# $\kappa$urvature for galaxy structural analysis

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# Galaxy Morphology Landscape

# Methodologies for galaxy classification.

**automated bulge+disk decompositions;**
**(or more components – multiple Sérsic fits)**;
(Caon et al., 1993; Gadotti, 2008, 2009; Simard et al., 2011)

**non-parametric measurements: e.g. CAS-system + $GM_{20}$+H** $\sigma_\psi$;
(Abraham et al., 1994; Conselice et al., 2000; Ferrari et al., 2015; Lotz et al., 2004)

**others techniques such as unsharp masking, structure maps, ellipse fitting, etc...**
(Erwin and Sparke, 2003; Kim et al., 2012; Pogge and Martini, 2002)

**machine learning algorithms (e.g. MORFOMETRYKA)**;
(Barchi et al., 2019; Ferrari et al., 2015; Gauci et al., 2010)

## Our work: the curvature $\kappa(R)$

- development of a non-parametric measure of galaxy structure based on **curvature** $\kappa$;
- unveil galaxy components (number of and type of ) by the shape of curvature;
- our research is driven by the following question:

**what is the true structure of a galaxy?**

# Curvature

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# Galaxy structural analysis with the curvature of the brightness profile

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**ABSTRACT**

In this work, we introduce the curvature of a galaxy brightness profile to identify its structural subcomponents in a non-parametrically fashion. Bulges, bars, discs, lens, rings, and spiral arms are key to understand the formation and evolution path the galaxy undertook. Identifying them is also crucial for morphological classification of galaxies. We measure and analyse in detail the curvature of 14 galaxies with varied morphology. High (low) steepness profiles show

# What is curvature (from geometry)?

- it measures the deviation of a function (or a set of data points) in relation to a line or a plane (Tenenblat, 2008);
- proportional to the osculating circle passing through neighbouring points of the path;
- requires normalization of the variable $(R)$ and the function $(I)$;

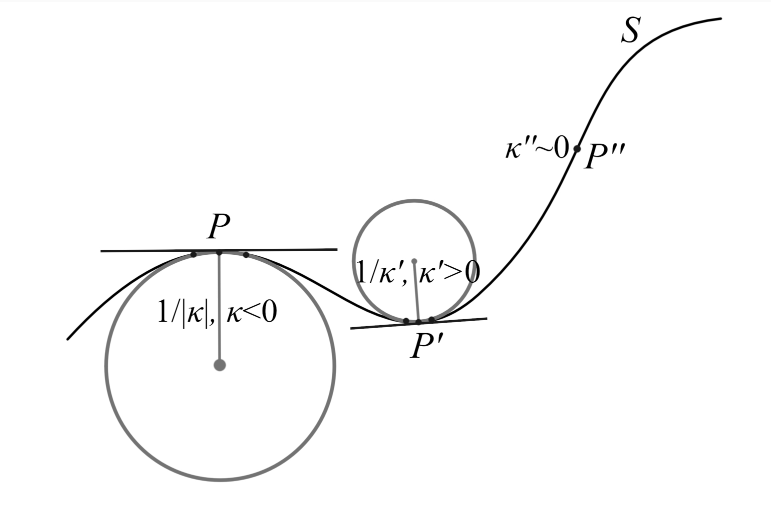



Figure 1: Adapted from Lucatelli and Ferrari (2019).

