THE VLA ULTRADEEP FIELD

The case for an ultradeep component to the VLASS

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We propose an ultradeep component to the VLASS. Such a component will take full advantage of the VLA upgrade to image a single pointing to ~100nJy depth and subarcsecond resolution. This observation will allow us to characterize the source population at microJy levels, including number counts and size distributions crucial for planning SKA continuum surveys, especially those using radio weak lensing. Besides these fundamental measurements, we will be able to obtain a first look at SKA continuum survey science, including the evolution of magnetic fields in star-forming galaxies via polarization measurements and the far-infrared radio correlation at z>2. A worthwhile survey could be done in about 1500hr of on-field integration time.

Science case

Concept

The idea of narrow, ultradeep fields has been common to many telescopes, the most famous examples being the Hubble Ultradeep Field (HUDF) and the Chandra Deep Field South (CDFS). Typically, they involve exposures of up to 4Ms (1Ms=280hr) over areas a few square arcminutes in size, with the aim of characterizing the source population at very faint flux levels.

Such ultradeep fields have been attempted in the radio with the historical VLA, most notably the Owen & Morrison (2008) deep field in the Lockman Hole, and EVLA follow-up by Condon et al. (2012). Ongoing surveys with the EVLA include surveys to microJy depth in ELAIS-N1 by R. Taylor & collaborators, a deep survey in the HDF-N, the CHILES survey to 1.5muJy in L-band, and the Hubble Frontier fields survey (PI Murphy). However, these surveys are still typically finding rare objects in the galaxy population such as LIRGs, ULIRGs and AGN, rather than normal star-forming galaxies.

The radio source population at sub-microJy levels has yet to be characterized directly, but is likely to be dominated by normal galaxies. This requires a paradigm shift in our thinking about radio surveys as we enter the SKA era - instead of radio surveys finding radio sources, they will become galaxy surveys that happen to be carried out in the radio. The VLA provides important capabilities for characterizing the very faint radio source population to feed back into SKA plans for continuum surveys, because only the VLA can provide the combination of extreme depth and subarcsecond resolution needed to do this. In particular, the main gain of the VLA upgrade - improved continuum sensitivity at high frequency (and hence high spatial resolution) - is crucial for this observation to succeed. An ultradeep field with sub-microJy sensitivity and subarcsecond resolution was not amongst the suggestions in the original round of white papers for the VLASS, so we are proposing this to ensure that a high depth, small area survey is at least considered by the committee.

Science goals

To explore the ultradeep part of survey parameter space, we propose a single pointing to be carried out to an RMS sensitivity ~100nJy in one of the Hubble Frontier Fields or the CDFS. The science goals are:

1. **Directly measure the source counts of sources at the sub-microJy level and resolve the radio background contributed by galaxies.** We will validate the current *P(D)* analyses (Condon et

al. 2012, Vernstrom et al. 2013) for the faint radio source population, and use fluctuation analysis ourselves to search for any faint source population that might possibly constitute the mysterious background found by the ARCADE-2 experiment (Fixsen et al. 2011). Reliable counts are needed for confusion estimates for the SKA.

2. **Obtain the size distribution of the submicroJy population.** This is one of the key "known unknowns" for SKA continuum surveys, in order to find out whether there is a natural confusion limit, at which the isophotes of radio sources overlap. The source size distribution will be an essential input into SKA simulations of the faint radio sky, and for radio weak lensing.

3. **Study the far-infrared radio correlation at the highest redshifts** (in conjunction with ALMA observations). The far-infrared radio correlation is expected to break down at high redshift as the CMB energy density approaches that of the magnetic field in normal galaxies (Mao et al. 2011; Figure 1). We will be able to constrain better when this occurs, and hence constrain the magnetic field strengths in high-z galaxies.

4. **Study the polarization properties of the microJy population.** Radio emission in star forming galaxies is polarized at the few percent level, we will be able to measure this in star-forming galaxies out to z~2, again constraining the evolution of magnetic fields in galaxies.

