74 MHz Science Results from the VLA

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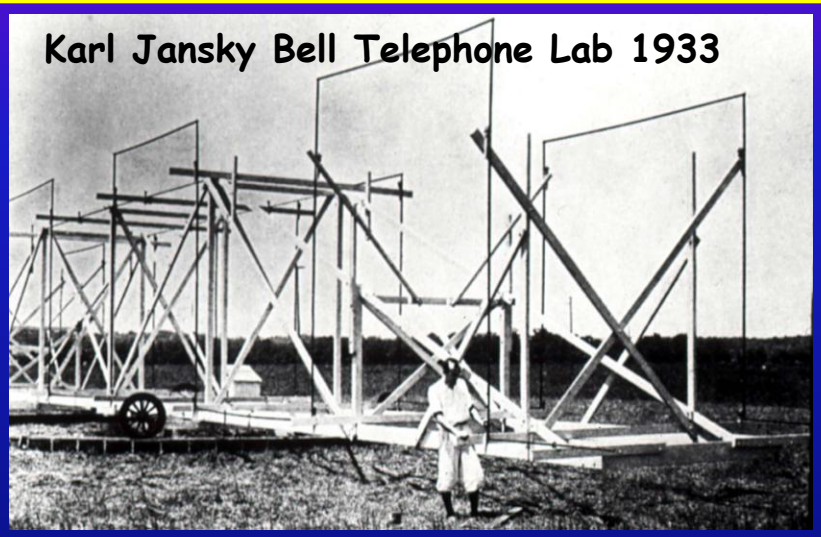
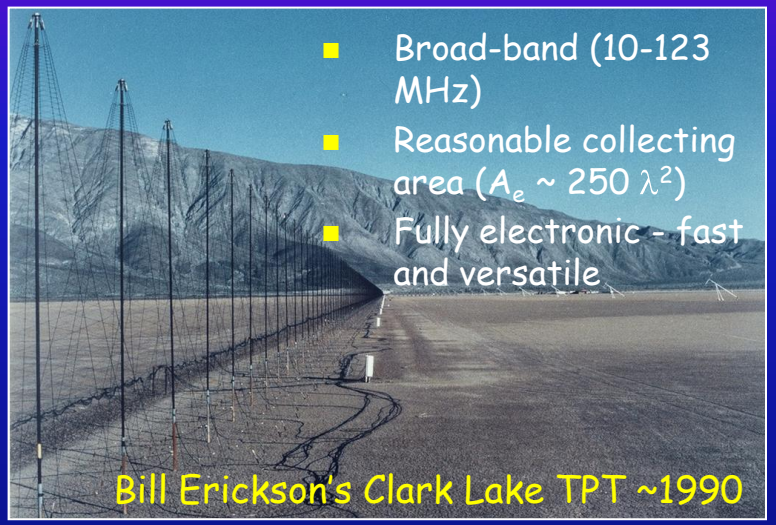
(LF ≡ LW ≡ 20-80 MHz)

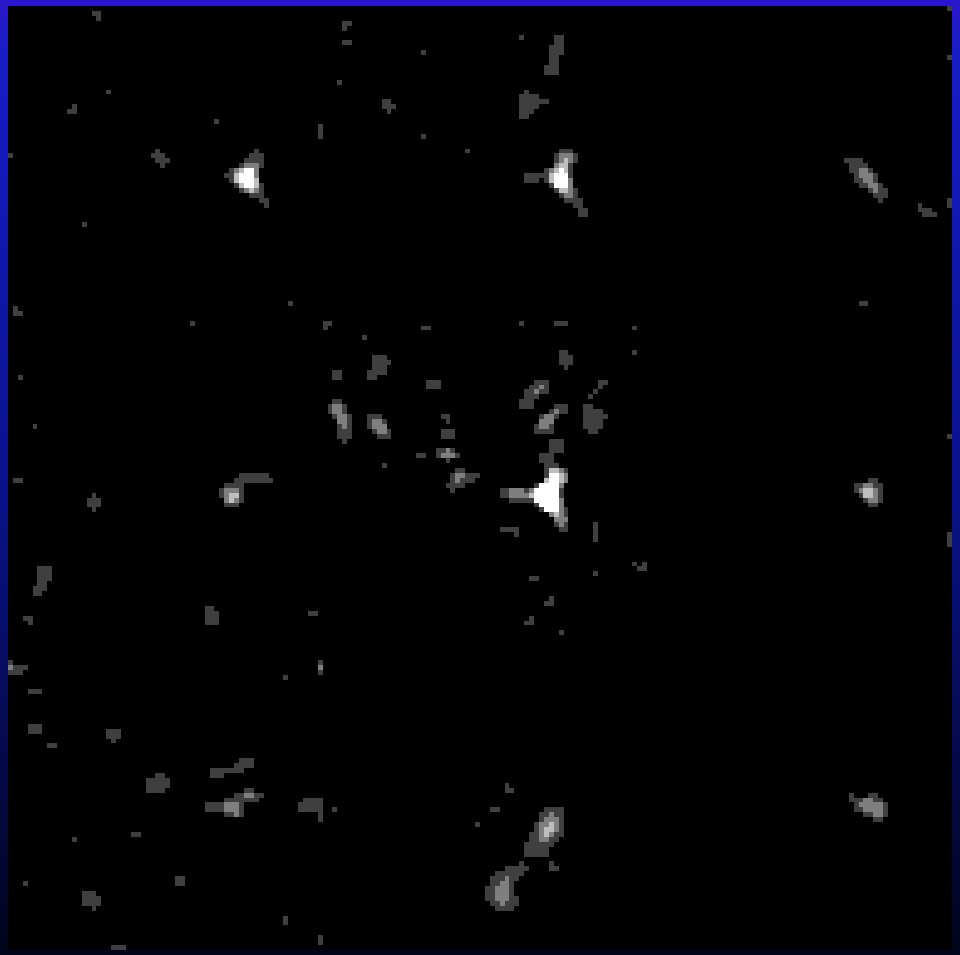
LF Telescopes in the Era before Self-calibration





- *1931-35: Discovery of cosmic radio waves, **birth of radio astronomy** (Jansky)*
- 1935-40: ***Discovery of nonthermal emission** (Reber, Henyey, Keenan)*
- *1942: Discovery of solar radio emisson (Hey)*
- *1946: **First radio interferometers** (Pawsey et al., Bolton et al., Ryle)*
- *1946-50: **Discovery of discrete cosmic radio sources** (Hey, Bolton et al.)*
- *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***

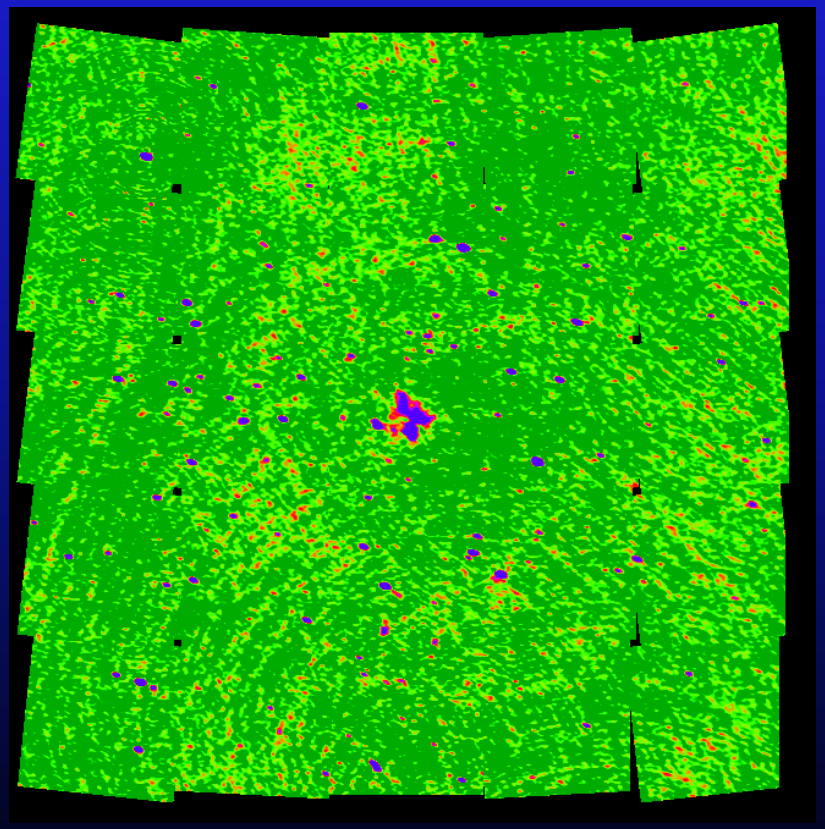
Ionosphere Limits Resolution (baseline length)



- The ionosphere limited the maximum baseline of interferometers below 100 MHz to ≤ ~5 km.
- As main-stream radio astronomy went to high resolution and sensitivity with the VLA, LW radio astronomy was left behind.
- Other problems: RFI. 3D imaging – computational tedium that has only recently become manageable

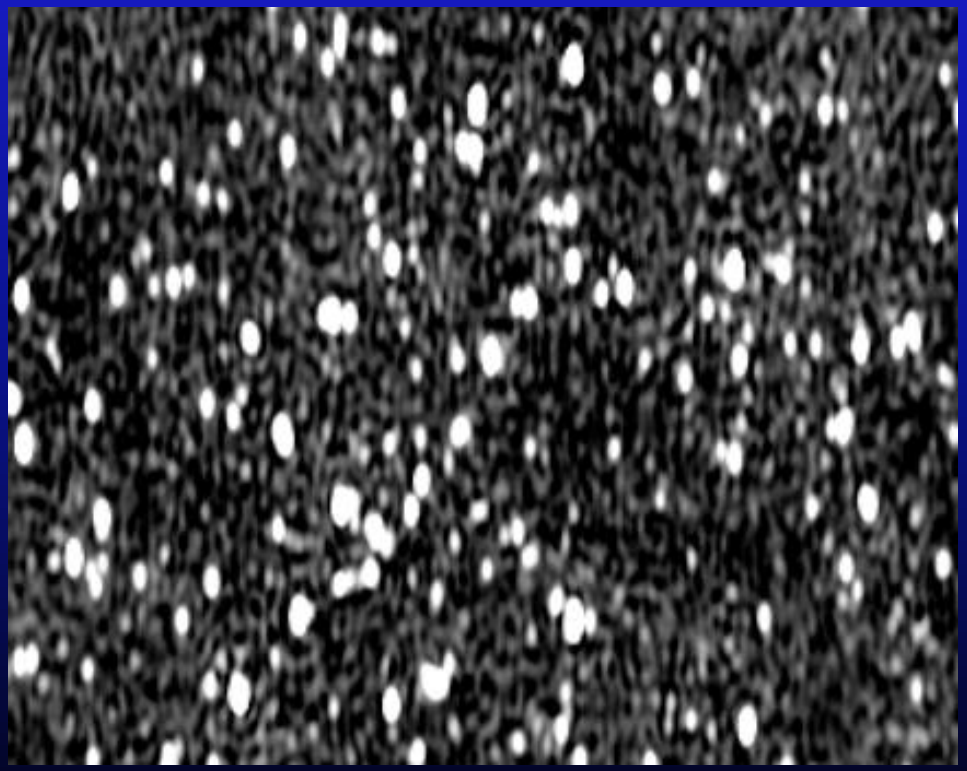
Poor Resolution Leads to Confusion that Limits Sensitivity

