MSc/PhD Project 2024

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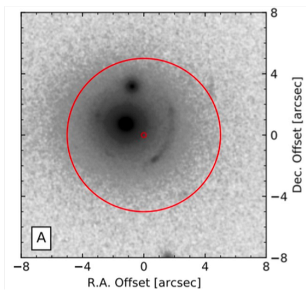
Multi-Wavelength Studies of Strong Gravitational Lensing

Background: 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.

The project: We have recently completed an Hubble observing program (see image) and coordinated SALT spectroscopic program pioneering a new strong gravitational lens selection method, combining Herschel Space Observatory observations with multi-wavelength ancillary data, generating a large sample (~ 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/lensing properties of some of the sources. The main scientific focus of the project can be agreed together with the student according to her/his main interest. The analysis is by nature modular and can therefore accomodate both honours and MSc projects. Some background in VO tools, python scripting, programming and astronomical observations/data reduction is desirable. The student would also have the opportunity to learn lens modelling codes such as LensAstronomy (`https://github.com/lenstronomy/lenstronomy`) and pyautolens (`https://pyautolens.readthedocs.io/en/latest/`) as part of this project.



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 co-supervised by Dr Mattia Negrello from Cardiff 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
- Gonzalez-Nuevo et al. 2019, A&A 627, A31
- Negrello et al. 2017, MNRAS 465, 3558–3580