Science Drivers for the EVLA System

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Overall EVLA Goals

- The EVLA Project seeks to improve, by an order of magnitude or better, all observational capabilities of the VLA:
  - Sensitivity
  - Spectral Resolution
  - Frequency Accessibility
  - Operations and Data Management
  - Spatial Resolution

Sensitivity, Spectral Resolution, Frequency Accessibility, Operations and Data Management — Phase I

Spatial Resolution — Phase II

Overall EVLA Goals

- The project will achieve these by:
  - Retaining the antennas, array layout and present infrastructure
  - Replacing virtually all of the electronics with new, modern-technology electronics.
  - Redesign of operations computing, and inclusion of EVLA computing needs into NRAO's 'e2e' project.
- The enormous increase in scientific capability brought by the EVLA is enabled by the use of modern electronics and modern computing.

Overall System Requirements

- From the users' perspective, the EVLA will provide:
  - ~1 μJy continuum sensitivity (rms, 12 hr) in all bands
  - Complete frequency coverage from 1 to 50 GHz
  - Broad and flexible spectral resolution, to ~1 Hz.
  - Full polarization capability
  - Spatial dynamic range > 60 dB.
    - N.B. >90 dB is the limit (1 μJy noise with 1000 Jy object)
  - Spectral dynamic range > 50 dB.
  - Polarization dynamic range > 40 dB.

Overall System Requirements

- From the users' perspective, the EVLA will provide:
  - OTF mapping and mosaicing modes at rates up to 2.5 deg/min.
  - Pulsar binning with > 1024 bins
  - Capability to handle most solar activity
  - Near-real-time user interaction with the observing system and data products
  - Comprehensive archiving

EVLA Science Goals

- A comprehensive list of science benefits of the EVLA is given in the proposal to the NSF.
- From these, and from further honing of technical capabilities, specific EVLA science goals are being developed for the EVLA Project Book.
- Some of these are given at the end of this presentation.
- These are selected to demonstrate the need for various technical improvements.

Design Goals
Antennas

- Antenna pointing accuracy of 6” (rms, blind) and 2” (rms, referenced).
- Antenna tracking accuracy of 2” (rms, referenced) at speeds up to 10 times sidereal (2.5 deg/min).
- High efficiency:
  - 60% from 4 to 18 GHz,
  - 50% from 1 – 2 and 18 – 40 GHz,
  - 40 % from 40 – 50 GHz.

Design Goals -- Electronics

- Complete frequency coverage from 1 to 50 GHz, at Cassegrain focus, in 8 bands.
- Maximum bandwidth of 8 GHz, per pol^{n}.
- Maximized G/T_{sys} across all bands.
- Cross-polarization (after calibration) < 0.1%
- Amplitude stability (after calibration) < 0.1%
- System phase stability ~ 1 ps (after calibration)
- 'Closure' errors < 0.01% (after calibration)

Design Goals -- Electronics

- Bandpass stability sufficient to permit detection of < 0.01% absorption line.
- Fast, calibrated gain response (~ 20 msec) to accommodate solar flares and fast slews.
- 20 – 40 dB gain attenuation to accommodate solar observing, while maintaining good imaging capability.
- Immunity to RFI, when $P_{RFI} > 20\ P_{noise}$.

Design Goals -- Correlator

- High immunity to RFI (and other large, rapidly varying signals):
  - Highly linear correlator (>50 dB).
  - Ability to avoid especially large RFI signals.
- A minimum of 16384 spectral channels over 8 GHz bandwidth x 4 polarizations.
- A special capability for ~1 Hz resolution over a few kHz.

Design Goals -- Correlator

- The ability to 'zoom' in on spectral regions of special interest.
- The ability to avoid narrow spectral regions which are not of interest, or have the potential to be especially damaging.
- Independent subarray capability.
- Multiple simultaneous correlator modes.

Design Goals -- Correlator

- Flexible sharing of internal resources
  - The ability to trade off bandwidth for spectral resolution
  - The ability to trade off polarization modes for spectral resolution
- Binning capabilities (~ 1024 bins) for pulsar observations
- Time resolution of ~10 milliseconds
- ‘VLBI-Capable’

Design Goals -- Computing

- Flexible, science-oriented on-line proposal preparation and handling system.
- Fixed and dynamic scheduling, to optimize usage of telescope resources.
- Modernized, flexible M&C system giving real-time tools for operators, technical staff, and scientific users to test, control, monitor, maintain and calibrate the instrument.

Design Goals -- Computing

- Image Pipeline – users will automatically receive a ‘default’ image produced in near real-time, using canned procedures.
- Data Archive – all original data, plus ancillary data will be archived, and will be accessible on-line.
- Post-Processing – a full suite of applications for optimal scientific processing will be provided.

