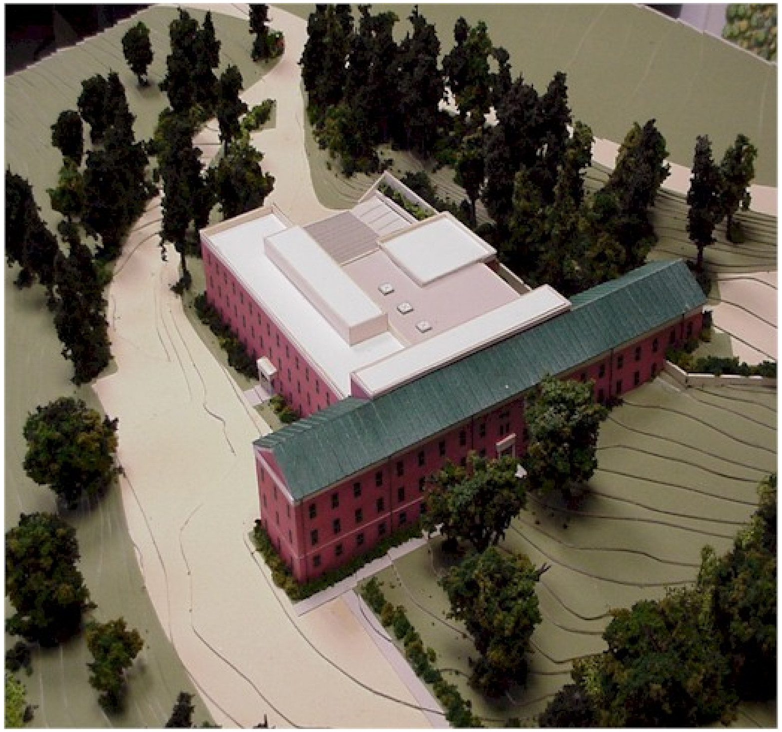
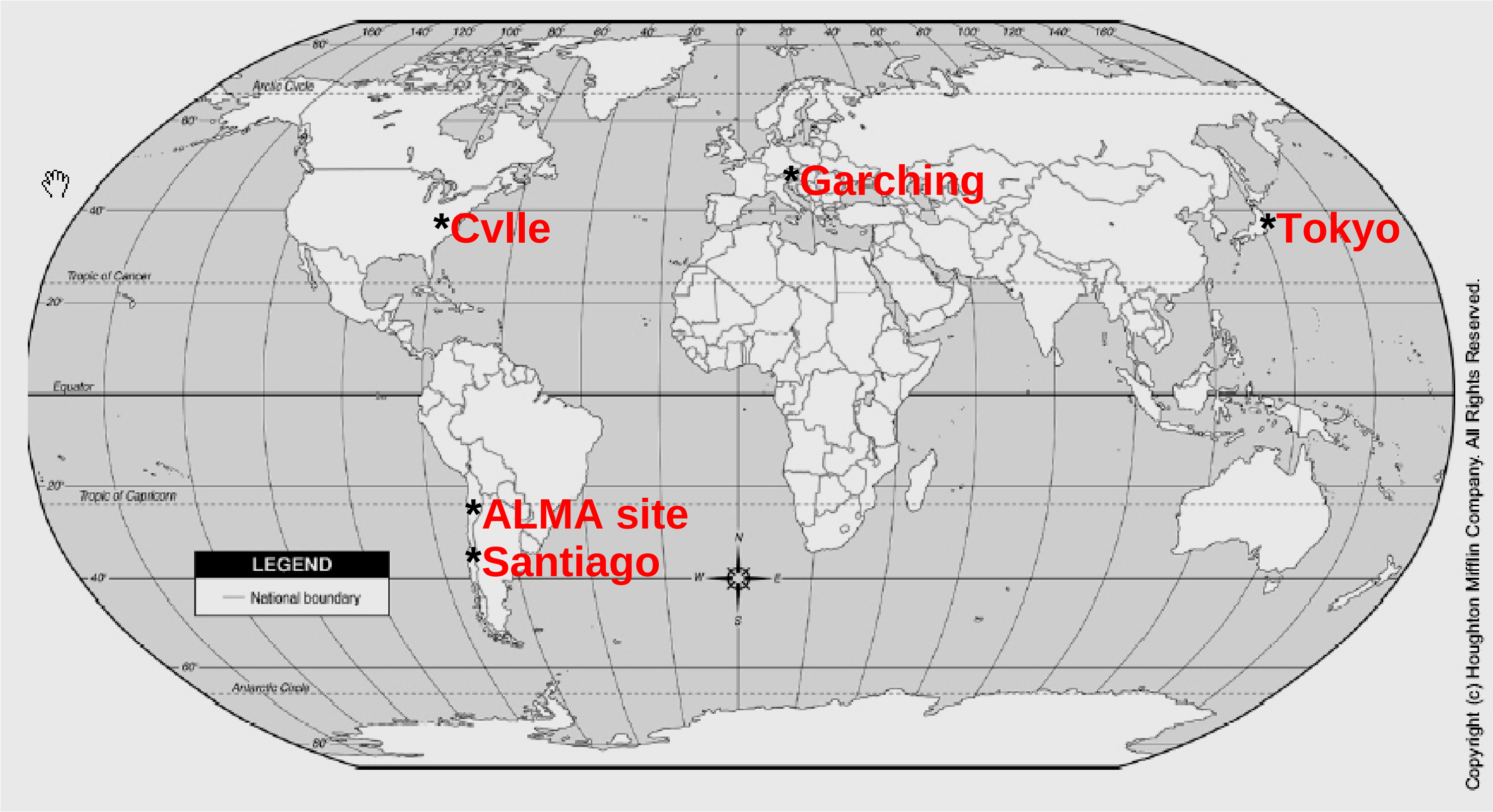
The North American ALMA Science Center



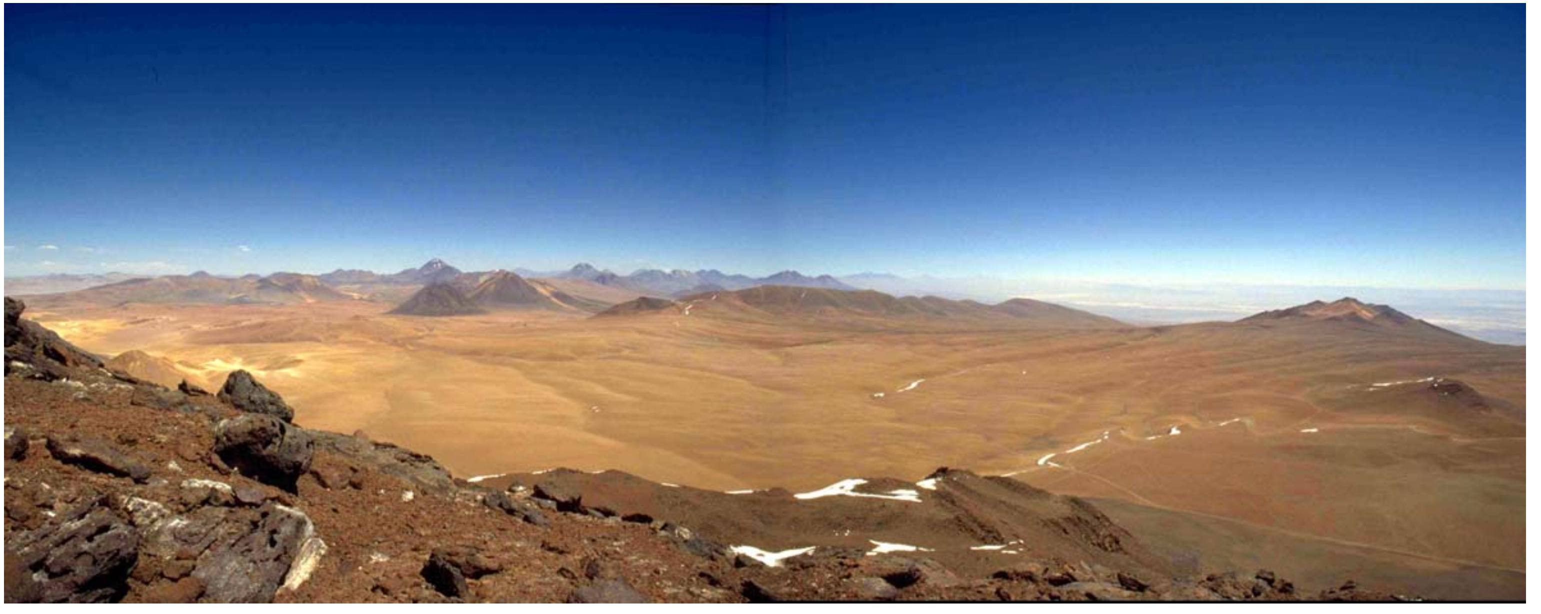
The NAASC will be housed in an addition to the NRAO Edgemont Road building in Charlottesville.

ALMA is a world array



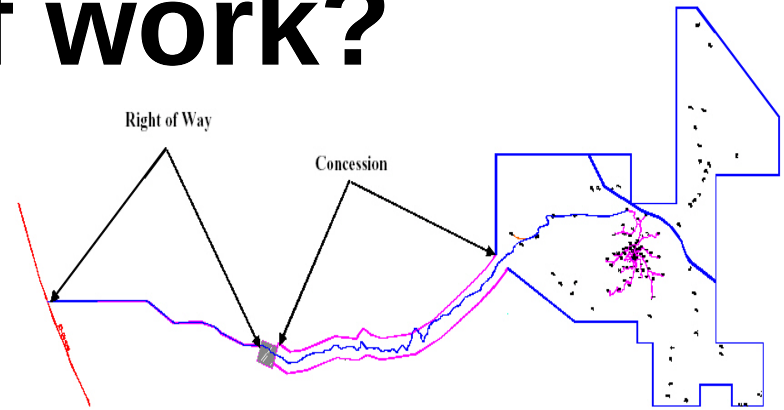
ALMA is being built *where*?

The array is on a 16,500 ft elevation site, called the Array Operations Site (AOS).

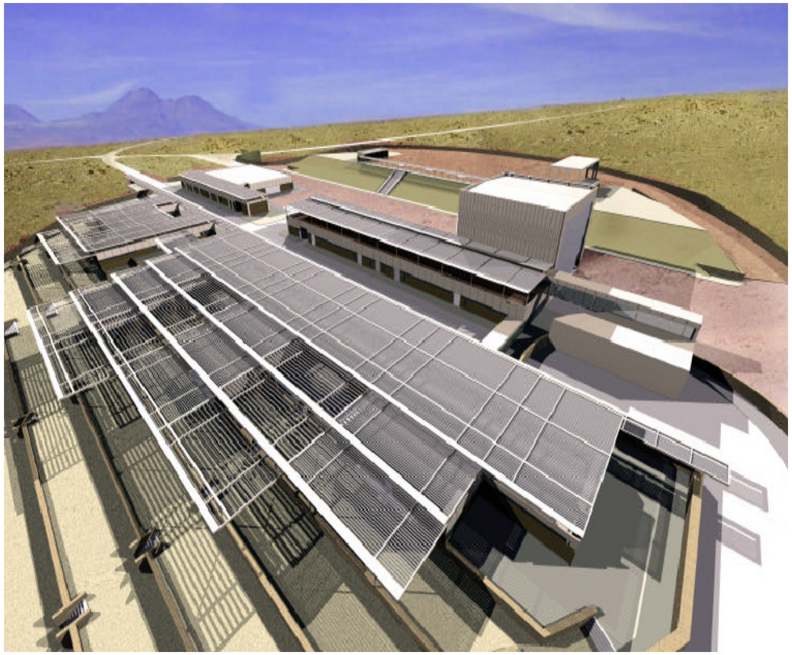


Where in Chile is the ALMA Site?

Where does the ALMA operations staff work?



Most staff are to work at the operations support facility (“OSF”) at an elevation of ~9000 ft, on a new road connecting the high site with the San Pedro/Tocanao highway.



The OSF has lodging and dining for ~ 100 people.

The OSF is about a 45 minute drive from metropolitan San Pedro.

Joint ALMA Observatory

The Joint ALMA Observatory (JAO) headquarters will be in Santiago, at a suitably neutral location.

The JAO headquarters is currently in rented space in a new office tower in central Los Condes.

Staff will live in Santiago and work at the OSF on the “turno system”.

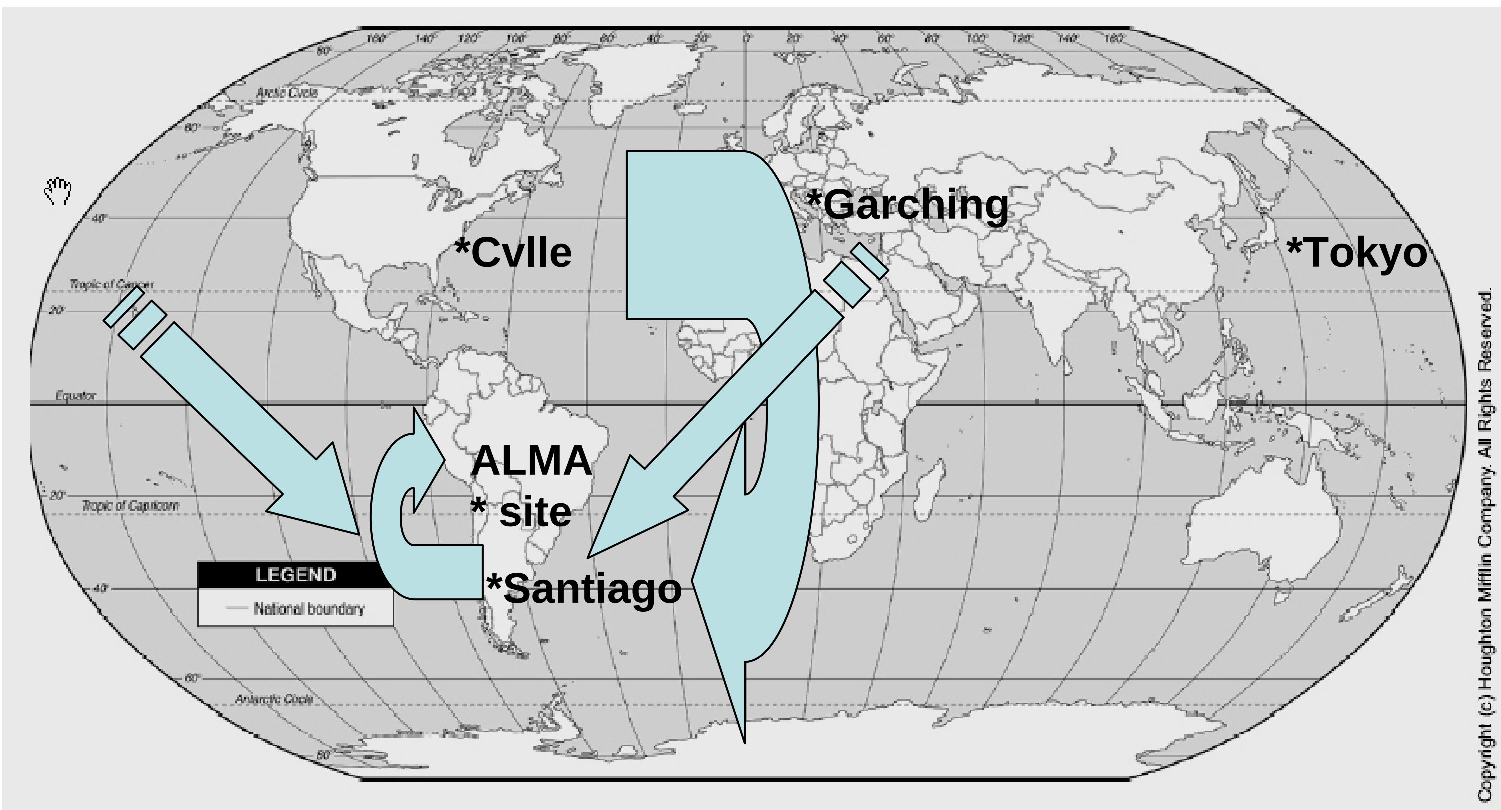
ALMA Regional Centers

The JAO will have user interfaces known as "ARCs" in each of the three partner regions: North America, Europe, & Japan.

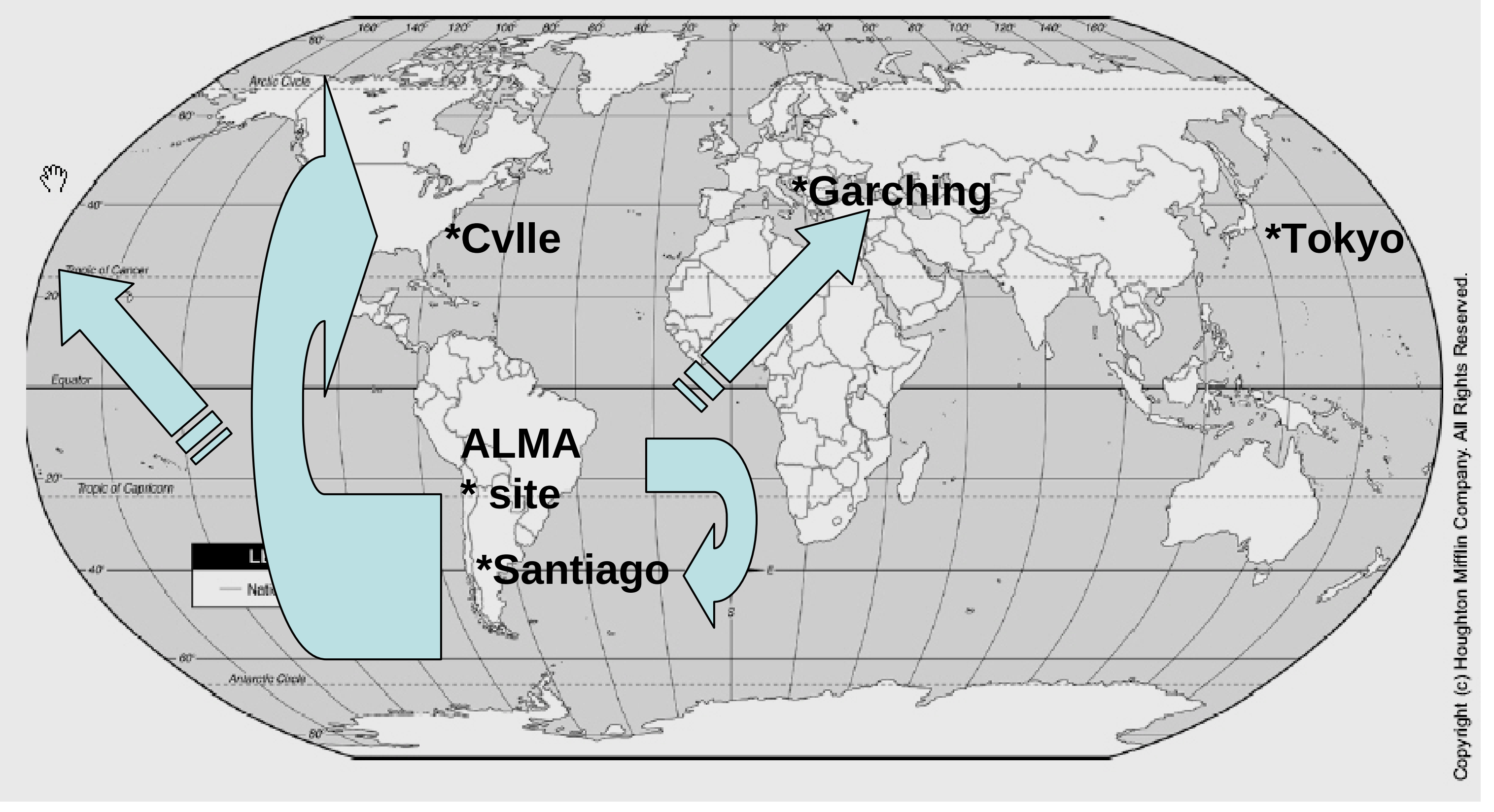
The ARCs will conduct activities needed to receive and process proposals from observers and return data to users, all archive based and organized.

The ARC archives are mirror archives of the central archive in Santiago; they all contain the same data, all the data.

Proposals/Observing Files are sent from ARCs to JAO



Recorded data is sent to the JAO and on to the ARCs



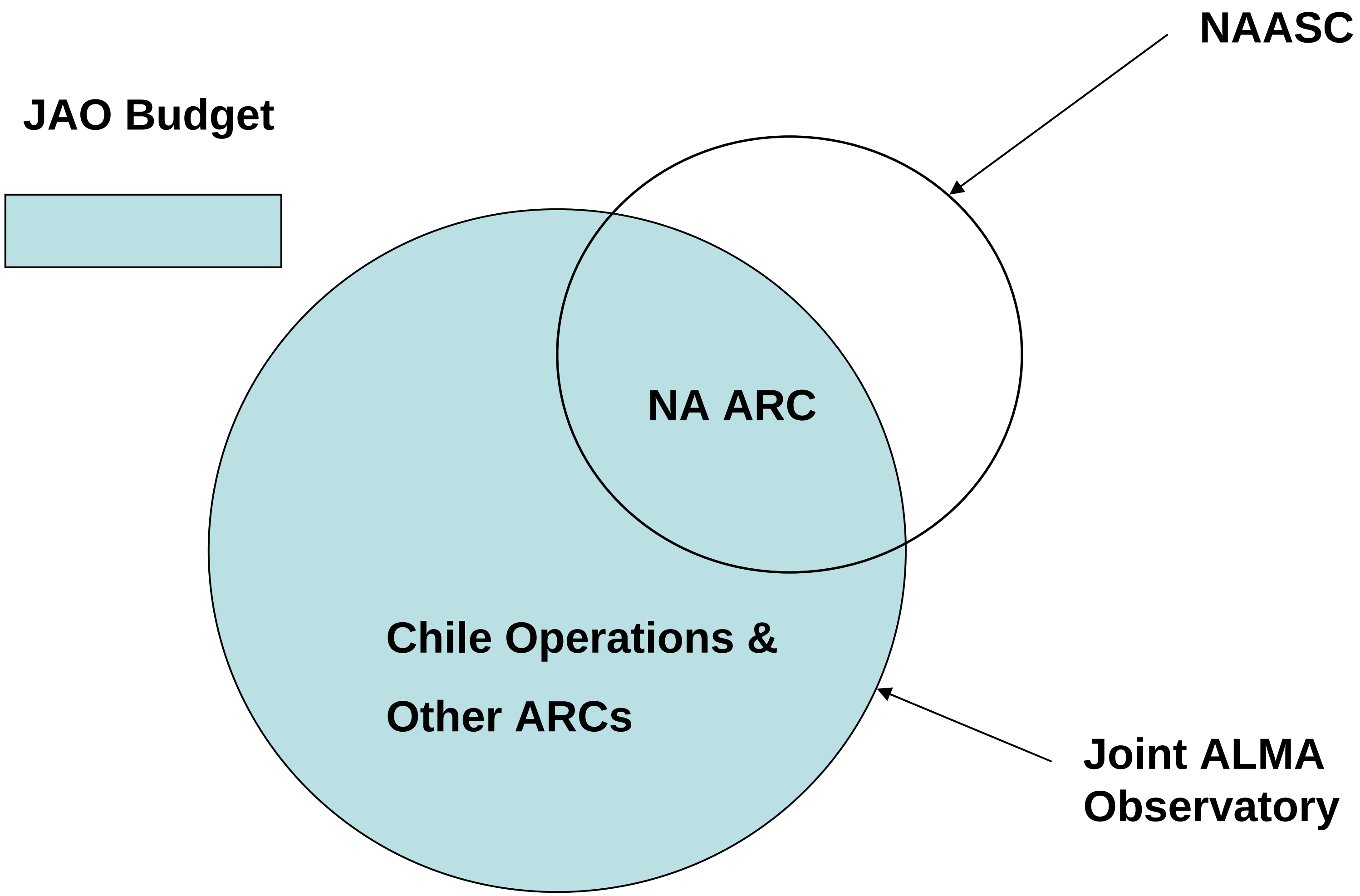
Data Flow is LARGE

During full operation, the data flow into the archive is estimated to be ~ 100 Tbytes per year. (*Total* flow to date into the HST archive is $\lesssim$ 20 Tbytes).

A small dataset might be ~ 50 Gbytes; a large dataset might be ~ 1 Tbyte.

Dataset includes proposal, u-v data, a reference image with pipeline processing history, calibration data, . . .

Beyond the ARCs



NA ARC

- NAASC Head & Admin. Asst.;
- (6) Astronomers – proposal functions;
- (8) Astronomers – archive functions;
- (10) Engineer/tech – hardware repair;
- (10) Programmers – software maint.;
- $5,000,000 per year – development;
- M&S, travel, capital; overhead.

NAASC Beyond the NA ARC

- Data analysis grants program;
- (12) ALMA Fellows;
- Pre-doctoral & co-op students;
- (+4) Astronomers – archive functions;
- EPO program;
- (3) Systems Admin.;
- Business & library services;
- Office of Chile Affairs.

European ARC ++

Carefully defined core functions will be done at ESO – Garching.

Much, especially "hand-holding", will be outsourced by ESO to national facilities, for example, Jodrell Bank, Dwingeloo, IRAM, Onsala, . . . , *to be paid for by national budgets*.

Japanese ARC

The Japanese ARC will almost certainly be part of the National Astronomical Observatory of Japan and located on the NAOJ grounds in Mitaka, a suburb of Tokyo.

Canada

- **Obligated to contribute 7% of the North American share of the JAO budget;**
- **This includes 7% of the NA ARC, but no contribution to NAASC beyond the ARC;**
- **Could choose to contribute, in part, with personnel, to Chile and to the NA ARC.**
- **Could reasonably expect to get 7% of the Development work.**

Key NAASC Science Tasks For First Science (2007)

- **Inform community of science capabilities, observing modes, available resources, via meetings, workshops, webpages; solicit feedback *pre 2006***
- **Proposal preparation/user support (proposal call mid-2006) *pre 2006***
- **Proposal review/scheduling *starting 2006***
- **Testing data reduction scripts/cookbooks *pre 2007***
- **Develop calibrator & spectral line databases *pre 2007***
- **Post-observation user support: help users with offline data reduction; re-reduce data; submit bugs *starting 2007***
- **Help software developers develop/test advanced data processing procedures/tools. *starting 2007***


I WANT YOU
for the N.A.A.S.C.
ENLIST NOW

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Long Wavelength Array - LWA

NRAO New Initiatives Workshop

Socorro, NM

December 13, 2004

South West Consortium - SWC

Namir Kassim, NRL

Tom Gaussiran, UT Austin

Frank Gilfeather, UNM

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LWA Science

Namir Kassim

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(http://lwa.nrl.navy.mil/)

History of Long Wavelength Astronomy

- *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***

Clark Lake:

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

The last and most sophisticated LW instrument – closed down nearly a decade ago – WHY?

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Why Has LW Astronomy Languished?

- 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 – ***sensitivity 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.

