The Jansky Very Large Array

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National Radio Astronomy Observatory

Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

EVLA Project Overview

- The EVLA Project is a major upgrade of the Very Large Array. Upgraded array → Jansky VLA
- The fundamental goal is to improve all the observational capabilities of the VLA (except spatial resolution) by at least an order of magnitude
- The project will be completed by early 2013, on budget and schedule.
- Key aspect: This is a leveraged project – building upon existing infrastructure of the VLA.

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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
  - All digital design to maximize instrumental stability and repeatability.

- New correlator with 8 GHz/polarization capability
  - Designed, funded, and constructed by 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.

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Jansky VLA-VLA Comparison

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Parameter	VLA	EVLA	Factor	Current
Point Source Cont. Sensitivity (1σ,12hr.)	10 μJy	1 μJy	**10**	2 μJy
Maximum BW in each polarization	0.1 GHz	8 GHz	**80**	2 GHz
# of frequency channels at max. BW	16	16,384	**1024**	4096
Maximum number of freq. channels	512	4,194,304	**8192**	12,288
Coarsest frequency resolution	50 MHz	2 MHz	**25**	2 MHz
Finest frequency resolution	381 Hz	0.12 Hz	**3180**	.12 Hz
# of full-polarization spectral windows	2	64	**32**	16
(Log) Frequency Coverage (1 – 50 GHz)	22%	100%	**5**	100%

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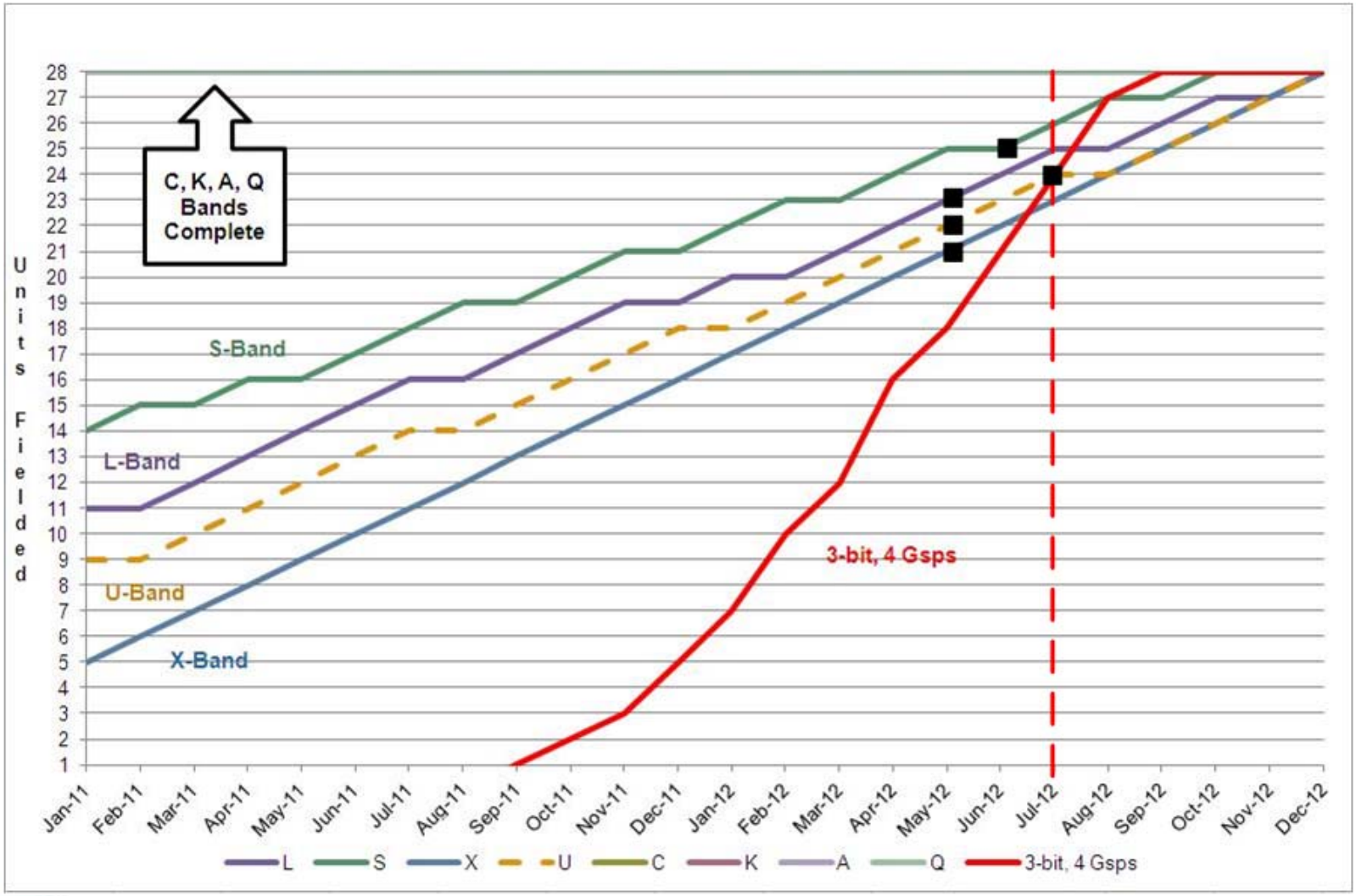
EVLA Project Status

- Installation of new wideband receivers now complete at:
  - 4 – 8 GHz (C-Band)
  - 18 – 27 GHz (K-Band)
  - 27 – 40 GHz (Ka-Band)
  - 40 – 50 GHz (Q-Band)
- Installation of remaining four bands completed late-2012:
  - 1 – 2 GHz (L-Band) 19 now, completed end of 2012.
  - 2 – 4 GHz (S-Band) 21 now, completed Sept. 2012.
  - 8 – 12 GHz (X-Band) 16 now, completed end of 2012.
  - 12 – 18 GHz (Ku-Band) 18 now, completed end of 2012.
- In addition (but outside the Project), we are outfitting a new wideband low-frequency receiver (paid for by NRL).
  - Two prototypes now outfitted, the rest through this year and next.

