# Sparse Aperture Arrays for Neutral Atomic Hydrogen Surveys

Danny Price

Worcester College

University of Oxford

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# Acknowledgements

In my life, whenever two roads have diverged in a yellow wood, I have always had someone to guide me...

# Abstract

Here, we present the Opto-Acoustic Parametric Amplifier (OAPA), a novel device which couples optical and acoustic degrees of freedom...

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# Chapter 1

# Introduction

## 1.1 Introduction

### 1.1.1 Fourier Series

For a function $f(x)$ you can write the Fourier Series:

$$f(x) = \sum_{-\infty}^{\infty} c_n e^{inx},$$

where the coefficients $c_n$are given by

$$c_n = \frac{1}{2\pi} \int_{-\pi}^{\pi} f(x) e^{inx} dx$$

### 1.1.2 Maxwell's Equations

There are four of the buggers, and I like them in terms of total charge and current:

$$\begin{array}{cc} \nabla.\mathbf{E} = \frac{\rho}{\varepsilon_0} & \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \\ \nabla.\mathbf{B} = 0 & \nabla \times \mathbf{B} = \mu_o \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} \end{array}$$

Where $\mathbf{B}$ is the magnetic field, $\mathbf{E}$ is the electric field and $\mathbf{J}$ is the total current density. Also, $\varepsilon_0$ is the permittivity of free space (electric constant) and $\mu_0$ is the permeability of free space (magnetic constant).

It's good to know what these mean in words and integral forms, so:

- *Gauss' Law:* Electric flux through any closed surface is proportional to the enclosed electric charge:

$$\Phi = \oint_S \mathbf{E}\, d\mathbf{A} = \frac{Q_{enc}}{\varepsilon_0}$$

- *Gauss' Magnetic Law:* Magnetic monopoles don't exist:

$$\oint_S \mathbf{B}\, d\mathbf{A} = 0$$

- *Faraday's Law of Induction:* The induced electromotive force in any closed circuit is equal to the rate of change of the magnetic flux through the circuit:

$$\epsilon = -\frac{d\Phi_B}{dt}$$

- *Ampere's Law:* The relation between integrated magnetic field and current flowing:

$$\oint_S \mathbf{B}\, d\ell = \mu_0 I_{enc}$$

That should be enough to get you started.

## 1.2 Thesis Overview

# Chapter 2

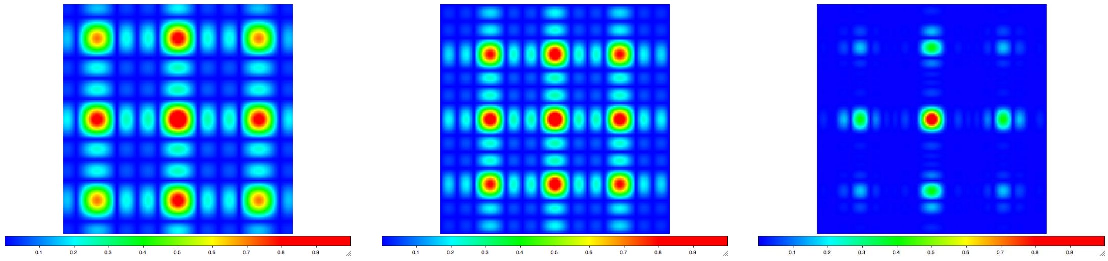
# The Nature of Dark Energy

## 2.1 Baryon Acoustic Oscillations

**Some example text:** One of the most important issues in cosmology today is determining the properties of dark energy [1]. Over cosmological distances, dark energy acts as a repulsive force [6] which causes an acceleration in the rate of expansion of the universe, an observation first made using distant Type 1A supernovae [8, 7]. By measuring the rate of expansion, we can learn about the nature of dark energy which in turn can reveal a deeper understanding of the standard model of cosmology and the origin of the universe.

The rate of expansion of the universe can be determined from a measurement of its size at different epochs. A cosmological 'standard ruler' [2] is an object whose size relative to the universe remains fixed with the expansion of the universe. One such standard ruler is the typical length scale present in 'baryon acoustic oscillations' (BAO) [4]. These oscillations are the peaks and troughs in the spatial power distribution of baryonic matter which correspond to over- and under-densities of matter at specific length scales. The pressure resulting from over-densities present in the primordial plasma after the inflationary period created spherical acoustic waves which radiate outward from these over-densities at around half the speed of light.

As the Universe expanded and cooled, the electrons and protons eventually combined into neutral hydrogen atoms. At this point, referred to as recombination, the Universe became essentially transparent to photons, removing the outward pressure and effectively freezing the matter distribution. Over time, some of the dark matter at the centre of the original over-density was attracted to the location of the sound horizon [3]. Since the BAO are imprinted into the large-scale structure of the Universe they remain unchanged in relation to the size of the Universe. The BAO signal was first measured in the power spectrum of the cosmic microwave background (CMB)



(a) $2\lambda$ element spacing (b) $\frac{5\lambda}{2}$ element spacing (c) Product beam

Figure 2.1: An example of attenuation of grating lobes in the product beam of two arrays. In a) and b), we have the radiation power patterns at $300MHz$ for a $4 \times 4$ gridded array with spacing $2\lambda$ and $5\lambda/2$, respectively. Sub-figure c) shows the product beam, in which the grating lobe response is attenuated.

[5]. If one could measure the BAO signal at a different epoch this would constitute a standard ruler, which would provide a measure of the expansion rate of the universe.

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# Appendix A

# Appendix Name

Colourless green ideas sleep furiously.