In HI Science Assessment Workshop Summary

2013 September 25

Summary

For HI and galaxy evolution, the Baseline Design (BD) of SKA1 offers a number of potentially significant improvements over current (or soon current) radio telescopes:

- An increase in sensitivity (SKA1-Mid) over the most sensitive array. This increased sensitivity can be used for detecting fainter and/or more distant objects, for improved column density sensitivity and for higher-resolution observations of the ISM in galaxies in the nearby Universe.

- An increase in survey speed (SKA1-Survey and SKA1-Mid). This offers exciting opportunities for a variety of large-area surveys aiming at a wide range of topics ranging from HI in the Galaxy and Magellanic Clouds, the smallest HI objects in the nearby Universe and gas-rich galaxies out to look-back times of ~10 Gyr.

- The improved performance is achieved out to very high redshift

Assuming these improvements, and considering the HI work that will be done in the coming years with existing and upcoming telescopes, the HISWG identifies a number of themes for HI work with SKA1. We note that for many of these themes, the synergy with ALMA is particularly exciting. The two most important themes are:

- Galaxy evolution: perform large-area HI surveys to use HI as a tracer and a tool to study galaxy evolution. The combination of high sensitivity and high spatial resolution imply that important progress will particularly come from *resolved* studies of HI emission in and around galaxies over a broad range of masses, types and environments covering $0 < z <\sim 1$ (~8 Gyr look-back time). Statistical studies of global HI properties will be possible out to higher redshift (at least $z\sim 2$ or ~10 Gyr look-back time). The results from such large-area HI surveys will provide, over most of the life span of the Universe, essential input for multi-wavelength, multi-archive studies of galaxy evolution.

- ISM at high resolution: high-spatial resolution studies of the HI in nearby galaxies to study, in combination with data from other wavebands, the physics of the ISM and star formation down to scales where the statistical relations, such as the Kennicut-Schmidt law break down (<500 pc). This will help to develop detailed understanding of how galaxies really work and this will be important for detailed models of galaxy formation and evolution.

Other exciting science themes are:

- HI absorption studies (statistical and of individual objects) down to the highest redshifts offered by SKA1 to study the IGM (intervening absorption) as well as the role of AGN feedback in galaxy evolution (associated absorption) out to very large lookback times.

- Detailed HI studies of the physical processes at play in the Galaxy and Magellanic Clouds to parsec scale, through observations of the HI emission over all Galactic and Magellanic environments, of HI absorption against polarised background and

towards continuum sources, probing both cold and warm HI. High spectral resolution is required (~0.1 km/s, over 5 MHz) and a spatial resolution of better than 10 arcsec at 1 K sensitivity

- Low-resolution (~1 arcmin) observations of low-column density HI around nearby galaxies to study the gaseous interface between galaxies and the IGM (the Cosmic Web) as well as the physics of gas accretion. SKA1-Mid offers the first possibility to image at the right resolution (arcminute scale) column densities well below 10^{18} cm^{-2}.

- Baryonic-acoustic oscillations through Intensity Mapping

The HI Science Working Group (HISWG) sees, however, a number of issues that it wants to bring forward. We feel that, from the HI point of view, the BD is not entirely balanced and that some design aspects are such that the full potential of the improvements is not realized and that the scientific progress will not be as large as hoped for. In some areas, the improvement over existing facilities is even only modest. The main concerns are summarized here (and some are more detailed below):

