PhD thesis: Radiative-transfer modelling of strongly-lensed supernovae

Location

- **Main location :** Laboratoire d'Astrophysique de Marseille (LAM), Marseille, France
- Possibility to spend part of the PhD at the European Southern Observatory (ESO) in Garching, Germany (TBD)
- Regular collaboration visits to the Garching research campus near Munich, Germany

Funding

- International grant awarded by the *French Agence Nationale pour la Recherche* (ANR)
- The German *Deutsche Forschungsgemeinschaft (DFG), SuperEarly:* Constraining Supernova Progenitors through Strong Lensing in the Rubin LSST Era

Dates & duration

- Desired starting date: September 1st 2026
- Duration: 3 years

Supervisors

- Jean-Claude Bouret (LAM), research director
- Stéphane Blondin (ESO/LAM), astronomer and senior researcher

Collaborators

- In France: Raoul Cañameras (LAM), Luc Dessart (IAP)
- In Germany: Stefan Taubenberger (TUM), Sherry Suyu (TUM/MPA)

Context : Understanding supernovae (SNe) is crucial given their important role as cosmological probes, heavy-element factories, and sources of kinetic energy in galaxy evolution. However, the nature of SN progenitors and the mechanisms by which different types of stars explode remain the subject of ongoing debate. One major hurdle is the lack of appropriate observational data, both sufficiently close in time to the explosion and at sufficiently short wavelengths (rest-frame UV), which exhibit the largest signatures of the exploding star (radius, surface composition and pre-explosion mass loss) and its potential binary companion.

A strongly lensed SN offers a unique opportunity to access this observational sweet spot. When a SN is strongly lensed by a foreground galaxy, multiple images of the explosion will appear at different times. By detecting such an event based on the first appearing SN image, one can use the predicted time delays between the multiple images to catch the SN right at the moment of its next appearance, and hence access the first hours/days of its evolution. Moreover, the magnification of lensed SNe enables the discovery and follow-up of high-

redshift events, whose rest-frame UV radiation can be observed with ground-based facilities at optical wavelengths.

Proposed work : The upcoming Vera Rubin Observatory will discover more than 100 lensed SNe of all types with sufficiently long and accurately determined time delays during its ten-year Legacy Survey of Space and Time (LSST). Our three-year project will allow us to obtain the earliest rest-frame UV observations of SNe ever made. Our complementary expertise in deep-learning classification, lens and SN modelling, combined with our access to LSST data and follow-up facilities, will yield unprecedented constraints on the progenitors of all types of SNe shortly after they explode.

Our project is inherently interdisciplinary as it relies on the combination of machine-learning algorithms, astronomical observations, and numerical simulations, to reach our targeted goal of constraining supernova progenitors. These various tasks will be distributed among the French and German partners. **The PhD student at LAM will focus on radiative-transfer modelling of supernovae.** We will compute synthetic spectra and light curves of various supernova types at early times, to compare with the observations of lensed SNe to be discovered by Rubin/LSST. We will use the radiative-transfer code CMFGEN to post-process previously published explosion models, e.g., such as those available for SNe Ia on the HESMA archive (https://hesma.h-its.org). We will also carry out an extensive exploration of the predicted observable properties of existing radiative-transfer simulations computed by our group and available on the Zenodo repository (https://zenodo.org/communities/snrt/).

The PhD student based at LAM will spend the first few months selecting the SN models to run, under the supervision of J.-C. Bouret and S. Blondin, who will also provide training for the CMFGEN code. Preliminary model runs will be performed on the local computing cluster at LAM, before running more extended model grids. The resulting library of early-time synthetic SN spectra will serve as the basis for the data analysis and will have a value for the community.

Team & Environment : Our proposed project builds upon the results from the HOLISMOKES program that was funded by the European Research Council until May 2024. The PI of that program, Sherry Suyu (TUM/MPA), is also part of the project team. At LAM, in addition to the supervisor J.-C. Bouret, the PhD student will also work closely with postdoc Raoul Cañameras (expert on deep-learning algorithms to search for lensed supernovae) and an additional postdoc to be recruited for this project. There will be regular collaboration visits (twice per year) to our German collaborators on the Garching campus near Munich, Germany. There would also be a possibility for the student to spend part of their PhD (up to 1-2 years, TBD) at the European Southern Observatory (ESO) on the same campus, where the co-supervisor S. Blondin is also located. The PhD student will benefit from full data access rights to the Rubin/LSST project.

References

Blondin, S. et al. 2022b. 'StaNdaRT: A Repository of Standardised Test Models and Outputs for Supernova Radiative Transfer'. *A&A* 668: A163. DOI, arXiv

Cañameras, R. et al. 2024. 'HOLISMOKES: XI. Evaluation of supervised neural networks for strong-lens searches in ground-based imaging surveys'. *A&A* 692: A72. DOI, arXiv

Dessart, L. et al. 2016. 'Models of Interacting Supernovae and Their Spectral Diversity'. *MNRAS* 458: 2094–2121. DOI, arXiv

Hillier, D. J. and L. Dessart. 2012. 'Time-Dependent Radiative Transfer Calculations for Supernovae'. *MNRAS* 424 (1): 252–271. DOI, arXiv

Suyu, S. H. et al. 2020. 'HOLISMOKES. I. Highly Optimised Lensing Investigations of Supernovae, Microlensing Objects, and Kinematics of Ellipticals and Spirals'. *A&A* 644: A162. DOI, arXiv

Keywords: Supernovae – Gravitational lensing – Radiative transfer – Deep learning – Transient surveys