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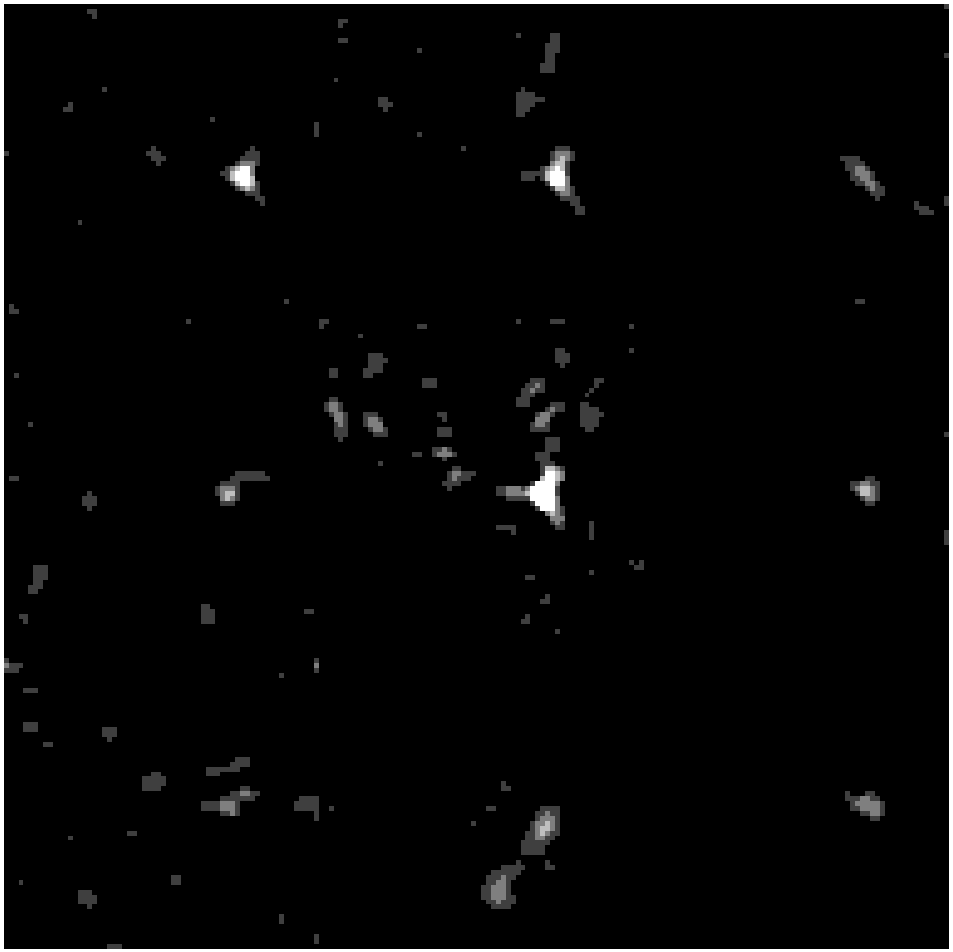
Ionospheric Phase Effects (among other challenges)



- Limited baselines 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

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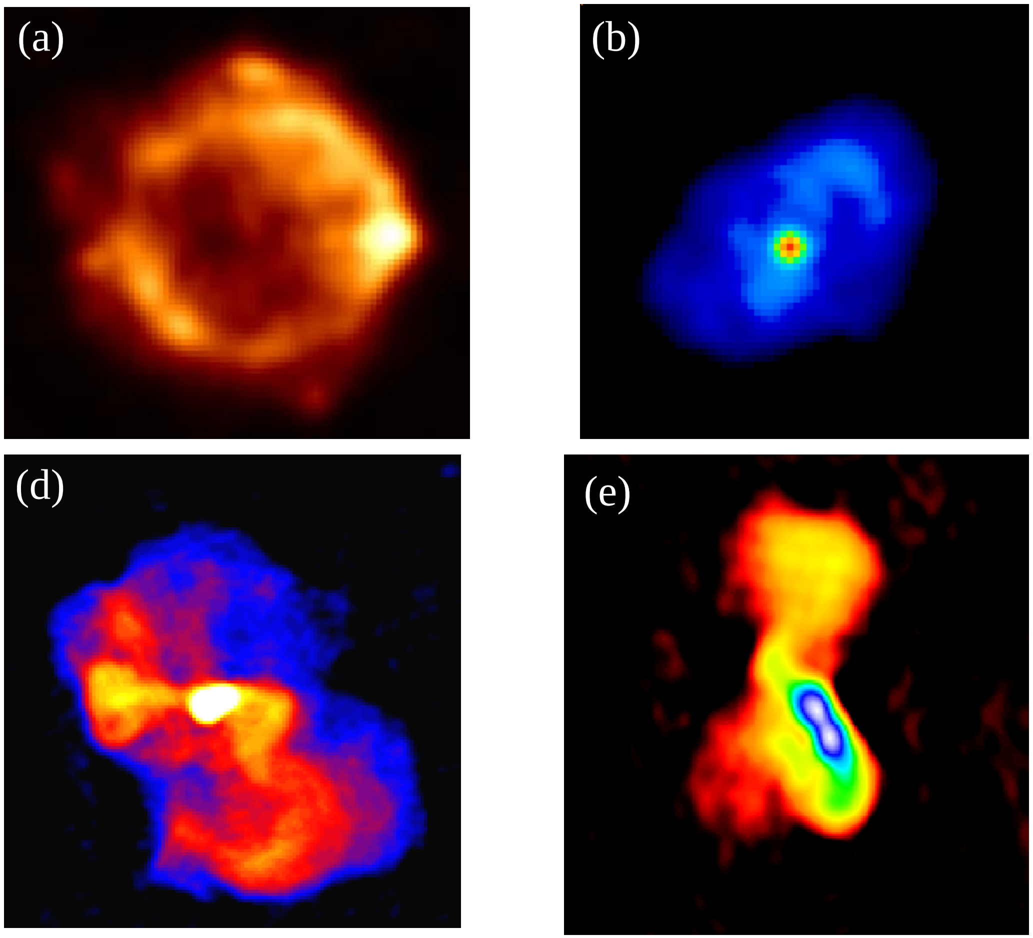
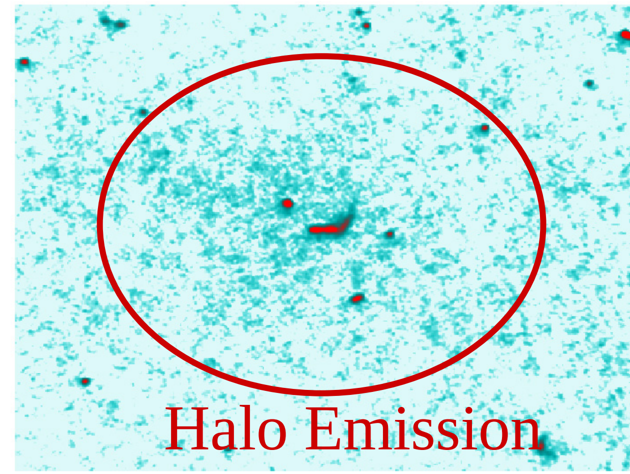
Technological Breakthrough: Breaking the ionospheric barrier with the 74 MHz VLA



(c)



(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)

74 MHz VLA validating LWA science case and building new user community.

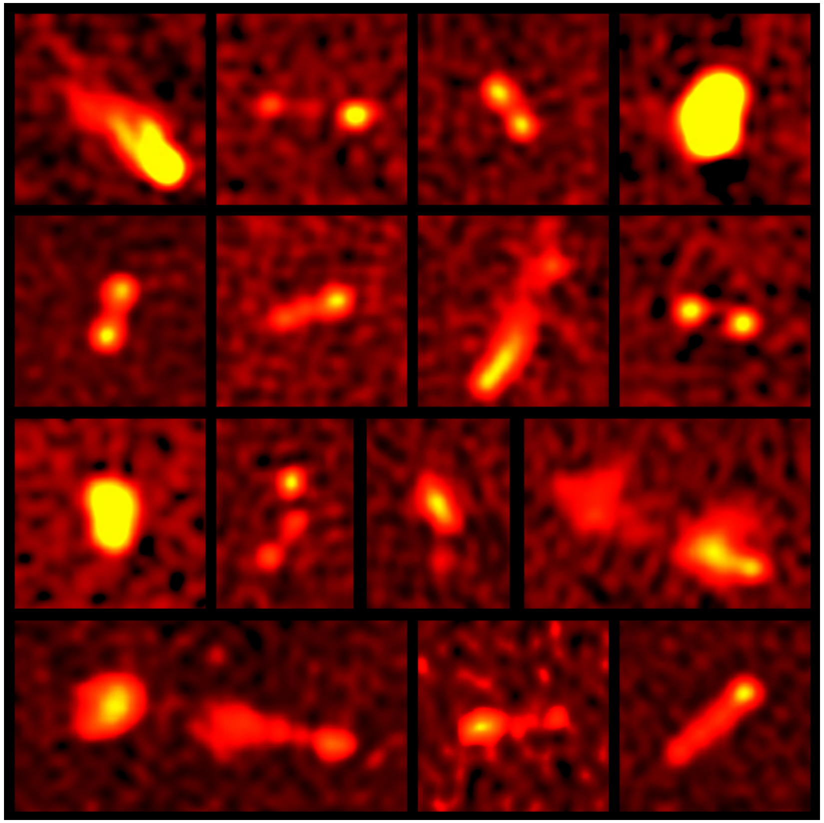
LWA Key Science Drivers
(< 90 MHz)

- ***Cosmic Evolution from the Dark Ages to the Present***
  - The High Redshift Universe
    - The first supermassive black holes, HI absorption during the EOR.
  - The Evolution of Large Scale Structure – Dark Matter & Energy.
    - Clusters – radio emission as a discriminator between merging and relaxed systems.
- ***Acceleration***
  - In SNRs in normal galaxies at energies up to 10^{15} ev.
    - The distribution, spectrum, and origin of Galactic cosmic rays
  - In radio galaxies & clusters at energies up to 10^{18} ev.
    - Self-absorption processes, low-γ electrons, IC magnetic fields, merger shocks
  - In ultra high energy cosmic rays at energies up to 10^{21} ev and beyond.
    - Via CR air-showers – ultimate source unknown.
- ***Turbulence in plasmas from the Earth's Ionosphere to the ISM of Galaxies.***
  - Plasma Astrophysics
    - Propagation, scattering, & absorption in the ISM of the MW & normal galaxies.
  - Ionospheric turbulence, solar & planetary science
    - Ionospheric waves, space weather, Jupiter, Solar bursts.

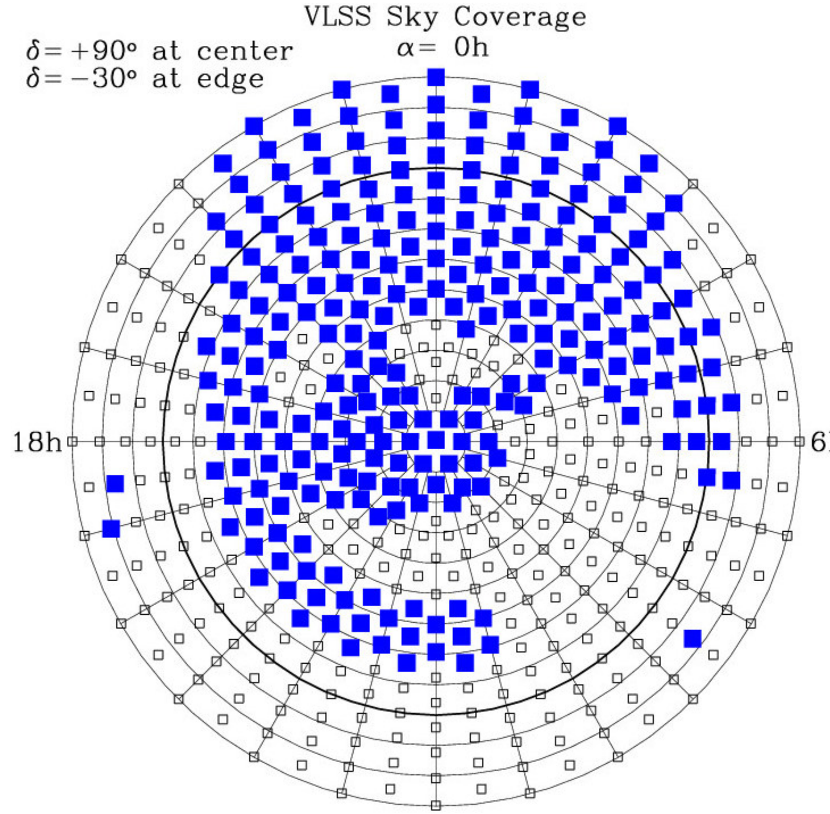
LWA science plan & instrument concept recommended in Astronomy Decadal Survey report

Exploring the High Redshift Universe

Source Samples



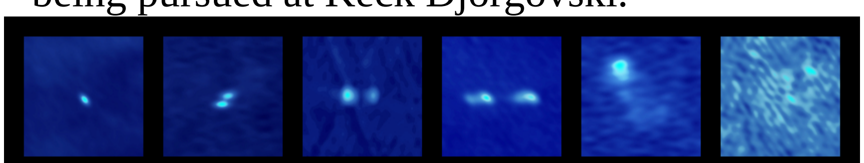
Current Sky Coverage



VLA Low-Frequency Sky Survey

http://lwa.nrl.navy.mil/VLSS

20 cm follow-ups of VLSS HZRG candidates - being pursued at Keck Djorgovski.



"USS" VLSS Sources: What are they?

- High Redshift Radio Galaxies?
- Fossil Radio Galaxies & Cluster Halos
- Pulsars?
- Something else??

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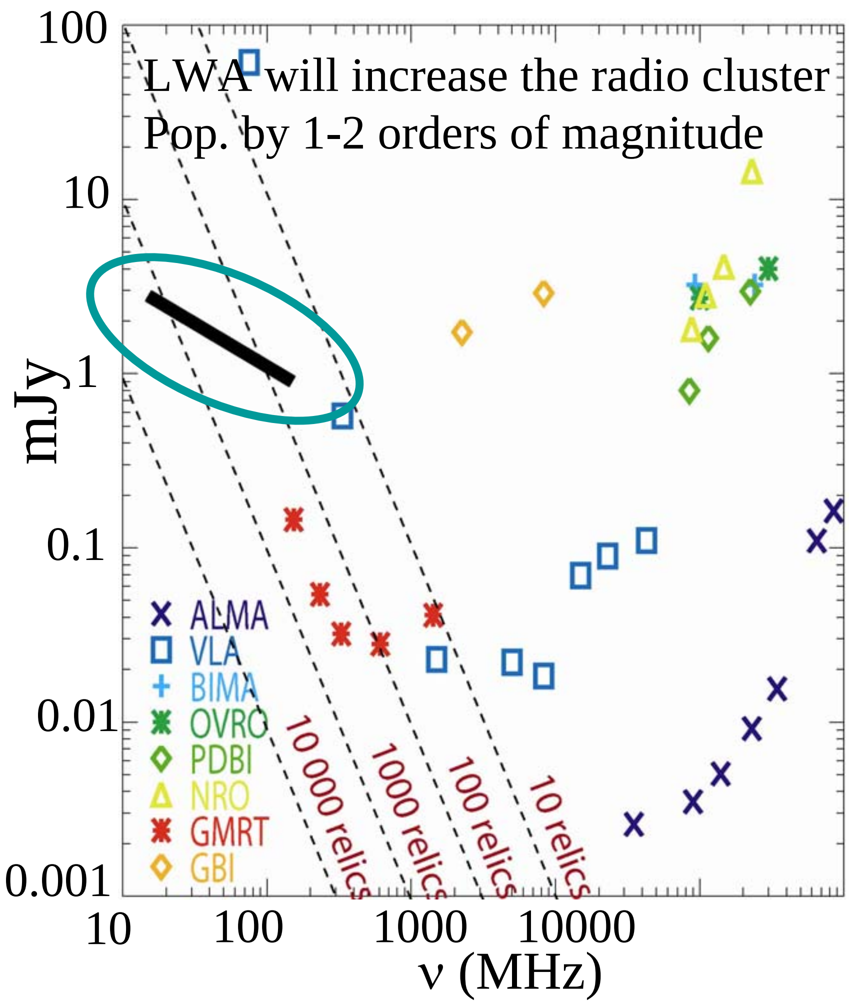
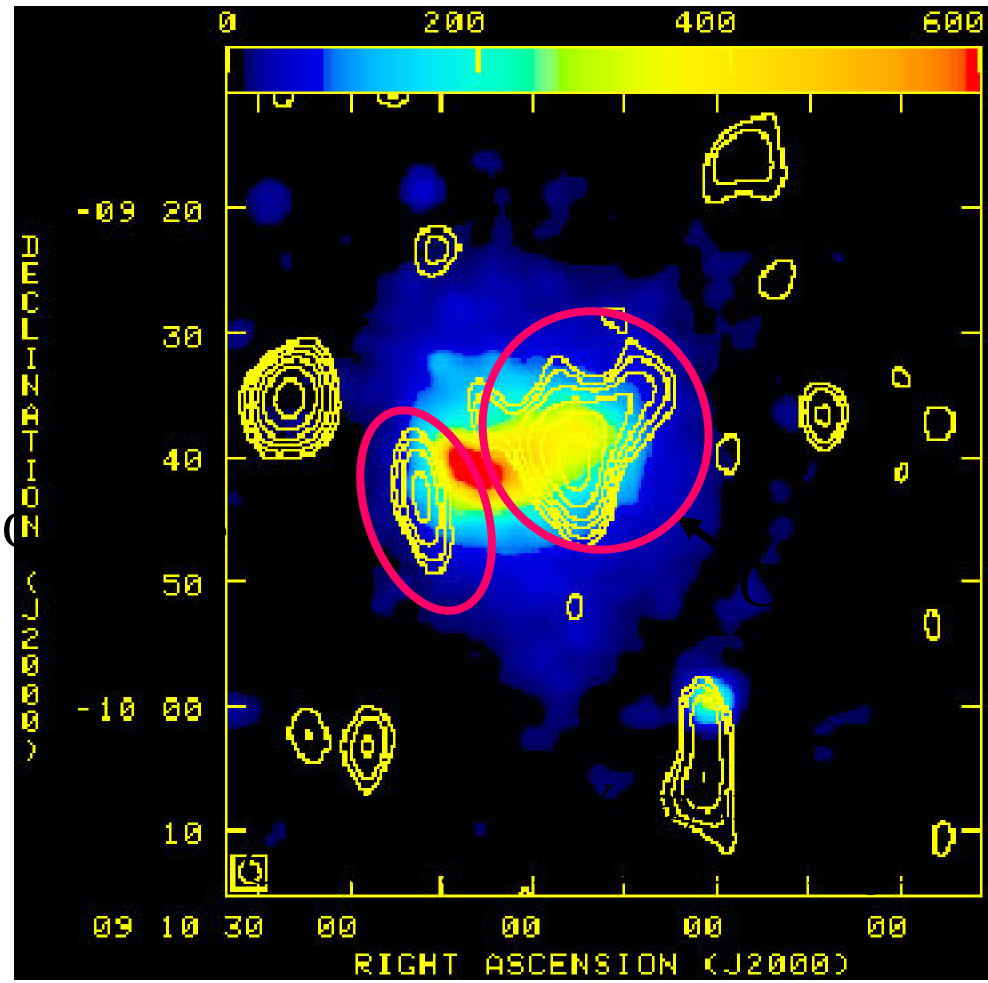
Clusters & Relics:

Tracing the evolution of large scale structure as a function of redshift

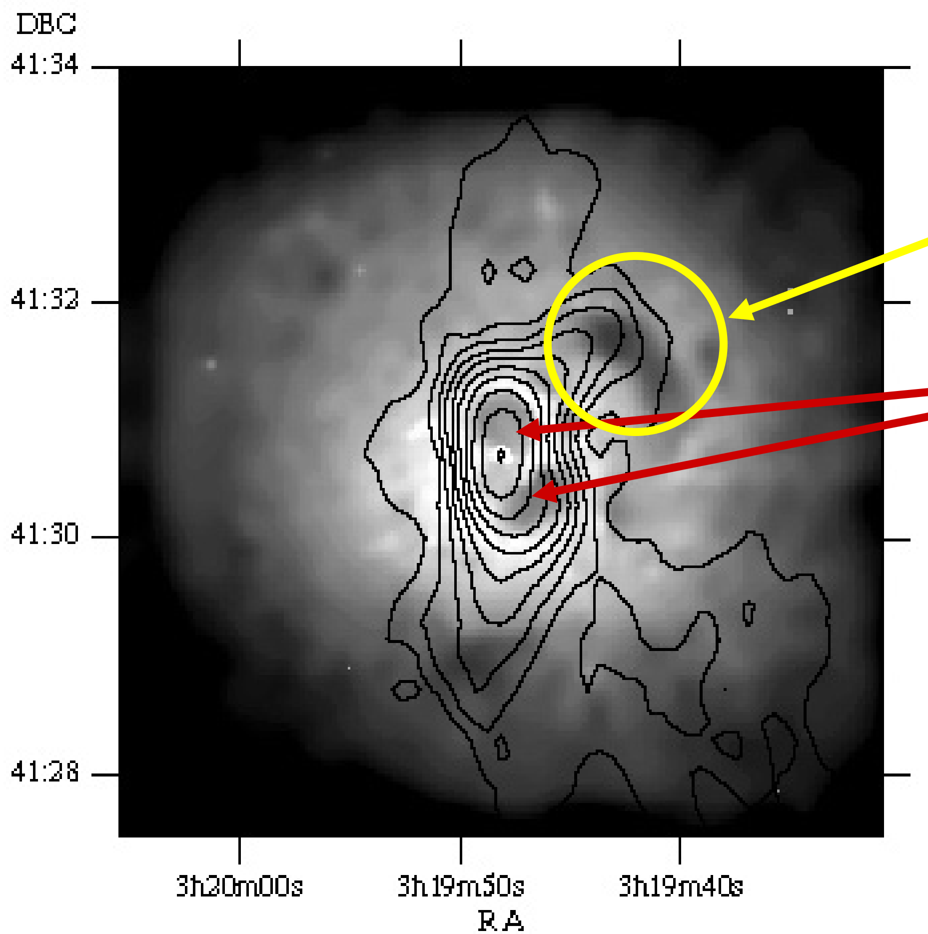




Kassim et al. 2001

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

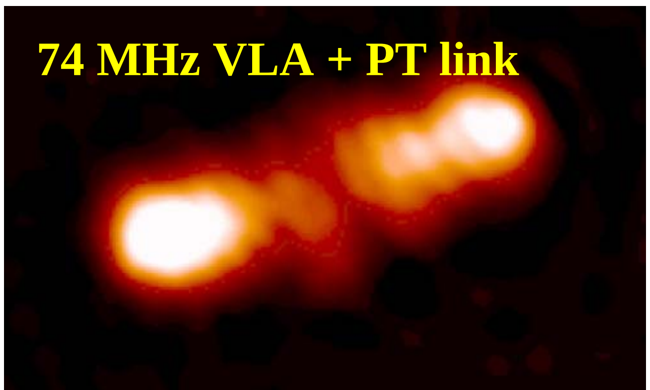
X-ray bubbles coincident with jets of 3C84 radio galaxy

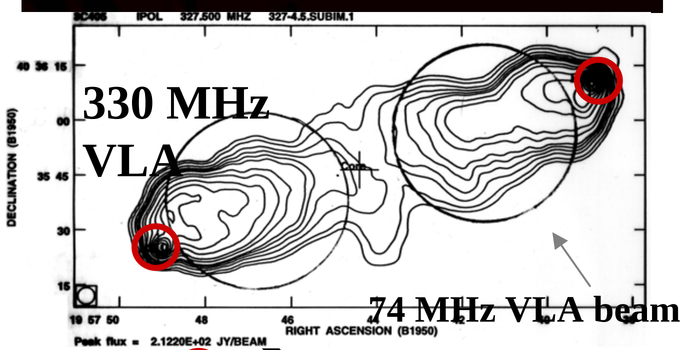
Key issues include:

- Pressure balance between radio & X-ray gas.
- Bubbles as means of solving cooling flow crisis, transporting magnetic fields.
- Influence of AGN on cluster environment.

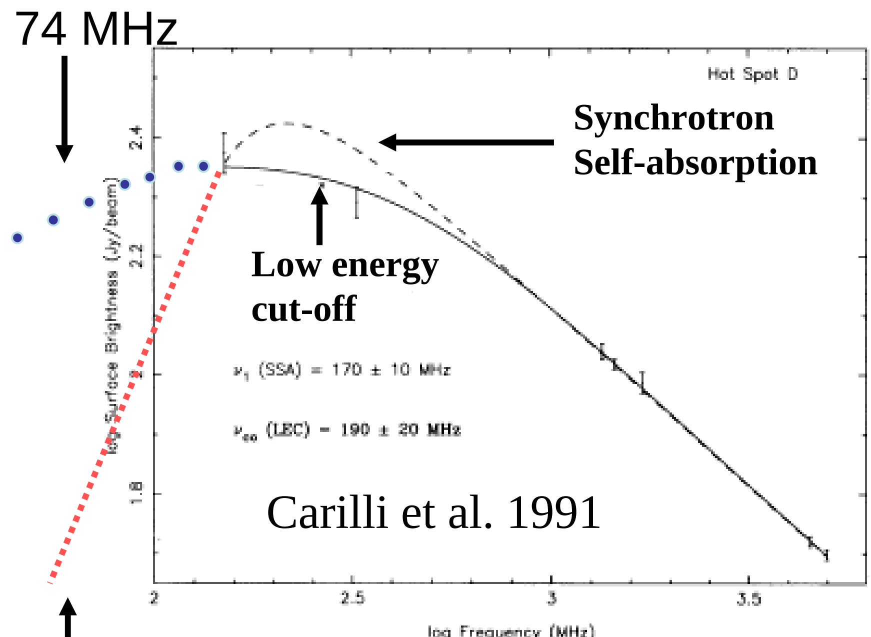
Physical Processes in Radio Sources

- Radio Galaxies
  - Low energy electrons
  - Self-absorption processes
  - Evolution & Death
- Normal Galaxies
  - Ionized gas via absorption
  - Magnetic fields in interactions
  - Cosmic ray propagation (halos)





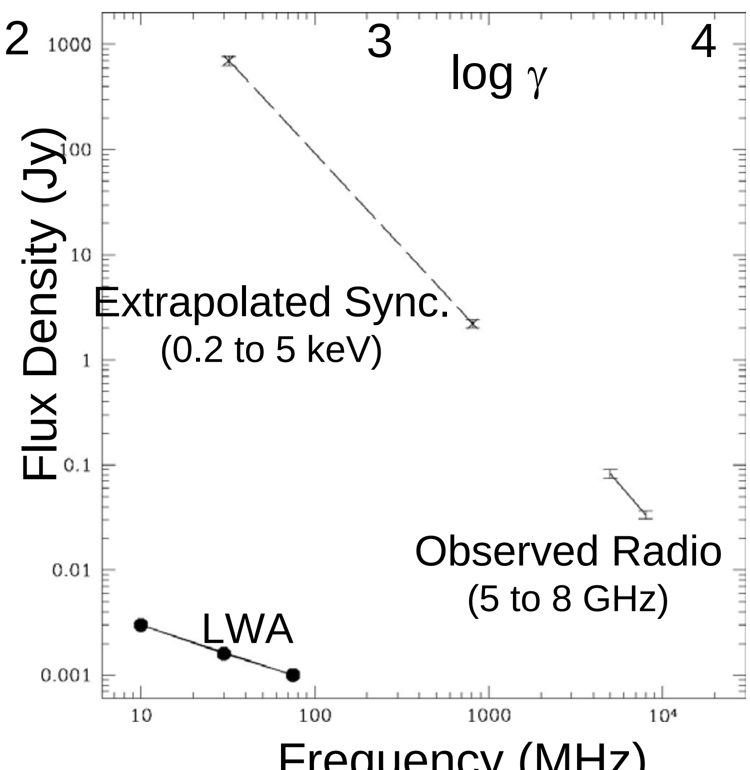
○ ➔ "Hotspots"

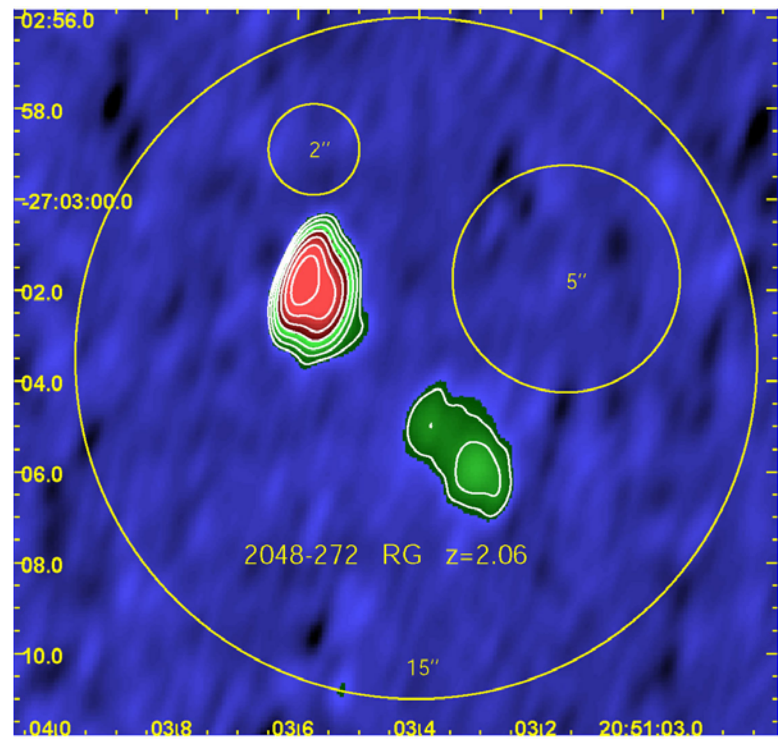


Resolution of the hotspots at 74 MHz will differentiate between competing models for spectral turnover

Low γ electrons: where the energy is.

