Postdoctoral position
Energy budget of galaxies

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Scientific context – The build-up of galaxies is regulated by a complex interplay between gravitational collapse, galaxy merging, and feedback related to AGN and star formation. All these processes regularly inject massive amounts of mechanical energy in the interstellar gas, generating a highly turbulent multiphase environment. This release of energy has to dissipate for the gas to cool, condense, and form stars. Yet, how the gas cools and in which phase the mechanical energy dissipates are still open questions. In this context, the observation of molecules in galaxies is a challenging providence. Because of the intermittent nature of turbulence, dissipation occurs in bursts through the formation of coherent dynamical structures that alter the molecular composition of the gas. By radiating a substantial amount of the initial mechanical energy, molecular emission lines are not only tracers of dissipative processes but contributors to the gas cooling. This link between turbulent dissipation and molecular line emission is at the root of the ERC project MIST.

Recent achievements – Quantifying the impact of turbulent dissipation on observational tracers requires dedicated models that follow the non-linear couplings between dynamics and chemistry. In the MIST project, dissipative structures are studied with the Paris-Durham shock code[1], a state-of-the-art model developed to study the physics of molecular shocks. The recent developments of the model to shocks irradiated by an external or a self-generated UV field (Godard et al. 2019; Lehmann et al. 2020) allows to study the impact of dissipative structures in a wide variety of environments including diffuse and dense gas bathing in regions of low or high star formation activity.

One remarkable application is the interpretation of molecular lines detected in extragalactic environments. The model was combined with a radiative transfer code to quantify the emission and absorption of an ensemble of shocks in galaxies located at any redshift (Lehmann et al. 2021). Such a tool allowed to estimate the mechanical energy required to explain the CH^+(1-0) emission line observed in the Eyelash starburst galaxy (Falgarone et al. 2017) and to predict the counterpart in tens of other atomic and molecular tracers (including Lyα, H_2, and CO). In spite of what intuition dictates, molecules can be highly resilient: strong external UV radiation field and dissociative shocks boost the emission of several molecular lines which become new quantitative tracers of the mechanical energy budget of galaxies.

Objectives – In the following years, we intend to extend this pioneering work to interpret the emission lines of H_2 detected by the *Spitzer* satellite in different types of galaxies (Fig. 1). The rotational and rovibrational lines of H_2 are the most efficient molecular coolant of gas heated by mechanical energy. Moreover and as shown in Fig. 1, the first rotational lines of H_2 integrated over entire galaxies radiate, in many sources (above the blue dashed line in Fig. 1), a total power that cannot be explained by the sole reprocessing of the available UV radiative energy (e.g. Guillard et al. 2009). These results show that H_2 lines can be unambiguous tracers of turbulent dissipation. As the *JWST* will give access to the observations of infrared lines of H_2 in hundreds of galaxies, a quantitative interpretation of ancillary data is of paramount importance. In particular, the existing data already allows to

1. derive the mechanical energy required to explain the rotational and rovibrational emission of H_2 detected in a wide variety of galaxies, and

2. explore observational and theoretical tendencies by comparing different samples (e.g. starbursts galaxies and AGN).

[1] available on the ISM plateform http://ism.obspm.fr.

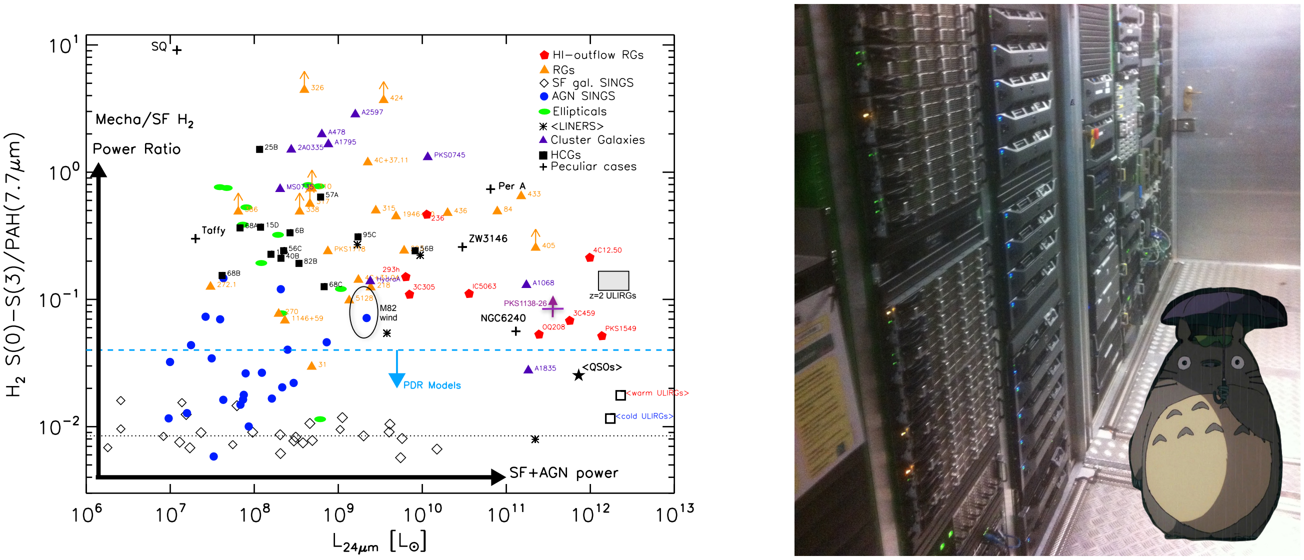

Figure 1: (Left) Ratio of the mid-IR H_2 line (summed over S(0) to S(3)) to the PAH 7.7μm luminosities vs. 24μm continuum luminosity (Guillard et al. 2015). This ratio traces the relative contributions of mechanical and radiative heating for a wide variety of galaxy types. (Right) Picture of the computing cluster *Totoro* composed of 16 nodes of 40 last generation intel processors.

Required skills – We are looking for a candidate with a good background in physics and astrophysics along with computational skills in python or fortran. An observational or theoretical expertise of extragalactic environments would be an invaluable asset to the project.

Perspectives – The interpretation of ancillary data will be followed by the analysis of the first data collected by the *JWST*. The *JWST* will allow to observe the infrared rovibrational lines of H_2 with a sensitivity and a spatial resolution 100 to 1000 times greater than *Spitzer* and *VLT/SINFONI/KMOS*, and will therefore open the possibility to spatially and spectrally resolve H_2 line emission in the population of galaxies explored in this project.

Application procedure – The postdoctoral position is a two years contract of full-time employment at ENS (Paris) **starting in 2022**. An extension to a third year is possible. Applications including

- a CV with a complete list of publications,
- a statement of past and current research (max 2 pages),
- one letter of recommendation and two references who can be contacted for verbal references,

should be sent electronically **before February 15, 2022** to **benjamin.godard@obspm.fr**.

References

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