Revealing Exoplanets by Leveraging Hidden Molecular Signatures in Cross-Correlated Spectra with CNNs

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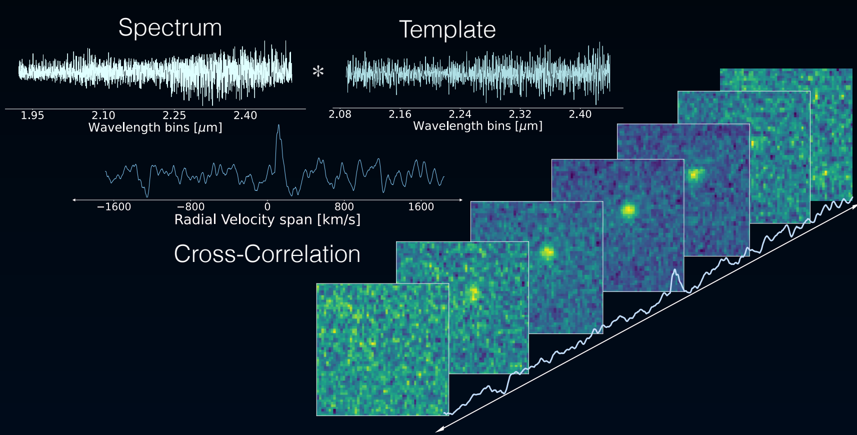
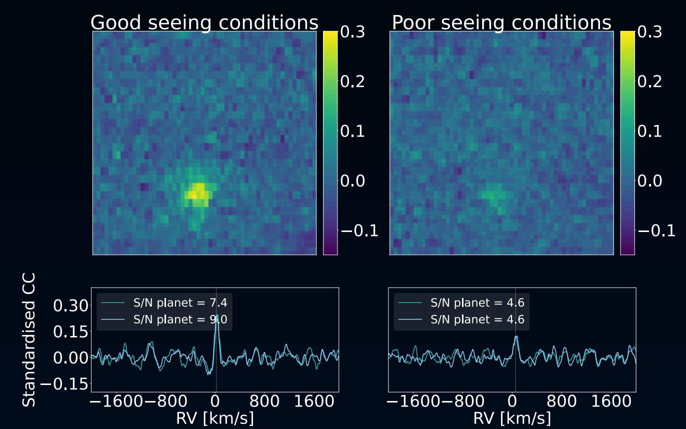
Cross-Correlation Spectroscopy and Molecular Mapping

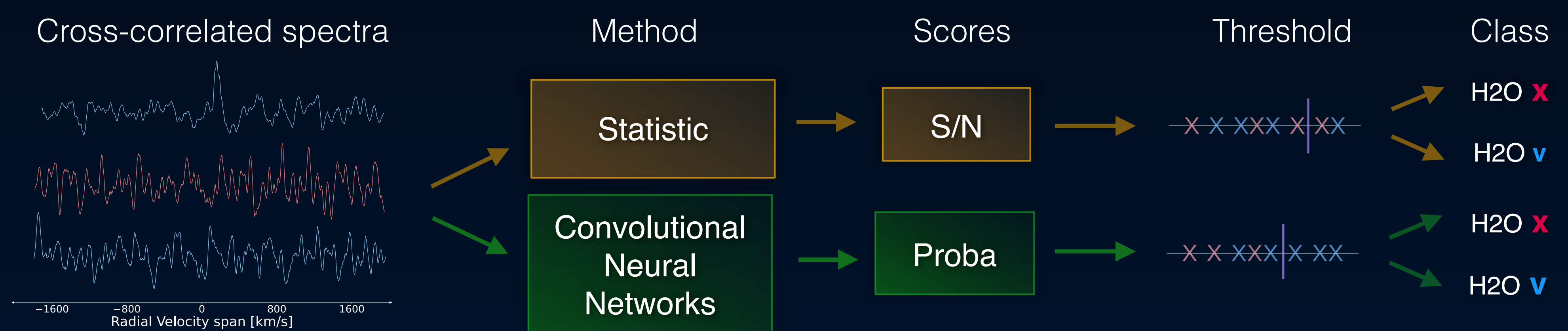


⇨ Molecular mapping is a special case of cross-correlation spectroscopy; By cross-correlating every spatial pixel of an integral field unit (IFU) cube with a template of a single molecule, it is possible to separate the molecular signature of a planet from its host star light. We can thus unveil it by finding the cross-correlation peak at the radial velocity (RV) of the planet. However, in some cases such as poor observing conditions, the effectiveness of molecular mapping may decrease. The same planet was observed on two different nights, with different conditions and does not present the same S/N detection strength for H2O. ⇦

Detection Sometimes Gets Challenging…



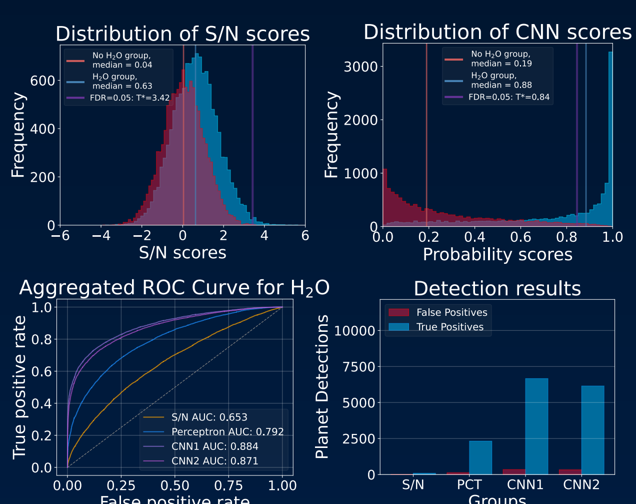
We replaced detection by S/N with Machine Learning to find more planets in cross-correlated spectra



