Using Local Volume data to constrain Dark Matter dynamics

Q. Lannuzy (lannuzy@iap.fr), R. Mohayaee, S. Colombi, R. B. Tully
Institut d’Astrophysique de Paris, 98bis Bd Arago, 75014 PARIS, FRANCE
CNRs/Universite Pierre et Marie Curie

I will present here the Monge-Ampère-Kantorovich peculiar velocity reconstruction method applied to mock catalogs mimicking some observational biases encountered in real life. The method is then applied to a 3000 km/s deep galaxy catalogue to recover the peculiar velocities of these galaxies in our neighborhood.

I. Introduction

Okamoto: Recovering peculiar velocities of galaxies from their redshift position $z = H_0 \tau + g(x, z)$, with $g$ its comoving position, $v$ its velocity, $H$ the Hubble constant. Comparison to large Local Volume measurements may reveal new constraints on $H_0$.

Poster is organized as follows:

• Short presentation of the Monge-Ampère-Kantorovich Lagrangian reconstruction method + Algorithm.
• Test on large-scale simulations.
• Two examples of observational biases to which the method is sensitive:

1. Catalogue geometry limited by visibility of objects — general boundary problem (limited access to galaxy field and velocity field variance).
2. Volumetric distribution of the density mass, (i.e. $M < 10^{12} M_{\odot}$).

A direct application to NBG-3k follows, which shows the reconstructed velocities in our neighborhood.

II. The Monge-Ampère-Kantorovich (MAK) reconstruction

Theory

Motivation: Zel’dovich approximation (Zel’Dovich, 1970), which is the first development order in the Lagrangian perturbation theory, works really well on Large scales. It leads to considering the displacement field of the dark matter from initial conditions is deriving from a current potential. We remind that in general Zel’dovich approximation writes $q_{ij} = -\nabla_{l} B_{ij}$, with $B_{ij}$ the current potential. EDV: the linear growth factor.

Hypothesis: the displacement field traced by galaxies is deriving from a current potential.

Problem: Find the corresponding displacement field given an initial (homogeneous/density field and the current observable density field $\nabla\Phi(x)$) (¹).

→ Brenner et al. (2003) determined the maximum of $S_{\Phi}$

$S_{\Phi} = \sum_{(x, q_{ij})} S_{q_{ij}} (x)$

(1)

according to $\Phi$ to solve the above problem, with $\Phi$ representing homogeneous sampling of the mass distribution, where the $x_i$ are the current positions of these particles, and the $q_{ij}$ are distributed on a regular grid. An illustration of the minimization is given Fig. 1.

Algorithm

Minimization of Eq. (1) is computationally difficult problem (time complexity $O(N^2)$). To overcome it, Brethorst (1978). "Active" algorithm is minimizing cut-off problems and can be adapted to minimization of $S_{\Phi}$ (time complexity in $(N^3)$) (²). Particles, put at $\Phi_i$, compete against other particle $j$ to acquire the minimum of the potential. $H_0$ goes to $0$ if the representation is possible globally. When the equilibrium is reached, the current assignment corresponds to the solution of minimizing $S_{\Phi}$ (3). However efficiency depends a lot on the degeneracy of the solution.

Implementation

On Dual-core AMD Athlon 64 4800+ 3GHz implementations, 79,000 particles $(1000 \times 1000 \times 1000)$ took $20$ min.

3D velocities of the same data. Algorithm has also been implemented but only performant for sufficiently large number of particles or dense problems ($10^9 < 10^{12}$ particles).

III. Applications to cosmological simulation.

Figure 2: Top left: A slice of the density field of the AMOK simulation ($\Delta_x = 0.3333 \times 0.3333 \times 0.3333$) that is used for the tests (color coding is by scale). Top right: Velocity field of the same simulation rendered using MAK reconstructed velocity field of the same slice. Linear color scale: dark blue=9000 km/s , white=+9000 km/s, red=−9000 km/s. Bottom left: Scatter distribution showing the scatter distribution of individual reconstructed velocities of haloes in redshift space, R lifetimes. Bottom right: Result of a reconstruction of a mock catalogue placed randomly in the catalogue. Center panels: Results obtained when one tries to find an optimal compromise between disintegrating the mass in haloes and randomly in the background field (hence $0<\Omega<1$ and the rest in the background).

Figure 3: Reconstruction setup when one does not know the Lagrangian density of a galaxy (bullet particle) but galaxy (Zel’dovich approximation).

$\nabla\Phi(x)$ (MAK reconstruction). One assumes that the geometry of the catalogue is conserved between $t = 0$ and $t = t_s$.

$M$: magnification $\Psi(x)$.

