Presenting DAWIS : Detection Algorithm with Wavelets for Intra-cluster light Surveys

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A - Introduction

The Intracluster Light (ICL) is a diffuse component of galaxy clusters or groups, composed of stars that do not belong to any specific galaxy, but that are more generally linked to the global gravitationnal potential of their cluster/group. While its existence has been known for almost seventy years – the first mention of it was made by Zwicky in 1951 [1] -, the ICL has been a rather forgotten field of research, mainly for instrumental and technical reasons. Indeed, the very low surface brightness of this diffuse component (few percent of the sky background) makes it easy to be contaminated by various phenomena (scattered light, galactic cirrus, blending into galaxy luminosity profiles...), and hard to detect. Here we choose a multi-scale approach to the problem, considering the galaxy cluster optical images as a mix of bright sources (galaxies and foreground Milky Way stars) superposed on diffuse low luminosity sources (ICL). We present a Detection Algorithm with Wavelets for Intra-cluster Surveys (DAWIS) in order to detect and separate such sources, with in mind the fact that wavelet based image processing algorithms, while being efficient, are very CPU time consuming. Taking this into account, DAWIS is optimized and parallelised, making it possible to run on large photometric surveys and images. For now, the code is tested on simulations of galaxies (see Section D) and on some real data (see Section E), in order to test its performance.

B – DAWIS : Wavelet transform and noise modeling

DAWIS is based on Mallat's « a trous » algorithm [2]. The concept is fairly simple : the original image is smoothed several times using the following B-spline kernel relation, Φ being the pixel value at the position x and i being the scale/index of the image :

$$\Phi_{i+1}(x)=0.0625(\Phi_i(x-2.2^i)+\Phi_i(x+2.2^i))+0.2500(\Phi_i(x-2^i)+\Phi_i(x+2^i))+0.3750\,\Phi_i(x)$$

This corresponds to a wavelet transform, with the wavelet coefficients given by the difference between two additional scales i and i+1. It now contains the detail informations of the image going from a scale to another.

