The Expanded Very Large Array:

Phase I Science and Technical Requirements

Rick Perley

NRAO - Socorro

The Very Large Array

The `D'-Configuration

The VLA is the world's most productive and powerful radio telescope, located at 7000' in central NM.

- 8 frequency bands: 74 MHz to 50 GHz
- 4 spatial configurations
- 512 spectral channels (max)
- Full polarization
- 10 μJy sensitivity

The Very Large Array – Designed and Built in the 1970s

- Designed and built in the 1970s, completed in 1980, the VLA still employs the original technology in the critical areas of signal transport (waveguide) and signal processing (25-year-old digital correlator).
- The VLA is inefficient – only 100 MHz of the ~50 GHz of information available at the antenna focus can be processed at the correlator at any one time.
- The correlator can generate only 16 channels at maximum bandwidth (50 MHz), and no more than 512 channels at narrow BW (< 1.6 MHz).
- Yet the major components – the antennas, site, and infrastructure, are in excellent condition (and paid for!). A skilled staff is in place.

The EVLA Concept

- It is hugely expensive to built a major new array from scratch.
- It can be very cost effective to upgrade/expand an existing facility, using new technologies to leverage a sound existing facility.
- The EVLA Concept is to:
  - Utilize the existing VLA infrastructure
  - Modernize the electronics, data transmission, and processing
  - Expand the array to explore new regions of astronomical measurement space.
- The Key Point: This is a leveraged project, providing >10 times the scientific capability, with basic operational costs increased by ~10% over existing levels.

The EVLA

- The EVLA Project's Goal is to multiply at least tenfold the capabilities of the VLA in all areas.
- By broad category:
  - Continuum Sensitivity -- by a factor of 2 to 40.
  - Frequency Coverage -- complete from 1 to 50 GHz.
  - Spectral Capabilities -- through a new correlator of remarkable power and flexibility.
  - Imaging Quality -- noise-limited imaging at all bands in all polarizations.
  - Spatial Resolution – 10 times higher by addition of 10 antennas (8 new, 2 converted VLBA) via optical fiber.
  - User Access -- through a comprehensive E2E program.

Key EVLA Capabilities

- Frequency Coverage:
  - Complete from 1 to 50 GHz from Cassegrain focus, using 8 frequency bands.
  - Add two new bands (2 -- 4 and 26 -- 40 GHz), and new feeds and receivers on six existing bands.
  - Two narrow-bandwidth low-frequency ‘legacy’ bands (at 90, and 400 cm) retained without change.
- Continuum Sensitivity: (1-σ in 4 hours)
  - < 1 μJy in 6 frequency bands between 2 and 40 GHz.
  - < 2 μJy for 1—2 GHz and 40 – 50 GHz bands.
  - Obtained from more efficient receivers, improved optics, and wider bandwidths.
  - Maximum bandwidth (per polarization) expanded from 100 MHz to 8 GHz.

Key EVLA Capabilities

- Correlator Capabilities:
  - New correlator (designed, built, and paid for by our Canadian partners).
  - Fantastic new capabilities:
    - Minimum 16384 channels; maximum 4 million channels;
    - full polarization; flexible sub-banding (to zoom in on spectral regions of interest, or to avoid RFI);
    - 55 dB dynamic range (to handle RFI);
    - extensive pulsar capabilities;
    - phased-array capabilities;
    - sub-arraying; and
    - VLBI-ready.

Key EVLA Capabilities

- Noise-limited Imaging. This requires development and implementation of new algorithms to:
  - Provide dynamic range > 10^6
  - Correct for errors induced by the antenna primary beam (I,Q,U,V)
  - Correct for antenna pointing errors.
  - Enable efficient non-coplanar imaging.
  - Incorporate angle-dependent self-calibration.
  - Implement full-field background source removal.
- Improve User Interface:
  - An expanded program to open radio imaging to all users.
  - Automated image formation, archiving, access.
  - Improved interfaces for proposal generation, submission, scheduling, monitoring, interaction.

Phase II

- Expanding the array to provide 10 X the resolution not included in Phase I proposal.
- This component, plus low-frequency coverage and low-resolution coverage (E-Config.) required further development – deferred to a 2^{nd} proposal.
- Low frequencies subsequently dropped – very difficult to employ on VLA antennas.
- Phase II proposal submitted to NSF for consideration in April 2004.
- NSF decision to not fund announced Dec 2005.

EVLA Science

- The science case is built upon the unique capabilities of radio astronomy, and the benefits of increased sensitivity frequency access, and resolution.
- The Four Themes on which the science case for Phase I was based were:
  - **Magnetic Universe:** Measuring the strength and topology of magnetic fields.
  - **Obscured Universe:** Unbiased surveys and imaging of dust-obscured objects.
  - **Transient Universe:** Rapid response to and imaging of transient sources.
  - **Evolving Universe:** Tracking the formation and evolution of objects ranging from stars to spiral galaxies and active nuclei

Key EVLA Science Goals

- Mapping the magnetic field structures within clusters of galaxies through measurements of the Faraday rotation of background sources.
  - Current studies limited to those few clusters with bright embedded extended radio sources.
  - Clusters without such sources can only be studied statistically.
  - EVLA will permit RMs on > 20 background sources for each of more than 80 Abell clusters.
- Imaging Young and Proto-stellar Objects, to:
  - Disentangle thermal dust, free-free, and synchrotron emission processes,
  - Map the emission of galactic jets from their origins through to the working surfaces
  - Directly measure temporal variations in flow rate and direction of outflows.

