Strong lensing; towards a pipeline from discovery to modeling

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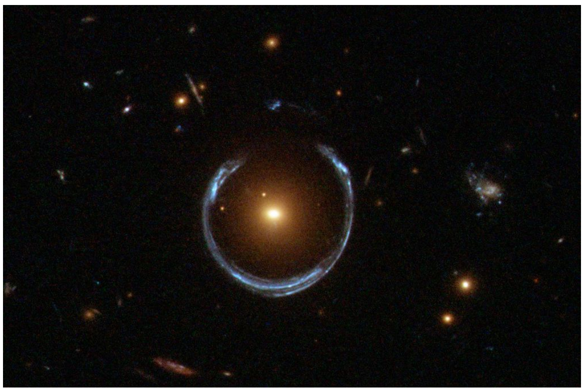
1 Astronomical background

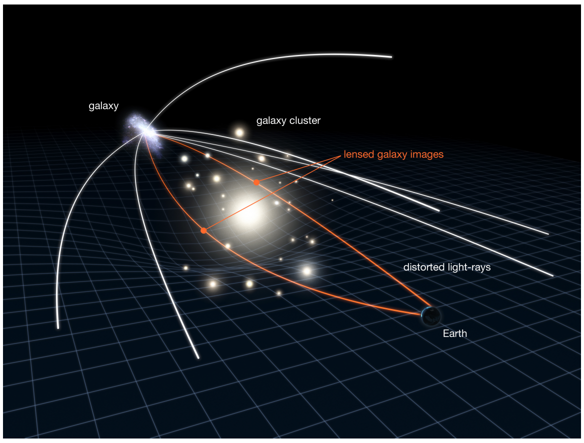
Strong gravitational lensing is a phenomenon in physics and astrophysics that occurs when the gravitational field of a massive object, such as a galaxy or a cluster of galaxies, bends and distorts light from a more distant object behind it. This bending of light can result in multiple distorted and magnified images of the background object. This forms a "lens-like" appearance, hence the term "gravitational lensing."

The gravitational bending of light is caused by the warping of space-time around massive objects (as predicted by Einstein's theory of general relativity). When light from a background source passes through the gravitational field of a massive object, such as a galaxy or a galaxy cluster, it follows a curved path due to the gravitational pull. As a result, the light can be deflected and focused toward the observer.

Strong gravitational lensing is called "strong" because it produces noticeable and often dramatic effects, such as the formation of multiple images, rings, and arcs of light around the lensing object, such as in figure 1a. These lensing effects can provide valuable information about the mass and distribution of matter in the lensing object, as well as the properties of the background source, such as its distance, size, and shape. Strong gravitational lensing has been widely used in astrophysics to study the properties of distant galaxies, galaxy clusters, and the large-scale structure of the universe, and it has provided important evidence for the existence of dark matter and dark energy.



(a) Galaxy LRG3-757, a typical example of a strongly lensed galaxy. The lensing can be quickly identified because of the clear ring shape. Credit: ESA/Hubble.



(b) An infographic explaining gravitational lensing. Credit: ESA.

Figure 1: Images depicting gravitational lensing.

2 Current state of the field

Astronomers studying gravitational lenses generally have two goals; first, they want to find strong lenses in large amounts of data, and second, they want to model these lenses. For both steps, deep learning algorithms are implemented. To optimize this process, a future goal is to create one pipeline that can do both processes back to back. However, currently, human intervention is still needed. This is becoming increasingly difficult since the amount of data gathered by telescopes is increasing exponentially. With sky surveys like *Euclid* launching in a couple of years, human intervention will become nearly impossible.

One paper proposing such a pipeline is Savary et al. (2022) [1]. In this study, 2344002 images of potential lensed galaxies were put through a convolutional neural network that was trained on a mix of simulated lenses and known lensed galaxies. The algorithm selected 10 000 possible lensed candidates. After visual inspection, the researchers found that only 130 galaxies were actual lenses.

3 Thesis goal

The main goal of this thesis will be to improve the results from Savary et al. (2022). In the original paper, only one color image per galaxy was used. This means that the image of each galaxy only contained red wavelengths. However, often lensed galaxies have a red center and a blue ring around them. To improve the existing machine learning algorithm, I will include color information by expanding the neural network. This can be done with a process called multitask learning. Multitask learning is a type of machine learning where a model is trained to perform multiple related tasks simultaneously, using a shared set of features or representations. In other words, instead of training separate models for each task, a multitask learning approach trains a single model to perform multiple tasks jointly, leveraging shared information across tasks to improve the overall performance.

My personal goal is to do more research in astrostatistics because for me that is the perfect intersection between astronomy and statistics.

References

[1] E. Savary, K. Rojas, M. Maus, B. Clé ment, F. Courbin, R. Gavazzi, J. H. H. Chan, C. Lemon, G. Vernardos, R. Cañameras, S. Schuldt, S. H. Suyu, J.-C. Cuillandre, S. Fabbro, S. Gwyn, M. J. Hudson, M. Kilbinger, D. Scott, and C. Stone. Strong lensing in UNIONS: Toward a pipeline from discovery to modeling. *Astronomy &amp Astrophysics*, 666:A1, sep 2022.