Towards a new classification of early-type galaxies: an integral-field view

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Abstract. In this proceeding we make use of the two-dimensional stellar kinematics of a representative sample of E and S0 galaxies obtained with the SAURON integral-field spectrograph to reveal that early-type galaxies appear in two broad flavours, depending on whether they exhibit clear large-scale rotation or not. We measure the level of rotation via a new parameter ($\lambda_R$) and use it as a basis for a new kinematic classification that separates early-type galaxies into slow and fast rotators. With the aid of broad-band imaging we will reinforce this finding by comparing our kinematic results to the photometric properties of these two classes.

1. Introduction

The origins of the morphological classification of galaxies date back from early work by Jeans in 1929. The latter addition of the S0 galaxies as a new class by Hubble (1936) resulted in the "tuning-fork" diagram that we know and use today. The Hubble classification is a continuous sequence between ellipticals (E), lenticulars (S0) and spirals (S) with the S0s occupying the transition region. Elliptical and lenticular galaxies are usually gathered into the so-called early-type category given the large number of global photometric properties they share (de Vaucouleurs et al. 1991).

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Figure 1. Stellar velocity fields for 4 elliptical galaxies in the SAURON sample of early-type galaxies. The maps are sorted from left to right by increasing value of the $\lambda_R$ parameter. The first two (on the left) galaxies belong to the Slow rotator class, whereas the last two are Fast rotators. Note the different kinematical substructures despite belonging to the same elliptical class. Numbers on the top right corner of each map indicate the velocity cuts applied to the data, which have been adjusted as to properly emphasise the observed velocity structures.

More recently, with the advent of CCD imaging, there has been several attempts to revise the current scheme to introduce a more physical description of the objects, and therefore go beyond a purely descriptive tool. With this goal in mind Kormendy & Bender (1996, hereafter KB96) updated the Hubble sequence by sorting ellipticals in terms of photometric quantities, used as a proxy for the importance of rotation. They used the disciness or boxiness of the isophotes to define refined types: E(d) galaxies (for discy ellipticals) making the link between S0s and E(b) galaxies (for boxy ellipticals). This extension of the Hubble types has the merit of upgrading our view of Es and S0s via some easily accessible observable parameter that, at the same time, includes some physics into the sorting criteria. It did, however, use a photometric indicator as an attempt to quantify the dynamical state of the galaxy, which may deem unreliable.

In this contribution, we revisit the early-type galaxy classifications above using the available full two-dimensional kinematic information coming from the unique data set obtained with the SAURON integral-field spectrograph. A more compelling study of the kinematics for this sample with a discussion on the kinematical classification presented here can be found in Emsellem et al. (2007).

2. A kinematical classification of galaxies

The velocity fields for our sample of 48 E and S0 galaxies, basis for this study, were presented in Emsellem et al. (2004). They revealed a large variety of kinematical structures including decoupled cores, velocity twists, misalignments, cylindrical or disc-like rotation. A close examination of the maps suggests that early-type galaxies come in two broad flavours: one which exhibits a clear large-scale and rather regular rotation pattern, and another which shows perturbed velocity structures (e.g. strong velocity twists) or central kinematically decoupled components with little rotation in the outer regions. Here, we illustrate these features in Figure 1 using 4 elliptical galaxies (NGC 4486, NGC 4458,
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NGC 4621, NGC 2974). From the figure it is easy to recognize the large differences in kinematical substructure between the galaxies despite belonging to the same E morphological class.

In order to build a robust classification based on the observed kinematics we need a simple measurable parameter which quantifies the global dynamical state of a galaxy, and that can be applied to all galaxies in our sample. The ideal tool would be a physical parameter which captures the spatial information included in the kinematic maps. Since we wish to assess the level of rotation in galaxies, this parameter should follow the nature of the classic $V/σ$: ordered versus random motion (see Emsellem et al. 2007 for a detailed explanation of the pitfalls of the $V/σ$ parameter as a reliable classification parameter). Following this idea, we have defined a new quantity $λ_R$:

$$λ_R ≡ \frac{⟨R|V|⟩}{⟨R\sqrt{V^2 + σ^2}⟩},$$

that measures the amount of specific (projected) angular momentum from the velocity maps. The parameter has been defined such that is insensitive to small features in the maps, and therefore provides a robust measurement of the global rotation. As we go from galaxies with low to high $λ_R$ values (from left to right in Fig. 1), the overall velocity amplitude naturally tends to increase. More importantly, there seems to be a qualitative change in the observed stellar velocity structures. Rotators with $λ_R < 0.1$ exhibit low stellar mean velocities at large radii, with very perturbed stellar kinematics and all have large-scale kinematically decoupled components. In Figure 2 (left) we show the distribution of our galaxies as a function of $λ_R$. There are 36 fast rotators and 12 slow rotators (75% and 25% of the total sample), their median $λ_R$ values being $∼ 0.44$ and $0.05$ respectively. Within the class of slow rotators, three galaxies have $λ_R$ significantly below 0.03 (their mean stellar velocity maps being consistent with zero rotation everywhere). These are among the brightest galaxies of our sample (NGC 4486, NGC 4374 and NGC 5846).

3. Comparing photometry and kinematics: misalignments and twists

In order to assess whether our kinematical classification based on the $λ_R$ parameter is solid, it is desirable that the structural differences seen in the kinematics are also reflected in the photometry. In Figure 2 (right) we show that slow and fast rotators display clear differences in the global alignment between their photometric and kinematic major axes ($Ψ ≡ |PA_{phot} − PA_{kin}|$). The figure illustrates that all fast rotators, except one, have misalignments $Ψ$ below $10^\circ$. The only exception is NGC 474 which is an interacting galaxy with well-know irregular shells (Turnbull et al. 1999). In fact, the few galaxies which have $5^\circ < Ψ < 10^\circ$ (NGC 3377, NGC 3384, NGC 4382, NGC 4477, NGC 7332) are most probably barred. In contrast, more than half of all slow rotators have $Ψ > 10^\circ$, and none of these exhibit any hint of a bar. This difference in the misalignment values of slow and fast rotators cannot be entirely due to the effect of inclination, mainly because even the roundest fast rotators do not exhibit large misalignment values.

Independent evidence in support for our kinematical classification comes from the observed velocity twists in the SAURON kinematic maps: only 6 galaxies
Figure 2. (left) Distribution of galaxies as a function of $\lambda_R$: the horizontally striped bar indicates the bin for slow rotators, whereas diagonally striped histogram corresponds to fast rotators. (right) $\lambda_R$ versus the kinematic misalignment $\Psi$ between the global photometric major-axis and the kinematic axis within the SAURON field. Slow rotators are represented by filled circles, fast rotators by solid triangles. The vertical dashed lines correspond to $\Psi = 5^\circ$. Nearly all fast rotators have small $\Psi$ values ($< 10^\circ$), the only exception being NGC 474, the photometry of which is perturbed by the presence of irregular shells. This contrast with slow rotators which show significantly non-zero $\Psi$ values.

out of 48 exhibit strong velocity twists larger than 30° outside the inner 3′′, with 3 out of these 6 having large-scale counter-rotating stellar components (NGC 3414, 3608, and 4550). All these galaxies are in fact slow rotators. This implies that only fast rotators have a relatively well defined (apparent) kinematic major-axis, which in addition is roughly aligned with the photometric major-axis. As emphasized above slow and fast rotators exhibit qualitatively but also quantitatively different kinematical properties. This suggests that slow rotators are not just scale-down versions of fast rotators.

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