5.**Conduct a weak lensing study of the cluster in the Frontier Field**, testing techniques that will be used in field studies by the SKA , such as using polarization to identify intrinsic alignments of foreground galaxies (Brown et al. VLASS white paper).

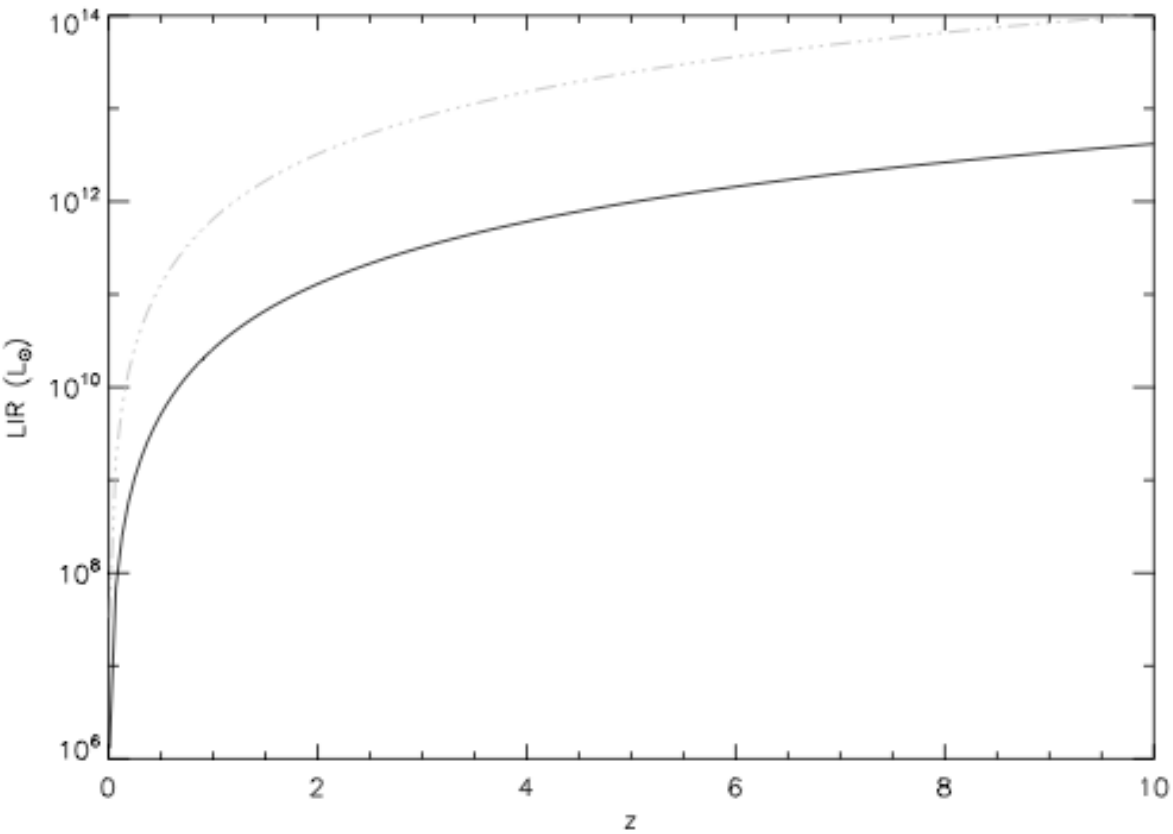

Figure 1: The solid line shows the expected 5-sigma sensitivity of our survey to star forming galaxies of a given luminosity. Our survey can detect normal star forming galaxies out to z~1, LIRGS to z~2 and ULIRGs to z~6. The dot-dashed line shows the limit for the study of Mao et al. (2011).

