Reconstructing the Universe with Machine Learning.

Suárez-Pérez, J.[1]**, Forero-Romero J.**

Astroandes, Universidad de los Andes, A.A. 4976, Bogotá D.C., Colombia

jf.suarez@uniandes.edu.co

Introduction

Machine learning has found its way into observational cosmology by tackling on of the most relevant problems in the field: inferring the large scale distribution of Dark Matter (DM) in the local Universe. The DM spatial distribution is not directly observable and must be inferred from the observational data. In this poster we will show how machine learning methods can help us to solve this task. We will present preliminary results for our reconstruction efforts based on Illustris-TNG (TNG) simulation and comment on its implications and strategies for improvement.

Classification of environments in the cosmic web

It is possible to make a environment classification as a function of the local density through the gravitational potential. In [1] was exposed a cosmic web classification based on the eigenvalues of the deformation tensor of a matter density field over a grid. The deformation tensor $T_{\alpha\beta}$ is defined by the Hessian of the gravitational potential ϕ.

$$T_{\alpha\beta} = \frac{\partial^2 \phi}{\partial r_\alpha \partial r_\beta} \quad (1)$$

The eigenvalues of the tensor allow us define the environments of the cosmic web. A void correspond to a tree no positive eigenvalues, a sheet to one positive, a filament to two positive and a peak to tree positive eigenvalues. Using this definition the Fig.1a shows peaks over the density field for a slice of width one.

Our purpose is to make this environment classification using the information of the distribution of galaxies in order to understand the distribution of DM as [2]. Applying the β-skeleton algorithm over the galaxy distribution we can extract some features to train an algorithm of ML to predict the environments.

In order to inferred the environments from the distribution of galaxies, we have used TNG simulation. This was analyzed, and applied the β-skeleton algorithm to find graphs and extract some features, Fig.1b; as the number of connections (nc), the average distance (ad) [3], the principal moments of the inertial tensor (a,b,c) and the pseudo-density ($\rho \sim 1/(abc)$). With the environments grid and the distribution of galaxies we can make a first classification showed in the Fig.1c.

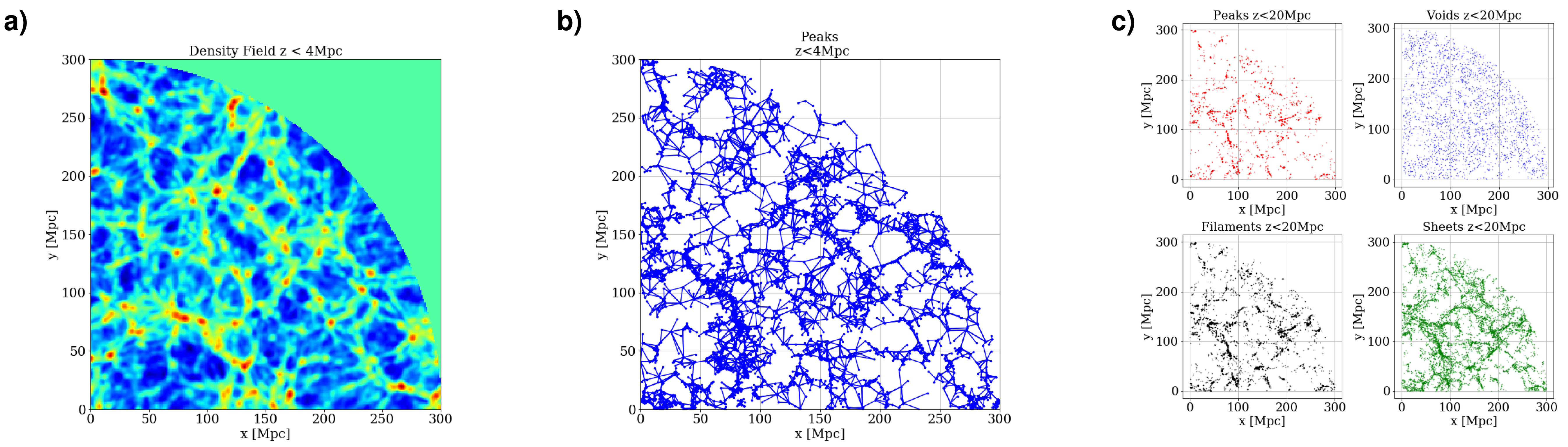

Figure 1: ***a)*** *Density field for* $z < 4Mpc$. ***b)*** *β-keleton applied over a distribution of galaxies for* $z < 4Mpc$. ***c)*** *Classification by environments using the classification defined by the deformation tensor.*

