Exploring non-parametric morphological features of elliptical, spiral and lenticular galaxies in S-PLUS

Geferson Lucatelli, Arianna Cortesi, Claudia L. Mendes de Oliveira, Clécio de Bom, Paola Dimauro, Fabricio Ferrari, Laerte Sodre Junior, Luciana Dias and S-PLUS Morpho Group.

June 2, 2021

Presentation Outline

The study of galaxy structure through galaxy images.

- Image processing tools that allow extracting quantitative information from galaxy images;
- investigate how the light is distributed in it;
- provide clues regarding differences between elliptical, spiral and lenticular galaxies;
- create a parameter space to identify them;

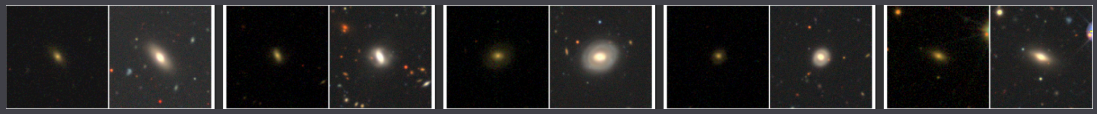
Presentation Outline

S-PLUS Galaxy Data set

- imaging data from Stripe82-DR1, comprising about $\sim$ 12 000 galaxies;
- they were given by (Nakazono et. al, 2021) classification using `prob_gal`> 0.6;
- and a magnitude cut of `r_petro`< 17;

Galaxy Classes and Galaxy Zoo

- GZ provides classification for $\sim$ 8500 of the 12K galaxies: 14% Elliptical, 34% Spiral, 52% Uncertain class;
- the lenticular class galaxy list was constructed by making a multi-step analysis:
  1. selection of `prob_S0`>0.6 & `T-Type`$\in [-2.5, 0.5]$ candidates in GZ;
  2. from Item 1, take only low `prob_E` and `prob_S` from (Bom et al., 2021);
  3. make a visual inspection of remaining objects in Item 2.



Presentation Outline

CAS System and Beyond

- Standard Measurements: Concentration C, smoothness S, asymmetry A , Gini G; momentum M_{20};
- Additional quantities: entropy H, spirality σ_ψ; kurvature κ; fractional radius $R_{\%i}$;
- curvature metrics: area A_k, median of curvature $\langle\kappa\rangle$;

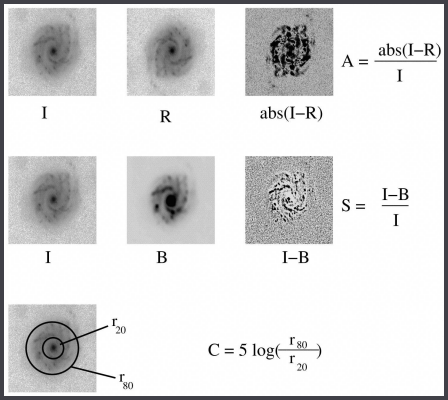
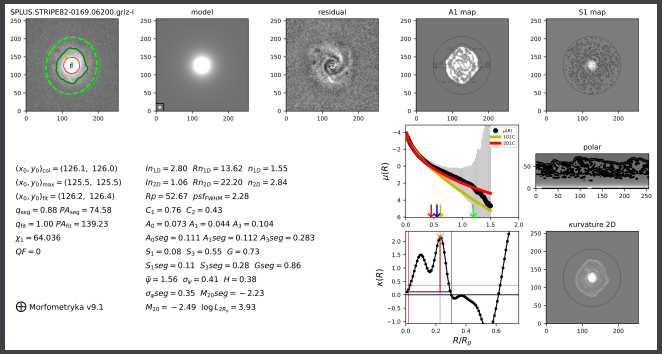


Figure 1: CAS-System. Adapted from (Conselice, 2014).

Morfometryka: Automated approach to compute these quantities before mentioned.