The MAK reconstruction is achieved between the catalogue and the right crystal plane (right: MAK reconstruction).

The catalogue is padded homogeneously to smooth out boundary effects (crystal box). The padded catalogue is MAK reconstructed using the right crystal plane.

Finite volume catalogue $\rightarrow$ unknwon catalogue (un鹏known large-scale tidal field) $\rightarrow$ mass reconstruction of trajectories of galaxies.

Scattering of the gravitational field by fluctuations of the density field has 2 consequences:

1. Different correction scheme to handle edge effects should not cause discontinuities at the edge.
2. Scatter between mass-reconstructed MAK solution (due to edge effects) and the unaffected solution may be big ($\geq 20$ Mpc/h).

Proposed solutions: Padding the original "spherical" catalogue as illustrated in Fig. 3 and assuming a Lagrangian domain of the same size $\rightarrow$ real space reconstruction results are given in Fig. 5.

Result: Given in Fig. 4. The central part of the velocity field is well reconstructed in both cases (Nabov and PadloDom). Individual velocity comparison shows that NabovDom is still a worse boundary condition than PadloDom.

IV. Outer boundary / Recovering Lagrangian domain

Figure 4: Outer boundary problems while doing finite volume catalogues. Color scale is the same everywhere (dark blue=−1000 km/s, white=+1000 km/s). Top left: Density field of the mock catalogue (log scale). Top right: Standard velocity field, smoothed with a 5 Mpc/h Gaussian window. White circle: Volume enclosed by the 4 Mpc/h sphere centered on the observer. Middle left: PadloDom velocity field, smoothed equally. Middle right: NabovDom velocity field, smoothed equally. The upper two panels are the center plots of reconstructed velocities of simulated haloes. Only objects inside the white circles have been represented. Lower left: NabovDom redshift reconstruction. Right: PadloDom redshift reconstruction.

V. Undetected diffuse mass

Figure 5: Diffuse mass. In this plot, we represent the fraction of the cluster mass below two mass resolution for WMAP7 type cosmology ($h_0=0.7, \sigma_8=0.8$). A SHCore power spectrum has been used. The curvature of the Universe is kept that while $\sigma_8$ increases, the fraction is plotted for two mass resolution: $2 \times 10^{13}$ M$_{\odot}$ and $10^{14}$ M$_{\odot}$ ($\pm 5\times 10^{15} L_{\odot}$). The fractions of mass below both of these limits is still considerable.

All in haloes
Optimal compromise
All to background

Figure 6: Fjere catalogue are separated in two phases: the halo catalogue ($M \geq 10^{14} M_{\odot}$) and the background field ($M < 10^{14} M_{\odot}$) representing 40% of the total mass. The higher resolution of particles represents the brightness component of a slice of the reconstructed velocity field smoothed in the same way, for different corrections of the diffuse mass. The lower resolution of particle gives the scatter distribution of individual reconstructed velocities of haloes in redshift space, R lifetimes. Results: Results for a reconstruction with background field composed of particles placed randomly in the catalogue. Center panels: Results obtained when one tries to find an optimal compromise between disintegrating the mass in haloes and randomly in the background field (hence 0<\Omega<1 and the rest in the background).

Figure 7: Top panel: Reconstructed and measured individual velocities. There is a preliminary result and a measurement is likely to be still based on the moment. Lower left: 3D velocities projected along the SGZ axis. Lower right: Scatter plot showing that the reconstructed displacement field $\xi_{ijk}$ is really correlated with the one obtained through direct measurements $\xi_{ijk}$. We remind that the displacement field is proportional to the velocity field in Zel’Dovich approximation. However, a scatter effect is still present. This reconstructed velocity has been produced assuming $\phi=0$ for objects of the NBG-3k catalogue.

VI. Direct Application to NBG-3k (Tully et al., 2007)

IV. Conclusion

Discussions:

• Simple padding scheme shows that velocities may be correctly reconstructed (but a buffer zone of 20 Mpc/h is needed).

• Diffuse mass may be accounted for but more tests on different cosmological simulations are needed to calibrate the way this mass is partitioned between haloes and background.

Problems & Prospectives

Look for better $M_{\odot}$ to have a higher correlation between reconstructed and measured velocities.

Better velocity reconstruction integrating more nonlinearities due to geostationary orbits (i.e. adding realistic the Euler-Poisson problem, in preparation).

References

Brethorst D. P., 1979, A Deterministic Algorithm for the Assignment Problem, MIT Prentice, Cambridge, MA
Tully B. R., 1977, AJ., 86, 84

1 I. Introduction

2 III. Applications to cosmological simulation.