The Expanded Very Large Array:

New Capabilities for New Science

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EVLA Project Overview

- The Expanded Very Large Array is a major upgrade of the Very Large Array.

- The fundamental goal is to improve all the observational capabilities of the VLA -- except spatial resolution -- by at least an order of magnitude

- Counting all sources, a $90M project.

- The construction phase began in 2000, and will be completed by the end of 2012.

- Implementation of the vast new capabilities offered by the array will be ongoing.

Key EVLA Project Goals

- Full frequency coverage from 1 to 50 GHz.
  - Provided by 8 frequency bands with cryogenic receivers.
- Up to 8 GHz instantaneous bandwidth
  - Provided by two independent dual-polarization frequency pairs, each of up to 4 GHz bandwidth per polarization.
  - All digital design to maximize instrumental stability and repeatability.
- New correlator with 8 GHz/polarization capability
  - Designed, funded, and constructed by our Canadian partners, HIA/DRAO
  - Unprecedented flexibility in matching resources to attain science goals.
- <3 μJy/beam (1-σ, 1-Hr) continuum sensitivity at most bands.
- <1 mJy/beam (1-σ, 1-Hr, 1-km/sec) line sensitivity at most bands.
- Noise-limited, full-field imaging in all Stokes parameters for most observational fields.

Overall EVLA Performance Goals

The EVLA's performance will be vastly better than the VLA's:

Parameter	VLA	EVLA	Factor
Point Source Sensitivity (1-σ, 12 hr.)	10 μJy	1 μJy	**10**
Maximum BW in each polarization	0.1 GHz	8 GHz	**80**
# of frequency channels at max. BW	16	16,384	**1024**
Maximum number of freq. channels	512	4,194,304	**8192**
Coarsest frequency resolution	50 MHz	2 MHz	**25**
Finest frequency resolution	381 Hz	0.12 Hz	**3180**
# of full-polarization spectral windows	2	64	**32**
(Log) Frequency Coverage (1 – 50 GHz)	22%	100%	**5**

The EVLA is a 'Leveraged Investment'

- The Project is making maximum use of existing hardware and infrastructure.
- The EVLA utilizes the VLA's 25-meter parabaloids.
  - Off-axis Cassegrain optics.
  - Change band by rotating subreflector
- Disadvantages:
  - Big and slow
  - Not the best choice for fast wide-field surveys
- Advantages:
  - Paid for!
  - Work well up to 50 GHz.
- Also retained:
 - Configurations, buildings, basic infrastructure, people.

Antenna 24 – the first EVLA antenna outfitted with all eight feeds.

Full Frequency Coverage with Outstanding Performance

- There are eight feeds, tightly packed around the secondary focus feed ring.

Band (GHz)		T_{sys}/ε (best weather)
1-2	L	60 -- 80
2-4	S	55 -- 70
4-8	C	45 -- 60
8-12	X	45*
12-18	Ku	50*
18-26.5	K	70 -- 80
26.5-40	Ka	90 -- 130
40-50	Q	160 - 360

* -- Initial test values
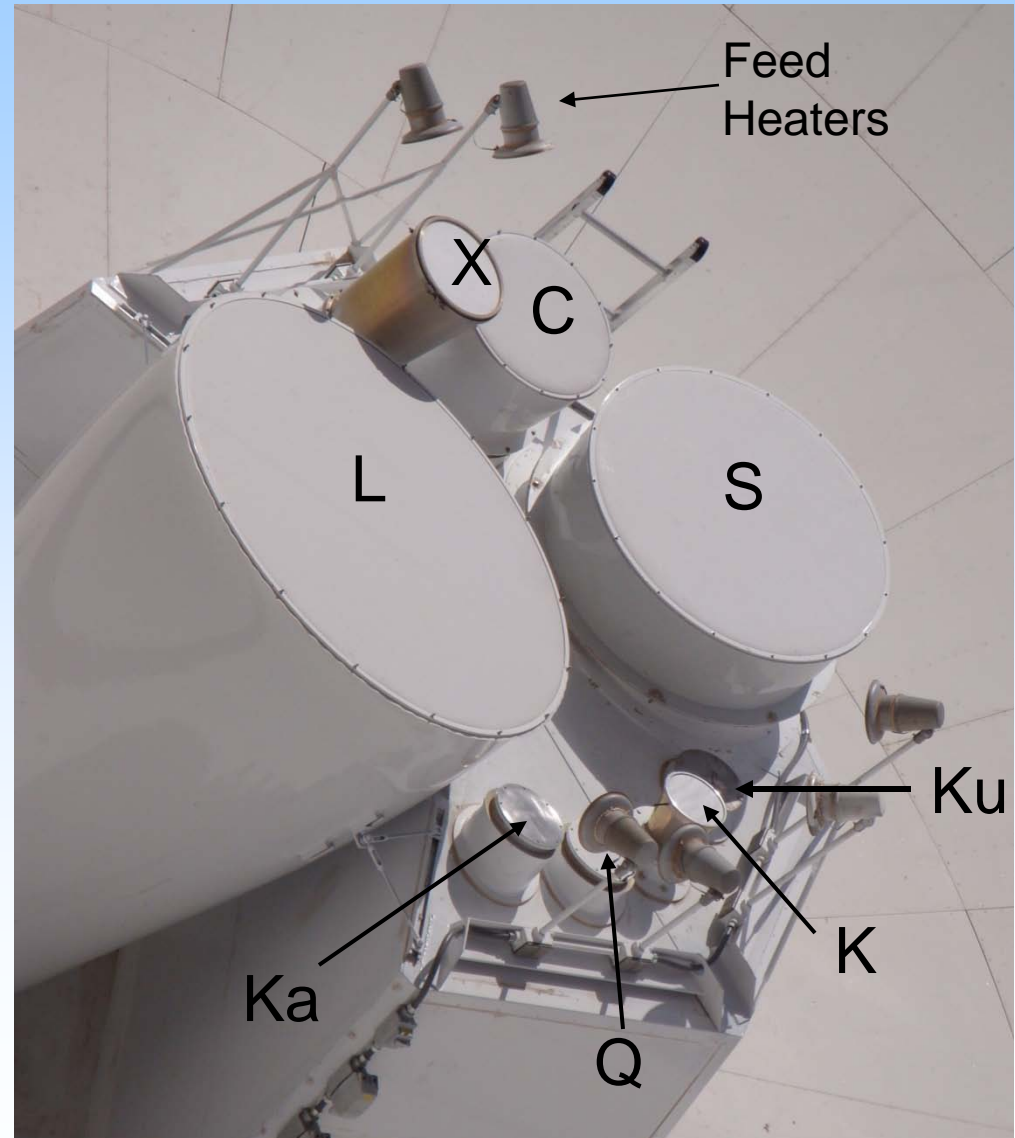
EVLA Sensitivity

- The array will provide unequaled sensitivity for both line and continuum observations.
- The table gives the 1-hour, 1-σ point-source sensitivities, in continuum and line (1 km/sec)

Band	Code	Effective BW	SEFD	σ(cont)	σ(line)
GHz		GHz	Jy	μJy	mJy
1 – 2	L	0.75	400	5.5	2.2
2 – 4	S	1.75	350	3.9	1.7
4 – 8	C	3.5	300	2.4	1.0
8 – 12	X	4	250	1.8	0.65
12 – 18	Ku	6	280	1.7	0.61
18 – 27	K	8	450	2.3	0.77
27 – 40	Ka	8	620	3.2	0.90
40 -- 50	Q	8	1100	5.6	1.4

EVLA Construction Progress

- All 28 antennas are now converted to EVLA standards.
- This process entailed:
  - New optics (feeds, towers, etc.)
  - New IF electronics
  - New samplers
  - New Digital Transmission System
- Antennas now cycle through maintenance as before.
- Configuration changes every ~4 months, but direction is reversed. (From small to large).
- However, not all receivers are on all antennas yet.

Full-Band Receiver Availability Timescale

- By the end of this year, four bands will be fully outfitted on all antennas: C band (4 – 8 GHz), and K, Ka, Q: (18 – 50 GHz).

- At 1—2 and 8—12 GHz, all antennas are equipped with a mix of old/new receivers
- 2 – 4 and 12 – 18 GHz band receivers are new.
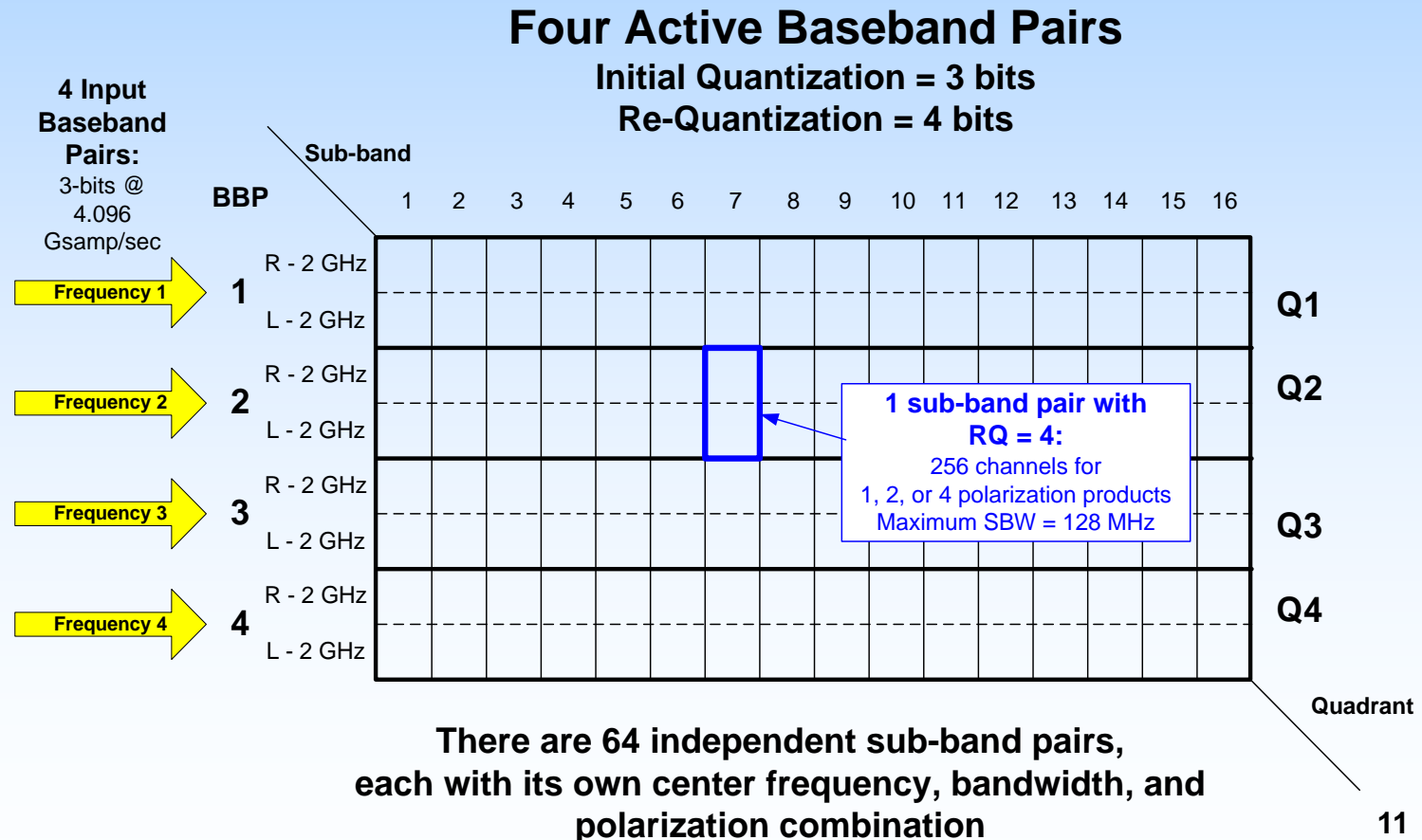- The dashed line shows the planned implementation of 3-bit samplers, needed for full 8 GHz BW.
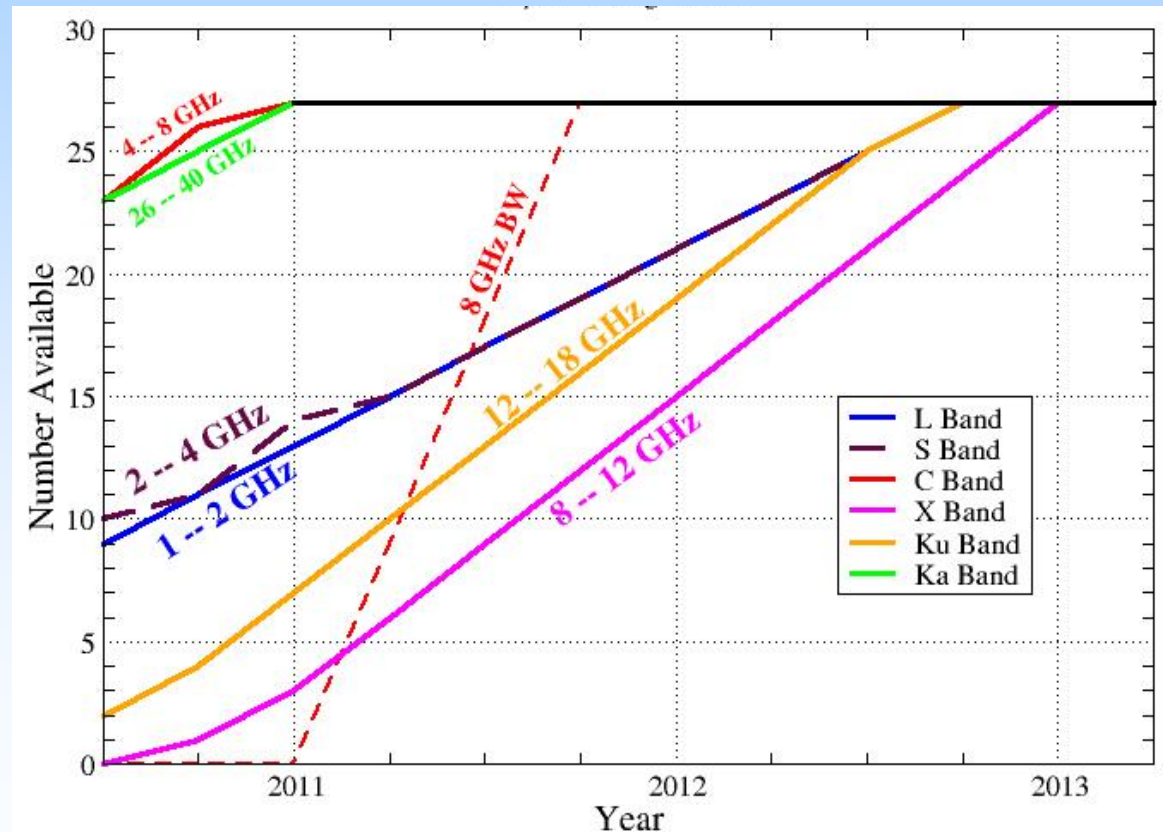
The 'WIDAR' Correlator