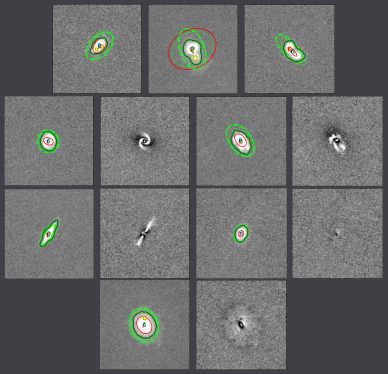


Figure 2: (Ferrari et al., 2015)

Curvature Approach

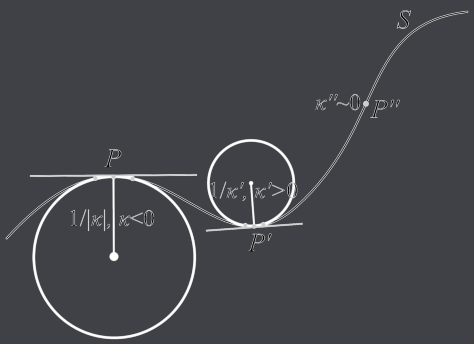
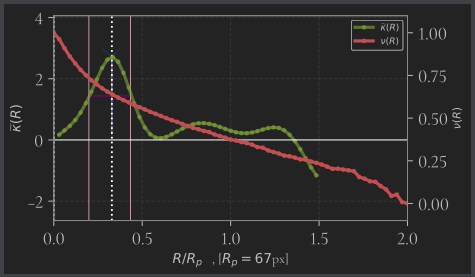


Figure 3: Adapted from (Lucatelli and Ferrari, 2019).

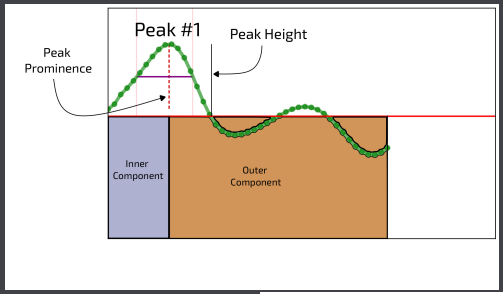
$$\widetilde{\kappa}(R) \propto \frac{d^2\nu}{d\chi^2}, \quad d\chi = \frac{dR}{2R_p} \quad \rightarrow \quad \chi \in [0,1] \tag{1}$$

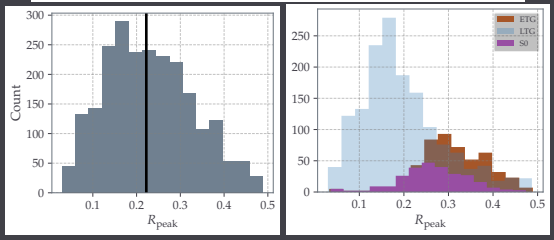
$$\nu = \frac{\log[I(R)] - \min(\log I)}{\max(\log I) - \min(\log I)} \quad \in [0,1] \tag{2}$$

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



Curvature Metrics





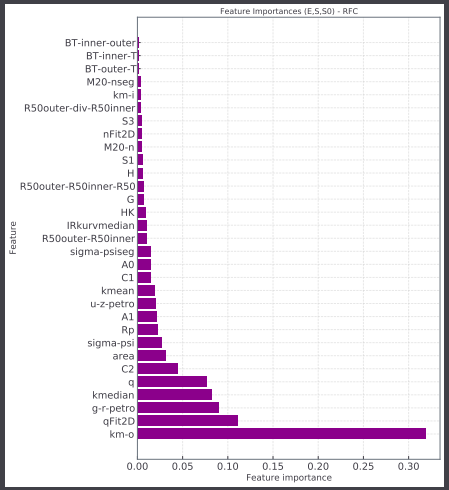
- curvature peak allows to split a galaxy into two regions: **inner** and **outer**;
- median radial position where the peaks are found: $\langle R_{\rm peak} \rangle \simeq 0.22 \times (2R_p)$
- with this, we can calculate metrics for each region.

Figure 4: Curvature peaks distribution.

