Isophotal shapes of early-type galaxies to very faint levels

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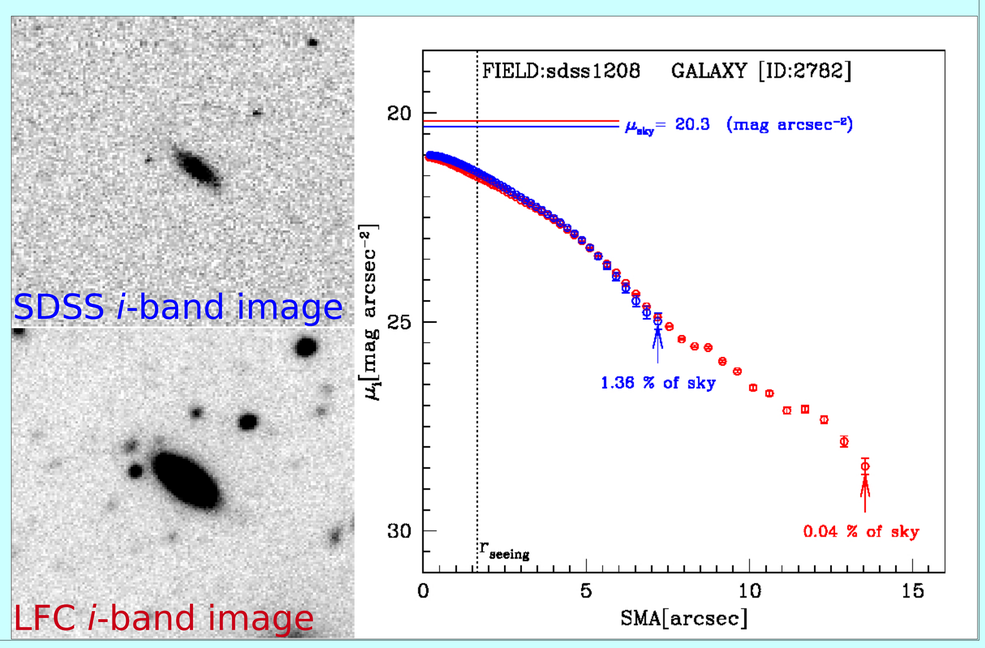
Abstract:

The study of isophotal shapes of early-type (E/SO) galaxies is important as the galaxies having boxy (rectangular) isophotes are known to have different physical properties as compared to the galaxies having disky (pointed) isophotes. We use deep images of 132 sample galaxies obtained from Large Format Camera (LFC) on Palomar 5m Hale telescope to explore the region of galaxies which is largely inaccessible through short exposures. We consider the radial variation of morphological properties and derive average values of isophotal shape parameters in four different radial bins along the semi-major axis of a galaxy, instead of assigning a single global characteristic value of a parameter for the galaxy as done by earlier researchers studying isophotal shapes. We find that the isophotal shapes of inner regions of our sample galaxies are statistically different from the isophotal shapes observed at outer regions. This has important implications for theories of galaxy formation and evolution as it suggests that outer and inner parts of the early-type galaxies may not have co-evolved.

We explore the largely inaccessible regions of the galaxies: 1

Comparison of surface brightness profiles of a galaxy, generated using i-band images of LFC (in red) and SDSS (in blue) images



Boxy and disky isophotes : 2

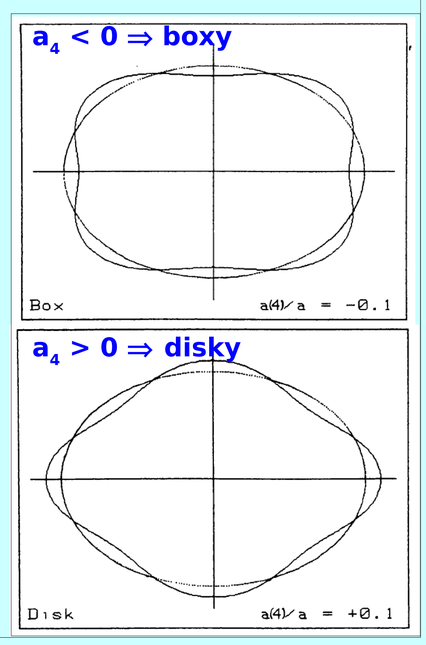
Isophotal shapes are generally analyzed by means of Fourier expansion of the difference between given isophote $r_{iso}(\theta)$ and best fit ellipse to the isophote $r_{ell}(\theta)$