- The key element of the EVLA is its Canadian funded `WIDAR' correlator – a 10 petaflop computer.

- Designed and built by the correlator group at HIA/DRAO in Penticton BC, to meet or exceed NRAO requirements.

- WIDAR is a 'full-service' correlator, designed to meet the diverse needs of our user community.

- Major capabilities:
  - 8 GHz/polarization maximum instantaneous bandwidth
  - Full polarization
  - # channels – 16384 minimum, 4.2 million maximum.
  - Spectral dynamic range up to 58 dB
  - Extensive special modes
  - 64 independently tunable full polarization 'spectral windows', each or which effectively forms an independent 'sub-correlator'.

The 'WIDAR' Correlator

- Accepts four input 'baseband' pairs of up to 2 GHz BW each.
- Each input is digitally sub-divided into 16 spectral window pairs.
- Each of the 4*16 = 64 spectral window pairs can be considered as a separate full-polarization 'sub-correlator', with 256 channels.

Four Active Baseband Pairs
Initial Quantization = 3 bits
Re-Quantization = 4 bits

4 Input Baseband Pairs:
3-bits @ 4.096 Gsamp/sec

Sub-band																
BBP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Frequency 1 → **1** R - 2 GHz / L - 2 GHz — **Q1**

Frequency 2 → **2** R - 2 GHz / L - 2 GHz — **Q2**

Frequency 3 → **3** R - 2 GHz / L - 2 GHz — **Q3**

Frequency 4 → **4** R - 2 GHz / L - 2 GHz — **Q4**

1 sub-band pair with RQ = 4:
256 channels for
1, 2, or 4 polarization products
Maximum SBW = 128 MHz

Quadrant

There are 64 independent sub-band pairs, each with its own center frequency, bandwidth, and polarization combination

11

WIDAR Flexibility

- Each of the 64 spectral windows:
    - Is independently tunable to any frequency
    - Has a frequency width of any of 128, 64, 32, …, .031 MHz
    - Provides 256 spectral channels, available for 1, 2, or 4 polarization products.
    - Has recirculation available (doubles the number of spectral channels for each halving of the spectral window width)
    - Can utilize the computational resources of any number of other sub-band pairs (trading bandwidth for channels).
- Frequency resolution ranges from 2 MHz to 0.19 Hz.
- N_{chan} is from 16384 to more than 4 million.
- Numerous special modes and capabilities.

WIDAR's Special Modes

- WIDAR offers many special modes, including:
  - Pulsar gating and binning:
    - 2 banks of 1000 bins each, with 100 μsec time resolution.
    - More bins (to 65536), and higher time resolution (15 μsec) available by reducing spectral channels.
  - Phased Array with the full bandwidth
  - Built in VLBI capabilities
  - Up to 8 subarrays
  - Burst mode
    - 100 msec time resolution with 65K spectral channels
    - Faster is possible with larger Correlator Back End.

- Basic observing modes are being commissioned first.
- Special modes come later.

WIDAR (Some Numbers)

170 KW power, and 120 tons of cooling

17308672 control/monitor bits

1473536 registers

24832 FPGAs

256 boards

16 racks

1 room
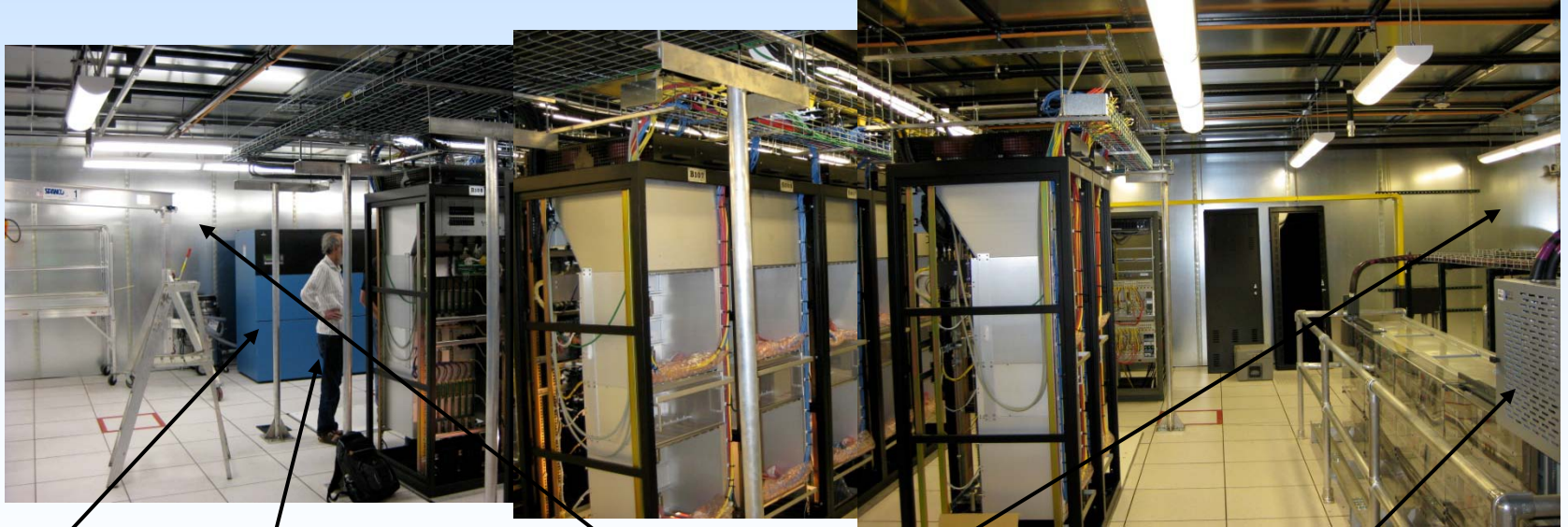
Air Conditioners

Ken Sowinski
(6'0")

~100 dB
Shielded Chamber

Power Backup/Conditioners

WIDAR Installation/Capabilities Progress

- WIDAR installation is nearly complete:
  - All 128 Station Boards and all 64 X-bar boards are in.
  - 123 of 128 Baseline Boards are in.
  - ¼ of the baseline boards are in use, 7/8 of the station boards.
- Testing of WIDAR functionality continues on many fronts:
  - Fast dumps (< 1 sec)
  - Recirculation
  - Switched power monitoring
  - Post-correlation (CBE) averaging
  - 3 bit sampler path (wideband mode)
  - Implementation of different subband widths
  - Implementation of different Nchan
  - High spectral dynamic range (anti-aliasing).

WIDAR Capabilities not tested (yet)

- Many functionalities have not been tested yet (time, personnel, higher priority issues …)
  - ¾ of the baseline boards
  - Pulsar modes
  - Burst modes (~ 1 msec outputs)
  - Individualized tuning of subbands
  - Providing all autocorrelations (get only half at one time)
  - 7-bit requantization
  - On-line RFI rejection
  - Post-correlation (CBE) frequency averaging/decimation.

Spectral Window Continuity

- Eight continuous subbands, each of 128 MHz, spanning full L-band.
- Only a global delay calibration has been applied.
- Note contiguous phase and amplitudes.
- Dips in amplitude are due to digital filters.
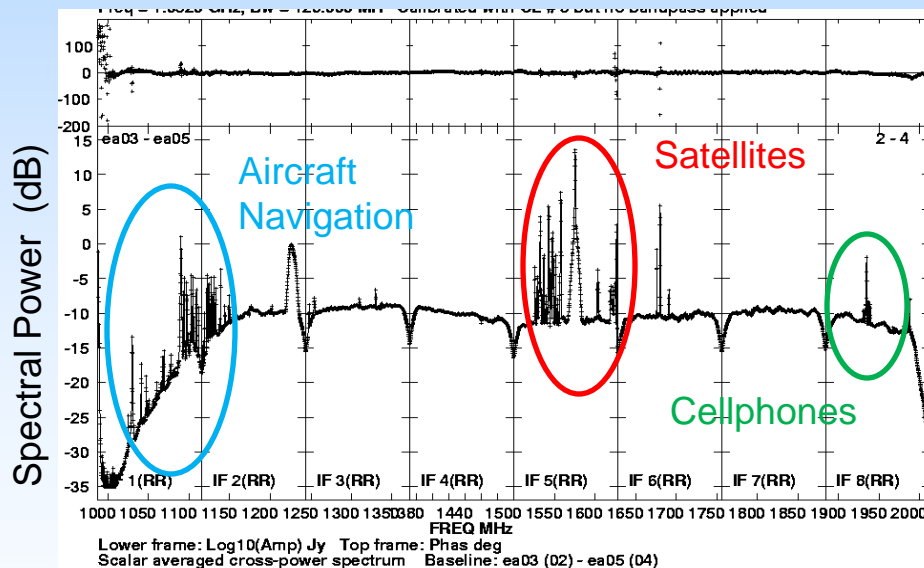
Ampscalar average shows the strong RFI: spectral powers nearly a factor of 1000 above noise.
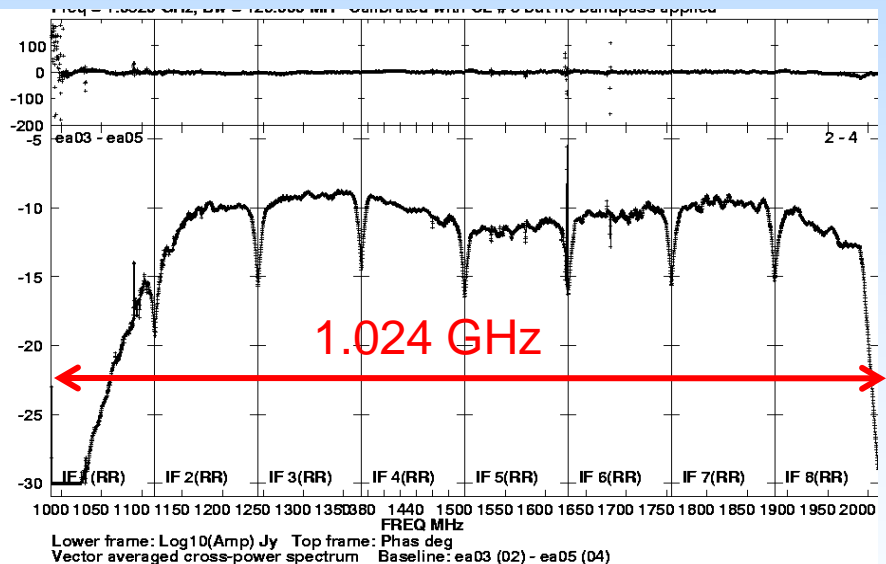
Vector average shows how RFI is 'wound down' due to differential phase.

