Vortex Image Processing (VIP) package for high-contrast direct imaging

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1. Overview

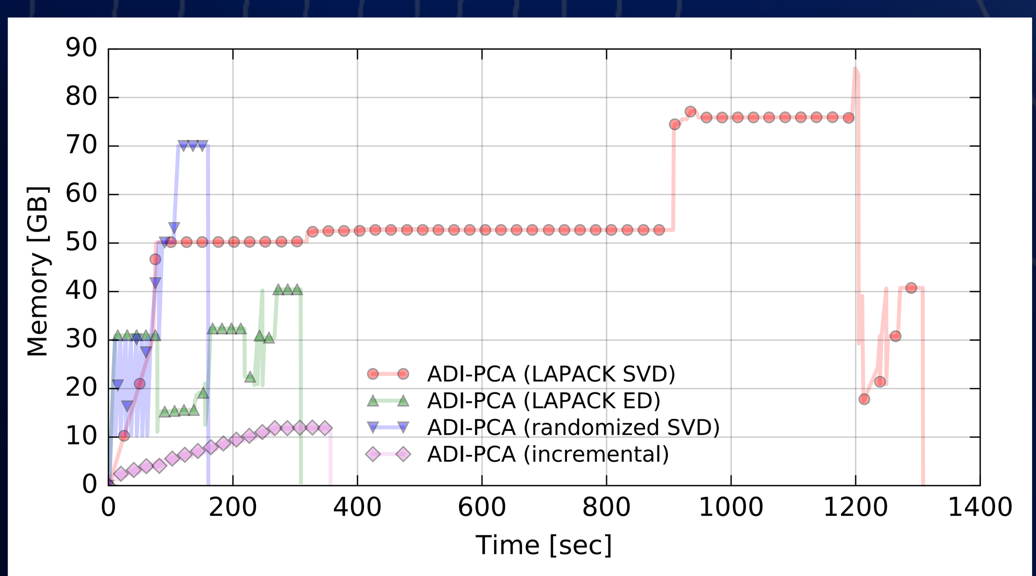
VIP [1] is a Python instrument-agnostic toolbox featuring a flexible framework for reproducible and robust data reduction. VIP currently supports three high-contrast imaging observational techniques: angular, reference-star and multi-spectral differential imaging.
VIP git repository on Github: http://github.com/vortex-exoplanet/VIP

Subpackage	General description
calib	Low-level image operations. Pre-processing and cosmetic procedures
conf	Timing, configuration and internal utilities
exlib	External libraries
fits	Fits input/output functionality
llsg	Local low-rank + sparse + gaussian-noise decomposition for ADI data
madi	Standard ADI recipe (median PSF reference)
negfc	Negative fake companion technique for flux and position estimation
nmf	Non-negative matrix factorization for ADI data
pca	PCA-based algorithms for ADI, RDI and mSDI data
phot	Signal-to-noise and detection of point-like sources. Contrast curve generation for ADI and RDI data
stats	Statistics from frames and cubes, correlation and sigma clipping procedures
var	Filtering, 2d-fitting, shapes extraction and other utilities

