The DTFE density and velocity fields of the PSC$_{z}$ catalog


We apply the Delaunay Tessellation Field Estimator to reconstruct the density and velocity fields of the linear model of the full sky galaxy survey PSC$_{z}$. The characteristics of the DTFE technique have allowed us to trace the density and velocity fields at both high and low density regions without losing resolution. A characteristic of the DTFE method is that velocity-gradient related quantities can be computed in a straightforward manner. We have reconstructed the DTFE divergence and shear components of the reconstructed velocity field. Our results show a great consistency between the velocity field and the density field.
9.1 Introduction

Within the gravitational instability scenario, large-scale flows of galaxies are a response to the underlying matter distribution and thus, peculiar velocity measurements are a critical probe for cosmology and large scale structure. Under the assumption that galaxies trace the matter distribution it is possible to reconstruct self-consistently density and velocity fields from a galaxy-redshift catalog. Comparison of the modeled velocity field with a real measured velocity field allows to test the gravitational instability picture, to measure the relative distribution of luminous and dark matter and to determine the parameter $\beta = \Omega_{m,0}^b/b$, where $\Omega_m$ is the cosmological mass density parameter, and $b$ is the bias of the galaxy distribution relative to the underlying matter density (Peebles 1980).

A common problem when performing this comparison is the fact that the sampled objects in the velocity and galaxy surveys are not the same. Although one could assume that both fields faithfully trace their respective underlying velocity and density fields, this might not be the case. It is therefore necessary to perform such analysis by counting with volume-weighted velocities that properly sample the surveyed region.

Reconstructing a continuous volume-weighted velocity field from a sparse sample of peculiar velocities is a challenging task. One needs to interpolate the peculiar velocities into those regions devoid of data, overcome shot-noise effects and to preserve the large and small scale characteristics of the peculiar velocities. Several authors (e.g. Bertschinger et al. 1990; Juszkiewicz et al. 1995; Lokas et al. 1995; Baker et al. 1998; Branchini et al. 1999; Dekel et al. 1999) filtered galaxy peculiar velocities with a Gaussian kernel of a fixed length to obtain the velocity field onto a regular grid. However, the use of a filtering algorithm smears out all the velocity information contained on scales smaller than the filter size. Also, in most of the cases, the smoothing procedures are implicitly mass-weighted.

Bernardeau & van de Weygaert (1996) showed that for the velocity field, conventional reconstruction techniques are unable of recovering this field accurately over its whole range of values from small-scale to large-scale. They introduced a tessellation based method to recover fully volume-covering and volume-weighted velocity field, the Voronoi and Delaunay tessellation methods. They demonstrated the success in reproducing analytical predictions by the Delaunay method. In particular this concerned the ability to reproduce the velocity-divergence distribution in the quasi linear regime. Based on the work of Bernardau & van de Weygaert, Schaap & van de Weygaert (2000) and Schaap (2005) developed a reconstruction method based on the geometrical concept of the Delaunay tessellation (Delaunay 1934), the Delaunay Tessellation Field Estimator [hereafter, DTFE]. The method enables a natural reconstruction of the density field from the sampling point set. In Chapter 6 we presented an extension of DTFE for peculiar velocities along the line of Bernardau & van de Weygaert. The method has been tested on $N$–body simulations. Given a discrete set of peculiar velocities, the processed DTFE velocity field is able to maintain the small and large scale characteristics of the peculiar velocities. It obtains continuous full coverage volume-weighted estimates. Implicitly, the method involves the computation of the velocity field gradient. This makes velocity related quantities such as the velocity divergence, shear and vorticity quite straightforward to compute.

In order to compute a self-consistent reconstruction of the density and velocity fields one needs to consider a uniform whole-sky sample with complete redshift information. This requirement has lead to the use of the IRAS catalogs. Here we concentrate on the last and best defined survey, the PSCz survey (Saunders et al. 2000). The intrinsic characteristics of the IRAS-PSCz catalog such as depth and sky coverage have made its reconstructed density and velocity fields into faithful representations of both fields in our nearby universe (Branchini et al. 1999; Schmoldt et al. 1999; Branchini et al. 2001; Teodoro et al. 2003).

