EMphot: Photometric Software with Bayesian Priors. Application to GALEX.

S. Conseil[a], D. Vibert[a], S. Arnouts[c], B. Milliard[a], M. Zamojski[b], A. Llebaria[a], M. Guillaume[d]

[a] Laboratoire d'Astrophysique de Marseille, OAMP, Université Aix-Marseille & CNRS; [b] California Institute of Technology; [c] Canada France Hawaii Telescope; [d] Institut Fresnel, Université Aix Marseille

Abstract

- **Context:** Photometry of astrophysical sources, galaxies and stars, in crowded field images.
- **Our purpose:** estimate the flux in a low resolution band using prior information (position and shape) from a better resolved band, in a Bayesian approach under the Poisson noise assumption.
  - Expectation-Maximization (EM) algorithm for solving the photometry.
  - Prior shapes deblending in high resolution images.
  - Astrometry correction, PSF optimization, background correction from the residual.
- **Application:** Deep Imaging Survey (DIS) of the GALEX mission, which observes in two UV bands with long exposure times (~ 70'000s), and produces deep sky images of 1 square degree, with hundreds of thousands of galaxies or stars.
  - Priors are computed from CFHTLS data.
  - Very faint signal dominated by the photon shot noise, with background level around 100 (resp. 10) counts in the near (resp. far) UV band.

