
Exoplanet detection in angular and spectral differential imaging by a local learning of background correlations

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Résumé

Detection of exoplanets by direct imaging is a very active research topic in astronomy for the characterization of young and massive objects. The very high contrast between the host star and its companions makes the detection particularly challenging. In addition to the use of an extreme adaptive optics system and a coronagraph to strongly attenuate the flux from the star, dedicated processing methods that combine images with different rotations of the field of view and at several wavelengths are required. The different temporal and spectral behaviors of the remaining stellar leakages and of the signal originating from the exoplanets make it possible to unmix them, and thus detect the planets and estimate their photometry. The integral-field spectrometer of a planet-finder such as SPHERE (Spectro-Polarimetry High-contrast Exoplanet REsearch) at the VLT provides 4-D spatio-spectro-temporal datasets. From a signal processing point of view, a major difficulty in the data analysis comes from the strong spatial and temporal fluctuations of the background that are due to (i) the speckle patterns (originating from the residual phase aberrations and misalignment of the coronagraph), and (ii) the detection noise and other perturbations (thermal noise, bad pixels) that are correlated by the interpolations performed during the data-reduction pipeline.

Generally, images are combined following a particular strategy (based on angular / spectral differences, or by removing the principal components) in order to reduce the background level. After this processing, the residual fluctuations are assumed to be uncorrelated and the detection is performed by simple thresholding with a radially-decreasing threshold to account for the spatial variations of the level of the fluctuations. Based on our recently published paper [1], we propose to follow a different approach: we model the background correlations using a local Gaussian distribution that captures the spatial correlations at the scale of a patch of a few tens of pixels. The decision in favor of the presence or the absence of an exoplanet is then performed by a binary hypothesis test. This local modeling accounts for the spatial variations of the background fluctuations and leads to a detection method that is parameter-free. Moreover, we perform a joint estimation of the flux of a detected source and of the background to provide an intrinsically unbiased photometric estimate.

We apply our method on datasets from two instruments of VLT/SPHERE: the dual-band differential instrument (IRDIS) and the integral field spectrograph (IFS). We compare the

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detection maps with standard techniques (TLOCI and KLIP) and show that our approach outperforms these algorithms with a much clearer difference between detection peaks at the actual location of sources and the small fluctuations in the background. We also show that the same statistical modeling can be used both at the detection step and to recover the spectrum of detected objects. We show that, thanks to the uniform response of the hypothesis test, a unique threshold can be applied to the detection maps to obtain consistent detection performance at all angular separations.

O.Flasseur, L.Denis, E.Thiébaud and M.Langlois, "Exoplanet detection in angular differential imaging by statistical learning of the nonstationary patch covariances: The PACO algorithm", *Astronomy & Astrophysics*, vol. 618, A138, 2018.