THE WIGGLEZ DARK ENERGY SURVEY: 1000 REDSHIFTS AND BEYOND

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Introduction

Here we outline design aspects and first results of the WiggleZ Dark Energy Survey that has recently been awarded long-term status on the AAT from the 2006B semester. The primary aim of the WiggleZ Dark Energy Survey is to use baryonic acoustic oscillations (BAOs) as a standard ruler to measure \( w(z) \), the parameterization of the equation of state of the Universe, and hence determine if dark energy is described by the cosmological constant model. Secondary aims include:

- Tests of CDM paradigm through accurate measurements of halo model parameters.
- Constraints on inflationary models.
- Tight upper limits on neutrino masses.
- Galaxy evolution studies such as star formation rates as a function of \( z \), luminosity, environment etc.

Arguably the most significant discovery in the present epoch of precision cosmology is that the expansion rate of the Universe is accelerating, as measured from type Ia supernovae (e.g. Riess et al. 1998; Perlmutter et al. 1999). Although initially met with scepticism, the acceleration of the Universe is now on firm ground owing to a strong concordance between different measurement methods (Knop et al. 2003; Tonry et al. 2003; Spergel et al. 2003; Riess et al. 2004). This acceleration of the Universe unambiguously requires new physics: either gravity is fundamentally different from Einstein’s vision or the Universe is dominated by a form of energy that has negative pressure – dark energy. The simplest solution would be that dark energy is the cosmological constant. However, the very small observed value of the vacuum energy is wildly inconsistent with quantum physics predictions. Therefore a more general equation of state, \( P=w\rho \), is proposed (e.g. Turner & White 1997).

Here an accelerating universe is produced if \( w<-\frac{1}{3} \), and vacuum energy is described by \( w=-1 \). If the dark energy is the product of new physics, such as quintessence (Ratra & Peebles 1988), then the resulting equation of state varies with redshift, \( z \), and must be treated as a more general function \( w(z) \) (Linder & Huterer 2003).

We will exploit the fact that the cosmic distribution of galaxies has a preferred scale to obtain precision measurements of \( w(z) \). The Universe contains a small excess of pairs of galaxies separated by the special distance of 150 Mpc (4.7x10^{24} m). The origin of this feature is very well understood (Peebles & Yu 1970; Sunyaev & Zel’dovich 1970). In the hot, dense early Universe baryons and photons were tightly coupled by Thomson scattering. As the baryons were pulled into cold dark matter potential wells, the resulting radiation pressure launched sound (compression) waves. As the Universe cooled, matter and radiation de-coupled at the recombination epoch, imprinting a snapshot of the sound waves at that time in both the matter distribution and the CMB radiation. The ‘acoustic’ scale of 150 Mpc is equal to the distance travelled by the sound waves before recombination (360,000 years after the Big Bang). The baryon oscillations have now been detected, as anisotropies in the CMB (Bennett et al. 2003) and, most recently, in the present-day galaxy distribution (both the 2dFGRS, Cole et al. 2005, and the Sloan Digital Sky Survey, Eisenstein et al. 2005). These galaxy samples are too nearby to be sensitive to the cosmic effects of dark energy, but provide a superb validation of the concept.

This scale provides the long-sought cosmic standard ruler. Measurement of the baryon oscillation scale in the galaxy distribution at high redshift gives a powerful cosmological test. A galaxy redshift survey measures the acoustic preferred scale in angle and redshift space. This gives a geometrical measurement of the Universe at different redshifts which delineates the cosmic expansion history with high accuracy and traces the effects of dark energy (Blake & Glazebrook 2003). It also provides a unique and direct measure of the expansion rate at high redshift (Glazebrook & Blake 2005). We aim to make the first measurement of the acoustic scale at high redshift, which will result in a 2% measurement of the cosmic distance and expansion rate up to \( z \sim 1 \). This experiment will serve as a powerful test of the dark energy model at high redshift. We will either produce the first refutation of the currently-favoured cosmological constant model, or a strong confirmation of the model.