L-Band Spectrum – Zoom In

- Four spectral windows, covering 512 MHz, with 500 kHz resolution.
- With 128 subbands total to edit, these illustrate the challenge in editing.
- Most of the notable RFI has well understood origins.
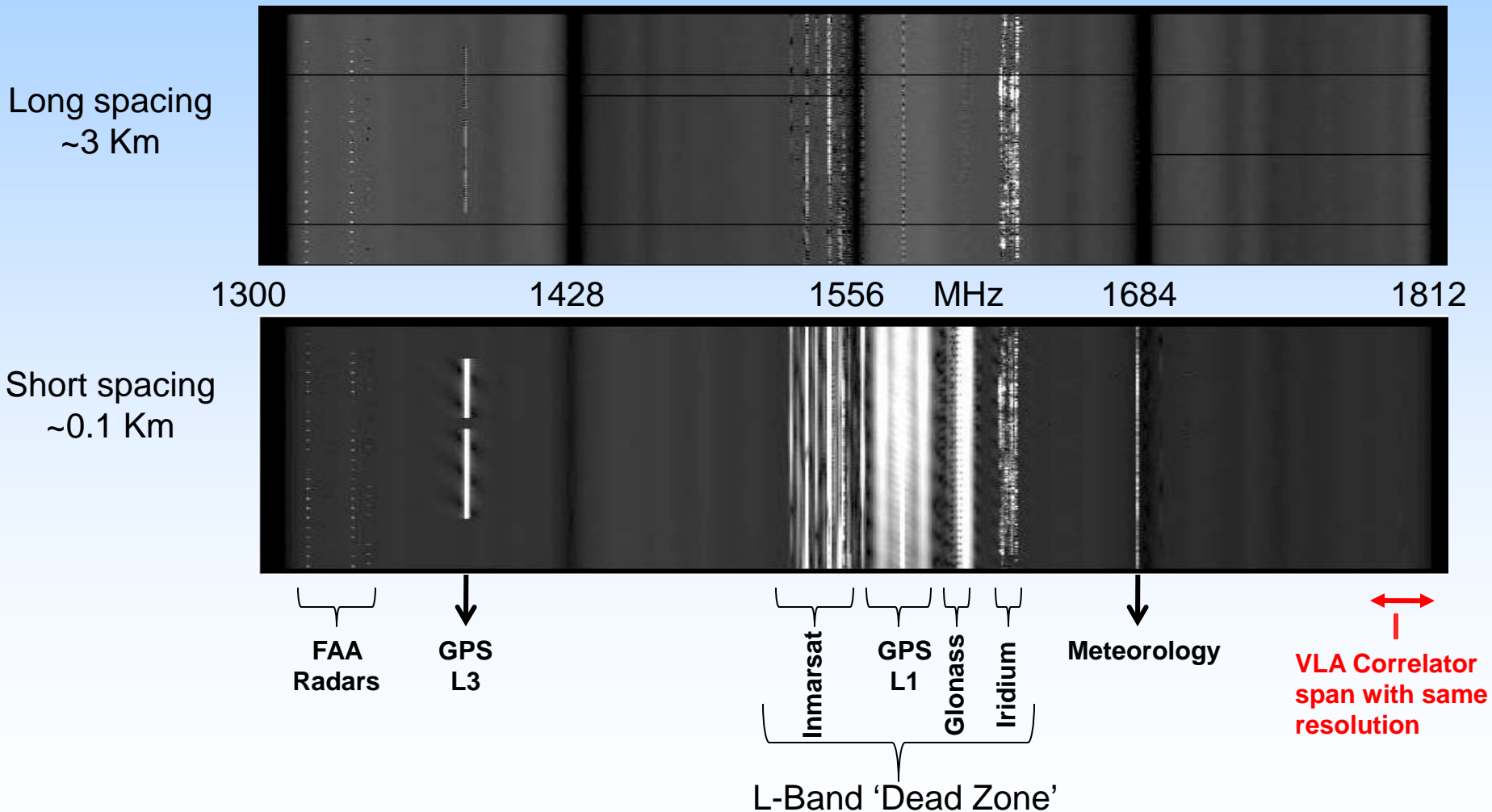
Current Status

- The EVLA is now up and running, with time approximately equally divided between science and testing/development.

- Progress towards smooth and efficient observing has been slowed by software issues surrounding the correlator:
  - Correlator software (both 'before' and 'after') very balky.
    - Getting stability and robustness proving difficult.
    - These issues slow down both correlator testing and development of new capabilities.
  - These issues affected data volumes and export.

- One remaining technical issue threatens to slow deployment of full (8 GHz) bandwidth:
  - 3-bit sampler path shows ~20% higher noise than expected on the eight prototype boards.
  - Major effort underway to diagnose/correct this issue.
  - Expect a delay in full-bandwidth observing.

Initial WIDAR Capabilities for Science

- VLA correlator was decommissioned on Jan 11, 2010.

- The array returned to service, using WIDAR, in early March 1, with 26 converted EVLA antennas.

- Array remained in D configuration until mid September, now in 'C'.

- We are now proceeding through the regular reconfiguration cycle – with the order reversed!

  - D -> C -> B -> A -> D …

- Until the end of 2011, there are two, parallel programs for early EVLA observing: 'OSRO', and 'RSRO'.

  - OSRO: For general observing: there will be two initial basic observational modes.

  - RSRO: For resident observing: a much wider range of expanded and more powerful observational modes.

- Growth in observational capabilities will be set by growth of software capabilities.

OSRO and RSRO

- OSRO = 'Open Shared Risk Observing'.
  - Is in fact a 'business as usual' observing protocol.
  - Observers access EVLA in same manner as current for VLA.
  - For continuity with existing VLA observing, the **initial** WIDAR capabilities have been based on old VLA capabilities.
    - But in fact, observers will get much more.
    - OSRO capabilities will increase 8-fold for next D-configuration.

- RSRO = 'Resident Shared Risk Observing'
  - For those willing to spend significant time in Socorro, and have skills & interest in assisting in implementing advanced correlator modes or calibration methodologies.
  - Participants will have much more extensive observing capabilities made available to them.

Two OSRO Modes

- Current OSRO offers 512 spectral channels, in two different modes:
  - **Mode A (Continuum):** Two independently tunable spectral windows, with 64 channels for each of all four cross-correlations, (total 512 channels)
  - **Mode B (Line):** A single spectral window, with dual polarization: 256 channels for each.
- For both modes:
  - the spectral window width can be set to one of: 128, 64, 32, … .03125 MHz.
  - Doppler setting (but not tracking) can be applied.
  - Minimum time averaging is 1 second.
- Beginning in the next D configuration, these two modes will be considerably expanded, likely to 8 or 16 spectral windows.

The RSRO Program

- Program runs to end of 2011.

- Application through regular proposal deadlines

- Intent is to attract skilled individuals to assist with commissioning process.

- Minimum residency ~ 3 months. Time available proportional to time spent in Socorro.

- Up to 25% of all observing time to be made available.

- NRAO able to provide housing in Guest House

- Applicants with their own support will definitely have advantage.

- Full details on: www.aoc.nrao.edu/evla/astro/rsro.shtml

RSRO Programs

- To date, 29 'RSRO' programs have been accepted for schedules, totaling about 2000 hours observing time.

- Distribution of requested bands:
  - L (1 – 2 GHz): 5
  - C (4 – 8 GHz): 15
  - K (18 – 27 GHz): 7
  - Ka (27 – 40 GHz): 14
  - Q (40 – 50 GHz): 5

- The range of science within these initial programs is very broad.

Accepted RSRO Programs – First Two Trimesters

I. Cosmology and Fundamental Physics

- Soderberg   Exotic Explosions, Eruptions, and Disruptions: A New Transient Phase-Space
- Soderberg   EVLA Can Reveal the Nature of Type Ia Supernova Progenitors
- Myers   An EVLA 30 GHz Survey of the CBI2 COSMOS Deep Field Region
- Russell   Testing the requirements for jet production in accreting black holes
- Fomalont   The Lobes of Fornax-A at 5 GHz

II. Galaxies across cosmic time

- Momjian   An unbiased K,Ka,and Q-band absorption survey at z=0.88582 towards B1830-210
- Owen   CO 1-0 in a proto-cluster at z=2.4
- Aravena   Deep search for CO line emission in a cluster of star-forming galaxies at z=1.5
- Owen   The Magnetized Intracluster Plasma
- Kellermann   Bimodal Luminosity Distribtion of QSOs: Starbursts and AGN?

III. Planetary Systems and Star Formation

- Chandler   Grain growth and sub-structure in protoplanetary disks
- Butler   Observations of Pluto/Charon and the Largest TNOs
- Brogan   A Diagnostic K-band Survey of Massive Young (Proto)stellar Objects
- Takahashi   A Millimeter Study of the Embedded Star-Cluster in the Orion Molecular Cloud
- Hofner   Deep Radio Continuum Observations of Massive Proto-Stars

Accepted RSRO Programs (continued)

IV. Galactic neighborhood

- Wrobel — A High Resolution Mosaicing of Large-Scale Leo HI Ring (Primordial vs. Stripped)
- Leroy — Resolving the Starbursts in Nearby LIRGs and ULIRGs
- Heesen — Star formation and magnetic fields in dwarf galaxies
- Kepley — Quantifying the Dense Thermal Gas in Nearby Star-forming Galaxies
- Marvil — A sensitive, multi-frequency continuum study of M82 and NGC2146
- Momjian — Resolved Physics and Chemistry in Nearby Star Forming Galaxies
- Ott — The Massive Star/ISM Interplay in the Galactic Center: An EVLA Pilot Study

V. Stars and stellar evolution

- Claussen — Imaging Line Surveys of Circumstellar Envelopes: A Pilot Project
- Sokoloski — What Shape Are Novae? --- Early Radio Emission from Nova Explosions
- Bastian — Dynamic Spectroscopy of the Radio Flares on AE Aquarii
- Hallinan — Broadband Periodic Dynamic Spectra of Ultracool Dwarf Pulsars
- Miller-Jones — Testing the radio/X-ray correlation in quiescent black hole X-ray binaries
- White — Deep Observations of Crowded Stellar Fields

- Special issue for ApJ: planned for Spring 2011
- Special AAS Session in January 2011 meeting (Seattle)

Realizing EVLA science themes

- The EVLA Project Science Justifications were based on four fundamental themes:

I. Evolving Universe: High z molecular gas = 'fuel for galaxy formation'

- Low order molecular transitions: total and dense gas mass
- High spatial/spectral resolution => sizes and dynamics
- Wide bands => large cosmic volume searches

II. Obscured Universe: Broad band spectroscopic imaging of star formation
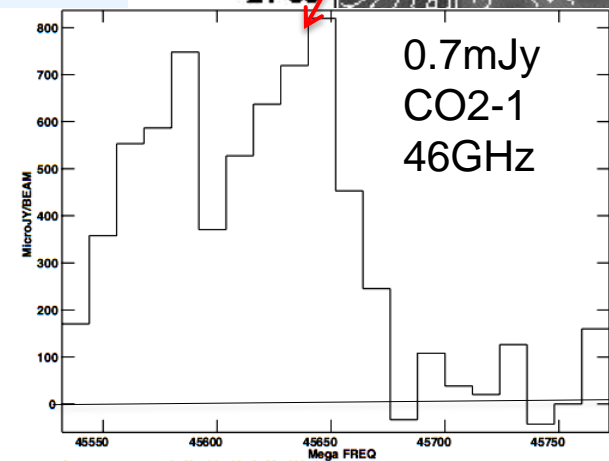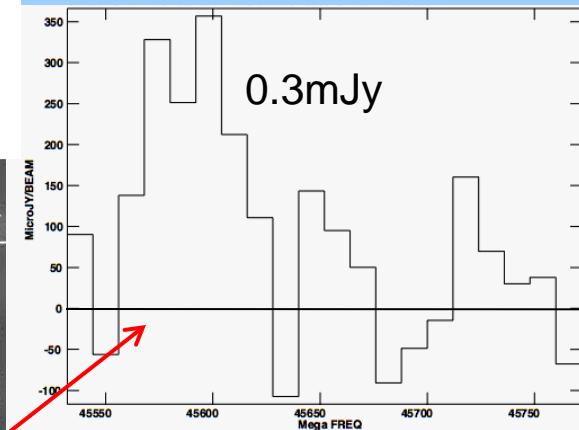
- Multiple, key diagnostic lines
- Sub-arcsecond imaging

III. Transient Universe

- Progenitors of Ia SNe

IV. Magnetic Universe: Galactic and intracluster magnetism

Evolving Universe

GN20 molecule-rich proto-cluster at z=4 (Daddi)
CO 2-1 in 3 submm galaxies, all in 256 MHz band

