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NRAO Internal Science Review:
Very Large Array Sky Survey Proposal

PREPARED BY	**ORGANIZATION**	**DATE**
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1 INTRODUCTION

As part of the scientific review of the VLASS, the NRAO Director called for a review by a representative sample of NRAO scientific staff. The review took place over the Month of November, and addressed the October 15, 2014 version of proposal. The charge to the reviewers included the following criteria:

- Large survey initiatives like VLASS require a large commitment of resources and must provide a strong and compelling scientific justification.
- The survey should be placed within the wider scientific context: what will the likely impact and influence of VLASS on the scientific community be?
- Will the proposed observations be regarded as an important resource by the community?
- Is it a critical component to multi-wavelength studies of problems of current interest or does it stand on its unique merits?

Eleven of the NRAO staff were asked to review the proposal, with a focus on areas of personal expertise, according to the main science themes of the proposal:

- Hidden Explosions = Transients
- Faraday Tomography of The Magnetic Sky = Polarization
- Imaging Galaxies Through Time and Space = Galaxy formation
- Peering Though Our Dusty Galaxy = Milky Way and nearby galaxies
- Radio Sources as Cosmological Probes = Cosmology
- Missing Physics = multiwavelength studies/other

The proposal and review results were made available to other interested scientific staff in an internal wiki. An open forum was held on December 3, for interested scientific staff to discuss the review results, and to allow for broader input into the discussion. This report presents a summary of these reviews and discussions.

The review is meant to provide constructive criticism to the Survey Science Group. All the review material will be made available to the Survey Science Group, as well as the community review, as per the original policy:

> *'All individual reviews will be provided to the SSG. The SSG will then have an opportunity to respond to the reviews, and to revise their proposal according to the feedback, before final submission. The final proposal will then undergo an external, Community Review…. All reviews will be anonymous, but will be made available to the Community Review panel.'*

In this summary, I try to capture the commonality between the internal reviews. I employ example quotes from the reviews throughout, as representative of broader opinions expressed by the committee (in italics). Section VI summarizes the main recommendations.

2 MULTI-TIERED PROPOSAL AND SCIENCE GOALS

The VLASS was the result of extensive input by a broad community, and hence represents an integration of many areas of science. This community process was generally seen by the reviewers as a useful exercise: *'I would also like to mention that the community aspect of the survey and the associated call for*

whitepapers was very fruitful in order to derive the best science cases as well as to integrate many parties of interest in the attempt for the best compromise.'

The resulting proposal is broad, and consists four tiers, in terms of area, depth, and resolution. In fact, the NRAO internal reviewers uniformly commented that the VLASS is really four proposals, with different science goals: *'Instead of choosing one survey, the group has proposed four surveys, apparently to satisfy the diverse opinions of the community.'*

The four surveys and main science goals can be summarized as follows:

1. All sky survey: 2 - 4GHz w. polarization, 2" res. Main science is standard survey products, at higher resolution than FIRST, full northern sky, 2GHz spectra, full polarization. Depth is comparable to FIRST (0.15mJy at 1.4GHz).
2. Wide: 2x deeper than all sky, 2" res, 4 epochs (15month cadence), cover SDSS/DESI region. Main science: transients (SNe, TDE, AGN, FRB?, other), RM grid, AGN and star forming gals.
3. Deep: 10 deg2, 0.7" res and 1.5uJy rms. Main science: imaging distant star forming galaxies and AGN, and cosmology (weak lensing, very LSS).
4. Galactic: Galactic plane to +/-5deg. New MSPs, Mdwarfs, YSOs, as well as study Galactic structure through PNe.

All four surveys are to be done in S band (2 to 4GHz). This band choice was considered reasonable by the reviewers: *'The survey also makes good use of the new Jansky VLA capabilities. It is a tough balance between bandwidth improvements, angular resolution, polarization, and sky coverage for any survey. Going to Sband may indeed be the best compromise, also in the light of surveys planned by other facilities.'*

The NRAO reviewers uniformly broke the survey into its four different parts, and considered each for its own merits. It is my understanding that the community review panel will have the same jurisdiction to consider the four components independently. The following sections summarize the pros and cons identified by the reviewers for each of the four proposals.