$$r_{iso}(\theta) - r_{ell}(\theta) = I_0 + \sum_{n=1}^{N} [a_n \cos(n\theta) + b_n \sin(n\theta)]$$

The a_4 parameter, most significant non-zero component

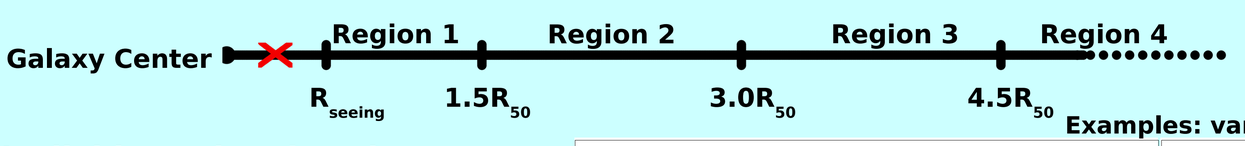
The study of isophotal shape is important

Early type galaxies with disky isophotes ⇒ fainter, rotationally supported, lack X-ray and radio activities boxy isophotes ⇒ brighter, supported by random motions, have significant X-ray and radio activities (Bender et al. 1989).



Isophotal parameters often vary along semi-major axis: 3

We derive average values of isophotal shape parameters in four different radial bins along the semi-major axis of a galaxy, instead of assigning a single global characteristic value of a parameter for the galaxy as done by earlier researchers studying isophotal shapes.



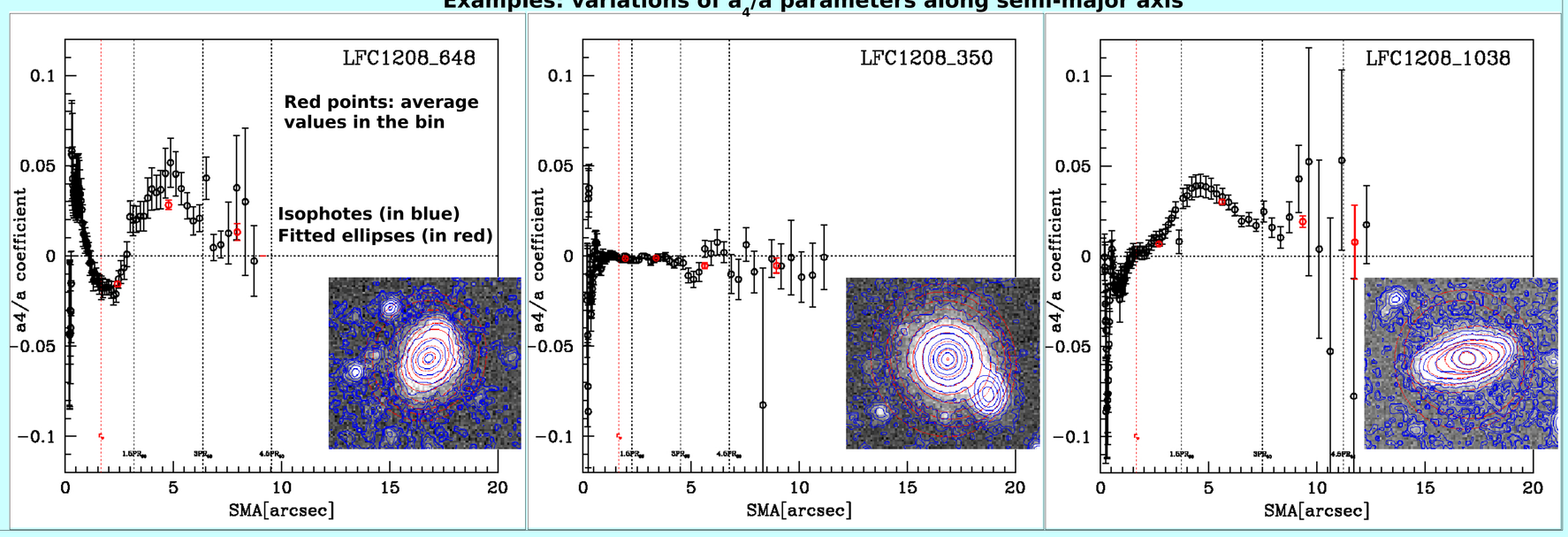
Inner Region: Region 1 and Region 2
Outer Region: Region 3 and Region 4

