A new bulge type indicator from the principal component analysis of surface density profile

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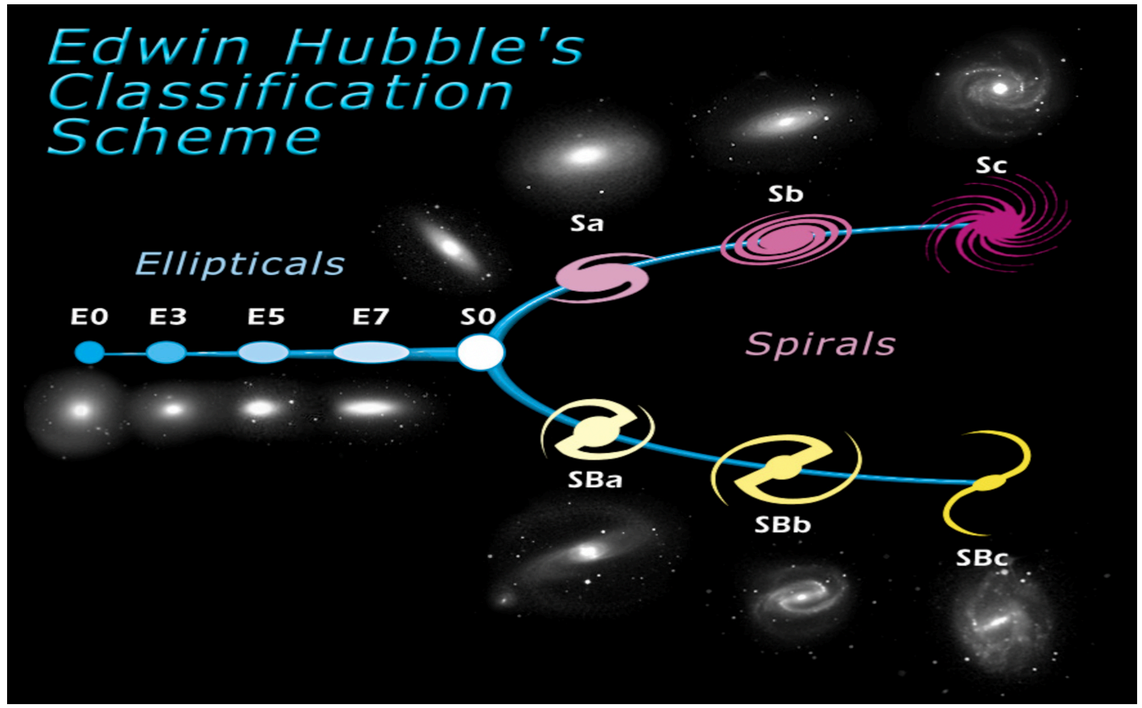
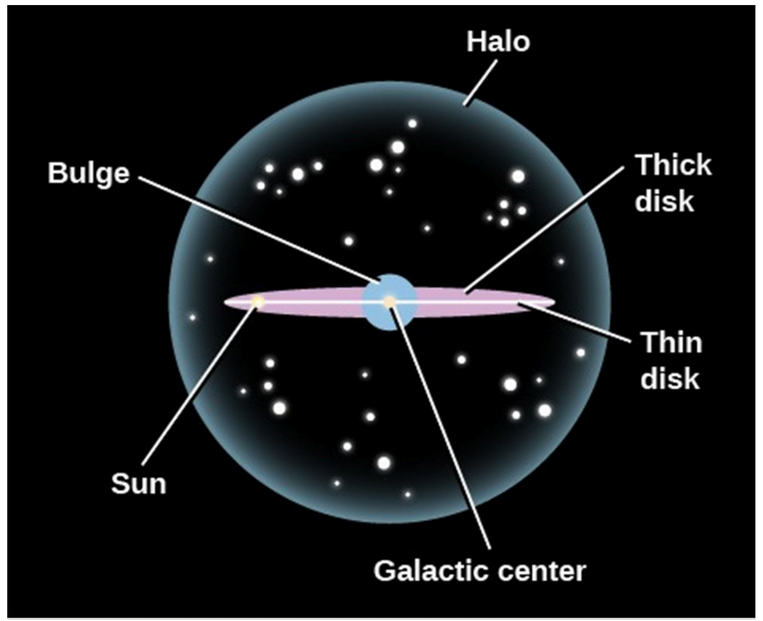
Introduction

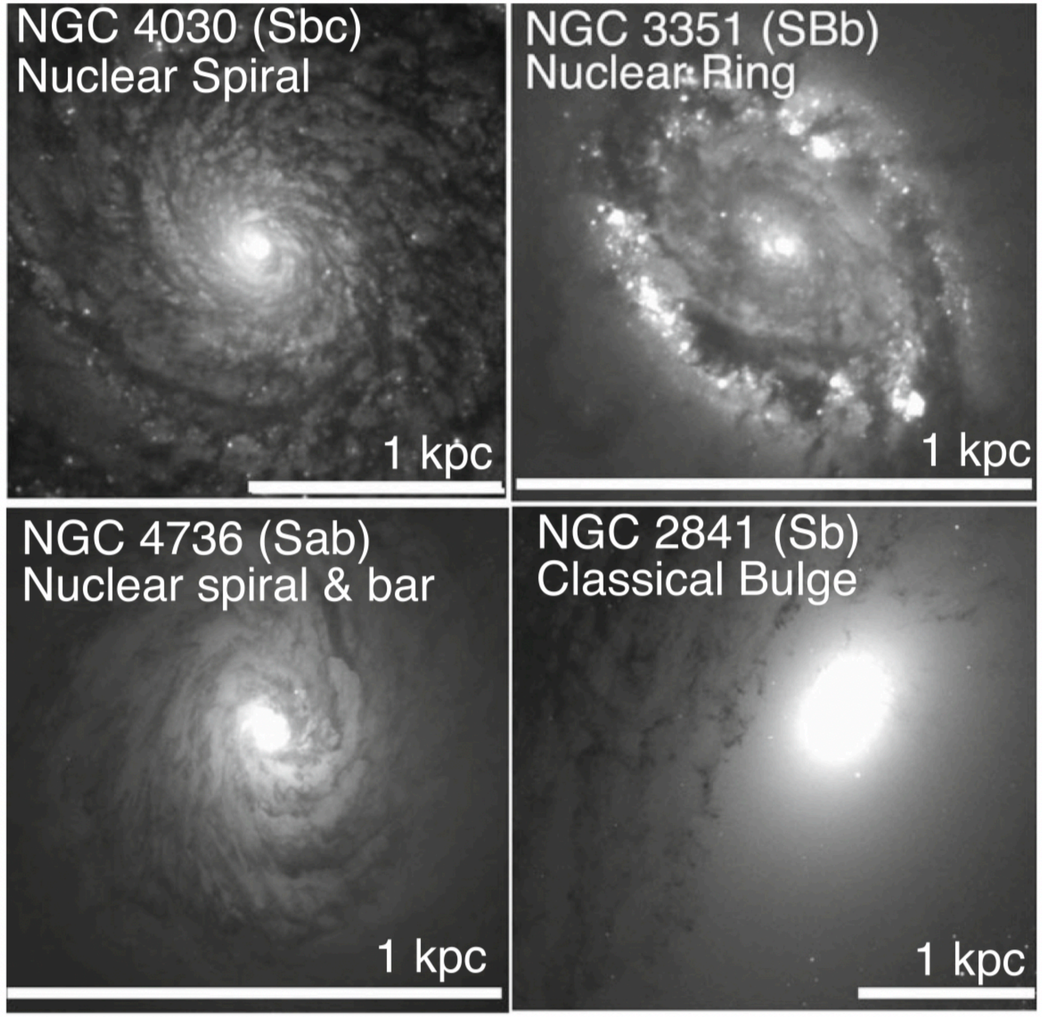
- The term ‘**bulge**’ is used to describe the dense spheroidal swarm of stars often found in the centres of spiral and S0 galaxies.
- For a long time, bulges were historically thought to be elliptical galaxies that happened to have a disk of stars around them.





