VLASS: Thoughts and Feedback

M.Y. Mao, E.A.C. Mills, L.O. Sjouwerman & M. Lacy

NRAO

February 20, 2015

Abstract

This document summarizes our thoughts and feedback of the final VLASS proposal. This document does not stand-alone, as it references other documents including the VLASS Proposal[1], VLASS reviewers' feedback[2], and Jim Condon's VLASS review[3]. **This document builds upon a previous version written after the internal review[4], however prior reading of this is not necessary as the text remains largely the same and changes are highlighted in bold.**

While the VLASS proposal has ostensibly decreased its request from four to two tiers, the "All-Sky" and the "Deep", the "All-Sky" has absorbed aspects of the "Galactic" and "Wide" science cases. As such, we have retained some text pertaining to "Galactic" and "Wide", and in general, comments regarding the well-received "All-Sky" tier, are referring to the previous iteration of "All-Sky". The time request for the VLASS remains essentially the same, and our major concerns have not changed. In our opinion, the final VLASS proposal does not fully alleviate the concerns raised by the internal reviews.

Our assessment of the views and material presented in these documents is that the community would be best served by adopting a single survey component of the four proposed, **at a markedly reduced time request**. If a single component were to be adopted, we suggest that this could be the "All-Sky" component, however based on survey speed and the dominant population of radio sources at centimeter-wavelengths having synchrotron spectra, we find L-band (in A array, to maximize resolution for cross-matching purposes) to be a more efficient use of telescope time than S-band for an all-sky full-polarization survey. However, we note that there are still a number of unanswered questions regarding the value and impact of this survey, and we identify a subset of these that we suggest should be considered by the upcoming community review.

1 The Final VLASS Proposal

The internal review of the VLASS proposal at the end of 2014 suggested the VLASS could be pared down greatly from ∼9000 hours, perhaps by selecting only one of the four proposed survey tiers. The final VLASS proposal has modified its survey definition from four to two tiers: the "All-Sky" and the "Deep", but not decreased its total requested time significantly. The "Deep" tier has not undergone any changes to its proposed size, depth, or time request. Although the "Galactic" and "Wide" tiers have been nominally removed from the proposal, the science justifications have been

[1] VLASS Proposal, Version Date February 5, 2015

[2] VLASS Internal Reviews

[3] Condon, J. An Analysis of the VLASS Proposal

[4] Mao, Mills, Sjouwerman, Jagannathan, Lacy, VLASS: Thoughts and Feedback, Version Date December 16, 2014

absorbed into the "All-Sky" science case thus the requested sensitivity has changed from 100μJy beam^{-1} to 69μJy beam^{-1}, and the time request remains ~9000 hours. This is largely to accommodate the depth requested by the "Hidden Explosions" science theme, and is somewhat shallower than the 50μJy beam^{-1} initially required for this science case. Sections 2, 3, 5 have not undergone any change and Section 4.2 has been modified for clarity.

2 Background

The NRAO VLA Sky-Survey (VLASS) initiative was announced in the July 11, 2013 NRAO eNews[5]. The goal of the initiative was to explore the scientific and technical opportunities of a new centimeter-wavelength survey that would complement existing and future multi-wavelength synoptic surveys such as that of the Large Synoptic Survey Telescope (LSST). In order not to constrain the development of a strong science case, there were no predetermined initial values for survey parameters or variables: the survey frequency, array configuration, sky coverage and maximum time were left largely free to be constrained by the science. The science program and key components would be defined by a community-led Survey Science Group (SSG) with the NRAO pledging to support the technical definition and implementation of the resulting survey. The principles of the survey include legacy, uniqueness, complementarity and quality[6]. Initial directives to the scientific staff were for a survey that would benefit the multiwavelength astronomical community and would rely only upon currently commissioned and tested technical capabilities. Table 2 summaries the current timeline of VLASS activity as it stands (Dec 2014). In addition to the scientific motivation of the survey, there was also an acknowledged political motivation in its timing: to strengthen the NRAO portfolio by 2018 in preparation for the next decadal survey (Astro2020).