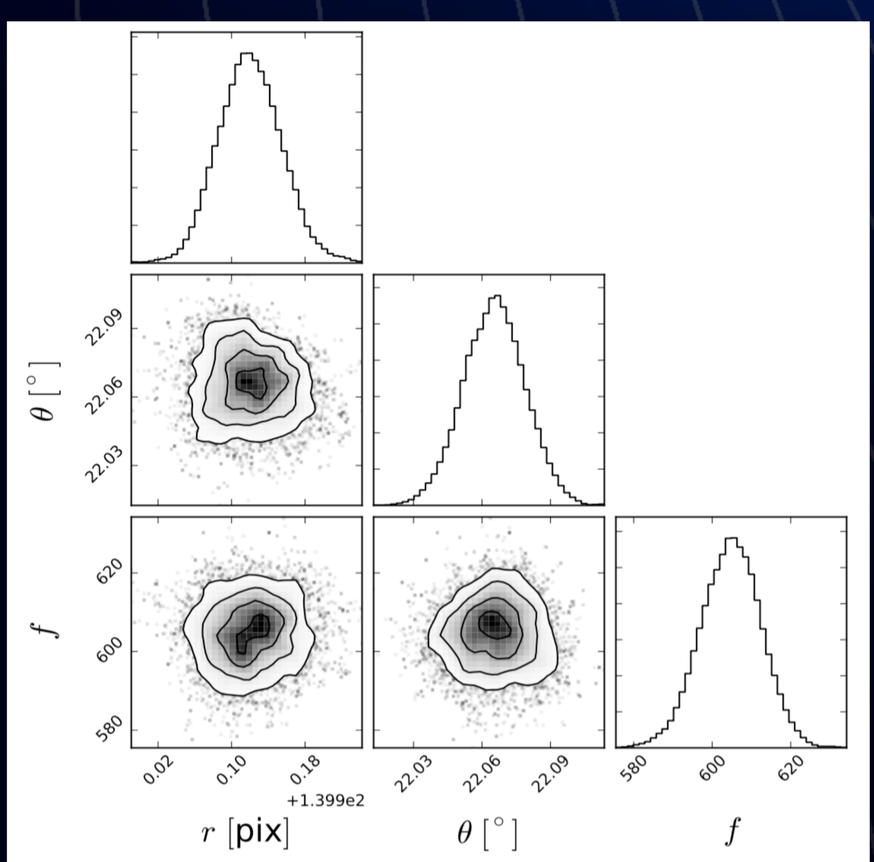
VIP package structure

2. Methods

Several post-processing algorithms for reference PSF subtraction from ADI data are implemented in VIP. For RDI and mSDI we implemented principal component analysis (PCA) based algorithms. VIP includes novel algorithms, such as LLSG [2] decomposition and NMF [1] based algorithm for ADI sequences. Also, VIP is capable of handling big datasets (larger than the available memory) with PCA thanks to the use of incremental PCA.



