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Neural Network for Stellar Spectrum Normalization

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Abstract. We present a deep fully convolutional neural network trained in the task of stellar spectrum normalization. We show that the proposed model is able to fit spectral continuum, including non-smooth instrumental pseudo-continuum, wide hydrogen, and narrow blended spectral lines. Proposed solution gives an opportunity to automate this step of stellar spectrum preprocessing, and achieve the accuracy similar to that of careful manual normalization. This approach may greatly simplify automated high-resolution spectra analysis.

1. Introduction

Spectrum, which is a distribution of photons per wavelength or energy bins, is an abundant source of information about many types of astronomical objects such as stars, galaxies, and exoplanets. In particular, the high-resolution spectroscopy is of special interest as it makes it possible to observe detailed profiles of absorption and emission lines. By using spectral lines itself, without need of absolute flux calibration, it is possible to investigate parameters of stellar atmospheres and abundances of chemical elements, and by studying their temporal variability also the topology of magnetic fields, and inhomogeneities on stellar surface. Nonetheless, spectrum needs to be processed via normalization to its continuum before any spectral line analysis.

2. Spectrum normalization

The normalization of stellar spectrum to its continuum is nontrivial task because spectrum contains diverse features as absorption and emission lines of various shapes, instrumental pseudo-continuum, missing data on some spectral ranges, and cosmic radiation spikes. Several automatized methods were proposed. One group of methods uses different kind of rolling filters and their combinations, i.e. average, maximum, asymmetric sigma clipping, and frequency domain filters, with subsequent low order polynomial fitting. They are often used in stellar parameters and abundances determination tools (e.g. iSpec, Blanco-Cuaresma 2019). More sophisticated methods based on convex-hull and alpha-shape theories were proposed recently (Xu et al. 2019; Cretignier et al. 2020). The most important drawback of the mentioned methods is the presence of parameters that have to be adjusted manually. The free parameters of mentioned methods are filter window size for rolling filter methods, the values of upper and lower sigma rejection thresholds in case of asymmetric sigma clipping, the frequency cutoff and filter type for frequency domain filtering, and the order of polynomial for methods that use polynomial fitting as final post-processing step. The method based on concept of convex hulls also includes the fine-tuning of 6 free parameters, and is based on important assumption that the local maxima of the spectrum can be considered to be its continuum, which is not the case for spectra with emission features and for spectra with heavily blended spectral absorption lines. Those problems significantly narrow the application field of methods mentioned above.

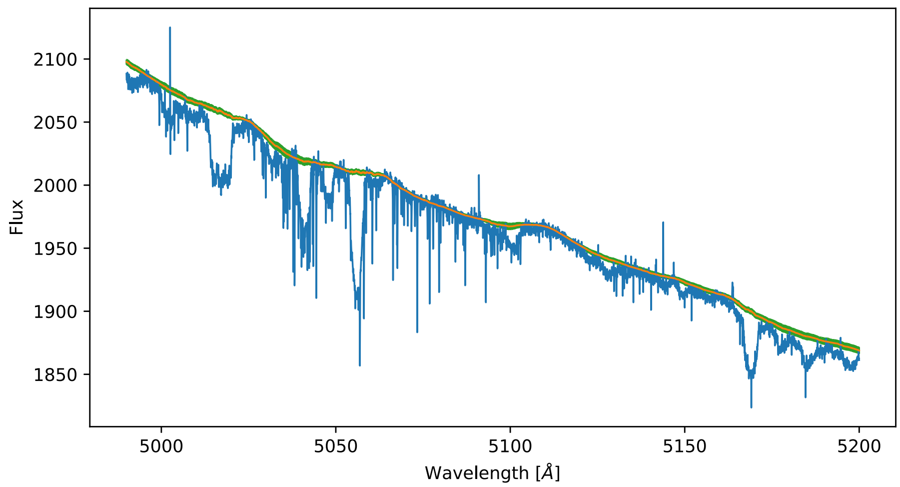

Figure 1. Part of the spectrum of HD 145842 (B8 V) with spectral lines of the star (broad absorption features), telluric lines (narrow absorption lines), and cosmic rays (narrow emission lines). The predicted continuum follows the pseudo-continuum, the shaded range gives the standard deviation of sliding window prediction.

