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

Presented by
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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.

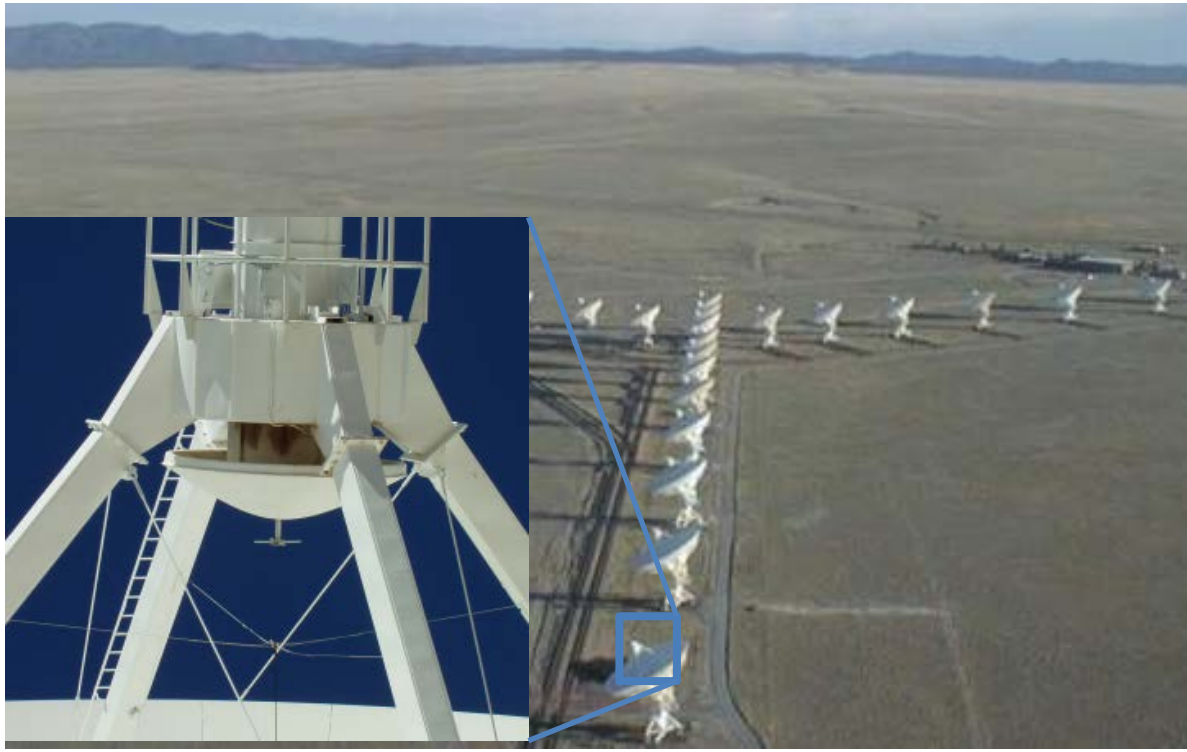
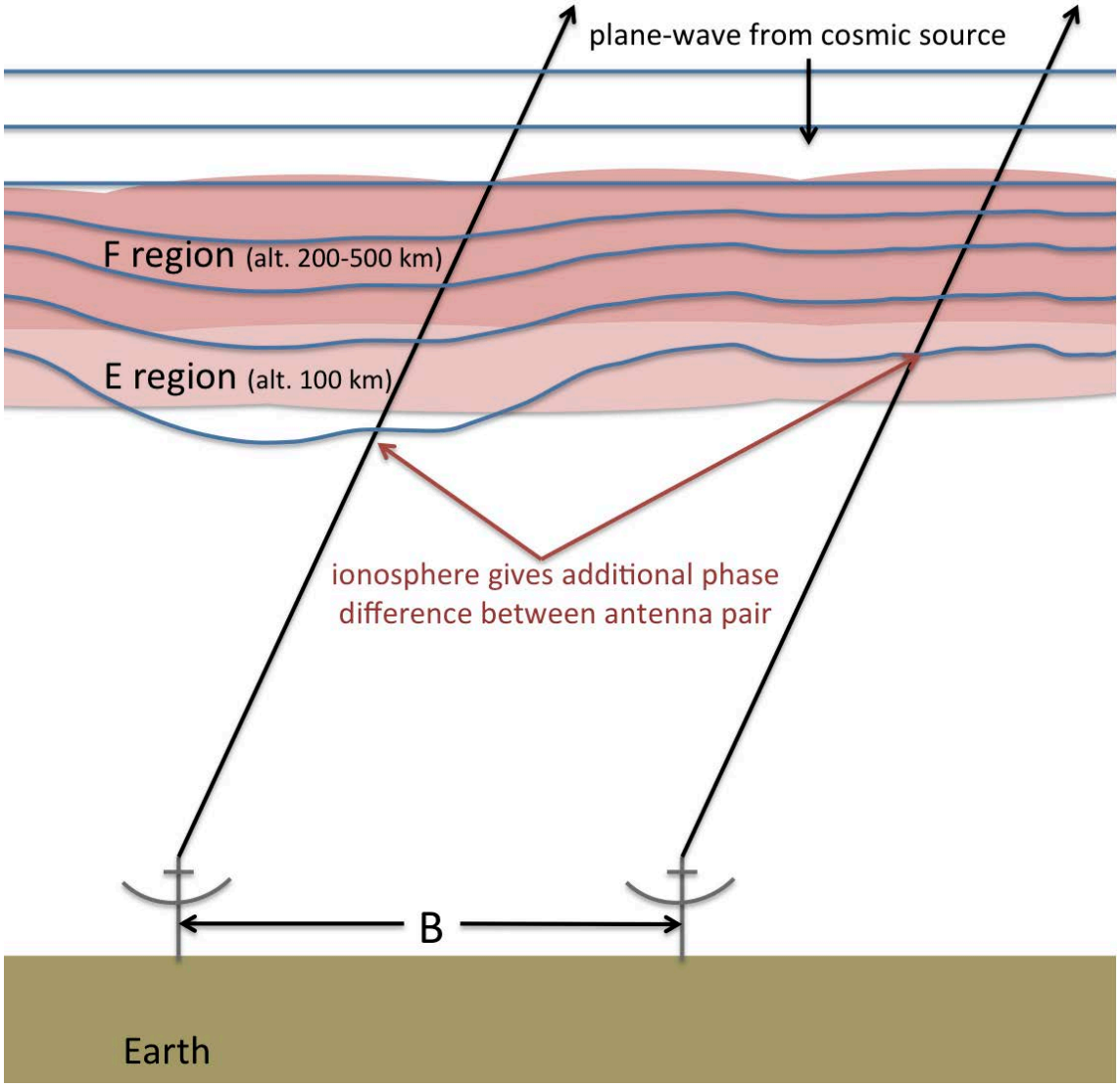


