset X-ray cooling in cluster



Galaxy Cluster Cores: AGN Feedback

74 MHz

Megasec Chandra image

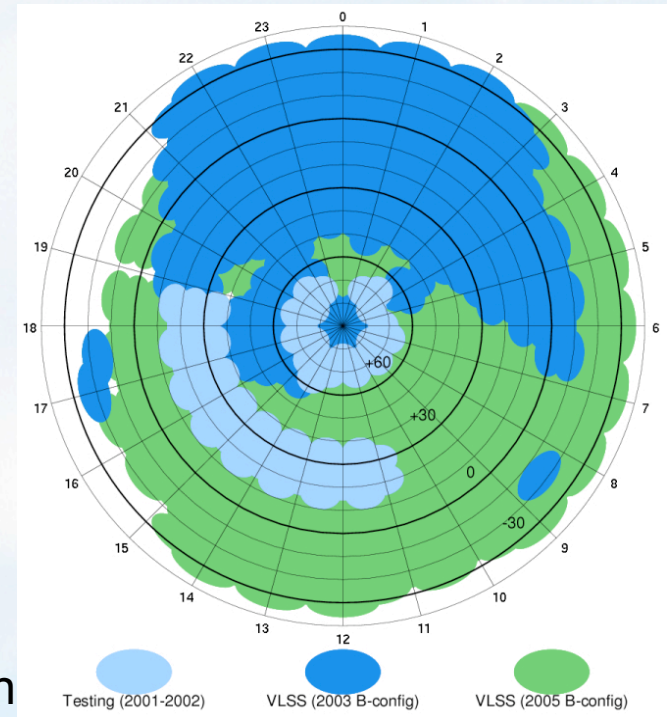


Fabian et al. (2002)



