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STUDY OF NGC4473: DOUBLE-SIGMA GALAXY

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Abstract. With the advent of IFU observations (SAURON survey, followed by ATLAS^{3D} survey) our picture of early-type galaxies that were thought to be monotonous (round, red, and dead) has changed dramatically. Early-type galaxies with two symmetric peaks in their velocity dispersion maps are dubbed double-sigma galaxies. One prototypical case is the NGC 4473 galaxy which is studied in this contribution using 3D spectroscopy that enabled detailed study of galaxy kinematics, age, and metallicity. Both spectroscopically and photometrically we decomposed the galaxy into three distinct components: one large de Vaucouleurs component and two smaller components counter-rotating compared to the large component. Large de Vaucouleurs component is dynamically hot while inner smaller structures are dynamically cold suggesting that numerous minor, gas-rich mergers are responsible for its formation scenario.

1. INTRODUCTION

Early-type galaxies (ETGs) have complex kinematics revealed with the advent of 3D spectroscopy. The visual distinction between kinematics becomes clear between "regular" and "non-regular" rotators. Regular rotators have velocity maps dominated by rotation; while non-regular rotators show more complex structures in their velocity maps. Krajnović et al. (2011) divided ETGs into five groups, according to the peculiar features in their velocity maps. One of the groups includes galaxies with two symmetric peaks in the velocity dispersion maps along the major axis, dubbed 2σ galaxies. They show significant tangential anisotropy indicating the presence of two counter-rotating disks. Cappellari et al. (2007) confirmed the presence of two populations of stars rotating in opposite directions by dynamical modeling.

The ATLAS^{3D} survey found 11 counter-rotating disks, all dominated by tangential anisotropy. The prototypical examples are galaxies NGC 4550 and NGC 4473. There are two possible formation scenarios: (1) a major merger of two disk galaxies and (2) gas-rich minor mergers. In the first case, the resulting disk associated with the gas will be dynamically hotter, and in the second case, the disk is expected to be dynamically colder. We studied one of these prototypical galaxies NGC 4473 using 3D spectroscopy obtained with the Multi Unit Spectroscopic Explorer (MUSE) instrument mounted on the Very Large Telescope (VLT).

2. PHOTOMETRIC DECOMPOSITION

The fully reduced IFU datacube of NGC 4473 was taken from ESO science archive[1]. A galaxy image was acquired by summing up all the images along the wavelength axis. Photometric decomposition was done with `Galfit` (Peng et al. 2010) code. Accurate

[1] `http://archive.eso.org`

Table 1: Photometric decomposition of NGC 4473 galaxy into three Sérsic components dubbed: Large, Inner, and Small according to the size of their effective radius. Modelling was done using `Galfit` code on the collapsed MUSE data cube. The columns are: component name, effective radius in arcsec, Sérsic index, minor-to-major axes ratio and position angle in degrees, respectively.

Components	$R_{\rm eff}$["]	n	b/a	PA[°]
Large	83.3	3.5	0.56	-86.6
Inner	6.8	1.9	0.54	-86.3
Small	7.2	0.6	0.6	10.0

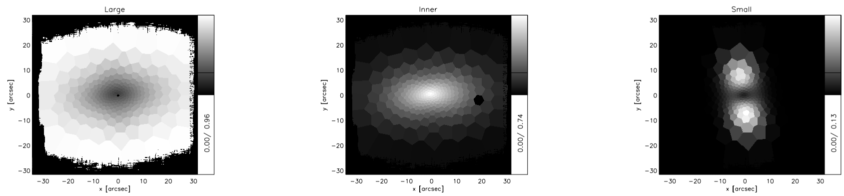

Figure 1: Flux contribution of the Sérsic components (Large, Inner, and Small), calculated for each spaxel of the collapsed MUSE data cube (Table 1).

photometric decomposition was needed to properly account for the contribution of different structure components in the galaxy image and thus in the spectrum. First, the single Sérsic profile was fitted and the best output parameters were slightly perturbed for the subsequent fit with two Sérsic components, keeping the center fixed to the best-fitted value obtained from the single Sérsic fit. The χ^2 reduced by 60% in comparison with the single Sérsic fit. Finally, we added the third Sérsic component that reduced χ^2 by about 14% (Table 1). The largest component (the one with the largest effective radius) has de Vaucouleurs profile (Sérsic index $n \sim 4$); inner component corresponds to a pseudo-bulge and the smallest one (so-called Small) is oriented orthogonal to the other two and according to its Sérsic index ($n \sim 0.5$) resembles a bar.

