SF2A 2018
P. Di Matteo, F. Billebaud, F. Herpin, N. Lagarde, J.-B. Marquette, A. Robin, O. Venot (eds)

THE IMPACT OF KINEMATICS ON THE STAR FORMATION PROCESS OF GALAXIES

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Abstract. The Herschel Reference Survey (HRS) is a complete K-band-selected, volume-limited sample of 323 nearby galaxies spanning a wide range in morphological type and stellar mass. We are gathering and analyzing high-resolution 2D Fabry-Perot spectroscopic Hα data for 261 star forming objects of the HRS in order to provide a complementary kinematical information to the sample. We have been actively participating in a long-term observing campaign started in December 2015 using two different instruments: GHASP at the OHP 1.93m telescope, and PUMA at the SPM 2.1m telescope. Combined with multifrequency data spanning the whole electromagnetic spectrum (from UV GALEX to FIR Herschel, including HI and CO), and multizone chemo-spectrophotometric models of galaxy evolution as well as with the CIGALE SED fitting code, the Fabry-Perot data will be used to study the role played by velocity rotation and turbulence down to kpc scales in the process of star formation occurring in normal late-type galaxies. This will be done by comparing the radial variations of the star formation activity of galaxies, corrected for dust attenuation, and modulated by the variation of the rotational velocity, to the gas surface density of the galaxies. The multifrequency dataset in hour hands allow us to determine in a self consistent way, and with unprecedented precision, the 2D-distribution of the different galaxy components (atomic, molecular, dust masses), the dust attenuation, the typical age and metallicity of the different stellar populations and several other properties critical for the study of the radial variation of the star formation history of these galaxies.

Keywords: Galaxies: spiral; irregular; dwarf, star forming; Galaxies: kinematics and dynamics; HRS: Herschel Reference Survey.

1 Introduction

One of the main processes regulating galaxy evolution is star formation. The gaseous component collapses inside molecular clouds and then stars are formed, which will produce and inject metals into the interstellar medium, later aggregated to form dust. All these ingredients contribute in regulating the matter cycle in galaxies. The formation of the molecular gas occurs primarily on dust grains. Dust also absorbs the interstellar radiation field, being an important parameter in the cooling process of the gas (Boselli (2011)). Massive stars inject a large amount of kinetic energy into the interstellar medium, favoring the ionisation of the surrounding gas and the dissociation of the molecular component.

In late-type galaxies, star formation is tightly correlated to the gas column density according to the Kennicutt-Schmidt law (Kennicutt 1998), which is often parametrized with a power law. The study of this law has been recently improved thanks to the SINGS/THINGS survey, when a sample of ~ 30 galaxies have been mapped at different wavelengths to accurately trace the relation between SFR and gas column density (HI + H_2) (Bigiel et al. 2008; Leroy et al. 2008). However, these studies just consider the Σ_{SFR} vs Σ_{gas} relation, and only explore occasionally on limited samples the role of disc kinematics on the star formation process (Kennicutt 1998; Boissier et al. 2003). Indeed, there are theoretical indications that the relation between star formation and gas column density is probably modulated at large scales by the differential rotation of the disc, while at

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smaller scales by non-circular motions (Wyse 1986; Larson 1992; Kennicutt 1998; Boissier & Prantzos 1999; Tan 2000; Kennicutt & Evans 2012). These processes favour cloud-cloud collisions and can directly participate in star formation.

With the purpose of studying the relation between the star formation process and the different components of the ISM, the SPIRE/Herschel extragalactic team has designed a volume-limited (15 < dist < 25 Mpc), K-band-selected complete sample of 323 nearby galaxies, the Herschel Reference Survey (HRS; Boselli et al. (2010)). This sample spans a wide range in morphological type (E - S0 - Sa - Im - BCD) and stellar mass ($10^8 < M_{star} < 10^{11} M_{\odot}$). Complementary to the KINGFISH/SINGS sample (Kennicutt et al. 2011) because of its statistical completeness (the K-band-selection is equivalent to a stellar mass selection according to Gavazzi et al. (1996)) and for the much larger number of objects in different environements, the sample has been ideally defined to study the role of the environment on the star formation process, galaxy evolution and for the comparison with all kinds of models and observations.