In this chapter, we apply the DTFE velocity interpolation method to the linear modeled PSCz velocity field of Branchini et al. (1999) [hereafter, B99]. Our main aim is to reconstruct in a volume-weighted fashion the discrete PSCz velocity field, to uncover the intricate velocity pattern in the local universe and to show the virtues of the DTFE method with “real” data. Testing the performance of the method with the well controlled spatial reconstructed PSCz catalog should give us confidence for applying the DTFE technique to the forthcoming surveys such as 2MASS and 6dF.
9.2 The DTFE method

The DTFE interpolation method was introduced by Schaap & van de Weygaert (2000) (see also Schaap 2005), for rendering fully volume-covering and volume-weighted physical fields from a discrete set of sampled field values. The method is self-adaptive and does not make use of any artificial smoothing procedure. It followed the pioneering work by Bernardeau & van de Weygaert (1996) for using the Delaunay tessellation of the point set as a natural and self-adaptive interpolation frame for recovering the continuous velocity field sampled by the velocities at those points. Schaap & van de Weygaert (2000) and Schaap (2005) extended this to the recovery of the density or intensity field when one assumes it to be fairly sampled by the spatial point distribution.

The DTFE algorithm as a linear multidimensional field interpolation scheme is the linear first-order version of the natural neighbouring algorithm for spatial interpolation (see Sibson 1981; Okabe et al. 2000). Related procedures have been implemented in a variety of other applied sciences. Successful examples may be found in geophysics (see e.g. Braun & Sambridge 1994; Sambridge 1999) and engineering mechanics (Sukumar 1998).

The primary ingredient of the DTFE method is the Delaunay tessellation of the particle distribution. The Delaunay tessellation of a point set is the uniquely defined and volume-covering tessellation of mutually disjunct Delaunay tetrahedra. A Delaunay tetrahedron is defined by the set of four points whose circumscribing sphere does not contain any of the other points in the generating set (Delaunay 1934) (triangles in 2D). The Delaunay tessellation is intimately related to the Voronoi tessellation of the point set, i.e. they are each others dual. The Voronoi tessellation of a point set is the division of space into mutually disjunct polyhedra, each polyhedron consisting of the part of space closer to the defining point than any of the other points (Voronoi 1908; Okabe et al. 2000).

It is straightforward to appreciate that on the basis of their definitions both Delaunay and Voronoi tessellation fully adapt to the local point distribution. Moreover, the minimal coverage characteristics of the Delaunay tessellation imply it to be optimal for defining a network of multidimensional interpolation intervals. The point in case for its pattern tracing characteristics is provided by the right-hand panel of Figure 9.1. It shows the 2-Dimensional Delaunay triangulation for a section along the \( z \)-supergalactic plane through the PSC\( z \) catalog, the galaxy set which we analyze in this work.

9.2.1 DTFE density and velocity fields

One of the important properties of a processed DTFE density field is that it resolves two of the main characteristics of gravitational structure formation. It objectively reproduces any anisotropic patterns in the density distribution without diluting their intrinsic geometrical properties. This is a great advantage when seeking to analyze the cosmic matter distribution, characterized by prominent filamentary and wall-like components linking up into a cosmic web. Also, it manages to outline the full hierarchy of substructures present in the sampling point distribution. Since we assume that structure in the Universe arose through the gradual hierarchical buildup of matter concentrations, the benefits of an objective tracer of such features are obvious. In addition, it has been recognized that the low density regions, e.g. the voids in the galaxy distribution, are evenly rendered as regions of slowly varying, moderately low density values through the interpolation definition of the DTFE field reconstruction. It manages to suppress automatically the shot noise in such sparsely sampled regions (see Schaap 2005).

The linear interpolated DTFE velocity field retains the same characteristics as that of the corresponding DTFE density field. In this thesis we have demonstrated that the DTFE velocity method has indeed the ability to resolve both small and large scale features of the velocity field. Note that a successful DTFE velocity field interpolation does not demand it to be uniformly sampled from an underlying density field. In this work, however, we assume that they do. The DTFE velocity fields are continuous and fully volume-covering. Bernardeau & van de Weygaert (1996) introduced the Delaunay method for velocity field interpolation in an attempt to reproduce volume-weighted velocity field estimates. The latter was deemed essential for testing theoretical predictions. Most analytical results concerning the statistics of velocity field related quantities, as they develop gravitationally from a primordial
Gaussian perturbation field, concern explicit volume-weighted expressions.

