The cosmological bulk flow in QCDM model: (In)consistency with ΛCDM

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ABSTRACT

We study the bulk flow of the local universe using Type Ia supernova data by considering a class of cosmological model which is spatially flat, (FRW) space-times and contains cold dark matter and Q component (QCDM models) of the fluid as a scalar field, with self interactions determined by a potential \( V(Q) = V_0 \exp(-\lambda Q) \) evolving in Universe. We use different cumulative redshift slices of the Union 2 catalogue. A maximum-likelihood analysis of peculiar velocities confirms that at low redshift \( 0.015 < z < 0.1 \), bulk flow is moving towards the \((l; b) = (302^\circ \pm 20^\circ; 3^\circ \pm 10^\circ)\) direction with \( v_{\text{bulk}} = 240 \pm 25 \text{ km s}^{-1} \) velocity. This direction is aligned with direction of (SSC) and agreement with a number previous studies at \((1 - \sigma)\), however for high redshift \( 0.1 < z < 0.2 \), we get \( v_{\text{bulk}} = 1000 \pm 25 \text{ km s}^{-1} \) towards the \((l; b) = (254^\circ \pm 16^\circ; 6^\circ \pm 7^\circ)\). This indicates that for low redshift our results are approximately consistent with the ΛCDM model with the latest WMAP best fit cosmological parameters however for high redshift they are in disagreement of ΛCDM and support the results of previous studies such as Kashlinsky et. al, which report the large bulk flow for the Universe. We can conclude that, in QCDM model, at small scales, fluctuations of the dark energy are damped and do not enter in the evolution equation for the perturbations in the pressureless matter, while at very large scales \((\sim 100 h^{-1} \text{ Mpc})\), they leaving an imprint on the microwave background anisotropy.

Keywords: Peculiar velocity, Dipole fit

1. INTRODUCTION

The Dipole Anisotropy (DA) is the best interpreted as motion of our Local Group (LG) with amplitude of \( 627 \pm 22 \text{ km s}^{-1} \), with respect to the Cosmic Microwave Background (CMB) towards preferred direction \((l; b) = (276^\circ \pm 3^\circ; 30^\circ \pm 3^\circ)\) in galactic coordinates (Kogut et al 1993). The measurements of the dipole anisotropy of the cosmic microwave background (CMB) have a long history (Lineweaver 1996). The first measurement was made by (Conklin 1969) using a ground-based differential radiometer working at 8 GHz and confirmed by the results of (Henry 1971). These studies followed by several studies (Lineweaver 1996) and consequently more precise determination was provided by (Smoot et al 1977). It was suspected that the gravitational attraction towards a nearby overdensity might be responsible for the LG motion. In this respect, the studies was focused on investigation the dipole induced by the gravitational influence of structures in our Local Universe and comparison it with CMB dipole. The first attempt was made by (Yahil et al 1980) using the Revised Shapley-Ames (RSA) catalog. This effort was traced by several studies (Davis et al 1982); (Davis & Peebles 1983); (Shaya 1984); (Yahil et al 1986); (Aaronson et al 1986); (Vilumsen & Strauss 1987); (Dressier et al 1987); (Lynden-Bell et al 1989); (Robinson et al 1990); (Lahav et al 1990); (Strauss et al 1992); (Hudson et al 2004).

At first, it was thought that the virgo cluster might be the source of this motion, however the direct measurements of the Virgocentric flow showed that this motion is not directly pointed at Virgo, and further regions of over density are required to fully explain the DA (Davis & Peebles 1983) and (Vilumsen & Strauss 1987). As pointed out by (Shaya 1984); (Tammann & Sandage 1985); (Aaronson et al 1986), the vector difference between Virgocentric flow and the
DA points in the general direction of the Hydra-Centaurus region. This indicates that the Local Group is feeling the attraction of its nearest mass concentration, the Hydra-Centaurus supercluster. Additional analysis by (Lahav et al. 1990) showed that the general mass distribution within a radius of $4000\text{km/s}$ might be responsible for the acceleration of the Local Group. Fuller sky coverage later revealed disconcertingly large positive velocity residuals (motion away from the observer) in the Hydra-Centaurus region [e.g., (Dressier et al. 1987)]. If Hydra-Centaurus is moving with respect to the CMB, then it cannot be the sole source of the observed DA, and a more distant mass concentration is required if the motion is gravitational in origin. More analysis by, (Lynden-Bell et al. 1988) led to a model in which bulk flow was replaced by flows that are driven by a rather large mass concentration (the “Great Attractor”) which lies beyond Hydra-Centaurus at a kinematic distance of $4350\text{km/s}$. Thus, the Local Group feels the accelerations of both the Virgo Cluster and the GA. A Large number of studies confirm that one might need to go well beyond $150\text{km/s}$ in order to fully recover the dipole motion (Lavaux et al. 2010); (Shapley 1930); (Scaramella et al. 1989); (Raychaudhury et al. 1991).

