Preparing an unsupervised massive analysis of SPHERE high contrast data with the PACO algorithm

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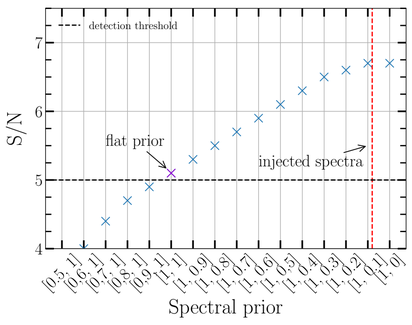
Introduction

We aim at searching for exoplanets on the whole ESO/VLT-SPHERE archive with improved and unsupervised data analysis algorithms that could allow to detect new massive giant planets around 5 au. To prepare, test and optimize our approach, we gathered a sample of twenty four solar-type stars observed with SPHERE using angular and spectral differential imaging modes during the SPHERE/SHINE F150 survey [1].
We use PACO ASDI [2], a new generation algorithm recently developed, that has been shown to outperform classical methods. We optimize the outputs of PACO to enhance the detection performance. We also develop custom built spectral prior libraries to optimize the detection capability of the ASDI mode for both IRDIS and IFS.

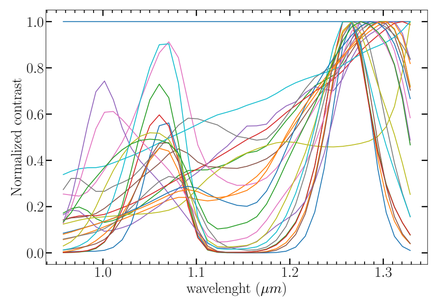
Spectral priors

PACO ASDI offers the possibility to combine multi-wavelengths datasets into a single S/N map, using specific weights to maximize the detection efficiency. These weights $\{w_\ell\}_{\ell=1:L} \in [0;1]$ are referred as spectral priors. Thus, we have defined sets of spectral priors representative of the variety of the spectra of the potential exoplanets to optimize the detection capabilities. The number of priors is a compromise between the gain in sensitivity and the computational time. A trade-off must then be found.



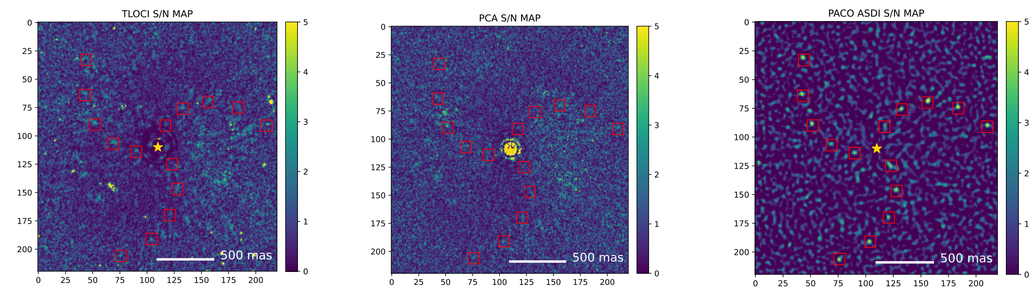
As expected, the S/N is higher when the spectral prior is similar to the planet spectrum.

In order to limit the number of false positives while increasing the detection probability, we selected 5 priors for IRDIS and we use 20 priors libraries for IFS.

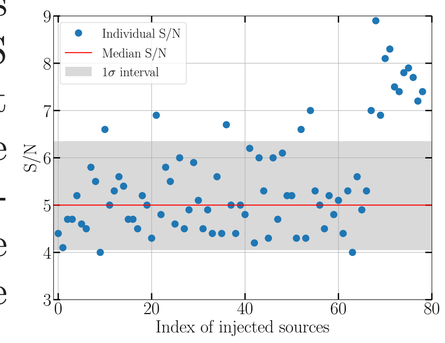


Contrast confidence

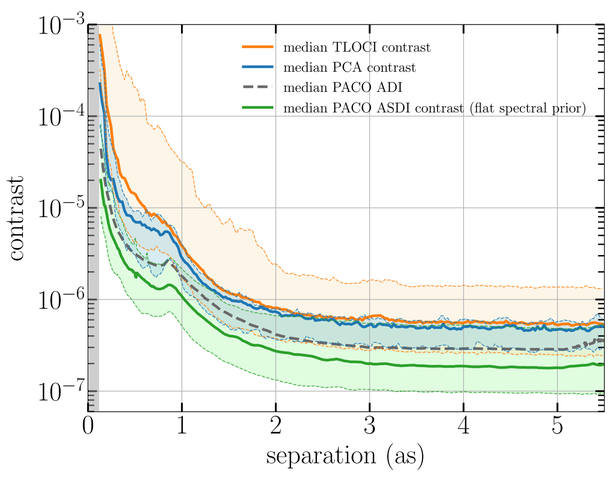
To compare PACO ASDI with TLOCI and PCA the algorithms used for the F150 analysis [3], we performed massive injections of fake planets at all separation and at contrast levels predicted by PACO (5σ) and we re-run the all the algorithms to quantify their real detection confidence. Examples of signal to noise (S/N) maps for such injections are shown below.

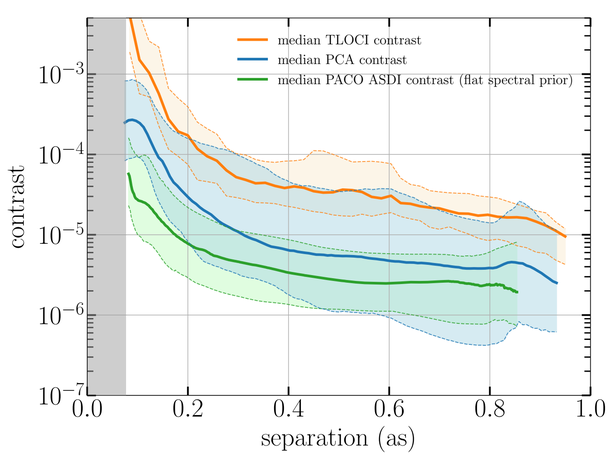


The median S/N retrieved is 5 for IRDIS and 4.3 for IFS which is in very good agreement with the injected contrast. We conclude that the contrast estimated by PACO for IRDIS are reliable while the IFS ones are slightly optimistic by 15%.



Results





For IRDIS, at close angular separations, PACO outperforms TLOCI (resp. PCA) by a factor 7 (resp. 5) at 0.5 and by 5 (resp. 5) at separations larger than 1 as. For IFS, the gain ranges between a factor 3 and a factor 5, depending on the separation, compared to PCA. We were able to verify that PACO's contrast curves are reliable on a heterogeneous sample at all separations and that its gain compared to other algorithms is as shown on both figures.
Moreover, due to the rigorus statistical approach of PACO, the number of false positives found during the analysis is coherent with what is expected at a 5σ confidence under a multivariate Gaussian hypothesis.

Conclusions

We have demonstrated on a small sample the benefits of PACO in terms of achievable contrast and of control of the confidence levels. Besides, we have developed custom tools to take full benefits of this algorithm and to quantity the total error budget on the estimated astrometry and photometry. This work paves the way towards an end-to-end, homogeneous, and unsupervised massive re-reduction of archival direct imaging surveys in the quest of new exoJupiters.

References

[1] S. Desidera et al., A&A, 651:A70, July 2021
[2] O Flasseur et al. A&A, 637:A9, May 2020.
[3] M Langlois et al. A&A, 651:A71, July 2021.