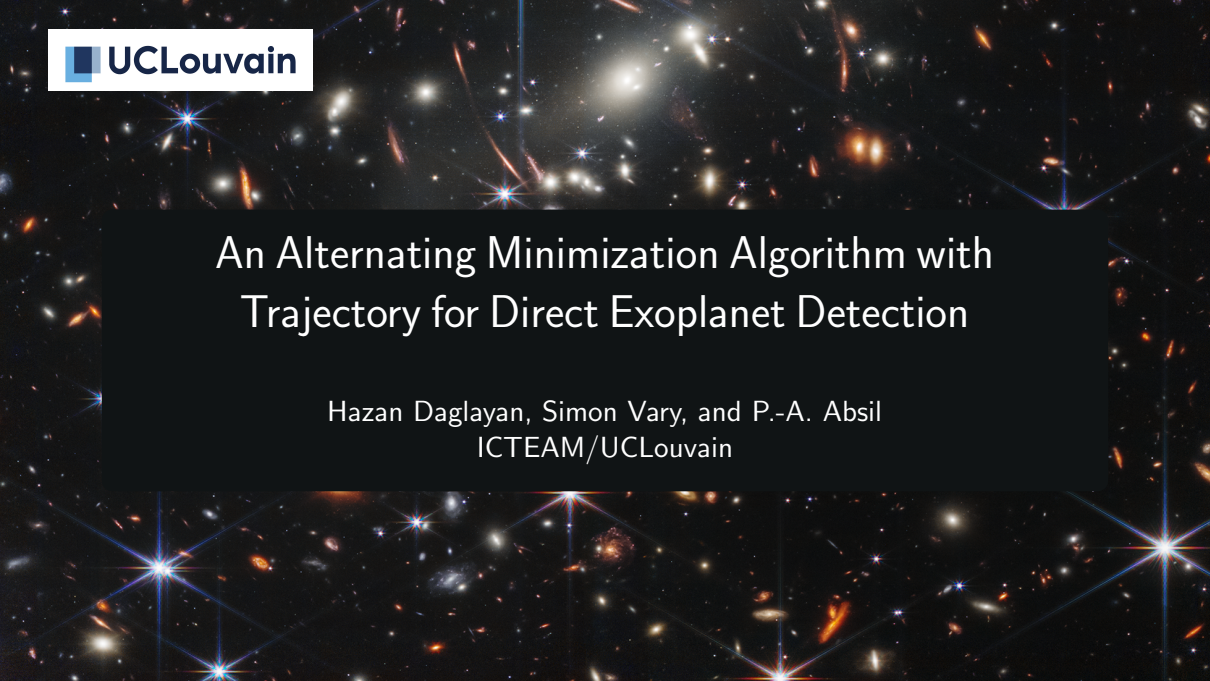
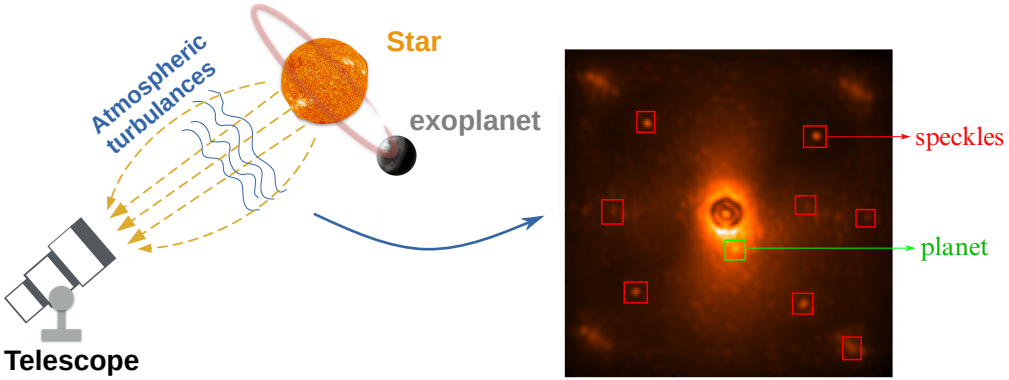


UCLouvain

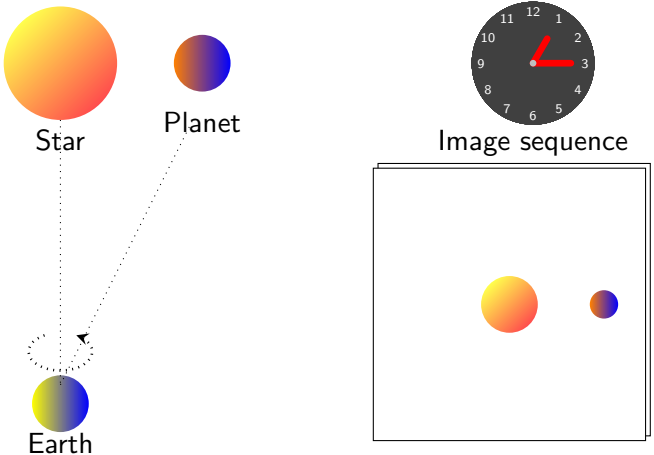
An Alternating Minimization Algorithm with Trajectory for Direct Exoplanet Detection