System Requirements: Transition

- Because the VLA is a unique and critical scientific tool, it cannot be shut down for any extended period during the Project.
- We will strive to maintain the VLA's scientific capabilities during the Project.
- Enhanced antennas will be compatible with the existing correlator and control system.
- All observing modes and methodologies will be retained.

Science Examples
Wideband Spectral Searches

- Unbiased Spectral Line Searches across a wide bandwidth.
  - Study of dust-shrouded QSO absorption lines can provide detailed information on dense star-forming ISM in nascent galaxies.
  - The transitions of CO, HCN and HCO+ will lie within the EVLA's upper three frequency bands for redshifts of 1.3 to 4.8 (or higher).

Science Examples
Wideband Spectral Searches

- An 8 GHz bandwidth, at Ka-band, with RR and LL correlations, and 16384 channels, gives 5 km/sec velocity resolution (1 pol'n)– perfect for detection of molecular absorption lines.
- With the EVLA sensitivity, the resultant sensitivity is 0.16 mJy/channel, allowing a 5-σ detection of 30% absorption against a 2.5 mJy background source (7 per sq. degree).

Science Examples
Bistatic Radar

- Bistatic Radar Experiments
  - Bistatic observations of solar system objects give unique probes of their material surfaces and their rotational characteristics.
  - A transmitted CW returns with a frequency spread characteristic of the body's rotational velocity.
  - Slow rotators (like Venus, or asteroids) have returned BWs of about 15 Hz.
  - A single (circular) transmitted polarization gives a return in both polarizations.

Science Examples
Bistatic Radar

– For good bistatic studies, especially at 2.7 GHz, a resolution of ~1 Hz, full polarization, over >1 kHz, is required.
– Both a wide ‘continuum’ correlation, plus the narrowband, high spectral resolution correlation, is required.

Science Examples
Recombination Lines

- The phenomenon of Zeeman splitting can measure the magnetic fields of the emitting region.
- The split is very small – 2.8 Hz/mG.
- Narrow lines are thus the favored targets, and detections so far are mostly with OH and H absorption lines, and OH masers.

Science Examples
Recombination Lines

- Zeeman splitting in recombination lines are expected to be outstanding targets for the EVLA.
- But this is a demanding experiment – estimates are the best chances will be in S-band (2-4 GHz).
- There are 30 recombination lines in this band.

Science Examples
Recombination Lines

- It will be necessary to be able to resolve all (or most) of these lines simultaneously, in both RR and LL polarizations.
- We want the lines, not the continuum in between them (lines are ~ 250 kHz wide, separated by 70 MHz).
- Need 10 kHz (~1 km/sec) resolution.

Science Examples

Recombination Lines

- These needs can be met with 16384 channels, if they can be assigned to the 30 lines, each with ~1.5 MHz bandwidth.
- Other multiple-line systems (OH, NH_3) can be profitably observed with a targetable correlator.

Science Examples

Solar Flare Physics

- Impulsive energy release in solar flares occurs in the low corona, and is accompanied by multitudes of type III radio bursts.
- These are caused by electron beams moving through the corona. Physics includes wave-particle, and wave-wave interactions.
- Imaging spectroscopy (principally in the decimeter bands) can probe the energy release of these bursts in detail.

Science Examples
Solar Flare Physics

- These mechanisms occur on millisecond timescales.
- The Sun is a very strong source (Tb ~ 10^5 at 20cm, and can double Tsys in 10 msec!).
- Timescales for the correlator:
  - 50 ms good for most experiments.
  - 20 ms will satisfy nearly all users.
- At octave of bandwidth, with 1 MHz resolution

Science Examples

Redshifted Hydrogen

- At $\lambda = 20$cm, an entire $z = 0.1$ cluster will fit within a single VLA beam.
- A single 36 hour integration with 3.2 km/s resolution over 2500 km/sec would provide a 6-σ detection of 700 million M_{sun} galaxies
- This would provide detailed kinematic information into the dynamic state of the cluster.

Science Examples

Redshifted Hydrogen

- But – the LO/IF-FO systems will be providing the entire 1 – 2 GHz spectrum to the correlator.
- A parallel experiment could utilize the 512 MHz below 1.4 GHz to do a deep search for modest HI galaxies, out to redshifts of ~0.6.
- A 40 km/sec resolution, with 36 hour integration, would detect a 4×10^9 M_{sun} galaxy at z = 0.2.

Science Examples
Redshifted Hydrogen

- Both of these experiments could be run simultaneously with 16384 channel correlator that could process the data input with two separate modes, one at high resolution, and one at low, with an equal number of channels in each.