Incremental PCA, suitable for handling big datasets without sacrificing accuracy

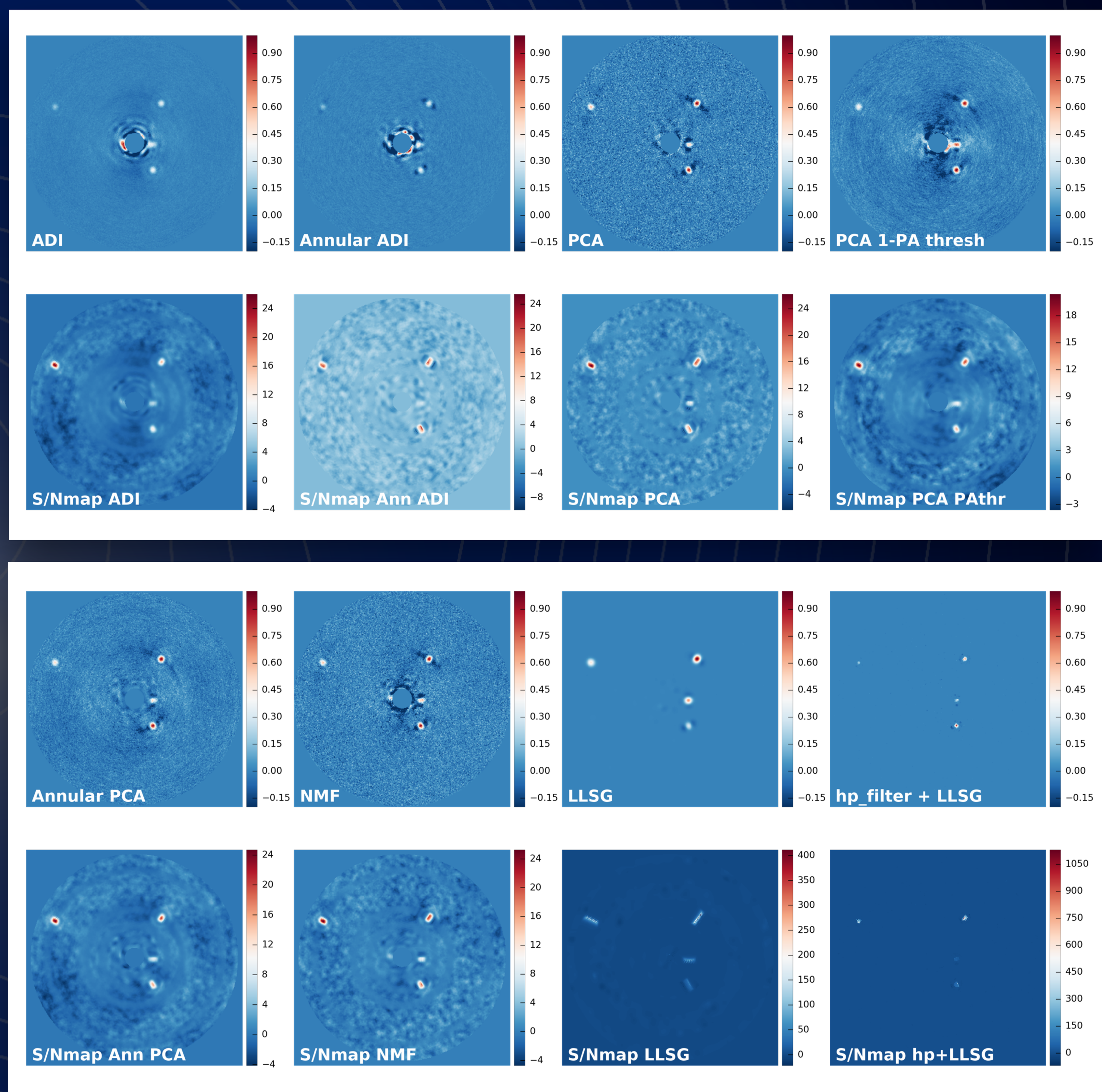


Corner plot for NEGFC+MCMC

VIP implements the negative fake companion (NEGFC) technique for the determination of the position and flux of companions. The NEGFC technique is an iterative process that aims at minimizing a well-chosen figure of merit. The optimization is run in three stages: a naive grid minimization varying only the flux, a Nelder-Mead simplex minimization varying both the position and flux, and the NEGFC+MCMC for sampling the posterior PDF of the parameters. The NEGFC technique coupled with MCMC sampling provides robust error bars. This statistical error of the position is taken into account for the astrometry total error budget [3].