- Ignorance of low γ spectrum: we do not have a good estimate of the energy and pressure of the plasmas we study.
  - Deviations from power laws? Low energy cutoffs? Unknown.
- Situation even worse for IC emission.
  - Rely on electrons with Lorentz Factors 1000 < γ < 50





Harris 2004

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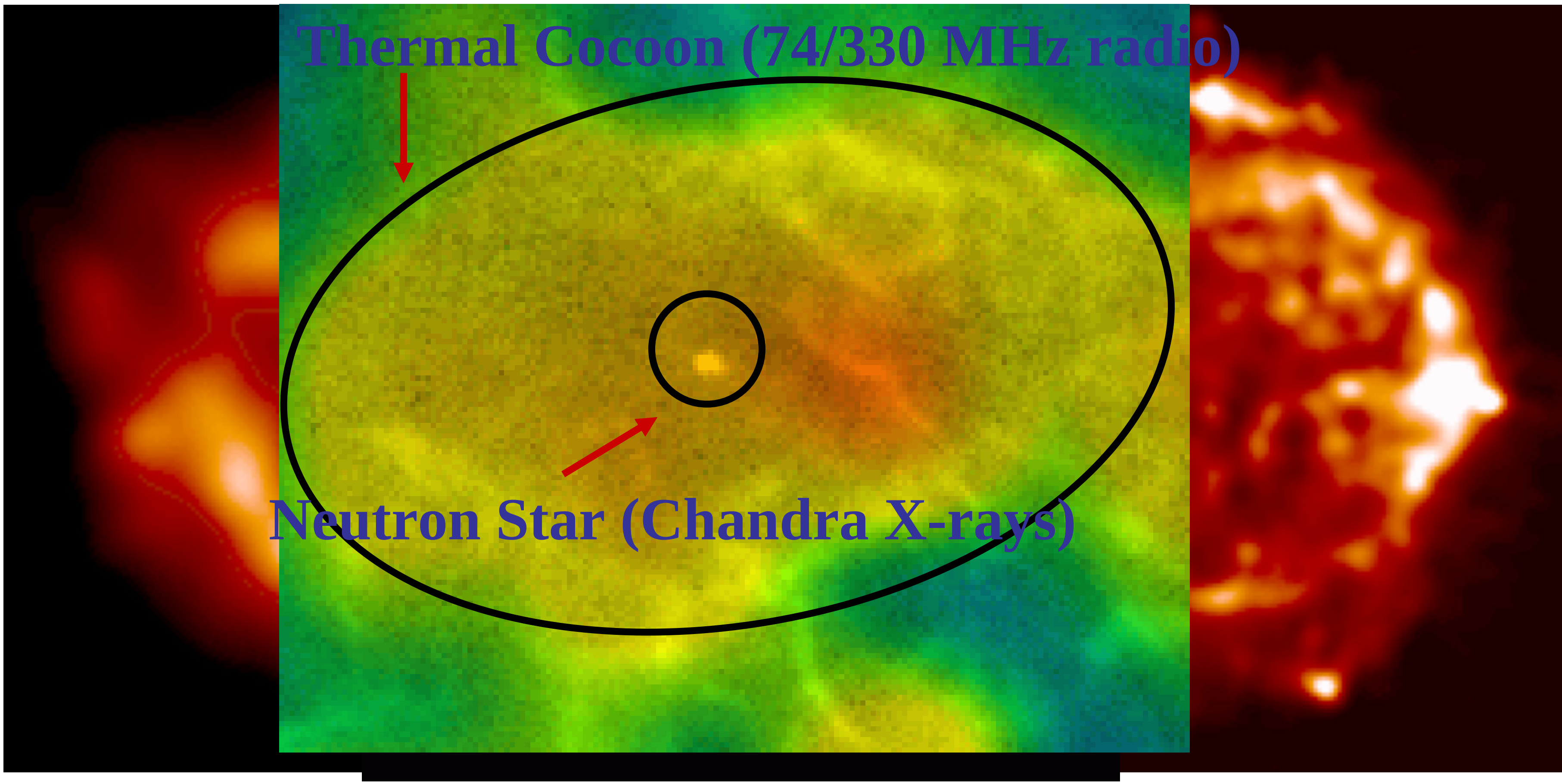
Shock Acceleration & Thermal Absorption

VLA "A configuration" (35 km)

VLA + Pie Town outrigger (73 km)



Cassiopeia A: Shock Acceleration & Thermal Absorption. T. Delaney – thesis project at UMN)

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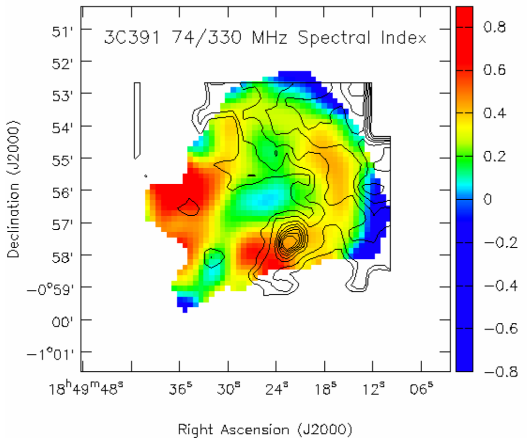
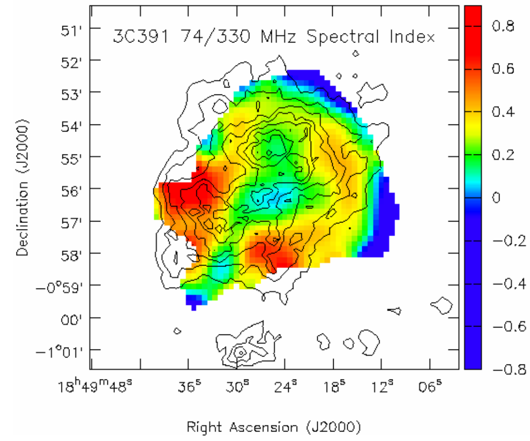
Thermal Absorption

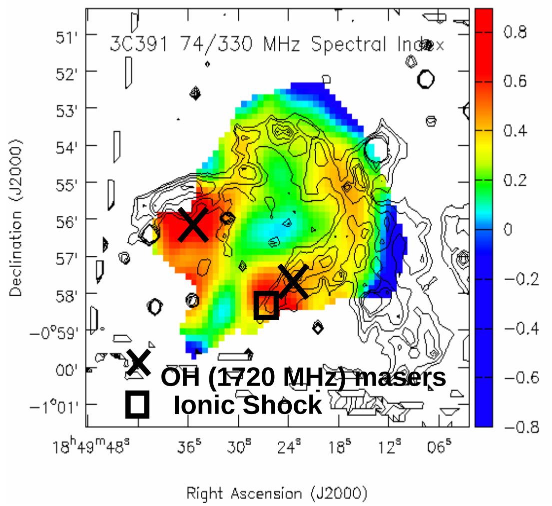


CO (2-1) integrated emission tracing MC (*Reach & Rho 1999*).

74 MHz absorption delineates sheath of absorbing ionized gas residing in the SNR/ molecular cloud shock boundary.



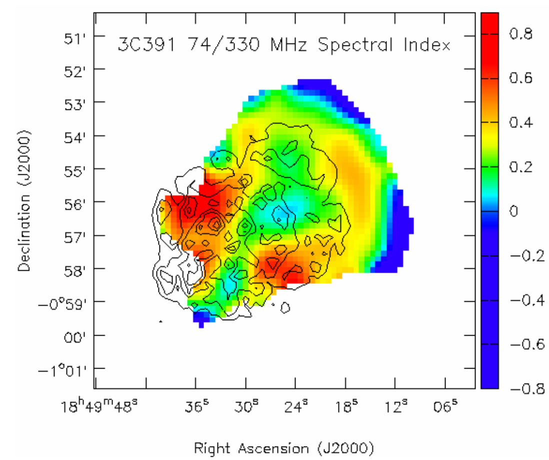
HARD X-rays showing full extent of SNR (*Chen & Slane 2001*)



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

Thermal absorption couples the power of kinematic (HI) ***distances*** to Galactic nonthermal sources, constrains relative radial positions in extragalactic sources.

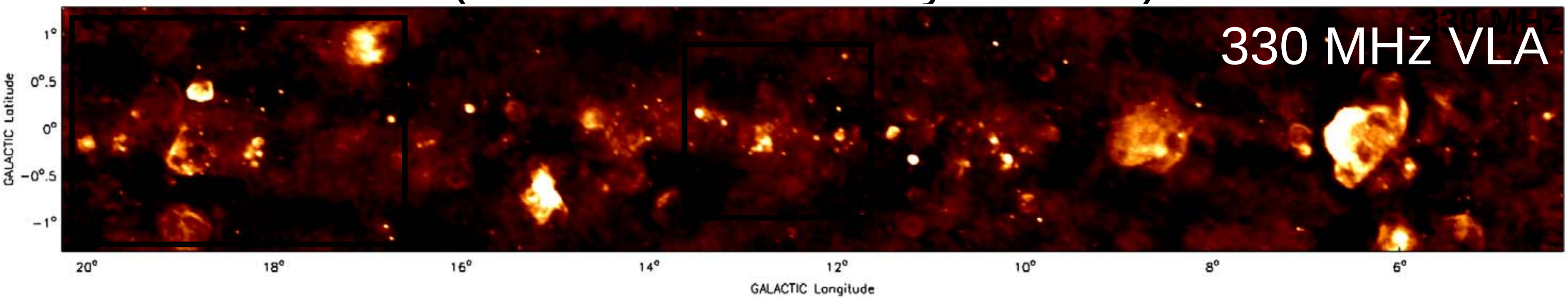
Brogan et al. 2004

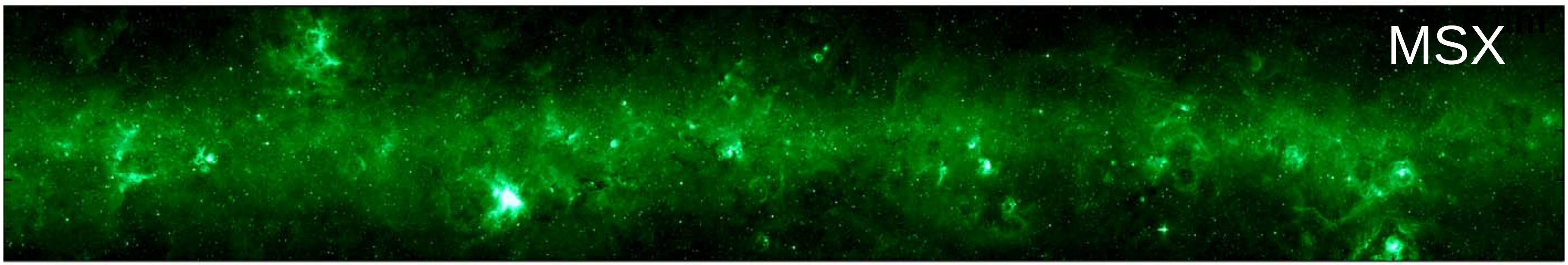


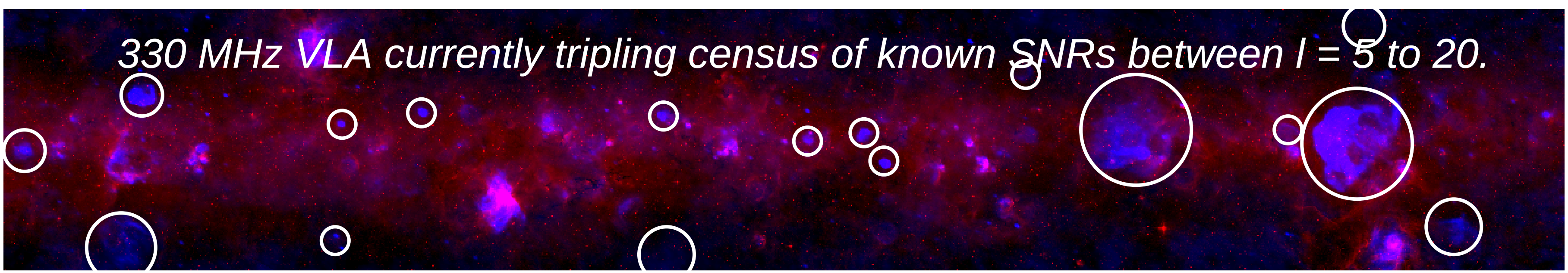
SOFT X-rays showing X-ray absorption (*Chen & Slane 2001*)

Full SNR census

(& distances to many of them)







(Brogan, Gaensler et al.)

2 Color Image:

Red: MSX at 8 μm

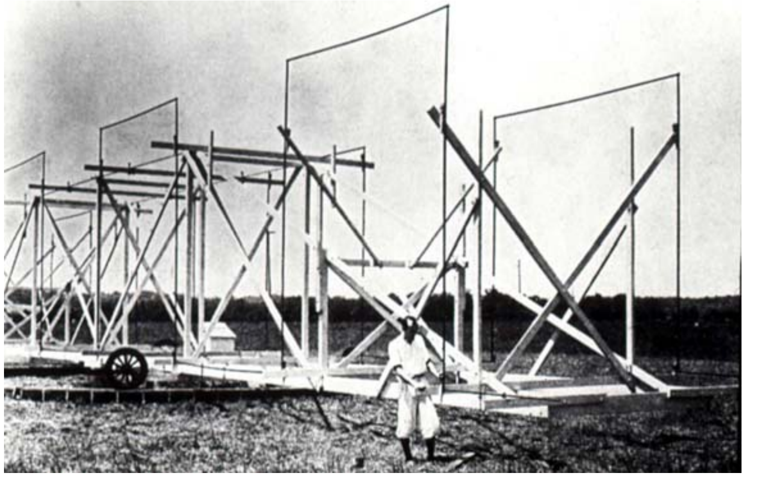
Blue: VLA 330 MHz

Discovery Science

Los Alamos NATIONAL LABORATORY EST. 1943 | The University of New Mexico | ARL The University of Texas at Austin | Naval Research Laboratory

Galileo builds his first telescope – birth of modern astronomy.

Jansky builds first HF/VHF radio telescope – birth of radio astronomy.



- The greatest discoveries in astrophysics have coupled key technical innovations with new spectral windows.
- Astrophysical discovery space – what is left?
  - New wavelengths – < 100 MHz last, poorly explored region.
  - Resolution & sensitivity – orders of magnitude to be gained.
  - Volume of space sampled – rare objects.
  - New observing paradigms: multi-beaming

} Natural strength of electronic LW arrays.

The LWA efficiently exploits the last remaining areas of discovery space for astrophysics.

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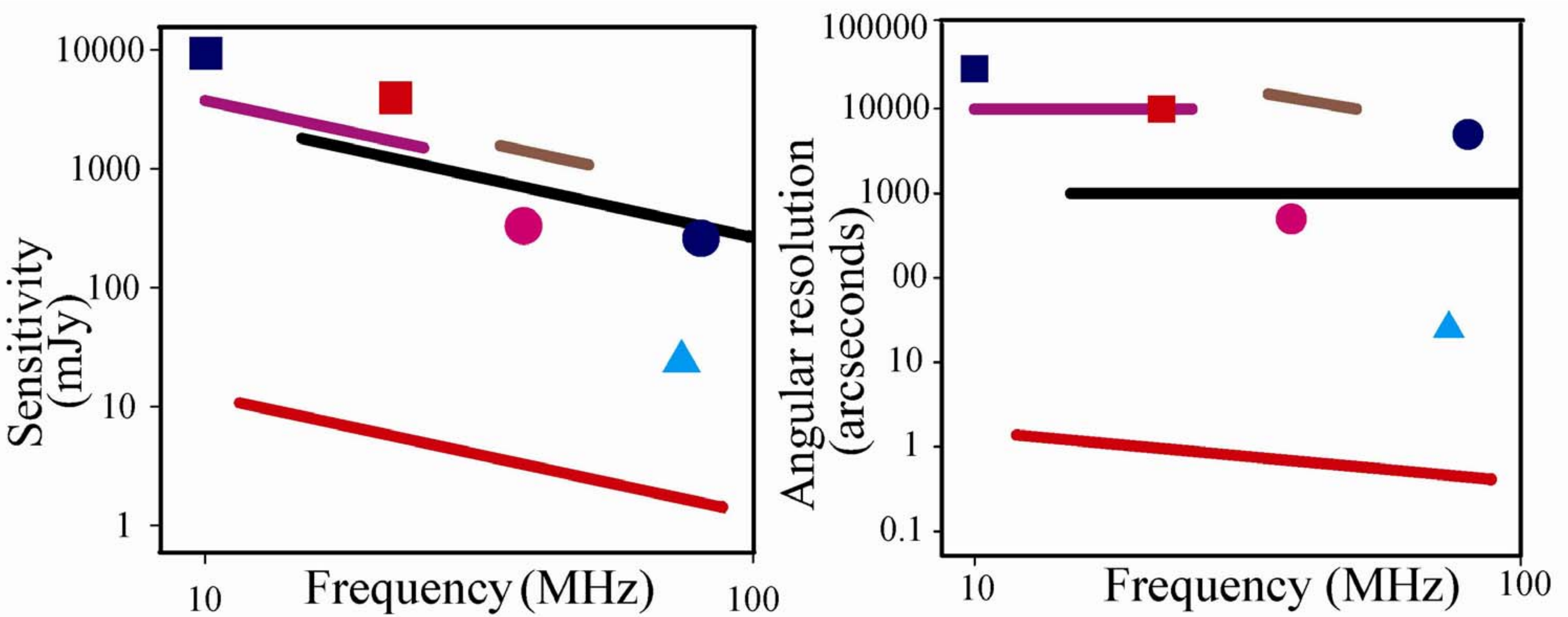
Naval Research
Laboratory

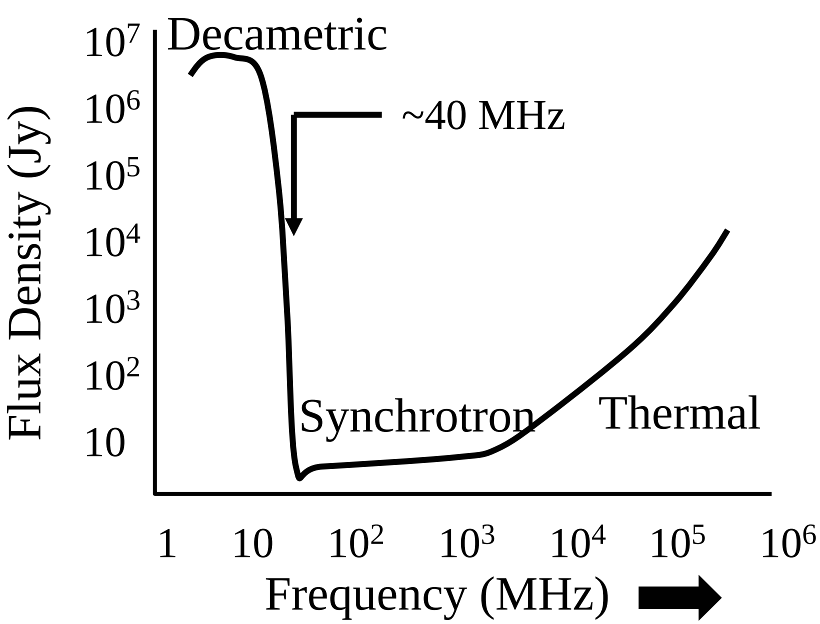
Opening a new window on the EM Spectrum

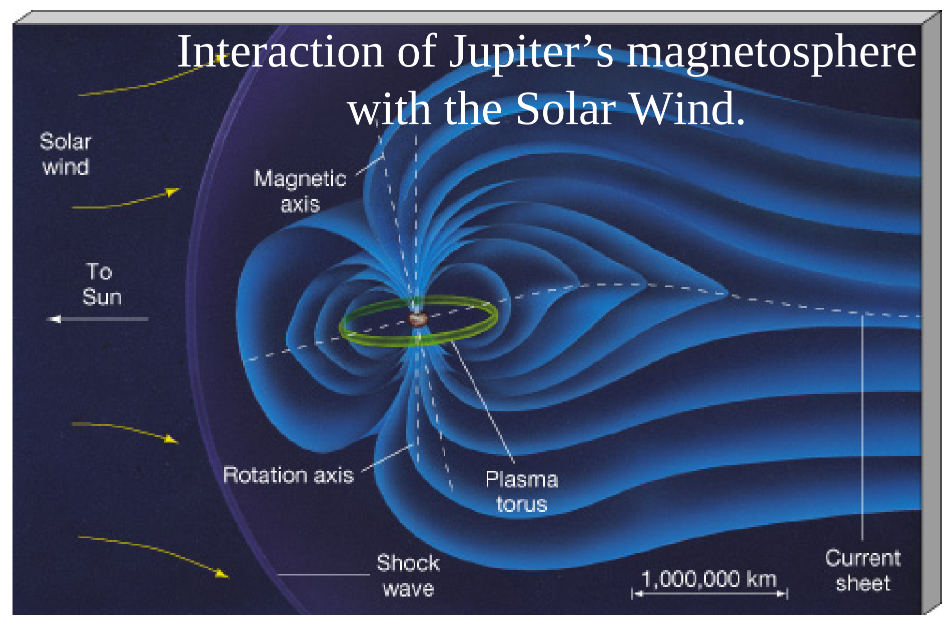


Tremendous improvement in imaging power brings the potential for exciting discovery science.

Potential for New Discoveries: Extra-solar Coherent Emission

- Below 40 MHz, Jupiter is the brightest object in the solar system.
  - Coherent cyclotron emission from interaction of Jupiter's magnetosphere with solar wind.
- The LWA has good chance of detecting emission from extra-solar "Jupiters".
  - Would provide independent verification of planetary systems using new technique.
  - Would confirm presence of magnetic field – pre-requisite for life as cosmic ray shield.





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LWA Technical

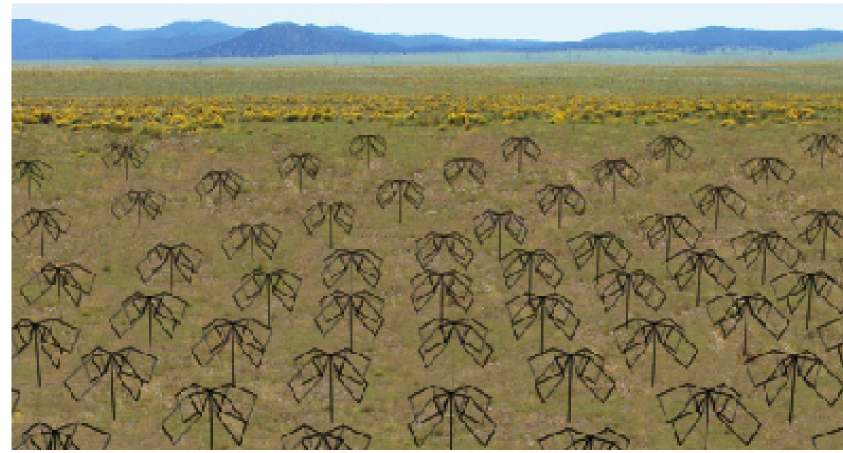
Thomas L. Gaussiran II
Applied Research Laboratories
The University of Texas at Austin

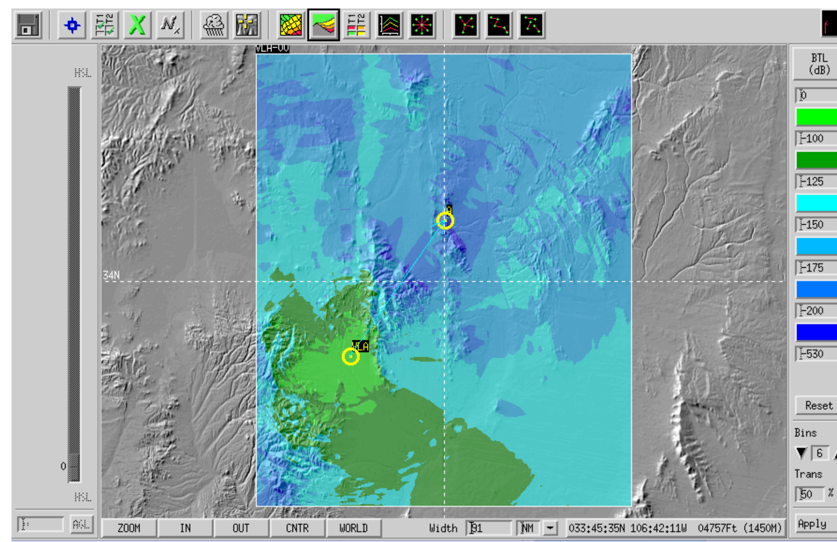
The Long Wavelength Array

- Consist of 52 stations
- Diameter of ~400 km
- Station provide good u,v coverage
- Cover 25 - 85 MHz
- Direct sample receivers
- 1-8 independent beams
- 32 MHz bandwidth
- Composed of dipole antennas
- Electronically steered
- Angular resolution
  - 5 arcseconds at 25 MHz
  - 1.4 arcseconds at 75 MHz
- Point source sensitivity (1 hr integration, 4 MHz IF)
  - 1.1 mJy at 30 MHz
  - 0.7 mJy at 75 MHz
- Dynamic range > 10^4
- Full Stokes polarization
- Time resolution 1 ms
- Implementation Plan
  - CY04 Phase 0 - Existing VLA
  - 04-06 Phase 1 - LWDA
  - 06-08 Phase 2 - Intermediate
  - 08-10 Phase 3 - LWA Core
  - 08-10 Phase 4 - High Resolution

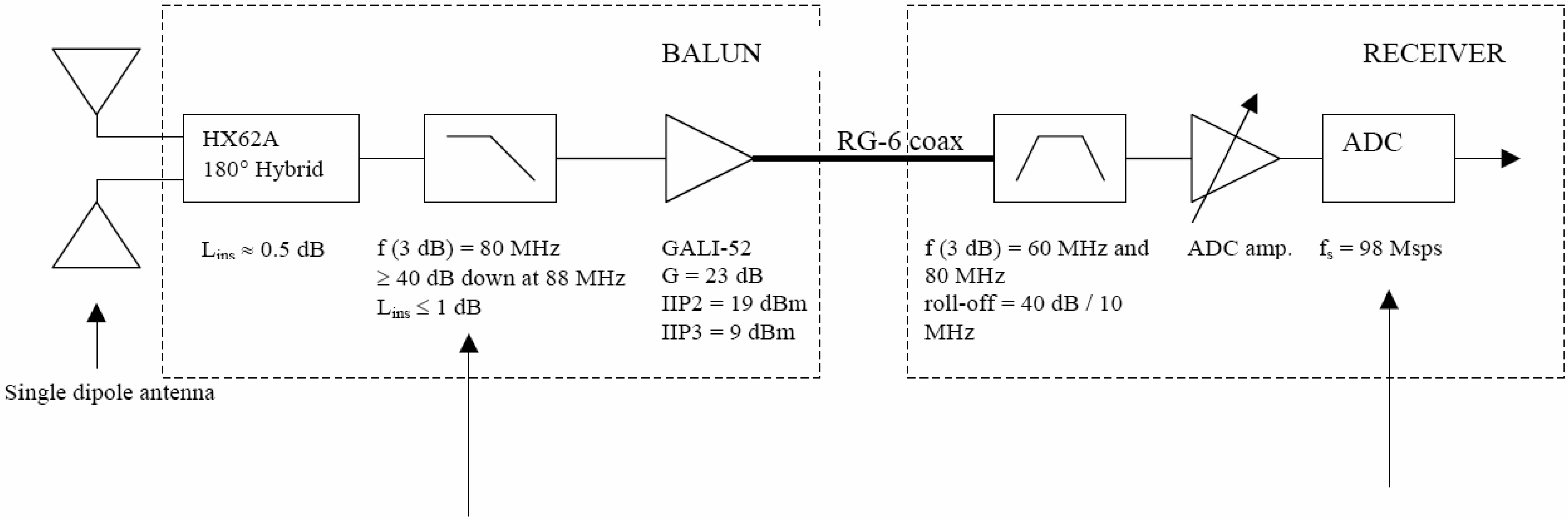
Station Level description

- Station composed of 256 dipole antennas
- Station diameter ~100 m
- Act as a single “dish”
- Sufficient collecting area to allow for self-calibration
- Multiple beams formed at the station level and transmitted back to central processor facility





Antenna Schematic



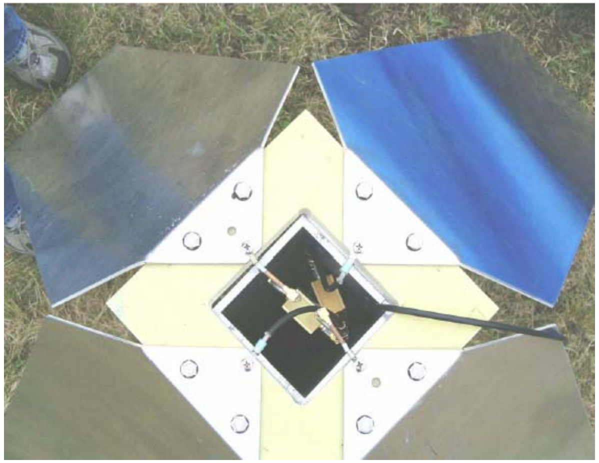
Filter before LNA for suppression of intermod's.

LPF allows receiver ADC to be upgraded later w/out changing balun.