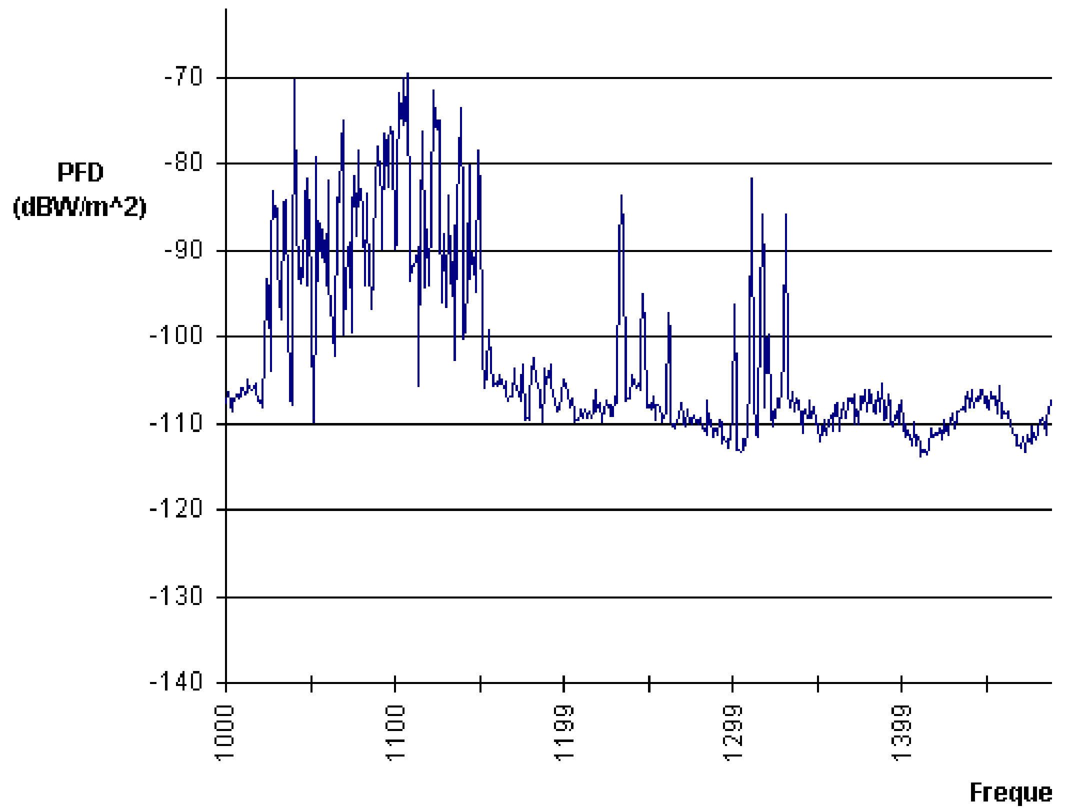
Science Examples

Redshifted Hydrogen

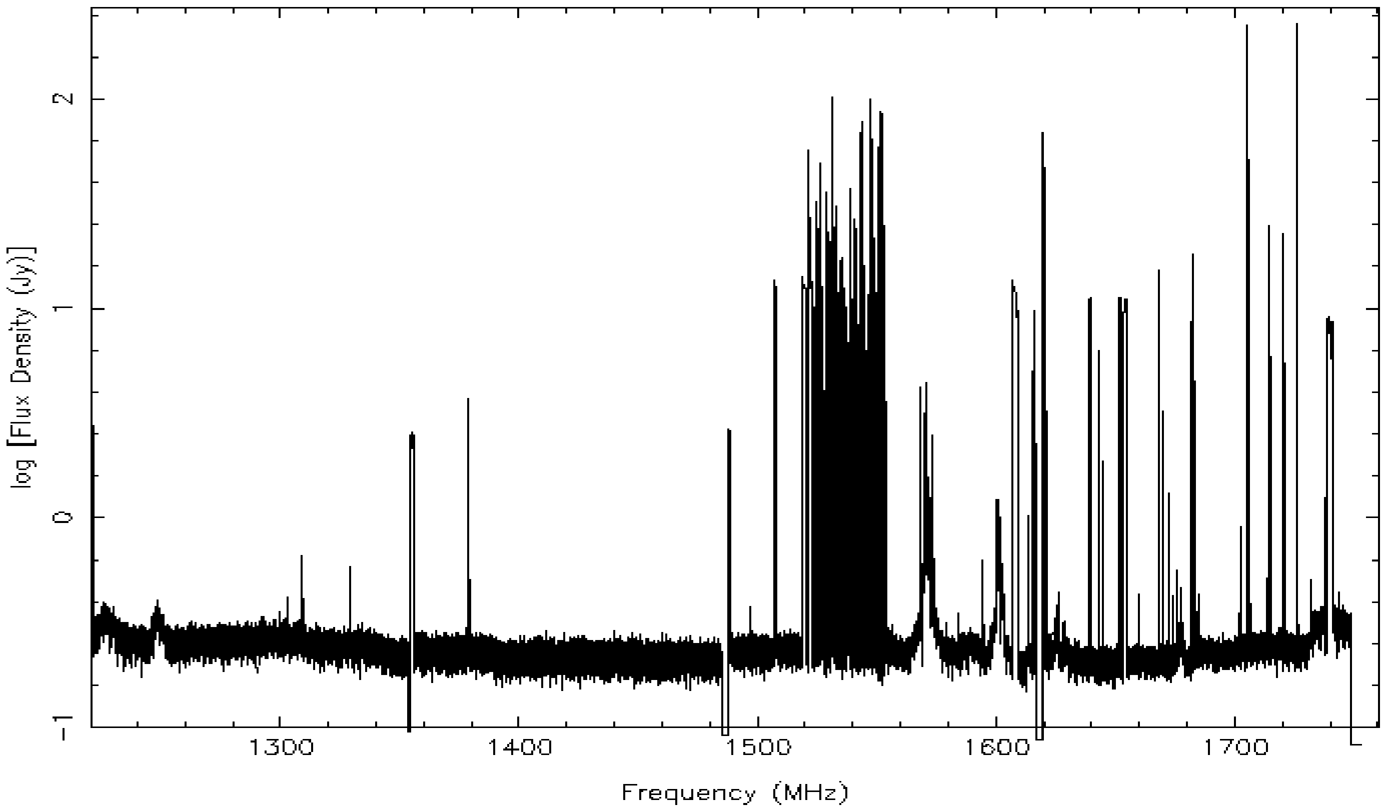
- However – the prior example will encounter strong RFI from aircraft distance measuring equipment (DMEs), between 1020 and 1140 MHz.
- It is estimated these signals are 20 X stronger than any other RFI in the 1-2 GHz band.
- Current spectral dynamic range (RFI/noise) is about 30 dB. Need >20 dB more.

Strong Signals in L-band

- A portion of the VLA spectrum, showing the DMEs and Abq. Radars.



Spectral Dynamic Range



Spectral Dynamic Range

- Another argument from the strongest astrophysical spectral lines – H_2O masers.
- The peak flux density is 10^6 Jy.
- These narrow lines are studied with resolutions of ~0.1 km/sec.
- System noise in this resolution in 1 second will be ~ 5 Jy.
- This argument indicates a required spectral dynamic range of >53 dB.

Mosaicing Orion

- The Orion Molecule Cloud is the closest laboratory for studying massive star formation.
- Orion B is several arcminutes in extent, and contains forming stars, dense molecular clouds, and an infrared cluster.
- High resolution (1”) high sensitivity (1K) observations are needed.

Mosaicing Orion

- Radio recomb lines in the 6 GHz band will give kinematics.
- Dynamics of the molecular gas studied by observations of CS and SiO, both in the 40-50 GHz band.
- The complex is much larger than the Q-band primary beam, so mosaicing is needed.
- High speed mosaicing (up to 10 x sidereal) useful.