A call for community white papers was issued in September 2013 in order to define the scientific direction of the VLASS, resulting in approximately twenty submissions. Although several of these were for smaller surveys more akin to PI-projects, major science themes did emerge which encompassed the broad areas of galactic, extragalactic, and transient studies. The working groups were then instructed to converge on a cohesive science case for the VLASS. Upon completion and circulation of a proposal draft in May 2014, it was apparent that a cohesive science case had not been converged upon[7]. While this does not necessarily detract from the scientific and legacy value of the VLASS, it does contravene the initial desire to have a strong cohesive science case to justify the large allocation of VLA time and NRAO resources being proposed for.

A final draft of a VLASS proposal was submitted to NRAO staff for internal review in October 2014[8]. In brief, the proposed survey requires 8915 hours of observing time, and comprises four distinct components (All-Sky, Wide, Deep, and Galactic) to be conducted at S-band using B, BnA and A-arrays. As proposed in that document, the VLASS would comprise 6 science themes (Hidden Explosions, Faraday Tomography of the Magnetic Sky, Imaging Galaxies Through Time and Space, Peering Through our Dusty Galaxy, Radio Sources as Cosmological Probes, Missing Physics) to be completed using a 3-tiered survey. More detailed descriptions of the science themes and survey tiers are given in the proposal document as well as in multiple documents on the Jansky VLA Sky Survey Scientific Staff Forum[9].

[5]NRAO eNews 07/11/2013, Volume 6, Issue 8
[6]S. Myers Presentation to the VLA Scientific Staff, 01/23/2014
[7]Meeting of the VLA Scientific Staff, 07/23/2014
[8]VLASS Proposal, Version Date October 15, 2014
[9]VLASS Scientific Staff Forum

Table 1: Actual timeline to date.

July 2013	VLASS First announcement
September 2013	Call for white papers
December 2013	First round of white papers collated
January 2014	Planning workshop at AAS
May 2014	Preliminary/strawman draft of VLASS proposal circulated
October 2014	VLASS Proposal submitted to NRAO for internal review
November 2014	Internal review
December 2014	Science review summary
January 2015	**Final VLASS Proposal submitted**

3 The current VLASS proposal

The conclusions of the internal scientific and technical reviews of the previous version of the VLASS proposal are summarized in presentations from the December 3 VLASS scistaff meeting[10,11]. As indicated in these summaries, several themes were apparent in the reviews. While all reviewers had positive comments to make about various aspects of the VLASS, we highlight the recurring critical comments, while noting that the science reviewers were also instructed to deliver only constructive criticism to the SSG. Among the scientific reviewers it was generally noted that the VLASS appeared less as a cohesive survey, and more as the proposal of four separate science cases. Additionally, of those reviewers who were asked to or chose to assess the survey proposal in its entirety, the majority found no compelling reason to include all four sub-surveys in the VLASS. There was also some question as to whether, based on these reviews, any of the proposed sub-surveys constitute truly "exciting" science.

From the technical reviews, it was clear that the adoption of the proposed survey would represent a significant demand on NRAO resources for the duration of the survey. While no single issue was characterized as a showstopper, it was noted that supporting the currently-proposed VLASS would require the cessation of all other observatory support and development. Furthermore, the large time request of the current VLASS proposal would take away substantial time from PI-science, which both the technical and scientific reviewers noted would not merely be limited to "low-ranked" science. Finally, it was noted that several aspects of the survey (particularly wide-field, on-the-fly mosaicked polarimetry) have not yet been demonstrated.

