



POST PROCESSING FOR HIGH-CONTRAST IMAGING

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KISS WORKSHOP

COHERENT DIFFERENTIAL IMAGING AND SIGNAL DETECTION STATISTICS

CALTECH, AUGUST 23, 2016

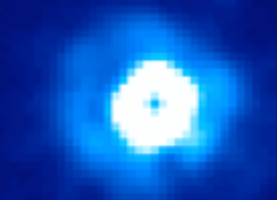
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de Liège



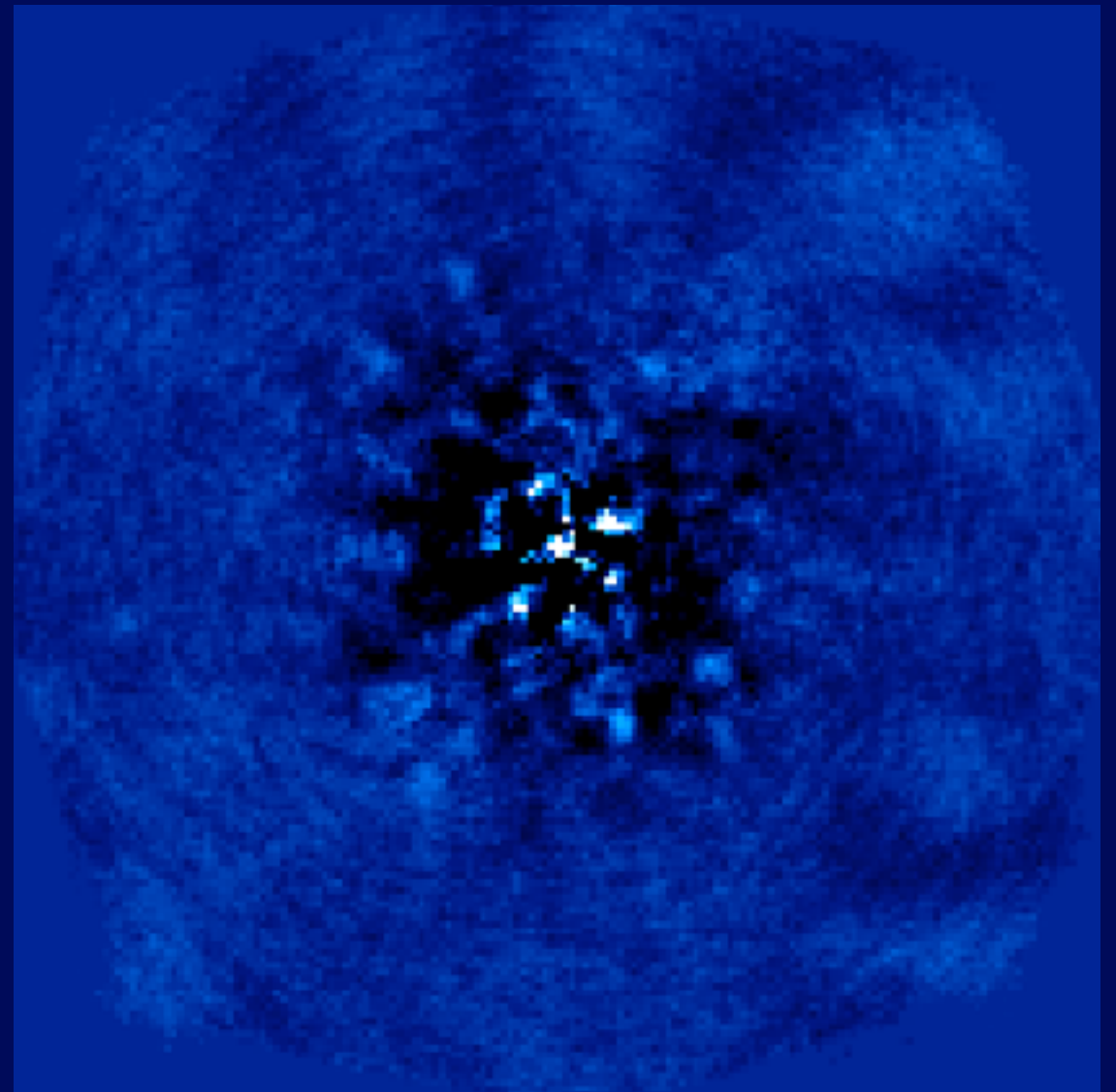
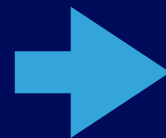
DIFFERENTIAL IMAGING

- ▶ Combining observing techniques with fine-tuned post-processing
- ▶ Generating a reference PSF
- ▶ Subtracting the scattered starlight and speckle noise pattern
- ▶ Enhancing the signal of interest

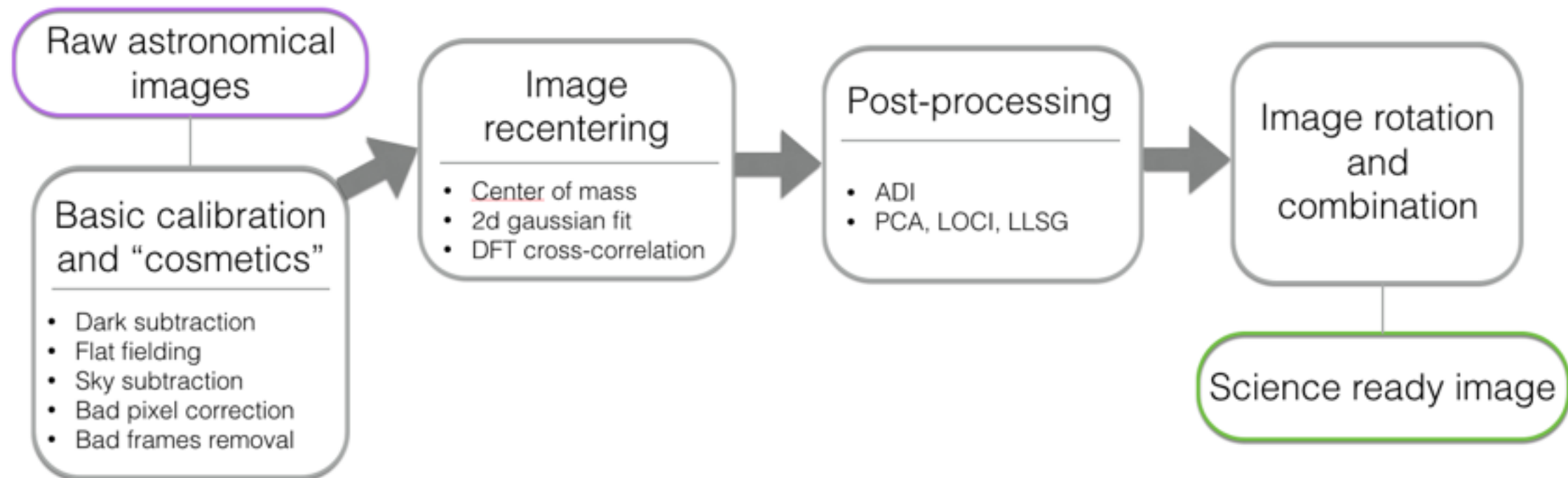
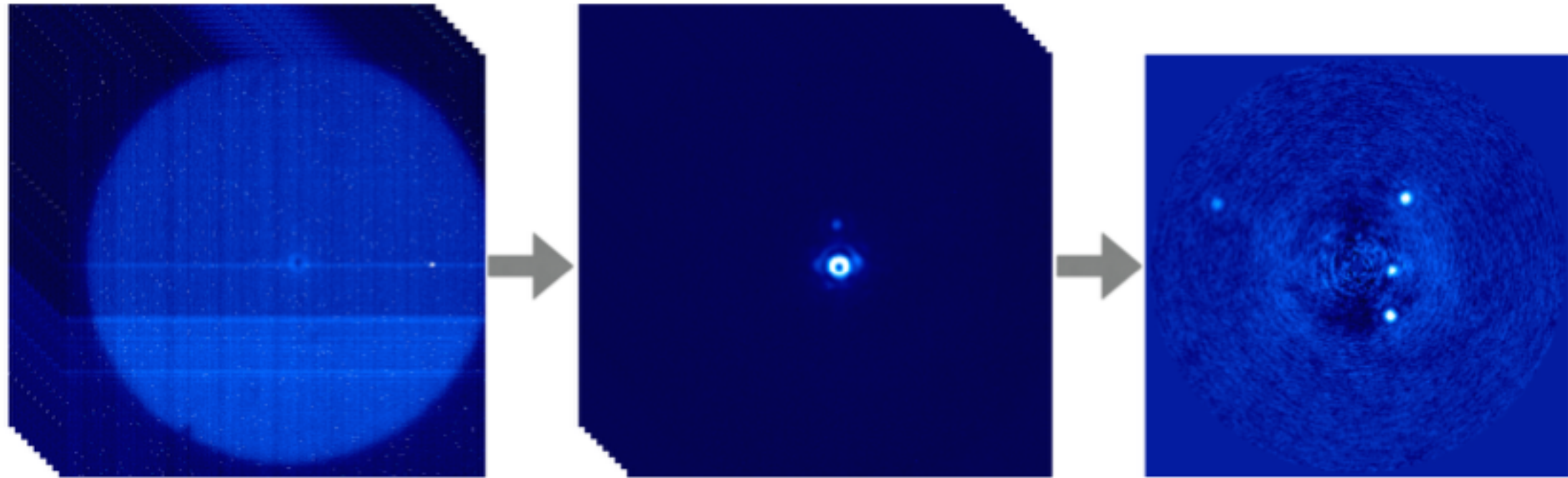
DIFFERENTIAL IMAGING



animation



TYPICAL PIPELINE



VIP – VORTEX IMAGE PROCESSING



- ▶ VIP is a toolbox for reproducible and robust data reduction, providing a wide collection of pre- and post-processing algorithms
- ▶ Supports three observations techniques: angular, reference-star, and multi-spectral differential imaging
- ▶ Mature ADI processing (paper submitted). RDI and mSDI in progress