Sample rate to avoid aliasing of FM band w/ "cheap" filter

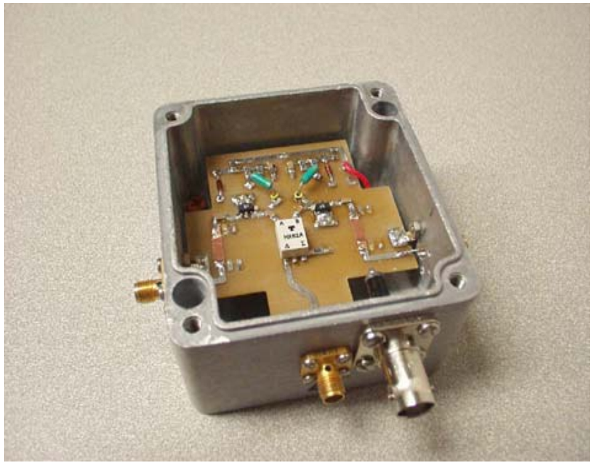
Dipole Antenna

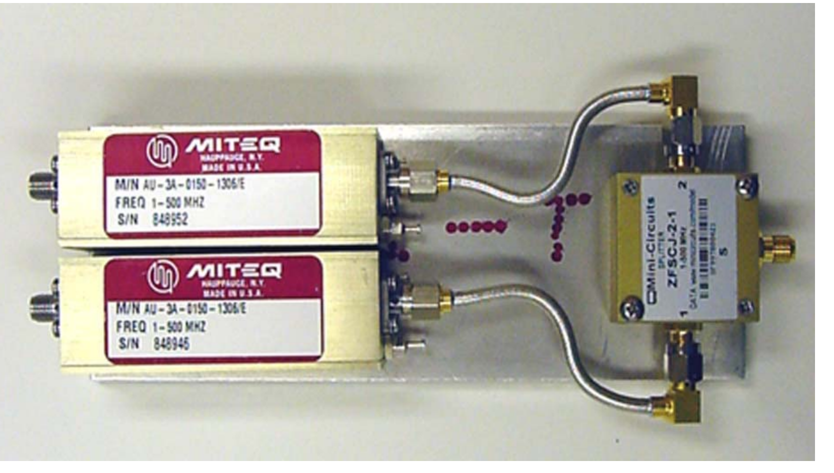
- Dual polarization
- “Blade” design
- Electronics housed in mast or at hut
- Blades are ~1 m
- Solid aluminum construction
- No ground plane



Balun/LNA

- 180 degree hybrid
- Low pass/band pass filters
  - Prevent intermodulation
  - 40 dB suppression from 80-88 MHz
- Provides 1st stage of gain
- IP2/IP3 metrics are critical
  - IIP2 = 19 dB
  - IIP3 = 9 dB
- Current design to be tested at VLA and Green Bank sites





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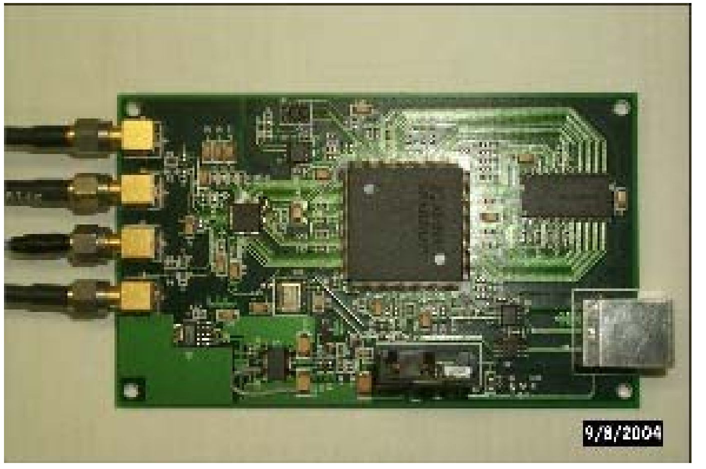
LWA Direct Sample Receiver

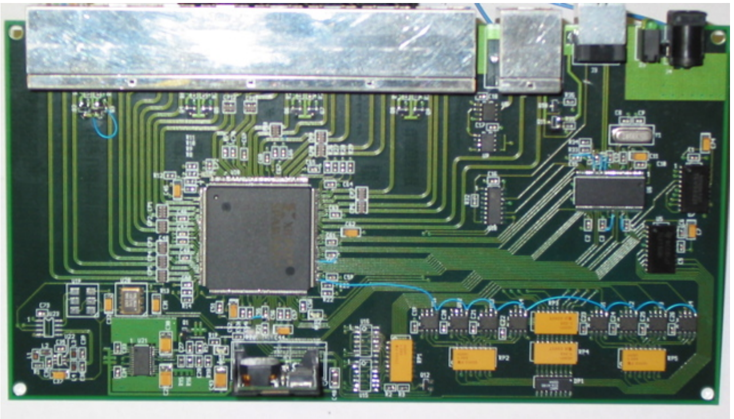


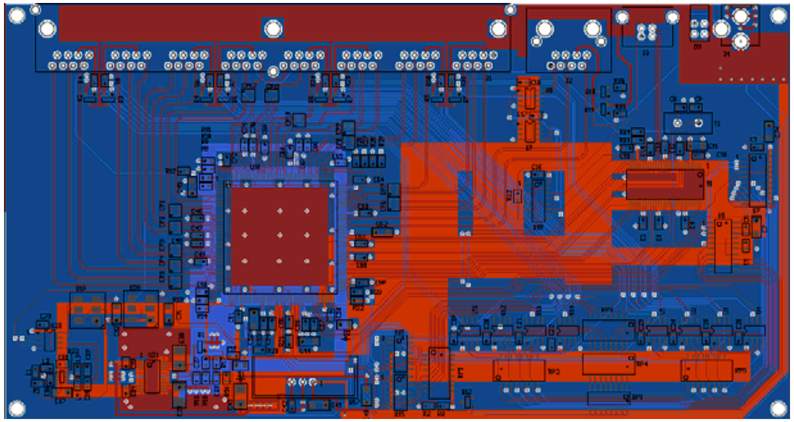
- Components
  - Bandpass filter
  - Gain Control Amp
  - 10 bit ADC
  - FPGA
- FPGA function
  - Integer sample delay
  - Fractional sample delay
  - Sub-band filter
  - Linear to circular
  - Clock disciplining
- LWDA RX operates in the 2nd Nyquist zone

- LVDS output
- Sampling Rate
  - LWDA ~ 98 Msps
  - LWA ~ 200 Msps
- Draws < 5 W
- 270 Mbps downstream
- 5 Mbps upstream

Beamformer

- Adds input from 8 different antennas
- Controls/provides voltage to each of the receiver
- Responsible for clock distribution/alignment
- Can be connected to other beamformers





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Software

- Command and Control software
  - Leverage the C&C designed for the EVLA
  - Implement based on the design laid out by NRAO
- Data reduction and Imaging software
  - Leverage the current 74 MHz reduction software
  - Develop specific imaging capabilities
- Computing – UNM High Performance Computing Center and LANL
- Science Center
  - Socorro near AOC
  - UNM utilizing LambdaRail network
  - Access via academic networks

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Organizing the LWA Team

Frank Gilfeather
University of New Mexico

Naval Research Laboratory

SWC Core Institutions

- University of New Mexico – science, computing and infrastructure support
- University of Texas – ARL – engineering and ionospheric studies
- Los Alamos National Laboratory – science and computing
- Naval Research Laboratory – science and engineering

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The Long Wavelength Array

- Re-vitalize university-based radio astronomy –add faculty and students
- Build in US South West – leverage EVLA and related project development
- Use existing infrastructure – power, fiber-optic networks
- Reasonable RFI environment at low frequencies – proven environment
- Synergy with Very Large Array and EVLA – joint activities
- Large, nearby population of astronomers, earth & space scientists, engineers – good for NM and region
- Initiate and expand educational programs - cooperation with NRAO

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Basic Premises

- Multi-disciplinary instrument – develop unique applications
- Multi-user instrument – open to the broad community
- Radio astronomy - using technology to make a software telescope
- Phased development plan – doing science as LWA develops
- Engage cooperation of individuals at many institutions – broad buy-in
- Develop a special cooperative relationship with EVLA/NRAO – as NM instruments

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Many Steps to LWA

- 1984 - Perley, R. A. & Erickson, W. C. (*VLA Scientific Memorandum* **146** (Socorro: NRAO) p. 1-65) - A proposal for a large, low frequency array located at the VLA site
- 1985 – LaRosa and Kassim (*Ap. J. (Lett.)* **299**: L13) – Galactic Center at 80 MHz with Clark Lake Telescope
- 1990 – Kassim, Perley and Erickson (1990, *BAAS* **22**: 802) – Report of first observations with initial 74 MHz system
- 1993 – Kassim et al. (*A.J.* **106:** 2281) – 8-element VLA
- 1998 – Full 74 MHz system becomes VLA facility instrument
- 1998 – Kassim and Erickson (*SPIE* **3357:** 740) – proposal to build large low-frequency array
- 1999 – concept incorporated in NAS Decadal Plan
- 2000 – establishment of International LOFAR Consortium
- 2003 – establishment of South-West Consortium
- 2004 – Wavelengths on Human Scales – September 8, 2004

74 MHz VLA System and Beyond

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The University of New Mexico

ARL The University of Texas at Austin

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LWA Timescale

2004	Phase 0	Existing 74 MHz VLA System
2004 – 2006	Phase 1	Long Wavelength Demonstrator Array (LWDA)
2006 – 2008	Phase 2	8-9 (6-7+2) Station Intermediate Array (LWIA)
2008 – 2010	Phase 3	Complete LWA Core Array
2008 – 2010	Phase 4	High Resolution LWA

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What we need to realize LWA

- Strengthen the constituency for the LWA – a university/national lab led, world-class observatory
- Strengthen internal organization – workshops, personnel
- Obtain significant R&D funding through diverse agencies
- Build-out through a phased development strategy
- Continue to overcome technical challenges - calibration
- Build synergy with other projects – FASR, MRA, etc.
- Firm a symbiotic relationship with NRAO

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Obvious questions

- Can we overcome engineering (software) challenges?
- Is our organizational structure sound and strong enough?
- Is there funding to do all the valuable projects in the national queue?
- How do we coordinate with other developing projects e.g. FASR?
- Is NRAO able to accommodate our effort – even if we work to accommodate their needs?
- Is the proposed timeline sensible?

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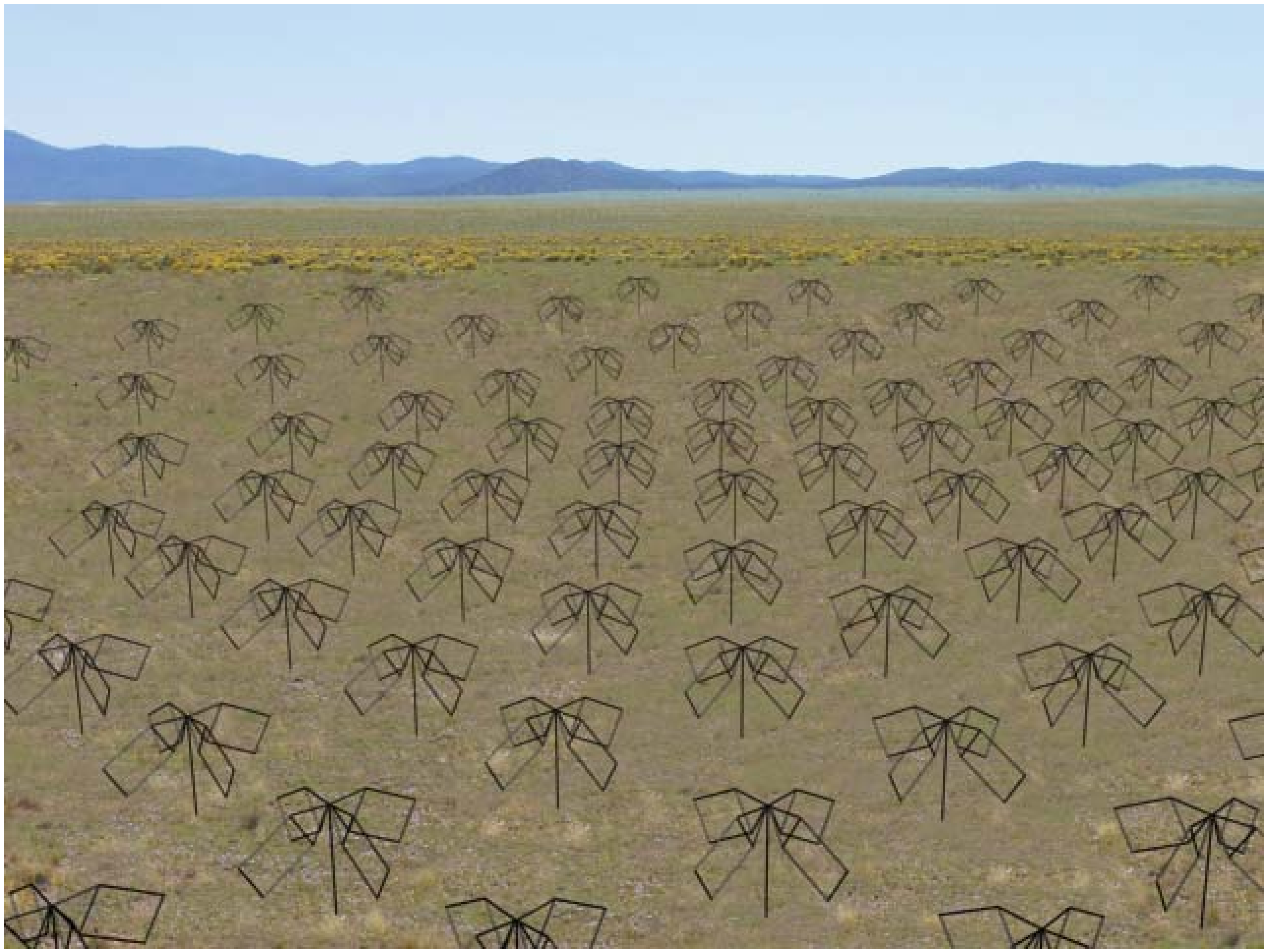
A new ‘species’ on the Plains



Thanks

Why should NRAO care about SWC/LWA ?

- First and foremost for the science.
- LWA opens up new parameter space for our user community.
- Great potential exists for new astronomical discoveries.
- Other scientific areas also benefit.

To Contribute and work with SWC on issues of common interest.

- Wide Field Imaging
- High Speed Computing
- Data Transport on optical fibers
- EPO
- Access to public land

To help revitalize the University Radio Astronomy Community.

- LWA brings UNM, University of Texas and Groups at several other universities into the project as major players.

To Involve Other National Labs

- NRL and LANL are major partners with extensive resources.
- They bring their own talents and energy to our general goal of stimulating radio astronomy and other related science.

To add new funding sources.

- NRAO is a NSF contractor and thus has primarily the NSF as its funding source.
- Universities and other National Labs have other sources of funding.
- At least for now the NSF funding pot looks severely limited.
- By working with the SWC we can find new ways to bring funding into projects we support.

Conclusion

The LWA project offers NRAO and new way to make use of it role as the National Radio Astronomy Observatory to do important new research. However, it also offers a new model for how we can extend our ability to facilitate radio astronomy for our community and to increase the vitality of our field.

But what is going on in A2125 to enhance the radio fraction ?

Are the excess radio emitters due to a merger ?

Is the excess AGN or star-formation driven ?

To help find the answer, we have obtained deeper VLA 20cm imaging, deeper, multiband optical imaging, much more spectroscopy, and a deep CHANDRA integration (80ksec).

New A2125 Dataset

- Deeper, higher resolution 20cm VLA imaging.
- 223 spectroscopically confirmed members
- 90 radio detected members
- Deep U,B,V,R,I,9170A,J,H,K imaging
- 3 fields imaged with HST
- 80ksec CHANDRA imaging

Velocity Field

Best fit to spatial and velocity information suggests 3 subclumps:

	N	Mean V	dispersion (km/s)
Primary:	141	73677	639
Sub#1	53	75946	709
Sub#2	29	71877	481

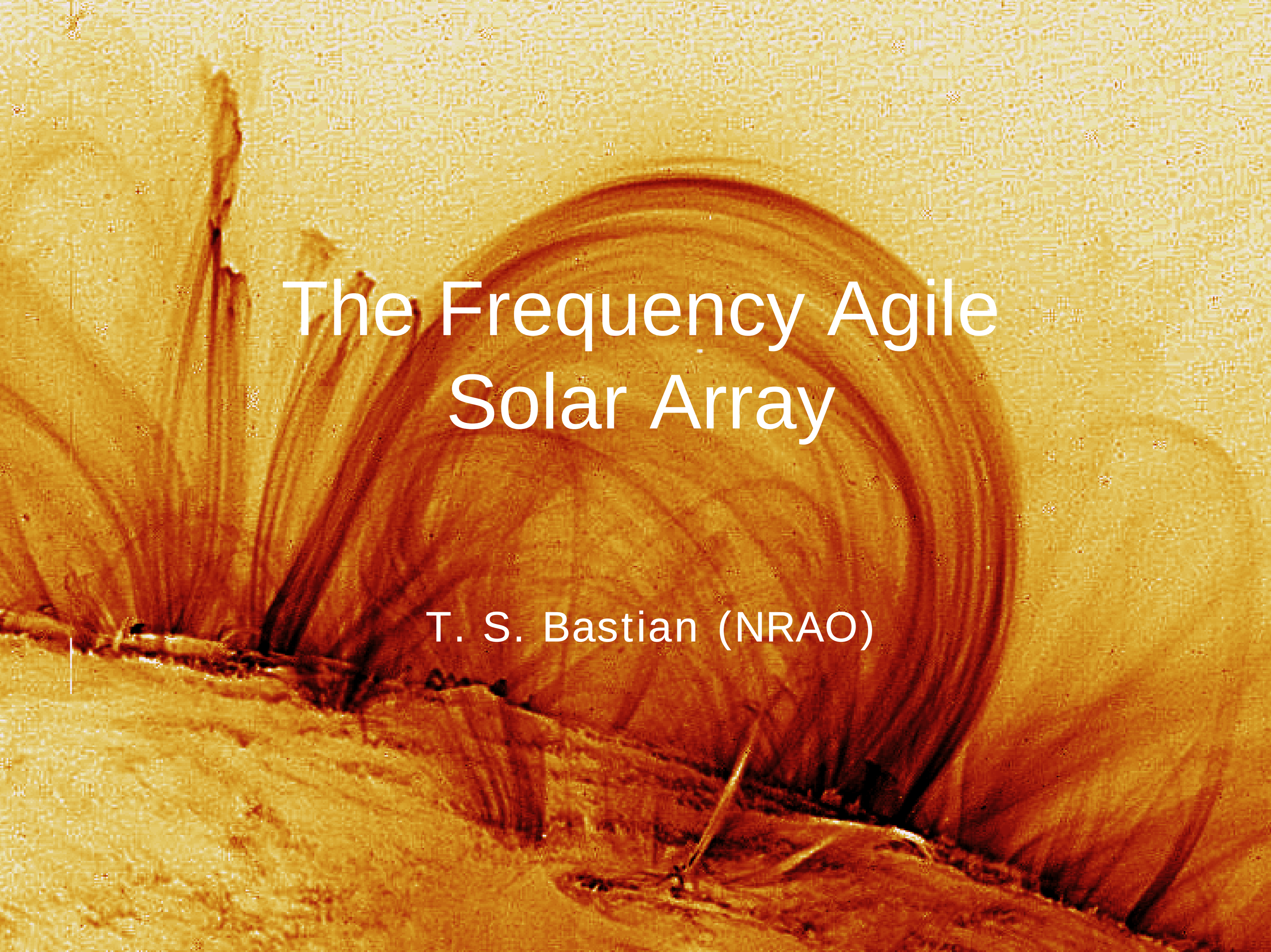
Summary

• A2125 appears to be in the middle of a major collision/ merger which is accompanied by an unusual amount of star-formation activity for such a rich massive system.

• The core appears to be a collision between massive cores of the two principal components of the system.

• Most of the excess radio emission is probably associated with star-formation, often hidden by significant dust obscuration.

• These results, combined with those for other clusters suggest much of the star-formation must have been induced by the collision/merger process.



The Frequency Agile Solar Array

T. S. Bastian (NRAO)

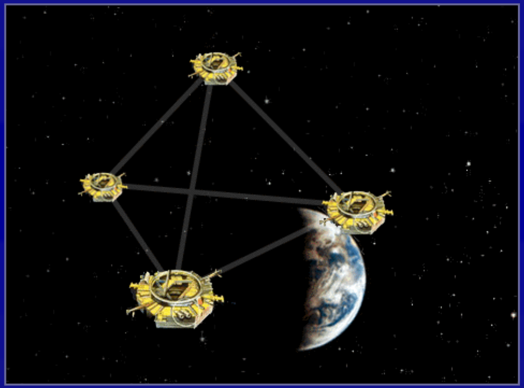
- Background
- FASR Overview
- FASR science
- Status and plans

In an exercise similar to the AASC decadal review the *NRC Solar and Space Physics Survey Committee* considered priorities for solar, heliospheric, magnetospheric, and ionospheric physics.

>$400M (large)

Solar Probe

Solar Probe will make the first in-situ measurements inside 0.3 AU, the innermost region of the heliosphere and the birthplace of the heliosphere itself.



$250-400M (moderate)

Magnetospheric Multiscale Mission (MMS)

The 4 MMS spacecraft will study the fundamental physical processes that transport, accelerate, and energize plasma in the boundary layers of Earth's magnetosphere.

<$250M (small)

Frequency Agile Solar Radiotelescope (FASR)

A multi-frequency (~0.1 - 30 GHz) imaging array composed of ~100 antennas for imaging the Sun with high spectral, spatial, and temporal resolution.

The essential idea

FASR is a solar-dedicated radio telescope designed to perform dynamic broadband imaging spectroscopy.

It will do so with time resolution, frequency resolution, and angular resolution commensurate with physical phenomena of interest.

It will be entirely unique.

Distinctive character of solar observations

- Sensitivity is not a driver (10^4 – 10^{10} Jy: T_{sys} is source-dominated)
- Angular resolution requirements are bounded (~20"/GHz)
- Snapshot imaging is often more important than earth-rotation synthesis
- Observations over wide band needed, ~ "continuous" in frequency

  NB: Most observations are outside protected frequency bands.

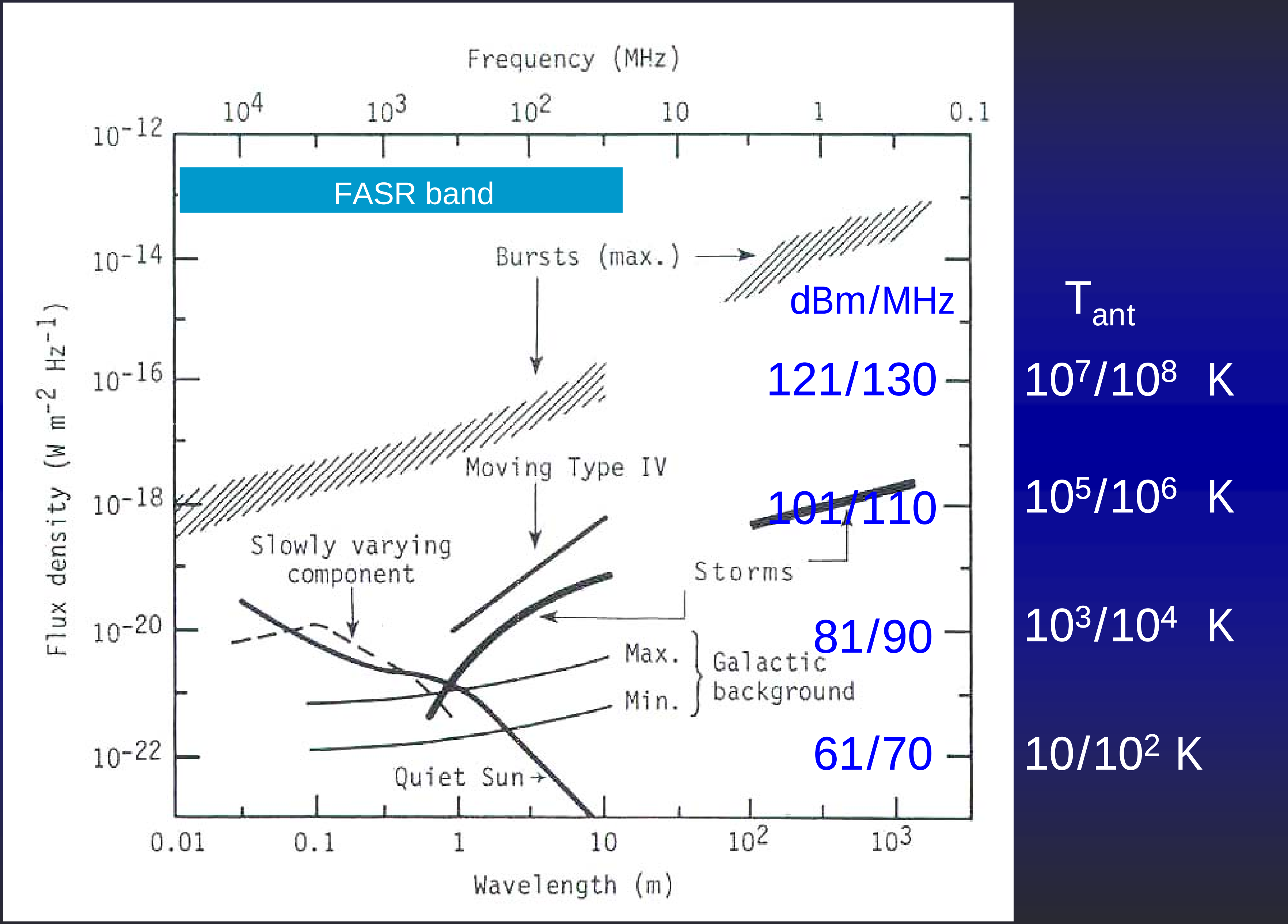
- Spectral resolution science requirements are modest (RFI driven)
- Time resolution science requirements frequency dependent

- Interpretation usually involves multi-wavelength analysis
- Users may not have a good understanding of instrumentation
- Time variable sources

  Poor match to pre-scheduled operations model

  Observational continuity is highly desirable

2/6 m antenna



Frequency (MHz)
10^4
10^3
10^2
10
1
0.1
FASR band
Bursts (max.)
Moving Type IV
Slowly varying component
Storms
Max.
Min.
Galactic background
Quiet Sun
Flux density (W m^-2 Hz^-1)
10^-12
10^-14
10^-16
10^-18
10^-20
10^-22
0.01
0.1
1
10
10^2
10^3
Wavelength (m)
dBm/MHz
121/130
101/110
81/90
61/70
T_ant
10^7/10^8 K
10^5/10^6 K
10^3/10^4 K
10/10^2 K

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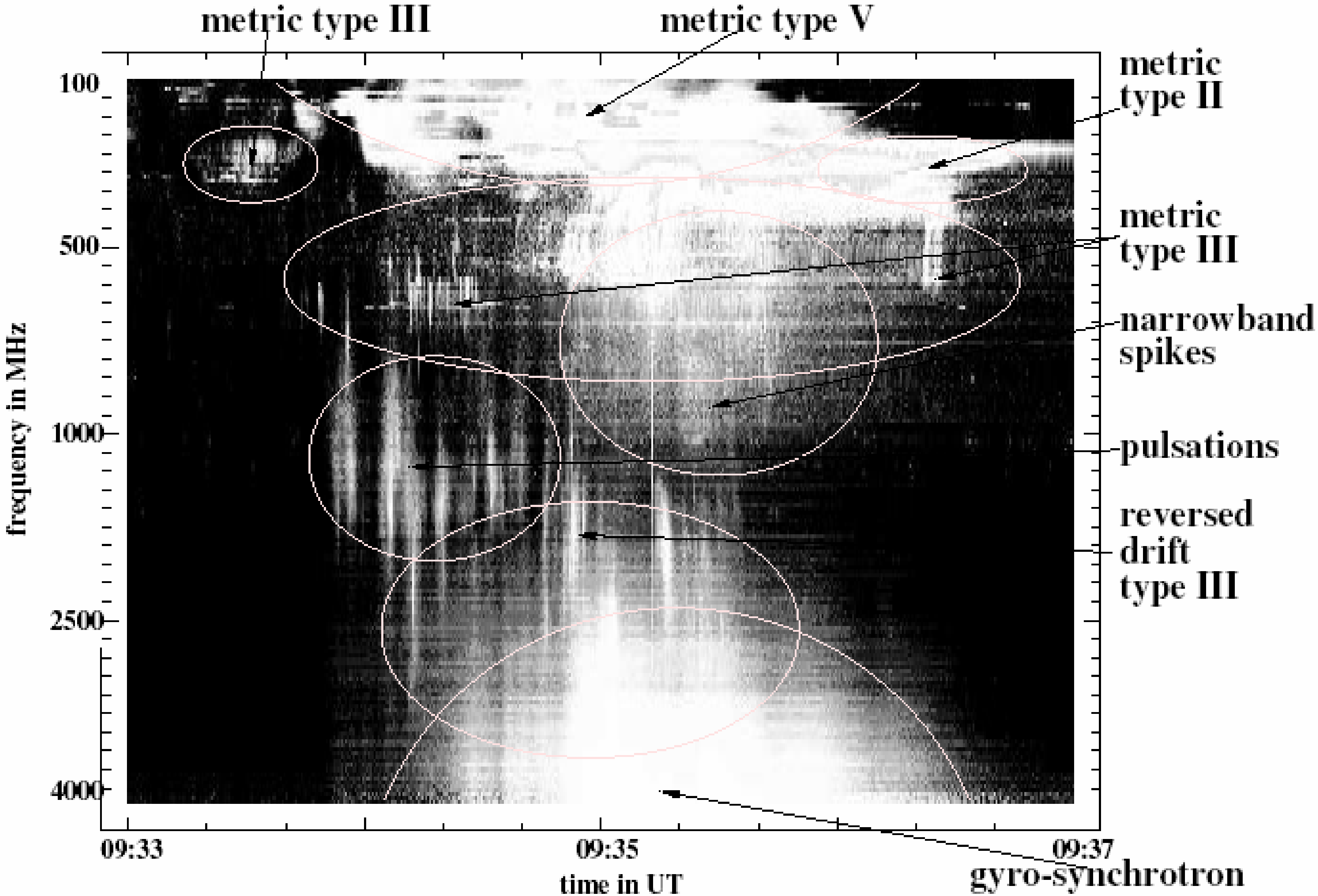

from Benz 2004

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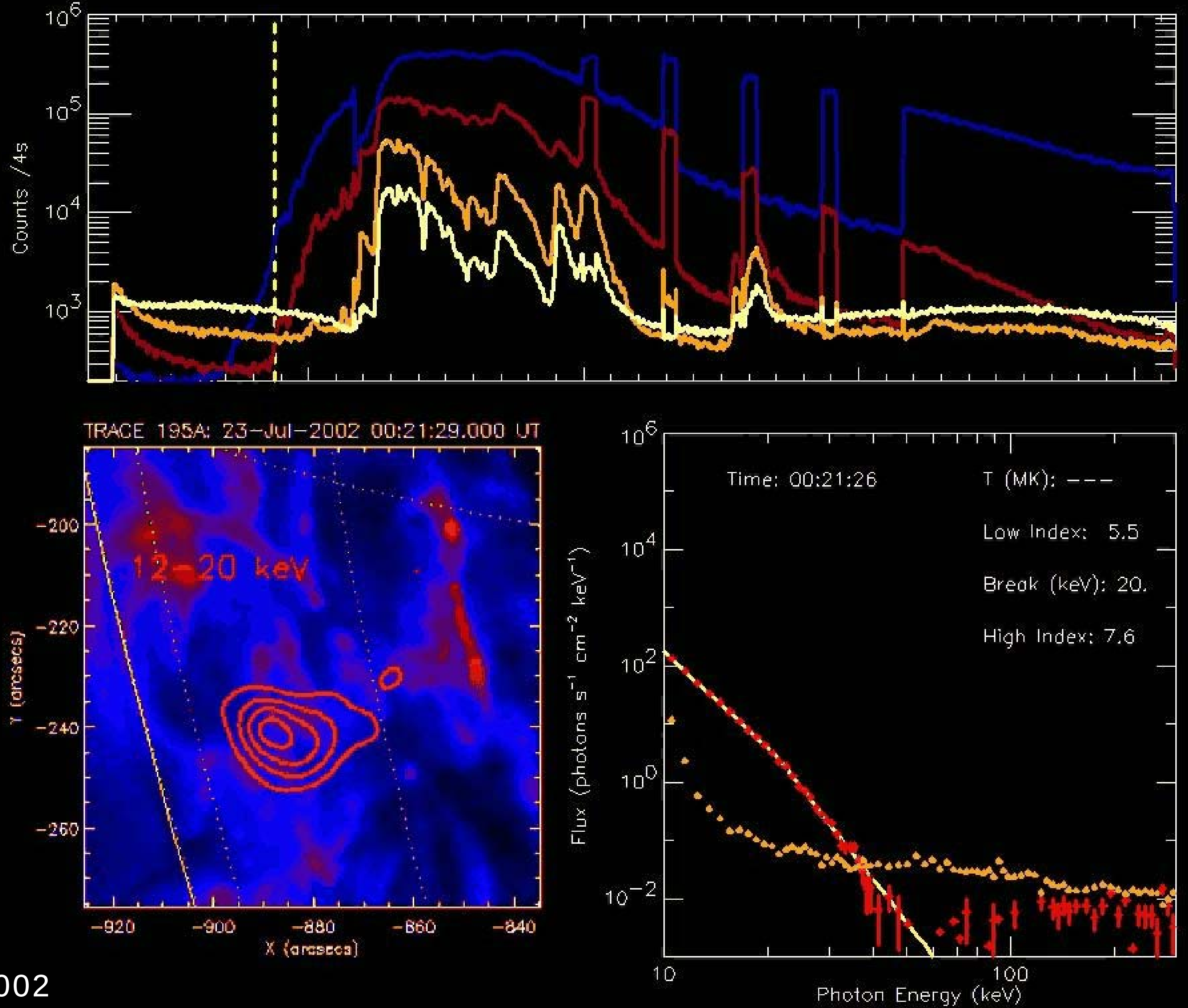

