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SPECIFIC ANGULAR MOMENTUM MAPS OF LATE-TYPE GALAXIES USING GHASP@OHP

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Abstract. We present a novel methodology for computing the spatial distribution of stellar specific angular momentum in late-type galaxies, applied to a sample of 30 irregular and spiral galaxies, part of the Gassendi Hα survey of SPirals (GHASP). Based on these distributions, we introduce a new classification scheme defined by the dominant substructures that host the bulk of the galactic angular momentum. This yields to five distinct morpho-kinematic categories: $j_\star$- ring, $j_\star$- spiral, $j_\star$- bar, $j_\star$- clump and $j_\star$- irregular. This innovative framework for galaxy classification seeks to enrich the discussion on the physical mechanisms driving the acquisition and redistribution of angular momentum within galactic discs.

Keywords: late-type galaxies, kinematics and dynamics, evolution, fundamental parameters, structure

1 Introduction

The complete picture of how galactic angular momentum is acquired and redistributed across cosmic time is still under construction. Within the hierarchical framework of galaxy formation in the ΛCDM paradigm, angular momentum originates in proto-galaxies as a result of their interaction with their surrounding tidal field (Hoyle 1949; Peebles 1969; Doroshkevich 1970). From this point on, the galactic angular momentum evolves through a combination of accretion, mergers, and gravitational interactions (White 1984; Barnes & Efstathiou 1987; Navarro & White 1994; Mo et al. 1998; Zavala et al. 2008). The construction of this theoretical framework has been made possible by the constant refinement of galaxy simulations; however, observations of galactic angular momentum have not evolved at the same pace.

The first observational estimations of the stellar specific angular momentum ($j_\star$) were made by Fall (1983), who confirmed the strong correlation expected by ΛCDM between $j_\star$ and the total stellar mass ($M_\star$), meaning that $j_\star \propto M_\star^\alpha$ with $\alpha \sim 2/3$. This relation is now known as the Fall relation and has been confirmed by multiple studies in which the dependence of $j_\star$ on the morphological type has also been proved. Late-type galaxies exhibit higher $j_\star$ than early-type galaxies (Emsellem et al. 2007; Romanowsky & Fall 2012; Cortese et al. 2016; Graham et al. 2018; Fraser-McKelvie et al. 2021; Hardwick et al. 2022). All observational studies mentioned so far estimate $j_\star$ as a global property of galaxies using one-dimensional radial profiles. However, thanks to the advent of wide-field integral field spectrographs, it is now possible to compute this property discretely and thus obtain its spatial distribution within each galaxy, opening a new field of possibilities for angular momentum observations.

In this work, we present a new methodology that allows us to estimate the $j_\star$ of galaxies pixel-by-pixel. This approach enables us to construct two-dimensional $j_\star$ maps for a sample of 30 spiral and irregular galaxies, in the local universe, part of the Gassendi Hα survey of SPirals (GHASP; see Garrido et al. 2002; Epinat et al. 2008a). We then categorize each galaxy depending on whether it stores most of its angular momentum. This new tool can contribute to the discussion about the evolutionary processes that originated each galaxy, deepening the connection between the galactic regions where the angular momentum is dominant and the processes that gave rise to them, providing complementary information to the Fall relation.

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2 Specific angular momentum maps

The $j_\star$ of galaxies is defined as their angular momentum normalized by their $M_\star$. This is a vector quantity that requires all six-dimensional information from the stellar phase space to be properly calculated. However, using a series of assumptions, it is possible to obtain an expression for $j_\star$ computable from observables (for the detail mathematical derivation see Pacheco-Arias et al. 2025). Using cylindrical coordinates (R, θ, z) with the galactic plane as a reference ($z = 0$), the three-dimensional stellar mass density of late-type galaxies can be decoupled into their stellar disc surface mass density $\Sigma_\star(R, \theta)$ and their stellar disc thickness profile $f(z)$. Assuming that their radial and vertical velocities can be neglected ($\mathrm{v}_R = \mathrm{v}_z = 0$), and that their thickness profile and tangential velocity are symmetrical with respect to the galactic plane, namely $f(z) = f(-z)$ and $\mathrm{v}_\theta(R, \theta, z) = \mathrm{v}_\theta(R, \theta, -z)$, we can formulate a discretized expression for $j_\star$ by following Emsellem et al. (2007), Cortese et al. (2016), and Mercier et al. (2023). Under this formalism a constant mass-to-light ratio is imposed throughout the galactic disc, and $\Sigma_\star$, v_θ, R, and θ are assumed constant within the surface of each pixel of position (x', y'), leading to the expression:

$$j_{\star,\mathrm{pix}}(x', y') = \frac{\mathrm{v}_\theta(x', y')\ B_\star(x', y')R}{F_\star}, \tag{2.1}$$

where $B_\star$ corresponds to the stellar disc surface brightness of each individual pixel and $F_\star$ is the bulge-free stellar disc flux within the maximum radius $R_{\max}$. R is computed at the position (x, y) in the galactic plane, while the conversion from the apparent position on the sky (x', y') to its location (x, y) in the disc plane is done considering all the geometrical parameters of each galaxy. Equation (2.1) is the core of this work since it allows us to generate, for the first time, the $j_\star$ maps. This approach contrasts with what is traditionally used in the literature, where $\Sigma_\star$ and v_θ are assumed to be independent of θ to build a cumulative profile (Romanowsky & Fall 2012; Posti et al. 2018; Piña et al. 2021; Hardwick et al. 2022; Sorgho et al. 2024).

3 The sample

We use a GHASP subset of 30 late-type galaxies first presented in Korsaga et al. (2019), for which we have their W_1 filter (3.4 μm) WISE surface brightness maps (see left column in Fig. 1), their Hα velocity fields and their HI rotation curves (see middle column in Fig. 1). The radially averaged surface brightness profiles of the galaxies, and their bulge-disc decomposition, were extracted from Korsaga et al. (2018). The Hα observations were carried out with the scanning Fabry-Perot interferometer at the 1.93 m telescope of the Observatoire de Haute Provence (OHP) and they are part of the GHASP survey (Garrido et al. 2002; Epinat et al. 2008a). The Hα rotation curves were computed from the velocity field using the Levenberg-Marquardt χ^2-minimization method described in Epinat et al. (2008b) (this routine is coded in MocKinG*), while the HI component was taken from van Eymeren et al. (2011) and Lelli et al. (2016). In Eq. 2.1, we infer v_θ from the hybrid Hα + HI rotation curves.

4 Specific angular momentum morphology

The estimation of $j_\star$ maps for our sample resulted in the emergence of a morpho-kinematic diversity never seen before. Our galaxies exhibit different predominant substructures that store most of their $j_\star$, allowing us to group them into five new categories: $j_\star$- ring, $j_\star$- spiral, $j_\star$- bar, $j_\star$- clump and $j_\star$- irregular. Examples of each of these categories can be seen in the right-hand panels of Fig. 1, arranged in descending order according to the above list. It is very important to mention that the de Vaucouleurs morphological type of our galaxies does not always match their equivalent $j_\star$- type, which indicates that $j_\star$ maps can provide new information about the evolutionary stage of galaxies by combining their photometry and kinematics. Details of how this new morpho-kinematic classification of galaxies relates to other global properties, as well as the physical mechanisms responsible for shaping the $j_\star$ maps, are described in Pacheco-Arias et al. (2025).

*https://gitlab.lam.fr/bepinat/MocKinG.

