The alignment of galaxies across all scales
Georgiou, C.

Author: Georgiou, C.
Title: The alignment of galaxies across all scales
Issue Date: 2019-12-12

Summary

The subject of cosmology has gained a lot of interest in the last few decades, as astronomical data improve and the precision with which we can measure statistical observable quantities in the Universe is increasing. A broad picture of the physical processes that dictate the evolution of the Universe has been developed, summarized in the standard cosmological model, which has been successful in describing increasingly more precise and independent astronomical observations.

The biggest questions yet to be answered within the standard cosmological model concern dark matter and dark energy, components that make up $\sim 95\%$ of the energy density of the Universe today. The former has the effect of speeding up the formation of structures and the latter the opposite. Some of the key questions surrounding these mysterious contents of the Universe are: how much dark matter is there, and how strongly does it cluster (encoded in the cosmological parameter S_8)? Is there a tension of the S_8 parameter in high- and low-redshift astronomical observations? What is the equation of state of dark energy (parametrised by w)? Is it a cosmological constant, or does it vary with time?

Observational techniques that are sensitive to dark matter and dark energy are required to shed light onto these questions. One such technique is weak gravitational lensing: the distortion of light sources (e.g. background galaxies) from the matter density between the source and the observer. The distortion caused by gravitational lensing depends on the intervening mass and geometry of the Universe, which makes it suitable to study dark matter and dark energy.

Future weak lensing surveys aim to greatly increase the statistical precision of lensing measurements. However, this means that the systematic uncertainty in the measurement needs to be controlled to very high accuracy. The most important astrophysical systematic contamination are intrinsic alignments, the alignment of the orientation of galaxies with the matter density field. Intrinsic alignments add in the data a distortion pattern that is not caused by weak lensing and can significantly bias the measurement of cosmological parameters, if left unaccounted for. In this thesis, the intrinsic alignment signal is measured from ground-based survey data with unprecedented image quality and data fidelity, and the dependence of the signal with various galaxy properties is examined. This knowledge will allow the development of more precise models for the intrinsic alignment signal, as well as help better mitigate its effect on weak lensing measurements and allow the full usage of the statistical power of the future weak lensing surveys.

In order to measure the intrinsic alignment signal from galaxies, we need galaxy distance information (i.e. redshift), to identify physical galaxy pairs that interact gravitationally, as well as deep, high-quality imaging data to determine the shapes of galaxies and quantify their alignment. Throughout the thesis, highly accurate redshifts are obtained from the Galaxy And Mass Assembly (GAMA) spectroscopic survey. The survey's high completeness ensures that redshift information is available for the vast majority of our galaxy sample, even for galaxies that are close together on the sky, and allows the robust determination of the alignment signal from large to small scales. Galaxy shapes are measured with imaging data from the Kilo Degree Survey, a survey specifically designed for weak lensing science. Because of this, the imaging data are deep, with minimal artifacts from the telescope's optics and the Earth's atmosphere (quantified by the point-spread function, PSF). The measurement of shapes is carried out using the DEIMOS method, which relies on measuring weighted galaxy surface brightness moments and uses a scheme to approximate the un-weighted moments while it also analytically treats the effects of the PSF.

Using this dataset, we begin in **chapter 2** by measuring shapes of galaxies in images obtained using three different broad band filters, g, r and i-band. The intrinsic alignment signal of our galaxy sample is found to appear stronger when observations are made in the g and i-band filters, compared to r-band. This difference is primarily sourced by red satellite galaxies, and is only evident in small scales, below a few Mpc$/h$. One possible mechanism that can explain this difference is the tidal nature of the intrinsic alignments, together with the colour gradients of galaxies: outer regions of galaxies are more susceptible to tidal fields, and intrinsic alignments are expected to more strongly affect these outer galaxy scales compared to inner regions. In addition, galaxies build up hierarchically, and the inner regions are generally more red, populated with older stars than the outer ones. Hence, observations at different wavelength can potentially reveal different regions of the galaxies. However, this picture is further complicated by the redshifting of galaxy spectral energy distributions and the 4000 Å break, with respect to the observed broad-band filters. While a prediction for the expected difference in alignment with wavelength is complicated, it is clear that there are interesting discoveries to be made about the alignment of galaxies at small scales.

We continue this thesis with **chapter 3**, where we look at the intrinsic alignment signal observed in the r-band, at large scales. The aim is to provide a direct measurement of the signal to be used as an informative prior for weak lensing studies, which will improve the constraints on the cosmological parameters. To do this, it was important that we use a representative sample of galaxies, as similar as possible to what would be used by a weak lensing survey. We find that intrinsically red galaxies exhibit a strong alignment signal while blue galaxies have a signal consistent with zero, in agreement with previous literature. Using these direct measurements of intrinsic alignments, we forecast that current weak lensing surveys can achieve significantly more accurate constraints on the measurement of the S_8 parameter.

We then focus on the alignment of galaxies in smaller scales, looking specifically at galaxy groups in **chapter 4**. We measure a significant radial alignment of satellite galaxies with respect to the group's centre, which reduces to zero at large separations. In addition, we find that the outer regions of satellite galaxies (probed by increasing the radial weighting of the shape measurement method) are more strongly aligned than the inner ones. Intrinsically red satellites exhibit a generally stronger alignment than blue ones. Moreover, central galaxies of these groups are also aligned with the distribution of the satellite galaxies, with outer regions of centrals being more strongly aligned than inner ones and red centrals showing a stronger alignment than blue ones. These measurements suggest that intrinsic alignments at small scales are generally complicated, and the dependencies studied here can be used to tailor and improve existing models of the alignment signal at these small scales.

In **chapter 5** we zoom in further and study the alignment of central galaxies with their host dark matter halo. To do this, we measure the anisotropic weak lensing signal around a sample of galaxies that is optimised to have small contamination of satellite galaxies. We constraint $f_{\rm h}$, a parameter sensitive to the relative ellipticity of the dark matter halo and the galaxy, as well as their average mis-alignment angle. We find that red central galaxies have a non-zero

$f_{\rm h}$ at a 2σ significance. The measured value of $f_{\rm h}$ significantly increases if we repeat the lensing measurement using galaxy shapes that are more sensitive to the outer parts of the galaxy. Since the average ellipticity of the shapes of inner and outer galaxy regions do not vary significantly, we conclude that outer galaxy regions are more aligned with their dark matter halo than inner ones.