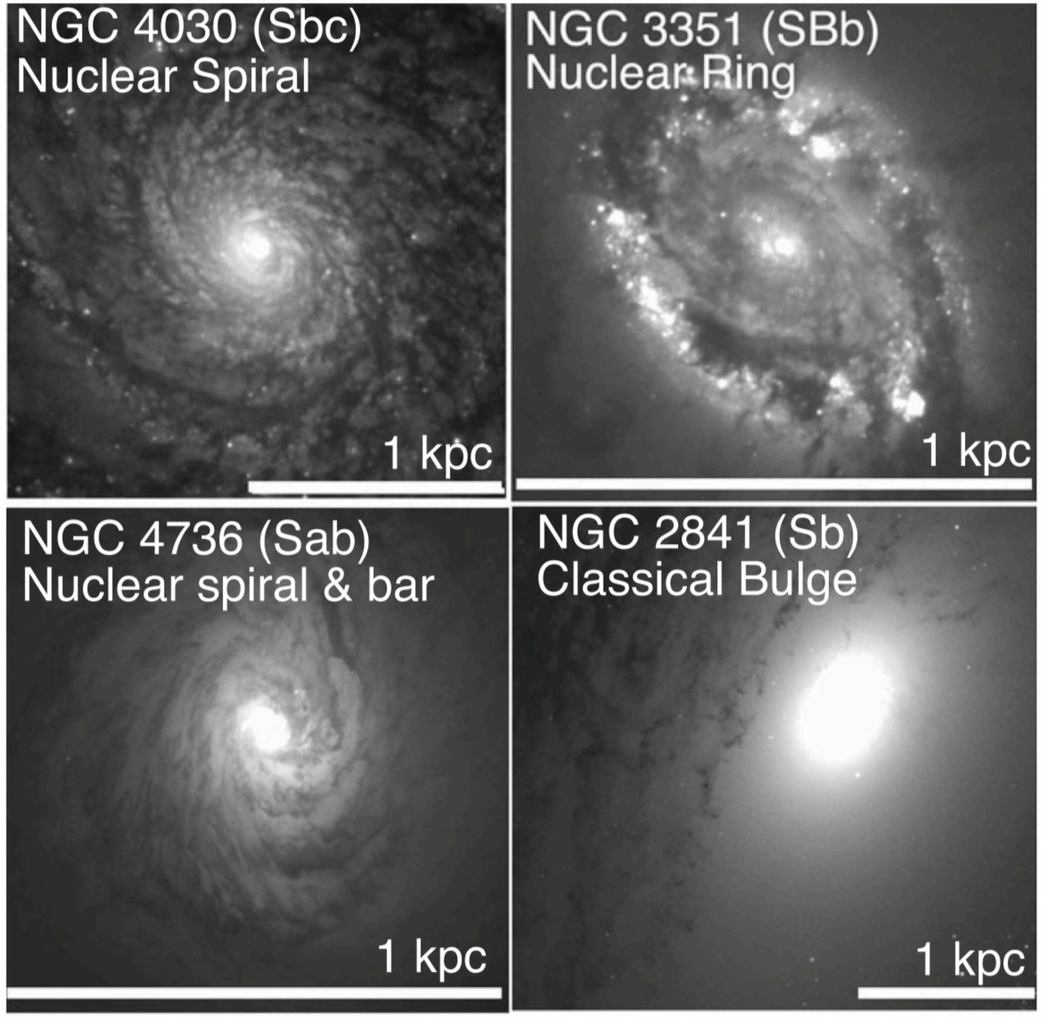
Introduction

- It is now thought that there are at least two types of bulges: bulges that are like ellipticals and bulges that are like disk galaxies, ie. **Classical bulge and Pseudo bulge.**



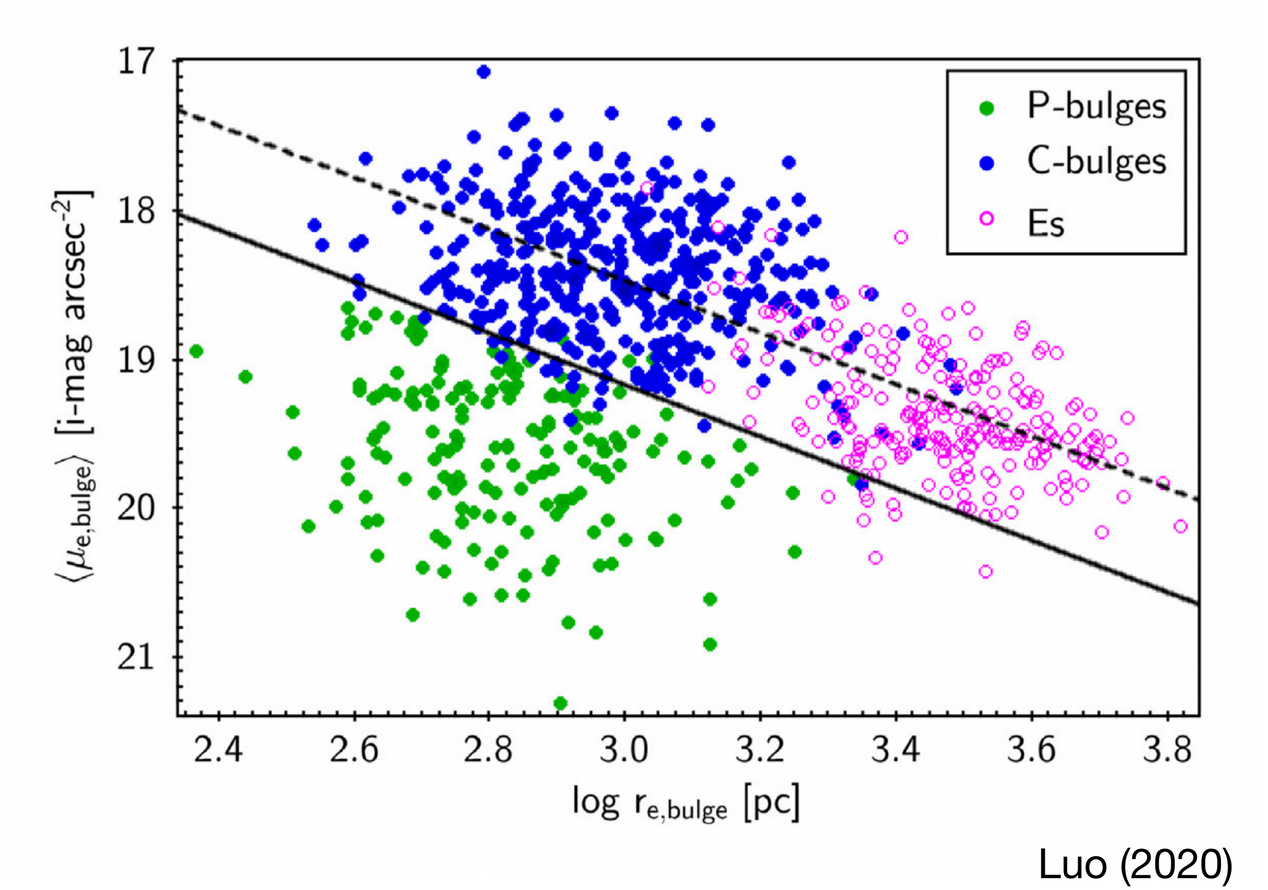
Introduction

- Classical bulges: red, old stars, low rotation, elliptical morphology, formed through violent processes, such as hierarchical clustering via minor mergers
- Pseudo bulges: blue, young stars, high rotation, disky morphology, often host nuclear bars and/or nuclear spiral arms, formed through longer time-scales, via disc instabilities and secular evolution processes
- Given their dissimilar origins, bulges hold crucial clues to galaxy formation and evolution.