3. SPECTROSCOPIC DECOMPOSITION

The method of Voronoi Binning (Cappellari & Copin 2003) was applied to the spectral data cube targeting the signal-to-noise ratio of 100 in the wavelength range 4750 - 7000 Å resulting in the total of 301 individual spectra. Systemic velocity and position angle were derived using `fit_kinematic_pa` procedure (Cappellari et al. 2007, Krajnović et al. 2006), and are estimated to 2242 ± 1 km/s and 93° ± 6°, respectively. The wavelength region 4750 - 6800 Å was used in the subsequent spectral analysis.

Spectral decomposition into multiple components is much more difficult than the photometric one. We have used `pPXF` code v7.0.0 (Cappellari 2017) with an option to input the fraction of each of the two components. This fraction keyword is simply

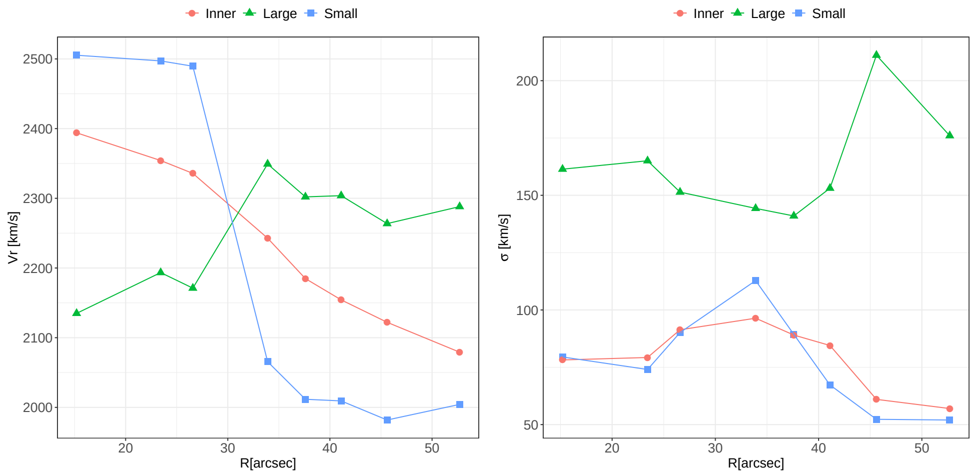

Figure 2: Kinematic decomposition of NGC 4473 galaxy into three distinct components: Large (triangles), Inner (circles), and Small (squares): radial velocity (left) and velocity dispersion (right). Lines connect the points represented by their mean values across the major axis inside predefined bins. Standard deviation is omitted since there are too few points inside the majority of the bins.

the ratio of the flux of a single component to the total flux and was introduced to weight the component with its relative contribution. The addition of the third component acquired fine-tuning of initial parameters with an assumption that this third component is "hidden" (blended) inside one of the previously measured two components. So, we run `pPXF` code two times. In the first passage, the fraction keyword was set to equal the ratio of the flux of the first component to the summed flux of the second and the third component. At the same time, radial velocity and velocity dispersion were restricted to the parametric space defined by two components. Then, in the second passage, the "blended" spectrum of the second and the third components was modelled using the fraction keyword reflecting their true mutual ratio (excluding the first component).

4. RESULTS

Structural components of the NGC 4473 galaxy reveal both photometrically and spectroscopically three distinct components that make up the galaxy. One component (dubbed Small) is orthogonal to the other two.

The largest component matches the "body" of the galaxy in which random motions dominate and is dynamically hottest ($V/\sigma \sim 0.3$) resembling a typical bulge (Sérsic index ~ 4), while two other components are dynamically colder (Small: $V/\sigma \sim 4$; Inner: $V/\sigma \sim 3$) showing significant rotation and are more disk-like. These two other components are both significantly smaller than the first one. One of them is orthogonal to the other two.

5. SUMMARY

Unprecedented spatial and wavelength resolution of MUSE spectrograph enables highly detailed study of nearby galaxies. They can be decomposed into distinct components for further analysis both photometrically and spectroscopically. Kinematics of individual components may distinguish between different scenarios responsible for galaxy formation.

Since the inner components (disks) are dynamically colder, the formation scenario in which minor, gas-rich mergers were in place is preferred over a single major merger that would make up a dynamically hotter disk.

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