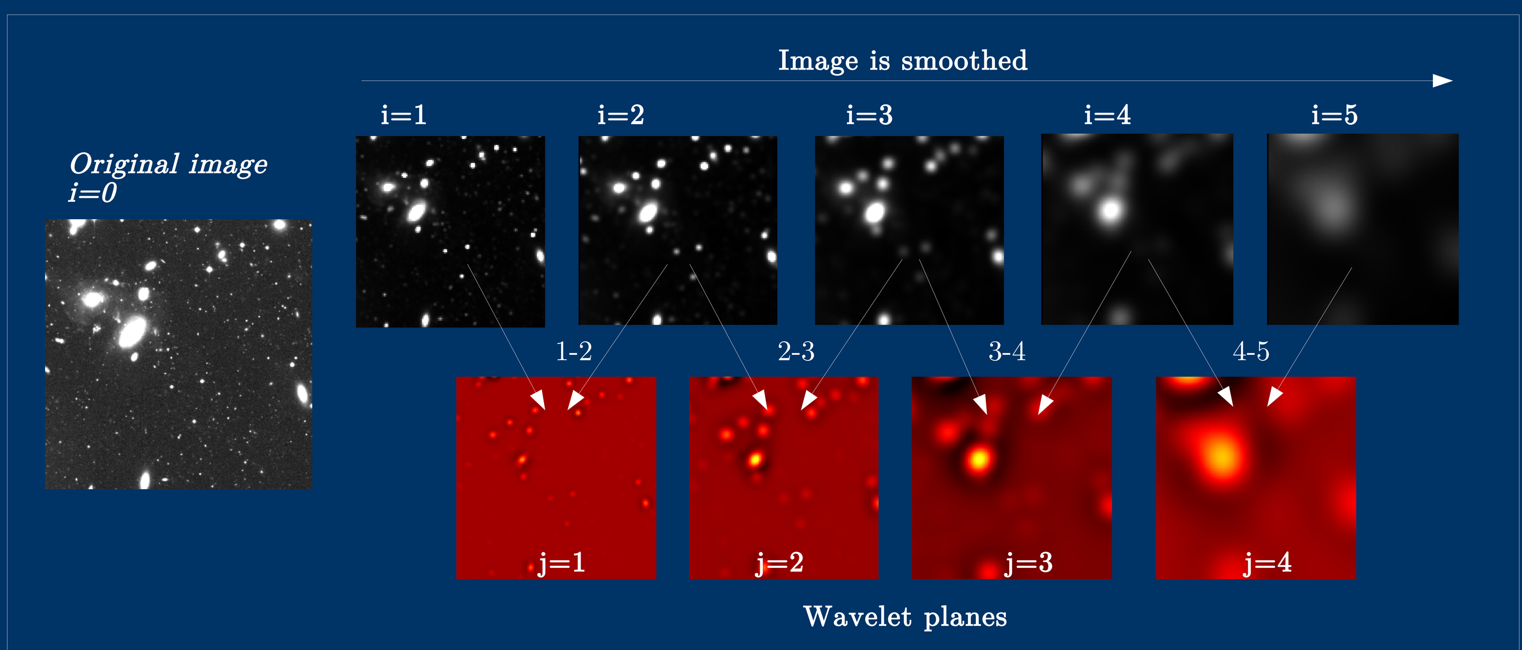

Figure 1 : Example of wavelet transform of an astronomical image, using the « a trous » algorithm.

The noise estimation is done in the 3D wavelet space, at each scale. For gaussian noise, the thresholding is done by comparing the pixel value Φ to the standard deviation of the noise σ_j at the scale j multiplied by a factor k (usually k=3). The value of σ_j depends on the standard deviation of the original image σ, and on the standard deviation at each scale $\sigma_{j,1}$ of a 1-σ gaussian distribution when applied a wavelet transform :

$$\text{If } \Phi(x)\geq k\,\sigma_j \text{ with } \sigma_j=\sigma\,\sigma_{j,1}, \text{ then x is significant.}$$

D – Validation on simulations

In order to validate DAWIS, we run it on a sample of 900 simulated galaxies, once without noise, and once with a gaussian background noise typical of space-based optical images. The galaxies are created using single Sersic profiles, with a magnitude range of 18-22, and feature satellites as faint as magnitude 27. Each galaxy is reconstructed by DAWIS (see figure 3 for some examples). We then fit Sersic profiles to the reconstructed images and compare their index to the Sersic index of the simulations (see figure 4).

In the case without noise, the reconstruction is consistent with simulations, even if for high Sersic indexes a bias appears. For the case with noise, some low surface brightness galaxies show a big discrepency with simulations, and the sample features the same bias around high Sersic indexes.

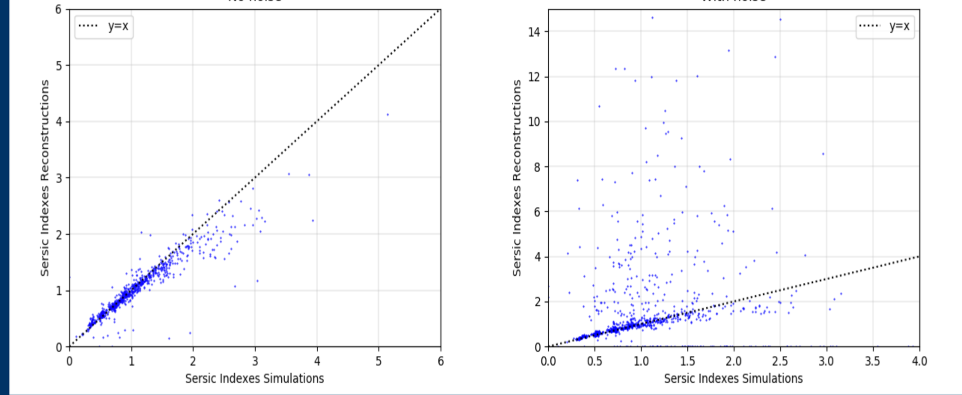

Figure 4 : Reconstructed Sersic indexes versus the Sersic indexes of the simulations. On the left the case without noise, on the right with gaussian noise. The dashed line

