Synergies between SKA and LSST surveys

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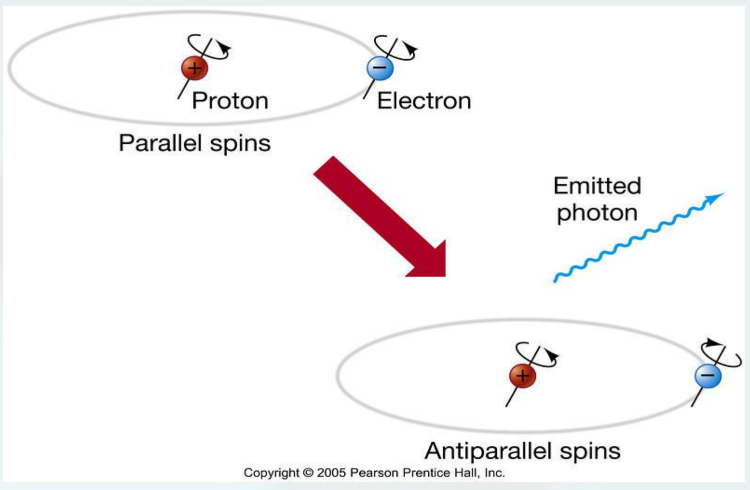
Abstract

Next-generation radio surveys from the Square Kilometre Array (SKA) mid-frequency telescope and its precursors will observe the universe with high spectral precision. The 21-cm neutral hydrogen (HI) emission line detected from these surveys is ideal for obtaining more accurate constraints on cosmological parameters. However, the HI line is intrinsically faint and difficult to detect at high redshift. For this work, we present a Bayesian framework, using a Markov Chain Monte Carlo (MCMC) sampling technique, to find the best-fitting HI line profile and extract precise redshift information. We propose an update of the Harrison, Lochner and Brown (2017) method by incorporating photometric redshift and spatial information from optical surveys such as the Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST).

1. Introduction

- The 21-cm HI line results from a spontaneous spin flip transition in neutral hydrogen.



- HI is intrinsically faint.