- The typical column densities of HI in galaxies are always in the range 10^{19}-10^{21} cm^{-2}. At lower column densities, the gas becomes ionised, at higher column densities molecular. Therefore, *resolved* HI studies are always column density limited and improved sensitivity is mainly used for imaging at higher spatial (or spectral) resolution. From this point of view, the spatial resolution of SKA1-Mid and its sensitivity do not match. The sensitivity of SKA1-Mid is potentially significantly better than that of current instruments and this would allow imaging at correspondingly higher resolution. However, although SKA1-Mid does contain long baselines, the maximum sensitivity is realized at resolutions of ~10 arcsecond (at 1.4 GHz). This is due to the concentrated array layout. This resolution is very similar (or even worse) to that of the deepest programs on current telescopes. At higher resolutions with SKA1-Mid, there is significant loss of sensitivity due to the necessary image weighting/tapering to obtain the right resolution and beam shapes. Given the potential sensitivity of SKA1-Mid (i.e. 6x the EVLA), the optimum sensitivity should be at 3-4 arcsecond. However, at this resolution, SKA1-Mid in the current BD offers only a modest improvement in sensitivity over the EVLA. At even the higher resolutions required for HI absorption work, the performance is actually fairly similar to the EVLA. The alternative array configuration proposed by Robert Braun offers an improvement, but further work should be undertaken.

  For SKA1-Survey, the match between sensitivity and resolution is better, but improving the coverage of the outer uv plane, in order to obtain better beam shapes, should be considered.

- The definition of the frequency bands for SKA1-Mid and SKA1-Survey is not optimal for HI work since the lower edge of Band 2 lies in the middle of the redshift range for deep HI studies. This break implies that deep HI surveys that aim to study galaxy evolution and that cover a large redshift range, will have to be done twice in order to cover the entire relevant redshift range. We feel that in view of the high priority given to HI science for SKA1 in the DRM, for SKA1-Survey Band 2 should be shifted to 560-1430 MHz and Band 3 to 1400-3700 MHz while for SKA1-Mid a better choice would be to define Band 2 as 770-1430 MHz and Band 3 as 1400-2590 MHz. Lowering the bands for SKA1-Survey would also have the advantage that the phased-array feeds can be optimized for lower frequencies which would give an increased field of view.

- A high-spectral resolution mode (~0.1 km/s) should be available for SKA1-Mid and SKA1-Survey. This to accommodate resolved spectral studies of the narrow spectral lines of the Cold Neutral Medium in the Galaxy and in nearby galaxies which have velocity dispersions of the order of 1 km/s. This is needed only over limited bandwidth (10-20 MHz) and can be part of a larger, coarser sampled bandwidth (zoom mode).

- Current array filling factors in the core of SKA1-Mid, SKA1-Survey, and the high-frequency end of SKA1-low, are too low to allow interesting work on Baryonic Acoustic Oscillations using Intensity Mapping. For SKA1-Mid, a more centrally concentrated core with 50 antennas within a radius of 100 m would result in a more useful brightness sensitivity. More detailed studies of the baseline distribution by the HI and cosmology WGs are required to properly assess feasibility and requirements.

- The BD does not specify requirements for the spectral dynamic range (bandpass stability). The best spectral dynamic range of current instruments is somewhat better that 10^4. The higher sensitivity of SKA1-Mid suggests that it should have a spectral dynamic range of about 10^5 while for SKA1-Survey this is few x 10^4. We note that, except for the case of very nearby galaxies, even very deep HI observations will not be image dynamic range limited. Algorithms for continuum subtraction exist that are insensitive to imaging errors as long as these errors are frequency independent. This implies that even in the presence of very strong continuum sources that limit the dynamic range for continuum work, the image errors in the spectral line cube do not depend on these strong continuum sources, but instead are determined by the stability of the bandpass calibration. Therefore, good bandpass stability is important for spectral line work.

- The HISWG is concerned that RFI mitigation (passive or active) does not appear prominently in the current BD, although we understand that basic RFI hardware standards are an integral part of the pre-con work packages. The HISWG is further concerned about the lack of availability, accessibility and usability of basic *up-to-date* RFI data for the SKA sites. Such data are of vital importance to science teams in the planning and execution of SKA HI observations, especially for large surveys. Experience with a number of telescopes (JVLA, WSRT, Parkes, ATCA, Arecibo) appears to show high levels of satellite RFI and the expectation is that these levels will increase in the near future, in particular in the satellite navigation band 1150-1300 MHz. This RFI will have a significant impact on L band SKA1 science.

