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Lenticular and other galaxies

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Abstract. We describe in this paper the surface photometry of a set of lenticular galaxies. We then consider important correlations between morphological parameters of the bulges of lenticulars and other types of galaxies. [1]

Keywords : lenticular galaxies - galaxy morphology - photometry

1. Introduction

Lenticular galaxies have been regarded as a a morphological transition class between ellipticals and early-type spirals. Lenticulars have disks with luminosity ranging from ten to hundred percent of the bulge luminosity, but without any conspicuous spiral arms. There are several scenarios possible for the formation of these galaxies. They could be of primordial origin, or could have been formed by the stripping of gas from spirals which changes the morphology (Abadi, Moore and Bower 1999), or through the mergers of unequal-mass spirals (Bekki 1998). There could be a significant difference in the ages of disks and bulges, in which case they should have different stellar populations, leading to different colours. A detailed multiband study of the morphology of representative samples of lenticulars, and comparison of their properties with those of ellipticals, and with the bulges and disks of spirals will be important in addressing these and other possibilities. With this in view, Barway et al., (2005a) have obtained a sample of 34 lenticular galaxies in the optical and near-infrared K' bands, and presented their surface and aperture photometry, together with colour profiles and mean colour gradients. Barway et al., (2005b,

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[1] A discussion on galaxies from the GOODS survey was included in the talk by A.K.Kembhavi at the Abu symposium on which this paper is based. That discussion is covered in a separate paper by A. Rawat and A.K. Kembhavi in these proceedings and will not be considered here.

to be submitted) have obtained a decomposition of the surface brightness distribution of the galaxies into bulge and disk components using the decomposition technique developed by Wadadekar, Robbason and Kembhavi (1999). Using the results of the decomposition, it is possible to see where the lenticulars are situated relative to the fundamental plane of ellipticals (Djorgovski and Davis 1987; Dressler et al., 1987) and the photometric plane for ellipticals and the bulges of spiral galaxies (Khosroshahi et al., 2000a,b). We will note in this paper some of the results obtained by Barway et al., (2005a), and consider the correlation between the morphological parameters of the bulges of lenticulars and other galaxy types. Results regarding the correlations are based on Ravikumar et al., (2005, to be submitted).

2. The lenticulars

The sample of lenticulars consists of 34 bright and medium sized galaxies from the Uppsala General Catalogue of Galaxies (UGC), with apparent blue magnitude brighter than $m_B = 14$, diameter $D_{25} < 3arcmin$ and declination in the range $5 < \delta < 64°$. The sample, though not complete, is representative of lenticular galaxies in the field with the above properties. The optical BVR-band CCD observations were carried out with the *Osservatorio Astrofísico Guillermo Haro* 2.1-m telescope at Cananea, Mexico. The near infrared K' band observations were obtained with the *Observatorio Astronomico Nacional* 2.1-m telescope at San Pedro Martir, Mexico using he CAMILA instrument which hosts a NICMOS 3 detector of 256×256 pixels. Details of the observations and data reduction are described by Barway et al., (2005a).

2.1 Photometry and colour gradients

Barway et al., (2005a) have presented detailed surface photometry of the lenticulars, and their integrated magnitudes and colours along with a careful comparison with results obtained by other authors. They have obtained colour profiles and colour gradients, and studied the presence and spatial distribution of dust using extinction maps and colour maps obtained from the optical and near-IR images.

Following usual practice, the colour gradient over the galaxy is defined as the slope $\Delta(B-V)/\Delta logr$, where r is radial distance in the galaxy measured from the centre of the galaxy which is evaluated by making a straight line fit between an inner radius taken to be ∼1.5 times the seeing FWHM, and an outer radius taken to be the point along the major axis at which the error on the mean surface brightness of the fitted ellipse reaches 0.1 mag arcsec^{-2}. The colours of the galaxies in the sample become bluer outwards, in keeping with the trend observed in ellipticals. After excluding the galaxy UGC3792 (which has a prominent dust lane), the mean logarithmic gradients in the $B-V, B-R$ and $V-K'$ colours are -0.13 ± 0.06, -0.18 ± 0.06, -0.25 ± 0.11 magnitude per dex in radius respectively. A comparison of the mean colour gradients with corresponding