Sidelobe Confusion



VLA 330 MHz

Classical Confusion



WSRT 330 MHz

- Ionosp
  - ~1
- Disrup
- **1980s**
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- 1990:
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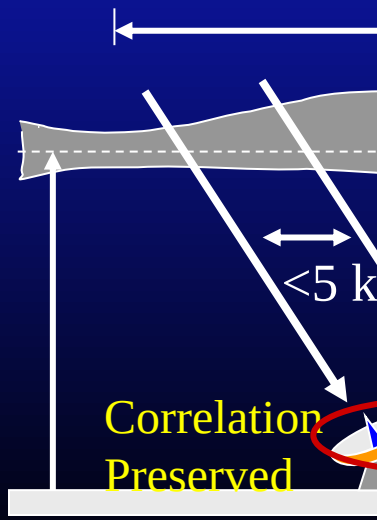

VLA SCIENTIFIC MEMORANDUM 146

A PROPOSAL FOR A LARGE, LOW FREQUENCY ARRAY LOCATED AT THE VLA SITE

R. A. PERLEY
National Radio Astronomy Observatory,
Socorro, N.M. 87801

W. C. ERICKSON
Astronomy Program, University of Md.,
College Park, MD. 20742

14 April, 1984

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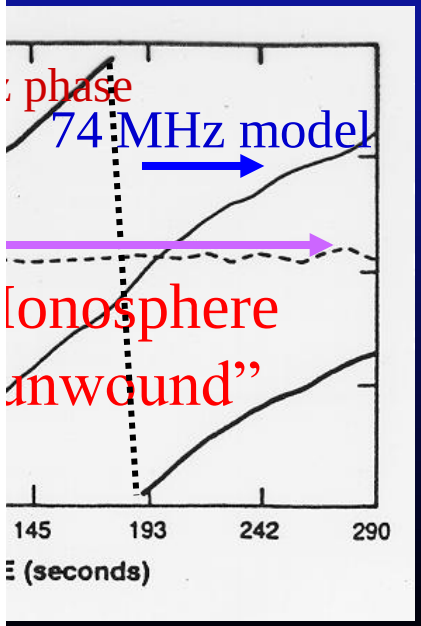
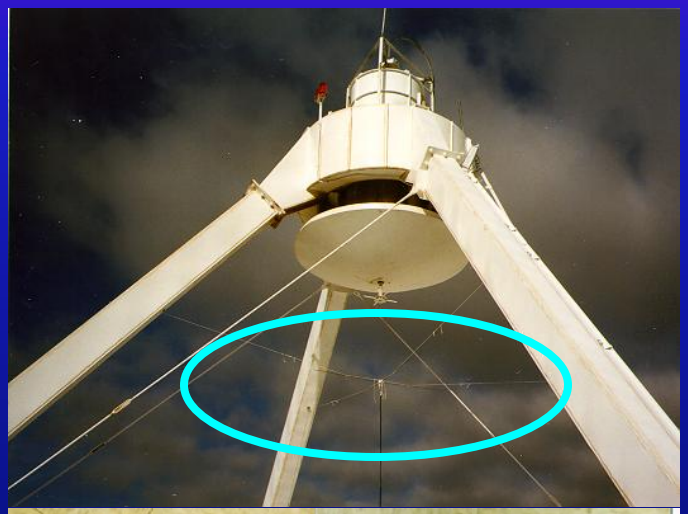
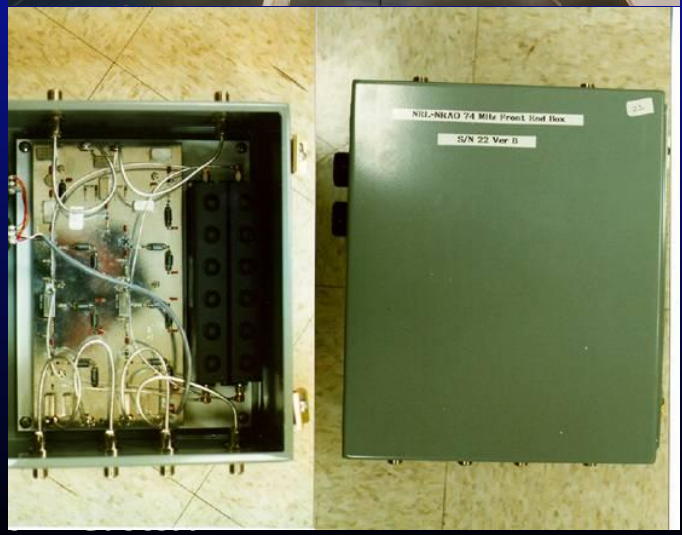


74 MHz Receiving System: Can Selfcal Break the Ionospheric Barrier?

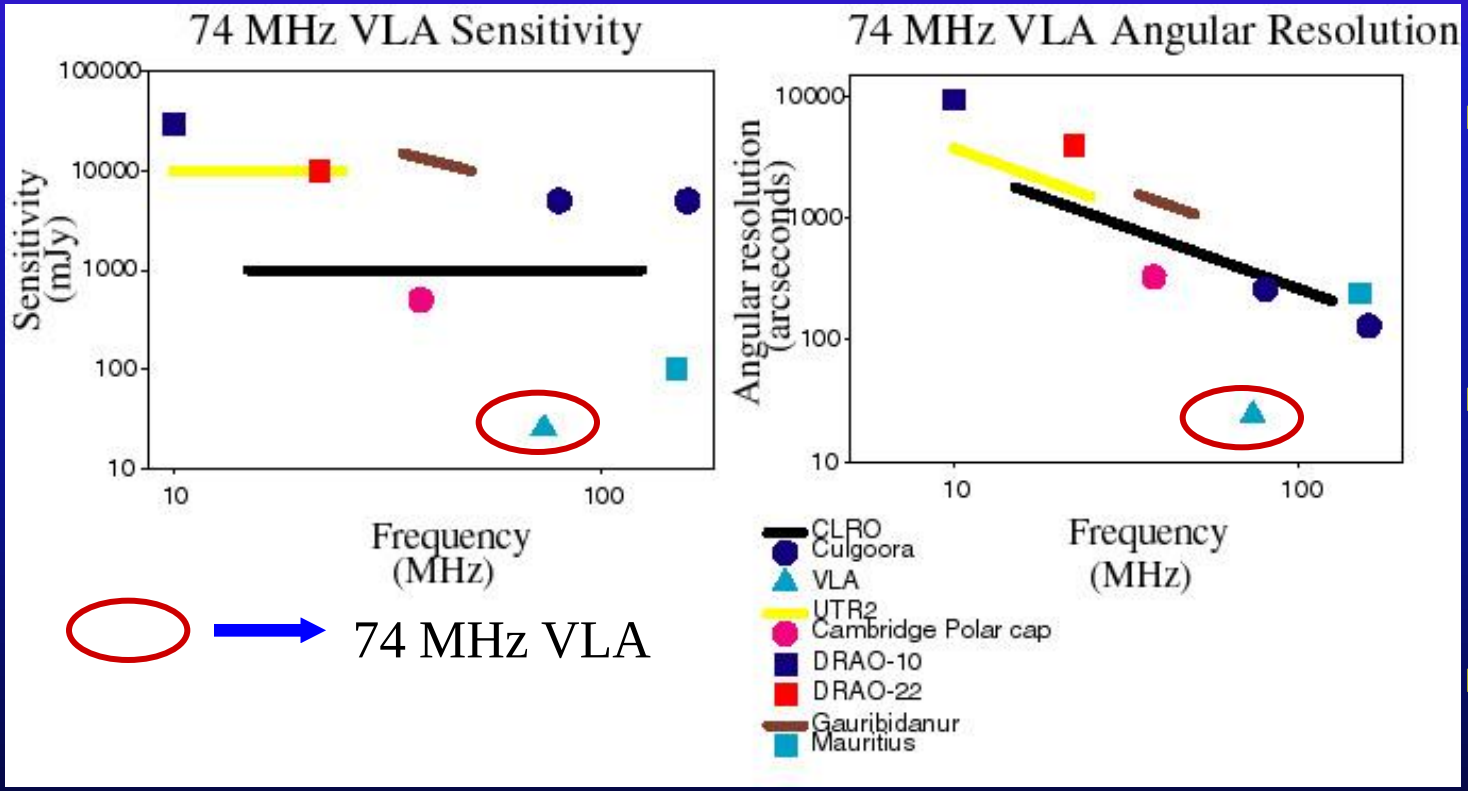




VLA Below 1 GHz

- 330 MHz dipoles installed on VLA in 1990, and in regular use until 2009
- 74 MHz dipoles installed on 8 antennas in 1991, complete system in regular use from 1998 to 2009
- Both the 74 and 330 MHz systems were developed in a cooperation between NRAO and NRL

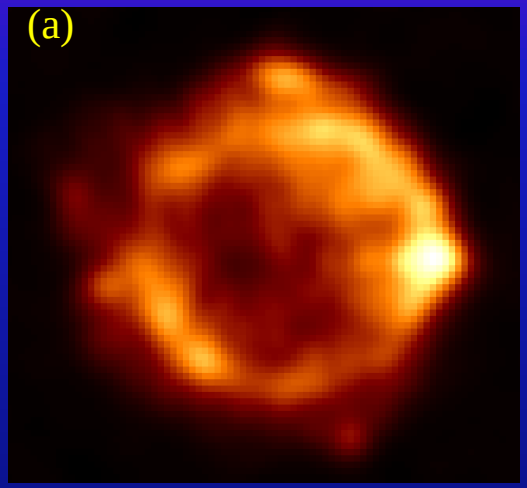
74 MHz VLA: Breakthrough in Sensitivity & Resolution

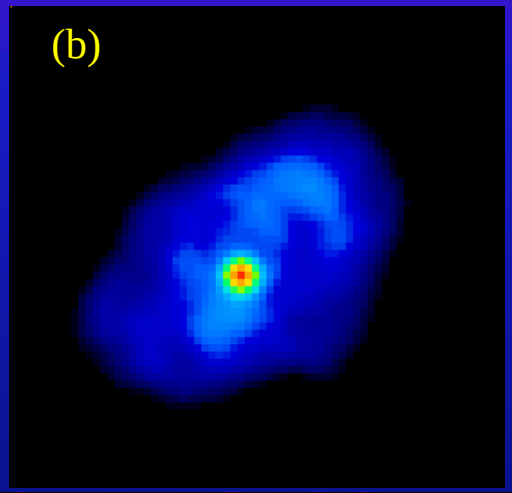


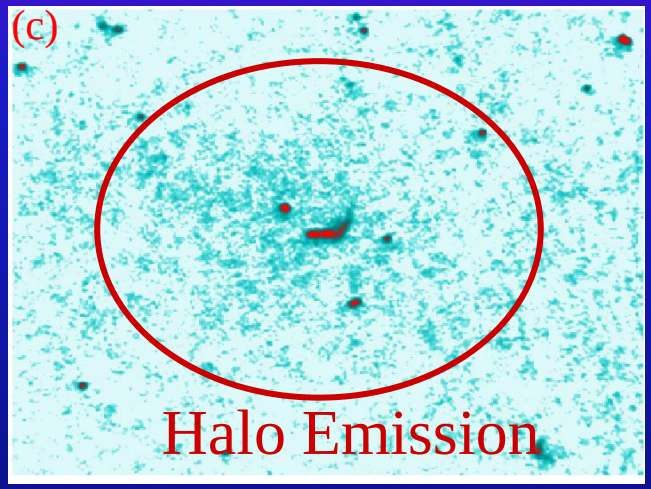
- Implemented by NRL and NRAO 1993-1997
- Facility instrument available to community 199
- Currently being upgraded