The Common Bulge Indicators

- Based on the Kormendy relation
- $\langle \mu_e \rangle$: The mean effective surface brightness within the effective radius.
- $\Delta\langle \mu_e \rangle$: Defined as the residual value of $\langle \mu_e \rangle$ relative to the Kormendy relation. (Gadotti 2009)



Luo (2020)

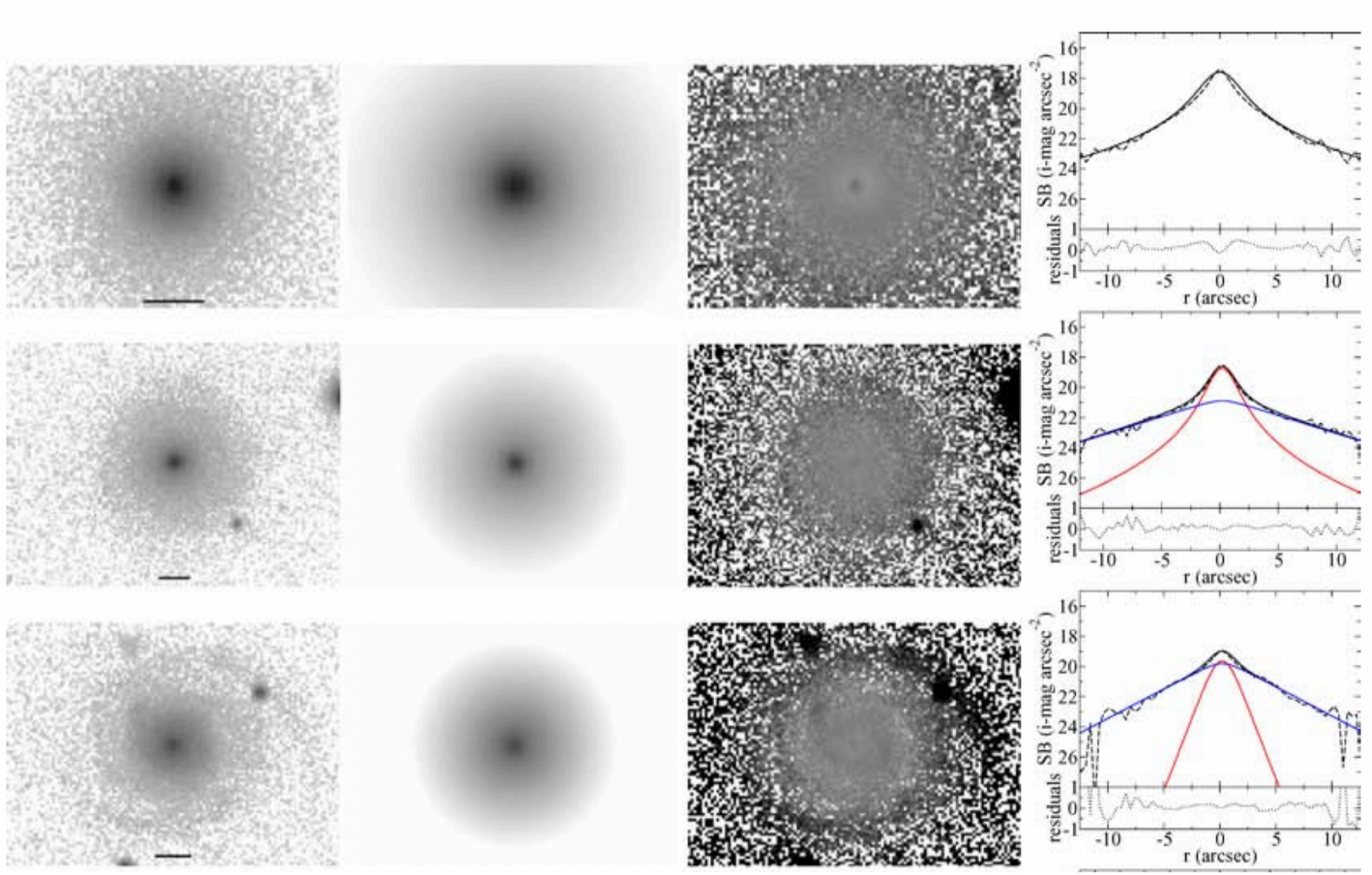
Introduction

The Common Bulge Indicators

- **Sérsic index (n):** Classical bulges: $n>2$ || Pseudo bulges: $n<2$
- **Bulge-to-total ratio (B/T):** Classical bulges: $B/T<0.35$ || Pseudo bulges: $B/T>0.5$
- **Concentration index (C):** Classical bulges: $C>0.4$ || Pseudo bulges: $C<0.4$
- **Faber-Jackson correlation:** Pseudo bulges: low-σ outliers
- Among these indicators we regard the **Kormendy relation** as the best reference, not only because it is based on strong physical theory but also proved to be the best single criterion out of the three other indicators (Sérsic index, concentration and F-J correlation)(Neumann et al. (2017)).

Motivation

- Although the Kormendy relation has been proved to be a physical and reliable way to separate the bulges, it **require a mount of calculation** to decompose the bulge from a galaxy.
- Therefore, in this work we aim to find another simpler way to separate bulges but also keeps agreement with the Kormendy relation.



Gadotti (2009)