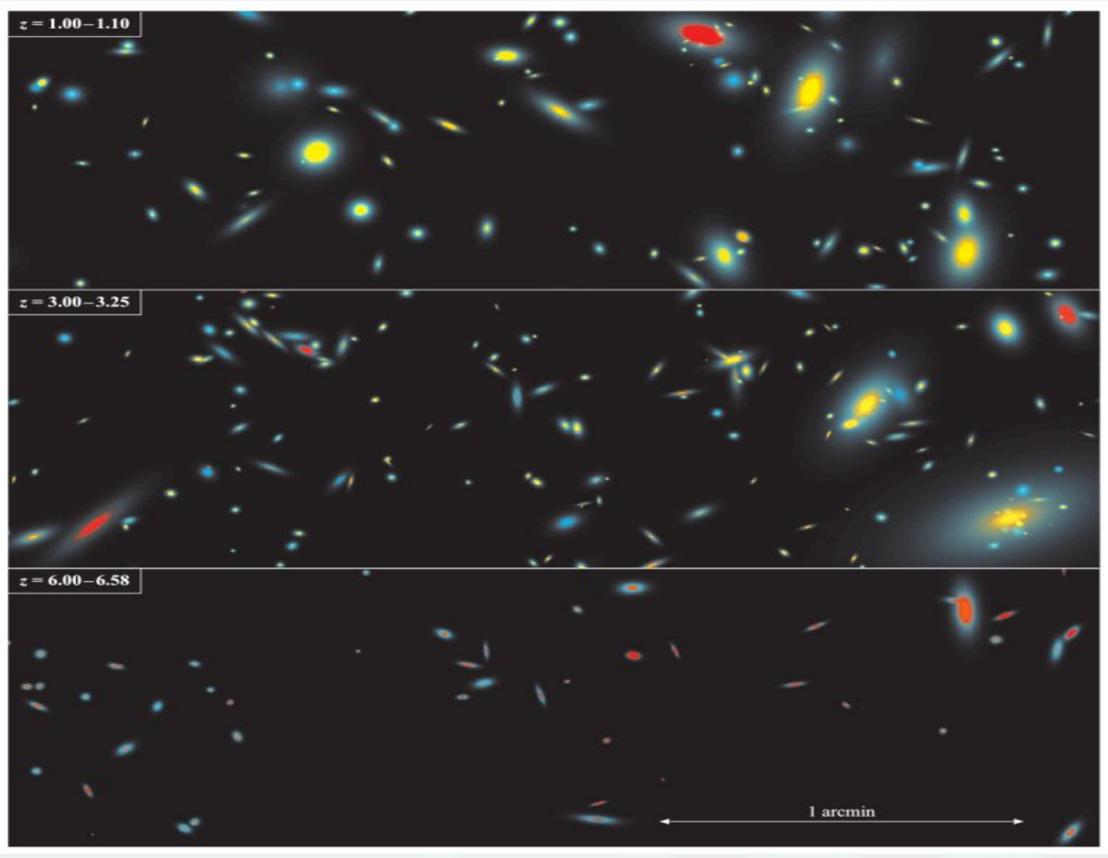


Figure 1: The SKA simulated sky displaying the HI and CO flux densities for galaxies at three redshift bins. Obreschkow et al. (2009).

2. Simulations

- Galaxies can be located spatially using optical data and the 1D spectrum then extracted.

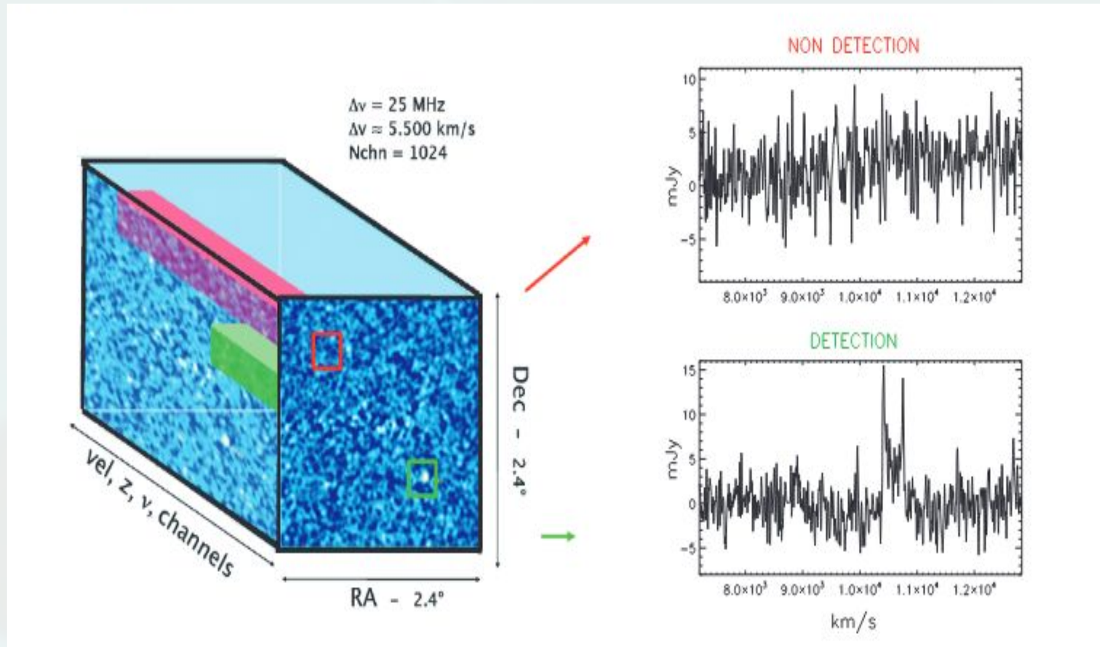


Figure 2: An illustration of how the 1D line spectra (right panel) is extracted from the sub-volumes of a radio data cube (left panel). Fabello et al.(2011)

- For a given radio galaxy population, the HI spectral data are contained within a data cube.
- For this study, we used the analytical model provided by Obreschkow et al.(2009) which is able to successfully recover line profiles from the S3-SAX catalogue properties.
- However, this model does not account for asymmetric line profiles.

3. Spectral line fitting

- The HI spectral line profile reflects the observed Doppler broadening due to the galactic rotation.

