I. semester report

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Thesis title: Advanced morphological analysis of spiral galaxies in the LSST era

Problem statement

My research focuses on galaxy morphology, which studies the shape and internal structure of galaxies in order to understand the processes that formed them [1]. Traditionally, the shape of galaxies has been described by visual classification or by relatively simple models, such as fitting mathematical curves to the brightness of the galaxy (so-called parametric methods) [2, 3, 4]. Other techniques include non-parametric measurements, which attempt to capture general patterns without relying on specific models. More recently, astronomers have begun to use machine learning to deal with the huge number of galaxies in modern surveys [5, 6].

One of the most exciting new tools for exploring this topic is the Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST) [7], which is expected to be one of the most ambitious sky surveys ever undertaken. During its ten years of observations of the southern sky, it will capture deep, wide-field images, collecting a large volume of data – around 20 terabytes every night. Thanks to its depth and resolution, the LSST will allow galaxies to be studied in much greater detail and over a larger area of the sky than ever before.

The main goal of this research is to develop a fast, scalable and reliable Python-based toolkit for analyzing the morphology of spiral galaxies in LSST images. A key challenge for LSST – with billions of galaxies expected to be included – is the sheer volume of data. My research focuses on creating a data processing pipeline that supports real-time or near real-time analysis, exploits parallel computation where possible, and is capable of operating at scale. The pipeline will integrate classical morphological measurements (e.g., Sérsic index fitting, concentration, asymmetry and clumpiness), as well as machine learning techniques for automatic classification and feature extraction.

There is also an opportunity to become involved in the international research community around the LSST project. The LSST Science Collaborations are working groups that tackle specific scientific goals. Engaging with these Science Collaborations can offer access to resources and feedback. Participation in the Galaxies Science Collaboration could amplify the impact of this research.

Research activities in the semester

In the first semester, I worked on implementing the methods published in "Automatic Morphological Classification of Galaxies" [2] in a modern Python environment. The result is a prototype library capable of de-projecting galaxy images (to approximate a "face-on" orientation), measuring their radial brightness profile, fitting (de Vaucouleurs) bulge- and (exponential) disk profiles, "unwinding" the spiral structure using log-polar transformation, determining the angle of spiral arms, and calculating a 1D profile of the spiral structure by collapsing the log-polar representation along the determined spiral arm angle. From the resulting 1D profile, it can determine the power of each spiral mode through Fourier analysis. During the execution of those steps, the tool determines simple morphological parameters, such as position- and inclination angles, half-light radius, disk-to-bulge ratio, angle of spiral arms and the relative power of various modes in the spiral structure.

Implementing the above involved the challenges of familiarizing myself with de-facto standard astronomical libraries (e.g., `astropy`, `photutils`), applying the routines provided by them, and providing my own implementation for the tasks not directly supported by them while avoiding prohibitive runtimes.

The implementation was tested on images of the Frei catalog [3], which contains reasonably well-resolved galaxies of larger angular sizes. On these images, the tool performs well in most cases. Still, to resolve some remaining issues – and as a preparation for extending support to galaxies with lower brightness and smaller angular sizes – I started building a test catalog of galaxy images from various more recent surveys, such as data from the Hyper Suprime-Cam [8] and the DAWN JWST Archive. To use images from these sources also required implementing support for bias-, dark- and flat-calibration of raw images. Testing on this catalog revealed a lack of robustness, specifically in utilizing image moments to determine position- and inclination angles, and the angle of spiral arms. Resolving these inconsistencies is a key next step.

During the semester, I joined the LSST Galaxies Science Collaboration, where I can follow a wide range of extragalactic research activities on LSST data, and eventually contribute and discuss my own results. I gained access to the Rubin Science Platform, where I can familiarize with the LSST pipeline, and eventually access the data products to be released in the future.

Publications

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Completed courses

- `[FIZ/5/019]` Cosmology (Kozmológia)
- `[csgalcsil1g17em]` Galactic astronomy 1 (Galaktikus csillagászat 1)
- `[cselmafiz1g17em]` Theoretical astrophysics 1 (Elméleti asztrofizika 1)

Participation in conferences

- Attended (online): Rubin Observatory Community Workshop 2025, Tucson, Arizona, USA
- Attended: 4th Regional LSST Workshop at HUN-REN CSFK Konkoly Observatory, Budapest, Hungary

References

[1] Christopher J. Conselice. “The Evolution of Galaxy Structure Over Cosmic Time”. In: *Annual Review of Astronomy and Astrophysics* 52 (Aug. 2014), pp. 291–337. DOI: `10.1146/annurev-astro-081913-040037`. arXiv: `1403.2783 [astro-ph.GA]`.

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[3] Zsolt Frei et al. "A Catalog of Digital Images of 113 Nearby Galaxies". In: *Astronomical Journal* 111 (Jan. 1996), p. 174. DOI: 10.1086/117771. arXiv: astro-ph/9510062 [astro-ph].

[4] Jennifer M. Lotz, Joel Primack, and Piero Madau. "A New Nonparametric Approach to Galaxy Morphological Classification". In: *Astronomical Journal* 128.1 (July 2004), pp. 163–182. DOI: 10.1086/421849. arXiv: astro-ph/0311352 [astro-ph].

[5] M. Huertas-Company et al. "A Catalog of Visual-like Morphologies in the 5 CANDELS Fields Using Deep Learning". In: *The Astrophysical Journal Supplement* 221.1, 8 (Nov. 2015), p. 8. DOI: 10.1088/0067-0049/221/1/8. arXiv: 1509.05429 [astro-ph.GA].

[6] H. Domínguez Sánchez et al. "Improving galaxy morphologies for SDSS with Deep Learning". In: *Monthly Notices of the Royal Astronomical Society* 476.3 (Feb. 2018), pp. 3661–3676. DOI: 10.1093/mnras/sty338. arXiv: 1711.05744 [astro-ph.GA].

[7] Željko Ivezić. "LSST: From Science Drivers to Reference Design and Anticipated Data Products". In: *The Astrophysical Journal* 873.2, 111 (Mar. 2019), p. 111. DOI: 10.3847/1538-4357/ab042c. arXiv: 0805.2366 [astro-ph].

[8] Satoshi Miyazaki et al. "Hyper Suprime-Cam: System design and verification of image quality". In: *Publications of the Astronomical Society of Japan* 70 (Jan. 2018), SP1. DOI: 10.1093/pasj/psx063.