HIGHZLENS: Studying the high redshift Universe using gravitational telescopes

The research carried out during this project covers different aspects of observational cosmology and physics of galaxies, taking benefit of massive clusters used as *gravitational telescopes*. Gravitational magnification allows us to probe more distant or intrinsically fainter objects, enabling us to do the kind of research that will only be achievable with the ELTs, but using 8-10 m class telescopes and their current or soon-forthcoming instruments.
The project was divided in two parts. First, it was necessary to perform a spectroscopic survey of multiple images in order to do the modelling of the mass distribution of the lensing clusters. This provided the sample of distant galaxies over which the science can be performed, and also allow to correct the results for the gravitational lensing effect. The second part of the project studies the lensed background galaxies in great details, and use this sample to infer the evolution in the physical parameters of distant objects.

1 - Modelling of lensing clusters

In order to use lensing clusters as gravitational telescopes to study background galaxies, it is necessary to model the cluster mass distribution accurately. This is done through the identification of *multiple images* that constrain the lensing potential, as well as their redshift measurements with spectroscopy. Indeed, gravitational lensing allows a direct measurement of the mass distribution of intervening structures over a wide range of spatial scales and, unlike X-ray studies, it does so without any additional assumptions about their baryonic content or dynamical state.
During the course of the project, the researcher analyzed spectroscopic data he obtained at Keck, VLT and Magellan telescopes to measure redshifts for multiple imaged systems found in strong lensing clusters, and performed their mass modelling using the `Lenstool` lensing software. The results of this modelling are the following:

• Clusters showing a large ($\sim$ 10 or more) number of multiple systems (e.g. Abell 1703: Richard et al. 2009 ; Abell 370: Richard et al. 2010a). The redshift measurements obtained allowed to set precise constraints on the location and geometrical shape of the critical line at that redshift, giving a much higher precision when deriving the magnification factors of new lensed sources. In the near future, we shall be able to perform cosmography with such clusters: using many multiply imaged systems at distinct redshift planes, strong lensing would allow to derive purely geometric constraints on cosmological parameters. The feasibility of this technique has been demonstrated in simulations (Gilmore & Natarajan 2009) and we recently applied it to HST observations of Abell 1689 (Jullo et al. 2010, Science).

• Large samples of strong lensing clusters (Richard et al. 2010b). The researcher led a large programme of multi-object spectroscopy at Keck with LRIS for two samples of $0.2 < z < 0.5$ strong lensing clusters, MACS (MAssive Cluster Survey, PI: Ebeling) and LoCuSS (Local Cluster Substructure Survey, PI: Smith), selected out of *snapshot* images with Hubble. So far, the main publication concentrated on the statistical analysis of a sample of 20 $z \sim 0.2$ LoCuSS clusters for which parameterized models of the mass distribution in the cluster cores have been produced.

2 - Formation and evolution of galaxies at $2 < z < 5$

Adaptive optics(AO)-fed integral field units (IFUs) offer the exciting prospect of securing resolved 2-D dynamical data for very distant ($z > 2.5$) sources. As such, a major science driver for the ELTs is 2-D dynamical studies of representative $z \sim 3-5$ galaxies, combining the power of the 30m aperture and AO-fed IFUs. However, we need not wait until 2016 to attempt such observations, provided we can find magnified systems behind lensing clusters with suitably strong emission lines. Highly magnified multiple images at high redshift ($z > 2$) are intrinsically much fainter than similar sources in blank fields. But more importantly, the natural magnification gives the opportunity to study them at a resolution of $0.1 - 0.2$ kpc, otherwise unreachable.

The researcher have been highly involved in the study of ~ 20 bright strongly lensed (magnified by a factor 10 to 30) galaxies at $z > 2$, taken from my spectroscopic surveys of well-modelled lensing clusters and follow them up using SINFONI on VLT and OSIRIS on Keck with AO-LGS, in order to measure the dynamics and the locate star formation rate at very small intrinsic scales. He has gathered a measurement of the near-infrared emission line fluxes for most of these galaxies (Richard et al. 2010c, submitted to MNRAS), and started demonstrating the feasibility of this programme using OSIRIS on Keck (Stark et al. 2008, Jones et al. 2010), as well as NIFS on Gemini for a $z = 5$ galaxy (Swinbank et al. 2009).

During the second part of the program, the researcher was granted IFU observations with SINFONI/VLT to measure velocity fields and metallicities in a larger number of high redshift galaxies, doubling the current sample of lensed objects with this kind of datasets. The analysis of these data is being carried out by PhD student Rachael Livermore, in collaboration with Mark Swinbank and Richard Bower at Durham University. The researcher also proposed a new Hubble program to select H-α emitting objects at high redshift from narrow-band imaging, which has just started to produce data.

The proposed work on PanStarrs data and planning of KMOS observations has been delayed to the near future due to technical difficulties which produced a delay in getting the first PanStarrs data. Nevertheless, the researcher participated in a pilot study using current ground-based data from SDSS to detect strongly-lensed features by galaxy groups and clusters selected visually by their shape and colors. The first results obtained are very promising for when PanStarrs will produce large amounts of data in the near future. The preparation of future KMOS observations will also benefit a lot from the identification of all the multiple images in the lensing clusters, as well as the objects detected in the Hubble narrow-band imaging program.