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Mapping the Jagiellonian Field of Galaxies

Irina B. Vavilova

Astronomical Observatory of the Kiev University, Observatornaya str., 3, Kiev 254053 Ukraine, E-mail: vavilova@rcrm.freenet.kiev.ua

Piotr Flin

Pedagogical University, Institute of Physics, ul.Lesna 16, Kielce 25-509 Poland, E-mail: sfflin@cyf-kr.edu.pl

Abstract. The analysis of two-dimensional galaxy distribution in the Jagiellonian Field (JF) was carried out by the wavelet technique. The positions of galaxies were taken from the Revised Jagiellonian Field Catalogue (RJFC) based on digitized scans of the JF original photographic plates. We discuss briefly the procedure of star/galaxy separation applied by us to the RJFC, the algorithm and the first results of mapping of the selected parts of the RJFC.

1. What is the Revised Jagiellonian Field Catalogue of Galaxies?

The region of the original Jagiellonian Field (JF) sky survey (Rudnicki, Dworak, & Flin 1973) was selected by Zwicky (Zwicky 1962) as a region which is enriched by clusters of galaxies and contains a small number of the brighter galaxies. The JF sky survey (photographic plates in three colors with coordinates of center $\alpha = 11^h 20^m$, $\delta = +35°26'$ (2000.0) taken with the 1.25 m Palomar Schmidt telescope) coincides with the CGCG field No. 185. The central part of the JF ($4° \times 4°$) was scanned and automatically processed by the COSMOS machine. This procedure allows one to digitize the images on the plate and to receive a set of parameters fitting the inertia ellipse to each image (e.g., Stobie 1980; MacGillivray & Stobie 1984).

Constructing a modern complete galaxy catalogue in the JF region, we decided to carry out an automated procedure of star/galaxy separation on the digitized images. We experimented with the possible combinations of parameters usually applied for such purposes on similar photographic data (e.g., Hewett 1981; Heydon-Dumbleton, Collins, & MacGillivray 1989; Odewahn et al. 1992; Weir, Fayyad, & Djorgovski 1995 with a brief review of discrimination philosophy).

Before applying the procedure, all small objects with the *COSMOS area* parameter smaller than 60 (in increments) were removed from our sample and about 35,000 objects remained to be analyzed.

Among the possible discriminators only three gave a clear separation of the loci of stars and galaxies. There were plots presenting the dependence on the *logarithm of image area* denoted as log($area$), the *width of Gaussian fit* (S) and the *intensity weighted second moment* (K_w) versus *COSMOS image magnitude* parameter *COSMAG*: $COSMAG = -2.5\log(\sum(I_i - I_{sky})/I_{sky})$, where I_i and I_{sky} are the intensity of i-pixel of the image and the intensity of the sky at the image centroid respectively.

For bright and intermediate magnitudes we used the *log(area) vs. COSMAG* discriminator. Due to lower surface brightness for this range of magnitudes, the galaxies lie above the stellar sequence on this plane.

For the intermediate magnitudes we applied the *intensity weighted second moment* discriminator K_w giving an estimate of the filling of the image by an ellipse fitted to its semiaxes: $K_w = \pi a_i b_i/(area)$, where a_i and b_i are the intensity weighted semi-major and semi-minor axes of the inertia ellipse respectively. The more centrally concentrated images (stars) have the smallest values of this parameter and occupy a tight locus under the galaxy sequence.

For the fainter and intermediate objects we used the *width of a best Gaussian fit* (S) to the threshold intensity and maximum image intensity: $I_{th} = I_{max}\exp(-(area)/2\pi S)$, where I_{th}, I_{max} are the threshold and maximum image intensity respectively. On this diagram the Gaussian width for stars is determined by the point spread function; galaxies lie above this sequence.

We checked all the brightest objects by visual inspection.

The principal point of the automated star/galaxy classification is: the statistical weight of stars exceeds that of galaxies for the whole range of considered magnitudes, and stars occupy the tighter sequence for each discriminator mentioned above. Therefore, for each magnitude in this range, it is possible to construct the histogram of distribution of the number of objects corresponding to the value of chosen discriminator. This histogram gives the main points for a spline to separate the star and galaxy sequences on the plot of discriminator. Notice that, for intermediate magnitudes, the loci of stars and galaxies are more separated, so we did a spline interactively.