- For very high-resolution follow up work of detections of HI absorption, good VLBI capabilities, such as the African Very Long Baseline Interferometry Network as well as the Australian and East-Asia network, are essential. The availability of optical instruments for efficient spectroscopic surveys, to be used in conjunction with the HI emission surveys, is also important.

- The success of the large HI surveys (or any other SKA1 survey) will, to a large extent, depend on the availability of the data and data products through open access data portal and archive. For many (probably even most) people, such a portal will be synonymous for SKA1 because it will be the only way they will use SKA1 data. Such data archives, the pipelines used to populate them, as well as the user interfaces and visualization, should be seen as integral part of the telescope and should be considered in the BD. The data resulting from large surveys (HI and otherwise) should be public very shortly (or even immediately) after the data have been taken and validated. The Science Working Groups should be involved in discussions about such Science Policy issues.

- Much of the science with SKA1 is likely to be done by large Key Science Teams. To increase flexibility and to stimulate scientific competition, a significant fraction of the observing time should nevertheless be available for smaller projects. In particular in the early phases of SKA1, when the final data quality needed for the surveys may not yet be achieved, much time should be available for smaller projects.

- The HISWG worries about the impact of the transition from MeerKat to SKA1-Mid and ASKAP to SKA1-Survey on the planned MeerKat and ASKAP surveys. Clarity about this transition, and the possible effect on planned surveys, should be given on a short timescale.

Some More Details

A few of the issues mentioned above are discussed in some more detail here.

Assessment of the Array configuration

Since much HI work is limited by column density sensitivity, instead of point source sensitivity, to optimally exploit a radio telescope for resolved HI work, the resolution and the sensitivity should match. This is in particular true because the typical HI column densities observed do not vary very much from galaxy to galaxy. Therefore increased sensitivity should facilitate imaging at higher resolution.
The HISWG considers resolved imaging studies of galaxies at high redshift as one of the main scientific opportunities of SKA1. The current practical resolution limit for resolved HI work at z = 0 is about 5-6 arcsec (EVLA B-array for deep integrations). This is based on the highest resolution with which it is feasible to detect the typical HI column densities found in galaxies within acceptable integration times. This resolution has been used, e.g., by the very successful THINGS project and is now, e.g., also being used for the ultra-deep HI survey CHILES. A rough argument is that if a telescope is a factor *x* more sensitive, the spatial resolution should be sqrt(*x*) better because then, in the same integration time, the same column density can be detected with the same S/N (at higher resolution). For SKA1-Mid this would imply that it should work at a resolution of 3 arcsec (for z = 0) and for SKA1-Survey this resolution is ~ 5 arcsec. Such a resolution for SKA1-Mid would make it possible to significantly improve on the THINGS studies of nearby galaxies, on the anticipated results from the Monghoose survey at MeerKat and would provide the right resolution for resolved observations of HI in high-redshift galaxies.

A more detailed analysis can be made by observing that, at z = 0, the average column density of the HI disks of galaxies is independent of galaxy size and mass. This follows from the fact that, over a large range of HI mass, the total HI mass scales as the square of the HI diameter. This means that if one knows the HI mass of a galaxy, one can predict the size of the HI disk. This, in turn, can be used for a given detection limit of HI, to compute the optimum resolution to detect that HI. Most progress for our understanding of HI and galaxy evolution will come from *resolved* HI studies over a range of HI masses extending below M* of the HI mass function. Only resolved observations will give information about important processes like accretion, stripping and interactions and will allow kinematical studies.