Bernardeau & van de Weygaert (1996) explicitly applied the Delaunay method to the velocity divergence field to test the validity of the second order perturbation theory results. This was particularly interesting as a mildly non-Gaussian velocity divergence distribution would enable the breaking of the degeneracy between the cosmic matter density $\Omega$ and the bias $b$ between the matter and galaxy distribution (Bernardeau 1994; Bernardeau et al. 1995). The later work by Schaap & van de Weygaert (2003) showed the first results on the succesfull reproduction by DTFE of the physical and spatial correlation between cosmic density and velocity fields in a large GIF $N$-body simulation (Kauffmann et al. 1999) (also see Schaap 2005). The corresponding density and velocity maps provide convincing evidence of the detailed tracing of the velocity flows in and around the cores of high-density regions. Within the same simulations, the voidlike regions were rendered as super-Hubble expanding bubbles, consistent with our view of void dynamics (Icke 1984; Sheth & van de Weygaert 2004).

### 9.2.2 The DTFE general reconstruction

The DTFE field reconstruction method can be summarized in the following sequence of steps:

1. Construction of the Delaunay tessellation from the point distribution.

2. In the case of estimating the density from the point distribution itself, with the extra requirement of the latter being an unbiased sample of the underlying density field, we first estimate the density values at the sampled points from the Voronoi tessellation.

3. Calculation of the field (velocity) gradient $\nabla f_j$ in each Delaunay tetrahedron $j$ by inversion on the basis of the field values and positions of the tetrahedron vertices.

   (a) In the case of the velocity field $v$, we may in each Delaunay tetrahedron, directly infer velocity gradient related quantities such as the velocity divergence, shear and vorticity.

4. Processing. This may involve various operations. The most important ones are “image reconstruction” and, subsequently, “filtering”. Image reconstruction consists of two steps:

   (a) For a set of image points (usually grid points) determine in which Delaunay tetrahedra they are located.

   (b) By (linear) interpolation compute field values at each of these points. For a point $x$ in a Delaunay tetrahedron $j$, having $x_0$ as one of its vertices, the resulting DTFE field value $\hat{f}(x)$ becomes:

\[
\hat{f}(x) = f(x_0) + \nabla f_j \cdot (x - x_0). \tag{9.1}
\]

### 9.3 The PSCz catalog

The IRAS-PSCz catalog (Saunders et al. 2000) is an extension of the 1.2-Jy catalog (Fisher et al. 1995a). It contains $\sim 15\,500$ galaxies with a flux at $60\mu$m larger than $0.6\,$Jy. For a full description of the catalog, selection criteria and the procedures used to avoid stellar contamination and galactic cirrus, we refer the reader to Saunders et al. (2000). For our purposes the most important characteristics of the catalog are the large area sampled ($\sim 84\%$ of the sky), its depth with a median redshift of $8\,500\,$km s$^{-1}$, and the dense sampling (the mean galaxy separation at $10\,000\,$km s$^{-1}$ is $\langle l \rangle = 1\,000\,$km s$^{-1}$).

Because of the flux-limited nature of the PSCz catalog, there is a decrease in the objects’ sampling as a function of distance from the observer. This is quantified by the radial selection function of the catalog, $\phi(r)$, where the selection function is defined as the fraction of the galaxy number density that is observed above the flux limit at some distance $r$. To recover the proper number density of objects one needs to weight each galaxy by the inverse of the selection function. In this work we adopt the selection function of B99 (see also Chapter 5).
Figure 9.1 — Modeled peculiar velocity field at the galaxy positions (left-hand panel). The plot represents a slice of $2.5 \, h^{-1}\text{Mpc}$ thickness centered along the $z$—supergalactic plane. Numbers indicate the major visible structures along the cut: 1- Local supercluster, 2- Great attractor region, 3- Pavo-Indus-Telescopium complex, 4- Shapley supercluster, 5- Coma cluster, 6- Camelopardalis cluster, 7- Perseus-Pisces supercluster, 8- Cetus wall, 9- Sculptor void. (From Branchini et al. 1999). The right-hand panel shows the respective Delaunay tessellation of the galaxy distribution. The shadowed regions illustrate the “contiguous Voronoi cell” concept for two given points (P1 & P2).