0.3mJy

z=4.055

4.051

4.056

0.7mJy
CO2-1
46GHz

0.4mJy

1000 km/s
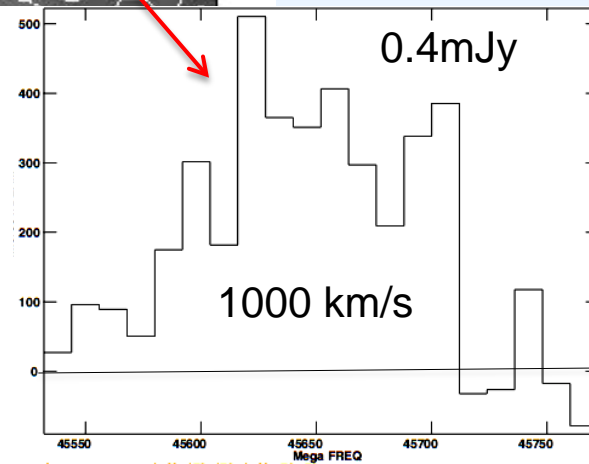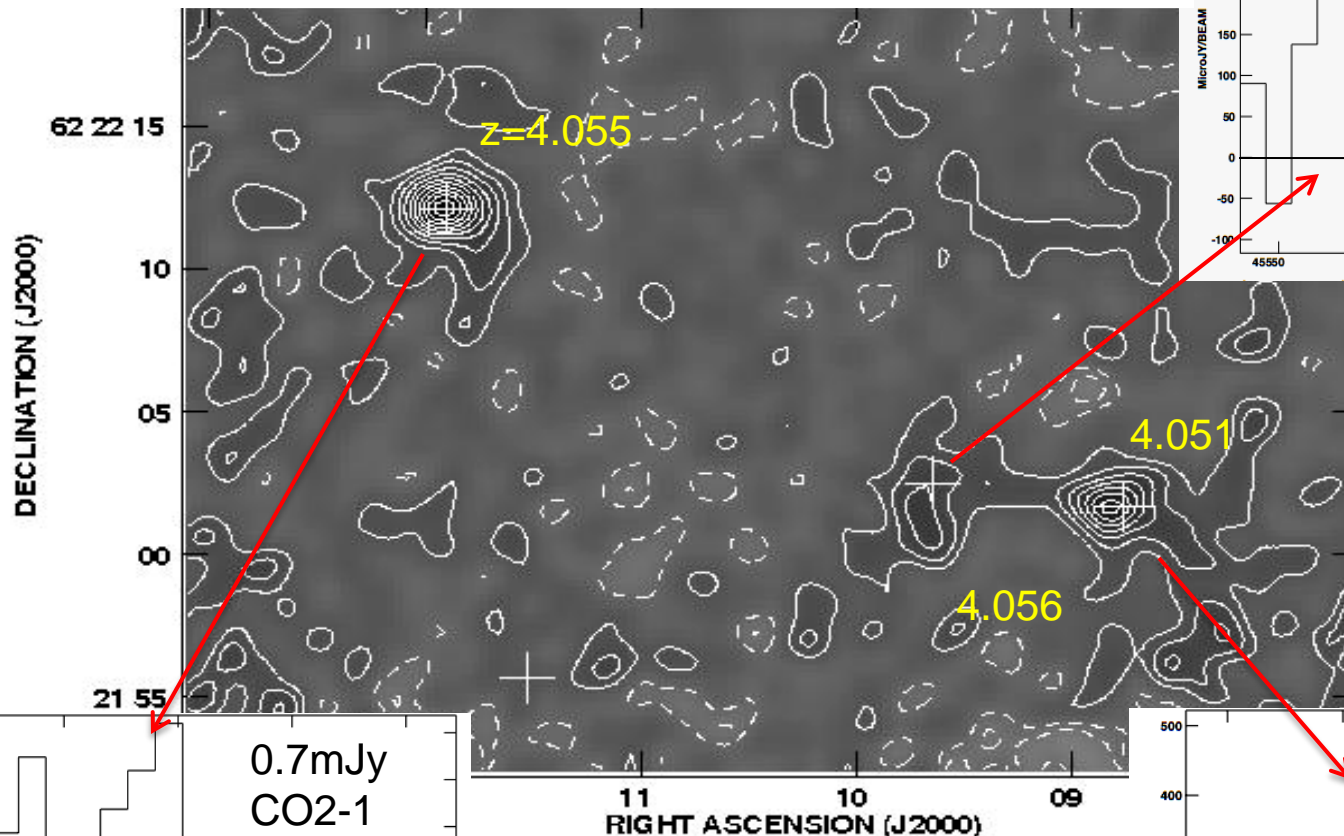
- SFR ~ 10^3 M_o/year
- M_{gas} ~ 10^{11} M_o
- Early, clustered massive galaxy formation

Obscured Universe

Orion hot molecular core

The hot core lies in the molecular cloud behind the nebula. Hot cores are thought to be signposts of the earliest phase of massive star formation; rich chemistry, high densities and temperatures
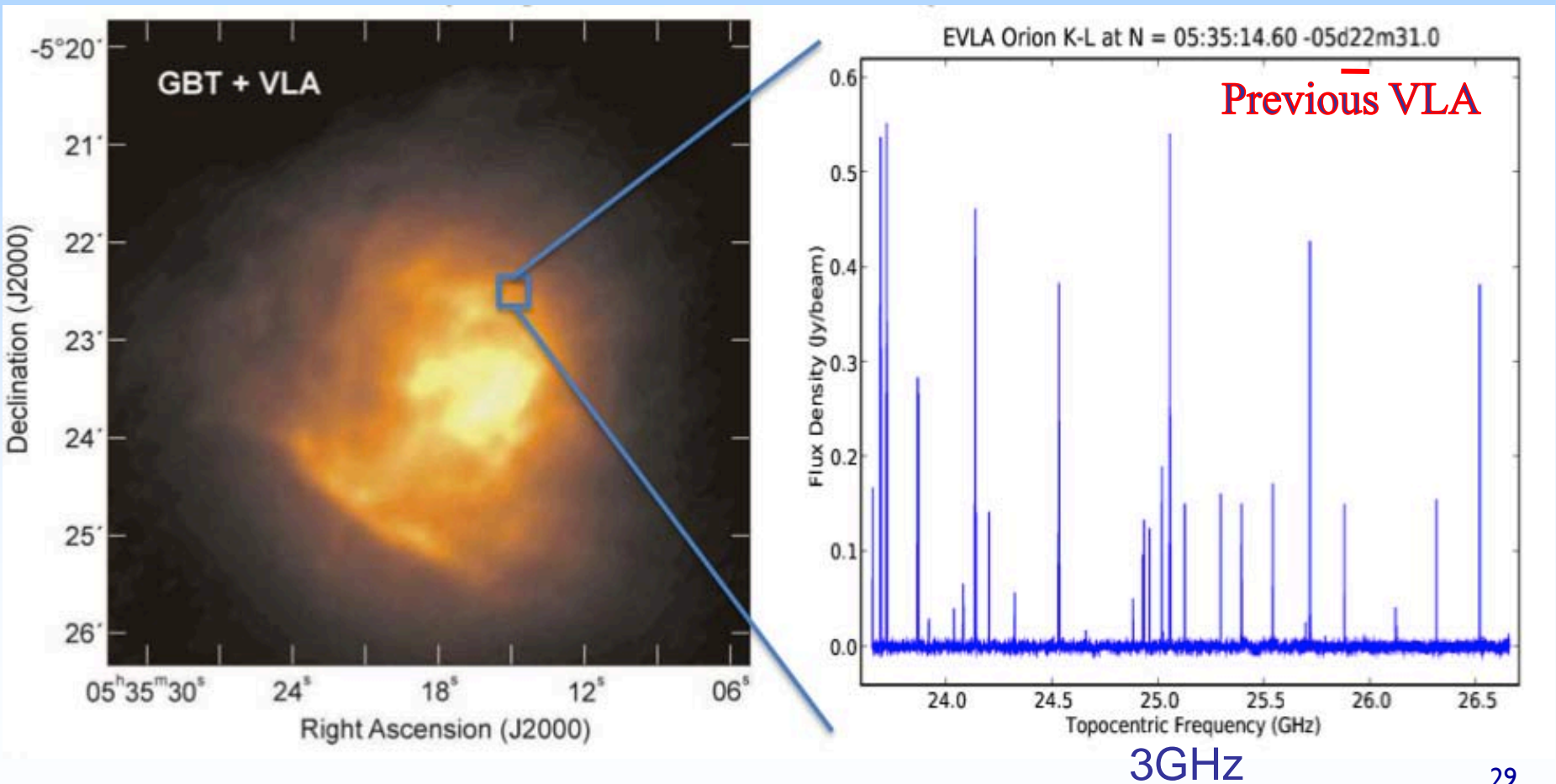
Orion-KL: Zooming in …

- **Left Side:** The lowest 1.0 GHz, showing identifications.
- **Right Side:** The two lowest meta-stable transitions, showing blended hyperfine structure.
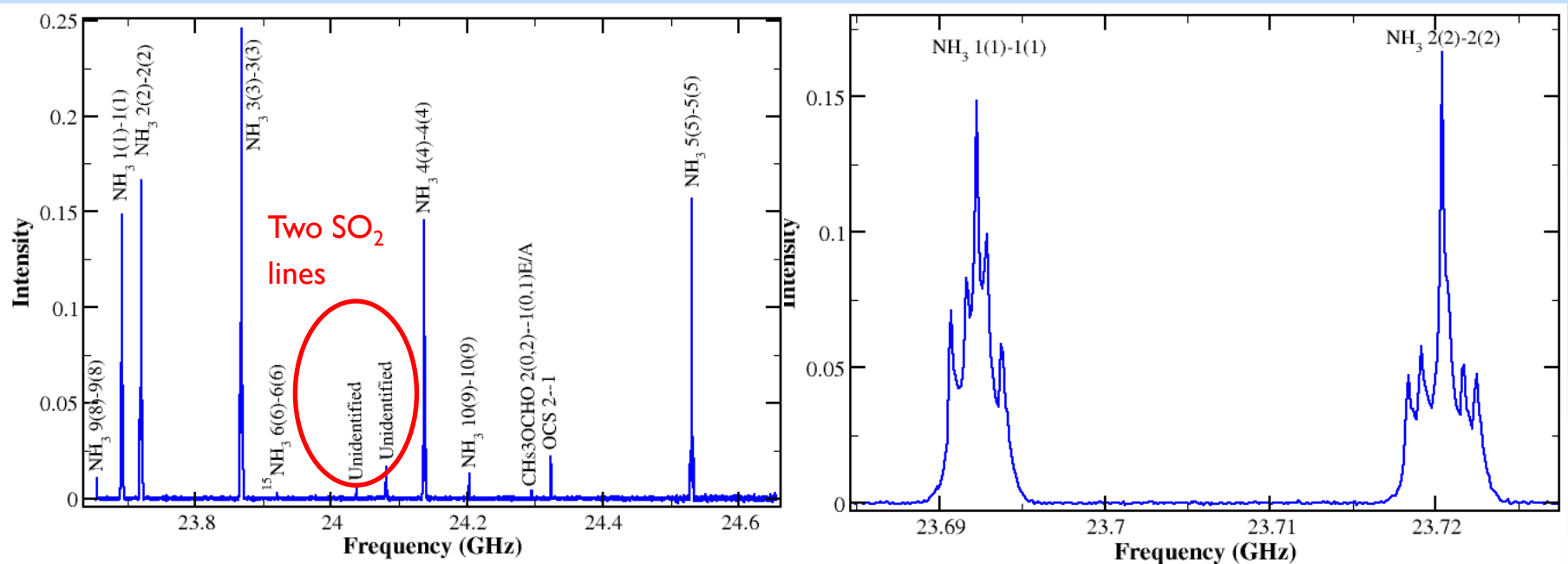
Spectra from the 128 x 128 x 24012 data cube