Method

- Principal Component Analysis (PCA), is a statistical technique for **reducing the dimensionality of a dataset**. This is accomplished by linearly transforming the data into a new coordinate system where (most of) the variation in the data can be described with fewer dimensions than the initial data.
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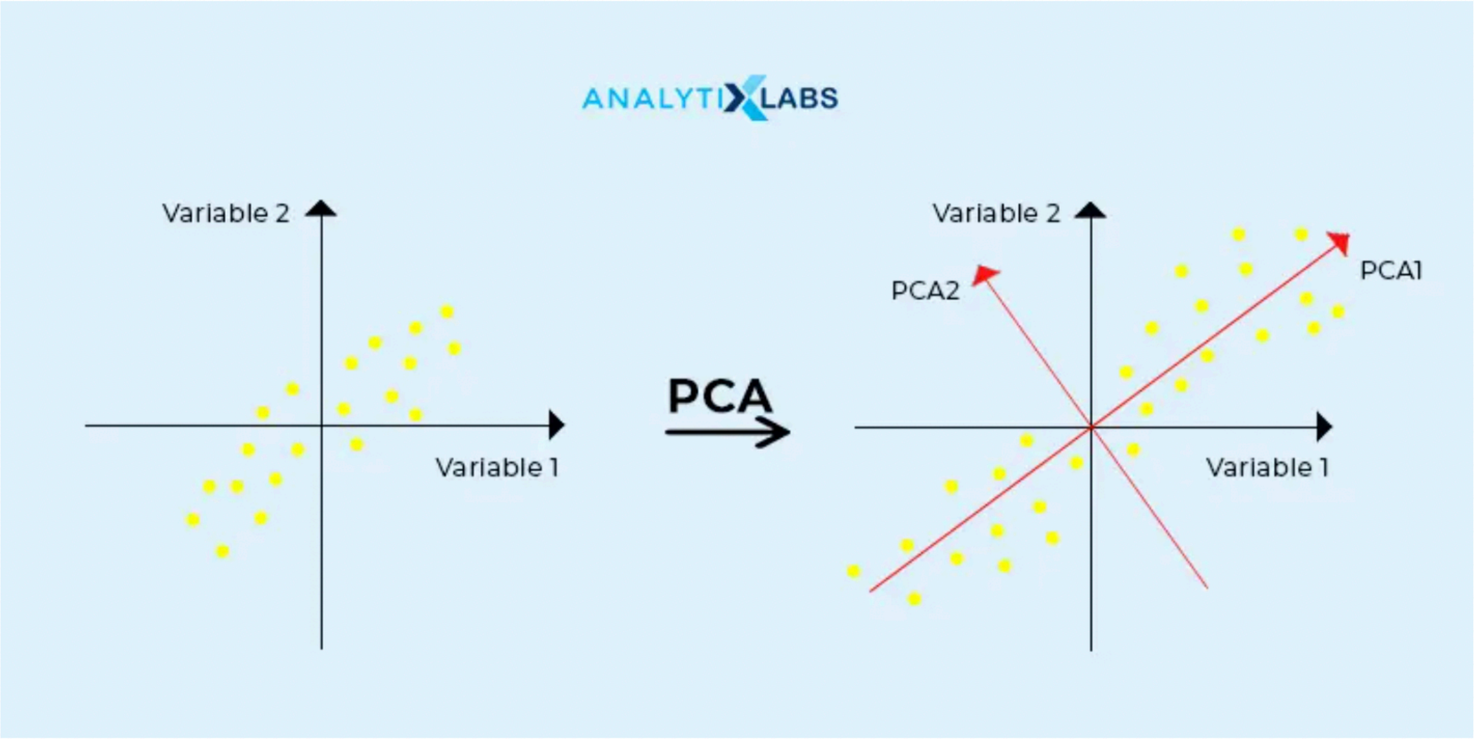


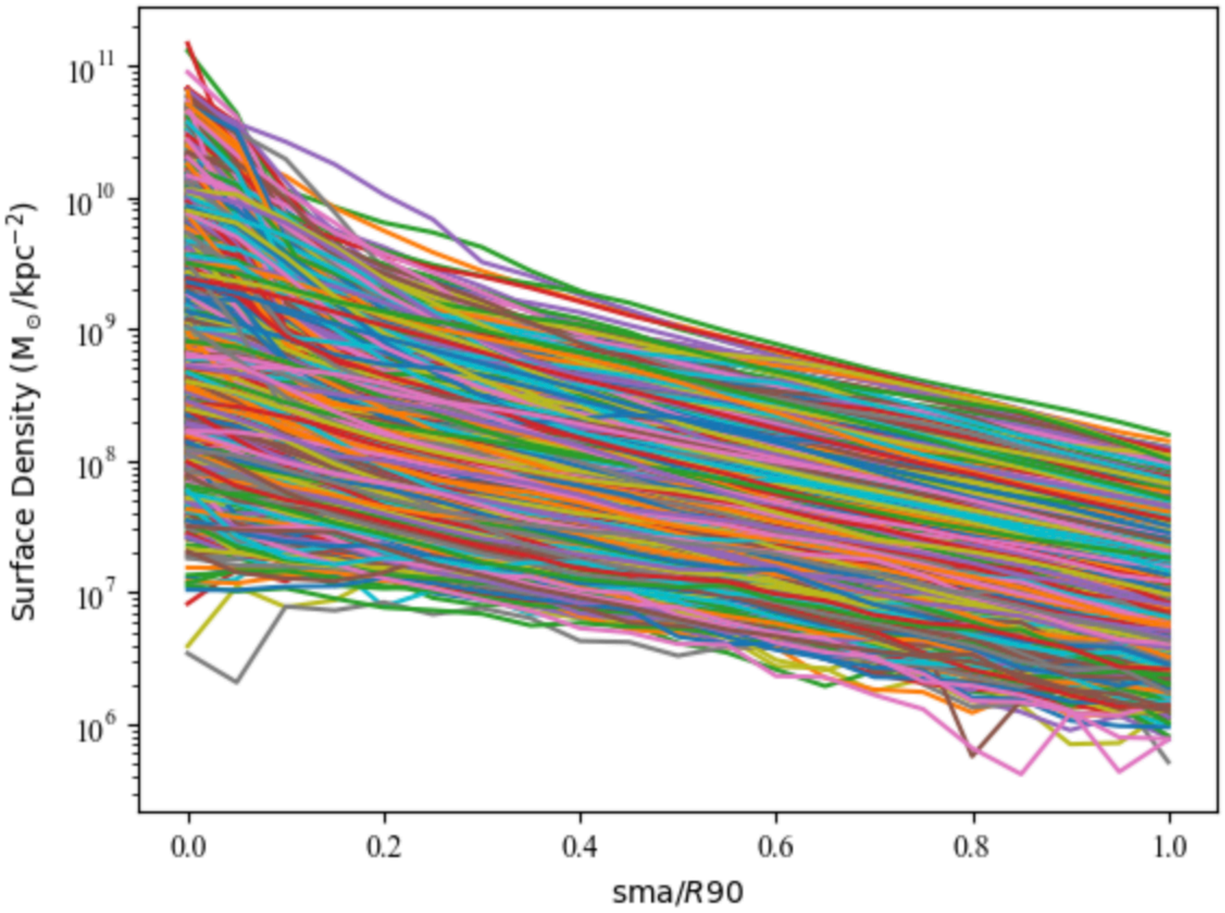
Data

- The Spitzer Survey of Stellar Structure in Galaxies (S^4G) is a volume, magnitude, and size-limited survey of 2352 nearby galaxies with deep imaging at 3.6 and 4.5 μm.

- In this work, we use the 3.6 μm images, and select galaxies with ellipticity less than **0.65** to exclude edge-on cases.

