Galactic Dynamics in the Era of Large Surveys
Proceedings IAU Symposium No. 353, 2019
M. Valluri & J. A. Sellwood, eds.

doi:10.1017/S1743921319008676

Spotting a counter-rotating galaxy

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Abstract. The presence of counter-rotating (CR) components in galaxies is not that rare but their origin is still unclear. Important clues to the formation and evolution of CR galaxies are provided by galaxy kinematics, such as the mass distribution and the shape of the gravitational potential. In order to better understand the origin and incidence of CR galaxies, we aim at modeling CR stellar disks, as they would be observed with Integral Field Units (IFU) instruments, and measuring the kinematics of these peculiar astrophysical objects to reveal the CR signatures. In the bi-dimensional maps of analysed models, the double sigma signature is the best diagnostic to spot the presence of a CR disk component.

Keywords. Galaxy: kinematics and dynamics

1. Introduction

The most modern IFU instruments enabled more and more detailed investigations of galaxy kinematics, in particular of CR galaxies (e.g. NGC 448, Nedelchev *et al.* 2019; IC 719, Pizzella *et al.* 2018; NGC 5102, Mitzkus *et al.* 2017). Analysing a large sample of early-type galaxies, Krajnović *et al.* (2011) identified several distinct features recognizable in the kinematic maps, especially among the galaxies defined as not-regular rotators (e.g. CR galaxies), and suggested that different kinematic features correspond to different formation processes. The advantage of studying CR galaxies is that it is possible to separate the contribution of the two CR components and characterize them independently (Coccato *et al.* 2011), which is crucial to understand their origin, how they evolve and how they interact each other (Morelli *et al.* 2017). The aim of our project consists in studying the kinematic signatures of two CR stellar disks by reproducing artificial IFU data of CR galaxy models and understanding what are their observational detection limits.

2. CR detection

In order to highlight the kinematic signatures of CR galaxies, we built artificial datacubes of two CR stellar thin disks (represented by two different single stellar populations) having a total luminosity which is the sum of the two single disk contributions. Varying the fractional light contribution (f) and the scale length ($h_{\rm CR}$) of the CR disk we analyzed whether it is detectable or not. Moreover, for those models characterized by a small contribution of the CR component ($f < 0.3$) in the central region we also varied the signal to noise ratio (S/N) of each single spaxel to check if decreasing the S/N the CR signature is still clear. To perform the kinematic measurements we adapted the Penalized Pixel-Fitting method (pPXF - Cappellari 2017) to fit lines which show strong gaussian deviations due to the presence of a CR secondary component.

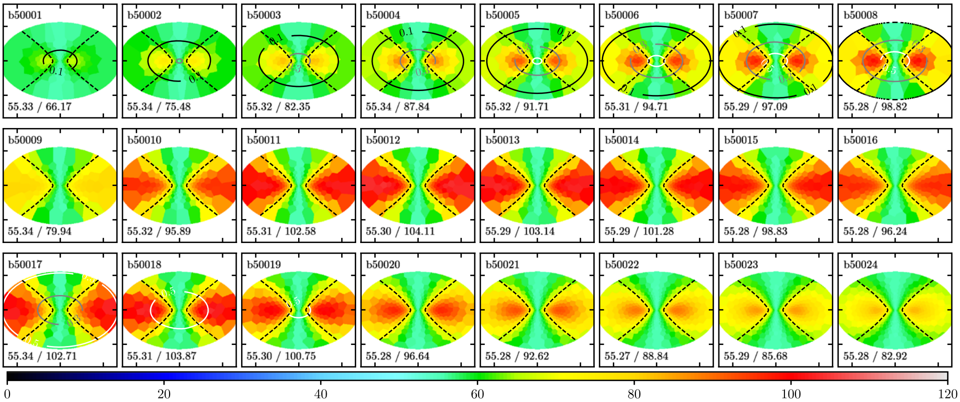

Figure 1. Velocity dispersion maps of a subsample of 24 CR models. All these models have fixed inclination ($i = 50°$), intrinsic rotation curve ($V_{\rm max} \sim 100$ km/s), constant velocity dispersion ($\sigma = 55$ km/s) and single stellar population model. We also fixed the scale length of the main disk profile ($h = 1.5$ kpc). The first row corresponds to models having $h_{\rm CR}/h = 0.66$, the second row to $h_{\rm CR}/h = 1$, the third row to $h_{\rm CR}/h = 1.33$. All maps share the same color coding. In each single plot there is the model's name (*top left*) and the min/max measured value in that map (*bottom left*). The dashed black lines indicate where the velocity separation ΔV between the two components is equal to 100 km/s. The solid lines draw the ellipses where the fraction f of the CR component is equal to 0.1 (*black*), 0.3 (*grey*) and 0.5 (*white*).

3. Results

The one stellar component pPXF fit is able to recover the line-of-sight velocity distribution of two CR components if we extract skewness (h_3) and kurtosis (h_4) in addition to velocity (V) and velocity dispersion (σ). Fitting only V and σ we find an increasing of the velocity dispersion in those regions where the velocity separation (ΔV) between the two components is greater than $\sim$ 100 km/s. In all analysed models (see a subsample in Fig. 1), the double sigma shape appearing in the bi-dimensional maps is the best diagnostic to spot the presence of a CR disk even if it contributing with only a small fraction in luminosity ($\sim$ 0.2 of the total luminosity). Considering those models with a faint CR component, we find that it is still clearly detectable as far as the S/N in each spaxel is above 20, in fact, after binning we see that the velocity dispersion shows a minimum increasing of $\sim 15\%$ with respect to the intrinsic value. Fitting also higher moments, we observe an increasing of the velocity dispersion until it drops since ΔV becomes large enough ($\gtrsim$ 120 km/s) so that the code recovers the dominant component and parametrizes the presence of the faintest one with high values of h_3 and h_4 ($\gtrsim |0.3|$). After this drop, σ increases again due to the larger ΔV. The values of h_3 and h_4 can be used together to infer from real spectra the fractional light contributions of the CR component and the ΔV between the two components.

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