A detailed study of the relation between star formation, gas column density and kinematics of galaxies requires multifrequency resolved images: the different stellar components can be observed from the UV to the near-IR spectral domain, dust emits in the mid and far-IR, while the content of molecular and atomic gas can be quantified through the CO and the HI emission lines. Multifrequency observations of the whole HRS have been carried out in the IR with PACS and SPIRE on Herschel Ciesla et al. (2012); Cortese et al. (2014) and Spitzer (Bendo et al. 2012; Ciesla et al. 2014), in the UV with GALEX (Boselli et al. 2011; Ciesla et al. 2012), HI and CO single-beam data with Arecibo and NRAO Kitt Peak 12m telescopes (Boselli et al. 2014), medium resolution integrated spectroscopy at the OHP (Boselli et al. 2013) and Hα imaging data at SPM (Boselli et al. 2015), while optical, near- and mid-IR, and radio centimetric data are available from the SDSS, NGVS (Ferrarese et al. 2012), VESTIGE (Boselli et al. 2018), 2MASS (Skrutskie et al. 2006), and NVSS all sky surveys (Condon et al. 1998).

To study the role of galaxy rotation and gas kinematics on the star formation process, we are undertaking a high-resolution 2D Fabry-Perot spectroscopic survey of 261 late-type galaxies of the HRS sample (Gomez-Lopez et al. in prep.) in order to obtain a set of kinematical data relative to the ionized gas and thus have a further observational constraint to trace the velocity variations into the star-forming objects down to a couple of km/s. The kinematical data, combined with the multifrequency data already in our hands, will allow us to make a pixel-by-pixel basis analysis in order to compare the star formation rate (SFR), the gas column density and the kinematics of galaxies down to kpc scales.

2 Methodology

The Hα emission is a good tracer of kinematics. Fabry-Perot observations are being carried out through coordinated campaigns at the Observatoire d'Haute Provence (OHP, France, using GHASP instrument) and at Observatorio Astronómico Nacional de San Pedro Mártir (SPM, Mexico, using PUMA instrument). We derived Hα datacubes from the Fabry-Perot observations in order to derive Hα maps, radial velocity fields, residual velocity fields, rotation curves and the kinematical parameters for the sample. The high spatial and spectral resolutions ($\simeq$ 2" and $\simeq$ 10 km/s) provided by the instruments allow us to derive the kinematical properties of the galaxies down to a couple of km/s. The sensitivity is $\simeq 10^{16}$ erg s^{-1} cm^{-2} arcsec^{-2} for a 2 hours exposure per galaxy.

As mentioned before, kinematics of galaxies can participate to the star formation process in two different ways. The first one at large scales (galaxy rotation) through the compression of the gas in the density waves associated to spiral arms. The second one at small scales through the instability of the gas ion the giant molecular clouds (velocity dispersion). We would like to test the importance of these 2 mechanisms; while the rotation is easy to measure, turbulence requires a sufficiently high angular resolution. The typical scale of a Giant Molecular Cloud (GMC) is $\sim$ 80 pc and could reach up to 200pc, equivalent to $\sim$ 0.8" and 2" at 20 Mpc, the average distance of the HRS.

At the same time, we want to derive in a self consistent and most accurate way all the parameters related to the Kennicutt-Schmidt law, but this is hampered by the lack of a full set of data with the same angular resolution; for example, GALEX NUV data have an angular resolution $\sim$ 5.3", while NGVS (optical) provides an angular resolution of $\sim$ 0.6", and PACS-100 (FIR data) has an optical resolution of $\sim$ 8".

For this reason, we first try to investigate the importance of angular resolution using a representative galaxy, NGC 4254, for which we have the best set of data in hand. We first keep the best angular resolution ($\sim$ 2" of kinematical data) by comparing Hα (SFR) to CO (gas column density), correcting Hα with simple recipes (constant Balmer decrement and [NII] contamination). We then degrade the resolution to the coarsest angular resolution (∼ 8" of PACS-100 data) but increase in accuracy in the derivation of the physical parameters using the SED fitting code CIGALE (Noll et al. 2009), and study the impacts of these assumptions on the Kennicutt-Schmidt law. Once we fully control the resolution effects on our study, we will extend this analysis to a larger sample, ideally including the whole HRS, to see the impact of stellar mass, kinematics and environment on the process of star formation.