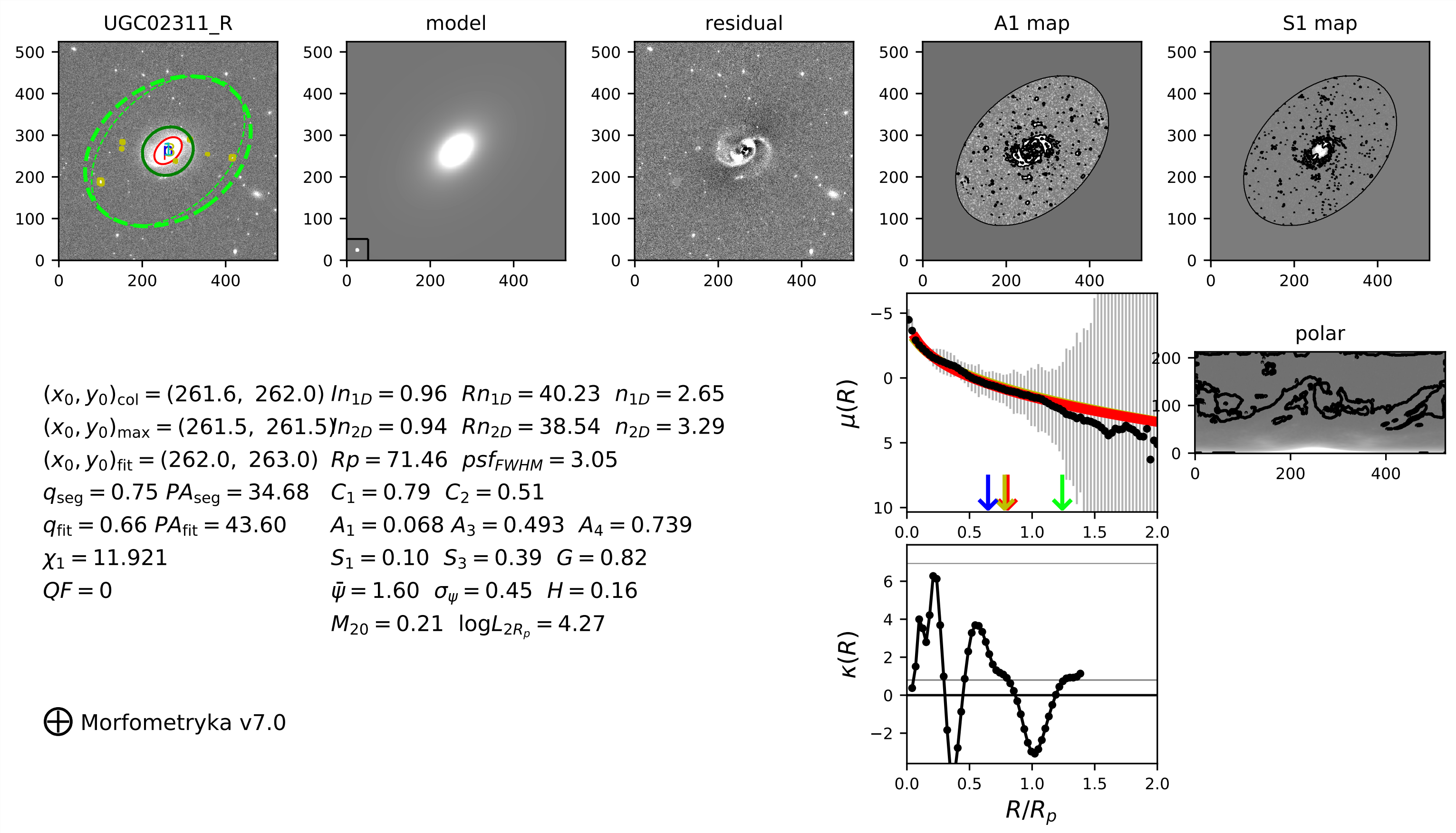
$$\kappa(R) = \frac{\dfrac{d^2 I}{dR^2}}{\left[1 + \left(\dfrac{dI}{dR}\right)^2\right]^{3/2}}, \tag{1}$$

**normalized:** $$\widetilde{\kappa}(R) = 4R_p^2 \frac{d\nu^2}{dR^2}\left[1 + 4R_p^2\left(\frac{d\nu}{dR}\right)^2\right]^{-3/2} \tag{2}$$

$$\nu = \frac{\log[I(R)] - \min(\log I)}{\max(\log I) - \min(\log I)} \in [0, 1] \tag{3}$$

$$d\chi = \frac{dR}{2R_p} \tag{4}$$

The basic measurements (masking, elliptical parameters, surface brightness profile) we do with MORFOMETRYKA Ferrari et al. (2015).