Remaining Hardware Implementation

- 3-bit samplers
  - 24 antennas outfitted with 4 IF pairs
  - Installation on 28th antenna to occur before 9/1
  - 27 spare cards assembled, basic testing will require 2 months and commence in September
  - 56 spare sampler chips (25%)
  - Spare assemblies/chips will be used to replace underperforming field units

EVLA


C, K, A, Q Bands Complete
S-Band
L-Band
U-Band
X-Band
3-bit, 4 Gsps
Units Fielded
28
27
26
25
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Nov-12
Dec-12
L
S
X
U
C
K
A
Q
3-bit, 4 Gsps

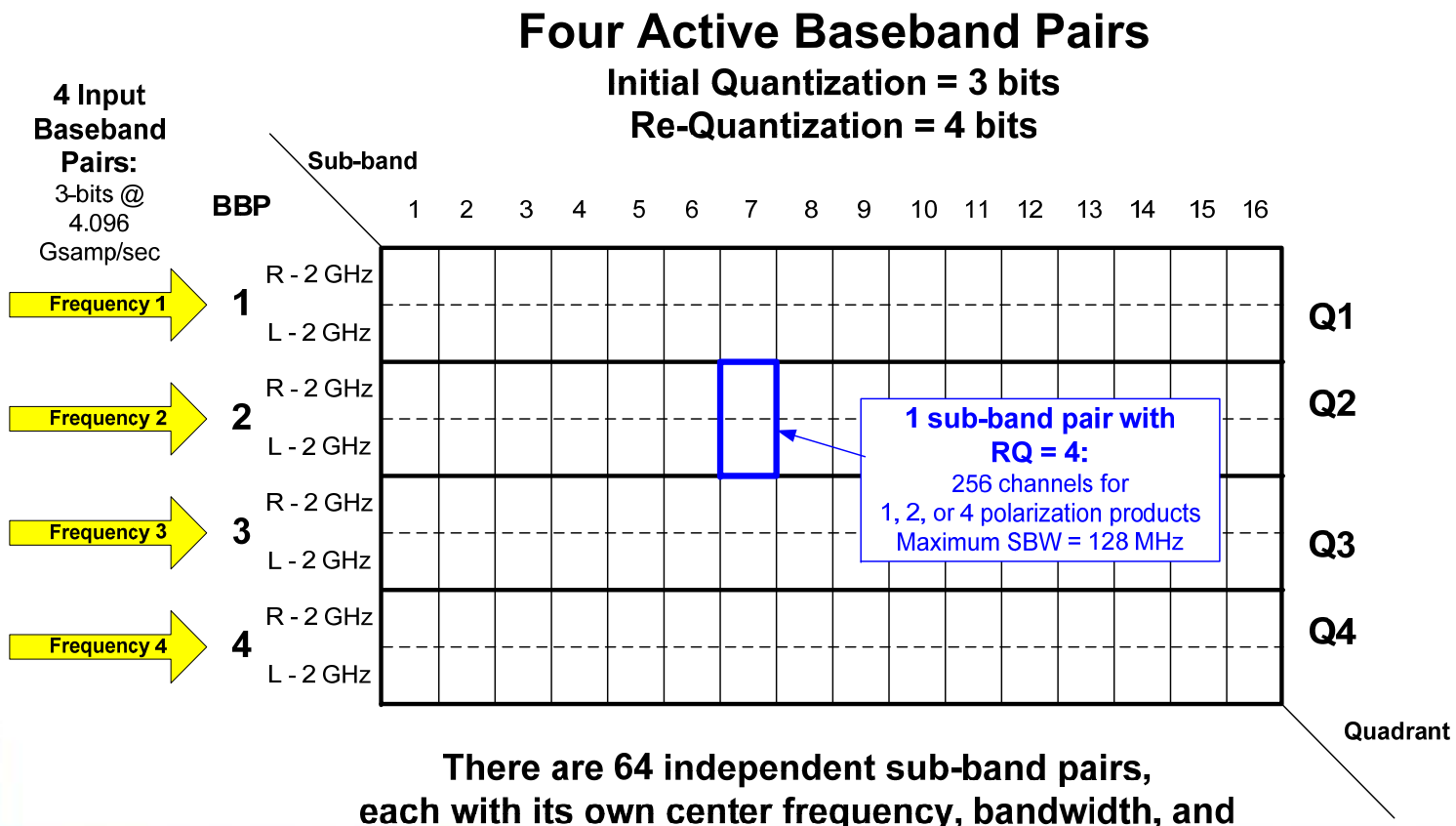
The 'WIDAR' Correlator

- The JVLA's correlator was built to NRAO's requirements by the DRAO correlator group, located at the HIA facility near Penticton, BC.
- This 'WIDAR' correlator was paid for by the Canadian government, as part of a cooperative agreement between NRC and NSF.
- This extraordinarily flexible machine is now fully installed at the VLA site, and is working magnificently.
- We are far from deploying all of its capabilities, however. This is a lengthy process, which is months to years away from completion.
- Installation of WIDAR began Jan 2010, astronomy Mar 2010.

The 'WIDAR' Correlator

EVLA

- 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.



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

WIDAR Flexibility

- Each of the 64 spectral windows:
  - Is independently tunable to any frequency within the baseband.
  - Has a frequency width of any of 128, 64, 32, …, .031 MHz
  - Provides 256 spectral channels in its basic mode.
  - Has two ways to increase spectral resolution, to meet the users' science goals, at the cost of reducing bandwidth coverage.
- Frequency resolution ranges from 2 MHz to 0.19 Hz.
- N_{chan} is from 16384 to more than 4 million.
- Numerous special operating capabilities, including phased array, fast dumps, burst modes, pulsar binning modes.

VLA Operations

- Observing with WIDAR (a watershed event) began March 2, 2010.
- At that time, the OSRO/RSRO program began:
- OSRO ('Open Shared Risk Observing').
  - Modeled after the former standard observing system.
  - Users not required to come to observe.
  - Basic, well established, but limited, range of observing modes.
  - Acquired data sent to user (internet, or disk).
  - Original limited capabilities now increased to full 2 GHz BW.

VLA Operations (cont.)

- RSRO ('Resident Shared Risk Observing')
  - Users have access to 'leading edge' capabilities, in exchange for an extended period of residency in Socorro.
  - Duration of residency tied to length of time granted on array.
  - Intentions of the program were twofold:
    - Acquire skilled labor to materially assist in commissioning the new correlator and array observing modes.
    - Expose a new generation of users to the JVLA, and utilize them as 'ambassadors' to help spread the word about the new capabilities.
    - Along with the latter, the new energy and enthusiasm brought to Socorro should help our own staff's enthusiasm.
  - The latter goal has certainly been met! The former – less so, as the kind of ace users/instrumentalists were not common amongst those applying for time.

Development

- Efficient, effective use of the Jansky VLA needs development in a number of areas.
- Hardware: Major items include:
  - Pipeline Cluster.
  - Expanding the correlator's CBE.
  - Addressing the ACU Issue.
- The antenna control units *must* be replaced over the next few years, starting very soon. This is not an EVLA funded item, but some contingency money is being allocated to test a proposed design.
- New monies will be required, over the next few years, to complete this essential replacement.

EVLA

Future: Software Development

- Software improvement/upgrade will be ongoing for many years. Some important areas include:
  - Continued development of more complex correlator configurations.
  - Establishment of the Jansky VLA data pipeline in CASA
  - Improved algorithms for RFI identification, flagging, and (eventually, in some cases) subtraction.
  - Improved algorithms for wide-field, wide bandwidth imaging. (Especially important at lowest two frequency bands, L and S). !!
  - Improved algorithms to enable correction of full-Stokes images for the antenna polarization and primary beam shapes.