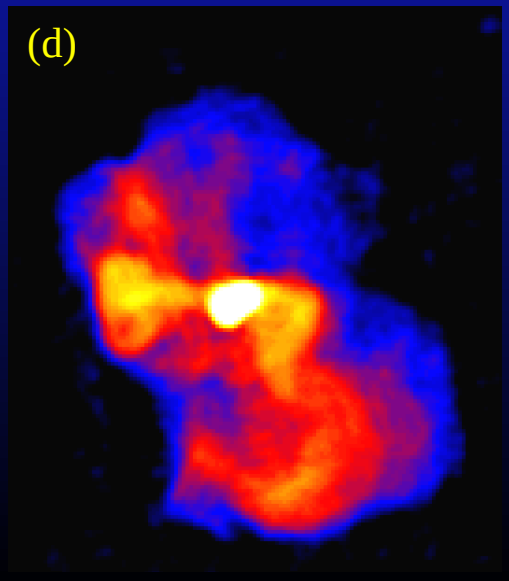
- Erickson designed system demonstrates selfcal can remove ionospheric distortions
- Catlyzes movement towards larger, dipole-based arrays

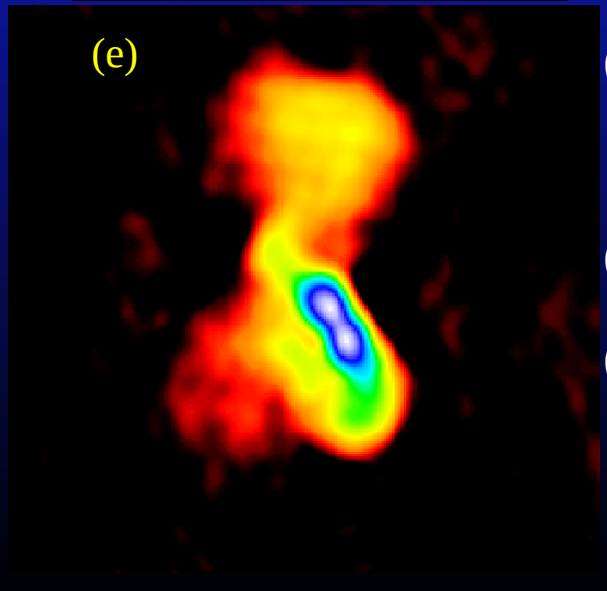
1st Images from 74 MHz VLA











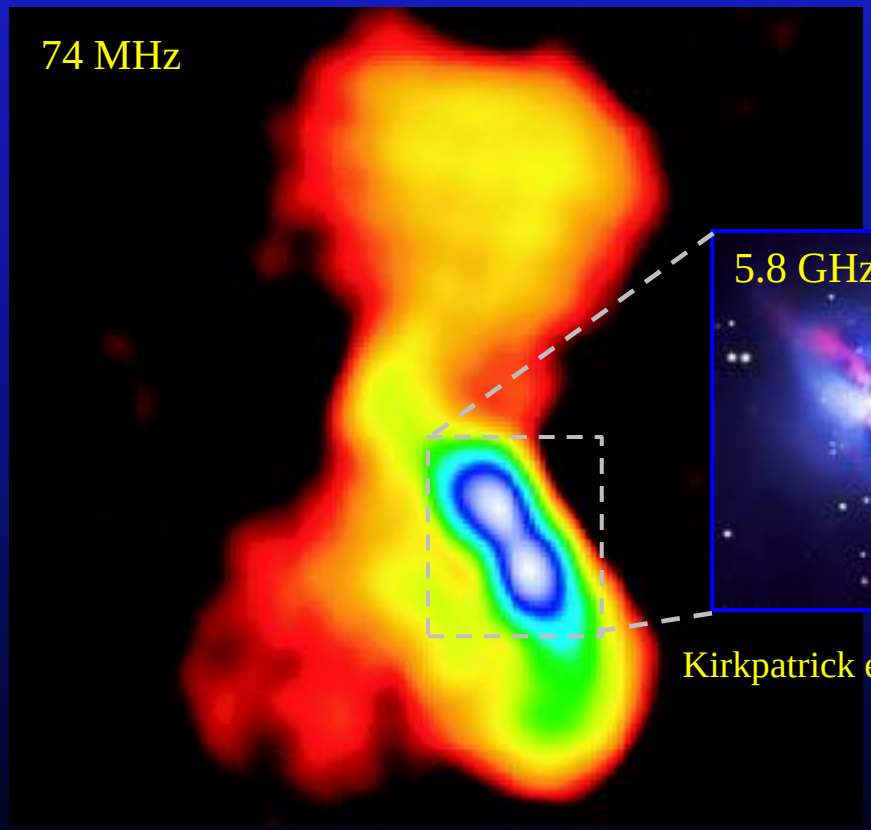
(a,b) shock physics of SNRs (a: Cas A - Kassim et al. 1995; b: Crab Nebula – Beitenholz et al. 1996)

(c) emission from relics & clusters (c: Coma - Kassim et al. 2004)

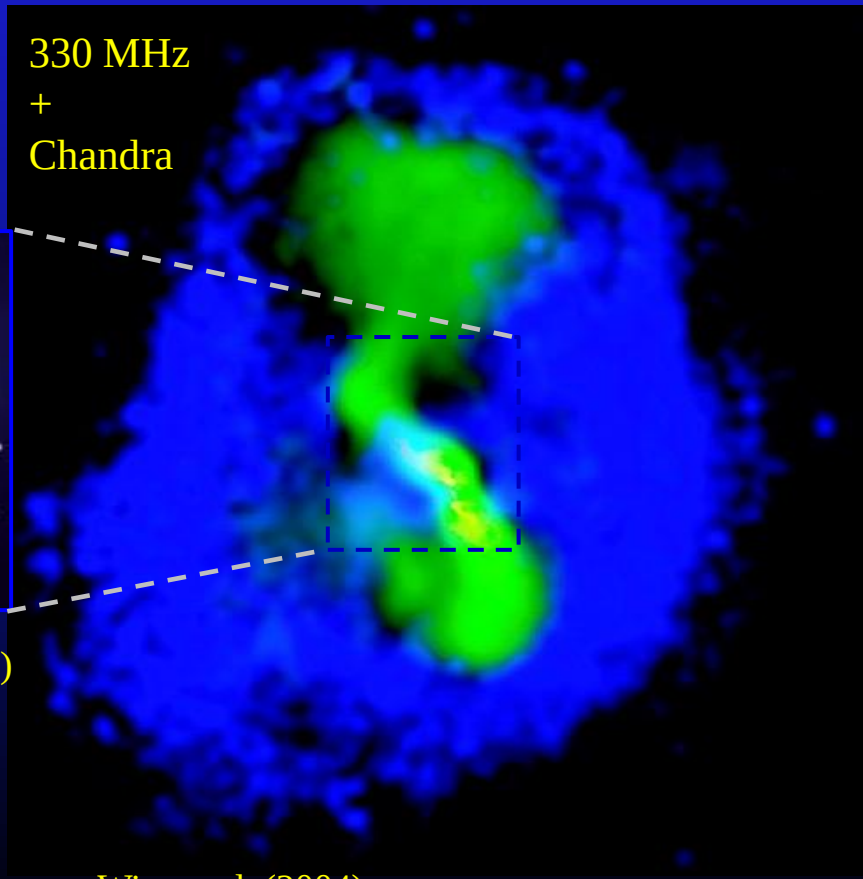
(d,e) radio galaxies (d: Virgo A – Kassim et al. 1993; e: Hydra A - Lane et al. 2004)

VLA Low Frequency Science

- Natural sensitivity to high energy astrophysics, coherent transient phenomena, unique absorption processes; intrinsic large field of view
- High surface brightness sensitivity to extended, non-thermal emission
  - VLA 74/330 MHz observations of powerful radio galaxy Hydra A
  - Radio lobes extend 5 times beyond well-known inner jet system



Kirkpatrick et al. (2009)

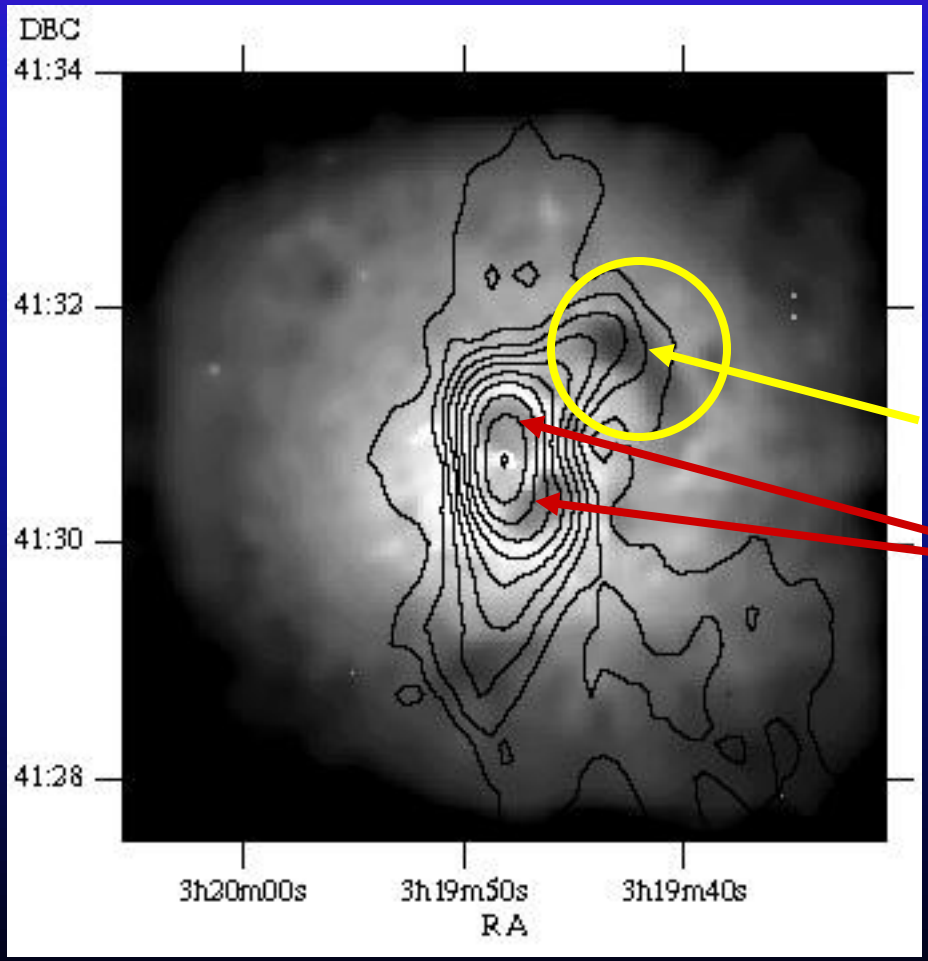


Lane et al. (2004)

Wise et al. (2004)

Buoyant Bubbles of Relativistic Electrons?