Over larger distances, (Kashlinsky et al. 2008) reported a coherent bulk flow out to $d \geq 300\text{km/s}$ by analyzing the X-ray galaxy clusters using kinematic Sunyaev-Zeldovich (kSZ) effect. In their latest results (Kashlinsky et al. 2008)-(Kashlinsky et al. 2012), the bulk flow was found pointing to $(l, b) = (283^\circ \pm 14^\circ, 12^\circ \pm 14^\circ)$ with the peculiar velocity up to $1000\text{km/s}$ at the scales up to $\sim 800\text{km/s}$. A bulk flows with this amplitude on such a large scale can not be fully identified. For example, (Kocevski & Ebeling 2006) found that the GA only accounts for 44% of the dipole anisotropy in a large X-ray cluster sample, with the rest evidently caused by more distant sources such as the Shapley Supercluster (SSC) at a distance of $105 - 165\text{km/s}$ ($0.035 < z < 0.055$) in the direction $(l, b) = (306.44^\circ, 29.71^\circ)$. A Large number of studies confirm that one might need to go well beyond $150\text{km/s}$ in order to fully recover the dipole motion (Lavaux et al. 2010); (Shapley 1930); (Scaramella et al. 1989); (Raychaudhury et al. 1991).

The other intriguing feature of slowly rolling quintessence (the “Great Attractor”) which is that it behaves like variable cosmological constant (Ratra & Peebles et al. 1988), slowly evolve with time and to the lowest order approximation, dark energy behaves like a cosmological constant (Its EOS, $w = \frac{P}{\rho} \approx -1$). The Klein-Gordon equation of the quintessence field is

$$\ddot{Q} + 3H\dot{Q} + \frac{dV}{dQ} = 0$$  

The evolution equations for the model are

$$H^2 = \frac{\kappa^2}{3}(\rho_\gamma + \frac{1}{2}Q^2 + V)$$

$$\dot{H} = -\frac{\kappa^2}{2}(\rho_\gamma + p_\gamma + \dot{Q}^2)$$

$$\dot{\rho}_\gamma = -3H(\rho_\gamma + p_\gamma)$$
2. THEORETICAL CALCULATION OF BULK FLOW

For the study of anisotropies and bulk flows present in SN Ia data the dipole fit (DF) method based on, (Bonvin et al 2006) is used to determine the bulk flow velocity in redshift shells

\[ d_L(z, v_{bulk}, \theta) = d_0^L(z) + d_{dipole}^L(z, v_{bulk}, \theta), \]

where

\[ d_0^L(z) = c(1 + z) \int_0^z \frac{dz'}{H(z')}, \]

\[ d_{dipole}^L(z, v_{DF}, \theta) = \frac{v_{DF}(1 + z)^2}{H(z)} \cos(\theta). \]

Several authors have attempted to derive an expression for luminosity distance in a perturbed RW Universe. (Sasaki 1987) has studied the luminosity distance as function of redshift for a general perturbed space-time. Sasakis analysis gave an explicit expression for an Einstein de-Sitter universe. An explicit expression for the luminosity distance was derived by (Pyne & Birkinshaw 2004) and was later corrected by (Hui & Greene 2006). In this study, they have derived an expression for the luminosity distance fluctuation that is accurate to first order, and has a number of terms which can be loosely divided into four categories: peculiar motion (first line), gravitational lensing (second line), gravitational redshift (third line) and integrated Sachs - Wolfe (fourth and fifth lines) (see Eq. (C21)) of (Hui & Greene 2006). They have shown that among all first order terms, the peculiar motion and lensing terms dominate in realistic applications[ see (Eq.18) of (Hui & Greene 2006)]. This is because we are generally interested in fluctuations on scales smaller than the horizon. The high redshift SN surveys generally cover a small fraction of the sky while the low redshift surveys, even though they cover a significant fraction of the sky, do not extend out to a sufficient depth to be sensitive to horizon scale fluctuations. Further discussions can be found in [Appendex C of (Hui & Greene 2006)].

The above studies provided a unified treatment valid at both low and high redshift and revealed clearly how the lensing and peculiar velocity effects come to dominate at high ($z > 0.1$) and low redshifts ($z < 0.1$) respectively. Following this studies,(Bolejko et al 2013) have noted that the standard lensing convergence effect is overwhelmed at low redshifts by a relativistic Doppler term that is typically neglected.