Hazan Daglayan, Simon Vary, and P.-A. Absil
ICTEAM/UCLouvain

Direct Imaging



Angular Differential Imaging



Problem Setup & Goal

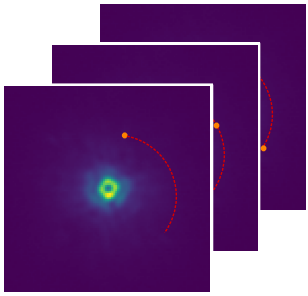
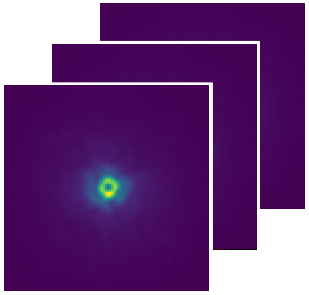


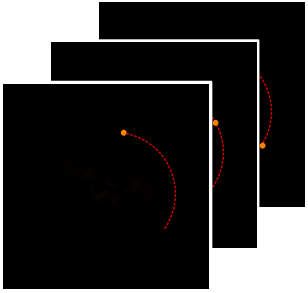
Image sequence

$=$



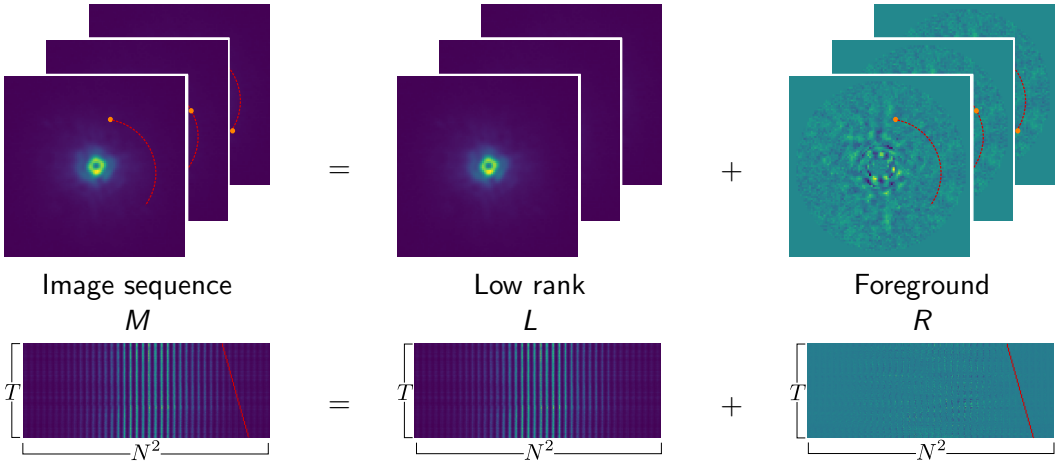
Background
(star+speckles)

$+$



Foreground
(planet)

Background: (Annular) PCA[1,2]



[1] Amara and Quanz, 2012
[2] Soummer, et al., 2012

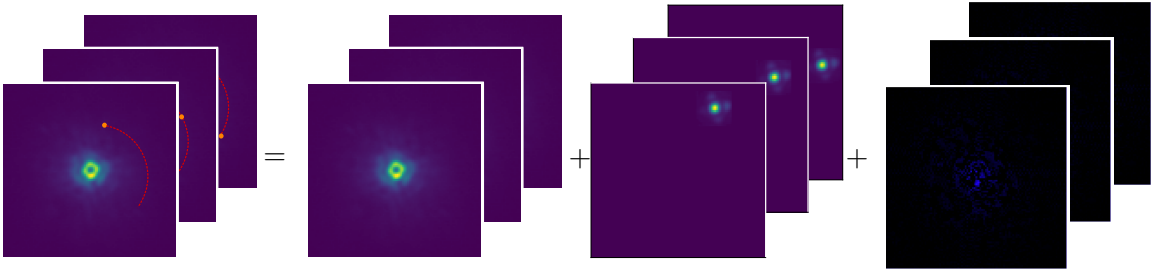
State of art: LLSG[3]

Original cube M = Low rank L + Sparse S + Gaussian G

$$\mathrm{rank}(L) \leq k, \quad \mathrm{card}(S) \leq s$$

[3] Gomez Gonzalez, et al., 2016

Alternating Minimization Algorithm with Trajectory (AMAT)