(Fabian et al 2002, MNRAS, 331, 369)



Perseus A at 74 MHz

Steep spectrum radio emission coincident with Chandra X-ray bubble: lifetime of synchrotron Emission matches dynamical lifetime of bubble

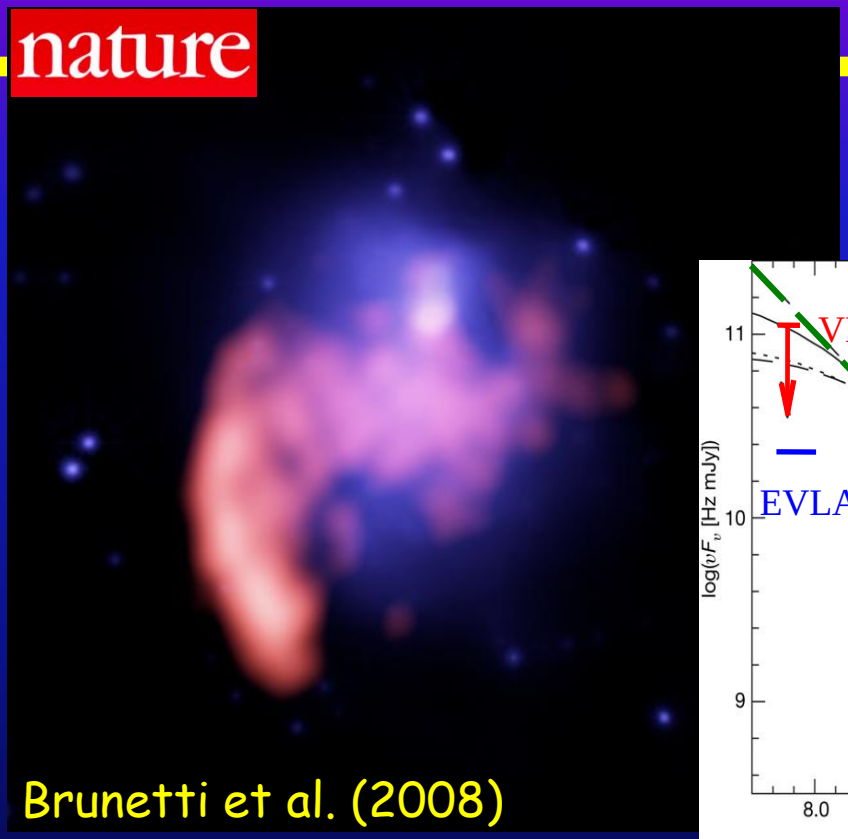
X-ray bubbles coincident with jets of 3C84 radio galaxy

Can bubbles:

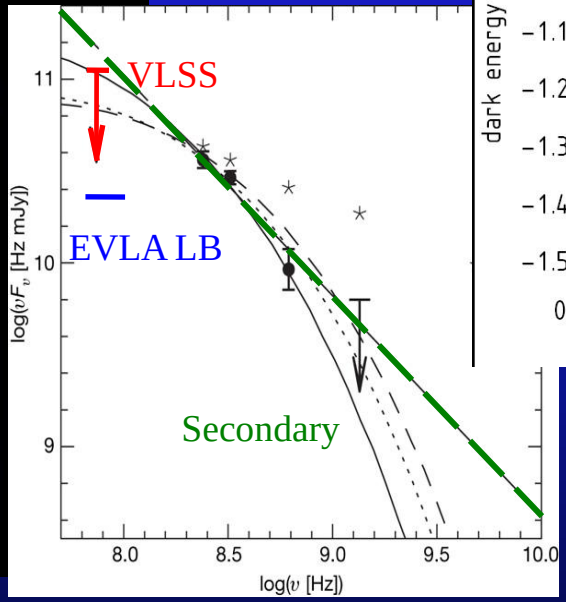
1. Solve cooling flow crisis?
2. Transport magnetic fields?

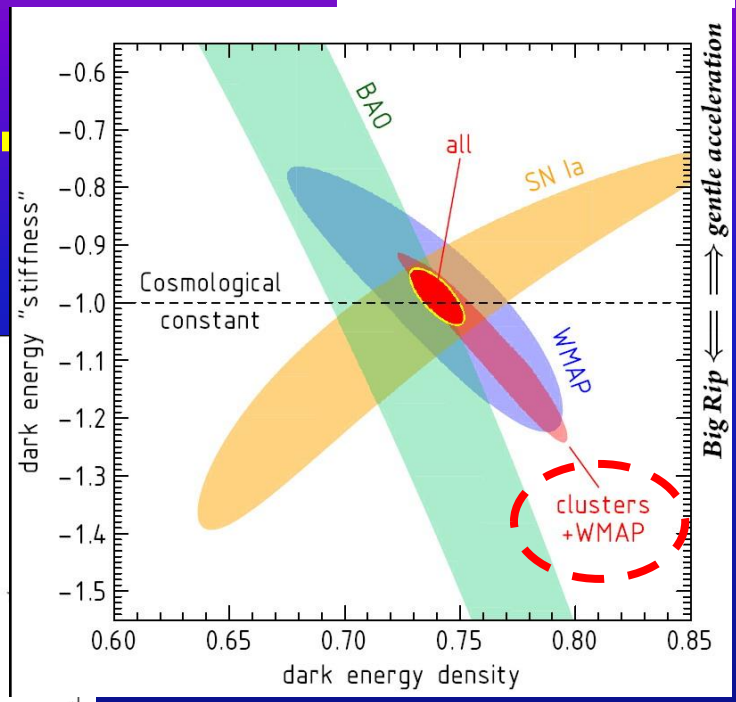
New Window on Structure Formation

Abell 521 USS halo, GMRT 240 MHz



Brunetti et al. (2008)



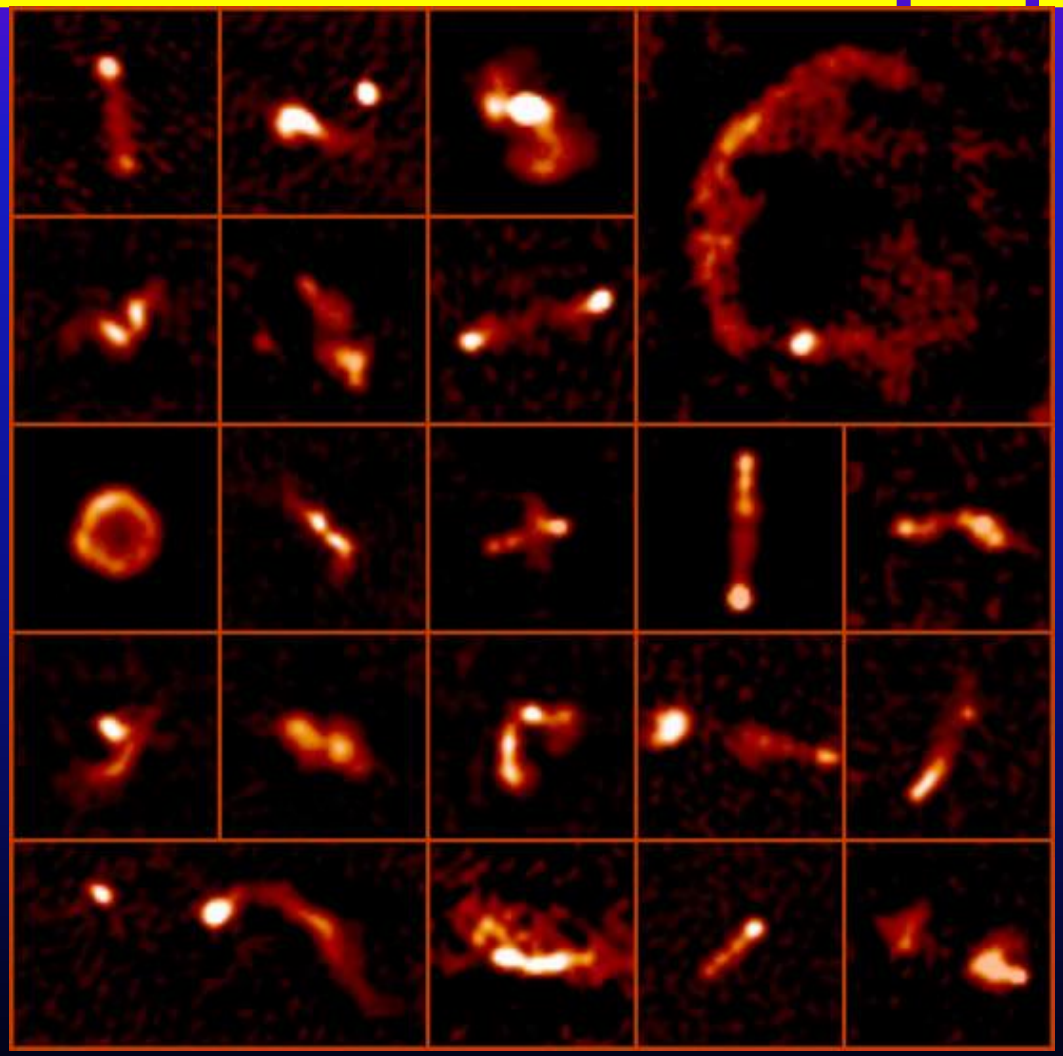


Vikhlinin et al. (2009)

- VLA 74 MHz Sky Survey (VLSS) upper limit on A521 halo rules out certain models
- EVLA *low band* sensitivity should easily detect halo and constrain B_0
- Survey of merging clusters w/o diffuse emission will test merger/halo connection
- Predict large number of such systems tracing ubiquitous weak cluster mergers
- Important link to precision cosmology

VLA Low Frequency Sky Survey

VLA 74 MHz Sky Survey has 80" resolution and sensitivity of ~ 100 mJy/bm

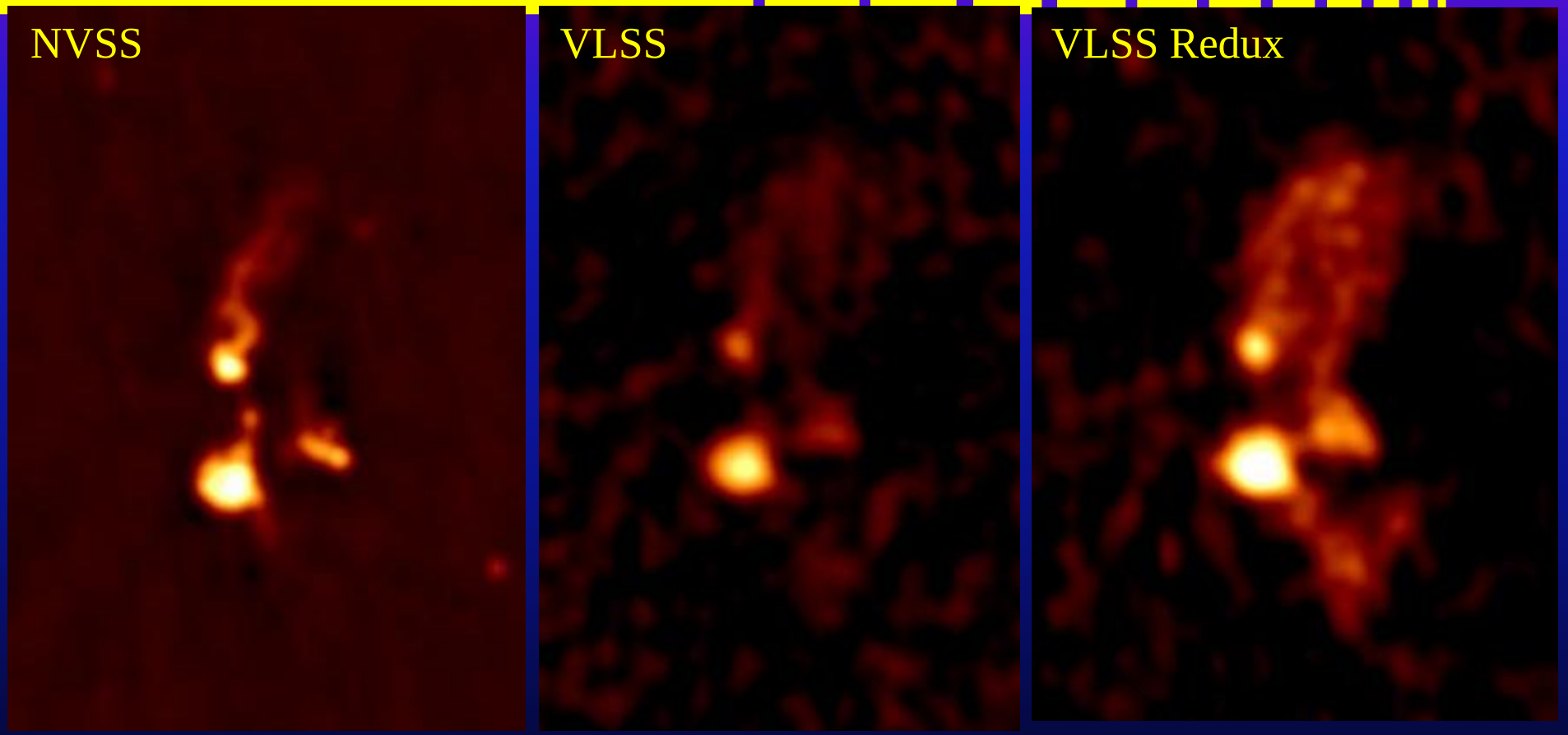


- Mapped most of the sky north of δ=-30°
- Initial full release catalog contains 70,000 sources
- All FITS images and the source catalog are available
- Data were also used to study ionospheric effects