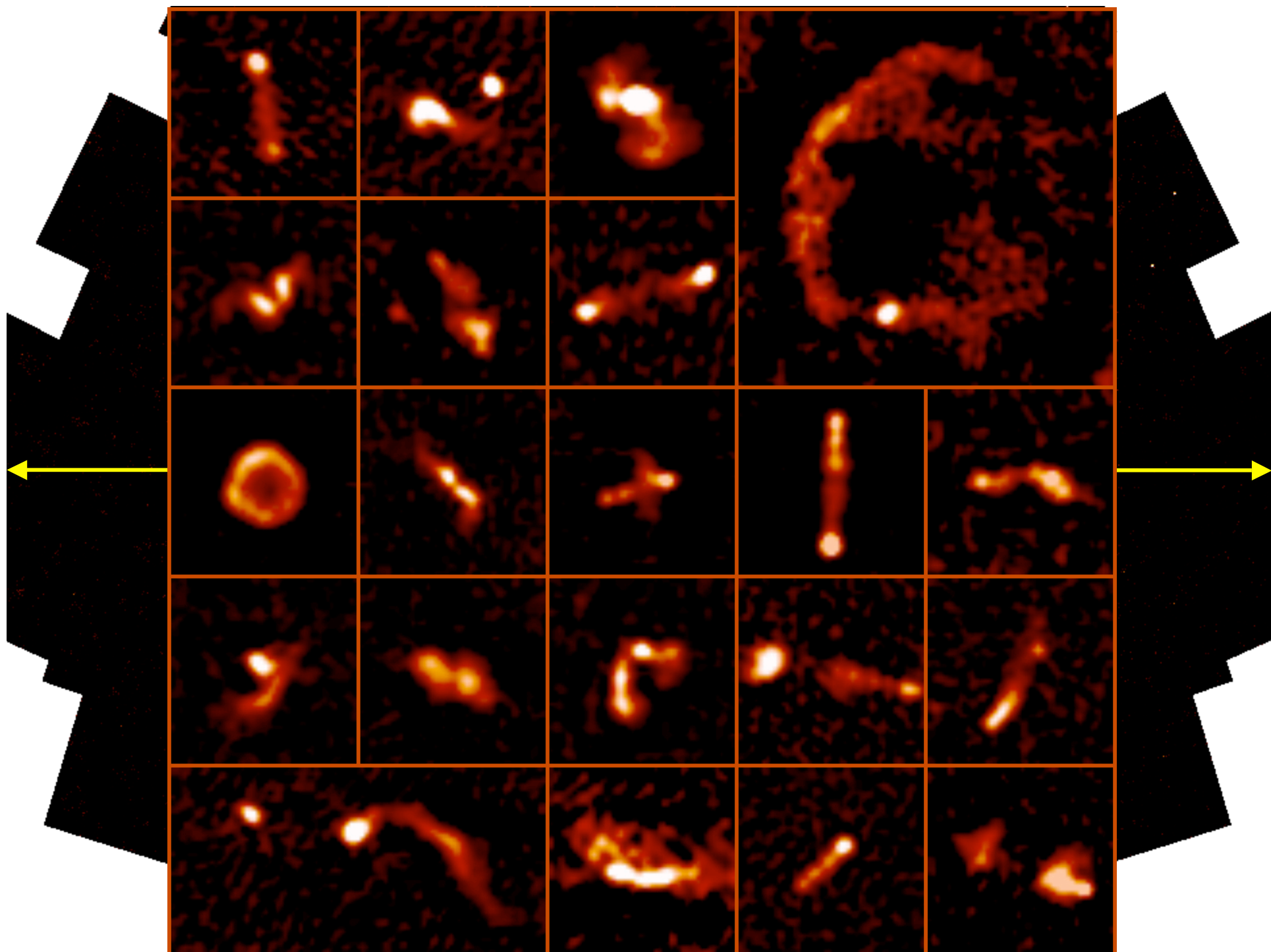
VLA Low Frequency Sky Survey: VLSS

- **Survey Parameters**
 - 74 MHz
 - Dec. > -30 degrees
 - 80" resolution
 - rms ~100 mJy/beam
- **Deepest & largest LF survey**
 - $N \sim 10^5$ sources in ~ 80% of sky
 - Statistically useful samples of rare sources
=> fast pulsars, distant radio galaxies,
cluster radio halos and relics
 - Unbiased view of parent populations for unification models
- **Important calibration grid for VLA, GMRT, & future LF instruments**
- **Data online at:** <http://lwa.nrl.navy.mil/VLSS>
- ***Condon, Perley, Lane, Cohen, et al***



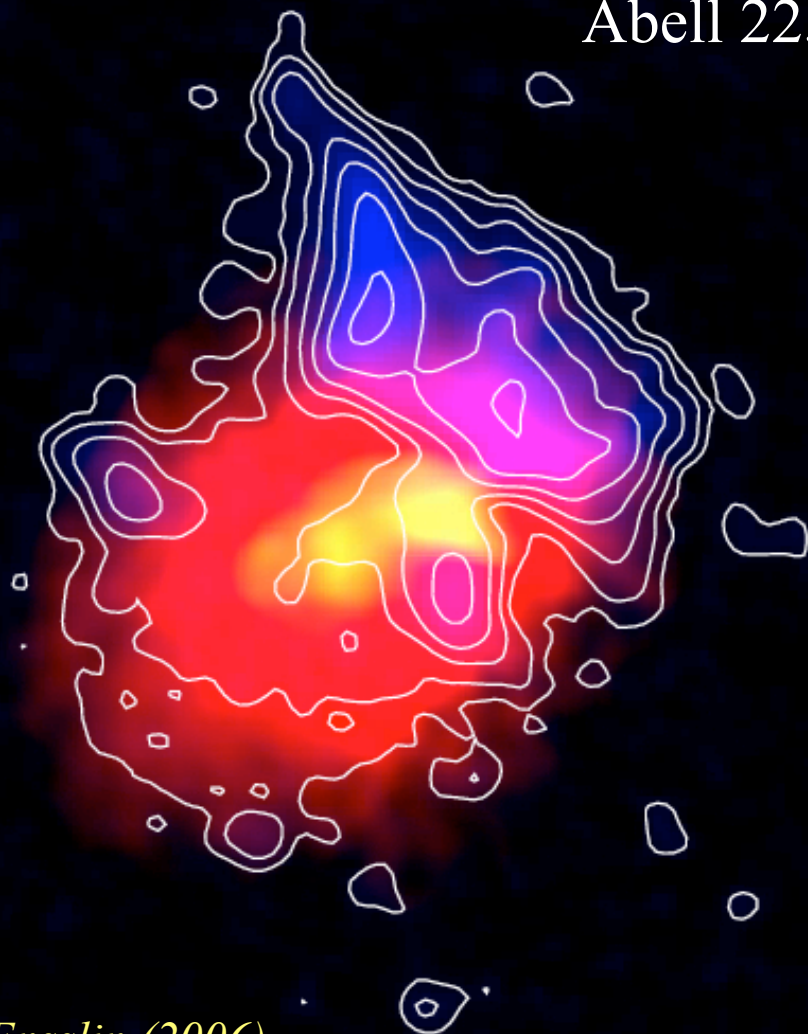
~ 95 % complete





Cluster Mergers: Diffuse Synchrotron Emission

Abell 2256



Several clusters display large regions of diffuse synchrotron:

- 'halos' & 'relics' associated with merging clusters
- radio emission is generally steep spectrum
- location, morphology, spectral properties, etc... can be used to understand merger geometry

Clarke & Ensslin (2006)



Low Frequency In Practice: Not Easy!