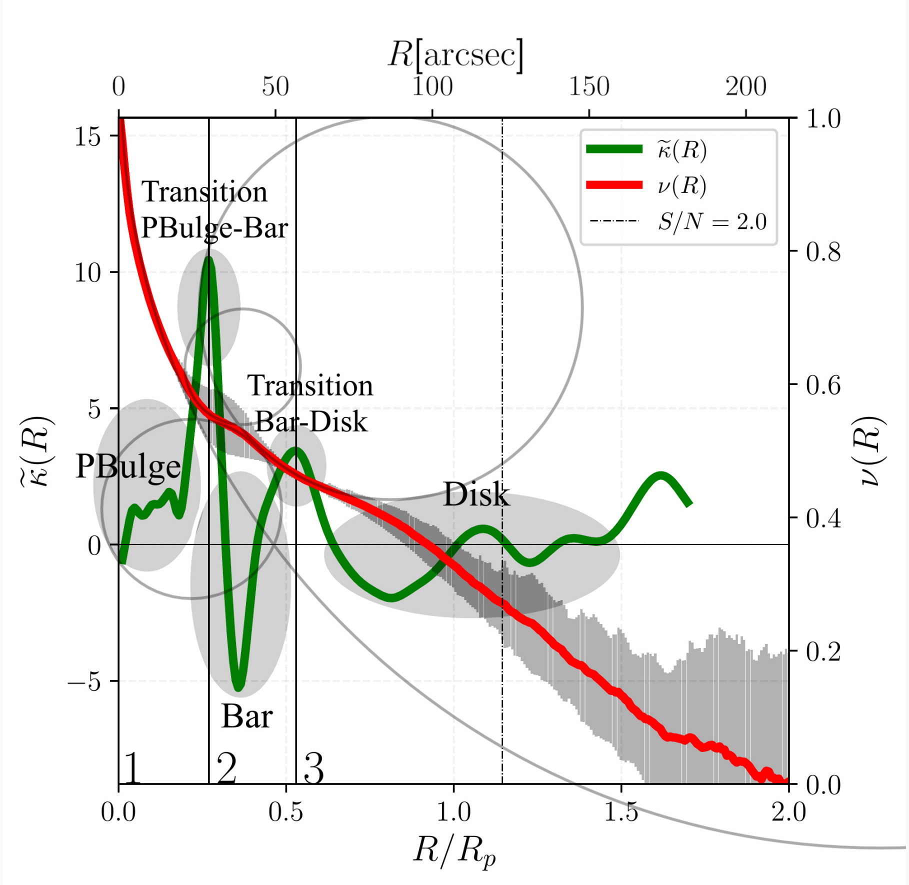
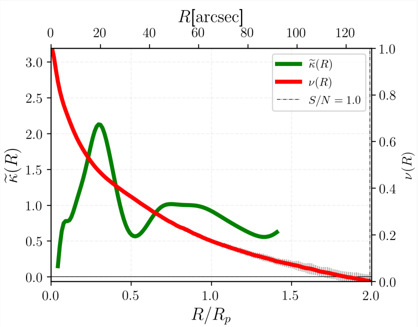


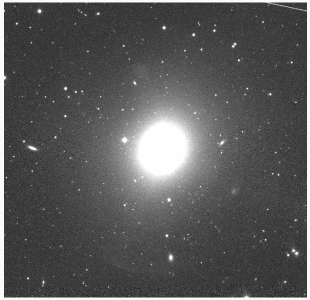

FIGURE 2: Adapted from Lucatelli and Ferrari (2019).