By introducing the following dimensionless variables

\[ \Theta_1 \equiv \frac{\kappa \dot{Q}}{\sqrt{6}H}, \Theta_2 \equiv \frac{\kappa \sqrt{V}}{\sqrt{3}H}, \Theta_3 \equiv \frac{\kappa \sqrt{\rho \gamma}}{\sqrt{3}H} \]

It is possible to write the evolution equations as a phase plane autonomous system as

\[ \frac{d\Theta_1}{dN} = -3\Theta_1 + \sqrt{\frac{3}{2}} \lambda \Theta_2^2 + \frac{3}{2} \Theta_1[2\Theta_1^2 + \gamma(1 - \Theta_1^2 - \Theta_2^2)] \]

\[ \frac{d\Theta_2}{dN} = -\lambda \sqrt{\frac{3}{2}} \Theta_1 \Theta_2 + \frac{3}{2} \Theta_2[2\Theta_1^2 + \gamma(1 - \Theta_1^2 - \Theta_2^2)] \]

Where, $N = \ln a$. Also the important parameter, $\frac{\dot{H}}{H^2}$, in terms of new variables will be

\[ \frac{\dot{H}}{H^2} = -\frac{3}{2} \left( 2\Theta_1^2 + \gamma(1 - \Theta_1^2 - \Theta_2^2) \right) \]

The above parameter is one of the useful parameters which can relate the theoretical model with observation. In fact by using this parameters and introducing two new variables $\Gamma = H$ and $\vartheta = \frac{d_0^L(z)}{\Gamma}$, we can convert the equation (7) to the two equivalent differential equations as follows

\[ \frac{d\vartheta}{dN} = -\left( \vartheta + \frac{e^{2N}}{\Gamma} \right) \]
\[ \frac{d\Gamma}{dN} = \varepsilon \Gamma \]  

(14)

Where, we have supposed, \( \varepsilon = \frac{\dot{H}}{H^2} \). Thus in order to find the bulk flow velocity we need to solve the set of equations (13, 14) and (10, 11) simultaneously as a equations set as

\[ \frac{d\Theta_1}{dN} = -3\Theta_1 + \sqrt{2} \lambda \Theta_2^2 + \frac{3}{2} \Theta_1[2\Theta_1^2 + \gamma(1 - \Theta_1^2 - \Theta_2^2)] \]  

(15)

\[ \frac{d\Theta_2}{dN} = -\lambda \sqrt{\frac{3}{2}} \Theta_1 \Theta_2 + \frac{3}{2} \Theta_2[2\Theta_1^2 + \gamma(1 - \Theta_1^2 - \Theta_2^2)] \]  

(16)

\[ \frac{d\vartheta}{dN} = -\left( \mathbf{\dot{\theta}} + \frac{\varepsilon N}{\Gamma} \right) \]  

(17)

\[ \frac{d\Gamma}{dN} = \varepsilon \Gamma \]  

(18)

3. NUMERICAL ANALYSIS

In this paper, we use the Union2 compilation (Amanullah et al 2010) of 577 SNe and covers the redshift range 0.015 < z < 1.4.

In order to fit the Union2 dataset to a dipole anisotropy we proceed as follows:

- We convert the equatorial coordinates of each supernovae to galactic coordinates.
- We find the Cartesian coordinates of the unit vectors \( \hat{n}_i \) corresponding to each supernovae with galactic

\[ \hat{n}_i = \cos(l_i)\sin(b_i)\hat{j} + \sin(l_i)\sin(b_i)\hat{j} + \cos(b_i)\hat{k} \]  

(19)

where \( (l_i, b_i) \) is the galactic coordinates of the \( i \)th supernova. Also \( \hat{p} \) is the unit vector in direction of dipole then:

\[ \hat{p} = \cos(l)\sin(b) + \sin(l)\sin(b)\hat{j} + \cos(b)\hat{k} \]  

(20)

which \( (l, b) \) is bulk flow direction in galactic coordinate, so

\[ \cos\theta_i = (\hat{n}_i, \hat{p}) = \cos(l)\sin(b)\cos(l_i)\sin(b_i) + \sin(l)\sin(b)\sin(l_i)\sin(b_i) + \cos(b)\cos(b_i) \]  

(21)

We can constrain on the direction and bulk flow velocity by minimizing the \( \chi^2 \), which is constructed as follow.

\[ \chi^2 = \sum_i \left| \mu_i - 5 \log_{10}(d_L^\text{dipole}(z, v_{DF}, \theta_i)/10\,\text{pc})^2 \right| \]  

(22)

Where,

\[ \mu_i = 5 \log_{10} d_L(z) + 42.384 - 5 \log_{10} h_0 \]  

(23)

The numerical analysis for different redshift ranges is as follows:

3.1. Numerical analysis for redshift 0.015 < z < 0.035

We first concentrate on the nearest redshift shell, 0.015 < z < 0.035 \( (45 - 105h^{-1}\,\text{Mpc}) \). This range includes 109 supernovas of 557 supernova Union2. We use the maximum likelihood analysis method to find the bulk flow. Probability of bulk flow direction in galactic longitude \( l \) and galactic latitude \( b \) using \( 2 \times 10^5 \) datapointss for \( 0.15 < z < 0.035 \) have been shown in Fig(1). As can be seen there is a bulk flow of \( v_{\text{bulk}} = 268^{+130}_{-130}\,\text{kms}^{-1} \) towards \( (l, b) = (292^\circ \pm 20^\circ, 10.5^\circ \pm 17^\circ) \). In r.h.s of top panel of Fig(1), the results of some studies which are comparable with our result at \( 1 - \sigma \) confidence level have been shown. Our results are very close to (Collin et al 2011) who found a bulk flow of \( v_{\text{bulk}} = 250^{+190}_{-160}\,\text{kms}^{-1} \) towards \( (l, b) = (287^\circ, 21^\circ) \) , (Feindt et al 2013) who estimate a bulk flow of \( v_{\text{bulk}} = 292^{+96}_{-96}\,\text{kms}^{-1} \) towards \( (l, b) = (290 \pm 22, 15 \pm 18) \) and (Wang & Wang 2014) who found \( v_{\text{bulk}} = 271^{+101}_{-101}\,\text{kms}^{-1} \) towards \( (l, b) = (270 \pm 20, 10 \pm 18) \) using the same data and in the same scale. Also the result is compatible with some previous studies at the same scale. Using a maximum likelihood approach, (Watkin et al 2009)computed \( v_{\text{bulk}} = \)
416 \pm 78\,\text{km/s} \text{ towards}(l, b) = (282^\circ, 6^\circ)$. Their results correspond to a sample with an effective Gaussian window of $50h^{-1}\,\text{Mpc}$. (Hoffman et al. 2001) within a $60h^{-1}\,\text{Mpc}$ top-hat sphere, based on the Mark III peculiar velocity catalogue found $v_{\text{bulk}} = 366 \pm 78\,\text{km/s}$ towards $(l, b) = (300^\circ, 13^\circ)$ At this scale, (Turnbull et al. 2012) presented new minimal variance bulk flow measurements based upon the First Amendment compilation of 245 Type Ia supernovae $(\text{SNe})$ peculiar velocities and find a bulk flow of $v_{\text{bulk}} = 249 \pm 76\,\text{km/s}$ towards $(l, b) = (319^\circ, 7^\circ)$ For a sphere of radius $40h^{-1}\,\text{Mpc}$ centered on the MW, (Nusser & Davis 2011) derive a bulk flow of $v_{\text{bulk}} = 333 \pm 38\,\text{km/s}$ towards $(l, b) = (276^\circ, 14^\circ)$. While at this scale the direction of bulk motion in our study is consistent with (Kashlinsky et al. 2010) who found $v_{\text{bulk}} \approx 1000\,\text{km/s}$ towards $(l, b) = (287^\circ, 7^\circ)$ at $(1\sigma)$, the amplitude is much lower and aligned with expectation of $\Lambda\text{CDM}$. Using a statistical method based on an optimized cross-correlation with nearby galaxies, (Lavaux et al. 2013) extract the kSZ signal generated by plasma halo of galaxies from the cosmic microwave background $(\text{CMB})$ temperature anisotropies observed by the Wilkinson Microwave Anisotropy Probe (WMAP). By considering only the galaxies within $50h^{-1}\,\text{Mpc}$ they found $v_{\text{bulk}} \approx 533 \pm 263\,\text{km/s}$ towards $(l, b) = (324 \pm 27^\circ, -7 \pm 17^\circ)$. Although, we find that the direction of motion at this scale is approximately aligned with the direction of the CMB dipole and HydraCentaurus supercluster at $(1\sigma)$ confidence level, the amplitude of bulk flow is less than half of the amplitude of the CMB dipole.

3.2. Numerical analysis for redshift $0.015 < z < 0.06$

Such as (Lavaux et al. 2010), we find that less than half of the amplitude of the CMB dipole is generated within a volume enclosing the HydraCentaurusNorma super cluster at around $40h^{-1}\,\text{Mpc}$. (Kocevski & Ebeling 2006) found that the GA only accounts for $44\%$ of the dipole anisotropy in a large X-ray cluster sample, with the rest evidently caused by more distant sources such as the Shapley Supercluster (SSC) at a distance of $[105 - 165h^{-1}\,\text{Mpc}]$ $(0.035 < z < 0.055)$ in the direction $(l, b) = (306.44^\circ, 29.71^\circ)$. Due to dominant superclusters such as Shapley Supercluster (SSC) at a distance of $105 - 165h^{-1}\,\text{Mpc}$ $(0.035 < z < 0.055)$, it is believed that it be largely responsible for this bulk flow. Hence most of the studies have been focused in this region. However, it is expected that both HydraCentaurusNorma super cluster and Shapley Supercluster (SSC) affect the motion of Local Group. Hence, in order to consider the both effects together, we perform our analysis in $(0.015 < z < 0.06)$ region. This range includes 142 supernova of 557 supernovas Union2. Fig(2) shows the results of our analysis. As can be seen, we find the bulk flow of $v_{\text{bulk}} \approx 257 \pm 120\,\text{km/s}$ towards $(l, b) = (300^\circ \pm 18^\circ, 6^\circ \pm 14^\circ)$ This direction is very close to centaurus constellation and aligned with direction of (SSC) at $(1 - \sigma)$ confidence level, however bulk flow and direction of CMB dipole does not improve. Our results are consistent with some previous studies. (Kocevski & Ebeling 2006); (Nusser & Davis 2011); (Feldman et al 2010); (Macaulay et al 2012); (Colin et al 2011).