To correct for the selection function, as well as for the 16% of the missing sky devoid of data due to the cirrus emission and unobserved areas and to correct for redshift distortions, we have used the spatial reconstructed PSCz catalog of B99. The positions and velocities in real space were computed following the method of B99. In this approach, the technique of Yahil et al. (1991) was implemented to minimize redshift-space distortions (see B99 for a more complete explanation of the method).

### 9.3.1 The linear modeled PSCz catalog

An important constraint in the spatial reconstructed model of B99 is the fact that the reconstruction is valid only in the limit of small density fluctuations. The gravity field was smoothed with a top-hat filter of radius $500 \, \text{km s}^{-1}$ to assure the validity of linear theory and thus to obtain the smoothed peculiar velocity at each galaxy position.

The end product of such procedure is the real spatial position and peculiar velocity for each individual galaxy for a given value of the $\beta$ parameter ($v \propto \beta g$). In our adopted reconstructed catalog $\beta = 0.5$, in agreement with the results of Branchini et al. (2001) and Zaroubi et al. (2002) from density-density and velocity-velocity comparisons. Velocity predictions were made in the Local Group frame [LG, hereafter] to minimize the uncertainties derived from the lack of information on scales larger than the PSCz catalog.

The final spatial positions and peculiar velocities can be seen in the left-hand panel of Figure 9.1, in which a slice of $2.5 \, h^{-1}\text{Mpc}$ thickness centered along the $z$—supergalactic plane is shown. Velocities are displayed at the galaxy positions and normalized to the maximum amplitude within this slice. The Local Group is located at the origin. The main large-scale structures have been labeled and can be easily recognized by their gravitational effects in their surroundings. Cluster such as Coma and Camelopardalis, and superclusters like the Local supercluster, the Great Attractor region (GA, Hydra-Centaurus supercluster, H-C), the Pavo-Indus-Telescopium (P-I-T) complex, Shapley and the Cetus
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wall are noticeable in the map. Also, underdense regions such as the Sculptor void can be identified. A peculiar characteristic of the modeled velocity field is the lack of a backflow in the GA region, implying that the Shapley supercluster is still a major source of the LG velocity field (e.g. Rowan-Robinson et al. 2000; Plionis & Kolokotronis 1998; Basilakos & Plionis 1998).

Around high density regions (cluster of galaxies) where shell crossing might have occurred, there are triply-valued regions. In Chapter 5 we addressed this problem by considering two different samples, one where triply-valued regions were collapsed, and another without collapsing them. Results showed that the smoothing procedure used to linearized the data minimized this effect. Differences between collapsed and uncollapsed samples are less than 10% for their bulk flow and velocity shear components, and consistent at the 1σ level. The velocity model we have chosen leaves triply-valued regions uncollapsed. In this way, we reduce a source of error at high-density regions in the DTFE procedure.

Since the PSCz velocities have been linearized, the vorticity modes in the peculiar velocity field have been minimized, although not completely erased. Dekel et al. (1999) employed a Gaussian kernel of 12 h⁻¹Mpc in order to linearize completely the measured velocity field from the Mark III catalog (Willick et al. 1997a). The reliability of the modeled density and velocity fields has been confirmed in several studies and in density-density and velocity-velocity comparisons with other surveys (e.g. Branchini et al. 2001; Zaroubi et al. 2002).

9.4 DTFE reconstruction of the PSCz density and velocity fields

In order to reconstruct the continuous volume-weighted DTFE density and velocity fields from the PSCz catalog, we have made use only of the linearized data within a spherical volume of radius 180 h⁻¹Mpc. This radius is large enough to enclose the main sources that contribute to the local velocity field (e.g. B99, see also Chapter 5). The selected number of galaxies at this radius is 13432. The DTFE density and velocity reconstruction was performed following the steps described in Section 9.2. In our analysis we only present DTFE density and velocity maps up to a radius of 120 h⁻¹Mpc in order to have a more qualitative comparison with those from B99 and Schmoldt et al. (1999). At this radius, the sample contains 10651 galaxies with an inter-object separation of ≈ 14 h⁻¹Mpc.