3 Preliminary results

We already accomplished Fabry-Perot observations for 250 of the 261 star-forming galaxies along 7 runs at OHP (89 nights) observing 160 galaxies, and 8 runs at SPM (48 nights) observing 54 galaxies. We checked the consistency of the rotation curves by comparing our maximum velocities to those derived from HI data, or predicted from the i-band and NIR Tully-Fisher relationships. The different sets of data are consistents with previous works (see Fig. 1).

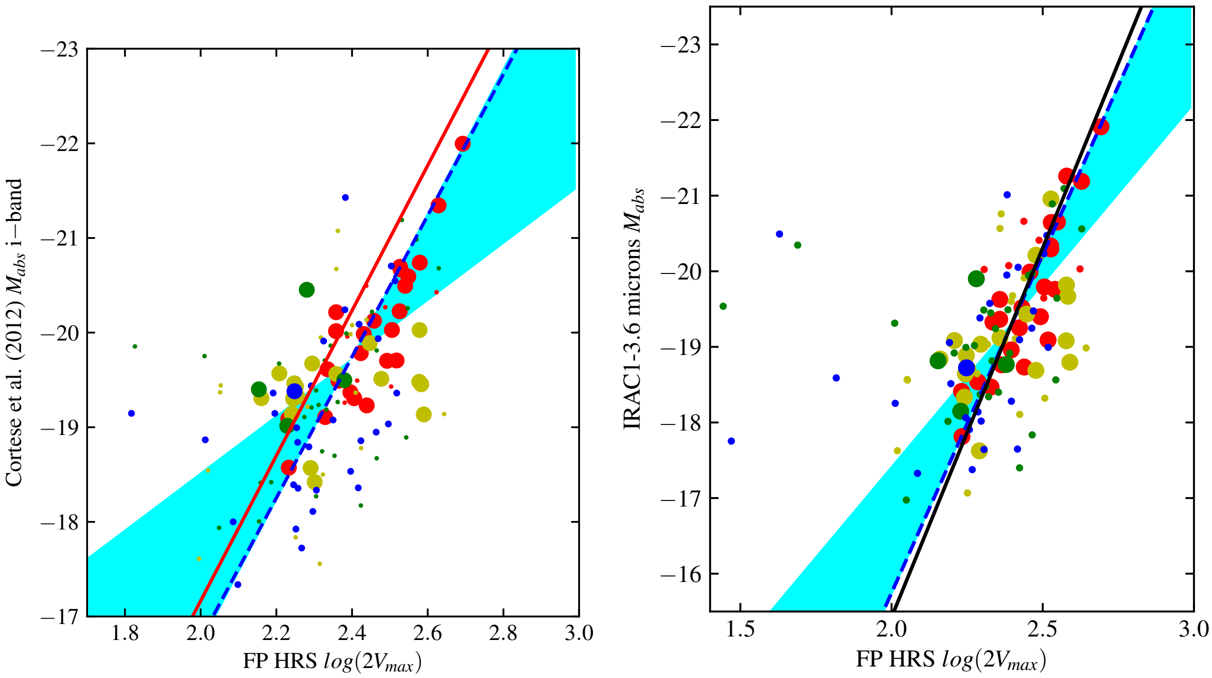

Fig. 1. Left: i-band Tully-Fisher relation. The solid red line represents the i-band Tully-Fisher relation determined by Masters et al. (2006) for nearby galaxies, while the dotted blue line represents the orthogonal linear regression to our data. The cyan shaded area represents the dynamical range of 6 different linear regression methods. **Right:** NIR IRAC1 3.6μm band Tully-Fisher relation. The solid black line represents the IRAC1-band Tully-Fisher relation determined by Sorce et al. (2014) for nearby galaxies, while the dotted blue line represents the orthogonal linear regression to our data. The cyan shaded area represents the dynamical range of 6 different linear regression methods. The big dots represent those galaxies for which the quality of the rotation curve is good enough, different colours from red to blue represent from the best to the medium quality of the rotation curves.

The main problem concerning the study of the relationship between the SFR, the gas column density and the kinematics of galaxies in a pixel-by-pixel basis is the angular resolution. We are first studying the role of resolution in a representative case: the galaxy NGC 4254. We are testing the different theoretical relations between the kinematics, the gas content and the SFR already existing in the literature in order to see if the angular resolution plays an important role in our pixel-by-pixel study (see Fig. 2).