The HISWG has looked into this in detail. A rough summary of this study is that the sensitivities of SKA1-Mid and SKA1-Survey are such that one can detect, after long integrations, an M* galaxy out to z ~ 1 with SKA1-Mid and z ~ 0.6 with SKA1-Survey. The physical size of the HI disk of an M* galaxy is about 50 kpc. To be able to just resolve this, one needs a resolution of about 6 arcsec at z ~ 1 and about 8 arcsec at z = 0.6. This translates into a resolution at 1.4 GHz of 3 arcsec for SKA1-Mid and 5 arcsec for SKA1-Survey. It is, by the way, no accident these figures are very similar as the rough estimates given above, because both are based on the argument to detect the typical column densities found in galaxies at the highest resolution.

For nearby galaxies, the relative sensitivity of SKA1-Mid vs the EVLA means that detecting column densities of 10^{20} cm^{-2} at a resolution of about 2 arcsec in the ISM of nearby galaxies is possible. This will make it possible to study the ISM (structure *and* kinematics) at scales down to 100 pc in galaxies out to 10 Mpc. This would be a significant improvement on THINGS and similar studies (500-700 pc) and would allow to study the regime where statistical relations such, e.g, the Kennicutt-Schmidt law, break down. Such high-resolution work would also be a very interesting complement to studies of the molecular gas in nearby galaxies done with ALMA, which will have similar or better resolution.

An additional requirement is that these resolutions should be obtained with (more or less) Gaussian dirty beams *and* with image weighting that is not close to natural. Image weighting not close to natural are needed in order to obtain image noise characteristics that favour detection of faint, extended sources.

For HI absorption studies, in particular of the interaction of AGN with the surrounding HI, one requires very high spatial resolution in order to be able to locate where the HI absorption occurs in relation to the AGN. The current limit (apart from VLBI) on this is the EVLA A-array with resolution of ~1 arcsec. Given the higher sensitivity of SKA1-Mid, this implies resolutions below 1 arcsec with for this improved sensitivity.

Several members of the HISWG have done extensive simulations of beampatterns and noise levels as function of weighting and tapering and we have obtained a good picture of the performance of SKA1 for HI. Figure 1 (from R. Braun, in prep.) summarises the results.

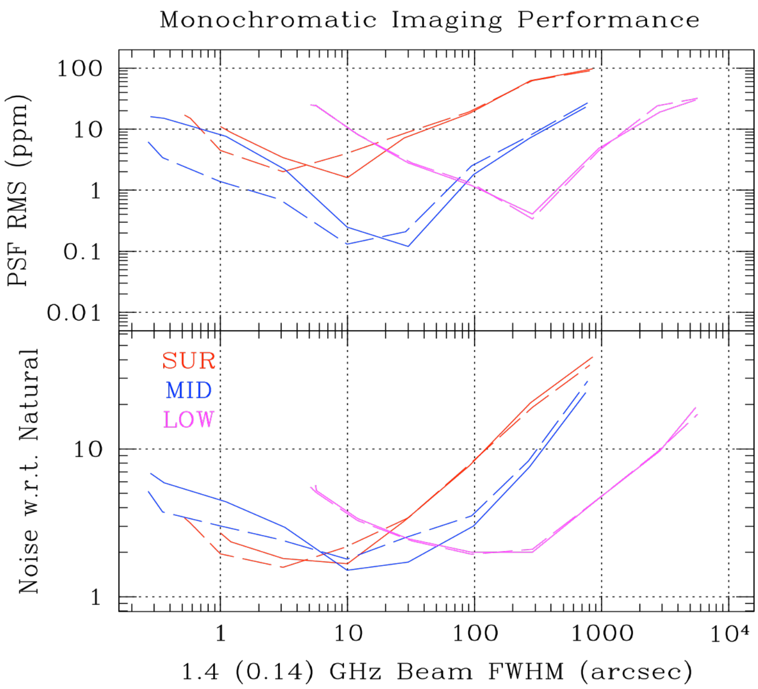

Figure 1. Monochromatic image noise and PSF quality performance of the SKA1 configurations as function of angular scale. The drawn lines are for the array configurations as in the BD. The dashed lines are for slightly modified configurations as discussed by Braun (2013)

