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The cosmic flow in the Local Supercluster:
Tracing PSCz tidal influence through optimized Least Action Principle

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Abstract. We assess the extent to which the flux-limited PSCz redshift sample is capable of accounting for the major share of mass concentrations inducing the external tidal forces affecting the peculiar velocities within the Local Supercluster (LS). The investigation is based upon a comparison of the "true" velocities in 2 large N-body simulations and their reconstruction from "observation-mimicking" mock catalogues. The mildly nonlinear "mock" LS and PSCz velocities are analyzed by means of the Least Action Principle technique in its highly optimized implementation of Nusser & Branchini's Fast Action Method (FAM). For both model N-body Universes, we conclude that the dipolar and quadrupolar force field implied by the PSCz galaxy distribution would indeed be sufficiently representing the full external tidal force field[1].
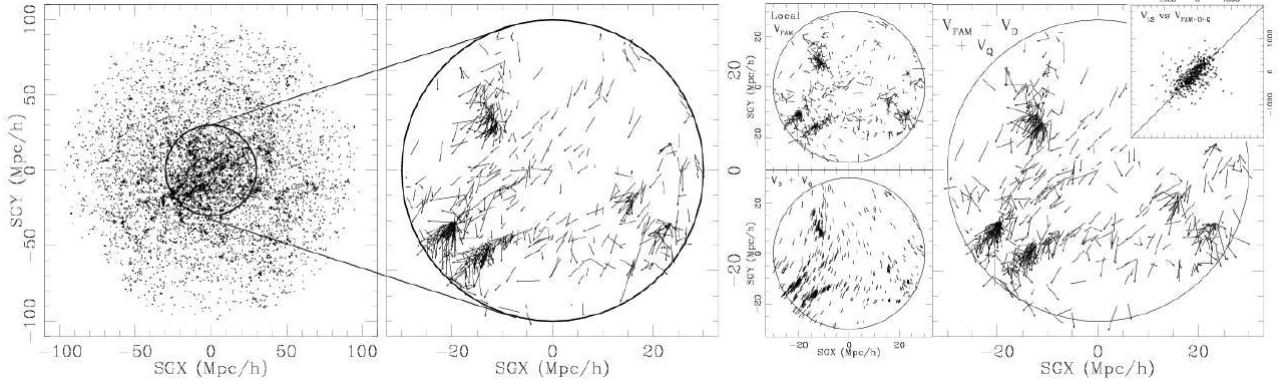
Figure 1: Left: The analyzed "mock" Local Supercluster + PSCz galaxy distribution, with the sample of "mock" measured Local Supercluster peculiar velocities. Right: FAM analysis of local velocity field: restricted to local cosmic volume (top left). Including full PSCz volume: external dipole and quadrupole components (D-Q, bottom left). Total of locally induced velocities + D-Q external contribution (right frame): agreement with full "mock" velocities illustrated by scatter plot (insert).

1 Cosmic flows: internal and external forces

Migration flows of cosmic matter are one of the major physical manifestations accompanying the emergence and growth of structure out of the virtually homogeneous primordial Universe. Within the gravitational instability scenario of structure formation, the displacements are the result of the cumulative gravitational force exerted by the continuously growing density surpluses and deficits throughout the Universe. This establishes a direct causal link between gravitational force and the corresponding peculiar velocities.

Given a suitably accurate measurement of peculiar velocities within a well-defined "internal" region of space, V_{int}, we may invert these velocities, relate them to the gravitational force and whence trace and possibly even reconstruct the source of the measured motions. The gravitational force $\mathbf{g}(\mathbf{x})$,

$$\mathbf{g}(\mathbf{x}) = \mathbf{g}_{int}(\mathbf{x}) + \mathbf{g}_{ext}(\mathbf{x}) = \mathbf{g}_{int}(\mathbf{x}) + \mathbf{g}_D + \mathbf{Q_g} \cdot \mathbf{x} + \ldots \qquad (1)$$

is the netto sum of the individual contributions from each cosmic location. We decompose the total integrated gravity $\mathbf{g}(\mathbf{x})$ into an internal component $\mathbf{g}_{int}$, representing the integrated contribution from the density fluctuations within V_{int}, and the externally induced gravitational force $\mathbf{g}_{ext}$, generated by the fluctuations outside V_{int}. Often details of the external matter distribution are not relevant for the dynamics in some local region, so that sizable external force contributions are usually restricted to the

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[1]a complete version of this work is reported in Romano-Díaz, E., Branchini, E., van de Weygaert, R., 2001, MNRAS., *submitted*

dipole and quadrupole components in $\mathbf{g}_{ext}$, $\mathbf{g}_D$ responsible for its "bulk" motion and $\mathbf{g_Q}(\mathbf{x}) = \mathbf{Q_g} \cdot \mathbf{x}$, agent of the shear in the flow field. In principle involving the complete visible Universe, we expect significant contributions to be limited to some finite volume whose typical scale will be that of the largest cosmic structures. Although not exactly known, its size may amount to $\approx 100 - 200h^{-1}$Mpc.

