White Paper: "Free" meter-wavelength, commensal measurements during VLASS with VLITE

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1. Executive Summary

The proposed NRAO VLASS survey will likely be undertaken in the cm regime. Using one or more cm-wavelength receivers, the survey strategy of sky-coverage and depth is yet to be determined. We propose that commensal observations using the low band system be considered for inclusion as part of the survey. Clarke et al. (2013) motivate scientific drivers for the VLA Sky Survey (VLASS) in the case of cluster astrophysics. This is only one area of astronomy that naturally benefits from a "free" extension to meter-wavelength, nonthermal continuum emission through commensal observations with the VLITE (VLA Ionosphere and Transient Experiment) system. VLITE will access meter wavelengths from the prime focus of 10 selected VLA antennas with a projected timeline that would fit well with the VLASS survey. The science goals of a VLITE OTF mosaic survey include: (1) imaging and spectral index constraints of cm-wavelength VLASS sources, (2) searches for slow and fast source transients, and (3) ionospheric remote sensing, including Travelling Ionospheric Disturbances (TIDs). At present, the baseline VLITE specifications exclude it from being used during OTF mosaic mode. The compelling requirement is the software for VLITE observing is possible within the OTF mode.

2. Introduction

The VLASS project will survey the sky visible at the VLA in the centimeter wavelength range, using On-the-Fly (OTF) mosaicking interferometry. The VLITE system (center frequency 350 MHz, bandwidth 64 MHz) will be installed on 10 antennas with a completion date of October 2014. The VLITE system will have an independent path for data from the P band receivers mounted at the prime foci of 10 antennas and will have a backend, including software correlator, independent of WIDAR. It will operate from 2014 to 2017. The purpose of the design of VLITE is to acquire data in the "piggy-back" or commensal observing mode. ***The most important additional resource needed to carry out a VLITE survey during VLASS is NRAO-developed software for DifX to allow VLITE observing in the OTF mosaic mode. A secondary consideration would be the requirements for data storage and a processing pipeline for the data. If the VLASS survey uses 1000 hours of JVLA time then VLITE would produce a total of roughly 1TB of raw visibilities which would not be an issue for archival storage or image processing.***

VLITE aims to utilize 50% of JVLA science time through commensal observations spanning 2014-17. In this operational scheme, VLITE observing is restricted to JVLA pointed measurements, excluding OTF mosaicking observations. With the inclusion of OTF observing in VLITE, the commensal observing time would be increased greatly, and allowing more reliable comparisons across the VLASS and VLITE observing bands through simultaneous data streams.

3. **Overview of the Science**

The science to be done with VLITE can be divided into three areas: (1***) imaging*** of Galactic and extragalactic radio sources, (2) fast and slow ***time variability*** of radio sources, including PSR and related (e.g. RRAT), and (3) ionospheric remote sensing, including ***TIDs in the ionosphere***. The images complement the VLASS data, allowing for the determination of source properties at multiple frequencies. VLITE imaging offers a powerful constraint on slow transients from comparisons with second- and minute-scale imaging. Additional goals are searches for fast transients and pulsars, that is, on time scales of a few seconds or shorter. The fast transient searches with VLITE will use hardware and software provided by NRL.

For ***imaging***, the P Band measurements will access a field of view an order of magnitude (in area) larger than VLASS, providing redundant measurements. When combined, the *(u,v)* plane coverage and integration times for VLITE will be improved greatly, allowing VLITE imaging to approach full VLA synthesis. The exact details on the quality of imaging reconstruction will of course depend on the details of the imaging strategy and depth used for the VLASS. Compact sources will be well-recovered by even snap-shot type surveys but extended emission requires better *uv* coverage. We note that simulations of VLITE extended source recovery show very promising results for well-sampled *uv* data sets (Helmboldt et al., 2013 VLITE memo).

For extragalactic sources, Clarke et al. (2013) have given examples of the science that can be done in the realm of clusters of galaxies. For these extended, low brightness sources, the observational emphasis favors weak, low surface brightness, steep-spectrum synchrotron emission. Thus, the VLITE data expands the census of relativistic electrons in clusters and thus our opportunities to understand the evolution and physical state of these systems.

For Galactic sources, there are two main applications. For the inner Galactic plane, repeated images may be used to detect slow transients. For the outer parts of our Galaxy, the images made by combining repeated measurements will certainly surpass imaging derived from the legacy P band system. For both Galactic and extragalactic sources, the combination of the VLASS and VLITE data will constrain continuum spectra allowing the opportunity to deduce physical parameters of the sources that are detected with both frequency bands.

FRBs and Variability: A comparison with previous source data would allow estimates of slow time variability. For rapidly time-variable sources, NRL is developing a system to detect msec-timescale transients. The advantage of using a P band commensal system during VLASS is the increased amount of observing time combined with the substantially larger P band field of view (>3 times wider than VLASS). Thornton et al. (2013) have detected 4 sources at 1.4 GHz during a large survey. This reinvigorated an international search for Fast Radio Bursts (FRBs) at cosmological distance, by bringing to bear to the world's most powerful radio telescope in the game. **The most powerful enhancement to ongoing transient searches is localization through interferometry – a radio transient with a poor positional determination is almost useless.**

Since pulsars, and related phenomena such as RRATs radiate more intensely at lower frequencies (e.g. talks from CAASTRO 2013), the VLITE part of this survey will unveil new discoveries With the high angular resolution of the VLA, any detection would immediately lead to a very accurate position on the sky.

Traveling Ionospheric Disturbances: VLA meter-wavelength observations have opened a new field of ionospheric remote sensing (e.g. Helmboldt 2012a-e). These include the study of TIDs, manifested through interferometric phase variations towards cosmic radio sources. The study of TIDs, and related ionospheric fluctuations, is a primary goal of the VLITE project that would be enhanced by additional VLASS observations. These data should allow a better understanding of TIDs and a larger data set that can be compared and correlated with other phenomena such as vertically-propagating gravity waves generated via airflow over mountains or by significant seismic events. The P band VLASS data will be supplemented by results from more than 30 GPS receivers across the state of New Mexico, which operate continuously and provide additional and complementary ionospheric measurements. Contemporaneous VLA and GPS results provide an expanded TID data set, and broaden pathways for funding radio interferometers from the atmospheric physics community.

4. Conclusions and Configuration Considerations

With commensal OTF mapping with VLITE during the VLASS, the scientific returns would be substantial. It would allow:

- low frequency images of clusters of galaxies, and other nonthermal sources (e.g. Galactic SNRs),
- spectral index constraints for all detected sources,
- an increase of the search time for slow and fast variable sources, including FRBs
- an enhanced data base for ionospheric remote sensing, including TID studies
- an expansion of the breadth, and funding base, of the VLA towards atmospheric science – only one scientific area relevant outside the traditional, and narrow framework of radio astronomy.

An important consideration to keep in mind for commensal P band observations is the configuration which will be used for the VLASS. The VLA D configuration confusion limit of 4 mJy/beam is reached nearly instantly for P band and thus is of little to no use for addition to a survey. Similarly the C configuration confusion limit of 0.4 mJy/beam is also quickly reached and combined with the low resolution is not ideal for commensal use but could still be important for transient searching. VLA A and B configuration commensal observations at P band with VLITE during VLASS would not be subject to confusion issues and would be a very valuable addition to the science.

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