# 4 Science

## 4.1 Early Universe, Cosmology and Large Scale Structure

### 4.1.7 BAO with Intensity Mapping [R. Ansari, S. Torchinsky, M. Bucher, C. Magneville]

The statistical properties of the matter distribution in the Universe encodes invaluable information about the cosmological parameters, such as the mean cosmic matter and energy densities, the physics underpinning the Standard Cosmological Model, especially General Relativity, Modified Gravity, and Dark Energy. Most of this information can be extracted from the large-scale statistical properties of the matter distribution on comoving length scales of 10 Mpc and above, corresponding to apparent angular scales larger than a few arc minutes. The cosmological matter distribution, dominated by dark matter, can be probed through tracers such as galaxies, which are often detected and observed through their optical emission, their position being determined by imaging and their redshifts by spectroscopy.

Since the first astronomical observation of 21 cm emission by Ewen and Purcell (1951) following the suggestion by van de Hulst (1945), galaxies are known to harbour neutral hydrogen (H I) that is destined eventually to form stars. Galaxies can thus be detected and observed in radio through the 21 cm line emission of this neutral atomic hydrogen. Moreover, the redshifted 21 cm feature pinpoints directly the galaxy positions in redshift space. In contrast, optical surveys cannot obtain accurate redshifts easily. Optical surveys rely on photometric redshifts which are not very accurate and are prone to error due to misidentification of the object type for distant objects. Alternatively, more accurate redshifts can be obtained through costly spectroscopic follow-up on a subset of the catalogue.

The SKA H I line survey provides a method similar to optical surveys to map matter distribution through compact H I cloud detection in radio, through the 21 cm hydrogen hyperfine transition. This method has the advantage of determining the source redshift $z$ by a direct comparison of the observed radio frequency with the intrinsic emission frequency of 1420 MHz (Abdalla & Rawlings, 2004). The expected number of such accurate redshift measurements in the SKA survey exceeds that from planned optical and infrared surveys by at least an order of magnitude (Abdalla & Rawlings, 2004). Yet these two approaches are complementary. Having both will help to clarify a number of astrophysical questions, such as the relationship between the luminous stellar populations and the gas from which they form, and the star formation history.

A large galaxy survey such as expected from the SKA H I line survey will provide precision measurements of the statistical properties of Large Scale Structure (LSS) and the corresponding power spectrum $P(k)$. In particular, it is possible to extract the precise measurement of the angular diameter subtended by the $\sim$ 110 Mpc/h baryon acoustic oscillation (BAO) feature as a function of redshift. This feature, a remnant of the tight coupling between photons and baryons in the early Universe, is imprinted on the galaxy distribution during the epoch of decoupling of photons and baryons at $z \sim 1100$. It is one of the most robust cosmological probes used to constrain Dark Energy properties. On intermediate angular scales ($\lesssim \deg$) the survey will resolve the cosmic web (filaments, walls, and the voids they enclose), which is emerging as a rich target for defining cosmological observables.

By using the BAO signature alone to map the expansion history of the Universe during the acceleration epoch, one can establish the onset and shape of dark energy domination (Blake & Glazebrook, 2003, Seo & Eisenstein, 2003). Using the H I galaxy survey and BAO, SKA-1 will be able to measure the expansion rate $H(z)$ and the angular diameter distance $D_A(z)$ with a relative precision of $1-2\%$ for redshifts up to $z \lesssim 0.5$. The relative precision on $H(z), D_A(z)$ measurements will reach $0.2-0.5\%$ over the redshift range $0.5 \lesssim z \lesssim 1.5$ with the second phase of SKA (Yahya et al. 2015). This is a conservative estimate since it uses only the information from this one scale. Analysing the entire correlation function and modeling the way galaxies trace the underlying matter distribution would further reduce the expected error bar on the Dark Energy equation of state parameters.

