Towards the Local Group dipole measurement with Supernovae type Ia

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Together with our Local Group of galaxies, our Galaxy is moving towards nearby mass concentrations. Dipole observed in Cosmic Microwave Background is interpreted as the result of this motion. A similar dipole should be observed in the peculiar velocity of nearby galaxies. Such a dipole should be then observed in the distribution of local galaxies being supernova type Ia (SNIa) hosts. However, to make use of SNIa as the galaxy velocity field tracers, we need to account for a number of systematic errors. For this purpose, we create a set of mock catalogs of SNIa host galaxies from Millennium XXL simulation to assess its effect on the chances of recovery of the underlying galaxy velocity field. We present preliminary results of how realistic SNIa sampling affects the reconstruction of the galaxy velocity field based on them.

1 Introduction

The Local Group (LG) is moving in space due to the influence of the nearby mass concentrations such as Virgo cluster, Centaurus cluster, the great attractor and the Local Void (Tully, 2008) in resultant direction of the gravitational pull. The motion of the Local Group of galaxies can be measured from the dipole in the Cosmic Microwave Background (CMB) spectrum. This dipole is interpreted as the result of the Doppler boosting of the monopole caused by the Local Group motion relative to the nearly isotropic black-body field of the CMB. A shift can also be seen in the peculiar velocity field of local galaxies (Giovanelli et al., 1998; Dale et al., 1999). In principle, these two dipoles should converge.

Peculiar velocity of a galaxy is its velocity relative to the Hubble Flow. However, peculiar velocities of single galaxies can only be measured if their redshift-independent distance measurement are available. This is possible if SNeIa are used as standard candles. However, SNeIa are rare, and due to observational constraints (such as zone of avoidance, observations made in different fields with different timescales, etc.,) we have a very limited and biased sample of spectroscopically confirmed SNeIa. It poses a significant difficulty to make use of them to estimate velocity dipole of galaxies.

In this work, we focus on the effect of systematic bias in the existing SNeIa samples in order to recover peculiar velocity field of local galaxies. To assess the role of systematic bias, we create a set of mock catalogs of SNIa host galaxies from Millennium XXL simulation (MXXL).

2 Data and Method

We compile a sample of all known and spectroscopically confirmed SNeIa at redshift $z \leq 0.1$ from the following catalogs: Joint Light-Curve Analysis (Betoule et al., 2014), MLCS2k2 (Jha et al., 2007), Pantheon (Scolnic et al., 2018), and Cosmicflows-3 (Tully et al., 2016). Our combined sample contains 573 SNeIa. Each of these catalog uses different light-curve models to estimate the distance. To make our sample consistent, all measurements were homogenized with respect to the cosmological model (ΛCDM model with parameters $\Omega_{\rm m} = 0.308$, $\Omega_{\rm r} \sim 10^{-4}$ and $\Omega_{\Lambda} = 0.691$) and with respect to different light-curve models (to SALT2 model) according to a method given by Courtois & Tully (2012).

We extract properties of host galaxies of our SNIa galaxy sample from a catalog compiled by Childress et al. (2013). We find that the stellar mass range of host galaxies of our sample is between $10^8 - 10^{12}$ $\rm M_{\odot}$, and their apparent B-band magnitudes are between 9-20 mag. According to Childress et al. (2013), SNIa host galaxies seem to be typical of the average optically-selected galaxy population, which means we do not need to apply any additional constraints on host galaxy properties.

To create a mock catalog of SNIa host galaxies, we make use of the MXXL simulation (Angulo et al., 2012) at $z{\sim}0$ with box length of $500\,{\rm Mpc}\,h^{-1}$. MXXL is the high resolution N-body simulation which follows nonlinear growth of the dark matter structures in the ΛCDM cosmology. Its simulated volume, $4.11\,{\rm Gpc}^3$ is equivalent to that of the whole universe up to $z \sim 0.72$. We use the properties of SNIa host galaxies discussed above and their distributions in order to create a mock catalog of 65,328 galaxies. A LG-like observer is located at the center of the box, with added reflex motion of $V_{\rm obs}$= 635 km s^{-1} towards the direction of (269°,28°). expected to observe from observer‘s reference frame.

