Unveiling Stellar Nature through Oscillations Pattern Recognition

Unsupervised classification for Red Giant stars

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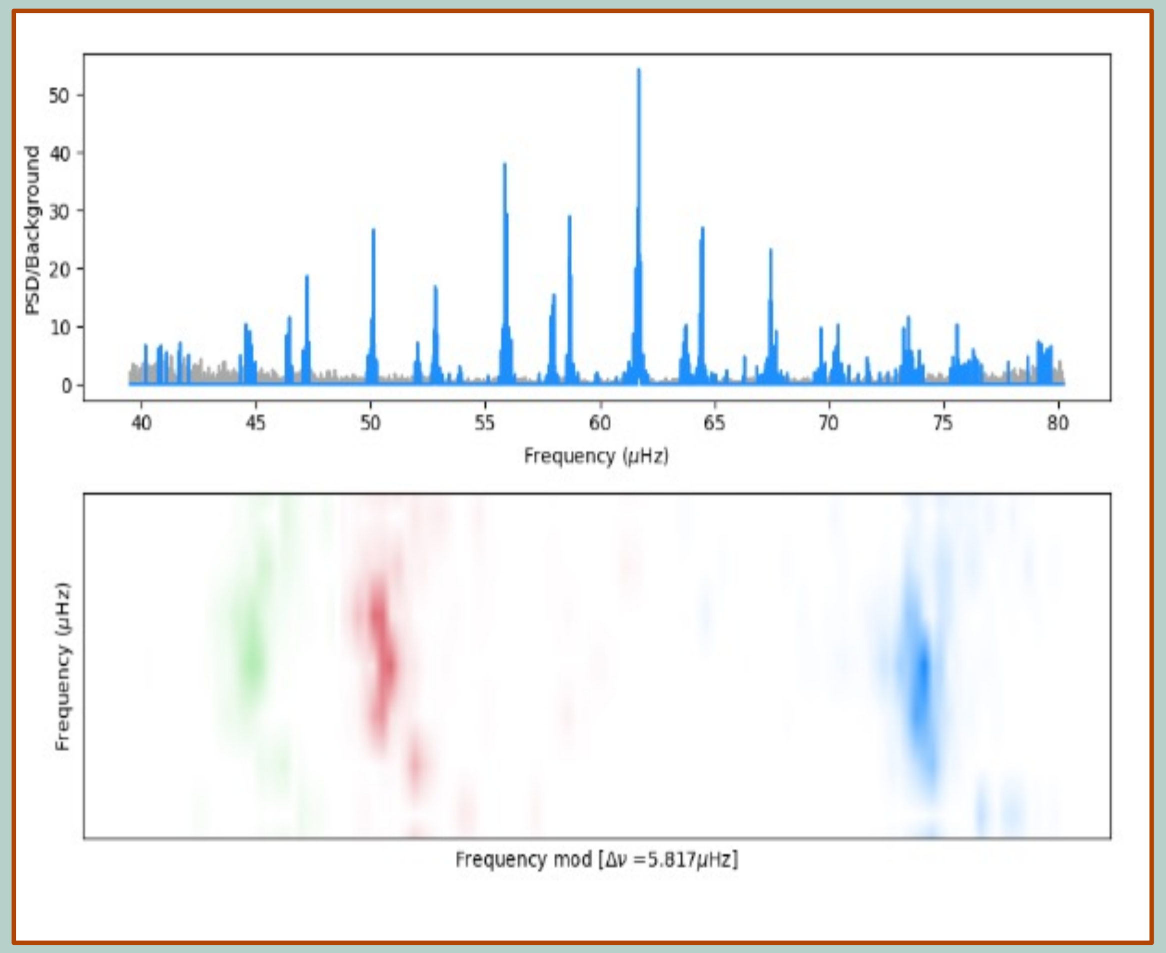
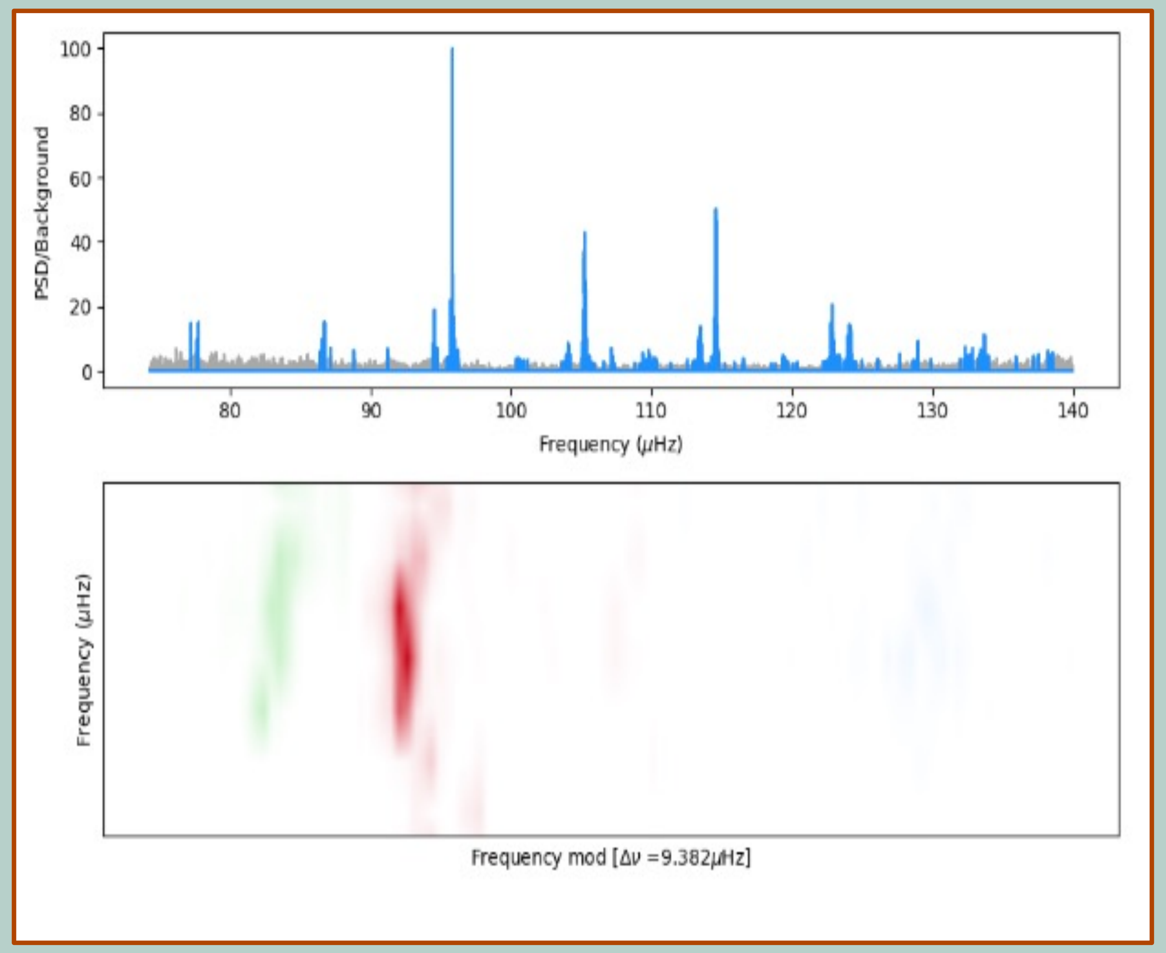
I. Context & Method

