Structural Parameters and Colour Distribution of Peanut Bulges

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Abstract

We have studied the bulge morphologies for a large complete sample of edge-on galaxies using the Digitized Sky Survey (DSS) and additional CCD observations. In this sample we find 40 peanut–shaped bulges (Lütticke et al. 2000a). This number leads to the result that $4 \pm 1\,\%$ of all bulges in edge-on disk galaxies (S0-Sd) have such a pronounced shape. Strong bars viewed almost side-on are the most likely explanation for the origin of peanut–shaped bulges. In order to quantify the peanut structure we use five objective parameters. We present these parameters and discuss them in connection with a general classification of bulge shapes in edge-on galaxies. Further we present an outlook for testing peanut bulge formation scenarios with the photometric colour distribution of the disk, bar, and peanut structure.

1 Background

In our statistical study (Lütticke et al. 2000a) of ~ 1350 edge-on galaxies with diameters (D_{25}) larger than $2'$ and axis ratios larger than 2 derived from the RC3 (de Vaucouleurs et al. 1991) we have visually classified bulge shapes in three types of box/peanut (b/p) bulges (type 1: peanut–shaped, type 2: box–shaped, type 3: bulge is nearly box–shaped) or as an elliptical bulge (type 4) using images of the Digitized Sky Survey (DSS). Our analysis has revealed that 45 % of all bulges (S0-Sd galaxies) are b/p–shaped. Approximately 10 % of the b/p bulges have a prominent peanut structure (type 1). Together with additional CCD observations we have compiled a list of 40 peanut bulges. 12 of these bulges are classified as peanut–shaped for the first time (Lütticke et al. 2000a).

2 Origin of Peanut Bulges

The high frequency of b/p bulges must be considered for theories explaining the formation process of b/p bulges. The most promising scenario describing the origin of b/p bulges are bar resonances coupled with bending instabilities. This scenario is strongly supported by N-body simulations (Combes et al. 1990, Raha et al. 1991, Pfenniger & Friedli 1991), kinematical observations (Kuijken & Merrifield 1995, Bureau & Freeman 1999, Merrifield & Kuijken 1999), and surface photometry in the NIR (Lütticke et al. 2000b). These NIR data as well as N-body simulations (Combes et al. 1990, Pfenniger & Friedli 1991) and bar diagnostics (Bureau & Athanassoula 1999, Athanassoula & Bureau 1999) explain the different degree of boxiness mainly by the aspect angle of the bar. Additionally, there is a dependence of the bulge shape on the bar strength (Friedli 1999, Lütticke et al. 2000b). In this way peanut bulges result from strong bars seen nearly side-on.

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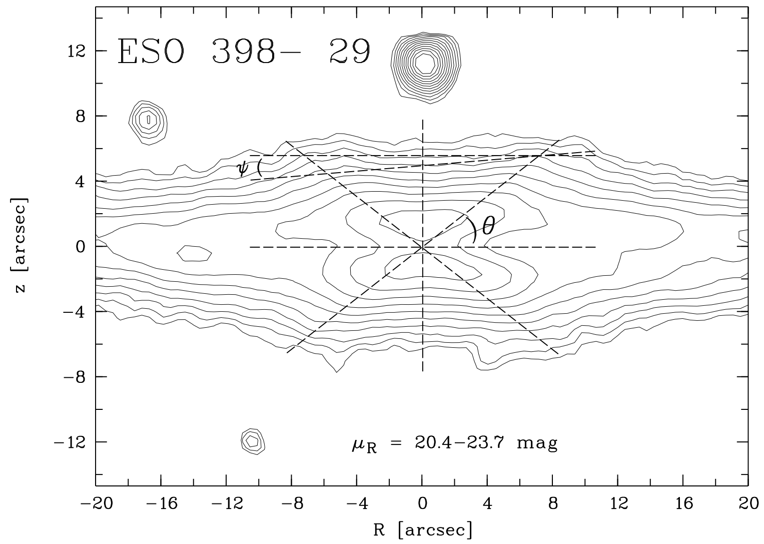

Figure 1: Characteristic angles of a peanut bulge (cf. text). ESO/La Silla, 0.9m, R-band, 12.5 min. The range of θ is between 31° and 50°; ψ has a size of 7° for one of the most prominent peanut bulges (NGC 128).

3 Observation

Our optical CCD images were obtained in several observing runs at Lowell Observatory (1.06m), Calar Alto (1.23m), and ESO/La Silla (0.9m, 1.54m, 2.2m, and NTT) (partly published in Barteldrees & Dettmar 1994, and Pohlen et al. 2000). We have observed 60 % of all galaxies with peanut bulges. For the analysis of the remaining galaxies we use the DSS.

