The LOw Band Observatory (LOBO): A VLA-based "Radio LSST" for Continuous, sub-GHz Observations in the LSST Era

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OVERVIEW

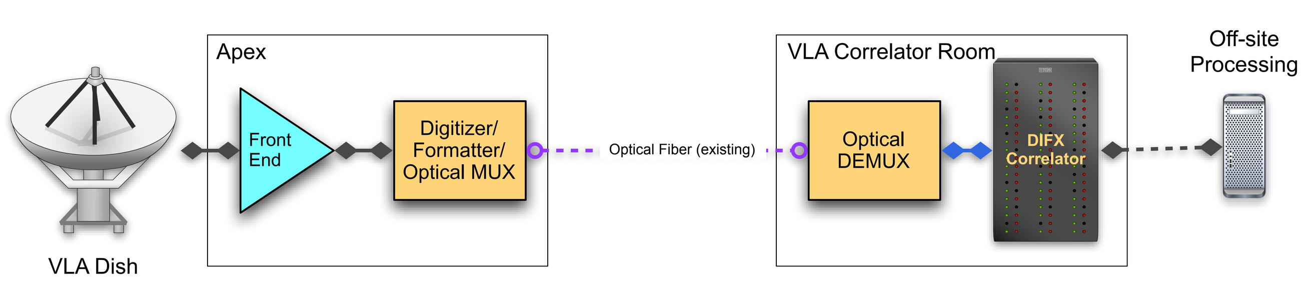
LOBO is a proposed, dedicated, radio synoptic, high-z spectroscopy, and real time transient and ionospheric monitoring capability of the VLA. It will make use of the primary focus, 330 MHz feed to observe in parallel with the higher frequency, Cassegrain feeds. LOBO will have dedicated samplers, fiber transmission, and backend processing systems; the latter to include correlator and pipelined calibration, imaging, and archive systems. With ~5 deg^2 field-of-view in the 330 MHz band (236 $< \nu <$ 492 MHz), LOBO will perform continuous, blind searches for non-thermal transients and high-redshift spectral lines. LOBO will provide synoptic, wide-field continuum images in a publicly available archive of all targeted VLA fields, annually surveying over 25% of the available sky. We explore the potential for leveraging the scientific potential of this "Radio LSST" capability in the LSST era. Low frequency, propagation related delays to LSST optical transients could provide a unique means of detecting new classes of sources. Over the next several years we hope to develop a LOBO capability in anticipation of parallel, complimentary operations with LSST.

The VLA Below 1 GHz

- 330 MHz (λ=90 cm): ~1990-2009
- 74 MHz (λ=400 cm): ~1998-2009
- Both systems state-of-the art over their lifetimes
  - Two narrow-band legacy receivers: 74 MHz: $\Delta\nu$=1.6 MHz, 330 MHz: $\Delta\nu$= 6 MHz
  - Decommissioned by VLA upgrade
- **Low frequencies back on VLA as "Low Band" & much better than before!**
  - Single receiver accesses to ~50-500 MHz
  - Current feeds utilizing 54-86 MHz, 236-492 MHz – LOBO will initially access the 330 MHz band.