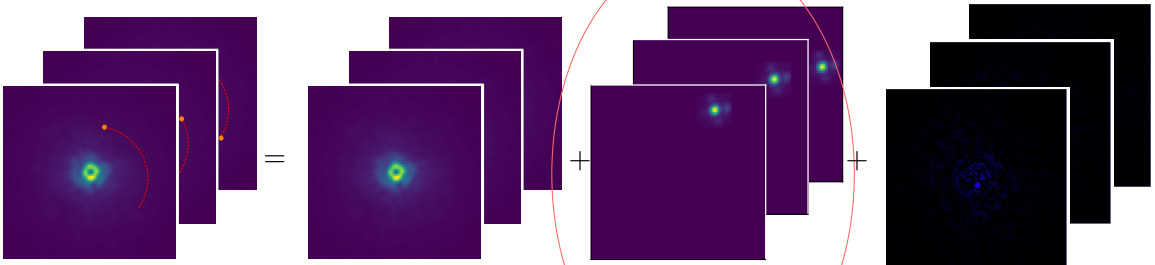
Original cube M | Low rank L | Planet Signature $a_g P_g$ | Noise E

$$\text{rank}(L) \leq k, \quad P_g \in \Lambda$$

AMAT

$$\min_{L \in \mathbb{R}^{t \times n}, a_g \in \mathbb{R}} \|M - L - a_g P_g\| \quad \text{s.t.} \quad \text{rank}(L) \leq k$$

Alternating Minimization Algorithm with Trajectory (AMAT)



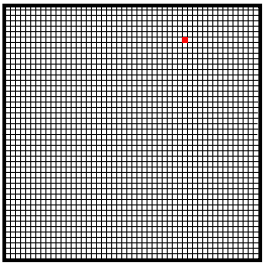
Original cube M | Low rank L | Planet Signature $a_g P_g$ | Noise E

$$\text{rank}(L) \leq k, \quad P_g \in \Lambda$$

AMAT

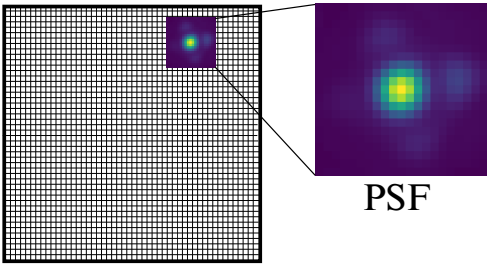
$$\min_{L \in \mathbb{R}^{t \times n}, a_g \in \mathbb{R}} \|M - L - a_g P_g\| \quad \text{s.t.} \quad \text{rank}(L) \leq k$$

Planet Signature



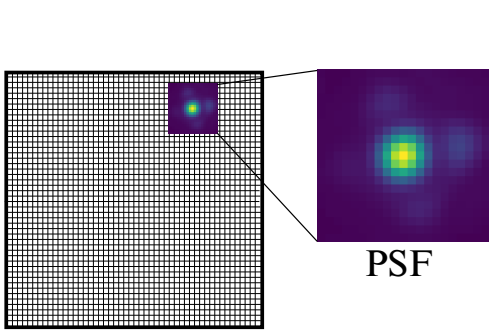
$g \in [N] \times [N]$

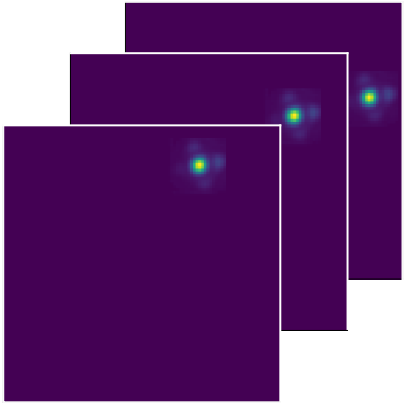
Planet Signature



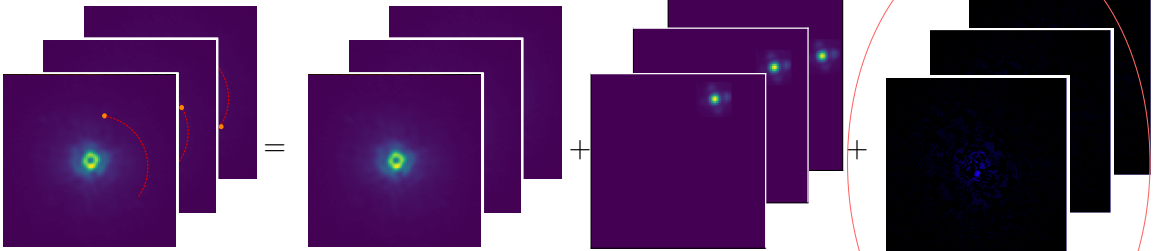
$g \in [N] \times [N]$

Planet Signature





Alternating Minimization Algorithm with Trajectory (AMAT)



