Doctoral School 352

Physics and Science of Matter

Thesis subjects

Name of the laboratory: **LAM** (Laboratoire d'Astrophysique de Marseille)

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Preliminary note: We only offer one thesis subject, but the student can choose the subject that interests him the most among the following two topics:

First subject's title: **Dark matter distribution in galaxies across ages**

Subject description:

Since the 1970s, the study of rotation curves enables to establish the presence of dark matter (DM) in gas-rich galaxies and to constrain its halo distribution. However, the so-called core-cusp discrepancy (de Blok, 2010) of dark halo central density distribution between observations and simulations remains a challenge for the standard cosmological model. To tackle this issue, high resolution kinematics in the inner parts, and ideally neutral gas kinematics beyond the optical disk, are necessary as well as high-resolution imaging to constrain baryonic mass distribution. Using these techniques, e.g. Spano et al. (2008) were able to constrain DM distribution for some low mass systems in the local Universe and suggested that galaxies hosted cored halos. This result was extended to higher masses by e.g. Korsaga et al. (2019).

Theories, numerical simulations and last decade observations permit to progress in the frame of galaxy evolution. Dynamical processes might be at work to transform cuspy halos into core during galaxy evolution, like e.g. violent feedback during star formation (Oh et al. 2011). Λ-CDM numerical simulations indicate that DM halo concentration declines with increasing mass and redshifts (e.g. Bullock et al. 2001). On the other hand, numerical investigations including effects of baryonic physics on the time evolution of DM central density profiles predict that, one of the most firm predictions of the Λ-CDM theory, namely the existence of a universal cuspy profile, is no longer valid when galaxy formation is taken into account (e.g. Tollet et al. 2016). However, at higher redshift, rotation curves are not yet resolved enough to tackle the cusp-core problem. Recently, using SINFONI and KMOS data, Genzel et al. (2017) and Lang et al. (2017), tried to constrain the DM fraction in the inner regions of galaxies using both seeing limited and observations assisted with adaptive optics (AO) as well as stacking techniques. Their results points towards a low DM fraction which is supported by the observation of decreasing rotation curves. However, these results remain highly controversial (see e.g. Tiley et al. 2019) because the spatial resolution is rather low, the extent of rotation curves is limited and because the seeing may not be properly taken into account. Larger telescopes are expected to go further. The instruments NIRSpec and MIRI on the JWST (launch date 31 October 2021), HARMONI (foreseen in 2025) and MOSAIC (foreseen in 2030) on the ELT, in which LAM is strongly involved, will be the first integral field spectrographs able to reach the spatial resolution needed to disentangle the baryonic from the DM distribution for samples of intermediate redshift galaxies.

As briefly mentioned below, to fully describe the DM distribution at large radius, the neutral gas component, which usually extents the rotation curves (much) further away that the visible component, should complete the panel. To pursue the work initiated in our team by Blais-Ouellette et al. (2004), followed by Spano et al. (2008) and Korsaga et al. (2019), Adamczyk (2020, PhD) have completed a full re-analysis of the WHISP survey (~313 galaxies) that should be combined to optical GHASP data. On the other hand, in preparation of the SKA1 (foreseen in 2024, and SKA2, foreseen in 2030+) all-sky survey, further neutral gas observations (HI) are expected, for instance with the SKA pathfinder MeerKAT that started, in 2020, to make deep observations of 30 nearby galaxies in the project MHONGOOSE (de Blok et al., 2020). In addition to those deep observations of local galaxies, a major push is planned to get resolved HI data of spiral galaxies as function of redshift through medium wide, medium deep and deep surveys out to z∼0.3, ∼0.5, ∼1 respectively.