The LOBO System

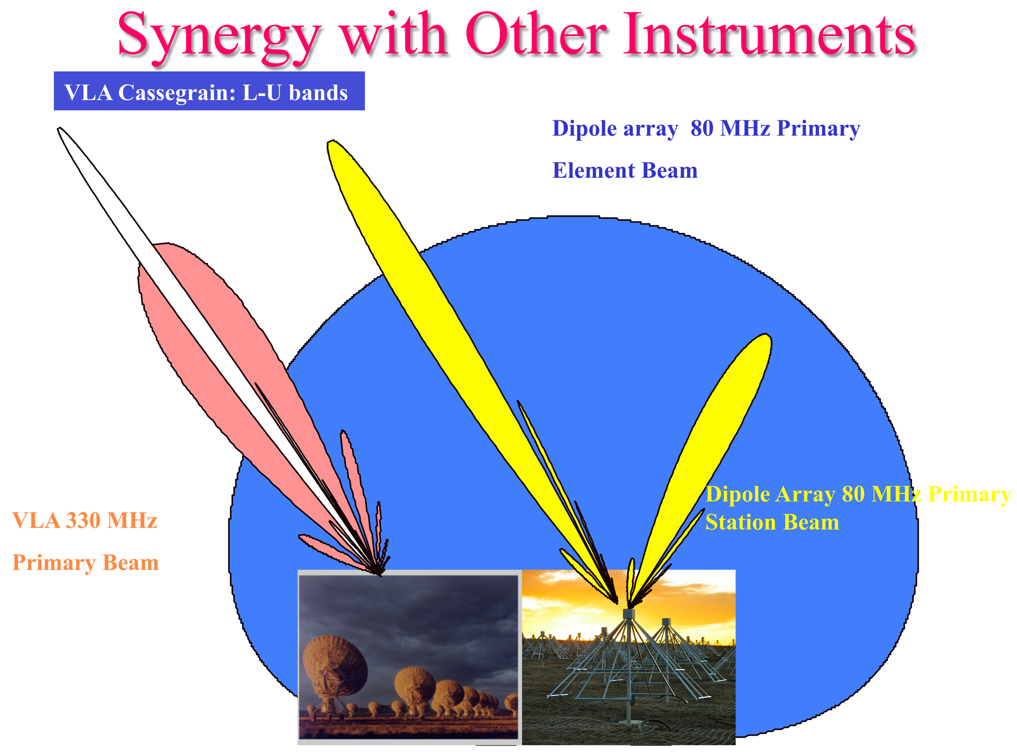
Below is a block diagram of the proposed LOBO system. The VLA dishes and optical fiber infrastructure are existing assets. The NRL Low Band Front Ends (cyan) will be completed this year under previous NRL funding. The orange components are the new components required to realize LOBO.



Parameter	LOBO
Feed	Crossed Dipoles at Primary Focus
Frequency Range	230–436 MHz
Bandwidth	206 MHz
Availability	>7000 hours/year (80%)
Tsys	150 K
Field of View	5 deg^2
Number of Antennas	10
Polarization	Dual Linear
Receiver Location	Apex
A/D Sample Clock	1024 MHz, 8 bit sampler
Correlator HW	15 Dual 8-core Intel Xeon CPUs
Spectral Resolution	10 kHz
Correlator Input Data Rate	1024 MB/s per antenna

Block diagram (above) and specs (left) of the proposed LOBO system. LOBO will initially operate in the 330 MHz band, but could be expanded to include the 74 MHz band in the future.

Synergy with Other Instruments



Telescopes sharing the VLA sky, especially dipole arrays, including LWA1, LoFASM, LWA-OVRO, LOFAR can track the LOBO FoV.

LOBO Key Science

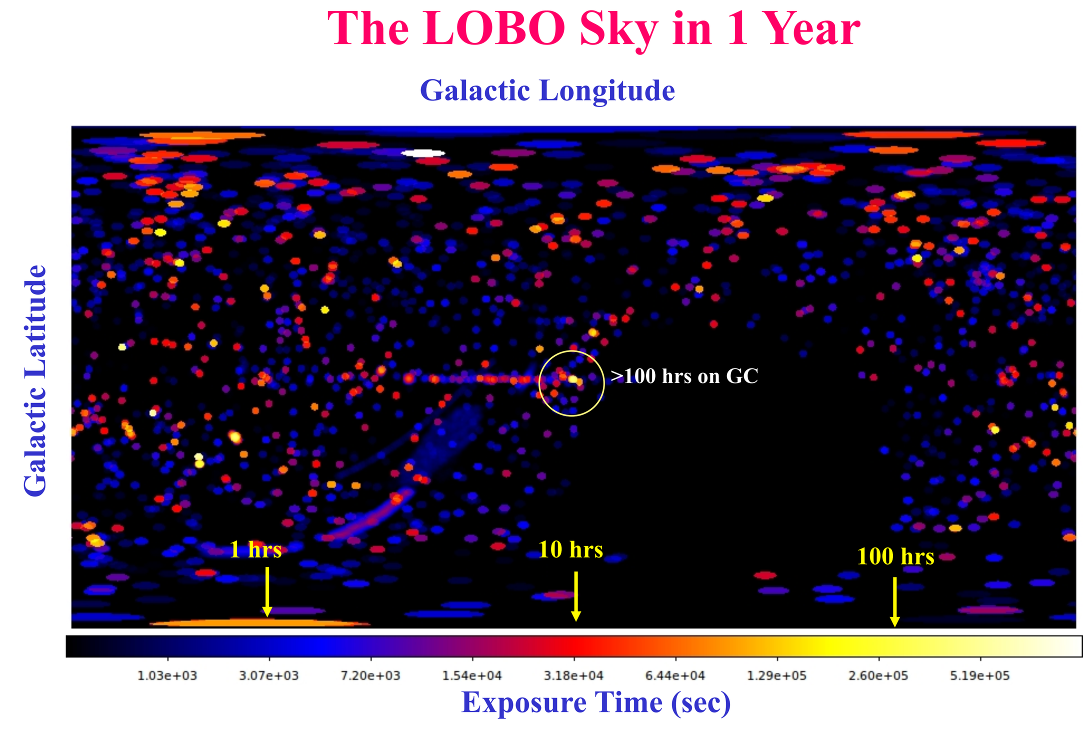
Transients: Requires maximizing Ω (field-of-view) * t (observing time). Dish-based, cm-wave telescopes are inefficient because transient observing time is scarce and Ω is small. LOBO naturally inflates Ω & t, offering monitoring with tremendous advantages over GHz searches. The statistics of slow, radio-selected, low frequency transients alone indicate LOBO should detect *thousands* of transients annually. Moreover, for an isotropic distribution of "fast transients", the search is independent of pointing direction.