Original cube M | Low rank L | Planet Signature $a_g P_g$ | Noise E

$$\text{rank}(L) \leq k, \quad P_g \in \Lambda$$

AMAT

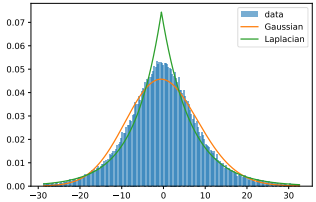
$$\min_{L \in \mathbb{R}^{t \times n}, a \in \mathbb{R}} \|M - L - a_g P_g\| \quad \text{s.t.} \quad \text{rank}(L) \leq k$$

Noise

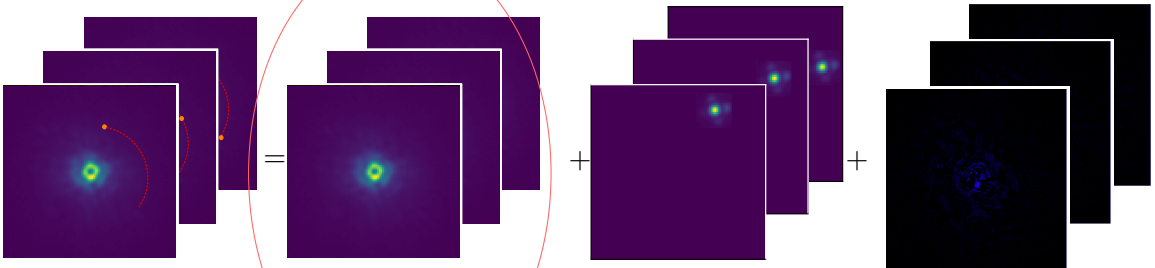
- Gaussian
- Laplacian

Noise

- Gaussian
- Laplacian



Alternating Minimization Algorithm with Trajectory (AMAT)



Original cube M | Low rank L | Planet Signature aP_g | Noise E

$$\text{rank}(L) \leq k, \quad P_g \in \Lambda$$

AMAT

$$\min_{L \in \mathbb{R}^{t \times n}, a \in \mathbb{R}} \|M - L - a_g P_g\| \quad \text{s.t.} \quad \text{rank}(L) \leq k$$

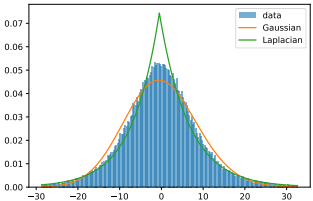
Low Rank Approximation

- PCA
- L1LRA[2]
  - an exact block cyclic coordinate descent method

[2]Gillis, N., Vavasis, S.A.: On the complexity of robust pca and ℓ_1-norm low-rank matrix approximation. Mathematics of Operations Research 43(4), 1072–1084 (2018)

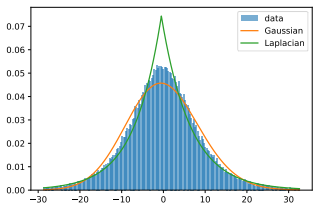
Noise

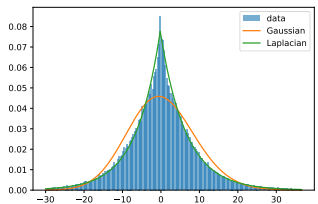
- Gaussian
- Laplacian



Noise

- Gaussian
- Laplacian





Daglayan H., et al. Direct Exoplanet Detection Using L1 Norm Low-Rank Approximation. BNAIC/BeNeLearn 2023, (Accepted).

AMAT

$$\min_{L \in \mathbb{R}^{t \times n}, a \in \mathbb{R}} \|M - L - a_g P_g\| \quad \text{s.t.} \quad \operatorname{rank}(L) \leq k$$

AMAT

$$\min_{L\in\mathbb{R}^{t\times n},a\in\mathbb{R}} \|M - L - a_g P_g\| \quad \text{s.t.} \quad \operatorname{rank}(L) \leq k$$

Alternating Minimization

$$L^{(i)} = \arg\min_{L\in\mathbb{R}^{t\times n}} \|M - L - a_g^{(i-1)} P_g\| \qquad (1)$$

