Point Spread Function extraction in crowded fields using blind deconvolution

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The extraction of the Point Spread Function (PSF) from astronomical data is an important issue for data reduction packages for stellar photometry that use PSF fitting. High resolution Adaptive Optics images are characterized by a highly structured PSF that cannot be represented by any simple analytical model. Even a numerical PSF extracted from the frame can be affected by the field crowding effects. In this paper we use blind deconvolution in order to find an approximation of both the unknown object and the unknown PSF. In particular we adopt an iterative inexact alternating minimization method where each iteration (that we called outer iteration) consists in alternating an update of the object and of the PSF by means of fixed numbers of (inner) iterations of the Scaled Gradient Projection (SGP) method. The use of SGP allows the introduction of different constraints on the object and on the PSF. In particular, we introduce a constraint on the PSF which is an upper bound derived from the Strehl ratio (SR), to be provided together with the input data. In this contribution we show the photometric error dependence on the crowding, having simulated images generated with synthetic PSFs available from the Phase-A study of the E-ELT MCAO system (MAORY) and different crowding conditions.

Introduction

Adaptive Optics (AO) has become a key technology for all the main existing telescopes (VLT, Keck, Gemini, Subaru, LBT) and is considered a kind of enabling technology for future giant telescopes as the European Extremely Large Telescope (E-ELT). To obtain high-precision quantitative information and improve the scientific exploitation of AO data, several efforts in a PSF extraction robust method in a code for image analysis are needed.
We present in this poster the photometric analysis of an interesting science case using the blind deconvolution as a method for the reconstruction of the PSF. We tested the blind deconvolution method in extreme conditions, measuring the photometry accuracy in two locations within a Giant Elliptical Galaxy in the Virgo Cluster (distance ≈ 18 Mpc), that represents an interesting and challenging science case [1] for the future high angular resolution camera MICADO@E-ELT, coupled with the Multi Conjugate Adaptive Optics module MAORY.
The images have been simulated using the MAORY PSFs in J and K_s bands available in the website (`http://www.bo.astro.it/maory/Maory/Welcome.html`).

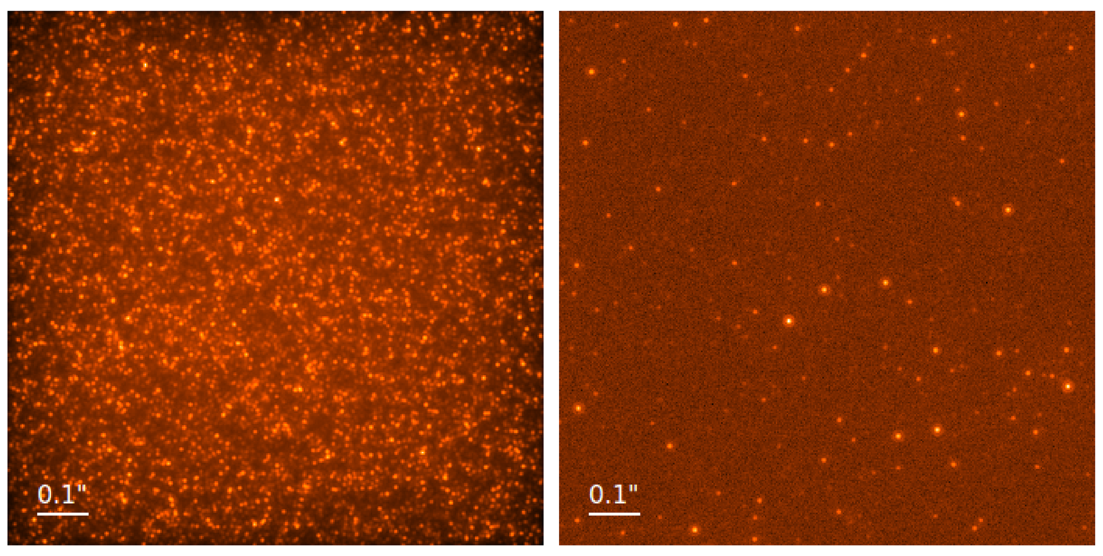


Figure 1: Simulated images of a $1'' \times 1''$ stellar field in J band with two different crowding conditions. *(Left)*: extremely high crowding condition (≈ 126000 stars/$arcsec^2$). *(Right)*: low crowding condition (≈ 1000 stars/$arcsec^2$). These levels of crowding are typical at 0.1 and 2 effective radii respectively of an Elliptical galaxy in Virgo Cluster. The total integration time = 2 hours. The simulated images include stars with $24 \leq Ks \leq 31$ and $25.3 \leq J \leq 31.7$.