⇩

The S/N can be seen as a classifier which scores cross-correlated spectra. Setting a threshold on such scores allows to assess detection of molecules. However, this metric is based on a point-wise approach that relies on the location of the cross-correlation peak and prior knowledge on the planet's orbital constraints. We propose to replace this statistic with a Machine Learning approach. We use Convolutional Neural Networks (CNNS) which take a holistic approach to detect molecules in the cross-correlated spectra, based on all RV features. We evaluate the resulting scores distribution and classification both on individual spectra and IFUs. The CNNs we implement are invariant to RV shifts of planets, allow agnosticity to atmospheric structure and composition, and are adaptable to different spectroscopic instruments.

Results on individual spectra



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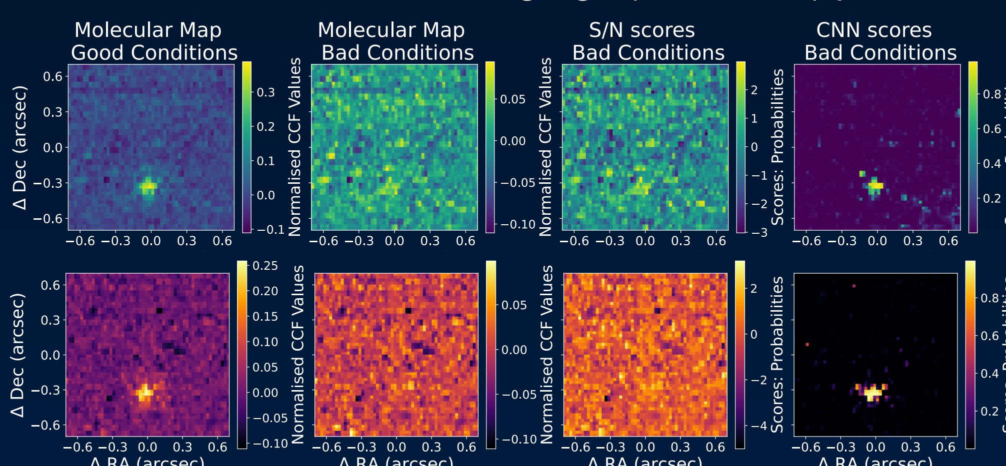
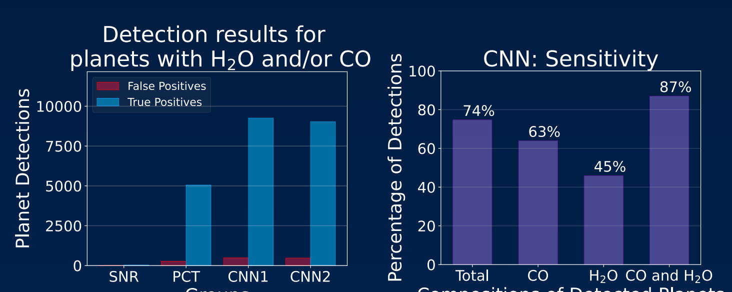
To formalise the results, we simulated many planets and injected them randomly in true SINFONI noise. We then tried to detect those which contained water. The histograms (top) give qualitative insights into scoring effectiveness (i.e. how well the method separates the groups). The ROC curves and AUC (lower left) quantitatively measure scoring quality. A threshold is applied on scores to separate classifications optimally, limiting the false discoveries to 5% of the predicted detections. The bar plot (lower right) show the amount of planets we can find. The CNNs show outstanding results compared to the perceptron and S/N benchmarks.

Results on imaging Spectroscopy



⇨ We simulated planets which we injected as blobs in true SINFONI IFUs. Then, we detected them based on their content in H2O (top row) and CO (lower row). The CNNs are still trained only in the cross-correlation dimension in a spatially decorrelated scheme. Without using the spatial dimension, and only by leveraging the molecular harmonics and non-gaussian noise (c.f. paper) in the cross-correlated spectra, we can learn important features which allow to highlight the simulated planet in the IFU in reproduced poor observing conditions in instrumental noise.

Search Broader using Agnosticity



⇩

By construction, our CNNs use molecular templates as filters (c.f. paper). Thus, we tested the possibility to include templates from two molecules simultaneously, to detect planets without making assumptions on the composition. We find that by doing so, the CNNs effectively combines information of each template to detect planets containing both molecules, but can also detect planets with either one of the molecules.

Summary and Outlook

- CNNs can detect more Exoplanets by using agnosticity to composition.
- They can detect Individual Molecules with agnosticity to atmospheric parameters.
- Our 1D CNNs are designed to be used flexibly regarding telescope instruments.
- They are expected to be useful for present and future instruments (VLT/ERIS, JWST/MIRI, ELT/HARMONI, ELT/METIS).

For more details, results and references, c.f. paper on ARXIV:

Swiss National Science Foundation
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