$$a_g^{(i)} = \arg\min_{a_g\in\mathbb{R}} \|M - L^{(i)} - a_g P_g\| \qquad (2)$$

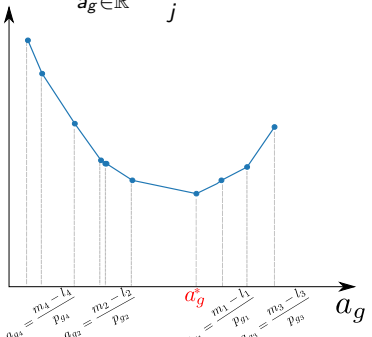
Intensity a_g

- L2 norm

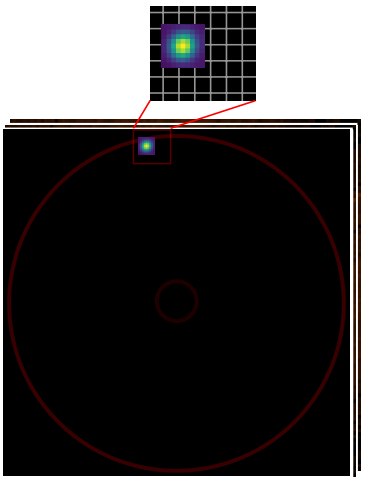
$$a_g^{(i)} = \arg\min_{a_g \in \mathbb{R}} \sum_j (m_j - l_j - a_g p_{g_j})^2 = \frac{\langle P_g, M - L_i \rangle}{\|P_g\|_F^2}$$

- L1 norm

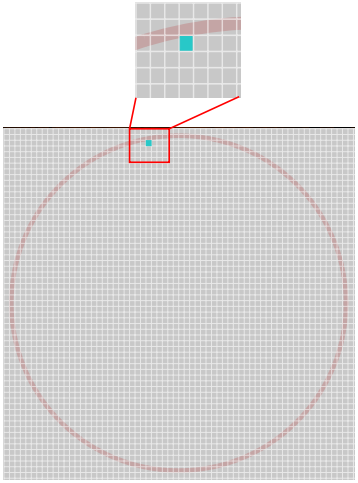
$$a_g^{(i)} = \arg\min_{a_g \in \mathbb{R}} \sum_j |m_j - l_j - a_g p_{g_j}|$$