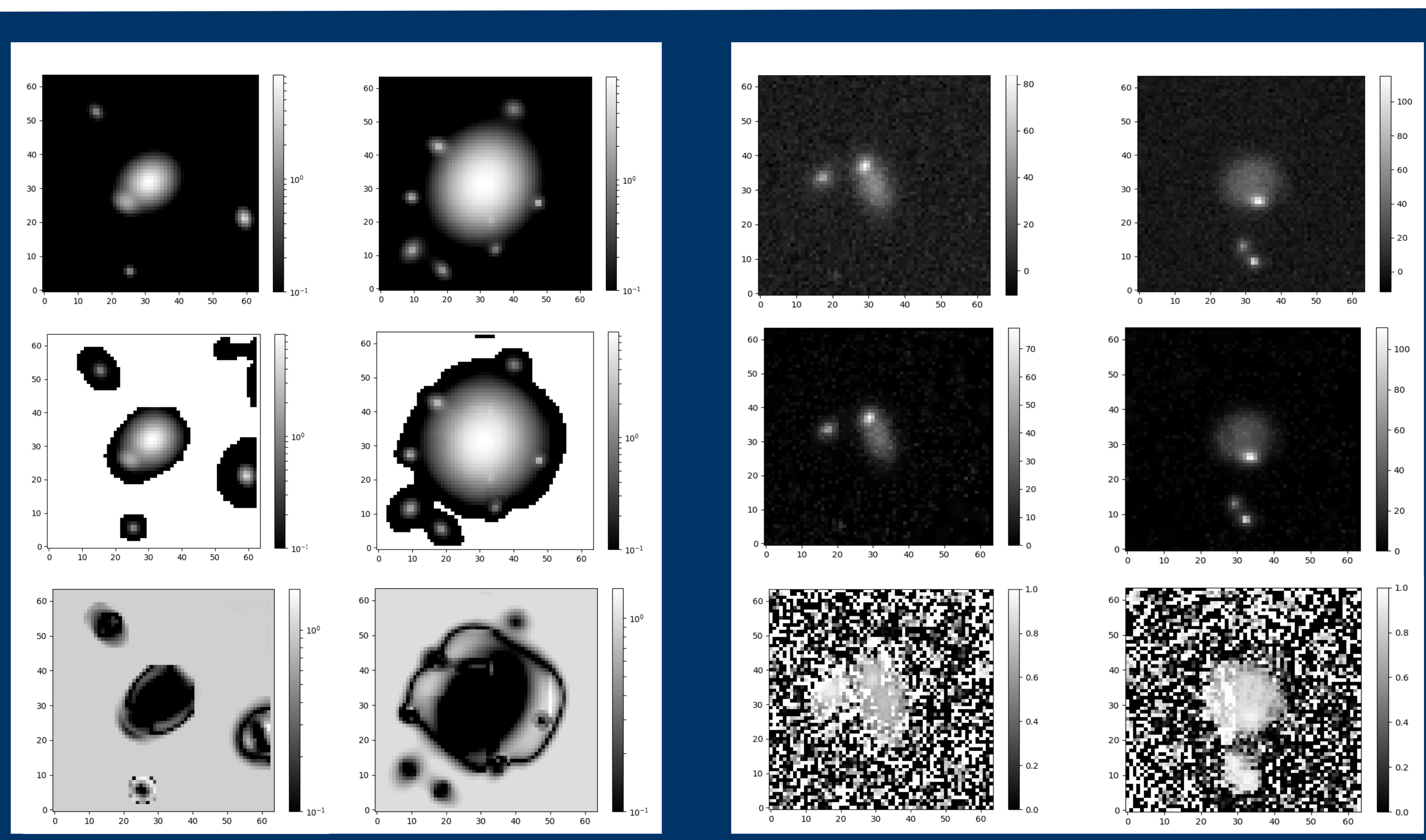

Figure 3 : Reconstruction by DAWIS of two simulated galaxies. From top to bottom – original image, reconstructed image, and residuals -. On the left, the case with no noise. On the right, the case with gaussian noise. Residuals are given by (original-reconstructed)/original.

C – DAWIS : Object detection and reconstruction

Once the statistically significant pixels have been estimated, we create the support of the image : we give them a boolean value of 1, while non-significant ones are given a value of 0. We then segment the support into labelled regions (packs of 1-value pixels surrounded by 0-value pixels). After this, we analyse the interscale connectivity : informations about an object are found in several consecutive wavelet planes, with regions at the same spatial position (see figure 2). We link those regions together before reconstructing the object using an iterative conjugate gradient algorithm [3]. The quality of the reconstructed object depends on the form of the initial object, and on the constraints (number of iterations, convergence parameters...) applied to the reconstruction.