Analysis of the reconstructed PSFs

We applied the blind deconvolution method to the input images. The initial guess of the algorithm is the autocorrelation of the diffraction limited PSF of the telescope, which satisfies the SR constraint. The output of the blind deconvolution and the numerical PSF reconstructed by means of StarFinder are shown in Fig. 2.

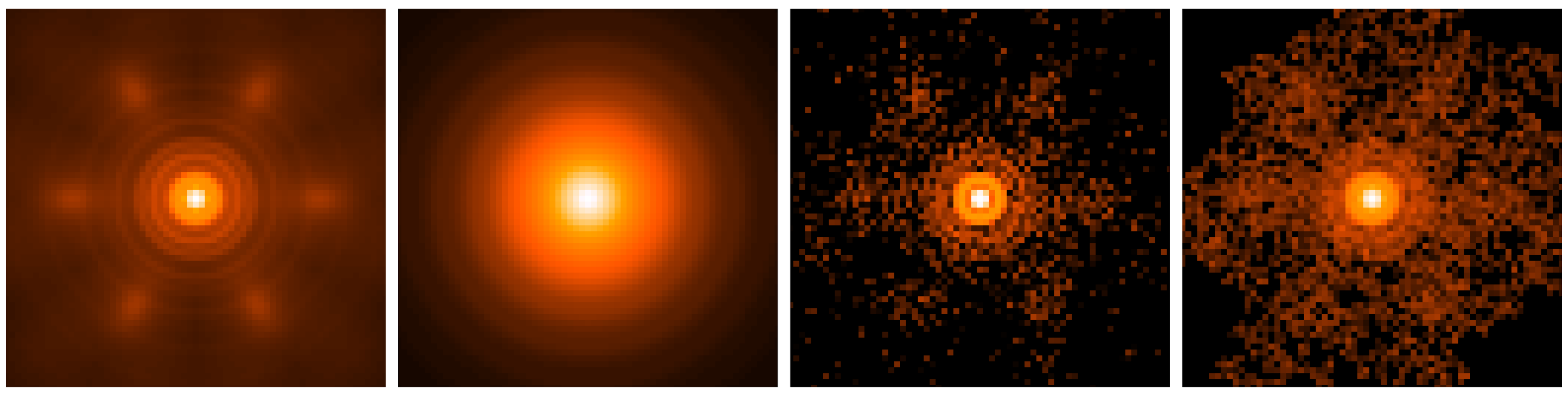


Figure 2: *(from left to right)*: the true PSF, the initial PSF ($\mathbf{h}^{(0)}$), the blind PSF, and the numerical PSF (computed by StarFinder) in one of the four cases presented.

Results

We tested the blind deconvolution PSF extraction method by performing the photometric analysis on the previously described images using the StarFinder code [2], a program specifically designed for high resolution AO images. The package itself is able to estimate the background and extract a numerical PSF template from the frame, but it can also accomplish the analysis using a PSF and a background frame supplied by the user. We show a comparison among the analysis accomplished by using three different PSFs: the true one, used as input for the frames generation, the one extracted by the frame using the blind deconvolution method, and the numerical PSF extracted by the frame using the StarFinder specific package. We checked the performance of the algorithm when the background is perfectly known and when it has been estimated from the data. In this last case, the PSF estimation requires two iterations: (1) a first background estimation and PSF extraction; (2) after a preliminary photometric analysis, most of the stars can be subtracted and the background refined by smoothing the residual image. The new background frame can be used for the final PSF estimation.

