SPHERE data centering using satellite spots

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Outline

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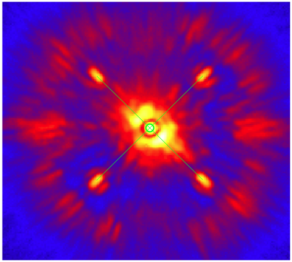

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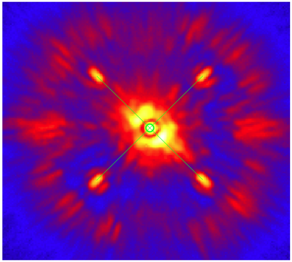
- 4 symmetric replicas of the PSF at $\simeq 14\lambda/D$
- displayed either as an $\times$ or $+$ shape
- allows computing the rotation center at the middle of the square pattern
- either elongated (BB) & point sources (NB)



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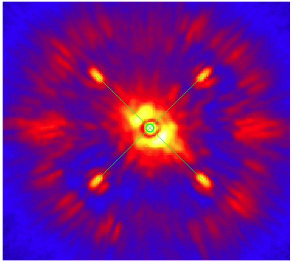

$\rightarrow$ Need to **fit** the positions of the **satellite spots** to estimate the rotation center

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The model

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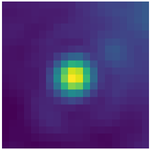

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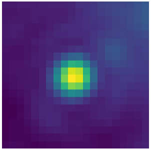

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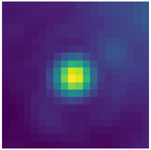

Goal :

Solve the following non-linear least mean square constrained optimization problem:

$$\widehat{\boldsymbol{\xi}} = \min_{\boldsymbol{\xi}} \left\{ \sum_{i=1}^{N} \left(d_i - g_i(\boldsymbol{\xi})\right)^2 : \boldsymbol{\xi}_l \leq \boldsymbol{\xi} \leq \boldsymbol{\xi}_u \right\}$$

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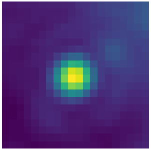

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Solver: STIR algorithm (Subspace Trust region Interior Reflective)

General 2-D elliptical Gaussian function

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$$g(x, y, \boldsymbol{\xi}) = A \exp\Bigg(-\left(\frac{\cos^2\theta}{2\sigma_x^2} + \frac{\sin^2\theta}{2\sigma_y^2}\right)(x - x_0)^2 - \left(\frac{\sin^2\theta}{2\sigma_x^2} + \frac{\cos^2\theta}{2\sigma_y^2}\right)(y - y_0)^2 \\ - 2\left(\frac{\sin 2\theta}{4\sigma_x^2} - \frac{\sin 2\theta}{4\sigma_y^2}\right)(x - x_0)(y - y_0)\Bigg) + c$$

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where $\boldsymbol{\xi} = [A, x_0, y_0, \sigma_x, \sigma_y, \theta, c]^\mathsf{T}$ with

- A, the amplitude
- x_0, y_0, the center coordinates
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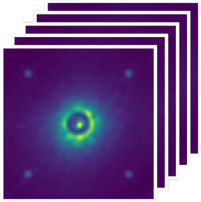
The discrete 2-D elliptical Gaussian function at pixel i is:

$$g_i(\boldsymbol{\xi}) = g(x_i, y_i, \boldsymbol{\xi})$$

Extracting & fitting the satellite spots



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$\{\boldsymbol{r}_k\}_{k=1:K}$

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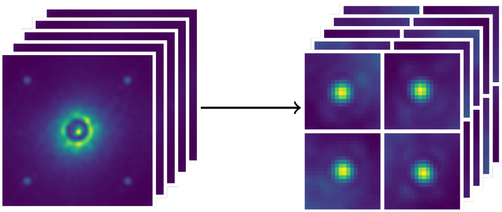

