Science Drivers for the EVLA Correlator

Rick Perley

EVLA Project Scientist

2 Nov 2001

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
  - Spatial Resolution

Overall EVLA Goals

- This will be done by:
  - Retaining the antennas, array layout and present infrastructure
  - Replacing virtually all of the electronics with new, modern-technology electronics.
- Probably the most prominent, and easily the most important component, is the new correlator.

Overall Correlator Requirements

- Key Correlator Capabilities must include:
  - Wide instantaneous bandwidth
    - LO/IF-FO systems being designed to deliver 16 GHz of bandwidth (2 poln. @ 8 GHz each).
  - 40 stations input
    - Phase II will add ~8 antennas
    - Local VLBA antennas will bring sum to 40.

Overall Correlator Requirements

– Expandability to include full VLBA, and more
  - Correlator should be 'VLBI-enabled'.
– A minimum of 16384 spectral channels over 8 GHz bandwidth x 2 polarizations.
– Full Polarization capability.
– A special mode for ~Hz resolution ('radar')
– Binning capabilities for pulsar observations
– Time resolution of ~10 milliseconds

Overall Correlator Requirements

- High immunity to RFI within the correlated bandwidth.
- Independent subarray capability.
- Multiple simultaneous correlator modes.
- Flexible sharing of internal resources
  - The ability to trade off bandwidth for spectral resolution
  - The ability to trade off polarization modes for spectral resolution

Overall Correlator Requirements

– 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.

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.
- Timescales for the correlator:
  - 50 ms good for most experiments.
  - 20 ms will satisfy nearly all users.
  - 1 ms will surely be useful, when provided.
- At least an octave of bandwidth, with 1 MHz resolution, will be needed.

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

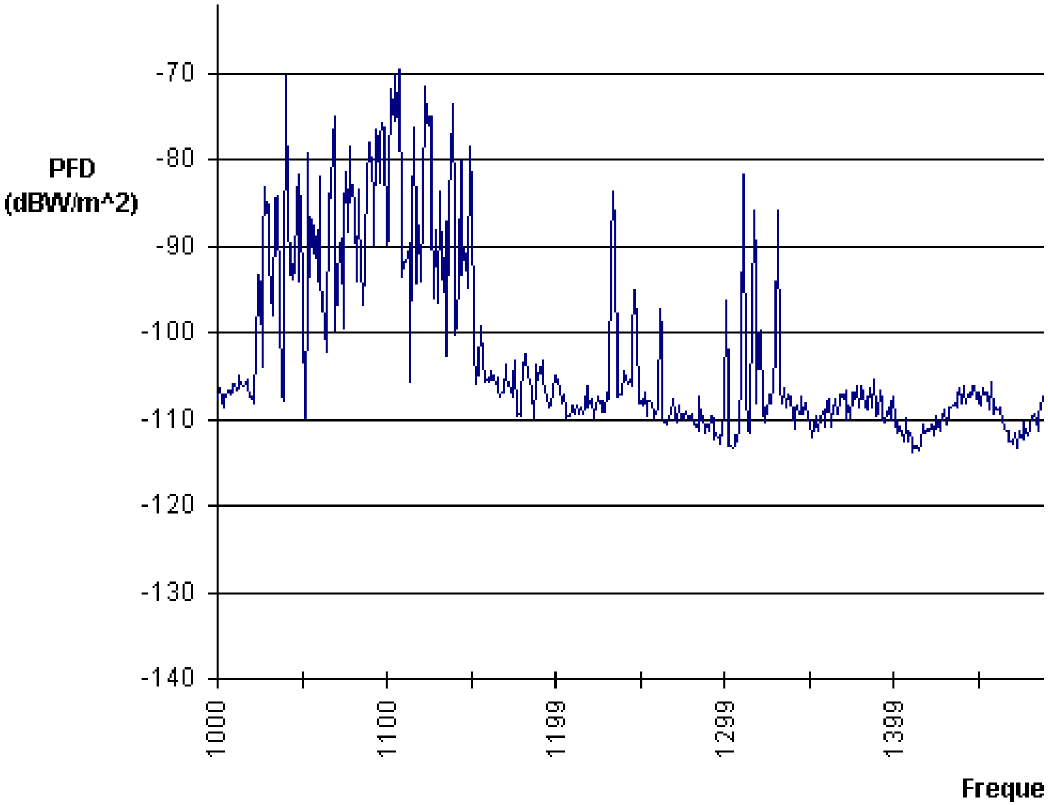
- Both of these experiments could be run simultaneously with 16384 channel correlator that could process the data input with two separate modes, one at high resolution, and one at low, with an equal number of channels in each.

