Thesis subject

Name of the laboratory: Laboratoire d'Astrophysique de Marseille

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Subject's title: K-Stacker, an algorithm to hack the orbital parameters of planets hidden in the speckle residuals of high contrasts imaging and detect them

Subject description:

Most of the 4000 exo-planets detected until now have been found using indirect methods such as radial velocity technique and photometric transit. Indeed, it is extremely difficult to detect the planet light that is drowned in the diffracted light of its host star. **A Jupiter and an Earth like planets are about $10^8 - 10^{10}$ fainter than their parent star in the visible.** Nevertheless, huge improvements have been done during the last decade with adaptive optics [to correct the phase errors induced by the atmosphere] and coronagraphic systems in order to attenuate the light of the star and to be able to detect directly the light of the planets. Since 2014, a new instruments SPHERE (Beuzit et al. 2019, A&A, 631) equipped with last technologies such as an extreme adaptive optics (XAO) system and an apodized coronagraph has started his scientific observations. For the first time this instrument is able to reach a contrast level of 10^{-6}, and can detect young Jupiter-like planets [we detect the thermal light produced by the planet in the near-infrared]. But, even if SPHERE has perfectly reached its objectives in term of technical performance (high contrast at separation > 0.1 arcsec), after more than five years in operation, the number of new exoplanets detected is small. Taking into account the last statistics of the SPHERE/SHINE survey, the radial velocity surveys and planetary formation models, the planets could be closer to their star and more difficult to detect than expected.

Recently, we have proposed a new method of observation and reduction, Keplerian-Stacker that could improve the detection limit of high contrast instruments such as SPHERE, up to a factor of 10. It consists in combining the images recorded during different nights, accounting for the orbital motion of the putative planet that we are looking for. Even if in each individual observation taken during one night, we do not detect anything, **we show that an optimization algorithm, K-Stacker can align the planet images according to keplerian motions** (ex: 25 images taken over a long period of several months), increase the signal-to-noise ratio, **and detect the planet otherwise unreachable** (Le Coroller et al. OHP2015; Nowak, M. et al. 2018, A&A, 615, 12). This method can be used in combination with the "Angular Differential Imaging" techniques (Marois et al. 2006) or any other high contrast data reduction method (TLOCI, PCA ASDI, etc.) to further improve the global detection limit. K-Stacker also directly provides orbital parameters of the detected planets, as a by-product of the optimization algorithm. Finally, this method could also be used as part of a new scheme of observation, in which exposures would not be made sequentially in one night, but would be spread over multiple nights, in order to obtain better constraints on the orbit in an equivalent total exposure time.

Proposed work:

We have already tested K-Stacker (Python language) on simulated images of SPHERE [the IRDIS sub-system with atmospheric errors] taken over several months with fake planets introduced at very low signal to noise ratio, down to ≃ 1 in the individual frames. We have proved that the K-Stacker algorithm (a brute-Force + local gradient to maximize the total signal to noise ratio) can re-combine these images and detect the planets hidden in individual images.

This year, we have **tested K-Stacker by introducing fake planets in real data** that have been reduced with the last ASDI-PCA technique (using SPHERE-VLT SHINE survey data; https://sphere.osug.fr/?lang=en). We show that we can detect the planets with the same reliability than on simulated IRDIS images (Le Coroller et al. 2019, A&A, in preparation).

1 - A theoretical works (+ simulations) will have to be done by the student to **calibrate this technique in order to extract, the photometry and astrometry of the detected planets.**

2 - The student will compare the orbital parameters found by K-stacker with the 'classical' solutions of the MCMCs methods on the positions of the companion in each image. K-Stacker could provide more robust orbital parameters than the algorithms working on the positions that are biased at very low signal to noise.

3 - SPHERE has been working for 5 years. At the end of this Phd, we will have 8 years of observations. **Several interesting stars are followed** to study their disks, or a planet already known. The student will search for new planets by launching K-Stacker on these data. K-Stacker could allow to detect the smaller planets at 'short' separation (5-10 a.u.) with the high contrast imaging technique. Only a few new candidates (ex: 1-2 new planets detected in the survey of more than 700 stars) will bring very important constraints for the statistic of the survey and will help to better understand the planet formation mechanisms. **We are also proposing a program of observation with K-Stacker on SPHERE.** Beyond K-Stacker, **the student will have the possibility to be involved in the largest imaging survey ever (SHINE)** for the exo-planets search and their characterization with SPHERE. He will participate to the observations (at VLT/Chili) and data reduction.

4 - Adjustment of K-Stacker on future techniques: As part of this work, the goal is also to validate this method on future instruments such as SPHERE+ or on the **European-Extremely Large Telescope** focal systems in particular **to detect exo-earths like planets.** K-Stacker could be the solution to reach the required contrast at the end of all the chain: XAO, coronagraph, ADI/SDI reduction with the E-ELT. More generally, we will study new techniques [image processing and instrumental] that could help to detect and characterize exo-earths. In particular, we would like to study a nulling recombination with the E-ELT (Le Coroller, HDR 2015: http://lecoroller.obs-hp.fr/uploads/htmlHerve/HDR_LeCoroller_PLUS_Annexes.pdf). This work is more prospective and instrumental, but the goal is quite similar: increasing the contrast limit to be able to detect earths like planet, and eventually to search for bio-signatures. The goal is to propose a very accurate sensor, and a very efficient nuller, able to detect earth like planets at contrast of 10^{-9} in the visible/IR.

During the PhD, the student will have the possibility to take the leadership of projects around these topics (instrumental and/or observations with K-Stacker).

Bibliography:

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