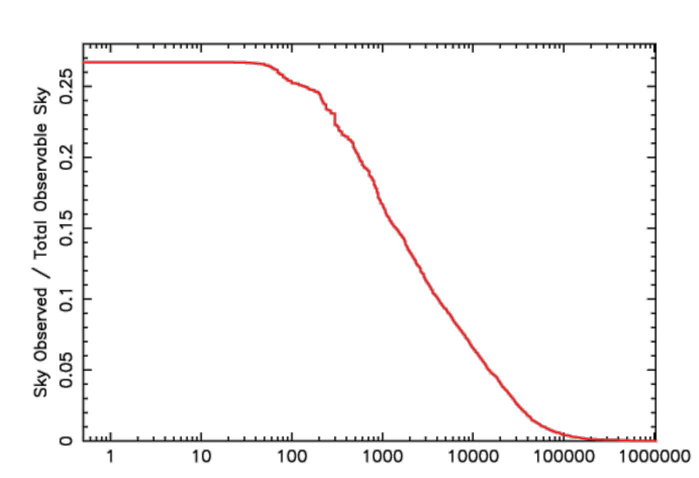
Spectroscopy: LOBO will sweep through large swaths of the Universe. For 21 cm: - 1.9 < z < 5 (for 236 MHz < ν 492 MHz), and 64 Mpc^2 per pointing (z~4 at 330 MHz). Red-shifted HI and OH Gigamasers are two examples explored here.

Radio LSST: The simplest LOBO pipeline will deliver calibrated images & source catalogs. With time, these images will spread to cover the sky, generating a LOBO Global Sky Model. With the cadence afforded by revisiting popular Cassegrain targets (e.g. M31, Galactic center, etc), many fields will be revisited. The LSST analogy follows naturally, with LOBO providing a synoptic vision of the radio sky – slow transients are a natural byproduct.

Ionospheric waves: Continuous monitoring of ionospheric disturbances at far greater sensitivity than GPS.

The LOBO Sky in 1 Year





The fraction of the sky observable by the VLA as a function of dwell time. About 25% of the accessible sky was observed for at least 100 seconds per year, and about 10% was observed for at least 1 hour per year. For a future LOBO operating in the VLA's 74 MHz band, the numbers are 96% and 85%, respectively.