3. Neural network

In this work, we propose a fully convolutional neural network inspired by neural network architectures used in the task of semantic image segmentation. It can be considered as nonlinear filter, that translates spectrum to its continuum. It is composed of two parts, Feature Pyramid Network Module (Lin et al. 2017) and ResNet based decoder (He et al. 2015). The network was implemented using Keras API[1], and Tensorflow[2] back-end library.

For both training and prediction the proposed artificial neural network as input takes 8192 samples of the one dimensional spectrum re-sampled with 0.03 Å spacing, and returns the fitted continuum as the vector of the same length. In order to normalize the whole spectrum the network was use as rolling filter, and as it gives slightly different continuum estimate at each position it was possible to estimate model uncertainty.

The training dataset is composed of normalized theoretical spectra calculated with ATLAS9 and SYNTHE codes (Kurucz 1970) for effective temperatures $T_{\rm eff}$ from 3000 to 30000 K, and spectra from OSTAR and BSTAR grids (Lanz & Hubeny 2003, 2007) available for $T_{\rm eff}$ in the range 15000-55000 K. These synthetic spectra were resampled with 0.03 Å spacing, cut to randomly placed 8192 samples long parts in range 3800-7000 Å, then element-wise multiplied by arbitrary continuum (linear, sinusoidal, smoothed sawtooth, and 5-knots-cubic-spline), and augmented with Gaussian noise (SNR 50-500). The choice of sinusoidal and sawtooth-like continuum was guided by ripples present in many échelle based spectrographs.

Figure 1 shows the narrow part of stellar spectrum with predicted continuum including estimated error if its prediction. Figure 2 shows the predicted continuum in four different spectral ranges (in columns) for seven stars (in rows) from wide range of spectral types, from O to M.

The developed neural network gives results comparable to that of typical human normalization. Visual assessment shows that the proposed method is robust against cosmic radiation

[1]`https://keras.io`

[2]`https://www.tensorflow.org`

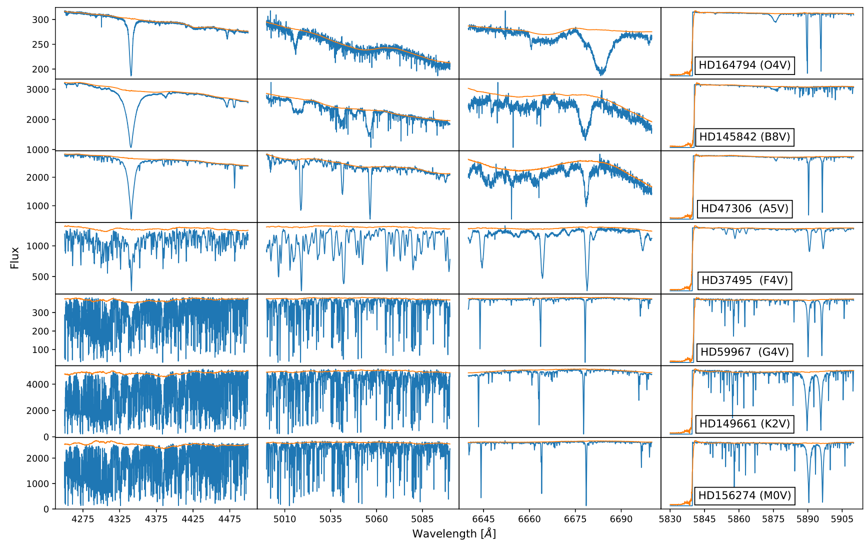

Figure 2. The comparison of continuum prediction for seven test stars.

spikes, wide and narrow spectral lines, ripples often present in many échelle based spectrographs, and works well for different levels of signal-to-noise ratio. The diagnosed problems that needs to be investigated further are unsatisfactory smoothness of neural net prediction (possible to deal with by some post-processing), unsuccessful normalization of wide emission features, e.g. Hα in some O type stars, and wide molecular bands in late type stars.

4. Summary

The proposed fully convolutional neural network can be effectively used for normalization of high-resolution spectra. It is robust to typical disturbances that are present in merged high resolution spectra. Results presented here are the first step towards fully automated stellar spectrum normalization method. A detailed analysis of the proposed architecture will be presented in the near future.

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