VIP

- ▶ Open-source. Find it on github
- ▶ Wanna use it? Clone it
- ▶ Found a bug? Raise an issue
- ▶ Wanna improve it? Fork it and code
- ▶ Wanna contribute? Send a pull request
- ▶ Publishing results? Please cite the code/paper

 [vortex-exoplanet](#) / **VIP**



Clone or download ▾

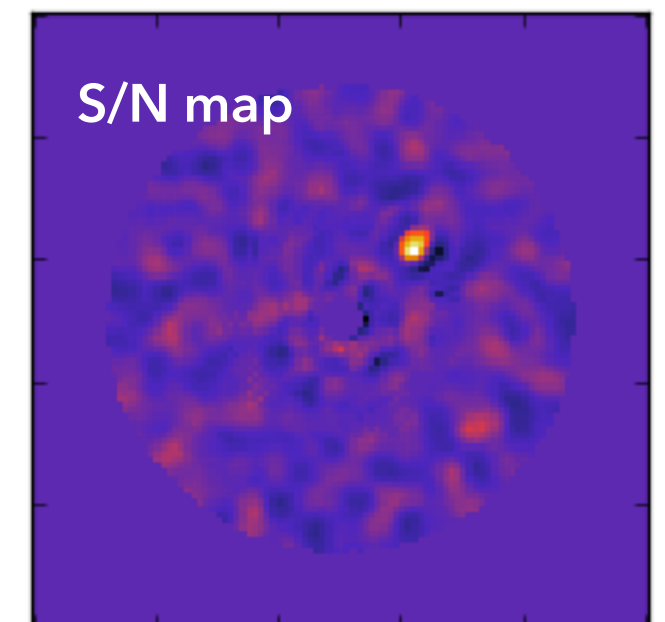
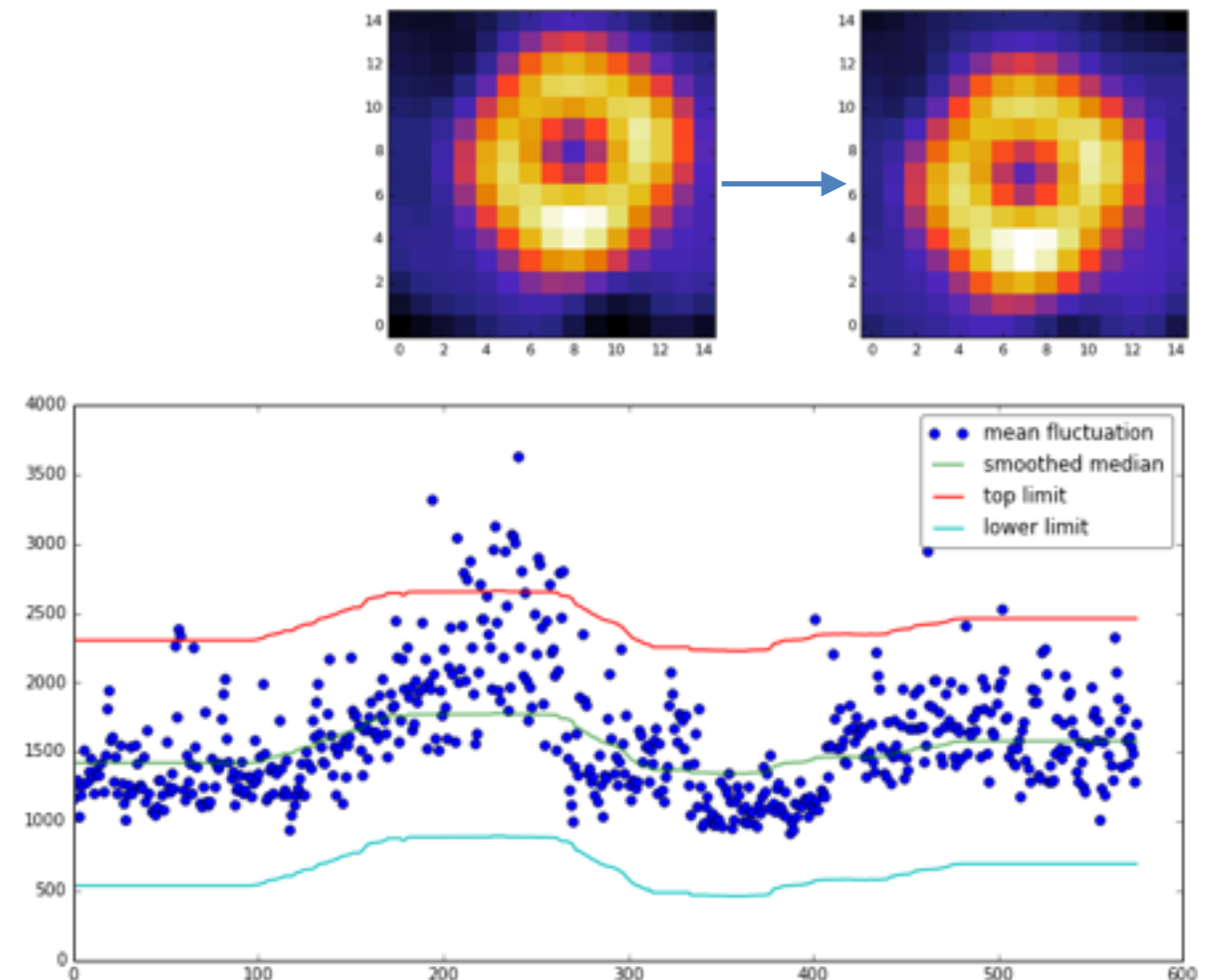
🔔 Issues **8**

🍴 Fork **3**

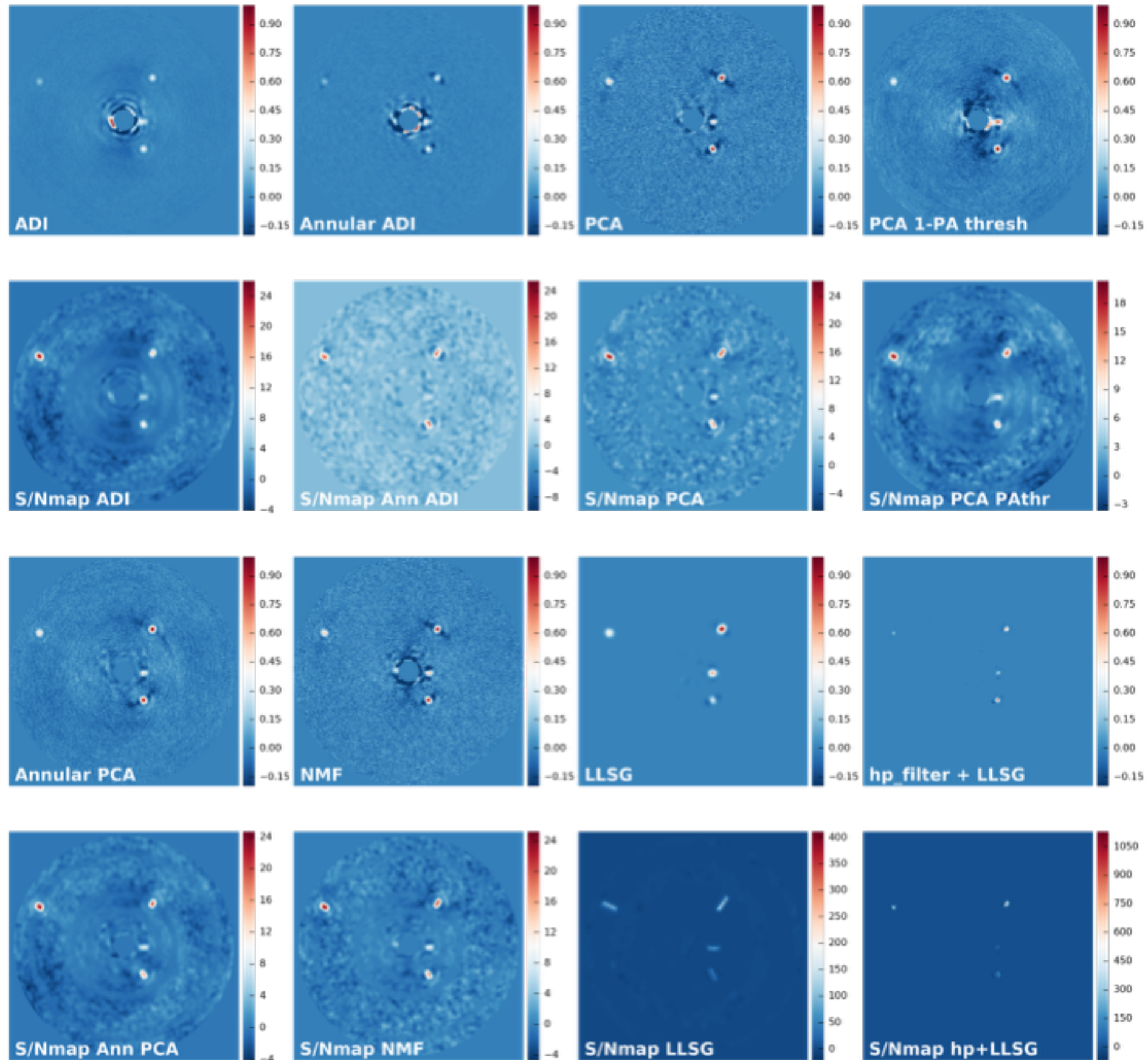
🔗 Pull requests

VIP

- ▶ Basic image processing operations
- ▶ Pre-processing functionalities including frames alignment, outlier detection
- ▶ S/N estimation
- ▶ Several PSF subtraction techniques