Science Examples
Redshifted Hydrogen

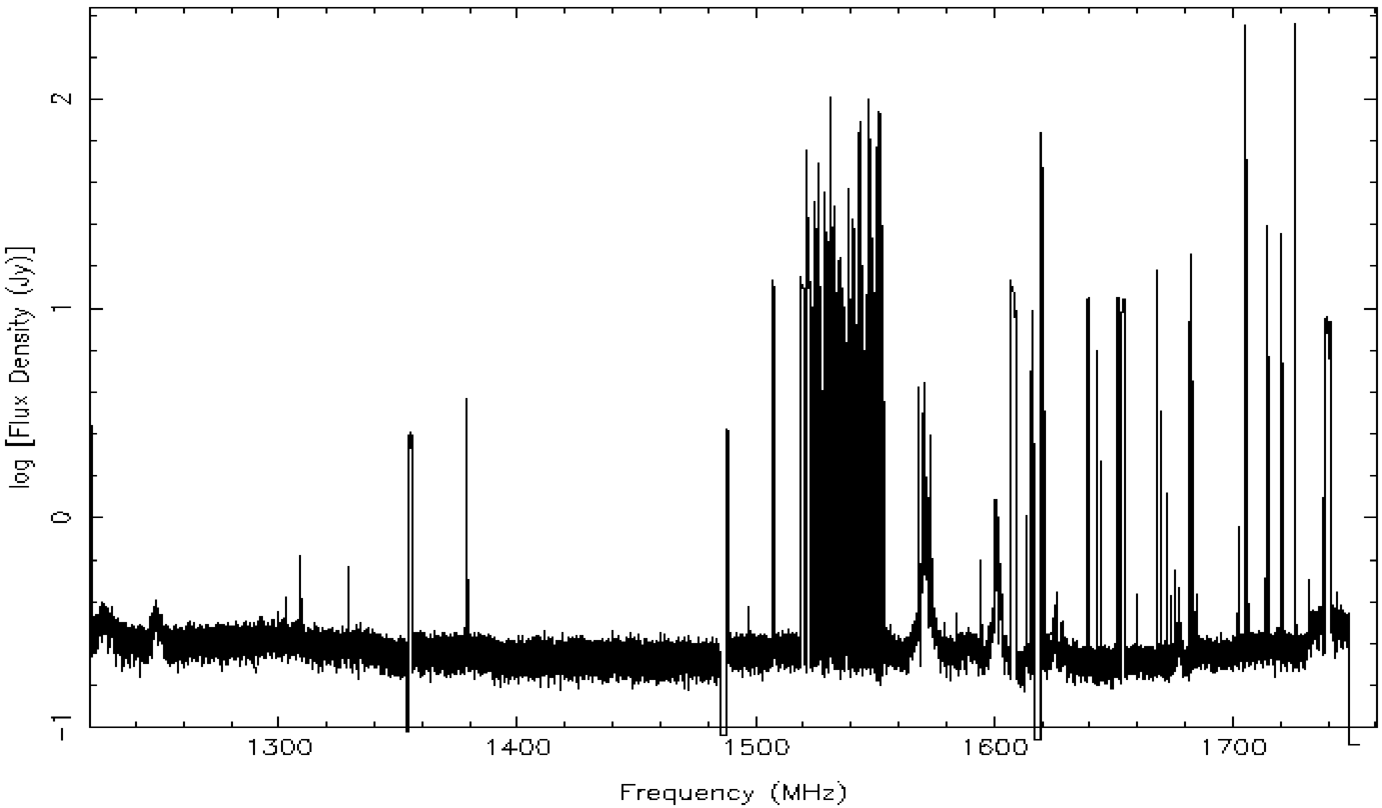
- However – the prior example will encounter strong RFI from aircraft distance measuring equipment (DMEs), between 1020 and 1140 MHz.
- It is estimated these signals are 20 X stronger than any other RFI in the 1-2 GHz band.
- Current spectral dynamic range (RFI/noise) is about 30 dB.

Strong Signals in L-band

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



Spectral Dynamic Range



Spectral Dynamic Range

- Current observed Peak/Noise is about 30 dB.
- If the DME-type signals are 20 dB worse, then the necessary (minimum) spectral dynamic range is > 50 dB.

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.

Spectral Dynamic Range

- This argument indicates a required spectral dynamic range of >53 dB.

Pulsar Astronomy

- Pulsar astrometry with the EVLA will derive the proper motions of at least 100 pulsars, with accuracies of ~0.5 mas/yr.
- Such measures will answer questions of the pulsar birth velocity distribution, and the pulsar dipole magnetic field decay timescales.

Pulsar Astronomy

- The optimum band for these observations will be the 4 – 8 GHz band.
- The full bandwidth, and two correlations are needed.
- To enhance SNR, binning in the pulse period is needed. 1024 bins, with < 100 microsecond resolution, is optimal.

Pulsar Astronomy

- The ‘non-pulse’ bins can be used to image the background sources, providing an accurate in-beam reference frame.
- Due to dispersion and to chromatic aberration, narrow frequency slices will be needed:
  - 1024 channels for L, S, C bands
  - 8192 channels for future wideband P-band.

Summary

- These example experiments indicate the need for a correlator with:
  - Wide bandwidth (16 GHz total)
  - Fast time dumps (< 10 msec)
  - High spectral resolution (~ 1 Hz)
  - Precise phase binning (1024 bins)
  - Extremely high spectral linearity (> 55 dB)
  - Very flexible sharing of resources.