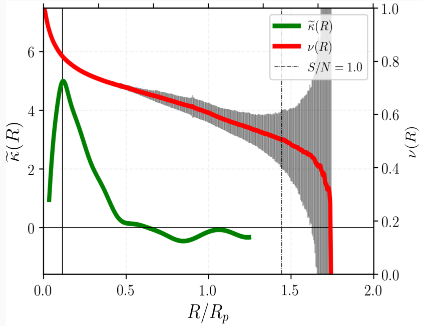
# Osculating Circle

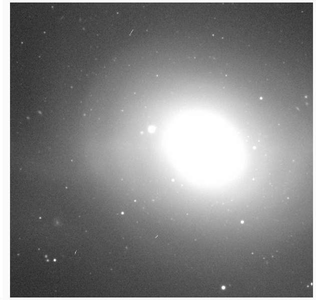
# Results

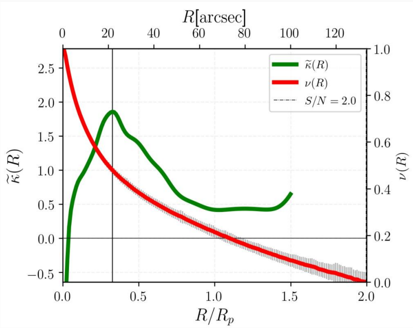
# Basic difference between elliptical and lenticular galaxies