Applying the Machine Learning algorithm

Using the features obtained from the β-skeleton and the environment computed we used the `DesicionTreeClassifier` for made predictions of the cosmic web environments.

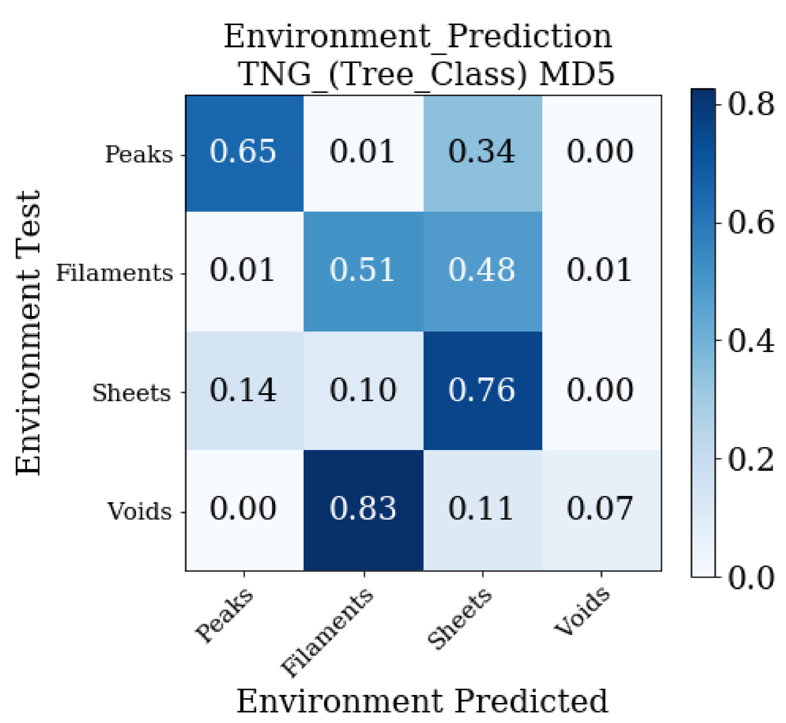

Figure 2: *Confusion Matrix to evaluate the prediction of the tree regression. Peaks was predicted better than voids.*

