FASTSOUND: PROBING THE ORIGIN OF COSMIC ACCELERATION BY GALAXY CLUSTERING AT $z \sim 1.3$

WITH SUBARU/FMOS

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ABSTRACT

The FastSound project is a galaxy redshift survey using Subaru/FMOS to detect Hα emitting galaxies at $z \sim 1.3$, for the purpose of probing the origin of the accelerated expansion of the universe. The survey has detected ~4,000 galaxy redshifts in a total area of 30 deg$^2$, and detected the redshift space distortion at this redshift range for the first time. The redshift space distortion (RSD) signal will be used to derive a measurement of the growth rate of large scale structure, which will provide a test for modified gravity as a possible origin of accelerated cosmic expansion. Here we present an overview and the current status of the project.

Key words: large-scale structure of Universe — dark energy

1. INTRODUCTION

The most significant mystery concerning our current picture of the Universe is the accelerating nature of the cosmic expansion. This is well-described by the ‘ΛCDM’ model which supplements dark matter with a repulsive cosmological constant. However this has severe conceptual problems, in that while it is consistent with all current observations (see Frieman et al. 2008, for a review) it is an entirely empirical model without a fundamental physical basis. The natural interpretation of Λ as representing the zero-point energy of the vacuum fails by 122 orders of magnitude and an extreme fine-tuning is required for it to appear now in the long history of the universe. This has motivated numerous ideas for new physics of ‘dark energy’ or ‘modified gravity’ to explain the large scale cosmic dynamics of spacetime (e.g., Caldwell & Kamionkowski 2009, for a theoretical review).

Large scale redshift surveys of galaxies are now widely recognized as one of the most powerful approaches to tackle this important and difficult problem. This is because they are able to simultaneously measure the effects of dark energy fields (which modify the expansion) and modifications of gravity (which also affect the growth of structures in the Universe). Low redshift surveys such as 2dFGRS and SDSS have delivered a wealth of cosmological results this way but the results remain consistent with ΛCDM and have, frustratingly, not provided new clues to the underlying physics.

The redshift space distortion (RSD) observed in galaxy redshift survey data is one of powerful tools to test the theory of gravity on cosmological scales. The core idea is to measure the two dimensional clustering of galaxies both across and along the line-of-sight. Because this is measured in ‘redshift space’ an anisotropic statistical distortion arises in galaxy clustering due to the peculiar velocity of galaxies falling in to larger structures. This distortion allows us to measure the infall rate, and comparison with the mass fluctuations then provides a constraining test of the theory of gravity (e.g. the review by Hamilton 1998). The quantity that will be measured is the growth rate $f_g \equiv d \ln D/d \ln a$, where $D$ is the growth factor [density fluctuation $\delta(t) \propto D(t)$] and $a$ the scale factor of the universe. This quantity is related to theory as $f_g(z) = \Omega M(z)^{\gamma}$ with $\gamma = 0.55$ to high-precision for a ΛCDM model. (Here, $\Omega M$ is the standard matter density parameter of the universe.) In models where the acceleration arises from modifications to gravity then this also affects the growth rate of perturbations and $\gamma$ is in the range $0.4 < \gamma < 0.7$ (Linder E. V., 2005), which is measurable by redshifts surveys as long as a sufficient baseline in redshift is attained.

The anisotropic distortion of galaxy clustering in redshift surveys can be measured by the two-dimension power spectrum in redshift space $P^s(k)$ of the galaxy density field. The RSD can be described as $P^s(k) = (b + f_g \mu_k^2) P(k)$ on large scales in the linear regime, where $P(k)$ is the isotropic matter power-spectrum without RSD, $\mu_k \equiv \cos \theta$, $\theta$ is the angle between the wave number vector $k$ and the line-of-sight direction, and $b$ is the linear bias parameter of galaxies. This formula tells us that we can measure $bf_g$ and $f_g \sigma_s^2$ from observed $P^s(k)$, where $\sigma_s$ is the standard normalization parameter of density fluctuations and $P(k) \propto \sigma_s^2$. Note that we can combine these measurements to constrain the ratio $\beta \equiv f_g/b$, which is often quoted as it removes the dependence on $\sigma_s$ from the observations. Given an
independent measurement of $b$ or $\sigma_8$ we can constrain $f_{g_0}$ alone. Precise measurements of $f_{g_0}(z)$ or $f_{g_0}(z)\sigma_8$ then give us an important test for gravity on cosmological scales. [Measuring $f_{g_0}(z)$ rather than $f_{g_0}(z)\sigma_8$ does not necessarily aid with model discrimination (Song & Percival 2009), thus reducing the need of independent measurement of $\sigma_8$ or $b$.]