- It is very difficult to constrain the evolutionary stage of observed stars.
- This can be done using asteroseismology, to probe the internal structure and dynamics of stars through signature on oscillations pattern.
- Our method is based on modes frequencies but also on their amplitude. The latter is essential for a fraction of intermediate-mass stars on the subgiant branch and on the early RGB that present strongly diminished dipolar and quadrupolar mode power [1]
- We propose a new data-based approach to classify evolved solar-like stars according to their asteroseismic signal.
- We use an unsupervised algorithm, which is innovative as it does not require preliminary classified data.

II. Data Processing



Echelle diagram of a “normal” Red Giant star

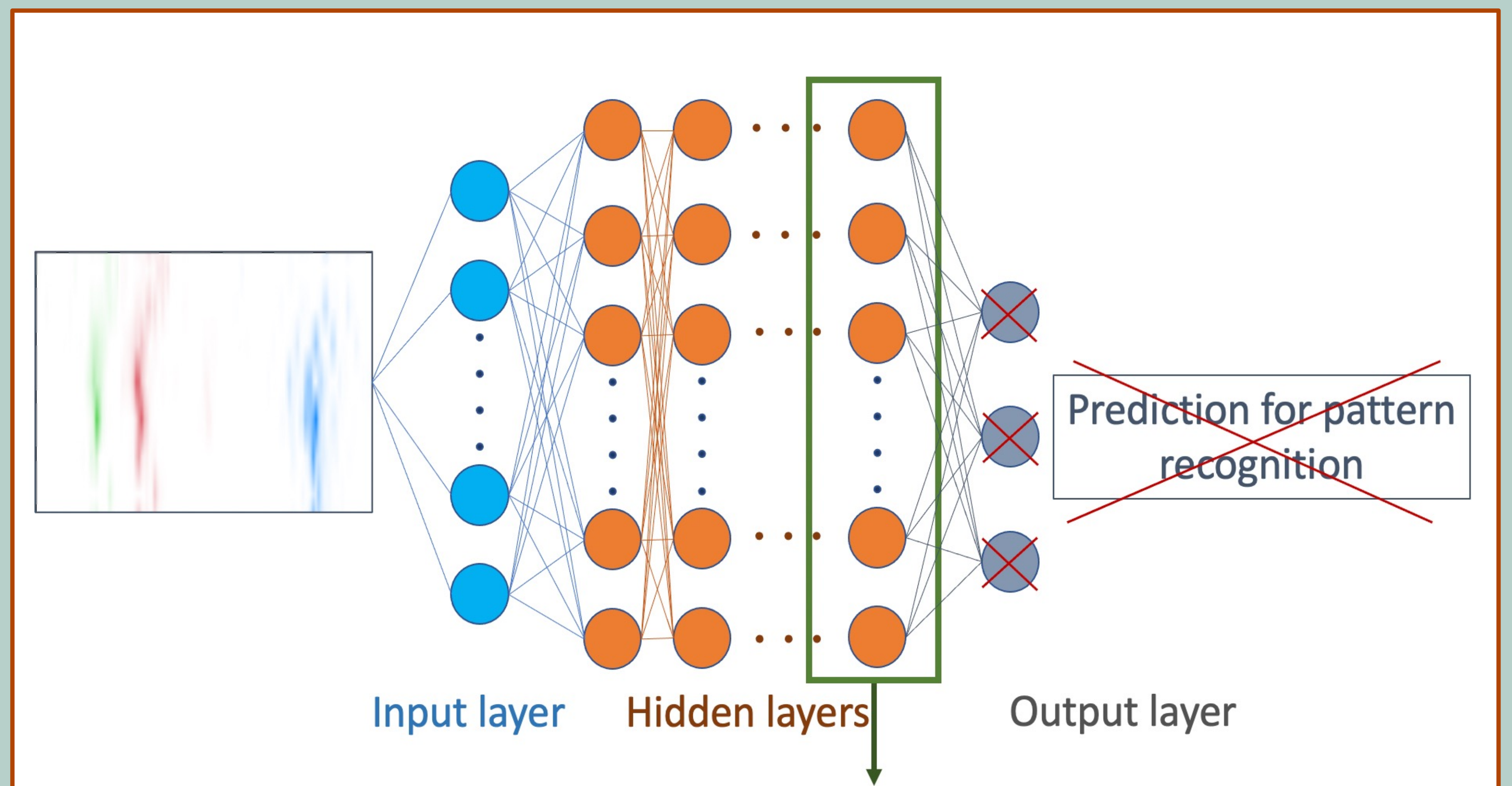


Echelle diagram of Red Giant star presenting low amplitude dipolar mode ($\ell = 1$ modes is not visible on the echelle diagram).

- Stars studied in this project are Red Giants observed by the Kepler mission. Global asteroseismic parameters νmax and Δν are the one provided by Yu et al. (2018).
- In order to extract oscillation signals, the components of the spectrum resulting from phenomena other than the oscillation modes, the "background"[2] is approximated following the method of Mosser et al. (2012). We also model the bell due to oscillation modes by a Gaussian law centered around νmax. This envelope represents the shape of the window for oscillation modes detectability. The PSD is then normalized by the background and by the Gaussian of the modes
- In order to compute echelle diagrams with modes in a given position for all stars, we also to know the frequency of the radial mode closest to νmax (hereafter called ν0). This measure is made by using the method described in Stello et al. (2016a). These echelle diagrams are constructed on an interval of 6 Δν centered around ν0.

III. Characterization Method

Stars are classified using an unsupervised algorithm based on patterns recognition in their echelle diagrams. This method is inspired by the work of Douglas Duhaime (Yale Univerity's Digital Humanities Lab). It is based on a Convolutional Neural Network (CNN) that has already been trained for the detection and classification of patterns in images. We choose to use the Inception CNN [3], which has been trained on the ImageNet database [4].