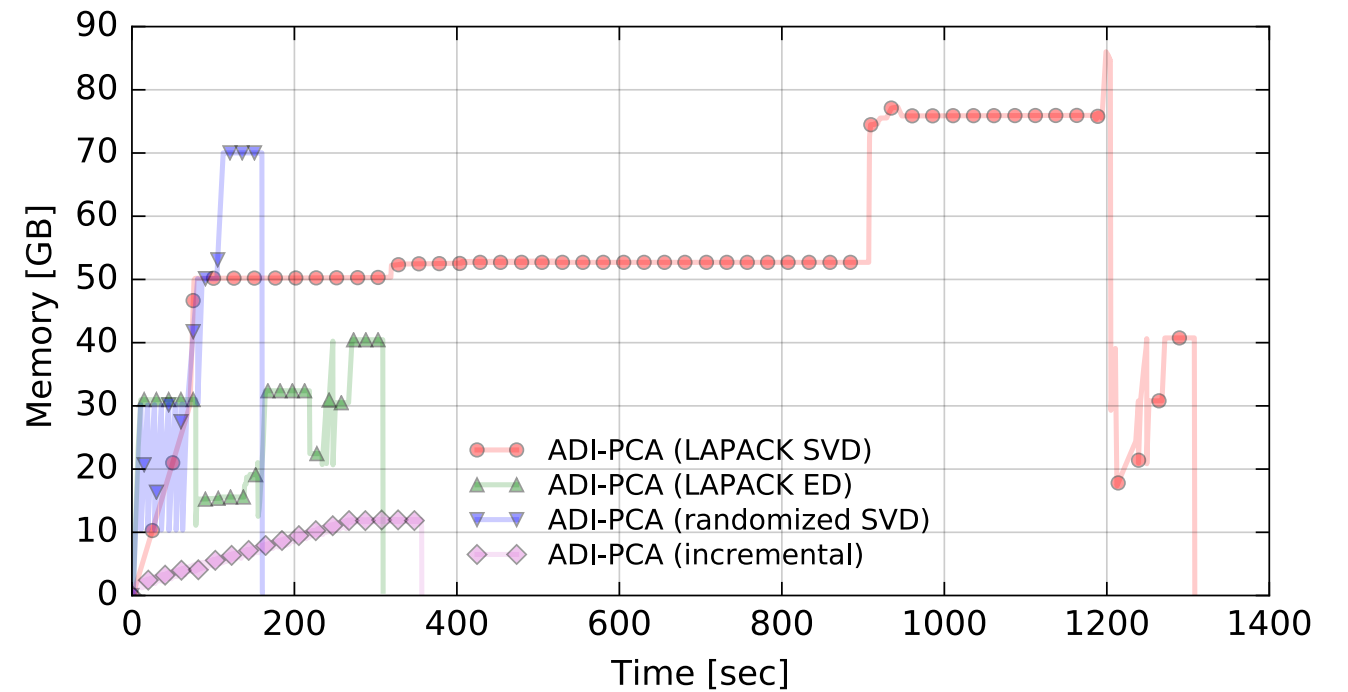


VIP



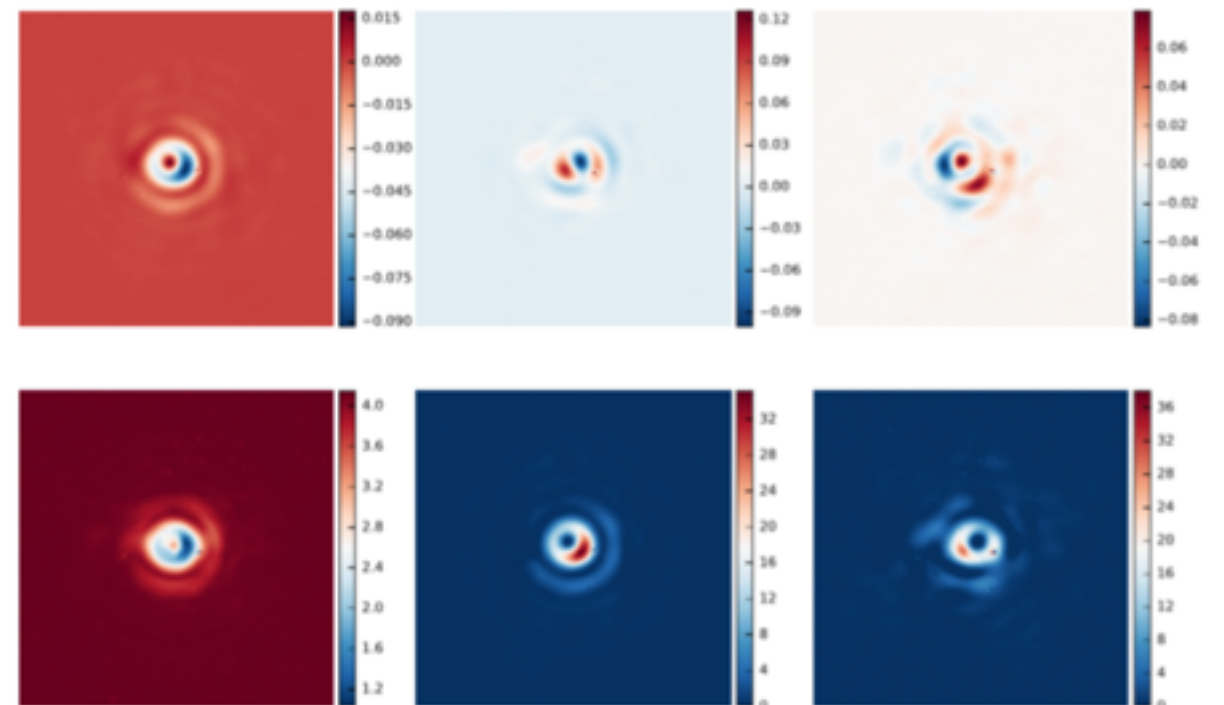
VIP

- ▶ ADI-PCA for big datacubes (larger than available memory)



- ▶ ADI-NMF

$$\min \left\| \mathbf{M} - \mathbf{W}\mathbf{H} \right\|_F^2 \text{ s.t. } \mathbf{W}, \mathbf{H} > 0$$



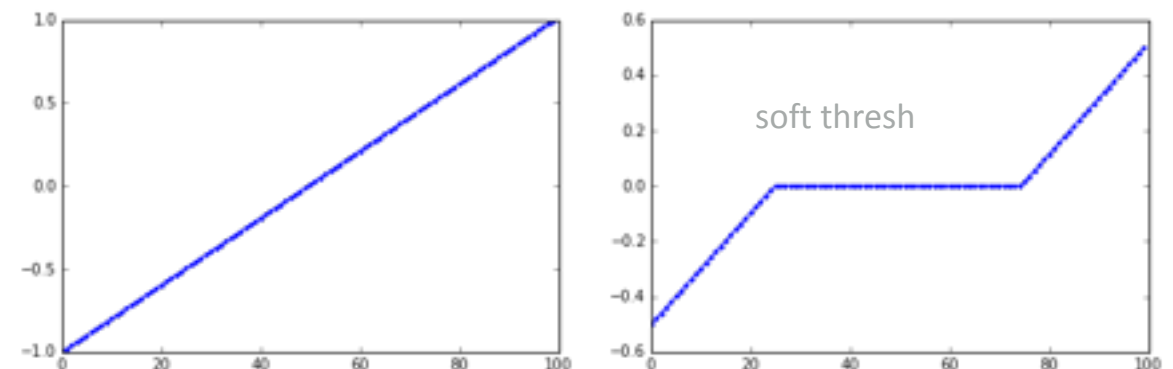
LLSG

- ▶ Local Low-rank plus Sparse plus Gaussian noise decomposition for ADI sequences (Gomez Gonzalez 2016)
- ▶ Based on (SS)GoDec (Zhou 2011, Zhou & Tao 2013)