End to end processing done in CASA by Steve Myers

Moment-0 Image

Data Cube available at: http://science.nrao.edu/evla/projectstatus/index.shtml
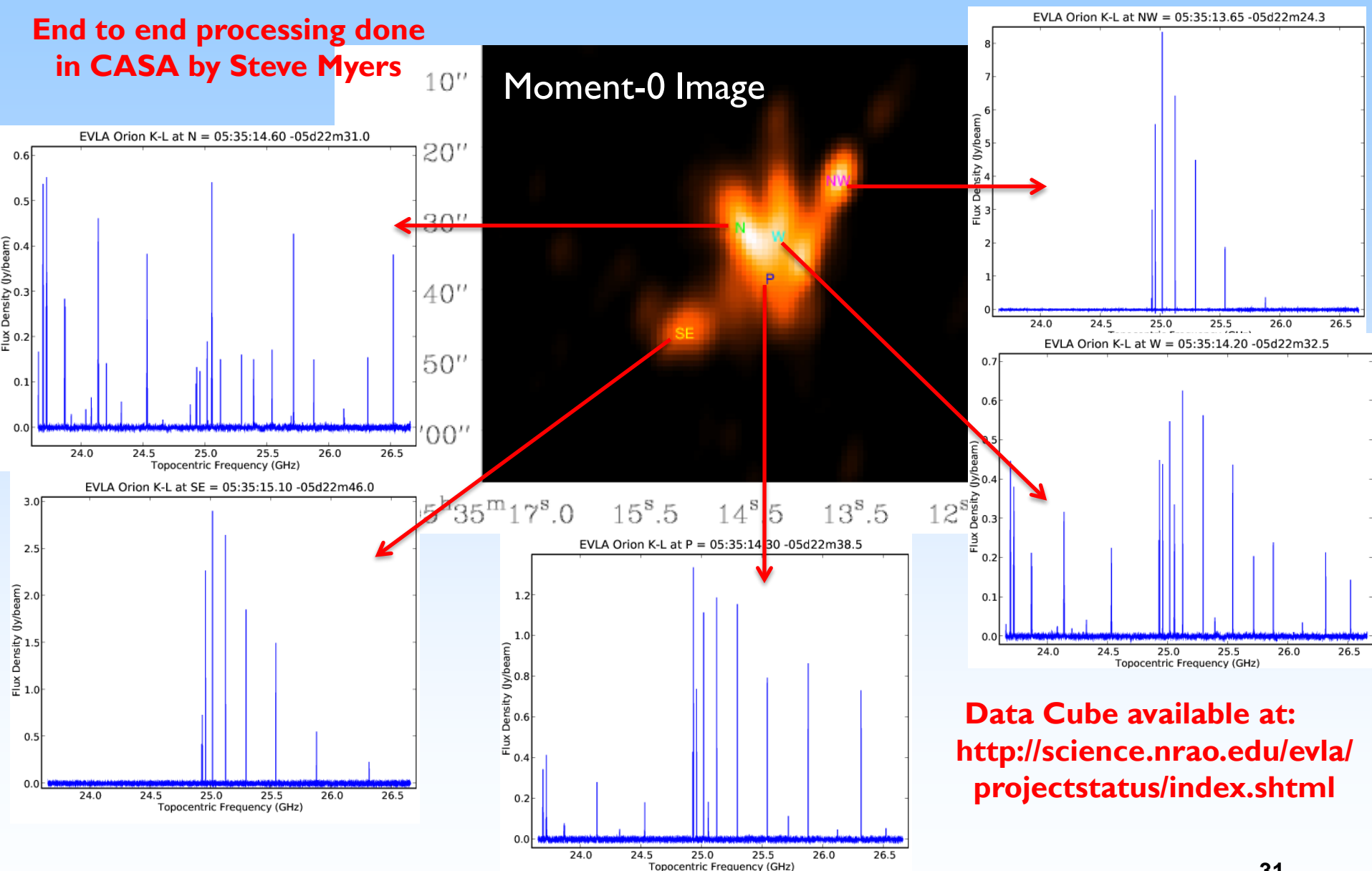
The Power of EVLA WIDAR: A Diagnostic K-band Survey of 30 Massive Protostellar Objects (Brogan + Hunter)
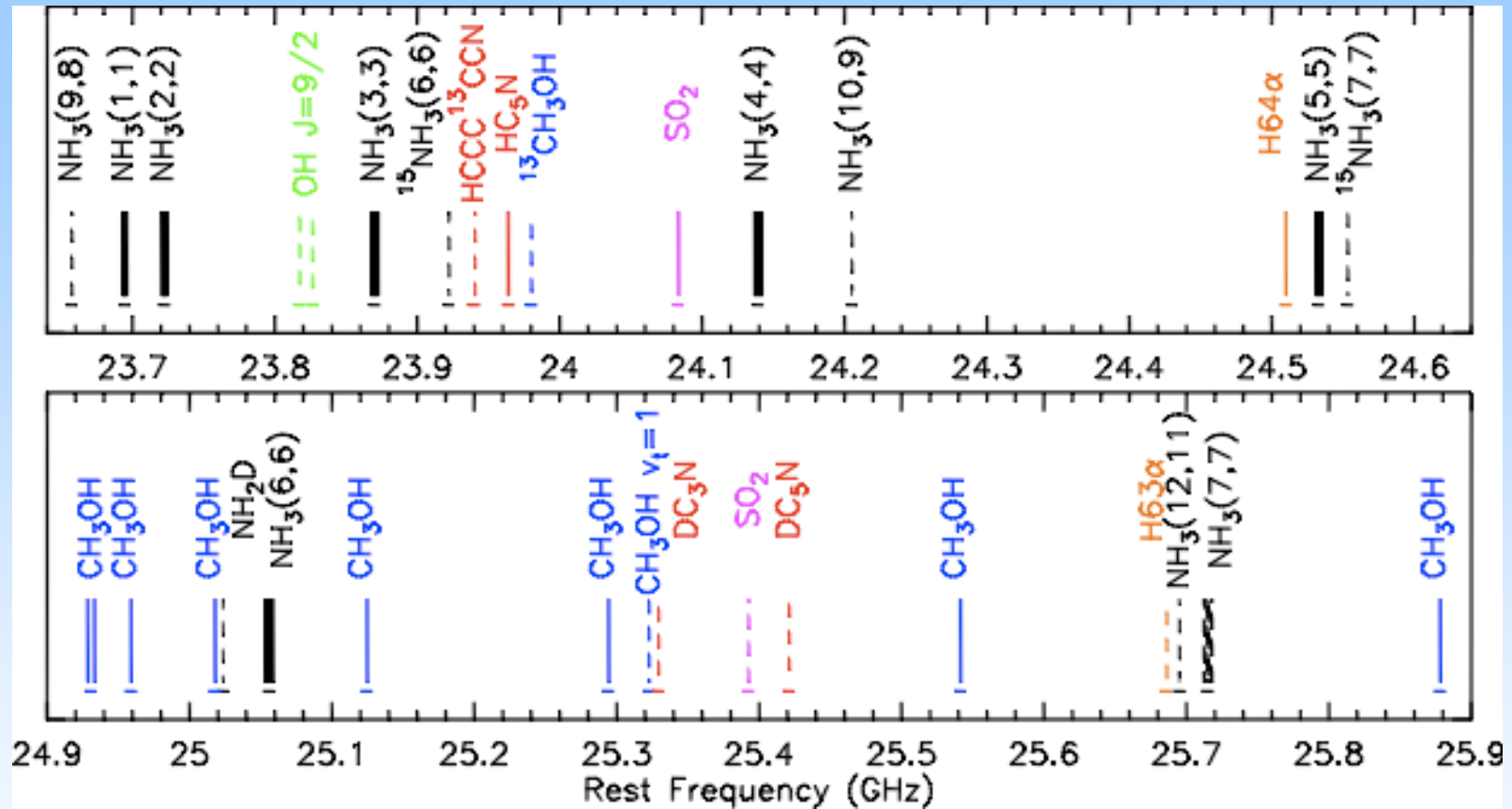
- Ammonia 1,1 to 7,7 – density and temperature
- Radio Recombination Lines – number ionizing photons
- Hot Core Lines (methanol, SO_2)
- Rare diagnostic lines including deuterated species

EVLA K-band: massive young stellar objects in NGC6334-I

- Initial test for start of RSRO project AB1346
- 8 x 8 MHz subbands with 256 channels RR only; referenced pointing
- 10 minutes on source!
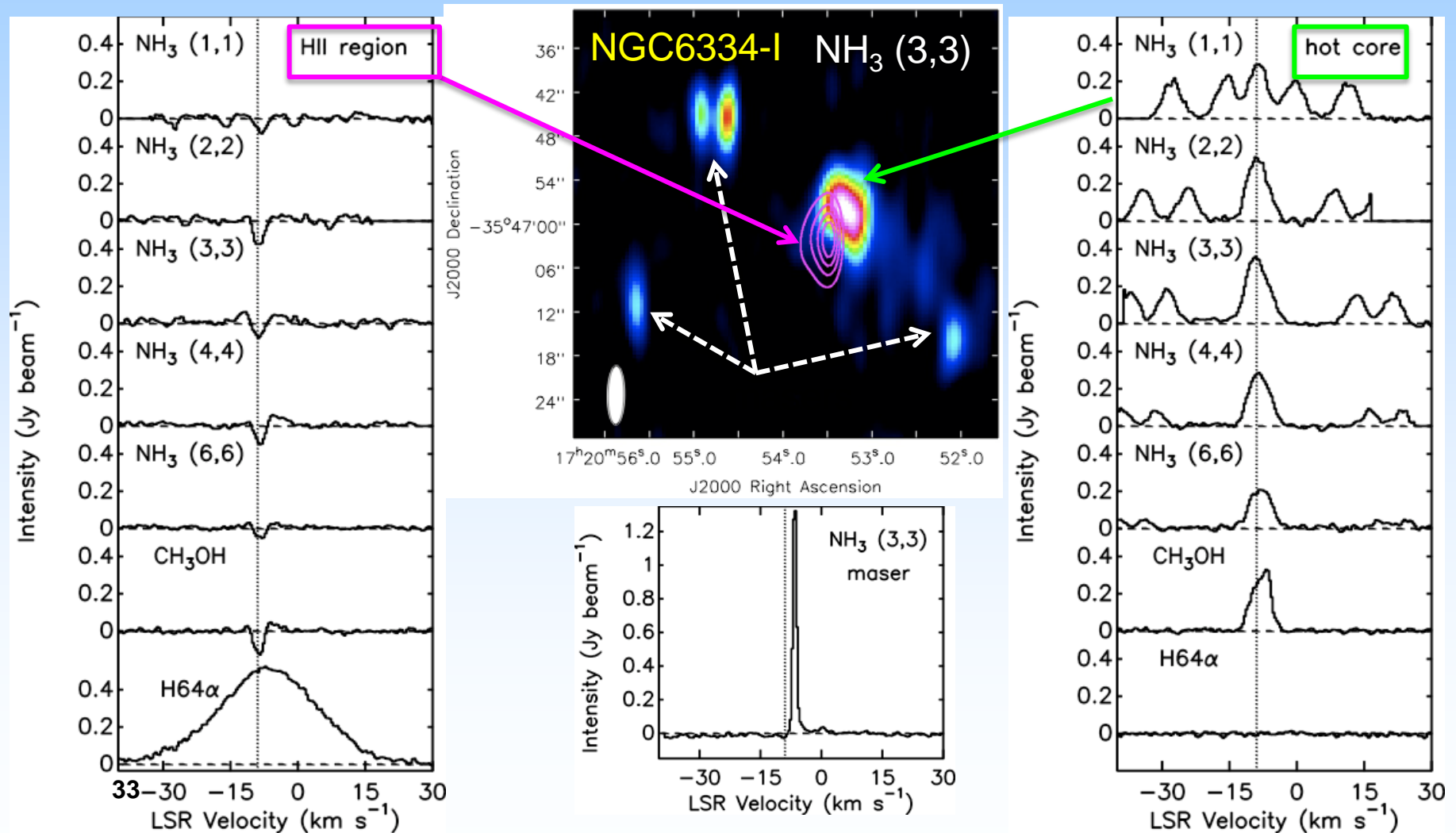
Current and Future Challenges

- All this fantastic new capability does not come without challenges. Here are a few:
- Observing Methodologies
  - Denser calibrator grids, improved referenced pointing
  - On-The-Fly imaging modes.
- Archiving:
  - How to store and distribute datasets generated by rates exceeding 100 MB/sec (and potentially as high as 1 GB/sec).
- Editing:
  - Efficiently removing bad data from 128 data streams
  - Blanking or (preferred) subtraction of external RFI.
- Implementation of Special Modes
  - Pulsar, phased array, multiple subarrays, 'radar' modes …

Future Challenges (cont.)

- Calibration:
  - Characterizing, calibrating, and correcting for system performance variations over 2:1 bandwidth ratios.
  - Particularly interesting is doing polarization calibration correctly.
  - Deciding what 'reference images' means, and how to do it.

- Imaging:
  - Full beam full Stokes imaging, over 2:1 bandwidth ratio, with non-coplanar baselines requires efficient implementation of new methodologies.
  - Beam corrections in I, Q, U, and V critical.
  - Eventually will want to combine these with mosaicing.

- Image Analysis:
  - What to do with all those images?
  - How to avoid 'Sensory Overload'? Data cubes can exceed 2048 x 2048 x 16384…

Wideband Calibration

- The first problem to be solved is calibrating data over 2:1 bandwidth ratios.

- AIPS and CASA had to be taught that flux densities and antenna polarizations vary continuously over frequency.

- Both systems now do this well.

