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Deep Learning strategies for detecting Earth-size exoplanets in HARPS-N stellar spectra

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Detecting Earth-sized exoplanets through the radial velocity method is particularly challenging due to stellar activity, which can contaminate or mimic planetary signals. In this work, we apply deep learning techniques to enhance the precision of Doppler shift measurements in stellar spectra obtained from the HARPS-N spectrometer. Our models are carefully trained exclusively on real observational data, deliberately avoiding the use of simulated data during training to ensure robustness and generalizability in real scenarios, while minimizing the risk of biases inherent in synthetic data. Using a supervised learning approach inspired by Zhao et al. (2024), based on a convolutional neural network applied to spectral shells (Cretignier et al. 2023), we demonstrate the ability to detect Doppler shifts as small as 10 cm/s in unseen data, highlighting the generalization power of our deep learning models. We also explore an unsupervised strategy using generative models, in particular variational autoencoders, to identify patterns in stellar spectra. This approach could be used either to derive RVs directly without using cross-correlation functions or other classical methods, or to derive activity indicators that could be used to mitigate spurious signals in RV timeseries. Together, these deep learning approaches provide data-driven frameworks for extracting planetary signals directly from real observations, offering an interesting complement to traditional radial velocity techniques.