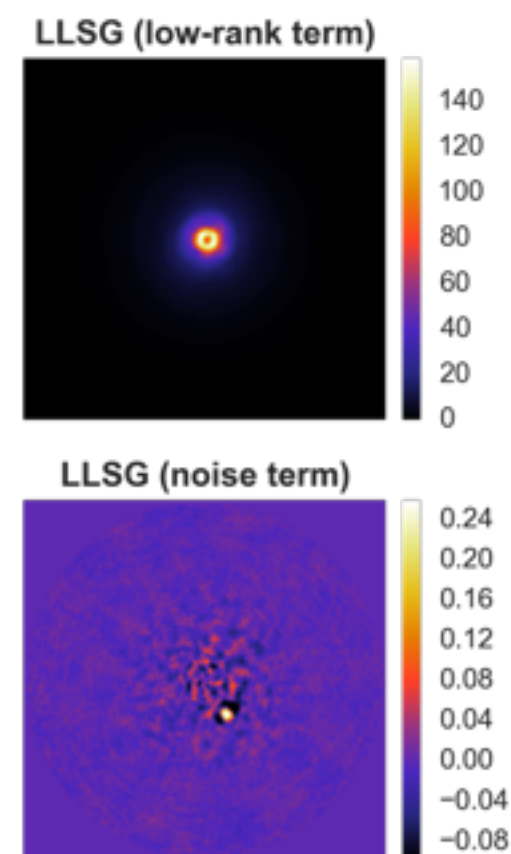
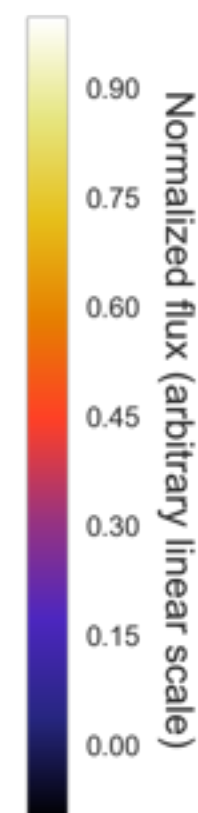
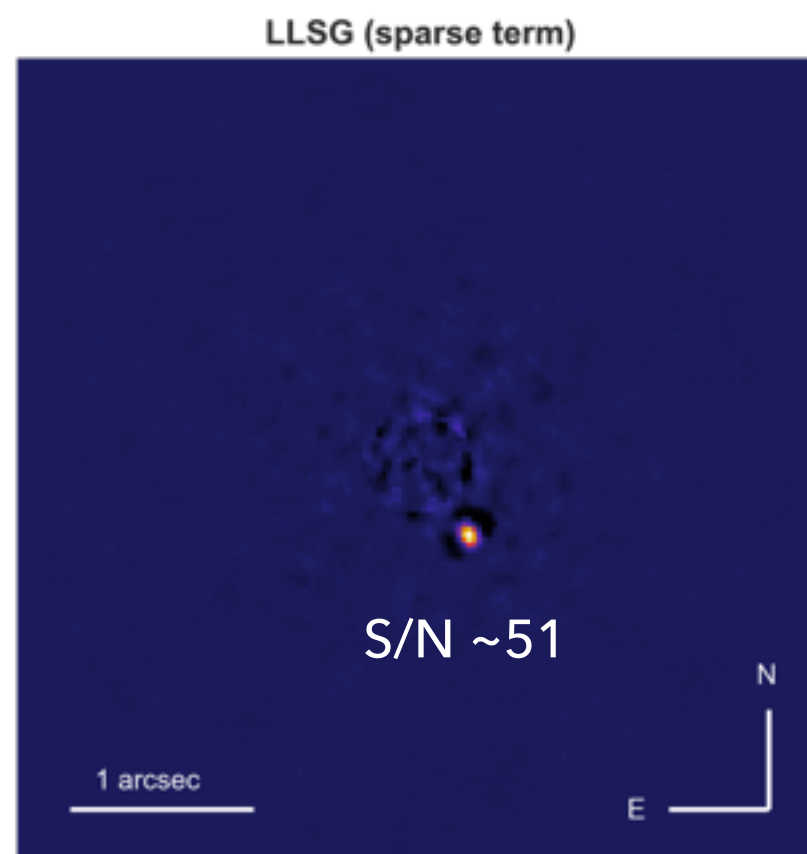
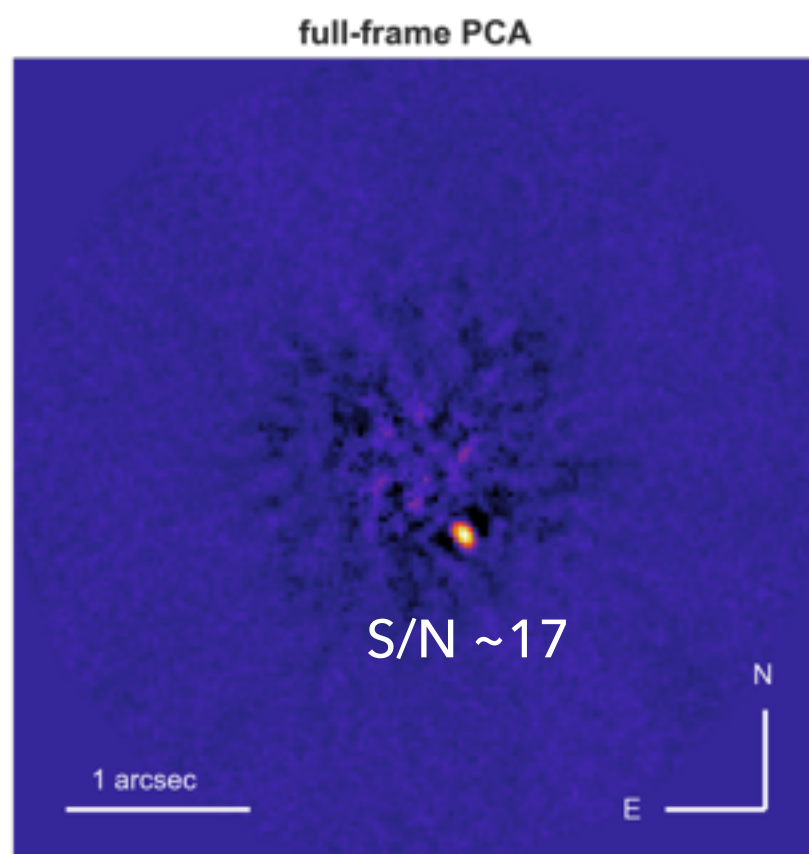
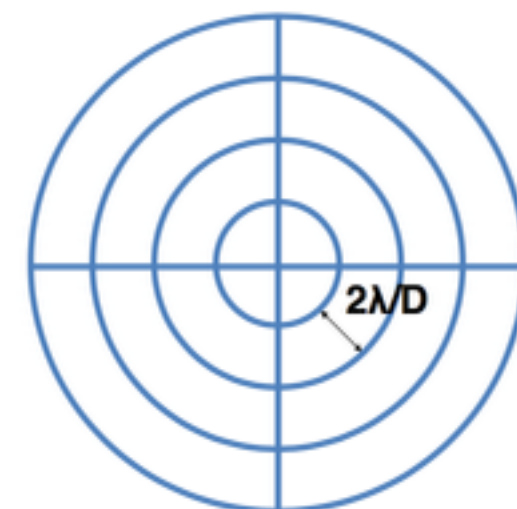
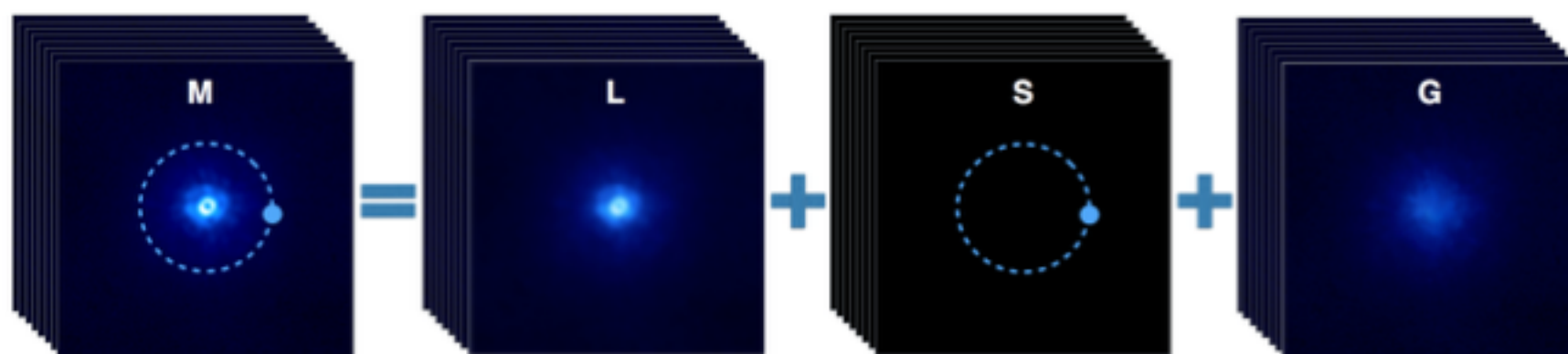
$$\min \left\| \mathbf{M} - \mathbf{L} + \mathbf{S} \right\|_F^2, \text{ s.t. } \text{rank}(\mathbf{L}) \leq k, \text{card}(\mathbf{S}) \leq c$$

- ▶ L updated through SVD or BRP
- ▶ S sparsity encouraged with soft-thresholding

$$S_{\gamma} \mathbf{X} = \text{sgn}(\mathbf{X}_{ij}) \max(|\mathbf{X}_{ij}| - \gamma, 0)$$