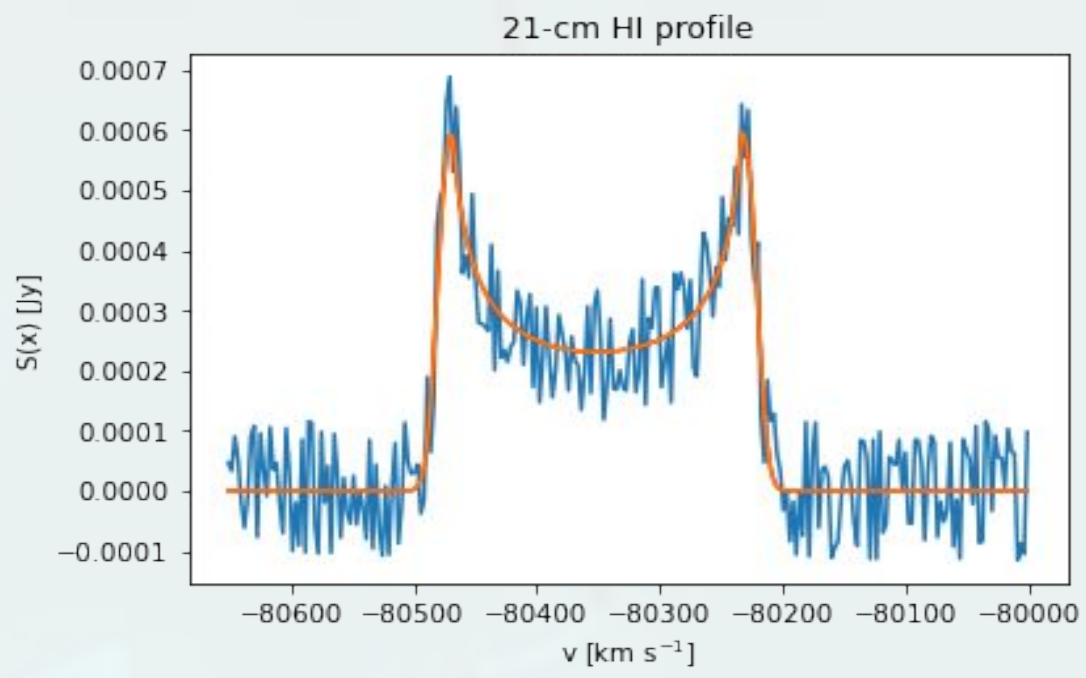
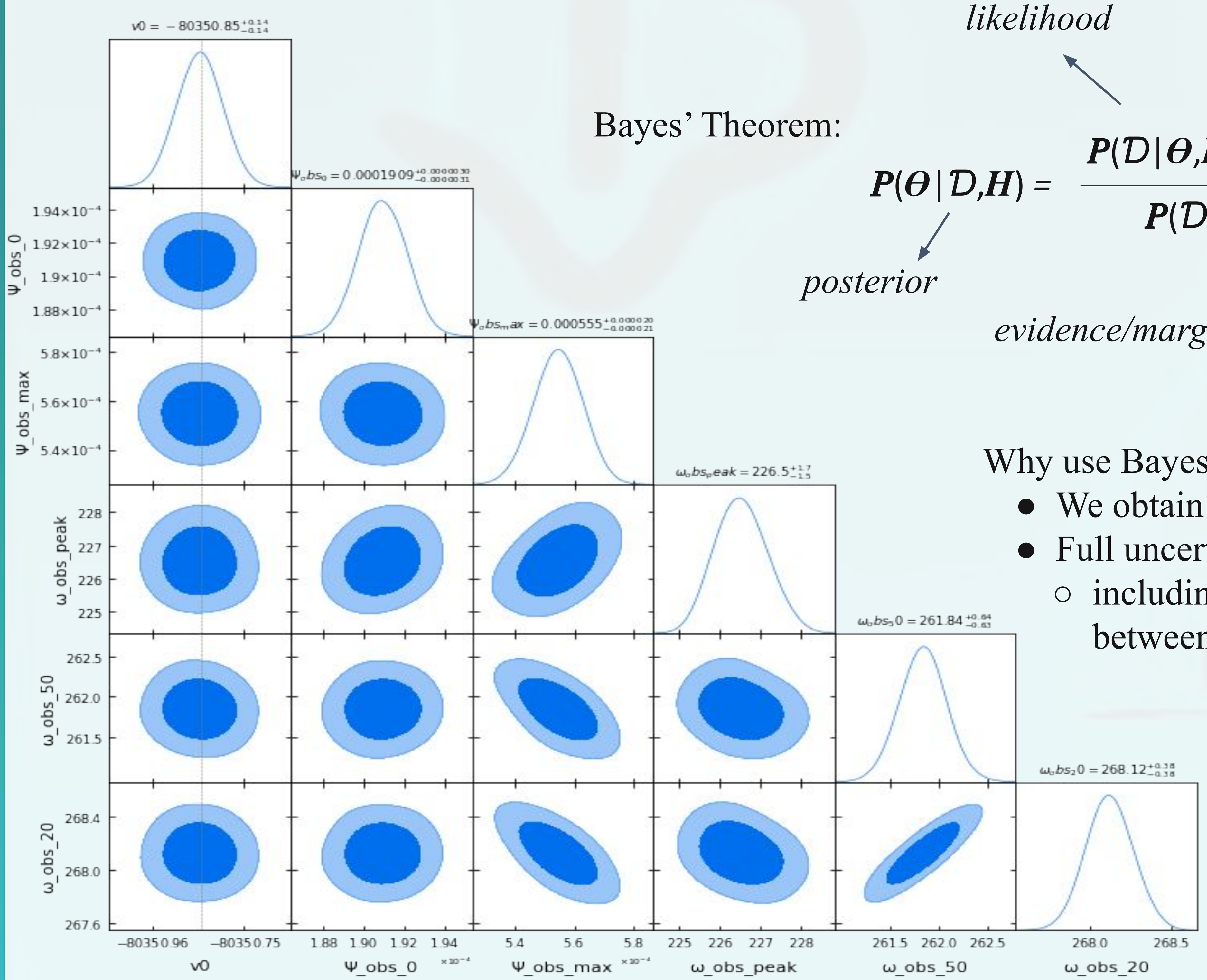