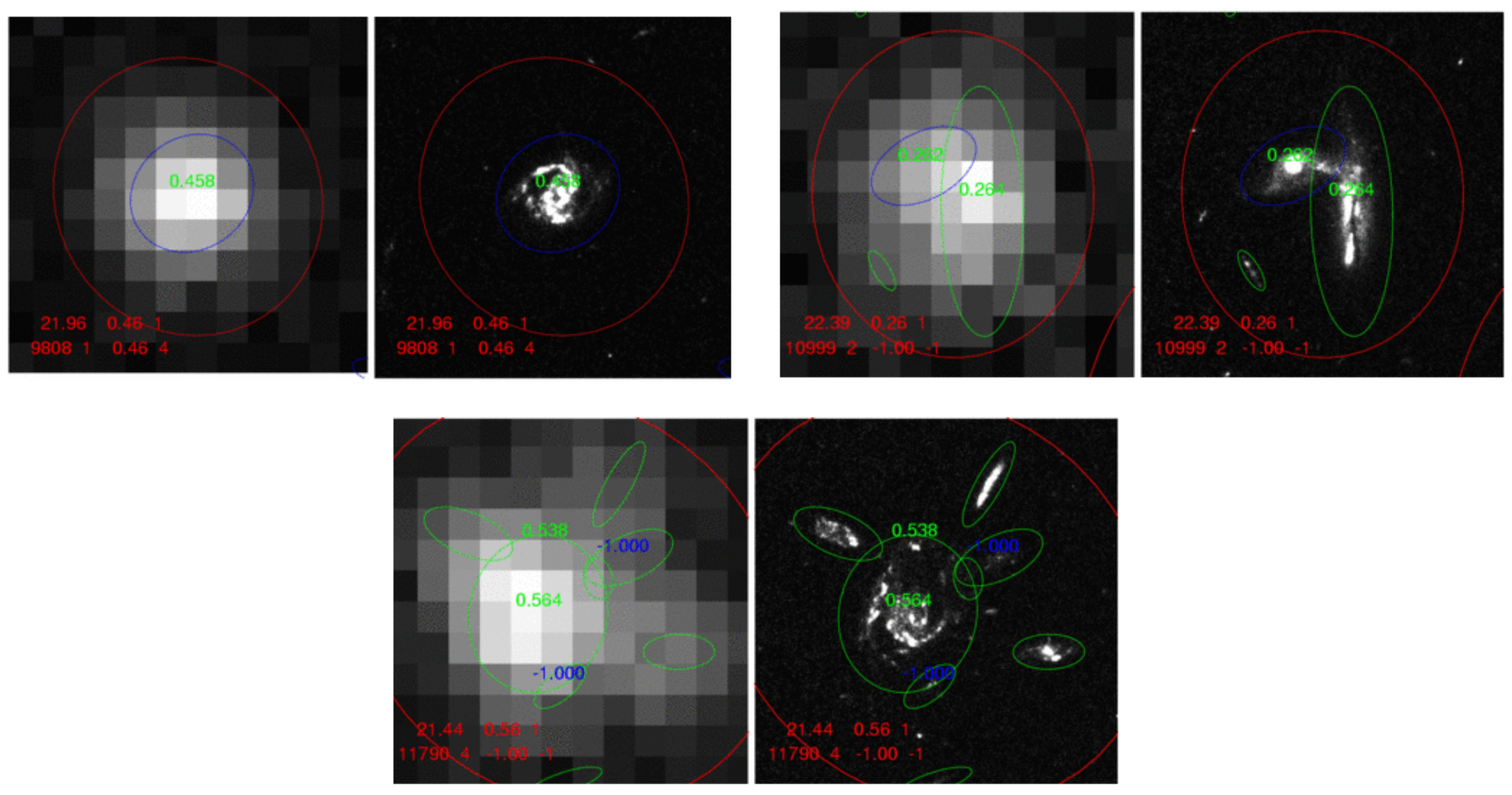


Figure: GALEX images (left) and their optical counterpart from ACS/HST (right).

Maximum Likelihood parametric estimation with Priors: Expectation-Maximization (EM)

- x_i : observed value on pixel i of the UV image, considered as a sample of the random variable X_i following a Poisson statistics law,
- $\mu_i = E\{X_i\}$: expected value,
- $h_{k,i}$: known relative value of object k on pixel i, results from the convolution between each object known profile $o_{k,i}$ with the PSF f_i of GALEX imaging system,
- α_k : unknown fluxes of these objects,
- b_i : known background level value.
- r_i : relative instrument response taking into account exposure time and efficacy of GALEX system.

We define the model for the UV image as follows:

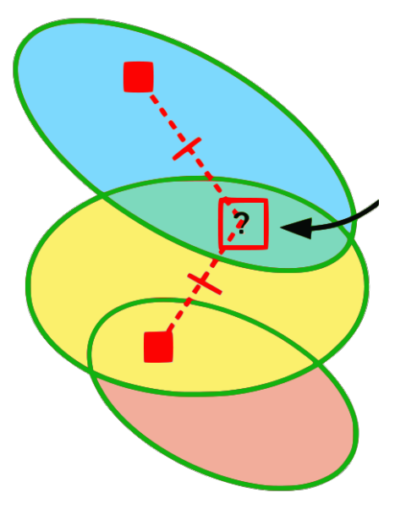
$$\forall i \in \{1,\dots M\} \begin{cases} \mu_i = r_i \sum_{k=1}^{K} \alpha_k h_{k,i} + r_i b_i \\ P\{X_i = x_i\} = \exp(-\mu_i)\frac{\mu_i^{x_i}}{x_i!} \end{cases} \quad \text{where} \quad h_{k,i} = \sum_j o_{k,j} f_{i-j}$$

The expectation-maximization iterative scheme (EM) gives the iterative algorithm:

$$\alpha_k^{(n+1)} = \alpha_k^{(n)} \frac{\sum_{i=1}^{M} \frac{x_i}{\mu_i^{(n)}} r_i h_{k,i}}{\sum_{i=1}^{M} r_i h_{k,i}} \quad \text{where} \quad \mu_i^{(n)} = r_i \sum_{j=1}^{K} \alpha_j^{(n)} h_{j,i} + r_i b_i$$

The E-step compares the data image x_i to the projection $\mu_i^{(n)}$ of the $\alpha_k^{(n)}$ estimates. The result is introduced in the M-step as the corrective ratio needed for the new set of $\alpha_k^{(n+1)}$ estimates.