3.3. Numerical analysis for redshift $0.015 < z < 0.1$

A large number of authors suggest that one has to go at least as far as the Shapley concentration at about $150h^{-1}\,\text{Mpc}$ in order to fully recover the dipole motion (Kocevski & Ebeling 2006); (Hoffman et al. 2001); (Lavaux et al. 2010); (Shapley 1930); (Scaramella et al 1989); (Raychaudhury et al 1991). The tentative observation show that the dipole motion does not appear to converge at a distances scale of the SSC, i.e. $150h^{-1}\,\text{Mpc}$ and convergence must occur well beyond $(z > 0.06)$ (Colin et al. 2011). Due to dominant superclusters such as Shapley or HorologiumReticulum in the southern hemisphere at scales above $120h^{-1}\,\text{Mpc}$, one might need to go well beyond $200h^{-1}\,\text{Mpc}$ to fully recover the dipole vector (Watkin et al. 2009). Here we make analysis for redshift range $0.015 < z < 0.1$. This range includes 165 supernovas of 557 supernova Union2. Fig(3) shows the results of our analysis. As can be seen, we find the bulk flow of $v_{\text{bulk}} \approx 257 \pm 120\,\text{km/s}$ towards $(l, b) = (302^\circ \pm 20^\circ, 3^\circ \pm 10^\circ)$ (Wang & Wang 2014) find a dipolar anisotropy in the direction $(l, b) = (309.2 \pm 15.8^\circ, 8.6 \pm 10.5^\circ)$ in galactic coordinates with a significant evidence $97.29\%$ (more than $2\sigma$). The direction and velocity of redshift range $0.015 < z < 0.1$ are consistent with the results from $0.015 < z < 0.035$ and $0.015 < z < 0.06$. The consistency between the results of high and low redshift may be interpreted as the following possibilities.

- In addition to attraction due to nearby over densities, the anisotropy may be caused by the other effects such as dark energy dipole, hence due to the non-local effect of dark energy, the direction is constant on all cosmic scale. If the anisotropy is caused only by the peculiar velocity, the anisotropic direction should be randomly distributed on different cosmic scales, because peculiar velocity is driven by emergent of large scale structure. (Cai et al 2013)
- Because of sparseness of the data at high redshift, the high-redshift results may be contaminated by the low redshift
Figure 1. Probability of bulk flow direction in galactic longitude $l$ and galactic latitude $b$ using $2 \times 10^5$ datapoints for $0.15 < z < 0.035$. The most probable direction pointing towards $(l, b) = (292^\circ \pm 22^\circ, 10.5^\circ \pm 17^\circ)$. Distribution of SNe Ia on the sky in galactic coordinates. In this Fig, the results of other studies have also been shown.
Figure 2. Probability of bulk flow direction in galactic longitude $l$ and galactic latitude $b$ using $2 \times 10^5$ datapoints for $0.15 < z < 0.06$. The most probable direction pointing towards $(l, b) = (300^\circ \pm 18^\circ, 6^\circ \pm 14^\circ)$. Distribution of SNe Ia on the sky in galactic coordinates. The result of other studies have also been shown.
So redshift tomography method may tell the differences between the dark energy dipole and peculiar velocity if high-z SNe data are available (Cai et al 2013)

3.4. Numerical analysis for redshift $0.015 < z < 1.4$

Here we use full union data to test the isotropy of the universe. (we find the bulk flow of $v_{bulk} \approx 253^{\pm 25} {\text{km}}/{\text{s}}$ towards $(l_0, b_0) = (296^\circ \pm 34.6^\circ, 1^\circ \pm 23.5^\circ)$) in galactic coordinates. The result is compatible with the results of previous studies of dark energy dipole in this redshift, (Mariano & Perivolaropoulos 2012); (Chang et al 2013); (Wang & Wang 2014); (Yang et al 2014); (Cai et al 2013); (Salehi & Aftabi 2016)(see Fig 4). An interesting result, the direction, magnitude of bulk flow and $h_0$ are approximately the same for all slices which contain low resift range $0.015 < z < 0.035$. Also their $(1-\sigma)$ errors are compatible (see Fig (5) and (6)). This hints that the high-redshift results may be contaminated by the lowed shift data, hence it encourages us to perform a cosmic tomography in which the data are sliced up in redshift and the question of isotropy is studied separately for each slice.