Trajectories

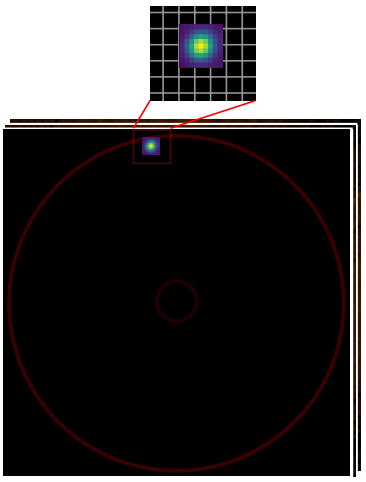


P_g

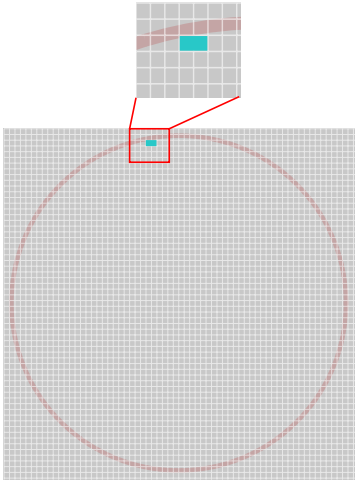


Flux map

Trajectories

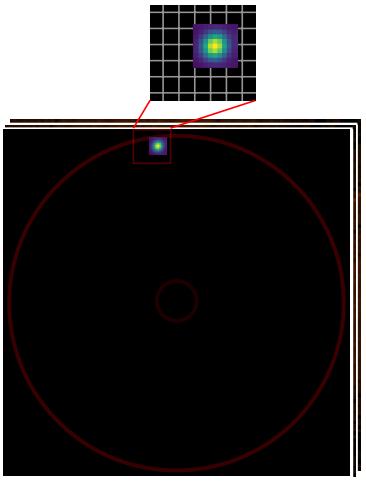


P_g

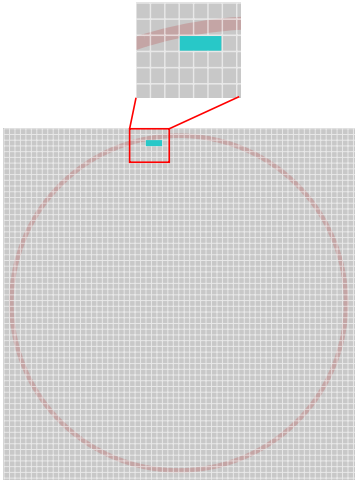


Flux map

Trajectories

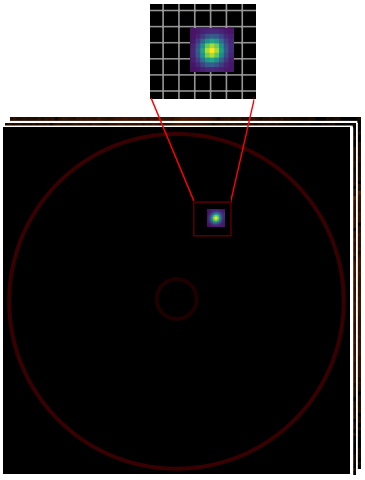


P_g

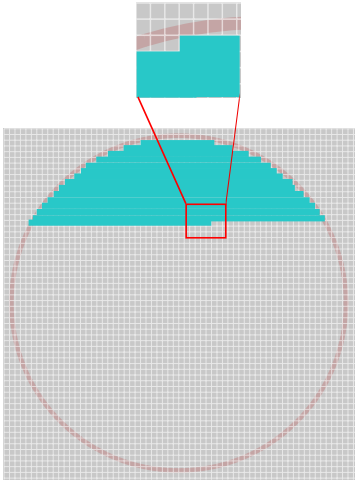


Flux map

Trajectories

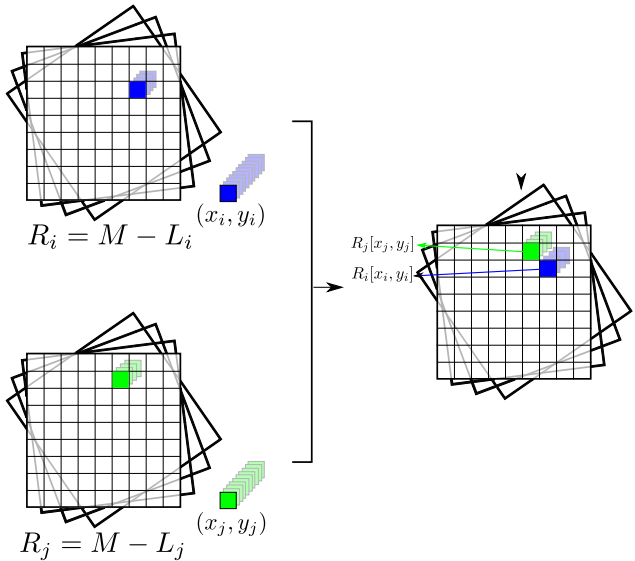


P_g

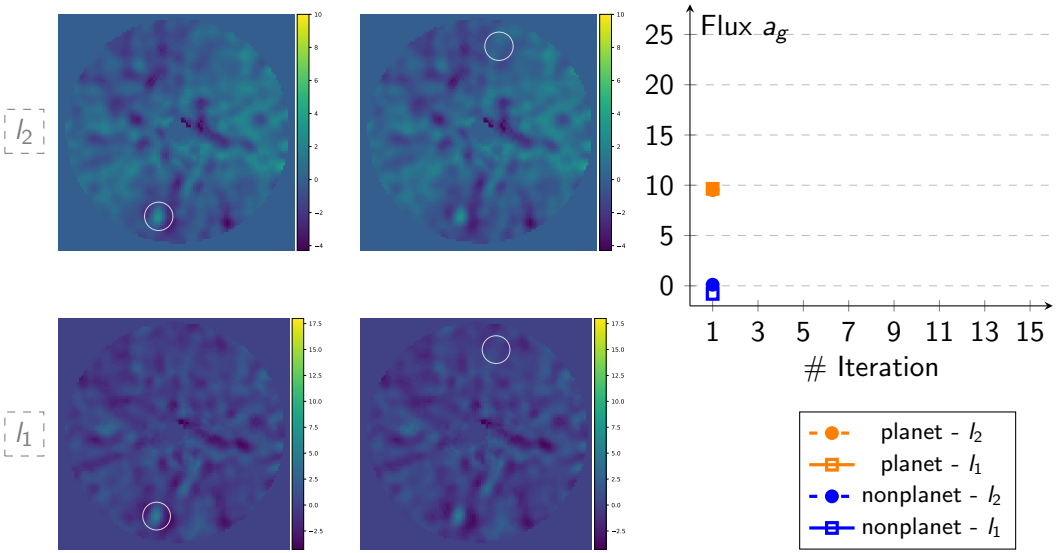


Flux map

Residual cube



Numerical Experiments



Numerical Experiments - Full vs Annular version

