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Towards a New Classification of Early-type Galaxies: An Integral-field View

Jesús Falcón-Barroso,[1] Roland Bacon,[2] Michele Cappellari,[3] Roger L. Davies,[3] P. Tim de Zeeuw,[4] Eric Emsellem,[2] Davor Krajnović,[3] Harald Kuntschner,[5] Richard M. McDermid,[4] Reynier F. Peletier,[6] Marc Sarzi,[7] and Glenn van de Ven[8]

[1]*European Space and Technology Centre, Keplerlaan 1, NL-2200 AG Noordwijk, The Netherlands*
[2]*Université de Lyon 1, CRAL, Observatoire de Lyon, 9 av. Charles André, F-69230 Saint-Genis Laval, France*
[3]*Sub-Department of Astrophysics, University of Oxford, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH, UK*
[4]*Sterrewacht Leiden, Universiteit Leiden, Postbus 9513, NL-2300 RA Leiden, The Netherlands*
[5]*Space Telescope European Coordinating Facility, European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748 Garching, Germany*
[6]*Kapteyn Astronomical Institute, University of Groningen, NL-9700 AV Groningen, The Netherlands*
[7]*Centre for Astrophysics Research, University of Hertfordshire, Hatfield, Herts AL10 9AB, UK*
[8]*Institute for Advanced Study, Einstein Drive, Princeton, NJ 08540, USA*

Abstract. In this proceedings paper 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 flavors, depending on whether they exhibit clear large-scale rotation or not. We measure the level of rotation via a new parameter (λ_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 elliptical (E), lenticular (S0), and spiral (S) galaxies, 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).

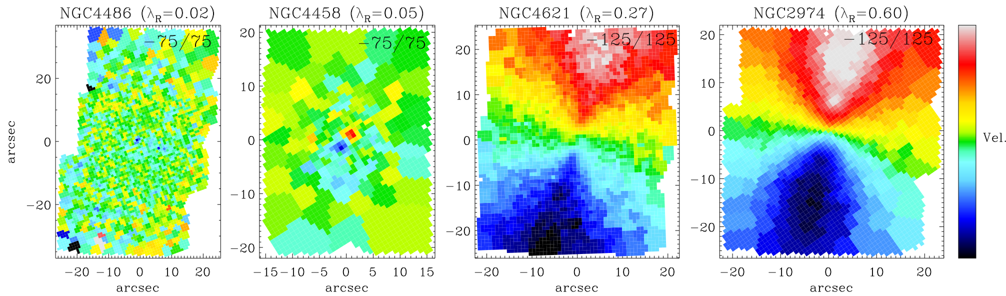

Figure 1. Stellar velocity fields for four elliptical galaxies in the SAURON sample of early-type galaxies. The maps are sorted from left to right by increasing value of the λ_R parameter. The first two galaxies (on the left) belong to the slow rotator class, whereas the last two are fast rotators. Note the different kinematic 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 so as to properly emphasize the observed velocity structures.

More recently, with the advent of CCD imaging, there have 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 diskiness or boxiness of the isophotes to define refined types: E(d) galaxies (for disky 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, introduces 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 be deemed 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 of the kinematic classification presented here can be found in Emsellem et al. (2007).

2. A Kinematic Classification of Galaxies

The velocity fields for our sample of 48 E and S0 galaxies, the basis for this study, were presented in Emsellem et al. (2004). They revealed a large variety of kinematic structures including decoupled cores, velocity twists, misalignments, cylindrical or disk-like rotation. A close examination of the maps suggests that early-type galaxies come in two broad flavors: 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 Fig. 1 using four elliptical galaxies (NGC 4486, NGC 4458, NGC 4621, NGC 2974). From the figure, it is easy to recognize the large differences in kinematic substructure between the galaxies, despite their 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 that quantifies the *global* dynamical state of a galaxy, and that can be applied to all the galaxies in our sample. The ideal tool would be a physical parameter that 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, such that

$$\lambda_R \equiv \frac{\langle R\,|V|\rangle}{\langle R\,\sqrt{V^2+\sigma^2}\rangle}\,,$$

measures the amount of specific (projected) angular momentum from the velocity maps. The parameter has been defined such that it 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 $\lambda_R < 0.1$ exhibit low stellar mean velocities at large radii with very perturbed stellar kinematics, and *all* have large-scale kinematically decoupled components. In Fig. 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 $\sim$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 in our sample (NGC 4486, NGC 4374, and NGC 5846).