Features



- **Prior shapes:**
  - Deblend using SExtractor ellipses to define objects contour. Central symmetry is used to determine the flux assigned to each object blended in one pixel.
  - Degrade the resolution of the image to that of the GALEX image.
- **Astrometry correction:** cross-correlate the positions of the brightest objects (detected with SExtractor) with the brightest objects of the prior catalog and warp with a 2^{nd} order polynomial fitting.
- Image processed by **tiles**, typically 64×64 + margin for PSF convolution.
- **Initial fluxes** $\alpha_i^{(0)}$: use U-band value or estimate from the image using a PSF weighted sum:

$$\alpha_k^{(0)} = \frac{\sum_{i=1}^{M} h_{k,i}(x_i - b_i)}{\sum_{i=1}^{M} h_{k,i}^2}, \quad \forall i \in x_i > b_i$$

- **Prior flux constraint** from U-band magnitude to avoid faint sources taking the flux of a nearby stronger source, using this relation: $\text{mag}_{UV} > \text{mag}_U - 1 \Leftrightarrow F_{UV} < F_u \times 10^{0.4}$
- **PSF rescaling:** the PSF is not deconvolved from the optical (priors) PSF and is averaged over imprecise recentering which causes an artificial enlargement. We find an optimally rescaled PSF using a maximum-likelihood algorithm with a parametrized PSF and fixed fluxes.
- **Error estimation** from the residual:

$$\widehat{\sigma}_k^2 = \frac{\sum_{i=1}^{M} h_{k,i}(x_i - \widehat{\mu}_i)^2}{\sum_{i=1}^{M} h_{k,i}^2}$$