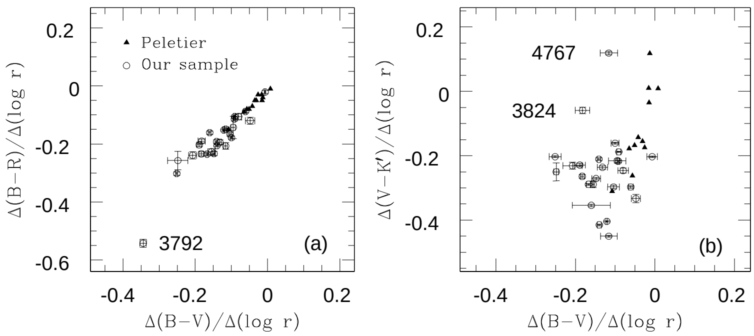

Figure 1. Correlation between different colour gradients. The gradients for our lenticulars and a sample of elliptical galaxies (Peletier et al., 1990a,b).

values from the literature for ellipticals and bulges of early-type spirals shows that the colour gradients for lenticulars are more negative than the gradients for ellipticals, while the $B-R$ gradient for lenticulars is less negative than the corresponding gradient for bulges of early-type spirals. The steeper colour gradients could imply that the metallicity gradients are stronger in lenticulars and/or that there is more recent star formation in the outer parts of lenticulars as compared to those of ellipticals. Bothun and Gregg (1990) reported significant differences in the colours of bulges and disks in lenticulars which they interpret as being due to age difference, and not metallicity difference, between the bulge and disk components. The large rms error in the mean colour gradient of our sample could be due to the different colours of the bulge and disk components and varying proportion of these components in different lenticulars.

Correlation between different colour gradients have been noted by various authors, and have been used to derive information about the physical processes in galaxies. Such correlations for the lenticulars are shown in Fig. 1. A clear correlation is seen between $B-V$ and $B-R$ gradients, with correlation coefficient 0.90 at a significance level better than 99.99 percent. The plot of $V-K'$ against $B-V$ gradients shows large scatter, but we do not see any correlation of the type reported by Peletier et al., (1990b). It is necessary to investigate how the separate bulge and disk colour gradients affect the total colour gradients and hence the correlation between them. We will address in future these issues using a bulge-disk decomposition based technique which will allow us to study the colour distribution in these components separately.

3. Correlations between morphological parameters

The surface brightness distribution of the light from a galaxy can in general be decomposed into bulge and disk components, with each of these being characterized by a small number of parameters. Here it is assumed that the two structures are smooth, and features like spiral arms, dust lanes etc are averaged over (it is also assumed that any active galactic nucleus which may be present does not make a significant contribution, which is true for "normal" galaxies).

The surface brightness distribution of a bulge is characterized by the Sersic relation $I_b(r) = I_(0)e^{-2.303b_n(r/re)^{1/n}}$, where $I_b(r)$ and $I_b(0)$ are the surface brightness at r and at the centre respectively, n is a parameter which varies from galaxy to galaxy, and b_n is a constant dependent on n which is chosen such that half the total light from the galaxy is contained within the effective radius r_e. The Sersic relation is a generalization of de Vaucouleurs' law, for which $n = 1/4$. For the disk component the surface brightness has an exponential distribution $I_d(r) = I_d(r)e^{(-r/rd)}$ with scale length r_d. In this paper we will be concerned only with the bulge part of the brightness distribution.

Correlations between parameters which characterize the bulge and disk components, and other characteristic parameters of galaxies, like the central dispersion velocity, provide insights into the relationships between the gross properties of the stellar content of galaxies and their large scale morphological properties, leading to some understanding of the formation and evolution of galaxies. Important early examples of correlations between bulge properties for ellipticals are the Faber-Jackson and Kormendy relations, and the Tully-Fisher relation for spirals (see references in Khosroshahi et al., 2000a,b). For elliptical galaxies there is a very insightful correlation between their effective radius, mean surface brightness within the effective radius, and the central dispersion velocity, known as the fundamental plane (Dressler et al., 1987; Djorgovski and Davis 1987). A more recent three dimension correlation is the photometric plane (Khosroshahi et al., 2000a,b), which connects in a single planar relation the central surface brightness, effective radius and the Sersic index for ellipticals as well the bulges of early type spiral galaxies. This is the first relation which links together ellipticals and bulges, pointing to a common formation mechanism for these structures. In the following we will consider the photometric plane for the bulges of a variety of galaxies.