Cohen et al., (2007)

VLSS Redux – Diffuse Emission

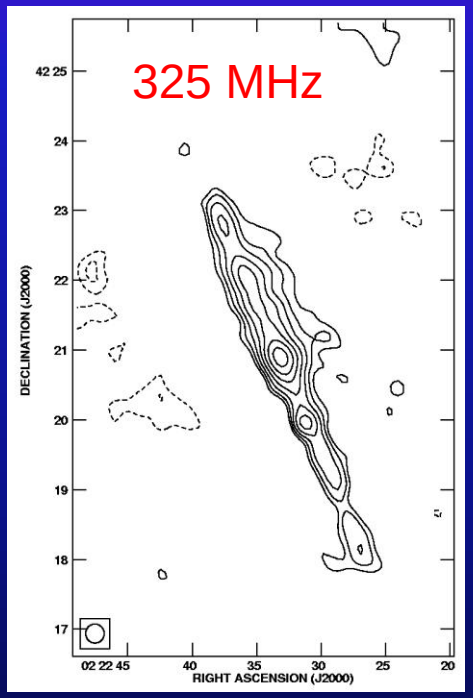
Abell 194 (Minkowski's object)

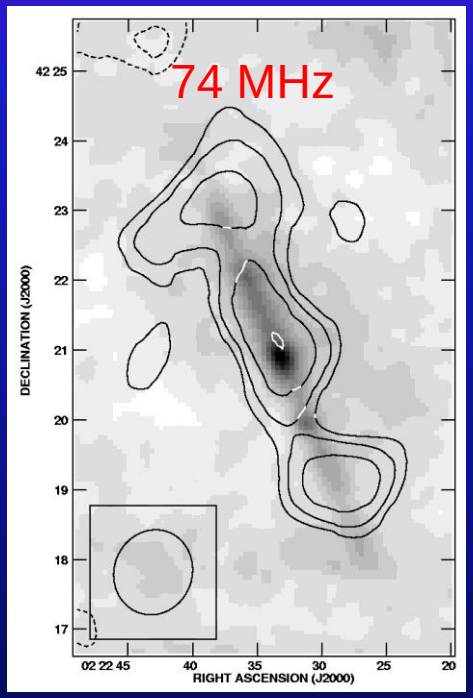


Fringe rotation base RFI correction recovers shortest interferometer spacings.

Spatially Resolved Absorption in Extragalactic Sources

NGC 891: POSS II image



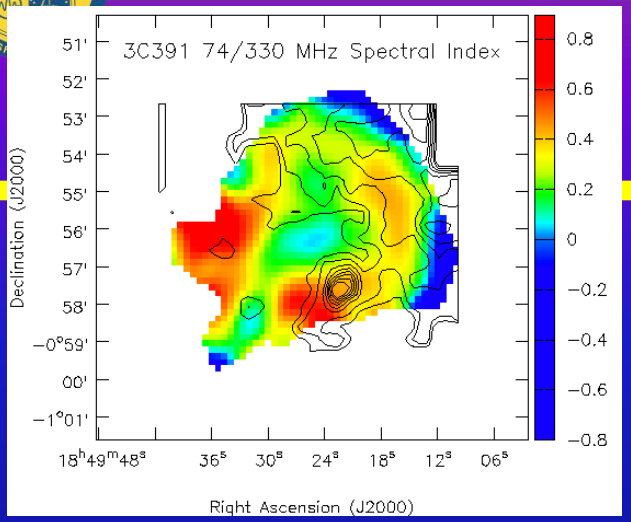


Cohen, Israel & Kassim, 2004

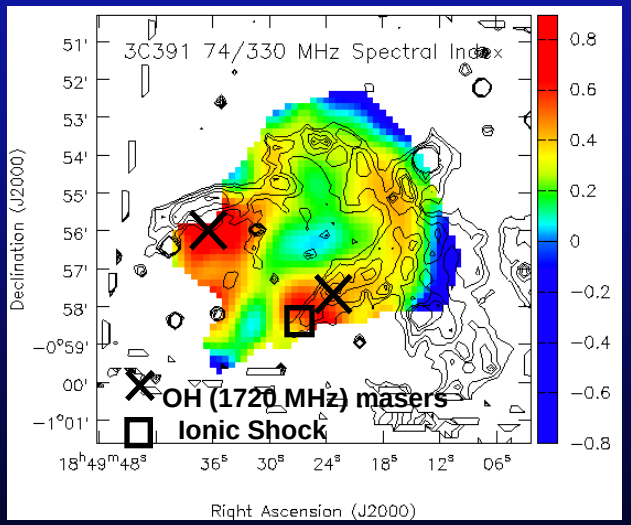
Resolved Spectral Turnover in NGC 891

- The spectrum is flatter in the central disk regions.
- More observations necessary to confirm.

SNR/ISM Interactions



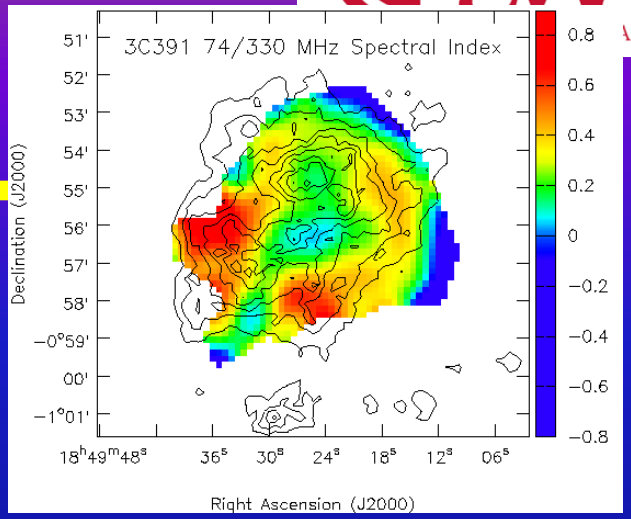
CO (2-1) integrated emission from **91 to 110 km/s** (*Reach & Rho 1999*).



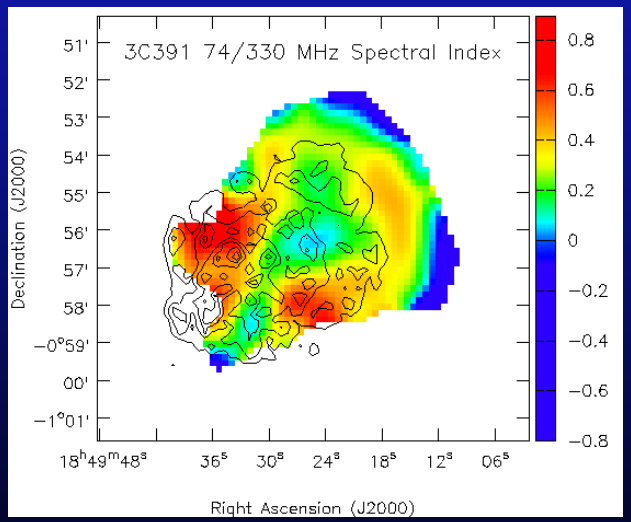
IR emission from 12-18 μm tracing shock boundaries (*Reach et al. 2002*).

Surprising agreement between regions of greatest 74 MHz absorption – delineates sheath of absorbing ionized gas residing in the SNR/ molecular cloud shock boundary!

Brogan et al. 2002

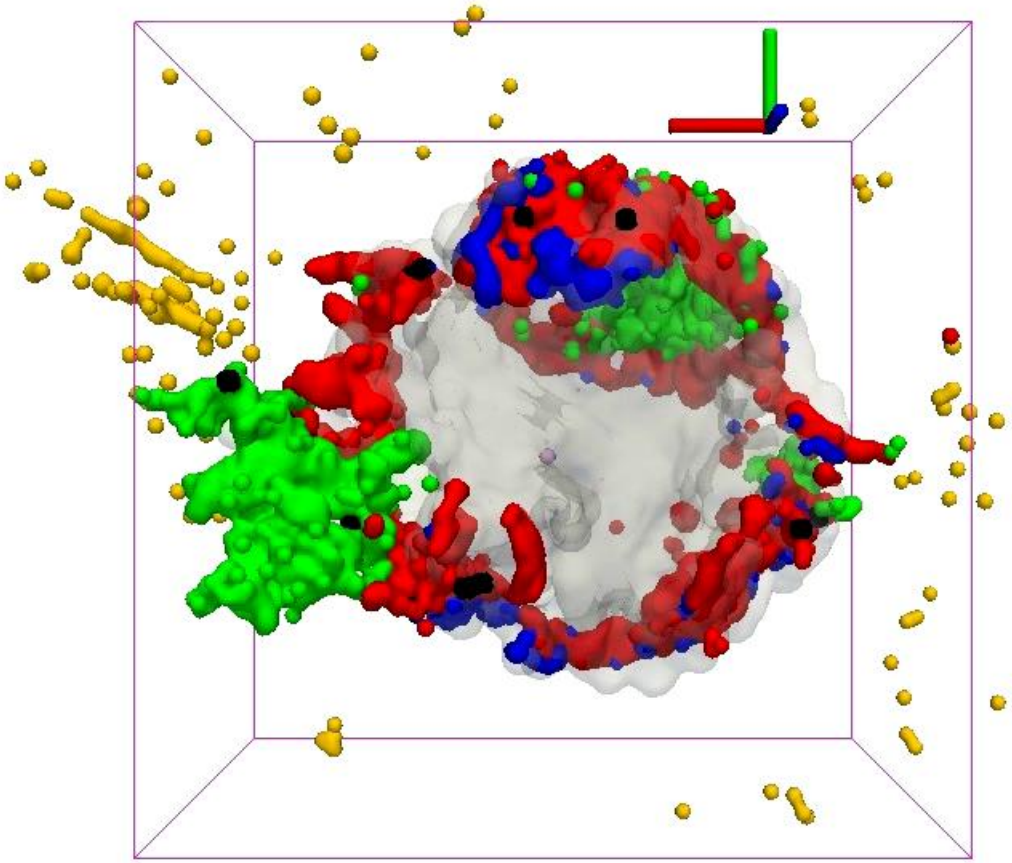


HARD X-rays from ASCA showing full extent of SNR (*Chen & Slane 2001*)



SOFT X-rays from ASCA showing X-ray absorption (*Chen & Slane 2001*)