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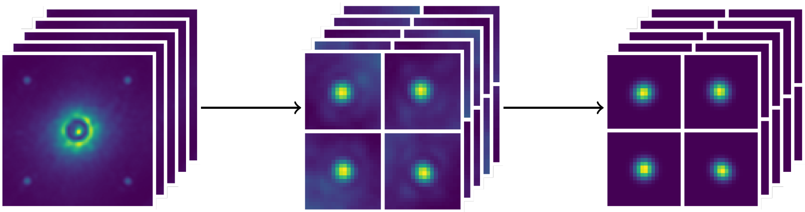

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Fitted spots $\left\{\{\boldsymbol{g}(\boldsymbol{\xi})_{n,k}\}_{n=1:4}\right\}_{k=1:K}$

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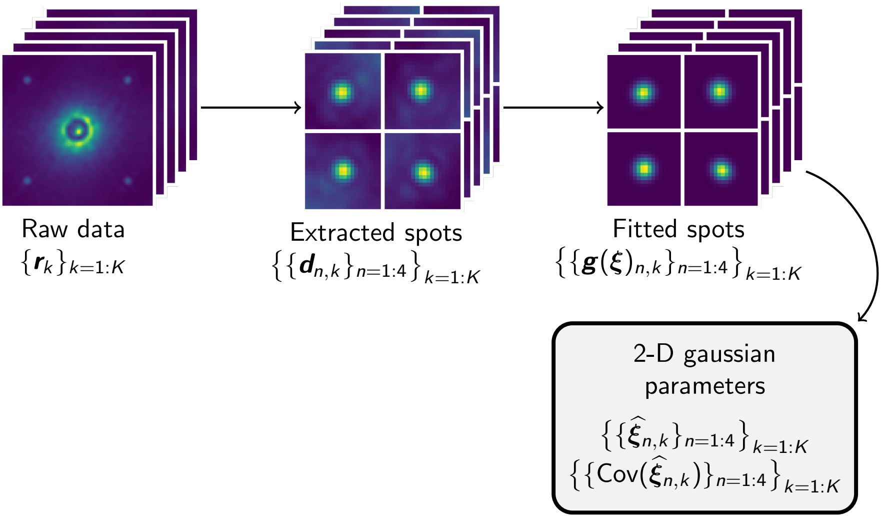

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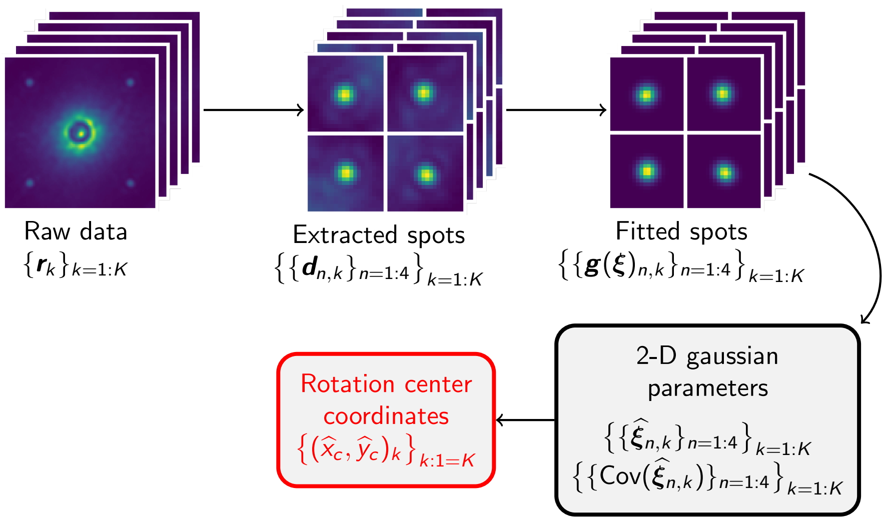
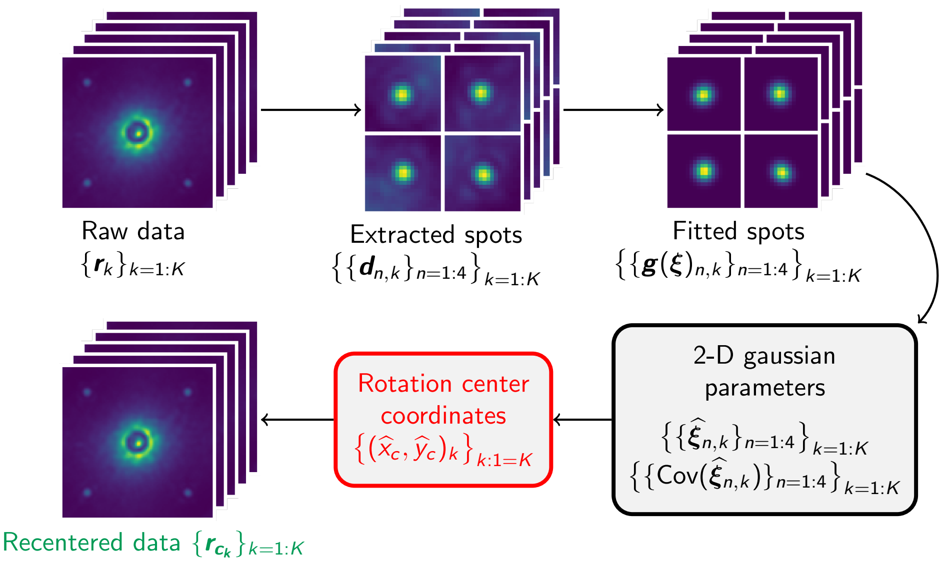