3.5. Redshift tomography

As we mentioned in previous section, since the high-redshift results may be contaminated by the lowred shift data, we perform a cosmic tomography in which the data are sliced up in redshift and the question of isotropy is studied separately for each slice. Our results for QCDM model are summarized in Table I and for three important redshift range $0.035 < z < 0.1$, $0.06 < z < 0.1$ and $0.1 < z < 0.2$, they have been depicted in Figs(7) to (9) There are interesting results in redshift tomography.

- The results of direction and amplitude of bulk flow have been obtained for a slice are much different from those obtained for cumulative redshift slices of the data.
- Surprisingly, for high redshift sells $z > 0.035$, we found a larger amplitude flow: $v_{bulk} \approx 500 - 1000 {\text{km}}/{\text{s}}$ which is in excellent agreement with the results of (Kashlinsky et al 2009)-(Kashlinsky et al 2010)-(Kashlinsky et al 2011)- (Kashlinsky et al 2012) nearly.
- Recently (Colin et al 2011) investigated anisotropies in discrete redshift shells using the Union2 compilation of Type Ia SNe (Amanullah et al 2010)(The data have been used in this paper). Although our results are in excellent agreement with in (Colin et al 2011) low redshift $z < 0.1$ , however in high redshifts $z > 0.1$, our results are different. In contrast to (Colin et al 2011) who found that in high redshifts the agreement between the SNe Ia data and the $\Lambda CDM$ model does improve, we found that contradiction between $\Lambda CDM$ and SNe Ia data is revealed more in high redshifts $z > 0.1$. Because of using same data, we can conclude that the disagreement between the results reefer to different background cosmological models($\Lambda CDM, QCDM$) which have a degenerate behavior in low redshifts and it would be break at high redshifts. In other word, "quintessence behaves as a smooth component: it does not participate directly in cluster formation, but it only alters the background cosmic evolution, however at very large scales($\sim 100h^{-1}\text{Mpc}$), Quintessence clusters gravitationally, leaving an imprint on the microwave background anisotropy"(Caldwell et al 1998).

4. CONCLUSION

Previous studies of bulk flow can be classified in two set of results. Some studies reported possible large bulk flows at scales of $\sim 100h^{-1}\text{Mpc}$, (Hudson et al 2004); (Kashlinsky et al 2008); (Watkin et al 2009); (Lavaux et al 2010); (Dai et al 2011); (Colin et al 2011); (Macaulay et al 2012); (Feindt et al 2013) while others reported bulk flow to be consistent with the expectation from $\Lambda CDM$; (Courteau et al 2000); (Nusser & Davis 2011); (Nusser et al 2011); (Branchini et al 2012); (Turnbull et al 2012); (Ma & Scott 2013)]. Over larger distances, (Kashlinsky et al 2008) reported a bulk flow out to $d \geq 300h^{-1}\text{Mpc}$. According to their results (Kashlinsky et al 2008)-(Kashlinsky et al 2012) the bulk flow is $\sim 1000{\text{km}}/{\text{s}}$ in the direction of the CMB dipole up to a distance of at least $\sim 800h^{-1}\text{Mpc}$. A flow of this amplitude on such a large scale is in contradict with that predicted by the $\Lambda CDM$ (one-dimensional rms velocity is $\sim 110{\text{km}}/{\text{s}}$)(Watkin et al 2009). In this paper, we study the bulk flow of the local universe using Type Ia supernova data in QCDM model. We find that at low redshift bulk flow is moving towards the $(l, b) = (302^\circ \pm 20^\circ; 3^\circ \pm 10^\circ)$ direction with $v_{bulk} = 240 \pm 25{\text{km}}/{\text{s}}$ velocity. This direction is aligned with direction of (SSC) and agreement with a number previous studies at $(1-\sigma)$, however for high redshift we get $v_{bulk} = 1000 \pm 25{\text{km}}/{\text{s}}$ towards the $(l, b) = (302^\circ \pm 20^\circ; 3^\circ \pm 10^\circ)$. This indicates that for low redshift our results are approximately consistent with
Figure 3. Probability of bulk flow direction in galactic longitude $l$ and galactic latitude $b$ using $2 \times 10^5$ datapoints for $0.15 < z < 0.1$. The most probable direction pointing towards $(l, b) = (302^\circ \pm 20^\circ, 3^\circ \pm 10^\circ)$. Distribution of SNe Ia on the sky in galactic coordinates. The results of other studies have also been shown.