In order to deliver a cohesive and scientifically-compelling survey (either in legacy value or innovation), as well as to lessen the impact on NRAO resources and PI observers, and to lower the risk of implementing un-demonstrated capabilities, it has been suggested that only one of the four proposed sub-surveys should be selected. Furthermore, the selection of a single survey component, thus cutting the observing time by roughly a factor of four, would benefit the apparent political push for the VLASS to be largely completed and available to the community in advance of Astro2020. For all of these reasons, we are strongly in favor of adopting a single sub-survey component from the proposal. Below, we assess the scientific merits of several of these sub-surveys in support of selecting just one component.

[10] Carilli, C. "VLA Sky Survey: NRAO Internal Scientific Review" 12/03/2014

[11] Butler, B. "Internal VLASS Discussion-Technical Reviews Overview" 12/03/2014

3.1 Constraining the VLASS

As mentioned previously, scientific reviewers who assessed the entire VLASS proposal did not generally find all four sub-surveys compelling, and generally advocated that at least one be dropped. While the reviewers oscillated between removing "Wide", "Deep", and "Galactic", there were generally favorable reviews for the legacy value of the "All-Sky" component, which currently asks for 1840h to cover 23885 square degrees[12]. Some of the reviewers have also suggested that both the "Galactic" and "Deep" science goals may be better achieved– or are already being achieved– by PI-led science teams (e.g. currently ongoing projects such as COSMOS[13], Stripe-82[14], GLOSTAR[15,16], and THOR[17]).

In choosing a single component of the VLASS out of these four, it seems likely that a decision as to the ultimate goal and purpose of this survey will have to be made: upon what will the "extremely strong justification" for the VLASS be based? If community legacy value is the primary driver then the "All-Sky" component would be the ideal choice, based on the consensus of the internal reviewers. Conversely, if a potential for innovative science is the primary driver for the VLASS, then it would appear that the "Deep" component is most likely to have the largest scientific impact on the community.

Many reviewers noted the potential of the "Deep" component to perform truly innovative science. The science case for weak lensing is highly compelling, especially at radio wavelengths due to the stable beam response of interferometers. It is unclear however that 10 square degrees down to an rms of $1.5\,\mu\mathrm{Jy\,beam^{-1}}$ at S-band is sufficient to detect the cosmic shear signal to a meaningful limit. From the Brown et al. white paper, to reach a $10\,\sigma$ detection requires 10000 hours (rms $\sim 1\,\mu\mathrm{Jy\,beam^{-1}}$) at L-band over 20 square degrees. At S-band the preferred rms noise level is $0.6\,\mu\mathrm{Jy\,beam^{-1}}$. Thus it may be that the current "Deep" parameters are insufficient to provide any useful constraints on the properties of dark energy. More certainly, "Deep" will observe star-forming galaxies at the peak epoch of cosmic star-formation, which is imperative for understanding galaxy evolution. We note however, that the justification for 10 square degrees is not well made, especially given that the much larger volumes probed at higher redshifts will mitigate the effects of cosmic variance[18]. At the detection threshold of the proposed "Deep" survey, the scatter in the source counts due to sample variance is just over $\sim 1\%$ over 4 degrees. Consequently, it is possible to linearly pare down the time request for "deep" without compromising the science goals simply by reducing survey area[19]. For instance, observing 4 square degrees to an rms of $1.5\,\mu\mathrm{Jy\,beam^{-1}}$ would require only 1356 hours. While deep surveys are currently being performed as part of PI-science, there are still many technical challenges faced by imaging deep fields. At this point, the dividing line between PI-led science and Observatory-led technical expertise is unclear. Addressing the technical challenges requires close collaboration with NRAO observatory staff. Having a Deep VLASS may funnel extra resources into the observatory to work on these problems. **The final VLASS proposal made no changes definition for "Deep".**

Given that we believe that a choice must be made and only one survey selected to move ahead with the VLASS, then for the purposes of the remainder of this document we will focus on the All-Sky Component (as per the previous version of the VLASS proposal), as it was the most uniformly

[12]To cover the entire Northern sky, the time allocation would be closer to ~2700h
[13]VLA-COSMOS Webpage
[14]VLA Stripe-82 webpage
[15]GLOSTAR Webpage
[16]GLOSTAR Technical specifications
[17]THOR Webpage
[18]See Heywood, Jarvis & Condon 2013, MNRAS, 432, 2625
[19]Although if it were determined that the VLASS's primary science case is weak lensing, perhaps the area should be *increased*.

well-received by the internal reviewers.

