Star Formation Histories of galaxies from deep multi-color images

Thesis advisor: Laure Ciesla
Email and address: laure.ciesla@lam.fr
Laboratoire d'Astrophysique de Marseille -Technopôle de Marseille-Etoile
38 rue Frédéric Joliot-Curie
13388 Marseille cedex 13 - France
Tel: +33-(0)4-91-05-59-50
HDR: no

Co-advisor: Olivier Ilbert
HDR: yes

Subject's title: Star Formation Histories of galaxies from deep multi-color images

Subject description:
One major challenge in observational cosmology is to understand how galaxies formed their stars along cosmic time. How a primordial cloud of gas could become a huge rotating system including billions of stars? What are the physical processes which govern the star formation rate? Is star formation history (SFH) linked to the galaxy morphological transformation? The thesis will participate in elucidating these questions by interpreting a massive dataset.
In the last decade, huge galaxy samples have been established with millions of galaxies observed from the ultra-violet to the far-infrared. We propose to work with one of the best sample available today to study galaxy evolution, i.e. the COSMOS survey. We created a catalogue with >1 million of galaxies observed in 30 bands (COSMOS2020, Weaver et al. 2021), with the best telescopes and methods available today, including galaxies as distant as z~8-9 (the light from these galaxies has been emitted when the Universe was only 700 million years old).
One of the main difficulty to understand galaxy evolution is that we don't follow the same galaxies over cosmic time : we see different galaxies at different epochs, and we try to connect these pictures of the Universe taken at different times. We could solve this problem by being able to reconstruct the SFH of an observed galaxy. Although methods have been recently develop to recover the recent SFH (Aufort et al. 2020; Ciesla et al. 2021), we don't have such a robust method, able to recover several billions years of history yet. In this thesis, we propose to overcome this problem : we plan to develop a new approach based on unsupervised machine learning to accomplish this challenging task. At the beginning, we rely on Self organizing Maps methods, but other methods will be investigated. We will first calibrate this method on cosmological simulations (Horizon-AGN simulation, Laigle et al. 2019). Preliminary results look promising (from the internship of K. Jegatheesan). We will study the reliability of our approach, and then apply it to the COSMOS data. The thesis will happen at a perfect timing with the launch of JWST. Our team will have access to the largest cycle 1 JWST accepted proposal, COSMOS-Webb. The student will benefit from this exquisite set of data putting additional key constraints on the SFH of galaxies and revealing the morphology of thousands of galaxies. We will be particularly interested in extreme events in the histories, like burst of star formation forming hundreds of stars per year, or a sudden suppression of any star formation activity in massive galaxies. Once we will have reconstructed the SFH of

our real COSMOS galaxies, we will have a unique sample in hand to study galaxy evolution. We will be able to understand how SFH depend on the galaxy morphology associating Hubble and James Webb space telescopes images, on the environment, on the energy radiated away by Active Galaxy Nuclei, etc. Such sample could open new avenues in our understanding of galaxy evolution.
Finally, we will also investigate if such approach could be applied to future surveys like the future space mission Euclid, or the imaging data from the LSST.

Bibliography:
Weaver et al. (2021) arXiv:2110.13923 — Ciesla et al. (2021) A&A,653A,6C — Aufort et al. (2020)A&A,635A,136A — Davidzon et al. (2019) MNRAS.489.4817D — Laigle et al. (2019) MNRAS.486.5104L — Ciesla et al. (2018) A&A,615A,61C — Davidzon et al. (2017) A&A,605A,70D — Laigle et al. (2016) ApJS,224,24L

Please provide a brief justification of the scientific importance of the subject and/or its strategic interest for LAM:
Star formation histories (SFH) plays a key role in most of observational extragalactic studies at it is one of the main hypothesis one has to make to derive the fundamental stellar mass and star formation rate measurements. Reconstructing galaxies SFH individually is thus of paramount importance to derive their physical properties. But above all this, constraining galaxies SFH is by definition studying the lifetime of galaxies and the mechanisms that impacted it (strong bursts or quenching of star formation). Naturally, a lot of effort is dedicated to the SFH reconstruction within the community, and the progresses made in the last decade in the quality of statistical analysis and codes make it possible. LAM has a strong expertise in this topic with two leading efforts: Olivier Ilbert (OI—and collaborators from IAP and COSMOS team) and Laure Ciesla (LC — with V. Buat & the CIGALE team). The proposed thesis will bring together these two approaches and strengthen LAM's influence on this aspect of galaxies evolution. Furthermore, with the launch of JWST and the acceptance of the COSMOS-Webb program for which OI and collaborators are responsible for the catalogue building, LAM will be at the forefront of the field in terms of both methods and data. This work is also a preparatory work to exploit scientifically the Euclid Deep fields.