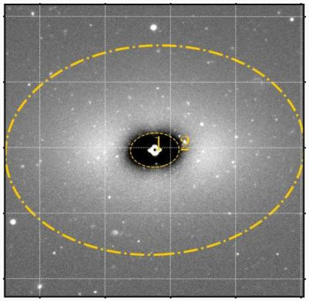


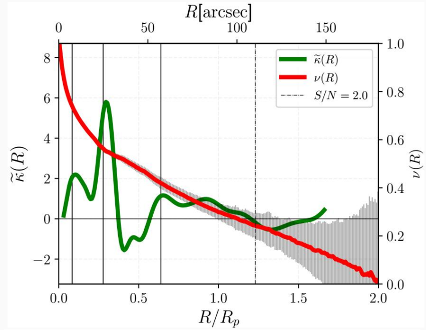



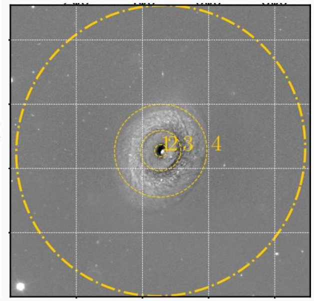


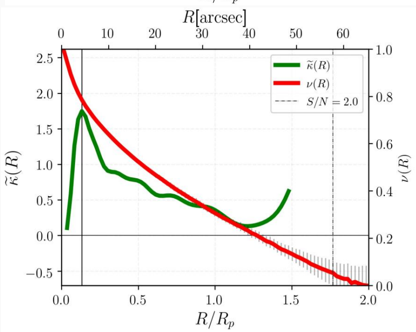



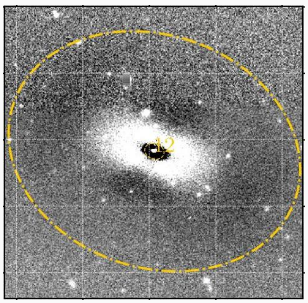


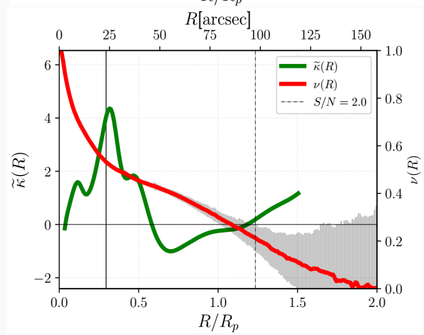



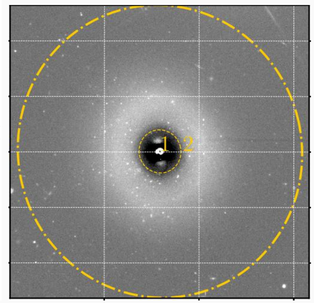



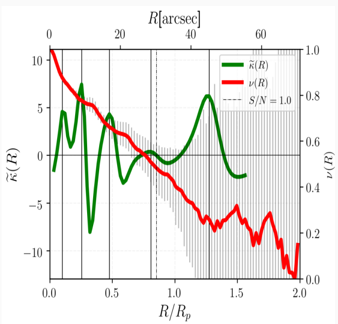



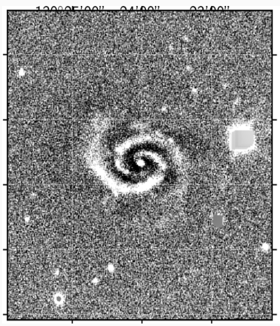
# Behaviours in the Curvature Profile

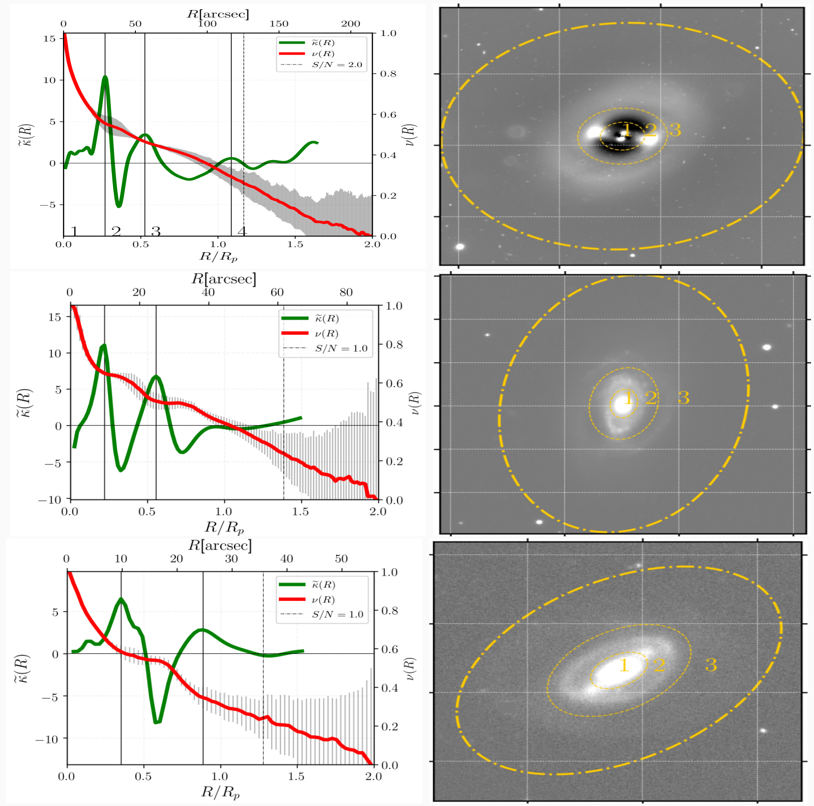
- **Local peaks are transition regions between different components**

