Title: Lentiptical galaxies and their non-extraordinary black holes

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Early-type galaxies include elliptical and lenticular galaxies. Lenticular galaxies are composed of a central spheroid (or bulge) of stars encased in a larger stellar disk. When perfoming bulge/disk decomposition, the spheroidal component is typically described with a Sérsic profile (ref sersic), while the disk is modelled with an exponential function. Theoretically, the bulge-to-disk ratio, which describes the relative importance of the spheroidal component over the disk component, can assume any positive value. However, several studies [ref] have taken into account only bulge/disk decompositions in which the exponential-disk function neatly dominates over the Sérsic-spheroid profile at large galaxy radii, and rejected those decompositions in which the exponential-disk function remains "embedded" within the Sérsic-spheroid profile, considering such decompositions as unphysical. Here we show that these "rejected" models correctly reproduce the photometric and kinematic properties of a class of early-type galaxies, intermediate between elliptical and lenticular galaxies, that we name *lentiptical*. Lentiptical galaxies have often been confused with lenticular galaxies and, consequently, their bulge luminosities have been largely underestimated. This mistake has led to some wrong conclusions, such as the claim that a number of lentiptical galaxies (MRK 1216 [ref yldrim+2015], NGC 1277 [ref vdb+2012], NGC 1271 [ref walsh+2015], and NGC

1332 [ref rusli+2011]) host a central black hole whose mass is abnormally large compared to expectations from its (underestimated) bulge luminosity. When lentiptical galaxies are modelled according to our simple prescription, which uses the lowest number of free parameters, they no longer appear as extreme outliers in the (black hole mass) – (spheroid stellar mass) diagram. Previous "anomalies" are explained and eliminated by one simple "rule". This nullifies the need of invoking different evolutionary scenarios for these galaxies and their non-extraordinary black holes.

1 Introduction

There are currently two well-known types of stellar disks in galaxies. The first are the large-scale disks (with sizes of a few kpc) that dominate at large radii in spiral and lenticular galaxies; the second are the small (tens to a couple of hundred parsec) nuclear disks observed in both early- and late-type galaxies (e.g. **????**). The origin of the nuclear disks has been speculated to arise from the infall of small satellite galaxies or gas clouds **refs**. The origin, or at least the on-going feeding and growth, of the large-scale disks has been attributed to cold gas flows, gas rich mergers and halo accretion events (e.g. **??????**). A thorough review can be found in Combes (arXiv:1309.1603 and 1405.6405).

A puzzling question, which has been unspoken for decades, is why are there not intermediate-sized disks; why are there not accretion events which create disks larger than the typical nuclear disks but which are not large enough to dominate at large radii? Here we report on the existence of these intermediate-sized stellar disks.

The majority of stellar disks have some level of inclination with respect to our line-of-sight, which makes them appear as flat, elliptical components, and helps us distinguishing them from the more spherical galaxy bulges. Yet, identifying the extent of these disks with respect to their bulge can be subtle. Two-dimensional kinematic maps represent an extremely powerful instrument to this purpose. However, only kinematic maps that extend beyond $\sim$2 half-light radii can help distinguish which galaxies, among those classified as central fast rotators (within $\sim$1 half-light radius), have increasing or decreasing specific angular momentum profiles at large radii [ref arnold+14]. A specific angular momentum profile that is rapidly increasing at large radii is a signature of a large-scale disk, whereas a profile that declines at large radii is consistent with the presence of an intermediate-scale disk. Unfortunately, such extended kinematic maps are not yet available for a large sample of galaxies in the local Universe. Nevertheless, there is another powerful instrument that can help identify the extent of stellar disks in early-type galaxies, and has the advantage of requiring only galaxy images (even photometrically uncalibrated), which are cheaper to acquire in terms of telescope time than spatially resolved two-dimensional kinematic maps. This instrument is the ellipticity profile of a galaxy's isophotes.

The toy model shown in Figure 1 illustrates the typical ellipticity profile for a large-scale disk that encases a bulge, as in lenticular (S0) galaxies, for an intermediate-scale disk embedded in a larger spheroid, that we name lentiptical (E/S0) galaxy, and for an elliptical (E) galaxy featuring a nuclear stellar disk. Note that, in the case of an intermediate-scale disk, the maximum value of the ellipticity should correspond to the minimum difference between the light profile of the bulge and that of the disk (vertical dashed line in Figure 1). Galaxy modellers that attempt to perform bulge/disk decomposition of early-type galaxies should always check that their model correctly matches the galaxy's ellipticity profile.