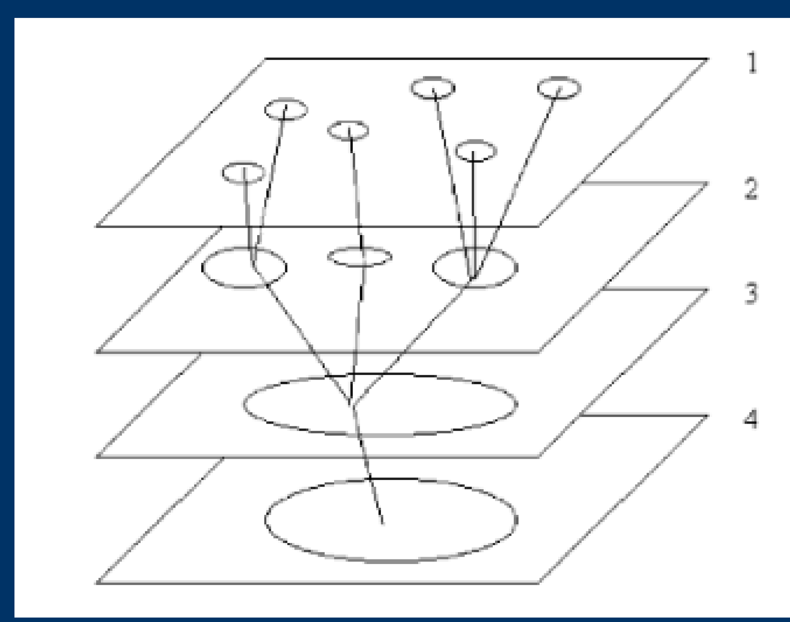

Figure 2 :Schematic view of interscale connectivity.

E – Test on astronomical data

We ran the code on MegaCam data from the Canada France Hawaï Telescope, in order to estimate its efficiency at detecting real sources. Since DAWIS does not need any model to detect and reconstruct objects, it is possible to decompose bright galaxies in several components (core, bars and disks). This should allow later a precise detection and removal of bright objects, leaving behind residuals and diffuse low surface brightness sources.

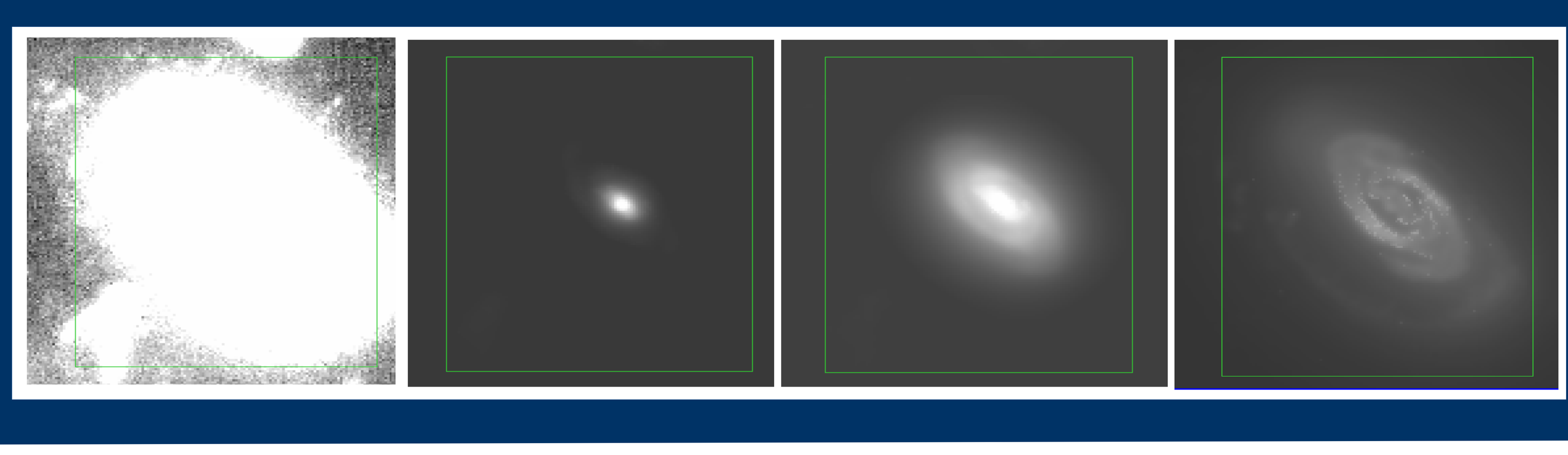

Figure 5 : Example of a spiral detected and reconstructed by DAWIS. On the far left the original image, and on the right the reconstruction of the bulb, the bar and the disk. The green box gives the spatial scale of the images. MegaCam image kindly provided by J-C.Cuillandre.

F – Conclusion and perspectives

We presented DAWIS, an algorithm using wavelets to detect sources and reconstruct them, and tested it on simulations and some data. The results are promising, beside some bias implied by the reconstruction of objects (see section D). The real challenge is now to apply it to ICL detection. Such diffuse sources need a pre-DAWIS processing in order to be detected : exquisite estimation of the PSF of the instrument, deep enough data to reach high magnitudes, high quality flat-fielding, etc.
We plan on running DAWIS on the data of the Ultraviolet Near-Infrared Optical Northern Survey (UNIONS) that has been processed by J-C.Cuillandre's Elixir-LSB pipeline, which is a pipeline created specifically to conserve low surface brightness features. We also plan on applying it on the Hubble Space Telescope Frontier Field, in order to compare our results to other previous works on ICL [4],[5].

References

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