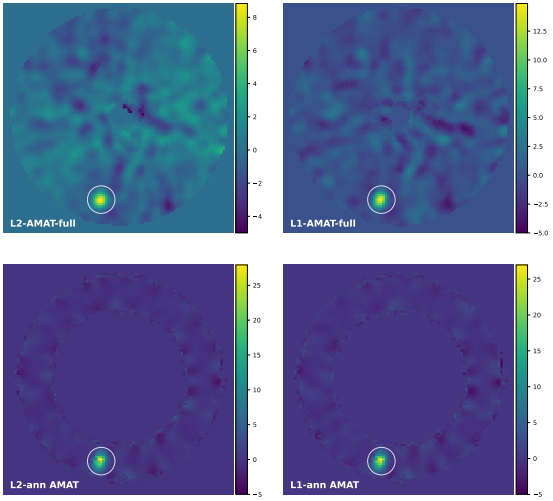
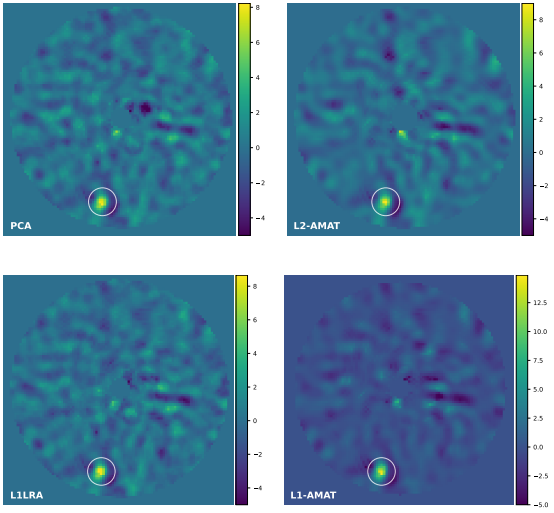


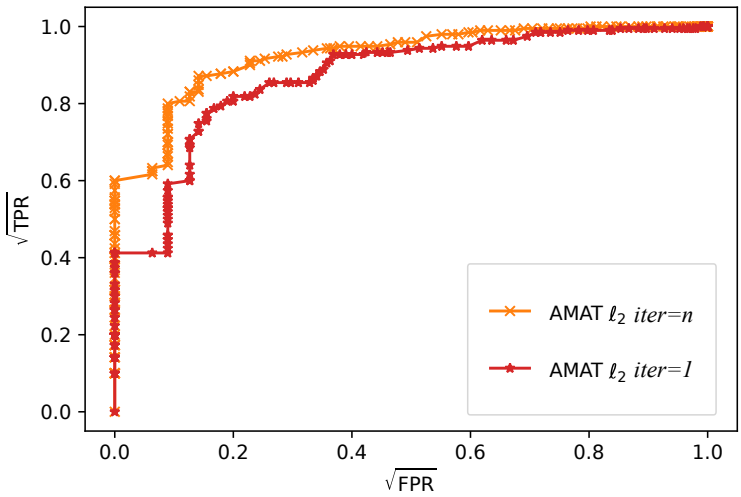
Figure: SNR map after applying full and annular AMAT using both norms. In these maps, P_g is located in the planet pixels.

Numerical Experiments - PCA/L1LRA vs AMAT



Numerical Experiments - ROC Curves

- Synthetic planets are injected.
- $\sqrt{\mathrm{TPR}}$ & $\sqrt{\mathrm{FPR}}$ are used instead of TPR & FPR.



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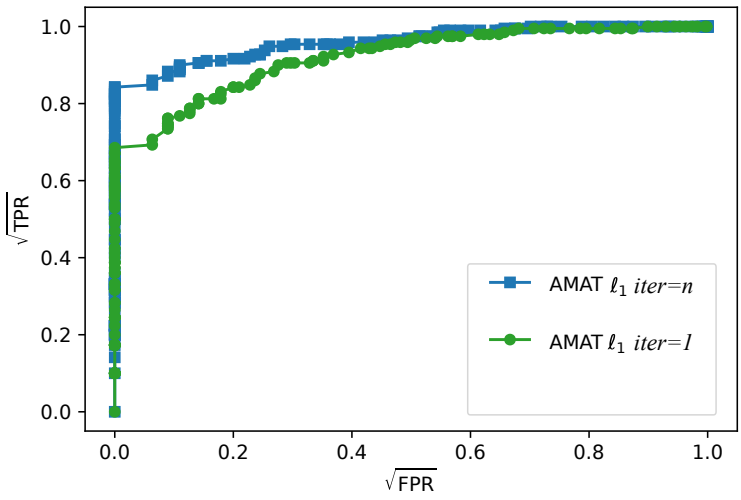