2 External influences in the Local Supercluster: a "mock" experiment

We investigate the question of whether it is feasible to trace the distant sources that have a noticeable influence on the dynamics in our local Universe. Concretely, we focus our attention on the Local Supercluster, and address the issue whether we can infer the extent and configuration of the external gravitational forces influencing its dynamics and evolution. In addition, we then to seek to assess whether such a study provides sufficient information to identify the responsible structures and objects from the present generation (or shortly available) galaxy redshift samples. To assess whether a genuine observational study may yield conclusive evidence, we follow the approach of studying idealized model circumstances. Conclusions are obtained from a comparison of the full model circumstances with the predicted results from specially selected subsamples, moulded such that they resemble the observational circumstances. For our model Universes we take two large N-body simulations, one of a ΛCDM structure formation scenario, the other of a τCDM scenario (Cole etal. 1998).

Within each model, we *first* identify 10 "mock" Local Superclusters, volume limited samples of galaxies in a spherical volume of $30h^{-1}$Mpc radius resembling the Nearby Galaxy Catalogue (NBG). With these galaxy distributions at our disposal, we determine the galaxy velocities that would result when gravity would be solely the result of the internal mass distribution, i.e. assuming a perfectly homogeneous external mass distribution. The deviations of the predicted velocity field from the full velocities (here: the N-body models) must then be ascribed to external forces. In a *second* step we then try to evaluate where the most influential external sources may be located. To this end, we use the PSCz galaxy redshift survey as the template for our investigation of the dynamically relevant external Universe. For the purposes of covering uniformly all possible relevant matter concentrations, the 15,500 galaxies contained in this survey constitute an ideal sample. It is based on an objectively defined IRAS flux selection, forms a near perfect uniform flux-limited selection, has an excellent 84% sky coverage, and probes to a useful depth, $\sim 200h^{-1}$Mpc. On the basis of its selection criteria we also identify, along with the LS "mock" samples, 10 PSCz "mock" PSCz galaxy samples. The lefthand frame of figure 1 depicts one specimen of our "mock" samples, showing the total LS+PSCz "galaxy" sample and zooming in onto the "LS region", of which also the velocities are shown.

The Local Supercluster is a mildly nonlinear cosmic structure. Instead of using simple linear dynamics or the Zel'dovich approximation we therefore invoke the gravitational Least Action Principle (LAP, Peebles 1989) for properly (re)tracing the galaxy orbits. However, the initial LAP implementation, suited for small galaxy groups, is not adequate for our situation. The "mock" LS and PSCz galaxy samples involves so many objects that the calculation would be rendered impracticable. Possibly even more fundamental is its inability to deal well with a flux-limited sample like the PSCz one. Of key importance therefore is the use of the Fast Action Minimization (FAM) optimization developed by Nusser & Branchini (2000). Involving numerical, force evaluation and base function optimizations at various stages of the LAP technique, it allowed the large "mock" sample computations in our analysis.

The results are highly encouraging. The righthand frame of figure 1 shows (topleft) the FAM velocity field prediction for the LS restricted sample. Statistical analysis proved its incompatibility with the full velocity field. But when the PSCz sample is invoked significant differences vanish. Moreover, when restricting ourselves to the corresponding dipole and quadrupole contributions, evaluations on the basis of point-to-point velocity comparisons (see insert in large righthand frame) prove these to represent virtually the complete external contribution.

3 Conclusions: "what's in a game"

The FAM computations restrict themselves to the matter concentrations within the realm of the PSCz selections and prove that the implied velocities correspond extremely well with the full "model" velocities. In other words, the PSCz selections appear to comprise the source of the non-internally induced motions. Hence, when we would live either in a ΛCDM or τCDM Universe, and if the PSCz galaxies faithfully trace the underlying mass distribution, we may plausibly argue the sample to contain all locally relevant density concentrations. Moreover, almost all relevant contributions can be ascribed to the dipolar and quadrupolar anisotropy in the PSCz mass distribution.