- Bandwidth smearing

Distortion of sources with distance from phase center

- Interference:

Can be severe at low frequencies, can be self-generated

- Phase coherence through ionosphere

Corruption of coherence of phase on longer baselines

- Finite Isoplanatic Patch Problem:

Calibration changes as a function of position

- Large Fields of View:

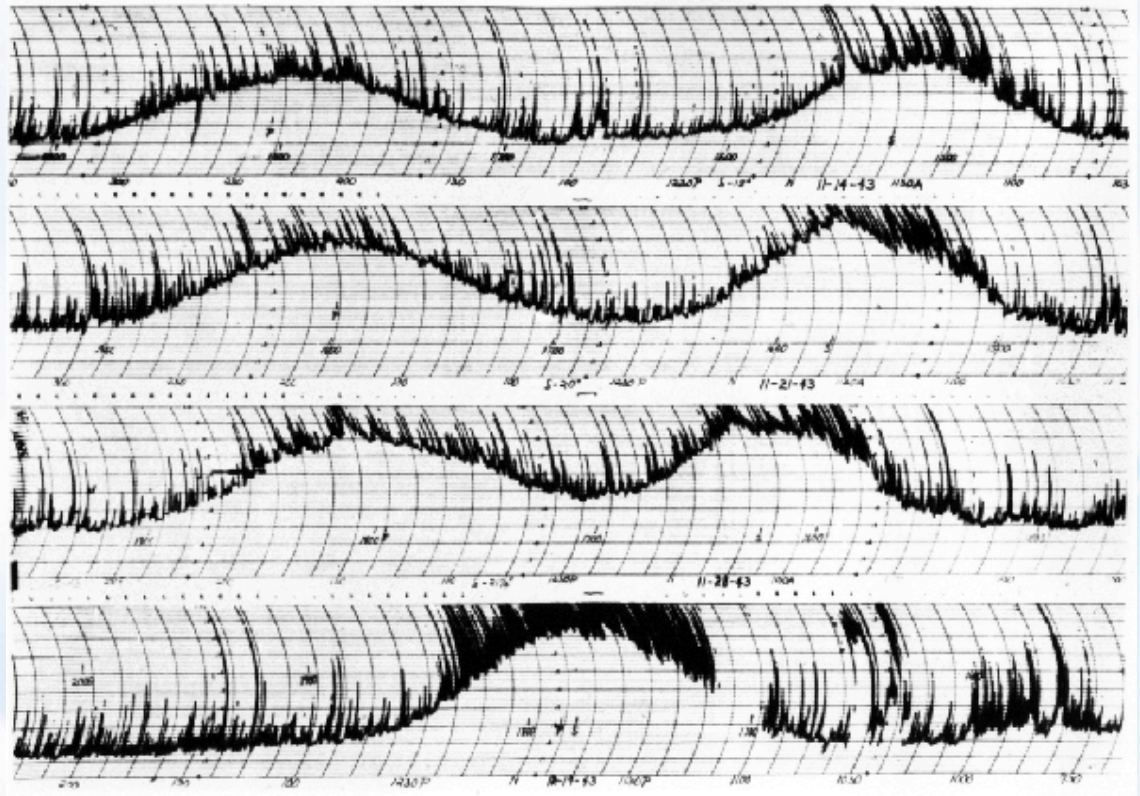
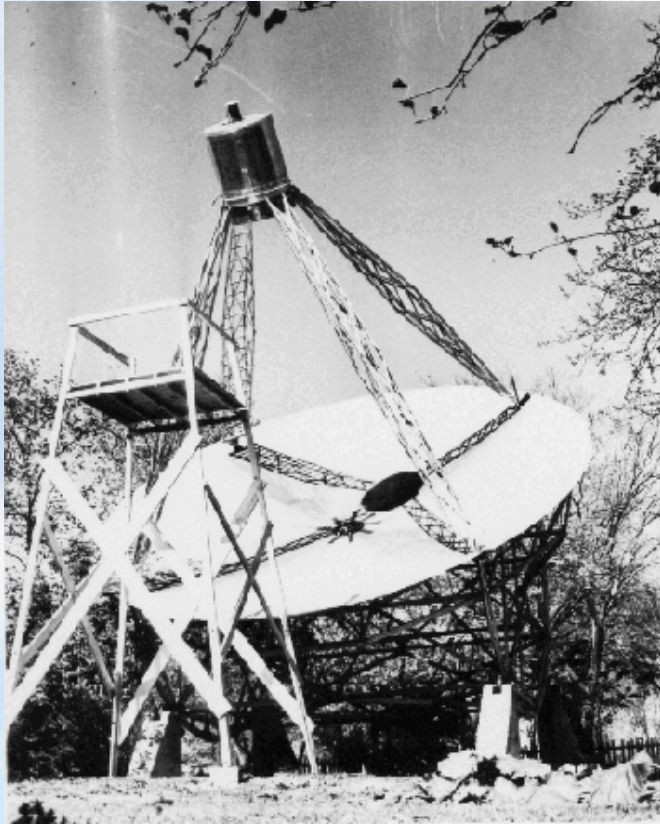
Non-coplanar array (u, v , & w)