Mosaicing Orion

- ALMA simulations show accurate mosaicing requires pointing stability of ~1/20 primary beam.
- This sets the goal of 2 – 3” pointing.
- The continuum sensitivity of the EVLA encourages exploration of an ‘OTF’ strategy – rates up to 10 x Sidereal may be possible.

Precision Polarimetry

- Faraday rotation of polarized emission passing through galaxy clusters gives information on the gas density and magnetic fields.
- Currently, only a few background objects are strong enough to enable these measurements.
- By similar means, the internal and external magnetic fields and thermal gas associated with radio sources can be measured.

Precision Polarimetry

- However, contamination of the polarization signal through ‘cross-talk’ (a.k.a. ‘leakage’) from Stokes’ I prevents measurement of polarization if a source with S > 1000 times stronger than the desired polarized signal is in the same field.
- The EVLA’s higher sensitivity will make this condition commonplace.
- Lower and more stable ‘leakage’ terms must be developed. Better software removal needed.

Summary

- These example experiments require a system with:
  - High sensitivity
  - Full frequency coverage
  - Precise polarimetry
  - Excellent gain stability (amplitude, phase)
  - Accurate tracking for mosaicing and surveys.

Summary

– Extremely high dynamic range (spectral, spatial, total power)
– Expandability for including the NMA,VLBA
– A powerful, flexible new correlator.
– A new and flexible interface with the user.