Figure 1 shows that the optimum sensitivity for SKA1-Mid is obtained for a resolution of about 10 arcsec. For resolutions around 3-4 arcsec, there is a loss of sensitivity, due to image weighting, of a factor 2 w.r.t. maximum sensitivity and the loss compared to full (potential) sensitivity of SKA1-Mid is about a factor 3. Because of the very different

character of the array configuration of SKA1-MID compared to the EVLA, noise levels for SKA1-Mid are more sensitive to weighting. This means that SKA1-Mid will only be at most a factor 3 more sensitive than the EVLA at resolutions around 3-4 arcsec. As a result, we will not exploit the full potential of SKA1-Mid for high-resolution HI work.
At higher resolutions (<1 arcsec), necessary for HI absorption studies, the loss in sensitivity is even worse and the sensitivity of SKA1-Mid at these resolutions is comparable to that of the EVLA.

The top panel of Figure 1 shows that the cleanliness of the dirty beams is best for resolutions above 10 arcsec and degrades quickly for higher resolutions. This indicates that high-quality imaging at high resolution, i.e. reliable detection of faint extended HI emission near brighter HI, will be difficult with SKA1-Mid.

Indicated in Figure 1 is also indicated the performance of an alternative array configuration considered by Robert Braun. This array performs somewhat better. The HISWG is aware that other applications of SKA1 (e.g. pulsars and transients) have desires for the array configurations that are conflicting with those of the HISWG, but we do recommend further work on alternatives to investigate whether more improvement can be made for the HI science case without large impact for other science cases.

Another issue with the array configuration of SKA1-Mid is that acceptable beam shapes can only be obtained for weighting schemes that are close to uniform (robustness < -1). For weighting schemes with robustness > -1, large, low level wings are resent in the dirty beam, which makes high fidelity imaging more difficult. The lack of room to use robustness as an instrument to tune the images to the objects to be detected is a distinct disadvantage of the array configuration.

For SKA1-Survey, the optimum sensitivity seems to be obtained for resolutions of 5-10 arcsec and this array seems to have a better match between sensitivity and resolution. It appears to be well suited for large-area HI surveys out to intermediate redshift. However, acceptable beams shapes (i.e. close to Gaussian and absence of large, low-level wings) are only obtained when tapering the images to lower resolution and as a result the relatively high resolutions suggested possible by Figure 1 cannot be used for imaging. The alternative array configuration, which has better uv coverage at larger radii, appears to perform better, but more work on possible improvements should be done.

A final, general, remark is that many of the well-known survey fields observed in other wave bands are located at or near the celestial equator. Improving the imaging performance of both SKA1-Mid and SKA1-Survey near the equator should be investigated.

Band definition

Given its goal of continuous frequency coverage across a wide range, the SKA has the flexibility to define band boundaries according to scientific priorities. The current baseline design effectively prioritizes continuous redshift coverage for OH lines, by virtue of setting the upper edge of Band 2 for the SKA1-survey PAFs to 1670 MHz and for the SKA1-mid SPFs to 1760 MHz. We suggest that in view of the high priority given to HI science over OH science for SKA1 in the DRM, it would be more appropriate to optimise redshift coverage for HI. This can be done by shifting the upper edge of Band 2 to 1430 MHz. This statement applies equally to SKA1-survey and SKA1-mid. We do not favor pushing the upper edge of Band 2 *below* the HI rest frequency, since if HI at $z = 0$ is only accessible at the lower edge of Band 3, the SKA would lose the ability to do a miniature blind redshift survey every time it does a deep observation of a nearby galaxy.