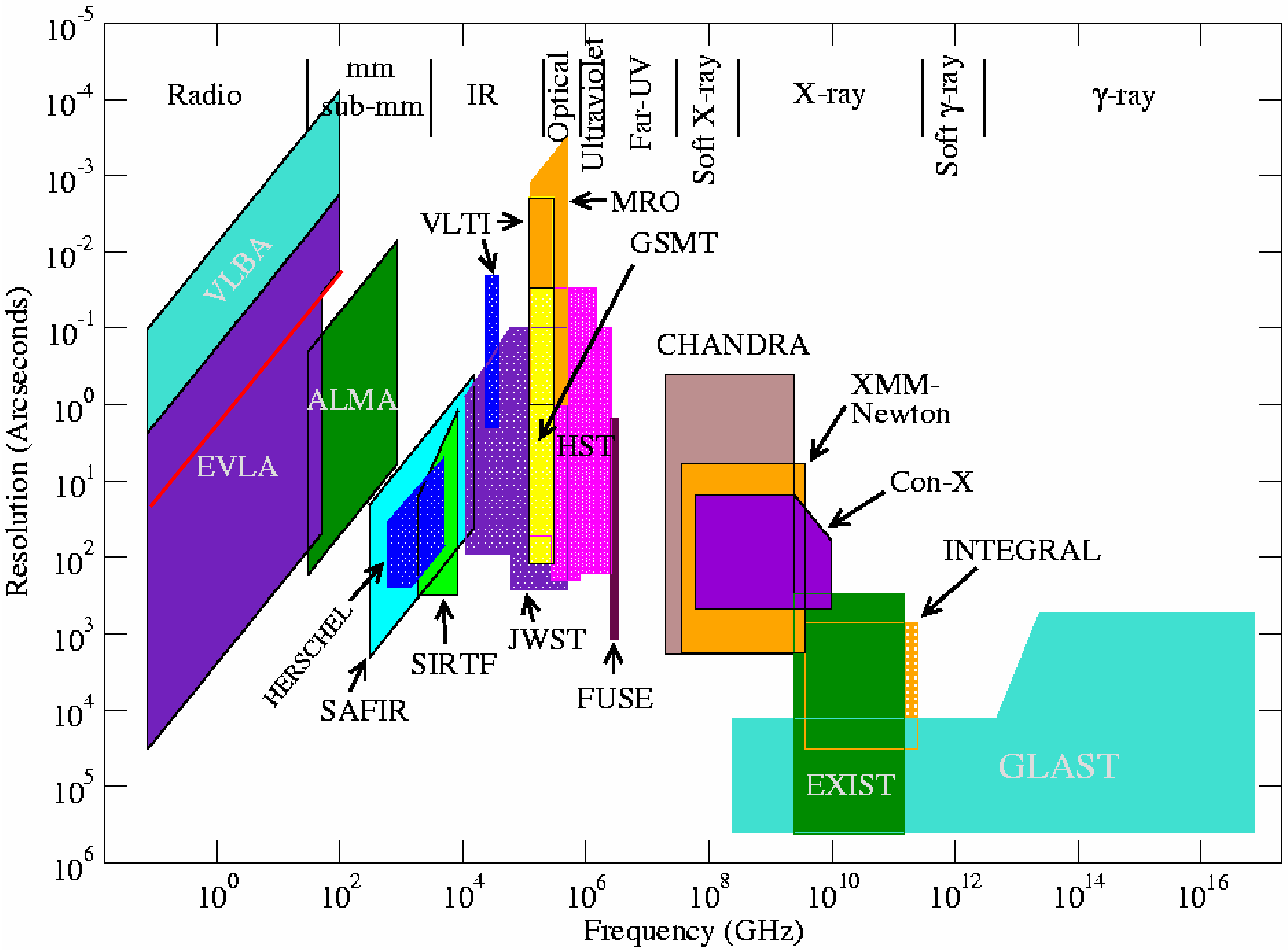
Key EVLA Science Goals

- EVLA will enable unbiased deep spectral line surveys over a large range of redshifts to determine the evolution of cosmic neutral baryon density from z = 0 to 3, without the uncertainties due to dust obscuration inherent in optical studies.
  - In HI absorption, covering z = 0 to 0.4
  - In molecular absorption, for much higher redshifts.
- Find and follow (including resolution via refractive interstellar scintillation) up to 100 GRBs per year, with greater detail, over a wider range of frequencies, and for longer times, than the current 1 or 2 per year that can be tracked now.

Key EVLA Science Goals

- Studying dusty, starforming galaxies at high redshift to complement the work in the near-IR and optical, and from ALMA.
  - Imaging CO emission for redshifts of 1.2 and up.
  - Imaging radio continuum, both synchrotron and free-free
  - Imaging dust emission
- The EVLA data will provide
  - Estimates of massive star formation rate, constraints on temperature and density of the ISM, magnetic field strengths and geometries, identification of possible AGN components, high resolution and astronomy of compact components, and photometric redshift estimates.
- This is an excellent example of the need for a multi-waveband, synergistic approach to astronomy.

`Astronomical Discovery Space'
The Frequency-Resolution Plane



Coverage of various future/current instruments is shown.

Upper limit set by diffraction, or detector.

Lower limits set by telescope or antenna field of view.

EVLA Phase I Technical Requirements

- The science requirements given in detail in the proposal generated a detailed list of technical requirements.
- These are listed in Chapter 2 of the EVLA Project Book.
- The various technical divisions have used these to guide their development of hardware and software.
- Produced hardware (and software) then tested by NRAO science and computing staff for compliance to requirements.
- Current status given in later talk.