VLASS Project Memo # 7

VLASS Tiling and Sky Coverage

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1. Introduction

This memo presents the sky tiling scheme for VLASS and the regions of sky to be observed in each half-epoch. Considerations relating to observing in the BnA hybrid configuration are included.

For the purposes of this memo, "tile" refers to a contiguous region of sky to be observed completely within a scheduling block; a single scheduling block will observe multiple tiles. An important note for clarity: VLASS Memo #4 (*VLASS Pilot Scheduling Block Creation*) drew a distinction between $8° \times 10°$ "tiles" and $4° \times 10°$ "mini-tiles". As discussed in this memo, we have settled on a tiling scheme based on regions that are (almost exclusively) 4°-tall in declination. We therefore refer to all such regions as "tiles" throughout this memo, though they correspond to "mini-tiles" as discussed in VLASS Memo #4.

2. VLASS Sky Tiling Scheme

A "standard" VLASS scheduling block (SB) will observe a contiguous region that is 8° tall in declination and 10° wide in right ascension ($8° \times 10°$) over a 4-hour period. However, an important lesson learned during the VLASS Pilot is that many areas will need observations of smaller chunks of sky (see VLASS Memo #4). In particular, far-southern declinations ($\lesssim -20°$?), declinations that coincide with the Clark Belt ($-16° \lesssim \delta \lesssim 4°$), and declinations that transit near zenith ($28° \lesssim \delta \lesssim 40°$) would be extremely difficult to schedule or observe using the standard tile shape. These regions in particular will be scheduled more easily if an SB observes two or more $4° \times 10°$ tiles that are separated by approximately two hours in LST.

For flexibility and ease of scheduling, we have decided to tile the entire sky into declination "tiers" that are 4° tall (with the exception of two 5°-tall tiers). Each tile will require approximately two hours of observing time. With this tiling scheme, we will have the option of combining multiple tiles in various ways as required by scheduling pressure.

The VLASS tiling scheme is presented in Table 1, specifying the size and number of tiles by tier. Each tier shall have a tile boundary at RA = 0. We aim to define tiles that can be observed in roughly two hours in the OTF scanning mode, including overheads. The VLASS survey speed is approximately 20 square degrees per hour, with the goal of 19% overhead; I used that survey speed to estimate the observing time per tile. The actual time to observe each tile depends on the overhead of the individual SBs. Each tier is restricted to have an integral number of tiles, all tiles in a tier shall have the same shape, and the estimated observing time for tiles in each tier ranges within ±10% of two hours. For certain tiers, based on declination, a different number of tiles could have been chosen to result in observing time estimates that would be closer to two hours than what is represented in the final tiling scheme. However, I often chose the tile sizes such that adjacent tiers will have the same size and number of tiles. This decision should aid in assigning groups of tiles to SBs for the purpose of SB scheduling.

At southern declinations ($\delta \lesssim -16°$), spillover from the over-illuminated secondary reflector when pointing at low elevation will decrease the telescope sensitivity. Tiles at the lowest tiers therefore will require a slower scan rate (and slower survey speed) in order to reach the VLASS noise level. Rick Perley (in a private communication) contributed measured values for the increased noise level; detailed calculations for the sensitivity loss as a function of declination (assuming hour angles ±1.5 from transit) are available in an online Python Jupyter notebook[1]. For tiers with declinations below $-16°$, Table 1 shows the required time increase factor (calculated at the mid-dec range of the tier) that is expected to account for the loss of sensitivity. These tiles are smaller, such that with the decreased survey speed they will still be observed in roughly 2 hours of telescope time.

In Table 1, the width (shape) of tiles for each tier is given in RA degrees, and the widths of the upper and lower edges are given in on-sky degrees. The table shows the area of tiles for each tier and the expected observing time assuming the survey speed of 20 square degrees per hour; in the south the survey speed has been modified by the appropriate factor to account for sensitivity loss at the low declinations.