VLA Pie Town Extension Science



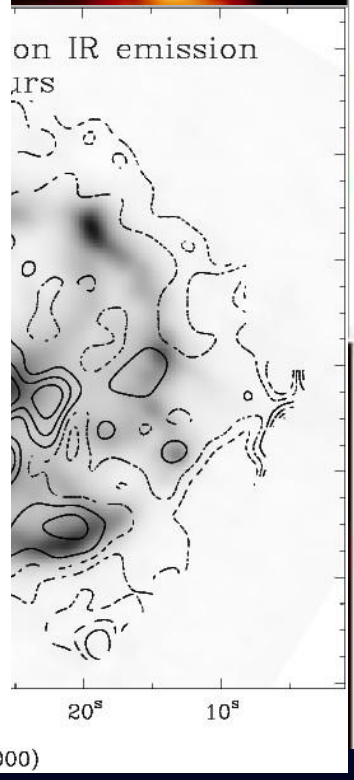
Cas A

VLA

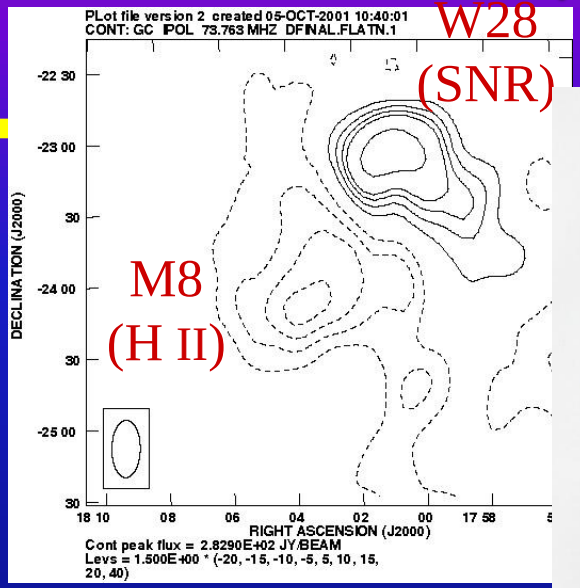
Thermal

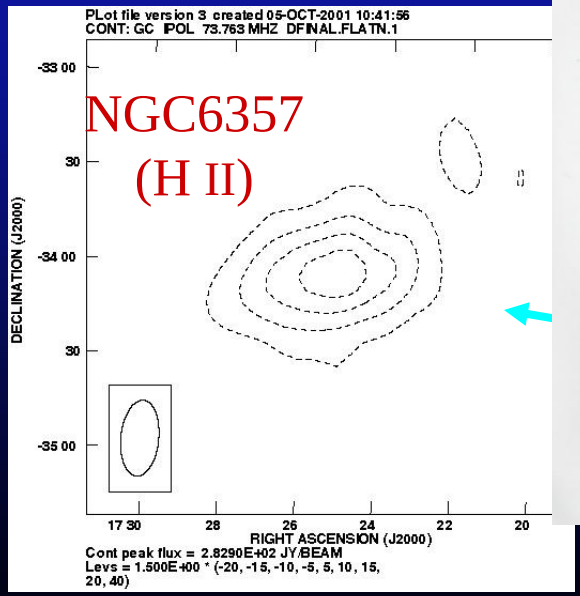
VLA

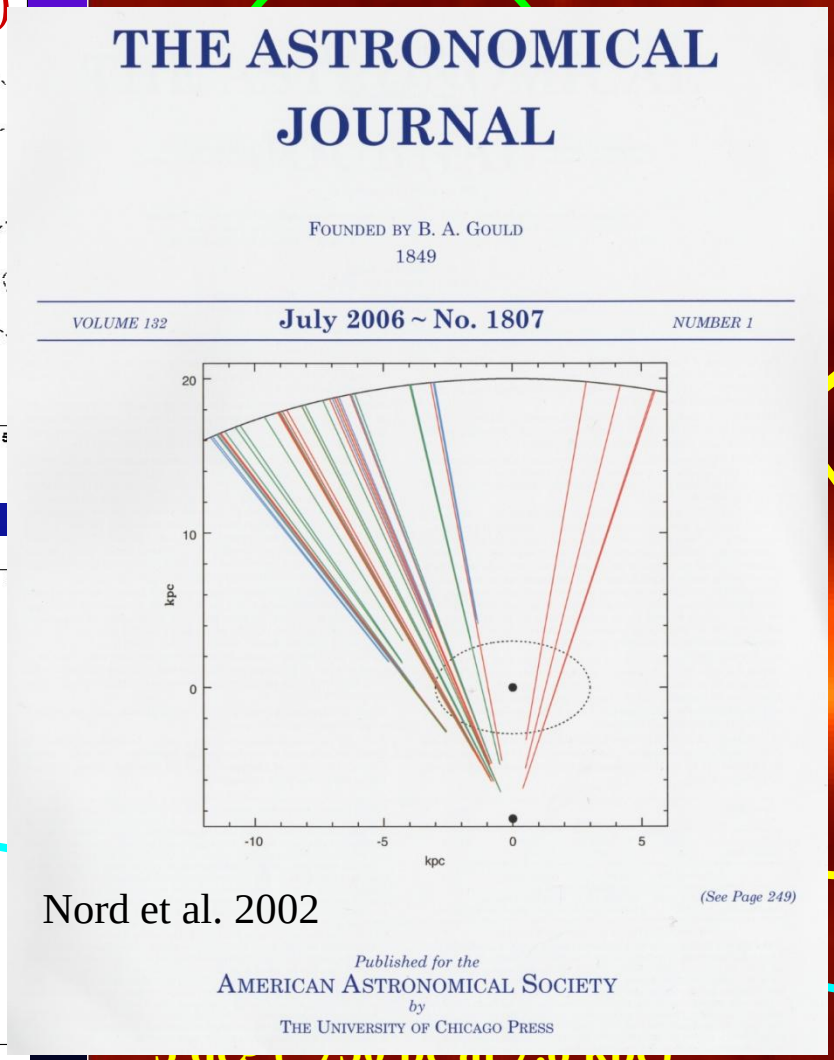
Neutron St

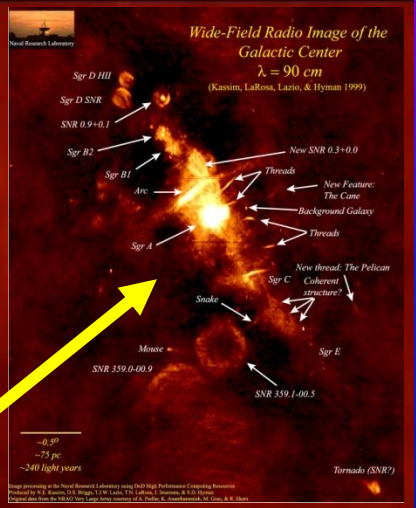


Discrete HII Region Absorption in the Galactic Center

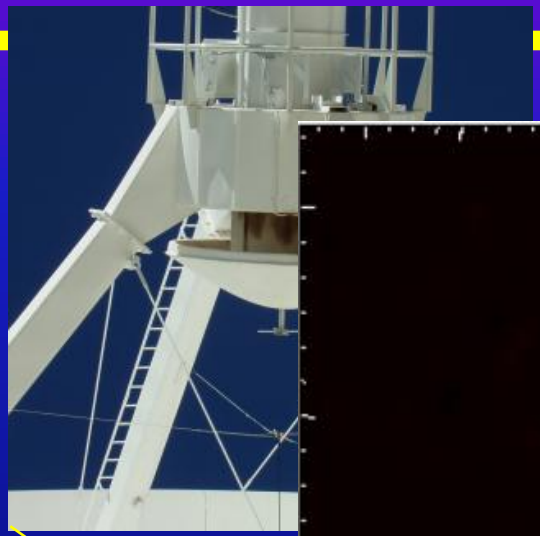




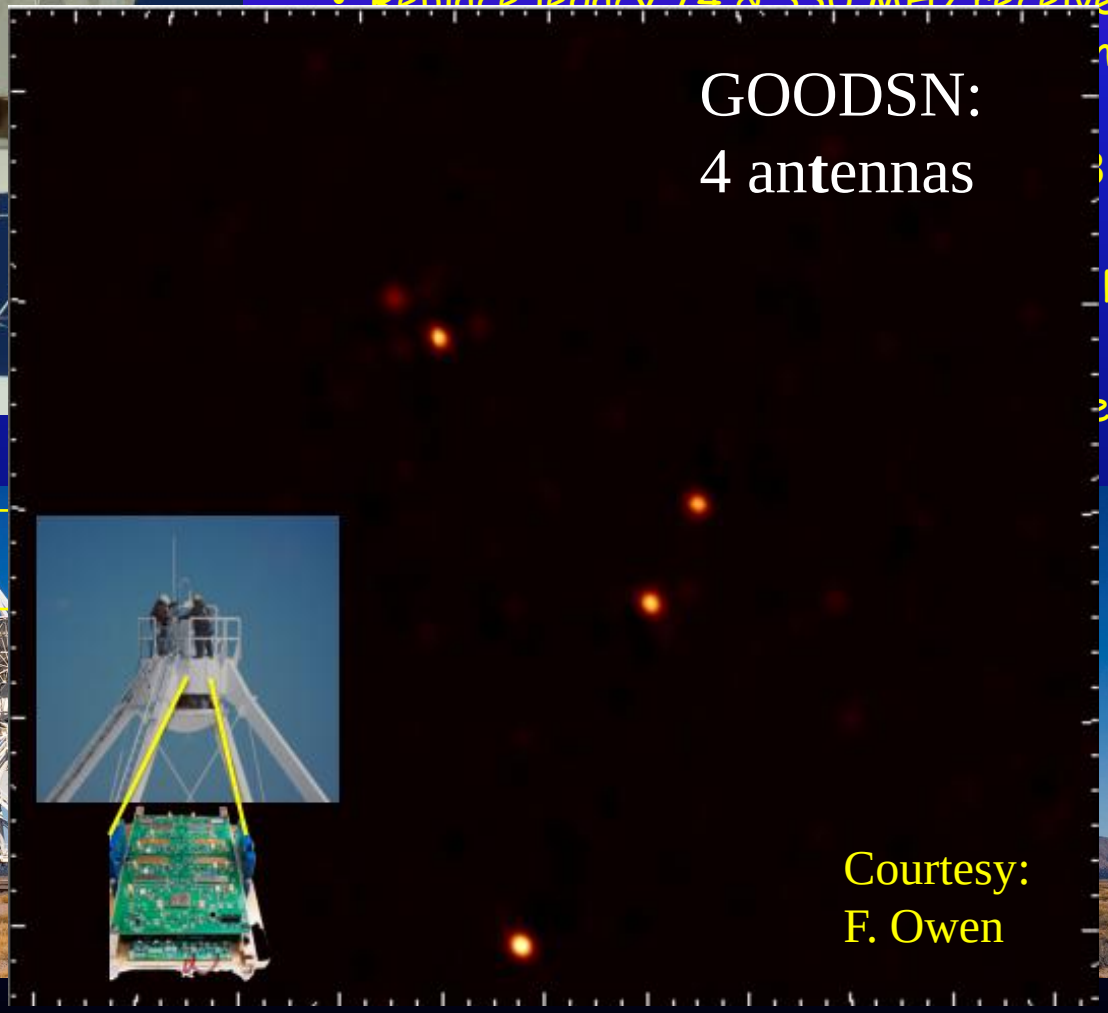




74 MHz System Upgrade: VLA "Low Band"



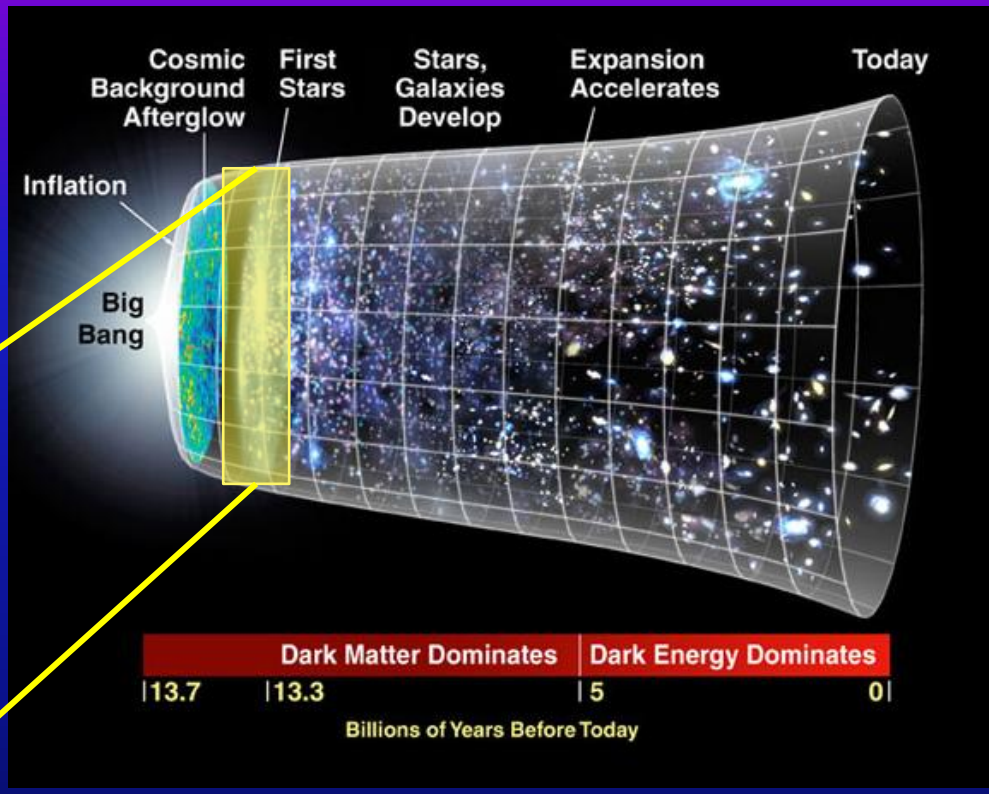
- Replace legacy 74 & 330 MHz receivers with
  ng ~56-470
  330 MHz
  bandwidth,
  ent to all 27