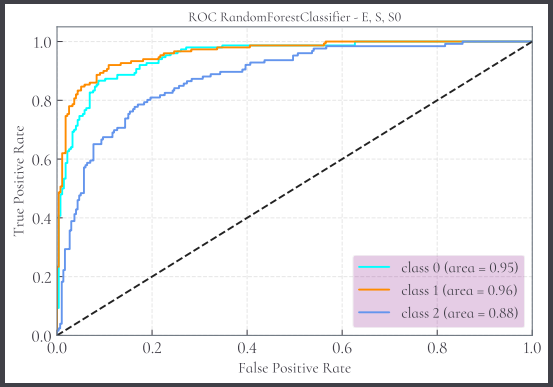
Presentation Outline

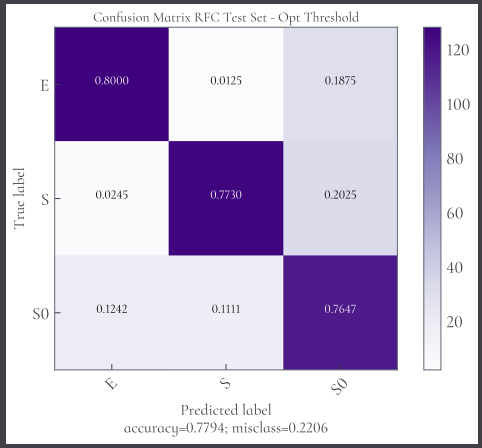
- Machine Learning is a practical way to deal with large data sets and classification purposes;
- we combine all available measurements performed by MFMTK with Machine Learning;

Features for the Random Forest



Machine Learning: Random Forest





Presentation Outline

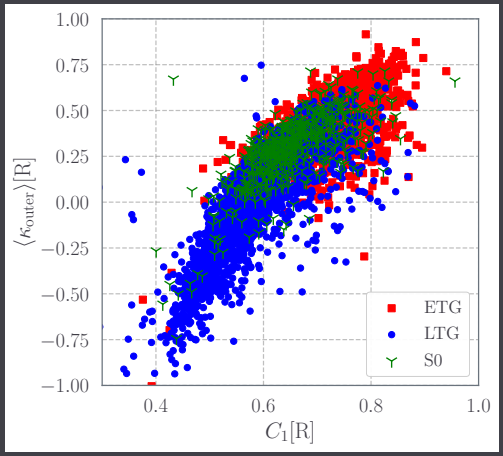


Figure 5: Mean values of outer-region curvatures vs concentration C_1.

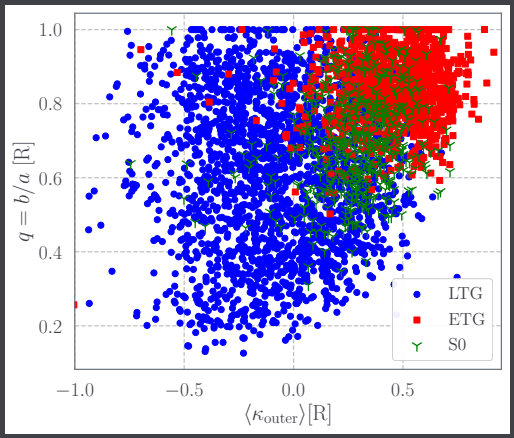


Figure 6: Entropy H vs concentration C_1 – averaged in all filters.

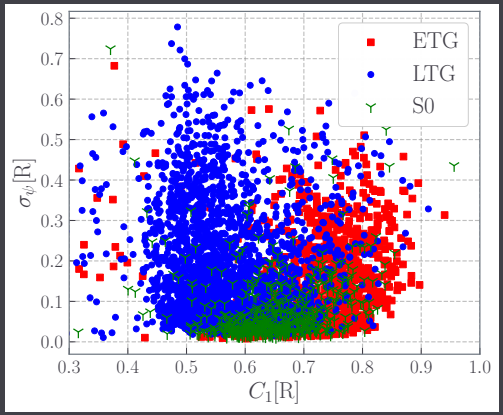


Figure 7: Spirality σ_ψ vs concentration C_1.