4 The All-Sky component of the VLASS

4.1 Current All-Sky Proposal

The reviewers were generally positive about the all-sky component of the VLASS, with two reviewers suggesting two passes of the entire northern sky, and one even suggesting four passes of the entire northern sky. Such multi-epoch data would be beneficial to transient science while enabling deeper continuum images. However, when we consider this component on its own, it is not entirely clear whether the current parameters of the All-Sky survey are fully optimized, or are the result of compromises made to be part of a "uniform" VLASS in conjunction with the proposed Deep, Wide, and Galactic components.

4.1.1 Array configuration

The motivation for the All-Sky component of the VLASS is to "provide a high-resolution radio reference for the entire northern sky". To this end, one criticism is that the choice of B-array yields lower resolutions than A-array for the purposes of cross-matching sources. It is possible that this is a compromise motivated either by the computationally expensive imaging algorithms required for A-array, the hope that the impact on PI-science in the less oversubscribed B-array is less severe, or to ensure accurate flux density measurements especially for extended sources. If the latter is the primary motivator for the lower resolution, we suggest that performing the survey in A-array supplemented with C-array would better achieve all of the goals of the All-Sky component.

4.1.2 Frequency

While the choice of S-band for an all-sky survey appears justified on the basis of survey speed, again, it appears to be a compromise. L-band would both be more complementary to upcoming radio surveys (providing a high-resolution analogue to EMU/WODAN), as well as be superior for polarization studies considering that the sensitivity to a given Rotation Measure is given by $\Delta\lambda^2$. As both the FIRST and NVSS surveys were conducted at L-band, performing a (higher-resolution) VLASS at L-band would also offer the greatest complementarity to existing NRAO survey data (However, the converse argument can also be made: that conducting the VLASS at a higher frequency would offer maximum uniqueness from existing and previous surveys by probing an underrepresented part of frequency parameter space).

4.2 An Alternate All-Sky Proposal

In order to minimize the impact of the VLASS on NRAO resources and PI observers, it would be desirable to achieve the goals of an All-Sky survey as efficiently as possible.

We first assess, based purely on the slew rate limitations of the VLA, the fastest speed at which it is possible to Nyquist-sample the entire sky at each of the frequency bands of the VLA. Table 2 shows the minimum amount of time required at each band to perform an observation of the entire sky north of –40. As expected, this can be done most quickly at the lowest frequencies (P and L-bands) due to the larger primary beam. However, the RMS noise for this single epoch of observations is optimized at higher frequencies (C, X, and Ku-bands). We note that the LSST proposes to image the entire sky at optical wavelengths every 3 nights. The VLA could conceivably image the entire sky at L-band every 3 days[20]! Moreover, to achieve an rms of $\sim$100 μJy beam^{-1} at S-band, which is the goal of the VLASS All-Sky component, the entire sky could actually be imaged $\sim$8 times leading to many more epochs for transient studies.

