MSc Projects 2021

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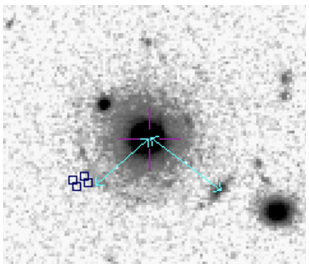
Multi-Wavelength Studies of Strong Gravitational Lensing

Problem statement. Gravitational lensing is one of the most dramatic predictions of Einstein's theory of general relativity, by which the gravitational field of a foreground object bends and focuses light rays originating from a background source. While weak gravitational lensing is ubiquitous in the Universe, the rarer strong gravitational lensing occurs when a foreground massive object (e.g. an elliptical galaxy), located between the observer and a distant background galaxy, acts as a lens on the light coming from the background galaxy. When this happens the light rays of the background galaxy are magnified, so that it appears to be brighter than it actually is as well as stretched and pulled into arcs (or multiple images) as the light passes close to the foreground object. Dark matter bends light in an analogous way to the baryonic or "visible" matter. Therefore, even though we cannot directly see dark matter, gravitational lensing allows us to measure the total (baryonic matter + dark matter) density.

For these reasons, the study of strong gravitational lensing is a powerful tool for observational cosmology, as it is one of the few probes capable of directly mapping the dark matter distribution, providing independent cosmological parameter estimates while also enabling the study of individual galaxies which are otherwise too faint for detailed analysis. Lensing is therefore one of the most powerful tools to study very distant galaxies and to probe galaxy evolution and the mass distribution of our Universe up to high redshift.



Aims & Objectives. An ongoing Hubble observing program and coordinated SALT spectroscopic program are pioneering a new strong gravitational lens selection method, combining Herschel Space Observatory observations with multi-wavelength ancillary data, generating a large sample ($\sim$ 500 sources) of lens candidates and obtaining SALT spectroscopy and Hubble imaging (see figure) for the most promising ones. This selection method has already proven to be highly effective and is providing the most interesting and accessible candidates for ALMA and IRAM-PdB/NOEMA follow-ups.
In this project, the student will have the opportunity to work with archival multi-wavelength data as well as these new HST/SALT data in order to analyse the physical properties of these sources and their environment. There are a number of scientific questions that can be investigated by mean of these data as well as a number of different approaches that could be undertaken, some more theoretical other more based on observations. Therefore this project can accommodate more than one student projects. The envisaged work in this context could involve any of the followings:

1. The construction of a cloud-based pipeline for the data reduction of the SALT and HST spectroscopic and photometric follow-ups of the lensing candidates.

2. The actual data reduction of the SALT and HST data taken in the program mentioned above.

3. The assessment of the nature of the phenomena by visually inspecting the spectra and the images to search for the presence of lensing features (e.g. the presence of overlapping spectra at a single pointing, the presence of multiple images or arcs in the HST images).

4. For those objects in which it is possible to confirm the lensing nature, it will be possible to proceed to the lens modelling using tools available from the literature like pyautolens (Nightingale et al. 2018). In this way the image of the background galaxy will be reconstruct and the mass content of the galaxy acting as a lens will be constrained.

5. For those objects in which it is not possible to confirm the lensing nature, as the HST/SALT images/spectra might not be deep enough or not sensitive to the redshifted emission of very high redshifts lensed candidates, there will be the opportunity to compile a plan for multi-wavelength follow-ups with ALMA and other ESO facilities such as the VLT.

6. The search for very rare un-lensed "extreme" starbursts (HyLIRGS) whose existence poses a fundamental problem for semi-analytic models of galaxy formation, but who are very difficult to find in other ways.

Some background in python scripting, programming and astronomical observations/data reduction is desirable.

The student will be supervised by the leader of the Hubble and SALT observing programs (Lucia Marchetti) and will also have a chance to be advised/co-supervised by national (Prof. Tom Jarrett, UCT) and international colleagues (e.g. Dr Mattia Negrello from Cardiff University, Dr Andrea Enia from Padova University) and contribute to international collaborations (e.g. the NOEMA *ZGAL* large program).

Potential impacts
This impacts of these studies are many:

1. a statitstical analysis of the the sub-mm selected lensing phenomena.

2. a better understanding of the dark matter content in lensing galaxies.

3. the possible identification of very rare Hyper Luminous InfraRed Galaxies (HyLIRGS).

4. a better understanding of the nature of very high-redshifts galaxies.

Alignment with National Imperatives
This project aligns with the following national imperatives:

1. NRF Broad Category:

   (a) Environmental, Material, Physical and Technology. Our research aims to exploit observations of the sky at various wavelengths to better understand the physical processes at play in the Universe.

2. National Priorities:

   (a) Job creation: Graduate training in astronomy will contribute to nurturing a new generation of professional Astronomers and data scientists.

   (b) Transformation: the scientific goals of this project aim to promote transformation in science by nurturing a new generation of researchers with the skills that are the basis for South Africa's development in science and technology.

3. National Strategies:

   (a) Grand Challenge – Astronomy: this project addresses SA's parallel needs to promote research excellence and innovation and drive human capital development and transformation identified as part of DSI/NRF's national strategy for multi-wavelength astronomy.

4. Sustainability Development Goal:

   (a) Quality Education: Graduate training in astronomy and STEM subjects will contribute to increasing the offer of quality education for all.

National Infrastructure Platforms
This project will make use of SALT and the IDIA/Ilifu cloud facility.

References :
- Peter Schneider, "Extragalactic Astronomy and Cosmology: An Introduction", Springer, Section 3.8 Galaxies as Gravitational Lenses
- Negrello et al. 2010, Science, 330, 800
- Gonzalez-Nuevo et al. 2012, ApJ, 749, 65
- Negrello et al. 2017, MNRAS 465, 3558–3580