- Getting rid of the galaxies, which are badly polluted by super bright foreground stars or the nearby galaxies, as well as lack of accurate distance estimation or other important parameters, leaving us **1608 cases.**

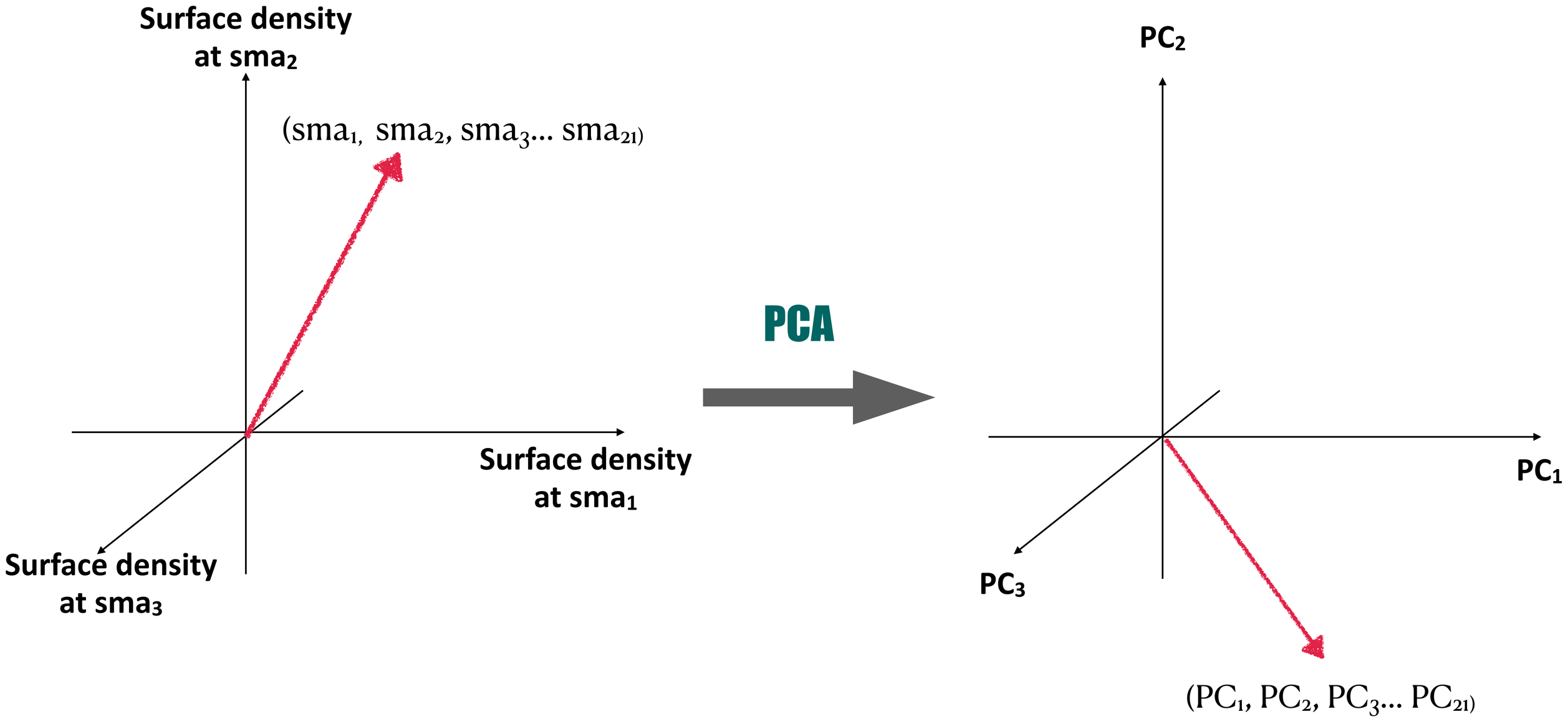
Results



1st point	Surface density at sma_1
2nd point	Surface density at sma_2
3rd point	Surface density at sma_3
……	……
21st point	Surface density at sma_{21}

- We interpolate each SDP to a common radial sampling using 21 points, with the interval being $R_{90}/20$

Results


Surface density at sma2
(sma1, sma2, sma3... sma21)
Surface density at sma1
Surface density at sma3
PCA
PC2
PC1
PC3
(PC1, PC2, PC3... PC21)

Results

$$SDP = \mu_0 + PC_1 * \mu_1 + PC_2 * \mu_2 + PC_3 * \mu_3 + \ldots + PC_{21} * \mu_{21}$$

Coordinate

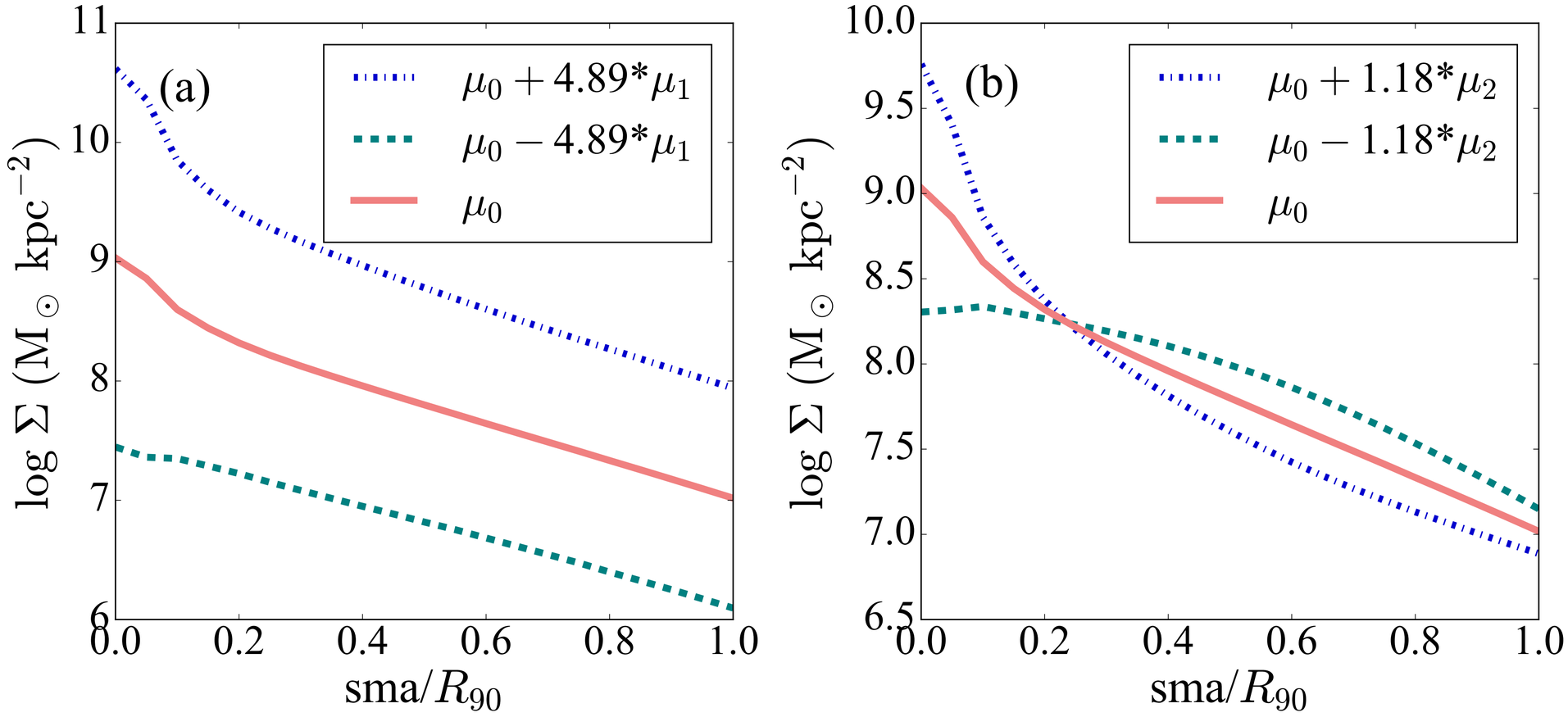
Direction of PC_1

What is the physical meaning of PC_1, PC_2… ?

