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Galaxy alignments from multiple angles

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Summary

Our current view of the Universe relies on the great discoveries that characterised the last century: from the formulation of the theory of General Relativity to the postulation of a ‘dark’, invisible matter to account for the velocity dispersion and the rotational curves of galaxy clusters and galaxies, to the discovery of the accelerated expansion of the Universe. From a theoretical point of view, we are now able to link the very early Universe to the formation of structures at large scales and provide a single model to describe multiple observations that invoke different scales and epochs. This model postulates the existence of two ‘dark’ components, the dark matter, which accounts for the extra gravity observed around galaxies and it is also expected to provide the seeds for structure formation, and a dark energy, responsible for the accelerated expansion. Those two ingredients account together for more than 95% of the total energy budget of the Universe. It is thus clear that, although successful in so many aspects, this model leaves open an enormous question: What is the true nature of the two main ingredients of the Universe?

While searching for a dark matter particle in the laboratories, we can also use observations of the Universe at large scales to investigate possible deviations from the standard paradigm of this model. In particular, we aim to know whether the dark energy has evolved over time, affecting the structure formation over the epochs, and to discriminate the gravitational effect of dark matter from a possible extension of general relativity. To do so, we need wide surveys that can collect an enormous amount of data: in this way, statistical uncertainties are reduced and we can capture deviations from the standard cosmological model. However, high precision needs to be paired with great accuracy: We need to control all the possible systematics, both observational and in the interpretation of the data to an unprecedented level. This is the main goal of this thesis.

One of the most powerful probes to investigate the dark sector of the

Universe is weak lensing, a phenomenon caused by the distortion of space-time by a mass distribution, which forces the light-rays to travel bent in the proximity of the mass. This generates correlated distortions of the images of background galaxies that can be used to infer the properties of dark matter along the line-of-sight.

Intrinsic alignment (IA) complicates the interpretation of this signal by adding a correlation between the orientation of galaxy shapes before being lensed. This is caused by the fact that galaxies form inside dark matter haloes and are subjected to the surrounding tidal fields: this imprints a preferred direction to their shapes. Since the overdensities responsible for the gravitational fields where the galaxies form are correlated, the alignment of galaxies is also correlated both at intermediate scales and at large scales. At small scales, the alignment is instead sourced by the intra-halo tidal fields.

Intrinsic alignment is thus not only an important contaminant to lensing that needs to be carefully modelled, but it is also a unique window to understand better the processes of galaxy formation and the dark matter-galaxy connection.

In this work, we mainly focus on understanding how IA depends on galaxy properties to capture the variation of amplitudes that the signal carries in a weak lensing analysis. We use observations to directly constrain the IA in specific subsets of data. We combine the observed complexity of IA signal on galaxy sample into a single model to forecast the impact on lensing. The gain is twofold: on one hand, we provide a model that can directly be linked to observations, such that the weak lensing analyses can use priors from the literature (which are always based on specific galaxy samples); on the other hand, this can be used to study the effective IA content in a specific data-set, and then learn the level of contamination expected, to inform effective models on which amplitude should be adopted as a prior.

In the following, we summarise in more detail the content of each chapter.

In **Chapter 2** we provide a model to account for the diversity of the IA signal as sourced by different kinds of galaxies, including the dependence on morphology (here accounted via galaxy colour) and type (central/satellite). This model allows predicting the total IA in any kind of data-set, given a mock for the galaxy population that includes colour and type. We applied such a method to a simulated weak lensing survey and studied the total signal and its scale dependence. We use this simulated signal to forecast the

impact of IA on ongoing and upcoming surveys, with a particular interest in investigating whether the use of simplistic models for IA would bias the inferred cosmological parameters. We found this to be negligible for ongoing surveys, but upcoming ones need to at least include an effective redshift dependence in their modelling to recover the correct cosmology.

In **Chapter 3** we constrain the IA amplitude of the luminous red galaxy (LRG) sample in the 4th data release of the Kilo Degree Survey. We measure the shapes with two different shape measurement algorithms and compare the resulting IA signal to investigate a possible dependence on the IA amplitude on the shape method adopted. We found the methods to be compatible. We then investigate the luminosity dependence by binning the sample in luminosity bins: when analysing these in combination with previous measurements from the literature, we found that these could be well described by a double power law. At low-luminosity we found the signal to be significantly less luminosity dependent than for bright objects. We explored the redshift dependence of the signal finding no support in the data for any evolution in the redshift range $0.2 < z < 0.8$.

In **Chapter 4** we use galaxy-galaxy lensing to infer the total masses of the LRGs used in Chapter 3. We model the signal using a halo model combined with a conditional luminosity function to populate the haloes: We bin our data in luminosity and fit all the resulting lensing signals with a single model. This provides a luminosity-mass relation that we use to re-analyse the IA signal measured in Chapter 3. We find that the IA dependence on halo mass is well described by a single power law, in a mass range that spans more than three orders of magnitude. We also investigate the tendency of the surrounding galaxies to point in the direction of the LRGs: in this case, we do not detect any signal.

Finally, in **Chapter 5** we investigate the impact of weak lensing magnification in the Large Synoptic Survey Telescope (LSST). We study how much the inclusion of magnification can improve the cosmological parameter constrain in a clustering analysis: We found it to be very mild. We also considered the combined case of clustering and shear signals on separate patches of the sky and investigated whether magnification could improve the shear calibration, but also in this case the improvement was small. Finally, we considered the effect of ignoring magnification in these analyses, and this time we found a significant deviation in the signal: We thus conclude that although the improvement by the including magnification is not

significant, it is crucial to include it in the analysis to avoid biasing the cosmological parameters.