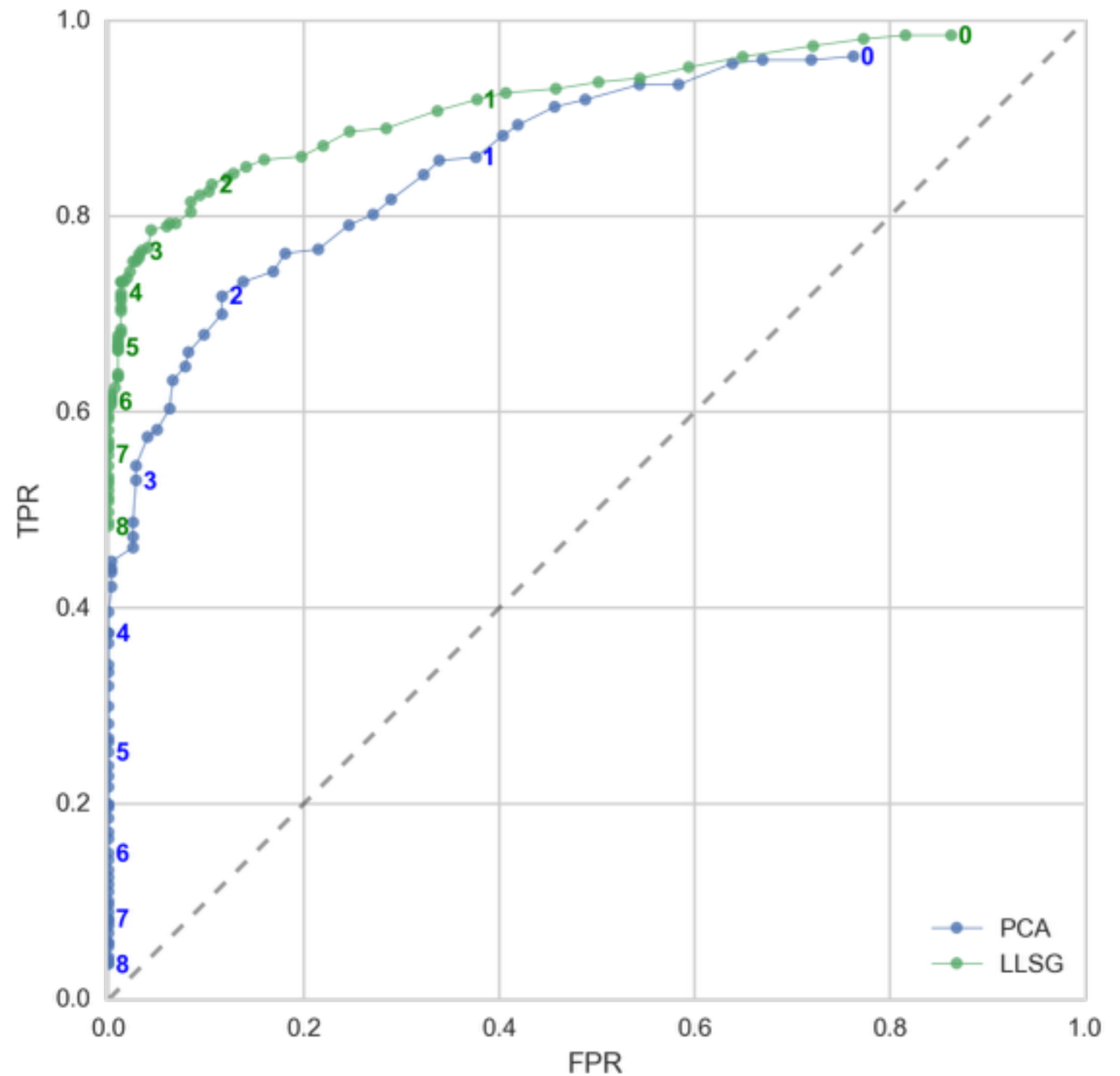


LLSG

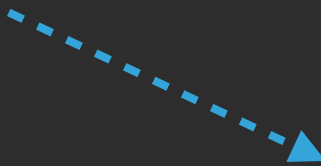


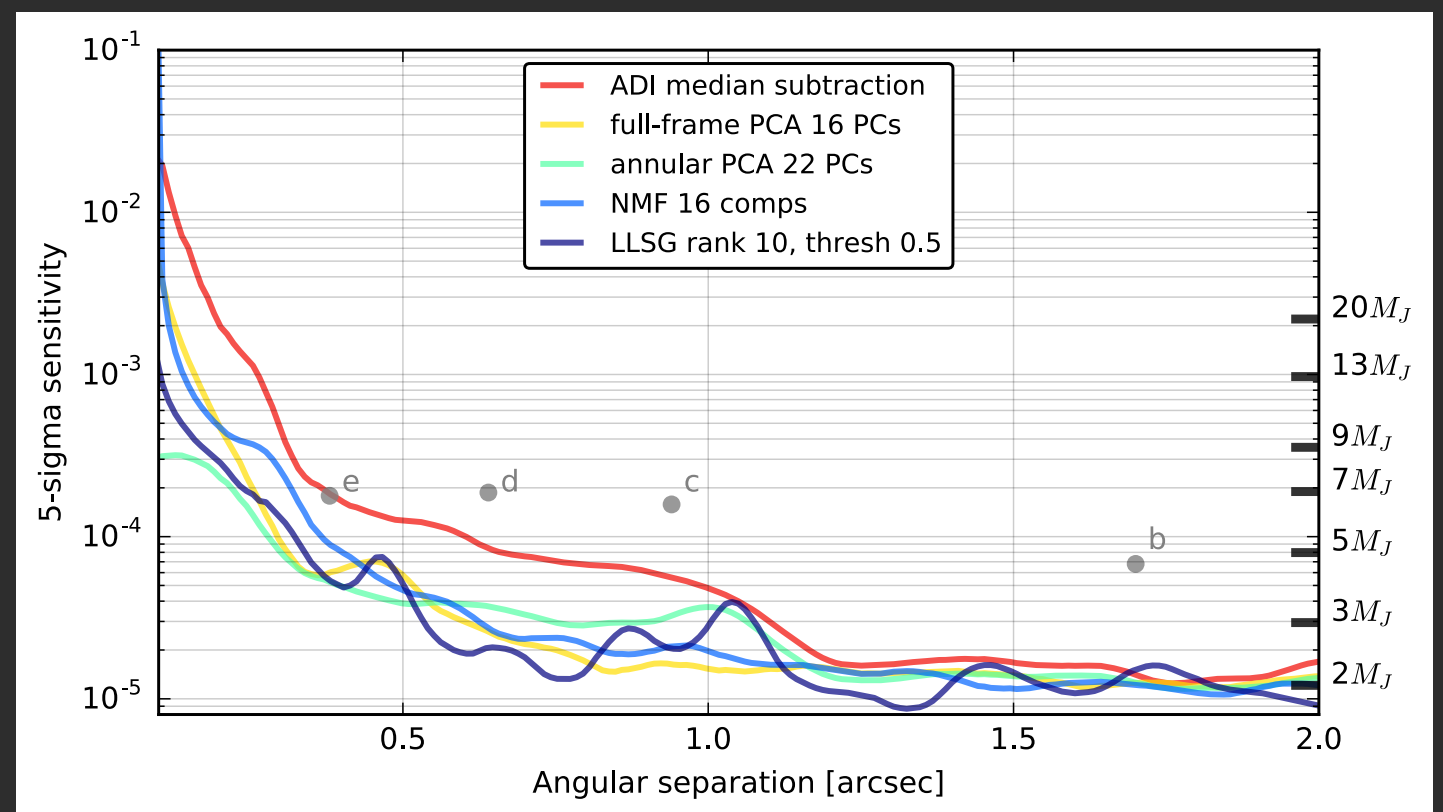
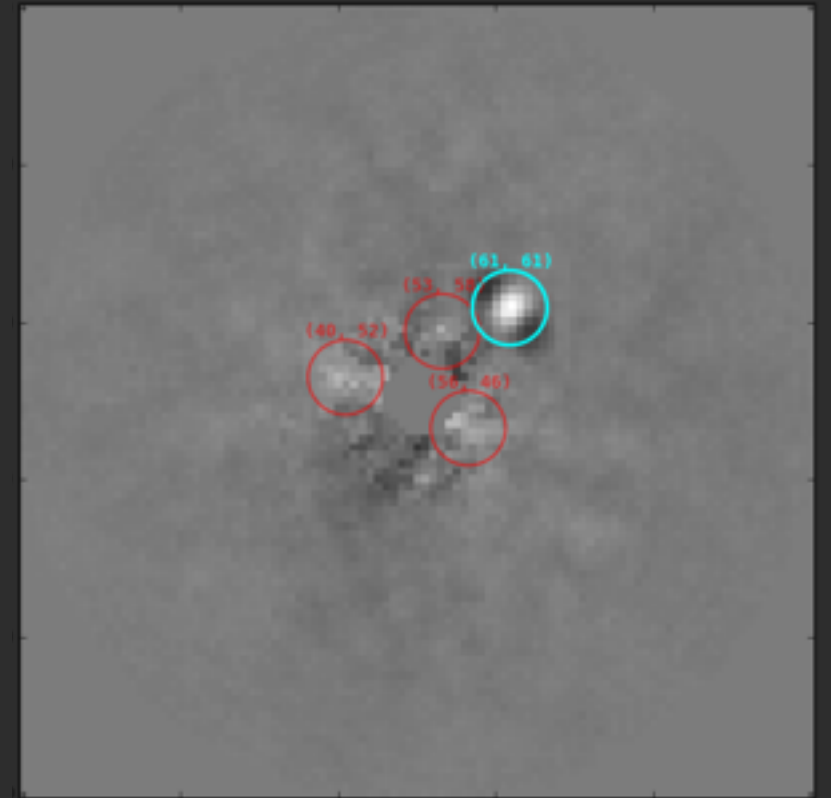
LLSG

	H_1 : signal present	H_0 : signal absent
Detection	True Positive	False Positive <i>type I error</i>
Null result	False Negative <i>type II error</i>	True Negative
	TPF = sensitivity = $TP/(TP+FN)$	FPF = 1-specificity = $1-CL$ = $FP/(FP+TN)$



THEN WHAT

- ▶ Detection 
- ▶ Contrast/ROC curves 
- ▶ Characterization:
position and flux of planet