We divide each galaxy into four regions defined by distance from the center along the semi-major axis in multiples of Petrosian half light radius (R_{50})

Example:
mean value of a4/a in Region 1 is obtained as

$$\left\langle \frac{a_4}{a} \right\rangle = \frac{\int_{r_s}^{1.5R_{50}} \frac{a_4}{a}(r) I(r) \left[\sigma_{\frac{a_4}{a}}(r)\right]^{-2} dr}{\int_{r_s}^{1.5R_{50}} I(r) \left[\sigma_{\frac{a_4}{a}}(r)\right]^{-2} dr}$$

Examples: variations of a_4/a parameters along semi-major axis



Isophotal shapes of inner and outer regions of galaxies are different: 4

The probability (P) given by two-sample Kolmogorov-Smirnov test (K-S test) that the two samples belong to the same parent distribution, is listed in the table.
Small values of P show that the cumulative distribution function of two samples tested are significantly different (see Press et al. 1992). The confidence that both the population does not belong to the same parent distribution is given by (1-P)X100.

Sample	Probabilty (P)		
	Region 2	Region 3	Region 4
Region 1	**0.855**	**0.005**	**6.41e-04**
Region 2		**0.014**	**5.44e-04**
Region 3			**0.383**

Results of two sample K-S test for a4/a parameter

The results clearly show the discontinuity in the distribution of a_4/a parameter as we go from Region 2 to Region 3. isophotal shapes of inner and outer regions of our sample galaxies are statistically different. This has important implications for theories of galaxy formation and evolution as it suggests that outer and inner parts of the early-type galaxies may not have co-evolved.

Frequency of boxy and disky isophotes: 5

Bender et al. (1989) found that ~1/3 of their sample galaxies show boxy isophotes, ~ 1/3 pointed isophotes and ~ 1/3 of isophotes have deviation smaller than 0.2% of the semi-major axis length.

Region	boxy	disky	$\lvert a_4/a \rvert \leq 0.2\%$
r_s - $1.5R_{50}$ (Region 1)	**25 %**	**48%**	**27%**
$1.5R_{50}$ - $3.0R_{50}$ (Region 2)	**28%**	**43%**	**29%**
$3.0R_{50}$ - $4.5R_{50}$ (Region 3)	**55%**	**36%**	**09%**
r > $4.5R_{50}$ (Region 4)	**54%**	**40%**	**06%**

Frequency of boxy and disky isophotes

We find
- **a larger fraction of disky isophotes in inner region;**
- **that the major fraction of galaxies have either boxy or disky isophotes in their outer regions;**
- **a higher frequency of boxy isophotes as compared to the disky in outer regions.**

It has been suggested by Nieto & Bender (1989) that tidal extensions may also cause pointed isophotes. The higher fraction of boxy isophotes in outer regions indicates (i) the presence of additional forces along with the tidal extensions and (ii) that such forces are either more frequent or more effective in outer regions

References:

Bender R., et al. 1989, A&A, 217, 35
Nieto J. L. & Bender R., et al. 1989, A&A, 215, 266
Press, W. H., et al. 1992, Numerical Recipes in Fortarn (Cambridge: Cambridge University Press), p.614