Table 2: Fastest all-sky observations possible with the VLA. This assumes a maximum slew rate of 20 arcmin per second and a minimum of 1 second between phase centres, **and ignores potential beam shape distortions in the imaging. Data rates are not taken into account and for the higher frequency bands may be greater than the 25MB per second constraint, if CBE averaging is not available.** The separation between mosaic rows uses the standard $\theta_{row} = \theta/\sqrt{2}$. The total area used for this calculation is 33827 square degrees (82% of the sky). **Sensitivies assume natural weighting and are obtained from the ECT.** Overheads are not taken into account in this table. **The previous version of this table erroneously used 22m diameter dishes instead of 25m diameter dishes in the calculation. This has been rectified.**

Band	Time (hours)	Time (days)	rms (μJy beam^{-1})
P	13.4	0.6	4616
L	78.9	3.3	606
S	315.8	13.2	278
C	1263.2	52.6	211
X	3508.8	146.2	198
Ku	7894.8	329.0	192
K	17370.8	723.8	309
Ka	38792.0	1616.3	355
Q	71053.2	2960.6	724

By simultaneously optimizing mapping speed and sensitivity, S-band is indeed the most sensitive for a given target rms. However, at these cm-frequencies the sky is dominated by synchrotron spectrum sources with the spectral index closer to $\alpha \sim -0.7$. In Figure 1 we calculate the time required to reach an rms of 100 μJy beam^{-1} at S-band. The time required at other VLA frequency bands is then calculated based on the spectral index. For example, consider a point source that is 500 μJy beam^{-1} (5σ) at S-band. To detect this same source at L-band would require an rms = 61.4 μJy beam^{-1} if α=+0.7, and rms = 100 μJy beam^{-1} if α=0, and finally an rms = 162 μJy beam^{-1} if α=–0.7 and the detected sources are primarily synchrotron, as we assume here. As stated previously, to reach an rms of 100 μJy beam^{-1} at S-band over the entire Northern sky requires $\sim$**2440** hours (including 17% overheads, this is $\sim$**2860** hours). However, to detect the same population of α=–0.7 sources at L-band requires just $\sim$**1100** hours ($\sim$**1290** hours with overheads)– significantly less time than currently allotted to the All-Sky component of the VLASS. Furthermore, while this sensitivity can be reached with 8 observing epochs at S-band, it can be reached with 14 epochs at L-band, providing an increased cadence for transient studies. Ultimately, to detect the same synchrotron spectrum sources at L-band that would be detected at S-band requires less than half the total observing time. If providing a high-resolution radio reference of the sky is the primary science driver, then L-band is the most logical and time-efficient frequency band to observe in.

An L-band, A-array all-sky survey to 162μJy/beam rms that would be equivalent to the

[20]There is some debate in the observatory as to the feasibility of dumping data once per phase centre per second and imaging reliably. While dumping data at a faster rate, may improve image quality, the data rate will increase linearly. The VLASS is capped at a data rate of 25MB s^{-1}, thus slower slewing may be required at the current default setups at higher frequencies (assuming 2 MHz channels). This may be mitigated in the future with CBE averaging.