First 2 GHz-Wide Spectra

- Shown are some of the first 2-GHz-wide spectra of 3C286.
- 16 subbands each of 128 MHz wide
- Spectral resolution 2 MHz.
- Data are calibrated in parallel hands (RR and LL) for gain, phase, and bandpass.
- Cross-hand data (RL, LR) are 'raw', showing high cross-polarization – up to 15%.
- New quadrature hybrids will soon be installed – expected to greatly improve cross-polarization.
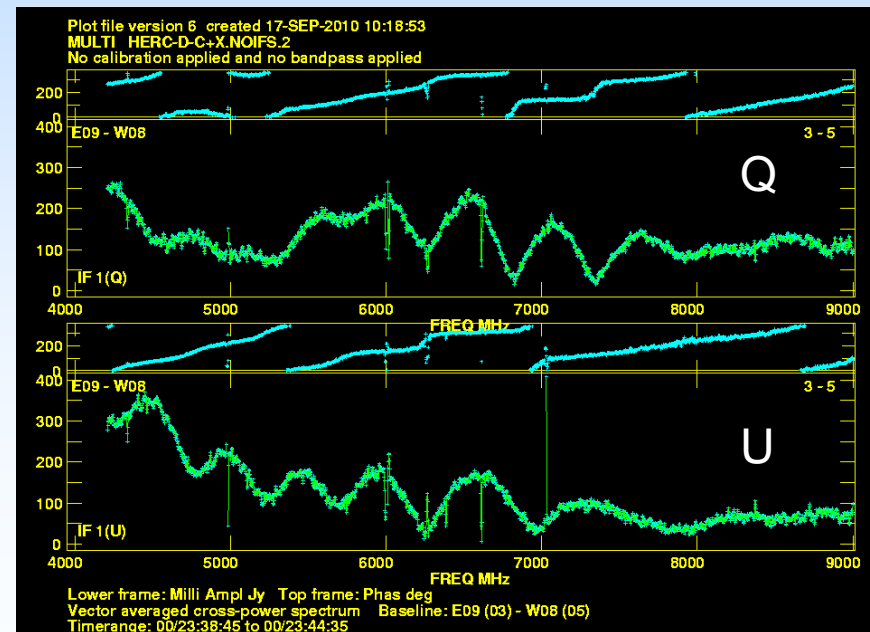

RR

LL

RL

LR

2048 MHz
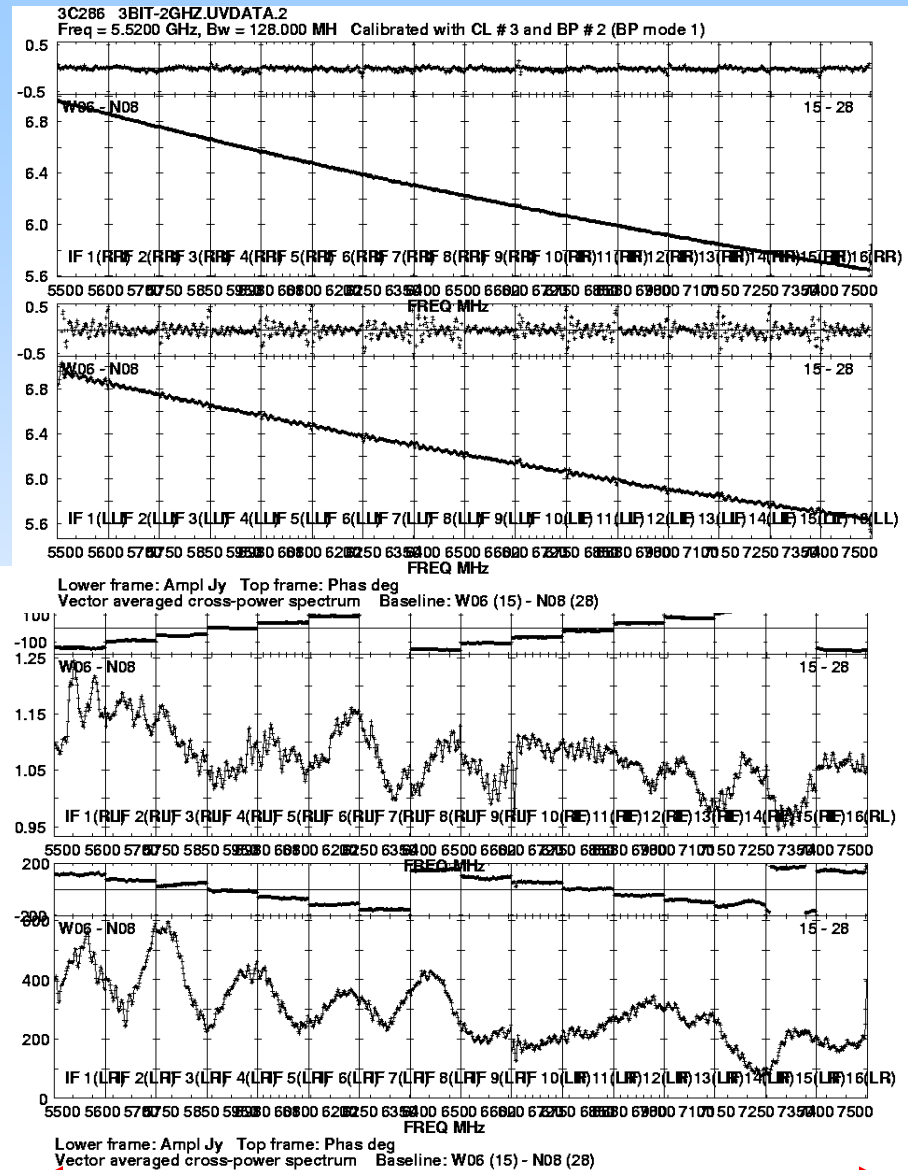
Super Wideband Spectra

- Below are shown the calibrated visibilities from Hercules A – part of an 'EVLA Demo Science' effort.

- Frequency span is 4.0 – 9.0 GHz. Resolution is 2 MHz.

- Single baseline, 1 km. Formed from 5 separate 'tunings', incorporating both C and X band receivers.

- Shows variation of visibility along a long 'ray' in (u,v) plane.
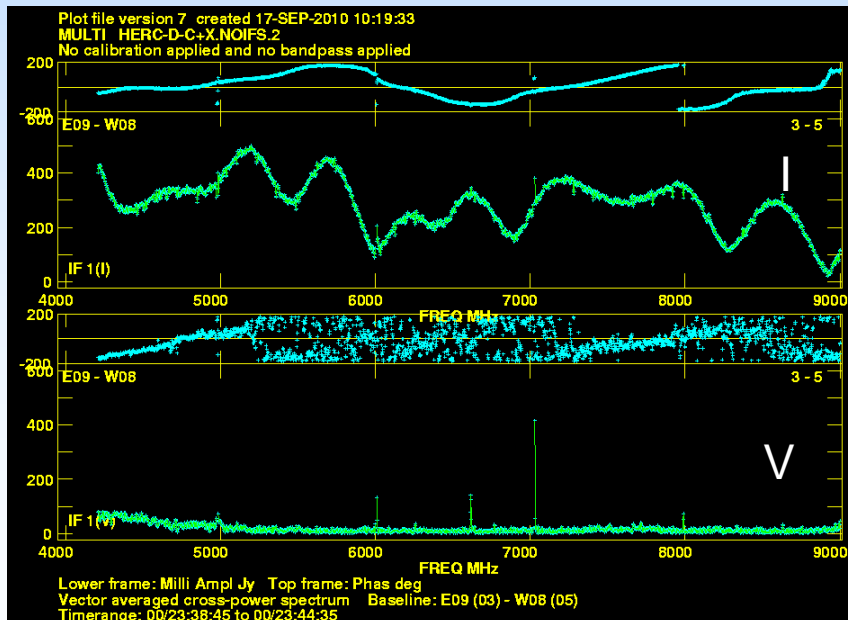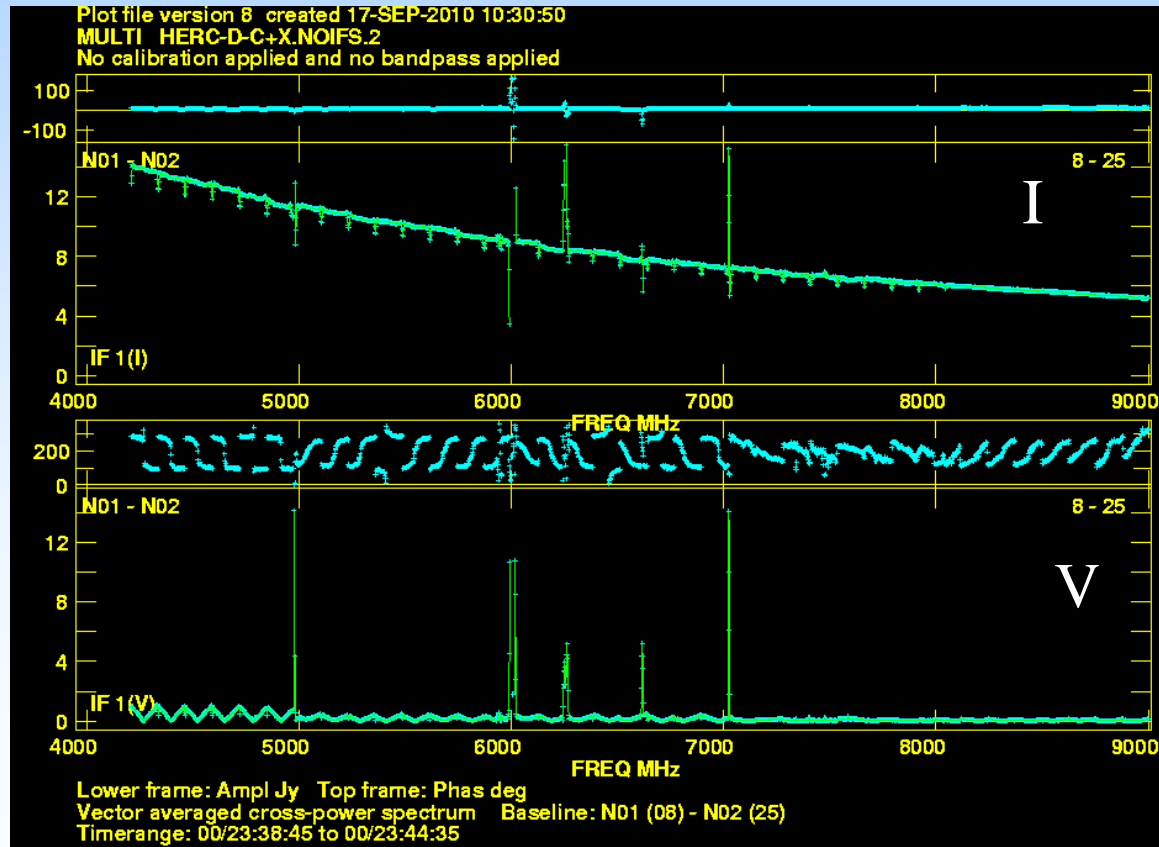

5 GHz   5 GHz

But not all is well …

- Here is a short (35 meter) baseline, in 'I' and 'V'.
- Stokes 'I' shows subband boundary effects.
- I have no explanation for Stokes 'V'…

Imaging with Wideband Telescopes

- The EVLA will often be operating in 'wideband' mode, with large fractional bandwidths: $\Delta \nu / \nu \sim 1$.

- Source structures change significantly over this range – cannot simply grid all channels on one transform plane.

- In addition, the primary telescope beam scales with λ^{-1} – introducing a 'false' spectral index.

- Deconvolving all background sources – beyond the primary beam – necessary to achieve full sensitivity.

- Urvashi Rao developing algorithms (within CASA) for these purposes.

- Bill Cotton (in OBIT/AIPS) is also studying these issues.