The awareness that many "elliptical" galaxies actually contain embedded stellar disks dates back at least three decades (**?????????????**) and, more recently, intermediate-scale disks were all but unfamiliar to **?**. However, the class of lentiptical galaxies has been missed out by many galaxy modellers, who labelled as "unphysical" those bulge/disk decompositions in which the exponential-disk function does not dominate over the Sérsic-spheroid profile at large radii. This unspoken bias has led them to reject any bulge/disk decomposition with an outcome similar to that illustrated in the middle panel of Figure 1.

Examples of lentiptical galaxies are the galaxies MRK 1216, NGC 1271, NGC 1277, NGC 1332, and NGC 3115. All of these galaxies can be easily described and explained with a simple two-component model: a Sérsic-spheroid plus an intemediate-sized exponential-disk. Our bulge/disk decomposition for the galaxy NGC 3115 is presented in Figure 1. Light profile extended out to 5 re kinematics

Models that "forcedly" describe the galaxy with an inner Sérsic-bulge encased within a large-scale exponential-disk can match the surface brightness distribution of the galaxy only in two cases. If the radial extent of the galaxy image is relatively small (less than or similar to one half-light radius), the outer rise of the bulge over the disk is not probed and a model with a large-scale disk can accommodate the observed surface brightness distribution. This problem can affect bulge/disk decompositions that use relatively shallow imagind data, such as 2MASS [ref vika, laurikainen]. When a more extended galaxy image is available, a model featuring a bulge encased in large-scale disk can only work with the addition of an outer Sérsic-envelope, that accounts for the outer portion of the spheroidal component. These three-component decompositions will typically result in an outer Sérsic-envelope with a curvature (regulated by the Sérsic index) similar to that of the inner Sérsic-bulge, (see the models of [ref lasker+2014] for the galaxies NGC 0821, NGC 3115, NGC 4342, NGC 4697; curiously, in these decompositions, the luminosity of the Sérsic-envelope is comparable or larger than that of the inner Sérsic-bulge).

Our two-component models (intermediate-sized disk embedded within a spheroidal component) require the lowest number of free parameters, yet they match the kinematic maps (when available) and the ellipticity profiles of lentiptical galaxies. Moreover, when lentiptical galaxies are modeled according to our prescription, they no longer are outlier in the (black hole mass) – (spheroid stellar mass) diagram, as shown in Figure 1. This eliminates the need of invocking a different evolutionary path ... compact relic...

For early-type galaxies, the bulge luminosity and the total galaxy luminosity can be used to predict the black hole mass with the same level of accuracy [cite me]. The fact that a galaxy hosts a black hole that is over-massive compared to expectations from the bulge luminosity, but is "normal" compared to expectations from the total galaxy luminosity, suggests that the bulge luminosity may have been underestimated. Indeed, none of these galaxies is an outlier in the (black hole mass) – (total galaxy luminosity) diagram [cite me].

The existence of intermediate-scale stellar discs suggests that a continuum of disc sizes may exist, rather than a dichotomy of nuclear vs. large-scale discs. The presence of intermediate-scale disks blurs the distinction between elliptical and lenticular galaxies. The existence of such disks is not only important for our understanding of disk growth in general, reducing or eliminating an old mystery, but accounting for such structure will impact on our galaxy scaling relations and surely see the reclassification of many "disky" elliptical galaxies and lenticular galaxies as *lentiptical* galaxies with intermediate-sized stellar disks that do not dominate at large radii.

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Figure 1 Illustration of the typical light profile (top plots) and ellipticity profile (bottom plots) of a galaxy featuring a stellar disk with varying size. For simplicity, we show separately the light profile of the bulge (or spheroid) in red and that of the disk in blue. The sum of these two contributions gives the galaxy's light profile (not represented here). The left panel shows the case of a large-scale disk, **prototipico** of a barless lenticular galaxy. The right panel displays the case of an elliptical galaxy with a nuclear stellar disk. The middle panel presents the case of a lentiptical galaxy with an inermediate-sized disk. Stellar disks typically have fixed ellipticity, dictated by their inclination to our line of sight. Bulges, instead, can have their ellipticities varying with radius, but they are usually rounder than inclined disks, thus their average ellipticity is lower than that of an inclined disk. If the ellipticity profile of a galaxy increases with radius, this can be ascribed to an inclined disk that becomes progressively more important over the bulge, whereas a radial decrease of ellipticity signifies the opposite case. Therefore the "shape" of the ellipticity profile can be decisive to distiguish between large- and intermediate-scale disks.

Figure 2

Figure 3