The effect of the Zone of Avoidance on the measurement of the acceleration of the Local Group

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One of the main assumptions of the standard family of cosmological models is the homogeneity of the Universe. But are the galaxies really uniformly distributed in the sky? Observations of the clustering dipole in the galaxy distribution can inform us about the movement of our Galaxy with respect to the rest–frame density field of galaxies and dark matter, and this measurement is independent of the estimations based on the Cosmic Microwave Background (CMB) dipole. However, all–sky galaxy surveys are needed for measuring this dipole. Is it possible to overcome the problems caused by the Zone of Avoidance?

1 Introduction

The main goal of our work is to determine if the Cosmological Principle – i.e. the assumption that the Universe is homogeneous and isotropic on large scales – is valid. From various galaxy surveys, such as e.g. the 2dF Galaxy Redshift Survey or the Sloan Digital Sky Survey, at the first glance we get the picture of clear inhomogeneities in the local matter distribution. However, when averaged over increasingly larger scales, these inhomogeneities decrease and disappear. There is no evidence of structures on the scales larger than 100 Mpc. There remains an open question whether there exists any scale on which the matter distribution in the Universe is truly homogeneous and isotropic. In the same time we are aware that our Galaxy is a part of a larger scale structure which has its own motions with respect to the surrounding structures. The well-known CMB dipole is interpreted as a peculiar velocity of the Local Group of galaxies with respect to the CMB. The measurement of the same dipole in the distribution of galaxies, i.e. a clustering dipole, is a measure of the acceleration of the Local Group induced by the gravitational pull from the surrounding structures (Bilicki et al., 2011; Erdoğdu et al., 2006). We want to answer the following question: is the clustering dipole inferred from galaxy surveys consistent with the CMB dipole?

The calculation of the clustering dipole is based on all-sky galaxy catalogues under the assumption that the visible matter is a good tracer of the real density field. Then we can calculate the dipole moment of all the sources in the catalogue and the possible convergence of its direction indicates the distinguished direction in our Local Universe. The vital problem in calculating the clustering dipole is presented by the existence of the Zone of Avoidance (ZoA). Stars and interstellar dust in the plane of our Galaxy obstruct the view of a significant part of the extragalactic sky,

resulting in the creation of the so–called ZoA. The ZoA covers around 20% of the sky and its shape and area depend mainly on the catalogue used and the wavelength of the observations. To calculate reliably the clustering dipole of the galaxies, an all–sky survey is needed. In practical calculations, this problem is usually addressed by filling the ZoA artificially. The main goal of this work is the analysis of the influence of the ZoA on the calculation of the clustering dipole.

2 The Data & Method

We based our calculations on the Two Micron All-Sky Survey (2MASS, Jarrett et al., 2000) data. 2MASS contains 1.6 mln sources and covers 99.998 % of the sky. It is complete for the sources brighter than $K_{\mathrm{s}} \approx 13.5$ mag.

In order to study the effects of filling the ZoA and to estimate the statistical errors, we complemented the 2MASS data with the Millennium XXL Simulation (Smith et al., 2017). Millennium XXL is an N-body simulation with more than 58 mln sources. We calculated the clustering dipole on both of these data sets, as a function of the limiting magnitude. We used several different methods to populate the ZoA, among which the main used ones are: (1) cloning the strips adjacent to the ZoA with mirror–like reflections; (2) similarly as above: cloning every second galaxy from twice as big adjacent strips; (3) random filling. Our aim in this work is to determine if the dipole measurement depends on the definition of the ZoA and on the way it is reconstructed, as well as to establish how reliable the dipole estimates are after the ZoA is artificially filled in. We considered four versions of the ZoA, varying in area and shape. For 2MASS data one of the definitions is omitted, as the true ZoA visibly extends beyond that definition.

Considered definitions of the ZoA:

- version A: $|b| < 5^\circ$ (Galactic plane); $|b| < 10^\circ$ for $l < 30^\circ \vee l > 330^\circ$ (bulge)
- version B: $|b| < 10^\circ$; $|b| < 15^\circ$ for $l < 30^\circ \vee l > 330^\circ$
- version C: $|b| < 5^\circ$ for $l < 135^\circ \vee l > 225^\circ$; $|b| < 10^\circ$ for $l < 75^\circ \vee l > 285^\circ$; $|b| < 15^\circ$ for $l < 30^\circ \vee l > 330^\circ$
- version D: $|b| < 5^\circ$; $|b| < 10^\circ$ for $l < 75^\circ \vee l > 285^\circ$; $|b| < 15^\circ$ for $l < 30^\circ \vee l > 330^\circ$

In order to determine if the galaxies are really uniformly distributed in the sky we used the following algorithm: (1) we used three methods mentioned above to reconstruct the ZoA; (2) we calculated the acceleration (value and direction) of the Local Group; (3) we calculated the misalignment angle – an angle between the CMB dipole and the clustering dipole; (4) we compared the results for different definitions of the ZoA and different methods of filling it in.

3 Preliminary results

We performed these tests on both the Millennium XXL Simulation, and on the real 2MASS data. Fig. 1 presents the dependence of the calculated dipole amplitude on the selected area of the ZoA. It is clearly visible that for both real and simulated data, the results depend quite significantly on the area of the ZoA. For 2MASS data the results vary within 7% of the mean, while for the Millennium XXL Simulation

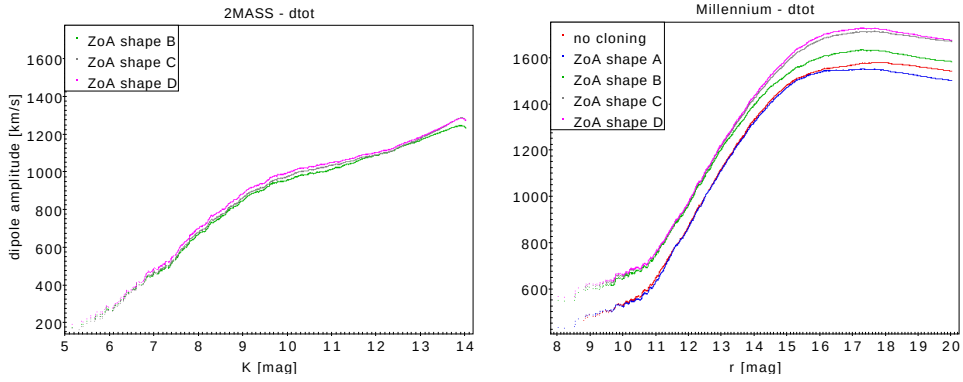

Fig. 1: The difference in the results (dipole amplitude vs magnitude) for 2MASS (left) and Millennium XXL (right); the colours indicate different definitions of the ZoA

the results vary within 27% of the mean. Moreover, it is visible that all curves, except for the blue one (ZoA shape A), show a systematic shift upward. The ZoA induced errors estimated e.g. by Erdoğdu et al. (2006) are on the level of 20%. Our analysis suggests that an additional uncertainty $\sim 27\%$ should be included into estimation made by those authors.

4 Conclusions

Calculating the clustering dipole of the galaxies based on all–sky surveys can provide us the means of verifying the validity of the Cosmological Principle. However, the realistic all–sky surveys are always flux–limited and suffer from the incompleteness caused by the Zone of Avoidance. In this paper we presented the tests of the methods of dealing with the latter as well as the preliminary results.

Presently being performed tests on the simulated catalogues (like Millennium XXL simulation) hold the promise of determining that dependence as well as establishing the most appropriate method of filling the Zone of Avoidance.

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