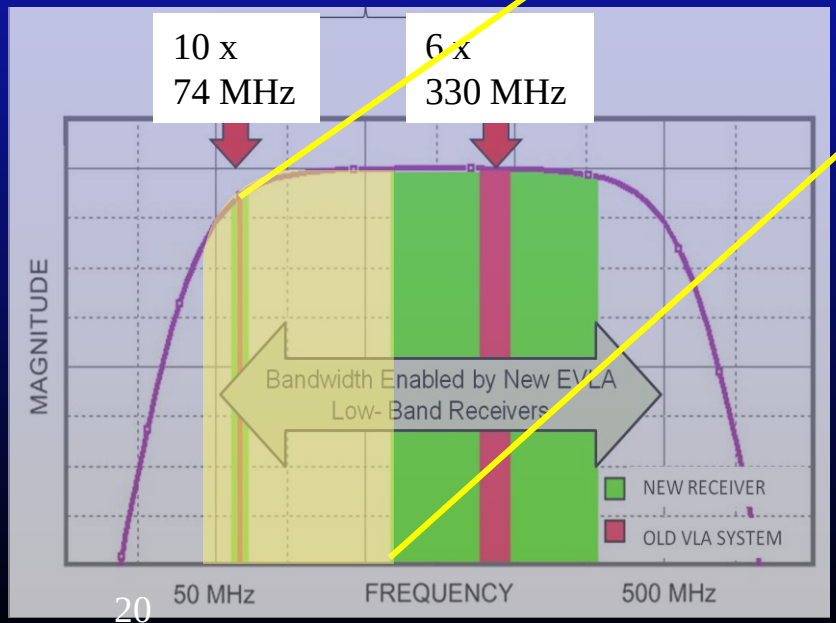
EVLA Low Band Upgrade: Looking Forward

- New EVLA range will include Dark Ages ($z > 10$) & Epoch of Reionization ($z \sim 6$) frequencies, but will require new broadband feeds
- **EVLA LB & other ground instruments: characterize foreground, help optimize approach for space**
- Classic astrophysics is accessible across the entire *low band* range

Hicks et al. (2006)



HI window



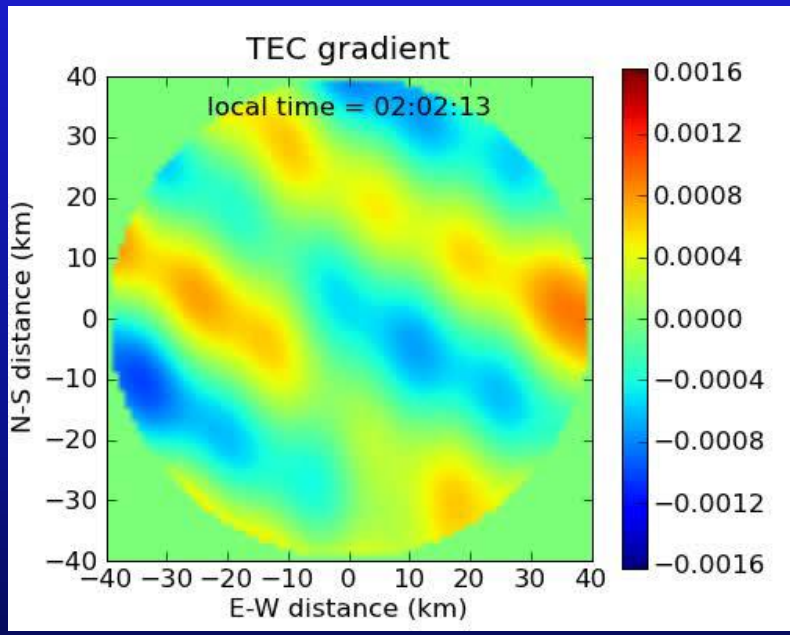
Low band science includes:

- Non-thermal phemonema
- Acceleration, propagation & turbulence
- Intrinsic & extrinsic thermal absorption
- Transients
- Extrasolar planet searches

Frontier LB Science: New Constraints on Ionospheric Dynamics

- Movie: ΔTEC (waves) gradient disturbances reconstructed from 74 MHz VLA data
- Highlights utility of the wide 74 MHz FoV (80 km at F region)
- Improved understanding of how ionospheric disturbances are generated
- Path towards empirical "nowcast" of when & where disturbances will occur
- Optimize performance of high-precision GPS applications – implications for forecasting and correction schemes
- Test ionospheric models to simulate coupled dynamics from scales of a few to hundreds of kilometers

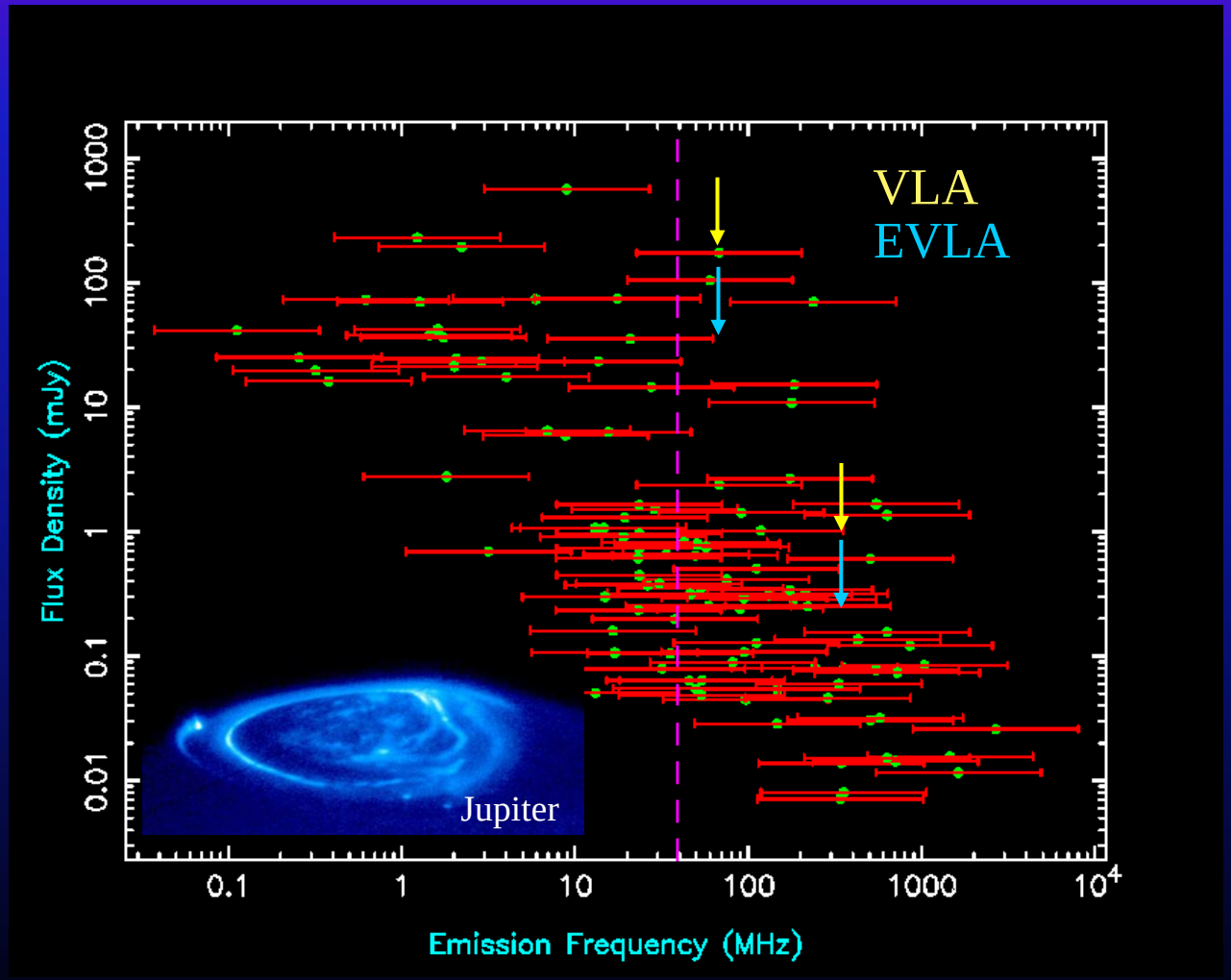
EXAMPLE RECONSTRUCTION OF TEC GRADIENT EVOLUTION FROM 74 MHZ VLA DATA



EVEN IF GPS DATA IS ADDED, SPATIAL SAMPLING OF STRUCTURES IS INCOMPLETE – NEED ACCURATE SIMULATIONS TO FILL IN "GAPS"

Helmboldt & Intema 2012

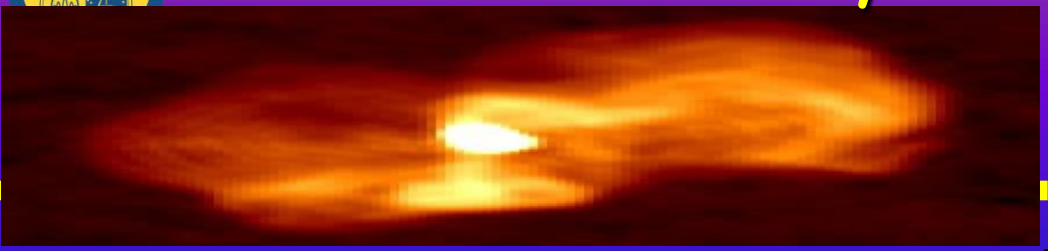
Frontier *Low Band* Science: Continuous Transient Monitoring with a Commensal system



- It's all about maximizing Ω * t
- Primary focus *on sky all the time*
- Large FoV sweeping sky continuously
- Maybe we'll find what we're not looking for!
  - 1 hour "fishing" at 330 MHz = 1 year at 10 GHz
- Together with free LF images of myriad interesting fields
- Follow continuously with LWA et al. beam

Lazio, Farrell et al. 2004

VLA LB Commensal System: with help from LWA et al.