The southernmost tiers will be observed in the BnA hybrid configuration, rather than in the B configuration, to mitigate the beam elongation at very low declinations. Based on having 293 hours proposed for VLASS to use in each BnA configuration cycle, we expect to fully observe tiers 1–6 ($\delta < -16°$) in the hybrid configuration. Tier 7 ($-16° < \delta < -12°$) will be mostly or completely observed in the hybrid, and some of tier 8 ($-12° < \delta < -8°$) will likely be observed in the hybrid. Tiers 9 and above ($-8° < \delta$) will be observed in the B configuration.

For Tier 32 ($85° < \delta < 90°$), we expect to use OTF scanning mode for declinations from 85° to 89.88°. We will also observe a single pointing at $\delta = 90°$.

[1] http://goo.gl/znDX0i

Table 1: Tiers and Tiling Definition for VLASS

Tier	decl.	N	shape	width (°)		area	factor†	hours‡	
#	range	tiles	RA × decl.	lower	upper	sq. deg.		tile	tier
1	[−40, −36]	48	7.5 × 4	5.74	6.07	23.64	1.73	2.05	98.4
2	[−36, −32]	48	7.5 × 4	6.07	6.36	24.87	1.43	1.77	85.1
3	[−32, −28]	36	10 × 4	8.48	8.83	34.63	1.23	2.13	76.8
4	[−28, −24]	36	10 × 4	8.83	9.14	35.94	1.12	2.00	72.2
5	[−24, −20]	36	10 × 4	9.14	9.40	37.08	(1.05)	1.95	70.1
6	[−20, −16]	36	10 × 4	9.40	9.61	38.03	(1.02)	1.94	69.8
7	[−16, −12]	36	10 × 4	9.61	9.78	38.80		1.94	69.8
8	[−12, −8]	36	10 × 4	9.78	9.90	39.38		1.97	70.9
9	[−8, −4]	36	10 × 4	9.90	9.98	39.77		1.99	71.6
10	[−4, 0]	36	10 × 4	9.98	10.0	39.97		2.00	71.9
11	[0, 4]	36	10 × 4	10.0	9.98	39.97		2.00	71.9
12	[4, 8]	36	10 × 4	9.98	9.90	39.77		1.99	71.6
13	[8, 12]	36	10 × 4	9.90	9.78	39.38		1.97	70.9
14	[12, 16]	36	10 × 4	9.78	9.61	38.80		1.94	69.8
15	[16, 20]	32	11.25 × 4	10.81	10.57	42.79		2.14	68.5
16	[20, 24]	32	11.25 × 4	10.57	10.28	41.71		2.09	66.7
17	[24, 28]	32	11.25 × 4	10.28	9.93	40.44		2.02	64.7
18	[28, 32]	32	11.25 × 4	9.93	9.54	38.96		1.95	62.3
19	[32, 36]	30	12 × 4	10.18	9.71	39.79		1.99	59.7
20	[36, 40]	30	12 × 4	9.71	9.19	37.82		1.89	56.7
21	[40, 44]	24	15 × 4	11.49	10.79	44.58		2.23	53.5
22	[44, 48]	24	15 × 4	10.78	10.04	41.67		2.08	50.0
23	[48, 52]	24	15 × 4	10.04	9.23	38.56		1.93	46.3
24	[52, 57]	24	15 × 5	9.23	8.17	43.54		2.18	52.2
25	[57, 61]	18	20 × 4	10.89	9.70	41.19		2.06	37.1
26	[61, 65]	18	20 × 4	9.70	8.45	36.31		1.82	32.7
27	[65, 69]	15	24 × 4	10.14	8.60	37.50		1.88	28.1
28	[69, 73]	12	30 × 4	10.75	8.77	39.06		1.95	23.4
29	[73, 77]	9	40 × 4	11.69	9.00	41.40		2.07	18.6
30	[77, 81]	9	40 × 4	9.00	6.26	30.52		1.53	13.7
31	[81, 85]	4	90 × 4	14.08	7.84	43.86		2.19	8.8
32	[85, 90]	2	180 × 5	15.67	0.00	39.24		1.96	3.9

† The multiplicative factor required to account for the loss in sensitivity at low declinations. Survey speed is decreased by this factor; equivalently time-on-sky is increased by this factor. Values in parentheses indicate tiers where we might maintain the fiducial survey speed.
‡ These times are based on a fiducial survey speed of 20 square degrees per hour, with an increase at southern declinations according to the above footnote.

