Peculiar Motions and the Galaxy Density Field

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Abstract. We use an all-sky, complete sample of nearby galaxies, extracted from the LEDA data base, to map the optical galaxy density field in the nearby universe. In order to determine this field, we correct the redshift-dependent distances by testing some peculiar velocity field models and we correct the galaxy number density for the incompleteness of the galaxy sample at large distances through the derivation of the galaxy luminosity function. Local galaxy density parameters calculated for different smoothing scales are meant to be used in forthcoming statistical studies of environmental effects on galaxy properties.

1. Introduction

Optical galaxy samples are more suitable than IRAS–selected galaxy samples for mapping the galaxy density field on quite small scales (< 1 Mpc). In our work, we attempt to recover this field using a 3D reconstruction procedure (based on peculiar velocity field models) which minimizes relevant systematic effects.

To this aim, we take an all-sky, magnitude-limited, optical sample of nearby galaxies (6392 galaxies with recession velocities \(cz < 5500 \text{ km/s}\)) extracted from the LEDA data base (Garcia, 1993). This sample, which is complete up to the corrected blue total magnitude \(B_T = 14 \text{ mag}\), comprises 3403 field galaxies and 485 systems with at least three members (for a total of 2989 galaxies).

In order to correct raw redshift–distances, we use two basic models of the peculiar velocity field: i) an optical cluster 3D-dipole reconstruction scheme devised by Branchini & Plionis (1996) that we modify with the inclusion of a local model of the Virgocentric infall; ii) a multi-attractor model, in which we adopt a King density profile for each attractor (i.e., the Virgo cluster, the Great Attractor, the Perseus–Pisces and Shapley superclusters) and we rely on the weakly non-linear peculiar series expansion by Regös & Geller (1989) for peculiar velocity. We fit the multi–attractor model to the Mark II and Mark III peculiar velocity catalogues (Willick et al., 1997).

Throughout we adopt the Hubble constant \(H_0 = 100 \text{ km s}^{-1} \text{Mpc}^{-1}\).
2. Results

Interestingly, as a result of the non–degenerate manner in which the cosmological density parameter $\Omega_0$ enters into the equations of motions, we find the best-fitting value of $\Omega_0 = 0.5 \pm 0.2$ for our multi–attractor model fitted on Mark III data (whilst Mark II data would yield $\Omega_0 \sim 1$). This is consistent with a picture in which a large part of the local peculiar flows ($< 8000$ km/s) is generated on a scale which is larger than the analyzed volume (from distant gravitational sources such as the Shapley concentration). Moreover, for the Great Attractor and Perseus–Pisces, the mass overdensity peaks, evaluated from our Mark III multi–attractor model at a radial distance of $1200$ km/s, are not much different from the reconstructed overdensity peaks of IRAS galaxies (Sigad et al., 1997) and optical galaxies (Hudson et al., 1995), calculated for a Gaussian smoothing of $1200$ km/s. This points to a bias factor $b$ of order unity for optical and IRAS galaxies over a $\sim 10$ Mpc scale (see Marinoni et al. 1998 for details).

Inverting the redshift–distance relations predicted by the above–mentioned velocity field models, we derive the distances of the field galaxies and groups of our sample. We overcome the ambiguity inherent to the triple–valued zones of the redshift–distance relations by using blue Tully–Fisher relations calibrated on galaxy samples having distances predicted by the velocity models.

The use of different velocity field models allows us to check to what extent differences in the description of the peculiar flows influences the estimate of galaxy distances in the nearby universe. We note that these differences turn out to be more prominent at the largest and smallest distances rather than for intermediate distances (i.e., for $2000 < r < 4000$ km/s, where $r$ is the distance expressed in km/s).

We correct the incompleteness of the sample at large distances through the derivation of the Schechter–type blue luminosity function of galaxies $\Phi(L)$. The incompleteness factor $F(r)$ which expresses the number of galaxies that should have been catalogued for each objet present in the sample at a given distance $r$, is related to the selection function $\phi(r)$ by the expression $F(r) = 1/\phi(r)$. The selection function is given by $\phi(r) = 1$ if $r < r_s$, where $r_s = 5$ Mpc, and is given by

$$\phi(r) = \frac{\int_{L_{\text{min}}(r)}^{\infty} \Phi(L) dL}{\int_{L_s}^{\infty} \Phi(L) dL}$$

(1)

if $r > r_s$, where $L_{\text{min}}$ is the minimum luminosity necessary for a galaxy at distance $r$ to be included in the sample. We set the lower limit of the integral in the denominator to $L_s = L_{\text{min}}(r_s)$.