- Should NRAO focus on producing science-ready data products?

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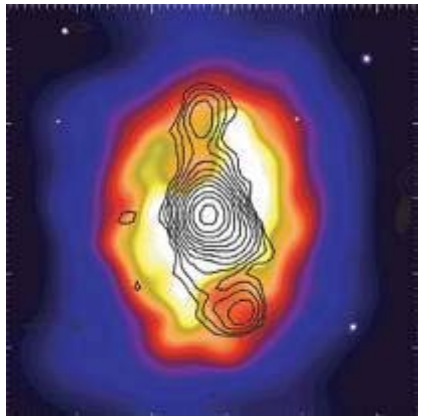
Jansky VLA Design Driven By Four Themes

Magnetic Universe

Measure the strength and topology of the cosmic magnetic field.



Obscured Universe

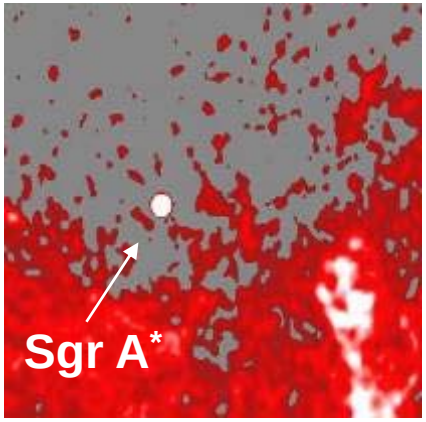
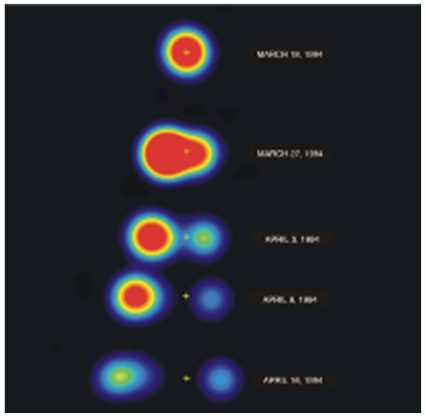


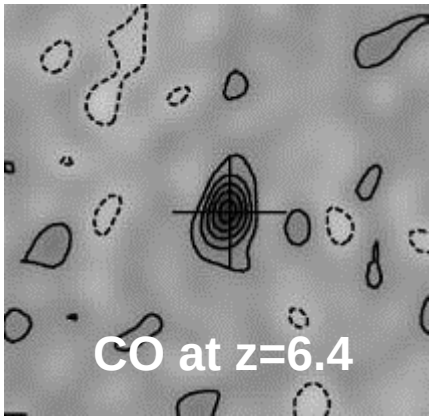
Image young stars and massive black holes in dust enshrouded environments.

Transient Universe

Follow the rapid evolution of energetic phenomena.



Evolving Universe



Study the formation and evolution of stars, galaxies and AGN.

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Magnetic Universe Theme

- Synchrotron emission from radio galaxies, quasars, SNR
  - Maps magnetic fields within sources
  - Provides age estimates of structure
- Faraday Rotation Studies
  - Plane of polarized emission is rotated by magneto-ionic medium, give estimate of line-of-sight magnetic field strength and structure.
- Zeeman Splitting Studies
  - Spectral transitions split into hyperfine structure by magnetic field.
  - Allows direct measurement of magnetic fields in line-emitting environments.

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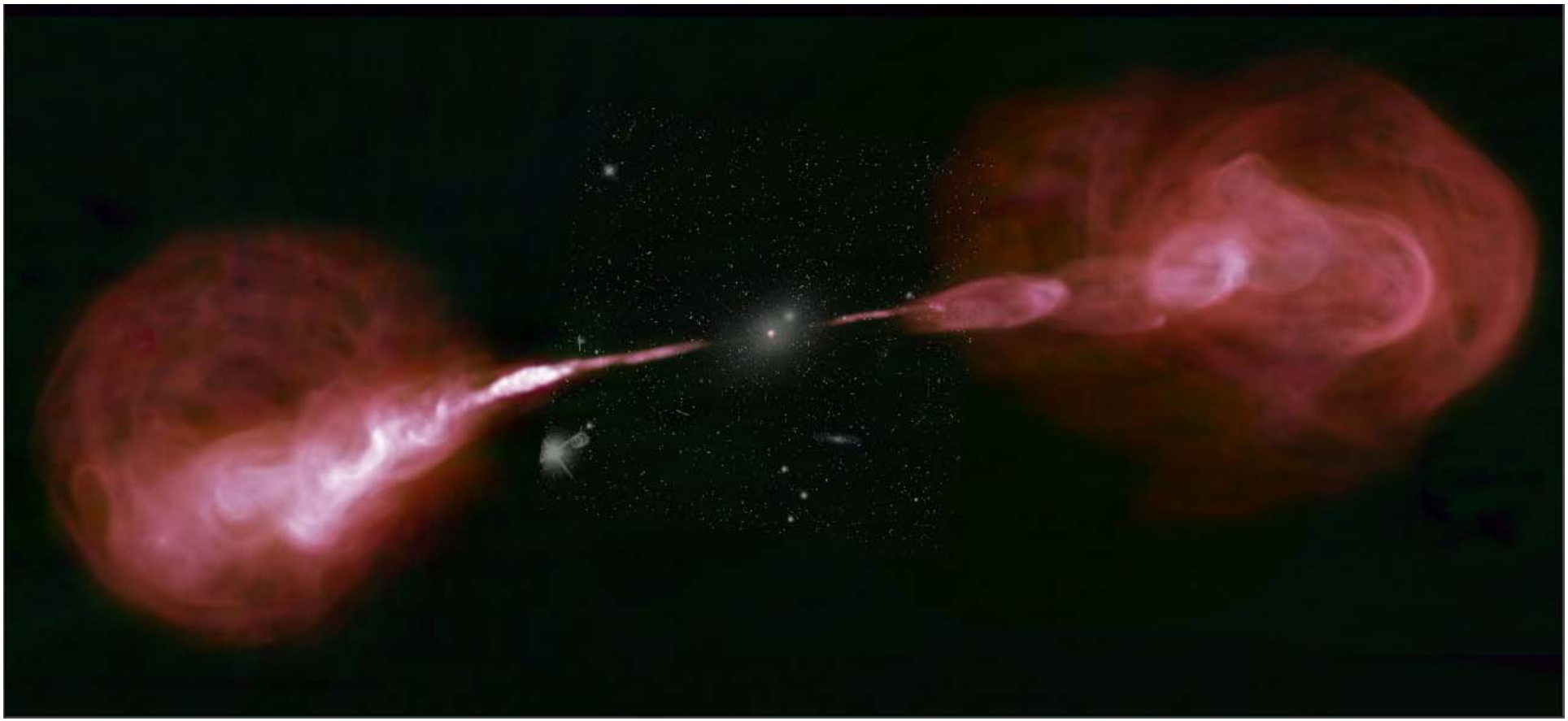
Hercules A (Perley and Cotton, demo)

- z = 0.154, radio galaxy. D = 710 Mpc, 1arcsec = 3.4 Kpc.
- 4-9 GHz color-code spectro-intensity image (redder = older). 1 Kpc res^{n}.
- EVLA data: 1 through 9 GHz, all four configurations, 1Kpc resolution.
- Shocks in western lobe indicate repeated ejection.



