Thesis subject

Laboratory : Laboratoire d'Astrophysique de Marseille

Thesis supervisor : Annie ZAVAGNO

Co-supervisor :

Title of the thesis subject : Quantifying the effect of early radiative feedback from high-mass stars on star formation

Description of the thesis subject :

Massive O and B stars ($M_* \geq 8\ M_\odot$) have a profound impact on their surrounding medium all along their life through their radiation and wind. Recent JWST-MIRI images of nearby galaxies, like that of the Phantom galaxy (NGC 628)[1], show how important this impact is in shaping the surrounding molecular medium. However, despite dedicated observation programs, little is known on the physics of this feedback and its evolution as a function of time and physical conditions of the medium where star formation occurs. In particular, the impact this feedback might have on star properties is highly debated. Is this impact constructive (favoring or accelerating the formation of new stars) or destructive (dispersing the gas and halt further star formation)? Numerical simulations tend to conclude that this feedback is destructive[2,3] while observations indicate the opposite, even favoring the formation of a new generation of high-mass stars observed at the edges of ionized (H II) regions formed by high-mass stars[4,5].

The aim of this PhD is to quantify the effect of feedback from high-mass stars by using results of dedicated numerical simulations combined with multi-wavelength and multi-scale observations. Understanding the importance of feedback on the molecular medium in galaxies is of key importance because it strongly impacts the way the gas will be converted into stars. This drives the star forming laws, such as the Kennicutt-Schmitt law[6] that is a key ingredient of galaxy evolution models.

The first part of the PhD will consist in determining the way the physical conditions (turbulence, magnetic field, density, temperature) impacts the feedback from high-mass stars. Different H II region morphologies (such as compact H II regions, bipolar H II regions, hub-filament systems) will be studied in details. In particular, the properties of their associated environment will be analyzed.
The second part of the PhD will consist in following the time evolution of the feedback, from the most compact stages of their evolution up to the impact of large and diffuse regions. This

evolution timescale is also poorly known and is important to constraint because it is directly linked to the star formation process timescale.

All the data needed for this PhD work are available through open archives and privileged access to large programs (such as the ALMA ATOMS[7] program) thanks to our ongoing international collaborations. We will use observational data of the Galactic plane that probe *the stellar content* of H II regions (optical, near infrared), *the young stellar object content* (from the near infrared to the millimeter domain), both in imaging and spectroscopy. The dynamics of the gas will be studied using spectroscopy, both in the optical (for the ionized gas) and in the millimeter (for the molecular gas).
Results of the dedicated numerical simulations will be available from the PhD work of P. Suin (defense in September 2025) and the ongoing collaboration with P. Hennebelle (CEA, Saclay) on numerical simulations of radiative feedback from high-mass stars.

The main output of this PhD work will be the first quantification of the radiative and wind feedback from high-mass stars as a function of the physical conditions that prevail in the surrounding medium and as a function of time on different spatial scales ranging from the milli-parsec to the > 10 pc scale. This will allow us to bridge the gap between our understanding of the feedback process using the resolved star formation observed in our Galaxy to the ~30-50 pc scale resolution obtained in nearby galaxies with the James Webb Telescope[1].

References :

1) E. J. Watkins, A. T. Barnes, K. Henny, et al., "PHANGS-JWST First Results: A Statistical View on Bubble Evolution in NGC 628," ApJL 944, L24 (2023). DOI.
2) S. Walch, A. P. Whitworth, T. G. Bisbas, et al., "Clumps and triggered star formation in ionized molecular clouds," MNRAS 435, 917–927 (2013). DOI.
3) S. Geen, J. Rosdahl, J. Blaizot, et al., "A detailed study of feedback from a massive star," MNRAS 448, 3248–3264 (2015). DOI.
4) L. Deharveng, F. Schuller, L. D. Anderson, et al., "A gallery of bubbles. The nature of the bubbles observed by Spitzer and what ATLASGAL tells us about the surrounding neutral material," A&A 523, A6 (2010). DOI.
5) S. Zhang, A. Zavagno, A. Lopez-Sepulcre, et al., "H II regions and high-mass starless clump candidates. II. Fragmentation and induced star formation at 0.025 pc scale: an ALMA continuum study," A&A 646, A25 (2021). DOI.
6) J. Kennicutt, Robert C., "The Global Schmidt Law in Star-forming Galaxies," ApJ 498, 541–552 (1998). DOI.
7) S. Zhang, T. Liu, K.Wang, et al., "ATOMS: ALMA three-millimeter observations of massive star-forming regions - XVIII. On the origin and evolution of dense gas fragments in molecular shells of compact H II regions," MNRAS, in press (2024). DOI.