So, the Revised Jagiellonian Field Catalogue (RJFC) is based on the digitized scans of the original JF photographic plates. The RJFC contains information on about 20,000 galaxies (Flin & Vavilova 1997, in preparation).

2. Mapping the Galaxy Distribution in Region of the RJFC

Modern astronomical data such as, e.g., DPS and digitized POSS II surveys, constitute an excellent base for finding large-scale structures. This structure search must be objective, which requires appropriate mathematical methods. The wavelet technique, being well-suited for approximation of data with sharp discontinuities, seems to be one such promising tool. For this reason we decided to verify the applicability of the wavelet analysis, having at our disposal data similar to DPS data, by carrying out the mapping of a small region of the sky.

Unlike Fourier analysis, the wavelet algorithms process data at different scales (resolutions). In the case of applying the wavelets for detachment of the structure of galaxy cluster, the task is to convolve the two dimensional galaxy distribution (*signal function*, $s(r)$) on a grid of N×N pixels by the *analyzing wavelet* $F(r, a)$, where a denotes the scale of the wavelet. This parameter determines an effective radius of wavelet or, in other words, the extent of spreading of the density distribution of galaxies in space of *wavelet coefficients* (WC). So, such convolution leads to the "spread" galaxy distribution in terms of a wavelet, and the further analysis of this distribution can be performed using just the corresponding WC. Adapting the best *analyzing function* $F(r, a)$ to data or cutting the WCs below a threshold we sparsely represent our data.

From the whole RJFC we chose small regions containing Abell clusters: A1226, A1228, and A1257, two of them never studied before. For the galaxy distribution in these three regions the *analyzing wavelet* $F(r, a)$ known as the "Mexican Hat" was adopted. Avoiding the edge effects where discontinuities occur, we analyzed a region greater than the cluster itself. The "Mexican Hat" function has a radial shape permitting however the detection of non-circular structure: $F(r, a) = (2 - r^2/a^2)\exp(-r^2/2a^2)$, where r is the distance between center and point (x, y) in which the "Mexican Hat" is calculated. This approach has already been described and performed for identification of structure of clusters of galaxies (e.g., Slezak, Bijaoui, & Mars 1990; Escalera et al. 1994).

Our procedure had several principal steps:

(*i*) normalizing the galaxy distribution data in the working zone of the wavelets through a linear transformation into the range $[-1, 1]$, so the radius of the analyzed zone is $R_f = 1$;

(*ii*) applying the "Mexican Hat" formula to the normalized data;

(*iii*) using a full set of scale wavelet parameters: the analysis starts at the largest scale $a = 0.25R_f$, where the structure of the whole cluster is detected, and ends at the smallest one, where only one galaxy is located inside the region;

(*iv*) performing a Monte-Carlo simulation using the same number of galaxies, distributed in the same zone, to verify the reality of detected structures and substructures;

(*v*) picking up the galaxies inside the detected structure of the cluster to study the properties of galaxy cluster.

3. Conclusion

The first results of mapping of the RJFC gave additional support for the correctness and efficiency of the wavelet analysis both for detachment of the structure of galaxy clusters itself and for the further investigation of their morphological properties (Flin & Vavilova 1995, 1996).

Notice that, in our case, the existence of the structures had been known *a priori* and the task here was to adapt the analyzing function. The problem of finding the structure of the galaxy cluster and the galaxy group (e.g., with low richness, having different geometrical scales, and lying close to each other in two- or three-dimensional space) in a general distribution is not easy. For mapping the general galaxy distribution in the whole RJFC, some other families of wavelet systems and approaches should be applied. It looks as if, in this case, it would be correct to use a hierarchical algorithm, sometimes called a *pyramidal algorithm* (e.g., Bijaoui 1996, private, communication), providing the multiscale vision of a sky survey like the RJFC.

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