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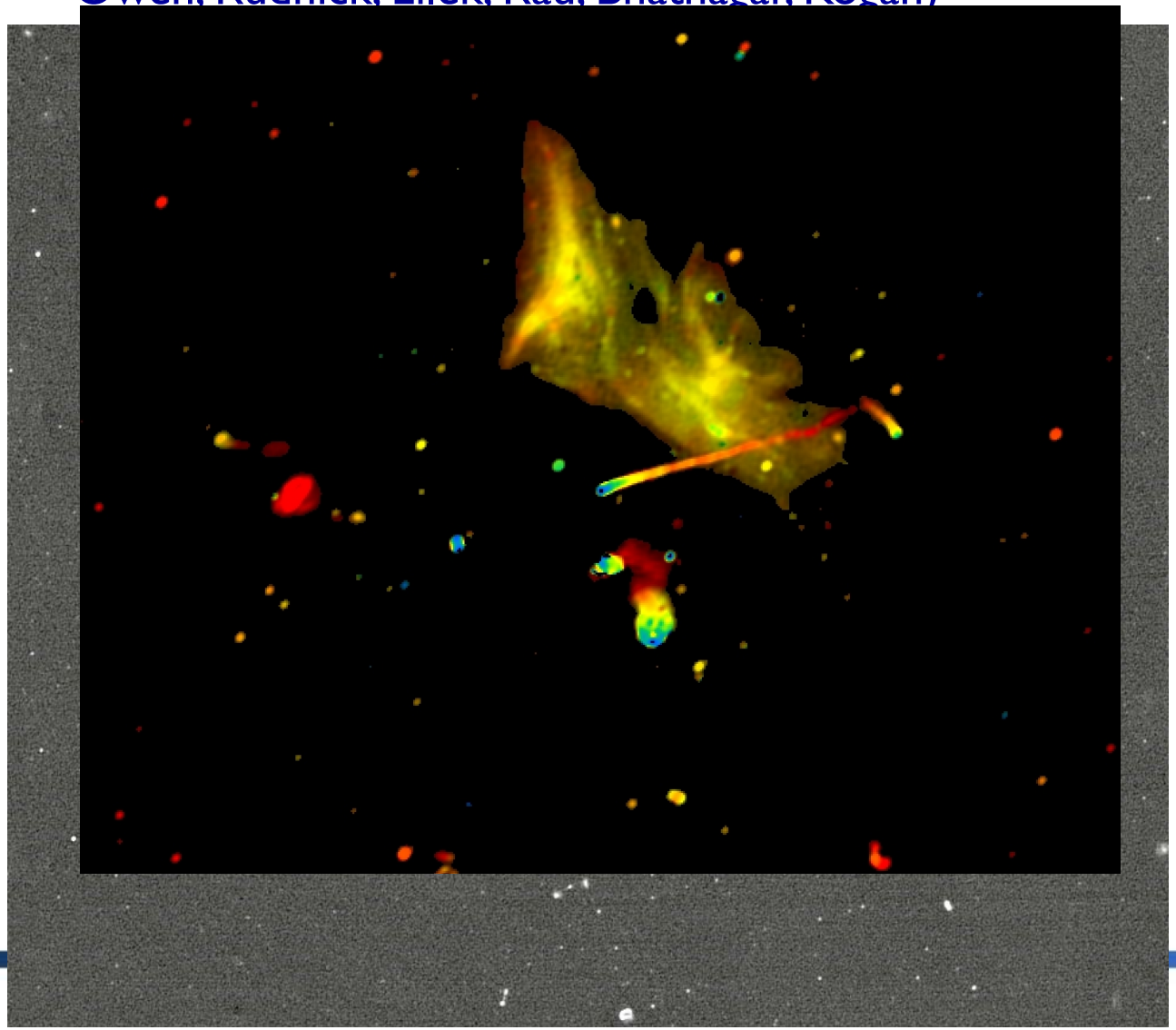
Relics and Jets in Abell 2256 at λ = 20cm

Owen, Rudnick, Eilek, Rau, Bhatnagar, Kogan)

- A merging rich cluster of galaxies
- z = .058, D = 270 Mpc.
- 1–2 GHz, 20-arcmin on a side (1.6 Mpc)
- Studies of the complex interactions between galaxies, AGN feedback, ICM, magnetic fields, and dark matter content of clusters
- Role of radio galaxies and relics in cluster evolution?



Evolving Universe Theme

- New micro-Jy sensitivity allows deeper continuum imaging.
  - Higher redshift continuum emission now within reach
  - More objects, more types, more classes, more extremes
- Wide spectral coverage, and full frequency coverage, allows studies of high-z molecular emission.
  - Can do 'double-blind searches' – no prior knowledge of specific transitions or specific sources.
  - 'Guaranteed' that there will be early galaxies, detectable in line emission, within a few hours integration, in any Ka or Q band beam!
  - 'gold rush' underway now.

