Jansky VLA Sky Surveys Performance

Steven T. Myers (NRAO)

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Performance of the VLA in survey (mosaic) mode

The estimated performance of the VLA for surveys to a snapshot image rms of 0.1 mJy (natural weighting) in various bands is given below:

Band (freq)	Mode (width)	Time(0.1mJy) s	PB FWHM	SS deg^2/hr
L (1-2 GHz)	8bit, 600MHz	36.69	30.00′	13.896
S (2-4 GHz)	8bit, 1500MHz	7.71	15.00′	16.532
C (4-8 GHz)	8bit, 1800MHz	5.54	7.50′	5.752
“	3bit, 3.03GHz*	4.42	7.50′	7.209
X (8-12 GHz)	3bit, 3.50GHz	3.87	4.50′	2.964
Ku (12-18 GHz)	3bit, 5.25GHz	3.51	3.00′	1.452
K (18-26.5 GHz)	3bit, 7.00GHz	7.09	2.05′	0.336
Ka (26.5-40 GHz)	3bit, 7.00GHz	9.75	1.45′	0.122
Q (40-50 GHz)	3bit, 7.00GHz	50.42	1.00′	0.011

Notes: * C-band 3bit performance estimated from tests in Mar 2013. Other values from the sensitivity calculator.

The final column gives the survey speed (SS) in deg^2/hour at 0.1mJy image rms, using natural weighting. We use natural weighting for sensitivity values and resolutions (given next section). For robust weighting, we estimate that the image rms is 1.2 times higher and resolution is 1.5 times better. Autumn weather at medium elevation is used in the sensitivity calculator (between summer and winter extremes). The “width” column contains the sampler mode (8bit or 3bit) and effective (RFI free) correlator bandwidth used for sensitivity calculations – the intrinsic maximum bandwidths are 2 GHz (8bit) and 8 GHz (3bit). For bands X and above we assume that 87.5% of the bandwidth is available (14 of 16 spectral windows). The “band” column gives the VLA band designations and the RFI span of those bands, the correlator bandwidth is assumed to be centered within the RF band if it is smaller.

To calculate the survey speed, we use the formula

$$SS = 0.5665 \frac{\theta_{PB}^2}{t_{int}} \ \mathrm{deg}^2\mathrm{hr}^{-1}$$

which assumes a fully-filled mosaic, with integration time t_{int} in seconds and primary beam FWHM θ_{PB} in arcminutes. See the VLA Mosaicking guide[1] for details.

Note that it is not practical to carry out surveys with the VLA at significantly higher flux density limits than 0.1 mJy/beam as the integration times per field will be too short, even at Q band. This limit is around 0.4 mJy (band dependent). At the lower frequency bands, the implied scanning rates to carry out mosaicking (e.g. using "on-the-fly" techniques) would also be too high for the VLA antenna control system to carry out in "tracking" mode..

Some Example Surveys

The choice of observing band(s), array configurations, sky coverage, and cadences of a suite of VLA synoptic sky surveys depends on the science goals driving these surveys.

For reference, the previous large/wide VLA surveys were:

- The D-configuration (resolution 45") NVSS covered ~30000 square degrees in two 42 MHz bandwidth IF channels centered around 1.4 GHz to an image rms level of around 0.45 mJy/beam in Stokes I. The source catalog completeness limit was stated as 2.5 mJy and contained around 2×10^6 discrete sources (Condon et al. 1998, AJ, 115, 1693). A total of 2932 hours was allocated to this project[2].
- The B-configuration (resolution 5") FIRST covered 10635 square degrees in two 42 MHz bandwidth IF channels centered around 1.4 GHz to around an image rms level of around 0.15 mJy/beam in Stokes I. The source catalog completeness limit was stated as 1 mJy and the 2012Feb16 version of the catalog contained around 950000 discrete sources. (Becker et al. 1995, ApJ, 450, 559; 2012yCat.8090). A total of 3200 hours was allocated to this project[2].

Below we outline some possibilities based on what we know about the performance of the expanded VLA and likely (continuum) science goals:

- A large NVSS-style 30000 square degree "all-sky" survey at 2-4 GHz. This would require around 1800 hours of integration time to reach an imaging rms of 0.1 mJy in a single epoch, or around 2700 hours duration with 50% overhead for calibration and slewing. This could be done in two configurations, e.g. A and C, which also provide two epochs spaced by about 8 months. This data would be taken using on-the-fly (OTF) mosaicking. It may be possible to scan the array fast enough to break each configuration into two further epochs (e.g. spaced by a year or more) reaching 0.15 mJy rms in each epoch. In A-configuration the resolution of a snapshot would be around 1" (at 3 GHz, natural weighting) allowing identification in optical/infrared surveys.

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[1] See https://science.nrao.edu/facilities/vla/docs/manuals/obsguide/modes/mosaicking

[2] From https://science.nrao.edu/observing/largeproposals/largeproposals

- A large FIRST-style 10000 deg^2 survey at 4-8 GHz. In around 1400 hours of integration time you could reach an imaging rms of around 0.1 mJy in a single epoch. With 50% overhead this would take 2100 hours per epoch. This could be repeated every other configuration cycle (32 months). In A-configuration the resolution of a snapshot would be around 0.5” (at 6 GHz, natural weighting). An alternative would be to do a deeper survey at S-band (it would take 2400 hours integration time to reach 0.05 mJy) or even L-band (it would take 2900 hours to reach 0.05 mJy, about half the FIRST rms limit).
- A medium-area 1000 deg^2 (e.g. Galactic cap, Galactic plane, or equatorial stripe) synoptic survey at 8-12 GHz. To reach an imaging rms of 0.1 mJy would take around 340 hours of integration. In A-configuration the snapshot resolution would be 0.3” (at 10 GHz, natural weighting), sufficient to resolve some gravitational lenses for example. B-configuration would have a resolution of 0.9”. The same survey at U band (12-18 GHz) would take 700 hours of integration, and have a resolution of 0.2” in A-configuration. This would be repeated every 16 months when the configuration recurs in the cycle, allowing identification and monitoring of long-duration transients such as tidal disruption events (TDEs). Some epochs could be repeated at a higher cadence to catch shorter duration transients. This would eventually build up a much deeper image of the static sky.
- The previously detailed 1000 deg^2 synoptic survey could, at little additional cost, include a lower-frequency L or S band contemporaneous observation. It would take only 72 hours at 1-2 GHz or 61 hours integration time at 2-4 GHz to reach 0.1 mJy.
- It is likely that by the time this survey commences, or shortly thereafter, the VLA will have a commensal low-frequency observing system (LOBO) for obtaining P band (230-470 MHz) and possibly 4 band (58-84 MHz) data in parallel with data from one of the standard (1-50 GHz) bands. In this event, a large survey would produce a contemporaneous low-band survey, which should be processed also as part of (or in parallel with) the main survey.

We have chosen a depth of 0.1 mJy for practical reasons, it gives reasonable total integration times for the various survey areas, and is comparable to the FIRST survey depth. A more detailed study based on science goals and expected source counts would refine this estimate into a final number, but one can easily scale the times required by the square of the change in depth.

This list is clearly not exhaustive, but should serve to initiate community discussion and give an idea of the types of surveys possible. Note that these have been framed in the context of continuum (synoptic) surveys – spectral surveys, such as redshifted CO galaxy surveys, are also possible. Note that the spectral resolution in continuum observing modes (1-2 MHz) may be sufficient to carry out some line studies as part of the continuum surveys outlined above (e.g. 2 MHz at 20 GHz is 30 km/s).