- **PBulges shows small values in $\widetilde{\kappa(R)}$.**

- **Bars, rings and spiral arms SHOW valleys in curvature in their regions**

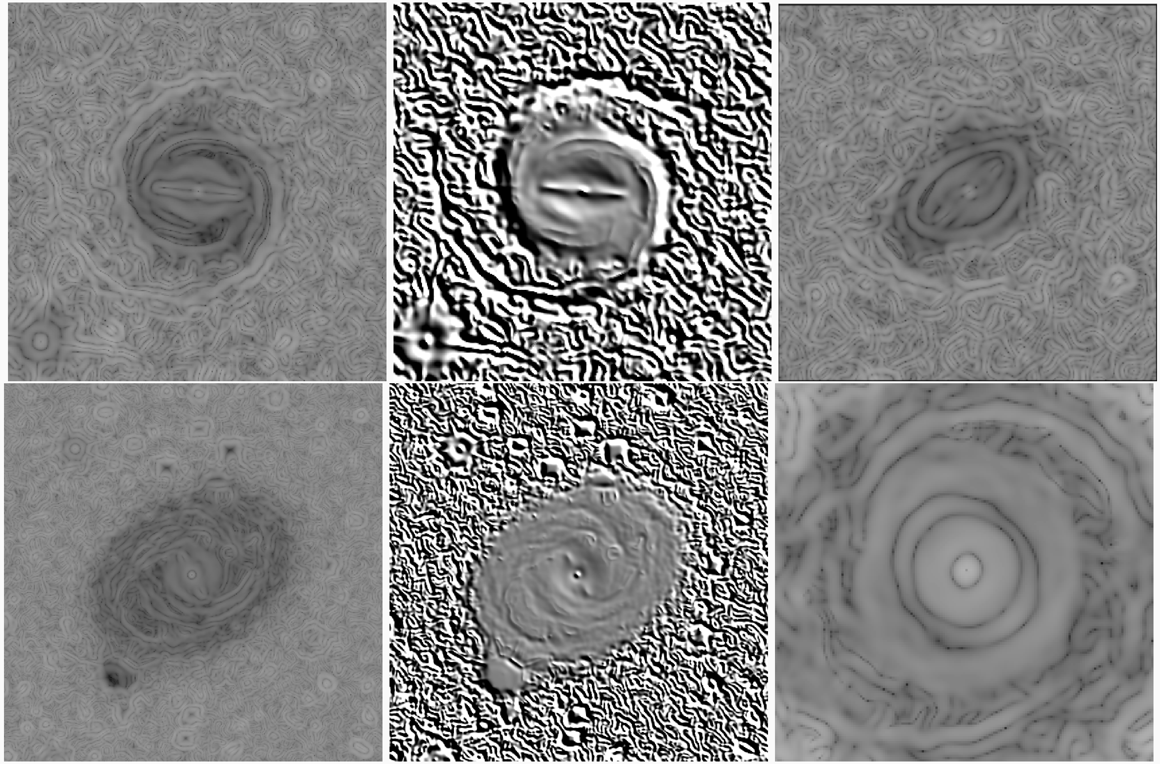




# Bi-Dimensional curvature ($\widetilde{\kappa}$2D) for better structural analysis

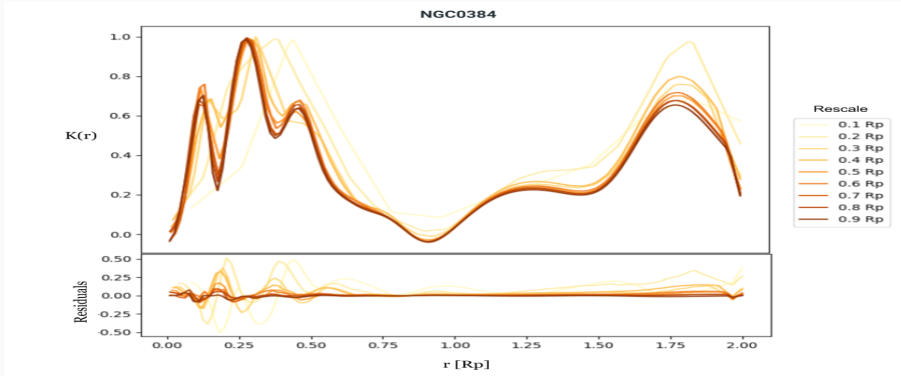
- spiral arms and bar detection
- rings
- $\widetilde{\kappa}$2D or $d^2I$ may be used for segmentation?