M82 – The Prototype Nearby Starbust Galaxy

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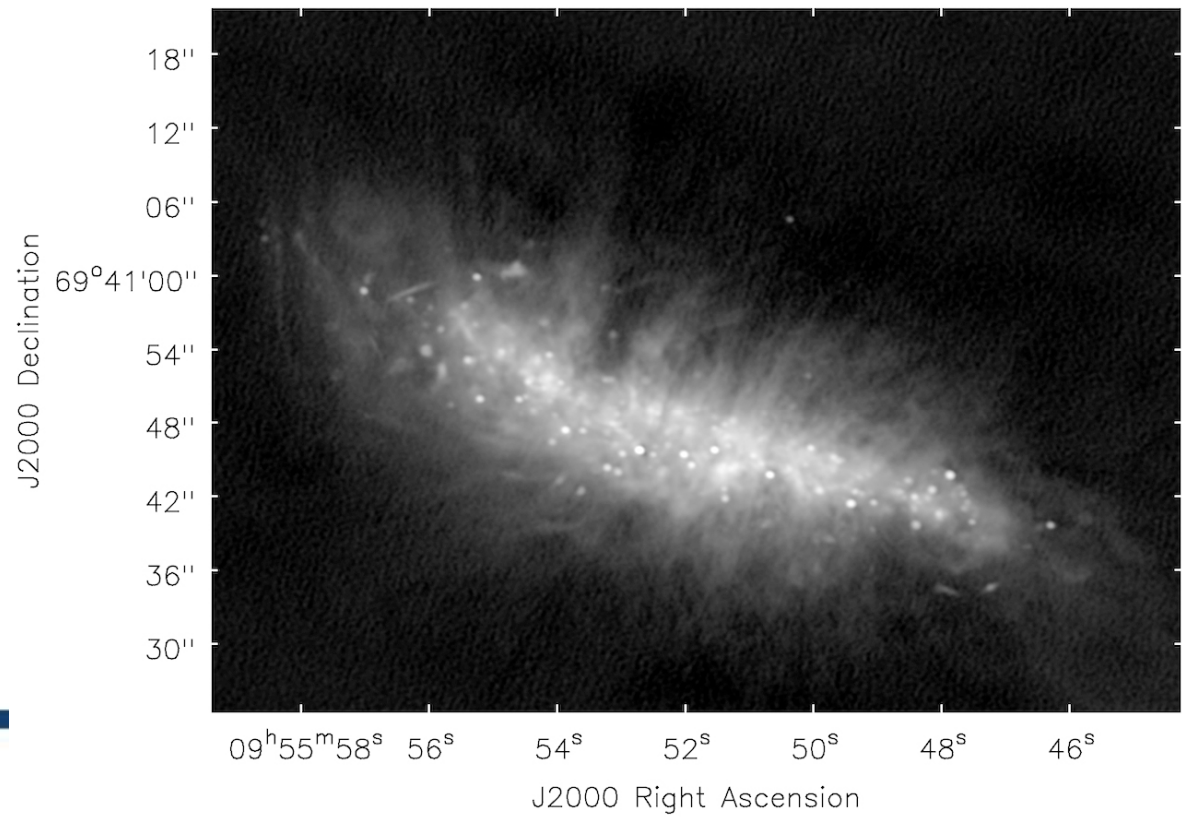
- Shown is a deep C-band VLA image, combining A and B configuration data.
- Resolution is 0.35 arcseconds (5 pc at distance of M82).
- Extreme nuclear starburst driving a superwind > 1Kpc above disk.
- Visible are: SNR and some HII regions throughout star forming disk.

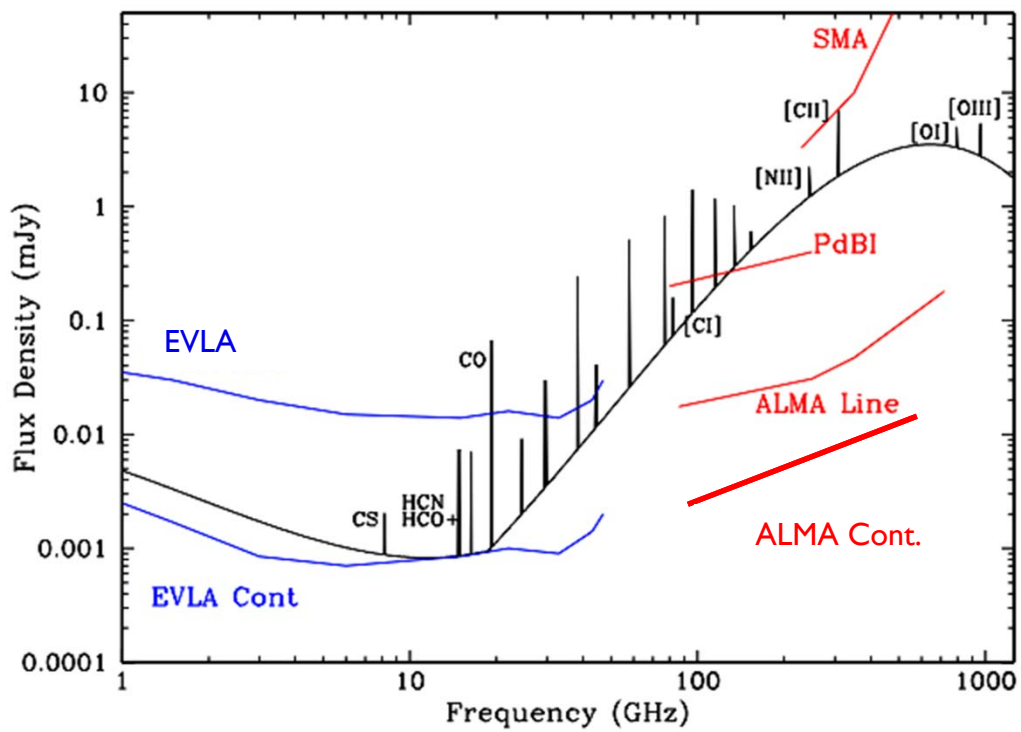
J. Marvel, Owen, Eilek

- Synchrotron radio halo shows filamentary structures
- Matches H-alpha and Xray images.
- Inhomogenous distribution of super-star clusters drives multiple outflow channels.



The "Radio Era" to Study Galaxy Evolution

- Stars and star formation studied to z ~ 8, i.e. 500 Myr after Big Bang
- Major unknown is the distribution and evolution of the cold gas reservoir
- EVLA and ALMA are poised to unveil the fuel for galaxy assembly…

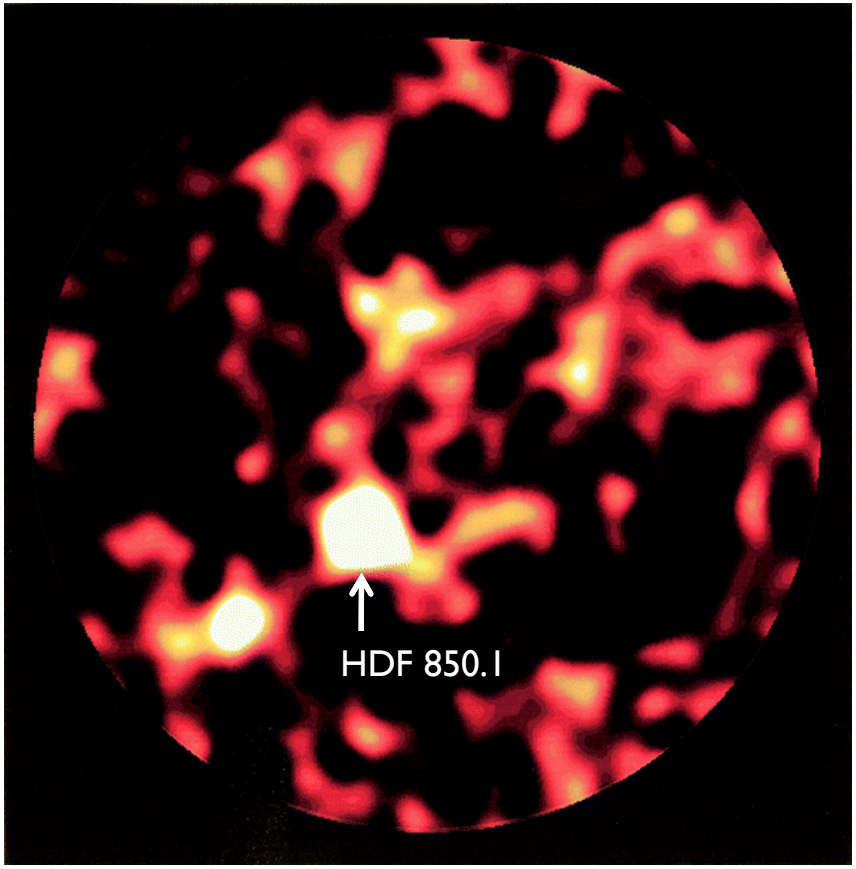


SED of galaxy forming 100 M_{sun} yr^{-1} at z=5

An Old Mystery in the High z Universe

Hughes et al (1998)