Large number of sources requiring deconvolution

Calibrators



Radio Frequency Interference



Grote Reber's telescope and Radio Frequency Interference in 1938



Phased Development of LWA

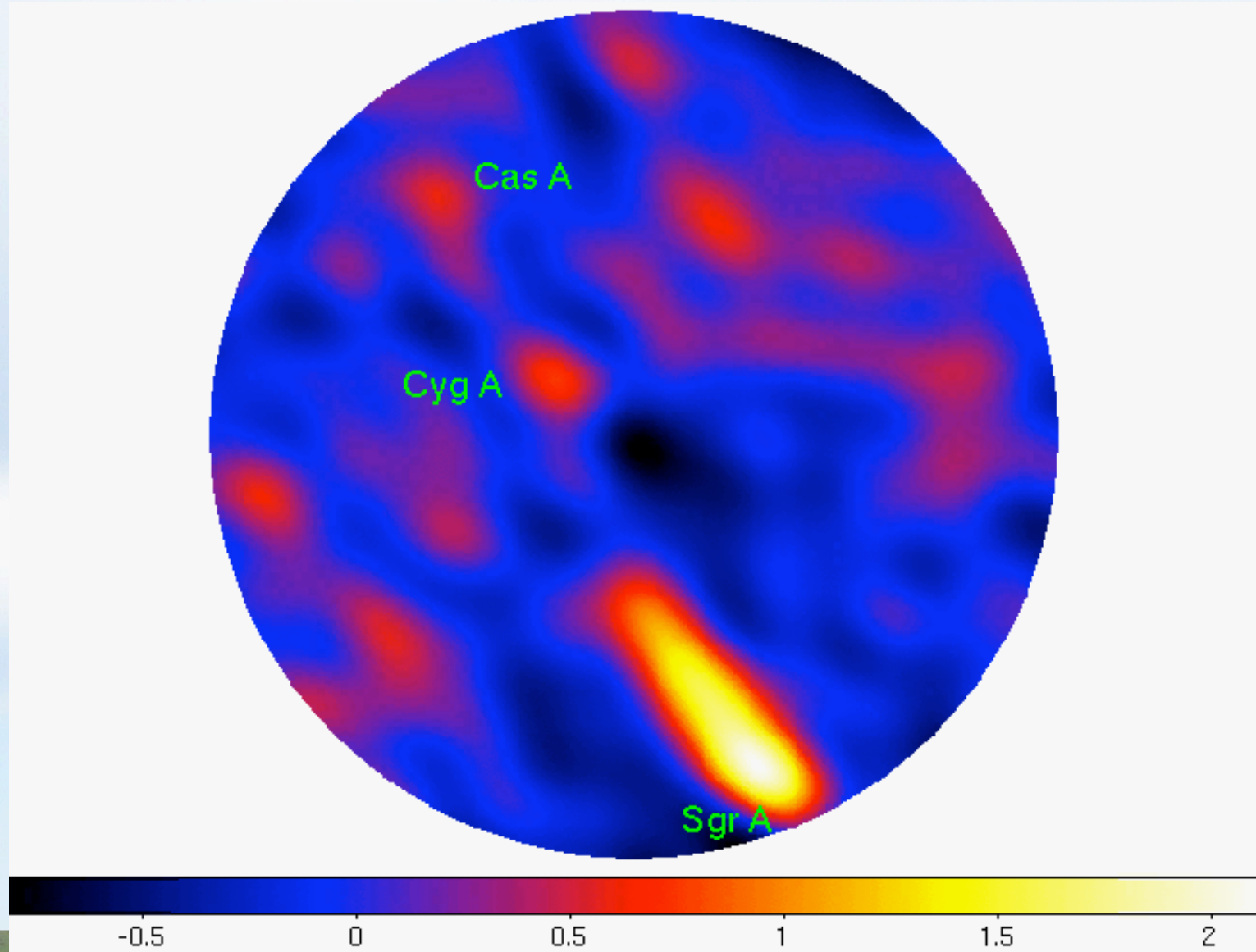
Time	Phase	Description	Acronym
2004	0	Existing 74 MHz VLA	VLA74
2006-2008	I Funded!	Long Wavelength Development Array +Long Wavelength Array Station #1	LWDA LWA1
2008-2010	II	9 station Long Wavelength Intermediate Array	LWIA
2010-2012	III	LWA Core + Outliers	LWAC
2012-2014	IV	High Resolution LWA	LWA
2009-	V	LW Operations and Science Center	LWOSC