Extracting & fitting the satellite spots



Some details of the fitting procedure

- The satellite spots are extracted in 30 pixels-wide squares centered on their theoretical positions ($\simeq 14\lambda/D$ away from the theoretical rotation center)

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- A circular mask is systematically applied to the extracted images to get rid of the stellar leakages in the corners
- If one satellite spot is not fitted correctly, the center is estimated with the 3 remaining ones
- Given the information on the spots pattern ($\times$ or $+$) and the width of the band (BB or DB), some Gaussian parameters are fixed in the optimization procedure (θ, $\sigma_x = \sigma_y$)

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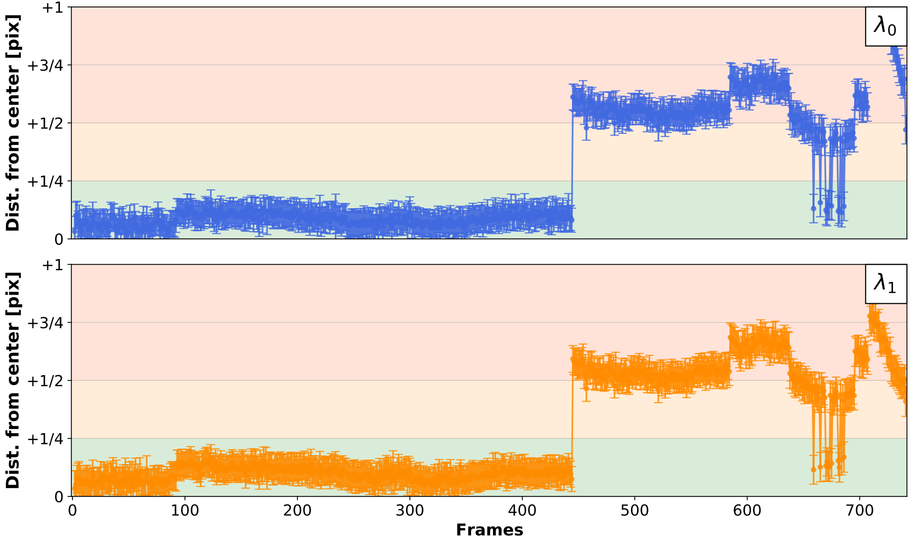
Example of HR 8799, Dual-Band J2-J3 (2015-07-29)