- The strongest submm source in the HDF lacks a counterpart or redshift.
- Known as HDF850.1, no identification with any optical/IR image was made for many years following its discovery in 1998.
- Dunlop et al. (2002) proposed an identification with deep imaging done with Subaru.
- Estimated redshift: 4.1

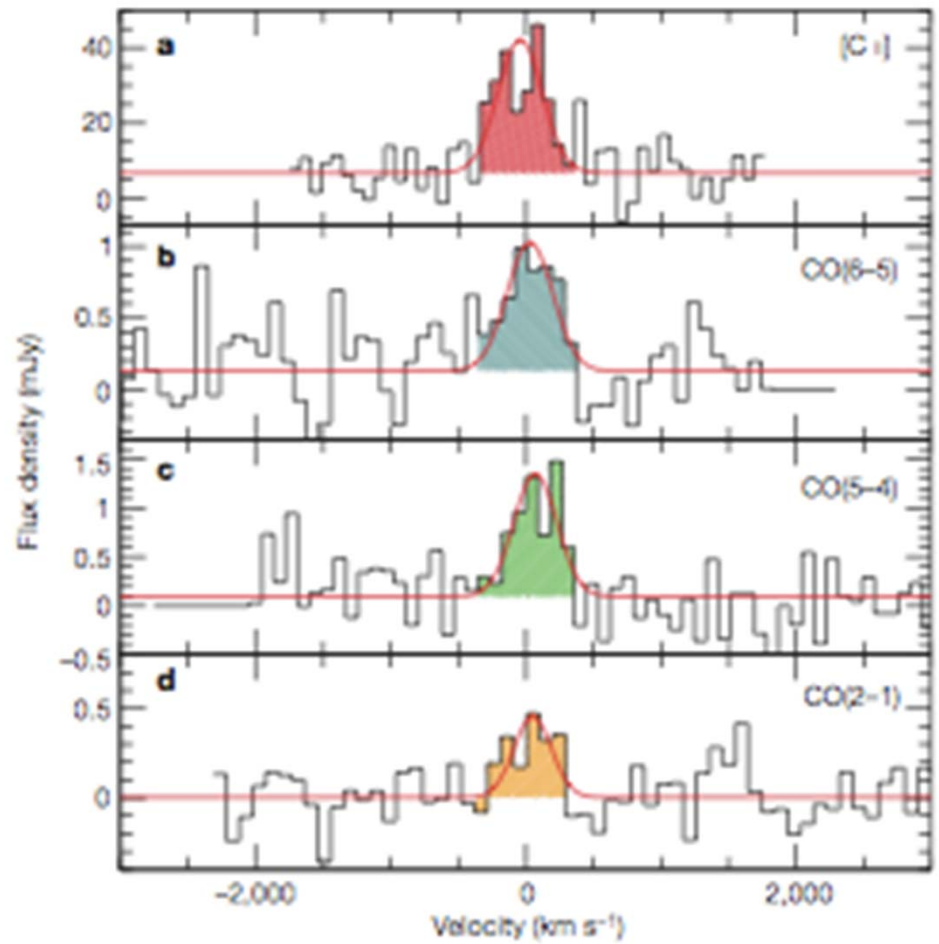


EVLA

An Old Mystery in the High z Universe

- The brightest submm source in the HDF lacks a counterpart or redshift
- Blind molecular line survey of HDF with PdBI identifies redshift
- Confirmed with EVLA CO(2-1)
- HDF 850.1 is a rare ultraluminous starburst galaxy:
  - z=5.183 (further than predicted)
  - In galaxy over-density at z=5.2
  - 850 $M_\odot$/year, $M_{dyn}=10^{11}$ $M_\odot$
- Still no optical/NIR counterpart
- Highlights the value of blind surveys and future ALMA and EVLA synergy

Walter et al, Nature in press (2012)



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Transient Universe Theme

- Searching for RRATs – pulsars with sporadic pulses.
- Solar flare science.
  - Radio studies ongoing since late 1940s.
  - Provides insight into particle acceleration and energy release.
  - Important role in discovery of CMEs.
- Flare star science
- Brown Dwarfs