Wideband Imaging

- Hercules A, total intensity and spectral index.
- From C and X band data. (from Bill Cotton).
- Data from D-configuration (10 arcsec resolution).
- Much more to come from other configurations
- This multi-frequency image is hardly better than a single-channel image made at the center frequency …
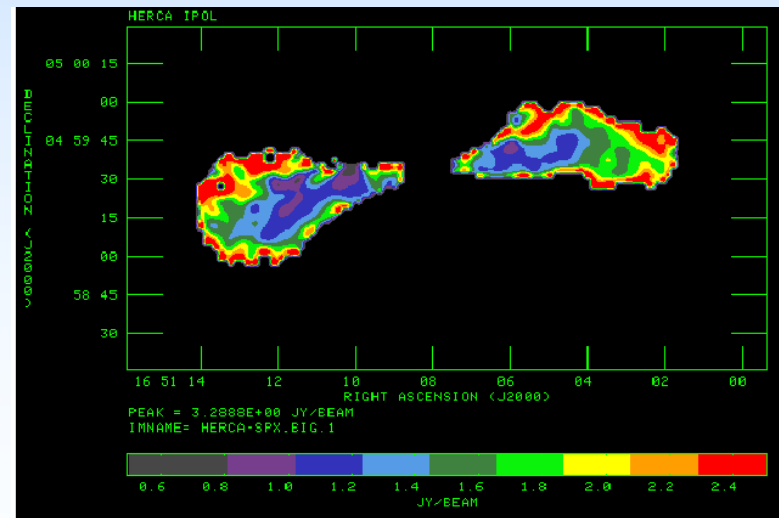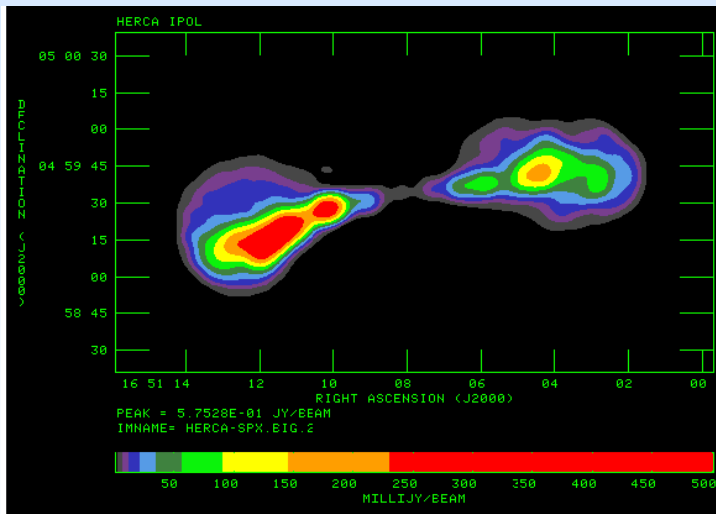
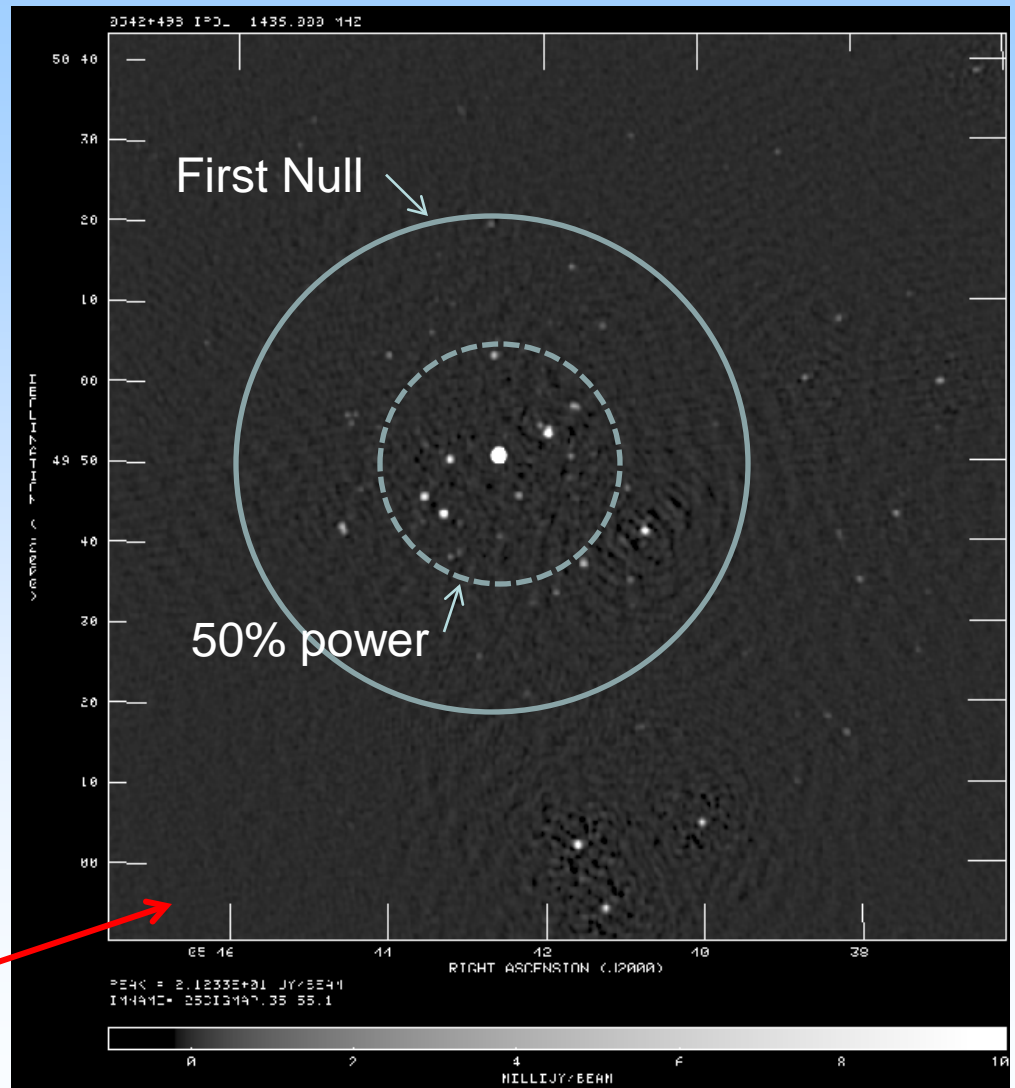# Multi-scale, Multi-frequency Deconvolutions
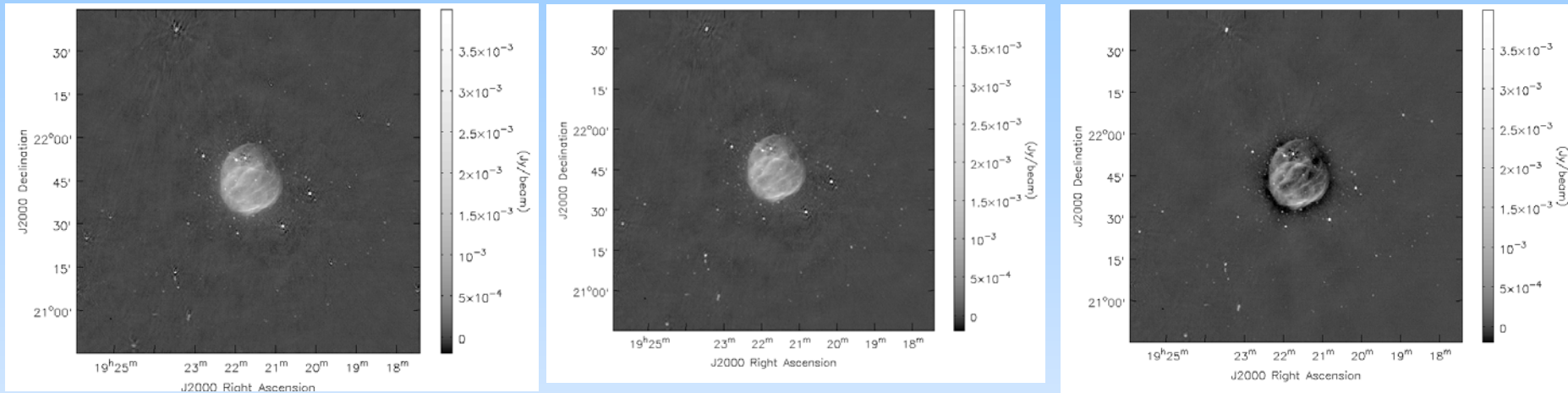
- Images of SNR G55.7+3.4 – RSRO Project AB1345, by Urvashi Rao
- Four 128-MHz-wide subbands, 2 MHz resolution, 7 hours' data, 300 GB! (20 GB after editing/averaging).
- Left: multi-scale with no w-projection
- Middle: multi-scale, with w-projection
- Right: multi-scale, multi-frequency, with w-projection.
- No self-cal on any of these.
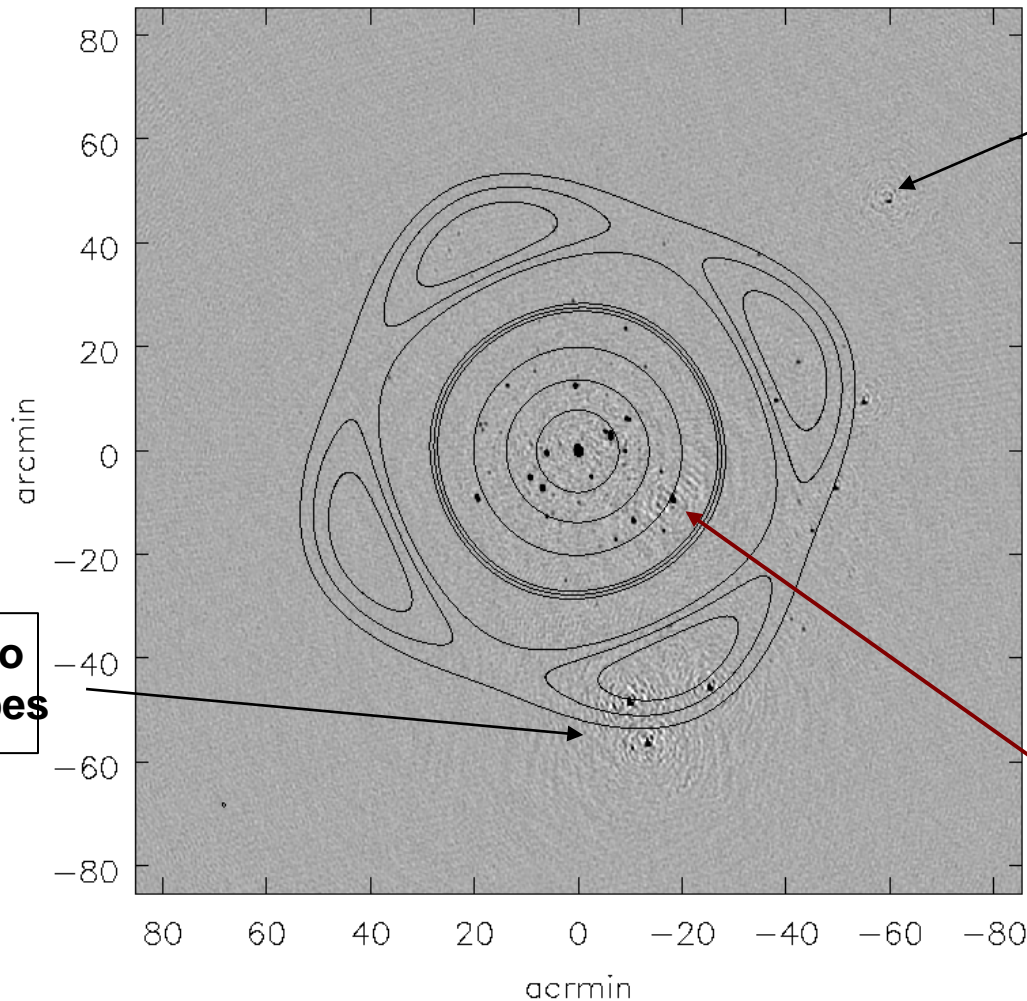- Rms noise: 12 μJy/beam. Pk residual 65 μJy/beam

High Fidelity Imaging

- The super-linear design of the EVLA should enable much higher DR (Fidelity!) imaging than we have previous been able to do.

- We will be quickly limited at virtually all bands by various pointing/main beam issues:
    - Pointing offsets
    - Unsteady tracking
    - Non-azimuthally symmetric beams
    - Polarization beams (special case of above).

- Sanjay Bhatnagar is working on developing algorithms to measure and remove these effects, using the observed field emission.
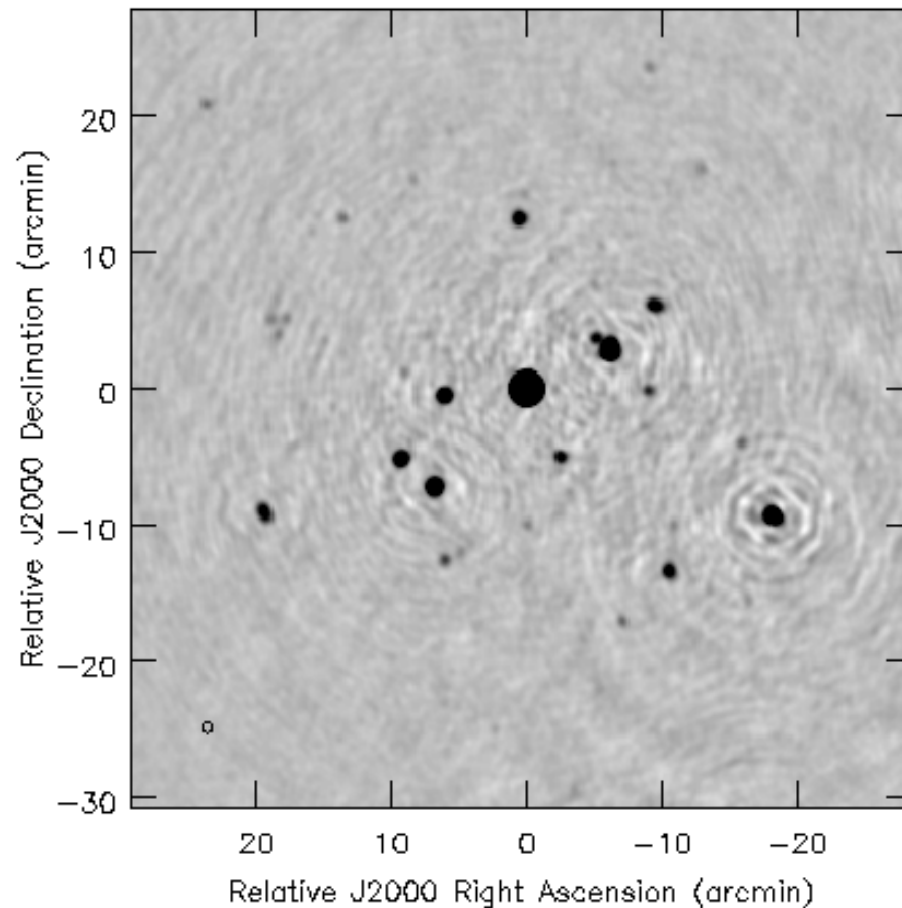
3C147 Deep Field @ 1440 MHz

- Detailed testing underway with 12-station, full polarization, 4 subband initial configuration.