Figure 3: An example of the HI emission line for an individual galaxy. The HI line profile is characterised by the distinctive "double-horn" feature, which is due to the rotation of the galaxy.

- By introducing Bayesian model fitting of the HI spectra, we are able to recover precise redshift information.
- We aim to combine photometric redshift information with HI spectra to obtain tighter constraints on the redshift of distant galaxies.

4. Bayesian Inference



Bayes' Theorem:

$$P(\Theta|\mathcal{D},H) = \frac{P(\mathcal{D}|\Theta,H)\,P(\Theta|H)}{P(\mathcal{D}|H)}$$

likelihood: $P(\mathcal{D}|\Theta,H)$; prior: $P(\Theta|H)$; posterior: $P(\Theta|\mathcal{D},H)$; evidence/marginalised likelihood: $P(\mathcal{D}|H)$

Why use Bayesian modelling?
- We obtain parameter estimates
- Full uncertainty distribution
  - including the covariance between the parameters

Figure 4: The full posterior distribution over all parameters (including the observed redshift - grey dotted line) with 1 and 2 sigma confidence regions shown in dark and light blue colours, respectively. In this case, the Metropolis Hasting (an MCMC variant) was used as our sampler.

5. Future work

- We propose an extension of the work by Harrison, Lochner, and Brown (2017) :
  - Account for asymmetric line profiles using the Busy function (Westmier et al. 2014)
  - Apply model comparison and introduce dynamic nested sampling.
  - Test the method on recent radio simulations/datasets.
  - Incorporate photometric redshift estimates .

6. References

[1] Obreschkow, et.al. ApJ 703 (2), 1890 (2009)
[2] Fabello et al. Mon. Not. R. Astron. Soc. 411, 993–1012 (2011)
[3] Harrison, Ian, Michelle Lochner, and Michael L. Brown. (2017).
[4] Westmier et al. Mon. Not. R. Astron. Soc. 438, 1176–1190 (2014) 2014.

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