Please provide a brief explanation about why the proposed subject is timely, and include an indication of the expected scientific landscape within 3 to 5 years after the defense:
This call for thesis proposals corresponds to the best timing for two reasons:
1) Launch of JWST: if everything goes as planed regarding JWST, the thesis will start while COSMOS-Webb data will be in acquiring phase. Then data reduction and catalogue building will provide enough time for the student to work and test the method to reconstruct star formation histories on simulations. Based on our on-going work and preparation, we expect that, once the COSMOS-Webb catalogue is ready, the student will have made enough progress to test his/her method on these new data.
2) Group dynamics: with our close collaborators from IAP (C. Laigle and H. J. McCraken), we obtained a postdoc[1] that will be based at IAP, with visits at LAM, on a complementary project. The postdoc is expected to start in Sept. 2022 for 2

[1] https://ipi-sorbonne-universite.fr/campagne-dattribution-des-contrats-post-doctoraux-ipi-2021-resultats/

years. A start of the thesis at the same time will greatly benefit the student as there will be an enhanced group activity at this period.

If JWST is not operational: In case of a dramatic event, the thesis will not suffer from the loss of JWST data. The proposed thesis was defined before knowing the acceptance of the COSMOS-Webb program. The COSMOS2020 catalogue is a state-of-the-art multi-wavelength data product from which the defined science goals can be reached with or without JWST data. In the absence of these data, the end of the thesis will then be focused on calibrating and preparing the SFH reconstruction method for Euclid and LSST observations.

Three or 5 years after the PhD defense, we do not expect any decrease in the community interests for studies regarding the SFH of galaxies. JWST, Euclid and LSST will be among the most important project in galaxy evolution in the next decade, offering to the student many opportunities. We do not expect difficulties in continuing in the topic after the thesis nor in finding a postdoc position, if this is what the student wishes to do.

Please provide a brief description of the work environment (resources, collaborations…) of the thesis:

The student will join the international COSMOS collaboration and will therefore have access to a wealth of ancillary data, especially data from the JWST cycle 1 COSMOS-Webb proposal. It is a very dynamic scientific environment with close collaborations with IAP (France), DAWN (Denmark), and Caltech (USA). Furthermore, as already explained, a postdoc will start in Sept. 2022 at IAP with planned visits at LAM. We expect the postdoc and the student of the proposed thesis to work in close collaboration. At LAM, the student will benefit from the expertise of OI, LC, but also V. Buat regarding SFH. Regarding machine learning, the GECO team developed some expertise in this field with collaboration with the I2M laboratory (P. Pudlo) but also through the ANR of S. Arnouts and the technical expertise of the CeSAM. The student will find all the support needed to pursue his/her project.

For resources, LAM receives recurrent funding from CNES every year to support the French part of the COSMOS collaboration. This funding will cover missions/ conferences expenses of the student as well as his/her equipment.

Please indicate if other (co-)funding has been requested/accepted:

No co-funding has been requested for this subject.

Please provide information about ongoing and past (over a 10 years period) supervision(s):

- L. Ciesla supervised two Master 2 internships that both led to a publication (Aufort, LC, et al. 2020; Hamed, LC, et al. 2021) and never supervised a PhD thesis.
- O. Ilbert co-supervised at 50% two PhD students: T. Moutard got a CNES followship (2012-15) to work on Euclid photo-z & O. Kauffmann (2017-20) to work on MIRI and COSMOS2020. He also supervised two postdocs (I. Davidzon 2015-17) & T. Moutard (2021-now) and >15 internships in the last 10 years.