Dist. b/w the measured center of each frame and the theoretical rotation center

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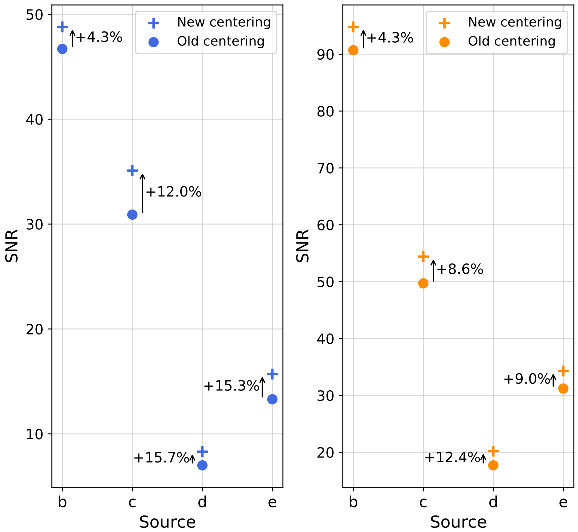
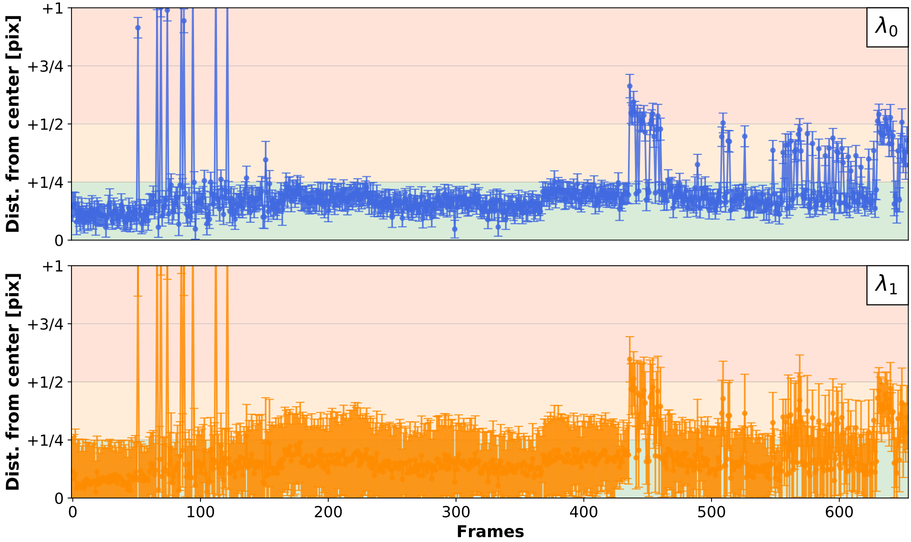


Comparison of PACO's SNR retrieved on the old dataset & the recentered one

Example of HR 8799, Dual-Band K1-K2 (2015-07-30)



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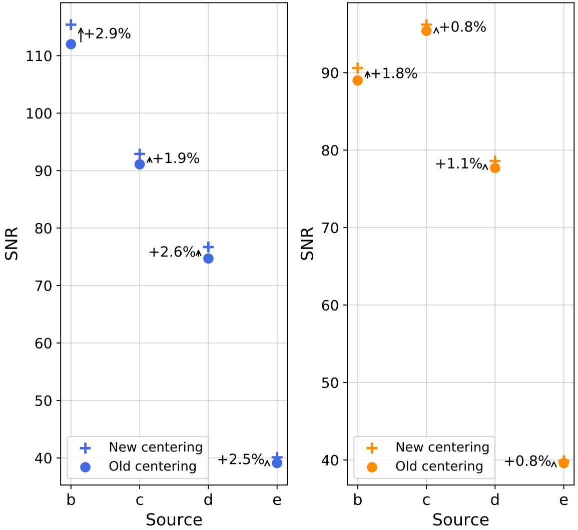

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It could be improved

- joint & simultaneous estimation of the 4 spots
- improve the robustness with a weighted least mean square optimization
- change the model (not perfectly gaussian), 2-D Moffat ? Bessel function ?
- the extracted ROIs have to cover the satellite spots for the method to work...