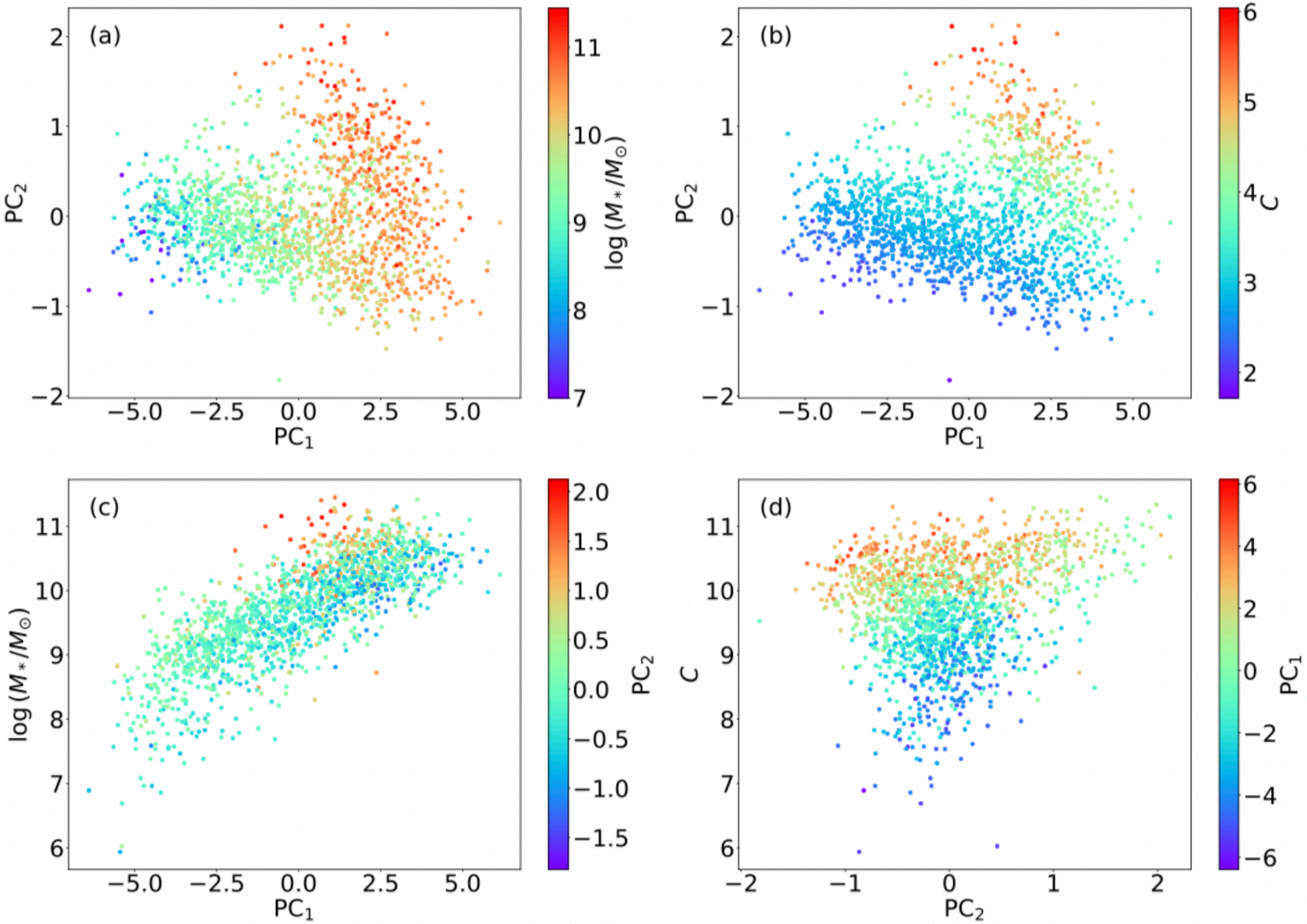
Results

$$\mathrm{SDP} = \mu_0 + \mathrm{PC}_1 * \mu_1 + \mathrm{PC}_2 * \mu_2 + \mathrm{PC}_3 * \mu_3 + \ldots + \mathrm{PC}_{21} * \mu_{21}$$

How the PC_1 and PC_2 influence the SDPs.

