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Automated morphological classification of galaxies using wavelet transform

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Abstract. The wavelet transform acts to segregate objects in function of their size. We apply this method on images of galaxies to decompose them into coefficients representing only objects of the same size. The total fluxes of the wavelet coefficients describe the cumulative power spectrum of spatial frequencies. Based on this spectrum, we propose a new parameter to quantify the galaxy texture. As expected, it remains small and quite invariant for early-type galaxies, while it covers a large range and takes larger values for late-type galaxies. Combined with a second parameter, our determination of the texture is able to successfully separate galaxy types. By thresholding the wavelet coefficients, we detect luminous lumps. In irregular galaxies, their radial distribution seems to show a double peak. This could be the trace of a privileged radial distance of strong star formation regions.

Keywords. galaxies: fundamental parameters (morphology, classification), galaxies: structure, techniques: image processing, methods: data analysis

1. The wavelet transform

The wavelet transform projects an image onto a basis of finite support functions, whose spatial scales vary. Wavelets are families of functions that integrate to zero and are produced by scaling and translating a single function, called the mother wavelet.

As the wavelet's support is finite in space, it is not sufficient to project the image onto a unique function. We must create a set of translating functions by frequency. Consequently, instead of obtaining a scalar as coefficient, we get an image; and this for each spatial frequency. There would be many redundancies if we would compute the coefficient for all spatial units. To avoid that, the projection is performed only onto wavelets whose spatial frequencies l, expressed in pixels, are powers of 2: $l = 2^s$, where $s = 1, 2, 3, ..., n$ determines the scale.

Thus, the wavelet transform yields a set of images, one per scale: the wavelet coefficients. These are composed of objects with characteristic sizes, without losing their locations, and are therefore representations of the structure or texture of the image. The sum of all coefficients recovers the original image.

In our case, the mother wavelet is a B-spline function.

2. Spatial power spectrum

We apply the wavelet transform on images of galaxies from the Sloan Digital Sky Survey – SDSS (York *et al.* 2000). The objective is to quantify the texture of the galaxies, in order to be able to better classify them morphologically. We base our study on a sample of 2253 galaxies visually classified by Fukugita *et al.* (2007).

Using wavelet transform, the original images of the galaxies are decomposed into coefficients. The wavelet transform acts to segregate the objects, such as bulges, stellar clusters, spiral arms or strong star formation regions, depending on their size. The total fluxes of the coefficients define the cumulative spatial power spectrum. Its derivative is the flux emitted by objects of specific size described by the scale s.

3. Galaxies texture

Using the power spectrum, we propose a quantification of the galaxies' texture. By definition, a cumulative spectrum is an increasing function. The light emitted from one-pixel elements is basically noise and its integrated flux is 0. The total flux of the galaxy can be normalized to 1. Then, every spectrum has a similar shape: growing from 0 to 1 along the scale of the galaxy. The simplest way to measure the growth is the linear approximation of the function taken in logarithm. Our parameter is thus defined as the inclination of the cumulative spatial power spectrum on a logarithmic scale.

As expected, our texture parameter remains small and quite invariant for early-type galaxies. On the contrary, for late-type galaxies, it covers a large range of values and can be much larger. Combined with a second parameter, such as the concentration index (Doi *et al.* 1993; Abraham *et al.* 1994), our parameter is able to successfully separate galaxy types. The concentration-texture plane shows a smooth sequence following the Hubble scheme.

4. Radial distribution of lumps

Luminous peaks in the wavelet coefficients are detected by thresholding. A peak present on two successive scales defines a lump. For each lump, we calculate the distance to the galactic center, deprojected from the elliptical shape of the galaxy. The radial distribution of the lumps shows a different behaviour according to galaxy type.

In irregular galaxies, the lumps can be identified with star forming complexes. Their radial distribution seems to manifest a double peak as already observed by Parodi & Binggeli (2003). This could be an indication of a privileged radial distance of strong star formation regions, possibly induced by shearing due to differential rotation in the outer part of the disk.

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