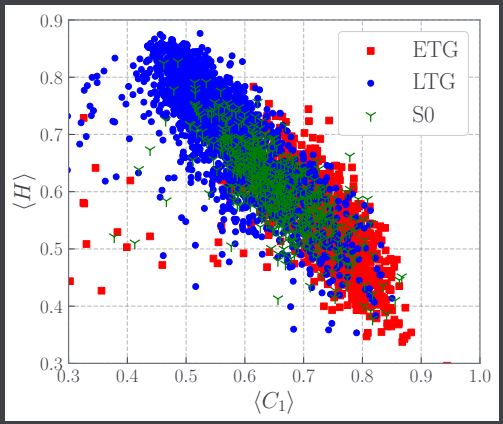


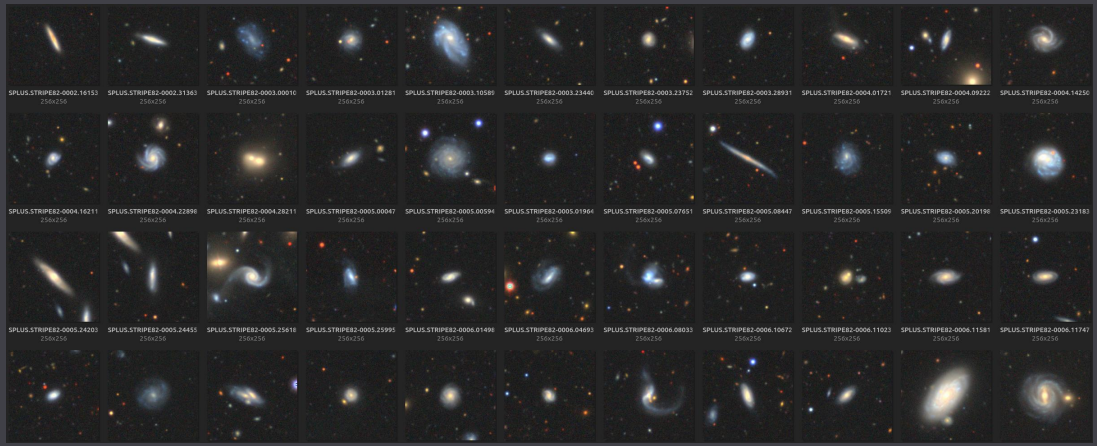
Figure 8: Entropy H vs concentration C_1 – averaged in all filters.

Results: Predictions in Blind Set

Elliptical

Results: Predictions in Blind Set

Spiral



Results: Predictions in Blind Set

Lenticular

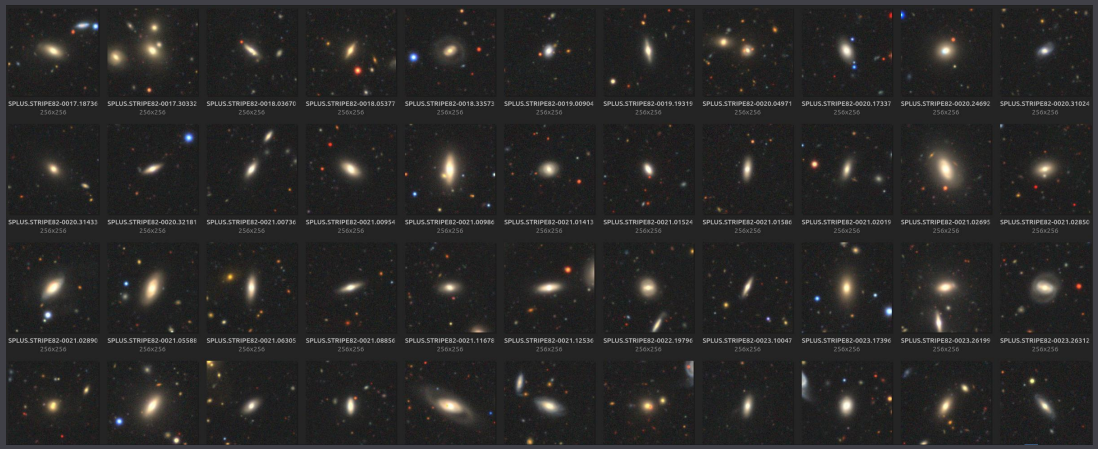


Figure 9: Spiral galaxies with smooth spiral arms resembling lenticular galaxies.