10^6
10^5
10^4
10^3
Counts /4s
TRACE 195A: 23-Jul-2002 00:21:29.000 UT
12-20 keV
-200
-220
-240
-260
Y (arcsecs)
-920
-900
-880
-860
-840
X (arcsecs)
Time: 00:21:26
T (MK): ---
Low Index: 5.5
Break (keV): 20.
High Index: 7.6
Flux (photons s^-1 cm^-2 keV^-1)
10^6
10^4
10^2
10^0
10^-2
10
100
Photon Energy (keV)

Lin 2002

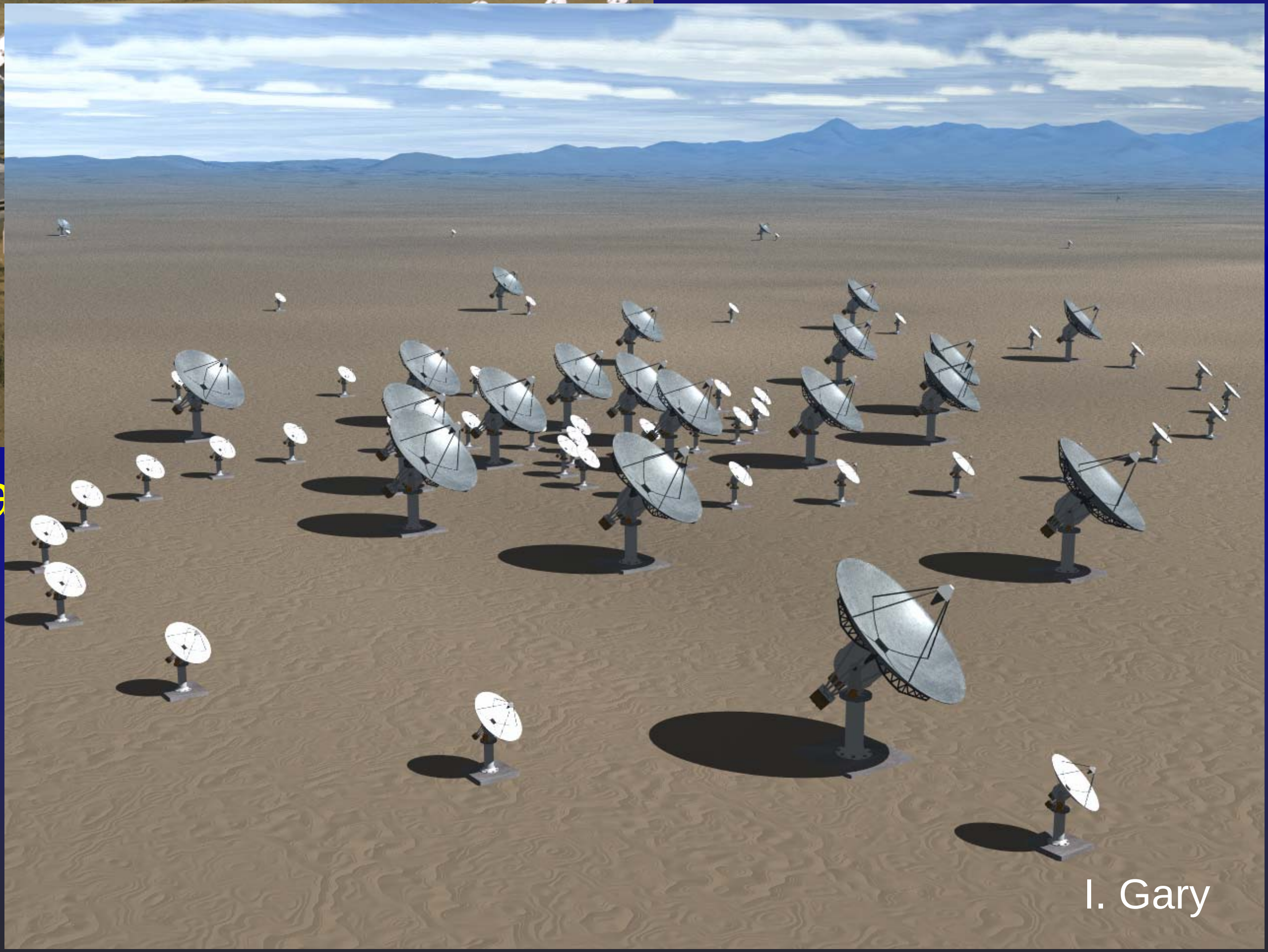
System Overview

- FASR will perform Fourier synthesis imaging
- It will be composed of sub-arrays of antennas, e.g.,

30-300 MHz	fixed LPDA or similar	~60 antennas
0.3-3 GHz	steerable 6 m para	~80 antennas
3-24 GHz	steerable 2m para	~100 antennas

- No cryogenics required
- Simple, robust electronics in the field
- Broadband data transmission on optical fiber links
- Use of interim archive for ~10 Tbytes/day
- Pipeline calibration, imaging, and deconvolution

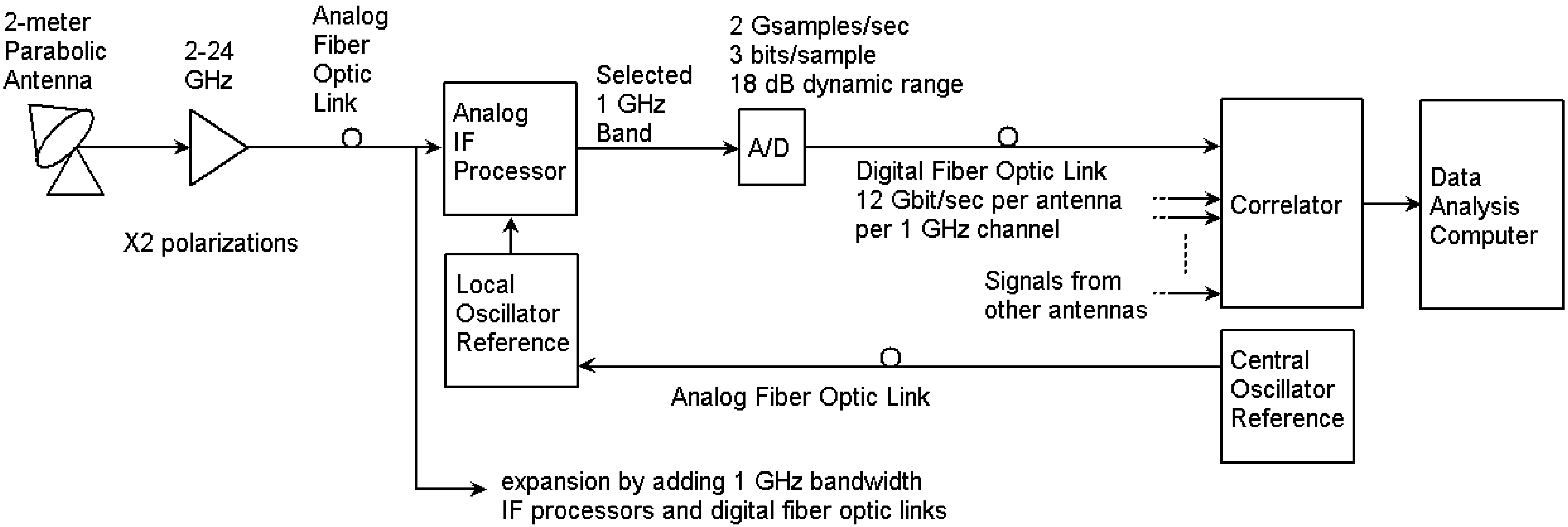
Nobeyama



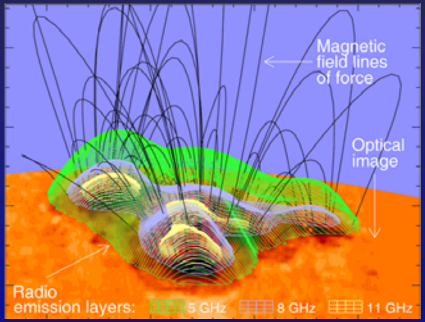
FASR Specifications

Frequency range	30 MHz - 30 GHz
Frequency resolution	1%, 30 - 300 MHz 0.1%, 0.3 – 3 GHz 1%, 3 – 18 GHz
Time resolution	100 ms, 30 – 300 MHz 10 ms, 0.3 – 3 GHz 100 ms, 3 – 18 GHz
Number antennas	~100 (4950 baselines) ~80 (3160) ~60 (1770)
Size antennas	LPDA, 6 m, 2 m
Polarization	Stokes IV(QU)
Angular resolution	$20/\nu_9$ arcsec
Footprint	~6 km
Field of View	>0.5 deg

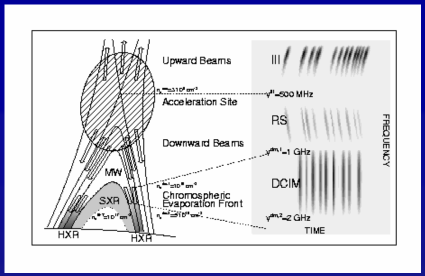
High Frequency Array Straw Man Block Diagram



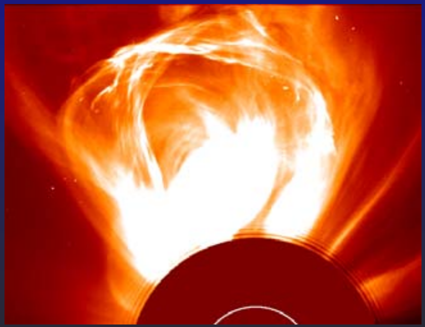
FASR Key Science



- ❑ Nature & Evolution of Coronal Magnetic Fields
  - Measurement of coronal magnetic fields
  - Temporal & spatial evolution of fields
  - Role of electric currents in corona
  - Coronal seismology

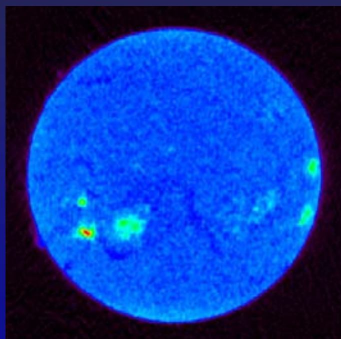


- ❑ Flares
  - Energy release
  - Plasma heating
  - Electron acceleration and transport
  - Origin of SEPs



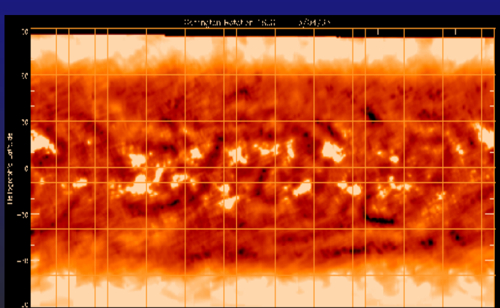
- ❑ Drivers of Space Weather
  - Birth & acceleration of CMEs
  - Prominence eruptions
  - Origin of SEPs
  - Fast solar wind streams

FASR Science (cont)



- ❑ The “thermal” solar atmosphere
  - Coronal heating - nanoflares
  - Thermodynamic structure & dynamics
  - Formation & structure of filaments

- ❑ Solar Wind
  - Birth in network
  - Coronal holes
  - Fast/slow wind streams
  - Turbulence and waves



- ❑ Synoptic studies
  - Radiative inputs to upper atmosphere
  - Global magnetic field/dynamo
  - Flare statistics

Summary

- FASR will perform broadband imaging spectroscopy of the Sun
- Imaging spectroscopy provides access to a number of unique diagnostics that have been unavailable to date
    - measurement of coronal magnetic fields
    - magnetic energy release
    - electron distribution function and its evolution
    - origin and propagation of MHD shocks/waves
- Imaging spectroscopy provides an integrated picture of solar phenomena from the chromosphere into the corona
- With STEREO/SWAVES and possibly, SIRA, FASR will provide an integrated picture of radio phenomena from the Sun to Earth
- FASR will be well-positioned to make new discoveries!

FASR Planning and Construction Phases

1. Implement a design and development plan (DDP), via a proposal to NSF/ATM under the leadership of the NRAO, that will result in a proposal to design, build and operate FASR
2. Transition the FASR project to a new center, institute, or observatory under management of AUI. This new organization would be responsible for implementing the proposal to design, build and operate FASR.

DDP Task Areas

1. Technical design of the instrument
2. Software and data management planning
3. Science and operations planning
4. Site evaluation and selection
5. Project implementation planning
6. Education and public outreach

Institutional Partners

- National Radio Astronomy Observatory
- University of Michigan
- University of California, Berkeley
- New Jersey Institute of Technology
- University of Maryland
- Caltech & JPL
- University of New Mexico
- Naval Research Lab
- Paris Observatory

Technical systems

Basic division of labor: NRAO – analog, U. Mich - digital

Antennas/optics: UCB, NRAO

Front ends: NRAO

RF/IF conversion: NRAO

LO and timing: JPL, NRAO

Phase switching and fringe rotation: NRAO, JPL

Calibration: NRAO, JPL, U. Mich.

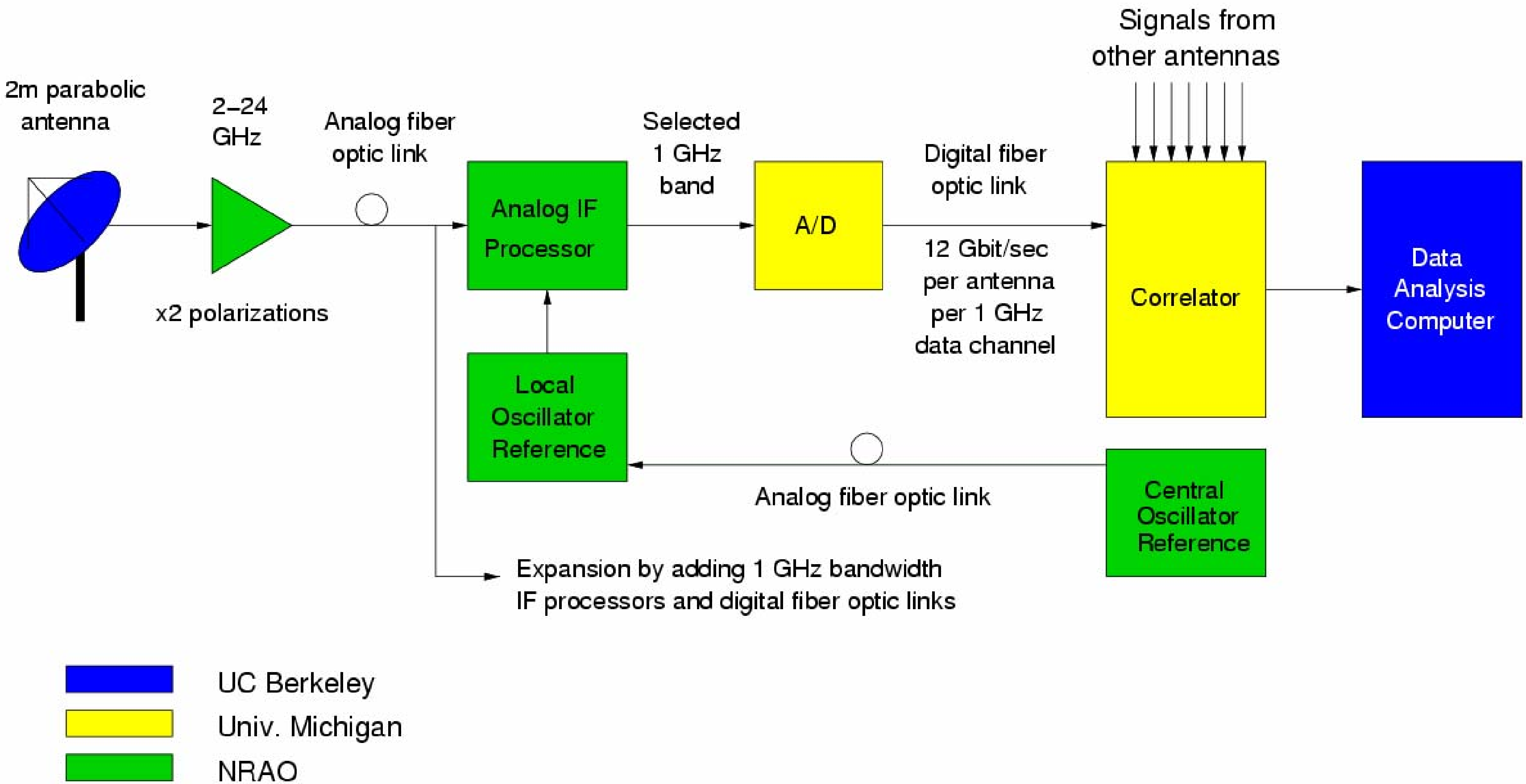
Analog signal distribution: NRAO

Digital signal distribution: U. Mich.

Analog to digital: U. Mich with input from NRAO, Paris Obs., NJIT

Correlator: U. Mich. with input from NRAO

High Frequency Array (FASR A)
Straw Man Block Diagram



Schematic Schedule

2005 FASR DDP proposal (NRAO)

2006 FASR proposal for construction and operation (AUI)

2007 Construction begins

2009 First FASR science

2011 Project completed

Focal Plane Arrays for the VLA?

Walter Brisken (NRAO)

and collaborators:

Christophe Craeye (UCL, Belgium)
Peter Napier, Rick Perley (NRAO)
Bruce Veidt (DRAO)

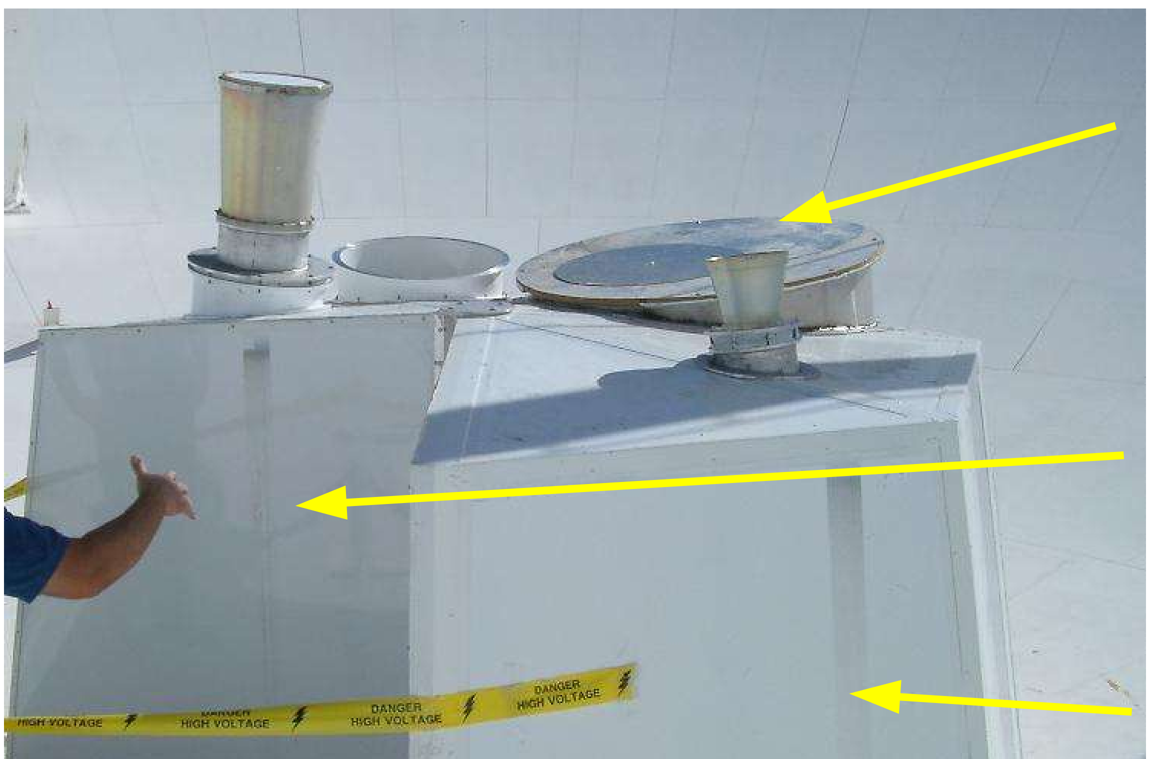
New Initiatives, Socorro, NM Dec 13, 2004

Extending frequency coverage downwards...

- Currently has 74 and 330 MHz dipoles
- Goal : complete the frequency coverage down to 240 MHz
  - Top of LOFAR / LWA band
- Originally part of EVLA phase II plan
  - 2 or 3 horn antennas at prime focus spanning the 240 to 1000 MHz band
  - Dropped because of complexity, cost

No room at secondary focus

- Feeds need to be 9λ wide to illuminate the subreflector efficiently
- 1.2 GHz is the lowest possible freq. here



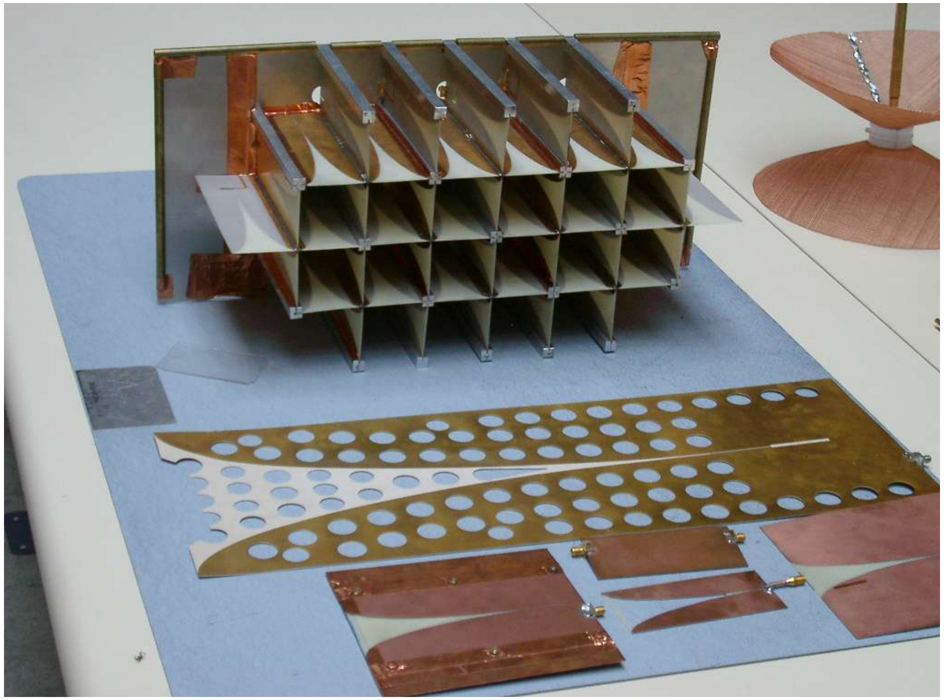
Prime focus is inaccessible

- Could rotate subreflector out of way
  - Allows space for several horn feeds
  - Expensive
  - Structural change
- Out of focus feed / off axis feed
  - Too inefficient
- Phased array feed
  - Add 0.3 m travel to subreflector
  - Deploy array feed in front

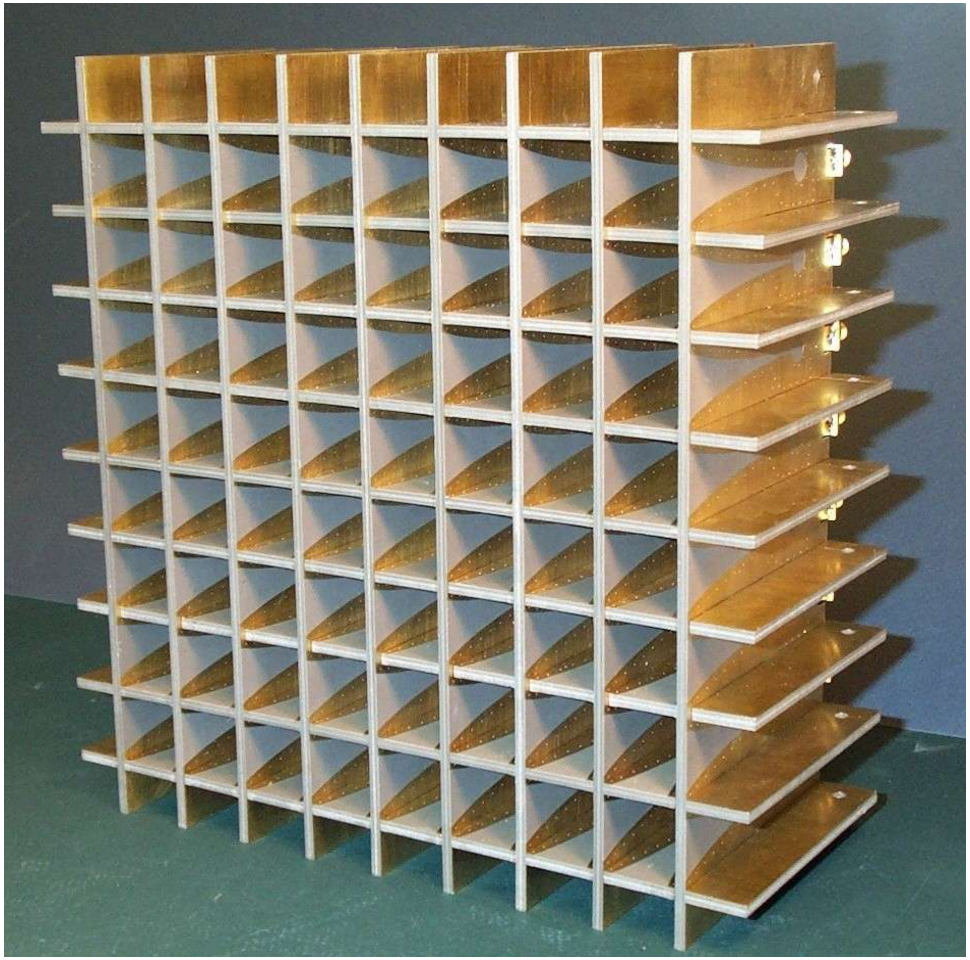
Phased Array Advantages

- Potentially low cost
- Minimal antenna changes required
  - Add additional travel to subreflector
- Performance
  - Phased beam can be highly optimized
- Multi-beam possibility

Vivaldi Arrays



Vivaldi elements and array designed and
built by Ed Reid at DRAO.



UMass Antenna Lab designed, fabricated and
tested the above 8x9x2 array. Support was
from ASTRON. Picture courtesy Dan Schaubert.

