Ionospheric Disturbances Observed with the VLA
Low-band Ionospheric and Transient Experiment
(VLITE)

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Introduction

- NRL Remote Sensing and Space Science Divisions with the National Radio Astronomy Observatory (NRAO) have developed, implemented, and commissioned a new backend for the Very Large Array (VLA) in New Mexico.

- Exploits unique feature of the optical design to continuously capture and process signals at P-band (320-384 MHz).

- Our scientific goals are to study the dynamics of Earth’s ionosphere and to search for and characterize cosmic transient emitters.

- Uses dedicated signal processing/analysis and imaging pipelines that run in (near) real time and offline using archived data.

- Highest-level ionospheric data products are temporal and spatial fluctuation spectra of total electron content (TEC) gradient.
VLITE

- VLA used to have two relatively narrow low-frequency bands at 74 and 330 MHz. Were decommission during VLA upgrade starting in 2009. New upgraded P-band system developed and commissioned with NRL’s help; has 10 times the bandwidth (224—480 MHz).

- New 74 MHz system in development/testing phase; uses “box”-mounted, modified J-poles to reduce aperture blockage.

- Building on this success, NRL funded new VLITE project.

- VLITE exploits separate low- and mid/high-frequency “optics” to continuously record, process, and image at one low-frequency band (350 MHz) using 10 VLA antennas over three-year period.
Ionospheric Remote Sensing with the VLA

- Interferometers simultaneously observe celestial sources and ionospheric structure

- Effect of the ionosphere $\sim \nu^{-1}$ → VHF interferometers are excellent probes of find-scale structure

- Measure differential TEC to precision as good as $10^{-4}$ TECU; translates to TEC gradient precision $\sim 2 \times 10^{-4}$ TECU km$^{-1}$. 

Schematic of observations through the ionosphere (not to scale).
Baseline phases have other contributions besides ionosphere, including cosmic source structure, instrumental response, telescope pointing errors, troposphere, and noise.

Signal processing mitigates these, except troposphere; rely on VLA monitoring system to flag times when troposphere too active.
VLITE Pipeline: Processing & Analysis

(a) Raw phases; 4 sub-bands, 2 polarizations

(b) De-trend, convert to δTEC, and combine

(c) Polynomial fit converts δTECs to antenna-based TEC gradients.

(d) Fluctuation spectra
VLITE Pipeline: GPS Analysis

- Complementary pipeline runs daily on 24-hours of GPS data from 20 stations within 200 km of VLA; performs similar 3-D spectral analysis.

GPS station layout near the VLA.

Simultaneous VLITE/GPS detection of localized TID.

Daily GPS spectra from pipeline.
VLITE was observing bright source (3C84) before, during, and after solar flare on 12 March 2015.

VLITE spectrogram w/ GPS data & spectrum of HF skywave (WWV @10 MHz)

Spatial frequency spectral maps at 0.0078 Hz

VLITE observations during last of 4 M-class flares that occurred on 12 March 2015.
Summary

- VLITE started science operations in November 2014. Have some exciting initial results, but have only just begun.

- Building a large repository of fluctuation spectra for statistical/climatological analysis; including value-added data from GPS, Boulder digisonde, seismic station in Albuquerque, GOES satellite (solar X-rays), and antarctic cosmic ray monitors to constrain nature of fine-scale fluctuations.

- Preliminary results from past few months (VLA B-config. Feb.-May.) suggest higher-frequency fluctuations (>0.1 Hz) dominated by thermospheric turbulence; lower frequency regime likely has significant gravity-wave contribution.

- But, it’s early days yet; stay tuned . . .