3. VLASS Sky Coverage by Half-Epoch

VLASS coverage is divided into regions of the sky to be observed in the "1st-half" and the "2nd-half" of each epoch. VLASS will observe the entire sky (above $\delta = -40°$) over three epochs. The observations will take place over six configuration cycles, with half of the sky observed in each cycle. In order to maintain a roughly even time-cadence for any area of sky, it is necessary to strictly define the 1st-half and 2nd-half sky regions, to be maintained throughout the lifetime of the survey. That is, the region of sky that is observed in the 1st-half of the first epoch will also be observed completely in the 1st-half of the second epoch and the 1st-half of the third epoch (and equivalently for the 2nd-half).

The rough guidelines for defining the 1st-half and 2nd-half regions of sky are:

- Maintain even observing pressure as a function of RA in both the northern (B) and southern (BnA hybrid) regions of the sky.
- Include in the 1st-half the regions of sky that were covered in the VLASS Pilot fields (see VLASS Memo #2).
- For the southern sky, each half-epoch shall include roughly half of the observable sky *at each declination*.
- Avoid observing a tile when any part of the tile is within 7° of the Sun, or within a few degrees of the Moon or Jupiter.
- Maintain tile boundaries, as defined in the first part of this memo.

The first guideline is based on an NRAO requirement that VLASS must have homogeneous observing pressure as a function of LST. In the southern sky, this virtually equates to maintaining constant coverage as a function of RA. The northern sky is much more flexible, but having constant pressure with RA allows the best chance of maintaining even LST pressure under varying scheduling constraints.

Avoidance of the Sun, Moon, and Jupiter is important for defining the tiles to be observed in the hybrid configuration, as the schedule will allow only about two weeks of hybrid observing per cycle. The southern sky for each half-epoch was carefully chosen to avoid overlap with any of these three bodies during the full lifetime of VLASS.

Figure 1 shows the regions of sky to be observed in each 1st-half of an epoch. VLASS Pilot fields and the *Kepler* field are indicated. Table 2 defines the RA boundaries of these regions. Each half-epoch will cover half of the sky in both the "northern" ($\delta > -8°$) and "southern" ($\delta < -8°$) regions, and each half-epoch will use half of the VLASS observing time in the north and south.

Figures 2 and 3 show the observing time pressure as a function of RA in the northern and southern regions, respectively. Figure 3 is based on the assumption that *all* of the sky below $\delta = -8°$ will be observed in the hybrid configuration. These graphs show that nearly constant/equal observing pressure can be maintained in both VLASS configurations, and that (virtually) exactly half of the sky will be observed in each half-epoch.