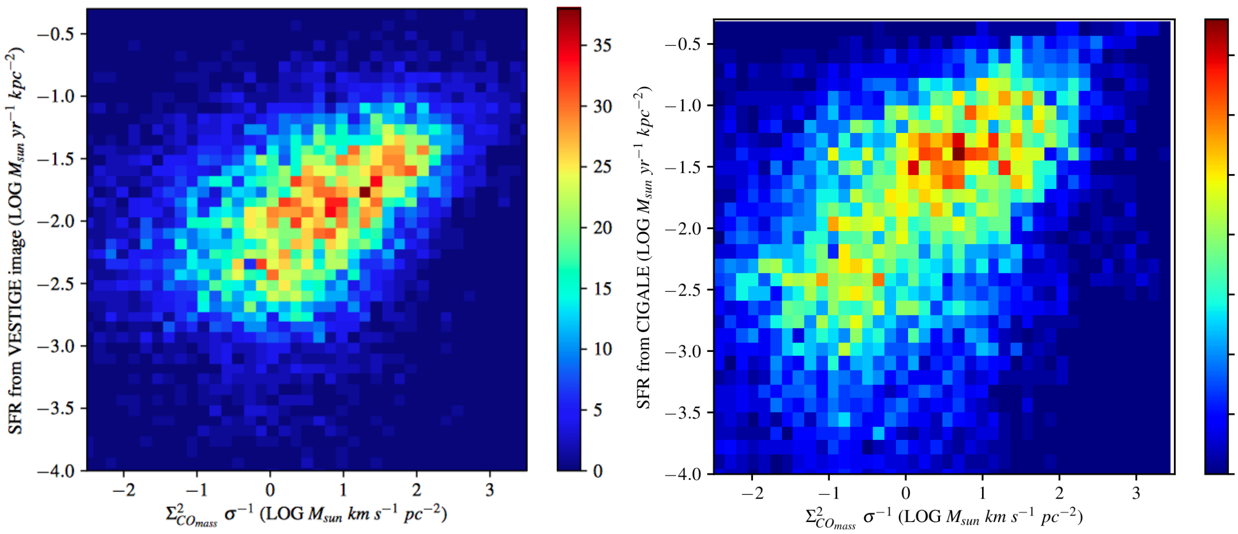

Fig. 2. Density plots testing the relation $\Sigma_{SFR} \sim \Sigma^2_{gas}/\sigma$, at high resolution (left panel) and low resolution (right panel) for the galaxy NGC 4254. The colour scale determines the number of pixels per bin. The density distribution in both cases present a similar trend.

4 Summary and perspectives

We have observed 250 late-type star-forming galaxies of the HRS using high resolution Fabry-Perot techniques. By now, this is the first spectroscopic dataset specially dedicated for the HRS, with a spatial sampling of $\sim$ 2" and spectral resolution R $\sim$13000 ($\sim$10 km/s). These data allows us to trace the kinematics in a precise and resolved way, down to kpc scales. These homogenised spectroscopic data will complement the unique dataset collected so far for the HRS, allowing us to study, in a resolved an accurate way, the kinematical properties of nearby galaxies of different masses and luminosities and situated in different environments.The data will also be used to study the role of kinematics on the star formation process and understand its implication on galaxy evolution.

Based on observations taken at the Observatoire de Haute Provence (OHP) (France), operated by the French CNRS. The authors warmly thank the OHP team for its technical assistance during the observations, as well as the SPM team in Mexico. This research has made use of data from the HRS project. HRS is a Herschel Key Programme utilising guaranteed time from the SPIRE instrument team, ESAC scientists and a mission scientist. This research has also made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. The authors have also made an extensive use of the HyperLeda Data base (`http://leda.univ-lyon1.fr`). The Digitized Sky Surveys were produced at the Space Telescope Science Institute under U.S. Government grant NAG W-2166. The images of these surveys are based on photographic data obtained using the Oschin Schmidt Telescope on Palomar Mountain and the UK Schmidt Telescope. The plates were processed into the present compressed digital form with the permission of these institutions. The authors warmly thank the IRAM team for its technical help provided for the manipulation of CO data. JAGL thanks the Consejo Nacional de Ciencia y Tecnología (CONACYT) of Mexico for the scholarship awarded during the PhD studies at the Aix-Marseille University.

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