From statistical learning to deep learning for modeling the nuisance component of high-contrast observations

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Résumé

Direct detection and characterization of exoplanets is challenging due to the very high contrast between the host star and the companions. In addition to the use of an extreme adaptive optics and a coronagraph, dedicated processing methods combining images recorded with the pupil tracking mode of the telescope are required to eliminate efficiently the nuisance component (speckles + noise) corrupting signals of the sought objects.
In recent works (Flasseur+ MNRAS & EUSIPCO 23), we proposed to combine a statistical model with a deep model in a three steps algorithm. First, a statistical model including the estimation of spatial covariances is learnt. Then, the data are centered and whitened locally to improve the stationarity and the contrast in a pre-processing step. Second, a convolutional neural network is trained in a supervised fashion to detect the signature of synthetic sources in the pre-processed data. Finally, the trained network is applied to the data and delivers a detection map. Photometry of detected sources is estimated by a second deep neural network. Both models are trained from scratch with custom data augmentation strategy allowing to generate large training sets from a single dataset. We applied the method on tens of datasets from VLT/SPHERE (IRDIS and IFS instruments) and compared it to state-of-the-art algorithms of the field, including PACO (modeling the nuisance by a statistical approach solely). The new method leads to a typical improvement by half a magnitude in terms of contrast. The ultimate detection sensitivity driven by the fundamental photon noise limit can also be reached far from the star on some datasets. A joint processing of spatio-temporo-spectral observations allows to further improve the detection sensitivity.
The future thirty meters class telescopes will enable exploring much deeper the inner environment of nearby solar-type stars than existing facilities. This goal raises three challenges from a data science point of view: (i) approaching the ultimate performance of the instruments by an optimal extraction of the signals of the sought objects, (ii) capturing a highly spatially structured nuisance component subject to strong temporal fluctuations, and (iii) building a model of the nuisance component from several datasets to bypass the limits of ADI at very short angular separations. Concerning points (i) and (ii), we will illustrate that data-driven approaches combining statistical modeling with deep learning could be highly valuable to model the complexity of such observations. Concerning point (iii), we will present our recent methodological developments in that direction. The methodology differs from RDI in the sense that a highly non-linear model is learned from the data, and it exploits several prior domain knowledge. Based on experiments conducted from SPHERE's archive, we will discuss the potential and challenges of such an approach.

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