Lensing studies using 21cm radiation from the EoR

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1. Results

It is possible that the EoR signal could be used to measure weak gravitational lensing. In [1] and [2] it was shown that if the EoR is at redshift $z \sim 8$ or later, a large radio telescope such as the SKA could measure the lensing convergence power spectrum. However a very large f_{sky} and a very compact low frequency array was assumed by those authors. Here the calculation is repeated with parameters that are more consistent with current SKA plans. The current plans for a 25 square degree survey with SKA_Low will preclude measuring cosmological parameters through their effects on the weak lensing power-spectrum because of large sample variance. (This is not true of the SKA_Mid at lower redshift where the survey area will be much larger. See section *** for more details.) It still might be possible to map the lensing convergence within the 25 square degree EoR survey area. This would allow us to actually "see" the distribution of dark matter in a typical region of the sky, something that is only possible with galaxy lensing around very atypical, large galaxy clusters.

The previously mentioned authors extended the Fourier-space quadratic estimator technique, which was first developed in [3] for CMB lensing observations to three dimensional observables, i.e. the 21 cm intensity field $I(\theta, z)$. The convergence estimator and the corresponding lensing reconstruction noise are calculated assuming that the temperature (brightness) distribution is Gaussian. This will not be strictly true during the EoR, but serves as a reasonable approximation for these purposes. Note that the lensing reconstructions noise contains the thermal noise of the telescope which is calculated using the formula

$$C_\ell^N = \frac{(2\pi)^3 T_{sys}^2}{\Delta \nu t_{obs} f_{cover}^2 \ell_{max}(\nu)^2} \, ,$$

(1.1)

where the system temperature T_{sys} at high redshifts is dominated by galactic synchrotron radiation, $\Delta \nu$ is the chosen frequency window, t_{obs} the total observation time, D_{tel} the diameter (maximum baseline) of the core array and $\ell_{max}(\lambda) = 2\pi D_{tel}/\lambda$ is the highest multipole that can be measured by the array at frequency ν (wavelength λ). f_{cover} is the total collecting area of the core array A_{coll} divided by $\pi(D_{tel}/2)^2$. For SKA_Low we can consider a $1,000$ hr observation time and we choose $\Delta \nu = 10\,\text{MHz}$, but with multiple bands that can be stacked to reduce the noise.

We assuming the SKA1 Baseline Design [4] parameters of $A_{coll} \simeq 0.4\,\text{km}^2$ with maximum baseline $D_{tel} = 6\,\text{km}$ and a more compact configuration of $A_{coll} = 0.75\,\text{km}^2$, $D_{tel} = 2\,\text{km}$. The estimated lensing noise is shown in Figure 1 along with the estimated signal. Here C_L is the displacement field power spectrum and N_L the lensing reconstruction noise assuming a reionization fraction $f_{HI} = 1$ at the source redshift $z_s = 8$.

These results show that it might be possible to map the lensing signal over a range of angular scales. This measurement would greatly benefit from a more compact array and/or the large collecting area that will come with Phase 2. The weak lensing power spectrum can be better measured for redshifts after reionization using SKAMid and the same 21 cm intensity mapping technique discussed, but over a much larger area of sky [5].

References
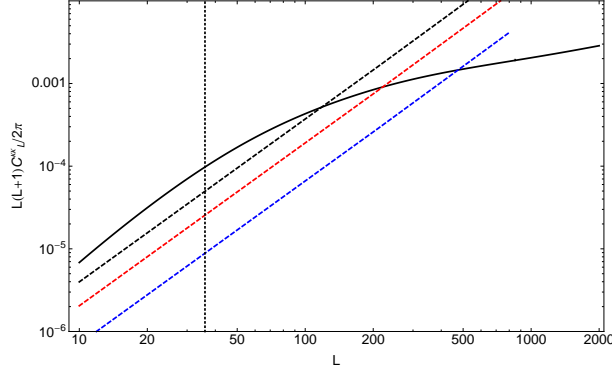
[1] Zahn, O., & Zaldarriaga, M., 2006, ApJ, 653, 922

Figure 1: The lensing displacement field power spectrum, C_L, for sources at $z = 8$ is shown as a solid black line and lensing reconstruction noise N_L as dashed lines. The black dashed curve is for the Baseline Design with 20 5 MHz frequency bins around $z = 8$ spanning the redshift range $z = 6 - 12$. The blue line is for the more compact array ($D_{\text{tel}} = 2\,\text{km}$) and the same frequency bins. The red line is the same as the blue but with 10 5 MHz frequency bins instead of 20, spanning the redshift range $z = 7 - 10$. The vertical line is approximately the lowest L accessible with a 5-by-5 degree field. Where the noise curves are below C_L typical fluctuations in the lensing deflection should be recoverable in a map.

[2] Metcalf, R. B., & White, S. D. M., 2009, MNRAS, 394, 704

[3] Hu, W., 2001, ApJ, 557, L79

[4] Dewdney, P. (2013), SKA1 System Baseline Design, SKA Project Documents, (pp. 1-98)

[5] Pourtsidou, A. & Metcalf, R. B., 2014, MNRAS, 439, L36-L40