9.4.1 The DTFE PSCz density field: Cosmography

The spatial DTFE density field is shown in Figure 9.2. The density field has been smoothed with a Gaussian filter of \( \sqrt{5} \) h⁻¹Mpc size in order to match the linearized velocity field. The isosurface level corresponds to structures at 3 times the smoothed mean density. Two major matter concentrations along the z = 0 plane dominate the field. The complex formed by the P-I-T and the H-C with its extension toward the Shapley concentration dominates the left side region. The PP and the Cetus wall located at the opposite side overshadow the other structures. There is a thin filamentary structure connecting both massive matter concentrations, the Local Supercluster.

A cut along the 3D density field is presented in Figure 9.3. The slice corresponds to the z-supegalactic plane. The color density contours represent the density field. The superimposed arrows correspond to the DTFE reconstructed velocity field discussed in Section 9.4.2. Also here the density field has been convolved with a Gaussian kernel of \( \sqrt{5} \) h⁻¹Mpc. The right-hand color bar indicates the amplitude of the density fluctuations.

High-density regions (reddish regions) as well as low density ones (dark zones) can be easily recognized along the map. Very conspicuous is the filamentary structure running from the Camelopardalis cluster ([SGX,SGY] ≈ [45,20] h⁻¹Mpc) toward the Shapley supercluster ([SGX,SGY] ≈ [−120,70] h⁻¹Mpc) and connecting the Local Supercluster with the Hydra-Centaurus supercluster. The Pavo-Indus-Telescopium supercluster is barely noticeable at ([SGX,SGY] ≈ [−40,−10] h⁻¹Mpc). The Perseus-Pisces supercluster is well defined at ([SGX,SGY] ≈ ...

\(^1\) We have used the fact that \( R_G = R_{TH}/\sqrt{5} \) (Suto & Fujita 1990). In our case, \( R_{TH} = 5 \) h⁻¹Mpc
9.4. **DTFE RECONSTRUCTION OF THE PSCZ DENSITY AND VELOCITY FIELDS**

Figure 9.2 — 3D reconstructed DTFE PSCz density field. The field has been smoothed with a Gaussian kernel of $5\, h^{-1}\text{Mpc}$. The isosurface represents structures at the 2 level of the mean density. Notice the two huge density concentrations around the $z = 0$ plane, the PP and Cetus wall complex to the right, and the H-C and P-I-T to the left side. A well delineated bridge connects both structures, the Local Supercluster.

We can also clearly recognize the voids. The Sculptor void, surrounded by the P-I-T complex and the Sculptor and Cetus walls is one of the most conspicuous empty features along the supergalactic plane. The Fornax void is located just at the bottom of the plot ($[S_GX, S_GY] \approx [0, -80] \, h^{-1}\text{Mpc}$). The small void located between the Coma cluster and the H-C region is clearly well defined.

9.4.2 **The DTFE PSCz velocity field**

We have reconstructed the continuous volume-weighted DTFE velocity field of the PSCz catalog. Because the input velocities have been linearized prior to the DTFE processing, we did not have to smooth the velocity field any further. This will also constraint our reconstruction in the sense that velocity flows smaller than the kernel size ($\sqrt[3]{5} \, h^{-1}\text{Mpc}$) will not be recovered.

In Figure 9.3 the projected DTFE velocity field along the same density cut is presented. The velocity arrows have been normalized to the maximum plotted velocity amplitude. Notice that both density and velocity fields are strongly correlated with each other. The processed DTFE velocity field
reveals intricate details along the whole volume. Large scale bulk flows, distortion patterns such as shear, expansion and contraction modes of the velocity field are clear features uncovered by our DTFE technique.

Positive velocity divergence modes within voids resemble very well the dips in the density field. Velocity shear patterns are also clearly visible in the map. Significant quadrupolar patterns in the matter distribution are correlated with corresponding shear patterns.

The gravitational influence of the H-C supercluster over its surroundings is more than evident. A pronounced bulk flow toward the H-C region dominates the general LG region motion. At the top of the plot the Coma cluster exerts the main gravitational attraction in the surrounding region.
9.4. DTFE RECONSTRUCTION OF THE PSCZ DENSITY AND VELOCITY FIELDS

Local Supercluster

Coma

Sculptor void

Perseus–Pisces & Cetus wall

Figure 9.4 — Density and velocity zooms for four different regions along the supergalactic plane indicated by the labels at the top of each frame. The density field has been convolved with a Gaussian kernel of $1 \, h^{-1} \text{Mpc}$ for a better impression of such field. The normalization of the velocity field is the same for the four panels.