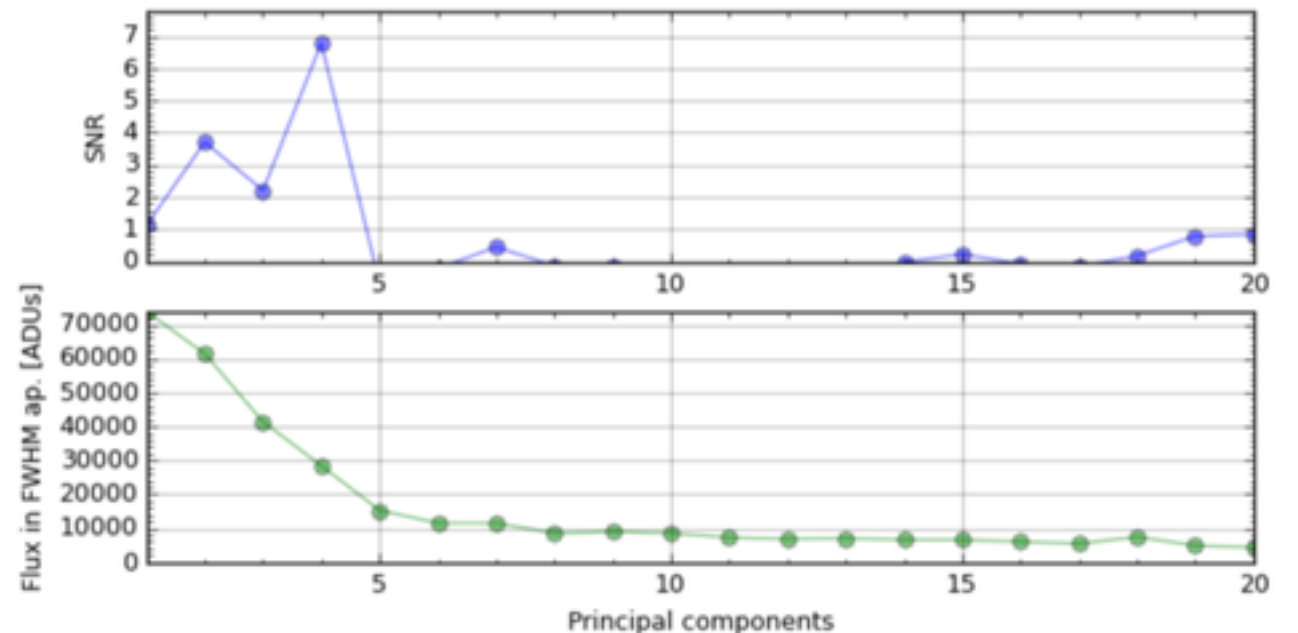
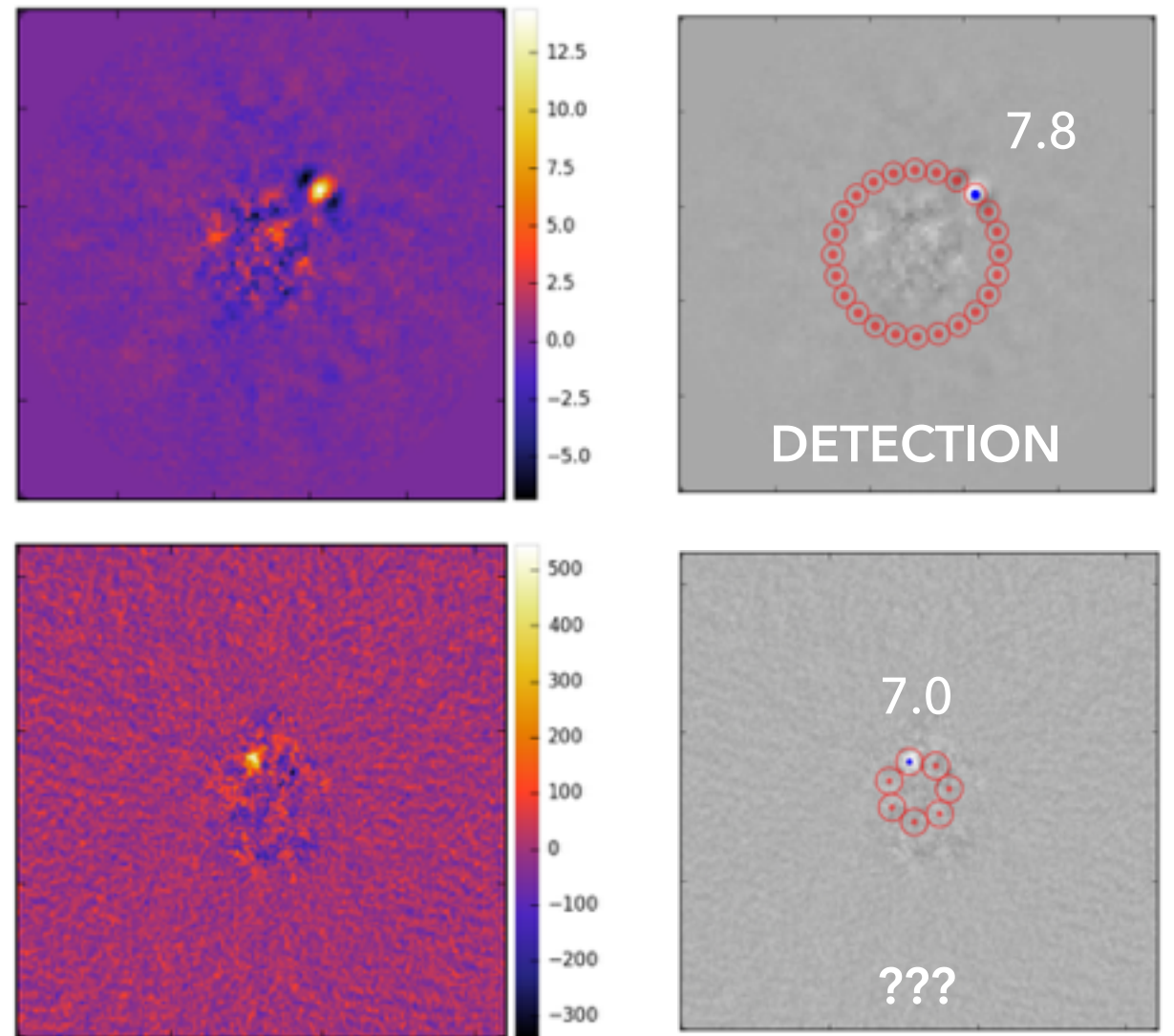


DETECTION, METRICS

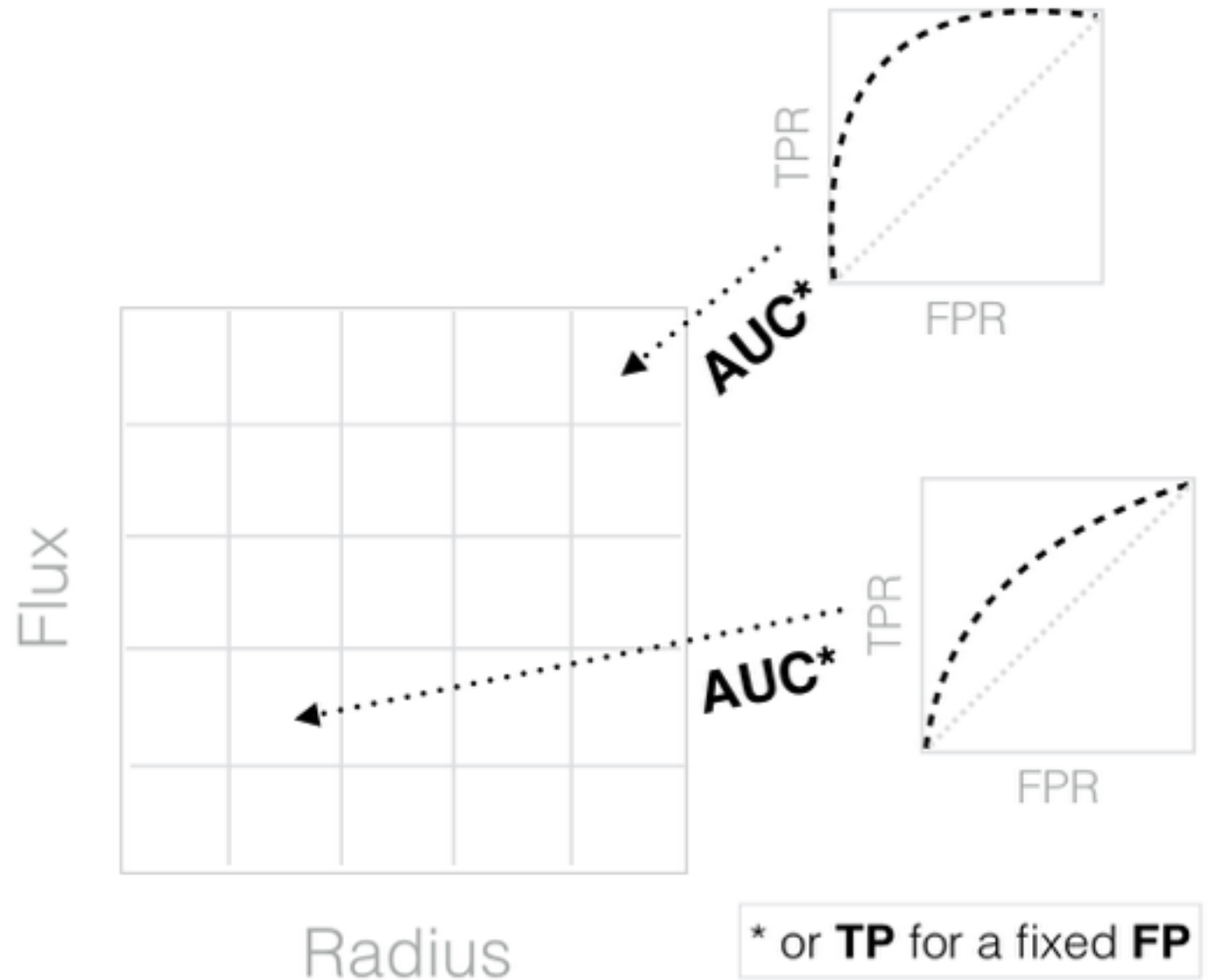
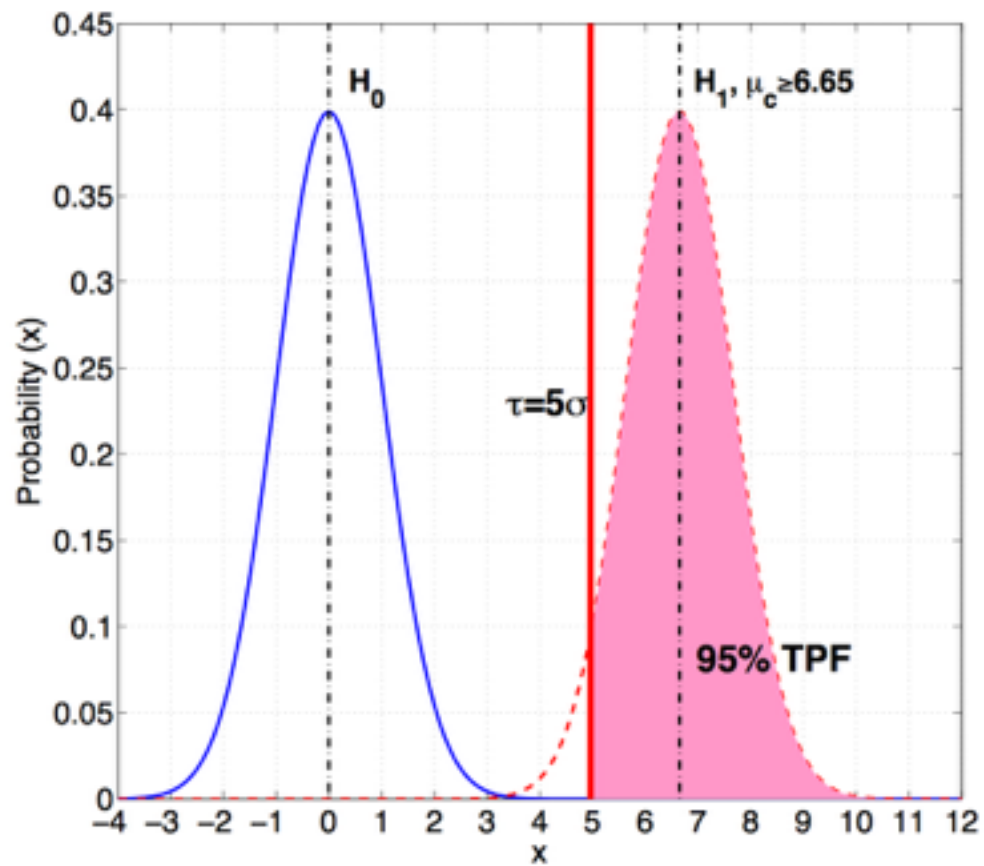
- ▶ Current practice: detection on 2d flux maps. Visual inspection + S/N metric
- ▶ S/N using a two-samples t-test, with one sample containing one element (Mawet et al. 2014)

$$SNR = \frac{\bar{x}_1 - \bar{x}_2}{s_2 \sqrt{1 + \frac{1}{n_2}}}$$

- ▶ Best we can do for detection?