3. Comparing ADI algorithms

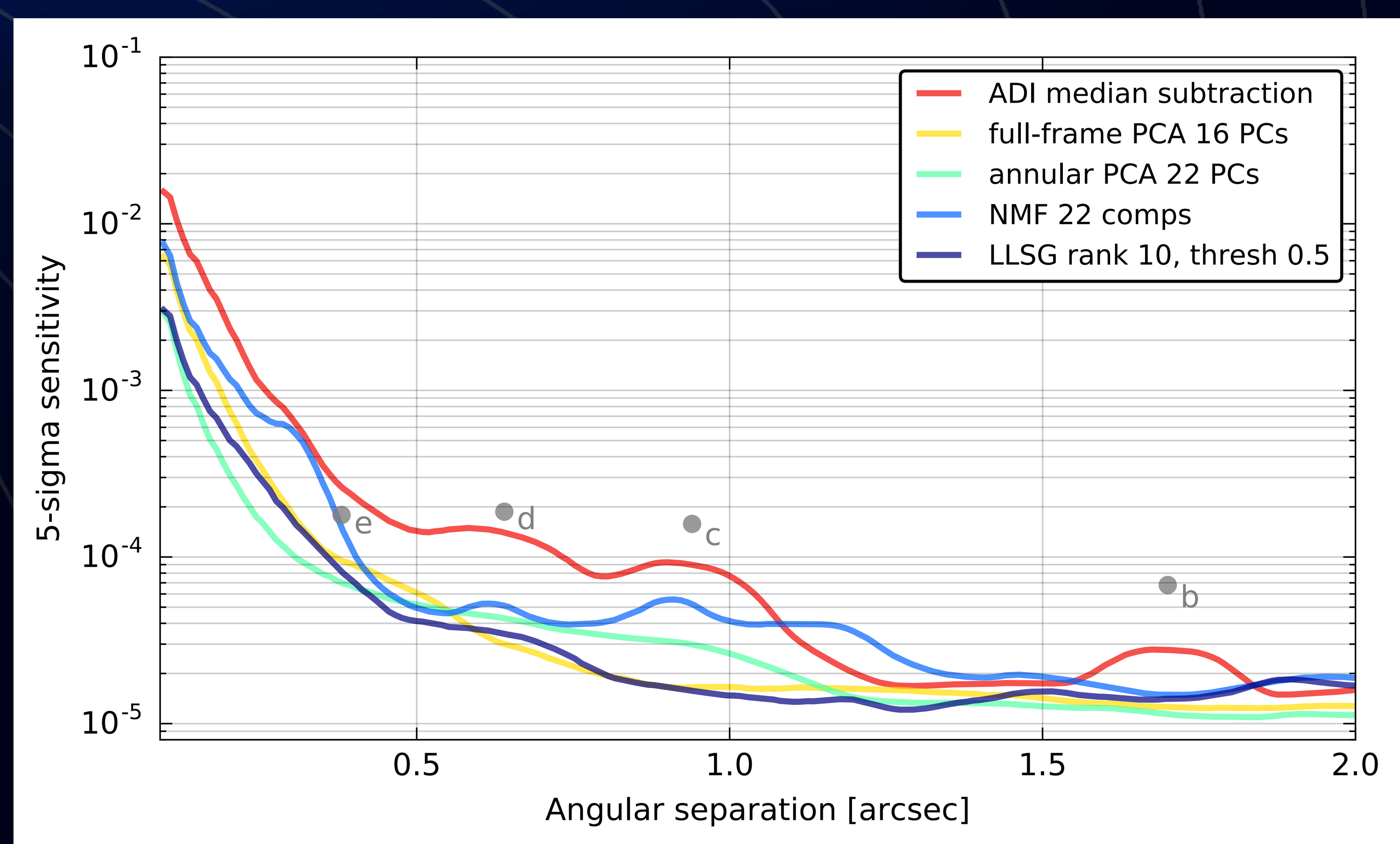
On-sky application of VIP to LBTI/LMIRCam (on its AGPM mode) ADI data on HR8799 [4]. Careful re-centering of frames and good frames selection has been applied with VIP. Below is shown a non-exhaustive compilation of the ADI post-processing options of VIP with varying parameters. The S/N is computed using a 2 samples t-test that takes into account the small samples statistics effect [5].



Post-processed final frames and below their corresponding S/N maps

4. Sensitivity limits

Sensitivity limits (in terms of planet/star contrast), often referred to as contrast curves, are commonly used for estimating the performance of high-contrast direct imaging instruments. The sensitivity curve is data-, algorithm- and parameter-dependant. In the figure below we show the 5-sigma sensitivities obtained with several ADI algorithms in VIP. The student-t correction [5] has been applied to these curves.



Comparison of 5-sigma sensitivities for all the available ADI algorithms in VIP

References

[1] Gomez Gonzalez C. et al. 2016, submitted.
[2] Gomez Gonzalez C. et al. 2016, A&A, 589, A54.
[3] Wertz O. et al. 2016, submitted.
[4] Defrère D. et al. 2014, SPIE.
[5] Mawet D. et al. 2014, ApJ, 792, 97.