Choice of field

The CDFS is an obvious choice, containing both the HUDF and the Chandra 4Ms field, but would not allow us to test the weak lensing component of the science program. The Hubble Frontier Fields, which image lensing clusters, would enable a test of the weak lensing aspect (and also improve our constraints on any ARCADE-2 ultra-faint but high space density, high redshift sources, which would be highly-magnified along caustic lines). Suitable fields should be visible to ALMA (for the FIR-radio correlation work), but not be too close to the equator for beam considerations. Of the six Frontier Fields, the best fields would thus probably be one of MACSJ0416.1-2403 or MACSJ1149.5+2223 (Abell 370 is also accessible to both telescopes, but is right on the equator). Full lens models are publicly available for these fields, so the effects of lensing could easily be modeled out of the counts. All Frontiers Fields also have deep warm Spitzer data. A detailed choice of field analysis would also require examination of the local radio source environment, which we do not attempt here.

Depth and frequency

We pick ~100nJy at 6GHz as our target rms as it is an other of magnitude fainter than other surveys, existing or proposed, and corresponds roughly to a galaxy forming stars at a rate of 1 solar masses/yr at z=2 (so a 5-sigma detection would correspond to 5 solar masses/year). Only such a significant leap in sensitivity will deliver a worthwhile gain in our knowledge of the faint radio source population, and be useful for planning of SKA surveys.

The requirement of subarcsecond resolution rules out L-band for this project, but S, C or X-band are all viable. S-band provides the greatest sensitivity to steep-spectrum sources and widest field of view, but with a resolution of 1.0" naturally-weighted will only marginally resolve the high redshift galaxy population, and it also suffers from RFI issues. It would thus not be our top choice, despite its speed. C-band provides 0.5" resolution in A-array, and is well-matched to the expected source size (median 0.8") (though if we pick the CDFS or southern MACS cluster the resolution in the N-S direction will be somewhat lower). X-band in A-array has ample resolution (in fact we would probably use an A/B-hybrid configuration), but less sensitivity to steep-spectrum objects, though its sensitivity to free-free emission from very high redshift galaxies is similar to that of C-band. Field of view is not a severe concern for this survey as the HST fields are much smaller than even the X-band primary beam. A larger field of view will give more sources to estimate source counts with, but would also include more confusing bright field sources. The source density at these flux levels will be ~30-100 sources per square arcminute (based on the SKADS simulations shown in the Brown et al. white paper), compared to fields of view of 5, 8 or 16 arcmin in X,C and S-bands, giving us ample sources for source counts in all bands.

Table 1 lists the trade-offs for notional S,C and X-band surveys to a fiducial depth of 100nJy (naturally-weighted) in C-band and equivalent flux limits (assuming a source spectral index of -0.8) for S and X-bands. Based on these, we would prefer a C-band survey. The plan would be that the proposed survey would be done in 2-3 steps, with a first step allocation ~500hr - once the technical feasibility of such deep observations has been proven we would wish to go to the full 1500hr depth.

BAND	DEPTH (NANO-JY)	ASSUMED BW	TIME (HR)	RESOLUTION
S	175	1.5GHz (8-bit)	705	1.0″
C	100	3.4GHz (3-bit)	1400	0.5″
X	66	4.0 GHz (3-bit)	2200	0.3″

Does this proposal fit in to the Survey Call?

Even though, by the standards of some of the other surveys, this is a smaller time request, it would require a very large time allocation to be done as a regular, PI led proposal. Typically other telescopes such as HST, Spitzer or Chandra perform ultradeep observations either as Director's time or as part of a special large proposal call. VLA does not currently have a large proposal category, we therefore believe this experiment is best done as a tier in the survey program.

References

Condon, J.J. et al. 2012, ApJ, 758, 23

Fixsen, D.J. et al. 2011, ApJ 734, 5

Mao, M. et al. 2011, ApJ, 731, 79

Venstrom, T. et al. 2013, arXiv:1311.6451