Similarity between S0 and ETG

Figure 10: Lenticular galaxies resembling elliptical galaxies.

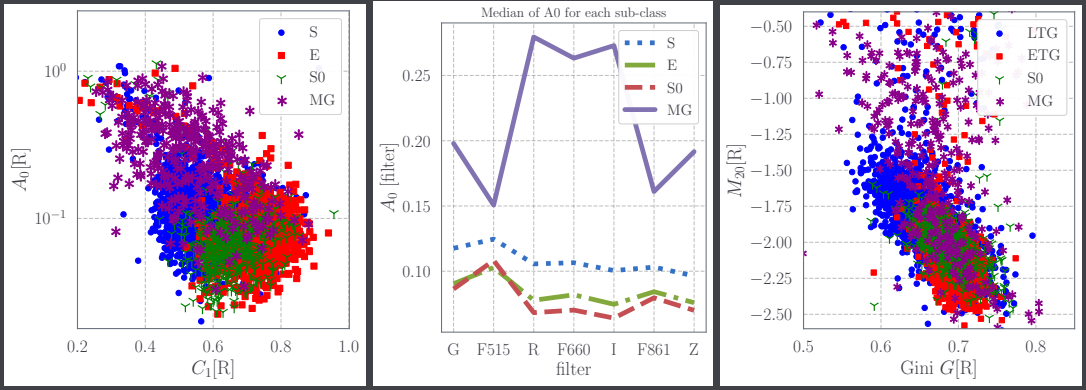


Figure 11: Including merger data.

Presentation Outline

Conclusions

Non-Parametric Morphology

- we have introduced new set of non-parametric quantities which demonstrated good relation between different types of galaxy morphologies ;
- combining multiple features improve our ability to distinguish properties of ETGs, LTGs and S0s.

Classification regarding resolution

- there are smooth similarities between S0 galaxies with both ETG and LTG;
- smooth spiral features may look like disks components of S0 galaxies;
- S0 galaxies having dominant bulges and smooth disk components may look like ETG;

Next steps

- for the paper on S0:
  - investigate the impact of individual filters for the classification.
- for the S-PLUS IDR3:
  - calculate morphological features for all galaxies in idr3;
  - predict and study all S0s galaxies in idr3;
  - investigate merging galaxies in idr3;
  - provide classifications E-S-S0-MG for all idr3 using morphological features.

Thank You!
Questions?

Acknowledgments:

To the S-PLUS team and USP for all support provided.

To the Morphological Group, for all the hard work we have been doing.

Presentation Outline

Bom, C. R., Cortesi, A., Lucatelli, G., Dias, L. O., Schubert, P., Oliveira Schwarz, G. B., Cardoso, N. M., Lima, E. V. R., Mendes de Oliveira, C., Sodre, L., J., Smith Castelli, A. V., Ferrari, F., Damke, G., Overzier, R., Kanaan, A., Ribeiro, T., and Schoenell, W. (2021). Deep Learning Assessment of galaxy morphology in S-PLUS DataRelease 1. *arXiv e-prints*, page arXiv:2104.00018.

Conselice, C. J. (2014). The Evolution of Galaxy Structure over Cosmic Time. *Ann. Rev. Astron. Astrophys.*, 52:291–337.

Ferrari, F., de Carvalho, R. R., and Trevisan, M. (2015). Morfometryka – A New Way of Establishing Morphological Classification of Galaxies. *The Astrophysical Journal*, 814:55.

Lucatelli, G. and Ferrari, F. (2019). Galaxy structural analysis with the curvature of the brightness profile. *Monthly Notices of the Royal Astronomical Society*, 489(1):1161–1180.