9.4.3 Small-scale details in the DTFE reconstructed fields

The ability of the DTFE method to resolve both small and large scale field characteristics can be appreciated from Figure 9.4. This four-panel plot zooms into four different regions of our supergalactic plane. To get more detail the density field has been smoothed with a Gaussian kernel of $1 \, h^{-1} \text{Mpc}$.

The top-left panel shows the complex velocity field in and around the Local Supercluster. The Virgo cluster is located just above the LG. Noteworthy is the presence of the Great Attractor region and its influence on the velocity field. It can be noticed that at the location of the LG there is a very pronounced velocity shear pattern, exerted by the influence of the GA and PP supercluster (e.g. see...
Figure 9.5 — DTFE velocity-divergence field projected along the \( z \)-supergalactic plane. The thin slice corresponds to the one presented in Fig. 9.3. The velocity-divergence is in units of the Hubble parameter. The color bar indicates the plotted velocity-divergence scale.

Chapter 5). Other shear patterns are easily recognized. An example is the region located between the Coma cluster and the Centaurus wall. The velocity field around the Centaurus wall clearly traces such filamentary structure. A prominent flow can also be observed near the P-I-T complex. The combined action of the nearby expanding void and the gravitational attraction of the heavy matter concentration itself generate a massive stream towards the latter. The top-right hand panel depicts how the Coma cluster, embedded within the Coma wall, distorts the velocity field in its surroundings. Infalling velocity patterns follow the density distribution. The shear pattern at the bottom-left corner is the response to the contrasting matter distribution around this region.

The bottom-right frame concerns the Perseus-Pisces supercluster and Cetus wall. Infalling velocity patterns following the cluster and filamentary structure show a clear dynamical connection between these two structures. Their gravitational influence can be recognized along the whole zoomed region. The velocity field around the underdense region located at \([SGX, SGY] \approx [45, -60] \text{ h}^{-1}\text{Mpc}\) is completely distorted by these two massive structures. At the top-left corner (near the LG location) a shear
9.4. DTFE RECONSTRUCTION OF THE PSCZ DENSITY AND VELOCITY FIELDS

Figure 9.6 — DTFE velocity shear field projected along the \( z \)-supergalactic plane. The slice corresponds to the one presented in Fig. 9.3. We have plotted the velocity shear amplitude in units of the Hubble parameter. The color bar indicates the plotted scale.

Pattern can also be recognized.

Finally, the bottom left-hand frame zooms in on the Sculptor void. The lowest measured DTFE density contrast value (smoothed at \( 1 \ h^{-1}\text{Mpc} \)) in this region is \( \approx -0.78 \) at the deepest of the void\(^2\). At the smoothed scale of \( \sqrt{5} \ h^{-1}\text{Mpc} \) the DTFE density threshold is \(-0.74\), in agreement with the reported value by Plionis & Basilakos (2002) of \(-0.69\). The velocity field of this almost “empty” expanding region is distorted by the surrounding matter distribution. Small, yet detectable, distortions delineate the dynamical borders of this void with its surrounding matter distribution, the Sculptor wall.

\(^2\) The theoretical expectation for a mature and shell-crossing void, with a characteristic inverse tophat density profile, is an underdensity of \( \Delta \approx -1. + (1./1.7)^3 \).
9.5 DTFE velocity-gradient related fields

Here we reconstruct and present these quantities for the same plane projection (z-supergalactic plane) as in Fig. 9.3.

In order to compute the full spatial peculiar velocity field it is necessary to calculate the nine elements of the velocity gradient matrix. At each Delaunay tetrahedron the velocity field gradient is constant. Therefore, the recovered velocity divergence, shear and vorticity are not continuous. However, they are volume-weighted and fully volume-covering. Having smoothed the velocity divergence, shear and vorticity fields with the same kernel as in the case of the reconstructed density field has provided them with the sense of continuity seen in Figure 9.5 & 9.6.