However, this distortion has so far only been measured with adequate precision at relatively low redshifts ($z \sim 1$), by surveys of 2dF, SDSS, VVDS, WiggleZ, BOSS, and VIPERS (Percival et al. 2004; Guzzo et al. 2008; Blake et al. 2011; Samushia et al. 2012; Reid et al. 2012; Beutler et al. 2012; de la Torre et al. 2013). A two sigma level measurement of RSD at $z \sim 3$ has been reported by the VLT LBG survey (Bielby et al. 2013). In future higher-redshift measurements may come from the HETDEX project (Adams et al. 2011), probing $1.9 < z < 3.5$ by Lyman-α emitters. However, RSD measurements at $z \sim 1–2$, where the dark energy component starts to become significant, are not yet obtained. At high redshifts, the Universe becomes more like a Einstein-de Sitter model, and dark energy ceases to be important. It is this change in the Universe that we wish to observe, and we can only do this using measurements before and after the onset of acceleration; high redshift measurements are extremely important as they provide a baseline against which the low-redshift effects of dark energy can be compared.

2. THE FASTSOUND SURVEY

The new instrument, FMOS, at the Subaru Telescope, has the potential to make a significant breakthrough in our understanding of the accelerating Universe by undertaking the first systematic cosmological redshift survey at $z > 1$, probing the early epoch of the Universe for the first time, due to the combination of the near-infrared $JH$ wavelength coverage (including Hα emission lines at $z \sim 1$), 400 fibers in a large field of view (30′ diameter) and the large photon-collecting power of the Subaru Telescope. The bright Hα emission line from the extensive star-formation of this epoch is visible to $z = 1.6$ and allows a rapid survey to be performed. This will enable the first precise measurement of the applicability of General Relativity to the growth of large-scale structure at $z > 1$ using the RSD technique, providing a fundamental comparison between dark energy and modified gravity.

The most efficient approach to covering a large area is to choose tracers of the galaxy density field whose redshift can be secured in the shortest exposure time. At high-redshift one approach is to use emission line galaxies, because an emission line can be detected in a shorter exposure than galaxy continuum light, and due to the evolution of galaxy star-formation rates (Hopkins 2004) high-redshift galaxies are much more luminous in bright lines such as Hα. However this line is only accessible in the near-infrared: FMOS can access it. Importantly the Hα luminosity function and clustering are already well measured from small surveys in this redshift range (e.g. Geach J. E., et al., 2008). An example of this emission line approach is the WiggleZ redshift survey on the 4m Anglo-Australian survey which is covering 1000 deg$^2$ and $0.3 < z < 0.9$ using the [OII] tracer and optical spectroscopy of only one hour exposures.

The detailed survey design is constrained by available photometric catalogs for target selection. Color-selection can easily isolate galaxies in the desired redshift intervals but a key problem is selecting from broadband properties the brightest few percent of line emitters.

After investigations of various photometric survey data sets, we have chosen the CFHT Legacy Survey Wide fields as the best input data set at the moment. There are four sub-fields of CFHTLS-W (W1–W4), each of which includes at least a 4×4 square degree area. In these fields, deep $u$, $g$, $r$, $i$, $z$ band photometric data are available. The limiting magnitudes are $\sim 24$ mag for $u$, $g$, $r$, $i$-bands and $\sim 23$ mag for the $z$-band, i.e., more than 2 mag deeper than the SDSS.

We studied various selection methods for galaxies having strong Hα lines using pilot FMOS observation data, and established the FastSound galaxy selection criteria, which is mainly based on the photometric redshift and star formation rate (SFR) estimates by the five CFHTLS bands, combined with some magnitude and color cuts (Tonogawa et al. 2014a, b).

The error on $f_{g_0}(z)\sigma_8(z)$ is determined by the total number of galaxies and the volume covered (see the Fisher matrix analysis of White et al. 2009). The total number is normally the most important term, as the distortion is scale independent in the linear clustering regime, but if fields are too small cosmic variance and non-linearities will dominate, requiring a survey of at least 10 deg$^2$ at these redshifts. Our proposed survey will detect $\sim 5,000$ Hα emitting galaxies over 30 deg$^2$, for which the expected fractional error on the parameter $f_{g_0}\sigma_8$ is calculated to be $\sim 20\%$.

3. THE CURRENT STATUS

FastSound was awarded 40 Subaru nights, and after using five nights as the pilot survey, the main survey using 35 nights started in April 2012, and finished in July 2014. The total number of the observed FMOS FoVs is 121 in the four CFHTLS W fields (10, 39, 54, and 18 for W1–4, respectively), amounting to a total area of 20 deg$^2$ by continuous hexagonal tiling. Though the total area is smaller than the original plan due to weather conditions and instrumental/telescope troubles, we have collected about 4,000 emission line galaxies above the threshold line detection S/N = 4.5, using the high resolution mode of FMOS. Various studies (narrow band survey results, multiple line galaxies in FastSound, and the stacked FastSound spectrum) indicate that about 90% of these are indeed Hα at $z \sim 1.2–1.5$. The 3-D map of about 1,000 galaxies detected in the W3 field is presented in Fig. 1.

The clustering analysis is currently underway, and the RSD signal is clearly detected. The final measurement of $f\sigma_8$ at $z \sim 1.35$ will be reported after examination of various systematic effects. Several papers are currently
in preparation for survey overview, the line catalog and properties of emission line galaxies, RSD and cosmological implications, and cosmic star formation history and Hα luminosity function evolution, and so on.

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