FY06+FY07 funds (\$5M): LWA1 + partial
build of LWA2 and LWA3

The Long Wavelength Demonstrator Array (LWDA) Site on February 18, 2007



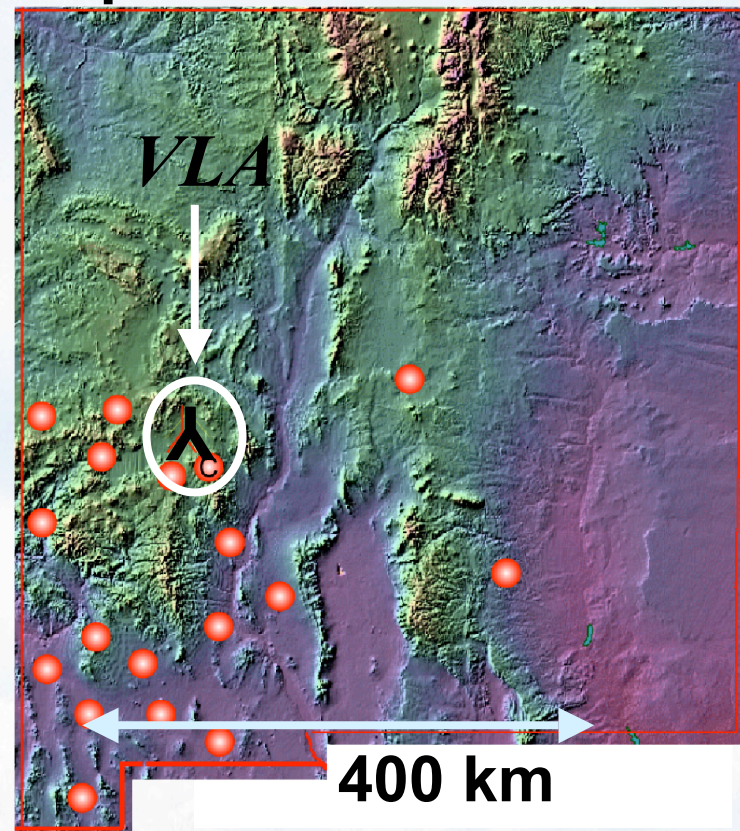
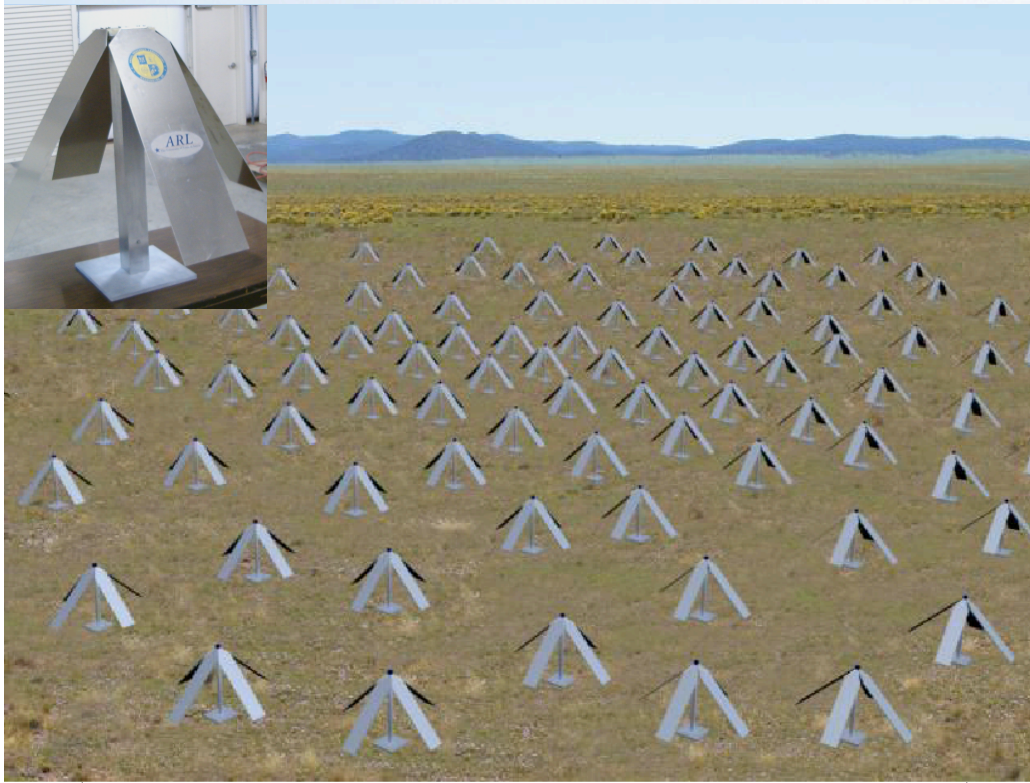
LWDA Movie 24 hours