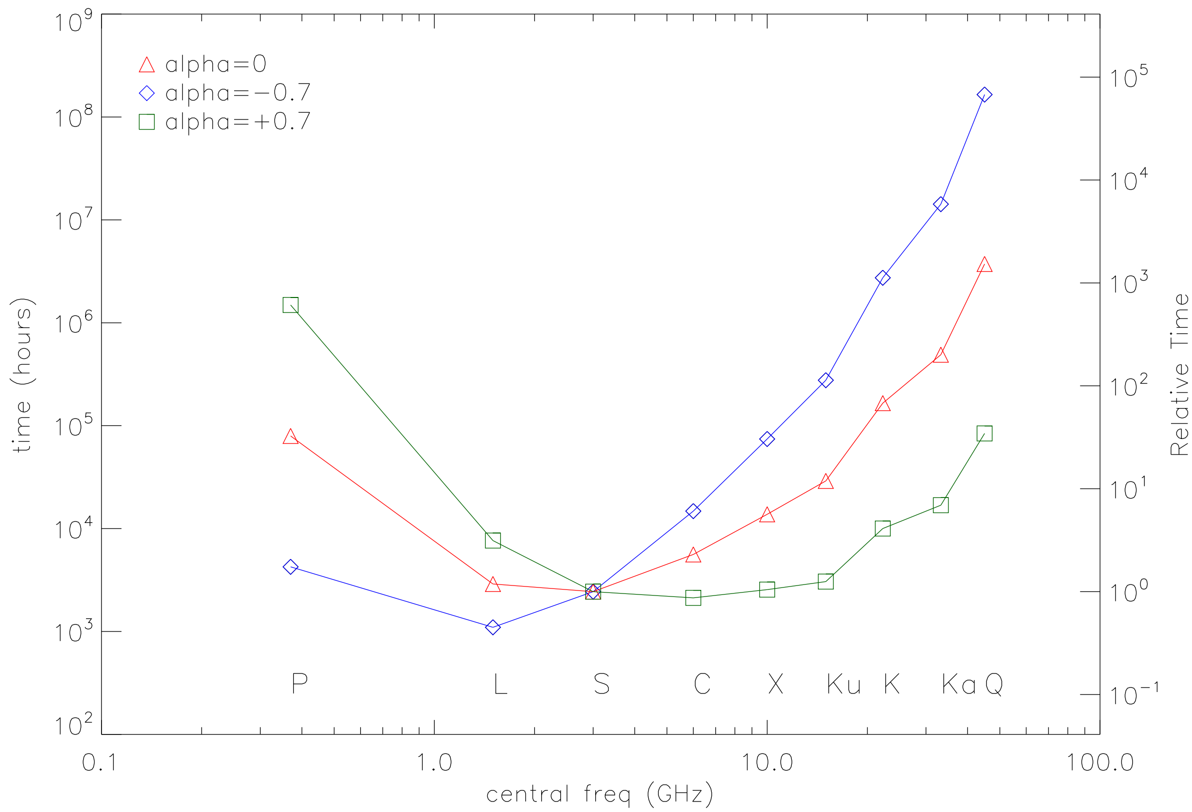

Figure 1: Time required as a function of frequency band to perform the all-sky survey down to $\mathrm{rms}_{S-band} = 100\,\mu\mathrm{Jy\,beam}^{-1}$. The left-axis shows the absolute time in hours for an all-sky survey without overheads taken in account and the right-axis shows the relative time scaling to the S-band time request. Data are shown for both flat-spectrum (α=0), synchrotron-spectrum (α=–0.7) sources, and for comparison, an inverted-spectrum (α=+0.7). Lines are plotted to guide the eye. The kink at K-band is due to the water line at 22 GHz.

currently-proposed S-band All-Sky survey would take ~1300 hours. This is only a **sixth** of the current proposed time allocation, thus over 5 years this would only displace ~ 3% of PI-science, and would place less pressure on NRAO resources. Alternatively, if the political motivations of completing a VLA survey for the broader astronomical community before Astro2020 are deemed more important than a slightly enhanced impact to PI science and observatory support, the timescale could conceivably be compressed to finish the survey before 2018. While such a smaller-scale survey is being carried out, much can be learned about scheduling, RFI, pipeline processing, OTFM, and polarization that could be used to support a future, larger survey. If after 5-years a deeper survey still seems compelling, deeper observations of a subset of the sky or another epoch of all-sky may be carried out. If sensitivity to extended sources is deemed important, such a second epoch should be carried out in C-array.

5 Remaining Questions

Whether implementing the entire proposed VLASS or just a subset of this survey, there will be a change to current VLA operations. PI-science will be displaced, and some amount of observatory support and resources will be diverted from their current areas to observing, calibrating, and making available the products of the VLASS. The question then is whether these discomforts can be justified.

In the initial VLASS Prospectus white paper[21] it was suggested that a multi-tiered survey strategy requiring ~6000 hours over a decade may be appropriate. However, an "extremely strong justification will be required if a VLASS is proposed for 5000 hours or more!" A similar sentiment is expressed on the VLASS FAQ page. There is no doubt that the proposed science case for the current VLASS is far-reaching, containing many ideas for excellent science. However, does the current VLASS make an "extremely strong justification" for its proposed 9000 hours? Does the "All-Sky" or any other individual survey component merit the displacement of PI time and observatory resources?