DETECTION, METRICS

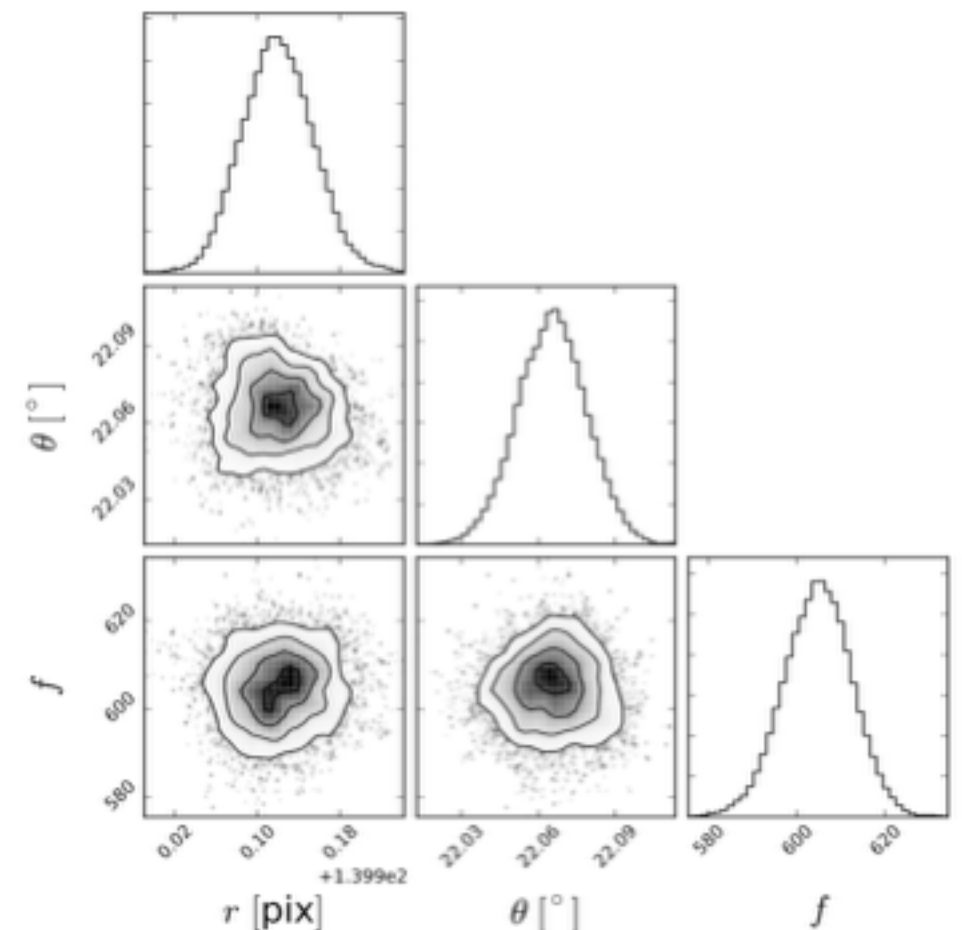
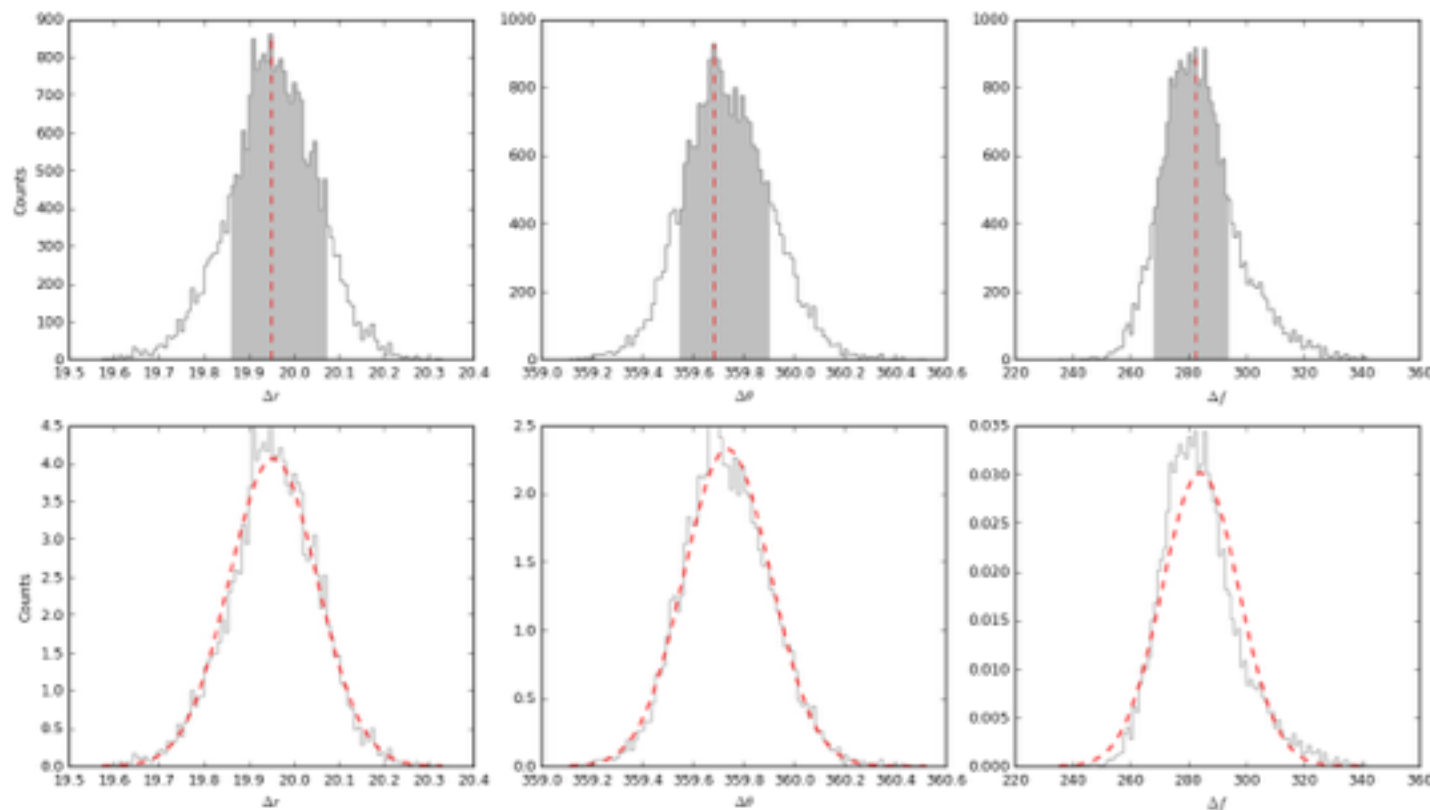


- ▶ ROC, LROC, FR-ROC?
- ▶ How to properly count FPs/TPs?
- ▶ One location vs several



CHARACTERIZATION

- ▶ Negative fake companion (NEGFC) for planets position and flux estimation by minimizing a function of merit (sum |pxs|) on an aperture in the final frame. Nelder-Mead minimization
- ▶ NEGFC coupled with MCMC sampling provides robust error bars (Wertz et al. submitted)