This Study : $(l,b) = (302^\circ, 3^\circ)$

- J.S. Wang : $(l,b) = (292.2^\circ, 7.7^\circ)$
- CMB dipole : $(l,b) = (276^\circ, 30^\circ)$
Figure 4. Probability of bulk flow direction in galactic longitude $l$ and galactic latitude $b$ using $2 \times 10^5$ datapoints for $0.015 < z < 1.4$. The most probable direction pointing towards $(l, b) = (296^\circ \pm 34^\circ, 1^\circ \pm 23.5^\circ)$. Distribution of SNe Ia on the sky in galactic coordinates. Red triangulares denote SNe with $0.015 < z < 1.4$. The results of other studies have also been shown.
Figure 5. The plot of ($\sigma$) confidence level of bulk flow direction in galactic longitude $l$ and galactic latitude $b$ for redshift ranges; $0.015 < z < 0.035$, $0.015 < z < 0.06$, $0.015 < z < 0.1$ and $0.015 < z < 1.4$.

The $\Lambda$CDM model with the latest WMAP best fit cosmological parameters, however for high redshift they are in disagreement of $\Lambda$CDM and support the results of previous studies such as kashlinsky et al which report the large bulk flow for the Universe.

There are several possible explanations for the discrepancy we have observed:

- Our results are in excellent agreement with in (Colin et al 2011) low redshift $z < 0.1$, however in high redshifts $z > 0.1$, our results are different. In contrast to (Colin et al 2011) who found that in high redshifts the agreement between the SNe Ia data and the $\Lambda$CDM model does improve, we found that contradiction between $\Lambda$CDM and SNe Ia data is revealed more in high redshifts $z > 0.1$. Because of using same data, we can conclude that the disagreement between the results refers to different background cosmological models($\Lambda$CDM, $QCDM$) which have a degenerate behavior in low redshifts and it would be break at high redshifts. In other word, ”quintessence behaves as a smooth component: it does not participate directly in cluster formation, but it only alters the background cosmic evolution, however at very large scales($\sim > 100h^{-1}Mpc$) and leaving an imprint on the microwave background anisotropy” (Caldwell et al 1998).
Figure 6. The plot of $(1, 2, 3\sigma)$ confidence level of $(v_{\text{bulk}}, h_0)$ for redshift ranges; $0.015 < z < 0.035$, $0.015 < z < 0.06$, $0.015 < z < 0.1$ and $0.015 < z < 1.4$.

- We can conclude that at small scales, fluctuations in the dark energy are damped and do not enter in the evolution equation for the perturbations in the pressureless matter. Thus quintessence behaves as a smooth component: it does not participate directly in cluster formation, but it only alters the background cosmic evolution, however at very large scales ($\sim 100h^{-1}Mpc$), Quintessence clusters gravitationally, leaving an imprint on the microwave background anisotropy. In other world, quintessence remains smooth like the cosmological constant on small length scales. The quintessence fluctuations are weak compared with the matter fluctuations at smaller scales.

- While the direction of the flow from different works agrees well, there is considerable variation in the magnitude of the flow. Part of the discrepancy between the results may be related to this fact that magnitude of the flow can depend strongly on the depth of the survey. For example comparison of results of (Kashlinsky et al 2008) and (Watkin et al 2009) shows that the direction of bulk flow in two studies are in excellent agreement, while the amplitude of their flow are considerably different. Note that (Kashlinsky et al 2008) sample(volume of radius of $\sim 120 - 600h^{-1}Mpc$) is very much deeper than (Watkin et al 2009) (volume of radius of $\sim 100h^{-1}Mpc$)
Figure 7. Probability of bulk flow direction in galactic longitude $l$ and galactic latitude $b$ for $0.035 < z < 0.06$. The most probable direction pointing towards $(l; b) = (4.8^{+12\degree}_{-18\degree}, -14.5^{+12\degree}_{-10\degree})$. Distribution of SNe Ia on the sky in galactic coordinates. Red triangles denote SNe with $0.035 < z < 0.06$. The results of other studies have also been shown.
Figure 8. Probability of bulk flow direction in galactic longitude $l$ and galactic latitude $b$ for $0.06 < z < 0.1$. The most probable direction pointing towards $(l; b) = (282.5^{+16}_{-13}; 15.5^{+29}_{-31})$. Distribution of SNe Ia on the sky in galactic coordinates. The results of other studies have also been shown.
Figure 9. Probability of bulk flow direction in galactic longitude \( l \) and galactic latitude \( b \) for \( 0.1 < z < 0.2 \). The most probable direction pointing towards \((l, b) = (254^{+16}_{-14}, 6^{+7}_{-10})\). Distribution of SNe Ia on the sky in galactic coordinates. The results of other studies have also been shown.
We found for each slice of data which contain low redshift (even the large slice with 0 amplitude of $v_{\text{redshift}}$ and the question of isotropy was studied separately. Surprisingly, for high redshift sells $z > 0.15$, we found a larger amplitude flow; $v_{\text{bulk}}$ is close to $250kms^{-1}$. Thus we performed a cosmic tomography where the data are sliced up in redshift and the question of isotropy was studied separately. Surprisingly, for high redshift sells $z > 0.35$, we found a larger amplitude flow; $v_{\text{bulk}}$ is close to $1000kms^{-1}$ which is in excellent agreement with the results of (Kashlinsky et al 2009)-(Kashlinsky et al 2010)-(Kashlinsky et al 2011)-(Kashlinsky et al 2012) nearly. This indicates that, due to sparseness of the data at high redshift, the high-redshift results may be contaminated by the low redshift data. Also at low redshifts $z < 1$, the Hubble law indicates a linear relationship between distance and redshift so the choice of cosmological model is irrelevant; however this becomes important at high redshift (Colin et al 2011).