For the SKA1-survey PAFs, the current baseline design defines Band 1 as 350-900 MHz (2.57:1), Band 2 as 650-1670 MHz (2.57:1), and Band 3 as 1500-4000 MHz (2.67:1). Preserving the existing band ratios, we recommend that Band 2 be shifted to roughly **560-1430 MHz** (2.55:1) and Band 3 to roughly **1400-3700 MHz** (2.64:1). The redefined Band 3 would include both HI and OH at z = 0, potentially convenient for Galactic surveys. The redefined Band 2 would *exclude* RFI from GNSS (1559-1610 MHz) and Iridium (1616-1660 MHz). The overlap of Bands 1 and 2 would define redshift shells 0.58 < z_{HI} < 1.54 and (for the main lines) 0.85 < z_{OH} < 1.98 that, usefully, would be observed 100% of the time for fields surveyed in both bands. If deployment of the Band 3 PAF is delayed, SKA1-survey would initially be unable to observe the OH main lines at z_{OH} < 0.16; however, with Arecibo having already polished off much of the most appealing z_{OH} < 0.2 science and Galactic applications not obviously demanding SKA1 sensitivity, this possible sacrifice appears scientifically tolerable.

Lowering the bands for SKA1-Survey would also have the advantage that the phased-array feeds can be optimized for lower frequencies which would give an increased field of view and hence an improved survey speed.

For the SKA1-mid SPFs, the current baseline design defines Band 1 as 350-1050 MHz (3:1), Band 2 as 950-1760 MHz (1.85:1), Band 3 as 1650-3050 MHz (1.85:1), Band 4 as 2800-5180 MHz (1.85:1), and Band 5 as 4.6-13.8 GHz (3:1). Preserving the existing band ratios, we recommend that Band 2 be shifted to roughly **770-1430 MHz** (1.86:1), Band 3 to roughly **1400-2590 MHz** (1.85:1), and Band 4 to roughly **2540-4700** MHz (1.85:1). The redefined Band 3 would include both HI and OH at z = 0, potentially convenient for Galactic surveys. The redefined Band 2 might become a more appealing option for pulsar searches in the Galactic plane; it also excludes RFI from GNSS and Iridium, although it adds the remainder (935-950 MHz) of the GSM-900 band to the portion (950-960 MHz) that overlaps with the current version of Band 2. If Band 1 remains at 350-1050 MHz as in the current baseline plan, the overlap between Bands 1 and 2 would define redshift shells 0.35 < z_{HI} < 0.84 and (for the main lines) 0.59 < z_{OH} < 1.16 that would be observed 100% of the time for fields surveyed in both bands. This HI redshift range spans 3.1 Gyr of cosmic time, encompasses 3.6 x 10^6 Mpc^3 comoving volume per SKA1-mid pointing, and offers excellent prospects for unique, spatially resolved science at depths that only SKA1 can reach. It is possible to envision at least two HI survey strategies focused on galaxy evolution that would take advantage of this overlap. First, a “bake your own wedding cake” approach would entail a Band 2 wide/shallow map, within which Band 1 is used to map narrower/deeper patches; large and overlapping volumes would help defeat cosmic variance at all redshifts. Second, a “go to town on a single pointing” approach would use Band 2 to focus on resolved science at z_{HI} < 0.35, while integrating long enough in Band 1 to extend resolved science to the range 0.35 < z_{HI} < 0.84 – thus also enabling unresolved science in the 0.84 < z_{HI} < 3.06 range.

An intriguing alternative is the redefinition of the SKA1-mid Band 1 as roughly 430-800 MHz (1.86:1), which would trade redshift overlap for improved performance at the highest redshifts and allow access to (still respectable) maximum z_{HI} = 2.30 and z_{OH} = 2.87. We note that in either case, it would be helpful for the successful long-term integration of the MeerKAT antennas into the SKA if they were equipped with Band 1/2 (L/UHF) receivers matching those that are eventually adopted for SKA1-mid.

Frequency resolution

For both the nearby galaxies and the Galactic HI cases, a higher velocity resolution over a limited bandwidth is essential. As profiles of the Cold Neutral Medium are known to have velocity dispersions <~ 1 km/s, a velocity resolution of ~0.1 km/s (0.5 kHz) is needed. This is only required over limited bandwidth (10-20 MHz corresponding to ~2000-4000 km/s at z=0) because detailed studies of the CNM are, due to beam smearing effects, only feasible at very low redshift.