LWA Overview: Far Larger than the VLA

1 “LWA Station” = 256 antennas

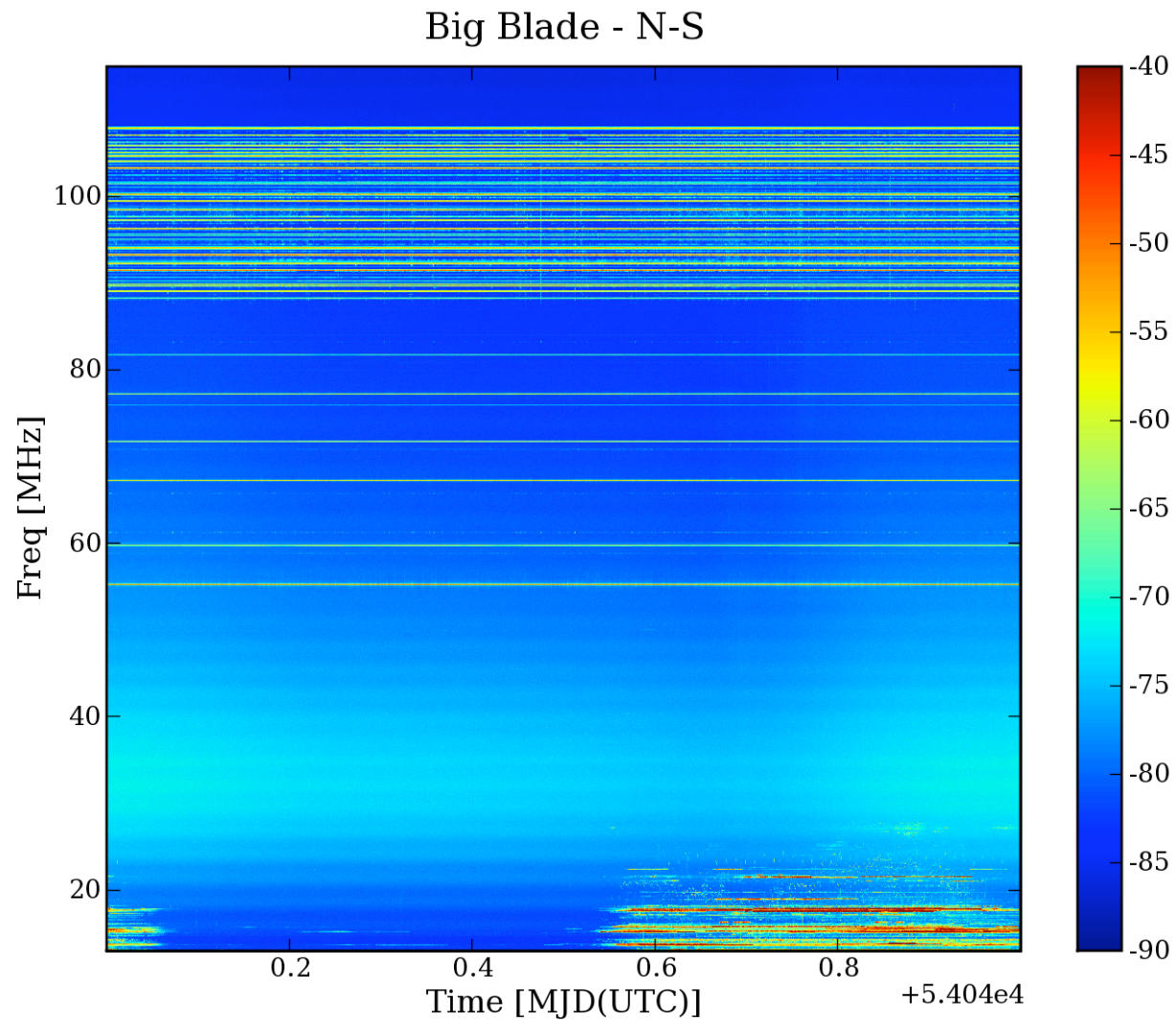
Full LWA: 52 stations