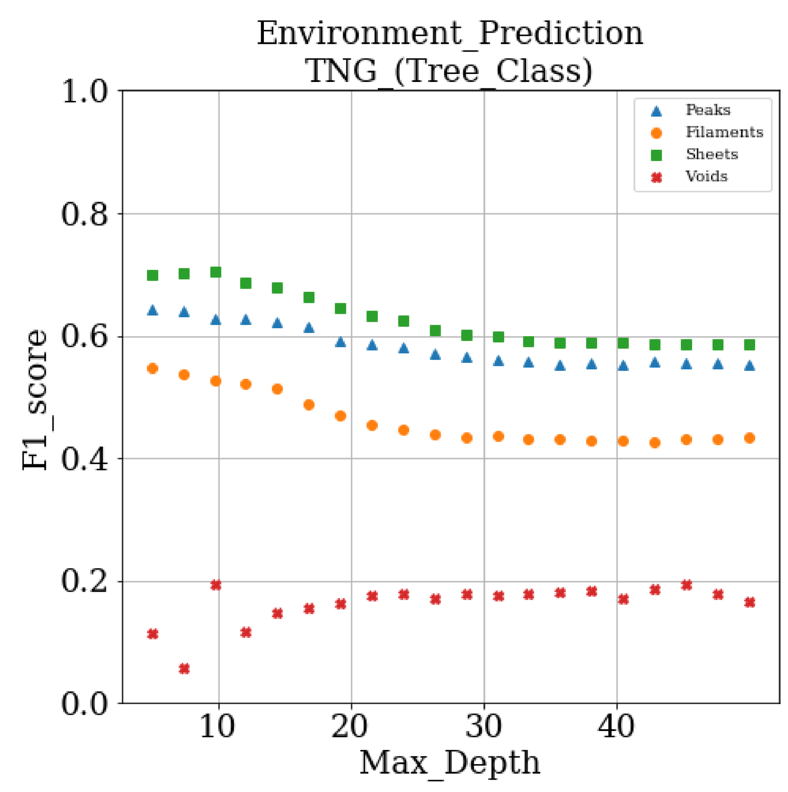

Figure 3: *The f1 score allow us evaluate the qualify of the prediction of environments. Sheets are the best predicted.*

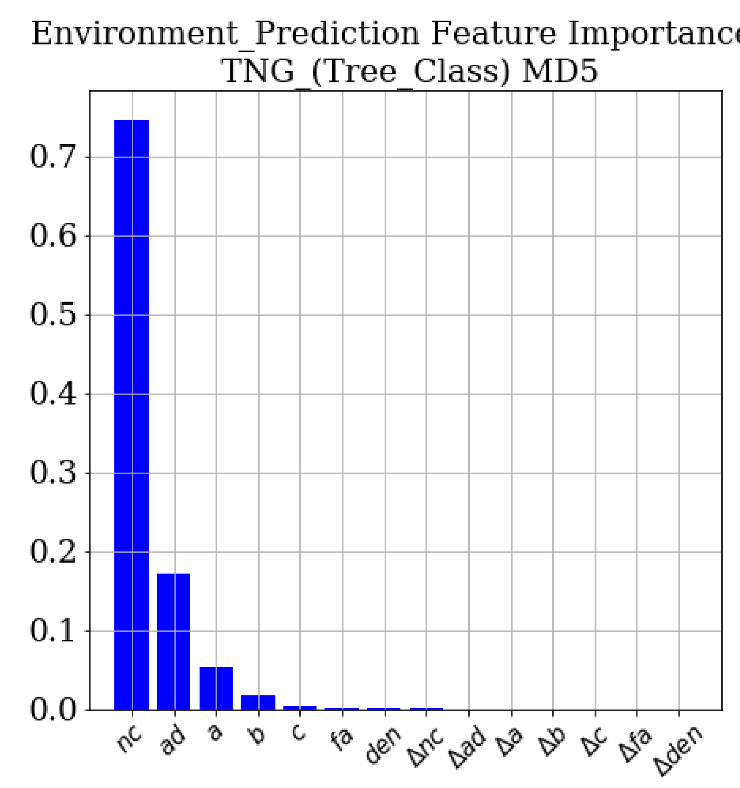

Figure 4: *With the feature importance is possible to evaluate the most relevant features to make a good prediction. The number of connections are the most important parameter.*

Conclusions

- It is possible use the β-skeleton to extract some features from the distribution of galaxies, that allow us describe the cosmic web.
- The tree classification results show us that it is a good method to predict the environments of cosmic web using the features extracted from the β-skeleton.
- The method of ML used allow us understand that the main feature to predict environments using the the β-skeleton mechanism is the number of connections.

References

[1] J E Forero–Romero, Y Hoffman, S Gottlöber, A Klypin, and G Yepes. A dynamical classification of the cosmic web. *Monthly Notices of the Royal Astronomical Society*, 396(3):1815–1824, 2009.

[2] Nicholas Luber, J. H. van Gorkom, Kelley M. Hess, D. J. Pisano, Ximena Fernandez, and Emmanuel Momjian. Large Scale Structure in CHILES. *arXiv e-prints*, page arXiv:1904.10511, 4 2019.

[3] Feng Fang, Jaime Forero-Romero, Graziano Rossi, Xiao-Dong Li, and Long-Long Feng. β-Skeleton analysis of the cosmic web. *Monthly Notices of the Royal Astronomical Society*, 485(4):5276–5284, 2019.