4 Objective Parameters of Peanut Bulges

We quantify the peanut structure to obtain fundamental information for the connection between bulge and bar and for scenarios describing the evolution of b/p bulges and thereby bulges in general. For the quantification we use three known as well as two newly introduced objective parameters:

- The angle θ is measured between a branch of the X-structure and the major axis (Shaw et al. 1990) (Fig. 1).
- The a_4 isophote shape parameter describes the deviations from perfect ellipses (Bender & Möllenhoff 1987). Therefore the minimum of a_4 is useful for quantifying the degree of the peanut shape. The most extreme bulges show values up to $a_{4\min} = -7\,\%$
- The fitting of the galaxy by disk and bulge component (Pohlen et al. 2000) with a following subtraction of the model and an elimination of structures near the galactic plane (e.g. bar) leads to an isolation of the excess luminosity (EL) of the peanut distortions (Shaw 1993) (Fig. 2+3).
- The maximum of excess to bulge luminosity ($[\mathrm{EL/BL}]_{\max}$) is measured in radial intervals from the galactic center (Fig. 2+3).
- The maximal depression of the isophotes along the minor axis can be measured by an angle (ψ). It is defined by the angle between the parallel line to the major axis, which is asymptotic

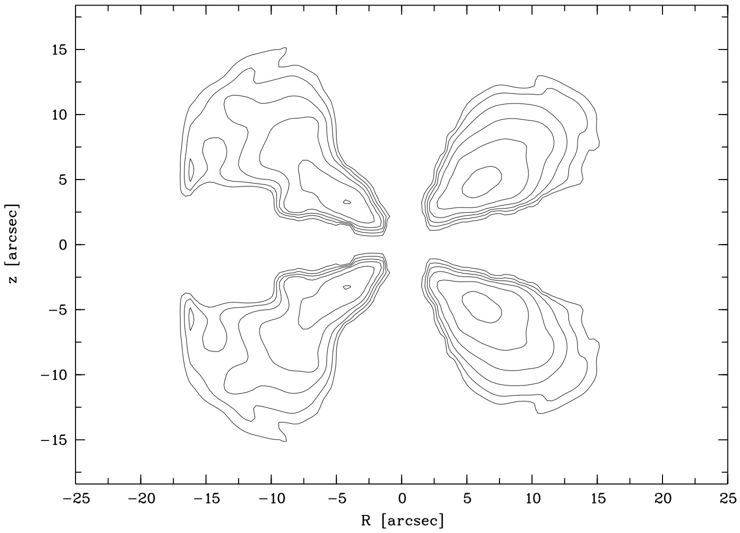

Figure 2: Excess luminosity (EL) of the peanut structure — also called X-structure — of NGC 6722. Only bottom side of the galaxy is plotted (logarithmically equidistant and mirrored on the main axis), due to the strong influence of dust and stars in the foreground on the upper side.

to the maximum of the peanut distortion, and the ray from the maximum to the intersection of this isophote with the minor axis (Fig. 1).

The parameters quantifying the properties of the peanut bulges ($a_{4\min}$, $[\mathrm{EL/BL}]_{\max}$, and ψ) are almost linearly correlated.

5 Objective Classification of Bulge Shapes

Proving the parameters of the peanut bulges for a general objective classification of bulge shapes, we obtain following results:
θ is not useful for a classification, since it is only a description of a structure, but not a measurement of the property. ψ is a parameter only for peanut bulges and therefore useless as general parameter of bulges. The application of a classification method using the excess luminosity is unpractical for a large sample of galaxies, since the determination of EL is very complex. The use of a_4 is problematic because the determination of the extreme value depends on the fitted region of the bulge. Fitting only the inner parts of bulges results in some galaxies in the undetection of the boxiness of the bulge which is most prominent in the outer parts. An additional disadvantage of the determination of this parameter is the influence of dust and bars for the ellipse fitting. Therefore $a_{4\min}$ is only suitable for uniform classification of a large sample of bulges, if NIR images are used (minimizing the dust influence), and a modelled disk and a possible bar are subtracted. However, models of high quality and fitting areas including the outer part of bulges need images with a high signal-to-noise ratio. This would result in unreasonable observing time for the whole RC3 sample. Therefore the classification by visual inspection seems to be the best method until NIR data of more objects are available.

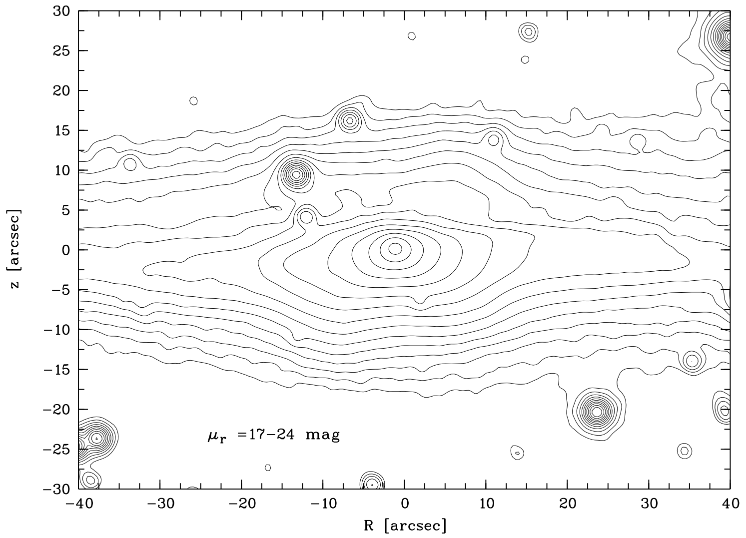

Figure 3: Peanut bulge of NGC 6722. 10min in r, ESO, 2.2m.

6 Outlook: Photometric Colour Distribution

With the photometric colour distribution of peanut bulges we will test the proposed bar driven formation scenario by comparing the colour of the peanut distortion, the bar, and the disk. In this scenario peanut bulge, bar, and disk have nearly the same photometric colours. Further we can also distinguish between the above scenario and a formation by soft mergers (Binney & Petrou 1985). In addition to the colour distribution, metallicities will provide a quantitative parameter to study the stellar population of the different galactic components. The metallicities are determined by observing the CO-absorption band in the NIR.

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