image courtesy of NRAO/AUI

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 $\sim 2\times10^{-4}$ TECU km^{-1}.



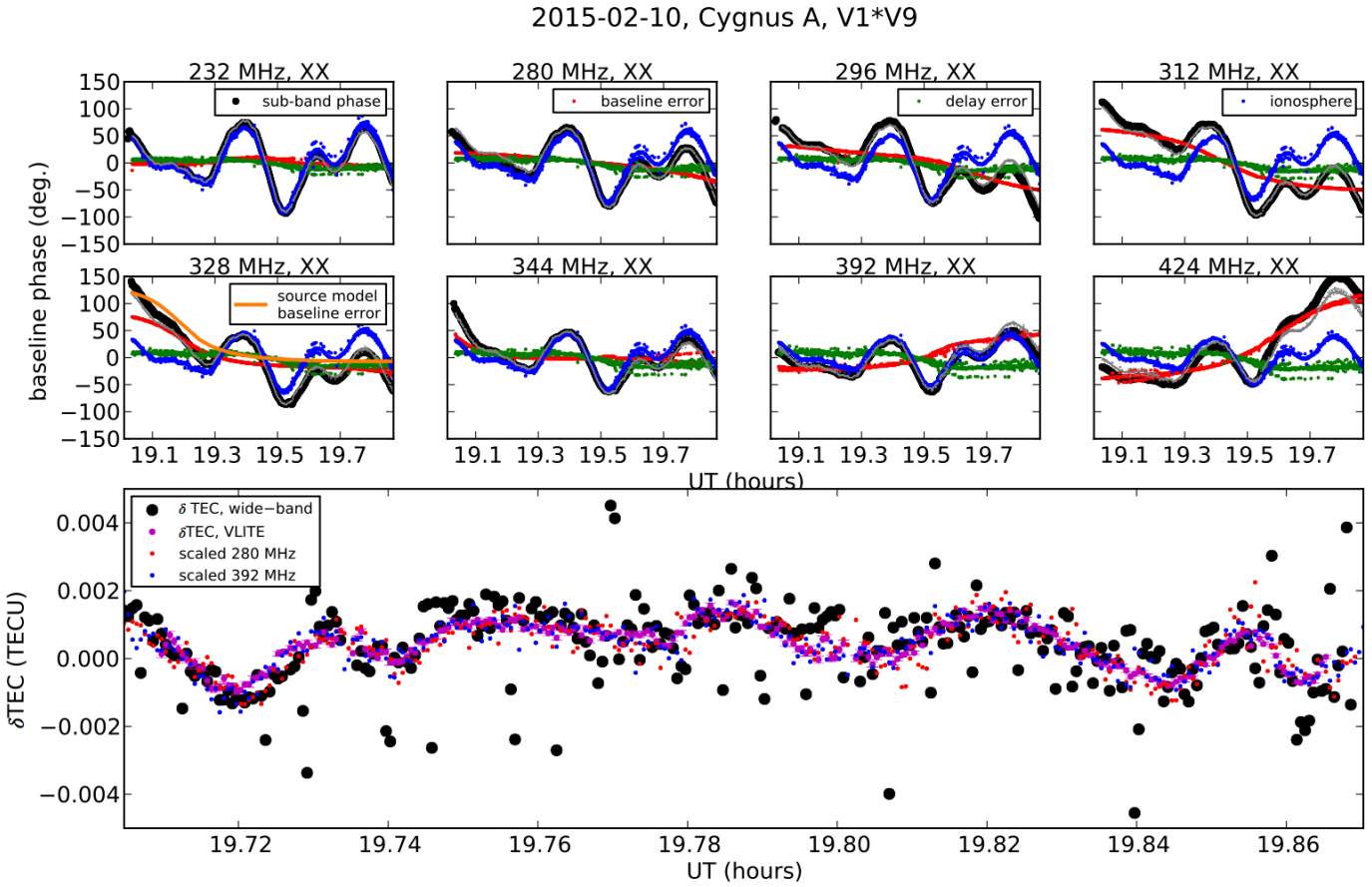
Schematic of observations through the ionosphere (not to scale).

VLITE Pipeline: Signal Processing

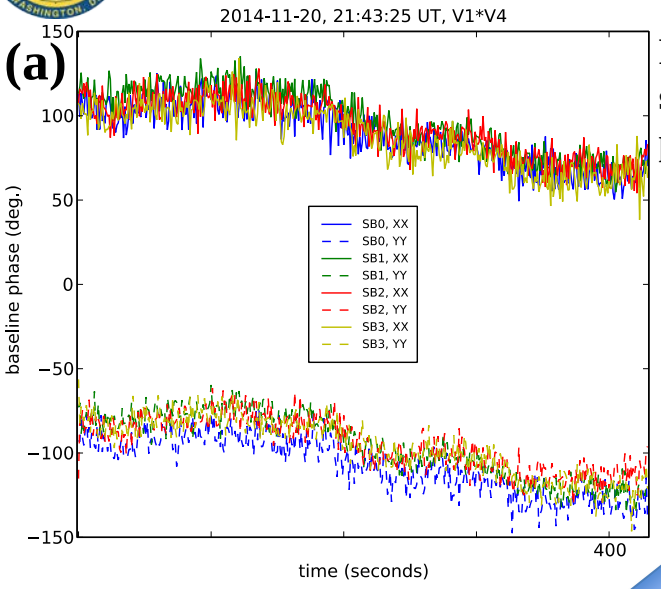
- Baseline phases have other contributions besides ionosphere, including cosmic source structure, instrumental response, telescope pointing errors, troposphere, and noise.

- Signal processing mitigates these, except troposphere; rely on VLA monitoring system to flag times when troposphere too active.