Finite Vivaldi Array Properties

- Elements are tightly coupled
  - Each element has a different beam pattern
    - Edge elements are the most exceptional
  - Element patterns are freq. dependent
  - Coupling exploited to increase bandwidth
- Bandwidth ratios of 5:1 are possible
- Shortest useful wavelength is about 2 element spacings

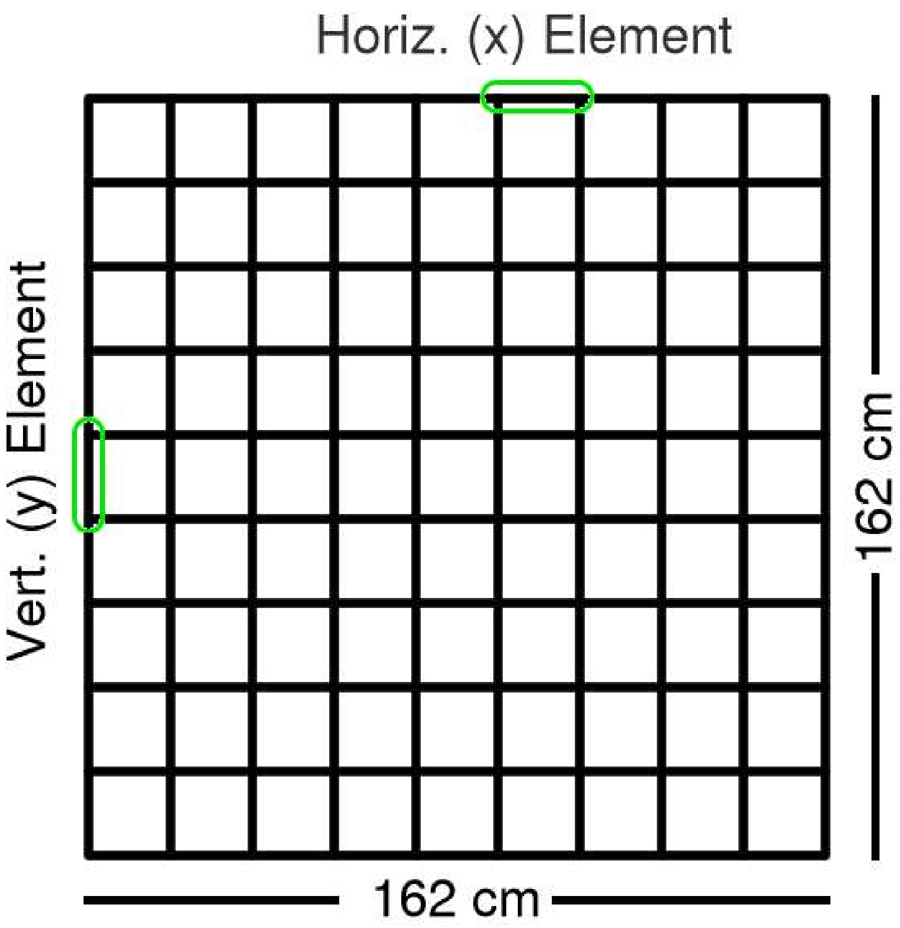
Goals of a detailed study for the VLA

- Synthesize wide-band feed with vivald array
- Use realistic Vivaldi beam patterns
- Use a realistic VLA antenna model
- Incorporate physical optics
- Determine array suitability based on
  - G/T_{sys}
  - phasing bandwidth
  - phased beam shapes

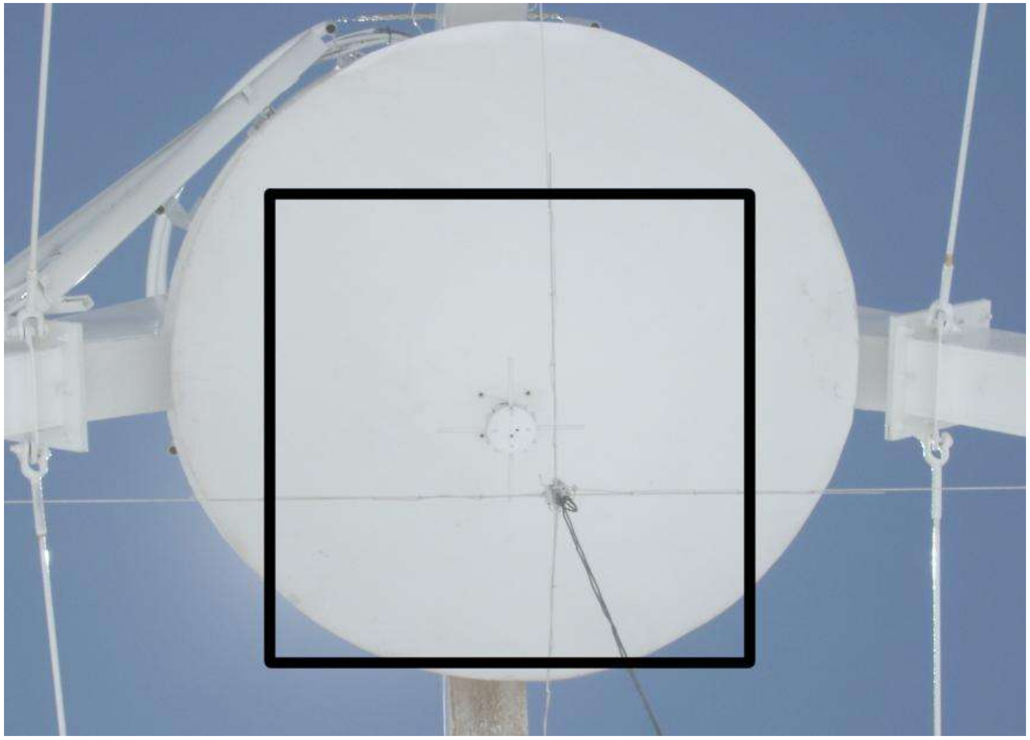
Vivaldi Array Model

- 180 elements: 9x10 array for each linear polarization
- Element size
  - 18 cm wide (1/2λ at 833 MHz)
  - 29.5 cm deep
- Operating range: <250 – 800 MHz
- Array centered at antenna prime focus

Vivaldi Array Geometry



9x10x2 Vivaldi Array

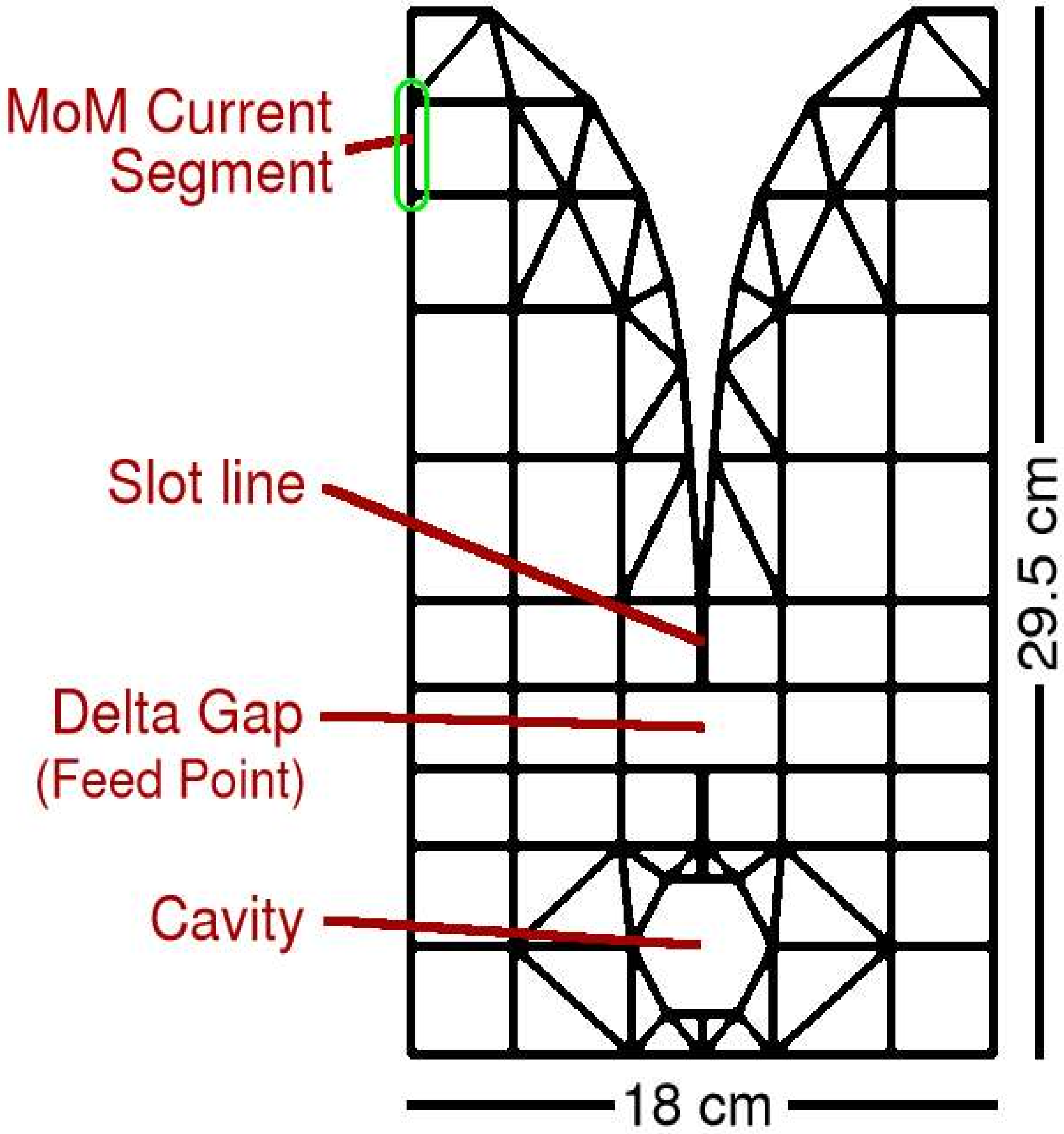


Size of array compared
to VLA subreflector

Vivaldi Element Patterns

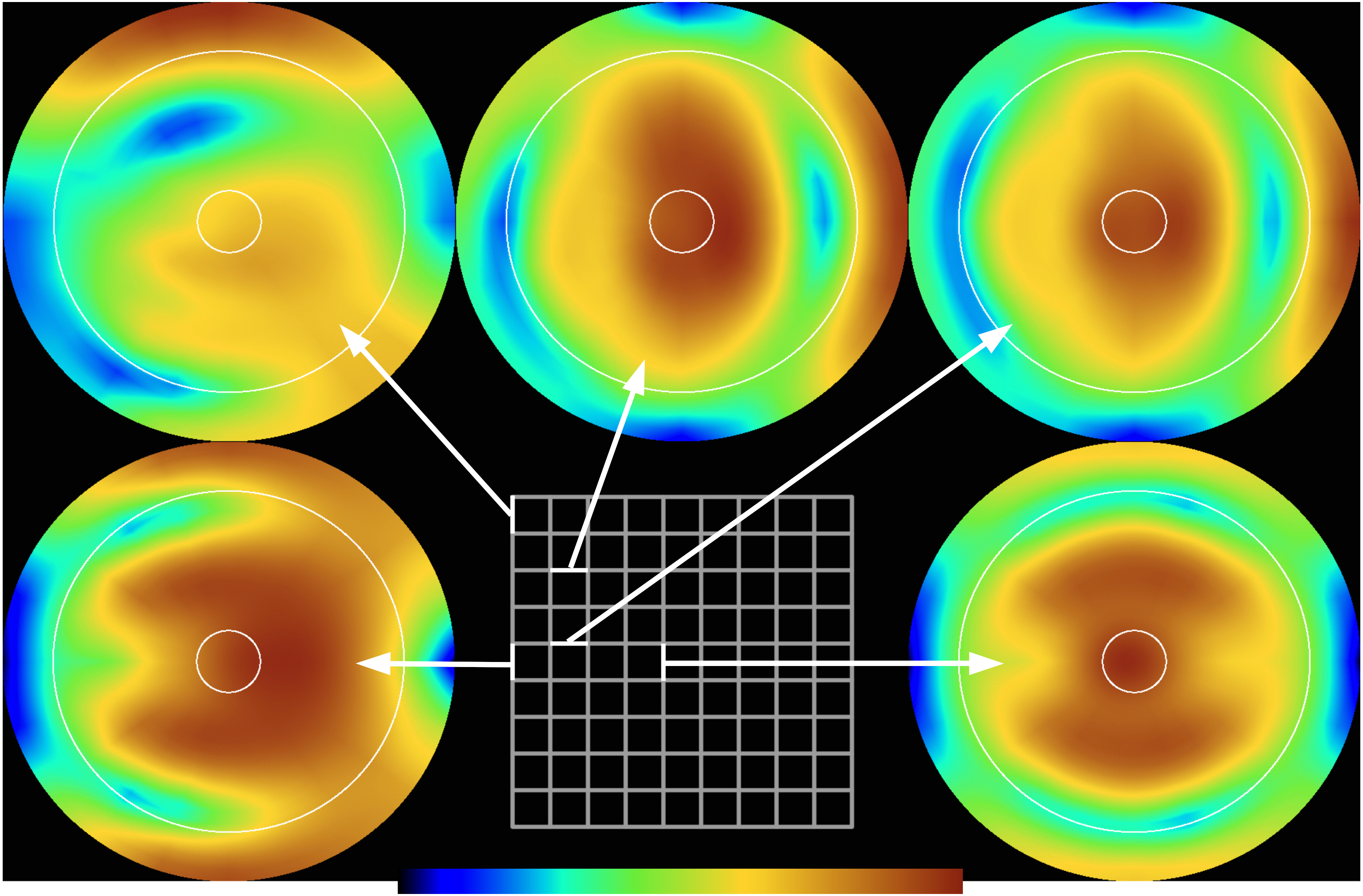
- Computed by Christophe Craeye (UCL)
- Method of Moments (MoM) used
- Each element pattern computed assuming all others are terminated
- Assumes infinite ground plane
  - Restriction can be lifted in future
- Computed for 25 elements – the others follow from symmetry
- Ohmic losses ignored

Element Geometry

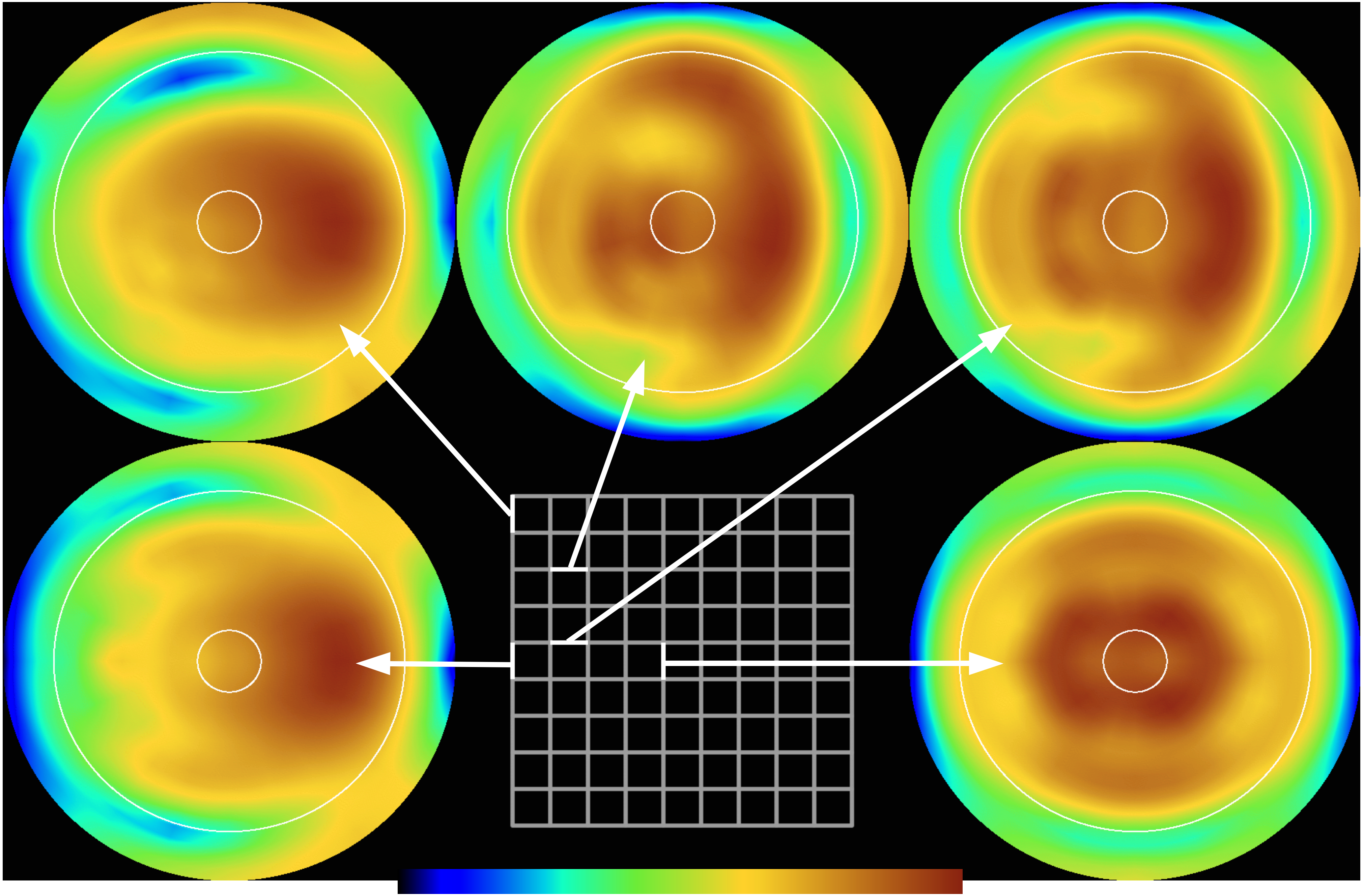


(Modified figure of C. Craeye. Gridding done by X. Dardenne)

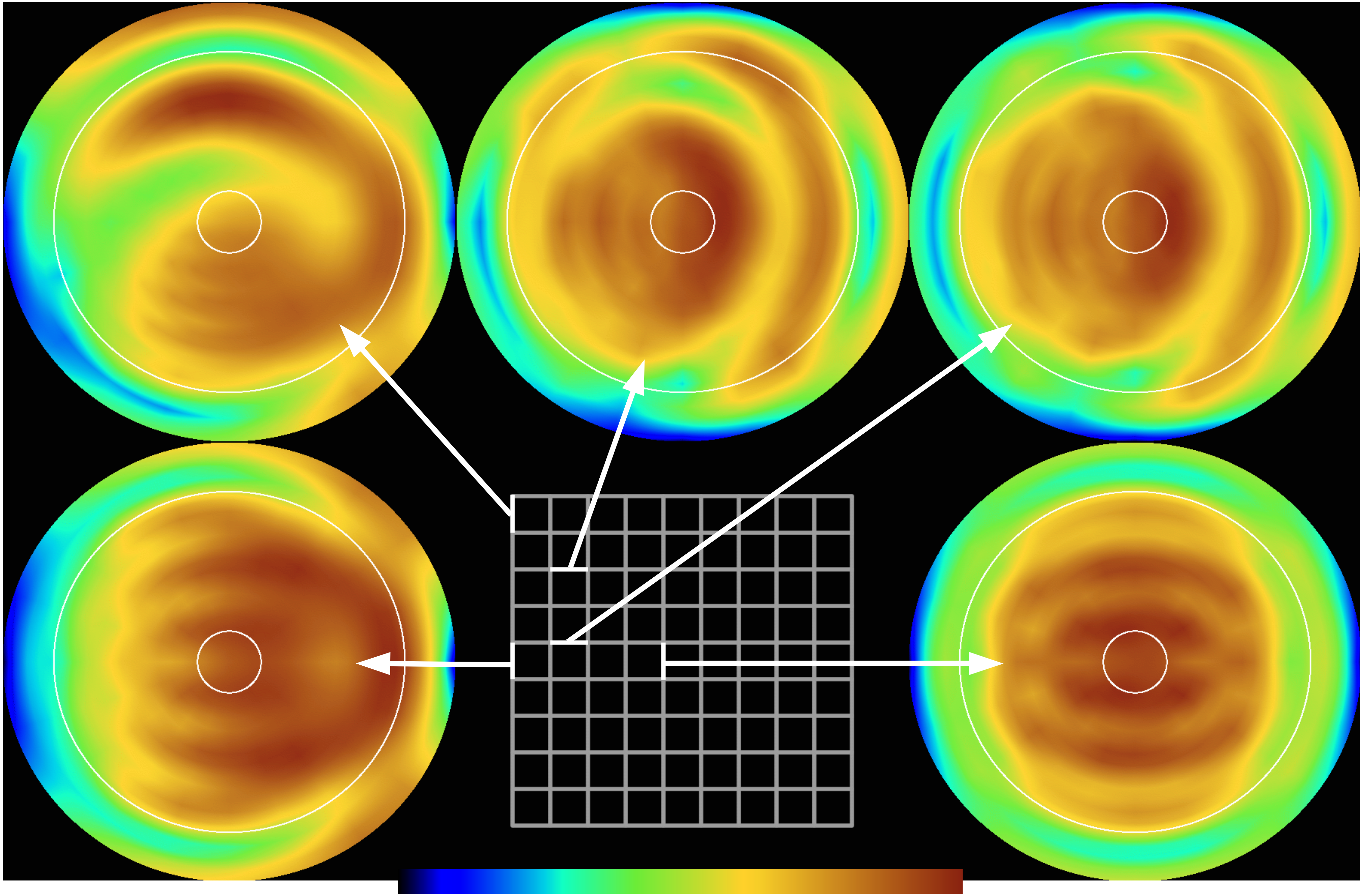
311 MHz Element Patterns



500 MHz Element Patterns



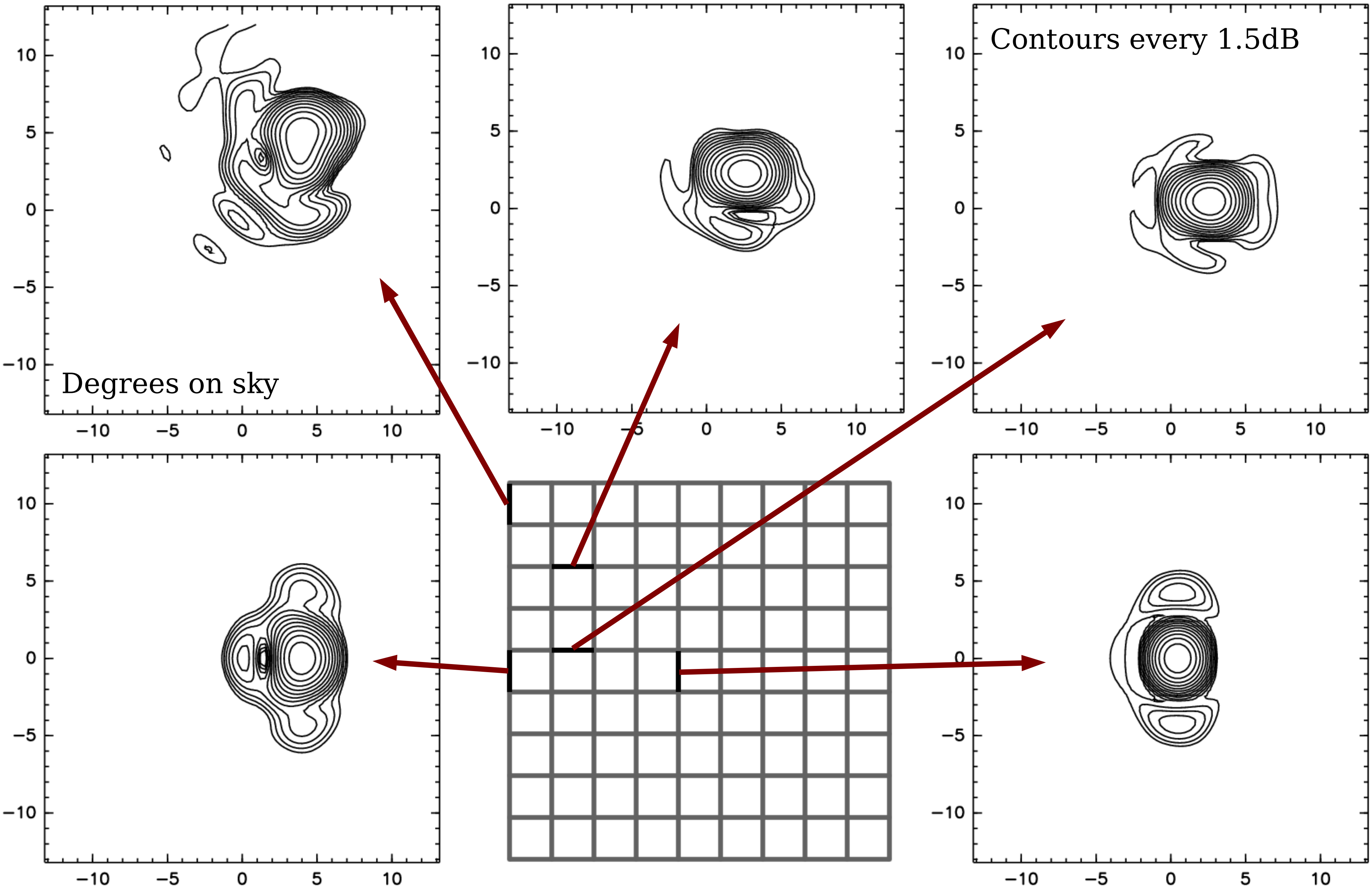
760 MHz Element Patterns



Antenna Model

- Shaped 25 m diameter primary
- 4 struts
- Subreflector
- Ticra's Grasp8 software used
- Approximations
  - Feed cone is symmetric
  - No scattering off of focal plane

311 MHz Antenna Patterns



Optimize beam pattern

- Assign a complex weight to each element.
- Express G and T_{sys} as functions of these weights
- Solve for weights giving maximal G/T_{sys}
- Sum beam patterns with these weights

Weights I: Total Power

Power Pattern

$$\frac{dP}{d\Omega}(\theta, \phi) = \frac{1}{2\eta} \left| \vec{E}_{\mathrm{a}}(\theta, \phi) \right|^2$$

Total Power

$$P_{\mathrm{tot}} = \int d\Omega \, \frac{dP}{d\Omega}(\theta, \phi)$$

$$= \vec{w}^H \cdot \mathbf{P} \cdot \vec{w}$$

Elements of Power Hermitian matrix

$$P_{ij} = \frac{1}{2\eta} \int d\Omega \, \vec{E}^*_{\mathrm{a},i} \cdot \vec{E}_{\mathrm{a},j}$$

Weights II: Forward gain

X-polarized forward gain

$$G_{\mathrm{X}} \equiv 4\pi \frac{\frac{dX}{d\Omega}(0,0)}{P_{\mathrm{tot}}} = \frac{2\pi}{\eta} \frac{\left|\vec{E}_{\mathrm{a}}(0,0)\cdot \mathbf{e}_X\right|^2}{P_{\mathrm{tot}}}$$

X-polarized power pattern

$$\frac{dX}{d\Omega}(0,0) = \frac{1}{2\eta}\left|\vec{E}_{\mathrm{a}}(0,0)\cdot \mathbf{e}_X\right|^2$$

$$G_{\mathrm{X}}(\vec{w}) = \frac{\vec{w}^H \cdot \mathbf{G}_{\mathrm{X}} \cdot \vec{w}}{\vec{w}^H \cdot \mathbf{P} \cdot \vec{w}}$$

Elements of X-polarized gain Matrix

$$G_{\mathrm{X}ij} = \frac{2\pi}{\eta}\left(\vec{E}_{\mathrm{a},i}(0,0)\cdot \mathbf{e}_X\right)^*\left(\vec{E}_{\mathrm{a},j}(0,0)\cdot \mathbf{e}_X\right)$$

Weights III: System Temperature

System temperature

$$T = \frac{\int d\Omega\ \left(T_{\rm rad}(\theta,\phi) + T_{\rm rec}\right) P(\theta,\phi)}{P_{\rm tot}}$$

Expressed as function of weights

$$T(\vec{w}) = \frac{\vec{w}^H \cdot \mathbf{T} \cdot \vec{w}}{\vec{w}^H \cdot \mathbf{P} \cdot \vec{w}}$$

Elements of Temperature matrix

$$T_{ij} = \frac{1}{2\eta} \int d\Omega\ \left(T_{\rm rad}(\theta,\phi) + T_{\rm rec}\right) \times \vec{E}^*_{{\rm a},i}(\theta,\phi) \cdot \vec{E}_{{\rm a},j}(\theta,\phi)$$

Optimization of G/T_{sys}

Maximize ratio of gain to T_{sys}

$$R(\vec{w}) \equiv \frac{G_X(\vec{w})}{T(\vec{w})} = \frac{\vec{w}^H \cdot \mathbf{G}_X \cdot \vec{w}}{\vec{w}^H \cdot \mathbf{T} \cdot \vec{w}}$$

Employ Cholesky Decomposition

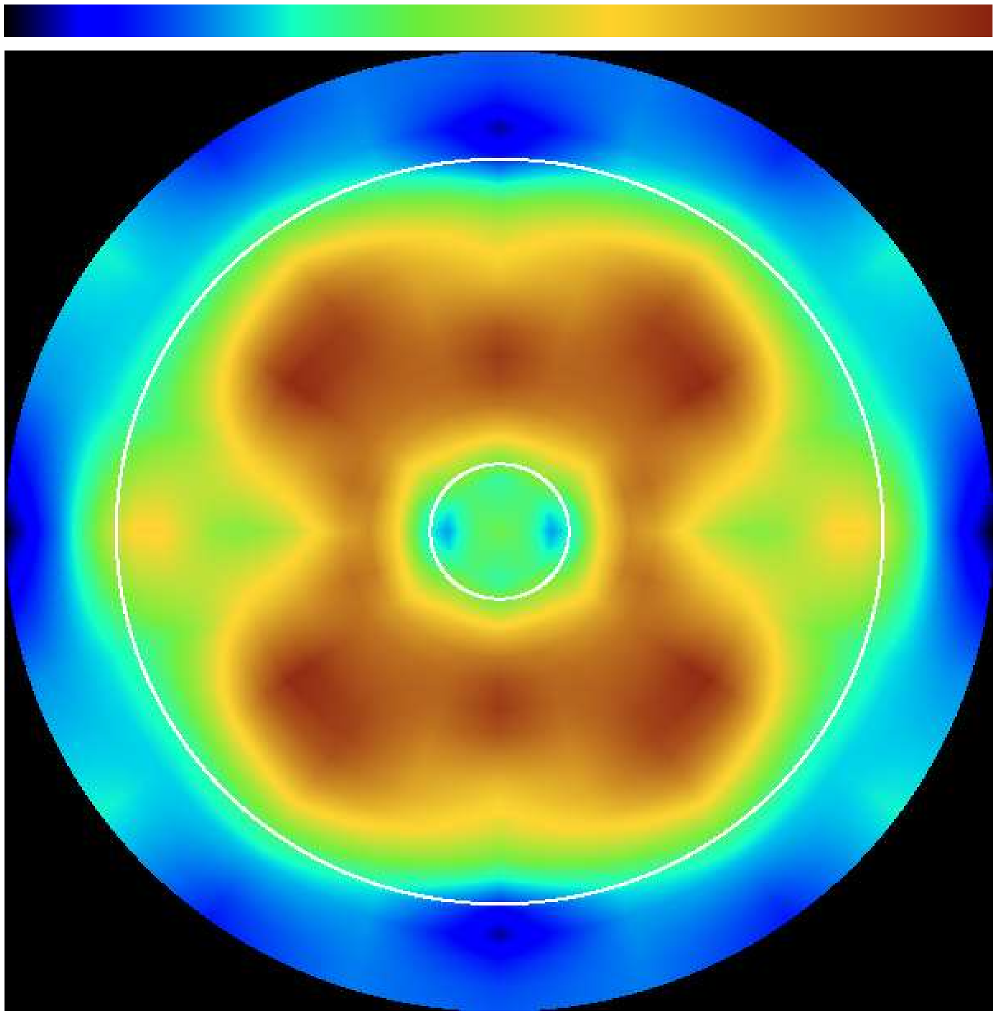
$$\begin{aligned}
\mathbf{T} &= \mathbf{L} \cdot \mathbf{L}^H \\
\vec{w} &= \mathbf{L}^{H^{-1}} \cdot \vec{z} \\
\vec{w}^H &= \vec{z}^H \cdot \mathbf{L}^{-1} \\
\mathbf{G}_X &= \mathbf{L} \cdot \mathbf{M} \cdot \mathbf{L}^H
\end{aligned}$$