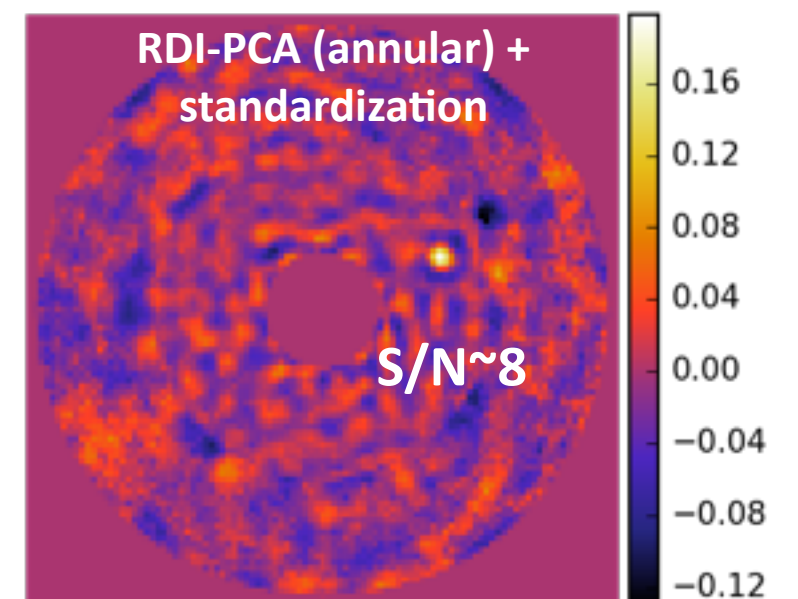
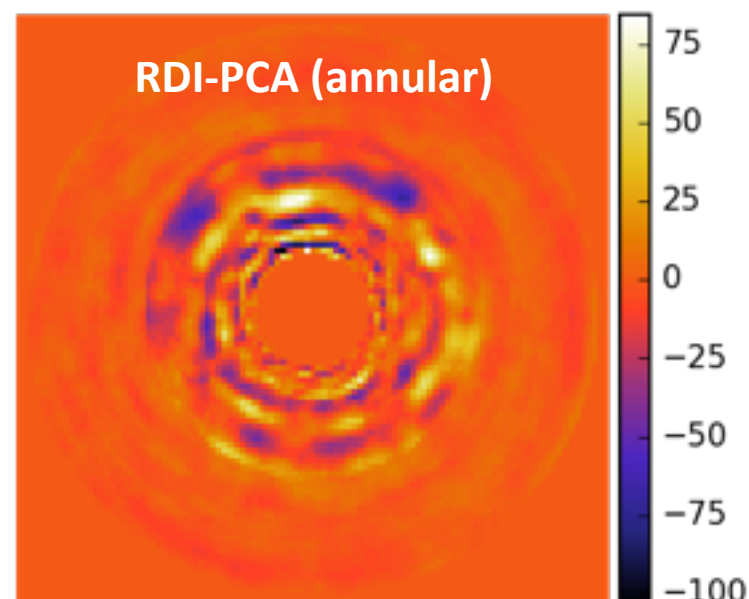
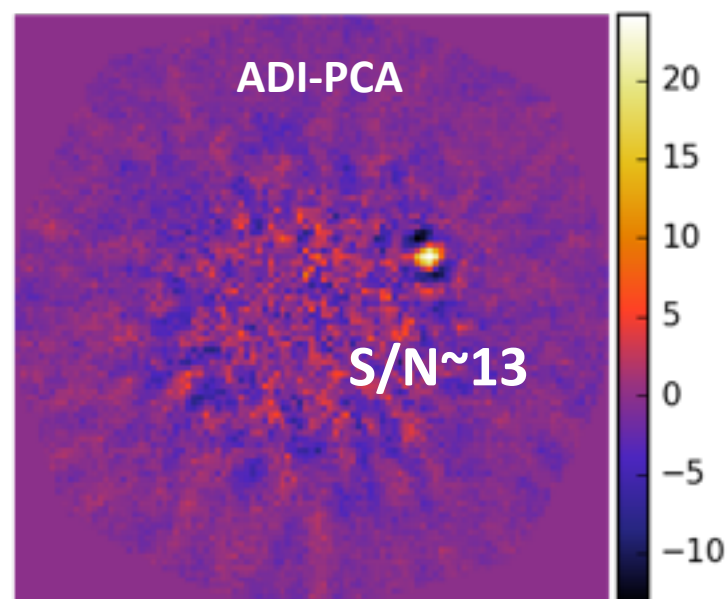


VIP – FUTURE PLANS

- ▶ Consolidate RDI post-processing
- ▶ mSDI (if time allows)
- ▶ Metrics sub-package with ROC curves (along with existing CCs)
- ▶ Andromeda
- ▶ LOCI (who wants to contribute?)

RDI

- ▶ Promising technique for exploring small angular separations. Also very demanding: (Mawet et al. 2012)
- ▶ Proper flux scaling of frames is not trivial task, difficulting one to one subtraction (Rameau 2012)
- ▶ Case of survey with many targets, how to use data? PCA?

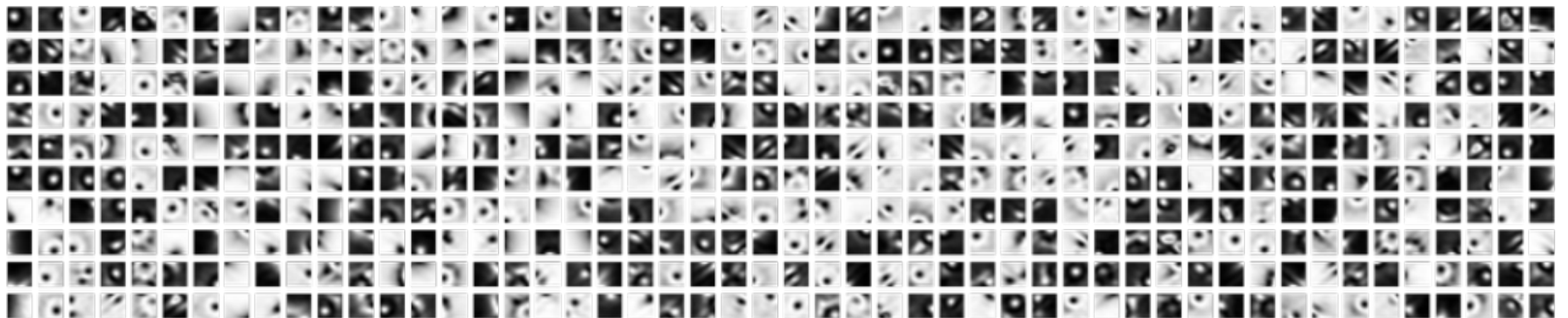


RDI – DICTIONARY LEARNING

- ▶ Dictionary learning for generalizing the task of image approximation (reference PSF) in terms of a “basis”

$$\arg \min_{(\mathbf{U}, \mathbf{V})} \frac{1}{2} \|\mathbf{X} - \mathbf{UV}\|_2^2 + \alpha \|\mathbf{U}\|$$

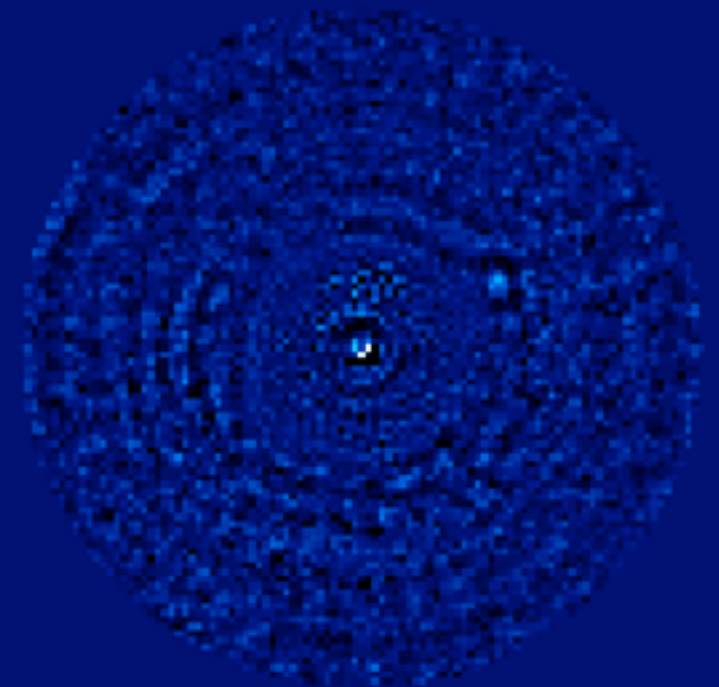
$$\text{s.t. } \|\mathbf{V}_k\|_2 = 1 \text{ for } 0 < k < n_{atoms}$$



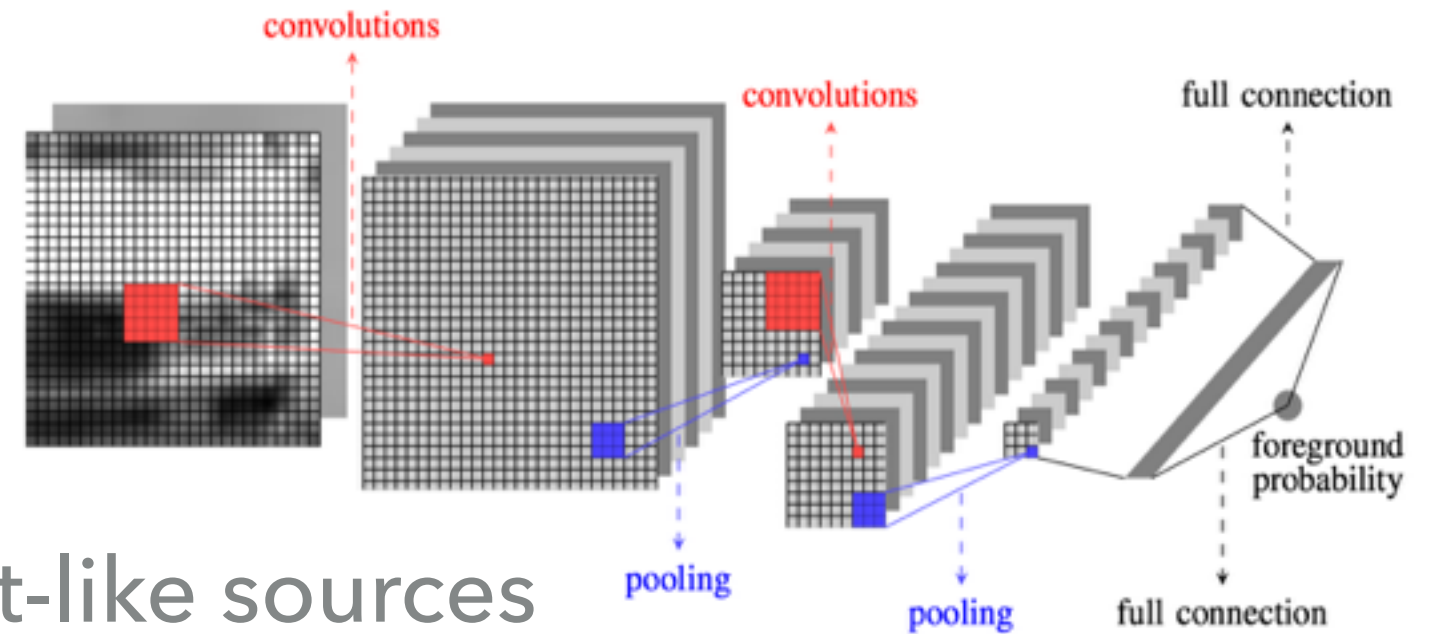
RDI – DICTIONARY LEARNING

- Orthogonal Matching Pursuit $\min \left\| \mathbf{X} - \mathbf{U}\mathbf{V} \right\|_2^2 \text{ s.t. } \left\| \mathbf{U} \right\|_0 \leq k$

WORK IN PROGRESS!!!



CONVNET



- ▶ Detect presence of point-like sources
- ▶ Probabilities of signal presence for each pixel

WORK IN PROGRESS!!!