Target Selection and Survey Design

Our targets are selected from the GALEX satellite and ground based optical imaging from SDSS using the ‘ultra-violet drop-out’ technique (Steidel et al. 1996). We exploit the fact that at \( z>0.5 \), the Lyman break enters in to the
FUV band (1344 – 1786Å), and therefore we are able to efficiently select high redshift galaxies by their red FUV–NUV colours. Simultaneously, the fact that the galaxy possesses a significant NUV magnitude implies that it is likely to contain young hot stars, which produce strong ultra-violet emission, and hence bright optical emission lines.

One problem in our target selection technique is that the GALEX positional accuracy is circa 2 arcsec – clearly inadequate for AAOmega follow-up. To obtain accurate positions for the spectroscopic follow-up the GALEX data are matched to optical images from the SDSS.

The basic parameters of our survey needed to obtain a 2% measurement of the acoustic scale, are: observation of 400 000 (z>0.5) galaxies within an area of 1000 deg² over 220 nights (including weather allowance).

The accuracy with which we can measure the power spectrum at a given scale (and hence the baryon oscillation standard ruler) is determined by two factors: the number density of galaxies and the total survey volume. We have made detailed simulations of our survey and results, assuming we only use galaxies in the range 0.5<z<1.0, owing to the reduced number density at z>1. A density of 400 galaxies per deg² over an area of 1000 deg² yields a 2% measurement, but preliminary results are possible using the first 500 deg². A simulation of the expected measurement accuracy from the full survey is shown in Figures 1 and 2.

Results from 2006A

In the 2006A semester, we obtained over 1000 redshifts from observations in both AAOmega Science Verification (SV) time and scheduled time. These observations demonstrated the capability of the new AAOmega instrument to carry out the WiggleZ Dark Energy Survey, specifically the ability of AAOmega to measure galaxy spectra to high quality, even at redshifts greater than one, using 1 hr exposures.

It should be stressed that our 2006A data were obtained during terrible observing conditions, including 5/8 cloud cover and seeing up to 4”. In Figure 3 we present a composite spectrum from the first observations. The figure illustrates the emission lines that are detected by AAOmega using 1 hr exposures with the 385R filter on the red camera.

To better demonstrate the ability of AAOmega to successfully redshift emission line galaxies in 1 hr, a fractional redshift distribution is presented in Figure 4. Of particular interest is the tail that extends to z~1.3. For z>1 this tail constitutes ~5% of the obtained redshifts. Again, it should be kept in mind that this fractional N(z) is of spectra obtained during terrible observing conditions.
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Fig 3: Composite (rest-frame) AAOmega spectrum of GALEX-selected galaxies demonstrating the strong emission lines we require.

Fig 4: The redshift distribution of GALEX-selected galaxies measured in our 1-hour AAOmega pilot exposures. The solid histogram shows all measured galaxies (N=1333); the dashed line shows just those measured with our optimised selection criteria (by putting the brightest targets in r' at lower priority we reduce the fraction of low-redshift galaxies). This results in a mean redshift of z=0.7 with 90% of the galaxies having redshifts z>0.5. The histograms are normalised for comparison purposes.

observing conditions. Our results here are an underestimate of the actual capabilities of the new AAOmega instrument.

Due to the weather it is only possible to determine lower limits using this data as to what can be achieved using AAOmega. Initial calculations of these limits suggest that 5 pointings per AAOmega field is necessary to meet the survey requirements. For 5 pointings these calculations estimate ~35 spare fibres per pointing. It is envisaged by the team that these spare fibres will be offered to the community via an as yet undetermined AATAC submission process. The exact number of fibres and the process for obtaining their use will be finalised after the true capabilities of AAOmega are determined from observations in better weather.

Summary

The WiggleZ Dark Energy Survey is getting underway in earnest from the 2006B semester. It is being carried out by a modestly sized international collaboration, yet remains identifiably Australian with Drinkwater in the role of PI for our AAT observations. A more detailed examination of our first results, including a full investigation of the correlation function of our emission line galaxies, will be presented in Jurek et al. (in prep.).

References

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