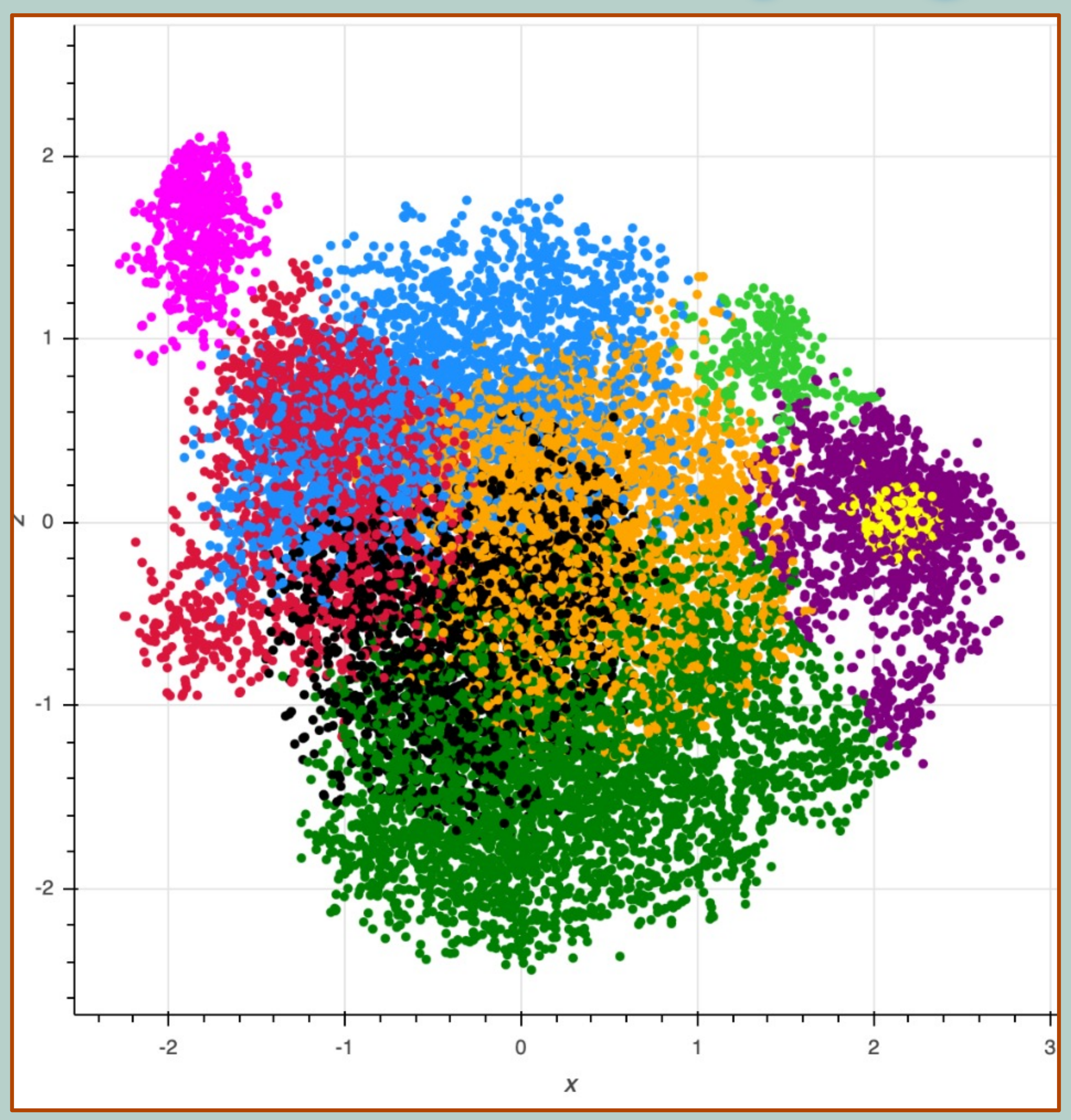


We're using the weights of the last hidden layer as output -> unique vector corresponding to each image (2048 real numbers)

Then, results are visualized using a t-SNE projections [5]. This statistical method uses nonlinear dimensionality reduction in such a way that we can visualize the data in 2 or 3 dimensions and close points correspond to similar data. Finally, different stages of evolution are identified using a spectral clustering algorithm [6].

IV. Classification of Evolutionary Stages

An example of classification for ~14,000 red giants from the Kepler data



Red Giants with low amplitude dipolar modes (black)
Stars of the Red Giant Branch (blue and dark green)
First clump stars (orange)
Problem with data (pink)
Unknown (for now!) (light green, purple and yellow)

V. Conclusion

- An innovative method of stellar classification and identification is presented based on image pattern recognition performed on echelle diagrams of Red Giant stars. The main benefit of our method is that the Machine Learning algorithm does not need to be trained.
- The results have shown that we are able to classify stars according to their evolutionary stages and to identify a large group of Red Giants presenting low amplitude dipolar modes of oscillations.
- The next steps on this project will be to determine if both the echelle diagram and t-SNE projections are effective methods of representing the data for observed stellar evolutionary stages.

[1] García et al. 2014, Stello et al. 2016b
[2] Mathur et al. 2011; Kallinger et al. 2014
[3] Szegedy et al., 2014; 2016
[4] Russakovsky et al., 2015
[5] Van der Maaten & Hinton, 2008
[6] Scikit-learn, Pedregosa et al., 2011

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