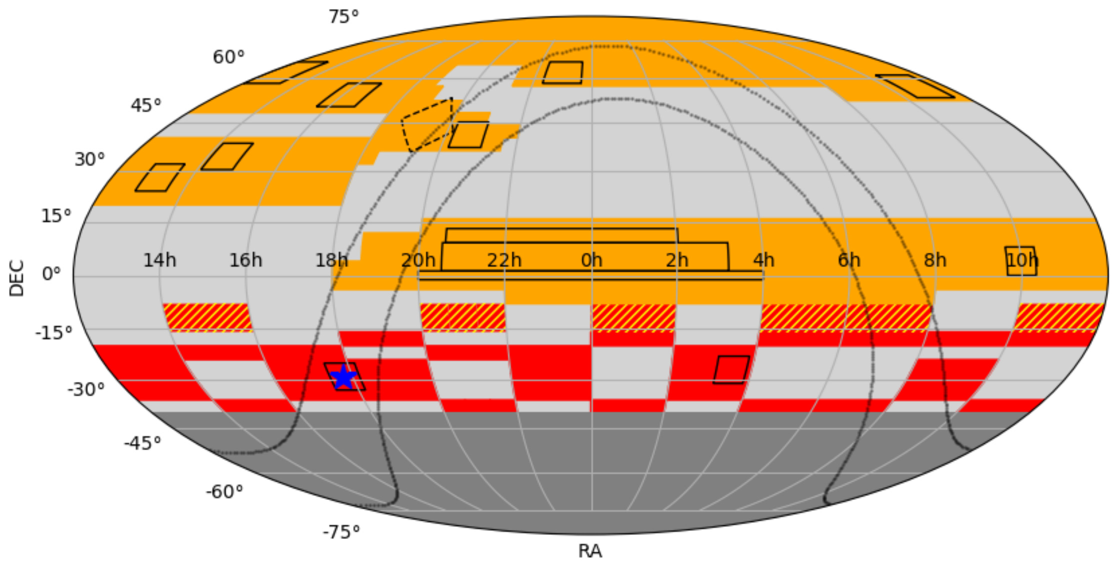

Figure 1: Sky coverage defined for the 1st-half of each VLASS observing epoch. Orange shading: regions of sky to be observed in B-configuration. Red shading: regions of sky to be observed in hybrid (BnA) configuration. Red/orange hatched shading: regions of sky that could be observed in either configuration; most of this area will be observed in the hybrid configuration. Solid black outlines show VLASS Pilot fields. The dashed-outline region indicates the Kepler field. The Galactic center is indicated by the blue star; the Galactic plane $\pm 10^{\circ}$ is indicated by the dotted curves. The dark grey below $\delta = -40^{\circ}$ is outside the VLASS coverage area. Unshaded regions will be observed in the 2nd-half of each epoch.

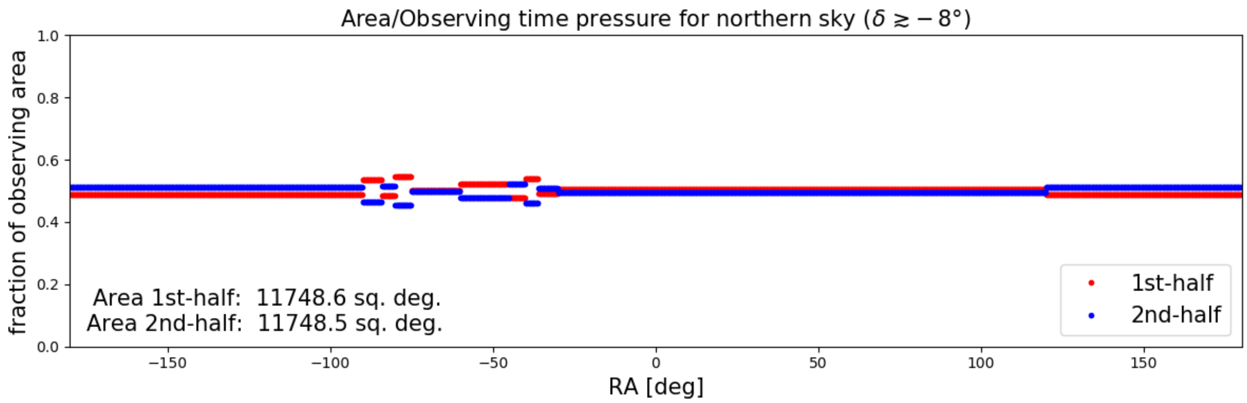

Figure 2: Area for $\delta \gtrsim -8°$, as a function of RA, to be observed in the 1st-half (red) and 2nd-half (blue) of each epoch. The constant survey speed at this declination range means that the area as a function of RA is equivalent to observing pressure. The total area for each half-epoch is indicated in the lower left of the graph. The two half-epochs will observe (almost exactly) equal area, while maintaining nearly constant (~ 0.5) observing pressure at all RA.