3 ALL SKY SURVEY: 1840HRS, 2"RES

Pros

1. Important reference all-sky radio images at arcsec resolution.

'Access to an arcsecond radio atlas of the sky will lower the bar for "radio-challenged" astronomers to make use of the radio spectrum.'

'All Sky survey is straight-forward and will be highly used by the community.'

2. Has unique attributes relative to eg. FIRST: All sky, 2" res, full pol, 2GHz spectrum
3. Comprises 21% of total time

Cons

1. Sensitivity is not much of a gain relative to FIRST
2. Lack of short spacings will miss larger structures (scales > 10" to 20")

4 WIDE: 2824HRS, 2"RES, 4 EPOCHS

Pros

1. Factor two deeper (wrt All Sky), in well studied SDSS/DESI regions
2. Synoptic: emerging transient science fields of SNe, FRB, TDE, GRB…
3. Polarization: map the RM grid ('Faraday tomography'), cosmic magnetism

Cons

1. A major time request: 32% of total time
2. The quantitative justification for the factor two increase in depth is lacking.

   'The justification for the increase in depth is hard to quantify — can they show a real break in the luminosity function or redshift space covered in which the factor 2 increase in depth pushes them into 'new science'?'

   'There is no good justification for observing a factor of two deeper... This factor gives no magic leverage.'

3. There were many concerns about the transient cadence, and how to differentiate between different types of variable sources: long/short transients, variable AGN…?

   'I cannot see how the proposed survey design helps to find hidden explosions. How would one distinguish those from other transient events? If the characteristic timescales of the related light curves are about a year, and the observations follow a 15 month cycle, the light curves will be quite under sampled. For neutron star binary mergers, the situation is the reverse; the merging timescale is of order milliseconds, which is considerably less than the integration time for each visibility (>=1s).'

4. RM grid: there was general concern that the depth of All Sky and Wide will not be adequate to realize the 'Faraday tomography' science.

   'If sources are 5% polarized (a fairly high degree of polarization to assume in general), sources for the all-sky survey will typically need to be > 20mJy to be detected at perhaps 200 rad m-2.'

5 DEEP: 3400HRS, 0.7"RES, 10 DEG2 (3 FIELDS)

Pros

1. Enables imaging of high z star forming galaxies
2. The Cosmology applications parallel the cutting-edge techniques that are being applied globally through DETF, future SKA applications, etc…

   'The VLASS deep tier is very well-suited to the requirements of radio cosmic shear measurements, and is unlikely to be surpassed for radio cosmic shear measurements by other SKA precursor telescopes -- largely due to the angular resolution requirement. Current forecasts are for a ~10 sigma detection of cosmic shear from VLASS (vs ~40 sigma in DES). However the VLASS higher median redshift, clean measurement strategy, and potential for assessment of astrophysical systematics suggest it will nevertheless be of considerable value.'

Cons

1. A major time request: 38% of total time

2. The justification for 10deg2 in the study of distant galaxies is lacking. Are current and planned deep field surveys (eg. Cosmos, HFF…) enough?

   'One could question how much of a lasting legacy the Deep survey will have on extragalactic science. If you plot the Deep survey point on Figure 5 of the Jarvis et al. 2014 JVLA White Paper, after correcting for the spectral index of typical sources, the proposed Deep survey is only marginally better than some of the existing surveys and significantly worse than planned future surveys.'

3. The DEEP survey comes closest to what could be considered 'PI' science, and may already conflict with on-going or planned surveys.

   'The proposal needs to make the argument that the depth they propose and the size of the fields they propose to observe gets around limitations of the PI work in the L, S and C-bands, including such data that would otherwise be taken over the five years of the survey. Also why is the VLASS limit just right? One of the fields, COSMOS, already has a deep survey. Why does VLASS need to go a factor of 1.3X deeper? I did not find any such arguments.'