9.5.1 The DTFE PSC\textsubscript{z} velocity divergence

The velocity divergence computed with DTFE is the sum of the trace of the velocity-gradient matrix given by:

$$\nabla \cdot \mathbf{v} = \left( \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} \right).$$  \hspace{1cm} (9.2)

The velocity divergence and the density contrast are related via the continuity equation (Peebles 1980). In the linear regime this is a strict linear relation. In the quasi-linear and mildly nonlinear regime the one-to-one correspondence between the two fields remains intact, be it that it involves higher order terms (see Bernardeau et al. 2002, for an extensive review about the topic). The density and velocity-divergence maps will therefore look very similar. This is why the density map and the velocity-divergence map are almost each other negative (see Figure 9.3).

The expanding and contracting modes of the velocity field can be discerned in Figure 9.5 where we have plotted the normalized divergence $\theta$ of the velocity field, $\theta = (\nabla \cdot \mathbf{v})/H_0$. Here $H_0$ is the Hubble constant\(^3\). Positive divergence modes, indicated by red to yellow tones, mark the location of the expanding voids. Clearly recognizable are the Sculptor and Fornax voids and the underdense regions around the Coma cluster. Other expanding regions like the one above the Camelopardalis cluster located at ([SGX, SGY] \approx [40, 45] h^{-1}\text{Mpc}) and the one at the right of the Cetus wall at ([SGX, SGY] \approx [50, -55] h^{-1}\text{Mpc}) are also notorious.

By constrast, negative divergence modes indicate infalling motions. These modes delineate the peaks of the density field. The largest contracting regions, represented by the blue tones are clearly identified with the most massive structures located along this slice. The H-C is the most prominent infalling region. Other clusters such as Virgo, Camelopardalis, Coma, PP, Cetus wall, P-I-T, and partly Shapley can be recognized.

The green scale contours delineate density regions just above the mean density contrast. Notice how all large scale structures are connected through a filamentary velocity-divergence pattern.

9.5.2 The DTFE PSC\textsubscript{z} velocity shear

Velocity shear can be due to the intrinsic asphericity of evolving structures and/or due to the external tidal stresses exerted by the surrounding large scale matter distribution. Bond, Kofman, & Pogosyan (1996) (see also van de Weygaert 2002) pointed out that the filamentary web is a consequence of the distribution and spatial coherence of the shear field in the medium. Hence, shear is expected to be present at linear, quasi- and non-linear regions. The recovered shear from the processed DTFE velocities corresponds to the symmetric traceless part of the velocity-gradient matrix given by

$$\sigma_{ij} = \frac{1}{2} \left( \frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial x_i} \right) - \frac{1}{3} (\nabla \cdot \mathbf{v}) \delta_{ij}. $$ \hspace{1cm} (9.3)

\(^3\)We have adopted a value of $h = 0.7 \ (H_0 = 100 \ h \text{ km s}^{-1} \text{ Mpc}^{-1})$ in agreement with the last reported measurements (e.g. Lahav & Liddle 2004).
9.6 Conclusions

The DTFE reconstruction of the PSCz catalog has been shown to represent a marked improvement over the previous field interpolations of B99 and Schmoldt et al. (1999). One of the main advantages of using DTFE is its large dynamic range for tracing small and large scale characteristics. DTFE traces underdense regions better and deeper. In addition, it clearly resolves high-density regions on small scales.

The estimated velocity field of B99 and Schmoldt et al. (1999) did not show small scale details because of their employed interpolation techniques. The diverse features of the linear velocity field have been exposed in detail by the DTFE technique. The self-adaptive nature of DTFE tracing the galaxy distribution without losing resolution and preserving the characteristics of both large and small scale contributions are also reflected in the reconstructed velocity field. The reconstructed DTFE velocity field has unveiled the expected infall, expansion and shear motions in our nearby universe.

One of the main virtues of the method is its ability to compute any quantity related to the velocity-gradient matrix in a very straightforward manner. The divergence and shear maps showed a great consistency with the reconstructed density field. Large scale structures can be recognized by their gravitational distortions reflected in the divergence and velocity shear components.

In order to explore in more detail the velocity field of our nearby universe, it would be desirable to compute the quasi-linear contributions to the velocity field. Techniques like the FAM–z of Branchini et al. (2002) combined with the DTFE algorithm applied to the forthcoming surveys such as 6dF will help us to understand more the dynamics of our nearby universe.