To determine this, there are a number of questions still to be considered or conclusively settled.

- Is the time-request for a VLASS justified as a function of science-quality? That is to say, would 9000 hours of PI science provide a similar or greater community impact? As noted by many reviewers, this is difficult to quantify, but it should be possible to at least make an informed, qualitative judgement (e.g., via consultation with the VLA TAC).

- Is the time-request for a VLASS justified as by the impact of the survey on the community? Again, as noted by many reviewers it is hard to effectively quantify this impact, with the citation-based statistics that have been put forward largely agreed to be misleading. If the impact of the survey is to be its legacy, how can that be quantified, and who should we be trying to benefit: radio astronomers or the general astronomy community? What about the general public?

- Is a VLASS ultimately beneficial to the NRAO? Potential concerns include the risk that utilising a large fraction of VLA time for the VLASS may alienate NRAO facility users, or adversely impact students and postdocs who have limited time constraints for moving forwards in their astronomical career.

- What is the optimal amount of VLA time and NRAO resources that ought to be dedicated to a VLASS to maximize both science-quality and legacy value?

[21]Myers, S. "A Karl G. Jansky VLA Sky Survey Prospectus"

- Is now the right time? A VLASS would provide lasting legacy data from an already strong telescope. However, the upgrade of the VLA has only just finished and neither observing nor data processing is very stable yet. Should a VLASS on this scale be performed when are only just starting to understand and exploit the system?

- Does this survey take full advantage of the new features of the VLA? According to one internal scientific reviewer "the polarization capabilities of WIDAR are perhaps the strongest reason to produce a new all-sky survey". However, demonstrating that OTFM will work with full polarimetry is a work in progress[22].

- **Should the VLA follow the practice of many other observatories and consider adding a new category of large proposals, and explicitly reserve a minimum fraction of available hours to proposals of (say) >500hr duration, in place of some or all of the VLASS components?**

While we do not presume to know the answers to most of these questions, it is imperative that these points are discussed. If these questions cannot be answered at present, is now the right time for the proposed VLASS?

6 Conclusions

The VLASS is an ambitious initiative that will undoubtedly produce valuable science. However the issue at hand is whether the extremely large time-request is justified by the likely scientific impact of current VLASS proposal. Based on the internal reviews, it has been suggested that the current proposal be pared down greatly, which could be accomplished by choosing one of the four sub-surveys that have been proposed. The "All-sky" component of VLASS was received most favorably by the internal reviews and is likely to have the largest impact upon the astronomy community, however as noted above the"impact" of this as for any component of the survey is still difficult to quantify. We find based on survey speed and the fact that the dominant source population at centimeter-wavelengths have synchrotron spectra, that L-band is the most logical choice for an all-sky full polarization survey. To achieve a depth comparable to the currently proposed S-band all-sky component of the VLASS, an L-band equivalent requires less than half the observing time ($\sim$1000h for L-band compared to $\sim$2700 hours to observe the entire northern sky at S-band). We suggest that the high-resolution of A-array would provide a better radio reference for the purposes of cross-matching.

Finally, we note that there has been a large amount of work already done by both the community and the NRAO in generating the current VLASS proposal. While no-one desires this work to have been in vain, we are fearful that the VLASS may be pushed ahead prematurely or too ambitiously due to the time already invested in this process. We are hopeful that the Community Review in early 2015 will address the outstanding questions about the impact of the VLASS and will commit to determining the best survey strategy for the overarching community. Inevitably, some subset of astronomers will be displeased with any decision, but it is our hope that the outcome of this review process will be a clear assessment of how the positive impacts of the chosen VLASS outweigh its costs.

[22] Mooley et al. (priv comm)