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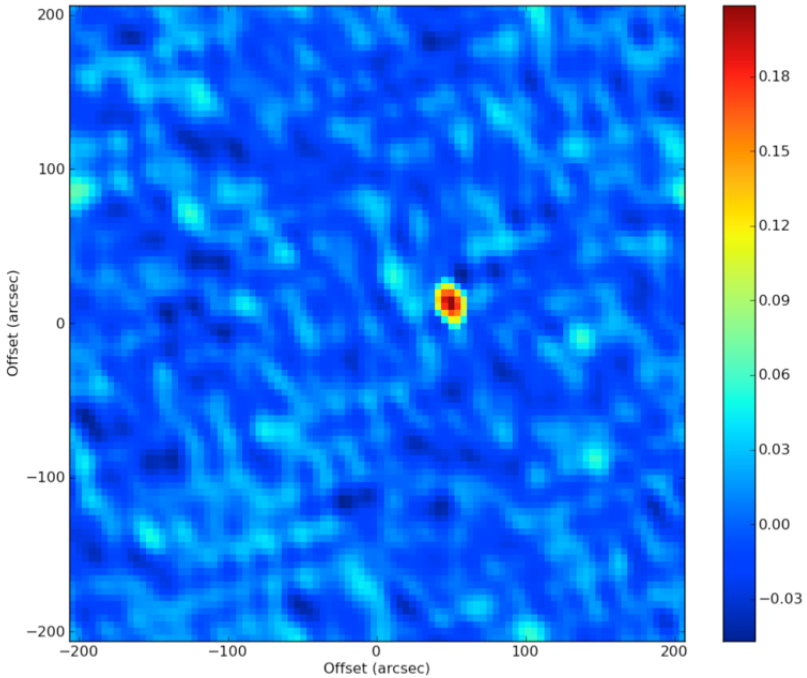
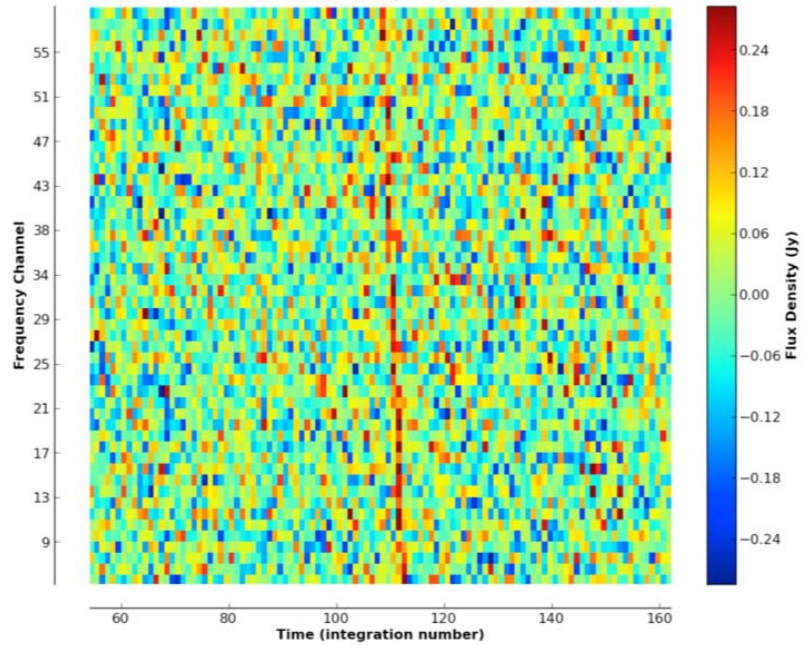
Transient Science – RRATs at the VLA

- Law and Bower (UCB) have taken 16 minutes of VLA data with 10 ms time resolution. This gives 90 GB data!
- Bispectrum analysis (Law & Bower, 2012) of raw data found a single pulse.
- Image of a single time interval, and its dispersion function shown below.

(Law et al., 2012)

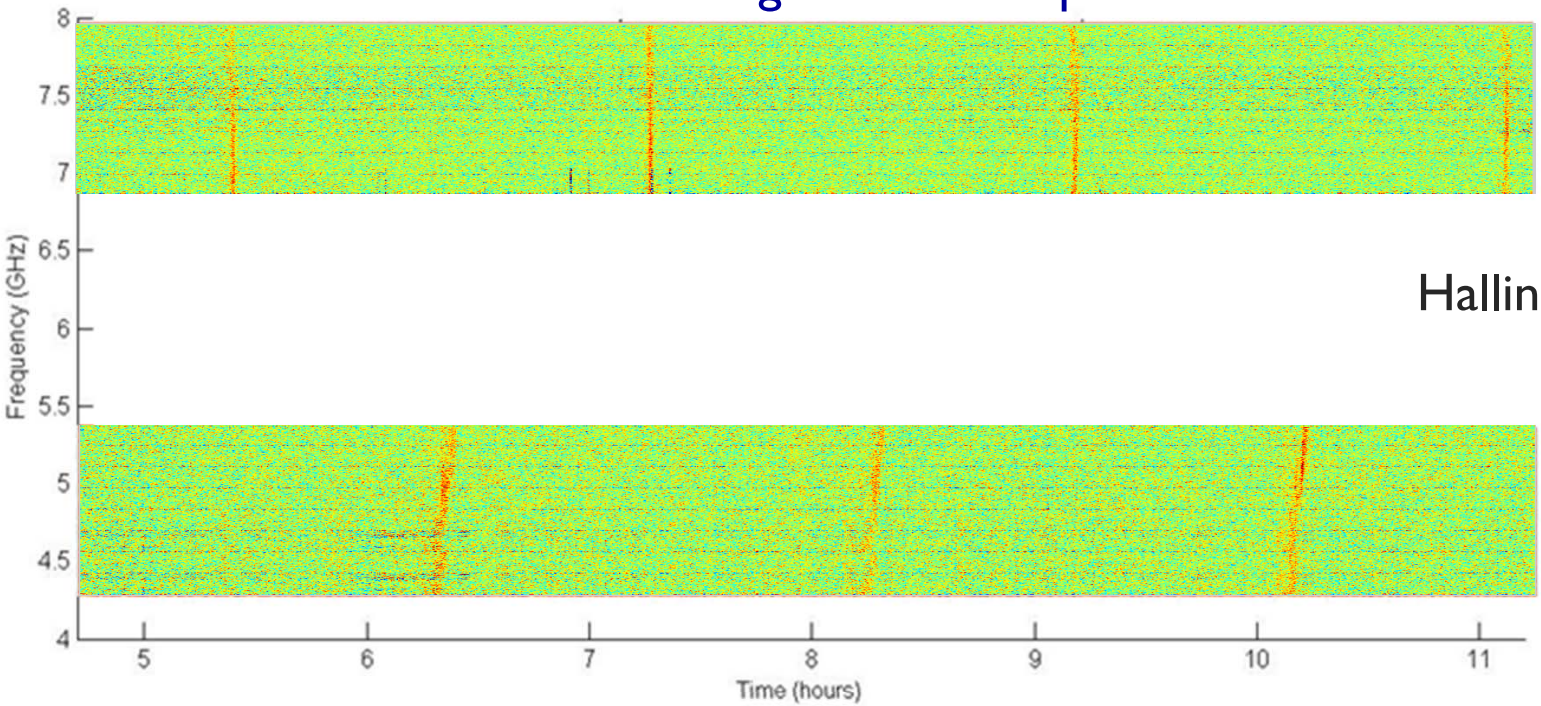




VLA: First results – 2MASS J0746+20

EVLA

- L Dwarf Star in solar neighborhood
- Shown are dynamic spectra, taken in C-band (2 x 1 GHz chunks)
- Period emission from a rotating auroral hotspot



Hallinan, 2012

- 2MASS J0746+20 -> L0+L1.5
- Period: 2.07 hours
- Magnetic field range: 1500 Gauss – 2800 Gauss