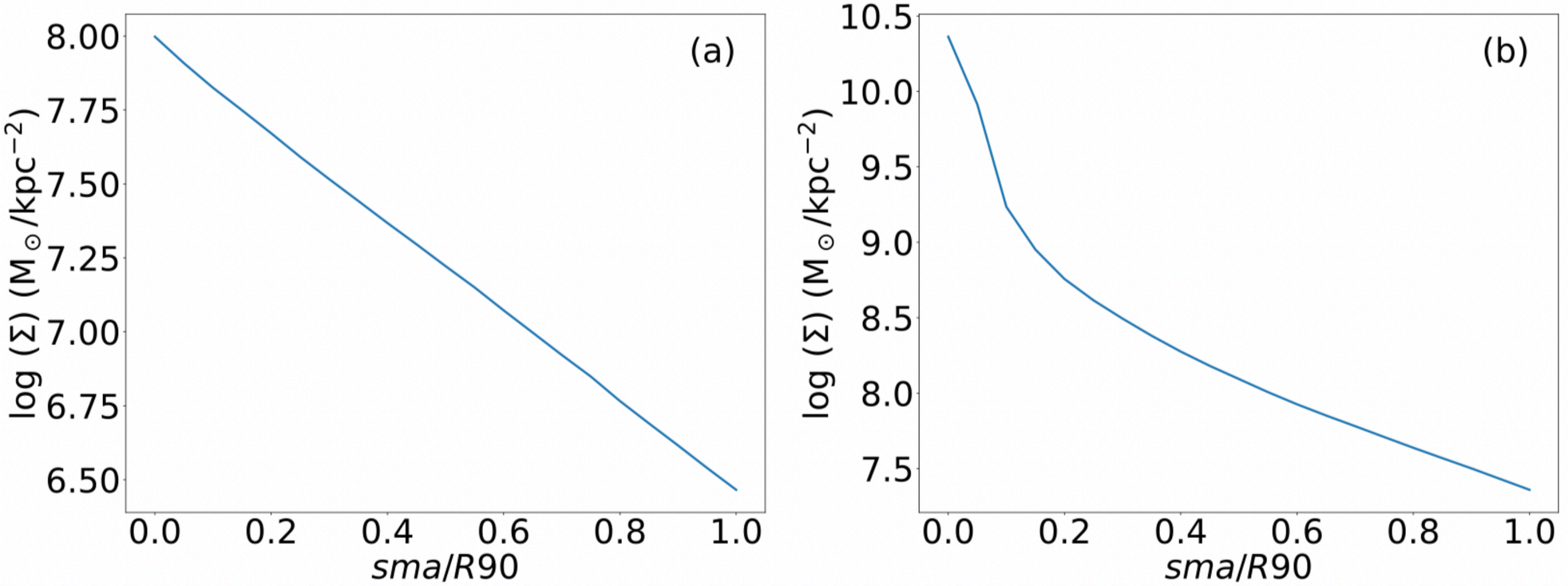


Results



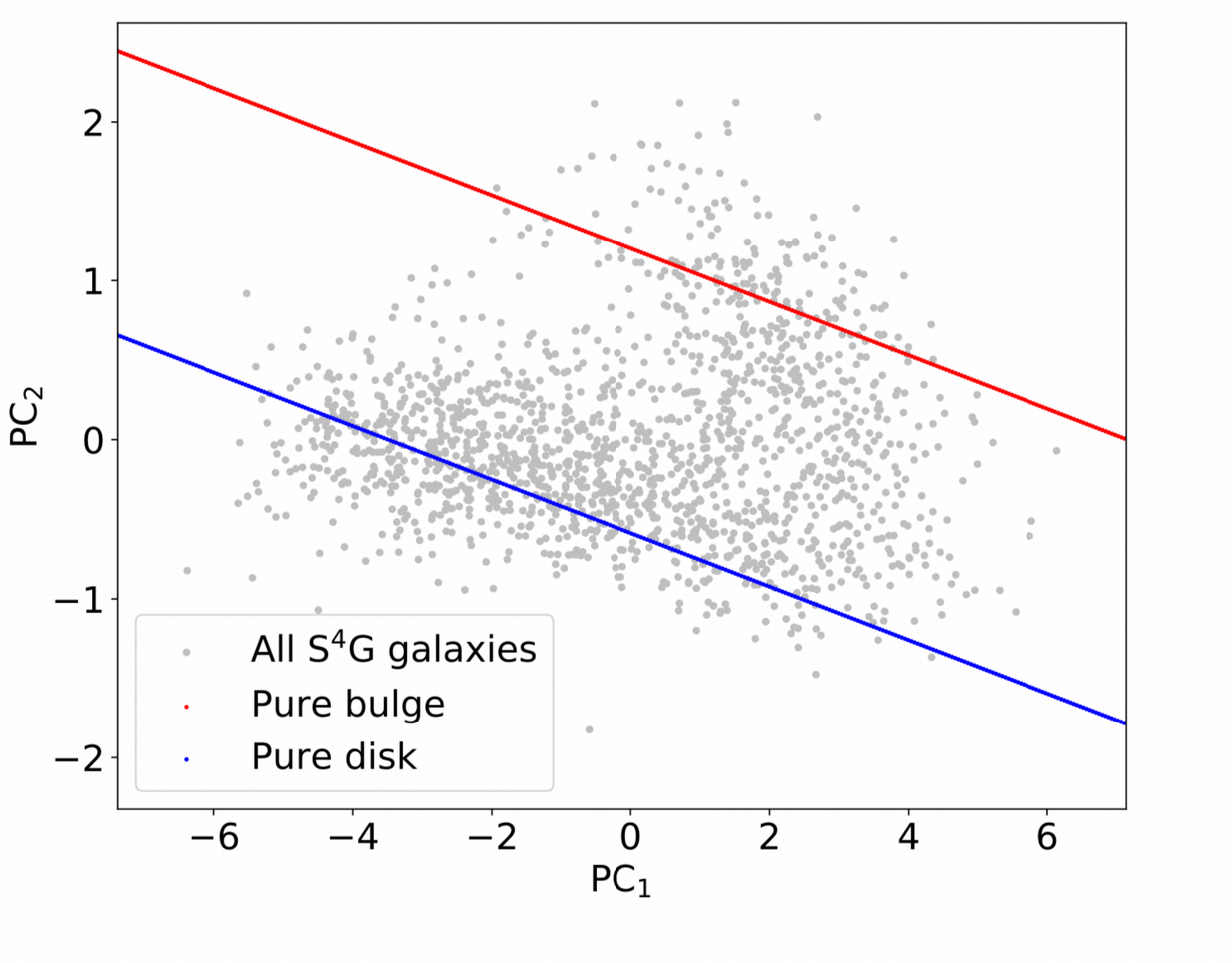
The relationship among PC1, PC2, stellar mass ($\log(M_*/M_\odot)$), and the concentration index (C)

Results



The averaged SDP of the pure disk and the pure bulge galaxies

Results



The distribution of the PC_1 and the PC_2 of all S4G galaxies, pure disk galaxies, and pure bulge galaxies, encoding with grey, blue, and red dots, respectively.