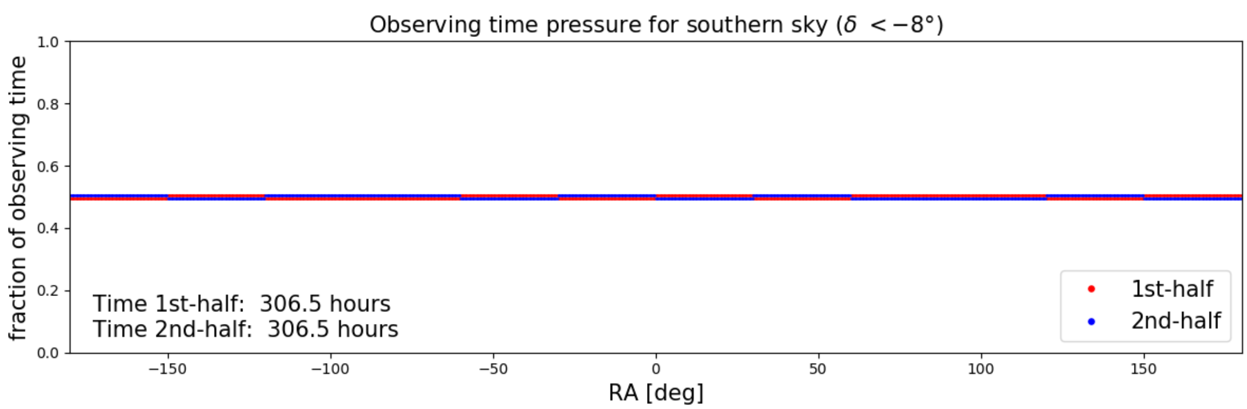

Figure 3: Observing pressure for $\delta < -8°$ as a function of RA to be observed in the 1st-half (red) and 2nd-half (blue) of each epoch. At low declinations, the variation of survey speed means that observing pressure is not the same as observed area. The total area for each half-epoch is indicated in the lower left of the graph. The two half-epochs of the northern sky will observe equal areas while maintaining nearly constant (~ 0.5) observing pressure at all RA.

Table 2: Sky to be observed in 1st-half of each VLASS epoch

Tier #	decl. range (degrees)	RA boundaries (ranges in RA decimal degrees)				
1	[−40, −36]	[−150, −120]	[−60, −30]	[0, 30]	[60, 120]	[150, 180]
2	[−36, −32]	[−180, −150]	[−120, −60]	[−30, 0]	[30, 60]	[120, 150]
3	[−32, −28]	[−180, −150]	[−120, −60]	[−30, 0]	[30, 60]	[120, 150]
4	[−28, −24]	[−180, −150]	[−120, −60]	[−30, 0]	[30, 60]	[120, 150]
5	[−24, −20]	[−180, −90]	[−60, 0]	[30, 60]		
6	[−20, −16]	[−90, −60]	[0, 30]	[60, 180]		
7	[−16, −12]	[−150, −120]	[−60, −30]	[0, 30]	[60, 120]	[150, 180]
8	[−12, −8]	[−150, −120]	[−60, −30]	[0, 30]	[60, 120]	[150, 180]
9	[−8, −4]	[−30, 120]				
10	[−4, 0]	[−90, 180]				
11	[0, 4]	[−90, 180]				
12	[4, 8]	[−80, 180]				
13	[8, 12]	[−80, 180]				
14	[12, 16]	[−60, 180]				
15	[16, 20]	(None)				
16	[20, 24]	[−180, −90]				
17	[24, 28]	[−180, −90]				
18	[28, 32]	[−180, −90]				
19	[32, 36]	[−180, −84]				
20	[36, 40]	[−180, −36]				
21	[40, 44]	[−90, −30]				
22	[44, 48]	[−90, −45]				
23	[48, 52]	[−180, −60]				
24	[52, 57]	[−180, −75]	[120, 180]			
25	[57, 61]	[−180, −80]	[−40, 180]			
26	[61, 65]	[−180, −80]	[−40, 180]			
27	[65, 69]	[−180, 180]				
28	[69, 73]	[−180, 180]				
29	[73, 77]	[−180, 180]				
30	[77, 81]	[−180, 180]				
31	[81, 85]	[−180, 180]				
32	[85, 90]	[−180, 180]				

Revision History

Revision	Date	Author(s)	Description
1.0	2016-01-31	Amy Kimball	Original
2.0	2017-06-27	Amy Kimball	Definition of epoch coverage updated to avoid Sun, Moon, Jupiter during BnA configurations