4. The Cosmology applications need 10deg2, and they make a reasonable case for detecting a given phenomenon (weak lensing, large scale radio clustering), but it lacks a quantitative comparison to other global efforts in these areas of cosmology: Where would the VLASS DEEP results stand with respect to other extensive DETF programs currently underway? Are these simply technique demonstration projects?

   'The VLASS case could be strengthened by directly comparing cosmological results expected, and the VLASS contribution to them, to results expected from competing techniques, using standard figures of merit (e.g., from the DETF; PCs vs z, etc.).'

6 GALACTIC PLANE SURVEY: 840HRS, 0.7"RES, +/-5DEG

Pros

1. Smallest time request: 10% total time
2. Will extend science from Cornish, Glostar
3. May characterize new radio populations: new MSP, M dwarfs, YSO
4. Can determine Galactic structure to 10kpc via PNe

Cons

1. The spatial resolution is not well justified, and will seriously over-resolve PNe

   'The proposal says that most major Galactic surveys (X-ray, optical, infrared, far-infrared, and millimeter) have spatial resolutions of ~1". There are no infrared, far-infrared, or millimeter Galactic surveys at 1" resolution (even Spitzer's near-IR Glimpse survey is only ~2" resolution).'

   'However, it wasn't clear why 0.7" resolution was needed for much of this work? i.e. could some of this science be done via All Sky at 2" resolution, perhaps with a synoptic component?'

2. How will they ID different source types?

'It is thus unclear to me how new PSRs will be identified and separated from other point sources….No mention is made of how distant PNe would be identified in comparison to for example distant compact HII regions.'

'I was astonished that polarization wasn't mentioned in this section at all. I'm even more astonished that star formation is never mentioned. What about compact and hypercompact HII regions, jets, time-variable chromo spherically actively pre-main sequence stars, etc.'

7 RECOMMENDATIONS TO THE SSG

The sections above give specific comments on the four areas of the survey. For more details, please see the individual reviewer reports. In the following, I summarize the broader themes and issues coming out of the review, with specific recommendations to the SSG. I split this into more general concerns, and the more substantial scientific issues. The comments below espouse the charge to the committee that the science case for each tier must entail some quantifiable 'home-run' quality applications, in the light of the very large time allocations being considered.

7.1 Major issues and recommendations: general

1. **All Sky:** The majority of the reviewers were supportive of All Sky as being a resource for the community, producing state-of-the-art radio reference images in the coming era of all sky surveys such as LSST and Euclid.

2. **Wide vs. All Sky**: The relative roles of Wide vs. All Sky need to be clearer. There needs to be a more quantitative justification of the additional depth over the specified field (see point 3 below), in light of the much larger time allocation for Wide. A number of reviewers point out there may be other options to obtain much (or perhaps even more), of the science in less time:

   I find myself considering a 2-pass (All Sky) survey that would achieve 70 uJy/beam sensitivity and would still characterize transients in the field. A 2-pass strategy would be 1400 hours cheaper (than All Sky + Wide).

3. **Justification of depth:** there was wide agreement among reviewers that the proposal needs a much more quantitative analysis of the required depths of the different parts of the survey to achieve the stated science goals:

   The sensitivity of the survey (maybe with the exception of the deep tier) is not well justified. The authors should answer the question how changes in survey sensitivity and area impacts the science cases, at which levels qualitative changes occur, and what accuracies in source statistics are needed to reach the science goals.

   The science cases rarely mention the number of sources that are needed to reach the individual scientific goals.

4. **PI science:** There was general concern as to 'crossing the line' between PI science (some of which is ongoing) vs. a 'community survey'. This was particularly relevant when considering the Galactic and DEEP parts of the survey. The SSG needs to demonstrate clearly how the science results represent a major improvement over current, or planned, PI large programs. The proposal should also be more explicit as to the breadth of the community served by each component.