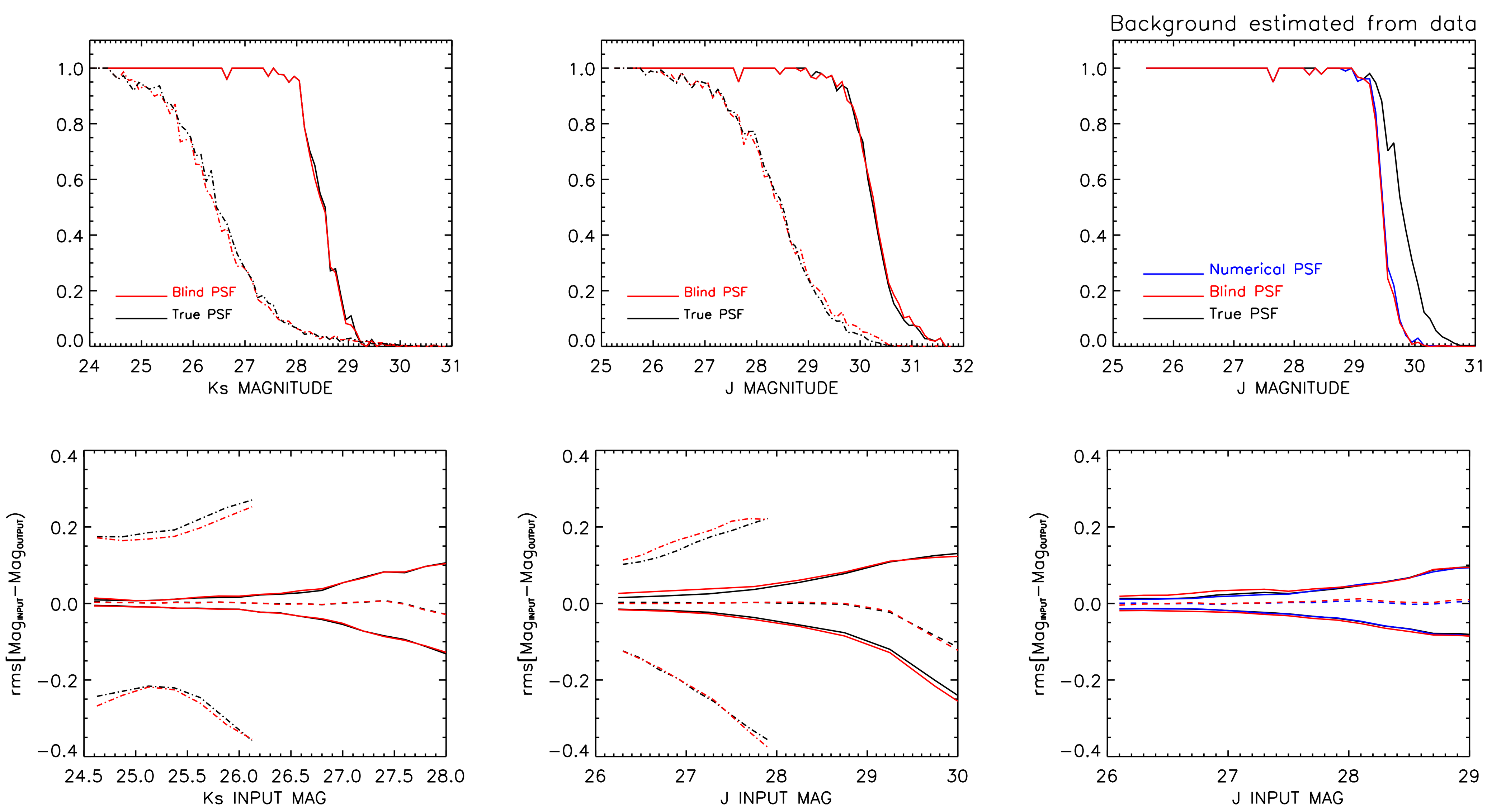
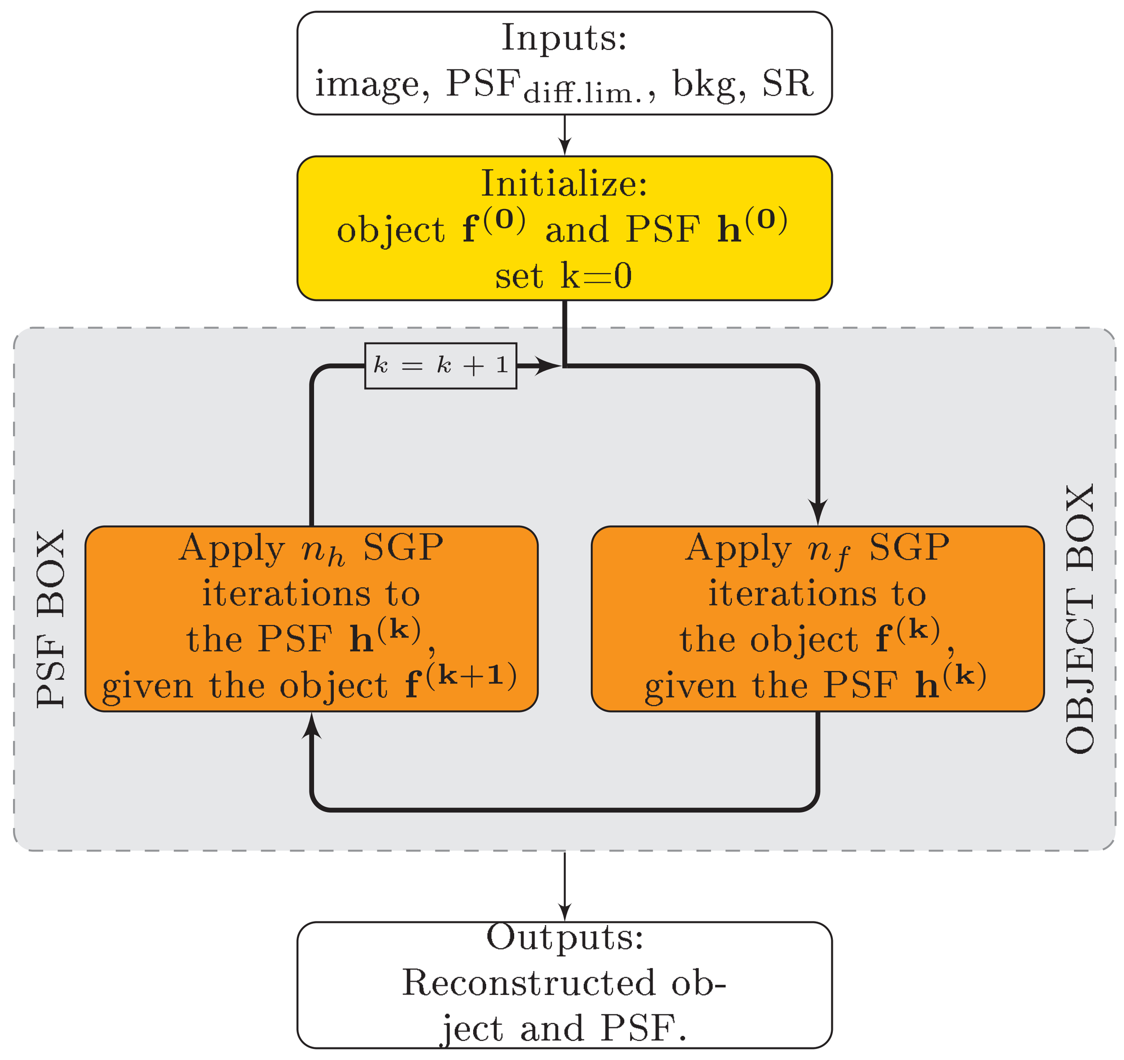