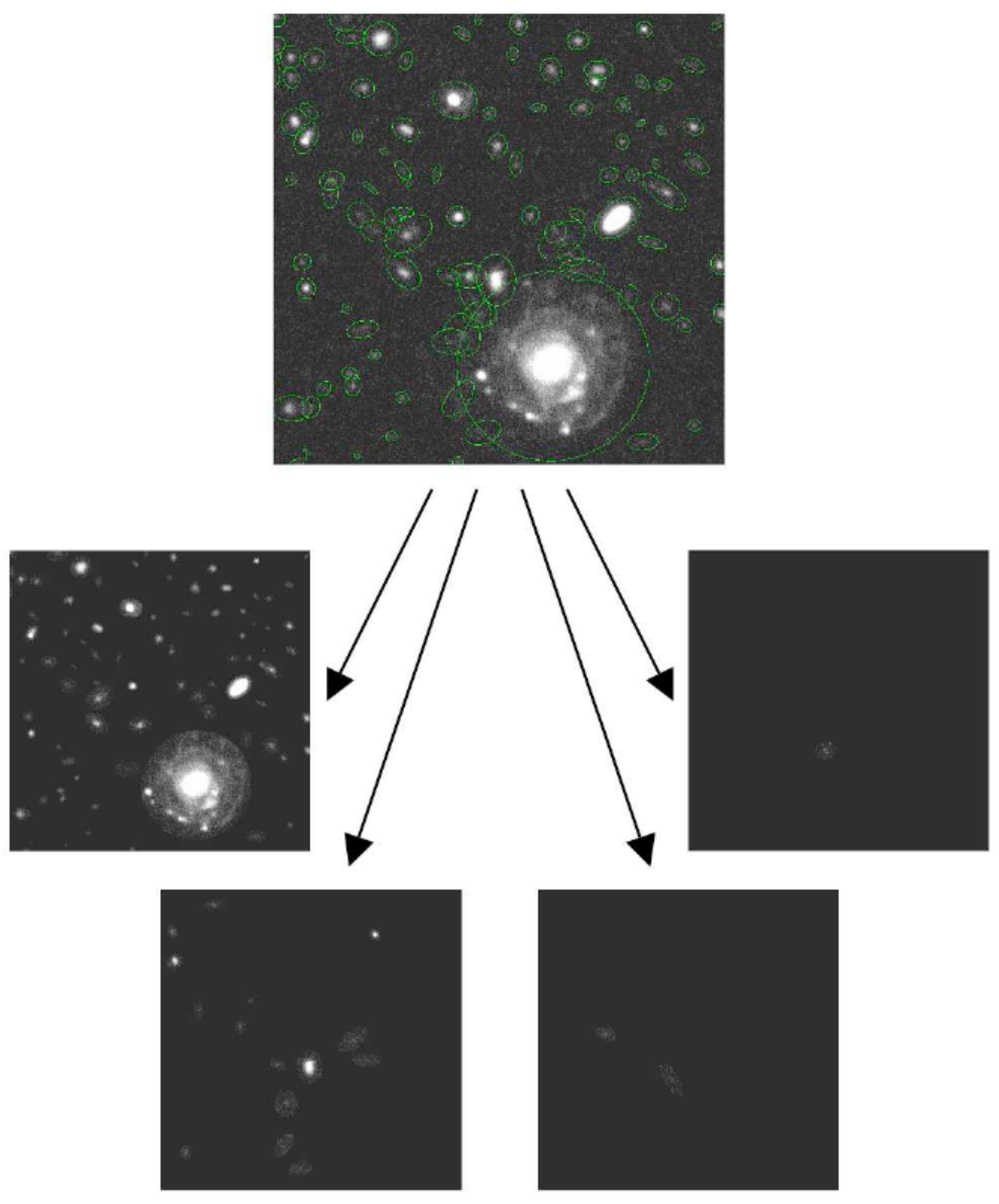


Figure: Prior shape deblending

- **Background correction:** mask and do the inpainting around objects artifacts in the residual, filter high frequencies and redo EM iterations with this new background.
- **Post-processing** of the output catalog: flag objects inside GALEX and CFHTLS masks, compute statistics on nearest neighbors, compare with GALEX catalog.

Simulations

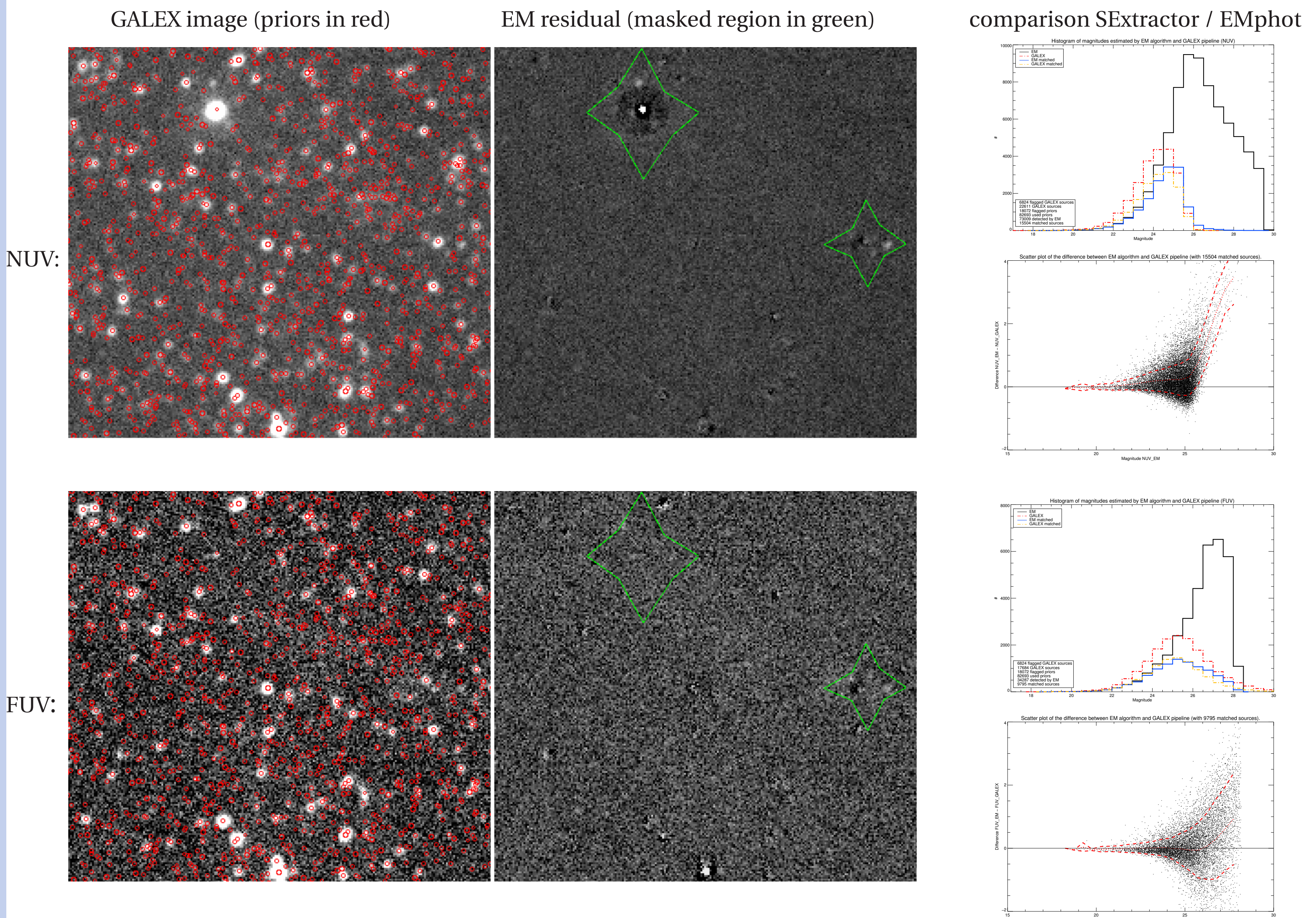
Error estimation is done using Monte-Carlo simulations:

- adding simulated objects to the real image,
- simulating all the objects, using the number counts from *[Xu et al., ApJ. 2005]*.

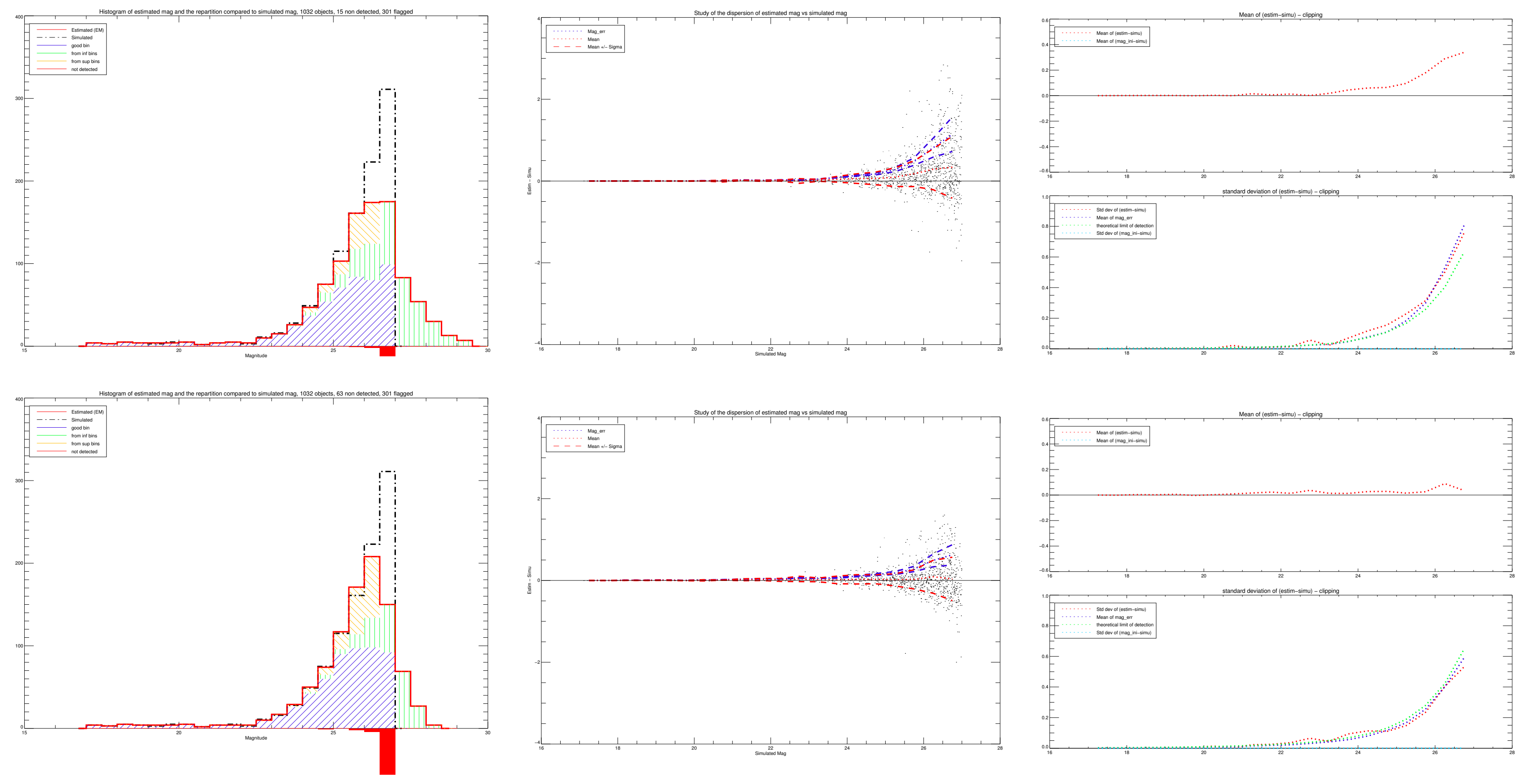
Simulations use astrometry corrections, stamps or an optimal PSF scale value to be consistent with the processing algorithm.

