Searching for the Missing Baryon Fraction with SPTpol and the Dark Energy Survey

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Statement of contribution:

This is to certify that:

- This thesis entitled "Studying weakly lensed galaxies with velocity maps" comprises only my original work except where indicated otherwise.
- Due acknowledgement has been made in the text to all other material used.
- The thesis is no longer than 50 pages in length, inclusive of tables, figures, bibliographies and appendices.

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Mitchell de Zylva

Acknowledgements:

You put all the people you want to thanks here :)

You need a statement of contribution, which you will sign before you submit.

Abstract

Abstract goes here..

Contents

Chapter 1

Introduction

1.1 The Cosmic Microwave Background

The basis for modern cosmology relies on several fundamental assumptions stemming from observation, the chief of which is the Big Bang Model. Following Hubble's discovery of a relation between distances to galaxies and their recessional velocities, the *Copernican Principle* leads to the conclusion that in the past, objects in the universe were much closer together. His observations gave rise to the Lemaitre's Hubble Law,

$$v \propto d \tag{1.1}$$

This suggests that at some point in the past, the universe was much smaller than it is at present, the conservation of energy then implies that at some point in the past, the universe must have been an incredibly hot, dense environment. Using general relativity, the extrapolation backwards in time yields a singularity of infinite density and temperature, which is commonly called the *Big Bang*

Another assumption stemming from observation is that of isotropy. Based on observation, there appears to be no favoured direction in the universe, since distributions of distant galaxies and other extragalactic sources seem to be evenly distributed across the sky. Perhaps the most spectacular example of this isotropy is the presence of the *Cosmic Microwave Background*.

Discovered in 1964 (**?**), it was noticed that there was isotropic black-body radiation at $T \approx 2.7\,\mathrm{K}$. Since the peak of this radiation is in the microwave section of the electromagnetic spectrum, it was termed the *Cosmic Microwave Background*.

The Cosmic Microwave Background (CMB) provides the most accurate and detailed measures of the primary cosmological parameters to date.

1.2 Cosmological Parameters

For a Λ CDM universe, there are six independant paramters which descirbe the evolution and behaviour of the universe, the physical baryon density $\Omega_b h^2$, the physical dark matter density $\Omega_c h^2$, the age of the universe t_0 (or its reciprocal, the Hubble constant H_0), the scalar spectral index n_s, the curvature fluctuation amplitude Δ_R^2, and the reionisation optical depth τ.

Currently, the highest precision measures of these features from the CMB come from Planck Collaboration et al. (2018), which details that baryonic matter only comprises $\approx 5\%$ of the universe's energy density. In principle, this component of the universe should be directly measurable. At just three minutes after the Big Bang, deuterium can be used as a tracer for this abundance (Steigman, 2007), and at redshift $z \geqslant 2$, the baryon fraction can be found in the absorption lines of quasars

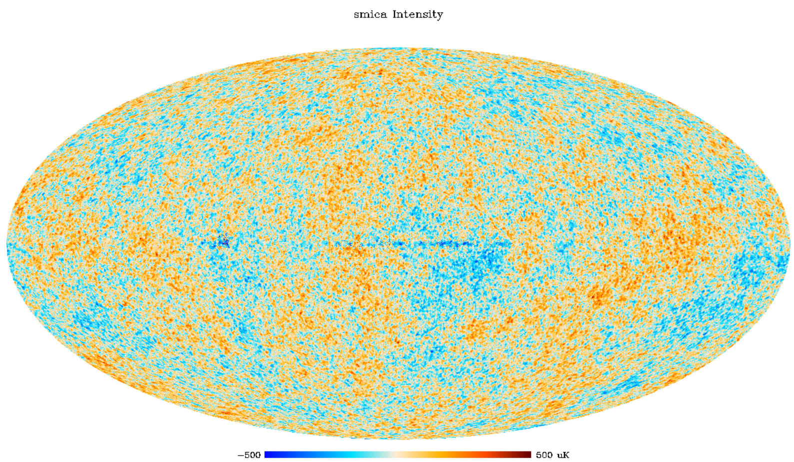

Figure 1.1: *Planck* Satellite Full Sky CMB Map

passing through the diffuse, photo-ionised intergalactic medium, known as the Lyman-α forest (Weinberg et al., 1997). However as the universe evolved, this gas became sparser as it became more ionised. This makes searching for the entirety of the baryon fraction at low redshift difficult. When this fraction is calculated directly from observations, it shows only one tenth of the baryonic content shown in high redshift measurements is contained in galactic structures (Persic & Salucci, 1992). Some revised estimates considered that the limitations of observations were primarily to blame for this discrepency, and not inherent new physics (Bristow & Phillipps, 1994; Fukugita et al., 1998)

The baryon content has been confirmed to a very high accuracy with recent CMB experiments, first with the *Wilkinson Microwave Anisotropy Probe* (WMAP) (Spergel et al., 2007), and then with the *Planck* Satellite (Planck Collaboration et al., 2018). When we quote quantities, we take values from the latest *Planck* paper

Parameter	Value	Error
$\Omega_c h^2$	0.120	±0.001
$\Omega_b h^2$	0.0224	±0.0001
n_s	0.965	±0.004
τ	0.054	±0.007
$100\Theta_\star$	1.0411	±0.0003
H_0 (km s^{-1} Mpc^{-1})	67.4	±0.5

Chapter 2

The Missing Baryon Problem

2.1 Stellar Baryons

2.2 Cold Interstellar Medium

2.3 Lyman α

2.4 OVI and BLA Absorbers

2.5 Hot Gas in Clusters

Chapter 3

The Warm-Hot Interstellar Medium

Chapter 4

The Sunayev-Zeldovich Effect

4.1 Atomic Physics

4.2 CMB Signal

Chapter 5

Stacking Methodology

Given the signal-to-noise ratio expected for the thermal Sunyaev-Zel'dovich effect of a single filament, many such filaments must be co-added, so as to drive the signal-to-noise to a detectable level. Initially outlined in Clampitt et al. (2016),

Chapter 6

Results

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Chapter 7

Conclusion

All your Concluding.

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