Figure 3: *(First row, left and center)*: Completeness plots in K_s and J bands for the two considered crowding conditions and using the true PSF (black lines) and the blind deconvolution PSF (red lines) for the data analysis (2 σ detection threshold). The background for both the blind PSF extraction and the data reduction has been considered as perfectly known. In each plot the extremely crowded case (dotted-dashed lines) and the less crowded case (continuos line) are overplotted. *(First row, right)*: Completeness plot in J band in low crowding condition using the blind PSF (red line) and the numerical PSF (blue line) extracted by StarFinder (3 σ detection threshold). The background has been estimated from the data. For comparison, also the completeness obtained using the true PSF and the true background is overplotted in back. *(Second row, left and center)*: matching the catalogue of the frame input stars and the result of the data reduction, we computed the photometric error in K_s and J bands (respectively) as a function of the input magnitudes. The asymmetrical distribution of the photometric errors is due to blending effects. *(Second row, right)*: Photometric error in J band in low crowding condition using the blind PSF and the numerical PSF extracted by StarFinder and using the estimated background.

The blind deconvolution method

In order to improve the PSF reconstruction (necessary for an accurate detection of a crowded field) we use a novel method of blind deconvolution [3] based on an inexact alternating minimization method.
The implemented algorithm is iterative and each iteration consists of alternating an update of the object and the PSF by means of fixed numbers of iterations of the scaled gradient projection (SGP) method [4, 5]. A scheme of the blind deconvolution is shown in the following figure.

For a detailed description of the SGP method, see *Carbillet, M. et al., Deconvolution-based super-resolution for post-adaptive-optics data, this conference.*



Conclusions

In this poster we presented the photometric accuracy and completeness using the blind deconvolution method for the extraction of the PSF from simulated data. The frames have been simulated using the predicted PSF of MAORY, the future MCAO module of the E-ELT telescope. The considered science case, an elliptical in the Virgo Cluster, represents an 'extreme' case in terms of crowding conditions and low SNR and therefore it is an interesting testbench for the blind deconvolution algorithm.
We conclude that:

- The blind deconvolution is a valid and robust algorithm for the PSF recontruction even in extremely crowded fields and in condition of low SNR;
- The blind reconstructed PSF is independent of the selection of the stars, while the numerical PSF is not;
- The estimation of the background is a crucial issue in both numerical and blind approach. An error in the background estimation strongly affects the limiting magnitude detectable. This is an important aspect when AO images of crowded fields are involved because of the strong contribution of the PSF extended halo to the background and it requires a greater effort in PSF extended halos modelling;
- However, the photometric error obtained using the blind PSF is slightly higher and this issue will be the subject of future work.

More information

References

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