Obscured Universe Theme

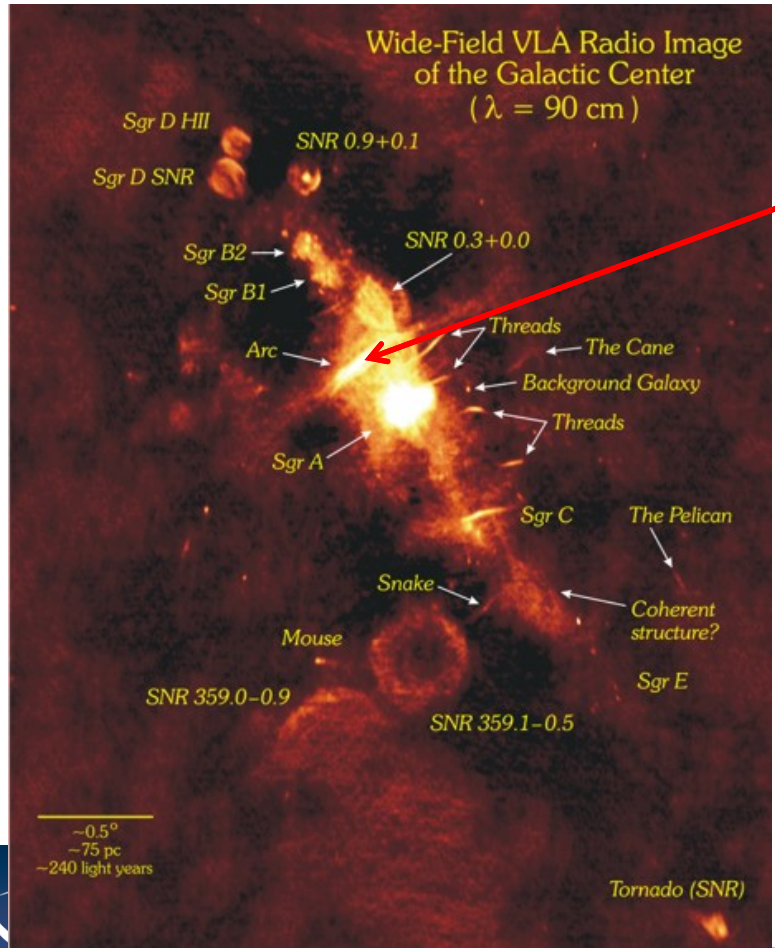
- Cm-wavelength observations nearly unattenuated by dust.
- VLA can detect regions too optically thick for visible, IR, and mm-wave instruments.
- Star-forming regions, protoplanetary disks, proto-stellar objects, HII regions, and much more are likely targets for high-resolution cm-wave studies with the VLA.

New K, Ka-band Observations of the Galactic Center (Mills et al.)

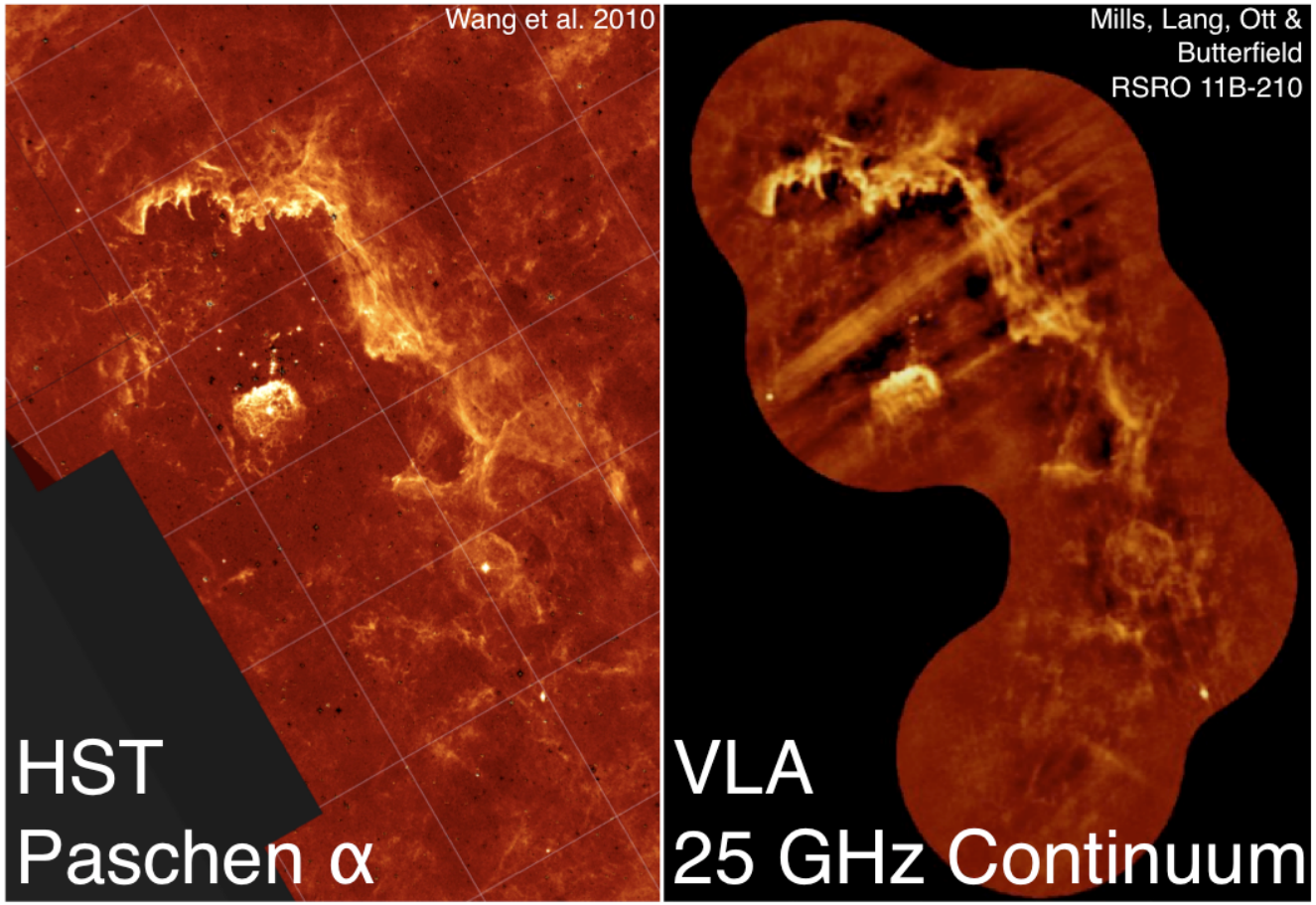
EVLA

The Galactic Center: A Busy Neighborhood!

Area of interest: The 'Sickle'



The Region in Paschen α (IR, 1870 nm) and 25 GHz (radio, 1.2 cm)



Summary

- The EVLA Project is near completion, and the Jansky VLA is available for science observing.
- The Jansky Very Large Array offers new capabilities, orders of magnitude better than any other cm-wave system.
- Users are responding with large numbers of proposals, targeting the new capabilities. Largest growth area – continuing a trend begun in VLA days – is in high frequency science: thermal science, and early universe science.
- Increased capabilities will be added over the next few years.

Summary

- Growth in capability will be limited by software, primarily in correlator and post-processing, some data management issues.
- Many challenges remain before full throughput is obtained.
- Coming synergy with ALMA, VLBA, GBT… powerful.
- The Jansky VLA will remain the dominant general-purpose, open-access, cm-wavelength telescope until a next-generation instrument is built.