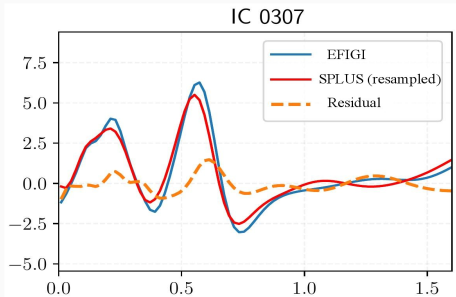
# Research: Now & Future

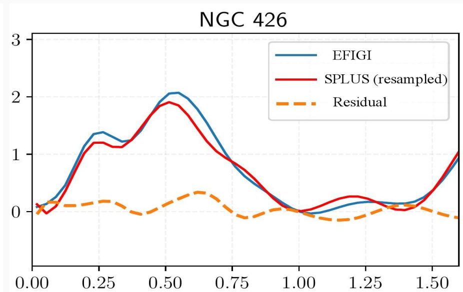
# Dependence with resolution, signal-to-noise and redshift

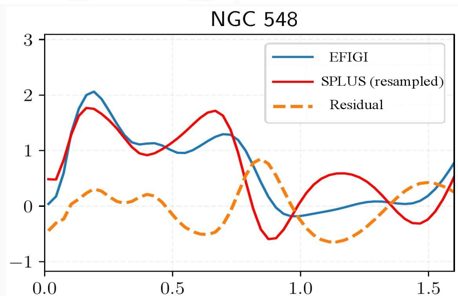
- Currently working with Leonardo de Albernaz Ferreira (University of Nottingham) to see how $\widetilde{\kappa}$ is affected by redshift $z$.
- Investigating kurvature for higher redshifts and galaxy mergers.




- A simple comparison between some S-PLUS galaxies with the same in EFIGI (SDSS, a slightly higher resolution) shows that the curvature does not change much.



## Establish a metric in terms of curvature.

- for ellipticals and lenticulars.
- automate information extraction from $\varkappa$ 2D?

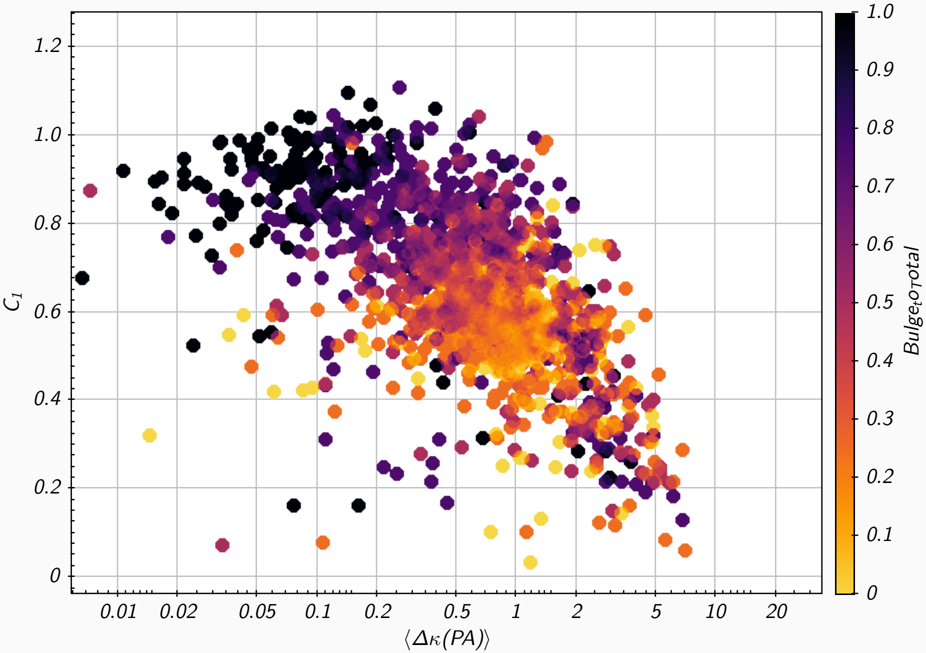
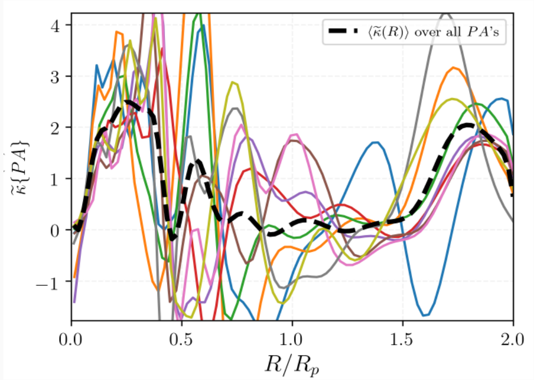
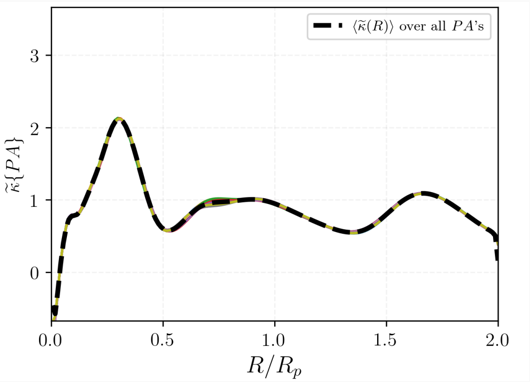