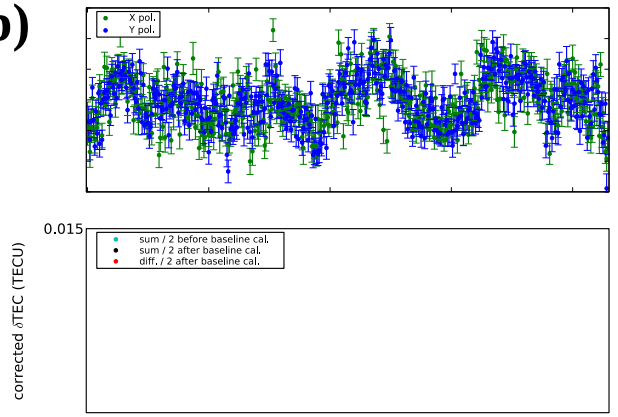
Baseline phases from observation of extremely bright source, Cygnus A, with the full VLA P-band system (uses 16×16-MHz sub-bands). Shows contributions from delay errors, source structure, and ionosphere. Lower panel shows de-trending (w/ linear fits) and baseline calibration remove non-ionospheric contributions from VLITE data.



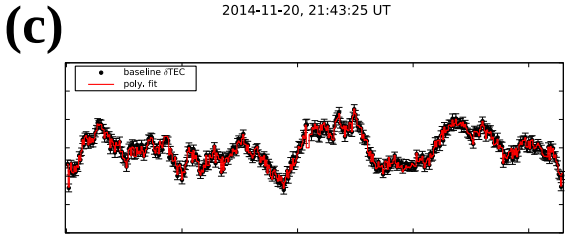
VLITE Pipeline: Processing & Analysis

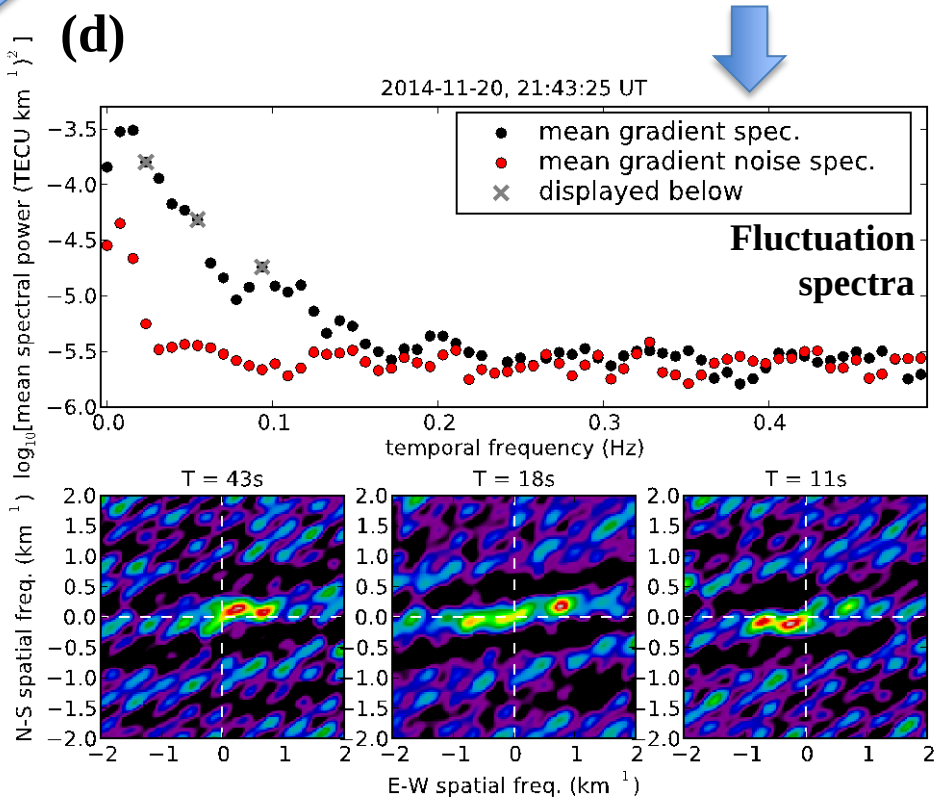


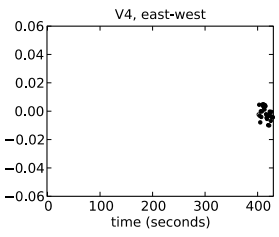
Raw phases; 4 sub-bands , 2 polarizations