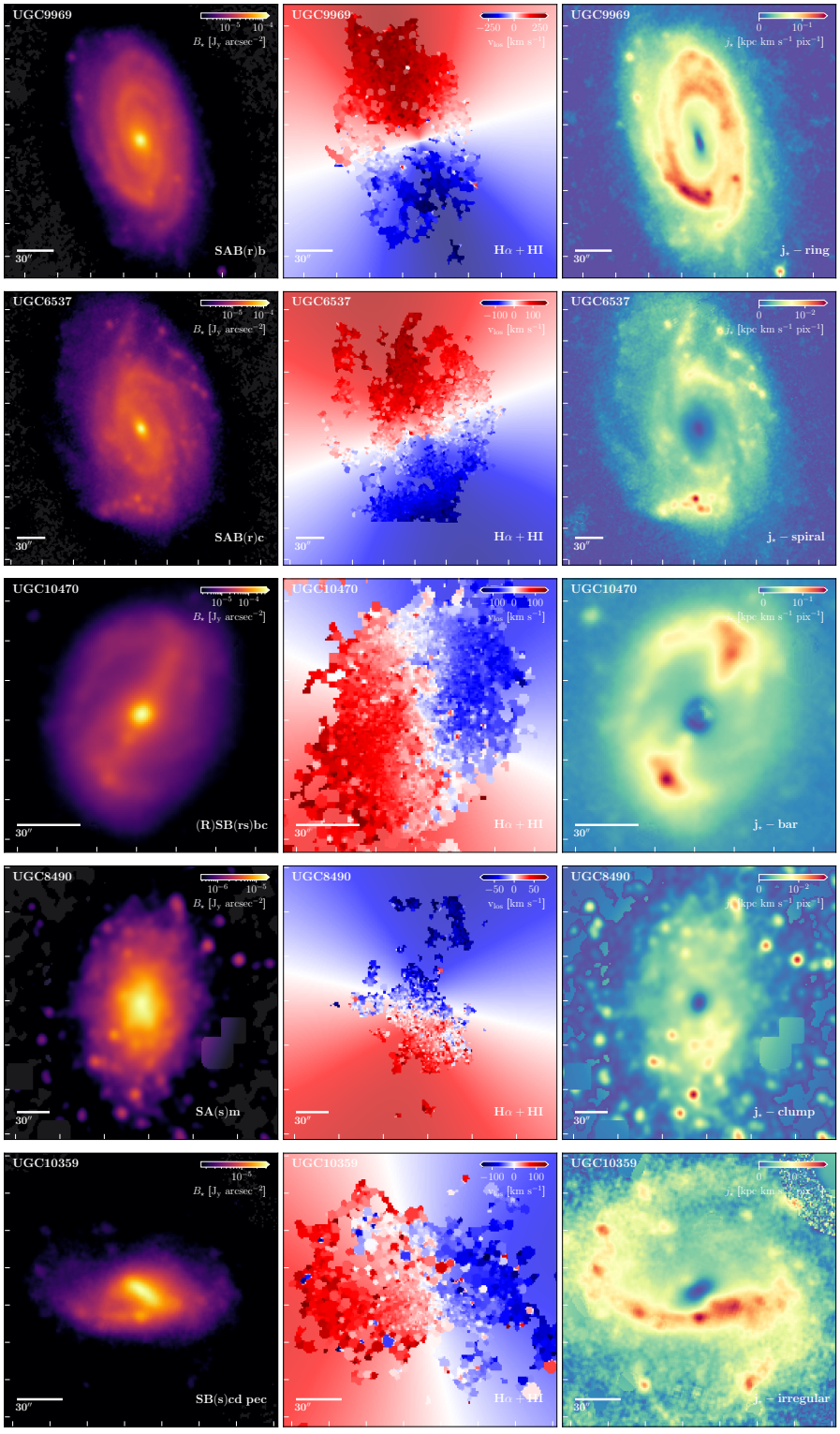

Fig. 1. Surface brightness map ($B_\star$) in the 3.4 μm WISE W_1 band (left), Hα velocity map (solid color) on top of the model velocity field (transparent color) built from the combination of the Hα + HI rotation curves projected on the sky (middle), and specific angular momentum per pixel maps ($j_\star$) computed using Eq. (2.1) (right) for five galaxies representative of the five $j_\star$ classes: UGC9969 ($j_\star$- ring), UGC6537 ($j_\star$- spiral), UGC10470 ($j_\star$- bar), UGC8490 ($j_\star$- clump) and UGC10359 ($j_\star$- irregular) from top to bottom.

5 Conclusions

The pixel-by-pixel estimation of $j_\star$ opens a new field of possibilities for studying the formation and evolution of galaxies, allowing us to visualize for the first time the spatial distribution of angular momentum within the galactic disc. Our $j_\star$ maps offer complementary information to the traditional estimation of total $j_\star$, enriching the discussion on the mechanisms responsible for the acquisition and redistribution of angular momentum within galaxies. The five morpho-kinematic classes presented here capture the diversity of galactic substructures responsible for storing most of the angular momentum in late-type galaxies in the local universe. We encourage the reader to refer to Pacheco-Arias et al. (2025) for a more in-depth discussion.

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