Solve for z using eigenvector techniques

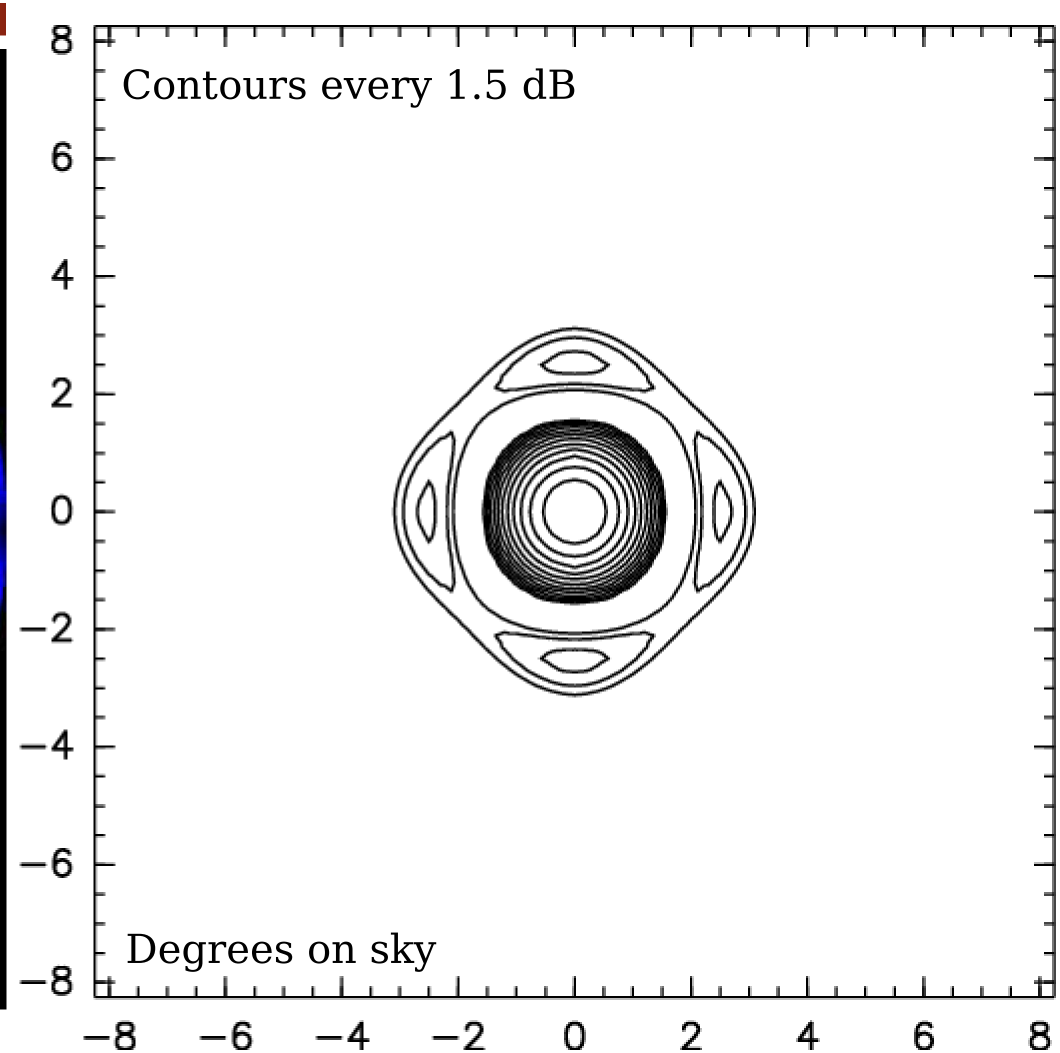
$$R(\vec{z}) = \frac{\vec{z}^H \cdot \mathbf{M} \cdot \vec{z}}{\vec{z}^H \cdot \vec{z}}$$

500 MHz Results (1)

Phased-array and antenna patterns



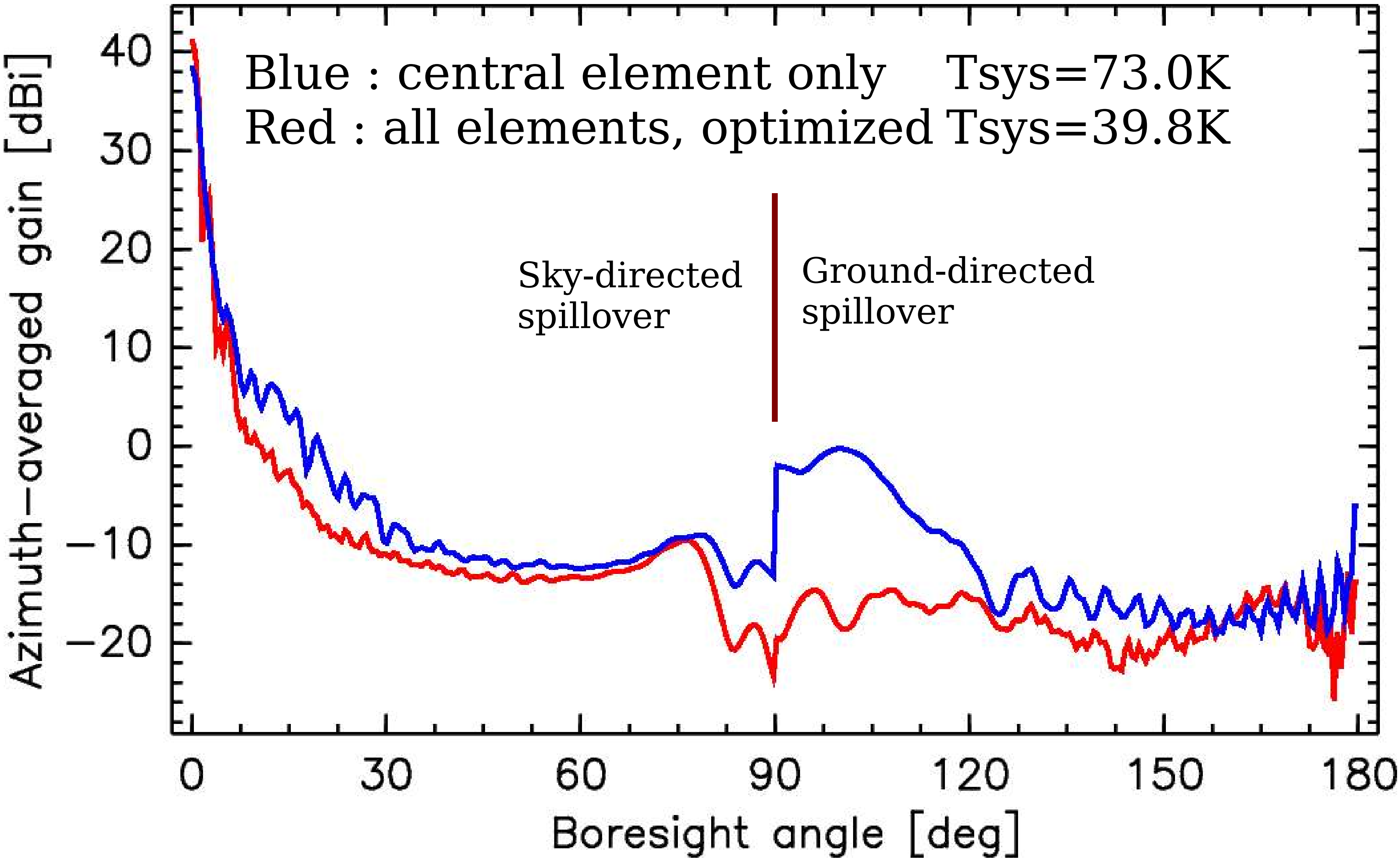
Optimized phased-array pattern



Optimized antenna beam

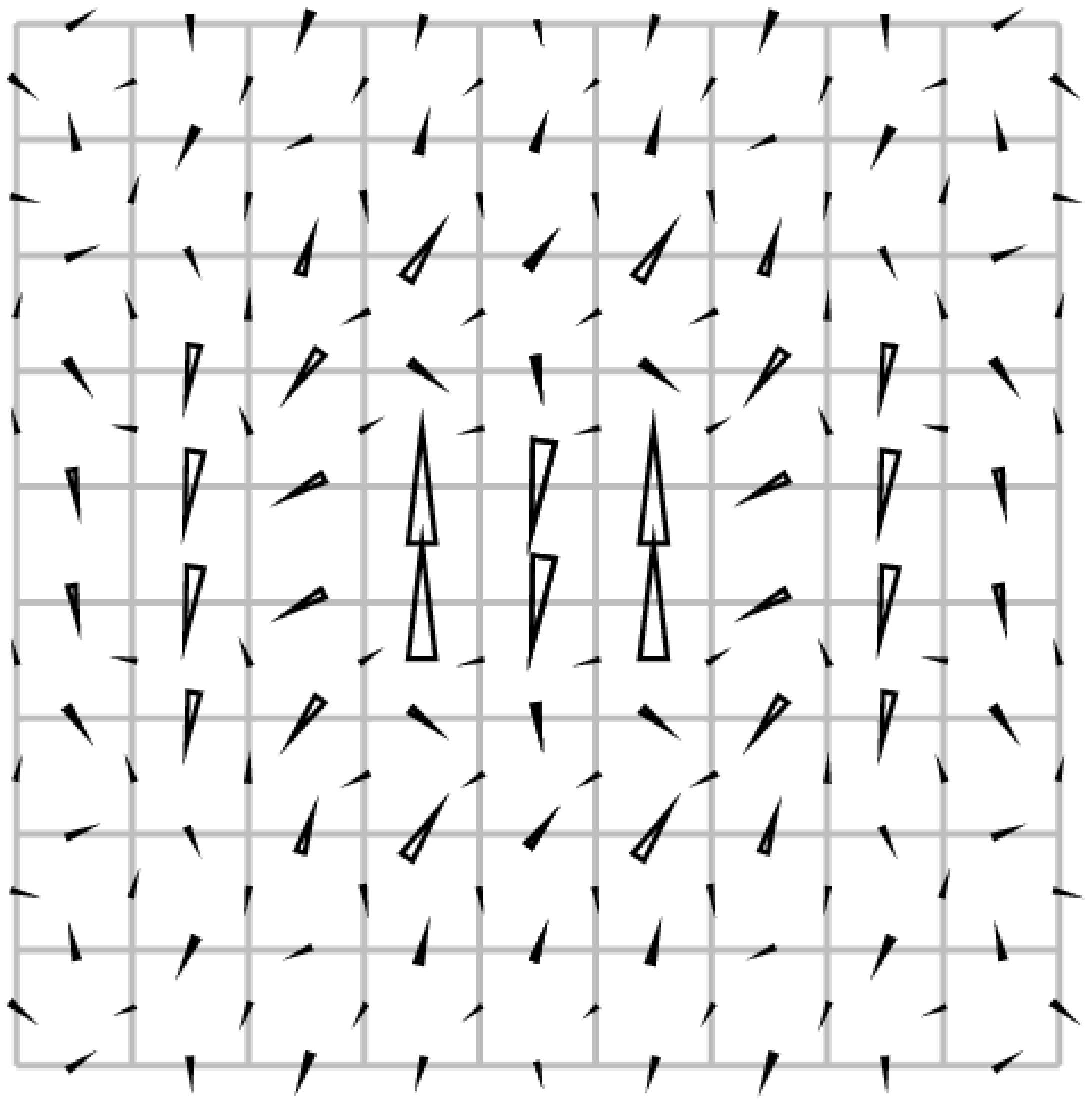
500 MHz Results (2)

Spillover cancellation



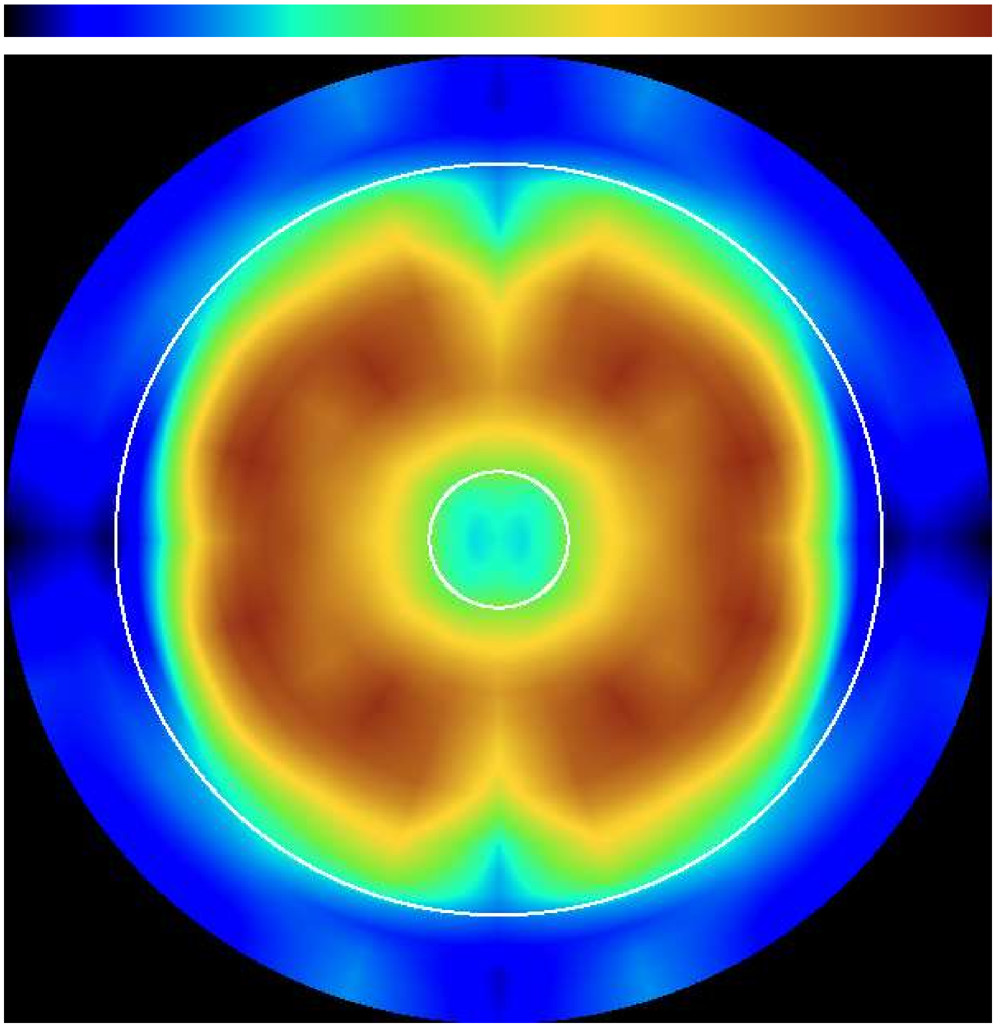
500 MHz Results (3)

Element weights

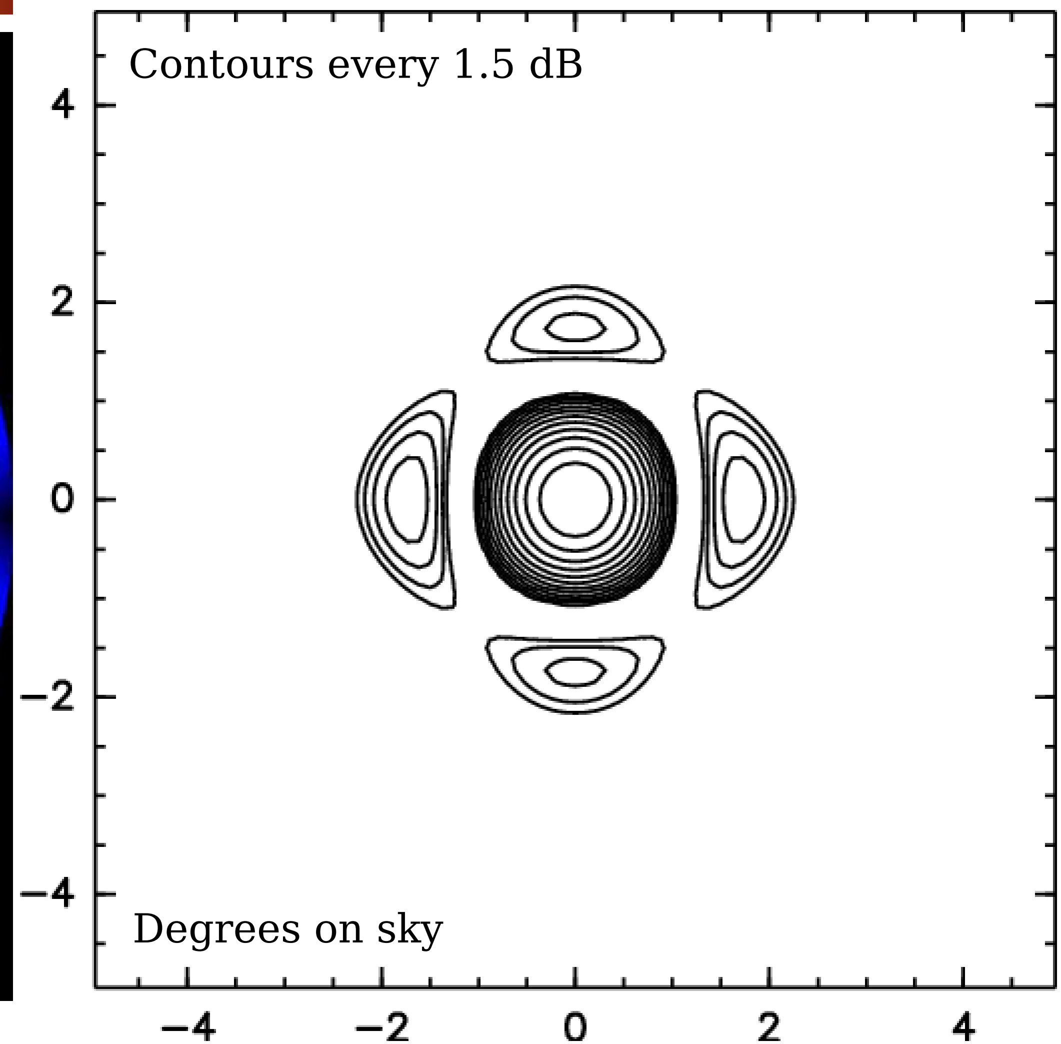


760 MHz Results (1)

Phased-array and antenna patterns



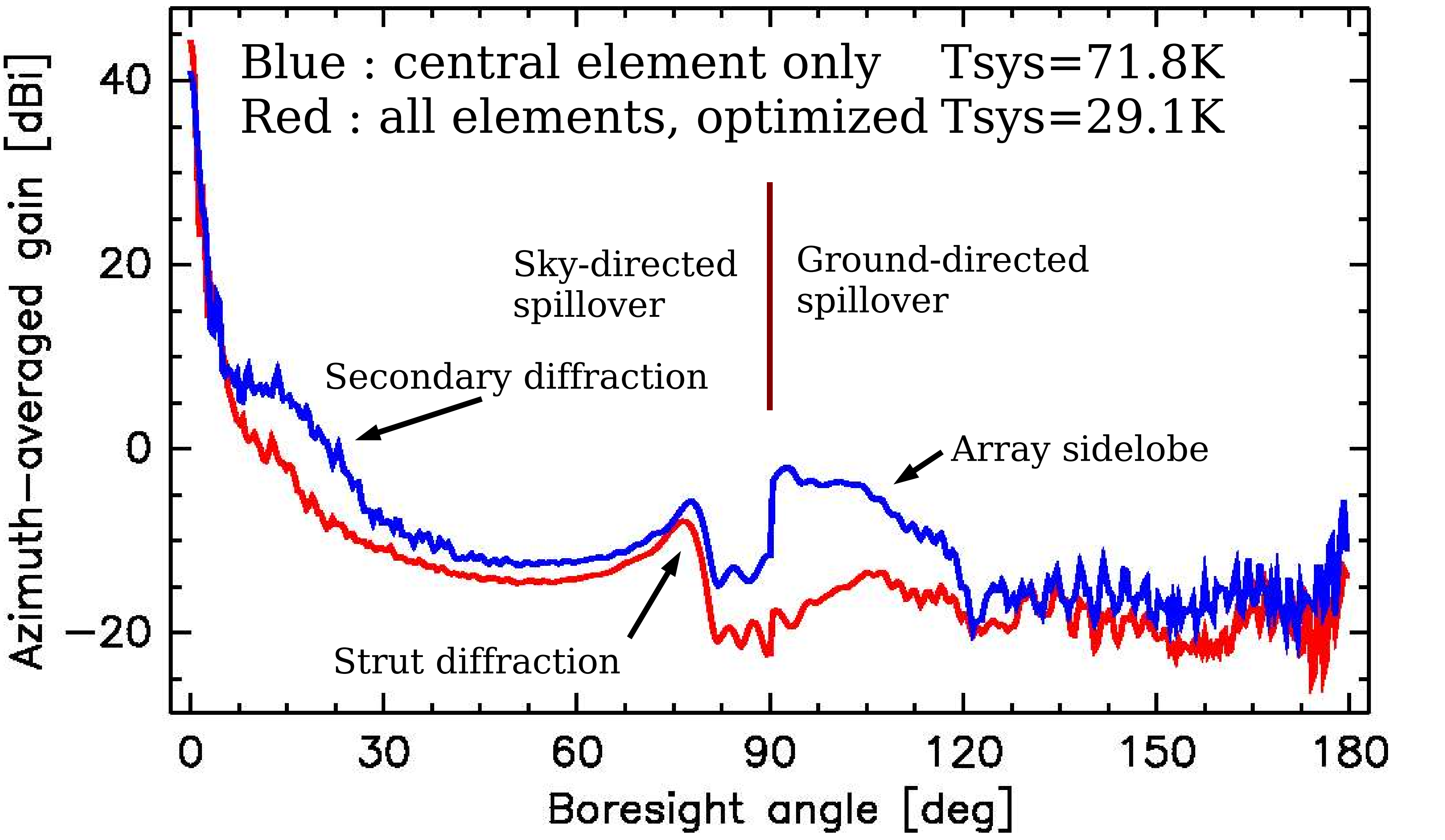
Optimized phased-array pattern



Optimized antenna beam

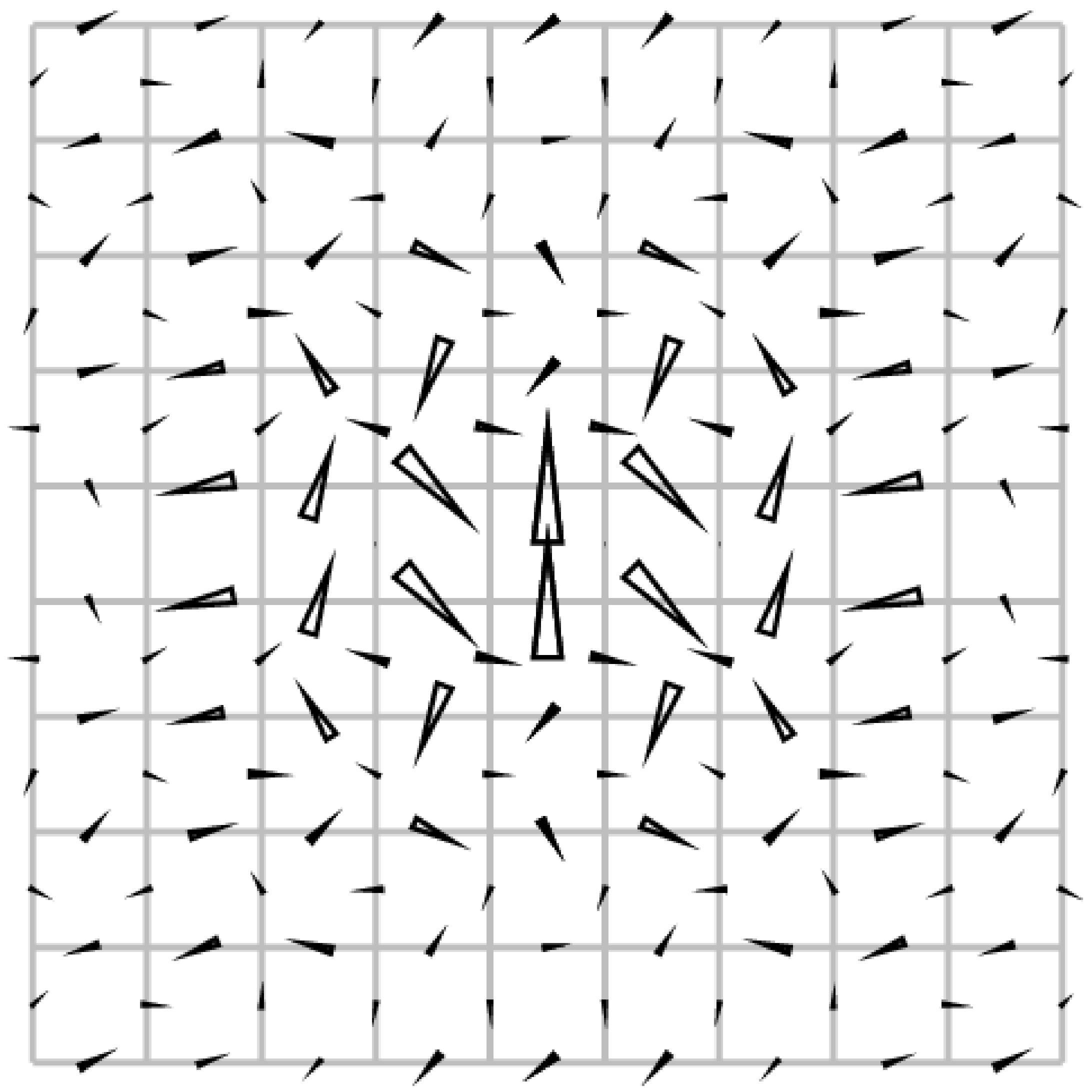
760 MHz Results (2)