3. Comparing Photometry and Kinematics: Misalignments and Twists

In order to assess whether our kinematic 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 Fig. 2 (*right*) we show that slow and fast rotators display clear differences in the global alignment between their photometric and kinematic major axes ($\Psi \equiv |\mathrm{PA_{phot}} - \mathrm{PA_{kin}}|$). The figure illustrates that all fast rotators, except one, have misalignments Ψ below 10°. The only exception is NGC 474, which is an interacting galaxy with well-known irregular shells (Turnbull, Bridges, & Carter 1999). In fact, the few galaxies that have $5° < \Psi < 10°$ (NGC 3377, NGC 3384, NGC 4382, NGC 4477, and NGC 7332) are most probably barred. In contrast, more than half of all slow rotators have $\Psi > 10°$, and none of these exhibits 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.

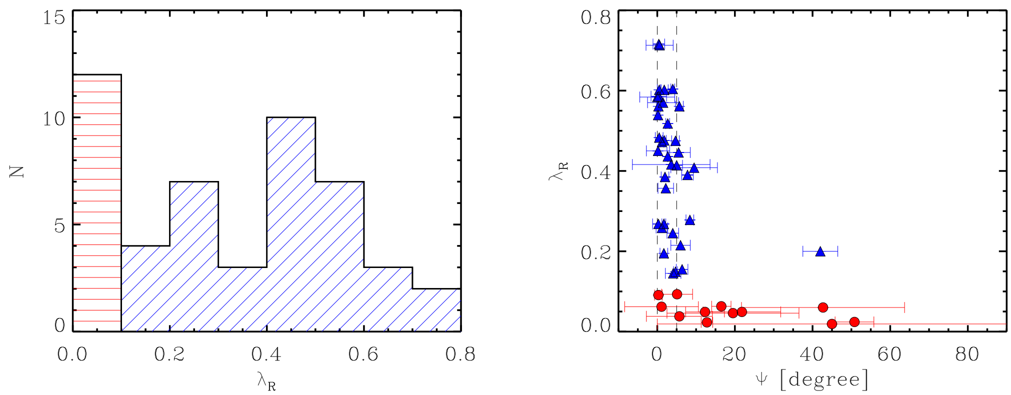

Figure 2. *Left:* Distribution of galaxies as a function of λ_R. The horizontally striped bar indicates the bin for slow rotators, whereas diagonally striped histogram corresponds to fast rotators. *Right:* λ_R versus the kinematic misalignment Ψ between the global photometric major-axis and the kinematic axis within the SAURON field. Slow rotators are represented by filled circles, and fast rotators by solid triangles. The vertical dashed lines correspond to $\Psi = 5°$. Nearly all fast rotators have small Ψ values ($< 10°$), the only exception being NGC 474, the photometry of which is perturbed by the presence of irregular shells. This contrasts with slow rotators, which show significantly non-zero Ψ values.

Independent evidence in support for our kinematic classification comes from the observed velocity twists in the SAURON kinematic maps: only six out of 48 galaxies exhibit strong velocity twists larger than 30° outside the inner 3″, with three out of these having large-scale counter-rotating stellar components (NGC 3414, NGC 3608, and NGC 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 kinematic properties. This suggests that slow rotators are not just scaled down versions of fast rotators.

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Discussion

Knapen: Can you indicate to what extent SAURON results for ellipticals are representative for the general population?

Falcón-Barroso: This is difficult to answer properly. As you know, the SAURON survey selection criteria intended to obtain a representative sample for the E/S0 population. Then, later on, we found the result I have summarized today on the slow/fast rotator classes. Since we did not expect to find this result, it is difficult to predict what the impact is of our selection on the intrinsic distribution of slow/fast rotators. It is precisely for that reason that we have started a new project, i.e., ATLAS3D, where we will observe a complete sample of galaxies. This new sample should be free of any particular bias and will give us the true fraction of slow/fast rotators in the nearby Universe.

Erwin: 1) What happens if an S0 galaxy, which ought to be a fast rotator, is viewed close to face on? Does it turn into a slow rotator? 2) You have made a good case for a distinction between slow and fast rotators. But is not there still a confusion within the fast rotator class, in that it's a mixed bag of what morphologists would call ellipticals and S0s?

Falcón-Barroso: 1) This is indeed an obvious question to ask. Since Λ_R is a projected quantity one may wonder what the dependence on inclination is. To understand this dependence we have built two-integral models and see how Λ_R varies with inclination. What we saw is that a galaxy with a measured $\Lambda_R = 0.05$, typical for a slow rotator, would need to be at a nearly face-on inclination (~20 degrees) to reach an intrinsic Λ_R value ~0.15 and therefore become a fast rotator. The probability that slow rotators are truly fast rotators is small and cannot explain the current population we see. 2) That is correct, however, remember that the slow/fast rotator classification is able to separate intrinsic properties of these galaxies unambiguously (something that cannot be done at present with the E/S0 classification). This is in fact the reason for our new scheme.

From left to right: Sergio Fernandez Acosta, Gelys Trancho, and Jesús Falcón-Barroso.