The higher velocity resolution could be implemented as a "zoom mode" so that in addition to the high-velocity resolution part of the band, a larger bandwidth at lower spectral resolution can be observed, serving as a "blind" commensal survey of HI at higher redshifts.

VLBI & other facilities:

The possibility to do VLBI follow up on detections of HI absorption is important. Any effort improving the VLBI capabilities in with the African Network as well as Australian and East Asia VLBI network should be supported.

For all surveys foreseen of the higher redshift universe, it became clear in recent years that much more optical follow-up facilities will be necessary to complement the radio data. New dedicated 4m-class highly multiplexed (few thousands fibers) spectroscopic telescopes need to become available in the coming decade. This was clearly identified last November at a meeting of the MeerKAT surveys' scientists. While certain facilities already exist in the South (e.g. AAOmega), this is clearly not sufficient to gather all the necessary optical spectroscopic follow-ups of the large radio samples that will be assembled, first by the pathfinders, and later by the SKA1 instruments.

RFI

1. RFI is an important issue for redshifted HI observations and other wideband SKA observations. For example, current telescopes are severely limited in their capability to detect galaxies at redshifts around 0.2 due to emissions from the L2 and L5 beacons of the Global Positional System (GPS). The situation appears to be worsening as existing positioning systems (GLONASS) are being enhanced and new systems (COMPASS, GALILEO, IRNSS) are being launched. In addition, there is the ever-present threat, even in the SKA radio-quiet zones, of terrestrial emissions such as GSM and digital TV.

2. The WG is concerned that RFI mitigation (passive or active) does not appear prominently in the current baseline design, although we understand that basic RFI standards are an integral part of the pre-con work packages.

3. Methods for the passive (e.g. flagging) and active (adaptive nulling) mitigation of RFI need to be pursued by the SKA design team. Some of these methods are well established, or only require limited optimisation, and should be implemented in the SDP or CDP. Some methods may be more in the research phase and members of the HISWG may be in a position to promote further studies. However, the SKA design needs to include "spigots" where such active mitigation devices or algorithms can be later added.

4. The WG is further concerned about the availability, accessibility and usability of up-to-date basic RFI data for the SKA sites. Such data are of vital importance to science teams

in the planning and execution of SKA HI observations, especially for large surveys, and HISWG members have been put in a difficult situation by not having access to these data. We would like to insist that all existing SKA and regional site data now be made publicly available in a suitably digestible form for the use of the HISWG and potential SKA science teams.

Intensity mapping

HI Intensity Mapping for large-scale structure studies ideally maps a large three-dimensional cosmic volume (> Gpc^3) with a resolution on linear/quasi-linear scales (~5-10 comoving Mpc/h). A large survey area (>1000 deg^2) over a range of redshifts, with low spatial (5 arcmin) and low spectral resolution (0.1 MHz) is desirable. IM maps the HI brightness temperature fluctuations in this 3D volume and requires high surface brightness sensitivity on short baselines. A compact antenna configuration with 50-400m radius (depending on redshift) is thus necessary to carry out such a survey efficiently. For example, a baseline of 200m resolves 10 Mpc/h comoving linear scales at z=1.7 (f=526MHz). Current array filling factors in the core of SKA1-Mid, SKA1-SUR, and the high-frequency end of SKA1-low are too low to meet this requirement. However, for SKA1-Mid, a more centrally concentrated core with 50 antennas within a radius of 100 m would result in a more useful brightness sensitivity. However, more detailed studies of the baseline distribution by the HI and cosmology WGs are required to properly assess feasibility and requirements.