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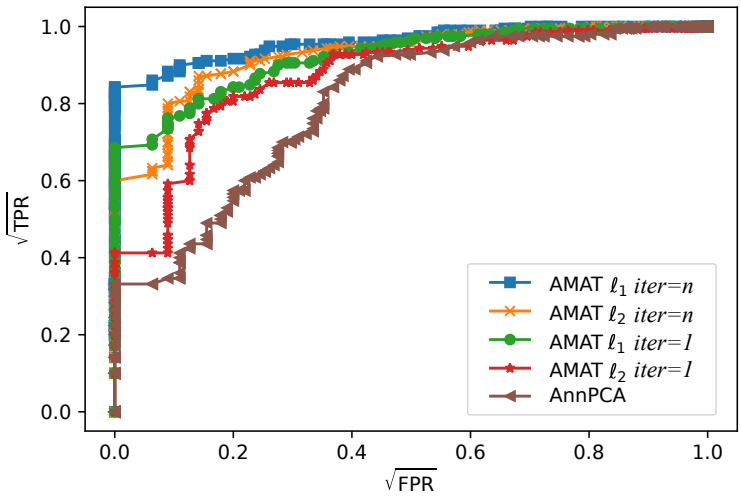
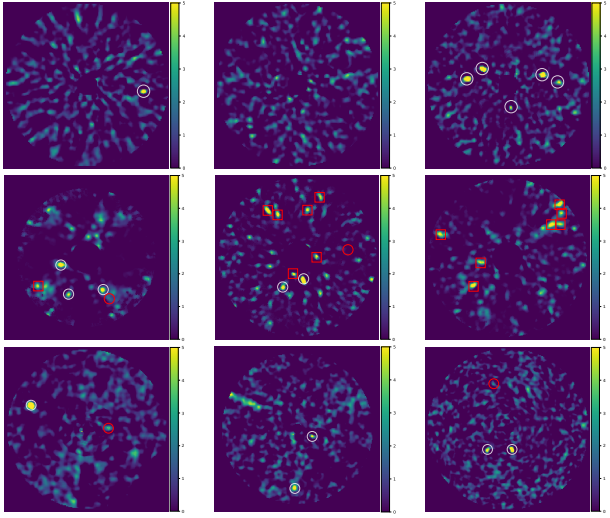
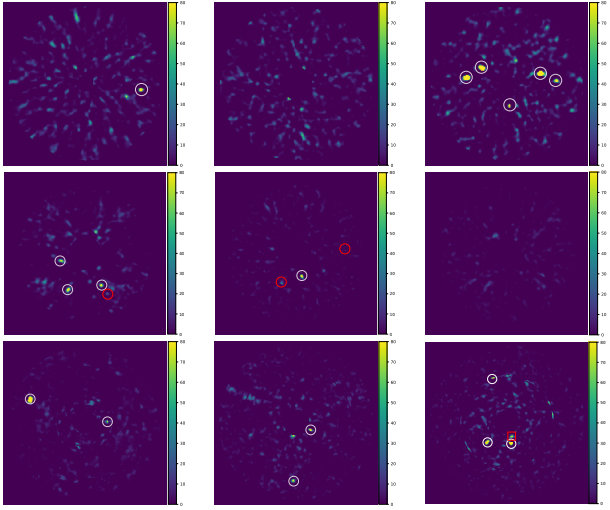


EIDC - SNR



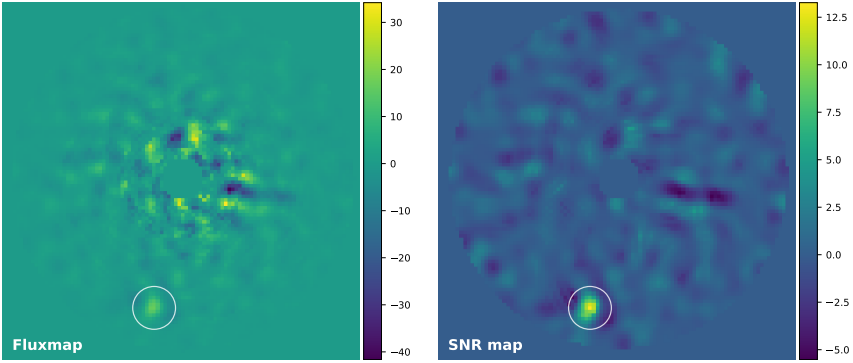
EIDC - Likelihood Ratio Map



Thank you for your attention!
Any questions?

hazan.daglayan@uclouvain.be
GitHub: hazandaglayan/AMAT

From Fluxmap to SNR



Contrast Curve

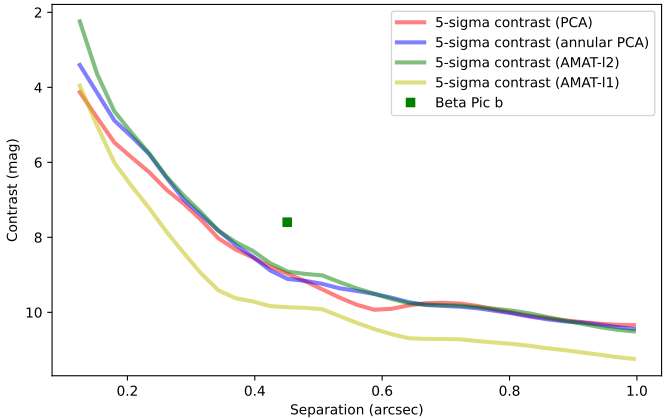


Figure: 5 σ contrast curve

Median frame vs Fluxmap