spread across NM



State of New Mexico



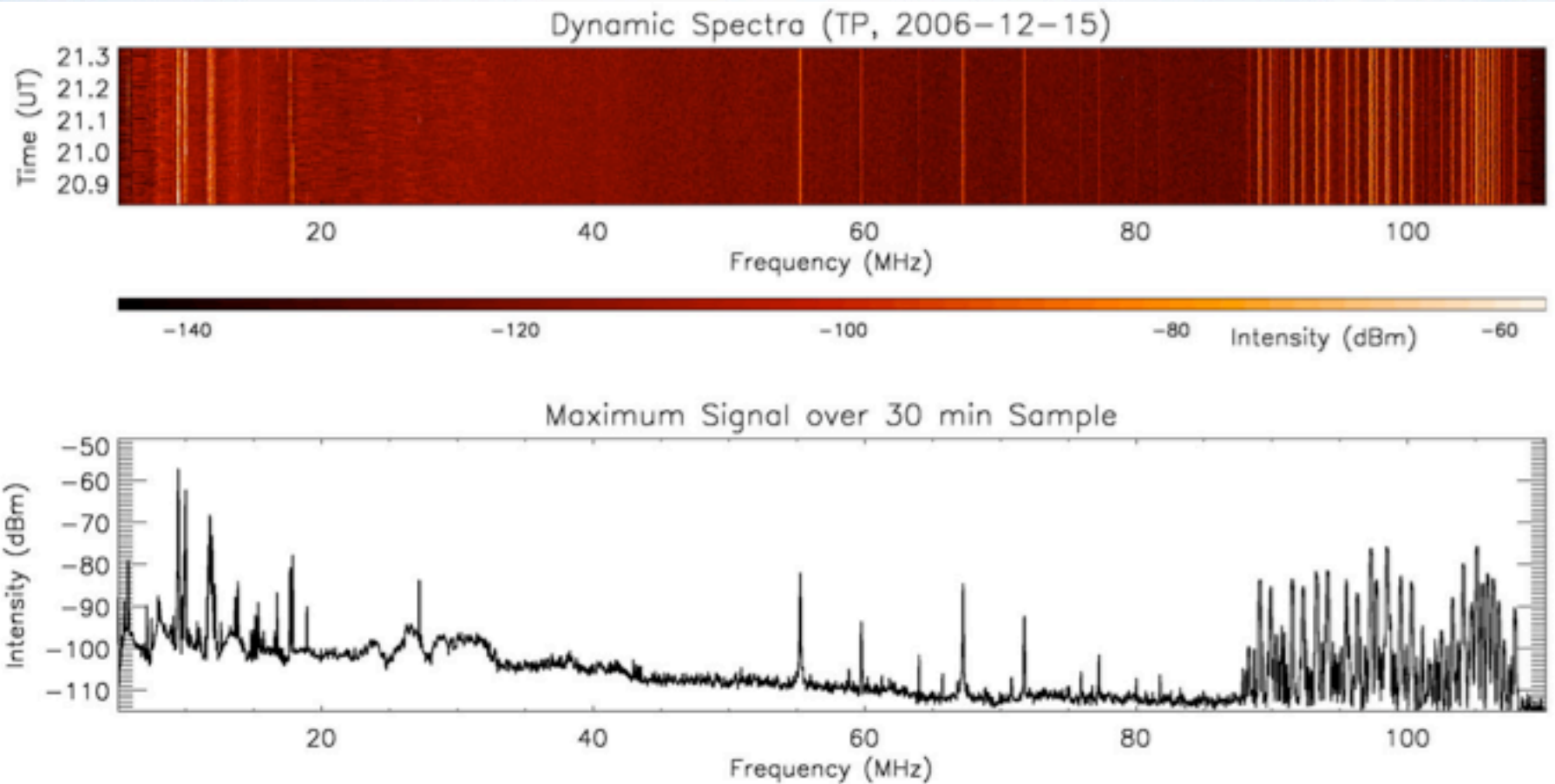
Dynamic Spectrum at VLA site, Nov 1, 2006