It is possible that the large observed flow is the result of a systematic error in the data, although the independence of the distance indicators (TF, FP and SN Ia) and methodology of the various surveys, as well as the agreement between different surveys makes this unlikely (Watkin et al 2009)

Cluster evolution offers a promising approach for breaking the degeneracy

While the quintessence fluctuations are weak compared with the matter fluctuations at smaller scales and the quintessence energy density is negligible when those length-scale enter the horizon, however, these fluctuations have a non negligible effect on the cosmic microwave background anisotropy and the mass power spectrum Steinhardt (2003)

### Table 1. The comparison of achieved Bulk velocity in this paper with other studies for dark energy dipole

| Range       | $l^\circ$  | $b^\circ$ | $x_0$ | $y_0$ | $\lambda$ | $h_0$ | $v_{\text{bulk}}$ | $\chi^2_{\text{min}}$ | data |
|-------------|------------|-----------|-------|-------|-----------|-------|-----------------|------------------------|------|
| 0.015 < $z$ < 0.025 | 244.5$^{19}_{-19}$ | $-19^{15}_{-15}$ | 0.425 | 0.834 | 2.32 | 0.698 | 300 | 46.1724321 | 58 |
| 0.015 < $z$ < 0.035 | 292$^{22}_{-22}$ | 10.5$^{17}_{-17}$ | 0.425 | 0.996 | $-0.098$ | 0.697 | 268 | 97.97402438 | 109 |
| 0.015 < $z$ < 0.06 | 300$^{18}_{-18}$ | 6$^{14}_{-14}$ | 0.451 | 0.896 | $-0.078$ | 0.699 | 257 | 130.4102306 | 142 |
| 0.015 < $z$ < 0.1 | 302$^{20}_{-20}$ | 3$^{10}_{-10}$ | 0.560 | 0.981 | $-0.095$ | 0.698 | 246 | 148.5758203 | 165 |
| 0.015 < $z$ < 1.4 | 296$^{34.6}_{-34.6}$ | 1$^{21.5}_{-23.5}$ | 0.395 | 0.839 | 2.2 | 0.697 | 253 | 530.61029 | 556 |
| 0.035 < $z$ < 0.06 | 4.8$^{12}_{-18}$ | $-14.5^{12}_{-10}$ | 0.161 | 0.796 | 2.1 | 0.702 | 858 | 27.36652794 | 33 |
| 0.06 < $z$ < 0.1 | 282.5$^{16}_{-13}$ | 15.5$^{29}_{-31}$ | 0.773 | 0.996 | 2 | 0.701 | 519 | 18.33498129 | 23 |
| 0.1 < $z$ < 0.2 | 254$^{34}_{-14}$ | 6$^{7}_{10}$ | 0.2 | 0.799 | 1 | 0.6976 | 1014 | 53.256270 | 55 |
| 0.2 < $z$ < 0.4 | 138$^{17}_{-14}$ | 24$^{14}_{11}$ | 0.259 | 0.848 | 1.5 | 0.6972 | 1200 | 108.5668242 | 124 |
| 0.4 < $z$ < 0.6 | 300$^{19}_{-15}$ | 60$^{17}_{-14}$ | 0.27 | 0.859 | 2.5 | 0.6974 | 597 | 100.728441 | 101 |
| 0.6 < $z$ < 0.8 | 202.5$^{18}_{-14}$ | 81$^{17}_{-12}$ | 0.26 | 0.837 | 1.4 | 0.7014 | 1200 | 47.07531 | 50 |
| 0.8 < $z$ < 1 | 360$^{15}_{-11}$ | 30$^{14}_{-10}$ | 0.349 | 0.829 | 2.2 | 0.701 | 570 | 47.5908633 | 40 |
| 0.1 < $z$ < 1 | 280.5$^{12}_{-13}$ | $-15^{8}_{-7}$ | 0.346 | 0.834 | 2.2 | 0.699 | 1050 | 364.5724654 | 372 |
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