Mark correlations

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Abstract. A formalism based on marked point sets allows us to conduct a well defined quantitative analysis of luminosity segregation in the galaxy distribution as well as to study the connections between intrinsic properties of galaxies and their spatial clustering (e.g. morphology, ellipticity). Moreover, they suggest a fresh look at the "bias".

1 Some comments on the "bias"

One of the major open problems in the theory of structure formation is how galaxy formation works in detail, and how it influences the observed large–scale distribution of galaxies. Typically our ignorance of the exact physical processes involved is summarized in the so called bias parameter, comparing the mass and the galaxy over–density. The relation is assumed to be (non–) linear and either deterministic or stochastic (see e.g. [4] and refs. therein). The definition of the bias parameter as the ratio of the local number density contrast $\delta(x) = (\rho(x) - \overline{\rho})/\overline{\rho}$ to the mass density contrast $\delta_m(x) = (\rho_m(x) - \overline{\rho}_m)/\overline{\rho}_m$ is theoretically well motivated for clusters of galaxies within the peak formalism [1]. However, on smaller scales, the physical processes lighting up galaxies are typically proportional to the local mass density $\rho_m(x)$ (e.g. depending on the angular momentum) or to $\rho_m(x)^2$ (e.g. scattering cross–sections). But only $\rho(x)$ and $\delta(x)$ are observable in galaxy catalogs (we ignore the perspectives offered by gravitational lensing). Hence, a non–linear and perhaps also stochastic relation between $\delta(x)$ and $\delta_m(x)$ may obscures the physical relations between $\rho(x)$ and $\rho_m(x)$ and especially their two–point correlations. It seems therefore advisable to compare the mass density with the number density, or the mass density correlations with weighted two–point correlations of the galaxy distribution.

Observationally, due to the nature of the *dark* matter, only indirect methods are feasible. In this line of thought, it seems promising to ask whether the clustering properties of galaxies depend on their mass, luminosity or morphological type. In [2] a new method tackling this problem was introduced. The distribution of galaxies with their intrinsic properties (e.g. luminosity, morphology) is thought of as a realization of a marked point process. Using *conditional weighted correlation functions*, we put an intermediate step in between the pure point process statistics of the galaxy distribution and the statistics of mass fields. In our description stochasticity is present from the very beginning.

2 Mark correlations

Consider a point set $\{x_i\}_{i=1}^N$ and attach a mark m_i to each point $x_i \in R^3$ resulting in the marked point set $\{(x_i, m_i)\}_{i=1}^N$. As a mark one may choose the luminosity, the morphological or spectroscopical type, the ellipticity or even the peculiar velocity of a galaxy. The spatial–mark product–density

$$\rho_2^{SM}((x_1,m_1),(x_2,m_2))\ dV_1 dm_1\ dV_2 dm_2, \tag{1}$$

is the joint probability of finding a galaxy at x_1 with the mark m_1 and another galaxy at x_2 with the mark m_2. The spatial product density $\rho_2(x_1, x_2)$ and the two–point correlation function $\xi(r)$ are obtained by marginalizing over the marks:

$$\rho^2(1+\xi(r)) = \int dm_1 \int dm_2\ \rho_2^{SM}((x_1,m_1),(x_2,m_2)). \tag{2}$$

with $\xi(r)$ only depending on the distance $r = |x_1 - x_2|$ of the points in an homogeneous and isotropic point set.

This allows us to define the conditional mark density:

$$M_2(m_1,m_2|r) = \frac{\rho_2^{SM}((x_1,m_1),(x_2,m_2))}{\rho^2(1+\xi(r))} \tag{3}$$

with the mean mark $\overline{m}$ and for $1+\xi(r) \neq 0$. $M_2(m_1,m_2|r)dm_1dm_2$ is the probability of finding the marks m_1 and m_2 at two galaxies located at x_1 and x_2, under the condition that they are separated by $r = |x_1 - x_2|$. To condense the information even further we look at the mean mark of a galaxy pair at a distance of r

$$k_m(r) = \int dm_1 \int dm_2\ \frac{1}{2\overline{m}}(m_1+m_2)\ M_2(m_1,m_2|r). \tag{4}$$

In addition, other mark correlation functions are considered in [2] to quantify more aspects of the mark distribution.

We estimate $k_m(r)$ from a volume–limited sample with 100 Mpc/h depth of the Southern Sky Redshift Survey 2 [3], using the luminosity of each galaxy as the mark. Figure 1 shows that the galaxies in close pairs typically have higher luminosities. Also morphology segregation could be confirmed [2]. One of the new results is that the morphology segregation does not cause luminosity segregation and vice versa, both effects are irreducible.

Preliminary results from the SDSS [5] commissioning data show a type segregation similar to the morphology segregation. The huge amount of upcoming data will allow a detailed study of both luminosity and morphology

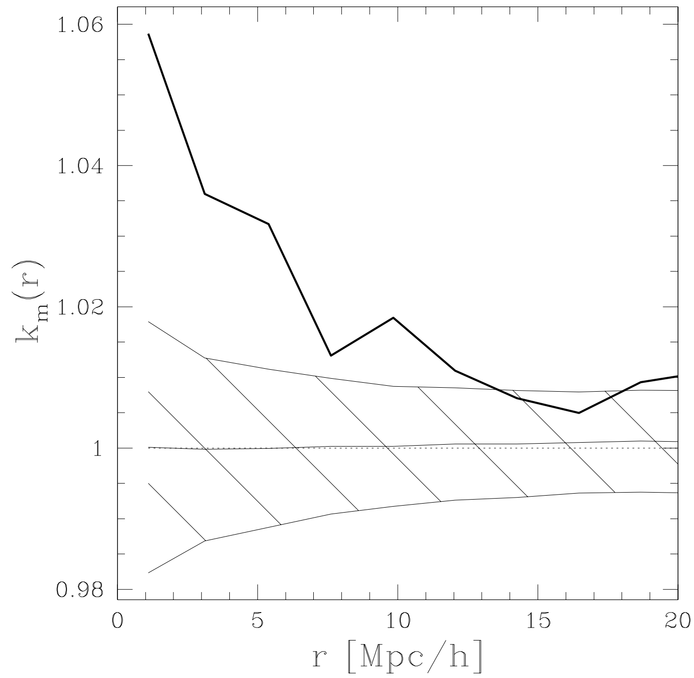

Fig. 1. The $k_m(r)$ function determined for a volume limited sample with 100 Mpc/h depth from the SSRS2. The shaded one–σ area is obtained by randomizing the marks on the given point set.

segregation. Studies are under way to quantify the influence of luminosity dependent clustering on the estimates of the correlation function from volume– and magnitude–limited samples.

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