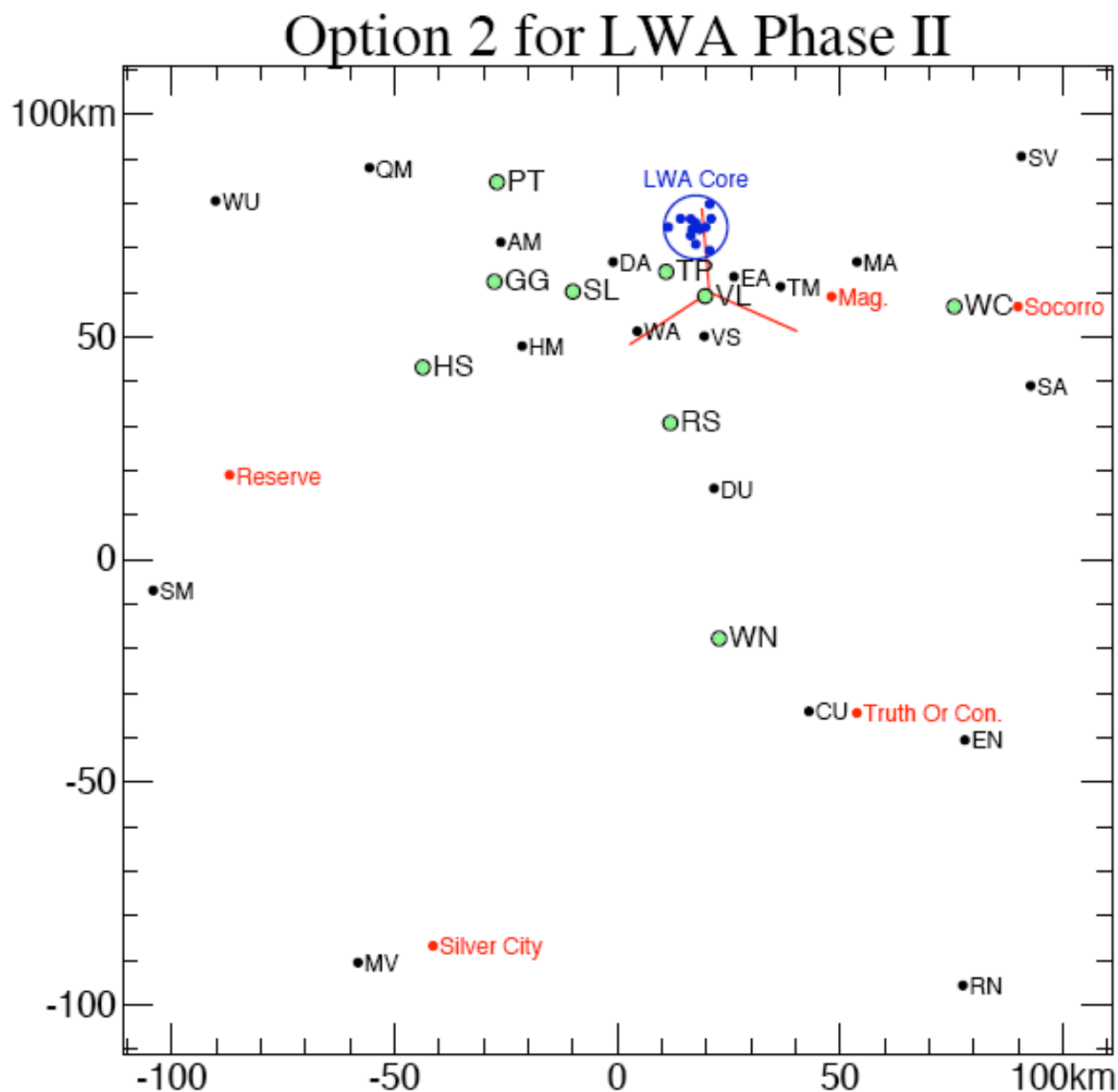


Site Testing at Twin Peaks, December 2006

Results of Radio Interference testing at Twin Peaks site



Phase II 9 stations



LWA efforts

- Establishing the Project Office
- Evaluating possible sites
- Testing of the new fork antenna design
- Develop Monitor and Control software using LWDA
- Predictions of dipole collecting area
- Testing new Balun design
- Receiver design work
- Consideration of Station Layout
- Design of communications system
- Implementing ionospheric models at UNM (see Watts)
- Simulation of LWA data (see talk by Kuniyoshi)