3.1 The photometric plane

In Fig. 2 we have shown an edge on view of the photometric plane (PP) $logn = 0.153logr_e - 0.066\mu_b(0) + 1.132$ for a sample of 38 elliptical galaxies from two Abell clusters in the K' band. The rms scatter around the best fit plane is small (0.037 when measured along the $logn$ axis). Also shown in Fig. 2 are edge on views of the PP for the bulges of lenticulars, early and late type spirals, and dwarf ellipticals. The PP coefficients

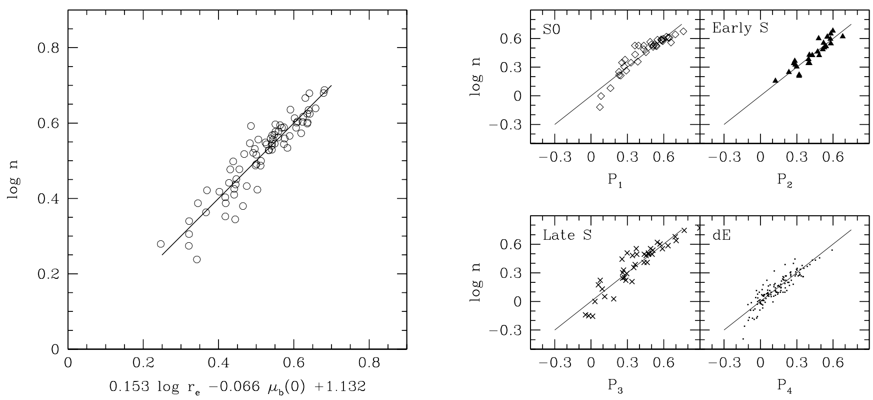

Figure 2. The large panel on the left shows an edge on view of the photometric plane for elliptical galaxies from two Abell clusters. On the right, the upper panels show the edge on views of the plane for bulges of lenticulars and early type spirals; the bottom panels show the views for the bulges of late type spirals and of dwarf ellipticals. $P_1 = 0.21 \log r_e - 0.11\mu_b + 1.54$, $P_2 = 0.13 \log r_e - 0.07\mu_b + 1.21$, $P_3 = 0.23 \log r_e - 0.07\mu_b + 1.29$, and $P_4 = 0.16 \log r_e - 0.08\mu_b + 1.60$

for the bulges of early type spirals and ellipticals are equal, within 1σ errors. The PPs for bulges of S0s and late type spirals are, however, significantly different from the PP for ellipticals, as can be seen from the coefficients and the angles between the normals to the planes. The scatter about the PP in these cases is also larger than that for the ellipticals. The sample of dwarf galaxies is somewhat unique in their properties in the sense that they show a PP very similar to that for ellipticals, but with much larger scatter, implying that a high degree of inhomogeneity is present in the individual galaxies.

It is clear from Fig. 2 that the bigger and brighter bulges (which have large n values) form a PP with much less scatter them the fainter ones. The dichotomy is clear in Fig. 3 where we have shown the distribution of deviations $|\delta_{PP}|$ for each galaxy, from the PP defined by ellipticals. Also shown is the absolute deviation for each galaxy in our sample from the photometric plane for the ellipticals. There is no noticeable trend in the case of log$n$ and $logr_e$; however, the $|\delta_{PP}|$ show significant correlation with the central intensity and luminosity of the bulges, with the average deviations increasing systematically as these values become fainter.

Following the prescription of Márquez et al., (2001), we have obtained the specific entropy for the bulges in our sample, using their morphological parameters. The specific entropy for dwarf ellipticals and ellipticals is more tightly distributed than for the other Hubble types, which indicates greater homogeneity for these galaxies and suggests that they are at a local maximum of the entropy, i.e., of stability. The average specific entropy shows a systematic increase as we move towards the earlier types along the Hub-

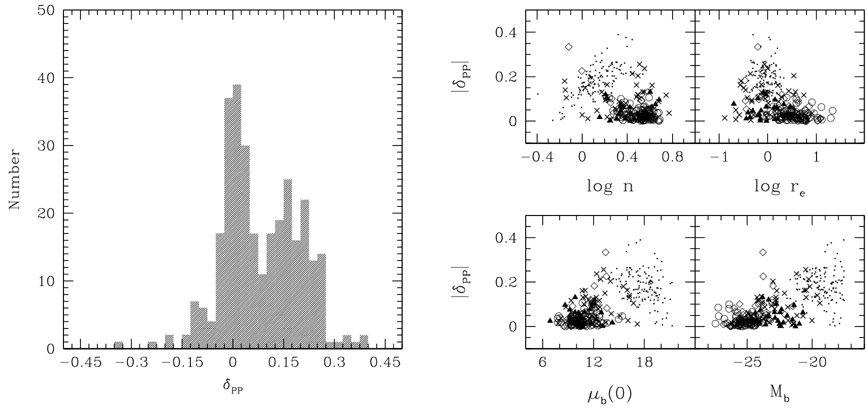

Figure 3. The large panel on the left shows the distribution of absolute deviations from the PP for individual galaxies. The panels on the right shows plots of these deviations against various parameters.

ble sequence, supporting a successive merging of smaller components as in the case of hierarchical clustering.

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