Universidade de São Paulo
Instituto de Física

Classificação de quasares, estrelas e galáxias com técnicas de aprendizagem automática

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Classifying quasars, stars and galaxies with machine learning

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Resumo

A próxima geração de levantamentos astrofísicos contará com grandes quantidades de dados. Esse cenário motiva o uso de ferramentas de aprendizagem automática para classificar objetos observados como fontes pontuais de emissão. A seleção de quasares, em particular, é de fundamental importância para obter vínculos de parâmetros cosmológicos, investigar a evolução do universo e desvendar o mistério da energia escura. Neste trabalho utilizamos algoritmos de aprendizagem automática para classificar quasares entre estrelas e galáxias. Em particular, desenvolvemos uma técnica para incluir as incertezas das medidas nesses algoritmos e mostramos, a partir de um modelo simplificado, que essa abordagem melhora a performance dos classificadores. Essas técnicas foram aplicadas aos dados de dois levantamentos fotométricos, S-PLUS e miniJPAS, que são caracterizados principalmente por suas configurações de filtros de bandas estreitas. As técnicas desenvolvidas aqui serão posteriormente utilizadas para construir catálogos de quasares e mapas de estruturas em grandes escalas.

Palavras-chave: Quasares, Estruturas em Largas Escalas, Levantamentos Fotométricos, Aprendizagem Automática.

Abstract

The next generation of astrophysical surveys will rely on large amounts of data. This scenario motivates the application of machine learning tools to classify objects which are detected as point-like sources. The selection of quasars, in particular, is of fundamental importance to constrain cosmological parameters, to investigate the evolution of the universe, and to unveil the mystery of dark energy. In this work we used machine learning algorithms to classify quasars, stars and galaxies. In particular, we developed a technique to include the uncertainties of the measurements in these algorithms and we proved, using a toy model, that this approach improves the performance of the classifiers. These techniques were applied in data from two photometric surveys, S-PLUS and miniJPAS, which are characterized mainly by their narrow-band filters. These techniques will be used to build quasar catalogs and maps of the large scale structures.

Keywords: Quasars, Large-Scale Structure, Photometric Surveys, Machine Learning.

Chapter 1

Conclusion

In the context of modern cosmology, the ΛCDM model shows good agreement with most (if not all) experiments. However, the nature of the dark energy component is still not well understood. The next generation of astrophysical surveys will rely on millions (or billions) of observed sources, allowing us to probe this theory over scales that have never been accessed before. In particular, narrow-band surveys will collect a huge amount of data, allowing for a good redshift estimation of extragalactic sources, thus providing high-quality data to study large scale structures.

An indispensable step to achieve the expected results is to provide a high completeness/high purity sample of quasars out of the hundreds of millions of stars and galaxies that form the vast majority of sources. This work compare several machine learning (ML) algorithms for this purpose. Moreover, we propose a new approach to account for error bars as input to ML models.

Applying the ML tools presented here we were able to successfully classify photometric data from the miniJPAS and S-PLUS surveys. There are multiple powerful ML algorithms in the literature. In this work we choose convolutional neural networks (CNNs) because of the nature of the narrow-band surveys data, which is sequential, and because it seems to be more suitable to deal with the data represented as a matrix encoding the measurements and associated uncertainties, as described in §**??**. CNNs are the baseline for image recognition, but are not commonly used for astrophysical sources classification. Therefore, we compare the CNNs to Random Forests, which is one of the most used ML model to classify astrophysical sources, and multiple works have proved its great performance in this task. We also test the LightGBM classifier, which became a very popular algorithm on ML competitions and in multiple market applications.

The next steps of this project include building a catalogue of quasars for both S-PLUS and miniJPAS surveys, and also continuing the study of our technique to include error bars as input to ML models. Besides, there are still some improvements we could make to our classifiers, for example trying new features such as morphological information, including other wavelengths (X-ray, IR), and variability.

The CNNs can be improved trying different architectures and hyperparameter tuning. In this work we tested different architectures and vary parameters by hand. But since there are many possibilities, there is always room for improvement. Recently, a technique called "automated machine learning" is increasingly gaining space in the literature and might be helpful to test different architectures and tune parameters in a more effective way. The same goes for the decision tree based models. Moreover, there are other powerful ML models that were not used in this work, such as support vector machines or self organizing maps that are also appropriate to tackle the Q-S-G classification task.

With these techniques we will be able to construct catalogues of quasars for both surveys, which is a requisite to build LSS maps. With these maps in hand, we will be able to build more reliable maps of the Universe, compute the matter power spectrum, constrain cosmological parameters, test ΛCDM as well as modified gravity models and, step by step, unravel the mystery of dark energy.

Chapter 2

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