VLASS Epoch 4

Summary

VLASS was conceived as a three-epoch project, bounded in time by the transition to ngVLA. As this transition has been delayed from its original timetable, we have an opportunity to continue VLASS beyond its initial three epochs into a fourth. The full science case for a fourth epoch would be developed by the VLASS Survey Science Group (SSG), but can be summarized as extending the time domain coverage of VLASS from the original ~5-year time coverage of any point in the sky to a project with an ~10-year time baseline. This helps to fill the gap in cadence of about 20 years between FIRST/NVSS and VLASS, and the VLASS time domain coverage. Extending VLASS towards the end of the 2020s will also allow overlap with the Rubin Telescope's Legacy Survey of Space and Time (LSST), and surveys with the Nancy Grace Roman Space Telescope, as well as bridging the gap between VLASS and proposed new time domain surveys with DSA-2000. Although we believe the science case for extending VLASS is strong, we recognize the large impact that VLASS has had on the operations staff in New Mexico, and outline some potential mitigations to allow a fourth epoch to proceed with a smaller impact. In particular, we recommend delaying Epoch 4 for 1-2 configuration cycles both to improve the cadence coverage and allow time for processing of the Single Epoch products.

VLASS Epoch 4 science

The fundamental importance of VLASS is as program that enables new phenomena to be found at radio wavelengths, not simply as follow up to interesting sources detected in other wavebands. This is especially true for the radio transient population, where VLASS is allowing unique insights into populations of transient sources obscured by dust in other wavebands. Although other telescopes are also now starting their time domain programs, they typically sample shorter cadences and study smaller areas (ASKAP/VAST, MeerKAT/ThunderKAT), at lower resolution and frequency. VLASS will remain unique for transient studies at least until the SKA era (see Box). VLASS results have been used in 94 papers as of May 1 2023, and the survey description paper has been cited 288 times. Some highlights from VLASS Epoch 1 and 2 observations are shown in Figure 1.

VLASS remains unique for transient studies

- ***Coverage of the whole sky*** *visible to the VLA.*
- ***High angular resolution*** *allows accurate transient location (e.g., distinguishing nuclear vs off-nuclear transient in a galaxy).*
- ***High frequency*** *allows identification of optically-thick transients earlier in their lifetimes.*

We have consulted both internally within the project team at NRAO, and with the VLASS Survey Science Group to determine the possible parameters of a 4th epoch. We considered changing the configuration and/or observing frequency. However, for the main goal of finding and understanding the transient population, a repeat with the same observational parameters was deemed most useful. We will bear in mind the other concepts (for example, a C-configuration S-band survey to fill in the uv-plane, and a C-band survey to improve spectral indices and find sources with extremely high Faraday rotation) for the transition from VLA to ngVLA.

The primary science justification for a 4th epoch is that it will fill in the gap in observational cadence between VLASS (sampling the same point in the sky 3 times over ~5 years) and FIRST/NVSS and VLASS (~20 years). Improving the cadence coverage will allow sampling of different populations of transients, and continued monitoring of those detected in prior VLASS epochs. Extension of VLASS to the end of the current decade will also allow the deployment of automated transient detection pipelines (currently under development by Caltech and the Canadian CIRADA collaboration), and temporal overlap with time domain surveys in the optical such as LSST and surveys with the Roman Space Telescope. A 4th Epoch of VLASS would also allow further data for the commensal projects that benefit from the all-sky observations of VLASS, such as VLITE, COSMIC-SETI and realfast (both VLITE and COSMIC have had issues early in Epoch 3.1 that have prevented them from operating at their full potential, in particular a 4th epoch would be valuable for COSMIC to ensure a uniform sky coverage).

The extra depth in the VLASS Cumulative images from a 4th Epoch would be small (15%), but, because the VLASS detection limit is at a flux density where the dominant source population is rapidly changing from AGN to star-forming galaxies, even a small increase in depth would open up scientific opportunities.