However, the relatively low radio brightness of these H I clumps has limited their detection to the cosmological neighbourhood of our galaxy with current instruments. SKA will significantly extend the detection redshift range thanks to its enormous collecting area combined with its large field of view. Despite the huge increase in sensitivity brought by SKA, the detection of H I galaxies at higher redshifts (i.e., $z \sim 1$ and beyond) will remain a challenge, and only the brightest H I galaxies would be detected by SKA at $z \sim 1$.

A technique to further enhance the cosmological signal is to image directly the 3D structure of the cosmic H I distribution by mapping the integrated 21 cm brightness. An early suggestion of this method (Hogan & Rees, 1979) and the idea to use 21 cm line observations for the determination of cosmological parameters (Scott & Rees, 1990) was later proposed as a radio astronomy technique called Intensity Mapping (Battye et al., 2004, Peterson et al., 2006) and further developed for radio interferometers (Ansari et al. 2008, Ansari et al. 2012). The Intensity Mapping technique eliminates the intermediate step of constructing a galaxy catalog since all photons are used without selecting only those that come from objects detected with high significance. By eliminating the necessity to reach detection thresholds for individual galaxies, the Intensity Mapping approach will allow using early stages of SKA to measure cosmological parameters before completion of the 'full instrument' (SKA-2). A number of instruments are currently in development (see Bull et al., 2015 for a comparison), and in particular the TIANLAI project (Chen et al., 2012), as well as HIRAX (Newburgh et al., 2016), has significant input from France. The proposed project called MANTIS (Cappellen et al., 2016) would be an early version of the SKA Mid Frequency Aperture Array, and ideally suited for Intensity Mapping. Using the Intensity Mapping technique, SKA-1 should be able to measure the Dark Energy equation of state parameters $w_0$ and $w_a$ with $5 - 10\%$ precision, close to the expected precision from Euclid (Santos et al. 2015).

Intensity mapping provides the most economical way to map huge cosmic volumes in three dimensions. The total H I emission from 3D cosmic volume cells of $\sim 5 - 10\ \mathrm{Mpc}^3$, arising from the combined emission of hundreds of galaxies and H I clouds, would be large enough to be detected by an instrument with a collecting area of a few 10 000 m$^2$ within a few hours integration time. Intensity Mapping up to redshifts $z \sim 2 - 3$ will thus require an instrument with a wide field of view on the order of tens of square degrees, a collecting area of $\sim 10000\mathrm{m}^2$ and high sensitivity, but with a modest angular resolution ($\sim 5 - 10$ arc min).

SKA aperture arrays will be well suited to perform Intensity Mapping surveys, covering a wide redshift range, up to $z \sim 3$. The SKA Intensity Mapping surveys will be used for competitive cosmological studies, including, but not limited to, precise determination of the BAO scale.

References:

Abdalla & Rawlings, 2004, NewAR, 48,

Ansari, et al., 2008, arXiv:0807.3614

Ansari, et al., 2012, A&A, 540 , 129

Battye, et al., 2004, MNRAS, 355, 1339

Blake & Glazebrook, 2003, ApJ, 594, 665

Bull et al., 2015, ApJ, 803, 21 (33pp)

Cappellen et al., 2016, arXiv:1612.07917

Chen, et al., 2012, Int. J. Modern Physics Conference Series, 12, 256

Ewen & Purcell, 1951, Nature, 168, 356

Hogan & Rees, 1979, MNRAS, 188, 791

Newburgh et al., 2016, Proc.SPIE Int.Soc.Opt.Eng. 9906, 99065X

Peterson, et al., 2006, arXiv:0606104

Santos et al., 2015, arXiv:1501.03989

Scott & Rees, 1990, MNRAS, 247, 510

Seo & Eisenstein, 2003, ApJ, 598, 720

van de Hulst, 1945, Nederl. Tij. Naturkuunde, 11, 201

Yahya et al., 2015, MNRAS, 450, 2251