1 YEAR of LOBO:

- ~6000 hrs on sky, ~25% of the VLA sky (~20% of full sky)
- VLA accessible sky ~ 33,000 deg^2

Two Examples of LOBO Science

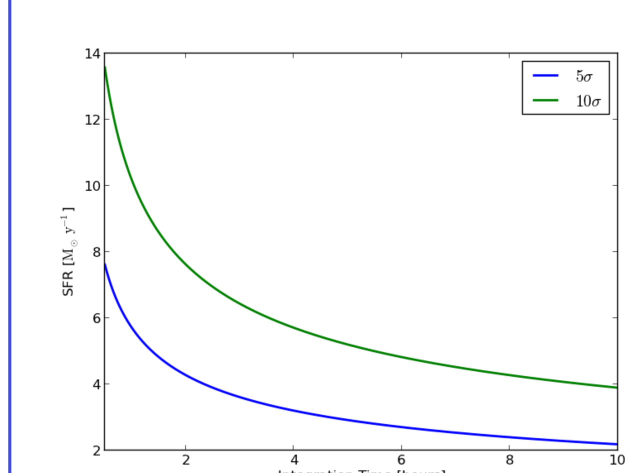
High z Spectroscopy

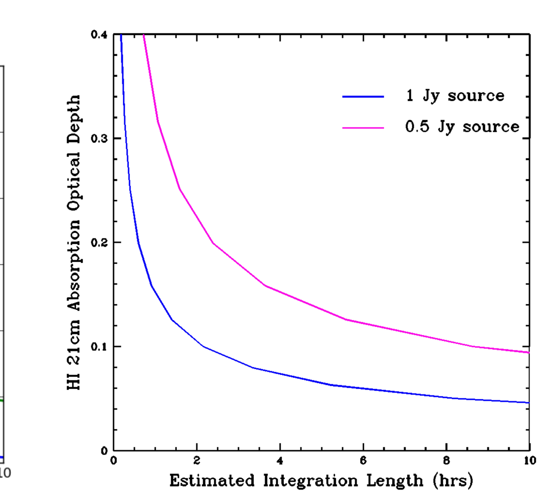
Redshifted HI Absorption in galaxies

- Damped Lyman-α systems: measured gas kinematics & derive spin temperatures.
- Detect intervening and associated absorption in gas-rich galaxies on sightline to radio sources.
- Trace the evolution of gas-rich galaxies and Ω_{HI}
- New HI lines powerful probes for cosmological studies such as z_dot and fundamental constants.

OH Gigamasers (OHGs)

- Lines @1665 & 1667 MHz $\geq 10^9$ X more luminous than typical HII region OH masers (Darling & Giovanelli 2002).
- Produced in major galaxy mergers with extreme Star Formation - blind OHG surveys to detect submm galaxies and get immediate redshifts, regardless of dust obscuration.
- Arise in regions of high opacity where UV, optical & near-IR emission is hard to detect.
- Measure extragalactic magnetic fields & gas kinematics.





Above: SFR required for a 10σ (green) & 5 σ (blue) detection vs. Int. time for an OHG at z~4. The flux of ~15-20 mJy at a spectral resolution Δv = 150 km/s are feasible in 10 – 20 hrs. (Based on local OHG estimates.)

Above: HI 21 cm τ vs. int. time for LOBO observations against a background source.~ 2 hrs & ~8 hrs to detect a typical τ~10%line against a 1 Jy (blue line) &0.5 Jy (magenta) source @z=3.5, respectively.

Slow Transients

Galactic: ~200 hrs of $\lambda \sim$ 1 m Galactic center monitoring (legacy VLA, GMRT; Hyman et al.)

- 3 types of radio selected transients: ~0.05 events per FoV, S > 50 mJy (t_{obs}~ 1.5 hr)

Extragalactic: ~100 hrs (10 epochs) of archival $\lambda \sim$ 1 m VLA observations of two fields.

- 1 event detected in 1 epoch: ~0.1 events per FoV, S > 2.5 mJy (t_{obs}~ 10 hr)

LOBO is $\geq$ 5X more sensitive then the legacy VLA:

GC: ~0.2 events per FoV, S > 12 mJy, t_{obs}~ 1 hr for a disk pop. (N ~ S^{-1}). 120 1 hr epochs/year: **24 sources; entire plane ~50**

XGal: ~0.2 events per FoV, S > 2 mJy, t_{obs}~ 1 hr for a sph. pop. (N ~ S$^{-1.5}$). 6000 1 hr epochs/yr: **1200 sources**

With > 2 detections per source: $\geq$ 2500 slow LOBO transients per year!

See Hyman et al. & Cutchin et al. posters for more about slow and fast low frequency radio transients.

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