Results

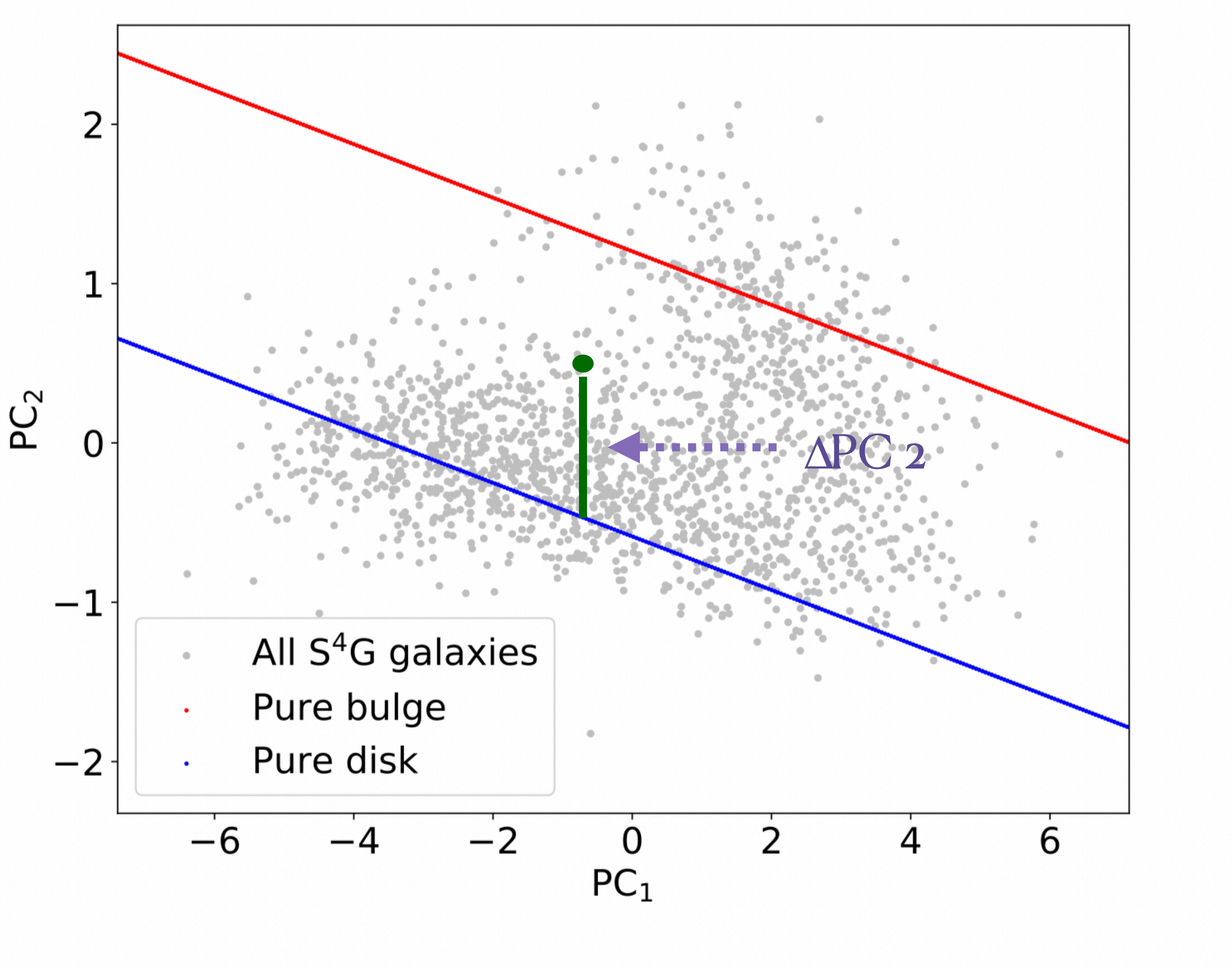
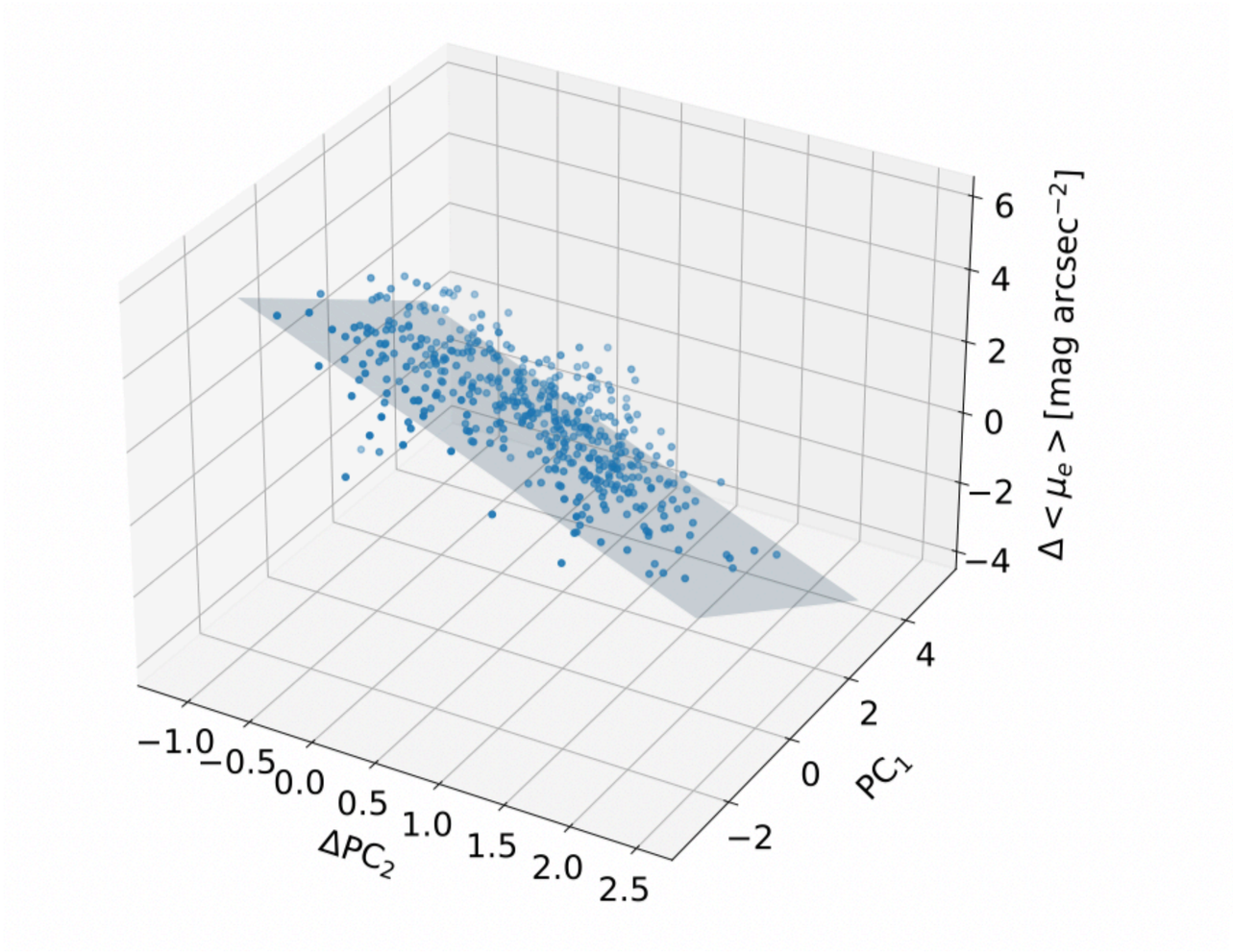
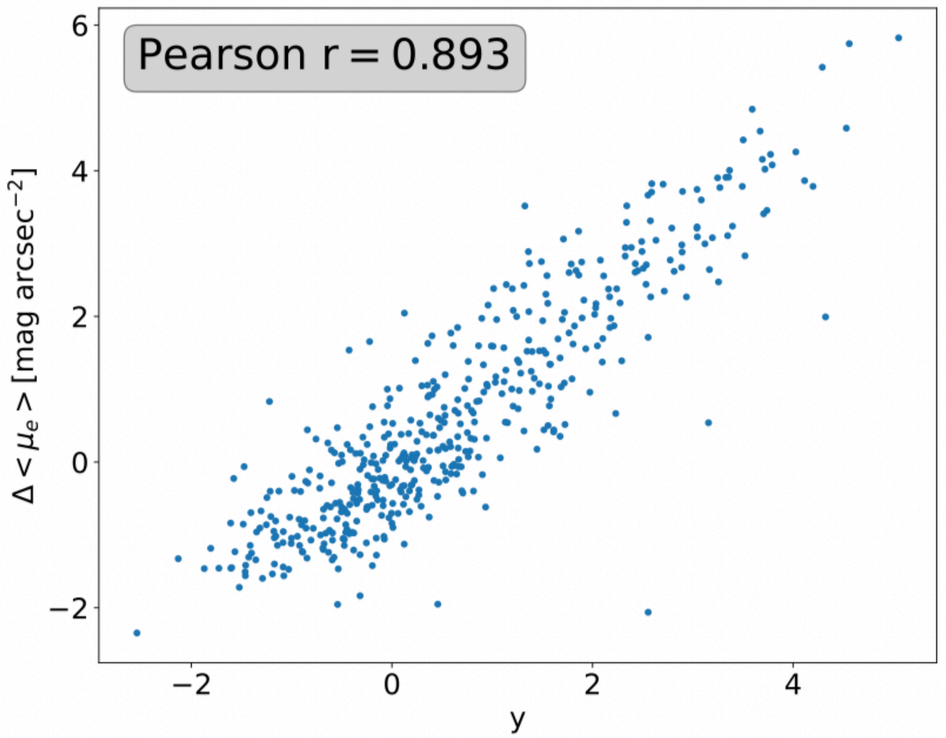


Illustration of how we define the ΔPC2

Results





$$y = -0.737 * \mathrm{PC}_1 - 1.433 * \Delta\mathrm{PC}_2 + 2.351$$

Summary

- In this work, we apply the principal component analysis (PCA) to the surface density profiles (SDPs) of the galaxies from the Spitzer Survey of Stellar Structure in Galaxies (S^4G).
- We find that the result of PCA is related to the shape of the SDPs, and can be used to quantify the contribution of bulge component.
- As a result, We define a new bulge type indicator, which turns out to be well consistent with the traditional bulge indicator $\Delta \langle \mu\, e \rangle$
- The major benefit of this method is less computation but more accuracy.
- For the future work, we will figure out what's the physical meaning of PC3, PC4.
- Moreover, we are considering apply the method to the high redshift galaxies and test whether the PCA works well.