Science requirements

The HI requirements for SKA1 can be summarized as that SKA1 should offer significant improvements over what is possible with current (or near-future) instruments. In concreto, this means:

For SKA1-Mid, the two main topics are the role of HI in galaxy evolution, and the very detailed studies of the ISM of nearby galaxies to match ALMA work. For galaxy evolution, SKA1-Mid should offer a significant improvement over the EVLA in terms of sensitivity and resolution. In practice this means it should be able to detect a galaxy with 10^{10} Msol of HI at z = 1 in 1000 hr and to be able to image at this redshift with a spatial resolution of about 6 arcsec = 50 kpc (i.e. 3 arcsec at z = 0).

For nearby galaxies, the SKA1-Mid requirement is to be able to detect an HI column density of 10^{20} cm^{-2} (width 20 km/s) at significantly higher resolution than the current EVLA. The velocity resolution should be ~ 0.1 km/s over limited bandwidth (10-20 MHz). For Galactic work, also high spectral resolution is required (~0.1 km/s, over 5 MHz) and a spatial resolution of better than 10 arcsec at 1 K sensitivity.

For SKA1-Survey, the main science theme will be to do large-area HI surveys at intermediate and at high redshift, and HI work in the Galaxy and the Magellanic Clouds. The sensitivity requirement for high-redshift work is to detect a 10^{10} Msol galaxy at z = 0.6 with a spatial resolution of 8 arcsec (5 arcsec at z = 0) after 1000 hrs of integration. This sensitivity is also required for large-area, shallower surveys aimed at lower redshift (at lower spatial resolution)

For HI absorption, the SKA1-Mid sensitivity should at least be equal to that of the EVLA, provided that it can be delivered at higher spatial resolution than the EVLA A-array (i.e. < 0.5 arcsec).

Reference Surveys

The HISWG has identified the following surveys that can serve as a guide and reference for HI work with SKA1:

SKA1-MID

- An ultra-deep single-pointing observation with a total integration time of 1000 hr for resolved studies of high-redshift galaxies and galaxy groups. Such a survey would directly detect an M_{HI*} galaxy out to z = 1. The bright parts of the HI in galaxies can be imaged with a spatial resolution of ~50 kpc at the highest redshifts.

- High-resolution imaging of a sample of nearby galaxies for detailed studies of the ISM in galaxies on scales < 500 pc. Integrating 200-300 hr per galaxy would allow to detect column densities around 10^{20} cm^{-2} at the required spatial resolution. Such observations can also be used to detect very low column density HI (<10^{18} cm^{-2}) in the immediate environment of the target galaxies at low resolution (~1 arcmin)

- Targeted and serendipitous HI absorption surveys out to the highest redshifts offered by SKA1-MID to study the role of AGN feedback and the IGM out to very large lookback times. An observation of 1 hr should detect HI absorption over 20 km/s with an optical depth of 0.01 in a source of 10 mJy, independent of redshift.

SKA1-Survey

- A very large-area HI survey (30,000 deg^2). A two-year survey would directly detect an M_{HI*} galaxy out to z = 0.2 and column densities around 10^{20} cm^{-2} can be imaged at resolution of ~15 arcsec. Such a survey would be the definitive census of the HI in galaxies of the local Universe.

- A Medium-deep survey covering 300 deg^2. A two-year survey would directly detect an M_{HI*} galaxy out to z = 0.65 and column densities around 10^{20} cm^{-2} can be imaged at resolution of ~5-10 arcsec, depending on redshift. Such a survey would bridge the gap between the very large-area survey of the previous bullet and the ultra-deep, high-redshift survey of SKA1-MID.

- A survey intermediate between the very large-area and the medium-deep survey covering 3000 deg^2. A two-year survey would directly detect an M_{HI*} galaxy out to z = 0.36 and column densities around 10^{20} cm^{-2} can be imaged at resolution of ~7-10 arcsec, depending on redshift. Such a survey would also make a deep inventory of the faintest HI objects in the nearby Universe (a galaxy with 10^5 Msol can be detected out to 10 Mpc)

The above mentioned surveys can be used for statistical studies (stacking) out to very high redshift, and for serendipitous surveys of, e.g., HI absorption.