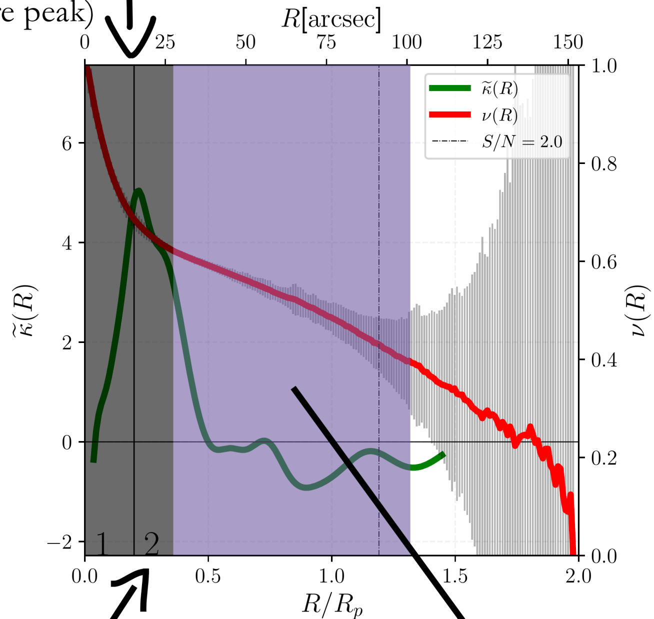

Figure 3: Data from EFIGI Baillard et al. (2011).



# Constrain the model parameter space in fitting routines

If the bulge is in this region (around the curvature peak)




$R_b \sim 0.2 R_p$

Why not constrain the bulge parameter $R_b$ (Sérsic) here, during a profile fitting?

The disk scale length also maybe somewhere in this region.

# Summary

**Curvature for:**

- identification of different structural componets;
- substantial distinction between lenticulars and ellipticals;
- intrinsic behaviour in spiral galaxies, bars and rings(using also $\widetilde{\kappa}$2D for better discriminant);

**Prospects & Future (with S-PLUS and others surveys)**:

- Obtain a statistic of the curvature of ellipticals and lenticulars for a large data sample:
  Fabricio Ferrari; Arianna Cortesi; Juliana Caffer.
- use S-PLUS to study the limits of $\widetilde{\kappa}(R)$;
- curvature for jellyfish galaxies:
  Ana L. Chies-Santos; Fernanda V. Roman-Oliveira; Fabricio Ferrari.
- redshift analysis in curvature:
  Leonardo de Albernaz Ferreira.
- investigate if the radial value of the transition region of each component is compatible with the respective model (radial parameters) fitted to the components;

Perguntas? Sugestões?

Questions? Suggestions?

# Gracie!

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