To assess the influence of the systematic observational effects present in our SNIa sample on the cosmic dipole, we create four sets of mock catalogs: (1) A full reference catalog of all potential SNIa hosts, containing all mock galaxies following the observed distribution of a real SNIa sample around our mock LG-like observer; (2) 10,000 mock catalogs mimicking *sparse sampling* effect, all containing 573 galaxies randomly chosen from a reference sample; (3) 10,000 mock catalogs with a realistic *photometric mask*, i.e. covering only parts of the sky from which SNIa data are available; (4) 10,000 mock catalogs with *realistic SNIa sampling*, of randomly chosen 573 galaxies in the realistic photometric masks.

In order to estimate reflex motion of the observer, we use a dipole estimator that maps the sample space to a set of dipole models using Nelder-Mead simplex where the free variables are dipole's velocity components in the Cartesian coordinate system. Then cumulative difference between galaxy's peculiar velocity and contribution of a given dipole model in the direction of given galaxy is computed. The reflex motion of the observer with respect to the whole sample is computed by χ^2 minimization of the dipole vector with respect to the mock sample‘s peculiar velocity field in the observer‘s frame.

3 Preliminary Results and Conclusions

Components of velocity vectors of an LG-like observer in all four varieties of our SNIa-like mock catalogs, measured by a method outlined above, in the Catesian coordinates are presented in Fig.1.

Figure 1 demonstrates that sparse sampling alone, as expected, does not cause any systematic change of the value - it only results in a large scatter. Taking into account a realistic photometric mask, i.e. the fact that only some parts of the sky

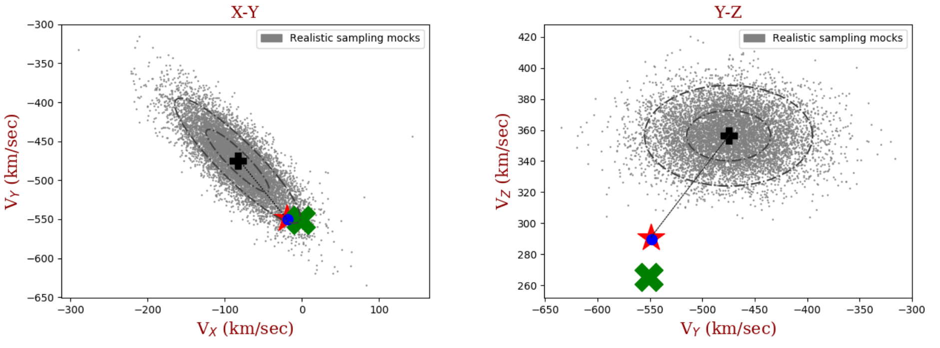

Fig. 1: Measured components of velocity vectors of an LG-like observer with respect to simulation box in SNIa-like mock catalogs in the Cartesian coordinates. Grey dots correspond to the observer‘s velocity vector in different mock catalogs with realistic SNIa sampling (case (4)). A black ”plus” represents the corresponding mean values, and ellipses represent the 1-σ and 2-σ confidence regions of the estimated dipole. The large red star indicates the velocity measured in the reference catalog (case (1)). The blue circle and green cross correspond to the mean velocities measured in the mock catalogs with sparse sampling applied (case (2)) and mock catalogs with photometric mask applied (case (3)), respectively. A dotted line indicates the shift of the estimated dipole with respect to reference value.

are observed, introduces a small bias, of the order of 20 km s^{-1}, on some velocity components. However, a much stronger bias results from the fact that these different parts of the sky are observed by different observing campaigns which results in significantly different object densities in them. In sum, in the most realistic case of mock catalogs, case (4), the dipole components are shifted from the reference $\mathbf{V}_{\rm obs}$=(-9.78, -560.58, 298.11) km s^{-1} to $\mathbf{V}_{\rm bias}$=(-83.31, -474.9, 356.38) km s^{-1} . It implies that instead of a dipole velocity of 635 km s^{-1} towards (269°, 28°) we measure a lower value 599.57 km s^{-1} towards (260.05°, 36.47°). The dispersion in the dipole components due to sparse sampling is (43.46, 37.39, 16.15) km s^{-1}.

The main conclusion from these results is that the measurement of the cosmic dipole from the SNIa data, in spite of all observational limitations, is not impossible - the values measured in mock samples with realistic observational constraints are biased, but not very far from reference values. Moreover, the bias can be modeled. Thus, in the next step of our work we plan to design and test an appropriate weighting scheme to mitigate the observational biases and to be able to recover the cosmic dipole from the real SNIa data.

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