De-trend, convert to δTEC, and combine



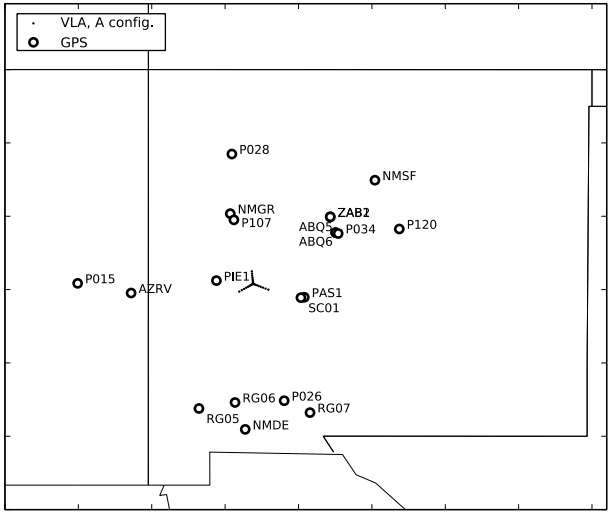




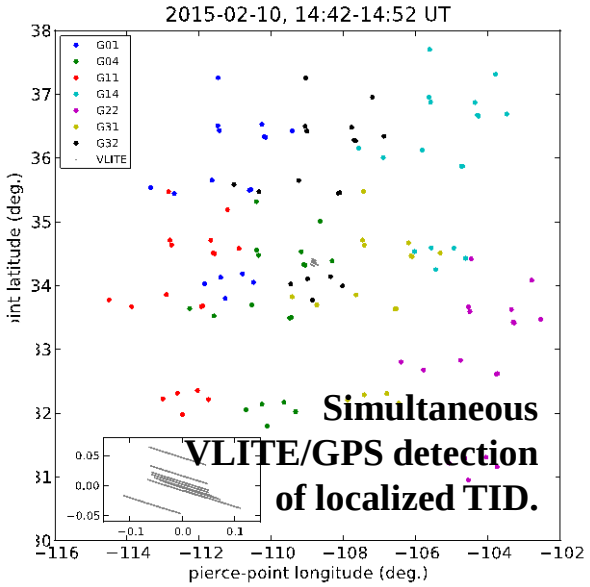
Polynomial fit converts δTECs to antenna-based TEC gradients.

VLITE Pipeline: GPS Analysis

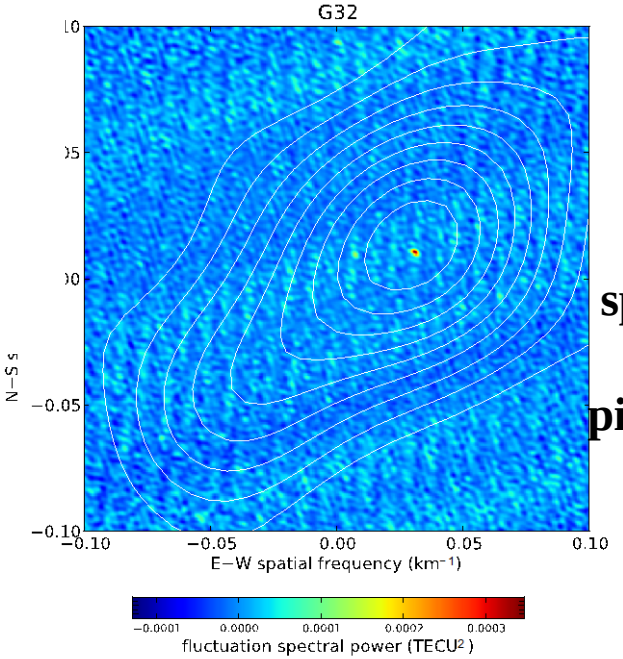
- Complementary pipeline runs daily on 24-hours of GPS data from 20 stations within 200 km of VLA; performs similar 3-D spectral analysis.