Results

- XMMLSS_00 field with 200 iterations, NUV (top) and FUV (bottom):



- Monte-Carlo simulations on XMMLSS_00 with 3×500 objects added to the image, NUV (top) and FUV (bottom):



Conclusion

- Compared to blind photometry estimation, the method leads to small and flat residual, increases the faint source detection threshold and provides a better accuracy for bright contaminated objects.
- As an important by-product, the method automatically solves the problem of determining the optical counterparts to UV sources, and shares the UV flux between partly resolved or unresolved nearby objects.
- Optimal approach for measuring drop-outs in FUV and NUV.
- On the processed DIS fields, EMphot provides good photometry and completeness down to magnitude 25.5, which is 1 magnitude deeper than the GALEX pipeline.

In development / Prospects

- PSF parametrization.
- Gaussian noise (BVLS), application to HERSCHEL.
- Model selection method for reducing prior number.
- Astrometry improvement with a maximum-likelihood recentering.

References

2009 Vibert D., Zamojski M., Conseil S., Llebaria A., Arnouts S., Milliard B., Guillaume M., *Photometry in UV astronomical images of extended sources in crowded field using deblended images in optical visible bands as Bayesian priors*, Computational Imaging VII, Proceedings of SPIE Vol. 7246 (2009).

2008 Llebaria A., Magnelli B., Arnouts S., Pollo A., Milliard B., Guillaume M., *Multi-channel 2D Photometry with Super-resolution in Far UV Astronomical Images using Priors in Visible Bands*, SPIE 2008.

2006 Guillaume M. , Llebaria A., Aymeric D., Arnouts S., Milliard B., *Deblending of the UV photometry in GALEX deep surveys using optical priors in the visible wavelengths*, SPIE 2006.

CeSAM

The "CEntre de donnéeS Astrophysiques de Marseille" (CeSAM) from "Laboratoire d'Astrophysique de Marseille" (LAM) has been set up to provide access to quality controlled data via web based applications, tools, pipelines developments and VO compliant applications to astrophysical community. See poster P013-ADASS for details.

Laboratoire d'Astrophysique de Marseille, 38 rue Frédéric Joliot Curie, 13388 Marseille cedex 13, France

More information: simon.conseil@oamp.fr - `http://www.oamp.fr` - Created with LaTeX `beamerposter`