Please provide a small section on the approximate fraction of astronomers that will directly benefit from each tier.

There are currently two ongoing Galactic Plane surveys at the VLA: a C-band B- and D-configuration survey, GLOSTAR, and THOR, an L-band C-configuration survey. It is unclear to me what can be gained by the proposed, additional S-band A-configuration VLASS survey.

5. **Unnecessary text:** There were a couple of statements in the proposal that were gratuitous, and off-putting to the reviewers. These could be removed with no loss of content or impact.

    i. **Low ranked science:** The argument that the surveys will only displace low-ranked science irked a number of the referees:

    *'I was distracted by a comment in Section 2. The claim is that the survey will impact only "the lowest rated and frequently only partially completed PI proposals". This statement is somewhat disingenuous, and maybe even untrue. On the oversubscribed VLA, an *accepted* proposal is a good proposal. But more to the point, the Tier 2 survey includes a heavily- subscribed part of the sky, and it will apparently not be dynamically scheduled. The fixed-scheduled Wide and Galactic surveys will, therefore, displace some well-rated, high-frequency projects that could have observed in the good weather used by the survey.'*

    ii. **Citation statistics:** Likewise, the use of citation statistics was called-out as misleading, possibly wrong, and generally unnecessary.

    '*In addition, the discussion that is provided on paper citations in section B.2. is not exactly a fair comparison…Restricting to the 1995-2009 publication date papers, the numbers are 1300 papers (NVSS/FIRST) and 42,000 citations (total). The NVSS/FIRST surveys are thus only a small fraction of this number and citations of non-survey data exceeds by more than an order of magnitude.'*

7.2 Major science issues and recommendations

1. **Deep – Distant galaxies:** The most significant concern for DEEP and galaxies was the duplication of science relative to the current on-going PI programs. The proposal would be much stronger if they included:

    - A summary table of the on-going or planned deep fields.
    - A clear delineation of how the proposed observations improve substantially upon the ongoing surveys (note: simply 'more' is not good enough).

    'The deep survey does reach interesting depths for star-formation but competes with many existing or proposed P.I. surveys. The science justification does not effectively address the question of what new VLASS will contribute, especially since the variety of current surveys completed and underway address the cosmic variance issue.'

2. **Deep – Cosmology:** it was difficult to tell from the proposal how the expected VLASS results compare to other efforts under the DETF umbrella. Is this just a technique demonstration project? The proposal needs to include:

- A quantitative comparison of the expected cosmological constraints from VLASS weak lensing and large scale structure measurements, relative to techniques being pursued elsewhere. Will the VLASS represent a major new tool in cosmology?
- If this is just a technique demonstration project, they need to justify more clearly why 10 deg^2 and 3000 hours is needed.

3. **Galactic structure:** a few referees pointed out that Planetary Nebulea will be heavily resolved at 0.76" resolution – of order 100 beams over the source, even at 8kpc distance! In fact, the sources may be undetectable in A array, given the roughly factor 10 to 20 'spatial dynamic range' of an A array snapshot (ie. shortest vs. longest baselines). The proposers need to demonstrate that they can indeed detect PNe, and detect them at a level useful for Galactic structure studies.

4. **Galactic sources:** there were significant questions concerning source identifications. For instance, the proposers need to demonstrate that the MSP search has some major advantage over other techniques currently being used.

5. **Faraday Tomography:** a few referees performed detailed calculations that show that the sensitivity in the RM synthesis, even for Wide, will be inadequate to perform a proper RM-grid experiment. While the aspiration of true Faraday tomography is laudable, the proposers need to go beyond aspiration, and address this sensitivity concern – how will the VLASS will make a major step forward in this field?

6. **Transients and cadence**: Numerous reviewers questioned the cadence of Wide and its ultimate usefulness for 'hidden explosions'. The proposers need to explain how they will categorize different transient events in light of the 15month cadence of Wide, and why 4 epochs are required.

   'How are you going to tell the difference between the different kinds of explosions with one detection?'