It became readily clear that additional dynamical methods are requested to establish the amount and DM distribution, mainly because to the degeneracy between models with different stellar mass-to-light ratios. Constraints on global mass budget and on the baryonic mass distribution, as well as both 2D morphological and kinematics information has to be properly handled, and the impact of beam smearing has to be taken into account. This is possible using 2D velocity fields (or 3D data cubes) and mass maps, derived from multi-band imaging (e.g. de Denus-Baillargeon et al, 2013; Chemin et al., 2016). The student will participate to the developments of such methods to study the evolution of baryonic and DM distribution properties. The goal of this thesis is to pave the way to study DM distribution as well as kinematic properties, such as the angular momentum, as a function of redshift in a consistent way, from low to higher redshift galaxies. He/she will study ionised gas kinematics properties of samples of ~500 galaxies in the local Universe (GHASP, Epinat et al, 2008, 2010; HRS, Gomez-Lopez, 2019) observed with integral field spectroscopy techniques, completed by neutral gas kinematics (Adamczyk, 2020), as well as of samples of galaxies at intermediate redshifts (0.1 < z < 2) observed with SINFONI, MUSE and KMOS on the VLT. The student will participate to the development and the analysis of those methods in order to prepare the scientific exploitation of JWST, HARMONI and MOSAIC observations in simulating data for both instruments. He/she will possibly participate to the implementation of those new methods on the MHONGOOSE galaxy sample.

References:

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Second subject's title: **Impact of kinematics on star-formation in external galaxies**

Subject description:

Giant molecular clouds and HII regions are the fundamental scales to study how galaxies convert gas into stars as a function of dynamical processes and environmental variation within and between galaxies. The subkpc-scale allows to study the links between star formation, internal and environmental dynamical processes driving evolution through gravitation, velocity shear, disc structure, instabilities and turbulence mechanisms. The goal of this thesis is to study how galaxy dynamics acts on star formation processes, in combining multiwavelength and kinematical data of nearby galaxies, the only ones for which the spatial resolution is high enough.

Star-formation results from the gravitational collapse of gas clouds. The cold gas collapses into molecular gas, which in turn collapses to form star clusters. Once young and massive stars are formed, they ionised the gas around them. The star formation rate in a galaxy mainly depends on the gas density and is strongly impacted by the environment. However, star formation processes are dynamical, and depend on the gas motion from the molecular clouds up to the galaxy scales. In order to understand star formation processes, the kinematics of gas is requested: at large scale, velocity shear due to differential rotation may oppose to gravitation and impact the critical density necessary for the collapse; at small-scale, turbulence is preventing the collapse. Studies of the link between kinematics and star-formation are today limited due to the need for (i) the spatial distribution of gas, using e.g. molecular or neutral gas estimators, (ii) spatially resolved star-formation estimates which requires a large multi-wavelength dataset, and (iii) high resolution 2D kinematics information at both small and large scale, which is usually obtained from either neutral, molecular or ionised gas. In addition, while the Kennicutt-Schmidt law, an empirical relation between gas surface density and star-formation surface density at galaxy scales has been observed for a long time (e.g. Kennicutt 1998), such a relation at star-forming clouds scales have not yet been established on representative samples of galaxies.

The thesis will consist in analyzing the Herschel Reference Survey (HRS) for which ionised gas kinematics and multi-wavelength data are available (Gomez-Lopez et al., 2019). Molecular and neutral gas kinematics are also available for a subset of the sample. In order to get a higher resolution view of the star formation processes and to understand better the origin of the turbulence observed in unresolved HII regions, the sample will be complemented with more nearby galaxies observed with the SITELLE Fourier Transform Spectrometer (FTS) at the CFHT in the frame of the SIGNALS large program (Rousseau-Nepton et al., 2019). The latter observations have a resolution better than 50 pc, which is mandatory to resolve HII regions in external galaxies. They also provide key line diagnostics to study both kinematics and ionisation conditions in these regions. This will allow the student (i) to understand whether the velocity dispersion observed in these datasets is due to collapse, feedback or thermal turbulence, (ii) to study the impact of both large and small scale kinematics on the local Kennicutt-Schmidt law and (iii) to better understand the impact of spatial resolution on these analyses. The student will also have a unique opportunity to pursue kinematics studies of the HRS sample, in particular to understand how the angular momentum is distributed in these galaxies. In addition, the HRS sample contains galaxies in both field, groups and clusters, which will make this study unique to investigate the impact of environment on both star formation processes and kinematics.

Bibliography: Kennicutt-Schmidt, 1998, ApJ, 498, 541 -- Gomez-Lopez et al., 2019, A&A, 631, 71 --Rousseau-Nepton et al., 2019, MNRAS, 489, 5530