LWA 80 MHz Primary Element Beam

VLA Cassegrain: L-U bands

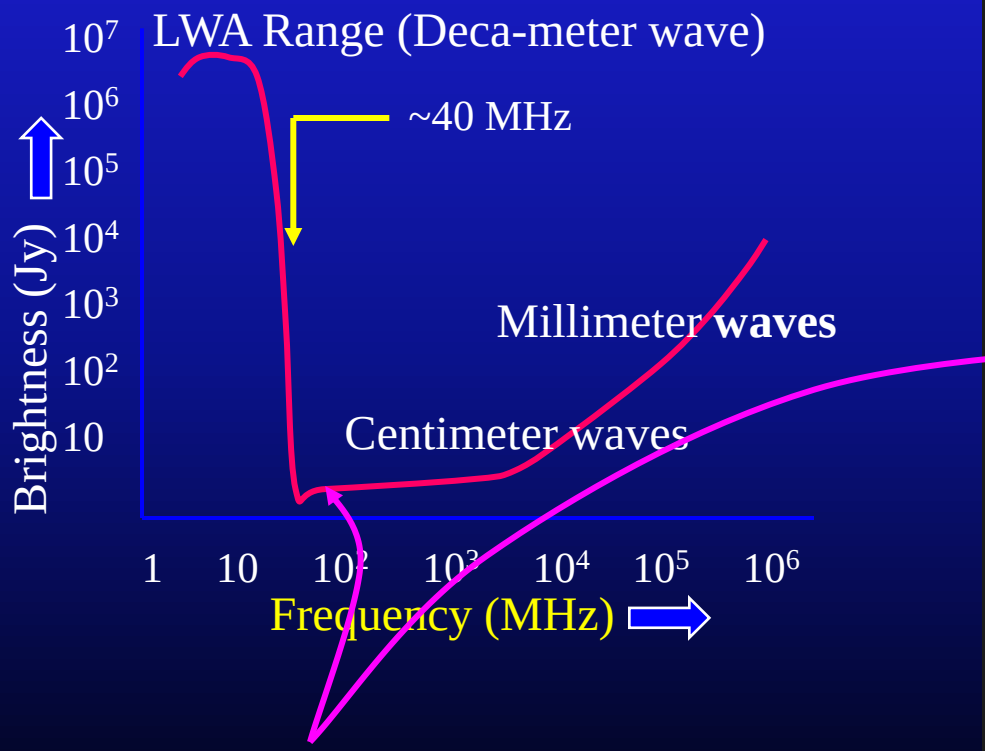
LWA 80 MHz Primary Station Beam

VLA 330 MHz Primary Beam

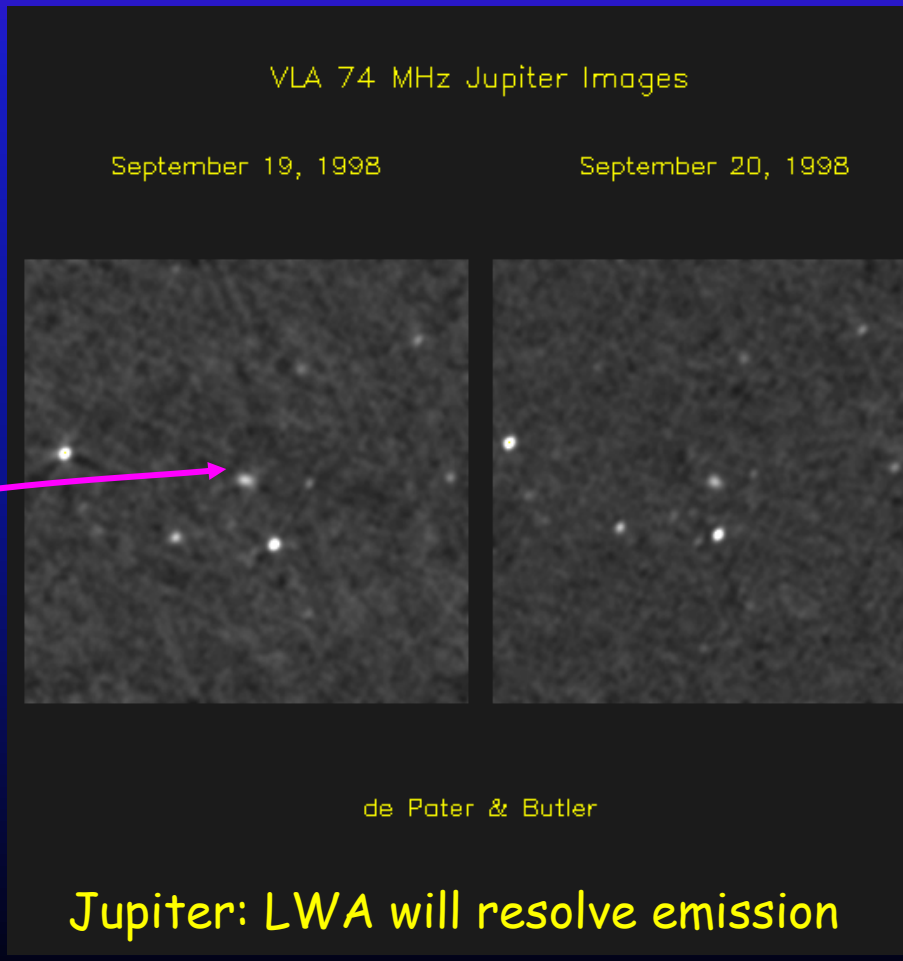
VLA 330 MHz Synthesized Beam

Jupiter

Coherent emission in LWA range



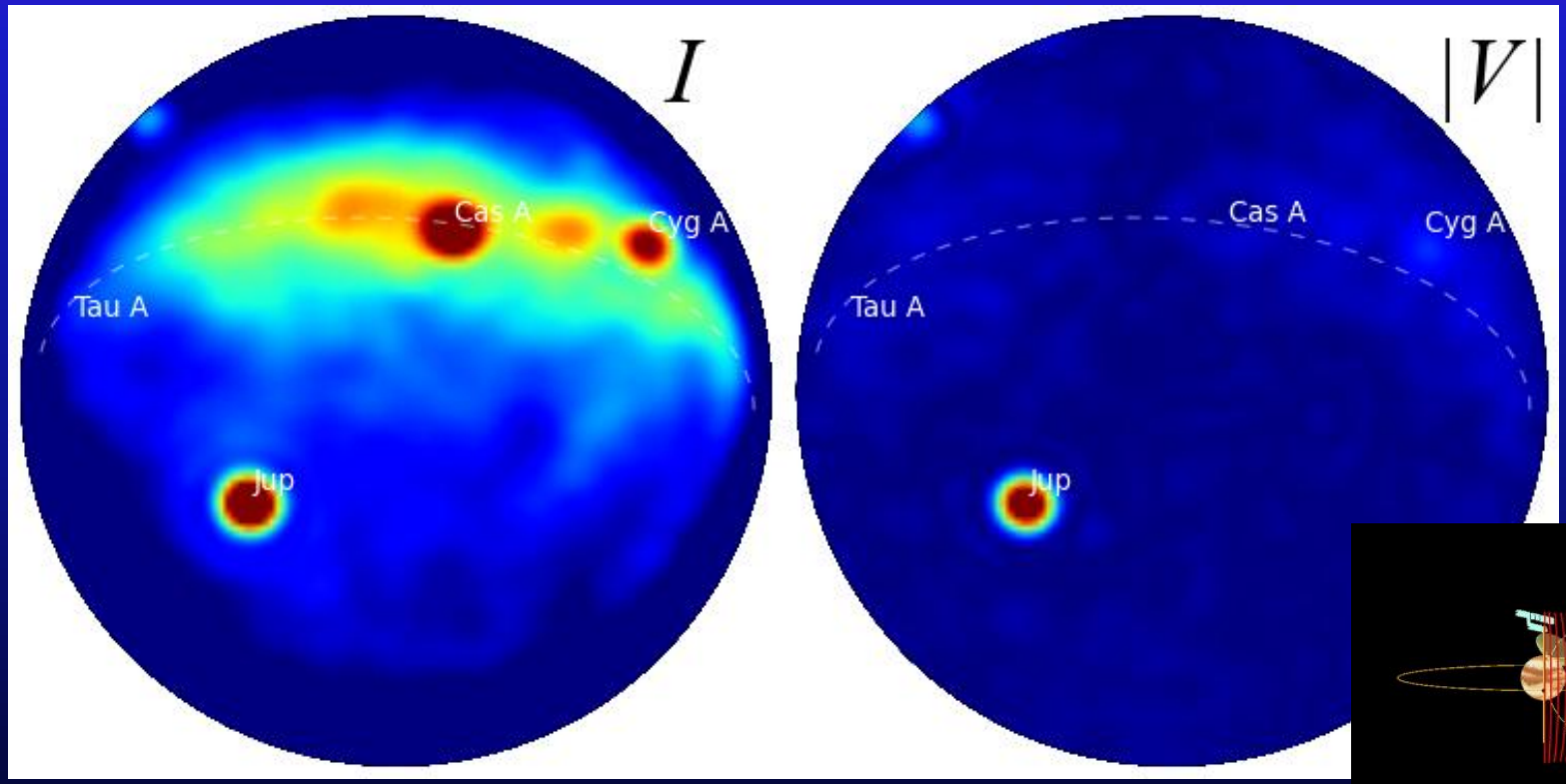
VLA SYSTEM
CAN DETECT QUIESCENT EMISSION

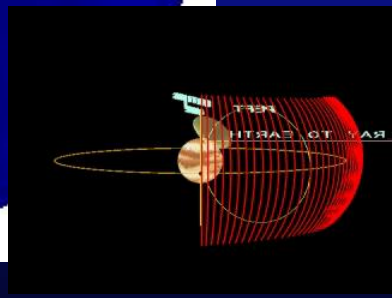


Jupiter: LWA will resolve emission

Jupiter & Extrasolar Planets (currently with LWA)

LWA1 all-sky imaging (courtesy J. Hartman, Taylor et al. 2012)





Jupiter MUCH closer than any Jovian extra-solar planet – but every journey starts with a single step!

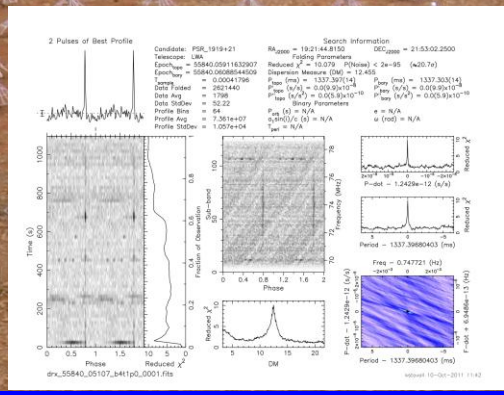
SUMMARY

- 1990s NRL-NRAO 74 MHz VLA opened poorly explored EM regions < 100 MHz
  - Catalyzed development of new LF instruments, incl. LOFAR, LWA, & MWA
- New NRL-NRAO EVLA "Low Band" system will greatly improve performance & open new regions of spectrum ***– 1st CFP early 2013***
  - Pushing ground based limits will strengthen case for space missions
  - E.g. characterize high-z foregrounds, learn technical lessons for space
- In looking back, what factors limited the full exploitation of the "legacy" 74 MHz system
  - Data reduction difficult – need pipelines
  - Lack of deployable dipoles limited observing time
  - Software underdeveloped
- Challenges of legacy system need to be tackled with new system

New system offers promise of continued new discoveries & pushing ground-based exploration to its limits

The LWA1 Radio Observatory*

Director: UNM, Assoc. Director: VT, Chief Scientist: NRL



10-88 MHz usable Galactic noise-dominated (>4:1) 24-87 MHz

4 independent beams x 2 pol. X 2 tunings each ~16 MHz bandwidth

SEFD ~ 3 kJy (zenith) S_{min} ~ 5 Jy (5σ, 1 s, 16 MHz, zenith)

All sky (all dipoles) modes: TBN (67 kHz-bandwidth; continuous)

TBW (78 MHz-bandwidth, 61 ms burst)

One “outrigger” antenna ~300 m to the East

LWA1 science: transients, pulsars, Sun, Jupiter & Ionosphere

Open skies

Support for operations and continuing development of the LWA1 Radio Observatory is supported by the National Science Foundation.