By applying a modified Turner (1979) method, which is insensitive to the presence of fluctuations in the sample, we derive the parameters $M^*$ (the characteristic magnitude), $\alpha$ (the slope of the faint tail), and $\Phi^*$ (the normalization factor) of this function on the basis of the distances predicted by velocity field models. Specifically, comparing the absolute magnitude distribution with that expected on the basis of the following estimator

$$N(M_i) \Delta M = \Phi(M_i) \Delta M \sum_{j=0}^{j_{\text{lim}}} \int_{-\infty}^{M_{\text{lim},i}} \frac{N(r_j) \Delta r}{\Phi(M') dM'}$$

(2)
we obtain $\alpha = -1.06 \pm 0.04$, $M^* = -20.12 \pm 0.06$ and $\Phi^* = 1.01 \cdot 10^{-2} \ Mpc^{-3}$ for the distances predicted by the Mark III multi–attractor model and $\alpha = -1.18 \pm 0.04$, $M^* = -20.19 \pm 0.06$ and $\Phi^* = 9.91 \cdot 10^{-3} \ Mpc^{-3}$ for the redshift-distances evaluated in the CMB frame. Similar values result from sets of distances relative to other velocity field models such as the Mark II multi–attractor model and the cluster dipole model. Thus, within the current views on the kinematics of local peculiar flows, corrections of galaxy distances for peculiar motions appear to have a small impact on the galaxy luminosity function, which in our case is a quantity calculated over a very large solid angle.

We devise a method of 3D reconstruction of galaxy groups, which prevents members to be spuriously placed in high–density regions and we calculate the local galaxy density $\rho_\sigma$ (in galaxies per $Mpc^3$) in terms of the number density of galaxies which are found around every galaxy. This is done by smoothing every galaxy with a Gaussian filter having a fixed smoothing scale parameter $\sigma$ (in Mpc) (see also Giuricin et al., 1993; Monaco et al., 1994):

$$\rho(r_i) = \frac{1}{(2\pi \sigma^2)^{3/2}} \cdot \sum_{j \neq i} \exp \left( \frac{|r_j - r_i|^2}{2\sigma^2} \right) F(r_j)$$

This quantity gives the number of galaxies (brighter than the absolute magnitude $M_B = -17.4$ mag) per $Mpc^3$, which are located within a distance equal to $\sim \sigma$ from the specified galaxy of the sample; $F$ is the correction function for the incompleteness of the catalogue at large distances. The sum is carried out over all galaxies except the one whose density we are calculating.

Choosing different values of the smoothing scale parameter $\sigma$ allows us to explore the 3D galaxy density field on different high–resolution scales. In particular, for sets of galaxy distances relative to different velocity models, we have calculated the local galaxy density $\rho_\sigma$, choosing $\sigma = 0.25, 0.5, 1, \text{and } 2 \ Mpc$.

Fig. 1 shows the comparison between the $\rho_\sigma$-values based on redshift–distances (in the LG frame) and on distances predicted by Mark III, Mark II, and cluster dipole (cd) models, for $\sigma = 0.25$ and $2 \ Mpc$. We also show the comparison between the Mark III $\rho_\sigma$-values for $\sigma = 2 \ Mpc$ and the galaxy densities which are deduced from the IRAS 1.2 Jy redshift survey through smoothing with a Gaussian whose dispersion is equal to the local mean galaxy separation (Fisher et al., 1995). On large scales ($\sigma = 2 \ Mpc$), the agreement between the different sets of $\rho_\sigma$-values is satisfactory at low or intermediate galaxy densities; at large galaxy densities, Mark III and Mark II multi–attractor models tend to give greater values than those of the IRAS galaxy sample and lower values than those of the other models. On the other hand, in general there is a poor agreement between the various sets of $\rho_\sigma$-values on small scales ($\sigma = 0.25 \ Mpc$).

In conclusion, corrections of galaxy distances for peculiar motions appear to have a large impact on the evaluation of the local galaxy density on small scales ($< 1 \ Mpc$). This is an important parameter to be used in statistical studies of environmental effects on the properties of nearby galaxies.
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Figure 1. Comparison between the local galaxy densities (in $Mpc^{-3}$) relative to the 3D optical galaxy distribution based on different velocity field models and to the IRAS 1.2 Jy galaxy sample.