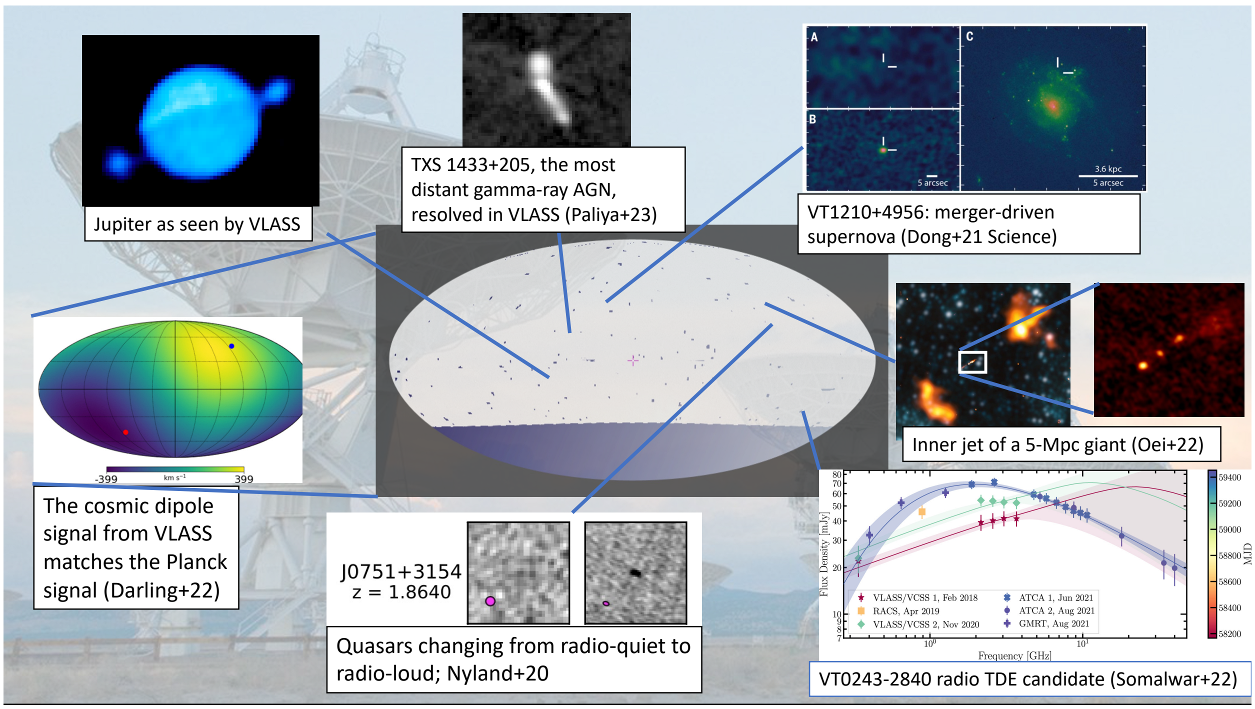

Figure 1: some highlights from VLASS Epoch 1 and 2.

Wider benefits to NRAO

VLASS is the only NRAO program that is working on optimizing the computing cluster usage by running hundreds of simultaneous jobs using the High Throughput Computing (HTC) paradigm that will be essential for ngVLA processing. The VLASS imaging problem is also pushing development of high speed, GPU-enabled gridders that will be needed to solve the wide-field imaging problem for noise-limited imaging with ngVLA at cm wavelengths. VLASS has been pioneering automated QA of imaging projects using both heuristic and machine learning approaches, again, these will be essential in the ngVLA era. A 4th epoch will provide further impetus for development and optimization of the HTC, QA and imaging algorithms.

VLASS is also important for NRAO's broader impacts efforts. VLASS data products do not require a detailed knowledge of interferometry to be used scientifically, and are thus ideal for undergraduate or bridge program projects. The RADIAL program's work-study component is designed around VLASS.

Challenges and impacts of a 4th epoch

VLASS has a significant impact on VLA operations. The BnA configuration needs to be made available for the southern VLASS fields, the scheduling is a large amount of work and the VLASS operations team will need to process and quality assure another epoch of the survey. The impact on the observatory staff is thus high, and any decision to press ahead with a 4th epoch should bear this in mind.

We propose two mitigations to reduce the impact of a 4th epoch. For both scientific and programmatic reasons it makes sense to delay the 4th epoch by 1-2 configuration cycles (16-32 months). This will stretch out the cadence coverage to include slower transients, and provide a better intermediate cadence point between VLASS and VLASS/FIRST-NVSS, while allowing the operations team to catch up with the SE processing. This may, however, push VLASS4.2 into the VLA/ngVLA transition period, so this plan will depend on the report of the committee that was assembled to consider VLA operations during ngVLA commissioning, expected this summer. There is another risk associated with this, namely that the expertise needed to schedule the VLASS observations may be lost in any delay. This can be mitigated by careful documentation of the procedure for creating scheduling blocks for VLASS at the end of epoch 3 observing. We note that the VLASS manager software will continue to be used to process the SE products during the gap in observations.

The second mitigation is to only produce Single Epoch (SE) products for Epochs 2-4. The VLASS storage plan only covers three epochs of observations and storing a 4th epoch of the SE cubes would be prohibitively expensive. This also means we would not need to produce SE products for the VLASS1.1 data, that, owing to a problem with 2/3 of the antenna pointings, can currently only be produced using the very compute-intensive aw-project algorithm. We thus anticipate that, although the Quick Look imaging for VLASS Epoch 4 will occupy the processing clusters for about 10 months in total, the savings in processing time by not having to make SE products for VLASS1.1 will largely compensate for that. For cumulative images, we will perform image combination of the SE images for epochs 2-4 as these can be made very quickly once SE processing is complete. The highest quality cumulative images will be produced from combined visibility data for which we will need to use the aw-project algorithm in any case, so we will include all four epochs in those products (which would appear some months after the image-combined products).

Given that the infrastructure already exists at NRAO for VLASS operations, it makes sense to keep the processing for Epoch 4 on-site. However, we will ask the proposers (who we expect to be led by the SSG, as was the case for the initial VLASS proposal), to contribute effort (for example, improving our QA algorithms, or helping to design optimal array configurations during the ngVLA transition period for both VLASS and other projects).