- Most demanding testing is at L-band, short spacings.

- 12 antennas, 110 MHz, 6 hours integration

- Best image so far: 400,000:1 DR for 3C147. (850,000:1 to noise in corners).

- Some artifacts visible – due to non-azimuthal symmetry in the antenna primary beams.
  - 'Peeling' software can deal with this.

- RMS noise in corners = 1/millionth of the peak.

First Null

50% power

3C147: Residual errors in full field

**Smearing
+ W-Term errors!**

**Errors due to
PB side-lobes**

Errors due to
pointing errors

•EVLA L-Band Stokes-I: Before correction

- 3C147 field at L-Band with the EVLA
- Only 12 antennas used
- Bandwidth: 128 MHz
- ~7 hr. integration

- Dynamic range: ~700,000:1

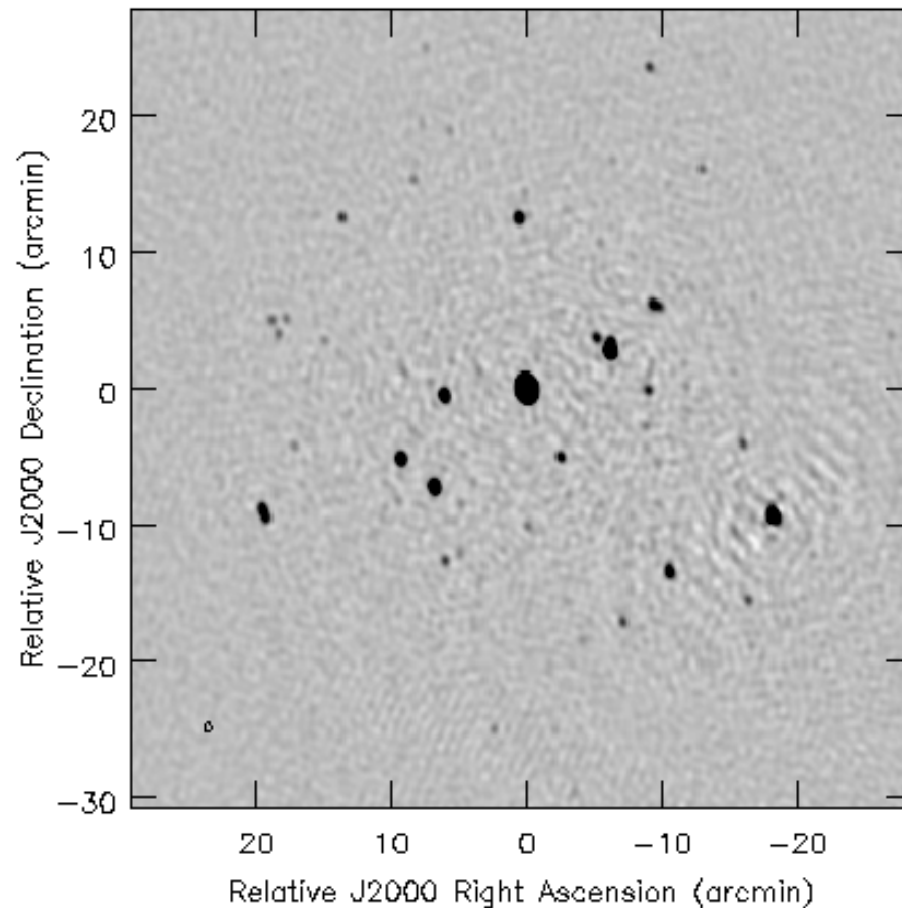# •EVLA L-Band Stokes-I: After correction

- 3C147 field at L-Band with the EVLA
- Only 12 antennas used
- Bandwidth: 128 MHz
- ~7 hr. integration

- Dynamic range: ~700,000:1

# High-Fidelity Imaging – Cygnus A

- Issues with the primary beam, or signal linearity are not the only ones limiting accurate imaging.

- Observations of Cygnus A, made with WIDAR last month at X-band (3.6 cm), self-calibrated and imaged with the best modern methods, provided an image:
  - No better than that which I made 25 years ago with the VLA
  - A noise level 1000 times the thermal noise!
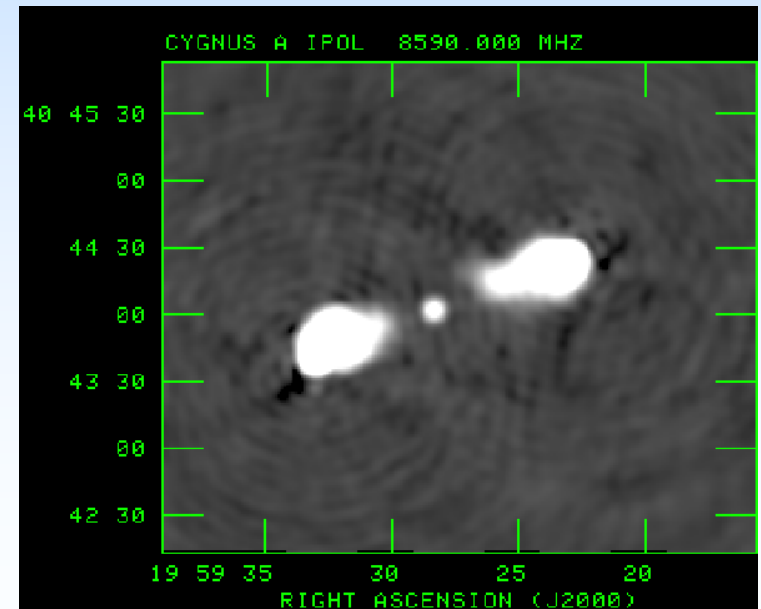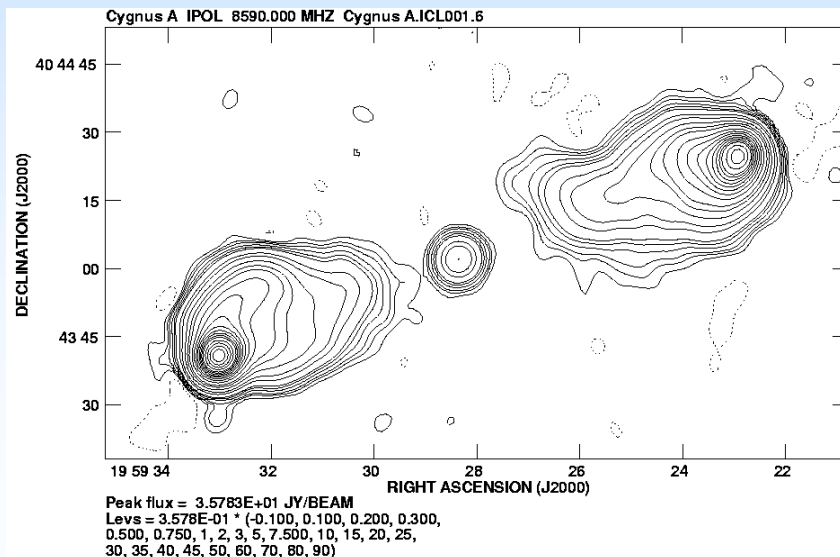
What is Wrong Here?

- Images made of the nearby calibrator were noise limited at a DR of many hundreds of thousands!

  - Image of J2007+4030 -- the calibrator for Cygnus A
  - Data taken same time as Cyg A.
  - DR is ~650,000:1
  - Noise is 6 μJy – the thermal level.
  - 2 hours on-source
  - 512 MHz BW
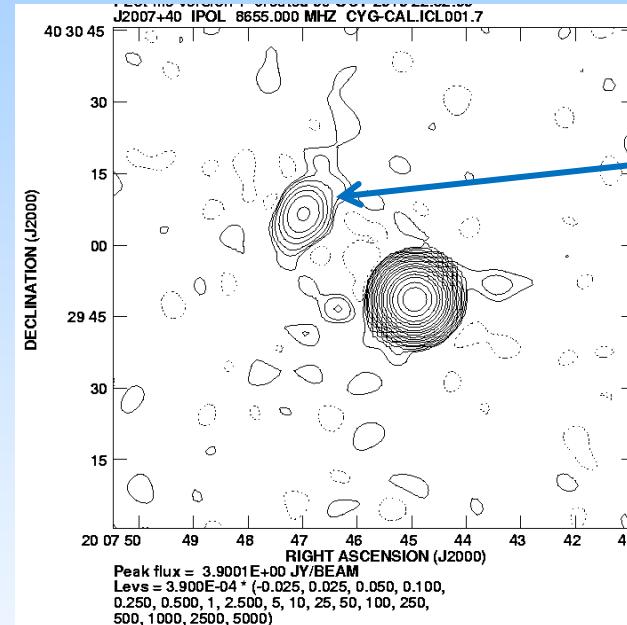
0.004% of peak!

- What is wrong with Cyg A?
- Clearly associated with the cycle of imaging/self-calibration.
- Many ideas – little progress…
- Very important problem which must be solved.

WIDAR Growth: 2010 and forwards

- The expansion in observational capabilities through 2010 and 2011 will be rapid, but measured.

- Current RSRO observations are with the 'fundamental homogeneous correlator setup'
  - All spectral windows are adjacent and have the same width and channelization.

- Resident observers (RSRO program) should have access to:
  - 2 GHz/polarization BW (all antennas) by mid-2010
  - 8 GHz/polarization BW (all antennas) by end of 2011.
  - Recirculation (increased spectral resolution) by late 2010
  - Independent spectral window tuning by early 2011
  - Flexible resource allocation (trading spectral windows for more spectral resolution) by mid 2011.

Final WIDAR Capabilities

- The capabilities of the completed WIDAR are too vast to describe in one or two slides.

- We will certainly be offering the following on a short timescale:

  1. The Basic Homogenous Mode – full band coverage

     - Spectral windows arranged to cover the entire width of a particular band
     - All spectral windows have the same width and number of channels.

  2. Targeted spectral windows for higher resolution.

     - Each spectral window tuned to a specific frequency, with individual frequency width and spectral resolution.

Summary of Wide-band Coverage:

- For dual (RR,LL) polarization, **with recirculation**
- For full polarization, resolutions are 2 x poorer.

	Freq.	IF BW	SW Width	# SWP	Freq. Res.	Vel. Res.	Nch per	Nch	Data rate*
	GHz	GHz	MHz		kHz	km/s	spctrm	total	MB/s
L	1—2	1.024	16	64	15.6	3.1	1024	131072	50
S	2—4	2.048	32	64	62	6.3	512	65536	25
C	4—8	4.096	64	64	250	12.5	256	32767	12
X	8—12	4.096	64	64	250	7.5	256	32767	12
U	12—18	6.144	128	48	1000	20	128	12288	4.8
K	18—26.5	8.192	128	64	1000	13	128	16384	6.2
A	26.5—40	8.192	128	64	1000	9	128	16384	6.2
Q	40--50	8.192	128	64	1000	6.5	128	16384	6.2

- For cold molecules, this resolution is insufficient – frequency coverage will have to be sacrificed to increase velocity resolution.

 * With 10 second averaging.

The Next Step – Flexible Tuning with Adjustable Sub-band Widths.

- Individual tuning of each of the 64 spectral window pairs is scheduled for RSRO availability in T1 2011.
  - Each of the 64 spectral window pairs would be digitally tunable to any frequency within the input bandwidth.
  - The spectral window width and spectral resolution of each will also be variable.
- This will enable greatly improved capabilities in studying spectral emission of atomic and molecular emission from specific regions, where:
  - Full bandwidth coverage is not needed, or
  - Spectra resolution better than ~10 km/sec is needed, or
  - Adjustable spectral resolution is advantageous.

Concluding Remarks

- The EVLA is near completion, and available for science observing.

- Many key, and new functionalities are already available.

- Increased capabilities will be added over the next few years.

- Growth in capability will be limited by software, primarily in correlator and post-processing.

- Many challenges remain before full throughput is obtained.

- The array will remain the dominant cm-wavelength, general purpose telescope for decades to come.