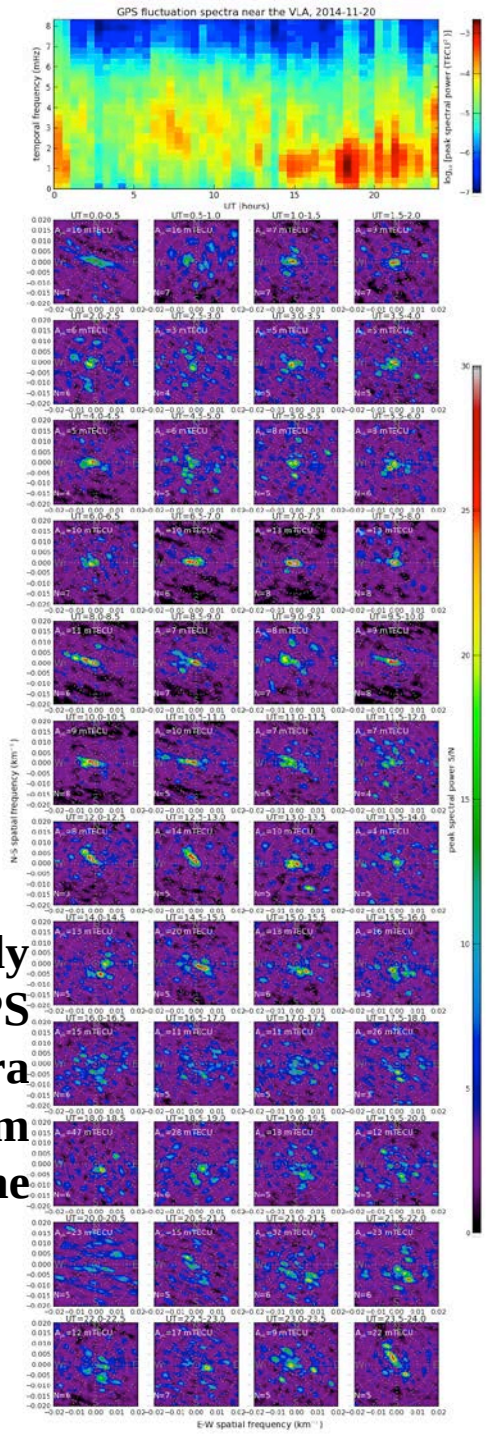


GPS station layout near the VLA.



Simultaneous VLITE/GPS detection of localized TID.