Spillover cancellation

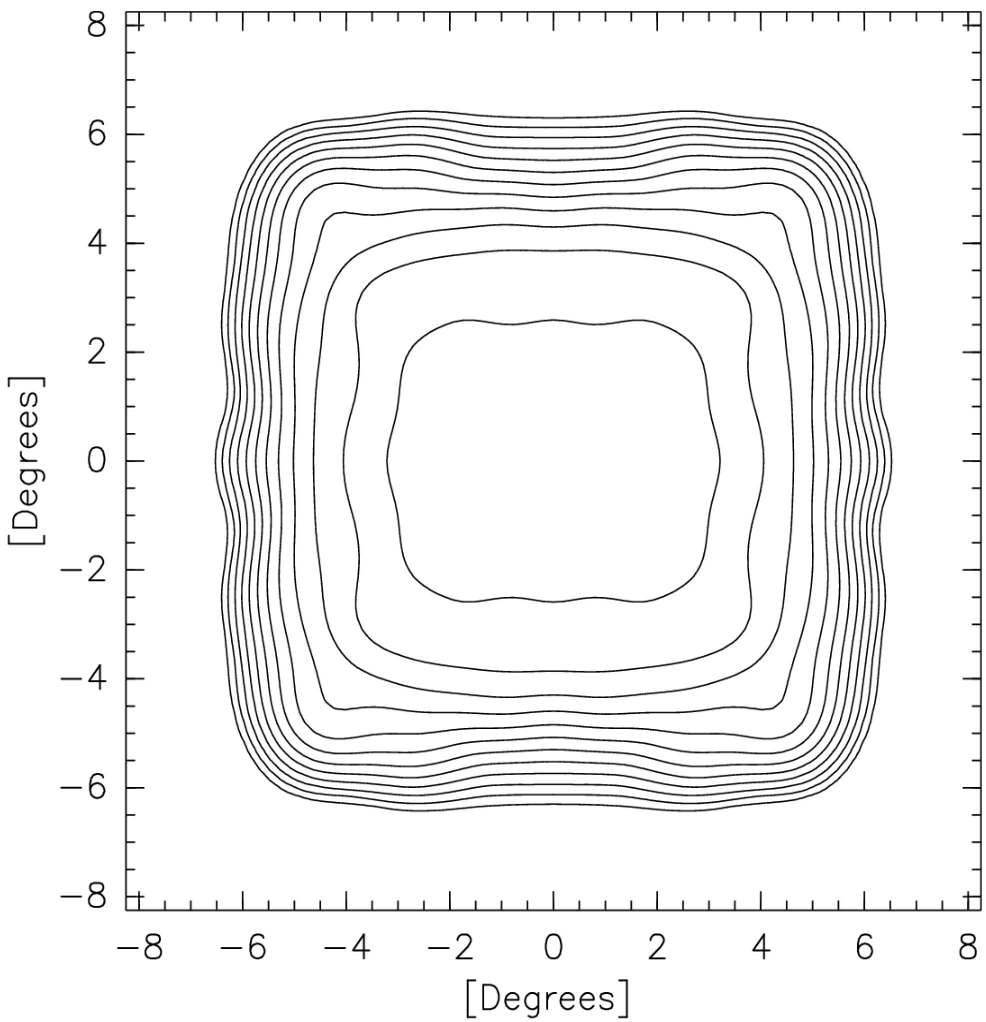


760 MHz Results (3)

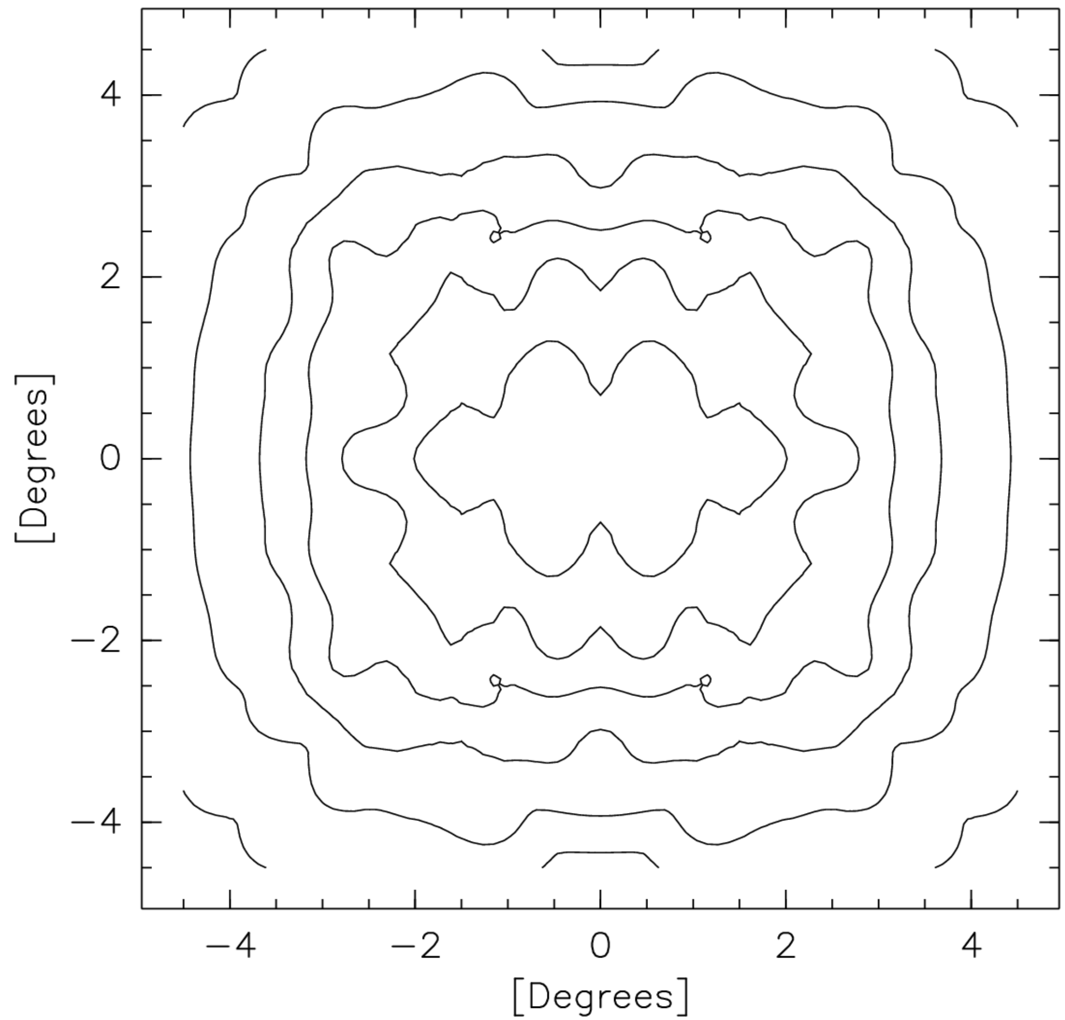
Element weights



X-pol offset phasing

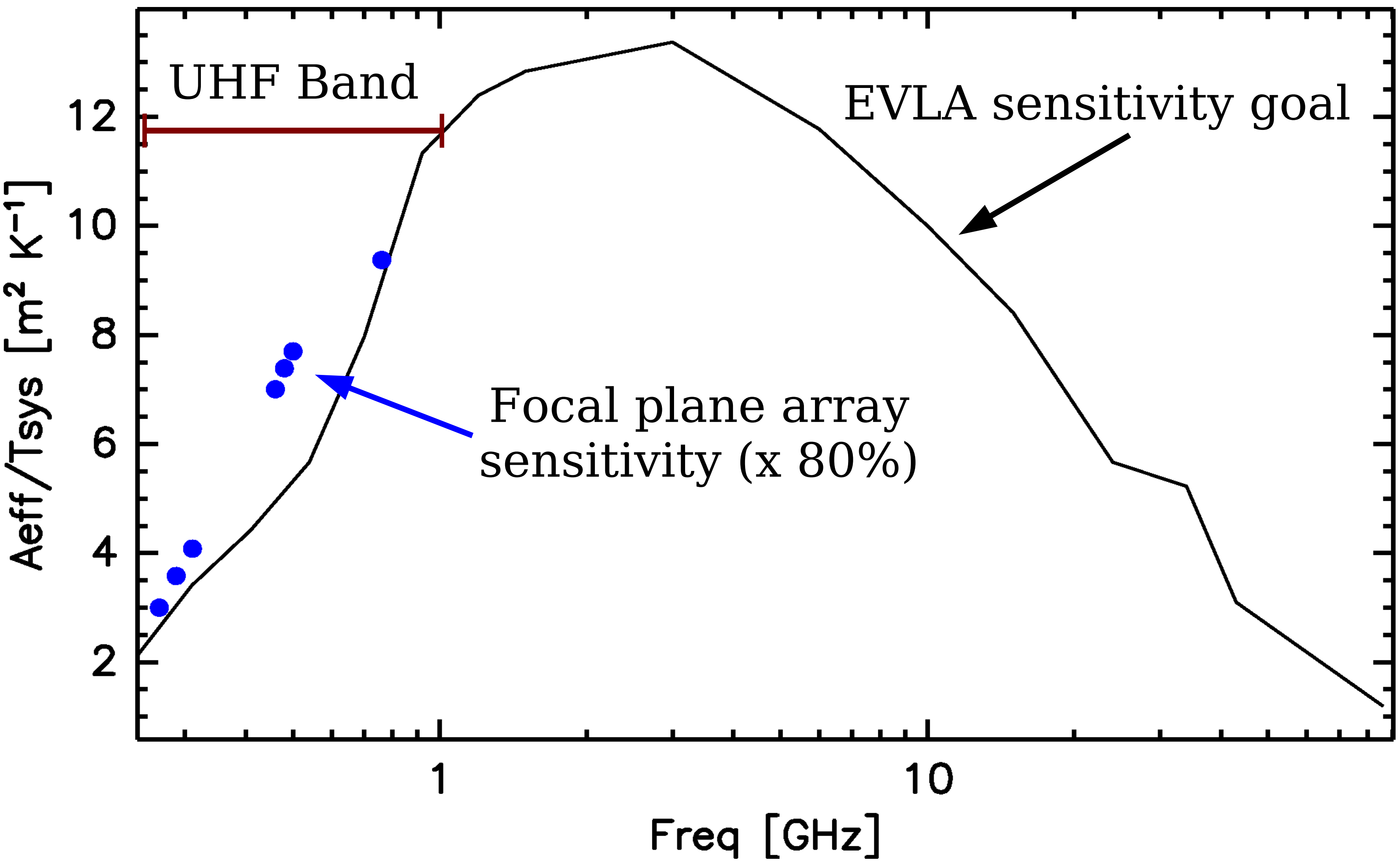


500 MHz



760 MHz

Performance



Conclusions

- Great performance is possible!
- Useful tunable bandwidth > 2.5:1
- Useful cophased BW > 1.25:1 (20%)

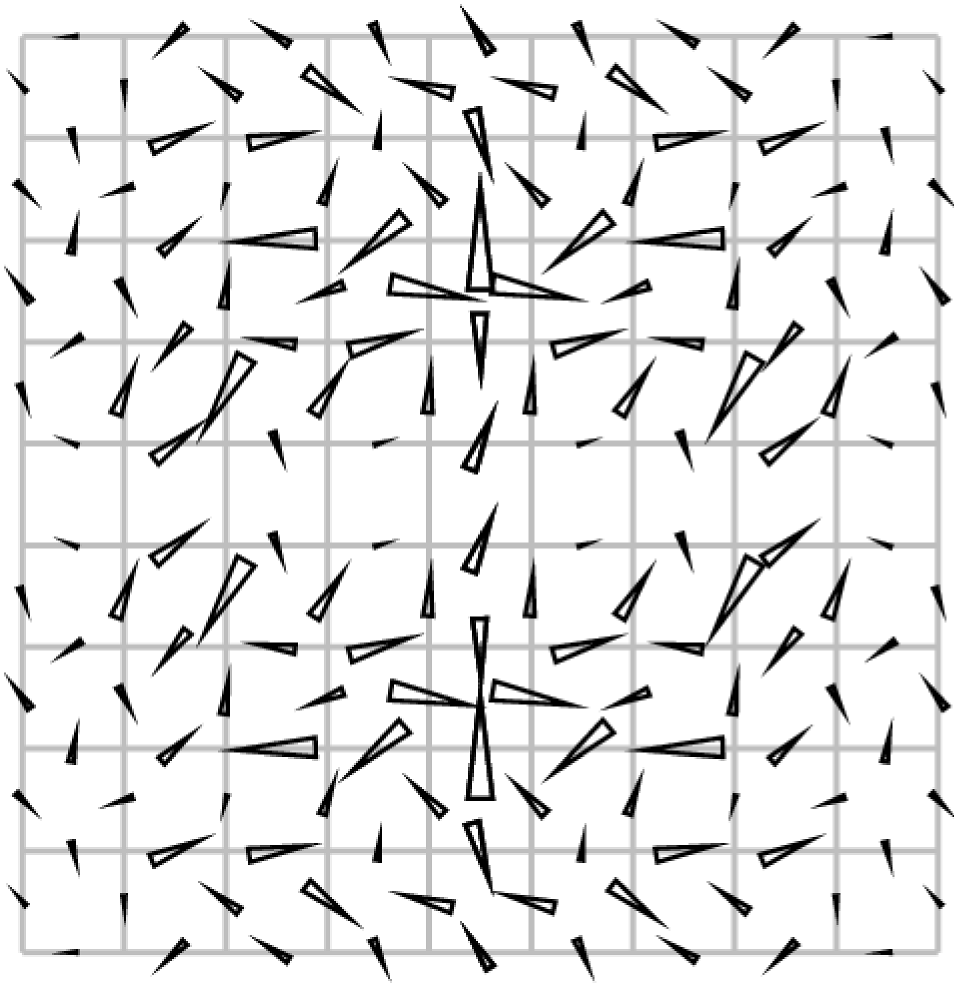
Future Directions

- Use finite ground plane
- Use more realistic elements
  - Add dielectric
  - Simulate new balun
- Optimize over a finite bandwidth
  - Mathematics becomes tricky and figure of merit is less well defined
- Receiver noise should be investigated
  - Is noise corellated?
  - Ohmic loss

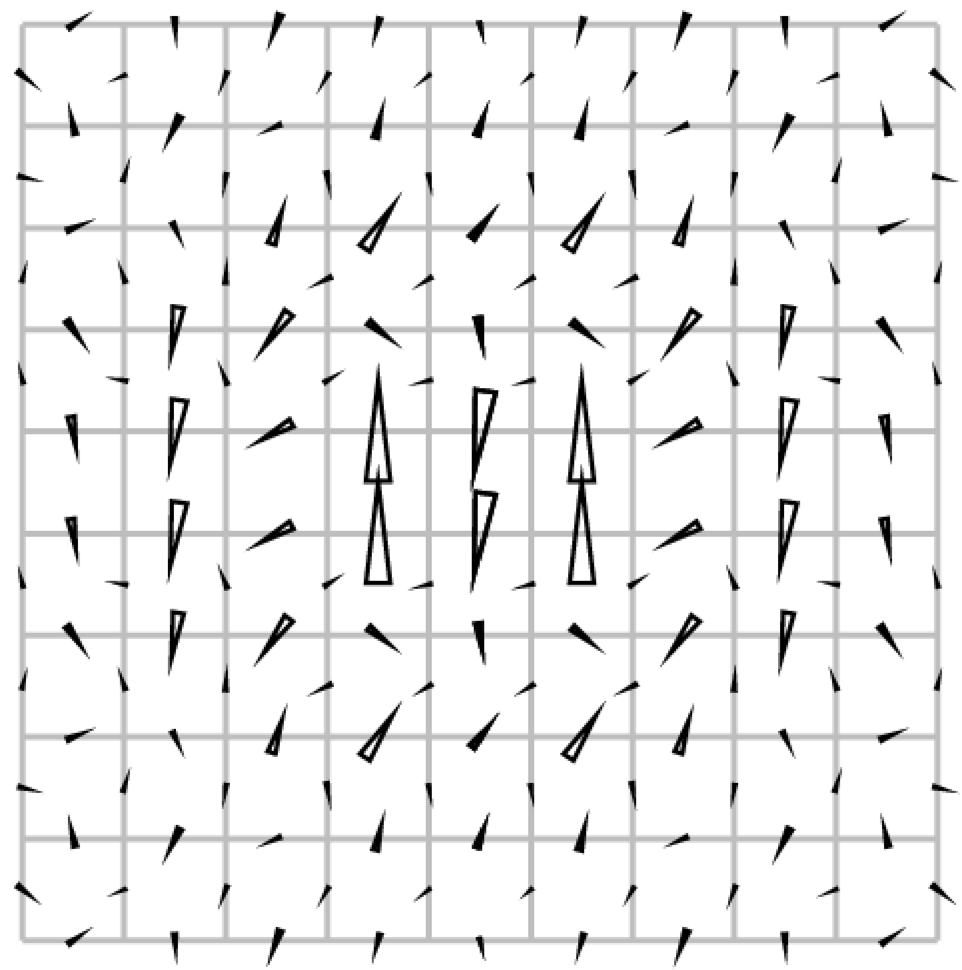
The End

500 MHz Results (3)

Element weights



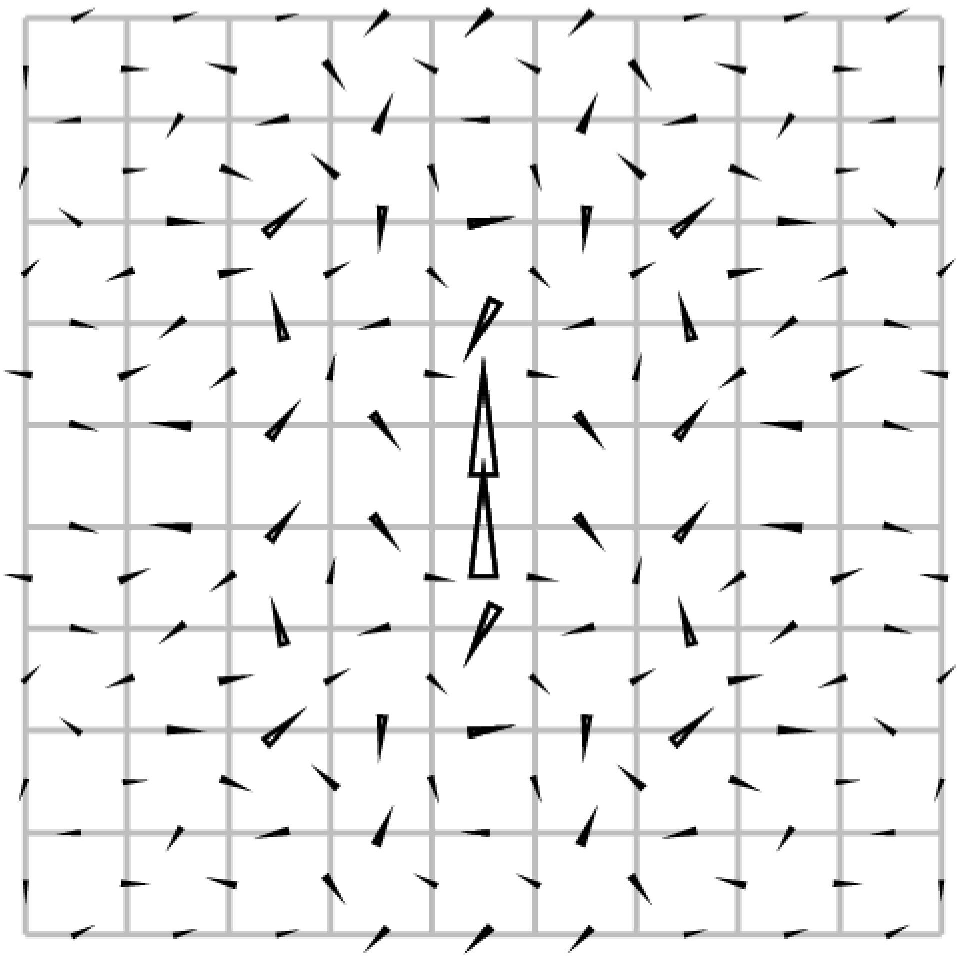
Voltage weights



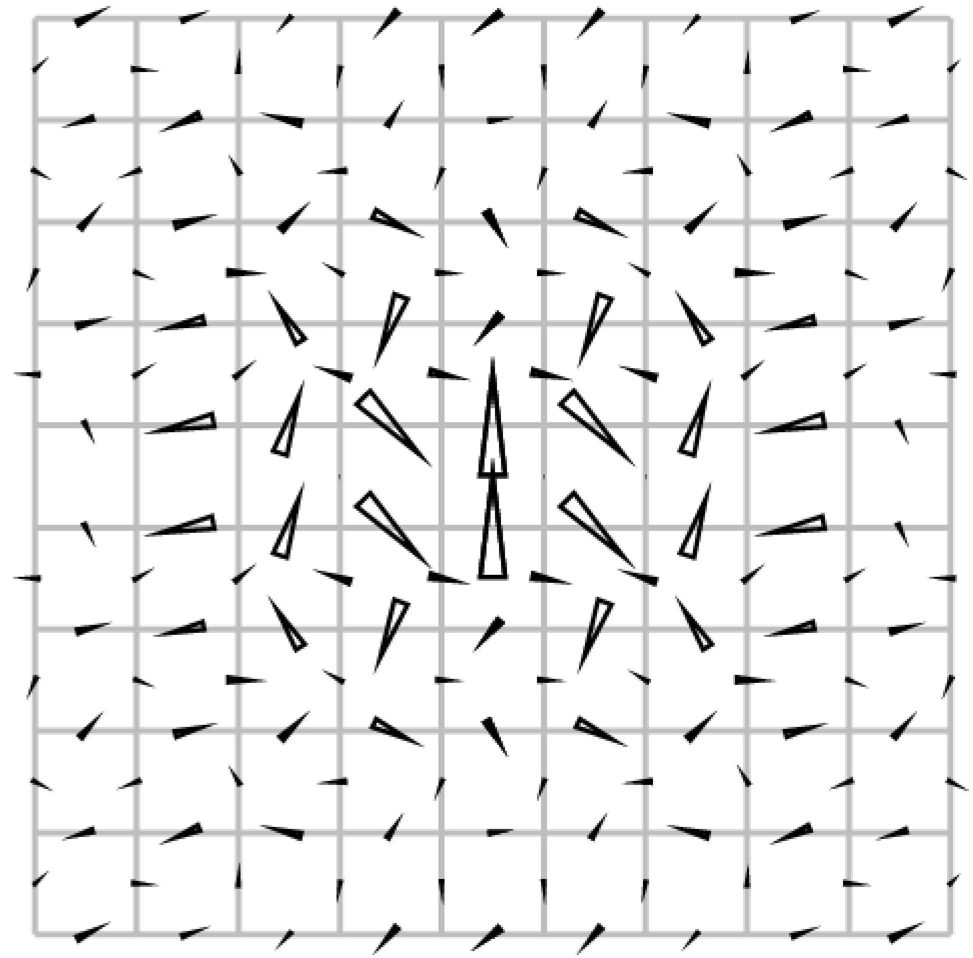
Current weights

760 MHz Results (3)

Element weights



Voltage weights



Current weights

TODO

- Efficiency as func of number of phased elements
- Broad band optimization
- Delays, not phases

VLBA Upgrade

A Response to the VLBI Future Report

R. Craig Walker

Socorro NM

(Yes, we need a better name)

Associated Universities, Inc.

NRAO

VLBI FUTURE REPORT

- "Mapping the Future of VLBI Science in the U.S."
  - Prepared by committee of 9 convened by the directors of NRAO and MIT Haystack Observatory
    - Led by Greg Taylor and Colin Lonsdale
  - Result of a year-long activity consulting many in the U.S. VLBI community and the broader scientific community
  - Submitted to NSF
- Reviewed scientific highlights of VLBI and VLBA
- Projected future science prospects
- Presented a technical roadmap

VLBI FUTURE REPORT RECOMMENDATIONS

- Hardware investment
  - Implement Mark 5 disk based recording on the VLBA, with priority
  - Equip Arecibo and the Green Bank Telescope with state of the art VLBI equipment, and increase participation of these facilities with the VLBA and global VLBI
  - Perform inexpensive upgrades to exploit the full 22-86 GHz performance potential of the VLBA antennas.
  - Investigate connections with the Expanded VLA (ELVA) and future facilities to enhance VLBI capabilities.
  - Support the development of sensitive VLBI at millimeter wavelengths using new and planned telescopes such as SMA, CARMA, LMT, and ALMA.

VLBI FUTURE REPORT RECOMMENDATIONS

- Software investments:
  - Dedicate new resources at the 3 to 5 person level, for the purpose of overhauling user software support for the VLBA, and for global VLBI
  - Coordinate these activities with foreign partners, and the US university community
- Astronomical community investments:
  - Provide a funding mechanism for the improved support of graduate students at US universities to work on VLBI related research. Multiple possible avenues are identified and should be explored
  - Investigate the provision of funds for financial support attached to time granted to US observers on VLBI networks.

VLBA UPGRADE WBS

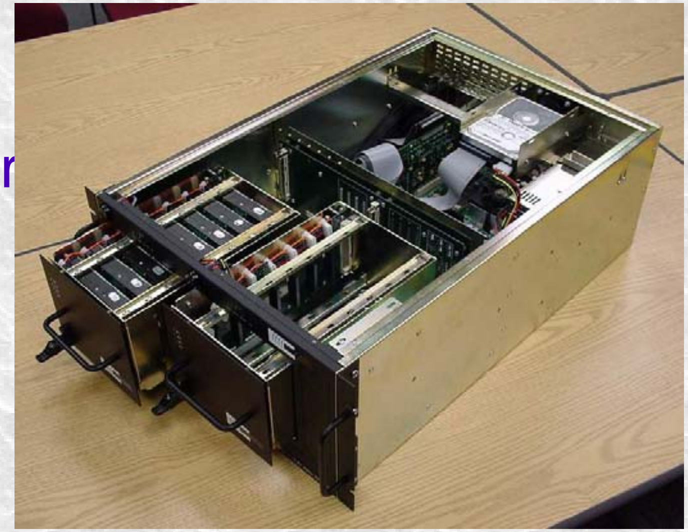
- An effort to cost the enhancements requested by the VLBI FUTURE report
  - Consolidates many existing and planned projects
- Major items:
  - Project management
  - VLBA Software
  - Bandwidth expansion (dominates cost – goes >>1 Gbps)
  - eVLBI Test Plan
  - High Frequency Improvements
  - Front End Systems (33 GHz and 4-8 GHz systems)
  - Education and Public Outreach (mainly student funding)
- 5 yr (3 yr for lower cost items, 2 yr for rest)
- Total cost roughly $30M
- Note: Does not reach final goal of full EVLA integration

VLBA SOFTWARE

- Scheduling
  - New hardware, GUI, Info to PP, WIDAR correlator
- Real time systems
  - Mark5B (1Gbps). Later wider bandwidth support
- Post processing
  - VLBI in aips++ (fringe fitting, Tsys/gain, pulse cal, autocorrelation corrections, ionosphere corrections, spectral shifting, geodesy/astrometry, correlator model awareness, model fitting, pipeline)
- Archives
  - Disk space and access tools

BANDWIDTH EXPANSION

- Recording system upgrade to Mark5
- Electronics upgrade to EVLA style
  - Basically everything between receivers and r
  - Allows 4 GHz or more bandwidth
- Transition to WIDAR correlator
  - Needed for > 256 Mhz
- “Mark6” Wider band upgrade from Mark5
  - Needed for > 1 (2) Gbps



eVLBI Test Plan

- Real time or near real time data transmission
    - Much research going on elsewhere
- Last mile costs
  - Connect VLBA and GBT to fibers
- eVLBI capability on the VLBA
  - Determine the costs of fiber access for real time operation
  - Develop the eVLBI capability
- Does not include transition to eVLBI
  - Don't know the fiber access cost
    - Could be extremely expensive (> NRAO budget)
    - Could be free on research networks

HIGH FREQUENCY IMPROVEMENTS

- Enhance VLBA high frequency performance
  - Subreflector and primary surface improvements
  - WVR testing and development efforts
  - Test and implement frequency band switching
  - Pointing improvements using 500 MHz
  - Research on pointing improvements
- VLBI backends for CARMA, ALMA, SMT, SMA ...

RECEIVERS

- Ka Band (26-40 GHz)
  - Needed for spacecraft navigation
  - Very good for high resolution astronomy
- C band (4-8 GHz)
  - Prime phase referencing range
  - Need bandwidth if go above 1 GHz
  - Several interesting spectral lines near 6 GHz
- Upgrade 22 and 43 GHz low noise amplifiers
- Finish 3mm receivers
- Hardware upgrades for 3mm receivers

EPO

- Student award program
  - Modeled on Green Bank program
- Public outreach:
  - Displays (including at each site)
  - Web
  - Passport program
  - Informational and promotional brochures handouts and CDs

BUDGET SUMMARY

WBS	VLBA Cost Summary for (M&S, Labor, Travel, FTE Overhead, Contingency)	Phase I			Phase II		
WBS	Task Name	2005	2006	2007	2008	2009	Total
	Project Total	3943.5	3821.7	3718.4	8117.1	9675.3	29276.1
XX.01	Project Management	30.0	30.0	30.0	30.0	30.0	150.0
XX.02	VLBA Software	25.0	35.0	50.0	70.0	100.0	280.0
XX.03	Bandwidth Expansion	677.0	628.0	586.0	3135.6	4483.4	9510.0
XX.04	E-VLBI Test Plan	264.2	209.4	209.4	0.0	0.0	683.0
XX.05	High Freq. Improv.	65.0	65.0	65.0	400.0	400.0	995.0
XX.06	EPO	323.1	323.1	323.1	323.1	323.1	1615.3
XX.07	FE Systems	455.2	477.4	419.4	313.4	313.4	1978.7
	M&S Total	1839.4	1767.9	1682.9	4272.0	5649.8	15211.9
	Wages & Benefits	1231.0	1200.8	1193.6	2066.6	2051.0	7743.0
	Travel per year	92.7	92.7	92.7	177.9	177.9	633.8
	FTE Overhead per year	266.1	261.9	264.3	541.8	534.6	1868.7
	SubTotal	3429.1	3323.3	3233.4	7058.3	8413.3	25457.5
	Contingency	514.4	498.5	485.0	1058.8	1262.0	3818.6
	Project Total	3943.5	3821.7	3718.4	8117.1	9675.3	29276.1
	AUI Fee @ 2.5% of Total Budget						731.9
	GRAND TOTAL						30008.0

FUNDING PROSPECTS

- Mark5: Top priority for current funding
  - Operations funding, reduced tape maintenance, lowering staff. Doing everything possible to fund the switch
  - NASA and ESA/JIVE gave 6 Mark5 units for Huygens observations
- Possible NASA funding for spacecraft navigation:
  - Mark5 units and disks
  - Ka band receivers and X/Ka dichroic
  - eVLBI development
- 3mm: Past and possible future MPI contribution
- EVLA2: Some integration of NMA with VLBA included
  - Inputs to WIDAR correlator for VLBI
  - Conversion of LA and PT to EVLA electronics
- Rest: Some from operations, but new money needed for most

INTERMEDIATE BANDWIDTH OPTION

- Bandwidth break points:
  - 256 MHz Maximum for current samplers and correlator
  - 1 GHz Maximum for current LO/IF. Requires WIDAR
  - 4 GHz Maximum for shared WIDAR correlator stations
  - 16 GHz Full EVLA bandwidth. Requires WIDAR upgrade
- Upgrade plan “does it right” with EVLA LO/IF
- Could handle 1 GHz with with a “digital BBC”
  - Models being developed at Noto, Berkeley ...
  - EVLA station board might serve
- Should we consider a 1 GHz plan
  - Much cheaper, but no expansion beyond 1 GHz

PROJECT MANAGEMENT

- Two half time people for 5 years
- Some M&S support
- Advisory committee support