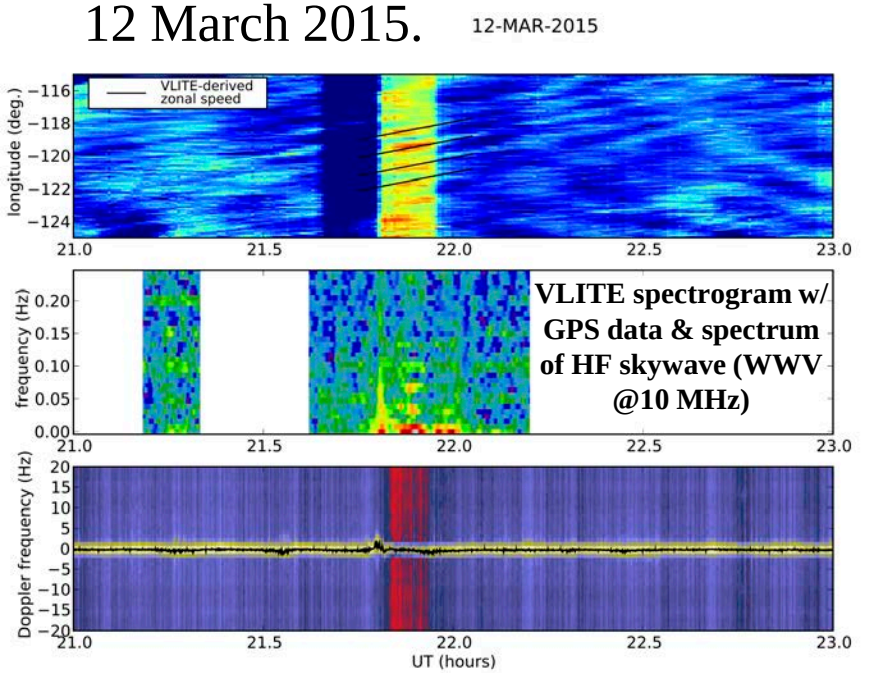


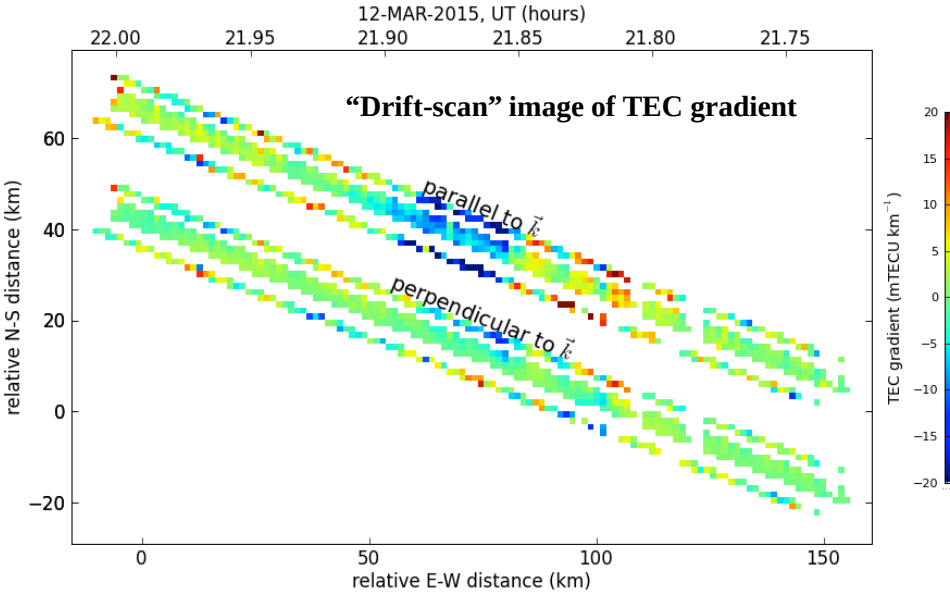


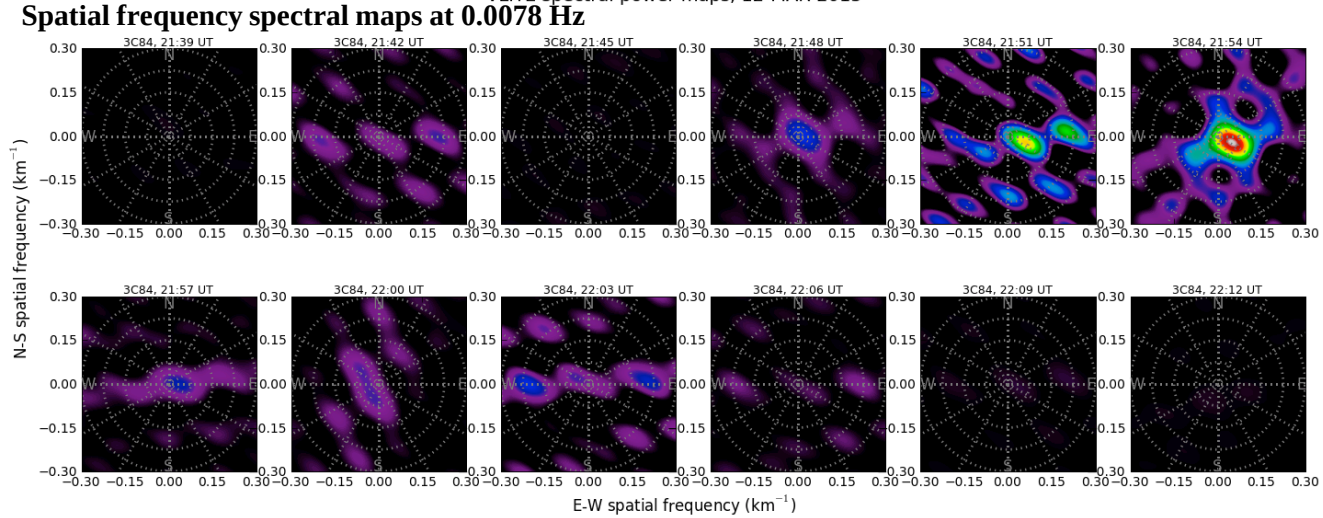
Daily GPS spectra from pipeline

Example Science: Impact of a Solar Flare

- VLITE was observing bright source (3C84) before, during, and after solar flare on 12 March 2015.







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 . . .